Geophys. J. R. astr. Soc. (1987), **89**, 209-216

Some unsolved BIRPS problems

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Summary. BIRPS has 8000 km of records around Britain that are relevant to the rheology of continents and to faulting of the lithosphere. Problems include the need to measure seismic velocities with better resolution and to eliminate multiples in deep water, the question "Are blank bits of records due to noise increase or to geology?" and the need to know the physics of the origin of deep reflections in order to answer geologists' questions.

1. Introduction

The British Institutions Reflection Profiling Syndicate now has 8000 km of 15 second records collected since 1981 in the waters round the British Isles (Fig. 1), within an area whose size is very similar to the Basin and Range province of the U.S.A. The geology of Britain is dominated by the Palaeozoic Caledonian and Variscan orogenies. Both orogenies were followed by extension of the upper crust, in Devonian and Permo-Triassic time respectively. Extension was renewed during the Jurassic and Lower Cretaceous and this extension culminated in the opening of the North Atlantic. There are 30 "Mesozoic", i.e. post-Carboniferous, basins in and around Britain. During the Tertiary there was Eocene vulcanism in the west, thermal subsidence in the major basins, and "Alpine" compression leading to some basin inversion.

Lines shot prior to 1984 were to the west of Britain and were arranged to cross the Caledonian and Variscan structures. Results have been reviewed by Matthews & Cheadle (1986), Brewer & Smythe (1986), Cheadle, McGeary & Warner (in press). In the period 1984-86 we have collected 5000 km of profiles, mostly to the east of Britain. Some of this data was taken with oil industry partners and is not yet available for comment but the rest is discussed in this volume. Most of the lines were shot with geological exploration as the motive, but we have also acquired lines intended to check ideas: DRUM (McGeary & Warner, 1985); WAM (Hobbs & Peddy, this issue); NEC (Klemperer & Matthews, in press). Clearly, more such experiments will be made worldwide in the future; and there is also a need for computer experiments to test the origin of deep reflections that come from beneath the reach of the drill.

2. Technical Problems

No one wants to know echo times to deep reflectors; everyone wants to know depths. To turn reflection times into reliable depths we need to increase the resolution of velocity measurements above that available from existing wide-angle reflection (ESP) and refraction techniques and to do it in 3-D rather than in 2-D. It is not easy to see how this can be done. BIRPS acquisition north of Scotland in 1986 is intended to address this problem in 2-D. We shall obtain a single-ship grid survey and a two-ship synthetic aperture profile.

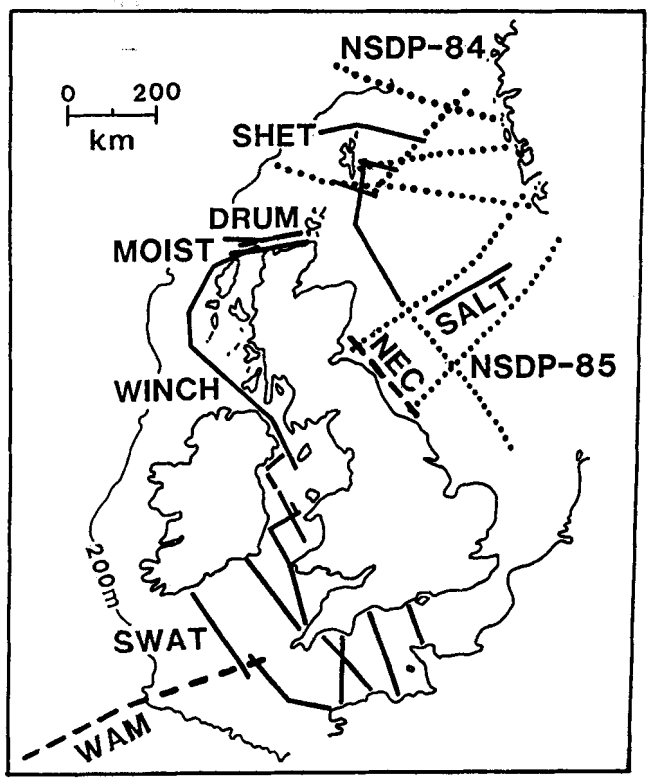

Figure 1. Map showing BIRPS profiles, 1981 to July 1986. A two-ship synthetic aperture profile between MOIST and DRUM, and a grid of single ship lines between them, will be obtained in 1986.

A second technical problem, not so far solved, is how to eliminate water-bottom multiples when profiling down the continental slope in water depths greater than about 400 m (c. 500 ms t.w.t). With such long multiple spacing it is not possible to use ordinary predictive deconvolution. At some point down the continental slope the strong multiples obscure the Moho and adjacent reflections. They do so on WAM (Fig. 1). Only in truly oceanic depths, greater than about 4000 m, does the oceanic Moho appear clear above the first bottom multiple. So far no one has managed to trace the oceanic Moho unequivocally into the continental Moho. F-K filtering, or other computational wizardry may help, but it would clearly be much easier if we could use a hydrophone streamer considerably longer than the conventional 3 km, thus increasing the normal-moveout distinction betwen sub-bottom reflections and water-bottom mutliples occuring at the same echo time.

We are aware of the many pitfalls that surround the unwary interpreter, and of the curious raypaths by which energy may be returned to the hydrophones. However, amplitude modelling by Bernard Raynaud (1986) and his predecessors gives some confidence that the majority of the reflections with sufficient amplitude to be visible above the noise come from more or less planar reflectors, larger than the Fresnel zone and essentially beneath the ship, not from curved reflectors well out to the side. But what of the places on equalised or on "true-amplitude" records where no reflections from the crystalline rocks can be seen? Are we there being deafened by a temporary increase in noise?

Noise can be ambient or signal-generated: swell noise and diffractions are examples. When the noise increases are we unable to make out reflections that would have been seen on

quieter records? An example on WAM (Fig. 1) is dealt with by Hobbs & Peddy (this issue). On WAM the reflections from the lower crust are clearly visible at the eastern end of the line but become invisible before the continental margin is reached. Why? Was it a change in geology or an increase in sea noise as the ship approached the ocean? The base of the reflective lower crust (Fig. 2) is widely recognised as the Moho (Barton, 1986); but what controls the top of the reflections from the lower crust? If the impedance contrasts responsible for the lower-crust reflections become gradually smaller in the upper crust, then the reflections from the lower-crust will vanish from the record where they are swamped by the signal-generated noise from the upper crust. Under granites we see these reflections several seconds shallower than elsewhere (BIRPS and ECORS, 1986). Is this because the homogeneous granites produce less signal-generated noise than surrounding areas of metamorphic rocks? Or is it real geology, basic layering at the bottom of the batholith?

Dr. Warner has demonstrated that an increase of noise can prevent one from recognizing the sub-horizontal reflections from the lower crust. He took a portion of a processed record that shows strong reflections from the lower-crust and a strong reflection from the Moho (Fig. 3a). He added carefully simulated noise, and reprocessed identically. The lower-crustal layering can no longer be seen; only the Moho remains (Fig. 3b).

3. Problems in interpretation

Moving now from technical problems in geophysics towards problems of geological interpretation, we have obtained reflections from 80 km depth (McGeary & Warner, 1985) but we still do not know the physics of the origin of reflections from crystalline rocks. This is a fundamental problem. We do not know whether reflections are due to constasts in mineralogy or mineral orientations in essentially dry rocks, or are due to the effects of fluids within the rocks. Without an answer we are unable to answer the questions that geologists rightly ask: what does it mean, what are the rocks?

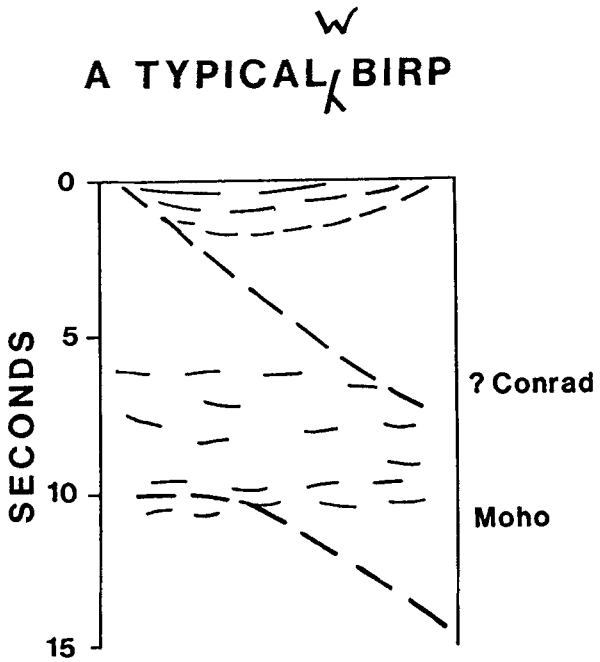

Figure 2. Cartoon of line drawing of typical data which applies west of Britain.

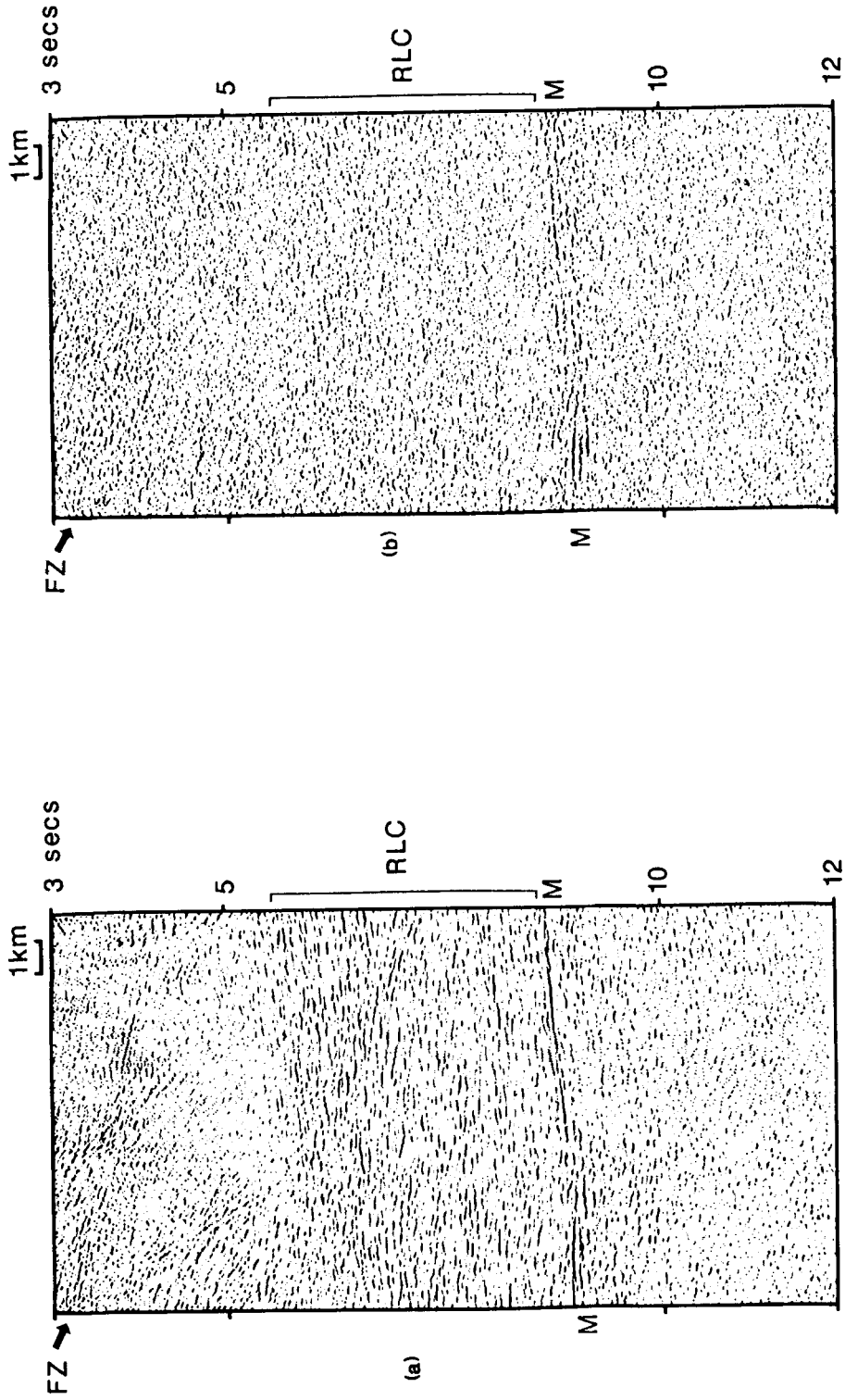

Figure 3. (a) Processed data from DRUM line. (b) Identically processed data but with noise added to field tapes.

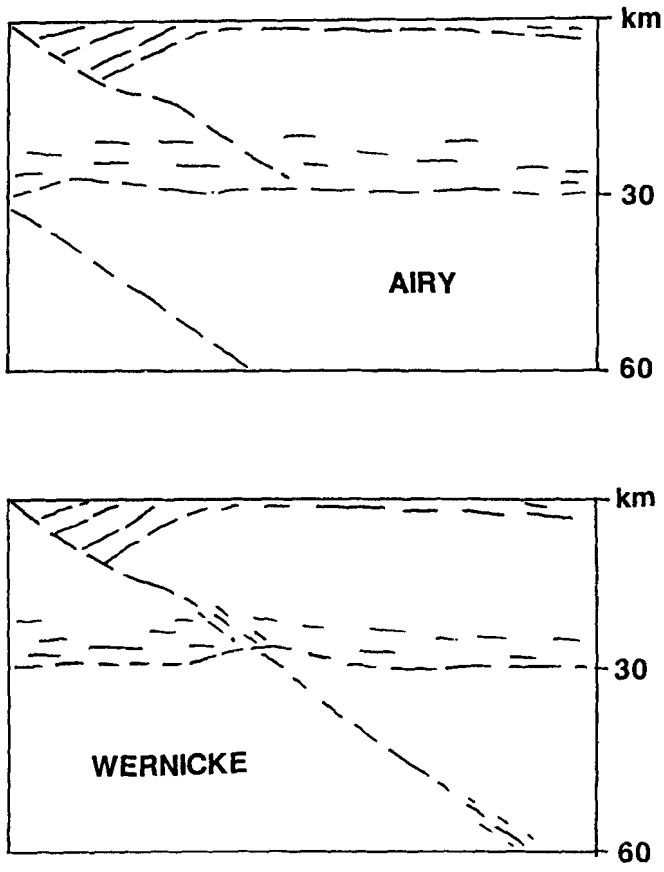

Figure 4. Contrasting structural cartoons showing deflection of the Moho. (top) Airy compensation under the basin (corresponds to existing BIRPS records); (bot) crustal thinning transferred along detachment cutting the lithosphere, after Wernicke 1986 Fig. 3.

Reflection data is relevant to the rheology of the lithosphere. Dipping reflectors in the crust and upper mantle, identified as low-angle faults (Matthews & Cheadle, 1986) sole out in the ductile lower crust (Meissner & Strehlau, 1982). Reflection and refraction data have been used to map the Moho under Britain (Meissner *et al.*, in press). The work is preliminary but it is clear that under Britain no roots remain under the Palaeozoic Caledonian and Variscan mountains and that the Mesozoic basins in the west have only very small antiroots. But the Moho is not flat under the North Sea (McGeary, this issue; Barton, 1986). So mountain roots go after 300 Ma but antiroots persist for more than 100 Ma. The flat Moho may be a young feature (Klemperer *et al.*, 1986), due either to intrustion of melt or to ductile flow in the crust and lithosphere (Kusznir & Meissner, in prep.). We need a comprehensive mathematical model of the rheology of the continental lithosphere as all embracing as Plate Tectonics for the ocean. Is compression and thickening of the lithosphere always followed by extension ..... ?

Deep reflection records are crucial to the controversy about lithospheric faulting, sedimentary basins, and displacements of the Moho, which is illustrated in Fig. 4. Is the Moho raised up, if it is raised at all, immediately beneath the sedimentary basin, or is it raised up where it is intersected by a dipping detachment surface? We, like industry, infer steep faults from the displacement of reflectors in sediments. But in the crystalline rocks

this cannot be done. The dipping reflections from crystalline rocks that we can see offshore round Britain we interpret as being from low-angle normal faults, although onshore they are mapped as Palaeozoic thrusts. Wernicke *et al.* (1985) and Wernicke (1986) in America, and Gibbs (unpublished) in Europe see evidence in our records of low-angle detachments faults that go from near surface through the lithospheric upper mantle. Beach *et al.* (1986) similarly interpret a record released by Britoil. The modelling of Peddy *et al.* (1986) suggests that one low-angle normal fault north of Scotland displaces the Moho. McGeary (this issue) suggests that a vertical strike-slip fault displaces the Moho. But the BIRPS group has never seen a fault reflection that is collinear from crust down into the upper mantle. Our records show separate bright reflections that we interpret as shear zones in both crust and upper mantle, which after migration dip at 30-40°. But we have never yet seen a collinear event that we can trace from near the surface down into the upper mantle.

4. Conclusion

Of the unsolved questions mentioned here, the most searching is that about the physics of reflections from crystalline rocks. There exists a depressing possibility that there is no neat single-value solution, that no single mechanism will account for all the impedance contrasts responsible for reflections from rocks.

Acknowledgements

BIRPS is supported by the Natural Environment Research Council and has received much generosity from Shell, Merlin, Geoquest, SSL and GECO.

References

Barton, P.J., 1986. Comparison of deep reflection and refraction structures in the North Sea,in *Reflection Seismology: a Global Perspective: Geodynamics Series*, vol. **13**, pp. 297-300, eds Barazangi, M. & Brown, L., American Geophysical Union, Washington, DC.

Beach, A, Bird, T. & Gibbs, A., 1986 (in press). Extensional tectonics and crustal strusture: Deep Sesimic Reflection data from the Northern North Sea Viking Graben, in *Continental Extension Tectonics* , eds. M. Coward & J.F. Dewey, Spec. Publ. Geol. Soc. London.

BIRPS & ECORS, 1986. Deep seismic reflection profiling between England, France and Ireland, *J. geol. Soc., Lond.* **143**, 45-52.

Brewer J.A. & Smythe, D.K., 1986. Deep structure of the Foreland to the Caledonian Orogen, NW Scotland: Results of the BIRPS WINCH profile, *Tectonics* **5**, 171-194.

Cheadle, M, McGeary, S. & Warner, M.R., 1986 (in press). Extensional structures on the UK Continental Shelf: a review of evidence from Deep Seismic Profiling, in *Continental Extension Tectonics*, eds. M. Coward & J.F. Dewey, Spec. Publ. Geol. Soc. London.

Gibbs, A. 1986. NDSP-84: Viking Graben tectonic interpretation. Unpublished report, Midland Valley Exploration Ltd, 14 Park Circus, Glasgow, Scotland.

Klemperer, S.L, Hauge, T.A., Hauser, E.C., Oliver, J.E. & Potter, C.J., 1986. The Moho in the northern Basin and Range province, Nevada, along the COCORP 40°N seismic-reflection transect, *Geol. soc. Amer. Bull.*, **97**, 603-618.

Klemperer, S.L. & Matthews, D., 1986 (in press). Iapetus Suture located beneath the North Sea by BIRPS deep seismic reflection profiling, *Geology*.

Kusznir, N.T. & Meissner, R., 1986 (in prep). Moho topography decay and its isostatic consequencies. (*Annales Geophysicae*).

Matthews, D.H. & Cheadle, M.J., 1986. Deep reflections from the Calenonides and Variscides west of Britain, in *Reflection Seismology: A Global Perspective, Geodynamics Series*, vol. **13**, pp. 5-19, eds Barazangi, M. & Brown, L., American Geophysical Union, Washington, DC.

McGeary, S. & Warner, M.R., 1985. Seismic profiling in the continental lithosphere. *Nature*, **317**, 795-797.

Meissner, R. & Strehlau, J., 1982. Limits of stresses in continental crusts and their relation to the depth-frequency distribution of shallow earthquakes, *Tectonics*, **1**, 73-89.

Meissner, R., Matthews, D.H. & Wever, Th., 1986 (in press). The Moho in and around Great Britain, (*Annales Geophysicae*)

Peddy, C.P., Brown, L.D. & Klemperer, S.L. Interpreting the Deep Structure of Rifts with Synthetic Seismic Sections, in *Reflection Seismology: a Global Perspective: Geodynamics Series*, vol. **13**, pp. 301-311, eds Barazangi, M. & Brown, L., American Geophysical Union, Washington, DC.

Raynaud, B. 1987. Seismic Studies of the Lower Crust. *Unpubl. Ph. D. thesis*, Cambridge University.
Wernicke, B. 1986. Whole-lithosphere normal Simple Shear: an interpretation of deep reflection profiles in Great Britain, in *Reflection Seismology: The Continental Crust, Geodynamics series*, vol. 14, pp. 331-339, eds Barazangi, M. & Brown, L., American Geophysical Union, Washington, D.C.
Wernicke, B., Walker, J.D. & Beaufait, M.S., 1985. Structural discordance between Neogene detachments and frontal Sevier Thrusts, Central Mormon Mountains, Southern Nevada, *Tectonics*, **4**, 213-246.