PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Contrasts in the Structure of the Passive Margins of the Bay of Biscay and Rockall Plateau

D. G. Roberts and L. Montadert

Phil. Trans. R. Soc. Lond. A 1980 **294**, 97-103
doi: 10.1098/rsta.1980.0016

Phil. Trans. R. Soc. Lond. A **294**, 97–103 (1980)   [97]
Printed in Great Britain

Contrasts in the structure of the passive margins of the Bay of Biscay and Rockall Plateau

By D. G. Roberts† and L. Montadert‡
† *Institute of Oceanographic Sciences, Wormley, Godalming, Surrey GU8 5UB, U.K.*
‡ *Institut Français du Pétrole, Rueil-Malmaison, France*

Multichannel seismic reflexion profiles across the passive margins of the Bay of Biscay and Rockall Plateau have revealed important contrasts in structural style. The Armorican margin of Biscay is characterized by a series of tilted and rotated fault blocks and a clearly defined continent–ocean boundary. In contrast, tilted and rotated fault blocks are absent on the Rockall Plateau and the continent–ocean transition is blurred. Although the exact cause of these differences remains obscure, it may be related to changes in the thickness and rheological properties of the crust as a function of age and tectonic history.

Introduction

Within the framework of the plate tectonics hypothesis, passive margins are considered to mark the initial site of rifting apart of a plate that is now the continent–ocean boundary within an accreting plate. The borders of the Atlantic Ocean are, for the most part, examples of passive margins formed principally by rifting and by transform faulting associated with the relative movement of the offset trailing edges of the continents.

Before the Ipod phase of the Deep Sea Drilling Project, only a gross geometric picture of such passive margins was available, based on limited geological and geophysical studies often reconnaissance in type. Application of multichannel seismic reflexion techniques to the study of passive margins has, however, provided new insight into the importance of structural style. Further, correlation of the drilling results with these new data has provided a firm basis for erecting structural models of passive margin evolution (Curray, this volume; Burk & Drake 1974).

In this short paper, we discuss the contrasts in structural style between the margins of the Bay of Biscay and the Rockall Plateau revealed by multichannel seismic reflexion profiles obtained by the Institute of Oceanographic Sciences funded by the Department of Energy (U.K.) and by the Institut Français du Petrole. The seismic data were acquired by using an air gun array or a Flexichoc and a 48-channel cable with 50 m between traces. The digitized data were subjected to true amplitude recovery before 24-fold processing with deconvolution before and after stack, and time varied filtering.

North margin of the Bay of Biscay

The Bay of Biscay is an unusual triangular ocean basin (figure 1) formed by the anticlockwise rotation of Spain from Europe (Carey 1955; Bullard *et al.* 1965; Bacon *et al.* 1969; Debyser *et al.* 1971; Montadert *et al.* 1974). The southern or Iberian margin of the Bay is associated with an infilled trench, overthrust structures and gravity tectonics that bear a close spatial relation to the Pyrenean orogen. The margin apparently underwent active deformation between late

Cretaceous and Oligocene–Miocene time (Boillot *et al.* 1971; Laughton, Berggren *et al.* 1972; Montadert *et al.* 1974). In contrast, the Armorican or northern margin of the Bay and its prolongation in the Aquitaine Basin bears many similarities to other passive margins, and consists of a series of horsts, grabens, tilted and rotated fault blocks (figures 1 and 2) buried beneath thin and rarely faulted Lower Cretaceous to Recent sediments. New seismic profiles across the Armorican margin show that the tilted and rotated fault blocks can be followed from the shelf break to the outer part of the rise. These fault blocks (figure 1) typically trend WNW–ESE, subparallel to the margin, but are displaced by NE–SW and E–W trending fractures, possibly influenced by structures within the Hercynian basement. Towards the Goban Spur, the fault blocks change trend to NNW–SSE. In both areas, the position of the continent–ocean boundary is clearly shown by a sharp change to a strongly diffracting opaque reflector that contrasts strongly with the tilted reflectors typically observed within the fault blocks (de Charpal *et al.* 1978).

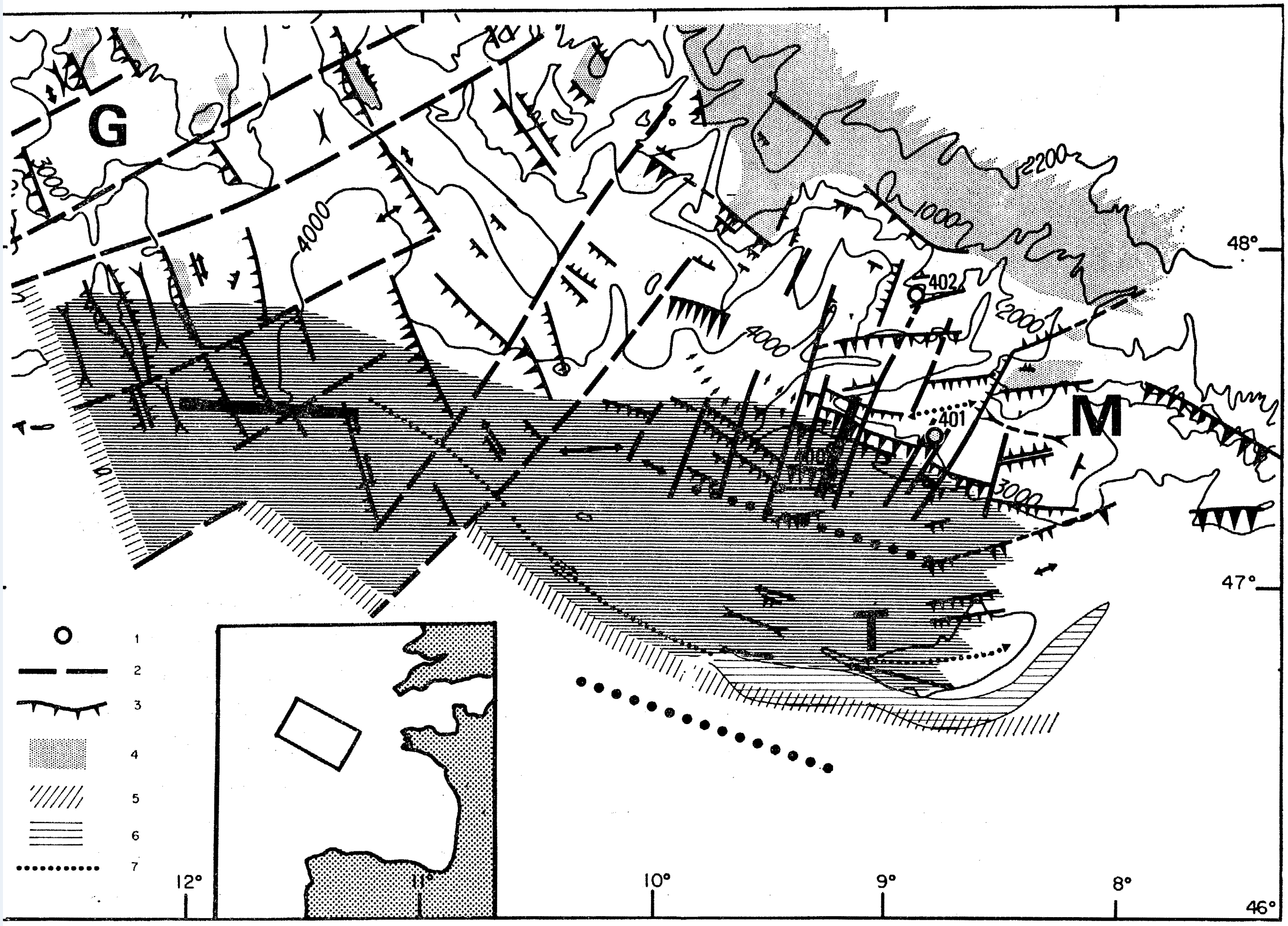

FIGURE 1. Schematic tectonic map of the rifted margin of North Biscay: 1, Sites 400, 401, 402; 2, faults; 3, listric faults with arrows downdip; 4, pre-Aptian erosional surface; 5, continental–oceanic crust boundary; 6, tectonized area along Trevelyan due to late Eocene compression; 7, late Eocene strike-slip fault or folds. Heavy dotted line: seismic refraction profile. Heavy full line: seismic reflexion profiles of figures. Horizontal hachures: areas where deep reflector S can be seen.

The fault blocks are typically spaced at about 20–30 km and the bounding faults curve and flatten with depth (figures 2, 3). In the vicinity of the rise (figure 3), a prominent flat-lying reflector 'S' is observed below the irregular surface of the fault blocks at depth of between 9.0 and 11.0 s (two-way time). Observation of this reflector beneath the slope was precluded by the 12.0 s recording length. However, reflector 'S' dips towards the continent (figure 4) and is not displaced even though the lystric faults above have throws of as much as 2000 m. Observation of a 8.2 km/s refractor at or close to the depth of reflector 'S' suggests that it may arise from or close to the Moho (Avedik *et al.* 1979; de Charpal *et al.* 1978; Montadert *et al.* 1979).

Regional geological studies, dredging and drilling results suggest that an early phase of rifting in Triassic time was followed by gentle epicontinental sedimentation and subsidence until the Upper Malm (Winnock 1971; Montadert *et al.* 1974; Pastouret & Auffret 1976; Montadert, Roberts *et al.* 1977). Between the Upper Malm and Lower Cretaceous, regional

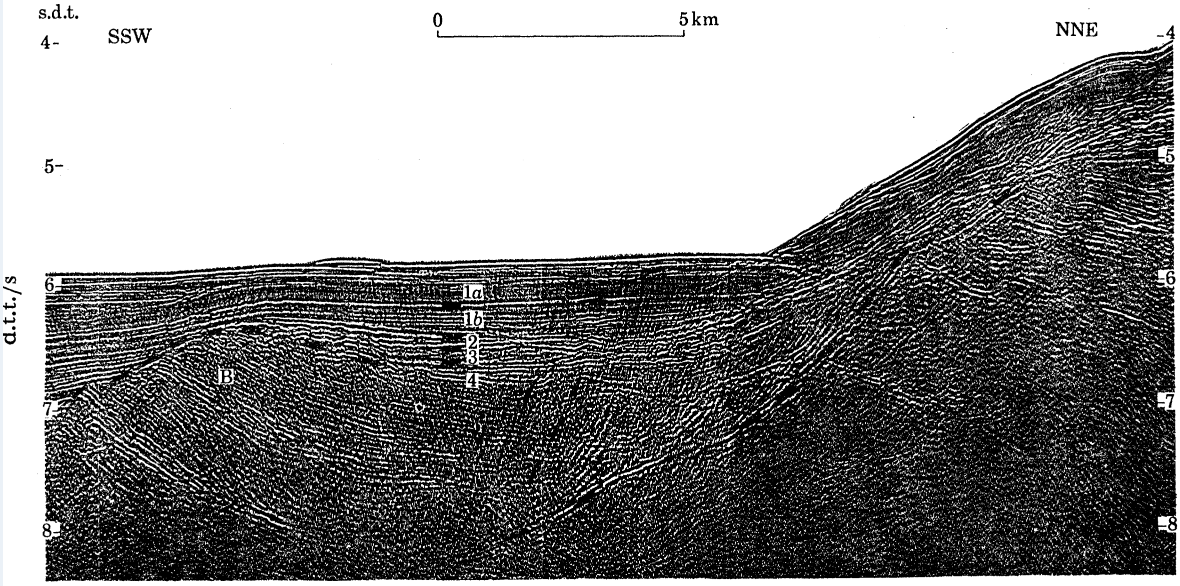

Figure 2. Tilted block and listric fault (see figure 1 for location). Acoustic basement B is probably composed of Jurassic and Early Mesozoic sediments tilted and faulted during rifting.

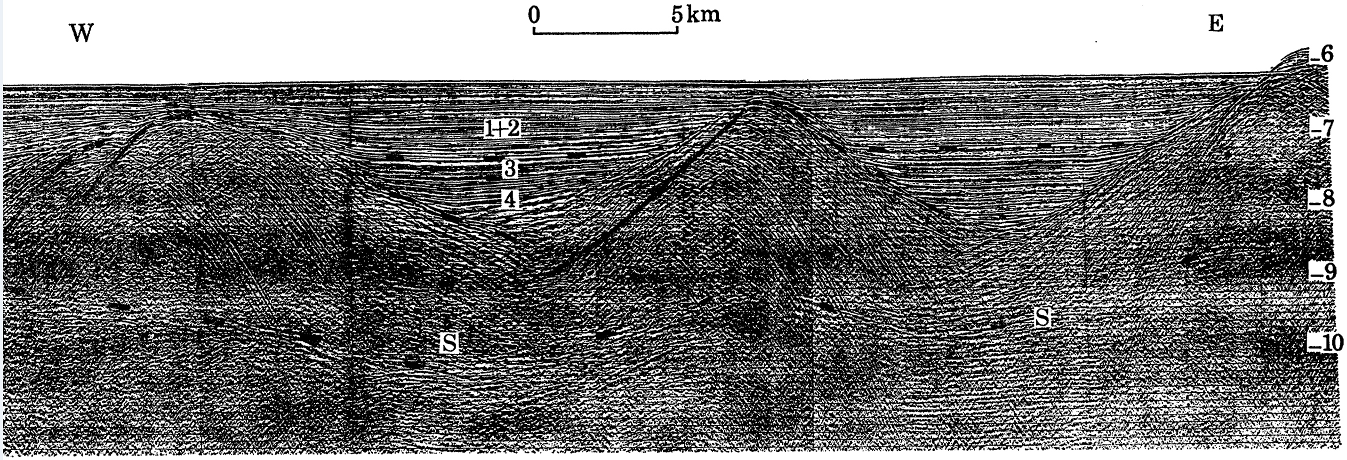

Figure 3. Seismic profile south of Goban spur showing tilted blocks with listric faults. Note the horizontal reflector 'S' below the tilted blocks. On Trevelyan, 'S' corresponds to the boundary between a 4.9 km/s velocity layer and a 6.3 km/s velocity layer; the Moho lies at about 12.5 km below sea level.

epeirogenesis led to the development of the major rift structures described above and the initiation of spreading in Lower Cretaceous time. Rifting was not accompanied by major volcanism and resulted in the creation of some 2000 m of submarine relief at the onset of spreading (Montadert, Roberts *et al.* 1977; Montadert, Roberts, *et al.*, this volume).

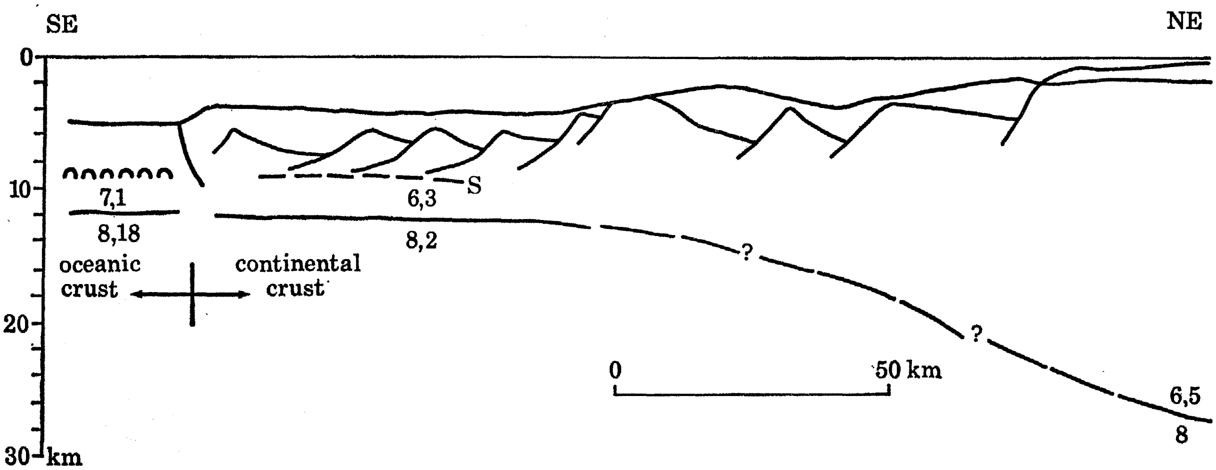

FIGURE 4. Schematic crustal section through the margin of north Biscay.

THE SOUTHWEST MARGIN OF THE ROCKALL PLATEAU

The southwest margin of the Rockall Plateau has been structured by rifting that also contrasts in age and structural style to the Bay of Biscay. Transform faulting has also been important but is not discussed here. The margins of the Rockall Plateau microcontinent were formed during three distinct phases of rifting and spreading, of which the earliest opened the Rockall Trough between Lower and Upper Cretaceous time (Vogt *et al.* 1971; Laughton 1971; Vogt & Avery 1974; Roberts 1974, 1975).

The rectilinear southwest margin of the Rockall Plateau was shaped during the last two phases. At about 73 Ma, spreading ceased in the Rockall Trough and the axis jumped to the line of the Labrador Sea spreading Greenland–Rockall away from North America (Vogt *et al.* 1971; Le Pichon *et al.* 1972; Laughton 1971; Roberts 1974, 1975; Olivet *et al.* 1974). This phase created the Gibbs Fracture Zone and the prominent east–west scarp of the southwest margin. Magnetic anomaly data indicate that the scarp may have been a continental margin transform active between 73 and 52 Ma during the early opening of the Labrador Sea. Motion along this transform may have been partly contemporaneous with the rifting between Greenland–Rockall that initially structured the younger and adjacent northeast–southwest margin before the final phase of spreading at 52 Ma.

The latter margin is structured into a series of northeasterly trending basins that parallel anomaly 24 but curve and converge westward with the east–west transform (Roberts *et al.* 1979). These basins do not exhibit the characteristic pattern of narrow tilted blocks and half grabens observed in Biscay, although they are probably controlled by normal faults. For example, the basin in which Sites 403 and 404 were drilled is defined on its east side by a change in basement depth topographically expressed as the linear west scarp of Edoras Bank. The western edge of the basement, which lies close to the continent–ocean transition, is also marked by a prominent high that can be followed along much of the west margin of the Rockall Plateau. The greatest differences from the Bay of Biscay are shown by the nature of the seismic sequence within this basin and its relationship to the adjacent ocean crust. From gravity, magnetic and seismic refraction evidence (Gaskell *et al.* 1958; Scrutton 1972; Vogt & Avery 1974; Roberts 1975) the basin is considered to be underlain by continental basement although it is rarely seen as a clear reflexion on seismic profiles. Within the basin, the seismic sequence is divided into three parts by two prominent reflectors (Montadert, Roberts *et al.* 1979). The uppermost sequence of post-Oligocene age consists of foraminiferal nanno chalks and limestones. The middle interval of late Palaeocene to middle Eocene age consists of interbedded volcanoclastics and terrigenous sediments deposited in shallow water marine conditions. Identification of the magnetic field reversal corresponding to magnetic anomaly 24 within this sequence indicates deposition was at least partly contemporaneous with the formation of the oceanic crust to the west. The palaeomagnetic anisotropy of these sediments indicates a westerly provenance from the then contiguous Greenland block (Hailwood & Sayre 1979). The underlying sequence of strong reflectors of pre-Late Palaeocene age thus pre-dates the spreading. Contemporaneous rifting and subsidence are independently indicated by faulting and the attitude of the reflectors (figure 5). Although the lithology of the low interval has not been determined by drilling, high interval velocities and the basal conglomerate penetrated at Site 404 suggest it may be composed of interbedded volcanoclastics and sediments. In contrast to the clear transition and distinction between the rifted sediments and ocean crust at the continent–ocean boundary in Biscay, no clear relation can be defined here. Reflectors of late Palaeocene – Middle Eocene age can be traced across the inferred position of the continent–ocean boundary onto and into a 'stratified' ocean crust of anomaly 24 (52 Ma) age (Roberts *et al.* 1979). Comparable examples have been described from the Lofoten Basin, Voring Plateau and East Greenland (Hinz & Weber 1976;

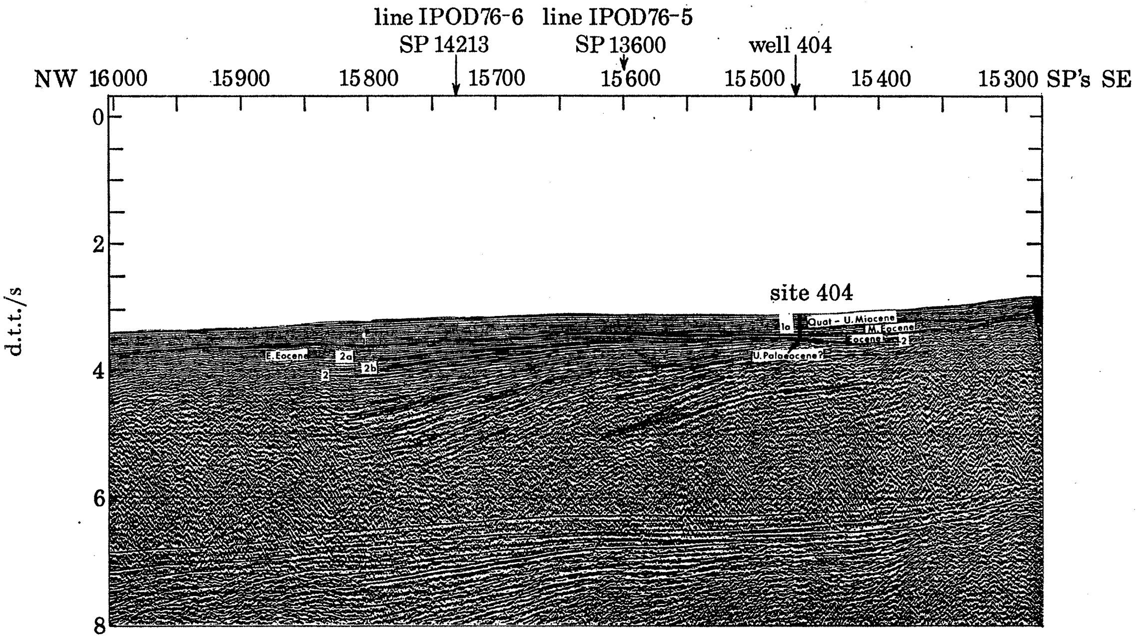

Figure 5. Multichannel seismic reflexion profile across the west margin of Rockall Plateau. Positions of Sites 403 and 404 are shown.

Eldholm, this volume; Featherstone *et al.* 1977). Clearly, the nature of the change from rifting to spreading and the conditions of first formation of the ocean crust were radically different in Rockall.

CONTRASTS – A DISCUSSION

Some of the more obvious contrasts in the structural style of the margins of Biscay and Rockall may be attributable to the nature and environment of the rifting.

In Biscay, dredging and drilling results as well as the seismic stratigraphy demonstrate that the rifting took place in a pre-existing epicontinental basin. Contrary to conventional models of rift development, the rifting did not here involve regional subaerial uplift accompanied by volcanism, followed by rapid subsidence and regional transgression at the onset of spreading (Falvey 1974; Roberts & Caston 1975; Curray, this volume; Montadert, Roberts *et al.*, this volume). In Biscay, the rifting was accompanied by minor volcanism and created some 2000 m of submarine relief by the onset of spreading. Studies of the geometry of the lystric faults and their relation to the Moho suggest that significant crustal attenuation was achieved by ductile flow in the lower part of the crust rather than by normal faulting of the crust alone (de Charpal *et al.* 1978; Montadert *et al.* 1979).

In the case of the Rockall Plateau and Greenland, geological and geophysical evidence shows that a Pre-Cambrian craton was rifted in contrast to the Mesozoic epicontinental basin of Biscay. The rifting created a large subaerial relief of the order of 1000 m and was accompanied by contemporaneous volcanism. In contrast to Biscay, only minor submarine relief existed by the onset of spreading. Accretion of the first oceanic crust may have taken place in shallow water and in association with rapid sedimentation. Under these conditions, the position of the continent–ocean boundary may have been masked by the complex interbedding of intrusives, extrusives and sediments (Montadert, Roberts *et al.* 1977).

The fundamental cause of these differences in rift tectonics remains obscure. Speculatively, the difference may be related to changes in the thickness and rheological properties of the crust as a function of age and tectonic history. In Biscay, the crust may have been weakened and thinned by earlier Mesozoic rifting imposed on a late Hercynian tectonic fabric. The older Pre-Cambrian crust of Rockall may have required heating causing uplift and volcanism before rifting by brittle fracture and ductile flow could take place. The nature of these outstanding problems emphasises the importance of comprehensive sampling of syn- and pre-rift sediments coordinated with a programme of study of the deep structure of passive margins.

We wish to acknowledge discussions with shipboard and shoreside colleagues who have collaborated in Leg 48 studies. D.G.R. gratefully acknowledges support from the Department of Energy (U.K.) for seismic survey, well logging and his participation in shipboard and shoreside studies of Leg 48. L.M. acknowledges the support of the I.F.P., C.N.E.X.O. and C.E.P.M. for acquisition of seismic profiles. D.G.R. and L.M. thank P. Guennoc and O. de Charpal for useful discussions.

REFERENCES (Roberts & Montadert)

Avedik, F. & Howard, D. 1979 In *Init. Rep. D.S.D.P.* vol. 48. (In the press.)

Bacon, M., Gray, F. & Matthews, D. H. 1969 *Earth planet. Sci. Lett.* **6**, 377–385.

Boillot, G., Dupeuble, P. A., Lamboy, M., d'Ozouville, L. & Sibuet, J. C. 1971 In *Histoire structurale du Golfe de Gascogne*, vol. II, pp. V6-1–V6–52. Paris: Technip.

Bullard, E. C., Everett, J. E. & Smith, A. G. 1965 *Phil. Trans. R. Soc. Lond.* A **258**, 41–51.

Burk, C. & Drake, C. L. 1974 *The Geology of Continental Margins.* New York: Springer–Verlag.

Carey, S. W. 1955 *Proc. R. Soc. Tasm.* **89**, 255–288.

Charpal, O. de, Guennoc, P., Montadert, L. & Roberts, D. G. 1978 *Nature, Lond.* **275.**

Debyser, J., Montadert, L. & Le Pichon, X. (eds) 1971 *Histoire structurale du Golfe de Gascogne.* Paris: Technip.

Falvey, D. A. 1972 *J. Aust. petrol. expl. Ass.* **12**, 86–88.

Featherstone, P. S., Bott, M. H. P. & Peacock, J. H. 1977 *Geophys. J.* **48**, 15–27.

Gaskell, T. F., Hill, M. N. & Swallow, J. C. 1958 *Phil. Trans. R. Soc. Lond.* A **251**, 23–83.

Hailwood, E. & Sayre, W. O. 1979 In L. Montadert, D. G. Roberts *et al.* (eds.) *Init. Rep. D.S.D.P.* vol. 48. (In the press.)

Hinz, K. & Weber, J. 1976 *Erdöl Kohle Erdgas Petrochem.* 3–29.

Laughton, A. S. 1971 *Nature, Lond.* **232**, 612–616.

Laughton, A. S., Berggren, W. *et al.* 1972 *Init. Rep. D.S.D.P.* vol. 12, 1243. (In the press.)

Le Pichon, X., Hyndman, R. & Pautot, G. 1972 *J. geophys. Res.* **76**, 4724–4743.

Montadert, L., Charpal, O. de, Roberts, D. G., Guennoc, P. & Sibuet, J. C. 1979 In *Maurice Ewing Series* **2.** American Geophysical Union, Washington D.C. (In the press.)

Montadert, L., Roberts, D. G., Auffret, G. A., Bock, W. O., DuPeuble, P. A., Hailwood, E. A., Harrison, W., Kagami, H., Lumsden, D. N., Muller, C., Schnitker, D., Thompson, R. W., Thompson, T. L. & Timofeev, P. P. 1977 *Nature, Lond.* **268**, 305–309.

Montadert, L., Roberts, D. G., Charpal, O. de & Guennoc, P. 1979 In *Init. Rep. D.S.D.P.*, vol. 48. (In the press.)

Montadert, L., Winnock, E., Delteil, J. R. & Grau, G. 1974 In *Geology of continental margins* (ed. C. Burk & C. L. Drake), pp. 323–342. New York: Springer–Verlag.

Olivet, J.-L., Le Pichon, X., Monti, S. & Sichler, B. 1974 *J. geophys. Res.* **79**, 2059–2072.

Pastouret, L. & Auffret, G. A. 1976 *Rev. Inst. fr. Pétrole* **31** (3), 401–425.

Roberts, D. G. 1974 In *Geology of continental margins* (ed. C. Burk & C. L. Drake), pp. 343–359. New York: Springer–Verlag.

Roberts, D. G. 1975 *Phil. Trans. R. Soc. Lond.* A **278**, 447–509.

Roberts, D. G. & Caston, V. N. D. 1975 Panel Discussion 5 (2) in *Proc. 9th World Petroleum Congress Tokyo* 1975. London: Applied Science Publishers.

Roberts, D. G., Montadert, L. & Searle, R. C. 1979 In L. Montadert, D. G. Roberts *et al.*, *Init. Rep. D.S.D.P.* **48.** (In the press.)

Scrutton, R. 1972 *Geophys. J.* **27**, 259–275.

Vogt, P. R., Johnson, G. L., Holcombe, T. L., Gilg, J. G. & Avery, O. E. 1971 *Tectonophysics* **12**, 211–234.

Vogt, P. R. & Avery, O. E. 1974 *J. geophys. Res.* **79**, 363–389.

Winnock, E. 1971 In *Histoire structurale du Golfe de Gascogne*, vol. IV, 1, pp. 1–30. Paris: Technip.

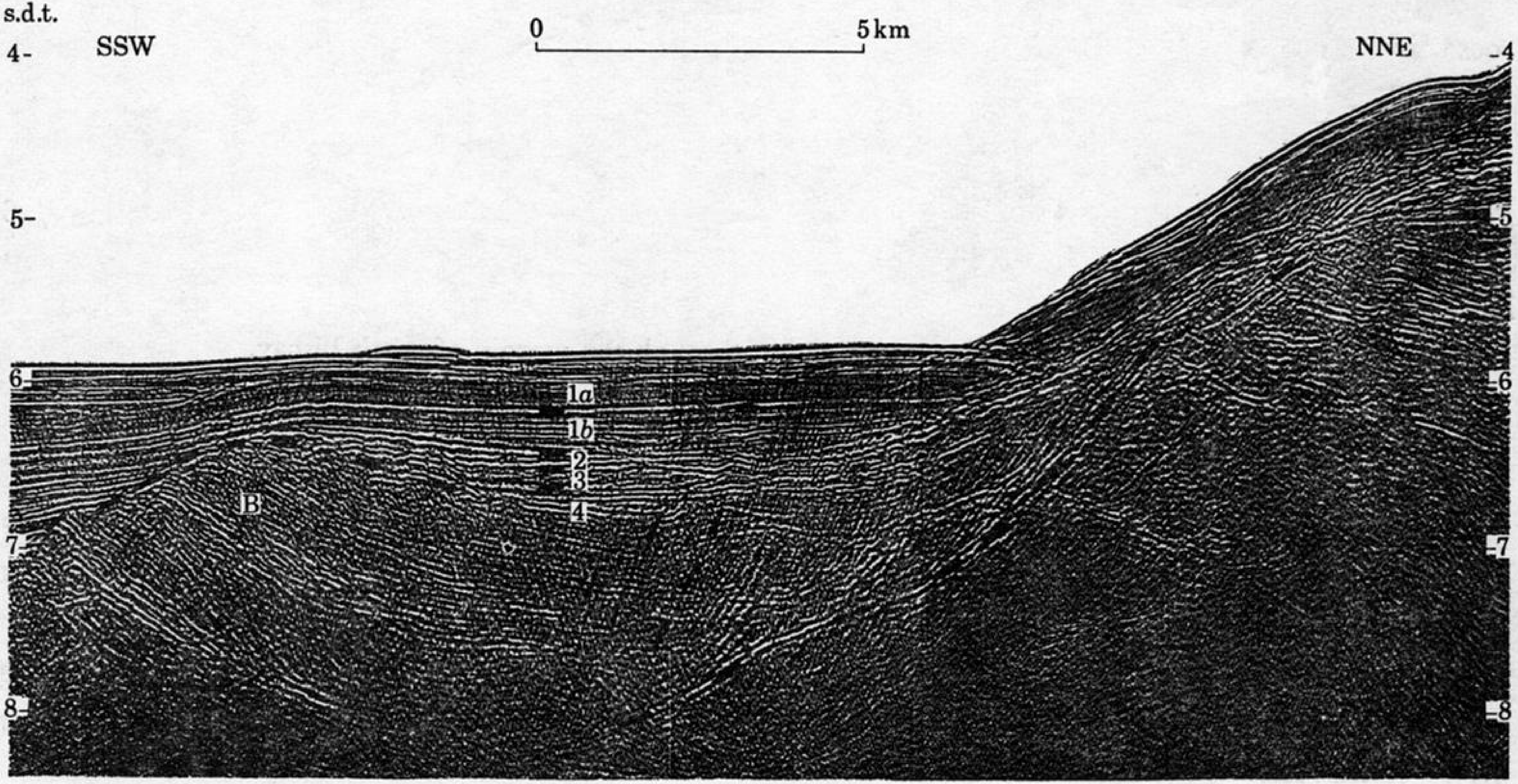

FIGURE 2. Tilted block and listric fault (see figure 1 for location). Acoustic basement B is probably composed of Jurassic and Early Mesozoic sediments tilted and faulted during rifting.

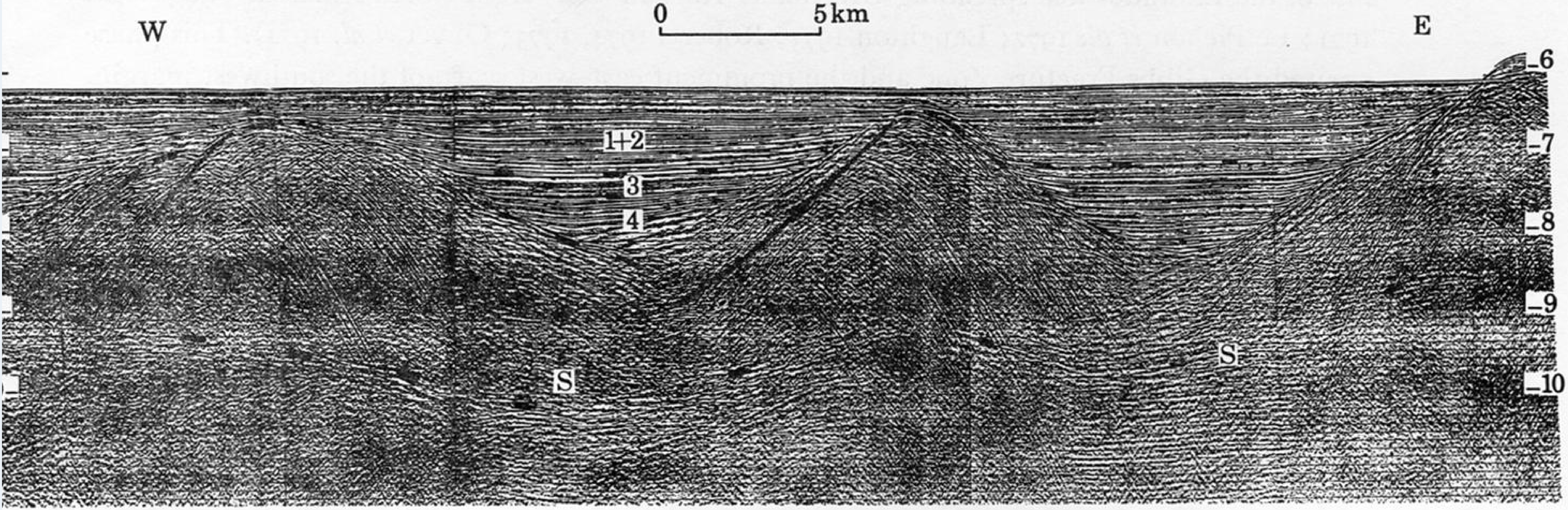

FIGURE 3. Seismic profile south of Goban spur showing tilted blocks with listric faults. Note the horizontal reflector 'S' below the tilted blocks. On Trevelyan, 'S' corresponds to the boundary between a 4.9 km/s velocity layer and a 6.3 km/s velocity layer; the Moho lies at about 12.5 km below sea level.

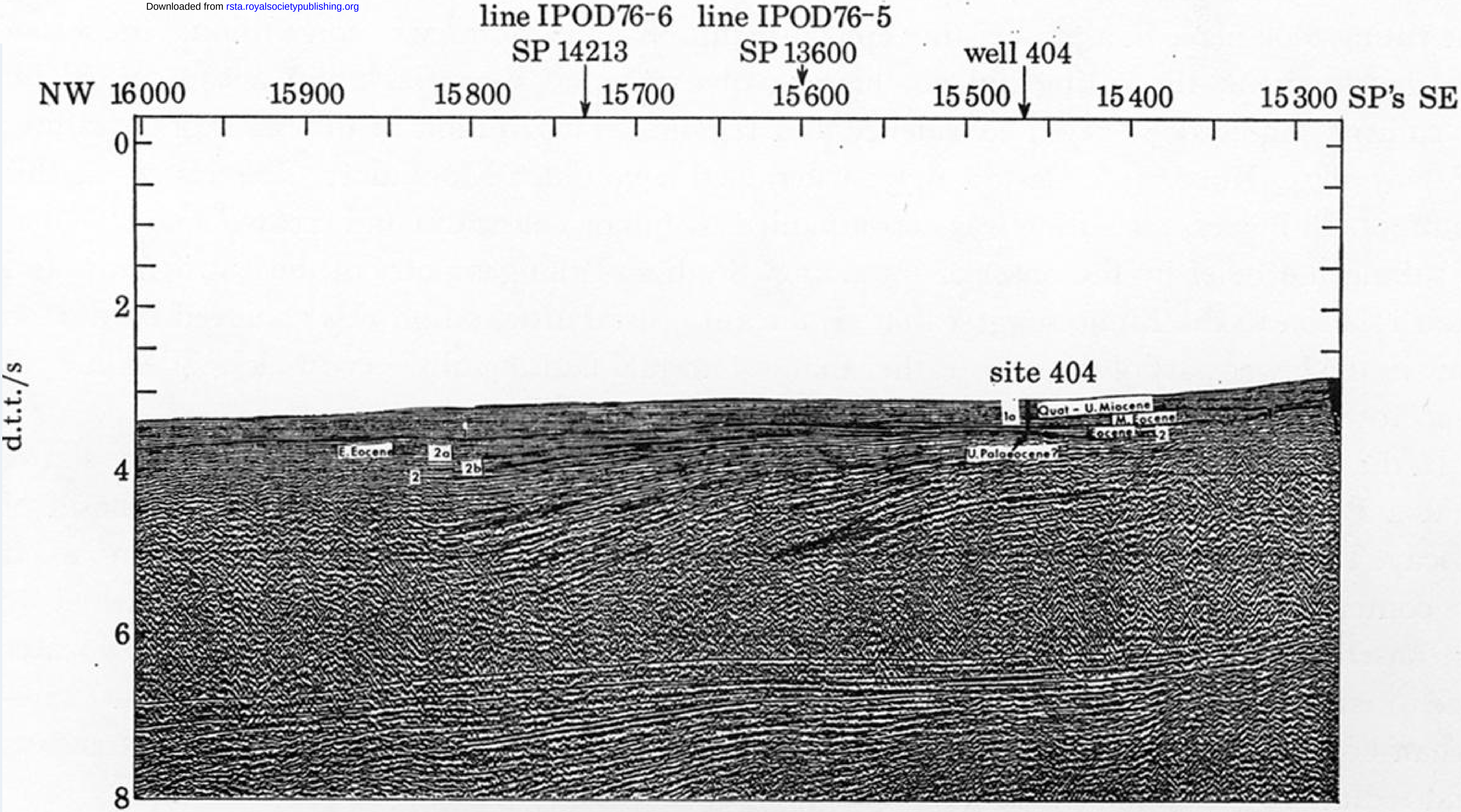

Figure 5. Multichannel seismic reflexion profile across the west margin of Rockall Plateau. Positions of Sites 403 and 404 are shown.