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ORIGINAL CONTRIBUTION

Evidence for Deeper Hydrocarbon Exploration: New Insight from the Hydrocarbon Plays in the North Celtic Sea Basin

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***Abstract*— This study adds to previously published works, which were based on 1D modelling, by generating 2D models using PetroMod™ software. Seismic data have been used to reconstruct the regional structural framework, while the integrated wireline logs and geochemical data provided lithological, porosity, and palaeothermal information. The palaeothermal values and available vitrinite reflectance data have been used to calibrate the models to present-day heat flow of 52mW/m^2. Results from this study show that hydrocarbon maturation, generation, and migration were affected by the Triassic and Late Jurassic rifting activities, resulting in a complex charge history and trap modification through time. The Late Jurassic source rocks (PurbecK) attained peak maturation for oil in the late Cretaceous, while the Early Jurassic Source rocks (Liassic and Toarcian) entered the gas window in the Early Cretaceous. Analysis of the petroleum systems for deeper hydrocarbon prospecting suggests that two expulsion phases of hydrocarbons occurred in the Late Jurassic and Early Cretaceous, respectively. This result suggests that there is potential for the charge of suitable reservoir facies at depth if the reservoir quality can be preserved. Hydrocarbon preservation risk is low in anticlinal structures, but there is a high risk of hydrocarbon remigration along modified fault planes in fault-dependent structures. The study demonstrates how basin geometry has changed through time due to multiple tectonic events, leading to modification of older traps .**

***Index Terms*— North Celtic Sea Basin, 1D & 2D Basin Models, Migration, Expulsion Onset, Phase Change**

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I. INTRODUCTION

Deep (> 3000m) hydrocarbon prospecting requires a robust understanding of the geological evolution of the petroleum systems contained in a given basin. Many deep-seated reservoirs worldwide are underexplored due a to lack of sufficient information (e.g. Celtic Sea Basin, North Caspian Basin, and the North Ustyurt Basin) [1-2]. Therefore, accurate quantification of the timing of maturation, charge history, migration, and preservation of hydrocarbons are poorly understood. Consequently the volume of hydrocarbons that can be assessed and optimum exploration strategy are difficult to predict.

Moreover, it is not clear how these reservoirs may be assessed to optimise recovery at the lowest possible risk. Therefore, effective risk management requires vital information on source presence, reservoir presence, charge history, trap and sealing potential, migration pathways, and fault modifications through time.

Previous studies have investigated the timing of hydrocarbon maturation in the North Celtic Sea Basin (NCSB) using 1D models [3-5]. This paper adds to the previously published studies by generating 2D models in order to assess the control of structural evolution of the NCSB on the timing of hydrocarbon maturation, charge history, migration, and remigration. The aim is to examine the potential for deeper hydrocarbon exploration in the NCSB, offshore Ireland. Hydrocarbon exploration in Ireland began in 1957, at the time when the offshore designated area was quite small, and there was a widespread view that the Ireland had little or no petroleum resources [2, 6]. During that period, initial exploration activity was confined to onshore areas with majority of the onshore wells encountering limited volumes of gas [6]. In 1967, the Continental Shelf Act was enacted, which enabled operators to drill up to 200m depth contour and beyond, where technology permitted [2].

Encouraged by successes in the North Sea, exploration in offshore NCSB began in 1971, when the first well (48/25-1) was drilled [5, 7, 8]. The giant Kinsale Gas Field (1.5TCF) was later discovered in 1971 by the third well (48/25-2), which flowed at a rate of 26.5MMCFPD, producing from the Cretaceous Wealden and Greensand reservoirs [7, 9, 10].

Although oil accumulations were tested in the Upper and Lower Jurassic reservoirs, subsequent exploration activities continued to target majorly the Cretaceous reservoirs [2, 6, 9]. In 2012, a successful drilling appraisal activity targeted at reservoir sands located at depth between c.4,500m and 7, 550m TVD was carried out on Seven Heads Field [6, 11, 12, 13]. This drilling activity led to the discovery of the giant Barryroe oil field, which rekindled the interest for deeper hydrocarbon exploration in the NCSB.

II. LITERATURE REVIEW

The study area is located in the NCSB, offshore of the Southern Ireland (Fig. 1). The basin contains a complex tectonic history, involving reactivation of the older basement lineaments [14, 15] and the formation of transform faults that offset the basin margin. During the Triassic and Jurassic, rifting events occurred along a dominant NW-SE trend of the basin, producing a series of half grabens that developed along the Southern margin

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of the Iris Massif and the Northern margin of the Rockall basin (Fig. 1) [14]. During the Late Cretaceous-Palaeocene and Oligocene-Miocene, two structuration inversions occurred resulting in the formation of intra-rift anticlinal structures, which form the regional traps in the NCSB.

The sedimentary fill of the basin is largely controlled by the structural development of the basin and comprises of up to 9km thick Triassic to Cretaceous sediments (Fig. 2) [5, 15]. Sediments deposition was curtailed by the basin-wide inversion during the Tertiary. The main sedimentary fill includes the continental fluvio-deltaic deposits in the Cretaceous and Jurassic, and the Triassic Sherwood sandstone overlain by a thick Mercia mudstone and evaporites (Fig. 2) [5, 7, 15]. Marine condition prevailed over much of the basin while the Triassic and Jurassic rifting events provided a thermal sag. Tectonic activities were subdued during the Early Jurassic and Late Cretaceous. The Early Jurassic succession comprises of the marine shale (Liassic) source rock and the Sinemurian sandstone, a carbonate ramp in the Middle Jurassic, and the Oxfordian sandstone, Kimmeridgian shale, and the Purbeckian shale in the Late Jurassic (Fig. 2). The Wealden sandstone and Greensand were deposited during the Cretaceous period. The Cretaceous transgression culminated in a thick succession of mid-outer shelf chalk deposited conformably on the Upper Cretaceous Limestone [4, 15].

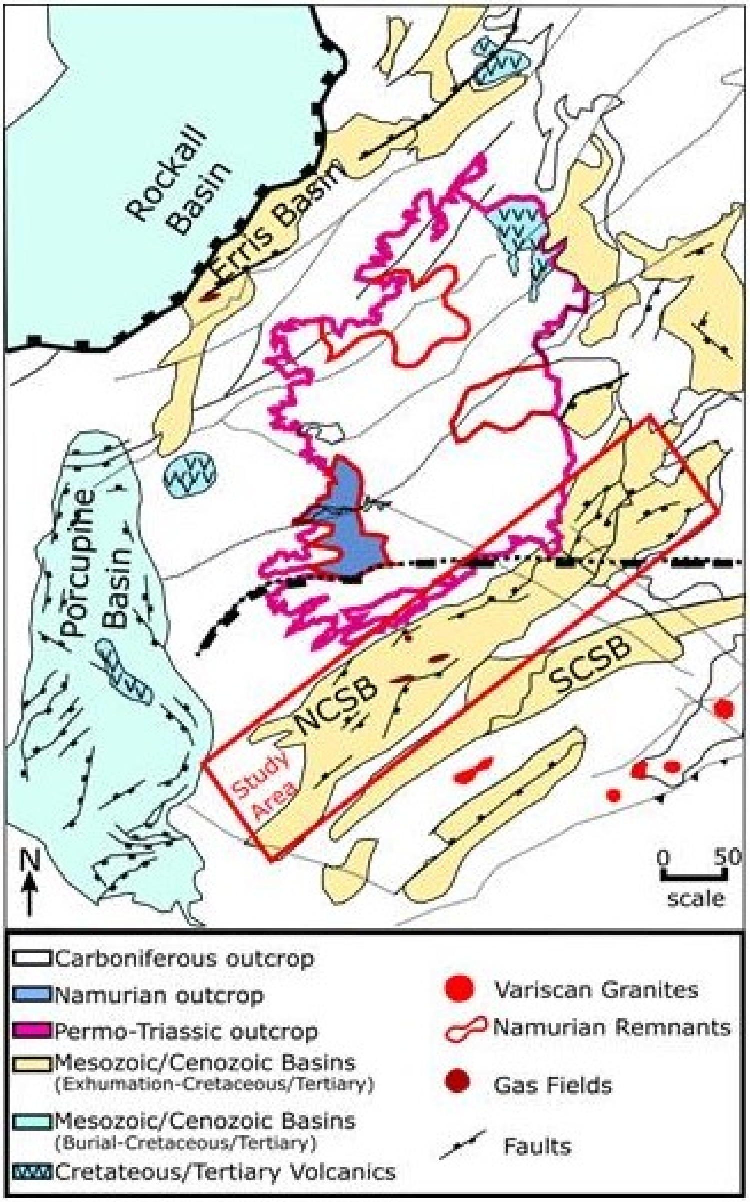

Fig. 1. Map of the study area showing the location of preserved onshore and offshore basins, major tectonic lineaments, Mesozoic and Cenozoic outcrops (adopted from [14])

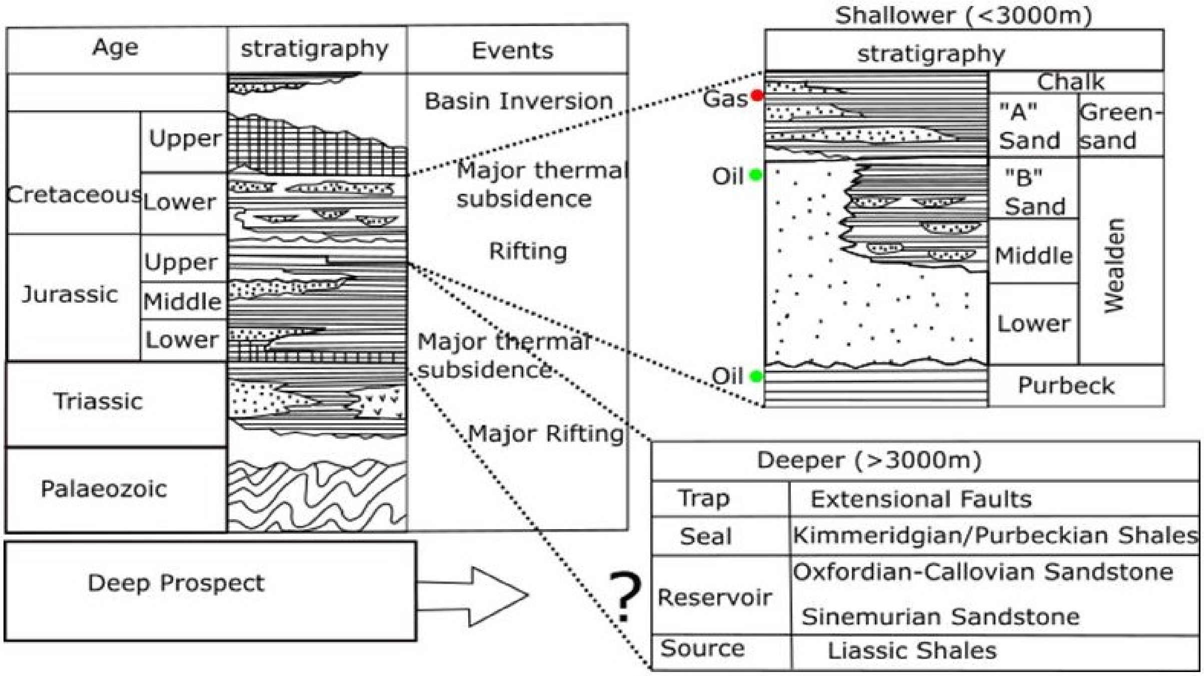

Fig. 2. Chronostratigraphic framework, illustrating the plays and sequence of events interpreted in this study. This highlights areas of hydrocarbon exploration in the Cretaceous reservoirs and deeper targets in the Jurassic reservoirs of the NCSB (after [4], [5], [7], [8], [15], [17])

III. DATASETS AND METHODS

This study has been carried out using 2D seismic data to reconstruct the regional structural development of the basin, and two well logs (48/25-1 and 48/25-2) of Total Depth (TD) 3400m and 2500m respectively, providing lithological and porosity information. Both wells are located on the Northern and Southern flank of the basin. They were chosen because they contained the deepest reservoir sands and penetrated through the major stratigraphic sequence in the basin. Well synthetics and velocity modelling were applied to depth converge the seismic data in order to delineate top reservoir zones across the basin. Well correlation panel was used to calculate the source thickness, reservoir thickness, and distribution across the basin.

A transient heat flow modeling approach has been applied since the geothermal gradient measurements from wells represent a linear measurement with respect to depth. Therefore, they do not reflect changes in compaction, porosity, and bulk thermal conductivity. The models were calibrated to present day heat flow of 52mW/m^2 using the available Vitrinite Reflectance (VR) and palaeothermal values assuming a sediment surface temperature of 5°C and geothermal gradient value of 36.8°Ckm (Table. I). The models include a non-depositional hiatus in the middle Jurassic (Callovian) and two phases of Tertiary uplift and erosion in the Palaeocene and Oligocene-Miocene. The net amount of eroded sediments in the Palaeocene and Oligocene-Miocene were calculated directly from the available well logs as 305m and 899m respectively [16].

TABLE I
CALCULATED GEOTHERMAL GRADIENT USING THE PALAEO TEMPERATURE VALUES FROM WELL 48/25-1

Depth (m)	Bottom Hole Temperature (°C)	Dominant Lithology
859.5	36.6	Chalk
1158.5	40.6	Limestone/Chalk
1994	46.1	Sandstone/Shale
2453.6	60	Sandstone/Shale
2881.6	75.6	Shale
3185.7	91.1	Shale

Geothermal gradient (Gg) = Bottom hole temperature – Surface temperature)/Total Depth
Gg = (BHT-TS)/TD
Gg = (36.6 – 5))/859.5
Gg = 36.8oC/km

IV. RESULTS

The timing of the source maturation, charge history, hydrocarbon migration, and remigration in the NCSB has been assessed using 1D and 2D basinwide models. Result shows a source transformation ratio of nearly hundred percent (Fig. 4) with the Cretaceous source rocks entering their early oil maturation (Fig. 3) (V.R: 0.7-1.0%). The Upper Jurassic source rocks (i.e., Purbeck shale) attained peak maturation for oil (V.R: 0.7-1.0%) in the Early Cretaceous, while the deeper section (> 3000m) of the Purbeck shale entered the late gas maturation window (V.R: 1.0-1.3%) prior to the Tertiary inversion. The Lower Jurassic source rocks (i.e., Liassic and Toarcian) attained peak maturation for oil (V.R: 0.7-1.0%) in the Late Jurassic and Early Cretaceous, and gas window (V.R: 1.3-4.0%) in the Early Cretaceous (Fig. 3). Analysis of hydrocarbon migration shows that two phases of hydrocarbon expulsion occurred in the Late Cretaceous and Late Jurassic. Hydrocarbon accumulation was observed in some fault-bound reservoir sands (Fig. 5A) (e.g., Sinemurian reservoir), while there is little to no hydrocarbon accumulations in some fault-bound reservoir sands, and hydrocarbon migration, and re-migration occurred through faults (Fig. 5B).

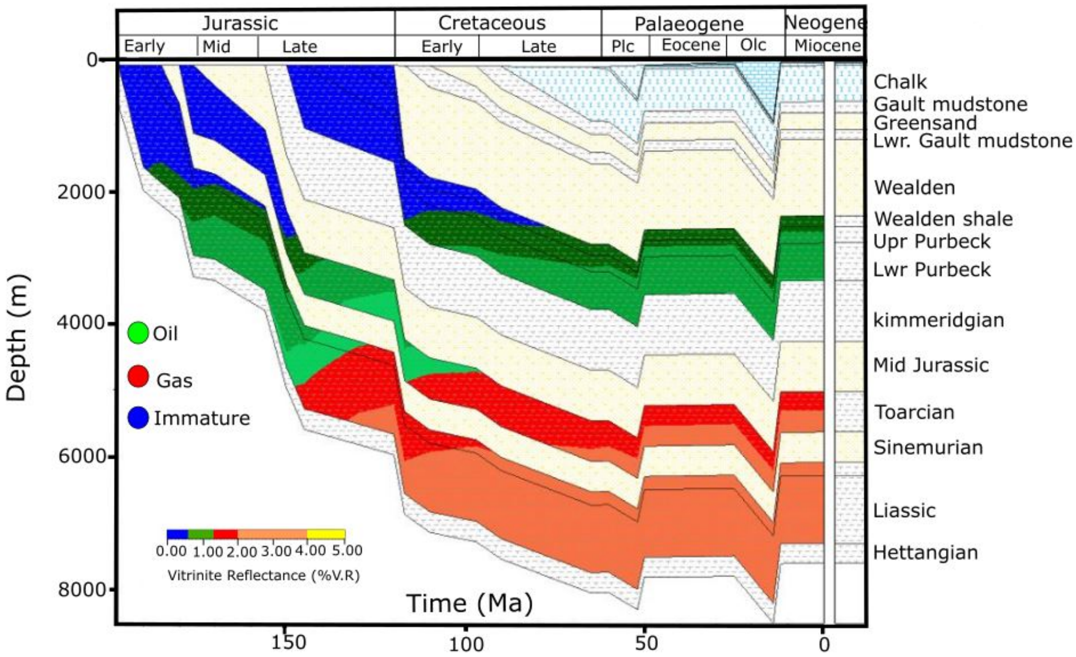

Fig. 3. 1D hydrocarbon maturation model illustrating the timing of source maturation with respect to burial. The model shows that the upper Jurassic source rocks (Purbeck) attained peak maturation for oil in the Early Cretaceous while the Lower Jurassic source rocks (Liassic and Toarcian) entered the gas window during the early Cretaceous due to reburial

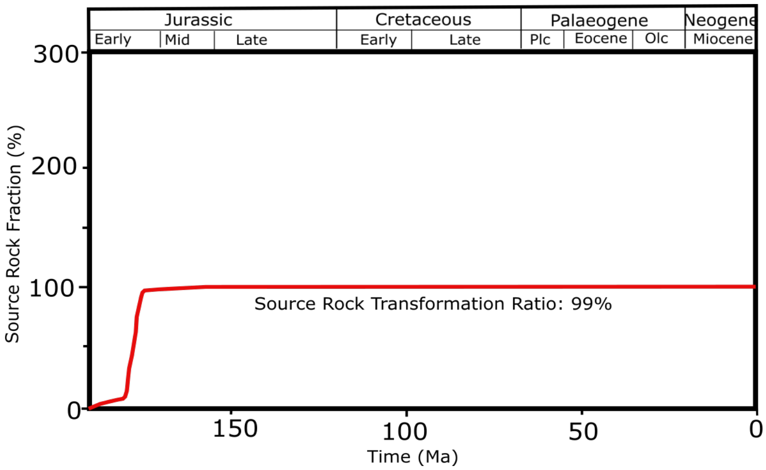

Fig. 4. Transformation ratio plot shows that all the hydrocarbon bearing source rocks have attained peak maturation level of nearly 100% total conversion

V. DISCUSSION & IMPLICATIONS FOR DEEPER HYDROCARBON PROSPECTING

The transformation ratio of nearly hundred percent signifies that most of the hydrocarbon bearing source rocks in the basin had attained peak maturation for oil and gas before the end of Cretaceous prior to the Tertiary inversion. The two maturation periods (i.e., Late Jurassic and Early Cretaceous) observed for the Jurassic source rocks imply that hydrocarbon maturation was punctuated by the Jurassic rifting and Tertiary inversion events. The Jurassic rifting event created more accommodation space for sediment deposition that generated thermal subsidence in the basin. Later, hydrocarbon maturation continued due to reburial and thermal subsidence developed as a result of sediment overburden during the Palaeocene-Miocene [3, 5]. This allowed the Upper Jurassic shale (i.e., Upper Purbeck) to enter the peak maturation window for oil and the deeper section (> 3000m) to enter the gas window [4, 5]. As thermal subsidence continued, marine transgression occurred and deposited the marine Gault mudstone above the Cretaceous sandstone, which acted as a regional cap rock for the Cretaceous reservoirs.

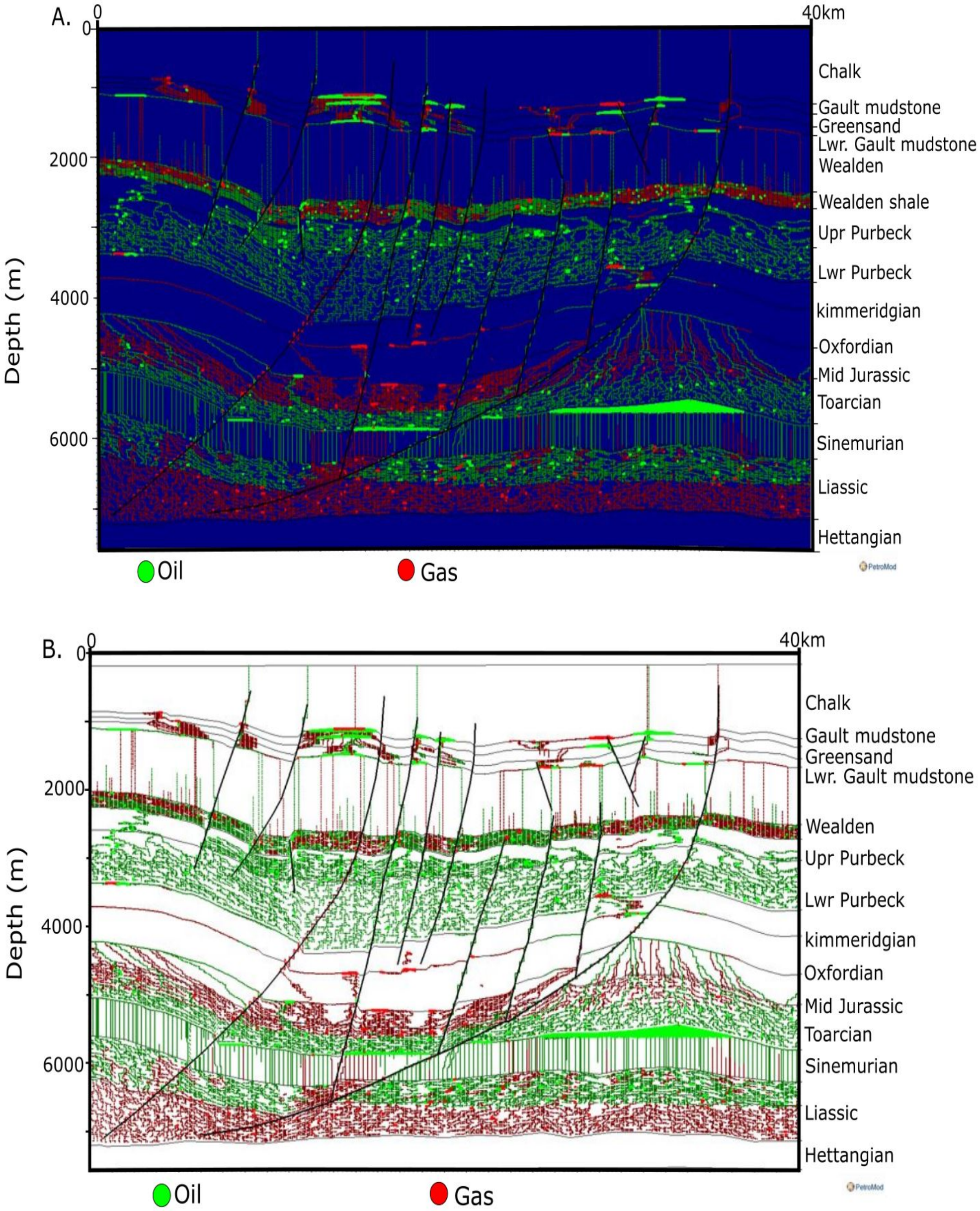

Fig. 5. 2D models illustrating the charge history, hydrocarbon accumulation, migration, and remigration. (A) The model shows there is potential for charge of deeper reservoir facies (e.g., hydrocarbon accumulations in the Sinermurian and Oxfordian sandstones). (B) The model shows the results of the fault sealing analysis, which indicates faults have been modified through time, due to multiple tectonic events, leading to hydrocarbon remigration and widespread hydrocarbons observed in the model

The Palaeocene and Oligocene-Miocene structuration events produced elongated anticlinal structures, which harbour majority of the hydrocarbon volumes in the basin, while also modifying the older Triassic and Jurassic fault traps. Traps formed during the Palaeocene and Oligocene-Miocene structuration events exhibit timing problem since majority of the hydrocarbon bearing source rocks had reached peak hydrocarbon maturation by the end of Cretaceous. Few fault traps in the Triassic and Jurassic retained their sealing potential while majority of the Triassic and Jurassic fault traps have been modified, giving rise to hydrocarbon remigration and phase change from oil to gas. Analysis of hydrocarbon expulsions indicates that there is potential to charge deeper reservoir facies of the Sinemurian and Oxfordian sandstones, if the reservoir quality can be preserved (Fig. 5A). There is low risk of hydrocarbon remigration in anticlinal-dependent structures than in fault-dependent structures (Fig. 5).

VI. CONCLUSION AND IMPLICATIONS

This study demonstrates that hydrocarbon maturation and accumulation in the NCSB began at about 151Ma in the Late Jurassic. Analysis of the petroleum systems suggest a favourable timing, a sequence of source rock deposition, followed by the reservoir and seal deposition with the Triassic and Jurassic traps being present prior to the onset of hydrocarbon generation. Although the Triassic and Jurassic fault traps have been modified by the Tertiary uplift event, but there is potential for deeper hydrocarbon prospecting in anticlinal dependent structures. Additional 3D seismic data are required to completely delineate the regional reservoir facies distributions across the entire basin. Future work will concentrate on integrating 3D seismic data and additional well logs to construct a 3D model in order to quantify the extent of deep-seated reservoirs in the basin.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

[1] D. Okere and S. Toothill, “New Insights into hydrocarbon plays in the Caspian Sea, Kazakhstan,” *Petroleum Geoscience*, vol. 18, no. 3, pp. 253–268, 2012. **DOI:** https://doi.org/10.1144/1354-079311-045

[2] P. M. Shannon and D. Naylor, *Petroleum Geology of Ireland*. Tulsa, OK: AAPG European Region Newsletter, 2012.

[3] N. J. Murphy, M. J. Sauer and J. P. Armstrong, “Toarcian source rock potential in the North Celtic Sea Basin, offshore Ireland,” *Geological Society, London*, vol. 93, no. 1, pp. 193-207, 1995. **DOI:** https://doi.org/10.1144/GSL.SP.1995.093.01.14

[4] I. C. Scotchman, “Petroleum geochemistry of the Lower and Middle Jurassic in Atlantic Margin Basins of Ireland and the UK,” *Geological Society, London*, vol. 188, no. 1, pp. 31-60, 2001. **DOI:** https://doi.org/10.1144/GSL.SP.2001.188.01.03

[5] D. R. Taber, M. K. Vickers and R. D. Winn, “The definition of the Albian ‘A’Sand reservoir fairway and aspects of associated gas accumulations in the North Celtic Sea Basin,” *Geological Society, London*, vol. 93, no. 1, pp. 227-244, 1995. **DOI:** https://doi.org/10.1144/GSL.SP.1995.093.01.16

[6] P. M. Shannon and D. Naylor, “An assessment of Irish offshore basins and petroleum plays,” *Journal of Petroleum Geology*, vol. 21, no. 2, pp. 125-152, 1998. **DOI:** https://doi.org/10.1111/j.1747-5457.1998.tb00651.x

[7] J. M. O'Sullivan, "The geology and geophysics of SW Kinsale gas accumulation," in *The Petroleum Exploration of Ireland’s Offshore Basins*, E. M. Shannon, P. D. W. Haughton and D. V. Corcoran, Eds. London, UK: Geological Society, 2001.

[8] P. Rowell, "Tectono-stratigraphy of the North Celtic Sea Basin," *Geological Society, London,* vol. 93, no. 1, pp. 101-137, 1995. **DOI:** https://doi.org/10.1144/GSL.SP.1995.093.01.11

[9] V. N. D. Caston, "The Helvick oil accumulation, block 49/9, North Celtic Sea basin," *Geological Society, London,* vol. 93, no. 1, pp. 209-225, 1995. **DOI:** https://doi.org/10.1144/GSL.SP.1995.093.01.15

[10] Gevirtz, J. L. (2002). *Surface hydrocarbon characterization of Kinsale head gas field, Celtic Sea, offshore Ireland* [Online]. Available: https://goo.gl/DSXZNV

[11] P. F. Croker and P. M. Shannon, “The petroleum geology of Ireland’s offshore basins: Introduction,” *Geological Society, London,* vol. 93, no. 1, pp. 1-8, 1995. **DOI:** https://doi.org/10.1144/GSL.SP.1995.093.01.01

[12] Fastnet Oil and Gas. (2012). *Independent technical evaluation report on the molly malone licensing option in the South Celtic Sea Offshore Ireland* [Online]. Available: https://goo.gl/63uvrh

[13] Griffiths, P. (2013). *PESGB Irish branch building on Barryroe new exploration targets in the Celtic Sea* [Online]. Available: https://goo.gl/i82iRX

[14] D. V. Corcoran and A. G. Doré, “A review of techniques for the estimation of magnitude and timing of exhumation in offshore basins,” *Earth-Science Reviews*, vol. 72, no. 3, pp. 129-168, 2005. **DOI:** https://doi.org/10.1016/j.earscirev.2005.05.003

[15] P. M. Shannon, “The development of Irish offshore sedimentary basins,” *Journal of the Geological Society*, vol. 148, no. 1, pp. 181-189, 1991. **DOI:** https://doi.org/10.1144/gsjgs.148.1.0181

[16] T. J. Howell and P. Griffiths, “A study of the hydrocarbon distribution and lower Cretaceous green sand prospectivity in blocks 48/15, 48/17, 48/18 and 48/19, North Celtic Sea Basin,” *Geological Society, London,* vol. 93, no. 1, pp. 261-275, 1995. **DOI:** https://doi.org/10.1144/GSL.SP.1995.093.01.19

[17] K. Rassiah, M. M. H. Megat Ahmad and A. Ali, “Effect on mechanical properties of rice husk/e-glass polypropylene hybrid composites using Sodium Hydroxide (NaOH),” *Journal of Advances in Technology and Engineering Research*, vol. 2, no. 4, pp. 105-112, 2016. **DOI:** https://doi.org/10.20474/jater-2.4.1

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