FULWELL HILLS QUARRIES (MAINLY SOUTHWICK QUARRY)

OS Grid Reference: NZ3859

Highlights

The several preserved quarry faces in the Concretionary Limestone of Fulwell Hills, Sunderland (box 2 in Figure 3.2), are representative of more than 40 former exposures. They contain a unique range of complex and spectacular calcite concretions, including some claimed to simulate organic structures such as those of some corals and blue-green algae, and have yielded many fish remains from a thin bed near the base of the exposed sequence; the fish include *Acentrophorus varians* (Kirkby), this being the type locality. The rocks are unevenly gently folded and fractured, probably mainly by differential foundering caused by dissolution of the formerly underlying thick Hartlepool Anhydrite.

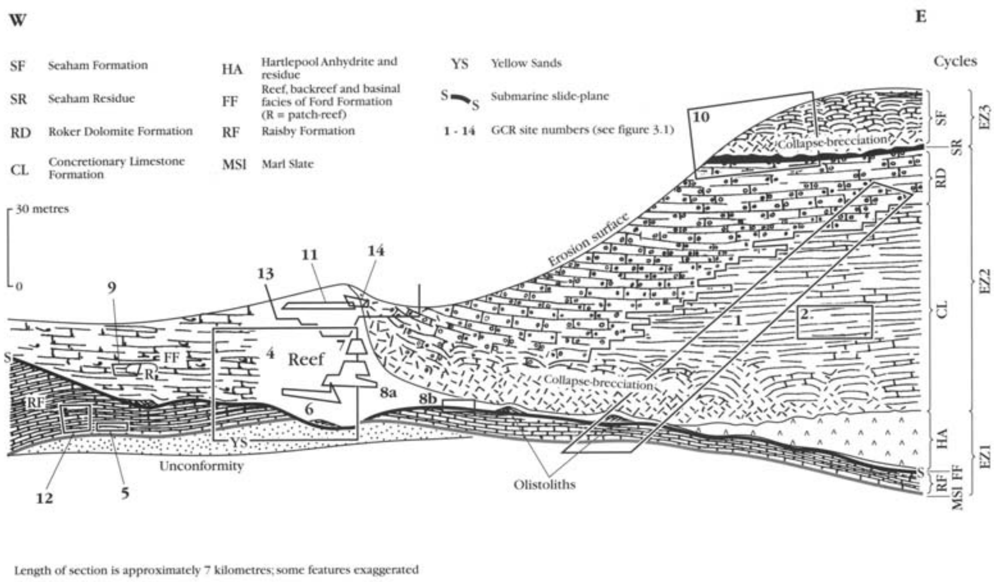

Figure 3.2: Approximate stratigraphical position of GCR marine Permian sites in the northern part of the Durham Province of north-east England (diagrammatic). Some sites in the southern part of the Durham Province cannot be accommodated on this line of section and have been omitted. The Hartlepool Anhydrite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

Introduction

The vast complex of quarries in the Concretionary Limestone of Fulwell Hills, in the north-western outer suburbs of Sunderland, has long been justly famous for its bewildering array of bizarre calcite concretions. Quarrying started before 1746 and ceased in 1957. In that time almost all the concretion-bearing beds were removed from an area exceeding a 0.5 km², largely for lime burning and building purposes; much of the output was transported by wagonways to ships on the River Wear, 2 km to the south.

Only a few of the many faces once worked have been preserved, but records of 36 faces examined in 1954 are lodged in the fieldnote files of the British Geological Survey. About 26 m of strata are now visible, out of a former total of about 35.7 m, and are thought to lie in about the middle of the Concretionary Limestone Formation. Concretions from Fulwell are to be found in many museums, with substantial collections at the Hancock Museum (Newcastle upon Tyne), Sunderland Museum, Nottingham University and the British Museum of Natural History;Abbott (1914) also cites collections at Oxford and Aberdeen University museums and museums at Haslemere and Copenhagen. They feature strikingly in many local walls and buildings, and in hundreds of private and public gardens in the South Shields and Sunderland areas.

The calcite concretions of Fulwell Hills were first noted byWinch (1817) and described in more detail by Sedgwick (1829); they were further described, classified and freely illustrated by Abbott (1907, 1914), Holtedahl (1921) and Tarr (1933). Briefer descriptions and attempts (so far not wholly successful) to explain the genesis of the concretions in the formation as a whole have been made by Garwood (1891), Woolacott (1912, 1919a, b), and Holmes (1931), and a detailed study on calcitization and compaction in rocks of the formation was made by Braithwaite (1988). Browell and Kirkby (1866) and Trechmann (1914) published much-quoted analyses of a selection of rocks from Fulwell Quarries and the site is also the type locality of the Fulwell Fish-Bed from which Kirkby (1863, 1864, 1867) recorded two species of fish. Finally, Fulwell Quarries and other local localities in these strata have been mentioned and/or illustrated in a number of regional accounts (Trechmann, 1925; Smith, 1970a, 1980b, 1994; Pettigrew, 1980) and for many years they have been a favourite venue for excursion parties whose visits have been recorded in the proceedings of various learned societies. Drift deposits formerly present at about +45 m O.D. on the north side of the hills contained a gravel lens interpreted by Howse (1864) and Woolacott (1897, 1900a, b) as a Quaternary raised beach, and Kirkby (1860) describes sand-filled pipes up to 3.5 m deep in the underlying limestone here.

Tarr (1933, p. 268) waxed lyrical over the limestones of Fulwell Quarries and wrote 'This exposure should be permanently preserved as one of the most outstanding examples of nature's ability to build artistically in stone'. The faces to which he referred have, unfortunately, long since disappeared, but those now preserved are reasonably representative of the many formerly available for study.

Description

Most of the several quarries on Fulwell Hills (including Fulwell Quarry itself) have been filled and partly or wholly landscaped, though a number of small faces have survived in addition to those scheduled for preservation. The quarries were worked under a number of names, but the main preserved faces are in the former Southwick Quarry; the scheduled areas are shown on Figure 3.19.

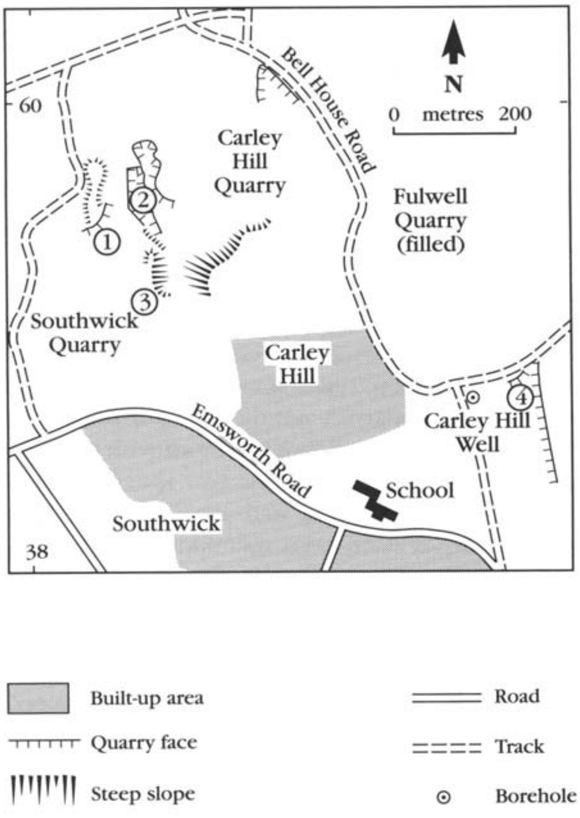

Figure 3.19: Preserved faces within the complex of former limestone quarries on Fulwell Hills, Sunderland; numbers refer to quarry faces described in the text.

The Concretionary Limestone strata of the Fulwell Hills Quarries totalled about 35.7 m in thickness, and comprise four main lithological units; the general sequence formerly visible is shown below.

	Thickness (m)
Drift, mainly red-brown, silty, stony clay, but with patches, sheets and lenses of limestone brash, gravel, sand and laminated clay	0–6.0
——– unconformity ——–	
Limestone, grey and brown, very finely crystalline, mainly finely and evenly laminated, but with many thin unlaminated beds (some graded), interbedded with and passing into subordinate very finely saccharoidal, cream and buff dolomite; the laminated limestones contain abundant, but patchy, coarse, radially crystalline, brown calcite, including coarse spherulites, and many displacive lenses and tongues of white calcite; the unlaminated limestones contain patchy, radial/concentric calcite concretions and the dolomites contain scattered to abundant subspherical to lobate calcite concretions. Marked lateral variation	*c.* 21.0
Limestone, grey and brown, very finely to very coarsely crystalline, mainly finely and evenly laminated, but with many thin unlaminated beds (some graded) and with a widespread 0.5 m bed of cream and buff, very finely saccharoidal dolomite 2.4–2.9 m from top. Most of the limestone is massive and comprises a wide range of spectacular reticulate, lobate and spherulitic calcite concretions,	

with some lateral passage into finely saccharoidal dolomite containing scattered to abundant subspherical and/or lobate calcite concretions; some beds deformed by submarine slumping	*c.* 7.6
Limestone, grey and buff, very finely crystalline, mainly very finely and evenly laminated, but with some thin unlaminated beds (some graded); scattered, coarse, radial calcite crystals in the laminated beds, and small subspherical calcite concretions in the unlaminated beds	1.8–2.0
Dolomite, cream-grey, very finely saccharoidal, soft	5.5+

Of these units, the uppermost is by far the most laterally variable; even when many faces were fully exposed, correlation between sections was uncertain unless the faces were either very close or in contact; most parts of this unit are now obscured. In contrast, the 7.6 m unit comprises relatively laterally extensive thick and massive beds that could be traced readily with the aid of the recessive 0.5 m dolomite bed; this 7.6 m unit was the main quarrying target and the floor of the quarry widely followed its base. The 1.8–2 m bed near the base of the sequence is the 'Flexible Limestone' of the literature, although only the thinnest laminae here are noticeably flexible; it includes, near the top, the slightly bituminous Fulwell Fish-Bed discovered and recorded by Kirkby (1863, 1864, 1867) but which is only very sparingly fossiliferous in the solitary section now exposed. The lowest unit is the Great Marl Bed of the quarrymen (Woolacott, 1912) although Kirkby (1863, 1864, 1867) and Browell and Kirkby (1866) used the term in a different (perhaps the original and more correct) sense for a bed at the base of the 21.0 m unit.

Except in the fish-bed, fossils are very uncommon at Fulwell but a few were recorded by Kirkby from near the base and top of the Flexible Limestone, from four levels low in the 7.6 m unit and from a single level high in this unit; they comprise the conifer *Ullmannia frumentaria*, obscure plant remains, and the nektonic fish *Acentrophorus varians* (Kirkby) and *Acrolepis* (rare); Pettigrew (1980) records that whole *Acentrophorus* (0.04 m), for which this is the type locality, have been found within the visceral cavity of the much larger (0.25–0.35 m) predatory *Acrolepis*. Kirkby (1864) commented that only the fish-bed was worth examining for fossils and that fish discoveries in other beds were almost invariably accidental and made in the course of quarrying. Although bivalves commonly form the nucleus of (or lie within) concretions in the Marsden and Roker areas, none have been found in the Fulwell Hills Quarries (Woolacott, 1912).

Almost all the strata in the Fulwell Hills Quarries (including those in faces now covered) are gently folded and fractured, with dips of up to 40ø, but generally 5 to 10ø; a few small almost-completely brecciated areas also occur, mainly in faces now covered. The pattern of folds and fractures appears to be random, and is unrelated to well-documented structures in underlying coal workings.

The calcite concretions in the rocks at Fulwell Hills Quarries are bewilderingly varied, but there is a general tendency for the most complex types to be concentrated in the 7.6 m unit where they characterize beds traceable for some hundreds of metres. The most spectacular concretions are in the laminated limestones and comprise three-dimensional reticulate combinations of rhythmic bands and radial calcite crystals on scales ranging from millimetres to several decimetres (depending on the spacing of nucleation centres); spaces between the concretionary calcite are either empty or partly to wholly occupied by powdery cream dolomite which, in places, contains calcite scalenohedra up to 0.05 m long. Many of the concretions in the laminated limestone are clearly spatially and genetically related to joints, cracks and bedding planes, but others appear to be unrelated to such features; as Sedgwick (1829, p. 95) noted, the lamination commonly passes uninterruptedly through the concretions, although slight disruption is common. Concretions also persist through many of the thin unlaminated beds, whereas the thicker unlaminated beds are mainly of dolomite and are either concretion-free or patchily contain rod-like, lobate, or subspherical ("cannon-ball') types (Figure 3.20);

some of the last exceed 0.3 m in diameter. Analyses byBrowell and Kirkby (1866), Garwood (1891) and Trechmann (1914) showed that the calcite concretions contain up to about 22% of dolomite and that the dolomite between the concretions is slightly calcitic; thin sections (Trechmann, 1914, p. 237 and plate 36, fig. 5) reveal that the dolomite in the concretions forms inclusions in the calcite and that the 13% of calcite in the dolomite of the Great Marl Bed is concentrated in narrow veins. Most of the limestone beds display traces of a complex diagenetic history, and evidence of leaching, stylolitization and partial auto-brecciation is widespread; infiltrated and crystalline cavity-fill commonly have reduced the secondary porosity created by leaching and brecciation.

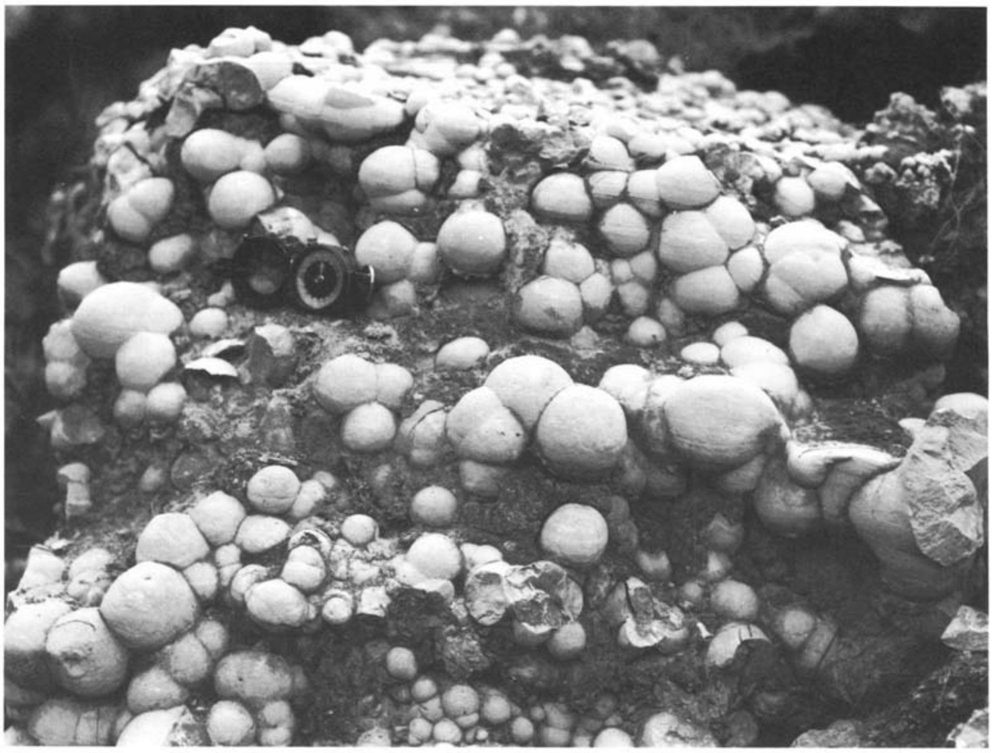

Figure 3.20: Mutually interfering subspherical calcite concretions ("cannon-balls') in a matrix of fine-grained dolomite. Note the parallel bedding traces preserved on the surface of some of the concretions. Loose specimen from floor of Southwick Quarry. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (NL 130).

The site contains several faces of which four are especially noteworthy (1–4 in Figure3.19); three are in the former Southwick Quarry and one in an unnamed quarry (not Carley Hill Quarry) on the east side of Carley Hill.

Face 1. This upstanding rock-face is about 10 m high and 70 m long; it is overlain by quarry spoil which obscures much of the south-western part of the exposure. Strata (about 18.6 m in total) dip north at up to about 20ø and comprise several thick to very thick beds of hard concretionary limestone separated by relatively continuous, but generally thinner, beds of softer cream dolomite; the base of the section is probably slightly above the top of the Flexible Limestone and the sequence exposed comprises most of the 7.6 m unit and the lower beds of the 21 m unit. The limestone beds are mainly finely laminated and feature a wide range of highly complex calcite concretions, including many reticulate types; strong contemporaneous slump contortion is a feature of one of these beds a few metres above ground level on the south-east corner of the face. Most of the dolomite beds contain subspherical non-radial calcite concretions and some contain particularly fine examples of radially-crystalline large calcite lobes.

Face 2. This face surrounds a large excavation in the quarry floor. Strata in it dip generally northwards, in continuation of Face 1, and comprise about 25.5 m of beds of which the uppermost 13 m lie in the 21 m unit and the remainder form the 7.6 m unit and the Flexible

Limestone; only the extreme top of the Great Marl Bed is exposed. Interest in this face centres on the Flexible Limestone exposed near the south-west end of the face, and the sparingly fossiliferous Fulwell Fish-Bed near its top.

Face 3. Strata in this face dip southwards at about 5ø and comprise about 16 m of much the same sequence as Face 1; finely plane-laminated crystalline limestone predominates, with some calcite crystals exceeding 0.2 m in length. A 5.5 m bed of cream dolomite in the middle of the sequence is atypically thick, however, and is probably the 'Great Marl Bed' ofKirkby (1867); it should not be confused with the bed at the base of the sequence that was accorded the same name by Woolacott (1912) and Trechmann (1914).

Face 4. This comprises two main parts, a small section along the northern side of the old quarry and a long and somewhat overgrown face on the east side. Interest focuses on the small northern face, which furnishes one of the best exposures of complexly reticulate calcite concretions in which the spatial influence of cracks, joints and bedding planes is especially clear. This face is in massive limestone near the top of the 7.6 m unit. The long eastern face is mainly in this unit together with basal beds of the 21 m unit (total about 14 m), and displays both the rolling character of the strata and the great lateral variability of the limestones; the intervening soft cream dolomite beds are more uniform and persistent, as in faces 1–3. In common with many faces in the quarry complex, rockhead in the north of this face features evidence of cryoturbation and large slabs of limestone are embedded in the overlying drift.

Interpretation

The calcite concretions of Fulwell Hills are renowned worldwide for their complexity and variety, and the quarry faces preserved there contain a unique blend of unusual concretionary forms on a wide range of scales; equivalent strata are widely exposed in quarry and coastal cliff sections between South Shields and Whitburn and also at Hendon (a southern district of Sunderland), but none exhibit quite the range exhibited at Fulwell. The Flexible Limestone at Fulwell is generally less flexible than at Marsden, where its flexibility was first noted by Nichol (reported by Winch, 1817), but it is generally richer in fish remains. The cause of the flexibility is not known, but the fineness of the lamination and the preservation of bituminous films and fish remains points to slow accumulation under anoxic conditions well below wave-base.

All the strata exposed in the Fulwell Hills Quarries lie wholly within the Concretionary Limestone Formation as redefined by Smith (1971a), though the 'Great Marl Bed' at the base of the sequence was formerly classified (e.g. Woolacott, 1912; Trechmann, 1914) as Middle Magnesian Limestone. Records of the Carley Hill Well (NZ 3872 5951) in the south of the quarry complex show interbedded marl (i.e. soft dolomite) and laminated limestone to 26 m below the quarry floor, suggesting that at least 22 m of the Concretionary Limestone Formation lies below the Flexible Limestone here. The base of the 0.1 m Marl Slate lies in the well at a depth of 58 m (about -3.4 m O.D.) and the Yellow Sands lie at 95.8 m (about -41.2 m O.D.).

The Concretionary Limestone (up to 120 m) is the thickest carbonate formation of the English Zechstein sequence and its land outcrop spans most of the area between the reef and the present coast (Woolacott, 1912, fig. 5, which mistakenly includes the Seaham Formation); coal exploration boreholes have shown that the formation also crops out on the sea floor (or beneath drift) for several kilometres east of the present coast (Smith, 1994, fig. 34), and extends farther eastwards in the subsurface.

Interpretation of the stratigraphical relationships of the Concretionary Limestone Formation is complicated by its great lateral variability, lack of outcrop continuity and complex foundering, but the writer (Smith, 1970a, 1971a, 1980a, b, 1994) believes that it is co-extensive with the slope facies of the Cycle EZ2 carbonate unit and passes upwards and westwards into a shelf facies represented by the Roker Dolomite; the beds exposed at Fulwell Hills probably were formed on about the middle of the slope, in anoxic water below a basin-wide oscillating pycnocline. The proximity of Fulwell Hills Quarries to the reef at West Boldon shows that the shelf facies may have been less than 2 km wide here. The foundering of the Concretionary Limestone results from the dissolution of the formerly underlying thick (?100 m+?) Hartlepool Anhydrite and is undoubtedly the cause of most of the folds, fractures and brecciation seen in the Fulwell Hills Quarries. Other sedimentological and subsidence features of the formation are further discussed in the account of the coast sections at Marsden Bay, and it will suffice to note here that a slope origin for the Fulwell Hill strata is consistent with the evidence of submarine slumping seen in Face 1 and of the prevalence of thin unlaminated beds (many graded) that are interpreted (Smith, 1970a, 1971a, 1980a, b, 1994) as turbidites.

The origin of the calcite concretions in the Concretionary Limestone has been the subject of endless speculation, but remains uncertain. Sedgwick (1829) recognized that the concretions were secondary and that most of them were formed after much of the rock was partly or fully lithified, and Garwood (1891) showed that the chemical changes could have taken place in a closed system and resulted from a major redistribution ("segregation') of components rather than from the large-scale introduction or removal of matter. Later workers (e.g.Woolacott, 1912, 1919a; Trechmann, 1914; Holmes, 1931; Tarr, 1933) have pondered on the detailed chemistry of the profound mineralogical changes and speculated on the possible involvement of former organic matter, calcium sulphate and other salts; Shearman (1971) and Clark (1980, 1984) considered the possible role of sulphate-reducing bacteria. The petrography, geochemistry and evolution of the Concretionary Limestone in general (but not specifically at Fulwell Hills Quarries) was reviewed in detail by Al-Rekabi (1982) and Braithwaite (1988), who give full references.

Future research

The regional distribution, stratigraphical relationships and sedimentology of the Concretionary Limestone Formation are reasonably well known, although Fulwell Hills Quarries yield only a small part of the evidence on which this understanding is based. The quarries, however, remain a unique repository of almost the full range of concretions in this enigmatic formation, and the exposures here are an essential part of any further studies of the origin of these bewildering structures and of the rocks as a whole. Now that extraction of limestone has ceased, this is no longer a good site for the study of fossil fish, though good specimens are still to be found by the lucky or diligent searcher.

Conclusion

The Fulwell Hill Quarries complex is an internationally important GCR site. The site is justly famous for the enormous range of spectacular calcite concretions which characterize the aptly named Concretionary Limestone, as well as for the Fulwell Fish-Bed for which this is the type locality. It also features a range of structural features caused by the dissolution of the underlying Hartlepool Anhydrite. The origins of the concretions are still poorly understood and therefore this site provides essential exposures for their future study.

Reference list

Abbott, G. (1907) Concretions. *South-eastern Naturalist*, 1–7.
Abbott, G. (1914) Discoid limestones which simulate organic characters. A case of inorganic evolution. *The Pioneer*, 1–8.
Al-Rekabi, Y. (1982) Petrography, porosity and geochemistry of the Upper Magnesian Limestone of NE England. Unpublished Ph.D. Thesis, University of Dundee.
Braithwaite, C.J.R. (1988) Calcitization and compaction in the Upper Permian Concretionary Limestone and Seaham formations of north-east England. *Proceedings of the Yorkshire Geological Society*, **47**, 33–45.
Browell, E.J.J. and Kirkby, J.W. (1866) On the chemical composition of various beds of the Magnesian Limestone and associated Permian rocks of Durham. *Transactions of the Natural History Society of Northumberland*, *Durham and Newcastle upon Tyne*, **1,** 204–30.
Clark, D.N. (1980) The diagenesis of Zechstein carbonate sediments, in *The Zechstein Basin with Emphasis on Carbonate Sequences* (eds H. Füchtbauer and T.M. Peryt), Elsevier, Amsterdam, pp. 167–203.
Clark, D.N. (1984) The Zechstein in NW Europe, in *Carbonate Geology* (course notes), Open University, Milton Keynes, pp. 150–71.
Garwood, E.J. (1891) On the origin and mode of formation of the concretions in the Magnesian Limestone of Durham. *Geological Magazine*, **8,** 433–40 + 1 plate.

Holmes, A. (1931) Concretionary and oolitic structures of the Permian rocks, in *Contributions to the Geology of Northumberland and Durham*, *Proceedings of the Geologists' Association*, **42**, 255–8.

Holtedahl, O. (1921) On the occurrence of structures like Walcott's Algonkian algae in the Permian of England. *American Journal of Science*, **5,** 195–206.

Howse, R. (1864) On the glaciation of the counties of Durham and Northumberland. *Transactions of the North of England Institute of Mining and Mechanical Engineers*, **13**, 169–85.

Kirkby, J.W. (1860) On the occurrence of 'sand-pipes' in the Magnesian Limestone of Durham. *The Geologist*, **3,** 293–8, 329–36.

Kirkby, J.W. (1863) Fossil fish in Magnesian Limestone at Fulwell Hill. *Transactions of the Tyneside Naturalists' Field Club*, **5,** 248.

Kirkby, J.W. (1864) On some remains of fish and plants from the 'Upper Limestone' of the Permian series of Durham. *Quarterly Journal of the Geological Society of London*, **20**, 345–58 (reprinted 1867 in the *Transactions of the Natural History Society of Northumberland*, *Durham and Newcastle upon Tyne*, **1,** 64–83).

Kirkby, J.W. (1867) On the fossils of the Marl Slate and Lower Magnesian Limestone. *Transactions of the Natural History Society of Northumbria*, **1,** 184–200.

Pettigrew, T.H. (1980) Geology, in *The Magnesian Limestone of Durham County* (ed. T.C. Dunn), Durham County Conservation Trust, pp. 4–26.

Sedgwick, A. (1829) On the geological relations and internal structure of the Magnesian Limestone, and the lower portions of the New Red Sandstone in their range through Nottinghamshire, Derbyshire, Yorkshire and Durham, to the southern extremity of Northumberland. *Transactions of the Geological Society of London*, **3,** 37–124.

Shearman, D.J. (1971) Discussion on paper by F.W. Beales and E.P. Onasick. *Transactions of the Institution of Mining and Metallurgy*, **80**, B50–2.

Smith, D.B. (1970a) Permian and Trias, in *The Geology of Durham County* (complier G.A.L. Johnson), *Transactions of the Natural History Society of Northumberland*, *Durham and Newcastle upon Tyne*, **41**, 66–91.

Smith, D.B. (1970b) The palaeogeography of the British Zechstein, in *Third Symposium on Salt* (eds J.L. Rau and L.F. Dellwig), Northern Ohio Geological Society, Cleveland, pp. 20–3.

Smith, D.B. (1971a) *The Stratigraphy of the Upper Magnesian Limestone*: *a revision based on the Institute's Seaham Borehole*, Report 71/3, Institute of Geological Sciences, 12 pp.

Smith, D.B. (1980a) The evolution of the English Zechstein Basin, in *The Zechstein Basin with Emphasis on Carbonate Sequences* (eds H. Füchtbauer and T.M. Peryt). Contributions to Sedimentology, 9, Elsevier, Amsterdam, pp. 7–34.

Smith, D.B. (1980b) Permian and Triassic rocks, in *The Geology of North-east England* (ed. D.A. Robson), Special Publication of the Natural History Society of Northumbria, pp. 36–48.

Smith, D.B. (1994) *The Geology of the Sunderland District*, Memoir of the British Geological Survey, Sheet 21.

Tarr, W.A. (1933) Origin of the concretionary structures of the Magnesian Limestone at Sunderland, England. *Journal of Geology*, **41**, 268–87.

Trechmann, C.T. (1914) On the lithology and composition of Durham Magnesian Limestones. *Quarterly Journal of the Geological Society of London*, **70**, 232–65 + 2 plates.

Trechmann, C.T. (1925) The Permian formation in Durham. *Proceedings of the Geologists' Association*, **36**, 135–45.

Winch, N.J. (1817) Observations on the geology of Northumberland and Durham. *Transactions of the Geological Society of London*, **4,** 1–101.

Woolacott, D. (1897) *Geology of north-east Durham*, Hills and Co., Sunderland, 31 pp.

Woolacott, D. (1900a) On the boulder clay, raised beaches and associated phenomena in the east of Durham. *Proceedings of the University of Durham Philosophical Society*, **1,** 247–58.

Woolacott, D. (1912) The stratigraphy and tectonics of the Permian of Durham (northern area). *Proceedings of the University of Durham Philosophical Society*, **4,** 241–331.

Woolacott, D. (1919a) The Magnesian Limestone of Durham. *Geological Magazine*, **6,** 452–65, 485–98.