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Investigation of Geothermal Potential in the Irish Carboniferous Palaeokarst

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ABSTRACT

In accordance with Ireland's National Mitigation Plan (July 2017) and the GSI Research Roadmap, the GSI commissioned a short-call research project focused on investigating geothermal potential of the Irish Carboniferous karstified limestones at depth. Anecdotal evidence of dropped rods, cavities and non-recovery of core from mineral exploration drilling in Ireland casts doubt on the assumption that Palaeozoic rocks at depth have negligible porosity and permeability. Evidence from the oil and gas industry shows that coalesced collapsed palaeocave carbonate reservoirs exist in the Ordovician Ellenburger Ramp Carbonate play of West Texas. So why not in the Irish Carboniferous? The 'Coalesced Collapsed Palaeocave' play, characterised by moderate porosities and permeabilities in the Ellenburger is considered to be a good analogue for geothermal resource potential of the Waulsortian Mudbanks. A review of numerous published articles, well-reports, etc. and personal meetings with Irish Carboniferous Geology experts provided substantial evidence to support the hypothesis of the presence of preserved karst within the Waulsortian at depth. Between the two main Carboniferous Basins viz. Dublin Basin and Shannon Trough, the latter was considered as the better prospect to intercept the Waulsortian coalesced mud mounds at depths of more than 1000m. A focused seismic interpretation was carried out on four recently acquired 2D seismic lines in the north of the Shannon Trough (Kilbricken Mine area) by Hannan Metals Ltd. The analysis showed a number of 'karst indicators' (sag features, polygonal faults etc.) towards the base of the Waulsortian Formation which were inferred to be related to preserved collapsed structures, like those observed in the Ellenburger Group. The 'Kilmurry Prospect' is a proposed drilling target, intersecting a collapsed palaeocave at ~900m depth with a potential for temperatures of up to 30°C. Drilling the prospect will allow the acquisition of a comprehensive suite of wireline logs to prove the exploration model. A recommendation is made to investigate the potential of similar Waulsortian karst systems, in the deeper parts of the Shannon Basin i.e., south of the Kilbricken area, in the Adare region, once the Kilmurry Prospect is proven.

1. INTRODUCTION

Limestone (and dolomite) is susceptible to dissolution when it encounters mildly acidic water. This results in the formation of topography known as 'Karst' which is characterised by a drainage system of caves and sinkholes. Almost half of the island of Ireland is underlain by limestone, of which a high proportion has been karstified. The karstification is believed to be extending to depths of >2km in the subsurface in some areas. Recent studies have identified regional tectonic inversion of the island in the Tertiary period, causing limestones to be uplifted, thus becoming more susceptible to karstification. In addition to the evidence for Tertiary uplift and karstification, there are indications that similar processes occurred in the Jurassic and Permian in Ireland (Drew & Jones, 2000).This would imply that older (and therefore, deeper) limestones such as the Waulsortian may have been karstified; and if karsts were preserved at considerable depth, it is believed that these limestones could be exploited for deep geothermal energy.

In accordance with Ireland's National Climate Mitigation Plan (July 2017) and the Geological Survey of Ireland (GSI)'s current Research Roadmap, the GSI commissioned the authors to conduct a short-call research project in 2017 focused on investigating geothermal potential of the Irish Carboniferous karstified limestones at depth.

1.1 Oil and Gas Analogue

The Ellenburger Group of the Permian Basin in West Texas, USA, is part of a Lower Ordovician carbonate platform sequence. The Ellenburger group is a prolific oil producer. The oil is being produced from a 'collapsed (coalesced) palaeocave' formed due to karstification of the limestone formation. Such 'collapsed coalesced palaeocaves' may be characterised by reservoirs that are hundreds to thousands of metres across, thousands of metres long, and tens to hundreds of metres thick. Internal spatial complexity is high, resulting from the collapse and coalescing of numerous passages and cave-wall and cave-ceiling strata. These breccias and fractures are commonly major reservoirs in the Ellenburger Group as they have good porosity and permeability that allows the storage or flow of oil (and water). Hydrocarbon production ranges from as shallow as 856 ft (261m) in West Era field in Cooke County, Texas, to as deep as 25,735 ft (7844m) in McComb field in Pecos County, Texas. (Loucks R. , 2003).

If we were able to find potential 'collapsed coalesced palaeocaves' in the deep Waulsortian Limestones onshore Ireland, we could exploit similar highly porous and permeable limestones for deep geothermal energy.

2. STRATEGY

The investigation strategy was to identify from the literature and anecdotal evidence where karst features might occur at depths of more than 800m (a minimum depth for finding warm hydrothermal fluids). The database included data from various public sources

(borehole data, well logs, bedrock geology, aquifer maps etc.), as well as recently acquired seismic data kindly provided by Hannan Metals Limited1 for the purpose of this study.

Good quality hydrocarbon reservoirs are proven in karsts as in the Ellenburger Group, thus, techniques and lessons learned from the oil and gas exploration industry were applied to the data to investigate the potential for geothermal energy as part of this study.

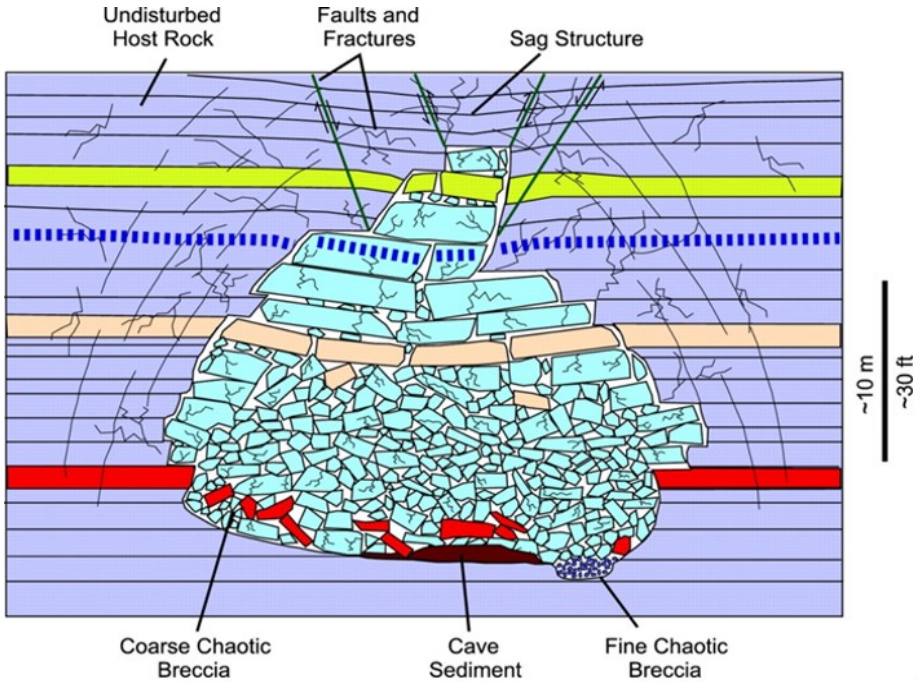

Fig 1. Burial evolution of a palaeocave system (Loucks R. , 1999)

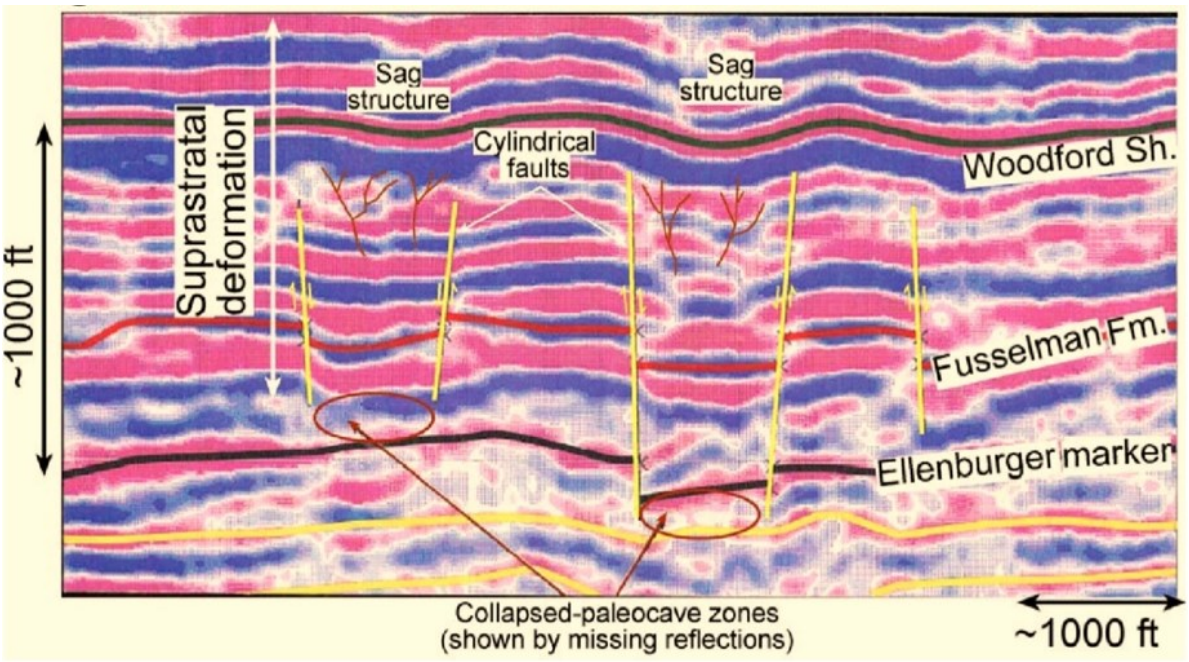

Fig 2. Seismic example over an Ellenburger palaeocave system, West Texas (Loucks R. , 1999)

[1] www.hannanmetals.com

3. FINDINGS

Of the two main Carboniferous basins, in which the Waulsortian mudbank limestone, one of the most extensive limestone formations onshore Ireland, formed viz. Dublin Basin and Shannon Trough, the latter was determined to host the Waulsortian Limestones at potentially greater depths. It was important to prove that the Waulsortian at depth had been karstified (at some time in the past) and that enhanced porosity and permeability due to karstification had been preserved. With the available sources of data, evidence of karstification was gathered as described below:

i. Karst features in outcrop/borehole data
Anecdotal evidence and that from borehole drilling reports and core descriptions clearly record occurrences of cavities and breccias that are related to karstification and possibly collapse.

ii. Uplift and erosion post-dating deposition of Waulsortian
Post depositional uplift of carbonates may cause exposure of surfaces, making karstification more likely. Multiple episodes of uplift are recorded in the literature (Drew & Jones, 2000) and there may have been instances of Waulsortian karstification.

iii. Marine incursions
The action of mixed marine and fresh water on carbonates makes susceptibility to karstification increase. Multiple events of marine incursion are recorded in the literature (Wilson, Permian and Mesozoic, 1981), (Fritz, Wilson, & Yurewicz, 1993).

iv. Faults as conduits of fluid flow
The presence of large faults increases the potential for a formation to be karstified as these faults are likely to be conduits of upward (and downward) fluid flow.

With the evidence observed and data gathered, the project moved into its next phase – *Seismic Analysis*. In the Ellenburger Group, the coalesced collapsed palaeocaves were identified (interpreted) on the seismic data at locations where 'missing reflections' coincided with locations above which supra-stratal deformation (in the form of sag structures, cylindrical faults etc.) was observed (*Fig 2.*). The analysis aimed at identifying similar features in the 2D Seismic dataset provided by Hannan Metals, in the Kilbricken regions of the Shannon Trough, Co Clare.

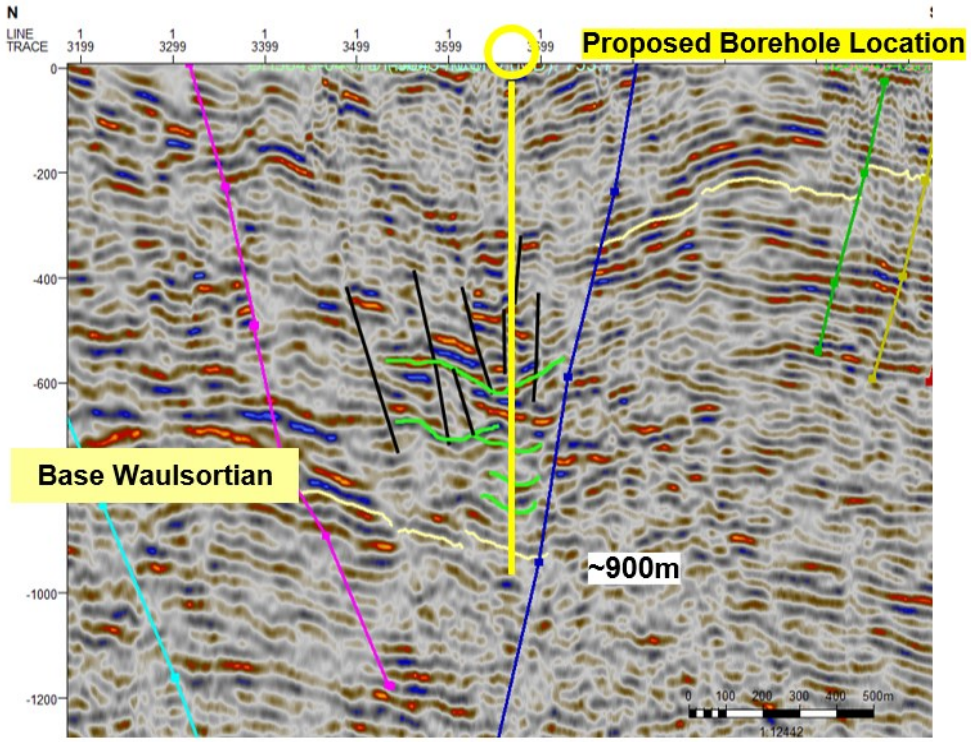

Fig 3. Proposed location for borehole to drill Kilmurry Prospect – Coalesced Collapsed Palaeocave with target at ~900m depth. Comparison with Ellenburger conceptual model. (Data Courtesy of Hannan Metals)

4 DISCUSSION

The base of the Waulsortian was interpreted to be as deep as 900m in one of the 2017 2D lines. With the primary objective in mind, the analysis was focused only on regions where the Base-Waulsortian was deepest. A general deepening of the Waulsortian was observed towards the south, and this is supported by regional geological mapping. One of the major faults in the south (dipping north), in the Kilmurry area, had a displacement of greater than 200m, with the depth of the Base of the Waulsortian on the hanging wall at ~900m. Large faults are known to be conduits for upwards movement of fluids from deeper sources.

Interestingly, sag patterns were observed in the high amplitude reflectors between 400m-700m above the deepest point of the Waulsortian (against the fault). The reflectivity was observed to reduce with depth; however, polygonal faults in the overlying strata appeared to be radiating from a focal point (location).

In addition, a well located 200m away, projected on the seismic line, that appeared to intersect many of these sag features, was recorded to have several zones of breccia and cavities at depth. The deepest cavity recorded was 0.35m at 710m depth.

We interpret this to be the location of a 'Coalesced Collapsed Palaeocave' at the base of the Waulsortian, caused by a collapse of overlying strata into the cave hollow, thus forming sag features and polygonal faults.

5. CONCLUSION

As a result of this preliminary research project, several conclusions can be made.

- The anecdotal evidence of cavities, brecciated zones, missed sections at depth from mineral exploration drilling in Ireland is confirmed from borehole records.
- Review of Palaeozoic geology in Europe (N. Belgium) and the US (W. Texas) confirms the existence of porous and permeable carbonate reservoirs preserved at depth associated with karstification.
- New seismic data acquired from mineral exploration onshore Ireland displays features indicative of coalesced collapsed palaeocave systems at depth as observed in the Ellenburger Group, W. Texas.

An opportunity exists to collaborate with the mineral exploration sector to drill a deep exploratory research borehole to test the 'coalesced collapsed palaeocave' exploration model.

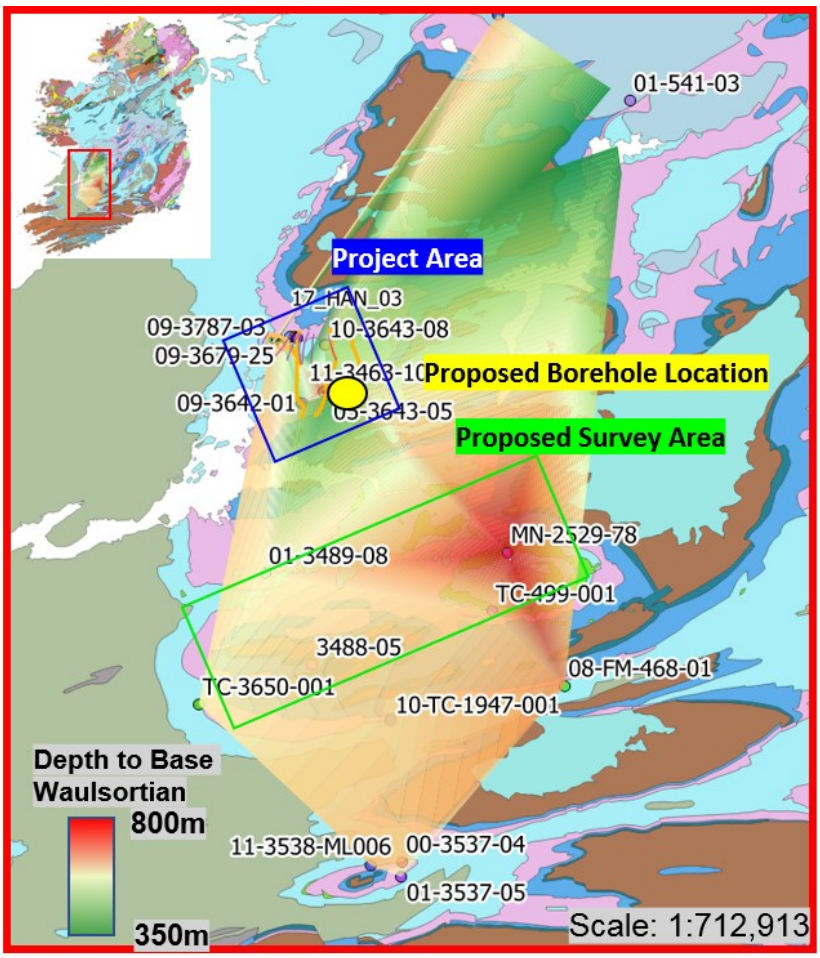

Fig 4. Depth to Base Waulsortian as described in released deep boreholes

6. RECOMMENDATIONS

I. Drill the proposed "Kilmurry Prospect" to verify seismic interpretation of karst indicators, intersecting a collapsed paleocave at ~900m depth with a potential for temperatures of up to 30°C.
II. Acquire Petrophysical logs while drilling to better characterise the stratigraphy and create a more constrained model for identifying karst indicators on seismic.
III. Acquire seismic data, (preferably 3D Seismic) further south where the Waulsortian is predicted to be deeper (*Fig 4*.).

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