British Silurian Stratigraphy

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Chapter 6

The Přídolí Series

P. D. Lane

INTRODUCTION

The Přídolí, the fourth, the uppermost, and the series most recently added to the Silurian System, derives its name from the district of that name, near Velká Chuchle, in the Barrandian area of the Prague Basin. The name, definition, and correlation of this series have provoked more discussion, disagreement, and the smallest majorities in the decisive voting of the members of the Subcommission on Silurian Stratigraphy of the International Commission on Stratigraphy than any of the others. The history of the final acceptance of the name, and all other related decisions by the Silurian Subcommission were related by Holland (1989). With a duration of perhaps only two million years (Harland *et al.*, 1990), it is also the shortest of the Silurian series.

In Bohemia, the name Přídolí as a designator of a stratigraphical unit was formerly and originally given to a lithostratigraphical unit – the Přídolí Formation. Upon acceptance of the name as that of the fourth series of the Silurian, the lithostratigraphical unit was renamed the Požáry Formation (Kříž *et al.*, 1983).

The boundary stratotype for the base of the series is defined in the fully marine graptolitic sequence of the Požáry section, near Reporyje (Kříž *et al.*, 1983), where its base is coincident with the base of the *Monograptus parultimus* Biozone. It is the only Silurian series in which stages have not been established.

OCCURRENCE

In Britain, rocks of undoubted Přídolí age are confined to England and Wales (Figures 6.1, 6.2). The main areas of outcrop are Pembrokeshire, central Wales (Clun Forest, Builth and the Llandovery area), the Welsh Borderland (Shropshire), south Staffordshire, and the Lake District. In these areas, the Přídolí Series is represented by rocks formerly designated as the 'Downtonian', 'Raglan Group' or 'Red Marls' and in the Lake District of north-west England (the Windermere area) as the 'Scout Hill Flags' (Cocks *et al.*, 1971; 1992). The relationship of the Přídolí to older rocks has been shown to have a systematic variation over the main outcrop in England and Wales (Bassett *et al.*, 1982). In Shropshire and the Welsh Borderland there is a conformable sequence from the Ludlow, with a bone bed present; in central Wales, the sequence is conformable but lacks a bone bed, and in southern and western Wales there is an unconformity beneath the Přídolí (Figure 6.2).

In Scotland there is no proved Ludlow to Přídolí transitional sequence. However a sequence of red and purple sandstones and conglomerates interbedded with tuffs immediately south of the Highland Boundary Fault at Stonehaven was considered to be of Přídolí age based on fish and arthropod faunas (Westoll, 1951). More recent work on the palynomorphs (Marshall, 1991; Wellman, 1993), suggests that at least part of this sequence is older (late Wenlock or early Ludlow). Also in Scotland, a red sequence in Ayrshire (the Portencross Inlier; Patterson, 1949) yielded a spore assemblage 'of Downtonian–Dittonian type' (Downie and Lister, 1969); a more precise stratigraphical age has not been determined.

Přídolí rocks with marine faunas occur beneath Mesozoic cover at depth in a series of boreholes in east England (e.g. the Little Missenden borehole) indicating a widespread extension of sedimentation into this area (Butler, 1981). There is no proved Silurian beneath the undoubted Devonian sequences of south-west England (Matthews in House *et al.*, 1977b).

PALAEOENVIRONMENTAL SETTING

The Přídolí was a time of change in the palaeogeographical and tectonic setting of Britain. The last stages of the Caledonian Orogeny saw the final hard docking of Avalonia and Laurentia with the consequent demise of the Iapetus Ocean. Thus the assembly of the Old Red Sandstone continent, on the south margin of which Britain was placed, saw the change in time from marine conditions to a locally highly variable suite of largely continental environments. These fluviatile and lacustrine dominated sediments were variously sourced and deposited in separate basins, correlation between which is difficult on account not only of their geographical isolation but also the lack of biostratigraphically useful suitable floras and faunas. Undoubtedly during Přídolí times the land was being extensively colonized by the earliest land animals (Jeram *et al.*, 1990; Dunlop, 1996), and vascular plants (e.g. Richardson and Edwards, 1989).

Minor marine incursions from the Rheic

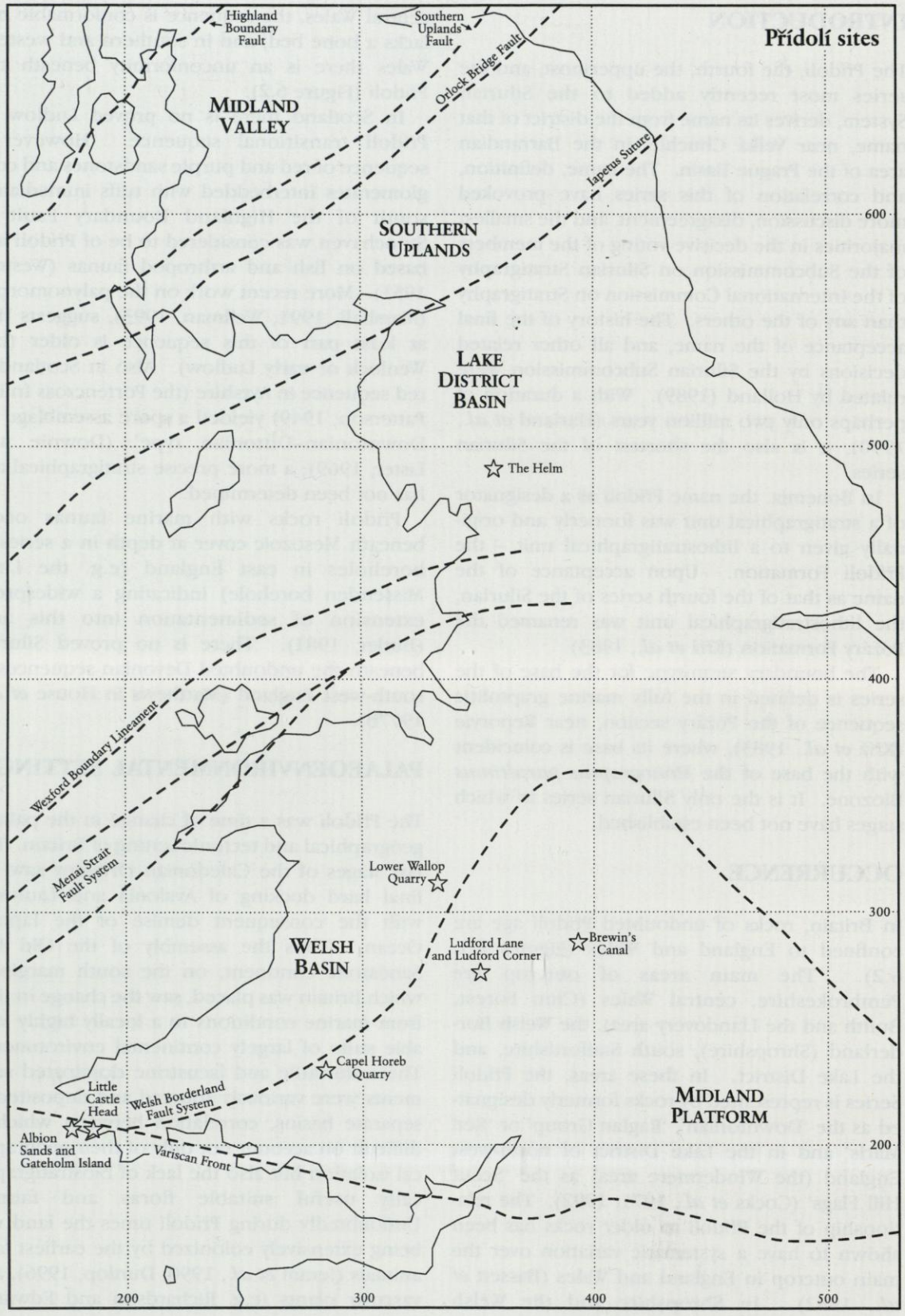

Figure 6.1 Distribution of the Geological Conservation Review sites for the Přídolí Series, set against the palaeogeographical elements of Silurian Britain.

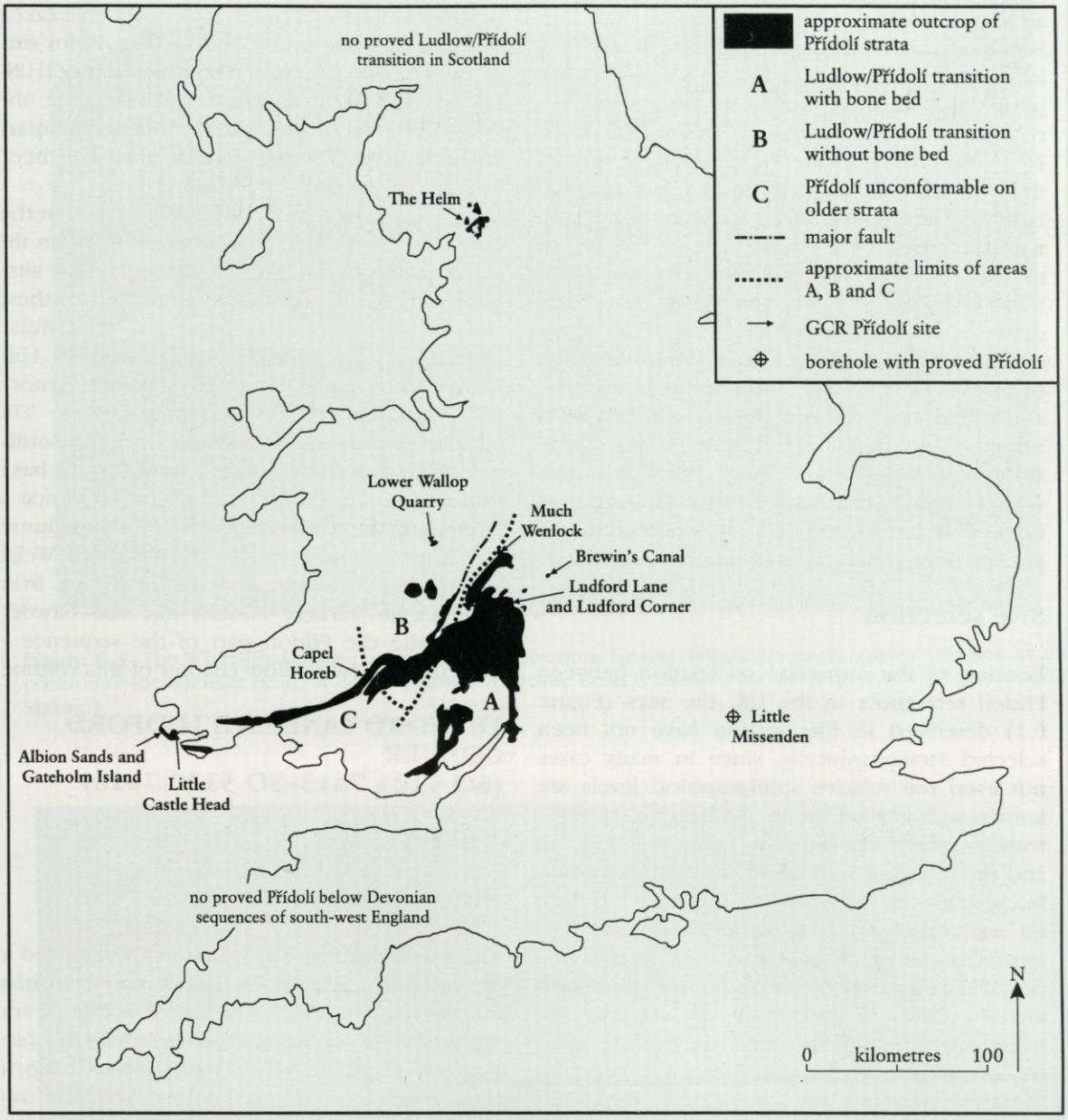

Figure 6.2 Approximate outcrop of Přídolí strata in England and Wales, with relationship to older strata (delimited as in Bassett *et al.*, 1982).

Ocean, which was situated to the south and south-east, can be recognized in the sequences of the Welsh Borderland, but these were rare. Intriguingly, those Přídolí sections that occur farthest to the south-west in Wales, and thus theoretically nearest to oceanic conditions, exhibit no marine influence at all, even though these Silurian–Devonian sequences were transported from even farther south on thrusts during the Variscan Orogeny. At the base of the Přídolí in the Welsh Borderland, however, strong marine influences are indicated by the occurrence of ostracods, trilobites, and brachiopods for instance. Volcanic intercalations usually of ash-fall type are seen in many, but not all, Přídolí sequences, though their source is moot.

BIOSTRATIGRAPHY

Because the Přídolí of the UK is developed

almost entirely in the continental Old Red Sandstone facies, direct biostratigraphical correlation with the type area has so far proved not possible. A 'web of correlation', however, allows recognition of the equivalence of the base of the Downton Group of the Welsh Borderland (i.e. the base of the Ludlow Bone Bed Member; see Ludford Lane and Ludford Corner site report) with the base of the Přídolí Series. The top of the Přídolí is automatically defined by the base of the Devonian System, which has also been defined in the graptolitic sequence of Bohemia, at the base of the *Monograptus ultimus* Biozone (Chlupáč, 1972). Correlation of this horizon to, and within, the UK is not possible with any biostratigraphical precision, but by consensus a level at the base of the Ditton Group, which coincides with the base of the 'Psammosteus' Limestone as defined by Greig *et al.* (1968) is accepted as a general approximation in practice.

Site selection

Because of the imprecise correlation between Přídolí sequences in the UK, the sites (Figure 6.1) described in this section have not been selected stratigraphically, since in many cases not even the relative stratigraphical levels are known with any precision. Rather the selection tries to reflect not only the variable sequences and the differing settings in which they formed but also a wide geographical coverage and their different relationships to underlying strata. The imprecise dating of these rocks means that it is possible that parts of the sequences described are not wholly of Přídolí age, but the best and most recent geological data have been used to try to minimize the imprecision of correlation. Thus, for example, the Little Castle Head, and the Albion Sands and Gateholm Island sites are from a palaeogeographical position closest to the presumed position of the developing Rheic Ocean; they occur in faulted blocks (Sanzen-Baker, 1972; Powell, 1989), which were displaced an unknown, but probably considerable distance from the south, in the Variscan orogeny. The Capel Horeb site is one that illustrates the sub-Přídolí unconformity seen in the general surrounding area of mid-Wales. Lower Wallop, Ludford Lane and Ludford Corner, and Brewin's Canal sites are all sequences in the Welsh Basin and its shelf showing significant marine influences; in each there is a continuous sequence from Ludlow strata below and a thin Bone Bed is present (Figure 6.2), the base of which is taken to mark the base of the Přídolí. The Helm site, along with two sites in the Ludlow chapter (Hills Quarry and Benson Knott), demonstrate the final silting up of the Lake District sedimentary basin of north England, which itself had been initiated in the early Ordovician.

Additional to those GCR sites described in this chapter, Přídolí strata are also present within the geographical boundaries of certain Ludlow sites described in the Ludlow chapter above; these sites – all of which occur in the Welsh Borderland, are Brook House, Longhope Hill, Perton Road and Quarry, Tites Point, Turner's Hill, Wood Green, and Woodbury Quarry. The Silurian section in the Sawdde Gorge in southern Wales has strata of late Llandovery to basal Přídolí age; the Přídolí part of the sequence is treated in the Ludlow chapter of this volume. The Linton Quarry site in the southern Welsh Borderland has strata that range in age from Wenlock to earliest Přídolí; like the Sawdde Gorge site the Přídolí part of the sequence is described in the Ludlow chapter of this volume.

LUDFORD LANE AND LUDFORD CORNER (SO 5124 7413–SO 5120 7410)

David J. Siveter

Introduction

This classic locality was traditionally regarded as the reference section for the Silurian–Devonian boundary in Britain. Currently it is one of several key sites that define the Ludlow Series (see Holland *et al.*, 1963) and Downton Group in their type area of the Ludlow Anticline and Downton Syncline. The site contains internationally important faunas and floras.

The outcrop occurs for more than 100 m along Whitcliffe Road ('Ludford Lane') and continues to the junction with the A49 Leominster road ('Ludford Corner'), just south of Ludford Bridge at Ludlow, Shropshire (Figures 5.6, 5.15). Its geology and palaeontology have been been extensively documented for more than 150 years in books and papers (e.g. Murchison, 1839; Harley, 1861; Elles and Slater, 1906; White, 1950; Holland *et al.*, 1963; Allen, 1974; Antia, 1979, 1980; Bassett *et al.*, 1982; White and Lawson, 1989; see especially Miller, 1995 and references therein) and field guides (Lawson,

Figure 6.3 The Whitcliffe Group (Ludlow Series)–Downton Group (Přídolí Series) boundary (marked by the position of the hammer head) at Ludford Lane ('Whitcliffe Road'), Ludlow; see also Figure 6.5. (Photo: David J. Siveter.)

Figure 6.4 Hummocky cross-stratification sequences in the Sandstone Member, Downton Castle Sandstone Formation, along the A49 road at Ludford Corner, Ludlow, Shropshire. (Photo: David J. Siveter.)

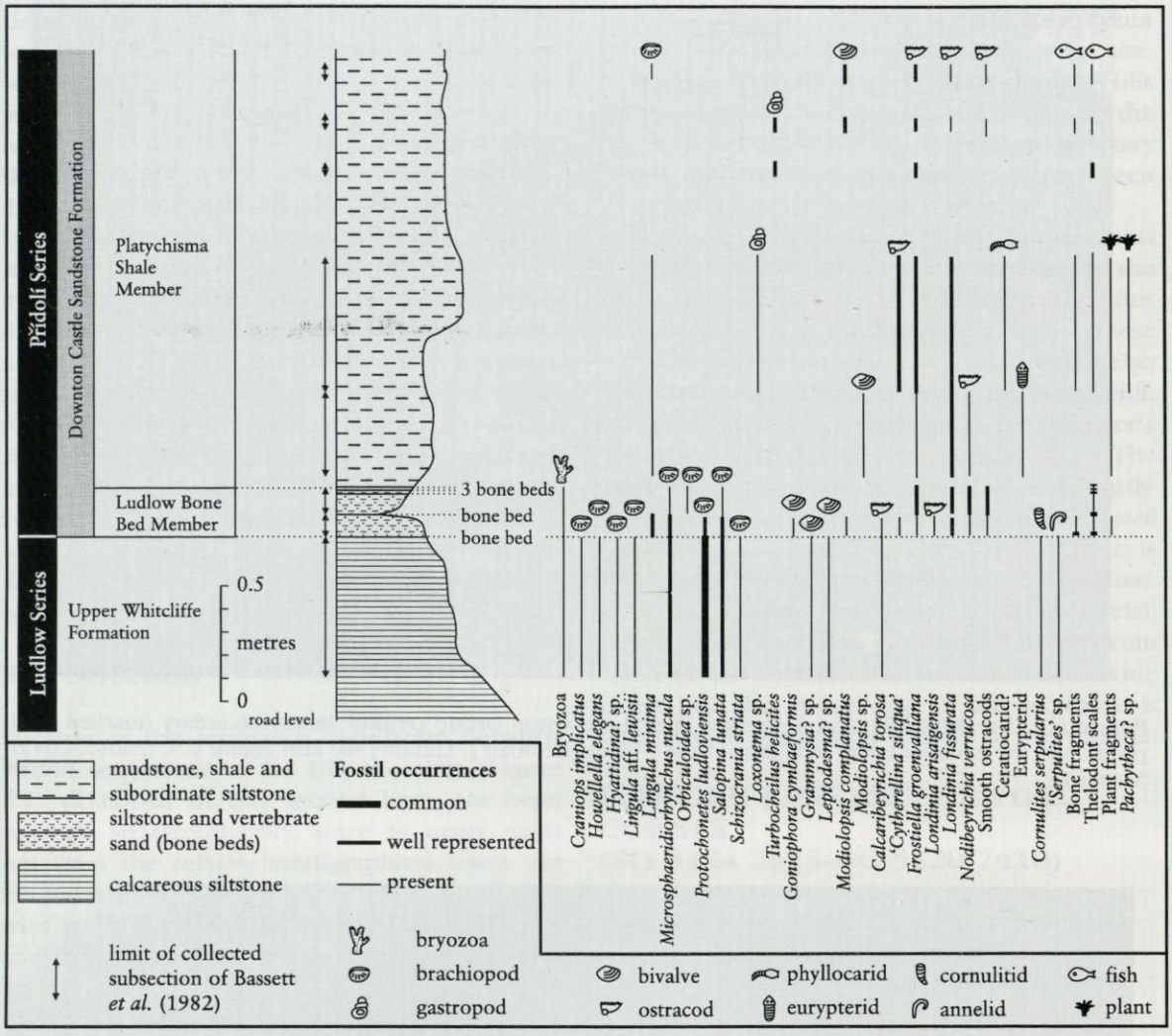

Figure 6.5 Lithological and faunal succession across the Whitcliffe Group (Ludlow Series)/Downton Group (Přídolí Series) boundary at Ludford Lane (see Figure 6.3), Ludlow, Shropshire (after Bassett *et al.*, 1982; modified from Siveter *et al.*, 1989).

1977b, locality 13; Siveter *et al.*, 1989, locality 3.2; Jenkinson, 1991, locality 13). The historical background of the study of the site and its pivotal role in the complex development of the concept and age determination of the Downton Group are detailed especially in White (1950) and Bassett *et al.* (1982).

Both the Ludford Lane and Ludford Corner exposures show the uppermost parts of Upper Whitcliffe Formation of the Ludlow Series overlain by the lowermost part of the Downton Castle Sandstone Formation of the Přídolí Series (Figures 6.3–6.5). In the work to provide an internationally agreed chronostratigraphy for the Silurian, and following the notions of White (1950) and Holland *et al.* (1963) regarding the base of the Downtonian sequence of rocks, this site was promoted as a possible basal boundary stratotype for the fourth and youngest series (to be termed the Downton) of the Silurian (Bassett *et al.*, 1982). In the event, a stratotype candidate from the Czech Republic was preferred, hence the name Přídolí Series. The Ludford Lane and Ludford Corner site displays a body stratotype for the Upper Whitcliffe Formation, the type sections for the Ludlow Bone Bed and Platyschisma Shale members of the Downton Castle Sandstone Formation and a reference section for the Sandstone Member of the Downton Castle Sandstone Formation (Bassett *et al.*, 1982; Lawson and White, 1989; White and Lawson, 1989).

Description

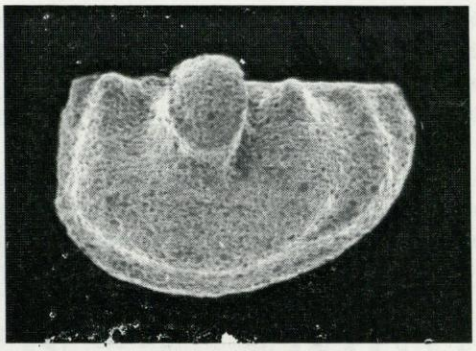

Figure 6.6 Cast of external mould of the ostracod *Frostiella groenvalliana* Martinsson, 1963 (tecnomorphic left valve, × 24) from the Platyschisma Shale Member, Downton Castle Sandstone Formation, Přídolí Series; about 1.5 m above Ludlow Bone Bed Member, north side of Ludford Lane, Ludlow, Shropshire. (Photo: David J. Siveter.)

The Ludlow Bone Bed Member, discovered in 1835 by Dr J. Lloyd and the Reverend T.T. Lewis (Murchison 1839, p. 197), occupies a distinct cleft along the section in Ludford Lane and at Ludford Corner. It consists of some 0.2 m of lenticular and ripple-laminated siltstones containing several thin layers of discontinuous vertebrate-rich sands, the basal one of which is *the* Ludlow Bone Bed *sensu stricto* (Figures 6.3, 6.5). The bone comprises mostly fish remains, such as acanthodian scales and agnathan denticles (e.g. Agassiz, 1939; Harley, 1861; White, 1950; Turner, 1973; see also Dineley and Metcalf, 1999). Murchison (1839, p. 198) noted that '... so brilliantly black are many of the organic [fish] fragments, that when discovered, this bed conveyed the impression that it inclosed [*sic*] a triturated heap of black beatles cemented in a rusty ferruginous paste'.

The succeeding Platyschisma Shale Member (up to 2 m thick) comprises parallel- and cross-laminated and unlaminated mudstones and shales with subordinate siltstones. The overlying Sandstone Member, consisting mostly of sandstones and siltstones alternating with thin mudstones, is best seen high in the outcrop along the A49 at Ludford Corner (Figure 6.4) and is also present at the top of the section in Ludford Lane itself.

The olive calcareous siltstones of the Upper Whitcliffe Formation (>0.5 m seen) have a fully marine fauna that includes articulate and inarticulate brachiopods, bivalves, bryozoans and also the ostracod *Calcaribeyrichia torosa*. Some of these faunal elements also occur in the overlying Ludlow Bone Bed Member but in general the Downton Castle Sandstone Formation is characterized by a reduced diversity assemblage of different aspect (Figure 6.5). At the base of the Downton Castle Sandstone Formation several brachiopods disappear and *Modiolopsis* bivalves, the inarticulate brachiopod *Lingula minima* and the biostratigraphically important ostracods *Frostiella groenvalliana, Londinia arisaigensis* and *Nodibeyrichia verrucosa* enter the sequence (Figures 6.5–6.7). Associates in that formation include remains of a diverse fish fauna of about 14 species (mostly from the lower two members), gastropods such as *Turbocheilus helicites* and *Loxonema* sp., many eurypterid species (e.g. *Hughmilleria acuminata*; see Kjellesvig-Waering, 1961, Manning, 1993), arthropleurid arthropod remains (Shear and Selden, 1995) and fragments of early land plants such as *Cooksonia* (e.g. see Lang, 1937; Bassett *et al.*, 1982, p. 14; Jeram *et al.*, 1990; Edwards *et al.*, 1996). The Ludlow Bone Member at Ludford Corner has yielded trigonotarbid arachnid and centipede cuticles (Figure 6.8), the earliest direct evidence globally of terrestrial animals (Jeram *et al.*, 1990; Dunlop, 1996, 1999).

Conodonts are rare, but include *Ozarkodina* cf. *crispa* from just below the top of the Whitcliffe Formation and *Ozarkodina confluens, Ozarkodina excavata, Coryssognathus dubuis* and *Ozarkodina remscheidensis eosteinhornesis* in the Ludlow Bone Bed Member (Aldridge and Smith, 1985; Miller and Aldridge, 1993, 1997; Miller, 1995). In the basal few metres of the Downton Castle Sandstone Formation land-derived spores substantially increase in numbers and marine phytoplankton, principally acritarchs, show a corresponding decrease (Richardson and Lister, 1969; Richardson and Rasul, 1990).

Based on a complex web of correlation, mainly involving microfossils such as conodonts and especially ostracods, the base of the Downton Castle Sandstone can be correlated across to North America and, via fully marine Baltic sequences, to the base of the type Přídolí Series in the Czech Republic (Martinsson 1963, 1967; Shaw, 1969; Siveter, 1978, 1989; Bassett *et al.*, 1982, 1989; Hansch *et al.*, 1991; Hansch and Siveter, 1994; Miller, 1995; see Figure 6.7). No

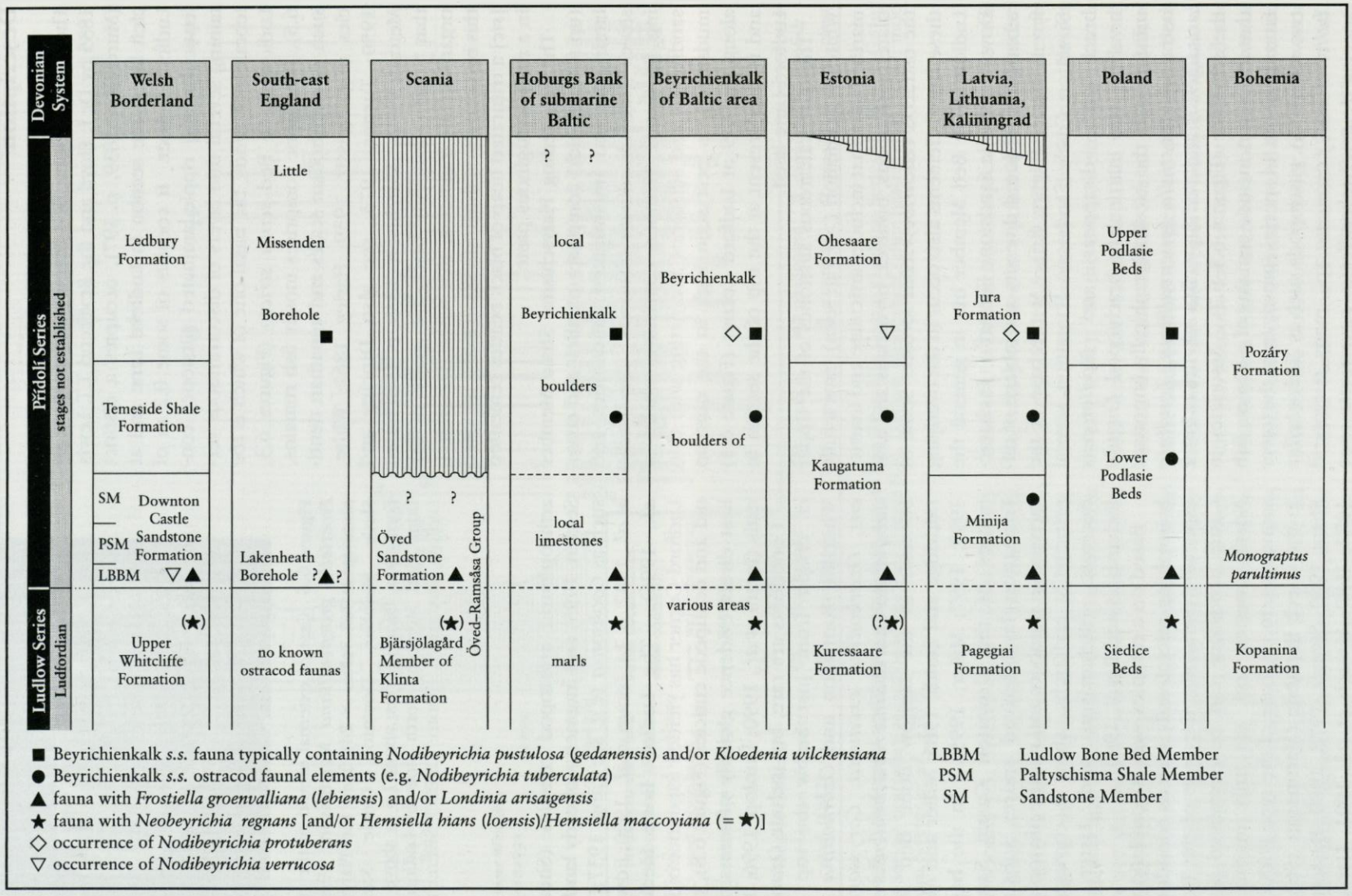

Figure 6.7 Correlation of latest Ludlow–Přídolí ostracod faunas of Britain, Baltoscandia and the Czech Republic (after Hansch and Siveter, 1994, fig. 1; see also Bassett *et al.*, 1982, fig. 7; Siveter 1989, fig. 164, and Miller, 1995, fig. 14). Symbols denote the presence (mostly only the *earliest* occurrence) of a fauna within a stratigraphical unit, not their exact positions. Vertical columns not to scale.

measurable amount of time is missing within the basal part of the Downton Group in its main outcrop in the Welsh Basin. However, some microfossil evidence suggests that the top of the Ludlow Series may not be represented in the shelf area in the Welsh Borderland (Miller *et al.*, 1997; Viira and Aldridge, 1998).

Interpretation

This overall regressive sequence formed on the Midland Platform of the remnant Welsh Basin (Siveter *et al.*, 1989, fig. 11; Bassett *et al.*, 1992, figs S5b, S8b). The sediments indicate a fairly quick but fluctuating change from a relatively shallow, mainly clear but sometimes turbid proximal shelf environment (conquinoid siltstones of the Whitcliffe Group) to near-shore, perhaps coastal plain conditions (Sandstone Member, Downton Castle Sandstone Formation) (see Watkins, 1979; Allen and Tarlo, 1963; Allen, 1974, 1985; Bassett *et al.*, 1982; Miller, 1995).

The notable faunal and sedimentological change at the base of the Ludlow Bone Bed Member is ascribed by most authors to a sudden regression and transgression (see Miller, 1995) and the sediments themselves may reflect shallow subtidal to low intertidal conditions, recurrent storm reworking and the accumulation of vertebrate-rich lags (Smith and Ainsworth, 1989). Certainly the presence of land animals and plants indicate proximity to shore.

The Platyschisma Shale Member probably represents intertidal environments. The occurrence of complete hummocky cross-stratification sequences in the Sandstone Member at Ludford Corner (Figure 6.4) indicates shallow marine, subtidal to intertidal, storm generated conditions (Siveter *et al.*, 1989; Smith and Ainsworth, 1989). Overall, the sedimentary and restricted faunal characteristics of the Sandstone Member suggest the formation of sand bodies in a marine-influenced environment close to land.

Ludlow–Přídolí boundary sequences are also present, in facies similar to that at Ludford Lane and Ludford Corner, at GCR sites in the English West Midlands (Brewin's Canal and Turner's Hill), the southern Welsh Borderland (Linton Quarry, Gorsley Inlier; Wood Green and Longhope Hill, May Hill Inlier; Woodbury Quarry, Abberley Hills; Perton Road and Quarry, Woolhope Inlier; Tites Point, near Tortworth) and South Wales (Brook House, Usk Inlier). The equivalent sequence at GCR site Lower Wallop Quarry in the Long Mountain area, west Shropshire, reflects a more basin margin setting. The Sawdde Gorge and Capel Horeb sites in southern Wales also have Ludlow–Přídolí sequences but in both cases the Přídolí lies unconformably on late Ludlow strata. The GCR sites at The Helm, Hill's Quarry and Benson Knott collectively embrace the Ludlow–Přídolí transition in the Lake District.

Conclusions

This is a world famous locality of primary importance to the history and definition of Silurian stratigraphy, the evolution of the biosphere and the history of the Lower Palaeozoic Welsh Basin. It displays the basal boundary stratotype for the Downton Group (Přídolí Series) resting on a body stratotype for the Upper Whitcliffe Formation (Ludlow Series). The Downton Group here contains the earliest known land animals in the world, early land plants, unusual arthropods and the famous Ludlow Bone Bed containing fish remains. It is the type locality for many taxa.

The site is studied by researchers and secondary and tertiary level educational parties and should be rigorously protected and maintained. Hammering is normally strictly forbidden, though limited collections for research purposes can be obtained from the Ludford Lane section after obtaining the appropriate permission.

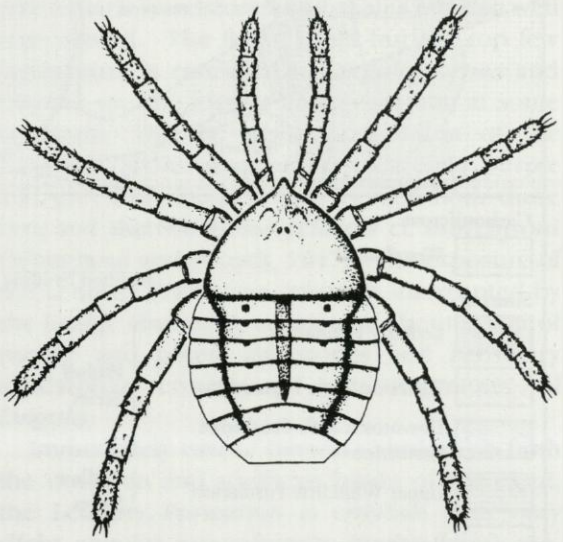

Figure 6.8 Reconstruction of *Palaeotarbus* Dunlop, 1999, a trigonotarbid arachnid, based partly on material from the Downton Castle Sandstone Formation, Ludford Corner, Ludlow, Shropshire. Carapace is *c.* 1 mm long (from Dunlop, 1996).

BREWIN'S CANAL (SO 9365 8765–SO 9355 8737)

David J. Siveter and P. D. Lane

Introduction

This GCR site lies next to Saltwells Local Nature Reserve. Situated adjacent to Lodge Farm Reservoir, about 2.5 km SSW of Dudley in the West Midlands (Figure 6.9), the site consists of several sections: those on both sides of the cutting of the Dudley Canal at Brewin's Bridge (SO 9365 8765), just north of the reservoir; outcrops now mostly overgrown, along strike immediately west of the road on the west flank of the reservoir (SO 9365 8765–SO 9355 8740); and further exposures along strike in a former tramway cutting (SO 9355 8737) at the western extremity of the reservoir. The Silurian rocks are of late Ludlow and Přídolí age (Figure 6.10) – a part of the Silurian sequence that is rarely seen in central England.

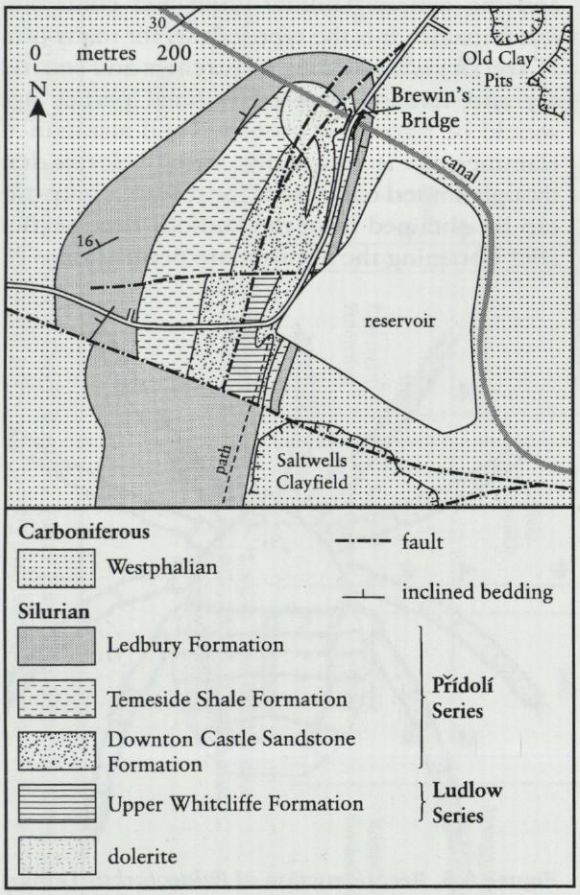

Figure 6.9 Geology of the Netherton Anticline, near Dudley, West Midlands (based on an unpublished 1936 map by H.B. Whittington and after Hardie, 1971).

The sections are on the eastern limb of the Netherton Anticline, a pericline that plunges to the north and south. Ludfordian beds occupy the centre of the fold and Přídolí of Old Red Sandstone facies lies on the outer part of the limbs. The whole structure forms an inlier surrounded by Middle Coal Measure strata, the latter being well exposed at Saltwells (otherwise known as Doultons) Clayfield just south of Lodge Farm Reservoir.

The unpublished map made by H.B. Whittington in 1936 is the most detailed map of the Netherton Anticline (Figure 6.9). The geology of this GCR site was elucidated by King and Lewis (1912) and later by the British Geological Survey (Whitehead and Eastwood, 1927; Whitehead and Pocock, 1947). Ball (1951) correlated the Ludlow to 'Downton' sequence of Turner's Hill and Gornal, some 3 km north-west of Dudley, with that at Brewin's Canal (Saltwells). Conodont, ostracod and thelodont microfossils have also been reported from the Silurian of the Brewin's Canal site (Turner, 1973; Aldridge, 1985; Siveter, 1989; Hansch *et al.*, 1991; Miller, 1995; Miller and Aldridge, 1993, 1997). The site, together with nearby Coal Measure localities at Saltwells, also feature in Geologists' Association (Hardie, 1971) and Black Country Geological Society (Cutler, 1981) excursion guides.

Description

On the east limb of the Netherton Anticline rocks dip generally at about 25° NNE. About 5 m of Ludlow Series rocks, which belong to the upper part of the Upper Whitcliffe Formation, are recorded in a strike section in the old tramway cutting (Whitehead and Pocock, 1947; Figure 6.10), the site of a former mineral railway that connected Saltwells Clayfield with the Dudley Canal at Brewin's Bridge. The rocks consist of grey, sandy, calcareous siltstones with nodular limestone horizons and yield a shelly macrofauna dominated by the brachiopods *Protochonetes ludloviensis* and *Microsphaeridiorhynchus nucula*. Richly abundant conodont faunas have been recovered from limestone nodules (Aldridge, 1985; Miller 1995; Miller and Aldridge, 1993, 1997): *Panderodus serratus*, *Coryssognathus dubius*, *Ozarkodina excavata* and *Ozarkodina confluens* are com-

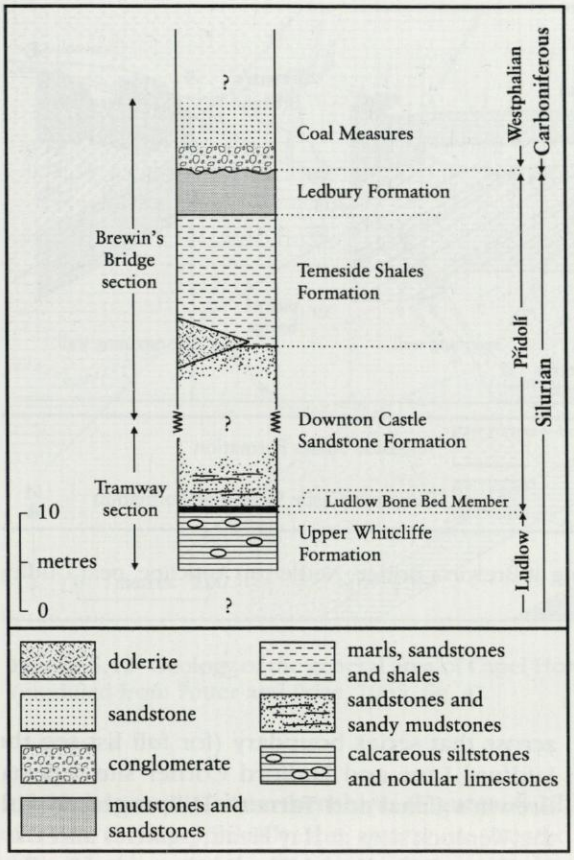

Figure 6.10 Generalized composite section of the Silurian and Carboniferous rocks at Brewin's Bridge and in the tramway cutting (see text for thicknesses), Netherton Anticline, near Dudley, West Midlands.

mon; *Panderodus recurvatus*, *Ozarkodina remscheidensis eosteinhornensis* and *Walliserodus* cf. *santiclairi* also occur.

The basal Přídolí Ludlow Bone Bed Member and the lowest strata of other, overlying, parts of the Downton Castle Sandstone Formation are also present in the tramway section (0.32 m total thickness seen; Miller, 1995), in which the Ludlow–Přídolí contact is displaced by several small dip faults. The Ludlow Bone Bed Member never exceeds 50 mm in thickness and is of typical aspect. It is an accumulation of phosphatic vertebrate remains: dermal plates of the agnathan fish *Thelodus parvidens* and *Loganellia ludlowiensis* are relatively common (Turner, 1973) and there are also fragmentary remains of acanthodian scales, and brachiopods such as *Lingula* and *Orbiculoidea*. The Downton Castle Sandstone Formation in the Trackway has also yielded *C. dubius* and *O. confluens* conodont elements (Miller, 1995) and the only known specimen from central England of the biostratigraphically important (lower Přídolí) ostracod species *Frostiella* cf. *groenvalliana* (Siveter, 1989; Hansch *et al.*, 1991). Neither the Ludlow Series nor basal part of the Downton Castle Sandstone Formation crop out at Brewin's Bridge itself, being cut out by a combination of faulting and a dolerite intrusion (Figure 6.9).

The yellow and buff massive sandstones and sandy mudstones of the Downton Castle Sandstone Formation also occur in the now largely degraded strike section immediately west of the road on the west flank of the reservoir. That stretch of ground, from just north of the tramway section to coeval outcrops on the south side of the canal cutting west of Brewin's Bridge, contains in total a few tens of metres of the formation, from which lingulid brachiopods, bivalves (*Modiolopsis*) and plant (*Pachytheca*) and eurypterid arthropod (*Eurypterus*, *Pterygotus*) fragments have been recovered (Whitehead and Pocock, 1947).

The north bank of the canal cutting at Brewin's Bridge contains the top 10 m of the Downton Castle Sandstone Formation and is there conformably overlain by about 13 m of Temeside Shales Formation and about 4.5 m of Ledbury Formation ('Red Downtonian' of Whitehead and Pocock, 1947) strata (Figure 6.11). The Temeside Shales Formation comprises a multicoloured section of mostly purple and green marls; sandstones and shales are also well represented. The fauna in all but the top few centimetres is restricted to *Lingula cornea* and *Onchus* sp., the former being common at some horizons. In the uppermost 0.4 m of the Temeside Shales Formation micaceous purple and green mudstones have yielded both these taxa and the fish *Hemicyclaspis* cf. *murchisoni* (Whitehead and Pocock, 1947). The exposure of the Ledbury Formation, which is interrupted by the bridge abutment, consists of about 4.5 m of purple and green mudstones and subsidary sandstones containing rare fragments of *Lingula*.

Immediately east of Brewin's Bridge, on both the northern and southern banks of the canal, the Ledbury Formation is overlain with only slight angular unconformity by the basal conglomerate and sandstones of the Westphalian Coal Measures. The small intrusion exposed just west of Brewin's Bridge, on the south side of the canal, is also of possible Carboniferous age.

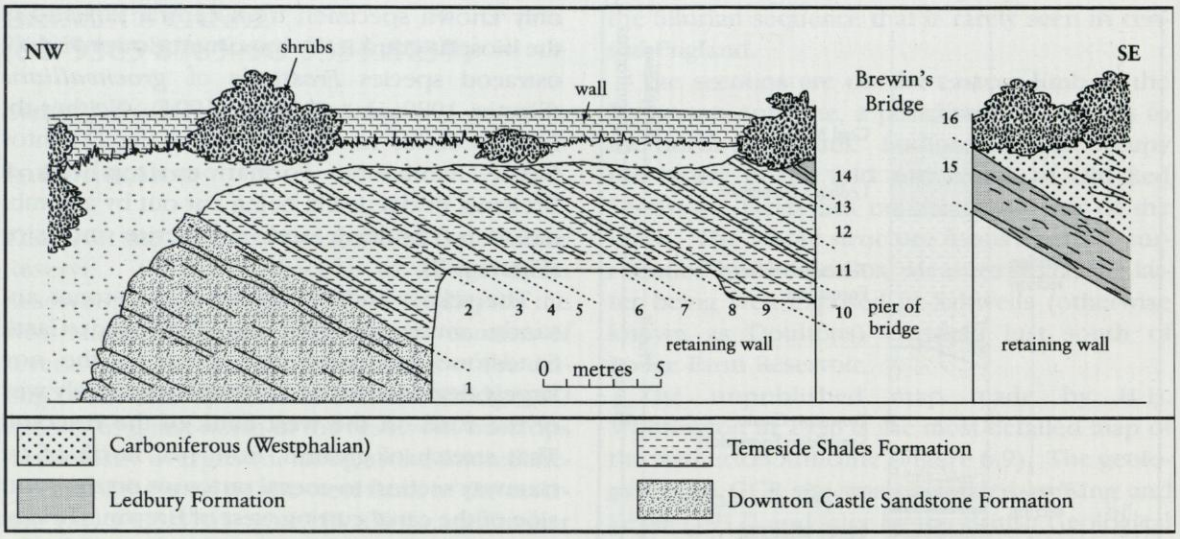

Figure 6.11 Section in the north bank of the canal cutting at Brewin's Bridge, Netherton Anticline, near Dudley, West Midlands (after Whitehead and Pocock, 1947).

The Carboniferous of the Netherton Inlier is best examined in the old workings at Saltwells Clayfield, which has all the rock types typical of the Productive Coal Measures: coal, fireclay, ganister, carbonaceous shale, ironstone and sandstone.

Interpretation

This sequence accumulated on the central part of the Midland Platform, the shelf area that formed the eastern border to the Welsh Basin (Siveter *et al.*, 1989, fig. 11; Bassett *et al.*, 1992, figs S5b, S8b, S9). The late Ludlow to Přídolí sediments, fauna and flora here record the shallow marine to non-marine transition that represented the final demise of this basin (see, for example, Allen and Tarlo, 1963; Allen, 1974, 1985; Bassett *et al.*, 1982; Miller, 1995). Uplift and folding of the Silurian and then deposition and erosion of Devonian sediments preceded burial by late Carboniferous deposits. Post-Carboniferous tectonic activity (Hercynian orogeny) produced further folds and faults in the area.

Netherton is one of several north–south aligned Silurian inliers in the West Midlands. As at Brewin's Canal, the GCR site at Turner's Hill, just north of Dudley, also contains a Ludlow to Přídolí sequence. These are just two of many GCR sites in the Welsh Basin that contain strata across that series boundary (for full list see the Ludford Lane and Ludford Corner site report). Brewin's Canal and Turner's Hill, together with the Wenlock sites at Hay Head Quarries and Daw End near Walsall and Wren's Nest near Dudley, all of which are in central England, provide the network of evidence for the proximal part of the Midland Platform.

Conclusions

This site has stratigraphical, palaeogeographical and palaeoenvironmental significance and, therefore, should be conserved. It is one of only a few localities that display a Ludlow–Přídolí boundary sequence (including the Ludlow Bone Bed Member) within central England. The environments represented are of a proximal setting and record the terminal stages in the depositional history of the Welsh Basin. Brewin's Canal is also noteworthy in exhibiting the nature of the Carboniferous–Silurian contact in the West Midlands.

CAPEL HOREB QUARRY (SN 8445 3234)

Introduction

The Capel Horeb site is a large disused quarry situated on the north side of the A40, 5.5 km ESE

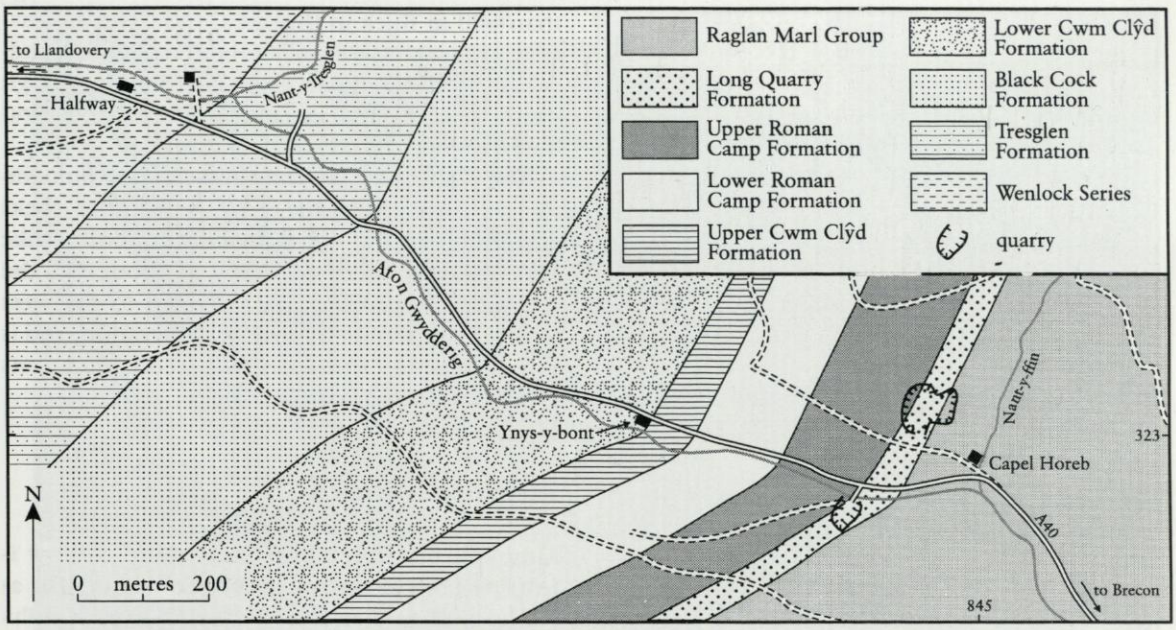

Figure 6.12 Geology of the general area of Capel Horeb Quarry in the Afon Gwydderig Valley, Carmarthenshire (modified from Potter and Price, 1965, fig. 4).

of Llandovery, Carmarthenshire (Figures 6.12, 6.13). Stratigraphically the quarry is situated towards the top of the Silurian in the steeply dipping Ordovician to Devonian homoclinal sequence on the south-east side of the Towy Lineament. Exposed at this classic and famous site are the marine Ludfordian Upper Roman Camp Formation, unconformably above which the Přídolí Long Quarry Formation and Raglan Marl Group are seen (Figures 6.14, 6.15); these beds demonstrate decreasingly marine influence on the sedimentation. The regional overstep of the Přídolí here has cut out beds that are broadly equivalent to the latest Ludfordian (Upper Whitcliffe Formation) of the Welsh Borderland to the north-east.

The quarry was known to Murchison, who produced a description of the geology of both the quarry and the surrounding area, and included the geological detail on sections (Murchison, 1839, pp. 182, 348, pl. 34, figs 1, 3). He listed faunas from both the Ludlow and Přídolí parts of the sequence.

This site also appears in Siveter *et al.* (1989); the geology of the general area is to be found in Potter and Price (1965). The floras of this site have particular importance with regard to the evolution of vascular land plants (Edwards and Davies, 1976; Bassett and Edwards, 1982).

Description

The western face of the quarry (Figures 6.14, 6.15) shows large bedding plane exposures of the Ludfordian Upper Roman Camp Formation, dipping at 60–70° to the ESE. The lithology is predominantly micaceous dark grey siltstones, with interbedded grey laminated mudstones; rippled surfaces are a conspicuous feature. The recorded fauna (Potter and Price, 1965) includes the brachiopods *Microsphaeridiorhynchus nucula*, *Protochonetes ludloviensis*, *Salopina lunata*, *Sphaerirhynchia wilsoni*, *Dayia navicula* and *Chonetoidea grayi*, the bivalves *Pteronitella retroflexa* and *Modiolopsis* sp., pelmatozoan ossicles and gastropods (*Loxonema* and *Platyschisma*). Trilobites (species of *Dalmanites*, *Calymene* and *Encrinurus*) and eurypterid fragments occur in the Upper Roman Camp Formation at other localities in the area. A major interest of this formation is the land flora, which at some horizons comprises common fragmentary, dichotomizing Y-axes of the rhyniophytes *Cooksonia* sp. and *Steganotheca striata* (Edwards, 1970); the flora was derived from the nearby land area (Pretannia of Cope and Bassett, 1987) to the south, as was the micaceous component of the sediment. *Cooksonia* in the Ludfordian Upper Roman Camp Formation at

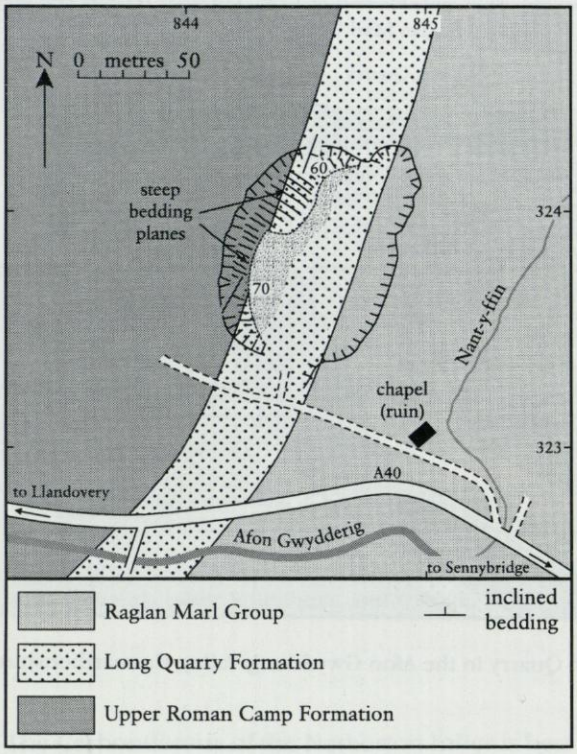

Figure 6.13 The geology of Capel Horeb Quarry, Carmarthenshire (modified from Siveter *et al.*, 1989, fig. 93).

the Capel Horeb site is of particular importance; it is the earliest occurrence of a plant with vascular tissue in place, and as such provides unequivocal evidence for the existence of the earliest land plants.

The NNE face of the quarry shows a dip section of the Přídolí Series Long Quarry Formation. It is about 20 m in thickness and comprises green-grey, highly micaceous sandstones, with thin intraformational conglomerates. The lowest 7 m are grey carbonaceous siltstones and sandstones, with micaceous sandstones; the brachiopod *Orbiculoidea rugata* has been recorded, as have the same two plant taxa recorded from the Upper Roman Camp Formation below. The upper part of the Long Quarry Formation has lenses crowded with fossils: the gastropods *Loxonema* sp., *Turbocheilus helicites* and *Sellinima? williamsi*, the bivalves *Modiolopsis complanata* and *M. laevis*, rare brachiopods (*Microsphaeridiorhynchus nucula*) and the cephalopod *'Orthoceras'* sp. also occurs. The overlying red beds at the base of the Raglan Marl Group crop out at the top of the east end of the northern quarry face. This group, perhaps more than 600 m thick in this area, shows an alternation of mudstones, siltstones and fine sandstones, with abundant cross-bedding. Although predominantly red in colour, brachiopods and molluscs occur in occasional layers.

The surface of unconformity is not immediately obvious (Figures 6.14, 6.15); the rocks above and below the unconformity both strike ESE, the older series dipping at about 70°, the younger nearer 60°. The overstep to the west becomes apparent on further observation, and is most obvious from regional considerations (Potter and Price, 1965).

Interpretation

Although the uppermost part of the Ludlow is not present in this area, the sequence as exposed illustrates the decreasing marine influence on the sedimentation. Fossils in the Ludfordian Upper Roman Camp Formation are not common, but the aspect of the fauna, which is dominated by articulate brachiopods, suggests a more marine influence than that of the Přídolí Long Quarry Formation, where bivalves and gastropods predominate. The flora of both formations is similar; presumably in both cases it has been transported from a not far distant landmass. The evidence provided by the Raglan Marl Group indicates that the environment was perhaps brackish, on an extensive delta top. Fully terrestrial deposition is not indicated until near the top of the group, which although there is no biostratigraphical control is probably near the base of the Devonian above.

Like this Capel Horeb Quarry site, the Sawdde Gorge site 15 km south-west along strike, also has Ludlow strata unconformably overlain by Přídolí strata. The GCR site at Wernbongham farther to the south-west has rocks of disputed Přídolí age that overstep a Wenlock Series sequence. All these sites network with the lower Silurian Sawdde Gorge site and other Llandovery and Wenlock sites in the Llandeilo and Llandovery area to give a picture of the position and evolution of the shelf to slope transition of the southern margin of the Welsh Basin during the Silurian.

Conclusions

This is another site illustrating part of the marine to reduced marine transition generally illustrat-

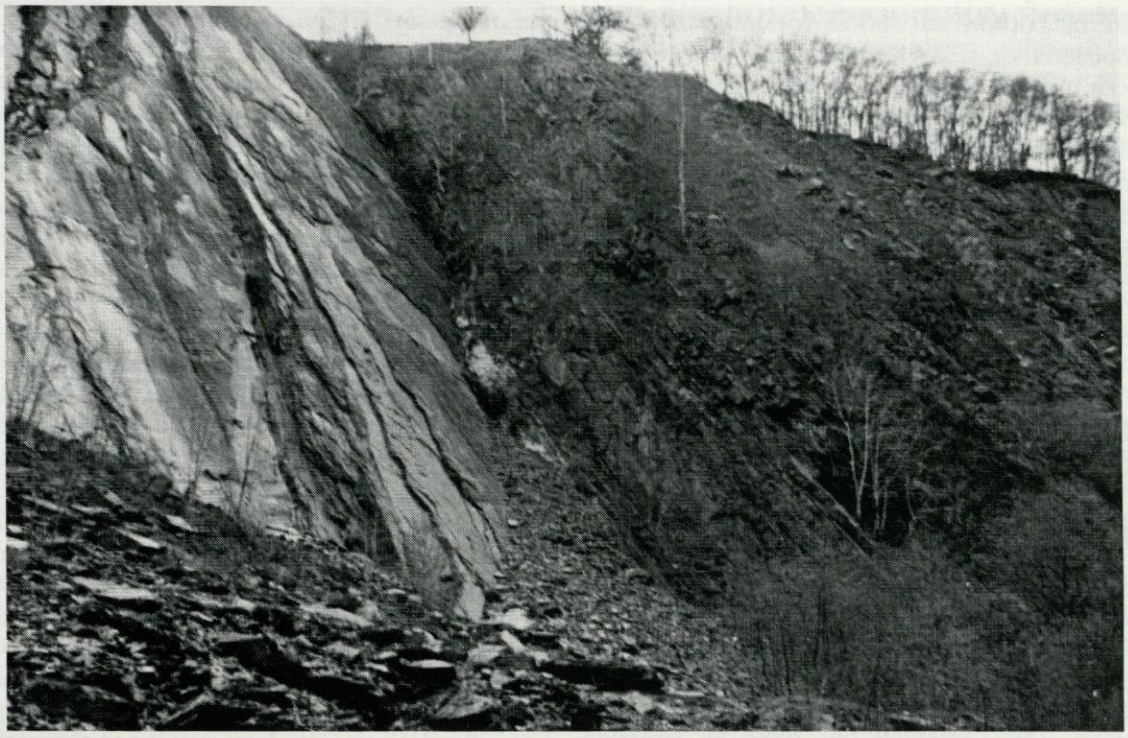

Figure 6.14 Capel Horeb Quarry, Carmarthenshire, looking approximately north (see Figure 6.15). (Photo: P.D. Lane.)

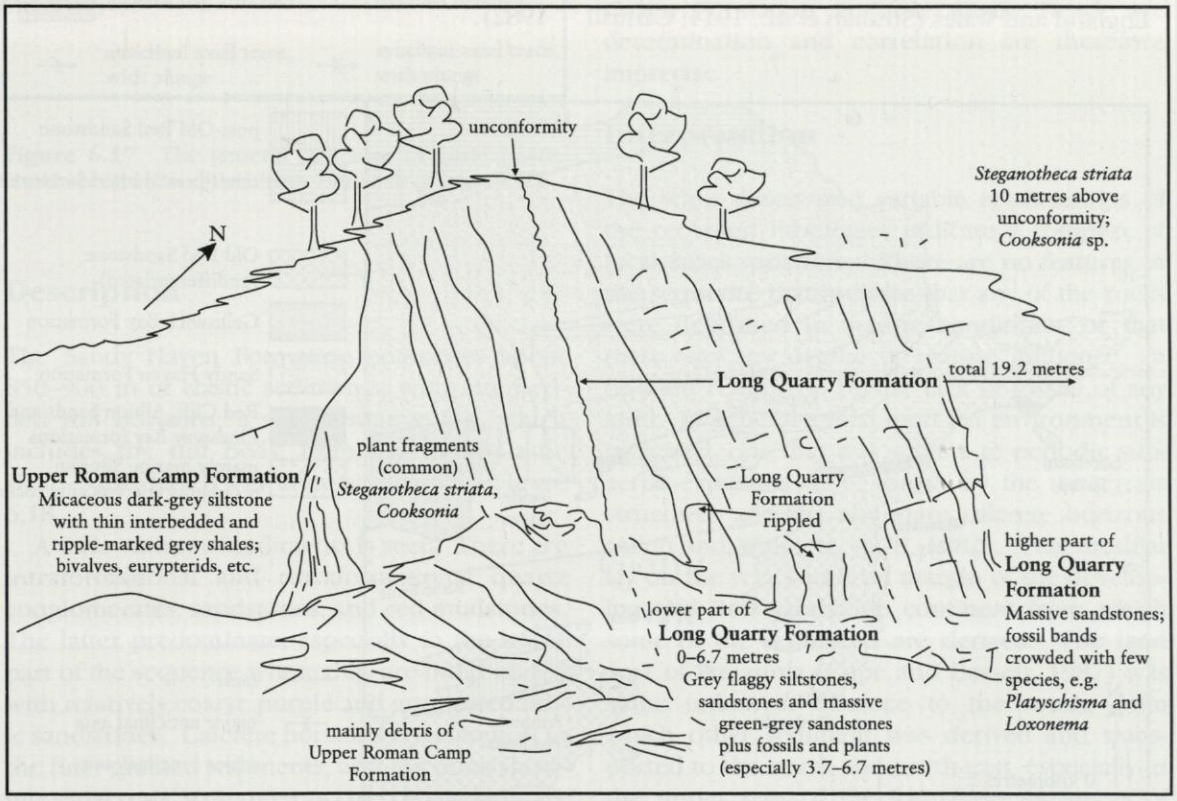

Figure 6.15 Interpretation of the geology of Capel Horeb Quarry, Carmarthenshire, illustrating the main stratigraphical divisions, and the surface of unconformity (see Figure 6.14; after Edwards and Richardson in Friend and Williams, 1978).

ed in Ludlow to Přídolí rocks of the Welsh Borderland. It lies at the western end of a shallow marine dominated shelf which itself lay to the north of the Pretannia landmass (Cope and Bassett, 1987). The site has national and international importance because of its flora. Although the taxon is known from older rocks, specimens of *Cooksonia* sp. from the Ludlow sequence in Capel Horeb Quarry have yielded the earliest undoubted vascular land plant tissue.

LITTLE CASTLE HEAD (SM 855 065)

Introduction

The Little Castle Head section lies on the north shore of Milford Haven, south-west Wales, about 4.5 km west of Milford itself (Figure 6.16). Most exposure is to be seen on the foreshore from the south side of Little Castle Head to Sleeping Bay, 250 m to the north (Figure 6.17). The first general description of note of the general geology of the area, was made by the Geological Survey of England and Wales (Strahan *et al.*, 1914; Cantrill *et al.*, 1916). Přídolí rocks here form the base of a thick Old Red Sandstone sequence, the Milford Haven Group, which cumulatively totals a maximum of 4500 m. The main Přídolí sequence exposed is the lower to middle part of the Sandy Haven Formation (Allen and Williams, 1978; Allen *et al.*, 1982; Williams, 1971; Williams *et al.*, 1982); it includes tuffs, the thickest and most widespread of which is the Townsend Tuff Bed (Allen and Williams, 1981; Figures 6.18, 6.19). These authors suggested that, until the faunas or floras in the Sandy Haven Formation become better known, the latter tuff might be regarded as the local reference level for the base of the Devonian System in southern Wales and the Welsh Borderland.

Structurally, the sequence lies in a fault-bounded slice – the Winsle block of Sanzen-Baker (1972), that is, to the north of the Ritec Fault and to the south of the Benton Fault (Figure 6.16). This block is one of five in the region that have been brought together by north verging thrusting in the Variscan Orogeny. Locally, the tectonics have produced tight folds on the 100 m scale, the axes of which trend a little south of east (Figure 6.17; Hancock *et al.*, 1982).

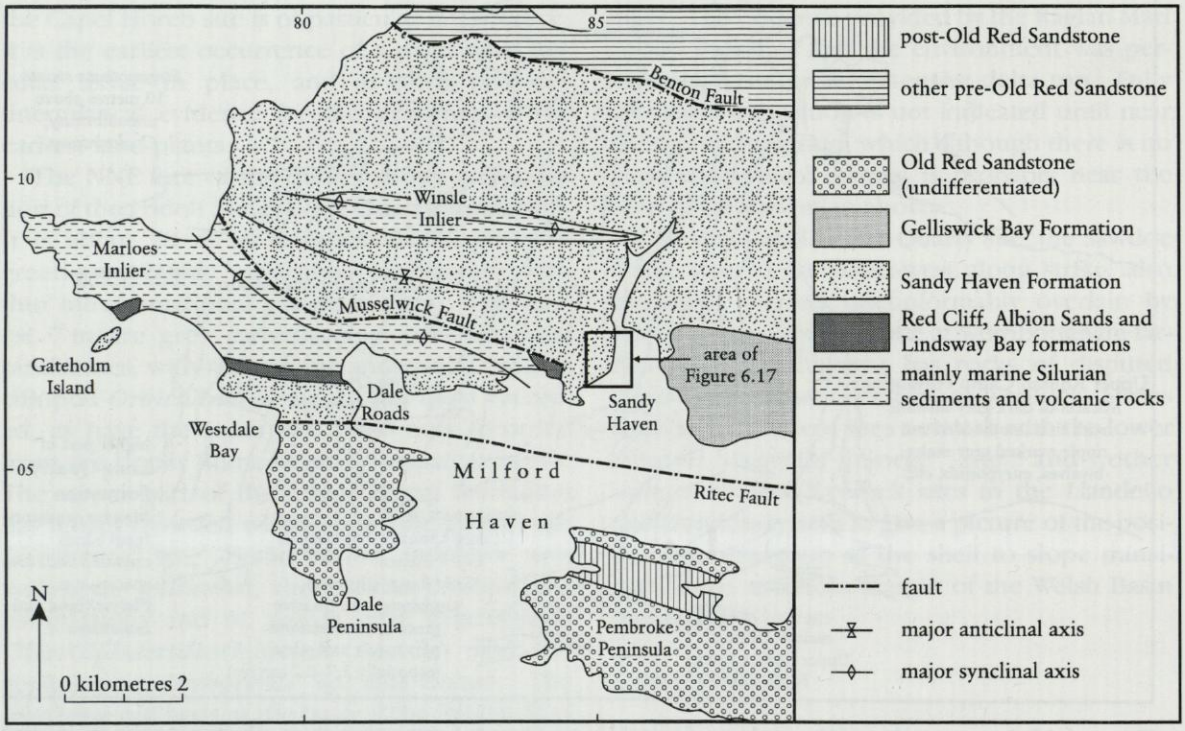

Figure 6.16 The geology of the Milford Haven area (modified from Allen and Williams, 1978).

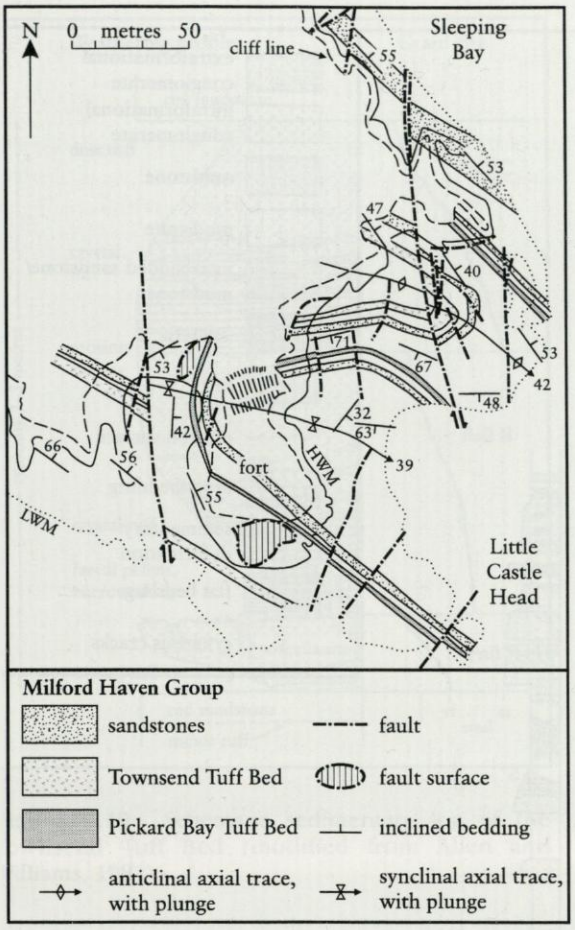

Figure 6.17 The general structure of Little Castle Head section (modified from Hancock *et al.*, 1982).

Description

The Sandy Haven Formation comprises about 850–900 m of clastic sediments, with interbedded tuff horizons; a representative log, which includes the tuff beds, from the Little Castle Head–Sandyhaven Pill area is shown in Figure 6.18.

A wide variety of sediments is seen. There are intraformational and extraformational quartz conglomerates, sandstones, and red mudstones. The latter predominate, especially in the lower part of the sequence where they are interbedded with relatively coarse purple and grey-green lithic sandstones. Calcrete horizons are common in the finer-grained sediments, and horizons showing synaeresis structures occur. Many primary sedimentary structures can also be seen in these sediments, including cross-bedding and cross-lamination. In the higher parts of the formation, sandstones become commoner, although of finer grain size than the rarer sandstones lower in the sequence. The sediments are predominantly purple, red or bright red, although green colouration is also seen. These different lithologies and structures occur in a complex relationship to one another.

Yellow, red, blue, magenta, and purple coloured air-fall tuffs occur in the middle to upper part of the formation; the Townsend Tuff Bed as recorded by Allen and Williams (1981, p. 17; Figures 6.18, 6.19) is 4.95 m thick and the Pickard Bay Tuff Bed, which occurs some 15 m higher in the sequence, has a thickness of about 3 m. The Townsend Tuff Bed is widespread, occurring over an area from south-west and central South Wales, to the Forest of Dean and Clee Hill areas; it has its thickest development in the Little Castle Head section. It always comprises three distinct normally graded air-fall elements each of which has a crystal tuff at its base that grades up to a green siliceous muddy tuff ('porcellanite' of Allen and Williams, 1981; Figure 6.19).

No fossils have been recorded in the Sandy Haven Formation at Little Castle Head; age determination and correlation are therefore imprecise.

Interpretation

The wide variety and variable relationships of the recorded lithologies indicate a complex of local facies variations. There are no features in the sequence that indicate that any of the rocks were deposited in marine conditions, or that there was any degree of marine influence, an opinion reinforced by the lack of fossils of any kind. In general a tidal mud flat environment is indicated, one that was subject to periodic subaerial exposure, as is shown by the synaeresis structures and the abundant calcrete horizons (Allen and Williams, 1978, 1982). This mudflat lay on the very southern margin of the developing Old Red Sandstone continent from which some of the sediments are derived. The land area of Pretannia (Cope and Bassett, 1987) was some unknown distance to the south, from which other sediment was derived and transported to the north and north-east, especially in the upper part of the formation, by rivers of modest size. Thus as is usual in the Přídolí of the UK, stratigraphical, environmental and geo-

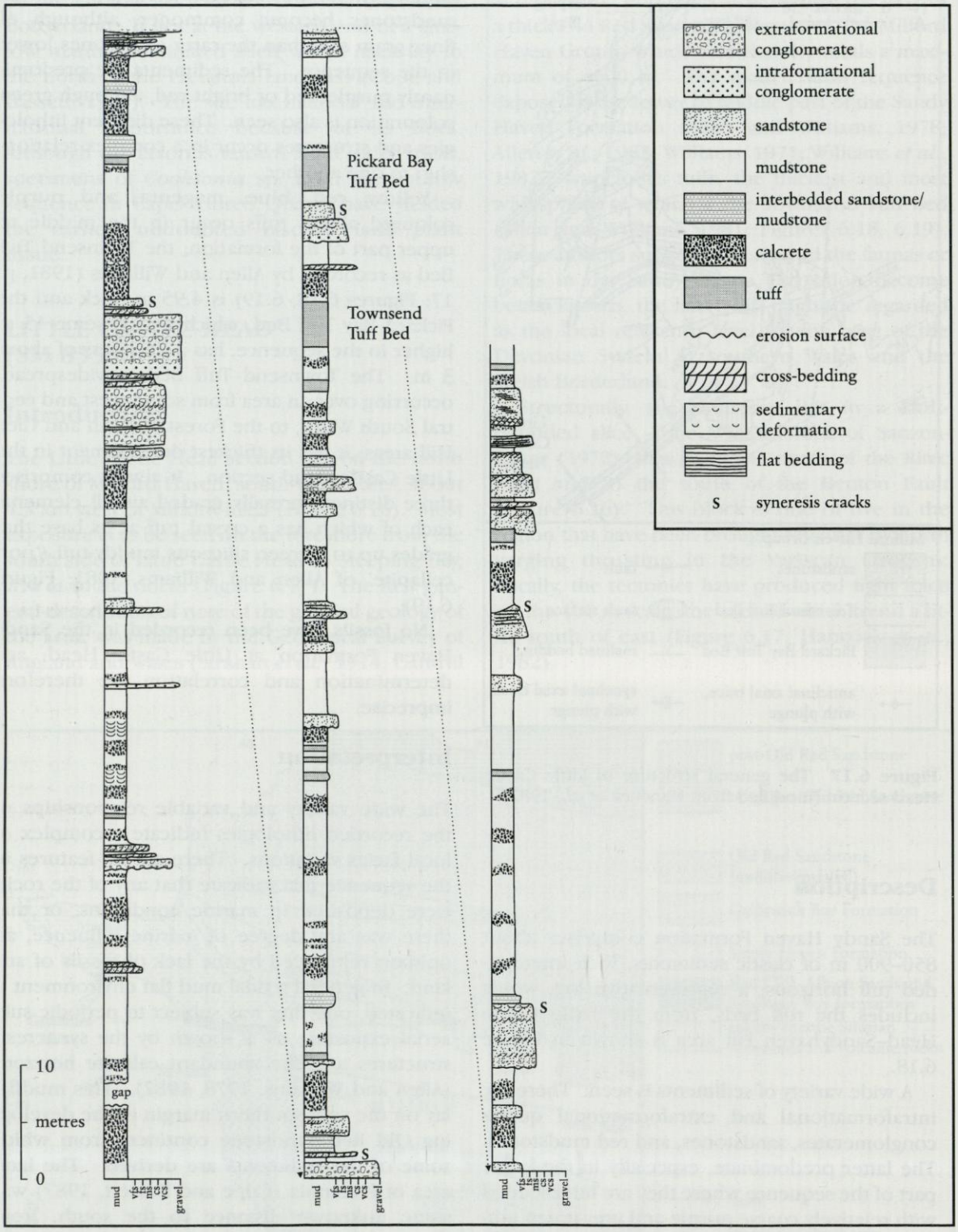

Figure 6.18 A measured representative sedimentary log of part of the Přídolí Sandy Haven Formation in the Little Castle Head–Sandyhaven Pill area, Pembrokeshire (modified from Allen and Williams, 1978).

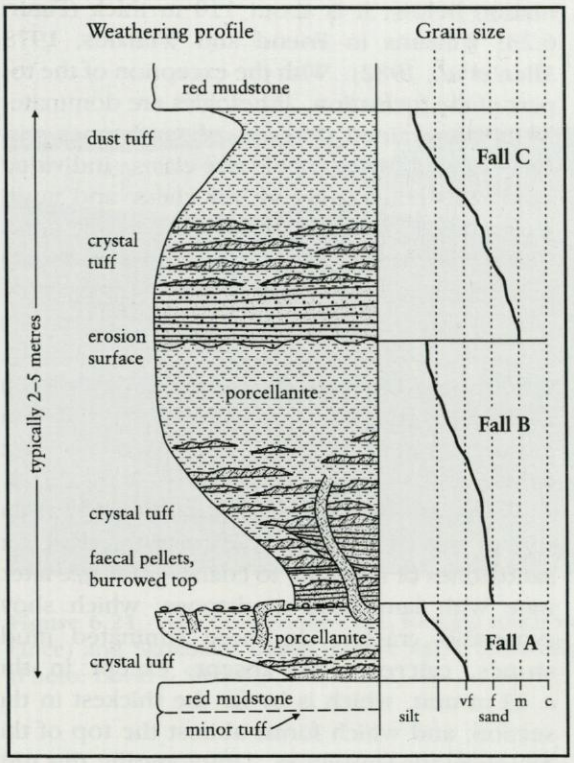

Figure 6.19 Schematic sedimentary log of the Townsend Tuff Bed (modified from Allen and Williams, 1981).

graphical conditions between possibly brackish and continental, but certainly not fully marine are represented.

No volcanic source is known for the widespread Townsend Tuff Bed, which in this section has its thickest development, although it is represented throughout south central Wales and as far north as the Clee Hills in Shropshire. It is known that volcanic activity was occurring even farther to the north than Shropshire at about the same time, in what are now the Southern Uplands and Girvan, and to the north of the (presumably closed) Iapetus Suture. As this southern Wales occurrence of the Townsend Tuff Bed is relatively far to the south of Scotland, Allen and Williams (1981) suggested that the source instead might be either to the west or east, directions related to the west to east strike line of the developing Rheic Ocean. From the field evidence, these authors imagined that powerful Plinian-type eruptions of ash were dispersed by strong winds from one of these directions. South Wales, and the areas to the south were under active extension at the time (Powell, 1989), so that the source of the volcanic material might have been to the south, bordering the Cornwall–Rhenish Basin.

This site like that at Albion Sands and Gateholm Island lacks any evidence of fully marine influence in Přídolí times. Also like the Albion Sands site and the nearby Marloes (which is described in the Llandovery and Wenlock chapters) there are volcanic rocks. Also of note is the early onset of terrestrial red bed sedimentation in the Ludlow – or possibly even Wenlock times. These three Pembrokeshire sites are situated in fault-bounded blocks that, in the Variscan Orogeny, were transported an unknown, but probably not inconsiderable distance from the south.

Conclusions

The Little Castle Head section illustrates the conditions of deposition in a totally non-marine environment towards the southern margin of the Old Red Sandstone continent. Although of all Přídolí sites, Little Castle Head and Albion Sands and Gateholm Island sites are nearest to the presumed position of the Rheic Ocean here in the Winsle Block, there is no evidence of a direct link to this ocean.

The original spatial relationships of the five fault blocks that can be traced in the Palaeozoic geology of Pembrokeshire is not known (Sanzen-Baker, 1972; Powell, 1989). However, tracing them from south to north, the sedimentological features indicate a marine to increasingly terrestrial environment of deposition. The local effects of the Variscan orogeny on these Lower Palaeozoic sediments are well displayed in the folds seen at this site.

ALBION SANDS AND GATEHOLM ISLAND (SM 771 074)

Introduction

This section in the cliffs, the foreshore, and on Gateholm Island, which is some 24 km southwest of Haverfordwest (Figures 6.20, 6.21), exposes the top part of the Red Cliff Formation (Ludlow to Přídolí), the Albion Sands Formation (Přídolí), and the lower part of the Sandy Haven Formation (of Přídolí to Lower Devonian age; Figure 6.22); an interbedded wedge of the Přídolí age Lindsway Bay Formation may also be

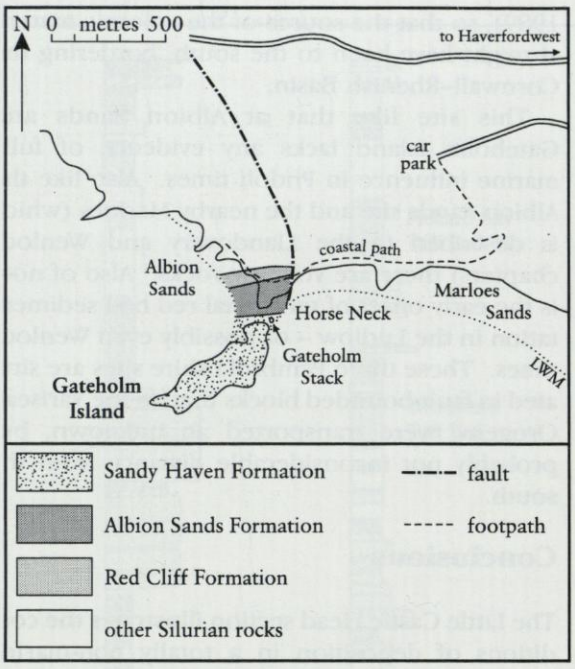

Figure 6.20 General geology of the Albion Sands to Gateholm Island area, Pembrokeshire (after Williams in Friend and Williams, 1978).

seen. In total, about 250 m are continuously exposed. The Red Cliff Formation and Albion Sands Formation are exposed in the cliffs and foreshore on the east side of Albion Sands and are visible in any tidal conditions. The Sandy Haven and Lindsway Bay formations, which may be seen in the cliffs and foreshore of Gateholm Island (SM 772 075), are largely covered or cut off at high tide.

General descriptions of the strata involved were given by Strahan *et al.* (1914) and by Cantrill *et al.* (1916). In these publications the Old Red Sandstone facies was divided only into the Red Marls below and the Cosheston Group above; these lithostratigraphical units occupy a stratigraphical interval of Ludlow to what is possibly the Emsian. A revised stratigraphical scheme was presented by Allen *et al.* (1982; see also Williams, 1971; Allen and Williams, 1978; Williams *et al.*, 1982; Figure 6.22). The locality is also described in a field guide to Dyfed (Bassett, 1982).

Description

The Albion Sands Formation, here at its type section, is conformable with the Red Cliff Formation below; it is about 110 m thick (Figure 6.23; Williams in Friend and Williams, 1978; Allen *et al.*, 1982). With the exception of the top part of the formation, lithologies are dominated by coarse-grained deposits of sandstones with included pebble to cobble size clasts. Individual sand beds reach 2 m+ in thickness, and multistorey beds, which are common, reach about 5 m in thickness. These beds are predominantly pale yellow to buff in colour, and contain a great deal of igneous material; they have sharp tops and bases, and above the latter, intraformational mud flake cobble-size conglomerates overlie the erosional surface. The pebble beds and conglomerates have clasts of fine-grained lavas, and vein quartz.

Both towards the base, and particularly at the top of the Albion Sands Formation, dark red sandstones of medium- to coarse-grain size alternate with laminated mudstones, which show synaeresis cracks. In these laminated mudstones, calcretes are absent, except in the *c.* 11 m unit, which is by far the thickest in the section, and which forms almost the top of the Albion Sands Formation. Lithologically, this unit seems to have much more in common with the Sandy Haven Formation, which lies conformably above.

In the Albion Sands Formation sequence, both the pale yellow to buff and the red sandstones show planar and trough cross-bedding to an equal degree. Air-fall and crystal tuffs occur throughout the Albion Sands Formation; these generally occur as thin (on the scale of 0.1 m) individual beds, although two more substantial ones on the scale of 0.5–1 m were recorded by Allen *et al.* (1982, p. 132).

The contact between the Albion Sands and Sandy Haven formations is lithologically transitional. The lower part of the Sandy Haven Formation is largely exposed on Gateholm Island; about 85 m have been recorded. Its base is drawn at the top of a 0.88 m thick unit of alternating coarse sandstones and mudstones that can be seen at the base of Gateholm Stack; this unit overlies the calcrete unit mentioned above.

Between about 69 m and 76 m above the base of the Albion Sands Formation, near Horse Neck (SM 7718 0751; Figure 6.20), there are four pebble conglomerate beds interbedded with ill-sorted granule-rich mudstones. The pebbles in the conglomerates are of igneous origin from some unknown source, and the clasts in the mudstones are predominantly vein quartz. This part

Figure 6.21 View from Sandy Lane, looking south-west across Marloes Sands to Gateholm Island (centre distance) and Skokholm Island (centre left). Strata dip at high angle and young seawards, from right to left. (Photo: David J. Siveter.)

of the sequence was named the Lindsway Bay Formation by Allen *et al.* (1982). This formation at its type locality in Lindsway Bay, 8 km to the east, attains a thickness of about 70 m.

The greater part of the Red Cliff Formation is thought to be of Ludlow age, although its lowest part might be Wenlock (Figure 6.22; see Marloes GCR site report in the Wenlock chapter). The Albion Sands Formation, which overlies the Red Cliff Formation conformably, is of Přídolí age. There is no biostratigraphical evidence to demonstrate the age of the lithological boundary between the two formations, although Cocks *et al.* (1992) indicated that in Pembrokeshire the uppermost part of the Red Cliff Formation is of earliest Přídolí age. The Sandy Haven Formation is largely of Přídolí age, although in this area its uppermost part is considered to be Devonian (Cocks *et al.*, 1992).

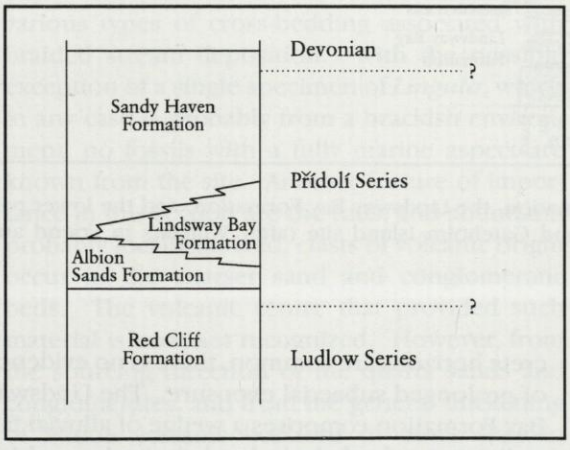

Figure 6.22 The lithostratigraphy of the Albion Sands to Gateholm Island area, Pembrokeshire, with possible relationship to chronostratigraphy.

Within the middle part of the Sandy Haven Formation the Townsend Tuff Member occurs but is not well exposed. This distinctive and widespread unit occurs at localities from Pembrokeshire to Shropshire (Allen and Williams, 1978; 1981). It generally has a thickness of 3–4 m and comprises a complex of three ash fall tuffs (see GCR site report for Little Castle Head in this chapter).

Fossils have been recorded only from two quartz pebble conglomerates from the basal part of the Sandy Haven Formation (Allen *et al.*, 1982). The lower conglomerate has yielded the plant *Pachytheca,* fish scales and spines referable to '*Onchus*' *wheathillensis*, and a specimen of *Lingula* sp.; the upper conglomerate has yielded only similarly determined fish spines.

Interpretation

The Přídolí age rocks of this section demonstrate developing continental conditions. The sedi-

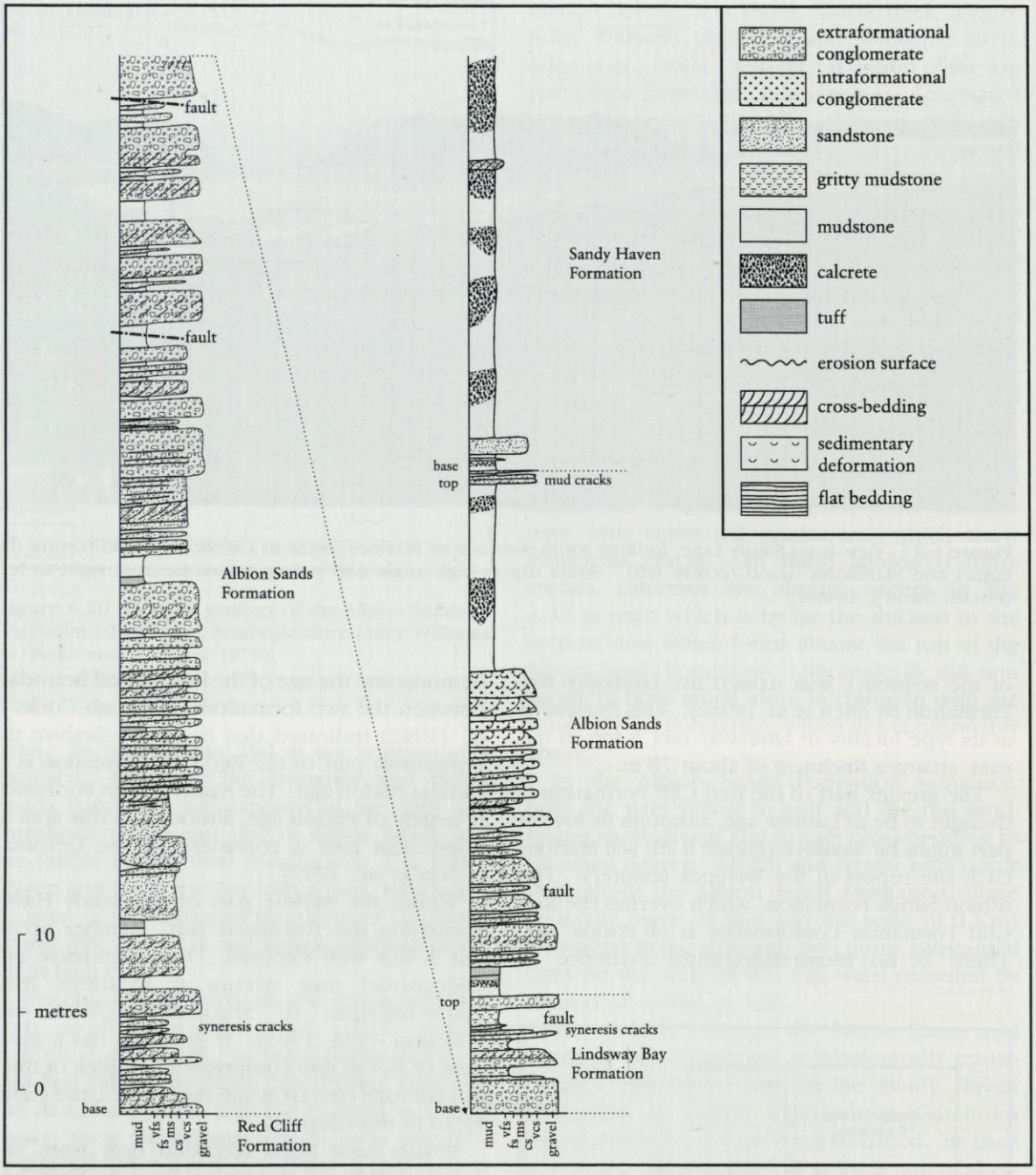

Figure 6.23 Sedimentary log of the Albion Sands Formation, the Lindsway Bay Formation, and the lower part of the Sandy Haven Formation at the Albion Sands and Gateholm Island site (after Williams in Friend and Williams, 1978).

mentary sequence of the Albion Sands Formation is interpreted as having been deposited by braided streams; the sediments were sourced first and mainly from the south. Unlike in the Red Cliff Formation below, and the Sandy Haven Formation above, in both of which calcrete horizons are common, there is no evidence of prolonged subaerial exposure. The Lindsway Bay Formation comprises a wedge of alluvial fan sediments, of relatively local derivation, which were derived from the south or south-east. The Sandy Haven Formation is suggestive of a coastal

mud flat horizon environment that was at times subject to periodic marine incursions, but at other times scoured by rivers or owing to more prolonged subaerial exposure shows more stable surfaces. The air-fall tuffs of the Townsend Tuff Member accumulated on the coastal mud flats, as indicated by the sedimentary features of the Sandy Haven Formation; the Townsend Tuff Member originated from powerful Plinian eruptions from an unknown, but distant, source.

Other than the record of a single specimen of *Lingula*, this site like that at Little Castle Head shows no marine influence in Přídolí times. Like the nearby Marloes site (see the Llandovery and Wenlock chapters, this volume) there are volcanics, and red-bed sedimentation of Ludlow age indicate the early onset of terrestrial deposition. These Pembrokeshire GCR sites lie in fault-bounded blocks that were transported an unknown distance from the south, during the Variscan Orogeny.

Conclusions

The site has been selected for the GCR because it shows a complete, conformable, and almost uninterrupted succession through Old Red Sandstone facies of the Ludlow, Přídolí, and earliest Devonian. The Přídolí strata at this site provide an excellent example of a fully terrestrial environment of deposition that is in sequence with the marine Wenlock and the Ludlow rocks below. The strata exhibit classic sedimentary features of such terrestrial environments, including impressively developed calcretes, intraformational and extraformational conglomerates, and various types of cross-bedding associated with braided stream deposition. With the possible exception of a single specimen of *Lingula*, which in any case is probably from a brackish environment, no fossils with a fully marine aspect are known from the site. Another feature of importance in this section are the tuffs, and abundant, probably locally-derived, clasts of volcanic origin occur in the coarser sand and conglomeratic beds. The volcanic centre that provided such material is now not recognized. However, from the sourcing direction of the quartz sands and conglomerates, and from the general thickening of Přídolí volcanic horizons in other sites in Pembrokeshire (e.g. Little Castle Head), the provenance is thought to be from the south or south-west.

LOWER WALLOP QUARRY (SJ 3150 0725)

Introduction

The abandoned Lower Wallop Quarry is situated 3 km north of Brockton, and 18 km WSW of Shrewsbury in Shropshire (Figure 6.24) and forms part of a private property. The quarry exposes the best section of the Wallop Hall Member of the Causemountain Formation, Přídolí Series, in the Welsh Borderland. The sec-

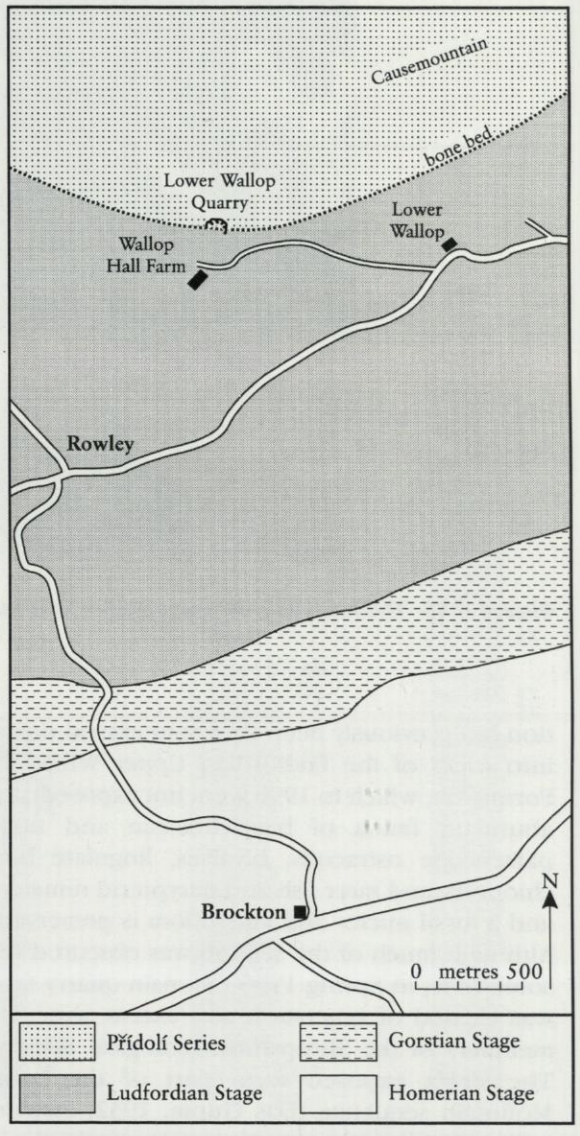

Figure 6.24 Geological map of the area around Lower Wallop Quarry, Shropshire (modified from Das Gupta, 1932).

Figure 6.25 The main face of Lower Wallop Quarry, Shropshire; metre rule for scale. (Photo: P.D. Lane, June 1996.)

tion has previously been shown to extend down into rocks of the Ludfordian Upper Whitcliffe Formation, which in 1996 were not exposed. An abundant fauna of beyrichiacean and non-palaeocope ostracods, bivalves, lingulate brachiopods, and rarer fish and eurypterid remains, and a fossil micro- and macroflora is preserved. Although much of the section was obscured for some time, in Spring 1996 the main quarry face was cleared of vegetation and excess scree, by members of the Shropshire Geological Society. The strata exposed form part of the Long Mountain sequence (Das Gupta, 1932; Palmer, 1970, 1972).

Details of the stratigraphy and the stratigraphical occurrence of the flora and fauna may be found in a number of publications; the general stratigraphy, fauna and microflora (Das Gupta, 1932; Antia, 1981); ostracods (Shaw, 1969; Miller, 1995); the macroscopic flora (Bassett and Edwards, 1982; Edwards, 1990 and references therein), and the palynomorphs (Richardson and Rasul, 1990).

Description

The main exposure (Figure 6.25) shows about 4 m of section, the base of which lies an estimated 2 m above a bone bed. This bone bed has been considered a possible correlative of the Ludlow Bone Bed (Richardson and Rasul, 1990) which

crops out in the Wenlock Edge–Ludlow area some 30 km to the south-east; it is obscured by talus produced in clearing the main quarry face, and by removal of a dangerous overhang. A few metres east of the main face, the lower part of the section in which Palmer (1970, 1972; Miller, 1995; Figure 6.26) recorded the same bone bed, is normally obscured by vegetation. Another exposure of what is possibly the same bone bed about 100 m to the east (D. Palmer, pers.

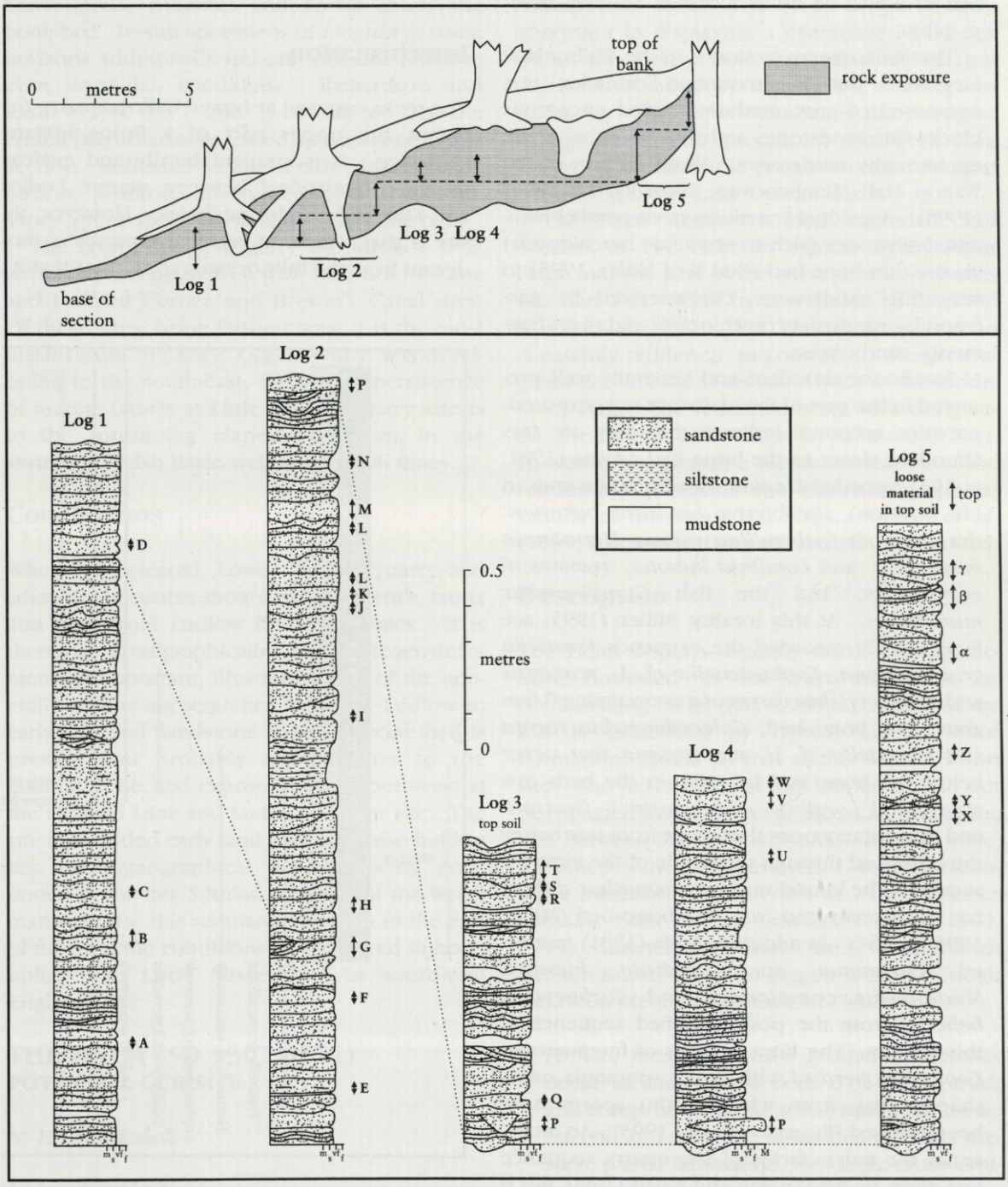

Figure 6.26 Log of previously exposed section in Lower Wallop Quarry, Shropshire, exposed a few metres to the east (right) of the main face shown in Figure 6.25 (modified from Miller, 1995, text-fig. 11).

comm.) is not presently available for study. In the Welsh Borderland several bone beds occur at about the Ludlow-Přídolí stratigraphical boundary; because of the difficulty of biostratigraphical correlation in the increasingly terrestrial facies represented by the sequences it cannot be assumed which bone bed is the precise correlative of which at other localities (Miller, 1995, p. 341).

The main quarry section is in the Wallop Hall Member of the Causemountain Formation; it is composed of grey, medium-bedded micaceous blocky fine sandstones and siltstones that grade up into silty mudstones. About 4.75 m of the Wallop Hall Member were recorded by Miller (1995). A gradual transition from parallel-laminated siltstones (rich in articulate brachiopods) via the thin bone bed (Bed K of Miller, 1995) to very fine sandstones, characterized by gastropods, inarticulate brachiopods and plant fragments, can be seen.

Fossils are abundant and generally well preserved in the part of the main face now exposed; previous accounts indicate that they are less abundant closer to the bone bed. Antia (1981, p. 193) recorded *Lingula cornea* (sometimes in life position), the bivalve *Leodispis barrowsi*, the ostracods *Cytherellina siliqua*, *Hermannia marginata* and *Londinia kiesowi*, remains of eurypterids, and the fish *Gomphonchus murchisoni*. At this locality, Miller (1995; see Figure 6.27) recorded the ostracods *Frostiella groenvalliana*, *Lophoctenella* cf. *L. scanensis* and *Nodibeyrichia verrucosa* as occurring 0.6 m above the bone bed, *Calcaribeyrichia torosa* and *Hemsiella* cf. *H. maccoyiana* that occur below the bone bed but also in the beds just above, and *Londinia arisaigensis*, *L. fissurata* and non-palaeocopes that occur from just below the bone bed through the whole of the exposed section. The conodont *Coryssognathus dubius* has been recovered from the bone bed (Miller 1995, p. 364). In addition, Antia (1981) recorded *Loxonema* sp., *Londinia kiesowi*, *Modiolopsis complanata* and *Turbocyclus helicites* from the post-bone bed sequence at this locality. The flora consists of fragments of *Cooksonia pertoni* with fertile sporangia on Y-shaped axes, from which in-situ spores have been isolated (Rogerson *et al.*, 1993). An analysis of the palynofacies of the quarry sequence was given by Richardson and Rasul (1990, figs 6 and 7), who used the relative occurrence of sporomorphs, polygonomorphs and sphaeromorphs to give a measure of 'inshore index'.

The occurrence of *Cooksonia pertoni* (see Rogerson *et al.*, 1993) and *Frostiella groenvalliana* (see Miller, 1995) in the exposed part of the quarry (above the bone bed) indicates the Přídolí age of this part of the sequence (see also Richardson and Lister, 1969).

Interpretation

The rocks exposed at Lower Wallop Quarry represent the upper part of a fining-upwards sequence. It is stratigraphically and environmentally transitional between marine Ludlow and Old Red Sandstone facies. However, this site is that which on regional grounds is most distant from the fully oceanic conditions that it is

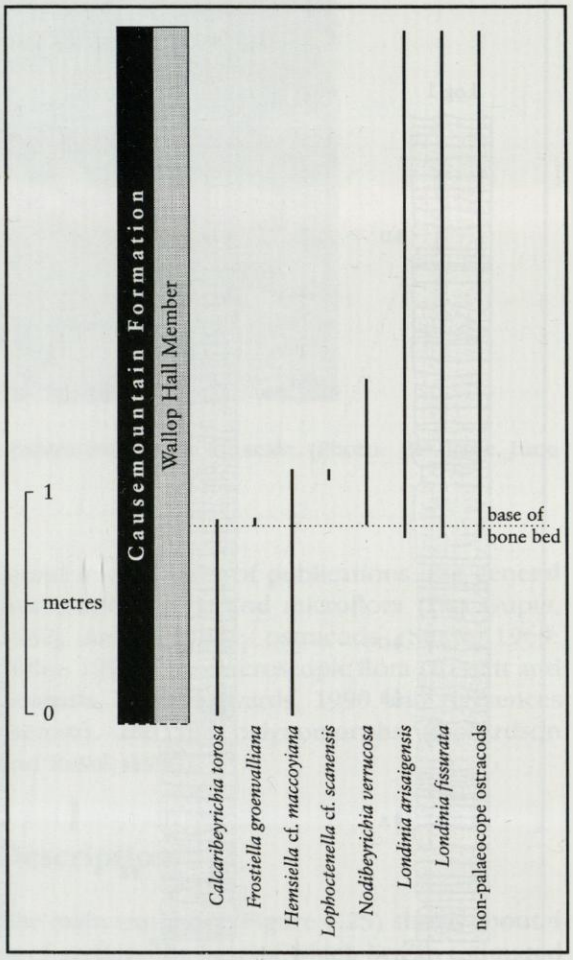

Figure 6.27 Stratigraphical range of ostracods in Lower Wallop Quarry, Shropshire (modified from Miller, 1995, text-fig. 12).

proposed were situated to the south-east (Cope, *et al.*, 1992, p. 55, fig. S9). Although regarded as shallow marine in the Přídolí, the sequence exhibits synaeresis cracks that indicate intermittent emergence or possibly very shallow conditions, and the latter is further borne out by the lack of 'fully' marine groups such as articulate brachiopods, trilobites and corals above the bone bed. In-situ specimens of *Lingula* at some horizons additionally indicate possible shallow, even intertidal, conditions. Richardson and Rasul (1990, figs 6 and 7) considered that the Přídolí palynofacies as traced up sequence in this section indicated a generally increasingly inshore position, interrupted by a small 'offshore' event about 1.6 m above the bone bed.

The Lower Wallop Quarry site forms a GCR network particularly well with the Ludford Lane and Ludford Corner, and Brewin's Canal sites. Of these sites, being farthest west it is the most distant from the Rheic Ocean, which was developing to the south-east; the longer persistence of marine faunas at Little Wallop Quarry attests to the continuing marine conditions in the shrinking Welsh Basin well into Přídolí times.

Conclusions

When fully cleared, Lower Wallop Quarry and adjacent exposures show a rock sequence, fauna and flora from Ludlow to Přídolí times. It is therefore stratigraphically and palaeoenvironmentally important, illustrating part of the generally shallowing sequence from late Ludlow to early Old Red Sandstone facies. A bone bed is present that probably approximates to the Ludlow Bone Bed exposed to the south-east at the Ludford Lane and Ludford Corner site. The site has yielded early land plants. It also holds a key palaeogeographical position being positioned in the late Silurian remnant of the Welsh marine basin; this remnant basin lies to the east of fully marine conditions as evidenced in boreholes (e.g. Little Missenden) in south-east England.

THE HELM (SD 5307 8871)

POTENTIAL GCR SITE

N. H. Woodcock

Introduction

The elongate hill of The Helm has its summit 1 km south of Oxenholme and 4 km SSE of Kendal, Cumbria. Natural exposures and small disused quarries provide an incomplete but informative section through the upper part of the Kirkby Moor Formation. The origin of this lithostratigraphical term is discussed in the introduction to the Benson Knott (Ludlow Series) GCR site. The Helm is particularly important in displaying a distinctive lithofacies within the Kirkby Moor Formation, designated the Helm Member by King (1992; see Figures 6.28a, b). The Helm Member is the youngest stratigraphical unit present in the three sites chosen to illustrate the progressive late Silurian shallowing of the Lake District Basin.

The Helm Member is both underlain and overlain at The Helm by typical Kirkby Moor Flags, and the part of the succession it occupies was dated as Přídolí by correlation of ostracod faunas (Shaw, 1971a, b). The whole succession is patchily reddened, in contrast to the general green-grey colour of the main body of the Kirkby Moor Flags. The reddened units were designated the Scout Hill Flags by Shaw (1971a). However, the probable secondary nature of the reddening questions the lithostratigraphical validity of the Scout Hill Flags. Kneller *et al.* (1994) recommend that the term be abandoned.

Description

The Helm displays a gently north-dipping section, bounded to the east and west by NNE–striking faults (Shaw, 1971a). Much of the hill is underlain by typical Kirkby Moor Formation, similar to that at the Benson Knott site. The description of this lithofacies will not be repeated here. However the south end of the hill, between SD 5298 8854 and SD 5320 8900, is formed of the distinctive Helm Member, reaching a thickness of about 140 m. This member contains beds of four lithofacies (King, 1992, 1994), numbered to match those shared with Benson Knott. A typical logged section through the Helm Member is shown in Figure 6.29.

3. *Thin to medium-bedded graded sandstones* occur as sharp-based beds 0.05–0.3 m thick and comprise micaceous fine sand grading up into silt and clay. The sandstone intervals preserve planar lamination, low-angle cross-lamination, ripple cross-lamination and occasional convolute lamination. The mudstone tops are often bioturbated.

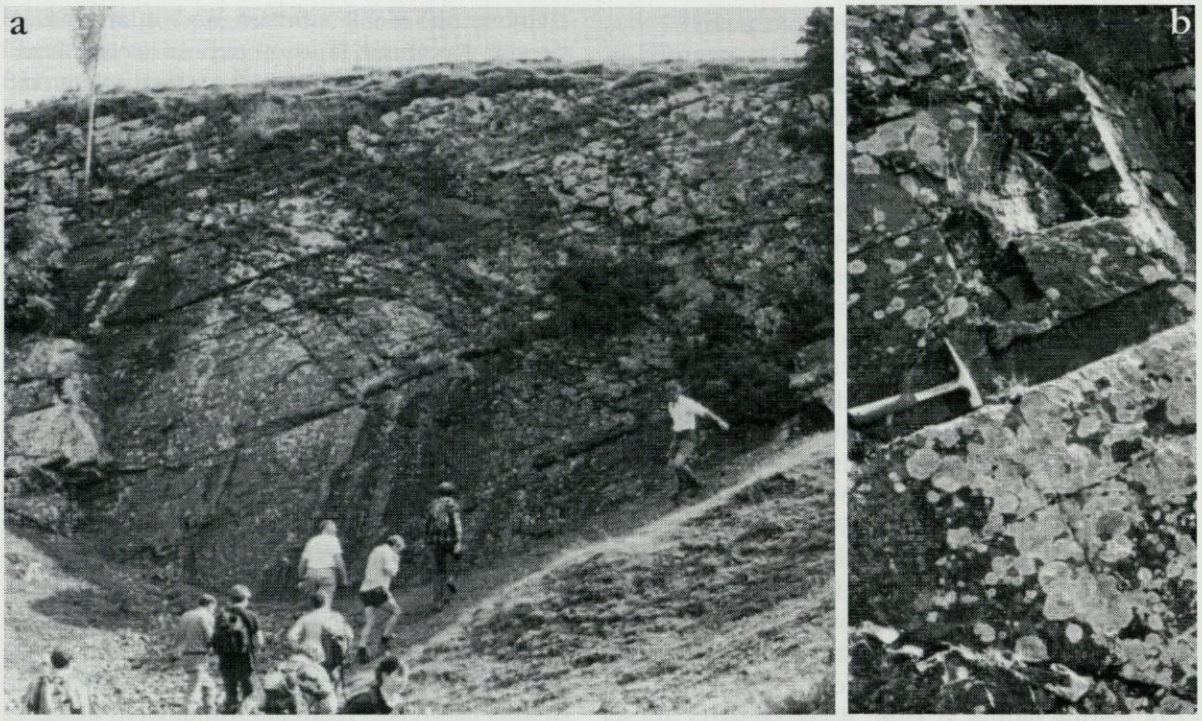

Figure 6.28 The Helm, Cumbria (a) outcrop displaying the Helm Member (Přídolí Series) of the Kirkby Moor Formation, (b) close-up of the strata. (Photos: David J. Siveter.)

4. *Thick-bedded stratified sandstones* occur as beds 0.2–2.0 m thick, often amalgamated, comprising fine-grained micaceous sandstone, which may grade up into mud. They show similar internal structures to lithofacies 3, although some beds may be massive. Low-angle hummocky cross-stratification and symmetrical ripple cross-lamination are widespread. The mud tops to beds may be bioturbated, often by vertical *Skolithos* burrows. The bed bases may be planar, but are usually erosive or loaded. This lithofacies predominates in the Kirkby Moor Formation but becomes a subordinate component in its Helm Member.
5. *Thick-bedded massive sandstones* are similar to lithofacies 4, but lack internal structure. They occur in tabular beds 0.5–1.0 m thick at SD 5298 8854, one showing large-scale planar cross-stratification through the whole bed. The beds may be topped by symmetrical ripples. These sandstones occur in a packet near the base of the Helm Member
6. *Heterolithic siltstones* comprise alternating irregular laminae of siltstone and silty mudstone. The mudstone laminae are generally thinner (0.5–2 mm) than the siltstone laminae (2–10 mm), and tend to occur as mud drapes defining flaser bedding. Bi-directional cross-lamination foresets can occur in the siltstones. Bedding surfaces can display symmetrical or asymmetrical ripples, irregular undulations and prod marks. Bioturbation is rare. The heterolithic siltstones are the predominant and characteristic lithofacies of the Helm Member.

As in the rest of the Kirkby Moor Formation, fossils occur as shelly lenses within or at the base of beds of lithofacies 3 and 4. Shaw (1971a) did not distinguish faunas from the Helm Member from those of the rest of the reddened 'Scout Hill Flags'. Comparing the fauna of the whole 'Scout Hill Flags' of the southern 'Kendal area', with that of the underlying Kirkby Moor Flags he noted a 26% decrease in the number of species. Significant disappearances include the trilobites *Alcymeres neointermedia, Acastella prima, Homalonotus knighti* and *Acastella? spinosa*, and the ostracod *Aechmina* sp.. Importantly, the ostracod *Frostiella groenvalliana* is introduced into the sequence, together with an increase in

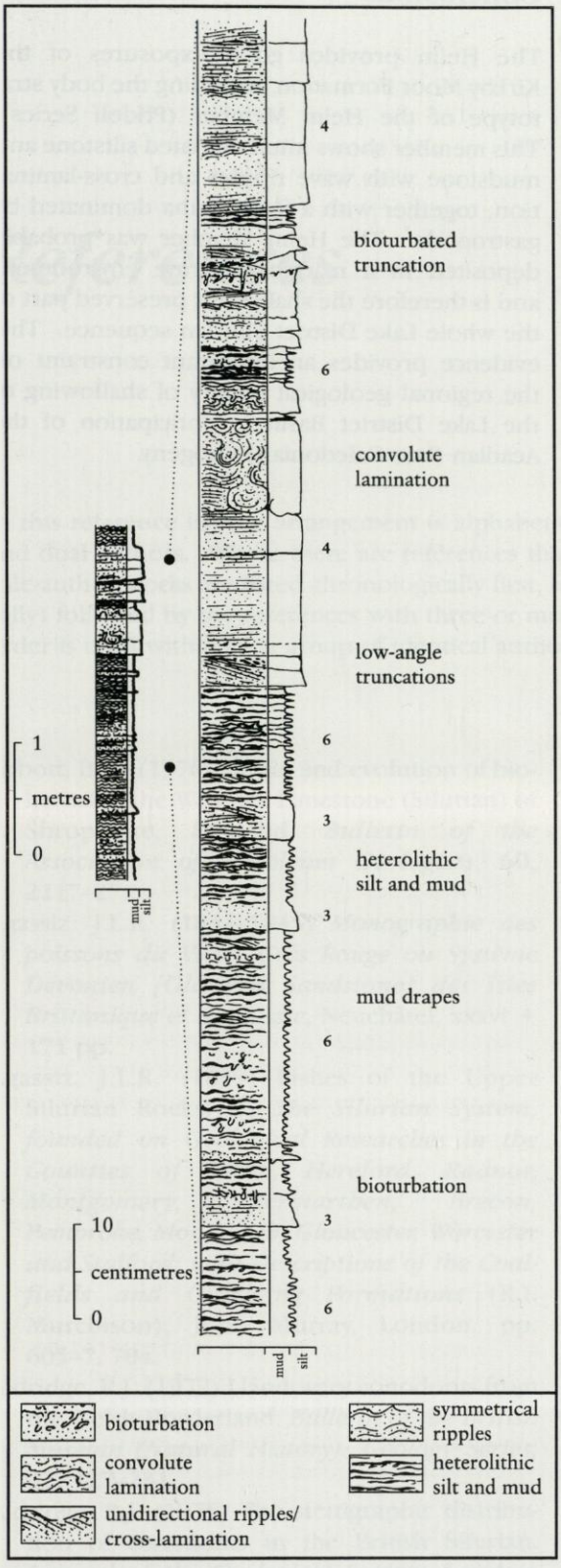

Figure 6.29 Representative log of the Helm Member of the Kirkby Moor Formation at The Helm (SD 5307 881; modified from King, 1992). Beds are assigned to one of several lithofacies (see text), numbered to match similar facies in the main Kirkby Moor Formation (see GCR site report for Benson Knott); in this particular section at The Helm, Cumbria, only lithofacies 3, 4 and 6 occur.

the abundance of gastropods and fish remains. The latter fauna correlates with that at the base of the Downton Castle Sandstone Formation in the Welsh Borderland (see GCR site report Ludford Lane and Ludford Corner), and with the internationally defined base of the Přídolí Series (Martinsson, 1967; Shaw, 1969; Siveter, 1978, 1989).

Interpretation

The sediments at The Helm accumulated at a late stage in the history of the Lake District marine basin. The heterolithic siltstones of lithofacies 6 that characterize the Helm Member are interpreted as the product of fair weather waves in a very shallow water marine environment (King, 1994). This interpretation is based on the bi-directional cross-lamination and the short wavelength of the ripple sets. This marine environment was sheltered from the pervasive effect of storms, suggesting deposition in a bay or lagoon behind a barrier bar or island (see Figure 5.81). Sporadic storm deposition, probably breaching or overtopping this barrier, is recorded by the graded and stratified sandstones of lithofacies 3 and 4. These sandstones are fully diagnosed in the site description for Benson Knott, the diagnostic sedimentary structure being hummocky cross-stratification. The thick-bedded massive sandstones of lithofacies 4 are insufficiently exposed to diagnose accurately. Their position near the base of the Helm Member suggests deposition in an intermediate environment between the storm-dominated shelf and the lagoon, perhaps as part of a sand-bar complex (Figure 5.81).

The Helm Member therefore represents the most inshore component of the late Silurian basin-shallowing sequence in the Lake District. This marginal marine assignment is supported by the decrease in faunal diversity and the increase in the abundance of vertebrate debris (Shaw, 1971a, b). The Helm offers a tantalizing last glimpse of an environment that probably

continued to accumulate marginal marine then non-marine sediment well into Devonian time.

The Helm, Benson Knott and Hills Quarry sites form the network that demonstrates the gradual, late Silurian shallowing of the Lake District Basin. Benson Knott illustrates the typical Kirkby Moor Formation, there dated as upper Ludfordian Stage, Ludlow Series. Hills Quarry exposes the somewhat deeper environments recorded in the Underbarrow Formation, there dated as lower Ludfordian Stage. In its chronostratigraphical position and palaeoenvironmental signature in the history of its sedimentary basin The Helm is comparable to GCR site Ludford Lane and Ludford Corner of the Welsh Basin.

Conclusions

The Helm provides good exposures of the Kirkby Moor Formation, including the body stratotype of the Helm Member (Přídolí Series). This member shows interlaminated siltstone and mudstone with wave ripples and cross-lamination, together with a fossil fauna dominated by gastropods. The Helm Member was probably deposited in a marginal marine environment and is therefore the shallowest preserved part of the whole Lake District Silurian sequence. This evidence provides an important constraint on the regional geological history of shallowing of the Lake District Basin in anticipation of the Acadian (late Caledonian) Orogeny.