Rialtas na hÉireann
Government of Ireland

CARBONIFEROUS

Merlin Energy Resources Ltd

PIP
Petroleum Infrastructure Programme

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D.3. CARBONIFEROUS

Carboniferous rocks are the most frequently occurring Palaeozoic aged successions in offshore Ireland and are known from 38 wells and boreholes. The Carboniferous of offshore Ireland is represented by a succession of Mississippian to Pennsylvanian rocks ranging from marine (Mississippian) to non-marine (Pennsylvanian) in origin.

The stage and substage divisions of the Carboniferous used in this report are those that are traditionally used in Western Europe, as shown in **Figure D. 3.1** (after Heckel & Clayton, 2006). The figure shows a comparison between the stages and substages and the "global" stages and series in the Ogg *et al*. (2016) scheme. Note that the terms Lower Carboniferous and Upper Carboniferous are no longer recommended for use (Gradstein *et al*., 2012) and have been replaced by Mississippian and Pennsylvanian Epochs, respectively. This is because there were several different usages of the terms Lower and Upper Carboniferous among workers, with no consistency regarding usage or separation.

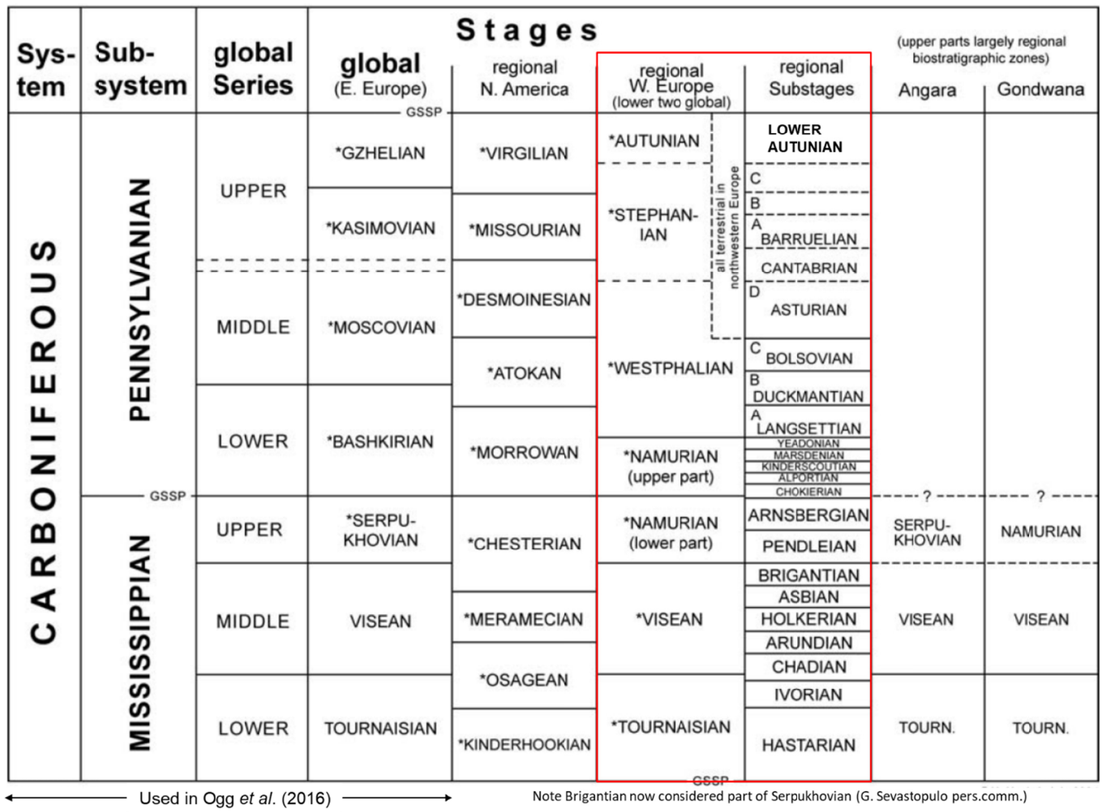


Figure D. 3.1. ***Carboniferous chronostratigraphic subdivisions and correlation of global series with regional European stages and substages that are recognisable in western Europe, including Ireland, highlighted (after Heckel & Clayton, 2006).***

Note that the Autunian regional Western European stage spans the Carboniferous/Permian boundary (Heckel & Clayton, 2006; Davydov *et al*., 2012) and this stage is therefore informally split into lower and upper substages (see Heckel & Clayton, 2006, Figure 1; Waters *et al*., 2011, Figure 9). The Lower Autunian therefore represents the youngest stage of the Carboniferous. Rocks of this age have been recognised in offshore Ireland, as the new Sorrel Group, where they are dated biostratigraphically as "early" Autunian.

Sedimentary rocks of Carboniferous age have been penetrated in wells and boreholes in the Rockall, Donegal, Erris, Slyne, Porcupine, South Bróna, Irish Mainland Platform, Fastnet, North Celtic Sea, South Celtic Sea, Central Irish Sea and Kish Bank basins (see **Figure D. 3.6**). Many of the wells, however, penetrate partial Carboniferous sections, which frequently occur at TD where rocks of this age have often been regarded as economic "basement" in hydrocarbon exploration in offshore Ireland. The overall Carboniferous succession proven in offshore Ireland is incomplete, in particular a large part of the Namurian stage is absent from the wells drilled to date in the region (see **Figure D. 3.2)**. Also notable is the presence of late Stephanian and early Autunian sedimentary strata in offshore Ireland, an interval that is absent from most of the Carboniferous successions of the nearby onshore (Ireland and UK) and offshore (UK offshore, for instance the East Irish Sea Basin) areas.

Although Carboniferous strata are present over a wide area of offshore Ireland, it is difficult to establish clear stratigraphic continuity from between depositional areas due to the patchy proven occurrences in the wells and boreholes, and frequently poor seismic data quality in pre-Mesozoic intervals. While there are similarities between the successions of the different regions (west of Ireland, and south and east of Ireland), there are sufficient differences, allied to unproven stratigraphic continuity, to justify the erection of a separate lithostratigraphic nomenclature scheme for each area. For the same reasons, it has been rarely possible to correlate between the offshore Carboniferous occurrences and the onshore Ireland outcrops. This is compounded by the existence of many different lithostratigraphic nomenclature schemes for onshore Ireland making it difficult to extrapolate any one onshore scheme to the offshore area. Therefore, it has been necessary to introduce some new lithostratigraphic names for the offshore area. Where deemed appropriate some names that are in use in the UK offshore East Irish Sea Basin have been incorporated into the nomenclature schemes for the Kish Bank and Central Irish Sea basins in the Irish offshore sector.

The Clare Basin proposed by Croker (1995) as a Carboniferous basin that was considered as an extension of the onshore west of Ireland West Clare Namurian Basin into the offshore area, is not followed in this atlas. Instead, reference is made to the western edge of the Irish Mainland Platform as the area upon which the 36/16-1A well sits, updip and east of the Porcupine Basin bounding fault.

Carboniferous successions appear to be present on many of the highs or platform areas flanking major Mesozoic – Cenozoic basins, for example the eastern and western flanks of the Porcupine Basin. These were often areas of erosion, for instance, during the Late Jurassic, and as a result, reworking of Carboniferous palynology associations are a frequent component of Jurassic biostratigraphic samples. This can create uncertainties regarding the correct identification of Carboniferous versus Jurassic successions, due to the frequently high concentrations of reworked Carboniferous palynomorphs. A good example of this is the TD section in well 34/19-1 which contains high numbers of Carboniferous spores, that are considered here to be reworked into the Upper Jurassic, as a result of erosion of the footwall high to the west of the well. Such highs may have comprised provenance areas for some Upper Jurassic sandstones, for example in the 26/28 (Connemara) and 35/8 (Spanish Point) successions which also contain reworked Carboniferous palynomorphs. This was noted also by Smith & Higgs (2001) who recorded significant Upper Carboniferous palynomorphs in the Upper Jurassic of wells from the Connemara area (26/28-A1Z, 26/28-A1) and 35/8-2, and in the Lower Cretaceous of 35/19-1 (Berriasian, Sól Sandstone Member) and 35/8-1 (Aptian, Boladh Sandstone Member).

A summary of the overall lithological development of the Carboniferous across the various basins offshore Ireland, with the proposed lithostratigraphic subdivisions, is shown in **Figure D. 3.2.** Stratigraphic breaks are also shown and how these relate to the defined stratigraphic sequences.

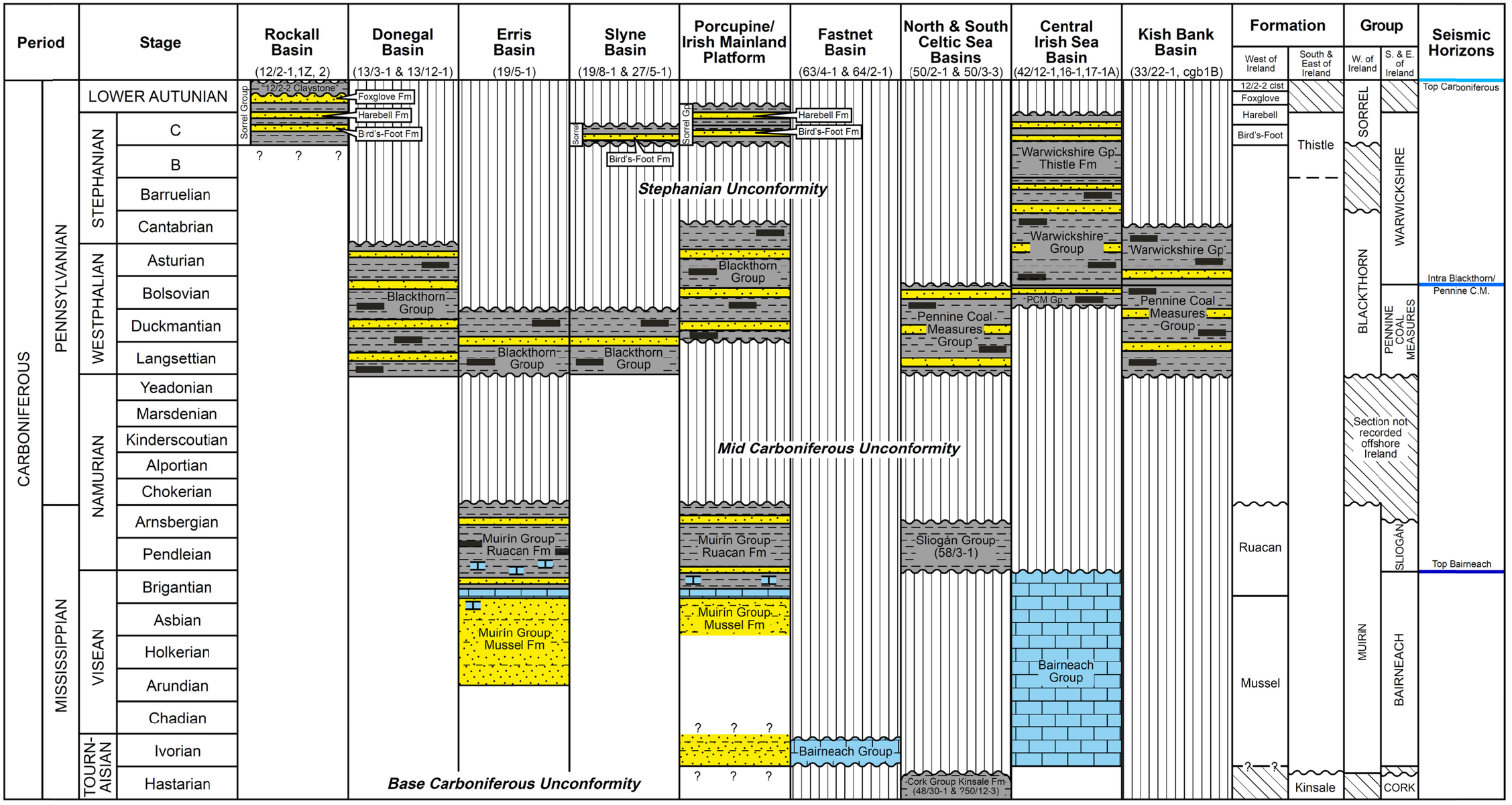


Figure D. 3.2. ***Carboniferous stratigraphy offshore Ireland***.

CARBONIFEROUS SEQUENCE STRATIGRAPHY

No sequence stratigraphic analysis has been carried out on the Carboniferous interval. This is due primarily to the small number of well and borehole penetrations of section of this age, combined with the general lack of complete successions over a sufficiently wide area to demonstrate the continuity of any stratigraphic packages recognized in individual sections. In addition, the seismic data in the Carboniferous is often of insufficient quality to provide a detailed sequence stratigraphy. Nevertheless, three unconformities are identifiable in the well successions and these are described below, without formalizing sequences between them.

Three seismic horizons have been recognised in this project in the Carboniferous succession, named here the Top Carboniferous, Carboniferous (Intra-Blackthorn/Pennine Coal Measures) and Carboniferous (Top Bairneach) horizons (see **Figure D. 3.2, Figure D. 3.4**). The Top Carboniferous horizon, which frequently equates to an unconformity above which considerably younger section sits, is identified in the Donegal, Slyne, Porcupine, Fastnet, Central Irish Sea and Kish Bank basins. In some areas it may merge with the Top Bairneach horizon. The Intra-Blackthorn/Pennine Coal Measures horizon is seen in the Porcupine Basin (e.g. well 34/5-1A) and Central Irish Sea Basin (e.g. 42/17-1A) and the Top Bairneach horizon is recognised in the Fastnet, Central Irish Sea and Kish Bank basins.

Stephanian Unconformity

A stratigraphic break is apparent between the Sorrel Group and the Blackthorn Group in the Slyne and Porcupine basins. At its minimum extent, this omits section of Pennsylvanian, Stephanian, Barruelian to Stephanian B in age.

Mid Carboniferous Unconformity

The presence of a major break at the Pennsylvanian/Mississippian junction is demonstrable in the Erris Basin 19/5-1 well, on the basis of the available biostratigraphic data. Here, the Muirin Group (Ruacan Formation), of Mississippian (Brigantian – Arnsbergian) age is overlain by Blackthorn Group sediments of Pennsylvanian (Langsettian – Duckmantian) age, omitting five substages of the Namurian (Chokierian – Yeadonian).

The development of this mid Carboniferous unconformity in offshore Ireland was noted by Tate & Dobson (1989) and Waters (2011), and was mentioned by Sevastopulo (2001), as the Serpukhovian/Pennsylvanian unconformity. Robeson *et al*. (1988) also noted the lack of proven middle Namurian strata offshore Ireland.

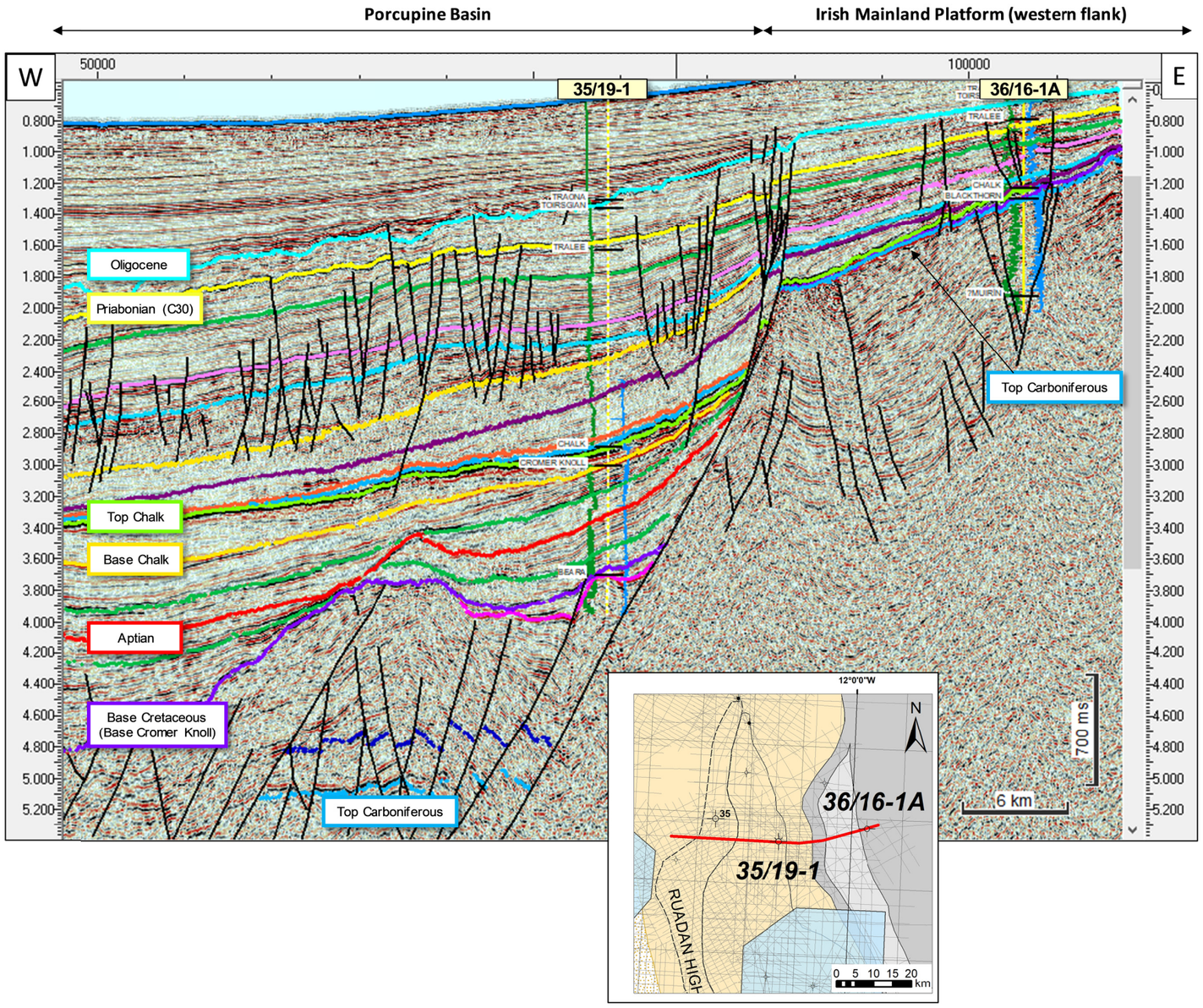
Floodpage *et al*. (2001) and Maingarm *et al*. (1999) have interpreted the presence of an equivalent intra-Carboniferous unconformity in the Central Irish Sea Basin between the Kidston Group (Stephanian – Westphalian; Warwickshire Group in the current study) and the Garwood Group (Dinantian, Mississippian; Bairneach Group in the current study), and also in the Solway and Peel basins at the same level. This break is recognised in the 42/17-1A well between the Pennine Coal Measures Group (Westphalian) and the Bairneach Group (Tournaisian – Visean) in the current study, although no angular discordance is apparent on seismic data across this boundary (see **Figure D. 3.4)**. This break is shown in the Carboniferous well correlation panel (Figure D.3.7) where the unconformity can be correlated between the 19/5-1 well (at the Blackthorn Group/Muirín Group boundary) and the 42/17-1A well (at the Pennine Coal Measures/Bairneach Group boundary). An equivalent break can be postulated at the Blackthorn/Muirín group boundary in the 36/16-1A well, and in the North and South Celtic Sea basins between the Pennine Coal Measures and Sliogán groups.

The Top Bairneach seismic horizon approximates to this unconformity both in the 42/17-1A well (Central Irish Sea Basin), and also in the 55/30-1 well (Fastnet Basin) well, where a truncated Bairneach Group section (of early Mississippian, Tournaisian, Ivorian, age) occurs unconformably beneath Triassic Sherwood Sandstone Group sediments (see **Figure D.2.2**).

A correlative Mid Carboniferous unconformity, omitting all but the basal part of the Namurian, has also been reported from onshore Nova Scotia, Eastern Canada by Utting *et al.* (2010) indicating a regional expression of this break across the North Atlantic region.

Base Carboniferous Unconformity

The contact between the Mississippian (Bairneach Group) and the underlying Devonian Darrig Formation is penetrated in the Fastnet Basin 55/30-1 well. This is a sharp contact between Darrig Formation sandstone and claystones and Bairneach Group limestones, which is likely to represent an unconformity. This is supported by the absence at the well of the lowermost Tournaisian (Hastarian) Kinsale Formation (Cork Group) that is proven to be present in the 48/30-1 well in a position stratigraphically beneath the Bairneach Group.



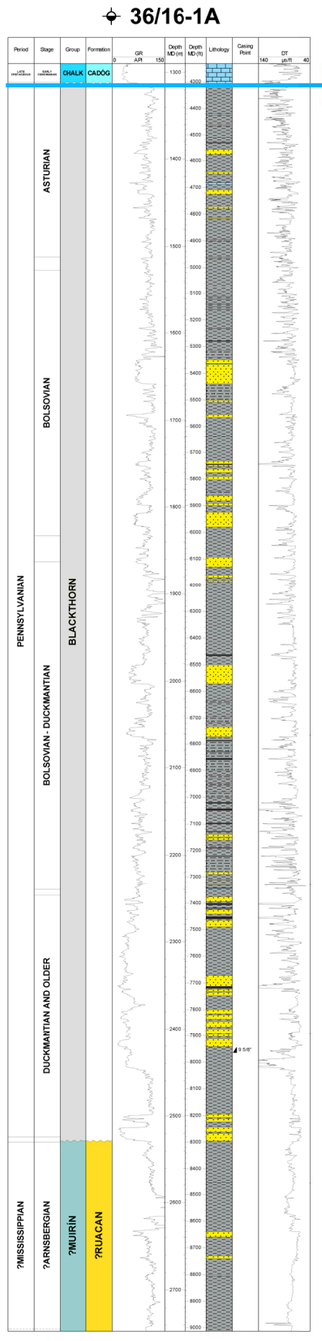


Figure D. 3.3. ***Seismic lines across flank of Porcupine Basin and Irish Mainland Platform to show Carboniferous succession and tie to 36/16-1A well. 2D Seismic line PW93-304.***

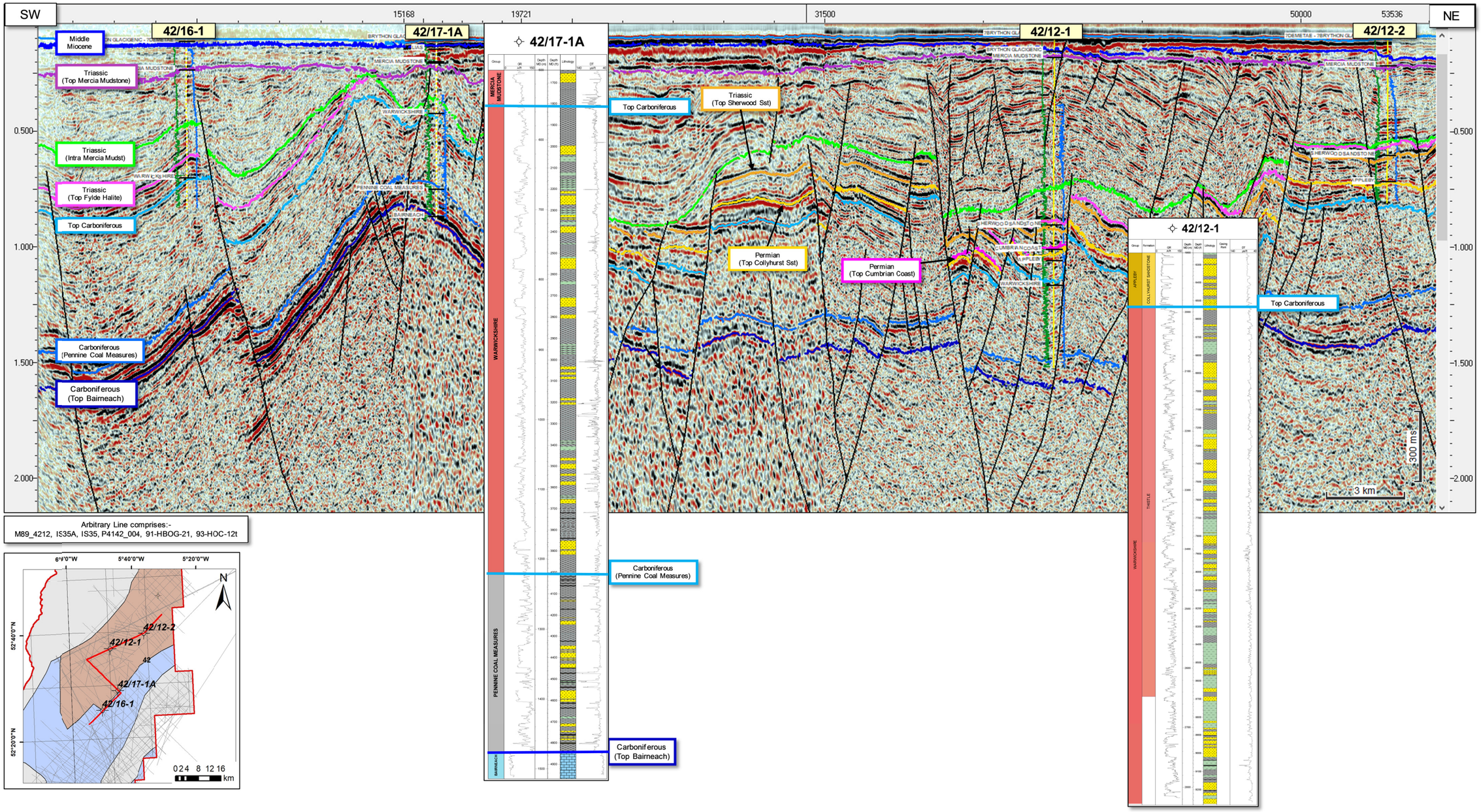


Figure D. 3.4. ***Seismic line and wells in Central Irish Sea Basin showing the Carboniferous – Triassic succession and tie to the 42/12-1 and 42/17-1A wells. Arbitrary line comprises M89_4212, IS35A, IS35, P4142_004, 91-HBOG-21, 93-HOC-12t.***

CARBONIFEROUS PALAEOFACIES DISTRIBUTION

The interpreted distribution of Carboniferous palaeofacies offshore Ireland is illustrated in **Figure D. 3.5.** with reference to the Mississippian. This map shows the distribution of the Bairneach Group and overlying Sliogan Group in the Kish Bank (?), Central Irish Sea, North Celtic Sea and Fastnet basins. Within this area, sedimentation is limestone dominated, particularly in the Bairneach Group. The occurrence of limestone lithologies, yielding common crinoids, foraminifera and conodonts is indicative of a warm water, shallow marine, carbonate-rich environment. Based on seismic interpretation, sediments of this group are considered to extend from the Fastnet Basin, across the Celtic Platform and into the Goban Spur Basin.

In contrast, in western offshore Ireland basins, for instance the Porcupine Basin, sediments are referred to the Muirín Group typified by interbedded sandstones and claystones, but with thin limestones. The depositional setting is considered to have ranged from continental (Mussel Formation), possibly alluvial fan, through marginal marine to inner shelf marine (Ruacan Formation). The arenaceous units of the Ruacan Formation suggest deposition in a continental to marginal marine environment, while the limestones are indicative of warm water, shelfal marine environments.

These sediments are believed to extend into the western part of the Irish Mainland Platform, based on the presence of the Muirín Group in the 36/16-1A well (see above and below for discussion, and **Figure D. 3.3**). Sediments of this group are also present in the 19/5-1 well (Erris Basin) where they are sandstone dominated.

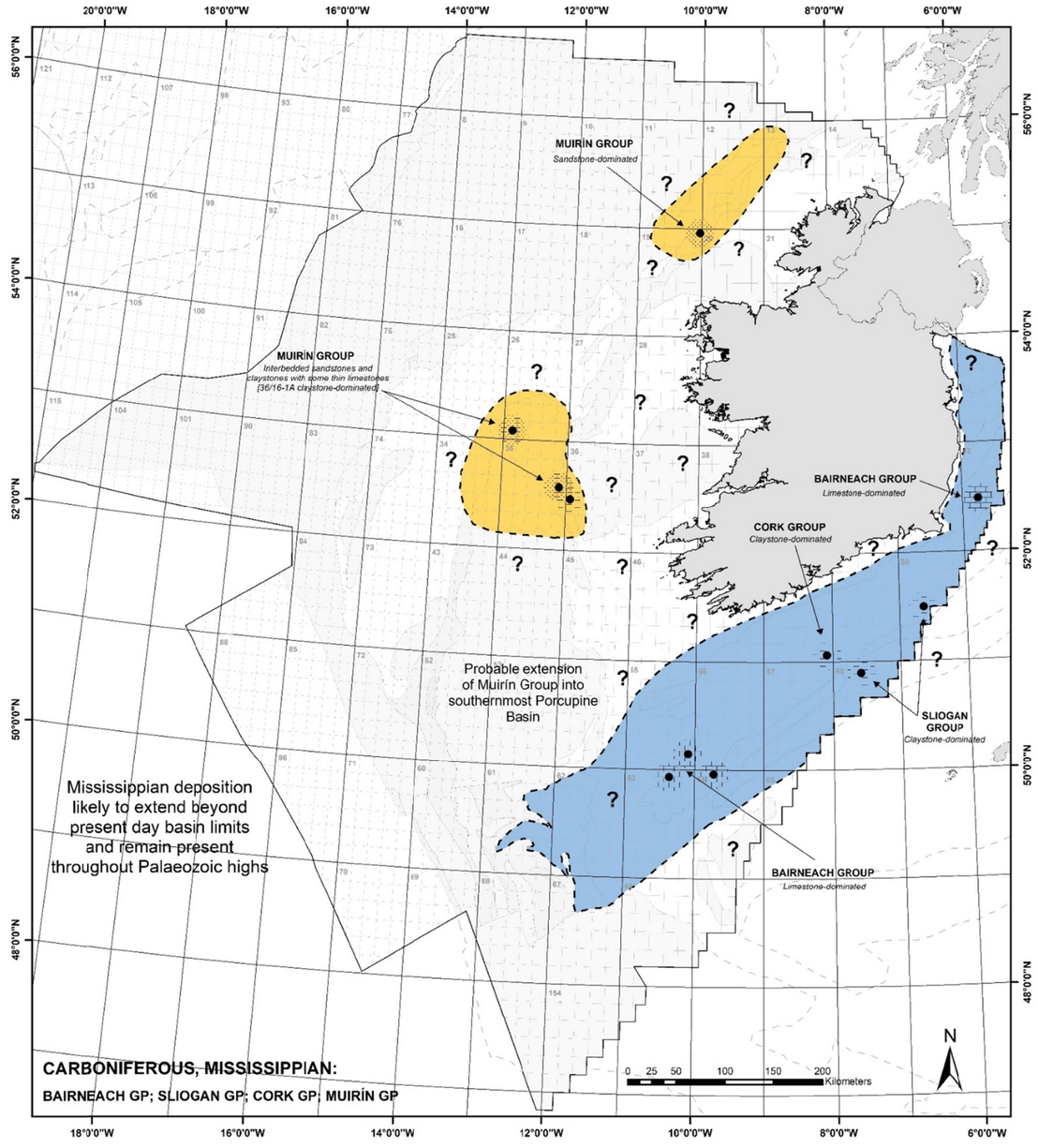


Figure D. 3.5. ***Mississippian palaeofacies map, offshore Ireland.***

CARBONIFEROUS LITHOSTRATIGRAPHIC SUBDIVISIONS

No formal lithostratigraphic scheme has previously been defined for the Carboniferous rocks of offshore Ireland. The lithostratigraphic subdivision that is applied here to the Carboniferous of the area combines existing terminology that has been defined for the UK onshore region (e.g. Powell *et al*., 2000; Waters *et al*., 2009; Wakefield *et al*., 2016) and extended into the East Irish Sea Basin offshore area, for example by Jackson & Johnson (1996). Due to the strong similarities between the East Irish Sea succession and those of the Kish Bank and Central Irish Sea basins, the UK terminology has been extended here into these two basins in offshore Ireland.

For offshore areas that are further afield, however, it has been necessary, in most instances, to erect new terminology for most of the Carboniferous succession, for instance the new Sorrel, Blackthorn, Muirín, Sliogán and Bairneach groups, with their constituent new formations. This is due to the lithological differences and lack of demonstrable subsurface continuity across the region. In only one instance, that of the Cork Group (Kinsale Formation) has a Carboniferous lithostratigraphic unit that is recognizable onshore Ireland been applied in the offshore area. For several of the groups, no age equivalent rocks are known from onshore Ireland, for instance, the Sorrel Group. The geographic distributions of these groups are shown in Figure D.3.6. Coeval groups are shown on the same maps in this figure.

A correlation of key wells across the offshore Ireland area is shown in **Figure D. 3.7** and illustrates the new subdivisions of the Carboniferous and their lateral relationships.

New Carboniferous lithostratigraphic units are named after native Irish plants (Pennsylvanian) and shellfish (Mississippian). Pennsylvanian formation names were selected for native Irish plants, which also contain the name of an animal. For the Stephanian, the flowers chosen are typically red-pink-purple to reflect the red bed nature of this stratigraphic interval. In the Mississippian, new lithostratigraphic units are named after shellfish.

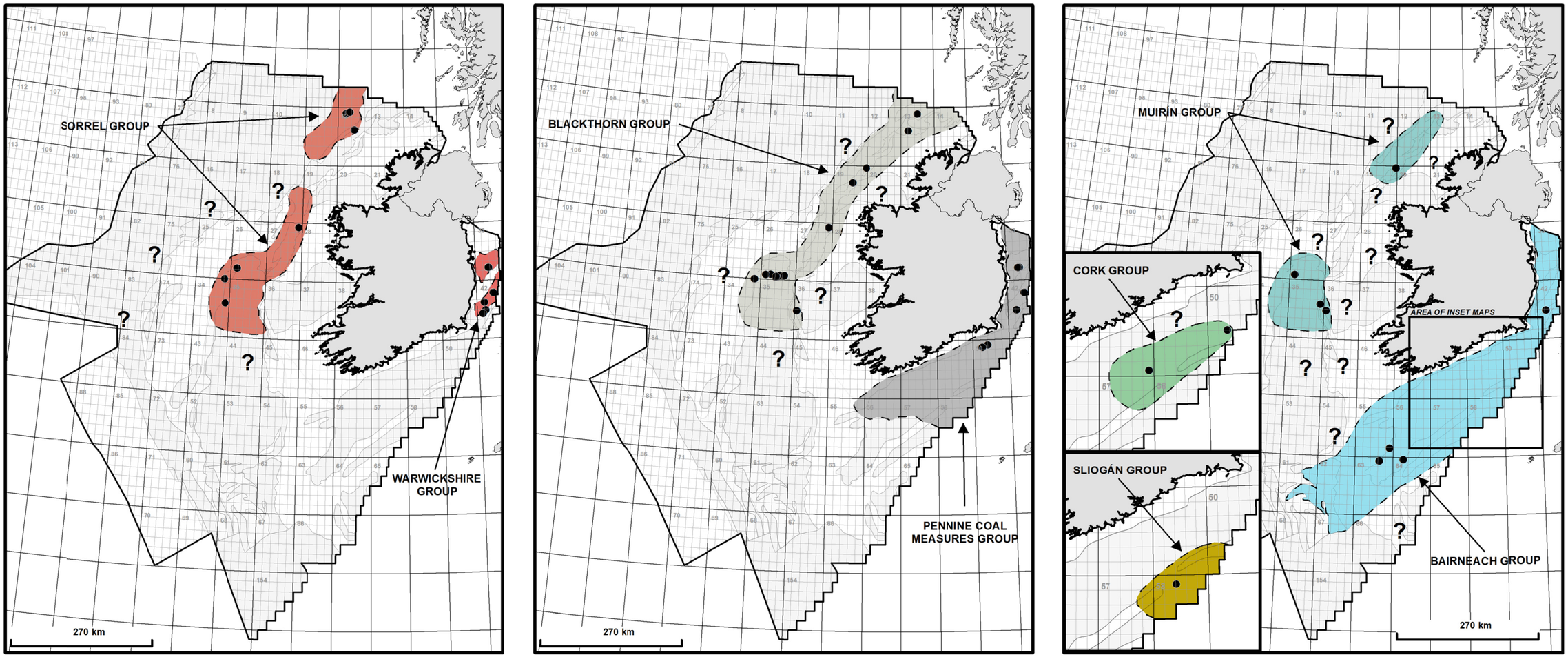


Figure D. 3.6. ***Carboniferous lithostratigraphic group distributions, offshore Ireland. Black dots represent proven well and borehole penetrations***.

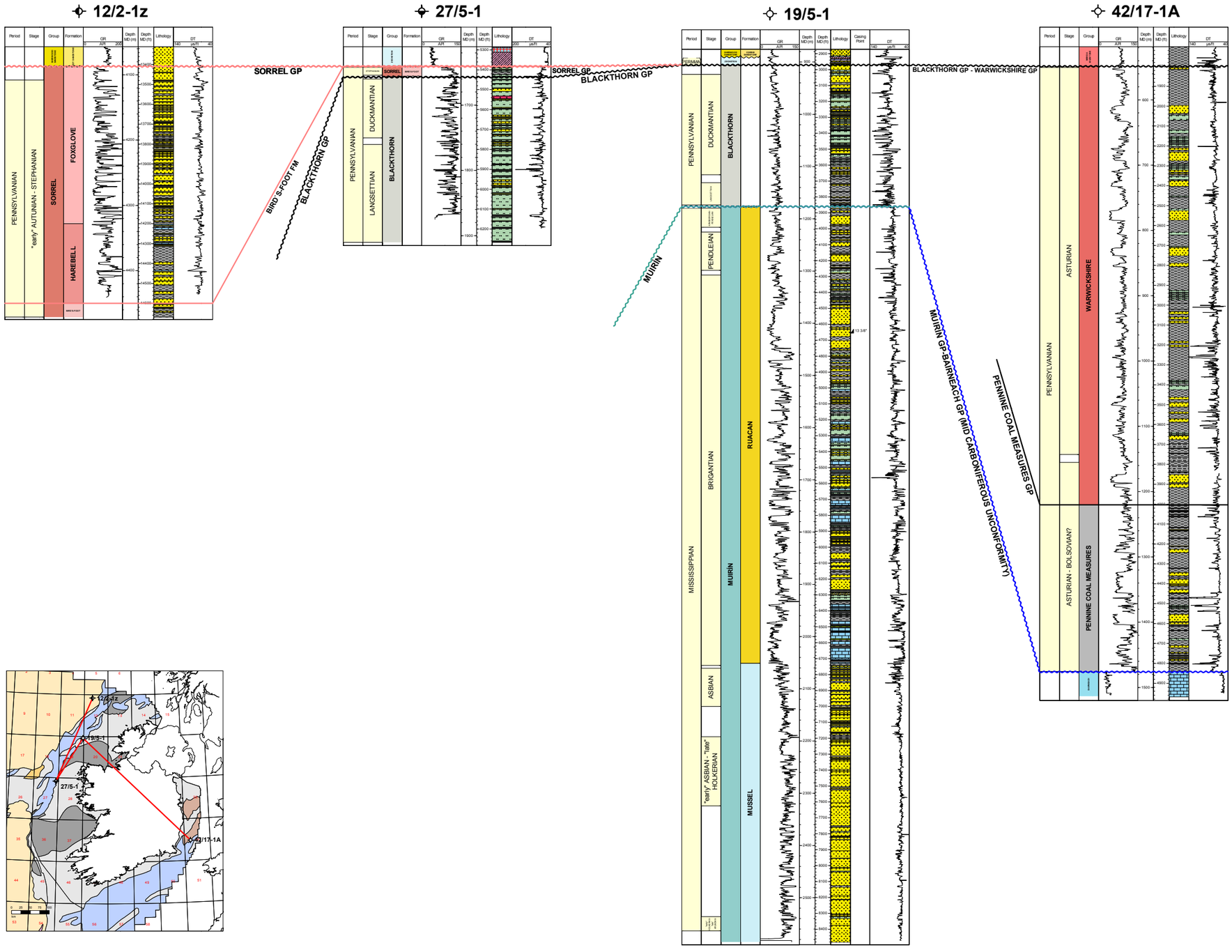


Figure D. 3.7. ***Correlation of key Carboniferous well sections, offshore Ireland, 12/2-1Z, 27/5-1, 19/5-1, 42/17-1A.***

SORREL GROUP (NEW)

The Sorrel Group is introduced here for a succession of varicoloured (primarily red, secondarily grey), argillaceous and arenaceous rocks of Carboniferous, Pennsylvanian, "early" Autunian to Stephanian C, age, located in the Porcupine, Slyne, Erris, Donegal and Rockall basins. No equivalents to these rocks are known from onshore Ireland.

Three new formations are proposed; in descending stratigraphic order; Foxglove Formation, Harebell Formation and Bird's-Foot Formation. An informal thin argillaceous unit ("12/2-2 Claystone") has also been recognised, which unconformably overlies the Foxglove Formation.

Name. After the native Irish plant.

Reference sections. 12/2-1Z: 4087-4471m (TD) below KB. 12/2-2: 4374-4455m (TD) below KB. 26/21-1: 2030.5-2176m (TD) below KB. 34/15-1: 4000-4446.35m (TD) below KB. 27/5-1: 1640.5-1657m below KB. See **Figure D. 3.8**, **Figure D. 3.9**, **Figure D. 3.10**.

Lithology. The group comprises an interbedded succession of sandstones, siltstones and claystones, in association with rare coals and beds of limestones and anhydrite. The sandstones are off white to medium dark grey, very pale orange, brownish grey, olive grey, moderate reddish brown, fine to medium grained, locally coarse to very coarse grained, poor to well sorted, subangular to subrounded, locally feldspathic, micaceous or argillaceous and locally containing carbonaceous debris. The claystones and siltstones are varicoloured, ranging from light grey to dark grey, black, light greenish grey-greenish grey, greyish brown, dark brownish red, greyish red, moderate reddish brown to reddish brown, locally waxy or micaceous, non to slightly calcareous. Rare coal fragments, black, vitreous lustre, occur within some intervals. Rare black carbonaceous claystones and coal laminae are also noted. A number of limestones, cream, tan, light grey to dark grey, light to dark brownish grey, yellowish grey, red, mudstone to packstone, locally oolitic and/or bioclastic, micritic to cryptocrystalline, are also noted. Beds of white, clear crystalline, soft to brittle, anhydrite, rare sphaerosiderite nodules and mustard brown and dusky red iron nodules are locally recognised.

A downsection increase in grey colouration is recognised within the lower parts of the Bird's-Foot Formation.

Wireline log character. The group displays a highly serrated log profile, reflecting the interbedded nature of the lithologies. Many of the claystones exhibit high gamma ray values (100° API and 160° API), particularly within the Foxglove Formation.

Upper boundary. The top of the group is everywhere marked by an unconformity. At this boundary the juxtaposed lithologies and the resulting wireline log responses are extremely varied. The junction is placed at a marked downsection lithological change to varicoloured claystones, which are generally more indurated than the overlying unit. On wireline logs, the upper boundary is very variable due to the different rock units that unconformably overlie the group. The boundary may be taken at a downsection increase in gamma ray values, in association with a corresponding decrease in sonic velocity, as in the 27/5-1 and 26/21-1 wells, or at a decrease in gamma values in the 12/2 wells. In the 34/15-1 well, at its junction with the overlying Upper Jurassic Minard Formation, is not expressed by any significant change on wireline log criteria.

Lower boundary. The base of the group is only recognised in one well (27/5-1) where it unconformably overlies the Blackthorn Group. This junction is marked by a downsection lithological change from varicoloured claystones to the grey claystones of the Blackthorn Group. On wireline log criteria, the boundary is taken at a subtle downward increase in gamma ray values, in association with a corresponding slight decrease in sonic velocity.

Subdivision. A four-fold subdivision of this group is proposed. In descending order; Foxglove Formation, Harebell Formation and Bird's-Foot Formation. An informal thin argillaceous unit ("12/2-2 Claystone"), which conformably overlies the Foxglove Formation, is also recognised.

Biostratigraphic characterization. Palynomorph recovery from the Sorrel group is variable. Assemblages are dominated by miospores which have enabled the recognition of miospore zones within the range VC – N.B.M.

Age. Carboniferous, Pennsylvanian, "early" Autunian to Stephanian C.

Depositional environment. Continental to marginal marine, with local inner shelf intercalations. The presence of primary reddened beds, only rare coals, carbonaceous claystones and sphaerosiderite nodules, is suggestive of deposition in a dry arid climate. Sediment deposition is considered to have taken place in low lying coastal alluvial swamps depositional environment, with caliche palaeosols, locally derived molasses, overbank deposits and distal ephemeral rivers. The presence of coals and limestones (locally oolitic) is suggestive of minor marine incursions.

Distribution. To date the Sorrel Group has been recorded from the Rockall Basin (Block 12/2), Erris Basin (12/13-1A), Slyne Basin (27/5-1) and the Porcupine Basin (three wells).

Seismic expression. The Top Carboniferous seismic horizon ties to the top of the Sorrel Group in the 12/2 block wells and in the 34/15-1 well. The group overall has no distinctive seismic character.

Regional correlation. Precise correlation of the Sorrel Group with rocks assigned to the Warwickshire Group, Thistle Formation, of the Central Irish Sea basin is severely hampered by the lack of biostratigraphic control, however, the group is thought to correlate with the uppermost part of the Warwickshire Group (which is dated as Stephanian C age in the 42/16-1 well in the Central Irish Sea Basin). Age equivalents of this group are not recognised onshore Ireland or in the UK onshore or East Irish Sea Basin.

Comparison with Eastern Canada. No Carboniferous, Pennsylvanian, "early" Autunian to Stephanian C aged successions have been recognised either onshore or offshore Newfoundland.

"12/2-2 Claystone"

This unit comprises the uppermost part of the Sorrel Group in the 12/2-2 well, above the Harebell Formation. The unit differs lithologically from the latter formation in comprising grey to greyish black silty claystones, whereas the Harebell Formation comprises sandstones and grey to red claystones. This claystone unit was previously dated as Permian by the operator of the well.

Type section. 12/2-2: 4374-4385m below KB. See **Figure D. 3.9**.

Lithology. This unit is dominated by dark grey to greyish black, micromicaceous, non-calcareous, silty claystones. Rare, stringers of grey, very fine to fine grained, well sorted, subangular, non-calcareous, sandstones are also noted.

Wireline log character. This unit displays a slight serrated log profile, reflecting the dominance of argillaceous lithologies.

Upper boundary. The top of the unit is marked by an unconformity. The top of this unit is placed at a downsection lithological change from the sandstones of the Sybil Formation, "12/2-2 Lower Sandstone Unit" to the silty claystones of the "12/2-2 Claystone". On wireline log criteria, the boundary is taken at a marked downward decrease in gamma ray values, in association with a corresponding increase in sonic velocity.

Lower boundary. The base of the unit is marked by an unconformity. The base of the unit is marked by a downsection lithological change from claystone to the sandstones of the Harebell Formation. On wireline log criteria, the boundary is taken at a marked downsection decrease in gamma ray values, in association with a corresponding increase in sonic velocity.

Thickness. 11m thick in the 12/2-2 well.

Biostratigraphic characterization. Dating of this unit is solely by miospores. The miospore assemblages from this unit indicate the *Vittatina costabilis* (VC) Zone (Clayton *et al*., 1977).

Age. Carboniferous, Pennsylvanian, "early" Autunian.

Depositional environment. Continental to marginal marine. The presence of grey claystones, which yield only miospores, is suggestive of deposition in a low-lying coastal swamp.

Distribution. To date the "12/2-2 Claystone" has only been recorded in the 12/2-2 well in the Rockall Basin.

Regional correlation. This unit represents the youngest Carboniferous rocks recorded in the Irish offshore area and as such no regional correlatives can be recognised.

Comparison with Eastern Canada. No Carboniferous, Pennsylvanian, Autunian, rocks are recognised either onshore or offshore Newfoundland.

Foxglove Formation (New)

The Foxglove Formation is defined for an interbedded succession of pale orange to grey sandstones and grey to red claystones of Carboniferous, Pennsylvanian, "early" Autunian, age. This unit lies between the "12/2-2 Claystone" and the Harebell Formation. This formation is only recognised in the Rockall Basin well 12/2-1 and its vertical sidetrack 12/2-1Z.

Name. After the native Irish plant.

Type section. 12/2-1Z: 4087-4328m below KB. See **Figure D. 3.8**.

Reference section. 12/2-1: 4078.5-4141m below KB. See **Figure D. 3.8**.

Lithology. This formation comprises an interbedded succession of very pale orange sandstones and commonly reddened claystones, in association with rare limestones and coal fragments. The sandstones are very pale orange, light brownish grey, light grey, fine to medium grained, locally coarse to very coarse grained, poor to well sorted, subangular to subrounded, locally feldspathic or argillaceous, and micaceous. The claystones are varicoloured, light grey, light greenish to grey-greenish grey, or more commonly dark brownish red, greyish red, reddish brown, locally waxy or micaceous, non to slightly calcareous. Rare stringers of soft limestone, light grey, mudstone and packestone may be present. Rare coal fragments, black, vitreous lustre are also observed.

The limited core data from the top of this formation in the 12/2-1z well exhibit common low angle cross stratification and minor ripple cross lamination within the sands.

Wireline log character. This unit displays a highly serrated log profile, reflecting the interbedded nature of the lithologies. The claystones exhibit high gamma ray values (between 100° API and 160° API).

Upper boundary. The top of the formation is marked by an unconformity (as seen in cores in the 12/2-1z well; Tyrell *et al.,* 2010). It is placed at a marked downsection lithological change from the clean sandstones of the Triassic Cot Sandstone Formation to the more heterogeneous sediments of the Foxglove Formation. On wireline log criteria, the boundary is taken at a significant downward decrease in gamma ray values, in association with a corresponding slight increase in sonic velocity.

Lower boundary. The base of the Foxglove Formation is marked by a downsection lithological change from the varicoloured claystone to slightly more prevalent grey claystone of the Harebell Formation. On wireline log criteria, the boundary is taken at a marked downsection decrease in gamma ray values, in association with a corresponding slight increase in sonic velocity.

Subdivision. No subdivision is recognised.

Thickness. The formation attains a thickness of 238m in the one well in which the upper and lower boundaries are seen, 12/2-1Z.

Biostratigraphic characterization. Dating of this unit is solely by miospores. Palynological recovery is poor to moderate throughout the well sections. Miospore assemblages suggest an age within the range of the *Vittatina costabilis* (VC) Zone to *Potonieisporites novicus-bharadwaji – Cheleidonites major* (N.B.M) Zone of Clayton *et al.* (1977).

Age. Carboniferous, Pennsylvanian, "early" Autunian.

Depositional environment. Continental to marginal marine. Sediment deposition is envisaged to have occurred in a low lying coastal alluvial swamp depositional environment. The occurrence of dominantly reddened sediments is indicative of deposition in a dry, arid climate. Caliche deposition is also envisaged to occur.

Distribution. This formation has only been recognised in the Rockall Basin wells 12/2-1 and 12/2-1Z (**Figure D. 3.8**). Its distribution is considered to possibly extend further to the south west along the south eastern margin of the Rockall Basin (**Figure D. 3.8**).

Regional correlation. Similar to the overlying "12/2-2 Claystone" unit, the Foxglove Formation comprises young Carboniferous (early Autunian) sediments, which have few regional correlatives both onshore and offshore UK and Ireland. Stephanian strata are largely absent within the British Isles, though Carboniferous, Pennsylvanian, early Autunian sediments are known from the Midland Valley of Scotland (Waters, 2011). Age equivalents of this formation are not recognised onshore Ireland or in the UK onshore or East Irish Sea Basin.

Comparison with Eastern Canada. No Carboniferous, Pennsylvanian, "early" Autunian aged sediments have been recognised either onshore or offshore Newfoundland.

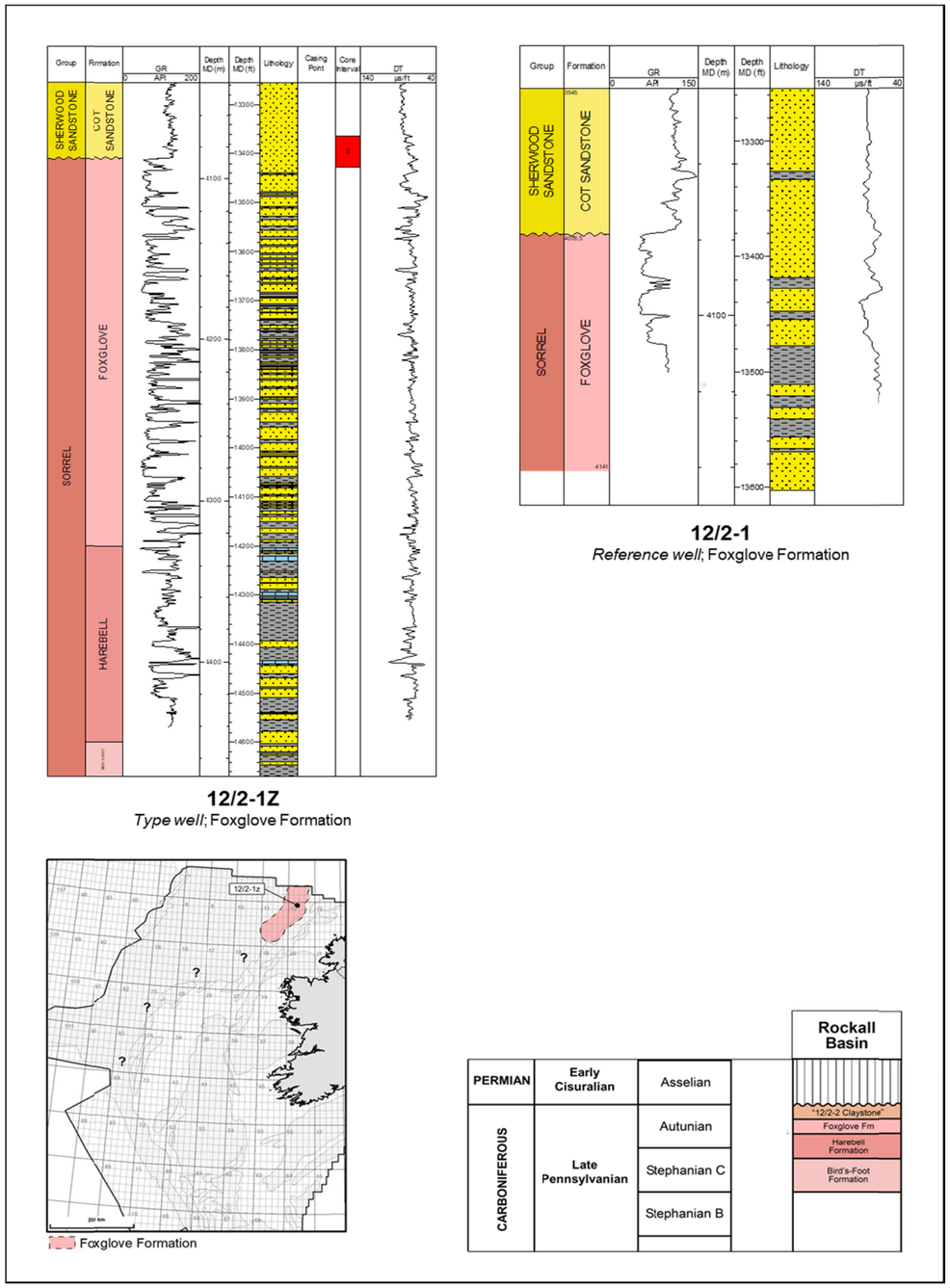


Figure D. 3.8. ***Foxglove Formation type and reference wells, with location and distribution map.***

Harebell Formation (New)

The Harebell Formation is defined here for an interbedded succession of varicoloured sandstones and often reddened claystones, in association with beds of limestone, of Carboniferous, Pennsylvanian, "early" Autunian to Stephanian C, age. This unit lies between the Foxglove Formation and the Bird's-Foot Formation. This formation is recorded from both the Rockall and Porcupine basins.

Name. After the native Irish plant.

Type section. 12/2-1z: 4328-4450m below KB. See **Figure D. 3.9**.

Reference sections. 12/2-2: 4385-4436m below KB. 34/15-1: 4000-4400m below KB. See **Figure D. 3.9**.

Lithology. This formation comprises an interbedded succession of sandstones and claystones, with subsidiary limestones. The sandstones are off white to grey, pale orange, light olive grey, moderate reddish brown, fine to medium grained, generally well sorted, subangular to subrounded, locally argillaceous, with rare carbonaceous debris, non-calcareous, and well indurated. The claystones and siltstones are varicoloured, light to dark grey, light greenish grey to greenish grey, moderate reddish brown to brick red, waxy, non to slightly calcareous. Rare black, carbonaceous claystones and coal laminae are also present. Beds of limestone, cream, tan, light to dark grey, mudstone to packestone, cryptocrystalline, are also recorded. In the 34/15-1 well the limestones exhibit packestone textures and are locally oolitic and/or bioclastic (bivalve debris), grading to dolomitic limestone. Beds of white, clear crystalline anhydrite, rare sphaerosiderite nodules, and mustard brown and dusky red iron nodules are also present in the 34/15-1 well.

Wireline log character. This unit possesses a highly serrated log profile, reflecting the interbedded nature of the lithologies. The claystones may exhibit high gamma ray values up to 160° API. Many of the sandstone units possess sharp erosive bases, with a number exhibiting either coarsening up or fining up profiles.

Upper boundary. The top of the formation is placed at a downsection lithological change from the varicoloured claystones of the Foxglove Formation to the slightly more prevalent grey claystones of the Harebell Formation. On wireline log criteria, the boundary is taken at a subtle downward decrease in gamma ray values, in association with a corresponding subtle increase in sonic velocity.

Lower boundary. The base of the formation is marked by a downsection lithological change from sandstone to the more prevalent grey claystone of the Bird's-Foot Formation. On wireline log criteria, the boundary is taken at a marked downward increase in gamma ray values, in association with a corresponding decrease in sonic velocity.

Subdivision. No subdivision is recognised.

Thickness. The formation attains a maximum thickness of 400m in the 34/15-1 well, but only 51m in the 12/2-2 well (where the upper boundary is thought to be unconformable) and 120m in the type well, 12/2-1z (MD).

Biostratigraphic characterization. Dating of this unit is solely by miospores. This formation contains miospore assemblages indicative of the *Potoniesporites novicus-bharadwaji – Cheiledonites major* (N.B.M) Zone (Clayton *et al*., 1977.).

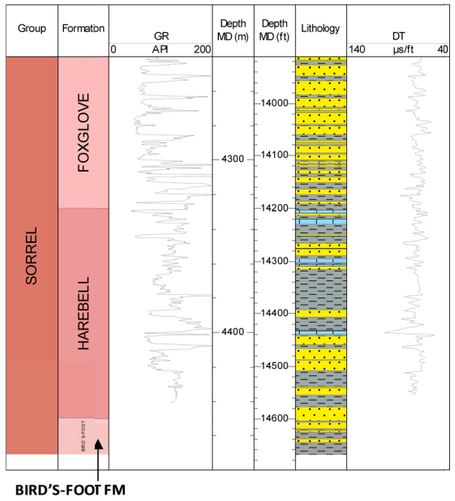
Age. Carboniferous, Pennsylvanian, "early" Autunian to Stephanian C.

Depositional environment. Continental to marginal marine, locally inner shelf. Deposition is envisaged to have taken place in a low lying coastal alluvial swamp environment. The occurrence of dominantly reddened sediments is suggestive of deposition in a dry arid climate, with local caliche formation. The presence of oolitic and bioclastic limestones, plus rare marine ostracods, is indicative of localised marine influences, most likely inner shelf, locally high energy due to the occurrence of oolitic limestones.

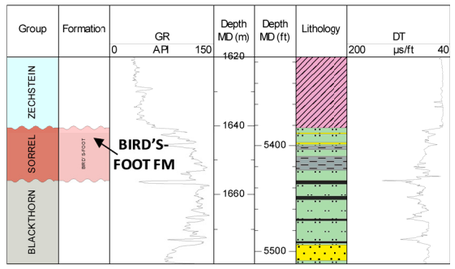
Distribution. The formation has been recorded from three wells, two in the Rockall Basin (12/2-1z and 12/2-2) and one in the Porcupine Basin (34/15-1). Its distribution may extend to the south west of the Rockall 12/2 area along the margin of the basin. The formation is considered likely to extend into the Porcupine Basin further south of the 34/15-1 well (**Figure D. 3.9**).

Regional correlation. The Harebell Formation is a lateral equivalent to uppermost part of the Warwickshire Group, Thistle Formation, of the Central Irish Sea Basin. Age equivalents of this formation are not recognised onshore Ireland or in the UK onshore or East Irish Sea Basin.

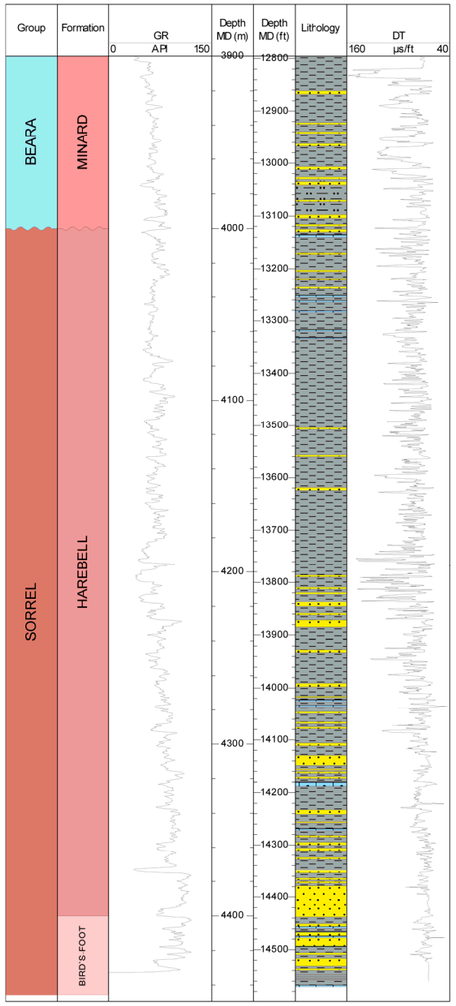
Comparison with Eastern Canada. No age equivalent succession is recognised in either onshore or offshore Newfoundland.



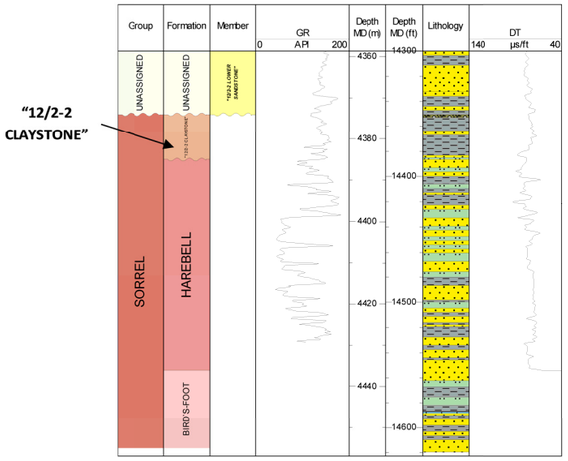
12/2-1Z
Type well; Harebell Formation, Bird's-Foot Formation



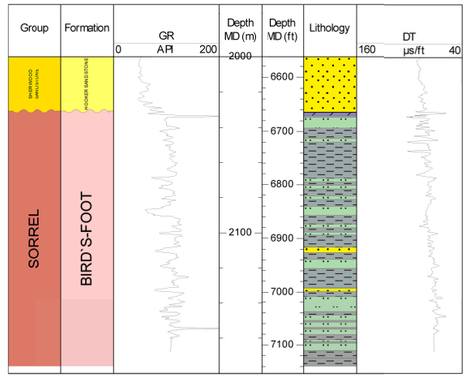
27/5-1
Reference well; Bird's-Foot Formation



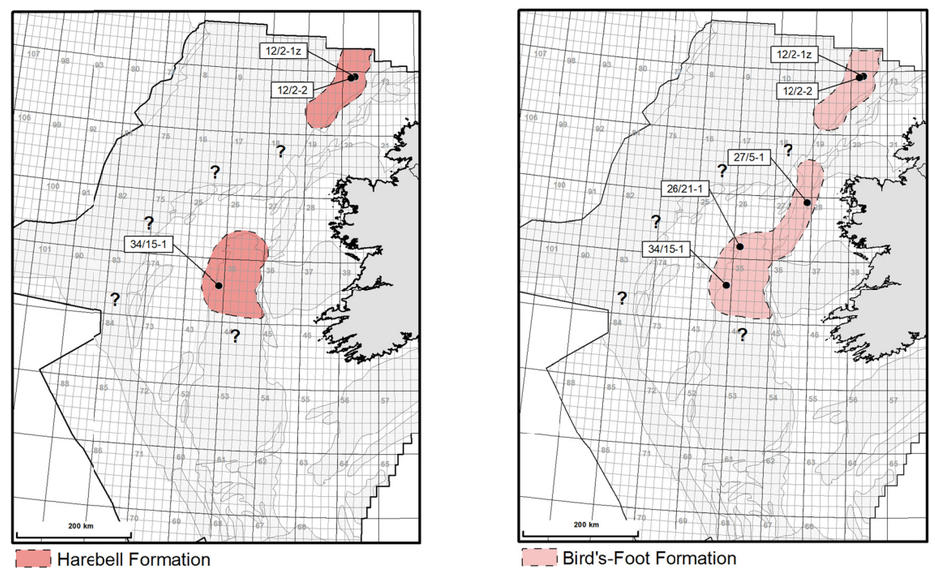
34/15-1
Reference well; Harebell Formation, Bird's-Foot Formation



12/2-2
Reference well; Harebell Formation, Bird's-Foot Formation.
Type well; "12/2-2 Claystone"



26/21-1
Reference well; Bird's-Foot Formation



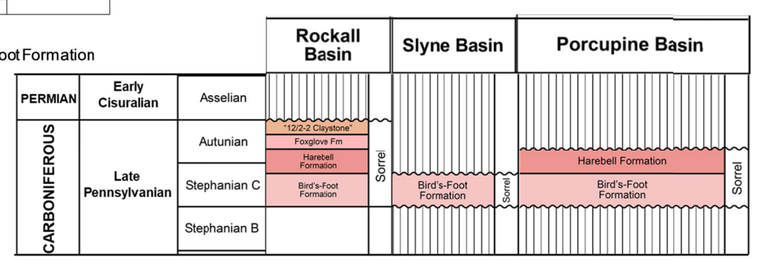


Figure D. 3.9. ***Harebell Formation and Bird's-Foot Formation type and reference wells with location and distribution maps.***

Bird's-Foot Formation (New)

The Bird's-Foot Formation is defined here for an interbedded succession of varicoloured sandstones and claystones, in association with beds of bioclastic and/or oolitic limestone, of Carboniferous, Pennsylvanian, Stephanian C, age, that occurs in the western offshore Ireland basins (Rockall, Slyne and Porcupine basins). This formation possesses greyer colouration than other formations within the group, which is more prevalent in the lower sections. This formation lies below the Harebell Formation.

Name. After the native Irish plant.

Type section. 26/21-1: 2030.5-2176m (TD) below KB. See **Figure D. 3.9**.

Reference sections. 34/15-1: 4400-4446.35m (TD) below KB. 27/5-1: 1640.5-1656m below KB. See **Figure D. 3.9**.

Lithology. This unit comprises an interbedded succession of varicoloured sandstones, siltstones, claystones and occasional limestones. The increase in grey colouration of the rocks is noticeable within this formation. The sandstones are off white to light grey, very fine to coarse grained, poor to well sorted, subangular to subrounded, micaceous, non to calcareous and moderately well to well indurated. The claystones and siltstones are off white, yellowish grey, medium light grey to dark grey, orange pink, pale red to dark reddish brown, greenish grey, locally waxy, and generally non-calcareous. Greyer argillaceous sediments are more prevalent in the lower part of the formation. Stringers of cream, red, mudstone to packstone, micritic to microcrystalline, locally oolitic or bioclastic (ostracodal) limestones are also developed.

Data from core 1 at the base of the formation in the 34/15-1 well exhibit few sedimentary structures, only localised lamination, burrowing and load marks.

Wireline log character. This unit displays a serrated log profile, reflecting the interbedded nature of the sandstone, claystone and limestone lithologies.

Upper boundary. The top of the formation is placed at a downsection lithological change from the sandstones of the Harebell Formation to the claystones of the Bird's-Foot Formation, reflected on wireline logs by a marked downward increase in gamma ray values and an associated decrease in sonic velocity.

Lower boundary. The lower boundary of the formation is recognised in only one well (27/5-1) offshore Ireland, where the formation unconformably overlies the Blackthorn Group. This boundary is developed as a downwards lithological change to siltstones and coals of the Blackthorn Group, which is expressed on wireline log criteria as an increase in gamma ray log values and a decrease in sonic velocity.

Subdivision. No subdivision is recognised.

Thickness. The formation attains a maximum observed thickness of 145m in the 26/21-1 well, however, in this well the basal boundary was not penetrated, as is also the case in many of the other well penetrations.

Biostratigraphic characterization. Miospore assemblages suggest a zonal assignment within the range from lower part of the *Potonieisporites novicus-bharadwaji-Cheiledonites major* (N.B.M) Zone to the *Angulisporites splendidus – Latensina trileta* Zone Clayton *et al*., 1977.)

Age. Carboniferous, Pennsylvanian, Stephanian C.

Depositional environment. Continental to marginal marine, locally inner shelf. The occurrence of reddened sediments strata in the upper intervals is suggestive of deposition in a dry arid climate, while downsection the sediments become consistently greyer in colour, indicating a less harsh arid climate. Sediment deposition is envisaged to have taken in a low lying coastal alluvial swamp depositional environment through to deposition within a delta top environment. Local caliche deposition is recognised. The rare occurrences of marine ostracods, oolitic and bioclastic limestones suggests periodic marine, inner shelf, influences.

Distribution. The formation has been recognised in three of the basins to the west of Ireland; the Rockall Basin (12/2-1z and 12/2-2), the Slyne Basin (27/5-1) and the Porcupine Basin (26/21-1 and 34/15-1). The formation is considered likely to extend into the Porcupine Basin further south of the 34/15-1 well (**Figure D. 3.9**).

Regional correlation. The formation is most likely correlateable to the uppermost sediments of Warwickshire Group, Thistle Formation, within the Central Irish Sea Basin. Correlation is rendered difficult due to the presence of dominantly biostratigraphically barren reddened sediments. The youngest palynologically dated sediments in the central Irish Sea Basin are of Pennsylvanian, Stephanian C age in well 42/16-1. Age equivalents of this formation are not recognised onshore Ireland or in the UK onshore or East Irish Sea Basin.

Comparison with Eastern Canada. The Bird's-Foot Formation has no lateral representatives on or offshore Newfoundland.

WARWICKSHIRE GROUP

The Warwickshire Group was defined by Powell *et al.* (2000) for those Carboniferous sediments which overlie the Pennine Coal Measures. The Warwickshire Group replaced a variety of earlier names for the succession of coal-barren red-beds such as Barren Coal Measures and Red Measures. The name is derived from the Warwickshire Coalfield, Pennine Basin, central England, where the group attains a maximum thickness (1225m). The group is also present in Lancashire, Nottinghamshire, South Yorkshire, South Wales, North Wales, the Forest of Dean and the Bristol area.

The depositional extent of the group was extended into East Irish Sea offshore area by Wakefield *et al*. (2016), replacing the upper part of the former Kidston Group that had been utilised by Jackson & Johnson (1996). This revision also allocated the lower part of the former Kidston Group to the Pennine Coal Measures in this basin. This usage is extended into the Kish Bank and Central Irish Sea basins of offshore Ireland in this report.

The succession in offshore Ireland predominantly comprises reddened argillaceous and arenaceous sediments of Pennsylvanian, Stephanian C to Westphalian, "late" Bolsovian, age. There are no lateral equivalents to these sediments onshore Ireland. In the offshore UK East Irish Sea Basin, the Warwickshire Group ranges no higher than Carboniferous, Pennsylvanian, Stephanian, Barruelian, in age. However, within the Central Irish Sea Basin, these reddened sediments range up to Carboniferous, Pennsylvanian, Stephanian C, in age. For this reason, this Pennsylvanian, Stephanian B to Stephanian C aged red beds unit is recognised as a new formation (Thistle Formation).

In onshore UK the boundary between the Warwickshire Group and the underlying Pennine Coal Measures Group is highly diachronous, with the onset of primary red bed deposition that defines the base of the Warwickshire Group, ranging in age from Westphalian, Bolsovian to Asturian (Waters *et al*., 2009).

Several authors have discussed the development of Pennsylvanian (Stephanian) red bed sediments in the Central Irish Sea Basin. Maingarm *et al*. (1999) referred to these sediments as the "Reddened Upper Carboniferous (RUC)" and the presence of this red beds succession was also documented by Floodpage *et al*. (2001) in the same basin.

The key sections for the group are from onshore wells and boreholes in North Wales (Wakefield *et al*. 2016).

Reference sections in offshore Ireland. 42/12-1: 1990-2827.6m below KB. 42/16-1: 1150-1451.2m (TD) below KB. See **Figure D.3.10.**

Lithology. The unit comprises an interbedded succession of sandstones and predominantly red claystones, with coals towards the base of the group. The claystones and siltstones are purplish brown, brownish grey, reddish brown to dark reddish brown, purple, locally light to dark grey, black, light greenish grey, and are mottled in part, locally silty, waxy, locally carbonaceous, and non to slightly calcareous. The sandstones are orangey red, light purple, reddish brown, light greenish grey, light to dark grey, olive grey, and are locally mottled, fine to coarse grained, locally pebbly, poor to well sorted, angular to rounded, partly argillaceous, partly anhydritic, loose to friable and non-calcareous to calcareous, and grade locally to argillaceous conglomerates. Rare dolomite and limestone, off white to light grey, yellowish brown, mudstone, micritic to cryptocrystalline, are also present. Rare coals and carbonaceous debris, black-greyish black, brittle fracture, are also observed.

An increase in grey and light greenish grey sediments, plus rare coals, in association with a decrease in reddened colourations occurs within the lower sections (Carboniferous, Pennsylvanian, Westphalian, Asturian, pre-Thistle Formation) towards the Warwickshire/Pennine Coal Measures group boundary.

Core data from the 33/22-cgb1B borehole show localised ironstone bands/nodules, very common seatearths, massive to locally laminated mudrocks containing rare shell debris, plant debris and rootlet developments. Rare thin coal laminations are also recognised. Core data from the 42/16-1 well exhibit a number of sedimentary features including poorly developed planar foresets, parallel lamination, climbing ripples both fining and coarsening upwards sand units, and small scale basal conglomerates with erosional bases.

Wireline log character. The group exhibits a highly serrated log profile, reflecting the interbedded nature of the sandstone and claystone lithologies. A number of sandstone beds exhibit sharp erosive bases, with some possessing coarsening up or fining up sedimentary profiles.

Upper boundary. The top of the group is everywhere marked by an unconformity. At this boundary the juxtaposed lithologies and the resulting wireline log responses are varied.

Lower boundary. The base of the group is placed at a marked downsection lithological change from predominantly reddened sediments of the Warwickshire Group to the dominantly greyer claystones and sandstones of the Pennine Coal Measures Group. On wireline log criteria, the boundary is taken at a subtle increase in gamma ray values, in association with a slight decrease in sonic velocity.

Subdivision. The Thistle Formation is recognised within the group.

Biostratigraphic characterization. Miospore zones N.B.M. to TP have been identified in the Warwickshire Group.

Age. Carboniferous, Pennsylvanian, Stephanian C to Westphalian, "late" Bolsovian. The lower part of the group, typified by the incoming of minor coals and grey sediments, is of Westphalian, Asturian, age.

Depositional environment. Continental to marginal marine. The occurrence of dominantly reddened sediments, with only very rare coal beds towards the base of the succession, indicates deposition in a dry arid climate Sediment deposition is envisaged to have taken place in distal alluvial fans, as caliche palaeosols in overbank deposits, locally derived molasses and fluvial distal ephemeral rivers.

Distribution. The Warwickshire Group has only been recorded from a small number of wells in the Central Irish Sea and Kish Bank basins.

Seismic expression. In the Central Irish Sea Basin, the group is developed as a unit of indistinct seismic character between the high amplitude stratified layers in the Triassic sediments above and the Pennine Coal Measures Group below (**Figure D. 3.4**). In this area, the top of the group equates to the Top Carboniferous seismic horizon, and the base of the group to the Pennine Coal Measures horizon (**Figure D. 3.4)**.

Regional correlation. The Warwickshire Group sediments occurring in the Central Irish Sea Basin are part equivalent in age to strata assigned to the Warwickshire Group in the East Irish Sea Basin (Waters *et al.,* 2011, Wakefield *et al.*, 2016, figure 2). The youngest Carboniferous sediments proven in the East Irish Sea Basin are of Pennsylvanian, Barruelian age, equivalent to the lower part of the Warwickshire Group in the Central Irish Sea Basin, whereas this group in the Central Irish Sea Basin ranges up into the Pennsylvanian, Stephanian C. The youngest Late Carboniferous sediments proven in the Kish Bank Basin are equivalent to the early part (Westphalian, Asturian – latest Bolsovian) of the Warwickshire Group in the East Irish Sea Basin, and England and South Wales (Waters *et al*., 2011).

Lateral equivalents to the upper intervals of the Warwickshire Group (Thistle Formation) comprise the lower part of the Sorrel Group (Bird's-Foot and Harebell formations) offshore west of Ireland.

Comparison with Eastern Canada. No age equivalent sediments are recognised in either onshore or offshore Newfoundland.

Thistle Formation (New)

The Thistle Formation is defined here for a succession of dominantly red sandstones and claystones, of Carboniferous, Pennsylvanian, Stephanian C to Stephanian B, age. This is younger than the upper age extent of the Warwickshire Group in the East Irish Sea Basin, hence, these previously unseen red beds are recognised as a new formation.

This unit has only been recorded from the Central Irish Sea Basin.

Name. After the prickly plant found throughout Ireland.

Type section. 42/12-1: 1990-2647m below KB. See **Figure D. 3.10**.

Reference section. 42/16-1: 1150-1310m below KB. See **Figure D. 3.10**.

Lithology. The formation comprises an interbedded succession of sandstones and predominantly reddened claystones. The claystones and siltstones are chocolate brown, brownish grey, reddish brown to dark reddish brown, purple, locally light grey, light greenish grey, locally silty, waxy, locally carbonaceous, and non to slightly calcareous. The sandstones are orangey red, light purple, reddish brown, yellowish brown, light greenish grey, light to dark grey, olive grey, very fine to fine grained, locally medium to coarse grained, locally pebbly, poor to well sorted, angular to subrounded, locally rounded, in part argillaceous, in part anhydritic, loose to friable, and non to calcareous. Rare dolomite and limestone, off white to light grey, light greenish grey, yellow brown to dark yellowish brown, mudstone, micritic to cryptocrystalline, are recognised. Rare coal fragments are also observed.

A slight increase in grey and light greenish grey sediments, in association with a slight decrease in reddened colourations occurs within the bottom sections of the group.

Wireline log character. The formation exhibits a highly serrated log profile, reflecting the interbedded nature of the sandstone and claystone lithologies. Many of the sandstone units possess sharp erosive bases, with a number exhibiting either coarsening up or fining up profiles.

Upper boundary. The top of the formation is everywhere marked by an unconformity. At this boundary the juxtaposed lithologies and the resulting wireline log responses are varied. It is either placed at a marked downsection change to reddened claystones (42/16-1) or to less silicified and less indurated sandstones (42/12-1). On wireline log criteria, the boundary is taken at an increase in gamma ray values, in association with a corresponding decrease in sonic velocity (42/16-1) or at a marked increase in resistivity values, in association with a corresponding decrease in sonic velocity (42/12-1).

Lower boundary. The base of the formation is placed at a marked downsection change from predominantly reddened lithologies to dominantly greyer claystones and sandstones. On wireline log criteria in the 42/16-1 well, the boundary is taken at a marked increase in gamma ray values, in association with a decrease in sonic velocity, while in the 42/12-1 well, the boundary is denoted by a marked decrease in gamma values and a coincident increase in sonic velocity.

Subdivision. No subdivision is recognised.

Thickness. The formation attains a thickness of 655m in the 42/12-1 well and 160m in 42/16-1.

Biostratigraphic characterization. No palynological evidence was recorded from the interval assigned to the formation in well 42/12-1 due to unfavourable lithologies for palynomorph recovery (reddened oxidised sediments). Miospores suggesting a *Potonieisporites novicus-bharadwaji – Cheiledonites major* (N.B.M) Zone are recorded from the 42/16-1 well.

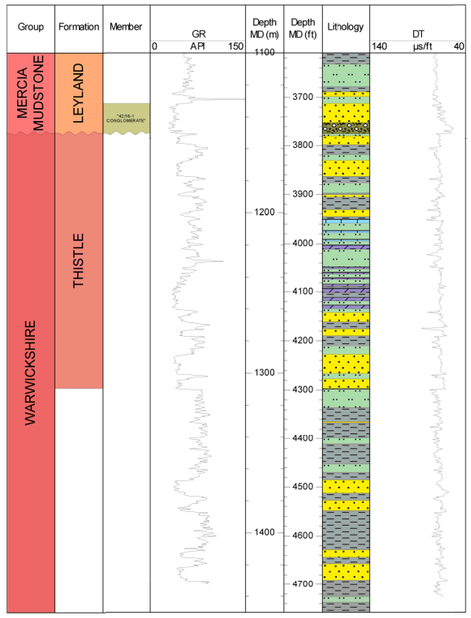
Age. Carboniferous, Pennsylvanian, Stephanian C to Stephanian B.

Depositional environment. Continental to marginal marine. The occurrence of dominantly reddened sediments, with only very rare coal fragments, indicates deposition in a dry arid climate Sediment deposition is envisaged to have taken place in distal alluvial fans, as caliche palaeosols in overbank deposits, locally derived molasses and fluvial distal ephemeral rivers.

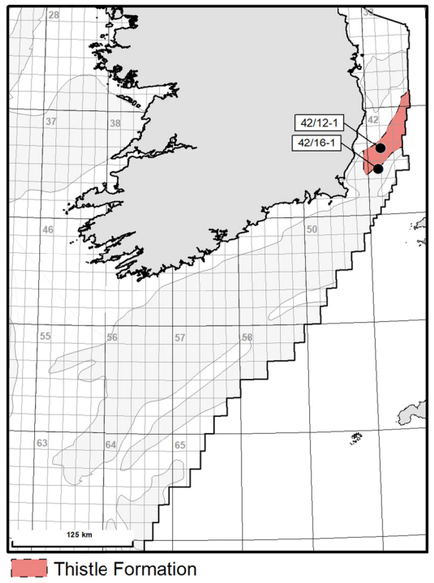
Distribution. The formation has been recorded from two wells (42/12-1 and 42/16-1) in the Central Irish Sea Basin and its extent is currently extrapolated to the limits of this basin (**Figure D. 3.10**).

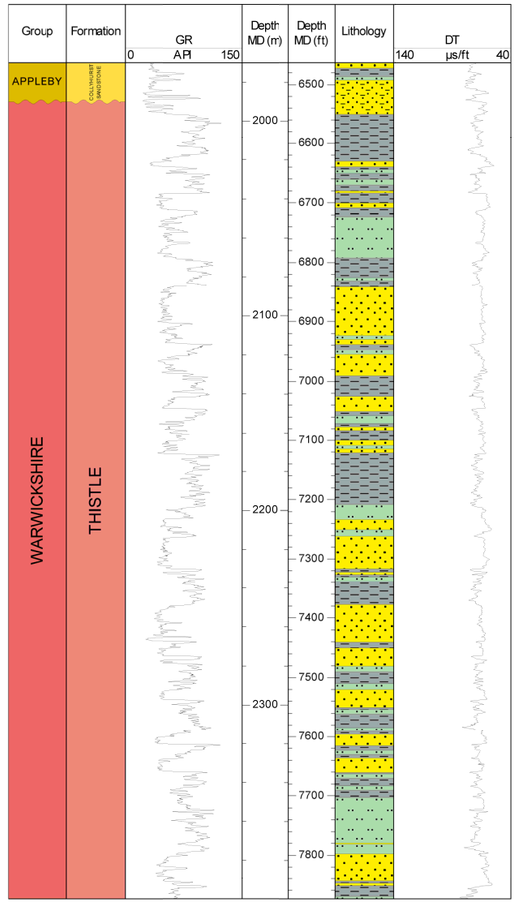
Regional correlation. The Thistle Formation is equivalent in age to strata of the lower part of the Sorrel Group (Bird's-Foot and Harebell formations) in the Rockall, Slyne and Porcupine basins west of Ireland.

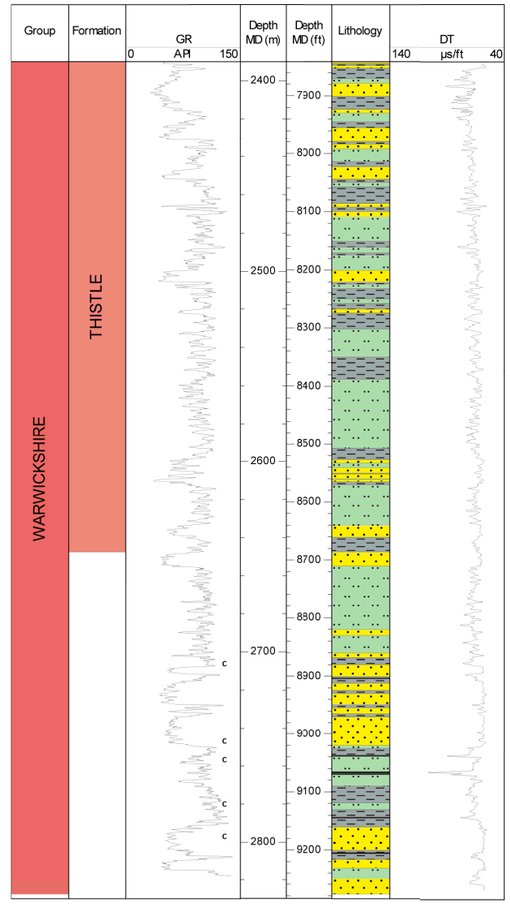
Comparison with Eastern Canada. No age equivalent sediments are recognised in either onshore or offshore Newfoundland.



42/16-1
Reference well; Thistle Formation







42/12-1
Type well; Thistle Formation

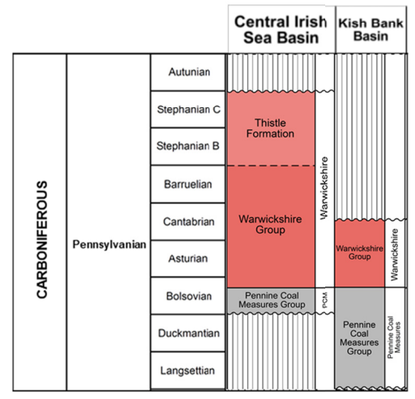


Figure D. 3.10. ***Thistle Formation type and reference wells with location and distribution map***.

BLACKTHORN GROUP (NEW)

The Blackthorn Group is defined here for Pennsylvanian age coal measures successions that are developed in the western Ireland offshore basins. These sediments, although partly contemporaneous with the Pennine Coal Measures Group that is developed in the Kish Bank, Central Irish Sea and North Celtic Sea basins, cannot be proven to be contiguous with the latter depositional areas, and therefore a new name has been applied for the western offshore Ireland areas.

The Blackthorn Group comprises a succession of grey, with less reddened, argillaceous and arenaceous sediments, in association with coal beds, of Carboniferous, Pennsylvanian, Stephanian, "early" Cantabrian to Westphalian, Langsettian, age, situated in Porcupine, Slyne, Erris and Donegal basins. The lower part of these successions (Carboniferous, Pennsylvanian, Westphalian, Duckmantian – Langsettian) have their lateral equivalents in Northern Ireland (Mitchell & Somerville, 2011).

Name. After the deciduous, thorny shrub found throughout Ireland. The name Blackthorn was also chosen to reflect the presence of coals within the group.

Type section: 36/16-1A: 1311.5-2528.38m below KB. See **Figure D. 3.11**.

Reference sections: 13/3-1: 378-1328.5m below KB. 26/28-1: 2735-3280m below KB. 27/5-1: 1657-1905m (TD) below KB. See **Figure D. 3.11**.

Lithology. This group comprises an interbedded succession of sandstones, siltstones and dominantly greyer claystones, plus a number of coal beds. Generally, the sedimentary successions are less reddened compared to the overlying Sorrel Group. The claystones are varicoloured, light to dark grey, brownish grey, greyish red, dark reddish brown, locally brownish black, locally silty, waxy, occasionally carbonaceous, non to slightly calcareous, grading to siltstone. The sandstones are off white to light grey, light greenish grey, olive grey, very pale orange, locally reddish brown, fine to medium grained, locally coarse grained, generally poorly sorted, angular to subrounded, locally feldspathic or argillaceous, non to calcareous. In both the 13/3-1 and 13/12-1 wells, the sandstones are locally tuffaceous. Beds and laminae of coal, black to brownish black, locally vitreous lustre, plus reddy brown and tan sphaerosiderite nodules are also recognised. Rare stringers of dolomite and limestone, medium light grey, light brownish grey, mudstone to packestone, sandy, and cryptocrystalline are noted in a number of wells.

Both the 13/12-1 and the 13/3-1 wells comprise the more sandstone dominated successions, and also sections which contain the greater number of coal units.

Cores exhibit a variety of sedimentological features including low angle cross, parallel and ripple lamination, localised bioturbation, rare plant debris and rare sandy lenses.

Wireline log character. Those wells in the more northerly parts of the Porcupine Basin (e.g. in block 26/28, including the 26/28-1 reference well) display less serrated wireline log profiles, due to the dominantly claystone lithologies, compared to their counterparts located in the Donegal (e.g. 13/3-1 well), Erris and western Irish Platform Margin (e.g. 36/16-1A well) which possess more serrated log profiles, reflecting the increase in arenaceous and coal units within their successions. A number of these sandstone units display sharp erosive bases, with both coarsening up or fining up log profiles.

Upper boundary. The top of the group is everywhere marked by an unconformity. At this boundary the juxtaposed lithologies and the resulting wireline log responses are highly varied. The junction is placed at a marked downsection lithological change to varicoloured, non-calcareous, generally well indurated, claystones, locally containing carbonaceous specks/debris, of the Blackthorn Group. On wireline log criteria, the boundary is generally taken at an increase in gamma ray values, in association with a corresponding decrease in sonic velocity.

Lower boundary. The base of the group is marked by an unconformity. At this boundary the juxtaposed lithologies and the resulting wireline log responses are again highly varied. Where the group overlies the Muirín Group, the boundary is placed at a downsection lithological change to grey silty claystones/siltstones, which are generally more indurated than the overlying sediments. On wireline log criteria, the boundary is taken at an increase in gamma ray values, in association with a corresponding decrease in sonic velocity.

Subdivision. No subdivision has been recognised.

Thickness. The group attains a maximum thickness of 1217m in the type well, though can be considerably thinner than this due to the presence of unconformable upper and lower boundaries.

Biostratigraphic characterization. This group has been dated using miospore assemblages. The miospore assemblages allow for the recognition of the palynomorph zones ranging from the *Thymospora pseudothiesseni* Zone (TP), *Angulisporites splendidius* Subzone (AS) to the *Dictyotriletes probireticulatus* Zone (DP) of Clayton *et al*. (2003).

Age. Carboniferous, Pennsylvanian, Stephanian, "early" Cantabrian to Westphalian, Langsettian.

Depositional environment. Continental to marginal marine, with episodic marine incursions. The depositional environment is envisaged to be a lower to upper deltaic flood plain in the lower intervals of the group, grading upwards to delta top and swamp in the upper sections. A variety of environments is recognised in the lower intervals, with sandstones deposition as interdistributary channelized sands, and the carbonaceous siltstones, claystones and coals formed in interdistributary swamps, lakes and overbank floodplain deposits. The localised coarsening up cycles within the sandstone are suggestive of prograding pro-delta deposits. Coal deposition is common. The presence of rare marine ostracods and acritarchs indicates thin sporadic marine incursions within the lower successions. Red bed deposition is also recognised, suggesting oxidation, and possible periods of emergence and/or aridity.

Within the upper sections of the group, sedimentary deposition progressively changes to more prograding coal bearing delta top, localised swamps, fluvial and mouth bar, deposits. A decrease in coal deposition towards the top of the group is suggestive of a dryer, more arid depositional environment. The presence of more reddened claystones is indicative of palaeosols, periodic aridity, better drainage with local emergence and local oxidation. The occurrence of marine ostracods and acritarchs indicates localised marine incursions, more so within the 34/5-1 and 36/16-1 well areas.

Distribution. The group is widely distributed within the west of Ireland offshore area, occurring in the Donegal, Erris, Slyne, Porcupine basins, together with the Porcupine High and the western margin of the Irish Mainland Platform (**Figure D. 3.10**). Its depositional area extends beyond the limit of the Porcupine Basin, being proven in the 34/5-1 well (Porcupine High) and in western Irish Mainland Platform well 36/16-1A (see **Figure D. 3.3**). It is possible that the group extends to the east of the latter well, however, available seismic data are poor in this area and extrapolation into this area is therefore very uncertain.

Seismic expression. In some areas, the Top Carboniferous seismic horizon ties to the top of the Blackthorn Group, as in the 36/16-1A type well (see **Figure D. 3.3**) and wells in the 26/28 block, including 26/28-1 and 26/28-2 (see **Figure D.1.3**). In these areas, the group displays no particularly distinctive internal seismic facies character, however, other than weakly expressed horizontal layering laterally from the 36/16-1A well.

In addition, a further seismic horizon has been identified, named the Carboniferous (Intra Blackthorn/Top Pennine Coal Measures) horizon, which falls within the Blackthorn Group in the Porcupine Basin, for example in the 34/5-1A well. The correlative horizon falls at the top of the Pennine Coal Measures Group in the Central Irish Sea and Kish Bank basins.

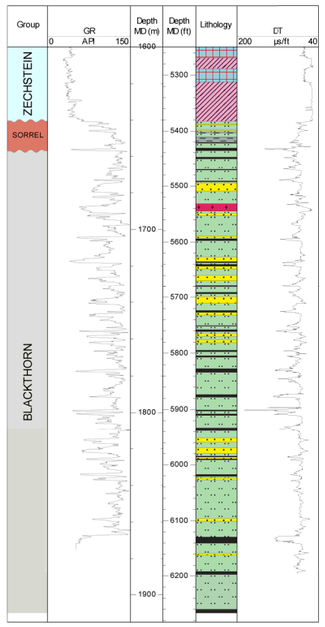
Regional correlation. The Blackthorn Group is the equivalent of the lower part of the Warwickshire Group and the Pennine Coal Measures Group of the North Celtic Sea, Central Irish Sea, Kish Bank and East Irish Sea basins. The lower sediments of the Blackthorn Group are also laterally equivalent to the Slievebane Group and Coal Measures of Northern Ireland (Mitchell & Somerville, 2007).

Source rock characterisation. The group appears to be geochemically heterogenous (Error! No bookmark name given.). Besides a range of samples with low TOC contents, there is a large number of organic-rich to coaly intervals present throughout the different basins. Very organic-rich to coaly samples are mainly seen in wells from the Porcupine and Slyne basins, whereas TOC contents in the western Irish Mainland Platform and Donegal Basin are comparatively lower.

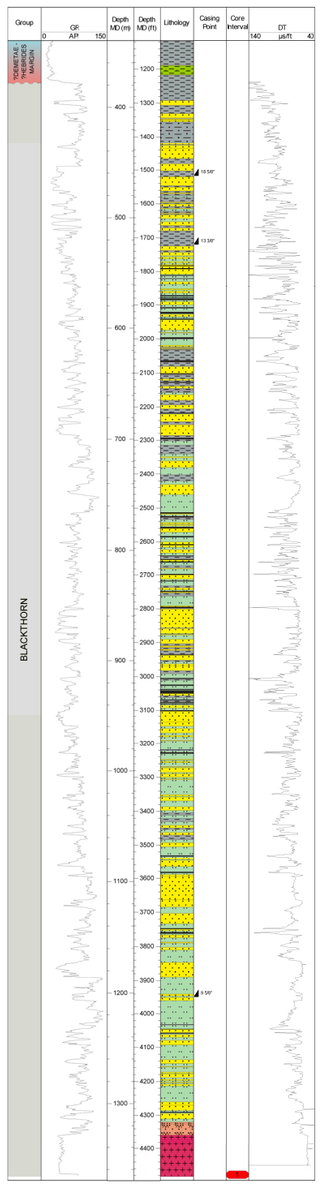
In the Porcupine and Slyne basins the group displays a Type II/III kerogen composition, with some samples showing a more Type II kerogen characteristics, and elevated HI values indicate mainly mixed oil and gas generation potential. In the western

Irish Mainland Platform and Donegal basins samples are characterised by low hydrocarbon yields, thus suggesting only poor source rock potential. Samples from the western Irish Mainland Platform in particular (36/16-1A well) show very high Tmax, vitrinite reflectance and spore colour index (SCI) values indicating high maturities. As a result of the high maturity in this well, the measured, present day source potential has decreased, and samples are likely to have originally had higher TOC and particularly HI values, potentially similar to samples in the Porcupine and Slyne basins. A plot of TOC and HI values through the group is shown in the Porcupine Basin 26/27-1B well (**Figure D. 3.13**).

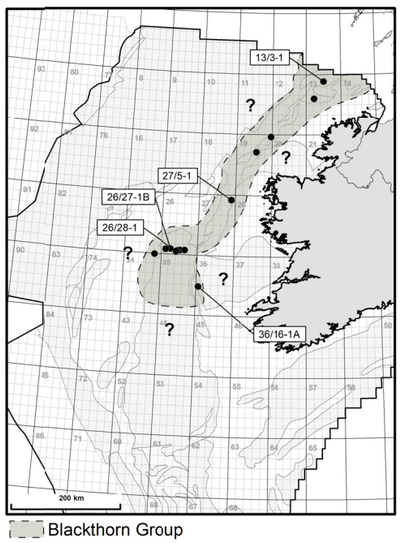
Comparison with Eastern Canada. The group is in part age equivalent to the Pictou Group in onshore western Newfoundland and in the offshore East Newfoundland Basin, which comprises sandstones and claystones, with associated coal beds (Knight, 1992; Mossman, 1992; Giles & Utting, 2004; Utting & Giles, 2008). The Barachois Group ranges no younger than Pennsylvanian, Westphalian, Bolsovian.



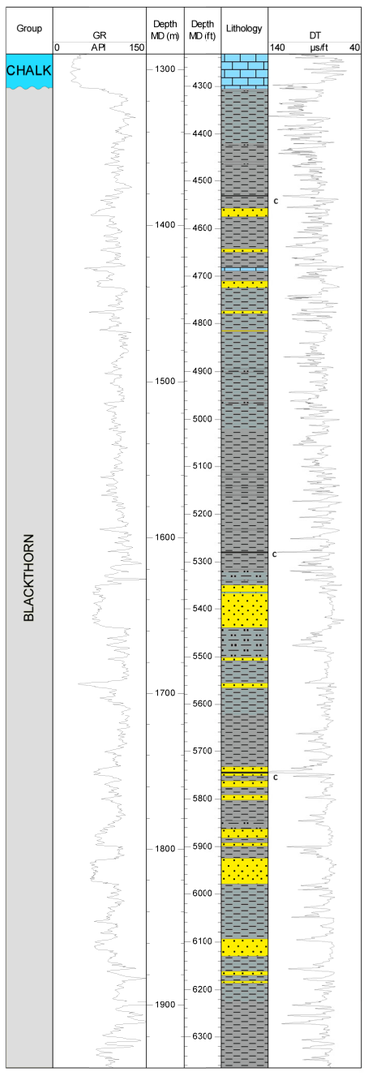
27/5-1
Reference well; Blackthorn Group

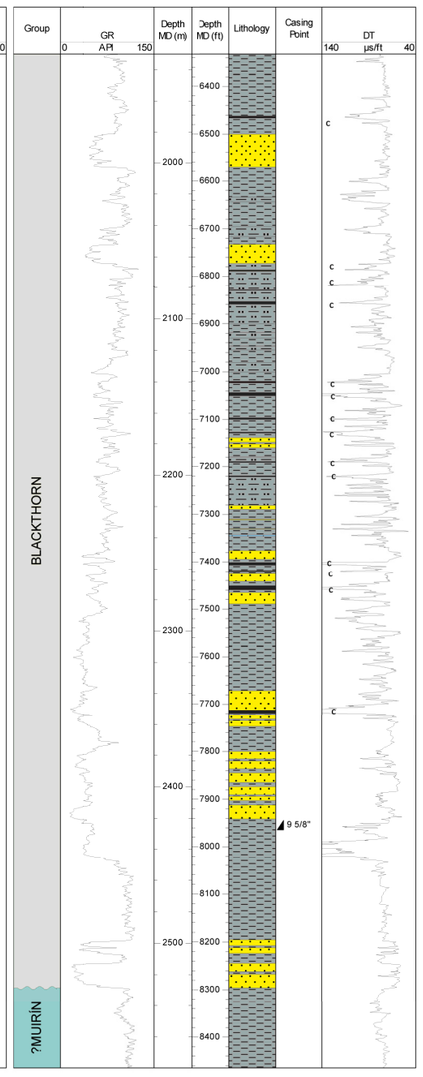


13/3-1
Reference well; Blackthorn Group

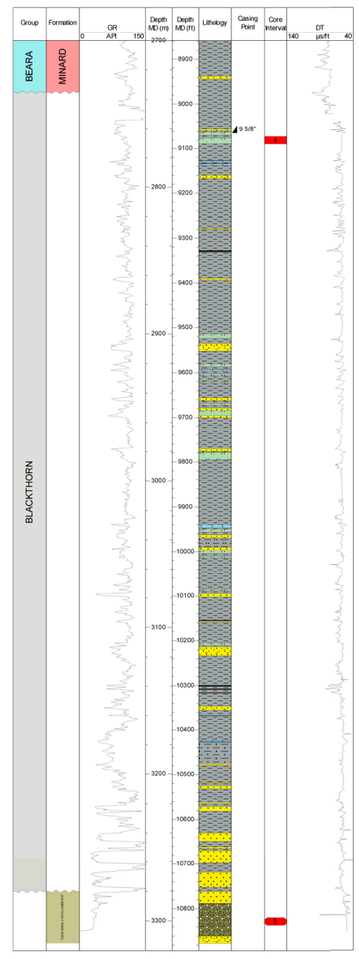


Blackthorn Group





36/16-1A
Type well; Blackthorn Group
(C = coal)



26/28-1
Reference well; Blackthorn Group

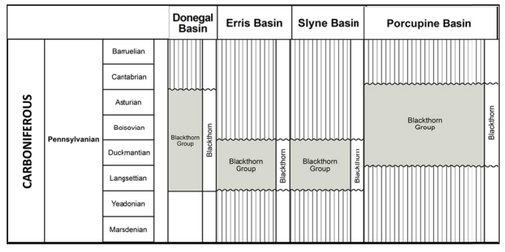
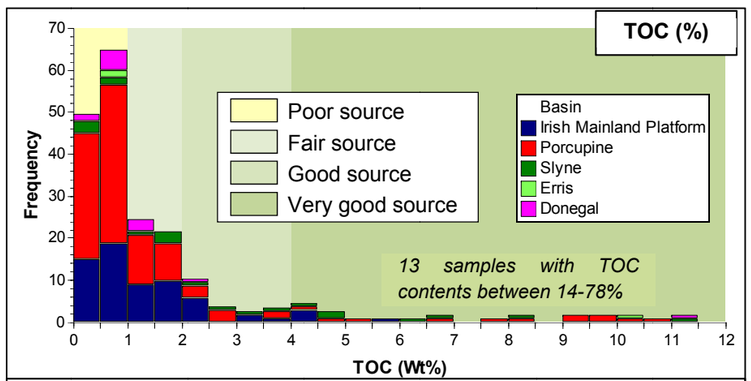
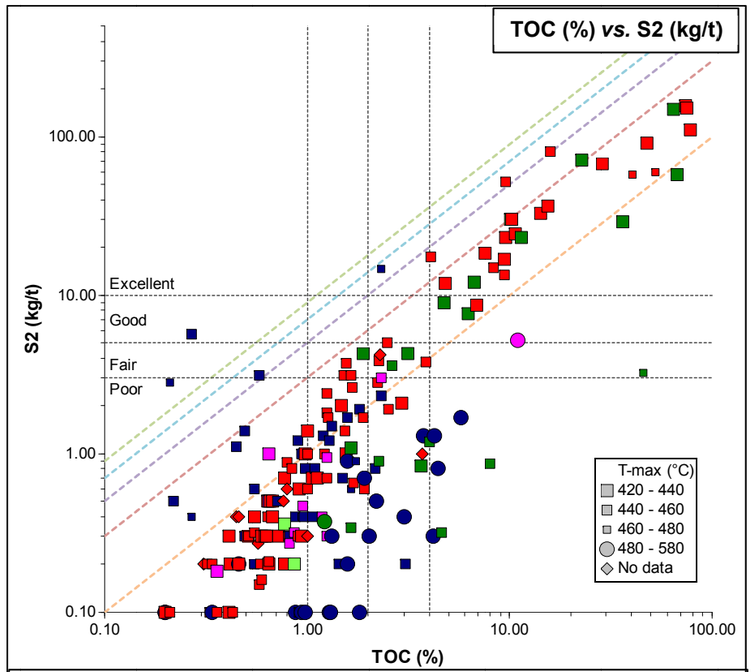


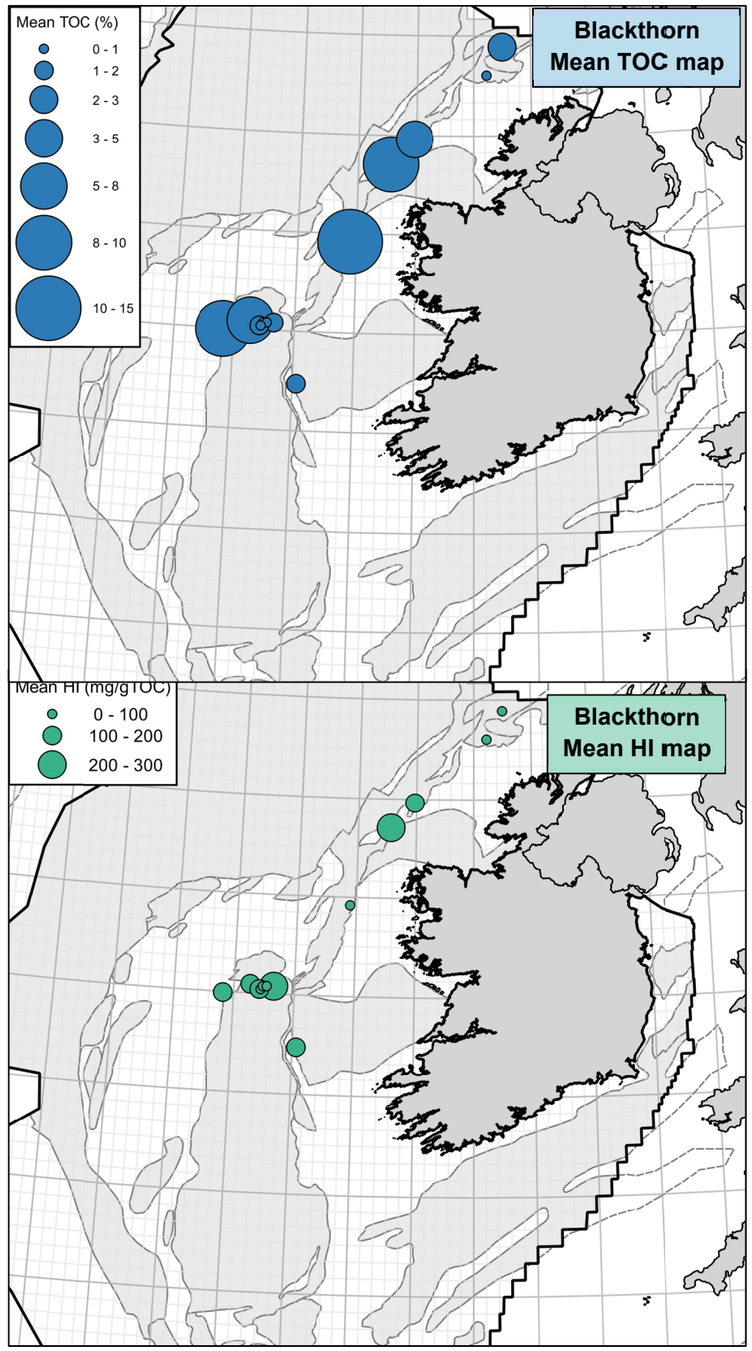
Figure D. 3.11. ***Blackthorn Group type and reference wells with location and distribution map.***

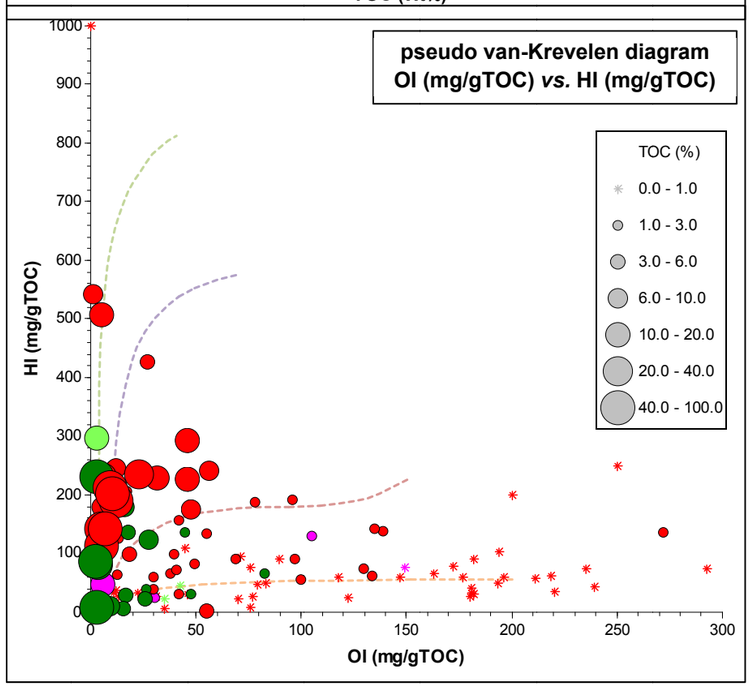
Blackthorn Group

Basin	TOC (%) No. Wells	TOC (%) No. Samples	TOC (%) Min	TOC (%) Max	TOC (%) Avrg.	HI (mg/gTOC) No. Wells	HI (mg/gTOC) No. Samples	HI (mg/gTOC) Min	HI (mg/gTOC) Max	HI (mg/gTOC) Avrg.
Irish Mainland Platform	1	66	0.07	5.72	1.36	1	56	6	1333	101
Porcupine	7	119	0.01	78.32	5.24	7	104	1	1000	119
Slyne	2	26	0.46	67.00	13.51	2	20	7	314	107
Erris	1	3	0.78	10.05	3.9	1	3	23	297	122
Donegal	2	12	0.18	11.02	1.79	2	11	24	154	64









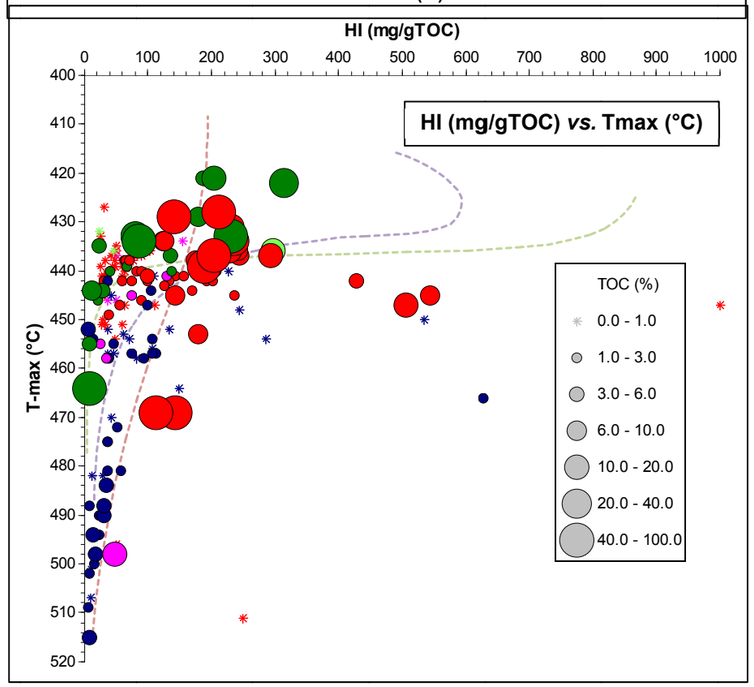


Figure D. 3.12. ***Source rock characteristics of the Blackthorn Group.***

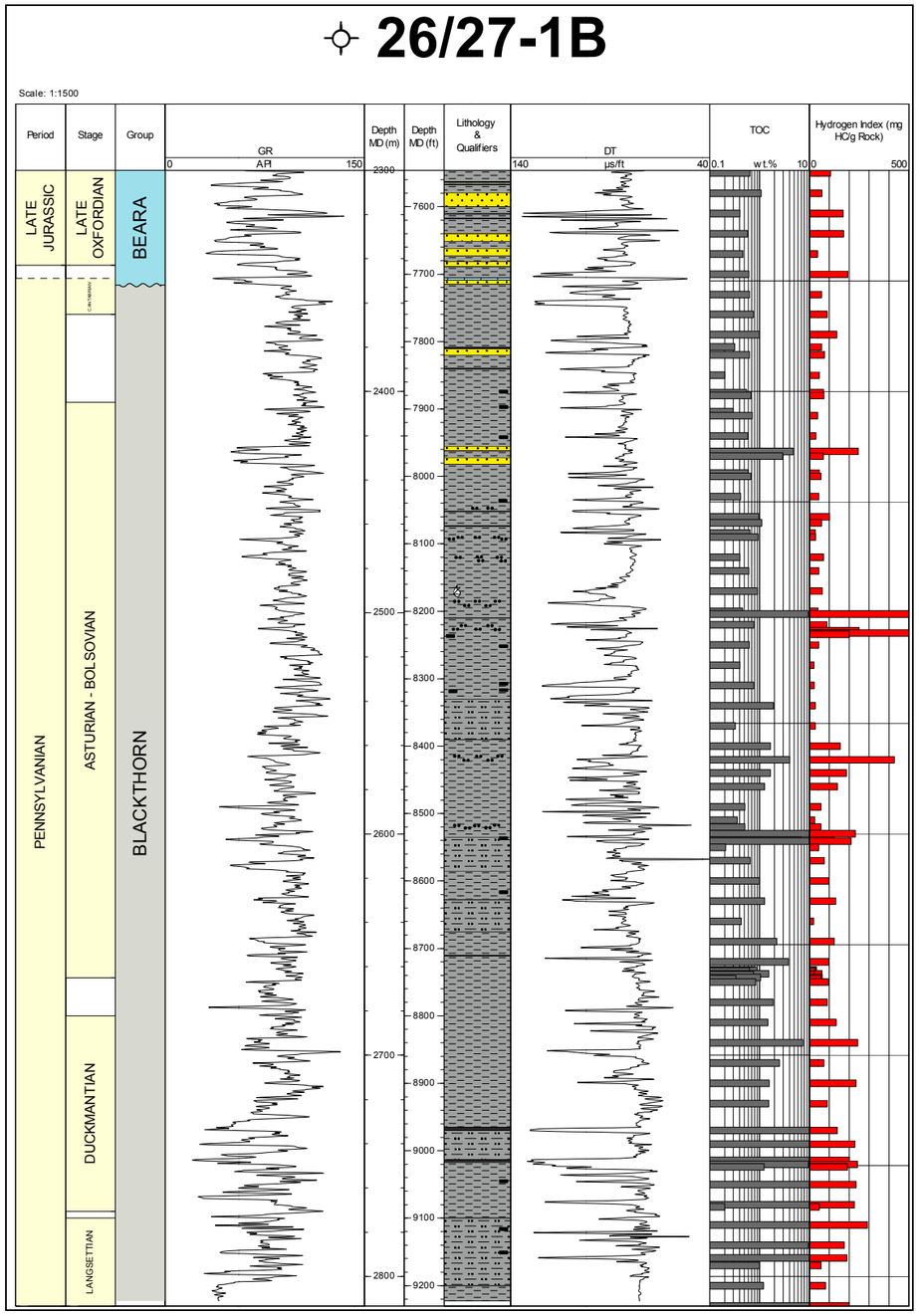


Figure D. 3.13. ***Blackthorn Group source rock data (TOC and HI) from Porcupine Basin well 26/27-1B.***

PENNINE COAL MEASURES GROUP

The "Coal Measures" was redefined as the Pennine Coal Measures Group by Waters *et al*. (2007) to equate to the main body of coal-bearing strata in the Westphalian succession in the UK. These authors defined the extent of the group from the Wales–Brabant High northwards to the Southern Uplands of Scotland, with thicknesses of up to 1000m. The group was given the epithet 'Pennine' to distinguish these coal measures from those present in the Midland Valley of Scotland, and from those south of the Wales – Brabant High where different names are used (Scottish Coal Measures Group in the former area and South Wales Coal Measures Group in the latter area). Use of the revised Pennine Coal Measures Group concept was extended into the East Irish Sea Basin by Wakefield *et al*. (2016), together with the use of the Warwickshire Group, both terms replacing the former Kidston Group that had been previously used in this basin (e.g. by Jackson & Johnson, 1996).

Similar sedimentary successions to those in the East Irish Sea Basin have been recognised in the North Celtic Sea, Central Irish Sea and Kish Bank basins in the current study, and therefore the name Pennine Coal Measures Group is extended into these basins in offshore Ireland. Wakefield *et al*. (2016, figure 2) had previously recognised the presence of the group in the Kish Bank Basin.

Wakefield *et al*. (2016) recognised three formations within the group in the East Irish Sea Basin, namely the Pennine Lower Coal Measures, the Pennine Middle Coal Measures and the Pennine Upper Coal Measures formations. No formal subdivision of this group has been attempted for the Irish offshore, however.

The Pennine Coal Measures Group underlies the Warwickshire Group in the Central Irish Sea and Kish Bank basins, with the boundary being defined as the base of the lowest conformably overlying major red-bed successions (Warwickshire Group), following Waters *et al*. (2007). The base of the Pennine Coal Measures Group is taken at the base of the coal-bearing succession, which also equates to the Subcrenatum Marine Band, as defined by Stubblefield & Trotter (1957) (Wakefield *et al*., 2016).

The lower part of these sections (Carboniferous, Pennsylvanian, Westphalian, Langsettian – Duckmantian) have their lateral equivalents onshore Ireland (Coal Measures of Northern Ireland and the Coolbaun Coal Formation of Ireland).

The key well sections for the group are from selected East Irish Sea wells such as UK 109/5-1 and UK 110/2b-10 (Wakefield *et al*. 2016).

Reference sections in offshore Ireland. 33/22-1: 631-866m below KB. 42/17-1A: 1220-1476m below KB. See **Figure D. 3.14**.

Lithology. This group comprises an interbedded succession of sandstones, siltstones, claystones and coals. The claystones are medium to dark grey, locally brownish grey, micromicaceous, locally rare to common carbonaceous specks/fragments, locally haematitic, non to slightly calcareous, locally subfissile, grading to siltstone. The sandstones are off white to medium light grey, purple, very fine to medium grained, generally well sorted, subangular to subrounded, locally argillaceous, locally coaly, non to slightly calcareous, friable to moderately well indurated, and grade to thinly developed sandy conglomerates. Beds and laminae of coal, black to brownish black, are present throughout.

Core data from the the 33/22-cgb1B and 33/22-cgb2z boreholes exhibit sandstones with mudstone flakes, abundant comminuted plant debris and coal clasts, parallel or wispy lamination, ripple cross bedding, rare ironstone bands, seatearths, rootlets, rare bioclastic limestone beds, and localised mudrocks containing shell fragments/debris.

Wireline log character. The group exhibits a serrated log profile, reflecting the interbedded nature of the sandstone, siltstone, claystone and coals. A number of the sandstone units possess sharp, erosive bases. Both fining up and coarsening up log profiles are recognised within the sandstones.

Upper boundary. The top of the group is marked by an unconformity in some cases. At this boundary the juxtaposed lithologies and the resulting wireline log responses are extremely varied. Where the group is overlain by the Warwickshire Group, the boundary is defined by the marked downsection increase in grey claystones and coal bearing lithologies, with a corresponding decrease in reddened sediments. On wireline log criteria, the upper boundary is taken at a subtle increase in gamma ray values, in association with a corresponding minor increase in sonic velocity. Wakefield *et al*. (2016) defined the boundary between the Warwickshire Group and the Pennine Coal Measures Group at the point where primary red coloured mudstones predominate over grey mudstones in the East Irish Irish Sea Basin.

Lower boundary. The base of the group is marked by an unconformity. It is only recognised in the 33/22-1 and 42/17-1A wells; the former contact is with the ?Cambrian ?Bray Group metasediments (slates) and the latter is with an underlying Bairneach Group limestones. In both cases, the basal boundary of the group is defined at the base of coal bearing succession. This accords with the definition of the group stated by Waters *et al*. (2007) and Wakefield *et al*. (2016), which also equates to the Subcrenatum Marine Band in UK onshore areas, as defined by Stubblefield & Trotter (1957).

On wireline log criteria, the boundary contact with the ?Bray Group is taken at a subtle increase in gamma ray values, in association with a corresponding increase in sonic velocity, while the boundary contact with the Bairneach Group is taken at a marked decrease in gamma ray values and corresponding marked increase in sonic velocity, reflecting the downwards incoming of limestones.

Subdivision. No subdivision is recognised.

Thickness. The group attains a maximum thickness of 256m in the 42/17-1A well and 235m in the 33/22-1 well, these being the only two wells in which upper and lower boundaries are observed.

Biostratigraphic characterization. Sediments of the group are typified by abundant miospore assemblages. Sections in the Kish Bank Basin are attributable to possibly the *Vestispora fenestrata* (VF) Zone to possibly the *Radiizonates aligerens* (RA) Zone. Miospore assemblages from well 50/3-3 are assigned to the *Vestispora cancellata* (VC) Zone and the *Spelaeotriletes arenaceus* (SA) Zone-?*Dictyotriletes probireticulatus* Zone.

Age. Carboniferous, Pennsylvanian, Westphalian, intra-Bolsovian – Langsettian.

Depositional environment. Continental to marginal marine. Deposition in the older, lower interval is envisaged to have taken place in a deltaic environment, lower to upper delta plain to low gradient alluvial plain, within distributary channels and interdistributary bays, with the upper, younger sediments being deposited in more fluvial, more arid environments. The sandstones are often cyclic, display sharp bases, and comprise both fining up and coarsening upwards profiles suggesting deposition in deltaic environments. Coal deposits are common in the lower and middle intervals, with deposition in prograding coal bearing delta top and localised swamps. Reddened sediments are recognised, suggesting oxidation, and possible periods of emergence and/or aridity. The upper parts of the succession display the more commonly reddened sediments, in association with a decrease in coal deposition suggesting drier, locally more emergent, more arid depositional environments. Fluvial deposition from large river systems is also envisaged.

Distribution. Sediments assigned to the group are known from the Kish Bank Basin (33/22-1 well and nearby boreholes), the Central Irish Sea Basin (42/17-1A) and the North Celtic Sea Basin (50/2-1 and 50/3-3). The extent of the group is taken to the limits of the Kish Bank and Central Irish Sea basins, and beyond to the Pembroke High and through the North Celtic Sea Basin, to its south western boundary with the Fastnet Basin (**Figure D. 3.14**). Carboniferous well penetrations in the Fastnet Basin demonstrate the absence of the group in this area. The north western limit of the group is notionally taken to close to the present-day Irish mainland, slightly beyond the limit of the North Celtic Sea Basin, on the basis of seismic data in this area. The distribution is extended across the Labadie Bank High and Pembroke Ridge which are cored with Palaeozoic rocks (in the former case, based on seismic interpretations undertaken in this project; in the case of the Pembroke Ridge, see Tappin *et al*., 1994, figure 18).

Seismic expression. In the Central Irish Sea and Kish Bank basins, the group is seen on seismic data as a distinctive layered, high amplitude package, the top of which is picked as the Pennine Coal Measures horizon (see **Figure D. 3.4**). This appears to be correlative with the seismic horizon identified within the Blackthorn Group ("Carboniferous [Intra Blackthorn]") in west of Ireland basins, such as the Porcupine Basin.

Regional correlation. The Pennine Coal Measures Group in the Kish, Central Irish Sea and North Celtic Sea basins are equivalent to the Blackthorn Group of the Donegal, Erris, Slyne and Porcupine basins to the west and northwest of Ireland.

The group correlates with the Coal Measures of Northern Ireland (Coalisland area), which are of Pennsylvanian, early Westphalian, Langsettian – Duckmantian age, and contain the Subcrenatum marine band (Mitchell, 2004). The group correlates with the Coolbaun Coal Formation of the Leinster coalfield, onshore Ireland (counties Carlow, Kilkenny and Laois), which is Westphalian (Langsettian) in age (Higgs & O'Connor, 2005). This correlation is proven by palynological assemblages from Kish Bank Basin in borehole 33/22-cgb2Z.

The group correlates with the Pennine Coal Measures Group in the East Irish Sea Basin and onshore UK (central and northern England).

Source rock characterisation. Source rock sample data availability from the group is very limited, with only a few samples with data being available for well 33/22-1 in the Kish Bank Basin. This includes some organic-rich samples with TOC contents up to ~7.3%, but low HI values indicating poor source potential. Based on vitrinite reflectance data the available samples are late mature and as a result of the high maturity, the measured, present-day source potential has decreased, and samples are likely to have originally had higher TOC and particularly HI values.

Comparison with Eastern Canada. The upper part of this group is laterally equivalent to sandstones and claystones of the Pennsylvanian, Westphalian, Bolsovian, Pictou Group onshore western Newfoundland (Giles & Utting, 2004; Utting & Giles, 2008).

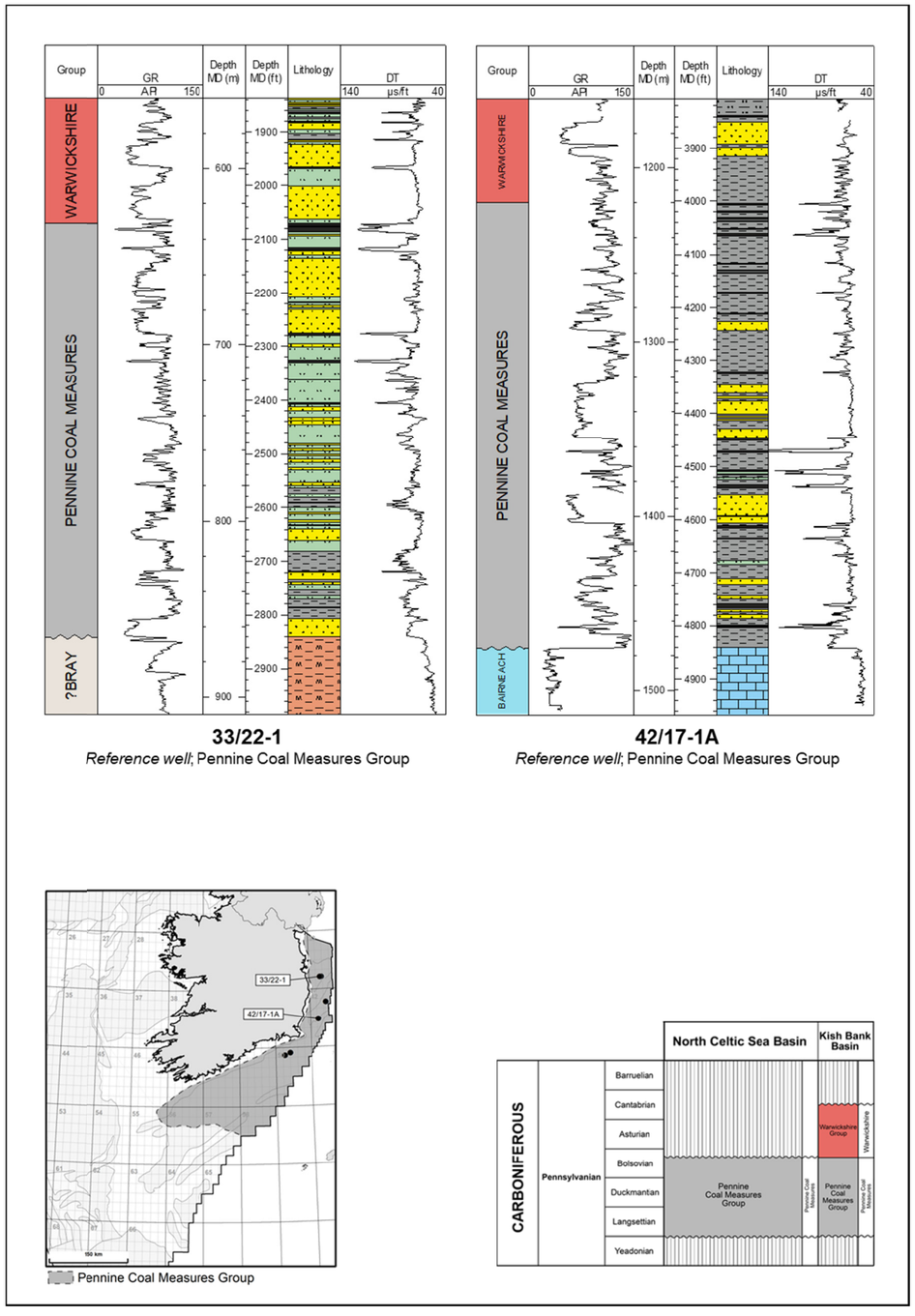


Figure D. 3.14. ***Pennine Coal Measures Group reference wells with location and distribution map.***

MUIRÍN GROUP (NEW)

The Muirín Group comprises a succession of grey and red claystones, siltstones and sandstones, in association with subsidiary pale coloured limestones and a small number of coal beds, of Mississippian, lower Namurian, Arnsbergian, to Visean, Arundian, to possibly ?Tournaisian, ?Ivorian, age. The group lies beneath the Blackthorn Group ("coal measures") but differs lithologically from the approximately age equivalent Sliogán and Bairneach groups as developed to the south east and east of Ireland.

This group is recognised in both the Erris and Porcupine basins, offshore west of Ireland. Two new formations are proposed; in descending stratigraphic order; Ruacan Formation (Mississippian, Namurian, Arnsbergian to Visean, "late" Brigantian) and the Mussel Formation (Mississippian, Visean, intra-Brigantian to "late" Arundian, to possibly Tournaisian, Ivorian). The Ruacan Formation comprises interbedded sandstones, claystones and limestones, while the Mussel Formation is the more sandstone dominated sedimentary succession.

Lateral equivalents to this group are noted onshore Ireland (Leitrim and Tyrone groups). These group names have not been used in the Irish Offshore due to their lithological differences compared to their onshore Irish counterparts.

Name. Muirín means shellfish in Irish.

Reference sections. 19/5-1: 1176.5-2584.4m (TD) below KB. 26/26-1: 801.5-1130m below KB. See Figure D. 3.15.

Lithology. The group comprises an interbedded succession of varicoloured sandstones, siltstones and claystones, together with coals and limestones. The lower part of the group, represented by the Mussel Formation, is particularly sandstone dominated. The claystones and siltstones are light grey to dark grey, greenish grey, pale red, brick red, dark brown, greyish brown, micromicaceous, non to slightly calcareous, and locally carbonaceous. The sandstones are off white to light grey to medium dark grey, locally light greenish grey, reddish brown, fine to coarse grained, poor to well sorted, angular to subrounded, feldspathic and/or micaceous, and non to calcareous. Locally developed conglomerates (19/5-1) comprising quartz fragments, granitic clasts, occurring within a sandy matrix, are developed at the base of a number of intervals. Beds of limestone, cream to off white, tan, mudstone to packestone, micritic to microcrystalline, and locally bioclastic (crinoid and bivalve debris) are also noted. A small number of coals, black, vitreous lustre, are also observed. Rare anhydrite laminae/nodules are developed in some of the reddened claystones.

The sediments present in core 1 situated at the base of the group in the 35/15-1 well are well indurated, splintery, with the claystones exhibiting a waxy appearance, which may possibly very low grade metamorphism. These sediments are cut by abundant calcite veins and fractures.

A light grey, banded, ignimbritic tuff occurs in the 35/15-1 well.

Wireline log character. The group possesses a highly serrated log profile, reflecting the interbedded nature of the sandstone, claystone and limestone lithologies. Many of the claystones exhibit high gamma ray values (between 100° API and 160° API), particularly within the Ruacan Formation. The sandstone units exhibit either coarsening up or fining up log profiles, while a number possess blocky wireline log profiles. Many of the sandstones possess sharp erosive bases. The limestone beds generally display blocky log profiles.

Upper boundary. The top of the group is everywhere marked by an unconformity. At this boundary the juxtaposed lithologies and the resulting wireline log responses are extremely varied. Where this group underlies the Blackthorn Group, the boundary is placed at a marked downsection lithological change to grey silty claystones/siltstones, which are generally more indurated than the overlying sediments. On wireline log criteria, the boundary is taken at a downsection increase in gamma ray values, in association with a corresponding decrease in sonic velocity.

Lower boundary. The base of the group is only observed in one well (26/26-1), where it unconformably overlies Dalradian metasediments. On wireline log criteria, the boundary is taken at a marked downsection increase in gamma ray values, in association with a corresponding subtle increase in sonic velocity.

Subdivision. Two formations are recognised, in descending stratigraphic order, Ruacan Formation and Mussel Formation.

Biostratigraphic characterization. The group contains miospore assemblages ranging in age from the Mississippian, lower Namurian, Arnsbergian, *Lycospora subtriquetra – Krauselisporites ornatus (SO) Zone, Lycospora subtriquetra – Apiculatisporis variocorneus* (SV) Subzone to possibly the Mississippian, Tournaisian, Ivorian *Schopfites claviger* (ScCl) Zone.

A questionable record of the group is interpreted in the 36/16-1A well, located on the western edge of the Irish Mainland Platform. As this is a key well for the Carboniferous west of Ireland, it merits further discussion regarding the age of the section assigned here questionably of the Muirín Group. Robeson *et al*. 1988 (fig 3) assigned a Namurian age to the lower part of the well which yielded very sparse assemblages. In the text they state that the section "*is very poorly dated and could conceivably be lower Namurian rather than upper Namurian*". Haddow (2012, Thesis), interpreted the section below c.8300ft (2529.8m) as ?Early Namurian, ?Arnsbergian (fig. 6.19). Haddow carried out no new analyses and relied on purely occurrence data from the original Palaeoservices report and the Robeson *et al*. (1988) paper. In the current study, several new samples were analysed and one of these yielded several specimens of *Schulzospora campyloptera* which suggests an age not younger than Early Namurian, which thus supports the interpretation of Haddow (2012).

Age. Mississippian, lower Namurian, Arnsbergian, to Mississippian, Visean, "late" Arundian, to possibly Tournaisian, Ivorian.

Depositional environment. Continental/marginal marine through to inner shelf marine. The arenaceous units of the Ruacan Formation locally exhibit coarsening up profiles, suggesting deposition in a continental to marginal marine environment, while the presence of common plant debris would suggest proximity to land. The limestones, which yield persistent marine microfaunas below 1408m in the 19/5-1 well, are indicative of a shelfal marine environments. Those limestone containing ooliths and crinoid debris are indicative of deposition within an inner shelf, warm carbonate-rich environment, which were locally agitated.

The Mussel Formation was deposited in continental through to possibly marginal marine environments. The presence of pebbly sandstones at the base of the formation in the 26/26-1 well is envisaged to represent a continental, alluvial fan deposit. The reddened lithologies are suggestive of arid, continental conditions.

Distribution. The group has been recorded from the Erris Basin (19/5-1) and the Porcupine Basin (26/26-1), and tentatively in the Irish Mainland Platform well 36/16-1A. Muirín Group sediments have also been recorded in the 35/15-1 well, however, precise dating of this section is not possible due to poor palynomorph recovery which is most likely due to the high maturation levels encountered in the well.

Seismic expression. No seismic horizons have been interpreted in this study that relate to the Muirín Group.

Regional correlation. This group is equivalent in age to the Leitrim and Tyrone groups of northwest Ireland and Northern Ireland, the Cork Group of the south Munster Basin, the Pembroke Limestone Group of South Wales, the Clwyd Limestone Group of North Wales, the Garwood and Craven groups of the Irish Sea Basin and the Milverton, Fingal, Cruicetown and Knockbrack groups of the Dublin Basin (Davies *et al.,* 2007; Jackson *et al.,* 2007; Somerville & Waters, 2007; Waters *et al.,* 2007; Waters & Somerville, 2007).

Biostratigraphic data from the 36/16-1A well (see above) implies that the Muirín Group section in 36/16-1 is equivalent to the marine Clare Shale Formation (Shannon Group) seen in the onshore Clare Basin (see age data in Sevastopulo, 2009). It is notable that the latter formation is fully marine, and it is likely therefore that somewhere between the 36/16-1A well and the onshore sections, there is a lateral facies change between the Muirín Group and the Shannon Group. The upper part of the latter group in the Clare Basin (e.g. the Doonbeg No. 1 borehole), corresponding to the Ross Sandstone and Gull Island formations, is of Namurian age (Pendleian – Chokierian), representing some of the Namurian section that is not seen in the offshore area; hence it is possible that the latter rocks are partly cut out by the Mid Carboniferous Unconformity on passing westwards from the onshore succession.

Comparison with Eastern Canada. The group is equivalent in age to the predominantly arenaceous sediments of the Barachois, Codroy and Deer Lake groups of onshore western Newfoundland (Knight, 1992; Giles & Utting, 2004; Utting &

Giles, 2008).

Ruacan Formation (New)

The term Ruacan Formation is introduced for an interbedded succession of light-coloured sandstones and grey claystones, in association with locally well-developed limestones of Mississippian, Namurian, Arnsbergian to Visean, "late" Brigantian, age. This succession of sediments lies below the Blackthorn Group. This formation is recorded from the Erris and Porcupine basins.

Name. Ruacan means cockle in Irish, paired with Mussel below, reflecting the traditional Irish song of Molly Malone.

Type section. 19/5-1: 1176.5-2051m below KB. See Figure D. 3.15.

Reference section. 26/26-1: 801.5-994m below KB. See Figure D. 3.15.

Lithology. This formation comprises an interbedded succession of pale coloured sandstones, siltstones and claystones. Well-developed limestones are present in the lower half of the formation. The claystones and siltstones are light grey to dark grey, greenish grey, micromicaceous, non to slightly calcareous, and locally carbonaceous. The sandstones are off white to buff, light grey to medium dark grey, fine to coarse grained, poor to well sorted, angular to subrounded, locally feldspathic and/or micaceous, locally common plant debris, and non to calcareous. Locally developed conglomerates (19/5-1) comprising quartz fragments, granitic clasts, occurring within a sandy matrix, are developed at the base of a number of intervals. Well-developed limestones, cream to off white, tan, locally mottled, mudstone to packstone, micritic to microcrystalline, locally silty or sandy, and locally bioclastic (crinoid and bivalve debris) are recognised in the lower intervals of this formation. A small number of coals, black, vitreous lustre, are also observed.

Wireline log character. The formation displays a highly serrated log profile, reflecting the interbedded nature of the arenaceous, argillaceous and limestone lithologies. A small number of the claystones exhibit high gamma ray values (between 130° API and 160° API). The sandstone units exhibit either coarsening up or fining up log profiles, while a number possess blocky wireline log profiles. Many sandstones have sharp erosive bases. The limestone developments generally have blocky log profiles.

Upper boundary. The top of the formation is marked by an unconformity. At this boundary the juxtaposed lithologies and the resulting wireline log responses are varied.

Lower boundary. The base of the formation is placed at a marked downsection lithological change to grey or greyish brown claystones. On wireline log criteria, the boundary is taken at a marked increase in gamma ray values, in association with a corresponding decrease in sonic velocity.

Subdivision. No subdivision is recognised. With future well penetrations, this formation may possibly be subdivided into two members; a lower unit which is characterised by significant limestone developments and an upper unit which comprises claystones, siltstones and sandstones, with no significant limestone beds.

Thickness. The formation attains a thickness of 875m in the 19/5-1 well and 192.5m in 26/26-1.

Biostratigraphic characterization. The formation is characterised by miospore assemblages ranging from the Mississippian, lower Namurian, Arnsbergian, *Lycospora subtriquetra – Krauselisporites ornatus* (SO) Zone, *Lycospora subtriquetra –Apiculatisporis variocorneus* (SV) Subzone to the Mississippian, late Visean "late" Brigantian *Tripartites vetustus* Zone.

Foraminifera and ostracods have been described from the 19/5-1 well from the lower part of the Ruacan Formation section that has been dated palynologically in the current study as Brigantian in age. The foraminiferal assemblages include agglutinated bethonic forms such as *Tetrataxis* and calcareous benthonic genera such as *Archaediscus* and *Endothyra*, *Loeblichia ammonoides* and *Climacammina* cf. *patula*. These are all interpreted by Paleoservices as being long ranging taxa indicative of a Namurian to Late Visean age. Beneath this fauna, an association of *Archaediscus karreri*, *Endothyra bowmani*, *E. globulosa*, *Stacheia marginulinoides* and *Tetrataxis paleotrochus* is recorded, stated by Paleoservices (1978) as being indicative of a late Visean age in Britain. This is accompanied by a rich ostracod fauna including the recorded genera *Bairdia* and *Glyptopleura*. A limestone unit at the base of the formation (at the base of the defined Brigantian) in the 19/5-1 well contains common *Archaediscus* spp. foraminifera.

Age. Mississippian, Namurian, Arnsbergian to Visean, "late" Brigantian.

Depositional environment. Continental/marginal marine to inner shelf. The sandstones in the upper part of the formation locally exhibit coarsening up profiles, suggesting deposition in a continental to marginal marine environment. The occurrence of common plant debris would indicate proximity to land. The occurrence of persistent marine microfaunas below 1408m in the 19/5-1 well, in association with the incoming of limestones indicates a shelfal marine environment in this interval, while the limestones, which contain ooliths and crinoid debris would suggest deposition in inner shelf, warm, carbonate-rich environments, which were locally agitated.

Distribution. The formation is only confidently recorded in two wells, 19/5-1 (Erris Basin) and 26/26-1 (Porcupine Basin), with tentative records from the 36/16-1A (western margin of Irish Mainland Platform) and the 35/15-1 (Porcupine Basin). The lateral extent of the formation is uncertain but is considered likely to extend further south into the main part of the Porcupine Basin (Figure D. 3.15).

Regional correlation. The formation is laterally equivalent to the Leitrim Formation of northwest Ireland and Northern Ireland. Other notable age equivalents include the uppermost sediments of the Cork Group of the south Munster Basin, the Oystermouth and Aberkenfig formations of South Wales, the Red Wharf Limestone and Pentre Chert formations of North Wales, the upper units of the Garwood and Craven groups of the Irish Sea Basin and the uppermost sediments of the Milverton and Fingal Groups, plus the Knockbrack Group of the Dublin Basin (Davies *et al.,* 2007; Jackson *et al.,* 2007; Somerville & Waters, 2007; Waters *et al.,* 2007; Waters & Somerville, 2007). See Muirín Group discussion above for correlation with onshore Co Clare succession.

Source rock characterisation. Data availability for the Ruacan Formation is limited and only a limited number of samples with data from well 19/5-1 were available (**Appendix E**). A few of these samples are organic-rich to coaly and although hydrocarbon yields are mainly low, two samples with high TOC contents fall on the Type II to Type I kerogen trendline indicating some source potential.

Comparison with Eastern Canada. The Ruacan Formation sediments of Arnsbergian to Brigantian age in the 19/5-1 and 26/26-1 wells are equivalent in age to those of the upper Codroy Group and Barachois Group of western Newfoundland and the Deer Lake Group of West Newfoundland (Giles & Utting, 2004; Utting & Giles, 2008).

Mussel Formation (New)

The Mussel Formation is defined here for an interbedded succession of varicoloured sandstones and claystones, of Carboniferous, Mississippian, Visean, intra-Brigantian to "late" Arundian, age. Sediments tentatively dated as Late Tournaisian, Ivorian, age are also present in 26/26-1 well and are included in the formation. This sedimentary succession lies below the Ruacan Formation. This formation is recognised in both the Erris and Porcupine basins.

The formation correlates with the Tyrone Group of onshore Ireland (and Northern Ireland), but differs in being more clastic dominated, in contrast to the predominantly limestone lithofacies of the Tyrone Group.

Name. After the shellfish which is native to Ireland paired with Ruacan (Cockle) above reflecting traditional Irish song of 'Molly Malone'.

Type section. 19/5-1: 2051-2584.4m (TD) below KB. See Figure D. 3.15.

Reference sections. 26/26-1: 994-1130m below KB. See Figure D. 3.15.

Lithology. This formation comprises an interbedded succession of sandstones, siltstones and claystones. The claystones and siltstones are light grey to dark grey, locally light greenish grey, pale red, brick red, dark brown, greyish brown, micromicaceous, non to slightly calcareous, and locally carbonaceous. The sandstones are off white to light grey locally light greenish grey, reddish brown, fine to coarse grained, locally pebbly, poor to well sorted, angular to subangular, locally subrounded, feldspathic, micaceous, locally containing plant fragments, and non-calcareous. Rare anhydrite laminae/nodules are developed in some of the reddened claystones.

A light grey, with dark grey mottling, banded, ignimbritic tuff, with well-developed amygdales is developed in the 35/15-1 well.

Wireline log character. The formation displays a highly serrated log profile, reflecting the interbedded nature of the sandstone and claystone lithologies. A number of sandstone units exhibit either coarsening up or fining up log profiles, while a number possess blocky wireline log profiles. Many sandstones possess sharp erosive bases. The limestone developments generally have blocky log profiles.

Upper boundary. The top of the formation is placed at a marked downsection lithological change to grey or greyish brown claystone. On wireline log criteria, the boundary is taken at a marked increase in gamma ray values, in association with a corresponding increase in sonic velocity.

Lower boundary. The base of the formation is only observed in one well (26/26-1), where it unconformably overlies Dalradian "metasediments". On wireline log criteria, the boundary is taken at a marked increase in gamma ray values, in association with a corresponding subtle increase in sonic velocity.

Subdivision. No subdivision is recognised.

Thickness. The formation attains a thickness of 533m in the 19/5-1 well (where the basal boundary was not seen) and 136m in 26/26-1.

Biostratigraphic characterization. The formation contains miospore assemblages indicative of the *Triquitrites marginus* (TM) Zone (Asbian) to the *Knoxisporites stephanephorus* (KS) Zone (Arundian). Miospore assemblages of the *?Schopfites claviger* (ScCl) Zone, tentatively suggesting a Mississippian, Tournaisian, Ivorian age are present in the 26/26-1 well.

Age. Mississippian, Visean, intra-Brigantian to "late" Arundian, and tentatively Tournaisian, Ivorian.

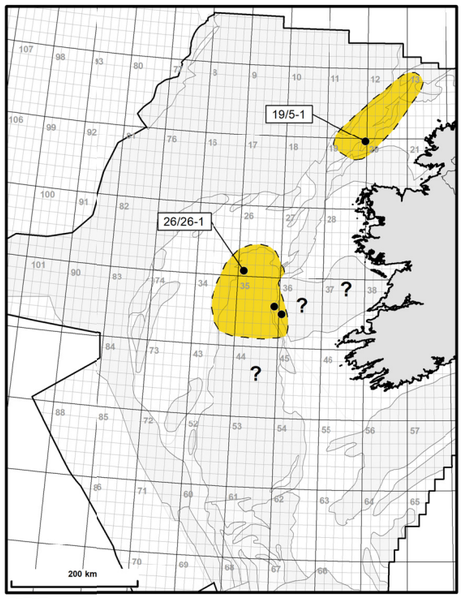
Depositional environment. Continental through to possibly marginal marine. The presence of pebbly sandstones at the base of the formation in the 26/26-1 well is suggestive of a continental, alluvial fan deposit. The reddened lithologies are indicative of arid, continental conditions.

Distribution. The formation has been recorded in two wells from the Erris Basin (19/5-1) and Porcupine Basin (26/26-1). The lateral extent of the formation is uncertain but is considered likely to extend further south into the main part of the Porcupine Basin.

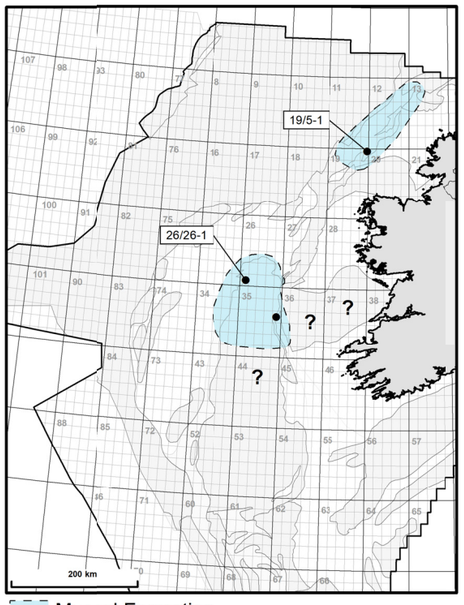
Regional correlation. The Mussel Formation is equivalent in age to the Tyrone Group and possibly the lowermost part of the Leitrim Group of northwest Ireland and Northern Ireland. This unit is also laterally equivalent to the Cork Group of the south Munster Basin, the Pembroke Limestone Group of South Wales, the Clwyd Limestone Group of North Wales, the Garwood and Craven groups of the Irish Sea Basin and the Milverton, Fingal and Cruicetown groups of the Dublin Basin (Davies *et al.,* 2007; Jackson *et al.,* 2007; Somerville & Waters, 2007; Waters *et al.,* 2007; Waters & Somerville, 2007).

Comparison with Eastern Canada. The sediments tentatively dated palynologically as Late Tournaisian, Ivorian, age in the 26/26-1 well are equivalent in age to the Late Devonian – Tournaisian Anguille Group of onshore western Newfoundland (Knight, 1992).

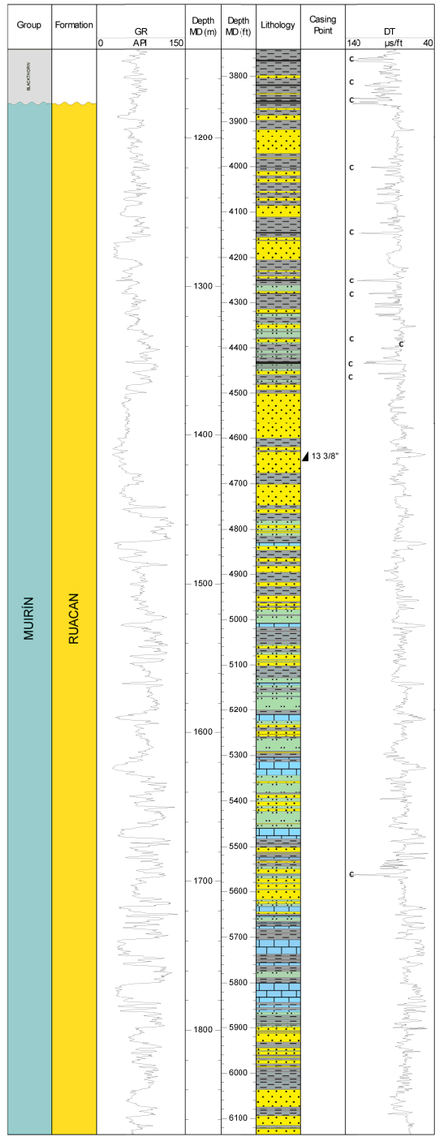
The Mussel Formation sediments dated on palynological evidence as possibly intra Brigantian-Asbian age (26/26-1) and Asbian-Late Arundian age (19/5-1) are equivalent in age to the Codroy Group of onshore western Newfoundland (Knight, 1992).



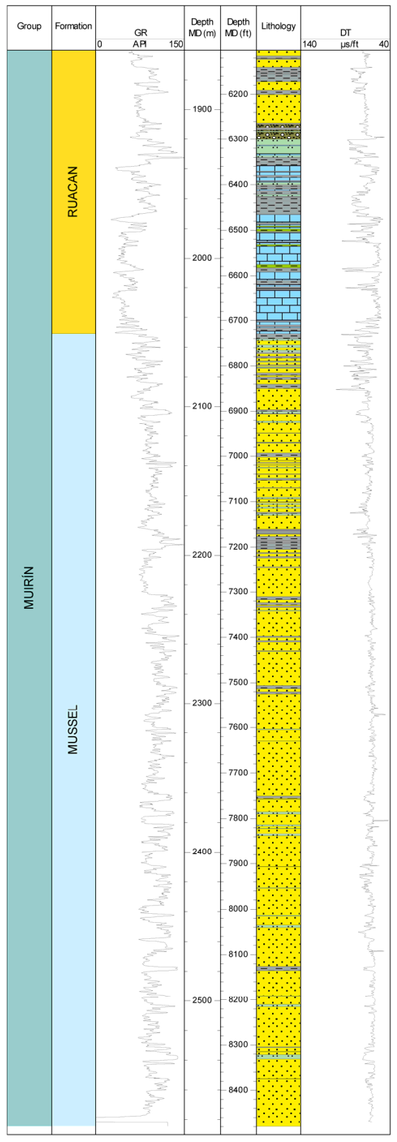
Ruacan Formation

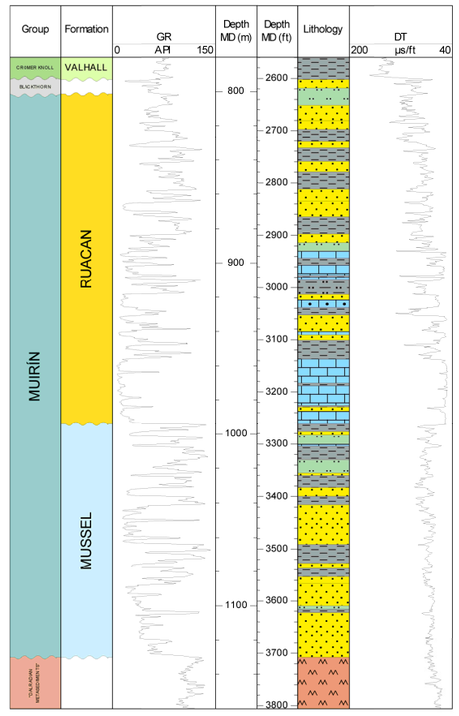


Mussel Formation



19/5-1
Type well; Ruacan Formation, Mussel Formation





26/26-1
Reference well: Ruacan Formation, Mussel Formation

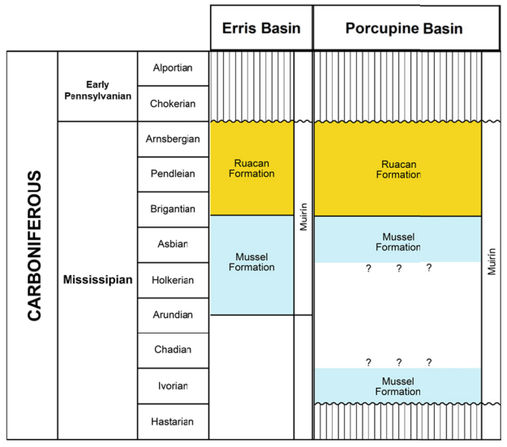


Figure D. 3.15. ***Ruacan Formation and Mussel Formation type and reference wells with location and distribution maps.***

SLIOGÁN GROUP (NEW)

The Sliogán Group is defined for a dominantly grey claystone succession, of Carboniferous, Mississippian, lower Namurian, "early" Arnsbergian? to Pendleian, age. Only a single well (58/3-1), situated in the South Celtic Sea Basin, offshore south of Ireland, has to date penetrated these sediments. No age equivalent section is present in any other well to the south and east of Ireland. The succession in the well is distinctly different lithologically, and age wise, from the overlying Pennine Coal Measures and underlying Bairneach groups.

Name. Sliogán means shell in Irish.

Type section. 58/3-1: 2644-2857.4m (TD) below KB. See **Figure D. 3.16**.

Reference section. Not encountered in any other wells.

Lithology. The succession is dominated by medium to dark grey, brownish grey, non-calcareous, well indurated, claystones, which locally grade to siltstones. A stringer of clear to white, very fine to medium grained, poor to well sorted, subangular to subangular, loose to friable, non-calcareous, sandstones is also present.

Core data from the 58/3-1 well exhibits a well indurated, splintery, non-calcareous claystone, with localised small veinlets.

Wireline log character. No wireline logs were run below the 9 5/8" casing in the type well**.** Hence definition of the wireline log profile is poorly constrained and confined to the top third of the formation. The wireline log profile over the logged section is essentially parallel/linear, with moderately high gamma ray values and consistent sonic velocity (**Figure D. 3.16**).

Upper boundary. The top of the group is marked by an unconformity. The upper boundary is placed at a sharp downsection lithological change to claystone from the overlying Sherwood Sandstone Group. On wireline log criteria, the boundary is taken at a marked increase in gamma ray values, in association with a corresponding decrease in sonic velocity (**Figure D. 3.16**).

Lower boundary. The base of this unit has not been penetrated.

Subdivision. No subdivisions are recognised.

Thickness. The group is 215m thick in the 58/3-1 well, however, this is the only well penetration known of the unit and in this well the basal boundary was not seen.

Biostratigraphic characterization. The base of the group contains miospore assemblages within the zonal range *Mooreisporites trigallerus* (MT) Zone – *Cingulizonates* cf. *capistratus* (CC) Zone, *Verrucosisporites morulatus* (VM) Subzone. The miospore assemblages recorded above this zone, although of restricted composition, are consistent with this zonal assignment.

Age. Carboniferous, Mississippian, lower Namurian, "early" Arnsbergian? to Pendleian.

Depositional environment. Marine, inner to outer shelf, though rather poorly constrained due to limited well data.

Distribution. The group has only been recorded from one well in the South Celtic Sea Basin (58/3-1) (**Figure D. 3.14**). The lateral extent of the group is unknown.

Regional correlation. The group is equivalent in age to the White Strand Formation of the South Cork Subbasin, onshore Ireland. Similar age sediments are also recorded from Whiddy Island, West Cork, the East Point Formation and Middle Battery Formation of the West Cork Subbasin (Naylor *et al*., 1978, Higgs & Forsythe, 2007).

Comparison with Eastern Canada. The group may be a lateral equivalent to the Barachois Group, the upper Codroy Group and the Deer Lake Group of onshore western West Newfoundland (Knight, 1992; Giles & Utting, 2004; Utting & Giles, 2008).

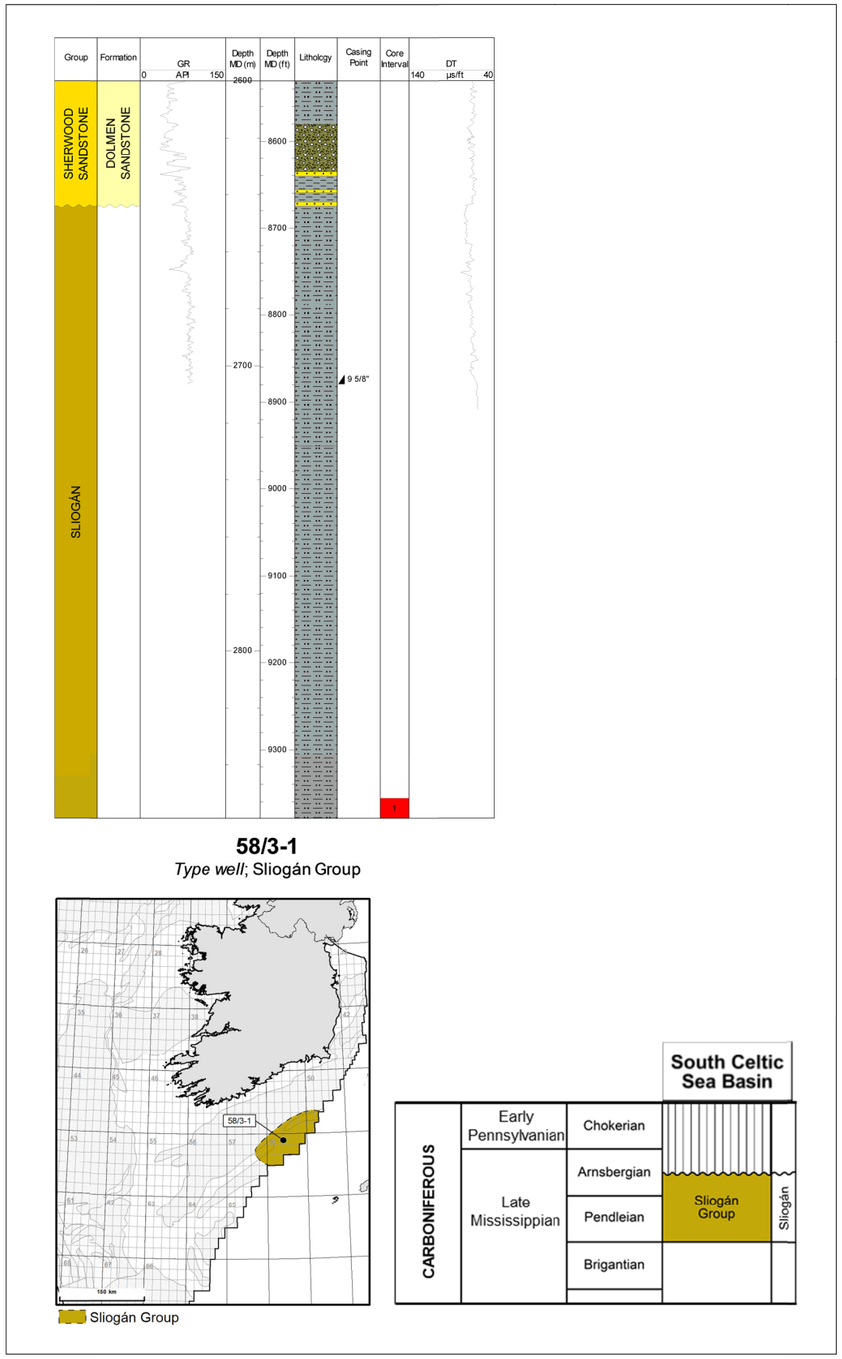


Figure D. 3.16. ***Sliogán Group type well with location and distribution map.***

BAIRNEACH GROUP (NEW)

The Bairneach Group is established here to encompass all Carboniferous, Mississippian, Late Tournaisian, Ivorian to Visean, Brigantian, limestone successions from offshore south and east of Ireland. No formal lithostratigraphic subdivision of this group has been undertaken in this study due to the limited number of well penetrations, each of which is incomplete.

Four wells to date have penetrated these rocks in the south and east regions offshore Ireland, three within the Fastnet Basin (55/30-1, 63/4-1 and 64/2-1) and one within the Central Irish Sea Basin (42/17-1A).

Type section. 63/4-1: 1508 – 1645.2m (TD) below KB. See **Figure D. 3.17**.

Reference sections. 42/17-1A: 1476-1513.33m (TD) below KB. 55/30-1: 2563-2602.5m below KB. See **Figure D. 3.17**.

Name. Bairneach means limpet in Irish.

Lithology. The group comprises white to light grey, locally pink to reddish brown, crystalline, well indurated limestones, which are locally dolomitic or silicified. In the 42/17-1A well, the limestone is stylolitised and brecciated.

Cores exhibit well indurated limestones which are locally siliceous, often bioclastic, stylolithic, veined or fractured, and with localised mudrock partings.

Wireline log character. The group possesses a blocky log profile, with low gamma ray values and high sonic velocity, reflecting the well indurated crystalline limestone lithologies.

Upper boundary. The top of the group is marked by an unconformity and is overlain, for instance by Warwickshire Group (42/17-1A) or Sherwood Sandstone Group (as in 55/30-1 and 63/4-1 wells). The upper boundary is placed at a marked downsection incoming of limestone, with an associated marked decrease in gamma ray log values, and with a corresponding increase in sonic velocity.

Lower boundary. The base of the group has only been penetrated in the 55/30-1 well, where it is marked by an unconformable contact with the underlying conglomerate of the Devonian Darrig Formation. On wireline log criteria this boundary displays a marked downhole increase in gamma ray values and a decrease in the sonic velocity.

Subdivision. No subdivision is recognised.

Thickness. The group attains a maximum penetrated thickness of 137m in the 63/4-1 well, however, the base of the group was not drilled in this well. The only well in which both upper and lower boundaries were encountered is 55/30-1 where the group is 40m thick, due to the presence of unconformable, truncated upper and lower contacts (with the Triassic above and the Devonian below).

Biostratigraphic characterization. Conodonts have been recovered from the lower part of the group in the 63/4-1 well (see below).

Age. Of the four known well penetrations of the group, only the 63/4-1 has yielded any significant biostratigraphic data, namely a conodont assemblage indicative of the *Polygnathus communis carina* Zone, of Mississippian, Tournaisian, Ivorian, age for the base of this section.

Depositional environment. Marine, inner shelf. The occurrence of limestone lithologies, yielding common crinoids, foraminifera and conodonts is indicative of a warm water, shallow marine, carbonate-rich environment.

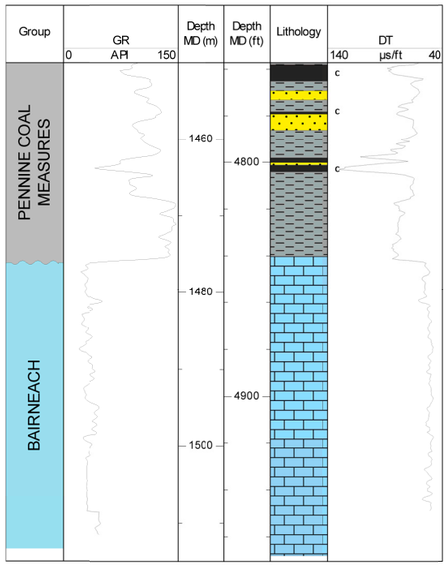
Distribution. Sediments assigned to the Bairneach Formation have been recorded in three wells from the Fastnet Basin (55/30-1, 63/4-1 and 64/2-1) and one well 42/17-1A from Central Irish Sea Basin (**Figure D. 3.17**). The extent of the group is taken to the Kish Bank Basin in the north east. Although a Top Bairneach seismic horizon has not been identified in this basin, there is room for the group in the main basin centre (east of the 33/21-1 well) for the group to be present between the Intra Pennine Coal Measures horizon and the Top Bray (?Cambrian) surface.

The group is present as far south west as the Fastnet Basin (mapped seismically to this point, see **Figure D.2.2**), and most likely extends through the Celtic Platform (on the evidence of seismic interpretation of the Carboniferous interval). There is no proof of the extent of the group into the basins west of Ireland as yet, though this is considered possible. The north western limit is taken to close to the present-day coastline of Ireland; it is likely that the group passes laterally into rocks of the same age that currently outcrop onshore Ireland. The group is likely to be present through the Pembroke Arch and most likely extends into the UK sector of the South Celtic Sea.

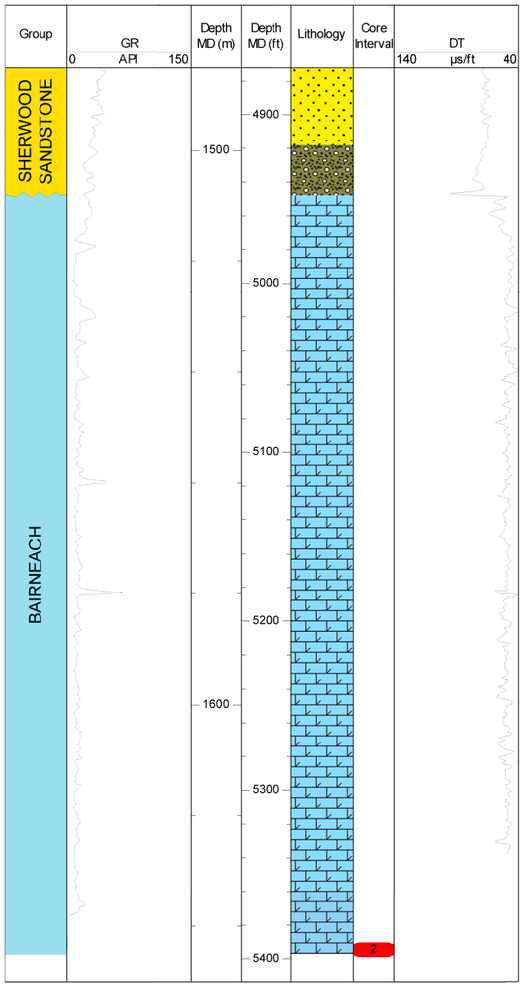
Seismic expression. The Carboniferous (Top Bairneach) seismic horizon ties to the top of the group and has been recognised in the Central Irish Sea Basin (see **Figure D. 3.4**) and Fastnet Basin (see **Figure D.2.2**). The top of the group is expressed, particularly in the Central Irish Sea Basin, as a high amplitude seismic package beneath the banded seismic facies that equates to the overlying Pennine Coal Measures Group). In the Fastnet Basin (see **Figure D.2.2**) the group displays a more homogeneous seismic character.

Regional correlation. Limestone successions that are correlative of the Bairneach Group include the Carboniferous Limestone Supergroup, the Clywd Limestone, Craven, Bowland High and Pembroke Limestone groups of the Central Irish Sea Basin, North Wales, Northern Ireland, and central and northern England, and in part to the Courtmacsherry Formation of the South Munster Basin, plus the Waulsortian limestone facies of central Ireland (Davies *et al.,* 2007; Jackson *et al.,* 2007; Somerville *et al.,* 2007; Wakefield *et al.,* 2016; Waters & Somerville, 2007; Waters *et al*., 2007).

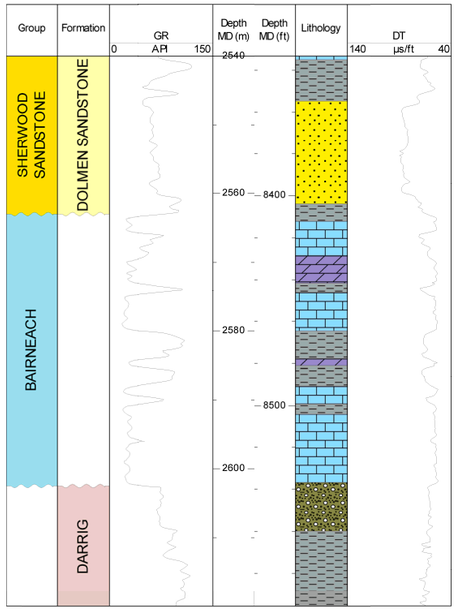
Comparison with Eastern Canada. No comparable limestone developments of Carboniferous, Tournaisian or Visean, age have been recognised offshore Newfoundland. The Bairneach is age equivalent to the Codroy Group and the upper part of the Anguille Group of onshore western West Newfoundland (Giles & Utting, 2004; Utting & Giles, 2008).



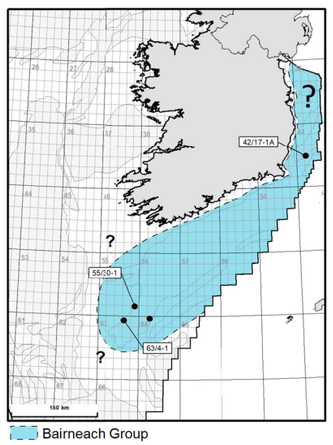
42/17-1A
Reference well; Bairneach Group



63/4-1
Type well; Bairneach Group



55/30-1
Reference well; Bairneach Group



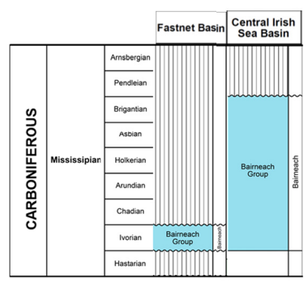


Figure D. 3.17. ***Bairneach Group type and reference wells with location and distribution map***.

CORK GROUP

The Cork Group is of Carboniferous, Mississippian (Tournaisian, Ivorian to Visean, Arnsbergian) age and was defined by Sleeman (1991) in the onshore South Munster Basin, Ireland, where a thick (2.5km) succession of shallow to deep marine clastic sediments of this age are present. The Old Head of Kinsale, in County Cork, southern Ireland, is the type section for the group (Naylor, 1966), which comprises three formations, the Kinsale Formation at the base, overlain by the Courtmacsherry and Lispatrick formations of Mississippian, Tournaisian (Hastarian) to Visean (Brigantian) age (Waters & Somerville, 2011). Only the lower of these, the Kinsale Formation, is recognised here in the offshore area. A significant unconformity appears to be present in the succession offshore above the preserved Kinsale Formation and it may be that younger formations of the group will be encountered in future wells drilled in the region.

Offshore Ireland the Cork Group has only been definitely recognised in one well (48/30-1) and tentatively in one other (50/12-3) within the North Celtic Sea Basin.

Biostratigraphically the group has been dated using miospores, conodonts and goniatites. However, the latter two fossil groups only occur intermittently throughout the succession, whereas miospores are abundant throughout.

Kinsale Formation

The Kinsale Formation comprises the lower part of the Cork Group, County Cork, onshore Ireland. The usage of the name has been extended into the North Celtic Sea Basin on the basis of lithological similarity and age equivalence.

Reference section in offshore Ireland. 48/30-1: 2749-2909.32m (TD) below KB. See **Figure D. 3.18**.

Lithology. In the 48/30-1 well, this formation is dominated by medium light to dark grey, purplish grey, micaceous, silty, non-calcareous to dolomitic, fissile, claystones. Rare off white to light grey, siliceous, well indurated siltstones and fine-grained sandstones, plus yellow to buff, cryptocrystalline dolomite stringers, are also present.

TD core 3 in the 48/30-1 well recovered a highly fractured, well indurated claystone, containing white dolomite inclusions, with a possibly slaty cleavage.

The sediments from the 50/12-3 well are dominated by light to medium dark grey silty claystones and siltstones. Thin light to medium grey, locally pale red, very fine to fine grained, micaceous, locally feldspathic sandstone laminae are also present. Some of the claystones possess aligned mica flakes along the bedding planes, suggesting possible low-grade metamorphism.

Wireline log character. The wireline logs in the 48/30-1 well are finely serrated, comprising moderately high gamma ray values, reflecting the dominance of claystone lithologies. The gamma ray values in the 50/10-1 well exhibit a more serrated wireline log profile, plus they also display higher sonic velocity values, reflecting the more interbedded claystone/siltstone lithologies.

Upper boundary. The top of the formation is marked by an unconformity and is overlain by the Triassic Cairn Formation in the 48/30-1 well. The boundary is placed at a marked downsection change to grey, non-calcareous, fissile claystone reflected on wireline logs by an increase in gamma ray values, in association with a corresponding decrease in sonic velocity.

Lower boundary. The base of this unit was not encountered in the one well (48/30-1) that to date has penetrated this formation.

Subdivision. No subdivision is recognised.

Thickness. The formation is 160m thick in the one well in which the unit has been penetrated to date, 48/30-1.

Biostratigraphic characterization. The 48/30-1 well contains miospores indicative of the *Cristatisporites hibernicus* (CD) Zone (Higgs, 1983). The Kinsale Formation in the onshore South Munster Basin and overlying Courtmacsherry and Reenydonegan Formations (Members 1-3) have yielded relatively well preserved miospores of Tournaisian, Hastarian to Ivorian, age (VI-CM Biozones) (Higgs & Forsythe, 2007).

Age. Carboniferous, Mississippian, Tournaisian, Hastarian.

Depositional environment. Poorly constrained due to an absence of data. The Kinsale Formation in the South Munster Basin, onshore south Ireland was deposited in a variety of environments from coastal plain fluvial channels, floodplain, tidal flats/delta, through lower shore to deeper storm influenced distal settings. Overall the formation shows a general water deepening, in association with a decrease in sand input (Sevastopulo & Wyse Jackson, 2009). A similar depositional setting is inferred for the offshore occurrence in the North Celtic Sea Basin.

Distribution. The group has been confidently recorded from one well in the North Celtic Sea Basin (48/30-1), and tentatively also in the 50/12-3 well.

Regional correlation. The formation recognised offshore correlates with the outcrops of Kinsale Formation in the South Munster Basin, southern Ireland. The group correlates with the Lower Limestone Shale Group of County Clare, western Ireland and with the Avon Group of South Wales, onshore UK (see Somerville *et al*., 2011; Waters *et al*., 2011).

Comparison with Eastern Canada. Age equivalent (Tournaisian) clastic sediments in eastern Canada are assigned to the Anguille Group (Giles & Utting, 2004; Utting & Giles, 2008).

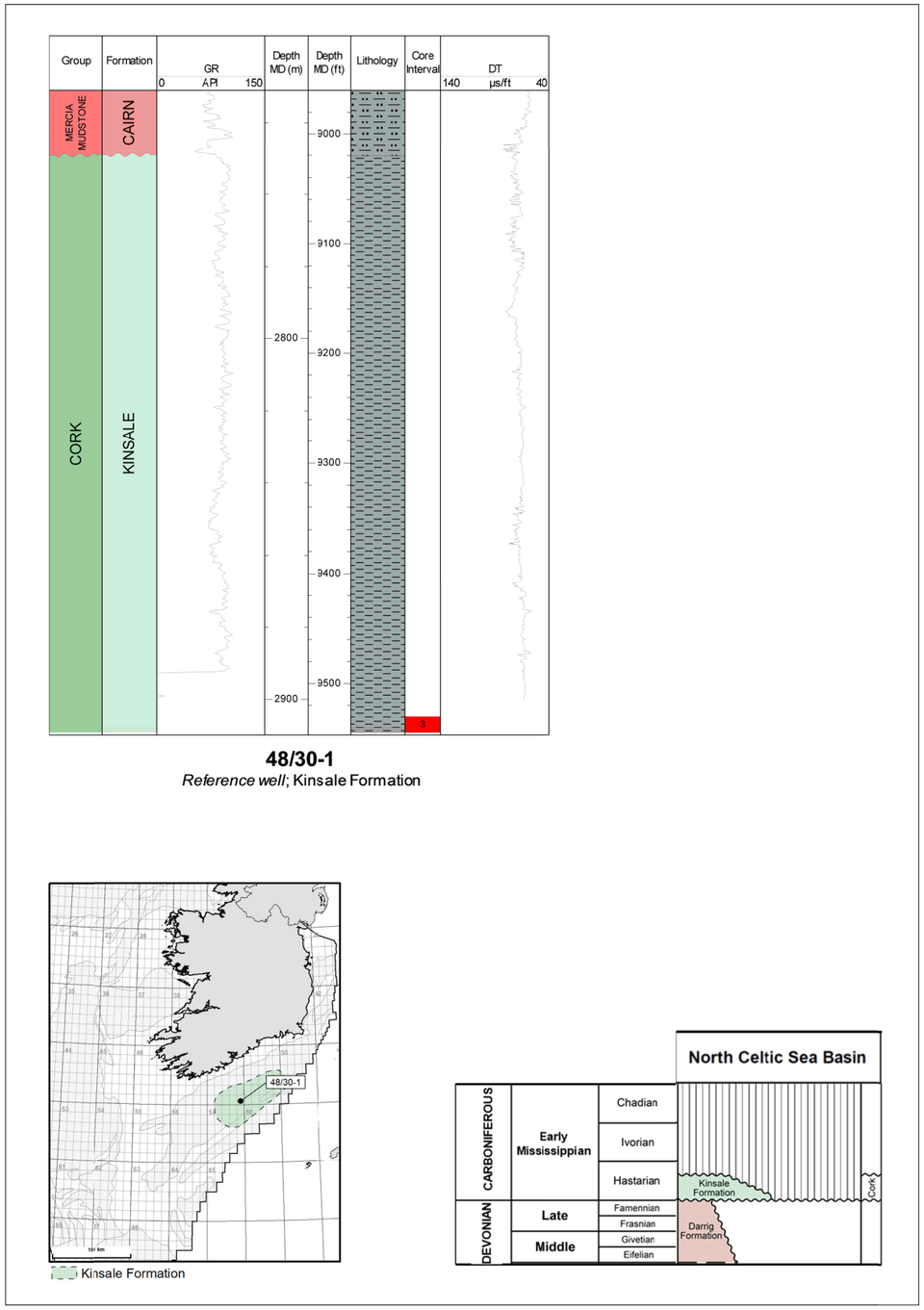


Figure D. 3.18. ***Cork Group, Kinsale Formation reference well with location and distribution map.***