

# Late Permian environment and lithostratigraphy, Northern England

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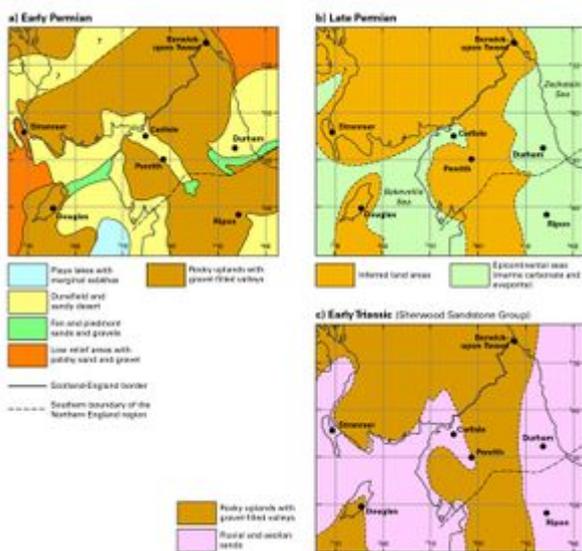
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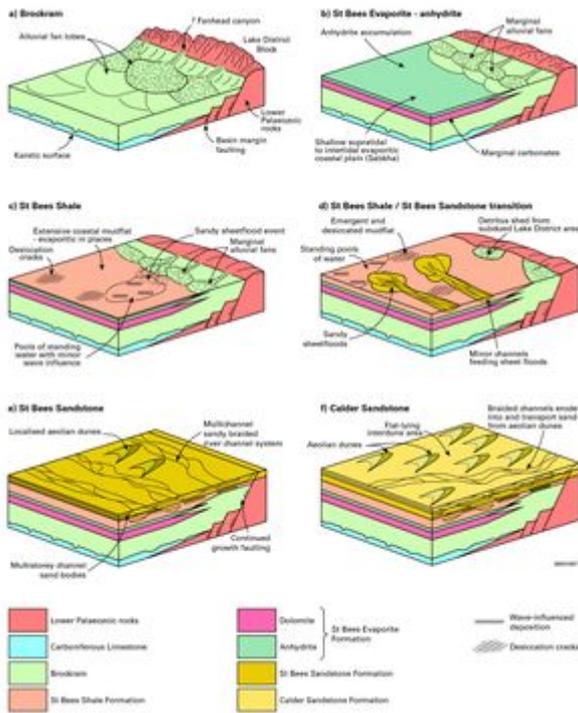
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## Introduction



Distribution of depositional environments across northern England during Permian and Triassic times (after Cope et al., 1992. Atlas of Palaeogeography and Lithofacies, Geological Society of London Memoir, No. 13). P916085.



Cartoons illustrating the changes in depositional regime through Permian and Triassic times (after Akhurst et al., 1997. The geology of the west Cumbria district. BGS Memoir). P916086.

GROUP	EAST IRISH SEA AND SOLWAY FURTH BASINS		CARLISLE BASIN	VALE OF EDEN BASIN
	OFFSHORE	ONSHORE (West Cumbria)		
JURASSIC	Less Group	Less Group (unroofed)	Less Group (unroofed)	
	Pecarth Group	Lilstock Formation	Lilstock Formation	
		Wesbury Formation	Wesbury Formation	
TRIASSIC	Merca Mudstone Group	Blue Anchor Formation Elsick Mudstone Formation Warton Mable Formation Downbridge Mudstone Fin Preston Mable Formation Layland Formation	Blue Anchor Formation Stenwic Shales Formation	
		Ormskirk Sandstone Formation	Ormskirk Sandstone Formation	Kilbrink Sandstone ? St Bees Sandstone Formation
PERMIAN	Cumbrian Coast Group	Barnmouth Mudstone Formation	Eden Shales Formation	Eden Shales Formation
		St Bees Evaporite Formation	St Bees Evaporite Formation	
Appley Group	Collywest Sandstone Formation and Brookman	Brookman	Pecarth Sandstone Formation and Brookman	Pecarth Sandstone Formation and Brookman

CARBONIFEROUS ROCKS

Lithostratigraphical subdivision of the Permian, Triassic and Jurassic rocks of north-west England. P916115.



Fossil fish remains. (*Palaeoniscus*) from the Marl Slate Formation in the now-backfilled Down Hill Quarry, West Boldon, Sunderland [NZ 349 601]. (P552051).



Collapse-brecciated limestone of the Roker Formation produced following dissolution of the underlying Hartlepool Anhydrite. Trow Point, Sunderland [NZ 385 666]. (P693034).

Following deposition of the dominantly aeolian strata of early Permian times, a profound environmental change occurred over much of northern England ([P916085](#))<sup>b</sup>. The principal factors driving this change were repeated temporary marine incursions into large areas of the region, and the effects of the resultant higher water table on sedimentation in the surrounding areas. The high ground of the Pennines, Lake District, Isle of Man and the Southern Uplands of Scotland suffered continued erosion and, by the end of the Permian Period, were reduced to areas of very low relief or in some areas had become sites of deposition.

### **West of the Pennines: Cumbrian Coast Group**

To the west of the Pennines, the Bakevellia Sea flooded into low-lying areas. Marine conditions were established in the main depositional centres of the Solway Firth and East Irish Sea basins, whilst carbonate platforms developed in many marginal marine areas such as south and west Cumbria. Extensive evaporitic sabkhas surrounded the marine areas and, at times of marine regression, extended into the basin centres. Adjacent to high ground and sources of sediment supply, siliciclastic deposition locally overwhelmed the evaporitic sabkhas. As a consequence of this range of palaeoenvironments, the strata of late Permian age in north-west England are highly variable.

In areas close to sources of sediment supply, evaporite beds are thin and separated by significant thicknesses of reddish-brown siltstones interbedded with fine-grained sandstone and with some conglomerate and breccia. These strata form the Eden Shales Formation and crop out in northern Cumbria, around the margins of the Carlisle and Vale of Eden basins. The outcrop between the two basins is contiguous, indicating that, unlike the situation in the early Permian, late Permian sedimentation was more widespread and not restricted to isolated basin areas. The siltstones and sandstones of the formation are both regularly and irregularly bedded and are locally structureless. The irregularly laminated rocks were deposited by accretion of wind-blown sand and silt; the more evenly laminated strata were deposited by muddy sheet floods. Towards the base of the formation thin beds of gypsum and anhydrite occur, suggesting the periodic establishment of sabkhas and ephemeral shallow lakes that dried out to leave desiccation cracks in siltstone and to produce dried mud flakes that were incorporated into overlying beds of sandstone and conglomerate. East of Appleby, the basal strata comprise laminated sandstone interbedded with calcareous siltstone containing abundant carbonaceous plant debris. These strata are collectively known as the Hilton

Plant Beds and probably accumulated as sheet-flood deposits peripheral to a desert lake. The plant beds are well exposed in Hilton Beck (NY 7196 2058). Generally in the Vale of Eden sequence, four distinct evaporite beds exist and are known locally as 'A' (the lowest) to 'D' (the highest) Beds. The 'A' bed anomalously contains halite in addition to gypsum and anhydrite. It is likely that the halite was deposited subaerially within the silty sediment of a sabkha environment, possibly causing volume increase of the sediment and so elevating it to a subaerial position where desiccation produced mud cracks.

In basinal areas, distant from the sources of sediment supply, dolostone, anhydrite and halite, with subordinate mudstone, built up to form the St Bees Evaporite Formation ([P916086](#))b, which is the lateral equivalent of the lower part of the Eden Shales ([P916115](#)). The formation is best known from cored boreholes and mine workings in Cumbria where anhydrite is dominant but with gypsum as a secondary replacement. At a shallow depth the evaporite strata may be removed from the sequence by percolating ground waters leading to collapse of the overlying beds. Offshore the formation is less well known but does contain beds of halite, locally in excess of 100 m thick, in addition to anhydrite. Onshore, in south and west Cumbria, carbonate rocks form a major part of the formation and these, together with the evaporite rocks, appear to have formed in response to cyclic sea-level changes. The carbonate rocks contain locally abundant bivalves, stromatolites and ooids that suggest marine deposition in dominantly shallow water ([P916086](#))b. Coeval with the marine deposition of the carbonate rocks, gypsum-anhydrite beds formed in sabkhas and shallow saline lakes peripheral to the marine basins. At times of relatively low sea level the evaporitic facies encroached into the central parts of the basins.

Onshore, in west Cumbria, the St Bees Evaporite Formation is overlain by the St Bees Shale Formation ([P916086](#))c; offshore it is overlain by the Barrowmouth Mudstone Formation ([P916115](#)). Both of these overlying formations are the lateral equivalents of the upper part of the Eden Shales Formation and share many of its lithological characteristics.

### **East of the Pennines: the Zechstein Group**

To the east of the Pennines, transgression of the Zechstein Sea ended the early Permian continental phase and initiated a prolonged period of marine conditions. The County Durham area lay on the western margin of the Zechstein Sea with the inferred shoreline only slightly to the west of the current Permian outcrop ([P916085](#))b. Reefs developed just offshore and subparallel to the coast, generating a large, shallow lagoonal environment in which significant evaporation could take place. Periodic marine flooding and evaporation led to cyclic sedimentation of carbonates and evaporites. Traditionally, carbonate-evaporite English Zechstein Cycles have been identified, each consisting of sequentially deposited clastic rocks, carbonates and sulphates and culminating in the precipitation of halite and highly soluble potassium and magnesium salts. Five such cycles characterise the marine Permian deposits of north-eastern England, although the cycles are rarely complete and are usually dominated by carbonate deposition. A slightly different picture now emerges from the application of a modern, sequence-stratigraphical approach where sequences are defined as relatively conformable successions of genetically-related strata bounded by unconformities. The unconformities are the result of relative sea-level fall and hence the initial strata of a sequence are those deposited at times of lowstand, or by the ensuing transgression. In north-east England, this alternative approach identifies seven Zechstein Sequences (ZS) consisting of evaporite-carbonate (rather than the traditional carbonate-evaporite) successions. Correlation between Zechstein Sequences and the lithostratigraphical nomenclature of north-eastern England is given in ([P916116](#)).

The first sequence (ZS1) began with an initial rapid transgression of the Zechstein Sea that flooded wide areas of early Permian desert. The oldest marine Permian strata preserved in north-east England represent this initial transgression and are the laminated, silty, dolomitic mudstones of the

Marl Slate Formation ([P221601](#)). The unusual lithology of the formation has prompted alternative interpretations of its origin, either as a shallow-water lagoonal deposit or as a deeper-water basin deposit. The currently prevailing view is that deposition took place in a barren basin with stagnant waters roughly 200 to 300 m deep, though water depths would have varied significantly, particularly in eastern County Durham, where the flooded draa of the Yellow Sands Formation gave rise to significant variations in sea-floor topography.

The Marl Slate Formation can be traced throughout the entire marine Permian outcrop of north-east England. At outcrop it is yellowish brown in colour but when unweathered it can be seen to consist of alternating bands of dark grey and black sediment that are finely laminated and often bituminous. Locally, the clastic units are interbedded with thin beds of dolostone and dolomitic limestone. Thin layers of aeolian sand are present in many places, particularly near the base of the formation, and are interpreted as Yellow Sands material reworked into the Marl Slate succession by rapid marine transgression. Pyrite, galena and sphalerite coat bedding planes and joints throughout the formation and are thought to have a syngenetic origin, although some degree of diagenetic redistribution is likely. The Marl Slate is well known for its fossil fauna and flora. Plant remains are abundant and well-preserved fossil fish have been collected from a number of localities ([P552051](#)); their preservation may well have been assisted by syngenetic mineralisation.

The top of the Marl Slate Formation is typically marked by a sharp contact with the overlying deposits although in some places, particularly the south-west of County Durham, the contact appears more transitional with thin beds of Marl Slate lithology interbedded with the lowest beds of the overlying formation, known traditionally as the Magnesian Limestone and divided into lower, middle and upper divisions ([P916116](#)). These equate formally to five formations: in ascending order, the Raisby Formation (traditionally the Lower Magnesian Limestone), the Ford Formation (traditionally the Middle Magnesian Limestone) and three formations, the Roker Dolostone, Seaham Residue and Fordon Evaporite (Edlington), and Seaham formations spanning the traditional Upper Magnesian Limestone.

Deposition of the Marl Slate partly filled the early Permian sea-floor topography and gave rise to an undulating, eastwards inclined, marine slope on which the overlying Raisby Formation was deposited. Likely water depths in the depositional basin ranged from approximately 100 m (in present-day coastal areas) to 200 to 300 m in the central parts (now offshore). The Raisby Formation has only a narrow outcrop in north-east England although it does extend beneath younger strata to the east. It is composed of yellow or cream-coloured dolostone and pure, grey limestone (although the latter is rare), which are exposed along an escarpment 30 to 60 m high between Hetton-le-Hole and Ferryhill, County Durham. The formation can be divided into three lithological units distinguished by colour, bedding thickness, texture and compositional variations. The lowermost unit comprises rocks of dolomitic composition through to almost pure limestone in regular beds 15 to 30 cm thick. Laminated argillaceous layers with galena, pyrite and sphalerite are common towards the base of the unit, particularly where there is a transition from the Marl Slate. The middle unit of the Raisby Formation is the most commonly seen in outcrop and consists predominantly of dolostone although, in places, calcitic dolostone is common. These rocks are grey to buff coloured, finely crystalline and thinly bedded in layers 5 to 10 cm thick. The bedding is planar on the large scale, but may be very uneven and nodular in fine detail; abundant stylolitic bedding laminae bear thin films of argillaceous residue. Widespread stratified but brecciated levels exist towards the top of the middle unit, often interbedded with gypsum. The upper unit of the Raisby Formation comprises buff to brown dolostone in irregular lenticular beds up to 45 cm thick. Stylolites and brecciated patches are less common than in the underlying middle unit.

Deposition of the Raisby Formation all but eliminated the sea-floor topography leaving a generally smooth, eastward-dipping surface that was steep enough to cause intermittent instability of the

partially lithified sediment accumulation. Contorted and chaotic rock structures produced by minor submarine avalanches and slumping can be seen locally, particularly in the coastal cliffs to the south of South Shields. Such structures are most prevalent towards the top of the formation where the effects of depositional slope angle were probably accentuated by a relative fall in sea level of several metres.

Overlying the Raisby Formation is a thin sequence of fine-grained, clastic dolostone that forms the lowermost strata of the Ford Formation and represents initial lowstand deposition of Zechstein Sequence 2 (ZS2). These beds are known informally as the transitional beds as the junction between them and the underlying dolostone of the upper Raisby Formation is usually indistinct. The earliest transitional beds are barren but the abundance of a fossil shelly fauna increases upwards. The transitional beds are interpreted as marine deposits laid down during a gradual and irregular dilution of the highly saline waters in which the upper parts of the Raisby Formation accumulated. The uppermost transitional beds were probably deposited in near-normal marine conditions, with most of the Ford Formation deposited in the subsequent, shallow-water shelf environment. Shells accumulated in sufficient numbers to form an elongate bank on which a reef-forming fauna could gain a foothold. The formation of the shell bank and subsequent shelf-edge reef had a profound influence on the environment and led to contemporaneous but locally highly varied depositional settings.

The reef itself is perhaps the best-known feature of the upper Permian succession of north-east England. During the early stages of reef formation, growth was predominantly upwards, but there was some lateral expansion subsequently. The lower parts are composed of massive dolomitic limestone and dolostone containing a prolific fauna of brachiopods, bivalves and polychaetes. As the reef built upwards to a maximum height of about 60 m, shallower water encouraged more rapid growth of calcareous algae, whilst increasing salinity led to the gradual extinction of much of the earlier fauna. Consequently, the uppermost parts of the reef are largely of algal origin and contain a wide variety of stromatolitic growth forms, many similar to those found today in the intertidal zone of hypersaline lagoons such as those seen at Shark Bay, Western Australia.

On the western (landward) side of the reef, within a shallow and protected lagoonal environment, a varied sequence of granular ooidal and pisolitic carbonates accumulated with the rate of deposition keeping pace with the upward growth of the reef. These rocks form most of the Ford Formation outcrop and are almost universally dolomitised. The recrystallised platy dolostone crystals, up to 5 mm across, give the rock a characteristic texture known locally as 'felted', which is mostly confined to the lagoonal beds of the Ford Formation. The uppermost lagoonal strata interdigitate with the reef deposits.

On the eastern (basinal) side of the reef, deposition was comparatively slow except in the immediate vicinity of the reef edge where wedge-shaped, fore-reef talus aprons developed from detrital material eroded from the front of the reef. The earliest talus aprons were buried by continuing reef growth but have been proved underground in sections at Easington Colliery and in boreholes. Later aprons are exposed within County Durham at Blackhall Rocks ([P221294](#)) and Crimdon Beck.

The various reef facies of the Ford Formation crop out in a sinuous belt extending south-south-east from Down Hill (near Sunderland) towards Hartlepool. The reef lithologies are often more resistant to erosion than the surrounding strata and in places form distinct topographical features such as Beacon Hill near Easington, County Durham. The extent of the reef southwards from Hartlepool is uncertain, although indirect evidence from gravity surveys and boreholes suggest that it may well continue as far south as Seaton Carew. South and west of Seaton Carew, semi-open shelf conditions prevailed during deposition of the Ford Formation, rather than the lagoonal environment present to the north, and its strata are difficult to distinguish in boreholes from those of the underlying Raisby

Formation.

Towards the end of Ford Formation times, construction of the reef was terminated by a fall in sea level of several metres. The uppermost member of the Formation is the Hartlepool Anhydrite, which was deposited in shallow water as the lowstand wedge of Zechstein Sequence 3. It consists of dense aggregates of very finely crystalline laths that form nodular masses of almost pure anhydrite. At outcrop in the Tynemouth area, the anhydrite has been largely removed by solution and all that remains is a solution residue of grey-brown, argillaceous and sandy dolostone.

With continuing deposition on the lagoonal and basinal sides of the reef, the Zechstein Sea became increasingly shallow and saline. By the end of Ford Formation times, the reef was largely buried and exercised only minimal control on sedimentation. The Zechstein Sea was by then a very shallow-water, hypersaline and inhospitable shelf-edge environment.

Deposition of the Roker Formation on the shelf and adjacent basin slope marks the onset of the next major marine transgression. The slope facies is one of the most highly varied and spectacular carbonate units of the Permian succession in northern England. At the base of the formation, the Concretionary Limestone Member comprises thinly bedded granular dolostone that is locally recrystallised and contains calcite concretions ([P693033](#)). In the Sunderland area, these concretions are spectacularly well developed and the unit is known informally as 'cannonball rock'. In the coastal exposures of County Durham, the concretionary limestone can be divided into a lower unit up to 15 m thick containing abundant concretions and an upper unit, up to 20 m thick, in which they are absent. However, overall distribution of concretions is laterally variable. Where concretions are not present, the rock is largely a soft granular dolostone with traces of small-scale cross-bedding and ripple marks. Slightly below the middle of the member is a thinly laminated impure dolostone that is creamy-grey in outcrop but grey and bituminous at depth. It can be split into paper thin, flexible sheets and is known informally as the Flexible Limestone. This unit has yielded fish remains in the Sunderland area whilst plant remains are common throughout its outcrop in northern England. In County Durham and the Tynemouth area, the Concretionary Limestone has been brecciated by collapse following solution of the underlying Hartlepool Anhydrite, and now consists of angular and rounded fragments of grey-brown crystalline limestone in a matrix of brown dolomitic limestone ([P693034](#)).

The shelf deposits of Roker Formation consist mostly of the Hartlepool and Roker Dolostones, which are composed almost entirely of soft, granular and ooidal, cross- and ripple-bedded dolostone with little significant variation in lithology. The dolostone units are mainly exposed in coastal cliffs around Roker and Seaham and to the north of Hartlepool, where many have foundered as a result of solution of the underlying Hartlepool Anhydrite. The lithology of the dolostones is consistent with deposition in a shallow-water shelf environment, but the presence of rip-up clasts and minor erosion surfaces may indicate the subaerial emergence of sediment deposited partly within the intertidal zone.

After deposition of the Roker Formation, marked sea-level oscillations have been inferred, the evidence drawn from a curious evaporite that contains sedimentary features characteristic of both shallow and deepwater conditions. This is the Seaham Residue and Fordon Evaporite Formation. Within it, Fordon Evaporites are present today only in the subsurface offshore where they reach a thickness of up to 90 m and consist primarily of gypsum, halite and anhydrite with some dolostone. They formerly extended westwards at least as far as the present coastline, but there they have been largely removed by solution, leaving only the Seaham Residue and resulting in significant foundering of the overlying rocks. The Seaham Residue is up to 9 m thick at its type locality of the coastal cliffs at Seaham Harbour and consists primarily of limestone and a dolomitic clay residue. The formation is believed to represent the lowstand facies marking the initiation of Zechstein Sequence 4, with

parasequences within it indicating subordinate sea-level oscillations. In the Stockton area, south of the Seaton Carew Fault, the lateral equivalent of the Seaham Residue and Fordon Evaporites ([P916116](#)) is the Edlington Formation (traditionally the Middle Permian Marls).

Deposition of the Fordon Evaporite largely completed the filling of the Zechstein Basin. Sedimentation thereafter took place in a relatively shallow water environment, perhaps less than 20 m deep, below the tidal zone and with little or no basin floor relief. Under these conditions the Seaham Formation accumulated. It is relatively uniform in lithology and comprises the transgressive strata of Zechstein Sequence 4. It consists mostly of mudstone (some calcareous), limestone and dolostone and is exposed in the coastal cliffs around Seaham. The whole formation has been severely disrupted and locally brecciated by foundering arising from solution of the underlying Fordon Evaporite, now represented only by the Seaham Residue. Foundering is generally less severe and less extensive than that affecting the stratigraphically lower Concretionary Limestone. The Seaham Formation carries a distinctive assemblage of bivalves and algae with abundant, small tubular remains of the probable alga *Calcinema permiana*. Algal laminates and sedimentary features such as cut-and-fill structures, low angle cross-lamination, and low amplitude-long wavelength ripples, all increase in abundance upwards through the formation and may indicate shallowing to a high subtidal environment by the end of its deposition.

The limited diversity, but great abundance, of fossil remains within the Seaham Formation indicates unique environmental controls on the plant and animal population, most probably indicating hypersalinity of the water. Coupled with decreasing water depth, this led to the development by the end of Seaham times of sabkha conditions under which the youngest Permian strata of northern England were deposited. The Billingham Anhydrite Formation is now present only in the offshore area where it is 3 to 6 m thick and composed of gypsum and anhydrite with some dolostone. Offshore to the east of Billingham, the anhydrite is overlain by the much thicker Boulby Halite Formation. The Billingham and Boulby formations contain deposits assigned to Zechstein Sequence 5.

The disappearance of permanent open water and the re-establishment of arid conditions over north-east England are indicated by the nature of the succeeding Rotten Marl Formation. It consists of dull, dark red-brown, silty mudstone commonly with scattered halite crystals and cut by a network of veins containing fibrous halite and gypsum. This formation demonstrates the first real clastic input into the basin but is preserved only in the south-east of the region, south of the West Hartlepool Fault, and offshore. Although the Rotten Marl can be distinguished from the overlying Roxby Formation in offshore boreholes, the same distinction is not possible at outcrop in the Durham area where the boundary between the two units is transitional, with the Rotten Marl commonly represented only by a thin residual layer. This is incorporated stratigraphically at the base of the Roxby Formation which, in such a situation, directly overlies the Boulby Halite Formation. In its lower part, the Roxby Formation is a dominantly mudstone sequence, but the frequency and thickness of siltstone and sandstone interbeds increase upwards until the Roxby Formation passes gradually upwards into the Early Triassic Sherwood Sandstone Group.

The sequence stratigraphy of these upper Zechstein strata is somewhat subjective due mainly to the limited data available. The Rotten Marl Formation was deposited at a time of low sea level, on coastal flood plains, in salt pans and in lagoons. It is more proximal than the Boulby Halite Formation, which implies a sequence boundary between the two with the Rotten Marl representing the initiation of Zechstein Sequence 6. The Roxby Formation was deposited at a time of higher sea level and may represent a further sequence, Zechstein Sequence 7, with related shallow water deposits out towards the basin centre, or it may represent the uppermost strata of Sequence 6.

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