

## BOTTOM TOPOGRAPHY AND INTERNAL LAYERS IN EAST DRONNING MAUD LAND, EAST ANTARCTICA, FROM 179 MHz RADIO ECHO-SOUNDING

by

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### ABSTRACT

Extensive echo-sounding was carried out in east Dronning Maud Land during the 1984 field season. A 179 MHz radar with separate transmitting and receiving antennae was used and the echoes were recorded by a digital system to detect minute reflections. The results gave cross-sections of the ice sheet along traverse routes from lat. 69°S. to 75°S. Detailed observations on the ground at Mizuho station showed that there was elliptical polarization in the internally reflected echoes when two antennae, kept in parallel with each other, were rotated horizontally. The internal echoes were most clearly distinguished when the antenna azimuth was oriented perpendicular to the flow line of the ice sheet. The internal echoes with a high reflection coefficient were detected at depths of 500–700 m and 1000–1500 m at Mizuho station. Since a distinct internal echo at a depth of 500 m coincides with a 5 cm thick volcanic ash-laden ice layer found in the 700 m ice core taken near the observation site, these echoes may correspond to the acidic ice layers formed by past volcanic events in east Dronning Maud Land.

### INTRODUCTION

The Japanese Antarctic Research Expedition (JARE) has carried out extensive glaciological work in the inland area of east Dronning Maud Land since 1982. During the last two seasons, radio echo-sounding was conducted at the lower altitudes (Nakawo and others 1984; Nishio and others 1986). They used 60 MHz radar for the ground survey and 179 MHz radar for the airborne survey.

The authors carried out the ground survey by 179 MHz radar at the higher altitudes during the 1984 field season. A-scope data were recorded every 10–20 km along the new traverse route (Fig.1). The object of the observations was to measure the ice thickness along the route and the positions of the internal echoes.

### RADAR SYSTEM

The radar transmits a 1.5 kw (peak) pulse in a repetition frequency of 1 kHz. The receiver has a sensitivity

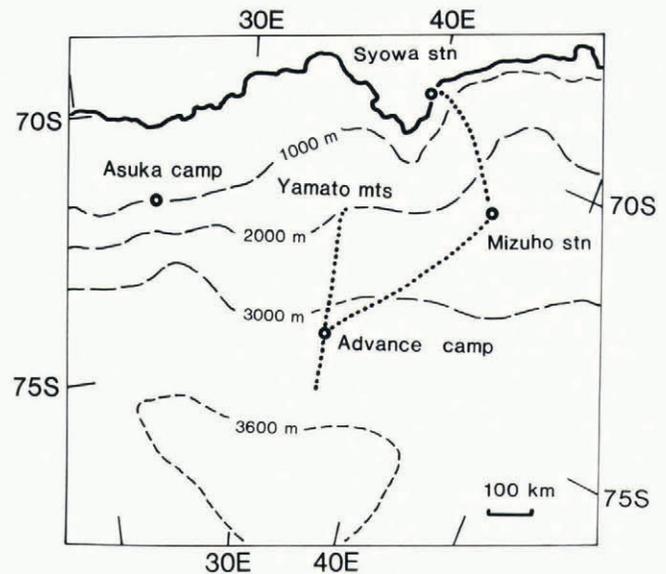


Fig.1. Inland traverse route during 4 October–5 December 1984.

of  $-104$  dBm, whose receiving frequency is  $179$  MHz  $\pm$  2.5 kHz. Six-element Yagi antennae were used as the transmitting and receiving aeriels which had linear polarizations. These antennae were set up on the snow, maintaining parallelism to each other at a distance of 3 m during the observations.

Wada and others (1982) reported that this radar with a three-element Yagi antenna failed to detect echoes from the bed deeper than 1500 m when the radar was used for airborne surveys. In order to detect minor echoes, we have analyzed the A-scope data by a digital recording system. After having been digitized at 50 ns intervals, 256–512 received echoes were stacked in a memory to eliminate random noises. The A-scope echo shown on the CRT was also recorded as a photograph which was exposed for 20–30 s. This photographic film also represents the optically averaged echo from 20 000–30 000 received signals.

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RESULTS AND DISCUSSION

The radar system successfully detected all of the echoes from the bed along the route. Fig.2 shows a cross-section of the ice sheet along the traverse route obtained both by the echo-sounding and the surveyed altitudes of the ice

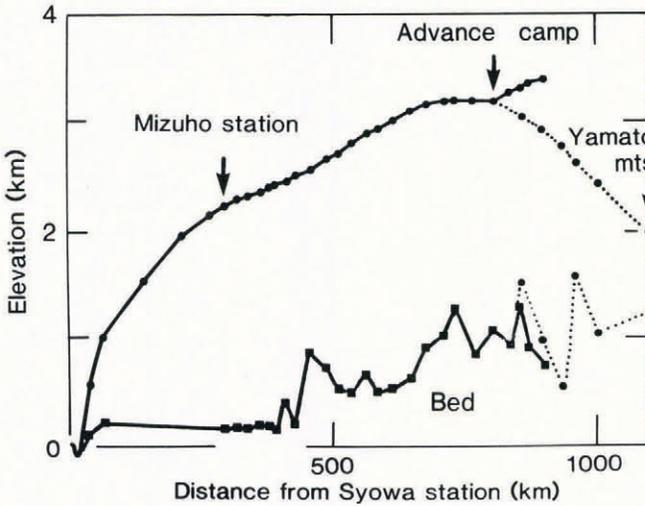


Fig.2. Cross-section of the ice sheet along the traverse route. Surface elevations of the ice sheet are based on the data of Fujii and others (1986).

surface. The ice thickness was determined by the echo time from the bed, assuming that the radio-wave velocity in the ice is 169 m/μs. The bed elevations in latitudes lower than 72°S. are 100–200 m a.s.l. In the higher-latitude area, the bed elevations increase to 500–1000 m and the bottom topography is extremely rough. The thickest ice along the route was 2650 m at lat. 75°S. The traverse party of JARE-26 extended this route to lat. 78°S. in 1985 and reported 3500–4000 m thick ice there (personal communication from K. Kamiyama).

The observations on the internal echoes were carried out at Mizuho station (lat. 70°42'S., long. 44°20'E., 2230 m a.s.l.). Although polarization in the ice sheet, observed when the transmitting antenna was rotated around the fixed receiving antenna R, has been reported in a number of papers (e.g. Hargreaves 1978, Woodruff and Doake 1979), few observations on polarization when two aerials are kept parallel to one another have been reported (e.g. Bentley 1975). Furthermore, these reports are based on analyses of the bottom-reflected signals; it seems that there have been virtually no reports on polarization resulting from internal echoes. Since the bottom-reflected echoes are affected not

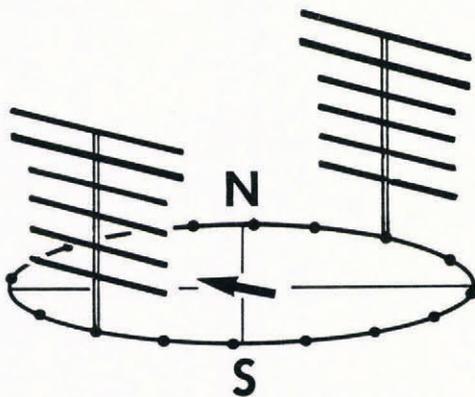


Fig.3. Setting of the antennae. The ice-flow direction is shown at the center. This direction is equal to that of the principal axis of the extending strain of the ice sheet (Naruse and Shimizu 1978).

only by the birefringence of the ice but also by the morphology of the glacier bed (Berry 1975), it is necessary to analyze the internal echoes in order to determine the birefringence of the ice body itself. We observed the A-scope data for the internal echoes, when the receiving antenna was rotated around the transmitting antenna, and kept parallel to one another at a distance of 3 m. Measurements were repeated at 22.5° intervals (Fig.3). In order to evaluate the relationship between the polarization and the strain of the ice sheet, the antennae were installed on the snow at the center of a strain-grid which had been set up for observation of the strain-rate of the ice sheet.

Fig.4 shows the noise-reduced A-scope data at the same travel-time (depth) scale which clearly indicates

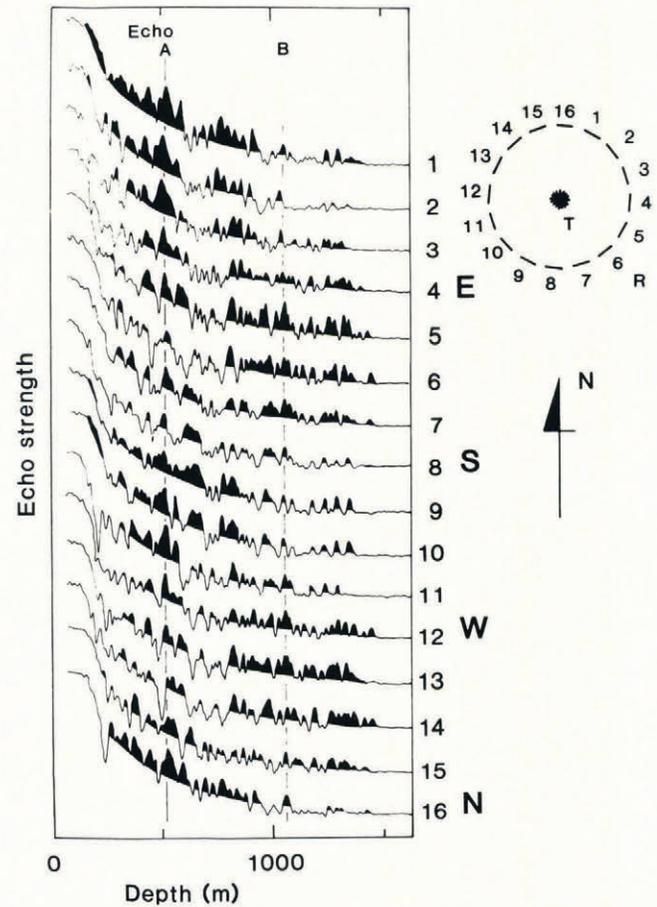


Fig.4. Internal echoes at 16 different antenna azimuths observed by A-scope data. Echo strengths above the average level of the 16 data sets obtained by A-scope are coloured dark. R and T represent the two parallel antennae, receiving and transmitting aeriels, respectively. The observation was carried out in May 1984.

polarization of a radio wave in the ice sheet. The internal echoes from a depth of 1000–1500 m are strongest when the receiving antenna R is situated at east-south-east from the transmitting antenna T (No. 4, 5, 6 in the illustration) or west-north-west (No. 12, 13, 14).

In order to analyze the echo strength with respect to the antenna azimuth, two internal echoes at depths of 500 m (echo A) and 1050 m (echo B) were chosen. Fig.5 shows the results. Both echoes A and B show an elliptical pattern, which confirms the birefringence of the ice sheet. The difference between the maximum and minimum echo strengths is a gain of 7–10 dB, which is a significant value for the receiver sensitivity.

The A-scope records in Figs.4 and 5 indicate that the internal layers could be most clearly distinguished when the azimuth was perpendicular to the flow line. The internal echo from a depth of 1050 m (echo B) became strongest

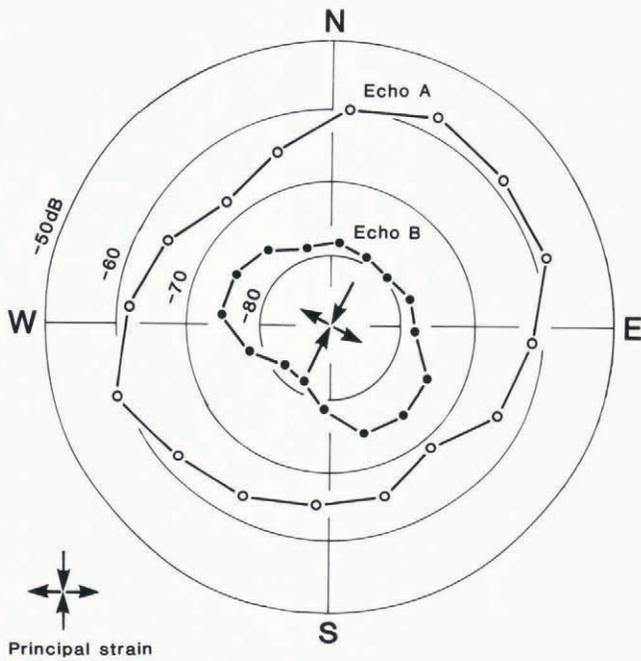


Fig.5. Echo strength as a function of the direction of the two parallel antennae. The positions of echo A and echo B are shown in Fig.3. The directions of the principal strain axes of the ice sheet observed at the same time are shown at the center of the circle graph.

when the antenna azimuth faced  $030^\circ$  or  $210^\circ$  (R was situated at  $120^\circ$  or  $300^\circ$  (from T)). This antenna azimuth is very close to that of the principal compressive strain of the ice sheet, which is perpendicular to the flow line at the observation site. This coincidence of the azimuth may suggest that the birefringence was caused by the ice flow. Narita and others (in press) have examined the 700 m deep ice core from Mizuho station and have reported that the c-axes of the ice crystals below 400 m depth become aligned along the vertical plane. It is plausible that the strain history of the ice has caused this orientation fabric, which may determine the birefringence of a polycrystalline ice sheet as Hargreaves (1978) has argued in a theoretical study.

Another possible cause of this polarization could be explained by the depositional pattern of the internal layers. Internal layers, such as volcanic ash layers, probably have prolonged patch-patterns due to the strain deformation of the ice sheet. The reflection coefficients of these irregular patches would depend on the azimuths of the antennae.

Millar (1981) has analyzed the internal echoes in the Greenland ice sheet and he concluded that the internal echo layering was formed by layers of ice of changed composition, which are probably composed of acidic ice formed after volcanic eruptions. Since we have found a 5 cm thick volcanic ash-laden ice layer at Mizuho station (Narita and others in press), the A-scope record when the antenna azimuth was perpendicular to the flow line has been compared with the position of the ash-laden ice layer. The result (Fig.6) represents a strong echo up to 20 dB peak at the depth of the volcanic ash-laden ice layer. This coincidence suggests that the echo strength/depth profile corresponds to acidic layers caused by past volcanic activity in east Dronning Maud Land.

Although dating of the ash-laden ice layer at 500 m depth has not yet been completed, from the annual accumulation rate of 7 g/year at Mizuho station (Watanabe and others 1978) the age can be estimated as  $\sim 8 \times 10^3$  year B.P. Other internal layers with high reflection coefficients seem to be located at 1000–1500 m depth. The ages of these ice layers can be estimated as between 20 and  $40 \times 10^3$  year B.P. These ages of the internal layers seem to coincide with those of volcanic ash bands found in the ice core at Byrd Station (Gow and Williamson 1971); this coincidence

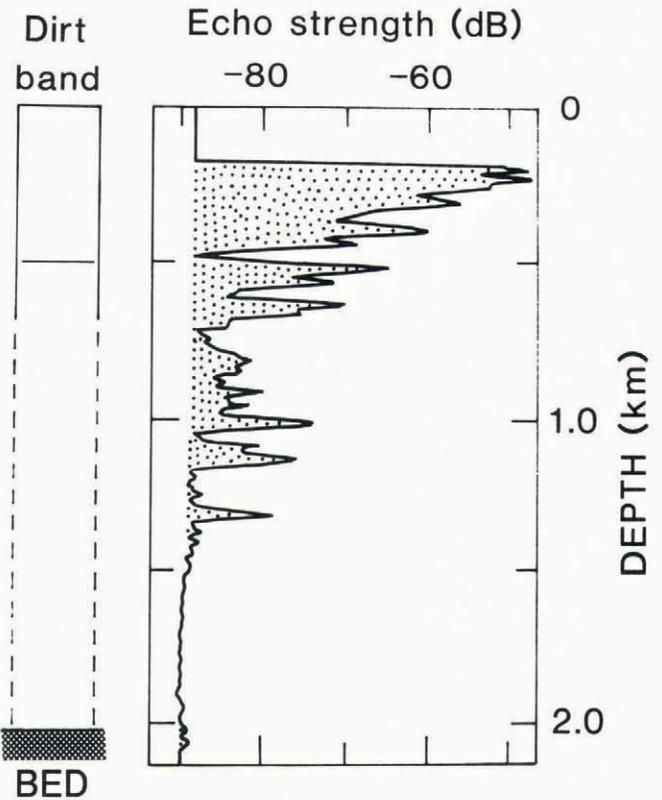


Fig.6. Internal echo and the depth of the volcanic ash layer at Mizuho station. The antennae azimuths were perpendicular to the direction of ice flow. Echo sounding was carried out in December 1984.

may suggest the extensive fall-out of acidic aerosols on the Antarctic ice sheet. Further echo-sounding of internal layers will undoubtedly reveal the areal distribution of these volcanic ash layers during the last glaciation.

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