

## DEEP SEISMIC INVESTIGATIONS IN THE UK : BIRPS 1981 - 1987

by

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(4 figures)

**ABSTRACT.**- At present BIRPS has 12,000 kms of profile recorded to 15 seconds or more. Does this data relate to the distribution of strength with depth in the lithosphere ? The character of the profiles varies from place to place but does not correlate with surface geology; terranes cannot be distinguished. Ongoing work on the Iapetus Suture provides an example. Palaeozoic thrusts in the upper crust have been reactivated as normal faults during Mesozoic extension. These faults are lost in the reflective lower crust. Reflections interpreted as shear zones in the upper mantle are also lost in the lower crust. The evidence suggests that the crust is strong (brittle) at the top, weak (ductile) in its lower part. The uppermost mantle is also rather strong, at least when the shear zones formed.

**RESUME.**- BIRPS (British Institutions Reflection Profiling Syndicate) a jusqu'à présent recueilli 12.000 km de profils sismiques réflexion relevés sur des épaisseurs (double trajet) d'environ 15 secondes. Sur chacun d'entre eux, nous avons pu distinguer les bassins sédimentaires mésozoïques, surmontant une croûte continentale supérieure exempte de réflexions; la croûte inférieure se caractérise par de fortes réflexions horizontales et repose, sous Moho (défini par réfraction), sur un manteau supérieur transparent. Nous avons également observé les traces de réflexions assez longues et à fort pendage, recoupant à la fois la croûte et le manteau supérieur, que nous interprétons comme de grandes zones de cisaillement. Dans la croûte, elles correspondent à l'Outer Isles Fault (exposée dans les Hébrides au NW de l'Ecosse), à la suture de l'Iapétus et au front varisque. Dans le manteau supérieur, nous avons reconstitué la Flannan Fault à partir d'une série de profils; d'autres cas, examinés avec moins de précision, peuvent également être décelés dans l'English Channel et au large du Pays de Galles.

Récemment, dans l'espoir de recouper les prolongements des structures précédentes, des profils sismiques ont été réalisés au large des côtes ouest de l'Irlande; nous y avons décelé les traces d'un cannevas de réflexions crustales différent qui couvre la zone allant des lignes méridionales de MOBIL jusqu'au Massif Londres-Brabant.

Nous pensons que certains de nos résultats ont un intérêt à l'échelle du globe, en particulier pour ce qui concerne le comportement sous tension de la lithosphère, le développement des zones de faiblesse qui la traverse, les phénomènes d'extension qu'elle subit et la formation des bassins.

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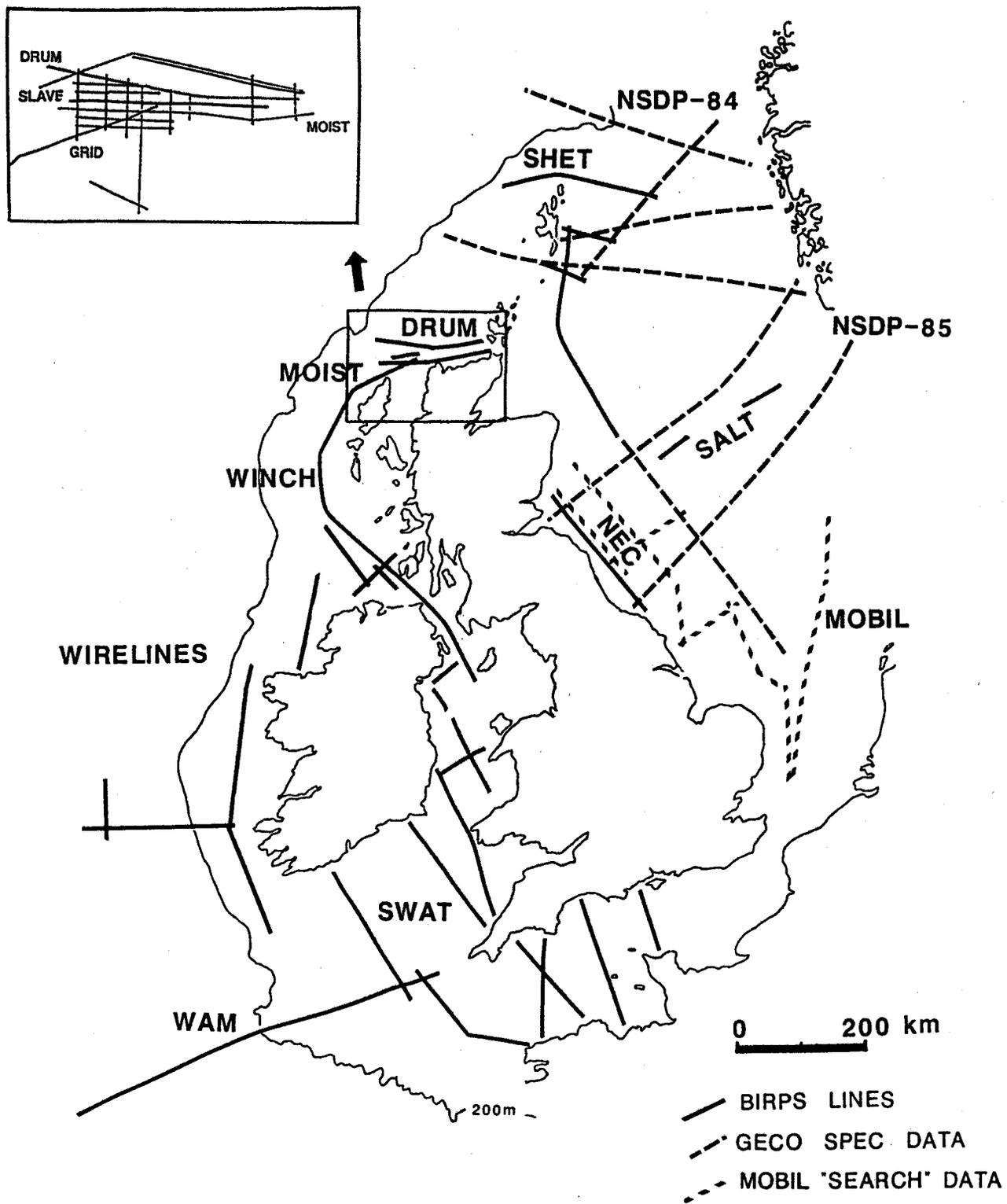


Fig. 1.- BIRPS lines at sea 1981-1987, shown by solid lines. Dashed lines show GECO speculative survey lines shot for a consortium including BIRPS and available from Merlin Geophysical Company. Diagonal slashed line show data shot for BIRPS free of cost by Mobil North Sea Ltd in summer 1987.

## INTRODUCTION

BIRPS, came into existence in 1981. The first profile, MOIST, 200 km, was shot in that year, parallel to the north coast of Scotland, to find out whether reflections could be obtained from deep within the crust, using the ships and techniques of the prospecting contractors without modification except to select from available options those which most favour reflections from the deep crust and upper mantle (Warner, 1986). Largely by chance we stumbled on an area where deep reflections were easy to obtain, and some of our best profiles have subsequently come from thence. Now, in October 1987, we have 12,000 kms of profiles around the British Isles, fig. 1. All but the newest of these records can be bought at the cost of reproduction from the British Geological Survey in Edinburgh and preliminary accounts have been published.

Twelve thousand kilometres around the British Isles, an area comparable in size with the Basin and Range province of the USA, makes this the best known area of the lithosphere, so far as its reflective character is concerned. Even a cursory study of so much data raises several questions of more-than-local interest. One problem of importance, posed in 1984, concerns the strength and rheology of the lithosphere. Do the fractures accumulated during 3,000 million years of earth-history cause the continental lithosphere to react to horizontal stress like a pile of concrete blocks pushed by a bulldozer, or have the deeper fractures annealed long ago so that the lithosphere reacts more like a slab of toffee which is cool on top but warm below, yielding by ductile flow except in its brittle uppermost parts? In this paper we will mention evidence from Palaeozoic terrane boundaries and from reactivated Palaeozoic faults that allows a provisional answer to be given to this question. A better answer will not be possible until we have the results of profiles crossing Mesozoic structures in the Alps, Tertiary structures in the Pyrenees, and Recent Structures in the Aegean.

## TERRANES

Figure 2 shows in its centre a cartoon drawn in 1984 of an imaginary typical record. It shows a Mesozoic sedimentary basin, well known to the oil industry, on the reflection-free upper crystalline crust. The lower crust is characterised by short (2-20 km) reflections, dominantly sub-horizontal. The reflective lower crust terminates at the Moho (Matthews, 1986) which in some places is, and other places is not, marked by a bright horizontal

reflection. Dipping reflectors which extend from the surface to the layered lower crust correlate with known Palaeozoic thrusts on land, but their relation to the sedimentary basins in their hanging wall suggests that under the sea the last movement along them was extensional. Similar dipping reflections in the upper mantle cannot be positively identified but are believed by some geologists to be shear zones. Arranged around the outside of the diagram are examples drawn from BIRPS profiles most of which were shot after 1984. McGeary (1987) has attempted to classify the BIRPS profiles into six types. We now have profiles that ring the British Isles around (fig.1) but the groups into which they may be classified make no sense in relation to the age of deformation of the overlying crystalline crust; McGeary concludes that they form a continuum. The geology of Britain records the effects of several continental collisions; we cannot see clear evidence of these terranes in our reflection profiles.

We are presently working on one terrane boundary, the Iapetus Suture, the zone of collision which took place during the Caledonian orogeny in the Silurian. The suture has been proposed on geological grounds to extend from northeast England (NEC on fig. 1) to southwestern Ireland. When all the profiles have been processed we should have six crossings: WIRELINES (1987), WINCH (1982), NEC (1985), MOBIL (1987), NSDP (1985). The WINCH crossing in the Irish Sea and the inshore line in the North Sea, NEC, have been compared by Klemperer & Matthews (1987). On both lines a dipping event in the lower continental crust was equated with the suture. No horizontal reflections were visible in the lower crust to the **north** of this line on WINCH or to the **south** of this line on NEC (fig. 3). This would seem to imply that the lower crust layering is younger than the Silurian and that the two terranes cannot be distinguished by the character of reflection profiles across them. However examination of provisional stacks of MOBIL and NSDP records does suggest a continuity of imaged structures across more than 50 kms of the North Sea. It is clear that the last word has not been said about profiles across the Iapetus Suture.

Reflection profiling has been combined with seismic refraction to produce a contour map of the Moho around Britain (Meissner *et al.*, 1986). No crustal roots can now be seen under the Caledonides or Variscides, though roots remain under the Alps and an anti-root under the North Sea graben. Assuming that the Caledonides and Variscides once had crustal roots, they have vanished in the last 300 MY. This implies that the lower crust has been ductile and that the Moho as we now see it is a post-Palaeozoic feature. If we do not see consis-

tent differences across terrane boundaries we can believe that the reflectors in the lower crust also formed in Mesozoic, Tertiary, or even in Recent time. The unsolved problem (Matthews & BIRPS, 1987) of the origin of lower crust reflections requires observations in areas where the deformation is younger than in Britain.

**REACTIVATED FAULTS IN THE CRUST;  
SHEAR ZONES IN THE MANTLE.**

Interpretation of the first BIRPS line, MOIST, led to the recognition that half grabens of much younger sedimentary rocks lie in the hanging wall of faults that are identified by analogy with land geology as Palaeozoic thrusts. Thus the last signi-

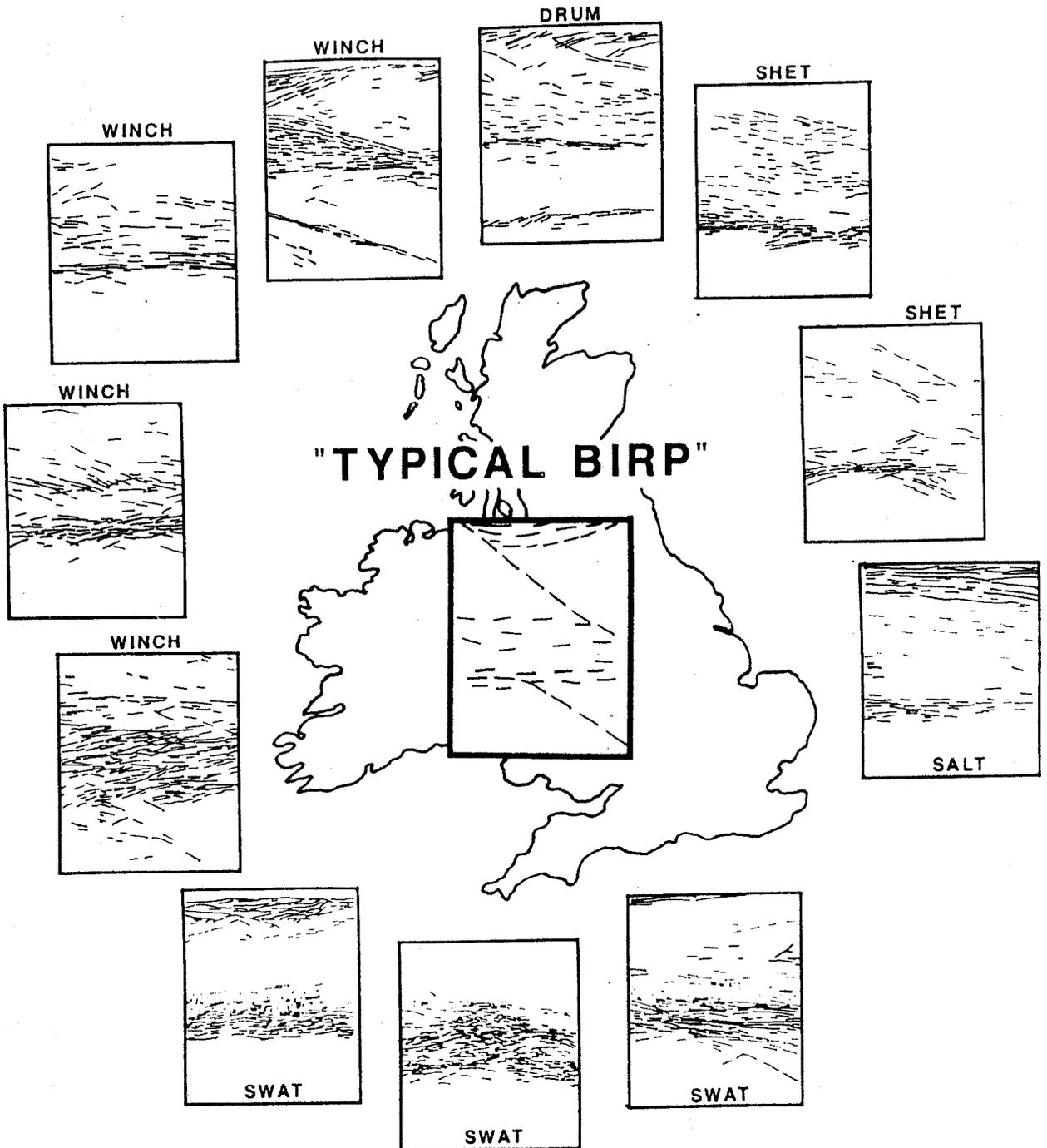


Fig. 2.- Cartoon of a line drawing of a typical record (see text). Arranged around the outside are line drawings of short sections of records. For positions of surveys see Fig. 1.

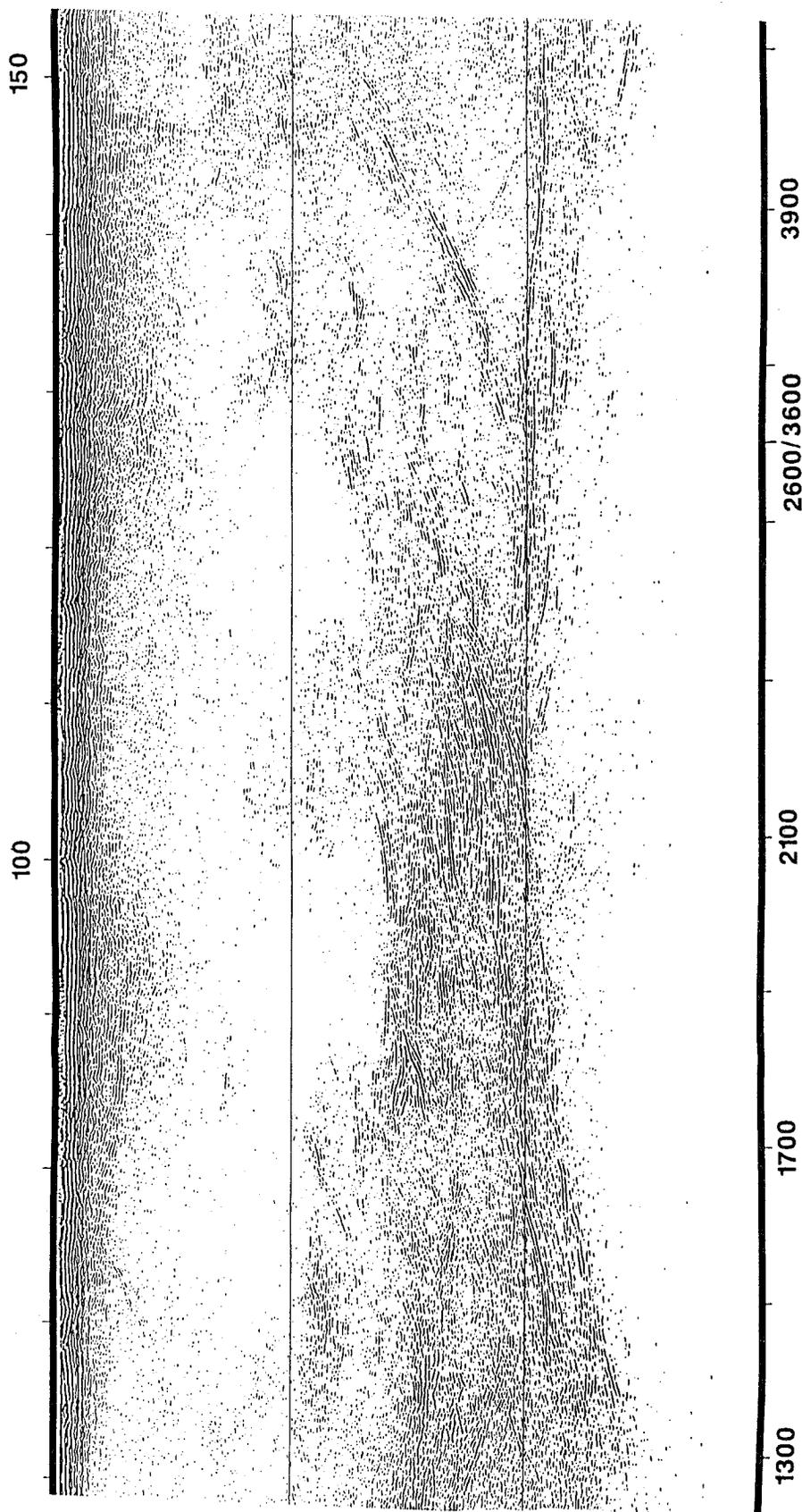


Fig. 3.- Migrated record of part of the North East Coast line (NECline) showing the Iapetus Suture zone. Numbers at the top are distance in km from the north end of the line. Those at the bottom are shot-point numbers.

ficant movement on these fault planes was in a normal sense (Brewer & Smythe, 1984). Particularly clear examples occur on one crossing of the North Celtic Sea Basin south of Ireland, where the Variscan Front has been reactivated at least in the vicinity of the SWAT 4 reflection profile (BIRPS & ECORS, 1986), and north of Scotland where the Outer Isles Fault, a Caledonian or pre-Caledonian thrust, has been reactivated as a normal fault with the North Lewis basin in its hanging wall (fig. 4). Evidence for fault reactivation is discussed by Cheadle *et al.* (1987).

All these reactivated Palaeozoic thrusts can be followed down into the crust by strong dipping reflections. Within the crust they must widen into mylonitic shear zones. The reflections are lost within the sub-horizontal reflections of the lower crust. The Outer Isles Fault, clearly visible on the many profiles of the GRID survey, is lost some 4 kms above the Moho; the Variscan Front and the easterly dipping reflectors, seen at the east end of DRUM in figure 4, is lost near the top of the layered lower crust. We take this as evidence that at the time the reflection formed - either at the time of thrusting, or extensional reactivation, or when fluids passed along the shear zone - the lower crust was ductile.

DRUM (Deep Reflections from the Upper Mantle, fig. 4) also shows the best known example of a dipping reflector in the mantle. This feature, the «Flannan fault» has been contoured throughout the area of the GRID survey (McGeary, pers. comm.) After migration it can be seen to extend to 80 kms depth, 50 kms below the Moho. This reflection, too, is lost in the layered lower crust. It does not appear to deflect the Moho. The reflection from it is thought to have negative polarity but clearly it cannot be identified from geologic evidence. Its origin and the origin of similar features in the English Channel has been discussed by Warner & McGeary (1987) who conclude that it may be a mantle fault or shear zone. If this is so it would imply that at the time of its origin the uppermost mantle was somewhat rigid.

## CONCLUSION

So how does the lithosphere react to stress, like concrete blocks or like toffee?

The evidence outlined here suggests concrete blocks above toffee in the crust, above more blocks in the uppermost mantle. The cool upper crystalline crust contains fractures that have not annealed since the Palaeozoic and are available for reactivation in a new stress field. The lower crust, siliceous and warm, is ductile (or has been ductile) - shear-zone-reflections from upper crust and upper mantle, become sub-horizontal and are lost there. In the hot but refractory mantle, reflec-

tions can be interpreted as discrete shear-zones. (although off Vancouver Island such reflections have been interpreted as subduction zones, active and fossil.)

The strength-versus depth relations implied are very similar to those envisioned by Meissner (Meissner & Strehlau, 1982; Meissner & Kusznir, 1987). In considering such schemes it is important to remember the slow strain-rates of geological deformation. Very different stress-strain relations apply to rapid fault rupturing during earthquakes, or during the passage of a seismic wave through the rocks. Moreover, one of the disadvantages of deep seismic profiling is that it is impossible to date the formation of the impedance contrasts, so we cannot tell whether the zones of ductility implied by reflection data are co-eval or not.

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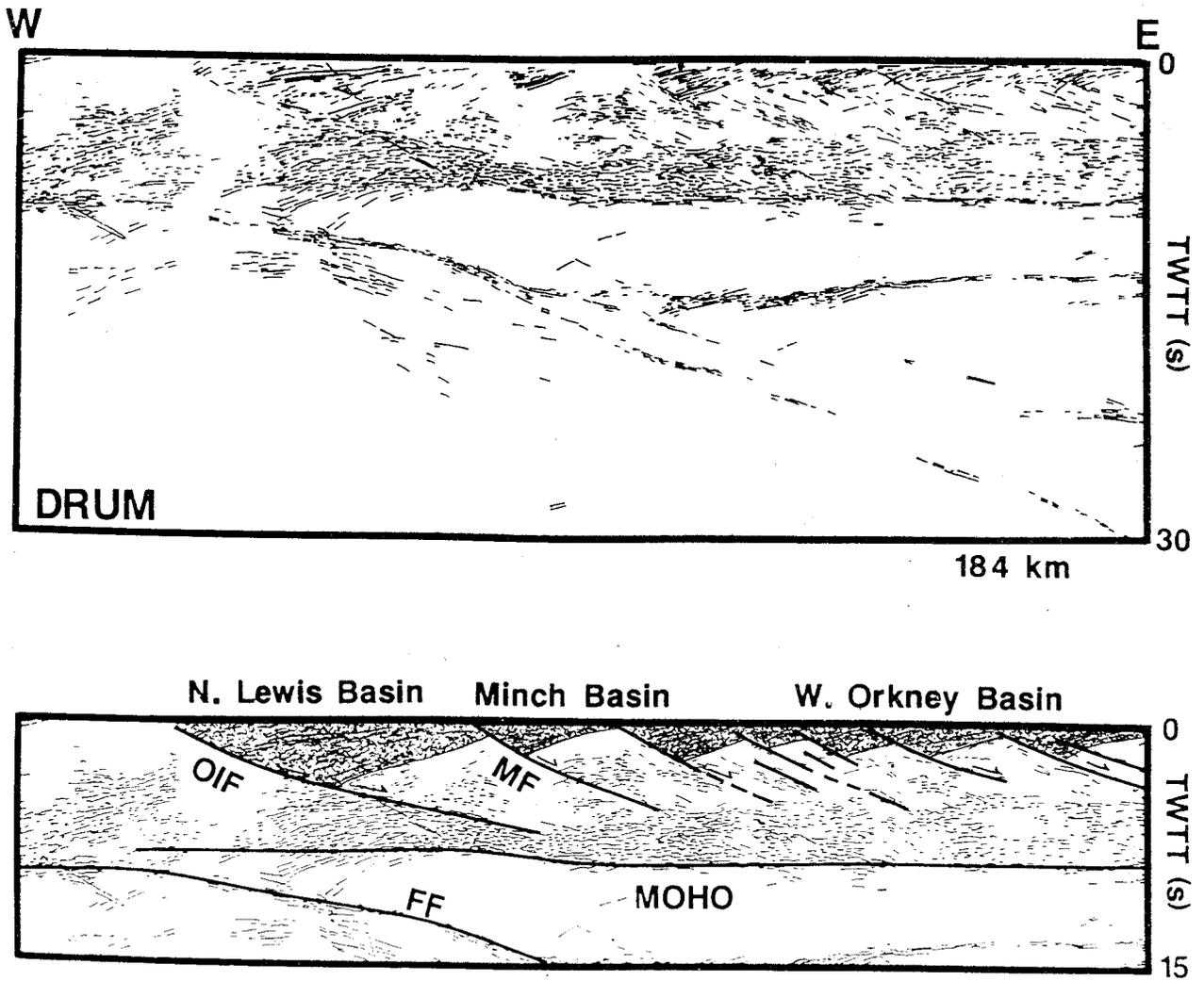


Fig. 4.- Line drawing of profile DRUM (see Fig. 1 for location) with interpretation of its uppermost 15 seconds. OIF Outer Isles Fault. MF Minch Fault. FF Flannan Fault.

Warner, M.R., 1986.- Deep seismic reflection profiling of the continental crust at sea. In : Barazangi, M. & Brown, L. (eds.) *Reflection Seismology : A global perspective. Am. Geophys. Union. Geodynamics Series*, v. 13 : 281-286.

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