EXCURSION

Oilfields of the East Midlands

Leaders: Paul Guion; Paul Hargreaves (Star Energy), and Kevin Topham (Duke's Wood Oil Museum)

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The objective of the field excursion was to examine an outcrop of the Crawshaw Sandstone, the principal hydrocarbon reservoir of the East Midlands oilfields. This was followed by a tour of the surface facilities at the Welton oilfield, near Lincoln, operated by Star Energy, and a visit to the Duke's Wood Oil Museum, on the site of the former Eakring - Duke's Wood oilfield.

Hydrocarbon exploration in the East Midlands was initiated during the First World War as a consequence of government concern about security of supplies, and small quantities of oil were found within early Carboniferous rocks at Hardstoft, Derbyshire, in 1919. However, production was only a few barrels per day, and ceased in 1927. Some exploration took place between the wars, but nothing of major significance was found; however, oil seepages in collieries suggested that oil exploration in the East Midlands may be fruitful. A major exploration effort took place just before and during the Second World War, aided by experts from the USA, resulting in the discovery of the Eakring - Duke's Wood, Caunton and Kelham Hills Oilfields from 1939-43, with the oil being produced mainly from late Carboniferous sandstones. After the war, BP discovered numerous small oilfields in the 1950s and 1960s, benefiting from the wealth of NCB coal exploration data.

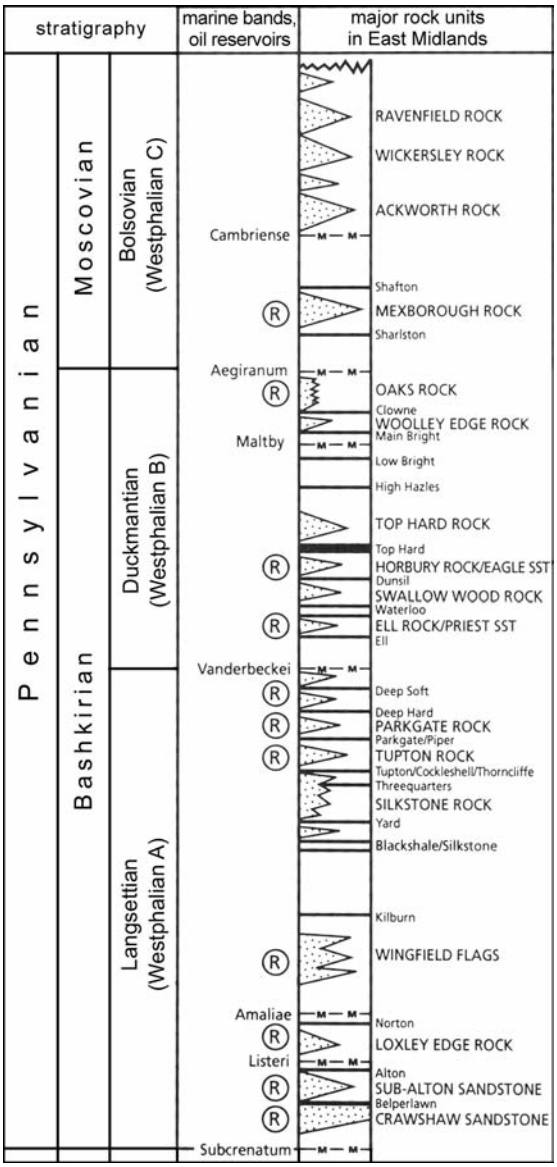
Exploration virtually ceased in the late 1960s, but oil price rises resulting from the 1973 Middle East War prompted a new phase of exploration, leading to the discovery of the Welton Oilfield, Britain's second largest field, several smaller fields, and a significant gas field on the Lincolnshire coast. BP pulled out of the area in the 1980s, and several smaller companies took over BP's interests, continuing to discover and develop new fields. A new round of exploration is now taking place, and further discoveries are anticipated.

Westphalian geology

Although there are minor occurrences in Lower Carboniferous (Visean and Tournaisian) rocks and some production from the Namurian, the majority of hydrocarbon reservoirs are of Westphalian age. These rocks consist of sandstones and mudstones with interbedded coals, which are considered to have been deposited in delta plain environments.

Marine fossils are lacking throughout much of the sequence, but a number of thin, laterally-extensive marine bands, with distinctive goniatite faunas, are present, which have been extensively used to provide a refined biostratigraphical framework, and generally have a good gamma ray response on geophysical logs, enabling correlation between oil wells. Former extensive NCB exploration and production yielded a wealth of data, with coal seams being chemically 'fingerprinted' enabling precise correlation, but further to the east, away from former mining areas, correlation is less certain. Between the marine bands, there is much vertical and lateral variability of rock bodies, creating a challenge for exploration geologists.

In the late Carboniferous, a major basin, the Pennine Basin, existed between landmasses situated in the area of the Scottish Southern Uplands Massif to the north, and the English midlands to the south. This basin is thought to have developed as a result of late-Devonian to early Carboniferous rifting which occurred in response to back-arc lithospheric stretching induced by a northward-dipping subduction zone in southern Europe. This crustal extension gave rise to a series of relatively small, linked sub-basins with their corresponding fault-bound blocks. The formation, position and orientation of these



Stratigraphy of the Westphalian A-C of the East Midlands, with the main hydrocarbon reservoirs, coal seams and marine bands; the column covers about 940 m of strata (after Guion et al., 1995).

The 'Three Ships' outcrops showing planar cross bedding in the Crawshaw Sandstone on Birchen Edge.

extensional sub-basins were controlled in part by inherited Caledonian structures. The basins have an asymmetric profile with thickening of sediment into the hanging wall, typical of tilt-block half-grabens. The basins accumulated thick mud sequences, particularly in the Dinantian and early Namurian. Differential subsidence between blocks and basins produced disproportionate thicknesses of Carboniferous sediments in the troughs or gulfs, with condensed sequences on the blocks.

Namurian deposition took place within the inherited Dinantian palaeobathymetry during a post-rift phase of basin development. In the East Midlands these elongate basins, include the Gainsborough Trough, Edale Gulf, and Widmerpool Gulf. Basins were filled progressively from north to south through the Namurian. By uppermost Namurian times the separate identity of the blocks and basins had progressively reduced, and by the Westphalian A, sedimentation was influenced more by regional subsidence related to thermal sag.

In Namurian times, clastics arrived from a northerly igneous and metamorphic source, thought to be in East Greenland, and were transported and deposited by major fluvio-deltaic systems. These systems carried sediment across the East Midlands shelf, where they consequently swung towards a west-northwest trend, broadly parallel to the axes of the sub-basins, depositing thick sand bodies. More rapid subsidence took place within the basins, which continued to be infilled with sediment. The East Midlands Shelf remained a positive feature throughout Namurian times when thin, condensed, or incomplete sequences formed. Marine bands are sometimes absent or poorly developed on the more elevated shelf areas, which may be either a consequence of non-deposition or erosion. The Namurian sediments generally rest on Dinantian strata. In the basins the contact is often conformable, but on the shelf-basin margins there is commonly an onlap unconformity and sometimes an erosional contact between the Dinantian and Namurian; in parts of the subsurface. especially on shelf areas, the entire Namurian may be absent, with Westphalian rocks resting on Dinantian or older strata.

A gradual change of sedimentary style took place from late Namurian times into the Langsettian (Westphalian A). The basal Westphalian Crawshaw Sandstone is similar in style, provenance and gross petrological characteristics to the underlying Namurian, and contemporaneous tectonics influenced palaeoflow and sand body development. However, higher in the Langsettian, by the time of deposition of the Wingfield Flags, above the level of the Amaliae Marine Band, marine incursions were generally rare, channel sandstones were generally fine grained, contemporaneous tectonic influence was subtle, and a significant change in provenance occurred, with dominant flows from the west.

The Crawshaw Sandstone and its subsurface equivalents form the principal hydrocarbon reservoirs. It outcrops as coarse pebbly sandstones in some areas, and fine to medium micaceous sandstones elsewhere. Production has also been obtained from a number of other Westphalian sandstones, particularly at the horizons of the Loxley Edge Rock and the Tupton Rock. These and other sandstones above the Wingfield Flags of western derivation are finer grained, 'dirtier' and less permeable than the underlying northerly-derived sandstones.

The Variscan orogeny in the late Westphalian to early Permian resulted in the non-deposition or erosion during the latest Carboniferous and early Permian and inversion of half-grabens such as the Widmerpool Gulf, with the development of inversion anticlines. Hydrocarbons accumulated in these structures, if they had sufficient four-way closure, such as at Eakring and Welton. The thick mud-rich sequences within the basins which are considered to be distal prodelta mudstones provided the main source rocks for the East Midlands oilfields. Geochemical studies indicate an origin from mixed marine/terrestrial kerogen. In addition, Westphalian Coals provided an abundant source of gas, but only limited oil. Regional seals in the East Midlands hydrocarbon province are the marine bands, such as the Amaliae Marine band, deposited during episodes of raised sea level.

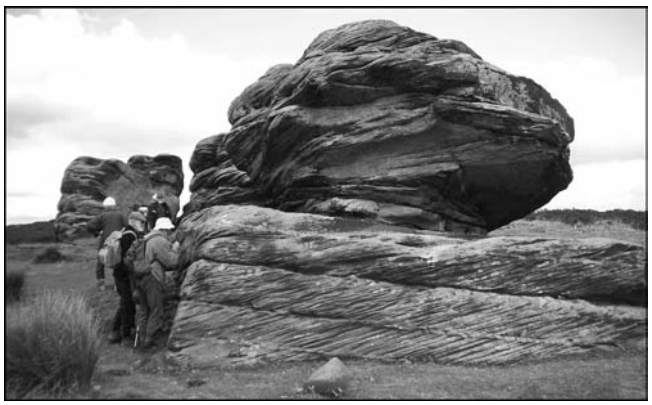
Birchen Edge, Derbyshire

The party parked at the Eric Byne Car Park near the Robin Hood pub, just off the A619 Baslow – Chesterfield road [SK281722], and followed the ascending path to the outcrop of Crawshaw Sandstone just below Nelson's Monument [SK280728].

Birchen Edge is a west-facing edge typical of those in the eastern part of the Peak District, where up to 15 m of Crawshaw Sandstone are well exposed; however, the thickness at outcrop is undoubtedly less than the full thickness, which is in excess of 30 m in nearby

boreholes. The Crawshaw Sandstone is the lowest major Westphalian A (Langsettian) sandstone and lies between the Subcrenatum and Listeri Marine Bands. It is usually overlain by a thin coal, variously termed the Belperlawn, Soft Bed or Coking Coal. Between this coal and the Listeri Marine Band, there is a variable development of strata. In many areas, this interval consists of up to four cycles of thin coals, seatearths and mudstones containing Carbonicola or Lingula. However, sandstone may also be developed in this interval in certain areas, termed the Sub-Alton Sandstone, which may locally be thick and oil-bearing (e.g. Bothamsall Oilfield). The Listeri Marine Band possesses unusually high radioactivity, and thus can usually be readily detected on gamma-ray logs, enabling the underlying Crawshaw Sandstone to be identified in the subsurface. It was previously miscorrelated with the underlying Namurian Rough Rock both during early surface and subsurface mapping, so in the early days of exploration, there was uncertainty regarding which horizons were producing oil.

The Crawshaw Sandstone at Birchen Edge consists of coarse-granular, kaolinitic sandstone with pebbly horizons containing quartz and altered feldspar clasts. Above the main outcrop is Nelson's Monument erected in 1810, and three isolated outcrops with carved names commemorating his ships Royal Soverin (*sic*), Victory and Defiance. These are separated from the main outcrop by unexposed ground, suggesting that the Crawshaw Sandstone occurs as two leaves, separated by soft mudstones. The dominant sedimentary structures, both of the main outcrop and the isolated outcrops above, are planar cross bedding to broad trough cross bedding, with some massive or horizontally stratified beds. Laterally-extensive, low-angle surfaces overlain by pebble conglomerates may be traced along the outcrop. Large sets of cross stratification with smaller 'intrasets' suggest that small bedforms migrated in a variety of directions on the fronts and backs of larger sand bars. In general, there is an upward diminution of set size. Palaeocurrents, measured from the orientation of cross bedding, are mainly directed to the west on the main outcrop, although those on the 'Three Ships' are in a more northerly direction.



Society members examining planar cross bedding in the upper leaf of the Crawshaw Sandstone on Birchen Edge (photo: Tim Pharaoh).

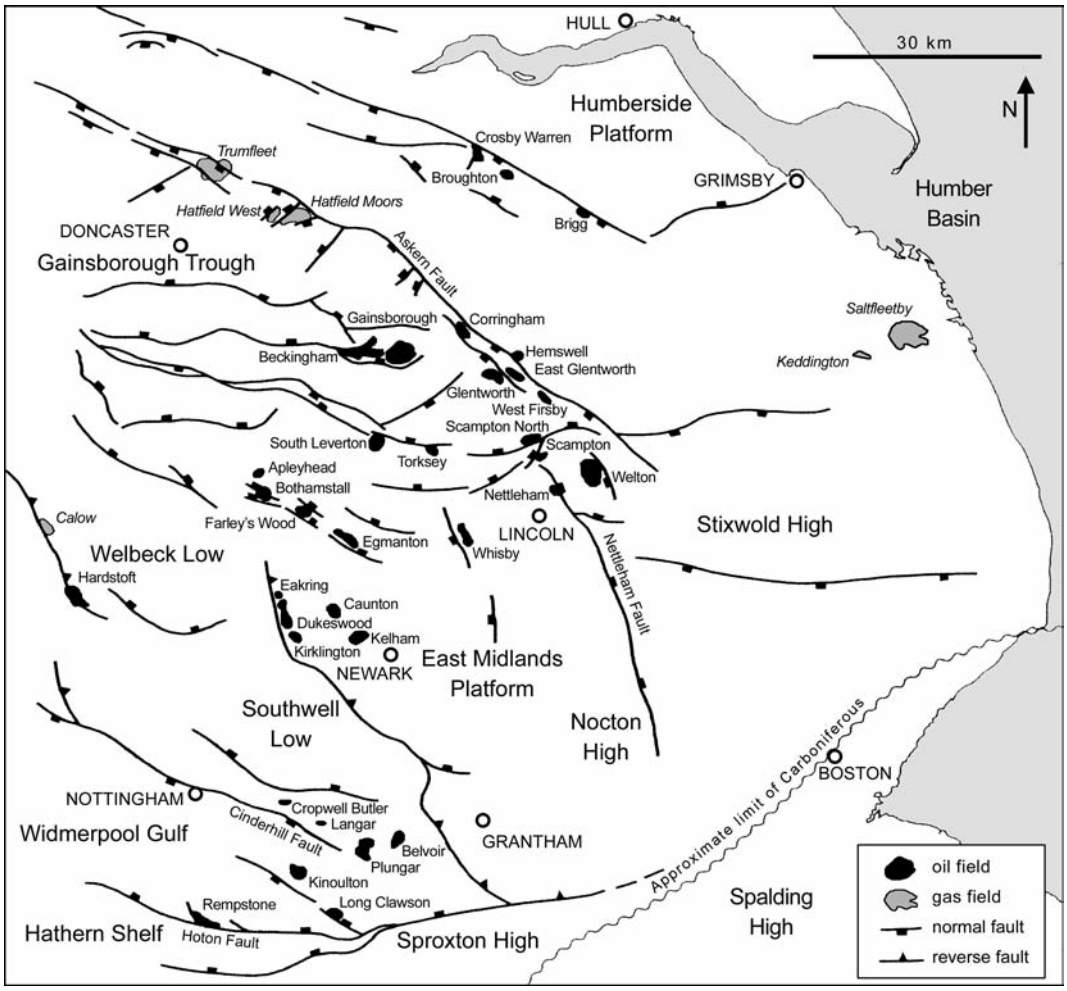
The Crawshaw Sandstone at this locality is interpreted as the deposits of braided low-sinuosity fluvial systems that crossed a delta plain and fed fluvial-dominated deltas. Transverse to lobate bars were present, with superimposed smaller dunes. Gradual upward reduction of set size is attributed to gradual abandonment of given reaches of river, causing bedforms to gradually diminish in size. Birchen Edge coincides with the axial region of the Edale Gulf, and the westerly-directed palaeocurrents are believed to indicate flow of the fluvial system from east to west along the gulf. However, south of Birchen Edge, and on the 'Three Ships', palaeocurrents are generally from a southerly or southeasterly direction. The palaeocurrents from the south were from a slightly later channel system flowing along the Widmerpool Gulf and turned north towards the Edale Gulf.

Thick channel sands are present at this horizon in the Edale Gulf, the Widmerpool Gulf and the southeastern part of the Gainsborough Trough, as well as on some shelf areas. The thickest developments of sandstone appear to be in the Edale Gulf, suggesting higher rates of subsidence than in adjacent areas, possibly as a consequence of movement on bounding faults, or alternatively as a consequence of differential compaction. In addition, the Ashover and Crich Anticlines may have been active during Crawshaw Sandstone sedimentation, causing local deflection of palaeocurrents, lateral replacement of channel facies by overbank and interdistributary facies, and resulting in the development of thick coals on their crests where subsidence rates were lower.

The Crawshaw Sandstone is petrographically similar to underlying Namurian sandstones, with a similar northern provenance, but with an additional contribution from the Wales-Brabant Massif. Tectonic elements, such as the Widmerpool and Edale Gulfs and the Wales-Brabant Massif, deflected the fluvial systems to the west or north, so that in some cases they appear to be flowing towards their source area.

Welton Gathering Centre, Lincolnshire

The Welton Gathering Centre [TF045748], stands near Reepham, situated about 7 km northeast of Lincoln, close to the A158, serving the Welton Field and a number of adjacent fields. Crude oil from the Welton Field, plus a number of satellite fields such as Scampton North, is piped to the Gathering Centre. Water and gas are removed from the oil, which is stored in tanks before being transported to the refinery at Immingham on the East Coast. Gas, which is produced along with the oil, is used to generate electricity on site. The Welton oilfield was originally discovered by BP in 1981, and production commenced in 1984. The Crawshaw Sandstone at the base of the Westphalian is the largest reservoir (of nine) on the field, and has been the principal objective of most wells. It sits with marked unconformity on Visean limestones, and lies at the base of a sequence comprising three stacked channel deposits, termed



Main accumulations of oil and gas, and the major faults, within the East Midlands hydrocarbon province (after Fraser and Gawthorpe, 2003).

Units 1, 2 and 3. These units form a sequence broadly termed the 'Basal Succession' of which the top corresponds to the laterally extensive Amaliae Marine Band. This is a strong seismic reflector and enables the Basal Succession to be mapped on a regional scale. The aforementioned Listeri marine band (top of Unit1/Crawshaw sandstone) is discernible from well logs, but does not provide a strong seismic reflector.

The field is located on the East Midlands shelf near the southeast margin of the Gainsborough Trough. The adjacent Basal Succession fields on the shelf, Cold Hanworth, Nettleham, Stainton, and Fiskerton Airfield, share similar reservoir characteristics.

The Basal Succession at Welton was originally interpreted to be highly compartmentalized by a series of NW-SE faults dissected by NE-SW strike-slip faults. Many of the compartments were thought to have slightly different geochemical and fluid properties. Recent work, including data acquired from newly-drilled wells suggest that many of the faults are not sealing, and fluid contrasts can be explained by a tilted oil-water contact.

The Welton field employs about 70 wells, many of which exist as sidetracks from original 'donor' wells which subsequently watered out. Production also occurs from shallower higher horizons in the Westphalian A, namely the Parkgate, Tupton, Deep Hard, and Deep Soft Rocks. The laterally-extensive Deep Soft Coal is the prominent seismic event used to map this sequence. Numerous re-completions also exist, as rates have declined and lower-rate targets (usually higher in the sequence) are then brought on stream. Production from the Basal Succession has exceeded 13 million barrels, and from the secondary reservoirs, around 3 million.

Extraction takes place by means of beam pumping units or 'nodding donkeys'. Although the plant was designed for much higher production rates, production in May 2008 was 1280 barrels/day. The field has changed hands several times, and is owned by Star Energy, which is now a subsidiary of Petronas, the Malaysian oil company.

The Welton oil is somewhat waxy, in common with other East Midlands oils, and is rather 'sour' (sulfur-rich), in contrast to other oils in the region, and facilities are present for the removal of H_2S gas, which is re-injected into the reservoir. The source rock in believed to have been primarily Carboniferous prodelta mudstones deposited in deep sub-basins such as the Gainsborough Trough.

The geology of the field was explained to the party by Paul Hargreaves, the Star Energy Geologist, followed by a tour of the facilities conducted by Peter Marsh, the Facilities Manager.

Duke's Wood Oil Museum, Nottinghamshire

The museum is situated just to the east of the Kirklington - Eakring road on the site of the former Eakring - Duke's Wood Oilfield [SK677603]. The site is also a nature reserve operated by Nottinghamshire Wildlife Trust. The oilfield is now abandoned, but the combined production from both fields has exceeded 6.5 million barrels. However, there are believed to considerable reserves still in the ground, and studies carried out in the 1990s have suggested that it may be possible to obtain further production from these fields, hence there is recent interest in these and adjacent fields. The oil was trapped in a NNW-trending anticline, bounded by a fault on the west. The main reservoir, originally believed to be the Namurian Rough Rock, has been shown subsequently to be the Westphalian Crawshaw Sandstone. Production has also been obtained from other units, including some from the Carboniferous Limestone.

Kevin Topham, a former Anglo-Iranian and B.P. Exploration oil driller, who is now Curator of the Duke's Wood Oilfield Museum, welcomed the party. He has travelled extensively worldwide, giving talks on the first North Sea Gas strike in 1965, and the disaster on Boxing Day of that year when the Sea Gem offshore rig collapsed and sank with the loss of 15 lives. We were introduced to another ex-oilman, Duggie Wallace, who has drilled wells around the world and was working at Duke's Wood - Eaking in 1943 when American oilmen were drilling there.

The party was shown a short DVD presentation made by the BBC, which gave an invaluable insight into the early history of the fields, especially the role of the American specialists who came over from Noble Drilling of Oklahoma to drill wells and produce oil, which was vital to the War Effort. For example, 'Pluto' and 'Fido' were invaluable during the D-Day landings, and both structures were supplied with oil from Duke's Wood. An account was also given of the invention of the turbo jet drilling bit by Sir Frank Whittle, of jet engine fame. This was a significant advance in drilling technology, which was perfected in working oil wells at Duke's Wood.

Nodding donkey at Duke's Wood Oil Museum.

A number of artifacts were examined by the party at the museum including nodding donkeys and well heads, oilfield paraphernalia and documents, oil and core samples and a statue, the 'Oil Patch Warrior', dedicated to the American roughnecks who spent their time drilling for oil in Sherwood Forest. A duplicate of this statue is situated in front of the Chamber of Commerce at Ardmore, Oklahoma, which was visited by Kevin Topham in May 2008. Members of the party also took the opportunity to examine some of the rare flora in the nature reserve, some of which is believed to have been introduced to the site in drilling mud for the wells. The museum has an excellent website, giving a full account of its background and history, at www.dukeswoodoilmuseum.co.uk, and copies of the DVD may be obtained from Mr Topham.

Literature

Aitkenhead, N., Barclay, W., Brandon, A., Chadwick, R.A., Chisholm, J.I. Cooper, A.H. & Johnson, E.W., 2002. *British Regional Geology; the Pennines and Adjacent Areas (4th Edition).* British Geological Survey, Nottingham.

Chisholm, J.I. & Hallsworth, C.R., 2005. Provenance of Upper Carboniferous sandstones in east Derbyshire: role of the Wales-Brabant High. *Proc. Yorks. Geol. Soc.,* **55**, 209-233.

Department of Trade and Industry, 2006. *The Hydrocarbon Prospectivity of Britain's Onshore Basins: Promote UK 2007.* http://www.og.dti.gov.uk/UKpromote/geoscientific/Onshore_petroleum_potential_2006.pdf

Falcon, N. L. & Kent, P. E., 1960. *Geological Results of Petroleum Exploration in Britain, 1945-1957.* Geological Society London, Memoir **2**.

Fraser, A.J. & Gawthorpe, R.L., 1990. Tectono-stratigraphic development and hydrocarbon habitat of the Carboniferous in Northern England. *Geological Society Spec. Publ.*, **55**, 45-86.

Fraser, A.J. & Gawthorpe, R.L. 2003. *An Atlas of Carboniferous Basin Evolution in Northern England*. Geological Society, London, Memoir **28**.

Fraser, A.J., Nash, D.E., Steele, R.P. & Ebdon, C.C., 1990. A regional assessment of the intra-Carboniferous play of northern England. *Geological Society Spec. Publ.*, **50**, 417-440.

Guion, P.D. Banks, N.L & Rippon, J.H. 1995. The Silkstone Rock (Westphalian A) from the east Pennines, England: implications for sand body genesis. *Journ. Geol. Soc.,* **152,** 819-832.

Guion, P.D. & Fielding, C.R., 1988. Westphalian A and B sedimentation in the Pennine Basin, U.K. *in* Besly, B.M. & Kelling, G. (eds), *Sedimentation in a Synorogenic Basin Complex: The Upper Carboniferous of Northwest Europe.* Blackie, Glasgow & London, 153-177.

Guion, P.D., Gutteridge, P. & Davies, S.J., 2000. Carboniferous sedimentation and volcanism on the Laurussian margin. *in* Woodcock, N.H. & Strachan, R.A. (eds), *Geological History of Britain and Ireland.* Blackwell Science, Oxford, 227-270.

Lees, G.M. & Taitt, A.H., 1945. The geological results of the search for oilfields in Great Britain. *Quart. Journ. Geol. Soc.,* **101**, 255-317.

Rothwell, N.R. & Quinn, P., 1987. The Welton Oilfield. *In:* Brooks, J. & Glennie, K. (eds), *Petroleum Geology of Northwest Europe.* Graham & Trotman, London, 181-189.

Smith, E.G., Rhys, G.H. & Eden, R.A., 1967. Geology of the Country around Chesterfield, Matlock and Mansfield. *Memoir of the Geological Survey of Great Britain.*

Storey, M.W. & Nash, F.W., 1993. The Eakring Dukeswood oil field: an unconventional technique to describe a field's geology. *in* Parker, J.R. (ed), *Petroleum Geology of Northwest Europe. Proc. 4th Conference.* Geological Society, 1527-1537.

Taylor, F.M. & Howitt, F., 1965. Field meeting in the UK East Midlands Oilfields and associated outcrop areas. *Proc. Geol. Assoc.,* **76**, 195-209.

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