Rialtas na hÉireann
Government of Ireland

GEOCHEMISTRY

Merlin Energy Resources Ltd

PIP
Petroleum Infrastructure Programme

TABLE OF CONTENTS

LIST OF TABLES

B. GEOCHEMISTRY RESULTS SUMMARY

B.1. INTRODUCTION

A broad regional evaluation of the source rock potential for offshore Ireland has been conducted to identify all formations with hydrocarbon generation potential based on the newly developed stratigraphy of this project. For this characterisation all available geochemical data for offshore Ireland that were provided by PIP and PAD for this project were used, which did not include any raw data for DSDP/IODP/ODP holes. The data were originally extracted from the source reports and files together with data from new analysis as part of an earlier PIP project (IS16/01 "Atlas of Source Rocks and Oils in Mesozoic Basins Offshore Newfoundland-Labrador and Ireland", BeicipFranlab, 2017) and have been compiled into one integrated geochemical database for the current study, using *p:IGI-3* software. It should be noted that only selected sections of the BeicipFranlab project report were made available to the present project, which mainly included individual Excel files with geochemical data for each well, as well as a tabulation of all source rock intervals by well that were identified in project IS16/01.

To identify organic richness, kerogen type, and hydrocarbon yield of the individual formations Total Organic Carbon (TOC) contents, as well as parameters derived from Rock-Eval pyrolysis have been used. While the TOC contents provide information on the organic richness of a rock interval, the Rock-Eval pyrolysis derived data allow characterisation of the kerogen type, maturity and hydrocarbon generation potential. Raw data derived from Rock-Eval pyrolysis comprise the S1, S2, and S3 values, as well as the Tmax value. The S1 peak represents the abundance of free hydrocarbons already present in the sample. The S2 peak represents hydrocarbons produced by the pyrolysis of the kerogen and is a measure of the likely hydrocarbon yield of the kerogen upon further maturation; higher yields indicate better petroleum generative potential. Together with measured TOC contents the S2 value is used to calculate Hydrogen Index values, with HI = [S2/TOC]*100. The S3 parameter represents the amount of carbon dioxide generated during pyrolysis, and thus provides a measure of the oxygen content of the kerogen and is further used to calculate Oxygen Index values (OI = [S3/TOC]*100). Tmax represents the temperature of the maximum S2 yield during Rock-Eval pyrolysis. Early- to mid-oil window mature source rock samples typically have Tmax values between 430-455°C, whereas post mature samples typically show values greater than 465°C. A range of industry standard plots using these parameters have been produced for each interval to demonstrate its source rock potential.

- A cross plot of TOC *versus* S2 allows the identification of the organic richness, as well as the sample's hydrocarbon generative capability.
- The pseudo-van Krevelen diagram, using Hydrogen Index and Oxygen Index values, is used to identify and compare kerogen types, and hence the tendency for generation of oil and/or gas given sufficient burial and maturation of the kerogen.
- Another cross plot used to identify the kerogen type, as well as maturity trends uses HI *versus* Tmax. S2 values and as a result HI values decrease with increasing maturity once hydrocarbon generation commences, which may result in the misinterpretation of the kerogen type. Using the HI *versus* Tmax plot and the kerogen trendlines allows evaluation of the kerogen type and thus source potential whilst considering the maturity of the samples.

TOC data were available for a total of 12,721 samples and Rock-Eval pyrolysis data for 6,458 samples. The data have not been filtered prior to interpretation and the plots for each formation with source potential show all data points available, with comments being included where significant outliers are present. The interpretation and characterisation of all source intervals were based on present day measured TOC and Rock-Eval pyrolysis parameters and no calculations to estimate the original source potential have been carried out. However, for older and more deeply buried source intervals some consideration of their maturity, mainly based on Rock Eval pyrolysis data, has been made in order to avoid mis-interpretation (underestimation) of hydrocarbon potential. As well as considering elevated maturity, possible effects of sample contamination, e.g. increased Production Index values (S1/[S1+2]) at low maturity suggesting either the presence of migrated hydrocarbons or oil-based drilling mud, have been considered where appropriate.

B.2. SUMMARY OF IDENTIFIED SOURCE POTENTIAL

Considering the data types described above, a total of 21 formations with source potential have been identified throughout the different basins offshore Ireland, with another 10 formations which each include a few samples showing some hydrocarbon potential (**Table B**. 1). Detailed plots and descriptions for the 21 selected source intervals are included in the respective chapters of each individual formation (**see section D**), whereas the plots for the 10 additional formations with limited source potential are shown in the appendix (**Appendix E**).

Identified source rock formations are mainly of Early Cretaceous to Early Jurassic age, although the Paleogene Gweedore Formation and Carboniferous Blackthorn Group also show significant source potential.

Based on the available data, none of the Upper Cretaceous or Triassic formations showed hydrocarbon generative potential. Data availability for the Permian and Devonian and older intervals is very limited such that we are unable to comment on the source potential of these formations. Furthermore, data for the Erris Basin, Central Irish Sea Basin, and Kish Bank Basin are also very limited and thus these basins are therefore not included in **Table B**. 1.

ROCKALL BASIN

The Rockall Basin includes two formations that show some source potential. The Early Cretaceous Valhall Formation is organic rich, but available samples appear affected by contamination and a reliable characterisation of its source potential is thus not possible.

In addition, an organic-rich interval has been identified in the Upper Jurassic. This Tithonian-Kimmeridgian age Dawros Formation shows a Type II to Type II/III kerogen composition and mixed oil and gas potential.

DONEGAL BASIN

In the Donegal Basin only a few samples from the Carboniferous Blackthorn Group are available for the characterisation. Although the interval shows elevated TOC contents, the hydrocarbon yields are low indicating only limited source potential. Available maturity data shows the samples to be of very high maturities and as a result the present-day source potential has decreased, and samples are likely to have originally had higher hydrocarbon generation potential.

SLYNE BASIN

Several intervals with source potential were identified in the Slyne Basin, with ages ranging from Late, Middle, and Early Jurassic, to the Carboniferous.

The Upper Jurassic shows only limited source potential in this area and with a largely Type III kerogen composition it appears mainly gas prone. Only few samples are characterised by a more Type II kerogen composition, indicating some mixed oil and gas generative potential.

Source potential in the Middle Jurassic is also limited, but again includes samples in the Dun Caan Shale Formation that show a Type II kerogen composition with elevated hydrocarbon yields and hydrocarbon generative potential.

The best source potential in the Slyne Basin is observed in sediments of Early Jurassic age. These include the Toarcian aged Whitby Mudstone Formation and Pliensbachian Pabay Shale Formation that show good to excellent oil potential, being organic-rich Type II source rocks, that are found throughout the basin.

Further source rock potential is seen in the very organic-rich to coaly Carboniferous Blackthorn Group that appears mainly gas prone.

IRISH MAINLAND PLATFORM

Data availability for the Irish Mainland Platform is very limited (well 36/16-1A) and data required for the source rock

characterisation are mainly reported for the Carboniferous with only single data points for other intervals. The Carboniferous Blackthorn Group is relatively organic rich, but present-day hydrocarbon yields are fairly low. Considering the elevated maturity of the samples it is likely that the TOC and particularly HI values were originally higher and source characteristics might have been similar to the Porcupine Basin.

Formation	Epoch	Age/Stage	Rockall Basin	Donegal Basin	Slyne Basin	Porcupine Basin	Irish Mainland Platform	Goban Spur Basin	Fastnet Basin	North Celtic Sea Basin	South Celtic Sea Basin
Gweedore	Eocene-Paleocene	Ypresian-Thanetian				Xx					
Bradán	Early Cretaceous	Albian-Aptian				X					
Valhall	Early Cretaceous	Aptian-Berriasian	Xx?			Xx					
Wealden Group	Early Cretaceous	Aptian-Valanginian								XX	
Pike	Early Cretaceous	Valanginian-Berriasian								XXX	
Perch	Early Cretaceous	Berriasian								XXX	
Pollan	Early Cretaceous	Berriasian								XXX	
Dawros	Late Jurassic	Tithonian-Kimmeridgian	Xx		Xx						
Dursey	Late Jurassic	Tithonian				XXx					
Bolus	Late Jurassic	Kimmeridgian-Oxfordian				XX					
Minard	Late Jurassic	Oxfordian			X	XX					
Knockadoon	Late Jurassic	Tithonian								XX	
Baginbun	Late Jurassic	Kimmeridgian								XX	
Dun Caan Shale	Middle-Early Jurassic	Aalenian-Toarcian			Xx						
Tacumshin	Middle-Early Jurassic	Aalenian-Toarcian							x	X	
Whitby Mudstone	Early Jurassic	Toarcian			XXX			X	X	XXx	
Pabay Shale	Early Jurassic	Pliensbachian			XXx			X	X	XX	
Glenbeg	Early Jurassic	Sinemurian						X	Xx	XX	XX
Currane	Early Jurassic	Sinemurian							X	XX	XX
Leane	Early Jurassic	Hettangian							X	Xx	
Blackthorn Group	Carboniferous	Asturian-Langsettian		X	XX	Xx	XX?				

Formations with few samples showing limited source potential: Eel Formation (Aptian), Rainbow Claystone Formation (Barremian-Valanginian), Sybil Formation (Kimmeridgian-Oxfordian), Galley Formation (Oxfordian), Kestrel Formation (Bajocian), Harrier Formation (Bajocian-Aalenian), Inagh Formation (Sinemurian), Meelagh Formation (Sinemurian-Hettangian), Caragh Formation (Hettangian), and Ruacan Formation (Carboniferous)

Table B. 1. ***Formations and groups with identified source rock potential and their presence in individual basins offshore Ireland.***

X's are an indication for the general source potential of the formation; X = limited, XX = good, XXX = excellent, and the use of lower case 'x' indicating stages in-between.

Colours indicate the main hydrocarbon generative potential of the formation; green = oil potential, yellow = mixed oil and gas potential, red = gas potential. Where gradients of two colours have been used, formations are characterised by a heterogenous kerogen composition that did not allow to include them to just one of the groups. The hydrocarbon types should be considered only broadly indicative.

PORCUPINE BASIN

The Porcupine Basin includes formations with identified source potential in the Eocene-Paleocene, the Lower Cretaceous, the Upper Jurassic and the Carboniferous.

The source potential in the Eocene-Paleocene Gweedore Formation and the Lower Cretaceous Bradán and Valhall formations is limited, however. Although organic-rich intervals occur, hydrocarbon yields are fairly low and samples are mainly gas prone. Only a few wells in the area show a greater Type II kerogen contribution and thus increased oil generation potential.

The best source potential is seen in the Upper Jurassic, especially in the Dursey and Bolus formations. Including samples with a Type II/III to Type II kerogen composition, an average TOC content of ~2%, and elevated HI values the Dursey Formation shows good to very good hydrocarbon potential in this area. Similar source potential is seen in the Kimmeridgian-Oxfordian Bolus Formation, although average TOC contents are slightly lower. Another Late Jurassic organic-rich interval is the Minard Formation, but with a more Type III to Type II/III kerogen composition its source potential is lower compared to the Dursey and Bolus formations.

Further source potential is seen in the very organic-rich Carboniferous Blackthorn Group, where samples show a Type II/III kerogen composition and mixed oil and gas potential.

GOBAN SPUR & FASTNET BASINS

The Goban Spur and Fastnet basins include some organic-rich intervals, but the source potential appears mainly to be low. Formations with increased TOC contents are found in the Upper Jurassic and Lower Jurassic. The Upper Jurassic Galley Formation includes just a few samples with elevated hydrocarbon yields in the Goban Spur Basin that indicate some hydrocarbon generative potential.

The Lower Jurassic Whitby Mudstone and Pabay Shale formations are characterised by high relative input of terrestrial material in these areas and with a Type III kerogen composition are mainly gas prone. Formations from the Sinemurian to Hettangian age intervals show variable kerogen compositions and only few samples show noticeable hydrocarbon potential.

NORTH & SOUTH CELTIC SEA BASINS

The North and South Celtic Sea basins include several formations that are characterised as showing source rock potential. Good to excellent source potential is seen in the three formations belonging to the Lower Cretaceous Purbeck Group in the North Celtic Sea Basin. The Pike, Perch, and Pollan formations are geochemically very similar and present throughout the basin, and with a Type II to Type I kerogen composition and high hydrocarbon yields they can be characterised as oil-prone source rocks.

Other organic-rich Lower Cretaceous formations from the Wealden Group (Aptian-Valanginian) show lower source rock potential with mainly mixed oil and gas to gas-prone kerogen.

Within the Upper Jurassic, the Tithonian-Kimmeridgian Knockadoon and Baginbun formations show the best hydrocarbon generative potential in the North Celtic Sea Basin. The kerogen composition, and as a result the source rock potential, of these intervals appears somewhat heterogenous, but the formations include intervals with Type II, oil-prone kerogen.

In the Lower Jurassic Lias Group, good source potential is seen in the Toarcian-Pliensbachian Whitby Mudstone and Pabay Shale formations, although to a lesser degree than in the Slyne Basin. The kerogen composition is characterised by greater input of terrestrial material and these formations are only mixed oil and gas prone in this area. Further source potential is seen in the Lower Jurassic where several organic-rich formations have been identified in the Sinemurian to Hettangian in both the North and South Celtic Sea Basins. Within this interval, the Glenbeg, Currane, and Leane formations show very similar source rock characteristics and, with a Type II/III kerogen composition, are mixed oil and gas prone.

B.3. COMPARISON WITH PROJECT IS16/01 RESULTS

Comparing the results of this overview of source rocks with the results of project IS16/01 reveals some differences, mainly related to changes in age due to the updated stratigraphy of this project. Up to 13 regional source rock intervals within the stratigraphic column were identified offshore Ireland in PIP project IS16/01 based on ages recorded in original well reports. The current study identified 21 formations with source potential, as well as 10 additional formations that include few samples with some hydrocarbon potential. Formations with source potential could be assigned to most source intervals identified in project IS16/01, although some differences occur.

Project IS16/01 identified the Late Cretaceous source interval Ksup 1 that has now been assigned to the Gweedore Formation and is thus considered to be of Eocene-Paleocene age. No equivalent of the Ksup 1 interval has been identified in any of the basins, but additional intervals with source potential have been identified in this study that were not accounted for in the previous project. This includes the Hettangian age Caragh Formation, that contains a few samples in the North Celtic Sea Basin showing some source potential, as well as the Carboniferous Blackthorn Group interval that was characterised as a potential source interval in various basins. Project IS16/01 did identify a Cenomanian age source interval Ksup 2 in DSDP Leg 80 Hole 549 and also at DSDP Site 1276, corresponding to the Plenus Marl; this potential source interval is not further illustrated in the current study as no raw data for these boreholes were provided for the geochemical database.

In wells 49/9-1 and 50/6-1 in the North Celtic Sea Basin samples of the Merlin and Sparrowhawk (49/9-1 well only) formations correspond to the source rock interval Mid J1 that was identified in project IS16/01 and characterised as a Type II/III source rock with oil and gas potential. The BeicipFranlab report (IS16/01) states that “A thick organic interval (165 to 200m), dated Bathonian, is shown by *Carbolog* in well 49/9-1 and by Rock-Eval data in well 50/6-1. In spite of this thickness, the TOC average is rather low 1.3% and the mean HI is only around 100mgHC/gTOC. The associated sediments were deposited under well-oxygenated marine shelf claystone and a Type II//III source rock is interpreted”. *Carbolog* data were not available for the current study and based on available Rock-Eval data for the two wells, the Merlin and Sparrowhawk formations were characeterized as not showing significant source potential. Overall low TOC contents, as well as low hydrocarbon yields indicate that samples show a more Type III/IV kerogen composition and are at best gas prone. No equivalent to source rock interval Mid J1 has been identified in the current study for the North Celtic Sea Basin.

Details of the changes in the stratigraphic assignment of specific source rock intervals in individual wells are shown in **Table B. 2**. A table comparing the ages used in project IS16/01 with the stratigraphy of the current project for all all source intevals as identified in project IS16/01 is included in **Appendix E**.

Basin	Well	Top (m)	Base (m)	IS16/04 Project stratigaphy	IS16/04 Project formation age	Previous age from IS16/01	IS16/01 source interval
Slyne	18/20-1	2791.24	2866.49	Whitby Mudstone	Toarcian	Pliensbachian	LowJ2a
Slyne	18/20-1	3039.81	3216.16	Pabay Shale	Pliensbachian	Sinemurian	LowJ1
Slyne	19/08-1	1340	1440	Minard	Oxfordian	Bajocian	MidJ
Porcupine	26/27-1B	733.47	775.949	Gweedore	Ypresian-Thanetian	Santonian-Campanian	Ksup1
Porcupine	26/28-1	2288.88	2313.99	Minard	Oxfordian	Kimmeridgian	LateJ3
Porcupine	26/28-1	2501.41	2569.53	Minard	Oxfordian	Bathonian/Bajocian	MidJ
Slyne	27/13-1A	1215.44	1332.3	Minard	Oxfordian	Bajocian	MidJ
Slyne	27/13-1A	2154.68	2173.69	Whitby Mudstone	Toarcian	Pliensbachian	LowJ2a
Slyne	27/13-1A	2318.9	2413.97	Pabay Shale	Pliensbachian	Sinemurian	LowJ1
Porcupine	34/15-1	2827.48	2840.44	Bolus	Kimmeridgian-Oxfordian	Tithonian	LateJ5
Porcupine	34/15-1	2879.58	2939.83	Bolus	Kimmeridgian-Oxfordian	Early Tithonian	Late J4
Porcupine	34/15-1	3101.9	3130.99	Minard	Oxfordian	Kimmeridgian	LateJ3
Porcupine	34/15-1	3526.81	3570.44	Minard	Oxfordian	Bathonian/Bajocian	MidJ
Porcupine	35/02-1	2864.87	2924.99	Bolus	Kimmeridgian-Oxfordian	Early Tithonian	Late J4
Porcupine	35/02-1	3236.68	3252.37	Minard	Oxfordian	Kimmeridgian	LateJ3
Porcupine	35/06-1	3631.05	3650.78	Minard	Oxfordian	Bathonian/Bajocian	MidJ
Porcupine	43/13-1	4079.91	4161.97	Bolus	Kimmeridgian	Oxfordian	LateJ1
North Celtic Sea	48/19-1A	1966.65	2106.27	Pollan	Early Berriasian-Late Tithonian	Tithonian	LateJ5
North Celtic Sea	48/19-1A	3253.45	3357.8	Baginbun to Whitby Mudstone-Merlin	Oxfordian-Bajocian	Oxfordian	LateJ1
North Celtic Sea	48/30-1	1984	2012	Glenbeg	Sinemurian	Pliensbachian	LowJ2a
North Celtic Sea	49/13-2	858.6	910.8	Pollan and Baginbun	Berriasian - Kimmeridgian	Tithonian	LateJ5
North Celtic Sea	49/13-2	1114.9	1156.16	Galley	Oxfordian	Kimmeridgian	LateJ3
Porcupine	49/15-1	1077.4	1147.5	Perch and Pollan	Berriasian	Tithonian	LateJ5
South Celtic Sea	49/29-1	1706.77	1872.46	Glenbeg	Sinemurian	Pliensbachian	LowJ2a
North Celtic Sea	50/03-2	423.7	615.7	Pollan and Knockadoon	Berriasian - Tithonian	Tithonian	LateJ5
North Celtic Sea	50/11-3	1308.12	1408.86	Perch and Pollan	Berriasian	Tithonian	LateJ5
Fastnet	56/21-1	1815.89	1910.01	Whitby Mudstone	Toarcian	Pliensbachian	LowJ2a
North Celtic Sea	57/02-1	1008.76	1110.18	Eel	Late Aptian	Barremian/Aptian	Klow1
North Celtic Sea	57/02-1	3274.97	3362.27	Glenbeg	Sinemurian	Pliensbachian	LowJ2a
North Celtic Sea	57/07-1	1565.74	1652.52	Tacumshin	Aalenian-Toarcian	Toarcian	LowJ2b
North Celtic Sea	57/07-1	2111.89	2197.59	Glenbeg	Sinemurian	Pliensbachian	LowJ2a
Fastnet	63/10-1	2219.13	2299.41	Tacumshin and Whitby Mudstone	Aalenian-Toarcian	Pliensbachian	LowJ2a

Table B. 2. ***Summary of source rock interval ages identified in project IS16/01 compared to the current study.***

Only those intervals are listed in the table above where ages changes between the two studies are seen. The ages used in project IS16/01 are largely based on information given in original well reports.