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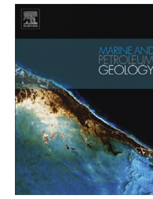

Research paper

Organic geochemistry of Mississippian shales (Bowland Shale Formation) in central Britain: Implications for depositional environment, source rock and gas shale potential

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ABSTRACT

Marine Carboniferous shales are proven hydrocarbon source rocks in central Britain. In this contribution the depositional environment and shale gas/liquid potential of the lower Namurian part of the Bowland Shale Formation is studied using 77 thermally immature samples from the Duffield borehole.

The Bowland Shale Formation comprises mudstone and turibidite lithofacies reflecting a pronounced sea level controlled cyclicity. The total organic carbon (TOC) content of the mudstones lithofacies (including marine bands) and of fine-grained rocks within the turibidite lithofacies varies between 1.3 and 9.1%. Hydrogen index (HI) values imply the presence of kerogen type III-II.

According to biomarker ratios and bulk geochemical parameters, marine bands (maximum flooding surfaces, mfs) were deposited in deep water with slightly enhanced, normal, or slightly reduced salinity. Mudstones of the highstand systems tract (HST) were deposited in environments with normal to reduced salinity, whereas photic zone anoxia favoured the preservation of marine organic matter during deposition of the mfs and the HST. The supply of landplant debris increased during the HST. Turbidites and their non-calcareous mudstone equivalents represent lowstand systems tracts deposited in low salinity environments. Terrestrial organic matter dominates in turbiditic sediments, marine organisms prevail in time-equivalent mudstones. Mudstone beneath marine bands represents transgressive systems tracts when normal marine conditions and photic zone anoxia were re-established.

The mudstone lithofacies exhibits a very good to excellent potential to generate conventional mixed oil and gas. TOC content of fine-grained rocks in the turbidite lithofacies depends on the amount of detrital minerals supplied from the south. Moreover, their organic matter is gas-prone. High TOC contents and large thicknesses of the mudstone lithofacies show that the Bowland Shale Formation holds a significant shale gas/liquid potential in areas with appropriate maturity. A relatively low average HI and high clay contents may have negative effects on the shale gas potential.

1. Introduction

Carboniferous organic-rich basinal marine shales are considered source rocks for conventional hydrocarbon fields onshore central Britain (DECC, 2010). In addition, Carboniferous shales may hold a significant shale gas/shale liquid potential (Selley, 2012, 2005; Andrews, 2013). Apart from their economic significance, the cyclic pattern of Carboniferous rocks controlled by glacio-eustatic sea level fluctuations has attracted considerable attention (e.g. Ramsbottom, 1977, 1973; Holdsworth and Collinson, 1988; Martinsen et al., 1995; Waters and Condon, 2012). Both a short-term (cyclothems or minor cycles) and a long-term cyclicity (mesothems or major cycles) have been recorded. In sequence-stratigraphic terminology (Posamentier et al., 1988) minor cycles equate to parasequences, whereas major cycles would be considered equivalent to sequences (Waters and Condon, 2012). Typically, minor cycles consist of geographically widespread marine shales with acme ammonoid faunas ('marine bands') at the base of marine to non-marine upward-coarsening cycles (e.g. Holdsworth and Collinson, 1988).

In the present contribution we study the depositional environment and the source potential of the Namurian (Pendleian and

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Arnsbergian) part of the Bowland Shale Formation based on bulk geochemical parameters, biomarker data and mineral assemblages. The study results will be discussed in relation to different lithofacies (marine bands, mudstone lithofacies fine-grained rocks in the turbidite lithofacies), minor and major cyclicity.

The Duffield borehole (Aitkenhead, 1977), located in the Widmerpool Trough north of the Wales–Brabant High (Fig. 1b), has been selected for the investigations, because it is one of the reference sections for the Bowland Shale Formation (Waters et al., 2009) and because it penetrated thermally immature Bowland Shale. The lithological log of the Namurian section of the Duffield borehole based on Aitkenhead (1977) is presented in Figure 1d.

2. Geological setting

Deposition of Carboniferous basinal shales in central England occurred during the syn- and post-rift stages of a Lower Carboniferous back-arc basin. Tournaisian and Visean shales, deposited during the syn-rift stage, are restricted to graben and half-grabens, separated by platforms and tilt-block highs (Warr, 2000). The WNW-ESE trending Widmerpool Gulf is one of these half-grabens (Fig. 1b, c). Namurian shales have been deposited in a much broader region between the Southern Uplands and Wales–Brabant High (Pennine Basin), controlled by thermal subsidence (Leeder, 1988; Waters and Davies, 2006).

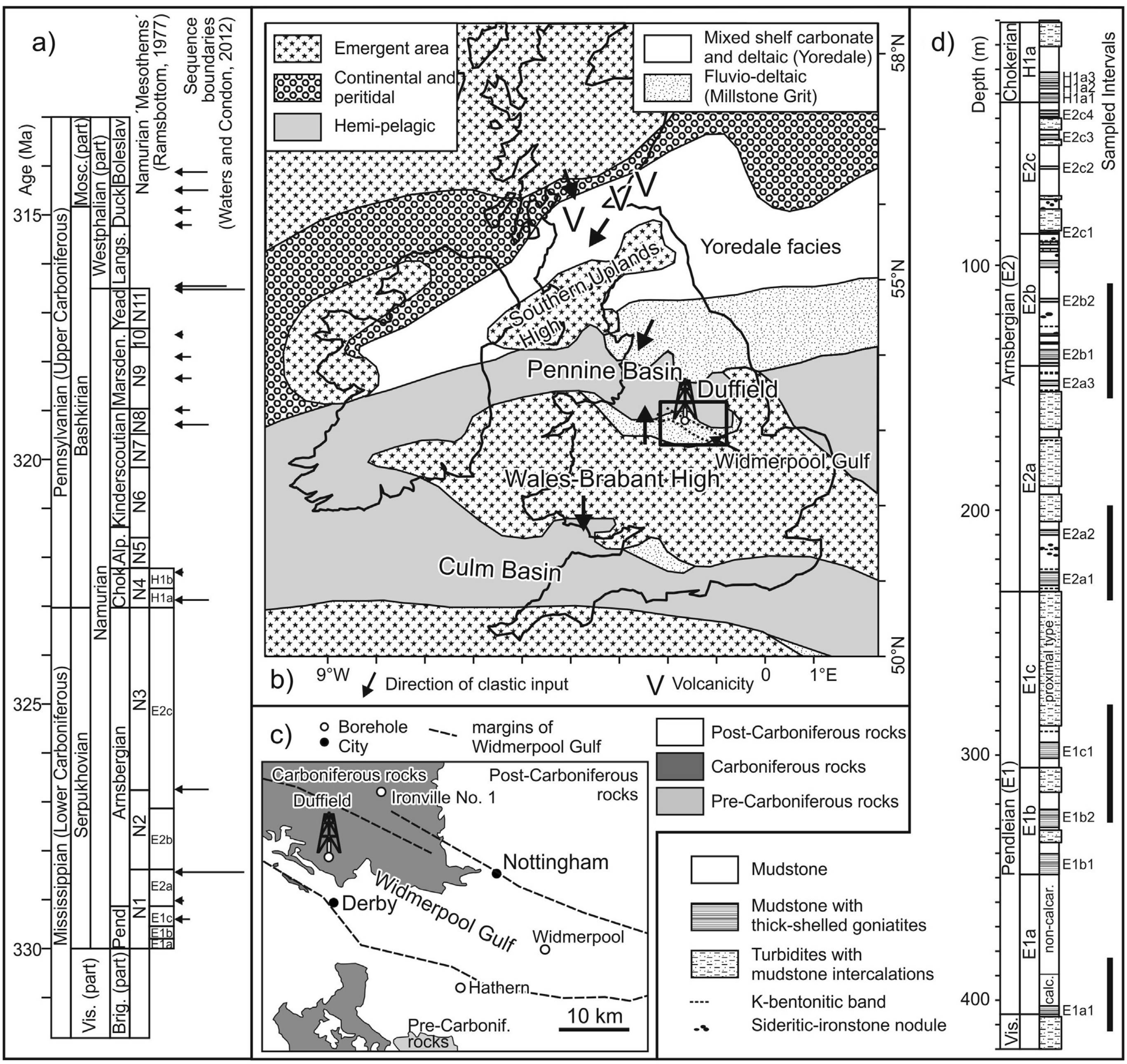

Figure 1. a) Mid-Carboniferous timescale showing global and European subdivisions, Namurian "Mesothems" (Ramsbottom, 1977), and the timing and extent (represented by arrow lengths) of sea level lowstands (Waters and Condon, 2012). b) Paleogeographic reconstruction showing deposition of main lithofacies during Arnsbergian time (after Waters and Davies, 2006). The location of the Duffield borehole and the (Visean) Widmerpool Gulf are also shown (modified after Kombrink et al., 2010; Aitkenhead, 1977; Waters and Davies, 2006). The black rectangle marks the area of Fig. 1c c) Position of the Duffield borehole in the Widmerpool Gulf (modified after Aitkenhead, 1977) d) Gamma-Ray log and lithological section of the Namurian part of the Duffield borehole (Aitkenhead, 1977).