The use of Virtual Outcrop Models, digital geology and legacy data to reappraise Devonian basin evolution in NE Scotland and Shetland: Analogues for the offshore Clair Basin and Clair Oil Field, West of Shetland.

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Extended Abstract:

Introduction

The Clair Field, west of Shetland, represents the largest hydrocarbon resource in the UKCS. It comprises fractured Devonian-Carboniferous sandstones, overlying a fault bounded ridge of Precambrian metamorphic basement. The onshore, broadly extensional Orcadian Basin, has long been used as an analogue for the Clair Field, but it is possible that it formed in a rather different tectonic setting, as it lies in a separate basin to the west with some significant differences.

Some of the known complexity in sub-surface structures and basement-cover relationships may suggest that strike-slip tectonics played a role in the evolution of the Clair Basin during the Devonian-Carboniferous period. The role of strike-slip tectonics has been linked to the development of the Devonian basins of Norway (Seranne & Seguret 1987; Osmundsen & Andersen 2001; Séguret et al. 1989; Fossen 2010; Fossen et al. 2017), with similar structures having also been recognised in Shetland (Seranne 1992). Thus, our aim is to try to better understand how strike-slip tectonics may have influenced the development of the Devonian basins of Northeast Scotland and Shetland.

The Digital Geological Age

The extraction of 3D geological information from virtual outcrop models created using drone-based photogrammetry allows for the collection of fully geospatially referenced and valuable geological data, quickly and with relative ease, from areas previously inaccessible, overlooked and considered to be ‘missing’ or ‘lost’ (See Fig.1). Outcrops can then be re-visited at any time, on ‘virtual’ fieldtrips, allowing for improved geological, spatial understanding and further geological analysis, producing data and knowledge which can be now be more easily shared and viewed in 3D.

New digital geological methodologies are not a replacement for traditional fieldwork, but should be seen as the ‘norm’ and used to supplement and complement traditional fieldwork, desk-based studies and geological data analyses. The integration of these techniques with the results of re-interpretation and re-examination of large quantities of onshore and offshore legacy data generated by industry and academia represents a more cost-effective and time efficient approach. Vast quantities of data can now be collated, interrogated and analysed in new ways, deriving new value, and highlighting trends and features hidden away within solitary datasets and in archives.

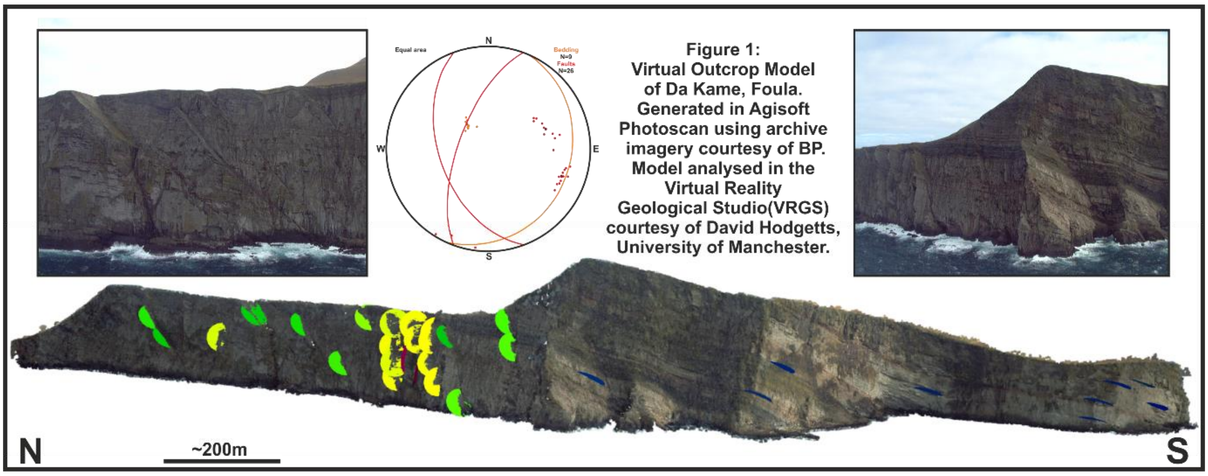

Figure 1: Virtual Outcrop Model of Da Kame, Foula. Generated in Agisoft Photoscan using archive imagery courtesy of BP. Model analysed in the Virtual Reality Geological Studio(VRGS) courtesy of David Hodgetts, University of Manchester.

<u>Reappraisal of Devonian Basin Development</u>

We illustrate this using a reappraisal of the stratigraphy, structure and tectonic evolution of onshore analogues for the Devonian-Carboniferous Clair Basin that includes detailed analysis of basement/cover contacts, and the structural architecture of the overlying Devonian sequences. This is achieved through the integration of multiscale, topographic, photogrammetric, bathymetric, geological and geophysical data. Both legacy and new, onshore and offshore data has been collated and is used in conjunction with fieldwork, structural analysis, heavy mineral provenance analysis, detrital zircon geochronology and the production of Virtual Outcrop Models (VOMs).

Our new synthesis extends from Shetland, Orkney and Caithness, and consistently reveals evidence for synchronous Devonian-age growth faulting and growth folding in all areas. These observations are consistent with models of constrictional extension during regional sinistral transtension along the Walls Boundary and Great Glen Fault Zones. The presence of folds that formed during early basin development, synchronous with basin filling and not due to later reactivation, is important for the assessment of petroleum systems. This is primarily due to the formation of potential hydrocarbon trapping geometries created during basin formation in proximity to potential Devonian lacustrine source rocks, which in the Orcadian basin were mature during the Carboniferous (Astin 1985; Astin 1990; Hillier & Marshall 1992; Marshall et al. 1985). Importantly, this is before basin inversion and exhumation in the Permo-Carboniferous, to which many of these folds have traditionally been attributed. Furthermore, these structures may be present for later reactivation and/or act as traps for hydrocarbon accumulations in other petroleum systems.

Analysis of offshore data from Caithness/Orkney has also provided new insights into some of the large scale structures present within the Orcadian Basin, which are poorly exposed onshore. Large scale folds and significant numbers of faults and fracture zones can be observed at the sub-seismic scale, and allow the linking of what is seen at outcrop in coastal section, to what is imaged in subcrop the subsurface (Figure 2).

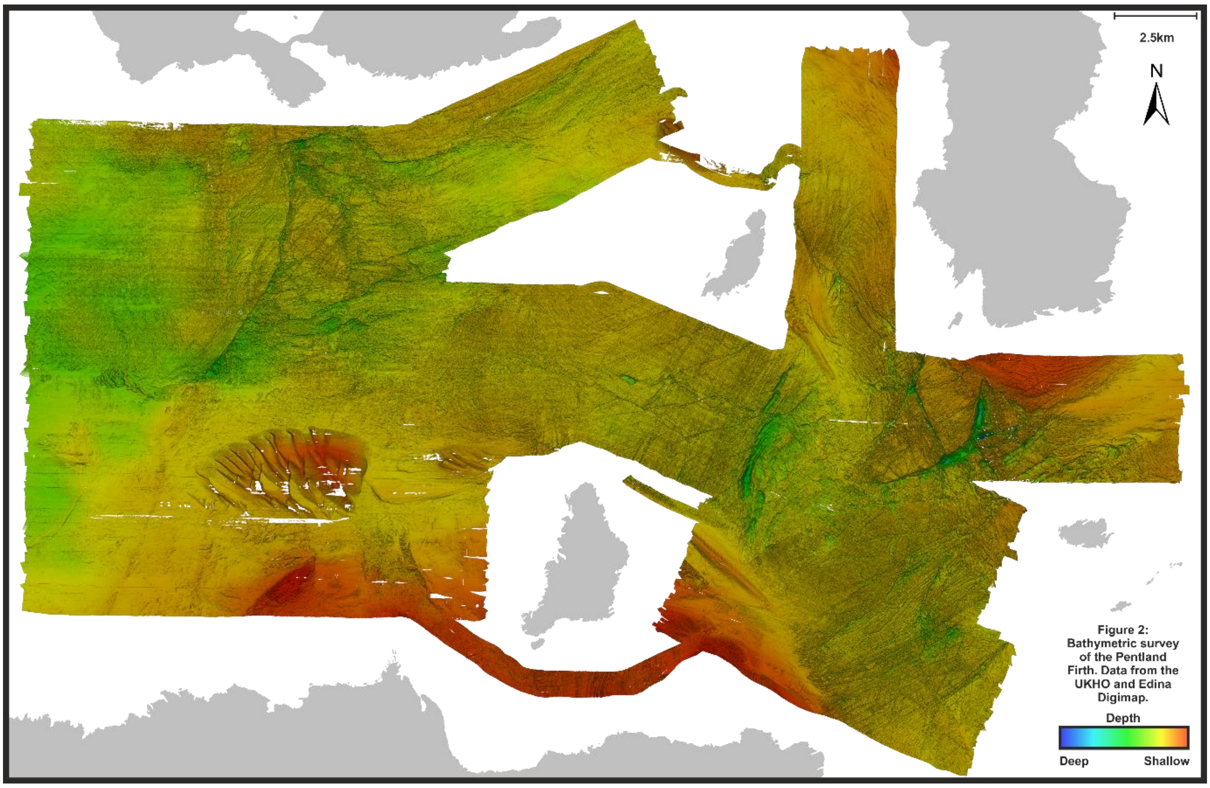

Figure 2: Bathymetric survey of the Pentland Firth. Data from the UKHO and Edina Digimap.

New heavy mineral analysis has revealed subtle differences in sediment provenance between the Devonian Basins of Shetland and Foula, an island 25km to the Southwest. The similarity in provenance signature of Foula, to the Devonian sediments of the Clair Basin and Orkney, suggest similarities in source region, and a large-scale, linked depositional system. This hypothesis is supported by detrital zircon geochronology which has identified the East Greenland continental margin, as the source of sediment into the Clair Basin. More mixed provenance signatures in Caithness/Moray Firth and Shetland reflect both distal, and local sources in Northern Scotland and Shetland respectively. (Schmidt et al. 2012; Sasnowski 2015). The contrasting provenance signatures reflect the complex interplay of climate and tectonics controlling the source of sediment into the Orcadian and Clair Basins.

Conclusions

The unusual basin architecture, diversity of basement/cover relationships, together with the distribution, type, and size of structures apparent in the Orcadian Basin could lead to difficulties in exploration and appraisal of resources offshore. This knowledge can be taken further for exploration in offshore settings such as the developing fractured basement play, West of Shetland (Belaidi et al. 2016; Trice 2014) where an improved knowledge of the nature of the unconformity and fracture systems in the basement and cover sequences could improve seismic imaging and direct drilling campaigns, saving costs, minimising downtime and improving safety.

We propose that the established models for Devonian basin development used offshore may require further revision and that some analogues in Shetland, such as the island of Foula, may represent the missing link between the Clair Basin and the larger Orcadian Basin, preserving a snapshot in the structural and stratigraphic evolution of the Devonian basins of Northeast Scotland.

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Presenter Biography:

Tom is a graduate of Keele University, where he obtained a Master of Geoscience Degree in 2013 with a final year thesis titled: '3D architecture of vein and flat type mineralisation in the North Pennine Orefield'. He gained industry experience working as geophysicist and surveyor before starting an industry funded research position at the University of Liverpool in 2014, looking at diagenesis and reservoir quality in the Brent Group of the Northern North Sea. At present he is working towards a PhD at Durham University titled: 'A reservoir scale structural reappraisal of onshore Devonian analogues of the Clair Group in the Fair Isle-Shetland region' which is funded by the NERC CDT in Oil & Gas and supported by the Clair JVG. His project reappraises the stratigraphy, structure and tectonic evolution of alternative onshore analogues for the Clair Field through the detailed study of basement/cover contacts, and the structure of the overlying Devonian sequences.