



Atlantic Ireland 2009

A Research Conference

Sponsored by PIP-ISPSPG

at

Institute of Management of Ireland Conference Centre

Sandyford Road, Dublin 16, Ireland

Abstracts Volume



Monday 19th and Tuesday 20th October 2009

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Institute of Management of Ireland Conference Centre
Sandyford Road, Dublin 16

Sunday, 18 October

Registration and Poster Setup (16.30 – 19.00)

Day 1

Monday, 19 October (08.00 – 19.30)

Opening Remarks, Welcome Address & Overview of Activities

Sessions 1 & 2: Basin Structure, Development & Sedimentary Fill

Session 3: Petroleum Systems

Session 4: Data Acquisition, Processing & Modelling

Reception and Poster Session (18.00 – 19.30)

Day 2

Tuesday, 20 October (08.30 – 14.00)

Plenary Session (open to all delegates)

Working Sessions of the steering groups on **Plate Reconstruction** and **North Atlantic Petroleum Systems Assessment (NAPSA)** will be convened following the Plenary Session. Separate agenda will be sent to committee members in due course.

*Note: **Posters** will be displayed concurrently with the Oral Sessions, throughout the Conference.*

ORAL PROGRAMME

Monday 19th October 2009

08.00 – 08.45 REGISTRATION - COFFEE / TEA AVAILABLE IN ATRIUM

08.45 – 09.00 Conference objectives and E&P research overview – Noel Murphy, PAD-DCENR

09.00 – 09.15 Welcome Address by Minister of State, Mr Conor Lenihan T.D.

Session 1 Session Chair Pat Shannon (UCD)

BASIN STRUCTURE, DEVELOPMENT & SEDIMENTARY FILL

Introduction by Session Chair

09.15 – 09.30 Dooish - the first discovery in Irish Rockall - **Geir Jansson** and Jeanette Henssen, Shell

09.30 – 09.45 Irish Passive Margins Modelling Project (IPmmP): 3D gravity and magnetic modelling of the Irish margin – **Geoff Kimbell**, Derek Ritchie and Sandy Henderson, BGS Keyworth and BGS Edinburgh

09.45 – 10.00 Regional basin and crustal structure – **Franz Hauser** and Brian O'Reilly, DIAS

10.00 – 10.15 Porcupine & Slyne-Erris basin structure, mapping, denudation and thermal histories – **Frédéric Biancotto**, Rob Hardy and Steve Jones, TCD

10.15 – 10.30 A summary of BGS research in the Hatton-Rockall region: everything from metamorphic basement to modern carbonate mounds – **Ken Hitchen**, BGS Edinburgh

10.30 – 10.45 Discussion for Session 1 papers

10.45 – 11.15 COFFEE BREAK IN ATRIUM

Session 2 Session Chair John Conroy (Shell)

BASIN STRUCTURE, DEVELOPMENT & SEDIMENTARY FILL

Introduction by Session Chair

11.15 – 11.30 Jurassic and Cretaceous tectono-stratigraphy of the Porcupine region - **Cedric Bulois**, Yongtai Yang and Pat Shannon, UCD

11.30 – 11.45 An integrated study of Permo-Triassic basins along the North Atlantic passive margin - **Brian Williams**, University of Aberdeen on behalf of the UCD-Aberdeen-Manchester Permo-Triassic research team

11.45 – 12.00 Carboniferous offshore Western Ireland – **Alastair Haddow** and Geoff Clayton, TCD

12.00 – 12.15 Igneous sills – recognition, distribution and implications for Irish exploration – **Karina Fernandes**, Steve Jones and Rob Hardy, TCD

12.15 – 12.30 Controls on the Lower Cretaceous carbonate habitats of the South Porcupine and Goban Spur Basins, offshore Ireland - **John O'Sullivan**, Providence Resources

12.30 – 12.45 Discussion for Session 2 papers

12.45 – 13.45 LUNCH BREAK - SANDWICHES SERVED IN ATRIUM

Session 3 Session Chair Steve Boldy (Lansdowne Oil & Gas)

PETROLEUM SYSTEMS

Introduction by Session Chair

13.45 – 14.00 Geology and Hydrocarbon Plays of the Rockall-Faroe Shetland-Møre Basin System – **David Mudge**, Ternan

14.00 – 14.15 Kimmeridgian Source Rock Super-Highway in the North Atlantic - **M. Enachescu** (MGM Energy and Memorial University), I. Atkinson (Nalcor Energy), J. Hogg (MGM Energy), D. McCallum (GNL DNR) and C. Rowe (CNLOPB)

14.15 – 14.30 Source rocks and unconventional shale gas deposits in the Wessex Basin, Mid-Cretaceous Sea Way, North Slope Alaska and the North Sea – **Joe Macquaker**, MUN

14.30 – 14.45 Mesozoic sand dispersal into NW European margin basins: insights from Pb in K-feldspar provenance tool - **Shane Tyrrell**, Peter Haughton, Stephen Daly, Pat Shannon, Andreas Siemes and Áine McElhinney, UCD

14.45 - 15.00 Heavy mineral provenance studies, offshore Newfoundland - **Paul Sylvester**, MUN

15.00 – 15.15 Nova Scotia/Moroccan Conjugate Margins – tectonic modelling – **Hamish Wilson** et al, PARAS / RPS Group

15.15 – 15.30 Discussion for Session 3 papers

15.30 – 16.00 TEA / COFFEE BREAK IN ATRIUM

Session 4 Session Chair Eugenio Antonielli (ENI)

DATA ACQUISITION, PROCESSING & MODELLING

Introduction by Session Chair

16.00 – 16.15 The INFOMAR programme, the Griffiths Awards and other Irish marine research – **Koen Verbruggen** and Yvonne Sheils, GSI / Marine Institute

16.15 – 16.30 Ireland - UK drilling proposal and site investigation cruise – **Ken Hitchen**, BGS Edinburgh and Clare Morgan, PAD-DCENR

16.30 – 16.45 Proposed new WARRP surveys offshore both Ireland and Canada - **Brian O'Reilly**, DIAS and Kim Welford, MUN

16.45 – 17.00 Exploring the resource potential of a dormant deepwater tight gas condensate accumulation using modern seismic technology – the Spanish Point discovery, Main Porcupine Basin, Offshore Ireland - **Stefano Pugliese**, Sosina Exploration

17.00 – 17.15 An overview of the Connemara Field and the exploration upside – **Robert Murphy**, *John Tingas and Jim Lance*, Island Oil & Gas

17.15 - 17.30 Prospectivity of the Ordovician Lower St. George Group Carbonates in Western Newfoundland, Canada and Implications of Dolomitisation for Porosity Controls – **Karem Azmy** and James Conliffe, MUN

17.30 – 17.45 Prospectivity on the Erris Ridge (Licence 7/97) – High Risk/High Reward Frontier Exploration on the Irish Atlantic Margin - **Andrew Howard**, ENI

17.45 – 18.00 Discussion for Session 4 papers

18.00 – 19.30 RECEPTION AND POSTER SESSION IN ATRIUM

Tuesday 20th October 2009

08.30 – 09.00 COFFEE / TEA AVAILABLE IN ATRIUM

09.00 – 09.15 Perspectives on the exploration history of the North-West Irish Continental Margin – **Ciaran Nolan**, Serica Energy

Plenary Session (open to all delegates)

Session Chair Viv Byrne (SLR)

(with Eugenio Antonielli, Steve Boldy, John Conroy, Noel Murphy and Pat Shannon)

09.15 - 09.20 Introduction to Session

09.20 - 10.45 Discussion on the forward research programme and opportunities for collaboration

10.45 – 11.00 Concluding Remarks

11.00 – 11.30 COFFEE BREAK IN ATRIUM

Please note that the poster session and possibly some informal presentations will continue to lunchtime (14.00) when the main conference will close

11.30 – 13.00 Plate Steering Group meeting (restricted to invitees only)

13.00 – 14.00 LUNCH BREAK - SANDWICHES SERVED IN ATRIUM

14.00 – 15.30 NAPSA Steering Group meeting (restricted to invitees only)

N.B.: Speakers are shown in bold italic.

ORAL PRESENTATIONS (in order of presentation)

Dooish - the first discovery in Irish Rockall

Geir Jansson and Jeanette Henssen, Shell E&P Ireland Ltd, Corrib House, 52 Lower Leeson Street, Dublin 2, Ireland.

The Irish Rockall Basin, lying on the Atlantic Margin of NW Europe, is an under-explored frontier deep-water basin. In 2002 Enterprise Oil Ltd drilled the Dooish well (12/2-1) to test Mesozoic and Palaeozoic sections, with specific emphasis on the fault bounded 'Pre-Rift Play' (thought to be Pre-Jurassic in age).

The well successfully discovered wet gas within the Pre-Rift section but was unable to reach a hydrocarbon/water contact and became suspended, due to mechanical problems, unforeseen over-pressures and a closing weather window.

Shell E&P Ireland Ltd re-entered the well (12/2-1Z) in 2003 and side-tracked to find hydrocarbons within the Middle Jurassic sands and the Early Permian sands/ conglomerates, with a hydrocarbon column height exceeding 200m.

In this paper we will present the well results and discuss the "Dooish" Play, specifically:

- Reservoir: High net to gross Middle Jurassic and Early Permian sands are the primary reservoir units, with some uncertainty over the presence of Triassic
- Top Seal: Dooish is sealed by the overlying Lower Cretaceous and potentially the Upper Jurassic marine shales. However the effectiveness of the seal is uncertain, as a shorter hydrocarbon column height was discovered than expected. There is a possibility of un-sampled and sub-seismic Upper Jurassic thief sands

The Dooish discovery, the first Pre-Rift test within the Irish Rockall Basin, proves the presence of a working hydrocarbon system in the basin which remains under-explored and commerciality has still to be demonstrated.

Irish PmmP: 3D gravity and magnetic modelling of the Irish margin

Geoff S Kimbell, British Geological Survey, Keyworth, Derek Ritchie and Sandy Henderson, British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA, UK (email: khi@bgs.ac.uk)

The Irish Passive Margin Modelling Project undertook 3D gravity and magnetic modelling covering the entire Irish Designated Area and employing data from the Irish National Seabed Survey. The cover sequence component of the model comprised Cenozoic and pre-Cenozoic sedimentary layers, together with a Cenozoic volcanic layer in the Hatton Basin area. Allowance was made for the effect of compaction on sediment densities and the pre-Cenozoic sedimentary rocks were assigned variable overcompaction associated with uplift and erosion in the shelf areas. The Moho geometry was initially estimated on the basis of local isostasy and then refined by inversion of long-wavelength gravity anomalies. The geometry of the pre-Cenozoic sedimentary layer was optimised by inversion of shorter wavelength gravity anomalies. The modelled crustal thickness variations generally compare well with the results of deep seismic experiments, replicating the high stretching factors and degree of asymmetry that have been observed across the Rockall and Porcupine basins. Optimisation of the cover sequence geometry introduced sharp changes in its thickness which were not present in the initial model but can be validated by comparison with detailed seismic mapping. For example, the faulted margins of the Slyne and Erris basins, and the distinct change in trend between these basins, are well-resolved. In the frontier area further west, the modelling resolves local,

previously unrecognized, NE-trending basins on the Rockall High and suggests that rifts with a similar trend underlie the Hatton Basin. Forward magnetic models, based on the geometries defined by gravity modelling, help to identify a long-wavelength component of the observed magnetic field that can be explained in terms of changes in the thickness of the crystalline crust. Superimposed on this are shorter wavelength magnetic anomalies associated with variations in basement magnetisation and the products of Cretaceous and Palaeogene magmatism.

Regional basin and crustal structure offshore Ireland: a review

Franz Hauser^{1,2}, Brian M O'Reilly¹, Peter W Readman¹ and Pat M Shannon²

¹*Geophysics Section, Dublin Institute for Advanced Studies*

²*School of Geological Sciences, University College Dublin*

Acquisition of wide-angle seismic profiles in the Irish offshore began in the 1970s and 1980s across the broad region between the Celtic Sea and the Hatton Continental Margin. These were targeted to solve outstanding scientific problems concerning lithospheric development and sedimentary basin structure in the North Atlantic region. The acquisition continued through the 1990s into the present century in the deep-water Rockall and Hatton basins, with the most recent data (2002-2004) being gathered in the Porcupine Basin. These controlled source experiments resolved details of structure, hitherto unknown, within the crust and Mesozoic to Recent sediments. They have led to the development of new ideas regarding the mechanisms of extension in passive margin hyper-extended crust. The data are also of importance in the assessment of hydrocarbon prospectivity in the Atlantic margin region and have yielded new information of the likely sedimentary thickness and regional sedimentary architecture of the frontier Atlantic margin basins.

One of the main results to emerge from this substantial body of work was that continental lithosphere extends unbroken from Ireland to the Hatton Continental Margin. The process of continental break-up and sea-floor-spreading did not begin until the early Eocene and had a major stratigraphic impact on the post-Mesozoic evolution of the Irish margins. Crustal thickness varies widely (~2 km to 32 km) with the thinnest crust occurring below the Rockall and Porcupine basins. Beneath these basins exhumation of serpentinised cold mantle lithosphere sporadically occurs in response to differential extension, involving normal low-angle detachment surfaces. Magmatic underplating, associated with early Cenozoic volcanism, is confined to the outer fringes of the Hatton Continental Margin. The thickness and seismic velocity structure of the basin-fill sediments is similar in the Rockall and Porcupine basins. Within these basins a lower sedimentary layer is interpreted as predominantly Triassic/Jurassic syn-rift sediments, overlain by a post-rift sequence of Cretaceous to Recent age. Crustal thickness below the Hatton Basin is ~15 km with the seismic velocity structure suggesting a predominantly pure shear mode of extensional deformation, as opposed to the mixed shear (differential stretching) mode that dominates the Rockall and Porcupine basins to the east. Two sedimentary packages are defined across an unconformity surface that formed in response to uplift, driven by thermal convection within the mantle, which drove magmatic underplating of the highly extended crust along the western extremity of the margin. The insights into the geologically protracted development of the Irish continental lithosphere have been important in developing scientific understanding of extensional tectonic processes. They have also contributed much to our regional understanding of the petroleum systems and hydrocarbon potential of the Irish offshore.

Porcupine & Slyne-Erris basin structure, mapping, denudation and thermal histories

Frédéric Biancotto, Robert J. Hardy and Stephen M Jones, *Department of Geology, School of Natural Sciences, Trinity College Dublin, Ireland*

Exhumation describes vertical displacements of rocks from maximum depth of burial that results from the removal of overburden material. In this study we invert seismic velocity profiles from 2D and 3D seismic reflection datasets to constrain the distribution and the magnitude of exhumation within the Slyne Basin, offshore NW Ireland. The method has already been successfully applied to 2D datasets offshore Britain and Africa; this study is the first attempt to extract exhumation estimates from 3D seismic data. Inversion of 3D seismic velocity data yields a continuous map of exhumation across the entire 3D footprint. Exhumation estimates from 2D seismic sections agree with estimates from co-located 3D data. However, there is greater scatter in the 2D-derived exhumation estimates, most easily seen at line ties. This scatter in the 2D measurements arises because 2D seismic stacking velocities are less well constrained than 3D velocities. Together, the 2D and 3D seismic stacking velocity profiles can be used to estimate exhumation patterns on spatial scales >10 km to an accuracy of 200m. Many estimated changes in exhumation are associated with geological structures, suggesting confidence in the results. The margins of Slyne Basin have undergone about 1km more erosion than the basin centre to form the Jurassic-Miocene composite unconformity. Inversion anticlines in the centre of the basin have undergone a few hundred metres more erosion at their crests than at their flanks. There is good agreement between 3D seismic-derived exhumation estimates and existing exhumation estimates using traditional techniques applied to borehole data. Overall, our results show that regional exhumation can be mapped in hitherto unprecedented detail using good quality seismic stacking velocity data.

A version of this paper was first presented at SPE Offshore Europe 2009 in Aberdeen.

Summary of BGS research in the Hatton-Rockall region: everything from metamorphic basement to modern carbonate mounds

Ken Hitchen, *British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA (email: khi@bgs.ac.uk)*

Gravity and magnetic modelling across the Hatton-Rockall margin has been undertaken for the BGS UK Passive Margins Modelling Project and the Rockall Consortium. Example maps across the Rockall Trough are shown including an estimate for the apparent extension factor, depth to Moho, thickness of crystalline crust and thickness of sedimentary layer.

A sea-bed sample of 'basement' from 50km west of the Outer Hebrides (obtained with the BGS 15m RockDrill) is a syenite and may give cause for the re-positioning of the Caledonian Front. Other sea-bed short cores from the Nun Rock area include granite, pegmatite, schist and gneiss. Analytical work is ongoing. Results will enhance the structural understanding of the area and add constraints to basement terrain investigations - hence affecting any proposed refit between Scotland and Greenland.

Large Mesozoic (and ?older) basins in the core of the Hatton High are confirmed by BGS and TGS/Fugro HR07 data. Compressional forces during the Cenozoic caused numerous large-scale folds and unconformities (Tuit, 2009). 'Lumps and bumps' observed on the ISPSG HA04 data, especially within the Palaeogene interval, may be structural, volcanic and/or ?diapiric in origin.

The Eocene is seen as a potential reservoir interval for hydrocarbons. It contains high-porosity prograding wedges, pinch-outs and onlap/downlap trapping styles and is overlain by Oligocene to Pliocene mudstones and oozes.

Habitat mapping in the region has identified numerous carbonate mounds especially on Hatton Bank. There is a range of styles and some are developed over faults. New data over some of these mounds were acquired in 2009.

Multibeam data from the oceanward side of Hatton Bank image the large Talismán Slide and segmented linear ridges. Most of the Rockall Trough and adjacent banks are now covered by multibeam datasets. Examples from Rosemary Bank are shown.

BGS plans for the future include nearshore multibeam acquisition using the new BGS vessel 'White Ribbon', using the BGS 15m RockDrill to obtain sea-bed short cores in the greater Hatton-Rockall region and, in conjunction with PAD and ISPSG, the drilling of a number of shallow boreholes.

Tuitt, A. 2009. *Timing and controls of structural inversion in the NE Atlantic Margin*. Unpublished PhD thesis, University of Edinburgh.

Jurassic and Cretaceous tectono-stratigraphy of the Porcupine region

Cédric Bulois, Yongtai Yang & Patrick M. Shannorr School of Geological Sciences, University College Dublin, Belfield, Dublin 4, Ireland (email: cedric.bulois@ucd.ie)

The Porcupine Basin, offshore Ireland, has been the subject of intermittent petroleum exploration leading to the Connemara (Quadrant 26), and the Spanish Point and Burren (Quadrant 35) discoveries. Hosted in Mid- to Upper Jurassic and Lower Cretaceous sandstones, the reservoirs in these accumulations developed during a major rifting phase. The present study reviews extensive 2D and 3D seismic data correlated to petrophysical logs to detail the rifting architecture in the basin and re-evaluate the basin development in a regional context.

Extensional fault structures of various ages and orientations are developed in the Upper Jurassic to Lower Cretaceous succession. The main rift activity took place predominantly along inherited NE-SW and E-W faults-zones in Quadrant 26, whereas N-S structures are of more major importance further south. Within the Jurassic, four main lithostratigraphic packages have been recognised through the wells and the seismic volume. The base of the Jurassic succession (Zone I), a thick sandy sequence deposited in a fluvial-lacustrine environment, is linked to Bathonian downwarping. During the Late Jurassic, a progressive sea-level rise, coincident with growth-faulting, produced Oxfordian transitory fluvial-lacustrine/marginal deposits (Zone II) passing from the Early Kimmeridgian to restricted marine deposition (Zone III). Fully marine conditions progressively took place in the Late Kimmeridgian and Portlandian/Volgian (Zone IV). Notable thickness variations in adjacent fault-blocks are linked to the development of regional unconformities and several rift pulses, mainly in the Oxfordian, Early Kimmeridgian and Portlandian/Volgian. These packages are overlain by variable thicknesses of marine Neocomian strata, with deposition driven by successive regional uplift phases preceding reactivation of major fault-zones.

The lateral facies distribution is interpreted as a series of changes in magnitude and timing during tectonism. Compartmentalised sub-basins probably opened through the Late Jurassic, before a regional basinwide subsidence through the Neocomian. A similar pattern of rifting and uplifting phases is interpreted in the Jurassic and Early Cretaceous of other Irish and UK sedimentary basins, suggesting regional-scale tectonic movements which may be linked to major crustal extension in the Rockall region and seafloor spreading on the Iberian margin.

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

An integrated study of Permo-Triassic basins along the North Atlantic passive margin

Brian P.J. Williams¹, Patrick M. Shannon², Jonathan Redfern³, Sophie Leleu¹, Ivan Fabuel Perez³, Kateřina Štolfová, ²Shane Tyrrell², Peter D.W. Haughton², J. Stephen Daly², Xavier Van Lanen³, Dave Hodgetts³, Catherine Baudon³, Arie Speksneider⁴

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⁴ Shell International Exploration and Production B.V., The Hague, Netherlands

Permian / Triassic rift basins offer important hydrocarbon targets along the Atlantic margins. These relatively lightly explored basins span both the Atlantic and Tethyan realms and developed above a complex basement with inherited Variscan, Caledonian, Grampian and older controlling structural fabrics. They are filled with a complex suite of sediments dominated by continental red beds, comprising braided fluvial, alluvial fan, aeolian, floodplain and lacustrine facies. The poor constraints on their depositional geometries and sedimentary architecture in offshore regions are further impeded by deep burial beneath younger strata, combined with the effects of later tectonism and continental breakup.

This study provides a multidisciplinary analysis of basins along the North Atlantic margin. Regional seismic and well data, combined with geochemical provenance analysis from the European North Atlantic margin are integrated with detailed outcrop studies in Morocco and Canada. The research provides new insights in the regional basin tectonostratigraphic evolution, sediment fill, reservoir distribution, architecture and quality.

Regional seismic mapping suggests a variety of large-scale basin geometries and development including post-orogenic collapse basins, focused narrow rifts and low-magnitude multiple extensional depocentres. Significantly, Permo-Triassic basin geometries are different and more varied than the overlying Jurassic and younger basins. Application of a new "Pb K-feldspar" provenance technique to Triassic sandstones in NE Atlantic margin basins offer new and robust controls on sediment dispersal patterns in the North Atlantic region.

Analysis of key outcrops of age equivalent Permian-Triassic rifts in Morocco and Canada involved detailed sedimentological logging and LIDAR analysis. The results document the evolving sedimentary architecture and allow the identification and characterization of key marker horizons and sequence boundaries. They provide insights into the interplay of tectonic and climatic influences on sedimentation, which has significant implications for reservoir distribution and quality.

Carboniferous Offshore Western Ireland

Alastair Haddow, Department of Geology, School of Natural Sciences, Trinity College Dublin, Ireland (email: haddowa@tcd.ie)

Carboniferous strata have been penetrated by hydrocarbon exploration wells in the Porcupine, Slyne, Erris, Donegal and Rockall sedimentary basins offshore Western Ireland. The rocks have been almost exclusively dated using plant spores (palynostratigraphy). Coal-rich Upper Carboniferous strata are widely perceived to be the source rock of gas encountered in the 1996 Slyne Basin Corrib field discovery and the 2003 Rockall Trough Dooish gas condensate discovery.

Geological uncertainties concerning the offshore Western Irish Carboniferous succession include the dating and correlation of well sections, the reconstruction of palaeogeographic timeslices and the regional mapping of source, sealing and reservoir lithologies.

Previous Carboniferous palynostratigraphic interpretations of the well sections were often based on the original Carboniferous Western European miospore zonal scheme (Clayton *et al.*, 1977). Recent advances in the palynostratigraphy of Western Europe, in particular the North Sea and onshore Great Britain, have resulted in a modified zonal scheme (Clayton *et al.*, 2003). The new zonal scheme approximately doubles the number of biozones and sub-biozones that can be identified, with most refinement occurring in the late Mississippian and Pennsylvanian. Applying the revised zonal scheme to palynological data from both previous studies and new cuttings samples has enabled higher resolution palynostratigraphic reinterpretations, the repositioning of key regional substage boundaries and improved precision in the correlation of well sections.

Previous biostratigraphic studies of cuttings samples from Porcupine Basin wells identified possible Autunian and Lower Cantabrian age marine intercalations based on the occurrence of marine ostracods. As marine incursions of this age are unknown from onshore Ireland or Great Britain, new palynological samples have been analysed for further evidence of marine deposition. Unfortunately the new results are inconclusive, as the samples consistently contain the freshwater to brackish algae *Botryococcus* in addition to rare marine palynomorphs.

Ongoing work includes the integration of the reinterpreted palynostratigraphy with seismic based sequence stratigraphy in order to reconstruct the palaeogeographic evolution of offshore Western Ireland during the Carboniferous and determine the regional distribution of potential source, reservoir and sealing lithologies.

Clayton, G., Coquel, R., Doubinger, J., Gueinn, K.J., Loboziak, S., Owens, B. And Streel, M. 1977. Carboniferous miospores of Western Europe; illustration and zonation. *Mededelingen Rijks Geologische Dienst, Nederland* 29,1-71.

Clayton, G., Owens, B. And Mclean, D. 2003. Carboniferous palynostratigraphy: recent developments in Europe. *Abstracts of XVth International Congress on Carboniferous and Permian Stratigraphy, Utrecht, Netherlands*, 103.

Igneous sills – recognition, distribution and implications for Irish deep water basin exploration

Karina Fernandes (email: fernandk@tcd.ie), Stephen M. Jones & Robert J. Hardy
Department of Geology, School of Natural Sciences, Trinity College Dublin, Ireland

The deep water basins offshore western Ireland are part of the NE Atlantic volcanic continental margin. Igneous sills intruded high within the sedimentary succession account for a significant portion of the volcanic content of such margins. These intrusions are known to cause serious seismic imaging problems. Sills in the Porcupine, Hatton, and Slyne-Erris basins have been identified, catalogued and mapped using an areally extensive 2D seismic database. Areas in Porcupine and Erris basins have been selected for more detailed observation using 3D seismic data. The planform distribution of sills is uneven. In Porcupine Basin, most sills were intruded in the north-east and along the southeastern border of the Porcupine Ridge. Intrusion density varies along strike in the Erris basin. Fewer sills have been found in Hatton, though this may reflect sparse seismic coverage. Sills occur mostly at depths of 4 to 5.5 seconds TWTT in Porcupine and Erris basins, while they are commonly seen at depths of 2 to 2.5 seconds TWTT in Hatton basin. Sill morphology ranges from planar to saucer-shaped. Sill size and morphology does not appear to be controlled by lithology or

basin structure but there is a tendency for sills to intrude preferentially just below the Cretaceous chalk. The sills are observed to impair sub-sill imaging quality to varying extents. In addition to igneous rock thickness, the thickness of the thermal aureole surrounding the sill may also contribute to depreciation of the underlying seismic image. To investigate the effect of migration on sub-sill imaging, a synthetic velocity model of a sedimentary succession intruded by sills and feeder dykes was constructed, based on typical observations from the seismic mapping. The velocity model was used to create a synthetic seismic dataset, which was migrated using Kirchhoff, one-way wavefield, and two-way (reverse time) techniques. Reverse time migration produced a superior final image; even sub-sill feeder dykes and subtle faults within the sedimentary succession were recovered.

The Lower Cretaceous carbonate potential of the South Porcupine & Goban Spur Basins, offshore Ireland

John M. O'Sullivan, *Providence Resources*, **Stephen M. Jones & Robert J. Hardy**, *Department of Geology, School of Natural Sciences, Trinity College Dublin, Ireland*

Exploration drilling together with 2D seismic data suggests the presence of an extensive Lower Cretaceous carbonate depositional province in the South Porcupine and Goban Spur Basins, offshore southwest of Ireland. Interpreted environments of deposition range from large scale carbonate shelf development through platform margin to isolated offshore carbonate build-ups. During the Late Jurassic to Early Cretaceous period, these basins underwent a phase of normal detachment faulting and regional subsidence associated with high degrees of lithospheric extension. This phase of tectonic activity is interpreted to have exerted a primary regional control on carbonate development in two ways: rapid development of accommodation space limited the influence of clastic sediment input in basin margin depocentres; and the rotated, up-standing footwall crests of normal fault blocks provided intra-basinal bathymetric shoals for carbonate colonisation. Locally, both eustatic and isostatic changes are interpreted to have controlled carbonate deposition, providing a linkage from macro-scale stress fields to micro-scale reservoir architecture. Trophic conditions such as paleo-latitude, ocean circulation and wind direction appear to have exerted a secondary influence on carbonate development. These Lower Cretaceous carbonate sequences can be correlated with world class petroleum reservoirs which span the northern hemisphere from the Middle East to the Gulf of Mexico. Such carbonate systems could form the basis of an important paradigm shift away from the traditional Mesozoic clastic-dominated play systems of the Atlantic Margin in the future exploration of these emerging frontier deepwater basins.

This paper was first presented at SPE Offshore Europe 2009 in Aberdeen.

A Refined Approach to Play Mapping in the Northeast Atlantic Province

David Mudge

Ternan Ltd, Ternan House, North Deeside Road, Banchory, Aberdeen, AB31 5YR, Scotland

A petroleum systems analysis of the Rockall and Porcupine basins was carried out for the PAD in 2006. This work has been extended northwards to include the West of Hebrides and West of Shetland areas, linking with an earlier Ternan study of the Norwegian Sea. These studies, which have been produced in GIS, provide a consistent view of Mesozoic and Tertiary hydrocarbon prospectivity in the Northeast Atlantic province from offshore Ireland to the Lofoten Islands. Geological mapping of palaeogeography and depositional environments is based on plate reconstruction of the conjugate northwest European and Greenland margins, and the stratigraphic analysis of more than 400 exploration wells. Palaeogeographic mapping has been used to produce palinspastically restored gross depositional environment maps for individual plays. These maps show predicted depositional facies distribution for selected geological horizons, with the effects of later stretching and Tertiary uplift and volcanism removed. Regional sediment distribution based on well and seismic data, and depositional

environment maps have been combined to produce a present-day reservoir distribution map for each play. Similar maps display the distribution of source rock facies in the Lower and Upper Jurassic.

Plate reconstruction has been fundamental to understanding the tectonic and depositional history of the Northeast Atlantic basin system, which has suffered overprinting by extension, thermal uplift and volcanism followed by break up and separation of its Greenland margin during Tertiary sea-floor spreading. The North Atlantic province including offshore eastern Canada and Ireland is geologically more complex, and the regional geological mapping carried out for the 2006 PAD study was based on older plate reconstructions. It is anticipated that the proposed ISPSG plate reconstruction project will provide a more robust template on which to base new palaeogeographic and depositional environments mapping of the North Atlantic basins, which can be integrated with current work in the Northeast Atlantic and Labrador Sea.

Kimmeridgian Source Rock Super-Highway in the North Atlantic

Michael Enachescu (MGM Energy and Memorial University), **Ian Atkinson** (Nalcor Energy), **John Hogg** (MGM Energy), **David McCallum** (GNL DNR) and **Craig Rowe** (C-NLOPB)

In the past decade, offshore Atlantic Canada has become an important petroleum producing province. The largest hydrocarbon discoveries were made during the 1979-1984 period, when drilling in the high-risk, high-cost North Atlantic waters were stimulated by a Canadian Federal Government's Petroleum Incentive Program (PIP). Currently 55646 m³ (350,000 bopd) are produced from three oil fields of the Jeanne d'Arc Basin offshore Newfoundland, while 12742581 m³ (450 MMcft/d) flow daily from the five gas fields of the Sable sub-basin offshore Nova Scotia. These basins had a complex geodynamic evolution including Mesozoic extension, salt tectonism, subsidence and localised exhumation that have created numerous hydrocarbon trapping styles.

The main ingredient of the Atlantic Canada's petroleum system however, is the presence of rich Kimmeridgian-aged source rock that is predominantly restricted marine in the Grand Banks basins and predominantly terrestrial derived on the Scotian Shelf and slope basins, due to source rock deposition in different palaeogeographic conditions. Initially indicated by seismic mapping and basin-to-basin correlations, the presence of Late Jurassic in other Newfoundland offshore basins was recently confirmed by drilling. The 2003 Mizzen L-11 well in the Flemish Pass Basin has intersected a Late Jurassic source rock and discovered reservoir oil, while the Great Barasway F-66 well in the East Orphan Basin intersected a Late Jurassic sequence that may contain source rocks.

This proves that these two basins were part of the Kimmeridgian-aged source rock super-highway partially following the Atlantic rift trend connecting the Scotian Shelf to offshore Newfoundland basins and extending into the Porcupine, Rockall Trough and Slyne basins, West of Ireland and from here into the North Sea and Norwegian Sea basins and sub-basins. While not directly proven by drilling, it is hypothesized that arms of this Kimmeridgian Sea extended into Labrador Sea basins situated now on the slope and deep waters of both Greenland and Labrador margins. Identifying and mapping with regional seismic grids the Late Jurassic source rock super-highway is the key to further oil and gas discoveries in this region of the North Atlantic.

Dispelling myths about the optimal environments of organic-carbon enrichment in the rock record with implications for the origin of source rocks and prospective shale gas reservoirs

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Organic-rich fissile mudstones ("black shales"), deposited on ancient marine continental shelves, are commonly interpreted as having been deposited in low energy environments under conditions of bottom water anoxia associated with times of reduced clastic dilution. In these settings sedimentary detritus is typically interpreted as having been delivered to the sediment water interface as hemipelagic rain below zones of high primary production and in settings where the bottom waters were persistently anoxic. Fabrics and component variability revealed by recent advances in microscopy, coupled with high-resolution stratigraphic sampling suggest this view is rather naive, even in the most organic-rich successions.

In order to investigate the fundamental controls on sediment delivery and the conditions at and close to the sediment water interface during source rock formation, selected, Mesozoic aged, organic-rich siliciclastic mudstones (e.g., Kimmeridge Clay, and Cleveland Ironstone Formations) have been investigated utilising high-resolution stratigraphic techniques combined with geochemical, optical and electron optical methods.

Analyses of these successions reveals that individual genetic beds are commonly very thin (<10 mm), upward-grade, and have bioturbated tops. Moreover, they show that much of the sediment has been pelleted and organized into organo-mineralic aggregates. They also demonstrate that agglutinated foraminifera may be abundant, and starved ripple laminae, intraclasts horizons, concretionary cements and shell pavements are present at some levels. Finally, bioturbation in these units is common and comprises a variety of diminutive trace (<1.0 mm) fossil assemblage.

Together these data indicate that during deposition of these organic-rich rocks: a) conditions at the sediment water interface were predominantly oxic / dysoxic; b) hemipelagic sediment was delivered as phyto-detritus aggregates (marine snow), c) the sediment was regularly reworked by currents (particularly storms) and d) at least episodically there was sufficient energy at the sediment water interface to rework the sediment forming intraclasts and concentrate the shell debris into pavements. These data also indicate that the significance of long term bottom water anoxia as a pre-requisite for enhanced organic carbon preservation have been overestimated, genetic thin-beds have commonly been misinterpreted as laminae, the benthic faunal communities were restricted because of the existence of rapid sediment accumulation rather than bottom water anoxia. Moreover they show outer shelf environments, during deposition of these sediments, were much more dynamic than most researchers believe. Finally, they show that sediment enriched in organic carbon do not just form associated with condensed sections, rather they form in settings where clastic dilution did not significantly dilute the organic components, rates of sedimentation were fast enough to bury the organic matter, and significant amounts of organic matter were being produced.

Organic-carbon-rich sediments are certainly not boring and monotonous!

Mesozoic sand dispersal into NW European margin basins: insights from the Pb in K-feldspar provenance tool

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The Pb-in-K-feldspar provenance tool provides a powerful means of constraining the provenance of sandstones. It is based on variations in the Pb isotopic composition of detrital K-feldspar that reflect erosion of regional-scale Pb isotopic domains in the continental crust. Because Pb isotopes vary regionally on the scale of drainage systems, this technique can help to determine the size and geometry of ancient depositional systems, with implications for the prediction of sand distribution. Detrital K-feldspar is generally first-cycle in origin, therefore determining its source/s can provide better constraints than those offered by more conventional provenance methods (i.e., heavy mineral analysis, zircon geochronology).

The Pb-in-K-feldspar provenance tool has been successfully applied to arkosic and sub-arkosic reservoir sandstones in sedimentary basins on the NW European margin. Ongoing provenance research in these basins has suggested alternative drainage routes to those previously proposed for important reservoir sandstones (e.g., the Corrib gasfield, Slyne Basin) and has, in other cases, indicated linkage of drainage systems between basins. These studies have also demonstrated the key role played by Archaean and Proterozoic basement in both controlling drainage and supplying sediment during the Mesozoic, especially in basins farther to the north and west. Isotopically distinct K-feldspar populations vary with stratigraphy, implying “switching” of tributary systems over time and suggesting that the technique could be used as a correlative tool in barren strata. Higher resolution sampling enables potential links between provenance and facies to be investigated. The integration of the Pb-in-K-feldspar method with U-Pb zircon geochronology has permitted the identification of recycled grain populations, which could, if unrecognised, compromise palaeodrainage modelling.

Heavy mineral provenance studies, Offshore Newfoundland

Paul Sylvester (Memorial University), Dave Lowe (Memorial University), and Michael Enachescu (MGM Energy and Memorial University)

The provenance of clastic sedimentary rocks has long been inferred from their inventory of detrital heavy mineral accessory phases such as zircon, monazite, apatite, rutile and tourmaline. Recent advances in automated scanning electron microscopy (SEM) can provide systematic, quantitative measurements of the relative abundances, sizes and shapes of the phases. When combined with chemical measurements on detrital tourmaline or garnet by electron microprobe analysis (EPMA), and uranium-lead isotopic measurements on detrital zircon or monazite by laser ablation-inductively coupled plasma mass spectrometry (LA-ICPMS), the identification of source regions, paleodrainage systems and stratigraphic correlations are constrained more robustly.

An example of this approach is illustrated from the Flemish Pass and Orphan basins, located approximately 400-500 km to the east - northeast of St. John's Newfoundland. These are deep water (>500m) frontier oil and gas exploration areas, formed during Mesozoic intra-continental rifting that preceded the breakup of Pangaea and seafloor spreading in the North Atlantic. Recent regional geophysical studies suggest these basins may have been in syn-

depositional communication with the prolific Jeanne d'Arc basin during syn-rift sedimentary deposition, and therefore may contain similarly large oil and gas fields.

Provenance analysis of potential oil- and gas-reservoir, Late Jurassic to Early Cretaceous sandstones from three industry exploratory wells were made using modern SEM-EPMA-LA-ICPMS methods. Results for Jurassic sandstones in the Flemish Pass Basin support the idea of an open seaway and paleodrainage communication between the Orphan and Flemish Pass basins during the Jurassic. Thus the East Orphan Basin is likely to contain Late Jurassic, Kimmeridgian-aged source rocks, increasing the prospects for petroleum reservoirs to be found there. In the Flemish Pass basin, source regions switched from distal northwestern and western hinterlands to more proximal hinterlands during the Late Jurassic to Early Cretaceous North Atlantic rifting stage. Early Cretaceous sandstones with reservoir potential in the Flemish Pass basin can be correlated stratigraphically using detrital heavy mineral measurements. This approach may be applied to other reservoir and source rock units in this region and in others such as the nearby Irish Basins to help guide exploration drilling for new fields.

Tectonic modelling - Moroccan and Nova Scotian conjugate margins

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Emerging new plays in Brazil (subsalt), Ghana (Cretaceous), Morocco (Jurassic) have triggered interest in searching for analogue plays in their respective conjugate margins. The evaluation of paired margins is proving to be a powerful way to evaluate basins in search for overlooked plays. For example insights gained from the Rockall and Porcupine basins of Ireland and the Orphan Basin of Newfoundland have been used to evaluate play systems and plan exploration programmes.

Interest in Morocco and Nova Scotia has been triggered by licence activity on both margins. RPS Energy are involved in managing play fairway evaluations on both margins. The use of data and maps across the margin has proved vital in understanding the critical synrift and early post rift play systems. This presentation is based on work that has been undertaken for the OETR organisation in Halifax and various studies that RPS Energy have completed on the Moroccan margin.

Morocco and Nova Scotia have had patchy exploration histories; although commercial discoveries have been made, results have been disappointing. However both margins show evidence for elements of petroleum systems that when integrated into play analyses show the potential for significant volumes of hydrocarbons. The use of conjugate margin models has proved critical in developing models on which the hydrocarbon prospectivity can be de-risked.

On both margins reservoir and trapping models can be developed.

- Jurassic and Cretaceous delta systems with associated slope turbidites can be postulated and de-risked using high quality seismic data.
- Reservoir deposition and salt movements are inter-related and numeric models backed up by seismic data are demonstrating that reservoir quality facies can exist.
- The Jurassic carbonate bank is a proven play system in Nova Scotia (Encana Deep Panuke Field) as well as in Morocco (the Cap Juby discovery). Work will be shown on how conjugate margin modelling is helping understand the distribution of this play on both sides of the Atlantic.

Proving a world class source system is vital to the hydrocarbon prospectivity of both margins. Extensive shows, commercial discoveries, and evidence of by-passed oil demonstrate that there are source systems that produce hydrocarbons. The paper will show forensic

geochemical work that is being used to type the shows and link to the fluids to specific source bed sequences.

Traditional models for sourcing both margins have relied on Jurassic and Cretaceous delta systems. However these models may not be completely supported by the geochemical data. We postulate that there must be a deeper source. The location of the break up unconformity and the relationship between evaporite deposition and lacustrine environments will be explained. These models are based on plate scale tectonic modelling combined with fault mapping using high quality deep seismic available on both margins.

The paper will show the development of play models at both Jurassic and Cretaceous levels. A number of plays will be shown, including Jurassic carbonates, delta and deep marine reservoir systems, sourced locally or from deeper syn-rift lacustrine sediments. Extensive large-scale salt related structures show the potential of a high value petroleum province on both sides of the Atlantic. The play evaluations are based on a rigorous understanding of sequence stratigraphy built on existing and new biostratigraphic and seismic stratigraphic studies.

The INFOMAR programme, the Griffiths Awards and other Irish marine research

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Ireland has a designated continental shelf area of some ten times its landmass and has appropriately become a world leader in the process of seabed mapping over recent years. The first major marine surveys of the continental shelf margin took place in 1995 and 1996, specifically to support extended continental shelf submissions being developed under UNCLOS. In 1999 the government approved the Irish National Seabed Survey (INSS) project, which ran from 1999 until 2005 and mapped all Irish designated waters over 200m water depth and a considerable area shallower than that. This project not only completed the continental margin mapping but also provided a groundbreaking dataset of bathymetric, magnetic, gravity and ancillary datasets to support a range of activities and research. In 2006, a successor programme to INSS, INTEGRATED mapping FOR the sustainable development of the MARine Resource (*INFOMAR*) was approved, with priority given to inshore areas and an expanded brief to not only complete the seabed mapping but to integrate and supply the data and support the development of a range of added-value products and projects. Collectively these projects amount to one of the largest civilian marine mapping programmes undertaken worldwide and not surprisingly have resulted in a considerable growth in related marine research.

This research is a mixture of work on the datasets being generated, research and researchers funded directly from the projects and collaborative research leveraging either data, expertise or seed finance from the projects. Complimentary to the current INFOMAR research, which has a budget of c. €300k p.a. is the work being carried out in certain areas of the *Griffiths Research Programme*, a Geoscience Research programme being funded, like INFOMAR, by the Department of communications, Energy and Natural Resources under the Science Technology and innovation component of the National Development Plan. The Griffiths awards, which are being managed by the GSI, amount to over €10m in funding over a 7 year period, funding some 13 post doctoral researchers and a similar number of PhDs and spread across 8 Irish research institutes, both North and South. Finally regarding marine research, the Marine Institute have taken a strategic overview of the area in developing *Sea Change* – a Marine Knowledge, Research and Innovation Strategy for Ireland 2007- 2013, which presents a national agenda, comprising science, research, innovation and management, aimed at a complete transformation of the Irish maritime economy. This programme provides a clear and

realistic picture of future opportunities and challenges and a roadmap for selective and managed investment in marine research and innovation for the next seven years. It incorporates applied and basic research programmes, which aim to increase industry competitiveness, build new research capacity and address policy issues.

Ireland – UK drilling proposal and site investigation cruise

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In 1999 PAD and BGS (and sponsoring PIP and UK Rockall consortia) undertook a highly-successful shallow drilling programme of continuously-cored boreholes (maximum penetration 177.4m below sea bed) on the Atlantic Margin of the British Isles. Some results are published (e.g. Haughton *et al.* 2005; Hitchen 2004). A second collaborative programme is now planned. There are three stages:

(1) Selection of potential borehole sites

This stage is complete. Sixteen sites have been identified (7 in Irish waters, 9 in UK). The sites are located on Porcupine Bank, Rockall Bank, Hatton Bank and in the SE Hatton Basin. Prognosed target intervals range in age from Palaeozoic to Eocene, but there are more potential Mesozoic targets than any other.

2) Site surveys across each site

This stage is complete. Using the *RRS Discovery*, BGS undertook site surveys across all 16 sites in August and September 2009. These data are currently being assessed to ensure safety for drilling and to confirm the lat/longs for the optimum drilling locations.

3) Securing funds, drilling and reporting

Planning in PAD and BGS will continue in order to establish a funding model, confidentiality constraints, availability of suitable vessels, costs etc. A costed proposal (or possibly separate proposals for UK and Ireland) will be prepared and offered to industry for funding. Drilling will take place as soon as possible after sufficient funding support is confirmed and a suitable vessel becomes available.

Haughton, P. et al. 2005. First results from shallow stratigraphic boreholes on the eastern flank of the Rockall Basin, offshore western Ireland. In: Doré, A. and Vining, B. (eds.) Petroleum Geology: North-West Europe and Global Perspectives – Proceedings of the 6th Petroleum Geology conference. The Geological Society, London. 1077-1094.

Hitchen, K. 2004. The geology of the UK Hatton-Rockall margin. Marine and Petroleum Geology, 21, 993-1012.

Proposed new wide-angle-seismic profiles across the Irish/Newfoundland continental margins: a requirement for margin reconstruction**Brian M. O'Reilly¹**, J. Kim Welford², Patrick M. Shannon³¹*Geophysics Section, Dublin Institute for Advanced Studies*²*Department of Earth Sciences, Memorial University of Newfoundland*³*School of Geological Sciences, University College Dublin*

It has long been known that the Mesozoic sedimentary basins found along the broad continental margins of offshore Ireland and Newfoundland are a conjugate system with a deeply shared but yet poorly understood geological history. In order to understand the petroleum geology of individual basins within the Irish and Newfoundland parts of the system (i.e. Rockall/Porcupine/Celtic Sea and Orphan/Jeanne d'Arc basins) knowledge of the regional to global deep structural architecture of the entire basin system is required. To achieve this well constrained models of the pre-rift crust, mantle lithosphere and basin-fill sediments are needed to de-stretch and reconstruct the early syn-rift history of this global-scale basin system, with implications for local (basin specific) to regional (inter-basinal) tectonic and sedimentological processes. These processes are fundamental in the assessment and de-risking of the now proven petroleum systems along both the Newfoundland and Irish margins. Plate tectonic reconstructions assume rigid plate motions and are reasonably valid for the early Cenozoic configuration of the North Atlantic; as to a good approximation oceanic plates behave rigidly. They fail completely for the earlier Mesozoic stretching history of the continental lithosphere across the conjugate margins, when deformation was diffuse and quasi-continuous. This presentation describes proposed new deep crustal seismic profiles required to address the problem of "de-stretching" and reconstruction of the Irish/Newfoundland conjugate basin and margin system. A new integrative approach to margin reconstruction is outlined that is aimed at understanding the interlinked syn-rift tectonic/seismic-stratigraphic development of the entire system. The multidisciplinary geological and geophysical methods necessary to address the problem of margin de-stretching are described with some examples from the Irish continental margin.

Exploring the resource potential of a dormant deepwater tight gas condensate accumulation using modern seismic technology – the Spanish Point discovery, Main Porcupine Basin, Offshore Ireland**Stefano G. Pugliese**, David J. Davies, *Sosina Exploration, 53 Chandos Place, Covent Garden, London, WC2N 4H* and John M. O'Sullivan, *Providence Resources Ltd.*

The Spanish Point gas condensate discovery is located in the Main Porcupine Basin, approximately 150 km off the west coast of Ireland in water depths of 300–400m. The discovery well, which was drilled in 1981 by Phillips Petroleum, is situated near the crest of a number of NE–SW trending rotated fault blocks and encountered a gross c. 400m hydrocarbon-bearing interval in a series of stacked over-pressured Upper Jurassic deep-water gravity flow sands. Drill stem testing yielded rates of 4.85 MMscf/D and 925 BOPD from the shallowest of four logged hydrocarbon-bearing intervals at a depth of c. 4,000m. Individual sandstone units are medium to thick bedded with average sandstone units of 50m which are separated by shales of the Kimmeridge Clay Formation. The well test data imply relatively low permeabilities (generally <1 mD), which may be due to the presence of clay minerals within the sands, or to secondary hydrothermal alteration as a result of local igneous intrusions. The latest geological model, which is based on modern rock-physics and seismic inversion has significantly increased the potential resource base and suggests a median un-risked recoverable contingent resource of 1.4 Tcf and 160 MMBO. Whilst the Spanish Point discovery is primarily a structural trap, mapping of its northern extent indicates that the spill point may be shallower than the gas-down-to seen in the 35/8–2 discovery well. This

observation, together with the over-pressured reservoir regime, which is not seen in wells further to the north, raises the possibility of a stratigraphic component to the trapping mechanism. A 3D seismic survey acquisition programme is planned for 2009, which aims to further enhance our understanding of this accumulation as well as being of use for positioning of any potential future appraisal well locations.

This paper was first presented at SPE Offshore Europe 2009 in Aberdeen.

An Overview of The Connemara Field and Exploration Upside on North Porcupine Licence FEL 1/04

Robert Murphy, John Tingas, Jim Lance, Island Oil & Gas Ltd, 27 Lower Mount Street, Dublin 2, Ireland

Block 26/28 was awarded to a BP led consortium in the First Round of Offshore Licensing in 1976. The Connemara Field was discovered by well BP 26/28-1, drilled in 1979. The well flowed a total of 5,589 bopd from three zones in sandstones of the Middle and Upper Jurassic, with oil gravity varying from 32 to 38 API. Over the next ten years BP drilled a number of appraisal and exploration wells on the licence and acquired a 3D seismic survey over the Connemara accumulation. BP exited the Licence in 1990 and Aran Energy became the Operator. A Lease Undertaking over the Connemara Field area was granted to Arran in 1993 and contiguous exploration Licence 2/95 was awarded to Arran in 1995. Statoil became the operator of both the Connemara Lease Undertaking and Licence 2/95 as a result of acquiring Arran in 1995. Statoil shot a new 3D seismic survey in 1996, together with regional 2D seismic data and drilled three wells in the Connemara accumulation before eventually relinquishing in 1999.

In 2004, Licence 1/04 was awarded to a consortium led by Island Assets Porcupine Limited (Island). The Licence area covers blocks 26/28 and part blocks 26/27, 35/2 and 35/3. It includes the Connemara Field, together with associated Jurassic and Lower Cretaceous exploration upside. Island's work to date on the licence includes (i) reprocessing of the Statoil 3D seismic survey, together with selected 2D data, (ii) remapping of the Connemara Field structure, (iii) a sedimentological and sequence stratigraphic study, drawing on all available core and log data, (iv) a petrophysical study of all field wells, (v) an oil geochemistry study, (vi) static and dynamic modelling of the Oxfordian reservoir and (vii) mapping of exploration upside on the licence. Work is currently progressing on a pilot development programme for the field and on firming up exploration prospects in the area.

A brief review of previous seismic and drilling results over the Connemara Field area will be presented, together with new insights from work items conducted by Island over the FEL 1/04 licence area.

Origin of Dolomitisation of the Lower St. George Group Carbonates in Western Newfoundland, Canada: Implications for Porosity Controls

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The lower part of the St. George Group of western Newfoundland consists of Tremadocian shallow marine carbonates of the Boat Harbour (~ 180m thick) and the underlying Watts Bight (~ 60m thick) formations. Petrographic examination suggests that the succession has been affected by at least three phases of burial dolomitisation, which influenced the final rock porosity. These phases have crystal-size ranges of ~ 4 to 40µm (earliest dolomite D1), 50 to 150µm (D2), and 300µm to 20mm (saddle dolomite D3). They exhibit dull (D1 and D3) to zoned (D2) luminescence under the cold cathodoluminoscope. The near-micritic size

dolomites may suggest that dolomitisation started at low temperatures during early stages of diagenesis. The lack of evaporite interbeds and the depleted $\delta^{18}\text{O}$ values ($\sim -6.2\text{‰}$ VPDB) as well as the low Sr contents ($\sim 170\text{ppm}$) of D1 likely exclude a sabkha origin. The Sr/Ca molar ratios (~ 0.0045) of D1 suggest a mixture of marine and meteoric waters possibly in a mixing-zone environment. The petrographic and geochemical attributes of D2 and D3 phases, such as their depleted $\delta^{18}\text{O}$ values ($\sim -6.9\text{‰}$ and -8.3‰ VPDB, respectively) and Sr contents (~ 175 and 115ppm , respectively), suggest that they were formed under relatively deeper burial conditions and possibly from hydrothermal fluids which is supported by homogenization temperatures (up to 135°C) and estimates of salinities (up to 23 wt\% NaCl) in the latest dolomites (D3). Based on visual estimates from thin sections, the porosity varies from $< 1\%$ in most of the formation to $\sim 10\%$ in dolomitised algal lime mudstone beds a few meters below the Boat Harbour Disconformity and also near the base of Watts Bight Formation. Except for some vugs, the majority of pores are intercrystalline and associated with D2 which is interpreted to be formed under relative closed conditions.

Prospectivity on the Erris Ridge (Licence 7/97) – High Risk/High Reward Frontier Exploration on the Irish Atlantic Margin

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Frontier Exploration Licence 7/97 is located 115km offshore north-west Ireland and directly overlies the Erris Ridge. The ridge is an enigmatic, narrow, segmented, NE-SW orientated structural high which lies between the Erris Basin to the east and the Irish Rockall Trough to the west and which, to date, remains un-drilled.

Seismic data quality across the Erris Ridge is typically poor and correlation with the sparse offset well database is challenging. Zones of poor seismic imaging are associated with combinations of complex shallow volcanoclastics, possible intrusive features and large-scale Tertiary channels/entry points which overlie older lineaments and segment the ridge along its length. Displaying considerable complexity and structural variation along strike, seismic based interpretations provide models ranging from a shallow basement horst to preservation of significant thicknesses of Palaeozoic and Mesozoic sediments.

Recent work by Eni identifies the potential for prospective section to be preserved on the Erris Ridge resulting in two large prospects, Fiachra and Conn, and a number of leads being identified. The Fiachra Prospect is a large fault assisted four-way dip closure situated within a crestal location on the Erris Ridge and forms the focus of an exploration well in 2010. An early Triassic sandstone play (Sherwood Sandstone Group equivalent) is prognosed as the primary reservoir target interval, although several secondary targets also exist.

After an intensive evaluation programme the critical geological risk remains modelling the presence of sedimentary section with reservoir potential in areas where the quality of seismic data is very poor. However, it is concluded that Licence 7/97 possesses good potential for deepwater frontier exploration; the Corrib gas field to the south of the licence area and the Dooish gas discovery to the north indicate the potential for a favourable location within an effective petroleum system.

This paper was first presented at SPE Offshore Europe 2009 in Aberdeen.

Exploration of the North-West Irish Continental Margin – a personal perspective of the past, present and future

Ciaran Nolan, *Serica Energy, 87-89 Baker Street, London, W1U 6RJ*

Thirty two years ago in 1977 the billion barrel Brent Oil Field was in its first year of production. It was the same year that Shell spudded the first well West of Ireland (WOI) in the Porcupine Basin. Since then 39 exploration wells have been drilled WOI, roughly one per year, and this has resulted in 6 discoveries; 3 in the Porcupine, 2 in the Slyne and 1 in the Rockall. Whilst at Enterprise Oil, Shell and Serica Energy I was part of the Exploration Teams responsible for Corrib, Dooish and Bandon, the three most recent discoveries WOI. This talk gives a personal perspective on these recent successes and the potential for finding a giant such as Brent.

There are numerous reasons for the relatively slow pace of exploration WOI, but probably the most significant factor in the past was the lack of an early commercial discovery at a time when significant discoveries were being made in the North Sea. Early hopes that the Porcupine would be another North Sea have never materialised. Outside of the Porcupine only 14 wells are in the North-West Continental Margin Basins of the Slyne, Erris, Donegal and Rockall. Exploration in these Basins has also been hindered by water depth and the poor seismic data quality caused by Tertiary volcanism. The Rockall is similar in size, age and fill to the Norwegian Møre and Vøring Basins, where possibly one of the most significant gas discoveries (Gro) since Ormen Lange (14 Tcf) was made by Shell earlier this year.

At the current exploration rate it is unlikely that a giant such as Brent or Ormen Lange would be discovered in our lifetime. It probably does exist, but the 64 million dollar questions are where, and what new technologies can be applied to find it.

Bumps and lumps in the Hatton Basin: volcanic, structural, diapiric or what?

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The PIP/ISPSG/BGS HA04 survey was acquired with the *ILV Granuaile* mainly across the Irish sector of the Hatton Basin in 2004. A single 210in³ airgun was fired every 25m into a 96 channel streamer with group lengths of 12.5m. Record length is 4s. Approximately 2700kms of widely spaced data were collected.

Line HA04-9010 passes within 2.6km of DSDP borehole 555. This is the best tie point to the deeper geology although links to DSDP/ODP and BGS boreholes can be made using existing seismic data.

Some of the interesting features imaged on the seismic data include numerous 'bumps and lumps' at Palaeogene level. Some of these are undoubtedly structural in origin and suggest that uplift and/or compression has occurred on at least three or more occasions. Other 'bumps and lumps' are likely to have a volcanic origin. However some features are more difficult to explain. Miocene sediments appear to onlap some 'bumps' but are domed over others. In the latter case, is it due to drape over an existing structure or due to intra-Miocene (local) inversion? Might mud diapirism play a part? Is the volume of tuffaceous material, proved within the Lower Eocene by DSDP borehole 555, significant in this?

All polite suggestions welcome.....

POSTER PRESENTATIONS (in alphabetical order by author surname in bold)

The Irish Porcupine Basin Hydrocarbons - A Detailed Geochemical Characterisation of Provenance and Quality

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Summary

- 26 wells have been drilled in the basin to date;
- 21 had hydrocarbon shows in multiple pay zones.

This provides clear evidence that there are active petroleum systems in the area.

A comprehensive study has been conducted:

- on flowed oils;
- on oil entrained in rock (cuttings and core).
- a modern high quality geochemical data base has been created.

The results are contained in:

- a comprehensive analytical data base
- a fully documented interpreted hard and digital copy report.

Conclusions

- effective source rocks are mostly of Jurassic age;
- biomarker and isotopic data confirm there are at least two different source rocks;
- source depositional environments are not so well documented;
- additional and different source rocks may occur in presently undrilled areas.

Glacial and glacially-related features on the continental margin of north-west Ireland mapped from marine geophysical data

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Despite over a century of research, reconstructions of the western margin of the last British-Irish Ice Sheet remain controversial. This is mainly because the ice sheet extended offshore onto the continental shelf and therefore significant portions of the glacial record are below present sea level. The availability of high resolution multibeam swath bathymetric and geophysical sub-bottom data over ~30,000 km² of the north-west Irish continental margin (between 55°40' and 54°18' N, and 7°50' and 11°4' W) has made it possible to map glacial features on the continental shelf and glacially-related features on the continental slope and rise. The resulting map, presented here at a scale of 1:260,000, shows that the major glacial features consist of sub-glacial bedforms and nested arcuate moraines of different orientations across the width of the shelf. Distal to these moraines, the outermost shelf and upper slope are crossed by sub-parallel and cross-cutting furrows created by iceberg scouring and meltwater runoff at the ice margin. A well developed system of gullies and canyons and frequent escarpments incise the continental slope. Several large mass transport deposits related to the delivery of vast amount of sediment at the ice margin are found in inter-canyon areas and at the base of the slope (mass transport deposits). Collectively these data show an extensive ice sheet margin across the whole shelf and that slope sedimentation was also greatly affected by the presence of the ice margin at the shelf edge.

Estimating Denudation from Seismic Velocities: an example from 2D & 3D inversion in the Slyne Basin, offshore Ireland**F. Biancotto¹, R.J.J. Hardy¹ & S.M. Jones¹**¹ *Department of Geology, Trinity College Dublin*

Accurate measurement of the temporal and spatial variation of uplift and denudation can improve our understanding of the way in which mountain building and mantle convection modify the Earth's surface (Mackay & White, 2006). Measuring uplift directly is generally impossible because reference levels are usually destroyed or at least modified by processes of erosion. A way to address this problem is to evaluate the magnitude and distribution of denudation at regional unconformities. Most common methods used exploit the thermal or mechanical properties of rocks, such as apatite fission track, vitrinite reflectance, sonic velocity modelling, but they all have the disadvantage of being restricted to boreholes locations (Walford & White, 2005). In addition there is often a large scatter in these sparsely distributed measurements. In this study I invert seismic velocity profiles from seismic reflection datasets to constrain the distribution and the magnitude of denudation within extensional sedimentary basins. The results are very important to oil exploration in the region in order to calibrate maturity models. They also can give new constraints on the mechanism driving the uplift by establishing the relative importance of epeirogenic uplift, which is probably controlled by mantle processes, and tectonic uplift related to horizontal plate motion.

This abstract uses data and survey results acquired during a project undertaken on behalf of the Irish Shelf Petroleum Studies Group (ISPSG) of the Irish Petroleum Infrastructure Programme Group 4.

Preliminary fluorescence lifetime measurements on hydrocarbon-bearing fluid inclusions from the Porcupine Basin, offshore Western Ireland**Nigel Blamey¹** (Nigel.Blamey@nuigalway.ie), Alan Ryder¹, Martin Feely² and Peter Owens.¹¹ *National Biophotonics Laboratory, Dept. of Chemistry, National University of Ireland, Galway, Ireland*² *Dept. of Earth and Ocean Science, National University of Ireland, Galway, Ireland*

Fluorescence Lifetime Imaging Microscopy (FLIM) shows considerable advantages over conventional fluorescence microscopy for the quantitative analysis of Hydrocarbon bearing Fluid Inclusions (HCFI). This is particularly true in cases of complex sample substrates where sample turbidity and morphology can severely distort the fluorescence image or data. Our laboratory in Galway published the first fluorescence lifetime study of HCFI in 2004, where the qualitative assessment of changes in oil composition in HCFI could be achieved by comparison with data from bulk crude oils. In 2005 a new FLIM system was acquired which enables the high resolution (both spatial and temporal) imaging of HCFI using the frequency domain (FD) method for the first time in Ireland. As part of a current project to develop a quantitative method to analyse HCFI by FD lifetime measurements, four HCFI samples from the Irish Porcupine Basin were studied in detail. The HCFI were hosted in quartz grains in sandstone and UV-fluorescent light (~360 nm) observation showed two principle UV fluorescent colours (yellow and bluish/greenish white). Yellow fluorescent HCFI occurred as primary inclusions within cement while the bluish/greenish white fluorescent HCFI were associated with secondary cross-cutting trails and thus postdate the yellow fluorescent HCFI. Fluorescence lifetimes for the full emission spectrum were then measured. Short lifetimes (1.4 – 3.0 ns) are associated with the yellow fluorescent HCFI, and occur at shallower depths. The longer lifetimes (6.0 – 9.4 ns) correlate with bluish/greenish white fluorescence. The short lifetimes originate from immature oils whereas the longer lifetimes are more representative of mature oils. The HCFI show an evolution in petroleum development within the Porcupine

Basin from immature oil during cement growth to mature petroleum that was trapped in secondary fractures within sediment grains.

Atlantic Margin MegaProject Interpretation

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PGS Reservoir has produced a regional interpretation across the Irish Atlantic margin based upon a well merged dataset consisting of approximately 6,000 km² of 3D, over 50,000 km of 2D seismic data and reports from over 80 wells. Four regional horizons plus the seabed have been picked and are referred to as near Top Eocene, Base Tertiary, Base Cretaceous and Mid Jurassic Marker. The near Top Eocene horizon is a shallow level unconformity across most of the data and is truncated by the seabed in areas of recent erosion. The Base Tertiary is also represented by an unconformity across large parts of the data area, particularly on basin flanks, and is the most extensive horizon picked in the data area. The Base Cretaceous is a major regional unconformity and is truncated by the Base Tertiary on the basin flanks, placing Tertiary material on Jurassic and older rocks. The Mid Jurassic Marker has been picked to define the prospective Mesozoic basins and occurs as a high amplitude unconformity usually adjacent to a regional fault.

The main petroleum systems in the area have been identified, and the seismic data demonstrates a number of undrilled structures which have the potential to contain good reservoirs. Tilted fault blocks that have been positioned by Mesozoic rifting are regarded as major exploration targets. Targets have also been identified in the post rift Paleocene as submarine fans and in the pre rift where large deformation structures have been observed. The Mid Jurassic Marker horizon defines Mesozoic rift basins and highlights areas where mature source rock might be present.

Multiphase Late Jurassic – Early Cretaceous rifting in the Porcupine Basin, offshore Ireland

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The Porcupine Basin contains a thick sedimentary succession developed during the northward propagation of the Atlantic rift system. In this study, 2D and 3D seismic data are integrated with petrophysical logs to examine the detailed Late Jurassic to Early Cretaceous evolution of the northeastern part of the basin, in the region of the Connemara oil accumulation. Syn-rift faulting during the Late Jurassic to Early Cretaceous controlled the development of depositional systems within a series of sub-basins in the region.

Well data show a progressive regional sea-level rise from Oxfordian to Neocomian times. However, seismic analysis suggests a complex sub-basin architecture during the Late Jurassic, followed by a regional flooding during the Early Cretaceous. Clear variations in thickness, facies and geometry occur within and between Jurassic fault-controlled sub-basins resulting from successive extensional pulses. The rift events are linked to a number of erosional unconformities of regional extent and, locally, to second-order erosional surfaces. Although evidence of growth-faulting along Early Cretaceous normal faults remains ambiguous, the Neocomian succession shows evidence of discrete rift phases resulting in Base Cretaceous and intra-Neocomian angular unconformities. Synrift footwall degradation offers the potential for sedimentary reworking and the generation of potential reservoir rocks within the sub-basins.

The project is funded by the Petroleum Infrastructure Programme.

The new fission track laboratory in Trinity College Dublin**David Chew***Department of Geology, Trinity College Dublin, Dublin 2, Ireland.*

The fission track laboratory in Trinity College Dublin Geology Department was installed in Autumn 2007. It was funded by Science Foundation Ireland (SFI) and the Petroleum Infrastructure Programme (PIP) of the Petroleum Affairs Division (PAD). All sample preparation material has been installed and several irradiation packages of samples and standards are now being processed.

The system in TCD is based on a state-of-the-art Carl Zeiss Axiolmager Z1m microscope, using an Autoscan AS3000i/f stage system in conjunction with Sony linear sensors for improved positioning accuracy, and an Olympus/SIS CView 3 high-resolution digital colour camera. The system is controlled by Autoscan Trakscan software, which also has an automated track counting module. The data produced by the automated track counting module can be reviewed (and modified, if necessary) by the operator.

Projects utilizing the laboratory include assessing the utility of low temperature thermochronometers (apatite fission track, (U-Th)-He apatite) in quantifying the timing of exhumation in various tectonic settings. These include crystalline basement samples obtained by the MeBo seabed drilling rig from the northern Porcupine high, along with projects investigating the timing of exhumation in the Tanzanian sector of the East African Rift, the Peruvian Andes and the Isthmus of Panama. A major project in conjunction with the University of the Algarve has also just commenced, with a Ph.D. student using the facility to reconstruct the burial and exhumations histories of the South Portuguese Zone and Algarve Basin on the southern Iberian margin.

Understanding Late Midlandian and Holocene depositional history of Donegal Bay: a high resolution seismic reflection interpretation.**Cathal Clarke¹** (clarke_cathal@hotmail.com), **Colin Brown¹** and **Sara Benett²**¹ *Department of Earth & Ocean Sciences, National University of Ireland, Galway (Ireland)*² *School of Environmental Sciences, University of Ulster, Coleraine (UK)*

High resolution seismic reflection data and sediment cores are used to investigate the stratigraphy of the sub-surface sediments of Donegal Bay. The Last Glacial Maximum (LGM), occurring ca. 22 ka, and a subsequent re-advance at ca. 17 ka sustained large ice domes over the northwest Irish lowlands. During both of these events Donegal Bay formed a major conduit for gravity forced ice mass flowing away from these centres. This has been widely studied onshore but much of the evidence that holds the key to unlocking the extent, dynamics and chronology of these events is buried offshore beneath the seabed. During INFOMAR research cruise CE08_16 onboard the R.V. Celtic Explorer, sub bottom profiler data were acquired on three transects across the bay. This data, in combination with nine sediment cores acquired by vibro-coring, reveal the subsurface structure of Donegal Bay in relation to the last glaciation. The data suggests the confluence of ice masses in the inner bay from alternate sources during the LGM and the post-LGM re-advance. The data also shows the mass deposition of marine mud coupled with the presence of ice rafted debris during the last deglacial phase. The acquired data is synthesised with the existing INSS (Irish National Seabed Survey) multibeam and sediment data and, as a result, it is possible to subdivide the bay into an outer coarse sediment region and an inner sediment basin filled with soft sediment.

Dolomitisation in the Lower Ordovician Watts Bight Formation of the St Georges Group, Western Newfoundland

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The Watts Bight Formation is the lowest unit in the St. George Group of western Newfoundland and consists of two sequences of low-energy bioturbated and mound carbonates overlain by higher energy facies that include mounds and grainstones. The Watt's Bight Formation carbonates are extensively dolomitised and porosity is associated with the dolostones. The Watts Bight dolomites are classified, based on petrography and cathodoluminescence, into three main generations (D1, D2 and D3) ranging in crystal size between < 25µm (almost micritic) and 400µm. Dolomites occur as both replacements and cements and record multiple phases of dolomitization. Early and pervasive replacement micritic dolomites are fine grained and indicate that dolomitisation began during early stages of diagenesis. The $\delta^{18}\text{O}$ of the earliest (D1) dolomitising fluids (-6.4 to -8.4‰ VSMOW) fall between the estimated $\delta^{18}\text{O}$ of the Tremadoc sea and meteoric waters and support a mixing-zone dolomitisation, as has been suggested elsewhere in the St. George Group.

Later-stage replacement dolomites (D2) are associated with enhancement in porosity through the development of intercrystalline pores, while latest stage saddle dolomite (D3), and late burial calcite cements, significantly occluded the pores in some horizons. The D2 dolomite crystals are often coated by a bituminous material which suggests possible emplacements of hydrocarbons after D2 dolomitisation. Fluid-inclusion microthermometric data imply that D2 and D3 dolomites were formed from warm, saline fluids of hydrothermal origin. The $\delta^{18}\text{O}$ fluid of D2 ranges from -4.5 to 3.6 ‰ VSMOW and for D3 dolomites $\delta^{18}\text{O}$ fluid ranges from 1.4 to 8.4 ‰ VSMOW, suggesting an influx of basinal brines.

The occurrence of high porosity associated with D2, combined with tight limestone beds, presence of favourable source rocks and thermal maturation, may suggest that the Watts carbonates are possible potential hydrocarbon reservoirs and suitable targets for future hydrocarbon exploration in Western Newfoundland.

Hydrocarbon migration in Jurassic sandstones from the Porcupine Basin, offshore Ireland: evidence from fluid inclusion studies

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A petrographic and microthermometric study of fluid inclusions in Jurassic and Cretaceous sandstones from the Porcupine Basin, offshore Ireland was integrated with innovative fluorescence lifetime measurements of hydrocarbon-bearing fluid inclusions to determine the compositions of the fluids associated with diagenesis and post-diagenetic fluid migration and the extent of hydrocarbon and aqueous fluid migration pathways. Petrographic analyses indicates that Jurassic strata were the main fluid migration pathways for hydrocarbon fluids and that hydrocarbon migration occurred relatively late in the diagenetic history of these sandstones. UV fluorescence and fluorescence lifetime measurements have recognised at least two chemically distinct hydrocarbon groups (Type 1a and Type 1b) with dissimilar lifetime-wavelength (?-?) profiles, consistent with at least two petroleum charges derived from different sources. Primary aqueous inclusions in authigenic cements show that cementation in Cretaceous sandstones occurred at relatively shallow levels at low temperatures (<50°C),

while inclusions in authigenic cements in Jurassic sandstones were trapped at higher temperatures (70 to 120°C) at deeper levels. Aqueous fluid inclusions in intergranular trails indicate that post-cementation fluid migration occurred at high temperatures (up to 175°C). These high temperature fluid migrations are interpreted to be associated with plume-related activity during the opening of the North Atlantic.

Keywords: Porcupine Basin; Fluid inclusions; Fluorescence lifetime; Hydrocarbon migration.

Modelling cetacean distribution in Irish waters - A pilot study using PIP-generated data

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The importance of Ireland's offshore area as an important habitat for cetaceans and seabirds has been established in the Cetaceans & Seabirds at Sea (CSS) Study 1999-2002. Prior to that, research into the distribution and abundance of these animals in Irish waters was limited and undertaken in an ad-hoc manner. A follow-up study examined the relationship between the distribution of cetaceans and environmental variables. The data on cetacean sightings collected during the CSS study were modelled using generalized additive modelling techniques to demonstrate the significance of simple benthic descriptors in the distribution of dolphins and pilot whales. The GAM models showed a significant association between dolphin sightings and latitude with more sightings in more southerly latitudes of the area surveyed. The model also showed a significant relationship between sea depth and sightings with increased sightings in shallower waters. These results indicate that dolphins are more likely to be encountered in shallower southern latitude waters within Ireland's EEZ than northern offshore areas. Conversely pilot whale sightings were found to increase with increasing latitude, longitude, slope and depth. This suggests that pilot whales prefer deeper offshore waters in the northern areas of Ireland's EEZ. These findings support distribution plots resulting from the CSS study and show that different species have different habitat preferences. Using more sophisticated modelling techniques predictive plots could be produced to highlight critical habitat for these species. Such models will be useful in mapping sensitive areas and advising on the timing of industrial activities in Irish waters which may be of potential threat to marine mammals.

Mapping offshore geology from multibeam data south of Waterford Harbour

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In late 2007, as part of the ongoing INFOMAR seabed mapping programme, the area south of Waterford Harbour was mapped by the R/V Celtic Voyager using Simrad EM1002 multibeam and 3.5 kHz pinger sub-bottom profiler systems. The survey revealed an area of exposed bedrock some 180 sq km in size bisected by the narrower than expected, sediment-filled outflow channel of the Barrow/Nore/Suir river system. The multibeam data provides superb imaging of this unique exposure of bedrock from Upper Devonian Old Red Sandstone facies to Lower Carboniferous limestones in a continuous, gently-dipping sequence some 7 km in length. Preliminary interpretation has revealed two significant unconformities and fault sets of NE to NNW orientation, many of which show good correlation with faults mapped onshore.

Crystalline basement drilled by the MeBo drill rig on the northern Porcupine High, offshore western Ireland

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New features of the basement geology offshore western Ireland are revealed by an outcrop of granitic orthogneiss cored using the MeBo seabed drilling rig on the previously unsampled northern Porcupine High. Ion microprobe U-Pb zircon dating indicates a crystallization age of 1310 Ma, signifying a period of magmatism not previously recognized in the region. Metamorphism, of probable Grenville age, is manifest by ringlets of garnet developed around plagioclase ("rapakivi") rims on K-feldspar megacrysts. Thermobarometry on the resulting granulite-facies assemblage of garnet+plagioclase +clinopyroxene+quartz yields PT conditions of c. 12 kbar and c. 740°C. In situ laser-ablation Hf isotopic analysis of the zircon suggests that the orthogneiss is derived from the melting of pre-existing continental crust, such as the Palaeoproterozoic of the Rockall Bank or the Annagh Gneiss Complex of NW Mayo. K-feldspar Pb isotopic data favour the former, and imply that an important boundary lies on the Irish continental margin, possibly aligned with the trend of the Slyne-Erris basins.

The MeBo sea floor drilling programme was funded jointly by the ISPSG and the Marine Institute and managed by the PAD. Work on the MeBo core was funded by Petroleum Infrastructure Programme (PIP) Project IS06/10, which is gratefully acknowledged.

Analytical facilities at the National Centre for Isotope Geochemistry

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The National Centre for Isotope Geochemistry is housed within UCD School of Geological Sciences and is a joint initiative of University College Dublin, Trinity College Dublin and University College Cork. The National Centre was initially funded in 2006 through a Science Foundation Ireland (SFI) Equipment Award to a consortium from UCD, UCC and TCD. Within UCD, funding was provided by the President's Strategic Fund, the College of Engineering Mathematical and Physical Sciences, UCD School of Geological Sciences, UCD School of Physics and UCD School of Biology & Environmental Science. In addition to SFI's support, external funding was provided by the Higher Education Authority, Environmental Protection Agency, Trinity College Dublin and University College Cork.

The initial investment of c. €1.5 M has led to the establishment of a world-class analytical facility comprising state-of-the-art thermal ionisation (TIMS) and high-resolution multiple collector inductively-coupled plasma mass spectrometers (HRICPMS) that are unique on the island of Ireland. The equipment includes a Thermo Scientific Triton TIMS and a Neptune ICPMS. A laser ablation system will shortly be coupled with the Neptune instrument. The Centre also houses a VG354 TIMS, a New Wave Merchantek Micromill (shared with Trinity College Dublin and University College Cork) and a suite of clean-air work stations (refurbished with funding from SFI and Trinity College Dublin).

In the past year, the major items of equipment have been commissioned and routine analyses for Sm-Nd, Rb-Sr, Pb, U-series and Th isotopes can now be undertaken. Techniques for Fe,

Zn and U-Pb isotopic methods are under development, the latter in co-operation with Trinity College Dublin.

The National Centre will facilitate new developments and applications relevant to petroleum geoscience. In the field of sedimentary provenance studies, these include laser-ablation isotopic analysis of detrital K-feldspar (Pb), zircon (U-Pb, Lu-Hf) and titanite (U-Pb, Sr).

Deep Structure of the Porcupine and Goban Spur basins, SW Ireland

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New seismic data has recently been acquired SW of Ireland which is specifically targeted to image the deep crustal structure of the Mesozoic Rift Basins. Specially tuned seismic sources with 10 km long streamers and recording time of 18 secs have produced pre-stack depth migration seismic imaging of the Moho on the eastern flank of the Porcupine Basin. The Moho is situated at 19 km depth on the basin flank rising to 15 km depth near the centre of the basin. Crustal thickness is estimated to be only 5 km below the centre of the basin. The sediment thickness reaches up to 11.5 km in the deepest half graben, with a thick sequence (4 km) of parallel bedded sediment at the base which is interpreted to be Palaeozoic to Triassic. Large normal faults are interpreted to root down onto a flat-lying folded detachment surface which cuts the Moho. The Mesozoic strata on the southwestern margin of the basin are folded and several undrilled potential traps may be present at shallow depth

The Dunquin structure in the central Porcupine has been interpreted as both a mantle serpentinised peridotite intrusion and as a magmatic ridge. The new seismic data indicate that Dunquin is not rooted, and is unlikely to be a serpentinised mantle intrusion. Continuous reflectors of Jurassic/early Cretaceous age are visible below the ridge, suggesting it is a high level (4-9 km depth) intrusion.

Goban Spur

The Goban Spur Basin consists of at least three large Jurassic age rotated fault blocks with up to 5 km of clastic fill in the deep half-graben. These are separated by large basement highs. The half-grabens are covered by less than 1 km of Cretaceous to Cenozoic age strata, so the southern part of the basin is starved and the southernmost part of the basins has exposed Jurassic age fault scarps still preserved at the seabed. The main rift faults downthrow to the southwest. Each half-graben is a simple structure with little intermediate faulting and no obvious structural traps, stratigraphic pinch out of reservoirs to the southwest onto the structural highs will be required for hydrocarbons to be trapped. Only one well 62/07-1 has been drilled in the basin which encountered minor hydrocarbons in excellent Middle Jurassic reservoir sandstones. Further exploration is warranted given the large combination structural/stratigraphic traps which may be present.

Petroleum Migration Studies at NUI Galway

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Fluid inclusions occur in natural crystals and can be simply considered as sealed microscopic (usually < 50 mm in length) vacuum flasks that contain a sample of fluid trapped during (or after) formation of the host crystal. Determination of the chemistry of the fluid components trapped in the crystal cavity provides fundamental information which can facilitate the reconstruction of the conditions of mineral growth. This in turn leads to a better understanding of the physical and chemical environment of such economically important geological processes as petroleum and ore deposition. Fluid inclusions can record fluid trapping and migration. HCFI can be used to trace hydrocarbon flow in oil wells that otherwise record no oil show. The Geofluids Research Group employs a variety of non-destructive analytical techniques to help constrain the fluid history of a sedimentary basin. These techniques included: Fluid Inclusion Petrography; UV Fluorescence; Fluid Inclusion Microthermometry; Laser Raman Microprobe Spectroscopy; Time Resolved Fluorescence Spectroscopy; Structured Light Illumination.

Irish Sills and the Palaeocene-Eocene Thermal Maximum

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Igneous sills intruding organic-rich sediments may bake the organic content, generating methane and carbon dioxide. These greenhouse gases can escape to the atmosphere through hydrothermal vents. In large enough quantities, liberated gases might influence, or possibly even trigger, a global warming event. Based on seismic data from offshore Norway, a recent proposal suggests that intrusion of North Atlantic Igneous Province (NAIP) sills may have provided enough greenhouse gases to have influenced the Palaeocene-Eocene Thermal Maximum (PETM, 56 Ma) global warming event. Potential greenhouse gas emissions associated with sills in the Irish sector of the NAIP will be calculated using a comprehensive seismic dataset along with vitrinite reflectance and Total Organic Carbon (TOC) measurements of the metamorphic aureoles of intrusions. Initial results indicate that the potential greenhouse gas flux per unit area from the Irish sector is significantly lower than that from the Norwegian sector. The lower gas flux reflects a smaller flux of intruding magma, which in turn reflects a greater distance from both incipient NW Europe/Greenland continental break-up and the centre of the NAIP. These results will allow the greenhouse gas budget for the entire NAIP to be refined.

This project is supported by the Irish Petroleum Infrastructure Programme.

Mapping hard substrate at, or near, the sea bed offshore Northern Ireland

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Since 2008 the BGS has been working with DEFRA, DOENI and the Scottish Government to map areas of rock outcrop or coarse gravels that provide a hard substrate for benthic

communities. This project allows updating of the BGS 1:250,000 sea-bed map series with an additional layer. Two of the first regions studied were the Northern Irish territorial waters and the UK offshore waters of the Irish Sea. Updating is being achieved through a review of BGS sample and shallow seismic records and the incorporation of further sources of information, such as multibeam bathymetric surveys (e.g. the JIBS survey). The data review and new interpretation allows substantial improvement in our knowledge of the sea floor which generally reflects the amount of new data collected in the 20 years or so since the BGS 1:250,000 sea-bed map series was published.

Within the Northern Irish territorial waters, which cover 6000 km², 485 areas of hard substrate were identified at or near the sea bed (less than 50 cm depth) covering a total of 464 km². In the UK offshore waters of the Irish Sea, which cover ~17,400 km², 214 areas of hard substrate were identified covering more than 350 km².

The evolution of Irish passive margins: implications for locating the transition between continental and oceanic crust

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Defining the exact location and nature of the transition between continental and oceanic crust is of key importance to understanding the structure and evolution of continental passive margins. The Irish passive margins provide an excellent natural laboratory for studying such processes, as they display a large variety of styles, including narrow, wide, volcanic and non-volcanic margins. Integration of new seismic, potential field and well calibration data allows us to clarify the structure and stratigraphy of both the West Hatton margin (WHM) and the south Rockall/Hatton margin (SRHM). The WHM represents a Late Paleocene-Early Eocene volcanic margin, as suggested by the typical volcano-stratigraphic sequence (Inner SDRs, Outer High, Outer SDRs, oceanic crust) observed near the breakup axis. Thin and intruded sediments and continental crust typically underlie the Inner SDR wedges. Oceanward, the deep structures of the Outer High and outer SDRs features are underlain by a massive, uniformly thick, high-velocity lower crustal body interpreted as break-up underplating that probably controlled the SDRs emplacement of structures that produce SDRs by a mid-crustal updoming.

To the south, the SRHM is a complex rifted zone linking the WHM with the Celtic and Iberian non-volcanic margins. The SRHM was also influenced by an earlier Cretaceous phase of break-up and, compared to the WHM, the nature of the continent-ocean transition is different. Close to the C34 magnetic anomaly, the continent-ocean transition is defined by a sharp contrast between a smooth oceanic basement and block-faulted structures that exhibit both syn- and post-breakup features. Close to the oceanic crust, the C34 may not necessarily represent 'true' oceanic crust but the complex may represent a combination of serpentinized peridotites and/or intruded continental basement. No SDRs are imaged, but evidence of magmatism is identified. Thin lava flows and transgressive sill complexes, magmatic plugs and seamounts intruding the Cretaceous oceanic crust are observed near the SRHM. Close to the Charlie-Gibbs Fracture Zone the West Thulean Rise, defining the southern end of the volcanic province, is also imaged. It probably represents a thick Paleocene oceanic volcanic plateau, uplifted and block faulted during Cenozoic time and interacting with the oceanic spreading initiated earlier in the Porcupine Abyssal Plain.

The age of the magmatism along the SRHM and adjacent basins is controversial. Evidence of Palaeogene magmatism can be observed but Early Cretaceous igneous activity is also indicated. The best example is the Barra Volcanic Ridge, which is reinterpreted here as a structural horst (serpentine or continental block) cut by Early Cretaceous extrusives and intrusives and subsequently by Tertiary dykes. Detailed stratigraphic analysis documents the contrasting subsidence/uplift patterns that differentiate the sedimentary architecture of the WHM and the SRHM.

This project is funded by the Geological Survey of Ireland and the Irish Petroleum Infrastructure Programme.

New methods of improving seismic data to aid understanding of passive margin evolution: A series of case histories from offshore west of Ireland

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Deep-water sedimentary basins are attracting increased attention from the hydrocarbon industry and academia as they remain one of the last geological frontiers still to be fully explored and understood. As part of a regional project to understand basin development offshore Ireland, we have developed and tested new ways of improving seismic images, and of incorporating these improvements into geological interpretations. Here we illustrate this methodology using three case histories from the Porcupine, Slyne and Erris Basins. In each case, the first stage of the workflow consists of re-processing a selection of key seismic data. Processing flows include relative amplitude preservation, advanced demultiple and interpretation-driven prestack depth imaging. Interpretation of the data is assisted by incorporating products such as multiple models, prestack gathers, velocity models and attributes. Finally, we show how a velocity model can be inverted to exhumation estimates. The results and approach developed here can be applied to other deep-water exploration areas.

Automated processing strategies for rapid generation of calibrated images of water-layer reflectivity

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The recent discovery that seismic reflection profiles can image oceanic thermohaline structure means that the seismic database collected by the oil industry can potentially be used to investigate the interior of the deep ocean. The vast size of the legacy oil industry database demands rapid, automated processing flows to enable evaluation of its oceanographic potential. Such flows are possible because of the initial simplicity of water-layer processing. We suggest that the following design features are important: to rapidly process large volumes of data to a good and consistent standard; to permit comparison of data collected using different acquisition systems; and to use freely available software that can be easily obtained and installed, including by oceanographers with no previous experience in seismic reflection methods. We have tested various processing strategies on profiles from several different legacy seismic surveys collected within Rockall Trough, NE Atlantic.

The following simple processing flow produces good results on all of the datasets: amplitude normalization, noise removal, NMO correction using a simplified velocity field, and stacking

over a limited offset range. Calibration of reflection amplitudes between surveys is achieved in an approximate manner using direct arrival energy as a common reference. This can account for small intra-survey variations in source energy and bandwidth, although it is impossible to exactly match surveys acquired with very different source characteristics. Although background noise levels (e.g. swell noise and cable tug) may be significant, in general the most problematic noise comes from the direct arrivals themselves, which are especially dominant at near offsets and shallow reflection times. A variety of methods of dip-filtering may be used to effectively suppress this energy. As ever, there are trade-offs between ease of implementation and impact on amplitude and frequency content in the prestack data. Conventional hyperbolic velocity corrections are based on simple zero-dip, dip-compensated or non-hyperbolic relationships between time and source-receiver offset to define the velocity field.

For reflections within the water-layer, particularly at longer offsets, the geometry of the reflection can be affected by oceanographic processes as well as seismic velocity variations. Our flow therefore uses a constant velocity function, which can be derived from near offsets or generalised oceanographic parameters to produce an initial stacked image. The processing flow executes rapidly and produces good results on a range of datasets. Parameterisation is simplified due to the restricted number of processing steps required. All processing can be performed using a free, script-based package such as Seismic Un*x, enabling reproduction by other groups. Both stacked images and pre-stack gathers for more detailed analysis of water motion can be generated automatically. Overall, the approach developed illustrates the feasibility of reprocessing large volumes of legacy seismic data in a consistent and repeatable manner for minimal expense. In future, this sort of approach should facilitate the generation of a global atlas of high-quality and readily comparable images of water-layer reflectivity.

Seismic imaging of variable water layer sound speed in Rockall Trough, NE Atlantic, and implications for seismic surveying in deep water

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Natural variation in sound speed within ocean water can degrade sub-seabed images from 2D, 3D and 4D seismic reflection datasets. Degrading effects include vertical offset of reflections between adjacent or intersecting sail lines, and difficulties in suppressing multiples from water layer reverberations. Rockall Trough, offshore Ireland, is a natural laboratory to investigate water layer variability in water depths ranging from 200 m to 3.5 km. A compilation of vertical sound speed profiles, calculated from temperature and salinity profiles obtained by probes lowered from ships, shows that the mean sound speed in the water layer mostly varies between 1490 and 1500 m/s. Vertical offsets of up to at least 15 ms two-way travel time at line intersections are predicted. A significant amount of the total observed sound speed variability can occur along a single seismic sail line. These effects result mainly from spatial and temporal fluctuations in the thicknesses of, and vertical sound speed gradients within, an upper layer of North Atlantic Central Water and a mid-depth layer of Mediterranean Outflow Water. Seismic sections across Rockall Trough show strong lateral variability in reflectivity within these same two water layers. Some reflective packages contain lens-shaped structures consisting of reflective rims and transparent cores and with diameters between 10 and 50km. Other reflective packages have abrupt, almost vertical boundaries and no distinct transparent core. The lateral boundaries of the reflective packages are likely to be associated with significant variations in average water layer sound speed. When processing 2D, 3D and 4D seismic surveys of regions of high oceanic variability, such as Rockall Trough, it is necessary to employ techniques that can solve for and then remove the effect of significant fluctuations in water layer sound speed over time periods as short as a few hours and distances as short as a kilometre.

3D gravity and magnetic modelling of the Irish margin

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The Irish Passive Margin Modelling Project undertook 3D gravity and magnetic modelling covering the entire Irish Designated Area and employing data from the Irish National Seabed Survey. The cover sequence component of the model comprised Cenozoic and pre-Cenozoic sedimentary layers, together with a Cenozoic volcanic layer in the Hatton Basin area. Allowance was made for the effect of compaction on sediment densities and the pre-Cenozoic sedimentary rocks were assigned variable overcompaction associated with uplift and erosion in the shelf areas. The Moho geometry was initially estimated on the basis of local isostasy and then refined by inversion of long-wavelength gravity anomalies. The geometry of the pre-Cenozoic sedimentary layer was optimised by inversion of shorter wavelength gravity anomalies. The modelled crustal thickness variations generally compare well with the results of deep seismic experiments, replicating the high stretching factors and degree of asymmetry that have been observed across the Rockall and Porcupine basins. Optimisation of the cover sequence geometry introduced sharp changes in its thickness which were not present in the initial model but can be validated by comparison with detailed seismic mapping. For example, the faulted margins of the Slyne and Erris basins, and the distinct change in trend between these basins, are well-resolved. In the frontier area further west, the modelling resolves local, previously unrecognized, NE-trending basins on the Rockall High and suggests that rifts with a similar trend underlie the Hatton Basin. Forward magnetic models, based on the geometries defined by gravity modelling, help to identify a long-wavelength component of the observed magnetic field that can be explained in terms of changes in the thickness of the crystalline crust. Superimposed on this are shorter wavelength magnetic anomalies associated with variations in basement magnetisation and the products of Cretaceous and Palaeogene magmatism.

Processing of Seismic Data from the Irish Sector of the Hatton-Rockall Plateau

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The Hatton-Rockall Plateau consists of a series of sedimentary basins separated by NE-SW trending basement ridges. It is located between 100 and 450 kilometres west of Ireland, in Irish and British waters.

Exploration in Irish waters has only revealed small amounts about the overall structure and stratigraphy. In 2004, a high resolution multi-channel seismic survey was undertaken by the Geological Survey of Ireland, the Rockall Consortium and the Irish Shelf Petroleum Studies Group with the aim of better understanding the structure and stratigraphy of the area. It was shown that the data from the on-board processing could be improved if it had a revised processing route applied to it.

From this reprocessing, a greater amount of geological information can be observed from the seismic sections. The higher resolution of the data means that features, such as sedimentary layers, folds, and faults are better defined than in the on-board data. As part of the interpretation, velocity analysis will be used to determine the lithologies present and the crustal structure will be analysed to better understand the tectonic history of the Hatton-Rockall Plateau.

Morphology and evolution of mounds and pinnacles on Hatton Bank, NE Atlantic

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Shallow seismic data acquired as part of the British Geological Survey (BGS) Regional Mapping Programme (part funded by the BGS Rockall Consortium) have been used to investigate the morphology and evolution of sea floor mounds and pinnacles located on Hatton Bank. These isolated topographic features comprise either bedrock cropping out at sea bed or the accumulation of material over time forming a layered mound. These features are of particular interest to ICES (International Council for Exploration of the Sea) as these isolated topographic features may host cold water corals - some sites have already been visually confirmed.

Broadly speaking the mounds and pinnacles can be subdivided into those comprising probable basalt cropping out at sea bed, basement rock intrusions, and mounds which have probably evolved over a long period of time both on harder bedrock and on softer post-basalt sedimentary sequences. These reach up to 40m in height and several hundreds of metres in diameter, and are frequently located above cliff faces where upwelling currents may assist cold-water coral growth.

Multibeam echosounder data acquired for the Strategic Environmental Assessment (SEA) of Hatton Bank in 2005 and 2006, and data acquired by the Spanish Instituto Español de Oceanografía on the western flank of Hatton Bank have been used in conjunction with the BGS seismic database. Combining these two datasets improves studies on the spatial distribution, morphology and the evolution of these features.

The Structural Evolution of Highly Extended Terranes

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The structural evolution of continental crust at very high extensional strains, such as at Non-Volcanic Rifted Margins and margin basins (Rockall Trough and Porcupine Basin), cannot be fully described by accepted models of continental extension. Extension in the upper crust of these regions is apparently far less than the extension that is observed for the whole crust/lithosphere, creating an extension discrepancy. The three main hypotheses that attempt to account for the apparent extension discrepancy are; 1) depth-dependent stretching (DDS), 2) polyphase faulting, and 3) detachment faulting.

Here we present a fourth alternative - progressive polyphase faulting succeeded by development of detachment faults. This model avoids volume conservation issues associated with DDS, as it provides a means of allowing large amounts of extension and thinning without inferring composition and rheological behaviour of the lower crust. Moreover it accounts for a significantly greater amount of extension minimising the apparent discrepancy.

Our model requires 3 stages of deformation during rifted margin development. These are 1) stretching, 2) thinning and 3) exhumation. The Porcupine Basin may demonstrate evidence for all 3 stages whilst the Rockall Trough may represent the transition from 2 to 3.

Presented here are preliminary models for crustal strain accumulation following progressive polyphase faulting, both mono- and di-polar (See-Saw) configurations. Future work will involve generating synthetic seismic sections for these models. This modelling will be further tuned

using field data from the Betic Cordillera, SE Spain, where up to 20 km of thinning has occurred. Comparison between real and synthetic seismic data will allow better interpretation of extensional structures in the Porcupine Basin, Rockall Trough and W. Iberian Margin. Palinspastic restoration of seismic sections using MOVE will be incorporated to test validity of interpretations.

Deep-water multibeam seabed characterization for large-scale physical habitat and environmental mapping within the Irish EEZ

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High frequency multibeam (EM120-12 kHz) bathymetry and backscatter datasets acquired during the Irish National Seabed Survey (2000-2002; www.infomar.ie) have been used in this study to characterise over 700,000 km² of the Irish EEZ (circa 7 times the size of Ireland). Large-scale seabed automated image classification on backscatter data has been performed, to provide baseline physical seafloor maps, over water-depths ranging between 500 and 5,000m, primarily for use in habitat and large-scale environmental studies (e.g. IOSEA). In general, the multibeam backscatter response within the study area ranges from low to moderate (interpreted as a range of fine mixed sediments), with discrete high levels corresponding to hard seafloor patches. Supervised backscatter image classification results shows a number of consistent classes across the study area related to soft-hard and smooth-rough descriptors. The primary control over the image classes are intensity features (e.g. mean, quantiles), however, textural features (particularly variance) provide valuable insight into the morphological aspects of the near-seabed composition. Bathymetric features (e.g. slope, rugosity) have been integrated and correlated to the backscatter results. Furthermore, classification scales, image features, validation and interpolation techniques have been topics examined and discussed.

Shallow geophysical characterisation and fluid flow processes in two large pockmarks on the Malin Shelf, NW Ireland

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Shallow geophysical datasets and ground-truthing have been used to characterise two large gas related depressions, from a recently discovered pockmark field on the Malin Shelf, northwest Ireland. Pockmarks are aligned with the main faults of the region, the SW-NE Skerryvore and the E-W Stanton Banks faults. High resolution multibeam bathymetry reveals the surface expression of these features to the meter scale. They appear as sub-circular depressions of a few hundred meters in length, up to 8 meters deep, and present several units within a generally smooth seabed. Shallow seismic and single-beam echosounder records reveal evidence of gas related activity within the subsurface sediments. In general, conductivity measurements, as recorded by the electromagnetic equipment, show a high degree of correlation with sediment grain size patterns. In contrast, unexpected positive conductivity anomalies were observed within and around depressions, associated with increased gas accumulation.

South Porcupine Seismic Stratigraphic Project Phase1 - PIP Project IS06/14

Clare Morgan and Noel Murphy, *Petroleum Affairs Division (PAD), Department of Communications, Energy and Natural Resources, Adelaide Road, Dublin 2, Ireland*

The objectives of the project are to identify the major (mega) sequences across the southern Porcupine Basin with a view to assessing the petroleum prospectivity of the area. Comparative geological horizons/seismic picks are to be interpreted on available seismic profiles in the Canadian Orphan and Flemish Basins and inferences drawn. The ultimate objective is to high grade areas within the southern Porcupine Basin that are perceived to be prospective for hydrocarbons based on a seismic sequence stratigraphic approach.

Hydrocarbon exploration in the Porcupine Basin got under way over thirty years ago. Although the basin is of significant size (43,000 sq.km), only 28 exploration wells have been drilled, of which 4 tested significant amounts of hydrocarbons. However, the basin has not achieved any commercial production to-date. Only 6 exploration wells have been drilled in the basin in the past 20 years and of those, only one well, 43/13-1 was drilled on the western margin of the southern part of the basin. Recent studies show that significant remaining untested prospectivity exists in the basin.

A poster entitled 'Prospectivity in the southern Porcupine Basin – a seismo-stratigraphic approach' has been generated to highlight Phase 1 of the Project. A basemap was generated for the entire Porcupine Basin showing labelled seismic lines and surveys colour coded to show vintage. Industry wells and research boreholes are included. A Spreadsheet listing selected seismic lines that would be useful for trans-Atlantic interpretation from the Orphan Basin, Flemish Pass and Porcupine Basin has also been generated. Some of these profiles have already been interpreted and appear on the poster. Seismic examples also illustrate the variety of potential leads across the southern portion of the Porcupine Basin.

The study was sponsored by the Irish Shelf Petroleum Studies Group of the Petroleum Infrastructure Programme (PIP).

Proposed Core Sites on the Rockall & Porcupine Highs – Offshore Ireland – PIP Project IS06/11a

Clare Morgan and Noel Murphy, *Petroleum Affairs Division (PAD), Department of Communications, Energy and Natural Resources, Adelaide Road, Dublin 2, Ireland*

The objective of the project is to review all existing seismic and potential field data to create a prospect inventory for proposing shallow coring sites in the Hatton-Rockall and Porcupine areas. Recommendations were made on the proposed sites for 3 broad categories (a) shallow drilling <50m using RockDrill or MeBo equipment and (b) drilling from 50-350m using a Bucentaur-type drill ship vessel and (c) drilling in water depths >350m. The proposed borehole sites are ranked with supporting geophysical and geological data. The proposed borehole sites include a predicted forecast of the likely geology. The ultimate objective is to obtain ground truth data to increase regional geological understanding.

The borehole sites have been proposed on areas fitting the following criteria:

- (i) New geological information gained is maximised (consider: areas where ground truthing would help resolve a geological problem, existing data available)
- (ii) The suitability of the site for investigation (consider: water depth, sediment thickness, presence of volcanics, seabed conditions etc.)

- (iii) There is a good geographic spread (consider: remoteness, current data available).
- (iv) Proposed sites are to be located on one or more good quality, recent vintage seismic lines.

Note that few proposed borehole locations in the area meet all the listed criteria.

The work was conducted as a GIS project. 13 priority core sites are identified for the area. The poster displays two candidate sites each for the Rockall and Porcupine Highs, illustrated with seismic examples and expected stratigraphies. Site surveys acquired in 2009 for each proposed core site comprise 6 lines centred on the target; all lines are 5km in length and are 1km apart. Sparker and airgun were deployed simultaneously.

The assistance of the Geological Survey of Ireland in providing access to INSS/INFOMAR seabed data for site screening etc. is acknowledged.

The 2009 site surveys were acquired by the BGS/NERC's vessel RRS Discovery on behalf of the Irish Shelf Petroleum Studies Group of PIP and the UK Rockall Consortium.

PLATE WIZARD™ – A new global, deformable, plate tectonic plate reconstruction tool

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Plate tectonic reconstructions are essential for placing geological data in their correct spatial context, to understand depositional environments, to define basin evolution, and to serve as a basis for palaeogeographic mapping e.g. for palaeo-climate modelling. A well-known problem with traditional 'rigid' plate reconstructions is overlap and under-fit of plates when restored in their pre-drift assemblages. This is attributed to internal deformation during (or after) continental break-up, calculation errors of finite poles of rotation within the global plate circuit (assuming rigid plates), and difficulties in resolving the position of the continent-ocean boundary at passive margins. To address these challenges, a new global high-resolution palaeogeographic plate reconstruction model known as Plate Wizard™ has been developed for the Mesozoic and Cenozoic that restores the extensional deformation occurring at continental margins.

Continent-ocean boundaries (COB) have been redefined by utilising gradient changes in gravity anomalies, crustal thickness depth to Moho, differences in gravity signature over continental, transitional and oceanic crust, and the presence of extended fracture zones in oceanic crust. The relative motions between major plates are determined by matching fractures and magnetic anomalies of similar age in oceanic basins. The relative plate motions of minor plates are calculated by Euler Pole addition in a global circuit, with central Africa at the uppermost position of the plate motion chain. For modelling extension on a global tectonic scale, beta factors have been calculated from the overlap of stretched conjugate passive margins over the relevant geological time span.

To remove the deformation effects produced by overlap in the reconstructions, an ArcMap™ extension has been developed (PLATE WIZARD™). This program creates displacement vector maps that allow restoration of the plate margins by 'warping' the mapped extended regions. The program also allows the restoration of the geometries of geo-referenced datasets that intersect with the plate margins defined by the model.

To date, modelling of the post-Palaeozoic rifting events at the Atlantic margins has yielded good results, proving the deformable plates method by producing valid stretching factors that are consistent across a global coverage.

Mantle exhumation and serpentinisation in the Porcupine Basin: seismic evidence

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New wide-angle seismic data along a 230km profile that runs across a deep structural feature (Porcupine Arch) within the Porcupine Basin, are presented. Sixty-five ocean bottom seismometers were deployed at ~3km intervals and airgun sources fired at 100-150m intervals along it. Results of forward modelling indicate that the continental crust is extremely thin (locally <2km) across the basin centre, and in places may be absent. The sedimentary succession is up to 12km thick and comprises three distinctive seismic layers. The uppermost two layers are interpreted as a post-rift succession of Cretaceous and Cenozoic strata, deposited following a major phase of Jurassic lithospheric extension. The lower layer is interpreted as a succession of predominantly Jurassic syn-rift sediments, whose large-scale geometry reflects the response to the focussing of extensional strain, produced by a simple shear mode of differential lithospheric extension. A strong asymmetry in crustal geometry is probably related to this mode of extension. Crustal thinning is greater than in the adjacent Rockall Basin. Local exhumation of continental mantle lithosphere may have occurred in parts of the Porcupine Basin, as suggested by very low Pn velocities. This project is funded by the Geological Survey of Ireland and the Irish Petroleum Infrastructure Programme.

Cold-water coral ecosystem development in the NE Atlantic: Evidence for strong coupling with Pleistocene and Holocene climate change and slope failure

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The NE Atlantic continental margins between Norway and North Africa contain widespread provinces of cold-water carbonate mounds comprising an aphotic ecosystem as diverse in faunal composition as warm water tropical reefs. In each province the mounds occur in clusters or as dispersed individuals within single populations of up to several hundred mounds, some of which can be up to 300 m high. The main framework constructors of these "cold-water-reefs" are the ahermatypic corals species *Lophelia pertusa* and *Madrepora oculata*. One such population is present west of Ireland along the eastern margin of the Rockall Trough in water depths of between 700 - 900m. These are developed within the transition region between the glaciated and non-glaciated (Pleistocene) parts of the margin and strong NE flowing contour currents flowing at up to 1m/s appear to streamline their shape. Deep towed sidescan images of the population were used to build a statistical distribution for the sizes of up to 140 imaged mounds. The main characteristics of the distribution can be accounted for with an ecosystem development model in which mound growth and substrate colonization rates are simply coupled to changes in bottom current regime. This development model allows an age structure for the population to be determined using biological growth rate estimates for the main framework species. It also indicates that the form of the population distribution is likely to be highly correlated with climatic change, slope instability and related change in global ocean circulation patterns during the late Pleistocene and Holocene. This project was undertaken on behalf of the Irish Petroleum Infrastructure Programme.

The fine-scale structure of the upper lithosphere within the Irish Caledonides

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The VARNET-96 experiment was originally designed to examine the 'Variscan Front' in the south-west of Ireland. The seismic experiment consisted of two lines running SSE-NNW, straddling the boundary between the Laurentian and Avalonian tectonic plates, along the Iapetus Suture Zone. A detailed knowledge of onshore crustal structure is required to understand tectonic strain variations within the upper lithosphere across the region straddling the continental shelf between Ireland and the Porcupine Basin. The basic foundation for this study is a 2-D model for the P- and S-wave structure of the crust and its chemical composition, based on travel-time inversion of first arrivals and reflections observed during VARNET. The excellent quality and relatively broad frequency range (e.g. 1-20 Hz) of the P- and S-wave coda permits fine structure in the upper 40 km of lithosphere to be resolved using waveform methods than would be possible using just primary seismic phases. Petrophysical and geochemical measurements on felsic lower crustal xenoliths and the amplitudes of the seismic coda constrain velocity fluctuations in the lower crust and upper mantle. The results support tectonic theories for the origin of the crust by the accretion and melting of predominantly sedimentary and volcanoclastic materials derived from oceanic, island-arc and continental margin sources during the Caledonian orogenic cycle. The results are important in understanding modes of extension below the Irish offshore basins to the west.

Large-scale Acoustic Classification of Multibeam Echosounder Datasets within the INFOMAR Program

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Examination of gravity cores along a depth transect (800-2750m water depth) from the western flank of the Porcupine Bank has revealed sedimentary facies characteristic of contourite deposition. A combined micropalaeontological and geochemical approach has been used to determine the influence of productivity and varying water mass distributions on benthic foraminifera preserved in these facies. From these units, the down slope distribution of key benthic foraminifera is discussed. The distribution of *Rupertina stabilis* appears to reflect the glacial-interglacial migration of a specific bottom current, shoaling its maximum occurrence during the last glacial relative to the previous interglacial and the Holocene. Fisher's Alpha diversity data reveals a mid slope diversity maximum, which is the result of a dynamic equilibrium between slope (environmental) stability and productivity which is consistent through different glacial-interglacial climate regimes. Combined phosphorus vs. $\delta^{13}\text{C}$ reconstructions for three cores suggests three distinct modes of water mass distribution for the previous interglacial, the last glacial and the Holocene. A key finding is the apparently greater volumetric flux of AAIW during the previous interglacial compared to the Holocene.

Evidence for thermohaline currents and palaeoproductivity on slopes west of Ireland – a micropalaeontological study

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Examination of gravity cores along a depth transect (800-2750m water depth) from the western flank of the Porcupine Bank has revealed sedimentary facies characteristic of contourite deposition. A combined micropalaeontological and geochemical approach has been used to determine the influence of productivity and varying water mass distributions on benthic foraminifera preserved in these facies. From these units, the down slope distribution of key benthic foraminifera is discussed. The distribution of *Rupertina stabilis* appears to reflect the glacial-interglacial migration of a specific bottom current, shoaling its maximum occurrence during the last glacial relative to the previous interglacial and the Holocene. Fisher's Alpha diversity data reveals a mid slope diversity maximum, which is the result of a dynamic equilibrium between slope (environmental) stability and productivity which is consistent through different glacial-interglacial climate regimes. Combined phosphorus vs. $\delta^{13}\text{C}$ reconstructions for three cores suggests three distinct modes of water mass distribution for the previous interglacial, the last glacial and the Holocene. A key finding is the apparently greater volumetric flux of AAIW during the previous interglacial compared to the Holocene.

Seismic Data Quality Assessment Offshore Ireland - Atlantic Margin

Paras Consulting and the Petroleum Affairs Division (PAD)

The purpose of this assessment is to map and document the variation in seismic data quality offshore Ireland's Atlantic basins and to provide possible solutions to improve data quality including research recommendations. The area covered includes the Irish Rockall Basin, Slyne Basin, Erris Basin, Donegal Basin and the Porcupine Basin. The study is based on all released 2D and 3D seismic data acquired between 1989 and 2005.

The study was conducted jointly by Paras Consulting and the Petroleum Affairs Division and sponsored by the Irish Shelf Petroleum Studies Group of the Petroleum Infrastructure Programme (PIP).

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Using seismic reprocessing and interpretation to determine the thermal and temporal history of a deep water sedimentary basin. Case study: The Porcupine Basin, offshore Ireland

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Deep water sedimentary basins can be challenging objects to study. Poor geological and geophysical constraints in some parts of the basin and processing issues related to variations in water depth are among the issues that need to be addressed in order to derive better constrained geological models. In this case study of the Porcupine Basin, we tackle some of these issues by reprocessing vintage multichannel seismic reflection data with state-of-the-art processing techniques, and with a careful interaction between interpretation and processing. We also show the improvement upon depth imaging quality and accuracy, and their benefits in terms of interpretation and uncertainty reduction, key steps for the production of accurate strain rate and thermal models for the Porcupine Basin.

Cenozoic pull-apart basins of the British Isles

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Pull-apart basins, which are associated with the Cenozoic reactivation of northwesterly-trending faults, have been mapped in SW Britain, Northern Ireland and the Southern North Sea and are probably present elsewhere in the British Isles. This poster presents a series of maps, based partly on 3D seismic and gravity data, which summarises the distribution of these basins. Comparison of their scale, stratigraphy, age, fault relationships and structure in a plate margin setting, at a time when onset of Atlantic Ocean opening was contemporaneous with Alpine orogenesis, contributes to a fuller understanding of Cenozoic tectonics and may have other implications for the deep geology of the UK.

In Northern Ireland, the Tellus airborne magnetic survey has further detailed the many linear magnetic anomalies related to Palaeogene dykes and faulted offsets indicating strike-slip movement. Some anomaly trends show clear sinistral offsets of up to 2.5km along reactivated, NE-trending, Caledonian and Variscan faults. The Lough Neagh pull-apart basin was formed by mid Paleocene dextral transtension acting upon right-stepping NNW-trending faults. South of the Lough, the Newry and Camlough faults each have a mapped dextral displacement of 2km and may represent a continuation of the Codling Fault zone northwards from the Irish Sea.

Archaeological applications of the Joint Irish Bathymetric (JIBS) data

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Existing bathymetric charts for the north coast of Ireland are Victorian in vintage, compiled from lead-line soundings and sextant positioning. They are severely outdated and therefore unsuitable for marine research and stewardship. More importantly, due to the nature and size

of marine archaeological artefacts and sites, these charts are wholly unsuitable for research as they are of such low-resolution that they offer little functional use in archaeological investigations. To address the need for high-resolution bathymetric data, the Joint Irish Bathymetric Survey (JIBS) was instigated as a partnership between the Maritime and Coastguard Agency (MCA) and the Marine Institute (MI), funded under the INTERREG IIIA Programme. The JIBS project commenced on 10 April 2007 and was completed by 30 September 2008, providing [1] full-coverage multi-beam bathymetry data within the 3 nautical mile coastal strip from Fanad Head (Co. Donegal) to Torr Head (Co. Antrim) and [2] ground-truthed, geo-coded backscatter data for the same area. In 2008 and 2009, the authors were awarded Heritage Council funding under the INSTAR scheme to assess the JIBS data for archaeological applications. The INSTAR study proved beyond any doubt that the archaeological applications of the JIBS data are many. While the quality and resolution of the JIBS data has proved even better than expected, interpretation of these data has already uncovered many previously unrecorded submerged sites of archaeological potential.

Quantitative seismic imaging of the crust by frequency-domain full-waveform inversion

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Wide-angle seismic surveys are deployed to investigate the structure of the Earth's crust. They are designed to yield sufficiently large offsets to record refracted and reflected waves at depths of interest. Resulting data are usually processed by traveltimes inversion techniques returning information on the large-scale velocity distribution. Full-waveform inversion based on an accurate resolution of the full-wave equation can increase our understanding of crustal processes. Nevertheless, applications of this technique to real wide-angle seismic data have remained rare since they require dense acquisition coverage and very large computational resources. Recent advances in technology now make it possible to address the challenge of crustal-scale imaging. New applications to real wide-angle seismic data have shown that the approach is very promising. While these applications provided accurate and interesting results, the methodology currently relies on approximations about the medium and the data. In order to properly image the deep structure of the Hatton ocean-continent margin, improvements to the technique are needed. I will describe the existing frequency-domain full-waveform inversion technique and show results of its application to real onshore wide-angle seismic data from the Southern Apennine Thrust Belt. Then we will explain the problems that need to be addressed to apply this technique to image the Hatton margin.

This project has been funded by the Geological Survey of Ireland and the Irish Petroleum Infrastructure Programme.

Seismic imaging of the Hatton Continental Margin: Results from travel-time tomography

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The western seaboard of Ireland comprises a number of large Palaeozoic to Cenozoic sedimentary basins affected by several rifting episodes preceding continental breakup in late Paleocene time. The Hatton volcanic margin forms an excellent natural laboratory to investigate tectonic processes associated with widespread magmatism during continental rupturing and breakup in the early Cenozoic. However these igneous and volcanic rocks emplaced during the opening of the Atlantic Ocean severely limit the penetration and quality of

near-vertical seismic reflection data. The HADES (HATton DEep Seismic) experiment was thus carried out in this area to image better the Continent-Ocean Transition and the deeper part of this volcanic margin. Three new wide-angle seismic reflection/refraction profiles were acquired with 100 OBS (Ocean Bottom Seismometers) deployed on each profile with a very close spacing of about 3 km. The number and close spacing of OBSs make this survey exceptional and unique in Europe. To process this extremely large dataset, we are using a two-step tomographic approach specially designed for this type of multifold wide-angle acquisition: the first step consists of first-arrival traveltimes tomography to define the large-scale velocity distribution in the medium. This derived velocity model is then used as a starting model to initiate frequency-domain full-waveform inversion of the data. Results from first-arrival traveltimes tomography show that the oceanic crust is defined by a simple velocity structure with high velocities ($V_p=7$ km/s) at shallow depths (8-10 km) whereas the continental crust is characterised by sedimentary basins separated by basement highs. High velocity bodies ($V_p=7.2-7.3$ km/s) are also imaged at the Continent-Ocean Transition and correlate well with Magnetic Anomaly C24. To define rapidly the thickness of these high velocity bodies, forward modelling of the PmP reflected energy phase was used to define the Moho position in these models. The detailed shape and seismic velocity structure of the bodies are, however, not completely resolved and application of full-waveform inversion is required to resolve the uncertainties.

This project is funded by the Geological Survey of Ireland and the Irish Petroleum Infrastructure Programme.

Seismic anisotropy in the crust of southwest Ireland from analysis of controlled source shear-wave seismic data

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Travel-time analysis of controlled source shear-wave (S-wave) data recorded in southwest Ireland has been used to investigate the magnitude of crustal anisotropy. The data were recorded from 20 in-line shots on three-component short-period stations deployed at approximately 1-km spacing along two parallel profiles. Analysis of travel-time differences between vertically and horizontally polarised S-waves was undertaken using seismic phases travelling near the Earth's surface (Sg) and reflected from the Moho (SmS). Travel-time differences for both phases scatter largely within the range ± 0.2 s, or about the uncertainty in the measurements, with no observed coherent variation with shot-receiver offset. Synthetic S-wave seismograms were also computed from 1-D S-wave velocity models with varying degrees of anisotropy in the upper and in the lower crusts. Travel-time differences of Sg and SmS phases picked from these synthetic seismograms confirm that for anisotropies with probable symmetries of magnitude 1-2% in either the upper or lower crust should result in an observable variation of travel-time differences with source-receiver offset. The study shows that crustal anisotropy does not contribute significantly to the marked anisotropy recently deduced from SKS measurements, which is therefore confirmed to mainly reside at sub-crustal and deeper mantle levels.

A comparative approach to the petroleum systems of peri-Atlantic basins with a Tethyan influence – the example of the Lusitanian Basin (Portugal)

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The Lusitanian Basin (LB) is located in the western façade of Iberia, representing today a passive margin of the North Atlantic Cretaceous opening. However, its evolution has been more complex and started much earlier, with the Triassic and Jurassic crustal stretching of this region, in which the spreading and closure of the Tethys, as well as the opening of the Central Atlantic, played also important roles.

To understand the petroleum systems of this basin, a regional geodynamic approach must be applied, by integrating the lithological and oil-related data into a broader palaeogeographic framework. We present a comparative analysis of the LB with other basins which were close to the LB during its Mesozoic evolution: the Algarve Basin (SW Iberia), the Essaouira Basin (W Morocco) and the Jeanne D'Arc Basin (NE America).

Correlation between the sedimentary infills of these peri-Atlantic basins, supports important tectono-sedimentary correlations, related with the opening of the Central and North Atlantic, spreading of the Alpine Tethys and detachment of Iberia from Africa and later from Eurasia. Petroleum systems of these basins may also be compared, showing some correlative elements distribution.

Tethyan-related Early Jurassic rift basins show the presence of important Toarcian (or even earlier) source-rocks. Atlantic-related Late Jurassic rift basins show important Oxfordian-Kimmeridgian source-rocks. Atlantic-related Cretaceous rift basins show several Albion to Turonian source-rocks. Only the Lusitanian Basin, due to its frontier location, presents source-rocks from all these different stages. Maturation into the oil-window has been reached first at the Jeanne D'Arc and Lusitanian Basins, then at the Essaouira Basin and latter at the Algarve Basin.

This work is a contribution to Project Atlantis – “Geological model for the Jurassic Riftings of the Lusitanian Basin (Portugal)” - financed by Petrobras (Brazil) and developed by the Universities of Coimbra, Lisbon (Portugal) and Sergipe (Brazil).

Engineering Downtime Analysis Offshore Ireland Points the Way to Cost Effective Drilling

George Ross, *SPD Ltd, Aberdeen* **Graham Ross**, *SPD Ltd, Aberdeen*, **Nick O'Neill**, *PIP Secretariat, Dublin*

Engineering downtime analysis of all Irish exploration wells drilled to date provides indicative drilling time-depth curves that could be used as a reference for estimating budgets for summer drilling in different sectors offshore Ireland. The downtime analysis allows recommendations to be made to improve drilling performance offshore Ireland.

Wells were grouped for analysis into 5 areas with similar metocean and subsurface conditions: 1. Central Irish Sea and Kish Bank Basins; 2. North and South Celtic Sea and Fastnet Basins; 3. Erris, Slyne and Donegal Basins; 4. Porcupine and Goban Spur Basins and 5. Rockall Basin. Well data was tabulated and charts produced for each area in order to examine historical drilling activity, establish time vs depth curves for each area, determine most significant areas for drilling downtime and identify where improvements have been made over 30 years of offshore drilling in Ireland.

The continental lithosphere in tectonic extension: analogue and numerical experiments in the Porcupine Basin

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This study compares the results of lithospheric scale analogue models to those of numerical simulations, using the deep-water Porcupine Basin in the northeast Atlantic, off the west coast of Ireland as a template. Recent controlled source seismic studies have provided an insight into the extensional processes that deform the crust and uppermost mantle lithosphere in the region. Both analogue and numerical methods seek to address similar problems, regarding the development of extensional sedimentary basins. It is therefore reasonable to assume that these methods will generate similar results when applied to an identical problem. Some authors have already considered crustal scale comparisons with relative success. This study extends these comparisons to lithosphere scale, in an extensional context, using analogue models and the numerical code GALE. This is an area which presents challenging problems in terms of boundary conditions for both methods. As far as possible, measured parameters for the analogue models are replicated in the numerical models to ensure a valid comparison. Results are seen to be broadly similar, which provides encouragement in the consistency of both methods. The numerical simulations reproduce the gross geometry of the analogue models, and the greatest divergence in agreement between the two methods is found in regions experiencing a brittle response.

Provenance, depositional processes and diagenesis in Upper Jurassic sandstones in the northern Porcupine Basin, offshore western Ireland

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Mesozoic sandstones in under-explored North Atlantic margin basins are increasingly targets for hydrocarbon exploration. Provenance analysis is an important tool in such basins, as it enables assessment of ancient drainage patterns and can help constrain the distribution of potential reservoir sandstones. In the northern Porcupine Basin, well 35/8-2 tested hydrocarbons from an Upper Jurassic reservoir (Spanish Point Gas condensate discovery). The interval comprises a succession of clean to muddy sandstones, mudstones, conglomerates and mud breccias in an unstable submarine slope or basin floor environment. Facies analysis reveals potential links between provenance, depositional processes, diagenesis and reservoir quality.

The Pb composition of detrital K-feldspar has proved a particularly useful provenance indicator, as it likely records a first-cycle sediment supply. A pilot study of Pb in detrital K-feldspar grains from Jurassic sandstones in the Porcupine Basin revealed two cryptic Pb populations. These populations are consistent with a small scale sedimentary routing system (< 100 km) that straddled the boundary between two different crustal terranes. The sediments were most likely derived from the north (Porcupine High), with possible input from the eastern and western basin margins also.

This study presents the first results of a high resolution study in the Porcupine Basin, investigating the relationship between provenance, facies, diagenetic overprinting, and reservoir quality. Future work will entail high-resolution analysis of the Pb compositions of detrital K-feldspar populations within their depositional and diagenetic context.

Linking the geology and the biology on Hatton Bank, NE Atlantic

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Data acquired for the Strategic Environmental Assessment (SEA) of Hatton Bank in the NE Atlantic in 2005 and 2006 have been used to interpret the substrate type and geomorphology of the bank. The geological interpretations have been utilised as a framework on which to place smaller-scale biological interpretation. The relationship between the biological communities and the underlying geology has been used to extend the biological interpretation over the entire survey area which is crucial for the development of a network of Marine Protected Areas.

The geomorphology and sea-bed sediment layers have been overlain with the interpreted biological communities, mapped from video and digital camera data, within a GIS. A clear relationship between the two is evident. Areas of cold-water coral reef tend to correspond with areas of rock outcrop forming positive topographic features. Similarly, areas of lithic gravels, associated with iceberg ploughmarks, form havens for rock fish communities, and general areas of featureless sea bed host xenophyophores where bottom currents are accelerated over subtle undulations of the sea bed.

These results will feed into ongoing work to designate Special Areas of Conservation as defined under the EC Habitats Directive and the use of Marine Protected Areas as a conservation tool.

Petroleum Systems Analysis of Atlantic Ireland - A Fresh Approach to Prospectivity Evaluation

Ternan Ltd, Ternan House, North Deeside Road, Banchory, Aberdeen, AB31 5YR, Scotland & the **Petroleum Affairs Division**, Department of Communications, Energy and Natural Resources, Adelaide Road, Dublin 2

A series of posters will be on display in the Erne Room.

Interpretation and reconstruction of the tectonic and structural evolution of the North Atlantic from rift to drift. New regional play fairway analysis of the offshore Ireland area, including integration of play trends with the more mature petroleum provinces on the Canadian conjugate passive margin. Regional depositional environment interpretation at key stages in the structural evolution of the North Atlantic used to predict reservoir potential in the Rockall and Porcupine basins. Gravity data interpretation indicates pre-Cretaceous sediments in the Rockall Basin with likely presence of source rocks and potential hydrocarbon generation. Basin modelling and DHIs predict active petroleum systems throughout the Ireland offshore area

New seismic data offshore Ireland

TGS-NOPEC Geophysical Company (UK) Limited, Graylaw House, 21/21A Goldington Road, Bedford, MK40 3JY, UK and **Fugro Multi Client Services (UK) Ltd**, Fugro House, Hithercroft Road, Wallingford, Oxfordshire, OX10 9RB, UK.

(5 panel display)

A cold-water coral carbonate mound palaeoclimate archive: analysis of the lithic record (IODP exp. 307)

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During IODP Expedition 307 Challenger Mound, one of the large (~155 m high) cold-water coral mounds along the NE Atlantic continental margin (Porcupine Seabight), was successfully drilled. The complete recovery of this carbonate mound's sedimentary sequence provides us for the first time with material documenting the entire mound development process and is therefore crucial in our quest to unravel the mechanisms driving and maintaining the build-up of these bio-geological systems.

Changes in the hydrodynamic and sedimentary regime are suggested as amongst the main controls on cold-water coral mound evolution (e.g. Rüggeberg et al., 2007). Therefore, in this study high-resolution (siliciclastic) particle size analyses and their end-member modelling (Weltje, 1997), in conjunction with additional data (XRD, foraminiferal assemblages, grain surface textures), are chosen as primary tools for disentangling the different sedimentary contributors to the Challenger Mound system and their palaeo-environmental implications.

The results, so far, enable the differentiation and identification of 4 sets of sediment producing and transporting mechanisms. Based on the presence and intensity of these mechanisms distinct variations in the hydrodynamic environment can be observed throughout the entire mound sequence, which are inferred to be (predominantly) climatically steered. A clear and significant shift in sedimentation and/or preservation style can be noted around 22-23 mbsf, supporting and refining the two-phase mound development model proposed by Kano et al. (2007), who located a significant (~1 Ma) "mound crisis" around this depth. A higher resolution palaeo-record appears to be located below this "mound crisis", in the lower part of the mound (23- 155 mbsf), rather than above, revealing the potential of cold-water coral mounds as intermediate water depth, continental margin, Early-Mid Pleistocene palaeo-archives. Furthermore it seems that the specific role of cold-water corals in these sedimentary systems may be primarily in stabilisation and preservation of the matrix records.

Kano, A., Ferdelman, T.G., Williams, T., Henriot, J.-P., Ishikawa, T., Kawagoe, N., Takashima, C., Kakizaki, Y., Abe, K., Sakai, S., Browning, E.L., Li, X. and the IODPexp.307 Scientists (2007). Age constrains on the origin and growth history of a deep-water coral mound in the northeast Atlantic drilled during Integrated Ocean Drilling Program Expedition 307. *Geology* 35, 1051-1054.

Rüggeberg, A., Dullo, C., Dorschel, B. and Hebbeln, D. (2007). Environmental changes and growth history of a cold-water carbonate mound (Propeller Mound, Porcupine Seabight. *International Journal of Earth Science* 96, 57-72.

Weltje, G.J. (1997). End-member Modelling of Compositional Data: Numerical- Statistical Algorithms for Solving the Explicit Mixing Problem. *Mathematical Geology* 29 (4), 503-549.

Late Quaternary climatic and oceanographic controlled stratigraphy and sediment distribution on deep water marine slopes west of Ireland

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An extensive grid of gravity cores (>70 cores) have been collected along slopes west of Porcupine Bank on the Irish Atlantic margin. The cores (up to 3 m long) are from a range of water depths (~500m to ~3000m) and are being studied in order to understand the depositional response to glacial-interglacial cycles and to document evidence for Quaternary oceanographic current variations on different parts of the slope and hence different depths in the palaeo-water column. Whereas detailed palaeoceanographic records exist from surrounding banks and ocean floor deposits, such as the Rockall Bank and Feni Drift, slopes in the area are less well understood. The cored slope deposits are potentially interesting as they are from a relatively low gradient part of the margin in an area of low sediment supply. Slope failure is therefore minimal. A thin and largely undisturbed sediment record is present extending back to at least c.500,000 years (MIS 13). Investigations reveal cyclic sediment alternations, highlighted by paler, dominantly pelagic calcareous deposits consisting largely of calcareous nannoplankton and planktonic foraminifera (interglacials); and darker siliciclastic muds, sandy muds and sands (glacial). Correlation between the cores is achieved using a repeating pattern of calcareous and siliciclastic intervals, distinctive marker beds, bioturbated horizons and prominent erosional surfaces, with coherent lithological variations traceable over an area of >50 km². The stratigraphy is expanded on the deepest slope (~2750m) and more condensed at shallower depths (~800m) with cores here showing greater reworking and minor soft-sediment deformation. Integration of core descriptions with quantitative textural and micropalaeontological (specifically foraminifera) data help distinguish glacial/interglacial periods and superimposed higher frequency variations. Ultimately such data will help reconcile offshore and onshore climate proxies from the North Eastern Atlantic region.

Compression and unconformity formation in the Rockall-Faroe area, in the NE Atlantic “passive” continental margin

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Passive continental margins are generally thought to be characterised by tectonic quiescence as they experienced gentle thermal subsidence following the extensional events that originally formed them. Analysis of newly acquired and pre-existing 2-D seismic data from the Rockall Plateau to the Faroe Shelf, however, has demonstrated that the NE Atlantic Margin was the site of significant active deformation. Seismic data have revealed the presence of numerous compression-related Cenozoic folds, such as the Hatton Bank, Alpin, Ymir Ridge and Wyville-Thomson Ridge anticlines.

The distribution, timing of formation and nature of these structures have provided new insights into the controls and effects of contractional deformation in the region. Gravity models support the presence of low-density sediments in the core of major anticlinal or domal structures. This is consistent with folds developed due to the inversion of sedimentary basins. The spatial

extent of the deformation could thus reflect the differing underlying basin morphologies. Growth of these compressional features occurred in five main phases: Thanetian, late Ypresian, late Lutetian, Late Eocene (C30) and Early Oligocene. Compression has been linked to hotspot-influenced ridge push, far-field Alpine and Pyrenean compression, asthenospheric upwelling and associated depth-dependent stretching.

The regional studies make clear that compression can have a profound effect on sea-bed bathymetry and consequent bottom-water current activity. Bottom-water currents have directly formed the early Late Oligocene, late Early Miocene (C20), Late Miocene – Early Pliocene, and late Early Pliocene (C10) unconformities. The present day Norwegian Sea Overflow (NSO) from the Faroe-Shetland Channel into the Rockall Trough is restricted by the Wyville-Ymir Ridge Complex, and takes place via the syncline (Auðhumla Basin) between the two ridges. The Auðhumla Basin Syncline is now thought to have controlled the NSO into the Rockall Trough and the resulting unconformity formation and sedimentation therein, no later than the Mid Miocene.

Ireland's first ITRAX™: a marine sediment prospective

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The UCD School of Geography, Planning and Environmental Policy (GPEP) has recently acquired a state-of-the-art ITRAX™ Core Scanner as part of the HEA 2007 Research Equipment Renewal Grant Scheme. The Core Scanner is unique in Ireland and currently one of only 13 such instruments in the world. It enables rapid (typically a 1 m sample takes 12 hrs), non-destructive optical and X-radiography imaging and XRF analysis of core samples (inter alia rock, sediment, soil, wood, speleothem), down to sub-100µm resolution for XRF and ca. 20 µm for Xradiography.

The XRF detector records x-ray intensity (peak area counts per sec) for up to 80 elements from Al to U, which can be converted to concentrations with the use of standard reference materials or matrix-matched standards. This paper reports on some preliminary reproducibility tests conducted on marine sediments cores (TH08_VC02 & TH08_VC03) taken from the Porcupine Bank by the INFOMAR team (GSI & Marine Institute). This comparative assessment of replicated ITRAX™ XRF profiles, obtained using the GPEP facility and the instrument housed at the National Oceanographic Centre, Southampton (NOCS), identifies some important considerations for sample preparation, and highlights both the prospects and some potentially limiting factors for the analysis of heterogeneous marine sediment cores.

Interplay of Alpine collisional tectonics and Icelandic mantle plume-related deformation and magmatism in the Early Palaeogene of Northern Ireland: new constraints from the Tellus high resolution geophysical survey

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The Cenozoic tectonics of NW Europe is generally attributed to some combination of three principal controlling factors: North Atlantic opening, Alpine collision and Icelandic mantle plume activity. The relative contribution of each of these factors is the subject of debate. Using constraints derived from the Tellus high resolution geophysical survey, we suggest that the Palaeocene tectonics of Northern Ireland, which hosts extensive exposures of early Palaeocene igneous rocks from the North Atlantic Igneous Province, involved Alpine-related strike-slip faulting caused by approximately N-S compression, punctuated by pulsed magmatic intrusive and extrusive events associated with NE-SW to E-W directed plume-related extension. Strike-slip faulting conforms to conjugate pairs of NNW-striking dextral and ENE-striking sinistral faults, with the latter defined by kilometre-scale displacements of older reactivated Caledonian/Carboniferous faults. The known onshore occurrence of Palaeocene intrusive central complexes and extrusive flood basalts, and the identification herein of four distinct dyke swarms is consistent with pulsed mantle plume activity as previously diagnosed from offshore submarine fans. Whilst the background tectonic deformation arising from approximately N-S Alpine compression is periodically overwhelmed by plume-related deformation (e.g. to form dyke swarms), related strike-slip faulting may have controlled the location of volcanic and sedimentary depocentres and of igneous intrusive complexes.

Lithospheric density variations and Moho structure of the Irish Atlantic continental margin from constrained 3-D gravity inversion

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A 3-D density anomaly model of the Irish Atlantic continental margin was generated from a regional inversion of the free air gravity data constrained by bathymetric and sediment thickness information. The model results are compared against profiling results from other geophysical surveys, mostly against velocity models from crustal-scale wide-angle reflection/refraction surveys. Using the model a regional map of Moho structure across the margin agrees well with available seismic constraints and provides information in areas lacking deep seismic coverage. The density anomaly structure of the crust across the margin is investigated along model slices and using volume rendering of crustal layers. These views reveal extreme thinning of upper crustal type densities and a dominance of lower crustal type densities in regions where exhumation of serpentinised mantle has previously been interpreted. Using the regional view afforded by the inversion, the areal extent of these zones is tracked into regions lacking seismic constraints. Using the regional density anomaly model, sediment thickness and crustal thickness are compared to identify zones, which deviate from local isostatic compensation. These zones generally correlate with faults and rifting trends providing insights that could be useful for future palaeo-reconstructions of North Atlantic rifting.

Drilling Complete Sequences through Cold-Water Coral Carbonate Mounds (ESF-Carbonate): Drilling Expedition Results and Core Analysis

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Cold-water coral carbonate mounds form common features at intermediate water depth on the European, African and American continental margins. They can be several hundred metres tall and more than a kilometre across. Features are both exposed at the seabed and buried within upper seismic sequences. A significant concentration of large carbonate mounds exist on the Irish margin. Exposures on land are rare with most information on internal properties coming from shallow cores and one long borehole (155m) through one mound (the Challenger Mound - IODP Exp. 307).

The ESF-CARBONATE project aims to recover complete mound sequences through a range of carbonate mounds in different settings and elucidate the timing and factors controlling carbonate mound genesis, generate a robust carbonate mound development model for different environmental setting and estimate the influence of climate change in carbonate mound development. In addition, CARBONATE will derive palaeoenvironmental signals from carbonate mound sequences and assess the role of cold-water coral carbonate mounds in the global carbon cycle.

Detailed analysis of 525,000 km² multibeam echosounder coverages and existing information identified a range of carbonate mound provinces and potential drill targets. A pre-drilling site survey was conducted in October 2007 (RV Pelagia) with the acquisition of high resolution seismics, box-cores, piston cores, video tows and monitoring of seabed environmental dynamics using the BoBo lander platform. A number of drill targets were then selected.

Deep-sea drilling of cold-water coral carbonate mounds was undertaken at various sites along the European continental margin (Aug. to Sept. 2008) from Mauritania to northern Norway. Analysis of these cores is revealing a climatically induced pattern of cold-water reef development.

See <http://www.esf-carbonate.org>

Cold-Water Coral Carbonate Mound Borehole Records: High Resolution Palaeoenvironmental Histories, Palaeoclimatic Controls on High Biodiversity Habitats and Excess Carbonate Accumulation Centres (ESF-CARBONATE)

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The ESF-CARBONATE has recovered long and complete mound sequences through a range of carbonate mounds in different settings on a latitudinal gradient from Mauritania to northern Norway.

Analysis of core material is on-going to:

- elucidate the timing and factors controlling carbonate mound genesis,
- generate a robust carbonate mound development model for different environmental setting,
- estimate the influence of climate change in carbonate mound development,
- derive palaeoenvironmental signals from carbonate mound sequences, and
- assess the role of cold-water coral carbonate mounds in the global carbon cycle.

Detailed analysis of 525,000 km² multibeam echosounder coverages on the Irish margin (where the largest and highest density of coral carbonate mounds are) has been supplemented by new environmental data collected during a pre-drilling site survey (October 2007 - RV Pelagia: high resolution seismics, box-cores, piston cores, video tows and monitoring of seabed environmental dynamics using the BoBo lander platform). Appraisal of this data provides, for the first time, an accurate appraisal of mound volumes and excess carbonate storage on a regional scale, which can be compared to tropic carbonate systems, and an understanding of the diversity of environmental settings where these systems grow.

See <http://www.esf-carbonate.org>

University research using Tellus data

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GSNI urges researchers to consider geological and environmental research projects using the Tellus geophysical and geochemical data. Financial support for research and degree projects may be available.

GSNI released the results of the Tellus geochemical and airborne geophysical surveys of Northern Ireland in 2007. These are the most comprehensive and detailed geoscience survey results ever acquired in the United Kingdom on a regional scale.

The project is an excellent example of how integrated geoscience surveys can encourage economic development and stimulate research by providing high quality information, for academic research as well as for industrial and government applications. Following release of Tellus data, 70% of Northern Ireland has been licensed for mineral and hydrocarbon exploration, with an associated commitment of £15 million over two years, thus demonstrating the fiscal value of basic geological data collection to the wider economy.

More than 30 university research projects, PhD and MSc studies have used or are using Tellus data. This poster shows brief summaries of some of these. Topics include regional tectonics and magmatism; the effects of soil and stream geochemistry on human and animal health; urban geochemistry and pollution; geostatistics; aquifer modelling; gold and nickel prospecting; and the mapping of carbon in soil.

Regional interpretation of new airborne geophysical imagery of Northern Ireland

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In 2006 the Geological Survey of Northern Ireland (GSNI) completed the national low-level airborne geophysical survey of Northern Ireland, as part of the Tellus Project. Datasets and imagery of the following are available:

Total magnetic field and various transformations,

Electrical conductivity (two and four frequency electromagnetic survey),

Gamma-ray (total count, uranium, thorium, potassium, caesium).

Regionally, the airborne geophysical imagery refines existing structural mapping. Prominent magnetic anomalies correspond notably with major igneous complexes and the extensive Palaeocene Antrim basalts. At least four generations of Palaeocene dykes are distinguished on the basis of their magnetic signatures and major regional faults are well defined. The electromagnetic survey maps electrical conductivity differences between the Precambrian, Lower Palaeozoic and younger rocks, as well as environmental effects. Radiometric results display significant differences in the radioactivity of different lithologies, including some of the most radioactive granites in the United Kingdom. At a local scale the imagery reveals outstanding structural detail.

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Dave Burghardt	Vermilion Energy
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