British Lower Carboniferous Stratigraphy

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GCR Editor: L.P. Thomas

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Chapter 10

Culm Trough

M.J. Whiteley

INTRODUCTION

The Lower Carboniferous rocks of Devon and Cornwall are quite dissimilar from those of an equivalent age elsewhere in Britain. There are no thick developments of bedded limestone to produce characteristic landforms such as steep scars, upland pavements and deep gorges, but instead a relatively thin sequence of shale and chert forms rolling countryside in the lee of Exmoor and Dartmoor. Nevertheless, this very difference attracted the attention of many eminent geologists during the early 19th century and it is their work that provides the basis for our current stratigraphical understanding in this area.

Whilst Conybeare and Phillips (1822) first introduced the concept of the 'Carboniferous System', it was Sedgwick and Murchison (1840) who defined the sedimentary rocks of Carboniferous age in south-west England as 'Culm Measures'. This stratigraphical term is entrenched in the literature but its main purpose these days is to distinguish the fill of the E–W-trending Culm Trough from better known Carboniferous Limestone, Millstone Grit and Coal Measure sequences farther north. The core of the Culm Trough is dominated by rocks of Silesian age, but two narrow and discontinuous outcrops of Dinantian rocks occur along the northern and southern margins, creating a broadly synclinal pattern (Figure 10.1). This simple pattern, however, obscures a more complex tectonic setting because the northern outcrop is tightly folded and occurs largely *in situ*, whilst farther south, most of the Dinantian succession has been transported into its present position by low-angle thrust faults in the region between Bodmin and Dartmoor.

History of research

In 1797, William Maton, a Fellow of the Linnaean Society, published a geological map of south-west England based on the observations he had made during his extensive travels around the peninsula between 1794 and 1796. Maton's map differentiated the major rock types but did not distinguish their age or structure. These refinements emerged when Sir Henry De la Beche conducted a series of field mapping projects during the 1820s that were to form the basis of the early [British] Geological Survey maps. These early maps distinguished a 'Grauwacke Group' that De la Beche correlated with similarly deformed sequences in Wales. Although Conybeare and Phillips (1822) had recognized the Carboniferous System at about the same time, De la Beche considered the 'Grauwacke' to pre-date it and this view was widely held until the 1830s.

Meanwhile, Sedgwick and Murchison began work in Devon in 1836 that led them to consider a Carboniferous age for much of the 'Grauwacke'. When their findings were published in 1840 they introduced the name 'Culm Measures', and distinguished between shale-dominated Lower Culm and sand-dominated Upper Culm successions. De la Beche was obviously influenced by their ongoing research for he adopted the same terminology in his regional memoir (1839) and subsequent map revisions.

A second phase of mapping began in 1870 through the efforts of William A.E. Ussher who was involved in the revision of almost all the existing [British] Geological Survey maps in south-west England. Remembered principally for his meticulous fieldwork, maps and accompanying memoirs, he also published several refinements (Ussher, 1887, 1892, 1901) to the Culm Measure stratigraphy of Sedgwick and Murchison (1840). Hinde and Fox (1895), who worked extensively on the distinctive radiolarian cherts of the Lower Culm, provided another important contribution during this period. Their Culm Measure succession, comprising basal dark shales with limestones, overlain by thin sandstones, cherty mudstones and a thick sequence of shales and sandstones, has survived, in principle, to the present day.

Subsequently, major advances in understanding the complex Lower Carboniferous stratigraphy were gained through systematic palaeontological studies around the Devonian–Carboniferous boundary (Goldring, 1955; Selwood, 1960; Selwood *et al.*, 1982) and within overlying horizons (Butcher and Hodson, 1960; Prentice, 1967). This emerging biostratigraphical framework was complemented by regional mapping projects that addressed both the northern outcrops (Prentice, 1958, 1960; Thomas, 1963a) and those farther south, around the flanks of Dartmoor (Dearman and Butcher, 1959). Much of this work is summarized in the regional guide for south-west England (Edmonds *et al.*, 1975).

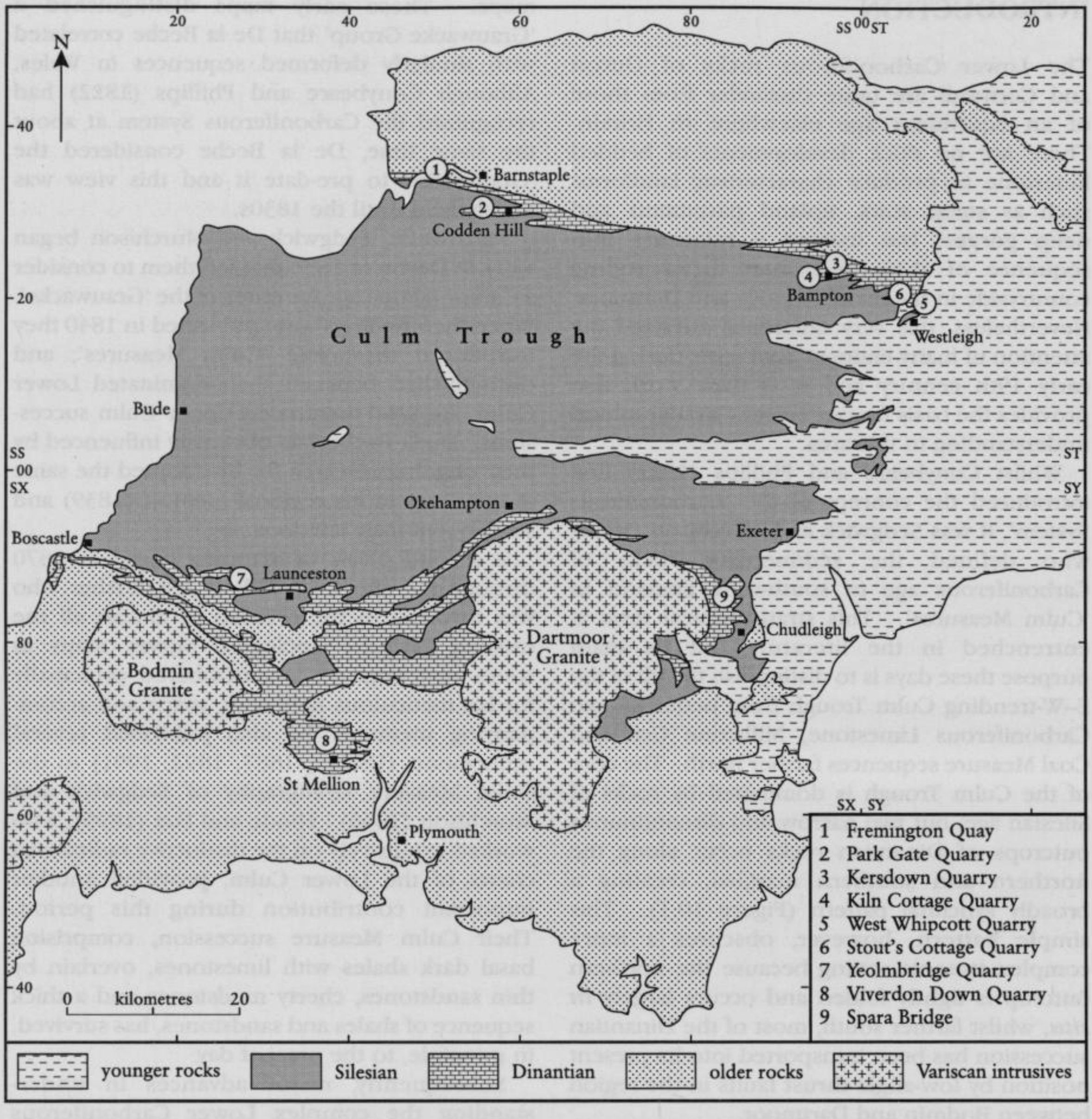

Figure 10.1 Simplified geological map of central south-west England showing the northern and southern outcrops of Dinantian strata and the locations of GCR sites described in the text. Based on [British] Geological Survey maps of the area (Institute of Geological Sciences, 1969c,d, 1974a,b,c,d, 1975c, 1976c,d,e, 1977d, 1980a,b, 1982; British Geological Survey, 1993b, 1994, 1995b,c, 1998).

Systematic field mapping over the last three decades, mainly under the auspices of the British Geological Survey, has resulted in a series of 1:50 000 map sheets and explanatory memoirs that refine our geological understanding and challenge existing theories. These important sources of reference are, however, necessarily detailed and they sometimes fail to convey the regional sense that emerges only when adjacent areas are examined. More palatable, perhaps, are two books that consider the geology of Devon (Durrance and Laming, 1982) and Cornwall (Selwood *et al.*, 1998) as a whole. They serve to remind the reader that two centuries of research have contributed substantially towards integrating the Lower Carboniferous of the Culm Trough into the wider context of British stratigraphy.

Stratigraphy

Sedgwick and Murchison (1842) first made the observation that many of the Lower Carboniferous sequences in the Culm Trough resemble those in the Belgian and north German segments of the Variscan fold belt, a view amplified by subsequent workers (e.g. Matthews, 1977a,b; Franke and Engel, 1982). The Culm Trough has now been mapped in some detail and a plethora of lithostratigraphical schemes have been established (Figure 10.2). These reflect a wide range of depositional facies which, along with poor exposure and tectonic complexity, conspire to hinder correlation.

There is no obvious lithostratigraphical boundary at the base of the Carboniferous System in south-west England. It occurs within a shale-dominated sequence that formed during a widespread phase of reduced subsidence and sedimentation (Goldring, 1962). Only occasionally do the shales contain adequate fossils to enable the Devonian–Carboniferous boundary to be recognized.

The overlying Dinantian beds of the Codden Hill Group are 250–275 m thick around Barnstaple, where they comprise grey shales, overlain by a thicker development of pale-weathering cherts, then more dark shales containing large lenses of limestone (Edmonds *et al.*, 1985). This succession has been resolved by Jackson (1991) into a more formal stratigraphy and tentatively correlated with British stage names. Farther east, in the Bampton and Westleigh region, the Dinantian sequence contains a greater proportion of limestone, including thick limestone turbidites, but is less securely dated (Figure 10.2).

In the area between Bodmin and Dartmoor, the structural setting is more complex due to large-scale overthrusting (Isaac *et al.*, 1982). A variety of paralic, shelf and basin facies are contained within successive nappes and there is no continuity between the stratigraphy at **Yeolmbridge Quarry** and **Viverdon Down Quarry** (Figure 10.2). Interestingly, although the Teign Valley is on the same trend (Figure 10.1), its succession more closely resembles that around Barnstaple, both being dominated by basinal shales and cherts. There is, however, greater evidence of contemporaneous volcanic activity in the Teign Valley, where numerous tuff bands and dolerite sills punctuate the sequence. Whilst the Teign Valley succession is strongly folded into an anticlinorium, Selwood *et al.* (1984) suggest that it is largely *in situ* and occurs at the base of a pile of thrust sheets.

Towards the top of the Dinantian sequence, distinctive grey, calcareous and siliceous shales locally yield abundant bivalves and ammonoids. This important interval, informally called the 'Posidonia Beds' or 'Neoglyphioceras spirale Beds', is of Brigantian (P_{1b}–P_{1d}) age and is the most widespread stratigraphical marker in the basin (Figure 10.3). Above it, black shales and, ultimately, turbiditic sandstones predominate. The sandstones herald the onset of a diachronous phase of flysch sedimentation which resulted in the filling of the Culm Trough by the end of Westphalian C (Bolsovian) times. The Carboniferous System is unconformably overlain by the New Red Sandstone.

Biostratigraphical control is only patchily developed in the Culm Trough but correlation with the standard stages recognized elsewhere in Britain (George *et al.*, 1976; Riley, 1993) is gradually emerging. Shelf macrofossils are generally scarce but conodonts, miospores, ammonoids and bivalves are more widespread and underpin most age determinations (Figure 10.3). The conodont scheme (Stewart, 1981) used here has proved particularly useful in the Culm facies, as has the miospore zonation that was developed principally for the Carboniferous succession of Ireland (Higgs *et al.*, 1988a,b). However, the detailed correlation between these microfossils and the ammonoids is still insecure because they rarely occur together in the same strata. Trilobites, brachiopods and ostracodes provide stratigraphical refinement locally, particularly in the Courceyan and Chadian stages, but successions of Arundian, Holkerian and Asbian age are more difficult to discriminate because they are usually condensed and poorly fossiliferous. For this reason the assignment of lithostratigraphical units to particular stages is, in the Culm Trough, the exception rather than the rule.

Geological setting

During Devonian times, south-west England was located at the southern margin of the 'Old Red Sandstone' continent. Intense tropical weathering produced an enormous volume of sediment that was deposited in continental and

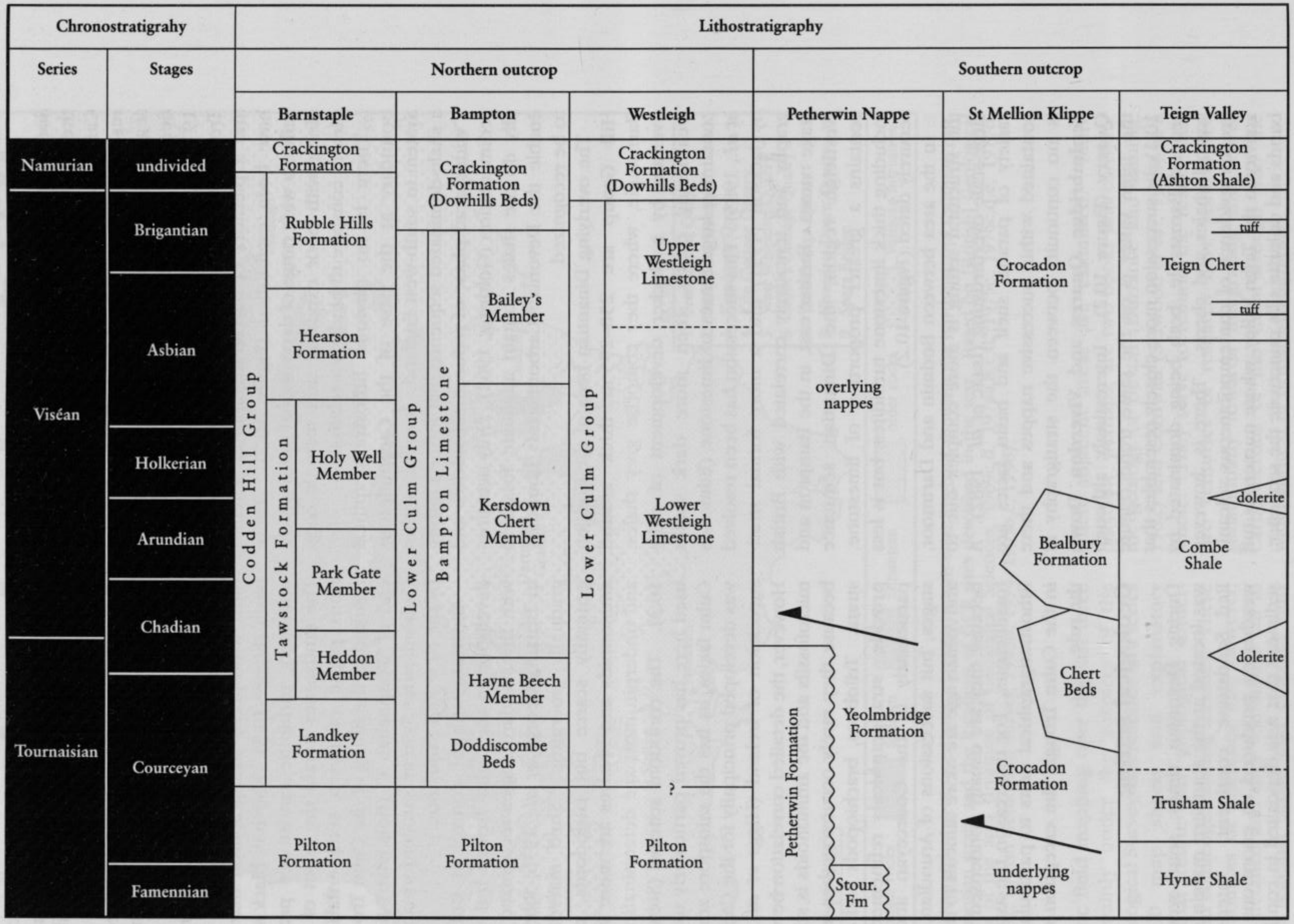

Figure 10.2 Simplified stratigraphical chart for the Lower Carboniferous strata of the Culm Trough. Compilation based on information from Selwood and Thomas (1987), Jackson (1991) and Owens and Tilsley (1995). Much of the stratigraphical nomenclature in the Culm Trough is informal and is reproduced here according to common usage. The aim is to summarize a range of differing successions rather than imply that the rock units are well dated and have isochronous boundaries. Note that the Chert Beds and the Bealbury Formation in the Crocadon Formation of the St Mellion Klippe may be olistoliths or isolated thrust-bound units; see **Viverdon Down Quarry** GCR site report (this chapter) for further details. Half-arrows represent thrust faults. Stour. Fm – Stourscombe Formation. Not to scale.

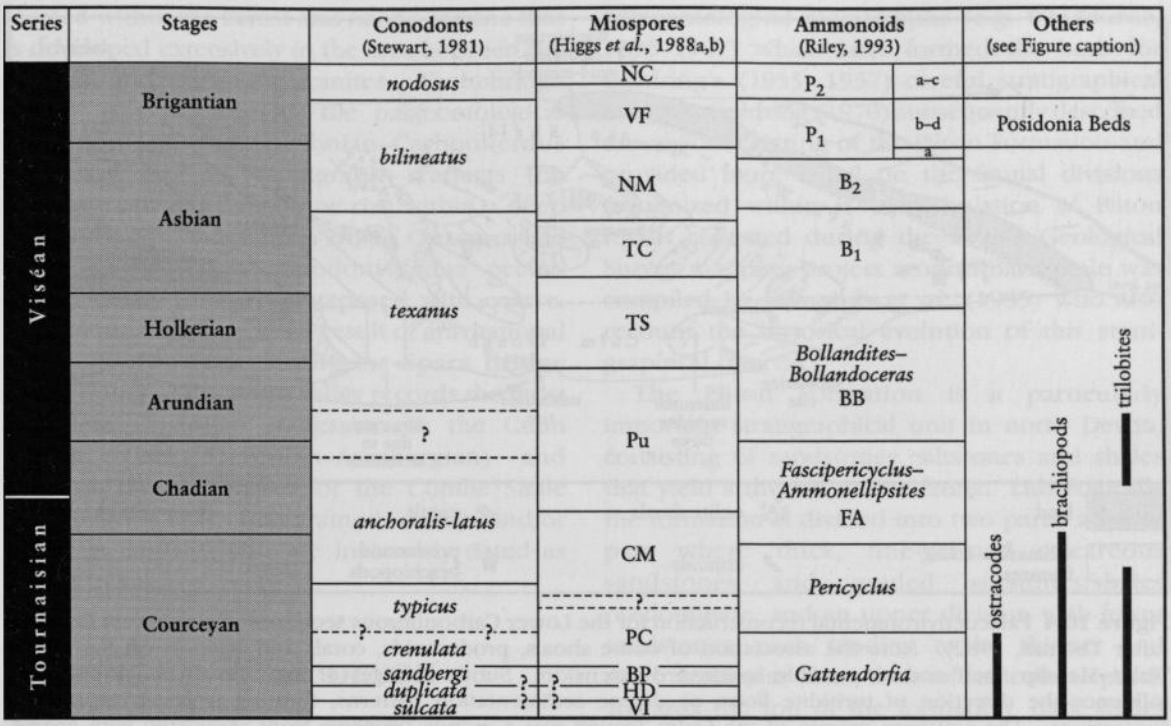

Figure 10.3 Biostratigraphical schemes for the Lower Carboniferous strata in the Culm Trough based on conodonts, miospores and ammonoids. The distribution of other useful fossil groups is also shown; entomozoid ostracodes are locally abundant in the Courceyan Stage (Selwood *et al.*, 1982; Gooday, 1983), as are diverse trilobite and brachiopod faunas (Goldring, 1955, 1970). Trilobites are more sporadic in the Chadian (Owens and Tilsley, 1995) and younger stages (Prentice, 1967) but the concurrence of *Posidonia becheri* and *Neoglyphioceras spirale* is a common feature within the early Brigantian Posidonia Beds (Thomas, 1982; Riley, 1993).

nearshore settings whilst, in the deeper water farther south, shales, limestones and contemporaneous volcanic rocks accumulated.

Sedimentation during Dinantian times was influenced by rapid subsidence and an episodic northward marine transgression (Clayton *et al.*, 1986) that drowned the Devonian coastline and created a deep basin – the Culm Trough. This basin, variously attributed to a foreland, thrust-top or pull-apart tectonic setting, was effectively starved of sediment input and received only small amounts of shale and radiolarian chert and even less coarse-grained sediment. In north and mid-Devon, sediments and fossils were swept into the basin by turbidity currents that scoured the carbonate shelf area to the south of the Wales–Brabant Massif (Thomas, 1982). Farther south, in mid-Cornwall and south Devon, the Dinantian succession is equally thin and comprises radiolarian chert, black shale and volcanic tuff. Occasional coarse deltaic and turbiditic sandstones developed in advance of the migrating Variscan deformation front that formed the southern margin of the Culm Trough. The range of palaeoenvironments envisaged for the Culm Trough during Dinantian times is illustrated in Figure 10.4.

Throughout Silesian times, clastic sedimentation assumed increasing importance as the basin filled, initially with sandy turbidites and then with thick, south-prograding deltaic and paralic sequences (Thomas, 1988). At the close of the Carboniferous Period, the Variscan deformation culminated in widespread folding, thrusting and the intrusion of major granitic plutons such as Bodmin Moor and Dartmoor. The thrust and nappe terrane to the south (Isaac *et al.*, 1982), with its wide range of facies, indicates that the Culm Trough was originally far more extensive before suffering tectonic shortening of at least 50% during the deformation phase. Thus the current Dinantian outcrops do not convey their

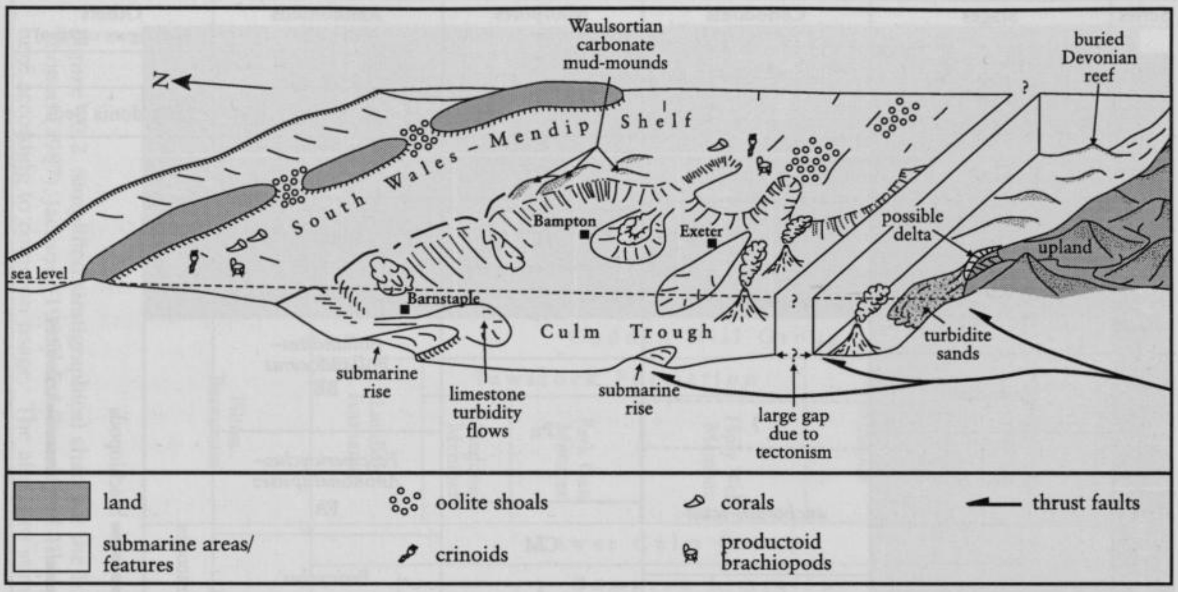

Figure 10.4 Palaeoenvironmental reconstruction for the Lower Carboniferous sequence of south-west England (after Thomas, 1982). Note the association of oolite shoals, productoids, corals and crinoids on the South Wales–Mendip Shelf and its possible southward extension. Subtle changes of basin-floor topography may influence the direction of turbidite flows or dictate sedimentation patterns, forming isolated rise-related successions. The southern margin of the Culm Trough was a mobile orogenic front associated with coarse clastic and volcanic rocks. Half-arrows represent northward-propagating Variscan thrust faults.

spatial relationship at the time of deposition, but rather reflect large-scale, northerly directed thrusting that has telescoped the southern successions to within 40–50 km of the folded, but little displaced, northern outcrops between Barnstaple and Westleigh (Figure 10.1).

GCR site coverage

The nature of exposures in the Culm Trough is very variable. Although the coastal sections are unrivalled, most of the Lower Carboniferous outcrops are restricted to quarries and road cuttings. Consequently, they tend to be limited in scale, accessibility and permanence. The nine sites, discussed below, range from latest Devonian to Arnsbergian in age and thus encompass the entire Lower Carboniferous interval. Fossil evidence for the Pendleian and Arnsbergian stages is rather meagre although the basal beds of the Crackington Formation in mid-Devon yield ammonoids that suggest there is a conformable passage between the Lower and Upper Carboniferous sequences in south-west England. Cleal and Thomas (1996) specifically address sites within the Upper Carboniferous sequence, concentrating mainly on the Namurian sections exposed along the north coast.

The first six sites are located in the northern outcrop (Figures 10.1 and 10.2) and they illustrate a wide stratigraphical diversity. In the Barnstaple area, the **Fremington Quay** coastal section spans the Devonian–Carboniferous boundary and includes the stratotype for the upper part of the richly fossiliferous Pilton Formation. Nearby, the chert-dominated succession at **Park Gate Quarry** provides important fossils of Chadian age and the stratotype for the Tawstock Formation. Farther inland, around Bampton, the disused quarry at **Kersdown Quarry** reveals an important stratotype for part of the Viséan chert and limestone succession; the transition beds across the Brigantian–?Pendleian boundary are exposed at **Kiln Cottage Quarry**. At the eastern end of the outcrop, a thicker development of limestone (the Upper Westleigh Limestone) is spectacularly preserved in the disused quarry at **West Whipcott Quarry**. Similar lithologies at **Stout's Cottage Quarry** contain unique fossil assemblages that indicate a late Viséan age for this localized turbiditic sequence that was derived from an adjacent shelf.

The remaining three sites occur much farther south (Figures 10.1 and 10.2). **Yeolmbridge Quarry** and **Viverdon Down Quarry** are located within the thrust and nappe terrane that is developed extensively in the area between the Bodmin and Dartmoor granites. Yeolmbridge Quarry is a key site for the palaeontological definition of the Devonian–Carboniferous boundary and its stratigraphy reflects the development of a submarine rise within a deep marine basin. At Viverdon Down Quarry, a late Courceyan–Chadian conodont fauna occurs within cherts that are juxtaposed with coarse, feldspathic sandstones as a result of gravitational sliding or thrusting. Finally, the **Spara Bridge** road cutting in the Teign Valley records the most complete Dinantian succession in the Culm Trough (late Devonian–Arnsbergian) and includes the stratotypes for the Combe Shale and Teign Chert, fine-grained clastic and/or siliceous deposits that are insecurely dated as Viséan in age.

FREMINGTON QUAY, DEVON (SS 517 337)

Introduction

The Fremington Quay GCR site is located on the southern bank of the River Taw estuary (SS 517 337) near Barnstaple in north Devon. It provides the most complete succession through the Pilton Formation, a clastic sequence of Famennian–Courceyan age which encompasses the Devonian–Carboniferous boundary. Whilst the exposure is relatively poor and tectonically complex, it provides the stratotype for the upper part of the formation. Rich brachiopod, bivalve and trilobite faunas facilitate comparison with sequences in Devon, Cornwall and Germany (Paul, 1937; Richter and Richter, 1951; Goldring, 1955, 1957), whilst, more recently, miospore assemblages have provided stratigraphical refinement (O'Liatháin, 1993). The most informative account of the site geology is by Goldring (1970).

Description

Phillips (1841) first introduced the name 'Pilton' into the geological literature when describing strata now known to straddle the Devonian–Carboniferous boundary. Since then, the rich fossil assemblages of the Pilton Formation have attracted the attention of many research workers and resulted in several museum collections and palaeontological monographs (e.g. Whidborne, 1896–1907) which later formed the basis for Goldring's (1955, 1957) careful stratigraphical analysis. Goldring (1970) subsequently described the regional setting of the Pilton Formation and provided more detail on the faunal divisions recognized within it. A tabulation of Pilton fossils collected during the British Geological Survey mapping project around Barnstaple was compiled by Edmonds *et al.* (1985) who also recount the historical evolution of this stratigraphical interval.

The Pilton Formation is a particularly important stratigraphical unit in north Devon, consisting of sandstones, siltstones and shales that yield a diverse neritic fauna. Lithologically the formation is divided into two parts: a lower part where thick, fine-grained calcareous sandstones and graded siltstones/shales predominate, and an upper division with fewer sandstones, each tending to be thinner and more lenticular than their older counterparts. Towards the top of the formation, dark shales with siliceous horizons become increasingly common and it is these lithologies that are represented at Fremington.

Exposures exist on the muddy foreshore of the River Taw estuary and in the low cliffs that are mantled with raised beach deposits. They are best examined by walking from north to south, starting near the disused limekiln (SS 517 340) and finishing at the quay (SS 517 335). In general, the succession dips and youngs to the south but is much complicated by steep folds and minor thrust faults (Figure 10.5).

Opposite the limekiln, and for 150 m southwards, the Pilton Formation consists of folded and cleaved shales with sparse lenticular sandstones and phosphatic nodules. Modern tidal sediments often obscure the blue-grey, lustreous shales, which have yielded a sparse Famennian macrofauna with *Phacops accipitrinus* and *Whidbornella caperata*. Well-preserved and diverse miospore assemblages dominated by *Retispora lepidophyta* and *Verrucosisporites nitidus* have also been recovered from the upper part of this section, confirming a latest Famennian age (O'Liatháin, 1993).

At the first prominent exposure of blue-grey shales beneath the low cliff, and from overlying grey-green shales, a more diverse shelly fauna has been recovered. It is dominated by productellid brachiopods such as *Avonia*

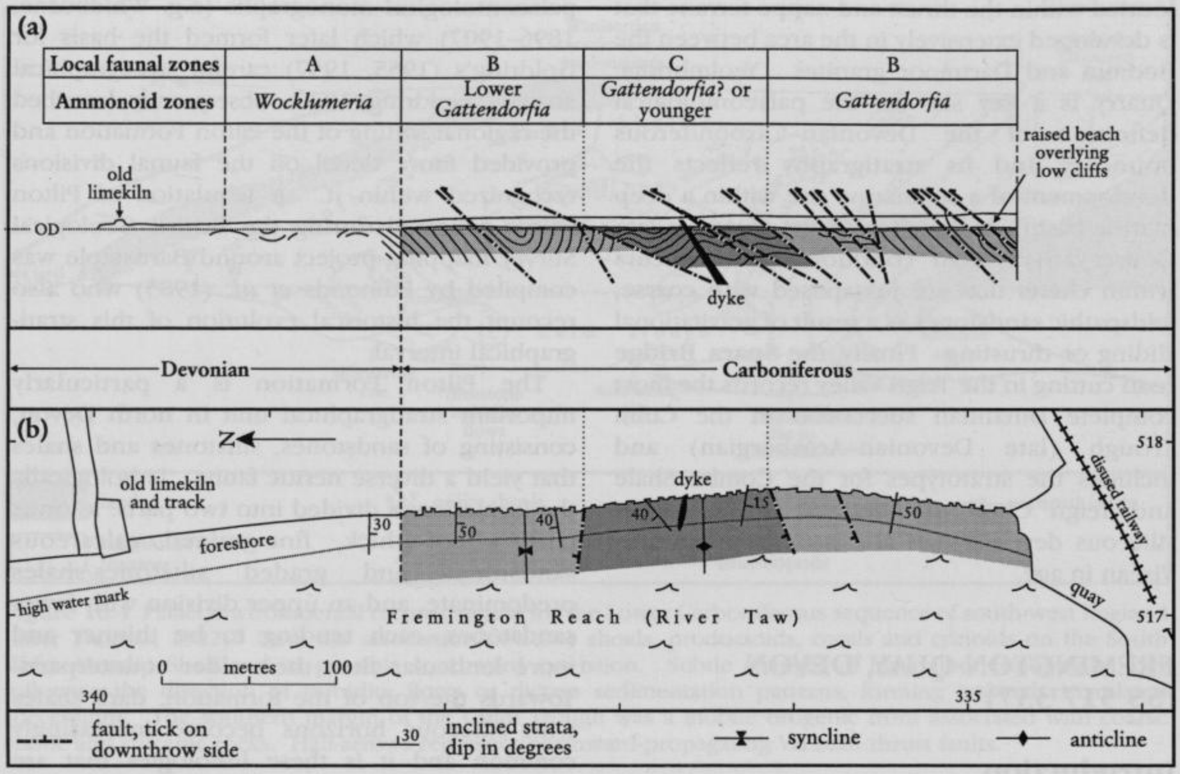

Figure 10.5 (a) Section and (b) map of the shoreline geology at the Fremington Quay GCR site, north Devon. After Goldring (1970).

schmidti, *Cleiothyridina roysii*, *Ovatia spinulifera*, *Productinella fremingtonensis* and *Strophonema paeckelmanni* and includes the trilobites *Phillibole duodecimae* and *P. hercules*. This assemblage is indicative of earliest Carboniferous (Courceyan) times. Again, further age refinement is provided by laevigate miospore genera such as *Punctatisporites* and *Retusotriletes*, which characterize the basal Carboniferous VI miospore zone (Figure 10.3). The marked palaeontological change that occurs between these two apparently conformable sections defines the Devonian–Carboniferous boundary to within a few metres.

Southwards, the exposure is much disrupted by faulting. A useful reference point, however, is a thin lamprophyre dyke (SS 517 336) which is overlain by folded siliceous shales with calcareous and siliceous concretions. The fauna here includes *Brachymetopus maccoyi*, *Piltonia salteri*, *Productinella fremingtonensis* and *Unispirifer tornacensis*, which together suggest a slightly higher position in the succession (Goldring, 1978) and a possible late Tournaisian age. The presence of well-preserved bryozoan fronds and crinoid debris indicates that the fauna has been little transported.

Approaching the quay at the southern end of the site, the shales become increasingly imbricated, but remain quite fossiliferous. Lenticular sandstones and black, organic-rich shales with crinoidal bands yield most of the same brachiopod taxa that occur just above the Devonian–Carboniferous boundary, plus *Brachythyris ratingensis* and *Derbyia steinhagei*.

Interpretation

The Pilton Formation is about 500 m thick and incorporates a diverse neritic fauna that indicates deposition in a transgressive setting – the brachiopods and bivalves in coastal waters, and the trilobites and ammonoids in deeper water (Edmonds *et al.*, 1985). Goldring (1955) collected new faunas widely from the Pilton Formation and established their stratigraphical significance by defining three local range and assemblage zones (Figure 10.6). The oldest (A) zone has been further subdivided by Goldring

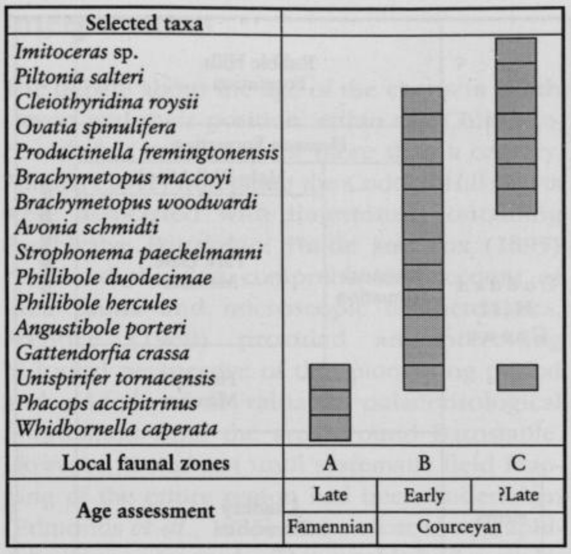

Figure 10.6 Selected ammonoid, brachiopod and trilobite taxa of the Pilton Formation and their distribution in Goldring's (1955, 1970) local faunal zones.

(1970), but in essence it is characterized by productellid brachiopods such as *Cyrtospirifer verneuili* and *Whidbornella caperata* which also occur in the Late Devonian Etroeungt Schichten of Germany (Paul, 1937). In addition, the presence of *Phacops accipitrinus* clearly indicates correlation with the *Wocklumeria* ammonoid zone.

Fremington is the type locality for the middle (B) zone, which is dominated by phillibolid trilobites and productoid brachiopods. Selected taxa are shown in Figure 10.6, the majority of which characterize the early Courceyan sequence (including the *Vaughania vetus* coral–brachiopod zone) according to Riley (1993). Only *Brachymetopus maccoyi* and *Unispirifer tornacensis* range up into the Viséan Series. Ammonoids are rare in the Pilton Formation but *Gattendorfia crassa* has been reported from neighbouring localities. This reinforces the early Courceyan age determination for zone B because Bartzsch and Weyer (1988) note that *G. crassa* occurs within the *Siphonodella sandbergi* conodont zone (see Figure 10.3). That the Devonian–Carboniferous boundary falls between Goldring's zones A and B has been further corroborated by characteristic miospore assemblages (O'Liatháin, 1993).

Zone C is the youngest recognized, but Goldring (1970) cautions that nowhere has a conformable passage between zones B and C been observed. Characteristic species include *Piltonia salteri*, *Productinella fremingtonensis* and *Unispirifer tornacensis*, along with longer-ranging taxa such as *Brachymetopus maccoyi* and *Imitoceras*. Further work is required to establish whether zone C falls within or above zone B.

Correlations are not easily made between the clastic Pilton Formation and the carbonates of the South Wales–Mendip Shelf area because they represent quite different facies. However, there is a much closer comparison to be drawn between the Pilton Formation and the German Etroeungt Schichten, both of which supported a diverse brachiopod assemblage during Late Devonian times (Paul, 1937). As the transgression progressed and deeper water conditions were established during Courceyan times, phillibolid trilobites became established in the Devon area (Prentice, 1967), Cornwall (Selwood, 1960) and Germany (Richter and Richter, 1951).

Conclusions

This site provides critical information about the stratigraphy of the upper part of the Pilton Formation. Extensive historical research has focused on the collection and identification of diverse fossil assemblages that define the base of the Carboniferous System in a continuous section and allows accurate correlations to be made at a local and regional scale. Although complicated by faulting, the southern end of the site is the type locality for Goldring's (1955) zone B fossil assemblage of Courceyan age.

PARK GATE QUARRY, DEVON (SS 557 297)

Introduction

The Park Gate Quarry GCR site is a disused quarry in the crest of the hill at Tawstock (SS 557 297), near Barnstaple (Figure 10.1). It exposes the middle part of the Dinantian Codden Hill Group, which is widely developed in north Devon. The site is particularly important because it is the stratotype for the chert-dominated Tawstock Formation, formerly part of the Codden Hill cherts recognized by Phillips (1841). Beds within the Tawstock Formation contain a rich and varied macrofauna that includes trilobites, ammonoids, brachiopods, corals and crinoids of late Chadian age. The most useful stratigraphical accounts of this locality are provided by Edmonds *et al.* (1985) and Jackson (1991); the faunas have been described by many authors, notably Prentice (1960) and Owens and Tilsley (1995).

Description

Near-vertical bedding planes form the prominent northern face of this quarry but the rather degraded dip-section along the eastern flank provides the most stratigraphical information. Jackson (1991) nominated this site as the stratotype for the Tawstock Formation (Figure 10.2), a mappable unit of siliceous mudstones and cherts, but noted that no single exposure provided a complete sequence through the formation, which is estimated to be 125 m thick.

The lowest beds at Park Gate comprise some 12 m of dark, laminated siliceous mudstones that occasionally include large wood fragments and show some evidence of bioturbation. They are overlain by 15 m of pale-weathering, siliceous mudstones with a distinctive platy fracture and a porous, open texture that suggests they were originally calcareous. Fossils are common within this interval; trilobites and crinoids are often finely preserved as moulds in deeply weathered, partially silicified limestones, whereas the ammonoids are usually found crushed on bedding planes. Above the pale fossiliferous beds, a further 18 m of alternating pale and dark mudstones are exposed, the unit becoming increasingly indurated as thin (5–10 cm) dark-grey, siliceous mudstones predominate. In total, some 45 m of succession is exposed, and Jackson (1991) regards it as sufficiently distinctive to be called the 'Park Gate Member' of the Tawstock Formation (Figure 10.7).

Above the Park Gate Member, several metres of poorly exposed, uniformly dark siliceous mudstones and blocky cherts occur. They are interbedded with thin shale partings at about 5 cm intervals and commonly include phosphatic nodules. Abundant, well-preserved radiolarians tend to be concentrated into discrete bands or laminae but otherwise no useful fossils have been found. Jackson (1991) considers this succession to form part of the Holy Well Member, the uppermost of three members that comprise the Tawstock Formation (Figure 10.7).

Prentice (1960) first described the macrofossils from this site following his discovery of a richly fossiliferous horizon (Bed X) in the pale-weathering mudstones of the Park Gate Member. This horizon, and loose material from the scree below, yielded a rich fauna dominated by trilobites, ammonoids, brachiopods and corals. Prentice's original material has been the subject of much discussion and taxonomic revision (see Owens and Tilsley, 1995 and references therein), particularly with respect to the assemblage of phillipsiid trilobites.

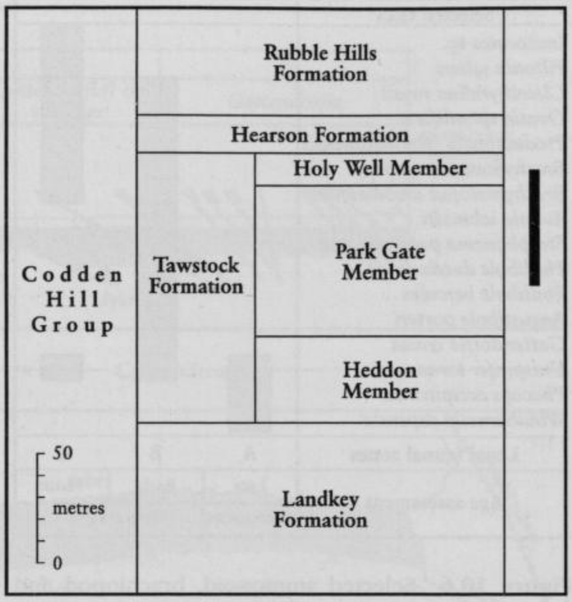

Figure 10.7 Lithostratigraphical subdivisions of the Codden Hill Group, north Devon (after Jackson, 1991). The extent of the Tawstock Formation at Park Gate Quarry is indicated by a vertical bar in the right hand column.

As a result of extensive new collections made between 1988 and 1992, Owens and Tilsley (1995) recorded the following trilobite taxa from Park Gate: *Aprathia kobele*, *Archegonus 'Phillibole' habena*, *Liobole glabra proxima*, *Liobole* aff. *glabroides*, *Spatulina spatulata*, *Tawstockia longispina* and *Wagnerispina coddonensis*. These species are either small-eyed or blind, with relatively thin and unornamented cuticles.

Associated ammonoids, including *Ammonellipsites*, *Eonomismoceras* and *Merocanites*, have been described by Prentice (1960) and dated as late Chadian age by Riley (in Edmonds *et al.* 1985). Rather unusually, they co-exist with a coral–brachiopod fauna that includes *Cladochonus michelini* and small chonetoids such as *Lissochonetes* cf. *laguessianus*, *Pliochonetes buchianus* and *Tornquistia polita*.

Interpretation

The debate about the age of the cherts in north Devon and their position within the Culm succession has continued for more than a century. Phillips (1841) noted that the Codden Hill cherts were associated with limestones containing the bivalve *Posidonia*; Hinde and Fox (1895) produced the first comprehensive account of their fauna and microscopic characteristics. Prentice (1960) provided an interesting historical perspective of that pioneering period and added much valuable palaeontological information from the area around Barnstaple. However, it was not until systematic field mapping of the entire region had been undertaken (Edmonds *et al.*, 1985) that a clear stratigraphical picture emerged. This established a shale-dominated Lower Carboniferous succession about 250 m thick, typically with a thickly developed and widespread chert unit in the middle part of the succession.

Further palaeontological work, integrated with field data, allowed Jackson (1991) to divide the long-established Codden Hill Group into a more formal stratigraphy based on local type sections. Of the formations defined, the Tawstock Formation is further subdivided into three members, as illustrated in Figure 10.7. The Heddon Member (*c.* 40 m) is characterized by black siliceous mudstones and shales whilst the overlying Park Gate Member (*c.* 70 m) is predominantly paler and includes a moderately diverse fauna. It is the upper 45 m of this member that is exposed at Park Gate and, as that constitutes the most complete succession in the area, it provides the designated stratotype (Jackson, 1991). The Holy Well Member (*c.* 15 m) is poorly exposed and much faulted but includes highly siliceous black cherts. Whether this stratigraphical refinement proves to be durable remains to be seen, but it provides some context in which to consider the palaeoenvironmental and biostratigraphical value of the Park Gate trilobite fauna.

Owens and Tilsley (1995) noted that the trilobites are all either blind, or have eyes that are reduced to a small number of lenses. This is a feature common to other Dinantian taxa that are adapted to deeper water environments such as the Craven Basin of north-west England (see **River Hodder** GCR site report, Chapter 6) and the German Rhineland. Despite this similarity, there is little correspondence between these assemblages at the generic level, probably because of differences in age and substrate. However, *Archegonus 'Phillibole' habena* and *Liobole glabra proxima* are known from the Brezina shales of Moravia in the Czech Republic, which are correlated with the German cuIIγ ammonoid zone (Chlupác, 1966). This is consistent with the late Chadian age indicated by the ammonoids that Riley (1991) ascribes to the late FA ammonoid zone (Figure 10.3).

The origin of the bedded chert sequence at Park Gate Quarry, in common with equivalent facies elsewhere in the Culm Trough, is subject to several interpretations. These include re-deposition of siliceous pelagic sediments by turbidity currents and biogenic segregation of initially homogeneous siliceous muds into silica-rich cherts and silica-poor mudstones. Such interpretations generally imply a deep-water origin although, as noted by Hesse (1988), shallow-water cherts are not unknown in the geological record.

Conclusions

This classic locality is of national importance and it has contributed significantly to the understanding of Dinantian stratigraphy in north Devon. It provides the stratotype for both the Tawstock Formation and one of its components, the Park Gate Member. The well-preserved trilobites facilitate valuable taxonomic and palaeoenvironmental studies, whilst the ammonoids provide information about the age of the cherts. Together, the fossils help to establish correlation links with other areas in Britain and northern Europe.

KERSDOWN QUARRY, DEVON (SS 964 222)

Introduction

The Kersdown Quarry GCR site is a deep disused quarry (SS 964 222), developed in a pronounced ridge overlooking the town of Bampton in east Devon. It is an important reference section for the Viséan Bampton Limestone succession in an area where many former exposures have been lost to quarrying or reclamation. Limestones at this locality have been interpreted as turbidity current deposits and they occur, with increasing frequency, within a thin sequence of fine-grained cherts. Despite its significance, little information has been published about the site apart from isolated references to its fossils (Thomas, 1962; Prentice and Thomas, 1965; Matthews and Thomas, 1974) and a more comprehensive stratigraphical synthesis by Jackson (1985).

Description

Following extensive field mapping, Thomas (1962, 1963b) determined the principal lithostratigraphical divisions of the Lower Carboniferous succession around Bampton and Westleigh. He recognized that basal black shales were succeeded by limestones and cherts, passing up into soft, black, silty shales and greywackes. That succession has subsequently been refined (Selwood and Thomas, 1987) and the broad age-equivalence between the Bampton Limestone and Westleigh Limestone is well established (Figure 10.2).

Successive levels in the quarry reveal about 60 m of the Bampton Limestone succession in a tightly folded anticline that plunges towards the south-west (Figure 10.8). The northern limb of the fold provides the most informative section and allows the three members that comprise the Bampton Limestone to be recognized.

About 40 m of uniform, thin-bedded (*c.* 10 cm) siliceous shales occupy the core of the fold. They form the upper part of the Hayne Beech Member and are interbedded with a few thin silicified limestones and ash bands that pass upwards into thin mottled and dolomitized limestones.

The overlying Kersdown Chert Member is 7 m thick and comprises cherts with interbedded shales and some fine-grained limestones (Webby and Thomas 1965; Matthews and Thomas, 1974). Weathered surfaces of the cherts are pale in colour, but fresh samples are dark grey or black, finely laminated and contain relict radiolarian tests. On average, the chert beds are 10–50 cm thick and they are usually well jointed and blocky. The cherts are interbedded with thinner shales that are slightly silicified and contain radiolarians and siliceous nodules. Some limestones up to 50 cm thick also occur, particularly towards the top of the member where they show evidence of grading, loading and bioturbation. They have a rottenstone appearance although their matrix is slightly siliceous.

Fossils from the Kersdown Chert Member include small corals, brachiopods, ammonoids and conodonts. The ammonoids are typically crushed and poorly preserved but siliceous nodules in the lower part of the member have yielded rare examples of *Merocanites* cf. *similis* and *Bollandites* (Thomas, 1962; Prentice and Thomas, 1965). Conodonts extracted from an overlying limestone bed include *Gnathodus texanus pseudosemiglaber*, *G. t. texanus* and *Mestognathus beckmanni* (Matthews and Thomas, 1974). Despite concerns that some of the conodonts may be reworked, an early- to mid-Viséan age is indicated.

Figure 10.8 Tight, asymmetric anticline developed in beds of the Bampton Limestone succession, Kersdown Quarry, east Devon. (Photo: J. Jones.)

The upper levels of the quarry show a gradation into the overlying Bailey's Member of the Bampton Limestone succession (Figure 10.2). Some 15 m thick here, the member comprises black, faintly laminated siliceous shales at the base with alternations of pale-weathering limestones and mudstones above. Individual limestone beds are laterally persistent with sharply defined bases, but mottling attributed to bioturbation obscures internal structures. Towards the top of the member, black shales become more abundant and at nearby localities both *Michiganites hesteri* and *Posidonia becheri* occur at a corresponding level. These fossils indicate an Asbian–Brigantian age.

Interpretation

The Bampton Limestone succession is characterized by fine-grained limestones, mudstones and cherts. At Kersdown Quarry and other localities, the thin silicified limestones occasionally display graded bedding, sole markings, burrowing and ripple cross-lamination which suggest they form part of a distal turbidite influx (Thomas, 1962; Matthews and Thomas, 1974). The limestones are subordinate to the thicker and more extensive sequences of laminated cherts, shales and mudstones that are generally considered to have accumulated in a sediment-starved, deep-water basin (Prentice, 1958; Thomas, 1982). However, van Adrichem Boogaert (1967) described similar shales and cherts of upper Tournaisian age from the Vegamián Formation of Cantabria, which formed in shallow water, probably under anoxic sea-floor conditions caused by high plankton productivity and high oxygen depletion rates. In similar vein, Edmonds *et al.* (1985) favoured a comparatively shallow, perhaps lagoonal, origin for these 'background' sequences.

A palaeoenvironmental reconstruction for the Lower Carboniferous sequence (Figure 10.4) illustrates a carbonate shelf and ramp extending south of the Wales–Brabant Massif. Sediment from this area was transported basinward by turbidity currents, augmenting the rather thin, condensed sequences in the basin. The progressive upward increase of limestone turbidites at Kersdown Quarry is mirrored by an increase of other re-sedimented beds elsewhere in the northern part of the Culm Trough (Thomas, 1963b; Jackson, 1991). This suggests that submarine topography continued to influence depositional patterns during Dinantian times in the northern part of the Culm Trough, just as it did farther south (Isaac *et al.*, 1982).

Conclusions

This is the best site in the Culm Trough for illustrating the stratigraphy of the Bampton Limestone succession. More specifically, it is the type locality for the thin sequence of inter-bedded cherts and limestones that constitute the Kersdown Chert Member. The persistent limestone horizons are believed to represent part of a distal turbidite flow that inundated the basin during Viséan times.

KILN COTTAGE QUARRY, DEVON (SS 950 222)

Introduction

The Kiln Cottage Quarry GCR site is a disused quarry (SS 950 222) near Bampton, east Devon. It reveals a Brigantian–?Pendleian section extending from the upper part of the Bampton Limestone succession into the lower part of the Dowhills Beds (Crackington Formation). It is the most informative of the few localities in Devon that record the cessation of limestone turbidite deposition within the sediment-starved Lower Carboniferous basin. Ammonoids confirm that this shift in depositional pattern occurred during Brigantian times in the Bampton area (Thomas, 1982). Although there is no comprehensive account of this site to date, it is mentioned in field guides (e.g. Webby and Thomas, 1965; Thomas, 1971) and unpublished theses (e.g. Jackson, 1985).

Description

Although much of the site has been infilled, some 30 m of section is still visible in the north-west face of the quarry. It records the transition from dark shales and impure limestones of the Bailey's Member (topmost beds of the Bampton Limestone) into weathered black shales of the overlying Dowhills Beds (lowermost part of the Crackington Formation) (Figure 10.2). A log of the partially exposed succession indicates that the Bailey's Member is about 23 m thick whereas the Dowhills Beds are considerably thicker, although only the basal 5–6 m are currently exposed (Figure 10.9).

Near the base of the succession is a thick (0.75 m) deeply weathered limestone overlain by dark-grey, siliceous mudstones and thinner limestones. Above an interval obscured by talus, three prominent limestone beds 20–40 cm thick with pronounced honeycomb weathering occur, separated by beds of dark, locally cherty, mudstone. These limestones show no sign of internal structure or bioturbation

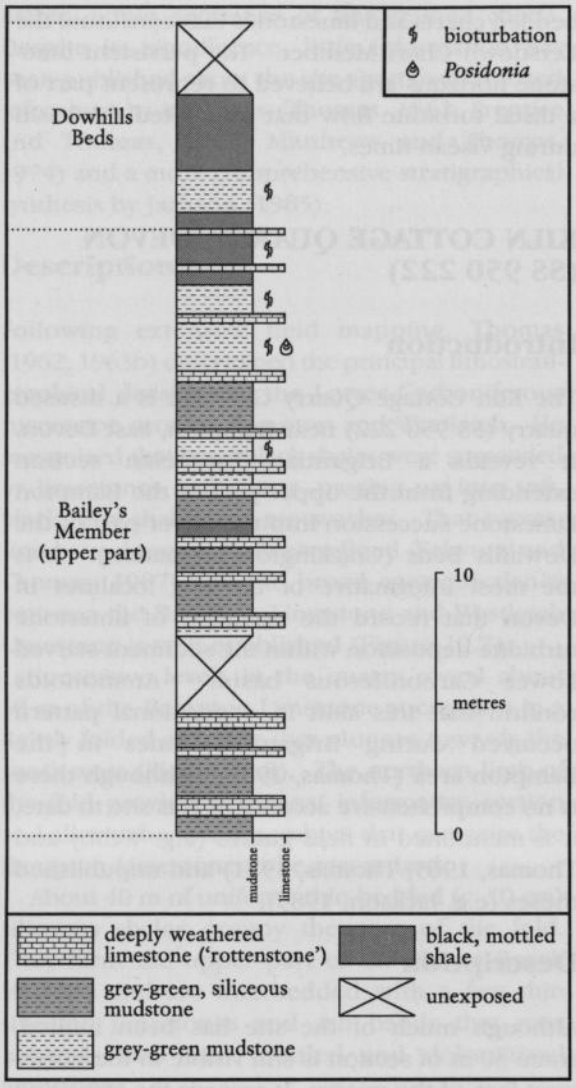

Figure 10.9 Simplified log of the upper part of the Bailey's Member (Bampton Limestone succession) and the transition into the Dowhills Beds (Crackington Formation), Kiln Cottage Quarry, east Devon. After Jackson (1985).

although they are characteristically sharp-based and muddy. From 11–18 m, the limestones are thinner (Figure 10.10), more frequent and are interbedded with grey and black shales that are patchily siliceous and mottled. At 19 m, poorly preserved *Posidonia* occurs, above which the shales become darker and more mottled.

Matthews and Thomas (1974) defined the top of the Bailey's Member at the top of the last limestone bed. This may equate to the thin, weathered limestone or 'rottenstone' at 23 m (Figure 10.9). Above this, the Dowhills Beds consist of unfossiliferous, finely laminated shales and thin siltstones that are locally micaceous and rich in plant debris. The remainder of the section is hidden but elsewhere in the Bampton region the Dowhills Beds range up into the Pendleian and Arnsbergian stages (Edmonds, 1974).

The section between 19 m and 25 m yields *Posidonia becheri*, *Neoglyphioceras spirale* and *Lusitanoceras granosus*, and is a classic example of the Posidonia Beds. These taxa characterize the P_{1b}–P_{2a} ammonoid zones (Figure 10.3), and, although they are imprecisely located, they adequately bracket the waning of limestone deposition in this area as a feature of early Brigantian times.

Interpretation

Matthews and Thomas (1974) interpreted the laterally persistent limestones within the Bailey's Member as distal turbidites that originated from extensions of the carbonate shelf to the north. They are broadly similar in age to the Upper Westleigh Limestone (Figure 10.2) but are generally finer grained. This might be readily anticipated since the composition of turbidites is easily influenced by subtle changes taking place in provenance areas and in sea-floor topography. It is also interesting to note that, at a local level, the Posidonia Beds occur in a black shale facies around Bampton whereas at Westleigh, only 10 km to the south-east, the same horizon is interbedded amongst thick detrital limestones.

However, in a regional sense, Thomas (1982) has noted that limestone deposition in the Culm Trough is generally at its most widespread at about Posidonia Beds time. He suggested that the abundance of preserved bivalves and ammonoids reflected high organic productivity, reduced sedimentation rates and perhaps a better-ventilated water column. Certainly the causative factors have to be sought at a basin scale since the Posidonia Beds are uniformly developed throughout the present northern and southern outcrops, areas that were separated by more than 75 km at the time of deposition.

The Dowhills Beds are one of several euxinic black shale sequences (e.g. Ashton Shale, Limekiln Beds) that have been recognized below the thick turbiditic sandstones of the Crackington Formation (Edmonds, 1974). This

Figure 10.10 Deeply weathered limestone bed within dark siliceous mudstones of the Bailey's Member (Bampton Limestone succession), Kiln Cottage Quarry, east Devon. Note coin for scale. (Photo: J. Jones.)

has led to a proliferation of stratigraphical synonomy during the course of localized mapping projects. Edmonds (1974) sought to simplify the problem by proposing that all the black shale intervals should be considered part of the Crackington Formation, a view reflected in Figure 10.2. This is logical since the euxinic shales provide background sedimentation throughout the Crackington Formation whereas the more conspicuous sandstone bodies provide variation in terms of bedform and origin.

Conclusions

This important site records the conformable passage from sequences containing mudstones, cherts and limestone turbidites into younger beds characterized by black shales and coarse, sandy turbidites. The fine-grained deposits accumulated more-or-less unchanged in a long-lived, sediment-starved basin, but the obvious shift from limestone to clastic turbidites occurred from Brigantian times onward. A fundamental re-arrangement of the hinterland around the Culm Trough must account for the marked change in sediment type made accessible to the basin.

WEST WHIPCOTT QUARRY, DEVON (ST 069 186)

Introduction

The West Whipcott Quarry GCR site is a large, disused quarry (ST 069 186), located to the west of the Grand Union Canal, 1.5 km north of Westleigh, east Devon. It provides one of the best exposures of a thick sequence of Viséan limestones and interbedded shales known as the 'Upper Westleigh Limestone'. Lithological and palaeontological evidence suggests a turbiditic origin for these limestones, which are only developed locally in the typically thin, chert-dominated sequences of east Devon. There is no recent detailed account of the Westleigh Limestone and what follows is based on the field observations of Thomas (1963a, 1971) and the palaeontological analysis of Matthews and Thomas (1974).

Description

The relationship between the largely coeval Westleigh Limestone and Bampton Limestone successions is shown in Figure 10.2 but the boundary between them appears to be abrupt and is probably complicated by faulting or slumping (Thomas, 1963b). In the numerous quarries around Westleigh it is possible to distinguish a lower unit and an upper unit within the Westleigh Limestone succession. Thinly bedded detrital limestones with few interbedded shales characterize the lower unit, whereas the overlying limestones are thicker, coarser and occasionally conglomeratic.

The Upper Westleigh Limestone at West Whipcott consists of calcarenites and calcirudites, typically < 0.5 m thick, which include chert horizons and nodules, along with some evidence of graded bedding and sole marks. Although the succession is complicated by folding and faulting, at least 25 m of well-bedded limestone is preserved in successive benches of the quarry. Some beds are coarsely conglomeratic and contain angular blocks of micritic and/or skeletal limestone set in a matrix of oolitic and crinoidal debris. Comminuted fossils such as bryozoans, crinoids, corals and brachiopods are recognizable in some of the larger (up to 5 cm) clasts. The thicker limestones are massive, sharp-based and poorly sorted but may possess a thin (*c.* 5 cm thick), laminated upper horizon that grades into the overlying shale.

The interbedded buff and purple micaceous shales are slightly calcareous, finely colour-banded and often bioturbated. Nodular developments of chert and limestone occur commonly and spectacular examples of concentric weathering are evident on many joint and bedding surfaces. There is no evidence of a benthic fauna here, although in adjacent quarries some brachiopods, trilobites and crinoids have been recorded, as have flattened pelagic fossils such as *Goniatites crenistria* and *Posidonia* (Thomas, 1963a; Matthews and Thomas, 1974).

Several large angular folds are well exposed in the lower levels of the quarry and abrupt changes in dip suggest localized faulting (Figure 10.11). At the top of the quarry, a thin veneer of New Red Sandstone is preserved above a pronounced angular unconformity. The ferruginous sandstones impart a red surface coloration to many of the underlying limestones and shales.

Figure 10.11 Sequence of stacked, massive calcarenites and thin shales of the Upper Westleigh Limestone succession, West Whipcott Quarry, east Devon. (Photo: J. Jones.)

Interpretation

Lithological evidence from Whipcott and neighbouring quarries indicates that the limestones contain reworked 'shelf' material such as ooliths, pellets, fossil fragments and some coarsely conglomeratic horizons with angular clasts of medium-grained limestone. These features, occurring in beds that are commonly sharp-based and graded, are attributed to limestone turbidites (Thomas, 1963a). In contrast, the intervening shales with their fine lamination and sparse benthic fauna show little sign of transportation. Indeed, there is evidence that certain fine-grained intervals such as the Crenistria Limestone were deposited during periodic oxic conditions in an otherwise anoxic deep-water basin that extended throughout the Rhenohercynian Zone (Jackson, 1990; Warnke, 1997).

Ammonoids originally provided the basis for dating the Westleigh Limestone succession. Poorly preserved prolecanitids described by Prentice and Thomas (1965) indicate a late Viséan (Asbian–Brigantian) age for the upper unit. Towards the top, shales interbedded with thick limestones yield both *Neoglyphioceras spirale* and *Lusitanoceras granosus*. These species characterize the P_{1d}–P_{2a} ammonoid zones of the Brigantian Stage (Figure 10.3), indicating that these beds represent the youngest phase of limestone sedimentation in the Culm Trough.

Matthews and Thomas (1974) subsequently undertook a more detailed biostratigraphical study, using conodonts in an attempt to isolate the indigenous and reworked components of the succession. Abundant gnathodids (particularly *Gnathodus bilineatus*) were recovered from various localities in the area and they confirmed the age determination provided by the ammonoids. In addition, a number of significantly older species, such as *Scaliognathus anchoralis* and *Polygnathus communis*, occurred in the conglomeratic horizons, implying that an admixture of Tournaisian sediment had been acquired, either at source or during deposition. These species are common components of the 'Avonian' limestones in the Mendip area (Butler, 1973).

By combining the evidence above, Thomas (1982) concluded that the laterally continuous limestone beds in the Westleigh succession resulted from turbidity currents sweeping into the area from nearby shelf sequences. This interpretation requires that the provenance lay to the north-east of Westleigh and was perhaps a southward extension of the Mendip Shelf facies (Figure 10.4). Whilst there are obvious differences in detail, this pattern of deposition is a common feature of the Dinantian sequence throughout much of the Rhenohercynian Zone (e.g. Franke *et al.*, 1975; Bełka, 1987).

Conclusions

West Whipcott Quarry is one of the most informative and extensive exposures of the Upper Westleigh Limestone and it is particularly important because other sites in the area are either actively quarried or largely overgrown. The limestones were deposited in a deep marine trough that received sediment from a shallow marine shelf located many kilometres to the north-east. Turbidity currents transported the limestones and fragments of fossils down the sloping seabed into the trough.

STOUT'S COTTAGE QUARRY, DEVON (ST 048 192)

Introduction

The Stout's Cottage Quarry GCR site is a deep, elongated depression resulting from former quarrying on the edge of Waterslade Copse (ST 048 192), 3 km north-west of Westleigh, east Devon. Now much overgrown, it nevertheless provides crucial evidence for the age and origin of the Upper Westleigh Limestone. The limestones are believed to have formed in shallow water and were transported to this area by turbidity currents during late Viséan times. Webby and Thomas (1965) first described the lithologies and macrofossils from this site, and conodonts have been used subsequently (Matthews and Thomas, 1974) to corroborate their Asbian–Brigantian age.

Description

The Stout's Cottage section is developed in the steeply dipping southern limb of a minor anticline. The small exposure reveals about 10 m of typical Upper Westleigh Limestone but the faunas are unusually diverse and abundant. Distinct and massive calcarenites 20–60 cm thick dominate the succession, the coarser beds containing ooliths and crinoid debris. Each bed is sharp-based and laterally continuous, but poorly sorted. Intervening fine-grained limestones are thinner (15–20 cm) and show evidence of weakly developed graded bedding. Webby and Thomas (1965) recorded one thick horizon that contained a variety of clasts, one of which was part of a colonial coral identified as *Lithostrotion arachnoideum* (now *L. araneum*).

The interbedded shales are grey, but commonly weather pink due to iron staining. They are locally siliceous and yield numerous crushed ammonoids including *Michiganites* cf. *hesteri* and *Goniatites*, which are indicative of late Asbian times (Prentice and Thomas, 1965; Riley, 1993). Benthic faunas have not yet been recorded from this site and the only other macrofossils known are *Posidonia becheri*, indeterminate orthocones and abundant comminuted plant debris (Webby and Thomas, 1965).

A limestone situated 7 m above the occurrence of *M.* cf. *hesteri* produced an impoverished conodont assemblage that includes *Gnathodus bilineatus*, *G. commutatus commutatus*, *G. c. homopunctatus*, *Pseudopolygnathus triangulus pinnatus* and *Ps.* cf. *dentilineatus* (Matthews and Thomas, 1974). This suggests a Brigantian age, which accords well with the underlying ammonoid and bivalve data, although the presence of *Ps. triangulus pinnatus* and *Ps.* cf. *dentilineatus* also indicate reworking of older, Tournaisian conodonts (N. Riley, pers. comm., 2002).

Interpretation

The succession exposed here can be compared with that at **West Whipcott Quarry** and the evidence provided by the reworked shelf debris, such as coral fragments and ooliths, in the limestones confirms a shallow-water origin. Thomas (1982) considered the coarse limestone beds of the Upper Westleigh Limestone succession to be proximal turbidites, characterized by thick detrital limestones containing reworked, shallow-water faunas. In contrast, the interbedded shales possess fossil assemblages that comprise pelagic and benthic taxa showing little sign of transportation. Thus the shales imply deposition below wave-base and represent background sedimentation into which the turbidites were intercalated.

The thick, sharp-based, massive calcarenites at Stout's Cottage Quarry are comparable with the Viséan Kohlenkalk in the West German Rheinisches Schiefergebirge (Franke *et al.*, 1975). In particular, the well-bedded, bioclastic limestone facies is characterized by beds of variable (0.5–2.5 m) thickness that often lack internal structures and have few shale partings. The German facies attains a maximum thickness of about 100 m and it thins to 10 m on the flank of a submarine high. Franke *et al.* (1975) interpreted these rocks as proximal turbidites derived from an adjacent carbonate platform.

At a regional scale, Franke *et al.* (1978) note that the association of black shales, cherts and limestone turbidites form condensed pelagic sequences throughout much of the Rhenohercynian Zone. This phase of diminished subsidence and sedimentation, the so-called 'stagnation phase' or 'bathyal lull', probably took place in water depths that ranged from several hundred metres up into the photic zone. Franke *et al.* (1978) distinguish this upper bathyal setting from abyssal depths (> 2000 m) because there is no evidence that a Rhenohercynian ocean existed.

Conclusions

Stout's Cottage Quarry is an important site because it yields a variety of fossils that indicate a late Viséan age and further constrain the age of the Upper Westleigh Limestone succession. Detrital limestones containing shallow-water debris are thought to result from powerful submarine currents that transport slurries of partially consolidated sediment into low areas on the seabed. They add considerably to the overall thickness of Viséan strata in the area.

YEOLMBRIDGE QUARRY, CORNWALL (SX 322 875)

Introduction

The Yeolmbridge Quarry GCR site is a large, partially flooded quarry near Launceston, Cornwall (SX 322 875). It provides an invaluable reference section for the Yeolmbridge Formation, a succession of black silty slates and limestones that are generally poorly exposed in the area. Early records of trilobites and ammonoids established an Upper Devonian age for the slates in the lower, submerged part of the quarry, but Tournaisian macrofaunas and miospores have since been discovered in the overlying horizons. Several authors (e.g. Reid *et al.*, 1911; Selwood, 1960) have described fossils from this site that establish a conformable succession spanning the Devonian–Carboniferous boundary. The regional setting further suggests that sedimentation occurred in the vicinity of a submarine rise that was drowned as sea level rose during early Carboniferous times (Stewart, 1981; Selwood *et al.*, 1998).

Description

Yeolmbridge Quarry was first described by Reid *et al.* (1911) as one of several Devonian inliers that occurred near Launceston. Subsequent regional mapping has shown that they result from complex faulting and form part of a widespread tract of Upper Devonian and Lower Carboniferous rocks in the region between Boscastle, Launceston and Okehampton (see Figure 10.1). Correlation between these isolated successions relies critically upon the recognition of distinctive lithofacies, and in this respect the quarry is particularly notable because it also provides a variety of key fossil assemblages.

As parts of the succession are concealed beneath water, the presence of the underlying Devonian strata must be inferred from historical records. Reid *et al.* (1911) described Upper Devonian faunas from distinctive nodular limestones found in the spoil heaps of early workings. Subsequent re-examination of this material by House and Selwood (1957) determined a *Wocklumeria* Zone age. This supports a correlation with the Stourscombe Formation (Figure 10.2).

The exposed part of the quarry is developed entirely within the Yeolmbridge Formation and comprises a 12–15 m succession of dark-grey to brown silty slates with finely banded micaceous siltstones and infrequent cross-bedded sandstones up to 15 cm thick. Horizons of soft, black carbonaceous shale and thin (20 cm) micritic limestones occur intermittently. The youngest part of the sequence occurs in the southern face of the quarry where a 3 m green and grey slate unit is overlain by a thin tuff band and dark shales containing numerous decalcified limestone nodules (Witte, 1983).

Selwood (1960) discovered proetid trilobites and ammonoids at this locality, mainly within the decalcified limestone nodules exposed high in the southern face. The diverse fauna included species of *Cyrtosymbole* ('*Macrobole*') and the important ammonoid *Gattendorfia*, which established a Tournaisian age for this part of the Yeolmbridge Formation. In an attempt to corroborate this age determination, Whiteley (1983) prepared palynological samples from shale horizons immediately above the fossiliferous nodules. These yielded a miospore assemblage dominated by species of *Punctatisporites* and *Retusotriletes*, with subordinate representatives of *Auroraspora macra*, *Calamospora*, *Grandispora echinata*, *Raistrickia* cf. *condylosa* and *Verrucosisporites nitidus*. This palynoflora is referred to the mid-Tournaisian VI miospore zone (Figure 10.3) according to comparisons with other assemblages from western Europe (Clayton *et al.*, 1977; Higgs *et al.*, 1988a,b); it thus provides an age determination in accord with Selwood's (1960) macrofauna.

Interpretation

An understanding of the stratigraphy in the Yeolmbridge area has evolved only slowly, hindered by complex facies relationships and poor exposure. Selwood (1960, 1971) first established a local succession based on the distribution of ammonoids and trilobites, noting that the Devonian–Carboniferous boundary occurred in the black slate facies of the 'Yeolmbridge Beds'. More detailed mapping in the surrounding area and a careful analysis of conodont faunas allowed Stewart (1981) to recognize the age-equivalence of several distinctive lithologies within the Upper Devonian and erect a more formal stratigraphy that typically characterizes a tectonic unit known as the 'Petherwin Nappe' (Isaac *et al.*, 1982). However, part of that stratigraphy also occurs at Yeolmbridge where, in contrast, it appears to be largely *in situ* (or autochthonous) and is exposed through a combination of high-angle faults that locally breach the Upper Carboniferous cover rocks (Selwood *et al.*, 1998).

The dark, siliceous slates of the Stourscombe and Yeolmbridge formations at this site contain some limestone beds and horizons containing decalcified, fossiliferous nodules. Elsewhere, these formations pass laterally into more calcareous units (within the Petherwin Formation; see Figure 10.2) where the limestone nodules coalesce to form flaser-bedded limestones up to 50 cm thick. The limestones are richly fossiliferous and contain ammonoids, brachiopods and conodonts, the latter indicating deposition in shallow water. Stewart (1981) compared this distinctive facies with the German Cephalopodenkalk described by Schmidt (1925) from the Rheinisches Schiefergebirge.

In terms of depositional environments, the Cephalopodenkalk characterizes submarine rises from which fine material is winnowed and transported into adjoining basinal areas (Figure 10.12). Denser shell debris and flaser-bedded limestones dominate the core of the rise but they are typically thin, stratigraphically condensed and areally restricted. They pass laterally into more extensive calcareous slates with nodular limestones on the rise margins and this is the setting envisaged for the Yeolmbridge succession. In the basinal areas, thicker argillaceous sequences bearing pelagic ostracodes and some brachiopods occur.

The black shale facies at this site persisted from Upper Devonian to Tournaisian times, suggesting that the associated submarine rise was a relatively long-lived feature. Stewart (1981) noted that the decline of rise-controlled sedimentation occurred during late Tournaisian times as limestone conglomerates, thought to represent slump deposits, developed along the over-steepened margin of the rise (Figure 10.12). At the same time, black shales progressively onlapped the rise complex and more uniform bathymetric conditions became established during Viséan times.

Conclusions

This site is of great historical importance because crucial fossils were found here when the quarry was actively worked in the early 20th century. They confirmed an Upper Devonian age for the oldest strata, which are no longer exposed. Overlying slates and limestones contain Lower Carboniferous fossils and thus establish a conformable passage across the Devonian–Carboniferous boundary. The Yeolmbridge succession also provides evidence for a long-lived submarine rise that influenced patterns of sedimentation in this part of the Culm Trough.

VIVERDON DOWN QUARRY, CORNWALL (SX 374 675)

Introduction

The Viverdon Down Quarry GCR site is a small disused chert quarry (SX 374 675) near St Mellion, in east Cornwall. It is surrounded by coarse-grained sandstones that comprise the largest and most southerly Carboniferous outlier in Britain. The site reveals a Lower Carboniferous conodont-bearing chert succession that forms part of a discrete block within the sandstones. Hinde and Fox (1895) first mentioned the cherts in the context of their research into radiolarians, but the presence of

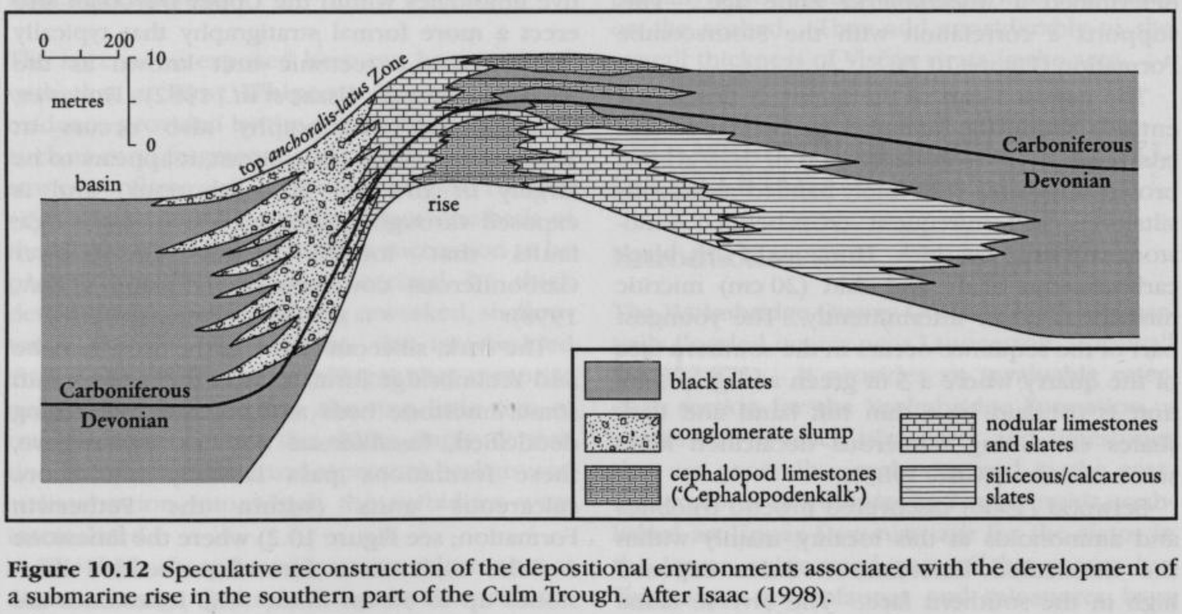

Figure 10.12 Speculative reconstruction of the depositional environments associated with the development of a submarine rise in the southern part of the Culm Trough. After Isaac (1998).

conodonts was not recorded until Matthews (1961, 1966a, 1969) described the diverse fauna and discussed its stratigraphical implications. During a more recent regional mapping programme Devonian rocks were discovered at the site (Whiteley, 1981, 1983).

Description

The area of relatively high ground north of St Mellion is called Viverdon Down and it comprises mainly Lower Carboniferous sandstones and shales known locally as the 'Crocadon Formation' (Whiteley, 1983, 1984). The formation is probably 150–250 m thick and it is thrust over older successions, creating an extensive tectonic outlier or *klippe*, known as the 'St Mellion Klippe' (Figure 10.2). Interleaved within the Crocadon Formation are several large sedimentary blocks up to 1 km in length that appear to bear no structural or stratigraphical continuity with the sandstone–shale sequence. Two such blocks are partially exposed at the quarry.

The first of these is a cherty development comprising at least 5 m of well-bedded, blocky chert and siliceous shale. It forms the major face of the quarry (Figure 10.13) but trenching in the vicinity indicates that the block is about 100 m long and perhaps a little thicker than presently seen in the quarry face. The cherts are thinly bedded (< 10 cm), strongly jointed and dark in colour, although weathered surfaces have a distinctive creamy-yellow coloration, particularly along fractures and minor joints. Thin siliceous shale partings are common and the bedding is essentially horizontal with locally steepened zones close to minor faults.

Some 2 m above the western end of the quarry floor, several thin (5 cm) beds of siliceous shale with finely micaceous parting surfaces yield abundant moulds of conodonts (Matthews, 1969). This fossiliferous interval is only about 20 cm thick and it occurs at about the mid-point of the exposed succession which is generally devoid of conodonts. Representatives of the long-ranging genera *Bryantodus*, *Ligonodina* and *Lonchodina* dominate the assemblage but more significant are moulds of delicately preserved platform elements that are studied as latex casts. They include *Doliognathus lata*, *Gnathodus delicatus*, *Gn. punctatus*, *Gn. texanus*, *Hindeodella segaformis*, *Palmatolepis*

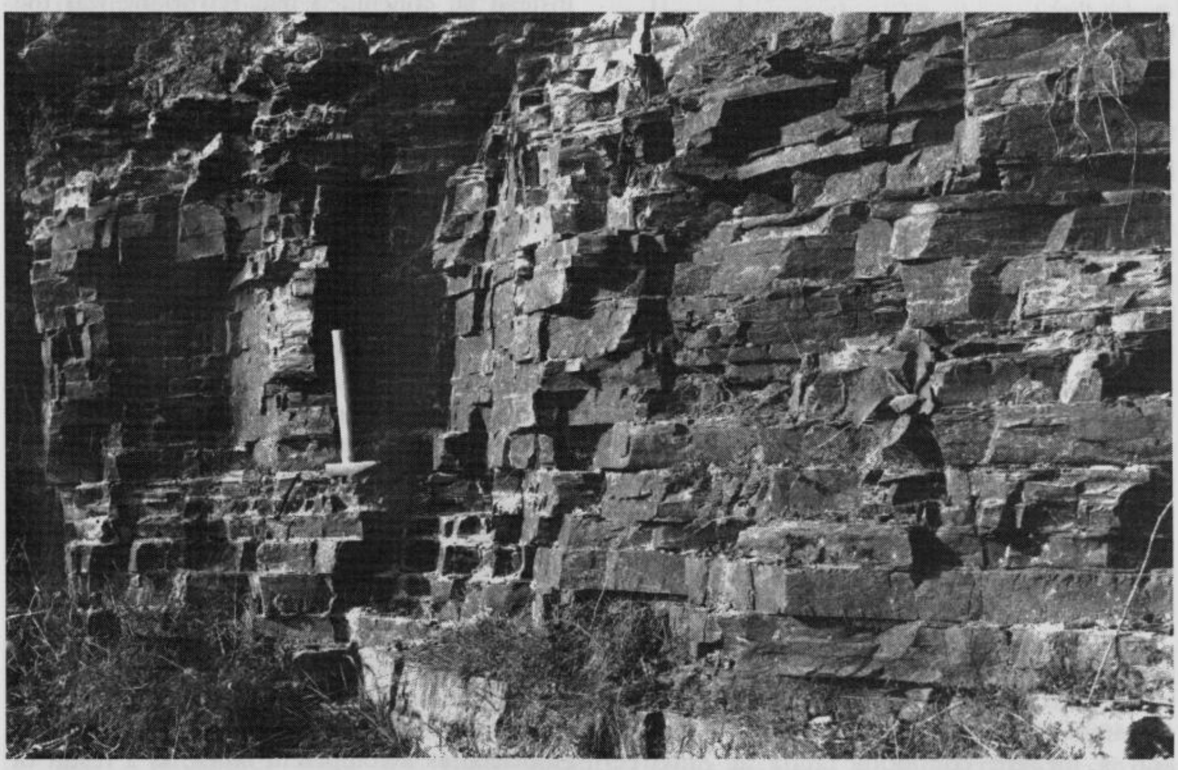

Figure 10.13 Thinly bedded Viséan cherts with fine shale partings, Viverdon Down Quarry, east Cornwall. (Photo: J. Jones.)

gonioclymeniae, *Pa. gracilis gracilis*, *Pa. perlobata schindewolfi*, *Pa. rugosa trachytera*, *Polygnathus communis*, *Pseudopolygnathus triangulus pinnatus*, *Ps. tr. triangulus*, *Scaliognathus anchoralis* and *Siphonodella obsoleta*.

This assemblage is closely comparable with the *anchoralis*-Zone faunas described by Voges (1959) from the German Sauerland. It includes several species that are regarded as indices of that zone and provides a late Courceyan–Chadian age for the middle part of the chert unit (Figure 10.3). The assemblage also includes older (Upper Devonian) palmatolepid forms.

Part of the second sedimentary block is exposed at the eastern end of the quarry where a thin sliver (0.75 m) of pink and buff shale is juxtaposed above the highest chert bed, some 3 m above the conodont-bearing horizon. This distinctive lithology has been recorded in temporary excavations for several hundred metres away from the quarry (Whiteley, 1981) and is mappable locally as the Bealbury Formation (Figure 10.2). It contains a diverse fauna of entomozoid ostracodes, conodonts, trilobites and ammonoids that clearly indicate an Upper Devonian (late Famennian) age.

Interpretation

Reid *et al.* (1911) mapped the Viverdon Down area before concluding that low-angle faulting probably contributed to the observed structural complexity. This theme was developed by Matthews (1966b), who noted that much of the Carboniferous succession was inverted and associated with detached *klippen* of chert. On the basis of more extensive mapping it now appears that the entire Crocadon Formation represents a sand-rich, shallow-water facies that has been thrust northwards into its present position (Whiteley, 1983, 1984). The isolated blocks of chert (unnamed) and shale (Bealbury Formation) may be interpreted as sedimentary olistoliths that were incorporated into the Crocadon Formation by gravitational sliding at the time of deposition (Selwood *et al.*, 1998).

Within a few kilometres of Viverdon Down Quarry, other chert blocks have been recognized at Amytree (SX 362 667) and Smeaton (SX 400 673). Their lithologies are very similar and a meagre conodont fauna at Amytree confirms their age-equivalence. As the cherts were deposited at about Tournaisian–Viséan boundary times and they show no evidence of soft-sediment deformation, they must have been lithified and emplaced within the Crocadon Formation during late Viséan times. One possible scenario is that syn-orogenic Crocadon sandstones prograded into the precursor basin, incorporating lithified blocks of chert and shale derived from active submarine fault-scarps (Selwood *et al.*, 1998). Another explanation is that the interleaving of these varied lithologies is the result of local thrusting within the St Mellion Klippe.

Apart from providing information about the age of the cherts, the Viverdon Down conodont fauna contributes to the debate about how characteristically Upper Devonian palmatolepids co-exist with indigenous Lower Carboniferous forms. Matthews (1969) was concerned to address this situation having observed that it was also a feature of several *anchoralis*-Zone assemblages in Germany (Voges, 1959; Krebs, 1963, 1964). Matthews considered, and then dismissed, the possibilities of either extending the ranges of palmatolepids into the Carboniferous Period or accepting that the younger occurrences were regenerated homeomorphs. Instead he concluded that reworking was the most likely explanation for the mixed faunas, although he could find no supporting evidence within the uniformly fine-grained cherts themselves. The implications are that very subtle physical processes operating in starved sequences may rework conodonts and no major uplift or emergence within the basin need be invoked.

Conclusions

This site is valuable in many respects. The cherts yield a rich conodont fauna that facilitates comparison between similar sequences in the Crocadon Formation and elsewhere in the Culm Trough. Many of the same conodont species also occur in the Lower Carboniferous successions of Germany, confirming the widespread nature of the distinctive chert facies. Despite the fact that the cherts appear undisturbed at Viverdon Down Quarry, their abrupt juxtaposition with the shallow-water sandstones of the Crocadon Formation indicates that they were emplaced as a competent block, as a result of either gravity sliding or thrusting.

SPARA BRIDGE, DEVON (SX 843 841–SX 841 849)

Introduction

The Spara Bridge GCR site is a road cutting developed along the minor road (B3193) that runs through the Teign Valley near Chudleigh, south Devon. It extends for nearly one kilometre northwards from Spara Bridge (SX 843 841) and provides intermittent exposure through the thickest and most complete Lower Carboniferous succession in the Culm Trough. The succession is entirely marine and represents some 30 million years of depositional history from the latest Devonian to early Namurian times. It has benefited from a long history of research, beginning in the mid-18th century with the pioneer work of Godwin-Austen (1842). A more detailed account emerged following the regional mapping by the [British] Geological Survey (Ussher, 1913) and this spawned several research papers during the course of the following 50 years. These are summarized in the most recent [British] Geological Survey memoir (Selwood *et al.*, 1984) that accompanies the current map of the Newton Abbot district (Institute of Geological Sciences, 1976c).

Description

The structure of the Teign Valley is dominated by an anticlinorium that plunges eastwards away from the Dartmoor granite and preserves conformable Lower Carboniferous sequences in several folds. This site provides a section through the southern limb of the Ashton Anticline from the road cutting at SX 841 849 to Spara Bridge. The beds dip steeply (40°–60°) south and the succession youngs in that direction. Beyond the southern end of the site, part of the same succession is re-introduced by a SW–NE-trending fault 500 m south of Lower Ashton village (Figure 10.14).

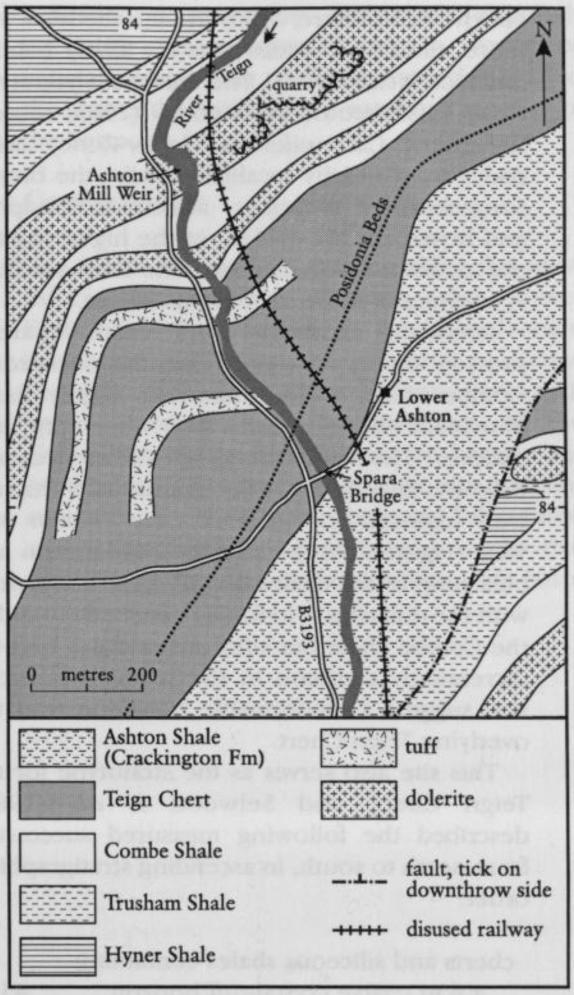

Figure 10.14 Geological map of part of the Teign Valley showing the location of the Spara Bridge GCR site, south Devon. The site runs along the roadside close to the River Teign, west of Lower Ashton. Note that minor roads and alluvium have been omitted for clarity. After the geological map of the Newton Abbot district (Institute of Geological Sciences, 1976c).

The oldest rocks are exposed in the road cutting north of Ashton Mill Weir and are ascribed to the Hyner Shale. They consist of grey-green and blue-green silty shales with tough calcareous siltstone bands. *Sanguinolites ellipticus* is abundant and a horizon bearing *Phacops granulatus* indicates a Late Devonian age. Miospores from the same locality (Whiteley, 1983; Dean, 1992) suggest an age that approximates to the Devonian–Carboniferous boundary whereas the lowermost Carboniferous index ostracode *Richterina latior* has been identified at a slightly higher stratigraphical level (Gooday, 1983). Thus the Devonian–Carboniferous boundary occurs in the upper part of the Hyner Shale.

A conformable passage into the overlying Trusham Shale is marked by increasingly micaceous and calcareous shales. This unit is about 60 m thick and is characterized by olive-green and pale-grey shales with a well-developed conchoidal fracture. They are interbedded with more micaceous shales that are finely banded and locally calcareous. The Trusham Shale is not richly fossiliferous, but Gooday (1983) records lowermost Carboniferous (*latior*-Zone) ostracodes from nearby localities, whilst the bivalve *Sanguinolites*? *ellipticus*, athyrid brachiopods and bryozoans are evident in the higher part of the succession. On this basis, the Trusham Shale is considered to be of Tournaisian age.

Roadside exposures and small quarries provide the type section for the succeeding Combe Shale, which comprises highly fissile blue-black or black shales with white silty laminations. The shales are about 150 m thick and they are intruded by two dolerite sills that are well exposed in quarries near Ashton Mill Weir (Figure 10.14). Localized induration and bleaching of the shales is evident at the contact with the dolerites. No fossils have been found in the Combe Shale but siliceous nodules become increasingly common in the younger horizons and suggest a conformable transition into the overlying Teign Chert.

This site also serves as the stratotype for the Teign Chert, and Selwood *et al.* (1984) described the following measured succession from north to south, in ascending stratigraphical order:

cherts and siliceous shales containing a 6 m coarse crystal-tuff horizon	45 m
cherts and shales with thin bands of jasper and mineralized (manganese) veins	27 m
radiolarian cherts and siliceous shale with thin tuff bands towards the top	109 m
gap in exposure	40 m
interbedded tuffs, shales and cherts, locally folded and sheared	42 m
well-bedded cherts and siliceous mudstones	55 m
pale-grey calcareous cherts and mudstones with radiolarians	13 m
black shale and grey limestone (Posidonia Beds)	4 m

The numerous volcanic tuff bands contribute to this unusually thick succession, but apart from poorly preserved radiolarians (Hinde and Fox, 1895; Ussher, 1913), no fossils have been found below the level of the Posidonia Beds. Other localities in the immediate vicinity show that the Posidonia Beds are typically 30–45 m thick and contain both large and small forms of *P. becheri* and the ammonoids *Neoglyphyioceras spirale* and *Sudeticeras* aff. *ordinatum*.

South of Spara Bridge (Figure 10.14), the beds are assigned to the Crackington Formation, the lower part of which is predominantly fine-grained and known locally as the 'Ashton Shale'. It consists of micaceous shales with some siltstone and sandstone horizons that rarely exceed 25 mm in thickness. The shales are pale grey-blue when fresh, weakly cleaved and contain thin carbonaceous bands yielding *Cravenoceratoides* of Arnsbergian (E_{2b} Zone) age. Some 150 m thick, they pass upward into laterally continuous sandstone beds that possess all the characteristics of distal turbidites.

Interpretation

The Spara Bridge succession in the Teign Valley is probably the thickest (*c.* 450 m) and certainly the most complete Lower Carboniferous succession in the Culm Trough. Although the exposure is not continuous, it does appear that the succession is conformable and wholly marine in origin. It is characterized by shales and cherts and in this respect resembles the stratigraphy in the northern outcrops around Barnstaple (Figure 10.2). There is, however, a major difference in that the Teign Valley succession has an abundance of penecontemporaneous igneous rocks, mainly tuffs, agglomerates and dolerites, which are virtually absent farther north. These provide evidence for submarine volcanic eruptions that formed vesicular lavas and produced sufficient airborne pyroclastic material to create thick, graded tuffs. At the same time, alkali dolerite sills were probably intruded into the sediments at no great depth because vesicles are widespread in both the sills and host rock. The similarity in chemistry, age and provenance of the igneous rocks suggests that the Teign Valley succession formed in an area of crustal instability, perhaps dictated by pre-existing fractures or by propagating Hercynian thrusts (Figure 10.4).

The palaeontology of the Teign Valley strata is also interesting. Faunas in the Upper Devonian (lower part of the Hyner Shale) strata are dominated by a variety of benthos, notably trilobites and brachiopods, but some pelagic elements are evident. A comparatively shallow-water setting, free from strong current activity, is envisaged, with uninterrupted access to deeper water allowing pelagic forms to drift into the area. The overlying Dinantian rocks become increasingly fine-grained and siliceous, with a rapidly diminishing benthos suggesting euxinic conditions. Increased levels of ventilation in the water column during late Asbian and Brigantian times are indicated by the sudden appearance of abundant pelagic forms in the Posidonia Beds and the associated development of calcareous lithologies (Thomas, 1982). The succession as a whole is interpreted as the product of an extended transgressive phase of Dinantian sedimentation, with the cherts representing a condensed sequence in a very widespread, starved sedimentary basin.

The structural setting of the Teign Valley succession is considered to be largely *in situ* or autochthonous (Selwood *et al.*, 1984). It thus provides evidence that the Culm Trough extended at least this far south, although overlying thrust sheets contain rocks of equivalent age that probably formed closer to the currently unidentified southern margin of the basin.

Conclusions

The Spara Bridge GCR site provides the most informative section through the Lower Carboniferous successions in the Culm Trough. Palaeontological data are sufficient to define the Devonian–Carboniferous boundary with some accuracy, and the presence of the *Cravenoceratoides* indicates an Arnsbergian age for the top of the succession. The site contains stratotypes for the Combe Shale and Teign Chert successions and abundant igneous rocks that contribute to an understanding of basin evolution.