British Upper Carboniferous Stratigraphy

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GCR Editor: L.P. Thomas

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Chapter 3

Culm Trough

There are about 3500 km^2 of Upper Carboniferous surface outcrop in north Cornwall, Devon and west Somerset, mainly in an area between Barnstaple and Bampton in the north, and Boscastle and Exeter in the south (Figure 3.1). The coastal exposures are particularly fine and have revealed exceptional stratigraphical and structural detail.

The Upper Carboniferous of this area consists mainly of marine or marginal marine deposits, quite different from the fluvio-deltaic sequences present in the rest of Britain. They are widely referred to as the Culm deposits, following Sedgwick and Murchison (1840), a term apparently referring to the thin, sooty coal seams that they contain (although Edmonds *et al.*, 1975 suggest a possible origin in the Welsh word 'cwlwm' (knot) referring to the contorted nature of the strata). These coals are generally of poor quality and are mainly restricted to a narrow belt between Greencliff on the coast near Bideford, to Hawkridge Wood near Chittlehampton. Despite their poor quality and tectonic disturbance, they were worked at least as far back as the Middle Ages and as recently as 1969 (Edmonds *et al.*, 1979). As well as a fuel, they were used as a pigment for black paint (hence the name of one of the principal coals, the Paint Seam).

History of research

Edmonds (1974) and Edmonds *et al.* (1975) discuss the history of research on these strata. The groundwork was done by Conybeare (1814, 1823), De la Beche (1834, 1839), Sedgwick and Murchison (1840) and, perhaps most significantly, Ussher (1881, 1887, 1892, 1900, 1901). Subsequent work by Arber (1907, 1911), Owen (1934, 1950) and Prentice (1960a, 1960b, 1962), culminated in a series of sheet memoirs by the British Geological Survey, which provide the most detailed accounts of the geology of this area (e.g. Freshney *et al.*, 1972, 1979; McKeown *et al.*, 1973; Edmonds *et al.*, 1979, 1985).

The Upper Carboniferous of Devon and Cornwall is not particularly rich in fossils, but intensive work mainly by Arber (1904), Rogers and Arber (1904) and Rogers (1909, 1910) provided enough material to establish the main details of the

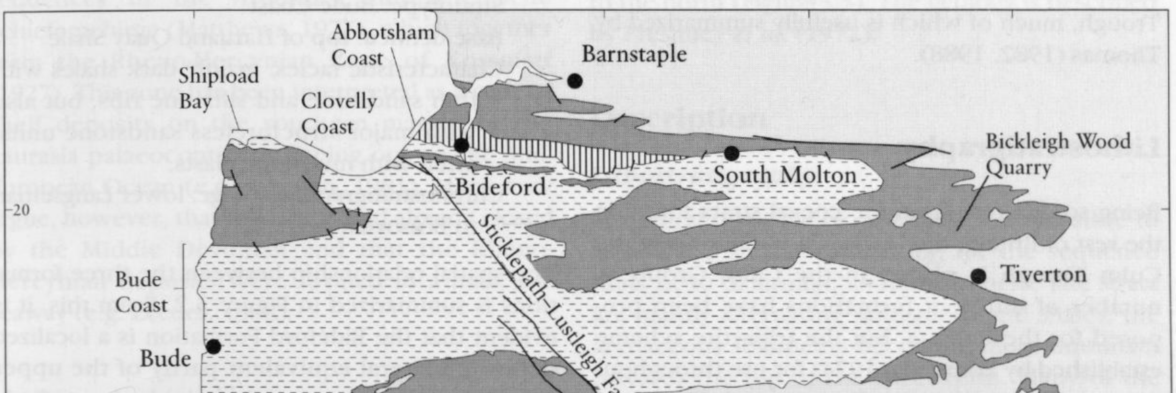
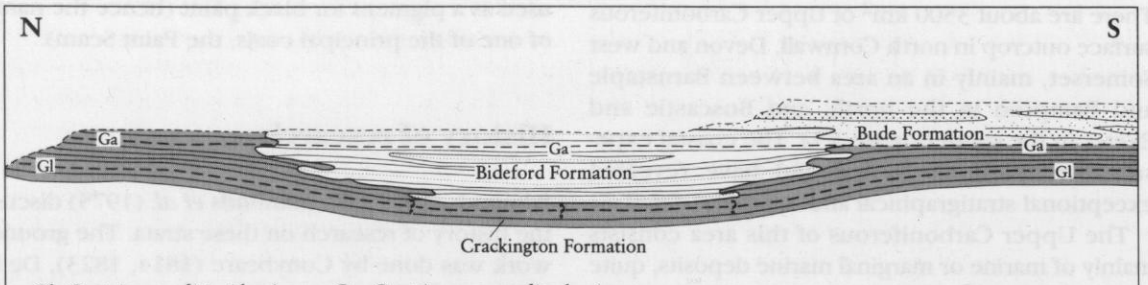


Figure 3.1 Map of parts of Devon and north Cornwall, showing the distribution of Upper Carboniferous deposits. Based on Thomas (1988, fig. 4.2).



Gl *Gastrioceras listeri* horizon Ga *Gastrioceras amaliae* horizon

Figure 3.2 Relationship between the Crackington, Bideford and Bude formations in southwest England. Based on Edmonds *et al.* (1979, fig. 8).

biostratigraphy (more recent data are reviewed by House and Selwood, 1966, Freshney and Taylor, 1972 and Edmonds, 1974). The most recent study is by Eagar and Xu (1993) on the bivalves of the Bideford Formation exposed on the Abbotsham coast.

Most recently, attention has turned to the sedimentology of these strata (Reading, 1963, 1965, 1971; Walker, 1964a; De Raaf *et al.*, 1965; Lovell, 1965; Burne, 1969, 1970; Higgs, 1984). From this work, it has been possible to build up a comprehensive history of the development of the Culm Trough, much of which is usefully summarized by Thomas (1982, 1988).

Lithostratigraphy

Being so different from the coeval strata found in the rest of Britain, the Upper Carboniferous of the Culm Trough is placed in the Culm Group. A number of different formations have been proposed for these strata, but the tripartite scheme established by Edmonds (1974) for use throughout the trough is now generally accepted. The three formations may be summarized as follows (largely based on Thomas, 1988).

Crackington Formation
- Stratotype: Widemouth to Crackington Coast
- Base defined: top of uppermost chert or impure detrital limestone in Culm Group.
- Characteristic facies: quartz-dominated, fine to medium grained (turbiditic) sandstones, interbedded with at least equal thicknesses of marine mudstones and shales.
- Chronostratigraphical range: Arnsbergian to lower Langsettian.

Bideford Formation
- Stratotype: Abbotsham Coast
- Base defined: Mermaid's Pool Sandstone
- Characteristic facies: medium-scale coarsening-upwards cycles, with black shales at the base, grading up through a range of silt stones and sandstones, and topped by a thick feldspathic, cross-bedded sandstone.
- Chronostratigraphical range: (?)Yeadonian to lower Langsettian.

Bude Formation
- Stratotype: Bude Coast
- Base defined: top of Hartland Quay Shale
- Characteristic facies: mainly dark shales with thin sandstone and siltstone ribs, but also with major structureless sandstone units, often with mudstone clasts.
- Chronostratigraphical range: lower Langsettian to Bolsovian.

The spatial relationship between the three formations is summarized in Figure 3.2. From this, it is evident that the Bideford Formation is a localized deposit, a lateral equivalent partly of the upper Crackington Formation and partly the lower Bude Formation.

Geological setting

The Culm Group is the infill of an east–west trending marine trough – the Culm Trough. In the Early Carboniferous, deep water sediments predominate (Goldring, 1962), except in the south, where there are various paralic, shelf and basin deposits (Selwood *et al.*, 1984; Selwood and Thomas, 1986; Turner, 1986). During the Namurian, however, uplift of neighbouring land, probably as a result of the northwards progression of the Variscan Front, caused an inflow of turbidites (Crackington Formation) into the trough. By the end of the Namurian, the marine trough had become effectively filled and subsequent sedimentation was essentially brackish to fluvio-deltaic, with only occasional brief marine interludes (Bideford and Bude formations). Deposition was eventually terminated by Variscan uplift, probably sometime in the late Westphalian (post early Bolsovian).

Palaeocurrents suggest that the turbiditic infill of the Culm Trough was derived from somewhere in the present-day Bristol Channel. Owen (1971e), Kelling (1974) and Cope and Bassett (1987) have postulated a landmass there (named 'Sabrina' by Kelling), supplying sediment to both the Culm Trough and the South Wales basin. It has been questioned whether such an apparently narrow feature could have supplied the quantity of sediment that is now found in those areas (e.g. Higgs, 1986). However, Kelling (1974) has argued that the Bristol Channel landmass was significantly larger than is indicated by the present distance between Devon and South Wales, and that it was subject to considerable crustal shortening, indicated by major Variscan folds and thrusts.

The Culm Group is best compared with sequences in the Ardennes and Rhenische Schiefergebirge (Matthews, 1977), which together form the Rheno-Hercynian Zone of Kossmatt (1927). This zone has been interpreted as a suite of shelf deposits on the southern margin of the Laurasia palaeocontinent, facing out on the Mid-European Ocean (e.g. Johnson, 1981). Many now argue, however, that this ocean had already closed by the Middle Devonian and that the Rheno-Hercynian deposits were formed in a back arc seaway (e.g. Leeder, 1988).

GCR site coverage

The core of the GCR site coverage for the Upper Carboniferous part of the Culm Group is provided by the stratotypes for the three formations: Widemouth to Crackington, Abbotsham and Bude coast sections. Of these, the least satisfactory is the Crackington Formation stratotype, because the strata have been subject to serious tectonic disturbance. Consequently, it was found necessary to include two additional sites, to fill some of the gaps in our understanding of the stratigraphy of this formation: Bonhay Road Cutting for the Alportian and possibly Arnsbergian, and Clovelly Coast for the Yeadonian to Langsettian. The Bonhay exposure is also of interest in that it apparently reveals a deeper water succession than in the stratotype.

In addition to these major sections, two other sites have been included on essentially sedimentological grounds: Bickleigh Wood Quarry for showing characteristic turbiditic features in the Crackington Formation, and Shipload Bay for shallow water sedimentary structures in the Bude Formation.

CRACKINGTON COAST

Highlights

Crackington Coast provides the most complete section through the Crackington Formation, ranging in age from Chokierian to Langsettian.

Introduction

This stretch of coast lies between Rusey Beach and Widemouth Sands, near Crackington Haven, north Cornwall (SX 123936–SS 198019). It shows a highly contorted succession through the Crackington Formation, between the Rusey Fault Zone to the south and the Widemouth South Fault to the north (Figure 3.3). The geology is described by Freshney *et al.* (1972).

Description

Lithostratigraphy

Structural disturbance has made it impossible to establish a stratigraphical log for the sequence here, or to determine its full thickness. The strata are mainly alternating sandstones and shales, the arenaceous sediments becoming more dominant towards the top of the succession. Many of the sandstones have sole marks, flutes, lodes and flames, typical of turbidites (Figures 3.4 and 3.5). Palaeocurrents established by Mackintosh (1964) suggest a westerly or north-westerly flow.

These strata were first named the Crackington Measures by Ashwin (1958). Edmonds (1974) later used the name to include both the original Crackington Measures and the Boscastle Measures, found south of the Rusey Fault Zone. However, Selwood *et al.* (1985) showed that the strata south of the fault were Lower Carboniferous, as well as being of completely different facies, and so restricted the Crackington Formation to the strata north of the fault.

Figure 3.3 Crackington Coast GCR site. Typical convoluted sequence of Crackington Formation. (Photo: R.A. Cottle.)

Biostratigraphy

The only stratigraphically diagnostic fossils found here are ammonoids. They are rare and usually poorly preserved, but sufficient have been found to identify several zones (Freshney *et al.*, 1972).

The Chokierian is represented by assemblages of both the *Isohomoceras subglobosum* and *Homoceras beyrichianum* zones, found between Rusey Cliff and Crackington Haven. Freshney *et al.* give few species identifications, however, beyond *I.* cf. *subglobosum* (Bisat) found on the south side of Crackington Haven.

The presence of Alportian fossil assemblages is questionable. Freshney *et al.* mention localities near Crackington Haven yielding *Homoceratoides*? and *Homoceras* of the *H. undulatum* Subzone, associated with bivalves *Dunbarella* sp. However, the fossils are badly distorted and their identifications are far from certain.

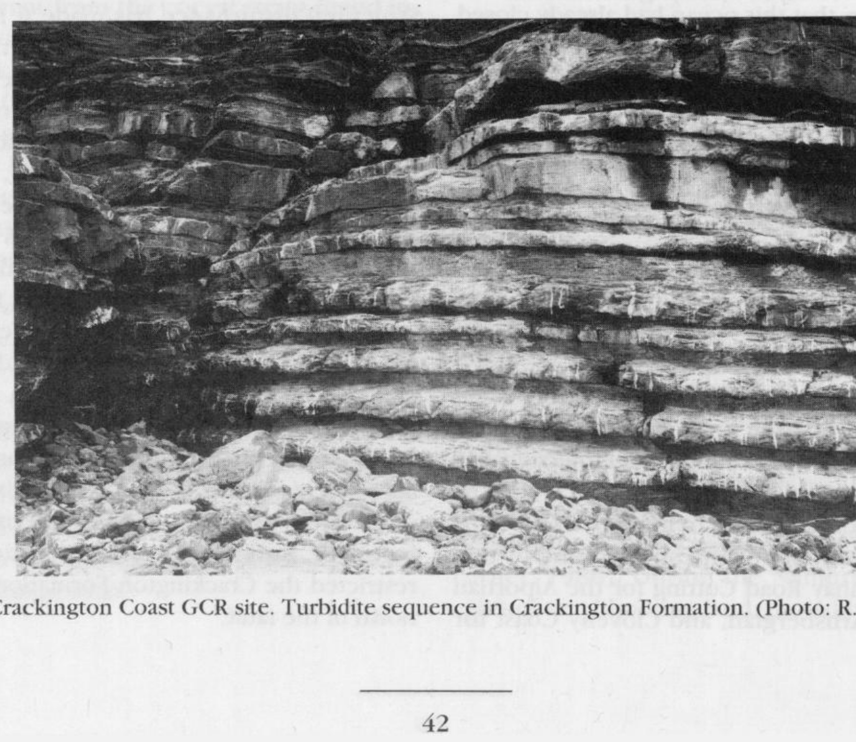


Figure 3.4 Crackington Coast GCR site. Turbidite sequence in Crackington Formation. (Photo: R.A. Cottle.)

Figure 3.5 Crackington Coast GCR site, south side of Crackington Haven. Sole markings in Crackington Formation. (Photo: R.A. Cottle.)

There is apparently rather better palaeontological evidence available for the Kinderscoutian, at several localities between Crackington Haven and Millook Haven. Freshney *et al.* mention assemblages belonging to the *Reticuloceras circumplicatile*, *R. nodosum* and possibly the *R. reticulatum* zones. However, the composition of these assemblages is not documented.

Basal Marsdenian fossils were reported from near Cancleave Strand, in the form of abraded goniatites of the *Bilinguites gracilis* Zone (although Freshney *et al.* again fail to give identifications). At Foxhole Point, *Verneuilites sigma* (Wright) and *Bilinguites* cf. *superbilinguis* Bisat have been reported. This suggests the *V. sigma* Subzone (*B. superbilinguis* Zone) at the very top of the Marsdenian.

Biostratigraphical evidence of the Yeadonian has yet to be found in this section. The Langsettian, in contrast, has been proved at two levels. Near Wanson Mouth, *Gastrioceras* cf. *coronatum* Foord and Crick, *G.* cf. *listeri* (Sowerby) and *Dunbarella* sp. have been found at several points and indicate a level equivalent to the Gull Rock Shale near Clovelly, and the Listeri Marine Band of coalfields to the north. Ammonoids have also been reported from a higher stratigraphical level near Wanson Mouth. They have been totally recrystalized as calcite and are thus unidentifiable, but Freshney *et al.* argue that they are very similar to ammonoids found in the Sandy Mouth Shale of the Bude Formation.

Interpretation

This site may be provisionally regarded as the stratotype for the Crackington Formation. It is far from an ideal choice, due to tectonic disturbance of the sequence. However, the interval was first named here (Ashwin, 1958) and it is the only known section through most of the formation with reasonable biostratigraphical control. Although Ashwin originally identified only the strata at Crackington as the Crackington Formation, following Edmonds (1974) it is now used for a variety of mainly Namurian deposits previously called the Limekiln Beds, Instow Beds, Westward Ho! Formation, Welcombe Formation and Appledore Formation (Ashwin, 1958; Prentice, 1960a; De Raaf *et al.*; 1965; Money, 1966).

The Crackington Formation, as currently defined, is widely distributed over north Devon and north Cornwall, and there are a number of other extensive coastal exposures, such as Clovelly (see below), Embury Beach near Hartland Point (Freshney *et al.*, 1979), and the Westward Ho! coast section (Edmonds *et al.*, 1979). However, these only show the upper part of the formation (Marsdenian to Langsettian). There are also a number of inland sites, such as Bonhay Road Cutting and Bickleigh Wood Quarry (see below), but these have relatively limited sequences. Only at Crackington Coast is the full Chokierian to Langsettian succession of the Crackington Formation demonstrated.

The evidence from Crackington suggests that the Culm Trough was filled during the Namurian by progressively more proximal turbiditic sediments. The broadly westerly palaeocurrents indicate that the turbidites flowed along the axis of the trough, although elsewhere, easterly orientated palaeocurrents have also been recognized (Edmonds *et al.*, 1968). Thomas (1988) argued that the turbidites were probably generated by slumping of sediments on the shelf margin. He also suggested that the flows were not constricted laterally, although Melvin (1986) has argued that they may have occurred within broad, shallow channels.

The Ugbrooke Sandstone Formation in south Devon is probably a lateral equivalent of the lower Crackington Formation. Typically, it consists of coarse, often feldspathic sandstones and conglomerates, interbedded with dark shales (Selwood *et al.*, 1984). At places, however, the Ugbrooke sandstones are rather similar to the Crackington Formation, and near Tavistock, McCourt (1975) was only able to distinguish them by the chemical composition of the shales.

The Rusey Fault Zone, at the southern limit of the site, is an important geological boundary in south-west England, separating rocks of different age, facies, structural style and metamorphic grade (Selwood *et al.*, 1985). According to the model of Selwood *et al.*, it marks where a complex suite of allochthonous nappes to the south under-thrust a more or less autochthonous flysch basin. In contrast, Turner (1986) has argued that the strata to the south represent a compartmentalized basin, in which sedimentation and structural evolution were controlled by movements along vertical basement faults, and that the Rusey Fault Zone was not a persistent line of under-thrusting. Whichever model is accepted, however, the Rusey Fault Zone is important for understanding the geological evolution of the Culm Trough.

Conclusions

Crackington Coast is the best place to study the Crackington Formation, an interval of rocks found widely in Cornwall and North Devon, ranging in age from about 322 to 315 million years old (part of the Namurian Epoch). They are thought to represent alternating layers of muds and sands deposited in deep marine water. The muds are typical deep-water deposits and include numerous marine animal fossils that have proved useful in establishing correlations with other areas. The sandstones, on the other hand, were probably originally river-delta deposits, transported into the deeper water by underwater currents known as turbidity currents, probably triggered by earthquake shocks. Evidence from here suggests that these sands progressively filled-up the marine basin, and by the end of the Namurian the area became essentially coastal in character.

BONHAY ROAD CUTTING

Highlights

Bonhay Road Cutting is the best available exposure of deeper water deposits of the Crackington Formation. It has several ammonoid-bearing horizons, including some not found in the coastal exposures.

Introduction

This cutting on the east side of Bonhay Road, overlooking the River Exe, Exeter, Devon (SX 914926) is one of the best inland exposures of the Crackington Formation, with numerous horizons yielding ammonoids. The strata are overturned and steeply dipping, and faulting causes some repetition of the sequence. The site has been studied by Butcher and Hodson (1960) and Grainger (1983).

Description

Lithostratigraphy

Exposed here are a series of cycles of shales and subsidiary sandstones. Typically, a cycle comprises of 20 cm of sandstone with scour and load structures at the base, grading up through 10 cm of finely laminated siltstone to 35 cm of dark shale. The sediments are very iron-rich, and there are ironstone nodules in the shales. The sedimentology suggests that the sequence represents distal turbidite deposits.

The mineralogy of the clays was studied by Grainger (1983), who showed that their illite crystalinity reflects a high diagenetic grade. Chlorite and illite were found in all samples, but kaolinite and vermiculite were only spasmodically present. Elsewhere in the Crackington Formation, a broad correlation has been reported between the pattern of clay mineral distribution and stratigraphy (Grainger and Witte, 1981), but this is not evident at Bonhay Road Cutting.

Biostratigraphy

Butcher and Hodson (1960) record ammonoids in ironstone nodules found here. These belong to the *Hudsonoceras proteus* and *Homoceras undulatum* zones (Alportian) and the *Reticuloceras circumplicatile* Zone (Kinderscoutian). There is also possible evidence of Arnsbergian ammonoids.

Interpretation

The presence of several ammonoid-bearing horizons makes this section of prime importance, allowing a direct correlation with the more extensive sections along the north Cornwall coast. Of particular significance is the presence of Alportian assemblages, only poorly represented at Crackington (see above).

In contrast to the sequences exposed further west on the coast, sandstones are a less prominent part of this succession, and it is likely that they deposited in deeper water conditions. This agrees with the palaeoenvironmental reconstruction provided by Thomas (1982, fig. 3.6), which places Exeter near the centre of the Culm Trough in the Late Carboniferous.

Conclusions

Bonhay Road Cutting is the best available exposure of fine-grained rocks of the Crackington Formation. They represent deep water muds, deposited between 320 and 318 million years ago, in an elongate marine basin that extended approximately east–west across from south-western Britain into northern France and Germany (the 'Culm Trough'). At several levels in the exposed succession are beds with abundant marine fossils, including the remains of animals known as ammonoids that have proved of great value in establishing detailed correlations with other exposed sequences of this age.

BICKLEIGH WOOD QUARRY

Highlights

Bickleigh Wood Quarry is one of the most important inland sites for studying the sedimentology of the Crackington Formation, and includes some of the best preserved flute marks known anywhere in Britain.

Introduction

This is a disused quarry east of the A396 Tiverton to Bampton road, Devon (SS 944180). It exposes steeply dipping sandstones and shales of the upper Crackington Formation. They are probably of late Namurian age, although there is no direct biostratigraphical control here. The site is mentioned briefly by Thomas (1982).

Description

This is a typical exposure of sandstones of the upper Crackington Formation. The sandstones are medium to dark grey, fine-grained and with some interbedded siltstones and shales. The sandstone beds vary from a few centimetres to 2 m in thickness, the thicker ones being near the base of the section.

Excellent examples of ripple marks, flute marks and squamiform load structures can be seen here. Horizontal burrows have been observed, meandering along the troughs of the ripple marks, and occasionally transgressing the intervening crests. It is not certain what type of animal produced such burrows.

Interpretation

This is a key inland site for sedimentological studies on the Crackington Formation. The sedimentary structures shown here, especially the flute marks, are typical of turbidites and are amongst the best examples of such structures of any age known in Britain.

Conclusions

Bickleigh Wood Quarry is the best site for investigating the sandstones of the Crackington Formation. These sandstones represent sands deposited about 320 million years ago in deep marine conditions. These currents show a number of distinctive structures that indicate that the sands had been transported there by underwater currents known as turbidity currents. They result from seismic shocks or other earth-movements disturbing unstable piles of sediment in shallow marine settings (e.g. river-delta fronts), causing them to flow into deeper water. This is one of the best examples of any age in Britain of such turbidity deposits.

Figure 3.6 Folded sandstones exposed 90 m NW of Clovelly Harbour, Clovelly Coast GCR site. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (A5925).

CLOVELLY COAST

Highlights

The Clovelly Coast shows the best fossiliferous sequence through the upper Crackington Formation, and combines extensive outcrop with good biostratigraphical control.

Introduction

Foreshore exposures between Wood Rock and Gallantry Bower, 1 km north-west of Clovelly, Devon (SX 314255–SX 305262), show part of the upper Crackington Formation. It includes a number of biostratigraphically significant horizons, and is part of a complex east–west trending anticlinorial structure (Figure 3.6). A detailed account of the geology is provided by Edmonds *et al.* (1979).

Description

Lithostratigraphy

The exposed sequence consists of 360 m of shales, siltstones and sandstones (Figure 3.7). The strata appear to represent the latter phases of basin infill by turbidites, typical of the upper Crackington Formation. The sandstones are thin to medium bedded and the siltstones predominantly laminated. Ripple-drift cross lamination is common and, at some points, slumping and sandstone volcanoes are present (Burne, 1969, 1970). Petrographic analysis has revealed a lower proportion of lithic fragments than in the overlying Bude Formation, which may explain the greater resistance to weathering of the former (Edmonds *et al.*, 1979).

The sequence includes six fossil-bearing shales, which have been identified in a number of the coeval exposures in north Devon and north Cornwall. These are assigned names as shown in Figure 3.7.

Biostratigraphy

The lowest horizon in this sequence to yield fossils is the Clovelly Court Shale, from which Edmonds *et al.* (1979) report the ammonoids *Verneuilties sigma* (Wright), *Cancelloceras* cf. *lineatum* (Wright) and an unnamed anthracoceratid. They also mention conodonts (*Hindeodella* sp.), ostracods (*Cypridina*?) and bivalves (*Dunbarella* sp.). According to Ramsbottom *et al.* (1978) and Edmonds *et al.* (1979) the ammonoids belong to the *Donetzoceras sigma* Subzone, indicating the topmost Marsdenian Stage.

The Skittering Rock Shale yields poorly preserved fossils, reportedly including ammonoids of the *Cancelloceras cancellata* Zone (Freshney and Taylor, 1972; Edmonds *et al.*, 1975, 1979; Ramsbottom *et al.*, 1978). However, the only published taxonomic list merely records the bivalves *Caneyella* sp. and indeterminate ammonoids possibly belonging to *Gastrioceras* (Edmonds *et al.*, 1979).

Another poor fossil assemblage occurs in the Deer Park Shale, including the bivalves *Caneyella* sp. and *Dunbarella* sp., and ammonoid fragments with fine lirae (Edmonds *et al.*, 1979). Ramsbottom *in* Edmonds *et al.* states that the ammonoid fragments are consistent with the Cumbriense Marine Band in South Wales, but no specific or even generic identifications are given.

A rather more diagnostic assemblage occurs in and immediately below the Embury Shale. Edmonds *et al.* (1979) record *Gastrioceras subcrenatum* (Frech) and *G.* spp. nov., and it is widely assumed that this level correlates with the Subcrenatum Marine Band in the South Wales and Pennines coalfields. If correct, the Embury Shale is the level of the Namurian–Westphalian boundary in the Crackington Formation.

The Gull Rock Shale yields another diverse fossil assemblage, including the ammonoids *Gastrioceras listeri* (Sowerby), *G. circumnodosum* Foord and *G. coronatum* Foord and Crick, together with the bivalves *Dunbarella papyraceae* (Sowerby) and *Caneyella* cf. *multirugata* (Jackson) (Edmonds *et al.*, 1979). This clearly invites comparison with the deeper-water assemblages from the Listeri Marine Band of the Pennines coalfields (Calver, 1968), and thus suggests a position in the lower part of the Langsettian Stage.

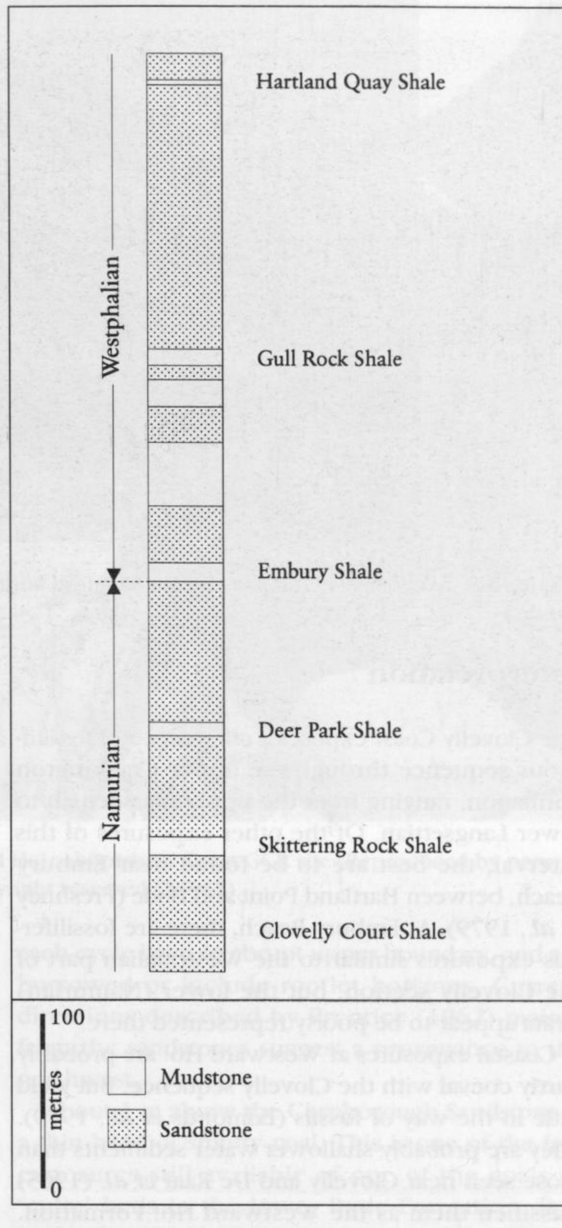


Figure 3.7 Stratigraphical log of the upper Crackington Formation exposed in the Clovelly Coast GCR site. Based on Edmonds *et al.* (1979, fig. 11(7)).

Towards the top of the sequence is the Hartland Quay Shale. At Clovelly, it has only yielded a single calcareous nodule with anthracoceratid ammonoids. Elsewhere, however, this bed has yielded *Gastrioceras* cf. *amaliae* Schmidt (e.g. Elmscott Beach south of Hartland Point – Freshney *et al.*, 1979) which suggests that it can be correlated with the Amaliae Marine Band of South Wales.

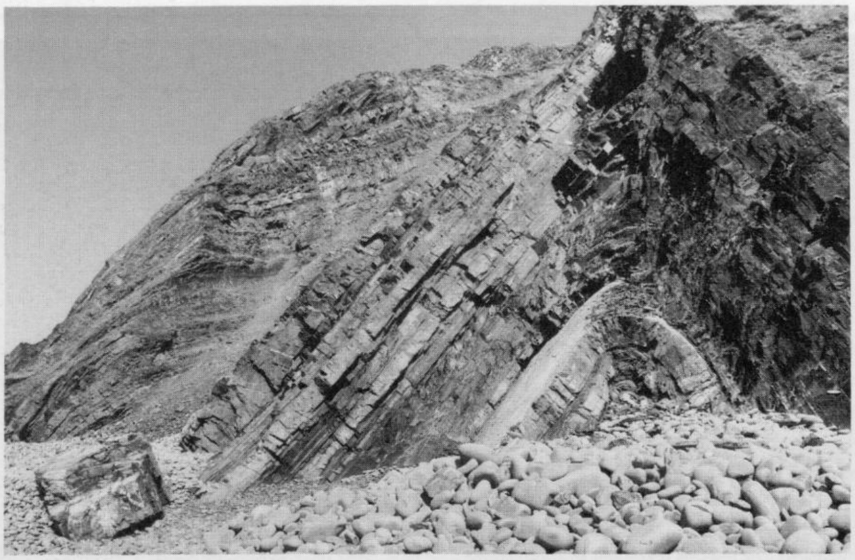


Figure 3.8 Abbotsham GCR site. Typical Bideford Formation succession folded into sharp anticline. (Photo: R.A. Cottle.)

Interpretation

The Clovelly Coast exposes a complete and fossiliferous sequence through the upper Crackington Formation, ranging from the upper Marsdenian to lower Langsettian. Of the other exposures of this interval, the best are to be found near Embury Beach, between Hartland Point and Bude (Freshney *et al.*, 1979). At Embury Beach, there are fossiliferous exposures similar to the Westphalian part of the Clovelly section, but the lower (Namurian) strata appear to be poorly represented there.

Coastal exposures at Westward Ho! are probably partly coeval with the Clovelly sequence, but yield little in the way of fossils (Edmonds *et al.*, 1979). They are probably shallower water sediments than those seen near Clovelly and De Raaf *et al.* (1965) classified them as the Westward Ho! Formation. However, the Westward Ho! Formation is now usually included within the Crackington Formation (Edmonds, 1974).

The Instow Fish Bed, exposed along the Torridge estuary near Bideford, is probably a correlative of the Gull Rock Shale at Clovelly and has yielded a more diverse fossil assemblage (Prentice, 1960a). However, the rest of the upper Crackington Formation is only poorly exposed at Instow.

Conclusions

The Clovelly Coast provides the best fossiliferous exposures of rocks known as the upper Crackington Formation, thought to be about 315 million years old. They represent the later phases of the infilling of a marine basin known as the Culm Trough, which extended from Ireland through south-west Britain to northern Germany. The rocks exposed here are especially important as they include beds containing diverse assemblages of marine animal fossils, which allow detailed correlations with other successions of similar age in the rest of Britain, and elsewhere in northern Europe and eastern North America.

ABBOTSHAM COAST

Highlights

Abbotsham Coast is the best available section through the Bideford Formation, providing detailed sedimentological and biostratigraphical information. It tends to confirm that the Bideford Formation is a lateral equivalent of the upper Crackington and lower Bude formations, and represents a localized development of fluvio-lacustrine, 'Coal Measures'-type deposits (Figures 3.8 and 3.9).

Introduction

The section of coast between Greencliff and Rock Nose, 5 km west of Bideford, Devon (SS 403269–SS 417291), is effectively the stratotype for the Bideford Formation. The strata are extensively exposed in a series of broad and slightly asymmetrical folds,

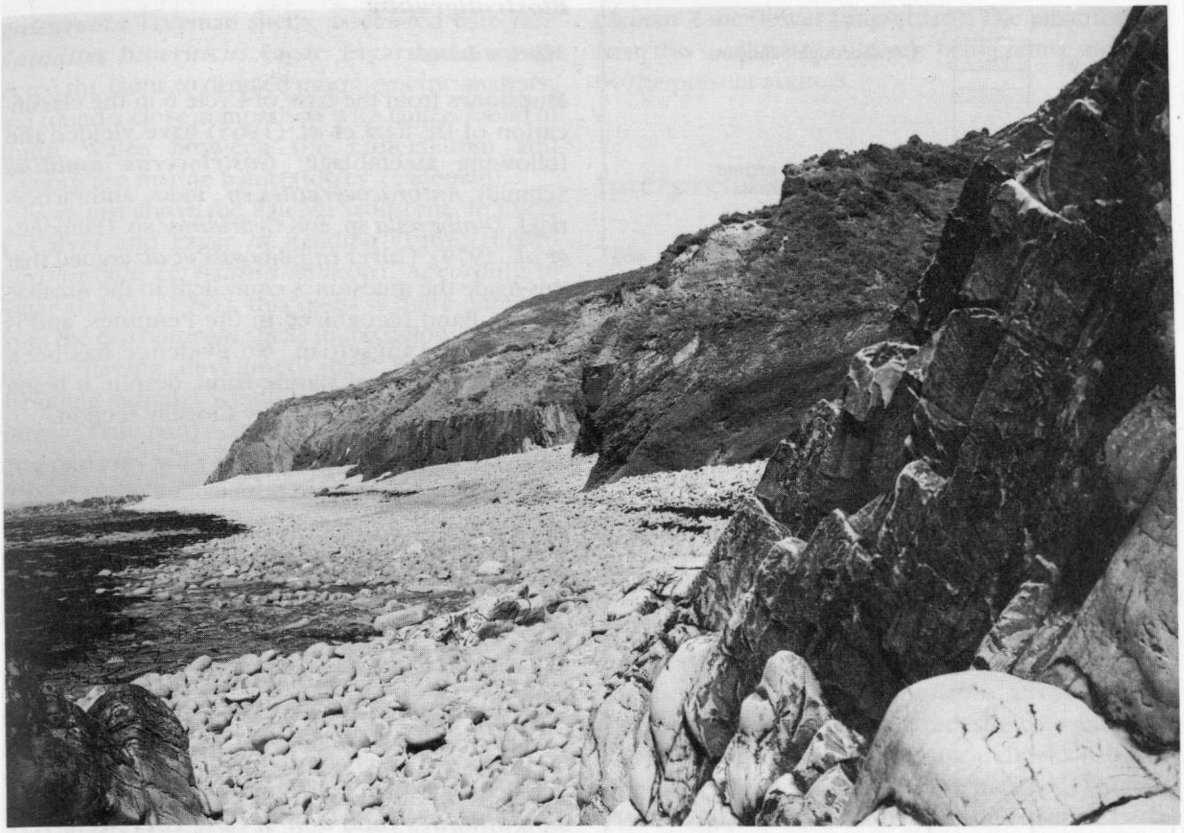


Figure 3.9 Cornborough Cliffs, 1.6 km SW of Westward Ho!, Abbotsham Coast GCR site. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (A5935).

causing repetition of the sequence. Further structural complications are provided by two sets of wrench faults. The exposure has been extensively studied, most recently by Prentice (1960b, 1962), Reading (1965), De Raaf *et al.* (1965), Elliott (1976), Edmonds *et al.* (1979) and Eagar and Xu Li (1993), the latter two studies providing detailed field descriptions of the site.

Description

Lithostratigraphy

A summary log of the sequence exposed here is given in Figure 3.10. It comprises of 750–800 m of mainly mudstones, siltstones and sandstones (De Raaf *et al.*, 1965; Edmonds *et al.*, 1979). De Raaf *et al.* divided it into nine sedimentary cycles, each grading upwards from black mudstones into coarser beds, eventually culminating in sandstones. Four of the most prominent sandstones have been assigned names by Prentice (1960b), as shown in Figure 3.10. The sandstones marking the top of each cycle have an abrupt upper boundary, and are burrowed or include rootlet horizons. Current directions described by Prentice (1962) mainly from the sandstones suggest a provenance to the northwest.

About 1 m above the Cornborough Sandstone is a thin band of smutty coal. This is one of the few exposures still available of one of the coals or 'culm' beds in the lower Bude Formation. It is badly disturbed by both tectonic activity and mining operations. However, it still shows some traces of a seat earth, confirming that it is an autochthonous deposit.

De Raaf *et al.* (1965) divided the sequence into Northam and Abbotsham formations, which were combined into the Bideford Group. This followed in essence the classification of Prentice (1960b). However, Edmonds (1974) argued that, from a mapping standpoint, it was better to assign the whole sequence to a single formation (the Bideford Formation), a view which has been accepted by most subsequent authors. In the Abbotsham section, the boundary between the Bideford and overlying Bude formations is taken at the top of the

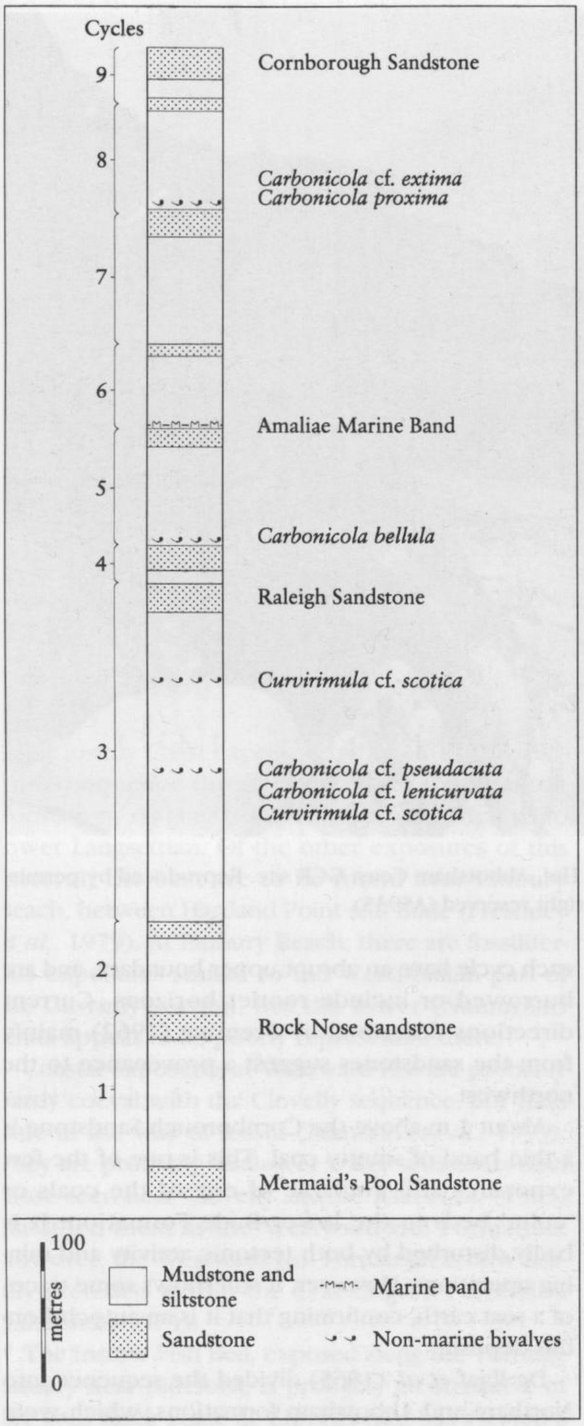


Figure 3.10 Stratigraphical log of the Bideford Formation at Abbotsham Coast GCR site. Based on Edmonds *et al.* (1979, fig. 9).

Cornborough Sandstone. Elsewhere, however, the relationship between the two formations is more complex, and it is almost certain that the upper Bideford Formation is coeval with the lower Bude Formation.

Biostratigraphy

Marine bands

Mudstones from the base of Cycle 6 in the classification of De Raaf *et al.* (1965) have yielded the following assemblage: *Gastrioceras amaliae* Schmidt, *Anthracoceratites* sp., indet. anthracoceratid, *Dunbarella* sp. and *Cypridina?* sp. (Edmonds *et al.*, 1979). Calver *in* Edmonds *et al.* argued that this made the mudstones equivalent to the Amaliae Marine Band recognized in the Pennines, and is thus lower Langsettian. No evidence has been found of the Listeri Marine Band, despite it being well developed in the nearby Clovelly section.

Non-marine bivalves

These have been reported from ten horizons in the section. The stratigraphically lowest is at 129 m below the Raleigh Sandstone. Edmonds *et al.* (1979) reported small examples of *Curvirimula* and *Carbonicola* from here. Eagar and Xu (1993) were unable to discover further examples of the *Curvirimula*, but shells of the type thought to be *Carbonicola* were collected and, following detailed investigation, found in fact to belong to *Sanguinolites* Hind *non* M'Coy. They were very similar to an upper Kinderscoutian fauna reported by Eagar (1977) from Sabden Brook (Cock Wood) in Lancashire, and are thought to represent marginal marine conditions.

Calver *in* Edmonds *et al.* (1979, p. 48) reported juvenile specimens of *Curvirimula* cf. *scotica* (Etheridge) from 82 m below the Raleigh Sandstone. Calver suggested that they tend to indicate a position in the topmost Namurian or possibly basal Westphalian but, by comparing with faunas in Belgium, Eagar and Xu (1993) claim that they are middle Namurian (Alportian to Marsdenian) and represent an assemblage unique in Britain.

A new fauna was discovered by Eagar and Xu (1993) from 43 m below the Raleigh Sandstone. Some of the shells were very similar to the *C.* cf. *scotica* found in the above band, but there was also present a second species with relatively long hinge lines, which they compared with *Curvirimula belgica* (Hind). This latter species tends to indicate the Marsdenian to Yeadonian.

From just below the Raleigh Sandstone, Eagar and Xu (1993) found two discrete bivalve bands, the lower one containing very small shells of the *Carbonicola bellula* (Bolton) group, associated with *Curvirimula* cf. *scotica* and *C.* cf. *belgica*. The higher band contained small *Carbonicola* aff.

lenicurvata Trueman shells, associated with rare *Naiadites hibernicus* Eagar. Eagar and Xu subjected the fauna to detailed morphometric analyses, and found a close comparison with faunas found in South Wales between the Cancellatum and Cumbriense marine bands (lower Yeadonian).

From just above the Raleigh Sandstone, in Cycle 4, Calver and Eagar *in* Reading (1965) record *Carbonicola* cf. *bellula* (Bolton). According to Eagar and Xu (1993), this fauna is quite different from the *Carbonicola* shells found below the sandstone, having developed their full size, and including varieties which tend towards *C. lenisulcata* (Trueman) and *C. pilleolum* Eagar. Comparisons with faunas from northern England (Eagar, 1956) indicate the basal Langsettian.

In Cycle 5 (just below the Amaliae Marine Band), Eagar and Xu (1993) record rare shells of the *Carbonicola exima* group, probably belonging to the *C. extenuata* Subzone.

The most diagnostic assemblage has been found at the base of Cycle 8 (Simpson, 1933). Calver and Eagar *in* Edmonds *et al.* (1979) identify the assemblage as including *Carbonicola extenuata* Eagar, *C. crispa* Eagar and *C.* cf. *extima* Eagar, indicating a position in the *Carbonicola proxima* Subzone (upper *C. lenisulcata* Zone). A similar fauna was also recorded by Eagar and Xu (1993) from a slightly lower level, in the upper part of Cycle 7.

The uppermost bivalve-yielding horizon in this section is 30–40 m above the base of Cycle 8, and has yielded an undiagnostic fauna of *Curvirimula* sp. and *Naiadites* sp. However, shales from below the Cornborough Sandstone exposed in a nearby inland exposure (Roberts Quarry) have yielded a fauna of the *C. torus* Subzone (lower *C. communis* Zone – middle Langsettian).

Plant macrofossils

Arber (1904) noted a number of specimens from shales associated with the 'culm' beds immediately overlying the Cornborough Sandstone. He concluded that they belonged to the 'Middle Coal Measures' (i.e. Bolsovian), but Crookall (1930b) argued that they were 'Lower Coal Measures' (i.e. Langsettian). Arber did not illustrate all of the species and so the assemblages are difficult to judge. However, they seem to include taxa such as *Neuropteris obliqua* (Brongniart) Zeiller, *Neuralethopteris jongmansii* Laveine, *Karinopteris acuta* (Brongniart) Boersma and *Sphenophyllum cuneifolium* (Sternberg) Zeiller, which tend to suggest the lower *Lyginopteris hoeninghausii* Zone (lower Langsettian). The plant fossils from this locality are currently being reinvestigated by the present authors.

Interpretation

This is by far the most extensive outcrop of the Bideford Formation, providing a more or less complete sequence through the unit. Edmonds *et al.* (1979, 1985) mention a number of small, inland exposures, mainly of the sandstone units, but nowhere else is the full sequence with biostratigraphical control available.

De Raaf *et al.* (1965) used evidence from here to suggest that the Bideford Formation represents a series of shoreline-fronted, fluvial deltas that progressed into a moderately deep basin. An essentially similar model was advanced by Elliott (1976) and Edmonds *et al.* (1979). However, this model is not supported by the absence of marine fossils, except from the mudstone at the base of Cycle 6. Also, in three of the mudstones, which are supposed to represent 'moderately deep basin deposits', there are non-marine bivalves. Thomas (1988) argued that this was evidence that the basin into which the deltas advanced was essentially non-marine, due to dilution of the sea-water by river inflow. Alternatively, the Bideford Formation might be seen as a set of fluvial deposits, albeit in a lower delta-plain setting, in which the sediments were transported into enclosed, inter-distributary bays. They can thus be compared with coeval strata in other parts of Britain, such as Lancashire (Fielding, 1987).

The biostratigraphical data available here are important for understanding the relationship between the Bideford Formation and the Crackington and Bude formations. If the marine band at the base of Cycle 6 is indeed equivalent to the Amaliae Marine Band, then it is also a correlative of the Hartland Quay Shale at Clovelly, the generally acknowledged boundary between the Crackington and Bude formations. Consequently, the Bideford Formation must be a lateral equivalent of the upper Crackington and lower Bude formations. This model is also supported by the presence of an apparently middle Namurian (Kinderscoutian) non-marine bivalve fauna in Cycle 3 of the Bideford Formation, which is older than the Clovelly Court Shale in the lower part of the Clovelly sequence (Eagar and Xu, 1993).

Figure 3.11 Maer Cliff, near Bude, Bude Coast GCR site. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (A5901).

Conclusion

Abbotsham Coast is the definitive section through the Bideford Formation, which is an interval of rocks about 315 million years old. The rocks are of the same age as the upper part of the Crackington Formation, such as exposed at Clovelly, but were deposited under quite different conditions, either in an estuarine or lower delta-plain setting. The abundant fossil evidence found at Abbotsham is of critical importance for establishing this relationship between the Bideford and Crackington formations, which in turn is significant for understanding the evolution of this part of Britain during the Late Carboniferous.

BUDE COAST

Highlights

Bude Coast is the best available site for the Bude Formation, providing excellent sedimentological and biostratigraphical data. The formation marks the last stages of the infill of the Culm Trough.

Introduction

This is the stretch of coast between Marsland Cliff and Bude Haven, Devon (SS 203068–SS 208170). Beds of the Bude Formation are folded here into a series of complex anticlinoria (Figure 3.11). The geology is best described by Freshney *et al.* (1979).

Description

Lithostratigraphy

The Bude Formation here is about 1290 m thick, a summary log of which is shown in Figure 3.12. The most distinctive facies are impersistent beds of sandstone, up to 20 m thick, showing a variety of sedimentary structures. These include sand volcanoes, indicating the rapid dewatering of the sediment (Burne, 1970), and hummocky cross-stratification, thought to be generated by storm waves in shallow water conditions (Harms *et al.*, 1975; Higgs, 1984). Merriman *in* Freshney *et al.* (1979) provides details of the petrography of these sandstones.

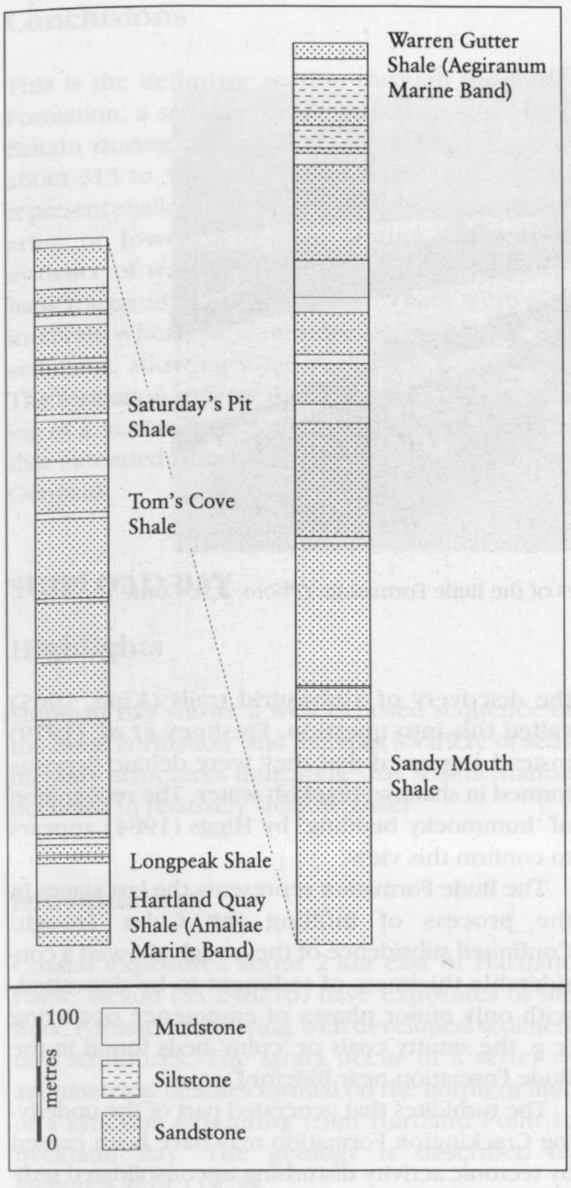


Figure 3.12 Stratigraphical log of the Bude Formation at Bude Coast GCR site, based on Freshney *et al.* (1979, fig. 3).

These sandstones occur against a background of mainly shale and mudstone deposits. Mostly, they are grey and more or less silty, but there are also occasional bands of black, sulphurous mudstones. The latter have proved laterally persistent (King, 1966, 1967; Freshney and Taylor, 1972) and often contain a variety of fossils, including ammonoids preserved in calcareous concretions, and fish bones and coprolites. In view of their stratigraphical usefulness, King named the most important black mudstones (in ascending order), the Longpeak, Tom's Cove, Saturday's Pit, Sandy Mouth, and Warren Gutter Shales.

The depositional environment of the Bude Formation has been the matter of some dispute. Higgs (1984) has argued that they were probably formed in a non-tidal, lacustrine setting, probably between storm-wave base and fair-weather wave base. This requires the existence of a large, relatively deep lake, in which fresh to brackish conditions prevailed, but interrupted periodically by marine incursions. In contrast, Melvin (1986) suggested that they represent turbidites deposited in a submarine fan setting, although there remain difficulties with this model, such as the restricted distribution of marine fossils to certain distinctive mudstone horizons.

At several points through the sequence, there is evidence of soft sediment deformation, in particular slumped bedding. Freshney *et al.* (1979) interpret this as due to seismic activity.

Biostratigraphy

Fossils here are mainly restricted to the five black sulphurous mudstones. The lower three mudstones have yielded mainly bivalves, ammonoid spat and fish. The latter are of palaeontological interest, especially those from the Saturday's Pit Shale, which include *Acanthodes wardi* (Egerton), *Cornuboniscus budensis* White and *Elonichthys aitkeni* Traquair (Owen, 1950). However, they are of little biostratigraphical significance. Edmonds *in* Ramsbottom *et al.* (1978) suggested that the Tom's Cove Shale might be a correlative of the Vanderbeckei Marine Band of South Wales, but there is no biostratigraphical evidence to confirm (or refute) this idea.

The lowest level with well preserved ammonoids is the Sandy Mouth Shale. Ramsbottom (1970) described from here the holotype of *Anthracoceratoides cornubiensis* Ramsbottom, one of the most characteristic ammonoids of the Langsettian Culm. Ramsbottom argued that this indicated a correlation between the Sandy Mouth Shale and the Meadow Farm Marine Band in South Wales. Edmonds *in* Ramsbottom *et al.* (1978), based on the relative thicknesses in the Bude Formation and the South Wales Coal Measures, instead argued that the Sandy Mouth Shale correlated with the Aegiranum Marine Band, but this now seems unlikely in view of evidence now available from the Warren Gutter Shale (see below).

The Warren Gutter Shale has yielded a diverse

Figure 3.13 Bude Coast GCR site. Typical thick sandstones of the Bude Formation. (Photo: R.A. Cottle.)

assemblage, including the ammonoids *Donetzoceras aegiranum* (Schmidt) and *Gastrioceras depressum* Delépine, together with the bivalves *Dunbarella macgregori* (Currie) and *Caneyella* sp., an orthocone nautiloid and a variety of fish fragments (Freshney *et al.*, 1979). Edmonds *in* Ramsbottom *et al.* (1978) had originally argued that the Warren Gutter Shale could be correlated with the Cambriense Marine Band, but now concedes that the biostratigraphical evidence clearly points to it being a correlative of the Aegiranum Marine Band (N.J. Riley, pers. comm.).

Interpretation

This is by far the best available exposure of the Bude Formation (Figure 3.13). There are other coastal exposures, such as near Hartland Point (e.g. Shipload Bay) and between Clovelly and Greencliff (Edmonds *et al.*, 1979). There are also some inland exposures, such as near Okehampton (Edmonds *et al.*, 1968). However, the coast near Bude is the only place to show the full sequence of Bude Formation, with at least some biostratigraphical control. Since it also provided the name for the formation, it seems reasonable to take it as the stratotype section.

It is also one of the best sections for analysing the sedimentology of the formation. Early work here suggested that the deposits were turbidites (Ashwin, 1958; Reading, 1963; Lovell, 1965), but the discovery of xiphosurid trails (King, 1965) called this into question. Freshney *et al.* (1979) instead suggested that they were deltaic deposits formed in shallow, brackish water. The recognition of 'hummocky bedding' by Higgs (1984) appears to confirm this view.

The Bude Formation represents the last stages in the process of infilling the Culm Trough. Continued subsidence of the trough allowed a considerable thickness of sediment to be deposited, with only minor phases of emergence occurring (e.g. the smutty coals or 'culm' beds found in the Bude Formation near Bideford).

The turbidites that generated part of the underlying Crackington Formation may have been caused by tectonic activity disturbing unconsolidated sediments on submarine slopes (Edmonds *et al.*, 1975). A continuation of this activity appears to be reflected by the existence of beds in the Bude Formation showing soft-sediment deformation. These movements were presumably linked with early Variscan earth-movements.

The distance between the Listeri and Aegiranum marine bands in the Bude sequence is 1261 m when the biostratigraphical position of the Hartland Quay and Warren Gutter shales is considered. This is about three times as thick as the equivalent interval in the central part of the South Wales Coalfield; in Britain, only the Lancashire and North Staffordshire coalfields, in the middle of the Pennine Basin, develop comparable thicknesses of strata.

Conclusions

This is the definitive section through the Bude Formation, a series of rocks formed in southwest Britain during the middle Westphalian Epoch, about 313 to 308 million years ago. They mainly represent shallow-water deposits formed in an estuarine or lower delta-plain setting, and show evidence of wave action, and some slumping perhaps triggered by seismic action. There were also intervals when the water-level fell exposing the sediment, allowing some vegetation to develop. The formation reflects the last phases of the infilling of a marine basin known as the Culm Trough, that extended from southwest Britain to northern Germany.

SHIPLOAD BAY

Highlights

Shipload Bay shows a well exposed sequence of the Bude Formation, and includes a variety of sedimentary structures indicating that sedimentation occurred in relatively shallow water.

Introduction

Coastal exposures about 2 km east of Hartland Point, Devon (SS 248276) have exposures of the Bude Formation showing well developed sedimentary structures. The strata occur in a series of asymmetrical flexures formed on the northern limb of a syncline extending from Hartland Point to Beckland Bay. The geology is described by Edmonds *et al.* (1979).

Description

The lithologies exposed here are dominated by thin- and medium-bedded sandstones with siltstones and shales. However, there is also a thicker sandstone unit exposed high in the cliff, more typical of Bude Formation sequences seen elsewhere. A prominent slumped interval of sandstone slabs in a dark, homogeneous mudstone matrix can be traced along strike for *c.*3 km, and probably represents a flow of liquefied mud coursing down underwater slopes, incorporating semi-consolidated sediment as it progressed. Sedimentary structures are particularly well exposed here, including flute and load casts, ripple marks, flame structures, mudflakes, and occasional fine-grained sandstones with cross- and wedge-bedding.

Interpretation

The sedimentary structures preserved here indicate strongly that sedimentation of the Bude Formation was in relatively shallow water, in a deltaic or lacustrine setting.

Conclusions

Shipload Bay shows particularly well exposed examples of sedimentary structures in rocks known as the Bude Formation, about 312 million years old. They provide evidence that these beds were formed in a shallow marine setting, and represent the last phases of the infilling of the area of sea known as the Culm Trough, that extended from Ireland and southwest Britain to northern Germany.