PIP
Petroleum Infrastructure Programme

31st October and 1st November

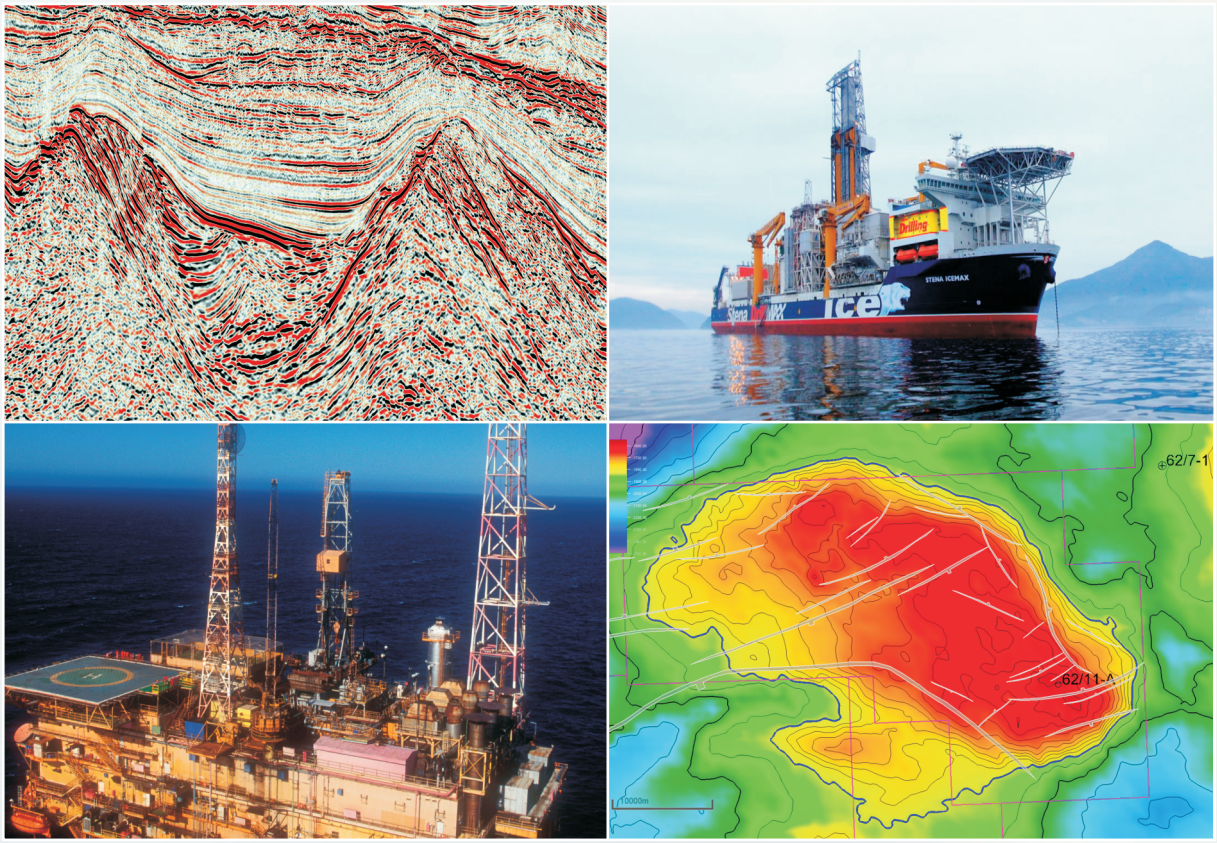
Atlantic Ireland 2017

Clayton Hotel - Burlington Road
Upper Leeson Street, Dublin 4

A Petroleum Conference Organised by PIP-ISPSG

A two-day conference and exhibition on Ireland's offshore hydrocarbon potential

Abstracts Volume



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ATLANTIC IRELAND 2017

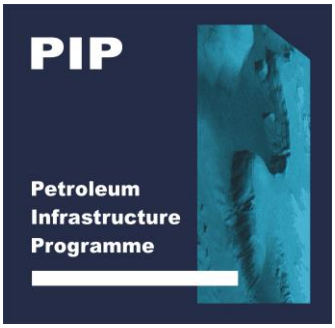
A Two Day Conference and Exhibition on Ireland's Offshore Hydrocarbon Potential Sponsored by PIP-ISPSG

PROGRAMME AND ABSTRACTS

Location: **Clayton Hotel, Burlington Road, Dublin, Ireland**

Date: **31st October – 08.00 to 19.00hrs &**
1st November 2017 – 08.00 to 13.00hrs

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



Edited by

Martin Davies & Charlie Carlisle

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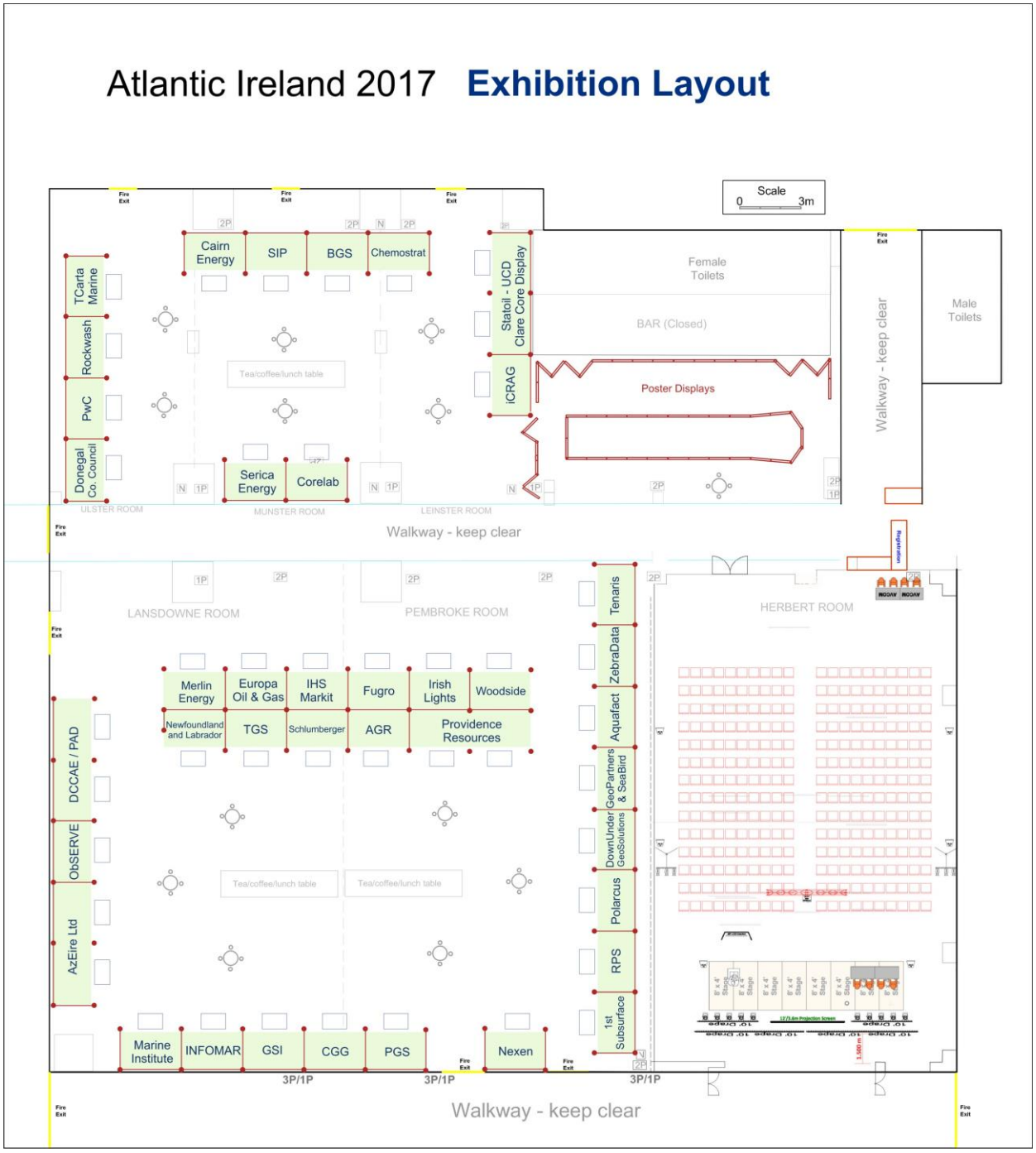

Technical Programme

Atlantic Ireland 2017 - Technical Programme

TUESDAY 31st October 2017 - Morning

08.00 - 08.55 **Reception - Coffee / Tea available in Exhibition Rooms**

08.55 - 09.00 *Welcome to Delegates*

09.00 - 09.30 **Address by Minister of State (DCCAE) - Seán Kyne TD**

09.30 - 10.40 **Session 1 - Government Initiatives**
Chair - Matthew Collins (DCCAE)

Clare Morgan (DCCAE/PAD) - "The Status of Exploration Offshore Ireland: New Data - New Knowledge"

Bill Morrissey (DCCAE/PAD) - "Policy regulatory update for the Irish offshore"

Chris Reynolds (Irish Coast Guard) - "Offshore Regulations"

Nick O'Neill (PIP Secretariat) - "Irish Shelf Petroleum Studies Group - De-Risking Hydrocarbon Exploration Offshore Ireland"

10.40 - 11.30 **Coffee Break and Poster Session** Kindly Sponsored by: nalcor energy, Newfoundland Labrador

11.30 - 12.50 **Session 2 - Regional Perspectives** Kindly Sponsored by CNOOC nexen
Chair - Rachel Whyte (ExxonMobil)

Ben Tomsett (Nexen) - "Evolution and prospectivity potential of Jurassic pre-to syn-rift sequences of the western Porcupine Basin margin"

Ian Sharp (Statoil) - "Rift to drift evolution and hyperextension in the North Atlantic - insights from a super-regional approach"

Stephen Corfield (Cairn Energy) - "New Aspects of the Petroleum System of the Porcupine Basin, West of Ireland"

David Sturt (AzEire) - "A holistic, technology focused approach unveiling new exciting prospectivity in the Porcupine, Fastnet and North Celtic Sea Basins, Offshore Ireland"

Andy Holman (CGG) - "The application of advanced seismic processing in the South Porcupine Basin"

Questions

12.50 - 14.00 **Lunch** Kindly Sponsored by Statoil

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Atlantic Ireland 2017 - Technical Programme

TUESDAY 31st October 2017 - Afternoon

14.00 - 15.05 **Session 3 - Research and Innovation**
Chair - Kara English (PAD)

Kindly Sponsored by EUROPA Oil & Gas

John Walsh (iCRAG) - "Irish Centre for Research in Applied Geosciences (iCRAG) - Progress to date and plans for 2018"

Tim McCarthy (NUI Maynooth) - "MarineWatch Demonstrator: Satellite & Drone Sensor Platforms" (iCRAG)

Peter Haughton (UCD) - "Emerging insights from iCRAG research focussing on Ireland's offshore basins"

Steve Jewell (on behalf of Kinetic Well Engineering) - "Strong Drilling Performance in a Remote, Harsh Operating Environment Offshore Ireland"

Questions

15.05 - 15.45 **Coffee Break and Poster Session** Kindly Sponsored by TULLOW

15.45 - 17.00 **Session 4 - Prospects and Opportunities**
Chair - Alan Blacklaw (Nexen)

Keith Byrne (Providence Resources) - "The Newgrange 62/11-A well - Ultra-shallow exploration in deep water"

Andrew McCarthy (Woodside) - "A multi-disciplinary approach to de-risking Porcupine Basin plays"

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

Myles Watson (Providence Resources) - "Subsurface considerations in planning the 48/24-K Barryroe East Flank appraisal well programme"

Graham Pritchard (Serica Energy) - "Giant Structural Closures in the Rockall Basin: New Insights into Reservoir and Source Rock Characteristics"

17.00 - 19.00 **Posters and Reception** Kindly Sponsored by Azeire, PROVIDENCE, nalcor energy, Newfoundland Labrador

Atlantic Ireland 2017

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Atlantic Ireland 2017 - Technical Programme

WEDNESDAY 1st NOVEMBER 2017

08.00 - 09.00 **Reception - Coffee / Tea available in Exhibition Rooms**

09.00 - 10.50 **Session 5 - Conjugate Margins – New Thinking**
Chair - John Conroy (Shell)
Kindly Sponsored by nexen

Ian Atkinson (Nalcor Energy) - "Newfoundland and Labrador Update: South Labrador"

Jon Hunt (NUI Galway) - "Fluid Inclusion and Mineral Liberation Analysis - A twin-track approach to the study of well cuttings from hydrocarbon prospective basins in the Newfoundland and Labrador Offshore Massif"

James Armstrong (Petroleum Systems Ltd) - "Oils of the North Atlantic: long lost families or just a similitude of strangers?"

Philip Copestake (Merlin Energy Resources Ltd) - "A Biostratigraphic, Lithostratigraphic & Sequence Stratigraphic Framework for Offshore Ireland"

Malcolm Gall (Oil and Gas Authority UK) - "Stimulating Frontier Exploration Activity on the UKCS"

Questions

10.50 - 11.30 **Coffee Break and Poster Session**

11.30 - 12.45 **Session 6 - New Data and Technologies**
Chair - Gareth Parry (Woodside)

Mark Jessopp (UCC) - "Abundance and distribution of protected cetaceans and seabirds in Irish waters: results from the two year ObSERVE Aerial project"

Simon Berrow (GMIT) - "ObSERVE Acoustic surveys for cetaceans in the Irish Atlantic Margin"

Andy Wheeler (UCC) - "ROV technologies for targeted rock drilling, coring and exploration of sensitive environment"

Dave Naylor (Petrel Resources) - "Prospects within Licensing Option 16/24, North-Western Porcupine Basin"

Allan McKay (PGS) - "De-Risking Exploration Offshore Ireland Using Towed Streamer EM and Seismic Data"

Questions

12.45 - 12.55 Closing Speech - **Pat Shannon** (IOOA / UCD)

12.55 - 13.00 **Martin Davies** (PIP) - Closing Remarks

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Cairn

Discovering Hidden Value

Cairn is one of the largest acreage holders in the Porcupine Basin, Ireland with equity in five Licences and Licence Options. A participant in the important deep water 53/6-1 exploration well during 2017, Cairn has also been a lead sponsor of two large 3D surveys in the area.

With near term production in the North Sea (Kraken and Catcher Fields) Cairn has significant growth opportunities in emerging basins such as Mexico, the Barents Sea and Senegal, where Cairn discovered oil in 2014 and has recently completed a successful appraisal campaign.

Cairn Energy PLC is an independent,
UK based oil and gas exploration and development company.

ORAL ABSTRACTS (in order of presentation - speaker is underlined)

Status of Exploration Offshore Ireland - New data, New Knowledge

Morgan, C.[1]

[1] *Department 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 licensing and regulating oil and gas E&P activities, both offshore and onshore Ireland. Our role extends from policy development to promoting the opportunity to invest in exploration in the Irish offshore to licensing and the regulation of licensed E&P activities. PAD also plays a lead role in initiating and supporting research directed at deepening knowledge of the petroleum potential of the Irish offshore.

The current status of exploration offshore Ireland is robust, despite the continued low oil price globally. Key performance indicators such as the number of active petroleum licences, the quantity of licence applications, the quality of associated work programmes, the number and calibre of companies as operators or joint venture partners, the amount of new seismic surveys acquired, forecasted drilling operations, the level of visits to the PAD dataroom & corestore and technical data sales, are all positive.

The number of exploration authorisations in recent years is at the highest level since exploration began in the Irish offshore in the 1970s. The current petroleum Concession Map offshore Ireland (Fig. 1) is healthy, particularly in the Porcupine Basin. Acreage awarded as a result of the 2015 Atlantic Margin Licensing Round (28 new Licence Options awarded to 14 companies) was granted in two stages in February and June 2016, with more than 75% of the awards located in the Porcupine Basin. The vast majority of licences awarded were a Licence Option of 2 years' duration, therefore companies are currently actively evaluating awarded acreage, to inform their decision on whether to convert the Licence Option to a Frontier Exploration Licence. Furthermore, the recent entry of additional exploration companies to the Irish Atlantic Margin, via farm-ins is welcomed.

A feature of the 2015 Licensing Round included strong work programmes associated with licences issued, in particular, a commitment to acquire and process new seismic survey data. As in 2016, there was a lot of seismic activity in 2017. Three very large separate 3D seismic surveys (total of 12,500sqkm) and a regional 2D seismic survey (1,700km) were acquired this summer, all located in the Porcupine Basin, mostly across licenced blocks.

This year also saw the drilling of the much anticipated deepwater Druid/Drombeg well 53/6-1, by Providence Resources and JV partners - the only well drilled offshore Ireland in 2017. The exploration well was a wildcat vertical well located in Frontier Exploration Licence 2/14 in the southern Porcupine Basin in c. 2,233m of water (the deepest water of any exploration well ever drilled offshore Ireland) and c. 220km off the southwest coast of Ireland. The well spudded on 11 July 2017 and had two targets to penetrate – the Palaeocene Druid prospect and the Lower Cretaceous Drombeg prospect. Logging together with down-hole sampling confirmed the presence of a porous water-wet reservoir interval encountered at both targets within pre-drill depth prognosis, with no commercially recoverable hydrocarbons. Following a comprehensive data acquisition programme, the well was plugged and abandoned as per programme. The new well data, when released, provides a valuable control point in a frontier area and results will be analysed and integrated into ongoing interpretations. The new data will provide new knowledge on play fairway mapping in the Porcupine Basin.

The Celtic Sea area continues to attract interest and a number of new Licensing Options and licence applications, with associated significant work programmes, have been awarded in the basin in recent years.

Petroleum production continued during 2017 from the Corrib gas field in the Slyne Basin and from the Kinsale field complex, the latter with declining gas production.

In respect of new legislation - the Oireachtas enacted the Petroleum and other Minerals Development (Prohibition of onshore hydraulic fracturing) Act 2017 on the 6th of July 2017.

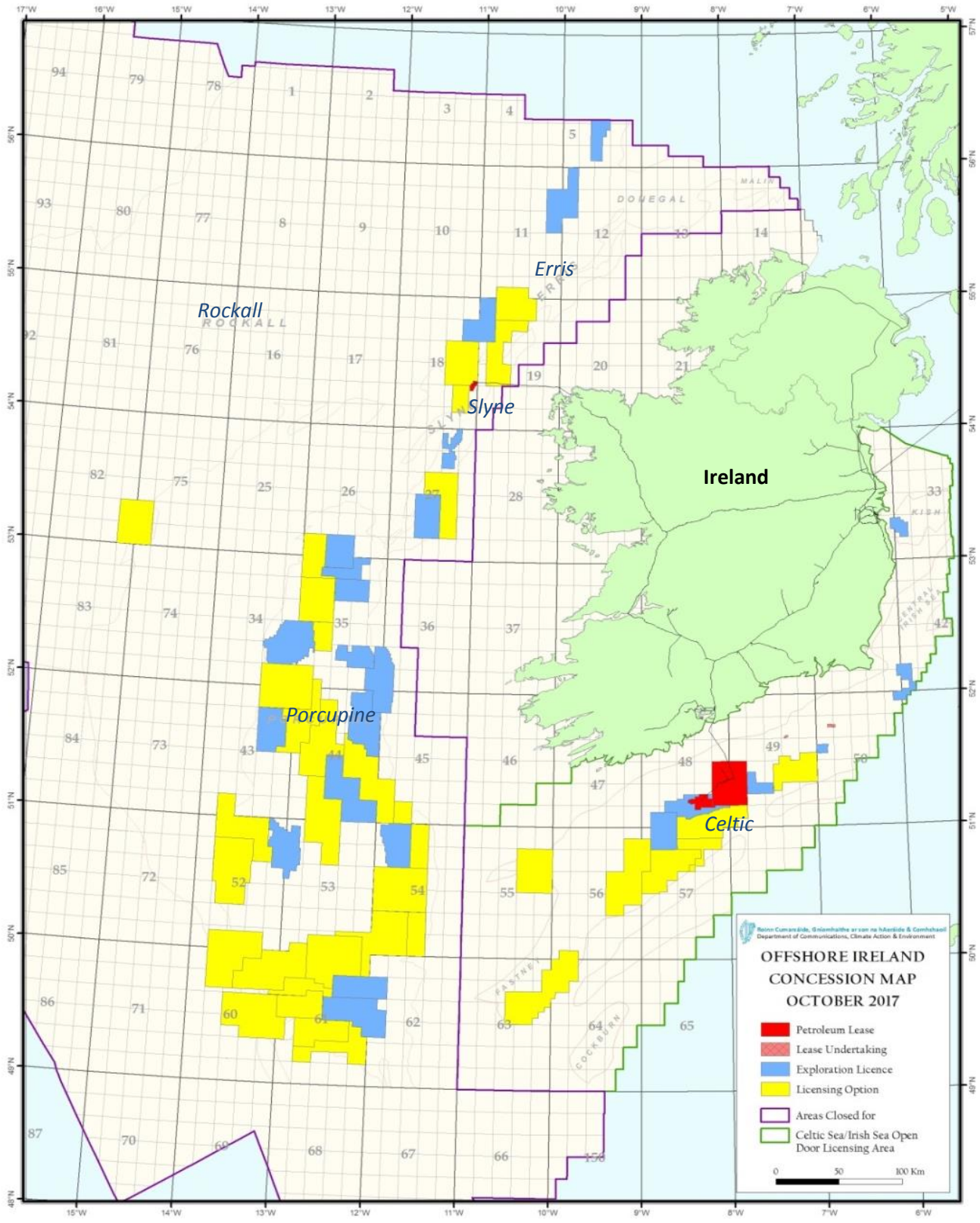
The PAD has an ongoing Promotional Strategy to inform the general public, companies, contractors, governments and researchers about E&P opportunities offshore Ireland and to encourage investment in our petroleum sector. The campaign has been effective in proactively outlining the prospectivity of Ireland's offshore basins, and particularly successful in recent years where the focus was on promoting the frontier Atlantic Margin. As in previous years, the promotional effort is carefully designed to spread throughout the calendar year, with specific, timely objectives, targeting a range of audiences nationally and internationally. In 2017 the promotional strategy included attendance and hosting a PAD booth at new venues, in an effort to target, inform and expand Australasian petroleum interests offshore Ireland. Engagement at this early stage with potentially new Far Eastern companies allows for the typical long lead-in time required to build robust relationships and initiate and develop new contacts in the interim period before the next Licensing Round. The campaign is supported by follow-up Dataroom appointments.

The Department's outreach programme continued in 2017 by taking a booth at BT Young Scientists' exhibition in Dublin and Seafest in Galway and by contributing to the Science & Technology in Action lesson plan for distribution to over 700 secondary schools in Ireland.

New data have provided new insights into our geological understanding of the basins offshore Ireland. A wide variety of exploration targets continue to be recognised including stratigraphic and structural traps in all our basins. Research initiatives, through PIP, iCRAG and NAPSA, aimed at deepening knowledge of the petroleum potential of Ireland's offshore continued in 2017. For example, 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 is in the final stages of completion. Other Department sponsored research projects have developed substantially, with new projects initiated in 2017 including the Drilling Downtime study. The ongoing Bio/Litho/Stratigraphic study is progressing as planned to provide a new, updated stratigraphic framework for all Irish offshore basins. The baseline aerial and acoustic data acquisition of the ObSERVE programme was completed this year and results are currently being compiled and analysed.

The knowledge gained from new technical data and petroleum research studies should assist in de-risking the prospectivity offshore and promote frontier and under-explored areas. Never before has the State had such good quality regional subsurface seismic coverage, including a new well control point (53/6-1) and substantial oil players (including international majors, mid capital companies and smaller companies) over blocks never previously licensed.

Oil and gas exploration offshore Ireland continues to be vital in order to provide energy security. The Department initiatives to support effective exploration to date have demonstrated how targeted intervention can have a positive effect in an emerging petroleum province and indications are that E&P interest will keep momentum in future years. The Department will continue to maintain an effective regulatory framework, continue to promote the investment opportunity, develop and manage appropriate and innovative licensing initiatives, facilitate data provision, take steps to address data gaps and continue to support, encourage, develop and participate in research projects.



Exploration interest offshore Ireland is demonstrated by the current Concession Map

Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment
Petroleum Affairs

Irish Shelf Petroleum Studies Group – De-Risking Hydrocarbon Exploration Offshore Ireland

O'Neill, N.[1]

[1] *ISPSG Secretariat* *Email: noneill@pip.ie*

The Irish Shelf Petroleum Studies Group (ISPSG) forms part of the Irish Petroleum Infrastructure Programme (PIP). PIP was founded 20 years ago this month and is an excellent example of successful industry-government research collaboration.

The ISPSG continues to respond to the needs of petroleum exploration companies exploring offshore Ireland. Regular member company workshops set priorities for multi-annual research activities. At the workshop held in 2015 members agreed that a litho and biostratigraphic framework for offshore Ireland was needed as a priority. A large-scale project to address this was initiated in 2016 and is now well advanced, aided by an active steering committee and significant input from the Petroleum Affairs Division and member companies. As with all projects of this scale, there has been a significant amount of data gathering, quality control and integration of old and new datasets which delivers significant assistance to new entrants to Irish exploration. A Stratigraphic Nomenclature Committee (SNC) has been set up to review the results from the Litho-biostratigraphic project and to recommend a robust and workable stratigraphic nomenclature for the Irish offshore basins that would have academic and industry buy-in. The Committee met for the first time in September, and future meetings are planned soon.

The need for a comprehensive source rock study of the conjugate margin basins offshore Ireland and Newfoundland and Labrador was identified many years ago. That study has now been completed, and the "Atlas of Source Rock in Mesozoic Basins of the North Atlantic Conjugate Margin, Offshore Newfoundland-Labrador and Offshore Ireland" (Beicip-Franlab, 2017) is in the final editing stages. By now all member companies will have received the comprehensive source rock and oil typing database generated by this very significant project. This project is another successful joint initiative with Newfoundland and Labrador through NAPSA, the North Atlantic Petroleum System Assessment group. During this week the NAPSA agreement will be formally renewed for another five years at a ceremony to be held at the Canadian Embassy.

At a well-attended members' workshop held in March this year, ISPSG research priorities were set for the next three years. The workshop provided members with an opportunity to collaborate in forming a common view and provide a clear direction for research to address the shared problems and issues in hydrocarbon exploration offshore Ireland. The members present established three key priorities under the headings Outreach, Engineering, Environmental, Geology & Geophysics, which will become the focus of ISPSG activities over the next three years.

ISPSG continues to support and direct the Irish Centre for Applied Geoscience (iCRAG). Many of you are participants on the Technical Advisory Committees that influence the future direction of iCRAG research. There was a large attendance at the recent iCRAG Porcupine Basin Workshop that brought together iCRAG researchers and ISPSG company members to discuss early research findings and influence the future direction of those projects. There has been significant feedback and follow up from this workshop with researchers invited by ISPSG member companies to attend in-house meetings to further develop exploration concepts.

Over the next two days, you will have the opportunity to hear presentations and view the posters of the many ongoing research projects 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.

Atlantic Ireland 2016 – Members of the Petroleum Affairs Division in discussion with Minister for State Seán Kyne

We would like to take this opportunity to thank all the ISPSG member companies who have actively engaged as mentors of projects, participated in project Steering Committees and contributed to our various workshops. As our President Michael D Higgins often says – "Ní neart go cur le chéile". There is no strength without unity.

Evolution and Prospectivity Potential of Jurassic Pre- to Syn-Rift Sequences of the Western Porcupine Basin Margin

Tomsett, B.[1], Jones, N.[1], Slater, L.[1], Jones, G.[1]

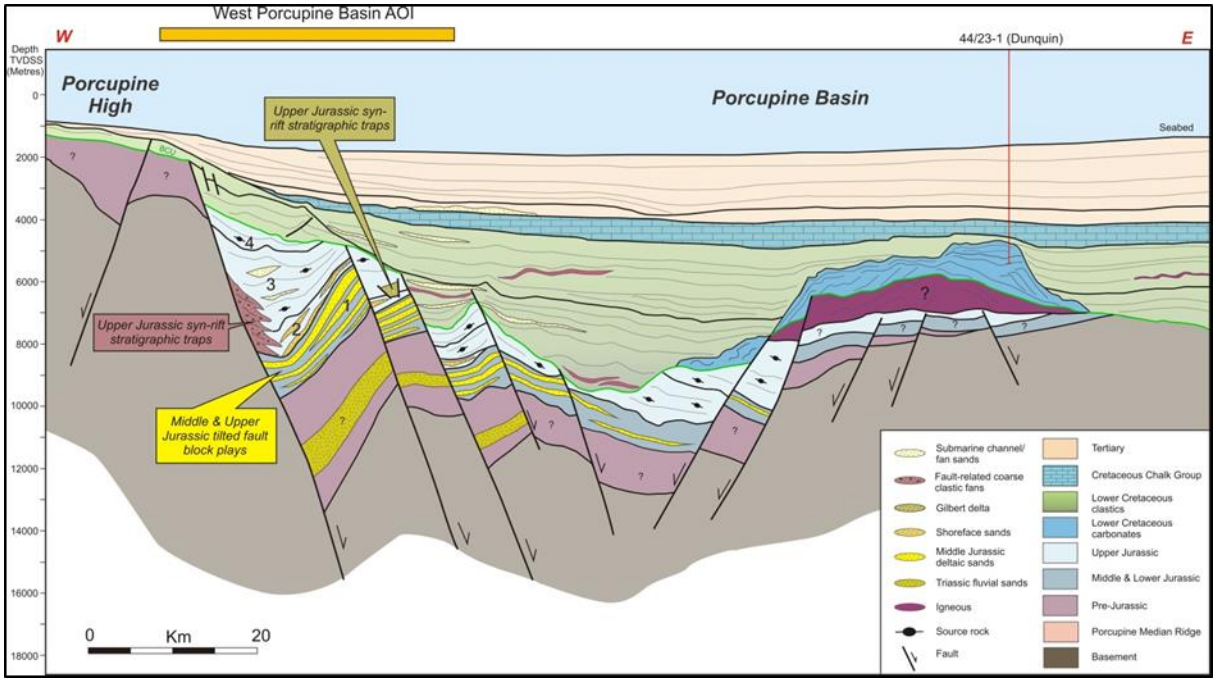
[1] *CNOOCNexen, Uxbridge, UK* *Email: Ben.Tomsett@nexencnoocltd.com*

Mesozoic basin margin structural plays have long formed exploration targets in the frontier Porcupine Basin, not least due to their strong apparent similarities to the giant fields of the North Sea province. A number of wells have tested this play in the northern part of the Porcupine Basin, with several proving trapped hydrocarbons, mostly oil. More recently, interest has been further renewed following discoveries on the Canadian conjugate margin in plays of this age. CNOOCNexen secured Licensing Option (LO) 16/7 in the 2015 Ireland bid round to capture a position in the primary Jurassic structural plays, together with secondary Cretaceous and Tertiary stratigraphic play potential.

3D broadband seismic acquisition (Polarcus/Ion 2014), integrated with a large regional 2D database, has allowed detailed interpretation of the architecture and evolution of Jurassic plays on this LO and surrounds. Structural mapping has shown that an approximately NNE-SSW trending Late Jurassic aged extensional rift system is present in the area, which forms a large-scale extensional fault relay system and associated structural nose, comparable to the Beryl Embayment in the North Sea. Tilted fault blocks and faulted anticline traps are seen at Jurassic levels, the largest of which (Iolar Prospect, 80km^2), is comparable in size to giant Brent Province fields of the North Sea and contains an interpreted pre-rift Mid Jurassic sequence up to ca. 1000m thick.

Four main Mid-Late Jurassic depositional sequences can be interpreted on seismic:

1. A pre-rift possible Lower to Middle Jurassic fluvial-deltaic sequence
2. early syn-rift transgressive sequence, interpreted as an Oxfordian marginal marine sequence deposited as rifting commenced
3. thick main syn-rift Kimmeridgian
4. Late syn-rift Tithonian sequences are interpreted to be developed below the Base Cretaceous Unconformity



Whilst the limited well control available makes exploring the play system challenging, 2D tie lines indicate that comparable seismic character packages were penetrated in part by BP's 43/13-1 well, 70 km to the north, significantly reducing the risk on both reservoir and source rock presence across the southwestern Porcupine terraces.

The key risks for the 16/7 Jurassic plays are considered to be reservoir quality and hydrocarbon migration pathways. Seismic data demonstrates that the Mesozoic sediments are derived from the Porcupine High to the west. This feature has likely been a potential source of reservoir quality sediment throughout Mesozoic and Cenozoic times, as also suggested by the outcome of recent drilling results in adjacent acreage. Combined with existing sequence stratigraphic facies prediction and seismic lithology indicators, this observation increases the chance of reservoir quality sands in the Jurassic play.

Extensive basin modelling and mapping of regional source rock potential in the adjacent West Porcupine Basin kitchens on high-quality long-offset and reprocessed 2D suggest that the Late Jurassic source rocks are widely developed. Finally, numerous short distance, fault-related migration pathways are expected to facilitate charge into the closures and charge will be further focused into the relay ramp as often seen in the North Sea.

Rift to Drift Evolution and Hyperextension in the North Atlantic – Insights from a Super-Regional Approach

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Unravelling the rift to drift evolution of the North Atlantic is key to place exploration opportunities within a super-regional basin evolution context. This is particularly the case for understanding the deposition, distribution and preservation of key source rock intervals. In this contribution, we outline the results of a regional exploration project that has addressed the plate tectonic and tectono-stratigraphic evolution of the greater North Atlantic Conjugate Margin (NACM). The study has focused on documenting the range of end member basins/margins developed in the NACM, from "failed" inboard rift systems such as the Porcupine, Flemish, Orphan, Jean d'Arc, Lusitanian and Galicia basins, to "successful" rift to drift margins, such as the Newfoundland and Iberian Atlantic margins. A unifying present-day observation based Structural Domain classification scheme is outlined (Figure 1), and evolutionary models presented (Figure 2) that could account for the observational domains.

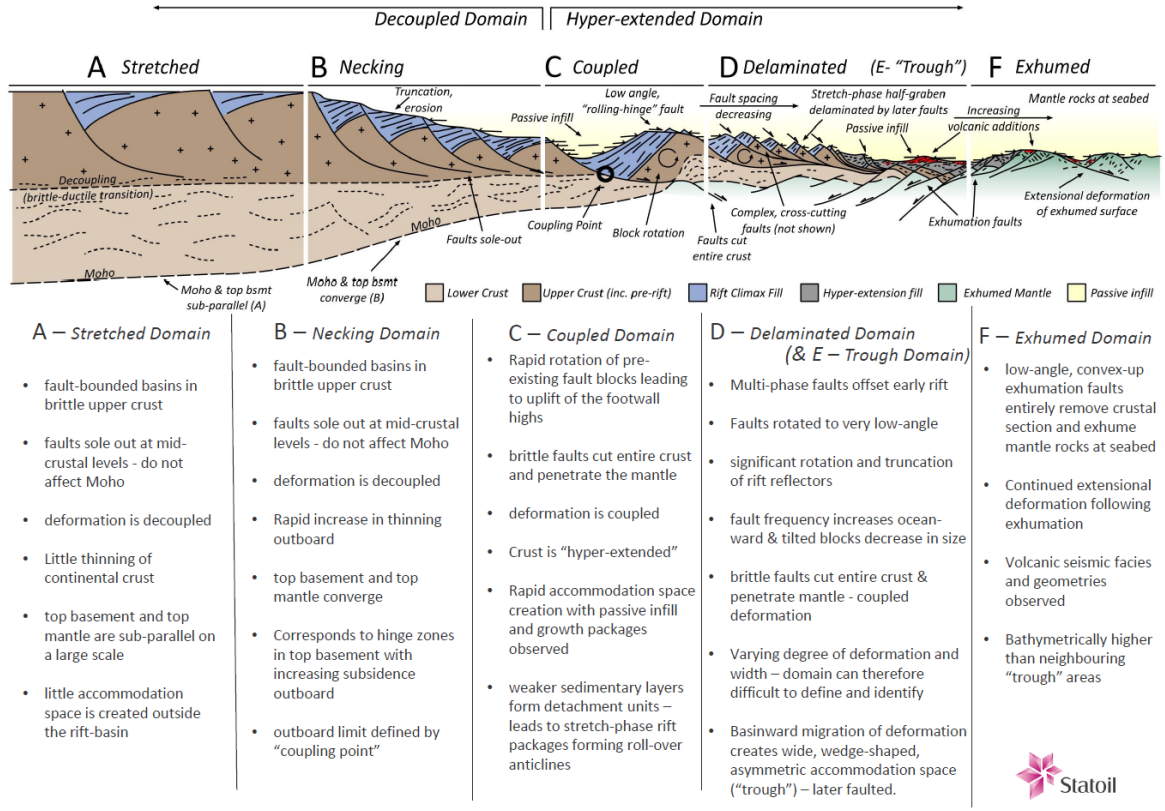

Figure 1: Structural Domain definitions within the NACM. Key observations and characteristics of each foundation domain are outlined. The scheme is based on case studies in a number of basins that border the NACM, including the Porcupine Basin (Figure 3)

Key themes that control basin evolution, structural style and eventual break-up in the NACM include ***i)*** the role of structural inheritance (Caledonide-Variscan fabrics and basement terranes), which impart a first order control on basin and fault segmentation, rift tip locations, structural style and early phases of basin fill (Triassic and older) ***ii)*** Poly-phase/pulsed extensional events - i.e. "Multirifting", from Permo-Triassic extensional collapse and distributed rifting, Early Jurassic passive subsidence, Mid Jurassic uplift and

volcanism, Late Jurassic rifting – ranging from decoupled rift climax half graben development (largely Oxfordian-Kimmeridgian) through to rift axis migration/focusing, fault coupling and the onset of hyperextension (largely Tithonian). The final stages of basin development can include eventual mantle exhumation, volcanic addition and, along "successful" rift to drift margins, eventual ocean crust emplacement. A further complicating post-break up modifier in the European basins is Alpine inversion, which has a marked impact on prospectivity. During this contribution we will show observations from a range of NACM basins, but will focus in on data, observations and implications for the Porcupine Basin.

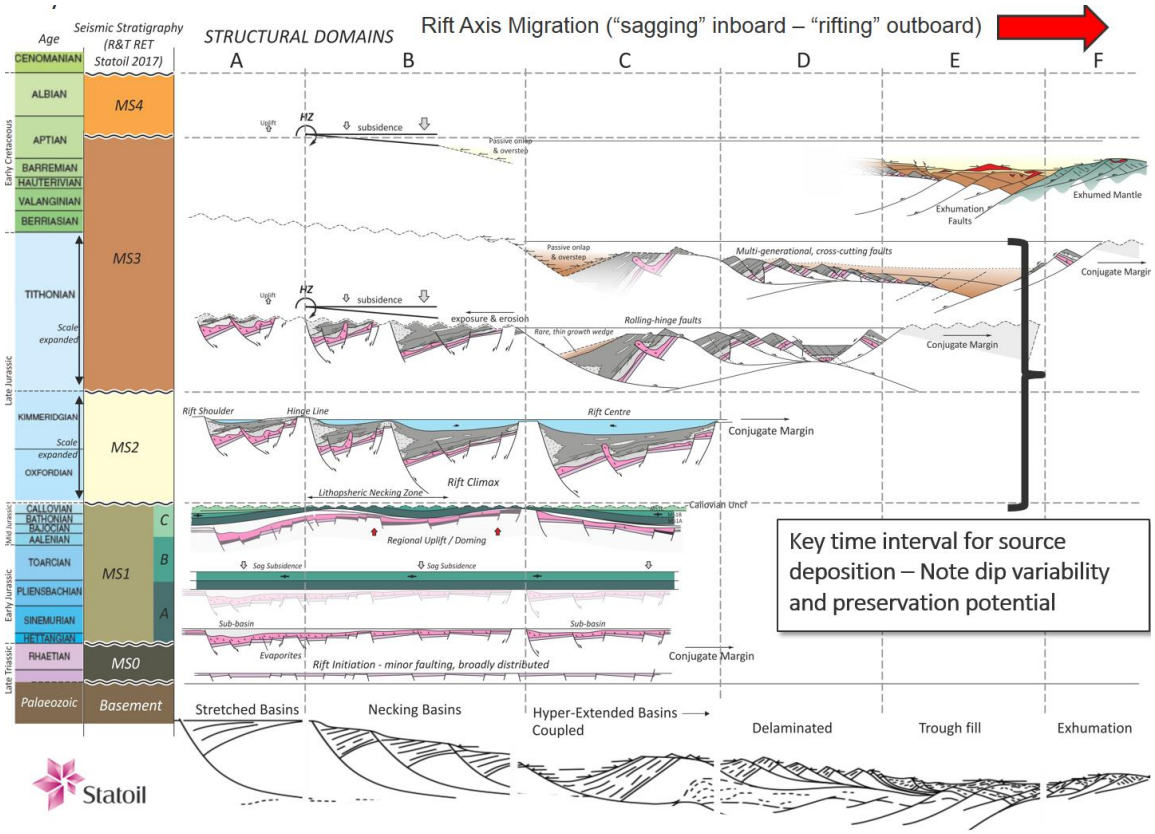

Figure 2: Conceptual time-space evolutionary model for rift to drift evolution within NACM basins

Extensional "Stages"		*Characteristics*	*NACM Basin Case Studies*
RIFTING	*- Rift Initiation to - Rift Climax & Necking*	*- Half-graben/graben sedimentary basins - Minimal thinning of continental crust - Minimal accomm. space outside rift-basin ...developing towards... - Rapid increase in thinning outboard - Top basement and top mantle converge - Faults sole out at mid-crustal levels*	*- Lusitania, Porto, GIB (prox) Alentejo (prox), Grand Banks (Whale, Carson, Horseshoe), Jeanne d'Arc, Flemish Pass, Porcupine (prox), Celtic Sea, Fastnet*
Key change in rift processes, subsidence & prospectivity	*decoupled coupled*		
HYPER-EXTENSION	*- Coupled crustal deformation*	*- Faults cut entire crust and intersect moho - Rotation of existing fault blocks - Multi-phase cross-cutting faults - Rapid subsidence - Sag-type basin over hyper-extended crust*	*- Perniche, Salar, Alentejo (distal), Orphan, Porcupine (central), GIB (central), Galicia Margin, Newfoundland Margin (Flem Cap*
EXHUMATION	*- Mantle exhumation - Increasing volcanic addition*	*- Serpentinised mantle rocks at seabed - Progressive oceanward migration of def. - Post-exhumation faulting with significant uplift of footwalls into "peridotite ridges" - Increasing intrusive & extrusive magmatism*	*- E.g. SIAP, Targus AP, Salar(distal)*
DRIFT	*- Unequivocal Oceanic Crust*	*- Potential pulse in magmatic activity to trigger final lithospheric breakup - No temporal or spatial mappable boundary*	*- E.g. Outboard of J-Anomaly NWFL-Iberia*

Figure 3: Extensional "stages", defining characteristics and NACM examples

New Aspects of the Petroleum System of the Porcupine Basin, West of Ireland

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Capricorn Ireland, a wholly owned subsidiary of Cairn Energy PLC, has been and remains an active operator in the Porcupine Basin for five years. Capricorn first acquired two frontier exploration licences in 2013 encompassing the discoveries of Spanish Point, a Jurassic gas and condensate field, and the Cretaceous Burren oil discovery. At this time, a third Licence Option was farmed in to and subsequently converted to a Frontier Exploration Licence. This licence covered the Ruadhan Ridge and Moling Sub-basin. All these licences were contained within the northern portion of the Porcupine Basin. From here, Capricorn has grown an asset position of five licences in both the north and south of the Porcupine Basin by means of farm-ins and the 2015 Atlantic Margin Licensing Round.

In 2016, Capricorn was awarded 100% equity and operatorship in Licence Option 16/18 on the northwest margin of the basin. This award was shortly followed by the farm-in to the adjacent licence LO 16/19 where a continuation of Cretaceous and Palaeocene plays was identified. Most recently Capricorn Ireland has farmed into the Frontier Exploration Licence 2/14 and participated in the 2017 exploration well targeting the Druid and Drombeg prospects. This well was the first exploration well to be drilled in the Porcupine Basin since 2013.

Preceding this growth in Capricorn's acreage position, significant investment in Capricorn's seismic and well databases has taken place including, but not limited to, the licensing of legacy and modern 2D and 3D seismic surveys. The most recent survey to be licensed is the TGS Crean Multiclient 3D survey covering 5,500km² including Capricorn's LO 16/18, LO 16/19 and surrounding acreage. With access to new data, Capricorn has been able to build a strong regional understanding of the petroleum system of the Porcupine Basin, resulting in Capricorn's highly active position offshore Ireland in the last two years.

To date, the Porcupine Basin has been viewed as analogous to the North Sea, the Flemish Pass or other basins in Eastern Canada. However important differences are now seen to play a big part in the petroleum system of the basin. An example of this is the identification of the hyperextended nature of the southern parts of this Mesozoic basin resulting in large areas where the Upper Jurassic source rock may be very thin or not present. The increase in modern seismic coverage has shown that the structural nature and history of the basin is more complex than originally thought. A shift away from a relatively simple asymmetrical basin morphology to that of one with distinct zones with differing structural architectures is now proposed to better reflect the observed basin geometries and internal structures. Examples of this architecture can be seen in the southwest of the basin, where large rifted fault blocks and terraces exist with at least two styles of faulting identified, 'basement linked' and 'non-basement linked' which sole out into an inferred early Jurassic or potentially Triassic, decollement surface. This architecture is in contrast to the southeast of the basin where a ramp-style architecture exists, in which structures tend to dip up towards the basin margins. This results in few large structural closures at the Base Cretaceous level (and shallower) having been generated such that there would have to be a higher reliance on combination or stratigraphic geometries in this area. These new regional aspects are discussed further in the paper.

Capricorn Ireland has significantly improved its mapping of the "Upper Jurassic" source rocks across the basin, identified the main play fairways and long-lived sediment entry points. Important correlations of old and young tectonic events to trap formation, charge and their seal integrity history has enabled Capricorn to target acreage with the best chance of encountering commercial hydrocarbon accumulations. Understanding the presence of numerous oil and gas shows in the existing wells has also been key. The integration of the data from the recent 53/6-1 (Druid and Drombeg) well, will also be important to better

understand the various Petroleum System elements. Capricorn has positioned itself in the basin (and continues to seek opportunities) to access each of the main Jurassic, Cretaceous and Palaeocene play types in an optimal position.

A robust regional understanding, based on a comprehensive subsurface database, has also been vital in allowing Capricorn Ireland to delineate prospects and leads in its existing licences, and screen the entire basin for new opportunities.

A Holistic, Technology-Focused Approach Unveiling New Exciting Prospectivity in the Porcupine, Fastnet and North Celtic Sea Basins, Offshore Ireland

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Holistic Definition (Business Dictionary): All-encompassing view based on the knowledge of the nature, functions, and properties of the components, their interactions, and their relationship to the whole.

As part of its wider Atlantic Margin strategy, Azimuth Group reviewed a number of candidate countries for entry based on key surface and subsurface criteria.

Ireland scored highly with a politically stable, attractive fiscal regime and an established oil and gas legislative system.

A review of the exploration history also pointed to a promising, but at that time overlooked, prospective area. A further attraction was the wealth of legacy seismic and well data readily available.

Azimuth Group, through its wholly-owned subsidiary AzEire Limited, entered Ireland by way of the acquisitions of Strike Oil and Charge Oil in 2012. This provided the company with an initial platform of three License Options, one in the North-West Porcupine and two in the Fastnet and North Celtic Sea Basins.

It is AzEire's view that the best way to assess the overlooked hydrocarbon potential of these areas was to review the basins in their totality through a thorough review of the extensive seismic, well and other data available in country. This led AzEire to acquire a significant database of all wells, 2D and 3D seismic at a very early stage.

Based on the positive outcome of these studies the Company was able to take an aggressive approach to acquiring licenses over what they believed to be the most interesting parts of these basins. It was also noted that there were some striking similarities to Namibia where Azimuth Group also holds a very significant footprint in the Walvis Basin. We strongly believe that a combination of our leading regional understanding and what we had learned about conjugate margins elsewhere led to further successful awards in the 2015 license round. Finally, the additional acquisition of a highly prospective FEL from a retiring explorer has provided AzEire with one of the largest acreage holdings Offshore Ireland (Figure 1).

Whilst holding extensive acreage positions helps build regional understanding and ensure exposure to all main play types, it is our belief that the use of modern technology is vital to be able to understand and identify the drillable prospects that are vital to successful exploration.

The short acquisition season in Ireland combined with a high level of activity and strict environment restrictions has meant that new seismic data acquisition has been at a premium. Whilst we have managed to acquire some new 2D and 3D broadband seismic, AzEire has also had to extract as much information from existing data as possible. Excellent geophysics in combination with modern pseudo broadband processing techniques, including de-ghosting and close attention to velocity model building, has led to some very impressive upgrading of signal quality in both legacy 2D and 3D seismic and additionally even in more modern 3D seismic.

These improvements are helping our interpreters gain new insights into the petroleum systems working in these basins. A fundamental reassessment of some of the widely held preconceptions about the Irish offshore has been undertaken based on these new images. The vastly improved signal quality means that rock physics, inversion and AVO techniques become more robust and reliable. Some of our early

findings have allowed the postulation of a viable Aptian / Barremian source rock releasing exploration from its reliance solely on a Jurassic source thereby opening the viable window for new prospects at different depths, positions and hydrocarbon phase.

This presentation will be illustrated with a number of examples which help show how these new ideas could ensure the recent revitalisation of exploration efforts in the region come to a successful conclusion this time around.

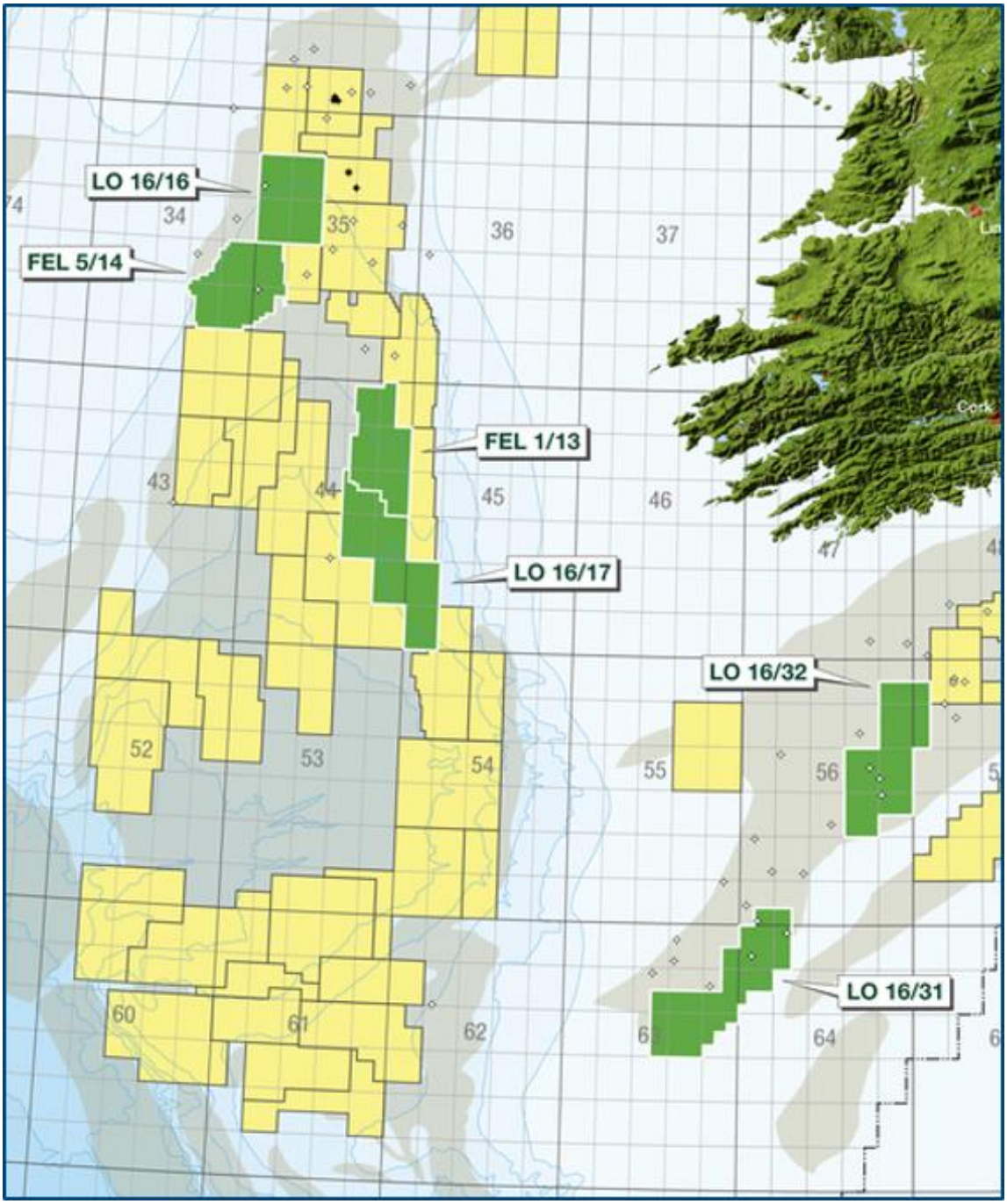

Figure 1: AzEire Licences and Licence Options, Offshore Atlantic Ireland

The Application of Advanced Seismic Processing in the South Porcupine Basin

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Introduction:

Exploration activity in the Atlantic margin has accelerated dramatically in recent years, and the interest generated by the 2015 licensing round reinforces the huge potential of the region. Within this area, the Porcupine basin has garnered particular attention. However, with the main seismic coverage of the Central and Southern Basin limited to legacy 2D data, this area now requires modern 3D seismic to further aid our understanding. Reservoir targets are expected within the Jurassic tilted fault blocks, but also potentially as stratigraphic traps within the Cretaceous turbidite fans. In order to fully resolve these features, the data requires an optimally-focused image and seismic reflectivity that is free from the interference of ghosts and free surface multiples. In this paper, we outline the advanced signal processing and imaging steps which were performed on newly acquired 3D seismic data with the objective of providing improved clarity and resolution in this key exploration area.

Geological setting:

The main hydrocarbon plays described in the South Porcupine Basin are found at Triassic/Jurassic, Lower Cretaceous and Tertiary stratigraphic levels. Syn-rift Jurassic tilted fault blocks observed at depth are truncated by a regional unconformity (namely the BCU: Base Cretaceous Unconformity). These fault blocks combined with the BCU can trap hydrocarbons within Triassic and Jurassic sandstone reservoir formations. The shallower Cretaceous and Tertiary targets comprise turbidite fans and channels and potentially some localised carbonate reef build-ups within the Lower Cretaceous. Throughout the basin, the likely hydrocarbon source is found in the Jurassic, which is stratigraphically well positioned to feed the Jurassic, Cretaceous and Tertiary reservoirs.

Seismic exploration focuses on imaging the Cretaceous-Tertiary turbidite systems, and the Jurassic tilted fault blocks in order to resolve their internal architecture, thin beds and potential pinch-outs.

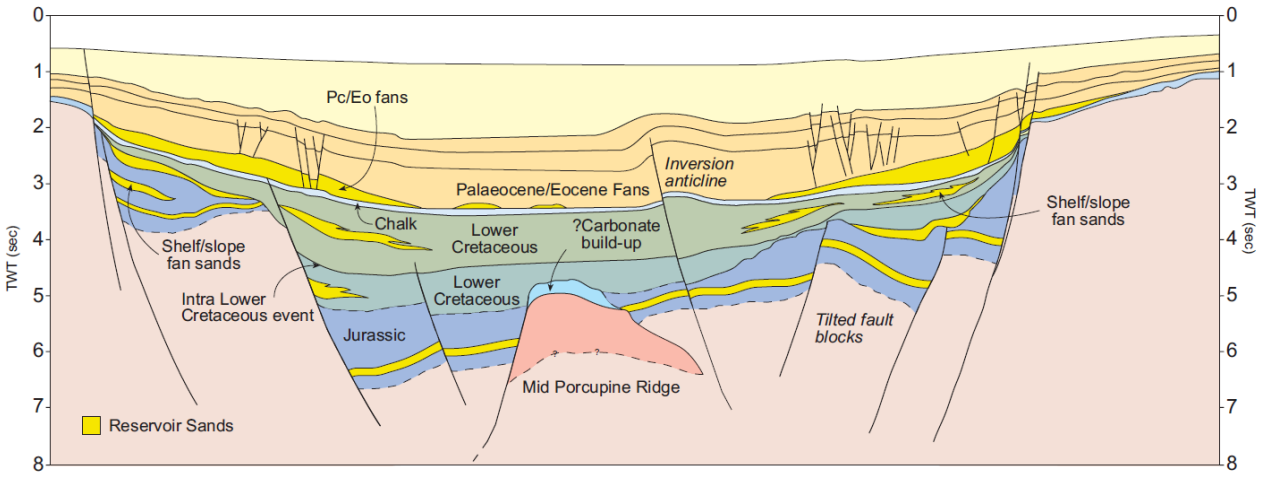

Figure 1: Geological section through the Porcupine Basin (extracted from PAD's 2006 Ternan study report)

Acquisition:

In 2016 two surveys were acquired in the central and southern Porcupine Basin, along with a tie line that linked to the nearby 62/7-1 well.

The two surveys are located in the northern half of Quadrant 52 and Quadrants 60, 61 and 53, and are approximately 1000 km^2 and 3100 km^2 in size respectively. Both surveys were acquired with the same configuration, comprising a twin source and 14 cables, with a length of 8000 m. Cables were towed at a depth of 12 m to provide a good balance between low-frequency content and reduced noise. With a source depth of 7 m, this places the source and receiver notches at 106 Hz and 62 Hz respectively. Overall the acquired data was of very good quality, aided by the deep-water setting (1000-3000 m water depth) and the relatively deep streamer tow.

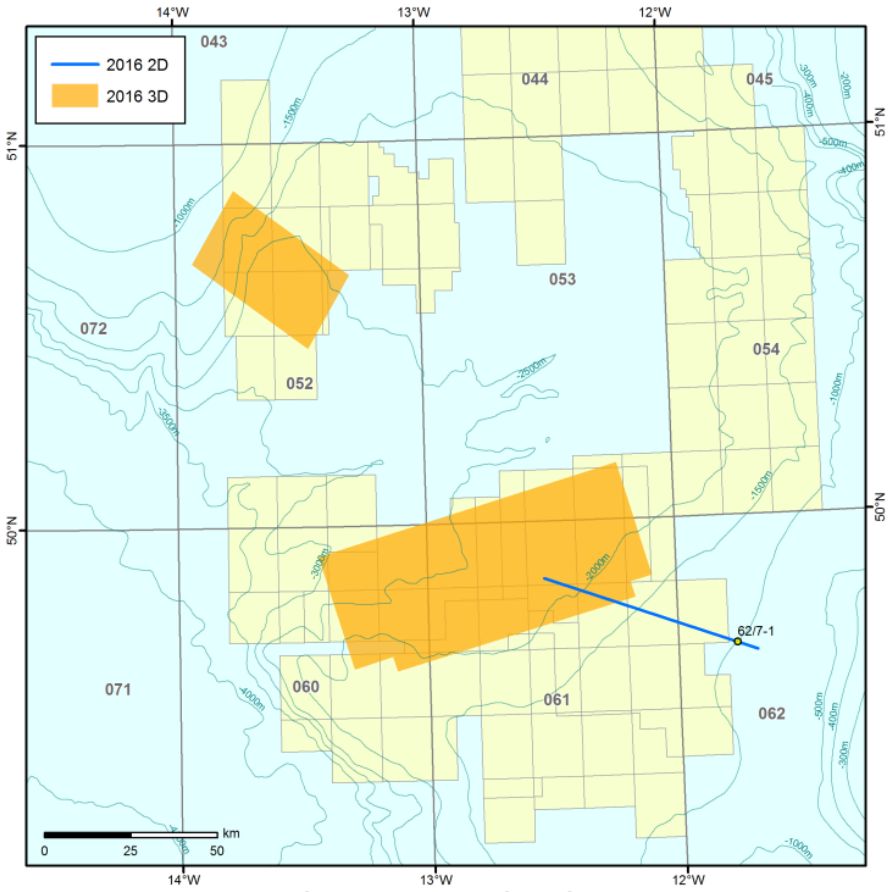

Figure 2: Survey locations

For both surveys, data acquisition was continued through the turns at the line-change on the Eastern end of the areas. This was principally carried out as a proof of concept to see if additional useable coverage to the prime data could be obtained and processed. Observations from this exercise are touched on later in this paper.

Processing and Imaging:

Deghosting is key to broadening the bandwidth of seismic data, leading to increased resolution of the reflection events. Deghosting is common practice in modern processing sequences, but significant advances have been made in recent years which have provided important uplifts. Near field hydrophone data recorded throughout acquisition was used to invert for the notional source signature for each gun within the source array. This information was then used as part of a modified 2D sparse Tau-P inversion

scheme to perform joint debubbling and source deghosting, (Poole et al., 2016). Receiver deghosting was also performed using sparse Tau-P inversion but this time accounting for the variability in the sea state, resulting in a more accurate modelling and attenuation of the receiver ghost (King et al., 2016). Final residual dephasing and gun signature shaping was then carried out on the debubbled and deghosted data. The 'turn-data' processing utilised a 3D implementation of the inversion scheme for deghosting to ensure an optimal result. The end result of the deghosting stage was a dataset with broad bandwidth and well controlled phase across the frequency spectrum.

Multiple attenuation in deep-water settings is much less of a challenge than it is for example in the central North Sea. In these two datasets, the first bounce free-surface multiple generally comes in fairly deep, however in some areas it runs through the upper Jurassic, meaning it needs to be handled carefully to avoid noise contamination following migration. The 3D SRME modelling utilised un-binned input sail line data in order to make full use of all available traces honouring their recorded azimuth. Historically binned data had been used for 3D surface-related multiple elimination (SRME) to ensure a regular distribution of shots and receivers for trace convolution within the aperture for multiple contribution gathering. The use of un-binned data on this project resulted in better modelling of small-scale diffracted features, ultimately leading to an improved subtraction result. The true azimuth nature of the modelling technique also meant that it was equally as effective on the 'turn-data' as it was on the straight sections.

Model building:

Fast track, full pre-stack time migration (PreSTM) and pre-stack depth migration (PreSDM) volumes were generated for both surveys, with the PreSTM data providing the initial interpretation required for PreSDM model building. Model building was performed using three passes of multi-layer tomography (Guillaume et al., 2012), which inverts for velocity and anisotropy and repositions horizons via a built-in map migration. The non-linear nature of this method allowed for flexibility in the model building flow, such that updates to the interpretation could be incorporated throughout the workflow. The value of FWI in optimising the shallow velocity model is well recognised. The lack of obvious shallow channels in the data suggested that the imaging uplift was not likely to be dramatic in this area, however the FWI was able to identify isolated areas of strong velocity contrast in the shallow section, which when incorporated into the migration velocity field had a positive impact on the imaging of the deeper section. The FWI also added less obvious, smaller scale velocity variations, which flattened subtle undulations in the subsurface and provides additional information which will be of benefit for interpretation (figure 3).

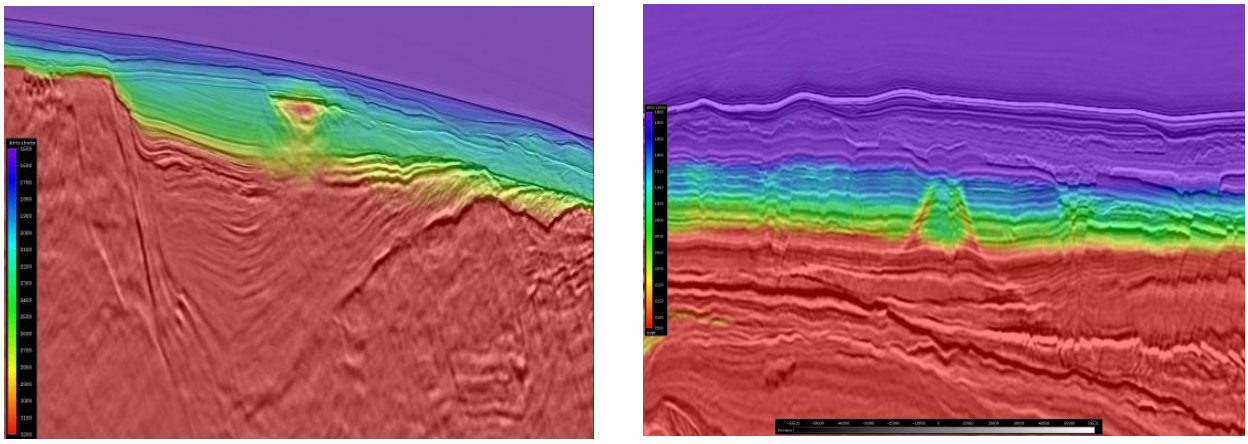

Figure 3: Inlines with FWI-updated velocities overlaid on seismic. The image (left) shows a high-velocity shallow body resolving an associated seismic pull-up and (right) a high-velocity feature thought to be associated with a diagenetic process.

FWI was run from 4 to 11Hz over 20 iterations, using the output from the second tomographic model update as the starting model. Penetration of the diving waves extended down to the BCU, however, where the chalk was present this limited the penetration to base chalk. The FWI update was subsequently merged with the iteration 2 model at base chalk/BCU and was followed by a third and final pass of multi-layer tomography.

The tie line intersecting the well 62/7-1 and the 3D data was used to provide some information about anisotropy for PreSDM model building and also to QC the phase of the wavelet after deghosting. The tie line was acquired with all 14 cables, effectively creating a narrow swath of 3D data from which a single 2.5D line was output. The seismic tie at the well was very good, and when measured over a targeted window showed a minimal phase error (-9°) and peak correlation of 86% with the local synthetic trace from well 62/7-1, providing confidence in the phase and timing of the acquired data. Anisotropy was estimated from the usable well section and provided a good initial estimate which was included in the initial PreSDM model.

Data example:

The image below is taken from the final PreSDM volume and clearly demonstrates the complexity of the pre-Cretaceous section. It is here that the amount of effort spent on the deghosting and depth model building is of particular benefit, in order to image the complex reservoir targets within Jurassic tilted fault blocks and to resolve potential stratigraphic trapping mechanisms such as lateral facies transitions and pinch-outs within the Cretaceous turbidite fans.

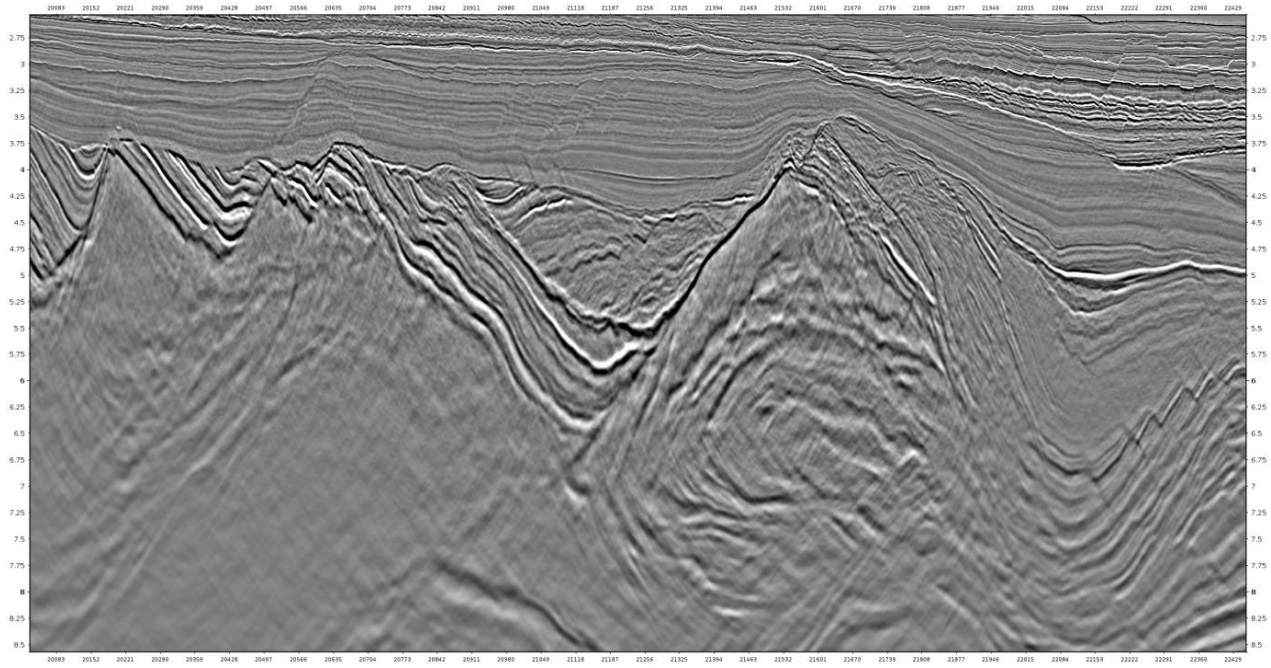

Figure 4: PreSDM imaged section through the Southern Basin

Conclusion:

The recent acquisition of two 3D surveys in the Porcupine Basin extends the 3D seismic coverage further South into this prospective but under-explored region. The application of the latest processing and imaging technology, in conjunction with constructive stakeholder collaboration, has resulted in high-

quality products which maximize the value of the seismic data and further reduces the exploration risks for efficient decision-making.

Acknowledgements:

The authors would like to thank CGG Multi-Client New Ventures for permission to publish this paper.

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Irish Centre for Research in Applied Geosciences (iCRAG) - Progress to date and plans for 2018

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iCRAG is a national research centre founded in 2015 which has transformed applied geoscience research in Ireland, performing research which is designed to deliver economic impact for a broad range of application areas and industries. The Centre brings together Ireland's leading geoscience experts focusing on a range of issues all of which underpin economic development - from safe and secure groundwater supplies through to the discovery of mineral/aggregate deposits, and from the de-risking of oil and gas exploration to ensuring that the Irish public is educated and informed on these issues. Supported by Science Foundation Ireland (SFI) and industry partners for the next three years, iCRAG is one of only 16 SFI Research centres and the first national geosciences initiative to be supported by SFI's flagship funding scheme. iCRAG is a collaboration between 150 researchers within UCD, TCD, NUIG, UCC, NUIM and DIAS and more than 50 industry partners who are working in partnership with government agencies involved in the geosciences sector.

ICRAG's research programme has been gearing up over the past couple of years, with the recruitment of most of our researchers (35 Post-Docs and 41 PhDs) and the start of 80% of our projects. iCRAG's research programme consists of five cohesive topics or 'spokes' in the areas of raw materials, marine geoscience, groundwater, hydrocarbons and geohazards/geotechnical engineering, which are built around four enabling technology and equipment based 'platforms' which focus on geophysical sensing and imaging, geochemistry, 3D geological modelling and public perception and understanding. The centre capitalises on Ireland's unique geological resources, including its world-class base metal deposits, its unusually extensive and highly prospective offshore basins and its world-class lowland karst and fractured bedrock aquifers. The principal goal is to embed the outcomes of high-quality research within industry practice in Ireland and overseas.

This talk briefly describes our progress over the past year on a range of issues, beyond the iCRAG marine and hydrocarbon research outlined in other talks in this session. Following a very brief overview of our research programme, we present some examples of platform and spoke research (including marine, geophysics and 3D modelling) which either support or are very pertinent to, our hydrocarbon research and the petroleum industry. We then outline some of our Education and Public Engagement initiatives and our newly started research on Public Perception and Understanding.

MarineWatch Demonstrator: Satellite and Drone Sensor Platforms

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Earth Observation provides different platforms and sensors to acquire data over coastal and offshore areas. These datasets can be processed in order to map and monitor sea-surface conditions, coastal zone environments, and offshore infrastructure, as well as support responses to emergency maritime events. Satellite remote sensing provides regular, wide area image updates using both synthetic aperture radar (SAR) such as Copernicus's Sentinel-1 as well as optical sensors such as Copernicus's Sentinel-2 over Irish coastal and offshore areas every few days. These satellite sensing systems provide freely available data and are quite effective at capturing synoptic, single snap-shot views of large features and surface processes at spatial scales in the order of tens of meters and temporal scales of days and weeks. However, for Ireland, cloud can often affect optical sensing systems whereas weather such as high winds and rain can affect the resulting data acquired by cloud-piercing and more complex SAR sensing systems such as Sentinel-1.

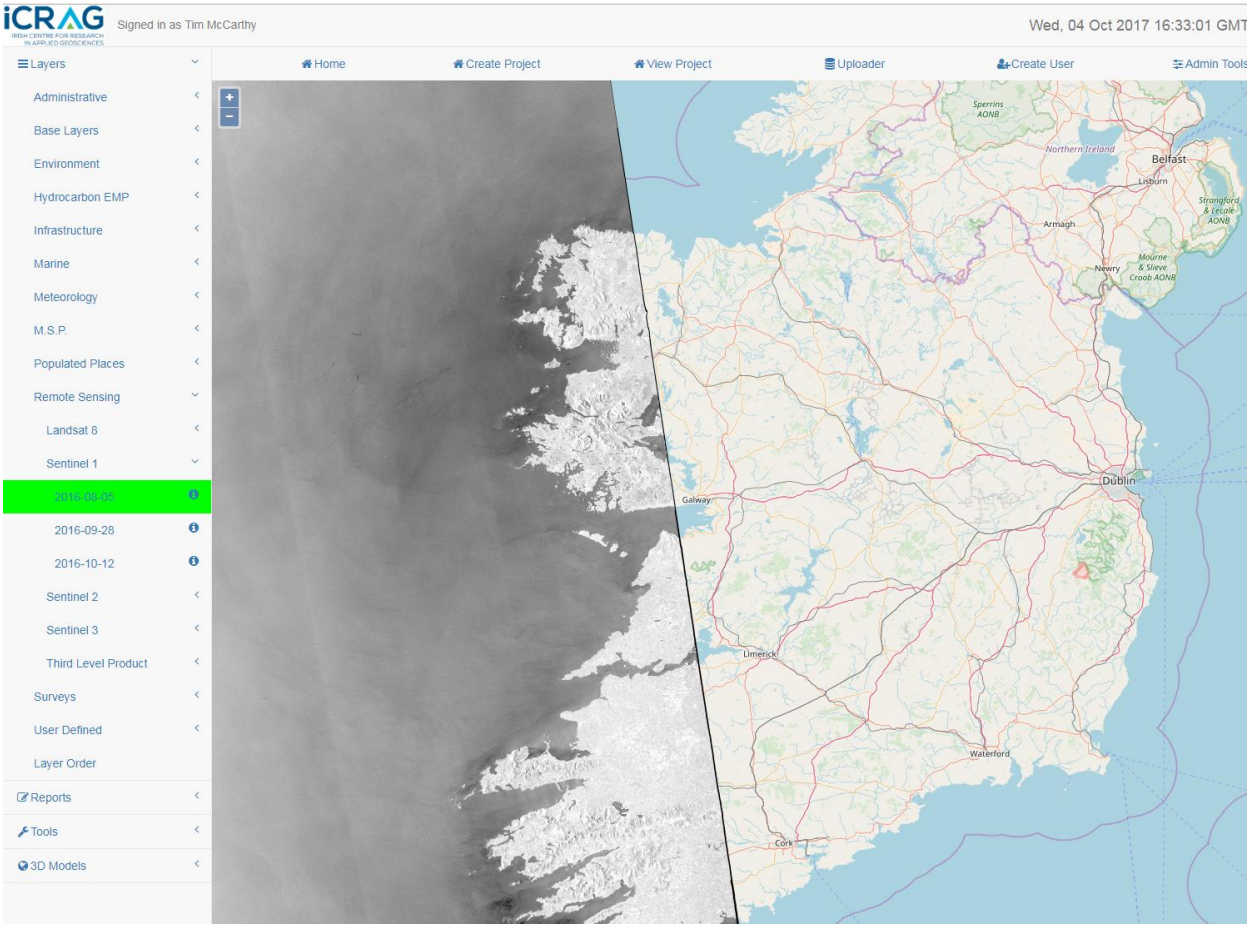

Figure 1: Screen-shot of MarineWatch Demonstrator, Sentinel-1 SAR (West Coast of Ireland) from iCRAG's MarObs platform.

Lower altitude unmanned aircraft systems (UAS) or drones have begun to appear in the last few years and are now routinely used for a variety of information gathering tasks, albeit in view of the ground-based operator. Intermediate class (15kg to 75kg) robotic, hybrid aerial platforms are now being developed and are capable of taking-off from confined areas, carrying up to 25kg sensor payload, remaining aloft for up

to three hours and travelling 100s of kilometres under strong winds and inclement weather conditions. Advances in optical sensor and artificial intelligence such as the Movidius Neural Compute stick now offer the opportunity to allow these drones to carry out autonomous monitoring, tracking and inspection tasks that were once carried out by human operators. Drone-mounted sensors can now be pre-programmed and tasked to acquire hyper-localised data where and when the operator wants this information. Operations of drones at distances, greater than a few hundred meters are not without challenges including various safety, security, regulatory and privacy concerns. However, the potential of autonomous, intermediate class drones to help support offshore exploration and production activities not only in terms of information gathering but also in logistical tasks is quite large.

Figure 2: Drones over coastal areas

This MarineWatch demonstrator project reports on the initial information content assessment of combined Satellite and Drone sensor to support offshore Oil and Gas operations. This assessment will consider spatial, thematic and temporal attributes and include an overall review of these sensor systems to map oil-slick features, carry out shallow-water bathymetric surveys, perform rapid coastal zone mapping (topographical as well as vegetation), autonomous offshore infrastructure inspection as well as supporting maritime emergency management. The very real and pragmatic issue of drone operations in terms of performance under harsh weather conditions, marinisation, safety, regulatory, communications will also be discussed. Various sensor data streams, information outputs and prototype analysis tools will be presented on iCRAG's MarObs platform, using data recorded from the recent MarineWatch project.

Acknowledgements

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Emerging Insights from iCRAG Research Focusing on Ireland's Offshore Basins

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iCRAG hydrocarbon-focused research aims to help de-risk exploration through the application of novel geoscience exploiting diverse datasets, new tools, fresh ideas and concepts. Now almost fully staffed, the programme is of sufficient scale to have research teams tackling basin development from different perspectives, ranging from the deep-lithosphere structure across broad hyperextended domains down to the structural evolution of individual basins and fault-blocks, the stratigraphic response to changing accommodation and sediment supply, thermal history and specific issues bearing on exploration risk (e.g. sand supply, up-dip seal, reservoir quality). iCRAG is working in all the main prospective basins and can thus take a regional view across the margin as a whole, including the links to the conjugate margin in Canada. New insights not only come from bringing together this diverse expertise, but also from levering insight from other parts of iCRAG. For example, researchers working in the parallel Raw Materials 'spoke' are dealing with similar issues including fault-controlled fluid flow, fault-reactivation and inversion, while synergies with the Marine 'spoke' on details of the near-seafloor stratigraphy are feeding into a better understanding of the marine environment and palaeo-oceanography on the NE Atlantic margin, as well as the assessment of shallow hazards and hydrate potential. Although some of the research employs standard industry workflows, a feature of the iCRAG programme is the development and testing of new tools that will also have applications beyond the Irish offshore. Thus, there are projects underway dealing with new subsurface imaging methods, advanced tools for sediment tracking and constraining hinterland uplift, reservoir modelling, and forward modelling to better understand fault system evolution and the interplay between tectonics and sedimentation in syn-rift settings.

Emerging insights include the application of travel time-tomography in the Porcupine Basin with the aim of highlighting the velocity structure in greater detail and revealing anomalies that may relate to fluid migration associated with reactivated faults. New geophysical constraints on the crustal structure and basin-scale stratigraphic architecture highlight important bulk strain variations (both spatial and temporal) in the crust that can be tested using high-resolution 2D stratigraphic surface grids and interpretations of the structural and stratigraphic evolution at shallower crustal levels. Detailed structural analysis is isolating faults of different ages that record different phases of extension, a range of styles of fault reactivation, and the role of pre-existing basement structures and fabrics in determining the location of transfer and inversion structures. Syn-rift fault systems in the Porcupine Basin are shown to have unusually low dips, and the associated sedimentary strata show several phases of fault-controlled subsidence with internal unconformities, local hanging wall folding and later whole-scale rotation as the main hyperextended depocentres developed. Seismic-stratigraphic analysis reveals late syn to post-rift depocentres now perched on the flank of the main hyperextended basins as erosional remnants or having been partly translated down slope with important associated unconformities. New gross depositional environment maps have been generated and the locations of potential deep-sea fan systems at Cretaceous level documented. Parallel work is investigating the likelihood of up-dip sealing using analogues and sediment transport theory to assess the potential for bypass in slope conduits. Inversion structures in the Celtic Sea occur at different wavelengths and coincide both with basin margins (short wavelength) and basin centres (long wavelength features). The timing of uplift of the onshore hinterland and offshore highs are being constrained using low-temperature thermochronology and new tools for tracking sand grains are being deployed to constrain sediment dispersal pathways, to investigate compositional modification during transport and to assess links between provenance and reservoir quality. As iCRAG progresses these various strands of research are becoming increasingly interlinked to provide a comprehensive picture of the Irish offshore.

Engineering Downtime Analysis and Cost Effective Drilling

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This study gives a broad overview of Irish drilling operations and may be useful in providing a starting point for well planning and cost estimation of future wells drilled in Irish waters. Due to the diverse nature of the geology and metocean conditions Offshore Ireland, the wells have been divided into five broadly similar areas. This is intended to highlight issues specific to certain aspects of the drilling operation, such as problems related to water depth, weather or formation. The study is an update of one conducted in 2004 and uses the same methodology to examine the historical drilling data from all wells drilled offshore Ireland. The well history and/or mud logging data for each well was reviewed and key data for each well recorded on a spreadsheet. Each spreadsheet contains the following information.

- Key well statistics.
- Estimated timings for various well phases.
- Estimated downtime under various categories.
- Data to allow simple drilling efficiency measure.
- Comments on downtime and general well design and performance.

The captured information was then tabulated for all wells within each of the geographical areas and charts produced in order to:

- Determine most significant areas for drilling downtime.
- Identify if improvements have been made over 30 years since offshore drilling in Ireland started
- Establish some very general duration vs depth curves for each area.

	Central Irish Sea and Kish Bank	North/South Celtic Sea and Fastnet	Donegal, Erris and Slyne	Porcupine and Goban Spur	Rockall	All Wells
Weather Downtime	5.0%	6.1%	5.7%	3.7%	2.4%	5.3%
Top Hole (open water)	6.0%	1.8%	1.2%	3.3%	1.0%	2.2%
BOP running/testing problems	2.6%	3.5%	3.0%	6.4%	6.6%	4.2%
Other rig equipment downtime	0.3%	1.3%	1.5%	1.9%	4.1%	1.6%
Stuck pipe, twist off, fishing	3.6%	2.8%	2.9%	3.1%	1.3%	2.8%
Hole condition	0.1%	1.2%	1.1%	1.1%	2.8%	1.2%
Casing and cementing problems	0.4%	1.3%	2.3%	1.1%	1.1%	1.3%
Coring/Logging/Testing/ Completion Problems	0.3%	1.0%	2.9%	1.8%	2.0%	1.5%
Well Control	0.0%	0.1%	0.2%	0.3%	0.4%	0.2%
Total Downtime	18.4%	19.1%	20.7%	22.6%	21.6%	20.3%

Table 1: Irish Shelf Downtime Summary

In the first part of the study each of the five areas, Central Irish Sea and Kish Bank Basins, North and South Celtic Sea and Fastnet Basins, Erris, Slyne and Donegal Basins, Porcupine and Goban Spur Basins, and Rockall Basin, is examined in relation to historical drilling activity, well duration, metocean conditions and related drilling difficulties, drilling rig types used, a breakdown of drilling downtime, an analysis and discussion of the downtime under different headings, a discussion on drilling performance and drilling successes followed by summary conclusions. Charts and graphs have been produced to highlight trends and identify any areas where improvements have been made through improvements in technology and operational practices over time. Where a particular drilling operation has been identified to cause significant lost time or additional cost, reasons for this are put forward along with suggestions for improvements.

Part Two of the study examines the latest industry trends, methods, operational practices and technologies which may be applied to Irish Shelf drilling operations in order to further reduce drilling costs. The focus of the study is on exploration and appraisal drilling, although some consideration is given to completion technologies which may be applicable.

Acknowledgements

The updated report was prepared by Kinetic Well Engineering Ltd on behalf of the Irish Shelf Petroleum Studies Group (ISPSG) of the Irish Petroleum Infrastructure Programme Group (PIP).

The Newgrange 62/11-A well – Ultra-shallow Exploration in Deep Water

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Providence Resources (80%, Operator) and Sosina Exploration (20%) have commenced well planning for the 62/11-A 'Newgrange' exploration well, which is anticipated to spud 2019/2020. The 62/11-A exploration well will target the really extensive c. 1,000 square km 'Newgrange' Base Paleocene four-way dip closure located on the southern margin of the Porcupine Basin (Figure 1). An additional stacked deeper pre-Cretaceous structural closure has also been identified which covers a gross area of c. 1,800 square kilometres. The previously drilled 62/7-1 exploration well has proven the presence of a thick porous Cretaceous aged carbonate reservoir interval together with overlying Cenozoic top-seal and underlying mature gas prone Lower Jurassic source rocks (Figure 2). Further Jurassic and/or Lower Cretaceous source rocks may be present in the Porcupine Basin to the north of the 'Newgrange' prospect. Seismic motif analysis suggests the presence of a carbonate interval within the 'Newgrange' prospect, whilst 2D seismic velocities are significantly lower than those logged in the adjacent 62/7-1 well suggesting the presence of porosity and potentially hydrocarbon charge (Figure 2). The proposed location of the 62/11-A well is on the crest of the 'Newgrange' structure (Figure 1), which is situated in c. 1,000-metre water depth and c. 500 metres BML. This talk will present various aspects of the 'Newgrange' prospect in the context of well design and planning for an ultra-shallow reservoir objective in a harsh deep-water environment.

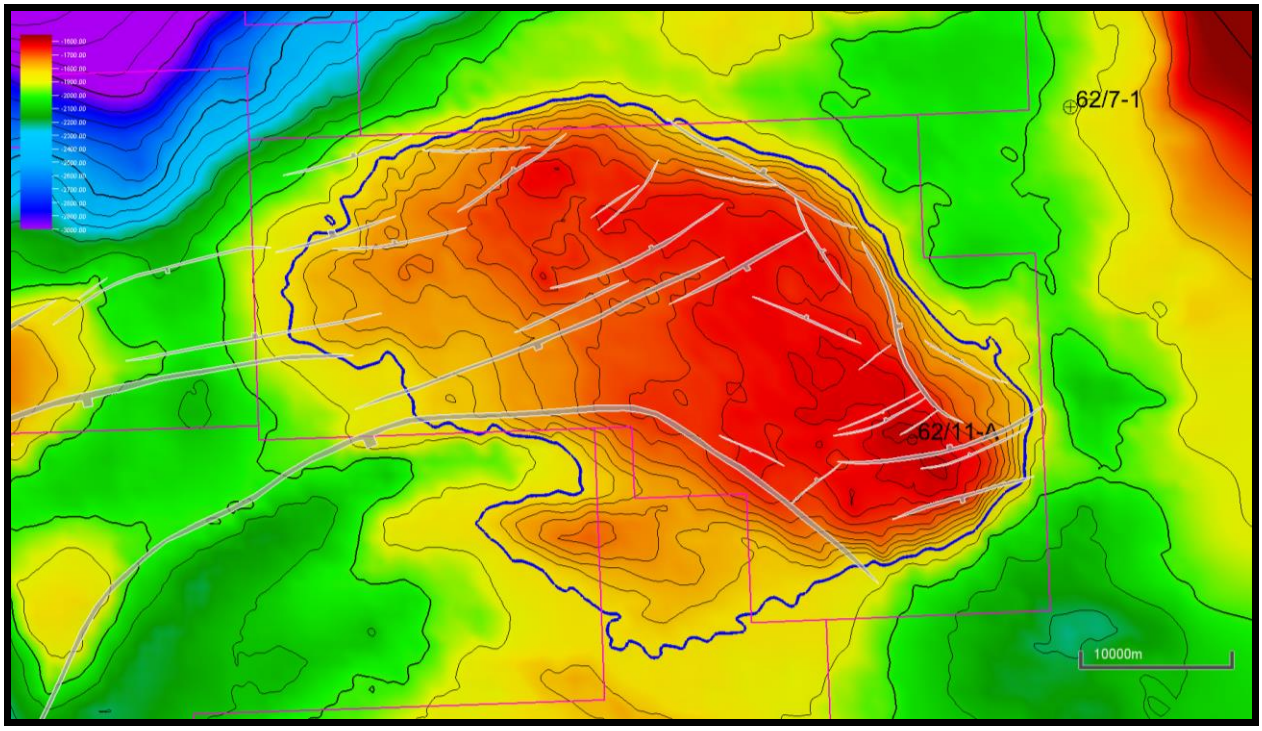

Figure 1: Base Paleocene depth structure map showing large four-way dip closure

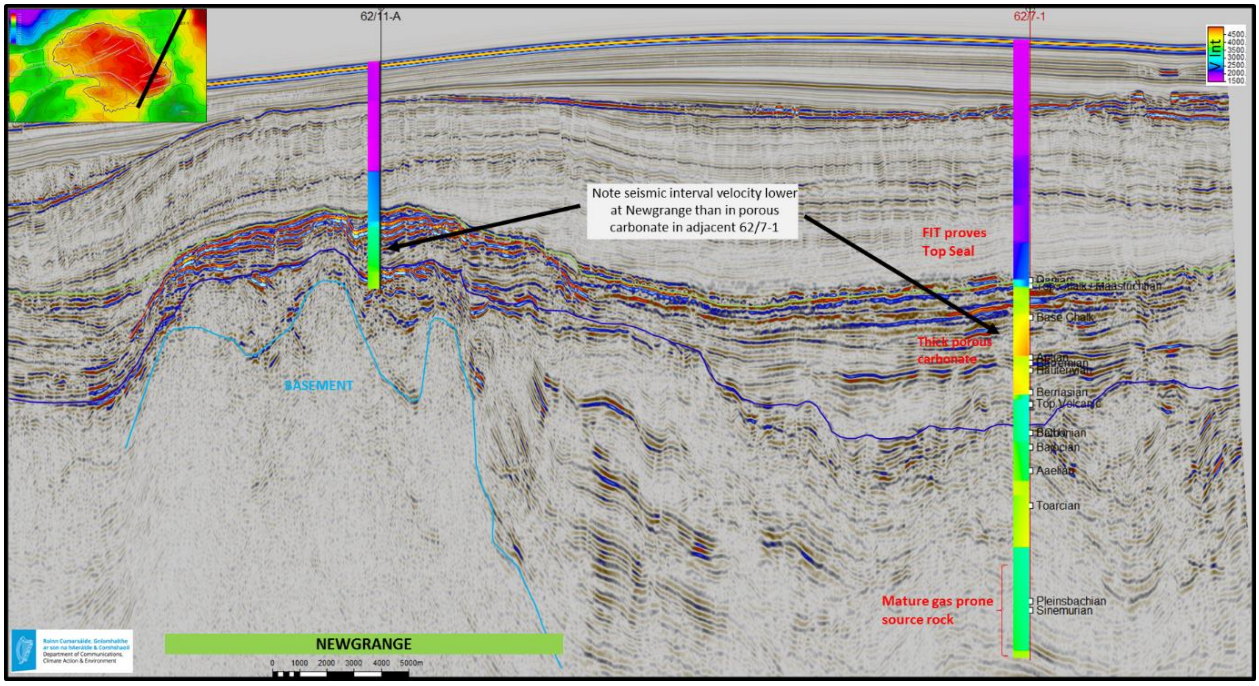

Figure 2: Seismic profile showing seismic interval velocity at 62/7-1 versus 62/11-A location

A Multi-Disciplinary Approach to De-Risking Porcupine Basin Plays

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Introduction

Woodside Energy has been exploring in the Porcupine Basin since late 2013 and is currently Operator of three Frontier Exploration Licences (FELs 5/13, 3/14, and 5/14) and one Licensing Option (LO 16/14) – see ***Figure 1***. Upon entering the basin, Woodside reprocessed to pre-stack depth migration two 1998-2000 vintage 3D seismic surveys. This resulted in a much clearer image of the pre-Chalk structure and stratigraphy, and the identification of a number of robust leads and prospects. In summer 2016 two new surveys were acquired, totalling more than 4000km^2. The Woodside Porcupine Basin portfolio, therefore, has almost complete 3D seismic coverage. A first exploration well will be drilled in the 2018-2020 period.

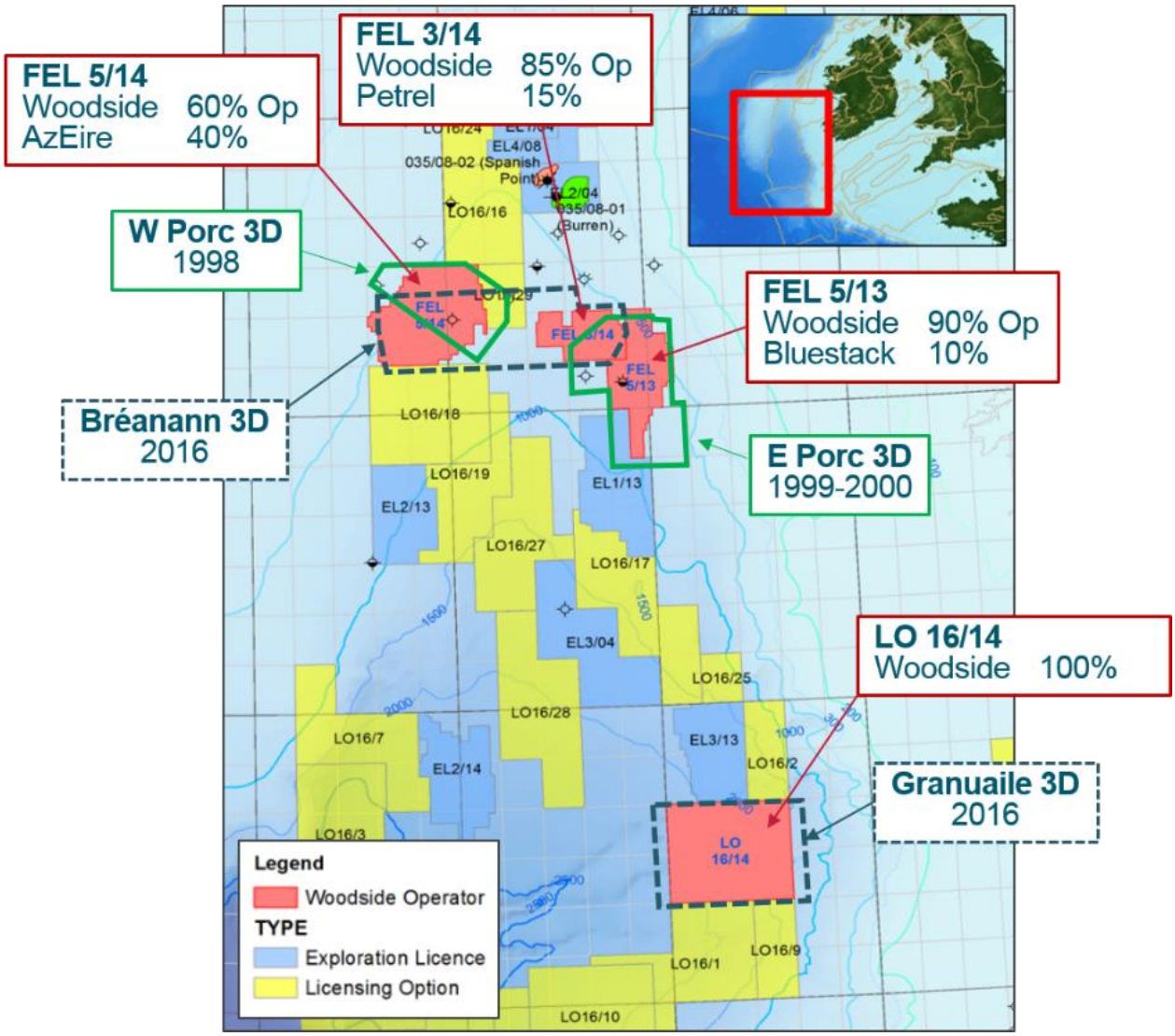

Figure 1: Woodside Porcupine Basin licence holding and 3D seismic coverage

Porcupine Basin background:

Exploration history

Following the drilling of the 53/6-1 well in summer 2017, a total of 27 wildcats have been drilled in the Porcupine Basin, but only 8 of those since 1982. Only two wildcats have been drilled on 3D seismic. Three discoveries have been made, with shows in a further 14 wells. The basin, therefore, contains a proven working petroleum system but can be considered truly underexplored.

Oil versus gas

The hydrocarbon potential of the basin is strongly skewed towards oil. The majority of shows in wells were of oil. Two of three discoveries made in the basin contained oil, while the fluid phase of the third is ambiguous. Middle to Upper Jurassic organic-rich intervals are demonstrably oil-prone. If present, Lower Jurassic and Lower Cretaceous potential source rocks are also likely to be oil-prone, based on depositional models.

Reservoir quality

Mesozoic reservoir quality in the Porcupine Basin is highly variable, but there are examples of good reservoir quality, e.g. in flow tests from the Jurassic of the Connemara discovery. The understanding of reservoir quality to date reflects the biased distribution of wells towards the shallower waters of the northern Porcupine, and the lack of 3D seismic data in most cases.

AVO & 'DHI's' and geophysical exploration techniques

Rock physics modelling of Jurassic sands indicates that negligible fluid effect is to be expected on seismic data. While younger targets may be amenable to AVO and related techniques, these must still be considered uncalibrated in most areas of the basin and should be viewed as marginal risk-modifiers at best.

Tectonic framework

The Porcupine Basin is a failed rift or aulacogen on the eastern side of the proto-North Atlantic, in which extreme stretching occurred before extension relocated westwards. There are rapid changes in structural style, degree of extension, and crustal configuration from north to south in the basin. The degree of magmatism related to Jurassic extension appears limited. The nature of the 'Porcupine Median Volcanic High' remains uncertain, but it was emplaced by the Early Cretaceous. Many mapped intrusive bodies are of Cenozoic age.

Regional work

Woodside's London-based Ireland exploration team undertakes regional studies focused on the requirements of our portfolio of licences in the basin. These include regional fault-mapping, basin modelling, and revision of gross depositional environment (GDE) and play maps. The integration of these disciplines with regional seismic interpretation of a combined 2D/3D dataset allows the team to update their understanding of basin prospectivity in an iterative manner.

The team recently revised some poorly constrained biostratigraphic picks in wells to be more consistent with the seismic interpretation and regional understanding. This resulted in the recognition of a distinctive latest Jurassic (Tithonian) post-rift package bound by regional unconformities, which can be mapped throughout the area of FELs 5/13 and 3/14, and beyond.

Prospectivity of the Woodside portfolio

FEL 5/13 in the east of the Porcupine Basin, is the most mature of Woodside's licences since it is largely covered by reprocessed 1999-2000 vintage 3D seismic. The Beaufort prospect (previously Ventry) has been matured to drill-ready status and comprises a fan-shaped body in the untested Tithonian section described above. Trapping is by a combination of clearly mapped lateral pinchouts and updip faulting. A proposed well location optimises the penetration of Beaufort but also allows for the stacking of the overlying Shackleton prospect – an Aptian canyon-fill play.

The application of advanced desktop imaging techniques in a workflow optimised by the team allows identification and delineation of sedimentary features in FEL 5/13 and elsewhere. In particular, distinction can be made between those features which appear to originate in slope failure, and those which can be mapped across to the shelf edge. The distinction is likely to have significant implications for reservoir presence and quality.

In FELs 3/14 and 5/14, the 2400 km^2 *Bréanann* 3D survey acquired in 2016 was processed to pre-stack depth migration and the final products recently delivered to Woodside and JV partners. Most previously identified prospects have been confirmed in preliminary analysis, while new leads have been identified. In particular, the identification of the Tithonian section as described above enables the description of a significant play containing the previously mapped Wilde and Yeats leads. As with FEL 5/13, the use of advanced imaging techniques is expected to be important in identifying sedimentary features and their provenance from either flank of the basin or along the basin axis from the north, and in delineating stratigraphic traps.

Preliminary analysis of the recently received 1600 km^2 *Granuaile* 3D survey over LO 16/14 in the southern part of the Porcupine Basin has confirmed earlier observations made on 2D seismic data. An onlapping Early Cretaceous play overlies tilted and folded sediments of probable Jurassic age. Once more, an early post-rift, unconformity-bound package can be identified and is likely to provide an attractive target. In both 2016 surveys, seismic data acquired during operational line turns have proved to be usable in processing and interpretation.

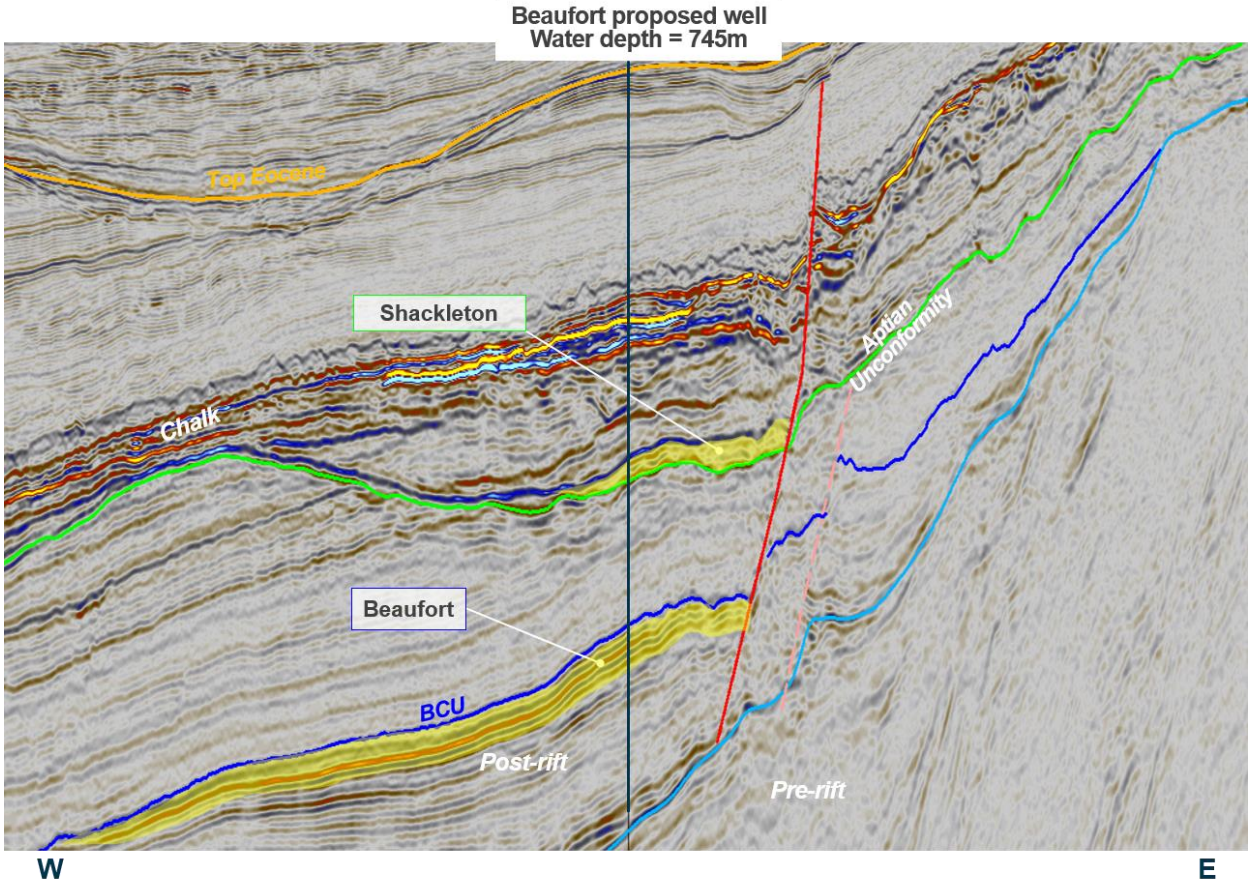

Figure 2: Stacked Beaufort (Tithonian) and Shackleton (Aptian) prospects in FEL 5/13

Petroleum fundamentals – migration pathways

The above considerations, and exploration well results to date, confirm the importance of understanding petroleum fundamentals in this frontier basin. The use of modern 3D seismic data and imaging/interpretation techniques serve to better understand these fundamentals when their limitations are recognised and when they are integrated with other observations rather than used in isolation.

Source rocks are identified, characterised and mapped. Basin models attempt to predict the evolution of these source rocks and their expulsion of hydrocarbons. The following step of defining migration pathways from source rocks to traps is equally essential. In the Porcupine Basin, Middle and Late Jurassic source rocks are proven, while Early Jurassic and Early Cretaceous source rocks may be present and effective.

Chances of accumulation are greatest where traps can be mapped in probable reservoir intervals which lie in close proximity to proven, mature source rocks, e.g. the latest Jurassic or earliest Cretaceous sections. The predominantly shaly/marly Early Cretaceous section tends to inhibit efficient migration. Prospects of this age or younger face high migration risk, potentially mitigated where:

- reservoir is interbedded with (unproven) mature source rock,
- faults with significant offset (mostly restricted to the margins of the basin) connect to proven, mature source rock, or;
- reservoir facies extend downdip into the oil window, facilitating carrier bed migration

Europa Oil and Gas – Progress and Prospects

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Europa is one of the leading explorers offshore Atlantic Ireland, with a diverse portfolio of seven Licenses or Licensing Options over some 5,800 km^2 (Figure 1). 2017 has seen new 3D acquisition over LO 16/19 (now operated by Cairn), new PSDM reprocessing completed over FEL's 3/13 and 1/17, and new PSDM reprocessing well underway on FEL 2/13.

Triassic and Middle Jurassic prospects in the Greater Corrib area (LO 16/20 & 16/21), historically well known to Shell and Statoil, have firmed-up and we expect to go into seismic reprocessing in at least one of these areas in 2018. In the Padraig Basin (LO 16/22) new geochemical work, identifying the bisnorhopane biomarker in shallow core extracts provides evidence for a working Upper Jurassic source rock system. We are working with iCRAG on understanding the stratigraphy here in the context of other "Perched Basins" as a prelude to petroleum systems modelling.

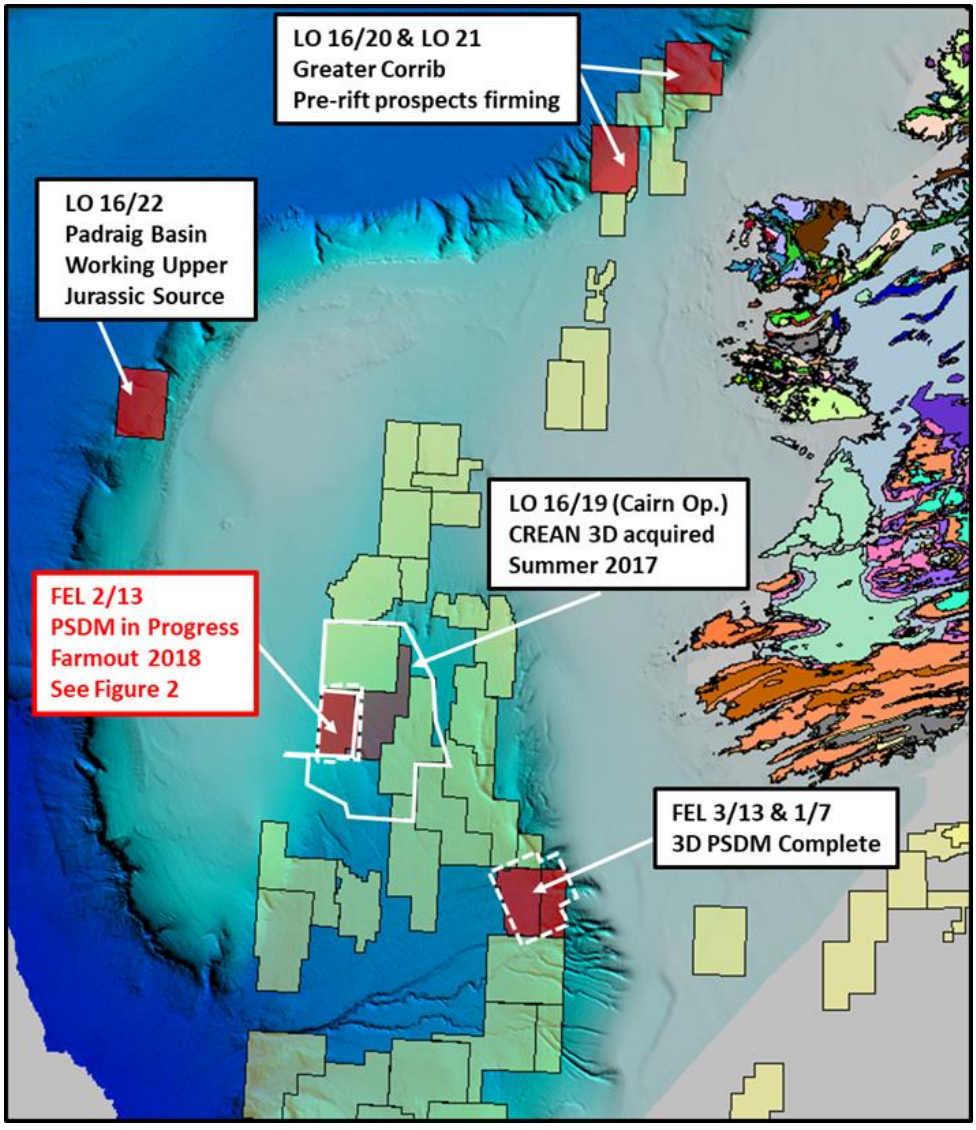

Figure 1: Europa Licences & Licensing Options, Offshore Atlantic Ireland

Amongst our key objectives for 2018 is securing a farm-out partner for FEL 2/13. Kosmos, who were completely focused on the post-rift, left this licence in 2016. In the early part of this year, we completed a review of the licence and identified prospects and leads at pre-rift, syn-rift and post-rift levels (Figure 2). At the moment, we believe the best three are:

1. "Kiely": a large and robust pre-rift tilted fault block at 3000mML. The key risk is the reservoir quality of the presumed Middle Jurassic sandstones.
2. "Keane": an apparent late syn-rift fan down-dip of 43/13-1 where there are proven source rocks and thin oil-bearing sand-stringers.
3. "Kilroy": an early post-rift slope apron fan which appears close in age to the proven source rocks of 43/13-1 and may not suffer from some of the up-dip trap risks which affect some of the point-sourced fans identified elsewhere in the basin.

Each of these prospects offers mean, unrisked prospective resources around or above 200mmboe.

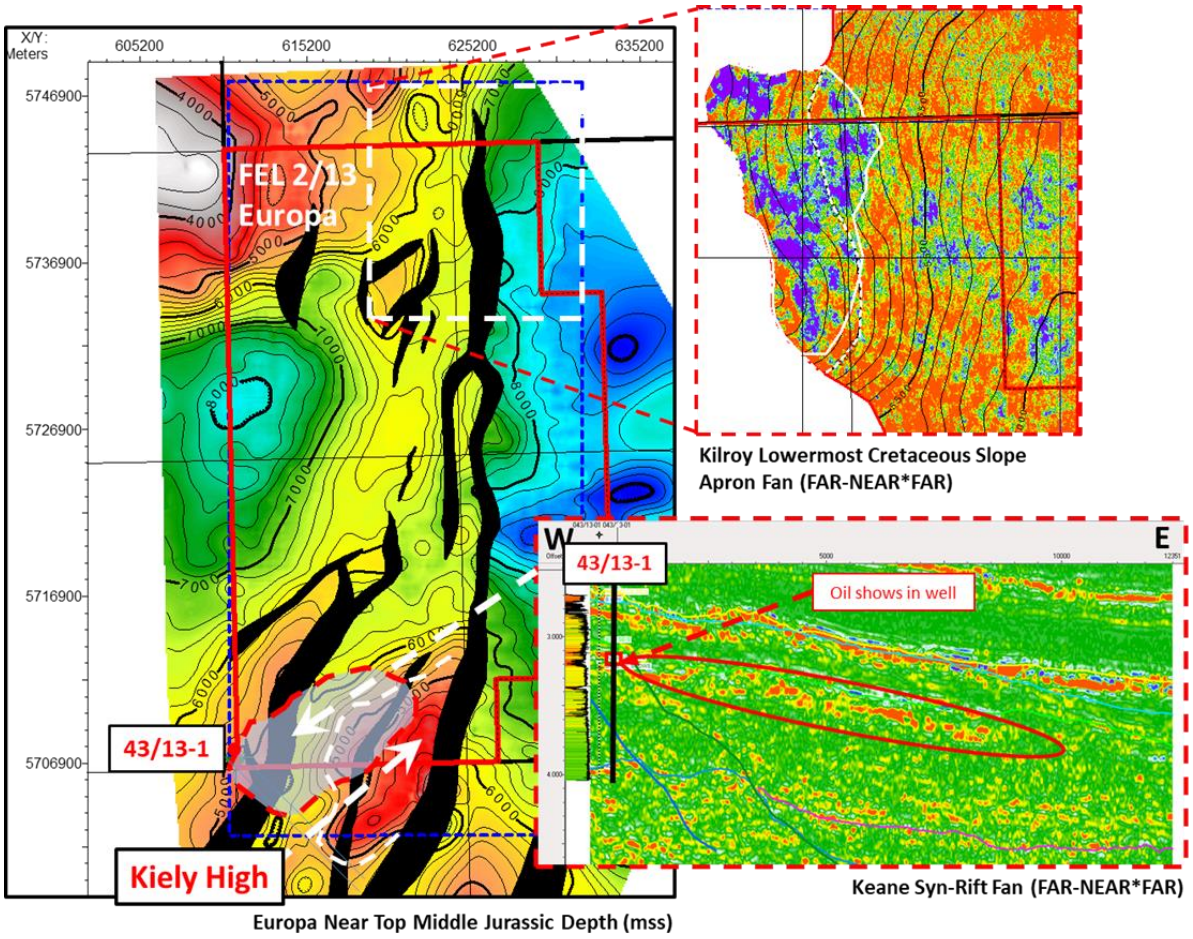

Figure 2: Key Prospects & Leads, Europa FEL 2/13

As with our SE Porcupine licences, full evaluation of FEL 2/13 was limited by the 2013 3D pre-stack time processing: pre-BCU events are poorly imaged and misplaced, and whilst AVO effects are hinted at in the syn- and post-rift, little reliance can be placed upon them due to a variable velocity field and the noise level of the gathers. Reprocessing has begun, and we are hoping for the same uplift we have seen in FELs 3/13 & 1/17. We expect reprocessed products in Q1 2018 and will be aiming to open an FEL 2/13 data room in Q2 2018 with a closing date in Q3 2018.

We anticipate completing detailed work on LO 16/22 (Padraig) and LO 16/21 (Erris) during 2018 and launching these farmouts at Atlantic Ireland 2018.

Subsurface Considerations in Planning the 48/24-K Barryroe East Flank Appraisal Well Programme

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Providence Resources (80%, Operator) and Lansdowne Oil & Gas (20%) have commenced well planning for the long-awaited 48/24-K Barryroe East Flank appraisal well in Standard Exploration Licence (SEL) 1/11 which is located in the North Celtic Sea Basin c. 50 km offshore southern Ireland. The well is currently expected to spud 2H 2018/1H 2019. The appraisal well programme is focused on the East Flank of the Barryroe Field on the same fault panel that was targeted by the 2011 48/24-10z well. This previous well successfully tested at rates of c. 4,000 BOEPD without artificial lift from a c. 7-metre perforated interval within a c. 30-metre gross package of Lower Cretaceous sandstones (see Figure 1). Regional well correlations suggest that this 'Basal Wealden' sand package is ubiquitous across several hundred square kilometres within the Barryroe area and is interpreted to have been deposited in a fluvial braid-plain environment.

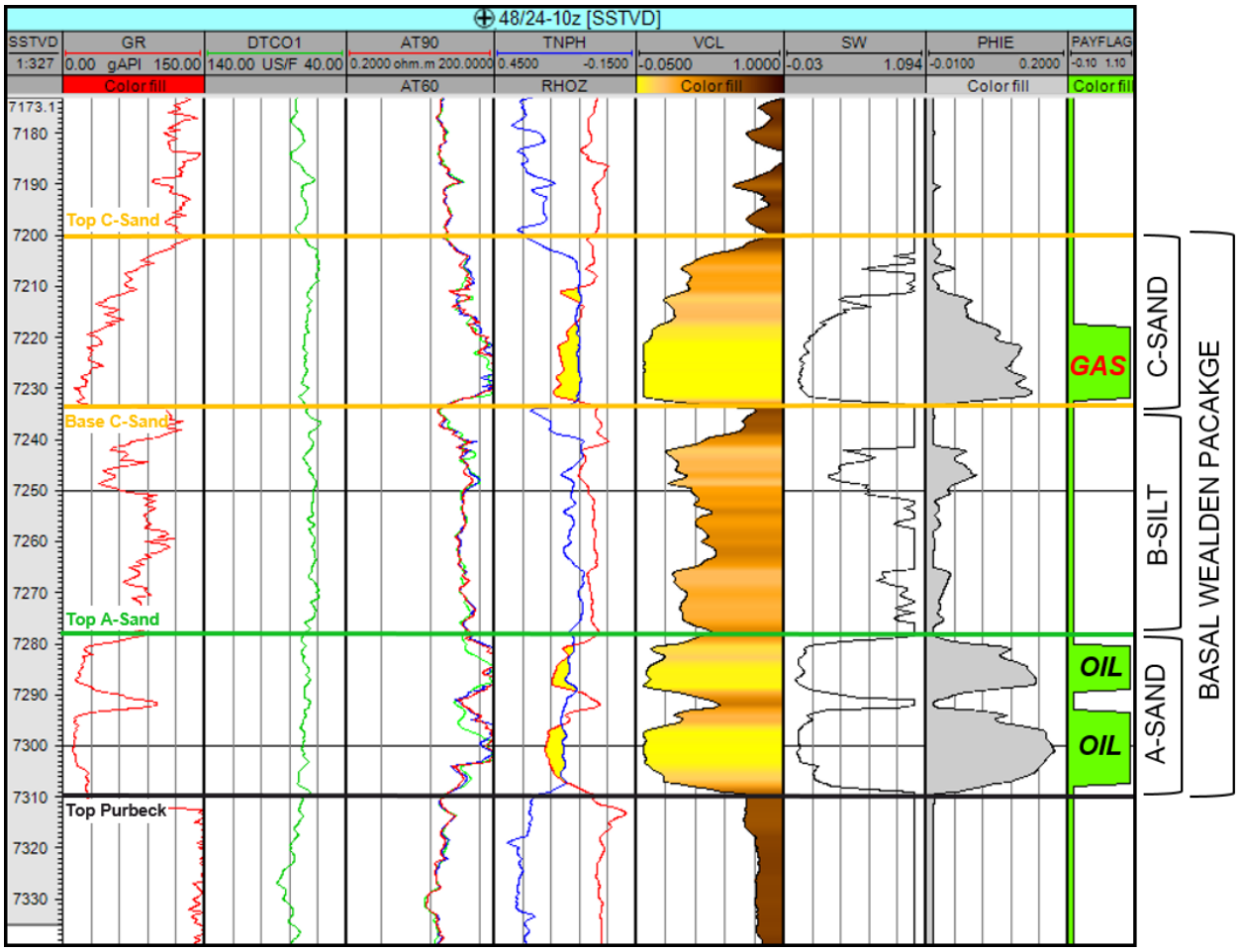

Figure 1: 48/24-10z wireline and petrophysical log curves across the productive Basal Wealden Sandstone Package

The upcoming 48/24-K appraisal well is currently planned to be situated c. 5 km SE of the 48/24-K well which is c. 60 metres up-dip from the previous well (see Figure 2). The objectives of the 48/24-K well are focused on:

- Reservoir Presence
- Reservoir Quality
- Connectivity
- Fluid Type/Distribution

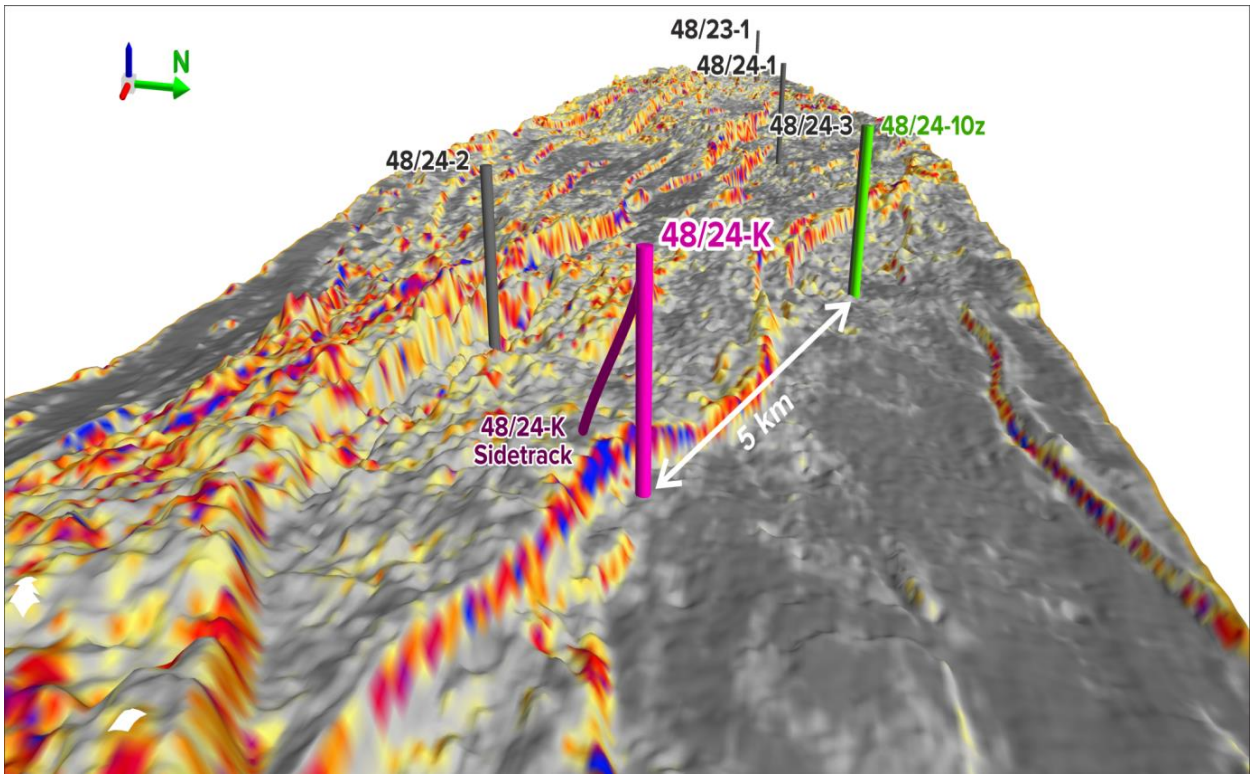

Figure 2: 48/24-K well location on 3D visualisation of Top Jurassic surface across the SEL 1/11 area.

Both side-tracking together with Jurassic deepening options are planned to be maintained through the planning and consenting process for the 48/24-K well programme.

Giant Structural Closures in the Rockall Basin: New Insights into Reservoir and Source Rock Characteristics

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The Rockall Basin pre-rift structural play contains all the key elements of a working hydrocarbon system. Working traps, source rocks, reservoirs and seals have all been proven by drilling. Serica's licences in the Irish Rockall Basin contain several large, clearly-defined, high-relief structural closures below the Base Cretaceous. Advanced seismic technology has now enhanced the visualisation of these opportunities and has further de-risked already robust prospects.

The nearby Dooish discovery contains high-quality reservoir, which is a key objective for the remaining undrilled structures across Serica's acreage. In order to investigate the reservoir potential within Serica's prospects, a reservoir characterisation study was undertaken using 3D seismic data across the FEL 4/13 licence. This study has identified a new fractured basement play within the Aghla Beg prospect, which represents a new and exciting opportunity for exploration in the region. A similar fractured basement play in the UK Atlantic, west of the Shetland Islands (the Lancaster Field) is due to commence oil production in 2018. Furthermore, the study has highlighted the relatively un-fractured nature of the adjacent Aghla More Prospect, which along with a strongly bedded internal seismic character, strengthens the interpretation that Aghla More comprises a clastic sedimentary section comparable to the reservoir found in Dooish.

In addition to the above study, a new geochemical analysis points to the late Jurassic Kimmeridge Clay as the source rock for the nearby Dooish condensate discovery. This source rock is interpreted to onlap the structures across Serica's licences and is ideally located to charge both the Aghla Beg and the Aghla More prospects.

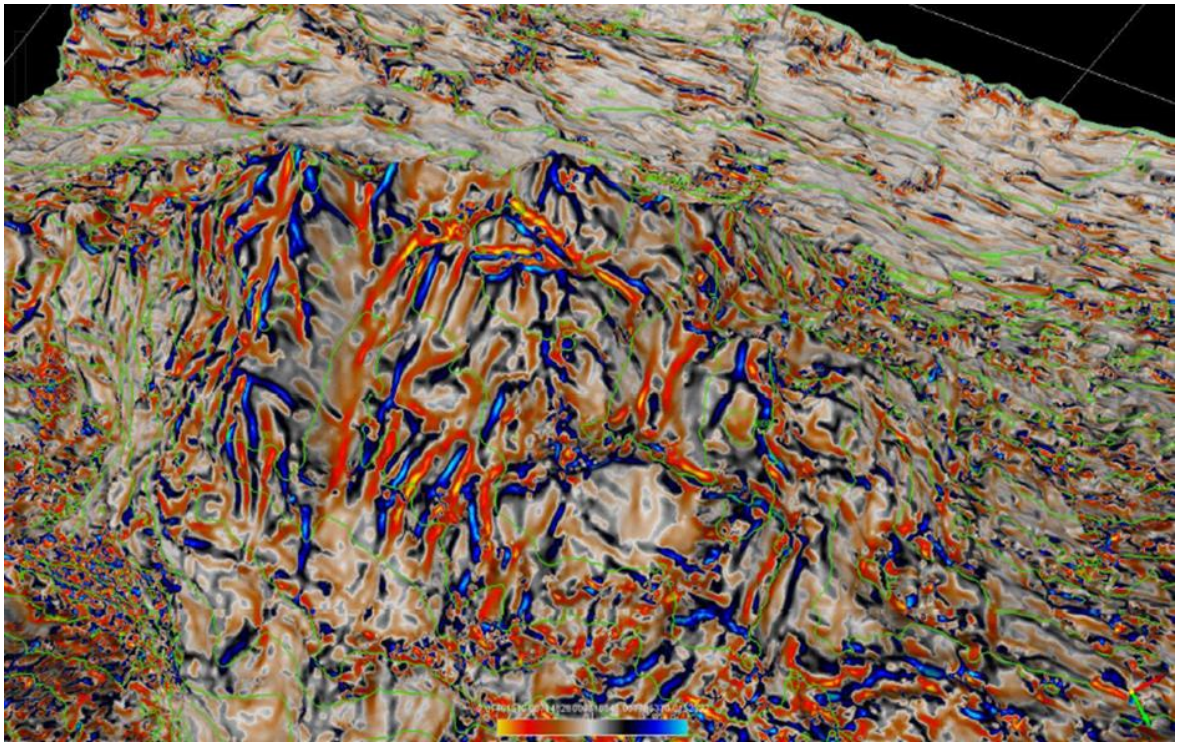

Figure 1: Aghla Beg Prospect: Maximum curvature extracted on the Base Cretaceous Unconformity, draped over Base Cretaceous depth perspective, exhibiting clear fault and fracture trends.

Newfoundland and Labrador Update: South Labrador

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Nalcor Energy's exploration strategy, initiated in 2009, continued through 2017 with the acquisition of new data and the completion of new geoscience studies that improve our understanding of the petroleum potential of the province's basins. At the end of 2016, the TGS/PGS partnership had acquired over 150,000 km. of broadband 2D seismic data in our offshore as part of this strategy. This year an additional 20,000 km of 2D data and a 9800 sq. km. 3D survey were acquired. The 3D survey covers part of the 2018 Land Sale area of the Orphan Basin.

In addition to the seismic data programs, Nalcor has funded and co-funded a number of projects, including, an expansion of the Metocean Study to the southern Grand Banks, fluid inclusion and MLA analysis of drill cuttings from selected wells, and a regional source rock study that was led by PIPCo and conducted by Beicip-Franlab. The source rock study compiled all of the existing geochemical data from the basins of Ireland and Newfoundland and Labrador conducted new analysis on selected wells and provided insight into the potential relationships between oils and oil families on both sides of the Atlantic.

Nalcor Energy also worked with Beicip-Franlab to complete a resource assessment of the upcoming Licence Round area in the South Labrador sector. This work has shed new light on the petroleum prospectivity of the slope and deep-water regions of Labrador. The leads that have been identified, most of which have AVO responses, point to the potential for liquid hydrocarbons. This is an important finding for a region that has traditionally been thought of as gas-prone. This presentation will show some of the play types and leads that have been identified.

Nalcor Energy's exploration strategy continues to build our knowledge and understanding of the petroleum prospectivity 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 at 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.

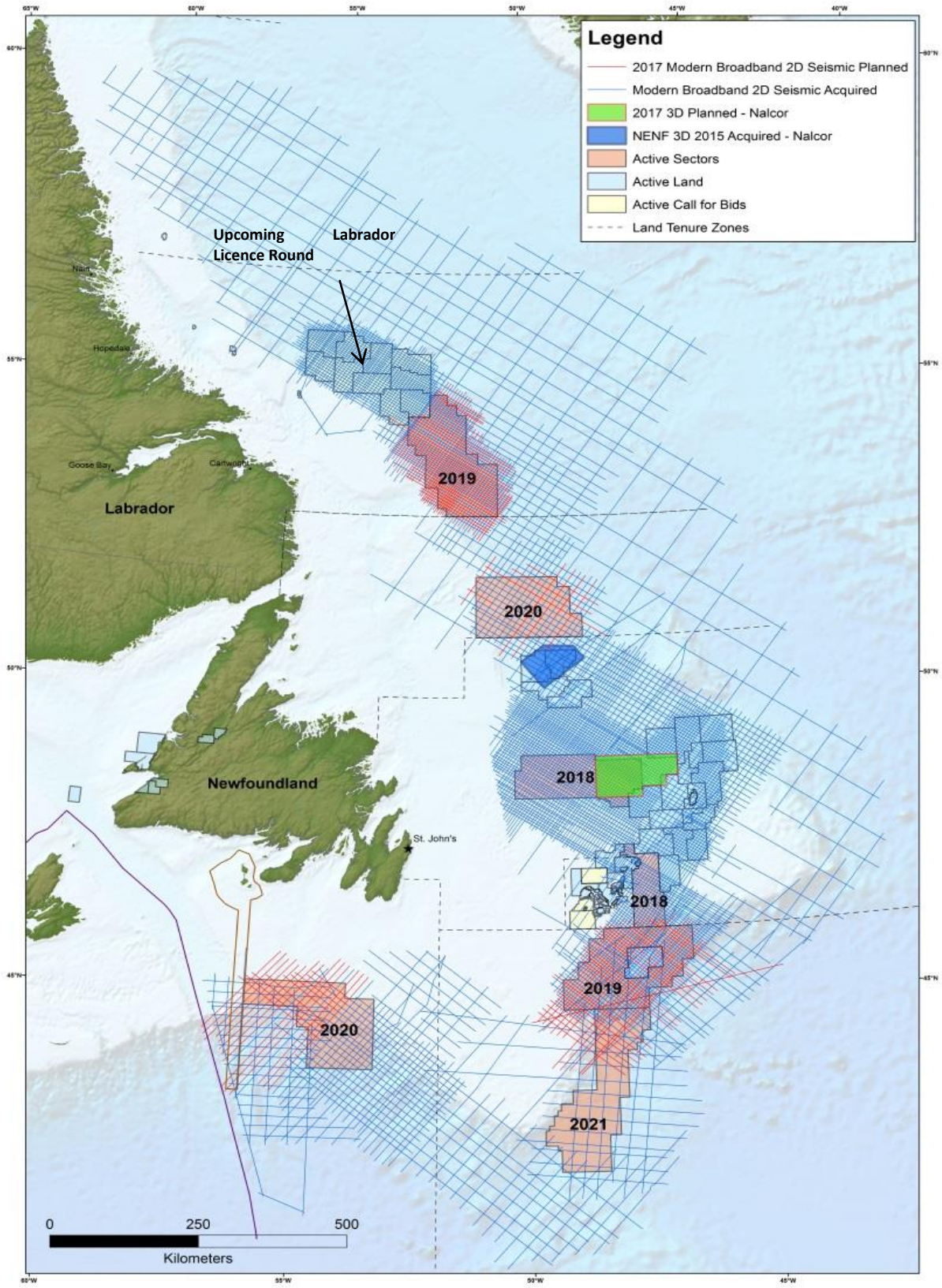

Figure 1: Map of TGS/PGS seismic data acquisition to 2017 showing the upcoming licensing rounds

Fluid Inclusion and Mineral Liberation Analyses – A twin-track approach to the study of well cuttings from hydrocarbon prospective basins in the Newfoundland and Labrador Offshore Massif

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[2]*Department of Earth Sciences, Memorial University, St John's NL, Canada.*

[3]*Nalcor Energy, St. John's NL, Canada.*

This ongoing project uses a range of microscopic techniques on well cuttings samples to enhance the understanding of petroleum systems and stratigraphic relationships within a frontier hydrocarbon exploration region. Firstly, the study of aqueous and hydrocarbon-bearing fluid inclusions (FIs) are analyzed to provide insights into their potential use as temporal markers of palaeo-oil migration events. Secondly, analyses are performed on the same suite of samples using Mineral Liberation Analysis–Scanning Electron Microscopy (MLA-SEM) techniques. This analysis can provide insights into provenance, as well as stratigraphic relationships within a given well.

We report on results pertaining to the study of the Margaree A-49 exploration well in the East Orphan Basin, offshore Newfoundland (Figure 1). Twenty-one well cuttings samples were used in the study, eight from the Upper Cretaceous limestone (Wyandot Fm. equivalent) and thirteen from two different sandstone intervals within the Upper Jurassic Tithonian (Jeanne d'Arc Fm. equivalent). FI analyses were carried out on the 13 Jeanne d'Arc Fm. equivalent samples and MLA-SEM analyses were conducted on all 21 samples.

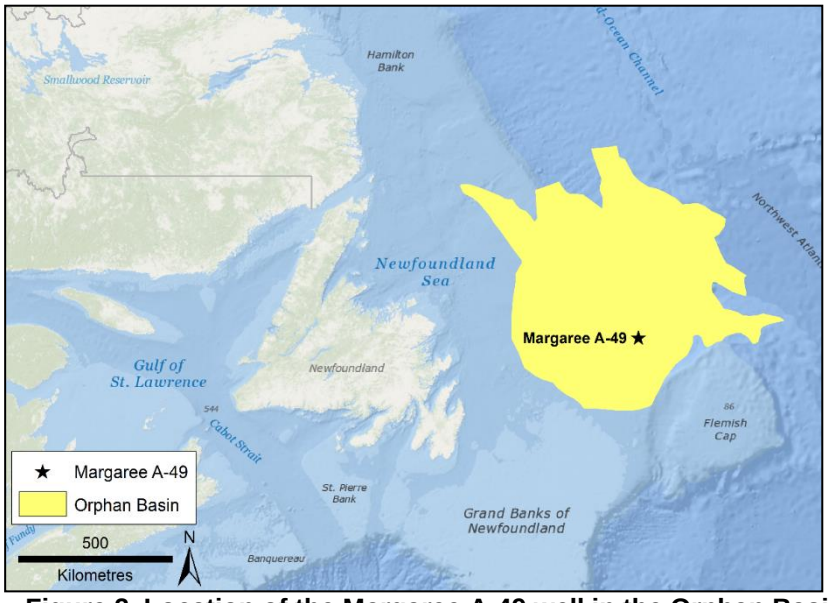

Figure 2. Location of the Margaree A-49 well in the Orphan Basin (basemap by ESRI, DeLome, GEBCO, NOAA, NGDC and Geonames.org. Basin outline and well location from Nalcor Exploration Strategy System (NESS)).

FI studies identified the presence of aqueous (2-20µm) and hydrocarbon-bearing (<2-15µm) fluid inclusions. Microthermometric data from the aqueous FIs indicate the presence of two distinct fluids: a low salinity-medium temperature fluid (~1 eq. wt.% NaCl and ~118°C) and a medium salinity-low temperature (~ 4 eq. wt.% NaCl and ~82°C) fluid. The hydrocarbon-bearing FIs exhibit a yellow/green fluorescence colour indicating oil with an estimated API gravity of 30°-35° (Figure 2). They occur along grain boundaries and in annealed microfractures suggesting at least two hydrocarbon trapping events.

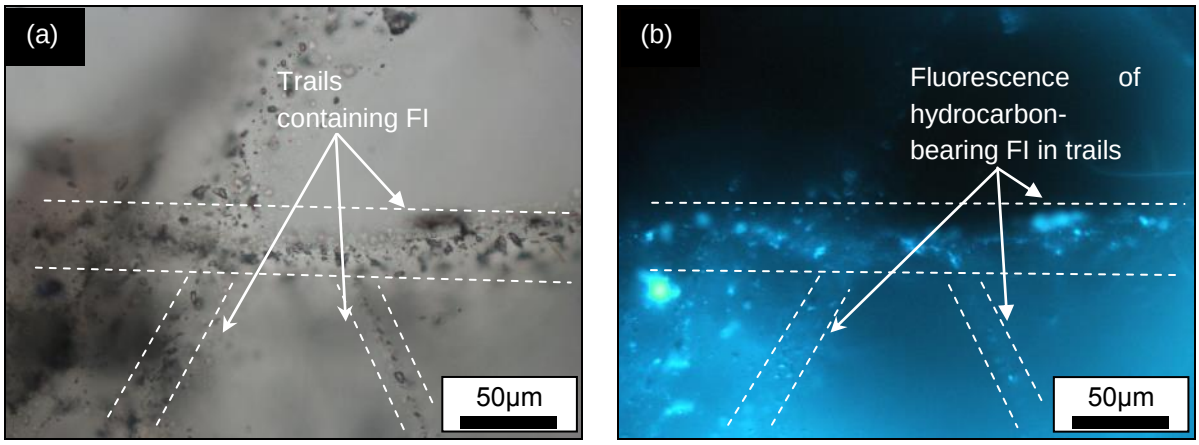

Figure 3. Photomicrographs of FI in Margaree A-49 samples. (a) Sample MAR13 (5820m). Trails of predominantly aqueous and hydrocarbon-bearing FI in detrital quartz; (b) Same view as Figure 2a under UV light displaying yellow/green fluorescence of hydrocarbon-bearing FI indicating API of ~30-35º.

MLA-SEM analyses of the cuttings indicate that both Tithonian sandstone intervals are composed of moderate to well sorted, subangular to sub-rounded detrital quartz grains of high sphericity. Texturally, the lower sandstone interval appears to be relatively more mature (grains are more rounded) than the upper one. The two sandstones have slightly different mineralogy and heavy mineral indices, which may be an indication of variability in sediment sourcing.

The twin-track approach adopted by this ongoing project facilitates the generation of data on provenance, stratigraphic relationships and oil charge history. Finally, results of combined studies of other wells will be integrated with the Margaree A-49 study and used to discuss their potential to inform petroleum exploration efforts in the Newfoundland and Labrador offshore massif.

Acknowledgements

The fluid inclusion studies/MLA-SEM analyses of the Newfoundland and Labrador offshore basins are funded by the Offshore Geoscience Data Program (OGDP) that is jointly administered by Nalcor Energy – Oil and Gas and the Department of Natural Resources, Government of Newfoundland and Labrador.

Oils of the North Atlantic: Long Lost Families or Just a Similitude of Strangers?

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This review of oils from basins of the North Atlantic realm of Ireland and Canada is part of a comprehensive study to further understand the development and distribution of source facies and their resultant hydrocarbon products in this tectonically complex setting. The resultant database from the study comprises over 100 individual analysed oil samples from Newfoundland and Labrador plus more than 40 similar samples from Ireland. These are supplemented by numerous extracted samples from reservoir facies. Integration of these data has confirmed some similarities but also the presence of some quite individual oils. Some of the key questions addressed by this study include:

- Can the produced oils and oil shows be related to one another and grouped into families?
- Are these oils or oil families related to known hydrocarbon sources?
- Do the geochemical characteristics of these oils allow for cross-basinal correlation?

To answer these questions consideration of the development of source facies must be considered. These are invariably linked with the tectonic history of the area which, in itself, is complex. From the review and interpretation of the extensive database that has been constructed, some 15 differing source rock horizons are noted across the study area within Mesozoic and Early Tertiary sediments. Of these, regionally the most significant are the sources of the Late Jurassic age (Figure 1).

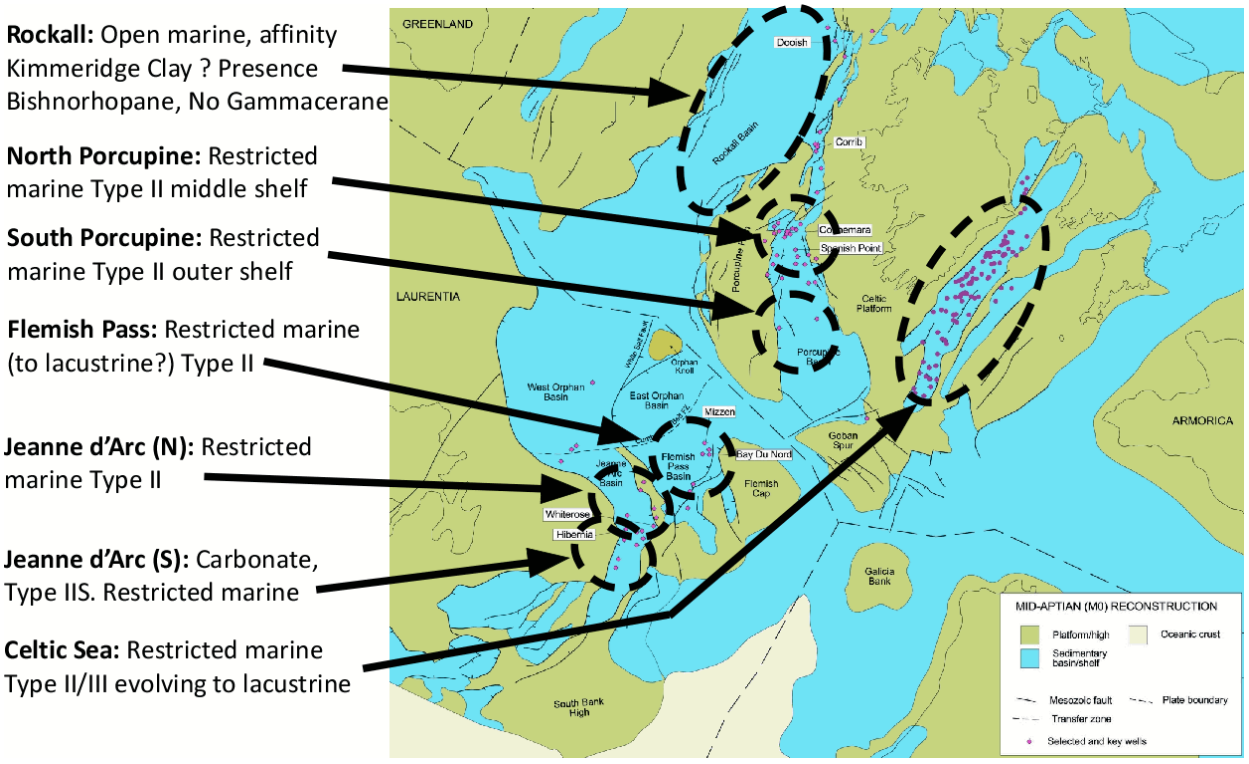

Figure 1: Summary of variation in organic facies in Kimmeridgian to Tithonian source rocks

From a broad overview of oils based on gas chromatography of selected examples from key basins (Figure 2) it is possible to conclude that:

- There is a wide variety of differing oils evident
- This is indicative of a number of differing source facies
- There are potentially several different oil families, within similarities across the conjugate margin

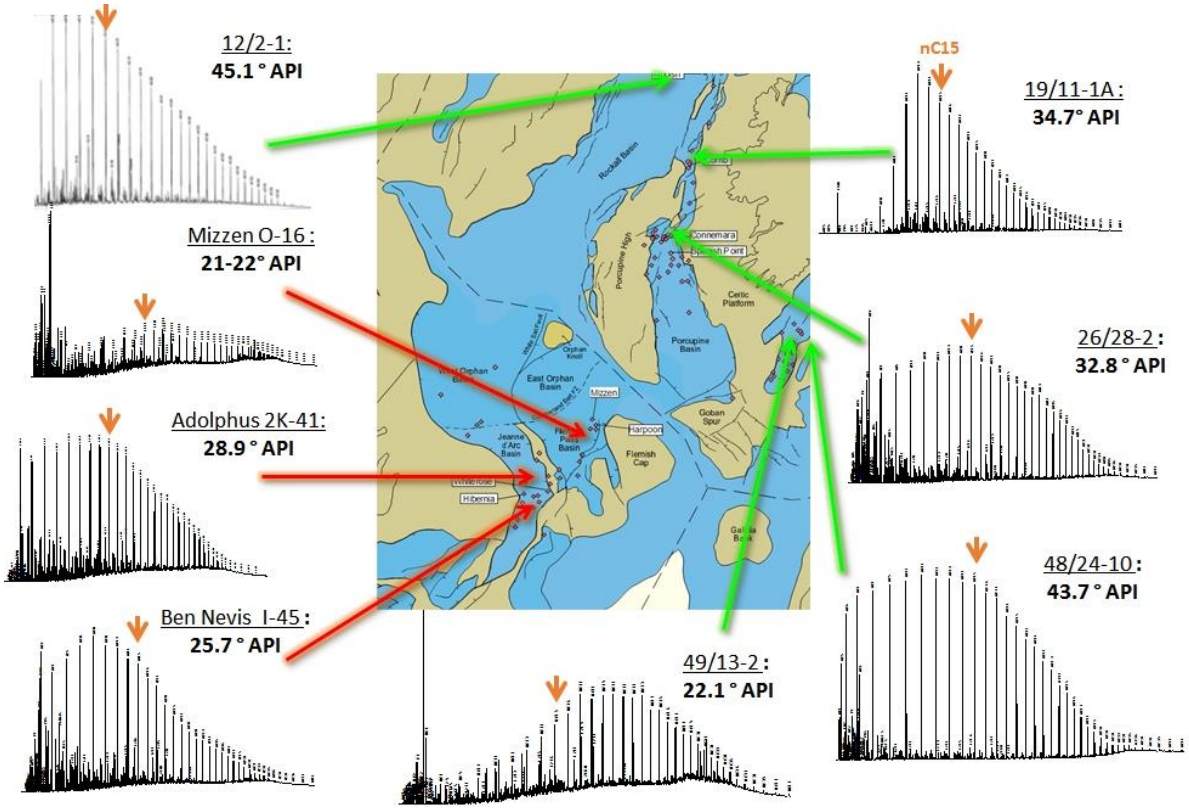

Figure 2: Examples of differing oils from offshore Ireland and Newfoundland/Labrador

The primary purpose of this presentation is to answer the questions highlighted above and to propose several “Super Families” of oils. These have numerous geochemical similarities and can be attributed to analogous source facies across these basins. However, the North Atlantic rifting events of the Mesozoic were complex, leading to the development of a series of narrow and elongated basins. The resultant environments of deposition for that time range from non-marine through shallow marginal marine to open marine. As a result, source facies of a particular age can vary quite markedly across the study area. Thus, there are rather complex sets of oil family relationships. However, some clear, cross-Atlantic relationships are evident.

This particular geochemical study is underpinned by the most comprehensive oil and source rock dataset accumulated for the Canadian-Irish conjugate North Atlantic basins. From this, it is now possible to directly compare the oils and also the parent source facies within and between each basin. This is especially important in the under-explored portions of some basins (e.g. the southern Porcupine Basin) where the lack of well data might be seen as a constraining element to exploration. Despite this lack of data, the results of the study have positive implications for petroleum prospectivity in offshore basins within the study area.

A Biostratigraphic, Lithostratigraphic & Sequence Stratigraphic Framework for Offshore Ireland

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The Irish offshore comprises 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 such a province 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 other evaluations. Despite its long history of hydrocarbon exploration (the first well, 48/25-1, having been drilled in 1970), such a unified framework has never been defined for offshore Ireland, and this has led different contractors and operating companies to use their own in-house schemes for particular regions and basins, with little consistency in terminology from area to area.

In addition to this, there are a number of known stratigraphic problems that exist in the region, regarding the chronostratigraphic interpretation and correlation of particular reservoir intervals and their relation to a broader regional scheme. For these reasons, PIPCo RSG commissioned a project to be carried out to establish and define a biostratigraphic, lithostratigraphic and sequence stratigraphic framework for offshore Ireland. This project, which commenced in July 2016, is based on the assessment and re-interpretation of all available existing legacy stratigraphic data from all released wells, shallow boreholes and DSDP/ODP/IODP holes, and has been supplemented by new biostratigraphic data (generated from new analysis of a significant number of cuttings, cores and sidewall core samples) focused on intervals and wells where gaps in the existing database exist, or where further data are required to improve the stratigraphic understanding of particular intervals. The reinterpreted legacy stratigraphic data (completed earlier this year) and its integration with the new biostratigraphic data, is being tied to a database of released seismic for the region, which is being reinterpreted to tie key wells across the region and to map into undrilled areas.

The database for the project comprises all exploration and appraisal wells and a considerable quantity of seismic data offshore Ireland.

The project is not yet complete. However, the presentation will provide an update on the current status of the work, which was first presented at Atlantic Ireland 2016. To date, reassessments of the legacy stratigraphic database have been completed, and this has been integrated with data from new biostratigraphic analyses. Some examples of our current level of understanding will be shown in this presentation. More detail, particularly of key seismic lines and well displays will be shown in the accompanying posters.

The new stratigraphic synthesis arising from the project will provide the basis for the establishment of a new lithostratigraphic and seismo-stratigraphic nomenclature, facilitated and guided by a newly established Stratigraphic Nomenclature Committee, and PIP industry participants in co-operation with the

Petroleum Affairs Division (Department of Communications, Climate Action and Environment). Progress has been made towards defining and formalising the subdivisions of several intervals including the Upper Cretaceous and Palaeozoic. However, work is still in progress regarding the other parts of the stratigraphic column.

The Cenozoic succession in the study area comprises a laterally variable and complex series of open marine carbonate, shallow marine carbonate, open marine clastic, marginal marine deltaic and non-marine sediments. A series of sequential units have been recognised to date through the Paleogene interval which will require new formal nomenclature.

The Upper Cretaceous is developed across most of offshore Ireland as carbonate-dominated facies referred to the Chalk Group, which passes northwards, in the Rockall Basin area into the Shetland Group claystone dominated facies; this development is analogous to the North Sea Basin. The thickest and most complete developments of the Upper Cretaceous are located in the Fastnet and Celtic Sea basins, with generally less complete sections in the Atlantic basins (although the thickest uppermost Chalk is developed there). Subdivision of the Upper Cretaceous Chalk Group into six new formations (provisionally numbered Chalk 1 to Chalk 6; which will later be formally named) is proposed. The Chalk 1 formation contains a commonly developed sandstone ("greensand") member in the Fastnet and North Celtic Sea basins. Chalk 2 comprises indurated, chert rich carbonates which are considered lateral age equivalent to the Herring Formation of the UK offshore. The Chalk 3/Chalk 4 boundary equates to the well developed "top Santonian" seismic horizon in the North Celtic Sea basin area. The boundaries between the intra Upper Cretaceous formations equate to the levels of major changes known across large areas of north-west Europe. In addition, several regionally developed marker beds can also be recognised across the region. Within the Porcupine Basin, a submarine basaltic lava flow occurs within the uppermost part of the Chalk. It is of Danian age and interfingers with sediments of this age that contain age diagnostic foraminifera and calcareous nannoplankton.

The project team are attempting to refine the dating of the basal Upper Jurassic/Middle Jurassic successions in the region, both west and east of Ireland. There has been considerable confusion in the past regarding the dating of difficult "red bed" successions. We are attempting to resolve this issue with the biostratigraphic re-evaluation of legacy data and new sample analysis. The current status of our interpretations on this issue will be presented.

All systems of the Palaeozoic are represented offshore Ireland, with Carboniferous sediments being the most commonly penetrated (38 wells), followed by Permian (8 wells), with 4 penetrations of Devonian (including two DSDP holes), one possible section of Silurian and one of Cambrian. The stratigraphy of all the well penetrations has been reassessed, and a standardised interpretation of them arrived at. This has allowed the recognition of lithostratigraphic units which will be formally described. A significant stratigraphic break has been recognised west of Ireland with Pennsylvanian (Langsettian/?Yeadonian) sediments resting on Mississippian (Arnsbergian/Pendleian) strata. A similar break has previously been recognised in Eastern Canada.

A number of major seismic sequence boundaries have been identified across the offshore region, in addition to several more local seismic horizons. West of Ireland, major seismic horizons are recognised within the Cenozoic interval at the Base Paleocene, Top Chalk, Intra Selandian, Thanetian, Base Lutetian, Base Priabonian, Intra Oligocene and Intra Miocene levels. Several of these comprise major downcutting unconformities. All major seismic horizons have been tied to, and their ages, constrained by the well data. Within the Cretaceous, five seismic sequence boundary horizons have been identified, one of which is probably of Aptian age. A Base Cretaceous horizon is prominent in some areas and has been tied in the wells to the base of the Berriasian (note that this, therefore, is at an older level than the "Base Cretaceous" horizon in the North Sea). This may correlate with a seismic horizon in the Fastnet-North Celtic Sea basins that falls near the base of the Purbeck. However, biostratigraphic dating of the Purbeck

interval in this area in terms of the standard chronostratigraphy is difficult. We are investigating the possibility of defining and naming a set of seismic sequences based on these boundaries, integrated with previous work on the area.

One of the key aims of the project is to compare the stratigraphy in offshore Ireland with offshore Eastern Canada (Newfoundland), other basins west of the United Kingdom and the North Sea. The results of the project have shown that there are significant comparisons with the UK basins, with some rock units being contiguous between the two areas. In these cases, pre-existing names will be used. At the same time there are significant differences in some areas, and for these, new nomenclature will be defined.

A geochemistry data set compiled by Beicip-Franlab as part of PIP project IS16/01 has been provided to this project covering all wells from which geochemistry data are available offshore Ireland, and all available data have been compiled into an integrated geochemical database. Once the new stratigraphic scheme is finalised, it will also be applied to all wells in the geochemical database and in the context of this new stratigraphy, ages of the source rock intervals will be confirmed or refined and potential lateral variations within basins will be highlighted.

A limited amount of new radiometric dating of key igneous bodies has been carried out within the project. Attention has been focused on extrusive igneous rocks from which a radiometric date would significantly aid the stratigraphic position of these rock units, e.g. the major lava penetrated by Goban Spur well 62/7-1.

The project report will include an atlas documenting and illustrating the new stratigraphy with a set of key regional seismic lines. Well tops, updated composite logs, seismic horizons, formation extents, and a GIS database will be provided in addition.

Acknowledgements

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We wish to thank PIPCo RSG and PAD for approval to publish and present this paper.

Stimulating Frontier Exploration Activity on the UKCS

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The United Kingdom Oil and Gas Authority (OGA) was created as one of the key recommendations of Sir Ian Wood's 2014 Review of the United Kingdom Continental Shelf (UKCS). It exists as a government company with the role of regulating, influencing and promoting the UK oil and gas industry. A series of strategies and associated delivery programmes set out how the OGA, UK government and industry should work together to maximise economic recovery (MER) from the UKCS. The Exploration Strategy supports the MER UK Strategy and describes three priority areas: regional exploration; licence and work programme stewardship; and subsurface technical assurance and portfolio management.

Under the banner of the regional exploration priority area, the OGA is undertaking several initiatives that aim to provide data and regional-scale interpretation to the industry. These initiatives include a regional mapping project covering the whole of the UKCS, the 21st Century Exploration Road Map (21CXRM) that seeks to promote collaboration across industry and three Frontier Basin Research post-doctoral projects at the Universities of Aberdeen, Heriot-Watt and Durham. In addition to these initiatives, additional funding from the UK Treasury in 2015 and again in 2016, allowed the OGA to acquire a significant amount of 2D seismic data over wide areas of the UKCS. This data, along with data from relevant exploration wells will be released to the industry in support of future exploration efforts.

In preparation for the UK 29th licensing round (held in 2016) the OGA, under the Open Government License, released 15,463 km of 2D seismic data covering areas around the North Rockall Basin (Figure 1). The seismic data was comprised of a combination of newly acquired (2014 and 2015) long-offset broadband lines (10,013 km, 101 lines), plus reprocessed and original legacy speculative survey lines (5,450 km). The seismic data release was supplemented with digital well data for 11 released UK wells.

The seismic data from the UK Rockall forms the core of a database used by the University of Aberdeen to evaluate the prospectivity of Rockall through one of the two-year Post-Doctoral Research Projects funded by the OGA. The objective of this study is to fully evaluate the exploration potential and petroleum system of the Rockall area. The work focuses on de-risking plays and identifying prospects using the OGA seismic data integrated with older data, Irish data and appropriate analogue outcrops. The results of the project will be made publicly available through a bespoke web-portal.

The OGA's 2016 seismic campaign included the acquisition of an extensive 2D broadband survey plus reprocessing of legacy seismic data in the SW Approaches, St Georges Channel Basin, East Irish Sea, and Minches areas (Figure 1). With the support of the Irish Petroleum Affairs Division, the programme included merging some of the newly acquired lines with the 2015 GeoPartners survey to ensure alignment of the data across the UK-Ireland median line. As with the 2015 seismic programme, all of these data will be released into the public domain in support of the 31st Frontier Licencing Round which will be held in 2018. The seismic data delivery will be complemented by well data plus an integrated summary of the OGA-funded 21CXRM studies carried out earlier in 2017 in the SW Approaches. These studies aimed to better understand the regional structural and basin geometries in the area plus provide an initial assessment of the potential for older Permian or Carboniferous source rock intervals within the post-Variscan basins.

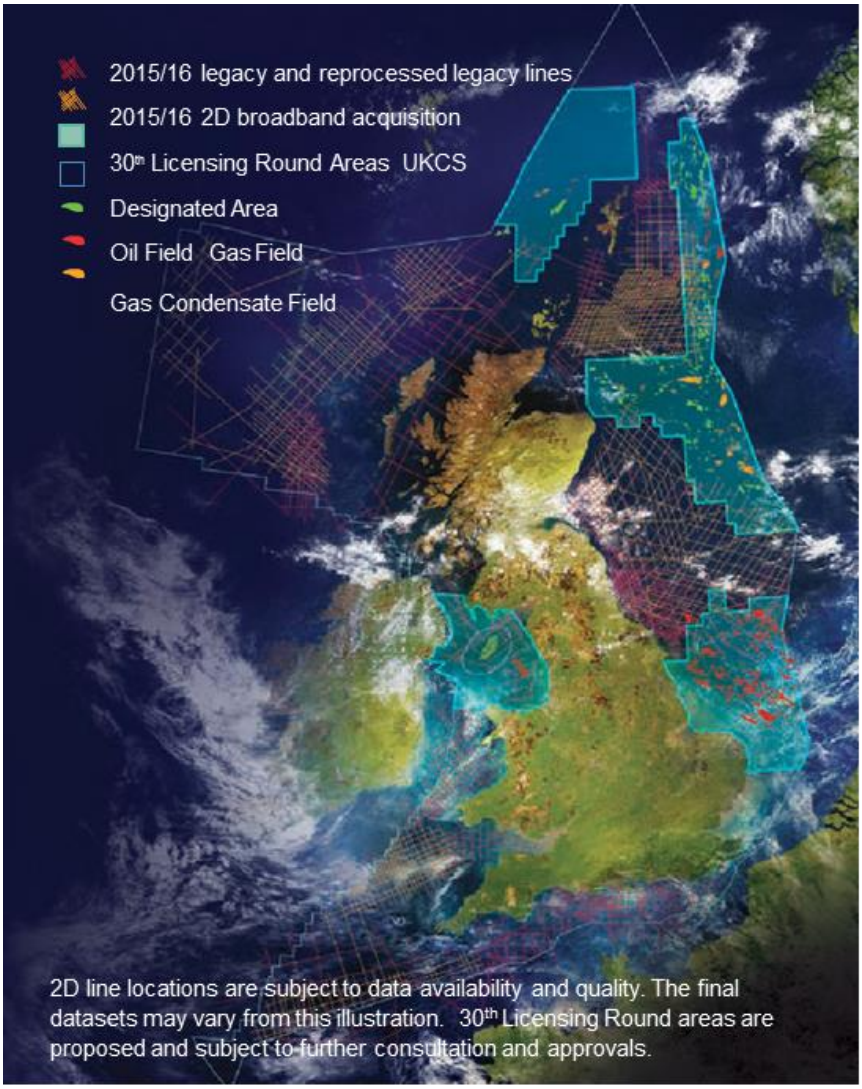

Figure 1: Map of the UKCS showing the OGA 2015 and 2016 seismic programmes areas

The OGA 2016 seismic data from the SW Approaches and surrounding areas forms a fundamental part of the database being used by the University of Durham, again through one of the OGA-funded post-doctoral research projects. This project aims to evaluate the structural and stratigraphic evolution of the SW Approaches area with a focus on the impact on the various petroleum system elements. Data from the Irish and French sectors have already been incorporated into the project database to ensure that the project works towards a consistent cross-border view of the subsurface.

Deliverables from both the Rockall and SW Approaches post-doctoral research projects will, in addition to being readily available in the public domain, be incorporated into the OGA's Regional Geological Mapping project for these areas. This is a three-year project being undertaken for the OGA by Lloyd's Register. The project aims to deliver a suite of geological maps and associated databases for all areas of the UKCS (examples of which are shown in Figure 2), working cross-border with key organisations where possible. To date, the project has delivered out maps and databases for the Central North Sea and Moray Firth areas of the UKCS and delivery of the Southern North Sea area, where the project has benefited from a good UK-Netherlands collaboration with TNO, is expected in October 2017. As the project moves to the west of the UK, cross-border collaboration into the Irish sector will be key for areas such as the Rockall Trough, East Irish Sea and SW Approaches to ensure that there is an aligned geological view across the median line.

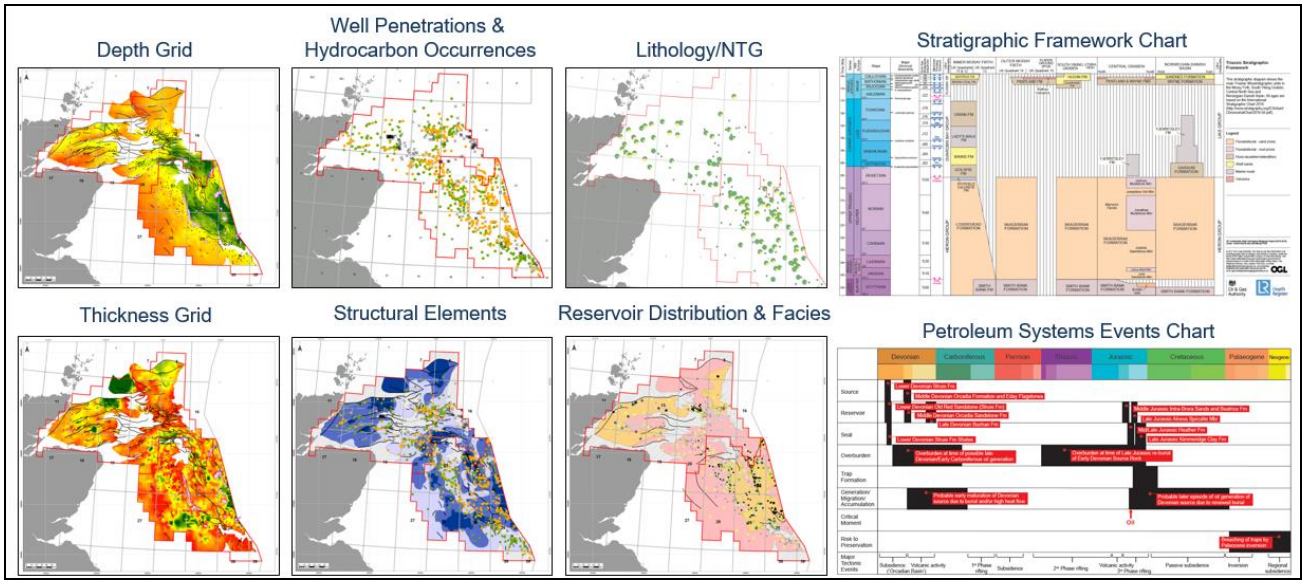

Figure 2: Example deliverables from the OGA UKCS Regional Geological Maps project

Abundance and Distribution of Protected Cetaceans and Seabirds in Irish Waters: Results from the Two-Year ObSERVE Aerial Project

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Aerial surveys of Ireland's offshore and coastal waters were conducted in summer and winter of 2015 and 2016 to investigate the distribution and abundance of key protected marine species. A total of 37,097 km of survey lines were flown both on and off the continental shelf using a fixed-wing, twin-engine aircraft fitted with bubble windows to provide an unobstructed view of the sea below. Visual observers concentrated on recording all marine mammals detected within 500m either side of the aircraft's survey line, and all seabirds within 200m either side of the survey line.

Observers recorded 1,846 sightings of 19 cetacean species comprising an estimated 8,635 individuals, and 9,433 sightings of 24 seabird species or species groups, comprising an estimated 23,051 individuals. Observations included extralimital sightings of beluga and white-tailed tropicbirds rarely seen in Irish waters. A data modelling approach using a range of environmental variables such as sea surface temperature, chlorophyll-a and water depth was used to produce density distributions and abundance estimates for individual species from raw sightings (see Figure 1). Cetacean species showed seasonal and inter-annual differences in both distribution and abundance. Harbour porpoises were distributed over a large spatial area during summer months but occurred more coastally in winter. Conversely, bottlenose dolphins were less frequently seen in coastal waters during winter than in summer. The Irish Sea was found to be important for minke whales in summer, but no sightings occurred in this area during winter surveys. Densities of common dolphins and bottlenose dolphins were much higher during the winter than the summer. At least three species of deep-diving beaked whales were recorded, and results highlighted the importance of waters overlying the continental shelf break and the Porcupine Basin as being important to these species. Beaked whales were recorded in both the summer and winter periods. The shelf break and continental slope waters were also an important area for fin whales and long-finned pilot whales (Figure 1).

There were also strong seasonal differences in seabird occurrence. Summer surveys were dominated by auks, petrels, northern gannets, northern fulmar and Manx shearwater, while winter surveys were dominated by black-legged kittiwakes and gull species, as well as increased abundances of northern fulmar. Coastal waters were particularly important for a range of seabird species throughout the year. Shelf waters remained important for gannets in both summer and winter, while offshore waters became increasingly important for auks (including razorbills, guillemots and puffins), kittiwakes, and northern fulmar in the winter. Nearshore coastal and continental shelf waters were important for Manx shearwaters and petrel species in summer, but both species were almost absent from Irish waters in the winter. Higher abundances of Manx shearwater and northern fulmar in summer than would be expected based on national colony census data suggest that Irish waters are also important foraging grounds for UK-breeding seabirds. Modelled estimates of total seabird abundance suggest that the survey area supports 439,280 seabirds (95% Confidence Intervals: 353,297 – 579,728) during the summer and 474,875 seabirds (95% C.I: 387,410 – 545,642) during the winter.

This is the first time that winter abundance has been estimated for cetaceans and seabirds in this geographical area of the north-east Atlantic, and the results highlight interesting seasonal differences in abundance. The results of the ObSERVE aerial survey project, which are due in 2018, can be used for informing consenting processes for offshore activities, for European reporting on species conservation status, as well as for assessing the risk from fisheries bycatch and oil spills for example.

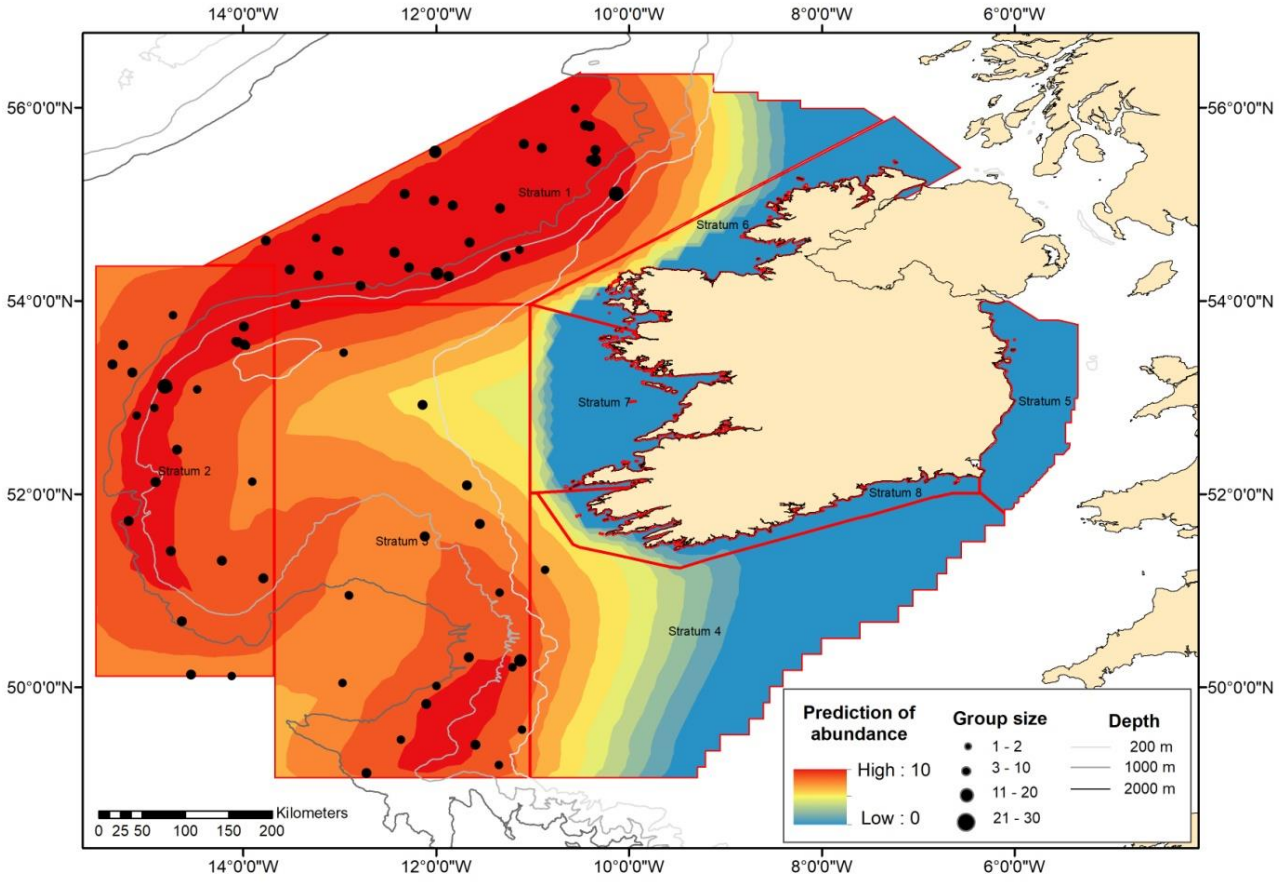

Figure 1: Predicted summer distribution of long-finned pilot whales (*Globicephela melas*) highlighting numerous sightings over the deep waters beyond the continental shelf break.

ObSERVE Acoustic Surveys for Cetaceans in the Irish Atlantic Margin

Berrow, S.[1], O'Brien, J.[1], Meade, R.[1], Delarue, J.[2], Kowarski, K.[2], Martin, B.[2], Moloney, J.[2], Wall, D.[3], Gillespie, D.[4], Gordon, J.[4], Porter, L.[4]

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The ongoing discovery, development and use of major hydrocarbon resources in Ireland's EEZ are potentially significant economic drivers for Ireland. Current areas of interest include along the western edge of the Irish continental shelf and down the continental slope in a broad region often referred to as the "Atlantic Margin". In October 2014 the Department of Communications, Climate Action and Environment established the ObSERVE Programme in partnership with the Department of Culture, Heritage and the Gaeltacht. In 2015 the programme's ObSERVE-Acoustic project began to obtain acoustic monitoring data along the shelf edge over two years in order to inform conservation management by assessing the importance of these shelf-edge habitats for whales and dolphins.

In the ObSERVE-Acoustic project, we used both static acoustic monitoring (SAM) at 8 stations from 55°N to 49°N (Figure1) and towed passive acoustic monitoring (PAM) along 600nml of vessel trackline in an area of 122,566km^2 (Figure 2). In order for the survey equipment to detect a whale or dolphin, the individual must be vocalising within the frequency and detection range of the equipment. Ambient, or background, noise can also influence the detection range of the acoustic receivers. During ObSERVE-Acoustic the dominant sound source was classified as either "Vessel", "Seismic" or "Ambient". Noise levels in the study area increased from north to south by 1-3 dB, with the highest difference observed in the 10-100 Hz band. Broadband noise levels in June were 18 dB higher at the southernmost monitoring station compared to those further north and by 22 dB in the 10-100 Hz band. This was largely due to seismic survey activity despite such vessels being around 150 km away. In October, background noise levels in all bands were lower in the absence of any seismic detections, and fin whale songs had a strong influence on ambient sound levels, resulting in an increase of 3 dB. Maximum detection ranges for SAM were estimated at up to 200km for blue whales, 80-100km for fin and sperm whales and 13km and 4km for Cuvier's and Sowerby's beaked whales respectively. Dolphin or pilot whale whistles were estimated to be detected from up to 2-30km from the survey equipment.

Five species of baleen whale and eight species of toothed whale were detected acoustically. Baleen whales were only detected by SAM as it acquired sufficiently low-frequency data. Sei and minke whales were detected infrequently and humpback whales for a short period during April to May 2016. Blue whale detections were absent through the spring and early summer but occurred sporadically in the late summer and through the autumn, most likely during migration. Fin whales were the most frequently detected baleen whale species, being detected on 51-100% of days at all SAM stations. Calls were more frequent in spring and autumn, with a reduction in summer; this is consistent with the known seasonality of song production by this species, and it does not necessarily represent a decline in fin whale occurrence. A clear north-south gradient in detection counts occurred during spring suggesting a preference for northern areas of the study region. Fin whale calls are increasingly likely to be masked with increasing background noise in their calling band, such as that associated with airgun pulses. Automated fin whale detectors were triggered by seismic surveys. Thus, high detection rates in late June 2016 were caused by seismic pulses not fin whale calls. However, the data suggests that despite high levels of seismic survey activity recorded, fin whale occurrence was not significantly affected by seismic survey activity.

Sperm whales were detected by SAM on almost all days at all stations but were most prevalent at stations surrounding the Porcupine Bank in comparison to those south-west of the Porcupine Basin, particularly in the spring (Figure 1). A total of 391 individual sperm whales were detected via PAM which resulted in predicted densities of between 0.010 and 0.025 individuals per km^2 and an overall abundance estimate of 380 sperm whales in the whole study area. Densities dropped off sharply in waters less than 1000m depth. Sperm whales were not detected in water depths <300m but occurred at average densities of 3.2 animals per 1,000 km^2 in areas with a minimum depth >300m. Sperm whale densities in the study area showed significant seasonal patterns with a peak in the summer. Sperm whale densities reported from acoustic surveys carried out at lower latitudes in the Atlantic were generally slightly higher. However, in order to robustly cover the continental shelf margin, the PAM component of the study was designed to include some outer shelf waters (Figure 2) which were less likely to be sperm whale habitat.

Three species of beaked whales (Ziphiids) were detected by SAM: Cuvier's and Sowerby's beaked whales and Northern bottlenose whale. Northern bottlenose whales were detected sporadically at most stations with more detections at northerly sites, and they were not detected at the two most southerly stations. Cuvier's beaked whales were rarely detected from May to August at the two most northerly stations but were almost continuously recorded at the southernmost stations. Detections at the northerly stations increased from September to December with calls detected on 9-64% of days monitored. Detections at the four most southerly stations increased with decreasing latitude. In contrast, Sowerby's beaked whale showed an increased detection rate with increasing latitude but were recorded at all stations especially in spring and early autumn. A total of 47 beaked whale detections were recorded via PAM, and these were categorised as BW70kHz (probably Sowerby's beaked whale) and BW40kHz (probably Cuvier's beaked whale). The best model estimating density for BW70kHz did not include depth but showed a strong latitudinal gradient (Figure 2). Predicted densities also increased with maximum slope. No modelling was carried out for BW40kHz due to a small sample size (n=9 individual detections).

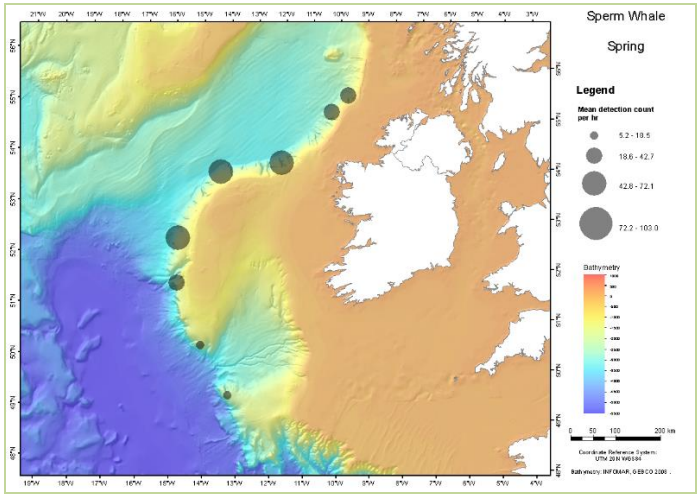

Figure 1: Mean detections per hour of sperm whales in spring

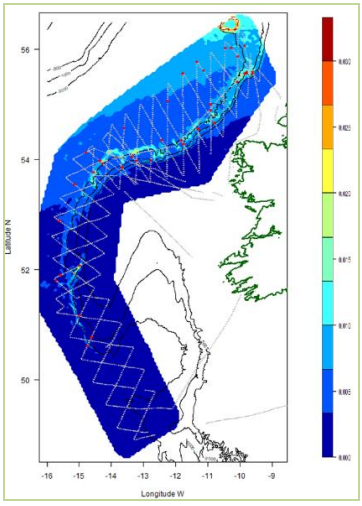

Figure 2. Predicted BW70 Densities

Pilot whales were detected on more than 87% of days at four most northerly stations from May to August 2015. Pilot whale detections decreased from September to December 2015 with a noticeable drop in mid-October after which detections became sporadic. Detections at the four most southerly stations were much less frequent, occurring on 22% of monitored days at the most southerly site. A total of 324 pilot whale whistle detection events were recorded. Predicted densities of pilot whales increased with maximum slope, and although the predictor variables for beaked whale 70kHz and pilot whales were different, there was a strong correlation in predicted densities suggesting a very high correlation in habitat use. Common dolphins were the most frequently recorded species using PAM with 1,106 events recorded. In spring, density was relatively low and concentrated on the continental shelf area while in

summer, density increased in continental mid-shelf area. In autumn densities were high in waters along the 1000m depth contour and over the continental shelf. Seasonal average predictions for common dolphin indicate the importance of the continental shelf break area. There was a clear temporal gradient in dolphin density with increasing densities through the year, but the timing of the surveys cannot fully capture the seasonal patterns. Predicted common dolphin densities showed a distinct peak in water depths of around 600m.

When considering habitat features and their influence on cetacean distribution and abundance, densities of all species detected acoustically were low in abyssal areas. Sperm whale presence peaked in the lower bathyal zone, pilot whales in the mid-bathyal, beaked whales and common dolphin in the upper bathyal zone. Common dolphin was the only identifiable species occurring in the deep circa-littoral and circa-littoral zones. Overall detection rates for the deep diving squid-eating species (sperm whale, beaked whale and pilot whale) were around twice that over sand and muddy sand substrates compared to mud and sandy mud. These observed differences were statistically significant for sperm whale and pilot whale. There was no difference for common dolphins.

The ObSERVE-Acoustic project has successfully generated a huge acoustic dataset containing information on the distribution, abundance and habitat use of a range of baleen whales and toothed whales in Ireland's Atlantic Margin. These data will provide baseline information and important insights that can contribute to the proper management of Ireland's offshore resources and biodiversity.

ROV Technologies for Targeted Rock Drilling, Coring and Exploration of Sensitive Environments

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Over the last few years, Ireland has invested heavily in upgrading its deep-water remotely-operated vehicle's (ROV's) capabilities particular in the area of high-resolution seabed mapping, precision rock drilling and coring. The ROV's capabilities have been tested and trailed with a proof-of-concept scientific survey (UCC/iCRAG CoCoHaCa survey: RH17002) in the deep-water Porcupine Bank Canyon undertaken last summer. The ROV can extract precision-located 2.5m vibrocores and rock-drill plugs down to 3000m water depth on extreme terrains as well as map, inspect and sample (high-resolution video and high-frequency multibeam echosounder data) on complex topography include vertical cliff bedrock exposures.

Despite extensive seismic exploration of the Irish offshore basins with ever increasing resolution, a limited number of boreholes have been drilled. Understanding the physical properties of reservoir, seals and "fluid migration pathway" rocks remains largely speculative. We need more physical samples. Understanding the petrological properties of source rocks that contribute to deltaic and fan reservoirs sands enables the remoter reservoir rocks properties to be better de-risked. Deep drilling is costly, and surface outcrop available for the relative cheaper seabed-deployed shallow drill rigs (e.g. MeBo or RockDrill) is limited.

However, sub-vertical bedrock exposures are relatively common on the margins of the Porcupine and Goban Spur where basement and Mesozoic basin lithologies outcrop. The development of an ROV-mounted horizontal bespoke hydraulic rock drill enables the collection of 120mm rock-plug samples to be taken from bedrock exposures on steep slopes at a fraction of the cost of other techniques. These samples can ground truth seismic units buried deep in the Bank where they outcrop at the Bank flanks and be made available for laboratory analysis.

In addition, Holland I ROV can collect precision-located vibrocores for site survey purposes. The MBARI, 5-barrel, 2.5 m vibrocoring rig enables core recovery from unconsolidated to semi-consolidated water-saturated sediment from muds to gravels. These corers work by attaching a motor that induces high-frequency vibrations in the core liner that in turn discretely liquefies the sediment directly around the core cutter, enabling it to pass through the sediment with little resistance but with no disturbance in the core. The vibrocorer is fixed to the front of the ROV, can take up to 5 core barrels per dive can be stored on the rig and are loaded by the ROV manipulator arms. ROV vibrocoring allows for the precision targeting of core sites with distinct advantages over gravity and piston cores, the coring process and can be monitored in real-time. Cores for environmental, gas-headspace, geochemical or geotechnical studies can all be retrieved. ROVs enable samples to be taken at specific locations (e.g. pockmarks) that can otherwise be hard to target. If coring does not work then another can be taken immediately, or another site found.

Holland I is a 3000m depth-rated, 100 hp, SMD Quasar work class hydraulic ROV with an A-Frame launch and recovery system. The system has a survey skid to accommodate a wide range of scientific equipment including various biological, sediment and water sampling systems and a CTD. It has seven and five function manipulators and a high definition camera system (video and stills) as well as powerful lighting to ensure high-quality observation and documentation of seafloor images. The ROV is flexible

enabling bespoke dive configurations including for multibeam echosounder mapping, rock-drilling and vibrocoring. The EM2040 200-400 kHz forward mounted multibeam echosounder is configurable in downward- or forward-facing modes to enable mapping of vertical faces.

A B

A) The vibrocorer mounted onto the front of the Holland I ROV and B) hydraulic rock-drill

The CoCoHaCa survey involved rock drilling and vibrocoring in the upper Porcupine Bank Canyon for scientific purposes with the new ROV-based vibrocoring rig successfully trailed and 10 vibrocores collected. A successful trial of the ROV rock drill in deep water was also undertaken with 2 rock plugs recovered sampling (85 and 116mm long at 970m wd and 1132m wd respectively). The Porcupine Bank Canyon is the largest submarine canyon incising into the Porcupine Bank exhibiting a fault-controlled sub-vertical rock cliff on the upper southern canyon margin. The Porcupine Bank is primarily basement (?gneissic) with ?granitic intrusions (Don and Lir Igneous Centres) with Palaeozoic-Mesozoic sedimentary basin rocks preserved on its flanks (Fursa, Macdara, Padraig, Cillian, North Bróna, South Bróna and Canice Basins).

Multibeam echosounder mapping of the cliff has enabled the construction of a digital terrain model of the outcrop. A series of high-resolution video transects up the outcrop video-mosaicking of bedrock exposures. Structural analysis of outcrops enabled lithologies to be distinguished based on variation in bedding, jointing, cleavage and weathering topography as well as the identification of faults.

Following proof of concept and with the availability of submarine cliffed bedrock exposures around the Porcupine Bank and Goban Spur, the time is right for a dedicated rock-drilling survey to increase our understanding of our offshore bedrock properties pertinent to reservoir properties.

Acknowledgements

We wish to thank the Marine Institute and iCRAG for funding the CoCoHaCa survey (RH17002) and Irish Lights Commission for the ILV Granuaile. We especially thank the Captain Harry McClenahan, officers and crew on the ILV Granuaile, scientists (Dr. Aaron Lim, Siobhán Bourke, Bogna Griffin, Findabhair Ní Fhoalain, Luke O'Reilly and Gerard Summers) and ROV technical team (Karl Bredendick, Rob Carpenter, Colin Ferguson, Liam Murphy, Martin Rouse and Ian Florence) for making this possible. This presentation 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.

Prospects within Licensing Option 16/24, North-Western Porcupine Basin

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Licence Option 16/24 covers Blocks 26/26, 26/27 (part), 35/1 and 35/2 (part) in the north-western Porcupine Basin. The Petrel Resources Plc applications in the 2015 Atlantic Margin Licencing Round were based on a regional re-appraisal of the Porcupine Basin using a large legacy seismic database, derived from earlier Licensing Rounds, together with more recently acquired seismic data. This study directed the company's main focus to the north-west sector of the basin. A number of basic elements were responsible for this focus;

- Mapping illustrated the northward narrowing and shallowing of the Late Cimmerian unconformity surface into a funnel shape across Blocks 35/1, 35/2. The basal Cretaceous was deposited on the eroded surface created by the Late Cimmerian tectonic pulses in latest Jurassic-earliest Cretaceous time. The location of submarine fans at Cretaceous level in the Porcupine Basin is typically topographically controlled, with potential reservoir sandstones preferentially focused into the topographic residual footwall lows.

- Water depths in critical locations are around 500 metres.

- Working petroleum systems have been demonstrated in the Porcupine Basin, with shows or flows of hydrocarbons recorded in many wells. In particular, the best results on test have been in the north of the basin, on blocks adjoining LO 16/24. The general northward shallowing of the basin means that regional migration of hydrocarbons is likely to have been northwards and towards the basin margins. A further positive point is that in LO 16/24 mature Jurassic source rocks are in close proximity to the overlying Lower Cretaceous mound features.

- Significant pulses of sand entered the basin during Early Cretaceous and Early Tertiary times, yielding potential reservoir rocks. Work by Evans-Young, (funded by Petrel Resources as part of the work commitment in the previous Round), has thrown light on the provenance of the Lower Cretaceous and Palaeogene sand influxes into the Porcupine Basin. A technique using the Pb isotopic composition of detrital K-feldspar was employed to determine the provenance of sandstone samples in the northern part of the basin. Primary source terrains identified were an offshore basement terrain such as the northern part of the Porcupine High, the Caledonian granites onshore in County Galway and an uncharacterised area, possibly from the east of the basin, such as the large Brendan Igneous Centre. Given the nature of the source terrains and the relatively long-reach river systems feeding into the basin from the north, it is probable that significant volumes of sand-dominated sediment were delivered.

Since the award of the blocks, Petrel Resources has purchased additional 2D seismic data and undertaken further interpretive mapping, selected line re-processing and inversion. Work has concentrated, in the main, on possible Cretaceous - Tertiary targets. This work, integrated with well analysis, has identified a number of promising leads. The lower part of the Cretaceous section is constrained by the basin floor topography and consists of a succession of shallowing sedimentary tongues, pinching-out to the NNE and gradually infilling the topography. In each case, pinch-out closure is best developed in Block 35/01 and the western part of Block 35/02 and present a picture of ponded turbidites, overlain by basin floor fan deposits. The critical factors in a consideration of the basal Cretaceous plays are those of reservoir quality and up-dip seal. Sub-sea drill depths on the basal Cretaceous pinch-outs are less than 4000 metres, in water depths of ~500 metres. In-house calculations

indicate that these pinch-out closures, individually or in sequence, could contain commercial quantities of recoverable oil – volumetric studies are continuing.

Petrel has also identified potential in the Apto-Albian, in the northern part of LO 16/24. Prospects here are at shallow drill depth, but the upper Albian, mostly in claystone facies in the 36/06-1 well, may provide an adequate vertical seal. Further south there are mounded Albian features that have mapped closure in Block 35/1. The Jurassic in this area must also be considered to have remaining potential, given the proximity of the Connemara oil accumulation. However, the mapped highs are structurally complex, and the existing 2D data are mainly of early vintage. An accurate assessment of prospects will require the acquisition of 3D data.

Petrel Resources has identified significant prospects in a sector of the Porcupine Basin where both water depths and drill depths are modest compared with those over much of the basin.

We look forward to discussing the potential in greater detail with potential partners.

De-Risking Exploration Offshore Ireland using Towed Streamer EM and Seismic Data

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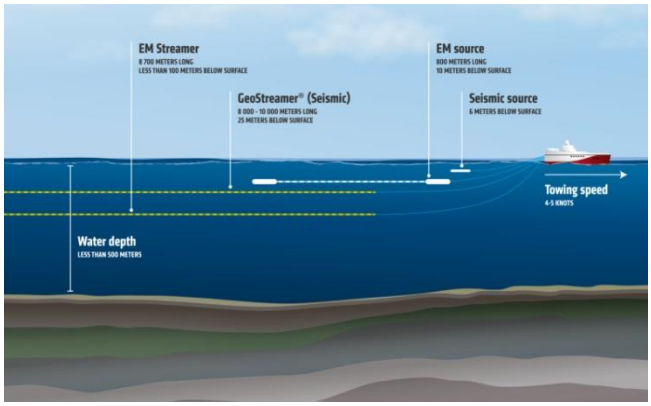
INTRODUCTION

Towed Streamer EM enables cost-effective and efficient frontier and prospect derisking in the context of increasingly brief international exploration licenses. This acquisition efficiency has resulted in a step change in the marine CSEM market; significantly more densely sampled 3D EM data can now be acquired in a dramatically reduced timeframe. Simultaneous acquisition of high-density EM and 2D seismic data (Figure 1) delivers two complementary geophysical datasets from a single vessel, as employed in the Celtic Sea in 2013. Towed Streamer EM data, when interpreted and integrated with seismic offers oil companies the ability to significantly de-risk frontier acreage, characterise specific prospects, extend asset life through effective near field exploration and even estimate levels of hydrocarbon saturation.



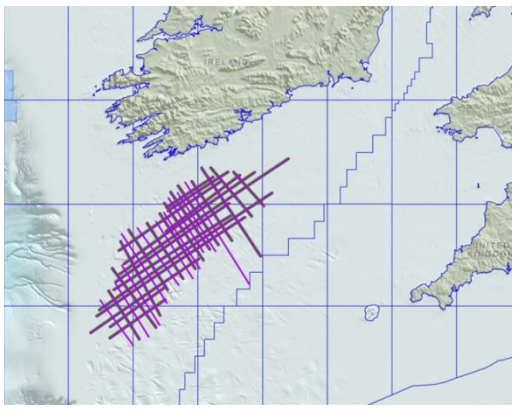


Figure 1: Simultaneous acquisition of Towed Streamer EM and GeoStreamer data

Figure 2: PGS MultiClient EM data in the Celtic Sea as of September 2017

The Towed Streamer EM system is designed for optimal imaging in shallow water, and as a rule of thumb, PGS is able to accurately recover subsurface resistivity in water depths between 40 – 500 m. In up to 500 m of water, PGS can map subsurface resistivity down to a depth of at least ~3 000 m below the mud line. It is worth noting that during the 2013 Celtic Sea survey the EM streamer was towed at a depth of 50 m (rather than the standard 100 m) where water depth was <100 m, highlighting the operational flexibility of the system.

SIMULTANEOUS EM AND SEISMIC ACQUISITION IN THE CELTIC SEA

PGS has been acquiring simultaneous 2D GeoStreamer and Towed Streamer EM data since 2013 and has experience of doing so offshore Ireland, Norway and the UK.

During the Celtic Sea project, approximately 3000 line km of simultaneous EM and GeoStreamer data were acquired (Figure 2). Average daily acquisition rates are in the order of 150 line km per day. When acquiring 3D EM data, this translates to 150 sq. km per day with PGS' standard high-density 3D EM 1 km line spacing.

Figure 3 shows the horizontal, vertical and anisotropy ratio for the same simultaneously acquired EM and seismic line in the southwest Celtic Sea. Horizontal resistivity is well suited to large regional trends and defining structure while vertical resistivity lends itself to imaging smaller anomalous features such as potential reservoirs. The ratio between the two is used in areas with a relatively low difference between background and target resistivity, to enable resistivity anomalies to be seen more clearly. Relatively low background resistivity is observed up to about 1 km depth with horizontal resistivity recovering the background trend well, including the deeper features (this clearly matches the structure seen on the seismic). Vertical resistivity shows localised anomalies, especially a slightly higher resistivity anomaly co-located with the stratigraphic pinch-out at around 500 m depth. The anisotropy ratio then "enhances" the anomalies visible on the vertical resistivity section. Higher resistivity anomalies in this part of the Celtic Sea may be associated with more resistive geology, or they may be indicative of hydrocarbon accumulations. Interpreting the seismic in conjunction with the different displays of resistivity described provides a more detailed picture of the geology and assists in better exploration decision making.

3D TOWED STREAMER EM ACQUISITION

For improved de-risking or higher resolution target characterisation purposes, 3D EM is employed. 3D Towed Streamer EM data is acquired using a single streamer with a line spacing of <1.5 km. PGS is able to invert 2.5D resistivity sections for each sail line, as well as deliver 3D resistivity volumes, enabling large areas of 3D acquisition with exceptional efficiency. If line spacing is >1.5 km, then acquisition is considered 2D, with 2.5D resistivity sections being delivered. EM deliverables include the frequency responses (navigation merged EM field deliverable) and 2.5D and 3D horizontal, vertical and anisotropic resistivity profiles and volume(s).

EM INVERSION AND INTEGRATION OF EM AND SEISMIC DATA

Unconstrained anisotropic inversion is an iterative, data-driven process starting from a homogeneous half-space, where the inversion is allowed to run until the model best fits the data. This fit is quantified by comparing modelled and measured data, and this QC information can be delivered to the end user of the data.

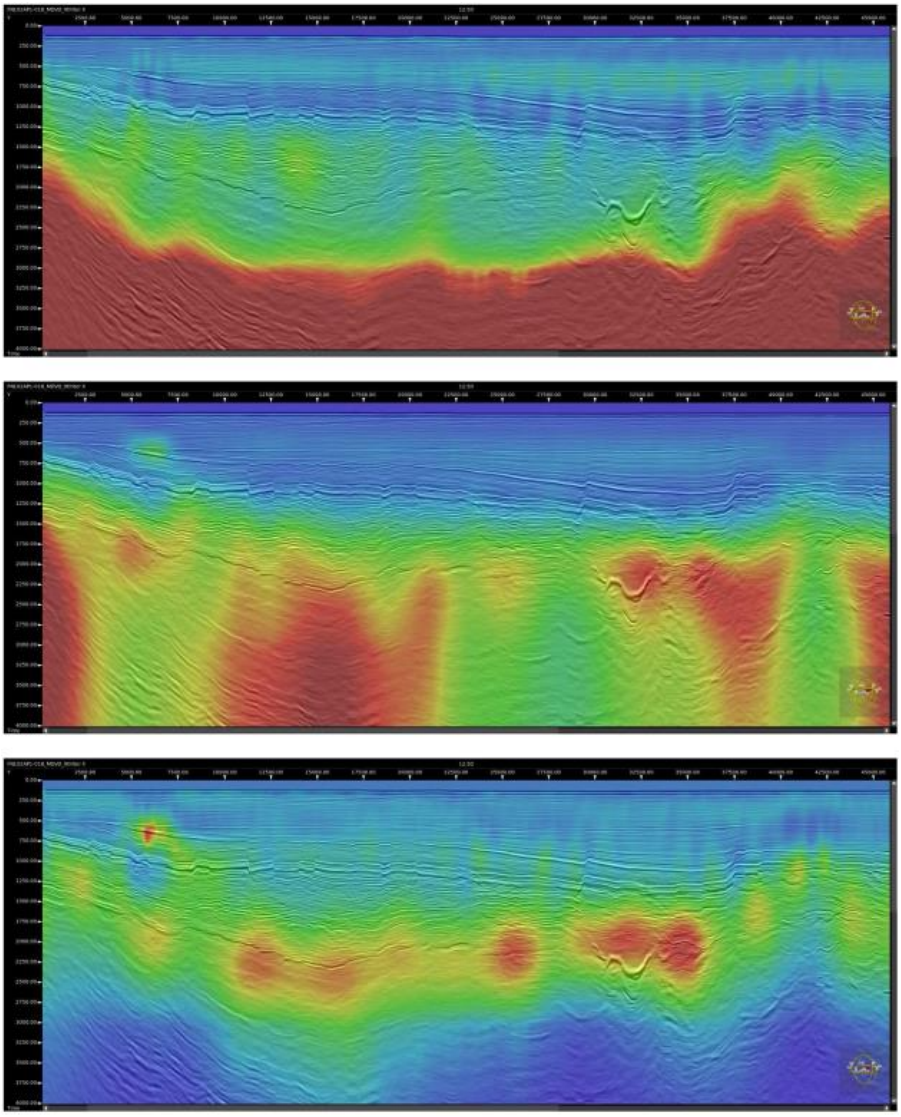


Figure 3: Top to bottom: horizontal, vertical and anisotropy ratio for the same simultaneously acquired EM and seismic line in the southwest Celtic Sea

To extract the maximum value from resistivity data, it is important to interpret it with seismic. The first step in the integration process is a simple co-rendering exercise where resistivity information is viewed overlain on structural data from seismic; this can be exceptionally valuable when exploring in frontier areas or de-risking seismically defined structures of interest. To extract further value from the resistivity data, it is possible to perform seismically guided inversion. This involves using one or more seismically defined horizons in the inversion process and improves resolution and structural conformity.

CONCLUSIONS

PGS' Towed Streamer EM system provides a step change in CSEM acquisition efficiency in conjunction with dramatically improved sampling density; expanding EM application from frontier exploration to more detailed reservoir imaging and characterisation.

The combination of renewed interest in exploration activity offshore Ireland and understanding and acceptance of CSEM technology, both in improving regional geological interpretation as well as de-risking prospects identified on seismic means it is highly applicable in the current cost-conscious environment.

STANDS

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POSTER ABSTRACTS (in alphabetical order)

Anatomy of early continental rifting: An integrated pedofacies, spectral gamma and paleomagnetic approach

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Hydrocarbon exploration in offshore 'Atlantic Ireland' rift basins carries significant risk for a number of different reasons and currently remains overly-dependent upon seismic surveys and their interpretation. Finding and documenting high-resolution, onshore analogue examples of continental syn-rift sedimentary lithofacies architecture and depositional styles will potentially help de-risk exploration in these basins in the future. The Lake Albert rift basin of the East African Rift System (EARS) exhibits all the classic tectonic, sedimentary, geomorphological and hydrological features of the early stages of continental rifting and has been used by exploration companies in the past as a direct recent analogue for the central North Celtic Sea Basin; it is of a similar structural size and style to Lake Albert, but with a fluvio-lacustrine fill from Upper Jurassic - Cretaceous. The PI undertook the first ever detailed geological survey and mapping of Exploration Area (EA) 1; northern Lake Albert (Murchison Falls National Park) for Tullow Oil from 2011-2013. This project, which started in September 2016, will build on the results of that Lake Albert survey to dissect the high-resolution sedimentary fluvio-lacustrine pedofacies and their spectral gamma ray response, developed during early continental rifting, and calibrate them against a palaeomagnetic polarity timescale. These data will then be used directly to reinterpret subsurface wells in the North Celtic Sea Basin.

Volumetric Considerations for Deepwater Pinchout Traps

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Stratigraphic traps formed by pinchout of turbidite reservoirs at the margins of deepwater basins are an important global exploration play type. Giant discoveries are necessary for commercial success to be achieved in many deepwater frontier basins. Simple geometric models are considered here to better understand the volumetric potential of stratigraphic pinchout traps. For the purpose of generic GRV calculations pinchout traps may be considered geometrically as i) bodies with uniform thicknesses; ii) onlapping bodies that thicken away from pinchout or iii) a mixture of both with onlap-related thinning near the slope passing into uniform thickness bodies downdip. Variations in dip with distance from pinchout, areal shape (i.e., channel, lobe or channel-lobe forms), number of pay zones and pinchout waste zone length scales are all important considerations. Hydrocarbon column heights and reservoir thicknesses used were taken from systems with deepwater pinchout traps. These models show that top reservoir structural dip angle is the single most important factor since field area and volume increases exponentially with decreasing dip angle. This is a key consideration, especially for channel systems with limited widths, since even modest dips can limit hydrocarbon volumes even in cases of relatively thick reservoir intervals with substantial hydrocarbon column thicknesses. Systems which decrease in structural dip or widen moving basinwards have far better potential, albeit this being strongly dependent on column height. These results are particularly pertinent to upslope stratigraphic traps on proximal slopes of basins, where relatively steep primary 'depositional' slopes and low net-to-gross systems encourage pinchout development but will limit hydrocarbon volumes. Stratigraphic traps at the lateral and distal margins of basins do not require steep primary depositional slopes for pinchout development.

These margins may, therefore, offer better potential, assuming limited structural tilt and suitable net-to-gross. Whilst the volumes of individual prospects must be considered on a case by case with detailed mapping, simplified analyses as presented can be useful for basin screening and high grading areas of giant stratigraphic trap potential.

Apatite Halogen Content Measurements by SEM-EDS and LA-Q-ICP-MS: a Provenance Analysis Approach

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Apatite is present across a wide range of lithologies, is reasonably resistant to mechanical and chemical breakdown during erosion and transport, and typically incorporates sufficient U to be a suitable target for U-Pb and fission track (AFT) thermochronology. As such, apatite has found considerable use as a provenance tool for identifying sediment sources with distinct (re)crystallisation ages and cooling histories. However, in cases when multiple candidate sources present indistinguishable crystallisation and cooling ages, U-Pb and FT dating methods become obsolete to trace the provenance of sediments. Single-crystal trace and minor element chemistry represents an alternative. Here we present a new provenance tool based on apatite halogen (F, Cl) content measurement, which complements existing rare earth element (REE) pattern analysis. We test the technique on apatites from five non-metamorphosed Caledonian granites (intrusion ages of ca. 435-400 Ma) and one modern river sediment for which single-grain apatite U-Pb ages range from ca. 380 to 520 Ma. Samples were collected in Scotland, which is an ideal test area where synchronously-intruded plutons with similar post-intrusion cooling histories represent a substantial potential source of sediments. Apatite fluorine content was measured by scanning electron mapping coupled to an energy dispersive X-ray spectrometer (SEM-EDS), and chlorine and REE content by laser ablation quadrupole inductively-coupled-plasma mass spectrometer (LA-Q-ICP-MS). Preliminary results of this study indicate that two groups of granites can be distinguished by combining F, Cl and REE measurements. Accordingly, apatite halogen content measurement appears useful in precise source tracking and can be routinely added to the REE analysis in future source-to-sink studies as both methods are complementary.

This project is funded by Science Foundation Ireland (iCRAG Research Center, project HC4.2PD6a).

The Sedimentary Architecture of the Hatton Basin from new 2D Seismic Reflection and Gravity Data

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[3] *School of Earth Sciences, University College Dublin*

The Hatton Basin is located at the western European Atlantic Margin, approximately 600 km west of Scotland and Ireland. 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. Here we present a preliminary interpretation of the large-scale sedimentary structure of the Hatton basin from new 2D regional long-streamer seismic reflection data and DSDP information. Gravity data and previous knowledge on the crustal structure of the basin are used to investigate its formation processes.

First interpretations of the seismic data suggest the presence of three megasequences referred to as Ha (Early Pliocene to Holocene), Hb (Late Eocene to Late Miocene) and Hc (Paleocene to middle Eocene), which are bounded by regional unconformities C10 (intra-Early Pliocene), C30 (intra-Late Eocene) and C40 (base Cenozoic) respectively. The C20 (intra-Early Miocene) surface is absent in the basin but is locally identified to the south of the study area. The mapped regional reflectors are recognised throughout the European North Atlantic.

Below the Cenozoic succession, the presence of Mesozoic and/or older rocks in the basin is proposed based on the seismic character of the reflectors and the apparent rotated fault blocks. In the lowest Cenozoic megasequence (Hc), a prograding sedimentary wedge system was identified at the basin margins that implies a relative sea-level fall during this period. In Late Paleocene-Early Eocene times, the basin was affected by extensive magmatism that resulted in the emplacement of volcanic intrusives and extrusives of basaltic origin. The deposition of megasequence Hb was controlled by strong bottom current activity as a consequence of rapid subsidence and deep marine conditions. The transition from sequence Hb to Ha is marked by the C10 unconformity, which records the late Cenozoic uplift and erosion of Ireland and Britain. Megasequence Ha is locally eroded and is characterised by contourite, debris flow and mass transport deposits.

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Validation of a New Sand Tracking Technique: Pb Isotypes in Detrital Plagioclase

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The Pb isotopic composition of detrital K-feldspar is a well-established provenance technique in both modern and ancient systems. However, source rock fertility bias means mafic source rocks, lacking K-feldspar, may be underrepresented by this approach when used in isolation, leading to erroneous interpretations of palaeodrainage and inaccurate models of relative contributions from source terranes. The Pb isotopic composition of plagioclase, alongside K-feldspar, may, therefore, offer a complementary yet improved insight into sedimentary provenance. In particular, plagioclase fingerprinting may hold the key to unravelling sediment pathways along active margin basins.

As a first step we ask (1) does the Pb isotopic composition of plagioclase, reflect that of its source rock? And if so, (2) does the Pb isotopic composition of detrital grains remain unchanged by weathering, erosion, transport, storage, burial and diagenesis? In order to answer these questions, the Pb isotopic composition of plagioclase from both felsic and mafic crystalline basement-arkose pairs are being analysed. Detailed mapping of isotopic and element patterns using high resolution in situ LA-ICPMS techniques are being used to reveal any discrete zoning present which could provide a means of micro-fingerprinting individual source rocks.

In order to test whether the Pb isotopic composition of detrital grains is retained from source to sink, the Pb isotopic fingerprint of plagioclase (as well as K-feldspar) from soil pedons across all major climates are being analysed. These field examples are complemented by on-going lab experiments studying the weathering of feldspar grains using organic acids in order to mimic natural weathering conditions.

This poster 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.

Conjugate Margins Conference - HALIFAX 2018

Brown, D.E.[1], Post, P.J.[1], Silva, R.L.[1], Wach, G.D.[1]

[1] *Organising Committee*

From August 19–22, 2018, the 6th Conjugate Margins Conference will be held at Dalhousie University in Halifax, Nova Scotia, Canada. This conference is dedicated to understanding the basin evolution, petroleum systems and exploration opportunities of the Atlantic margins. Halifax 2018 will bring together Atlantic Margin-focused delegates from the oil and gas industry, government and academia.

Past conferences in Halifax (2008), Lisbon (2010), Dublin (2012), St. John's (2014), and Recife (2017), provided unique opportunities for attendees to gather and integrate the results of hydrocarbon exploration, state-of-the-art seismic and other data from throughout the Atlantic conjugate margin basins using the latest concepts and interpretations. Halifax 2018 will continue this tradition of research focusing on the following themes:

- *Geodynamics-Rift to Drift*
- *Regional Geology*
- *Sedimentology & Stratigraphy*
- *Geochemistry & Petroleum Systems*
- *Exploration Thinking for the Atlantic Conjugate Margins*
- *Geoheritage*

Each thematic session will begin with a keynote address. Poster presentations, field trips, short courses, a core workshop, geological and geophysical data room(s), vendor displays and social events augment the conference programme.

Halifax 2018 will be an outstanding opportunity for geoscientists interested in the geology and hydrocarbon prospectivity of Atlantic conjugate margins to enhance their ability to generate petroleum discoveries. Please join us!

Onshore – Offshore Heavy Mineral Sand Exchange: Constraining the Location of Littoral and Offshore Irish Marine Placers

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Heavy mineral sands are highly concentrated in dense lucrative minerals and are an important source of Zr, Ti, Th, W and REEs. Their distribution and accumulation are controlled by source, hydrodynamics and a tendency to sort by individual mineral densities. Understanding sediment transport pathways is imperative in identifying spatial and temporal sediment sources. Heavy mineral sand deposits have been found on beaches and offshore Ireland at a number of key locations and may be forming placers. However, the economic viability is, until now, unassessed. This research will employ a multi-disciplinary approach to identify, quantify and characterise these deposits in NW Mayo, through a combination of

geophysical (high-resolution seismic and multibeam echosounder) and geochemical techniques (SEM-EDS, LA-ICP-MS, trace element analyses and provenance discrimination). Preliminary results show the presence of highly economic Fe-Ti oxides onshore and a significant volume offshore. The Irish geochemical ground, airborne and seabed mapping program (TELLUS/INFOMAR) led by the Geological Survey Ireland reveals onshore stream and soil anomalies that corroborate with initial findings. Ongoing fieldwork and analyses indicate an onshore-offshore heavy mineral exchange.

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 iCRAG industry partners.

A Hierarchical Compression-Based Geomodelling Workflow for Petrel

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The compression-based modelling approach is a relatively new scheme for building object-based reservoir models in which the interconnectivity of model objects is controlled by pre-defined geological targets rather than being an inevitable product of the modelling procedure. The current work aims to make the approach available to industry geomodellers by implementing a range of algorithms associated with the compression approach as plugins to Schlumberger's Petrel geomodelling package. Once this work is completed, it will be possible to integrate these new tools with the existing Petrel tools to define workflows for hierarchical compression-based object modelling. The implementation of the approach as Petrel plugins and workflows is on-going, but a clear procedure has been identified and will be outlined in this presentation. First, a hierarchy plug-in identifies the geological bodies present in a geomodel, and create locally refined grids that will be used in the modelling of hierarchically smaller models. Second, new object placement algorithms are being developed to improve the geological context of the objects. Recursive application of these two plugins will allow the creation of hierarchical models constrained to a quantified conceptual geological model at each level of the hierarchy. Third, an Upscaler plug-in has been developed to assemble the hierarchy of local grids into a unified grid without compromising the bed connectivity but minimising the grid size. Finally, the compression algorithm plugin is run on the upscaled grid to create the final geological model with target hierarchical object dimensional and stacking characteristics.

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.

Working Group on Sediment Generation Meeting, Dublin 2018

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The fourth biennial meeting of the Working Group on Sedimentation (WGSG) will be held in Ireland for the first time on the 27th - 29th June 2018 in Trinity College Dublin.

The Working Group on Sedimentation aims at increasing our understanding of sediment generation in the broadest sense of the word, by developing an integrated quantitative methodology that can be applied on different spatial and temporal scales. It includes topics such as sediment generation and dispersal, composition and provenance, as well as mass balancing and modelling of the relevant processes. The working group also aims to promote the education of early career researchers. The last two meetings in Leuven and Gottingen have attracted approximately 75 delegates; we expect this meeting to have closer to 100 attendees.

A healthy industry presence has been a feature of the previous WGSG meetings, and this has been hugely beneficial for all attendees, especially early career researchers. We wish to bring the event to your attention and to encourage you and your colleagues to participate.

A Biostratigraphic, Lithostratigraphic & Sequence Stratigraphic Framework for Offshore Ireland; Project Overview, Regional Seismic Lines and Well Ties

Ainsworth, N.R.[2], Bailey, H.W[3], Copestake, P.[1], Donato, J.A.[1], Farrimond, P.[4], Gallagher, L.T.[3], Gehlen, M.[4], Gueinn, K.J.[5], Hampton, M.J.[3], Lavis, O.M.[1], Loy, T.[1], Riley, L.A.[5], Wright, T.D.[1], Dominey, S.J.[1]

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The poster will present some details of the results of the PIP project IS16/04 (An Integrated Biostratigraphic & Lithostratigraphic Framework of Offshore Ireland) and complements a presentation on the same topic that will be presented at the conference.

The topics illustrated on the poster will be: -

- Project background and overview
- Summary of Palaeozoic stratigraphy of offshore Ireland
- Set of regional seismic lines across offshore Ireland, with significant well ties

Acknowledgements

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Microseism Source Distribution Observed from Ireland

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Ocean generated microseisms (OGM) are recorded globally with similar spectral features observed everywhere. The generation mechanism for OGM and their subsequent propagation to continental regions has led to their use as a proxy for sea-state characteristics. Also, many modern seismological methods make use of OGM signals. For example, the Earth's crust and upper mantle can be imaged using "ambient noise tomography".

For many of these methods, an understanding of the source distribution is necessary to properly interpret the results. OGM recorded on near coastal seismometers are known to be related to the local ocean wavefield. However, contributions from more distant sources may also be present. This is significant for studies attempting to use OGM as a proxy for sea-state characteristics such as significant wave height.

Ireland has a highly energetic ocean wave climate and is close to one of the major source regions for OGM. This provides an ideal location to study an OGM source region in detail. Here we present the source distribution observed from seismic arrays in Ireland. The region is shown to consist of several individual source areas. These source areas show some frequency dependence and generally occur at or near the continental shelf-edge.

Seismic Stratigraphy of Sediments on the outer Malin Shelf, Northwest Ireland

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Seismic reflection profiles crossing the outer Malin shelf north-west of Ireland show a seaward thickening sediment cover over a channelised bedrock erosion surface. The area's seafloor topography is mapped by high-resolution INSS and INFOMAR MBES surveys, associated acoustic sub-bottom profiles and current investigations. MESH sparker and commercial 2D multichannel lines are constrained by borehole data and indicate a Miocene to Plio-Quaternary cover over Carboniferous strata. Prominent reflectors bounding well-defined glacial-interglacial sequences on inner shelf profiles are correlated with cross-shelf reflectors, allowing the transfer of a BGS Pleistocene glacial stratigraphy to outer Malin Shelf edge sequences. The model proposes several phases of cross-shelf grounded ice extension from Scottish sources with morainal banks occurring near bedrock and the truncation of a stratified shelf edge sediment wedge that may form part of the Donegal Fan.

Predictive Distribution Mapping of Central-Place Foragers to Inform Marine Spatial Planning

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Large marine vertebrates, such as seabirds, are considered to be key indicator species for assessing the health of marine environments. Their distribution at sea has often been used for identifying important bird areas (IBAs) and further designating sites for protection as Marine Protected Areas (MPAs). Predictive distribution models have the potential to allow a quick assessment of distributions on a large scale and can help identify biodiversity hotspots for further investigation. This information is vital for conservation efforts as it will allow for more rapid risk assessment and inform allocation of MPAs. Here we report on a predictive distribution model that uses a foraging radius approach and can be applied to all central-place marine foragers. We have generated predictive distribution maps for all seabird species breeding in the UK and Ireland at $5km^2$ resolutions, for both individual species and feeding guilds.

The applications of the model and predictive distributions generated by it are wide-ranging, including highlighting at-sea abundance or biodiversity hotspots. One of the key advantages of the predictive distribution maps is the ability to assess impacts to biodiversity at a large community level, regional scale. Grid cells in the maps can be weighted by species-specific vulnerability indices across a range of potential impacts including susceptibility to oil spills or collision risk with offshore wind turbines to highlight areas of increased risk. An open-access online GIS platform has been developed concurrently to enable stakeholders, including fossil fuel and renewable energy sectors, to identify, manage and mitigate potential at-risk hotspots where vulnerable species occur.

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

Evaluating Controls of Acoustic Noise Propagation Across The Continental Margin

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Anthropogenic noise in the ocean, whether from offshore seismic surveys, pile driving or ships' passage is classed as a pollutant, and under the Marine Strategy Framework Directive should be quantified and monitored in Irish waters. This project aims to measure, quantify and model anthropogenic noise, as it propagates across the continental margin, from the Porcupine Basin to shelf seas at locations that provide contrasting ocean settings, i.e. submarine canyons vs typical slope conditions. Methods will include use of short-term acoustic monitoring mooring arrays in conjunction with controlled source airgun noise and prospectively a more long-term monitoring programme adjacent to active seismic surveys or drill sites. Results should feed into regulatory decision making, by providing an evidence-based assessment of anthropogenic sound sources. Any models built will be applicable to a wide range of end-users, from environmental to governance through to industry based.

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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. 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. 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.

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Return Periods for Extreme Waves in the Atlantic Offshore of Ireland

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The Atlantic Offshore of Ireland is a challenging environment for hydrocarbon or marine renewable energy operations. Strong winds are frequent, and there is a long fetch over which extreme waves may develop. In recent years, individual waves of over 20 m have been observed at wave buoys offshore of Ireland, with a single event of 25 m observed at the Kinsale Energy gas platform in 2014.

The spatial and temporal resolution of wave measurements offshore of Ireland is limited. Most long-running records contain only values of the significant wave height Hs (the average height of the highest 1/3 of the waves within an interval). However, recent improvements in wave measurement instrumentation have resulted in high-frequency measurements of sea surface elevation becoming available, although such data may be contaminated by numerical artefacts which must be identified and removed before further analysis.

Wave characteristics were calculated from raw data, and the Bretschneider distribution was fitted to the observed spectra. The fitted spectral parameters were then used to generate simulations of unidirectional random sea states in order to examine the relationship between significant wave height and maximum wave height in detail. This method can be used to generalise a relationship between Hs and the maximum wave height within the corresponding interval, Hmax.

We found that a maximum wave height of 21.8 m with a return period of approximately 4 years is possible at the Atlantic Marine Energy Test Site Berth A location off Belmullet, Co. Mayo. This is an enormous wave height with quite a low return period, therefore should be accounted for in offshore platform design.

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

Coupling Colour CL of quartz with Multiple Geochronological Proxies In An Attempt To Determine Extent Of Sediment Recycling in Devonian and Mesozoic Basins of Southern Ireland

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Detrital zircon, mica and apatite ages from samples in the Lower Devonian Dingle Basin, the Middle to Upper Devonian Munster Basin and the Triassic to Cretaceous basins of the southern Irish offshore (North Celtic Sea, Fastnet and Goban Spur basins) indicate the potential of multiple cycles of sedimentation. However, this evidence is somewhat inconclusive, and it remains a challenge to determine whether grains have been derived directly from the ultimate source or from recycling of older sedimentary rocks. Distinguishing between direct derivation of sediment and sediment recycling has important implications for prediction of sandstone maturity and hydrocarbon reservoir potential. Cathodoluminescence (CL) colour of quartz has, in the past, been used to determine the source of quartz in sandstones. However, the major concern for such an application is that there is large overlap of colours from different sources. In the present study, we hypothesise, based upon existing

geochronological and petrographic evidence, that the Upper Devonian Munster Basin sedimentary rocks were recycled during Mesozoic times into the southern Irish offshore basins. In order to test this hypothesis, we compare the relative proportions of different CL colours in quartz from potential sedimentary sources (i.e. the Devonian Dingle and Munster basins), with those from Mesozoic offshore basins of southern Ireland. Similarity only between relative proportions of quartz CL colours in these basins suggests recycling of sediments into the offshore basins during the Mesozoic. However, when coupled with petrographic observations, we conclude that the CL colour of quartz may not be a robust proxy for sediment recycling. A study of modern analogues is required to provide a true measure of the method's applicability to the problem of identifying sediment recycling.

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

Investigating the Link between Provenance and Reservoir Quality in the Slyne Basin, Offshore Western Ireland

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Reservoir quality is influenced by both primary sedimentological controls such as grain size, shape and sorting, and secondary diagenetic factors such as compaction and cement distribution. Sedimentological and diagenetic characteristics of sandstones are intimately linked to primary detrital mineralogy. Hence there exists an association, albeit cryptic, between provenance, diagenesis and reservoir quality. The extent of this relationship remains poorly understood. It is the aim of this project to assess and test this connection through the application of multiple sediment tracers. The Lower Triassic sandstones of the Slyne Basin (Sherwood Sandstone equivalents), including those of the Corrib Gas Field offshore west of Ireland, are the perfect test bed for this type of study due to the presence of sandstones with varying porosity and permeabilities occurring at a range of depths (1 – 4km) throughout the basin.

A multi-proxy approach is being employed to ensure rigorous provenance analysis linked to detailed assessment of diagenesis. High-resolution sampling of cores has been completed to encompass a full range of sedimentary facies and burial depths. Detailed characterisation of the sandstones is being conducted using optical microscopy, SEM microscopy, EDS, and autophase mapping, with a keen focus on diagenetic phases. U-Pb zircon geochronology, U-Pb apatite geochronology and Pb isotopic analysis of feldspar are being utilised to identify and constrain the relative contribution from possible source areas.

Results from the Pb isotopic analysis of K-feldspars reveal mixed Archaean - Proterozoic sources. Intriguingly, results from U-Pb geochronology of zircon and apatite appear to contrast with the feldspar data. This difference may be related to feldspar type and/or burial depth/diagenesis/preservation, recycling of zircons, or perhaps mineral fertility issues in the sourcelands. These results emphasise the importance of a multi-proxy approach in provenance studies.

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Basin Modelling of the Porcupine Basin, Offshore Ireland

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The Porcupine Basin (PB) is part of a chain of hyperextended basins extending along the north-western Atlantic margin. Key questions remain regarding its geological and thermal evolution, especially in undrilled areas in the south of the basin, which is the focus of current exploration interest. iCRAG research on the PB has direct relevance to understanding the driving mechanisms for the formation and evolution of hyperextended margins. A significant amount of information exists on the lithostratigraphy and depositional systems, the tectonics and timing of key geological events in the northern part of the PB. The extent of Jurassic crustal thinning linked to hyperextension appears to increase southward, yet the tectonic drivers remain uncertain. Mantle exhumation and serpentinisation have been suggested, while the products of Cenozoic igneous activity appear widespread.

Using numerical basin modelling tools, we evaluate a range of geological scenarios in the PB. A robust stratigraphic and tectonic framework has been developed using abundant seismic data available across the entire basin, and key structure maps and regional interpretations have been generated, serving as inputs for basin modelling. 1D modelling on wells drilled in the north of the basin have constrained the burial history, maturity and present-day geothermal gradient, but also highlighted a range of solutions largely depending on the heat-flow history and extent of Late Jurassic hyperextension. 2D basin modelling using the TecMod software, combining an inverse and forward modelling approach, is allowing us to test and model processes such as mantle serpentinisation and igneous activity (underplating, sill intrusion or extrusive flow), as well as reconstructing the evolution of the basin in time and space simultaneously (at the crustal and lithospheric scale) and evaluating critical elements including stretching factors, maturity and heat-flow patterns. Basin modelling results will be presented in the northern (good well control), central (little well control) and southern (no well controls) parts of the basin. These, coupled with enhanced details on crustal structure and paleo-thermal history, will yield an improved understanding of petroleum systems in the Porcupine Basin.

This presentation 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.

Stratigraphic Interpretation & Re-Evaluation: Upper Cretaceous Stratigraphy Offshore Ireland

Ainsworth, N.R.[2], Bailey, H.W.[3], Copestake, P.[1], Dominey, S. J.[1], Donato, J.A.[1], Dunford, G.[4], Farrimond, P.R.[5], Gallagher, L.T.[3], Gehlen, M.[5], Gueinn, K.[6], Hampton, M.J.[3], Lavis, O.M.[1], Loy, T.[1], Riley, L.A.[6] Stevenson, C.[7], Wright, T.D.[1]

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The offshore areas of Ireland were located on the margins of an epeiric sea during Late Cretaceous chalk deposition. Submerged and emergent structural highs defined distinct basins (including Fastnet, Celtic Sea and Porcupine). Changing basin physiography as a result of eustatic changes and tectonics has resulted in temporal and lateral changes in the nature of the chalk deposited and recognition of a number of chalk group subdivisions.

At some levels, the chalk displays large-scale cyclicity (evidenced in gamma-ray data and lithological variations) which, with the aid of biostratigraphy, can be correlated outside of the study area. Sequence stratigraphic concepts can be applied that build on ideas proposed by Hancock (1993), Bramwell (1999), Drake & Hawkins (2012) and Grant (1998). The most pronounced cycles (the most obvious 'C' shaped cycles with lowest API at the apex) align with mega sequences in Geological Time Scale 2012 (GTS2012). The boundaries between the intra Upper Cretaceous formations also equate to the levels of major so-called "sub-Hercynian" tectonic changes known across large areas of NW Europe.

The Upper Cretaceous is developed across most of offshore Ireland as carbonate-dominated facies referred to as the Chalk Group, which passes northwards, in the Rockall Basin area into the Shetland Group claystone dominated facies. The Group nomenclature utilises well known UK names, which have been used in contiguous areas to Ireland, such as the UK Rockall Basin.

The thickest and most complete developments of Cenomanian to Campanian sediments are in the Celtic Sea Basin. Conversely, the most complete developments of Campanian to Danian sediments are in the Atlantic basins.

Subdivision of the Upper Cretaceous Chalk Group into six new formations (provisionally numbered Chalk Unit 1 to Chalk Unit 6; pending formal description) is proposed.

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

An Integrated Geochemical Database for Petroleum Exploration Offshore Ireland

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The interpretation of geochemical data is important in hydrocarbon exploration, enabling identification and characterisation of source rock intervals, characterisation of oils and gases, and correlation of oils with their source rock(s). Although geochemical data are available for a majority of the wells drilled offshore Ireland, these data have not been available in an easily accessible, integrated format.

Geochemical data were provided by PIPCo RSG and PAD from all petroleum exploration wells for which such data are available offshore Ireland, and all available data have been compiled into a fully quality controlled integrated geochemical database in both p:IGI and Excel formats. This work was conducted as part of a Consortium Project led by Merlin Energy Resources Ltd. (IS16/04: *"An Integrated Biostratigraphic & Lithostratigraphic Framework of Offshore Ireland"*). The final database includes data for more than 18,000 samples from 146 drilled wells, covering all major offshore basins. Most of the data are from rock samples, but the database also contains data for a good suite of oil (228) and gas (267) samples. Data types range from Total Organic Carbon (TOC), Rock-Eval pyrolysis, and optical maturity data for the rock samples, through bulk fraction isotope data, to full sets of biomarker data for both rock and oil samples. The stratigraphy assigned to samples is currently as reported in the various geochemical source reports, but once the new stratigraphic scheme is finalised this will be included in the geochemical database allowing interpretation in the context of the updated stratigraphy. The compiled database enables interpretation of geochemical characteristics on a well by well basis, but due to its fully integrated character, interpretation on a basin scale or between different basins is also possible, enabling the identification of similarities or lateral variations between different areas.

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

Contribution of Submarine Groundwater Discharge (SGD) to the Marine Carbonate Biogeochemistry of the Western Irish Coastal Sea

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Over the past 200 years, human activities have altered the global carbon cycle. Perturbation due to the burning of fossil fuel has led to an increase of CO2 in the atmosphere. The scientific community has focused its attention on this phenomena because of the delay in the buffer capacity in the open ocean. However, nowadays, our interest is focused on the coastal area because there are other drivers and input that can modify the biogeochemical cycle, like rivers, submarine groundwater discharge (SGD) and all activities on the land. Submarine groundwater discharge has been often overlooked, however, as a supply of nutrients and carbonate that is important to take into account in order to understand the carbon cycle, the rate of respiration and photosynthesis. Due to the increasing of the CO2 dissolved in the water column, there is a decrease in pH. The changes of the pH value result in a decrease in the metabolic activities of calcified organisms, from zooplankton to commercial value species like mussels (Mytilus edulis). The coastal area has an important value on the aquaculture: to understand the health of the commercial value species and all organisms characterising this environment in terms of food web structure and functioning; we need to know the contribution of SGD to the amount of nutrients and carbonate.

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The Structural Evolution of The NE Rockall Basin Within Offshore Ireland and its Implications for Hydrocarbon Exploration

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This study combines structural analysis and 3D modelling of available 2D/3D seismic datasets, and associated well data, to define the architecture and timing of fault and basin development during the Mesozoic evolution of the Rockall Basin. Focusing on the NE margin of the basin, the study area is located on a major structural and basinal bend defined by faults with changing trends from NE-SW to N-S along the basin axis from the south to the north. Despite the seismic imaging problems arising from extensive Tertiary igneous bodies, particularly in the north, three episodes of rifting from Permo-Triassic, through to Upper Jurassic and Early Cretaceous (ca. Albian) are identifiable from interpreted seismic data and well control. This rifting produces a series of elongated horst and graben which transfer displacements via relay ramps or minor faults, with the regional change in fault trend not accompanied by extra complexity in fault patterns or geometry. The syn-rift sub-basins associated with Late Jurassic rifting are widespread across the area, although they are poorly connected because of faulting and erosion, whereas the Early Cretaceous sub-basins are only preserved in the north and south. Post-rift Tertiary igneous bodies are pervasive features seen in the area and caused substantial inflation of the Cretaceous sequence north of the study area. Our investigation suggests that Mesozoic syn-rift reservoir rocks can be strongly compartmentalised by faulting and erosion providing a relatively complex backdrop to hydrocarbon migration and trapping. Igneous bodies provide challenging conditions from an imaging perspective and may also have an impact on hydrocarbon prospectivity.

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Clare Behind-Outcrop Coring Project and Subsurface Training Initiative

Haughton, P.[1], Pierce, C.[2], Martinsen, O.J.[3], Shannon, P.M.[1], Lacchia, A.R.[1], Hussain, A.[1], Morris, E.[1], Pulham, A.[4], Barker, S.[3]

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A major behind-outcrop drilling campaign involving UCD and Statoil has now acquired over 1350 m of split PQ core from 12 boreholes behind the high sea cliffs in west Clare and north Kerry. The coring has targeted the Ross Sandstone Formation, a 500-m- thick Pennsylvanian deep-water fan system comprising nine high-frequency cycles of deposition forced by glacioeustasy. The cores have been integrated with additional outcrop work and ammonoid biostratigraphy and used to build a new framework and understanding of the system architecture and evolution. The new subsurface data have high value as an analogue dataset for use in training and reservoir characterisation. The ambition is to have selected cores available from this year in west Clare for use in both academic and industry courses. The

core on display, which integrates sections from various boreholes, captures some of the main architectural elements of the Ross Sandstone Formation, including muddy and sandy hybrid event beds, condensed sections, thin-bed deposits and mass transport deposits.

Integrated Early Jurassic Timescale and Earth System project (JET): International Continental Scientific Drilling Program (ICDP) Funded Drilling of the Complete Early Jurassic in the Cardigan Bay Basin (UK)

Hesselbo, P.[1] and the JET-science team (>60 researchers, from 10 countries)

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During the Early Jurassic, the planet was subject to distinctive tectonic, magmatic, and orbital forcing, and fundamental aspects of the modern biosphere were becoming established in the aftermath of the end-Permian and end-Triassic mass extinctions. The breakup of Pangaea was accompanied by biogeochemical disturbances including the largest magnitude perturbation of the carbon-cycle in the last 200 Myr, coeval with the now well-characterised hyperthermal, the Toarcian Oceanic Anoxic Event (T-OAE). Knowledge of the Early Jurassic is, however, based on scattered and discontinuous datasets, meaning that stratigraphic correlation errors confound attempts to infer temporal trends and causal relationships, leaving us without a quantitative process-based understanding of overall Early Jurassic Earth system dynamics.

The Llanbedr (Mochras Farm) borehole in west Wales, originally drilled 50 years ago, provides the basis for placing the T-OAE, and other possible Early Jurassic hyperthermals, in a long-term stratigraphic and timescale context. Here the drillcore represents 27 Myr of Early Jurassic time with a sedimentation rate of approximately 5 cm/kyr. Through the Integrated Early Jurassic Timescale and Earth System project (JET), a multi-faceted, international program of research on the functioning of the Earth system, new data from the old Mochras core will be combined with data from a new core to provide an understanding of global change and quantify the roles of tectonic, palaeoceanographic, and astronomical forcing on Earth's palaeoclimate and environment and associated marine and continental depositional environments and processes, at this key juncture in Earth history.

This project is funded by the International Continental Scientific Drilling Program (ICDP) and the UK Natural Environment Research Council (NERC).

Bed-scale Clay Distribution in Deep-Water Sandstones and the Implications for Reservoir Quality

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Detrital clay is considered a major factor driving flow behaviour, bed structure and reservoir quality in sediment gravity flow deposits. Quantifying and accounting for the details of the clay distribution at high-resolution vertically within single event beds and laterally towards bed pinch-outs remains a significant

challenge. High-resolution XRF core scanning coupled with petrographic and X-ray diffraction analyses have been used to document the details of clay distribution in eight different types of hybrid event beds (HEB1 to HEB8) from Pennsylvanian Ross Sandstone Formation (Ross Fm), western Ireland. The Ross Fm is a useful succession to explore the value of elemental profiling in that it comprises a simple bimodal mix of dominantly quartz-rich sand and clay. XRF profiling of key bed types shows that Si, K, Ca and Fe can be used as textural proxies for silt/sand grains, illite (including subordinate muscovite), chlorite and carbonates respectively. The data provide new insights into subtle but systematic vertical compositional trends that reflect hydraulic separation of minerals and textures, variable fractionation of different clay types and pulsed deposition of muddy sandstones and sandy mudstones. The technique can be further used to determine the likely source of clays incorporated in original flows and discriminate different types of vertically stacked mudstones.

Lateral trends are also being addressed at basal Ross level where turbidites and outsized hybrid event beds can be traced up to 18 km obliquely down-dip. The profiling is revealing strong lateral textural fractionation of platy grains, organic particles and clays. The elemental data has also helped identify vertical changes in sediment composition and sand input across the Ross Formation as a whole; early sandstones are coarser grained, have lower gamma, lower K and higher Si than younger parts of the Ross confirming that the deep-water part of the succession comprises at least two distinct systems.

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Hydrocarbon Potential of the Variscan Basement, SW Approaches and Celtic Sea Regions

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The UK's Oil & Gas Authority (OGA) is funding the NAWAB – New Appraisal of the Western Approaches Basins post-doctoral research project as part of its Frontier Basin Research programme. The NAWAB consortium includes the Universities of Durham, Keele and Leicester, collaborating with APT (UK) Ltd., Geospatial Research Ltd. and Trace Editors Ltd. The aim of the project is to evaluate the tectonostratigraphic evolution of the SW Approaches and Celtic Sea regions, to better understand their hydrocarbon potential. A cross-border, "geology without frontiers" philosophy underpins NAWAB research. One aspect of NAWAB, presented here, has been to evaluate the hydrocarbon potential of the pre-Permian, "Variscan" basement within the study area, by integrating borehole data from UK, Irish and French waters with published geological knowledge, particularly from onshore SW Britain.

The Variscan Front and Bristol Channel-Bray Fault (BCBF) appear to be key controls on the hydrocarbon potential of the Variscan basement. The former defines the northern limit of penetrative, Variscan deformation, whilst the latter is inferred to have been a dextral strike-slip fault, which was active during and after the Silesian and separates the Culm Basin from the South Wales Coalfield. Isotopic and trace element data indicate that the Culm Basin and South Wales Coalfield had distinct source areas during the Westphalian, consistent with significant separation of the two basins across the BCBF at this time. The Culm Basin contains Namurian-Westphalian sandstones, black shales and thin coals. Vitrinite reflectance data from North Devon suggest that the shales and coals locally retain gas generation potential. Gravity data, recently compiled by Getech as part of the OGA's 21st Century Exploration Roadmap Project, suggest that the Culm Basin extends westwards towards the South Celtic Sea Basin. Here, Irish and UK wells 58/3-1 and 93/6-1 penetrate possible Westphalian strata. Both wells display the

presence of background gas (predominantly methane) within the Carboniferous section, and gas was noted in a sandy facies of the overlying Triassic ("Keuper") section within 93/6-1. Although oil-based muds were used to drill the deeper parts of 58/3-1, the presence of up to 10-20% coaly fragments in cuttings associated with non-metamorphosed Carboniferous strata recovered from this well may suggest some potential for gas generation.

The main risks associated with any Carboniferous-sourced gas play in the South Celtic Sea region are: 1) the uncertain thickness and extent of Westphalian black shales and coals; 2) the challenge locating basement domains with limited Variscan metamorphic overprint; and 3) the critical timing between post-Variscan thermal maturation and regional reservoir, trap and seal development. Intra-Carboniferous reservoirs may exist but are likely to be highly deformed and structurally complex. By contrast, Westphalian strata to the north of the BCBF and Variscan Front are likely to be significantly less deformed and may share affinities with classic "Coal Measures" facies in South Wales and northern England, and gas prone sequences encountered in the East Irish Sea. In conclusion, the hydrocarbon prospectivity of potential Carboniferous, or Carboniferous-sourced, plays are likely to be greater to the north of the Variscan Front and BCBF than in the region to the south.

Perceptions of the Subsurface and Potential for Geological Training in West Clare

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The Pennsylvanian rocks of west Clare, Ireland, have been visited by geologists working in the industry since the late 1950s, 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 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. In order to facilitate training and wider geoscience outreach, a geosciences training and education centre in west Clare, Ireland, is in the initial phases of development. It is envisioned that the centre will involve the local community and wider public, facilitating links between natural resources, energy and environment. Public consultation is underway to ensure the centre fulfils the needs of the local community. The initial results of a pilot survey (run in July-August 2017) investigating the Clare locals' perception and understanding of the subsurface and of geological activities are outlined.

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High-Resolution Imaging of Seismic Properties in the Porcupine Basin by Full Waveform Inversion of Long-Streamer Data

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The Porcupine Basin is a failed rift located in the North Atlantic margin offshore southwestern Ireland. This hyper-extended basin was formed after several rifting and subsidence phases during Late

Palaeozoic and Cenozoic, with the most pronounced rift phase occurring in Late Jurassic–Early Cretaceous times. From the perspective of hydrocarbon exploration, the Porcupine Basin is one of the most attractive areas in the Irish Atlantic domain with potential hydrocarbon systems within the post-rift stratigraphic sequence (i.e. Cretaceous and Tertiary sediments). Yet, this area is not properly explored, and little is known regarding the properties of the rocks, such as porosity and fluid content, both critical for reservoir characterisation. In this work, we seek to characterise the Porcupine Basin by building high-resolution, quantitative models of seismic properties along 2D sections of the basin by full waveform inversion (FWI) of long-streamer data. FWI is a state-of-the-art imaging technique able to retrieve sub-wavelength images of multiple parameters such as seismic velocities, density or anisotropy that can be linked to rock porosity and fluid content through empirical relationships. Here we present the first step of a hierarchical approach, focusing on low-frequency, long-offset refracted signals. We start from a previous model obtained by first arrival traveltime tomography (FATT), which ensures kinematic accuracy for the considered long-offset refractions and mitigates the usual cycle-skipping issue. The resulting FWI velocity model brings more details on the western margin of the basin, where FATT already identified a low-velocity anomaly in the hanging wall of the basin-bounding fault, which suggests the presence of fluids. Further steps will include the estimation of density in the fault zone and its conversion into porosity, and the consideration of higher frequencies and shorter offsets for more detailed images. On the long term, we expect these images to provide new insights into the properties of the basin, the presence of fluids and their potential linkage with the growth of post-rift normal faulting, and therefore to contribute to the understanding of the tectonic history of the basins.

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Bathymetry and Sediments Effects on Ocean Wave Generated Acoustic/Seismic Noise Offshore Ireland

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In this study, we look at the comparison of 3D simulations of acoustic and seismic waves propagation with OBS data recorded across the shelf offshore Ireland and out into the Rockall Trough. Real and synthetic observations are combined to characterise both acoustic and seismic wavefields in the marine environment and particularly study secondary microseisms propagation from deep to shallow water to the land. Whereas the recorded OBS data show a strong change in the energy of “noise events” in the primary microseism band from the shelf to the land, the secondary microseism band is associated with the stronger signal in the deep water compared to the shelf area. Furthermore, the data also highlight seasonal variations in the seismic and acoustic wavefields likely related to changes in noise source locations. The 3D simulations of acoustic and seismic waves propagation in the Rockall Trough look promising to reconcile deep ocean, shelf and land seismic observations as well as the effect of the water column and sediments thickness on “seismic ambient noise” generation and propagation. For instance, the simulations reveal interesting results on the acoustic/seismic coupling and its implication on the secondary microseisms source origin.

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Coral Carbonate Mound Archives for Submarine Canyon Exchange Processes

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Submarine canyons are large, complex morphodynamic structures incised into continental shelves globally. Known for their diversity of substrate types and high-habitat heterogeneity, submarine canyons can alter the regional hydrodynamic regime. As such, canyon systems can be subjected to periodic intense currents, sediment slumping and turbidity flows. Their ability to act as conduits, transporting large volumes of sediment from the shelf to the deep-sea allows them to record environmental change at both millennial scales (sediment depo-centres) and decadal scales (coral geochemistry and microstructures).

The Porcupine Bank Canyon, one of Ireland's largest submarine canyons, is located at the centre of the Irish-Atlantic margin on the Porcupine Bank. Although designated as an SAC (Special Area of Conservation) until recently, it has largely been unexplored. Three research cruises (2015, 2016 and 2017) have been carried out, through this iCRAG project, to understand the contemporary and palaeo-environmental setting of the canyon and assess the fidelity of the cold-water corals (and associate mound structures) as local and regional palaeo-archives of environmental change. A series of novel marine surveying techniques (ROV-mounted multibeam and ROV-mounted vibrocoring) as well as more conventional techniques (ROV video, CTDs, hull-mounted multibeam and ROV sampling) have allowed to reconstruct the canyon water mass, geomorphology, substrate type, habitats and coral microstructure. Bedforms (e.g. ripples, scour) from video observations are being used to determine flow within the canyon. These data are being incorporated into a large GIS database where a facies distribution model will be created to understand the contemporary canyon setting. Initial results show that water mass characteristics influence coral distribution on a canyon-scale while slope and bedrock exposure influence facies distribution on a local-scale. This presentation represents work completed to date on the project.

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Quantifying Compensational Stacking in Deep Water Deposits: an Example from the Lettergesh Formation, West Ireland

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Compensational stacking, the tendency of younger sedimentary elements to avoid being deposited directly above older elements, has been recognised in different depositional environments, including deep water systems. It can have important implications in reservoir modelling since inter-element connectivity is in part controlled by the extent to which the elements are stacked compensationally. For this reason, studying this phenomenon is critical. Although different ways to measure stacking have been proposed during the last years, there is still an important lack of awareness about it.

The Lettergesh Formation, in the North Galway Silurian succession (West Ireland), is a 1500 meters thick sequence of deep-water turbidite lobes deposited in a small-scale basin. The lack of lateral bed

terminations and monotonous stratigraphy suggest that compensation is absent. However, drone photogrammetry and facies analysis differ from this conception. It is possible to recognise thickness variations and trends in 3D models, which suggest some degree of compensation. Facies analysis supports this idea since coherent vertical facies changes and amalgamation surfaces are noticeable. These observations are consistent with the idea of a small basin where accommodation space is narrow relative to the lobe width. Lobes will be deposited vertically, showing forced progradational and retrogradational stacking. Further work in this and other systems (e.g. Ross Formation) will lead to a better awareness of styles of compensational stacking in diverse geological systems and will have practical implications in reservoir modelling.

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Separation of the Diffracted and Reflected Wavefields by f-k Filtering

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Diffractions of seismic waves can be a powerful tool in a geophysicist's arsenal. Diffraction images can enhance features at the standard seismic resolution, helping identify features such as faults, pinch-outs, and fractures. However, in the conventional processing workflow, diffractions are not utilised. This paper aims to demonstrate diffraction imaging through a novel technique which suppresses reflections through filtering in the *f-k* domain. Herein, the *f-k* method is proposed and then applied to a synthetic and real dataset.

In the *f-k* domain, events are separated based upon their geometry and their velocity. As such, reflection events (which appear linear in the *f-k* domain) can be filtered, leaving the diffractions (which form fan shapes). These can then be migrated using a standard migration scheme to create a diffraction image. This technique was applied to both a synthetic and a real dataset alongside a plane wave destructor technique for comparison. It effectively suppressed the reflections from the wavefield, allowing the diffractions to be imaged. This was used in conjunction with a conventional reflection image to highlight channel discontinuities, faults, and breaks in geological horizons in the real dataset.

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Ambient Seismic Noise Applications at Boliden Tara: Preliminary Analysis

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Boliden-Tara mine is the second largest lead-zinc mine in Europe and is still expanding its operations. We are investigating the use of passive seismic (no shots) as an imaging tool for further exploration at the mine. We study the characteristics of the seismic noise field generated by mine activity (e.g. crushers, mine blasts) in order to see if it is suitable for imaging the geology of a defined area to the south west of the known ore body. New recently developed and developing techniques in seismology in some instances allow background seismic noise to be used as a source for seismic imagery.

By deploying sensors on the surface, we mainly focus on high-frequency noise from routine activity within the mine itself. Specifically, we explore the potential of reconstructing seismograms by cross-correlating and then stacking the background noise and the seismic coda (tails of seismograms) generated by blasts within in the mine.

The objective is that this methodology allows us to produce seismograms which can be analysed to produce seismic images of geological structure

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Testing the link between Jurassic-Paleocene Mantle Dynamics and the Western Irish Offshore Sedimentary Record

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Dynamic mantle processes exert a first-order control on the distribution and magnitude of uplift and exhumation, especially in tectonically passive regions. A mantle driver for the spatial pattern of uplift and exhumation observed across the British Isles has been proposed during the Late Jurassic, Cretaceous, and Paleocene (e.g., Jones et al., 2012, J. Geol. Soc. Lon.; Cogné et al., 2016, EPSL). Transient, dynamically-supported uplift should result in increased exhumation and drainage divide reorganisation, which in turn should be recorded in the offshore detrital provenance record by an increase in sediment flux and a change in sediment source as the onshore drainage area expands. Such shifts in provenance are crucial not only for validating exhumation histories and reconstructing paleo-drainage but also for assessing the nature and quality of potential reservoir rocks.

This project seeks to identify changes in sediment provenance in Jurassic to Palaeogene samples recovered from offshore wells in the North Porcupine and Slyne basins, and link shifts in provenance to onshore exhumation recently reported by onshore low-temperature thermochronometric studies (Cogné et al., 2014, J. Geol. Soc. Lon,; Cogné et al., 2016, EPSL). Here, we present new apatite and rutile U-Pb data collected from modern river sediment across Ireland and Scotland, which we use to characterise potential source areas and outline our offshore sampling program and progress to date.

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Conjugate Margin Architecture of Hyperextended Basins

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Many of the Atlantic margin basins west of Ireland, such as the Porcupine and Rockall basins, together with their conjugate equivalents on the Newfoundland-Labrador margin (Jeanne d'Arc, Flemish Pass and Orphan basins), represent important frontier exploration basins. In the central part of many of the larger basins, the sedimentary succession is underlain by differentially stretched ultra-thin continental crust. In the cycle of crustal extension and basin development, a four-stage process can be invoked, processing from stretching, through thinning, to exhumation and finally seafloor spreading. Remnants of the earlier rift basins are preserved beneath the successor basins as the extension and crustal rupture proceeds, resulting in a composite and complex basin architecture. The heat flow and basin architecture are critically determined by the mode of extension (pure, simple or mixed shear) and by the amount and rate of extension. Models for hyperextended crustal development in the large deep-water basins, including the Porcupine and Rockall basins, show polyphase deformation resulting in mantle exhumation along top-basement detachment faults.

This project focuses primarily on the sedimentary response and resulting basin-scale architecture, and especially on comparisons and identification of differences in sedimentary timing and style between conjugate margins. Using existing extensive high-quality wide-angle seismic data from the Irish and the Eastern Canadian offshore, integrated with regional normal-incidence industry reflection data, we are developing and testing models of the sedimentary response to crustal hyperextension.

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The Temporal Evolution of Provenance In The Mesozoic Rocks Of The North Celtic Sea and St. Georges Channel Basins

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Establishing the temporal evolution of provenance from source to sink in the North Celtic Sea (NCSB) and St George's Channel (SGCB) basins, offshore of Ireland's east coast, is an attractive target for hydrocarbon exploration. During the development of the basins, a series of syndepositional, thermal subsidence, fault reactivation and transgression events occurred which influenced transportation and deposition of sediments. High-quality reservoir sands were deposited during the Triassic and Jurassic. Identifying the provenance of these sediments has been hampered in the past by a lack of workable data and previously limited analytical techniques. Ongoing work has helped to distinguish source regions for parts of the western margin of the NCSB. However, more work is required to the east, northeast and south-east. This study will adopt a multidisciplinary approach including quantitative sedimentary petrology, detrital geochronology, grain shape and heavy mineral analysis (QEMSCAN) to elucidate the provenance and routing of sediments. Seismic interpretations may also be utilised. The study aims to

identify the contribution of UK, French and Irish sediments along axial drainage systems to Mesozoic Reservoir Sandstones.

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Detailed Characterisation of Thin-Beds In Deepwater Settings

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Thin-bedded deposits in deep-water settings are rarely investigated and relatively poorly understood, despite comprising a substantial volume of the deepwater sedimentary record, where they are important features of deep-water environments ranging from the basin floor (e.g. channel-lobe transition zone, lobe off-axis and lobe fringes) to the upper slope (e.g. frontal lobes, crevasse/avulsion splays, internal levees, external levees, and channel margins). Units of stacked thin beds are often used to subdivide lobes stratigraphically and to recognise hierarchical stacking arrangements in basin floor settings, whilst channel-related thin-beds record channel evolution from inception (frontal lobes), channel extension and growth (crevasse/avulsion splays, internal levees, terrace deposits, external levees and channel margins) to abandonment (abandonment drapes). Thin-bedded successions can also act important baffles and barriers within some hydrocarbon reservoirs, whilst in others, they form the producing reservoir (e.g. Ram/Powell field, Gulf of Mexico). As such, it is likely that they form an important component of the prospective Cretaceous and younger deep-water systems offshore Ireland where channel systems are increasingly imaged in 3D seismic datasets.

The extensive outcrops of the Ross Sandstone and Gull Island Formations of the Clare Basin in combination with a series of behind outcrop boreholes forms a unique dataset with which to examine thin-bedded sediment gravity flows. This project is in its very early stages and aims to develop a core and log based suite of criteria upon which thin-bedded deposits can be characterised and more fully understood.

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Application of the Sentinel Satellites 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. For example, the Sentinel 1 satellites, incorporating SAR bands, allow for the determination of surface slicks even under the cloudy conditions typically found along the Irish west coast. However, SAR by itself

is unlikely to accurately predict the nature of the observed slick and so predictive assessments will be made by combining SAR with ocean colour (Sentinel 3) and scatterometer winds (Sentinel 1). Overall our work has 4 main objectives:

1. Determine criteria for Good Environmental Status (GES) as per the EU Marine Strategy Framework Directive regarding the optical properties of seawater.
2. Identify CDOM components produced by natural blooms of phytoplankton in Irish waters.
3. Develop a spectral library of the optical properties of common maritime pollutants in seawater.
4. Develop an informed data analysis system for the identification of surface slicks from satellite data.

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Towards A Better Understanding of Sand Delivery To Passive Margin Basins

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This project focuses on investigating the changes in sand composition, prior to deposition, in a passive margin basin. Processes such as weathering, mixing or sorting can occur on the shelf or on the alluvial plain, preferentially impacting certain grains due to their inherent instability (e.g. feldspar or apatite), potentially resulting in variations in reservoir quality in the final sedimentary product. Careful investigation of sandstone composition could provide indications of the transport and/or storage that the sediment experienced prior to deposition. For example, during intermediate storage and transport, grains such as apatite will be dissolved more easily compared to a stable heavy mineral such as tourmaline. At the same time, the extent and duration of storage on the shelf or on the floodplain is closely related to sea-level fluctuations.

This study utilises the mid-Carboniferous Clare Basin, western Ireland, as a test bed for these ideas, and particularly the Tullig Cyclothem, a deltaic succession that was deposited under glacioeustatic sea-level fluctuations. Detailed sedimentary logging at three field localities show a delta progradation with a succession of prodelta mud, sandy mouth bar, interdistributary bay and channelised sand deposits. Quantitative petrographic analysis reveals that the sandstones are all mature. Heavy mineral analysis shows consistently higher apatite – tourmaline indices for the channel sandstones than for the mouth bar sandstone or the interdistributary bay deposits at two different locations. This could be highlighting the difference in transport and/or storage that the sediment experienced prior to deposition, with potentially more direct input of sediment through channel deposits than with the more mixed interdistributary bay or mouth bar deposits. As a change of sand provenance could also explain the variability observed in the sedimentary signal, U-Pb geochronology in zircon and apatite will be performed to better constrain the sourcing.

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Syn-Rift Basin Fill Architecture – Constraints from Forward Stratigraphic Modelling

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Triassic and Upper Jurassic rift-basin plays in the Irish offshore are relatively poorly imaged by seismic datasets and reflector geometry. Seismic attributes also only provide limited constraints on depositional architecture and potential reservoir distribution. The fault systems, however, that were active during and immediately prior to deposition in these basins are better imaged and preserved. These fault geometries and inferred fault system evolution may be used to predict aspects of the stratigraphic architecture and reservoir development that are otherwise poorly resolved. Insights gained through this predictive process could be key to identifying and risking prospects at the syn-rift level in the Irish basins.

Tectonic deformation has a major control on the sediment transport and accumulation in actively extending areas. Other prominent controls include variable sediment supply, water balance and base level, which have an influence on depositional response in rift basins. Hence climate and climate cycles are an important consideration, particularly in internally drained basins. Forward stratigraphic modelling is a powerful tool to use in this process given its ability to investigate the effect of competing controls on deposition and stratigraphic development during rifting.

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The Slyne And Erris Basins: Exploring Varied Structural Styles Along Strike in Narrow Rift-Basins

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The Slyne and Erris Basins belong to a chain of basins extending from the Norwegian Atlantic Margin in the north to the Porcupine Basin in the south. They are narrow, elongate and interconnected sub-basins orientated NE-SW (Erris) and NNE-SSW (Slyne) that began forming in the later Permian and Early Triassic. Basin fill consists of Permian, Triassic, Jurassic, Cretaceous and Cenozoic strata with key reservoir intervals in the Triassic, Lower- and Middle Jurassic.

The Slyne Basin is divided into northern, central and southern sub-basins. The northern sub-basin is a large graben with major NE-SW trending basin-bounding faults to the east and west, with considerable influence from salt-layers. The central sub-basin is a steeply dipping half-graben with a major fault along its western margin and significant detachment along Permian salt as well as diapirism up the basin-bounding fault. The southern Slyne sub-basin is a large graben cut by major, long-lived faults that also divide it from the Northern Porcupine Basin.

The Erris Basin can be divided into northern and southern, elongate grabens, bounded to the NW by the Erris Ridge and to the SE by the Irish Mainland Shelf. The northern sub-basin is locally affected by a

significant Base-Cretaceous Unconformity which removes most of the Jurassic section, while thicker Jurassic stratigraphy is preserved in the deepest parts of the sub-basin, bounding the crystalline Erris Ridge. The southern sub-basin preserves a thicker Jurassic sequence but has experienced prolonged uplift along its western flank during the Cretaceous and Cenozoic, with a significant angular unconformity placing the Base-Cenozoic against Middle and Lower Jurassic sediments.

The variety of structural styles within individual sub-basins produces a range of potential petroleum plays and trapping structures, most of which remain untested. The change in structural style is linked to the nature of the transfer zones separating the sub-basins, likely inherited from the deeper structures that separate Caledonian terranes. Understanding these zones will inform the structural history of both the Slyne-Erris area and other basins along the Irish Atlantic Margin.

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Long-Streamer Travel-Time Tomography of the Shallow Porcupine Basin, SW Offshore Ireland Reveals Across-Axis Variations in Petrophysical Properties

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The Porcupine Basin is a Mesozoic failed rift located in the North Atlantic margin, SW of Ireland, in which post-rift normal faulting is associated with an episode of thermal subsidence in the Early Eocene. Fault zones in sedimentary regions are known to act as both conduits and/or barriers depending on the fault permeability and contribute to hydraulic overpressure. Yet, little is known about the distribution of fluids and their relation to the tectono-stratigraphic structure of the shallow Porcupine Basin. Understanding of the distribution of fluids and characterisation of potential overpressured areas within the basin can contribute to drilling and environmental derisking during exploration of offshore resources. The best way to tackle this aspect is by assessing seismic (Vp) and petrophysical properties (porosity; φ) associated to the tectono-stratigraphic structure of the basin. Here, we use long-streamer data travel-time tomography of first arrivals to retrieve the 2D Vp structure of the post-rift sequence along a ~130 km-long EW profile across the North Porcupine Basin. The Vp structure of the basin is combined with the time-migrated seismic section to integrate tectono-stratigraphic information. This combination reveals several prominent vertical velocity anomalies on the western margin of the basin, coinciding with the location of a reactivated basin-bounding fault. While some of these anomalies appear to be explained by fracturing, others suggest the presence of fluid overpressure in the hanging wall of the fault. Extracting bulk density (ρ) and sonic log information from three coincident exploration wells to the seismic line, we build a new Vp-ρ relationship that we use to compute the ρ model and derive φ values across the basin axis. This result reveals lateral variations in φ that suggest differential compaction between the centre of the basin and its flanks. We propose a new model of fluid circulation that has implications for fluid overpressure and fault reactivation. Further work will include full waveform inversion to refine the tomographic results.

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Constraining the Exhumation of the Porcupine Basin and Surrounding Highs Using LA-ICP-MS-Based AFT and AHe Dating

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Understanding the timing, magnitude and causes of uplift and erosion events in sedimentary basins is critical for estimating the chance of success and volumetrics of oil and gas prospects. The northern part of the Porcupine Basin is characterised by a wealth of well and seismic data and legacy thermochronology studies and makes an ideal laboratory to integrate a large set of data and techniques in order to better constrain the exhumation history of this key part of the Irish Atlantic Margin.

This area is believed to have been affected by two important uplift events since the main Jurassic rifting phase, one in the Early Cretaceous and one in the Early Tertiary. A Neogene cooling event has also been recognised in some apatite fission track studies (AFT). However, large uncertainties remain due notably to the relatively low amount of erosion (and therefore cooling) that has been associated with these phases, or due to a lack of boreholes on the highs surrounding the basin.

Our project aims at building on top of these legacy stratigraphic and thermal studies by sampling key lithologies (sands, volcanic and metamorphic rocks) along vertical profiles in boreholes and using low-temperature thermochronology studies such as AFT and (U-Th)/He on apatites (AHe) as well as modern inverse modelling algorithms. We have sampled cuttings and cores from key intervals in 5 wells located in the Porcupine Basin and Porcupine High (16/28-sb01; 34/05-1A; 26/26-1; 26/30-1 and 35/15-1). After sample preparation and apatite grain selection, we plan to use the facilities at TCD to undertake the AFT studies and we will use a helium line in the UK to do the AHe analysis. The new low-temperature thermochronology results will be integrated with the legacy studies offshore and onshore Ireland along with well and seismic data to offer a new perspective on the uplift and erosion history of the area.

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Structural Style and Kinematic Analysis of Cenozoic Inversion Structures in the Central Part of the North Celtic Sea Basin, Offshore Ireland

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The Celtic Sea basins, on the continental shelf south of Ireland, consist of a set of elongate ENE – WSW trending basins that extend from St George's Channel Basin in the east to the Fastnet Basin in the west. The basins, containing a Triassic to Neogene sedimentary succession, evolved through a complex geological history that included multiple Mesozoic rift stages and later Cenozoic inversion.

Cenozoic tectonic inversion was characterised by N-S oriented moderate contractional strains that led to broad regional uplift accompanied by the growth of a series of inversion structures widely distributed through the Celtic Sea basins. Over the last 50 years, these structures have been a major target for hydrocarbon exploration as they provide structural closure for the main producing gas fields in the Celtic

Sea. Despite the importance of the inversion structures to the petroleum systems, their formation mechanisms are not yet well understood. This is partially due to poor seismic data quality which is compromised by a thick Upper Cretaceous chalk sequence subcropping at the seafloor. Therefore, the deeper parts of the inversion structures are often poorly imaged resulting in uncertainty about the structural style of these features.

The present work, based on structural mapping of several 2D regional and 3D seismic reflection surveys, provides examples of inversion structures located in the central part of North Celtic Sea Basin. The mapped inversion structures consist of 3-way and 4-way dip closed anticlines, and they are preferentially located within, and aligned parallel to, the basin axis in areas of thick Mesozoic cover. These structures are characterised by low relief, long wavelength asymmetrical anticlines bounded by Cretaceous and Jurassic normal faults. The observed size and geometry of these structures is interpreted to be controlled by a combination of both buttressing and partial reverse reactivation of the pre-existing normal faults. The interpretation of these structures, especially in poorly imaged areas, is supported by three-dimensional geometrical analysis and structural restoration to provide a better understanding of the mode of formation of the range of structures observed.

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Acoustic Evidence of Fluid Flow in Irish Offshore and Physical Property Measurements on Gas-Hydrate Bearing Sediments in Laboratory

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High-resolution geophysical datasets have been integrated into the west offshore Ireland sea area to determine the thickness of the GHSZ and the detailed morphology of its base, which is the focus of exploration activity. The objective of this study is to assist exploration for prospective NGH concentrations, which are dependent on migration pathways from source rocks or existing conventional hydrocarbon reservoirs and suitable host sediments within the GHSZ. The GHSZ thickness extends to a maximum depth below seafloor of 645 m and 784 m in the Rockall and Porcupine basins respectively. Petroleum systems have been confirmed in both these basins. Biogenic gas has been documented in shallow sediments. Seepage at the seafloor (pockmarks) as well fluid flow- related acoustic features in the shallow sub-surface, have been identified both within and outside the GHSZ regions.

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 Vp 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 Vp 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.

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Controls of Pre-Existing Structure on the Post-Jurassic Deformation of the Porcupine Basin, Offshore West Ireland

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Over the NW European continental shelf hydrocarbons have most often been encountered within Upper Jurassic traps, though increasing numbers of both structural and stratigraphic traps are hosted within younger Mesozoic and Cenozoic sequences. Many potential traps have been subjected to later deformation resulting in both localised compressional and extensional reactivation of Jurassic structures with both negative and positive implications for trap integrity and charge. This study focuses on the control of pre-existing Jurassic rift faults on the distribution and style of Cretaceous and Cenozoic normal faults within the Porcupine Basin as they could play an important role in hydrocarbon leakage from lower to higher structural levels and also in providing up-dip seal to post-rift stratigraphic plays. Our analysis of the post-Jurassic faults indicates that the degree of localisation and linkage with the underlying faults is controlled by three main factors: (a) relative orientation of later stretching and pre-existing Jurassic faults, (b) fault size (i.e. displacement), and (c) thickness and rheology of the intervening layer. Whatever the controlling factor, strong localisation during reactivation can provide up-fault pathways into post-rift strata, whilst weak localisation is unlikely to facilitate hydrocarbon leakage from lower to higher structural levels.

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A New Carbon Isotope Record of Lower Jurassic Age from the Slyne Basin (Offshore Ireland) and Implications to Investigate Source Rocks Around the Atlantic Margins

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The Lower Jurassic in the Central and Northern Atlantic basins coincides with a series of major environmental perturbations and dramatic changes in the marine biota. The Lower Jurassic interval is also a period of exceptional preservation of organic matter and is regarded as a main source rock interval in many basins around the world, including those offshore Ireland.

Here, we present an integrated assessment of total organic carbon, Rock-Eval pyrolysis, carbonate $\delta^{13}C$ and $\delta^{18}O$, and total organic carbon $\delta^{13}C$ record of Upper Sinemurian–Aalenian age from the Slyne Basin (well 18/25-1), offshore Ireland. Total organic carbon (up to 5.2 wt%) and Rock-Eval pyrolysis data highlights the Portree Shale Formation Equivalent (Lower–Middle Toarcian) as a mature (T_{MAX} ~440 ^{o}C) source rock dominated by Type II kerogens.

These new datasets and their interpretation add to the understanding of the paleoenvironmental dynamics during the Early–Middle Jurassic in the Northern European domain and opens new possibilities for hydrocarbon exploration in Ireland's offshore.

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Hierarchical characterisation of submarine channels for compression based object modelling.

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Submarine channels can host accumulations of hydrocarbons but are challenging from a reservoir modelling perspective. In confined channel systems, a six-level hierarchical classification scheme ranging from channel complex sets to beds has been recognised. The objective of current work is to establish a quantitative description of hierarchical channel deposits and to apply this description to create more realistic reservoir flow simulation models for them. The reservoir modelling is based on a novel hierarchical procedure (compression-based object modelling) developed for deep-water lobe deposits and adapted in this work to submarine channel deposits.

The modelling approach allows for independent input of net:gross (NTG) and amalgamation ratios (AR) in object-based models. This is a significant advance on pre-existing object-based methods in which the AR is inevitably equal to the NTG ratio, resulting in unnaturally well-connected geomodels at relatively modest NTG ratios. The models are conditioned to stacking and dimensional characteristics of channels measured in natural systems at different hierarchical levels. 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).

Preliminary results derive from outcrop observations compiled from published literature, and new analysis of 3D seismic data from the Taranaki Basin, offshore New Zealand. Results suggest that channel objects at smaller, sub-seismic hierarchical levels are better connected than at larger levels.

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Multidisciplinary Shallow Crustal Imagery at Boliden Tara Mines

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We aim to obtain the best geophysical images of the shallow crustal structure in the vicinity of the Boliden Tara Mines deposit at Navan, using a multidisciplinary approach. We will use passive seismic methods (receiver functions), and electromagnetic and gravity data sets to develop joint images in the target area, as part of a near-mine exploration effort. The receiver function data will be acquired from a deployment of broad-band seismometers, for up to one year. Electromagnetic data will include existing EM data at the site and the acquisition of additional MT data in the region. Gravity will include both existing data and additional data acquisitions. The area has good geological constraints and other geophysical data, so this offers us an opportunity to test the performance of joint inversion of multi-disciplinary geophysical datasets and use it to image unknown structures at increasing distances from the mine. The idea is to constrain the images over areas with good borehole and/or 2D seismic coverage and to move away from these constrained areas in 3D using passive methods.

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Significance of Heavy Mineral Populations in Cretaceous–Jurassic Clastic Units from Sedimentary Basins Offshore Western Ireland

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This research determines the extent to which deposition of Cretaceous–Jurassic hydrocarbon reservoir and source rock units along Ireland–Newfoundland conjugate margins are the result of regional, large-scale versus local, small-scale paleodrainage systems. Large-scale drainage systems are more likely to have led to the deposition of hydrocarbon reservoirs of more uniform quality, thickness and distribution across the region.

Cherty, calcareous and muddy sandstones and siltstones were collected as well cuttings from the Petroleum Affairs Division (PAD) in Dublin. The 64 to 125 micrometer sieve fraction was separated into heavy mineral concentrates (>2.9 g/cc), mounted and polished in 25 mm round epoxy mounts and mapped for mineral identity and abundance using Mineral Liberation Analysis (MLA) software on a Quanta 400 scanning electron microscope (SEM).

Distinctive heavy mineral enrichments are present in Cretaceous and Jurassic intervals within individual wells, and between different wells. In particular:

- Muscovite-magnetite-ilmenite-garnet in Upper Cretaceous units in two wells (5/22-1, 12/2-1z) on the eastern margin of the Rockall Basin.
- Magnetite-ilmenite in Lower Cretaceous and Middle Jurassic units in a well (35/30-1) on the eastern flank of the Porcupine Basin.
- Ilmenite-biotite-allanite-magnetite-muscovite-garnet in Lower Cretaceous and Upper Jurassic units in a well (43/13-1) on the southwestern flank of the Porcupine Basin, and in a Middle Jurassic unit in a well (35/6-1) on the southwestern flank of the Porcupine Basin. Similar mineral enrichments are present in a Lower Cretaceous unit of well 35/6-1; and Middle Jurassic units in wells in the Slyne (18/25-1) and Goban Spur (62/7-1) basins.

Heavy mineral proportions may reflect controls by acidic weathering, burial diagenesis and hydraulic transport but the distinctive mineral enrichments present in both Cretaceous and Jurassic intervals in the well from each site in the eastern (35/30-1) and western (43/13-1) Porcupine Basin suggests that a long-lived detrital supply from a distinctive source composition was the primary control in this case. Thus, clastic sources feeding the Porcupine basin may have been located both to the west and east, and differed in composition. The western source may have supplied a widespread Middle Jurassic paleodrainage system that deposited detritus as far north as the Slyne Basin and as far south as the Goban Spur Basin. These Middle Jurassic units may have the most consistent lithologic and petrophysical characteristics for hydrocarbon exploration.

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Improved Seismic Imagery in Shallow Highly Heterogeneous Environment

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Sub-basalt images are often of poor quality because of the large impedance contrast encountered at these high-velocity layers. The basalt layers result in attenuation of the seismic wave signal and cause broad-band backscattered energy as well as a lot of multiple reflections. To image target structures and subtle features beneath these layers, adequate energy must be available at depth to ensure a sufficiently high signal-to-noise ratio. The factors that affect the amount of energy available at deeper levels include the (i) layer thickness versus seismic wavelength relationship (ii) the details of the juxtaposition of various rock types (iii) the rugosity of the layer surfaces. Hence, the source frequency content is extremely important at the acquisition stage, and an understanding of how those frequencies attenuate and/or scatter with depth is key. Also, the subsequent processing of the data may be potentially suppressing important information which exists in the source spectrum. To understand the phenomenon a robust synthetic simulation is required that might help for better understanding of heterogeneity on seismic wavefield corresponding to the basalt structure. We prepare a real geological model with a high-velocity layer (basalt layer) with the rough surface to model the behaviour of the seismic waves with respect to basalt layer. We use 10 km long streamer data set from Rockall basin, where we see sub-sill structure prominently. We perform downward continuation to pick the refraction travel time with better accuracy, and it also helps to get shallower structure with better resolution. The travel time tomography will be carried out to get a smooth velocity model that will be used for full waveform inversion.

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Morphology and Development of the Deeps and Tunnel Valleys in the Western Irish Sea

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Deeps and valleys in the western Irish Sea such as the Lambay Deep, Codling Deep and Wicklow Trough, are believed to be part of a complex, linked valley system. During the last glaciation, the Irish Sea Basin was occupied by the Irish Sea Ice Stream. Interpretation of shallow seismic data by Whittington (1977) concluded that a till sheet blankets the pre-Pleistocene surface of the Irish Sea Basin and the valleys were cut into these subglacial sediments. The proposed formation of the channel system was (1) a sub-aerial fluviatile origin for the Codling Deep and Wicklow Trough during a period of low sea level based on morphology and minor tributaries from onshore rivers and (2) a subglacial stream erosion for the Lambay Deep. This late- to post-glacial, rectilinear drainage network is now partially infilled with Quaternary sediments, and at present, in parts, it is undergoing active erosion. The objective of our study is to reassess the morphology and formation theories of these deeps based on newly acquired seismo-acoustic data 40 years later and to define a Quaternary stratigraphic framework in the Irish sector of the Irish Sea. In spring 2017, we collected high resolution multichannel seismic and Sparker data on

R/V Celtic Voyager (CV17013) in the western Irish Sea. Interpretation of the seismic data together with the present bathymetry suggests that the Quaternary stratigraphy in the Irish sector of the Irish Sea is heterogeneous, complex and heavily influenced by channels. A poly-phase channel development is observed with the reoccupation of earlier ones. The interpretation also indicates that the Wicklow Trough and Codling Deep could likely be linked towards the north to a paleo-Liffey channel that possibly pre-dates the last glaciation and was reoccupied. Proposed mechanisms for the formation of the Codling Deep and Wicklow Trough are (1) subglacial meltwater erosion or (2) sub-aerial drainage channels from nearby ice fronts. The latter would implicate a non-marine deglaciation in the Irish Sea Basin.

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Textural Maturity Analysis and Sedimentary Environment Discrimination Based on Grain Shape Data

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Morphological analysis of clastic 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 collected from glacial, aeolian, beach and fluvial environments. A range of shape parameters are evaluated for their usefulness in textural characterisation of populations of grains. The utility of grain shape data in ranking textural maturity of samples within a given sedimentary environment is evaluated. Furthermore, discrimination of sedimentary environment on the basis of grain shape information is explored. 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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MarineWatch Demonstrator

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Earth Observation provides different platforms and sensors to acquire data over coastal and offshore areas. These datasets can be processed in order to map and monitor sea-surface conditions, coastal zone environments, offshore infrastructure as well support response to emergency maritime events. Satellite remote sensing provides regular, wide area image updates using both synthetic aperture radar

(SAR) such as Copernicus's Sentinel-1 as well as optical sensors such as Copernicus's Sentinel-2 over Irish coastal and offshore areas every few days. Lower altitude unmanned aircraft systems (UAS) or drones have begun to appear in the last few years and are now routinely used for a variety of information gathering tasks, albeit in view of the ground-based operator.

This MarineWatch demonstrator poster reports on the initial information content assessment of combined Satellite and Drone sensor to support offshore Oil and Gas operations. This assessment will consider spatial, thematic and temporal attributes and include an overall review of these sensor systems to map oil-slick features, carry-out shallow-water bathymetric survey, perform rapid coastal zone mapping (topographical as well as vegetation), autonomous offshore infrastructure inspection as well as supporting maritime emergency management. The very real and pragmatic issue of drone operations in terms of performance under harsh weather conditions, marinisation, safety, regulatory, communications will also be presented.

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A New Workflow For Generating Low Amalgamation, High Net:Gross, Hierarchical Geomodels Constrained To Well Data

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The ability to generate geologically realistic reservoir models that honour the available well data is an important step in predicting reservoir production behaviour. Many deep marine turbidite reservoirs are often 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. Recent work focused on understanding the internal architecture of deep-water lobes has recognised a general four-fold hierarchy, which is based on the characteristics of the fine-grained units that bound the sand prone bodies.

A new class of object-based model uses a so-called "compression" method in order to reproduce poorly amalgamated but high net:gross ratio sequences typical of many lobe reservoirs. The compression method allows the net:gross and amalgamation ratios to be separate inputs into the modelling workflow but is based on conventional object-based methods which are notoriously difficult to condition to well data. The recently-developed multiple-point statistics approach is pixel-based so models can be easily conditioned, and uses a training image to recreate the desired geological architecture. We have developed a new workflow that combines the compression algorithm with the multiple-point statistics method in order to create geologically realistic models that have realistic levels of sand amalgamation at different hierarchical scales, yet honour the available well data.

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Irish Centre for Research in Applied Geosciences (iCRAG)

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iCRAG is a national research centre founded in 2015 which has transformed applied geoscience research in Ireland, performing research which is designed to deliver economic impact for a broad range of application areas and industries. Supported by Science Foundation Ireland and industry partners for the next 3 years, iCRAG is one of only 16 SFI Research centres, and the first national geosciences initiative to be supported by SFI's flagship funding scheme. iCRAG is a collaboration between 150 researchers within UCD, TCD, NUIG, UCC, NUIM and DIAS and more than 50 industry partners who are working in partnership with government agencies involved in the geosciences sector.

iCRAG's research programme consists of five cohesive topics or 'spokes' in the areas of raw materials, marine geoscience, groundwater, hydrocarbons and geohazards/geotechnical engineering, which are built around four enabling technology and equipment based 'platforms' which focus on geophysical sensing and imaging, geochemistry, 3D geological modelling and public perception and understanding. The centre capitalises on Ireland's unique geological resources, including its world-class base metal deposits, its unusually extensive and highly prospective offshore basins and its world-class lowland karst and fractured bedrock aquifers. The principal goal is to embed the outcomes of high-quality research within industry practice in Ireland and overseas.

Instead of outlining the full range of iCRAG research, this poster describes some of the research conducted outside of the hydrocarbons spoke which is pertinent to technical issues confronted by the petroleum industry. This includes our marine-related research involving three main Targeted Projects: (i) Marine Acoustics, (ii) Enhancing knowledge and understanding of Ireland's seabed and (iii) Marine remote sensing applications. The broad range of research topics linked to offshore hydrocarbons is the subject of a separate poster.

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From Rifting To Hyperextension: Upper Jurassic – Cretaceous Tectono-Stratigraphy of the Porcupine Basin

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Middle-Upper Jurassic and Cretaceous successions of the Porcupine Basin on the Irish Atlantic Margin are currently attracting significant exploration interest. Major rifting during the Middle-Late Jurassic, progressing into hyperextension along the rift axis, produced fault-controlled half-graben depocentres which received continued sedimentation during a protracted phase of thermally-controlled subsidence during the Cretaceous. While numerous unconformity-bounded sedimentary packages are identified on seismic profiles in the main basin areas, many of these have not been penetrated by wells. The present study uses a combination of 2D and 3D seismic data and well information to identify, correlate and interrogate the character and distribution of the Upper Jurassic to Lower Cretaceous successions.

A detailed examination of both the eastern and western flanks of the Porcupine Basin indicates rifting initiated in the Middle-Late Jurassic. Major normal faults with large offsets defined the initial main rift basin. Termination of rift-related faulting in the Late Jurassic allowed confined depocentres to develop along the flanks in remnant underfilled topography followed by strain localisation. In the Cretaceous, a protracted phase of thermally-controlled basin-centred subsidence led to flank rotation which induced localised large-scale gravity-driven failure. The development of a highly erosive mid-Cretaceous unconformity referred to as the "Aptian unconformity" deeply eroded into the structurally-rotated lowermost Cretaceous successions.

Although considered predominantly mud-dominated, submarine fan sandstones are present within the Upper Jurassic and Lower Cretaceous succession. While submarine fans were deposited in the Late Jurassic – Early Cretaceous flank depocentres, many are identified at Aptian – Albian levels when sedimentation focused in the main basin. Seismic correlations and gross depositional environment maps at local and regional scale provide an enhanced understanding of the sedimentary response to hyperextension during the syn-rift to post-rift transition. The results are providing important clues to the timing, distribution and potential reservoir quality of sedimentary systems in the Porcupine Basin.

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Tracing Sand Provenance - Resilience of Provenance Signals in the Subsurface

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Conventional bulk-rock analyses, heavy mineral studies and single-grain geochronology are powerful and well-established tools in provenance and sediment tracking studies. However, these methods struggle with apportioning volumes contributed from different sources and unravelling possible grain recycling.

K-feldspar is likely to be preserved over long transport distances, and its common Pb isotopic composition can be linked to immediate sources. It can, therefore, provide additional insight alongside other provenance tools in terms of the ultimate source of the sand fraction and the relative contributions from different parts of the drainage basin. It is less likely to be biased by recycling and multiple phases of storage which can be an issue when using zircon geochronology alone.

However, K-feldspar is affected by burial and diagenesis, especially when exposed to pore fluids that dissolve the grains with increasing depth, to the extent that the overall framework composition may be significantly modified. Previous work has implied that arkoses may become quartz arenites with depth implying possible purging of the provenance signal.

The Jurassic Fulmar Formation in the Central North Sea is a well-studied arkosic sandstone with excellent reservoir properties. Thick successions of commonly highly bioturbated shallow-marine sands were buried to a range of depths between 3.2 km and 6 km depending on position relative to the basin margin. Typical diagenetic features of deep burial are highlighted by SEM imaging, showing increasing feldspar alteration and replacement at depth. Reactions include early dissolution and authigenic quartz, feldspar and ankerite overgrowths. Primary porosity is affected by micro-quartz cementation and carbonate cement redistribution and secondary porosity by feldspar dissolution with increasing depth.

Given the presence of dissolution features, the key question investigated here is the resilience of the provenance signal. Pb isotope analyses indicate two main provenance domains for the Fulmar

Formation, one with a $^{206}Pb/^{204}Pb$ ratio of 17.0-17.25 and one with $^{206}Pb/^{204}Pb$ between 18.0-18.5. Results indicate similar proportions of the two populations at depths of ~3.2km, ~4.3km, ~5.4km and ~5.7km. This information is critical for future work and integration in projects that include the Pb in K-feldspar method in multi-proxy provenance approach, especially when dealing with subsurface samples or recycled sediments.

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Michael Low	Vallourec Oil & Gas Ltd
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Jamie Collard	Westwood Global Energy Group
Kevin Whooley	Wood Group
Andrew McCarthy	Woodside Energy
Gareth Parry	Woodside Energy
Miguel-Angel Sanudo	Woodside Energy
Richard England	Woodside Energy
Shereen Nairne	Woodside Energy
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Eric Houston	Xodus Group
Fearghus Foyle	YAMSU Technologies Ltd
Jane Pickavance	Zebra Data Sciences Ltd
Liam Whitehead	Zebra Data Sciences Ltd
Paul Pickavance	Zebra Data Sciences Ltd
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Steven Miller
Allan Cree
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Brian Moorehead
Dennis Mike Ainsworth
Heather Bailey
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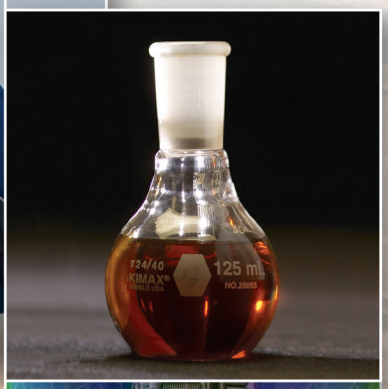
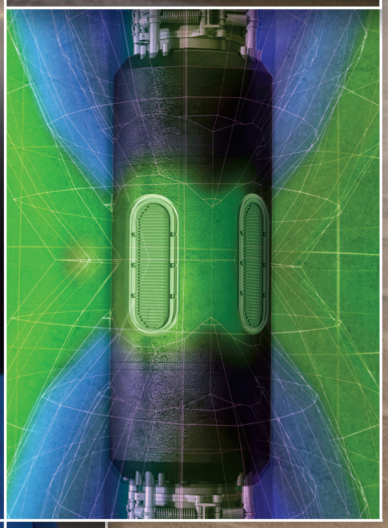
Paul Richardson
Sammy Sallam

Zenith Energy
The Skillful Pass

Saturn
3D RADIAL PROBE





Operator recovers high-quality fluids where not previously possible.

By switching from a conventional sampling probe to the Saturn 3D radial probe, a Norwegian Sea operator acquired fluids with contamination reduced by more than two-thirds to only 5%. Good-quality pressure transient and interference tests were conducted to estimate permeability anisotropy.

Read the case study at
slb.com/saturn

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