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# Hydrocarbon Habitat of the Rockall Trough, Northeast Atlantic Margin

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The Rockall Trough is a rift basin located on the North Atlantic passive margin, west of the UK and Ireland. It is a frontier basin with very limited well control. Most exploration wells are confined to the inboard basin areas and near igneous complexes. None of the wells drilled to date have penetrated source rocks, nor have any economically significant hydrocarbon discoveries been made. Consequently, explorers face considerable uncertainties in understanding key elements of the hydrocarbon system, such as the distribution of potential source rocks, their thermal maturity levels, and the timing of oil and gas yields.

Since the UK government's 17th licensing round announcement in November 1996, the area has been the subject of numerous studies for both industry and academia. This particular study was undertaken to:

- determine whether or not an effective oil-prone source rock is present,
- characterize the nature of any hydrocarbon seepage in terms of source rock organic facies, thermal maturity, geological age, and degree of post-generative alteration,
- evaluate migration pathways,
- determine the timing of oil and gas yield, by way of one-dimensional basin modeling, and apply the results from seafloor geochemistry analyses to audit the modeled hydrocarbon yield composition and yield timing, and
- determine the sensitivity of thermal maturity and hydrocarbon yield predictions to uncertainties in the sparse constraining data.

## Basin Evolution

The onset of seafloor spreading in the northern North Atlantic and the Norwegian-Greenland Sea is thought to coincide with the relaxation of compressional stresses related to the Laramide Orogeny (Ziegler, 1988). There is, however, considerable uncertainty in the literature as to how and when the Rockall Trough evolved. Roberts et al. (1983) correlated subdued magnetic features to magnetic anomalies 34 and 33 and thus inferred that seafloor spreading commenced during the Albian. Others, including Megson (1987), suggest that these anomalies are associated with rotated fault blocks. Our kinematic modeling of the greater northeast Atlantic area suggests that a N-S and NE-SW crustal fabric was established during repeated Devonian-Carboniferous and Permo-Triassic stretching and collapse. Only local sub-basins appear to have existed at the onset of the Jurassic, with the area between Europe and Greenland occupied by stretched continental fragments. By the end of the Jurassic the area was undergoing extension (Kimmerian event). Marine waters inundated the newly formed grabens from both the Atlantic and Arctic basins. For the Norwegian-Greenland Sea area Ziegler (1988) notes that the rate of crustal extension increased significantly during the Late Jurassic and Early Cretaceous. This was associated with rapid basin subsidence and the establishment of deep marine conditions. The integrated evaluation of gravity-magnetic data and plate reconstructions along this margin of the North Atlantic suggest that depositional environments conducive to the accumulation of organic-rich rocks may have existed in the Rockall Trough during the late Jurassic and early Cretaceous. During this time the Porcupine Basin evolved through stretching and formation of oceanic crust. Gravity and magnetics data show a series of parallel striations interpreted to be spreading ridges. The clockwise rotation of the Porcupine Bank was the main cause for stretching between the Rockall Bank and the British and Irish continental massif. The extensional tectonic regime persisted throughout the Cretaceous with continued widening of the Faeroe-Shetland Basin and the Rockall Trough. The Rockall Trough is dominated by a series of NW trending Mesozoic faults defining a series of Mesozoic terraces. This faulting was likely facilitated by pre-existing kinks in the Caledonian crust.

By the early Eocene oceanic crust had formed in the central parts of the Rockall Trough. We estimate the magnitude of stretching to be significant, with beta values between 2 and 6. During the Eocene, the spreading axis shifted to the north between Greenland and the Faeroe Plateau. During the late Early Paleocene to mid-Eocene (60 to 50 ma) the entire Arctic-North Atlantic rift system experienced widespread volcanism; referred to as the Thulean volcanic event. This volcanism is particularly evident on the Rockall-Hatton-Faeroe Bank which is covered by extensive plateau basalts which attain thicknesses of 2-3 km (Roberts, et al 1983, 1984).

The Lopra-1 well on the Faeroe Islands attempted to drill through the basalt, but failed to do so after penetrating nearly 2.4 km. Geochemical analyses of oil stains within the basalts of the Lopra-1 well have been correlated to a marine, siliciclastic source rock with a predominance of marine algal organic matter, akin to the Kimmeridge Clay (Laier, et al. 1997). Ziegler, (1988) notes that submarine extrusions in the Rockall Trough resulted in the construction of volcanic edifices that built up to sea-level and prograded laterally (e.g. the Rosemary Bank and Darwin sea mounts). In some cases, seaward dipping reflectors from sub-aerial lava flows can be used to estimate paleo waterdepths. These lava packages form an effective barrier to, and cause dispersion of seismic energy, resulting in poor imaging of the Mesozic section. They are also thought to function as a barrier to vertical migration of hydrocarbons.

Different parts of the Rockall Trough accomodated differing amounts of Paleogene and Neogene sediments. Areas with thick Neogene sections underwent the most recent thermal maturation and hydrocarbon yield.

## Stratigraphy

The stratigraphy of the Rockall Basin is complicated by a lack of deep well control and the fact that conventional seismic data has not been able to resolve pre-Tertiary structure of the basin due to the presence of Tertiary lavas and intrusive rocks. Only where there is a local thinning or absence of igneous rocks is the underlying structure observed with confidence. However, the stratigraphy of the basin can be generally divided into a pre-rift and a syn-rift succession.

In areas where deep seismic imaging is possible, a rotated syn-rift sequence lying in locally inverted tilted fault blocks is imaged. This succession, by extrapolation from adjacent basins such as the Faroe-Shetland Basin, is thought to contain Permo-Triassic red sandstones and siltstones, Jurassic fluvial to shallow marine sandstones and marine mudstones, Ryazanian organic-rich shales, and Lower Cretaceous mudstones. A top syn-rift unconformity of Albian-Cenomanian age caps the sequence.

Above the top syn-rift unconformity, the post-rift succession is better constrained by well data. This interval contains Upper Cretaceous mudstones overlain by a relatively complete Tertiary section. The Tertiary sequence is composed of rapidly deposited basin floor fan deposits interbedded with mudstones reflecting tranquil deep-water sedimentation. Extensive magmatic activity from the latest Cretaceous until the early Eocene resulted in the emplacement of large igneous centers in the axis of the Rockall Trough together with smaller satellite features and extensive lava flows. Prograding flow-front breccias also developed down-dip of the sheet lavas. It is the presence of these volcanics that has hindered the seismic interpretation of the deep stratigraphy in the basin.

## Hydrocarbon Habitat

One key uncertainty prior to this study was the existence of a Jurassic source-rock within the NE Atlantic passive margin and, in particular, within the Rockall Trough. Organic-rich rocks of early and late Jurassic age are the principal source rocks for oil and gas in most other basins around the British Isles (Porcupine Basin, Central Graben, Moray Firth, Viking Graben, and the Faeroe-Shetland basin), as well as in NE Greenland and offshore Mid-Norway. Although no oil-prone source rocks have been penetrated in the Rockall Trough, reservoired oils from the neighboring Faeroe-Shetland and Porcupine Basins have been correlated to a Kimmeridge Clay equivalent source. Indeed, Late Jurassic source rocks have been penetrated by exploration wells in the neighboring Faeroe-Shetland Basin, whereas Liassic source rocks are present in the Porcupine Basin. Furthermore, Jurassic source rocks are penetrated in shallow boreholes in the in-board basins along the Atlantic Margin of the British Isles (Hitchen and Stoker, 1993; Isaksen et al, 2000). These include the lower Jurassic Portree and Paba Shale Formations and the equivalent of the North Sea Kimmeridge Clay. Bathonian and Rhyazanian source rocks for oil generation are penetrated in the West Lewis and West Flannan Basins. Similar age oil-prone shales are present in outcrop on the Isle of Skye.

Geochemical evaluation of shallow seafloor samples provide compelling evidence for thermogenic hydrocarbon generation in the Rockall Trough (Isaksen et al, 2001). Well and borehole data from other basins along the northeast Atlantic margin, together with the geochemical characteristics of the seeps, strongly suggest that a Kimmeridge Clay-equivalent source rock is indeed operating along the western UK margin.

Geo-history and hydrocarbon yield modeling integrated with the character of the seafloor seeps indicate that the eastern margin of the Rockall Trough has experienced a recent (Neogene to present-day) charge of oil and gas from an Upper Jurassic source. Although many key exploration parameters are poorly constrained- a common problem in frontier basins - sensitivity analyses suggest that while some of these uncertainties are substantial, they have little impact on the viability of the hydrocarbon system in the region. Though its margins shift, the hydrocarbon system is fundamentally robust within the range of uncertainties addressed.

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