

ATLANTIC IRELAND 2018

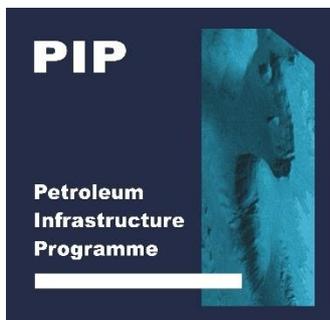
A Two-Day Conference and Exhibition on
Ireland's Offshore Hydrocarbon Potential
Sponsored by PIP-ISPSG

PROGRAMME AND ABSTRACTS

Location: Clayton Hotel, Burlington Road, Dublin, Ireland

Date: 30th October 2018 – 0800 to 1900hrs
31st October 2018 – 0800 to 1300hrs

Audience: Researchers, exploration companies, geophysical
contractors, government departments and agencies,
international guests



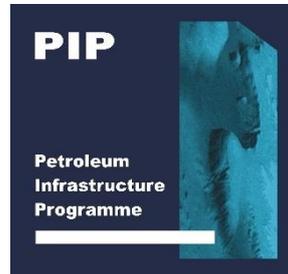
Edited by

Martin Davies and Lloyd Vaz

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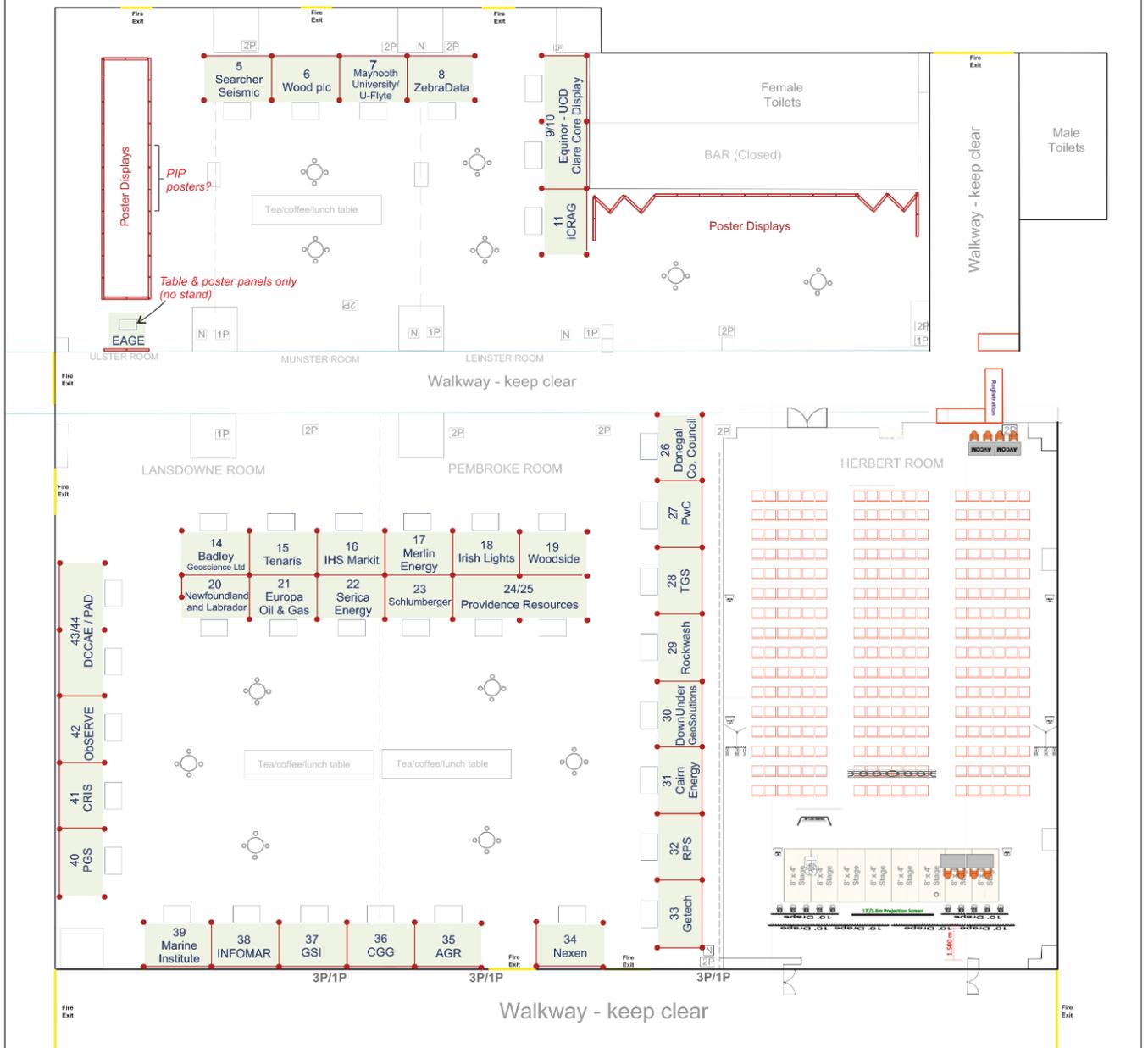
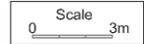
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Exhibition Layout

Atlantic Ireland 2018 Final Layout



Notes:

STAND DIMENSIONS: There are 3 panels at the back of each booth and 2 each side
Each panel is 970mm wide x 2360mm high x 3mm thick

Side panels of stands at row ends can be removed if requested in advance.

POSTER PANELS: 1m wide x 2.25m high

Technical Programme



Atlantic Ireland 2018 - Preliminary Technical Programme

TUESDAY 30th October 2018 - Morning

08.00 Reception - Coffee / Tea available in Exhibition Rooms

09.00 *Welcome to Delegates*

Address by Minister of State (DCCAE) Seán Canney TD

09.20 **Session 1 - Government Initiatives**
Chair - Matthew Collins (DCCAE)

Clare Morgan (DCCAE/PAD) - "Exploration Update Offshore Ireland"
Bill Morrissey (DCCAE/PAD) - "Policy and Regulatory Update"
Nick O'Neill (PIP Secretariat) - "Irish Shelf Petroleum Studies Group – The Next Decade"

10.00

Coffee, Exhibition & Posters

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11.00 **Session 2 - Regional Perspectives - 1**
Chair - Peter Haughton (UCD)

Edward Hetherton (ExxonMobil) - "Porcupine: A Basin of Two Halves"
Karize Oudit (CNOOC Nexen) - "Exploring the Southern Porcupine Frontier Basin (SPFB): Will the Eagle Spread its Wings?"
Richard England (Woodside) - "The Porcupine Basin, Ireland – Insights from New 3D Seismic"
Pablo Rodríguez-Salgado (iCrag) - "Structural style and timing of the inversion structures in the Celtic Sea Basins (offshore Ireland). Insights from the Mizen Basin."

Questions

12.20

Lunch

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Atlantic Ireland 2018 - Preliminary Technical Programme

TUESDAY 30th October 2018 - Afternoon

13.30

Session 3 - Regional Perspectives - II

Chair - Richard England (Woodside Energy)

Vicky Catterall (ExxonMobil) - "Evidence for a Mobile Substrate and its Impact on Trap Development in the Southern Porcupine Basin"

Lewis Whiting (iCRAG) - "From rifting to hyperextension: Implications for petroleum play development in the Porcupine Basin, Ireland"

Neil Parkinson (Europa Oil & Gas) - "The Lower Cretaceous of the South Porcupine Basin: spatial and temporal variation in sedimentation style from 3D seismic data"

Conor O'Sullivan (iCRAG) - "Structural and kinematic analysis of the Slyne Basin: exploring the links between structural evolution and traps"

Questions

14.50

Coffee, Exhibition & Posters

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15.30

Session 4 - "Regional Perspectives III and Plays & Prospects"

Chair – John O'Sullivan (Providence Resources)

Phil Copestake (Merlin Consortium) - "A New Standard Lithostratigraphic Framework for Offshore Ireland"

Stefano Baffi (ENI) - "Seismic Facies and Internal Architecture of an Isolated Cretaceous Carbonate Bank in the North Atlantic Porcupine Basin (Ireland Offshore)"

Adriana Ponte (Repsol) - "Analogues that help decrypting the Irish Dunquin carbonate play, Porcupine Basin"

Hugh Mackay (Europa Oil & Gas) - "Europa Oil & Gas – Progress and Prospects 2018"

Questions

16.45

Posters and Reception

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Atlantic Ireland 2018 - Preliminary Technical Programme

WEDNESDAY 31st OCTOBER 2018

08.00 Reception - Coffee / Tea available in Exhibition Rooms

09.00 **Session 5 - Conjugate Margins**
Chair – Mick Hanrahan (DCCAE/PAD)

David McCallum (Nalcor Energy) - "Newfoundland and Labrador Update: Emerging Plays"

Richard Whittaker (GeoArctic) - "Understanding the characteristics of hyperextended margins in Atlantic Ireland"

Jenny Omma (Rocktype Ltd.) - "Sediment provenance into Mesozoic basins of the Northern Grand Banks, offshore Newfoundland, Canada"

Kim Doane (Department of Energy, Nova Scotia) - "New Geoscience Research Initiatives Offshore Nova Scotia"

Timothy Grow (Hess) - "Shearing and Stretching the Porcupine Basin – A Tectonic Model Based on Integrated Geophysical Analysis"

Questions

11.00 Coffee, Exhibition & Posters

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11.20 **Session 6 - Environment and Safety**
Chair – Rory Dunphy (CNOOC Nexen)

Róisín Cullinan (CRU) - "CRU Petroleum Safety Permits"

Oliver Ó Cadhla (ObSERVE) - "From basis to Basins: Ireland's ObSERVE Programme"

Paul Rogers (OWRN) - "Oiled Wildlife Response Network – Building Capacity to Protect Wildlife"

David O'Sullivan (INFOMAR / Marine Institute) - "Sea Rover - collaborative exploration of Irish offshore reef habitat, contributing to sustainable development of our marine resources"

Eugene McKeown (RPS) - "Acoustic Impact of Seismic Surveys"

Questions

12.45 **Mieke Verkeyn** (ENI) "Closing Speech"

13.00 **Martin Davies** (PIP Secretariat) - Closing Remarks



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Oral Abstracts *(in order of presentation - speaker is underlined)*

Exploration Update Offshore Ireland

Morgan, C.¹

¹Department of Communications, Climate Action and Environment, Petroleum Affairs Division, Head of Technical Section Email: clare.morgan@dccae.gov.ie

The role of the Petroleum Affairs Division (PAD) is to maximise the benefits to the State from exploration for and production (E&P) of indigenous oil and gas resources. In doing this we ensure that activities are conducted with due regard to their impact on the environment and other land/sea users. PAD is responsible for regulating oil and gas E&P activities, both offshore and onshore Ireland. Our role extends from policy development, licensing, the regulation of E&P activities to outreach. PAD also plays a lead role in initiating and supporting research directed at deepening knowledge of the petroleum potential of the Irish offshore. PAD has initiated the acquisition of data where data gaps have been identified, conducts independent interpretation of technical data and occasionally issues Special Publications. PAD is the custodian of the National Data Repository and Archive for the petroleum sector.

Exploration Update 2018: The current status of exploration offshore Ireland is strong. The number of exploration authorisations in recent years is at the highest level since exploration began in the Irish offshore in the 1970s (Figure 1a shows licensed acreage since 1999). It is expected that the current exploration interest will lead to increased drilling activity in our offshore basins in the immediate future.

The petroleum Concession Map offshore Ireland (Figure1b) illustrates the present-day licence position and attests to industry interest in our offshore acreage, particularly in the Porcupine Basin. Acreage awarded as a result of the 2015 Atlantic Margin Licensing Round (28 new Licence Options awarded to 19 companies) was granted in two stages in February and June 2016. The Authorisations awarded were a Licence Option (LO), the vast majority of which were of 2 years' duration, and 2018 saw companies apply to convert the LOs to Frontier Exploration Licences (FEL). The positive response from industry to progress licences is encouraging and each FEL, as required, is accompanied with a strong work programme. The Department is pleased to state that all licence conversion applications awarded in Phase 1 are completed. The evaluation of LO to FEL conversions awarded in Phase 2 are on-going. The up to date position (Oct 2018) is that in the Atlantic Margin, of the 28 licences awarded in 2016, 13 have converted (Eni, Equinor x4, Europa, ExxonMobil x2, Nexen x4, Woodside), 7 applications are under consideration, 5 have surrendered and 3 more will not expire until 2019 as these LOs were granted for 3 years. In open acreage, the Celtic Sea area continues to attract players. Our Minister recently approved a three year Lease Undertaking in respect of both SEL 4/05 (Old Head of Kinsale) and SEL 5/05 (Schull).

There are currently 57 Authorisations awarded offshore Ireland with some 30 companies involved as operator or joint venture partners. There have been a significant number of assignments and this level of company interest may increase as additional exploration companies continue to enter into the Irish Atlantic Margin and Celtic Sea basins, via farm-ins.

There was a lot of seismic activity in our offshore basins in recent years. From 2015 to 2017 ten significant seismic surveys were acquired, located in the Celtic Sea and Porcupine basins (totalling 10500km of 2D data; 20500 sq km of 3D data). In 2018, seismic surveying as expected, given the life cycle of the licences issued as a result of the 2015 Licensing Round, was reduced. There was a very small amount of 2D seismic acquisition in our offshore this year, of limited extent and duration (80km over 26 hours), with the new profiles acquired in the Goban Spur area, as part of a site survey over Providence's Newgrange prospect in FEL6/14. No 3D seismic surveys were acquired in 2018. Any consent applications for seismic surveys are assessed in accordance with the Environmental Impact

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Assessment Directive, the Habitats Directive and the Birds Directive. The Department/Eni substantial 2D Regional Seismic survey acquired in 2013 and 2014 is now released for copying charge only. This valuable dataset includes 16,800km of PreStackTimeMigrated seismic data, velocity data, gravity data, magnetic data and field data in our Atlantic Margin basins.

No wells were drilled offshore Ireland in 2018. The 'Dunquin' exploration well 44/23-1, drilled in 2013 by ExxonMobil and partners in the Porcupine Basin, was released in July 2018. The new well data provides fresh knowledge on carbonate play fairway mapping and is a significant control point in this frontier area.

Petroleum production continued during 2018 from the Corrib gas field in the Slyne Basin and from the Kinsale field complex, the latter with declining gas production.

In other news, the 2018 Petroleum and other Minerals Development (Amendment) Climate Emergency Measures Bill passed a second stage debate in the Dáil in February 2018 and stakeholder hearings were held by the Joint Oireachtas Committee on Communications, Climate Action and the Environment in July this year. The Bill remains a legislative proposal. Government policies in respect of climate action, energy and offshore exploration, and the application of such policies, remain unchanged.

The PAD has an ongoing communications and outreach strategy to inform the general public, companies, contractors, governments and researchers about E&P offshore Ireland and to highlight our petroleum sector. As in previous years, the 2018 effort is carefully designed to spread throughout the calendar year, with specific timely objectives, targeting a range of audiences nationally and internationally. The programme is supported by follow-up Dataroom appointments. Some other initiatives that PAD was directly involved with in 2018 include supporting the launch of the GeoScience Careers (iGEO2018) inaugural symposium in January in NUIG, the launch of the Irish Association of Women Geoscientists (IAWG) at UCC in February and the Science & Technology in Action (STA) official launch of the 13th Edition in Dublin.

2018 saw a huge effort by PAD to digitally capture technical data to facilitate ease of data access, progress work programme time lines and to aid in disaster recovery.

Research initiatives, through PIP, iCRAG and NAPSA, aimed at deepening knowledge of the petroleum potential of Ireland's offshore continued in 2018. A NAPSA technical workshop was held in St. John's Newfoundland in June to foster research collaboration between Irish and Atlantic Canadian researchers. The aim was to identify current ideas, identify knowledge gaps in our understanding of North Atlantic Conjugate Margin petroleum systems and to suggest areas of study for new research projects. The Geology & Geophysics, Engineering and Environmental PIP ISPSG Technical Committees were active throughout 2018 and a number of very relevant projects are being scoped/on-going or completed.

The Trans-Atlantic Atlas of source rocks, oil characteristics and oil-source rock correlation in Mesozoic basins of the North Atlantic Conjugate Margin, offshore Ireland and offshore Newfoundland-Labrador and the Engineering Downtime Analysis & Cost Effective Drilling (2018 Revision) study were completed earlier this year. Other Department sponsored research projects have developed substantially with new projects initiated in 2018. The ongoing Bio/Litho/Stratigraphic study is progressing as planned to provide a new, updated stratigraphic framework and nomenclature for all Irish offshore basins. The baseline aerial and acoustic data acquisition of the ObSERVE programme was completed in 2017 and results and impact are currently being analysed, with data to be made publicly available before year end.

PAD continues to collaborate with other regulatory bodies, both in Ireland and other jurisdictions, with industry and with academia through a view to ensuring effective exploration in our offshore basins.

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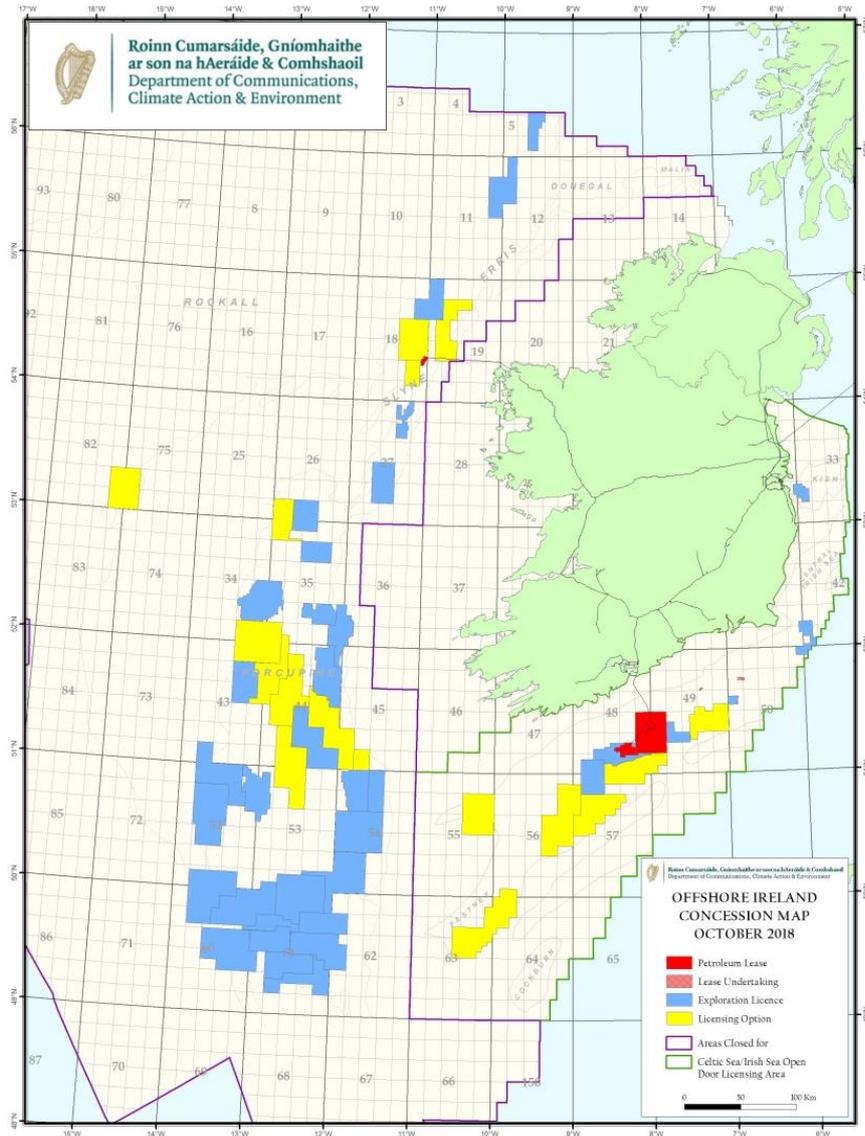
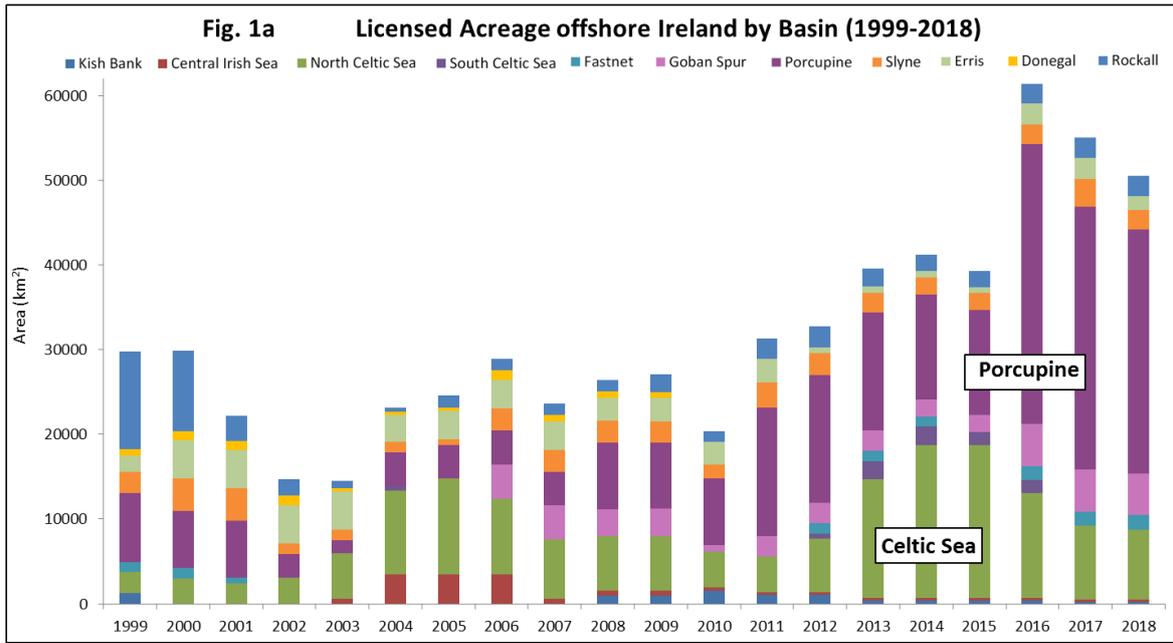


Figure 1b. The distribution of licences illustrates the exploration interest offshore Ireland

Irish Shelf Petroleum Studies Group – The Next Decade

O'Neill, N.¹

¹PIP Secretariat

Email: noneill@pip.ie

Who knows what the next decade will bring? Ireland is a nation where curious minds live, learn and discover. Science is part of our past, an immense part of our present and it is a key to our success. Together we shape the future. The Irish Shelf Petroleum Studies Group (ISPSG) research programme plays its part in supporting industry investment, future proofing our skills base and involving government, industry and academia in the potential of science and innovation to make a difference to Irish society and our economy.

The ISPSG undertakes thorough and balanced instrumental research that improves our understanding of the petroleum systems offshore Ireland and the marine environment in which we operate. In 2018, in line with objectives set at the ISPSG Members Workshop in March 2017, the ISPSG commissioned a large-scale project that addresses fundamental exploration issues offshore Ireland while continuing to fund applied innovative research in geology and geophysics through the Earth Resources spoke of the Irish Centre for Research in Applied Geosciences (iCRAG). You will hear more later about the “New standard lithostratigraphic framework for offshore Ireland” project from Phil Copestake of the Merlin Consortium who were contracted to carry out the work. The project results will be the basis for a Petroleum Affairs Division (PAD) Special Publication.

You will hear presentations from two of our iCRAG researchers Lewis Whiting and Conor O’Sullivan in this afternoon’s session. There are also posters outside that illustrate the ongoing research funded by the ISPSG. Do take the time to view the posters and meet with the researchers. There are sure to be ideas, concepts and new methodologies that will be of interest to your exploration efforts.

Each year at this conference we appeal to ISPSG member companies to become more engaged with the ISPSG research programme and realise the benefits it can bring to individual company exploration programmes. I am delighted to report that we now have very active technical committees developing concrete proposals for research focused on common industry issues.

The Environmental Technical Committee (ETC) has recently commissioned RPS Group to carry out a West and South Coast Tier 3 Oil Spill Response Capability Study to verify that the standard components of a response plan are executable in Ireland and that equipment and processes are in place that are in compliance with industry best practice and regulatory requirements. The ETC are also scoping a West and South Coast Oil Spill Sensitivity Mapping project while continuing to fund research to assess the distribution and vulnerability of seabirds at sea to inform marine spatial planning.

The Geology and Geophysics Technical Committee (G&G TC) are scoping a project to reprocess the PAD 2013-14 Long Offset 2D Regional Seismic Data and investigating options for acquiring stratigraphic boreholes.

As part of ISPSG outreach the Data Management and Support Services Committee is funding “Shorelines: The Coastal Atlas of Ireland” a 500-page publication containing over 400 maps and illustrations involving over 20 authors due to be published by Cork University Press in 2019. The ISPSG has previously funded the research of many of the authors who have contributed to the Atlas. “Shorelines: The Coastal Atlas of Ireland” will disseminate scientific knowledge about the coasts of Ireland and of the processes that are shaping them to the broader public, government and decision makers.

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So, what will the next decade bring for Irish offshore petroleum exploration? As George Friedman says “a century is about events. A decade is about people”. So together let’s future proof our activities through science and innovation.

Porcupine: A Basin of Two Halves

Hetherton, E.¹, Carwithen, L.¹

¹*ExxonMobil International Limited*

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In 2013, ExxonMobil Exploration and Production Ireland (Offshore) Limited and Partners drilled deep-water wildcat well 44/23-1 (Dunquin) in the Porcupine Basin, the first exploration well in the basin in over ten years. Prior to drilling this well, hydrocarbon exploration had been limited to shallower waters in the north of the basin. Some 25 exploration wells were drilled between 1977 and 2001, testing multiple plays and trap types with limited success. Currently (2018) only three wells have been drilled in the Southern Porcupine Basin; 44/23-1, 43/13-1 (BP, 1988), and the recent 53/6-1 (Providence, 2017). Further south, 62/7-1 (Esso, 1982) and a number of Deep Sea Drilling Project (DSDP) wells targeted stratigraphy on the Goban Spur. Much of the Southern Porcupine Basin therefore remains un-calibrated and open to new play ideas, as evidenced by the significant interest in the highly successful 2015 Ireland licensing round.

The disparity in the amount of well calibration between the north and the south of the basin is, however, only part of the story. The westward extension of onshore crustal lineaments such as the Variscan Front into the Irish offshore continue to be debated but are seen as potentially important controls on basement composition and deformation history in the northern and southern areas of the Porcupine Basin. Inherited structural grains and multiple episodes of tectonism throughout the Palaeozoic and Mesozoic have had a profound impact on the sedimentary fill and prospectivity in these two regions.

Regional structural domain mapping and observations from recently acquired 3D seismic reflection data highlight some of the key tectono-stratigraphic features in the Southern Porcupine Basin. Using a consistent methodology and nomenclature, the rifted margin has been divided into three distinct domains: (1) Proximal, low extension; (2) Intermediate 'necking' and (3) Hyper-extended distal. Observations from high quality 3D seismic data have been integral to the identification of key Mesozoic unconformities which have had a significant control on the distribution of play elements. This work, together with the incorporation of regional isochore maps and well data, has helped better understand the post-rift differences and subsidence histories of the two areas.

Acknowledgements

We would also like to thank our colleagues at ExxonMobil International Limited, Samira Souiki, Vicky Catterall, Helen Kallagher, Emin Jafarov and Duncan Erratt for their contributions.

Exploring the Southern Porcupine Frontier Basin (SPFB): Will the Eagle Spread its Wings?

Oudit, K.¹, Jones, G.¹, Tomsett, B.¹, Jones, N.¹, Slater, L.¹, Millington, J.¹, King, A.¹

¹CNOOC-Nexen, Prospect House, Uxbridge, UB8 1LU, UK

The Southern Porcupine Frontier Basin (SPFB) on the Irish Atlantic Margin is currently the focus of increased exploration activity. The basin is entering a defining phase with operators planning and executing regionally significant wells, testing the diverse play types present in this large area (ca. 50,000 km²), following the highly successful 2015 licensing round process.

The SPFB has been high-graded as the basin possesses most of the key attributes that would form the basis of a successful frontier basin entry strategy, namely:

- High quality seismic data in critical areas
- Multiple plays / ability to spread risk and exposure
- Robust structural traps with significant volumetric potential
- Offset well(s) /discoveries proving critical play elements
- High confidence in mature source rock systems(s)
- Ability to test more than one play with a frontier well
- Running room in the plays in the success case outcome

Investment in new datasets, including substantial areas of recently acquired 3D seismic data, is enabling the full diversity and complexity of plays in the SPFB to be clearly imaged for the first time. High resolution satellite derived potential field data also allow the seismic to be put in context within the wider basin architecture and pre-Mesozoic basin structure.

Integration of these new datasets has significantly furthered the understanding of the presence of the major components of the petroleum systems and has enabled high grading of exploration sweet spots. 3D seismic has highlighted the significant development of Jurassic (Kimmeridgian and Tithonian) source rock bearing sections (up to 5km thick) in parts of the SWPB, together with widespread development of internally complex clastic reservoir sequences of Mid to Late Jurassic age (up to 1.5km thick) in a classic extensional rift system.

CNOOC-Nexen entered the basin in 2016 and have accelerated the maturation of the captured opportunities, culminating in securing a joint venture partner for drilling the Iolar (Eagle) Prospect frontier exploration well (FEL 3/18; CNOOC-Nexen: 50% Op. ExxonMobil Exploration and Production Ireland (Offshore South) Limited: 50%) in 2019 (Figure 1). Iolar will target the interpreted pre to syn-rift Jurassic structural play on the west flank of the basin, analogous in numerous ways to the giant producing fields of the North Sea province in the UK and Norway.

High risk-high reward targets such as Iolar represent true frontier Atlantic Margin exploration. However, the SPFB is now a region where many of the fundamental factors required for exploration success can be shown to be in place to a degree of confidence not previously possible.

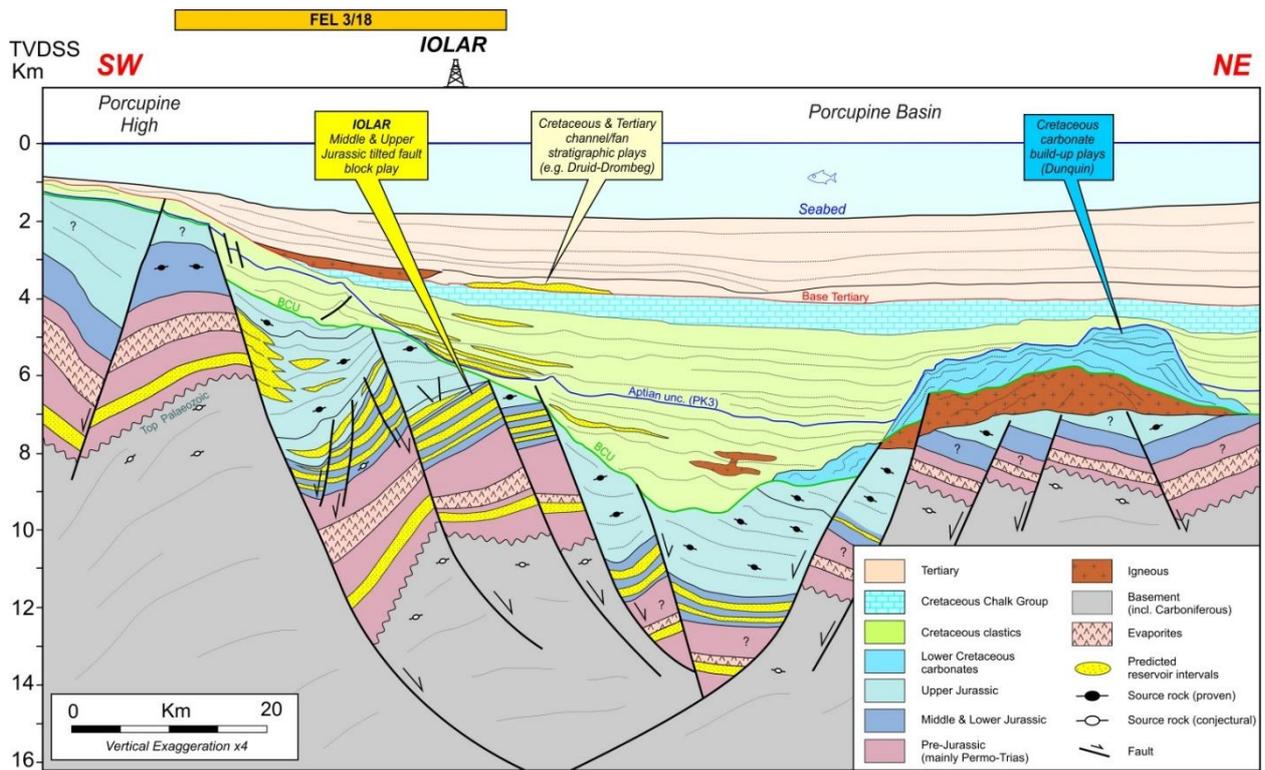


Figure 1. Play summary cartoon of the western and central areas of the SPFB.

The Porcupine Basin, Ireland – Insights from New 3D Seismic

England, R.¹

¹Woodside Energy (UK) Ltd, Pollen House, 10-12 Cork Street, London W1S 3NP

Woodside Energy (Ireland) Pty Ltd has been exploring in the Porcupine Basin since late 2013 with an acreage position built up through farm-ins and a 2015 licensing round. Basin entry was based upon a proven petroleum system, low above ground risk, excellent fiscal terms and as an emerging basin with the potential for new, untested plays. Known challenges to prospectivity include reservoir quality, structural complexity in the Jurassic and limited structures in the Cretaceous. Upon entering the basin, Woodside reprocessed to pre-stack depth migration two 1998-2000 vintage 3D seismic surveys. In the first phase of two Frontier Exploration Licenses (FELs) and one Licensing Option (LO) Woodside acquired c. 4,000 km² 3D seismic across two surveys. These have been processed, depth imaged, and subsequently interrogated through 3D seismic interpretation and evaluated in GeoTeric and Paleoscan software. The processing to depth resulted in a much clearer image of the pre-Chalk structure and stratigraphy, and the identification of a number of sediment input points and depositional systems in the basin.

In parallel, Woodside's London-based Ireland team have integrated regional 2D seismic and well data to refine the tectonostratigraphic framework of the Porcupine Basin and generate play based evaluation products. This regional work has fed into, and been updated by, block specific mapping on acreage with almost 100% 3D seismic coverage following the 2016 acquisition program. This presentation reviews certain data, with a view to addressing some fundamental aspects of prospectivity and exploration in the Porcupine Basin.

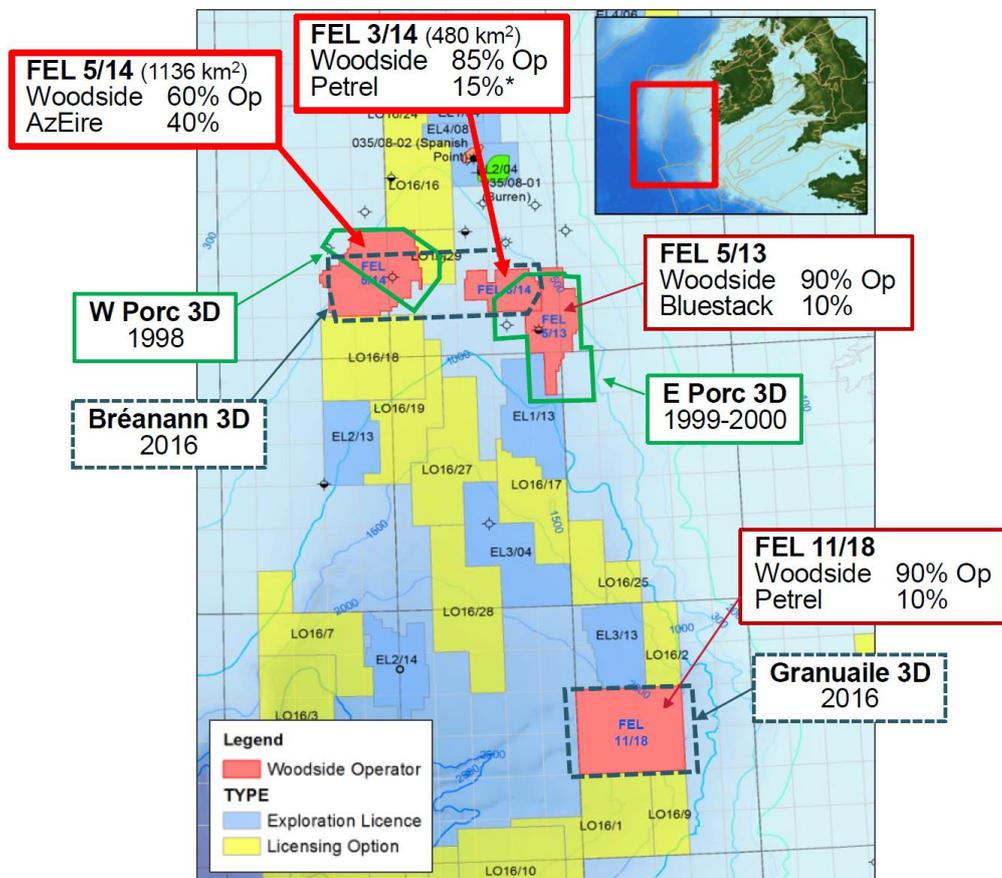


Figure 1. Woodside position in Porcupine Basin (May 2018)

Conclusion

The acquisition and processing of 4,000 km² 3D seismic across two surveys, and subsequent interpretation workflow, has revealed indications of sediment input and depositional systems. The integration of block specific mapping with regional well and seismic studies provides the basis for high-grading acreage and an updated view of the prospectivity of Woodside's Porcupine Basin licenses.

Structural style and timing of the inversion structures in the Celtic Sea basins (offshore Ireland): Insights from the Mizen Basin

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Inversion structures developed in the Celtic Sea basins as a result of Cenozoic intra-plate shortening have been a focus for hydrocarbon exploration for almost 50 years. These structures provide the structural closure for the main gas fields in the area (Kinsale Head, Seven Heads and Ballycotton) and several undeveloped gas and oil accumulations.

Despite the importance of these structures for petroleum systems, many details of their mechanisms of formation remain unclear. This is partly related to a lack of preservation of Cenozoic syn-inversion sequences in most of the Celtic Sea basins due to Cenozoic basin uplift and exhumation that caused the Upper Cretaceous post-rift chalk sequence to subcrop beneath the sea floor over the central and north-eastern parts of the Celtic Sea.

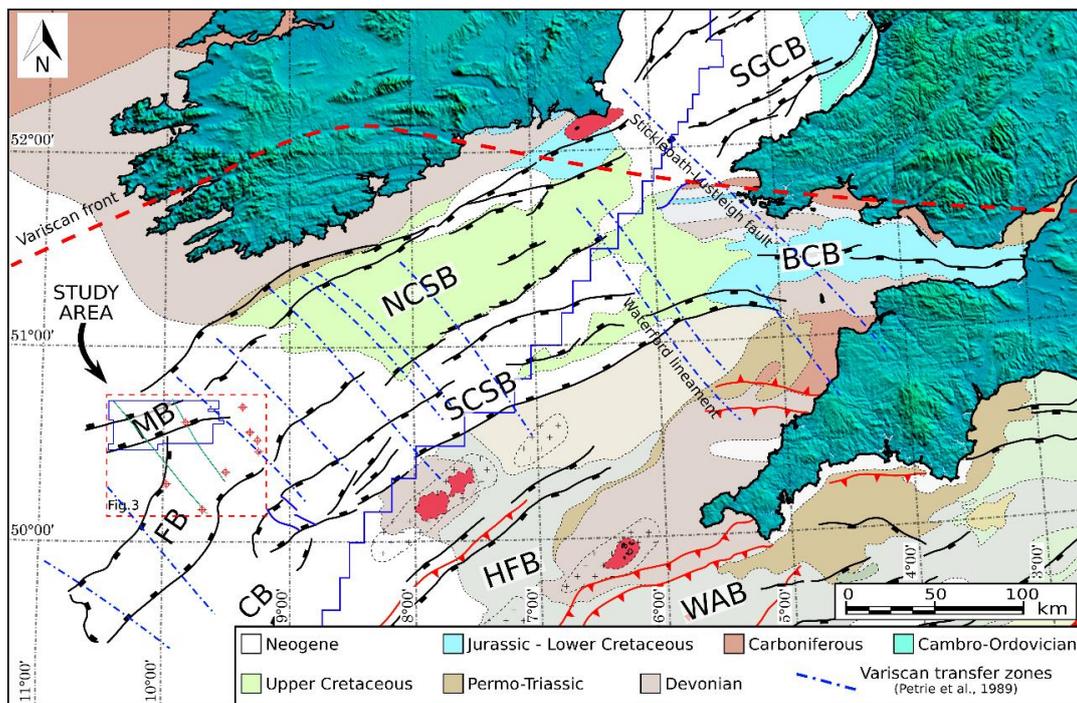


Figure 1. Map showing the main structural elements of the Celtic Sea basins and sea-floor subcrop map of the main lithological ages. Modified from (Pharaoh, 1996). MB: Mizen Basin (study area)

The Mizen Basin (Figure 1) lies at the western termination of the Celtic Sea basins and consists of two NE-SW trending half-grabens developed as a result of Mesozoic extension that reactivated older Caledonian and Variscan faults. The partially inverted basin contains a series of syn-inversion sequences that are much better preserved than in the basins to the east. This, combined with excellent 3-D seismic coverage of the basin, makes this area an excellent location to study the style and timing of inversion of the Celtic Sea basins.

Analysis of sediment thickness and fault displacement distributions indicate that the basin-bounding normal faults were active from Early Triassic to Late Cretaceous times under a NW-SE direction of extension. A later phase of Barremian to Cenomanian (Early to Late Cretaceous) N-S oriented extension

gave rise to E-W-striking minor normal faults and reactivation of the pre-existing basin bounding faults that propagated upwards as arrays of segmented normal faults (Figure 2).

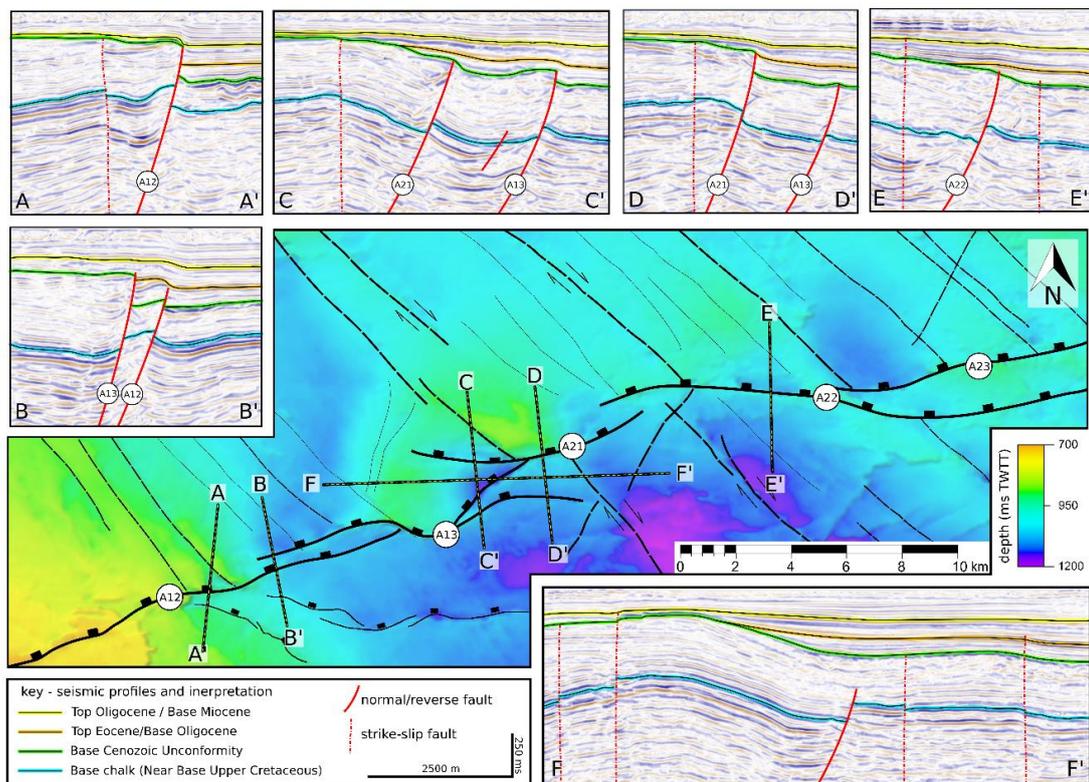


Figure 2. Detailed view of arbitrary seismic lines along the main segments defining the fault system A

The Mesozoic pre-inversion basin configuration played a key-role in the subsequent Cenozoic basin inversion. The late Mesozoic E-W segmented fault arrays, that link downwards onto the early Mesozoic basin bounding faults, were reactivated in compression. The array of segmented faults formed during extension was reutilised in compression and displacement variations on individual segments in compression mirror those that formed in earlier extension. Relay ramps between normal fault segments formed in extension, to a significant extent, control the geometries of anticlinal closures in the hanging-walls of the inverted faults.

A set of NW-SE trending dextral-strike slip faults (Figure 2) formed during inversion caused local shortening on the hanging walls of the main faults. The syn-inversion sequence indicates that most of the reverse fault displacement took place from Middle Eocene to Oligocene times. During the Miocene, a significant decrease of fault activity is recorded with shortening accommodated primarily by folding rather than faulting at this time. No syn-inversion sequences older than Middle Miocene are observed.

These observations provide insights to aid interpretation of inversion structures in other areas of the Celtic Sea affected by greater erosion and only covered with 2D seismic data.

Acknowledgements

We gratefully acknowledge the Petroleum Affairs Division (PAD) of the Department of Communications, Climate Action and Environment (DCCA) for providing the data used in this project and the permission to show the seismic profiles. We also thank the Petroleum Infrastructure Programme (PIP) for co-funding this research.

Evidence for a Mobile Substrate and its Impact on Trap Development in the Southern Porcupine Basin

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In 2018, a joint partnership between ExxonMobil Exploration and Production Ireland (Offshore South) Limited and Equinor Energy Ireland Limited converted six Licensing Options (LO's) to Frontier Exploration Licenses (FEL's) in the Southern Porcupine Basin. To better understand the structural and stratigraphic evolution and associated petroleum system of this large area, two 3D seismic surveys (Galway and Cairenn) were acquired in 2016 and 2017 by CGG.

Structural domain mapping in the Galway 3D shows the diversity of structural styles, with both brittle and ductile deformation prevalent. Spatial and temporal changes in depocentre location reveal a complex interplay between fault-related and mobile substrate-related deformation. Turtle structures, rotated onlap sequences and hangingwall fault-propagation folds are commonly observed and provide numerous, prospective trap types. Despite few salt penetrations in wells in the Porcupine Basin, the proximity to the Celtic Sea (Triassic salt basin) and the conjugate margin of Eastern Canada (Lower Jurassic/Triassic Argo salt), as well as observations from the new 3D seismic data make it likely that salt within the Southern Porcupine Basin may have had a significant influence on the structural evolution of the area.

Acknowledgements

We would like to thank our colleagues at ExxonMobil International Limited, Leah Carwithen, Samira Souiki, Edward Hetherington, Helen Kallagher, Emin Jafarov and Duncan Erratt for their contributions. We would also like to thank Equinor Energy Ireland Limited for giving permission to publish and present this paper. Contributors from Equinor Energy Ireland Limited include: Laurence Ashurst and Jonathan Bloomfield

From rifting to hyperextension: Implications for petroleum play development in the Porcupine Basin, Ireland

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Introduction

The Porcupine Basin, located on the Irish Atlantic Margin, is a ‘failed’ rift whereby hyperextended rifting terminated before oceanic crust could extensively form. West-East extension during the Middle- to Late-Jurassic was followed by a protracted phase of thermally-induced subsidence resulting in a catenary-shaped Cretaceous succession up to 6 km thick (Figure 1). The rift displays evidence for a strong southward increase in lateral strain, abruptly transitioning from ‘normal’-extended (low-magnitude extension) crust in the north to a widened zone of thinned, hyperextended crust with potentially exhumed mantle towards the south.

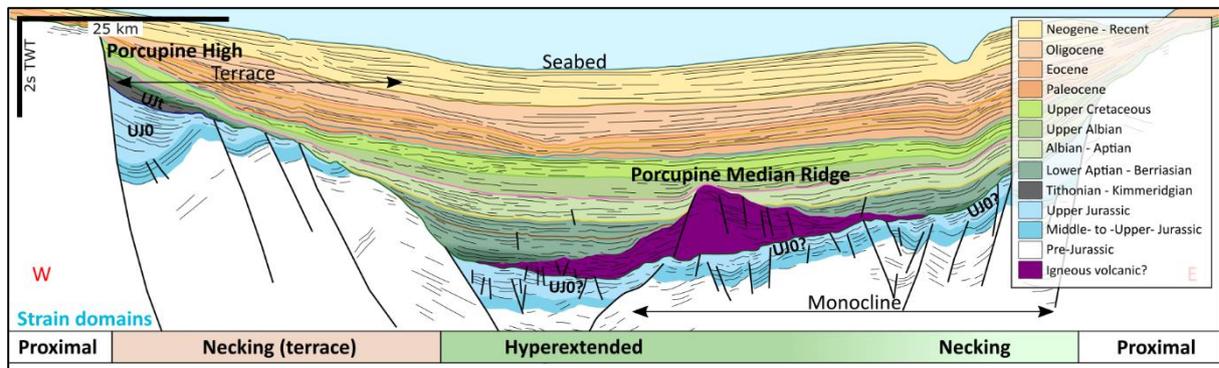


Figure 1. West-East seismic interpretation showing rift asymmetry

The timing of rifting and mechanisms involved during the evolution from early rifting to hyperextension are currently poorly constrained. However, the presence of variably-developed unconformity-bounded sequences (UJt in Figures 1 and 2) draped above highly-faulted topography form an important transition between the syn-rift and post-rift, providing a means to better constrain the timing of rifting. As Tithonian source rock intervals are associated with these transitional packages, their distribution has important implications for petroleum exploration. Well 43/13-1 sampled a rich Tithonian siltstone interval with S2 values of 47.7 kg/tonne (average), 10.7% TOC and hydrocarbon index of 585 at 3,180m MD. The present tectonostratigraphic study integrates extensive 2D and 3D seismic data with well information to analyse the timing, composition and distribution of syn-rift to post-rift sequences.

Diachronous rifting

While the syn-rift to post-rift transition is dated as Kimmeridgian – Tithonian on the basin margins, similar but younger Lower-Cretaceous packages (K0t in Figure 2), which may have source rock potential, are present towards the hyperextended rift centre. The spatial and temporal distribution of the transition sequences reveals a compartmentalised rift system which diachronously evolved from low to moderate extension in the Middle- to Late-Jurassic to extreme crustal thinning with strain migrating outboard towards the rift axis.

Rift configuration

Rifting was predominantly asymmetrical resulting in contrasting differences in the structural and stratigraphic architecture of the east and west margins (Figure 1). The western margin comprises a terrace characterised by large high-angle normal faults and half-graben depocenters, filled with thick well-defined syn-rift (UJ0) and transitional sequences (UJt). In contrast, the eastern margin, comprising a

broad basinward-dipping monocline, facilitated thinner, poorly-defined UJ0 sequences and largely absent UJt sequences. A significant change in rift architecture occurs at approximately 51°30' – 51°40' (Figure 2) where the rift asymmetry to the north switches margins to a terrace with well-developed UJt sequences on the east, contrasting with poor terrace development on the west. The abrupt change may reflect heterogeneities in the inherited pre-rift crust and/or the influence of rift-segmenting transfer zones.

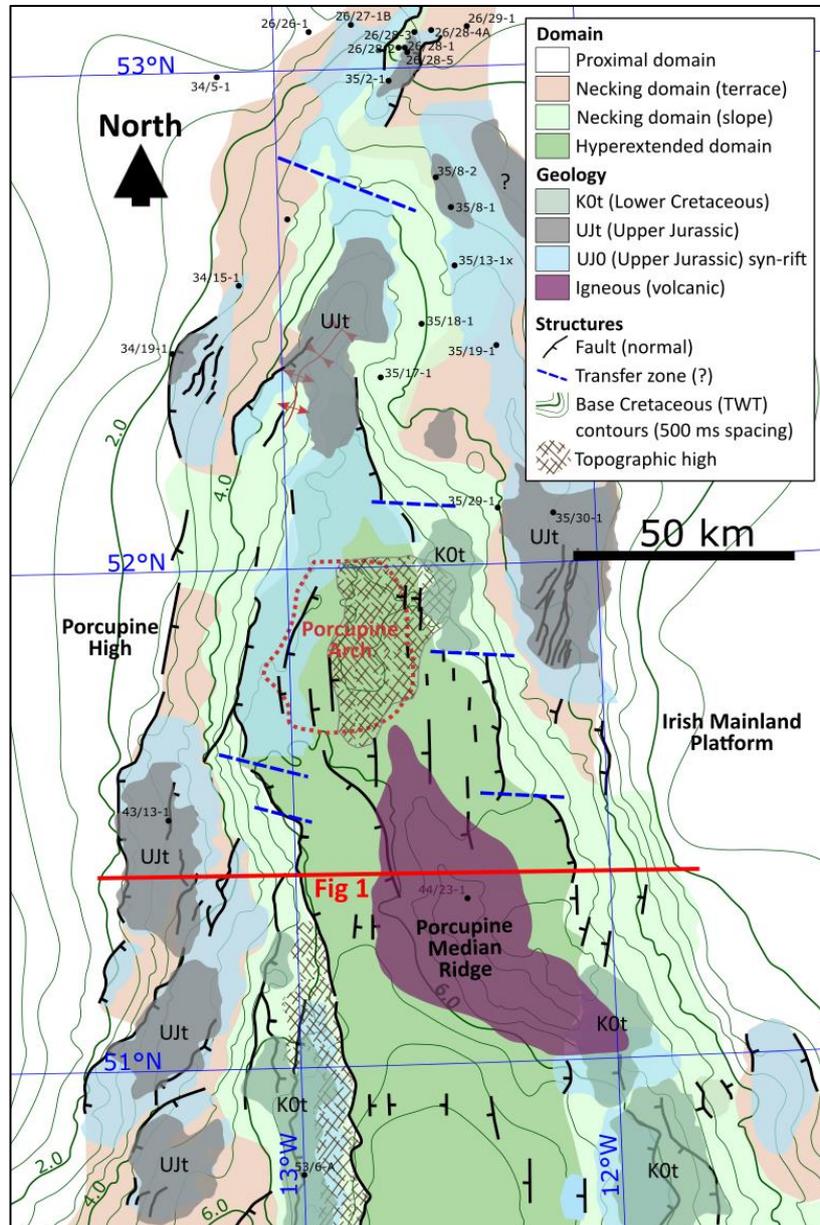


Figure 2. Syn-rift to post-rift transition (Kimmeridgian – Berriasian) map of Porcupine Basin

Implications for source rock presence

The distribution of Upper Jurassic – Lower Cretaceous source rock intervals in the Porcupine Basin is strongly controlled by the asymmetrical development of the rift system. The north, northeast and western parts of the basin favour the presence of Tithonian source rocks associated with the UJt sequences. However, potential lies in younger, undrilled, Lower-Cretaceous restricted marine depocentres (e.g. K0t sequences) which may have facilitated source rock accumulation. In addition to source rock potential, this study has implications for reservoir presence and trapping potential in the hyperextended setting.

The Lower Cretaceous of the South Porcupine Basin: spatial and temporal variation in sedimentation style from 3D seismic data

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2017-18 PSDM reprocessing of 3D seismic volumes from opposing flanks of the South Porcupine Basin provides, *inter alia*, much improved imaging of Lower Cretaceous deepwater sandstone systems. We illustrate four styles of deepwater sandstone development (Figure 1).

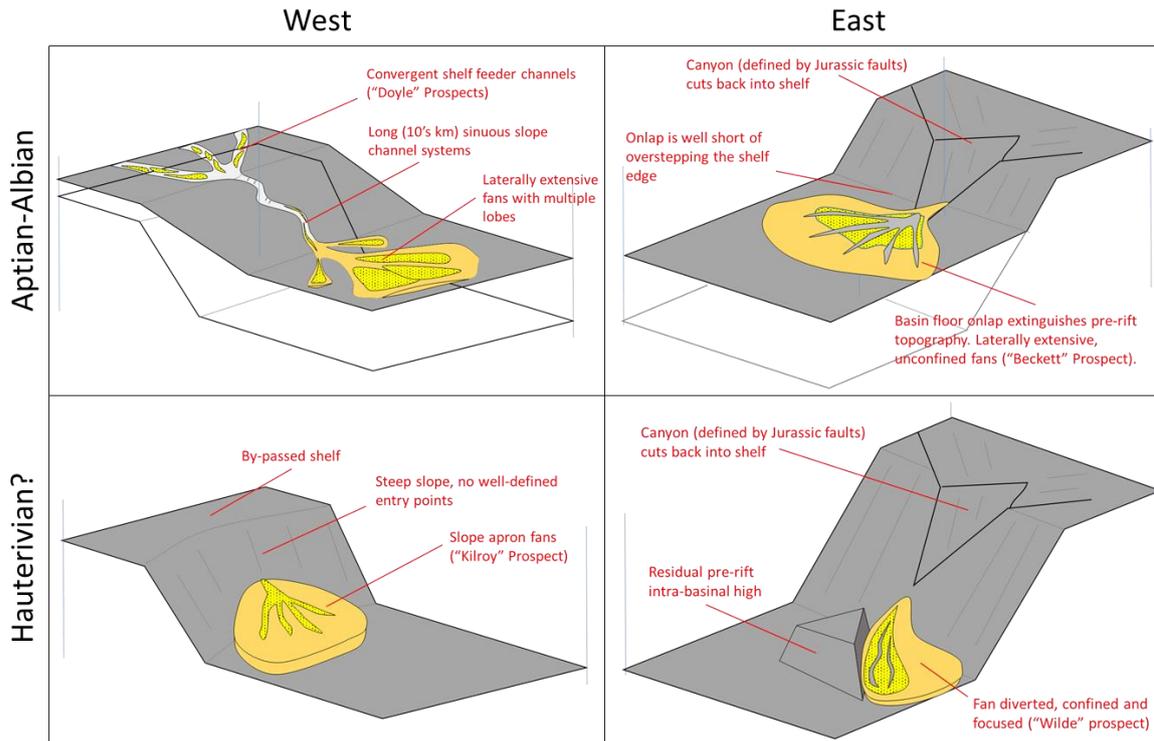


Figure 1. Schematics showing the four styles of deepwater system discussed

Early post-rift sedimentation is into a deep, steep-sided basin. Submarine fan development within this sequence (from regional correlation) is of approximately Hauterivian age. Late-rift fault patterns are critical: in northern Q54, the intersection of N-S late-rift normal faults and NW-SE relays sets up a canyon entry point. Fans spill out of a deep canyon and are further directed and confined by remnant rift topography. These features promote both fan detachment (chance of up-dip seal) and resource density ("developability"). Within Europa's "Wilde" fan it is possible to recognise hummocky, transparent and parallel seismic facies (Figure 2) which relate to the isopach envelope and are likely to represent medium, high and low net/gross areas respectively. Contourite reworking or slumping of the upper fan surface will also be suggested.

By contrast, on the opposite side of the basin, our "Kilroy" fan is a Brae-type slope apron feature which sits in a Base Cretaceous embayment but without a discrete entry point. Again, the steep basin margins early in the post-rift promote isolation and potentially high resource density. These deep fans also present fewer migration difficulties from an uppermost Jurassic source rock.

As the basin fills, the asymmetries become more apparent. Onlap of the shelf is demonstrable in many areas in the west. The mid-Cretaceous relative lowstand leads to incision of the shelf in FEL 2/13 (the “Doyle” channels). Elsewhere, a low-angle slope to basin transition is marked by sinuous slope channel systems which are 10’s of kilometres long, terminating in unconfined fans with multiple lobes. Such systems are associated with greater up-dip seal risks, imply extreme column heights and have potentially low resource density.

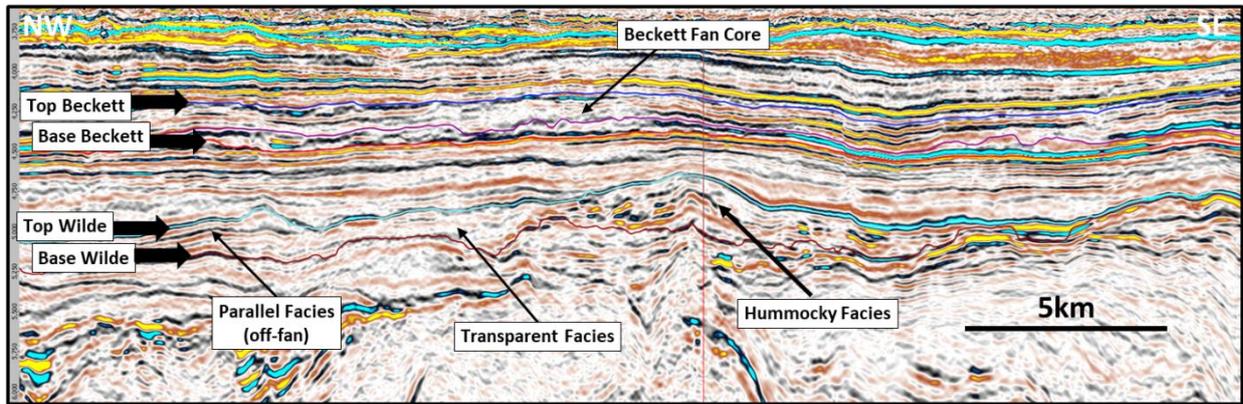


Figure 2. Seismic facies of Lower Cretaceous fans, strike line FEL 3/13 (Europa 2017 PSDM)

Our eastern mid-Cretaceous example is the Beckett-Shaw fan system (Figure 3). Onlap here remains significantly basinward of the slope-shelf break and sediment continues to reach the basin down defined canyons. However, the remnant pre-rift topography has by this stage been extinguished so the fans are unconfined. Seismic facies and isopach data will be used to demonstrate offlapping relationships within these fans.

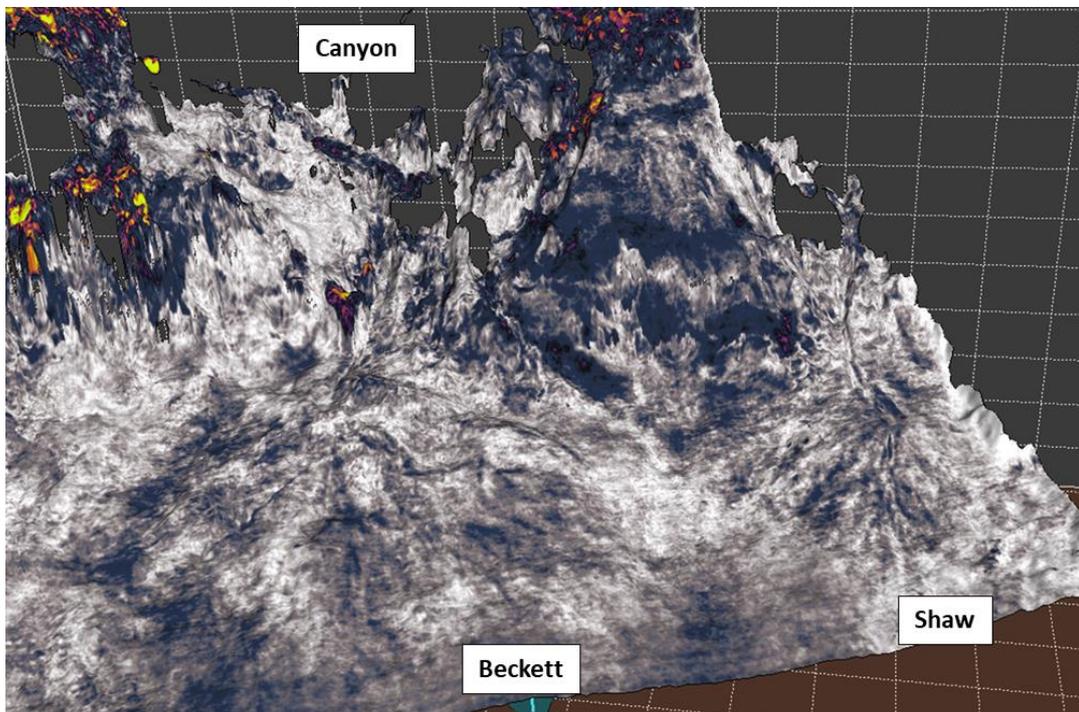


Figure 3. The Beckett and Shaw fans (mid-Cretaceous) of FEL 3/13 looking east up the entry canyon systems (Europa 2017 PSDM)

Structural and kinematic analysis of the Slyne Basin: exploring the links between structural evolution and traps

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The Slyne Basin is an elongate and narrow series of half-grabens and grabens bounded by transfer zones, located between the Rockall Basin, Porcupine High and the Irish Mainland Shelf. It belongs to a chain of rift basins extending along the NW European Atlantic margin. Basin formation began in the Late Permian, with a first phase of rifting continuing until the end of the Early Jurassic, when the basin experienced a period of uplift and erosion. The most significant phase of rifting initiated in the Middle Jurassic and continued until the end of the Jurassic. Significant erosion of the Late Jurassic strata during the Early Cretaceous created a distinct regional angular unconformity before a thin Cretaceous cover was deposited. A second phase of uplift and erosion during the Paleocene resulted in a subtle angular unconformity between Cenozoic and Cretaceous sediments and removed the Cretaceous section south of the Central Slyne Transfer Zone, juxtaposing Cenozoic and Jurassic sediments. Localised zones of strike-slip faults likely developed during this time. Eocene magmatism resulted in the emplacement of numerous sills within the Jurassic succession and extrusion of lava flows onto the Paleocene unconformity, followed by the deposition of Oligocene to Miocene sediments. Mild reactivation of a variety of structures occurred during the Miocene with evidence of both normal and reverse movements. A final minor period of erosion during the Miocene created a regional unconformity, upon which a thin cover of undeformed Miocene to Recent sediments was deposited.

The structural architecture of the Slyne Basin is influenced by the presence of major structural lineaments which transect the basin, dividing it into three distinct sub-basins of opposed polarity and unique structural styles. Extensional fault-related structures, typical of rift basins, are the main play types in this area. The geometry of these structures is strongly influenced by the presence of Permian and Triassic salt that mechanically detach the Mesozoic section from the underlying Palaeozoic basement, leading to rafting, salt withdrawal and forced folding above basement horsts. The Corrib gas field and the 18/20-7 (Corrib North) discovery are both salt-induced anticlines above basement horsts. Additionally, numerous culminations are observed in the hanging-walls of the basin-bounding faults, such as the structure containing the 27/4-1 (Bandon) oil discovery, which are likely to have formed by a combination of salt withdrawal and rapid subsidence during the Middle Jurassic. Post-rift evolution (exhumation and reactivation) possess a risk to the integrity of hydrocarbon traps, with the clearest example of this being the structure tested by the 27/5-1 (Avonmore) well, where a circa 100m residual oil column was encountered in a horst block with distinct Oligocene to Miocene age reverse movement on the bounding faults.

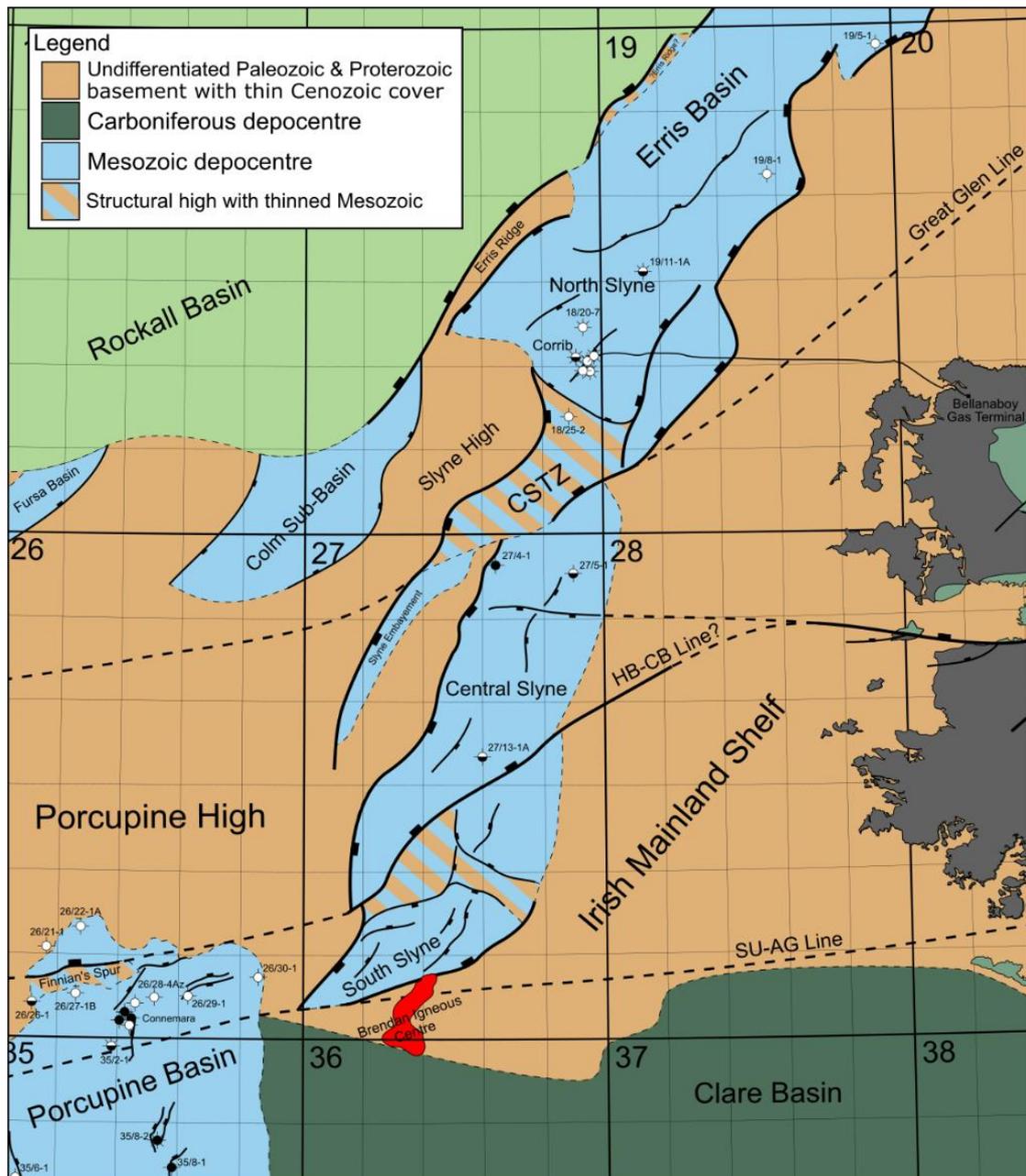


Figure 1. Simplified structural map of the Slyne Basin and surrounding tectonic elements. Onshore geology adapted from Worthington & Walsh (2011); Porcupine Basin geology adapted from Bulois et al., 2018. Abbreviations: CSTZ – Central Slyne Transfer Zone, HB-CB Line – Highland Boundary/Clew Bay Line, SU-AG Line – Southern Uplands/Galway-Antrim Line

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A New Standard Lithostratigraphic Framework for Offshore Ireland

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The Irish offshore area encompasses a diverse set of geological basins, both on the Atlantic margin and in the Fastnet, Celtic and Irish Sea regions, representing a wide range of geological and structural complexity. The efficient exploration of the region requires a standard stratigraphic understanding and consistently defined schemes (biostratigraphy, lithostratigraphy, sequence stratigraphy) that all operators, contractors, academia and regulators can use. This will provide a common language of communication and also a fundamental chronostratigraphic framework to underpin all subsurface geoscience evaluations. Despite its long history of hydrocarbon exploration (the first offshore Ireland well, 48/25-1, having been drilled in 1970), such a unified framework has not previously been defined for offshore Ireland, which has hampered understanding and geological correlation from area to area.

A new lithostratigraphic nomenclature has been established as part of PIP project IS16/04 and approved by the PAD for use as a standard across the Ireland offshore area. This scheme has been facilitated and guided by a newly established Stratigraphic Committee, and project Steering Committee in association with the Petroleum Affairs Division (Department of Communications, Climate Action and Environment). This scheme will be outlined in the presentation and is also illustrated in a poster at the conference.

The newly defined lithostratigraphic scheme combines new names with a selection of existing names. Existing names are extended into offshore Ireland for those rock units that are contiguous with nearby jurisdictions, particularly the offshore UK regions, onshore Ireland (Republic of Ireland and Northern Ireland) and onshore UK (England, Wales and Scotland). This means that some familiar terms are retained (for instance, Wealden and Gault in the Celtic Sea area). Nevertheless, there are many instances where new names are required. A total of around 250 lithostratigraphic units are defined for offshore Ireland, of which around 200 are newly named.

The following themes have been used for the naming of new rock units for specific stratigraphic intervals in the Ireland offshore area: Irish artefacts, jewellery, bays, fish, peninsulas, headlands and points, lakes, birds, plants, seashells, colours, folklore and archaeological features.

The presentation will provide an overview of the new lithostratigraphic scheme and focus on several intervals of exploration interest, including the Upper Jurassic of the Porcupine Basin and the Wealden-Gault of the Celtic Sea.

The Upper Jurassic of the Porcupine Basin is referred to the newly defined Beara Group, which is subdivided into the Minard, Bolus and Dursey formations, in ascending order. The Minard Formation is of Oxfordian age and, in the only two wells that penetrate older Jurassic in the basin (26/21-1A, 26/22-1), this section unconformably overlies the Lower Jurassic Lias Group sediments. Hydrocarbon-bearing sandstones in the Connemara Discovery (26/28 block) are referred to the Dursey Formation (Streedagh Sandstone Member) and the Minard Formation (Renard Sandstone Member). The reservoir sandstone in the Spanish Point Discovery (35/8-2) is referred to the Leck Sandstone Member, of the Dursey Formation, and is of Tithonian age.

ATLANTIC IRELAND 2018

In the North Celtic Sea Basin, hydrocarbon reservoirs fall within the Wealden Group and Selborne Group (Gault Formation), names familiar from UK onshore and offshore usage, that are extended into offshore Ireland. Within the Wealden Group, hydrocarbons are reservoirised in the newly named Rudd Sandstone Member (of the Eel Formation). The former informal units B Sand and A Sand, which are the reservoirs in the Kinsale Head area, are now named the Bream Sandstone and Agone Sandstone members, respectively, and are grouped in the Gault Formation.

The report from the IS16/04 project is nearing completion and will contain descriptions of all the offshore Ireland rock units, illustrated with type wells, reference wells, distribution maps and well-seismic ties, together with a set of regional seismic lines and a set of well summary logs for each well and borehole displaying the new stratigraphy. The main volume of the atlas will be publicly released on completion and the new scheme will be documented in a PAD Special Publication. A summary chart displaying the new stratigraphy is provided as a poster at this conference and is also shown on the PAD exhibition booth and on the Merlin Energy Resources stand. A copy of the chart, together with a listing of tops for all the new lithostratigraphic units in offshore Ireland wells and boreholes, will be available at the conference.

Acknowledgements

We wish to thank PAD and PIP for approval to deliver this presentation.

Seismic Facies and Internal Architecture of an Isolated Cretaceous Carbonate Bank in the North Atlantic Porcupine Basin (Ireland Offshore)

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The Dunquin North well (44/23-1) was drilled in 2013 in Frontier Exploration Licence 3/04 (Figure 1), in a water depth of 1,660 m, targeting one of two culminations sitting on top of the Porcupine Median Ridge and discovering about 500 m of Lower Cretaceous carbonates, consisting of low energy inner platform deposits, grading upward to medium-high energy platform margin deposits, with good reservoir quality and residual hydrocarbons.

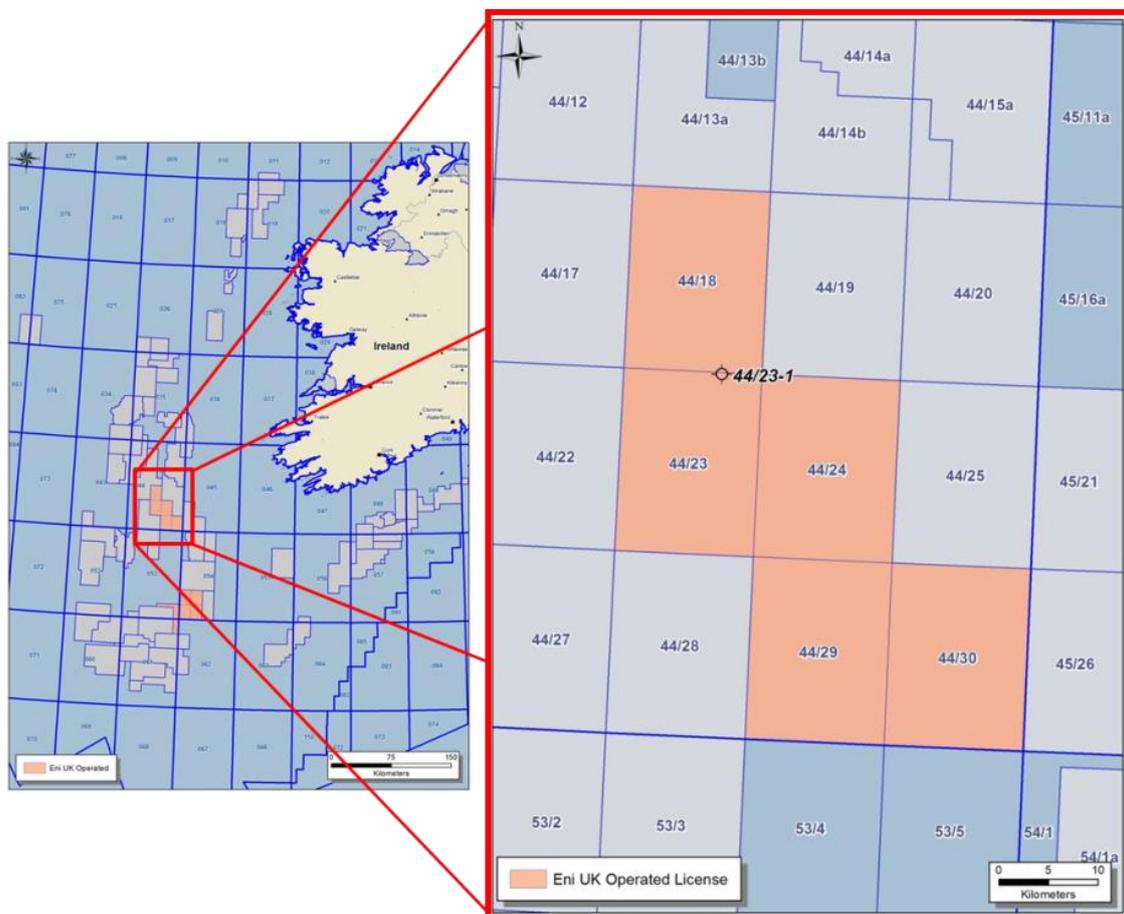


Figure 1. FEL 3/04 and Dunquin North well location

The Porcupine Median Ridge (Southern Porcupine Basin) is an intrabasinal high of discussed origin (volcanic, pre and/or syn-rift, or basement) extending across the Porcupine Basin into Frontier Exploration Licence 3/04 and hosting deposition of shallow water carbonates at the end of the syn-rift period. Regional seismic sections and relative interpretation display two separate build-ups above the Base-Cretaceous Unconformity, suggesting isolated carbonate banks (Figure 2).

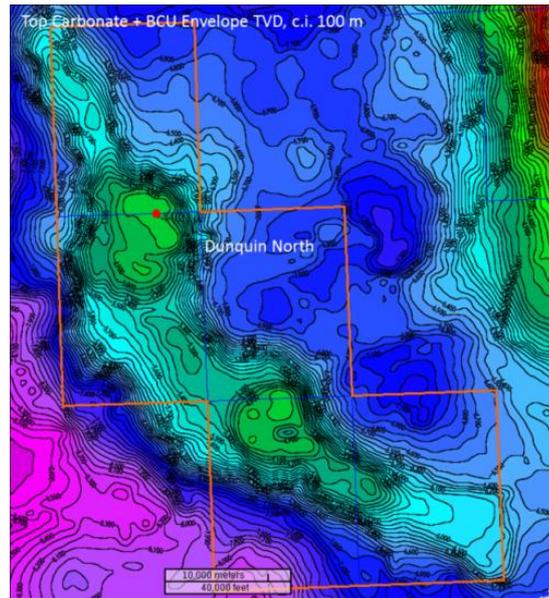


Figure 2. Depth grid (c.i. 100m) of BCU and Top Carbonate envelope showing the Dunquin build-ups on top of the Porcupine Median Ridge. Well 44/23-1 indicated by the red dot

The internal architecture of both build-ups display three seismic packages bounded by unconformity surfaces, however they differ in terms of reflections geometry and seismic morphology (Figure 3). The northern build-up is marked by significant back-stepping, suggesting a progressive shrinking of the shallow water carbonate factory up to the drowning unconformity at the top. This trend is supported by the deepening upward stacking pattern observed in the well. The southern build-up is marked by aggradation and infilling, suggesting a more persistent carbonate production and final subaerial exposure of the bank. Assuming the two banks developed in the same timeframe, the contrasting internal geometry may reflect variation of tectonic subsidence in different sectors of the Porcupine Median Ridge.

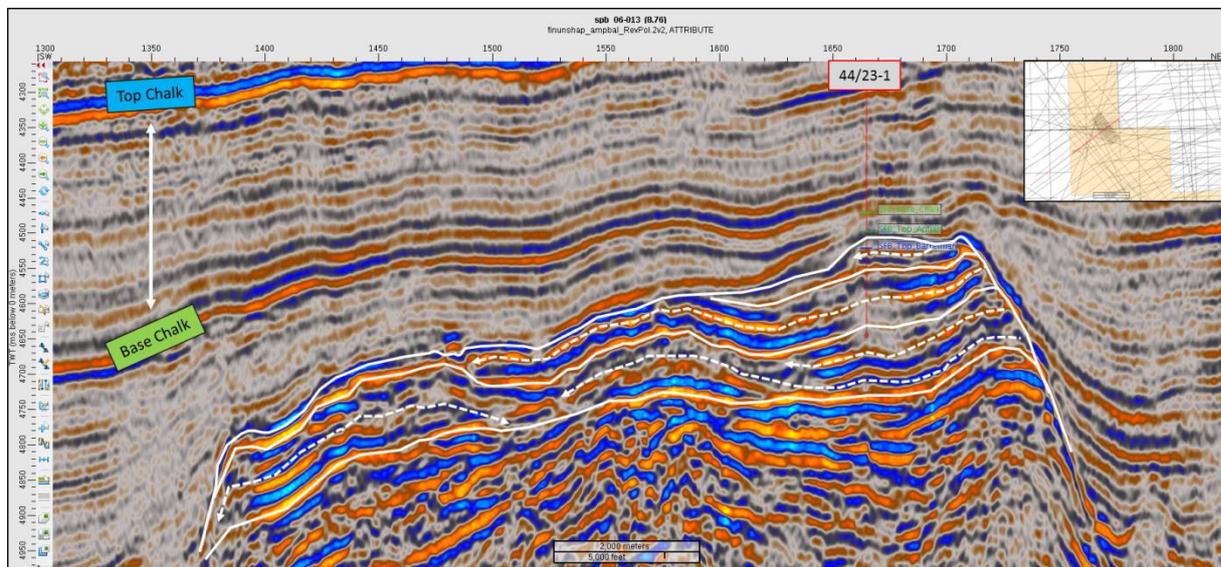


Figure 3. Seismic sections the Dunquin North carbonatic build-up and the proposed subdivision in three seismic facies packages

Combining quantitative textural analysis and observations on reflections geometry and continuity, six seismic morphological facies were defined and mapped within each seismic unit (Figure 4). Integration of well data and conceptual models from outcrop and subsurface analogues, allowed interpreting depositional settings within each unit.

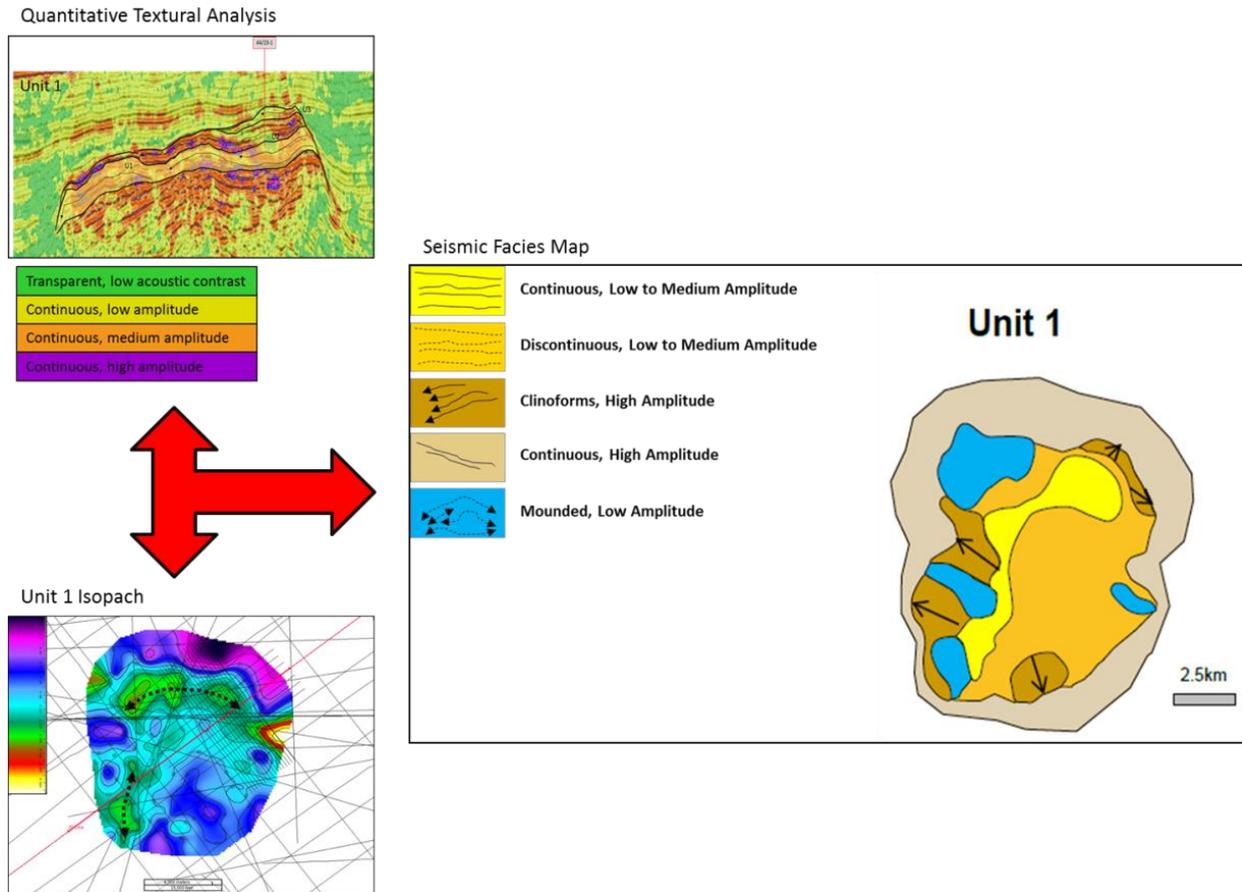


Figure 4. Example of integration of Quantitative attributes and interpretation data (Isopach) to derive seismic facies morphology maps.

High amplitude, variably continuous reflections are interpreted as inner platform deposits, likely alternations of grain- versus mud-rich Rudist and bioclastic carbonates. High amplitude clinoform reflections locally detectable at the bank margins are interpreted as slope to basin deposits.

Acknowledgements

We wish to thank Joint Venture partners (Providence Plc, Repsol Exploracion Irlanda and Sosina Exploration Ltd) for their continued support and input over the years. We would also like to thank the Petroleum Affairs Division, Irish Government Department of Communications, Climate Action & Environment and all the contributors in Eni E&P.

Analogues that help decrypting the Irish Dunquin carbonate play, Porcupine Basin

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Over the past few years there has been an upswing in the exploration momentum offshore Ireland which is currently at its highest ever level as reflected not only by the number of exploration authorisations, but also in the amount of seismic data acquired. However, when compared to nearby countries such as UK and Norway, those of which, almost 400 exploration and appraisal wells have been drilled since 2010, Ireland remains under-explored with just under 160 exploration and appraisal offshore wells since 1971, representing a very small number. The Porcupine Basin is a deepwater frontier rift basin located on the continental shelf (200 Km west of Ireland). Water depths range from 300-600 m in its northern part to 3500 m in the south, where it opens southwestwards onto the abyssal plain. The Irish platform is a broad, gently sloping shelf, restricted by the 500 m bathymetric contour. It is bounded to the north by the Slyne Ridge, to the east by the Irish mainland and by the Goban Spur basin to the south. The basin contains up to 9 km of Mesozoic and Tertiary sediments and is enclosed on three sides by shallow basement of Lower Palaeozoic age. Proved hydrocarbons are present in reservoirs of Middle and Late Jurassic, Early Cretaceous and Paleocene age.

The Dunquin play identified in FEL 3/04, consists of two isolated shallow marine carbonate platforms of mid-Aptian to Albian age: Dunquin North and South, with 4-way structural closures. Drilled in 2013, Dunquin North prospect found a total thickness of 250 meters of massive porous carbonate reservoir and confirmed 44 meters of residual oil column, interpreted as the result of seal breach. The presence of a paleo-oil column confirms an oil prone source rock present in the basin. The lack of a DST or production data from this type of reservoir in the basin is a matter of concern and has the obvious impact when performing economic studies and in strategic decision-making processes. The focus of this work is to narrow the gap of knowledge and build an analogue database for the Dunquin reservoir that allows a systematic evaluation of genetically related reservoirs providing guidance to identify common factors that control performance and recovery efficiency (reservoir main lithology, thickness, porosity, permeability, recovery factor and EUR/well).

Around 33 worldwide organic build-up reservoirs have been analysed on this study out of the more than 300 worldwide known carbonates. The filter has been based primarily on its dominant lithology, age and main depositional environment. In this case, Devonian, Mesozoic and Cenozoic platform-margin reef complex limestones are the chosen group of analogues, having the most accurate parameters comparable to Dunquin. The reservoir proportions for organic build-ups tend to be more homogeneous and have a smaller areal extent in comparison to other types of carbonates. Concerning average matrix porosity and average permeability distribution, the values may fluctuate due to the depositional, diagenetic processes and mechanical fractures. The average porosity range is between 9% (Judy Creek field) and 28% (Luconia F6 reservoir), with Dunquin reservoir porosity located inside a reasonable portion of this distribution. In the case of air average permeability, the series is between 10 mD (Bu Hasa reservoir) and 600 mD (Misrif reservoir). Having in mind that the reservoir performance and recovery factor are related to connectivity, permeability and mobility ratio, the recovery factor range is very wide, going from 10% (Siri reservoir) to 95% (Shurtan reservoir) with a worldwide mean of 56%.

Acknowledgements

The authors would like to thank colleagues from Repsol Specialist groups for their contribution. A special acknowledgement to our partners ENI Ireland, Providence and Sosina for giving permission to publish and present this paper.

Europa Oil & Gas – Progress and Prospects 2018

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Europa is one of the leading explorers offshore Atlantic Ireland, with a diverse portfolio of six Licences or Licensing Options over some 5000 km² (Figure 1). This presentation is an update on progress across our licences, with an emphasis on immediate farm-in opportunities and drilling plans.

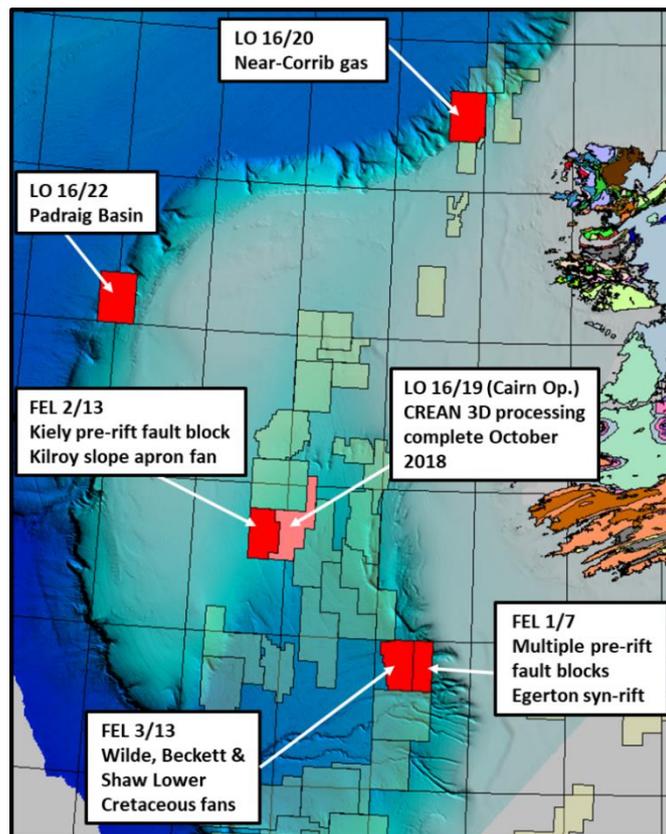


Figure 1. Europa Licences & Licensing Options, Offshore Atlantic Ireland

In the Corrib area, we have elected not to take LO 16/21 into an FEL and to focus our efforts on LO 16/20. In FEL 16/20 we have identified the Inishkea prospect, some 18 km northwest of Corrib. This holds a potential 2 tcf¹ of gas in several segments. Our burial history model suggests the possibilities of Corrib or better reservoir quality. Completion of PSDM reprocessing of the 2002 Enterprise 3D (extended to tie Corrib) is imminent and we are maintaining a stretch target of 2019 drilling.

In the Porcupine Basin, final processing of the 2017 CREAN multi-client survey, which includes both our FEL 2/13 and our LO 16/19 (Cairn operated) will be complete in October. FEL 2/13 is also covered by a new Europa-proprietary PSDM (completed April 2018). The front-runner prospects on FEL 2/13 are the large Jurassic tilted fault block “Kiely East” (280 boe¹) and the slope apron fan “Kilroy” (312 boe¹).

Our proprietary PSDM on FEL’s 3/13 and 1/17, on the eastern side of the South Porcupine, was completed in October 2017. In FEL 3/13 the primary targets remain the Wilde, Beckett and Shaw Lower Cretaceous fans. Better definition using isopachs and internal seismic architecture has enabled us to increase both the size and confidence of our resource estimates (Table 1). There is now evidence for faulted up-dip seal on Wilde and we regard this as the best initial drilling target on the licence, given its

¹ Mean unrisked recoverable resources.

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potential for stratigraphic isolation, its proximity to a Late Jurassic oil source, and its potential resource density. Drilling on Wilde will significantly de-risk Beckett and Shaw.

FEL 1/17 contains both large pre-rift tilted fault blocks and syn-rift prospectivity (Figure 2). The Edgeworth fault block (225 boe¹) is the largest and lowest-risk target. There is a compelling upside case for shallow marine Middle Jurassic reservoirs in these fault blocks which would offer well deliverabilities not previously seen in the paralic Jurassic reservoirs of the North Porcupine. We have also identified a syn-rift fault/subcrop structure in putative Tithonian sandstones, named Egerton. Drilling on Edgeworth will enable us to test a small (and probably gas-bearing) syn-rift target on the way to the main fault block.

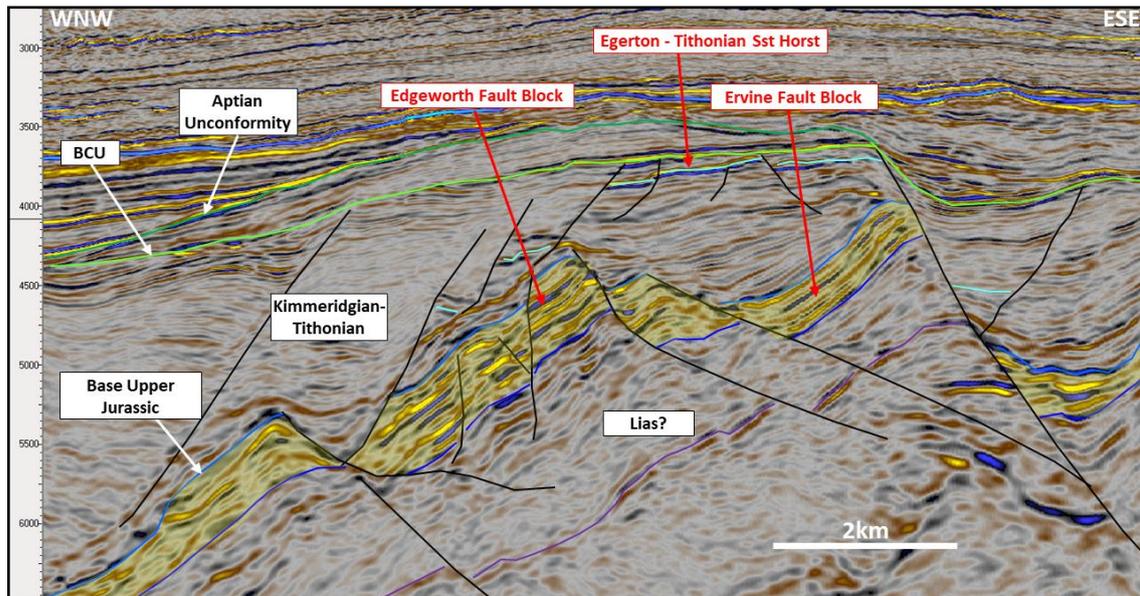


Figure 2. Line across FEL 1/17 showing pre- and syn-rift prospects (2017 Europa PSDM)

Licence	Prospect	Play	Gross Prospective Resources mmmboe*			
			Un-risked			
			Low	Best	High	Mean
LO 16/20	Inishkea	Triassic Gas				300
FEL 1/17	Ervine	Pre-rift	63	159	363	192
FEL 1/17	Edgeworth	Pre-rift	49	156	476	225
FEL 1/17	Egerton	Syn-rift	59	148	301	167
FEL 3/13	Beckett	mid-Cretaceous Fan	111	758	4229	1719
FEL 3/13	Shaw [†]	mid-Cretaceous Fan	20	196	1726	747
FEL 3/13	Wilde	Early Cretaceous Fan	45	241	1082	462
FEL 2/13	Kiely East [†]	Pre-rift	52	187	612	280
FEL 2/13	Kiely West [†]	Pre-rift	23	123	534	225
FEL 2/13	Kilroy [†]	Cret. Slope Apron	37	177	734	312
Total						4629

*million barrels of oil equivalent.

[†]prospect extends outside licence, volumes are on-licence

Table 1. Europa Key Prospects and Associated Resource Estimates (initial wells highlighted in yellow)

Our work on the Padraig Basin is ongoing, focusing on trial reprocessing of the existing 2D and the identification of key stratigraphic markers. The Wilde, Edgeworth and Kiely East prospects are our top ranked drilling candidates. Inishkea will join the list following interpretation of the new PSDM. We hope to survey all four drill sites in 2019 and be ready to drill by 2020, subject to suitable partnering arrangements.

Newfoundland and Labrador Update: Emerging Plays

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Nalcor Energy's exploration strategy, initiated in 2009, has greatly improved our understanding of the petroleum potential of the province's offshore basins. By the end of 2018, the TGS/PGS partnership will have acquired over 175,000 km of broadband 2D seismic data in our offshore as part of this strategy, as well as three large multi-client 3D datasets (combined size ~22,000 sq km). These multi-client seismic surveys provide modern, high quality datasets allowing new venture teams to analyse an area ahead of scheduled land sales (Figure 1).

In addition to the seismic data programs, Nalcor is working with global leading partners on strategic studies and projects to continue to evaluate Newfoundland and Labrador's frontier slope and deepwater basins for oil and gas potential. These studies are undertaken to address key risks and scientific uncertainties that may hold back new industry investment. They include seabed coring surveys with Furgro in the Orphan Basin and currently within the 2019 South-East Newfoundland Sector, an expansion of the Metocean study to the southern Grand Banks, fluid inclusion and MLA analysis of drill cuttings from selected wells, a drilling metrics report, biostratigraphy studies, regional geopressure report and a rock physics study by Ikon Science and a regional source rock study led by PIPCo. and conducted by Beicip-Franlab. A number of these studies have been commissioned and are available for free download on the Nalcor website.

The new data, studies and reports are demonstrating petroleum prospectivity in our under-explored basins that is much greater than was previously acknowledged. The independent resource assessments conducted by Beicip-Franlab for the 2015, 2016 and 2018 License Round areas predict the potential for material volumes of hydrocarbon accumulations. These resource assessments are also available on the Nalcor Energy website.

The data have also identified many new plays, and over 650 leads and prospects have been inventoried. One such prospect is the Cape Freels prospect, an Eocene-aged, turbidite fan complex in the 2016 land sale area². The depositional extent of the main fan complex covers approximately 550 sq km. This large feature was imaged in detail by the 2015 3D seismic survey, but it is not the only Eocene fan complex in the area. Separate fans have also been imaged by the regional 2D seismic data. Rock physics modelling of the AVO response on the 3D data has provided important insights into the potential fluid charge³. With a second high quality 3D dataset and 5x5 sq km 2D data, fan complexes, structural/stratigraphic leads of Cretaceous age and numerous Jurassic structural leads, all of which are demonstrating strong AVO responses, are imaged in the Southern Orphan Basin 2018 call-for-bids area⁴. Many of these leads are aligning with sea bed coring results showing the captured hydrocarbons in the core are thermogenic in origin. The Eastern Jeanne d'Arc area of the 2018 Call-for-Bids is also demonstrating Cretaceous and Jurassic potential⁵.

Nalcor Energy's exploration strategy continues to build our knowledge and understanding of the petroleum prospectively of the under-explored basins of the province. Our partnerships with key industry players like TGS, PGS and Beicip-Franlab are critically important to the successful implementation of this strategy. Additionally, partnership and collaboration with researchers at Memorial University of Newfoundland and universities and research institutes in Ireland have contributed to this success. Plans are in place to expand this R&D collaboration with universities in the future.

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The strategy will ensure sufficient data and information will be available to industry ahead of future scheduled land sales. This will allow the industry to make informed investment decisions potentially leading to major new discoveries in the future.

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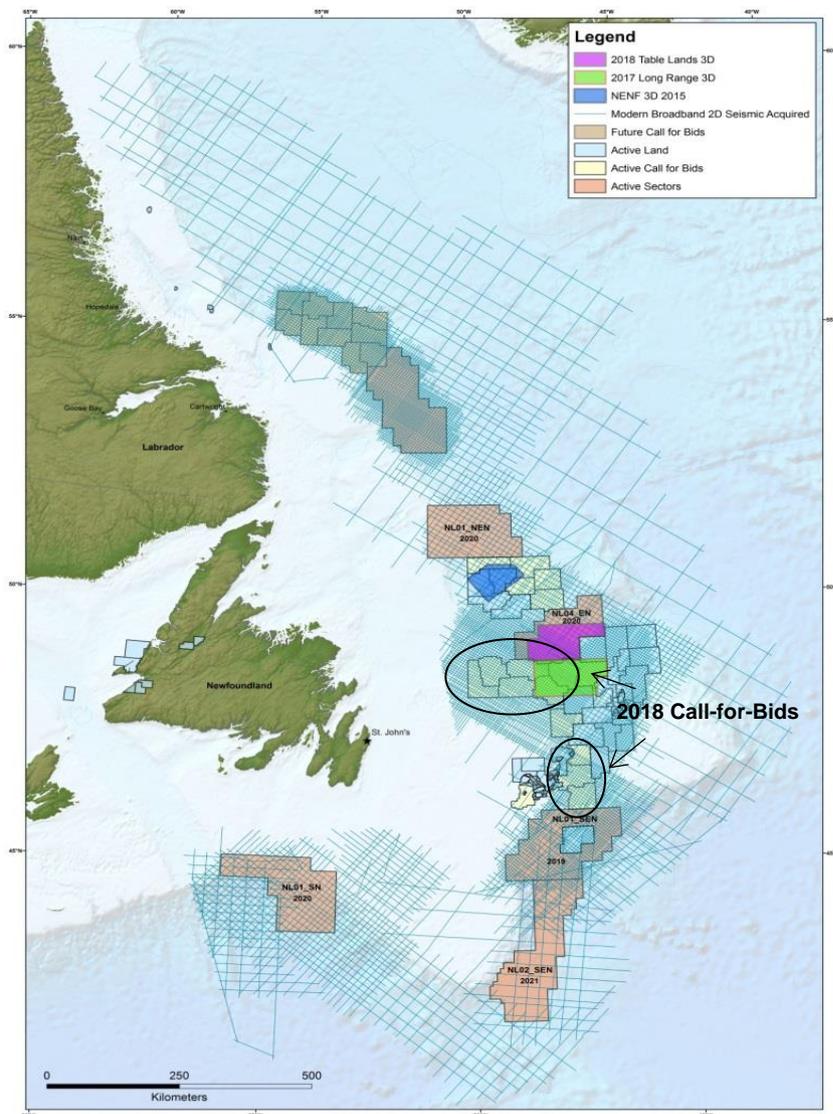


Figure 1. Map of Nalcor/TGS/PGS seismic data acquisition to 2018 and upcoming licensing rounds

Understanding the characteristics of hyperextended margins in Atlantic Ireland

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In recent years hyperextension, where stretching factors (beta) reach 3 or more, is increasingly recognised as a common extensional process on continental margins worldwide, including the Atlantic Ireland margin and its Newfoundland conjugate. For explorationists the complex history of hyperextended margins can be problematic. Extreme crustal stretching and thinning result in correspondingly high rates and amounts of subsidence, creating accommodation space into which sediments are deposited. This requires a re-evaluation of hyperextended margins in terms of the consequences for flexural uplift, basin architecture, basin connectivity and the associated play types. The creation of large amounts of accommodation space in hyperextended basins and the rate of subsidence strongly influences the development of these basins and their margins. As the lithosphere has an inherent strength and rigidity, load changes due to extension, thermal contraction, and sediment fill are not compensated locally, but are spread regionally. This effect is magnified significantly on hyperextended margins. The extent to which loads are spread is determined by the flexural properties of the lithosphere and can be modelled. Flexural uplift or flexural isostasy exert an important regional control on sequence thickness, fault geometry, and uplift and erosion in hyperextended basins.

Two key analytical tools for the re-evaluation of hyperextended margins will be discussed. The first is the restoration of conjugate hyperextended margins to their pre-rift configuration using a palinspastic deformable-margin plate model. Palinspastic deformable-margin plate models quantitatively restore the history of crustal deformation and multiple episodes of rifting and compression using geological and geophysical constraints. The second analytical tool is the 3D modelling of tectonic subsidence to determine the amount and extent of flexural uplift and subsequent erosion across the margin. The palinspastic deformable-margin model provides input into this 3D model, which includes the changing basin geometry, crustal thickness and beta through time.

By applying the combination of a palinspastic deformable-margin model and the 3D modelling of tectonic subsidence, we have evaluated significant hydrocarbon discoveries on the Newfoundland margin and SW Barents Shelf, and other recent discoveries associated with hyperextended basins. Our palinspastic deformable plate model extends from the Equatorial Atlantic to the Russian Arctic and includes exciting new areas such as the Guyana/Suriname-Mauritania/Senegal conjugate margins where significant discoveries have recently been made. This has provided insights into the characteristics of Atlantic deep water provinces in general that can be used to re-evaluate the Atlantic Ireland margin, including areas of interest such as the deep water Porcupine and Rockall basins. We show that many of these deep water hyperextended provinces share characteristic structural features associated with hyperextension such as deep water and starved basins on the distal margin, perched basins, uplifted basin margins and the development of submarine escarpments, highly rotated fault blocks, and localised shear zones. During extension the amount of stretching of the continental crust generally increases from the hinge line, which marks the transition from undeformed to deformed crust, to the distal parts of the margin where maximum stretching occurs. This causes a corresponding change in facies and palaeogeography across the margin, variations in subsidence and basin margin uplift, and has consequences for heat flow and hydrocarbon maturity.

Some of the characteristic features of hyperextended margins and adjacent structural highs are shown in Figure 1. These characteristics are often not yet fully recognised, but when the structural processes at hyperextended margins are better understood they could reveal potential new petroleum plays. Modelling the deformation, subsidence and uplift processes associated with this hyperextension should, therefore,

be considered an integral part of an integrated basin analysis approach for the assessment of petroleum systems.

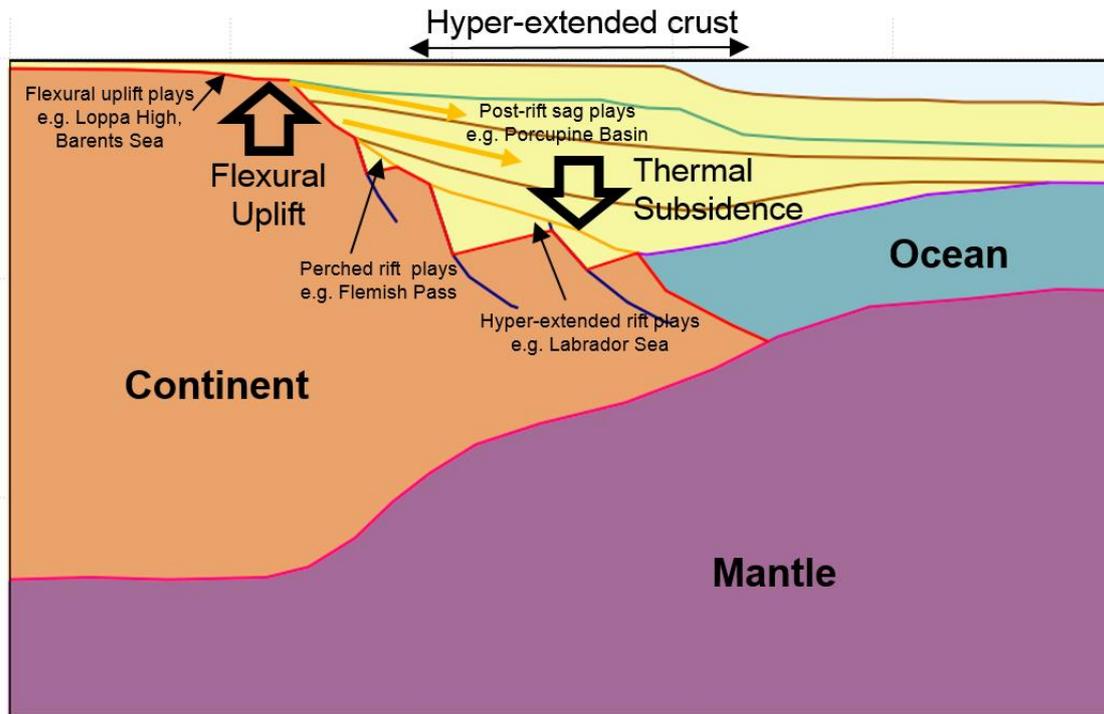


Figure 1. Schematic cross section of a hyperextended margin showing some examples of play types associated with this structural setting.

Sediment provenance into Mesozoic basins of the Northern Grand Banks, offshore Newfoundland, Canada

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The Northern Grand Banks, offshore Newfoundland, contains several large, underexplored Mesozoic age sedimentary basins. Constraining lithological properties and potential source to sink relationships for the basin fill is a key step to reducing exploration risk on plays in these basins, in particular for reservoir presence and reservoir quality elements.

We have conducted a lithology and sediment provenance study, based on all available cuttings samples (first returns to TD) from 22 wells from the West and East Orphan Basin, Flemish Pass Basin and Jeanne d'Arc Basin (Figure 1) creating 5000+ XRF datapoints, 700+ QEMSCAN datapoints and 500+ XRD data points.

Potential source areas to the basins considered in this study include (1) local sources of basement, exposed basin fill and volcanic rocks, (2) the eastern coast of Canada basement terranes and the conjugate margins of (3) western Iberia, (4) offshore Ireland and (5) southwest Greenland.

Time intervals investigated include Palaeozoic (basement and overlying sediments), Middle Jurassic, Late Jurassic (Kimmeridgian and Tithonian), Early Cretaceous (Berriasian-Hauterivian, Barremian and Aptian-Albian), Late Cretaceous (Cenomanian-Turonian and Coniacian-Maastrichtian) and Cenozoic (Paleocene-Eocene, Oligocene-Miocene and Pliocene-Quaternary) following the tectonostratigraphic subdivision of Gouiza *et al.*, 2017.

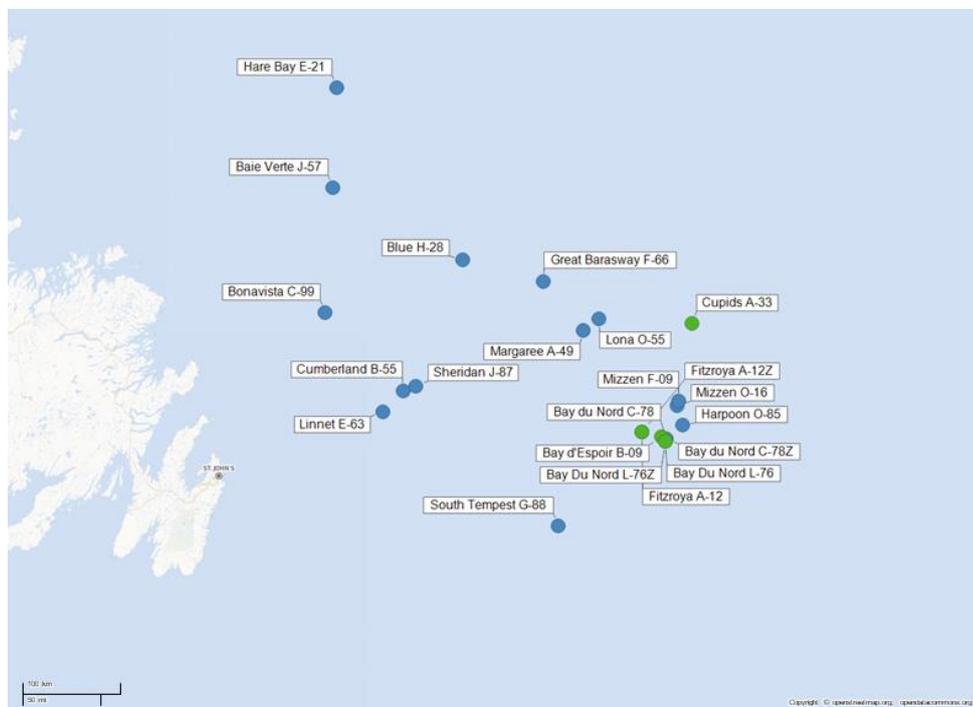


Figure 1. Wells included in this study. Phase 1 (16 wells, blue label) work has been completed and Phase 2 (6 newly released wells, green label) work is ongoing. The dataset includes all available cuttings samples from first returns to TD. Sampling was carried out courtesy of the C-NLOPB at their Core Storage and Research Centre, St. Johns, Newfoundland, Canada

This presentation will present key findings of this study. The study basins are rapidly forming during the time of investigation and surrounded by a range of different lithologically varied source areas, providing a rich lithological and sediment provenance dataset, with rapid switching of sediment source areas observed.

From the elemental XRF data, collected for all available cuttings samples, per sample lithotypes were determined highlighting pulses of immature and mature clastic sediment deposition and carbonate intervals within predominantly muddy sediments. For the subset of 700+ QEMSCAN samples, we determined for different lithotype in a cuttings sample detailed bulk mineralogy, grain size and where possible, porosity (Figure 2). XRD data were collected to support clay species determination.

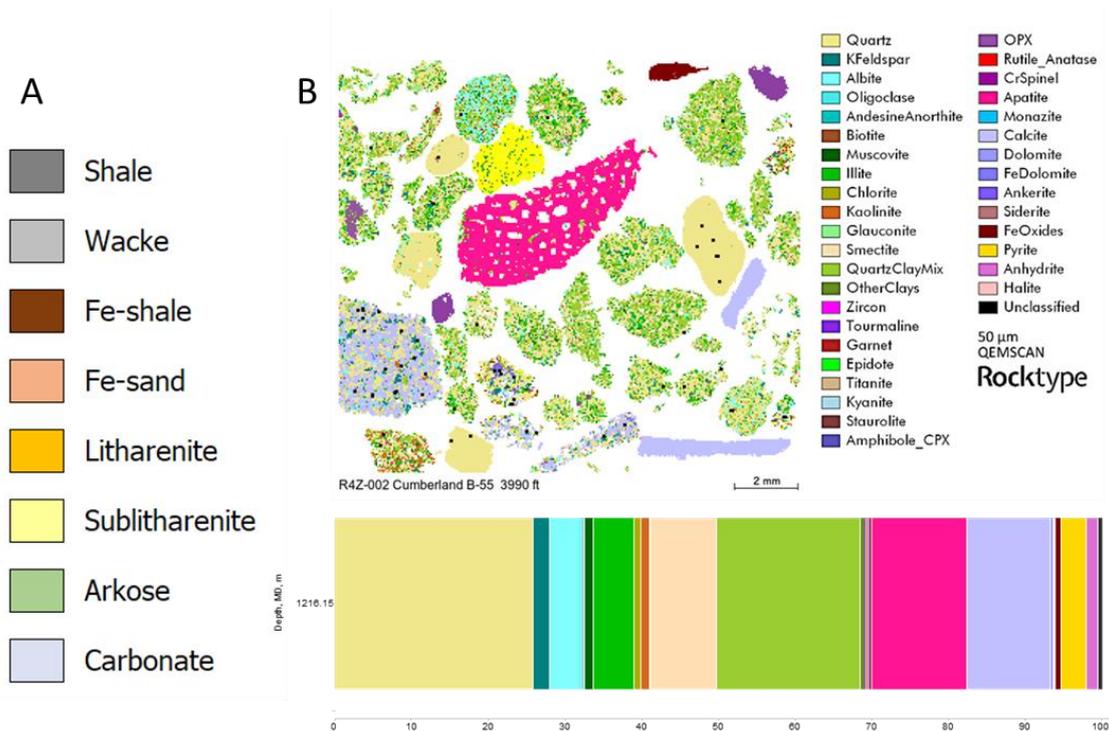


Figure 2. A) XRF lithotypes determined to subdivide sediments and track sediment pulses between wells. B) QEMSCAN image, simple mineral list and bulk mineralogy for one sample. Additional data include long mineral list (90+ mineral phases) and lithotyping of samples into sandstone, shale, carbonate and nodules (phosphate and pyrite)

Results of the combined XRF, QEMSCAN and XRD work show that there are clearly defined sources of granitic-metamorphic and volcanic sources into these basins and that the presence of these and their relative mixing provides information about the relative importance of different source areas throughout the formation of these basins during Mesozoic time. In particular, the arrival of volcanic sediments can be tied back to phases of volcanic activity offshore Ireland, in the Rockall and Porcupine areas (Haughton et al., 2005), providing further constraints on the joint tectonic evolution of these areas during prior to oceanic crust formation.

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New Geoscience Research Initiatives in Offshore Nova Scotia

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¹*Director, Petroleum Branch, Nova Scotia Department of Energy and Mines*

While Nova Scotia was maximising its royalty revenues associated with the Sable Offshore Energy project (2006/07), offshore exploration interest was diminishing and exploration licences were returning to the Crown. The prospect for renewing exploration in the short term was poor, mostly due to the general observation by explorers that the geology of offshore Nova Scotia was risky and not well understood.

In 2008, to address the degree of geological risk, the government of Nova Scotia funded a Play Fairway Analysis (PFA) of the offshore. In 2011 the Nova Scotia Offshore PFA was released. Industry responded with over \$2 billion dollars of exploration commitments, led separately by Shell, BP and Equinor.

Since 2011, the Nova Scotia Department of Energy has continued to fund, as well as, perform new geoscience research for offshore Nova Scotia. This includes refining areas of the PFA knowledge in the southwestern portion, the central Scotian Margin and undertaking a new PFA for the Sydney Basin (see Figure 1).

In addition to this new geoscience research, two large wide azimuth 3D seismic programs (Shell and BP) were carried out, and two modern day deep-water wells (Shell's Cheshire and Monterrey Jack wells) were drilled, with a third well (BP's Aspy well) currently being drilled. Shell announced that its Cheshire and Monterrey Jack wells did not discover commercial quantities of hydrocarbons. The confidentiality period for the Cheshire well ended in September 2018, the confidentiality period for the Monterrey Jack well expires in January of 2019 and the confidentiality period for the Shell 3D seismic data expires in March of 2019.

There is a wealth of new data currently being assessed by the Nova Scotia Department of Energy and Mines in collaboration with the Offshore Energy Research Association (OERA) of Nova Scotia. Earlier this year, the government of Nova Scotia committed just over \$11 million dollars for new petroleum research initiatives to be conducted over the next four years, which includes the analysis of new well and seismic data acquired since 2011.

The main purpose of the Atlantic Ireland 2018 "New Geoscience Research Initiatives in Offshore Nova Scotia" presentation will be to present an update of the results of the research work performed to date as well as to present new initiatives that are either underway or planned for the next four years.

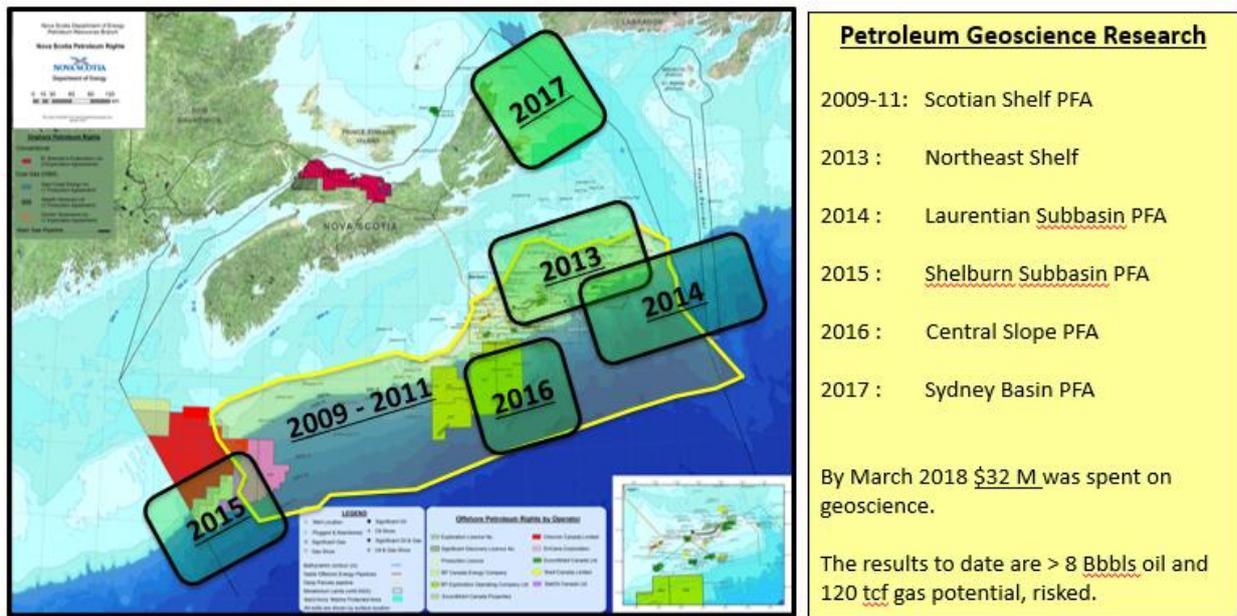


Figure 1. Areas of Geoscience Research since 2009 – Offshore Nova Scotia

Acknowledgements

I would like to acknowledge and thank the staff from the Nova Scotia Department of Energy and Mines, the Offshore Energy Research Association (OERA) of Nova Scotia and various experts within the Geological Survey of Canada, St. Mary's and Dalhousie Universities, the Canada-Nova Scotia Offshore Petroleum Board and the private sector for their collaborative technical efforts that have allowed us to achieve significant new learnings on the petroleum potential offshore Nova Scotia.

Shearing and Stretching the Porcupine Basin – A Tectonic Model Based on Integrated Geophysical Analysis

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The Porcupine Basin is located 150 kilometres offshore western Ireland. The basin bathymetry varies from less than 500 meters at its deepest in the north to nearly 3,000 meters along its southwestern fringe where a prominent bathymetric gap separates the Porcupine Bank from the Goban Spur. Along the basin's eastern and western flanks, the bathymetry deepens rapidly from the shallow waters of the Celtic Shelf and Porcupine Bank, respectively. The variation in bathymetry and the steep bathymetric gradients attest to the dramatic changes in crustal thickness that underpins this region. The basin was formed throughout the Early to Middle Mesozoic as the European and North American plates diverged. The crustal structure of the Porcupine Basin is interpreted through analysis of 2D reflection seismic, aeromagnetic and gravity data and published refraction lines. Collectively, the geophysical data confirm the results of previous studies which have suggested that the region experienced extreme rifting and thus the basin is floored with a combination of highly attenuated crust and exhumed mantle. The basin is defined by a series of north-south striking normal faults which have undergone various degrees of rotation. The rifting was guided by a series of pre-existing NE-SW striking, regional scale crustal sutures which outcrop onshore in Ireland and Scotland as well as on the conjugate margin of onshore Newfoundland. Our analysis proposes that these pre-existing orogenic sutures facilitated the basins formation by providing surfaces which sheared during an extended period of Mesozoic rifting and thus strongly influenced the present-day geometry of the basin. These ancient suture zones controlled the configuration of the southern limit of the basin as well as limiting the migration of rifting northward. The integrated analysis of all available data leads to a variation in the plate reconstruction of the Porcupine Basin relative to previous studies. The new reconstruction restores the crustal blocks of the Porcupine Bank to their early Jurassic pre-rift position against the Celtic Shelf by translating the blocks eastward. This eastward translation closes the Porcupine Basin with no significant rotation of the Porcupine Bank. The far southern regions of the basin are underlain by highly attenuated crust where it is postulated that Triassic rifting thinned the crust prior to Jurassic and early Cretaceous rifting.

From basis to Basins: Ireland's ObSERVE Programme

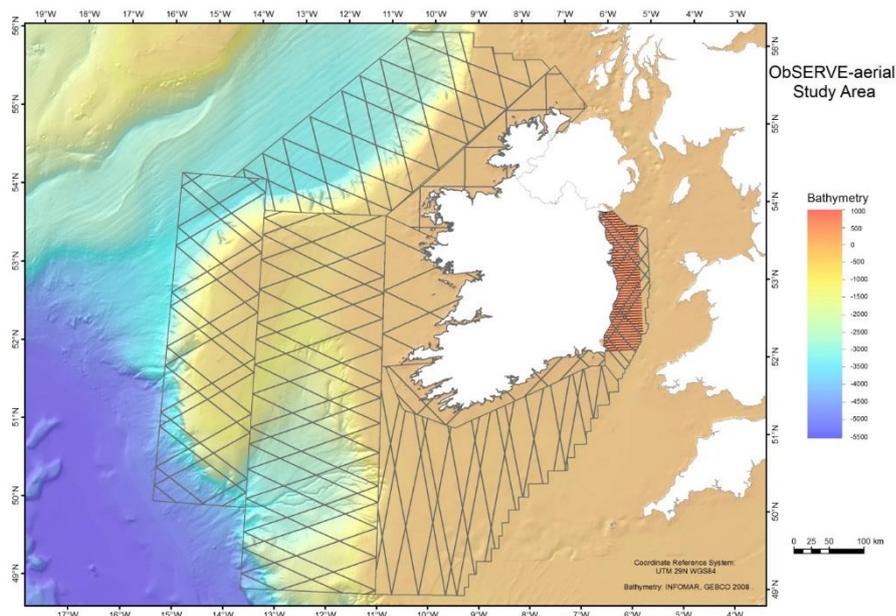
Ó Cadhla, O.¹, Marnell, F.¹, Tierney, D.¹, Kelly, E.¹, Casey, L.², Morgan, C.², O'Loughlin, O.², McManus, C.², Donovan, G.³

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When it comes to surveying, understanding and conserving diverse cetaceans in Europe, Ireland's Atlantic area is considered one of the most formidable and inhospitable environments there is. One consequence of this situation is that the knowledge-base used to inform management, regulation and conservation has previously tended to centre on more visible species and on late spring-summer months. However modern human activities such as petroleum exploration and development, which may place external pressures on such species, are not confined to narrow windows in either space or time. To address some of these challenges the Irish Government initiated its ObSERVE Programme in October 2014. This novel and strategic partnership between diverse Departments is focused around the management of sensitive habitats for cetaceans and other protected vertebrates. It has also set out to raise the bar in cooperation and coverage terms, in order to improve the quality and the interpretation of scientific data from Ireland's offshore. With total Government expenditure nearing €2.75 million to date, two ObSERVE projects that began in spring 2015 have just been completed. The initiative has demonstrated how effective national and international collaboration and partnerships can be forged to inform us on, and to tackle, some daunting scientific and management challenges. Together the *ObSERVE Aerial* and *ObSERVE Acoustic* projects, led by UCC and GMIT respectively, have resulted in almost all of Ireland's large EEZ being surveyed for a wide array of cetacean and seabird species and functional groupings (see Figures 1, 2a, 2b). Collective survey effort spanned two successive years of data acquisition and all seasons of the year with particular emphasis on summer and winter months. Among the many outcomes of the Programme so far are (i) the operational validation and implementation of new methods to effectively survey in Ireland's Atlantic Margin and the western Irish Sea, (ii) a vastly improved understanding of cetacean and seabird occurrence, abundance/density and seasonal variability in the study area, including for more cryptic species, and (iii) valuable and multi-faceted datasets which can be used for a wide range of future applications.



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Figure 1. ObSERVE Aerial project: Map of Ireland and surrounding marine waters showing combined aerial survey lines for coverage in summer and winter 2015-17 (grey zig-zag lines) and aerial survey lines targeting seabirds in the Irish Sea in summer/autumn/winter 2016 (red parallel lines)

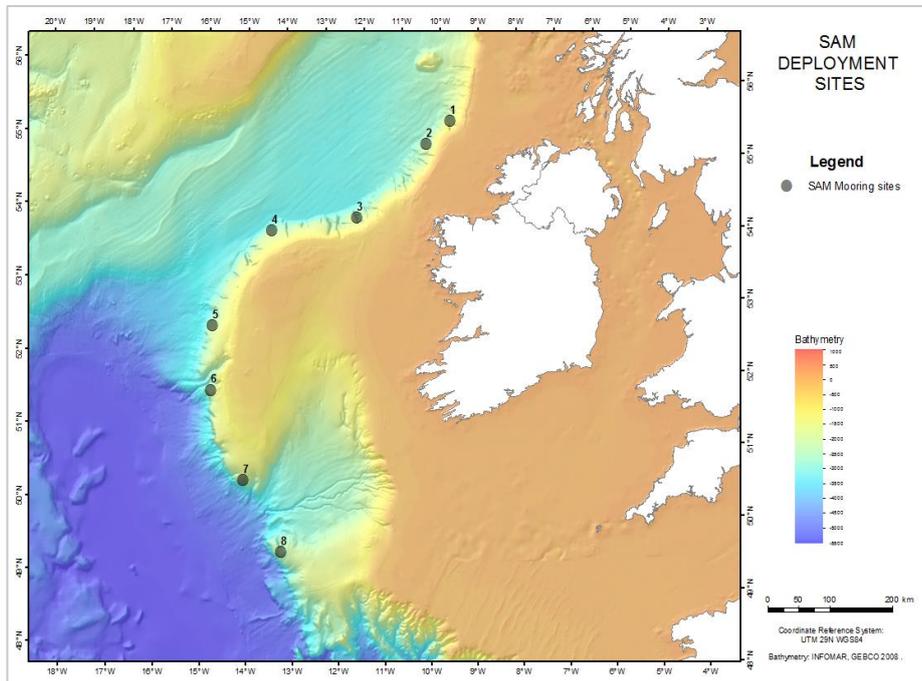


Figure 2a

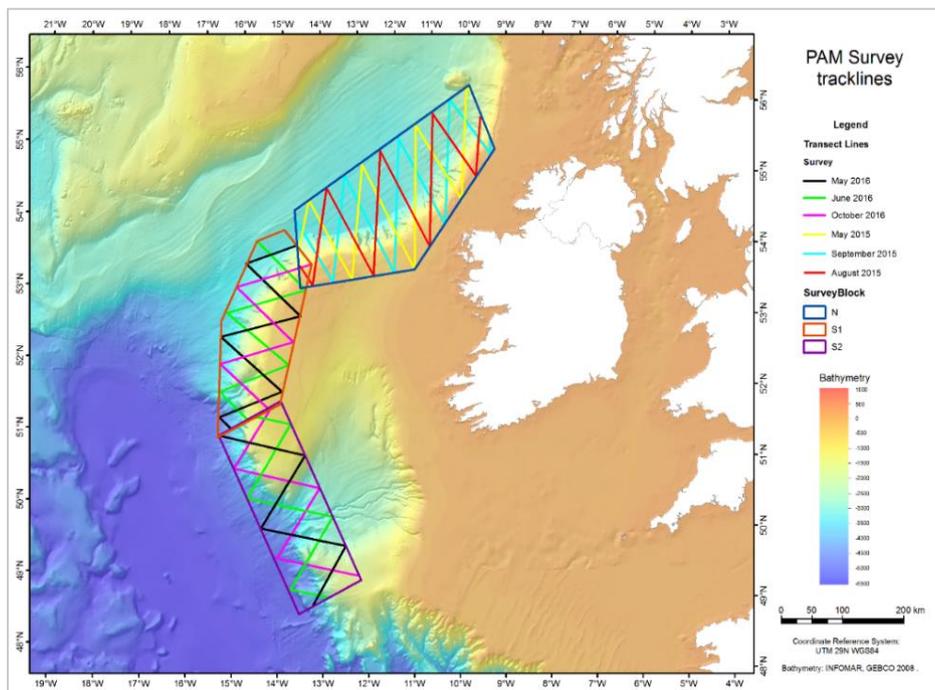


Figure 2b

Figures 2a, 2b. ObSERVE Acoustic project: Map of Ireland and surrounding marine waters showing (top) the positions of eight Static Acoustic Monitoring [SAM] systems for detecting and recording underwater sounds in spring/summer/autumn 2015-16, and (above) colour-coded survey lines for towed Passive Acoustic Monitoring [PAM] of cetaceans, which sampled the same seasons

Oiled Wildlife Response Network – Building Capacity to Protect Wildlife

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¹*Oil Wildlife Response Network (OWRN)*

<http://www.oiledwildliferesponse.ie/>

Established in 2015 and formally constituted as a company limited by guarantee (CLG) in 2017 the Oiled Wildlife Response Network's (OWRN) primary objective is to build 'capacity within Ireland to respond to the needs of wildlife in the event of a significant oil pollution incident using internationally **recognised protocols** and **training**, as **organisers and providers of training**, raising awareness and educating with members and the general public'.

The network is governed by a voluntary board of management and draws its membership from key organisations including: Birdwatch Ireland, the Irish Whale and Dolphin Group, the Irish Society for the Protection of Cruelty to Animals and the Dublin Society for the Protection of Cruelty to Animals.

Since its foundation, and with the support of the Irish Coast Guard, the OWRN has trained 172 volunteers in Dublin, Wexford, Cork, Kerry, Limerick, Galway and Donegal in tier 1 first responder training. In providing training the OWRN draws upon the Preparedness for Oil-polluted Shoreline Cleanup and Oiled Wildlife Interventions (POSOW) protocols developed under the European Union Civil Protection Financial instrument in co-operation with Sea Alarm and a number of other groups. POSOW provides training material in many areas of oil spill response and it is through Sea Alarm that the OWRN has accessed this training and continue to use it for our First Responders.



Pictured: First Responder Training, Howth 2017

The OWRN has also benefited from the international system of mutual assistance that exists between EU states and the Commission. Developed during 2015-2016 EUROWA has supported the establishment of a team of wildlife response experts and a stockpile of critical equipment both of which can be rapidly mobilised by governments in the event of a spill.

In maintaining a state of preparedness, the OWRN also takes part in annual oil spill response exercises, which have previously been held in Galway, Clare, Limerick and Kerry.

In October of this year the OWRN will hold its first Advanced Responder training programme which will take place over four days. This course is positioned immediately above the First Responder level and will support the development of a pool of personnel who can provide advanced care to oiled wildlife following standard protocols and independent from supervision.

This presentation will give a brief overview of the work of the Oiled Wildlife Response Network and its approach to building capacity to respond to the needs of oiled wildlife.

Acknowledgements

We wish to thank the Irish Coast Guard, Sea-PT and Sea Alarm for their continued support and guidance.

Collaborative exploration of Irish offshore reef habitat, contributing to sustainable development of our marine resources.

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Offshore reef habitats are critically important marine ecosystems, supporting significant marine biodiversity. Although Reef is listed as an Annex I habitat under the EC Habitats Directive (92/43/EEC), relatively few sites have been studied for their biological communities. A significant body of bathymetry and geophysical data exists from Irish National Seabed Survey, INFOMAR, and oil and gas exploration activities. Benthic surveys of reef were limited spatially however and principally targeted cold-water coral, or specific carbonate mounds or submarine canyons. The resulting lack of broad scale information on



reef extent and biodiversity impedes the management of the important associated biological resource, as well as the potential pressures these ecosystems are exposed to. Proactively addressing this, a three-year initiative was developed, incorporating lessons learned from a preliminary geogenic reef survey undertaken in 2009 by NPWS and INFOMAR. The ongoing SeaRover* deep-sea explorative programme of research and fieldwork was established in 2017 and is predominantly funded by the European Maritime & Fisheries Fund, and supported by Marine Institute, NPWS, Geological Survey Ireland, NUIG, and University of Plymouth.

Figure 1. Location of SeaRover survey sites along Irelands continental margin. The blue stars represent 102 transects from 2017 and 2018.

Integration and analysis of our extensive national data resources enabled survey locations to be designed to have a high likelihood of geogenic features, and areas with lower returns for fishing effort were prioritised for investigation. During 2017 and 2018, the INFOMAR coordinated SeaRover programme undertook comprehensive and widespread studies of seabed features (e.g. canyons, escarpments and mounds) and associated benthic and pelagic communities, deploying a remotely operated vehicle (ROV) Holland 1, and a multidisciplinary team of scientific experts onboard CIL's vessel ILV Granuaile. The Holland 1 employs high-definition cameras, various composite video feeds, and a robotic arm which facilitated sample collection in support of NUIG SFI funded studies into novel natural products associated with deep sea sponges and corals. SeaRover's primary scientific objective is to map

* SeaRover – Sensitive Ecosystem Assessment and ROV Exploration of Reef

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the distribution and abundance of geogenic and biogenic reef habitat, through a collaborative, capacity building process.



Figure 2. Example biological observations during SeaRover. (L-R) *Bolocera tuediae* (deeplet anemone); *Pseudoanthomastus sp* (soft coral); Two colour morphs of *Lophelia pertusa*

The extensive data acquired due to the success of the programme to date, has vastly improved our understanding of these sensitive marine ecosystems and their underlying geomorphology. Data accessibility and utility will be a key output of the initiative, and it is vital for future sustainable multi-sectoral development, for research prioritisation, and in particular to underpin government obligations and reporting commitments under CFP¹, MSFD², MSP³, the Habitats Directive, and OSPAR⁴. In addition, species imagery will contribute to the development of a North Atlantic standard image reference guide to benthic organisms.



¹ Common Fisheries Policy

² Marine Strategy Framework Directive

³ Marine Spatial Planning

⁴ OSPAR - Convention for the Protection of the Marine Environment of the North-East Atlantic

Acoustic Impact of Seismic Surveys

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Seismic surveys are carried out using air gun arrays as high energy acoustic sources. In order to protect marine mammals from the impact of underwater noise the Department of Arts, Heritage and the Gaeltacht has published *Guidance to Manage the Risk to Marine Mammals from Man-made Sound Sources in Irish Waters (NPWS 2014)*. The protection of marine mammals is required under the Habitats Directive and Birds Directive which are transposed into Irish law by the European Communities (Birds and Natural Habitats) Regulations 2011 (S.I. No. 477 of 2011) (as amended). Under Article 12 of the Habitats Directive, Annex IV species are afforded strict protection throughout their range, both inside and outside of designated protected areas. The protected species include cetaceans (whales and dolphins), pinnipeds (seals) and marine reptiles (turtles), all far ranging marine mammal species with the potential for interaction with seismic exploration activities. Therefore, it is necessary to be able to predict the levels of man-made noise from seismic surveys and model the likely noise emissions in order to determine likely significant effects.

The acoustic impact is a complex field involving marine mammal physiology, animal behaviour and the underwater acoustics of air gun arrays. Underwater acoustics is further complicated by lack of standardisation in terminology. Due to the use of simplified propagation loss formulae, the underwater noise level from a seismic array is often calculated incorrectly. Close to the source underwater noise levels may be significantly overestimated which, due to the exposure level, is the area of most concern for marine mammals. At greater distances simplified models do not account for variations in the water column or seabed characteristics and also overestimate noise levels.

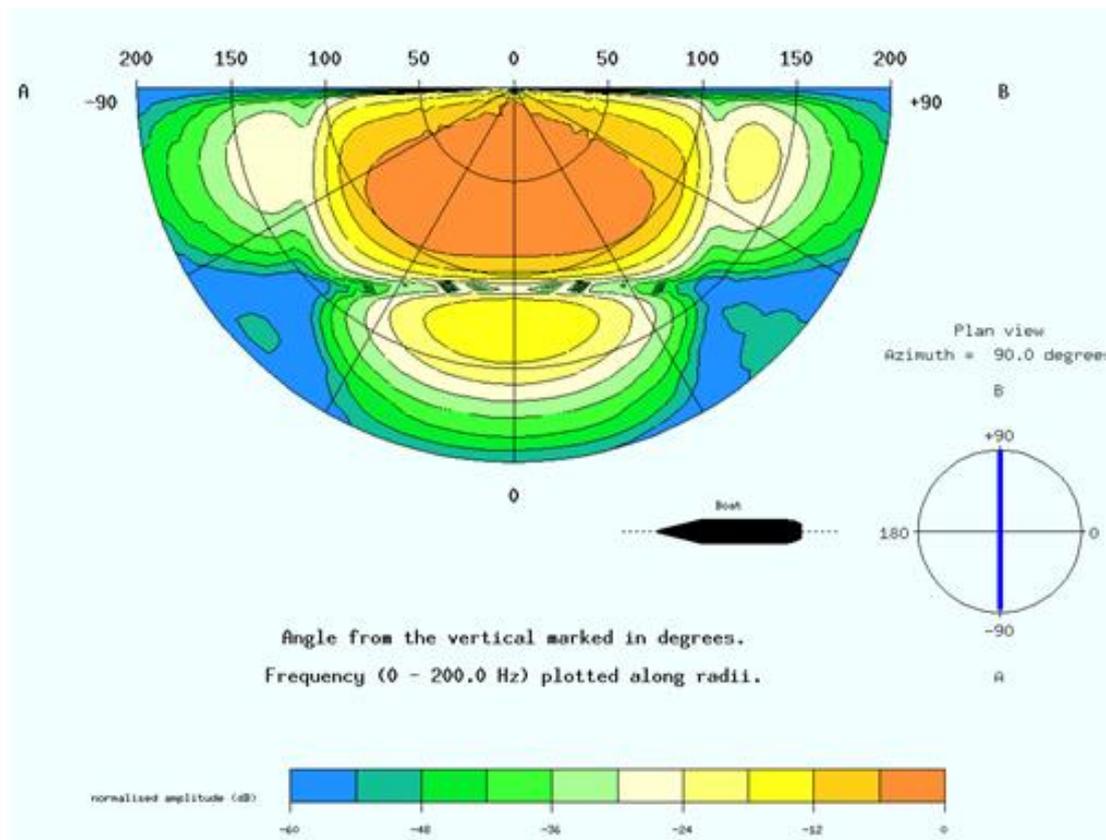


Figure 1. Source Directivity Plot – azimuth 90 degrees

The near field underwater noise level from an air gun array is directional, subject to significant variation over short distances. The 'source level' of the air gun array is a theoretical representation of the array, which typically extends some 8 x 16 m and comprises 20 to 30 individual guns acting in a programmed sequence. In practice the array does not behave as an idealised point source and the maximum sound pressure produced by an array is an order of magnitude lower than the idealised point source model.

Recent studies carried out by NUI Galway and RPS under the PIP programme have demonstrated that significant differences arise between measured levels and simplified model calculations. Work is continuing in the development of more accurate models taking into account the complex bathymetry and oceanographic conditions in Irish waters.

This presentation will provide an overview of two measurement campaigns and review published data on noise levels close to a seismic array. Reference will be made to the critical thresholds set out in the NPWS Guidelines and the spatial extent these may be found near a typical array.

Monitoring acoustic emissions from air gun arrays in Irish Waters can provide valuable data to assist the development of more accurate underwater noise emission models. Improved modelling can then be used to assist public authorities in determining what, if any, significant environmental effects are likely to arise.

Acknowledgements

We wish to thank our clients for their continued support over the years. We would also like to thank the Earth and Ocean Science Department at NUI, Galway for their assistance in preparing the presentation.

Stands

AGR	Maynooth University/U-flyte
Badley Geoscience Ltd.	Merlin Energy
Cairn Energy	Newfoundland and Labrador
CGG	CNOOC Nexen
CRIS	ObSERVE
Donegal County Council	PGS
DownUnder GeoSolutions	Providence Resources
DCCAE/PAD	PwC
EAGE	RockWash
Eqinor-UCD Clare Core Display	RPS
Europa Oil and Gas	Schlumberger
Getech	Searcher Seismic
GSI	Serica Energy
IHS Markit	Tenaris
iCRAG	TGS
INFOMAR	Wood Plc
Irish Lights	Woodside
Marine Institute	ZebraData

Poster Abstracts *(in alphabetical order)*

Apatite fission track analysis by laser-ablation: A novel fast grain mapping approach using the map interrogation tool 'Monocle'

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One of the main drawbacks of the apatite fission track (AFT) method is that not every sample yields sufficient high-quality, unzoned apatite grains with high spontaneous fission track densities. Counting zoned or damaged grains is thus sometimes unavoidable, while grains with low-track densities (low-U and/or very young apatites) cannot be excluded as this may bias the resultant fission track age. Current approaches to AFT dating by LA-ICPMS typically employ a spot ablation approach [1]. This method works extremely well when the U distribution is homogenous, and this rapid approach can also produce multi-element data (e.g. REE, Cl, other trace elements) which yields extra information on annealing kinetics or apatite provenance. However, in cases of U zoning or low-U grains where there are too few spontaneous fission tracks to detect zoning, it can be difficult to know where to place a representative LA-ICPMS spot. In contrast, a major strength of the external detector method (EDM) is that data are collected from identical areas on apatite grains and their mirror images in the muscovite detector, and therefore within-grain U heterogeneity is accommodated by this technique.

An alternative to spot analysis is to produce apatite U-distribution maps by LA-ICPMS which can then be spatially linked to the fission-track density. In this study, fission tracks were counted on apatite standards (Durango, Fish Canyon Tuff) and unknowns with (i) complex U zonation; (ii) cracks; or (iii) a low U-content; all previously dated by EDM. Uranium maps were then acquired using a Photon Machines Analyte Excite laser with an aerosol transfer device (ARIS; [2]) coupled to an Agilent 7900 ICPMS. Elemental maps were made using Iolite [3] and interrogated using the Monocle tool [4] for sub-domains of variable size within the zone of counted tracks. This mapping approach could represent a new benchmark for the AFT method by LA-ICPMS.

[1] Chew and Donelick 2012, Min. Assoc. of Canada Short Course 42, 219-247. [2] van Malderen et al., 2015, J. Anal. At. Spectrom., vol. 30 (1), 119 – 125 [3] Paton et al., 2011, J. Anal. At. Spectrom., vol. 26, 2058 –2518 [4] Petrus et al., 2017, Chem. Geol., vol. 463, 76 – 93

Integrating gravity and surface elevation with magnetic data: mapping the Curie temperature beneath the British Isles and surrounding areas

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We study the lithospheric structure of the British Isles using a methodology that allows for forward modelling of the Curie temperature depth based on seismic, elevation and gravity observations within an integrated geophysical-petrological approach (LitMod3D). We compute 3D thermal models and self-consistently determine the density in the mantle based on temperature, pressure and bulk composition. Finally, we derive Curie temperature depth maps and forward calculate magnetic anomalies at the airborne level using a spherical magnetic modelling software (magnetic tesseroids) to estimate the geothermal magnetic signal. Our results show lateral lithospheric variations across the model domain, with Great Britain being characterised in general by thicker and colder lithosphere, especially in the

south-east, and the thinnest and warmest lithosphere being located beneath west Scotland, Northern Ireland and in the north-west oceanic area. Our estimated Curie temperature depth map resembles the values obtained using other techniques (spectral method and surface heat flow inversion) in some areas, but discrepancies are notable in general. We determine that the effect of typical lateral temperature variations (i.e., Curie isotherm depth) accounts for 5-15%, on average, and up to 70% locally of the crustal magnetic signal at the airborne level (5 km altitude). Our lithospheric models are in general agreement with published tomography models as well as other geophysical studies.

This project is funded by the Science Foundation Ireland grant iTHERC to J. Fulla (16/ERC/4303).

Sedimentary architecture and Cenozoic magmatic evolution of the Hatton Basin, offshore Ireland, from seismic and potential field data

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The Hatton Basin is located next to the continent-ocean boundary in the Irish offshore. It is bounded by the Rockall Bank to the east and by the Hatton High to the west. Little is known about its structure and evolution within the context of the North Atlantic opening.

The interpretation of the 2D seismic reflection- and DSDP data suggest the presence of four sedimentary megasequences bounded by regional unconformities, ranging from possibly Early Cretaceous to recent in age. In addition, a probably Middle-Late Eocene angular unconformity is present in the basin, which corresponds to a basin-wide post-rift volcanic phase. Some of the paleo-volcanoes formed during this period were active until the Late Eocene. Moreover, evidence for younger (latest Eocene-Early Oligocene) magmatic activity was also observed on the seismic data.

Both magnetic and gravity data show NE-SW trending lineaments of positive anomalies, extending from the centre of the basin towards the southern end. The location of the mapped paleo-volcanoes in the basin are coincident to these anomalies. The connection between the volcanoes and the magnetic and gravity anomalies potentially reflect areas with stronger magmatic influence. The absence of these anomalies in the northern part of the basin implies that magmatic activity during basin evolution might have been stronger and more pronounced in the southern part of the area (resulting in a late post-rift volcanic period) and was weaker towards the north due to pre-existing zones of weakness in the crust.

This publication has emanated from research supported in part by a research grant from Science Foundation Ireland (SFI) under Grant Number 13/RC/2092 and co-funded under the European Regional Development Fund and by PIPCO RSG and its member companies.

Late Jurassic-Early Cretaceous Source Switching to the Scotian Basin, offshore Nova Scotia: A multi-proxy provenance study

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³*Natural Resources Canada, Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia, B2Y 4A2, Canada.*

During the Late Jurassic-Early Cretaceous, the Scotian Basin, offshore Nova Scotia, accumulated several kilometres of deltaic sandstones which today act as important oil and gas reservoirs. These sandstones were deposited in response to, and thus cryptically record, the evolution of the North Atlantic rift and associated palaeodrainage changes along the Canadian passive margin. Yet despite these major tectonic transitions, several lines of evidence including heavy minerals and U-Pb zircon geochronology suggest that the bulk of the sediment delivered to the offshore was consistently derived from the Appalachian orogen. However, uncertainty remains as to the volume of recycled grains in offshore wells. The potential for recycled material in the Scotian Basin is high, owing to the fact that the hinterland source terranes strike parallel to the basin margin. In order to decipher first cycle from polycyclic supply this study fingerprints Pb isotopes in detrital K-feldspars from over ten wells across the basin. K-feldspars are unlikely to survive multiple sedimentary cycles and thus can be used to track first cycle supply. Pb isotopic compositions reveal a striking change in sand supply which can be linked to the evolving Labrador Rift, but which is not observed in detrital zircon datasets. Detrital K-feldspars record a sharp shift across the Jurassic-Cretaceous boundary throughout the entire basin from proximal Appalachian to distal Grenville signatures. The results therefore suggest significant recycling of zircons in the lower drainage basin with only a small number of first cycle zircons being delivered from Meso-Palaeoproterozoic and Archaean rocks north of the Appalachians. The study showcases the utility of Pb isotopic fingerprinting of detrital feldspar and demonstrates the importance of coupling individual tracers of varying resilience to unravel sedimentary provenance.

This research is supported in part by a research grant from Science Foundation Ireland (SFI) under Grant Number 13/RC/2092 and is co-funded under the European Regional Development Fund, by PIPCO RSG and its member companies, and by the Nova Scotia Offshore Energy Research Association (OERA).

A new standard lithostratigraphic framework for offshore Ireland; regional chronostratigraphic summary chart

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⁴*Riley Geoscience Ltd*

The poster will display, in a chronostratigraphic layout, the new standard lithostratigraphic scheme for offshore Ireland, with individual columns for each offshore basin. This will be presented in a conference talk "A New Standard Lithostratigraphic Framework for Offshore Ireland", but the details will be on display

in the poster. The poster also displays the main seismic horizons and sequences that are recognisable across the region.

The Irish offshore area encompasses a diverse set of geological basins, both on the Atlantic margin and in the Fastnet, Celtic and Irish Sea regions, representing a wide range of geological and structural complexity. The efficient exploration of the region requires a standard stratigraphic understanding and consistently defined schemes (biostratigraphy, lithostratigraphy, sequence stratigraphy) that all operators, contractors, academia and regulators can use. This will provide a common language of communication and also a fundamental chronostratigraphic framework to underpin all subsurface geoscience evaluations. Despite its long history of hydrocarbon exploration (the first offshore Ireland well, 48/25-1, having been drilled in 1970), such a unified framework has not previously been defined for offshore Ireland, which has hampered understanding and geological correlation from area to area.

A new lithostratigraphic nomenclature has been established as part of PIP project IS16/04 and approved by the PAD for use as a standard across the Ireland offshore area. This scheme has been facilitated and guided by a newly established Stratigraphic Committee, and project Steering Committee in association with the Petroleum Affairs Division (Department of Communications, Climate Action and Environment).

The newly defined lithostratigraphic scheme combines new names with a selection of existing names. Existing names are extended into offshore Ireland for those rock units that are contiguous with nearby jurisdictions, particularly the offshore UK regions, onshore Ireland (Republic of Ireland and Northern Ireland) and onshore UK (England, Wales and Scotland). This means that some familiar terms are retained (for instance, Wealden Group and Gault Formation in the Celtic Sea area). Nevertheless, there are many instances where new names are required. A total of around 250 lithostratigraphic units are defined for offshore Ireland, of which around 200 are newly named.

The following themes have been used for the naming of new rock units for specific stratigraphic intervals in the Ireland offshore area; Irish artefacts, jewellery, bays, fish, peninsulas, headlands and points, lakes, birds, plants, seashells, colours, folklore and archaeological features.

The summary chart in this poster is also shown on the PAD exhibition booth and on the Merlin Energy Resources stand. A copy of the chart will be available at the conference.

Acknowledgements

This project is funded by the Petroleum Infrastructure Programme (PIP). We wish to thank PAD and PIP for approval to present this poster.

Understanding stratigraphic traps using modern turbidite systems

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Upslope stratigraphic traps, comprising deepwater sand bodies with updip terminations (pinchouts or erosional truncations) at their proximal end are a prime hydrocarbon exploration target in many deepwater basins including offshore Porcupine Basin. Examples of past discoveries inferred to have this type of trapping configuration include the Buzzard Field UK Central North Sea (~500 MMBO) and Marlim Field Brazil Campos Basin (~3000 MMBO). Whilst there is significant potential for further giant commercial discoveries, exploration is high risk principally due to the difficulty of predicting the presence of an effective sand pinchout: the resolution of conventional seismic means that thin sands, through which hydrocarbons can leak updip, are difficult if not impossible to detect. A wealth of high resolution

data from modern seafloor turbidite systems now exist and these can be used to better understand the locations of sand terminations and infer the processes responsible for their formation. Here we present examples of attached and detached turbidite systems from modern systems and models for stratigraphic pinchout development. Future work will compile further examples in order to test if certain system or local factors (e.g., grain-size, slope gradient, morphology etc.) are positively associated with upslope sand terminations: and thus, if these may be employed to help de-risk the presence of stratigraphic closures in analogous subsurface systems.

This project is funded by the Irish Centre for Research in Applied Geoscience (iCRAG).

Assessing the vulnerability of seabirds to oil pollution in Irish waters

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Seabird vulnerability to oil pollution has been highlighted during a number of high profile disasters such as Kowloon Bridge off west Cork and Deepwater Horizon in the Gulf of Mexico, where significant seabird mortality due to oiling has occurred. Understanding the risk posed by oil infrastructure is crucial for effective mitigation and management of risks. Vulnerability indices have previously been used to assess risk to seabirds from offshore energy infrastructure, most recently for wave and tidal turbine developments. However, available indices for oil pollution are out of date, and do not take into account more recent population estimates or changes to conservation status.

We develop a new Oil Vulnerability Index (OVI) that updates information on population size and conservation status as well as accounting for the potential attraction/avoidance of seabirds to offshore infrastructure. The new index shows that most Procellariidae species, such as the northern fulmar and European storm-petrel, are now considered more vulnerable to the risk of oiling, while previously high vulnerability species such as divers and skuas are considered lower risk. Conversely, seabirds which actively avoid oil infrastructure and service vessels may be impacted by subsequent displacement from habitats of importance. We found that divers and auks are particularly susceptible to displacement due to offshore activities. When applied to modelled distributions of seabirds in Ireland and the UK, the new index highlights areas of greatest risk for the most vulnerable species.

This project is funded by the Petroleum Infrastructure Programme (PIP).

Investigating acoustic noise propagation across various continental margin settings

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²*Irish Centre for Research in Applied Geosciences iCRAG*

Anthropogenic noise in the ocean, as classed by the Marine Strategy Framework Directive, is a pollutant and thus Ireland holds the responsibility of quantifying and monitoring this noise in Irish waters. Offshore

seismic exploration of hydrocarbons involves generating pulsed airgun signals targeted vertically at the seafloor below. A side effect of airgun use is horizontally propagating noise in the water column that attenuates with distance from source. Noise levels proximal to source may be harmful to marine life, while distal levels can vary from appreciable to negligible, depending on multiple parameters including distance, topography, sea surface roughness and substrate densities.

The main aim of this project is to investigate controls on airgun noise propagation across the Irish continental margin. Objectives include comparing various margin conditions, i.e. submarine canyon vs typical slope, on noise propagation and to assess hydrographic controls, e.g. internal waves, on that propagation. This summer an acoustic/hydrographic survey was successfully carried out, involving deployment of a fixed mooring hydrophone array and noise generation using a (mini GI) seismic airgun. Although postprocessing and analysis is only just underway, preliminary results suggest that canyons may focus rather than disperse incoming sound. Complete analysis will quantify variation in noise levels (or transmission loss), in varying topographic and hydrographic settings across the continental margin. Results shall provide regulatory bodies, industry and NGOs with evidence-based research on characteristics of anthropogenic noise propagation.

This publication has emanated from research supported in part by a research grant from Science Foundation Ireland (SFI) under Grant Number 13/RC/2092 and is co-funded under the European Regional Development Fund and by PIPCO RSG and its member companies.

Bottom Trawling at Whittard Canyon: Evidence for Seabed modification, trawl plumes and food source heterogeneity

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The dendritically shaped Whittard Canyon System attracts fishing vessels of various types and nationalities, due to the diversity and abundance of target species found there. Bottom and mid-water trawling are commonplace across canyon, from axis to adjacent shelf edge. Demersal bottom trawling is found here to be a probable cause of alteration to the seafloor roughness along the interflues between canyon branches. Vessel monitoring systems (VMS) data is correlated with an Arc Chord Ratio (ACR) rugosity index using a varied statistical approach. Over the rougher ground and/or steeper slopes, heavily fished areas show a more homogeneous rugosity distribution than those lightly fished, indicating possible smoothing of the seabed.

The action of bottom trawling proximal to canyon branches is known to generate turbid, energetic plumes within the canyon channel to 250m depth, with elevated concentrations of Suspended Particulate Material (SPM) detected up to 400m above the channel floor. Plume origin samples of organic material undergoing lipid biomarker analysis showed higher concentrations of total lipids at intensively trawled (eastern) locations. In comparison to less intensively trawled (western) locations, contributions of fatty alcohols were found to be higher. Phytoplankton biomarkers accounted for 93.4% of total lipids in eastern samples, suggesting rapid transport of liable compounds. Results suggest that changes to sediment transport due to intensive trawling will alter the natural sediment flux, complicating the interpretation of sediment transport and biogeochemical distributions at canyon systems, especially from single surveys.

Anthropogenically forced heterogeneity in sediment character and supply will also impact on habitat suitability for resident ecosystems and affect carbon flux from shelf to deep sea.

Tectono-stratigraphic evolution of the perched Mesozoic rift basins along the eastern margin of the Rockall Trough

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The Irish Rockall Basin remains a frontier area for petroleum exploration with only three wells and four shallow stratigraphic boreholes along the eastern flank of the basin. This project focuses on existing grids of 2D seismic data available for the South and North Bróna basins, the Pádraig Basin and the Macdara Basin along the western side of Porcupine High. Investigation of the origin and prospectivity of these poorly-known perched basins involves characterising, comparing and contrasting the stratigraphic and structural evolution of all four perched depocentres and comparing these with the adjacent analogous basins, particularly those on the east side of Porcupine High, as well as along the Slyne-Erris trend and beneath the NE Rockall margin. It is clear that the Mesozoic basins have suffered one or more phases of later westward slope rotation that may have impacted on trap integrity. The basins have also experienced significant but poorly constrained exhumation, and this will impact on their thermal history. This work entails detailed fault mapping and consideration of fault system evolution, as well as developing a tectonostratigraphy for both the fault-controlled basins and the Cretaceous and Cenozoic cover to address the possible impact of the post-rift events.

This publication has emanated from research supported in part by a research grant from Science Foundation Ireland (SFI) under Grant Number 13/RC/2092 and is co-funded under the European Regional Development Fund and by PIPCO RSG and its members companies.

Shorelines: The Coastal Atlas of Ireland

Devoy, R.¹, Cummins, V.², Brunt, B.¹, Bartlett, D.¹, Kandrot, S.²

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Ireland is an island surrounded by ocean, with a high percentage of its population living in the coastal zone; it is often referred to as an “island nation”. The importance of the coastal zone to Ireland is extremely high, given its economic value from tourism and recreation, fishing, aquaculture, energy, ports and linked industries. Although there are existing guides about Ireland’s coastal geology, physical geography and landscapes, these are fragmented and mostly of a local nature. There is no single text that explores the coast of Ireland as a whole, from both the physical and social perspectives. *Shorelines: The Coastal Atlas of Ireland* will fill this gap.

“*Shorelines: The Coastal Atlas of Ireland*” will be a 500 page, 34-chapter publication, containing over 400 maps and illustrations. Edited by Robert Devoy, Val Cummins, Barry Brunt, Darius Bartlett, and Sarah Kandrot, with digital production by Maxim Kozachenko, the publication involves the work of over 70 authors. It is due to be published by Cork University Press in 2019 as part of their celebrated atlas series from the Department of Geography at University College Cork.

A digital product will also accompany the publication. This will include a WebGIS linked to supporting videos, produced by the GEOCOAST project. The videos will include drone footage of selected sites and interviews with chapter contributors.

This project is part-funded by the Petroleum Infrastructure Programme (PIP).

Provenance of Triassic sandstones – Reconstructing Sand Dispersal in the Slyne Basin and Ulster Basin

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During the Triassic, Northeast Atlantic Margin basins lay within the Laurasian region of the Pangean supercontinent, approximately 15 – 20° north of the equator. Ongoing investigations of Permo-Triassic basins along the NE Atlantic margin aim to better understand large-scale drainage patterns throughout the Mesozoic, to better predict sand distribution across these basins, and to potentially identify links between basins on the Atlantic conjugate margins. This study aims to further on-going work on Mesozoic sedimentary basins in the NW Europe, by applying a multi-proxy approach to the Triassic sandstones of the Slyne Basin offshore western Ireland and the Ulster Basin, Northern Ireland. Sediment transport on the Irish Atlantic Margin during the Triassic remains relatively elusive. The dispersal systems supplying these basins are thought to be independent from those which fed UK basins, such as the Wessex and East Irish Sea basins. This study utilises a combination of three provenance techniques, U-Pb zircon and apatite geochronology and Pb isotopic analyses of K-feldspar. Results from the Pb isotopic analysis of K-feldspars in the Slyne Basin reveals mixed Archaean - Proterozoic sources. U-Pb ages of apatite and zircon grains are consistent with the sources identified by the Pb isotopic analysis of K-feldspar, however a Permian-aged population, with no clear equivalent K-feldspar, has also been detected. These results support the hypothesis of a drainage divide between the basins offshore western Ireland versus onshore UK and eastern Ireland. Pb isotopic analysis of K-feldspar from Ulster Basin also reveals a mixed Archean – Proterozoic source, however a significant southerly source has also been identified, which is not seen in the Slyne Basin. This would indicate that the Ulster Basin was situated at the drainage divide between the system supplying the basins offshore NW Ireland and those southerly derived systems sourced from the remnant Variscan Uplands. These data also reveal that supply to the Ulster Basin periodically fluctuated between these two systems during the Triassic.

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Contribution of submarine groundwater discharge (SGD) to the marine carbonate biogeochemistry of the Western Irish Coastal Sea

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Dissolved Inorganic Carbon (DIC), Total Alkalinity (TA), Partial pressure of CO₂ (pCO₂) and pH are important parameters in coastal areas to understand the local carbon cycling and particularly ecosystem metabolism, i.e. respiration, photosynthesis, and their mutual balance. Submarine groundwater discharge (SGD) has been often overlooked as a pathway supplying nutrients as Nitrogen, Phosphate and Silicate (N, P, Si) and carbonate system solutes into coastal ecosystems. Due to the increase of dissolved CO₂ in the marine water column, pH decreases, with the consequent reduction of buffer capacity in coastal areas. This results in a decrease of the metabolic activity of calcifying organisms, from zooplankton to commercially valuable species like mussels (e.g. *Mytilus edulis*) that are important in aquaculture. This study is focused on the parameters that characterise the marine carbonate system, DIC, TA, pCO₂ and pH. Specifically, this research aims to understand the impact of DIC and TA transported by SGD on ecosystem metabolism in Irish coastal areas. Two study sites, characterised by contrasting catchment hydrogeology, will be analysed. Kinvara Bay, which is located in a lowland but is fed by allogenic sources, is a limestone area, inserted into a karstic catchment area. Killary Harbour, which is characterised by shale, sandstone and conglomerates, is a long and deep harbour mainly fed by river discharge. This comparison will allow to identify the different drivers acting in coastal acidification processes.

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Distribution of organic matter in hybrid event beds from the Pennsylvanian Ross Sandstone Formation

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Hybrid event beds (HEBs) are the deposits of an enigmatic yet common class of sediment gravity flow involving turbidity currents that partly transform to debris flows as they run out. The deposits thus typically contain a basal clay-poor turbidite sandstone and an upper clay-rich debrite. Petrographic and sedimentological observations show that the linked debrites (H3) commonly contain significant volumes of fractionated terrestrial organic matter. Hybrid and related transitional flows thus provide an efficient mechanism for rapidly burying organic carbon in deep-marine settings. The H3 division may form both a conventional source of hydrocarbons, and an unconventional reservoir. The bed scale distribution of organic carbon is investigated here using behind-outcrop cores from Pennsylvanian Ross Sandstone Formation, western Ireland, the deposits of an ice-house tropical deep-sea fan system. Nine different types of HEB are identified, forming up to 27% of the Ross by thickness. Texture, composition, sedimentary structures and the inferred depositional mechanism are used to identify eight different lithofacies (LF1-LF8). A total of 55 core plug samples were collected from the different lithofacies and powdered samples were analysed using a LECO carbon analyser and Rock-eval to quantify the total organic carbon content as well as determining the organic matter type and their source potential. A subset of samples were further analysed by XRD, XRF and petrography for compositional and textural

analysis. The analysis reveals that the clay-rich facies (LF5, LF7 and LF8) have darker and finer-grained matrices associated with highest concentrations of both finely disseminated organic matter and plant debris (>1% TOC). In contrast, co-genetic sandy facies (LF1, LF2, LF3 and LF6) are much leaner (< 0.3% TOC). The detailed examination of clay and organic matter distribution vertically within individual event beds and laterally towards bed pinch-outs reveal similar trends suggesting strong coupling of these components.

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Thermal history of source facies in the Orphan Basin, Newfoundland, Canada

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The Orphan Basin is one of rift basins of the northwest Atlantic Ocean margin. It, like other similar basins in the region, results from a long and complex rift history spanning the Middle Jurassic to the start of the Late Cretaceous. Whilst large at approximately 150,000 square kilometres, the basin is under explored with only 12 wells having been drilled to date. Geochemical and other data are available for each well and also for a number of other wells in the nearby Flemish Pass and (northern) Jeanne D'Arc basins. Both of these basins have yielded commercial oil discoveries. Furthermore it is estimated that the oil and gas resource potential for the Orphan Basin exceeds 25 billion barrels of oil and 20 trillion cubic feet of gas.

The purpose of this study was to firstly identify and then characterise potential source rocks. Within the basins of northwest Atlantic Ocean margin known source facies are dominantly of Jurassic age, however, in some basins localised sources from outside the Jurassic are very significant. The Orphan needs a comprehensive review of this aspect of its petroleum system with analogues addressed in other similar basins. Once that had been achieved a series of 1D models have been produced to detail timing of key thermal maturity thresholds in both wells and undrilled locations. This aspect of the study looks into the variation in timing of expulsion based on differing types of organic matter that potential exist in the Orphan Basin. Differing types of organic matter have been recognised within the Late Jurassic of the Lona O-55 well in the East Orphan Basin. Additionally, potential sources of Late Jurassic age could be influenced by "Egret" type source facies or indeed, "Kimmeridge" like organic matter. The significance of these differing source scenarios is addressed in terms of timing of expulsion.

Public perception of the subsurface and of geological activities in west Clare: a mental models approach

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Since the late 1950s, the Pennsylvanian rocks of west Clare, Ireland, have been visited regularly by large numbers of academic and industry geologists. This is mainly because of the succession's analogy with hydrocarbon-bearing, deltaic to deep-water sedimentary rocks on several continental margins, such as in

the Gulf of Mexico. Since 2009, a programme of behind-outcrop drilling involving UCD and Statoil (now Equinor) has acquired over 1,350 m of core from 12 boreholes behind the sea cliffs of the Loop Head peninsula. The new subsurface data have high value as an analogue dataset for use in training and reservoir characterisation. The high sea cliffs of west Clare are also an ideal setting for non-geologists to learn about geology. A program of public engagement activities, informed by public perception research, in west Clare is currently underway in the Irish Centre for Research in Applied Geosciences (iCRAG). Here, we present the initial results of a survey investigating public perception and understanding of the subsurface and of geological activities in the west Clare community. Sketches of the subsurface, mining/quarrying, drilling and flooding made by experts (geoscientists) and non-experts (non-geoscientists) were compared and analysed using a mental models approach. The differences in the mental models of experts and non-experts can be used to inform inclusive, two-way dialogue between geoscientists and local communities.

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Seismic waveform tomography of western Ireland's offshore basins

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The offshore basins west of Ireland are of great interest for their potential as hydrocarbon reservoirs and for their tectonic history as part of the North Atlantic margin. In this work, we seek to characterise these basins by building quantitative models of seismic properties at different scales, from the ocean down to the basin scale. First, at the North Atlantic scale, we present new models of S-wave velocity and of its radial and azimuthal anisotropy in the crust and the upper mantle, obtained by asymptotic waveform inversion of S and surface waves. Seismic anisotropy is the consequence of the preferential orientation of structures due to deformation. The separate reconstruction of the shear-velocity isotropic average and of its anisotropy enables to distinguish between the effects of thermal or compositional variations and those of anisotropic fabric. The former can be interpreted in terms of lithosphere thickness and temperature, while the latter gives us insight into past and present deformation and flow in the lithosphere and the asthenosphere. Second, we present models of P-wave velocity in the Porcupine Basin, obtained by adjoint full waveform inversion (FWI) of long-streamer seismic data. Compared to the starting model obtained by first arrival traveltimes tomography (FATT), the FWI model brings more details on the western margin of the basin, confirming the presence of a low-velocity anomaly in the hanging wall of the basin-bounding fault already identified by the FATT and suggesting the presence of fluids. It also exhibits new features, such as a high and discontinuous velocity contrast associated to the chalk layer. Further steps will include the estimation of density in the fault zone and its conversion into porosity, as well as the consideration of higher frequencies for more detailed images. We expect these images to provide new insights into the reservoir properties and to contribute to a better understanding of the tectonic history of the basins.

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Hydrographic conditions during the PANiC survey – Propagation of Acoustic Noise in Canyons, June 2018

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Seismic acoustic noise propagation research is being conducted within the marine spoke of iCRAG. As part of this, a controlled noise experiment was conducted at the continental margin at a small canyon at the northern end of the Gollum Channel system in June 2108 from the RV Celtic Voyager. In addition to the deployment of a hydrophone array in the canyon and adjacent slope, together with a towed air gun, hydrographic conditions were monitored through CTD measurements, the MI Glider deployed within the canyon, and other sensors deployed on the hydrophone moorings.

Overall, the water mass distribution was dominated in the upper 500 m by Eastern North Atlantic Water (ENAW) with evidence for Mediterranean Water (MOW) influence below the permanent thermocline (>750m) which spread into the deeper canyon mouth. A seasonal thermocline was present between 30-50 m depth, not fully developed at the early summer period. Sensors on the Canyon hydrophone moorings showed strong semi-diurnal vertical movement in this thermocline region, suggesting potential enhancement of tidal currents in the canyon relative to the adjacent slope. Temperature sensors on these moorings indicated the presence of 1-2°C temperature oscillation ‘packets’ in the thermocline, with maximum amplitude occurring periodically with the tide. This is suggestive of internal soliton generation by the tidal currents at the margin. Such strong modulation of the thermocline structure will significantly alter noise propagation and will be a focus for interpretation of the acoustic data to be analysed.

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Project SEA-SEIS: Structure, evolution and seismicity of the Irish offshore

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Ireland’s largest sedimentary basins, hydrocarbon resources and natural hazards (offshore landslides) are in its vast offshore. The lack of broadband seismic sensors offshore has hindered our understanding of the deep mechanisms of the lithospheric hyper-extension that formed the basins, mechanisms of the Paleogene uplift and volcanism in and around Ireland (probably related to the enigmatic Iceland Hotspot activity, they affected the structural and thermal evolution of the basins), regional-scale structure and evolution of the area’s crust and lithosphere, and its current deformation and seismicity. In the project SEA-SEIS, we have deployed 18 new, broadband, ocean-bottom seismometers provided by the newly established Insitu Marine Laboratory for Geosystems Research (iMARL) across the entire Ireland’s offshore, with a few sensors also in the UK and Iceland waters. Seismic tomography with the new data will be performed at different scales, using waveform inversions and ambient-noise and teleseismic cross-correlations. A new offshore earthquake catalogue will be obtained. Lithosphere-scale thermal evolution of the basins will be modelled. The project will yield important new information on regional geodynamics and energy resource development.

All 18 OBSs have been deployed successfully from the Marine Institute's Celtic Explorer (17 September–5 October 2018). The SEA-SEIS Expedition received broad media coverage and had a significant outreach component, reaching many hundreds of secondary and primary school students through competitions and ship-classroom video links.

The SEA-SEIS project is co-funded by the Science Foundation Ireland, the Geological Survey of Ireland, and the Marine Institute.

Geochemical characterisation and Mapping of Inner Dublin Bay and Bull Island

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Mapping of inner Dublin Bay and Bull Island was conducted after analysis of sediment and soil samples for parameters such as particle size, organic matter and poly aromatic hydrocarbons (PAH). Sampling density and distribution was determined using a more modern geospatial approach in favour of the more traditional gridded approach often used in environmental sciences, thus ensuring a bias to areas where more heterogenous results were expected. A series of interpolated maps generated by using ArcGIS software highlighted the areas where organic matter was high and also correlated strongly with PAH concentration. These results can now set a baseline for future monitoring of chemical parameters within the bay.

Differentiating ocean induced seismic surface waves generated offshore Ireland

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3D simulations of acoustic/elastic waves have been performed in order to improve our understanding of the wavefield associated with seismic ambient noise induced by ocean waves activity. To do so, our 3D synthetic model comprises a broad area of the Irish offshore including key features such as the Rockall Trough and the Porcupine Basin. The model is defined by the water layer as well as sediments, crust and mantle layers and can therefore be used for several acoustic/seismic applications. To better characterise changes in the seismic wavefield generated from different "ocean noise" source locations, multiple areas of the model are investigated separately. The simulated wavefield recorded on synthetic seismograms enables us to look at the effect of the water column, sediments thickness but also steep gradient changes in bathymetry and sediments. Whereas Rayleigh waves are broadly observed in the simulations, Love waves become only significant for specific source locations. Understanding the radial and transverse seismic wavefield is important as both Rayleigh and Love waves will exhibit different sensitivity to the underlying velocity structures.

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Mapping, Modelling and Monitoring Key Processes and Controls on Cold-water Coral Habitats in Submarine Canyons (MMMonKey_Pro)

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Submarine canyons are dynamic environments that support diverse biological communities including fisheries. Recent work on the Irish Porcupine Bank Canyon (PBC), a natural laboratory isolated from terrigenous input, has revealed extensive speciose, high biomass cold-water coral (CWC) structural habitats. This “big science” project uses Irish state-of-the-art and new innovative marine exploration and analysis technologies to explore and monitor the PBC-CWC habitats and relate to ocean-climate environmental dynamics. The project will employ ROV-based multibeam bathymetry and novel 3D photogrammetric approaches for geostatistical analysis and habitat characterisation. Monitoring of canyon hydrodynamic and sedimentary processes, core and coral-morphotype analysis will reveal the process thresholds defining coral sub-habitats’ limits, in space and time, and allow predictive CWC, and habitat sensitivity, models to assist marine spatial planning. By assessing the magnitude of existing anthropogenic impacts within the constraints of the sensitivity model, recommendations can be extrapolated from the data for sustainable, responsible intervention in these habitats for fisheries and hydrocarbon exploration. Likewise, process thresholds will reveal the potential impact-response from climate change facilitating knowledge-based recommendations for effective management. This project adds to Irish seabed mapping capacity, develops a critical mass to generate large consortia, building further capacity and relationships with industrial (hydrocarbon)/international partners.

A new code for modelling hierarchical stacking patterns in deep-water lobes

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As a crucial oil-exploration target, deep-water lobe systems are usually linked to a high degree of uncertainty due to their inaccessibility. Therefore, the generation of accurate and realistic geological models of these systems is crucial in order to minimise development risk, yet conventional cell-based modelling techniques cannot reproduce complicated spatial structures. A code that merges stochastic object-based and rule modelling has been created, and it is an effective way to reproduce complex geometries at different scales in sand/shale binary systems.

The numerical models are able to reproduce a four fold hierarchy and the stacking relationships between successive deposits. Diverse realisations of lobes deposited in different basin settings (unconfined, confined and semi-confined) have been generated. The modelled systems show how an idealised seafloor affects stacking patterns and geometries at different hierarchical scales in these successions.

When lobes are too wide relative to the accommodation space, they show a vertical stacking trend, even when forced to be compensational. However, when they are deposited in unconfined settings they can migrate laterally easily. This lateral migration results in potential poor connectivity between complexes due to the deposition of relatively thick shale layers where the lobes are inactive. Semi-confinement derives in a combination of vertical and lateral stacking, with a main lateral migration direction. Further

work with theoretical systems and real systems (e.g. Ross Formation) will improve the code and, if successful, it would have implications in reservoir modelling.

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Diffraction Imaging by Plane-wave Destruction aided by Dip-filtering

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Seismic imaging is one of the most important aspects for exploration in the hydrocarbons industry. By tracking waves through the earth and their interactions with the geological features within, an image of the subsurface can be created. However, the conventional processing workflow favours only the specular reflections, reducing or removing the other interactions. These specular reflections are unsuitable for imaging sharp corners, such as those in fault zones and pinchouts, therefore diffractions are used instead. Unlike reflections, diffractions form when the wavefield meets an object which is small compared to the wavelength. This property of diffractions makes them excellent at imaging sharp corners as they not only image the structures themselves, but they are also not limited by the Rayleigh criterion (a resolution limit of 1/4 of the wavelength), and thus have the potential to image structures which may be too small to image in a conventional processing workflow.

Plane-wave destruction is a well-established method for removing reflections and imaging diffractions. However, this method assumes a continuously variable slope, and therefore fails to predict areas which do not follow this assumption. This includes synclines and areas where the dip is highly laterally variable such as fault drag. To remove the remnant energy in these areas and thus enhance the overall quality of the diffraction images, we propose a spatial-variable mute in the F-K domain based on the calculated dip field used for plane-wave destruction. To demonstrate the method, we have tested this on a range of synthetic data, complex synthetic data and real data.

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Comparing the effectiveness of apatite and rutile U-Pb as provenance proxies for metamorphic terranes

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Many U-Pb thermochronology and geochronology systems in accessory phases are affected by the presence of common-Pb (Pbc), here defined as environmental Pb incorporated either during crystallisation, or subsequent in-diffusion or infiltration, as opposed to radiogenic Pb generated in-situ by U and Th decay (Pb*). The degree to which different phases incorporate Pbc is controlled in part by the valence state of lattice constituents: zircon incorporates little Pbc because the typically divalent state of Pb inhibits substitution for Zr⁴⁺; indeed, the ready ability of radiogenic Pb⁴⁺ to substitute for Zr⁴⁺ may

partly account for the high retentivity of Pb in zircon (Frei et al., 1997; Kramers et al., 2009). In contrast, Pb²⁺ readily substitutes for Ca²⁺ in apatite. Increasing incorporation of Pbc strongly reduces the precision of the Pbc-corrected approaches to the U-Pb age calculation typically adopted for relatively low-U accessory phases such as apatite and rutile, which are increasingly used as detrital provenance tools.

We present multiple datasets of detrital and bedrock apatite and rutile U-Pb analyses, including Pbc and Pb* content, from samples collected in the Alps, Himalayas, Appalachians, and Ireland. Importantly, apatite that was sourced from medium- to high-grade metamorphic terranes (i.e. source areas subjected to reheating) contains systematically higher Pbc than does rutile from the same detrital samples; rutile exhibits lower absolute Pbc content, and a range of Pbc:Pb* ratios (likely reflecting variations in initial U content). This finding has implications for the use of rutile and apatite U-Pb as detrital provenance tools, because apatite from young (e.g., Neogene) metamorphic terranes may characteristically contain sufficient Pbc to render U-Pb dating difficult.

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The upper-crustal structure and sedimentary succession of the Porcupine Basin, offshore SW Ireland, based on multichannel seismic data.

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The Porcupine Basin is a failed rift located on the Atlantic margin southwest of Ireland. Its formation is the result of several rifting and subsidence phases during Late Palaeozoic to Cenozoic times, with the main rift phase occurring in Late Jurassic-Early Cretaceous times. Recent crustal scale seismic studies provide new information related to the nature, geometry and deep structure of the crust underlying the basin. These studies, using wide-angle seismic (WAS) data, indicate significantly higher stretching factors (β) along the basin axis than previous estimations derived from subsidence analysis. β factors decrease rapidly southwards indicating a dramatic change in the extension regime. In this work we present the results of a detailed tectono-sedimentary study of the upper-crustal part of the Porcupine Basin and the overlying sedimentary succession based on the extensive high-quality multichannel seismic data available on the region. We have mapped the detailed geometry of a major detachment fault surface (named “P-detachment” in previous works) and the associated low-angle normal faults likely to have facilitated the hyperextension and mantle serpentinisation in the north and central regions of the basin. The P-detachment grows southwards and flattens along the basin axis from north to south. The region where the detachment surface is most visible coincides with that where the distribution of the low-angle normal faults is spatially denser. According to previous WAS results, this region is also where the lowest mantle V_p was modelled (i.e., highest degree of serpentinisation) suggesting that faults controlled mantle hydration. In addition, we show the spatial and temporal relationship of the P-reflector with the Porcupine Median Ridge (PMR), a ridge feature that has been alternatively interpreted as a volcanic feature, a serpentinite mud diapir or a tilted block of continental crust. The P-detachment is identified below the thickest section of the PMR, but south of this point along the basin axis it loses reflectivity and cannot be identified. The depocenter is located in the southern half of the basin, where a deepening of the

sedimentary succession is also observed. These changes in the filling of the basin are likely to reflect a higher subsidence rate than in the central and northern regions of the Porcupine Basin, suggesting sudden change in the tectonic regime.

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Crustal composition of the Porcupine Basin from thermodynamically constrained joint inversion of seismic refraction, surface elevation and gravity data

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Information on the composition of the crystalline crust and the uppermost mantle is crucial for understanding the tectono-magmatic processes involved in the formation of the Porcupine Basin. We infer this information by probabilistic joint inversion of seismic travel times, surface elevation and gravity data. The unknowns of the inverse problem are the proportions of metastable mineral phases within the crust, geometry of the Moho, interfaces between different petrologies and serpentinite content in the uppermost mantle. For a given petrology, elastic moduli and density of the composite are computed as functions of pressure and temperature; the temperature is found as numerical solution of the 3D steady-state heat equation. This petrological forward problem provides seismic velocities and density distributions on finite-difference mesh, which are used to predict seismic travel times, gravity anomaly and surface elevation. A Markov chain Monte Carlo algorithm is used to sample the posterior probability density function of the model parameters.

We use wide-angle seismic data from the RAPIDS4 – a profile across the Porcupine Arch acquired in 2002 with 65 ocean-bottom seismometers, and free-air gravity anomaly from satellite altimetry. To resolve the sedimentary cover, we perform first-arrival traveltome tomography, predict density from the P-wave velocity and fix the resulting model of the sediments during the Monte Carlo inversion. First, to study the capabilities of the inversion algorithm, we apply it to synthetic data with the real experiment geometry.

Sedimentological character of thin-beds in behind-outcrop core from the Pennsylvanian Ross Sandstone and Gull Island formations, Co Clare, western Ireland

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A major behind-outcrop drilling campaign involving UCD and Equinor acquired over 1350 m of split PQ core from 12 boreholes behind the high sea cliffs in west Clare and north Kerry. The coring targeted the Ross Sandstone Formation, a 500-m- thick Pennsylvanian deep-water fan system, and the basal interval

of the Gull Island Formation, a mud-prone, unstable lower slope succession. The cores have been integrated with outcrop studies and ammonoid biostratigraphy to build a new framework and understanding of the system architecture and evolution. The subsurface dataset has high value as an analogue dataset for use in training and reservoir characterisation; currently, a selection of the core is now housed in west Clare, close to the outcrop, and is available for both academic and industry courses.

Recent outcrop and core-based studies from the Ross Fm, of the Clare Basin have demonstrated the occurrence of significant thin-bedded and fine-grained successions within the base-of-slope to basin floor deposits. Observations and interpretations of these successions have shown that they have a complex depositional history that is expressed in their character, facies distribution and geometry at outcrop. The core on display here, is from the 09-CE-UCD-02 borehole and captures a selection of the variety of thin-bedded deposits observed within the upper Ross and lower Gull Island formations; this includes a condensed section from the top of the Ross Formation, a succession of thin-bedded hybrid event beds that record the initial incoming flows following a system-wide shutdown, a section of the mud-prone and deformed thin-beds that comprise the bulk of the Gull Island Formation, and an apparently *in situ* succession of levee/overbank within the Gull Island Formation.

This project is part-funded by a Griffith Geoscience Award and is supported in part by a research grant from Science Foundation Ireland (SFI) under Grant Number 13/RC/2092 and is co-funded under the European Regional Development Fund and by PIPCO RSG and its member companies.

Detailed characterisation of thin-beds associated with submarine channels in Pennsylvanian Ross Sandstone Formation, Co Clare, western Ireland

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Submarine levee/overbanks are identifiable in seabed and subsurface datasets as constructional, wedge-shaped features that occur adjacent to channels; they form extensive deposits that can be tens to hundreds of metres thick and many kilometres wide. Previous outcrop-based studies have documented extensive levee deposits adjacent to channels on the submarine slope, however, detailed observations of the process sedimentology and depositional architecture of levee/overbanks on the base-of-slope to basin floor are rare due to limited outcrop exposure/extent or poor seismic resolution. Recent outcrop and core-based studies from the Ross Fm, of the Clare Basin have demonstrated the occurrence of significant thin-bedded and fine-grained successions adjacent to channels on the base-of-slope to basin floor. Observations and interpretations of these features have shown that they have a complex depositional history; their thickness and geometry is dependent on the distance from the parent channel, the height and slope of the constructional overbank, and the magnitude of individual flows. These potential overbank/levee features are dominated by thin-bedded low-density turbidites: intercalated planar laminated siltstones and very fine-grained sandstones that are typically ripple or planar laminated. These units display a predictable upwards facies transition from relatively thick-bedded sandstones that abruptly give way to thinner bedded and finer grained, siltstone dominated deposits – a trend that has been observed at multiple stratigraphic intervals within thin-bedded successions adjacent to channels. Where these deposits can be mapped, they are characterised by a wedge-geometry that thins over 10km and displays a thinning and fining lateral facies transition along this distance. In addition, palaeoflow is indicative of flows escaping from a lateral confinement (i.e. high-angle to regional palaeoflow). Overall, the thinning and fining upwards trend, and the lateral facies transition, in combination with the wedge-shaped geometry, implies that these features are levee/overbank deposits.

This project is part-funded by a Griffith Geoscience Award and is supported in part by a research grant from Science Foundation Ireland (SFI) under Grant Number 13/RC/2092 and is co-funded under the European Regional Development Fund and by PIPCO RSG and its member companies.

Synergies between the Sentinel Satellites and the use of Bio-optical and Flow cytometric measurements for tracing surface slicks along the Irish Western Shelf

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A key challenge facing the maritime industry at present is developing the capability to distinguish in real time, maritime accidents from naturally occurring phenomena such as phytoplankton blooms and natural oil seeps. The ability to correctly determine the nature of the observed surface slick will facilitate applications in maritime safety, oil exploration, harmful algal blooms/ecosystem services and other marine based activities. This project aims to link detection and monitoring of these natural and manmade surface slicks using satellite-based observations incorporating the new ESA sentinel series of satellites.

Predictive assessments will be made by combining SAR with ocean colour (Sentinel 3) and scatterometer winds (Sentinel 1). Methods will include baseline optical measurements of CDOM (absorbance and fluorescence) in surface waters along the west coast of Ireland over a range of spatial and temporal scales. Phytoplankton abundance will also be recorded at this time by analysing samples using flow cytometry (Accuri C6). Results should help with determining criteria for Good Environmental Status (GES) as per the EU Marine Strategy Framework Directive regarding the optical properties of seawater.

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A potential polycyclic provenance for sandstones of the Tullig Cyclothem of the mid-Carboniferous Clare Basin

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This study investigates the provenance of deltaic sandstones of the mid-Carboniferous Clare Basin, western Ireland. Provenance data from these rocks are sparse and detailed palaeogeographic reconstructions are poorly constrained with earlier studies, based on palaeocurrent data, interpreting contradictory sediment input. Previous zircon U-Pb geochronology results (Pointon et al., 2012) suggest a main age population (~600Ma) associated with Avalonian sources which likely lay to the south of the basin. Younger and older age populations were interpreted to have been derived from the north of the basin (Laurentia). In this study, sandstones from the Tullig Cyclothem have been logged in detail and sampled at three locations. A prograding deltaic succession is observed at two of the locations with the third location being interpreted as a transgressive shelf sand-body. Petrographic analyses indicate mineralogically and texturally mature sandstones. Heavy mineral analyses reveal high zircon-tourmaline-rutile (ZTR) indices, potentially indicative of polycyclic sourcing. Zircon U-Pb geochronology results show

minor variations from sample to sample, indicating a similar provenance throughout the different facies and across the basin. A main population from 550 to 750Ma corresponds with peri-Gondwanan terranes, located south of the studied area. Another population (400Ma – 470Ma) is interpreted to be associated with the Caledonian Orogenic Cycle. Finally, older grains show correspondence to the Grenville, the Pinwarian, the Labradorian orogenies and with the Lewisian Complex, hence these are all interpreted as ultimately originating from Laurentia, located north of the basin.

Given the maturity of the sandstone, the high ZTR indices and the contrasting zircon ages (northern and southern sources), it is likely that there is at least some, and perhaps a significant proportion, of polycyclic input into the basin. A comparison with recently published U-Pb zircon data from the Old Red Sandstone of the Dingle Peninsula (Fairey et al., 2018) highlights that this area could have supplied zircon to the Clare Basin. However, recycling from this source alone cannot account for all of the detrital ages recovered from the Tullig sandstones as peri-Gondwanan grains are relatively more abundant in the Clare Basin. Our provenance interpretation for the infill of the Clare Basin invokes sourcing entirely from areas to the south and south-west of the basin, involving recycling from Devonian sedimentary rocks with the addition of first-cycle detritus from a peri-Gondwanan basement source.

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Testing the ability of forward stratigraphic modelling to replicate tectono-sedimentary interactions in rift basins

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Tectonics plays a key role in controlling regional and local surface gradients, drainage patterns, sediment entry points, depocentre locations and across-rift asymmetry. Modern rift basins, ancient examples and both physical and numerical models have all contributed to understanding the interplay between tectonics, climate and sedimentation. Forward stratigraphic modelling is also increasingly used to assess the depositional response to variable subsidence, sediment supply and base level and can potentially help predict lithology where this is poorly constrained in the subsurface. However, it is important to verify that the forward models can replicate the behaviour of natural systems. One way to do this is to test the extent to which numerical simulations can reproduce the stratigraphy generated in scaled physical experiments where all the inputs are known. Many of the experiments in subsiding tanks have focused on changing base level combined with subsidence in the form of simple hinging, but Kim et al. (2010) introduced a pair of faults separated by a relay zone and showed that local fault-related uplift and subsidence could steer channels and divert them via a relay into rapidly subsiding hanging wall depocentre. They showed that the ratio of the timescale needed for tectonic tilting to produce a lateral slope comparable to the main fluvial slope and the timescale required for channels to visit a significant fraction of the basin surface determined whether or not channels were steered.

A set of numerical simulations using SEDSIM were run duplicating the experimental setup, the input sediment flux and the location, rates and pattern of subsidence, the latter including both a regional tilt and superimposed fault-related uplift and subsidence. Initially, channels in both the physical and forward

models were not steered and were free to sweep across the surface. After approximately 15 hours, channels in both models trenched across the footwall uplift entering the developing hanging-wall depocentre transversely, creating a fan. Continuing footwall uplift then steered the channels around the uplift and fault tip, but initially the ramp slope was insufficient to steer channels in a dominantly lateral pattern back into the hanging-wall depocentre. After 75 hours, the lateral ramp slope became steep enough, and axial deltas extended into the footwall basin. The two models show very similar behaviour in terms of channel development and overall timing and slicing of the stratigraphy shows both models generate comparable geometries with two coarse grained hanging-wall sandbodies. It appears the SEDSIM model captures many of the key aspects of the physical model.

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Structural and kinematic analysis of the Slyne Basin: exploring the links between structural evolution and traps

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The Slyne Basin is an elongate and narrow series of half-grabens and grabens bounded by transfer zones, located between the Rockall Basin, Porcupine High and the Irish Mainland Shelf. It belongs to a chain of rift basins extending along the NW European Atlantic margin. Basin formation began in the Late Permian, with a first phase of rifting continuing until the end of the Early Jurassic, when the basin experienced a period of uplift and erosion. The most significant phase of rifting initiated in the Middle Jurassic and continued until the end of the Jurassic. Significant erosion of the Late Jurassic strata during the Early Cretaceous created a distinct regional angular unconformity before a thin Cretaceous cover was deposited. A second phase of uplift and erosion during the Paleocene resulted in a subtle angular unconformity between Cenozoic and Cretaceous sediments and removed the Cretaceous section south of the Central Slyne Transfer Zone, juxtaposing Cenozoic and Jurassic sediments. Localised zones of strike-slip faults likely developed during this time. Eocene magmatism resulted in the emplacement of numerous sills within the Jurassic succession and extrusion of lava flows onto the Paleocene unconformity, followed by the deposition of Oligocene to Miocene sediments. Mild reactivation of a variety of structures occurred during the Miocene with evidence of both normal and reverse movements. A final minor period of erosion during the Miocene created a regional unconformity, upon which a thin cover of undeformed Miocene to Recent sediments was deposited.

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Preliminary LA-ICP-MS AFT and AHe Results Offshore West of Ireland

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In the Irish Atlantic Margin (IAM) large uncertainties remain about the exact timing, magnitude and causes of the main uplift and erosion events since the main rifting phase. The project aims to better constrain these exhumation events by modelling thermal histories from a large number of locations on the IAM using two low-temperature thermochronometers: apatite fission track analysis by LA-ICP-MS (LAFT) and apatite (U-Th)/He (AHe) from multiple samples along vertical profiles (i.e. boreholes).

Three sampling campaigns have now been successfully completed, two at the Petroleum Affairs Division (PAD) core store in Dublin and one at the Ifremer core store in Brest (France). Our dataset is composed of 76 individual samples (63 from cuttings, 4 from cores and 9 Ifremer seabed samples). A sub-set of the samples (20) have already been processed and partially analysed for AFT and AHe results. Out of these 20 samples, only 3-8 samples might yield usable results. This is mostly due to 1) a low yield of apatites from some of the sands (particularly the Lower Cretaceous and Eocene sands); 2) the poor quality of the apatite in some samples (heavily fractured grains or very small grain sizes); 3) loss during laser ablation due to loose etched grains in the resin mount. We present here preliminary results for well 13/03-1 in the Donegal Basin and well 26/26-1 in the North Porcupine Basin. Both wells provided moderately good AFT and AHe results that are used to derive possible thermal histories. Moreover, our apatite U-Pb ages provide for the first time an age constraint on the crystallisation age of the gabbro in well 13/03-1 (provisionally 311 ± 14 Ma) and the metasediments in well 26/26-1 (391 ± 15 Ma).

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Structural style and timing of the inversion structures in the Celtic Sea basins (offshore Ireland): Insights from the Mizen Basin

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The Celtic Sea basins lie on the continental shelf between Ireland and north western France and consist of a series of ENE - WSW trending elongate basins that extend from St George's Channel Basin in the east to the Fastnet Basin in the west. The basins, which contain Triassic to Neogene stratigraphic sequences, evolved through a complex geological history that includes multiple Mesozoic rift stages and later Cenozoic inversion. The Mizen Basin represents the NW termination of the Celtic Sea basins and consists of two NE-SW trending half grabens developed as a result of the reactivation of both Caledonian and Variscan faults.

Previous studies in the Mizen Basin and surrounding areas have been based on 2-D seismic datasets. The present work sheds new light on the Mizen Basin structure and evolution based on 3-D seismic reflection data combined with wireline log and biostratigraphic data. The aims of this work are to i) study the tectonostratigraphic evolution of the Mizen Basin, ii) study the style and timing of the inversion structures and iii) highlight the role of non-coaxial extension and shortening on fault reactivation and segmentation. 3-D seismic coverage and a syn-tectonic stratigraphic sequence that is much better preserved than in the basins to the east makes this area an excellent location to study and understand the style and timing of inversion of the Celtic Sea basins.

Seismic interpretation within the study area has revealed three main fault populations consisting of a set of NE-SW-striking basin bounding faults, set of E-W-striking minor normal faults and a set of NW-SE-

striking dextral strike-slip faults. Sediment thickness distribution and fault analysis indicates that the basin bounding faults were active as normal faults from Early Triassic to Late Cretaceous. Most of the fault displacement took place during Berriasian to Hauterivian (Early Cretaceous) times, with a NW- SE direction of extension. A later phase of Aptian to Cenomanian (Early to Late Cretaceous) N-S oriented extension gave rise to E-W-striking minor normal faults and reactivation of the pre-existing basin bounding faults that propagated upwards as arrays of segmented normal faults segments.

As for most of the Celtic Sea basins, the Mizen Basin experienced a period of major erosion during the Palaeocene attributed to tectonic uplift. Cenozoic Alpine inversion affected the study area from Middle Eocene to Miocene times causing reverse reactivation of the basin bounding faults and the formation of NW-SE-striking dextral strike-slip faulting. The different styles of deformation observed during extension and inversion are, to a large extent, controlled by the orientation of Variscan structures that localised strains throughout the evolution of these basins.

This project is funded by the Irish Centre for Research in Applied Geoscience (iCRAG).

Fluid flow in Irish offshore and its implications on natural gas hydrate formation

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High-resolution bathymetry, sea-bottom temperature from 4760 CTD casts, and geothermal data from four well logs were used to calculate the present-day extent and thickness of the Gas Hydrate Stability Zone (GHSZ) in the Rockall and Porcupine basins (seafloor area ~ 575,443 km²) under steady state conditions. The GHSZ thickness extends to 645 m in the Rockall Basin and 784 m Porcupine Basin below their respective seafloors. Geophysical and geological datasets were integrated as a first-order exploration objective for prospective natural gas hydrate (NGH) reservoirs. Subsurface structural interpretation has been emphasised in this work as NGH concentrations are highly dependent on subjacent fluid migration pathways and working hydrocarbon systems. In our NGH exploration model in Irish offshore, assessments of lithology, migration pathways of natural gas-saturated water, presence of source rocks or conventional reservoirs, along with appropriate host rocks for NGH within the GHSZ have been included.

Kilometre scale well-bed differentiated Cenozoic sediments were deposited in the Irish basins that could be excellent hosts for NGH. Sandy limestone and calcareous sandstone cores from a bore hole located on the eastern margin of the North Bróna Basin (slope between the Porcupine High and the Rockall Basin), have been retrieved from the formation within the modelled hydrate stability zone. Investigations in the laboratory such as: i) influence of NGH pore saturation on V_p wave velocity and resistivity measurements, and ii) effect of grain size distribution and sediment microstructure of these cores on NGH formation have been carried out after artificially growing NGH within these sediment cores. The anomalies in V_p and resistivity measurements can be used to indicate and quantify the presence of gas NGHs in the sediments, and further assist in evaluating NGH saturation and resource estimation.

This project is funded by the Irish Centre for Research in Applied Geoscience (iCRAG).

Hierarchical characterisation and modelling of deep-water channel fills using compression based object modelling

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Ancient deep-water channel fills can host commercial quantities of hydrocarbon but are challenging from a reservoir modelling perspective. In confined channel complex systems, a six-level hierarchical classification scheme ranging from channel complex sets to beds has been recognised. However, quantitative analysis of stacking and dimensional characteristics of objects with this hierarchy shows that only three architecturally distinct hierarchical levels are necessary in geomodelling. Hierarchical modelling workflow for a channel complex based on these results is proposed. The modelling is performed in Petrel, using a new plugin to apply the compression method.

The compression-based reservoir modelling adapted in this study allows for independent input of net:gross (NTG) and amalgamation ratios (AR) in object-based models. The models are conditioned to stacking and dimensional characteristics of channel storeys and beds measured in natural systems, and their location within respective containers is governed by spatial rules. Stacking characteristics include the fractional volume of the container occupied by the smaller object, and the AR, which defines the extent to which the objects are interconnected. Dimensional characteristics refer to the size of channel objects (thickness and width). Distribution of petrophysical properties (porosity and permeability) in the 'net' sandstone mimics the grain-size fining in vertical and lateral directions at relevant scale to create more realistic reservoir flow simulation models.

A sector of a reservoir scale channel complex flow model is used for sensitivity analysis of the hierarchical resolution (i.e., channel complex constrained to channel storey and bed scale respectively) on static connectivity and dynamic flow behaviour. The analysis reveals that bed resolution models have higher static connectivity than channel storey scale models, which is responsible for higher recovery factor and pore volume of water injected for them.

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Travel time tomography on Rockall Basin

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First-arrival travel time tomography is being used to obtain the image of sub-surface structure at various scales. We have applied first-arrival travel time tomography on 10 km long streamer data set acquired from the Rockall Basin. We start with downward continuation (DC) of 10-km long streamer data set that was recorded in 2013-2014 for the interest of industry and research purposes. DC is an efficient technique to extrapolate the recorded wavefield to an arbitrary surface. The DC process is carried out in three steps: (1) extrapolation of the receiver gathers vertically down to a particular datum ~100-200 m above the seafloor, (2) sorting of the extrapolated shot gathers into common receiver location gathers (CRL) and (3) DC of the shot positions to the seafloor and sorting back into shot gathers. DC improves

first arrival and increases the moveout, because more rays converge in the shallow sub-surface. That gives us an improved velocity model in shallow sub-surface. After DC, we pick the first-arrival travel time and apply travel time tomography to obtain the 2D velocity-depth model. We observe a very high velocity structure (~ 6-7 km/s) 3 km down to the seafloor and the velocity model follows the geological structure obtained by the pre-stack time migration. This velocity model is being used as starting velocity model for full-waveform inversion to obtain a high-resolution velocity model.

Acknowledgement.

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Application of image analysis in textural characterisation of sedimentary grains

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Textural analysis of siliciclastic sedimentary grains is an important source of information regarding the processes involved in their formation, transportation and deposition. However, a standardised approach for quantitative grain shape analysis is generally lacking. In this contribution we report on a study where fully automated image analysis techniques were applied to loose sediment samples and lithified samples. Unconsolidated sediment samples were collected from glacial, aeolian, beach and fluvial environments. Sandstone samples of fluvial and aeolian origin were sampled from across Dingle group and Caherbla group of the Dingle Basin. A range of shape parameters are evaluated for their usefulness in textural characterisation of populations of grains. The data gathered demonstrates a clear progression in textural maturity in terms of roundness, angularity, irregularity, fractal dimension, convexity, solidity and rectangularity. Textural maturity can be readily categorised using automated grain shape parameter analysis. However, absolute discrimination between different depositional environments on the basis of shape parameters alone is less certain. For example, the aeolian environment is quite distinct whereas fluvial, glacial and beach samples are inherently variable and tend to overlap each other in terms of textural maturity. This is most likely due to a collection of similar processes and sources operating within these environments. This study strongly demonstrates the merit of quantitative population-based shape parameter analysis of texture and indicates that it can play a key role in characterising both loose and consolidated sediments.

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Comparing the relationship between net:gross and connectivity using different conventional facies modelling methods

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The ability to generate geologically realistic reservoir models is an important step in predicting reservoir behaviour. In situations where the reservoir sands are treated as permeable and shales impermeable,

King (1990) found that the link between the volume of connected sand and the net:gross ratio could be described by percolation theory, where at a particular net:gross (the percolation threshold), a cluster spanning the entire model is formed. At net:gross values below this, the system is disconnected and above this value the connectivity rapidly rises. A percolation threshold of 27% net:gross exists for randomly distributed 3D objects (King, 1990), but subsequent work has shown that because of non-randomness such as compensational stacking, many geological systems are poorly connected at high net:gross ratios.

Many deep marine turbidite reservoirs are characterised by poorly amalgamated sand bodies interbedded with low permeability shales. Although these systems often have high net:gross ratios, the low connectivity of the sandstones has a strong control on reservoir performance but is often poorly reproduced in reservoir geomodels. This study compares four different conventional modelling techniques; sequential indicator simulation, truncated Gaussian simulation, object-based modelling and multiple-point statistics; investigating if the same relationship between sand connectivity and net:gross ratio is present regardless of which method is applied. It has been found that all four facies modelling methods are controlled by the random percolation threshold. Therefore, a different approach must be taken when modelling high net:gross systems with poor connectivity.

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From rifting to hyperextension: Implications for petroleum play development in the Porcupine Basin, Ireland

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The Porcupine Basin, located on the Irish Atlantic Margin, is a 'failed' rift whereby hyperextended rifting terminated before oceanic crust could form. West-East extension during the Middle- to Late-Jurassic was followed by a protracted phase of thermally-induced subsidence, resulting in a catenary-shaped Cretaceous succession up to 6 km thick. The rift displays evidence for a strong southward increase in lateral strain, abruptly transitioning from 'normal'-extended (low-magnitude extension) crust in the north to thinned hyperextended crust with potentially exhumed mantle towards the south. The timing of rifting and mechanisms involved during the evolution from normal-rifting to hyperextension are currently poorly constrained. However, the presence of variably-developed unconformity-bounded sequences draped above highly-faulted topography form an important transition between the syn-rift and post-rift, providing a means to better constrain the age of rifting. As Tithonian source rock intervals are associated with these transitional packages, their distribution has important implications for petroleum exploration.

The present tectonostratigraphic study integrates extensive 2D and 3D seismic data with well information to analyse the timing, composition and distribution of syn-rift to post-rift sequences. The spatial and temporal distribution of the syn-rift to post-rift sequences reveals a diachronously-formed, and predominantly asymmetrical, rift system with significant compartmentalisation. This work demonstrates the influence of inherited pre-existing crustal fabrics and structures during the progression to hyperextension. In addition to source rock potential, this study has implications for reservoir presence and trapping potential in the hyperextended setting.

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Testing for potential diagenetic bias in the Pb isotopic composition of detrital K-feldspar

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The common Pb isotopic composition of K-feldspar is increasingly employed in provenance and sediment tracking studies. It is well known that K-feldspar abundances can be significantly affected by burial and diagenesis. A key question is whether the progressive removal of K-feldspar via diagenetic reactions can bias the Pb isotopic composition of the feldspars that remain. A good place to test whether bias is introduced is the middle Jurassic Fulmar Formation in the Central North Sea. This comprises a succession of sands that were differentially buried to a range of depths between 3.2 and 6 km. Framework mineral abundances have been quantified using a novel imaging technique, recognising that it is easy to overlook detrital and/or diagenetic feldspar in the subsurface. BSE SEM imaging combined with element mapping confirms the framework composition changes with burial depth with K-feldspar >40% at 3.2 km depth, but only ~8% at 5.8 km depth. However, element mapping reveals that the plagioclase increases from ~3% at 3.2 km to ~20% at 5.8 km. The SEM imaging is used to document progressive dissolution of the remaining K-feldspar with burial and a proportionate increase in corroded grains. Pb isotope analyses of both the fresh and corroded K-feldspars by LA-ICPMS identifies the same main populations in all the samples, and whilst these vary in relative abundance with burial depth, no systematic pattern is revealed and hence these variations are thought to reflect changes in provenance rather than selective purging by dissolution and albitisation.

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