Decoding the evolution of the Carboniferous fluvial system using onshore-offshore correlation

Tim Kearsey, David Millward, Rachael Ellen, Katie Whitbread, Alison Monahan

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Oil & Gas Authority

OIL&GAS UK

1. Introduction

Understanding the evolution of the Carboniferous fluvial system in the UK offshore sector has historically been hampered by differences in stratigraphic nomenclature in the areas surrounding the Mid North Sea High and onshore. This has hindered the systematic regional understanding of the timing and controls on stacked source and reservoir rock intervals.

The joint industry-government 21st Century Exploration Roadmap Project, aimed at rejuvenating the exploration from the Central North Sea/Mid North Sea High to the East Orkney Basin, has provided the opportunity for a comprehensive re-evaluation of Carboniferous onshore-offshore UK stratigraphy. Over 130 well reinterpretations, tied to seismic interpretations, provide evidence of the inception and extent of the delta system.

2. Data and methods

This study had access to all wells, including company biostratigraphic reports, stored on the UK Oil and Gas Data (CDA) portal (www.ukoilandgasdata.com), previously unreleased British Geological Survey palynological reports and data donated by sponsors of the 21CXRM Palaeozoic Project.

550 wells that have penetrated Devonian or Carboniferous rocks in Quadrants 14–44 contain only a short succession of these strata and their distribution is uneven. Of these wells, 125 had sections of Carboniferous strata >100 m or were long enough to identify stratigraphic units. Of those, 69 had biostratigraphic control, predominately in the form of unpublished palynology reports.

This subset of 125 wells formed the basis for the reinterpretation of the sedimentary facies and stratigraphy in this study. A set of key onshore wells provided a link with the offshore stratigraphy. Three onshore wells in northern England were included: Seal Sands 1 (Johnson et al. 2011), Harton 1 (Ridd et al. 1970) and Kirby Misperton 1 (Andrews 2013). In Scotland, the Firth of Forth 1 and Milton of Balgonie 1 wells were considered (see Monaghan 2014). Seismic interpretations (Arsenikos et al. 2016) were also used to aid well interpretation.

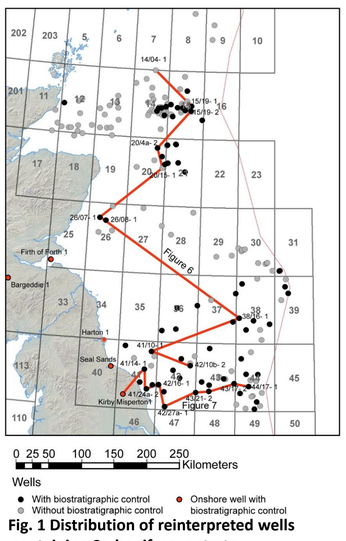


Fig. 1 Distribution of reinterpreted wells containing Carboniferous strata.

3. Stratigraphic framework

Eight lithostratigraphic units from the Tournaisian (lowest Carboniferous) to Kinderscoutian (middle Namurian) were identified in wells in the study area (Fig.2). In chronological order (from oldest to youngest), the Tayport, Fell Sandstone, Scremerston and Millstone Grit formations occur to the north and south of the Mid North Sea High, whereas the Cementstone, Firth Coal and Yoredale formations and the Cleveland Group are more locally restricted). Many of these units consist of different facies but are time-equivalent).

Previously, the Mid North Sea High has been used to separate Carboniferous stratigraphic nomenclature to the north and south of it. It is evident from wells in this study that the Tayport, Cementstone, Fell Sandstone, Scremerston and Millstone Grit formations are present to the north, south and over large areas of the eastern side of the Mid North Sea High (Fig. 3, 4). Although these units thin across this area (Arsenikos et al. 2018), it is clear that the Mid North Sea High did not form a barrier to sedimentary systems during the Carboniferous

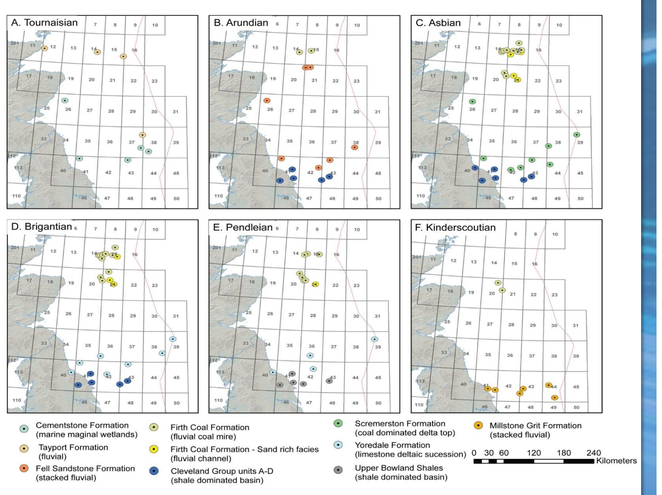


Fig. 2 Maps showing age equivalent stratigraphic units proved in wells with biostratigraphic control

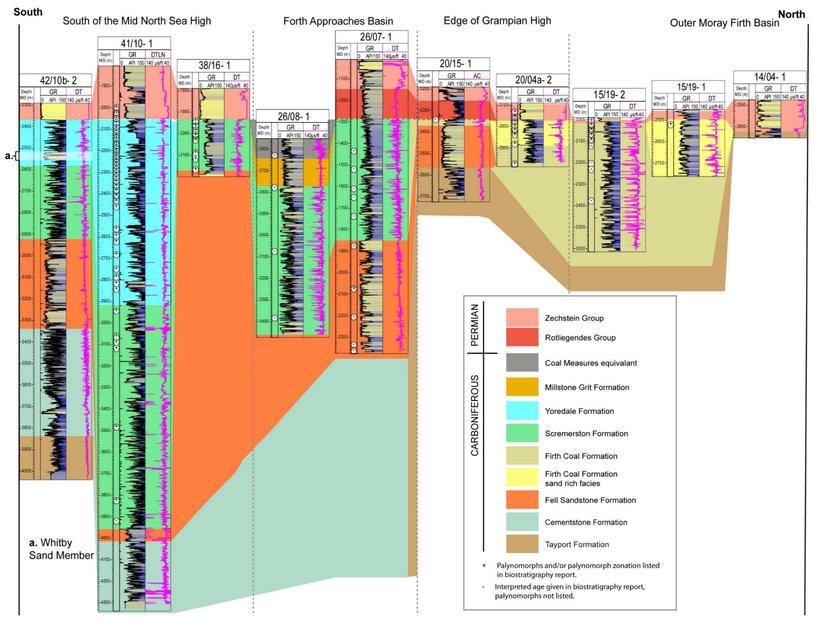


Fig. 3 Correlation panel of Carboniferous strata from south of the Mid North Sea High through the Outer Moray Firth Basins. The position of the Whitby Sandstone Member is marked by the letter 'a'.

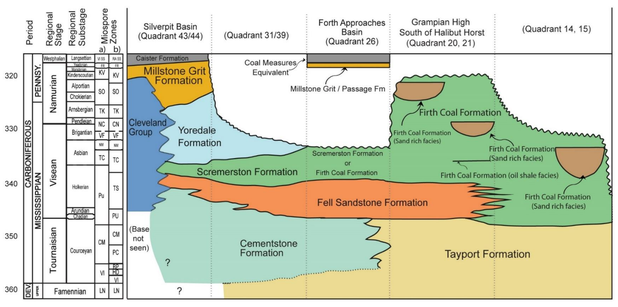


Fig. 4. Stratigraphic relationships of Upper Devonian to Carboniferous strata between the Outer Moray Firth Basin and the Silverpit Basin. Miospore

Our understanding of the stratigraphic position and regional extent of potential reservoir intervals, in both stacked fluvial (Fell Sandstone and Millstone Grit formations) and channel (Yoredale, Scremerston and Firth Coal formations) systems, has been improved.

The extent and inception of a long-lived Carboniferous fluvio-deltaic system and laterally equivalent basinal, mud-rich successions have been documented using a regional well dataset interpreted in a series of time slice

4. Evolution of the Carboniferous

A ***Tournaisian.*** In the Tournaisian, the North Sea was dominated by marginal marine Cementstone Formation. This was a large area marshes, lakes, sabkhas and abundant palaeosols, and was subjected to short episodes of marine flooding. Although there are small fluvial channels present there is no evidence of a large deltaic system.

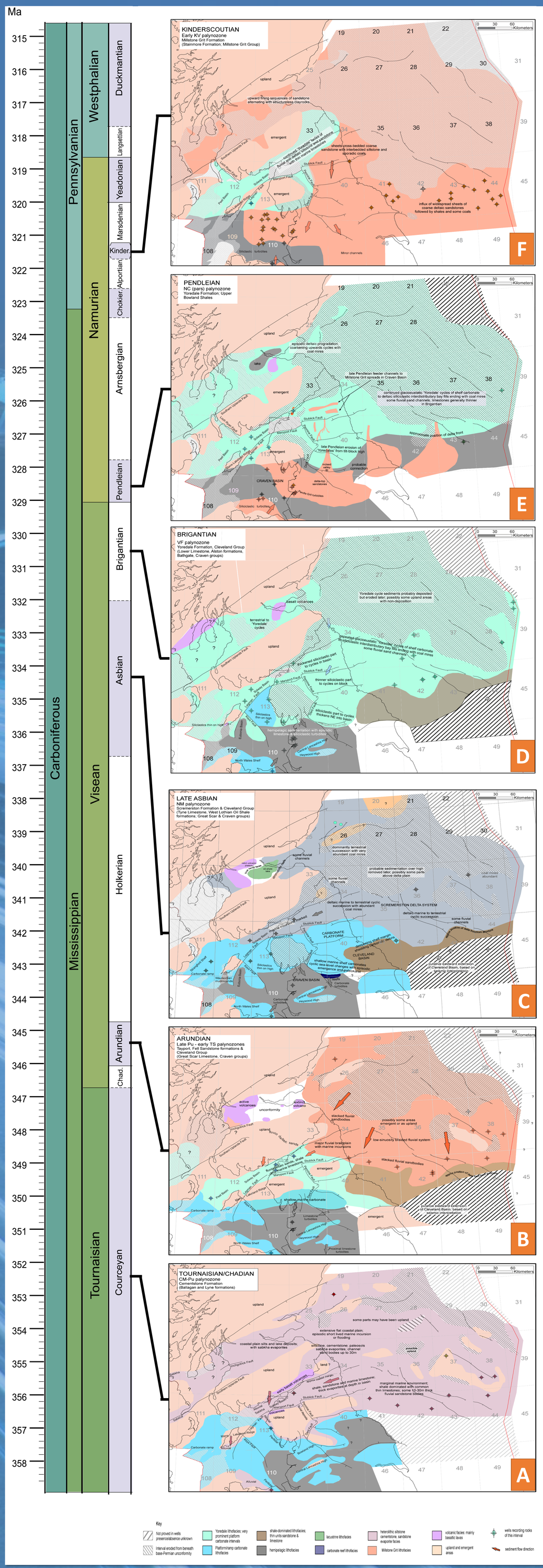
B ***Chadian Holkerian*.** A major clastic system was established across the region by Arundian times. A braided fluvial system, probably originating in the Caledonide Mountains or farther to the north, spread coarse-grained sand in stacked multi-storey sheets southwards. To the south, in the Cleveland Basin, the time equivalent rocks are the interbedded sandstones and mudstones of the oldest known part of the Cleveland Group, dominated by pro-delta and basal successions.

C ***Asbian.*** By the late Asbian, coal mires and fluvial facies had developed within the Carboniferous basins from the Outer Moray Firth Basin to the southern edge of the Mid North Sea Hig Asbian. The limestone part of the cycle is generally short-lived in the Scremerston Formation and the limestones may be very thin or absent from some cycles in north Northumberland and the Forth Approaches Basin. The Firth Coal Formation continued to be deposited to the north of the Forth Approaches Basin. Asbian strata record the first dated occurrence of the Firth Coal Formation sand-rich facies which was deposited by large-scale channel systems running north to south feeding the delta to the south.

D **Brigantian**. At the onset of Brigantian times, Yoredale-type fluvio-deltaic clastic sediments and shallow carbonate seas overstepped the Asbian carbonate platforms of the Alston and Askrigg blocks. The position of the transition to the mudstone dominated pro-delta and basinal succession of the Cleveland Group had not grossly changed since the Arundian. However, by Brigantian times, units of sandstone with subordinate interbedded mudstone, siltstone and some limestone were deposited suggesting that the delta had prograded into the Cleveland Basin.

E **Pendleian.** The Yoredale fluvio-deltaic clastic sediments and shallow carbonate seas continued to be deposited through the Pendleian. In the Cleveland Basin, a package of mudstones and silty mudstones with high gamma values (correlated to the Upper Bowland Shales) has a late Brigantian to Pendleian age. This suggests that a link between the Cleveland and Craven basins was established for the first time in the Pendleian.

F **Arnsbergian – Kinderscoutian**. The Arnsbergian sees the first occurrence of the Millstone Grit Formation in the North Sea. It spread across much of the North Sea through the Arnsbergian to the Alportian, filling the Cleveland Basin in the study area by the Kinderscoutian.



Further reading:

Kearsey, T.I.; Millward, D.; Ellen, R.; Whitbread, K.; Monaghan, A.A.. 2018. Revised stratigraphic framework of pre-Westphalian Carboniferous petroleum system elements from the Outer Moray Firth to the Silverpit Basin, North Sea, UK. In: *Geological Society Special Publication 471.* Geological Society, London.

Palaeography maps are available from : http://mapapps2.bgs.ac.uk/geoindex_offshore/home.html