Permo-Triassic basins, oil and gas, mineral resources, Northern Ireland

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In Northern Ireland, two main areas of thick Permian and Triassic sedimentary rocks are located in the Rathlin and Foyle basins, north of the Highland Border Ridge, and in the Lough Neagh and Larne basins, to the south (see Post-Variscan deformation and basin formation article) (P947901). The succession comprises up to 3000 m of Permian and Triassic volcanic and sedimentary rocks (P947846) and includes lithologies that are good potential reservoirs and seals, similar to those in the Morecambe Bay gasfield and in oilfields in the East Irish Sea Basin. The area is poorly explored primarily because of the difficulty in obtaining good quality seismic reflection data through the thick cover of Palaeogene basalt lava (see Mantle plumes, ocean spreading and the North Atlantic Igneous Province, Palaeogene extrusive igneous rocks article).
In 1971, the Newmill well was drilled in the Larne Basin on the basis of surface structure and nearby offshore seismic data. It encountered good reservoir rocks and seals but no significant hydrocarbons. In 1981 and 1983, the Northern Ireland Government commissioned VibroseisTM seismic reflection surveys in east Co. Antrim and west of Lough Neagh which demonstrated that sedimentary rocks beneath the basalt lavas could be imaged moderately successfully. Integration of that seismic data with gravity data and the results from deep boreholes sought to produce exploration models with the aim of stimulating further exploration \[1\], \[2\]. Since then further seismic exploration has been carried out and four (dry) wells have been drilled, two in the Larne Basin and two in the Lough Neagh Basin. Slight gas shows were found in the Ballytober Sandstone Formation in Newmill and Larne No. 2, and oil-staining in Annaghmore No. 1 (P947841) and (P947844) indicates the presence of hydrocarbons in these basins. No exploration wells have been drilled in the Rathlin Basin where the quality of seismic data is poor although deep boreholes, drilled for mineral and geothermal exploration, provide valuable information about the succession there.

**Play model**

The concealed basins of Northern Ireland contain three potential plays. The best-defined plays are within the Permian and Triassic rocks, with secondary potential in the Carboniferous. The Triassic play fairway occurs where reservoir rocks of the Early Triassic Sherwood Sandstone Group are sealed by the Mercia Mudstone Group. The Permian play is prospective where mudstones and evaporites of the Late Permian Belfast Group cap Early Permian Enler Group reservoir rocks. Both plays rely on an underlying Carboniferous source. Limited data are available for Carboniferous source, reservoir and seal rocks in the deeper parts of the basins but this play may have more potential in the western part of the Lough Neagh Basin where they occur at shallower depths.

**Reservoir**

The Sherwood Sandstone Group is a prolific reservoir in the Morecambe Bay gasfield and occurs in the Rathlin, Foyle, Lough Neagh and Larne basins. Sandstone in the upper part of the Group has the best reservoir parameters based on log and core analyses, with porosities of 15–25% and permeabilities between 10mD and 1000mD (P947908). The lower part of the Group is more argillaceous and includes a ‘silicified’ zone with lower poroperm values.

Although sandstone occurs above and below the Late Permian Magnesian Limestone the better potential reservoir target is in Early Permian sandstone which is thicker (up to 450 m) and more widely distributed. Sandstone located above the limestone is known only in the Lough Neagh Basin. Measured and calculated porosities and permeabilities in the Early Permian sandstone range up to 23% (average 15%) and 1705mD (average 212mD) respectively in Newmill (P947908). A particularly clean, relatively well-sorted, orange, fine- to medium-grained sandstone recognised in boreholes at Annaghmore, Ballynamullan, Ballymacilroy and Ballytober, at the top of the Early Permian Sandstone, may represent the marine reworking of fluvial sediments at the onset of the Bakevellia transgression (see Permian article). In the Larne Basin the Early Permian succession includes aeolian and fluvial sandstone overlying a volcanic and volcanioclastic succession and a basal breccia that has no reservoir potential (P947844).

**Source rocks**

The most likely source rocks for these plays are early Carboniferous organic-rich mudstone and oil shale and late Carboniferous coal. However, because the Carboniferous is only proven in the Magilligan borehole in the Foyle Basin \[3\], source rock properties are extrapolated from
Carboniferous rocks elsewhere in Northern Ireland and Scotland. Namurian and Westphalian coals occur in the Coalisland, Ballycastle and Ayrshire coalfields, and the early Carboniferous source rocks of Co. Fermanagh and south Co. Tyrone could occur beneath the Antrim Plateau.

Coal samples from Coalisland and Ballycastle have TOC contents of 42–66% and contain mainly gas prone organic matter (P947904) and (P947905). Cannel coal is present in both coalfields and this can typically generate oil as well as gas. The Ballycastle coalfield also contains oil shale with TOC contents in excess of 12%. The early Carboniferous strata may be thinner and more carbonate-rich than in Co. Fermanagh but good TOC values of 1.5–1.8% are recorded from the Rossmore Mudstone Formation in the Lough Neagh Basin. The Early Jurassic Waterloo Mudstone Formation is organic-rich but is immature for hydrocarbons.

**Maturity**

Vitrinite reflectance values (R0) from 0.5–0.6, marking the onset of oil generation, have been determined for coal samples from Coalisland, Ballycastle and the Magilligan borehole. If the maturity profiles for these source rocks are extrapolated to depth then source rocks in the basin depocentres probably have R0 values in the oil or gas windows. The oil trace in Carboniferous sandstone in the Magilligan borehole may indicate early oil generation. At present depths and temperatures gas generation is either suspended or confined to the deepest parts of the basins but there may have been several pulses of hydrocarbon generation in the basins since the Carboniferous.

**Seals**

The Mid- to Late Triassic Mercia Mudstone Group overlies the Sherwood Sandstone Group in the Rathlin, Foyle, Lough Neagh and Larne basins. While the Mercia Mudstone Group is usually between 300–500 m thick in boreholes the 951 m recorded in Larne No. 2 may be more typical of deeper parts of the Larne and Lough Neagh basins. In the East Irish Sea Basin a thickness of 300m for this Group has been found sufficient to provide an effective seal and significant hydrocarbon accumulations have been discovered at a shallow depth of 600 m below seabed [4]. Halite enhances the sealing capacity of the Mercia Mudstone Group but is only known to occur in the Larne Basin, south of the Sixmilewater Fault. However, an interpretation of seismic data suggests that there may be halite present north of that fault, both west and east of the Ballytober Horst (Figure 22.10a).

Late Permian mudstones may seal underlying Permian reservoir sandstones although these potential caprocks are variable in thickness and quality, particularly in the Lough Neagh Basin where sandstones are recorded (Annaghmore No. 1 and Ballymacilroy wells). In the Larne area, a thick Late Permian halite should prove an effective seal (P947844) to the Early Permian sandstone.

**Burial history, hydrocarbon generation and trapping mechanisms**

The Rathlin, Foyle, Lough Neagh and Larne basins are the preserved remnants of a basin complex that originally extended eastwards through the North Channel, Peel, Solway and East Irish Sea basins into the north of England. Permian and Triassic rocks, restricted now to the area of the Antrim Plateau, may have been almost continuous to the offshore basins west of Ireland. Carboniferous strata are preserved in Northern Ireland to the west of the basin complex and, to the east, they are found in the Midland Valley of Scotland.
The evidence from preserved sequences elsewhere in Northern Ireland, the Midland Valley of Scotland and in the Solway Firth suggests that a thick sedimentary pile of variable lithologies was originally deposited during the Carboniferous and then subsequently partly eroded during the Variscan Orogeny. The early Carboniferous succession thins from Co. Fermanagh eastwards to Ayrshire in Scotland. In contrast, the late Carboniferous succession is thicker in Ayrshire, where sedimentary and volcanic rocks up to Westphalian D age are preserved, than in Counties Fermanagh and Tyrone. The Carboniferous succession beneath the Antrim Plateau is expected to be intermediate between that of the two areas described above. An original total thickness of between 2000 m and 4000 m of Carboniferous strata will have been reduced by uplift and erosion associated with the Variscan Orogeny. The amount of uplift probably diminished to the north and east, although the effects of tectonism are still evident in differential uplift of fault blocks southwest of Lough Neagh.

In outcrops on the north side of the Highland Border Ridge, on the margins of the Rathlin and Foyle basins, there is a gap in the sedimentary record between the Tournaisian Roe Valley Group and the late Viséan-early Namurian Ballycastle Group. South of the Highland Border Ridge the unconformity extends from the early Chadian to the late Asbian. Although this gap may also occur in the Rathlin and Foyle basins it is possible that later deposition was almost continuous from the late Asbian through to the Westphalian. The Machrannahish Basin in Kintyre has 700 m of Namurian to Westphalian clastic sedimentary rocks whilst over 1000 m of Carboniferous strata have been interpreted on marine seismic sections west of Rathlin Island in the Malin Sea. A preserved Carboniferous fill of 1500 to 2000 m in the deepest parts of the Rathlin Basin is not unrealistic.

Gravity, seismic and well data indicate that Permo-Triassic basins are controlled by NNW-SSE, northwest-southeast and northeast-southwest fault trends. The Larne and Lough Neagh basins also occupy a northeast-southwest (Midland Valley) belt although they are internally segmented by both Caledonoid structures (e.g. Sixmilewater Fault) and north-south faults (e.g. Ballytober and Toome Bay faults). To the southeast many of the Permo-Triassic basins are preserved as half-grabens bounded by NNW-SSE faults that originated as Caledonian shears (e.g. Portpatrick and Stranraer Basins). The Southern Upland Fault Zone (SUFZ) separates the strongly asymmetrical, eastward thickening Portpatrick basin and the more symmetrical, westward thickening Larne Basin and appears to have acted as a transfer zone during ESE-WNW directed Permo-Triassic. The Sixmilewater Fault, at the northern margin of the Ballantrae-south Co. Antrim magnetic basement zone, may be a similar transfer zone en-echelon with the SUFZ onshore in Northern Ireland.

Seismic reflection data is of variable quality, generally poor in the Rathlin-Foyle basins and poor to moderate in the Larne and Lough Neagh basins. The presence of thick, high velocity, high acoustic impedance basalt lava of the Antrim Lava Group, with inter-flow weathering surfaces and an irregular top and bottom surface, degrades the seismic response from the underlying sedimentary rocks. The most important reflectors are the Top Sherwood Sandstone Group (SSG) and Top Magnesian Limestone (ML) which define the structure at the top of the main reservoir intervals. In the Rathlin Basin, because the Magnesian Limestone is not developed and the Top SSG reflector produces a small acoustic contrast, structure definition is poor. West of Lough Neagh reflector quality is moderate but structure mapping is hindered by the prevalence of faulting. North of Lough Neagh two-way time (TWT) maps on Top SSG and Top ML can be constructed in the vicinity of Toome but reflector quality diminishes to the north and east.

The Larne Basin is divided by the Sixmilewater Fault with the thickest Permo-Triassic section in the Larne area. Both the Magnesian Limestone to Sherwood Sandstone Group interval and the Mercia Mudstone Group appear to thicken northwards towards the Sixmilewater Fault. The
presence of Permian halite and possible thickening of the Sherwood Sandstone Group causes the increase in thickness of the lower interval. The better developed thickening of the Mercia Mudstone Group is confirmed by detailed palynological studies on well sections either side of faults and is the result of syn-depositional Late Triassic extension. Evidence for Early to Mid-Triassic extension is more equivocal although seismic data show that the Sherwood Sandstone Group thickens across the Ballytober Fault (Figure 22.10a). The structure north of the Sixmilewater Fault is dominated by the north-south trending Ballytober Horst, mapped at both Top SSG and Top ML level. To the east the reflectors dip and step down towards the (offshore) depocentre whereas on the west it is bounded by the Ballytober Fault with a large downdrop to the west. The dry Ballytober No. 1 well tested a 3-way dip closure, with a large areal extent but small vertical closure, bounded by the Ballytober Fault. Both the Sherwood Sandstone and Mercia Mudstone groups are relatively thin and the former has poor reservoir quality. The horst acted as a positive structural element during the Permian and Triassic.

**Trapping styles**

Seismic data from the Lough Neagh and Larne basins give an indication of their potential trapping styles. High quality offshore seismic from the Larne and Portpatrick basins also provides better images of potential structural targets at both Top SSG and Top Lower Permian Sandstone levels. Four-way dip closures on the footwalls of tilted fault blocks are prime targets, although combined dip/fault closures are more common. Many of the faults appear to have had a polyphase history of movement in both extensional and compressional stress regimes, from the early Carboniferous to the Miocene. Reactivation may result in minor modification of the tilted fault blocks, such as footwall uplift and drag, or the formation of more obvious inversion structures. The latter often have the appearance of a flower structure and may reflect transpressional movement. Additional traps recognised offshore are rollover anticlines in the hanging-walls of listric faults, such as the one targeted by the Laggantulloch well in the Portpatrick Basin. Similar structural settings may exist onshore, for example, adjacent to the Toome Bay or Ballytober faults, although seismic data in these areas is either absent or of poor quality.

Although the internal structure of the Rathlin Basin is largely unknown because of poor quality seismic data, geological models based on analogue basins and the succession in the Port More borehole envisage a Permo-Triassic half-graben developing against the Tow Valley Fault. Later movement on transfer faults would form tilted fault blocks and targets include both structural closures and combined stratigraphical/structural traps within the alluvial fan conglomerate-sandstone sequence.

There is little indication of potential trapping styles within the Carboniferous because it is poorly imaged in the Larne Basin. The 1981 and 1983 seismic surveys west of Lough Neagh indicate the presence of small, tilted fault blocks. (Figure 22.10b).

**The major risks in the Permo-Triassic exploration plays in Northern Ireland are:**

- Absence or immaturity of source rocks
- Trap formation after generation and expulsion of hydrocarbons from source
- Breach of trap and leakage of hydrocarbons

Models of the burial history of the different basins are shown in Figure 22.11. They utilise stratigraphical records from deep boreholes and estimates of the possible thickness of strata removed by erosion based on exposed sequences in Northern Ireland and adjacent areas. The estimates of uplift are comparable with those derived from apatite fission track, vitrinite reflectance,
density and sonic velocity data. Interpretation of these data is complicated by a lack of knowledge of palaeogeothermal gradients and by the effects of uplift and subsidence since the beginning of the Carboniferous.

If good quality Carboniferous source rocks are present in the deepest parts of the Rathlin, Lough Neagh and Larne basins then subsidence plots indicate that they should have generated gas. Prolonged periods of basin subsidence led to increasing source rock maturation and the generation of hydrocarbons. Intervening tectonic episodes were associated with the formation of structural traps, primary and secondary migration of oil and gas, and uplift leading to the interruption of hydrocarbons generation (P947958).

After the last period of subsidence associated with the Antrim Lava Group subsequent tectonic episodes may have downgraded the prospectivity of all basins by breaching traps and allowing leakage of hydrocarbons to the surface. In addition, it is possible that hydrocarbons may have been flushed from the Sherwood Sandstone Group reservoir by an influx of meteoric water. Oxygen isotope data indicates that formation water from those rocks in the Ballymacilroy and Larne No. 2 boreholes is almost identical to that of present-day meteoric water. However, similar effects have been recorded in other sedimentary basins with productive hydrocarbon systems, so it does not necessarily suggest that hydrocarbons have been driven out of the reservoirs.

References


Category:
- The geology of Northern Ireland