Some Magnetotelluric Measurements on the Faeroe Islands 1978

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Abstract

The results of magnetotelluric measurements at two locations on the Faeroe Islands are presented. We show the apparent resistivities and the interpretation in terms of Bostick resistivities and depths. The Bostick interpretation of our data suggests that the resistivity increases nearly monotonically from about 10 Ωm at a depth of 4 km to about 350 Ωm at a depth of 100 km.

Introduction

In the summer of 1978 Føroya Jarðfrøðisavn and the Geological Survey of Denmark had the opportunity to perform a few magnetotelluric measurements on the Faeroe Islands in connection with the bathymetric and magnetic marine investigation of the Faeroese shelf. The Laboratory of Geophysics, University of Aarhus, lent the magnetotelluric instrumentation and undertook the dataprocessing.

The magnetotelluric measurements were made at three lo-

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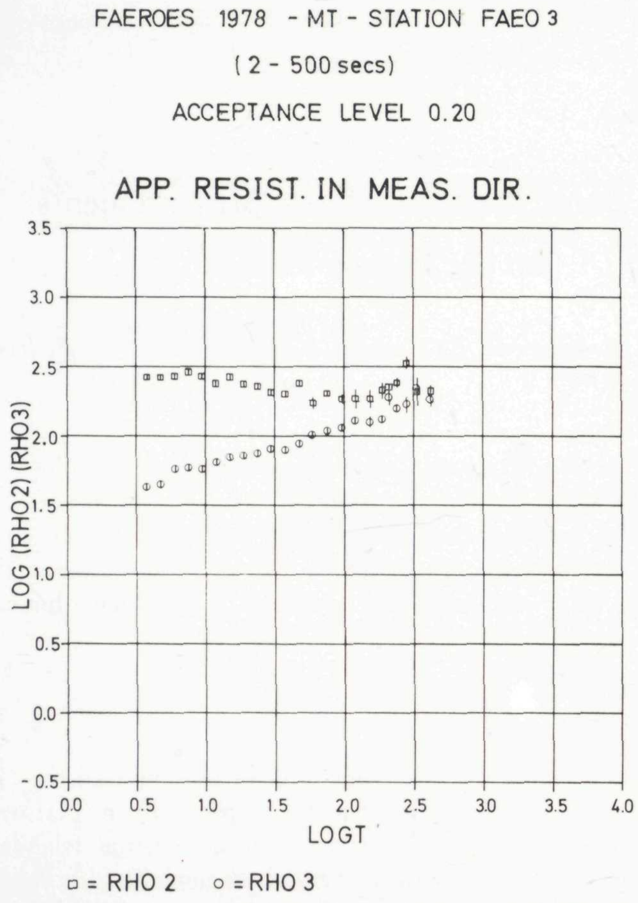


Fig. 1. *Apparent resistivities for the station in Saksunardalur. The directions are magnetic north-south (RHO2) and magnetic east-west (RHO3).*

cations, but the measurements at one location have proved to be useless. The other two locations were:

Havnardalur west of Tórshavn at 62°00!6 N 06°50!5 W (station 1) and

Saksunardalur at 62°13!6 N 07°07!7 W

In both cases the stations were placed in a valley with a

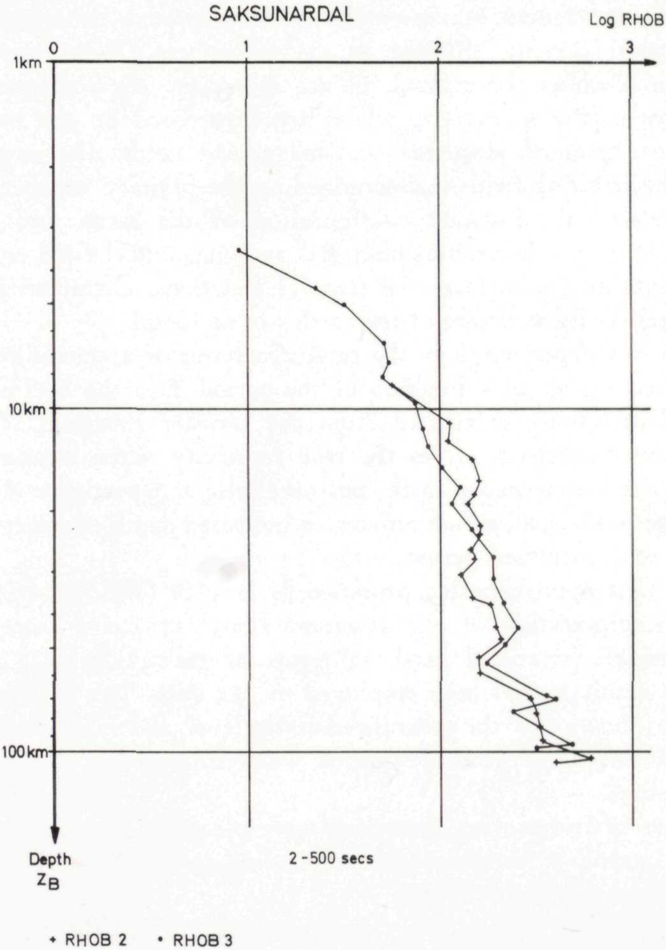


Fig. 2. *Resistivities for the station in Saksunardalur as function of depth in the directions magnetic north-south (RHOB2) and magnetic east-west (RHOB3). The resistivities were found using the Bostick approximation.*

small river and a rather irregular bottom of basalt, partly covered by sediments (gravel or peat).

The magnetotelluric method

The magnetotelluric method is based upon the impingement of electromagnetic waves on the earth, induced by alternating electrical current, situated in the ionosphere. These waves, when reaching the ground, induce secondary electromagnetic waves in the subsurface, which are superposed on the impingent, primary, electrical, and magnetical fields. The nature of the resulting fields is determined by the primary waves and the electrical resistivity configuration of the earth, and by measuring the horizontal electrical and magnetical field components at the surface, the transfer functions, characterizing the resistivity structure of the earth can be found.

In this paper we show the results in terms of apparent resistivities ϱ_2^a, ϱ_3^a as a function of the period T in the N-S and E-W directions, calculated from the transfer functions. The apparent resistivity gives the true resistivity when measured above a homogeneous earth, but otherwise a dependence with the period is seen, which reflects an increased depth of penetration with increased period.

A first approximation proposed by Bostick (Weidelt, 1979) for interpretation of the apparent resistivity curve from a horizontal, stratified earth in terms of resistivities ϱ_{B2}, ϱ_{B3} with depth z_B has been employed to our data. This interpretation shows only the general resistivity level, and rapid fluctuations in the curve are expected when bad quality data are present.

The two measuring directions were placed in the magnetic N-S and E-W directions, corresponding to 13°W and 77°E from the geographic North.

For further details about the data analysis and the results, reference is made to Rasmussen, Nielsen, and Pedersen (1981).

Results

Station FAEO3 (2—500 secs) — Saksunardalur.

An analysis of the data from this station indicated that the resistivity structure is 3-dimensional. A complex structure is also seen in the plot of the apparent resistivities (fig. 1), where decreasing difference between apparent resistivities in the N-S and E-W direction exists with increased period. For the N-S direction we observe a minimum at 100 secs which is likely to represent a low resistivity structure.

The Bostick inversion is shown in fig. 2. For the N-S direction a fairly constant value of 180 Ωm is obtained between 10 km and 65 km, whereas resistivities of 350 Ωm are seen below 70 km. The minimum in the apparent resistivity curve at 100 secs corresponds to a depth of 35 km, but a significant minimum is not seen in the Bostick curve. The resistivity curve for the E-W direction shows a general increase with depth from 10 Ωm at 3.5 km to about 350 Ωm at 100 km.

Station FAEO 1 (2—500 secs and 40—3600 secs) — Havnardalur.

The data analysis from this station showed a 2-dimensional earth structure, with the 2 possible directions of constant resistivity approximately in the magnetic N-S and E-W directions. The apparent resistivities are shown in fig. 3a,b and fig. 4a,b, and we note an increased separation between the 2 curves with increased period.

The Bostick resistivities are presented in fig. 5a and fig. 5b. For the long-period band, a fairly constant value for ϱ_{B2} between 17 km and 28 km is seen, followed by an increase in resistivity. The constant level at 30 Ωm seems to be in agreement with the short periodic band, where a nearly constant value of 25 Ωm is obtained between 11 km and 19 km. The most prominent feature of the curves is the large difference in the resistivities for the two directions. At depths bigger than 10 km resistivities smaller than 100 Ωm are not obtained in the E-W direction. For this direction we note a general increase in resistivity with depth, as is also seen at station FAEO3, and the resistivities are seen to be in good agreement.

Discussion of the results

For the magnetotelluric station at Havnardal we found a twodimensional structure, with the two possible strike direct-

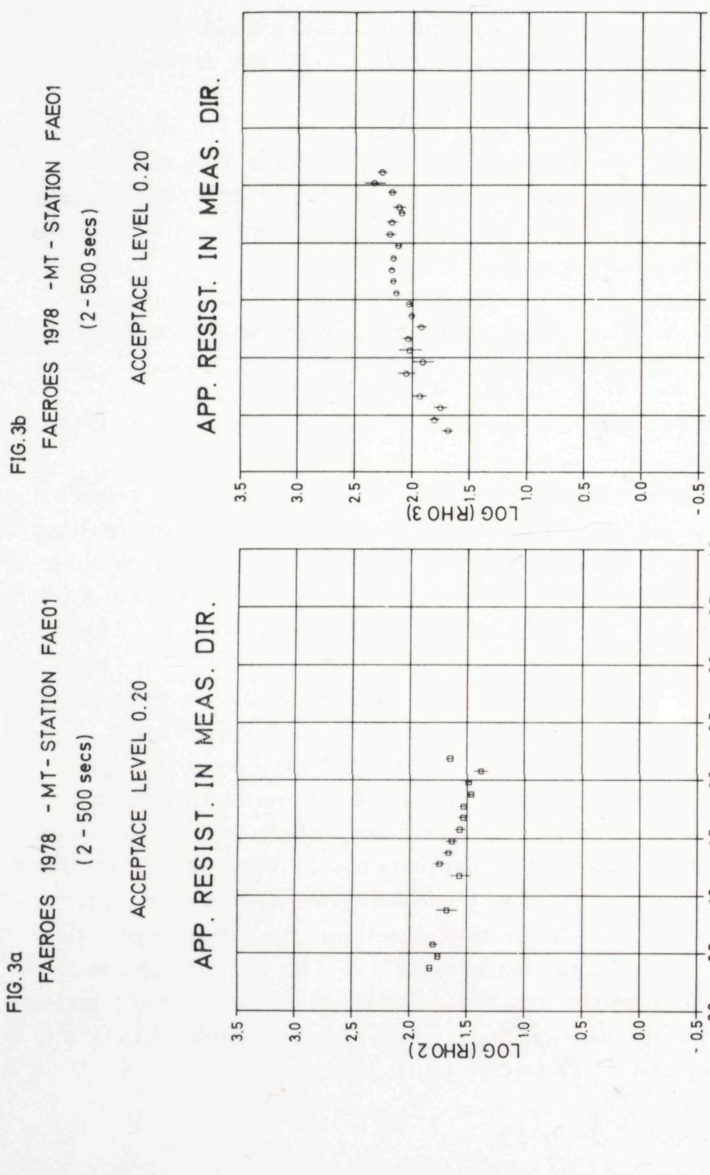


Fig. 3. *Apparent resistivities found from the short period registrations (2—500 sec) in Havnardalur.*

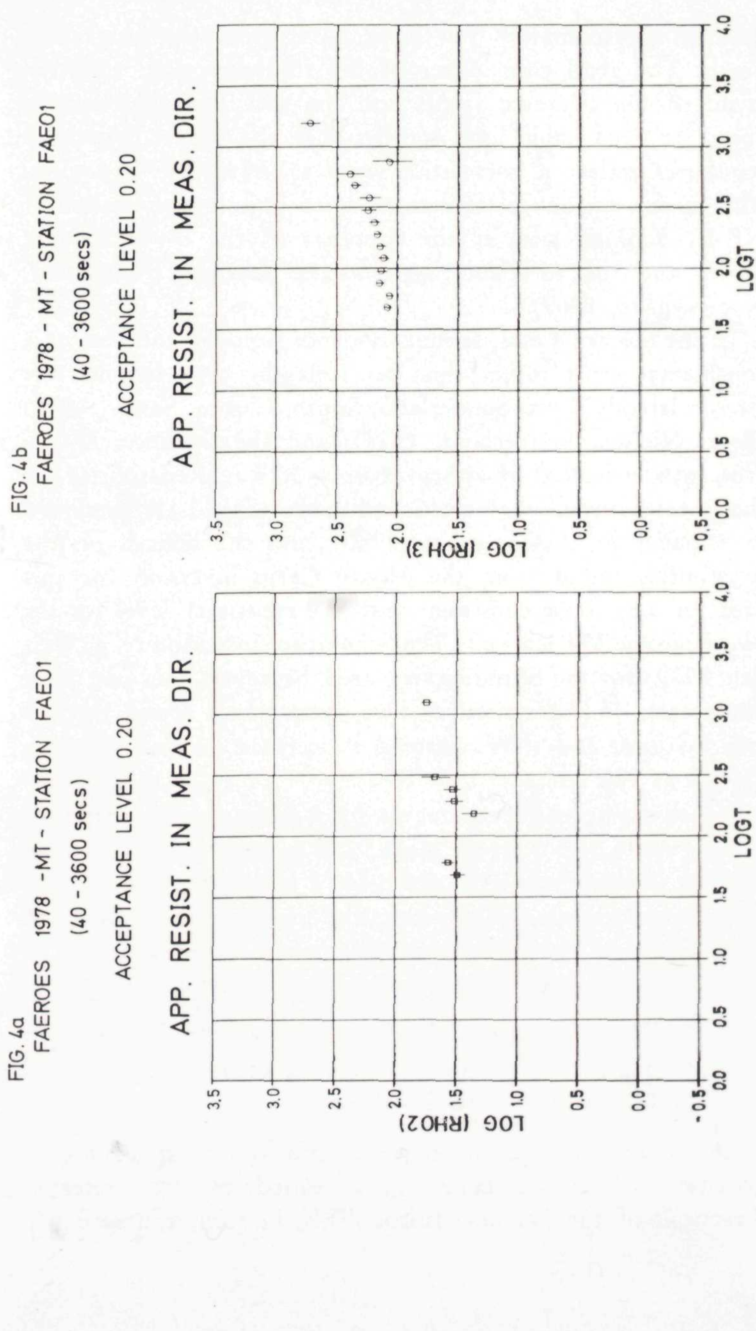


Fig. 4. *Apparent resistivities found from the long period registrations (40—3600 sec) in Havnardalur.*

ions at approximately 167°E or 77°E from the geographic north. The good coincidence of the first direction, with the trend of the Faeroese fjords and the tuff and agglomeratic zones, is remarkable and suggests that the deeper resistivity structures reflect a correlation with these surface structures. This seems to be in agreement with the interpretation of NE-SV striking rifts as the suppliers of the lower basaltic layers and the tuff and agglomeratic deposits (Rasmussen, Noe-Nygård, 1969).

In the last ten years, seismic evidence supports the idea of a continental crust rather than an Icelandic type beneath the Faeroe Islands (Bott, Sunderland, Smith, Casten, Saxov, 1974) (Bott, Nielsen, Sunderland, 1975), and the thickness of the crust was estimated at approximately 30 km. Resistivities for the upper mantle below the Scandinavian Shield are presented in a paper by A. G. Jones (1980), and the bounds on the resistivities found from the Monte Carlo inversion for this area are seen to be consistent with the resistivity level for the two Faeroese MT stations. The Schmucker inversion (e. g. Weidelt 1979) for the Scandinavian area, however, does not show an increase in the resistivity level with depth found for our two stations, and shows instead a decrease in resistivities to 90 Ωm at 100 km.

Resistivity/temperature curves for various mantle materials are shown in fig. 6 (from Haak, 1980), and we note that an increase in resistivity with depth for a given rock composition would result in an unlikely negative temperature-depth gradient. Therefore, we have to consider one or a combination of at least three possibilities to explain this problem:

1) Effect of crustal inhomogeneities on transfer functions
2) Significant variations in mantle composition
3) Influence of partial melting

Our data indicate the existence of deep crustal inhomogeneities, which we believe are related to the preferred directions of the Faeroese fiords. This, in turn, can seriously

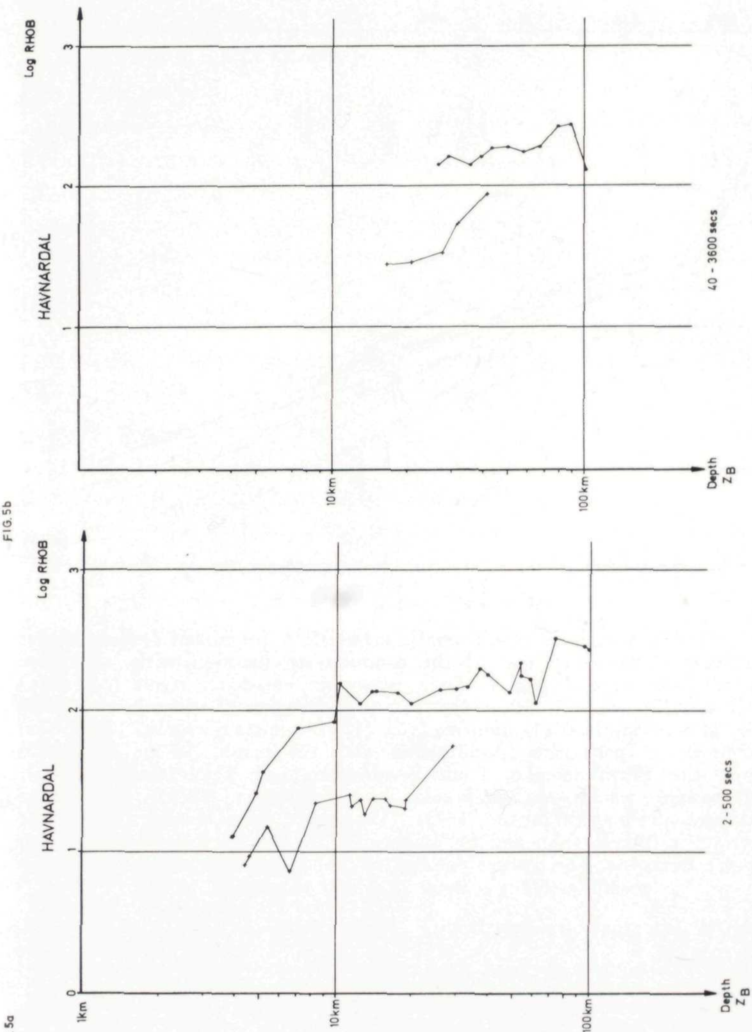
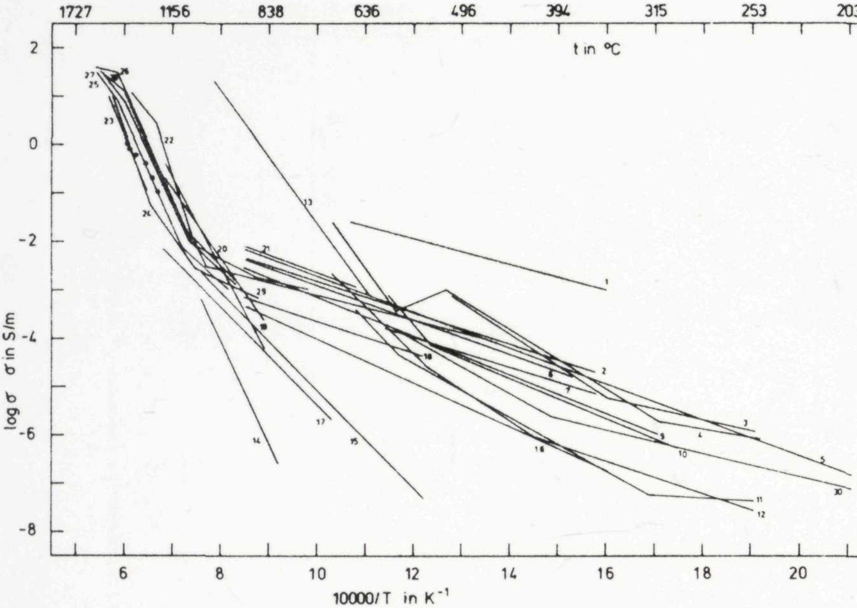


Fig. 5. *Resistivities for the station in Havnardalur as function of depth (Bostick approximation).*



Electrical conductivity of ultramafic material. A prominent feature of this material is the steep rise of the conductivity function with 'activation energies' between 2 and 4 eV, a somewhat enigmatic result (c.f. text.) (1), (2), (5), (6), (7), (9), (16), (18), (21) eclogites (Lastovickova, 1976); (3), (11) peridotites; (4) dunites; (10), (12) olivinites (Dvořák, 1973); (13) olivinite + peridotite (Bondarenko and Fel'dmann, 1973); (14), (15) peridotite (Parkhomenko, from Bondarenko and Fel'dmann, 1973) + plagioclase peridotite (Bondarenko and Fel'dmann, 1973); (17) dunite (Bondarenko and Fel'dmann, 1973); (19) pyrope spinel dunite; (20) pyrope peridotite (Bondarenko and Fel'dmann, 1973); (22) garnet websterite; (24) spinel lherzolite; (25) garnet peridotite; (26) garnet lherzolite; (27) garnet peridotite; (28) eclogite (Rai and Maghnani, 1978b).

Fig. 6. *The figure is taken from V. Haak (1980).*

distort the transfer functions corresponding to larger depths. We should, therefore, be cautious in putting too much quantitative emphasis on the geological interpretation of our data, and hence the apparent increase in resistivity with depth could well be an artifact.

If, on the other hand, the observed increase of resistivity reflects the true situation in the upper mantle, this could be explained as a change of composition (see fig. 6), but we do not here attempt to make a petrological interpretation.

The effect of partial melting on the upper mantle would reduce the resistivity level, but the high sub-moho velocity (Bott et al. 1974) found beneath the Faeroe Islands, does not support this possibility. Also, the presence of a low resistivity layer at the crust-mantle boundary found beneath Iceland (Beblo and Bjørnsson, 1979) is not observed in our measurements.

The results obtained for the high frequencies suggest pore fluids as the main factor in controlling the resistivities at the upper crust, but the few data and the 2- and 3-dimensionality of the crust make interpretation very doubtful.

Acknowledgment: One of the authors (PHN) wants to thank for support by a grant from Statens Naturvidenskabelige Forskningsråd.

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ÚRTAK

Magnetotelluriskar mátingar verða nýttar til at áseta ravmagnsmótstøðuna í ymiskum jarðløgum, vanliga millum 1 km og 100 km dýpi. Ravmagnsmótstøðan í grótsløgum er vanliga reiðiliga stór, men minkar, um grótslagið hevur í sær vætu, ella um hitin er høgur.

Tvær mátingar í Føroyum (í Havnardali og í Saksunardali) tykjast vísa, at ravmagnsmótstøðan ikki bara hongur á dýpdini, men grovliga tykist hon kortini at økjast frá umleið 10 ohm m á 4 km dýpi til umleið 350 ohm m á 100 km dýpi. Hetta merkir góða leiðing ovarlaga, kanska av poknuvatni í jørðini. Stóra mótstøðan longri niðri er størri, enn vit høvdu væntað, og merkir tað helst, at hitin ikki er óvanliga høgur har.