Excursion Guide: Basins and petroleum geology in the north of Ireland

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Introduction to basins in the north of Ireland

The pre-Devonian terranes of the north of Ireland consist, from northwest to southeast, of Dalradian and Moinian rocks forming the upland regions of Cos. Donegal, Londonderry and Tyrone, an Ordovician volcanic terrane which crops out in Co. Tyrone, and the Ordovician–Silurian Longford–Down Massif. The volcanic terrane is related to an ophiolite complex (Hutton *et al.* 1985), equivalent to the Highland Border Group in Scotland, while the Longford–Down outcrop is a continuation of the Southern Uplands of Scotland. Also, as in Scotland there are small outcrops of Ordovician and Silurian strata between these terranes which are relatively unmetamorphosed (Pomeroy and Lisbel-law inliers). These occur in the 'Midland Valley', unconformably overlain by Devonian (Old Red Sandstone) sediments which constitute the Fintona Block in Co. Tyrone.

The outcrop of Carboniferous rocks (Fig. 1) includes the North West Basin, which is contiguous with the Omagh and Slieve Beagh Basins, and thick sequences in East Tyrone and North Antrim. Permo-Triassic rocks accumulated in two major basins, the Magee or Larne–Lough Neagh Basin and the Rathlin Trough, separated by the 'Highland Border Ridge', a partly fault-bound high of Dalradian rocks. Triassic continental rocks are succeeded by Rhaetic–Lower Jurassic and subsequently Upper Cretaceous marine sediments which transgressed across the entire region. The northeast of Ireland was flooded by Palaeocene basalt lavas, while the Mourne plutonic complex intruded the crust of Co. Down. The youngest sedimentary basin is the Oligocene Lough Neagh Basin, a fault-bounded complex which developed on the basalt surface.

Reservoir prospects are in the Carboniferous and Permo-Triassic basins (Fig. 2). Potential source rocks are in the Carboniferous, which includes coals and several Dinantian shales (Fig. 3), and possibly the 'Midland Valley' Lower Palaeozoic outcrops.

Itinerary

1. *Scrabo*

Scrabo Hill is formed by a Tertiary sill complex intruded into Permo-Triassic sandstones. The sandstones were formerly quarried for building stone, particularly on the east face of the hill where it is possible to examine quite fresh faces in Triassic sandstone. The quarries can be reached by a footpath north of a car park at J 475724. The sandstones exhibit low to medium angle cross-stratification, with ripple marks, pebble lags, mudflakes, desiccation cracks and (?) rain pits. These rocks have in the past been interpreted as aeolian, but there is no supporting evidence for this. Rather they are the deposits of dune bedforms in river channels (Fig. 4A). Rounded grains in the Triassic sandstones are probably reworked from underlying Permian sandstones (Permian sandstones in the Enler borehole 4 km to the west consist of very well rounded grains) or from a desert hinterland beyond the main basinal region. The Triassic sandstones at Scrabo Hill have been partly baked by the sill, and have also been affected by hydrothermal activity associated with the intrusion. An unusual feature is a widespread cementation by the amphibole actinolite, first recorded by Preston (1962) and subsequently observed by electron microscopy as a network of pore-bridging fibres. The sandstone is also patchily cemented by calcite.

The Scrabo Hill outcrop occurs in a deep trough of Carboniferous to Triassic sediments developed within the Lower Palaeozoic Longford–Down Massif, the equivalent of the Southern Uplands of Scotland which similarly supports extensional basins of Carboniferous to Permian age.

2. *Larne*

The coastal section at Waterloo (Fig. 5), north of Larne is best approached from the swimming pool at D 412031, where vehicles can be parked. The coastal promenade passes a shore and cliff

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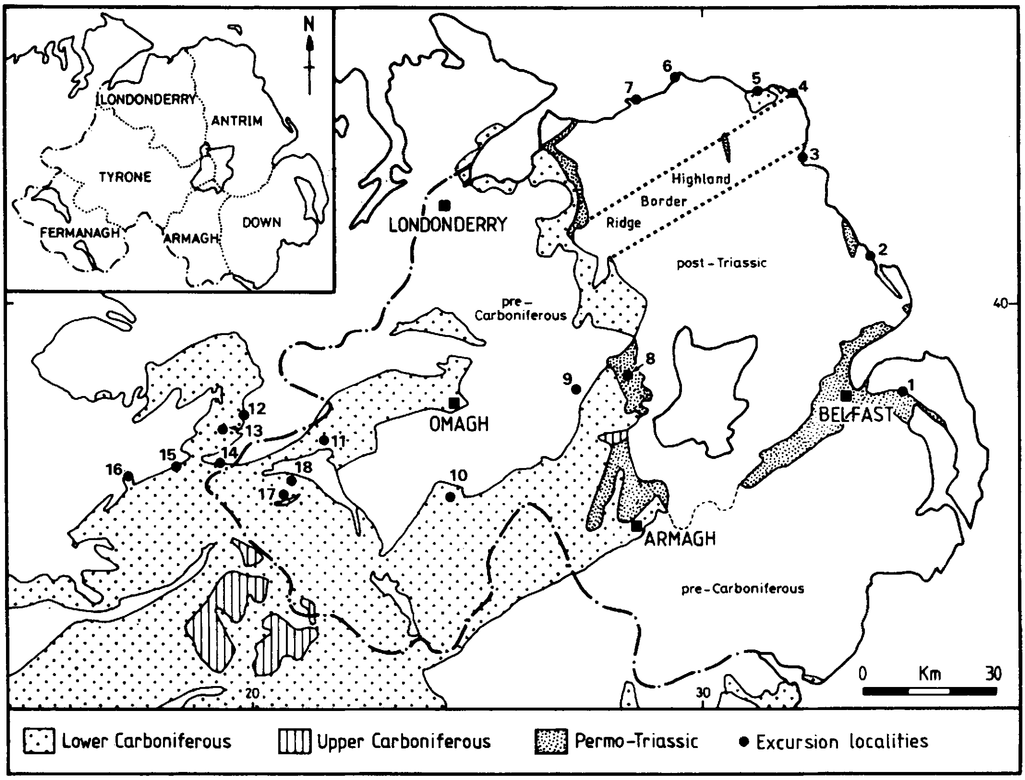

Fig. 1. Excursion localities, and distribution of Carboniferous and Permo-Triassic rocks which include possible hydrocarbon reservoirs.

section of upper Triassic (Mercia Mudstone Group, Rhaetic) and lower Jurassic (Liassic). The section is slightly complicated by faulting. The Larne No. 1 borehole, less than 2 km distant, penetrated 51.5 m Liassic beneath the drift, 20.5 m Rhaetic, 10.8 m Collin Glen Formation and 29.0 m Port More Formation, the latter two being subdivisions of the Mercia Mudstone Group (Manning & Wilson 1975). The thicknesses at Waterloo are of similar magnitude: the Rhaetic is 14.3 m thick on the shore, possibly with some loss due to faulting (Ivimey-Cook 1975).

The Port More Formation consists predominantly of brick red siltstones, with some horizons containing dark accretionary nodules within reduction spots. The nodules contain vanadium minerals here, and uranium and copper minerals elsewhere in Co. Antrim (Parnell 1988). Similar phenomena elsewhere are formed by an interaction of migrating hydrocarbons and metalliferous red bed groundwaters, and this explanation has also been suggested for the Larne nodules (Parnell & Eakin 1987).

It is not possible accurately to delimit the Port More Formation from the overlying Collin Glen Formation, but there is a transition upwards into grey-green mudrocks. In places these beds contain abundant pseudopisoliths; millimetre-scale concretionary structures which are clearly diagenetic and not mechanically deposited. Their origin has been attributed to volcanic emissions from the Larne Lough Fault offshore (Ivimey-Cook 1975), or to precipitation from saline fluids migrating from halite units lower in the Mercia Mudstone Group (Reid 1983). The grey mudstones contain no more than 0.5% total organic carbon (TOC).

The Rhaetic (Rhaetian) and Lower Liassic rocks are grey-black mudrocks with thin (<15 cm) limestone beds. The Rhaetic includes beds of compacted bivalve shells, particularly *Protocardia*. The boundary with the Lias is in the vicinity of an outfall pipe. The Lias contains numerous ammonite fragments, particularly *Psiloceras planorbis*, and represents the Hettangian and lower Sinemurian stages. Over 100 m of Liassic is present at Larne, and

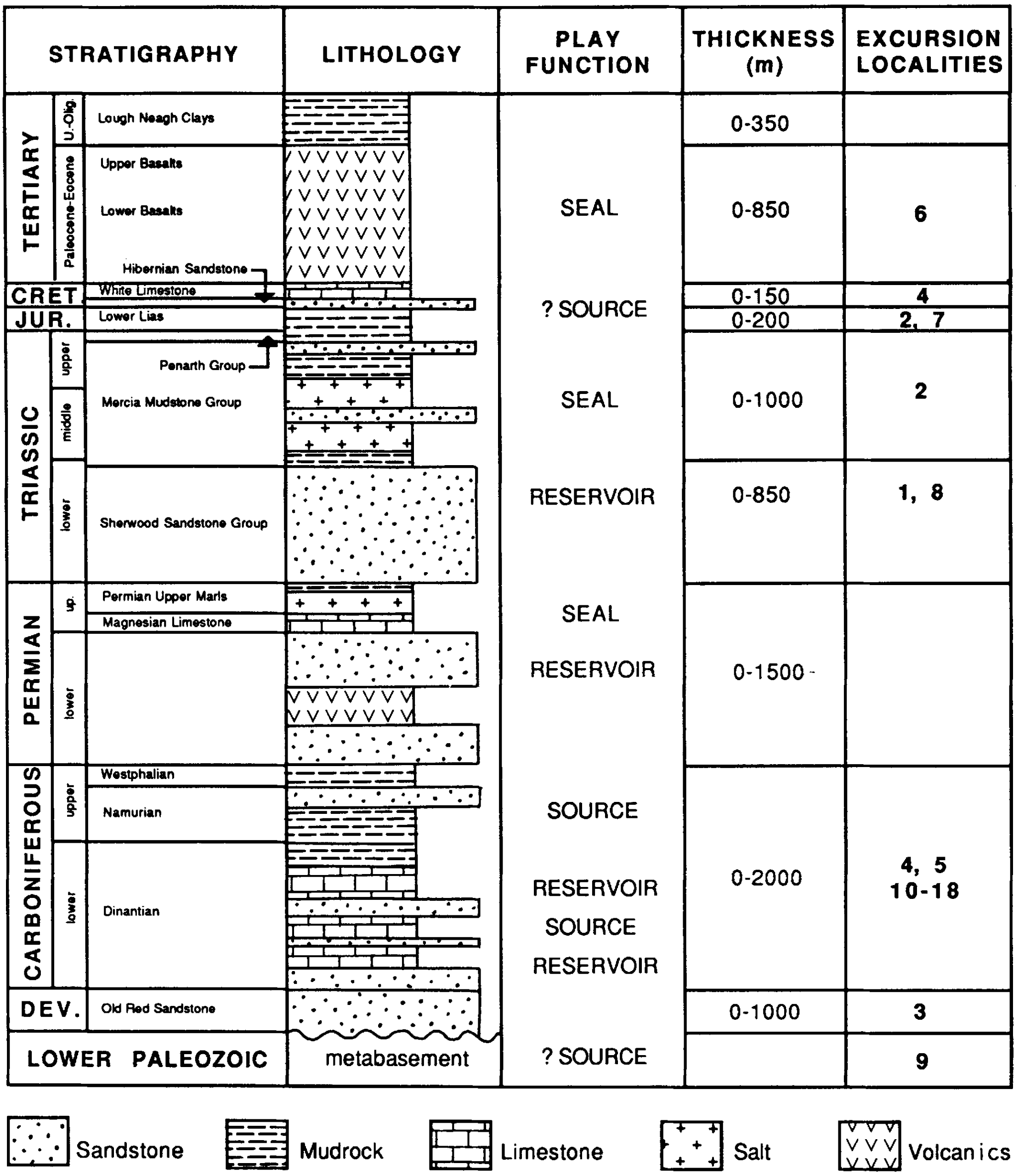

Fig. 2. Outline composite stratigraphy for Northern Ireland, indicating possible hydrocarbon play functions.

on the north Antrim coast the Liassic is almost 250 m thick in the Port More borehole, extending up to the Lower Pleinsbachian. Loose blocks suggest that even younger beds, of Middle Liassic age (Hartley 1933), were deposited in the region. The black mudstones have yielded up to 4% TOC.

3. *Cushendall*

Immediately adjacent to a jetty at the lifeboat station, Red Bay, Cushendall, are exposures of red conglomerate probably attributable to the Upper Old Red Sandstone. They form the base of an upward fining sequence about 400 m

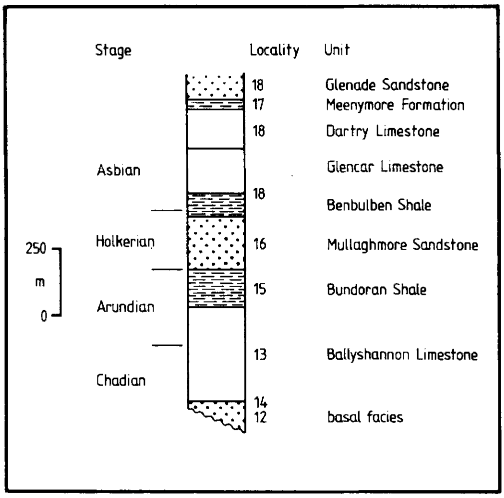

Fig. 3. Carboniferous stratigraphy for north west Ireland, highlighting shale and sandstone units.

thick. Conglomerate beds 0.5 to 1.5 m thick are interbedded with cross-stratified and parallel-laminated beds of pebbly sandstone. The conglomerates have erosive bases, weakly developed internal bedding, exhibit poor sorting and are clast-supported. The clasts are cemented with calcite and/or dolomite, and the most dolomitic rocks exhibit some vuggy porosity, as also seen in dolomitic basal beds of the Carboniferous on the west coast (see Assaroe Lake locality below). The remainder of the succession, exposed southwards along the coast to the Red Arch, has a generally fining-up trend and the sandstones become progressively more mature. The succession has been termed the Red Arch Formation by Simon (1984), who interprets it as an alluvial fan system. A major lineament which at present bounds the Dalradian 3 km to the northwest may have been an active fault boundary during fan sedimentation. Palaeocurrent data confirms the derivation of clasts from this

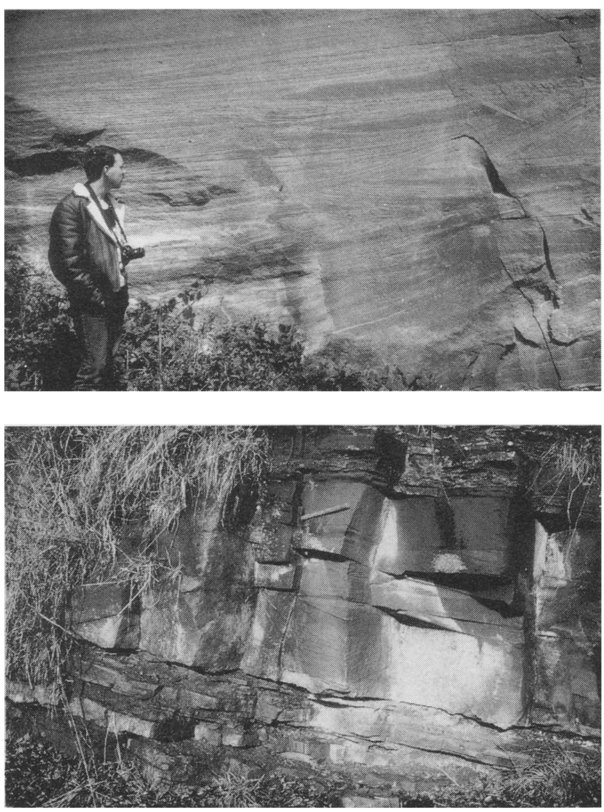

Fig. 4. Cross-bedded units of the Sherwood Sandstone Group, which has reservoir potential in some districts. A, dune bedforms, Scrabo Hill (locality 1); B, cross-bedded oolitic sandstone-limestone body and interbedded sandstones and mudrocks, Drapersfield (locality 8).

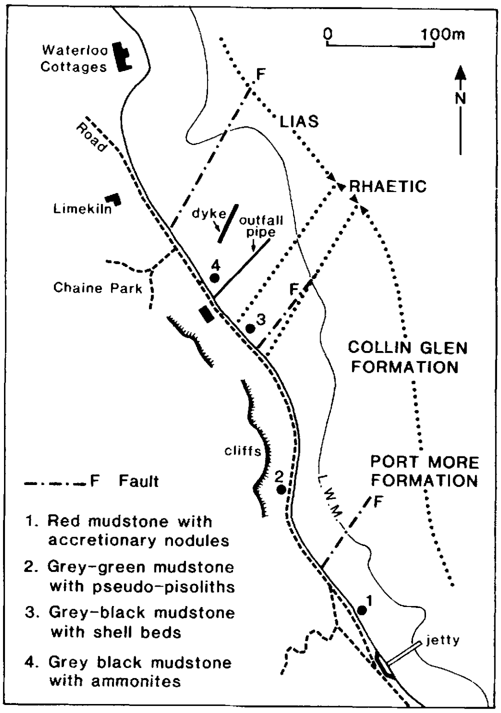

Fig. 5. Coastal section at Waterloo, north of Larne (locality 2), (partly after Ivimey-Cook 1975; Reid 1983).

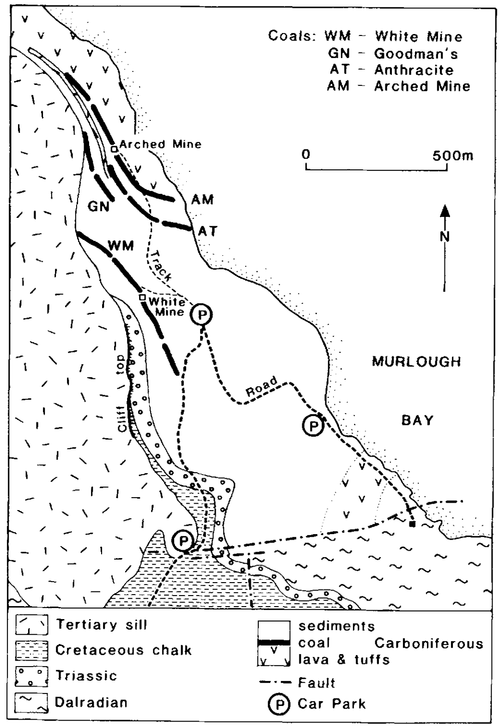

Fig. 6. Geology of Murlough Bay district (locality 4).

direction (Simon 1984). Along this major lineament Devonian sandstones are potential reservoirs where they occur updip from the Carboniferous which may include source rocks. They are sealed by Tertiary basalts inland to the west.

4. *Murlough Bay*

The cliff sections west of Murlough Bay expose a wide range of rocks, from Dalradian metamorphic basement, through Carboniferous, Triassic and Cretaceous sediments, to Tertiary intrusions (Fig. 6). The cliffs are capped by the Tertiary Fair Head Sill, which has a very distinctive profile when viewed from the west (locality 5, Fig. 7, and see Figure 184 of Holmes 1965). The dolerite sill transgresses upwards to the southeast in several stages, penetrating Carboniferous rocks in the north and Cretaceous chalk in the south. The region between the cliff and the shoreline includes several major landslips, in which successions of dolerite and Cretaceous to Carboniferous sediment appear undisturbed despite falling up to 100 m from their original positions.

At Murlough Cottage, Dalradian mica schists are seen at the shore in faulted contact with Carboniferous sandstones. On the cliff above, Triassic rocks lie directly upon the Dalradian to the south of the fault. There has clearly been movement on the fault between Carboniferous and Triassic sedimentation although it also cuts the chalk and must have a multi-phase history. Further south along the Antrim coast near Larne, evidence for the earlier phase of tectonic activity is available from a seismic section which shows the Permo-Triassic truncating older reflectors (Illing & Griffith 1986). The Carboniferous sandstones near Murlough Cottage are overlain by about 12 m of porphyritic basalt lavas, best seen at the shoreline. These Carboniferous volcanics can be correlated with similar rocks in the Midland Valley of Scotland, but do not occur elsewhere in the north of Ireland beyond northeast Antrim. Above the lavas are tuffaceous sediments followed by an extensive succession of sandstone, shales and coal seams, which have been mined at several points. The traces of the coal seams are indicated on Fig. 7.

A track from the car park half-way up the

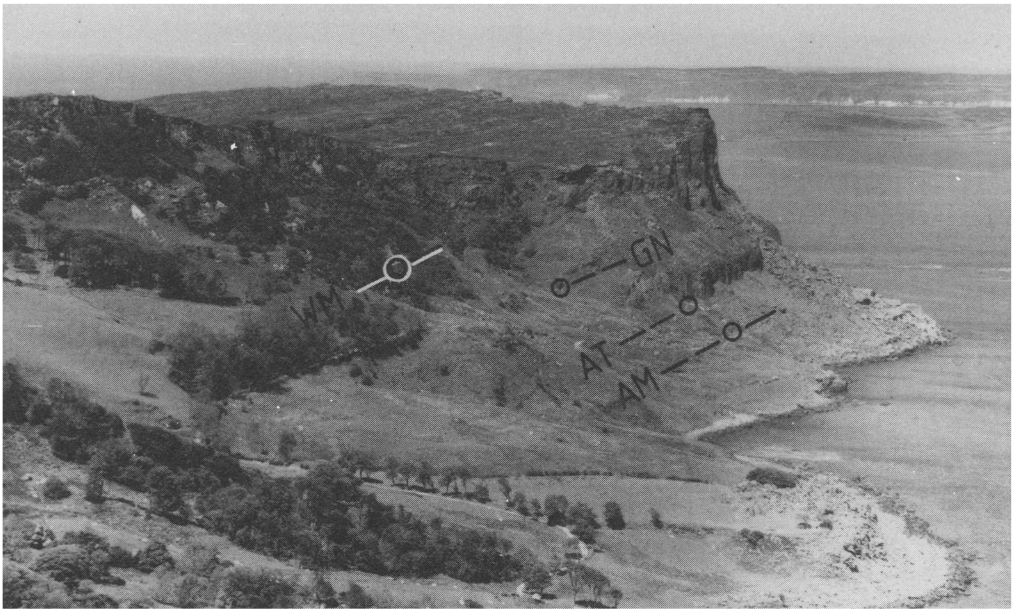

Fig. 7. Aerial view of Murlough Bay, dominated by the Fair Head Sill. Traces of coal seams and adits (encircled) marked, as on Figure 6. (Photograph courtesy of the Geological Survey of Northern Ireland).

coastal slope leads to the Arched Mine, which exploited the lowest coal (Dinantian) in the Ballycastle district. Immediately inside the right hand portal of the mine, black mudstone and canneloid coal are exposed in the walls of the workings. However, entering the workings is not advised; samples can be obtained from the spoil heap outside. Above and slightly south of the Arched Mine, other adits and spoil heaps can be found on workings into an 'Anthracite' horizon and Goodman's coal. A lower leaf of the Tertiary sill is prominent here, transgressing the 'Anthracite' horizon. Above these coal levels are about 100 m of red sandstones within beds of mudrock. Some Carboniferous sandstones to the west of Fair Head are similarly red. The red colouration is a late diagenetic pigment, probably due to deep weathering during the Permian. Sandstones are well exposed along the side track to the White Mine, which entered the highest coal seam on this side of Fair Head. The sandstones are mineralogically very mature and very porous.

The most accessible exposures of Triassic rock are at the base of the cliff to the south of the upper car park. Eight metres of red sandy mudrock lie upon 10 m of red sandstone which is pebbly towards the base and underlain by a further 10 m of breccia derived from the Dalradian. This Triassic succession is very thin in comparison with most in Northern Ireland, reflecting deposition on the northern edge of the 'Highland Border Ridge'. In the Port More borehole, just 12 km to the west but within the onshore part of the Rathlin Trough, over 1354 m (unbottomed) red beds were penetrated which may include beds of Permian age. The sandstone at Murlough Bay is tightly cemented with poikilotopic calcite despite the exposed position: waters draining downwards from the overlying chalk would be bicarbonate-saturated and incapable of leaching out the cement from the Triassic beds. By contrast some sandstones in the Port More borehole are porous.

Above the red Triassic rocks, the cliffs are composed of the distinctive white chalk. A basal facies includes glauconitic sandstone, with Dalradian, Triassic and Liassic pebbles, although the Liassic is not exposed in this district. Regional correlations of chalk stratigraphy show that the Highland Border Ridge was progressively drowned by the Cretaceous chalk sea and the marginal clastic facies localized about the ridge gave way to normal micritic chalk deposition (Reid 1971). The chalk (the Ulster White Limestone) does not exhibit the high intergranular porosity of equivalent rocks in England and the North Sea, possibly due to metamorphism/hydrothermal activity associated with Tertiary vulcanism. However it does exhibit fracture porosity and functions as an aquifer in this way.

5. *Colliery Bay, Ballycastle*

The shore/cliff section to the east of Ballycastle was once the scene of extensive coal mining operations, exploiting coal seams in both the Lower and Upper Carboniferous. Several adits are still visible and the track east of the cottage/car park at D 150419 is floored with much debris from the mines. Representative sediments can be examined by following the track to the old harbour at Murray's Port, and veering right and upwards towards a cliff section where black shale is visible (Fig. 8). The base of the section consists of a massive sandstone with an upper 10 cm bioturbated phase passing upwards into coaly black shale. The shale has prominent weathering blooms of sulphur (yellow) and gypsum (white). The shale is overlain by about 6 m of sandstone, generally massive but beds of quartz pebbles display some low angle cross-stratification. The underside is flaggy towards the top where it is interlaminated with siltstone, bioturbated and includes *in situ* plant rootlets. Above is a second shale unit, less coaly than the first and including a bed of siderite nodules. The shale is overlain by a further unit of coarse sandstone, which is red-pink and porous. The section as a whole can be traced for 50 m along strike, and viewed from below the sandstone units exhibit channel forms. The very high porosities in these sandstones are also found in boreholes in the region, and are secondary after carbonate dissolution.

The section is immediately below the position of the Main Coal (mostly worked out) at the Dinantian–Namurian boundary (details in Wilson & Robbie 1966). Although most of the sequence represents fluvio-deltaic environments, marine bands allow stratigraphic dating and show the sequence to be comparable with those in western Scotland rather than elsewhere in Northern Ireland.

The black shales and coals are barely mature at outcrop, but have a good hydrocarbon yield upon pyrolysis and could prove a viable gas source if they occur at depth further south in Co. Antrim, where the Carboniferous rocks may be buried beneath a thick Mesozoic basin.

6. *Giant's Causeway*

The Tertiary basalt lavas of Co. Antrim are generally divisible into Lower and Upper Basalts, whose deposition was separated by an Interbasaltic Period. In the vicinity of the Giant's Causeway the Interbasaltic Period includes the distinctive group of Tholeiitic Basalts (Fig. 9). These rocks are very fine grained, rarely contain megascopic crystals, and occur as lava flows typically 20 m thick. Following slow cooling, they exhibit a pronounced jointing, which is

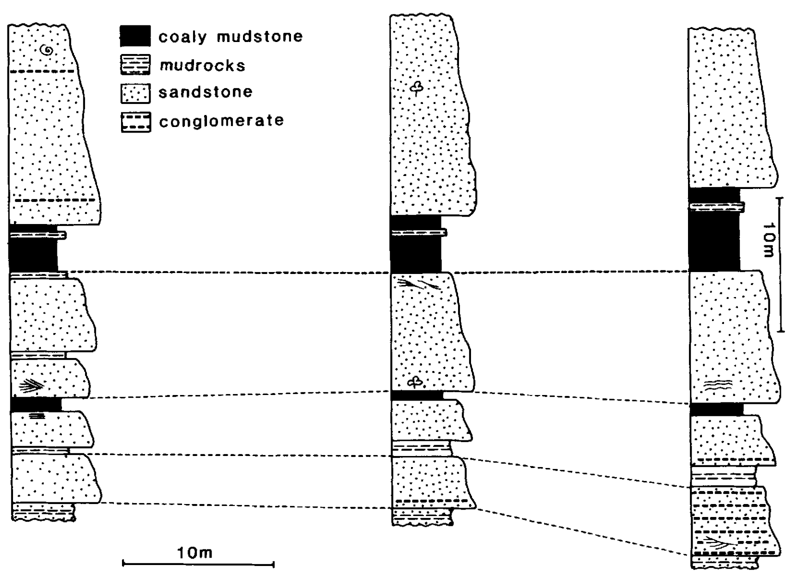

Fig. 8. Cliff section of Carboniferous sandstones, mudrocks and coaly mudstones, Colliery Bay (locality 5), showing limited lensing of channel sandstones (logs courtesy of W. Wang).

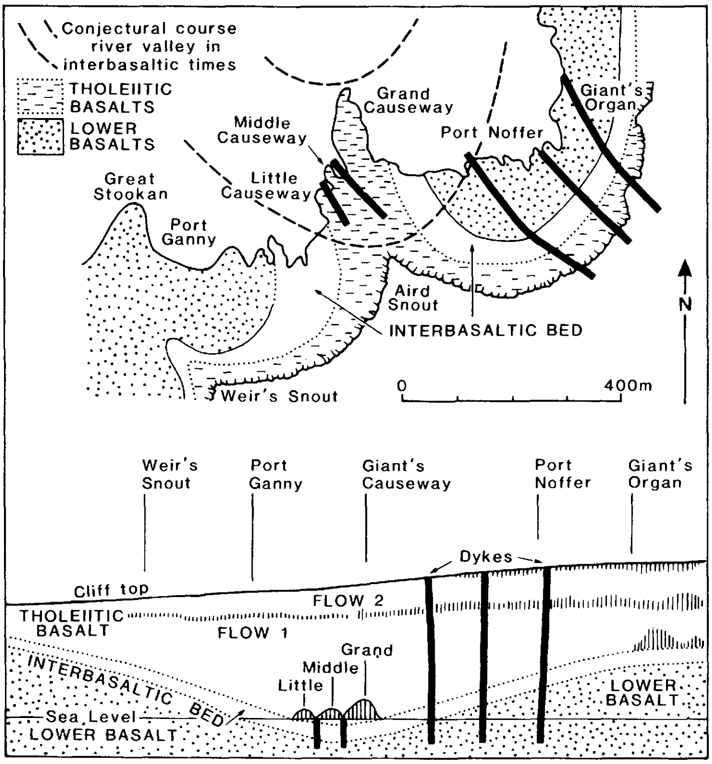

Fig. 9. Geology of Giant's Causeway district (locality 6; after Department of the Environment for Northern Ireland 1987).

divisible into a lower columnar portion (colonnade structure) and an upper more rubbly portion (entablature structure). At the Causeway itself a deep hollow, possibly a river valley, in the Lower Basalts was filled by the first flow of the tholeiitic lavas. Subaerial weathering of these basalts produced a red-purple lithomarge which consists largely of kaolinite and iron minerals, and which can be readily traced along the coastline. The weathered beds are sufficiently extensive to have formerly supported numerous small mines for bauxite and iron ore. Thin sediment layers also accumulated between flows, and lignitic beds can be seen on the cliff side of the Shepherd's path, east of the Causeway.

A number of texts record the occurrence of hydrocarbons in basalt at the Giant's Causeway. The ultimate source of this record is an account by Knox (1823) who distilled hydrocarbons from a number of igneous rocks. It is conceivable that hydrocarbons could have been generated from the lignitic beds as has been observed in Tertiary basalts above lignite in Iceland (Jakobsson & Fridleifsson 1990).

7. *Portrush*

Rocks of historical importance are exposed adjacent to an exhibition centre on the eastern side of the headland at Portrush (C 856413). Jurassic (Liassic: upper Sinemurian) mudstones are intruded by a Tertiary sill of olivine gabbro. At the contact, the mudstones are metamorphosed to a hornfels and the top of the sill is chilled to basalt. The margin between hornfels and basalt can be distinguished but they are sufficiently similar to cause some confusion and, 200 years ago, considerable debate. At that time, the origin of igneous rocks was fiercely contested by Plutonists who advocated a magmatic origin, and Neptunists who envisaged a subaqueous origin. The occurrence of numerous ammonites in the hornfelsed Liassic, which was mistaken for an igneous rock, was seen as evidence for the Neptunist theory and attracted visitors from far afield. The Liassic mudstones are particularly susceptible to intrusion: in the Port More borehole to the east 496 m of Rhaetic–Liassic section includes 223 m of Tertiary intrusion (Wilson & Manning 1978).

8. *Drapersfield*

A riverside quarry at Drapersfield (H 842767), reached through the grounds of a private nursing home, exposes over 10 m of the Sherwood Sandstone Group. Drapersfield is near the western limit of a 2 km deep Permo-Triassic basin which extends westwards from Larne across the Lough Neagh region. The bright red cross-bedded rocks (Fig. 4B) are typical of exposures in the valleys of East Tyrone. However, on closer examination much of this section is found to consist of cross-bedded oolitic limestone (either pure limestone or mixed siliciclastic–oolitic rock), whereas at many other localities the rocks are normal sandstones. The oolitic facies has been identified in boreholes in East Tyrone and South Antrim and extends to the east coast on Belfast Lough.

The section at Drapersfield also includes non-oolitic sandstones and mudrocks (Fig. 10). The beds exhibit broad channel structures, and planar cross-bedding representing dune forms in the river channels. Smaller scale cross-bedded sandstones, with some low-angle cross-lamination, were deposited under low flow regimes, and the mudrocks represent overbank deposits. The whole section is probably of fluviatile origin. The oolitic beds are the equivalent of the 'Rogenstein' recorded in the lower half of the Sherwood Sandstone Group in the southern North Sea and in continental Europe. They have not been recorded onshore elsewhere in the UK. Much of the oolitic rock is tightly cemented with calcite, i.e. it is non-porous. However some high porosity values are recorded in both oolitic and non-oolitic sandstones (Fig. 10). Borehole data show that the porosity is not simply a surficial feature. The porosity is secondary after dissolution of calcite, and in the porous oolitic rocks there is inter-layer porosity leached within individual ooliths. Porosity is more extensive in non-oolitic sections elsewhere, where bicarbonate activity in the local groundwaters would be lower. The distribution of the oolitic facies broadly coincides with the occurrence of Lower Carboniferous limestones beneath the Triassic.

Beneath the Permo-Triassic in East Tyrone is a thick Carboniferous sequence which includes shales and coals including canneloid shales which are likely to have a mixed potential for oil and gas (Parnell 1991).

9. *Pomeroy*

The Lower Palaeozoic rocks of the Pomeroy and Lisbellaw inliers are at the mature limit of the oil window and possibly have gas potential (Illing & Griffith 1986; Parnell 1989). The Pomeroy inlier contains graptolitic shales of Ordovician and Silurian age. A roadside cutting at H 702709 exposing the Ashgill Desertcreat Group and a riverbank adjacent to the road at H 711732 exposing the Llandovery Little River Group both yield samples with TOC contents up to 1%.

10. *Cole Bridge*

Clastic Lower Carboniferous sediments are extensively distributed between Lough Erne and Lough Neagh, but poorly exposed. One of the few informative localities is a roadside stream section north of Cole Bridge, near Fivemiletown, palynologically dated as Tournaisian (Sheridan *et al.* 1967). The section shows a fining upward transition from basal Carboniferous rudaceous sediments (Ballyness Formation) to sandstones and interbedded mudrocks and limestones of the Clogher Valley Formation (Fig. 11). Conglomerates occur in the stream at the northeast end of the section (H 443525) and sandstones with quartz cement can be examined beneath a small bridge over the stream. Some of these basal sediments are red, reflecting a transition from the underlying Old Red Sandstone. The Clogher Valley Formation includes tabular cross-bedded sandstones near a rubbish dump, overlain by alternating mudrocks and thin limestones. The mudrocks include grey to black shales, which are presently in the oil window. The limestones include beds with evaporite dissolution cavities and finely laminated beds which are probably algal deposits. These beds are accessible at a ford across the stream (H 443523).

11. *Clonelly*

In the Clonelly district and on Boa Island there are several small exposures of the Holkerian Clonelly Sandstone (= Mullaghmore Sandstone, locality 16). The Holkerian sandstones are generally regarded as fluviodeltaic, but the Clonelly Sandstone additionally contains bioclasts and ooliths which indicate a marine component. Over much of Northwest Ireland, the Holkerian sandstones contain sub-millimetre-sized bitumen nodules which contain thorite inclusions and represent an interaction between migrating hydrocarbons and thorium-rich groundwaters draining off the Caledonian granites of Co. Donegal (Parnell & Monson 1990). The nodules occur scarcely in the Clonelly Sandstone. A convenient roadside sampling stop is

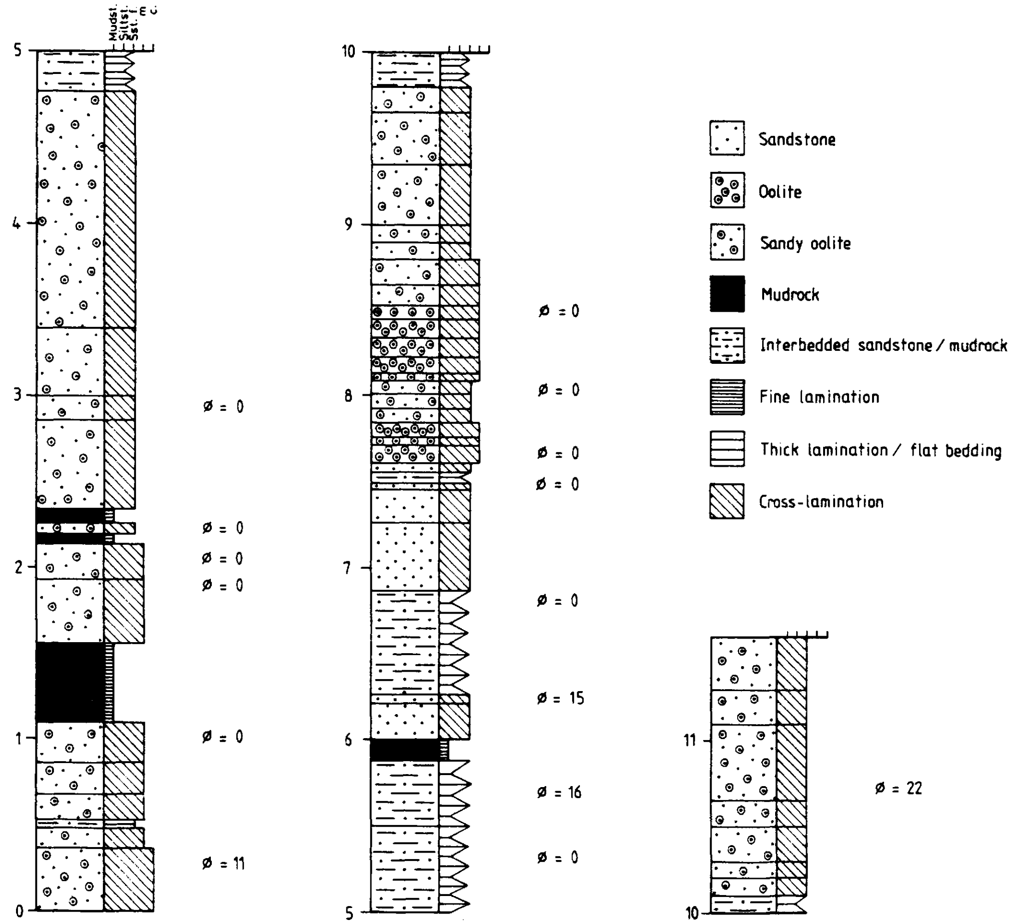

Fig. 10. Quarry section at Drapersfield (locality 8) exhibiting sandstones and oolitic beds in the Sherwood Sandstone Group. Porosity values (%) determined from point counts.

on the Kesh-Pettigo road (H 147663) where the sandstone occurs in the bank along the northern side.

12. *Shinnan Hill*

Between Clonelly and Shinnan Hill, which are in the distinct sub-basins of the Omagh Syncline and Donegal Syncline respectively, the route crosses boggy uplands formed by Moinian rocks. The Carboniferous rocks between the Moinian uplands and the coast of Donegal Bay are predominantly the Ballyshannon Limestone, a marine succession of interbedded limestones and calcareous mudrocks. However at the very margin with the Moinian basement is a thin fringe of coarse siliciclastic sediment, which represents a beach facies passing laterally into the Ballyshannon Limestone. At Shinnan Hill this facies is more quartzose than most sandstones in North West Ireland, and is also relatively porous. Exposures in a roadside ditch and the adjacent hillside north of a farmhouse at G 960705 show sandstones impregnated with solid bitumen (Fig. 12). To the south of the farmhouse the unconformity with the Moinian basement can be determined upon close inspection (N.B. The Moinian is quartzose and granular here and may initially be confused with Carboniferous sandstone).

13. *Bridgetown*

There are several working quarries in the Ballyshannon Limestone near the main road between Laghy and Ballyshannon, which can be visited with permission. In most of them traces of bitumen can be found in calcite/dolomite veins

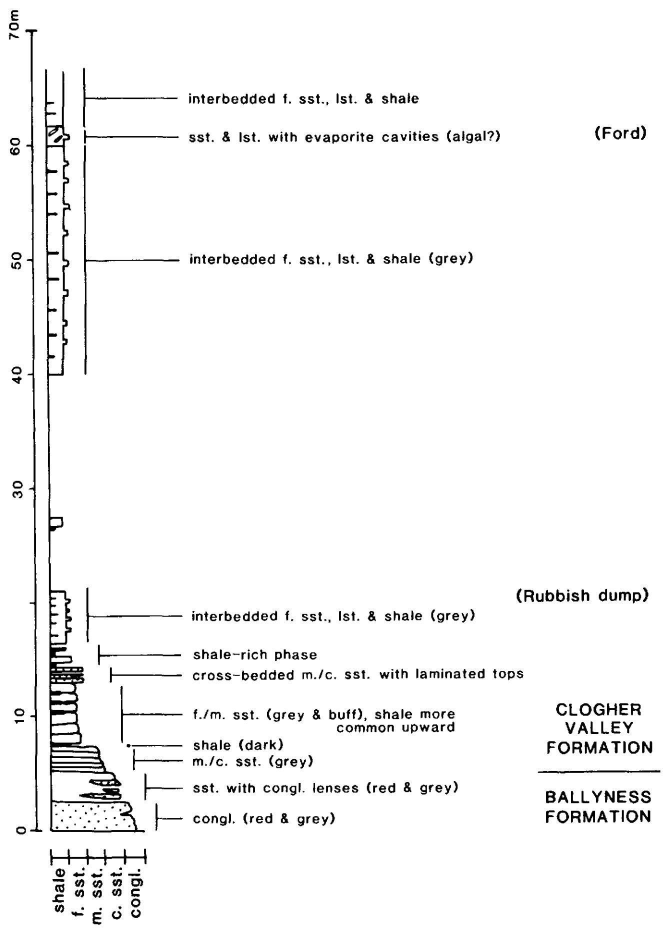

Fig. 11. Stream section in Tournaisian strata at Cole Bridge (locality 10).

cutting the limestone. The bitumen is almost certainly derived from within the Ballyshannon Limestone, which is bituminous particularly in the lower half. The rocks can also be examined at a convenient roadside exposure in Bridgetown, where interbedded limestones and dark shales form an anticlinal structure. A bituminous odour can be detected from freshly fractured surfaces of the limestone. Reflectance values from the kerogen in these rocks show that they are either at the extreme limit of the oil window ($R_0 = 1.3\%$) or have passed through it. Vein-hosted bitumens yield higher reflectance values and may have experienced higher temperatures due to hydrothermal activity; the veins also contain traces of sphalerite, galena and fluorite with fluid inclusion homogenization temperatures up to 140°C (Parnell & Monson 1990).

14. *Assaroe Lake*

Along the roadside on the north side of Assaroe Lake are several exposures of the unconformity between Carboniferous and Moinian. The unconformity is most clearly seen in a field behind the road, where there is a clear angular discordance between the two groups. The basal Carboniferous is a cement-supported pebbly sandstone, best seen opposite a small island. The coral *Syringopora* is locally conspicuous. The cement is dolomite, which has partially replaced the sandstone grains and exhibits vuggy cavities. The same phenomenon is seen in the basal Carboniferous sediments on the other side of the border on the north shore of Keenaghan Lough, Co. Fermanagh (G 975600). At Keenaghan the dolomitization also affects the overlying Ballyshannon Limestone and ap-

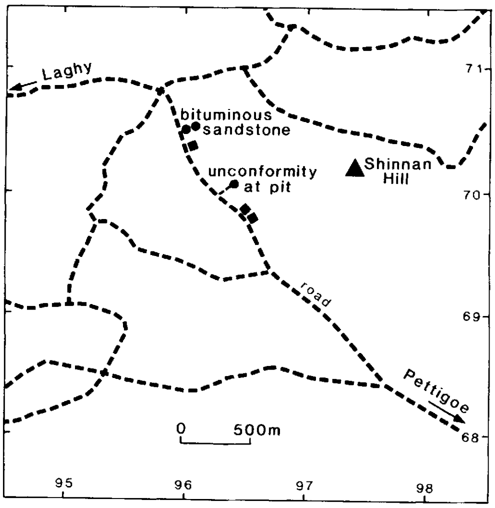

Fig. 12. Location of basal Carboniferous bituminous sandstones and unconformity in Shinnan Hill district (locality 12).

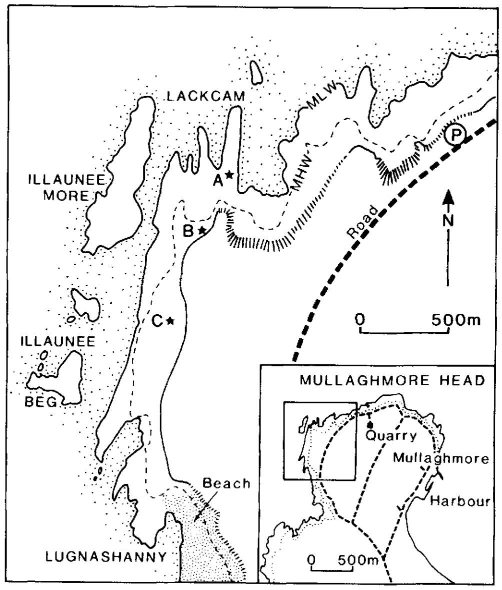

Fig. 13. Map of Mullaghmore Head showing location of quarry and shore sections (locality 16).

pears to be related to hydrothermal mineralization. Traces of copper mineralization are evident at the roadside (G 981597) and the locality was formerly mined. (N.B. The direct cross-border road along the north side of Assaroe Lake is closed).

15. *Bundoran*

In the centre of Bundoran, a car park between the main street and the shore is sited immediately above a good exposure of the Bundoran Shales. The Bundoran Shales are thinly interbedded marine limestones and shales, with conspicuous large crinoid stems orientated by currents. The shales have TOC values of up to 6%.

16. *Mullaghmore Head*

There are several good exposures of the Holkerian Mullaghmore Sandstone on Mullaghmore Head (Fig. 13). The sandstones represent shallow marine/deltaic sedimentation. The excursion incorporates a quarry section (Fig. 14) exhibiting bitumen-bearing sandstones, and a shore section (Fig. 15) in which the ichnofauna is important in reconstructing the environment.

At the south end of the quarry (furthest from the road), an 8 m section shows stacked channel sandstones, which near the top of the section are bituminous. The bitumen, which can be identified in the field, is intergranular and probably occupies secondary porosity after the dissolution of carbonate cement.

From a car park a kilometre west of the quarry, access to the shore can be gained by a five minute walk westwards along the cliff top, descending to the beach on the west side of the bay to the south east of Lackcam. Walking westwards to Illaunee Beg one ascends through the succession of approximately 25 m shown in Figure 15. The lower half of the succession is repeated south of Illaunee Beg, but access to this is only possible from the Lugnashanny side.

Sedimentologically, three broad facies units can be distinguished, these being shales/siltstones with varying amounts of interbedded sandstone, bedded sandstones with minor shales/siltstones, and major thick channel sandstones (with southward dipping cross sets). The first two facies also commonly contain channels, these typically being of a much smaller scale than those of the channel sandstones. Low angle and trough cross bedding are the major bedforms seen within the thinner sandstone units, lenses and streaks of sand often being seen in the more shale/siltstone dominated facies. 'Mega' and large-scale rippled surfaces are also seen, as are soft sediment deformation structures (often truncated), mudcracks, sandstone dykes, shelly lags, and large woody logs. Carbonaceous material is relatively abundant, particularly within the laminated sandstone on the northwest corner of the headland.

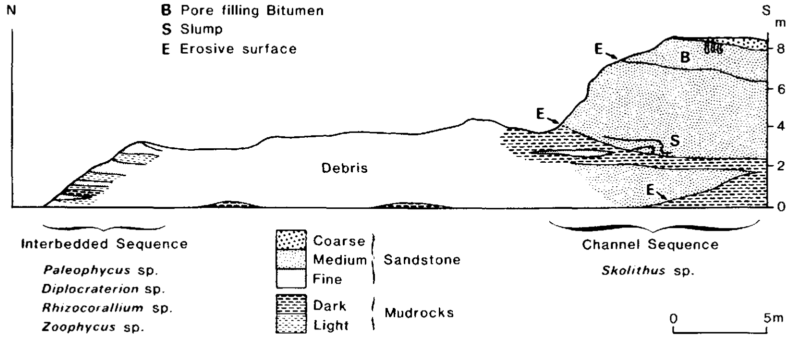

Fig. 14. Quarry section at Mullaghmore Head, exhibiting bituminous sandstones.

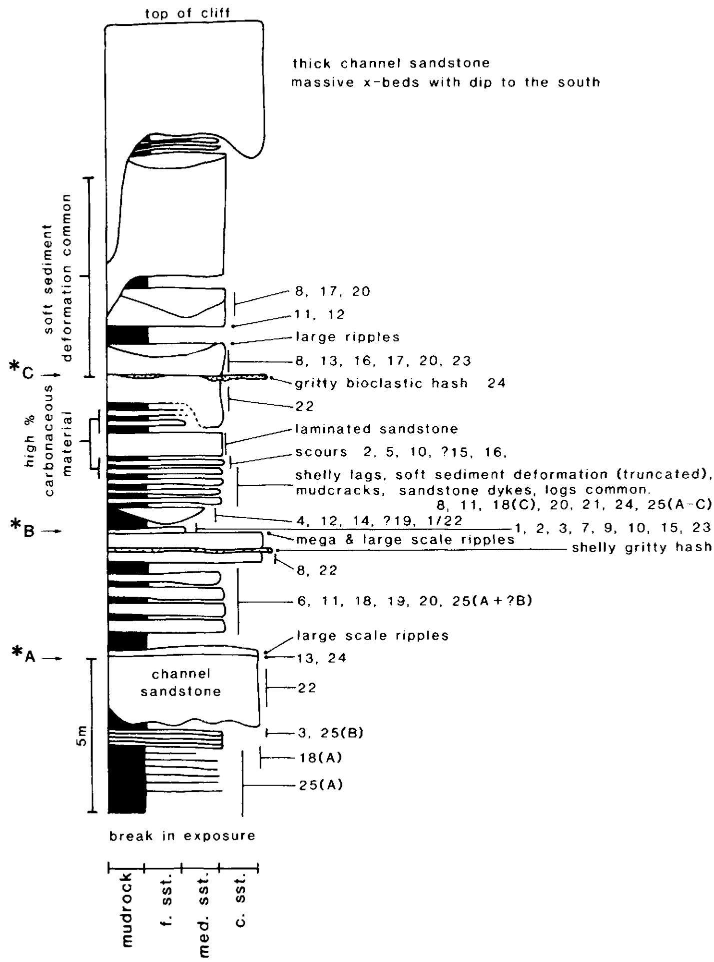

Fig. 15. Log of shore section, Mullaghmore Head, exhibiting diverse trace fossils: 1, *Arenicolites*; 2, *Asteriacites*; 3, *Aulichnites*; 4, Anemone resting marks; 5, bilobed hyporeliefs; 6, *Chondrites*; 7, *?Curvolithus*; 8, *Diplocraterion*; 9, furrow trace; 10, groove trace; 11, branched hyporeliefs; 12, *Lockeia*; 13, mounds cf. *Chomatichnus*; 14, *Neonereites*; 15, *Olivellites*; 16, *Archaeonassa*; 17, *Palaeophycus*; 18, *Phycodes*; 19, *Planolites*; 20, *Rhizocorallium*; 21, *Scalarituba*; 22, *Skolithos*; 23, *Taenidium*; 24, *Teichichnus*; 25, walled burrows (3 types).

Ichnologically the sequence is diverse and varied, with at least 25 common ichnogenera being represented. These are generally well displayed, but both ends of the section need to be visited to appreciate the full diversity and laterally somewhat sporadic occurrence of the ichnofauna. The predominant trace fossils seen within this section are the walled burrows (*Palaeophycus*, *Schaubcylindrichnus* and *Arenicolites*), *Skolithos*, *Diplocraterion*, *Teichichnus* and *Rhizocorallium*. Also more exotic traces such as *Asteriacites* (star fish resting marks), anemone resting/dwelling marks and *Archaeonassa* are found in varying abundance and state of preservation.

The Mullaghmore Sandstone is thought to represent shallow marine/deltaic conditions. At this locality the shale/siltstone-dominated facies represents lagoonal or intertidal environments, as indicated by the occurrence of both anemone resting marks and *Archaeonassa*, with intermittent subaerial exposure producing mudcracks. The bedded sandstones represent (?) storm deposits, and the thick channel sandstones represent deltaic migrating channel deposits, possibly fluviatile in part.

17. *Glennasheevar*

Vehicles may be parked at the entrance to a disused quarry on the north side of the road (H 035532) (Fig. 16). The quarry exposes the Meenymore Formation. The low hill to the north of the quarry is formed by an outcrop of the Tertiary Garrison Sill. The effects of contact metamorphism on the Meenymore Formation may be seen at the base of the sill, and are also very well exposed at a quarry at Slisgarrow (H 015516) where abundant garnetiferous clots have developed (Jones & Galwey 1966). The Meenymore Formation consists predominantly of mudrock and thin limestones, but the quarry at Glennasheevar exposes sandstones (the Quarry Sandstone Member) as well as some shale. The sandstone is well cemented with calcite and dolomite (orange-weathering), contains horizons of rolled marine fossils, and exhibits low-angle cross-stratification. Clasts also include drifted plant debris and fragments of a dolomitic limestone with worm borings (Mason 1980). This limestone is exposed *in situ* with other micritic limestones and mudrocks in a stream section on the opposite side of the road, accessible about 30 m east of the quarry entrance.

The section has also yielded fossil fish (Gardiner & Mason 1974) and it is important *not to hammer* the fossiliferous beds in this section.

The sandstone in the quarry is loaded down into the underlying mudrock in a small exposure which is modified by faulting. Nearby fractures through the sandstone are coated with brittle bitumen which may have been generated from the mudrocks. Analyses of the Meenymore Formation give good pyrolysis yields with potential for a mixture of oil and gas (Parnell 1991). Generation of the bitumen may possibly be related to the intrusion of the sill.

The Meenymore Formation is generally thought to represent a sabkha-type environment (there is evidence for evaporites in a stream section to the west at Meenacloyabane, and fluid bitumen in evaporite dissolution porosity), in which shallow marine micrites and mudrocks are interbedded with fluviodeltaic sandstones (Brandon 1977). The rolled marine fossils in the sandstones were probably eroded from underlying units.

18. *Lough Navar Forest*

A forest drive through the Blackslee part of Lough Navar Forest can be entered from the public road at Correl Glen (H 073546). At the first viewpoint, Aghameelan (Fig. 16), is the first of several exposures of a composite Tertiary dolerite dyke, which is intruded into a fault through the shales of the Meenymore Formation. The dolerite contains abundant xenoliths of sandstone which may be from the Carboniferous, Dalradian or Moinian. The dyke may belong to a swarm exposed extensively in Cos. Antrim and Down (Wilson 1964).

Further along the drive, at a left-hand bend shortly after a track junction to the right, there is a large quarry in the Dartry Limestone. The limestone is cherty and interbedded with dark shales which yield brachiopods.

The forest drive leads to a viewpoint above the Magho escarpment which gives excellent views across Lower Lough Erne to the basement rock uplands of Co. Donegal. The escarpment itself consists of steep cliffs of Glencar and Dartry Limestones above gentler slopes of Benbulben Shale. Landslides (rotational slumps and debris slides) occur on the slope due to failure on or within the shale (Prior & Graham 1974). To the south are further escarpments of the Glenade Sandstone. As the drive returns to the public road the sandstones are most accessible at Lough Achork. (N.B. The forest drive is a one-way system, and must be driven from east to west).

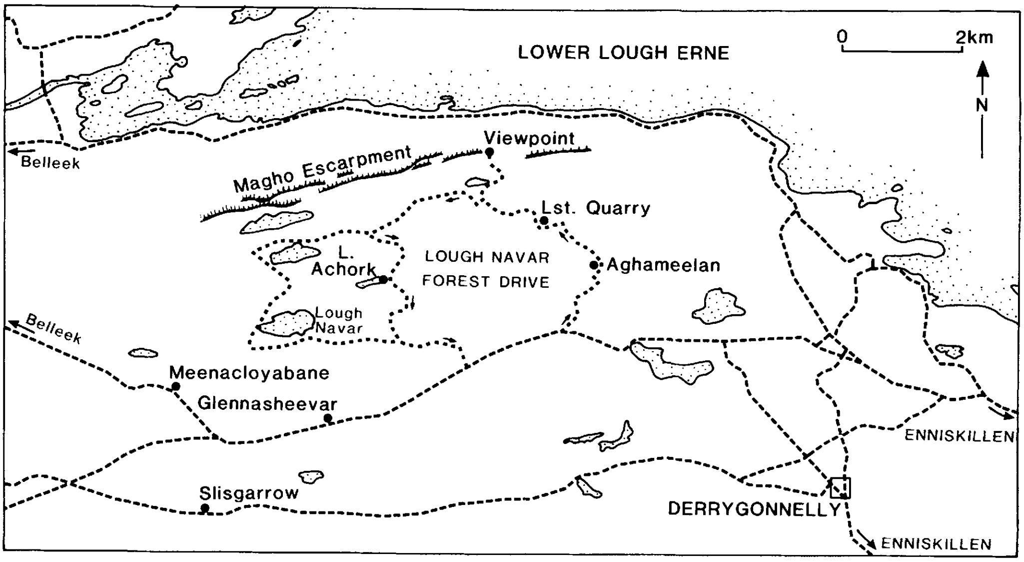

Fig. 16. Map of Lough Navar Forest region showing location of Glennasheevar Quarry (locality 17) and stops along forest drive (locality 18).

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