

Calum Knowles<sup>1</sup> and James Armstrong<sup>2</sup>

1: University of Manchester, UK (email: calumknowles1995@gmail.com) 2: Petroleum Systems Limited, Prestatyn, UK (email: jpa@petroleumsystems.co.uk)

## Project Background/Aims/Objectives

The Orphan Basin is one of the largest and least explored of the Mesozoic rift basins of the North-West Atlantic margin (Figure 1). Spanning approximately 150,000km<sup>2</sup> only 12 exploration wells have been drilled to date. It sits immediately to the North of the petroliferous Jeanne d'Arc Basin and West of Flemish Pass Basin. The Orphan Basin also formed along side the Porcupine and Rockall basins to the West of Ireland during the opening of the North Atlantic Ocean. In 2016 the Nalcor Energy, alongside Beicip-Franlab announced the oil and gas resource potential to be 25.5 billion barrels of oil and 20.6 trillion cubic feet of gas within the West Orphan Basin alone.

In order to better comprehend the petroleum potential of the Orphan Basin, this study aimed to answer the following questions:

- What are the key source facies within the Orphan Basin?
- Are these mature?
- Are these expelling?
- How much has been expelled?
- When did expulsion occur?
- How do the source facies of the Orphan Basin fit in regionally and across the Atlantic Ocean?

The study objectives were to:

- Comprehensively review the publicly available geochemical well data for the Orphan Basin in order to delineate and characterise potential source facies.
- Produce sets of 1D geohistory basin models on drilled locations and in undrilled locations to define maturity thresholds and estimate timing of generation and expulsion.
- Quantify and produce estimations of expulsion from the Jurassic sediments utilising local kerogen kinetics.
- Deduce typical depositional environments for the identified source facies and investigate the implications of the results on regional source rock distribution and Transatlantic relationships.

## Location Map

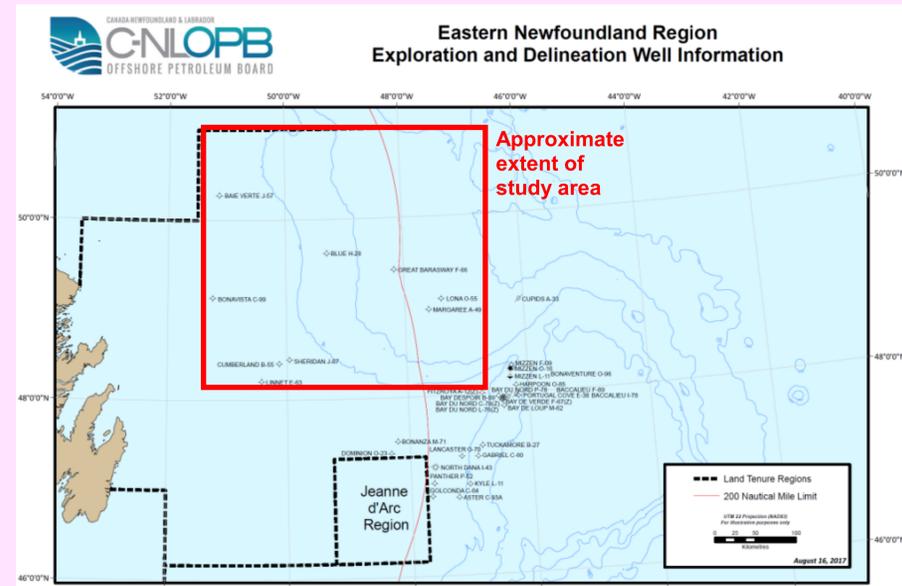


Figure 1: Outline of study area. Modified map taken from CNLOPB website (Geoscience Information section - <https://www.cnlopb.ca/wp-content/uploads/geoinfo/enmap.pdf>)

## Database

This study utilises open-file data, compiled and made available by the Canadian government via the Basins database. These datasets contain pyrolysis, organic petrology, well temperature and biostratigraphic data for the majority of the study wells. In addition, 12 sets of detailed kerogen kinetics were also provided from Jurassic sediments in Lona O-55. Baie Verte J-57, Blue H-28 and Great Barasway F-66 provided the most comprehensive datasets for the purposes of this study.

## Methodology

### Source Facies Delineation

Delineation through Rock-Eval and organic petrology data analysis in accordance with a criteria established for the study. Facies were assessed based on richness, quality and maturity.

### Basin Modelling

1D models were produced with the use of Sirius Exploration Geochemistry's Novva v:1.7.0 software. Models were constructed in drilled and undrilled locations and utilised a McKenzie rifting model with a simple heat-flow history and a stretch factor consistent with that established by Welford et al (2012) (see Figure 2). Novva calibrates heat flow history against measured vitrinite and temperatures from the study wells.

### Expulsion Models

Novva calculates generation and expulsion from the defined source horizons via the Arrhenius Equation. Where applicable locally derived kerogen kinetics have been applied. In the case of the West Orphan Basin analogue source kinetics were used.

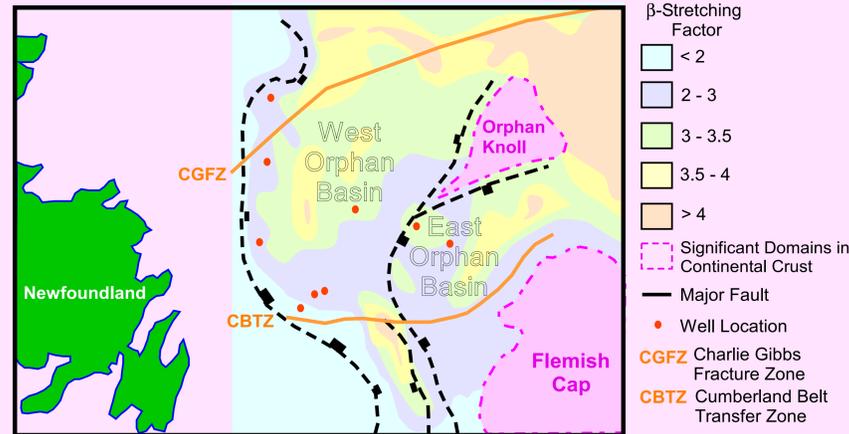


Figure 2: Stretching factor,  $\beta$ , at the initiation of sea-floor spreading within the general Orphan Basin area (modified from Welford et al (2012)). The assumed  $\beta$  factor at each modelling point was obtained from this map.

## Tectonic History

The East and West Orphan basins are considered to be failed rift basins. Initial rifting was in the Late Jurassic in the East Orphan Basin. The initiation of rifting in the West Orphan has been the subject of debate but Late Jurassic rift sediments are recognised in modern seismic analyses, so, rifting was probably near contemporaneous in both sub-basins. The final continental breakup occurred to the east, in the Early Cretaceous leading to the Aptian-Albian break-up unconformity. After this event, thermal relaxation and basin sagging is recognised. Principal oil-prone sources relate to the rift phase with further gas-prone facies developing during the early sag phase.

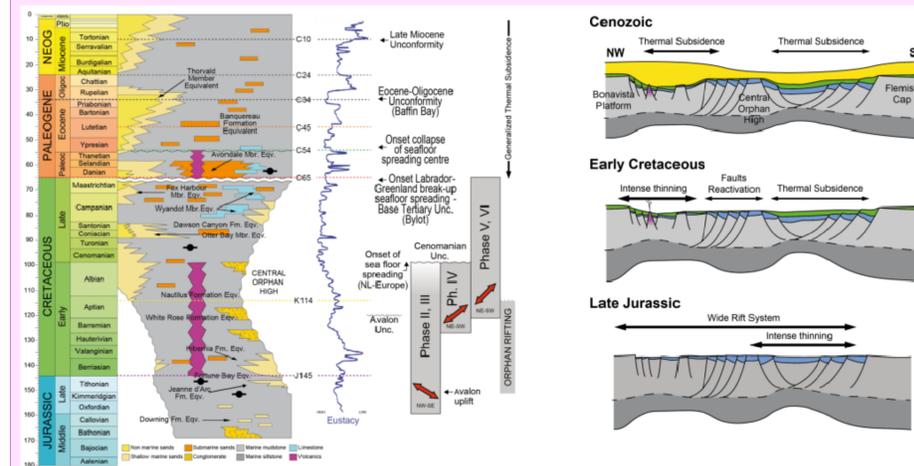


Figure 3: Outline tectonic evolution and sedimentary development in the Orphan Basin (after Beicip-Franlab, 2016)

## Source Rock Synthesis

| Era       | Period      | Epoch     | Age          | Tectonic Events |               | Potential Source Rocks | TOC Average (weights) | TOC Maximum (weights) | Hydrogen Index Average (mg/HC/g rock) | Hydrogen Index Maximum (mg/HC/g rock) | Kerogen Type & Product |           |     |     |
|-----------|-------------|-----------|--------------|-----------------|---------------|------------------------|-----------------------|-----------------------|---------------------------------------|---------------------------------------|------------------------|-----------|-----|-----|
|           |             |           |              | WOB             | EOB           |                        |                       |                       |                                       |                                       |                        |           |     |     |
| Tertiary  | Paleogene   | Oligocene | Chattian     |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
|           |             |           | Rupelian     |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
|           |             | Eocene    | Priabonian   |                 |               |                        | 1.46                  | 1.46                  | N/A                                   | N/A                                   | N/A                    |           |     |     |
|           |             |           | Bartonian    |                 |               |                        | 2.35                  | 3.58                  | 150                                   | 243                                   | III                    | Gas       |     |     |
|           |             |           | Lutetian     |                 |               |                        | 3.84                  | 7.95                  | 112                                   | 152                                   | III                    | Gas       |     |     |
|           |             |           | Ypresian     |                 |               |                        | 2.96                  | 6                     | 109                                   | 160                                   | III                    | Gas       |     |     |
|           |             | Paleocene | Thanetian    |                 |               |                        | 3.9                   | 10.85                 | 92                                    | 135                                   | III                    | Gas       |     |     |
|           |             |           | Selandian    |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
|           |             |           |              |                 | Danian        |                        |                       |                       | 3                                     | 4.7                                   | 72                     | 121       | III | Gas |
|           |             | Mesozoic  | Cretaceous   | Late            | Maastrichtian |                        |                       |                       |                                       |                                       |                        |           |     |     |
| Campanian |             |           |              |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
| Santonian |             |           |              |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
| Coniacian |             |           |              |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
| Turonian  |             |           |              |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
| Early     | Cenomanian  |           |              |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
|           | Albian      |           |              |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
|           | Aptian      |           |              |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
|           | Barremian   |           |              |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
|           | Hauterivian |           |              |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
| Jurassic  | Middle      | Late      | Valanginian  |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
|           |             |           | Berriasian   |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
|           |             |           | Tithonian    |                 |               |                        | 1.5                   | 3.7                   | 226                                   | 436                                   | II,III                 | Oil + Gas |     |     |
|           |             |           | Kimmeridgian |                 |               |                        | 1.7                   | 6.4                   | 220                                   | 564                                   | II,III                 | Oil + Gas |     |     |
|           |             |           | Oxfordian    |                 |               |                        | 1.4                   | 2.2                   | 232                                   | 320                                   | II,III                 | Oil + Gas |     |     |
|           |             | Middle    | Callovian    |                 |               |                        | 2.2                   | 3.7                   | 332                                   | 655                                   | II,III                 | Oil + Gas |     |     |
|           |             |           | Bathonian    |                 |               |                        | 1.8                   | 2.3                   | 222                                   | 363                                   | II,III                 | Oil + Gas |     |     |
|           |             |           | Bajocian     |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
|           |             |           | Aalenian     |                 |               |                        |                       |                       |                                       |                                       |                        |           |     |     |
|           |             |           | Triassic     |                 |               |                        | 2.5                   | 5.4                   | 244                                   | 627                                   | II,III                 | Oil + Gas |     |     |

The Early Tertiary of the West Orphan Basin contains six potential source rock horizons, all gas prone.

Several rich intervals have been identified in the West Orphan Basin Cretaceous sediments, based on TOC% alone. These not been included in the modelling stage of the study as there was insufficient pyrolysis data to characterise these sources.

The East Orphan Basin featured more oil-prone sources from the Jurassic sediments

Figure 4: Twelve potential source rock intervals identified within the Orphan Basin

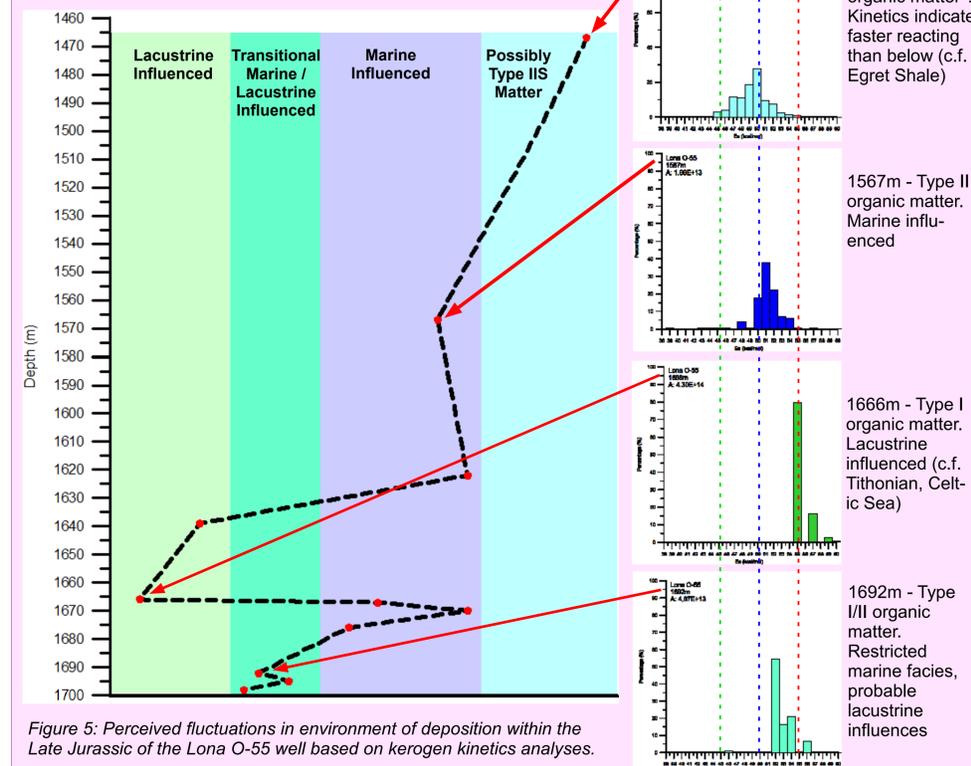


Figure 5: Perceived fluctuations in environment of deposition within the Late Jurassic of the Lona O-55 well based on kerogen kinetics analyses.