Bedrock Geology UK North: Carboniferous

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> **This topic provides descriptions of the rock types appearing on the British Geological Survey 1:625 000 scale map of the UK North and gives a brief explanation of their origins.**
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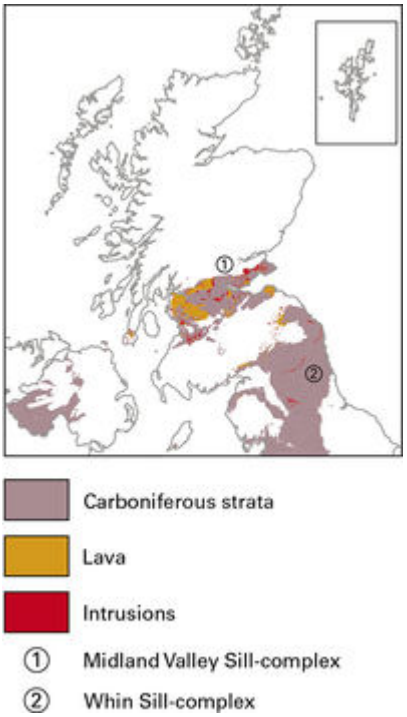
359 to 299 million years ago



P785810.

By early Carboniferous times Britain formed part of the southern margin of Laurussia and was situated in southern tropical latitudes; it drifted northwards during the remainder of the period to lie just north of the Equator. An initially arid climate became progressively more hot, humid and wet during that northward drift, and then reverted towards the end of the period. The tectonic regime was broadly extensional, with dextral strike-slip becoming progressively more important, particularly so in the Midland Valley of Scotland. The result was a sedimentary pattern controlled by basins and blocks of more or less subsidence. The blocks are characterised by thin and incomplete sedimentary successions. The basins were filled with thick and largely complete successions. They are commonly orientated north-north-east and in the Midland Valley are associated with growth synclines controlled by dextral strike-slip faulting. Intermittent volcanic activity, most notably in the Midland Valley, produced substantial lava fields locally, with related intrusion of sills, dykes and plugs.

The major extensional faults that controlled Carboniferous sedimentation and magmatism were commonly developed above older, Caledonian structures. The association is most clear at the margins of the Midland Valley where, by Carboniferous times, the Highland Boundary and Southern Upland faults were long-established terrane boundaries. Less obvious is the Caledonian influence on

the northern margin of the Pennine Basin where an important control on development of the Northumberland–Solway trough, the Stublick Fault, is rooted at depth into the Iapetus Suture Zone, the major Laurentia–Avalonia continental divide.

Whilst a broadly extensional tectonic regime affected northern Britain throughout the Carboniferous, things were very different farther south, where a continental collision in the mid Carboniferous brought together Laurussia and Gondwana to form the Pangaea supercontinent. In south-west England there was extensive folding and thrusting, with imposition of cleavage, at about 340 Ma—the Variscan Orogeny—but northwards the tectonic effects decrease and were produced later. Across northern Britain an increase in the relative importance of dextral strike-slip accompanied continued development of extensional basins, and contributed to the folding of the Carboniferous strata. However, there was no development of cleavage, and the truly orogenic effects of the Variscan event were restricted to south Wales and southern England, south of the 'Variscan Front'. By late Westphalian times significant sedimentation had ceased, general uplift was in progress, and there was widespread erosion.

Extensive spreads of Carboniferous strata now underlie large parts of northern England (the Pennine Basin), the Midland Valley of Scotland, and Northern Ireland. Isolated outliers with attenuated successions occur in the Southern Uplands, in Kintyre and on the island of Arran, and at a few localities in the western Highlands, but these parts of Scotland were mainly land areas with little or no deposition. Cyclic sedimentation was a dominant feature, controlled by the growth of large river deltas with the rock succession tracking a deepening marine environment (limestone to mudstone) into which deltaic sand built out until the delta top became emergent and was colonised by swamp vegetation. Additional cyclicity was induced by global changes in sea level, associated with the growth and melting of ice-sheets, interacting with more localised, syndepositional movement on the basin boundary faults. In general, the Carboniferous successions are laterally variable, particularly so in central Scotland where sedimentation was periodically restricted by the eruption of lava barriers.

The large-scale eruption of mainly basaltic lavas occurred intermittently throughout the Carboniferous, controlled by the broadly extensional tectonic regime. The extrusive rocks are most voluminous in the Midland Valley, where there are also innumerable minor intrusions: subvolcanic plugs, sill-complexes and dyke swarms. The latter in particular extend well beyond the areas in which Carboniferous lavas are preserved, and swarms of alkaline lamprophyre dykes have a wide distribution across the Highlands and as far north as the Orkney Islands. Radiometric dating shows that magmatism continued well into the Permian, even into the late Permian in Orkney.

Midland Valley of Scotland

Alternating beds of Tournaisian mudstone, dolomitic limestone and sandstone from the Inverclyde Group (Ballagan

Formation), seen in Ballagan Burn, Strathblane. P219228.

At the base of the succession lies the Inverclyde Group (C1), of Tournaisian age. It is characterised by nodular carbonate beds within an overall clastic sequence, and was deposited in meandering rivers and hypersaline lakes on coastal plains subjected to intermittent desiccation. The lowermost beds are upward-fining cycles of sandstone to mudstone. The sandstone is commonly cross-bedded and erosive and was deposited in braided, meandering river channels; the mudstone is the overbank deposit. Both main lithologies contain nodules and thin beds of pedogenic, concretionary carbonate (calcrete). The upper part of the group is made up mostly of mudstone containing thin nodular interbeds of argillaceous, dolomitic limestone (**Plate P219228**); thin sandstone beds are also ubiquitous. Thicker developments of fluvial sandstone mark the top of the group and contain pebble conglomerates derived both from Dalradian rock types and from intrabasinal limestone and mudstone. The thickness of the group varies considerably. It ranges up to almost 2000 m in some places but through a combination of local non-deposition and erosion is entirely absent in others.

Late Tournaisian tectonic uplift was responsible for the erosion of the Inverclyde Group, and for the deposition of the pebble conglomerates in its uppermost part. The erosional interval created a widespread unconformity, which now marks the base of the mainly Visean Strathclyde Group (C2). Above the unconformity, substantial thicknesses of volcanic rocks lie at the base of the Strathclyde Group: for example, the Clyde Plateau Volcanic Formation in the west of the region is dominated by mafic lava and may be as much as 1000 m thick (**Plate P064459**), in the east the Garleton Hills Volcanic Formation comprises almost 400 m of lavas and volcaniclastic rocks (**Plate P001097**). The major lava fields were probably fed by dyke swarms (though these are not obvious) whilst large isolated volcanoes, such as those now forming Arthur's Seat in Edinburgh (**Plate P001267**) and the Heads of Ayr were possibly up to 5 km in diameter and rose to heights of 1000 m above the surrounding plains.

Widespread, intermittent volcanism continued from the late Visean into the early Namurian, producing mostly mafic lava but with some volcaniclastic components. One major volcanic sequence that built up in the central and eastern parts of the Midland Valley, the Bathgate Group, may be as much as 1000 m thick and formed a partial barrier between sedimentary systems that persisted until well into Namurian times.

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  The lavas of the Clyde Plateau Volcanic Formation (Strathclyde Group) form prominent 'trap features' on the scarp

face of the Gargunnock Hills, near Stirling. P064459.

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Tuffs from the lower part of the Garleton Hills Volcanic Formation (Strathclyde Group) at Seacliff Harbour, near North Berwick, East Lothian, with the associated volcanic plug of the Bass Rock in the background. P001097.

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The Visean volcanic plug of the Arthur's Seat volcano, Edinburgh, cut by the probably Namurian dolerite sill of Salisbury Crags. In the foreground, Edinburgh Castle fortifies another volcanic plug. P001267.

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  Clackmannan Group cyclothems revealed in the face of the Blindwells opencast coal workings at Tranent, East Lothian. P005990.

In the west of the Midland Valley, west of the Bathgate Group barrier, the Clyde Plateau Volcanic Formation is succeeded diachronously by about 30 m of reworked, volcaniclastic strata, followed by about 250 m of largely fluviatile rocks, deposited in channel, floodplain and lacustrine environments. Sporadic, thin coal seams are developed in the latter sequence, whilst a few laterally persistent, marine limestone beds testify to intermittent marine incursions. In the east of the Midland Valley, the volcanic rocks are overlain by up to 800 m of interbedded sandstone and mudstone, with subordinate coal and limestone; the depositional environments were variously fluvial, deltaic and lacustrine. A more extensive lacustrine environment is then represented towards the top of the Strathclyde Group by a sequence of interbedded sandstone and mudstone that exceeds 1000 m in thickness and contains thin seams of oil shale that formed when the lakes were rich in algae. Subordinate lithologies present include coal, limestone (both marine and nonmarine varieties) and pale green, calcareous mudstone.

Towards the end of the Visean, localised uplift allowed erosion across the Clyde Plateau Lavas and their cover of Strathclyde Group sedimentary rocks. In the west of the Midland Valley the resulting topography was then buried by strata of the Clackmannan Group (C3-4), which has a late Visean to early Westphalian age range, spanning the Namurian. The resulting unconformity becomes less apparent eastwards until, in the east of the Midland Valley, the transition from the Strathclyde Group is conformable. The Clackmannan Group ranges up to about 1500 m in thickness and is largely made up of cyclically alternating repetitions of marine to paralic and fluviodeltaic sedimentary rocks (**Plate P005990**), although the top 350 m of the group consists largely of fluvial sandstone. Ideally, the cyclic sedimentary repetitions, or cyclothems, each show a typical upward sequence from limestone and marine mudstone, through deltaic sandstone capped by seatearth and coal, before a return to limestone (**Figure P785802**). Many scores of cyclothems make up the full succession, and many of them are incomplete or have different parts preferentially developed. Throughout accumulation of the Clackmannan Group, deposition was interrupted by tectonic instability, leading to local unconformities, sedimentary breaks, and renewed volcanism. During the same Namurian to early Westphalian interval, dolerite sills were widely intruded (**Plate P001267**).

The Coal Measures Group (Scotland) (C5–7) occupies much of the Westphalian in the Midland Valley. Some volcanic activity continued, with the thickest preserved sequence of mainly pyroclastic rocks now seen in Fife. The group is characterised by fluviodeltaic cyclothems with only a subordinate marine influence, although some of the marine bands that are present have a

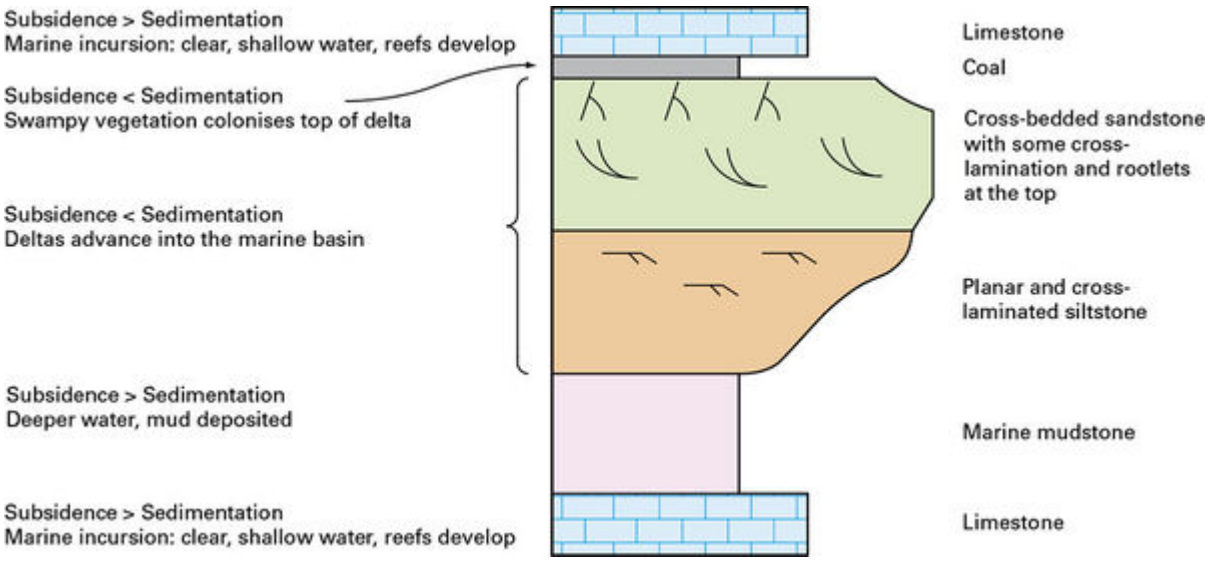
widespread distribution and form important links in stratigraphical correlation. Typical Coal Measures cyclothems show coal (and/or sideritic ironstone in places) overlain by mudstone with a fauna of nonmarine bivalves, and then by transgressive sandstone; in turn the sandstone is overlain by a seatearth and coal, followed by mudstone as the cycle repeats. Plant fossils are abundant. In broad terms, the region lay near the northern edge of an extensive coastal plain that covered much of north-west Europe and probably extended far to the west. As slow, northwards continental drift continued, the climate became increasingly seasonal and arid so that, within the uppermost Coal Measures, oxidized red beds and calcrete developments are increasingly common.

A particular feature of late Carboniferous magmatism was the intrusion of the large, tholeiitic, Midland Valley Sill-complex of eastern Scotland and an associated swarm of dolerite dykes that can be traced from the Outer Hebrides to the Central Graben of the North Sea. The sill-complex itself consists of one or more leaves, each 25 to 170 m thick and linked by transgressive dykes. The composite thickness reaches 200 m and the complex underlies an area of about 1900 km^2 around the inner Firth of Forth. Radiometric dating shows the Midland Valley Sill-complex to be about 306 million years old, a little older than the comparable Whin Sill-complex of northern England, to be described in a later section.

Southern Uplands

The Southern Uplands massif formed a mainly land area of minimal deposition during the early Carboniferous and was a relatively effective barrier between the Midland Valley and the Pennine Basin—the major depositional setting for the Carboniferous successions of northern England. Limited deposition at a few localities took place from the late Visean onwards with Clackmannan Group strata resting unconformably on Ordovician and Silurian rocks in, respectively, the Sanquhar and Thornhill outliers. The Clackmannan Group succession is severely attenuated relative to its Midland Valley expression, but it is succeeded by a more complete Coal Measures Group that is over 600 m thick at Sanquhar, although thinner, lacking in coal, and pervasively reddened at Thornhill.

Across southern Scotland there are numerous Carboniferous intrusions. Dolerite- or agglomerate-filled volcanic necks probably mark sites of mafic lava eruption, whereas a number of larger, sheet-like intrusions tend to be more felsic in character.



The lithological sequence in an idealised cyclothem. P785802.

Northern Ireland

The Carboniferous sequence in Northern Ireland reflects broad cycles of marine transgression

and regression with depositional environments developed close to the southern margin of Laurussia. Throughout the succession there is evidence of intermittent tectonic activity, comparable at times to that influencing contemporaneous deposition in the Midland Valley of Scotland. However, the stratigraphy of the two regions is significantly different, reflecting the interaction between local tectonics controlling basin subsidence, and global glacio-eustatic effects. The preserved Carboniferous sequence in Northern Ireland has a cumulative thickness of about 7000 m and is mainly made up of strata of Tournaisian, Visean and early Namurian age.

The lower part of the succession throughout much of the Carboniferous outcrop in Northern Ireland is assigned to the Tyrone and Carlingford limestone groups (C2) and their several lateral equivalents at the base of the sequence (C1). Deposition commenced in the Tournaisian or early Visean: fluvial to shallow marine clastic rocks alternate with limestone and mudstone and were deposited largely in continental and peritidal environments. Later, but still in the early Visean, marine transgression resulted in deposition of a thick sequence of fossiliferous limestone and mudstone; some deltaic sandstones with thin coal interbeds are also present. Further deepening in the marine environment, and northwards migration of the coastline, allowed the development of more massive, siliceous limestone at the top of the Tyrone Group (**Plate P225292**). However, at the eastern margin of the Carboniferous outcrop in counties Armagh and Tyrone, the late Visean succession is represented by the Armagh Group (C3), over 500 m of shallow water limestone (commonly oolitic), thin sandstone and mudstone. A small outlier of this sequence forms the Castle Espie Group at the north end of Strangford Lough. Within the Armagh Group succession there are numerous palaeokarst surfaces, covered by a residual reddish clay, which demonstrate periodic subaerial emergence and weathering of the limestone surface. In places, deep palaeodolines — fossil swallow holes — have been preserved.

Massive limestone from the upper part of the Tyrone Group forming the precipitous crags at Knockmore Cliff, County Fermanagh. P225292.

Late in the Visean, a regressive phase occurred and in the western part of the basin there is a disconformity below the succeeding Leitrim Group (C4) (550 m thick). Deposition of this group commenced in shallow water, intertidal, and fluvial environments with laminated (stromatolitic) limestone of sabkha facies being particularly distinctive. Succeeding strata of latest Visean and early Namurian age represent cyclothemic deposition of deltaic sandstone and shallow marine mudstone and closely resemble the Namurian Yoredale Group of northern England (see below). In north-east Antrim, the Ballycastle Group (C4) unconformably overlies Dalradian rocks and consists of about 700 m of late Visean basalt lava and tuff, and late Visean to early Namurian sandstone and mudstone with coal seams; it closely resembles the coalfield successions in the western Midland Valley of Scotland.

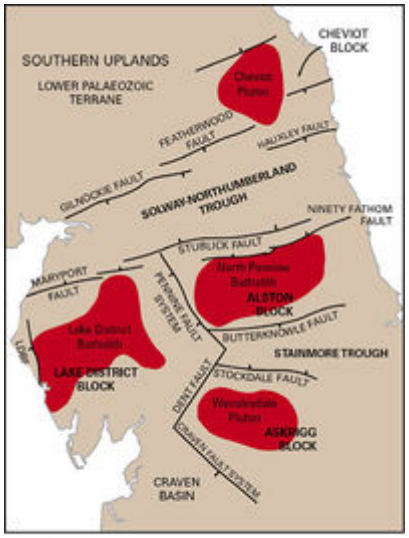
Elsewhere during the late Visean to early Namurian interval, continental sediments were deposited that now make up the Kilskeery Group (C4). Sandstone, conglomerate and mudstone with calcrete form a sequence, about 2500 m thick, in parts of counties Tyrone and Fermanagh and make up most of the structurally defined 'Fintona Block'. At the northern margin of the block, unconformably overlying Dalradian rocks, are 500 m of purple sandstone with thin rhyolitic lava intercalations. This sequence (Greenan Sandstone Formation) is also of late Visean to early Namurian age but was deposited in a different continental basin to the Kilskeery Group, despite the geographical proximity of their respective outcrops.

In Northern Ireland much of the Namurian is represented by a depositional hiatus. However, in the eastern part of County Tyrone, early and late Namurian fluvial to deltaic sandstone of the Millstone Grit Group is associated with seatearth and numerous coal seams up to 2.6 m thick; it is equivalent to part of the Scottish Clackmannan Group. In the same area, 275 m of Westphalian Coal Measures strata are mostly mudstone but include coal seams. At the northern margin of the Fintona Block, in the south-west of Tyrone, the early Westphalian Slievebane Group comprises about 80 m of thinly interbedded mudstone, siltstone and calcrete, succeeded by up to 1000 m of volcaniclastic conglomerate and sandstone.

Pennine Basin of Northern England

The Southern Uplands massif formed a barrier between the Carboniferous depositional systems of the Scottish Midland Valley and those in northern England. In the latter area, sedimentation patterns were strongly controlled by subsiding basins and more stable blocks, all developed within a larger basin that extended from Ireland, eastwards through north Wales, northern and central England — where it is known as the Pennine Basin — to the North Sea. Within northern England, the stable blocks of the Pennine Basin (**Figure P785803**) are underpinned by granite batholiths and characterised by thin and incomplete sedimentary sequences; the basins were infilled with sediment and contain thick and relatively complete sedimentary successions.

Along the northern margin of the Pennine Basin, Tournaisian strata similar to those seen in the Midland Valley extend the Inverclyde Group southwards. They were deposited as mud, sand and carbonate in fluvial, alluvial fan and lacustrine environments, by river systems flowing across a coastal plain. Contemporaneously, farther south and west, thin and patchily reddened successions of pebble conglomerate, limestone, sandstone and mudstone were deposited in more locally developed alluvial fan and paralic environments as basin subsidence commenced. These strata, the Ravenstonedale Group (C1), are up to about 300 m thick and are preserved in isolated outcrops at the base of the Stainmore Trough succession, across the Alston Block and in west Cumbria and the Isle of Man. Basaltic lavas occur locally, usually within the alluvial fan facies. They are particularly extensive along the northern margin of the Solway–Northumberland Trough, within the Inverclyde Group, but are also well developed in the northern Lake District around Cockermouth.



The fault network that controlled Carboniferous sedimentation patterns. P785803.

Sedimentation at the northern margin of the Pennine Basin continued from the Tournaisian into the Visean with accumulation of Border Group strata (C2). The group is fairly thin at the northern margin of the basin but thickens southwards to more than 1300 m in the centre of the Northumberland Trough. Its lower part comprises cyclical sequences of sandstone, mudstone and distinctive algal limestone with an irregular, nodular appearance; sediment accumulation took place in shallow and clear sea water. Higher in the group, the mudstone may be reddened locally and the sandstone is more variable, showing a range of fluvial to shallow marine characteristics, whilst seatearth and thin coals become fairly common. These changes demonstrate the encroachment of a deltaic to peritidal environment. At the top of the group, but appearing diachronously, is the Fell Sandstone, a sequence up to 500 m thick that is dominated by thickly cross-bedded and coarse-grained, deltaic sandstone becoming conglomeratic locally.


Limestone pavement formed near Orton, west of Kendal, by weathering of a surface within the Great Scar Limestone Group. The Vale of Eden and Alston Block form the distant background. P223200.

The Yoredale Group: the Great Limestone (Alston Formation) overlain by thick cyclothems of mudstone and sandstone (Stainmore Formation). Heights Quarry, Weardale, County Durham. P548113.

In the south of this region, the Visean succession above the Ravenstonedale Group, is characterised by its limestones, which produce karst scenery where they are exposed (**Plate P223200**). They dominate the Great Scar Limestone Group (C2) and accumulated in shallow, tropical seas. In the deeper parts of the basins, some of the limestones were deposited as clastic sediment, eroded from the shelf limestone and interbedded with marine sandstone and mudstone. Towards the basin margin limestone accumulation was interrupted by the influx of deltaic sand, perhaps in response to periodic marine regression that would also have left limestone exposed on the blocks, allowing karstic weathered surfaces to develop. Subsequent transgression then re-established limestone sedimentation. The Great Scar Limestone Group is about 100 m thick on the Alston Block, about 400 m on the Askrigg Block, and nearly 800 m in the Stainmore Trough.

From the mid Visean, and through much of the Namurian, a major delta system built out southwards, allowing sand and mud to encroach into the Pennine Basin. The resulting alternating sequence of marine (limestone/mudstone) and deltaic (sandstone/siltsone) deposits, the Yoredale Group, shows a strongly cyclic pattern of sedimentation, with a series of cyclothems that is similar in appearance to parts of the Clackmannan Group in the Midland Valley. As in that group, the rocks record the advance of sandy deltas into the marine basin, and the colonisation of the delta surfaces by swamp vegetation (**Plate** P548113**). The Yoredale Group was deposited in low-lying alluvial and deltaic flats that were subject to regular marine incursions. Its thickness varies from only a few tens of metres at the block margins to well over 1500 m in the centre of the basins.**

Across the north of England, three major divisions of the Yoredale Group are recognised. The lowermost is the Visean Tyne Limestone Formation (C2), up to 850 m of mainly mudstone and siltstone with thin limestone and sandstone interbeds. At the base of the formation in the east of the region, in Berwickshire and Northumberland, the sequence is deltaic with numerous thin coals. Above the Tyne Limestone Formation, the Alston Formation (C3) comprises about 350 m of bioclastic limestone, sandstone and mudstone, typically forming regular cyclothems; coal is relatively rare. At the top of the Alston Formation is the thick and widespread Great Limestone. The Namurian Stainmore Formation (C4) overlies the Great Limestone; it is up to about 1000 m in thickness and consists of cyclical repetitions of sandstone, siltstone and mudstone with sporadic thin limestone and some coal. A slightly different Namurian sequence seen in west Cumbria and the Isle of Man consists mostly of mudstone and laminated siltstone with thin coal seams and variable, channellised sandstone beds. In west Cumbria that sequence is about 200 m thick and has been assigned to the Hensingham Group.

The deltaic lithofacies that dominates the Namurian succession spread progressively southwards to eliminate the extensive carbonate reefs, although thin beds of black, calcareous mudstone mark recurring marine incursions and provide invaluable stratigraphical correlatives. Towards the centre of the Pennine Basin, around the Askrigg Block, stacked deltaic sandstone bodies dominate the succession and comprise the Millstone Grit Group (C4). The 'Millstone Grit' is typically a coarse-grained, arkosic sandstone. It was deposited through the repeated progradation of deltas into relatively deep water and thickens southward to over 1200 m. Thin delta-top sequences show the sandstone fining upwards into mudstone, associated commonly with seatearth and more rarely with beds of limestone, coal and ironstone.

Deep-water, hemipelagic limestone with thin mudstone interbeds from the Craven Group (Bowland Shale Formation), Scarlett Point, Isle of Man. GS1039.

Around the Askrigg Block the dominantly clastic Namurian sequence conformably succeeds a late Visean Yoredale Group sequence but, to the south and west of the Lake District Block, the distinctive calcareous mudstone of the Craven Group (C3) intervenes, spanning the Visean–Namurian boundary. The mudstone sequence includes thin interbeds of sandstone and bioclastic limestone. The latter accumulated through hemipelagic fall-out in deep water well ahead of the advancing deltas, whence sporadic turbidite flows introduced the sandstone interbeds. In south Cumbria and the Isle of Man (**GS1039**) the group is relatively limestone-rich and, respectively, only about 100 and 250 m thick. Included with the Isle of Man sequence is a thickness of about 50 m of volcaniclastic debris flows that include large rafts of basaltic pillow lava. Southwards, into the Craven Basin and beyond, the thickness of the Craven Group increases dramatically to more than 5000 m. Limestones developed locally on structural highs within the basin and are assigned to the Bowland High Group (C3).

By Westphalian times, the region had evolved into a low-lying landscape of rivers and lakes atop a major delta system. Lush equatorial vegetation was supported but there were still periodic marine inundations. In this environment the Pennine Coal Measures Group (C5–7) accumulated. It was originally deposited in a broad, continuous basin but subsequent tectonism and erosion has isolated the Coal Measures into separate coalfields where up to about 1000 m of strata are preserved. Cyclic sedimentation prevailed and has resulted in a sequence of cyclothems that individually range up to about 10 m thick. The base of each cycle is marked by a mudstone, usually nonmarine, above which there is an upwards and alternating progression from sandstone to mudstone, with an overlying assemblage of seatearth, coal and, in places, ironstone. The Pennine and Scottish coal measures groups are lithologically similar, and share a common origin, but their stratigraphical correlation is not precise.

The Great Whin Sill, looking south-west over Crag Lough towards Haltwhistle.
P222330.

The youngest Carboniferous strata seen are the late Westphalian to Stephanian red sandstones and mudstones of the Warwickshire Group (C8). These range up to about 500 m thick in the Craven Basin, across west Cumbria and into the Scottish border area. The base of the group is strongly diachronous. Deposition occurred in a fluvial to deltaic plain setting but under increasingly arid, oxidising climatic conditions; coal is largely absent and thin freshwater limestones occur locally.

As in the Midland Valley, late Carboniferous to early Permian magmatism produced a large tholeiitic sill complex. This, the Whin Sill-complex, is best known as providing the foundation to Hadrian's Wall (**Plate P222330**) but it also appears farther south and underlies at least 4000 km^2 of north-east England. The complex comprises at least four individual sills, and numerous associated dykes of tholeiitic quartz-dolerite, with the main body attaining a maximum thickness of about 80 m. Radiometric dating shows the Whin Sill-complex to be around 300 million years old, a little younger than the comparable Midland Valley Sill-complex described previously.

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