Pennine Coal Measures Group, Carboniferous, Northern England


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Introduction
Stratigraphical classification of the Carboniferous rocks of northern England.

Note 1 Although the Carboniferous Subcommission of the International Commission on Stratigraphy has recommended that the terms ‘Dinantian’ and ‘Silesian’ should no longer be used, they are such fundamental units in the description of British Carboniferous rocks that they are likely to be encountered throughout the currency of this guide.

P916112.

Outcrop of Westphalian strata and the location of the principal coalfields in northern England, showing variation in rank across the Northumberland and Durham Coalfield. P916075.
Strata of the Pennine Coal Measures exposed in the West Chevington opencast site [NZ 2440 9660], Northumberland. (P220607).

Schematic illustration of the facies variation within the upper delta plain depositional environment of the Westphalian, Pennine Coal Measures Group (after Guion et al., 1995). P916076.

Illustrative logs and interpretations for some types of high-frequency clastic sequences within the Yoredale and Pennine Coal Measures groups of northern England (after Tucker et al., 2003). P916071.

Selection of Carboniferous macrofossils: a Crinoid, Woodocrinus? from shale at the base of the Stainmore Formation, immediately above the Great Limestone
Member, at Mootlaw Quarry, Northumberland (DL4741, P589464); b Goniatite, *Cravenoceras cf. lineolatum* from shale at the base of the Stainmore Formation, immediately above the Great Limestone Member, at Mootlaw Quarry, Northumberland. (P587665), c Brachiopod, *Brachythyrhis* sp. from shale at the base of the Stainmore Formation, immediately above the Great Limestone Member, at Mootlaw Quarry, Northumberland (DL4353, P587666); d Brachiopods, large Gigantoproductids in the Sugar Sands Limestone, Stainmore Formation, at Sugar Sands Bay, Alnwick, Northumberland. (P643515); e Corals, a polished surface of ‘Frosterley Marble’ from the Great Limestone Member of the Alston Formation, showing detail of the abundant coral *Dibunophyllum bipartitum*, Weardale, County Durham. (P524822) x0.5; f Trace fossils, *Teichichnum*-type animal burrows preserved in sandstone from the upper part of the Appletree Limestone cycle of the Tyne Limestone Formation, Hindleysteel Quarry, Henshaw Common, Northumberland [NY 7496 7291]. (P222338).

Across most of northern England sedimentary deposition continued unbroken from the Namurian into the Westphalian. From the later part of the Namurian onwards, significant marine influence was progressively lost over the entire region and deposition was increasingly dominated by sand, silt and mud, carried into the region via large river deltas. These initially drained from a land area to the north or north-east but other provenances were active at different times and by the end of the Westphalian sediment input from the south and south-east was important. Subsidence balanced sedimentation so that a stable delta-top environment was maintained and the resulting Westphalian sequence is essentially continuous over large parts of the region. The Westphalian regional stage (formerly a series) is divided into four substages, originally identified as A to D, the three lowest having since been formalised as Langsettian, Duckmantian and Bolsovian; Westphalian D survives (P916112) and (P916114).

The lithostratigraphical units of Westphalian age present in northern England comprise the Pennine Coal Measures Group and the Warwickshire Group. The Pennine Coal Measures are predominantly grey in colour, nonmarine and characterised by vertically stacked, coarsening-upward cycles commonly up to 15 m thick. Each cycle is composed, in upward sequence, of mudstone, siltstone and sandstone and is capped by a seatearth and coal, though coal forms only a minor part of the sequence. Clay ironstone occurs within some of the mudstones. The Warwickshire Group consists of interbedded mudstone, siltstone and sandstone similar to those of the Coal Measures but distinguished by the presence of primary red beds; the overall colour range is from red-brown to grey, and coal is rare. Secondary reddening of the Coal Measures and older Carboniferous strata is common where these rocks lie close below, or have been exhumed from below the basal Permian unconformity. The zone of reddening can extend 100 m or more below the unconformity and is
accompanied by a general oxidation of the rock mineralogy. Farther south in the Pennine Basin, the Warwickshire Group ranges up into the Stephanian.

Westphalian strata were laid down over most (probably all) of the region, but the Variscan tectonics of the late Carboniferous and early Permian deformed them into gentle folds and produced extensive faulting. Uplifted areas were soon eroded, and Westphalian beds were preserved only in the downwarped areas that make up the present coalfields (P916075). The separation of the coalfields is not an original feature, therefore, but a product of Variscan deformation. Subsequent, post-Variscan sedimentation in the region commenced in Permian times and produced an extensive, unconformable cover of Permo-Triassic strata, much of which has since been stripped away by further erosion. 'Exposed' coalfields are those where the Westphalian strata crop out at surface; ‘concealed’ coalfields are hidden beneath Permo-Triassic strata.

Westphalian Coal Measures crop out, principally, in the west of the region in the Cumbrian Coalfield, and in the east in the Northumberland and Durham Coalfield which, in Northumberland has some of the best coastal exposures of Westphalian Coal Measures anywhere in Britain. Smaller outliers of Westphalian strata occur around Canonbie on the north side of the Solway Basin and spanning the Anglo-Scottish border, in the Tyne valley along the line of the Stublick Fault, and in the Stainmore Trough (P916075). Between the Cumbrian and Canonbie coalfields the Coal Measures are concealed beneath the Solway syncline, whence the subcrop continues from north Cumbria into the Vale of Eden.

At more than 1600 m, the thickness of Westphalian strata in the Solway Syncline is the maximum seen in northern England as described in this account. There, the Carboniferous rocks are commonly reddened to a depth of more than 100 m beneath the unconformable cover of Permo-Triassic desert sandstone. In the Northumberland and Durham Coalfield, about 850 m of Coal Measures strata are present in the axial zone of the Boldon Syncline, north-west of Sunderland, whilst offshore from Tynemouth the thickness is locally up to 830 m. The Coal Measures in the east and south-east of the Northumberland and Durham Coalfield are also concealed by Permian and Triassic rocks, but in general the zone of sub-Permian reddening is less well-developed east of the Pennines.

Deep mining in the Westphalian strata of the region has ceased since publication in 1971 of the previous edition of this British Regional Geology guide to Northern England; much of the final working was from collieries extending beneath the sea. Since then, new information has been acquired during development of sites for opencast coal extraction (P220607), and much of the region has been geologically resurveyed to modern standards. This has enabled major advances in our understanding of the geological development of the coalfields. In addition, the application of sequence stratigraphy has brought a new approach to interpretations of the Westphalian succession onshore and improved its correlation with the offshore sequences, particularly that beneath the North Sea.

The depositional framework

The Westphalian coal-bearing strata of central and northern England were deposited in the Pennine Basin, by then a single province continuous with the north-west European paralic belt, from which it became separated by later, Variscan folding. The Pennine Basin was bordered by the Southern Uplands and associated smaller-scale landmasses such as the Cheviot Block to the north, and by the Wales–Brabant Massif to the south (P916070). Deposition occurred in a widespread fluviolacustrine environment that developed on a low-lying and largely waterlogged plain subjected both to intervals of emergence and to intermittent marine transgressions that became less frequent with time. The succession throughout most of the Pennine Basin is complete.
The lowest Westphalian strata were deposited in a gently subsiding, lower delta-plain environment under the dominant influence of mainly fluvial delta systems. Southward progradation of this depositional system through time resulted in middle Westphalian strata being deposited in a more proximal, upper delta-plain environment dominated by river distributary channels and lacustrine deltas. Later in the Westphalian, a waning fluvial influence caused re-establishment of lower delta-plain conditions. The basin occupied an equatorial position and experienced a humid, tropical climate characterised by high precipitation rates. This combination of factors provided ideal conditions for the development of a high water table, poorly drained palaeosols, peat swamps and the eventual formation of coal seams. Overall, subsidence and sedimentation were able to keep pace with one another throughout deposition. Periodic emergence allowed development of the coal swamps but these were in turn buried by more river-borne sand and silt carried into the northern England sector of the Pennine Basin from the north and east.

During discrete marine incursions at periods of high global sea level, distinctive thin layers of sediment were deposited over wide areas. These marine bands contain characteristic fossil assemblages and have been the traditional means of stratigraphical correlation. Their modern integration with palynological data remains the primary means of correlation within and between coalfields in the Pennine Basin, and thence, from basin to basin, as far as eastern Europe. The marine bands have also allowed preliminary correlation of Westphalian strata onshore with those offshore beneath the North Sea. They represent geographically widespread, short-lived, marine flooding events and are fundamental to a proper understanding of the succession since they reflect the most significant changes in base level (relative sea level) across the entire alluvial plain. The main marine bands — Subcrenatum, Vanderbeckei and Aegiranum — are used to define the substages of the Westphalian (P916114).

An alternative means of long-distance correlation is provided by the beds of volcanic ash — now altered and known as tonsteins — that fell over the coal swamps. Tonstein beds are widely used in Europe for intra- and inter-basinal correlations, and their radiometric dating forms the basis of the modern geochronology for the late Carboniferous.

(P916076) illustrates the varied depositional environments within which the Pennine Coal Measures Group of northern England accumulated. There, and in most of the other coalfields throughout the Pennine Basin, the Coal Measures show a broad, threefold subdivision of lithofacies relative to stratigraphy:

- coal-poor with numerous marine bands in the early Langsettian
- coal-rich with relatively few marine bands in the later Langsettian to mid Duckmantian
- coal-poor with more numerous marine bands from the mid Duckmantian to mid Bolsovian.

The better-developed coals in the middle part of the succession, up to the Vanderbeckei Marine Band, probably reflect changes in relative sea level that occurred at an optimum pace for the initiation and long-term maintenance of coal swamps. The change from poorly developed to well-developed coals is relatively sharp in the Langsettian sequences preserved across the Pennine Basin coalfields of northern England. The subsequent Duckmantian change back to a coal-poor succession is less well defined.

**Clastic lithologies**

The cyclothemic nature of the Coal Measures has long been recognised and studied. At least 40 such cycles are known from the Pennine Coal Measures Group of County Durham with the main lithologies following one another in each cyclothem, in an ascending order of mudstone at the base (overlying the coal at the top of the underlying cycle), siltstone, sandstone, seatearth, coal
The nature and origin of the cyclothems have been much discussed, and it appears that no single explanation will suffice. Such cyclicity is a natural reflection of the interplay of sedimentary processes, and the only external mechanism needed to produce them is continuous subsidence. However, it is generally accepted that the periodic changes in sea level leading to marine flooding events are related to global glacial events, in this case the late Carboniferous glaciation of southern Gondwana which at that time lay over the South Pole. Some activity along the Stublick–Ninety Fathom fault system continued during the Westphalian but, in contrast to circumstances earlier in the Carboniferous, contemporaneous fault activity is not considered to have been a major influence on sedimentary patterns. Only local fault-controlled effects have been proposed and these include deposition of the Langsettian of Cumbria, and the stacking of channel sandstones in the Durham Coal Measures.

The intercoal sequences were deposited during the gradual infilling of shallow interdistributary bays and lakes by shallow-water, crevasse-splay delta complexes (P916076). They are interbedded with a number of prominent sandstone bodies that were deposited by the low-sinuosity, distributary channels feeding the crevasse-splay systems. These sandstone bodies can be stacked, one above another, to produce significant thicknesses; for example, in west Cumbria, a substantial sandstone thickness is developed where the Bannock Band Rock directly overlies the Main Band Rock.

Mudstones are generally well bedded and grey, but darker and more fissile when carbonaceous. Siderite commonly occurs in thin layers or as flattened nodules. Many of the mudstones contain a shelly fauna and this is usually indicative of a brackish-water depositional environment; marine mudstones are rare. Siltstones are also grey, commonly laminated and with a range of bioturbation structures. They grade imperceptibly into both mudstone and sandstone, the latter being mostly fine grained and quartzofeldspathic.

Seatearths, as preserved palaeosols, may be developed from any of the clastic lithologies and are gradational into the underlying facies. In contrast, the contact with any overlying coal seam is sharp. The seatearths contain abundant carbonaceous plant material (most commonly Stigmaria rootlets), and bright coaly stringers with disseminated pyrite. The rootlets increase in abundance upwards through the seatearth and disrupt any original lamination that might have been present. The seatearths typically break along irregular fracture surfaces that may be either covered with slickensides, or curved and polished. Some sandstone seatearths have been leached of feldspar and silicified to produce the distinctive hard beds called ganisters.

**Coal**

Across the low-lying, Langsettian to Duckmantian alluvial plain, coal swamps formed as mires developed on abandoned lacustrine crevasse-splay delta systems. Individual abandoned delta systems are thought to have been up to 10 km wide and 20 km long. The associated mires developed over prolonged periods of time and were not necessarily contemporaneous from one delta system to another. Lateral continuity and synchronicity would have been particularly unlikely along the more active marginal parts of the basin. Thus, variations in coal seam thickness across the alluvial plains are to be expected, although it should be stressed that most of the main coal seams, both in Cumbria and in Northumberland and Durham, can be widely correlated.

Mires develop under waterlogged conditions of rising base level and are able to maintain themselves for thousands of years in water depths of about 1 m, probably the optimum water depth for swamp growth. A lowered water table leads to oxidation and destruction of organic matter as the swamp environment gives way to better-drained conditions, no coals form, only overthickened palaeosols. A rise in water level allows the mire to be buried by clastic sediment. Peat-forming environments in
the Westphalian of northern England ranged from low-lying and brackish mires to seasonally flooded forest swamps. The resulting coal seams range up to about 2 m in thickness and so a peat:coal compaction ratio in the order of 10:1 would indicate that peats were originally up to 20 m thick; autocompaction during peat growth would reduce that decompacted thickness.

The character and quality of a coal is determined by the conditions in the swamp in which it was formed and by subsequent burial history. Alluvial plain coals typically have low ash and sulphur contents, the latter indicative of acid conditions. The effects of temperature and pressure over long periods of geological time tend to expel water and volatile constituents from coal. Thus, a coal that has been subjected to elevated temperatures typically exhibits a low volatile content, a high carbon content and high calorific value; it is said to have a high ‘rank’. Conversely, coals that remain high in volatiles and have a relatively low carbon content and calorific value are said to be of low ‘rank’. A notable feature of the Northumberland and Durham Coalfield is the geographical variation in the rank of the coals (P916075), with the highest rank found in west Durham but thence decreasing into other parts of the coalfield. No variation is apparent in the Cumbrian Coalfield’s broadly middle-ranking coals. The difference between the two coalfields arises from their contrasting histories of burial and geothermal heat-flow, the latter influenced by distance from the underlying, high heat-production Acadian granites of the North Pennine Batholith.

**Fauna and flora**

The Pennine Coal Measures Group of northern England contains an abundant and varied fossil fauna that includes both nonmarine and marine species. Nonmarine invertebrates include worms, gastropods, bivalves, eurypterids, crustaceans, insects and fish, whilst the marine faunas include foraminifera, worms, brachiopods, goniatites and conodonts (P222338). The nonmarine bivalves are of particular importance for biostratigraphical purposes and are the basis of a widely used biozonal scheme (P916114). Nonmarine fossils are concentrated in the few metres of argillaceous strata that form the basal zone of the various cyclothems, but many cyclothems have no preserved fauna or contain only a small range of invertebrate fossils. Apart from fish remains, a small range of vertebrate fossils has also been recorded, with amphibian bones recovered from mudstone above the Northumberland Low Main Seam at Newsham in Northumberland. Marine fossils are naturally restricted to the marine bands. However, some marine incursions in the southern part of the Pennine Basin failed to reach the more proximal Northumberland and Durham Coalfield, and most of those that did penetrate to the far north of the basin affected that area for only a relatively brief interval. Accordingly, marine bands in northern England (P916114) tend to feature a less varied and abundant fauna than those farther south.

Remains of the coal swamp vegetation are common fossils in the Coal Measures. Masses of compressed plant material make up the coal seams, roots are found in situ in seatearths, drifted leaf fronds and plant stems occur in mudstone and siltstone beds, and chaotic ‘log-jams’ of broken tree trunks and branches are a feature of some of the thicker sandstones. Study of Westphalian floras in northern Britain indicates that the flora of the floodplains was dominated by pteridosperms with some ferns, sphenopsids and lycopods, and that of the peat-forming swamps by lycopods. Today, the lycopod group is only represented by low-growing plants, but during the Westphalian some lycopods were tree-sized, the most familiar being *Lepidodendron*, with its distinctive bark pattern of rhomboidal scales, and its *Stigmaria* root system. *Calamites*, a giant relative of the present-day horsetail *Equisetum* was also common and grew around lakes and on point bars, whilst a range of pteridosperms grew on the levées alongside meandering rivers.

Following significant studies in the first half of the 20th century, a set of plant biozones was established for the Westphalian. More recently palynology, the study of plant spores of various
kinds, has become a standard biostratigraphical technique. It has the great advantage of requiring only a small rock sample as a source of many fossils, and been applied extensively in the correlation of borehole sequences of Westphalian strata from the North Sea and between the offshore and onshore basins. This has been an important development because, whilst correlations of the major Westphalian surfaces and marine bands are not in doubt, more precise local and regional correlations are hindered by the impersistent nature of Coal Measure facies which results in the lateral equivalence of major sandstone bodies and coals.

Bibliography


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