



## Research paper

## Carboniferous petroleum systems around the Mid North Sea High, UK



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## ABSTRACT

The existence of an extensive, prospective Visean–Namurian Carboniferous petroleum system in and around the hitherto under-explored Mid North Sea High is documented. Evidence is drawn from integrated analysis of over 50,000 line kilometres of seismic data and well data, together with regional source rock screening, reservoir analysis and basin modelling.

Visean–Namurian marine and non-marine mudstones and coal source rocks are interbedded within fluvial and marine reservoir sandstones within a stacked succession up to 5 km thick. Source rocks are dominantly gas-prone with oil-prone intervals, and have reached oil to gas maturity levels dependent on location. Burial/thermal history modelling indicates a kitchen area on the southern margin of the Mid North Sea High with northwest and northeastwards migration of gas and oil during Mesozoic and Cenozoic times. A variety of structural and stratigraphic traps are possible, including intraformational Carboniferous traps, with a regional seal at Permian (Zechstein) level. Synthesis of many previously unpublished datasets demonstrates the Visean–Namurian play south of the Mid North Sea High as part of an extensive petroleum system from the East Irish Sea, across onshore to offshore UK and into The Netherlands sector of the North Sea. The purpose of this synthesis is to highlight future exploration opportunities beneath and northwards of the productive Westphalian Southern North Sea gas basin, and to begin to de-risk the petroleum systems that are exemplified by the lower Carboniferous Breagh Field in a frontier area of the mature North Sea province.

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## 1. Introduction

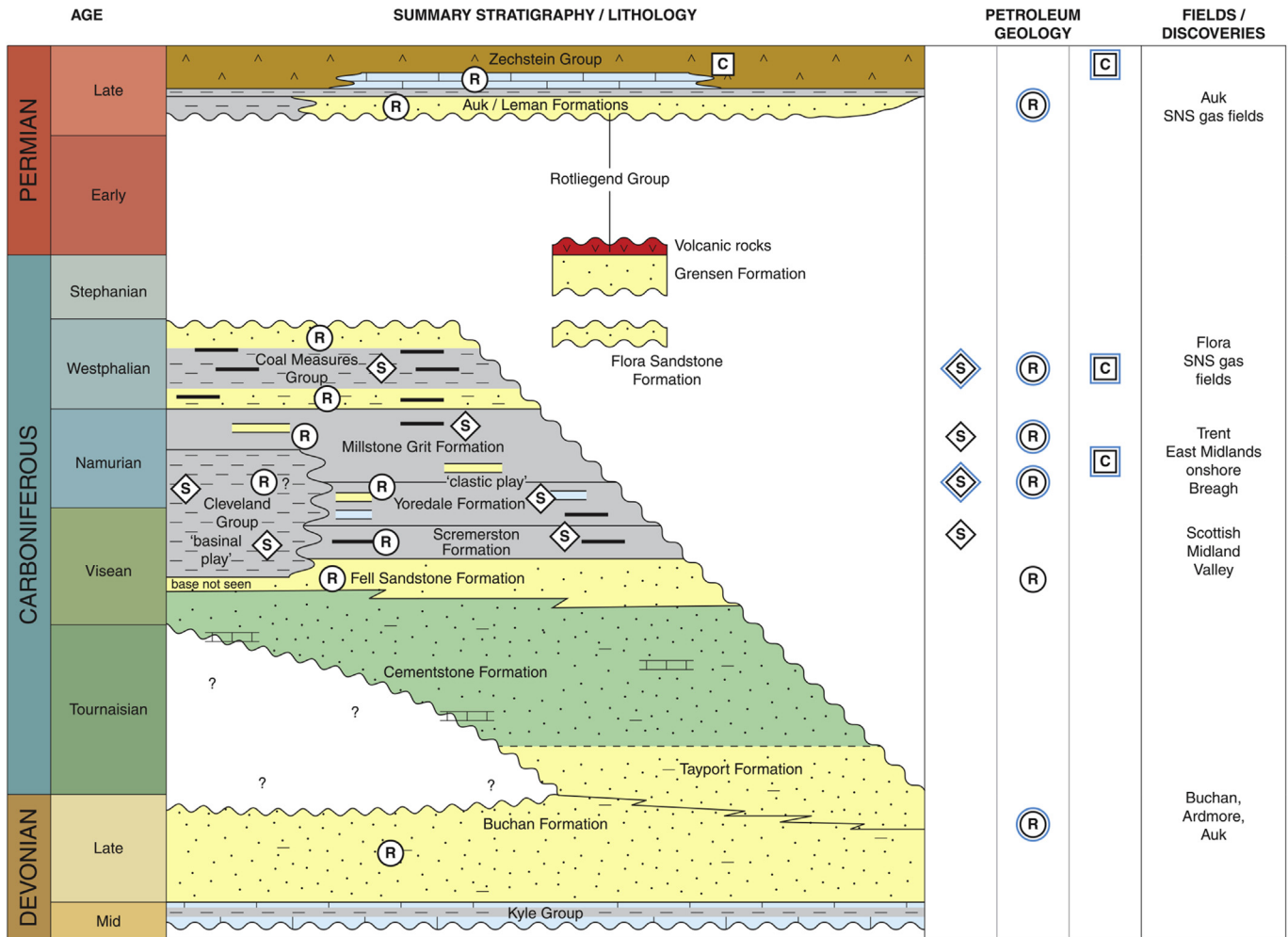
For both maximum economic recovery and security of energy supply, the UK Government and Oil and Gas Authority advocate extending the life of the mature North Sea province. This paper synthesizes regional datasets in a previously under-explored area to highlight a petroleum system beneath and northwards of the existing, world-class Southern North Sea gas province, potentially extending the life of the mature UK North Sea province into a frontier area.

The Breagh Field (blocks 42/12a, 42/13a; Figs. 1 and 2), with total recoverable reserves estimated at 19.8 billion cubic metres (699 billion cubic feet) gas (DEA Group, 2015), proves a working

petroleum system in older Visean–Namurian age strata than in the highly productive Westphalian strata predominant in the Southern North Sea gas province (Figs. 1 and 2; Cameron et al., 2005; Kombrink et al., 2010; Symonds, 2015; Symonds et al., 2015; Underhill, 2003). The spatially extensive Visean–Namurian succession subcrops at the base Permian unconformity on the southern margin of the ‘Mid North Sea High’ (Collinson, 2005) and has been seismically interpreted in Quadrants 29, 37, 38 and 39 of the UK Continental Shelf (UKCS) (Hay et al., 2005; Milton-Worsell et al., 2010), leading to suggestions of a potentially prospective petroleum system in these lower–middle parts of the Carboniferous succession (e.g. Milton-Worsell et al., 2010). Lessons learned from exploration and production within the Southern North Sea Westphalian–Permian play, such as the challenges of seismic interpretation beneath Zechstein evaporites, complex structure and correlation of sandstones lacking biostratigraphic control (Besly, 2005; Cameron et al., 2005), combined with sparse datasets

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- (S) Source rock inferred, double edged where proved in fields  
 (R) Reservoir rock interval, double edged where proved in fields  
 (C) Cap (or seal) rock interval, double edged where proved in fields

**Fig. 1.** Summary of upper Devonian, Carboniferous and Permian stratigraphy with potential source, reservoir and seal rocks indicated along with existing hydrocarbon fields. Note that the Cleveland Group includes the Upper Bowland Shale. The stratigraphy found in the north and east of the study area is broadly on the right hand side, the stratigraphy in the south and west of the study area is broadly on the left hand side.

and lack of regional geological knowledge, had led to Visean–Namurian Carboniferous petroleum systems being viewed as frontier and risky (e.g. Besly, in press).

Consultation following a major review of the UK oil and gas industry by Wood (2014) identified certain Devonian and Carboniferous potential plays of the UKCS as of top significance for building regional digital datasets and stimulating exploration, to maximise economic recovery. Together with the UK Government-funded seismic survey of the Mid North Sea High (MNSH) released in 2016 and the UK Government 29th Offshore Licensing Round, the 21st Century Exploration Roadmap (21CXRM) Palaeozoic Project (2014–2016) contributed to increased exploration activity of the 'frontier' MNSH region. This paper is a regional scale synthesis of the prospective Visean–Namurian petroleum systems evidenced in detail in the 21CXRM Palaeozoic project datasets and

explanatory reports released in 2017.<sup>1</sup> This work incorporates released and unreleased data, including thousands of previously unpublished biostratigraphic, geochemical and core sample analyses, to begin to challenge some of the 'founding myths' (Besly, in press) of Carboniferous prospectivity.

The study area covers Quadrants 25–44 of the UKCS (Figs. 2 and 3), encompassing the geographical area termed the 'Mid North Sea High' that separates the Southern and Northern Permian basins. The 'MNSH' is loosely defined and of varying extent within published maps and literature. The term is best applied at Permian level as the area includes a number of underlying Devonian–Carboniferous basins. A Carboniferous relative high is present under the southern part of Quadrant 26, Quadrants 27, 28 and northern parts of Quadrants 34, 35, 36 (e.g. Arsenikos et al., 2015, in press, Figs. 2 and 4), though the paucity and quality of data makes definition of its full extent difficult. Within this paper the term 'Mid North Sea High' is used in its loose geographical sense, with study sub-areas referred to as shown on Fig. 3. Western European stage and substage timescale names are used, with early/lower and late/

<sup>1</sup> BGS reports and 21CXRM Palaeozoic datasets can be downloaded from <http://www.bgs.ac.uk/research/energy/petroleumGeoscience/explorationRoadmap.html> or from <http://nora.nerc.ac.uk/>.

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