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FAEROE-SHETLAND ESCARPMENT AND CONTINENTAL MARGIN NORTH OF THE FAEROES

David K. Smythe

Institute of Geological Sciences
19 Grange Terrace, Edinburgh EH9 2LF

ABSTRACT

The Escarpment is re-interpreted as the buried feather-edge of a thick pile of early Eocene flood basalts, overlying a thinner but more widespread layer of basalts of late Palaeocene age. The Escarpment does not, therefore, define the continent-ocean boundary in the southern Norwegian Sea. In the Faeroe-Shetland Trough and Møre Basin the basalts overlie several kilometres of sediments ranging in age from Palaeocene to at least as old as early Cretaceous, resting in turn on thin crust, with the Moho at around 15 km. The continent-ocean boundary north of the Faeroes underlies a belt of north-dipping 'smooth' intra-basalt reflections seen on multichannel reflection data, which is interpreted as oceanic layer 2, formed during subaerial spreading immediately preceding anomaly 24 time.

INTRODUCTION

During the last decade the continental shelf and margin north and west of the Shetlands have been commercially surveyed for oil in increasing detail. The resulting data currently include multichannel seismic reflection profiles, aeromagnetic maps, and more than thirty wells (Figure 1). Regional interpretations, which maintain the confidentiality of sensitive and costly commercial data while providing a stimulus to the exploration industry, are now being published (e.g. Cashion, 1975; Ridd, 1981 and this volume). IGS makes confidential assessments of commercial data for the Department of Energy, and the present regional interpretation is also based on non-confidential IGS and academic information. This account deals briefly with two major geophysical

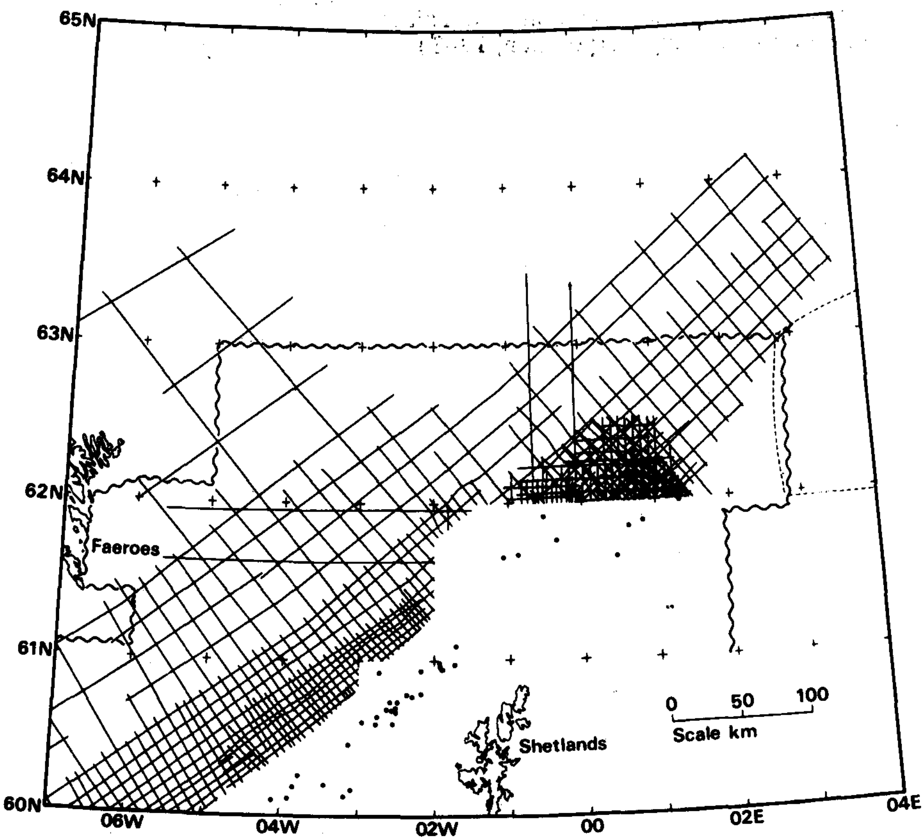

Figure 1. Commercial geophysical data acquired in the Faeroe-Shetland region since c.1972. Solid lines are multichannel reflection profiles (mostly 24-fold); round the Shetlands and south of 62°N into the North Sea the density of lines is too great to be shown. Dots are commercial wells drilled in the West Shetland area and northern Viking Graben. Wavy line denotes the outer limit of commercial aeromagnetic coverage, and dashed line is the SW limit of the published aeromagnetic map of the Norwegian shelf (Åm, 1970).

features of the region which are also relevant to other Atlantic marginal areas and which will be described in more detail elsewhere. These are (1) the nature and origin of the Faeroe-Shetland Escarpment (Smythe *et al.*, in press) and (2) the oceanward-dipping intra-basement reflections observed round the northern and western margins of the Faeroes Plateau (Smythe, in preparation).

FAEROE-SHETLAND ESCARPMENT

The Faeroe-Shetland Escarpment was originally identified by Talwani and Eldholm (1972) as two linear NE-SW trending segments, identified on eight geophysical traverses. The buried SE-facing escarpment feature was interpreted by them as the continent-ocean boundary, at which 'subsided continent', overlain by the sediments of the Faeroe-Shetland Trough and Møre Basin, is downfaulted against elevated early Tertiary oceanic crust on the NW. In 1974 IGS carried out a detailed geophysical survey covering the area between the two segments: 62°-63°N, 1°W-1°E (Figure 2). The results of our re-interpretation of the nature and origin of the escarpment (Smythe *et al.*, in press) are as follows:

(1) The escarpment is a single sinuous feature (Figure 2) caused by the wedging-out of a series of early Tertiary basalts

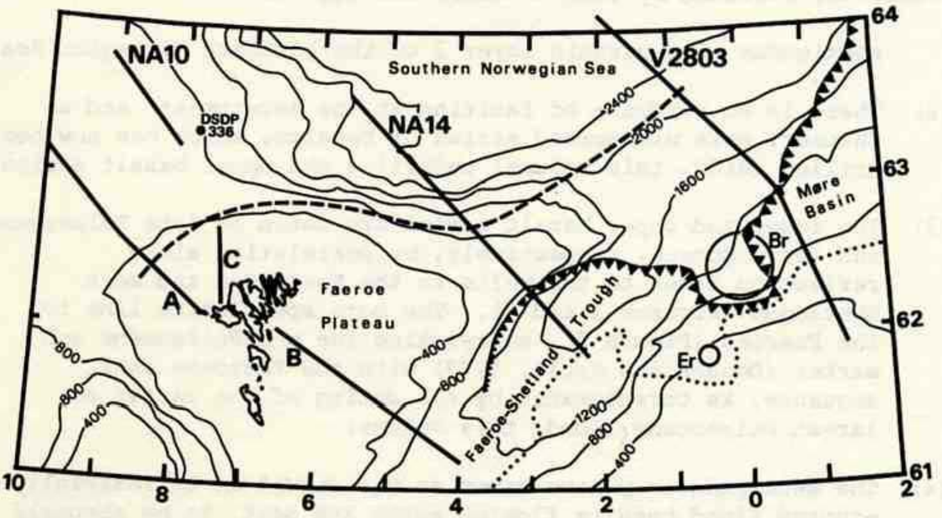

Figure 2. Subcrop of Faeroe-Shetland Escarpment (triangle ornament). Feather-edge of late Palaeocene basalts (see Figure 3) is shown (dotted line). Bathymetry in metres. V2803 - Lamont-Doherty profile (Figure 4). NA14, NA10 - Western Geophysical reflection profiles (Figures 5 and 6 respectively). A,B,C - NASP crustal refraction lines. Dashed line - southern boundary of Tertiary oceanic crust inferred from reflection profiles, gravity and converted P-waves. Round the northern flank of the Faeroes microcontinental block this line thus defines the continent-ocean boundary, but further to the NE it tentatively defines the 'ocean-ocean' contact between crust of different ages (see Figure 4 and text). Br (circle) - location of Brendan pre-Tertiary seamount below basalts. Er (circle) - Erland Tertiary volcanic centre.

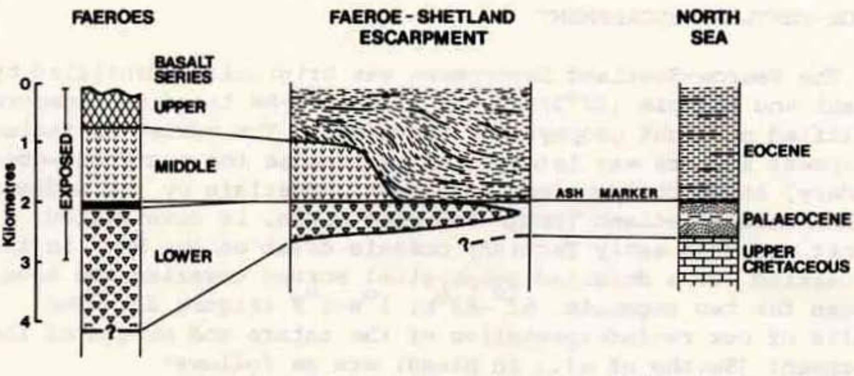

Figure 3. Diagrammatic regional correlation of the Palaeogene, with schematic depth scale. Proportion of succession exposed on the Faeroes is indicated; remainder of Lower Series of basalts is inferred from refraction surveys (Pálmason, 1965). Black band separating Lower and Middle Series represents 10m of coal-bearing sediments, overlain by 100m of tuffs and agglomerate.

contiguous with oceanic layer 2 of the southern Norwegian Sea.

(2) There is no evidence of faulting at the escarpment, and a thinner, more widespread series of basalts, which has now been drilled (Ridd, this volume) underlies the upper basalt series.

(3) The lower and upper basalt series are dated as late Palaeocene and early Eocene, respectively, by correlation along reflection lines to the wells in the North Sea and West Shetlands (Figures 1 and 3). The more speculative link to the Faeroes (Figure 3), correlating the end-Palaeocene ash marker (Deegan and Scull, 1977) with the Faeroese coal sequence, is corroborated by the dating of the latter as latest Palaeocene (Lund, this volume).

(4) The escarpment may have grown as the result of terrestrially-erupted flood basalts flowing south and east, to be abruptly halted at the contemporary shoreline bordering a restricted shallow-water shelf to the SE. The SE-facing protrusion in the subcrop (Figure 2) may thus mark a contemporary peninsula, formed by a slight relative elevation of the crust due to the underlying buried Brendan seamount (Br in Figure 2).

(5) Gravity and magnetic profiles over the escarpment show no consistent change in amplitude, wavelength, regional gradient, etc. ascribable to any major change in crustal structure beneath the escarpment. Figure 4 (bottom) is the interpretation of a 2-D gravity model (Smythe *et al.*, in press) along part of Lamont-Doherty profile V2803 (Talwani and Eldholm, 1972; Talwani, 1974), located in Figure 2. Standard densities

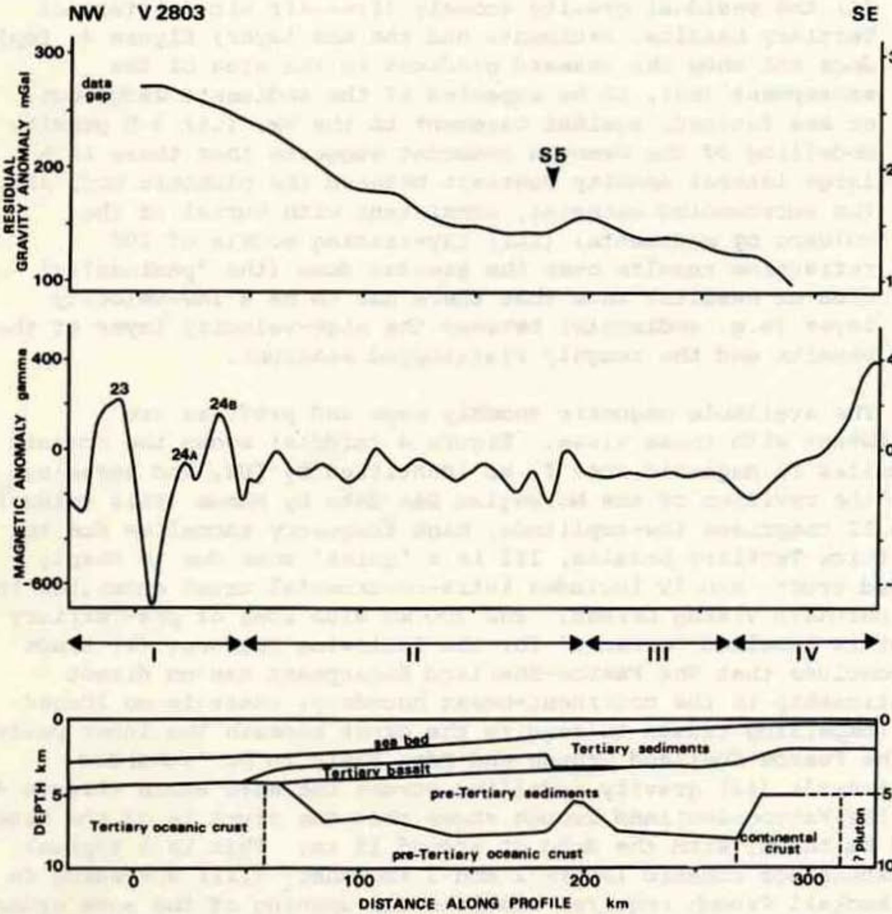

Figure 4. Gravity modelling along LDGO profile V2803 (located in Figure 2). Residual anomaly is free-air after removal of effects of sea layer, Tertiary basalts and Tertiary sediments (bottom cross-section). Note lack of gradient around S5, the location of the Faeroe-Shetland Escarpment. Zones I-IV of magnetic anomaly (middle profile) correlate respectively with Tertiary oceanic crust, Tertiary basalts, deeply buried crust, and continental crust. Airy-type modelling suggests a crustal thickness of 7-8 km for the Tertiary and pre-Tertiary oceanic areas, thickening to 20 km below the Viking Graben at the SE end of the model.

are used (Worzel, 1974). The supra-crustal part of the model is all directly constrained by seismic reflection, except the postulated continuation of the pre-Tertiary sediments beneath the thick basalts. The evidence for their continuation is; (i) the residual gravity anomaly (free-air minus effect of Tertiary basalts, sediments and the sea layer; Figure 4, top) does not show the seaward gradient in the area of the escarpment (S5), to be expected if the sediments wedge out, or are faulted, against basement to the NW; (ii) 3-D gravity modelling of the Brendan seamount suggests that there is a large lateral density contrast between the plutonic body and the surrounding material, consistent with burial of the volcano by sediments; (iii) ray-tracing models of IGS refraction results over the Brendan dome (the 'peninsular' area of basalts) show that there has to be a low-velocity layer (e.g. sediments) between the high-velocity layer of the basalts and the roughly flat-topped seamount.

The available magnetic anomaly maps and profiles are consistent with these views. Figure 4 (middle) shows the oceanic anomalies in magnetic zone I, as identified by IGS, and agreeing with the revision of the Norwegian Sea data by Nunns (this volume). Zone II comprises low-amplitude, high frequency anomalies due to the thick Tertiary basalts, III is a 'quiet' zone due to deeply buried crust, and IV includes intra-continental crust anomalies in the northern Viking Graben. The 200 km wide zone of pre-Tertiary crust is labelled 'oceanic' for the following reasons: (i) since we conclude that the Faeroe-Shetland Escarpment has no direct relationship to the continent-ocean boundary, there is no longer any compelling reason to require the crust beneath the inner parts of the Faeroe-Shetland Trough and Møre Basin to be 'subsided continent'; (ii) gravity modelling across the Møre Basin (Figure 4) and the Faeroe-Shetland Trough shows that the crust is of the order of 8 km thick, with the Moho at around 15 km. This is a typical thickness for oceanic layers 2 and 3 together; (iii) spreading in the Rockall Trough requires simultaneous opening of the same order in the Faeroe-Shetland Trough and eastern Norwegian Sea (Roberts, 1974, p.351; Bott, 1975, p.198). Since individual sections of this ribbon of pre-Tertiary thin crust are unlikely to have evolved by radically different processes from each other, and since the Rockall Trough is generally accepted as oceanic in origin (Scrutton, 1972; Roberts, 1974) it follows that the coeval crust north of the Wyville Thomson Ridge is also oceanic. Available evidence on the crustal structure of these northern regions, in particular, remodelling of Hinz's (1972) crustal refraction line in the eastern Norwegian Sea by (a) simple 'layer-cake' models, or (b) ray-tracing (my unpublished work) is consistent with an orthodox oceanic origin.

The thin crust beneath the Faeroe-Shetland Trough, Møre Basin and Eastern Norwegian Sea is now believed to be overlain by sediments which are at least as old as early Cretaceous in age (e.g. Talwani and Eldholm, 1972; Cashion, 1975; Jørgensen and Navrestad, 1981; Ridd, this volume; Smythe *et al.*, in press). The postulated episode of early Cretaceous sea-floor spreading here (Roberts, 1974) is therefore untenable. The alternative dating of the spreading episode as Stephanian to early Permian (Russell, 1976; Russell and Smythe, 1978) remains valid, as does the conjecture of an intra-continental rifting and subsidence episode during the same period. At present, sea-floor spreading is to be preferred as the mechanism, simply because it leads to clear predictions (as yet unrefuted) about plate geometry, crustal structure, regional magmatism etc., in contrast to the 'subsided continent' hypothesis as applied currently to these areas (Talwani *et al.*, 1981).

CONTINENTAL MARGIN NORTH OF THE FAEROES

Where is the continent-ocean boundary, if not at the escarpments? It is postulated here that the start of oceanic layer 2 can be defined by the lower end of the "oldest" of the oceanward-dipping series of intra-basement reflectors now commonly observed at passive margins on multichannel reflection lines. The example of the northern Faeroes margin (Figure 5) is particularly good, because it demonstrates the passage northwards from the nearly flat-lying early Eocene terrestrial flood basalts of the Faeroes Plateau into the dipping series, thence into 'normal' oceanic layer 2 which still, however, shows some dipping reflectors. The crucial point is that the dipping series below a smooth top basalt

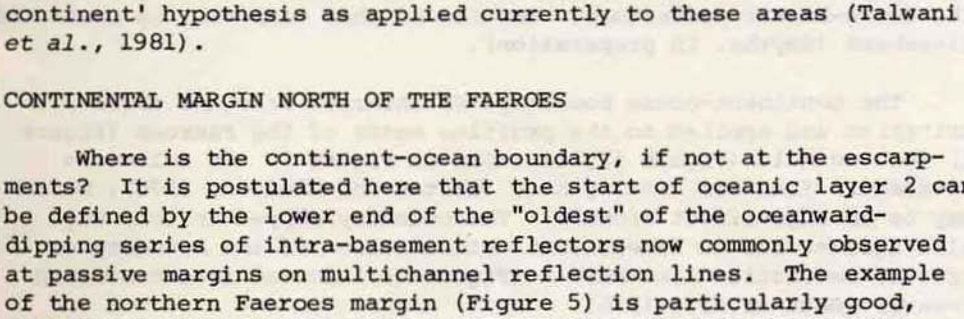

Figure 5. Line-drawing interpretation of Western Geophysical NA14 (located in Figure 2). Strong reflector is top of the basalts (stipple) inferred from reflector amplitude, high interval velocities beneath, magnetic anomalies, and since corroborated by drilling near the Erland pluton (Figure 2 and Ridd, this volume). COB - continent-ocean boundary, defined at onset of dipping reflections (see text). Portion of line 0-175 km has been reprocessed (Smythe, in preparation).

reflector (such as from 90-130 km on Figure 5) does not *overlie* oceanic crust (Talwani *et al.*, 1981), but that it is *part of* the oceanic crust. It may correspond to the mid-ocean ridgeward-dipping flows of the upper part of oceanic layer 2, as postulated by Cann (1974, figure 2). The continuity and length of the reflections, and the smooth upper surface, is considered to be due to subaerial spreading. The abrupt change in character (as at 90 km on Figure 5) from smooth to rough top basement, and from good to poor intra-layer 2 reflections, represents merely the change from subaerial to submarine spreading as the initially elevated mid-ocean ridge subsided below sea-level. Part of line NA14 has been reprocessed, including migration and depth conversion, by Western Geophysical (client IGS), in order to test further the nature of the intra-basalt reflectors. Details of this work will be presented elsewhere (Smythe, in preparation).

The continent-ocean boundary, as inferred from the above criterion and applied to the profiles north of the Faeroes (Figure 1) such as NA14 (Figure 5), is shown in Figure 2. It follows a crescentic free-air gravity high (Casten and Nielsen, 1975), which may be an edge-effect anomaly. The boundary mapped in this way also agrees with an independent determination of the boundary on crustal refraction line NASP A (Figure 2) inferred from converted P-waves (Bott *et al.*, 1976).

In plan, the continental crust beneath the Faeroe Plateau presumably wedges out north-eastwards in the region of 63°N, 2°W (Figure 2), so that pre-Tertiary oceanic crust is in direct contact with Tertiary oceanic crust (Figure 4). There are no multichannel profiles in this region (Figure 1), so the 'ocean-ocean' contact here is tentatively placed below the smooth NW-dipping portion of the top-basement reflector seen on the single channel airgun reflection profile V2803.

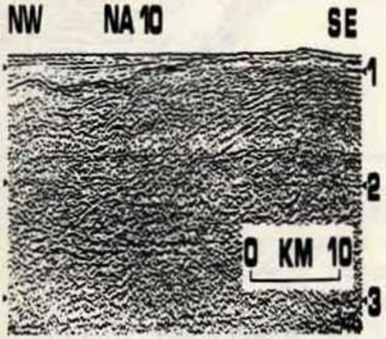

Figure 6. Photographic 'squash-plot' of the part of Western Geophysical reflection line NA10 (located in Figure 2) reprocessed for IGS. Vertical scale is in seconds of two-way time.

Part of reflection profile NA10 (Figure 2) has also been reprocessed by Western Geophysical for IGS. It lies on the NE flank of the Iceland Faeroe Ridge, about 12 km from DSDP 336, which penetrated subaerially weathered Eocene basalt (Talwani *et al.*, 1976). The reprocessed part (Figure 6) shows basalt at the sea bed towards the SE, but buried by up to 300 m of sediment towards the NW. The reprocessing has successfully reduced the amplitude of the strong sea-bottom multiples, and allowed the primary NW-dipping intra-basalt reflectors to stand out. The deepest of these extends to about 1.6 s TWT ($\sim$4 km depth) below the sea bed, in good agreement with the thickness of layer 2 on NASP A (Figure 2) of 5-7 km (Bott and Gunnarsson, 1980). Line NA10 thus provides further corroboration of the subaerial sea-floor spreading origin for dipping reflector sequences.

IMPLICATIONS FOR THE EARLY OPENING OF THE NORTH ATLANTIC

Preliminary 'pre-drift' reconstructions of the North Atlantic, using the continent-ocean boundary criteria discussed above and applied to various segments of the passive margins, result in a tight reconstruction, not unlike the classic 'Bullard' fit (my unpublished work). The Faeroes block fits tightly against the Blosseville coast of Greenland, interpreted as approximating to the continent-ocean boundary by GGU workers (Thorning, this volume). Hatton Bank appears to have rotated clockwise by several degrees about a pole in the northern Rockall Trough during the early Tertiary, and the nearby Outer Bailey Bank may have moved NW with Greenland (relative to a 'stationary' Europe) during the same interval. Furthermore, Ridd (this volume) suggests that the 'axial opaque zone' of the Faeroe-Shetland Trough may have been an incipient spreading centre in the Palaeocene, implying that the Faeroes block also moved NW relative to Europe by a few kilometres during that time. Irrespective of the earlier development of the Rockall and Faeroe-Shetland Troughs, it is thus apparent that the various microcontinental blocks flanking the Troughs' NW sides moved independently of one another by small, but not insignificant, amounts during the Palaeogene.

ACKNOWLEDGEMENTS

Western Geophysical kindly gave permission to reproduce the line drawing of their line NA14 in advance of the reprocessing subsequently carried out for IGS. This preliminary account of work involving many of my colleagues, to whom I am indebted, is published with the approval of the Department of Energy and of the Director, Institute of Geological Sciences (NERC).

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