Methane-rich glacial clays on top of a large sediment wave?

A. Katrien J.J. Van Landeghem *School of Ocean Sciences, Bangor University, North Wales, UK – k.v.landeghem@bangor.ac.uk*

B. Helge Niemann *Institute for Environmental Geosciences, Universität Basel, Switzerland – helge.niemann@unibas.ch*

C. Peter F. Croker *The M Horizon (UK) Limited, UK – peter.f.croker@gmail.com*

D. Dei G. Huws *School of Ocean Sciences, Bangor University, North Wales, UK – d.g.huws@bangor.ac.uk*

E. Lea Steinle *Institute for Environmental Geosciences, Universität Basel, Switzerland – lea.steinle@unibas.ch*

F. Shane S. O'Reilly *Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge MA 02139, USA – oreillys@mit.edu*

ABSTRACT: The Quaternary glacial history of our shelf seas influences the distribution and mobility of the marine sediments today, and thus the formation of sediment waves. Here we explore other ways the glacial legacy can influence sediment wave dynamics in the presence of methane seeps. A link between methane seeps and the formation of unusually large, trochoidally shaped sediment waves observed on continental shelves world-wide is deemed unlikely. However, clay-rich muds with high concentrations of methane were observed on top of very large sediment waves in a seafloor trench in the Irish Sea. It suggest that methane gas percolating upwards through sediment waves may be capped by these clay-rich glacial sediments. From sub-bottom evidence, seepage of shallow gas is seemingly guided by the underlying glacial geology and sedimentology. These processes may thus influence sediment wave dynamics and warrant further investigation.

1. INTRODUCTION

The sediments overlying bedrock in the Irish Sea are largely of reworked glacial origin, as the last British and Irish Ice sheet covered the entire Irish Sea during the Last Glacial Maximum at least as far south as the Isles of Scilly (Scourse and Furze 2001).

The Irish Sea also has many potential sources of both microbial and thermogenic methane (Croker 1994; Croker et al. 2005; Judd et al. 2007). Some of these sources are found in deep seafloor trenches. One of these seafloor trenches is called "Jürgen's Nightmare", and has a particularly steep western wall, exposing glacially derived sediments and with well-documented high concentrations of methane (Judd, 2005). This trench also hosts exceptionally high sediment waves relative to the global maximum height trend suggested by Flemming (1988) and are thus referred to as "anomalously high". They are trochoidally shaped and on top clay-rich muds with high concentrations of methane. It is this observation that lead to further explore the link between the seafloor's glacial legacy, sediment wave formation/dynamics and the seepage of methane.

2. OBSERVATIONS

2.1. Clays on top of sediment waves.

The sediment in the Jürgen's Nightmare trench contains up to 94% mud (Figure 1) and contained enhanced methane concentrations up to 7,354 nM, the highest measured in sediments recovered during the AmSedIS survey. The mud was further analysed and with a median grain size d50 of 3 µm was found rich in clay. The trench at the bottom of the cliff hosts a suite of very large trochoidally shaped sediment waves, the flank of one of which had mud contents between 30% and 85% and with methane concentrations reaching 4,193 nM. By contrast, sediments retrieved from other sediment wave flanks elsewhere in the Irish Sea all had negligible mud contents, including the samples from a large sediment wave in the Harvey's Trench located east of Jürgen's Nightmare (Figure 1b) which is not associated with a steep trench wall. Bottom water methane concentrations in Jürgen's Nightmare varied from 1.44–4.64 nM (Figure 1c), whereas no methane was recorded in the sediments from Harvey's Trench.

2.2. Gas seepage influenced by Quaternary sedimentary history

Whereas in Liverpool Bay the glacial character of the seafloor sediments is evident from the preserved palaeo-glacial landscape (Van Landeghem et al. 2009), the legacy of ice advance and retreat in the Central Irish Sea seems to be largely masked. In 2012, a seismic profile from the "Croker Carbonate Slabs" Special Area of Conservation in the Central Irish Sea seems to compare well with the seismic structure interpreted by Judd et al. (2007) as a prograding late Pleistocene facies of the Western Irish Sea Formation (the latter also described by Jackson et al. 1995). A high-amplitude reflector displays an intermittent inversion in the acoustic impedance, which could be due to the presence of gas in the overlying sediments consisting of relatively smaller gas bubbles. Where this reflector pinches out within ca. 1 m of the seafloor, a small carbonate mound is observed, around which the sediments are over-saturated with methane (Figure 2).

2.3. MDAC enabling enhanced sediment wave growth?

A study by targeting sediment waves within and outside areas of active gas seepage has determined that the large sizes of some sediment waves are not related to past or present gas seepage (Van Landeghem et al. 2015). In the literature, the theory of syndepositional stabilisation of the seafloor via methane seepage was tentatively applied to explain the very large size of some sediment waves (Hovland 1993; Judd et al. 2007), but our data does not support this theory.

3. INTERPRETATIONS

The nature of potential seepage of shallow gas is seemingly guided by the subsurface (glacial) geology and is discontinuous due to the intermittent presence of mud-rich layers in the sediments. Shallow gas in unconsolidated seafloor sediments is common in the NW European shelf seas (e.g. Schroot and Schüttenhelm 2003), and has caused concerns for safety during the many offshore developments currently ongoing world-wide (e.g. drilling operations and construction of wind turbine parks; Chivers 2013). The ability of (1) to understand which geological settings favour the build-up of shallow gas, and (2) to remotely identify the presence of shallow methane in the offshore environment is thus desirable and can be aided by a better understanding of the subsurface geology.

In Jürgen's Nightmare trench, any gas derived from the underlying Westphalian Coal Measures or the Dinantian/Namurian Holywell Shale would migrate through the overlying stiff diamictons (Judd 2005), which was found to be very rich in mud (up to 94%) and containing a significant clay fraction. Within the late Pleistocene Western Irish Sea Formation, this intermittent muddy layer may indeed have trapped the gas seeping from underlying sands and gravels. The stiff mud appears to have been eroded from the cliff and draped over some of the very large and trochoidally shaped sediment waves at the bottom of the trench. It is difficult to invoke any other mechanism in this high-energy environment to explain the presence of muddy sediments on top of very large sediment waves.

4. ACKNOWLEDGMENT

This scientific survey (CV12007) was funded for 8 days offshore, including all the shipment and travel, by the European Commission (EC Grant agreement nr. 228344) through the EUROFLEETS Project, a EU project funded through the EU FP7 Capacities/Research Infrastructures Programme, aiming at creating an alliance of European research fleets, bound to the general EC terms for project funding.

An extra 2 days offshore were funded by the Petroleum Affairs Division, which is part of the

Department of Communications, Energy and Natural Resources that regulates, protects and develops the Natural Resources of Ireland. The project partners at Bangor University, the University of Liverpool, University Basel and Università degli Studi di Genova funded 1 supplementary day on the RV Celtic Voyager. Helge Niemann was funded through a COST Short Term Scientific Mission (COST-STSM-ECOST-STSM- ES0902-190312-016289), Lea Steinle through the Swiss National Science Foundation (project 138057).

5. REFERENCES

Chivers A. 2013. Dogger Bank Creyke Beck Health and Safety Statement. Document nr. F-HSC-RP-001 prepared for Forewind by PMSS Consultancy Services.

Croker P.F. 1994. Shallow gas in the Irish Sea and associated seafloor morphology. In: NIOZ, 3rd International Conference on Gas in Marine Sediments, Texel, The Netherlands, 25–28 September, 1994.

Croker P.F., Kozachenko M. & Wheeler A.J. 2005. Gas-related seabed structures in the Western Irish Sea (IRL-SEA6). Technical report produced for Strategic Environmental Assessment of the Irish Sea (SEA6), UK Department of Trade and Industry, London

Flemming B.W. 1988. Zur Klassifikation subaquatischer, strömungstransversaler Transportkörper. Boch geol & geotech Arb 29: 44–47

Hovland M. 1993. Submarine gas seepage in the North Sea and adjacent areas. In: Parker JR (ed), Petroleum Geology of Northwest Europe: 4th Conference on, 29 March–1 April 1992, London, Proceedings: 1333–1338

Jackson D.I., Jackson A.A., Evans D.J.A., Wingfield R.T.R., Barnes R.P.& Arthur M.J. 1995. United Kingdom offshore regional report: the geology of the Irish Sea. BGS UK Offshore Regional Rep, HMSO, London

Judd A.G. 2005. The distribution and extent of methane-derived authigenic carbonate. Strategic Environmental Assessment of the Irish Sea (SEA6). UK Department of Trade and Industry, Tech Rep, London

Judd A.G., Croker P.F., Tizzard L. & Voisey C. 2007. Extensive methane-derived authigenic carbonates in the Irish Sea. Geo-Mar Lett 27: 259–267

Schroot B.M., Schüttenhelm R.T.E. 2003. Expressions of shallow gas in the Netherlands North Sea. Netherlands J Geosci/Geol Mijnb 82(1): 91–105

Scourse J.D. & Furze F.A. 2001. A critical review of the glaciomarine model for Irish Sea deglaciation: evidence from southern Britain, the Celtic shelf and adjacent continental slope. J Quat Sci 16: 419–434

Van Landeghem K.J.J., Wheeler A.J., Mitchell N.C. (2009) Seafloor evidence for palaeo-ice streaming and calving of the grounded Irish Sea Ice Stream: implications for the interpretation of its final deglaciation phase. Boreas 38: 119–131

Van Landeghem, K.J.J., Niemann, H., Steinle, L.I., O'Reilly, S.S., Huws, D.G. & Croker, P.F. (2015) Geological settings and seafloor morphodynamic evolution linked to methane seepage. Geo-Marine Letters, 35 (4): 289–304

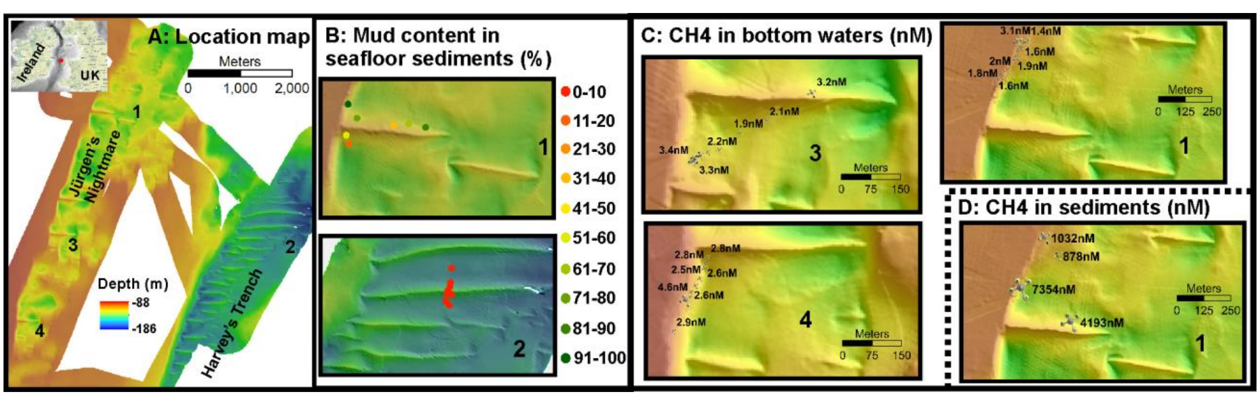

Figure 1. A: Seafloor bathymetry of Jürgen's Nightmare and Harvey's Trench. B: Mud content in seafloor sediments. C: Methane concentrations (nM) in bottom waters. D: Methane concentrations (nM) in seafloor sediments. From Van Landeghem et al., 2015

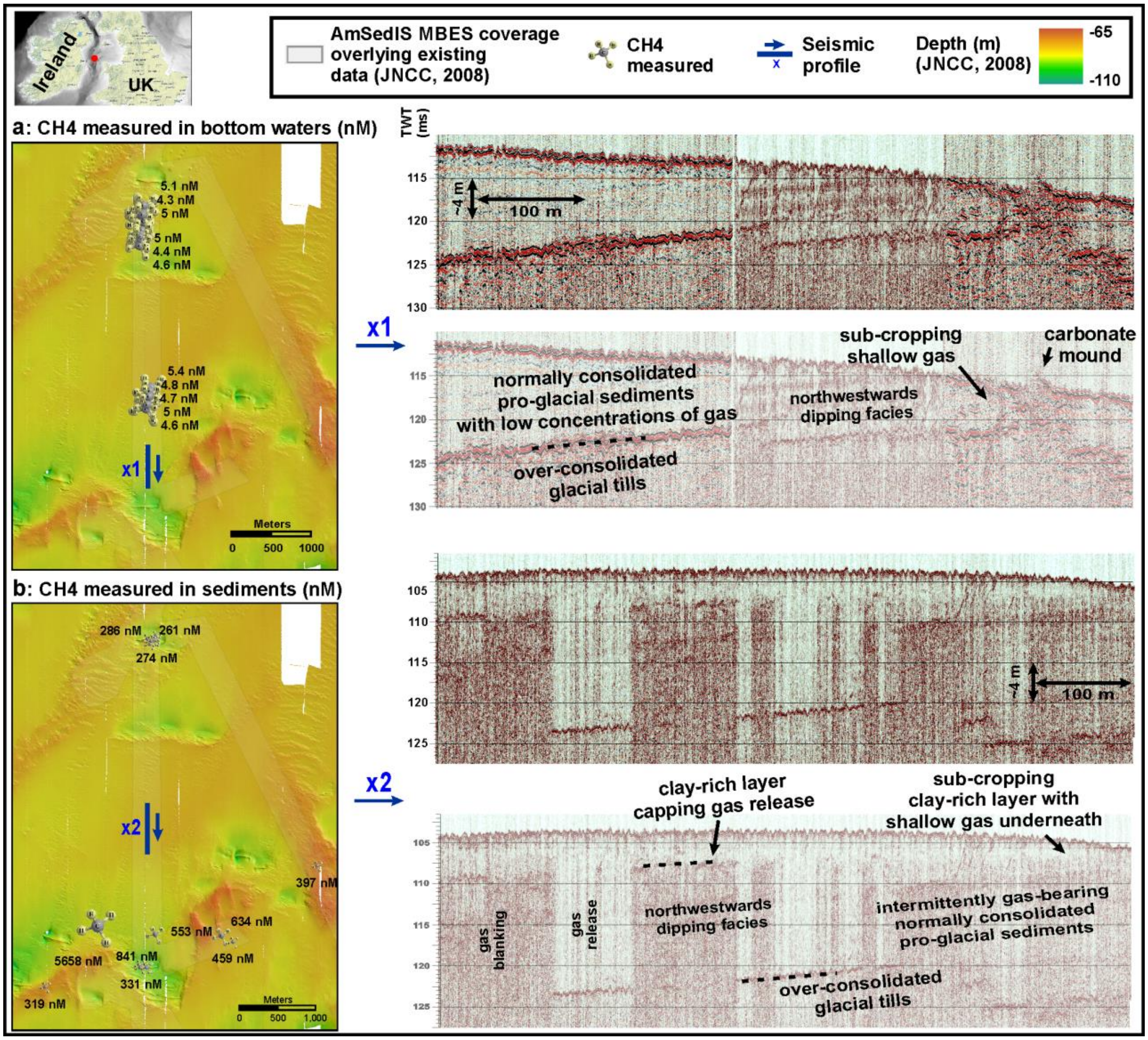

Figure 2. Methane concentrations (nM) in (A) bottom waters and (B) sediments seafloor of the Croker Carbonate Slabs SAC. Swath bathymetry data was collected during the AmSedIS project and by the JNCC in 2008 (©Copyright JNCC 2008). The blue lines locate the seismic profiles presented in cross-sections x1 and x2. From Van Landeghem et al., 2015