Geology of Caphouse Colliery, Wakefield, Yorkshire, UK

K. S. Davies-Vollum[1,2], P. D. Guion[2], J.A. Knight[3] & A. Smith[4]

[1]Department of the Natural and Built Environment, Sheffield Hallam University, Howard Street, Sheffield, S1 1WB, UK
[2]College of Life and Natural Sciences, University of Derby, Kedleston Road, Derby, DE22 1GB, UK
[3]Harworth Minerals Consultancy, 2 Church Street, Shirland, Alfreton, Derbyshire, DE55 6BJ, UK
[4]National Coal Mining Museum for England, Caphouse Colliery, New Road, Overton, Wakefield, WF4 4RH, UK
Correspondence: s.davies-vollum@derby.ac.uk

Abstract: The National Coal Mining Museum in West Yorkshire affords a rare opportunity for the public to visit a former colliery (Caphouse) and experience at first hand the geology of a mine. The geology at the museum can be seen via the public tour, limited surface outcrop and an inclined ventilation drift, which provides the best geological exposure and information. The strata encountered at the site are *c*. 100 m thick and are of latest Langsettian (Pennsylvanian) age. The ventilation drift intersects several coal seams (Flockton Thick, Flockton Thin, Old Hards, Green Lane and New Hards) and their associated roof rocks and seatearths. In addition to exposures of bedrock, recent mineral precipitates of calcium carbonates, manganese carbonates and oxides, and iron oxyhydroxides can be observed along the drift, and there is a surface exposure of Flockton Thick Coal and overlying roof strata. The coals and interbedded strata were deposited in the-Pennine Basin in a fluvio-lacustrine setting in an embayment distant from the open ocean with limited marine influence. A lacustrine origin for mudstone roof rocks of several of the seams is supported by the incidence of non-marine bivalves and fossilized fish remains whilst the upper part of the Flockton Thick Coal consists of subaqueously deposited cannel coal. The mudstones overlying the Flockton Thick containing abundant non-marine bivalves are of great lateral extent,

indicating a basin-wide rise of base level following coal deposition that may be compared with a non-marine flooding surface.

Caphouse Colliery (the National Coal Mining Museum) is situated on the north side of the A642 (Fig. 1), mid-way between Huddersfield and Wakefield [SE 2523 1638]. Strata that may be viewed in the present-day underground roadways extend from just beneath the Joan Coal down to the New Hards (Middleton Main) Coal (Fig. 2). Coal production at Caphouse ceased in 1985 when the mine closed in association with downscaling of the mining industry in the UK. In 1988, the site was re-opened as the Yorkshire Mining Museum with technical support and assistance from the British Coal Corporation. In 1995 it was granted national status and became the National Coal Mining Museum with the support of the Department of Culture, Media and Sport. Heritage Lottery funding in the early 2000s has allowed further development and expansion of the site (https://www.ncm.org.uk/about). The National Coal Mining Museum is one of the few locations in the UK where the public are able to participate in underground tours of a coal mine that are led by former coal mine workers. Public tours take visitors 140 m down the Caphouse No. 1 Shaft to view former workings and exhibits in the New Hards (Middleton Main) Seam workings (Fig.2). In addition to the public workings, it is possible for parties of up to 17 persons to visit by prior arrangement the inclined cross-measures ventilation drift (Figs. 3, 4), which acts as a second egress, and provides a unique educational resource for the study of Coal Measures rocks.

This account provides a description of the geology of Caphouse Colliery and summarizes its mining history, as well as giving more general background information that places the mine in the context of the regional geology. It is intended as a guide to the geology for visitors to the National Coal Mining Museum and is based in part on information previously published in Guion & Davies-Vollum (2013).

Brief History of Mining

Historical accounts of Caphouse Colliery have been provided by Goodchild (2000) and Schofield (2003), so only a brief summary is included here. A description of the surface features around Caphouse Colliery has been given by Brown & Goodchild (1978). There is evidence for small scale, open pit mining in the area prior to 1515. During the 18th century, the Flockton Thick Coal was initially worked from a series of shallow shafts spaced at 200 to 250 m intervals and later by pillar and stall, but by 1803 the Flockton Thick was exhausted or abandoned. Shaft 17 (also named the Wellington Shaft) corresponds to the present Caphouse winding shaft. Several of the shafts were later deepened to the Flockton Thin Seam (Fig.2), including Shaft 17. By 1850, the Flockton Thin Seam was exhausted, and this shaft, now named Caphouse, was deepened to work the Old Hards (2nd Brown Metals) Seam. In 1876, the Caphouse shaft was deepened again to mine the New Hards (Middleton Main) Seam, which was worked extensively, particularly in the late 1800s to early 1900s. The Furnace Shaft was sunk at the same time to improve ventilation. The top of this shaft, which is covered with reinforced glass, may be viewed in the museum at the start of the public tour. Prior to nationalization of the coal industry in 1947, Caphouse Colliery was part of Denby Grange Collieries Ltd., a group of small collieries centred on the Denby Grange Estate, located 2 km to the WSW of the Caphouse site.

Some of the roadways in the public section date from the 1940s and later; others were constructed to develop the underground public displays from the 1980s onwards. In the 1970s, a 1 in 16 roadway (the Caphouse Slit) was driven in a NW direction. This enabled the construction of a drift with a 1 in 4 gradient towards the surface in order to allow more efficient removal of coal from the workings (Figs 3, 4). A 1 in 4 drift was also driven downwards towards the NW to connect to the stratigraphically lower Beeston Seam level in Denby Grange Colliery (Figs 3, 4), enabling coal from Denby Grange to be brought to the surface via the drift.

Hope Pit is located approximately 600 m SW of the Caphouse Shaft with the two linked underground (Figs 1, 3). The Hope Pit shaft was sunk to the Old Hards Seam in 1832, but production was brief. It was deepened in 1840–1841 to the New Hards Seam, with further deepening between 1870 and 1893. Production of coal here also ceased in the 1980s.

Much of the coal between the Flockton Thick and New Hards seams was extracted using the traditional hand filling methods described by Schofield (2003), although there are records of pillar and stall extraction in the Flockton Thick and New Hards seams. Coal from Caphouse Colliery is mainly high volatile bituminous coal (Coal Survey 1960; National Coal Board 1965), which was primarily supplied for household use (Addison *et al.* 2005*a*). However, the Flockton Thick and New Hards seams in the local area were also used for gas production and coking coal, and the Green Lane Coal was used primarily for coking. According to Wray *et al.* (1930) and Addison *et al.* (2005*b*), the Old Hards Coal was formerly important as a source of sub-anthracite.

Local geological setting

The rocks exposed within the mine and adjacent areas are shown on 1:50,000 Geological Sheet 77 (Huddersfield) (British Geological Survey 2003), and recent summaries of the geology of the area have been published by Lake (1999) and Addison *et al.* (2005*a*, *b*). In addition, information gained from opencast working north of the colliery has contributed to geological knowledge. More general accounts of the Carboniferous of Britain, and in particular the Pennsylvanian of the east Pennines, include those of Aitkenhead *et al.* (2002), Waters & Davies (2006) and Davies *et al.* (2012).

Structural Geology

The mine is within the East Pennine Coalfield (Waters *et al.* 2009), which extends more than 120 km south from Yorkshire into Derbyshire and Nottinghamshire and is situated on the eastern flank of the north–south trending Pennine Anticline (Fig. 5), with a regional dip of 2–5° in an easterly direction, although dips may be locally higher, especially near to faults (Addison *et al.* 2005*a*, *b*). Faulting, which has affected both coal depth and mining operations, is extensive and includes both normal and strike-slip faults. The dominant fault direction is approximately NW–SE, although an apparently conjugate fault set of NE–SW trending faults is also developed. They are probably late Carboniferous in age (Addison *et al.* 2005*a*, *b*), although to the east of the mine site, some faults extend into Permo-Triassic strata indicating reactivation during the Mesozoic and/or Cenozoic (Lake 1999). A fault between the Hope and Caphouse shafts downthrows at least 32 m towards the NE, on the Caphouse side of the faults (Fig. 1). A fault that downthrows to the SW passes just north of Caphouse shaft.

Stratigraphy

Carboniferous litho- and chronostratigraphical nomenclature of northern England has undergone much recent revision. The terminology employed here is based on

Waters *et al.* (2007), Waters *et al.* (2009), Waters *et al*. (2011) and Davydov *et al.* (2012). There is a proliferation of names used to identify individual coal seams at both coalfield and local colliery level (Sheppard 2005). Hence, not only have multiple names been used for the same seam, but different seams may have been given the same name. The seam names at Caphouse are those generally used in seam plans, shaft sinking records and boreholes at the colliery (e.g. Figs 1, 2), but alternative seam names used nearby are also indicated in this account. Green Lane and Middleton Little are local names for the Parkgate Coal of the wider Yorkshire Coalfield, and Old Hards and Middleton Main are the equivalent of the Thorncliffe Coal.

The strata exposed in the mine and its surroundings extend from the Thornhill Rock down to the New Hards (Middleton Main) Seam (Figs 1, 2). There have been workings in seams at lower levels, including the Wheatley Lime, about 20 m below the New Hards, and the Beeston about 100 m below (Addison *et al.* 2005*b*), but these are now flooded and are no longer accessible. The sequence at Caphouse Colliery lies within the Bashkirian International Stage and belongs to the Pennine Lower Coal Measures Formation (Fig. 2).

The youngest strata exposed around the colliery are the sandstones known as the Thornhill Rock of Duckmantian age, which have been used widely for building stones. There are several outcrops in the Huddersfield–Wakefield area (Lake 1999; Addison *et al.* 2005*b*), including the prominent scarp of Thornhill Edge, about 2 km north of the museum. The Vanderbeckei (Clay Cross) Marine Band, which lies just below the Thornhill Rock, marks the boundary between the Duckmantian and Langsettian European substages. This bed has great lateral extent, and represents the product of a widespread marine transgression. The Caphouse Shaft is believed to have been sunk at about the level of the Joan Coal, stratigraphically just below the Vanderbeckei Marine Band. The Joan Coal, although extensive, is only around 60 cm thick and of poor quality, and thus underground working of it was limited. Abundant ironstone deposits, locally termed the Tankersley Ironstone, occur as bands beneath the Joan Coal, (Fig. 2). Abundant non-marine bivalves are present in the mudstones between the Tankersley Ironstone and the underlying Flockton Thick Coal. The Flockton Thick Seam (Fig. 2) may locally exceed 100 cm and consists of two leaves, separated by a mudstone (dirt) parting around 40 cm thick (Wray *et al.* 1930). In an area north of Caphouse, the upper leaf mainly consists of waxy cannel coal, which enabled it to be used for the production of oil and gas (Addison *et al.* 2005*a*).

Sandstones of the Emley Rock occur nearby between the Flockton Thick and Flockton Thin coals and attain up to 14 m in total thickness, although at Caphouse this interval is dominated by siltstones. The Flockton Thin Coal in the Caphouse region is *c.* 50 cm thick, with a thin mudstone parting near the base; despite this, it has been worked extensively underground and in opencast sites. Abundant bivalves and ostracods are present in the immediate roof of this seam.

The interval between the Flockton Thin and Green Lane (Middleton Little) coals (Fig. 2) is somewhat variable. According to Addison *et al*. (2005*b*), three coals, termed the First, Second and Third Brown Metals, occupy this interval north of Caphouse. The First Brown Metal Coal is a distinctive seam, but it unites to the north with the underlying Second Brown Metal, which is the equivalent to the Old Hards Coal of the Caphouse area (Addison *et al.* 2005b). The Old Hards Coal (Fig. 2) is up to 100 cm thick, and has been worked extensively. However, it is locally overlain by sandstone and accompanied by washouts. The identity of Third Brown Metal Coal is somewhat contentious, but it is believed to unite with the underlying Green Lane (Middleton Little) Coal to the east of Caphouse in the Wakefield Area (Lake 1999). The name Birstall Rock has been used for any sandstone overlying any or all of the Brown Metals Coals. Up to three phases of sandstone are present, with a total thickness of up to 30 m.

The Lepton Edge Rock occurs in the interval between the Third Brown Metal and Green Lane (Middleton Little) seams around Caphouse, and consists of flaggy sandstones (Addison *et al.* 2005*b*). The Green Lane Coal is around 55 cm thick and is overlain by mudstones containing non-marine bivalves and fish remains. The strata between the Green Lane and New Hards (Middleton Main) coals are dominated by mudstones with bivalves, fish fragments and ostracods. The New Hards Seam is widespread, is around 90 cm thick with a mudstone (dirt) band towards the base at Caphouse, and has been mined extensively.

Underground and surface exposures

Bedrock exposures in Caphouse ventilation drift

The ventilation drift (Fig. 3) consists of two legs, approximately 250 m in length with an abrupt change of direction between the two legs. Several coal seams, in particular the Flockton Thick, Flockton Thin, Old Hards, Green Lane and New Hards coals, are traversed (Fig. 4). The ventilation drift is supported by steel arches with timbering or metal sheets between each arch. Consequently, exposure along the drift is not continuous and is mainly accessible via a series of refuge holes, originally created to provide a safe space for miners to avoid passing coal tubs. The drift traverses approximately 100 m of late Langsettian strata (Fig. 2), including exposures of coal together with inter-seam strata of mudstone, siltstone and seatearths (paleosols). Minerals precipitated by mine waters that run into the drift include calcium and manganese carbonates as well as iron and manganese oxides and hydroxides. The drift enables access to the workings in the New Hards (Middleton Main) Seam; this seam is also accessible via the public tour. It is recommended that the drift (Fig. 6) should be descended from the surface rather than ascended.

The main features of the ventilation drift are summarized in Table 1. The exposures are described herein, assuming the visit commences from the top of the drift (Figs 4, 6). Exit may be made via the Caphouse Shaft, which is also the entrance and exit for the public tour. The position of exposures accessed via the refuge holes may be ascertained by reference to the distance signposted in metres from the ventilation drift entrance. Interpretations of lithofacies encountered in the drift are based on those published in Guion *et al.* (1995*a*).

There is very little exposure of bedrock in the drift until the **124–129 m** level where the Flockton Thick Coal may be observed. The seam here is 76 cm thick, with a mudstone-seatearth parting at its middle. The upper part of the seam consists of cannel, a type of sapropelic (hydrogen rich) coal formed by accumulation of fine-grained organic matter in a lake or sluggish watercourse. Numerous fragmentary fish remains have been recorded in the upper part of the seam elsewhere, attesting to its subaqueous origins (Wray *et al.* 1930). Old workings of this seam are still accessible by crossing the conveyor, although access is limited by their low roof. The lower part of the seam was mined first, the mudstone parting was used to fill the void, and then the upper part of the seam was worked. The roof measures of the Flockton Thick Coal consist of dark fissile claystones containing non-marine bivalves such as *Anthracosia* (Fig. 7). Non-marine bivalves are also present at **168 m**, probably in the roof of the Flockton Thin

Seam. Former workings in the Flockton Thin at around **180 m** are now closed up and inaccessible.

From **220 m** to the base of the first leg, in the roof of the Old Hards (2nd Brown Metal) Seam, there are exposures of massive siltstone containing ironstone nodules and bands together with drifted plant compression fossils such as *Neuropteris* and *Calamites*. These are also present in the upper part of the second leg. The Old Hards Seam is not visible, but an upright tree trunk is present at around **358 m**, probably in the roof of the Old Hards Coal. This represents the internal mould of a lycopsid tree; the trunk widens downwards and is filled with siltstone and surrounded by a thin layer of vitrain (bright coal). Such siltstone infills have a tendency to detach on the weak vitrain layer and fall into mine workings (Chase & Sames 1983; Fulton *et al.* 1995) and constituted an occasional hazard to miners in pre-mechanized days. At about this level, features resembling *Stigmaria,* the rooting organ of a lycopsid tree (Fig. 8), can be observed in a refuge hole.

Massive siltstones containing drifted plant remains have been interpreted both as overbank flood deposits or accumulations in abandoned channels (Guion *et al.* 1995*a*). However, *in situ* trees are more likely to have been preserved in overbank deposits that accumulated on the margins of an active channel (Guion 1987). The associated channel may be that responsible for a washout, caused by erosion at its base, recorded in the Old Hards Seam close to Caphouse (Fig. 1) by Wray *et al.* (1930). According to Wray *et al.* (1930) the Brown Metals group of coals shows complex relationships, including local changes in thickness, absence, splitting and uniting. These features are typical of those that accompany channels (Fulton *et al.* 1995).

Exposure is poor in the lower part of the drift, but at **425 m**, an upbore is present that feeds water into the drift and was drilled to drain water from old workings in the overlying Old Hards Coal. The Green Lane Seam is visible in a refuge hole at **460 m**, and exposes 56 cm of vitrain (bright coal) with well-developed cleat (closely spaced fractures resembling joints). Dark shales with non-marine bivalves overlie the seam, and pale grey mudstone seatearth containing rootlets is present beneath the seam. At **540 m**, there is an underground connection to the Beeston Seam (Figs 3, 4), which enabled coal worked at Denby Grange Colliery to be brought out via the drift. The public part of the former Caphouse workings may be accessed from a junction with this roadway via the 1 in 16 Caphouse Slit (Fig. 3).

Recent mineralization from mine waters in the ventilation drift

Water runs into and down the drift from the surface and via old workings and the upbore. Water in the mine is particularly noticeable after heavy rain, with mine staff observing a link between precipitation events and the inflow of water. The subsurface drainage of Caphouse and adjacent collieries was studied by Foster (2005), who noted that the volume of water flowing towards the pumping shaft at Hope Pit increased in response to intense rainfall. Water from the workings drains to Hope Pit where it is pumped to the surface at a rate of approximately 115 litres/second. Pumping typically takes place for 10–20 hours/day depending on surface precipitation. It is then sent to settling lagoons with reed beds and treated before discharge.

Underground water at Caphouse is associated with recent mineralization that can be observed along the drift. Kruse & Younger (2009) carried out a detailed study of the mineral precipitates associated with subsurface drainage in the drift. They reported that the mine water at Caphouse is neutral to slightly alkaline with a pH in the range 6.73–

7.93 (Kruse & Younger 2009). Mine waters that form in collieries are often acidic, although there is considerable variation. Such acid mine drainage is generally produced when sulphide-bearing material (usually pyrite, FeS_2) comes into contact with oxygen and water (Akcil & Koldas 2005). When pyrite oxidizes, it forms sulphate ions, which dissolve to give a low pH solution. Oxidation of pyrite is well understood and has been thoroughly described (Holmes & Crundwell 2000). Iron oxy-hydroxides, sulphates and hydroxysulphates often form in these conditions (Kruse & Younger 2009).

The alkaline nature of the mine water at Caphouse has resulted in precipitation primarily of calcium carbonate (both calcite and aragonite), manganese carbonate and ferric hydroxide (Kruse & Younger 2009). Black amorphous encrustations are probably hydrated manganese oxides (Fig. 9). Minerals precipitated along the drift are often layered and resemble flowstone (Fig. 10). Good examples of mineralization may be observed between **80 m** and **210 m**. The source of carbonate and manganese ions within the mine waters is uncertain. Kruse & Younger (2009) suggested interbedded limestone as a source, but there are no significant limestone interbeds within the local Westphalian strata. The closest source of abundant carbonate rocks is the Permian dolomites and dolomitic limestones situated about 20 km to the east (Lake 1999). Ironstone beds and nodules mainly consisting of siderite ($FeCO_3$) are common in the Pennine Coal Measures, and may have contributed carbonate ions. The Tankersley Ironstone, stratigraphically located just above the Flockton Thick Seam (Fig. 2), may be a local source of dissolved carbonate ions. Additionally, some East Pennine Coal Measures sandstones have carbonate cements in the subsurface (e.g. Greensmith 1957; Hawkins 1978), which could potentially be a source. The observed link between precipitation events and inflow of water to the drift indicates that mine water is likely to be influenced by surface conditions and that a local source of carbonate is possible.

Exposures in Public Districts

The parts of the workings open to the public are within the New Hards Seam. In this public district, many items of equipment may be viewed, such as a trepanner, shearers and roadheader, in addition to various exhibits including mock stables for pit ponies, and tableaux illustrating how coal seams were worked prior to mechanization. The coal is not always visible, and in places it has been replaced by fibreglass, but the resemblance to the real thing is quite remarkable. One section exposing the New Hards Coal is, however, visible in the new districts in the public area. The base of the seam is not exposed, but 87 cm of it are visible. The seam consists of bright coal in the lower part of the outcrop separated from mainly banded coal above by a thin carbonaceous mudstone parting. The coal passes upwards into dark mudstone containing ironstone bands about 5 cm thick and non-marine bivalves. The overall sequence marks a transition from the terrestrial conditions of the coal swamp into lacustrine deposits above. In addition, wave ripples, probably located stratigraphically just below the New Hards Seam, are visible in the floor of the workings adjacent to the trepanner cutting equipment (Fig. 11). Although wave ripples are not common in the Westphalian of the East Pennine Coalfields, they have been recorded elsewhere and are thought to have developed in shallow extensive lakes subject to wind (Davies-Vollum *et al.* 2012).

Surface outcrop near Hope Pit

Outcrops are present adjacent to Hope Pit surface buildings and next to the former rail access under the A642 (Fig. 1) [SE 2492 1613]. These provide somewhat overgrown exposures of the Flockton Thick Seam (Fig. 12) and the overlying roof rock. This is the same seam that outcrops in the drift and is present in the subsurface due to downthrow to the NE across the fault zone between the Hope and Caphouse shafts (Fig. 1). The upper part of the seam consists of strata not easily seen in the drift: cannel overlain by a roof rock of fissile carbonaceous claystone that grades upwards into grey silty mudstone. The mudstone roof rock contains sideritic (ironstone) nodules and bivalve fossils including *Anthracosia* (Fig. 7); it is soft and friable and can be easily split manually to collect fossils. A similar shell bed at this level has been identified over a large area of the East Pennine coalfields (Wray *et al.* 1930; Mitchell *et al.* 1947). Abundant ironstone that occurs a few metres above the Flockton Thick Seam, locally termed the Tankersley Ironstone, was worked extensively in the Emley area south of Caphouse in medieval times (Addison *et al.* 2005*b*). Deposits of ironstone at this stratigraphical level may be traced for around 100 km to the south into Derbyshire (Frost & Smart 1979).

Regional Geological setting

A summary of the regional geological setting is given here to provide context for the geology of Caphouse Colliery and the National Coal Mining Museum. Further detail can be obtained from the references provided herein.

Tectonic setting

The Carboniferous basins of Britain are believed to have developed as a result of late Devonian to Mississippian crustal extension, which occurred in response to back-arc lithospheric stretching induced by a northward-dipping subduction zone in southern Europe. The resultant north–south rifting resulted in series of graben and half-graben, separated by platforms and tilt-block highs (Leeder 1982). The orientation of the basinbounding faults has been inferred to be controlled by structures in the pre-Carboniferous basement (Fraser & Gawthorpe 2003). The resulting tilt blocks gave rise to highly differentiated rates of subsidence and, at times, bathymetry and this controlled the thickness and facies distribution during the Mississippian in the Pennine Basin.

The influence of differential subsidence in northern England diminished throughout the Carboniferous, such that by Pennsylvanian (Westphalian) times it was more uniform, related to a thermal subsidence or sag phase that dominated from the late Brigantian. Deposition occurred in the Pennine Basin, which was bounded by the Southern Uplands in the north and the Wales-Brabant High in the south (Fig. 5). Some of the major faults inherited from early Carboniferous extension continued to influence sedimentation during the Westphalian, including the regional NW–SE Morley-Campsall/Askern-Spittal Fault zone, which lies several kilometres to the north of the colliery (Fig. 5). Thus, thickness variations, seam splits, and channel stacking patterns have been attributed to a degree of tectonic control by some authors (Giles 1989; Lake 1999). However, details from mining and exploration data demonstrate that this is not common (J. Rippon, personal communication 2015).

By Duckmantian times, the influence of the Variscan Orogeny to the south of Britain became important. There is evidence for uplift and erosion at the level of the mid-Duckmantian Woolley Edge Rock (Aitken *et al.* 1999), accompanied by an abrupt change in provenance (Hallsworth & Chisholm 2000). At the end of the Carboniferous, there was a period of inversion that accompanied Variscan compressive deformation, giving rise to faulting and folding and separating parts of the basin into several isolated coalfields. Faulting and tilting affecting post-Palaeozoic rocks in northern England also suggests that a degree of deformation occurred in the Mesozoic and Cenozoic (Aitkenhead *et al*. 2002).

Cleat fractures are pervasive in British coalfields and may be observed at Caphouse. There is no consensus as to the origin of cleat, which has been attributed to both diagenetic and tectonic processes (Laubach *et al.* 1998). Rippon *et al.* (2006) considered that the dominant cleat orientation recorded Variscan horizontal stress. The main cleat throughout the East Pennine Coalfields has a NW–SE orientation, parallel to the principal horizontal stress generated by the Variscan deformation to the south.

Sedimentary Setting

The sedimentary setting of the Pennine Coal Measures Group has been discussed by Guion & Fielding (1988), Guion *et al.* (1995*a*), Rippon (1996) and Waters & Davies (2006). In addition, the influence of glacio-eustatic controls on sedimentation in the basin in the late Carboniferous has been the focus of a number of publications (e.g. Flint *et al.* 1995; Hampson *et al.* 1997; Cole *et al.* 2005, Waters & Condon 2012).

During the late Carboniferous, the Pennine Basin was situated near the equator within the narrow Eurasian Seaway, which had limited connections with the Palaeo-Tethys Ocean to the east (Blakey 2007; Wells *et al.* 2005). Marine transgressions and regressions during the earlier part of the Langsettian were accompanied by episodes of delta progradation in the basin, but by the later Langsettian and Duckmantian times, sediments were deposited in a waterlogged fluvio-lacustrine environment with less evidence of a marine influence (Davies *et al.* 2012). A mid-Langsettian to mid-Bolsovian facies model is shown in Figure 13, based on facies defined by Guion *et al.* (1995*a*). Major fluvial channels were the main pathways of sediment transport into the basin.

These fed sediment and water into shallow fresh water bodies via a system of minor channels, lacustrine deltas and crevasse splays. In many cases, the major channels appear to have been active over relatively long periods and gave rise to sandstone belts a few kilometres wide and tens of metres thick. They dominantly consist of very fine to medium grained, mature sandstones. The minor channels are complex in nature and contain a wide variety of fills. Major and minor channels show a variety of trends, with the orientation being controlled by several factors including position of source areas, tectonics, palaeoslope, avulsion and compaction. Important peat accumulations that were deposited in these fluvio-lacustrine environments gave rise to extensive workable coal seams in the upper part of the Langsettian and lower part of the Duckmantian, such as those coals observed at Caphouse.

Major fluvial channel systems have been interpreted by some authors as the infills of incised valleys cut during sea-level falls and lowstands in the Pennine Basin, for example the Thornhill Rock (Waters & Condon 2012). Mining information and other studies of major sandbodies in the Westphalian of the east Pennines (Aitken *et al.* 1999; Guion *et al.* 1995*b*; Rippon 1996) support an intimate relationship between the channel sands and adjacent strata that is not related to valley incision and backfilling. Typically, coal seams contemporary with major sandbodies have high mineral matter (ash) contents and show patterns of splitting towards the channels, and there is a higher proportion of interbedded sandy material close to the channel systems, indicating that overbank flooding events happened contemporaneously with nearby peat accumulation. Syntheses of the distribution of major sandstones and coals in the east Pennine Coalfields by Rippon (2005) and Sheppard (2005) showed complex patterns of seam splitting and union. They also showed that major fluvial channel belts existed at nearly all stratigraphical intervals. Some of these channels span a number of coal seams vertically, and were considered by Rippon (1996, 2005) to have formed as a consequence of continuous aggradation. The patterns of coal seams and sandbodies, together with the high ash content of coals adjacent to major channels, suggest that the channel systems represent long-lived, actively aggrading sedimentary systems rather than the product of incision followed by later back-filling.

Marine intervals such as the Vanderbeckei Marine Band (Fig. 2) are testimony to widespread eustatic rises and the incursion of marine conditions into the Pennine Basin (Flint *et al.* 1995; O'Mara & Turner 1999). Rippon (2005) maintained that many coals in the east Pennines also formed as a response to episodes of rising marine base level. The Flockton Thick Coal and its overlying mudstones may reflect deposition occurring as a consequence of a rising base level. The upper part of the Flockton Thick Seam consists of cannel coal containing fish remains, which forms as subaqueous accumulations of plant-rich organic material (Moore 1968). The presence of cannel in the upper part of the Flockton Thick Coal suggests that growing vegetation was ‘drowned’ as a consequence of a rise in water level with little input of clastic sediment. Abundant bivalves are present in the mudstones overlying the Flockton Coal (Lake 1999) and are generally interpreted as indicating non-marine conditions (e.g. Calver 1968). Similar mudstones have been assigned to a lacustrine facies by Guion *et al.* (1995*a*) and Davies-Vollum *et al.* (2012). The areal extent of lacustrine mudstones above the Flockton Thick Seam and its equivalents is indicative of an extensive, possibly basin-wide rise of base level causing inundation. This may be compared with a non-marine flooding surface (NFS), which was proposed by Diessel *et al.* (2000) for a widespread non-marine depositional surface considered to be the landward correlative of a marine flooding surface at the contemporary coast. An NFS interpretation for the cannel in the upper part of the Flockton Thick and the overlying non-marine mudstone would be consistent with the distance from the open ocean of the Pennine Basin at this time, with marine influence being minimal (Wells *et al.* 2005; Davies-Vollum *et al.* 2012; Waters & Condon 2012).

Sediment provenance

Large scale changes in provenance were important in the Pennine Basin during the Westphalian, which may be intrinsically linked to hinterland processes. Knowledge of the provenance of Pennsylvanian sandbodies stems from mapping the regional extents of the channel belt systems together with their grain compositions and maturities, as well as studies of heavy minerals, palaeocurrents and geochemistry (Leng *et al.* 1999; Hallsworth & Chisholm 2000, 2008; Hallsworth *et al.* 2000). Three main sediment source areas during the Westphalian for the East Pennines have been recognized (Fig. 5):

1. Northern source terrain (Namurian to early Langsettian).
2. Western source terrain (mid Langsettian to late Duckmantian).
3. Southeasterly source terrain (late Duckmantian to Asturian).

In addition, the Wales-London-Brabant High, which formed the southern boundary of the Pennine Basin (Fig.5), contributed a minor amount of sediment. The sequence at Caphouse Colliery was derived from a source area in the west.

Summary

The National Coal Mining Museum, West Yorkshire, is located in the East Pennine Coalfield in an area that has a history of coal extraction dating back over 500 years. The museum provides an opportunity to visit the former Caphouse Colliery to experience conditions in an underground mine and observe local coal geology. Five coals of late Langsettian age are traversed by the present underground roadways: the Flockton Thick, Flockton Thin, Old Hards, Green Lane and New Hards seams. These coals belong to the Pennine Lower Coal Measures Formation, which was deposited in a fluvio-lacustrine environment in the Pennine Basin with a provenance from the west. The inclined ventilation drift enables access to about 100 m of this stratigraphical interval, which includes economic coal seams and associated inter-seam strata as well as recent mineral precipitates including calcium and manganese carbonates, manganese oxides and iron oxyhydroxides. Strata occupying the stratigraphical position of the roof measures of the Old Hards Seam consist of massive siltstones containing abundant drifted plant remains and an *in situ* tree trunk, and are interpreted as overbank deposits derived from a nearby channel responsible for extensive washouts recorded in the Old Hards Seam. Several of the seams have roof rocks of dark mudstone containing non-marine bivalves (*Anthracosia*) indicative of lacustrine conditions. The upper part of the Flockton Thick Seam also consists of cannel, which has been interpreted as an organic lacustrine deposit formed in response to a rise in base level. The areal extent of the Flockton Thick Seam and overlying mudstones indicates that this base level rise may have been extensive, which could be interpreted as a non-marine flooding surface (NFS) in a location distant from the open ocean, with minimal marine influence.

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