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Hatton Bank (northwest U.K.) continental margin structure

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Summary. The continent-ocean transition near Hatton Bank was studied using a dense grid of single-ship and two-ship multichannel seismic (mcs) profiles. Extensive oceanward dipping reflectors in a sequence of igneous rocks are developed in the upper crust across the entire margin. At the landward (shallowest) end the dipping reflectors overlie continental crust, while at the seaward end they are formed above oceanic crust. Beneath the central and lower part of the margin is a mid-crustal layer approximately 5 km thick that could be either stretched and thinned continental crust or maybe newly formed igneous crust generated at the same time as the dipping reflector sequence. Beneath this mid-crustal layer and above a well defined seismic Moho which rises from 27 km (continental end) to 15 km (oceanic end) across the margin, the present lower crust comprises a 10-15 km thick lens of material with a seismic velocity of 7.3 to 7.4 km/s. We interpret the present lower crustal lens as underplated igneous rocks left after extraction of the extruded basaltic lavas. A considerable quantity of new material has been added to the crust under the rifted margin. The present Moho is a new boundary formed during creation of the margin and cannot, therefore, be used to determine the amount of thinning.

1. Introduction

The Hatton Bank continental margin (Fig. 1) lies far from any terrigenous sediment source and is buried beneath only a very thin (c. 250 m) veneer of post-rift sediments. There is little variation along the margin, which justifies the employment of two-ship expanding spread profiles (ESP) to determine the velocity-depth structure. We worked in a 100 x 80 km box straddling the continental margin, within which we recorded 1400 km of conventional single-ship mcs profiles, together with over 7500 km of magnetics, gravity and bathymetry profiles. Embedded in this detailed survey we shot eight two-ship ESPs along

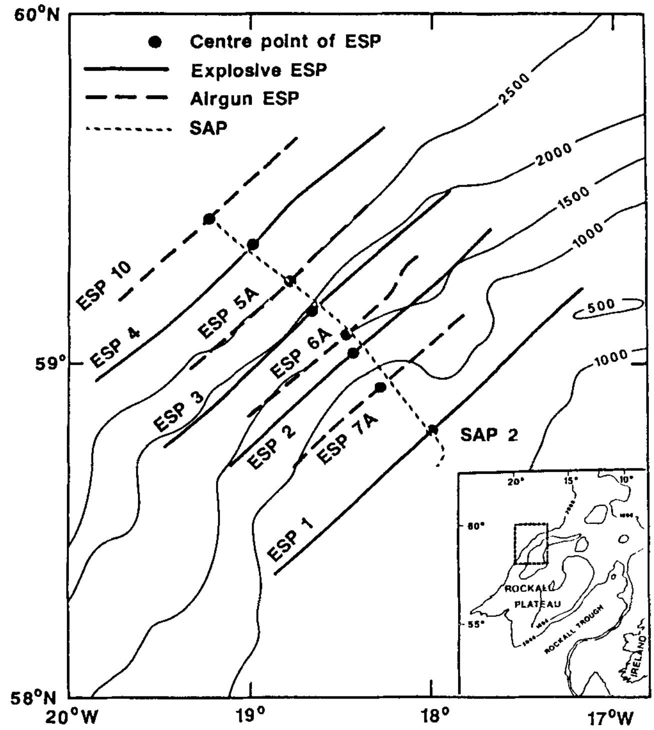

Figure 1. Map showing positions of two-ship expanding spread profiles across the continental margin used to construct the cross-section in Fig. 4, with location (broken line) of mcs profile from which an extract is shown in Fig. 2.

strike (Fig. 1) and one long dip line through the mid-points of the ESPs using both wide-angle mcs arrivals and ocean bottom seismometer records. Using synthetic seismogram full-wave reflectivity modelling, these data constrain the velocity structure in the crust and its lateral changes across the entire margin. Finally, four two-ship synthetic aperture profiles (SAP) were shot across the margin to image the internal structure of the crust.

There are two end-member types in the development of passive continental margins, which reflect differences in the response of the crust when continents rift apart. One end-member responds by thinning of the continental crust and the development of tilted, and subsequently subsided, fault blocks of pre-rift strata with little or no syn-rift igneous activity: e.g. the Biscay continental margin (Whitmarsh *et al.* 1986). The other end-member responds by the extrusion of large quantities of lava, often as seaward-dipping reflector sequences that form the upper part of crust generated by the incipient ocean ridge or that overlie stretched continental crust (Hinz 1981).

The Hatton Bank margin is of the latter type, with extensive development of seaward dipping reflectors. The oldest well-developed seafloor spreading magnetic anomaly adjacent to the Hatton margin is Anomaly 23 (c. 55 Ma). Anomaly 23, which is unbroken by fracture zone effects, lies over our most oceanward velocity determination from ESP10 (Fig. 4) which yields a typical oceanic velocity structure. Magnetic anomaly 24 can be discerned further to the south-west of our survey abutting the foot of the continental slope, but in the area of the seismic experiment it is not developed in its typical form.

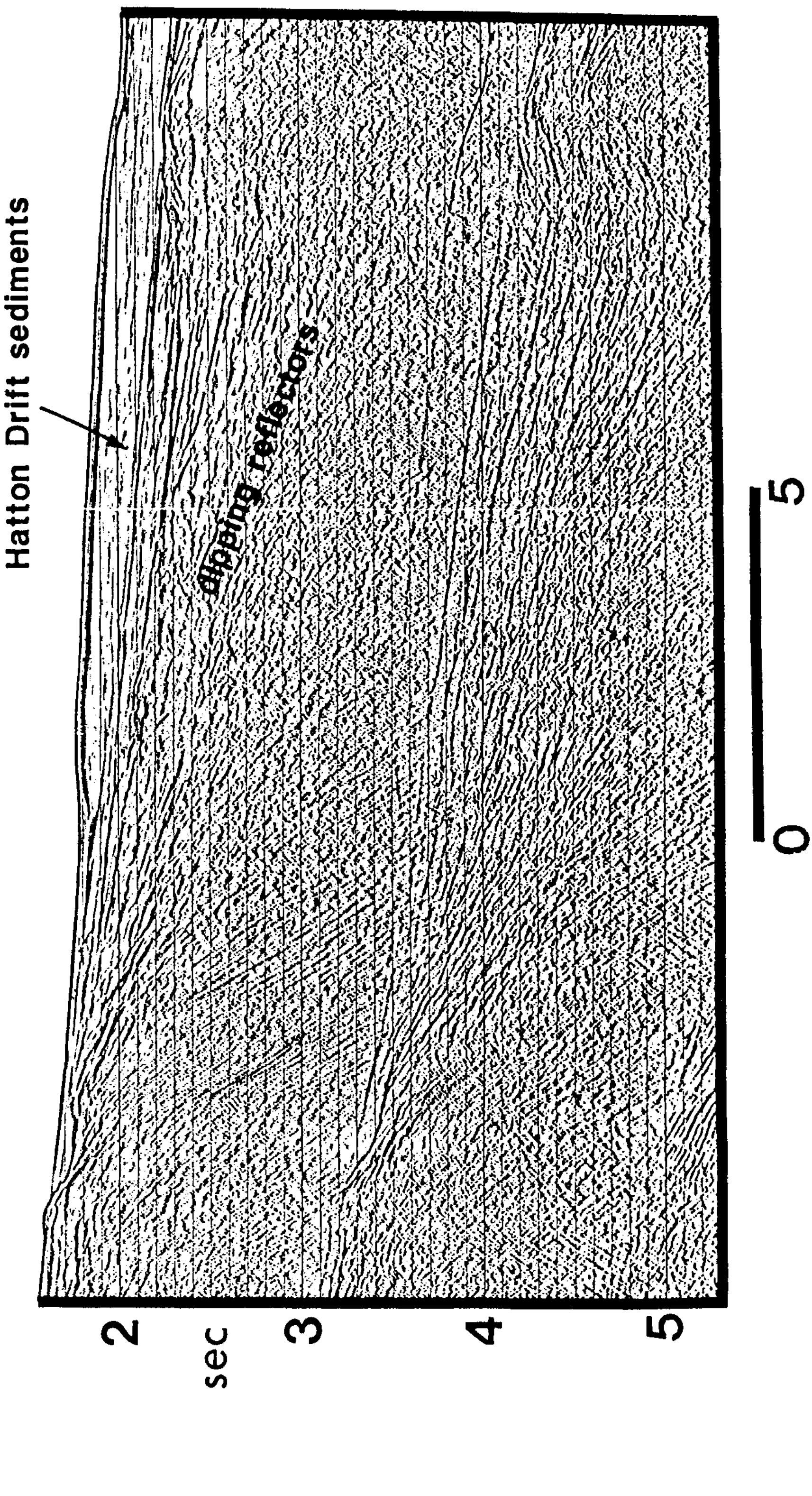

Figure 2. Portion of mcs profile across the set of dipping igneous reflectors on the continental slope.

2. Dipping reflectors

The landward feather edge of the dipping reflector sequence lies beneath 1300 m of water. The wedge thickens down the margin to a maximum of 3000 m (see Fig. 2). In common with the geometry seen on other margins, individual reflectors are arcuate, becoming somewhat steeper with depth as they are traced oceanward: from this an oceanward magma source is inferred, with the downbending due to the loading of subsequently erupted lavas (Mutter *et al.* 1982). In addition to the dipping reflectors located on the continental margin itself, a second prominent series lies beyond the foot of the continental slope, extending at least 25 km seaward of it and reaching over 4000 m in thickness (Fig. 4). As we show in the next section, the most landward dipping reflectors overlie stretched continental crust, the most oceanward overlie normal oceanic crust, whilst those in-between across the lower half of the margin overlie a section which could be either very thick oceanic crust or greatly stretched and underplated continental crust.

Seismic velocities increase through the dipping reflector sequence from typically 3.5 km/s at the top to about 6 km/s at the base. Synthetic seismograms show that the upper section can be modelled by layers typically 100 m thick of alternately high (c. 4.5 km/s) and low (c. 3.5 km/s) velocity material (Fig. 3). We interpret this as due to the interbedding of basaltic flows with lower velocity syn-rift sediment, rubble, or weathered basalt in the upper part of the section.

3. Deep structure

The most oceanward line, ESP10, exhibits typical oceanic crustal structure, falling well within the bounds of normal North Atlantic velocity-depth determinations (White 1984). The most landward line, ESP1, has a 26 km thick crust of typical continental structure. In the intervening section, the continental crust thins oceanward across the margin (Fig. 4).

Two important horizons are particularly well constrained by high amplitude wide-angle arrivals on our ESPs. One is the present Moho at the base of the crust (Figs. 3 and 4). The other is a mid-crustal horizon which separates an overlying region with velocities of 5.0 - 7.0 km/s and high velocity gradients from an underlying section with unusually high velocities of 7.1-7.4 km/s, but very low velocity gradients of only 0.01 /s (Figs. 3 & 4). The 7.0 km/s iso-velocity contour on Fig. 4 coincides with this mid-crustal boundary. Beneath the central region of the continental margin is a 15 km thick lens of 7.3 - 7.4 km/s material outlined by the 7.3 km/s contour and the Moho on Fig. 4.

The thick high velocity lower crust is quite unlike the normal lower continental crust found beneath adjacent mainland Britain and the continental shelf (e.g. Jones *et al.* 1984): there the seismic velocity never rises above 7 km/s. However, similar lower crustal layers with high velocities of 7.2 - 7.5 km/s are found beneath many continental rift zones such as the Basin and Range, the Rhinegraben, the Mississippi embayment, the Gregory Rift, the Rio Grande Rift, and the Salton Rift (e.g. Meissner 1986; Furlong & Fountain 1986). The high velocity lower crustal lens is apparently caused by the addition of igneous material in extensional regions.

There are two main ways of explaining the layer of high velocity lower crust: either the Moho was always at the base of the layer and the high velocities are caused by the intrusion of magmatic material into the pre-existing lower crust, or else the Moho was originally near the top of the layer and the high velocity material has underplated beneath it. We incline towards the latter view. The absence of fine scale layering in the lower crust, its homogeneity as indicated by the extremely low velocity gradient, and the high velocities of

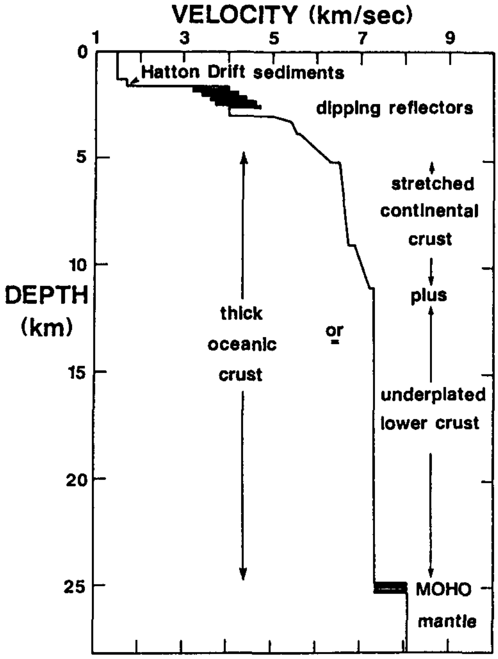

Figure 3. Velocity-depth variation constrained by synthetic seismogram modelling of two-ship expanding spread profiles from mid-way down the margin (location marked by arrowhead on Fig. 4). Detailed upper structure is from airgun ESP6A and deep structure from explosives ESP2. Note the thick lower crustal layer with a velocity of 7.35 - 7.40 km/s.

7.3 - 7.4 km/s found beneath the central part of the margin, all militate in favour of underplating rather than lower crustal intrusion.

The velocity-depth structure from the most landward ESP1 over Hatton Bank is similar to that found from Rockall Bank, and is interprted as continental crust. The most oceanward ESP10, and also ESP4, which both lie over the abyssal plain beyond the foot of the continental margin, exhibit velocity structures that lie within the bounds of normal oceanic crust (White 1984), and are interpreted as thick oceanic crust. In the intervening region the thin layer of crust above the underplated lens and beneath the seaward dipping reflectors may be stretched and thinned continental crust, or alternatively, may have been created by the same igneous processes that generated the overlying and underlying igneous rocks. The seismic velocities of this mid-crust layer lie between 6.0 and 7.3 km/s with velocity gradients that vary from 0.1 to 0.3 /s. This velocity-depth variation is similar to that found in Iceland and beneath the Outer Voring Plateau (Mutter *et al.* 1984), where it is interpreted as thick oceanic crust. However, the high velocity gradients are also typical of those to be expected from stretched continental crust (Whitmarsh *et al.* 1986). Hence from the velocity structure alone we cannot distinguish between oceanic and continental origin. We are at present investigating the subsidence pattern and detailed shape of upper crustal layers, which may help to resolve the problem.

5. Conclusion

The seaward dipping reflector sequences on the upper part of the continental slope overlie 20 - 30 km of continental crust, and at the foot of the slope they form the upper part of oceanic

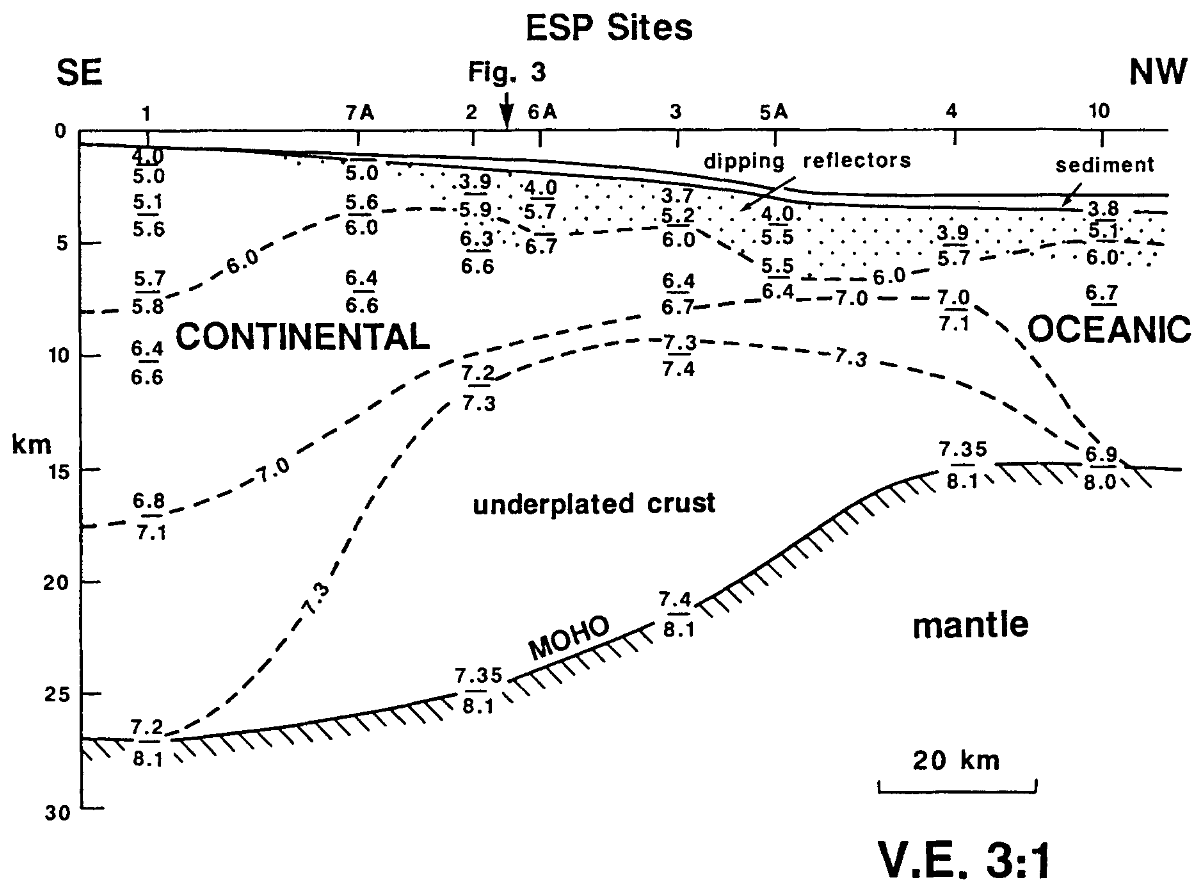

Figure 4. Section across the margin (along mcs profile shown by dotted line on Fig. 1). Velocity control from expanding spread profiles is at locations marked by numbers along the top. Extent of dipping reflectors (shown dotted) is from coincident synthetic aperture and single-ship mutlichannel profiles. Instantaneous velocities (in km/s) and major interfaces are annotated in a simplified form. Broken lines are iso-velocity contours of 6.0, 7.0 and 7.3 km/s.

crust that must have been subaerial at the time of formation. A layer about 5 km thick in the middle of this crust may be a thinned remnant of continental crust, but if so, it is probably so heavily intruded by igneous rocks that its cross-sectional form could not be used to estimate the degree of stretching that it has undergone. Whether or not thinned continental crust is present, the lower crust beneath the margin has been formed by the emplacement of igneous rocks during rifting and consequently the present form of the Moho is unrelated to the deformation of continental crust. The origin of most of the dipping reflector sequences appears to have been essentially that envisaged in the model of Mutter *et al.* (1982), but whether most of the crust of the margin is oceanic requires some reconsideration of current definitions, as during the early stages of formation it was an intra continental rift.

Acknowledgements

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