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Glaciological Investigations in the Grounding Line Area of the Foundation Ice Stream, Antarctica[1]

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Summary: During austral summer 1994/95, an extensive program of glaciological, geophysical and geodetic measurements along a flow line of the Foundation Ice Stream was carried out. The collected data are the basis for mass flux determinations in the entrainment area of the ice stream into the Ronne Ice Shelf. In this paper, the collected data and first results will be presented. During the expedition, 106 seismic soundings were performed to obtain information about ice thickness, water column thickness and the uppermost layered sea bed in the grounding line area of the Foundation Ice Stream. In addition, airborne radio echo soundings (RES) took place over the southeastern part of the Ronne Ice Shelf gaining more widespread information about the ice thickness. The ice thickness data derived from these different methods agree well. At the base camp at 83°10.0' S, 59°34.45' W, the supposed position of the grounding line, a gravity meter measured the tide induced vertical movement of the floating ice. The seismic and gravity measurements revealed floating conditions along the entire seismic profile. The radio echo sounding data indicate a position of the grounding line, which is some 40 km further south than expected. Therefore, the area of the Filchner–Ronne–Schelfeis (FRIS) is about 1700 km² larger than was previously thought. From the flow velocity and the ice thickness profiles perpendicular to the flow direction, a mass flux of 35 km³/a for the Foundation Ice Stream is determined.

Zusammenfassung: Während des Südsommers 1994/95 wurde entlang einer Fließlinie des Foundation Ice Stream ein umfangreiches Programm glaziologischer, geophysikalischer und geodätischer Arbeiten durchgeführt. Die gesammelten Daten dienen als Grundlage für Massenflußberechnungen im Einflußgebiet des Eisstromes in das Ronne Ice Shelf. Diese Daten, sowie erste Ergebnisse werden in diesem Artikel vorgestellt. Während der Expedition wurden 106 seismische Sondierungen durchgeführt, um Informationen über die Mächtigkeit des Eises, die Wassersäulenmächtigkeit darunter, und die obersten Schichten des Meeresbodens im Bereich der Aufsetzlinie des Foundation Ice Streams zu erhalten. Zusätzlich fanden über dem südlichen Teil des Ronne Ice Shelf Flugradarmessungen (RES) statt, um Informationen über die Eismächtigkeitsverteilung in dem Gebiet zu erhalten. Die Eismächtigkeiten, die mit Hilfe dieser unterschiedlichen Meßmethoden ermittelt wurden, stimmen gut überein. Am Basislager (83°10' S, 59°35' W), welches an der erwarteten Position der Aufsetzlinie errichtet wurde, registrierte ein Gravimeter die durch die Gezeiten verursachte vertikale Bewegung des Eises. Sowohl die seismischen als auch die gravimetrischen Messungen zeigen, daß das Eis entlang des gesamten seismischen Profils nicht mehr auf dem Untergrund aufliegt. Aus den Radarmessungen läßt sich schließen, daß sich die Aufsetzlinie etwa 40 km südlich von der bisher vermuteten Position befindet. Damit ergibt sich eine um 1700 km² größere Fläche für das Filchner-Ronne-Schelfeis. Aus den Fließgeschwindigkeiten und den Eismächtigkeitsprofilen senkrecht zur Fließrichtung des Foundation Ice Stream wurde ein Massenfluß von 35 km³/a für diesen bestimmt.

1. INTRODUCTION

The mass-balance of the Antarctic Ice Sheet, especially the outflow across the grounding line areas, is still a challenge for glaciological research in Antarctica. The basis for the examination of different drainage basins and the mass balance of the Antarctic Ice Sheet is a compilation of available data by GIOVINETTO & BENTLEY (1985). In this and a subsequent paper the authors point out that the mass flux across the grounding line of the ice streams is not well constrained by direct measurements. For the region of the Weddell Sea, LANGE (1987) determined the drainage from the inland ice by the mass flux across the front of the ice shelf. On the other hand, results from ice cores show that at the ice shelf front most of the material once deposited on the inland ice has already melted (OERTER et al. 1992). Calculations exist of the ablation at the base of ice shelves (JACOBS et al. 1992), but no comprehensive direct measurements especially in the area of the grounding line. To fill this data gap and to complete previous studies in the northern part of the eastern Ronne Ice Shelf, a glaciological and geodetic program on a flow line of the Foundation Ice Stream (FIS) (Figs. 1 and 3) was initiated during the „Filchner V" campaign in austral summer 1994/95. The aim was to study mass balance parameters such as the accumulation, ice thickness, surface topography, ice geometry, and their changes, as well as the water column thickness, in the area of the grounding line of the FIS. This ice stream contributes a major share of the total mass flux into the eastern part of the Ronne Ice Shelf (MCINTYRE 1986).

A cross section through the Ronne Ice Shelf along the traverse route (Fig. 2) based on the available data for the Filchner-Ronne-Schelfeis (FRIS; VAUGHAN et al. 1994), shows a lack of data in the grounding area of the FIS. Radio echo sounding profiles on FIS were flown in 1969–1970 by the National Science Foundation (NSF) and the Scott Polar Research Institute (SPRI) (ROBIN 1972), and in 1977–1978 and 1978–1979 by NSF, SPRI and the Technical University of Denmark (DREWRY & MELDRUM 1978, DREWRY et al. 1980). The radio echo signals from the ice shelf base collected during these flights varied in strength and quality. The presumed position of the grounding line at 83°10' S, where the base camp was installed during the 1995 field season, was based on the map of subglacial and sea bed topography of the Filchner-Ronne-Schelfeis (IfAG 1994). SPOT satellite data with a ground resolution of 10 m were also used to plan the traverse route.

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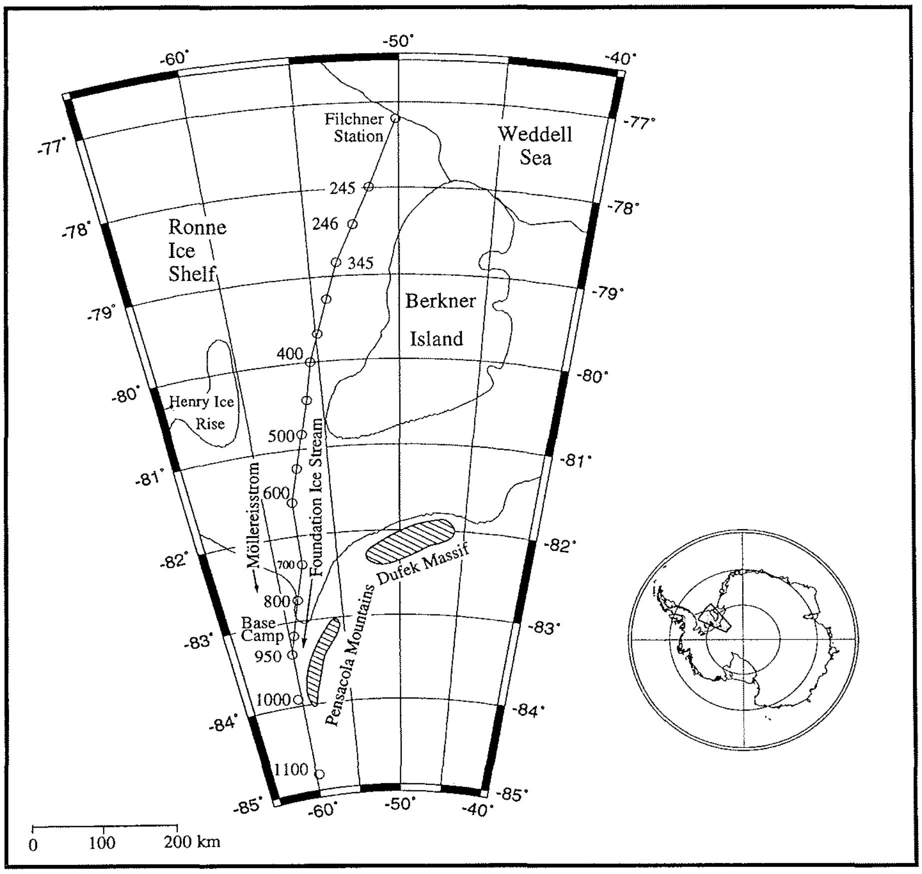

Fig. 1: Map of the eastern Ronne Ice Shelf. The traverse route from the summer base Filchner to the working area is shown as a line with small circles indicating the locations of firn core drillings. The base camp was established at 83°10.0' S, 59°34.45' W. The seismic soundings were made between point 800 and 950.

Abb. 1: Karte vom östlichen Ronne Ice Shelf. DieTraversenroute von der Filchner Station ins Arbeitsgebiet ist als Linie mit kleinen Kreisen eingetragen. Diese geben die Positionen der Firnkernbohrungen an. Das Basislager wurde bei 83°10.0' S, 59°34.45' W errichtet. Die seismischen Messungen fanden zwischen den Punkten 800 und 950 statt.

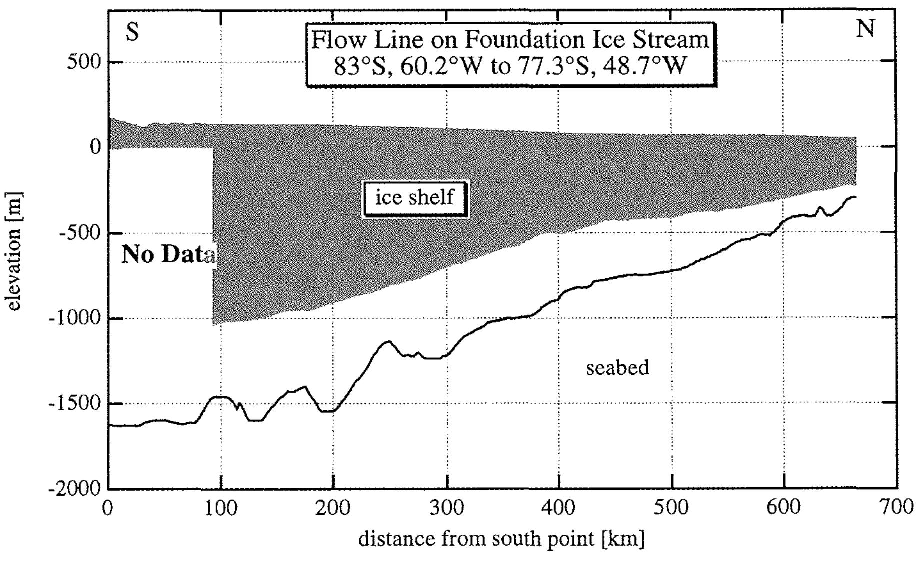

Fig. 2: Surface topography, ice thickness, water column thickness and sea bed topography along the flow line of the Foundation Ice Stream on the eastern Ronne Ice Shelf after VAUGHAN et al. (1994).

Abb. 2: Oberflächentopographie, Eismächtigkeit, Wassersäulenmächtigkeit und Meeresbodentopographie entlang einer Fließlinie des Foundation Ice Stream auf dem östlichen Ronne Ice Shelf nach VAUGHAN et al. (1994).

2. FIELD WORK AND MEASURING TECHNIQUES

During the austral summer 1994/95, from January 24th through February 24th, a 700 km traverse was carried out on the Filchner-Ronne-Schelfeis. The route went south from the Filchner station across the Ronne Ice Shelf towards the grounding line area of FIS. Six scientists from AWI and two from the Geodetic Institute of the Technical University of Braunschweig joined this expedition to perform glaciological, geophysical and geodetic measurements. For the work in the grounding line area, the base camp was established at 83°10.0' S, 59°34.45' W. The base camp was in operation from February 1st to February 18th. It served as a base for the work on the ice, as well as for the airborne survey. For the aircraft operations 9500 l of aviation fuel were carried south by the traverse group.

During 16 days of field work, 106 seismic soundings were carried out along a 74 km long profile from 83°23' S to 82° 45' S. The distance between the single seismic shots was usually 1000 m, reduced to 500 m in the area where the grounding line was expected. As energy source, 2 kg explosive charges (Nitropenta) were placed in 6 m deep hand drilled boreholes which were subsequently refilled with snow. 24 14 Hz vertically–oriented geophones, evenly spaced every 10 m and with an offset of 150 m from the energy source to the first geophone, detected the shots.

The seismic signals were recorded on a 24 channel GEOMETRICS Strataview seismograph with a sample rate of 250 µsec and a record length of 2 sec. The data were stored on hard disc in SEG2 format. A paper printout was used in the field to check the quality of the data and to allow preliminary interpretations.

In addition to the field work done in the area of the FIS grounding line, an airborne radio echo sounding program on the Ronne Ice Shelf took place (Fig. 3). The investigations focused on the transition zone between Foundation Ice Stream and Institute Ice Stream, and along the flow lines of the central Ronne Ice Shelf. In a total of 43.5 h of flight time, 9440 km of data profiles were collected. Three profiles are parallel to the seismic measurements (Fig. 3), two of them in close vicinity. Four profiles cross the area of seismic investigation. The data were acquired with radio echo sounding equipment consisting of an analog HF-Component and a digital recording system. The system transmitted a HF-burst of 60 or 600 nsec length at a frequency of 150 MHz.

During the entire period, a LaCoste Romberg gravity meter was used in feedback mode at the base camp on the Foundation Ice Stream to register the vertical movement of the floating ice caused by the tides. Due to the analog recording, gaps occured in the data when they exceeded the dynamic range of the system. Along the track from Filchner station to the base camp on the Foundation Ice Stream, gravity was measured at several locations.

A total of 16 shallow firn cores (approximately 12 m deep) were drilled along the traverse route at roughly 50 km intervals, in the area of the grounding line and on the ascent to the inland ice (83°55.1' S, 60°21.6' W and 84°49.05' S, 59° 38.05' W) at elevations of 482 m a.s.l. and 1191 m a.s.l., respectively (Fig. 1). The two southernmost drill locations on the grounded ice were reached with the aid of AWI aircraft POLAR 4. The firn cores will provide information about the accumulation rates.

The additional parameters necessary for calculations of the mass flux and mass balance have been determined by a geodetic survey group from the Technical University of Braunschweig. Ice velocities have been measured by differential GPS, whereas strain rates have been calculated from GPS and terrestrial measurements.

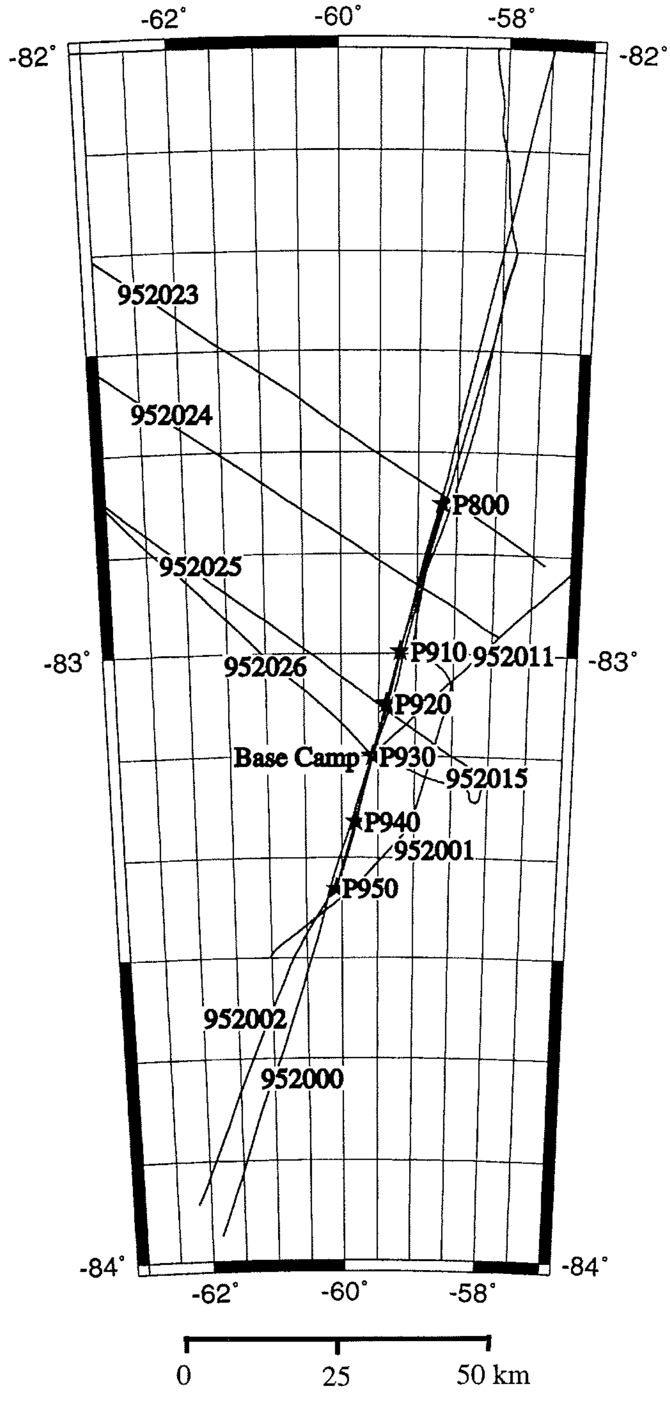

Fig. 3: Map of the position of the airborne radio echo soundings flown in the grounding line area of the Foundation Ice Stream.

Abb. 3: Karte der Profillinien der Radarflüge im Bereich der Aufsetzlinie des Foundation Ice Stream.

3. RESULTS

3.1 Gravity recording

The analog output of the feedback mode (LaCoste Romberg) was used to record the tidal movement of the Foundation Ice Stream. Gaps in the data record occured when the dynamic range of the data exceeded the range of the analog system. Besides these gaps, there are only two more breaks in the record. The missing values were interpolated using a method described by MELCHIOR (1966) and KOBARG (1988), that uses semidiurnal, diurnal and longperiodic tidal signals on both sides of the gaps. The record (Fig. 4) shows a strong, distinct tidal signal. The maximum range of 1.2 mgal corresponds to a vertical tidal movement of 4.5 m. The spectral analysis of the record (Fig. 5) shows clear semidiurnal tides M2 and S2 and also of the diurnal tide S1. Because of the short record length, no further spectral components could be resolved. This result is an indication that the grounding line of the Foundation Ice Stream is further south than expected.

3.2 Seismic and airborne radio echo soundings in the transition zone of the Foundation Ice Stream

3.2.1 Reflection seismic investigations

The seismic data were processed using the seismic processing package DISCO. Fig. 6 shows two typical shot records along the seismic profile. There are well defined, almost horizontal reflections of the ice base at 0.68 sec TWT (Two Way Travel time) and the water bottom boundary at 1.65 sec TWT. It is also possible to detect some reflections below the sea floor. The air wave from the detonations which arrives after 1.25–0.5 sec TWT unfortunately partly obscures the ice base reflection. The data also show strong surface waves. The multiple reflection produced by the strong impedance contrast at the ice-water boundary is seen at 1.36 sec TWT. At a few locations this multiple occurs at the same times as the sea floor reflections. A

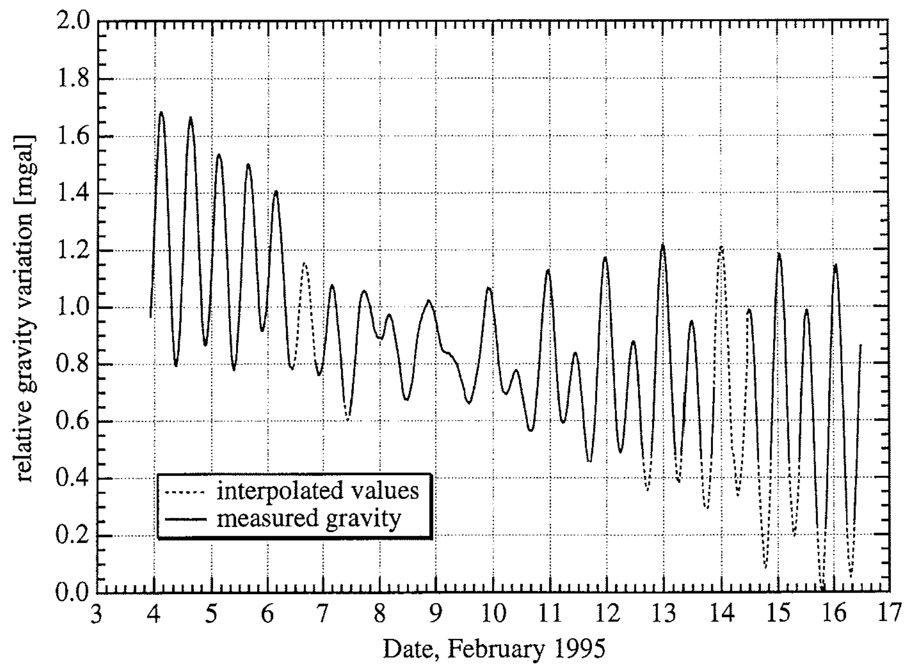

Fig. 4: Tidal record measured at the base camp on the Foundation Ice Stream.

Abb. 4: Darstellung der Gezeitenmessung am Basislager auf dem Foundation Ice Stream.

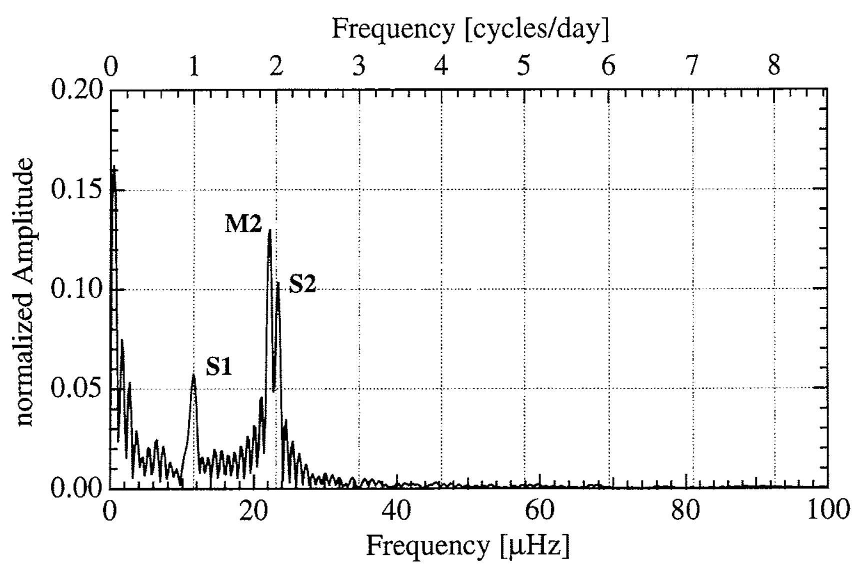

Fig. 5: Spectral analysis of the tidal record shown in Fig. 4.

Abb. 5: Spektralanalyse der Gezeitenmessungen von Abb. 4.

converted wave reflected from the ice shelf base is sometimes visible in the data. This can be seen in shot 94 (Fig. 6) at 1.05 sec TWT. Eventual existing reflections whithin the ice sheet are obscured by the overlaying strong surface waves. In order to suppress these surface waves, muting and frequency filtering techniques were applied to the data. To strengthen the reflections within the sea floor, frequency filtering techniques were used.

To convert the „picked" reflection travel times from the ice shelf base and the sea bottom to ice and water thicknesses, the velocities of the compressional seismic wave within the media must be known. In the absence of shallow refraction experiments to determine the velocity for the upper 100 m of firn and ice, an average velocity of 2,839 m/s was used, taken from measurements for the Rutford Ice Stream (SMITH & DOAKE 1994). From 100 m depth to 300 m above the ice shelf base a velocity of 3,811 m/s was used, corresponding to data from the Ross Ice Shelf (ROBERTSON & BENTLEY 1990). A velocity value of 3,750 m/s at the base of the ice shelf was calculated from a temperature dependent velocity gradient of -2.3 m/s °C (KOHNEN 1974) and a mean surface temperature of -30 °C (MAYER et al. 1995). Additionally, it is assumed that the basal ice is at the pressure melting point. With the assumption of a constant velocity down to 300 m above the base and a linear reduction of the velocity below this depth (SMITH & DOAKE 1994), an average velocity of 3,805 m/s was calculated within the ice shelf. In order to determine the seismic velocity in the sea water column, the expression

$$V = 1449 + 4.6T - 0.05T^2 + 0.0003T^3 + (1.39 - 0.012T)(S - 35) + 0.017Z$$

was applied, where T is the temperature in °C, S the salinity in ppt and Z the depth below sea level in meters (MACQUILLAN et al. 1984). For the Foundation Ice Stream, the values assumed were: T = - 2.8 °C (approximately the pressure melting point of ice at a depth of 1,400m), S = 34.6 ppt (NICHOLLS & JENKINS 1993) from the Rutford Ice Stream and Z = 1,400 m. We use the salinity values of NICHOLLS & JENKINS (1993), because there are no salinity values available underneath the Foundation Ice Stream. These values produce a seismic wave velocity for sea water of 1,455 m/s. The accuracy of 15 m/s for the velocity in the ice and of 0.5 m/s for the travel time picks gives an ice thickness error of ± 7.5 m. In the southern part of the profile, however, the reflection of the ice base could not be exactly identified, so the ice thickness error is much higher, around ± 50 m. The seismic velocity in the water column was determined with an accurancy better than ± 5 m/s, despite the uncertainty surrounding the salinity value. The final accuracy of the water column thickness is ± 5 m and in regions with a weak ice base reflection approx. ± 27 m.

The seismic profile was transformed to a depth section (Fig.7) to represent the topography of the sea floor in a realistic manner. It shows the ice thickness from north to south as well as an almost horizontal sea bed, slightly inclined to the south. The observed reflections within the sea bed are subhorizontal in the upper part and slightly inclined to the south underneath. South of shot 17, only a few reflections can be seen. The reflection of the ice shelf base is well defined between the northern end of the profile and shot 56. Further south, the reflection becomes much weaker and difficult to define, especially in the southernmost 6 km of the profile. There are two possible explanations for this:

i) The increased ice deformation in the grounding line area creates surface and bottom crevasses in the ice shelf. Therefore only a small part of the source energy reflected from the ice shelf base reach the geophones.

ii) Entrained moraine in the lowermost part of the ice leads to a strong scattering of the wave energy.

iii) Slush layers formed by freezing conditions underneath the ice shelf, form a gradual transition from water to firm ice and therefore give weak reflections. However, conditions under the ice, close to the grounding line, are not likely able to produce such a slush layer.

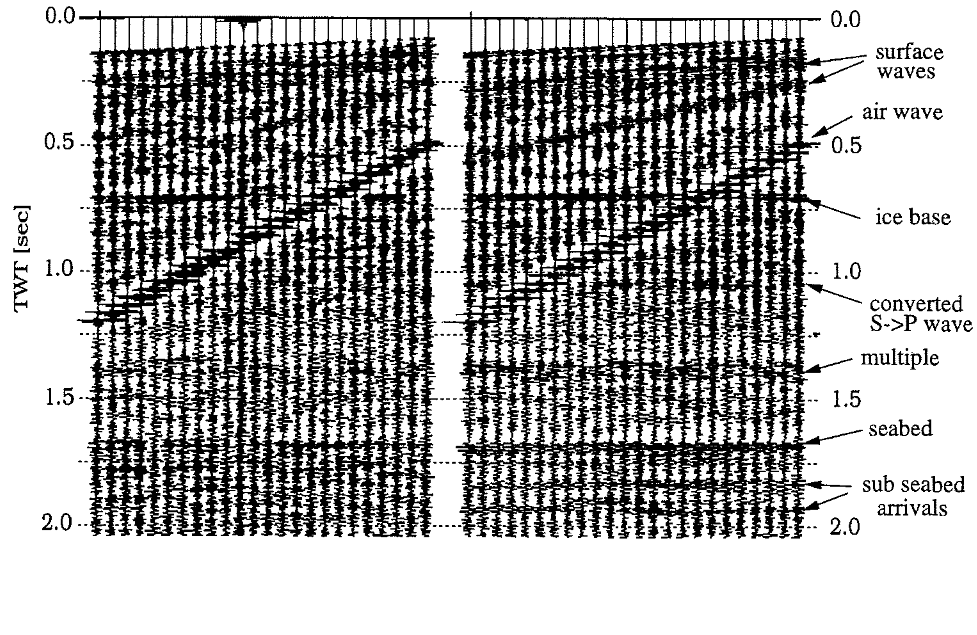

Fig. 6: Frequency filtered shot gathers.

Abb. 6: Frequenzgefilterte Schußabspielungen.

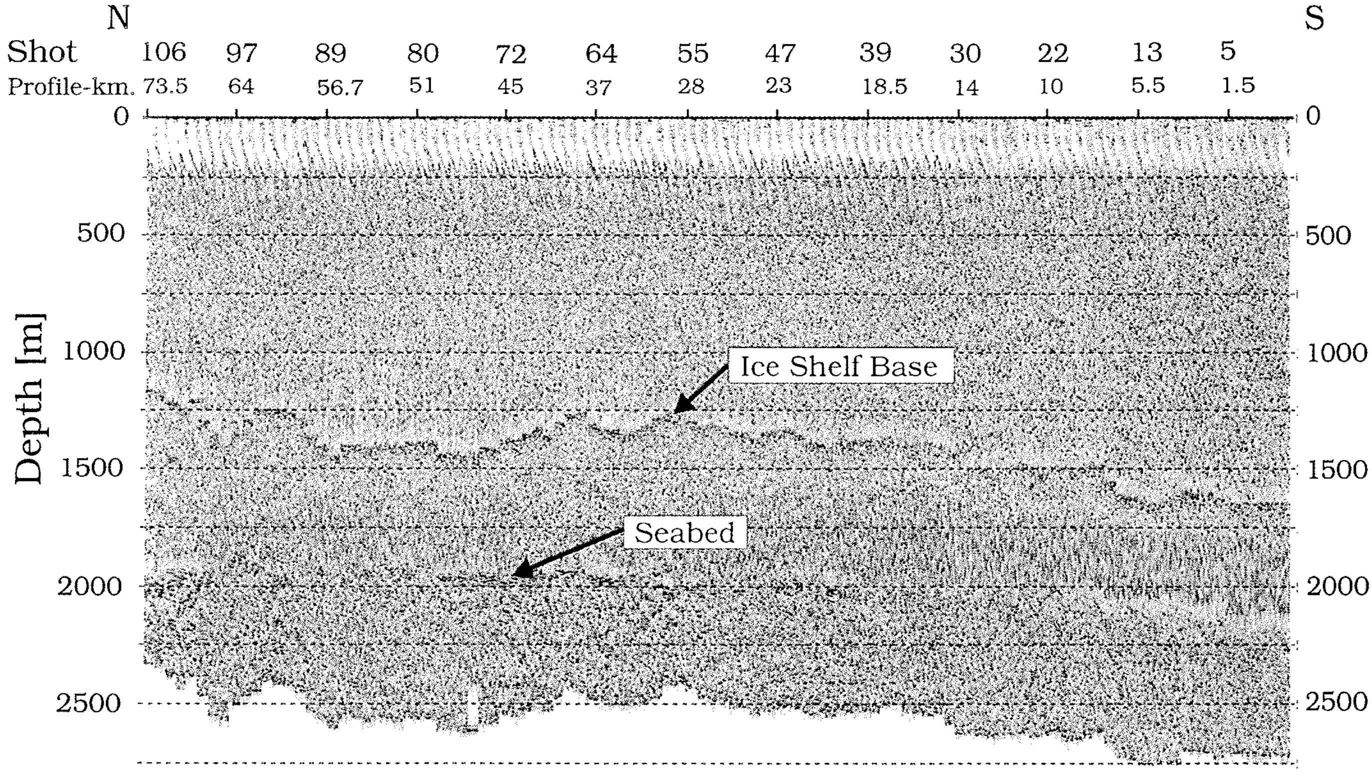

Fig. 7: Reflection seismic data of the grounding line area of the Foundation Ice Stream as depth section.

Abb. 7: Tiefensektion der reflexionsseismischen Daten im Bereich der Aufsetzlinie des Foundation Ice Stream.

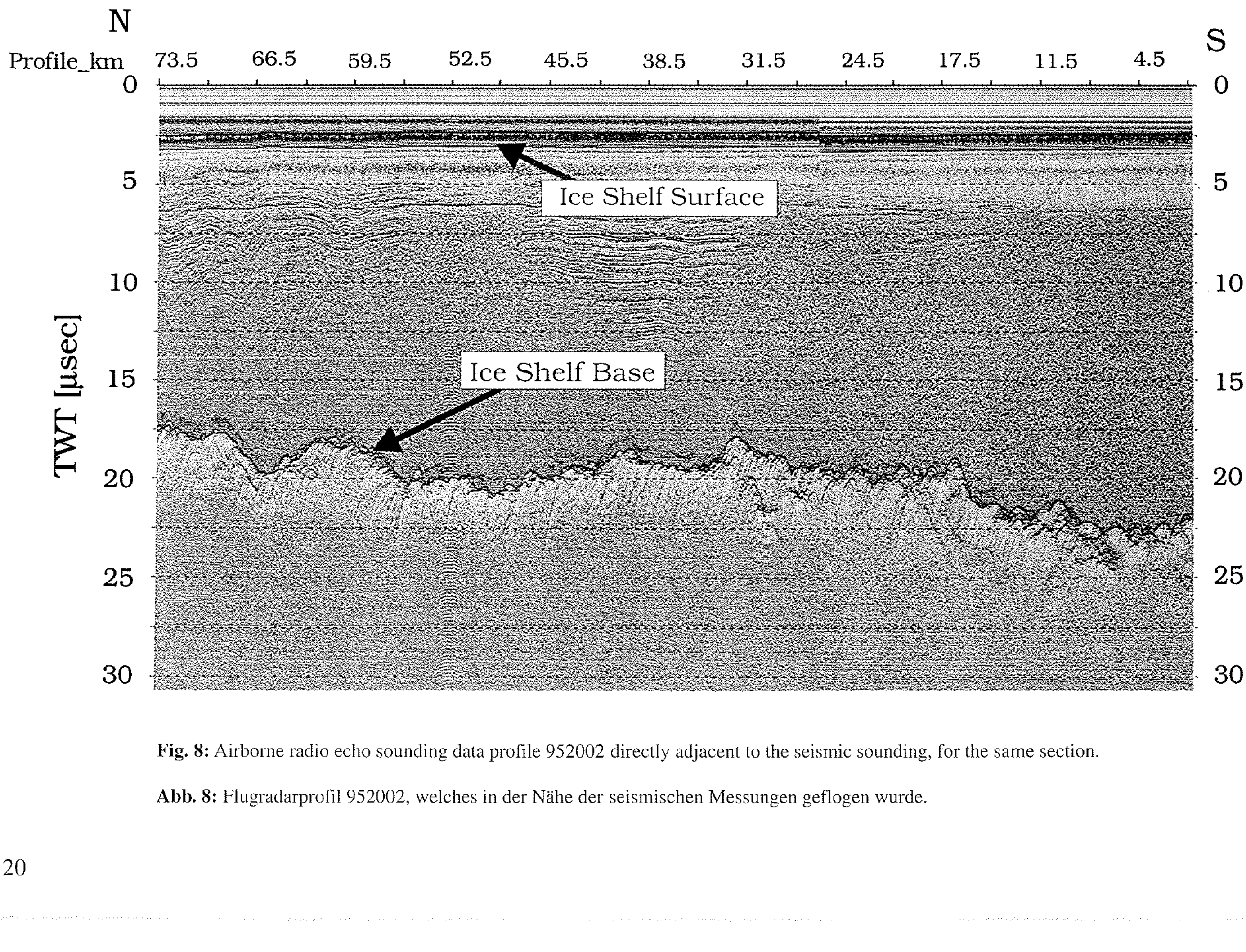

Fig. 8: Airborne radio echo sounding data profile 952002 directly adjacent to the seismic sounding, for the same section.

Abb. 8: Flugradarprofil 952002, welches in der Nähe der seismischen Messungen geflogen wurde.

3.2.2 Airborne radio echo sounding

For processing the radio echo sounding data, we used the same seismic processing package DISCO, we used for the seismic data. The digital signal stored on tape was first filtered with a differentiation filter, to form wavelets from the logarithm signal, then further treated by methods used in seismic data processing. Fig.8 shows a time section of the part of the radio echo sounding data which coincides with the seismic line. The equipment used is able to produce a vertical resolution of 10-20 m and a horizontal trace distance of about 3 m. Stacking of ten traces was applied to the data to improve the signal to noise ratio. The radio echo sounding data give information about the ice thickness, internal reflections of the ice body and the condition at the ice shelf base. The „picked" travel times for the ice shelf base were converted to depth values using an electromagnetic wave velocity in the ice of 168 m/µsec. Due to the higher velocity of up to 250 m/µsec within the firn, a general ice thickness correction of +10 m determined from density profiles was applied.

The reflection of the ice shelf base shows a rough topography. Many diffraction hyberbolas obscure the profile. Even after subsequent refreezing, seawater filled bottom crevasses will show hyperbolic traces in the radio echo sounding (ROBIN et al. 1983, NEAL 1979). The strength of the signal will be reduced in the case of bottom freezing by a saline ice layer, as this layer absorbs radio wave energy at the rate of 0.5–1.0 dB/m along the two-way path length as compared with 0.02–0.04 dB/m in non-saline ice (ROBIN et al. 1983, NEAL 1979). It is interesting to note that the intensity of the returned signals from an ice seawater interface underneath such a basal ice layer will show similar variations compared to those from a rough bottom surface beneath inland ice (ROBIN et al. 1983, NEAL 1979).

3.2.3 Discussion of the results

Fig. 9 shows the ice thickness distribution resulting from the seismic measurements and the adjacent parallel radio echo sounding profiles. The ice thins downstream from 1600–1700 m in the south to 1200–1300 m in the north. Strong ice thickness variation is a common feature of all profiles from both methods over the area. The values from the RES profile 952002, near the seismic measurements, agree well within 100 m with the ice thickness values determined from the seismic reflections. The ice thickness on profile 952000 shows differences of up to 150 m in the area of 83.1° S to 83° S and at its southern and northern ends. The profile 952001 stretches from 83° S to 83.3° S, at an offset of 12 km from the seismic profile, and shows considerable ice thickness differences in this area. The sea floor topography, ice thickness and the surface elevation above sea level are shown in Fig. 10. The elevation data resulting from the geodetic measurements increase from 120 m in the north to 200 m in the south (RIEDEL pers. communication). The ice thickness data are from the radio echo sounding profile 952002, which is situated adjacent to the seismic profile and the seismic soundings. Additionally, ice thickness values were calculated from the surface elevation data using hydrostatic equilibrium between the ice (mean density $\rho_c = 910$ kg/m³) and sea water (mean density $\rho_w = 1028$ kg/m³). A comparison of the calculated data values with the measured values shows good agreement except for the area between km 15 and km 33, where the measured ice thickness is up to 150 m smaller than calculated. The reason for this difference is the rough ice shelf base. Strong ice thickness variations perpendicular to the flow direction cause the differences between the seismic and the RES measurements on the adjacent profile (Fig. 11). This Fig. 11 shows the roughness of the ice shelf base on the FIS from the base camp to the north resulting from four radio echo flights perpendicular to the flow di-

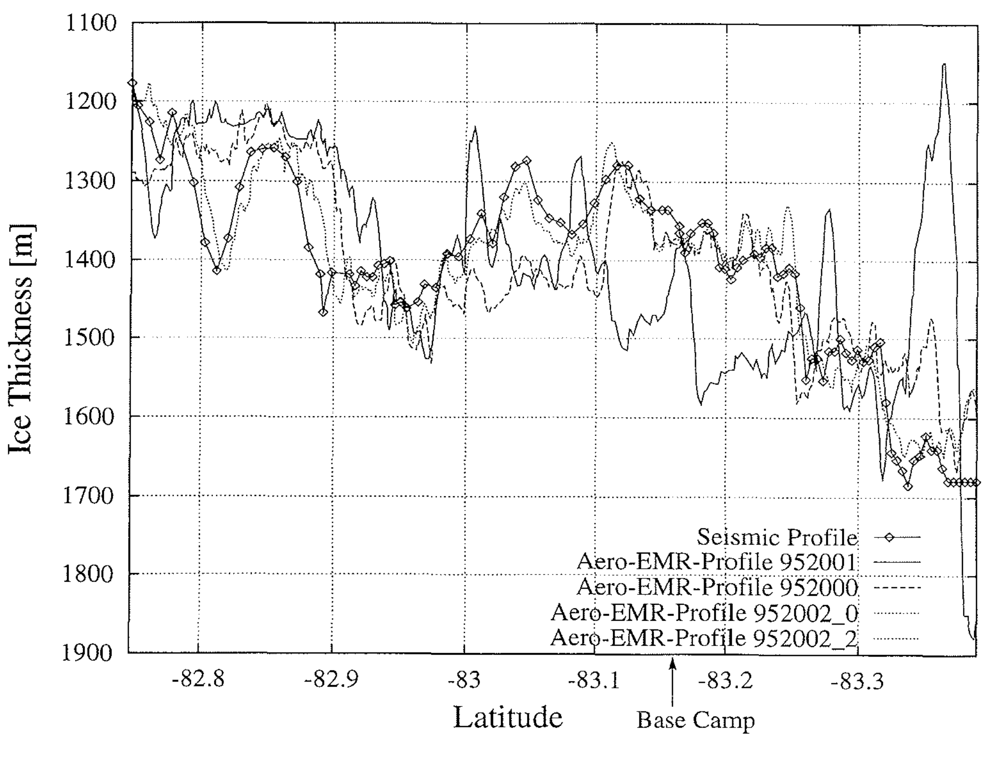

Fig. 9: Comparison of the ice thickness data in the grounding line area of the Foundation Ice Stream resulting from the seismic measurements and the airborne radio echo soundings.

Abb. 9: Vergleich der aus den seismischen Messungen und Radarmessungen ermittelten Eismächtigkeitsdaten im Bereich der Aufsetzlinie des Foundation Ice Stream.

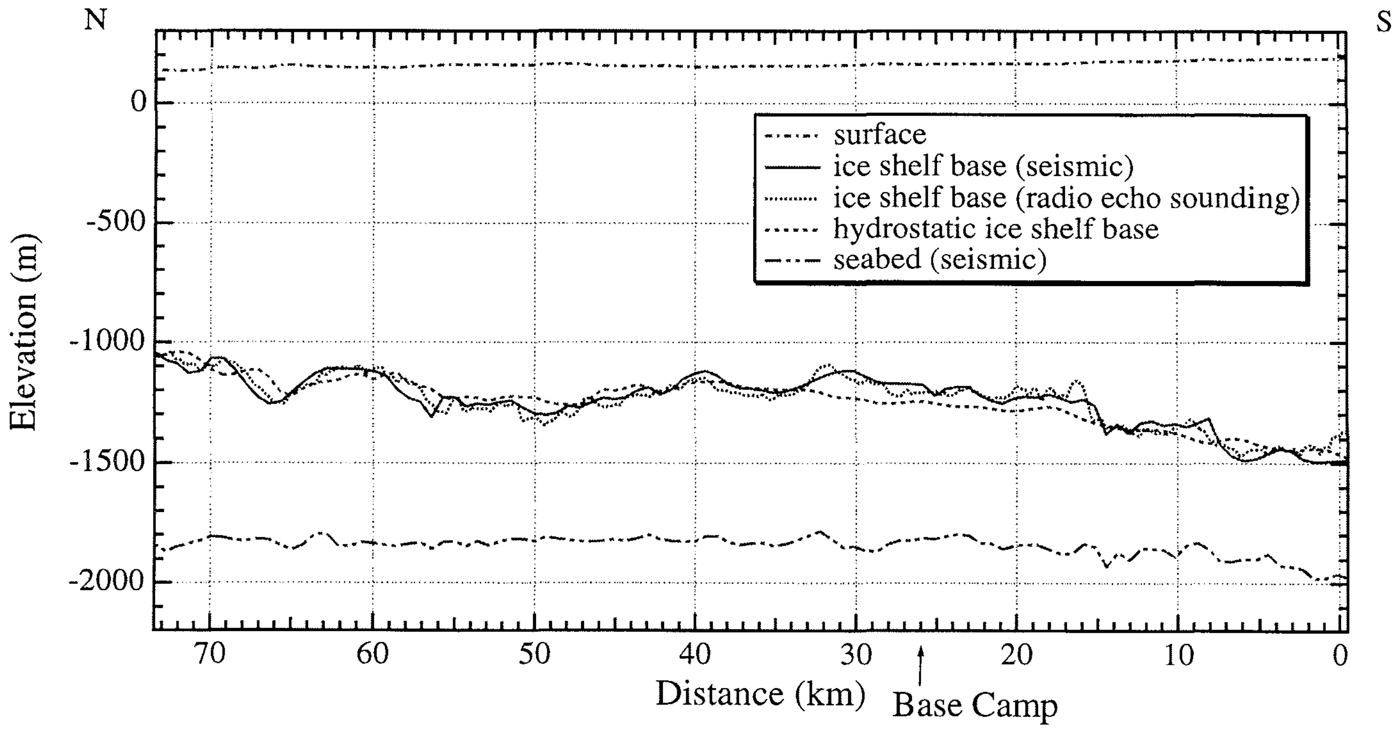

Fig. 10: Surface elevation from geodetic measurements, ice base determined from three different methods, and sea bed topography along the seismic profile in the area of the grounding line of the Foundation Ice Stream.

Abb. 10: Oberflächenhöhe, Eisunterseite ermittelt nach drei verschiedenen Methoden, sowie die Meeresbodentopographie entlang der seismischen Messungen im Bereich der Aufsetzlinie des Foundation Ice Stream.

rection of the ice stream (Fig. 3). The application of standard interpolation methods (as used in Fig. 12) do not support physical mechanisms, like mass transport due to ice shelf flow. Compared to longitudinal deformation rates in the order of $10^{-3} a^{-1}$, typical for ice shelves, the ice velocity in flow direction is much more effective in mass transport. Assuming steady state conditions, lateral thickness variations will show considerable stability along the main flow direction. Therefore the data were linearly interpolated along the flow direction, in contrast to common methods using available values in all directions. It is obvious that the seismic soundings do not exactly follow the flow direction of the ice stream in case of steady state conditions. This is confirmed by the direction of the ice flow gained from geodetic measurements (RIEDEL et al. 1996). In the western part of the area there is an elongated structure of greater ice thickness bounded by two thinner channels. This structure is crossed diagonally by the seismic soundings and yields the strong ice thickness undulations in this area. Differences between the ice thicknesses from radio echo sounding and seismic measurements in Fig. 10 result from the slightly varying measurement positions. The ice thickness calculated from surface data by assuming hydrostatic equilibrium represents a mean value over an area in which the stiffness of the ice is able to support small deviations from the equilibrium. For example, the first 10 km north of the base camp the seismic profile stretches along a channel of smaller ice thickness (Fig. 11). The mean width of this channel is 4.5 km, whereas the thickness variation is up to 100 m. Therefore the mean ice thickness, supported by bridging effects across this channel of just a few ice thicknesses width, represented by the calculated ice thickness, is higher than the values of the actual measurements. Consequently, this mean value is higher than the measurements in regions where the sounding position is located just above one of the thinner channels. The observed structure of thicker ice thins northwards from an excess of 250 m to 100 m in relation to the neighbouring channels. This cannot be explained by dynamic flow processes in the ice and indicates melting at the ice shelf base in this area, if steady state conditions are valid.

The sea bed topography, determined from the seismic measurements, declines from 1820 m in the north to 1970 m in the south (Fig.10). The sea floor appears flat with only small undulations. The water column thickness decreases in the same direction from about 800 m to 480 m along the seismic profile and is 520 m at the base camp, where the position of the grounding line of the FIS was expected.

Fig. 12 shows the ice thickness distribution determined by the radio echo soundings parallel and perpendicular to the seismic measurements in the area of the transition zone. A strong increase in ice thickness gradient is observed at point 950, at the southern terminal position of the seismic soundings. There the gradient changes from 4 x 10^{-2} to 5 x 10^{-3}. This large change of the ice thickness gradient indicates that the grounding line of the Foundation Ice Stream is situated about 40 km further south than formerly expected. Using the topographic features of the USGS

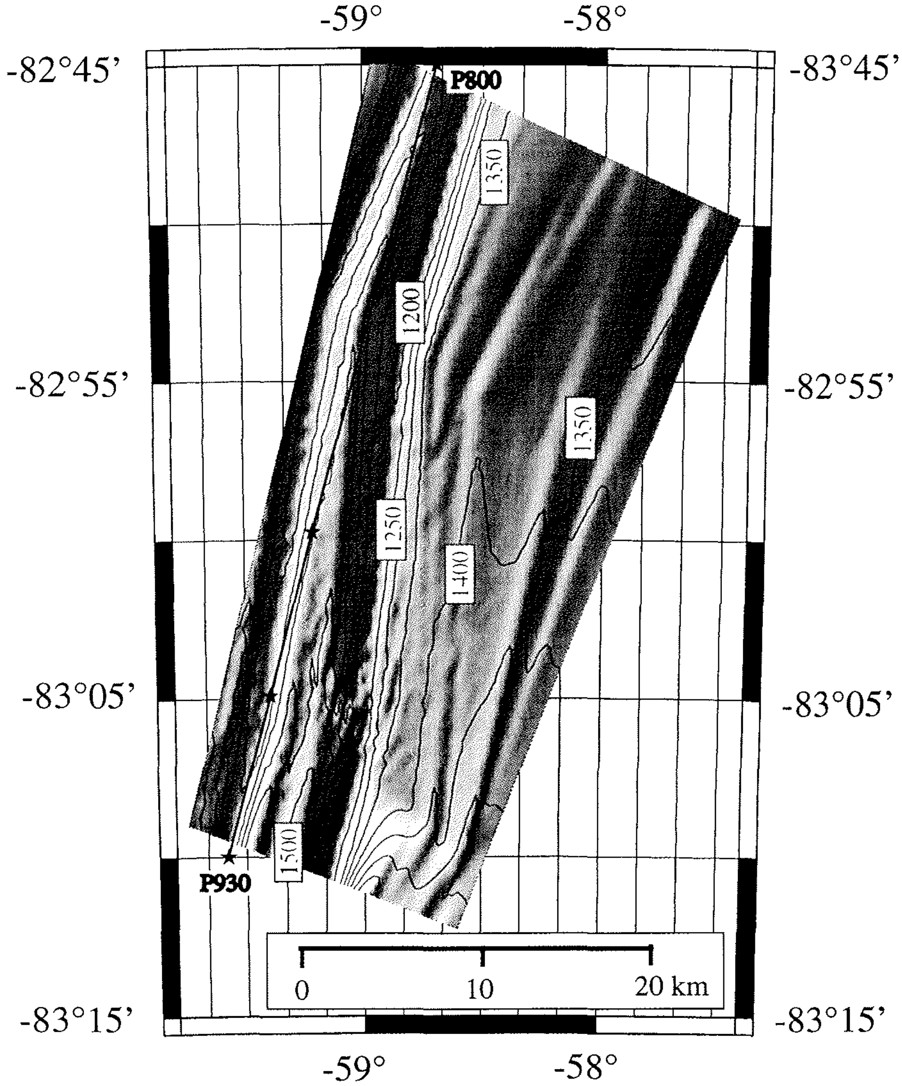

Fig. 11: Ice thickness distribution calculated from radio echo soundings. The contour interval is 50 m. The line marked with stars shows the position of the seismic profile from the base camp northwards.

Abb. 11: Aus Radarmessungen bestimmte Eismächtigkeitsverteilung. Der Isolinienabstand beträgt 50 m. Die mit Sternen markierte Linie zeigt die Lage der seismischen Messungen vom Basislager nach Norden.

Maps (USGS, 1967) to determine the lateral ice stream boundaries, the area of the FRIS is about 1700 km^2 greater than was previously believed. From the results of the radio echo soundings perpendicular to the flow line of the FIS and the corresponding flow velocities of 550 m/a, 526 m/a, 448 m/a and 394 m/a from north to south, a mass flux of 35 km^3/a was determined for the Foundation Ice Stream which is 24 km^3/a less than a previous value for the combined system of FIS and Möller Eisstrom (McIntyre 1986).

4 CONCLUSIONS

The measurements on the Foundation Ice Stream near the grounding line have provided new ice thickness, water column thickness and sea bed elevation data. Airborne radio echo sounding measurements in the same area complete the ice thickness data from the seismics. The data obtained from these two different methods agree well. Additionally new geodetic data on ice velocities and strain rates have been measured by the geodetic group.

The ice thins downstream from 1600-1700 m in the south to 1200-1300 m in the north. The base of the ice shelf is very rough and shows a conspicuous structure of thicker ice bounded by two thinner channels. The thinning of this structure along the flow direction, approved by several subsequent cross sections, indicates melting at the ice shelf base in this area. A strong change of the ice thickness gradient from 4 x 10^{-2} to 5 x 10^{-3} appears south of point 950. The grounding line of the Foundation Ice Stream is probably situated at the southern end of this area with the high ice thickness gradient, some 40 km further south of the former supposed position.

The water column thickness changes from 480 m in the south to 800 m in the north. At the base camp, the previously assumed position of the grounding line, the water column thickness is 520 m.

The sea floor slightly inclines southwards from 1820 m to 1970 m below sea level.

The gravity measurements indicate a tidal movement of 4.5 m at the base camp. This result also shows that the grounding line

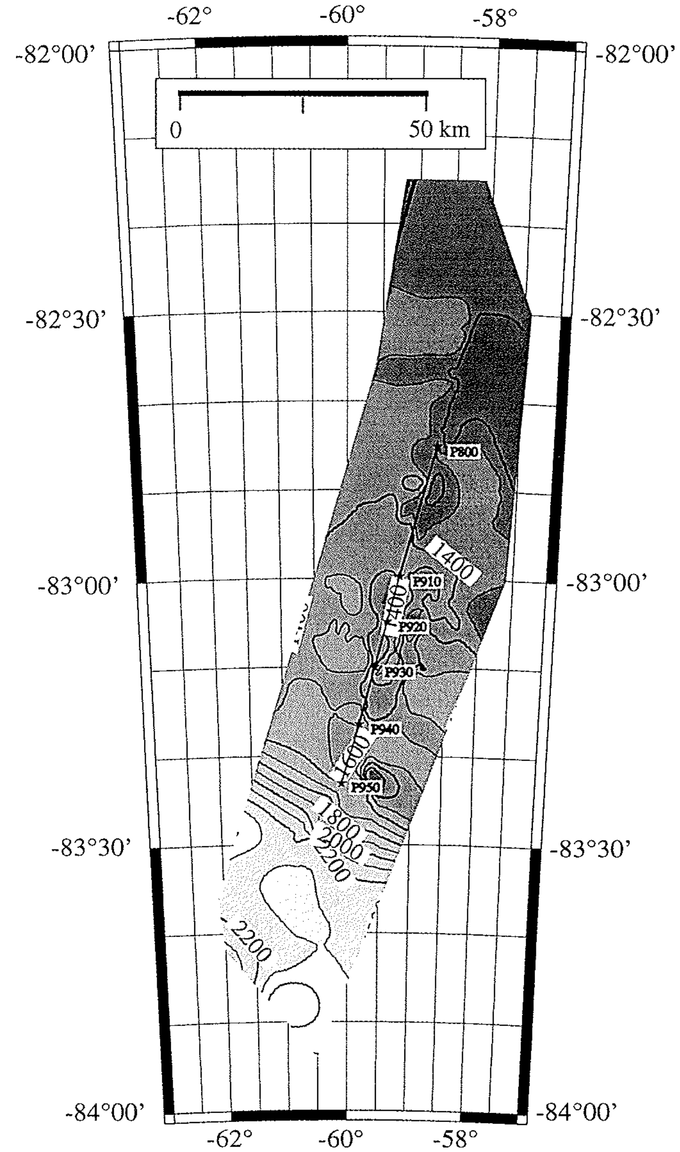

Fig. 12: The ice thickness within the transition zone of the Foundation Ice Stream from radio echo soundings, contours every 100 m. The line marks the position of the seismic profile.

Abb. 12: Die Eismächtigkeitsverteilung innerhalb der Übergangszone des Foundation Ice Stream bestimmt aus den Flugradarmessungen. Der Isolinienabstand beträgt 100 m. Die Linie zeigt die Position der seismischen Messungen.

of the Foundation Ice Stream is further south than was previously believed.

The determined surface elevation, strain rates and flow velocities complete the set of data, necessary for mass flux calculations on the Foundation Ice Stream. Calculations based on radio echo sounding cross sections and flow velocities yield a total mass flux of 35 km^3/a for the Foundation Ice Stream in the area of 83° S.

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