

Tertiary sediments in the Sea of the Hebrides

DAVID K. SMYTHE & NICHOLAS KENOLTY

SUMMARY

Marine geophysical surveys in the Sea of the Hebrides show that there are several basins containing sediments up to 1 km in thickness resting on the offshore extensions of the Palaeocene–Eocene lava piles of Skye and Mull. Close geological and geophysical similarities with the Lough Neagh Clays of Northern Ireland suggest that the sediments are argillaceous deposits of probable Oligocene age;

rocks of this age do not occur onshore in W Scotland. The early Tertiary history of the inner continental shelf now closely resembles that of the continental margin and Rockall trough, where an important Eocene–Oligocene unconformity preceded rapid Oligocene subsidence. South-west of Mull the main branch of the Great Glen fault downthrows the Tertiary to the SE. by about 0.5 km.

SUPPLEMENTARY Publication No. SUP 18007 (3 pages), deposited with the British Library at Boston Spa, Yorkshire, U.K. contains a summary of previous research in the area and technical details of the surveys described below. The earlier interpretation (McQuillin & Binns 1973; Binns *et al.* 1974) of a Mesozoic sedimentary infill up to 2.5 km thick beneath the Sea of the Hebrides is substantially correct; however, in the area 10–15 km NW of Canna there is crucial evidence concerning the age of the infill.

1. NW Canna area

Surveys (Fig. 1)

Navigational methods and corrections are described in SUP 18007. The irregular shallow sea-bed reflector between shot points (SPs) 1 and 15 (Fig. 1B) is the outcrop of the Tertiary lavas of the Canna ridge, which forms a pronounced bathymetric and magnetic feature extending 60 km SW from Skye. Between SPs 15 and 50 reflectors from the lavas and underlying Mesozoic sediments appear to be synclinally folded beneath shallow horizontal reflectors, and the presumed top-lava reflector crops out again on the sea bed around SP 55, at a narrow bathymetric ridge, from which fragments of basalt have been recovered. Thus in the centre of the basin, at about SP 35, there are about 400 ms of folded sediments between the lowermost horizontal reflector at about 400 ms and the probable top-lava reflector at about 800 ms.

The sparker record of line 2 (Fig. 1C) shows well-bedded folded sediments unconformable below thick Quaternary. The magnetic profile suggests that the highly magnetic lavas are present at depth between fixes 26 and 29. On line 3 (Fig. 1D) the thin layer above the downfolded top-lava reflector between fixes 52.5 and 54 is probably Quaternary. Lines 1–3, taken together, show that the basin axis trends NE–SW, and plunges NE between lines 2 and 3. The basin is absent on line 4 (Fig. 1E). Here the Canna ridge lavas end in a sea-floor scarp at fix 18.2, below which there are well-bedded sediments. The magnetic ridge

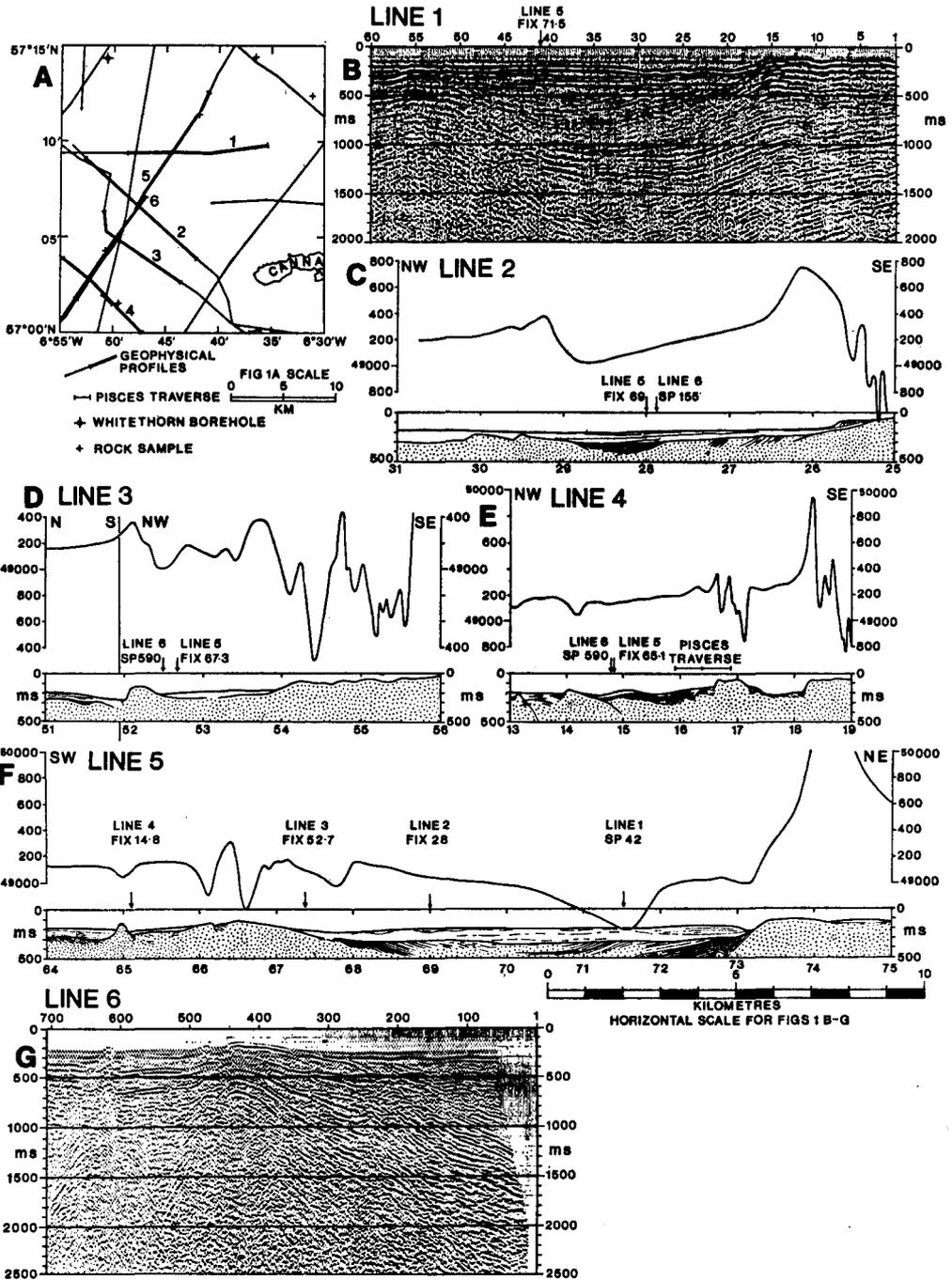


FIG. 1. Marine surveys NW of Canna. A, Location of survey lines and samples; bold sections of lines indicate those parts shown in 1B-G. B, Line 1, a 24-fold stacked seismic section (shot by Forest Petroleum UK Ltd in 1972). C-F, Lines 2-5 respectively; upper part of each shows magnetic profile in gammas observed at sea level; lower parts are line drawings of 1000J sparker records. G, Line 6, a 12-fold stacked seismic section shot along part of line 5. Vertical scales on seismic and sparker sections are in milliseconds of two-way time; shotpoints on former and fix marks on latter are shown for reference; arrows denote position of line-ties.

between fixes 16.6 and 17.2 has been traversed and sampled by the submersible Vickers 'Pisces' (Eden *et al.* 1971); it is an outlier of basalts resting on Mesozoic sediments, which can be seen on the sparker record. The small ridge at fix 14 is probably a dyke, trending at a low angle to the profile.

Line 5 (Fig. 1F) trends NE-SW along the axis of the basin and suggests that well-bedded folded sediments, below thick near-transparent Quaternary, rest on Tertiary lavas. The NE end of line 6 (Fig. 1G) roughly coincides with part of line 5, and is shown in Fig. 1 in its correct relative horizontal position below the former. Line 6 is a 12-fold stack deep seismic section, shot and processed by Seismograph Service Ltd. for the Institute of Geological Sciences. The strong reflector at the NE end of the line at about 1200 ms is probably the top of the lavas, and underlies up to 800 ms of seismically transparent sediments between it and the base-Quaternary reflector at about 350 ms. This transparency is uncharacteristic of Hebridean Mesozoic sediments, and is probably not a spurious effect of processing, since independent re-processing resulted in a similar section.

Interpretation

Interval velocities were obtained for three shot-points on line 1 from the cross-correlograms used to determine stacking velocities. That at SP 38, of good quality, shows an interval velocity of 4.1 km/s at depth, which probably corresponds to lavas. The correlograms for SPs 53 and 13 are of poor quality; an interval velocity of 3.0 km/s on the former probably corresponds to thin lavas and Mesozoic sediments together, and that of 3.6 km/s on the latter to rather thicker lavas with some underlying Mesozoic sediments, the base-lava reflector being absent in both cases. The velocities for line 6, obtained from a moveout scan over SPs 86-106 are more reliable; an interval velocity of 4.2 km/s corresponds to the lavas at depth. The layers immediately overlying the lavas on line 1 at SP 38 and line 6 at around SP 100 have interval velocities of 2.1 km/s and 2.25 km/s respectively. These figures are higher than what one would expect of Plio-Pleistocene clays—the only feasible alternative interpretation to Tertiary sediments. The corresponding thickness of over 800 m of the formation in the centre of the basin, with an angular unconformity of up to 25° below the flat-lying Quaternary, makes a Plio-Pleistocene age very unlikely, so the sediments are thus interpreted as post-Eocene, pre-Quaternary in age. Interpretation and compilation of data shown in Fig. 1 results in the geological map of Fig. 2A, which shows a narrow deep trough of sediments resting on the lavas of the Canna ridge. The isochrons on the base of these sediments are schematic, but with an assumed velocity of 2.0 km/s indicate the approximate depth and shape of the trough in metres. This map is consistent with the Bouguer anomaly gravity of the area (Binns *et al.* 1974) which shows a steep gradient of up to 5 mgal/km along the NW outcrop of the lavas. The NW limit of the lavas is characterized by a linear positive aeromagnetic anomaly (Bullerwell 1972), from tests by two-dimensional modelling. Thus the lavas are continuous below the postulated Tertiary sedimentary basin. The geological interpretation of line 1 is shown in Fig. 2B, seismic interval velocities discussed above being used to convert two-way time to depth.

The presence of this Tertiary basin fills a local gap in the geological history of

the Tertiary igneous province, whose record is more complete in Antrim. The similarity with the Lough Neagh Clays, of probable early- or mid-Oligocene age (Wilson 1972, p. 80) is very close: both areas lie in the centre of structural (and probably depositional) basins which have been intermittently active since Permo-Triassic times. At both localities Eocene lavas overstep Mesozoic sediments previously folded about a NE-SW axis, and themselves are overstepped by Tertiary sediments, which in the case of the Lough Neagh Clays come to rest directly on Mesozoic rocks (George 1967, figs. 4, 5). The area of outcrop of the

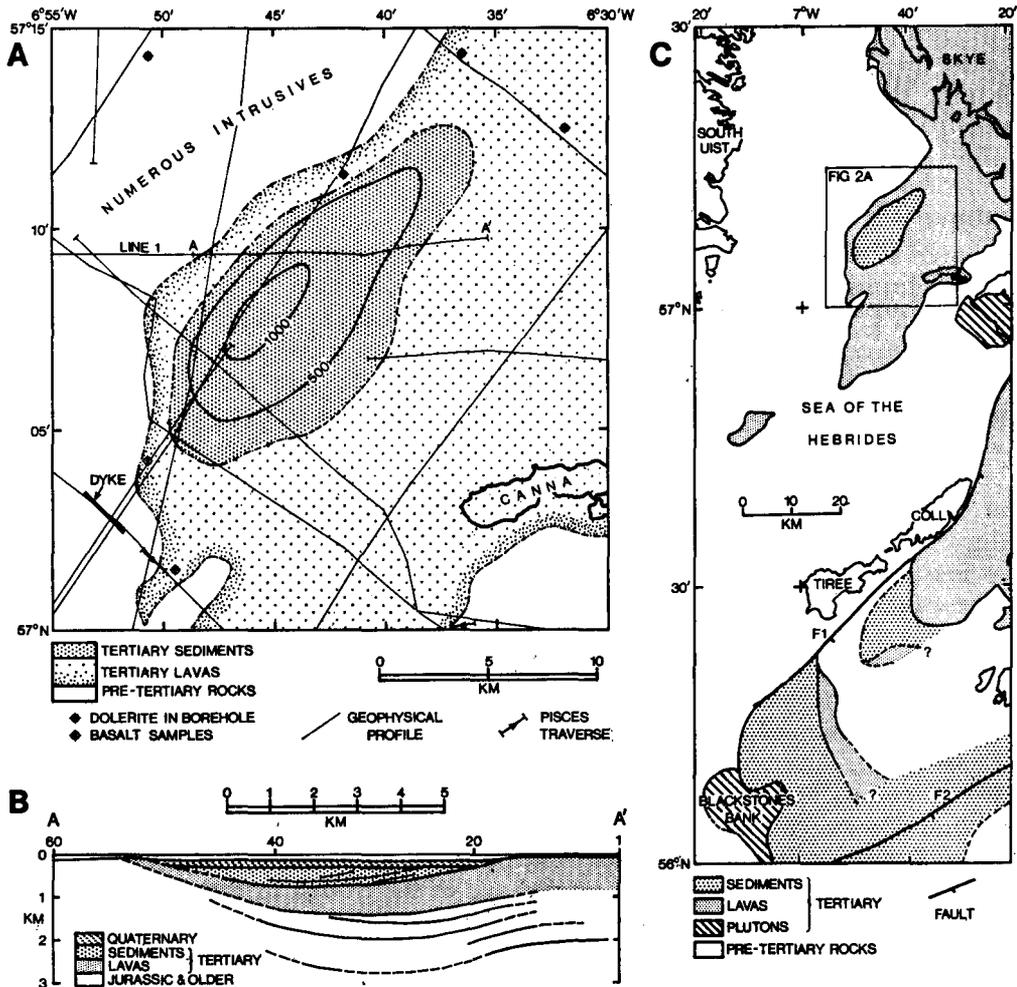


FIG. 2. A, Solid geology of NW Canina area. Geological boundaries: solid line—observed; dot-dashed—interpolated along bathymetric contours; dashed—uncertain. Contours on base of Tertiary sediments are in milliseconds of total two-way time. B, Section along A-A' on line 1, depth-converted using the interval velocities discussed in text. No vertical exaggeration. C, Tertiary rocks in the Sea of the Hebrides. F1—Camasunary-Skerryvore fault; F2—Great Glen fault.

NW Canna basin is less than half that of its Antrim counterpart, probably due to deeper glacial erosion of the former. Interbasaltic sediments on Canna are found to contain granophyre pebbles from the Western Granite of Rhum (Emeleus 1973) so that a great deal of erosion had already taken place by the early Tertiary, and the Canna area was a site of deposition of both sediments and basalts. The tilting to the E and the erosion of the Mesozoic sediments before deposition of lavas overstepping them to the W (Fig. 2B) is a local sequence of events identical to that at Neist Point, 30 km to the N on NW Skye (Anderson & Dunham 1966; 1" IGS sheet 'Northern Skye'). The thickness of about 1 km of sediments in the NW Canna basin is greater than the maximum recorded thickness of 350 m for the Lough Neagh Clays observed in a borehole at Washing Bay (Wilson 1972, p. 79). Since that borehole was near the edge of the clays outcrop, and the Bouguer anomaly map (Bullerwell 1967) shows marginal gradients of up to 5 mgal/km and wavelengths similar to those of NW Canna, the clays may well be up to 1 km thick beneath the Lough. Using the Nafe-Drake curve, a density of 2.0–2.1 g/cm³ can be inferred for the NW Canna Tertiary sediments from their P-wave velocity, which falls in the range 2.1–2.3 km/s. This density is close to that of the Lough Neagh Clays, viz. 2.10 g/cm³. Therefore since the two Tertiary sedimentary basins are very similar to each other in geological structure and physical properties, it seems likely that the NW Canna Tertiary sediments also comprise lignitic and sandy clays, laid down in a lacustrine or fluvial environment from the products of erosion of a variety of local rocks, and are probably also Oligocene in age.

2. Southern Sea of the Hebrides

The discovery of a substantial thickness of post-Eocene Tertiary sediments has led us to re-examine the existing geophysical records for the Sea of the Hebrides. In the absence of direct sample data, and where Palaeocene–Eocene lavas do not necessarily intervene, Tertiary sediments may be distinguished from Mesozoic sediments by a sufficiency of the following criteria: (a) interval velocities in the range 2.0–2.4 km/s, in contrast to the P-wave velocities of 2.5–3.5 km/s; (b) strong even reflectors observed on sparker records, with a corresponding absence of reflectors, or 'transparency,' on deep seismic records; (c) localized large negative Bouguer anomalies with steep gradients, implying the presence of near surface low density rocks; (d) absence of dykes and sills intruding the sediments of suspected post-Eocene age. Tertiary sediments are likely to have physical properties similar to those of Quaternary sediments, so that recognition of the Tertiary must additionally depend upon the existence of either: (e) a marked angular unconformity with overlying younger sediments, or (f) folding (with dips of at least 10°) and faulting of a sequence too thick to be Quaternary—say 800 m or more. Similar criteria have been successfully used in the S Irish Sea to discriminate between Mesozoic, Palaeogene and Neogene–Recent sediments (Blundell *et al.* 1971, Dobson *et al.* 1973) before the availability of extensive offshore sample evidence.

The areas which satisfy the above criteria in the Sea of the Hebrides are shown

in Fig. 2C. 500 m or more of Tertiary sediments are preserved in the Inner Hebrides trough below 200 m of Quaternary, on the downthrown side of the Camasunary-Skerryvore fault (Fig. 2C), and are probably underlain by lavas, which appear to wedge out westwards. To the SW the throw of the fault diminishes to zero, and the Tertiary sediments overstep Mesozoic sediments onto the N and E flanks of the Blackstones plutonic centre (McQuillin *et al.*, in press).

The Great Glen fault (Fig. 2C) bisects a large NE-SW trending basin of Tertiary sediments lying to the S and E of Blackstones Bank, and downthrows them to the SE by about 0.5 km. Again, the sediments are underlain by lavas and an indeterminate thickness of Mesozoic sediments.

The Tertiary sediments of the southern Sea of the Hebrides lie midway between Canna and Lough Neagh, and extend an unknown distance SW. It is likely that they also are Oligocene in age, although the much larger area of outcrop suggests that they may be of marine rather than terrestrial origin. Similar chronological and spatial relations also apply to the Tertiary of the S Irish Sea, where the Palaeogene terrestrial deposits of Tremadoc Bay are isolated from but probably contemporaneous with the extensive Palaeogene marine sediments of Cardigan Bay.

3. Discussion and conclusions

We have shown that Tertiary sediments of post-Eocene age occur widely throughout the Sea of the Hebrides. Comparisons with Northern Ireland and the southern Irish Sea suggest that they are probably of Oligocene age. If this is so, then the ending of igneous activity throughout NW Britain at some time during the Eocene was followed by a period of rapid erosion, together with localized downwarping, faulting and deposition, during the Oligocene. A closely comparable Tertiary history is recognized in the NE Atlantic (Roberts, in press): volcanic activity on Rockall plateau and contemporary sedimentation in the Hatton-Rockall basin and Rockall trough during the Palaeocene and lower Eocene were followed by a major depositional hiatus before subsidence resumed during the early Oligocene. The hiatus is marked by a prominent seismic reflector which can be traced from the flanks of the mid-Atlantic ridge to the continental margin W of the British Isles, and the dating of the immediately overlying sediments as Oligocene is arrived at by reference to the magnetic anomaly time-scale and Deep Sea Drilling Project holes 116 and 117. The reflector is observed on the outer continental shelf NW of Scotland and Ireland (Stride *et al.* 1969), and at around latitude 56°N it crops out only 60–70 km W of the southern Sea of the Hebrides Tertiary basin (Bailey *et al.* 1974). Thus we conclude from two independent arguments that the Tertiary sediments of the NW Scottish continental shelf are of Oligocene age, and that the early Tertiary history of the shelf matches that of the NE Atlantic more closely than hitherto believed.

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David Kenneth Smythe & Nicholas Kenolty, Institute of Geological Sciences,
Marine Geophysics Unit, 9 South St. David Street, Edinburgh EH2 2BW.