# Seismic investigations offshore South-East Greenland

*John R. Hopper, Dan Lizarralde and Hans Christian Larsen*

A high-resolution, shallow-seismic survey off the South-East Greenland coast was carried out during August and September 1997 aboard the R/V *Dana* of the Danish Ministry of Agriculture and Fisheries. This seismic survey supports two large ongoing regional research projects. The Danish Lithosphere Centre (DLC) is involved in a number of investigations to understand the tectonic evolution of the North Atlantic region since the early Tertiary, and a consortium of scientists from the Geological Survey of Denmark and Greenland (GEUS) and the Free University of Amsterdam (VU) are engaged in palaeo-oceanographic studies of climate change since the Neogene. The survey was thus a cooperative venture where ship time was shared between the participating research institutes. This report focuses on the DLC component of the cruise, which primarily involved the acquisition of site-survey data to be used in the planning and execution of drilling operations scheduled for 1998. These drilling operations are aimed at understanding the voluminous volcanic activity that accompanied continental rifting and the formation of the South-East Greenland margin. The GEUS/VU component of the cruise is summarised elsewhere in this volume (Kuijpers *et al.* 1998, this volume).

## Background

The East Greenland margin is a type example of a volcanic rifted margin. These margins, which have now been identified in many parts of the world, are characterised by the emplacement of large volumes of volcanic rock during continental breakup and the onset of seafloor spreading (e.g. Coffin & Eldholm 1994). Thicknesses of new igneous crust on these margins can exceed 25 km, which is about three times the thickness of normal seafloor-spreading (oceanic) crust. It appears that most of the Atlantic margins north of *c.* 58°N are volcanic and that their formation is somehow related to the Iceland plume, which today is producing igneous crust up to four times the thickness of normal oceanic crust (Bjarnason *et al.* 1993; Reid *et al.* 1997). Many questions surround the role that the Iceland plume may or may not have had on rifting, breakup, and seafloor spreading in the area. DLC research in South-East Greenland should help to answer these questions and thus give insight into the links between lithospheric and crustal scale processes and the dynamics of the underlying asthenospheric mantle.

There are currently a number of interdisciplinary research programmes designed to address these problems. Crustal-scale seismic reflection and refraction experiments have been conducted to determine the thickness and seismic velocity of the crust along and across the margin, providing a regional view of the mass fluxes associated with margin formation (Dahl-Jensen *et al.* 1995; Holbrook *et al.* 1997). In addition, direct sampling of the basalt flows has provided geochemical constraints on the temperatures and pressures of melting and on the timing of distinct magmatic episodes (e.g. Larsen & Saunders 1998).

An important component of DLC's sampling programme is offshore drilling to sample the basalts extruded during the earliest stages of volcanic margin formation. The basalts were deposited subaerially as extensive flows that have since subsided and rotated seaward, giving them a characteristic appearance on seismic-reflection records as sequences of seaward-dipping reflectors. Ocean Drilling Program (ODP) Legs 152 and 163 targeted these basalts along two transects – EG63 near 63°N and EG66 near 66°N (Larsen *et al.* 1994; Duncan *et al.* 1996). Unfortunately, a severe hurricane during Leg 163 caused that cruise to be terminated nearly a month early, leaving a number of drilling objectives unfulfilled, including almost the entire EG66 transect. In the summer of 1998, a commercial drill ship chartered by the DLC will continue and expand upon the drilling programme begun by ODP. The primary purpose of the R/V *Dana* survey was to collect additional data in support of this new drilling initiative.

  

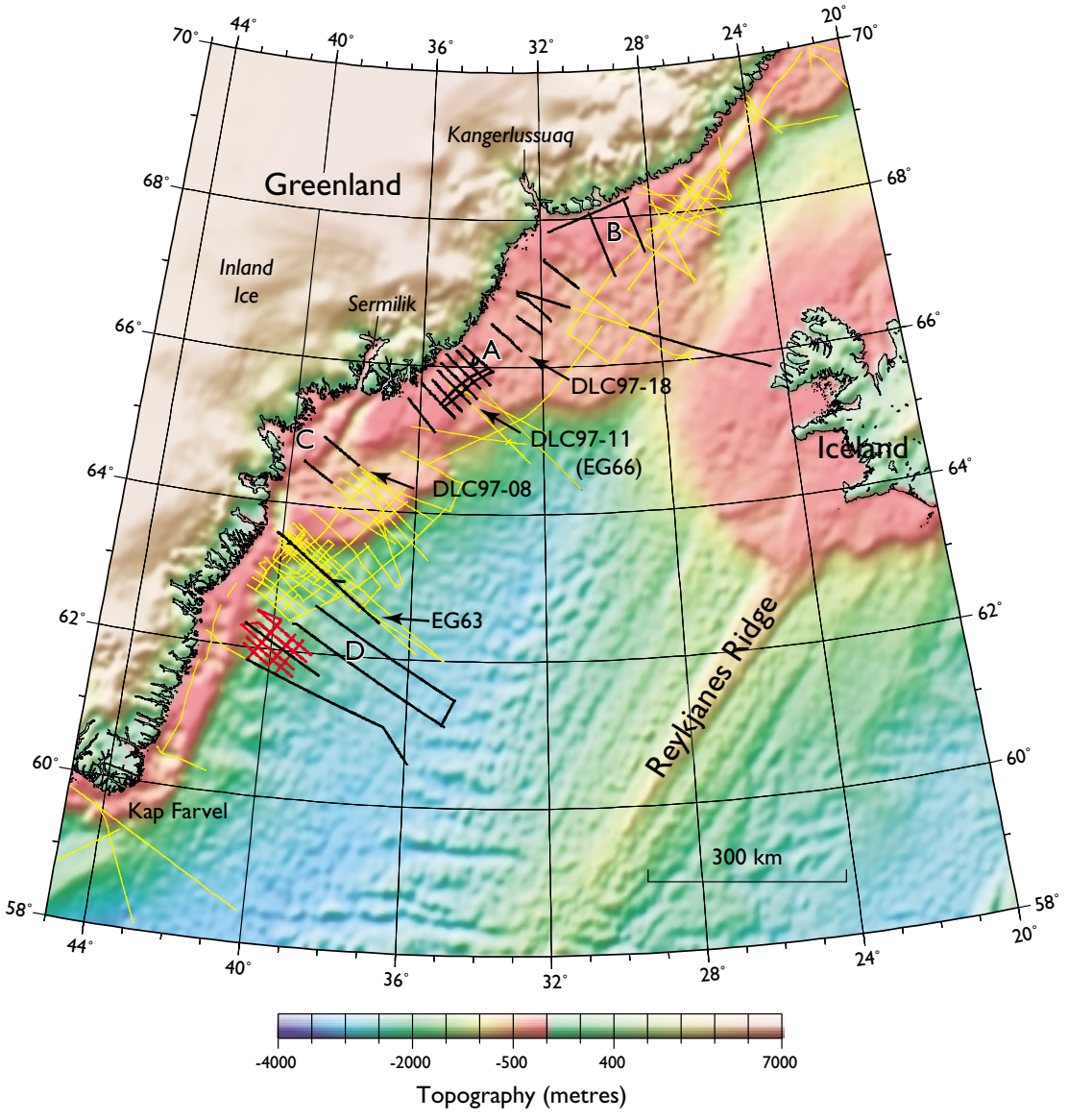


Fig. 1. Location map showing where new data were collected in 1997 on the R/V *Dana*. The thick black lines are data collected by the DLC and the red lines are data collected by GEUS and the Free University, Amsterdam. Tracks from previous seismic surveys are shown in yellow. Data from the lines labelled are shown in Figures 2, 3, 5. A, B, C and D are survey regions discussed in the text.

## The R/V *Dana* Survey

On the 1997 R/V *Dana* cruise we acquired 3781 km of new, high-resolution seismic data during 34 days at sea. Of this, 3052 km were shot for the DLC work and 729 km were for the GEUS/VU project. We recorded only 35 hours of down time due to weather, ice and equipment problems. We used the new acquisition system recently purchased by the Geophysics Department at the University of Aarhus (AU), Denmark. This includes a 96 channel, 594 m hydrophone streamer with a 6.25 m channel interval and a Geometrics R48 recording system.

The airgun array consisted of 4 × 40 in$^3$ sleeve guns chained together in a cluster with a centre to centre spacing of 50 cm. Navigation was controlled by Navipac software and positioning was provided by an Ashtech GG24 receiver that uses both the United States global posi-

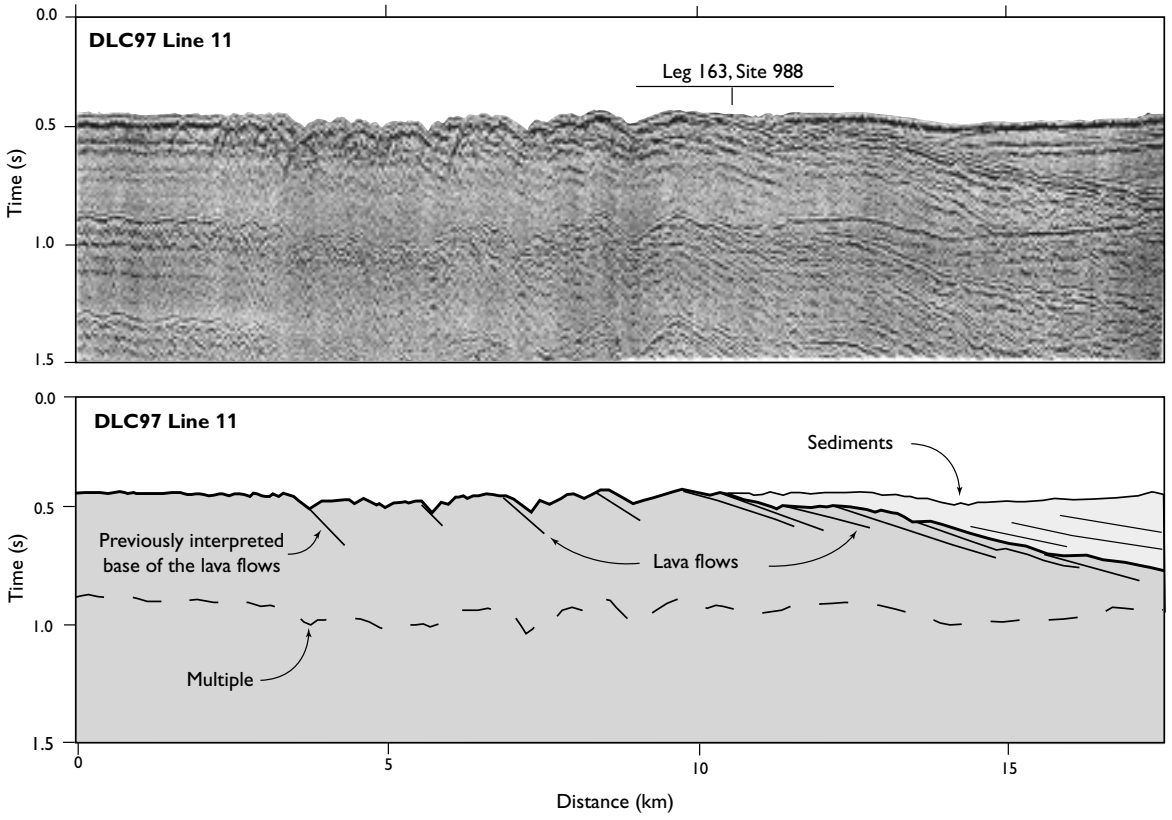


Fig. 2. Line DLC97-11, which coincides with the EG66 drilling transect. The top is the brute-stack produced on board and the bottom is a line drawing of the major features. The approximate location of site 988 from ODP Leg 163 is also shown.

tioning system (GPS) satellites and the Russian GLONASS satellites. As a backup, a second Ashtech GPS receiver recorded the raw GPS data for post-processing. For most of the survey, we also towed a Geometrics 866 marine magnetometer.

For the DLC part of the survey, seismic lines were shot in four main regions off the coast (Fig. 1). Region A is centred on the EG66 drilling transect and is the primary target area for the 1998 drilling. Region B lies offshore of the major DLC land-sampling and mapping areas (Larsen *et al.* 1995) and is close to the Greenland–Iceland Ridge, which is believed to be the hot spot track. Region C is an area that we hypothesised may be a zone of rifted continental crust inland of the seaward dipping reflectors. We shot two short lines to investigate this possibility. Region D includes a line shot over the EG63 drilling transect as well as several lines shot much farther out to sea. These latter lines were acquired to investigate the nature of the oceanic crust seaward of the volcanic margin. In this report, we discuss data from regions A and C and refer readers to the Cruise Report on file at the DLC for a more comprehensive description of the data collected (DLC 1997).

## *Region A*

A dense grid of seismic lines was shot in region A, one of the primary target areas for the forthcoming 1998 drilling. Geochemical data suggest that a strong along-margin gradient in mantle source properties existed between Kangerlussuaq and the EG63 drilling transect at the time of margin formation (Fitton *et al.* 1997). Results of the 1996 deep seismic reflection and refraction work (SIGMA) also reveal a major change in the magmatic flux along the margin during breakup somewhere south of this region (Holbrook *et al.* 1997).

The uppermost crustal structure typical of this part of the margin is illustrated by line DLC97-11, which coincides with the EG66 drilling transect (Fig. 2). A well defined set of seaward dipping basalt flows crop out from beneath the sediment cover near km 10.5. The

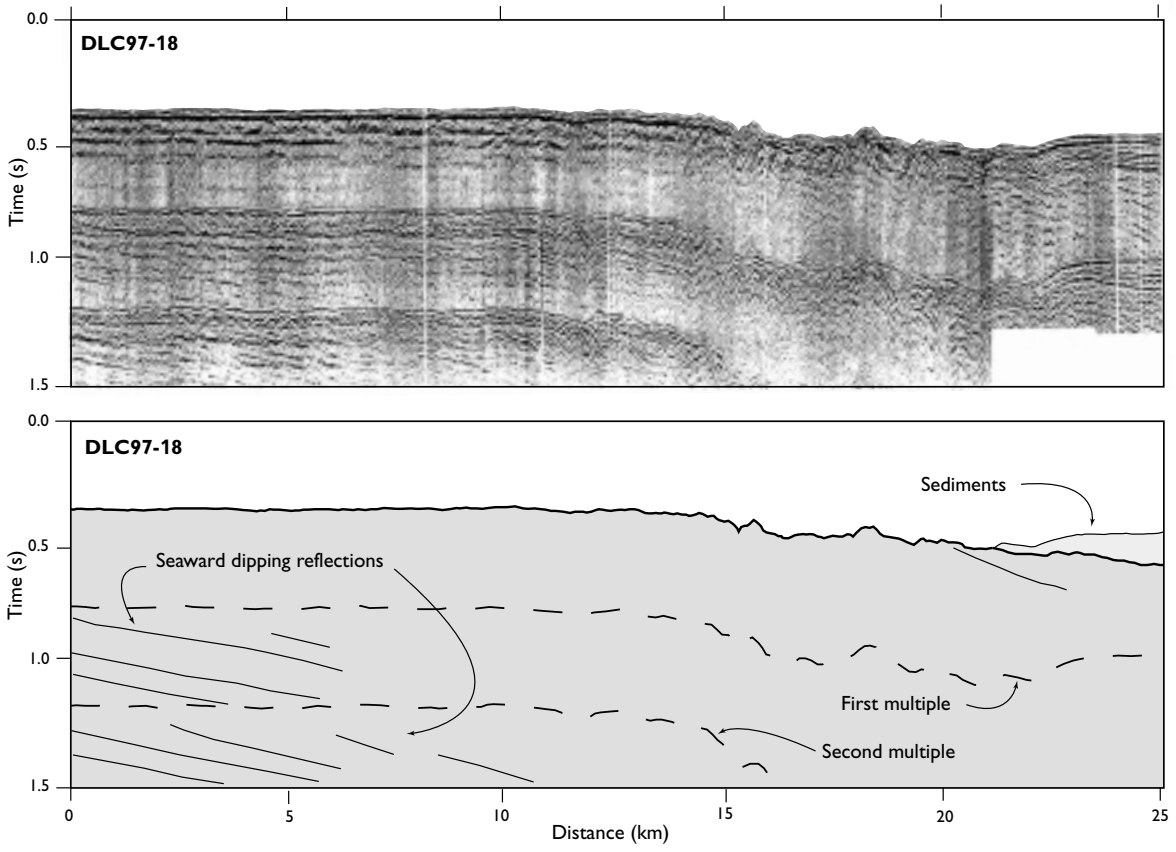


Fig. 3. Line DLC97-18, which is located farther north along the coast than the line DLC97-11 (Fig. 2). The data indicate that there may be seaward-dipping reflectors very similar to those produced by the basalt flows much farther landward than previously interpreted.

seafloor is very rough landward of this point, and this roughness probably represents the eroded edges of more seaward-dipping basalt flows. The seafloor becomes smooth again landward of km 2.5. This landward transition from rough to smooth had previously been interpreted as marking the base of the basalt flows deposited on continental crust (Duncan *et al.* 1996). This interpretation places one of the successful Leg 163 holes, Site 988 (Fig. 2), well within the main basalt flows. Thus, it was thought to be equivalent to either the pre-breakup lower series lavas or the breakup related upper series lavas, both of which are found on the EG63 transect. Those lavas are well constrained to be between 56 and 61 Ma (Sinton & Duncan 1998). Age determinations on volcanic material recovered from Site 988 have yielded much younger dates of 48 Ma (Tegner & Duncan in press), however, presenting an inconsistency that may call into question the regional chronological framework that needs to be tested with further drilling.

There are two likely explanations for the young age of the basalts recovered at Site 988. These rocks may have originated from late-stage, off-axis volcanoes situated on top of older basalts. However, the interpreted stratigraphic relations around the Site 988 basalts tend to argue against this explanation. It is also possible that the smooth to rough transition described above does not mark the landward edge of the base of the lava pile and that the basalts continue much farther landward, placing the Site 988 rocks higher in the stratigraphic column. This possibility is supported by evidence from the shipboard stack of line DLC97-18 (Fig. 3), where clear seaward-dipping reflectors are imaged in the first and second multiples. Similar events are observed on DLC97-13 (not shown). While further processing and analysis of the *Dana* data is necessary, we believe that these data and the new drilling results will show that the earliest basalts extend considerably farther landward than previously thought.

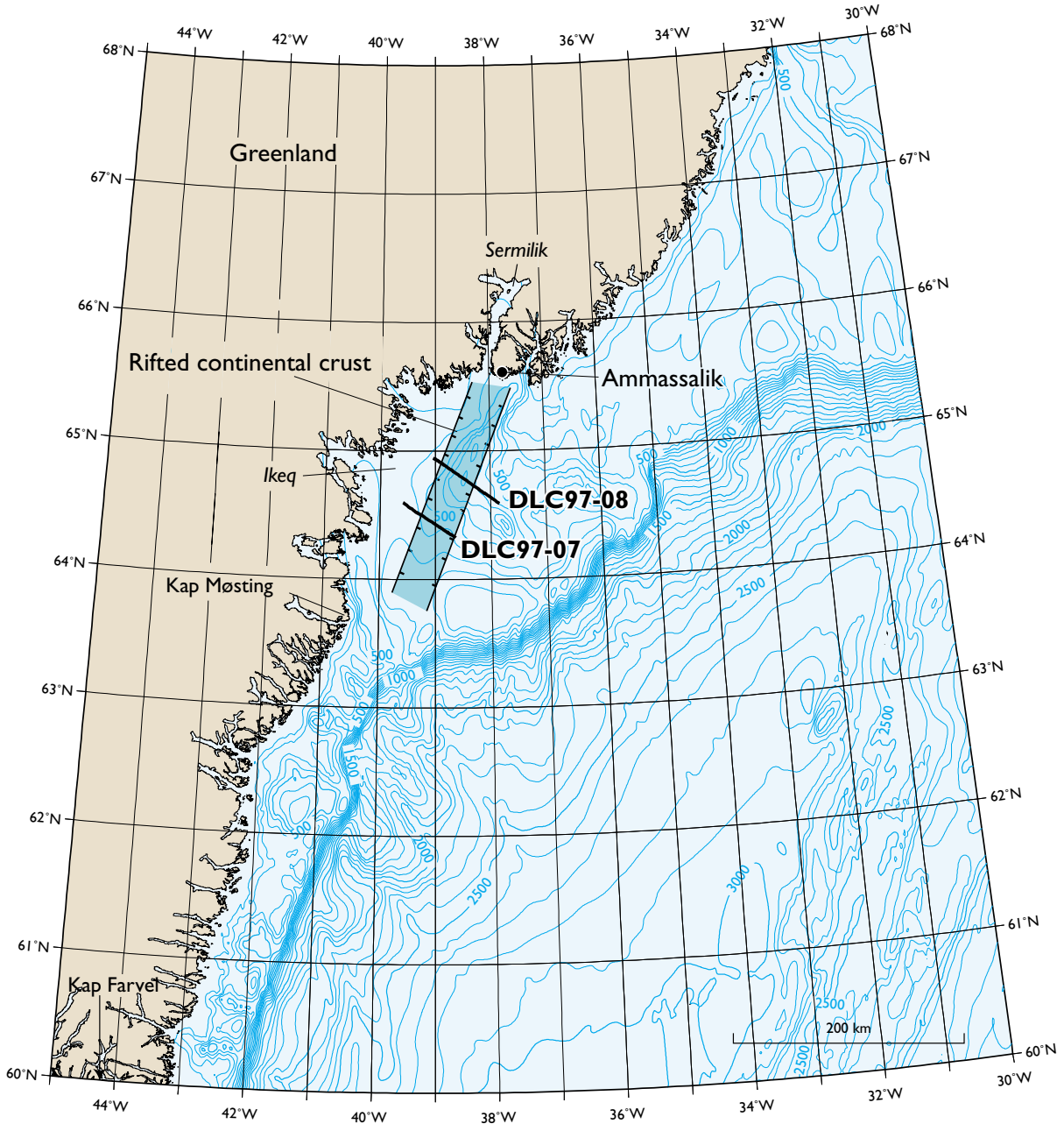


Fig. 4. Location of a hypothesised failed rift arm based on the new data. Seismic line DLC97-08 is shown in Fig. 5.

## *Region C*

A major change in the structure of the East Greenland margin occurs between 64°N and 66°N. The margin shelf is very narrow from Kap Farvel up to Kap Møsting but broadens significantly to the north (Figs 1, 4). In addition, the margin appears to be segmented, with a small offset in the strike of the margin just around Ammassalik. Some of the broadening of the margin is due to erosion and sedimentation patterns in the region. A major segment of the Inland Ice drains towards this area and recent glacial deposits are built up much far-

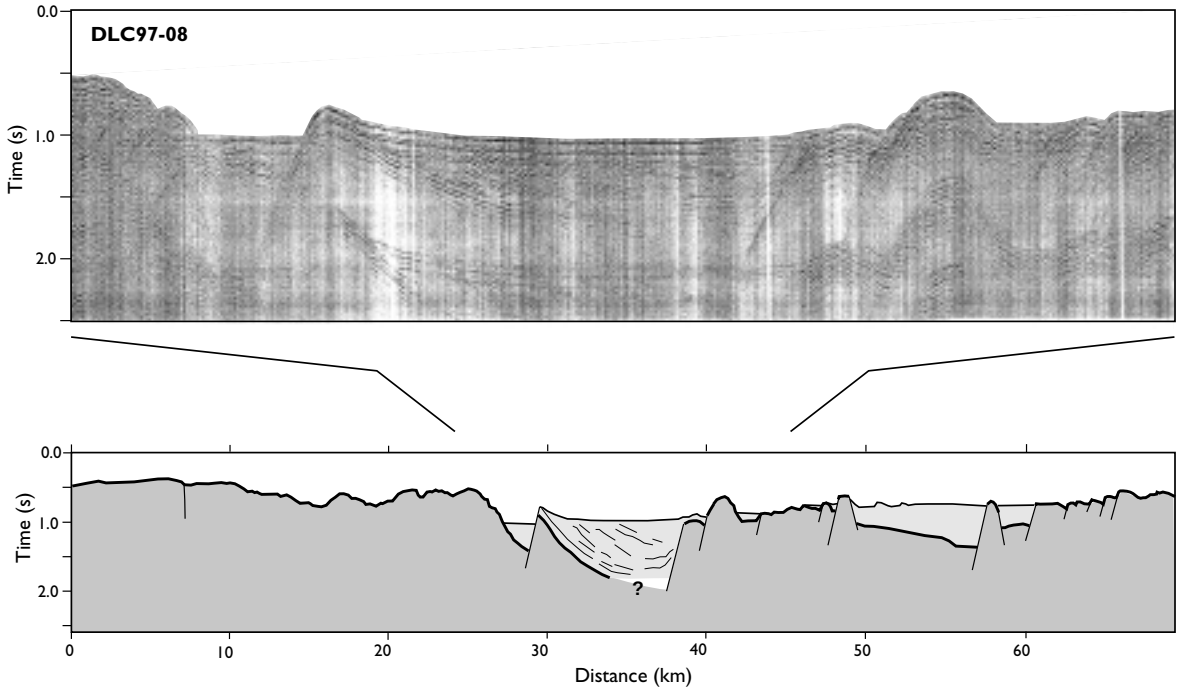


Fig. 5. Line DLC97-08, located south of Ammassalik, see Fig. 4. The possibility that a significant part of the margin in this area is underlain by thinned continental crust must now be considered.

ther out to sea than along other parts of the margin (Larsen 1990; Clausen 1998). However, there may be other factors that contribute to this change. Increased magmatism closer to the inferred plume track could have led to a more prolonged period of excess volcanism that resulted in a broader region of thick igneous crust. Another possibility is that there was a small change in spreading direction and we hypothesised that a failed rift system could extend towards Sermilik. Thus, the margin here may be underlain by rifted continental crust. Two transects (DLC97-07 and 08) were acquired in this region to extend previous seismic lines farther landward and to investigate the possible existence of a failed rift system here. The shipboard stack of DLC97-08 reveals intriguing features that strongly suggest the presence of a substantial rift basin in this region, including an interpreted down-thrown fault block rotated seawards (Fig. 5). The planned 1998 drilling operations will include this structure as a new target, providing information about the age of the basin, the nature of the infilling strata, and the implications of the feature for the tectonic evolution of the margin.

## Summary

Overall the cruise was very successful. New high-resolution seismic data were collected in all of the areas we had planned to survey. Although processing of the data is still in progress, the data has already provided us with significant new information that bears on our understanding of the region. Along the EG66 transect, the landward extent of anomalous volcanism appears to be much closer to the coastline than previous interpretations concluded. South of Ammassalik, we discovered evidence for extensional basins of unknown age. Much of this area thus appears to be underlain by rifted continental crust. Further work in this region is now necessary to fully understand the tectonic evolution of the area.

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**Authors' address:**

*Danish Lithosphere Centre, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark.*