Deep seismic reflection profiling of the Lewisian foreland

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SUMMARY: A number of marine deep seismic reflection profiles cross the Hebridean shelf, the Lewisian foreland to the Caledonian orogen. They include the BIRPS MOIST, WINCH and DRUM profiles, several recent commercial deep lines, and many old and new conventional commercial exploration profiles. Basement, comprising the upper crust, is largely devoid of coherent seismic reflections. In contrast, the mid-crust contains many reflectors which may be relics of early Palaeozoic, Caledonian (or earlier Grenvillian) eastward-dipping thrust zones, which pass into an acoustically strongly layered lower crust.

The Outer Isles Thrust is mapped from the surface to the mid-crust, and tied into its land outcrop on north Lewis. Reactivation of this thrust as a normal fault caused the formation of the Sea of the Hebrides, Minch and North Lewis Basins. The Moho is defined by a strong band of reflections at a rather uniform 27 km depth. The eastward-dipping Flannan Thrust can be mapped into the upper mantle from about 15 to 45 km depth.

The Moine Thrust, which carries rocks of the orogen over Lewisian foreland, dips at 20–25° to the east on MOIST, and is either the westernmost of a series of easterly-dipping reflections (thrusts) which flatten or terminate at 17–20 km depth, or a more easterly thrust which structurally overlies these easterly-dipping reflectors. In neither case are the easterly-dipping reflectors themselves likely to be simply 'Caledonised' Lewisian foreland.

The NW margin of the Caledonian orogen and its Proterozoic foreland to the west have been the subject of many crustal-scale geophysical surveys in the last decade. It is here that, in the last five years, marine deep seismic reflection profiling has demonstrated its ability to relate major crustal structure to near-surface geology. It has also revealed new lithosphere-scale structures such as the Flannan Thrust, which extends from the lower crust of the foreland to about 90 km depth beneath the margin of the orogen, that is, nearly to the base of the lithosphere.

The NW Scottish shelf was the focus of much of the first two years of marine deep seismic reflection research by the newly-set up British Institutions' Reflection Profiling Syndicate (BIRPS). The arguments in favour of acquiring seismic reflection data offshore, as a departure from the established American COCORP practice of working onshore, are firstly, that offshore data acquisition is an order of magnitude cheaper than onshore (processing costs being similar), and secondly, that offshore data are also of better quality than their onshore equivalent. The grave disadvantage, of course, is that marine reflection data cannot be as directly linked to land exposure as an onshore survey.

This review draws extensively on two papers, one dealing with the seismic reflection structure of the western margin of the orogen (Brewer & Smythe 1984), the other with the foreland itself (Brewer & Smythe 1986). The present paper summarizes this earlier work, but also refers to very recent work and new data not covered before.

Deep seismic reflection profiles

MOIST and WINCH

The first BIRPS line, the Moine and Outer Isles Seismic Traverse (MOIST), was recorded at sea just north of the coast of Scotland for the Institute of Geological Sciences in 1981 (Smythe *et al.* 1982). It crosses the northern margin of the Caledonian orogen (Fig. 1), in an analogous position to COCORP profiles in the Appalachians (Brewer & Smythe 1984).

The Western Isles–North Channel (WINCH) reflection profile was recorded for BIRPS in 1982 at sea along the west coast of Britain (Brewer *et al.* 1983). Its purpose was to study crustal and upper mantle structure of the Caledonian foreland and orogen. The WINCH profile was designed to extend the results of the highly successful MOIST traverse (Figs 1 and 2).

DRUM, SHET and other data

The DRUM line (Deep Reflections from the Upper Mantle) was shot in 1984 for BIRPS by GECO, and processing, which is still in progress at the time of writing, is being carried out by Seismograph Services Ltd (SSL). However, a preliminary report has been published (McGeary & Warner 1985). DRUM is an ultra-deep reflection line, sub-parallel to MOIST (Fig. 1), but shot and processed to 30 *s* TWT, that is, potentially 110 km penetration of the lithosphere.

The SHET lines north and south of Shetland

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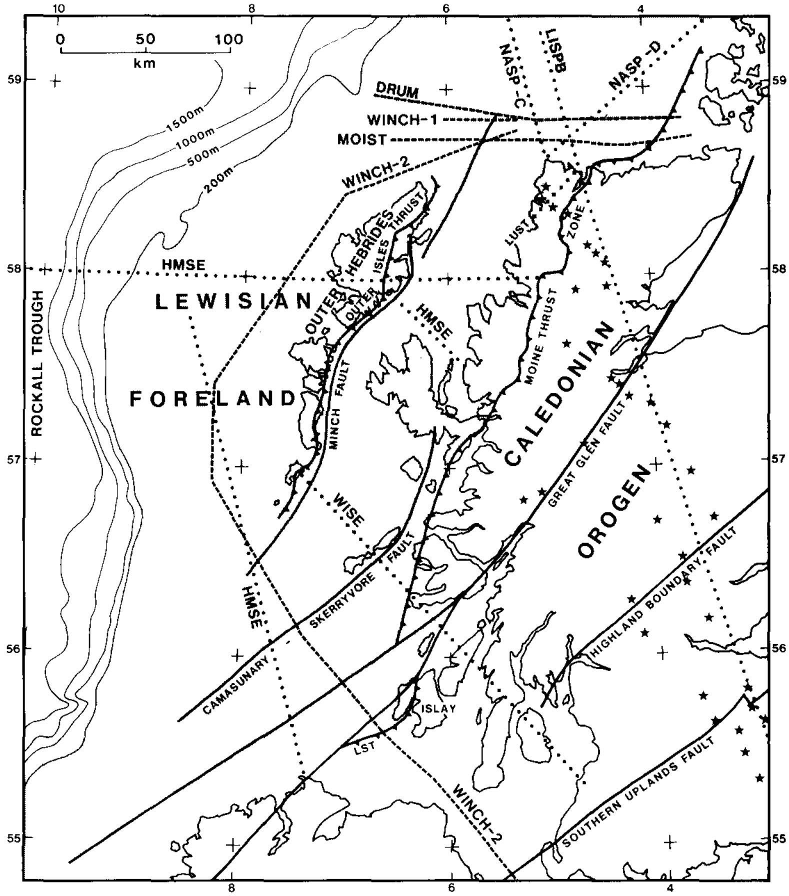

FIG. 1. Location of deep seismic profiles MOIST, WINCH and DRUM (dashed lines) in relation to the Caledonian orogen, foreland, and the passive continental margin of Rockall Trough to the west. Major faults are shown as solid lines. Dotted lines show locations of explosion crustal refraction profiles NASP, LUST, LISPB, HMSE (discussed in text) and WISE (unpublished). Stars show sites of the conductivity traverse parallel to LISPB (Hutton *et al.* 1980). LST—Loch Skerrols thrust.

have also been obtained for BIRPS, under the same arrangements as for DRUM, but are 'conventional' 15 *s* deep reflection lines. Like MOIST and DRUM, two of these lines cross the margin of the orogen. However, as processing and interpretation of these lines is at an earlier stage than DRUM they will not be discussed further.

Commercial speculative survey profiles, generally of pre-1973 vintage, are abundant in the foreland area west of the Hebrides. These data provide three-dimensional control on some basement reflectors, but in general are of limited value, because they are only recorded to 5 or 6 seconds (15–18 km depth) and, as discussed below, the upper crust down to these depths is generally rather transparent. Since 1981 there has been a revival of interest in exploration reflection profiling west of Scotland, although this has naturally been concentrated in the basin areas of the Minches, Sea of the Hebrides, and west of Orkney. Several of these lines have been shot to 15 *s*, and one, shot by Merlin Profilers in collaboration with BGS, has been recorded and processed, like DRUM, to 30 *s*. The result of all this activity is that one crucial area of the foreland (in deep reflection terms) NE of Lewis now has no less than six 15 or 30 *s* profiles crossing it.

Regional geology

WINCH and MOIST describe a complete traverse running from the western margin of the Caledonian orogen along the north coast of Scotland into the foreland west of the Outer

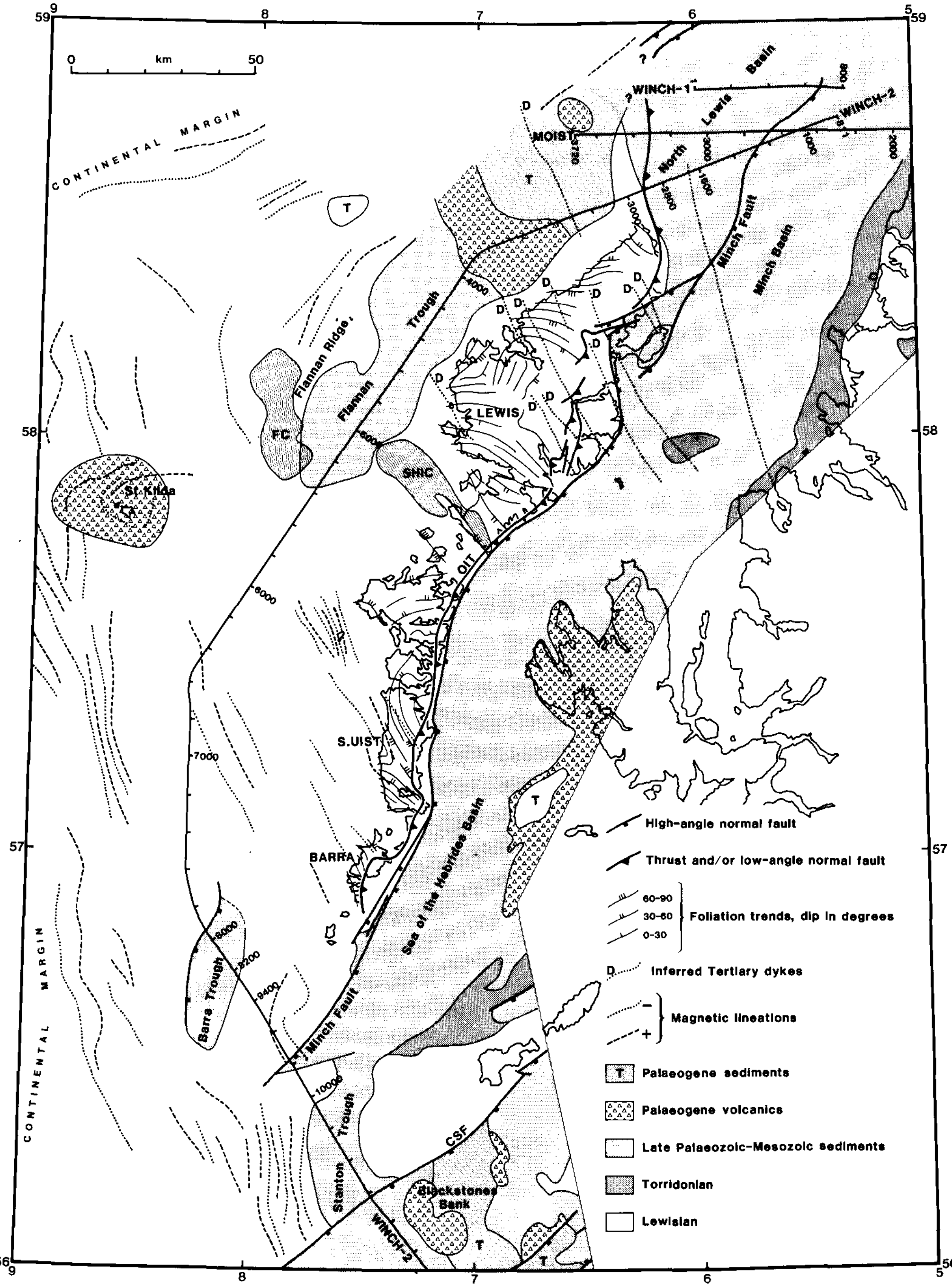

FIG. 2. Geology of the foreland relevant to the interpretation of deep reflection profiles. Foliation trends on the Outer Hebrides are taken from unpublished BGS tectonic maps. SHIC—South Harris igneous complex. FC—'Flannan complex' of high-amplitude magnetic anomalies. OIT—Outer Isles thrust. CSF—Camasunary–Skerryvore fault. Note how the throw of the Minch fault decreases to zero north and south of the Outer Hebrides (see text).

Hebrides (Fig. 1), crossing the boundary of the orogen again off the SW coast of Scotland near the island of Islay.

Figure 2 is a new compilation of the geology of the foreland region. It is based on interpretation of the BIRPS and commercial reflection data, and commercial, BGS and Hydrographic Office aeromagnetic and gravity surveys. Further details of these data are given in Brewer & Smythe (1986).

The Caledonian foreland is a complex of gneisses and granulites incorporating metasediments, metavolcanics and metamorphosed layered basic and anorthositic bodies, with various granites and pegmatites that constitute Lewisian basement rocks (see Watson 1975, for a review). The earliest recognizable structure (ductile shear zones, sometimes associated with gravity anomalies), generally characterized by a NNE grain, were established before the end of the Scourian episode (*c.* 2700 Ma). Tectonic and metamorphic activity continued intermittently until about 1600 Ma. The later phases, the Laxfordian deformation, created narrow NW–SE zones of strong deformation between blocks, within which pre-Laxfordian features are less severely modified. Granites and pegmatites were emplaced ubiquitously during the late stages of Laxfordian activity, accompanied by retrogression to amphibolite facies of granulites formed in earlier Laxfordian or Scourian episodes.

The Caledonian foreland is bounded to the west by the passive continental margin of the Rockall Trough (Fig. 1), a major rift formed during the early phases of opening of the North Atlantic.

Foreland Lewisian is overlain by two cover sequences: (1) the Torridonian, consisting of sandstones and conglomerates (1100–1040 Ma; Smith *et al.* 1983) thought to have been laid down in an extensional, block-faulted environment (Stewart 1982), and (2) Cambrian–Ordovician quartzites and carbonates thought to have been laid down in shallow, subtidal conditions on a continental shelf bounding the western margin of the 'proto-Atlantic' (Swett & Smit 1972).

To the east of the foreland lies the Caledonian orogen. On land, the orogenic front is defined by the Moine Thrust zone (Fig. 1). Proterozoic metasediments (originally mainly shallow marine or lacustrine sands or shales) of the Moine succession lie above this zone, and moved westward over the foreland an unknown distance during the late episodes (Silurian–Devonian) of the Caledonian orogeny (see the discussions in Watson & Dunning 1979, and Brewer & Smythe 1984).

The Moine Thrust is the structurally highest thrust of the Moine Thrust zone, and the zone itself consists of the intensely imbricated shelf sequence, including thrust slices of Lewisian and Torridonian, which were stripped off the autochthonous basement.

Lewisian-type inliers occur in the Moine schists either as basement onto which some of the Moines were laid down, or as thrust slices (Watson 1975). One of the key problems is the extent of foreland Lewisian basement under the orogen. Although estimates of the amount of shortening along individual thrusts range up to 60–70 km (Elliott & Johnson 1980), gravity and magnetic signatures suggest that autochthonous basement may only extend 20–30 km east of the Moine Thrust zone (Watson & Dunning 1979, p 73). Two groups of ideas have evolved, both based on surface mapping and on the interpretation of velocities obtained from the LISPB regional refraction survey (Bamford *et al.* 1978). Elliott and Johnson consider that the imbricated Cambrian–Ordovician succession under the Moine Thrust can be palinspastically restored. They suggest that up to 100 km of shortening has occurred in the region of the Assynt window. This implies that very gently-sloping foreland basement once extended this far east under the orogen. Thin-skinned models for the Moine Thrust zone have also been proposed by Coward (1980) and Butler & Coward (1984).

In contrast, a thick-skinned model has been postulated by Soper & Barber (1982), who consider that the thrust zone cuts through the crust at up to 45°, flattening out at the Moho. Blundell *et al.* (1985) have modified Soper & Barber's model to be compatible with the MOIST profile, which they have modelled with a synthetic seismogram. They show how the foreland is likely to have been cut by large, discrete thrusts propagating succesively deeper and farther west, as a consequence of the lower geothermal gradient there during the Caledonian orogeny, compared with the orogen.

Thrust faulting was apparently the only major effect of the Caledonian orogeny on the foreland. One major structure, which was compiled from earlier mapping and named the Outer Isles Thrust by Dearnley (1962), but is also known as the Outer Hebrides Fault (Sibson 1975, 1977) is subparallel to the Moine Thrust, and therefore assumed to be of Caledonian age, although it can only be said with certainty to be post-Laxfordian.

After the Caledonian orogeny the areas of the orogen and foreland which now lie offshore were subject to extension associated with the opening of the North Atlantic. Basins such as the Flannan Trough and Minch Basin were filled with Permo–Triassic and younger sediments. The general trend of these basins shows that their structure was controlled by the underlying Caledonian framework. The MOIST profile showed in detail that many of these basins formed by extensional reactivation of Caledonian thrusts (Smythe *et al.* 1982). In many areas, though, the sedimentary rocks in the deepest parts of the basins are undated, and it is possible that some of the basins are immediately post-orogenic (*ie* Devonian) in age. Some are probably as old as Torridonian (*c.* 1000 Ma); this is discussed below.

Other geophysical studies

Northern Scotland and the Scottish continental shelf have been the subject of many seismic studies on both regional and local scales, partly because of the extensive exposures of Precambrian basement, and the opportunity it allows to study rocks from deep within the crust. The regional refraction studies (LISPB, NASP and HMSE; see Fig. 1) have proved useful for locating the Moho (the crust–mantle boundary) whereas the local studies show velocity variations in the upper part of the crust possibly explicable in terms of varying basement geology. These refraction experiments are reviewed by Hall (this volume). However, the structure of the mid-crust, in particular along the boundary zone of the orogen, is not well understood.

Crustal structure of the foreland

The foreland is considered to extend as far to the SE as the Loch Skerrols Thrust (Fig. 1), which has long been thought to be the southwesterly extension of the Moine Thrust (Bailey 1917). The Loch Skerrols Thrust appears to mark a major sub-vertical offset of Lewisian basement (Westbrook & Borradaile 1978), and therefore may also mark the orogenic front to the Caledonian orogen.

The Outer Isles Thrust

The fault known on the Outer Hebrides as the Outer Isles Thrust (Dearnley 1962) was originally interpreted offshore, using commercial seismic reflection data, as a sequence of reflectors dipping at about 25° from the seabed north of Lewis into the lower crust (Smythe 1980). It was subsequently identified on MOIST (Smythe *et al.* 1982) and WINCH (Brewer *et al.* 1983), and traced into the lower crust. Figure 3 shows a newly-migrated version of WINCH-1, on which the thrust is clearly visible. It can be traced from WINCH and MOIST onto commercial seismic data, to within 4–5 km of the position of the fault onshore (Fig. 4*a*). However, on the offshore data the only demonstrable offset on the fault is extensional, as shown by the formation of the major half-grabens. All the evidence of thrusting comes from onshore studies, suggesting that the normal faulting observed offshore must be simply a reactivation of the pre-existing thrust. Since Wernicke *et al.* (1985) and Wernicke (1986) have questioned this prior existence of the normal fault as a thrust, it is worth summarizing the evidence in support of thrust movements. It includes: (1) a thick (up to 1 km) sequence of mylonites, pseudotachylites and cataclastic rocks, more commonly seen around thrusts than around normal faults. (2) a schistosity developed in the ductile shear zones which intensifies and curves in from the margins to the centre in a thrust sense. (3) the presence in the hanging wall of granulite facies rocks, of higher metamorphic grade (and therefore presumably originating from greater depths) than the amphibolite facies rocks which make up the footwall. (4) a shallow ($\sim 25°$) dip of the fault zone at the surface. See, however, White & Glasser (this vol.). Later dip-slip movement is indicated by a fairly ubiquitous series of late stage, asymmetric crenulations and chevron folds with consistent down-dip vergence (Sibson 1977).

Furthermore, if the Outer Isles fault feature mapped onshore were just the exposed plane of a low-angle normal fault, it would imply that the Minch-Sea of the Hebrides Basin (Fig. 2) once extended some way to the west over the Outer Hebrides, burying the present-day outcrop to a depth of several kilometres. There is no evidence for such a hypothetical burial and re-exhumation of the Outer Hebrides, which would have to have occurred in late Jurassic–Cretaceous time.

The age of the fault rocks is uncertain. They are definitely post-Laxfordian (they cut host rocks of this age), but the only radiometric investigations are whole-rock K–Ar experiments on micaceous mylonites which gave late Caledonian ages (see the discussion by R. H. Sibson in Steel & Wilson 1975).

The Outer Isles Thrust is conventionally regarded as of Caledonian age, but there is indirect evidence from offshore reflection interpretation that it may be of Grenville age. Williams (1969) interpreted the late Torridonian (Torridon Group) of NW Scotland as a piedmont fan deposit, with the source area of the retreating mountain front in the region of the present-day Minch Basin and Lewis. Extrapolation westwards of the mainland Torridonian outcrop below the Minches (Chesher *et al.* 1983), combined with the re-interpretation of earlier gravity modelling (Smythe *et al.* 1972), suggests that the basal part of the half-graben infill of the Minch and North

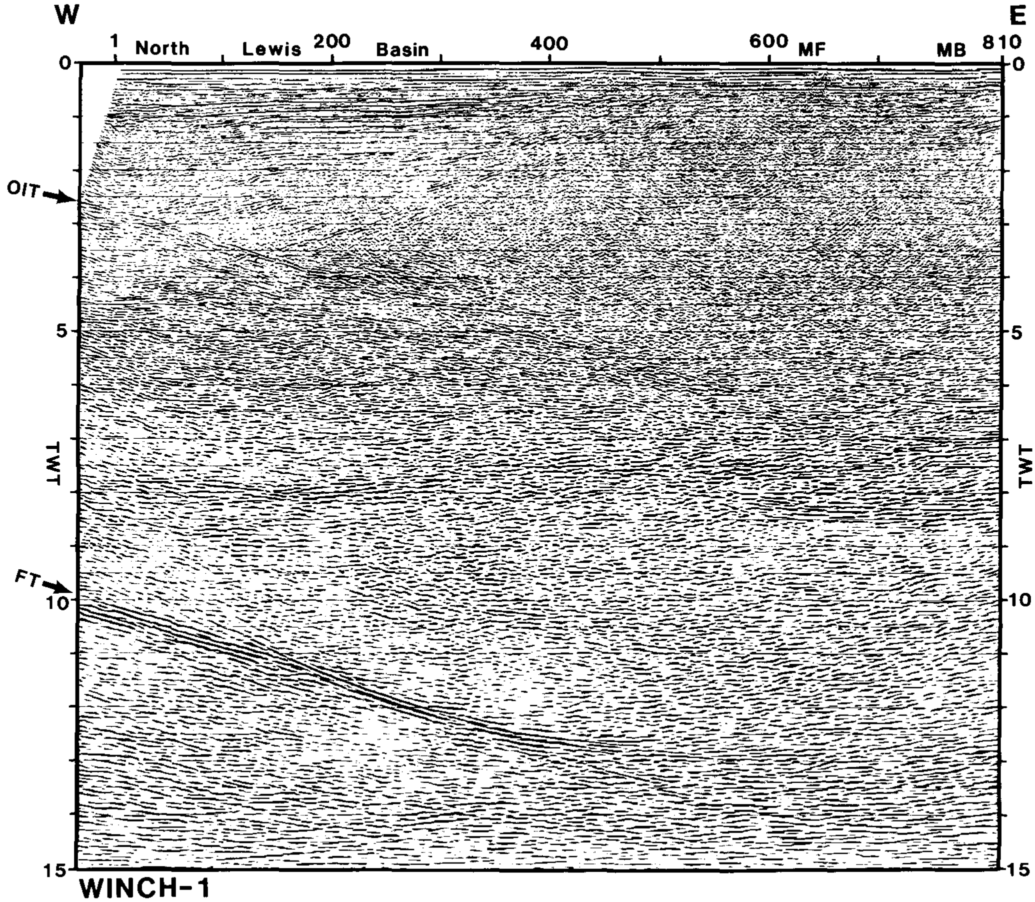

FIG. 3. WINCH-1 30-fold migrated section. Migration was done in the F–K domain using a 1-dimensional velocity function. 100 SP = 5 km. Processing through stack by GECO for BIRPS, 1982; post-stack migration and display by Western Geophysical for BGS, 1985. OIT—Outer Isles thrust. FT—Flannan thrust. MF—Minch fault. MB—Minch basin. To convert two-way time in seconds to approximate depth in kilometres, multiply by 3. Note that the Minch basin has almost died out this far north, and that upper crustal extension is taken up in the North Lewis basin, which directly overlies the Outer Isles thrust.

Lewis Basins is of Torridonian age, lying in the hanging wall of the Outer Isles Thrust. Given the palaeogeographic setting of these rocks, it is reasonable, firstly, that the fault now bounding the prism of sediment was the main normal fault active at *c.* 1000 Ma, controlling the deposition of the fan deposits. Secondly, and more speculatively, if the Outer Isles Thrust was active then as a normal fault, it may have been a reactivated thrust fault, originating in, say, Grenville time, *c.* 1100–1200 Ma.

The first part of this interpretation is now strongly corroborated by new (1985) commercial seismic reflection data in the Sea of the Hebrides (Kilenyi & Standley 1985), where a thick prism of Torridonian (dated by offshore sampling and by tying along strike to the Isle of Rhum) can now be clearly seen to be faulted on its western flank by the Minch Fault (the reactivated Outer Isles Thrust; see also Kilenyi & Standley 1985, Fig. 4). The Torridonian wedge is locally more than 6 km thick, making it rather unlikely that the fault which now truncates it on the west was simply a posthumous, as opposed to a syn-rift, fault.

Peddy (1984) has proposed, from reflection seismogram modelling of WINCH-1, that the Outer Isles Thrust does not flatten out near the base of the crust, as conventional stacked record sections or time migrations of them (such as Fig. 3) suggest. The crustal model used as the basis for the seismogram modelling has the thrust cutting the Moho near the eastern end of the line. Although the Moho is correctly offset at the place

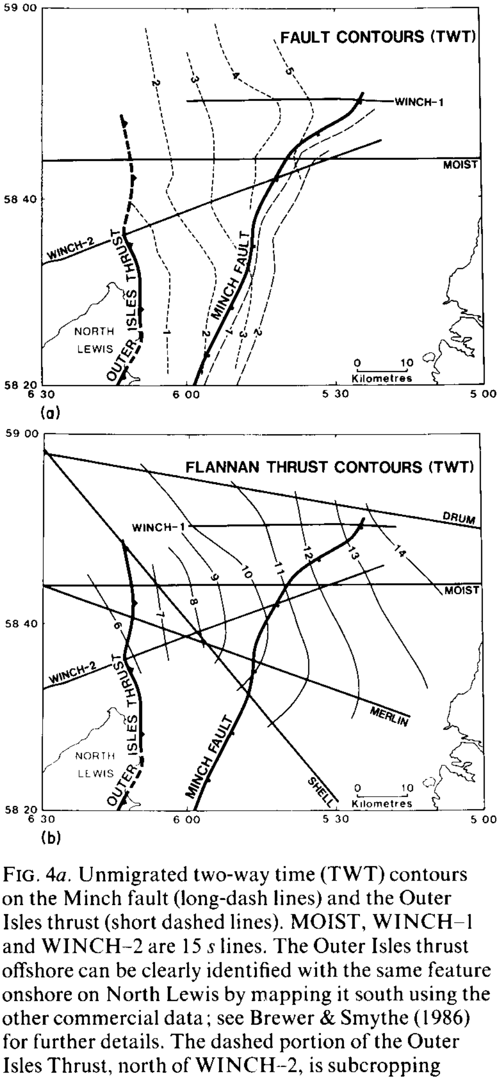

FIG. 4*a*. Unmigrated two-way time (TWT) contours on the Minch fault (long-dash lines) and the Outer Isles thrust (short dashed lines). MOIST, WINCH-1 and WINCH-2 are 15 *s* lines. The Outer Isles thrust offshore can be clearly identified with the same feature onshore on North Lewis by mapping it south using the other commercial data; see Brewer & Smythe (1986) for further details. The dashed portion of the Outer Isles Thrust, north of WINCH-2, is subcropping below sediments which overstep the fault to the west, hence the intersection of the fault trace with the 1 *s* contour.

FIG. 4*b*. Unmigrated two-way time (TWT) contours on the Flannan thrust, based on MOIST, WINCH-1 and WINCH-2 (Brewer and Smythe 1986), but also using the new 30 *s* DRUM line and a proprietary Shell line (McGeary & Warner 1985), together with a new Merlin Profilers 30 *s* line shot and processed in collaboration with BGS.

predicted by the synthetic seismogram, near the eastern end of the line (see Fig. 3), the new DRUM line (Fig. 1) does not show any sign of the thrust continuing in the mantle farther east (McGeary & Warner 1985), as might be expected from Peddy's hypothesis. Both alternatives—flattening out in the lower crust, or cutting through the Moho—would appear to remain plausible at present.

Crustal reflection character

Most of the Lewisian basement crossed by WINCH is devoid of significant cover rocks, and the upper part of the crust (to 3–4 *s*, or 9–12 km depth) is remarkably featureless and transparent, at least on the scale of the wavelengths used in seismic surveys. However, full seismic coverage is achieved only below 3 *s*, and thus it is conceivable that the transparent upper crust simply is due to the incomplete coverage above this travel time.

Notwithstanding the acoustic imaging problems, it is probably a valid generalization (based on observations from all the various processing stages of the reflection data) that the upper crust in the Caledonian foreland is largely transparent to seismic energy in the frequency spectrum 10–50 Hz. The NW–SE trending shear zones associated with Laxfordian deformation (Watson 1975, 1977; see Fig. 2) have not been acoustically detected, at least in the upper crust.

In contrast to the upper crust, the lower crust is highly reflective between about 4 and 8–9 *s* (about 12–30 km depth). Figure 5 shows a sample of WINCH data from west of Lewis, at the intersection with HMSE (Fig. 1). Bands of discontinuous (up to 5–10 km long) antiformal reflections (some of which may be off-line), subhorizontal and apparently north-dipping reflections and diffractions make up the lower crustal reflection sequence. Reflector density is somewhat variable. The Moho appears as a discontinuous reflector or band of reflectors between 8 and 9 *s* (26–29 km depth) at the base of the lower crustal layer.

The reflection character of the Lewisian foreland is quite different from the character of the foreland to the Appalachian and Ouachita mountain belts, where they have been crossed by three COCORP profiles (Ando *et al.* 1983; Cook *et al.* 1979, 1981; Nelson *et al.* 1982). The Grenville age foreland basement in all these areas is essentially devoid of internal reflecting horizons, and in most areas there is no clear Moho reflection. If a seismically transparent crust is indeed characteristic of the Grenville province then the position of the Grenville front under Scotland might be detectable on this basis.

The Moho and upper mantle

On much of MOIST and DRUM there is a sharp, high-amplitude Moho, but no strongly reflective

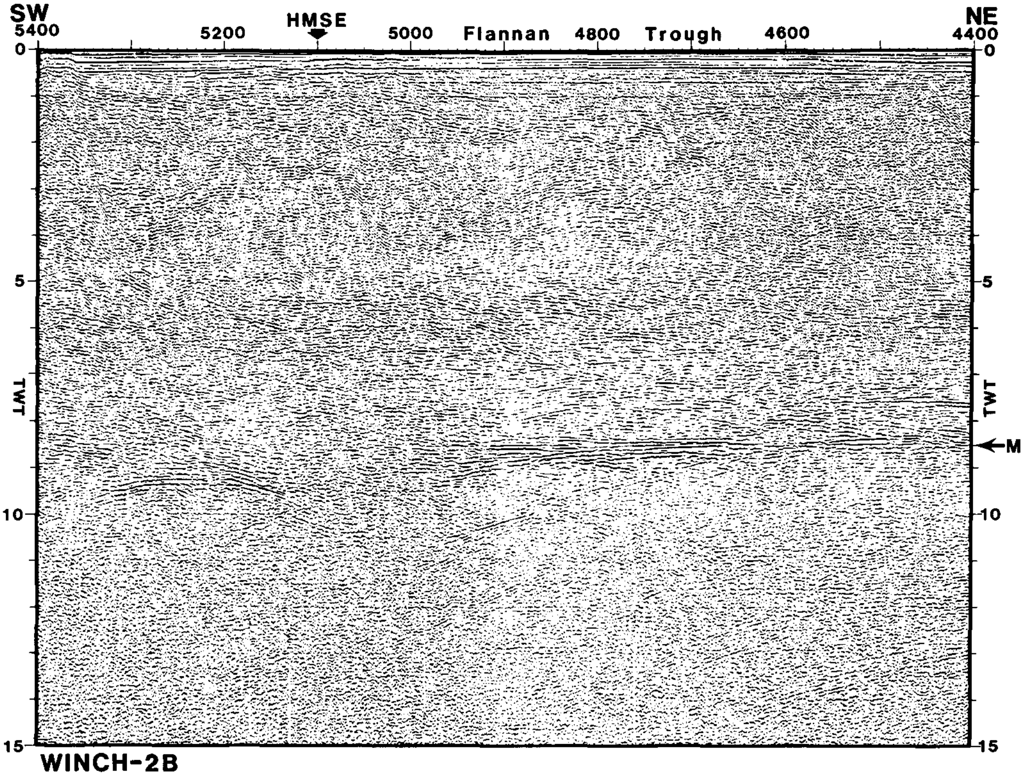

FIG. 5. Part of WINCH-2B (7.5–20 Hz bandpass display) over the foreland NW of Harris (Fig. 2). Gently N-dipping reflectors at 0–2 *s* are from within or just below the Flannan Trough, one of the few areas where upper crustal reflectors occur. The upper crust beneath (2–5 *s*) shows only incoherent reflections and diffractions, whereas the lower crust (5–8 *s*) is more reflective. The Moho band of reflections at around 8.4–9 *s* correlates well with the refraction-defined Moho on HMSE.

lower crust, whereas on WINCH a reflective lower crust occurs with a less well-defined Moho beneath. Jacob & Booth (1977) also inferred a sharp Moho boundary, based on a wide-angle seismic experiment which recorded good PS reflections east of the Outer Isles thrust. This result is consistent with the sharp Moho seen on MOIST and DRUM.

The Moho reflection differences between MOIST, DRUM and WINCH are not simply explicable by different processing parameters. Rather surprisingly, the travel time of the Moho reflection does not vary significantly with variations in upper crustal velocity structure. The most obvious example of this occurs under the North Lewis basin, where considerable velocity pull-down would be expected, but is not seen (Fig. 3).

The Flannan Thrust (Smythe *et al.* 1982) was interpreted as a thrust because it has a similar reflection character, and a similar geometry and Caledonian trend to the Outer Isles Thrust (Fig. 3). However, no definite structural offsets have been identified across it, so this must remain a working hypothesis. The thrust dips easterly at 25–30° (from depth migration of line drawings), subparallel to the Outer Isles thrust, from at least 14 *s* (about 45 km depth) and passes updip through the Moho, which is not clearly offset. The 3-dimensional control on the geometry of the thrust is now constrained by no less than six seismic reflection lines shot to 15 or 30 *s* (Fig. 4*b*). It can also be traced down-dip right along the length of DRUM (Fig. 1), on which it can be seen at a depth of about 90 km at its eastern end (McGeary & Warner 1985). The possible continuation of the Flannan Thrust south of the Hebrides is seen on the WINCH line in that area (Brewer *et al.* 1983, Brewer & Smythe 1986), and also on a new Merlin Profilers proprietary 15 *s* line. It is apparently linked to an extensive upper mantle reflector (see Hall *et al.* 1984, for further discussion).

Lewisian basement beneath the orogen

The Moine Thrust has been interpreted as one of the series of pronounced easterly and south-easterly dipping (20°–25° migrated dip) reflections which characterize the eastern 60 km of the MOIST line (Fig. 1), and which give the upper and middle crust under the orogen a very different seismic character from that of the foreland. These reflections flatten or die out at around 17–20 km depth, and close to the surface are either directly overlain by westerly-dipping ?Devonian and Permo–Triassic sedimentary rocks occurring in half-grabens, or pass into acoustically transparent ('blank') zones beneath the half-grabens. Figure 6 shows a piece of a newly reprocessed and migrated segment of MOIST from the margin of the orogen offshore (Fig. 1), on which the easterly-dipping reflectors can be seen to be truncated against the overlying westerly-dipping reflectors. The easterly-dipping reflections can be mapped along strike on commercial seismic lines (Brewer & Smythe 1984). These authors have argued that the lozenge-shaped packages of easterly-dipping reflectors, within some of which the seismic layering is rather planar, could represent Moinian rocks above the thrust zone. Alternatively (their preferred interpretation), they may originate from an offshelf sequence of metasediments (of uncertain origin), imbricated with the underlying basement and stacked up against the undeformed Lewisian shelf edge. The Moine Thrust zone would then be a structurally higher thrust.

In neither of Brewer & Smythe's alternatives are the easterly-dipping reflectors part of the Lewisian foreland. However, Butler and Coward (1984) have proposed a reinterpretation of the MOIST data, in which the easterly-dipping reflectors are due to imbrication of Lewisian foreland in a crustal-scale duplex, below a large culmination in the Moine Thrust zone. Offshore, in the area of MOIST, the Caledonian cover and the thrust zone have been stripped off, so that the two sequences of westerly and easterly-dipping reflectors (Fig. 6) represent, respectively, the Devonian to Triassic sediments, and imbricated foreland beneath.

Resolution of the problem of how far the Lewisian foreland extends—'Caledonised' or not—below the orogen requires a reinterpretation of the offshore data, including that obtained recently. It will be especially desirable to link the west Orkney and northern Scottish mainland area to Shetland, where the equivalent of the Moine Thrust zone has been successfully taken offshore to the SW on to recent commercial reflection lines there (Andrews 1985).

Conclusions

Deep seismic reflection profiles across the Caledonian foreland demonstrate that: (1) the upper

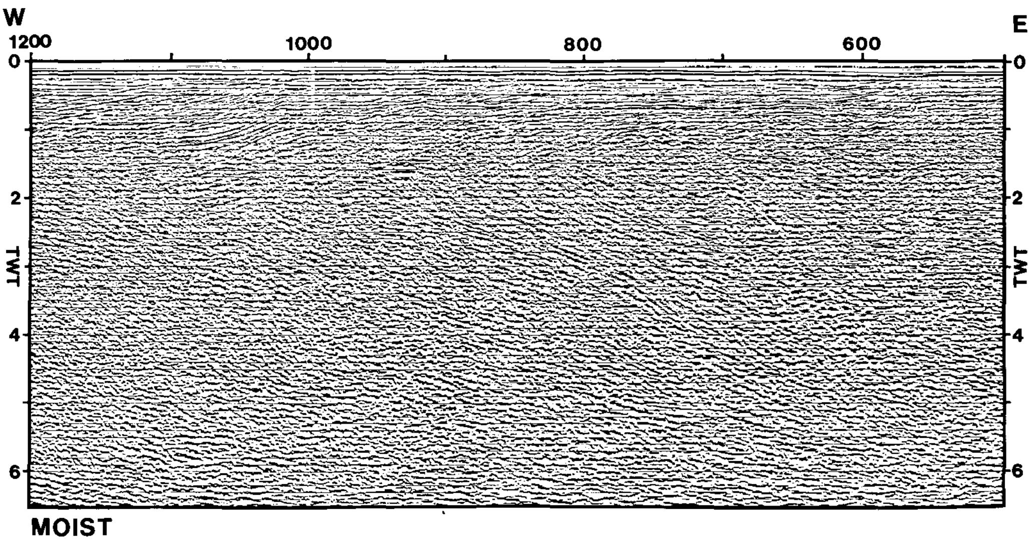

FIG. 6. New, migrated version of part of MOIST, reprocessed for BGS by Western Geophysical, 1985. It shows the easterly-dipping reflectors of the mid-crust at the margin of the orogen (Fig. 1) truncated by the overlying west-dipping Devonian to Triassic age sediments. The easterly-dipping reflectors could be from imbricated Caledonian cover rocks (Brewer & Smythe 1984), or else represent imbricated Lewisian foreland, with no Caledonian cover present in this area offshore (Butler & Coward 1984).

crust is largely acoustically transparent, and little evidence of the trace of Precambrian structures is seen. (2) in contrast, the lower crust is acoustically highly reflective, and in some areas of the Hebridean shelf contains structures whose trends are possibly of Caledonian or Scourian age. (3) the crustal reflection character of the foreland to the Caledonides differs from the areas of the foreland to the Appalachians studied with COCORP data, where Grenville crust is largely non-reflective. (4) the Moho is a fairly continuous reflector or group of reflectors, and is remarkably uniform in travel time, at about 8.5 *s* (≡27 km) below the foreland. It is apparently not significantly offset under the North Lewis and Minch basins, nor under the Outer Isles Thrust. (5) some of the basins on the Hebridean shelf are half-grabens formed by extensional reorientation of Caledonian thrusts. Conversely, where these thrusts do not exist, the shelf remained largely unaffected by extension. (6) the western margin of the orogen contains reflection sequences whose geometry is remarkably similar to those observed on parts of COCORP profiles recorded in the northern and southern Appalachians. The Lewisian foreland of NW Scotland probably does not continue eastwards below the Caledonian overthrust belt for more than 20–30 km east of the Moine Thrust zone.

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