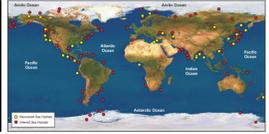
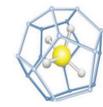


# Fluid flow in Irish offshore and its implications on natural gas hydrate formation



## DATA AND METHODS FOR EXPLORING NATURAL GAS HYDRATES IN IRISH OFFSHORE

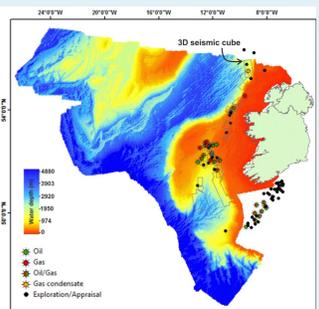


Figure 1A: 3D seismic cubes and wells overview by seafloor bathymetric data. Oil and gas finds in Irish offshore are shown in green and red dots.

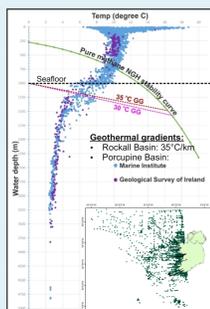


Figure 1B: Seafloor temperature from 4760 CTD casts. Geothermal gradients from well data.

Figure 1C (RIGHT): Gas Hydrate Stability Zone (GHSZ) thickness calculated from bathymetric data, geothermal gradients (from well data), and seafloor temperature data. Pixel-size of the map is 500 x 500 m.

- Gas chimneys and thermogenic hydrocarbon seeps are aligned along the continental slope, where the GHSZ thins to a few tens of meters.
- Hydrocarbon field discoveries lie below the GHSZ in NE Rockall and Porcupine Basin.

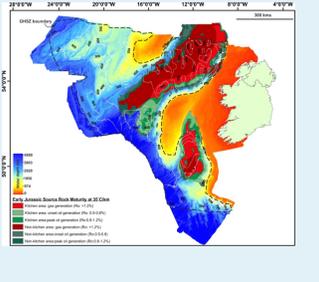
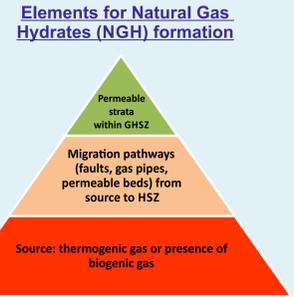


Figure 1D (LEFT): Source rock distribution in Porcupine and Rockall basins generally coincident with the GHSZ extent.



## MARINE GAS HYDRATE STABILITY ZONE IN IRELAND AND EUROPE

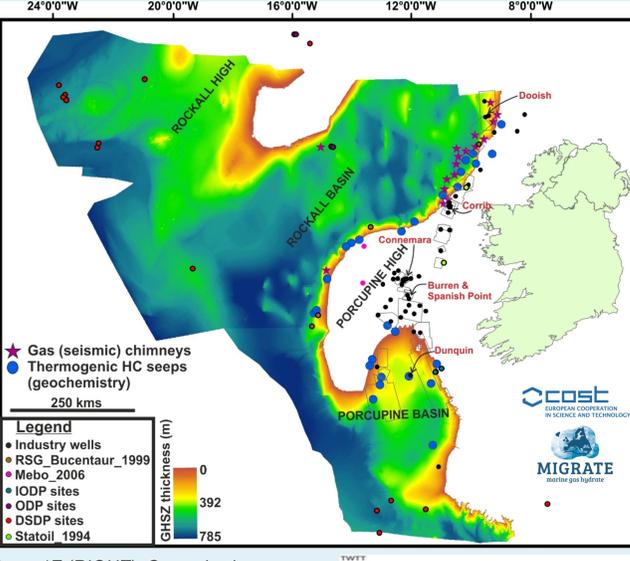


Figure 1E (RIGHT): Geo-seismic cross-section of Porcupine and Rockall basins, illustrating the morphology and thickness of the Cenozoic sections, which overlaps the margins of both basins in a symmetrical fashion.

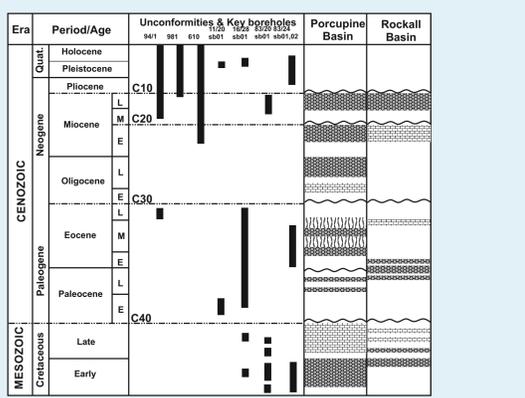
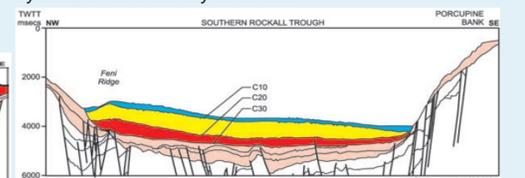


Figure 1F (TOP): Lithostratigraphic column for the Cenozoic successions in the Porcupine and Rockall basins derived from key research and industry boreholes.



## POTENTIAL NATURAL GAS HYDRATE RESERVOIRS

Evidence of fluid migration (gas chimneys) and polygonal fault systems above working petroleum systems have been observed on 2D & 3D seismic data in Rockall and Porcupine basins. BSR-like features (reverse polarity, high-amplitude, parallel to seafloor) have been found in association with fluid-escape pipes, pockmarks, and fault systems. Three types of potential NGH reservoirs have been identified in Irish basins: i) contourite deposits, ii) mass transport deposits (MTD), and iii) isolated sand bodies/channel systems.

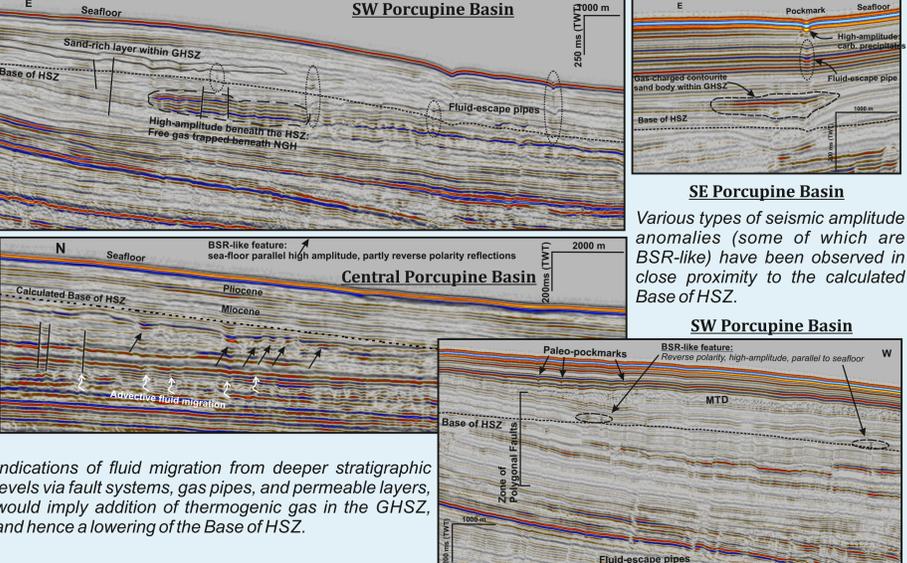
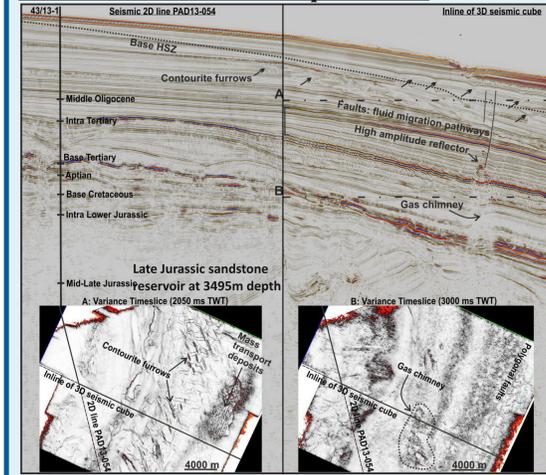


Figure 2 (LEFT): Composite line of 2D MCS data (tied to well 43/13-1) and an inline of 3D seismic data in the Porcupine Basin (Location: map on RIGHT). A gas chimney is shown to bring fluids from Jurassic source rocks to shallow contourite deposits.

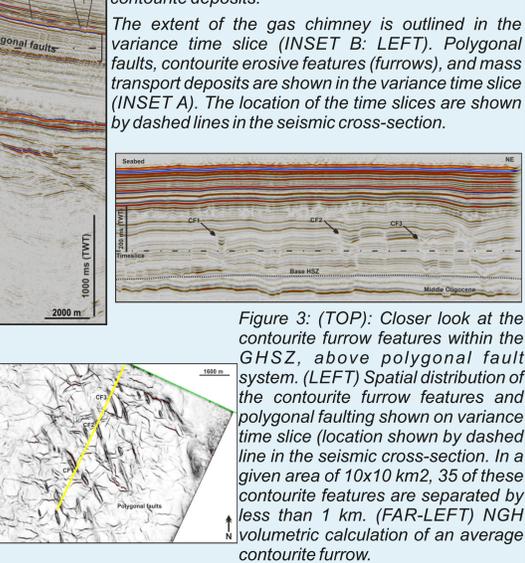
## NGH Volumetrics in Porcupine Basin



NGH Volumetrics of an average contourite furrow

	LOW CASE	MEDIUM CASE	HIGH CASE
Area (km <sup>2</sup> )	0.352	0.45	0.66
Net HSZ (km)	0.05	0.08	0.1
Gross Rock Vol (km <sup>3</sup> )	0.0176	0.036	0.066
Porosity	0.25	0.3	0.35
Hyd Saturation	0.1	0.15	0.2
FVF	160	160	160
GIIP (m <sup>3</sup> )	72160000	265680000	757680000
GIIP (bcf)	2.54	9.38	26.75

The extent of the gas chimney is outlined in the variance time slice (INSET B: LEFT). Polygonal faults, contourite erosive features (furrows), and mass transport deposits are shown in the variance time slice (INSET A). The location of the time slices are shown by dashed lines in the seismic cross-section.



## PETROPHYSICAL INVESTIGATION ON HYDRATE-BEARING SEDIMENTS IN LABORATORY

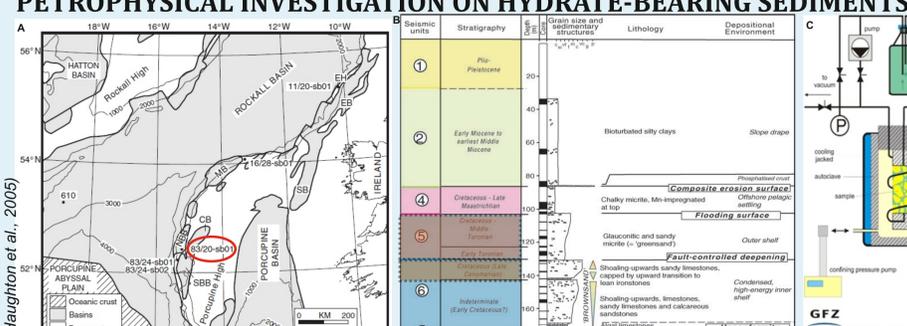


Figure 6: (A) Location of the 83/20-sb01 stratigraphic borehole site on the eastern Rockall margin, showing the main structural elements in the region. CB, Cillian Basin; EB, Erris Basin; EH, Erris High; SB, Slyne Basin; NBB, North Brona Basin; SBB, South Brona Basin; MB, Macdara Basin. (B) Description of the cored section in shallow borehole 83/20-sb01. (C) Schematic diagram of the experimental set-up. (D & F) Sonic velocities (Vp) and 2-electrode resistivity values were measured at various ice saturation levels. We observe an increase in the Vp at 22% ice saturation (as well as resistivity value), while methane was injected in the sample. The injected methane pressure (40 Bars) was above the hydrate stability, which might have led to the formation of cementing hydrate with the bound water in the core plug.

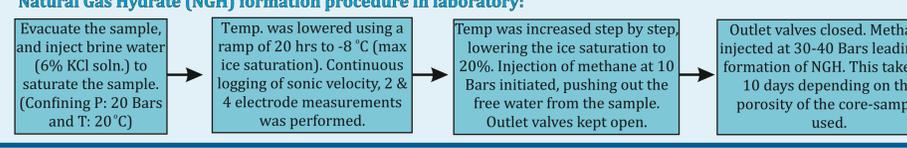


Figure 7: (TOP) Schematic diagram of the apparatus and the MRI for monitoring and controlling pressure and temperature during methane hydrate formation. (BOTTOM LEFT) MRI imaging of core sample while NGH was being formed. (BOTTOM RIGHT) 3D MRI image of core sample saturated with water.

## IMAGING NGH FORMATION USING MRI

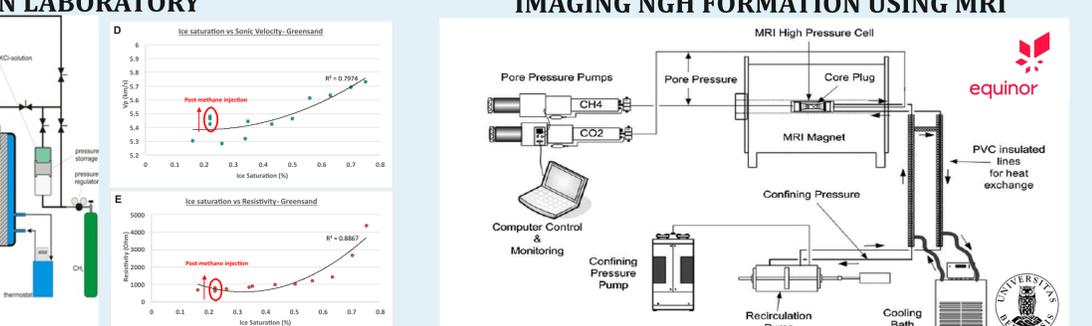


Figure 7: (TOP) Schematic diagram of the apparatus and the MRI for monitoring and controlling pressure and temperature during methane hydrate formation. (BOTTOM LEFT) MRI imaging of core sample while NGH was being formed. (BOTTOM RIGHT) 3D MRI image of core sample saturated with water.

## CONCLUSIONS:

- A high-resolution GHSZ thickness map has been calculated for Irish basins, which extends up to 785m below sea-floor. The aerial distribution of GHSZ is largely coincident with the potential source rock distribution in Irish basins.
- Prospective NGH reservoirs and migration pathways overlying proven source rocks have been identified in Rockall and Porcupine basins. Isolated sand bodies, mass transport deposits, and contourite deposits (primarily within Cenozoic sediments) could be potential targets for oceanic NGH exploration.
- BSR-like features (reverse polarity, high-amplitude, parallel to seafloor) have been observed in close proximity to the calculated base of HSZ, in association with fluid-escape pipes, faults, and pockmarks.
- Vp and resistivity values were measured in the laboratory following controlled formation of methane gas hydrate in core-samples collected from an area which is within the calculated GHSZ in Irish offshore. MRI imaging of these core samples have been done before and after formation of NGH. Physical and mineralogical properties of the sediment samples are being analysed to correlate with the kinetics of NGH formation.

## ACKNOWLEDGEMENTS:

We acknowledge the Geological Survey of Ireland, the Petroleum Affairs Division, the Petroleum Infrastructure Programme, the Marine Institute for providing the various types of geophysical and geological data sets for this work. SR is an Irish Research Council, Government of Ireland Postdoctoral Fellow.

## REFERENCES:

1) Haughton, P., Praeg, D., Shannon, P., Harrington, G., Higgs, K., Amy, L., Tyrrell, S., Morrissey, T., 2005. First results from shallow stratigraphic boreholes on the eastern flank of the Rockall Basin, offshore western Ireland. Geological Society, London 6, 1077-1094.  
2) Baldwin, B.A., Stevens, J., Howard, J.J., Graue, A., Kvamme, B., Aspnes, E., Erland, G., Husebe, J., Zornes, D.R., 2009. Using magnetic resonance imaging to monitor CH4 hydrate formation and spontaneous conversion of CH4 hydrate to CO2 hydrate in porous media. Magnetic Resonance Imaging 27, 720-726.  
3) Stoker, M.S., Praeg, D., Shannon, P.M., Hjelstuen, B.O., Laberg, J.S., Nielsen, T., Van Weering, T.C., Sejrup, H.P., Evans, D., 2005. Neogene evolution of the Atlantic continental margin of NW Europe (Lofoten Islands to SW Ireland): anything but passive. Geological Society, London, Petroleum Geology Conference series 6, 1057-1076.

This publication has emanated from research supported in part by a research grant from Science Foundation Ireland (SFI) under Grant Number 13/RC/2092 and co-funded under the European Regional Development Fund and by iCRAG industry partners. This research was carried out with the support of the Marine Institute under the Marine Research Programme with the support of the Irish Government.