Geological history of Northumbria

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Northumbria (Northumberland, Durham, Tyne & Wear and Cleveland north of the Tees) is dominated by rocks of Carboniferous age (Figure 1) (Figure 2). On the northern margin of the area, they rest on a range of older rocks in the Scottish borders, principally Silurian sediments and the lavas of the early Devonian Cheviot volcano. Lower Carboniferous sediments, which crop out on the coast of north Northumberland, form a broad belt inland, skirting the ancient volcanic pile and striking southwest parallel to the Scottish border, before turning south-southeast along the Pennine front. Gentle easterly and southeasterly dips bring in the mid Carboniferous to the southeast, forming a narrow triangular outcrop with its apex on the mid Northumberland coast and its base forming the north Pennine peaks and the Durham dales. The upper Carboniferous Coal Measures in turn form the south Northumberland coast and extend inland as a north–south outcrop, widest at the Tyne and narrowing into south Durham. There, the Coal Measures are overstepped by the Permian, which rests unconformably upon them. These Permian rocks form the high ground in the east of County Durham and the distinctive buff coastal cliffs of Durham and Tyne & Wear. They pass up into Triassic rocks underlying the low ground of Tees-side. Younger Mesozoic and Tertiary rocks, apart from some small igneous intrusions, are not preserved in Northumbria, but the effects of the Pleistocene glaciation are apparent everywhere. Tills mantle the solid rocks, particularly thickly in central and south Durham.

As well as dominating Northumbria geologically, Carboniferous rocks, with their natural resources, have been a major socio-economic influence on the region. Mineral deposits have long been worked in the Pennine dales, and the rich coal resources of the Northumberland and Durham Coalfield underpinned the heavy industry of Tyneside, Wearside and Tees-side. The Permian has contributed also, with salt and anhydrite deposits formerly worked under Tees-side. The region is still in transition following the painful contraction of its powerful industrial base of the earlier loth century.

The earliest geological events recorded in the rocks of the region are the final stages in the closure of an ancient seaway, the Iapetus Ocean, which separated the northern and southern halves of the British Isles in the Lower Palaeozoic (Figure 3)a. England, Wales and southeast Ireland were part of the microcontinent of Eastern Avalonia. This, together with Western Avalonia, moved northwards towards the equator from high southern latitudes, rapidly during the Ordovician and more slowly during the Silurian, as the ocean closed. Sediments deposited on the northern margin of the microcontinent, together with subduction-related volcanic rocks, are exposed in the Lake District and the west face of the Pennines, but only a very small inlier in Teesdale reveals a part of this sequence east of the Pennines in Northumbria. However, borehole evidence in central Durham proves rocks of this type at 860 m, thus showing they extend beneath the county at depth.

Scotland and northwest Ireland in the Lower Palaeozoic existed as parts of the margin of the Laurentian plate. During the later stages of closure and immediately afterwards, slices of the Laurentian plate margin were shuffled together along major strike-slip faults, producing the pattern of outcrops we see today. The Southern Uplands forms one of these slices, and along its southeastern margin Silurian rocks are exposed (Excursion 1, Excursion 2, Excursion 4, Excursion 10). These are thick turbidites, predominantly of sand-grade, with some shales, locally containing graptolites, sourced from rising land to the north and deposited in a narrow seaway, the remnant of the former ocean. Graptolites indicate a Llandovery age for outcrops on the coast between Siccar Point and St Abb's Head. Between Coldingham and Eyemouth, acritarchs suggest an early Wenlock age for some beds, but otherwise here and south to Burnmouth no diagnostic fossils have been found. Inland along the southeast margin of the Southern Uplands, scattered graptolite records indicate a Wenlock age. There are no records of younger Silurian sediments. Uplift, compression and deformation resulting from the collision of Eastern Avalonia and Laurentia affected the Southern Uplands area in late Silurian times and the Lake District-Teesdale area in the early Devonian. This orogenic episode concluded the long and complex Caledonian Orogenic Cycle, which resulted in a belt of fold mountains and uplands striking across the newly welded continental mass of Laurentia, Baltica and Avalonia, following the line of the former seaway. The area of the British Isles affected was from the Northern Highlands to North Wales.

As the Caledonian mountains rose, weathering under hot, arid conditions provided masses of debris which accumulated in alluvial fans in intermontane basins. These deposits constitute the Old Red Sandstone of Devonian age (Figure 3)b. In addition, the orogenic event caused melting within the crust which gave rise to early Devonian volcanic activity at the surface. The Cheviot area was one such volcanic centre, surrounded by thick sequences of pyroclastic rocks and lava flows, mainly of andesitic composition, and possibly exceeding t000 m thick (Excursion 4). Erosion deep into the volcanic pile has revealed a slightly younger granite intrusion into the core of the complex which now crops out at its centre. Other late Caledonian granites were emplaced in the Lower Palaeozoic rocks of the Alston and Askrigg Blocks (now covered by a few hundred metres of Carboniferous sediments but detected geophysically and proved by boreholes), the Lake District, Southern Uplands, and under what is now the North Sea (Figure 3)b. North of Cheviot, early Old Red Sandstone breccias, conglomerates, red sandstones, marls and calcretes up to 600 m thick are associated with the volcanic rocks and rest with strong unconformity on folded Silurian sediments. West and north of Cheviot, these in turn are overlain by a second cycle of similar sediments, with common calcretes towards the top, unconformable on the Lower Old Red Sandstone, Cheviot volcanics and Silurian greywackes (Excursion 1, Excursion 2, Excursion 10). In places, this sequence contains evidence of a late Devonian age and is thus referred to the Upper Old Red Sandstone. Elsewhere it passes conformably upwards into early Carboniferous fluvial and lacustrine sediments. This second pulse of coarse debris reflects a phase of tectonic activity in the mid Devonian that rejuvenated the upland source areas.

By the early Carboniferous, relief on the Caledonian mountains had been somewhat reduced. A period of crustal extension followed the end of the orogenic cycle and broad, fault-bounded half-graben basins began to develop to the north and south of the Cheviot Block. Locally, conglomerates accumulated at the base of the Carboniferous sequence flanking the Cheviot (Excursion 9). The largest of these basins, the Northumberland Trough, developed along the line of the Iapetus suture, bounded to the northwest by the Southern Uplands and to the south by the Ninety Fathom-Stublick-Maryport Fault system, and the Alston and Manx-Cumbria Blocks. It was itself split into an easterly Northumberland Basin and a westerly Solway Basin by a basement ridge in the Bewcastle area (Figure 3)c. Extension appears to have been marked by the localized outpouring of basaltic lavas in the early Dinantian (Lower Carboniferous), cropping out along the northwestern margin of the Northumberland Trough (Excursion 10). Lower Carboniferous successions are much thicker in the more rapidly subsiding basins, and thinner and less complete on the intervening blocks.

The Tweed Basin, north of the Cheviot Block, with 1300 m of sediments, and the Northumberland Basin, with c.5000 m, have similar depositional histories. In the early Carboniferous, sediments derived from the north and east fed a broad coastal plain of channel sandstones and floodplain siltstones with frequent thin bands cemented by dolomite (cementstones) in the lower part of the sequence. Conditions remained arid and ephemeral lake and flood-plain deposits contain crystals of gypsum, anhydrite and halite, now as pseudomorphs. These form the Cementstone Group (Excursion 1, Excursion 2, Excursion 9), which in places in the Tweed Basin transitionally succeeds the Upper Old Red Sandstone. The climate became warmer and more humid during the Dinantian. Uplift of the source area in wetter conditions caused the progradation of a braided river system across the Northumberland Basin depositing the Fell Sandstone Group, a sequence dominated by planar and trough cross-bedded sandstones (Excursion 2, Excursion 9). These rocks now form significant high ground across mid Northumberland. Crossing into the Solway Basin, with about 7000 m of Carboniferous deposits, the Lower Border Group consists of interfingering sandstones, shales and thin limestones, the result of deltas prograding from the northeast and northwest into a shallow marine gulf (Excursion 5). Fossils in some of the limestones reflect close to normal marine conditions, but others contain stromatolites and mounds of vermiform 'gastropods' indicating fluctuating salinity. Thick sandstone bodies in the upper part of the Lower Border Group and the Middle Border Group result from westward progradation of the Fell Sandstone delta.

Later in the Dinantian, the marine influence from the southwest increased as the elastic supply from the north and east diminished. Repeated cycles of marine limestone, shale and sandstone in the Upper Border Group of the Solway Basin transgressed across the Northumberland Basin, where in addition, thick coals developed at the top of many cycles, and into the Tweed Basin, where proximity to the shore line is reflected in thinner limestones and more persistent coals. These sediments form the Scremerston Coal Group of the Northumberland and Tweed Basins (Excursion 3, Excursion 10), whose coals have been widely worked. In the succeeding Lower and Middle Limestone Groups (Excursion 3, Excursion 6, Excursion 7, Excursion 11), which are equivalent to the Liddesdale Group in the Solway Basin, the marine influence is further enhanced, with limestones thicker and coals thinner or absent. These are classic Yoredale cycles. By the late Dinantian, conditions had become increasingly uniform across Northumberland and the differentiation into basin and block less marked. At this time, the sea began to transgress across the Alston Block to the south and in the latest Dinantian, uniform Yoredale facies extended, from the still emergent but reduced land mass of the Southern Uplands, right across the whole of the Northumbrian area (Excursions 15–17). These changes mark the beginning of a gradual transition from extensional, fault-bounded basinal subsidence to a phase of much broader subsidence caused by cooling and contraction of lower crustal rocks which affected the whole of Northern England. However, despite uniformity of facies, thickness differences between block and basin areas persisted through much of the Namurian.

In Northumbria, the Yoredale cycles extend up into the Namurian as the Upper Limestone Group (Excursions 7, Excursion 11, Excursion 15, Excursion 16, Excursion 17). Although the thickest of all the Yoredale limestones, the Great, marks the base of the Namurian, upwards the limestones thin and the sandstones increase in thickness. Towards the top of the Namurian, marine influences and the limestones die out and the succession is dominated by cycles of erosive, coarse-grained, fluvial sandstones with interbedded fine sandstones, siltstones and mudstones. This is a thin northern equivalent of the Millstone Grit of the Central Pennines (Excursion 7, Excursion 15). There, the grit facies is developed throughout the Namurian and exceeds 2000 m in thickness. In Northumbria, the Namurian thins from just over 500 m in the subsurface near Newcastle to about 270 m on the Northumberland coast, of which only the top 50 m or so is of Millstone Grit facies.

By the beginning of the Westphalian, Northumbria was part of a broad Central Pennine Basin, in which maximum subsidence was in the Manchester area (Figure 3)d. There, the Coal Measures are over 3000 m thick, compared to some 875 m in the Northumberland and Durham Coalfield (Excursion 8, Excursion 15, Excursion 17). Cyclic sedimentation of shale/mudstone–sandstone–seatearth–coal, continued under the influence of deltaic processes, often as small fluvially dominated deltas prograding into fresh to brackish water flood plain lakes. Major distributaries are marked by ribbons of erosive, cross-bedded sandstones cutting down into the coal-bearing sequences. Marine bands are most common in the lower part of the succession, and where present can be correlated over large areas. There is a gradual shift to more fluvial dominated conditions higher in the Westphalian. The thickest and most productive coals occur in the lower half of the Middle Coal Measures. Coal mining in Northumbria was at its peak in the igth and early loth centuries. The last 30–40 years have seen a drastic reduction in underground working as first the inland mines became exhausted or uneconomic and most recently the larger coastal pits have been closed.

The volcanic and intrusive activity that had continued throughout much of the Carboniferous further south in England was absent in the north. Northumbria, however, was distinguished by a single, PermoCarboniferous, intrusive event of considerable volume. This is the Whin Sill complex, a tholeiitic dolerite fed by dykes emplaced along approximately east–west extensional fractures formed at this time (Excursion 6, Excursion 10, Excursion 11, Excursion 16). The sill, in composite form, reaches 100 m thick and extends from Teesdale to the Scottish borders, abruptly changing its stratigraphical level via faults and joints from the mid Dinantian to the Lower Coal Measures. It is lowest in the sequence at its northern and southern extremities and highest around Alnwick (up to Namurian) and in the Midgeholme Coalfield (Figure 1). The term 'sill' originated locally to describe any persistent hard bed (e.g. the Firestone Sill — a Namurian sandstone) and only subsequently took on its modern restricted meaning as an igneous rock.

Carboniferous, particularly Lower Carboniferous sediments of the Alston Block, also host the many mineral veins and flats of the North Pennine Orefield (Excursion 14). Galena was the main mineral, extracted for lead, but sphalerite was also common together with, in the central area', minor amounts of pyrite, marcasite and occasionally chalcopyrite and pyrrhotite. The gangue minerals are zoned, with fluorite predominating in the central part of the Alston Block, surrounded by baryte, witherite or calcite. The zoning was temperature related, with fluids reaching 2 2 0°C in the fluorite area, dropping to as low as 60°C on the margins of the orefield. Ore-bearing fluids are thought to have originated as brines forced out of the thick surrounding sedimentary basins, stripping out metals as they migrated through the Carboniferous, Lower Palaeozoic and granite rocks, and channelled towards the block along its bounding faults. High heatflow from the Weardale Granite, a Caledonian intrusion in the Lower Palaeozoic basement of the Alston Block, set up a convection cell with the hottest brines rising through the granite and the Dinantian sediments of the block at its centre. The main phase of mineralization was most likely Permian, although potentially mineralizing fluids are still circulating in the area. The deposits have been worked probably since Roman times and extraction peaked in the Igth century. Today the gangue minerals, fluorite and baryte, are the main resource; lead and zinc ores are produced as by-products.

Only part of the Upper Coal Measures and no Stephanian sediments are preserved in Northumbria. A period of uplift, tilting and foiding, followed by deep weathering and erosion, occurred in late Carboniferous-early Permian times due to the compressional effects of the Variscan Orogeny to the south, and a major eustatic sea-level fall as water was locked up in the glaciation of the southern continent of Gondwana. A regional unconformity exists below the earliest Permian deposits, which overstep folded Coal Measures in the south of County Durham to rest on Namurian and locally Dinantian beds. Climatic conditions had changed from the tropical hot, wet regime of the Westphalian to a hot, arid regime in the early Permian as the British Isles drifted northwards from the equator. These conditions led to the formation of a zone of reddening 5–10 m, exceptionally 300 m, thick below the Permian unconformity. On this continental landscape, east of higher ground in the region of the Pennines, the surface had been reduced to a vast, rolling peneplain extending out into the area of the North Sea, on which the earliest sediments preserved are lag breccias and breccio-conglomerates (Figure 3)e. The succeeding Yellow Sands, now preserved as a series of east-northeast – west-southwest ridges up to 60 m thick in County Durham, are dune sands containing large-scale cross-bedded units indicating derivation from the east and northeast (Excursion 8, Excursion 13).

The beginning of the Upper Permian was marked by the rapid inundation of the low lying areas east and west of the Pennines (Figure 3)e. In the North Sea Basin, the Zechstein Sea reworked the upper part of the Yellow Sands. The deposits in the sea are strongly cyclic due to eustatic sea level rise and fall, resulting in the repeated expansion and contraction of the marine area under strongly evaporitic conditions. At the base of the first cycle is a very finely laminated deposit of alternating limestone or dolomite with organic rich layers, formed on the euxinic sea floor. This, the Marl Slate, is famous for the beautiful preservation of palaeoniscid fish, which swam in the oxygenated near surface waters, together with the remains of reptiles that fell or were transported into the sea. Euxinic conditions persisted throughout the first cycle in deeper parts of the basin but around the shallow oxygenated margins, oolitic carbonates developed, protected on their seaward side by a massive bryozoan-algal shelf edge reef, up to 100 m thick and more than 30 km long, that is well exposed in County Durham (Excursion 13). The cycle is completed by the basin-ward development of the Hartlepool Anhydrite, probably as a primary precipitate on the basin floor during a fall in sea-level. Four further cycles of carbonate and/or marl deposition, of decreasing thickness, with overlying and basin-ward evaporites are known. The carbonates are often oolitic and stromatolitic, with restricted faunas. Those of the second cycle pass into deeper water slope carbonates showing signs of slumping, and in which a wide range of concretionary structures are developed. At the top of the third cycle, the Billingham Anhydrite and overlying Boulby Halite have been extensively mined beneath Tees-side where they formed the basis for the local chemical industry. Further south in east Yorkshire, the halite gives way in its upper part to the Boulby Potash, which is mined at depth northwest of Whitby. Thus the third cycle represents the most complete development of an evaporitic mineral sequence in the region.

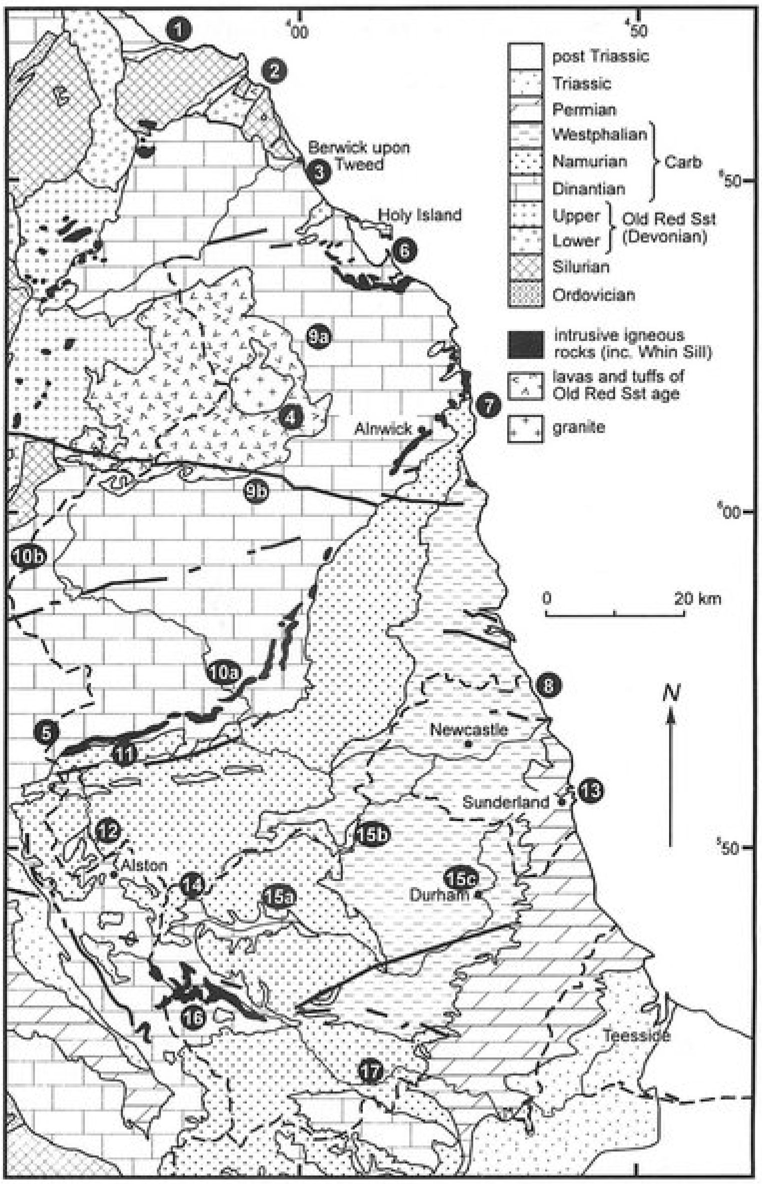
The cyclic deposits of the Upper Permian grade upwards into red marls with thin lenses of anhydrite and ultimately thick, dominantly fluvial sandstones of the Triassic Sherwood Sandstone Group in southeast Durham and Tees-side. These deposits are almost completely unfossiliferous and the Permo-Triassic boundary is placed as a matter of convenience at a distinctive level within the marls. The Sherwood Sandstone is succeeded, after a short break, by the Mercia Mudstone Group, a sequence of vari-coloured sandstones and red-brown and green marls, with beds of dolomite, anhydrite and evaporite residues in the lower part. These were the deposits of an extensive coastal plain, intermittently flooded by shallow saline waters from the southeast. Triassic rocks are now known almost exclusively from borehole evidence around Tees-side.

Younger deposits, excepting the widespread glaciogenic sediments of the recent past, are unknown in Northumbria, although evidence from outside the area suggests that the major marine transgressions of the Lower Jurassic and Upper Cretaceous may have covered the area. Any sediments deposited were subsequently removed, particularly during the Tertiary, when the northwestern parts of the British Isles underwent rapid uplift following the northward extension of Atlantic seafloor spreading between Greenland and Scandinavia. Associated igneous activity in centres in western Scotland extended its influence into Northumbria in the form of tholeiitic dykes, the best known being the Armathwaite-Cleveland Dyke in south Durham (Excursions 16, 17), and the Tynemouth and Acklington dykes in Northumberland. All have a similar late Palaeocene age and appear to be far-flung representatives of the Mull dyke swarm.

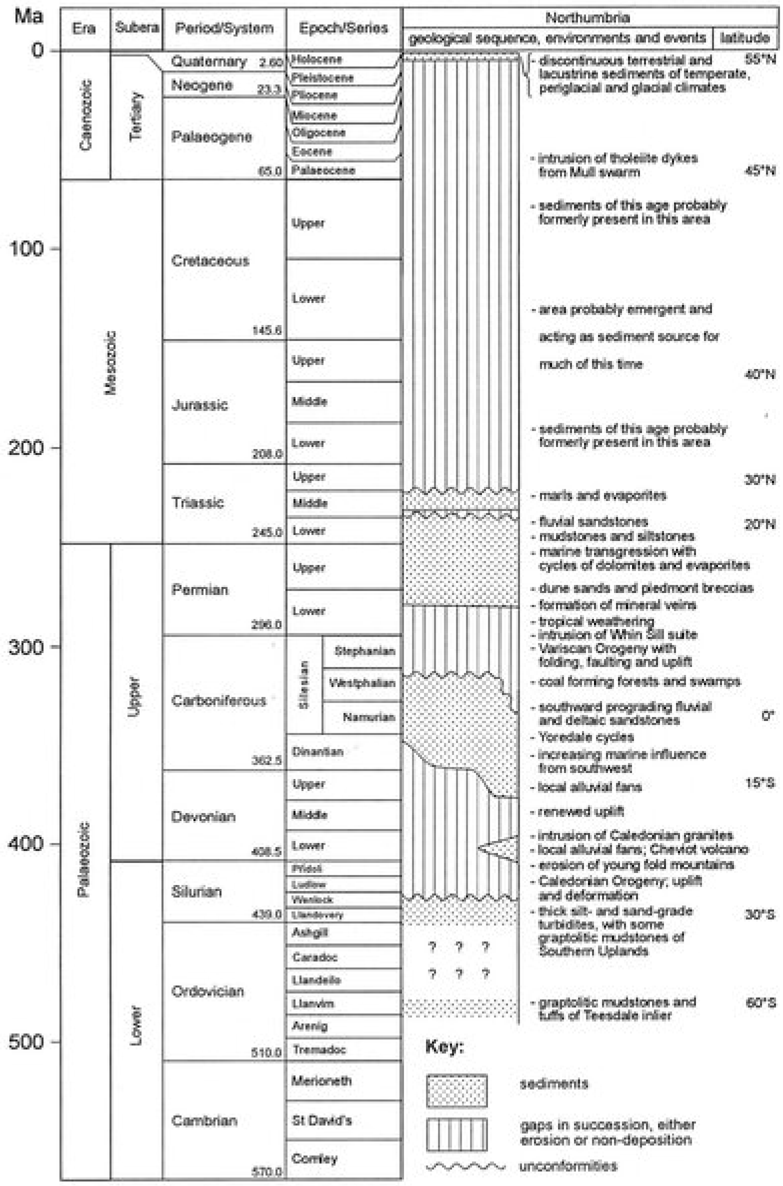
A general trend in global cooling begun in the early Tertiary culminated in the sequence of cold and temperate climates which have affected the British Isles over the last 2.6 Ma. Several advances of ice probably covered Northumbria but almost all the deposits now preserved relate to the last extensive ice sheet glaciation in the late Devensian, around 17 000 yr B.P. (Figure 3)f; Excursion 12. In upland regions, most of the soils and unconsolidated deposits were stripped off and the hills and ridges moulded and streamlined. Ice, moving southwards from Scotland and the Cheviot, and extending into the westernmost part of the North Sea Basin, deflected to the southeast ice moving into the region from the Lake District and Galloway. Vast quantities of debris were deposited in the lowlands, as tills and water-laid deposits, smoothing out the pre-Quaternary relief of southeast Northumberland and eastern Durham. River valleys, some graded to cold stage sea levels down to –50 m O.D., were plugged by clays, sands and gravels. As the ice withdrew, most rivers re-established themselves close to their original courses. Ice melt resulted in the formation of widespread sheets of glaciofluvial sand and gravel, some now standing as terraces above the main rivers, and also areas of hummocky ice-contact deposits including kames, kame terraces and eskers, with many kettle holes and dead-ice hollows. The persistence of coastal and sea ice dammed the eastward drainage of meltwaters leading to the formation of lakes in low-lying areas. In these, laminated clays and silts were deposited with sand and gravel deltas and fans at the margins. In upland areas, fine series of meltwater channels, such as those around the Cheviots, were eroded mainly by water flowing beneath the ice during melting.

The main event of the present interglacial has been the rise in sea level to give the coastal morphology we see today. Evidence of the rise is found in submerged forests and peats, extending to at least –5 m O.D., present on the coasts of Northumberland and Durham. With a low tide, and not too much beach sand, these features can be readily seen in several places, such as Hartlepool, Seaburn, Blyth Beach, Cresswell, and Hauxley south of Amble. In the uplands, extensive peat deposits have formed in the higher, wetter areas.

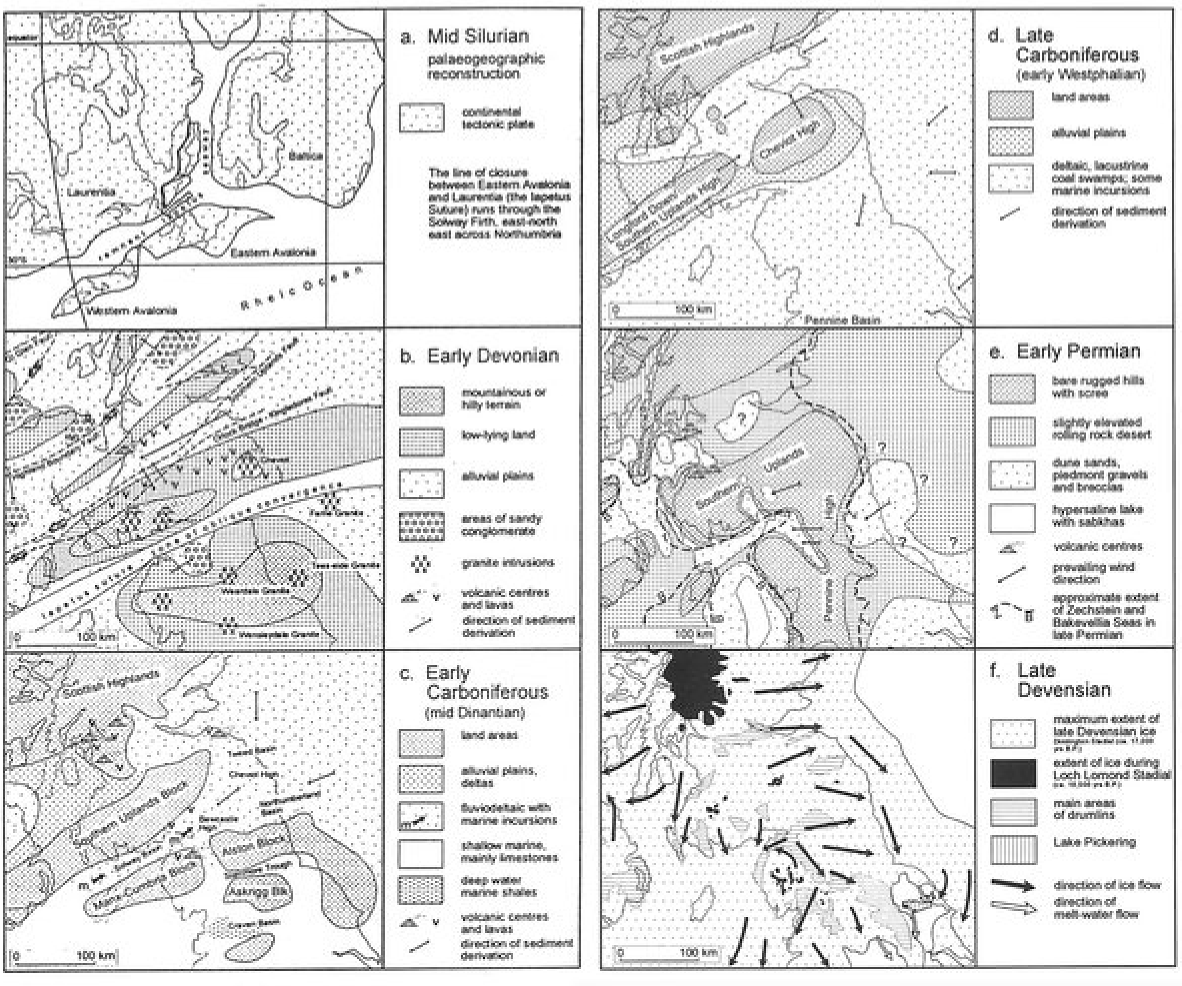
Bibliography



(Figure 1) Pre-Quaternary geological map of Northumbria and adjoining areas showing the location of excursions.



(Figure 2) Geological column, and sequence of environments and events in Northumbria. Epochs/Series are shown as of equal length within Period/Systems for convenience only.



(Figure 3) Palaeogeographic maps indicating: (a) the distribution of continental plates in the mid Silurian (based on Scotese & McKerrow 1990 and other sources) and (b–f) the distribution of land and major sedimentary environments at various times in Northumbria and surrounding areas (based on Cope, et al. 1992 and other sources).