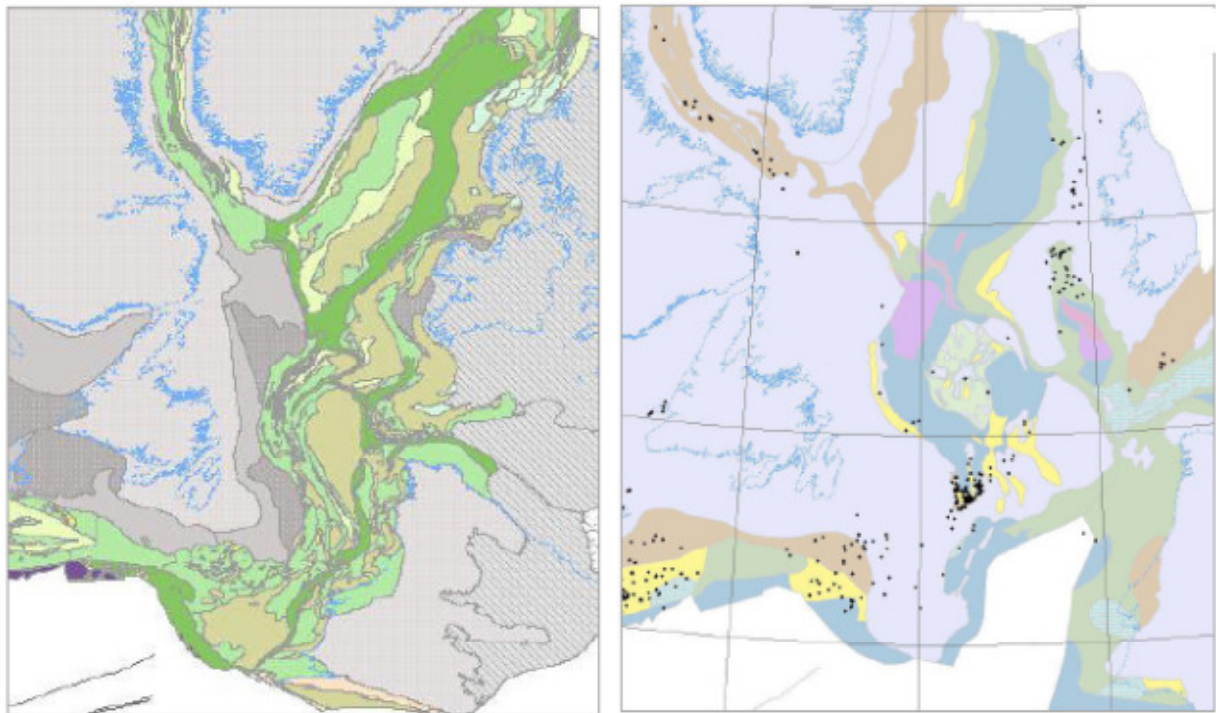




A New Kinematic Plate Reconstruction of the North Atlantic between Ireland and Canada



SUMMARY REPORT

April 2014

Introduction

This project was jointly funded by the Irish Shelf Petroleum Studies Group (ISPSG) of Ireland's Petroleum Infrastructure Programme (PIP) and Nalcor Energy (on behalf of the Offshore Geoscience Data Program with the Government of Newfoundland and Labrador) as a result of ongoing cooperation since 2005 within the North Atlantic Petroleum Systems Assessment (NAPSA).

The two-year study has produced a new kinematic plate reconstruction of the North Atlantic between Ireland and eastern Canada. The multinational project team, led by GeoArctic Ltd of Calgary, Canada, included researchers from Badleys Geoscience Ltd in the UK, University College Dublin (UCD) in Ireland, Memorial University of Newfoundland (MUN), the University of Liverpool, the Dublin Institute of Advanced Studies (DIAS), the Geological Survey of Canada (GSC), and others.

The new plate reconstruction employed emerging deformable plate reconstruction methods which allowed reconstruction of the changing location and geometry of sedimentary basins in the region through time, and enabled estimation of the amount, direction and timing of crustal extension prior to continental breakup and the formation of the North Atlantic Ocean. The model also facilitated analysis and comparison of the similarities and differences between the conjugate margins in the NW European and eastern Canadian offshore regions. This summary report documents the methods used and describes the results of the study.

The study provides strong evidence that very high crustal thinning factors observed in the central parts of the Porcupine, Rockall and Orphan basins are the result of hyperextension in Late Jurassic to Early Cretaceous times. The study also found that the Hatton-Greenland magma-dominated margin has been hyperextended due to stretching of the upper crust.

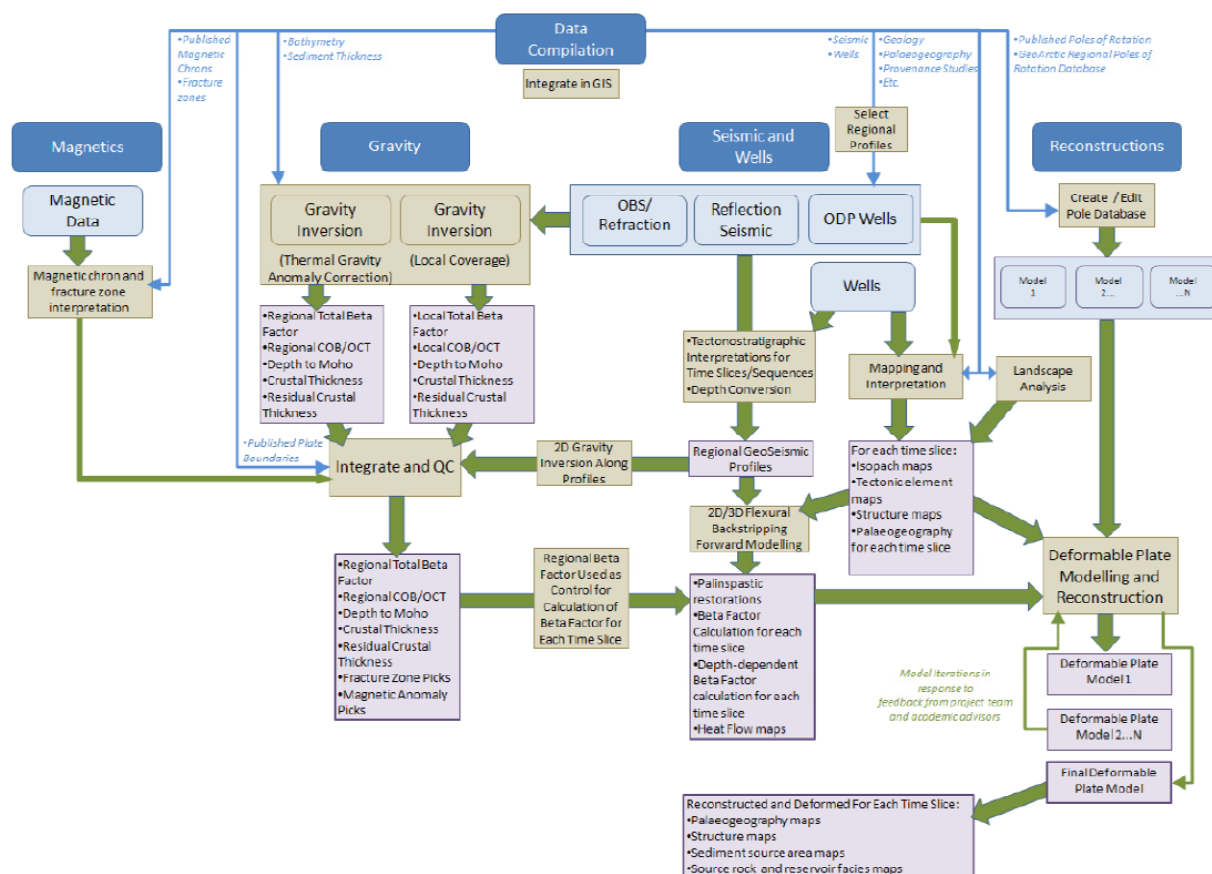
Structural and palaeogeographic reconstructions were made for several key Jurassic and Cretaceous stratigraphic intervals. These will help researchers and explorationists to understand potential source rock development on the margins and to predict the likelihood of source rock preservation and the location of potential reservoir fairways.

Methodology

Plate kinematic models describe rigid plate motions on the Earth's surface by means of Euler poles of rotation, which are geocentric rotation vectors given by the geographic coordinates of the rotation pole and the angular velocity. However, such rigid plate models do not adequately explain the complex multiphase break-up history in the North Atlantic. Crustal material underlying developing sedimentary basins can deform in a pure-shear or in a mixed shear depth-dependent manner with differential stretching of upper or lower parts of the crust. Deformable modelling of plate margins must be integrated with a plate kinematic model to remove the effects of such non-rigid and differentially deformed extensional and compressive deformation. Figure 1 provides a schematic of the workflow for the creation of a deformable plate kinematic model.

The workflow integrates seismic, well, magnetic and geological interpretation with the analytical techniques of 2D or 3D gravity inversion, flexural backstripping, fault analysis and forward modelling. This allows all available regional geological and geophysical data to be used to build a detailed structural and palaeogeographic history of the margin.

Figure 1. Deformable Plate Reconstruction Workflow



Stretching factor (β) grids are a primary input into the deformable plate model. These are extracted from interpreted deep seismic profiles and total β derived from gravity inversion for key time intervals (β -stripping). The β -stack is used with a proprietary suite of tools to compute cumulative movement for each grid cell around the margin in order to restore structure, palaeogeography, facies and other maps to their palaeo-geometry prior to reconstruction. In the modelling methodology one margin was fixed, and this has some implications for the final palaeo-geometry of the basins and structural highs. The results provide valuable information on the geometry of the basins and their spatial relationships with adjacent basins and sediment source areas.

The beta factors used are crucial to the model and to the resulting close fit of the conjugate margins. There are conflicting views on the beta factors computed from gravity inversion especially in the Orphan, Porcupine and Rockall Basins. The detailed interpretation of key seismic lines is fundamental to the model and alternative seismic interpretations are possible. There is a lot of seismic data that was not used in the project and seismic data is lacking in some areas. Also data quality and uncertainties in seismic interpretation vary from basin to basin.

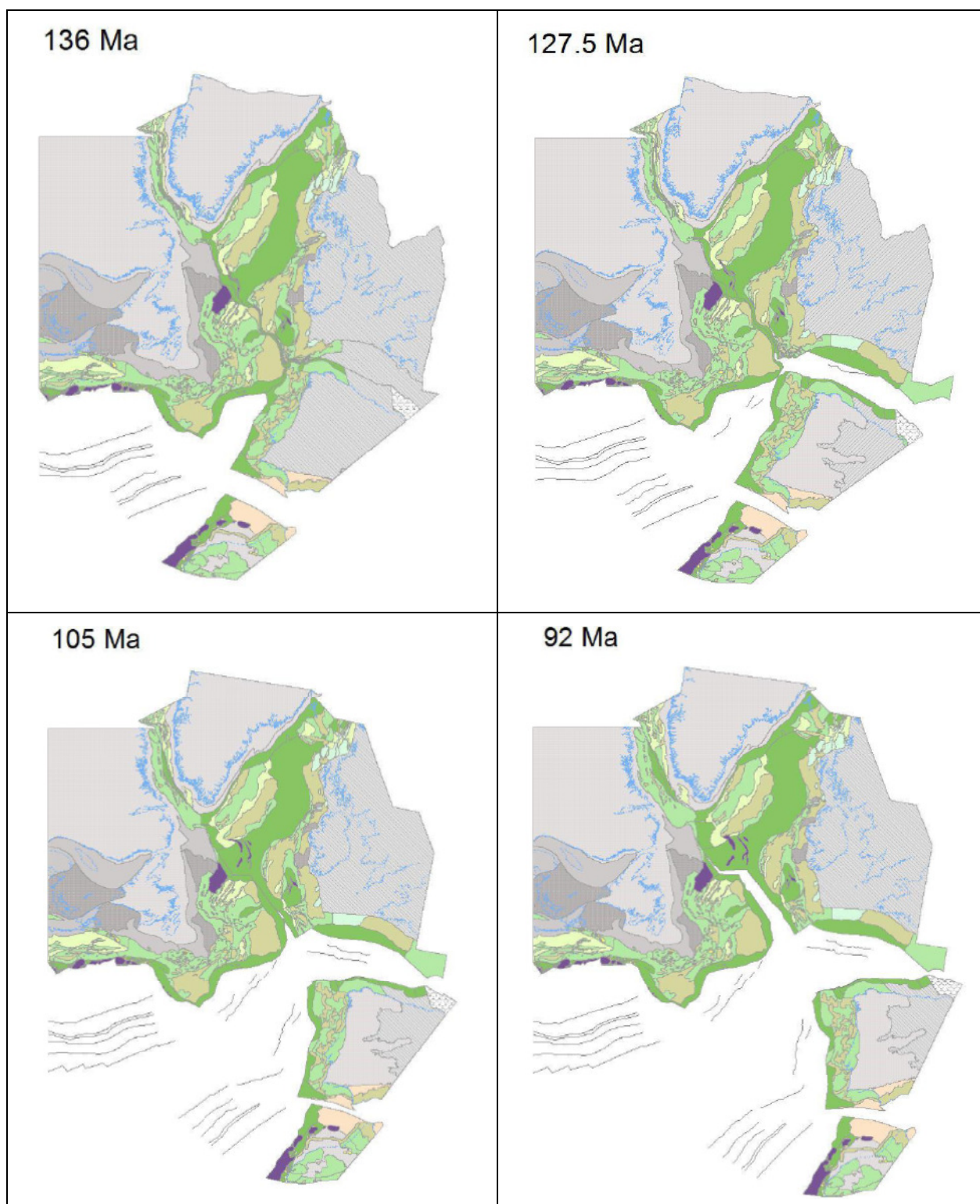
The Plate Model

GeoArctic developed two end-member deformable/plate kinematic models for the North Atlantic. These are a maximum extension model (Max Ext) and a depth-dependent thinning model (DDT). Tectonic elements maps and palaeogeography maps were created for both models to compare the potential effects of depth-dependent thinning.

A 50% depth-dependent thinning correction factor was applied for the period 140 – 150 Ma. The residual beta for this period was applied in its entirety to remove pre-rift extension (maximum extension model) or divided equally between pre-rift extension and depth-dependent thinning (depth-dependent thinning model). With both maximum extension and the

depth-dependent thinning models the depositional area of the basins changes dramatically from the present day when latest Late Jurassic to Early Cretaceous hyperextension is applied.

Figure 2. Plate Tectonic reconstructions of regional geology from Hauterivian to Turonian

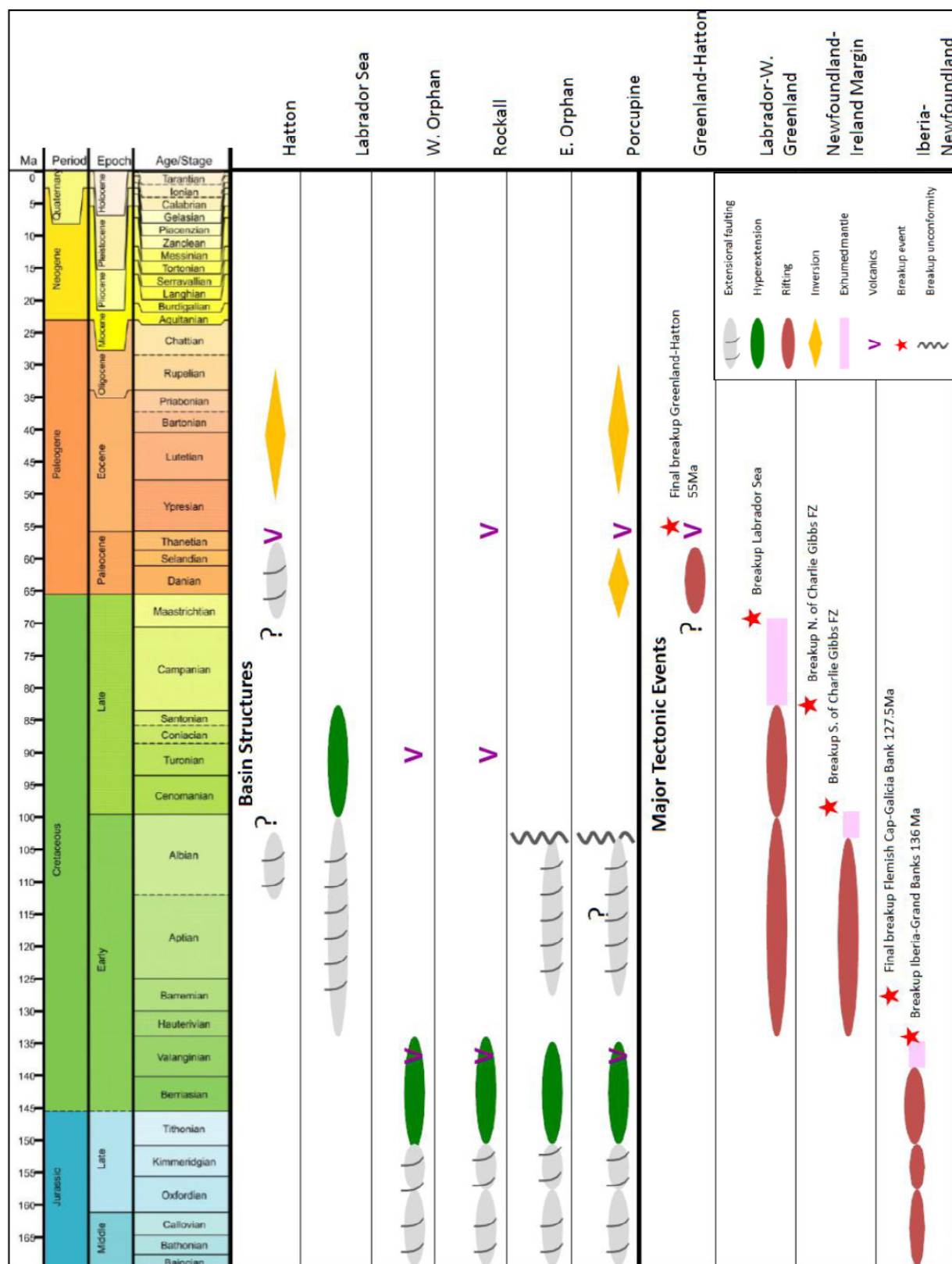


Strike-slip plate motion between Morocco and the southern Grand Banks resulted in transtension and transpression in the Middle Jurassic (170-159 Ma). The relative movement of Iberia away from Newfoundland was initiated by pre-breakup rifting in the Late Jurassic (Tithonian – 150 Ma) and mantle exhumation started at about 140 Ma. The amount of

extension farther north on the Newfoundland margin suggests hyperextension (i.e. $\beta > 3$) from Tithonian to Valanginian (150-136 Ma) times in the East and West Orphan Basins. The model suggests that the amount and timing of extension in the Rockall Basin is similar to that in the West Orphan Basin. The Porcupine Basin also shows highly thinned continental crust at this time and it can be inferred that this basin also shares a similar structural history with the East Orphan Basin. The hyperextension in these two basins therefore occurred from Tithonian to Valanginian times (150-136 Ma).

Rifting on the Newfoundland–Ireland and the Labrador Sea margins was initiated in Barremian times (~136 Ma). Breakup of Newfoundland and Ireland propagated from southeast to northwest from Albian (~105 Ma) to Santonian/Campanian times (~80 Ma). Breakup along these margins was accompanied by mantle exhumation and basins exhibit hyperextension. The final phase of breakup occurred between Hatton–Greenland in the late Paleocene (~56 Ma), when highly extended continental crust is associated with the formation of seaward-dipping reflectors (SDRs).

Figure 3. Summary of major tectonic and basin forming events in the key areas of the conjugate North Atlantic margins



Conclusions

In the central parts of the Porcupine, Rockall and Orphan basins highly rotated fault blocks, detachment faulting, mantle exhumation and high β factors (>3) in the Late Jurassic and Early Cretaceous (~145-136 Ma) provide strong evidence for hyperextension. Such hyperextension may have resulted in removal and erosion of some potential pre-rift source rocks within these basins but the models predict local preservation within the basins and especially on the basin flanks. New seismic data in these deep basins has helped to define areas where Late Jurassic formations are preserved. The new wells in the Orphan Basin have also demonstrated that the Late Jurassic preservation exists in these areas. The post-rift earliest Cretaceous in the Porcupine, Rockall and Orphan basins was a period of potential significant deposition of marine source rock facies in rapidly subsiding restricted basins. This source rock potential may even surpass that of the highly extended and fractured pre-rift source rocks.

The “post-rift” Cretaceous reservoir sands are potentially sourced locally from highs such as the Porcupine-Orphan Knoll-Flemish Cap high that the deformable plate model indicates formed one continuous high in the Lower Cretaceous. Greenland also formed a potential source for clastic reservoirs in the Cretaceous and there was a possible conduit for sand along the Hatton Basin to the south where Mesozoic extension may have formed a major fluvial system.

A key recommendation of this study is to investigate post-rift (i.e. post-hyperextension) source rock and reservoir fairways in the Ireland and Newfoundland offshore basins. Late Jurassic to Early Cretaceous restricted marine sediments could be of particular interest for hydrocarbon exploration in the future.

Data Providers

Seismic, well and potential field data provided by the Irish Department of Communications Energy & Natural Resources (DCENR). Additional seismic data is courtesy of TGS Nopec, ION GeoVentures, and the Geological Survey of Canada (GSC).

Gravity inversions by Badleys Geoscience Ltd and Dr Kim Welford (Memorial University, Newfoundland).