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Ice core processing at Dome Fuji Station, Antarctica

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Abstract: From 1993 to 1998, members of the Dome F project group carried out ice coring at Dome F station. They recovered a 2503-m-long ice core. Specific tasks for the ice core processing included (1) core storage, (2) cutting and packing the ice samples for transportation from the station to Japan, and (3) performing initial ice analyses that can be done at the station. In this report we outline the operation and describe our experiences related to the ice core processing to aid similar processing in the future.

1. Introduction

Following a pilot borehole drilled in 1993, deep ice coring was carried out at Dome Fuji Station, Antarctica (lat 77°19′S, long 39°40′E, 3810 m above sea level) in 1995 and 1996. It reached 2503.52 m in December 1996. Details of the drill system and coring operation have been reported elsewhere (Fujii *et al*., 1999; Motoyama *et al*., 1995; Tanaka *et al*., 1994). Ice core processing started immediately after core recovery at the station. Before starting, a committee of several members in the coring project defined the ice core project at Dome F (Shoji *et al*., 1994) and suggested the following processing procedures: (1) core storage, (2) core logging, (3) brittle zone handling, (4) field measurements, (5) sample preparation, and (6) core packing for transportation. The field operation then followed their plan. This report contains information that should be useful for similar processing operations.

2. Core storage

After drilling and removing the cores from the drill, ice cores were stored in a snow tunnel located next to the drilling site (see Fig. 1). The size of the tunnel is roughly 3× 7 m, and inside there are two sets of shelves to hold up to 500 m of an ice core as shown in Fig. 2. The tunnel temperature varied between −30°C and −50°C. Most core seg-

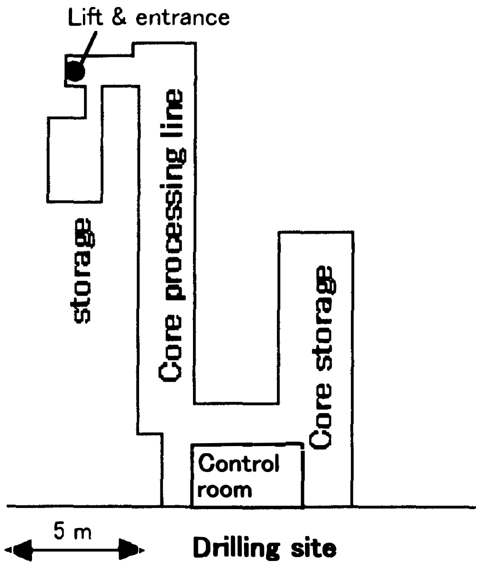

Fig. 1. Top view of the Dome Fuji drilling site and core processing room.

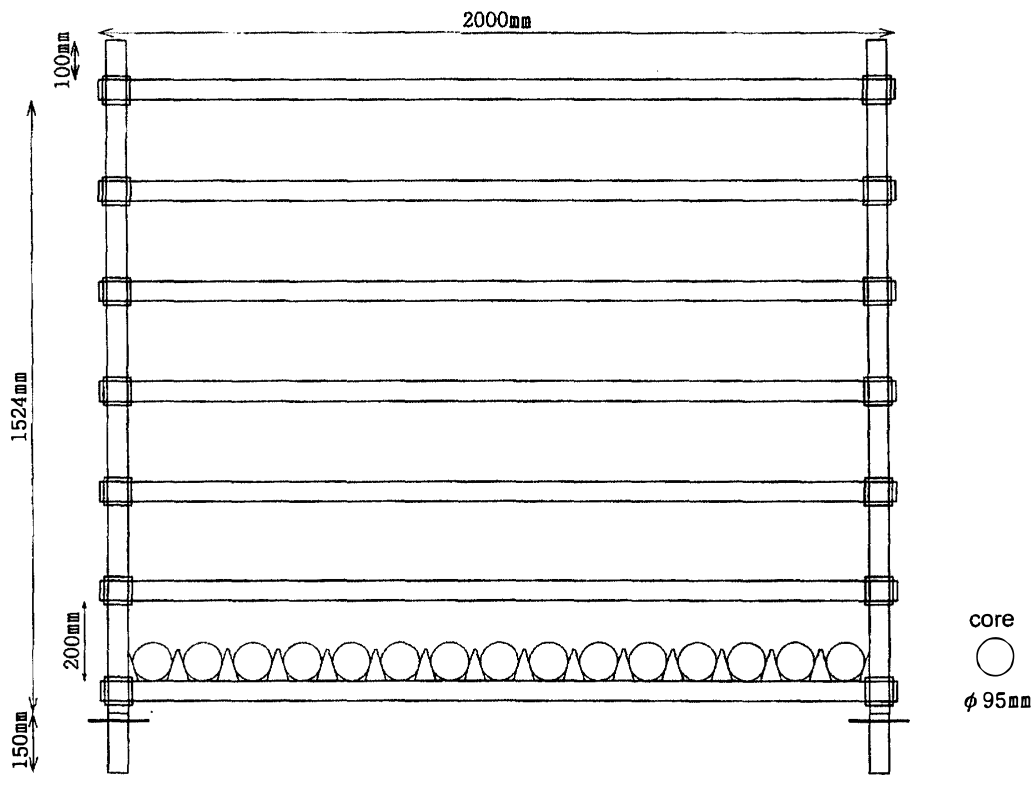

Fig. 2. Side view of a shelf for core storage.

ments were stored there for several weeks to a few months. This storage served as a buffer that was necessary because the core recovery speed was faster than the core processing speed. Each core sample was put in a tin trough. The trough shape is drawn in Figs. 3 and 4 shows the troughs with cores on a shelf in the core storage. The core troughs were strong

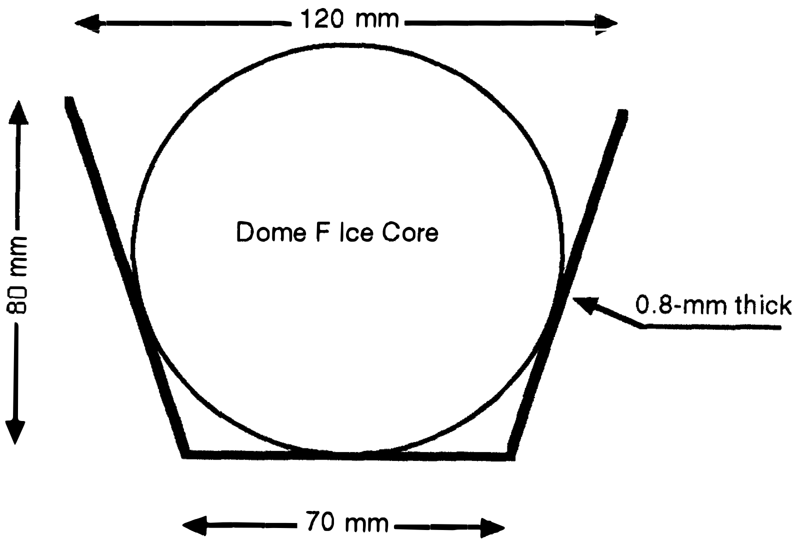

Fig. 3. Cross-section and dimensions of a core-storage tray.

Fig. 4. Core storage. Temperatures were between −30°C and −50°C.

enough to support ice cores in them. Ice core sections were typically 1.5–2.0 m long. The maximum was 2.4-m long, determined by the maximum length of the core barrel. Average diameter of the ice core was 93 mm. At the station, all of the cores in the troughs were carried by hand.

3. Processing plan

The original processing plan (Shoji *et al.*, 1994) is summarized in Fig. 5. First, the core's condition was recorded and the core was labeled. Bulk density measurements were

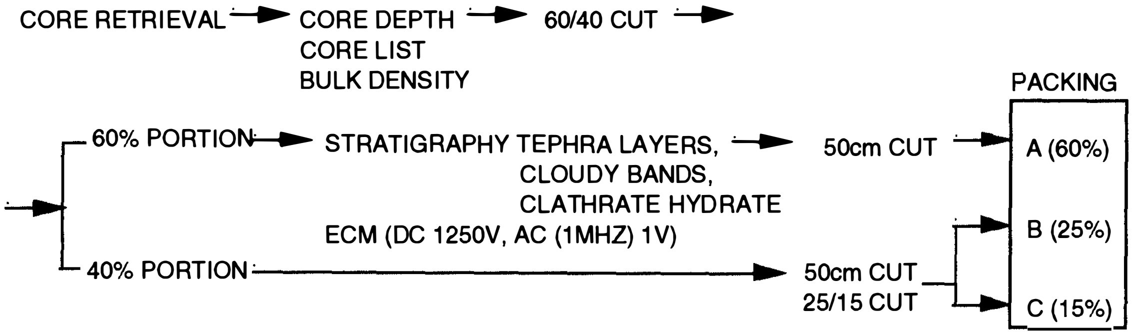

Fig. 5. Flow chart for the ice processing.

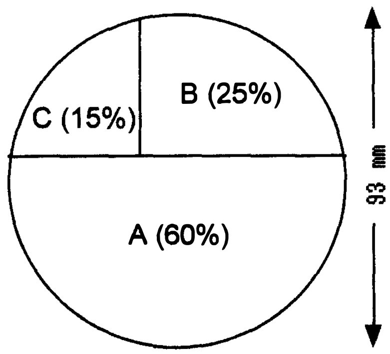

Fig. 6. Cross-section of a core showing the cutting plan.

also made. Continuity of each core was confirmed at this stage. Then, the depth of each core was determined. Next, with a horizontal bandsaw, the core was cut into a 60% section marked A in Fig. 6, and a 40% section composed of B (25%) and C (15%). Section A is saved for future analyses. Section B is for physical and gas analyses. Section C is for stable isotope and chemical analyses. The latter cutting of the section B and section C was done just before final packing and after the 50-cm cutting in Fig. 5. After cutting the core into section A and the 40% section, the cut surface of section A was microtomed and several measurements were made, including an ECM measurement (Hammer, 1980), an AC-ECM measurement (Sugiyama *et al.*, 1995, 2000), and visual stratification measurements. In the visual measurements, we identified cloudy-bands, tephra layers, bubble features, and clathrate hydrate crystals. At this stage, section A still had the same length as it had when drilled, up to 2.4 m long. After these measurements were completed, both section A and the 40% section were cut into 50-cm lengths for packing and transportation. Then, the 40% section was cut into sections B and C. Before packing, we photographed sections A, B, and C together for each core, that is, each photograph had one A, one B and one C section.

4. Tunnel for processing

A tunnel was made next to the core storage as shown in Fig. 1. This tunnel, which was next to the drilling site, had a temperature between −20°C to −32°C. For the

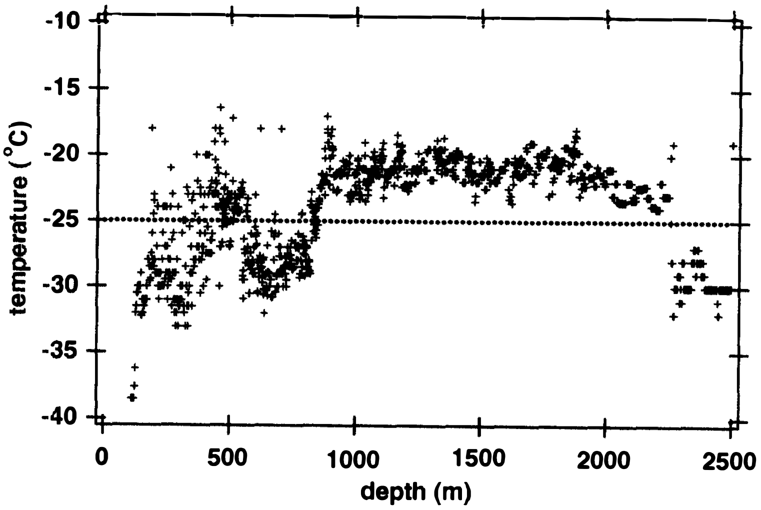

Fig. 7. Processing temperatures of ice core sections from different depths in the ice sheet. There temperatures are the same as those for the ECM measurements.

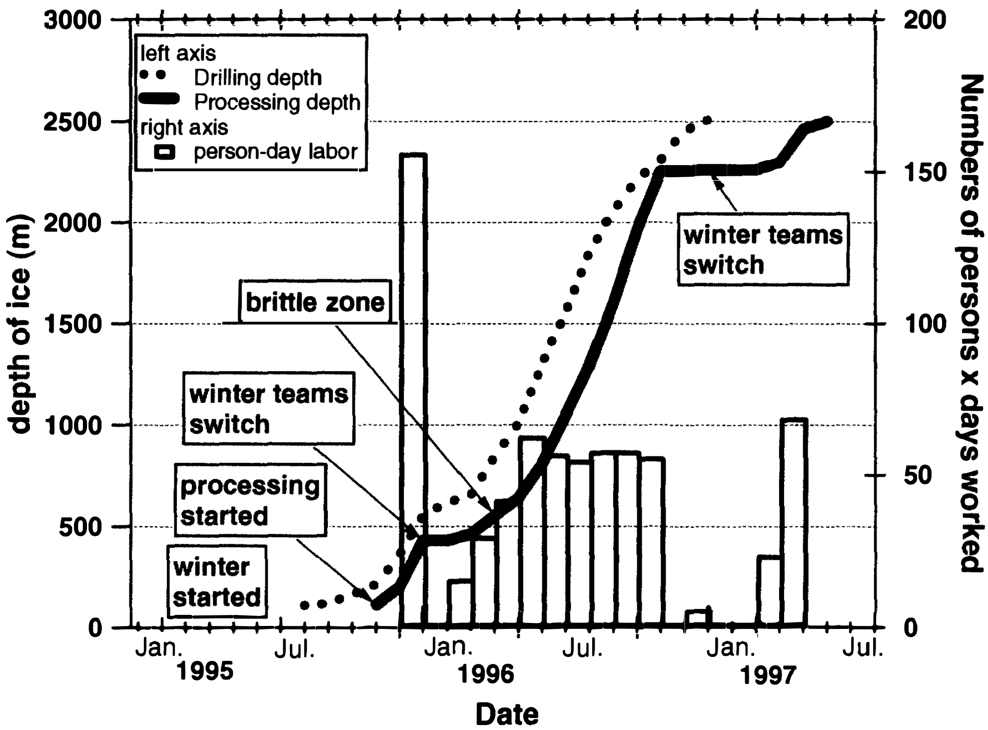

Fig. 8. The ice processing history. Typical processing speed per week varied from about 40 m/week in the brittle zone to about 80 m/week at ice depths deeper than the brittle zone. In contrast, the maximum drilling speed was about 70 m/week.

processing of cores from depths of 112 m to 850 m, the room (tunnel) temperature was not controlled. However, for the processing of cores from about 850 m and deeper, a heater was prepared in the room to keep the temperature at around $-21°C$, as shown in Fig. 7. This temperature control was required to stabilize the performance of the instruments and also the ice electrical properties.

5. Total amount of work

The processing of ice cores from depths of 112 m to 2503 m used three winter teams for a total amount of 700 person-days labor (number of persons x days worked). The history of the processing is shown in Fig. 8. The first winter team was the 36th Japanese Antarctic Research Expedition (hereafter, JARE), who worked from January 1995 to January 1996 to set up the processing site. They constructed snow tunnels and installed the instruments. They started processing in October 1995. In December, they did highly concentrated work in order to increase the amount of cores transported to Japan. Following JARE-36, the next winter team continued the work. At the initial stage from January 1996 to May 1996, the processing speed was slow because they were trying to make an optimum work environment and also because ice was from the brittle zone until they reached a depth of 870 m. For each winter team, a glaciologist and one or two assistants did the processing. The period from November 1996 to January 1997 was used to prepare the cores for transportation and also for glaciological work such as radar soundings (Fujita *et al.*, 1998). Finally, the third winter team, JARE-38, worked from January 1997 until January 1998 to complete the ice processing.

6. Manning of the station

Each of the three wintering teams had 9 members. As an example, the JARE-37 team was composed of two researchers in glaciology, two drillers, a meteorologist who was also a radio operator, two mechanics, a cook, and a medical doctor. All of them worked on both the drilling and the ice core processing, in rotation. One of the researchers worked only on the drilling as a chief. Another researcher worked only on the ice core processing also as a chief for it. On a given day, there were typically three teams, two teams each having two people working on the drilling, and the other team having two or three people working on the ice core processing. Each of the two drilling teams worked 8 hours. Except for the two chiefs, everybody did everything.

7. Details of the processing

Here, we describe specific details of the procedure. For processing of the ice, each core sample was moved from the core storage to the processing room. Because of the typically 20°C temperature difference between these two rooms, this moving was always done one day before any measurements to stabilize the temperature of the sample. Varying low temperatures can seriously affect properties of ice, particularly the electrical properties. On a given day, we processed a core length between about 2 m and 15 m, depending on the core quality. The ice core quality was excellent from the drilling until the horizontal cutting: there was no fracture for the entire depth range. Butyl-acetate, the borehole liquid that covered the core surface when the core was recovered (Fujita *et al.*, 1994), immediately disappeared by evaporation when we brushed off the core slush from the surface. We did not find any problems related to this borehole liquid in the ice core processing line. At the drilling site, we did not find particular problems either. As was suggested in our previous report (Fujita *et al.*, 1994), we made sufficient ventilation at the

Fig. 9. Recording the core's condition and labeling the core at the initial part of the processing line. The operator is checking the continuity and orientation of each successive core segment. The operator then determines the official depths of cores by considering the length of each core and also the drilling records.

drilling site; the drillers had sufficient liquid-proof clothes and goggles to prevent direct exposure to the liquid.

By measuring the diameter, length, and weight of the core, we calculated the bulk density. In addition to this bulk density measurement, we did a precise measurement using the floating method (Hondoh *et al*., 1999) for six portions of the 2503-m ice core. Precise data are important to determine density-relaxation processes after core recovery. A photo of this part of the processing line is shown in Fig. 9.

The horizontal core cutting into 60% and 40% sections was the most time-consuming procedure in the processing line (see Fig. 10). Hence, it determined the processing speed. Two major problems were found. One is core fracture that often occurred for depths between 500 and 870 m. This zone roughly agreed with the fracture zone that was predicted in advance (Shoji *et al*., 1994). More details of the fracture zone are described later. The second major problem was the high fracture rate of bandsaw blades. For processing 2 to 15-m lengths, we needed to change the bandsaw blades because they were broken. We suspect that this very high fracture rate might be due to the low temperature of the room (see the depths below about 850 m in Fig. 7). This was one of the reasons

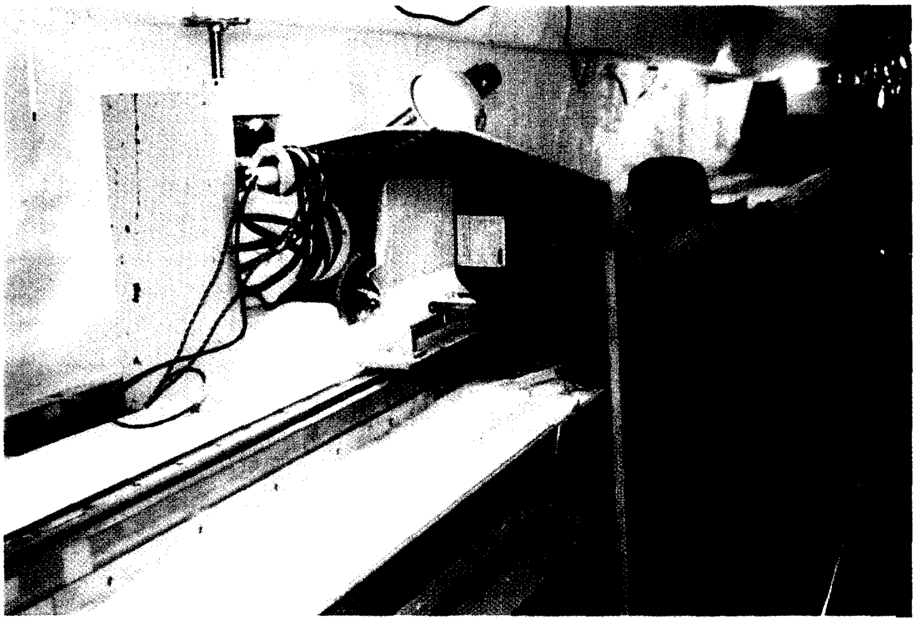

Fig. 10. Horizontal cutting.

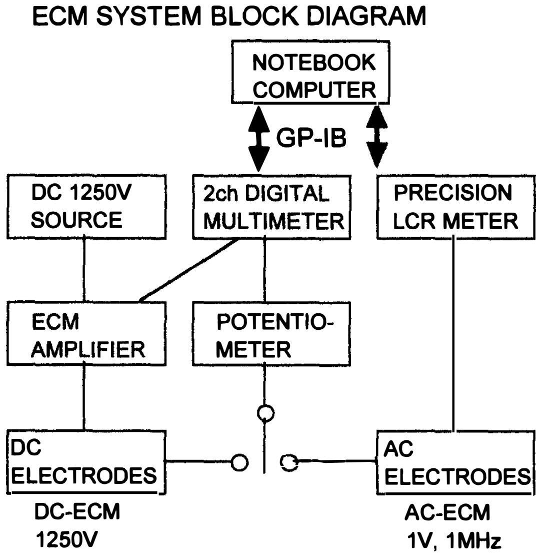

Fig. 11. ECM system block diagram.

that we raised the room temperature to about −21°C for processing ice that was deeper than about 850 m. All of the bandsaw cutting was done manually, and without any automatic cutting system. Considering the two major difficulties in cutting that we experienced, future development of an automatic cutting system will be very useful to liberate the operators from the time consuming process. We used the bandsaws INCA model EURO 260 and INCA model EXPERT 500. The bandsaw blades were LUNA model 8766-0700 and model 8766-1005.

After separation by a horizontal bandsaw, the flat surface of section A was microtomed. Using the flat surface as a window, the stratification was observed visually.

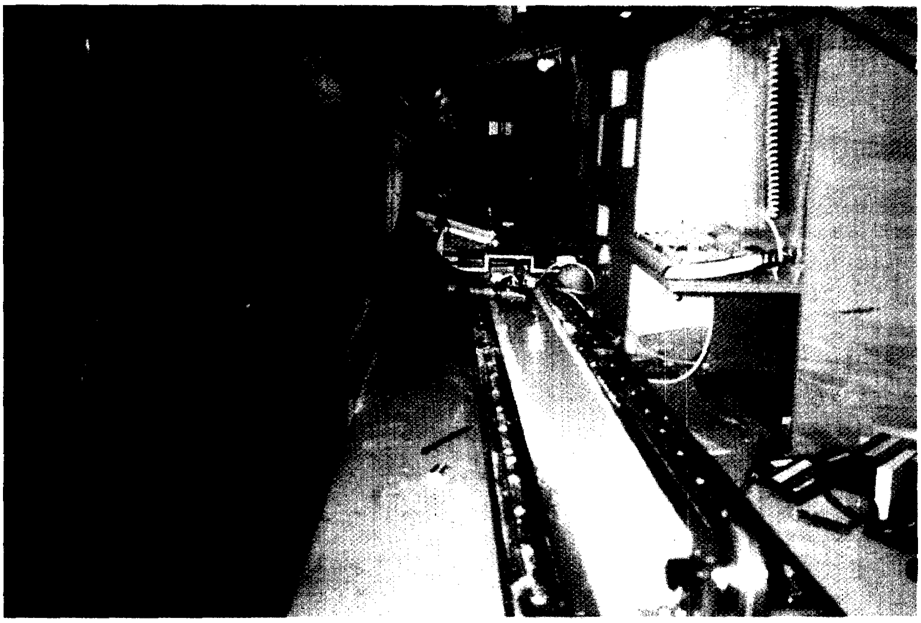

Fig. 12. ECM measurement. The operator drags electrodes along the ice core surface. Both the position of the electrodes and the electrical current between the two electrodes were recorded in a portable computer. For all core sections, we first measured the AC loss factor (AC-ECM, 1 MHz, 1 V) and then the DC current (DC-ECM, DC, 1250 V).

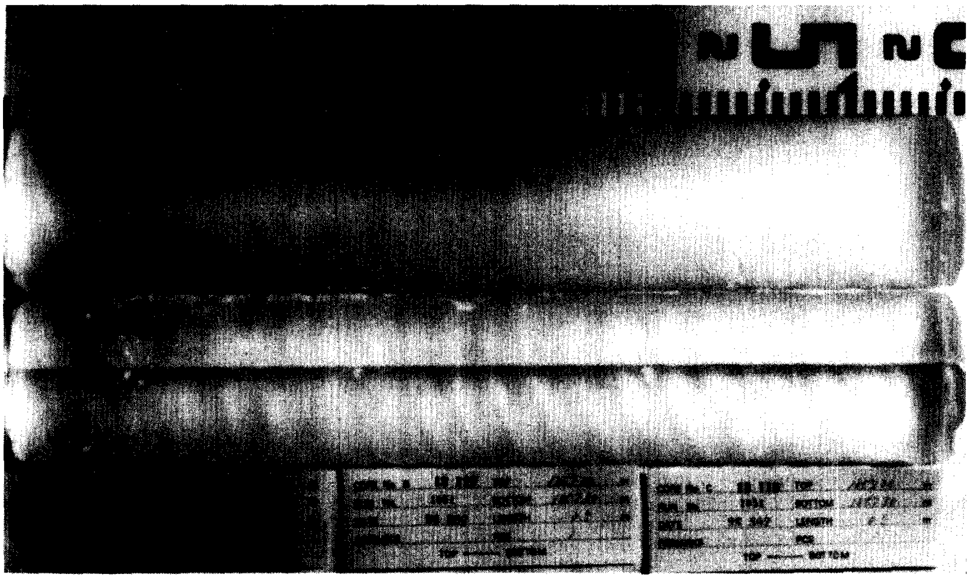

Fig. 13. An example of a photo taken at the end of the processing line. Images of sections A, B, and C were recorded with core labels. This is the last opportunity to see all A-C sections together. After taking this picture, the sections were packed for transportation. Each portion was then transported to different laboratories.

We identified more than 25 tephra layers and more than 2000 cloudy band layers. Both ECM and AC-ECM electrical stratigraphy measurements were then done on this surface. The measurements were done using the lengths of the ice core pieces as they were drilled (varying length). A schematic of the electrical measurement system is given in Fig. 11.

Fig. 14. The operator is packing cores into plastic bags.

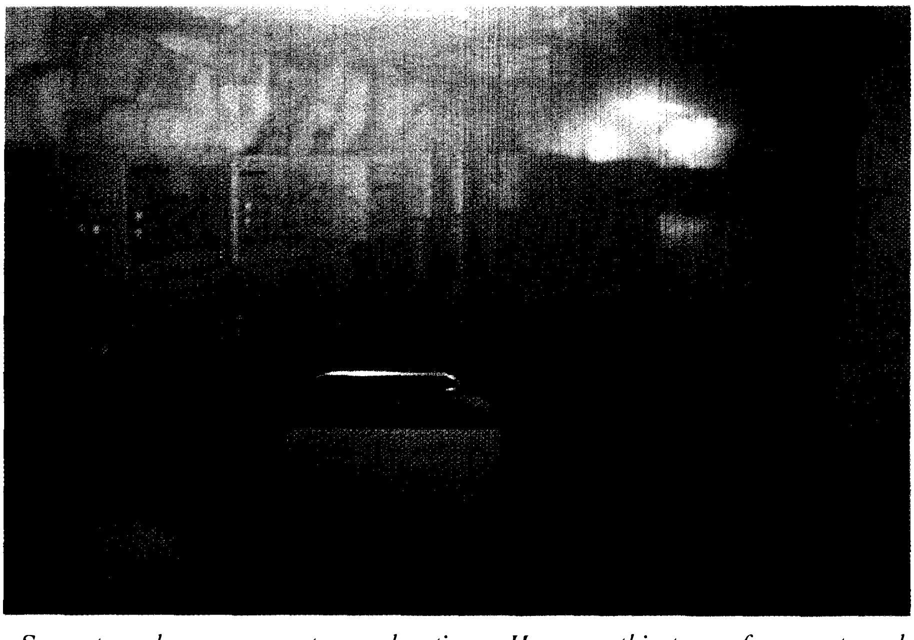

Fig. 15. Snow tunnel as a core storage location. However, this type of snow tunnel is very dangerous because the roof can easily collapse. See details in the text.

Using the same surface, AC measurements were done first using a voltage of 1 V and a frequency of 1 MHz. Then, DC measurements were done using 1250 V. Figure 12 shows a picture of this measurement in the processing line. The minimum resolution for data sampling was always less than 2 mm.

After these measurements were completed, the 40% portion was cut into sections B and C. For packing and transportation, all of the A, B, and C sections were cut into 50-cm long segments. Before packing, we photographed sections A, B, and C together for each core as shown in Fig. 13. Figure 14 shows the packing procedure.

After processing, the cores were packed in boxes and stored in a snow tunnel (Fig. 15) with a temperature below $-50°C$. Unfortunately, a few months after construction of this tunnel, most of the roof fell down and the cores were temporarily buried by snow and firn. Because the thickness of the roof exceeded 1 m in places, the collapse was very dangerous. This accident happened because snow and firn does not have sufficient strength at low temperatures. The sintering that connects ice particles does not generally occur in such inland stations in Antarctica. Because a collapsing roof can cause serious injury, one should never make such a wide snow tunnel like that in Fig. 15 unless sufficient supports for the roof are added.

8. Core quality

Finally, we mention core quality. Throughout the drilling and storage, core fractures mostly occurred during horizontal cutting. While cutting ice core from the bulk into the 50-cm long segments of A, B, and C, ice was brittle in the depths between about 500 m and 870 m. During the perpendicular cut, the fracture still occurred. We recorded the number of fractures that occurred while processing each 50-cm of the core. The data are plotted in Fig. 16. During a given cut, there could be from one to seven fractures. The ice was the most brittle at depths between 680 m and 870 m. In this depth range, for example, it sometimes took more than one hour to cut a 2-m long core horizontally.

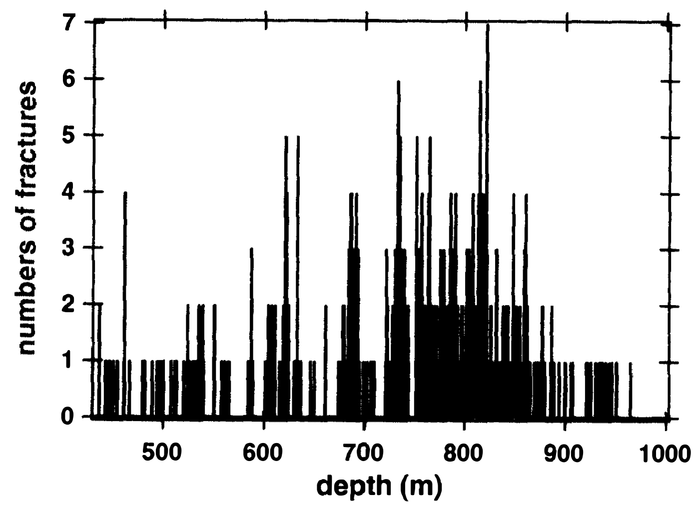

Fig. 16. Number of fractures while processing 50-cm-long ice cores in the brittle zone. All fractures occurred during horizontal cutting with the bandsaw. Cores from depths between 680 m and 870 m were the most brittle.

Operators needed to use extreme care; still, the fracture rate depended on the operator's skill. Therefore, the data in Fig. 16 show the general tendency of brittleness in each depth range; but the actual numbers depend on the operator's skill. Thus, this core cutting was generally the rate-limiting process in our processing line. We made no distinction in processing between brittle zone and non-brittle zone. That is, we processed the entire ice core from the shallower part to the deeper part without any distinction. The authors found that in 2001 in Japan, ice cores from the brittle zone were still as brittle as they had been at the processing line at Dome F station in 1996. It seems that five years preservation at a temperature of $-50°C$ at Hokkaido University did not change the brittleness of the core.

As for inclusions, the shallowest depth where clathrate hydrate crystals were found was around 480-490 m. Cloudy bands also started to appear from this same depth range. Ice was brittle below this and until the 870-m depth. Below 870 m, the core quality dramatically improved. After this depth, core processing started to catch up with the drilling speed (see Fig. 8). We found no problems with using butyl-acetate as the borehole liquid: the core quality, the ice measurements, and the operators' work environment all seemed unaffected by use of this liquid.

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