ICE CORE DRILLING AT A HIGH ACCUMULATION AREA OF LAW DOME, ANTARCTICA, 1987

by

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ABSTRACT

A 234 metre deep, 195 mm diameter ice core was drilled at DEO8, 16 km east of the summit of Law Dome summit in 1987. The details of the thermal drill facility are described. The ice core and borehole were measured and sampled on-site for all principal parameters and showed that the core reached back to about 1810 AD. The snow accumulation rate at the drill site is about 1200 kg m^{-2} a^{-1} and surface melting is very infrequent. The suitability of the core for gas composition studies and other analyses is discussed.

1 - AIMS

The aims of the 1986/87 ice core drilling at DEO8 were :

(i) to obtain an ice core from a cold, high accumulation zone suitable for analysis of recent changes in atmospheric trace gas composition ;

(ii) to test and develop a large diameter thermal drill ;

(iii) to test and develop an on-site core analysis scheme.

2 - BACKGROUND

Ice core drilling yields ice that contains information on past climates, atmospheres and terrestrial conditions on timescales of tens of years to hundreds of thousands of years. Of particular interest is the recent increase in the concentrations of some atmospheric trace gases which may contribute to the greenhouse effect. These gases (carbon dioxide, methane and nitrous oxide) have been measured in the air trapped as bubbles in ice cores (Barnola and others, 1987 ; Etheridge and others, 1988 ; Neftel and others, 1985 ; Rasmussen and Khalil, 1984). However, the age resolution of the ice core air has not been fine enough to allow precise comparison of the ice core results with recent direct readings which began as late as the last decade for some atmospheric species. This comparison would test the accuracy of the techniques used to extract and analyse the air and whether the air's composition changed whilst enclosed in the ice.

The age resolution of the air trapped in an ice sheet is predominantly a function of the snow accumulation rate and is normally deduced from the number of years over which 80 % of the air is trapped (Schwander and Stauffer, 1984). This is parameterised by density, where 795 kg m^{-3}

is defined as the density at which 10 % of the total air is trapped as bubbles and similarly 830 kg m^{-3} for the 90 % level. By drilling a core at DEO8, where the accumulation rate is about 1200 kg $m^{-2}a^{-1}$, (c.f. 650 for the Law Dome summit core BHD, 500 for Siple Station and 22 for Vostok), trapped air with an age resolution of about 8 a can be found. This compares favourably with other sites that have been analysed for gas composition : 17 a for BHD (Law Dome summit), 22 a for Siple Station and Dye 3, 370 a for Dome C and 590 a for Vostok. The precision of the DEO8 air dating should thus allow accurate calibration of the ice core gas record.

3 - THE DRILLING SITE

The DEO8 borehole (-66°43'19", 113°11'58", 1250 m.a.s.l., in April 1987) lies 16 kilometers east of the summit of Law Dome (Figure 1). Orographic effects create the high accumulation which increases rapidly going east from the summit. The ice thickness is about 1180 metres and because of the site's proximity to the ice divide, deformation due to shear is small especially in the upper region of the ice sheet. Thus, annual layers are well preserved. The mean annual temperature (i.e. 10 metre firn temperature) is about -19°C. The surface is smooth and soft, and the prevailing wind is from the ESE, which is also the direction from which most of the site's precipitation comes.

The site was first investigated by A.N.A.R.E. (Australian National Antarctic Research Expedition) in 1984. In 1985 a 46 metre core was drilled in the region, the results of which created interest in drilling further.

4 - DRILL FACILITY

The drill was a cable-supported thermal drill. Its design and method of operation was similar to the CRREL thermal drill as modified by Bird and Ballantyne (1971), but the dimensions and construction were quite different. It drilled a larger diameter hole (260 mm diameter c.f. 170 mm) to accommodate the borehole casing required by the electromechanical deep drilling system to be used in the future. It also took a larger diameter core (195 mm), which has many advantages for core analysis. It operated in a dry borehole.

The melt head consisted of a single-phase electric element, vacuum brazed to a copper substrate and bolted to a steel housing. The element could dissipate up to 3.5 kW. Six core 'dogs' (used to sever and catch the core) were housed in the head which was threaded on to a fibreglass drill barrel capable of taking a maximum core length of 1.95 metres. Melt water was sucked up heated tubes into an evacuated water tank above the drill barrel. The vacuum pump and electronics for drill telemetry (head current and temperature, water tank vacuum) and drill feed were contained in a module on top of the water tank. A 'Pajari' borehole surveying instrument was also housed in the module. The 12 mm diameter winch cable consisted of a double spiral outer sheath surrounding seven insulated conductors. The winch cable passed over a pulley, mounted on a hydraulic ram and was terminated at the drill in a suspension device. This device divided the weight of the drill between the cable and melt head by continuously triggering a valve which lowered the hydraulic ram during drilling. In this way smooth, controlled feed could be maintained and the hole could be kept vertical.

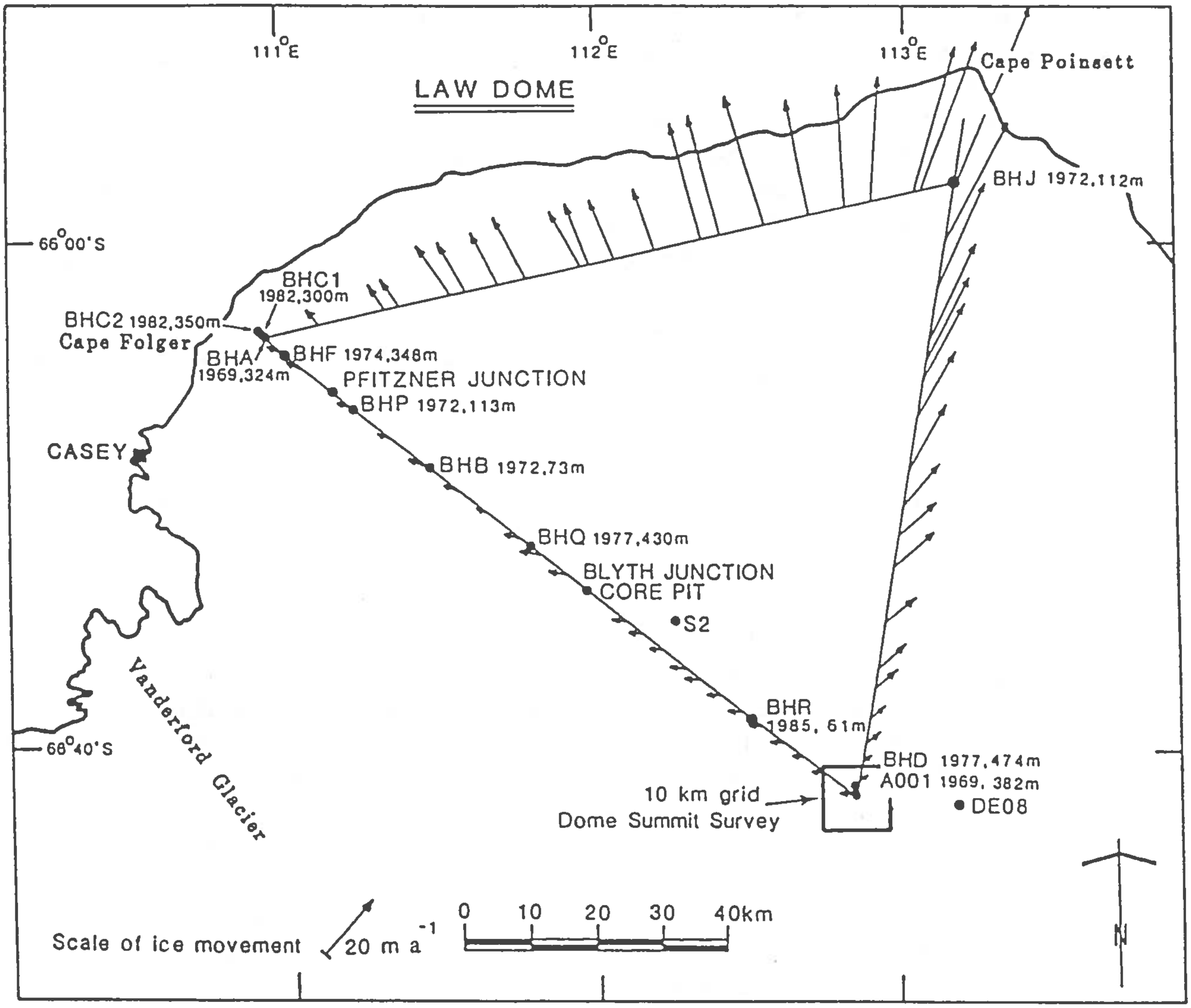

Figure 1 - Map of Law Dome, showing borehole locations and surface velocity vectors.

To assist breaking off such large cross section cores, a prototype device was incorporated in the top of the core barrel. This consisted of a powerful solenoid with a massive iron core. When tension was applied to the cable to withdraw the drill and core, the solenoid was energised, creating an impact that was transferred through the core dogs to sever the ice. The core barrel was suspended on rubber mounts to increase the effect. Although useful in some applications, the deeper, brittle ice cores were often damaged by severing cores in this way.

At the surface, the winch, hydraulics and drill controls were housed inside the fully enclosed 'drill van', which was set on a sled. The drill tower lay flat on the drill van roof until the drill site was reached where it would be raised hydraulically.

5 - DRILLING PROCEDURE

A typical coring run began with drill preparation : the hydraulic feed ram was raised, the core dogs were released, the melt water tank drains were close and the Pajari instrument set. The drill was then positioned above the hole and the depth counter set to zero. The electrics were switched on and the head current set to about 5 A before the drill was lowered.

When the drill reached the bottom of the hole, the head current was increased to 15A, the automatic feed was enabled and the drill was raised slightly until the feed was trigged. The head temperature would then increase, which would then be followed by a rise in vacuum, a drop in head temperature and the beginning of drill feeding. Drilling ceased when the top of the core met the end of the core barrel and stopped the drill feeding.

The method of severing the core depended on the type of ice encountered. Firn cores would normally sever cleanly by just retracting the drill after making sure the core dogs had caught. Ice was harder to sever, requiring more force and sometimes 'necking' - narrowing the end of the core by melting but not feeding. Using force to sever brittle cores however would usually shatter the ice. Instead, the core would be necked right through and then carefully lifted. The amount of tension on the winch cable was a valuable guide to the drilling and severing processes.

Drill feed rate, run turn-around time and melt water uptake are shown in Figure 2. Overall drilling progress is depicted in Figure 3.

6 - FIELD ITINERARY

The drill team departed Casey on January 11 1988 and arrived at DEO8 four days later after being slowed by a blizzard. Drilling and analysis began on January 17. A depth of 52 metres was reached by January 23 when a bolt and washer came adrift from the drill and lodged in the bottom of the hole. Efforts to drill past these failed (the bolt was retrieved but the washer prevented further passage), and on January 26 a new hole was begun, 2 metres ESE of the blocked one. On February 11 drilling ceased at 234 metres where the ice was deduced from conductivity analysis to be from approximately 1810 AD. The next 3 days were spent measuring borehole temperatures and diameter and breaking out the camp, much of which was deeply buried.

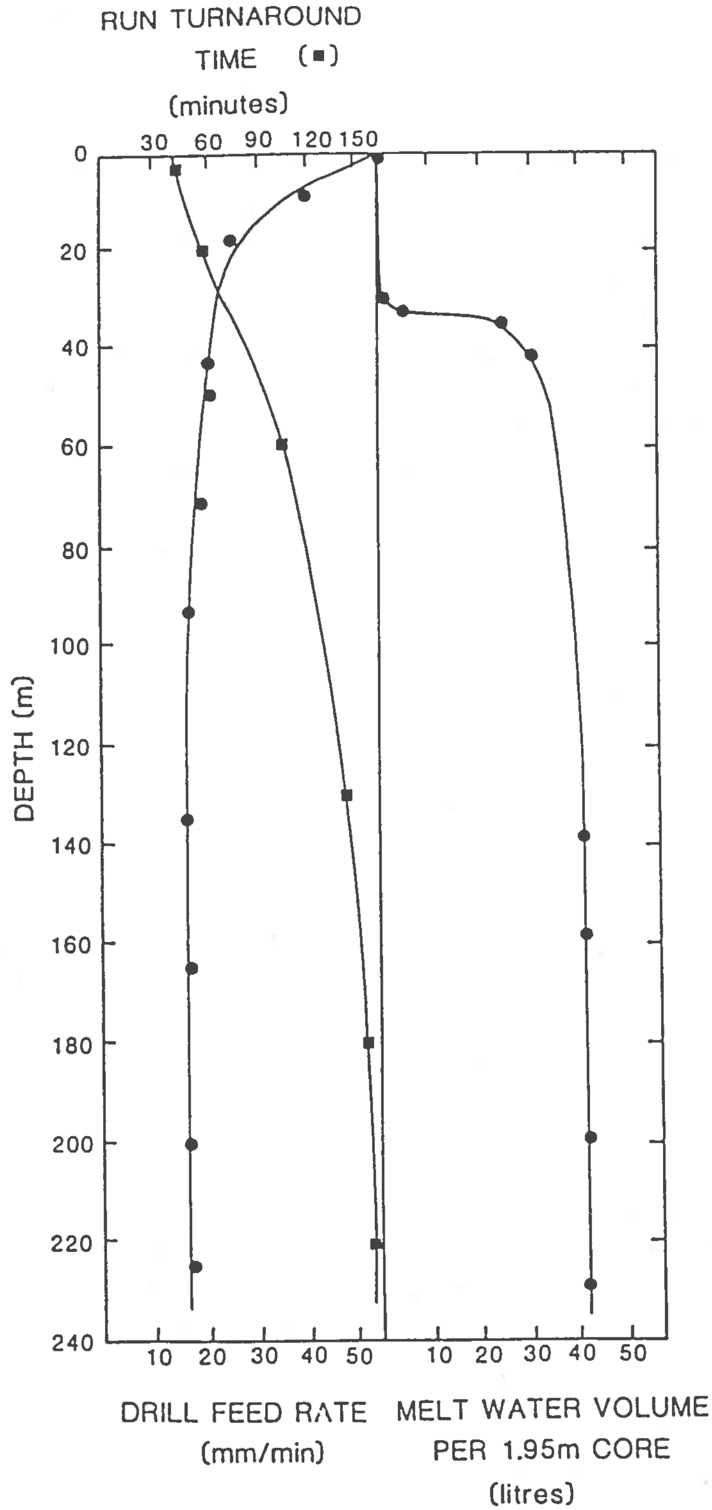

Figure 2 - Drill feed rate, run turn-around time (number of minutes per drilling run for a 1.95 metre core) and meltwater uptake.

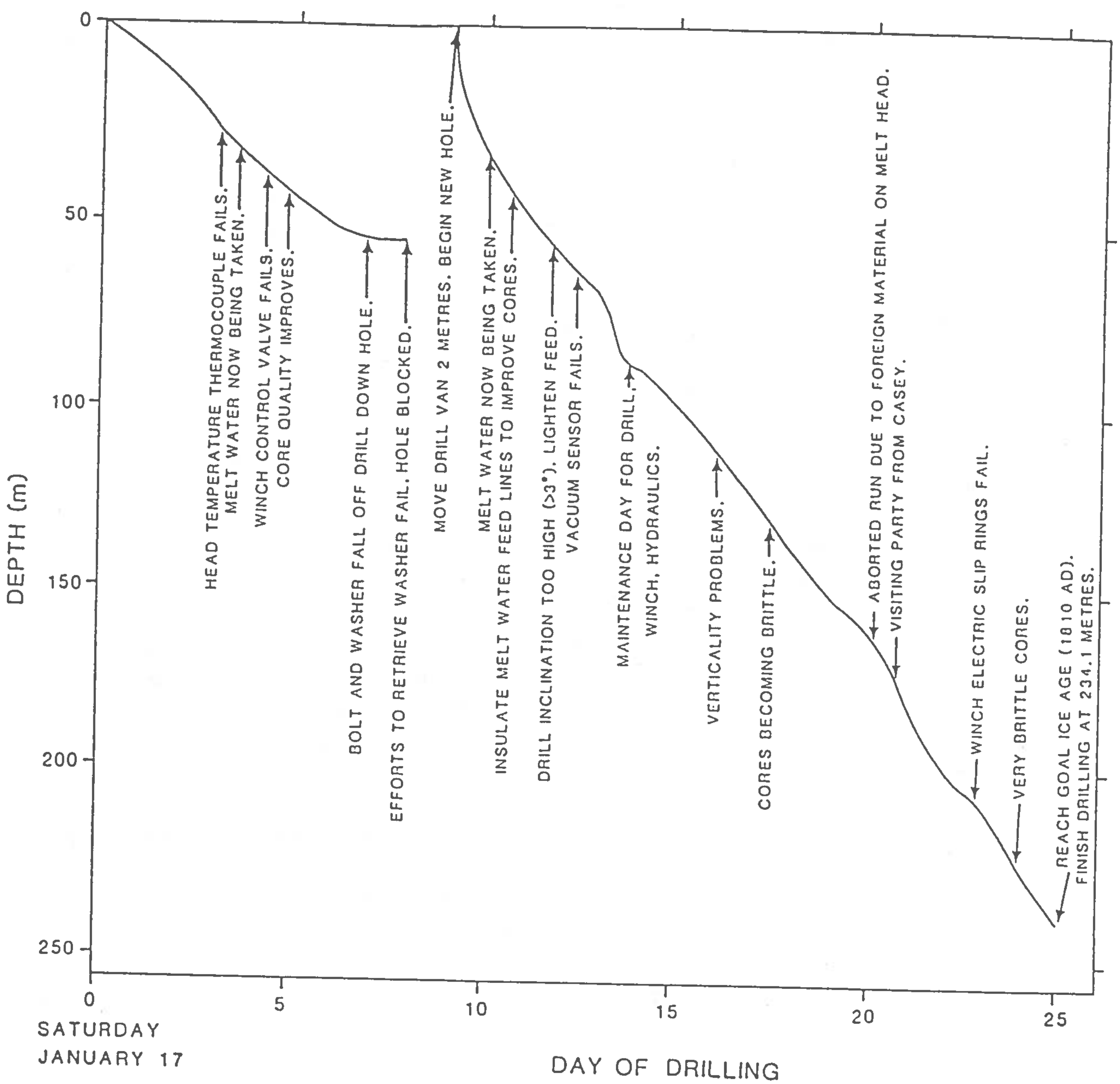

Figure 3 - Drilling progress chart.

7 - CORE DETAILS

Both cores to 52 metres were analysed on-site but only the first was retained, from 20 to 52 metres. The top 20 metres was heavily infiltrated by drill melt water and only samples were retained. The second core was analysed and retained from 52 to 234 metres. The duplication of the top 52 metres of core, although not planned proved very useful to determine the horizontal reproducability of core analysis results. The cores were sealed in plastic bags, labelled, placed inside cardboard tubes and plastic end-caps affixed.

The borehole reached to 234.1 metres and the cumulative core length totalled 233.2 metres. The difference was attributed to losses caused by necking completely through cores from the bottom 20 metres and by pieces being lost from brittle cores.

Core and borehole inclination was typically within 3° of vertical but occasionally this would increase to as much as 8°. The suspected cause was the flexible middle joint of the drill. Lightening the feed (i.e. biasing more drill weight to the cable) easily brought the hole back to vertical, with a small decrease in drilling rate.

Core quality below 20 metres was excellent. Typically, each 2 metre core was retrieved with a full, continuous cross-section and 2-3 horizontal breaks. Cores from 160 metres and deeper required careful handling because they were quite brittle. Storing these for about 10 hours was necessary before analysis. Importantly, excessive core heating by the thermal drill, which can damage the ice core gas and other records (Pearman and others, 1986) was avoided. Typical temperatures of the core immediately after removal from the drill were -14°C at 20 mm in from the core surface and -15°C at the centre.

Natural melt layers were found in the core at 81 metres depth (5 mm thick), 184 metres (3 mm), 188 metres (4 mm) and 204 metres (2.5 mm). Several bands of microfractures - horizontal wafering of the core - were seen at 229 metres and deeper. Many light bands of wind and/or radiation crust were observed throughout the core.

Drilling was terminated when ice from approximately 1810 AD was reached, as calculated from the annual cycles in the DC-conductivity record. This provided a sufficiently long age span for the gas record and included a region containing volcanic fallout from the Tambora (1815 AD) eruption, which was also used as a dating horizon. The age-depth relation is given in Figure 4.

All the retained DEO8 cores were kept at -15°C in a refrigerated container for transport to Casey and Melbourne and finally stored in scoops at a core storage facility at -30°C. The warmest temperature the cores were exposed to was -5°C, but this was for no more than an hour.

8 - DENSITY AND GAS ENCLOSURE

The DEO8 density profile is given in Figure 5(a). The density was found by taking a sample from the centre of the core, machining it into a rod and measuring its dimensions and mass. Using the densities of 795 kg m^{-3} and 830 kg m^{-3} to parameterise bubble close-off as described in Section 2, the air is 40 years younger than the ice and 80 % is trapped over 8 years. This does not include the possible effects of firn impermeability. It is possible that air from as

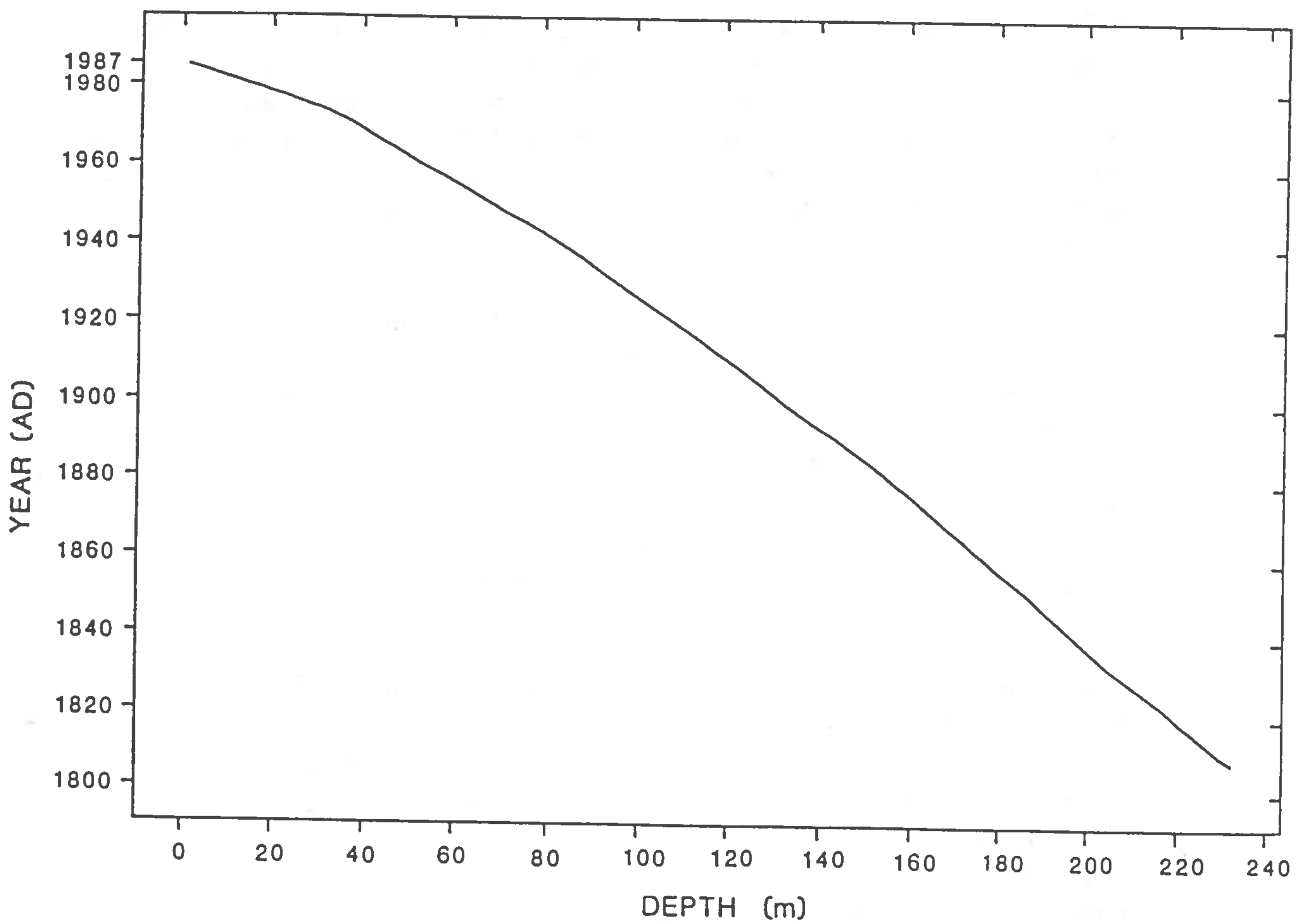

Figure 4 - Age-depth relation for the DEO8 ice core.

recent as the early 1980's is trapped as bubbles in this core.

9 - BOREHOLE TEMPERATURE

The dry borehole was measured for temperature using a Leeds and Northrup 8078 bridge and a cable mounted sensor. A 'Degussa' 100 Ω platinum resistance element was mounted on an insulated arm that could be extended when the instrument was down the hole, forcing the element against the borehole wall. This system ensured good thermal contact and low thermal inertia. About 30 minutes was needed for each measurement. Two sets of measurements were made (see Table 1 and Figure 5(b)). There is evidence that the bottom 30 metres was still slightly disturbed by the heating of the thermal drill, although the remainder of the hole, being drilled more than 2 days prior to temperature measurement, showed no such effects.

10 - SUPPLEMENTARY MEASUREMENTS

A 4 metre deep snow pit was dug about 100 metres south of the borehole and showed only one feature, a 2 mm thick coarse-grained layer. Daily readings of atmospheric pressure, temperature (screen height 1.5 metres) and weather conditions were taken. Surface velocity and bedrock profiles were measured and will be reported elsewhere.

11 - CONCLUSIONS

An ice core from the high accumulation site DEO8 was successfully drilled in 1987. The 195 mm diameter, 234 metre long core should allow accurate analysis of atmospheric greenhouse gases from about 1850 AD to as recent as the early 1980's. The core's high quality, fine age resolution and large diameter will also be ideal for detailed studies of climate, atmospheric chemistry and particles. The drill proved suitable both for intermediate depth core drilling and for drilling a pilot hole to accommodate a casing required for deep electromechanical drilling. The scheme for on-site core analysis and sampling provided useful information during drilling and significantly increased the efficiency of further core analysis back in the laboratory.

ACKNOWLEDGEMENTS

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Table 1 - Temperature measurements in DEO8 borehole.

Depth	Temperature °C	Hours after drilling measurement was taken
4.0	-18.49	400
12.0	-18.90	420
20.0	-18.98	400
40.1	-19.61	380
55.0	-19.81	400
70.0	-20.05	280
100.1	-20.18	240
130.0	-20.20	190
160.1	-20.25	140
175.0	-20.26	160
190.0	-20.25	90
205.0	-20.25	56
220.2	-20.06	46
220.0	-20.18	58
232.5	-20.30	28
233.4	-20.40	39

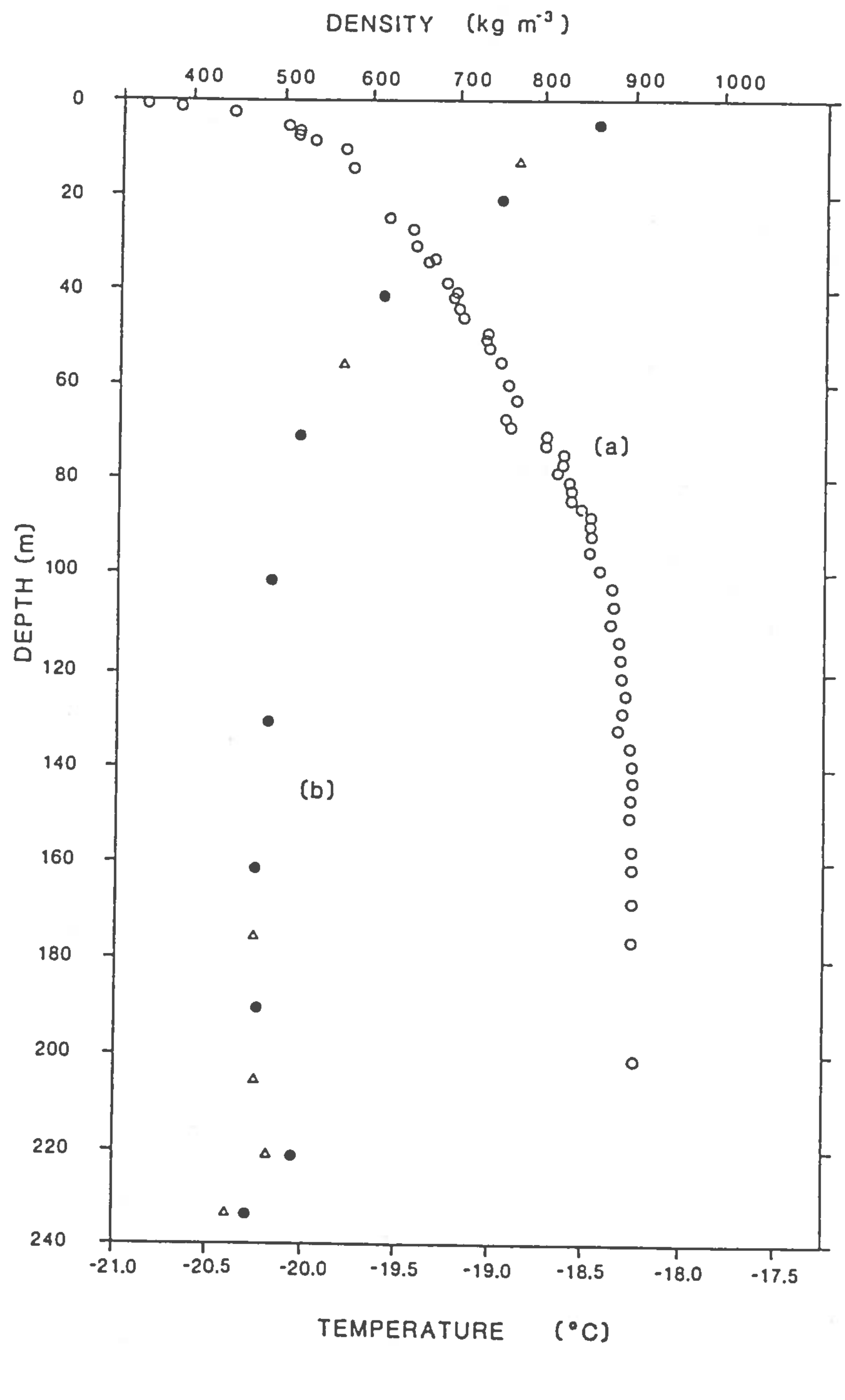

Figure 5 - Profiles of (a) density, and (b) temperature for DEO8.
The solid circles represent the results of the second temperature traverse.