Polarforschung 68, 71 - 82, 1998 (erschienen 2000)

The Sediment Distribution below the North Greenland Continental Margin and the adjacent Lena Trough

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THEME 5: The Barents Shelf and the East Greenland Margin: A Comparison

Summary: The continental shelf of Northern Greenland is one of the least explored regions of the Greenland island. Only hypotheses exist on the sedimentary and deeper structure of this area especially in relation to the conjugate margin off western Svalbard. Seismic investigations conducted in summer 1997 provide a first view on the structural fabric of the North Greenland margin. Sediments with a thickness of 8 km were modelled from two wide-angle recordings. High seismic velocities of 4.0 km/s close to the seafloor indicate the presence of Paleozoic-Mesozoic sediments close to the Greenlandic coast. The continental slope at 81 °N off Ob Bank has a steep dip and unusual rough slope topography. This might be explained with the vicinity of the Lena Trough, an active ridge segment of the North Atlantic spreading system. A thin veneer of sediments covers the central part of the Lena Trough, while thick drift deposits are present along the western Yermak Plateau margin. Their thickness is 2.8 s TWT, which corresponds to 2.5 to 3.0 km.

INTRODUCTION

The present deep water connection between the Arctic Ocean and the North Atlantic opened when the plate movements between Svalbard and Greenland changed from strike slip to oblique divergence some 35 Ma ago (VOGT 1986, MYHRE & ELDHOLM 1988). The proposed model for continent movements suggest that the continents were well separated around 20 Ma ago. The water depths at that time are unknown, as the subsidence history of the margins is poorly known. KRISTOFFERSEN & HUSEBYE (1985) proposed that a deep water passage existed at some time before 10 Ma, while LAWVER et al. (1990) date the opening of the deep Fram Strait as late as 7.5 to 5 Ma. Evidence for the large strike slip movement can be found onshore Svalbard and North Greenland. A Tertiary fold belt (TFB) formed along the western margin of Svalbard (Fig. 1). Here, the mountains are between 400 and 1000 m high. On the conjugate margin of North Greenland no such large-scale fold belt is exposed. However, the dominant tectonic trend onshore is northwest-southeast. A series of major faults parallel to this direction have been interpreted as an Earliest Tertiary strike-slip mobile belt (HÅKANSON 1979, HÅKANSON & PETERSEN 1982). It is suggested that northwest-southeast structures dominate the continental shelf of North Greenland (Fig.1, Ob Bank) and are complimentary to structures on the western Svalbard Shelf.

Finally, the occurrence of earthquakes (GREGERSEN 1982) indicates that the North Greenland Shelf is still tectonically active, which easily can be explained with the short distance to the mid-ocean Lena Trough just off the continental slope.

The lack of geophysical and geological data especially on the Ob Bank does not allow more specific models. Even basic information like bathymetry and/or sediment thickness is unknown. The reason for the sparse geological and geophysical data coverage of this area is its position relative to the Fram Strait, which is the gateway for large amounts of sea ice drifting from the Central Arctic into the North Atlantic. In general, dominating northerly winds press the ice floes against the North Greenland coast preventing the formation of a stable polynia during the summer. Only one ship-based geophysical experiment during the YMER-80 cruise acquired sonobuoy data from the Ob Bank (SCHYTT et al. 1981, ELDHOLM et al. 1984). In 1988 the northernmost MCS profile was collected as far north as 80 °N (HINZ et al. 1991). Therefore, the current models for the Fram Strait are mainly based on aeromagnetic surveys in the region north of 80 °N (VOGT et al. 1979) and the extensive geophysical data base from the western Svalbard margin south of 80 °N (EICKEN 1994, CRANE & SOLHEIM 1995).

The Alfred Wegener Institute for Polar Research (AWI) collected recently new geophysical data from the North Greenland region both by aircraft and with shipborne systems. The airborne programme concentrated on acquiring new aeromagnetic (1995) and aerogravity (1997) data across the coastal areas of northern Greenland and the adjacent offshore region (SCHLINDWEIN & MEYER 1999). The marine geophysical experiments were located on the Ob Bank and on the shelf north off Kronprins Christan Land (KCL) (Fig. 1). Multichannel seismic reflection (MCS) and gravity data as well as wide-angle data with offsets up to 40 km were acquired to enhance the geodynamic understanding of this area. The northernmost lines were terminated at 81°40'N, 16°02'W due to heavy ice conditions (Fig. 1). In total 1760 km of MCS data could be acquired off Kronprins Christian Land and across the Fram Strait.

In this contribution, data will be presented which add new information on the tectonic development of the North Greenland Margin. The data shown, therefore, are concentrated on the Ob Bank, its continental slope and the Lena Trough (LT). The data in the Lena Trough and the Yermak Plateau Margin will be discussed in view of results found to the south (EICKEN & HINZ

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Manuscript received 11 January 1999, accepted 15 October 1999

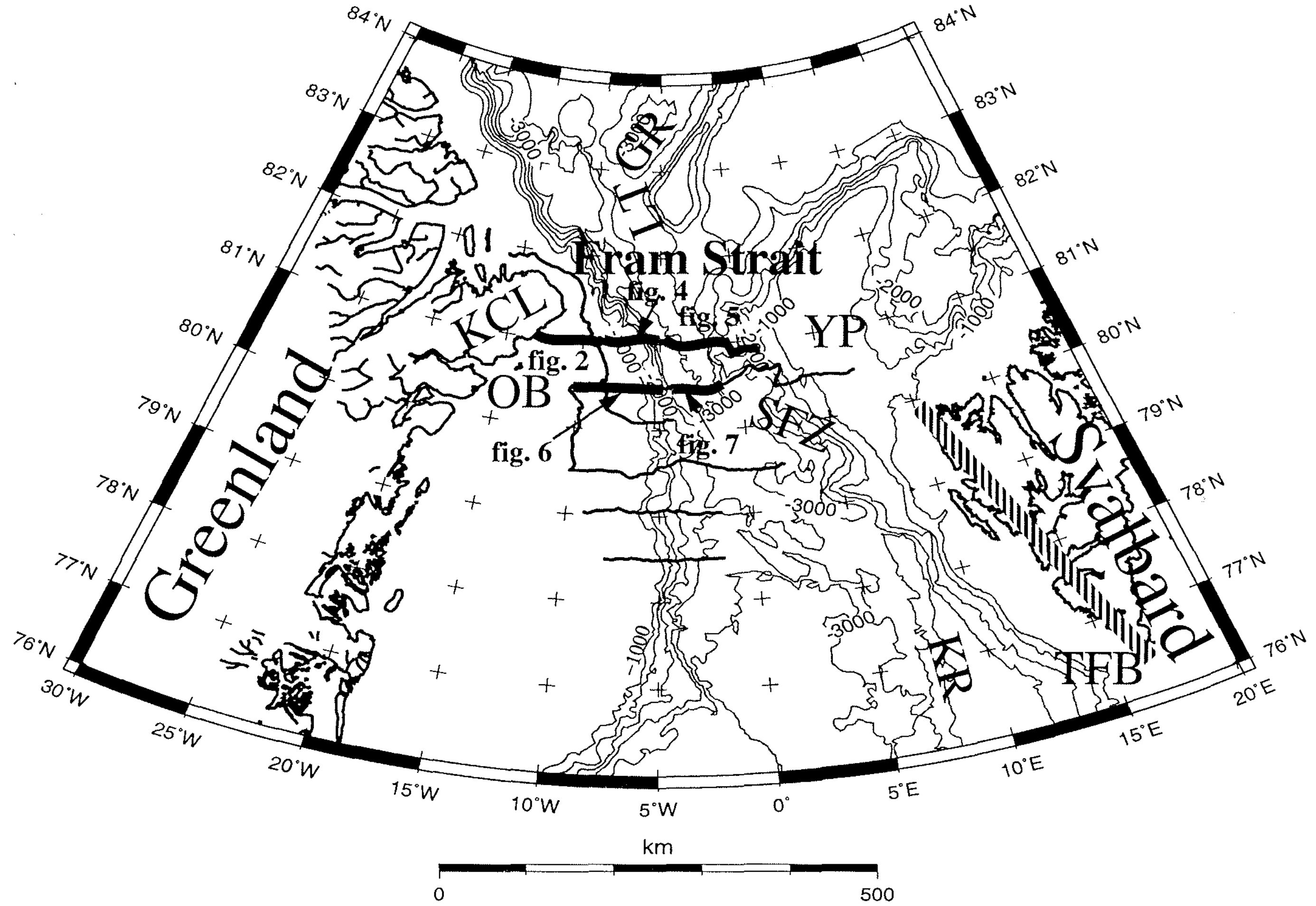


Fig. 1: Tectonic units in the area between North Greenland and Svalbard. The seismic network collected during the expedition in 1997 is indicated with white lines. The profiles presented are labelled black with the figure number. (GR = Gakkel Ridge, LT = Lena Trough, YP = Yermak Plateau, KCL = Kronprins Christian Land, OB = Ob Bank, SFZ = Spitsbergen Fracture Zone, KR = Knipovich Ridge, TFB = Tertiary fold belt).

1993). Due to the limited number of profiles this study cannot give a complete answer to the existing problems but will provide some new insights.

EXPERIMENTAL SET-UP

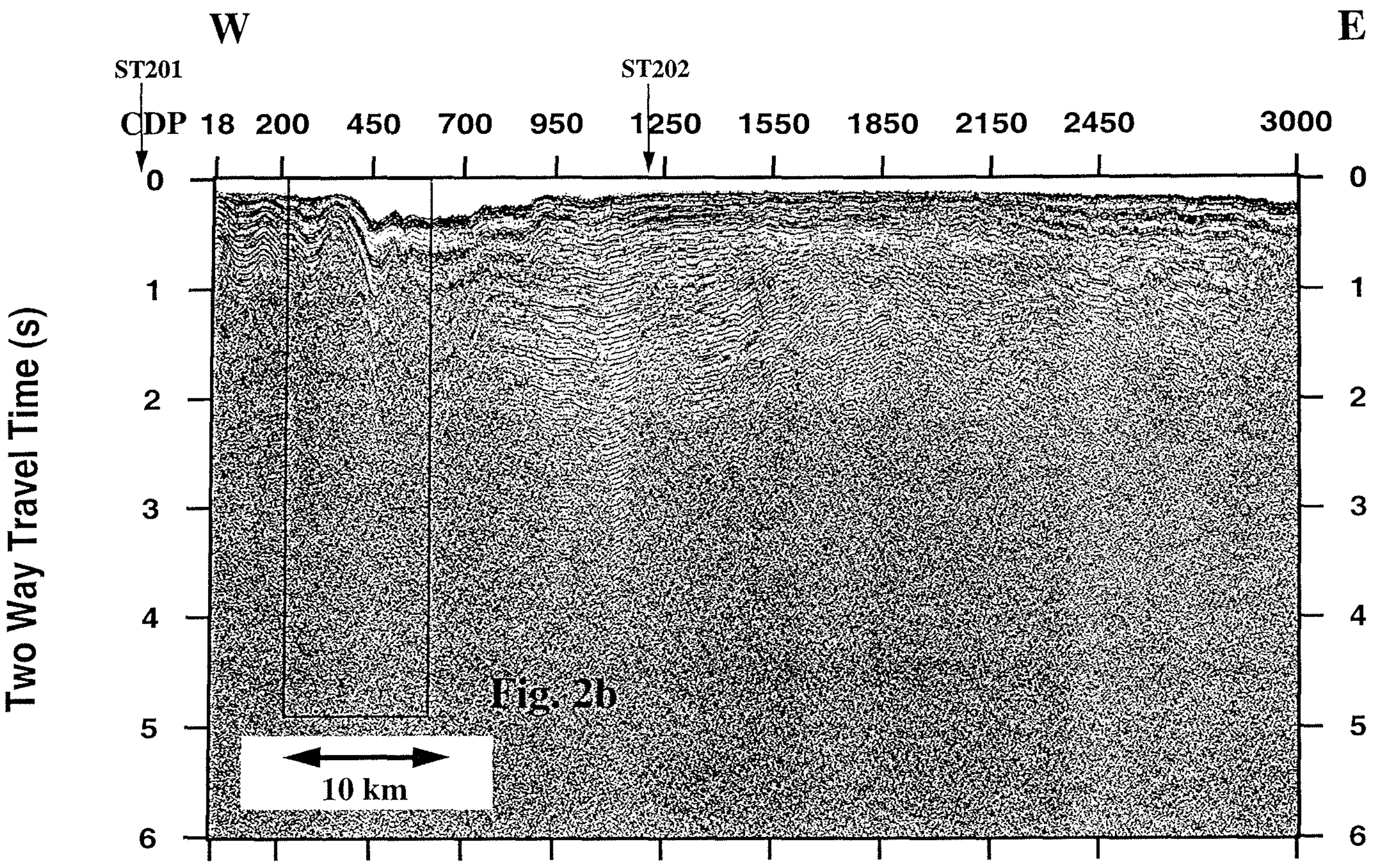
The seismic profiles were acquired with an 800 m long streamer (active length 600 m, 96 channels) and a 24l/12l airgun cluster consisting of 8 and 4 airguns respectively. The intermediate ice conditions did not allow the deployment of ocean bottom seismometers for a wide angle experiment. Consequently, only a few measurements on the deeper velocities could be performed. Three of four REFTEK stations were deployed on ice floes and recorded seismic signals up to 40 km. For further details on the acquisition parameters see JOKAT et al. (1998).

WIDE-ANGLE OBSERVATIONS

In this contribution two wide-angle observations will be presented to supplement the information from the seismic reflection data. For the modelling the RAYINVR software (ZELT & SMITH 1992) was used.

While station 201 was deployed onshore the North Greenland coast, station 202 was positioned on a drifting ice floe along the MCS profile 97200 (Figs. 1, 2, 3). Since the REFTEK station 202 recorded each hour its GPS position, the drift path of the floe was reconstructed and the offsets were corrected accordingly. For modelling of the sea floor, swath bathymetry data acquired parallel to the seismic data were used. Along this segment of line 97200 (Fig. 2, CDP18-300) water depths varies between 30-100 m. Due to the large initial offset at station 202 (Fig. 3b) velocities for the sediments just below the seafloor could not be identified on the wide-angle data. Velocities of 1.8-2.5 km/s, therefore, were determined from the standard CDP velocity analysis of the seismic reflection data.

The travel times of the stations 201 and 202 were picked with an accuracy of ±75 ms, in some exceptions with ±150 ms. The final model has an overall RMS error of 73 ms (73 travel time picks) between observed and modelled traveltimes. Based on the uncertainties described, the error for the seismic velocities is estimated to be ±0.1 km/s for values smaller 4.0 km/s. For velocities greater than 4.0 km/s, the error is estimated to be ±0.2 km/s. The errors in depth are estimated to be 10 % for velocities greater than 3 km/s.



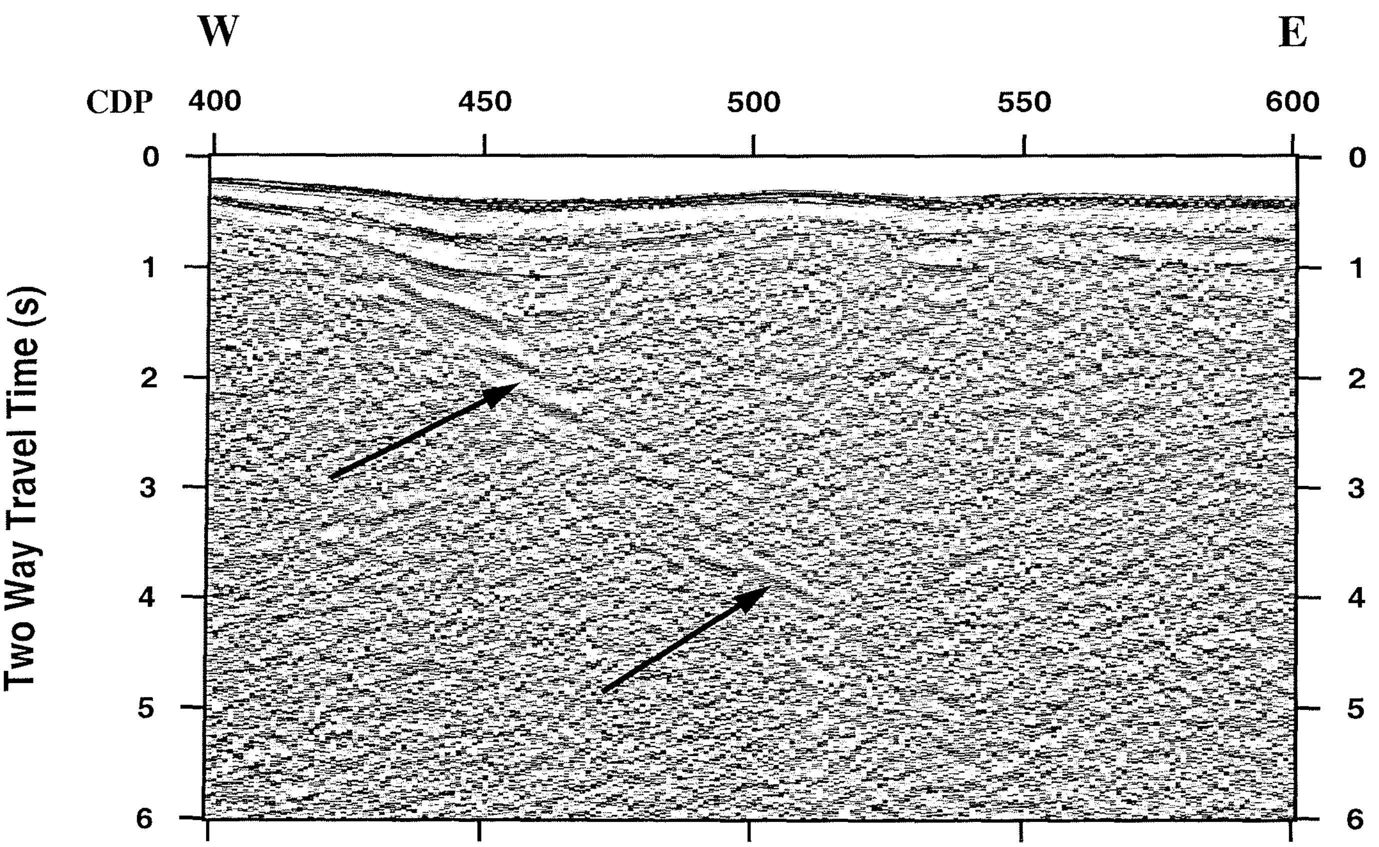
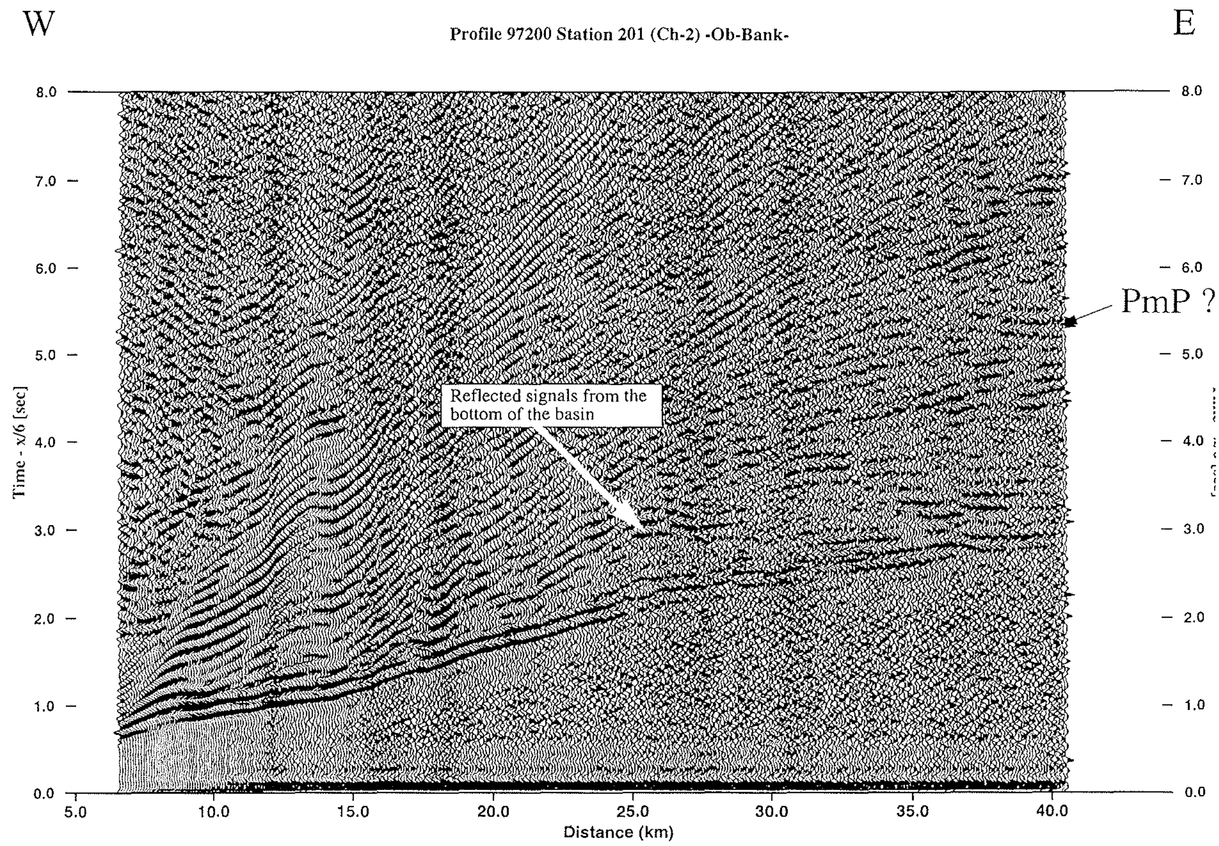


Fig. 2a: Part of line 97200 across the Ob Bank. The location of the wide angle recording stations is marked. Please note that the location of station 201 is west of the start of the profile.

Fig. 2b: Close-up area of profile 97200, where a steep escarpment of heavily compacted sediments is visible (arrows). It most likely represents the transition from old Mesozoic to young Tertiary sediments. This interpretation is also based on seismic velocities (see also Fig. 3).



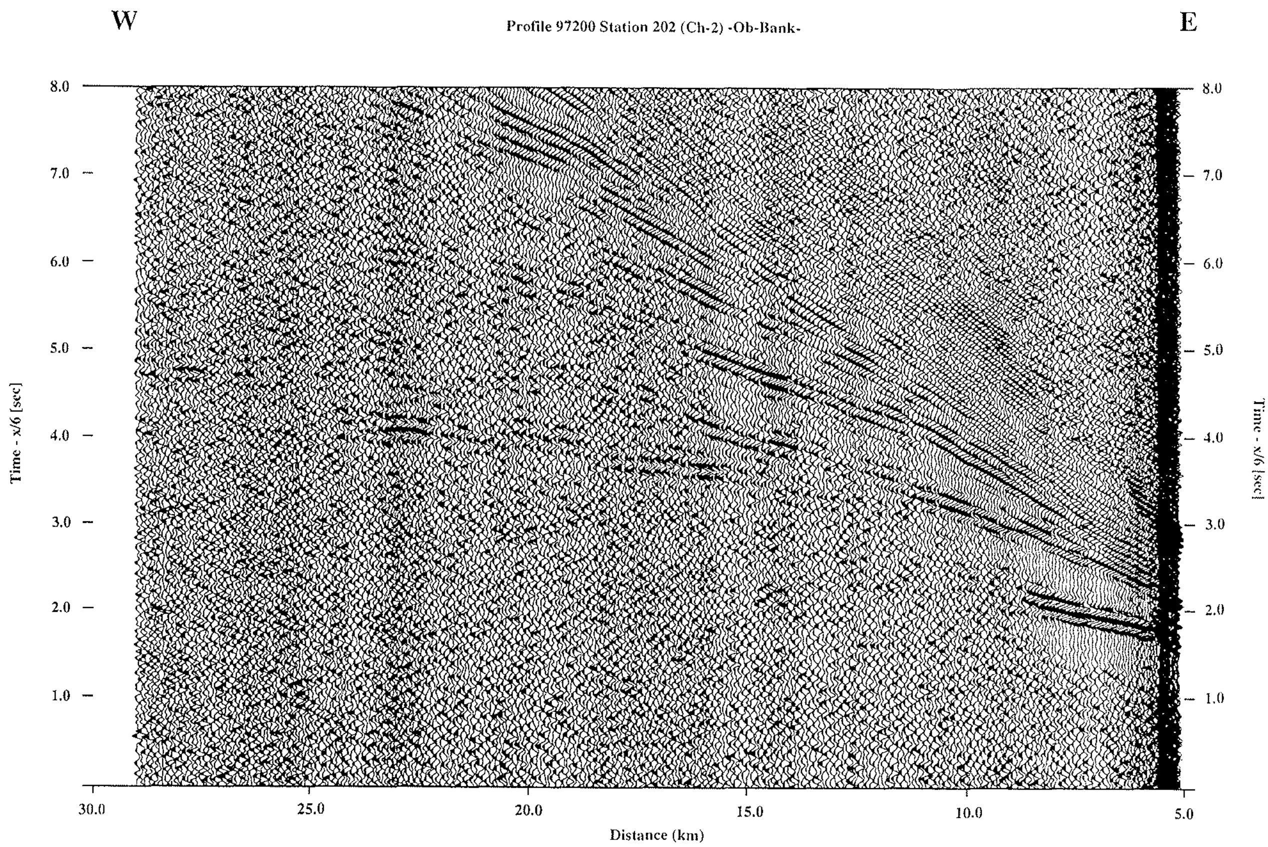


Fig. 3a: Record section of station 201 located onshore Greenland. The strong variations in the travel time curve are due to lateral changes in sediment thickness and velocities.

Fig. 3b: Record section of station 202. The break in the traveltime branch at approximately 10 km is not interpreted of being caused by a low velocity zone. It most likely represents an area with strong lateral variations in the sediment column. As the data quality is extremely bad between 10 and 15 km no final decision can be made.

Station 201 (Figs. 2, 3a) located onshore KCL, shows an almost constant velocity of 4.0 ±0.2 km/s up to a distance of 25 km. At greater offsets the first arrivals reveal the presence of a smooth velocity gradient. The seismic velocity increases to 4.6 ±0.2 km/s at 35 km offset. Depth conversion of the first arrivals by 2D-raytracing yield a sediment thickness of 6 ±0.6 km (Fig. 3c). The sediments below station 202 show significantly lower seismic velocities of 1.8 ±0.1 to 2.5 ±0.1 km/s (Figs. 3b, 3c) derived from standard CDP velocity analyses. This is confirmed indirectly in the record section of station 202, as the traveltimes are delayed by approximately 1 s at 5 km offset compared with station 201. The low velocities strongly indicate the presence of young, unconsolidated sediments. The units might be of Quaternary age, at least for velocities below 2 km/s (Fig. 3c). At 6 ±0.6 km depth seismic velocities of 4.6 ±0.2 km/s are observed. Reflected signals at offsets of 25 and 35 km are visible in the section, which may indicate the base of the sedimentary basin. The reflected arrivals were modelled to belong to an interface at 8 ±0.8 km depth representing the minimum estimate for the sediment thickness in this area. At the very end of the section seismic velocities of 5.5-5.8 ±0.2 km/s are observed and inverted to depths greater than 8 km. However, the velocities are not very reliable due to the short travel time branch. This depth level might represent a transition to more compacted or

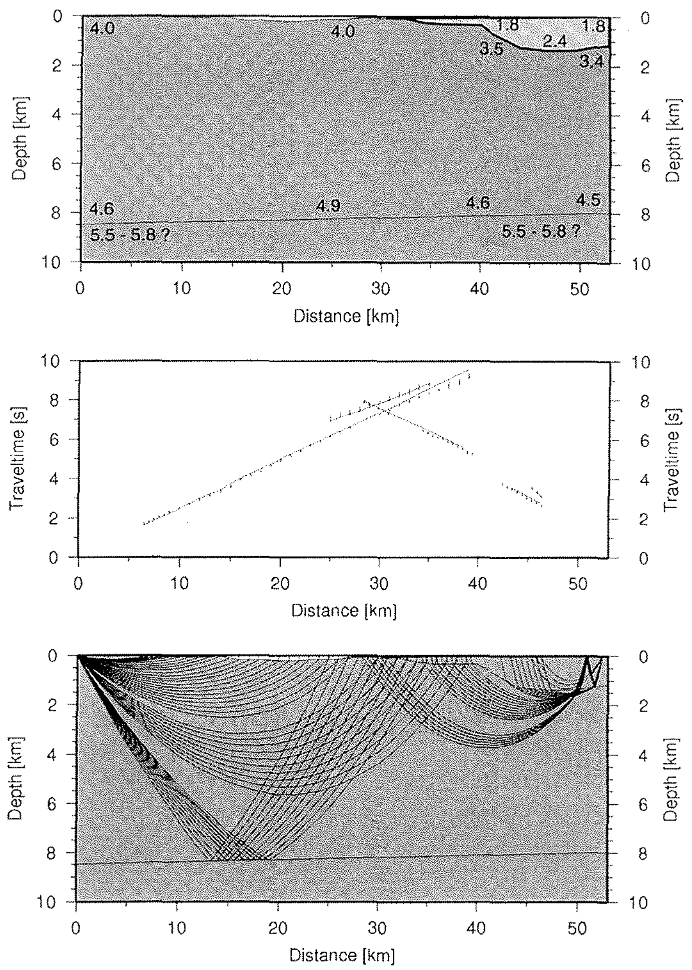


Fig. 3c: Velocity-depth model of stations 201 and 202 based on 2D raytracing. Upper panel: final raytracing model, velocities in km/s; middle panel: picked traveltimes and modelled arrivals; lower panel: ray coverage.

metamorphosed sedimentary units and/or stretched upper crustal crystalline rocks.

The seismic refraction data do not contain any detailed information about crustal thickness and the composition of the crystalline crust. Only on station 201 a short portion of a PmP reflection phase can be observed at 35-40 km offset (Fig. 3a). The hyperbola has a mean velocity of 5.0 km/s. The low RMS velocity for the whole crust supports the interpretation on the presence of a thick sequence of Mesozoic- Cenozoic sediments. The lower crust is obviously thinned due to extensional tectonics. The intercept time of this hyperbola is at 8.81 s unreduced traveltime and corresponds to a Moho depth of 22 km close to the coast of KCL. Due to the short travel time branch visible, this can only be a first order estimate of crustal thickness. Further information about the crustal composition will be derived from modelling the gravity data acquired parallel to the MCS lines.

SEISMIC REFLECTION DATA

In total, three seismic profiles across the North Greenland Margin and the adjacent deep sea will be discussed. The profile 97200 represents the first full MCS line across the entire North Greenland Margin. It starts approximately 5 km east off the coast of KCL and terminates on the western margin of the Yermak Plateau at 80° 53' N, 01° 18' E. For a simpler description of the profile, the line is divided into three parts, the Greenland continental margin, the slope and the Lena Trough region.

Line 97200, CDP 17-3000

The northern part of the East Greenland Shelf is named Ob Bank (OB in Fig. 1). Here, the water depth varies between 30-200 m. From the beginning of line 97200 to CDP 500 the MCS data are dominated by strong water bottom multiples (Fig. 2a) and show no sedimentary structures at deeper levels. This may be explained with the presence of basement rocks or highly consolidated sediment layers close to the sea floor. Between CDP 400 and 800 a trough with water depths around 200 m shallowing towards the east is visible in the data. It is most likely that the trough was created by glacier erosion during glacial periods. Younger sediments are not visible in this part of the line. This interpretation is supported by the two REFTEK recordings of the stations 201 and 202 (locations see Fig. 2a), which show high seismic velocities at shallow depths.

The western flank of this basin is moderately imaged by the seismic reflection data down to 3 s TWT (Fig. 2b). Towards the east (Fig. 2a), the sediments are folded at all levels with decreasing intensity at shallower depths. It is almost impossible to identify a regional unconformity, which can be followed across the entire basin. Between CDP 1500 and 2200 the continuity of the sediments is destroyed up to 0.8 s TWT. This almost 20 km wide zone indicates a time interval when the sediments were affected by strong tectonic activities. Towards

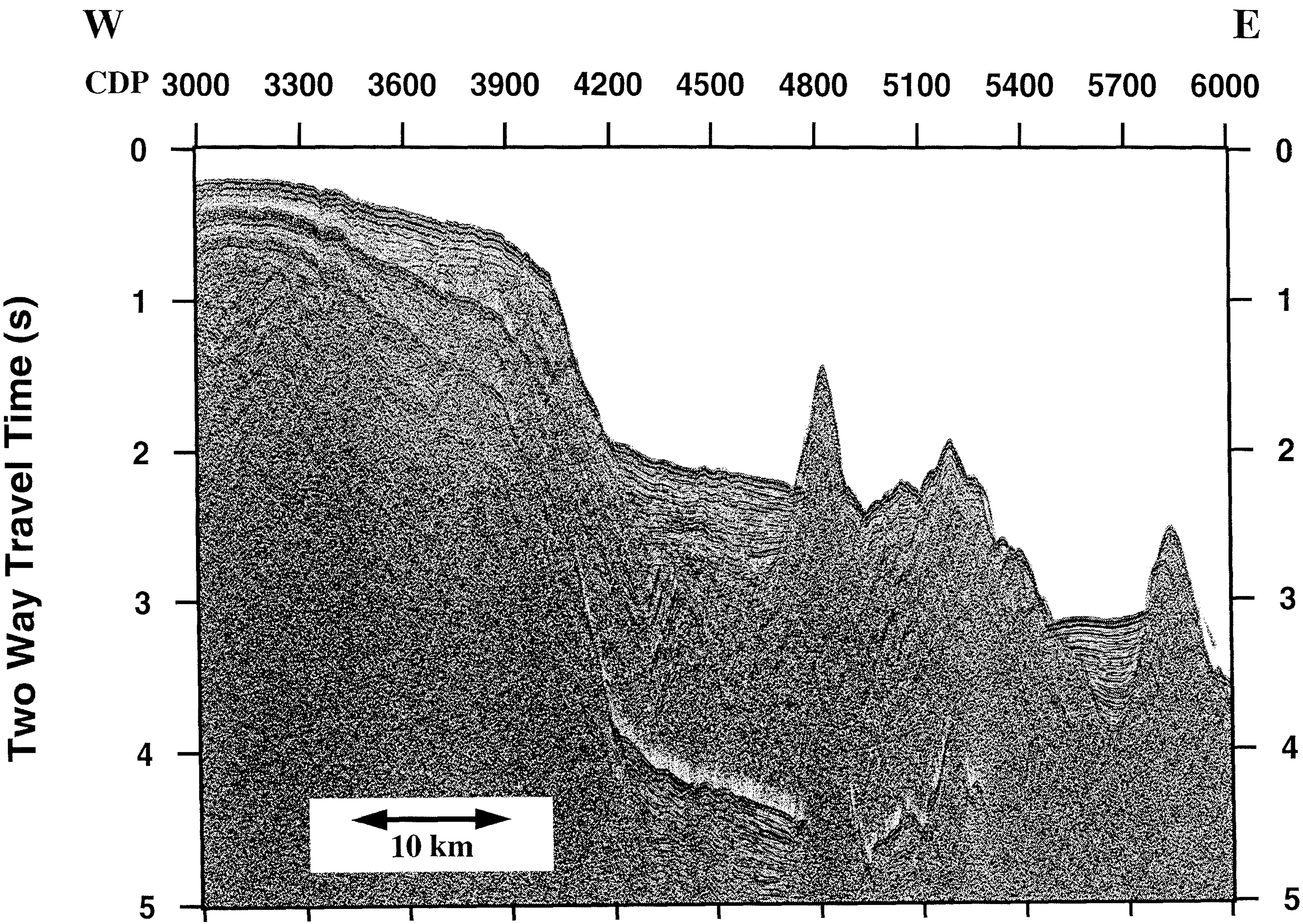


Fig. 4: Central part of line 97200 including the shelf break and the anomalous slope in this area. Please note the thin sedimentary cover on the topographic highs. The origin of the highs is unknown.

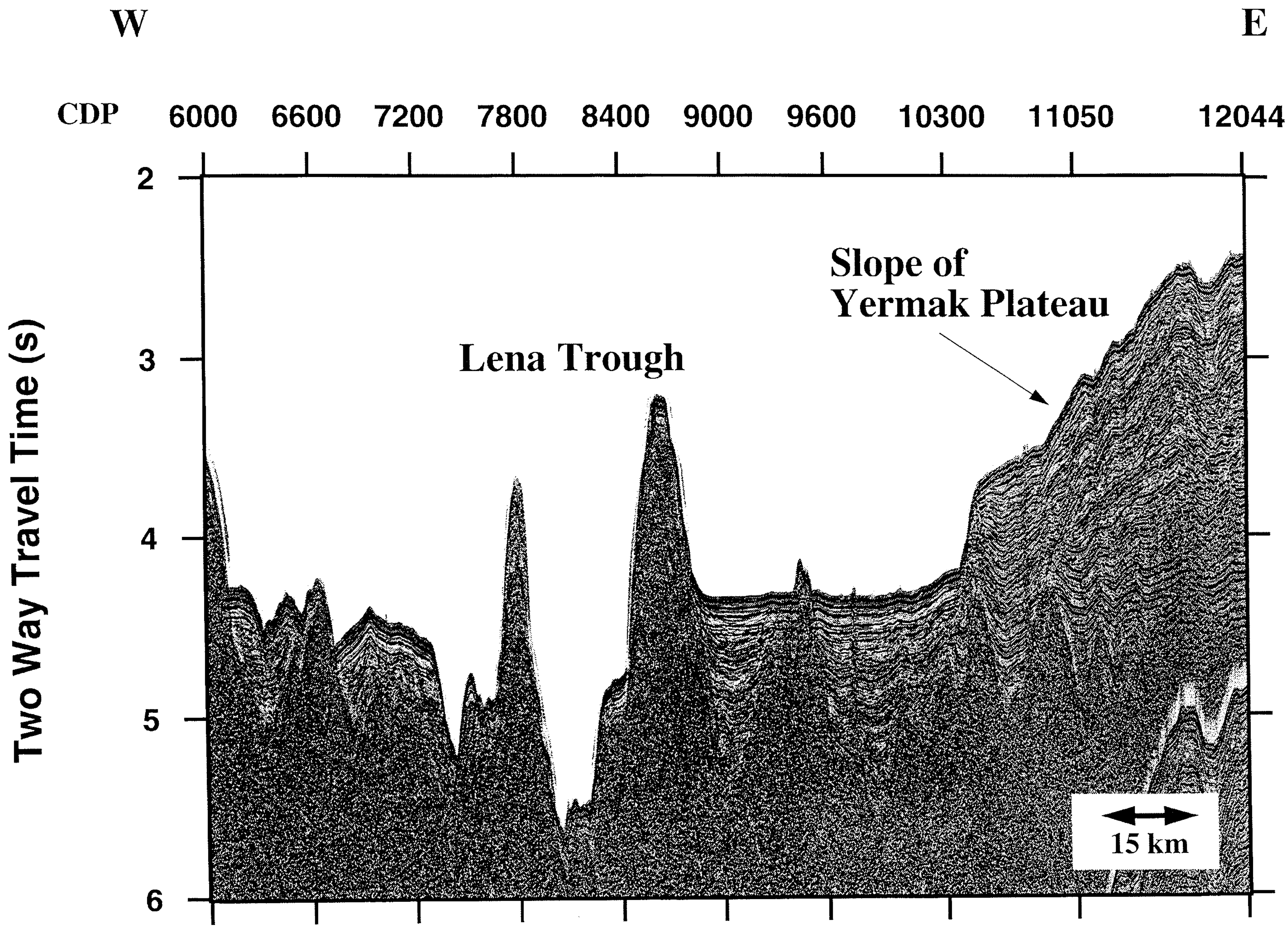


Fig. 5: Easternmost part of line 97200 crossing the Lena Trough. At the very eastern part the slope of the Yermak Plateau could be mapped. As the ships track became highly irregular due to ice, the topography of the slope in detail might not be real.

the east the quality of the data is getting worse as the seafloor multiples could be removed only with minor success.

Line 97200, CDP 3000-6000

East of CDP 3000, no continuous deeper signals can be observed (Fig. 4). Besides the problems with the multiples this might also be due to the folding of the sediments in this area. The strong diffractions beneath CDP 3300 at 1 s TWT might be an evidence for the latter interpretation. The seismic data do not show signals at deeper levels, possibly because highly folded sediments or basement highs, such as from CDP 4800 to 5400, are causing the oblique area. The shelf break can be located at 80° 58' N, 7° 30' W at a water depth of 600 m (Fig. 4, CDP 4000). The continental slope is absolutely non-typical compared with other passive margins. While the water depths increase within 5 km from 600 m to 1425 m (dip 9°), the rest of the slope is dominated by basement highs of unknown origin. The width of this zone is approximately 20 km. Between these basement highs, ponded sediments are seen in the data. Close to the margin a maximum thickness for the sediment units of almost 1.8 s TWT (Fig. 4, CDP 4500) are found. They are folded at all levels indicating active tectonic.

Line 97200, CDP 6000-12044

Water depths increase to more than 3000 m from CDP 6000 to 12044 (Fig. 5). The profile covers the oceanic part of the Fram Strait. Between CDP 7800-8700 the line crosses the Lena Trough. Here, the width of the trough is approximately 20 km between the flanks, which rise up to 2800 m in the west and 2300 m in the east. The maximum water depth of the trough is 4400 m in its central part. It is partly filled with sediments. The sediment structure (Fig. 5) on the eastern flank strongly suggests current controlled deposition. Towards the Yermak Plateau, the sediment thickness is significantly larger than on the Greenlandic side. Up to 1 s TWT of sediments are found directly in pockets at the eastern ridge flank thickening to 2.8 s TWT towards the plateau (Fig. 5; CDP 10300-12000). The data strongly suggest current controlled deposition of the sediments along the investigated part of the western Yermak Plateau Margin (Fig. 5, from CDP 10300 eastwards). Similar features more in the south have been interpreted by Eicken & Hinz (1993) to be built up of drift deposits.

Line 97245

Profile 97245 (Fig. 6a) is located at 80°30'N almost 50 km southwards of line 97200. Although, this line covers only 80 km of the shelf, the short section has a very different appearance compared with line 97200 more to the north. First, the water depth has an almost constant value of 300 m on the shelf. Strong water bottom multiples are observed, typical for glacially overprinted high latitude shelves and the continental slope has only a dip of 4°. Although the deeper part of the data beneath the slope shows no continuous signals, the sediments are strongly folded just 500 ms below the seafloor (Fig. 6b). A thin veneer of sediments has buried the previously rough topography.

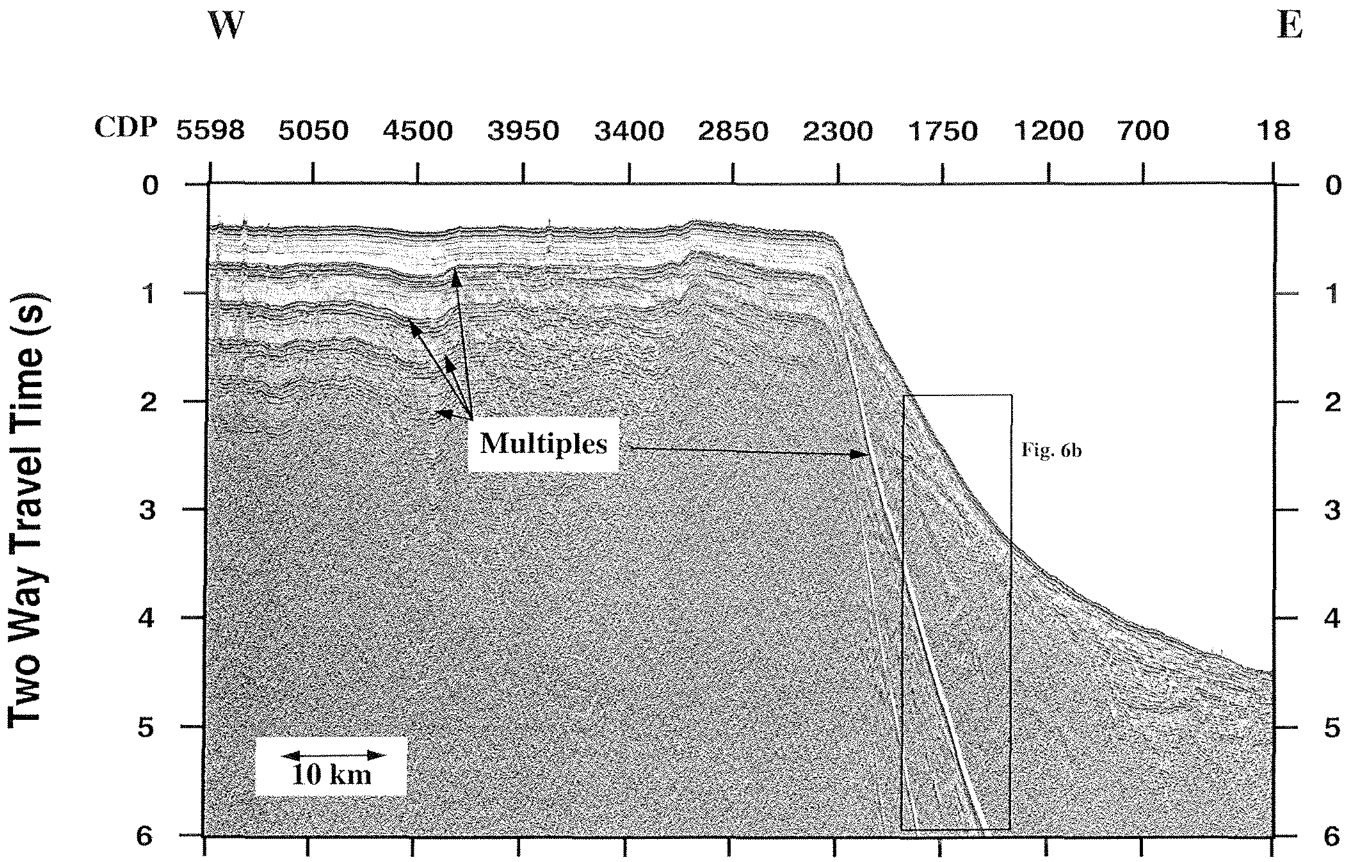
Line 97244

Further to the east, line 97244 crosses the Lena Trough (Fig. 7). The western flank of the trough is almost covered by sediments, which are 1.5 s TWT thick at CDP 600. Here, the sediments are folded indicating active tectonic movements, possibly in the Lena Trough. Small offsets at the sea floor (Fig. 7; CDP 300, arrow) are visible in the section.

The Lena Trough is filled with sediments and the flanks show evidence for large-scale slumps of sediment packages most likely triggered by earthquakes. Here, the width of the trough is approximately 35 km between the flanks (Fig. 7; CDP 1500-2900), which rise to 2500 m in the west and 3200 m in the east. The maximum water depth of the trough is 4350 m in its central part like along the northern line. It is not clear, that the data could image the basement along this line. The central part of the trough is covered by deposits at least 0.6 s TWT thick. Obviously both flanks have acted as dams for the sediments from both margins. Furthermore, sediment input directly from the south can be expected as the Lena Trough disappears as topographic depression at approximately 80 °N. Strong currents in the central part of the trough prevented the deposition of huge sediment packages here.

DISCUSSION

The deeper seismic data across the Ob-Bank confirm suggestions based on onshore geology (Håkanson 1979, Håkanson & Petersen 1982). The sediments at deeper levels are strongly folded, most likely a result of transpressional and/or strike-slip movements between Greenland and Svalbard. The few seismic lines, only one line covers the Ob Bank in W-E direction, do not allow to define any fault zones or trends. Some additional profiles with deeper penetration are necessary for such an interpretation. The wide-angle data support hypotheses suggesting that the shelf is underlain by thick Palaeozoic-Mesozoic-Cenozoic strata (Dawes 1990) at least for the area close to the coast, where a reasonable control on the seismic velocities exist. Velocities greater than 4 km/s are interpreted to represent highly compacted Palaeozoic-Mesozoic sediments. The low seismic velocities at station 202 indicate that this part of the line is located on the younger part of the basin with less compacted sediments. They represent most likely Cenozoic sediments deposited in a rift basin created through strike-slip movements. The seismic velocities together with the MCS data allow the interpretation that a transition from the Mesozoic sediments to a basin mainly filled by Cenozoic deposits underlain again by older strata can be located in an area close to CDP 450 (Fig. 2b). Due to the limited offset of the wide-angle records the complete thickness of the sediment basin is unknown.



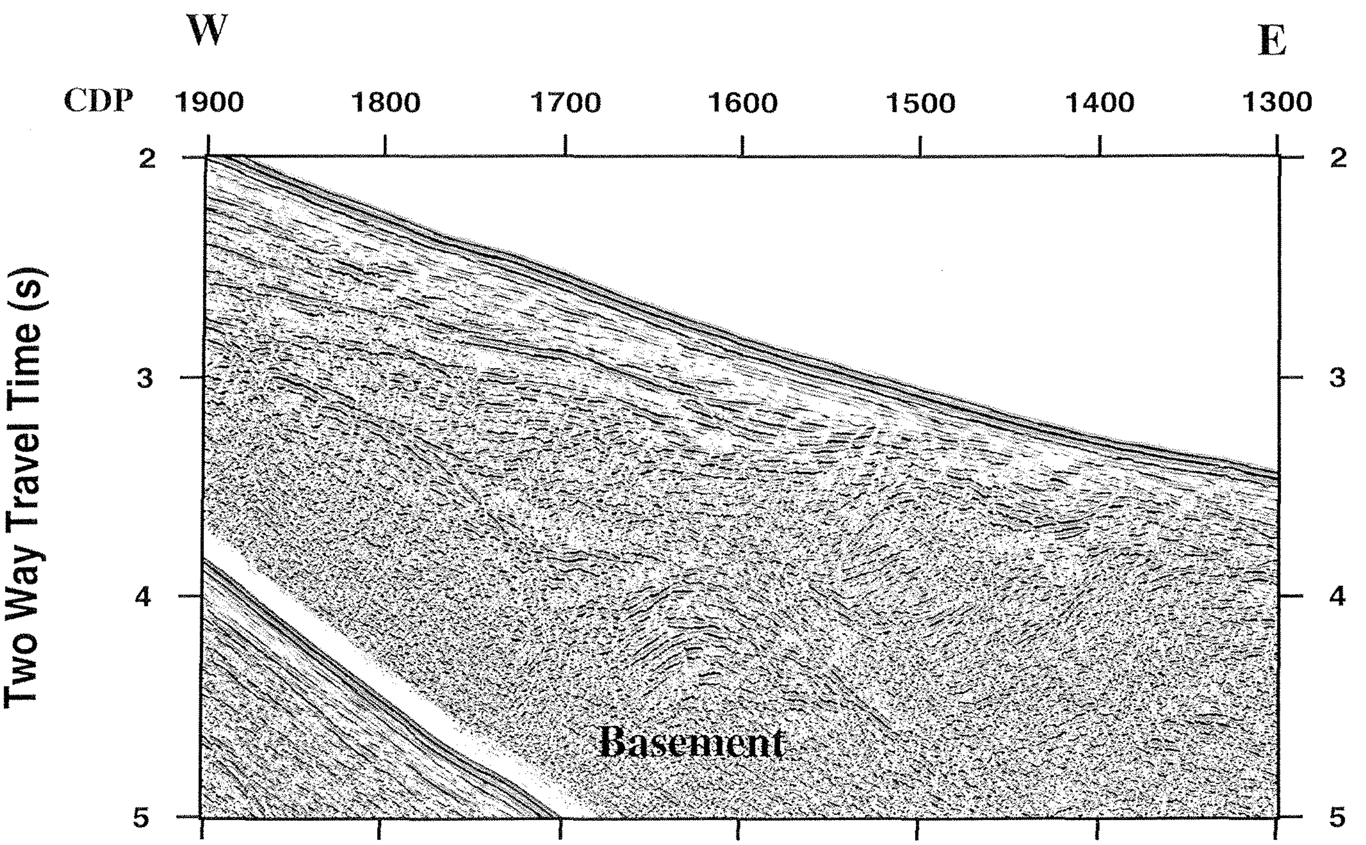


Fig. 6a: Profile 97245 across the continental margin at 80°30'N. Please note the smooth topography of the slope compared with Figure 4.

Fig. 6b: Close-up area of line 97245 to show the basement variations. Note that sediments are folded even close (500 ms) to the seafloor at CDP 1400-1500.

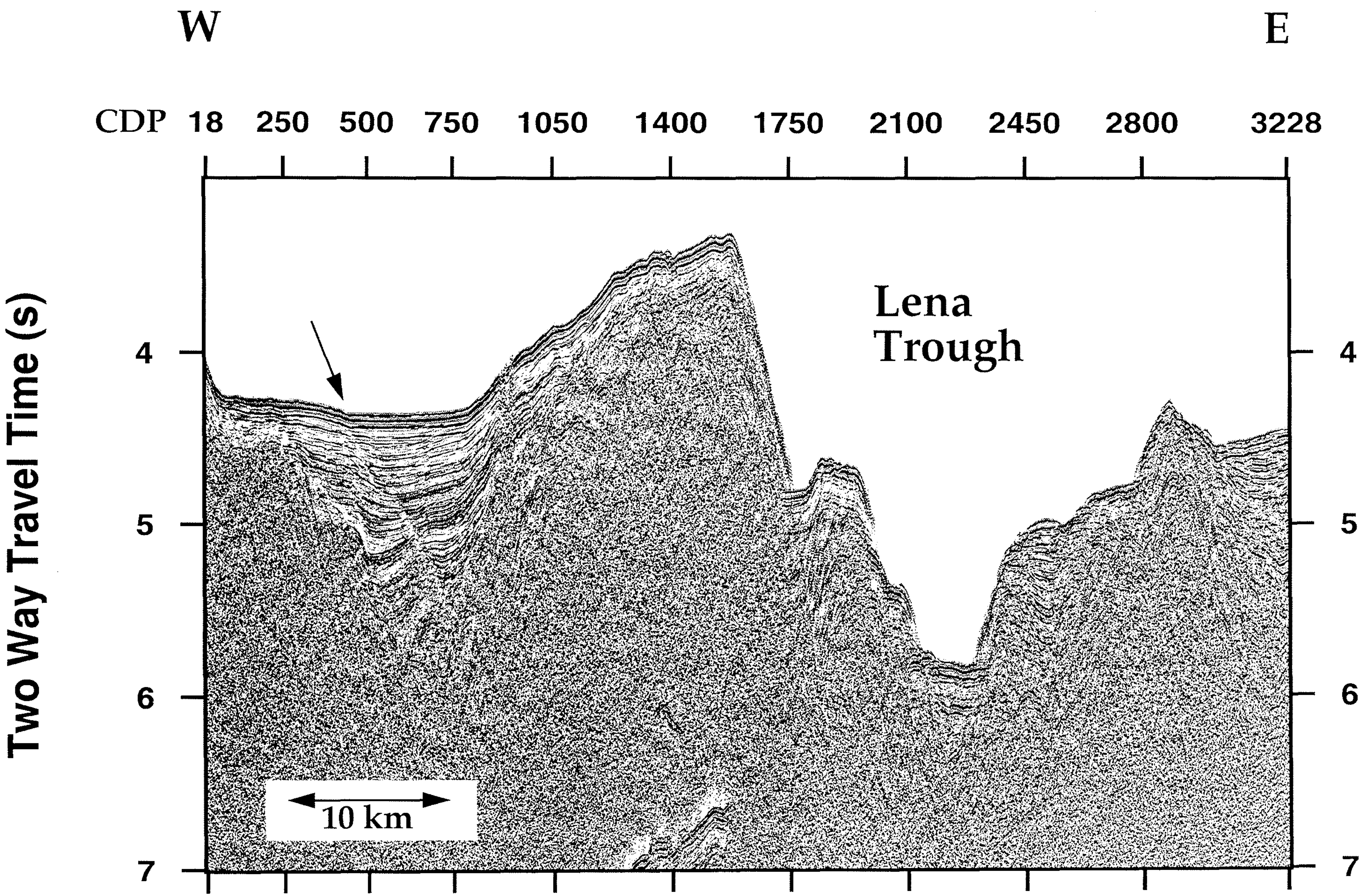


Fig. 7: Profile 97244 across the Lena Trough at 80° 30'N as a prolongation of line 97245.

Similar velocities to those interpreted from station 201 have been found in the Scoresby Sund area (FECHNER & JOKAT, 1996). Seismic velocities of 3.9 km/s (Upper Jurassic), 4.4 km/s (Permian to Middle Jurassic) and 5.5 km/s (Devonian) could be interpreted to be of Mesozoic age as some control from onshore geology exists. Also further north up to 76 °N such correlations are confirmed by seismic refraction work (SCHLINDWEIN & JOKAT 1999). The new data also fit to earlier sonobuoy measurements performed during the YMER-80 cruise (ELDHOLM et al. 1984). These data were so far the only available seismic velocity information from the Ob Bank. They show an average velocity structure of 2.2, 3.5, and 5.1 km/s in the upper crust.

The seismic data across the margin into the Lena Trough clearly show evidence for recent faulting. This is not surprising as active tectonics can be expected in the Lena Trough, which most likely represents an active segment of the mid-ocean ridge system. The rough topography at 81 °N again supports recent tectonic movements at the shelf slope. However, the seismic data allow no interpretation of the origin of the basement highs. They might be of continental or oceanic origin. The thick sediment strata found on the Yermak Plateau margin can be interpreted as current controlled deposits. Further to the south EICKEN & HINZ (1993) suggested the presence of contourites along the western margin of Svalbard. These deposits were mapped along the Svalbard margin up to 80 °N. Further north no data existed. The very eastern part of line 97200 support a continuation of these deposits at least to 81 °N. EICKEN & HINZ (1993) explain the formation of the contourites on the eastern side of the Fram Strait with deep, persistent currents at least since Late Miocene, differences in relative subsidence of both margins and by differences in sediment supply. The uplift of Svalbard and the Barents Shelf has provided significant larger volumes of sediments into the eastern part of the Fram Strait compared with the limited glacial erosion of the North Greenland Shelf. The new data support this interpretation and it may be suggested that these deposits will be also present as far north as 83 °N, where the Gakkel Ridge terminates against the North Greenland margin.

CONCLUSIONS

The new seismic data acquired by RV "Polarstern" in the summer of 1997 significantly enlarged the geophysical database in this remote area. The new data indicate that old Upper Palaeozoic-Mesozoic sequences are present close to the Greenland coast at 81 °N. They have a minimum thickness of 8 km. Unfortunately, the base of the sediments could not clearly be imaged, neither in the MCS nor seismic refraction data. Further to the east, tectonic processes during relative movements of Greenland and Svalbard folded the upper sediments beneath the Ob-Bank. The major event for the deformation of the sediments was Late Mesozoic/Early Cenozoic strike-slip movements between Greenland and Svalbard followed by oblique spreading.

The different shapes of the continental margins at 81 °N and 80° 30' N can be explained by the close distance of the northern line to the active Lena Trough and with the amount of sediments deposited during glacial times. While the ice shields south of Ob-Bank at 80° 30' N were most likely quite dynamic, the bank itself was covered by a relatively stable ice shield. This resulted in minor sediment input at 81 °N.

The oceanic basement between the continental slope and the Lena Trough shows a rough topography. Oblique and/or slow spreading processes might cause this. Both flanks of the Lena Trough have acted as a kind of dam for the sediments delivered from the Greenland and Svalbard margins, while strong currents in the central valley prevented the whole ridge from being completely buried by sediments.

ACKNOWLEDGMENTS

We thank the captain and crew of RV "Polarstern" as well as the helicopter crew and the chief scientist for their excellent support during the expedition. The excellent support of M. Commer, O. Eisen, N. Lensch, H. Martens, O. Ritzmann, J. Rogenhagen, K. Thalmann and E. Weigelt during the data acquisition was critical for the success of the expedition. Finally, I thank O. Ritzmann, who did the raytracing modelling of the two wide-angle stations. This is contribution No. 1681 of the Alfred Wegener Institute for Polar and Marine Research.

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