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Faeroe Islands - a Microcontinental Fragment?

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Abstract. The crust between the continental blocks of Europe and Greenland has a complex structure. Ridges, banks and abyssal plains in between are the dominant features, and different types of crustal structure have been investigated.

During summer 1972 the North Atlantic Seismic Project has been carried out with the aim to investigate the oceanic area between Scotland and Iceland. Thereby the results of refraction experiments on the Faeroe shelf show that the crust beneath the Faeroes essentially differs in two respects from the typical oceanic crust under deep sea basins and the anomalous crust beneath Iceland and the Iceland-Faeroe Ridge: (i) Two P_g-phases with velocities of 5.3 km/s and 6.1 km/s are typical for a metamorphic and granitic basement. (ii) Submoho P_n phases have apparent velocities from 7.1 km/s to 8.3 km/s and time terms of more than 3 s giving a depth to moho of more than 30 km. This means the crust is more like the continental type.

The Faeroes may be interpreted as a continental fragment like Rockall Bank and the western part of Vøring Plateau being left behind during the opening of the North Altantic in Tertiary.

Key words: Continental Fragments – North Atlantic Seismic Project – Time Term Analysis – Continental Type of Crust.

1. Introduction

The opening of the north-eastern part of the North Atlantic in Tertiary has left behind a crust between the continental blocks of Europe and Greenland, which shows a complex structure. The dominant features are expressed in the topography of the ocean floor and are determined by ridges and banks with abyssal plains in between. Fig. 1 shows the bathymetric contours of the sea between Northern Europe and Greenland.

Lying perpendicular to the Midatlantic Ridge and more or less parallel to the fracture zone of Jan Mayen the Iceland-Faeroe Ridge connects the plateau of Iceland with the Faeroe Bank. The velocity-depth distribution of the ridge corresponds partly to that of Iceland and is neither of the oceanic nor the continental type (Bott *et al.*, 1971).

The results of gravity surveys between Iceland and the Faeroes show lateral changes in crustal density. The Bouguer anomalies on the ridge have values up to 100 mgal and on the Faeroe shelf about 30 mgal. According to Bott *et al.* (1971) the crust under the Faeroes is less dense and thicker than the crust of the ridge. A half circular shaped anomaly north-west of the Faeroes with high positive values is supposed to be effected by the existence of a continental margin.

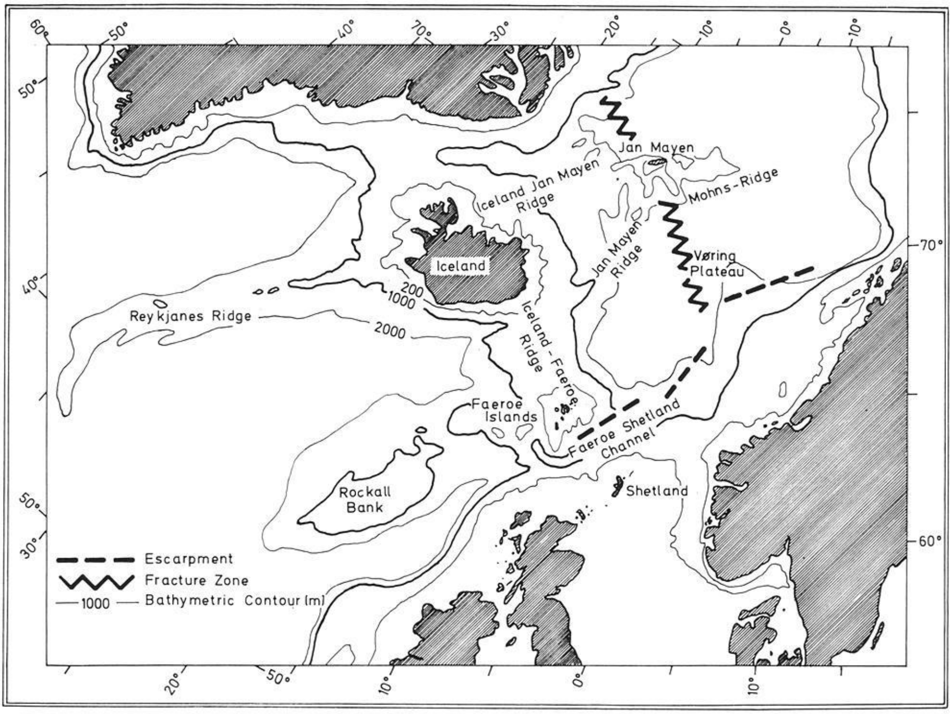

Fig. 1. The Atlantic ocean between Northern Europe and Greenland illustrating the complex structure of the ocean floor

The uppermost structure of the Faeroe Islands has a similarity with Iceland (Pálmason, 1965). Thick layers of basaltic lavas, radiometrically dated at 50 to 60 m. y. (Tarling and Gale, 1968), cover the substratum. Moreover the observation of refracted waves travelling with a velocity of about 6 km/s in a depth of 4 to 6 km has given reason for the supposition that sialic material underlies the basalts of the islands (Casten, 1970, 1973). Schrøder (1971) has interpreted low values of gravity by the presence of material with lower density.

Geophysical investigations (Talwani and Eldholm, 1972) have traced a burried marginal escarpment from Vøring Plateau in the Norwegian Sea down to the Faeroe-Shetland Channel. Its basement dips towards the continental shelf. Seismic soundings on the Vøring Plateau show parallel to it an uplift of lower crust (Hinz, 1972). Thus the part of the Vøring Plateau west of the escarpment is supposed to be a continental fragment. Rockall Bank south of the Faeroes shows a crustal thickness of more than 30 km. The structure of this part of the crust can be interpreted as typical for the continental type (Bott and Watts, 1970).

2. *Deep Seismic Sounding*

During summer 1972 the international North Atlantic Seismic Project has been carried out to investigate the deeper structure of the water covered area between Scotland and Iceland. The project was proposed, planned, and organized by the

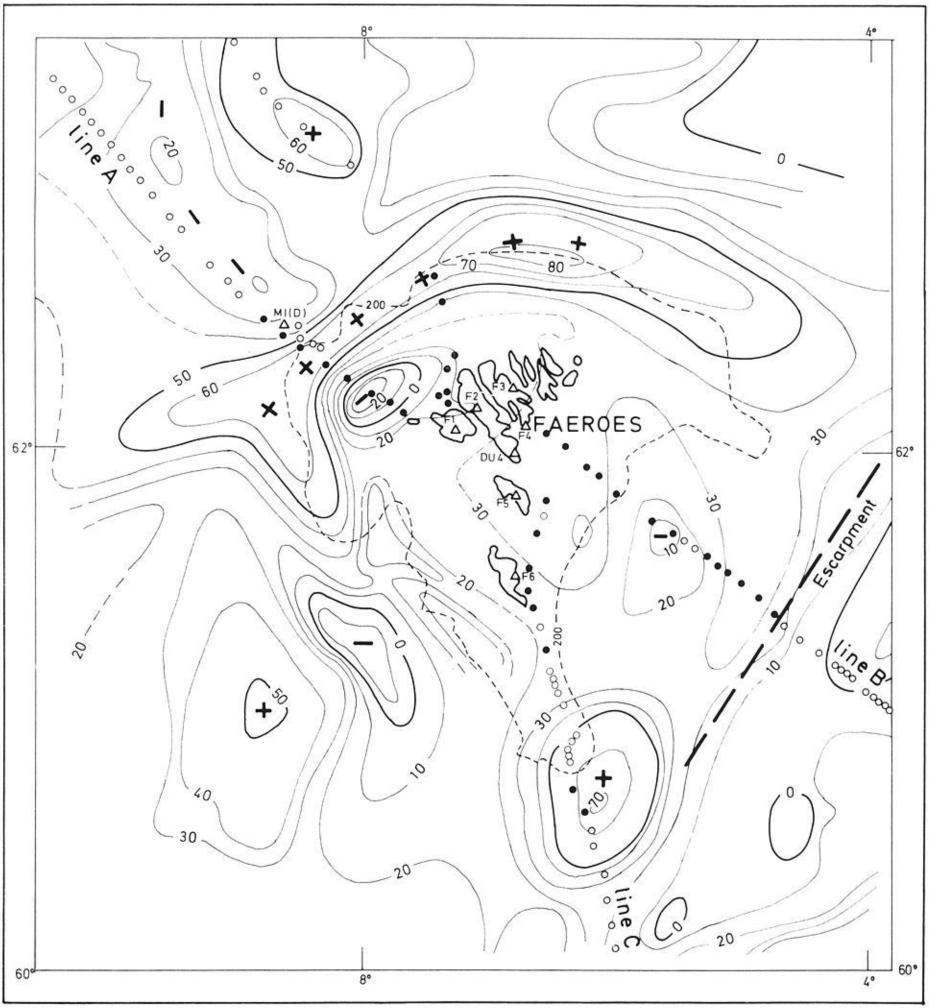

Fig. 2. Map showing the free-air anomalies (in mgal) from the area around the Faeroe Islands together with the shotpoints and stations of the North Atlantic Seismic Project

Department of Geological Sciences, University of Durham, including the participation of institutes from several countries. Shots with charges of 300 lbs, 600 lbs, and in some cases of 1200 lbs, were fired at sea and the seismic signals recorded by stations on land and additionally by two marine stations. Three of the shotlines were connected with the Faeroe Islands (Fig. 2). Line A was fired from the Faeroes to Iceland, line B from the Faeroes to Shetland, and line C from Scotland to the Faeroes and north of the islands.

The position of shots near the islands has been chosen with respect to the gravity anomalies of interest. So line A runs over a local minimum of about —20 mgal near the islands and then crosses the above mentioned maximum of more than +60 mgal. Line B runs over a minimum which is effected by sediments, and line C crosses a maximum of unknown origin.

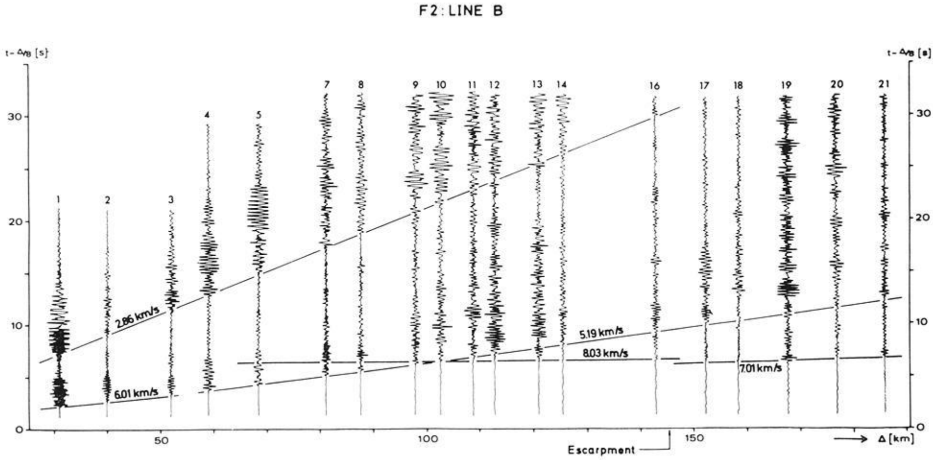

Fig. 3. Seismogram section from line B in reduced time scale (reducing velocity is 8 km/s) with straight line correlations. Signal numbers are the shotpoints

Altogether seven recording stations were placed on the Faeroes. Six stations (F1 to F6) using MARS 66 equipment were provided by the Aarhus University in cooperation with the Universities of Copenhagen, Hamburg and Kiel. One station (DU4) was provided by the Durham University. A hydrophone station (MI(D)) was placed north-west of the islands. The stations on the Faeroes and also on Iceland and Shetland successfully recorded signals from shots on the Faeroe shelf (bold dots on map of Fig. 2). The hydrophone station recorded signals only from shots on line A.

The inspection of seismograms showed that valuable information is given in most cases by first arrivals. Later ones with strong amplitudes are due to shear waves. As an example Fig. 3 shows the seismogram section with a reduced time scale containing signals from shotline B recorded at station F2. Correlating the P-arrivals four apparent velocities are derived: 6.01 km/s, 5.19 km/s, 8.03 km/s, and 7.01 km/s. By correlation of the *S*-arrivals a velocity of 2.86 km/s is derived. In a preliminary paper (Bott *et al.*, 1974) a velocity of 8.87 km/s instead of 8.03 was reported.

The change in velocity between shot 3 and 4 from a higher *P*-velocity to a lower one has been observed also in the seismogram sections from other stations. A second change in velocity occurs between shot 16 and 17. Shot 16 is located west of the escarpment and shot 17 east of it. The escarpment forms the edge of the Faeroe shelf in this part of the sea.

3. *Velocity Distribution*

The histogram in Fig. 4 shows the distribution of apparent *P*-wave velocities according to all the measurements on the Faeroe shelf and on the islands made up to now and including the results of the North Atlantic Seismic Project. The velocities have been calculated from distances and traveltimes using a least square method. Together five phases from different layers can be separated:

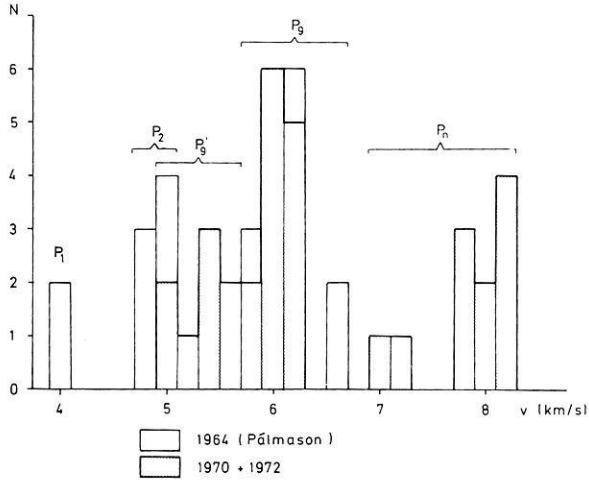

Fig. 4. Histogram of apparent P-velocities for the Faeroe Islands and the shelf. Pálmason's values have been obtained on land and the others on profiles at sea. The distribution is separated into phases from different layers

P_1, velocity 4.0 km/s, corresponds to the upper basalt layer being found only on the Faeroe islands above sea level.

P_2, velocity 4.9 km/s, corresponds to the middle and lower basalt layer and is found only on the islands. Due to a corresponding. S_2-phase,velocity 2.86 km/s, observed on line B and a S_2-phase, velocity 2.57 km/s, observed on an earlier profile north of the islands (Casten, 1974) it is supposed that the middle and lower layer – or at least the lower – are present in the shelf area around the islands.

P_g', average velocity 5.3 km/s, is observed on line B and on the south-eastern part of line C (C_{SE}). This phase corresponds to a layer below the known basalts.

P_g, velocity 6.1 km/s, is observed on line A, on the north-western part of line C (C_{NW}), and on the first part of line B. The corresponding layer also is situated beneath the basalts.

P_n, observed on line A, B, C_{NW}, and C_{SE}, is separated into two groups – 7.1 km/s and 8.0 km/s – yet it corresponds to one layer as it is controlled by two-way observation. This layer is situated in greater depth and has a downdip towards the centre of the Faeroes.

The P_1- and P_2-phase are known also from Iceland. The phases in the histogram with a velocity of 6.6 km/s are observed on short profiles on land only and therefore are quite uncertain. They correspond to a layer with the velocity of 6.4 km/s on Iceland (Pálmason, 1971). This has given reason for the assumption that the crustal structure of the Faeroes is similar to that of Iceland. However, this statement seems to hold only for the uppermost part of the crust built up by the Tertiary flood basalts. The lower crust beneath the Faeroes and the lower crust beneath Iceland differ essentially from one another because a 6.4 km/s or 6.6 km/s has not been observed in the shelf area of the Faeroes.

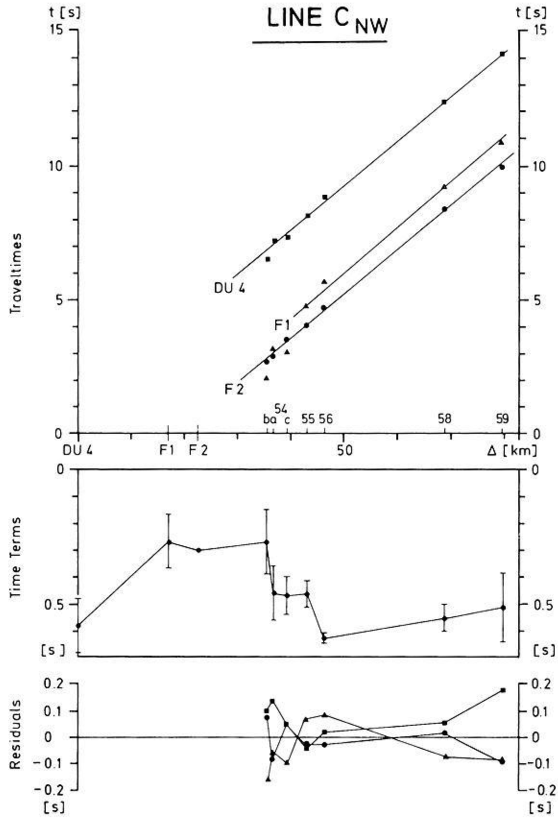

Fig. 5. P_g-traveltimes (upper part) from line C_{NW} observed at the stations DU4, F1 and F2 together with time terms and residuals (lower part). Least square calculation of apparent velocities yield: 5.93 ± 0.08 km/s (DU4), 5.96 ± 0.12 km/s (F1), and 6.04 ± 0.09 km/s (F2)

4. *Time Term Analysis and Crustal Model*

Traveltimes (corrected for water depth) of the phases P_g', P_g and P_n together with distances have been analysed using the time term method described among others by Willmore and Bancroft (1960) and Berry and West (1966).

The results for the P_g'-data from the southern shelf area give velocities in the range from 5.3 km/s to 5.5 km/s. This is distinctly more than 4.9 km/s of P_2 and distinctly less than the 6.1 km/s of P_g. That means, there must be a difference in the structure of the upper crust between the southern and northern part of the Faeroe shelf. It is to be seen from the change in velocity between shot 3 and 4 on line B. The calculation of P_g'-time terms has not been possible because of the too large error in velocity.

The analysis of P_g-data from the northern shelf region (line A and line C_{NW}) results in a velocity of 6.12 ± 0.14 km/s and time terms varying from 0.3 s to 0.9 s. Fig. 5 contains traveltimes, time terms, and residuals for line C_{NW} and Fig. 6 the same for line A. The comparatively high time term of 0.9 s belongs to shot 3 on line A, beeing situated in the centre of the gravity minimum west of the islands.

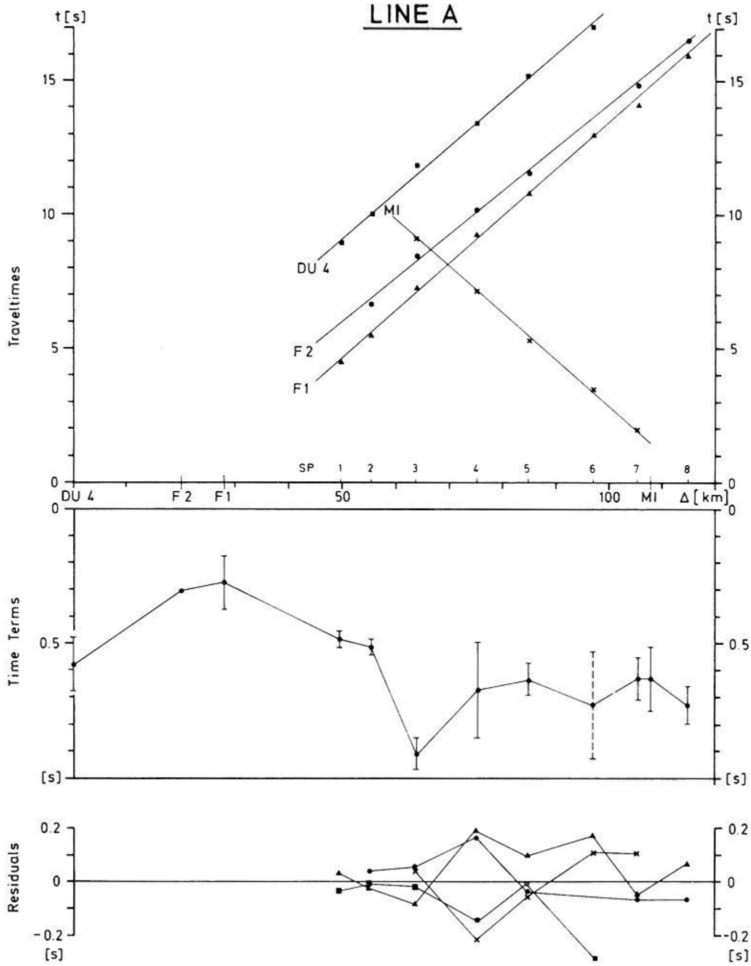

Fig. 6. P_g-traveltimes (upper part) from line A observed at the stations DU4, F2, F1 and MI together with time terms and residuals (lower part). Apparent velocities are: 6.13 ± 0.17 km/s (DU4), 6.18 ± 0.12 km/s (F2), 5.98 ± 0.08 km/s (F1), and 6.11 ± 0.26 km/s (MI)

It can be shown by calculation of gravity models that the delay in travel time is caused by a trough filled with sediments (Fleischer, 1971; Casten, 1974). A connection between time terms and the gravity maximum cannot be revealed. Due to the P-wave velocity of 4.9 km/s in the upper layer the time terms give values for the depth varying between 2 km under the stations and 5 km under the shotpoints.

Assuming a constant P_n-velocity in the shelf area around the islands the analysis of P_n-data from shot lines A, B and C yields values of 7.61 ± 0.22 km/s for P_n. Fig. 7 contains the time term values for the different lines. In the northern shelf area (line C_{NW} and line A) the values vary between 2 s and 3 s. In the southern area (line C_{SE} and line B) the time terms have values between 3 s and 4 s. Assuming a constant average velocity for the crust the refractor on these lines will be situated at a greater depth than north of the islands but be at the same depth when assuming a higher

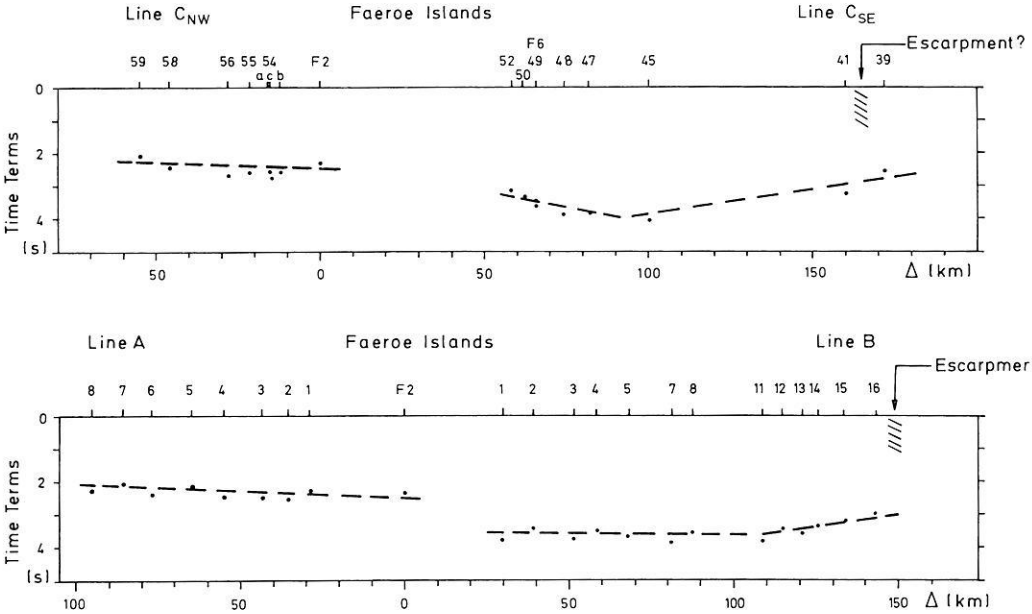

Fig. 7. P_n-time terms from the lines C_{NW}, C_{SE}, A and B arranged in two sections with station F2 as center point. Traveltimes have been used from stations on Iceland, the Faeroes and Shetland

average velocity. Taking into account the lateral change in P_g-velocities a lateral change in average velocity for the crust is very probable. In any case the refractor shows a raise towards the Iceland-Faeroe Ridge in the north-west and towards the Faeroe-Shetland Channel in the south-east. There it may be connected with the escarpment at the edge of the shelf. Line B crosses the escarpment between shot 16 and 17 and line C_{SE} possibly between shot 41 and 39.

A model of the crust showing a good fit between calculated and observed traveltimes is the following one: A surface layer with a thickness of 6 km and a velocity of 4.9 km/s covers the basement. This basement has a velocity of 6.1 km/s beneath the islands and northern shelf and a velocity of 5.3 km/s beneath the southern shelf. The average value for the crust beneath line B and line C_{SE} is 6.0 km/s and it is 6.5 km/s for the crust beneath line A and line C_{NW}. With these values the crust-mantle boundary is at a depth of more than 30 km beneath the islands and at about 20 km beneath the ridge and the escarpment.

5. *Discussion*

Two results give reason for the assumption that the properties of the crust beneath the Faeroes may be similar to those of a continental one:

The two P_g-phases with velocities of 5.3 km/s and 6.1 km/s, which are typical for a metamorphic and a granitic basement.

The sub-moho phase has apparent velocities from 7.1 km/s to 8.3 km/s which are results of a raise of 'moho' from about 30 km under the islands to about 20 km under the ridge and the escarpment.

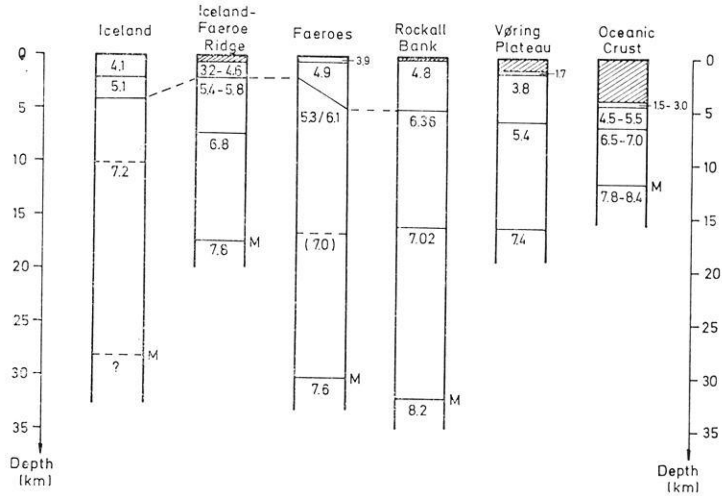

Fig. 8. Crustal structure of the Faeroes in comparison with results of deep seismic soundings in the North Atlantic. The Oceanic Crust is an average of results from different positions (Ewing and Ewing, 1959)

As the P_n-velocity of 7.6 km/s is less than normally observed on continents a classification of the Faeroe's crust as typical continental is not correct. Assuming this crustal element being a continental one before the opening of the North Atlantic ocean in Tertiary we find that the split up and then following drift of the continental blocks of Europe and Greenland must have effected a change of properties mostly in the transition zone between crust and upper mantle. This possibly explains the lower P_n-velocity. The conception of a continental fragment is in accordance with the gravity anomalies. The lower density of crust is effected by sialic material, and the greater thickness of crust beneath the Faeroes has been demonstrated clearly by the refraction measurements.

Another argument for the continental fragment is given by the Pre-tertiary distribution of continents in the area of the present North Atlantic ocean. Trying to achieve a best fit of the continental margins of Europe and Greenland, as it is done by Bott and Watts (1970), a continental crust is required under the Faeroes and also under Rockall Bank, because both together remain as a gap between the margins.

When comparing seismic results from different areas in the North Atlantic, as it is shown in Fig. 8, one may get the following picture: Neglecting the overlying water and sediments Iceland, the Iceland-Faeroe Ridge, the Faeroes, Rockall Bank, and the typical oceanic crust have near the surface of the crust basaltic material. The deeper crust is different. There is on one side the oceanic crust of deep sea basins, the continental crust of Rockall Bank, and the seaward fragment of Vøring Plateau, and on the other side the anomalous crust of Iceland and the Iceland-Faeroe Ridge. Clearly the structure of the Faeroe's crust corresponds to that of Rockall Bank and Vøring Plateau.

An apparent velocity of 7.0 km/s for the Faeroes, shown in Fig. 8, was observed at the stations F1 and F2 only from shot line A, on a profile section of the ridge (100 to 180 km). Using the calculated intercept time for the Faeroes the corresponding refractor is to be placed at a depth between 15 and 20 km. Its existence under the Faeroe shelf could not be proofed, yet similar refractors are present under Rockall Bank and Vøring Plateau.

The final conclusion is, that the deep seismic sounding in the area of the Faeroe Islands have made it possible to consider the crust beneath the islands as a micro-continental fragment left behind under the opening of the North Atlantic in Tertiary.

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