Annals of Glaciology 10 1988

INVESTIGATION OF THE ¹⁸O CONTENT OF A 100 m ICE CORE FROM THE RONNE ICE SHELF, ANTARCTICA

by

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ABSTRACT

A 100 m ice core from the Ronne Ice Shelf, drilled during the 1983–84 field season, was dated by isotopic stratigraphy, using the well-known seasonal variation in the ^{18}O content in firn and ice; the layers at a depth of 89 m are probably 400 years old. Layer thicknesses deduced from the ^{18}O profile indicate short-term variations of the snow-accumulation rate over the last 400 years. The area of deposition of the material recovered with the core is estimated by a two-dimensional flow model and by the ^{18}O content of the core, which decreases from −27.5‰ in the upper part of the core to −32.0‰ at 89 m depth.

INTRODUCTION

The glaciological and geodetic field work done in the eastern part of the Ronne Ice Shelf during the German Antarctic expeditions has provided recent data on snow accumulation, necessary for mass-balance studies; on the ^{18}O content of the near-surface layers, as a tracer for atmospheric water transport; on the 10 m firn temperature, representing the mean surface temperature (Reinwarth and Graf 1985); and on flow velocities and strain-rates of the ice shelf (personal communication from B. Ritter, 1986). Ice-core analysis provides information on the variations of these parameters in the past.

SAMPLING

In the 1983–84 field season the Filchner-I Traverse was carried out from Filchner Station to point 341 (Fig.1). At the grid points, snow-pit studies were carried out in addition to surveying, and samples were taken for measurement of the ^{18}O content of the near-surface layers, in order to determine the annual accumulation rates in this area by isotopic stratigraphy (Reinwarth and Graf 1985).

The ice core was drilled in the south-eastern part of the Ronne Ice Shelf at grid point 340, at a distance of 220 km from the ice edge. Drilling was performed with equipment designed by Rufli (University of Bern, Switzerland) and built and operated by the University of Bochum. With this equipment, bore-hole depths of 200 m or more can be reached. The depth of the bore hole at point 340 was limited to 100 m because of the restricted time available at the drilling site. The recovered cores, 3 inches in diameter, were generally of high quality. From 70 to 75 m only broken cores, disks and to some extent just chips were brought to the surface. After changing the type of knives on the drill, cores of very good quality continued to be recovered.

EXPERIMENTAL RESULTS AND DISCUSSION

Unfortunately the core melted in part, due to a failure of the power supply to the freezing chamber. Investigations were carried out to determine to what extent the isotopic signal was affected by this event.

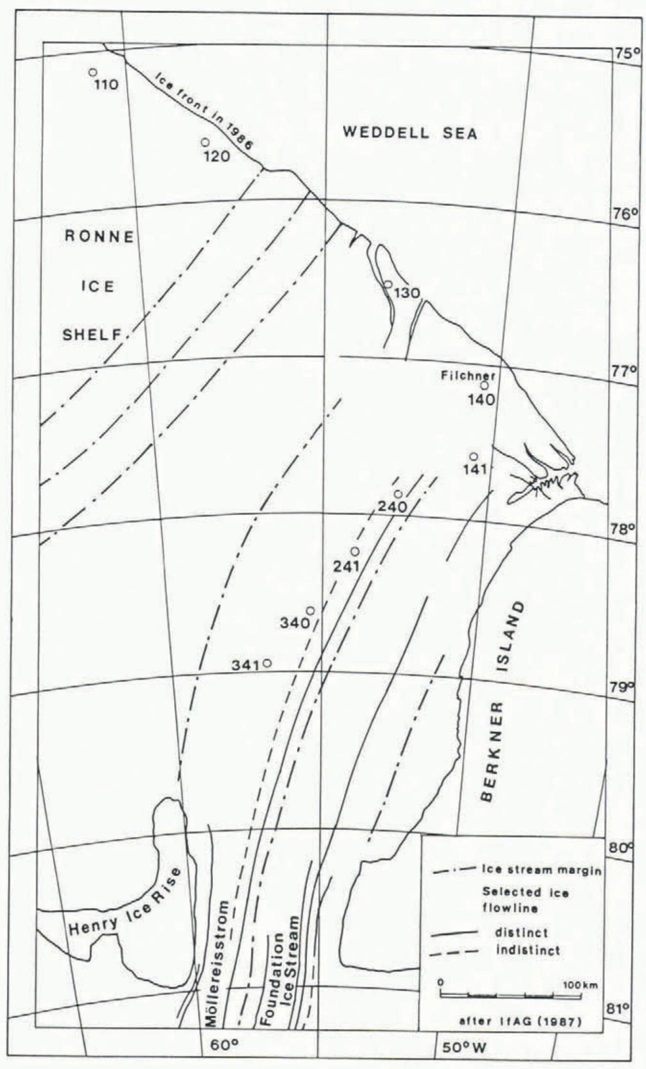

Fig.1. Location of the sampling points on the Filchner–Ronne ice shelves (map after IfAG 1987).

https://doi.org/10.3189/S0260305500004146 Published online by Cambridge University Press

The refrozen firn cores consisted of compact ice with firn grains embedded in the lower half of a cross-section; the upper half of the cross-section was firn. For a preliminary check, selected cores were cut into disks and the firn and ice portions of these disks were treated separately to determine their ^{18}O content. The ^{18}O content of the firn portion (Fig.2), indicated by a thicker line, is in general somewhat higher than the ^{18}O content of the ice part of the same disk. This difference can easily be explained by isotopic fractionation during melting (Dansgaard 1964). The melt water became depleted in ^{18}O compared with the firn and also the lower part of the refrozen core, which was impregnated by the melt water. The shape of the two curves is very similar and seasonal variations can be seen in both ^{18}O profiles. But the disappearance of the weak maximum in the ^{18}O profile of the ice at 13.3 m depth indicates that time-scales deduced from the entire profile may be inaccurate by 20 years or more.

In further analysis the firn and the ice portions of the core were no longer dealt with separately. The cores were sub-sampled in such a way that an annual layer was represented by at least ten samples. The samples were melted and analyzed for their electrolytical conductivity and their ^{18}O content.

Figure 3 shows the ^{18}O profile of the ice core; the last 11 m of the core, from 89 to 100 m, have still to be analyzed. This depth range should produce the best isotopic profile, because this part of the core is not affected by melting. Seasonal variations can be recognized along the entire profile. The range of the annual variation in the ^{18}O content amounts to 5–6‰ in the uppermost part and decreases slightly with depth. Firn or ice originating from summer precipitation is dark-coloured. It is characterized by a higher ^{18}O content than the material deposited during the winter. The base line, as shown in the profile, represents the variation in the mean annual ^{18}O content and may perhaps include some climatic information.

Though the core was measured in sufficient detail, the profile shows no marked variations in the depth range between 20 and 40 m, obviously due to the melting of the core. The seasonal variations in the isotopic content in this part of the core have almost been obliterated, and the interpretation of the corresponding profile is ambiguous. Along the whole profile 340 annual layers can be detected clearly; in addition, 60 years of accumulation should be inserted, if weak maxima are interpreted as boundaries of annual accumulation, so that the layers at 89 m depth are probably 400 years old.

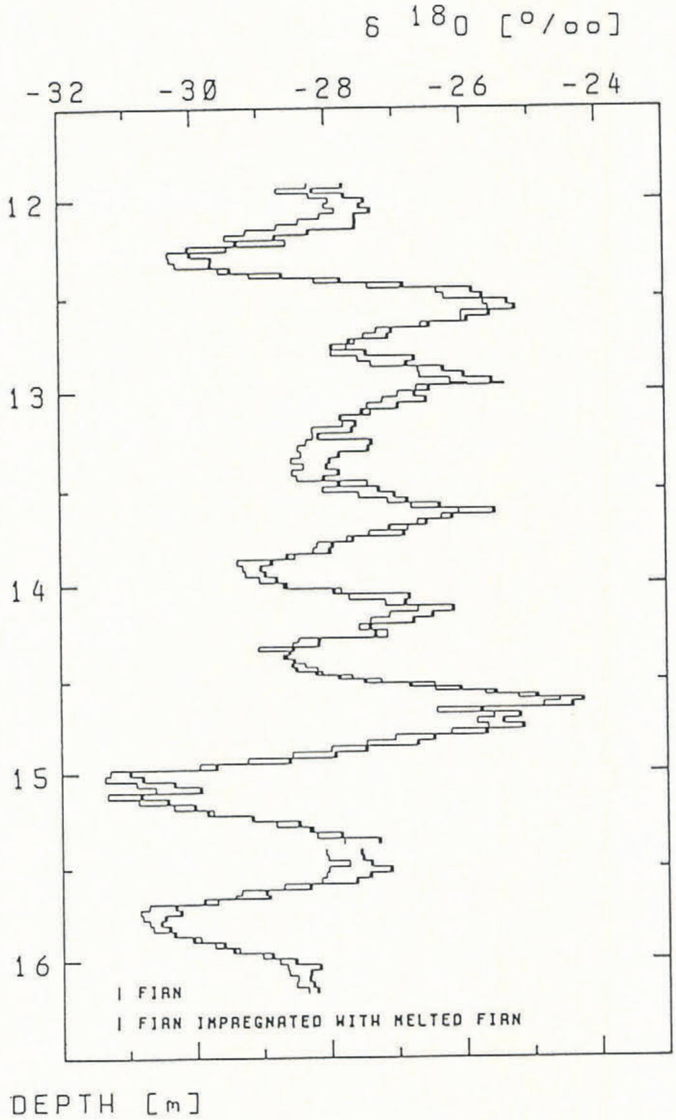

Fig.2. Ice core T340 drilled in 1984 at the Ronne Ice Shelf. ^{18}O profiles of firn and ice portions of the partially melted core melted between 12 and 16 m depth.

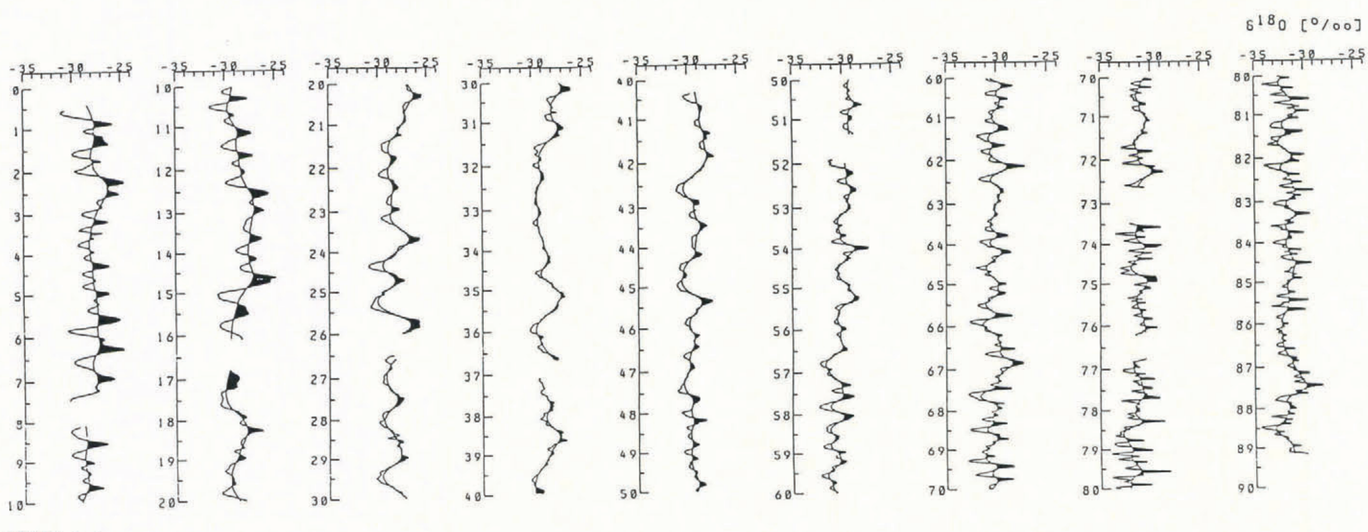

Fig.3. Ice core T340 drilled in 1984 at the Ronne Ice Shelf. ^{18}O profile of the ice core T340 between 0 and 89 m depth.

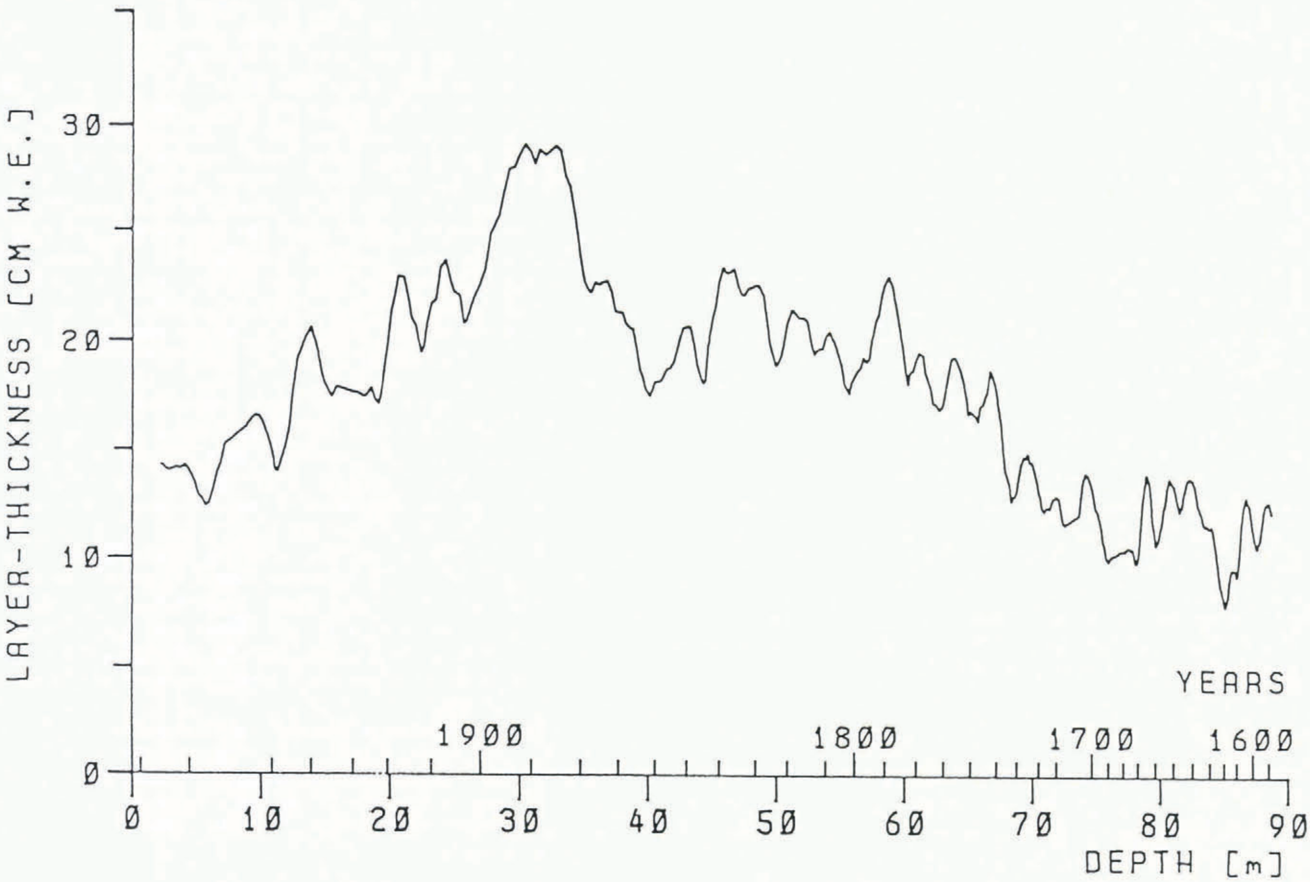

Fig.4. Thickness of the annual layers deduced from the ^{18}O profile of the ice core T340, as a function of depth and time respectively.

Using this dating and the density–depth relation

$$\rho(z) = 0.92 - 0.58 \exp(-0.033z) \quad (1)$$

ρ being the density (g/cm^3) and z the depth (m), the thickness of the annual layers (cm water equivalent) was calculated as a function of depth and time respectively (Fig.4). The thickness of the layers represents the lower limit of the accumulation rate in the area of deposition of the material recovered in the core, because it is most likely that the ice shelf thinned as it moved towards the ice edge. Without knowing the modification of the ice shelf due to the strain-rate since the time of deposition, the short-term variation in the layer thickness may be interpreted as a local and/or temporal variation in snow accumulation. Temporal and local effects can possibly be separated, if information about the recent accumulation rate in the catchment area of the core is available. The thickness of the annual layers is considerable between 20 and 40 m depth. Not every annual layer is likely to be detected in this range because of the weakness of the signals in the ^{18}O profile. Nevertheless, an increase in the accumulation rate since 1890 is also supported by results from the South Pole (Jouzel and others 1983).

The locations of deposits of the material recovered with the ice core can roughly be estimated by taking into account the decrease in the ^{18}O content of the core with depth, from −27.5‰ in the uppermost part to −32.0‰ in the lowest part of the core, due to the isotopic continental effect (Fig.5). This decrease can be compared with the change in the ^{18}O content of the surface layers along the traverse. The ^{18}O in these layers becomes progressively depleted with increasing distance from the ice edge. A gradient of 1‰ per 50 km was found in the northern part of the ice shelf (Reinwarth and Graf 1985). If this trend to lower isotopic values continues at a constant rate in the direction of the Foundation Ice Stream, the ice at the base of the core may originate from snow deposited between Berkner Island and Henry Ice Rise, about 230 km up-stream of the drilling site (Fig.1).

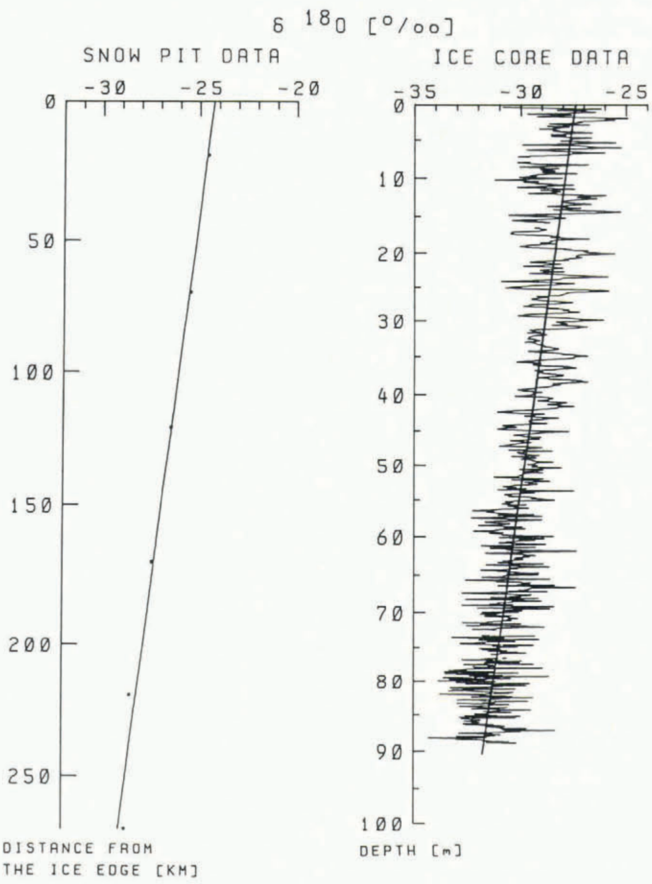

Fig.5. Estimate of the origin of the material recovered in ice core T340: the ^{18}O content of the surface layers along the Filchner-I Traverse, and the ^{18}O profile of the ice core as analyzed so far.

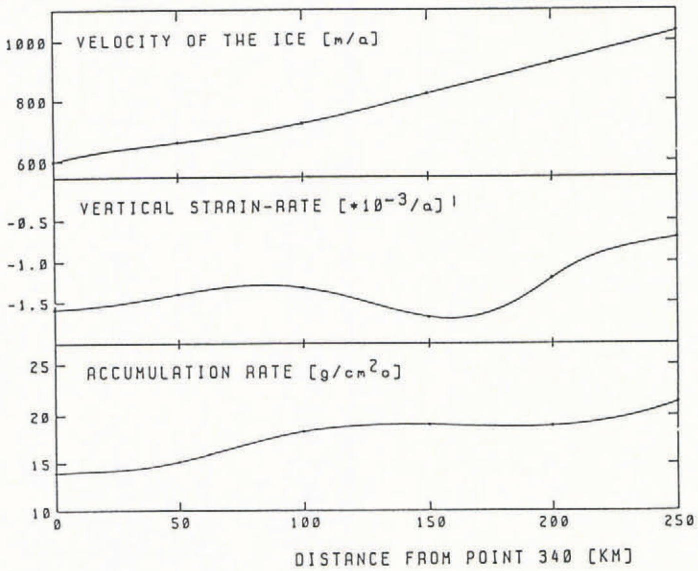

Fig.6. Parameters used to calculate the particle paths in the Ronne Ice Shelf along a flow line through the drilling site (measuring point 340 in Fig.1).

To get an idea of the annual layering in the ice shelf, a simple two-dimensional ice-flow model was adapted; it has been formulated to calculate the particle paths in the Brunt and Ross ice shelves, assuming steady-state conditions (Thomas 1973, Thomas and MacAyeal 1982). The parameters which must be known along a flow line are: the velocity of the ice, the vertical strain-rate, the accumulation rate, and the relation between firn density and depth. These model parameters are known for the measuring points of the Filchner-I Traverse, which more or less fit the flow line through the drilling site.

Figure 6 shows the local variation in the relevant parameters used in the calculations, assuming that the values at the measuring points hold for points along the flow line through the drilling site. The velocity of the ice increases as it moves seawards, from 600 m per year at point 341 to 1030 m per year at Filchner Station. The vertical strain-rate, derived from surface data and assumed to be constant throughout the ice shelf, ranges from -0.7×10^{-3} to -1.8×10^{-3} per year (personal communication from B. Ritter, 1986). The accumulation rates, as determined by snow-pit studies based on isotopic stratigraphy, decrease from Filchner Station to the interior of the ice shelf by about 40% (Reinwarth and Graf 1985). Up-stream of point 341, slowly decreasing ice velocity, a nearly constant strain-rate and a slight increase in the accumulation rate were assumed.

The calculated particle paths are shown in Figure 7. The bore hole at point 340 is indicated; the trajectory of the particles to the lowermost part of the hole, though somewhat doubtful because of the assumptions made, shows that only material deposited on the ice shelf itself could be recovered with a 100 m core. This result is also supported by the ^{18}O content of the core at 89 m depth. The ice takes about 340 years to move from point 341 to the ice edge. During this time a layer 72 m thick is accumulated. A particle at the bottom of the 100 m bore hole reaches the ice edge at a depth of about 120 m. Layers become thinner by about 35% as they move seawards, between point 341 and the ice edge.

Further drilling is planned on the Ronne Ice Shelf to provide more information on its structural features. New ice cores should recover ice originating from the Foundation Ice Stream, and even ice from the drainage basin which comprises the greater part of the Antarctic ice sheet (McIntyre 1986).

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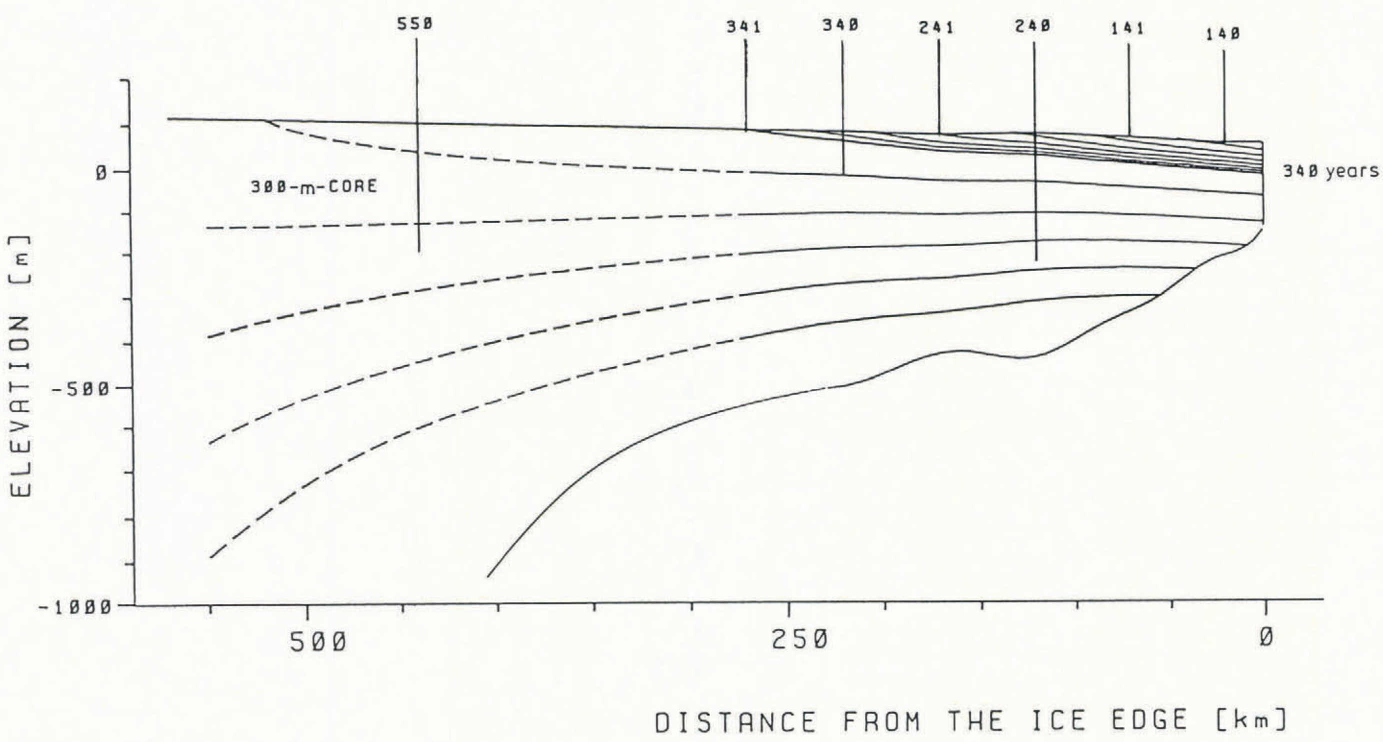

Fig.7. Particle paths in the Ronne Ice Shelf along a flow line through measuring point 340.

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