Seaham

[NZ 43 49]

Highlights

This coastal site (box 10 in (Figure 3.2)) is the type locality and by far the best surface exposure of both the Seaham Formation and the Seaham Residue, and is one of the best places in Britain for observing the effects of evaporite dissolution; it is also the best surface exposure of the highest beds of the Roker Dolomite Formation. The Seaham Formation here is unusual in its content of several thick units rich in calcite spherulites, some exceptionally large, and the Seaham Residue, the dissolution residue of the Cycle EZ2 (Fordon) evaporites, is at its thickest and most spectacular.

Seaham harbour is of interest in being an artificial anchorage created between 1828 and 1831 by the hollowing-out of a former limestone headland. An original Stephenson locomotive was used until the late 1950s on harbour maintenance work and a paddle tug, *The Eppleton Hall,* for many years plied the South Dock of the harbour before becoming an exhibit at the maritime museum in San Francisco.

Introduction

The south-eastward dipping rocks at Seaham are the highest Permian strata exposed on the Durham coast. They occupy a gentle asymmetric downfold on the north side of the Seaham Fault, a major west to east dislocation that has a northerly downthrow of about 200 m in Coal Measures rocks beneath the harbour, but perhaps only a small fraction of that in the overlying Permian strata. The sequence exposed comprises the uppermost part of the Roker Dolomite Formation (8 m+), the Seaham Residue (up to 9 m) and, at the top, the Seaham Formation (about 31 m). Breccia-gashes in the eastern part of the north wall of the North Dock contain foundered debris of higher strata including red 'marl' (mudstone/siltstone) and blocks of cellular limestone that may be the remains of calcitized evaporites. Fossils abound in the Seaham Formation (locally in rock-forming proportions) and comprise two species of bivalve and the supposed alga *Calcinema* (formerly *Filograna*) *permiana* (King); the same two species of bivalve have been found in the local Roker Dolomite beds.

The complex of exposures at Seaham was virtually ignored in the literature until the formal definition of the Seaham Beds and Seaham Residue by Smith (1971a); the name Seaham Beds was subsequently changed to Seaham Formation. The rocks of the Seaham Formation (Smith *et al.,* 1974) were informally known by Trechmann (1954) as the *Filograna* beds and were generally regarded as part of the Concretionary Limestone Formation (e.g. Woolacott, 1912; Trechmann, 1925). This attribution was accepted by Smith (in Smith and Francis, 1967), but was shown to be incorrect by Taylor and Fong (1969); these authors discovered calcite concretions in cores of late Permian marine limestones at two different levels separated by evaporites in boreholes in North Yorkshire and disclosed that those at the higher level were associated with the diagnostic biota of the Seaham Formation. Magraw (1975) proposed the term 'Upper Nodular Beds' for concretion-bearing limestones at about the level of the Seaham Formation in a number of partly cored, offshore coal exploration boreholes, but this name has found little favour.

The exposures of Roker Dolomite at Seaham lie towards the northern end of the designated area (Figure 3.39), and the top of the formation rises gradually northwards. These rocks were classified by Trechmann (1931) as Post-reef Middle Magnesian Limestone (=Ford Formation of modern usage), but their position immediately below the Cycle EZ2 Seaham Residue and above the inferred residue of the Cycle EZ1 Hartlepool Anhydrite in the nearby Seaham Borehole (Smith, 1971a) shows that this view cannot be correct.

The inferred presence of the residue of the Hartlepool Anhydrite in the Seaham Borehole, if correct, implies that all the Permian strata exposed at Seaham have foundered as a result of the dissolution of perhaps 120 m of underlying evaporites.

Description

Seaham [NZ 43 49] lies on the east coast of County Durham some 8 km south of Sunderland; the position of the GCR site there is shown in (Figure 3.39), together with the geological boundaries and the position of the main features of geological interest.

The general geological sequence in the designated area at Seaham is:

	Thickness (m)
Drift deposits, mainly boulder clay and beach deposits	up to 8
————unconformity ————	
Red mudstone/siltstone (Rotten Marl) occupying breccia-gashes	up to ?4
Seaham Formation (EZ3Ca), seen mainly in the harbour walls and at Red Acre Point	30–31.5
Seaham Residue (of the Fordon Evaporites, EZ2E), seen mainly in cliffs from the war memorial northwards	up to 9
Roker Dolomite (EZ2Ca), seen mainly from Red Acre northwards	8+

Roker Dolomite Formation

This formation lies at the base of the sequence exposed at Seaham, its top first appearing at beach level about 300 m SSE of Featherbed Rocks and rising cumulatively until it crops beneath drift about 350 m north of the designated area; beyond this the cliffs for several hundred metres are composed solely of drift on Roker Dolomite.

The Roker Dolomite Formation in the northern part of the site and in the cliffs to the north is composed mainly of fine-sand grade, hollow ooids (Trechmann, 1914, plate 37(5)), and generally is a cream to buff porous rock with less than 2% of calcite. The uppermost 1–5 m of the formation, however, is a hard, finely crystalline, grey limestone (dedolomite) with a network of fractures that in places is so dense that the rock has become a breccia; internal sediment is locally abundant in this breccia. The fractures, which doubtless once were filled with anhydrite, gypsum or salt, diminish in number downwards, and the proportion of dedolomite similarly diminishes until limestone forms only narrow selvedges alongside the downwards-tapering cracks. There is also clear evidence, in the form of irregular to stellate calcite-lined cavities up to 0.1 m across, of the former presence of abundant replacive and intergranular anhydrite.

Where least altered, the Roker Dolomite at Seaham exhibits a range of shallow-water sedimentary structures and has yielded two species of bivalves (*Liebea* and *Schizodus*) (Trechmann, 1914, p. 235) from 'a mass of rock isolated from the cliff-section' (presumably Featherbed Rocks).

The contact between the Residue and the Roker Dolomite is generally sharp and smoothly rounded at the southern end of its outcrop and has a local relief of up to 2 m; this relief diminishes towards the northern end of the site, where the contact is generally less sharp and locally interdigitates.

Seaham Residue

The Seaham Residue is not seen in the harbour walls, but its top is exposed at the foot of the cliffs about 200 m NNW of North Dock (dependent on the height of beach gravel) and rises gradually northwards for more than 200 m before cropping out beneath drift at the top of the cliff near Featherbed Rocks; much of the bed, however, is visible almost as far north as the former Vane Tempest Colliery [NZ 425 502], well north of the GCR site, as a result of several minor downfolds and small step faults.

The Seaham Residue was identified and defined by Smith (1970a, 1971a) and further described and illustrated by Smith (1972). It is thickest in the cliffs at Red Acre where it is also strongly contorted (Figure 3.40); despite great lateral variation, the residue has a roughly uniform general sequence exemplified in the cliff face [NZ 4303 4973] some 210 m south of Featherbed Rocks.

	Thickness (m)
Residue, mainly yellow-buff, comprising a weakly layered and partly contorted heterogeneous clayey dolomite or dolomitic clay with scattered small angular fragments of limestone. Top generally sharp, but uneven, relief up to 1 m	1–2.5
Limestone, white, grey and buff, thin-bedded and flaggy, partly contorted, an altered ooid grainstone, with thin beds of yellow-buff clayey ?residue	0.8–1.1
Limestone, off-white, ooidal, finely cross-laminated, with possible bivalve moulds	1.0–1.2
Residue, buff in uppermost part grading down to buff-grey, grey-buff and brown, comprising an upper unit (up to 1.2 m thick) of strongly contorted flaggy and thin-bedded limestone (partly ooidal) passing down to contorted calcareous clay and clayey dolomite with scattered to abundant angular blocks of altered ooid grainstone; some of the latter are cross-laminated and contain flat-pebble conglomerates	1.5–5.0

Traced northwards, the Seaham Residue thins gradually to 2–3 m and is less contorted and varied.

Seaham Formation

The several rock walls of Seaham harbour, Red Acre Point and the cliff section from 155 m to the north, together constitute the type locality of the Seaham Formation (Smith, 1971a); in general, the lower parts of the formation are exposed north of the harbour and the higher parts in the harbour walls. No single continuous section exposes the whole formation and the overall sequence (based on Smith, 1994) has been pieced together from several sections separated by minor faults and stretches of unexposed ground.

	Thickness (m)
Limestone, grey and brown, finely crystalline, hard, thin-bedded, unevenly algal-laminated, with abundant stellate and rectilinear cavities after former sulphate	1.2–1.5+
Limestone, buff, grey and brown, finely crystalline to finely saccharoidal, hard, flaggy to thick-bedded, but with discontinuous beds of calcite concretions and of limestone. Mainly thin-bedded, with symmetrical low amplitude massive coarsely-crystalline ripples, shallow cut-and-fill structures, low-angle planar and tabular cross-lamination and abundant graded bedding. *Calcinema, Liebea* and *Schizodus* at most levels, partly in rock-forming proportions	*c.* 27–28.5
Dolomite (exposed in cliffs from about 180 to 300 m NNW of the north-west corner of North Dock), cream and buff, soft, finely saccharoidal, mainly thin-bedded, with *Calcinema, Liebea* and *Schizodus*	*c.* 1.8+

Calcite concretions occur almost throughout the Seaham Formation, but are most abundant slightly above the middle where they merge patchily to form massive spherulitic beds individually up to 3 m thick (Figure 3.41); most of the spherulites are only a few millimetres to centimetres across, but in places they exceed 0.2 m in diameter and completely obscure primary sedimentary features. Seaham is the best and most readily-accessible place to study these concretions.

The tiny stick-like tubular remains of *Calcinema* are present in enormous numbers in much of the rock, and form dense swarms aligned roughly WSW/ENE to west to east at some levels; at other levels however, they appear to be disposed randomly or to form complex swirls.

The algal-laminated (stromatolitic) limestone at the top of the Seaham Formation is exposed for only a few metres on the north side of an artificial terrace, high in the north-west corner of the North Dock; although such algal-laminites are widespread in subsurface provings at this horizon, this small surface exposure is unique in north-east England.

The minor faults seen cutting the Seaham Formation in the dock walls may be partly tectonic in origin, and related to the proximity of the Seaham Fault, but most of them probably resulted from fracturing of the brittle rocks When the underlying Fordon Evaporites were dissolved. Total brecciation such as is seen in the Cycle EZ2 collapse-breccias is uncommon in the Seaham Formation, but step-faults, partial brecciation and contortion are widespread; an excellent section displaying some of these features is seen in the west wall of the North Dock. It is important to bear in mind that all the strata exposed at Seaham have also foundered by at least 100 m because of the dissolution of the Cycle EZ1 Hartlepool Anhydrite and that some dislocation in the Seaham Formation may have resulted from this cause.

Red mudstones/siltstones (Rotten Marl)

The Rotten Marl is well known in boreholes in County Cleveland (e.g. Marley, 1892), and is extensive on the sea bed off the Durham coast (Smith, 1994). Surface exposures of this formation are known, however, only as fragments in a few breccia-gashes in coastal cliffs between Ryhope [NZ 41 52] and Crimdon [NZ 48 37], and one of these was excellently exposed [NZ 4327 4950] near the eastern end of the north wall of the North Dock. About 4 m of fragmented, soft red-brown, argillaceous siltstone and silty mudstone were formerly seen here; it contained a number of large angular blocks of pale grey cellular limestones that may be the carbonate framework of the Billingham Anhydrite (EZ3A) or (less likely) cellular dolomite from the Sherburn Anhydrite (EZ4A); the former separates the Rotten Marl from the underlying Seaham Formation, but has been dissolved from all surface outcrops, and the latter overlies the Rotten Marl and has also been dissolved.

The uppermost 2–3 m of the breccia-gash were removed when a new road was constructed in 1980, and much of the remaining Rotten Marl has since been obscured by landscaping; the remainder of the breccia-gash, however, may be seen from the footpath along the northern lip of the North Dock, where the gash is about 7 m wide.

Interpretation

The site at Seaham is of national importance both as a reference section and for teaching purposes; several features exposed there are unique either in north-east England or in Britain as a whole, and the exposures together provide an unrivalled expression of the effects on carbonate rocks of the dissolution of interbedded and pervasive evaporites. The main features of interest and importance are discussed on pages 93–5.

Roker Dolomite Formation

The clear exposures of the uppermost beds of the Roker Dolomite Formation at the northern end of the Seaham site are unique in north-east England and their protection is important on this account alone; there are, moreover, no readily available records of cored boreholes through this part of the sequence, although it has been cored in confidential commercial boreholes at several places in Cleveland. The discovery by Trechmann (1914) of *Liebea* and *Schizodus* in these rocks at Seaham is also important in providing corroborative evidence that they are not part of the unfossiliferous post-reef Middle Magnesian Limestone as had been claimed previously.

Seabam Residue

The Seaham Residue at Seaham is a superb example of an evaporite dissolution residue, certainly one of the best in the British Isles and ranking highly amongst such features in western Europe; poorer exposures occur beneath the Seaham Formation in coastal cliffs north of Crimdon Park [NZ 48 37], Blackhalls Rocks [NZ 46 38] and Easington Colliery [NZ 43 43]. Its great lateral variability in thickness and composition, its commonly gradational contacts with the underlying and overlying strata and its local strong contortion are all typical of evaporite dissolution residues, and combine to make the main exposure a most valuable teaching section.

The stratigraphical affinities of the Seaham Residue leave no doubt that it is equivalent to the Fordon Evaporite Formation (Cycle EZ2), which, approximately along strike in North Yorkshire, is about 15–30 m thick and comprises interbedded anhydrite and halite with subordinate carbonate and siliciclastic rocks. The absence of red and grey siliciclastic rocks in the Seaham Residue, plus the presence of underlying Roker Dolomite, shows that it is not the residue of the Edlington Formation into which the Fordon Evaporites pass landwards (i.e. westwards). The unusually great thickness of the residue, although enhanced at Seaham by lateral flow into a minor anticline, presumably indicates that these evaporites had a high content of insoluble material.

Seaham Formation

The Seaham exposures were chosen as the type locality of the Seaham Formation because of the apparent permanence and ease of access of the various faces and the nearly complete coverage of the whole thickness of the formation; no other exposure offers these advantages. The sedimentary features and biota at Seaham harbour are generally typical of the formation in north-east coastal districts (so far as may be judged from limited alternative exposures) and, except for the graded bedding, are comparable with those in the equivalent Brotherton Formation in Yorkshire and the Plattendolomit in Germany. The removal of some important faces and the covering-up of others during the subsequent construction of a road along the north wall of North Dock was particularly unfortunate, but still left the best overall exposure of these rocks. Other exposures of the formation lie in the coastal cliffs north of Crimdon Park [NZ 48 37] (the only other large section), near Blackhall Colliery [NZ 46 39], Easington Colliery [NZ 44 43] and Dawdon Colliery [NZ 43 47], and in the valley of Seaton Burn [NZ 413 503], Seaham.

The calcitic concretions and massive beds of spherulitic limestone at Seaham have much in common with those of the Cycle EZ2 Concretionary Limestone of the Fulwell and Carley Hill Quarries at Sunderland and also of several other localities in the Cleadon–Marsden–Sunderland area; the main difference is that those at Seaham generally do not feature the fine parallel primary lamination of their Concretionary Limestone counterparts and white crystalline calcite is much less common. Striking exposures of coarse calcite spherulites lie low in the cliffs [NZ 4315 4951] immediately north of the harbour, where much of the rock is a massive coarsely crystalline limestone. Calcite spherulites are also abundant in parts of the Seaham Formation at its other main exposure in coastal cliffs north of Crimdon Park, but are smaller and less striking.

The composition and petrography of the Seaham Formation were investigated as part of wider studies by Al-Rekabi (1982) and Braithwaite (1988), who present illustrations (including photomicrographs) of several of the rock types present. Both authors inferred a late phase of leaching and partial internal collapse. Al-Rekabi concluded (albeit diffidently) that at least some of the radial calcite concretions may have had a sulphate precursor, but this view was disputed by Braithwaite who concluded that most of the late (i.e. post-burial) calcite replaced a range of earlier carbonate rock types without a sulphate intermediary or precursor.

Structural and petrographical effects of evaporite dissolution

The main structural effects of evaporite dissolution at Seaham cannot readily be seen, but their overall effect may be inferred from evidence visible at other exposures along the north-east coast and from reconstructions of regional stratigraphic relationships from boreholes in Yorkshire (Smith, 1974b; Taylor and Colter, 1975); these data show that all the strata exposed on the coast at Seaham must have foundered by more than 100 m as a result of the dissolution of the Cycle EZ1 Hartlepool Anhydrite. Farther north, study of cliff sections around Sunderland, Whitburn and Marsden shows that the fracturing and brecciation caused by such foundering die out upwards in the Cycle EZ2 Concretionary Limestone and Roker Dolomite formations, but that the less obvious effects persist upwards in the form of broad open folds and scattered faults. Presumably some such folds and faults have affected the sequence exposed at Seaham, but cannot now be distinguished from possible tectonic dislocation associated with the formation of the Seaham Fault and from the effects of the removal of the Fordon Evaporites.

The less severe effects of the dissolution of the Fordon Evaporites take the form of numerous minor faults and folds that break up much of the Seaham Formation into blocks commonly only a few metres across; most of the faults are normal and stepped, but a few reverse faults are present and also some minor troughs. Complete brecciation of parts of the

Seaham Formation occurs locally, but is not as widespread as that noted in foundered Cycle 2 strata (Smith, 1972). Late stage breccia-gashes are similarly less common than in Cycle EZ2 rocks.

The relative importance of the varied processes leading to brecciation in rocks associated with evaporites varies greatly from place to place and embraces fracture by and the injection of pressurized formation fluids, including those liberated by the dehydration of gypsum, into rocks both above and below the evaporite beds; it is probably this process that accounts for the network of evaporite-filled veins found at depth in many Zechstein carbonate rocks in north-east England and which ultimately accounts for the brecciation of the rocks when the evaporite veins dissolve and leave the fragments unsupported. The partial brecciation of the uppermost part of the Roker Dolomite Formation in the northern part of the site probably results from this process.

The petrographical effects of evaporite dissolution on the carbonate rocks at Seaham have not been studied in detail, but appear mainly to have resulted in dedolomitization. This process here has widely converted the uppermost part of the Roker Dolomite from soft, porous, ooidal dolomite into hard, dense limestone; the effect is general in the uppermost 1–3 m, but dies out downwards. The basal dolomitic parts of the overlying Seaham Formation have also locally been dedolomitized.

The dedolomitization of the uppermost part of the Roker Dolomite Formation presumably was caused by the reaction of the dolomite with pervasive calcium sulphate-rich solutions. These may have been released during burial by the dehydration of primary gypsum, but more probably originated during uplift when the anhydrite was hydrated and the resulting gypsum was dissolved by phreatic groundwaters.

Breccia-gashes

Most of the known breccia-gashes (under a variety of names such as gash-breccia and breccia-pipe) are in the Concretionary Limestone, but a few at Seaham and in cliffs to the north of Crimdon Park are in the Seaham Formation. Work on equivalent Cycle EZ3 strata in Yorkshire (Smith, 1972; Cooper, 1986) has shown that such gashes probably form through the collapse of caves located at the intersection of joints or faults, and propagate upwards until they choke with debris. According to Cooper, this choking occurs when the pipe is 5–10 times the original height of the cave, through the stoping of angular fragments of roof rock. The end results of this process are near-vertical bodies of breccia, some with slight fault displacement, composed of fragments of wall rock, but also commonly including fragments of rocks from strata since removed by erosion; such breccia-gashes are analogous to small faulted-in outliers, and afford valuable information on the former local stratigraphy. The breccia-gash near the east end of the north wall of the North Dock at Seaham, though now degraded, is an excellent example of a structure associated with a minor normal fault and in which are preserved fragments of younger strata, the Rotten Marl, now otherwise eroded away.

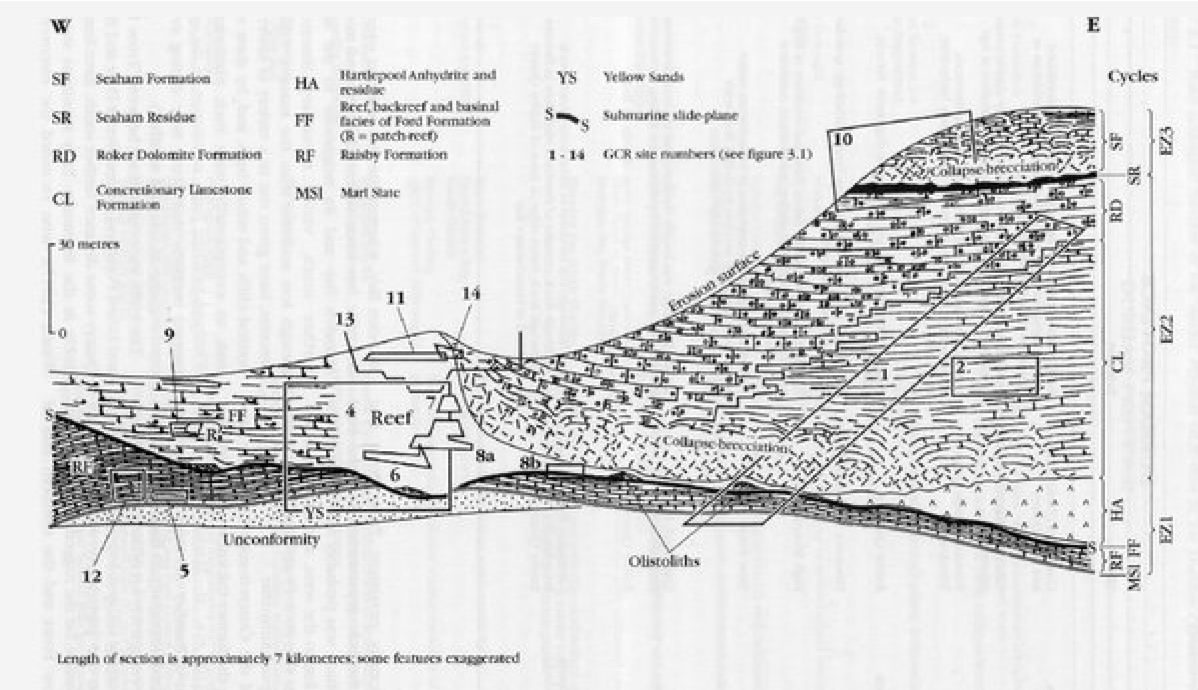
Future research

Although the broad outlines of the geology of the natural and man-made cliffs at Seaham are reasonably well known and understood, many details remain uncertain and would amply repay further research. Amongst the more fundamental aspects in need of investigation are (a) the geochemistry and petrology of the Seaham Residue, with the aim of determining the character, thickness and depositional environment of the Fordon Evaporites of which it is the insoluble remains, and (b) the precise thickness and sedimentology of the Seaham Formation, with the aim of accurately documenting this formation at its type locality and of attempting to deduce its depositional environment.

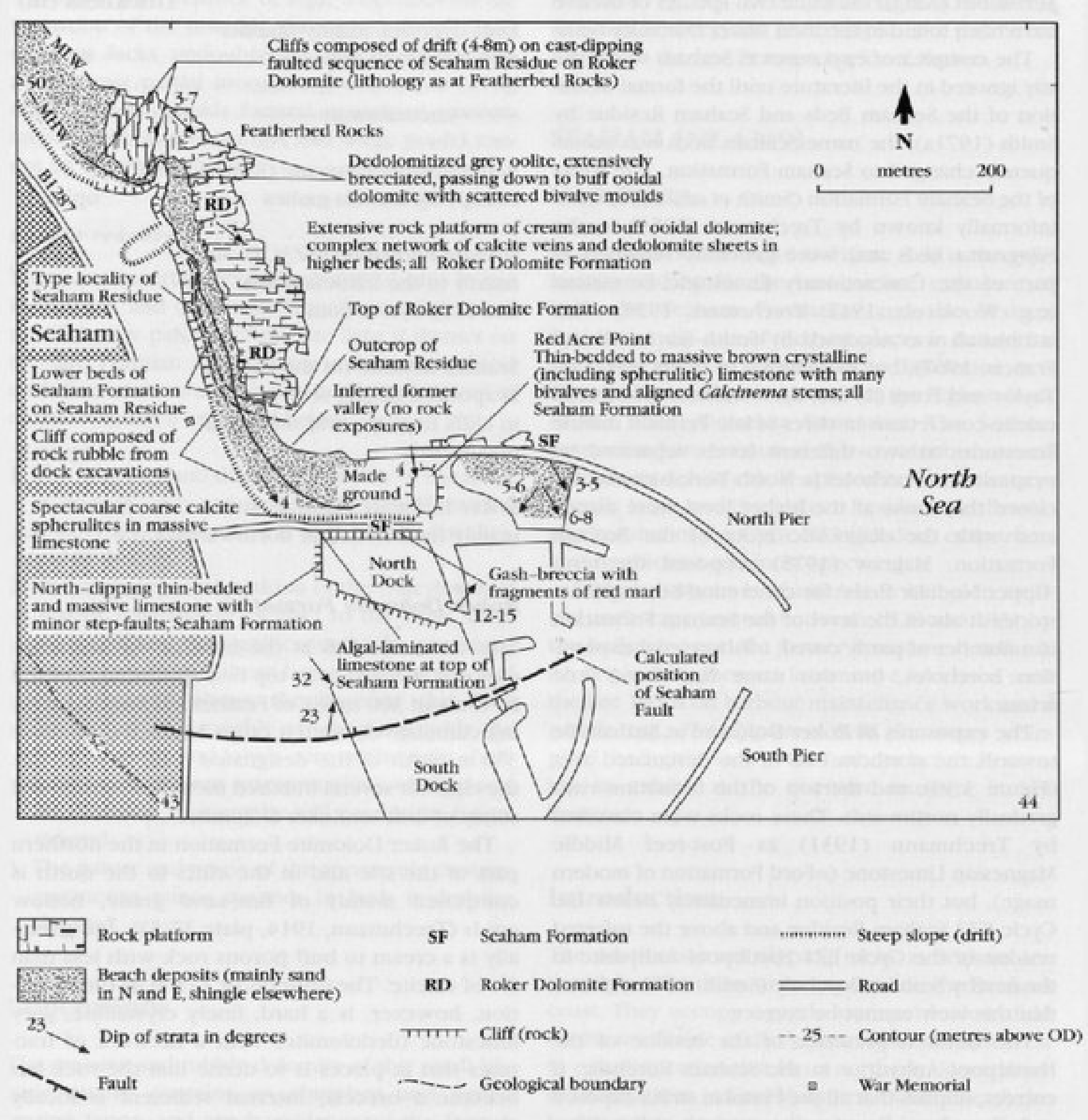
Conclusions

The coastal site at Seaham contains the highest Permian strata exposed on the Durham coast, and is the type locality of both the Seaham Residue and the Seaham Formation. This is a classic site for the study of post-depositional changes in sedimentary sequences. The site exhibits a range of features including unusually large calcite concretions in the Seaham Formation, together with the only known clear exposure of the top of the Roker Dolomite Formation. Of particular significance are the well-exposed remains of former evaporite beds since removed by dissolution. The evaporites resulted from the evaporation of the Zechstein Sea, producing salt and anhydrite concentrates. These were later taken back into solution by invading groundwater, leaving an insoluble residue and causing collapse of the overlying strata. In particular, breccia-gashes, which contain fragments of rocks which have elsewhere been eroded from the area, were created. The site is therefore of major importance in observing post-depositional changes in the Permian rocks of Durham.

References

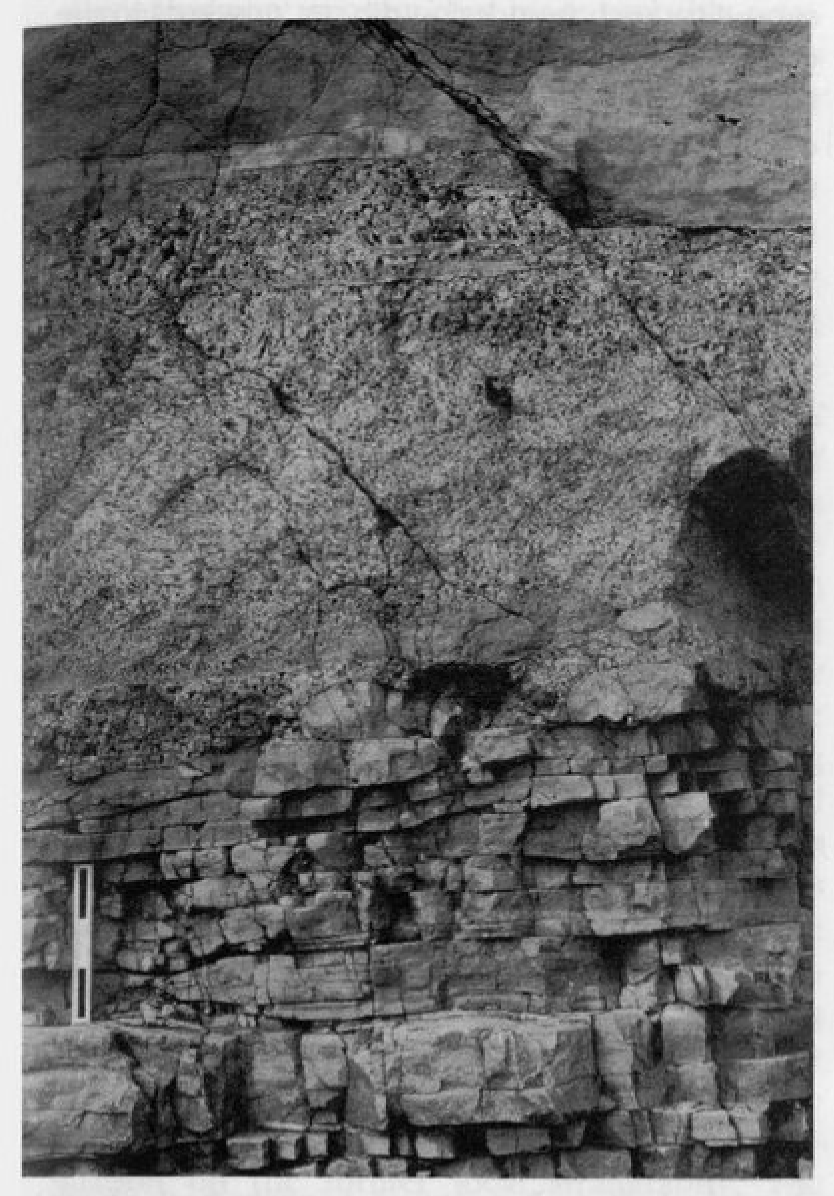


(Figure 3.2) Approximate stratigraphical position of GCR marine Permian sites in the northern part of the Durham Province of north-east England (diagrammatic). Some sites in the southern part of the Durham Province cannot be accommodated on this line of section and have been omitted. The Hartlepool Anhydrite would not normally be present so close to the present coastline but is included for the sake of completeness.



(Figure 3.39) The Seaham GCR site, showing the position of the main features of geological interest.

(Figure 3.40) Strong contortions in the lower part of the Seaham Residue at the type locality, showing detached blocks of cross-laminated ooid grainstone (middle) and the lowest part of the bedded ooid grainstones that here form a median unit in the Residue. Hammer: 0.33 m. (Photo: D.B. Smith.)



(Figure 3.41) Typical limestones of the Seaham Formation immediately north of the harbour at the type locality, showing massive secondary spherulitic limestone overlying unevenly, mainly thin-bedded, Ca[cinema bivalve calcite mudstones and wackestones with shallow mega-ripples and cut-and-fill structures. Note the minor step-fault at top right. Bar: 0.32 m. (Photo: D.B. Smith.)