British Silurian Stratigraphy

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Chapter 5

The Ludlow Series

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INTRODUCTION

The Ludlow Series takes its name from the historic market town in the Marches county of Shropshire. The various basal boundary and body stratotypes of the stratigraphical units of the Ludlow Series are located in its type area, the Ludlow Anticline. This district was identified by Murchison (1839; see also 1833, 1834 and 1835) as the reference area for his 'Ludlow rocks' (see Figure 5.2), which formed part of his 'Upper Grauwacke Series' of his Silurian System below the Old Red Sandstone. Holland *et al.* (1959, 1963) are acknowledged to have undertaken the seminal modern study of the type Ludlow rocks and, as a result, rekindled much academic study of British Silurian geology in general. This research was undoubtedly also spurred on through the informal network of friends of the Silurian, the 'Ludlow Research Group' (itself largely fostered by Holland, Lawson and Walmsley) and by the Silurian Subcommission of the International Commission on Stratigraphy, which, in the 1970s and 1980s (with Holland as Chairman 1976–1984), established the global standards for Silurian stratigraphy.

Holland *et al.* (1963) gave a detailed account of the history of study of the (type) Ludlow Series. Holland and Bassett (1989 and references therein) documented the work, deliberations and internationally agreed decisions of the Subcommission on Silurian Stratigraphy regarding the stratigraphical framework and internal divisions of the Ludlow and other series of the Silurian System.

There are two stages in the Ludlow Series: the Ludfordian, the base of which is defined at the GCR site called Sunnyhill, and the Gorstian. The base of the Gorstian is coincident with the base of the Ludlow Series and is defined at the GCR site at Pitch Coppice. Stratigraphically, the latter level approximates to the lower boundary of Murchison's (1834) 'Lower Ludlow rock', which he recognized as overlying the 'Wenlock and Dudley limestones'. In contrast, the exact position of the upper limit to the Ludlow Series (base of the overlying 'Downtonian' unit) and hence the position of the 'Silurian–Old Red Sandstone boundary' (White, 1950) has been a matter of greater contention for more than 150 years (see Holland *et al.*, 1963 for discussion; also Bassett *et al.*, 1982; Holland and Bassett, 1989; and Miller, 1995). Notwithstanding that local debate, historically and with reference to key sections in the Welsh Basin, the top of the Ludlow Series was generally accepted internationally to be the top of the Silurian System itself. However, at the time (1960) of the 'Bonn–Brussels Symposium' on Silurian and Devonian stratigraphy it was beginning to be more widely realized, on the basis of a labyrinth of trans-European correlation, that there was a top series 'missing' from the Silurian System. This fact was formally endorsed when the Silurian Subcommisson established the Přídolí as the fourth and youngest series of the Silurian. By a happy twist of fate, correlation of the base of the Přídolí, the basal boundary stratotype of which is located in the Czech Republic (see Holland and Bassett, 1989), lies at or close to the base of the Downton Group of the Welsh Basin. In other words, there is no measurable time (biozonal) gap represented in the basal Downton Group Ludlow Bone Bed Member of the Welsh Basin (see Bassett *et al.*, 1982; Siveter, 1989; Hansch and Siveter, 1994; Miller, 1995 and references therein); however, some authors (Miller *et al.*, 1997, Viira and Aldridge, 1998) suggest that the latest Ludlow may possibly be missing from the shelf sections of the Welsh Borderland.

OCCURRENCE

The Ludlow Series occurs in Wales, the English Midlands, the Lake District and in southern Scotland (see Cocks *et al.*, 1992). Some of the Silurian that occurs subsurface below eastern England is also of Ludlow age (Woodcock and Pharaoh, 1993).

The Ludlow is mostly or entirely complete in many of the Silurian sequences in the Welsh Basin, such as those in the English Midlands, the Welsh Borderland and much of southern Wales. The Ludlow is absent in the Mendips Inlier and the Haverfordwest area (in both, Upper Palaeozoic rocks rest on Wenlock strata) and does not crop out in western Wales (Cardigan Bay) and many parts of central Wales (Rhayader–Abby–Cwmhir). In northern Wales (Llangollen and Denbigh–Conway areas) approximately the upper part of the Ludlow is absent. Much or all of the Ludlow is also missing from most of the Silurian sequences in the Lake District Basin, such as in the western Lake District (Coniston to Ashgill), the Howgill Fells, Cross Fell and at Horton-in-Ribblesdale; however, the central

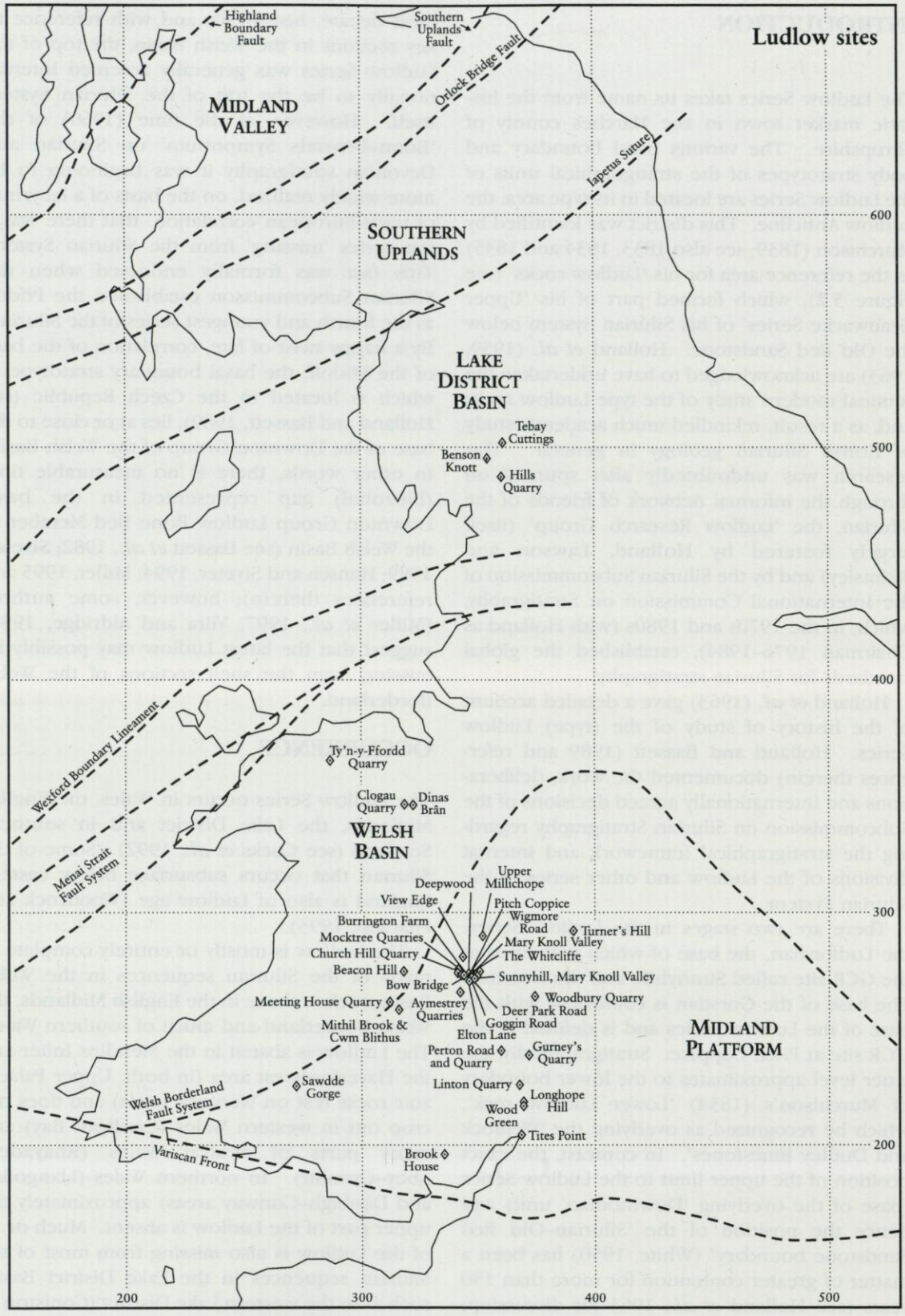
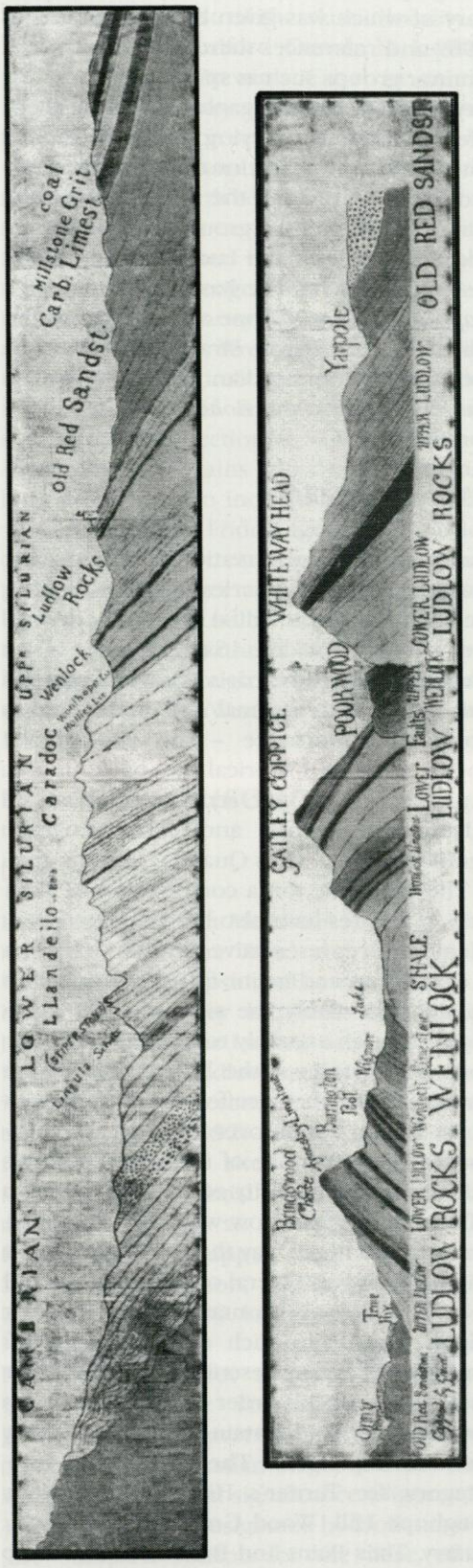


Figure 5.1 Distribution of the Geological Conservation Review sites for the Ludlow Series, set against the palaeogeographical elements of Silurian Britain.



Lake District (Windermere area) has a full Ludlow succession.

The Ludlow Series is, at best, poorly represented in Scotland. In the Southern Uplands and nearby Girvan and Craighead areas the Ludlow is missing and post-Silurian Old Red Sandstone rests on deposits of Llandovery (Craighead) and Wenlock age. The various Midland Valley Silurian inliers (Lesmahagow, Hagshaw Hills, Carmichael, Pentland Hills), just to the north of the Southern Uplands Fault, have proven lower Silurian sequences but it is problematic whether or not younger (lower Ludlow) Silurian rocks are present. Equally, the existence of Ludlow in the Stonehaven Group, which crops out immediately south of the Highland Boundary Fault, is debatable: its fish and arthropod-bearing strata are, traditionally, supposed correlatives of the Downton Group (Přídolí) of the Welsh Borderland, but palynological evidence suggests that at least part of the sequence is of late Wenlock to early Ludlow age (Marshall, 1991; Wellman, 1993).

PALAEOENVIRONMENTAL SETTING

The Ludlow sediments of Wales and the English Midlands were deposited in the Welsh Basin, situated mostly to the west of the Midland Platform microcraton that today underlies much of central England (see Siveter *et al.*, 1989; Bassett *et al.*, 1992; and Chapter 1 and Figure 5.1, this volume, for palaeogeography of the Ludlow of Britain). Coeval strata in the Lake District accumulated in another, slightly more outboard sedimentary basin, which can be traced south-westwards into parts of Ireland. The early Palaeozoic Anglian Basin, detected subsurface below parts of southeast England, the East Midlands and East Anglia, was also a depositional basin during Ludlow times. The Ludlow was, overall, a time of shallowing seas in the Welsh and Lake District

Figure 5.2 Geological cross-sections drawn by Sir Roderick Murchison for a lecture given in 1852 to the Ludlow Natural History Society and now housed in Ludlow Museum. The upper section runs from east to west, from the Cambrian of Wales, through Murchison's 'Lower Silurian' (now Ordovician) of the Stiperstones area of Shropshire and beyond to Ludlow Castle, to the Old Red Sandstone and, ultimately, the Carboniferous of the Clee Hills to the north-east of Ludlow. The lower section runs north–south, from Bromfield just north of Ludlow, across the Ludlow Anticline and into Herefordshire.

basins, both of which gradually silted up during that period.

The Ludlow of these areas represents mostly marine deposition across a wide range of palaeoenvironmental conditions and bathymetries, from platform to basin margin and true basinal settings. For example, in the Welsh Basin the Ludlow Series includes shell-rich shelf clastics and coral-bearing carbonate banks, submarine channel and slope apron deposits, deeper-water turbidites and associated graptolitic hemipelagites, deltaic sediments and even terrestrial red beds. Many of the major lateral lithofacies changes reflect shelf to basin transitions, and are typically associated with substantial changes in biota and thickness of sediments. Evidence of igneous activity in the Ludlow of Britain is particularly scarce, being confined to tell-tale degraded volcanic ash bands (bentonites).

Overall, the late Ludlow to early Přídolí interval witnessed the transition from marine to quasi-marine and ultimately to terrestrial conditions (Old Red Sandstone facies) in the Welsh and Lake District depositional basins. This change, charted in lithofacies and faunas and floras, marks the demise of the Iapetus Ocean. It is dramatically signalled in the occurrence, in the late Silurian of the Welsh Basin, of the earliest global stratigraphical record of land animals which, moreover, are associated with early vascular land plants. However, this important palaeoenvironmental shift was not coeval throughout Britain. For example, the transition occurred much earlier (variously, Wenlock to early Ludlow) in sequences in the Midland Valley of Scotland and even in parts of the Welsh Basin (south-western Wales).

BIOSTRATIGRAPHY

In its marine facies the Ludlow Series is highly fossiliferous in many areas of its occurrence in Britain, particularly in sediments that reflect relatively shallow-water settings. Virtually all forms of Silurian macro- and microbiota are represented.

In its type area the Ludlow Series is subdivided and correlated largely on the basis of a succession of brachiopod dominated, shelly-rich assemblages (Holland *et al.*, 1963). Acritarchs, conodonts, chitinozoans, ostracods and, most notably, graptolites also facilitate various formal and informal, and low to high resolution biostratigraphical schemes for the Ludlow, a summary of which was given by Lawson and White (1989 and references therein). Locally, relatively minor groups such as spores and even fish are very useful in biostratigaphy. All of these groups offer, though to varying extents, value and potential for international correlation of the Ludlow; in particular, the full correlative worth of various microfossil groups has yet to be realized. The base of the Ludlow in the type area lies at or close to the base of the *Neodiversograptus nilssoni* Biozone and the last true graptolites in the British stratigraphical sequence occur in the Ludfordian of the Welsh Basin, where they form the *Bohemograptus* proliferation Biozone.

SITE SELECTION

The Geological Conservation Review network of sites for the Ludlow Series has been built up by the selection of individual sites by many workers over several decades. Sites (Figure 5.1) have been selected on the basis of several types of criteria: their international and/or national stratigraphical importance – for example, Pitch Coppice; their historical or palaeontological (e.g. Beacon Hill) or sedimentological and/or palaeoenvironmental and palaeogeographical significance (e.g. Hills Quarry); or, as in the case of The Whitcliffe, on a combination of such criteria. The sites have also been selected in order to embrace representative localities of the basins of deposition and major facies of the Ludlow of Britain. Inevitably the sites selected acknowledge – though arguably to a numerically disproportionate degree – the historical and nomenclatural importance proffered to localities in the Welsh Basin. Moreover, in part as a consequence of the nature of the type Ludlow sediments, the vast majority of selected Ludlow sites reflect relatively shallow water shelf settings.

As a result of the way the site boundaries were originally drawn, several of the sites treated here as Ludlow sites also contain small thicknesses of Přídolí strata. In such cases deposits of the younger series are described together with the Ludlow deposits in order to provide a complete coverage and to maintain scientific integrity for the sites in question. The sites that fall into this category are Turner's Hill, Woodbury Quarry, Longhope Hill, Wood Green, Perton Road and Quarry, Tites Point and Brook House; the basal Přídolí at such sites includes the local equivalent

of the famous Ludlow Bone Bed Member. The main scientific interest of the classic locality of Ludford Lane and Ludford Corner in Ludlow, Shropshire and of Brewin's Canal in central England, clearly focuses on Přídolí deposits (rather than the also present Ludlow rocks) and, therefore, these sites are treated alongside the other sites of the fourth series.

In addition to those occurring at the GCR sites detailed in this chapter, Ludlow strata are also present within the geographical boundaries of certain Wenlock (Rumney River, River Irfon, Ty Mawr, Trewern Brook, Wren's Nest and Marloes) and Přídolí (Capel Horeb Quarry, Lower Wallop Quarry, Albion Sands and Gateholm Island) sites. The Silurian section at Sawdde Gorge in southern Wales contains mostly Wenlock and Ludlow strata but also includes deposits of late Llandovery and basal Přídolí age; in this particular case the locality is treated as two sites, one of which appears together with Wenlock sites and the other with the Ludlow sites. The Linton Quarry site, in the southern Welsh Borderland, exposes Wenlock through to basal Přídolí and is described in both the Wenlock and Ludlow parts of this volume.

PITCH COPPICE (SO 4723 7298)

Introduction

This disused quarry in Mortimer Forest is 35 m south of the Wigmore Road and about 4 km WSW of Ludlow, Shropshire (Figures 5.3, 5.6). It is one of several key localities defining the stratigraphy of the type Ludlow Series in an anticline south-west of Ludlow itself (Holland *et al.*, 1959, 1963 and references therein; see also Cocks *et al.*, 1971, 1992). Pitch Coppice is also one of 13 managed sites which, collectively, closely parallel the axial trace of the Ludlow Anticline and provide an educational trail summarizing the local upper Wenlock to lower Přídolí geology (Lawson, 1977b, locality 3; see also Siveter *et al.*, 1989, locality 3.3c, Jenkinson, 1991, locality 3).

The locality exposes the top of the Much Wenlock Limestone Formation (Homerian Stage) and the lower part of the overlying Lower Elton Formation (Gorstian Stage) and has international stratigraphical significance (Figures 5.4, 5.5). In 1963 it was designated by Holland *et al.* as the standard section for the base of the Ludlow Series, the (then) Eltonian Stage and the

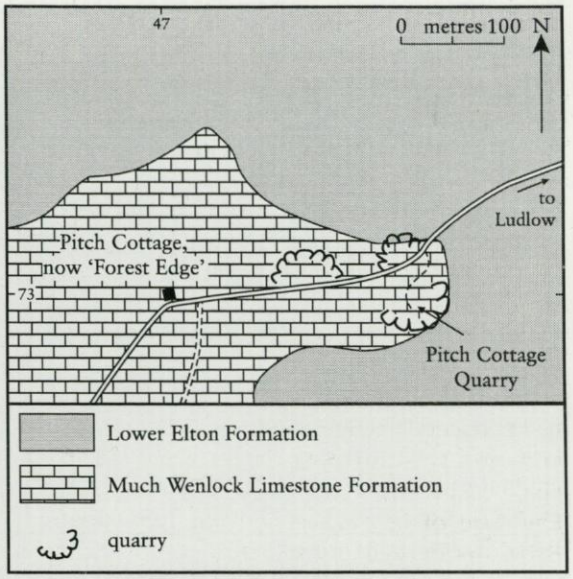


Figure 5.3 Location of Pitch Coppice, Wigmore Road, near Ludlow Quarry, Shropshire (after Lawson and White, 1989).

Lower Elton Beds. This decision was endorsed when the Subcommission on Silurian Stratigraphy of the International Commission on Stratigraphy (IUGS) selected the locality as the global boundary stratotype section for the base of the Ludlow Series and the coincident base of the Gorstian Stage (Bassett *et al.*, 1979; Holland, 1980a, b; Holland *et al.*, 1980; Martinsson *et al.*, 1981; see Lawson and White and other papers in Holland and Bassett, 1989). At Pitch Coppice this level is drawn at the base of lithological unit F of Holland *et al.* (1963), a horizon there coincident with the base of the Lower Elton Formation (Elton Group). Pitch Coppice is also the nominated standard basal boundary reference section for the latter lithostratigraphical unit (Holland *et al.*, 1963; Lawson and White, 1989).

Description

As seen, the Much Wenlock Limestone Formation consists of 3.35 m of grey, sparsely fossiliferous, predominantly nodular limestones with occasional thin shale partings. About 1 m above the base of the section a prominent, soft, calcareous shale (0.20 m) forms a marked erosional recess in the limestone. The Lower Elton Formation (1.76 m seen), in which shells and corals are more obviously present, consists of shaly siltstones with thin, impersistent limestone

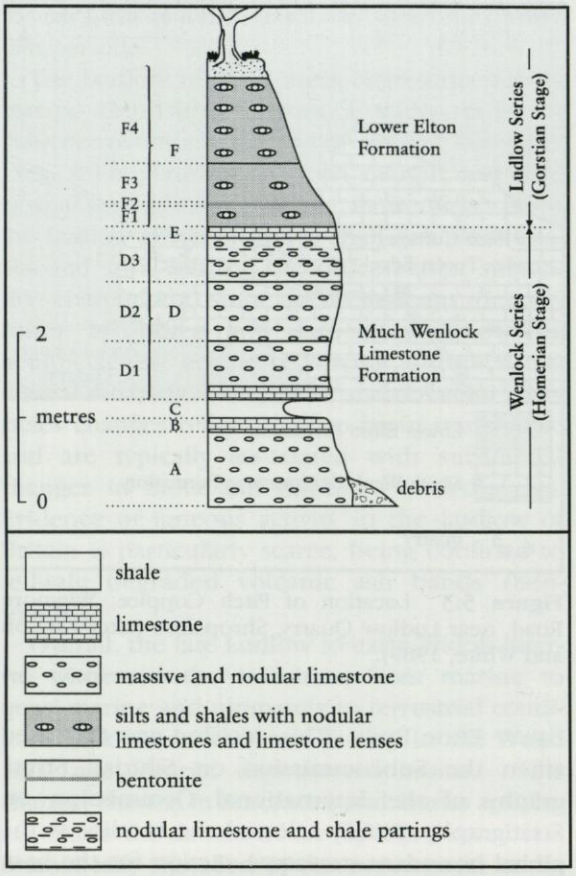


Figure 5.4 The boundary stratotype section for the base of the Ludlow Series and the base of the Gorstian Stage at Pitch Coppice, Wigmore Road, near Ludlow (Holland *et al.*, 1963; diagram after Lawson and White, 1989; both papers describe lithological divisions A–F).

lenses and nodules; 0.25 m above the formational boundary is a thin clay (bentonite) band. All strata are gently dipping (5–10°) in a generally easterly direction.

The lithological change from the Wenlock limestones to the fine clastics of the Elton beds is mirrored by a more gradual macrofaunal change from a coral–large brachiopod dominated assemblage to a characteristically small brachiopod dominated fauna in the early Ludlow (Holland *et al.*, 1963; Lawson and White, 1989). The Wenlock has yielded a diverse fauna of solitary and compound corals *(Favosites, Heliolites, Thecia),* bryozoans, brachiopods (e.g. *Atrypa reticularis, Gypidula galeata, Leptaena depressa, Resserella elegantula, Sphaerirhynchia wilsoni, Strophonella euglypha),* gastropods *(Poleumita),* trilobites *(Dalmanites myops)* and crinoid columnals. Much of the Lower Elton Formation fauna is fragmented and includes many relict Wenlock forms such as *Atrypa, Leptaena, Resserella* and *Calymene.*

Both formations at Pitch Coppice have a sparse conodont fauna (Aldridge and Smith, 1985), consisting mostly of the long ranging *Ozarkodina excavata* and *Panderodus equicostatus.* As with the conodonts, neither ostracods (Siveter, 1978, 1989; see also Lawson and White, 1989) nor chitinozoans (Sutherland, 1994) are precise indicators of the base of the Ludlow Series in the type Wenlock and Ludlow areas and miospores are extremely rare (see Lawson and White, 1989). Sutherland's (1994) informal chitinozoan Biozone 1 extends from within the Much Wenlock Limestone Formation to almost 15 m into the Lower Elton Formation. Several chitinozoan taxa, especially species of *Conochitina*, and sparse beyrichiacean ostracods range across the series boundary at Pitch Coppice itself. Scolecodonts also occur, most abundantly in the recessive calcareous shale horizon in the Much Wenlock Limestone Formation. Acritarchs are common at the Wenlock–Ludlow boundary stratotype: the junction between acritarch biozones W3 and L1 of Dorning is drawn at 0.6 m above the base of the Ludlow (Dorning, 1981b and pers. comm. in Lawson and White, 1989; see also Lister, 1970), but high resolution sampling has demonstrated an overlap of these two biozones (Mullins, 1996). Brachiopods and trilobites have also been documented from the quarry (Bassett, 1970a; Thomas, 1978).

The only graptolites documented from Pitch Coppice are fragments of ?*Saetograptus varians* and ?*Neodiversograptus nilssoni* from 0.03 m and 0.23 m, respectively, above the base of the Ludlow (White, 1981). However, scarce finds of graptolites in the type Wenlock and Ludlow rocks are consistent with the conventional notion (Holland *et al.*, 1969) that the base of the Ludlow Series lies close to the base of the *N. nilssoni* Biozone (evidence summarized in Lawson and White, 1989, pp. 81–2), and that graptolites hold the best potential of any group of fossils for the international correlation of the global stratigraphical section point.

Interpretation

The lithological sequence exposed at Pitch Coppice is typical of the uppermost Wenlock–

Figure 5.5 The boundary stratotype section for the base of the Ludlow Series and the base of the Gorstian Stage at Pitch Coppice, Wigmore Road, near Ludlow, Shropshire (for lithologies see Figure 5.4). (Photo: Jane Washington-Evans.)

lowest Ludlow of the Ludlow area. It represents carbonate and mud deposition on the mid- to outer part of a relatively shallow water, mid Silurian shelf of the Midland Platform, a stable microcraton that occupied much of the present day Welsh Borderland and contiguous areas, in central England (e.g. Bassett, 1974a; Siveter *et al.*, 1989, fig. 8; Bassett *et al.*, 1992, figs S3b, S4a). The presence of corals and other colonial organisms in the Wenlock rocks attest to prevailing modest water depths, but the absence of Wenlock age reefs in the vicinity of Ludlow suggests that that area was sited closer to shelf edge than the reef-rich deposits of Wenlock Edge (Bassett, 1974a, 1989a; Bassett *et al.*, 1975) some 10–30 km to the north.

The shift from carbonate to mud deposition across the Ludlow–Wenlock boundary is conventionally interpreted as a result of a change in sea level. Johnson *et al.* (1991) believed that a global rise in sea level occurred in latest Wenlock–early Ludlow times. Based on evidence from brachiopod dominated benthic communities Hurst (1975a, b) claimed that this was a rapid, eustatic event the inception of which is detected in the rock record about 3 m above the boundary itself. In contrast, Bassett (1976) argued that the transgression represented a gradual deepening because of local subsidence of the shelf. Recent opinion has such Silurian facies shifts related to episodic changes in climate and oceanic state (Jeppsson, 1990; Jeppsson *et al.*, 1995); indeed, both carbon isotope and palynofacies analysis of the stratotype section indicate a Wenlock–Ludlow series boundary event (Corfield *et al.*, 1992; Mullins, 1996).

The other GCR sites that display the Wenlock–Ludlow boundary in the Welsh Basin, either in shelf, basin margin or basinal settings are Easthope–Harley Hill (Shropshire), Wren's Nest (West Midlands), Linton Quarry (Gorsley Inlier), Gurney's Quarry (Ledbury area), Cwm-Ton Farm (Usk Inlier), Rumney River (Cardiff), River Irfon (Builth), Sawdde Gorge (near Llandeilo), Marloes (Pembrokeshire), Trewern Brook (Long Mountain) and Ty Mawr (Denbigh Moors).

Conclusions

Pitch Coppice is a site of international importance in stratigraphy. It is the internationally agreed site for defining the base of the Ludlow Series, and the coincident base of the Gorstian

Stage. As such it represents a globally unique locality at which a major time plane is drawn in the rock record of Earth history and is the standard succession against which all deposits of possible similar age should be correlated. The locality is also the basal boundary stratotype section for the Lower Elton Formation.

Its international scientific importance is reflected in the fact that the locality is studied by geological parties of all kinds, particularly researchers. The locality has been maintained and improved by the (then) Nature Conservancy Council, English Nature and the Marches Forestry District of the Forestry Commission and needs to be conserved rigorously.

WIGMORE ROAD (SO 4777 7329–SO 4981 7430)

Introduction

This site has previously appeared in GCR documentation under the name 'Ludford Lane Section, Mortimer Forest'. The appellation Wigmore Road is both more appropriate and prevents confusion with the famous section at 'Ludford Lane' itself (see Chapter 6), which is actually the terminal part of the road to Wigmore. The site consists of a series of small localities in the type area of the Ludlow Series, in the anticline south-west of Ludlow, Shropshire. Most of the exposures are either fenced quarries or excavations along the south side of the road from Ludlow to Wigmore (Figure 5.6). Elton, Bringewood, Leintwardine and Whitcliffe groups are represented.

The outcrops were key localities detailed in Holland *et al.* (1959; 1963, p. 126, fig. 8), research that established a modern stratigraphy for the Ludlow Series. None of the sites is designated basal boundary or body stratotypes, but each one is a locality of the Mortimer Forest Geological Trail (MFGT: Lawson, 1977b; Jenkinson, 1991), which aims to demonstrate an overview of the type Ludlow sequence for general educational purposes. Other, stratotype localities in this trail are the GCR sites at Pitch Coppice, The Whitcliffe and Ludford Lane and Ludford Corner. The Wigmore Road exposures are also described in a field guide to the Silurian of the Welsh Basin (Siveter *et al.*, 1989 locality 3.3) and are placed in regional context in Lawson and White's (1989) summary of the type Ludlow.

The macrofaunas of these localities are documented in Holland *et al.* (1963), Lawson (1977b) and Lawson and White (1989). Conodont (Aldridge and Smith, 1985) and acritarch and chitinozoan assemblages (Lister, 1970) have also been recovered from all of the exposures.

Description

The localities are near and parallel to the axial trace of the Ludlow Anticline for about 3 km; all beds dip gently north-west.

The stream-bank adjacent to the forestry track at the top of Mary Knoll Valley, in Mortimer Forest, exposes olive mudstones of the Middle Elton Formation (SO 4777 7329; Holland *et al.*, 1963, locality 17). The outcrop is very close to MFGT trackside locality 4 (SO 4775 7315) of the same horizon. The mudstones contain *Dalmanites*, brachiopods, orthoconic nautiloids and the graptolites *Neodiversograptus nilssoni* and *Saetograptus colonus*.

At the side of the forestry track at Gorsty, north of the Wigmore Road, exposures and an extended excavation display a long strike section of the Upper Elton Formation (SO 4789 7357 to SO 4760 7350; Holland *et al.*, 1963, locality 18 to MFGT locality 5). These evenly bedded, flaggy, calcareous siltstones contain a restricted, but relatively rich and mostly pelagic macrofauna. Nautiloids and the graptolite *Pristiograptus tumescens* are common; rarer associates include the conodonts *Panderodus* and *Ozarkodina excavata*, a few small brachiopods species such as *Lingula lata* and *Shagamella ludlovienisis*, and the bivalve *Cardiola interrupta*. The beds also yield palynomorphs.

The roadside quarry at SO 4828 7377 (Holland *et al.*, 1963, locality 19; MFGT locality 6) exposes olive calcareous siltstones of the Lower Bringewood Formation. The beds show undulating partings and are in some cases nodular. The modestly abundant macrofauna consists mostly of broken brachiopod shells; for example, *Leptaena depressa*, *Leptostrophia filosa*, *Mesopholidostrophia lepisma*, *Shagamella* and *Shaleria*. Fragmentary conodonts of the genera *Kockelella*, *Ozarkodina* and *Panderodus*, the trilobite *Dalmanites*, acritarchs and an unstudied ostracod fauna are also present.

The Upper Bringewood Formation, which forms a distinctive topographical scarp in the Ludlow Anticline, crops out at the roadside

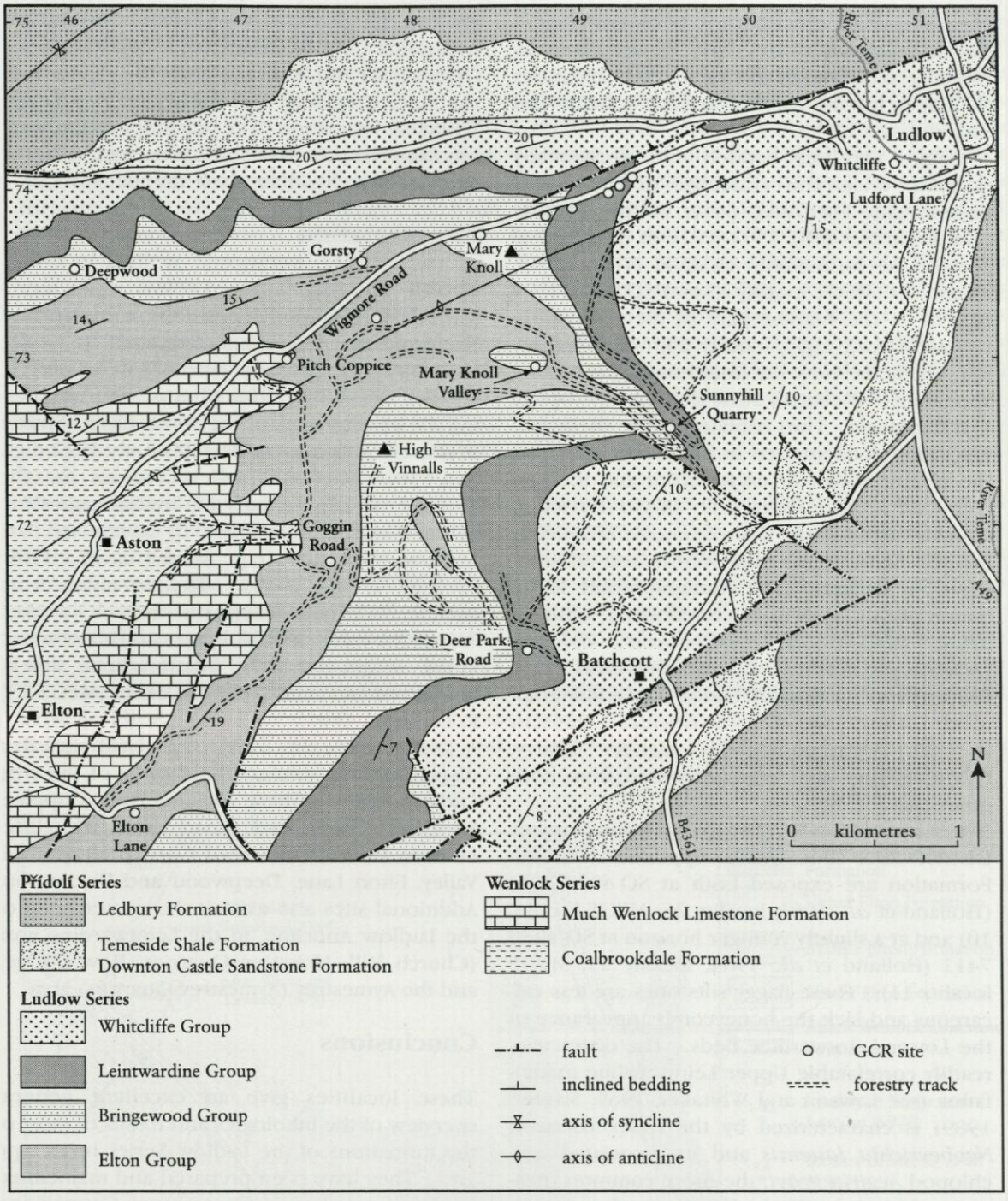


Figure 5.6 Map of the geology south-west of Ludlow, showing GCR sites along the Wigmore Road and elsewhere in the eastern part of the Ludlow Anticline (after Holland *et al.*, 1963; Lawson, 1977; Lawson and White, 1989).

locality at SO 4874 7389 (Holland *et al.*, 1963, locality 23; MFGT locality 7). More nodular, calcareous and harder than the Lower Bringewood Formation, it is also distinguished by having solitary and colonial corals *(Heliolites, Favosites, Rhabdocyclus)* and banks of the brachiopod *Kirkidium*. Other brachiopods present are *Atrypa reticularis*, *Gypidula lata*, *Leptaena depressa* and *Strophonella euglypha*. This locality has also yielded palynomorphs and abundant

specimens of the conodonts *Ozarkodina confluens, Ozarkodina excavata, Panderodus unicostatus* and *Panderodus recurvatus* and rarer *Kockelella variabilis, Ozarkodina scanica* and *Oulodus* sp..

Flaggy, regularly bedded and occasionally nodular, calcareous siltstones of the Lower Leintwardine Formation occur in the roadside quarries at SO 4887 7392 (*c.* 10 m of the basal part of the formation: Holland *et al.*, 1963, locality 24; MFGT locality 8) and SO 4912 7399 (*c.* 6 m of the highest part of the Formation: Holland *et al.*, 1963, locality 25; MFGT locality 9). The beds show the honeycomb weathering appearance so characteristic of local outcrops of that formation. They contain diverse shelly faunas, often concentrated in bands; for example, the bivalve *Fuchsella amygdalina* and the brachiopods *Atrypa reticularis, Dayia navicula, Isorthis orbicularis, Microsphaeridiorhynchus nucula, Shagamella ludloviensis* and *Sphaerirhynchia wilsoni*. The stratigraphically lower quarry yields abundant conodonts: *Ozarkodina*, *Panderodus*, *Distomodus*, *Pelekysgnathus*, *Oulodus*, *Pseudooneotodus* and *Decoriconus*. The early Ludfordian zonal graptolite *Saetograptus leintwardinensis* is present in the stratigraphically higher quarry. Palynomorphs have been recovered from both quarries.

Just west of the Forestry Commission Marches District Office about 3 m of Upper Leintwardine Formation are exposed both at SO 4922 7408 (Holland *et al.*, 1963, locality 26; MFGT locality 10) and at a slightly younger horizon at SO 4930 7411 (Holland *et al.*, 1963, locality 27; MFGT locality 11). These flaggy siltstones are less calcareous and lack the honeycomb appearance of the Lower Leintwardine beds. The distinctive, readily correlatable Upper Leintwardine macrofauna (see Lawson and Whitaker, 1969; Siveter, 1989) is characterized by the index ostracod *Neobeyrichia lauensis* and its associated brachiopod *Aegiria grayi*, the more common presence of bivalves (*Fuchsella*, *Goniophora*), gastropods (*Bembexia*), annelids (*Serpuloides*) and the brachiopods *Salopina lunata* and *Protochonetes ludloviensis*, and by the acme of the trilobites *Alcymene puellaris* and *Encrinurus stubblefieldi.*

As seen at the quarry at SO 4981 7430 (Holland *et al.*, 1963, locality 28; MFGT locality 12), some 1.5 km west of Ludlow, the loss of many brachiopod, trilobite and graptolite genera and the increased abundance of orthoconic nautiloids (e.g. *Kionoceras, Leurocyloceras, Orthoceras*) and bivalves signals the change into the more irregularly and thicker bedded Lower Whitcliffe Formation. The brachiopods *Camarotoechia*, *Protochonetes*, *Salopina* and, to some extent, *Dayia* maintain their abundances.

Interpretation

Overall, this sequence of Ludlow strata represents shallow marine deposition on the Midland Platform, the storm affected shelf (e.g. see Holland and Lawson, 1963; Watkins, 1979; Watkins and Aithie, 1980; Cherns, 1988) bordering the eastern flank of the Welsh Basin (Siveter *et al.*, 1989, figure 10; Bassett *et al.*, 1992, figs. S4a–S5b). General sea-level curves for the Ludlow indicate an early Ludlow transgression (Elton Group) superseded by a mid- to late Ludlow regression (e.g. Siveter *et al.*, 1989; Johnson *et al.*, 1991). The transition from marine Whitcliffe deposits into Old Red Sandstone facies of Přídolí age can be examined at the eastern end of the Wigmore Road; that is, at Ludford Lane and Ludford Corner (MFGT 13) at Ludlow.

Locally there are many other GCR sites that display various stratigraphical units of the type Ludlow Series. These include Pitch Coppice, Sunnyhill, Deer Park Road, The Whitcliffe, Ludford Lane and Ludford Corner, Mary Knoll Valley, Elton Lane, Deepwood and Burrington. Additional sites also exist at the western end of the Ludlow Anticline, in the Leintwardine area (Church Hill, Mocktree Quarries, Bow Bridge) and the Aymestrey (Aymestrey Quarries) area.

Conclusions

These localities give an excellent general overview of the lithologies and fossils of most of the formations of the Ludlow Series in its type area. They have been prepared and maintained by the former Nature Conservancy Council and the Forestry Commission in order to cater for the large number of geological parties that visit the region for teaching purposes. They are a valuable educational resource and have the added value of relieving the formally designated stratotype sections (many of which are situated in the subsequently made forestry tracks in Mortimer Forest) from casual and less research-based overuse.

GOGGIN ROAD (SO 4720 7189–SO 4765 7170)

Introduction

These uppermost Wenlock and lower Ludlow outcrops are on the south and east sides of a forestry track on the SSW slopes of High Vinnalls, Mortimer Forest, about 3 km southwest of Ludlow, Shropshire (Figures 5.6, 5.7). Cut in the 1960s by the Forestry Commission, the section was not available for study at the time of the seminal research on the Ludlow rocks of the Ludlow Anticline (Holland *et al.*, 1963). The stratigraphy of Goggin Road was noted by Lawson (1973a) and detailed by White and Lawson (1978). The sequence also features in an account of the global standard for the Silurian System (Lawson and White, 1989) and in field guides (Bassett *et al.*, 1979; Siveter *et al.*, 1989, locality 3.4).

Goggin Road was chosen for many of the reference horizons of the standard Ludlow Series. It contains the designated basal boundary stratotype for the Upper Elton Formation (SO 471 711); basal boundary reference sections for the Lower Elton (SO 4727 7184) and Lower Bringewood (SO 4765 7183) formations; and body stratotypes for the Lower (SO 4732 7178), Middle (SO 4746 7170 and SO 4747 7160) and Upper (SO 4764 7184) Elton formations (Lawson and White, 1989). With the loss of the original basal boundary stratotype section (near Owney Wood) for the Upper Elton Formation and the degradation of the basal boundary stratotype section (on a forestry path in Mary Knoll Valley) for the Lower Bringewood Formation, in the Ludlow Anticline (Holland *et al.*, 1963), the equivalent stratigraphical sequences on Goggin Road assume particular importance. The basal boundary stratotype for the Upper Elton Formation is a specially excavated (1981) exposure on a branch track of Goggin Road.

Description

The sequence is about 200 m thick and extends over almost 2 km (White and Lawson, 1978; Figure 5.7). Outcrops consist of intermittent, low profile track banks and other excavations; beds dip gently 10°–16° ESE.

The top of the Much Wenlock Limestone Formation occurs in the topographically and stratigraphically lowest part of the section, where its predominantly nodular limestones are succeeded by Lower Elton strata. White and

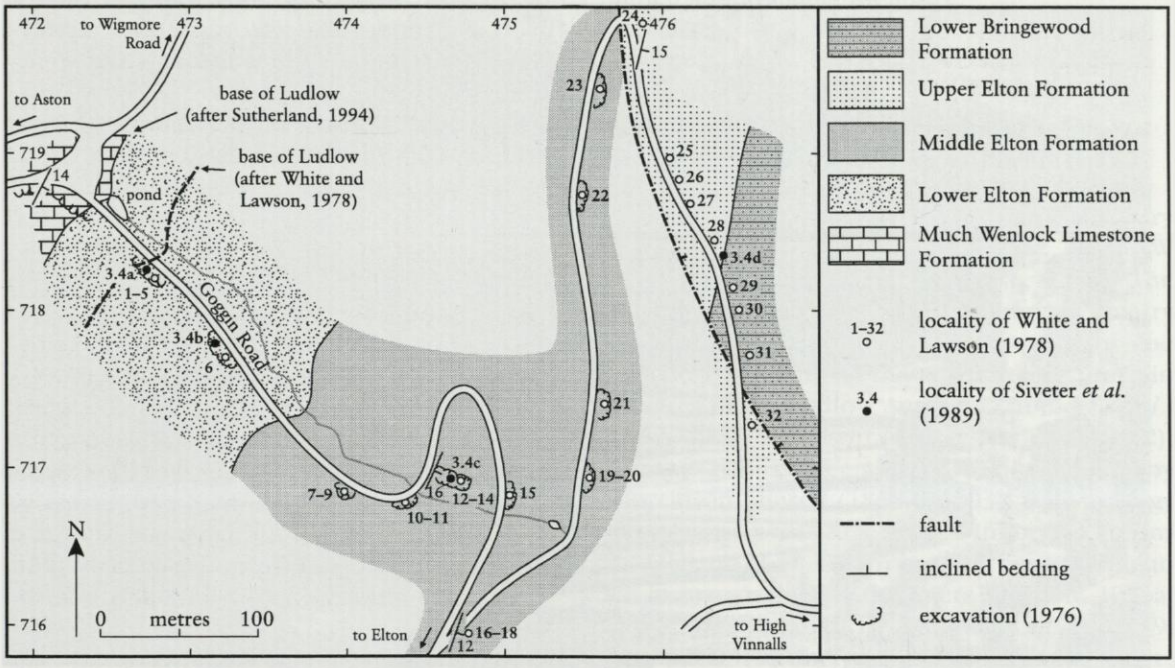


Figure 5.7 Geology of the section along the Goggin Road, Mortimer Forest, near Ludlow, Shropshire (after White and Lawson, 1978, with modifications from Siveter *et al.*, 1989 and Sutherland, 1994).

Lawson (1978) placed the formational boundary at the eastern end of their excavation 'locality A1–5' (SO 4727 7184), a basal boundary reference section for the Lower Elton Formation (Lawson and White, 1989). However, new faunal and lithological evidence has permitted more accurate correlation with the nearby basal boundary stratotype at Pitch Coppice, and the Wenlock–Ludlow junction at Goggin Road is now drawn at an horizon some 11 m stratigraphically lower in the section (SO 4724 7187: Sutherland, 1994; Mullins, 1996).

The Elton Group consists of soft, easily weathered, pale olive-grey mudstones and siltstones with some more calcareous and flaggy horizons. Bentonites are common throughout the Middle and Upper Elton formations, but their provenance is not readily identifiable (Figure 5.8). Graptolites are particularly common: *Saetograptus varians varians*, *Saetograptus chimaera chimaera, Saetograptus chimaera semispinosus, Spinograptus spinosus* and *Pristiograptus dubius* occur in the Middle Elton and, *inter alia*, *Pristiograptus tumescens* is fairly common in the Upper Elton (e.g. SO 4760 7190).

There is a scattered and diverse shelly macrofauna. The Lower Elton (e.g. SO 4732 7178), some 45 m thick, yields the brachiopods *Amphistrophia funiculata, Atrypa reticularis, Craniops implicatus, Dicoelosia biloba* and *Gypidula galeata,* together with *Dalmanites myops* and tabulate and rugose corals. Orthoconic nautiloids, brachiopods such as *Aegiria grayi, Shagamella ludloviensis* and *Lingula lata* and trilobites such as *Dalmanites, Raphiophorus, Acidaspsis* and *Leonaspis* occur in beds of the Middle Elton (*c.* 85 m thick) and/or Upper Elton (partly faulted out; 19 m recorded). The deep cutting in the middle part of the Middle Elton (locality A12–14 of White and Lawson, 1978; SO 4746 7170) is richly fossiliferous and shows several bentonites. Watkins' (1979, p. 259, fig. 23) log of the cutting records a small brachiopod/trilobite dominated *Glassia obovata* association, which includes bivalve, gastropod and ostracod associates.

The faunal change signifying the Elton–Bringewood boundary involves a marked reduction in the abundance of *Pristiograptus tumescens* and the introduction of several brachiopods, especially strophomenids such as *Leptostrophia filosa* and *Leptaena depressa* (see Siveter *et al.*, 1989, fig. 44). Lithologically there is a 2 m transitional sequence, passing into 17 m of hard, irregularly bedded calcareous siltstones of the Lower Bringewood Formation. At the top

Figure 5.8 Middle Elton Formation at White and Lawson's (1978) locality 16–18 along the Goggin Road, Mortimer Forest, near Ludlow, Shropshire: mudstones containing bentonites (whitish horizons). (Photo: Derek J. Siveter.)

of the section faulting cuts out part of the Lower Bringewood strata and re-introduces Upper Elton beds.

The section also contains abundant microfauna and microflora, of which both the chitinozoans and acritarchs (Figures 5.9) feature prominently in the high resolution biostratigraphical and biofacies studies of Sutherland (1994) and Mullins (1996). Ostracods occur through the sequence but are not yet documented.

Interpretation

The rocks at Goggin Road represent marine sedimentation on predominantly the relatively sheltered shelf area of the eastern, Midland Platform margin of the Welsh Basin (see Siveter *et al.*, 1989, figs 8–10; Bassett *et al.*, 1992, figs S3b–S4b; Watkins and Aithie, 1980). The lithofacies changes from the late Wenlock through to the late Gorstian, from carbonate to fine clastic to carbonate-rich clastic regimes, may represent shifts in sea level (e.g. see Hurst, 1975a, b; Bassett, 1976; Dorning, 1981a; Siveter *et al.*, 1989; Johnson *et al.*, 1991). A relatively sharp transgressive event (Much Wenlock Limestone Formation–Elton Group) may have preceded a more gradual and much weaker regressive episode (Upper Elton–Lower Bringewood formations). Alternatively, these lithofacies may be associated with changing climatic and oceanic conditions (Jeppson, 1990; Jeppson *et al.*, 1995). Such changes clearly influenced the palynofacies of the Lower and Middle Elton formations at Goggin Road (Mullins, 1996).

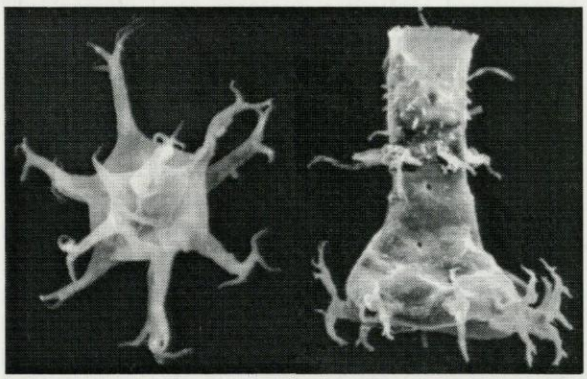


Figure 5.9 The acritarch *Multiplicisphaeridium variable* (Lister, 1970) Dorning, 1981 (left, × 1050) and the chitinozoan *Ancyrochitina gogginensis* Sutherland, 1994 (right, × 320), from the Lower Elton Formation, Goggin Road, Mortimer Forest, near Ludlow. (Photos: G. Mullins.)

Other Welsh Basin GCR sites that contain a Wenlock to early Ludlow sequence occur locally at Pitch Coppice and in the southern Welsh Borderland and east central and southern Wales. These embrace sites that have either platform facies (Pitch Coppice; Linton Quarry, Gorsley Inlier; Gurney's Quarry, Ledbury area; Cwm-Ton Farm, Usk Inlier; Rumney River, Cardiff) or more offshore, basin–basin margin settings (River Irfon, Builth; Sawdde Gorge, near Llandeilo; Trewern Brook, Long Mountain; Ty Mawr, Denbigh area).

Conclusions

Goggin Road has international status in stratigraphy and offers excellent potential for research. Its fossil-rich exposures collectively display perhaps the most complete sequence available through the latest Wenlock and Gorstian in the type area of the Ludlow Series. The section includes a basal boundary stratotype, basal boundary reference sections and body stratotypes for formations in the Elton Group and the Bringewood Group.

The site affords good accessibility and the opportunity to collect through a long sequence embracing most of Gorstian time, but outcrops tend to deteriorate rapidly. In keeping with its importance, the exposures should be maintained and available for study.

SUNNYHILL, MARY KNOLL VALLEY (SO 4950 7255–SO 4973 7244)

Introduction

This site is located adjacent to a track in Mary Knoll Valley, Mortimer Forest, about 2.7 km SSW of Ludlow, Shropshire (Figures 5.6, 5.10). The north-west face of the disused Sunnyhill Quarry contains a section that defines part of the chronostratigraphy of the type Ludlow Series in the area of the Ludlow Anticline (Holland *et al.*, 1959, 1963; see also Cocks *et al.*, 1971, 1992). 'Sunny Hill Bank' was a locality noted by Murchison himself (1839, p. 203). The geology of the quarry was first treated in modern terms by Holland *et al.* (1963) and has been highlighted in many subsequent papers (Lawson, 1973a; White and Lawson, 1978; Bassett *et al.*, 1979; Watkins, 1979; Cherns, 1988; Lawson and White, 1989; Siveter *et al.*, 1989, locality 3.6, figs. 48–50, 47 [*non* 51, in error], 53D).

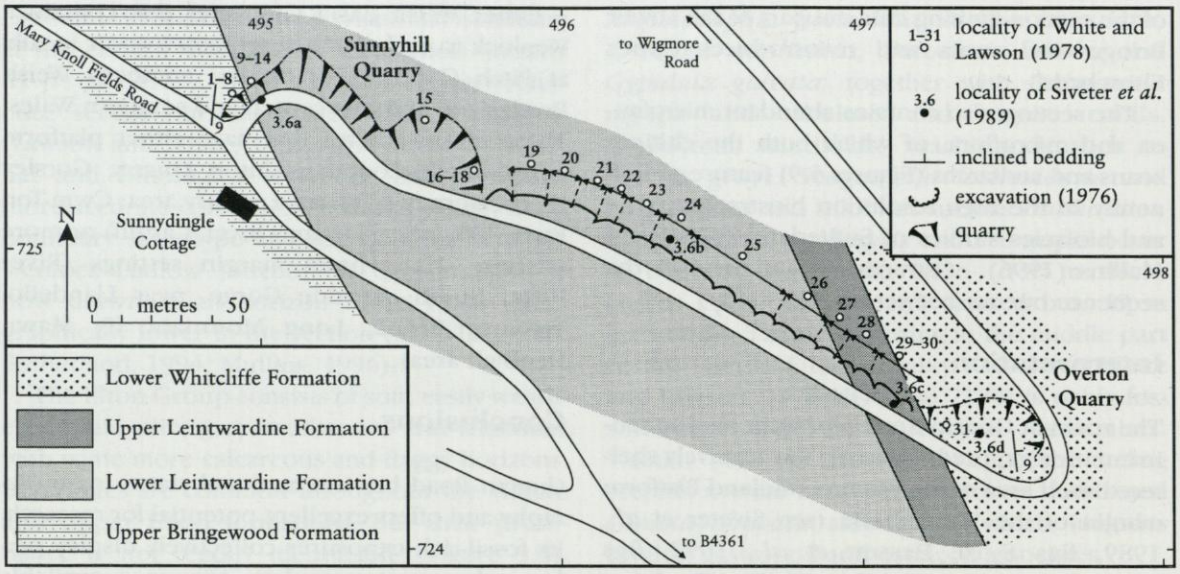


Figure 5.10 Geology of Sunnyhill Quarry and contiguous trackside section, Mary Knoll Valley, Mortimer Forest, near Ludlow, Shropshire (after White and Lawson, 1978, with modifications from Siveter *et al.*, 1989; localities 14 and 31 are repositioned after Lawson and White, 1989, p. 90, fig. 58).

Sunnyhill Quarry (SO 4953 7255) displays the lower part of the Lower Leintwardine Formation (Leintwardine Group, Ludfordian Stage) resting on the underlying Upper Bringewood Formation (Bringewood Group, Gorstian Stage) (Figures 5.10, 5.11, 5.12). Holland *et al.* (1963) designated this section as the standard locality for the base of the then Leintwardinian Stage and the Lower Leintwardine Beds, at a level coincident with the base of their lithological Unit C in the section.

Following rationalization of Ludlow stratigraphy, which established two rather than the previous four stages for the Series, the Subcommission on Silurian Stratigraphy of the International Union of Geological Sciences endorsed the work of Holland and co-workers by selecting Sunnyhill Quarry as the global boundary stratotype section for the base of the Ludfordian Stage, at a level there coincident with the base of the Lower Leintwardine Formation (Bassett *et al.*, 1979; Holland, 1980a, b; Holland *et al.*, 1980; Martinsson *et al.*, 1981; see Lawson and White, 1989). Sunnyhill Quarry is also the nominated standard basal boundary reference section for the latter lithostratigraphical unit (Holland *et al.*, 1963; Lawson and White, 1989). A 20 cm thick bentonite (Bed C4 of White and Lawson, 1978) occurring 3.45 m from the top of the Upper Bringewood Formation in Sunnyhill Quarry has been radiometrically dated at 407 ± 14 Ma (Ross *et al.*, 1982; Bassett, 1984).

The contiguous trackside outcrop to the south-east of the quarry has, for some 250 m, more or less continuous exposure. It displays (Lawson and White, 1989) a body stratotype of the Lower Leintwardine Formation (SO 4950 7255–4969 7246) and a basal boundary reference section and a body stratotype for both the Upper Leintwardine Formation (SO 4969 7246) and, in Overton Quarry, the Lower Whitcliffe Formation (SO 4973 7244).

Description

All strata dip gently ESE. The Upper Bringewood Formation exposure, seen at the western end of the quarry, consists of about 4.7 m of grey, fossiliferous, dominantly nodular silty limestones (the 'Aymestry Limestone' of earlier nomenclature). This facies also characterizes the basal 2.3 m of the Lower Leintwardine Formation, above which the latter consists of some 30 m of relatively thinly bedded, flaggy and laminated calcareous siltstones extending from the quarry itself into adjacent trackside exposures (Figure 5.13). Bed C of Holland *et al.* (1963), forming the basal lithological unit of the Lower Leintwardine Formation, is a 6 mm thick

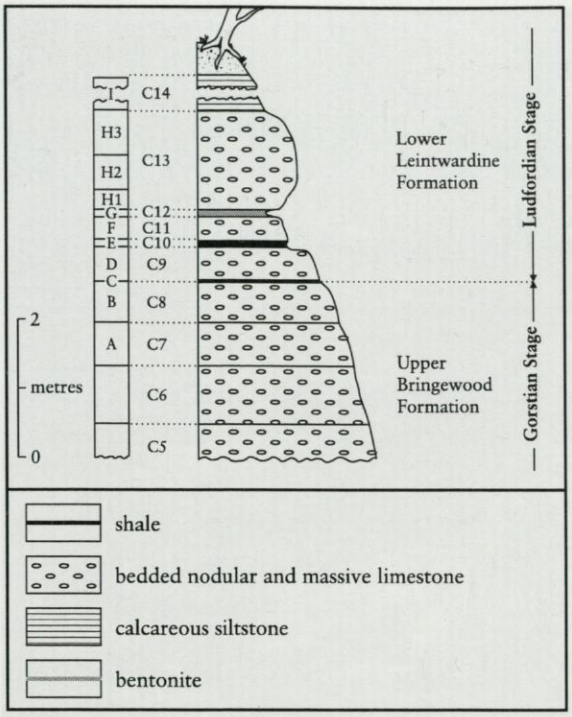


Figure 5.11 Log through the boundary stratotype section for the base of the Ludfordian Stage at Sunnyhill Quarry, Mary Knoll Valley, Mortimer Forest, near Ludlow, Shropshire (after Holland *et al.*, 1963, A–I = lithological divisions; and Lawson and White, 1989, C5–14 = combined locality and collection numbers).

shale parting, 48 cm and 91 cm above which are a 5 cm shale (possible bentonite) and 8 cm bentonite respectively.

Precise faunal definition of the base of the Ludfordian at the stratotype is currently difficult. Bivalve, gastropod, coral, bryozoan and especially (mostly long-ranging) articulate brachiopod species, together with fewer cephalopod, trilobite, graptolite and annelid species, comprise the main, generally diverse macrofaunal assemblages in the two formations at Sunnyhill Quarry (for a full macrofaunal list see Holland *et al.*, 1963; Watkins, 1979; Cherns 1988; Lawson and White, 1989). Although there are clear, overall shelly macrofaunal changes between the Upper Bringewood and Lower Leintwardine formations (see Cherns, 1988; Lawson and White, 1989), such changes are not as marked at Sunnyhill Quarry (partly because of the comparatively sparse nature of its high Upper Bringewood Formation 'residual' assemblages) as elsewhere in the type Ludlow area. Indeed, the macrofaunas 2 m either side the boundary at Sunnyhill Quarry are substantially similar (Holland *et al.*, 1963, p. 143). That said, it should be noted that Watkins (1979, p. 258, fig. 16) logged a faunal change in benthic invertebrates, from his *Mesopholidostrophia laevigata* Association to his *Sphaerirhynchia wilsoni* Association, at a level just below the base of the Lower Leintwardine Formation at Sunnyhill Quarry. Elliott's (1995) study recognized rich palynofloral assemblages at the stratotype section at Sunnyhill Quarry.

Based on shelly macrofossil evidence it is the reduced abundance or disappearance of several species at or just below the base of the Lower Leintwardine Formation that most obviously flags that level at Sunnyhill Quarry (Holland *et al.*, 1963; Lawson and White, 1989). This applies to the brachiopods *Kirkidium knightii*, *Strophonella euglypha* and *Eospirifer radiatus*, the trilobite *Dalmanites myops*, the gastropod *Poleumita globosa* and to solitary rugose (e.g. *Palaeocyclus*) and tabulate (e.g. heliolitid and favositid) corals. Based on local macrofossil correlation the Gorstian–Ludfordian boundary at Sunnyhill Quarry approximates to the base of the *Saetograptus leintwardinensis* Biozone. The latter taxon occurs in the basal parts of the Lower Leintwardine Formation in, for example, the nearby areas of Leintwardine and Aymestrey but is uncommon in the Ludlow area itself until the upper half of the formation (see Lawson and White, 1989). Sparse material of *S. leintwardinensis* subspp. indet. is recorded from various parts of the Lower Leintwardine Formation at Sunnyhill Quarry (Cherns, 1988).

The junction of Dorning's acritarch zones L2 and L3 appears to coincide with the Gorstian–Ludfordian boundary but the stratigraphical details needed to confirm this are not given (Dorning, 1981b, table 1; cf. Lawson and White, 1989, p. 86). The base of chitinozoan Biozone 9 of Sutherland (1994) is drawn at the appearance of his *Gotlandochitina*? sp. A, just below the Gorstian–Ludfordian boundary at Sunnyhill Quarry. Conodont faunas from both formations present at Sunnyhill Quarry are dominated by *Ozarkodina confluens*, *Ozarkodina excavata* and *Panderodus* spp.; the basal Lower Leintwardine Formation also contains *Kockelella variablis* and *Coryssognathus dubius* (Aldridge and Smith, 1985). Although only very sparse ostracods are recorded from Sunnyhill Quarry itself, a fauna with *Neobeyrichia nutans* and *Hemsiella* cf. *loensis* characterizes the Lower

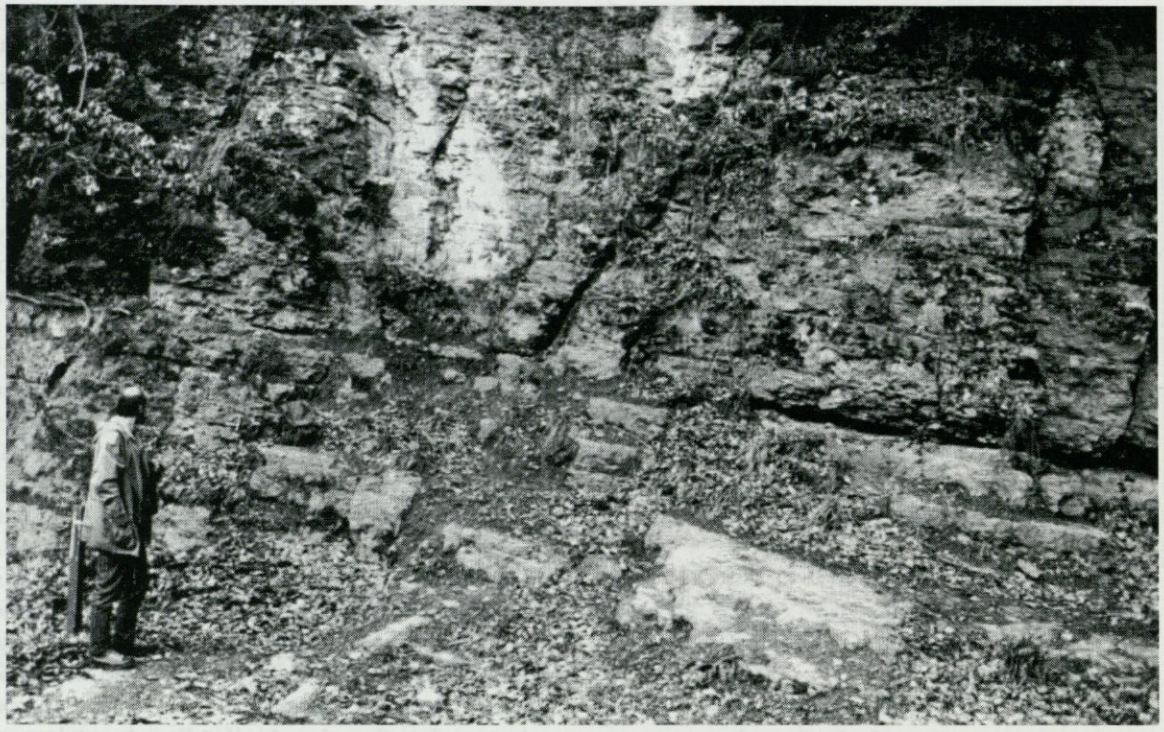


Figure 5.12 The boundary stratotype section for the base of the Ludfordian Stage at Sunnyhill Quarry, Mary Knoll Valley, Mortimer Forest, near Ludlow, Shropshire. The recessed horizon is 'C12' of Figure 5.11. (Photo: David J. Siveter.)

Leintwardine Formation and its correlatives in the type Ludlow and other Welsh Borderland districts and Baltic sequences (Siveter, 1978, 1989; see also Lawson and White, 1989).

Interpretation

The rocks at Sunnyhill represent sedimentation on the relatively shallow-water shelf of the Midland Platform, which occupied much of present day central England and contiguous areas in the Welsh Borderland throughout most of the Silurian (Siveter *et al.*, 1989, fig. 10; Bassett *et al.*, 1992, figs S4b, S5a). To the west lay the deeper areas of the Anglo-Welsh depositional basin.

The Upper Bringewood impure biocalcarenites and calcilutites, yielding brachiopods and corals, are thought to have formed in relatively low to moderate energy, muddy carbonate back-barrier shelf conditions (Watkins and Aithie, 1980). At Sunnyhill Quarry carbonate dominated deposition persists into earliest Ludfordian times and is succeeded by predominantly clastic silt sedimentation, which signals a general lowering of depositional energy levels on the shelf (Cherns, 1988). These calcareous (and in some cases nodular and laminated) siltstones of the Lower Leintwardine Formation reflect subtidal, sometimes storm-influenced, shelf environments with diverse, level-bottom, benthic macro-epifauna. Interbedded with the carbonate-rich muddy silts are mud- and grain-supported skeletal sand, representing lag deposits and episodes of higher current energy (Cherns, 1988).

Many other GCR sites in the Welsh Basin have strata recording the level of the middle Ludlow, Gorstian–Ludfordian boundary; most of these occur in the Welsh Borderland. Those of marine shelf aspect include Goggin Road, Deer Park Road, Wigmore Road, Aymestrey Quarries, Mocktree Quarries and Bow Bridge in the Ludlow to Leintwardine area of Shropshire; Woodbury Quarry in the Abberley Hills; Perton Road in the Woolhope Inlier; Wood Green at May Hill; Linton Quarry at Gorsley; and Turner's Hill in central England. In contrast the Sawdde Gorge section in southern Wales reflects a more basin margin environment.

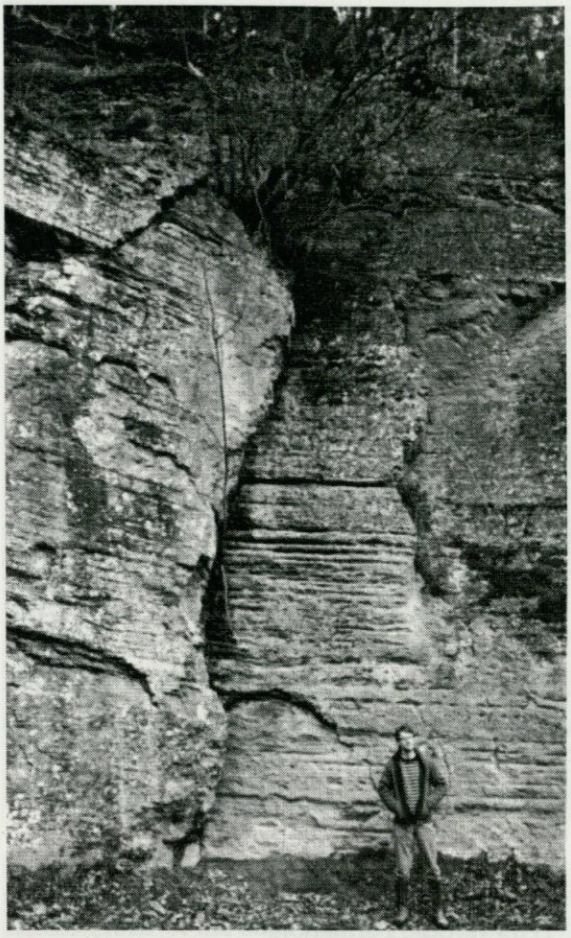


Figure 5.13 Flaggy, calcareous siltstones; Lower Leintwardine Formation, east part of Sunnyhill Quarry, Mary Knoll Valley, Mortimer Forest, near Ludlow, Shropshire. (Photo: David J. Siveter.)

Conclusions

An important time plane in global history is drawn in the fossiliferous marine sediments of Sunnyhill Quarry, a site that provides several important reference sections in type Ludlow stratigraphy. It is a site of international importance.

Sunnyhill Quarry has the global boundary stratotype for the base of the Ludfordian Stage of the Ludlow Series. The quarry is also the basal boundary stratotype section for the Lower Leintwardine Formation. The contiguous track-side sequence exposes a body stratotype of the Lower Leintwardine Formation and basal boundary reference sections and body stratotypes for both the Upper Leintwardine and Lower Whitcliffe formations.

The site is extensively studied by geologists, especially for research purposes. A very high priority should be given to conservation of the site.

DEER PARK ROAD (SO 4845 7135–SO 4899 7111)

Introduction

The exposures occur along the north side of Deer Park Road forestry track, in the Haye Park region of Mortimer Forest, about 2.8 km SSW of Ludlow, Shropshire (Figures 5.6, 5.14). The sequence helps to characterize formations within the Ludlow Series in its type area in the Ludlow Anticline (see Holland *et al.*, 1963). The rocks exposed were first recorded by Lawson (1973a), soon after the Forestry Commission had established a complex of tracks in Mortimer Forest. The stratigraphy of this and the other then new sections was detailed by White and Lawson (1978); Cherns (1988) gave additional data on the Bringewood and Leintwardine groups of Deer Park Road. Most of the Deer Park Road sequence later became designated reference horizons of the standard Ludlow Series (see Lawson and White, 1989) and also featured in field guides to the Silurian (Bassett *et al.*, 1979; Siveter *et al.*, 1989, locality 3.5, figs 45, 46, 51 [*non* 47, in error]).

The site extends for some 550 m and consists of fairly continuous, low bank exposure of fossil-rich strata. It includes body stratotypes for the Lower Bringewood (SO 4850 7128), Upper Bringewood (SO 4852 7122), Lower Leintwardine (SO 4878 7117), Upper Leintwardine (SO 4882 7116) and Lower Whitcliffe (SO 4884 7115) formations and basal boundary reference sections for the Upper Bringewood (SO 4852 7122), Lower Leintwardine (SO 4869 7119), Upper Leintwardine (SO 4882 7116) and Lower Whitcliffe (SO 4884 7115) formations (Lawson and White, 1989). With the deterioration of the original basal boundary stratotype section for the Upper Bringewood Formation (see GCR site report for Deepwood, in the Bringewood Chase part of the Ludlow Anticline; Holland *et al.*, 1963), the equivalent sequence on Deer Park Road assumes added importance.

Description

The section shows a total thickness of about 84 m; all beds dip gently, 10–15° ESE (White and

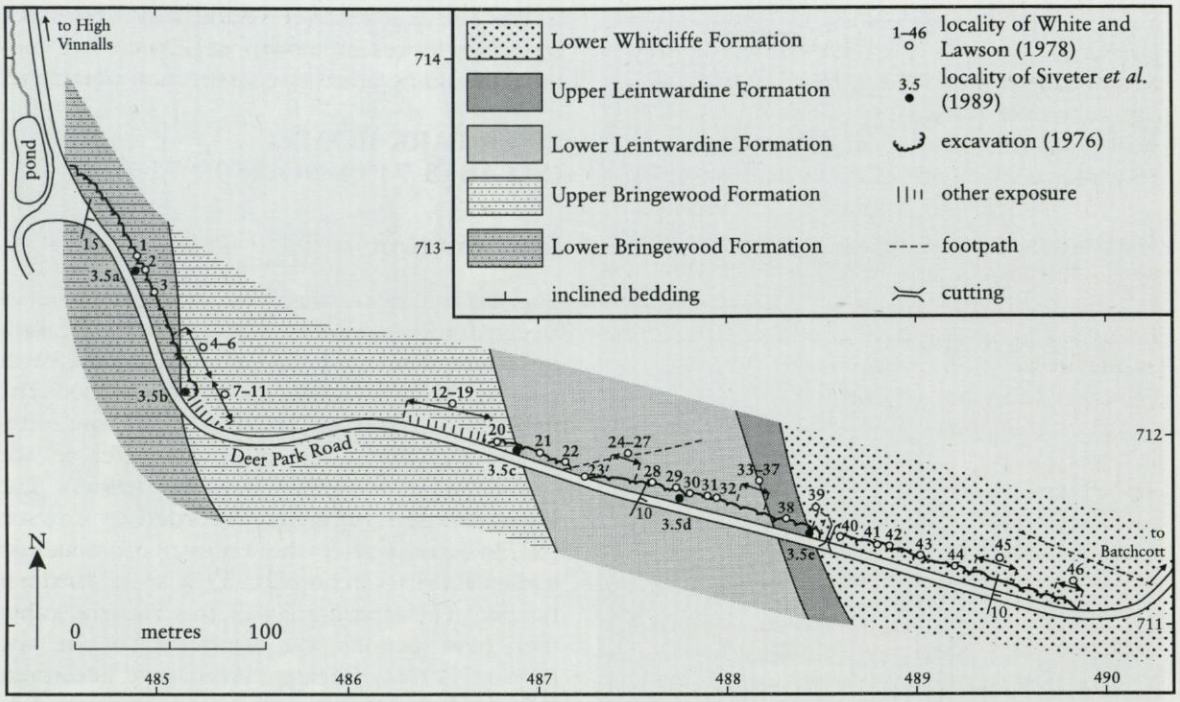


Figure 5.14 Geology of the section along the Deer Park Road, Mortimer Forest, near Ludlow, Shropshire (after White and Lawson, 1978 with modifications from Siveter *et al.*, 1989).

Lawson, 1978). Some 21 m of the upper part of the Lower Bringewood Formation is exposed, consisting of irregularly bedded, olive-grey, calcareous siltstones containing, in particular, brachiopods such as *Strophonella euglypha*, *Atrypa reticularis*, *Leptaena depressa*, *Sphaerirhynchia wilsoni* and *Pholidostrophia lepisma* and corals such as *Rhabdocyclus* and *Favosites*. Near the top of the Formation calcareous nodules are quite common and about 4 m below the junction with the Upper Bringewood Formation there is a 10 cm thick bentonite.

The Upper Bringewood strata consist of hard, grey, silty and in places nodular limestones. Only the lowermost 2 m and highest 5 m of the formation are recorded, the intervening 10 m being unexposed (White and Lawson, 1978). Chitinozoans are abundant and diverse in both the Lower and Upper Bringewood formations; particularly characteristic of the late Gorstian are *Belonechitina* and *Eisenackitina toddingensis* (Sutherland, 1994). The diverse Upper Bringewood macrofauna, typified by the brachiopods *Kirkidium knightii*, *Shagamella ludloviensis*, *Amphistrophia funiculata*, *Leptostrophia filosa*, *P. lepisma* and *S. euglypha* and by tabulate and rugose corals, is common up to the sharp lithological boundary with the overlying flaggy calcareous siltstones of the Lower Leintwardine Formation.

A complete Lower Leintwardine sequence, 20 m thick, is characterized especially by the brachiopods *Microsphaeridiorhynchus nucula*, *Howellella elgans*, *Dayia navicula*, *Salopina lunata*, *Isorthis orbicularis*, *Shaleria ornatella* and *Shagamella ludloviensis*. Several trilobite taxa including *Proetus obconicus*, *Warburgella ludlowensis* and *Alcymene* occur. The siltstones have also yielded the biozonal graptolite *Saetograptus leintwardinensis* (White and Lawson, 1978; Cherns, 1988).

The Upper Leintwardine Formation is represented by merely 3.5 m of strata, immediately west of a small man-made cut through the section (Figure 5.14). Lithologically similar to the Lower Leintwardine, it is easily differentiated by the occurrence of a varied macrofauna that includes the ostracod *Neobeyrichia lauensis* and the acme of *Aegiria grayi* and the trilobites *Encrinurus stubblefieldi* and *Alcymene puellaris* (Bassett *et al.*, 1979, fig. 25). The large, distinctive *N. lauensis* and/or its associates provide one of the best correlative tools in the type Ludlow, and can be traced into sequences in

Sweden, the eastern Baltic and Podolia in the former USSR (see Siveter, 1989). The Deer Park Road section ends with about 21 m of greyish, flaggy, Lower Whitcliffe calcareous siltstones with abundant *Protochonetes ludloviensis* and *M. nucula,* together with *D. navicula*, *Orbiculoidea rugata*, the worm tube *Serpuloides longissimus*, the bivalve *Fuchsella amygdalina* and orthoconic nautiloids (Bassett *et al.*, 1979, fig. 25). The latter stratigraphical unit and the Leintwardine Group have abundant microfloras and other palynomorphs (Elliott, 1995).

Interpretation

The rocks at Deer Park Road represent a variety of subtly different, relatively shallow water environments on the eastern, Midland Platform of the Welsh Basin (see Cherns, 1988, text-figs 13, 14; Siveter *et al.*, 1989, fig. 10; Bassett *et al.*, 1992, figs S4b, S5a). During mid-Ludlow times the Ludlow area was an inner shelf region (Watkins and Aithie, 1980). The Upper Bringewood Formation limestones at Deer Park Road represent relatively low energy, back-barrier deposits. These predominantly nodular and argillaceous, coarse-grained, sparitic carbonates (the Aymestry Limestone facies) also form the basal beds of the Lower Leintwardine Formation across much of the shelf region (e.g. as at Deer Park Road).

The upward transition into the calcareous siltstone facies typical of the Leintwardine Group in the Ludlow area signifies an increased influx of silt and frequency of skeletal sands (accompanied by higher abundance of skeletal fauna) relative to carbonate deposition, and a general lowering of depositional energy levels (Cherns, 1988). The siltstone sequence represents storm-influenced subtidal environments in which energy levels fluctuated: the winnowed skeletal sands formed as a result of episodes of marked current disturbance, such as storm waves; during quieter water periods carbonate and terrigenous muds and silts were deposited.

Coeval GCR sites of shelf aspect are represented locally at Wigmore Road, Sunnyhill and Aymestrey Quarries. The Welsh Basin shelf sequences at nearby Goggin Road, Mocktree Quarries and Bow Bridge sites, together with those at Woodbury Quarry, Perton Road, Wood Green and Linton Quarry in the southern Welsh Borderland and Turner's Hill in the West Midlands also, in part, duplicate the stratigraphical interval seen at Deer Park Road. Likewise, the Sawdde Gorge section near Llandeilo contains the same interval, but reflects a more basin margin setting.

Conclusions

This well-documented, abundantly fossiliferous locality has international status in stratigraphy. It provides one of the most complete sections available through the middle and upper parts of the type Ludlow Series and contains designated reference sequences of several of the standard lithostratigraphical divisions of the Ludlow: that is, basal boundary reference sections and body stratotypes for formations in the Bringewood, Leintwardine and Whitcliffe groups. The site should be adequately maintained and accessibility should be assured for researchers. Its scientific attractions include the potential to collect bed-by-bed through a continuous section of strata.

THE WHITCLIFFE (SO 5065 7444–SO 5120 7414)

Introduction

The Whitcliffe encompasses many historically and stratigraphically very important outcrops of Ludfordian age along a bluff on the southern side of the River Teme, between Dinham Bridge and Ludford Bridge at Ludlow, Shropshire (Figures 5.6, 5.15). The site was independently selected for the GCR for fossil arthropods and for fossil fishes (Dineley and Metcalf, 1999).

Murchison referred to the Whitcliffe exposures when he was establishing the 'Silurian System of Rocks' (1835, 1839) and they featured prominently in the standard research on the type Ludlow Series (Holland *et al.*, 1963; see historical survey and localities therein). Some of the key sections on the Whitcliffe were also logged by Watkins in his study of Ludlow benthic communities of the Welsh Borderland (1979, p. 258, fig. 16). More recently the sequence has been documented in two field guides (Bassett *et al.*, 1979; Siveter *et al.*, 1989, locality 3.1) and in a review of the global standard for the Silurian System (Lawson and White, 1989).

In establishing the standard stratigraphy for the type Ludlow Series, outcrops on the Whitcliffe were selected as basal boundary stratotypes and body stratotypes for the Upper

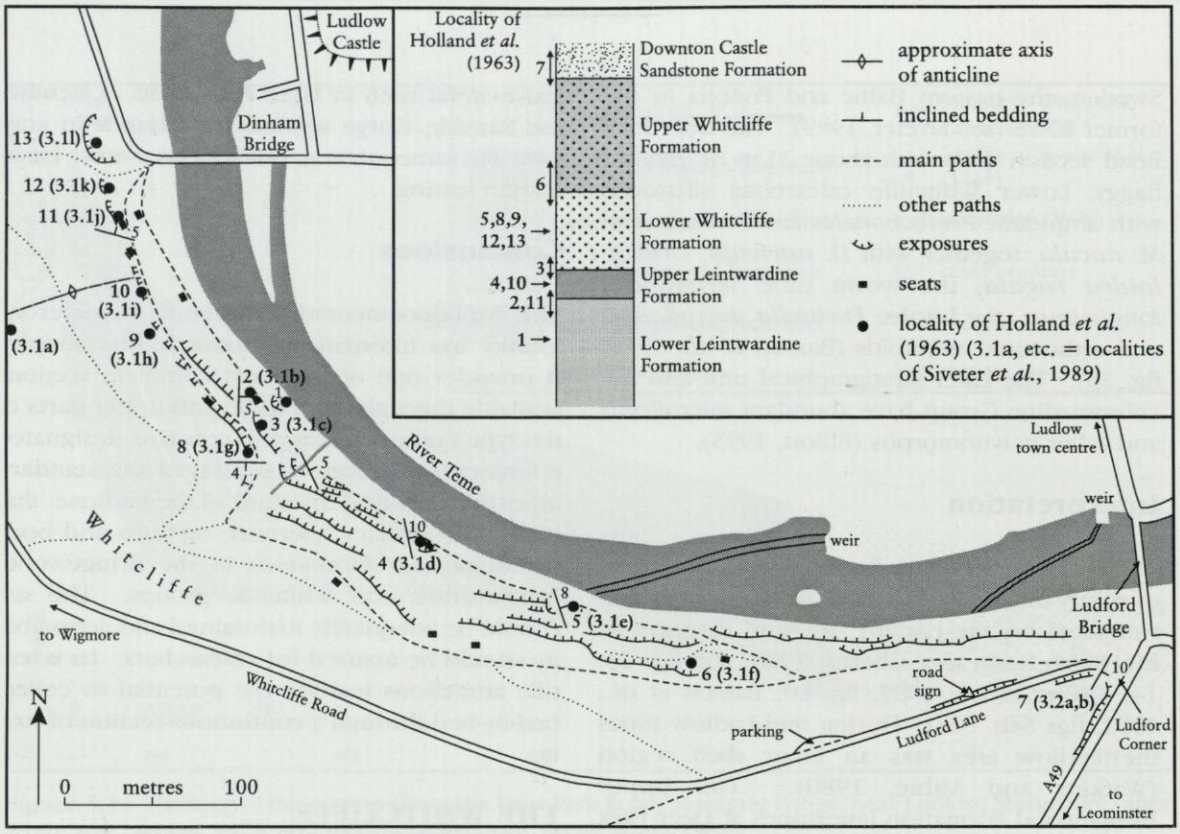


Figure 5.15 Location and general stratigraphical position of localities at GCR sites The Whitcliffe and Ludford Lane and Corner, Ludlow, Shropshire (after Holland *et al.*, 1963; modified from Siveter *et al.*, 1989).

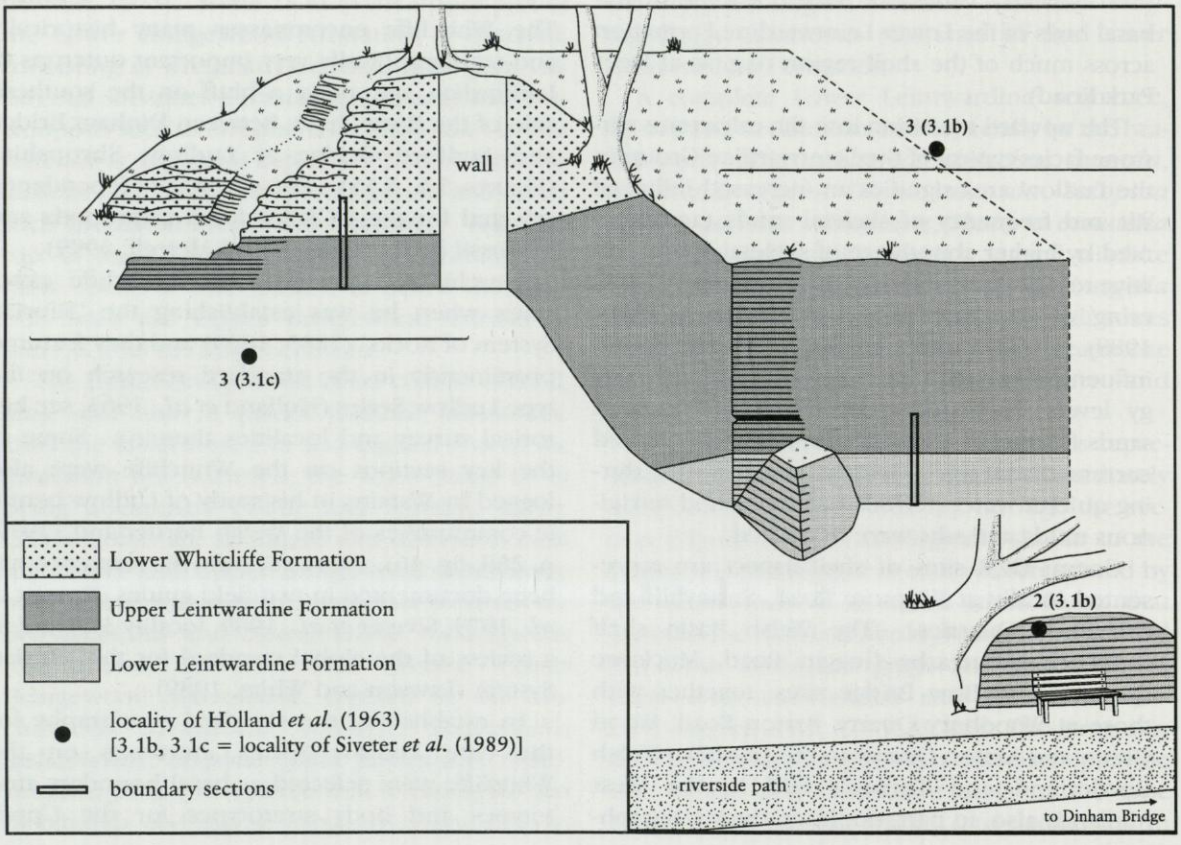


Figure 5.16 Geology of an area adjacent to the riverside path on the Whitcliffe, Ludlow, Shropshire, which shows the basal boundary stratotypes and body stratotypes for the Upper Leintwardine and Lower Whitcliffe formations (after Holland *et al.*, 1963; modified from Siveter *et al.*, 1989); see also Figures 5.17–5.19.

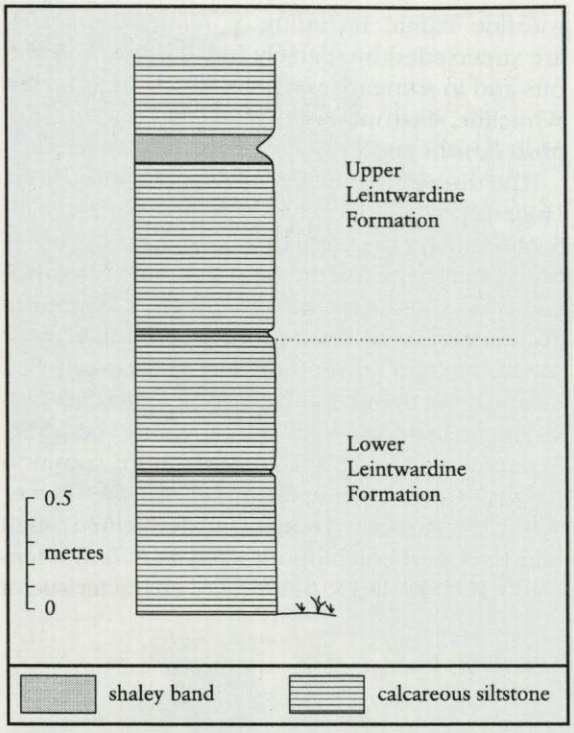


Figure 5.17 The boundary stratotype section for the base of the Upper Leintwardine Formation (see Figures 5.16 and 5.18), adjacent to the riverside path on the Whitcliffe, Ludlow, Shropshire (after Holland *et al.*, 1963; modified from Siveter *et al.*, 1989).

Leintwardine Formation (Leintwardine Group) and for the Lower and Upper Whitcliffe formations (Whitcliffe Group) of the Ludfordian Stage (Holland *et al.*, 1963; Lawson and White, 1989).

Description

The cliff above the seat beside the riverside path, some 150 m SSE of Dinham Bridge, has the basal boundary stratotype and body stratotype of the Upper Leintwardine Formation, which is a sequence of calcareous siltstones showing honeycomb weathering (SO 5071 7428, Holland *et al.*, 1963, locality 3; Figures 5.16–5.18). The boundary with the underlying calcareous siltstones of the Lower Leintwardine Formation is drawn just below a thin shaly recess and coincides with the introduction of the trilobites *Alcymene puellaris* and *Encrinurus* and the brachiopod *Aegiria grayi*. High in the cliff the Upper Leintwardine has yielded abundant conodonts, especially *Ozarkodina excavata*, *Ozarkodina confluens*, *Panderodus unicostatus* and *Coryssognathus dubius* (Aldridge and Smith, 1985). In addition, well-preserved palynomorph assemblages have been recovered from the Leintwardine Group at this locality (Elliott, 1995). However, *Neobeyrichia lauen-*

Figure 5.18 The Lower Leintwardine Formation and the basal boundary stratotypes and body stratotypes for the Upper Leintwardine and Lower Whitcliffe formations (see Figures 5.16, 5.17 and 5.19), adjacent to the riverside path on the Whitcliffe, Ludlow, Shropshire. (Photo: David J. Siveter.)

sis, the large ostracod so diagnostic of the Upper Leintwardine in several parts of the Ludlow Anticline and elsewhere in the Welsh Borderland, is not recorded from the Whitcliffe.

Immediately behind the seat (SO 5071 7429, Holland *et al.*, 1963, locality 2), the calcareous siltstones of the Lower Leintwardine Formation have yielded the biozonal graptolite *Saetograptus leintwardinensis* and the brachiopods *Atrypa reticularis, Dayia navicula, Isorthis orbicularis, Leptaena depressa, Microsphaeridiorhynchus nucula* and *Shaleria ornatella*.

At the top of the slope approximately 10 m south-east of the seat is the basal boundary stratotype and body stratotype of the Lower Whitcliffe Formation (SO 5071 7428, Holland *et al.*, 1963, locality 3; Figures 5.16, 5.18, 5.19). The boundary is established at an horizon where siltstones containing a characteristic Upper Leintwardine fauna, including *S. leintwardinensis,* are superseded by sparsely fossiliferous, calcareous and in some cases irregularly bedded Lower Whitcliffe siltstones with the brachiopods *Salopina lunata* and *Protochonetes ludloviensis*.

The disused Whitcliffe Quarry (SO 5096 7414, Holland *et al.*, 1963, locality 6; Figures 5.20, 5.21) displays the basal boundary stratotype and body stratotype of the well-bedded, olive calcareous siltstones of the Upper Whitcliffe Formation, there resting on the typically more thickly bedded Lower Whitcliffe Formation. The boundary is defined at the top of a laterally persistent 18 cm horizon of convolute bedding. Macrofossils are generally much more common in the Upper Whitcliffe than in the Lower Whitcliffe strata. Lenticular, decalcified shell bands, rich in brachiopods such as *P. ludloviensis, M. nucula* and *S. lunata*, are characteristic of

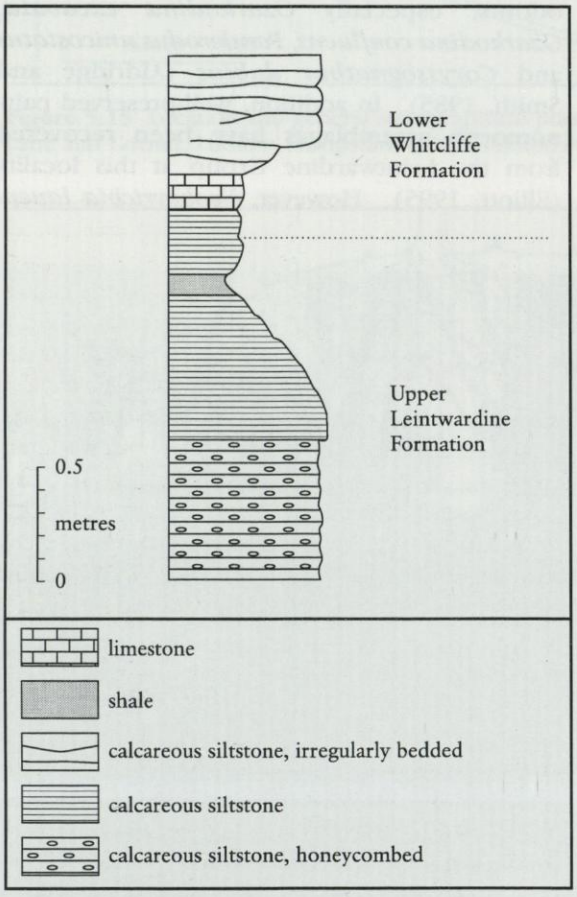


Figure 5.19 The boundary stratotype section for the base of the Lower Whitcliffe Formation (see Figures 5.16, 5.18), adjacent to riverside path on the Whitcliffe, Ludlow, Shropshire (after Holland *et al.*, 1963; modified from Siveter *et al.*, 1989).

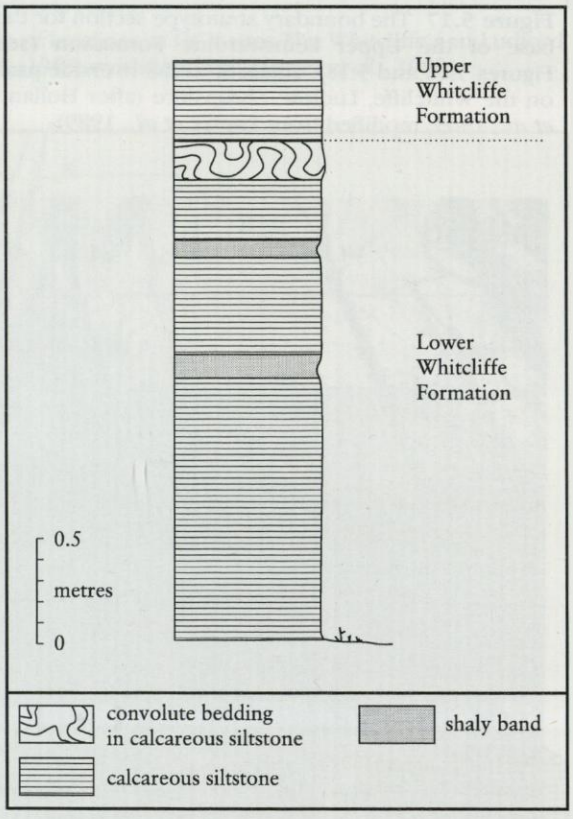


Figure 5.20 The boundary stratotype section for the base of the Upper Whitcliffe Formation, at the old quarry on the Whitcliffe (see Figure 5.21), Ludlow, Shropshire (after Holland *et al.*, 1963; modified from Siveter *et al.*, 1989).

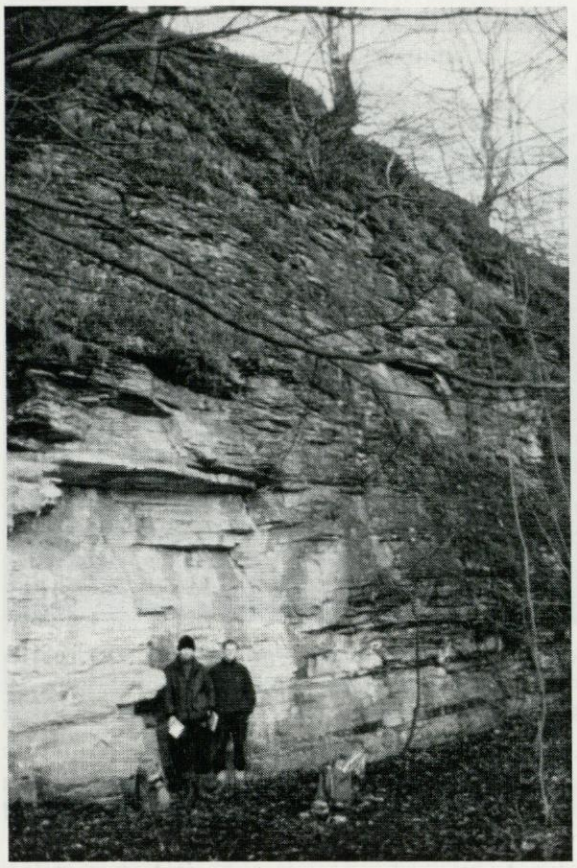


Figure 5.21 The Lower Whitcliffe Formation and the basal boundary stratotype and body stratotype for the Upper Whitcliffe Formation, at the old quarry on the Whitcliffe, Ludlow, Shropshire. (Photo: David J. Siveter.)

the upper unit. Associates include the bivalves *Fuchsella amygdalina, Goniophora cymbaeformis* and *Pteronitella retroflexa*, the annelid *Serpuloides longissimus,* orthoconic nautiloids and gastropods. Abundant conodonts, especially *Ozarkodina excavata* and *Coryssognathus dubius* elements, occur in the Whitcliffe beds (Aldridge and Smith, 1985; Miller and Aldridge, 1993, 1997; Miller, 1995), as do rare valves of the ostracod *Calcaribeyrichia torosa* (Siveter, 1978; Miller 1995). The formations on the Whitcliffe also yield chitinozoan (Sutherland, 1994), acritarch (e.g. Lister, 1970) and spore (e.g. Richardson and Lister, 1969) assemblages and eurypterids (Kjellesvig-Waering, 1961).

In addition to the stratotypes many of the other exposures on the Whitcliffe have aided characterization of their respective formations. These include (Figure 5.15) those immediately to the west of Dinham Bridge and also adjacent to a main path from Dinham Bridge to Whitcliffe Common, displaying the Leintwardine Group (SO 5065 7434, SO 5062 7440; Holland *et al.*, 1963, localities 10, 11) and the Lower Whitcliffe Formation (SO 5071 7425, SO 5065 7433, SO 5062 7442, SO 5062 7445; Holland *et al.*, 1963, localities 8, 9, 12, 13); and those just beyond the spring and at the rock steps adjacent to the weir, along the riverside path, which show Upper Leintwardine (SO 5082 7421, Holland *et al.*, 1963, locality 4) and Lower Whitcliffe (SO 5090 7417, Holland *et al.*, 1963, locality 5) strata respectively.

Interpretation

These marine sediments accumulated on the shelf of the Midland Platform, on the eastern margin of the Welsh Basin (see Siveter *et al.*, 1989, fig. 10; Bassett *et al.*, 1992, figs S5a, S5b). Sedimentation of the calcareous, in some cases coquinoid siltstones was perhaps subtidal but mostly within wave base. The coquinas may be the lag products of episodes of higher energy, storm sedimentation in a shallow, mainly clear, but often turbid proximal shelf environment (Watkins 1979; Cherns, 1988). The convoluted bedding of the Whitcliffe strata are interpreted as slumps and other wet sediment deformation features and attest to occasional periods of possible instability on the platform.

In the type Ludlow area Deer Park Road and Sunnyhill are other GCR sites that have fairly complete sequences of Ludfordian strata. The same applies to the sites at Turner's Hill in the West Midlands, Brook House and Sawdde Gorge in southern Wales and Wood Green, Longhope Hill and Perton Road in the southern Welsh Borderland. Some of these Welsh Basin sequences are shelf, and others are of basin margin aspect.

Conclusions

This is a much studied, classic site of international importance and has primary status in global Silurian stratigraphy. It includes basal boundary and body stratotypes of three stratigraphical divisions of the Ludfordian Stage of the Ludlow Series. The view from Whitcliffe Common (Figure 5.22), looking across to Ludlow and beyond, is one of the famous geological vistas in Britain. The site is regularly vis-

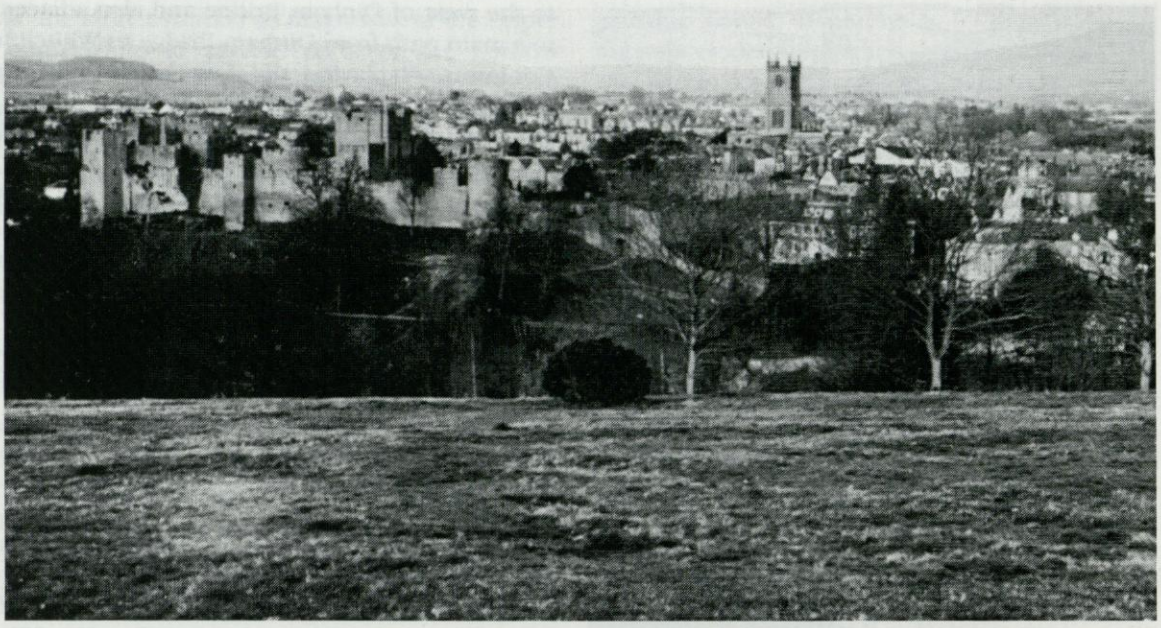


Figure 5.22 Looking north-east from Whitcliffe Common (SO 5053 7430, locality 3.1a of Siveter *et al.*, 1989); sited on the axial trace of the Ludlow Anticline, across Ludlow, Shropshire towards Titterstone Clee Hill (Devonian–Carboniferous). The regional dip and younging direction is north-west to south-east. (Photo: David J. Siveter.)

ited by many educational parties and researchers and has high scientific value to the geological community. The highest priority should be given to conserving the exposures.

DEEPWOOD (SO 4595 7352)

Introduction

This locality is a section of middle Ludlow rocks along Raddle Brook, a minor, northerly flowing tributary of the River Teme in Shropshire. The site is in woodland about 830 m south of Deepwood (Figure 5.6) on Bringewood Chase, and is about 5 km west of Ludlow.

The locality occurs in the type area of the Ludlow Series and is on the northern limb of the Ludlow Anticline. The stratigraphy of this region was established in modern terms by Holland *et al.* (1959, 1963) and has subsequently been summarized in a variety of papers, correlation charts and field guides (e.g. Cocks *et al.*, 1971, 1992; Lawson, 1977b; Lawson and White, 1989; Siveter *et al.*, 1989; Jenkinson, 1991).

Deepwood is the official basal boundary stratotype section for the Upper Bringewood Formation (Holland *et al.*, 1963, locality 131). Currently the section is very poorly exposed.

Description

As detailed by Holland *et al.* (1963) the stream exposes Lower and Upper Bringewood formations, dipping at about 26° north. The base of the upper unit is mapped at a distinct change in slope in the stream profile and formerly the unit itself was exposed for about 100 m north of that point. To the south of that point, upstream for about 7 m, the lower unit was exposed in a broader, flatter part of the stream bed. Above (i.e. to the south of) the latter stretch, a 1.1 m high cliff exposed the top part of the Lower Bringewood Formation. Beds of the latter unit were also exposed just to the west of the small cliff, at and immediately above a small waterfall.

The Lower Bringewood beds here are thickly flaggy to massive calcareous siltstones with some limestone lenses and nodules. Fossils are common and include brachiopods such as *Atrypa reticularis*, *Howellella elegans*, *Isorthis orbicularis* and *Sphaerirhynchia wilsoni* as well as gastropods, bryozoans, crinoids, ostracods and trilobite fragments. By contrast the Upper Bringewood strata are hard, flaggy limestones, recorded as bedding plane exposures in the stream. Fossils include solitary and compound corals such as *Favosites*, many brachiopod

species including *Kirkidium knightii*, together with gastropods, crinoids and trilobites.

Interpretation

The rocks here represent relatively shallow water sediments formed on the eastern margin (the Midland Platform) of the Welsh Basin (Siveter *et al.*, 1989, fig. 10; Bassett *et al.*, 1992, fig. S4b). During mid-Ludlow times Deepwood was positioned on the distal part of an inner shelf region that extended eastwards to Ludlow and beyond to the west Midlands area (Watkins and Aithie, 1980). Immediately to the west of the Deepwood site was a higher energy barrier zone of the shelf edge itself, as seen locally for example at the GCR sites at View Edge near Craven Arms to the north-west, Mocktree Quarries and Bow Bridge near Leintwardine to the west and Aymestrey Quarries in the southern part of the Ludlow Anticline. Sunnyhill, Deer Park Road and Goggin Road in the nearby Mortimer Forest area of the Ludlow Anticline are, in addition to Deepwood, other local GCR sites that have Bringewood carbonates of a back-barrier, shelf aspect.

The Deepwood section is now much degraded. Deer Park Road presents an alternative basal boundary reference section for the Upper Bringewood Formation (Lawson and White, 1989).

Conclusions

This fossiliferous section has national importance in stratigraphy in defining the base of a unit of the type Ludlow Series, namely the Upper Bringewood Formation. At the time when it was originally described (Holland *et al.*, 1963) it was considered to be a key locality, hence its formal stratigraphical and GCR status. However, though technically still the stratotype, its importance and utility has waned as other, much better exposed, more extensive and accessible Upper Bringewood sections have come to light within the Ludlow Anticline.

BOW BRIDGE (SO 428 729–SO 431 732)

Introduction

This site extends along the immediate flanks of the River Teme, between Downton Bridge to just north of Bow Bridge, 0.5 km south of Downton on the Rock, Shropshire (Figure 5.23). It contains late Gorstian to earliest Ludfordian, Ludlow strata.

Bow Bridge is situated on the northern limb of the Ludlow Anticline, which is also the southern limb of the contiguous Downton Syncline. The site, at the eastern end of the area of the type Ludlow Series, was mapped by Holland *et al.* (1959, 1963). The adjoining ground along strike immediately to the west, from exposures in the gorge of the Teme to the district around Leintwardine, was studied by Whitaker (1962). Bow Bridge was also a locality used in Watkins and Aithie's (1980) analysis of Upper Bringewood facies and in Lister's (1970) study of Ludlow microflora.

The type Ludlow sequence and its various stratotypes are reviewed by Lawson and White (1989); their paper is complemented by a field guide that includes an overview of local Silurian geology (Siveter *et al.*, 1989). Bow Bridge contains body stratotypes for the two Bringewood formations (Lawson and White, 1989) and lies within the SSSI known as Downton Gorge. The latter marks the position of an overflow channel of a proglacial lake that occupied the Vale of Wigmore in the central part of the Ludlow Anticline.

Description

The southern part of the site consists of Lower Bringewood Formation, a body stratotype of which is seen at two small disused quarries (SO 4289 7296: locality 17 of Lawson and White, 1989; Figure 5.23) above the east bank of the River Teme and north of the aquaduct at Downton Bridge. These flaggy calcareous siltstones with limestone bands, dipping 23° to the north, contain abundant shelly fossils, especially brachiopods. The fauna includes *Atrypa reticularis*, *Dayia navicula*, *Leptaena depressa*, *Protochonetes minimus*, *Sphaerirhynchia wilsoni*, *Strophonella euglypha*, bryozoans, crinoids and *Monograptus sensu lato* (Holland *et al.*, 1963).

The basal part of the Upper Bringewood Formation occurs about 70 m north of the Lower Bringewood quarries. This upper unit is well exposed in a laterally extensive, old quarry on the west side of the river (SO 4300 7311; Whitaker, 1962) and may also be examined in exposures (SO 4306 7313) dipping 20° to the

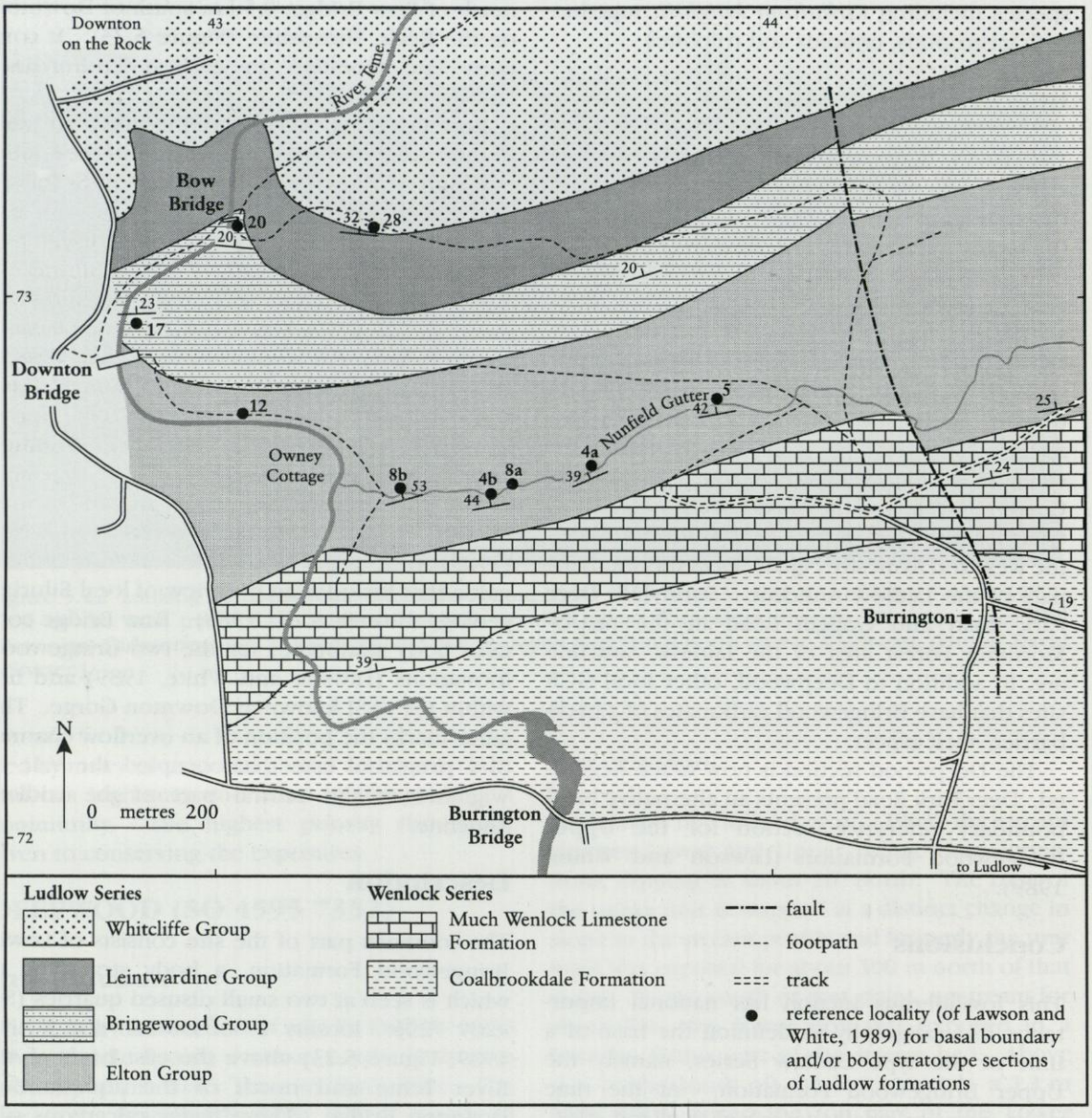


Figure 5.23 The geology between GCR sites at Bow Bridge and Burrington, in the western part of the northern limb of the Ludlow Anticline (after Holland *et al.*, 1963 and Lawson and White, 1989).

north on the east of the River Teme just south of Bow Bridge itself. Both these outcrops, which together constitute a body stratotype (locality 20 of Lawson and White, 1989; Figure 5.23), are of irregularly flaggy and nodular, silty carbonates displaying typical, shelly-rich, 'Aymestry Limestone' facies (for which see Alexander, 1936; Lawson, 1973b; Cherns, 1988), with bands of corals and banks of the large brachiopod *Kirkidium knightii*. The fauna also consists of many other brachiopod species, together with corals, crinoids and bryozoans. In the Downton Gorge area the Bringewood Group is about 68 m thick (Whitaker, 1962).

At the extreme northern end of the site, about 100 m north-east of Bow Bridge, Holland *et al.* (1963, locality 46) record a small exposure of calcareous siltstones of the Lower Leintwardine Formation. The sequence continues to young northwards through the Leintwardine, Whitcliffe and, in the vicinity of Downton Castle Bridge, Downton Castle Sandstone formations.

Interpretation

The shelly-rich, Upper Bringewood biocalcarenites of Bow Bridge accumulated in a relatively shallow, high-energy zone near the western shelf edge of the Midland Platform on the eastern margin of the Welsh Basin (Watkins and Aithie, 1980, figs 14–16; Cherns, 1988; Siveter *et al.*, 1989, fig. 10; Bassett *et al.*, 1992, fig. S4b).

Bow Bridge is one of many sites that define the Ludlow Series in its type area. Several such GCR sites that contain Bringewood Group strata occur nearer to Ludlow (e.g. see Deepwood, Sunnyhill, Goggin Road and Deer Park Road) and hence, compared to Bow Bridge, reflect somewhat more sheltered, inner shelf environments in the late Gorstian. Locally, GCR sites at Mocktree Quarries at Leintwardine to the north-west, at View Edge due north near Craven Arms and at Aymestrey Quarries at the southern end of the Ludlow Anticline also have, like Bow Bridge, Bringewood Group strata in facies indicative of the shelf edge zone (Watkins and Aithie, 1980).

Conclusions

The rock types and fossils present at Bow Bridge are not especially unusual or rare within the Welsh Basin. Rather, the site owes its significance as a body stratotype locality for the formations of the Bringewood Group. As such it has both national and international importance in stratigraphy and should be conserved.

BURRINGTON FARM STREAM SECTION (SO 4389 7278)

Introduction

This Herefordshire site consists of small exposures along a southern bend of the stream called Nunfield Gutter, approximately 650 m east of the River Teme and north-west of the village of Burrington, in the western part of the northern limb of the Ludlow Anticline. Its geology was documented by Holland *et al.* (1963, locality 69) when they established the stratigraphy of the type Ludlow Series. They chose this locality as the standard section for the base of their Middle Elton Beds. Its current stratigraphical status, as the basal stratotype for the Middle Elton Formation (Elton Group, Gorstian Stage), was reviewed and formalized by Lawson and White (1989, locality 5; see Figure 5.23). Since Murchison's (1839) time, the Burrington area has long been known for its Silurian geology and fossils.

As originally designated this GCR site was named Burrington Farm stream and trackside section. As such it also included a nearby locality, on the north side of a track on the north-eastern margin of Onney Wood, which displayed the then standard section for the base of the Upper Elton Beds (Holland *et al.*, 1963, locality 76; SO 4367 7283). On the loss of that outcrop because of degradation, a specially excavated (1981) exposure near the Goggin Road section in the Ludlow Anticline was selected as the basal boundary stratotype for the Upper Elton Formation (see Lawson and White, 1989 and GCR site report for Goggin Road).

Description

The rocks on site are the irregularly bedded, flaggy, calcareous siltstones with calcareous nodules at the top of the Lower Elton Formation, overlain by more thinly and better bedded siltstones of the Middle Elton Formation; beds dip 42° NNW (Holland *et al.*, 1963). The lithological and palaeontological transition between these formations occurs over about 1 m of strata and is seen at both western and eastern ends of the southern bank of a meander in Nunfield Gutter (Figure 5.24).

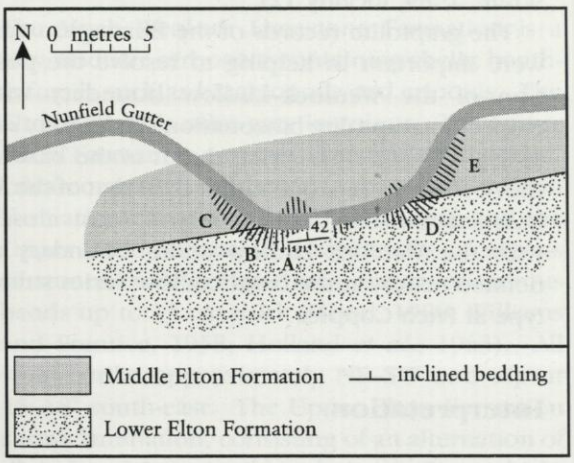


Figure 5.24 The location of the basal stratotype section of the Middle Elton Formation, at Nunfield Gutter, near Burrington, in the Ludlow Anticline (from Holland *et al.*, 1963). The letters refer to parts of the section as described by Holland *et al.* (1963).

The Lower Elton contains a rich, characteristically fragmentary shelly fauna, including the brachiopods *Atrypa reticularis*, *Aegiria grayi*, *Dicoelosia biloba*, *Glassia* sp., *Howellella elegans* and *Leptaena depressa*, the bivalves *Nuculites* sp. and *Pterinea* sp. and the trilobite *Dalmanites myops*. Up to 33 cm above a thin brown clay band, which is traceable west to east across the exposures at the meander, the beds have a transitional fauna consisting of several brachiopod species together with abundant graptolite fragments and the orthoconic nautiloid *Michelinoceras*. The base of the Middle Elton Formation is drawn at a horizon 46 cm above the top of the clay band. About 60 cm above that boundary typical Middle Elton strata are developed and yield *Neodiversograptus nilssoni* and *Monograptus uncinatus orbatus*.

Other localities in the vicinity of Burrington, which collectively span upper Coalbrookdale Formation (Wenlock Series) to Upper Elton Formation strata, are detailed by Holland *et al.* (1963, fig. 10; see also Lawson and White, 1989, Siveter *et al.*, 1989, locality 3.7 and Figure 5.23). They include exposures in Nunfield Gutter that display body stratotypes of the Lower (SO 4366 7266 and SO 4348 7262: localities 4a, 4b of Lawson and White, 1989) and Middle (SO 4352 7264 and SO 4337 7263: localities 8a, 8b of Lawson and White, 1989) Elton formations. Some 200 m to the north-west of Nunfield Gutter, in crags above the River Teme in Downton Gorge, there is a body stratotype section of the Upper Elton Formation (Lawson and White, 1989, locality 12).

The graptolite records of the Burrington area were important in helping to resolve the position of the Wenlock–Ludlow boundary with respect to graptolite biozonation (Holland *et al.*, 1969). They demonstrate that it is the base of the *N. nilssoni* Biozone rather than that of the *M. ludensis* Biozone that correlates most closely with the Wenlock–Ludlow series boundary as defined nearby at the basal Ludlow Series stratotype at Pitch Coppice.

Interpretation

These sediments were deposited on the shelf area flanking the eastern side of the Welsh Basin (Siveter *et al.*, 1989, figs 8–10; Bassett *et al.*, 1992, fig. S4a). The overall lithological transition across the Lower–Middle Elton boundary, which is also mirrored in a faunal shift from mostly shelly benthos to graptolite dominated assemblages, may reflect a gradual increase in water depth.

Locally, in the type Ludlow area, GCR sites at Goggin Road and Elton Lane also have the Lower and Middle Elton formations and the basal Ludlow stratotype at Pitch Coppice displays the lower unit. Elsewhere in Shropshire both formations can be examined at the Upper Millichope site.

Conclusions

Characteristic lithologies and faunas for two of the three formations of the Elton Group may be examined at this locality. As a basal stratotype section for the Middle Elton Formation of the type Ludlow Series it is of national importance in stratigraphy and should be conserved.

ELTON LANE (SO 4610 7030–SO 4678 7050)

Introduction

This series of small, poorly exposed outcrops occurs along a minor road (called Killhorse Lane on some maps), from 0.75 km to 1.25 km south-east of Elton (SO 457 708), in north Herefordshire (Figures 5.6, 5.25). Several stratigraphical units of the Ludlow Series bear the name of the village. The locality is sited on the southern limb of the Ludlow Anticline, just to the south-west of the area that was mapped in detail by Holland *et al.* (1963) when they rehabilitated the type Ludlow succession (see also White and Lawson, 1978; Lawson and White, 1989).

The section contains rocks of the Much Wenlock Limestone Formation (Homerian Stage, Wenlock Series) overlain by the Lower, Middle and Upper Elton formations (Elton Group, Gorstian Stage, Ludlow Series). Originally the three lithostratigraphical divisions of the Elton were each styled 'Beds' and the 'Eltonian' was the term given to the oldest of the then four stages of the Ludlow Series (Holland *et al.*, 1959, 1963). The change to Elton formations and the abandonment of the 'Eltonian' as a stage occurred when the terminology of the various stratigraphical units of the Ludlow Series was

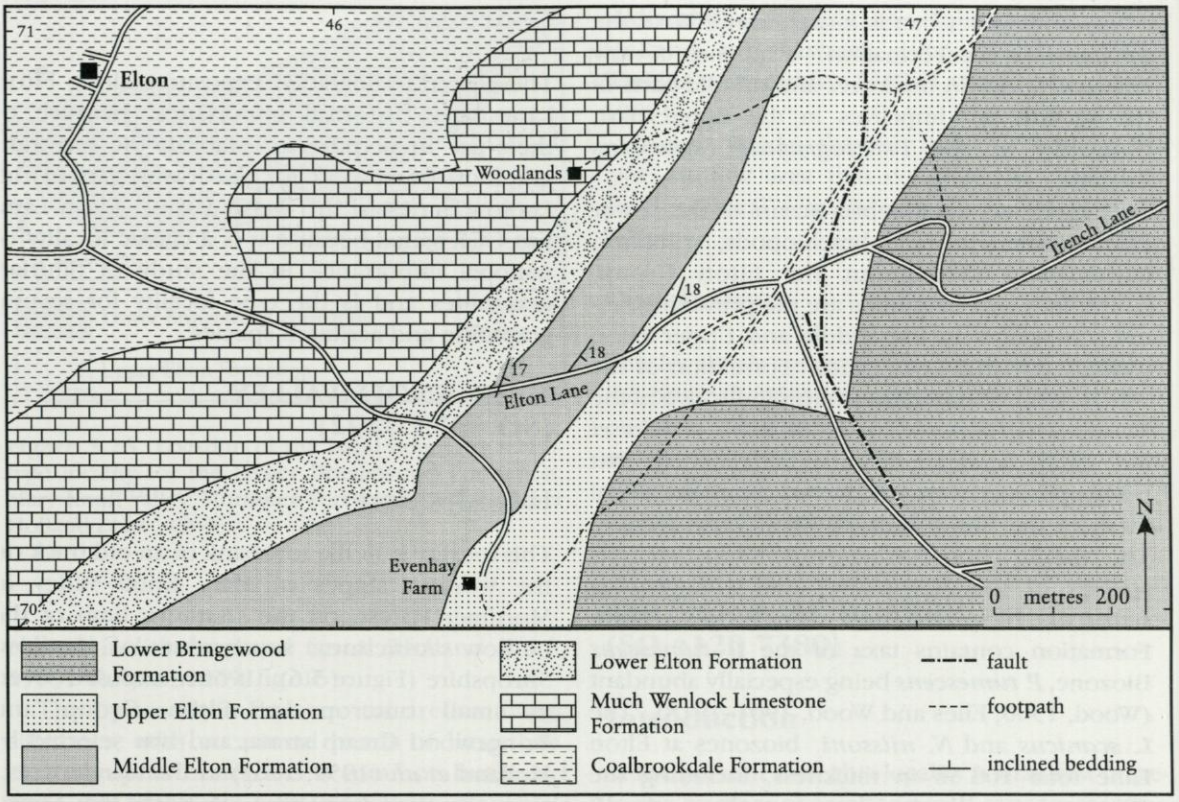


Figure 5.25 Geology of Elton Lane, Herefordshire, in the region of the Ludlow Anticline (after Lister, 1970; see also Wood, 1900 and Williams and Prentice, 1958).

formalized in accordance with modern concepts (Holland, 1980a; Holland *et al.*, 1980). The formally designated stratotypes of the Elton formations occur in the Ludlow Anticline, but not at Elton Lane (see GCR site reports for Pitch Coppice, Goggin Road and Burrington Farm Stream Section, this volume).

The stratigraphical and palaeontological value of the 'Lower Ludlow' at this site was known to Murchison (1939, p. 205). Elton Lane is important chiefly because it was one of the key sections detailed by Wood (1900) when she established her graptolite biozones for the 'Lower Ludlow Shales' of areas in Wales and the Welsh Borderland. Its graptolite faunas include several type and other figured specimens (see Elles and Wood, 1901–1918). In addition to yielding shelly macrofaunal taxa typical of the basal Ludlow Series (for which see Holland *et al.*, 1963; White and Lawson, 1978; Lawson and White, 1989), it also contains abundant acritarch floras, chitinozoans, spores and other microfossils (Richardson and Lister, 1969; Lister 1970). Williams and Prentice (1958; see also Maltman, 1987) described slump-structures from the Elton Beds of the section.

Description

The Much Wenlock Limestone Formation is a silty, nodular carbonate containing shelly, benthic fossils such as brachiopods and crinoids. The Elton Group is olive-grey in colour. The Lower Elton Formation consists of irregularly bedded, calcareous silty mudstones, the Middle Elton Formation comprises muddy siltstones and the Upper Elton Formation is essentially calcareous siltstones with conspicuous flaggy calcareous bands up to 15 cm thick (Wood, 1900; Williams and Prentice, 1958; Holland *et al.*, 1963). All strata strike approximately NE–SW and dip at 15–18° south-east. The Upper Elton Formation shows lamination, consisting of an alternation of dark-grey fine-grained bands (up to 2 mm thick) and light-grey, coarser, calcareous and silty bands (up to 8 mm thick), together with post-depositional slumping on various scales (Williams and Prentice, 1958; see also Maltman,

1987); the lighter bands form about 80% of the thickness of the Formation. Exposure is now extremely poor in the lower and middle parts of the section but improves in the upper part, especially in the *Pristiograptus tumescens* Biozone.

Fragmentary shell debris occurs in the Lower Elton Formation (e.g. brachiopods, trilobites, corals) and throughout the Elton Group. Graptolites and nautiloids are the prevailing faunal component in the Middle and Upper Elton formations. The Lower Elton Formation of the Welsh Basin contains graptolites indicative of the *Neodiversograptus nilssoni* Biozone (Cocks *et al.*, 1992); however, Wood (1900) records that no graptolites were recovered from the basal 40 m of the Elton beds of Elton Lane section. The Middle Elton Formation of Elton Lane has species of the *N. nilssoni* and *Lobograptus scanicus* biozones and the Upper Elton Formation contains taxa of the *P. tumescens* Biozone, *P. tumescens* being especially abundant (Wood, 1900; Elles and Wood, 1901–1918). The *L. scanicus* and *N. nilssoni* biozones at Elton Lane total 108 m in thickness, including the 40 m supposedly lacking graptolites; the *P. tumescens* Biozone is 68 m thick (Wood, 1900, p. 428).

Interpretation

The strata at Elton Lane represent deposition on the outer shelf to shelf slope part of the eastern margin of the Welsh Basin (see Siveter *et al.*, 1989, figs 8–10; Bassett *et al.*, 1992, figs S3b, S4a). The lithofacies and faunal changes, from late Wenlock, relatively clear and shallow water shell-rich carbonates to early Gorstian graptolite-dominated fine clastic sediments, may reflect a relatively rapid but perhaps (at least initially) modest rise in sea level in the early Ludlow (e.g. see Hurst, 1975a, b; Bassett, 1976; Dorning, 1981a; Siveter *et al.*, 1989; Johnson *et al.*, 1991). Alternatively, such changes in lithology and fauna may be controlled by variations in climatic and associated oceanic conditions (Jeppson, 1990; Jeppson *et al.*, 1995). The prevalence of only pelagic species in parts of the Elton Group may indicate conditions inimical to benthic life.

Other GCR sites in the type Ludlow area that include a late Wenlock to early Ludlow stratigraphical sequence are Goggin Road, Burrington (see both Wenlock and Ludlow site reports) and Pitch Coppice.

Conclusions

The currently degraded exposures along Elton Lane have historical importance, because of their use in helping to establish the biostratigraphical framework for the lower part of the Ludlow Series in the Welsh Basin. Elton Lane has GCR status because it is a classic locality of national importance in the study of Silurian graptolites and is the type locality for several graptolite and acritarch species.

MARY KNOLL VALLEY (SO 4873 7292)

Introduction

This locality is in the low bank of an old track on the western slopes of Mary Knoll Valley in Mortimer Forest, on the southern limb of the Ludlow Anticline, south-west of Ludlow, Shropshire (Figure 5.6). It once exposed several small outcrops of Elton Group and Bringewood Group strata, and was selected by Holland *et al.* (1959; 1963) as the standard section for the then base of both the Lower Bringewood Beds and the Bringewoodian Stage of the type Ludlow Series. However, with the international formalization of the type Ludlow stratigraphy (e.g. see Holland, 1980a, b; Martinsson *et al.*, 1981) the Bringewoodian Stage became redundant. The section is at present badly degraded and the Upper Elton Formation–Lower Bringewood Formation junction is currently best demonstrated locally in the nearby sequence at Goggin Road (see this chapter). Nevertheless, the locality in Mary Knoll Valley remains the stratotype for the base of the Lower Bringewood Formation.

The site featured in the field guide of the Subcommission on Silurian stratigraphy (Bassett *et al.*, 1979, locality 3.11) and in Lawson and White's (1989) account of the type Ludlow Series. In addition to rich macrofaunas (Holland *et al.*, 1963; Watkins, 1979) it has also yielded abundant palynomorph assemblages (Lister, 1970).

Description

The locality formerly exposed Upper Elton Formation and Lower Bringewood Formation, Gorstian Stage, strata dipping 10° ESE (Figure 5.26). The junction is drawn at a fairly rapid

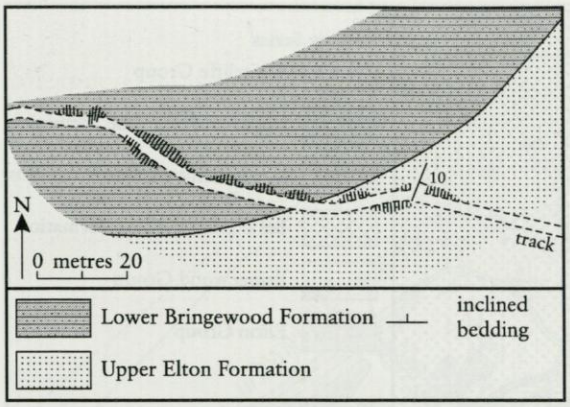


Figure 5.26 Location of the basal boundary stratotype locality for the Lower Bringewood Formation, Mary Knoll Valley, Mortimer Forest, Shropshire (after Holland *et al.*, 1963).

change in lithology and fauna (Holland *et al.*, 1963; Watkins, 1979, fig. 16).

The Upper Elton beds are calcareous, flaggy siltstones, with occasional bands of limestone. *Pristiograptus tumescens* is common but, apart from the brachiopod *Shagamella ludloviensis* and the trilobite *Dalmanites*, shelly fossils are sparse.

The Lower Bringewood beds are more irregularly and thickly bedded, lack flaggy limestone bands and decalcify to a brownish colour. Above the *P. tumescens*-bearing basal horizons of the Lower Bringewood, shelly fossils dominate, especially *S. ludloviensis, Microsphaeridiorhynchus nucula*, *Dayia navicula*, *Dalmanites myops*, bryozoans and ostracods. Watkins (1979, p. 258, fig. 16) recorded his brachiopod-dominated *Mesopholidostrophia laevigata* benthic association from this locality, with the eponymous brachiopod and *Eospirifer radiatus* and *Gypidula lata* being common in the Lower Bringewood Formation.

Interpretation

These marine deposits accumulated along the eastern margin of the Welsh depositional basin (Siveter *et al.*, 1989, fig. 10; Bassett *et al.*, 1992, figs S4a, S4b). The graptolite-bearing Elton beds reflect part of a possible eustatic transgressive pulse of early Ludlow (Elton Group) age (e.g. see Johnson *et al.*, 1991). The shell-rich, Lower Bringewood strata reflect shallower water deposition, also on the shelf evironment of the Midland Platform (e.g. see Holland *et al.*, 1963; Holland and Lawson, 1963; Watkins, 1979; Watkins and Aithie, 1980; Lawson and White, 1989).

Goggin Road is the only other GCR site in the type Ludlow area that contains the equivalent stratigraphical sequence as that at Mary Knoll Valley.

Conclusions

This locality is currently deteriorated and little of the original exposure remains, but renovation is possible. However, it remains the basal boundary stratotype for the Lower Bringewood Formation of the type Ludlow Series and is therefore of national importance.

CHURCH HILL QUARRY (SO 4120 7380)

Introduction

At the present time this locality is manifest merely as a number of small, grassed-over scars in the field near the crest of the western slope of the spur called Church Hill, about 750 m east of the bridge over the River Teme at Leintwardine, Herefordshire (Figure 5.27). These are all that remain of several exposures that have been a famous source of Silurian fossils from the mid-19th century onwards (e.g. Salter, 1857, 1959; Wyville Thompson, 1861). For all practical purposes these outcrops, and in particular the horizons from which the more celebrated fossils were recovered, have been unavailable for collecting for several decades: 'the quarries ... have been abandoned for more than half a century, and all but two are completely overgrown' (Hawkins and Hampton, 1927).

The Leintwardine area, which has Wenlock to Přídolí strata, lies at the extreme western end of the northern limb of the Ludlow Anticline, more or less along the axis of the complementary Downton Syncline. Its geology was first discussed by Murchison (1839) and was mapped in detail by Whitaker (1962; see also 1960). Accounts of the local middle Ludlow Series 'Aymestry Limestone' and Leintwardine Group were made by Alexander (1936) and Cherns (1988) respectively. The field guide of Siveter *et al.* (1989) also includes Silurian localities in the vicinity of Leintwardine.

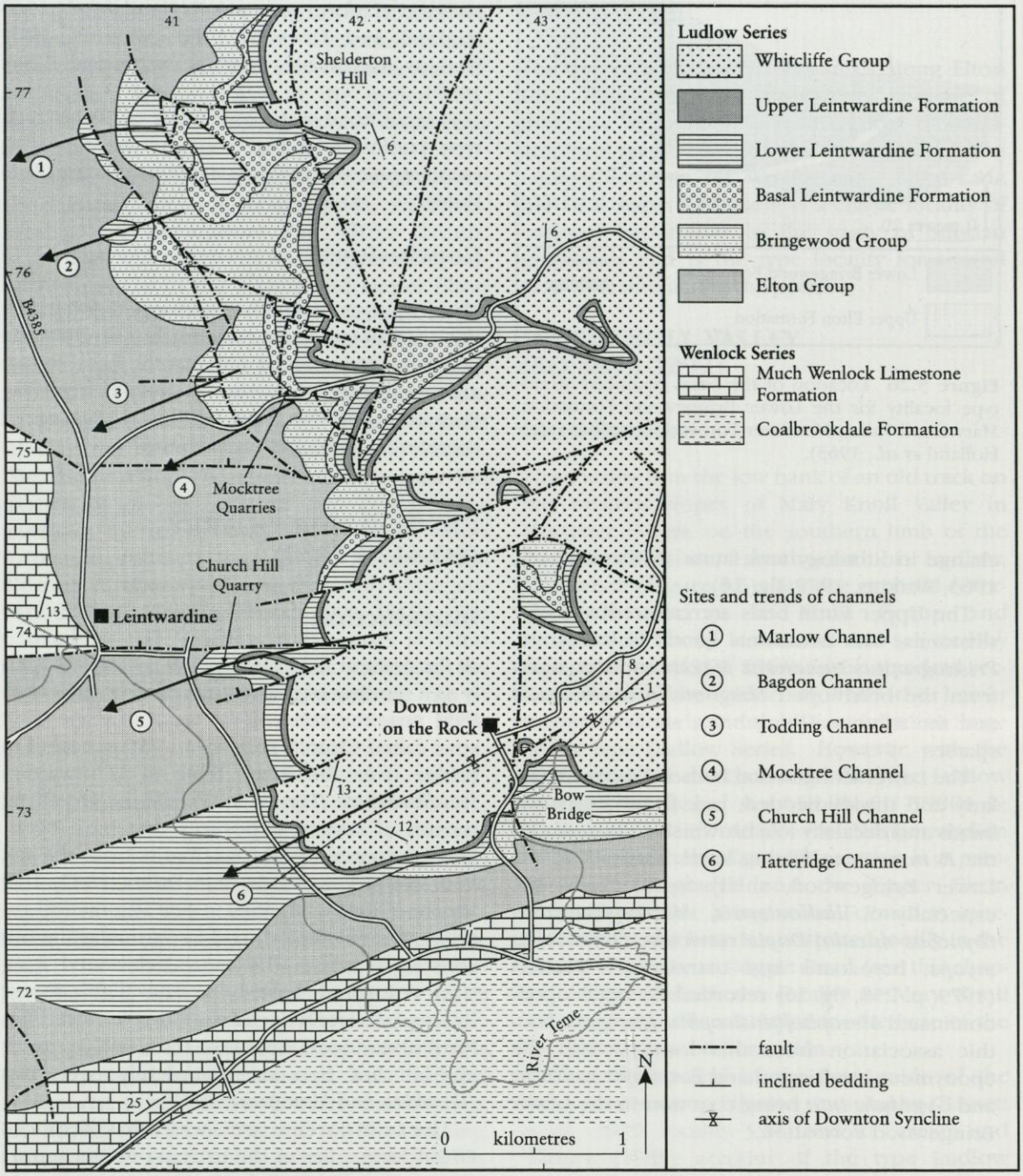


Figure 5.27 The geology in the vicinity of GCR sites Church Hill Quarry and Mocktree Quarries, Leintwardine area, Herefordshire (after Whitaker, 1962).

Church Hill consists of gently, easterly dipping Ludlow Series strata. Well-preserved, unusual Silurian invertebrates and vertebrates, including asteroids, crinoids, eurypterids and fish have been recorded by field parties and studied in detail by many authors (e.g. see Marston, 1865; Salter, 1857, 1859; Wyville Thompson, 1861; Woodward, 1866–78; Woodward and Dixon, 1904; Spencer 1914–1940, Hawkins and Hampton, 1927; Watson *et al.*, 1948; Ramsbottom, 1958; Blake, 1968). Alfred Marsdon of Ludlow is credited with the

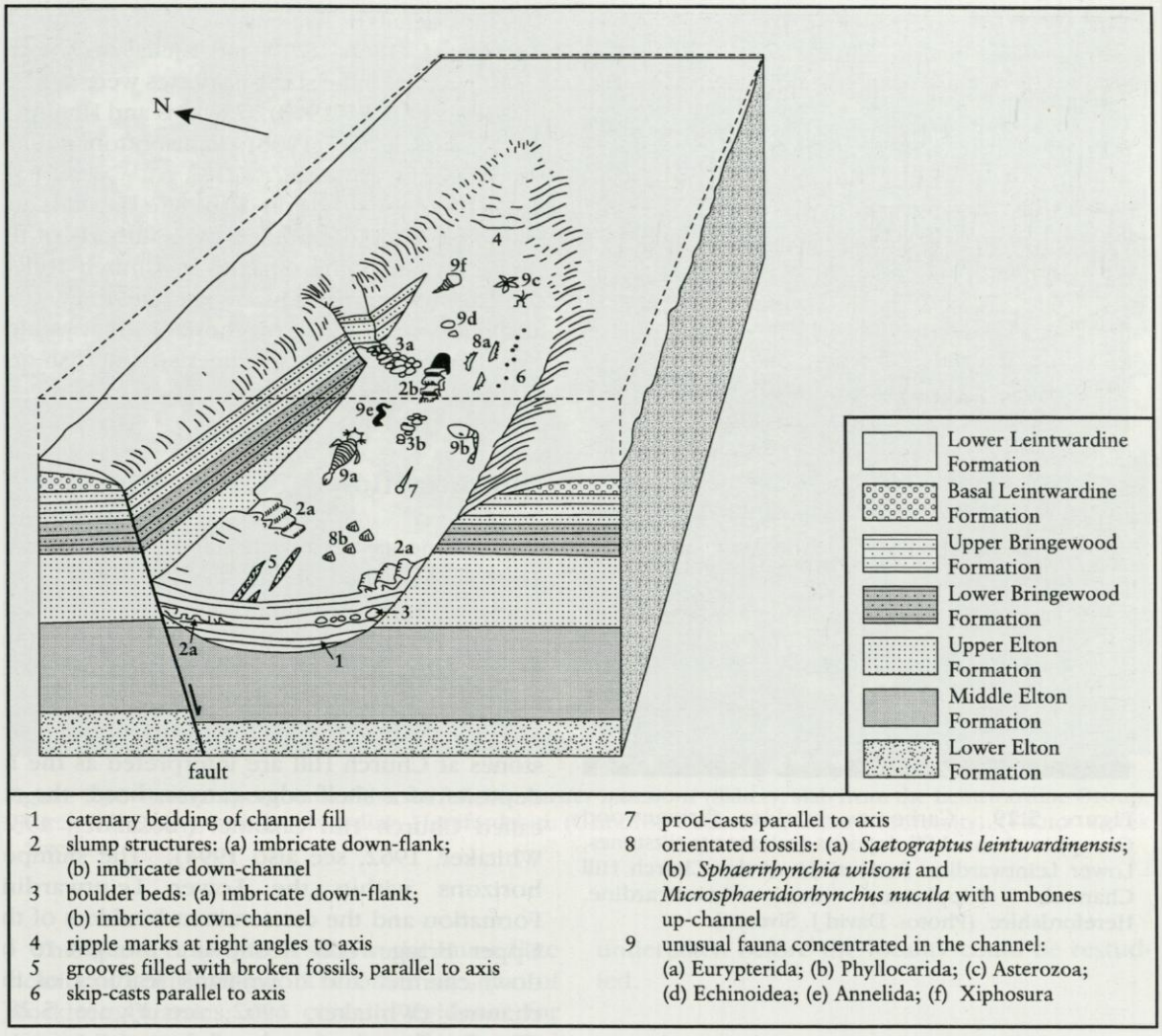


Figure 5.28 Schematic reconstruction (not to scale) of an idealized submarine channel-head of basal Ludfordian times (after Whitaker, 1962). Data from several channels. Note that down-cutting is more severe down-channel.

discovery of starfish from this and nearby localities (Lightbody, 1863). Several of these accounts, especially that of Hawkins and Hampton (1927), also provide information about the stratigraphy of the exposures and the main horizons that have yielded the well-known fossil finds. Church Hill is also the site of one of six submarine canyon-heads, of mid-Ludlow age, which are recognized locally (Whitaker, 1962; see Figures 5.27–5.33).

Description

The Middle Elton, Lower Leintwardine, Upper Leintwardine and Lower Whitcliffe formations succeed each other from west to east up the slope of Church Hill (Whitaker, 1962). The Lower Leintwardine Formation rests on the graptolite-rich Elton mudstones along a marked erosion surface. The Lower Leintwardine Formation (*Dayia* Beds of older literature) at Church Hill consists of calcareous siltstones, which at some horizons record slump structures and also contain rare boulders of the Upper Bringewood Formation (Aymestry Limestone of Alexander, 1936; Figure 5.29).

The Lower Leintwardine fauna at Church Hill occurs in bands. It includes the early Ludfordian biozonal graptolite *Saetograptus leintwardinen-*

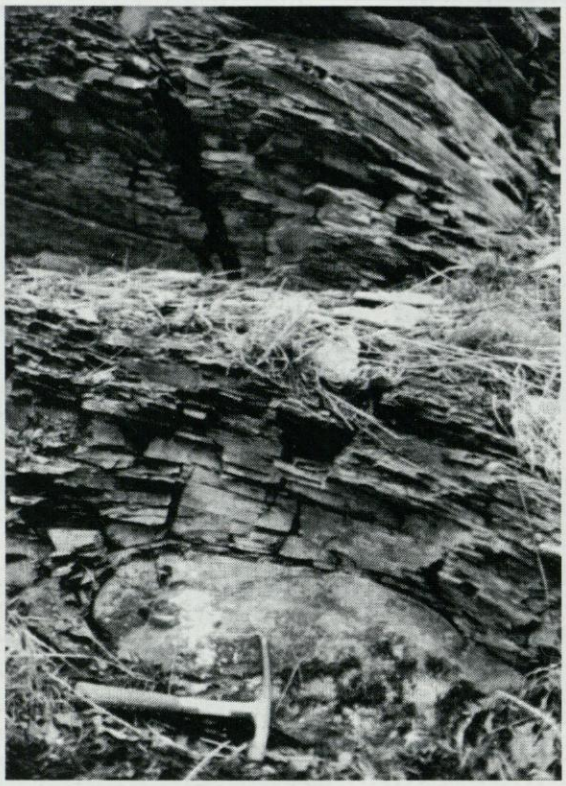


Figure 5.29 Carbonate boulder (Bringewood Group) in channel-fill deposits (calcareous siltstones, Lower Leintwardine Formation) of the Church Hill Channel, Trippleton, near Leintwardine, Herefordshire. (Photo: David J. Siveter.)

sis (Lapworth, 1880c), for which it is the type locality (see Wood, 1900, Elles and Wood, 1901–1918), and the brachiopod *Dayia navicula* (see Hawkins and Hampton, 1927; Alexander 1936). It is apparently also the source of the more spectacular fossil finds from the locality, such as starfish (e.g. *Echinocystus pomum*, *Furcaster leptosoma*, *Palaeodiscus ferox*, *Rhopalocoma pyrotechnica*, *Sturtzaster marstoni*, *Sturtzaster colvini* and *Lapworthura miltoni*; see Figure 5.30), eurypterids (e.g. *Salteropsis longilabium*; *Pterygotus arcuatus*), the small heterostracan fish *Archaegonaspis ludensis*, excellently preserved crinoids (e.g. *Eutaxocrinus maccoyanus*, *Gissocrinus ludensis*, *Mastigocrinus bravoniensis* and *Hapalocrinus quinquepennis*) and annelids (*Protoscolex*). The fish finds at Church Hill were mentioned in Roberts (1861) and many subsequent papers (e.g. Marston, 1870; Woodward, 1891; White, 1958; see Dineley and Metcalf, 1999 for details). The eurypterid taxa feature in Woodward (1866–1878) and Kjellesvig-Waering (1961); some of the starfish species were studied by Spencer (1914–1940), Hawkins and Hampton (1927) and Blake (1968); Ramsbottom (1958) described the crinoids.

On their re-excavation of the site Hawkins and Hampton (1927) identified the southerly of the then two remaining quarries at Church Hill as the famous 'Starfish Quarry' of Marston. They also managed to trace two horizons that yielded excellently preserved specimens of starfish and crinoids.

Interpretation

The sediments at Church Hill are fully marine. They accumulated at the western edge of the Midland Platform, a shelf area extending across central England during the mid-Silurian (see Siveter *et al.*, 1989, fig. 10; Bassett *et al.*, 1992, figs S4b, S5a; Figure 5.47).

The fossil-bearing Lower Leintwardine siltstones at Church Hill are interpreted as the fill deposits of a shelf edge canyon head, the so-called Church Hill Channel (Alexander, 1936; Whitaker, 1962, see also 1994). The slumped horizons within the Lower Leintwardine Formation and the concomitant boulders of the Upper Bringewood Group are thought to be down-channel and down-flank features of the channel (Whitaker, 1962; see Figure 5.28). Whitaker thought that the characteristic, unusual fauna of the Lower Leintwardine strata at Church Hill and similar, coeval assemblages documented from the other five submarine channels occurring locally were indigenous to such channel fill deposits (Figure 5.28). Hawkins and Hampton (1927) also considered that the fauna was indigenous, but in a very shallow lagoonal setting. Goldring and Stephenson (1972) maintained that the fauna was transported into the channels.

The margin of the Church Hill channel, with Lower Leintwardine resting unconformably on Middle Elton beds, is inferred at Church Hill itself (Alexander, 1936) and is seen at nearby Trippleton Farm Lane (Whitaker, 1962). The Church Hill Channel has a 10° gradient and has eroded out at least 180 m of Ludlow strata belonging to the Upper Elton, Lower and Upper Bringewood, and Basal Lower Leintwardine formations (Whitaker, 1962).

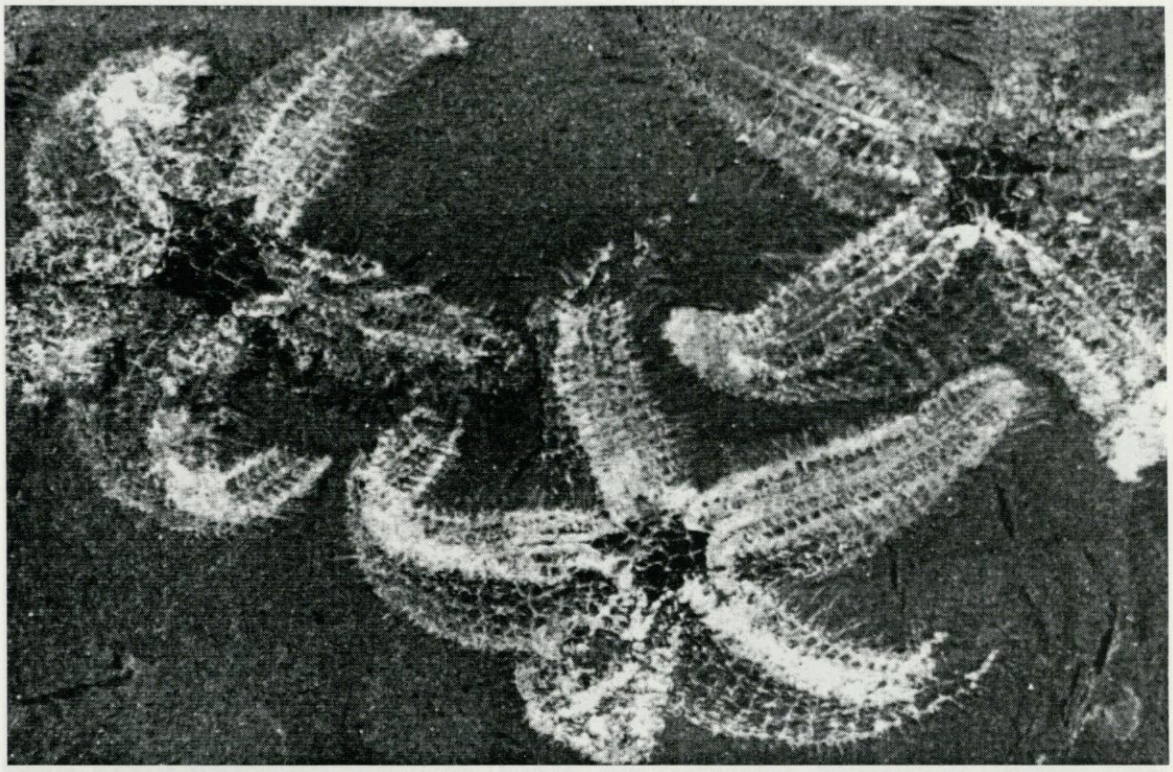


Figure 5.30 Several specimens of the starfish *Sturtzaster marstoni* (Salter); slab from the Leintwardine Group, Church Hill Quarry, near Leintwardine, Herefordshire (Grindrod Collection, Oxford University). (Photo: Derek J. Siveter.)

This is one of two GCR sites in the immediate vicinity of Leintwardine. The other site, that of Mocktree Quarries, also contains evidence for the existence of the same system of submarine channels. Both localities complement the many GCR sites that demonstrate the geology of the type Ludlow and contiguous areas of the Ludlow Anticline.

Conclusions

Church Hill Quarry is very important for historical, palaeontological and palaeogeographical reasons. Its famous marine fauna, recognized in the mid-19th century, is virtually unique in the British Silurian; it includes rare and unusual elements such as starfish, eurypterid arthropods and early fish specimens, and it is the type locality for many of the taxa found there. Its sediments accumulated in a mid-Ludlow age submarine channel at the edge of the eastern shelf of the Welsh Basin. The site is currently overgrown; careful re-excavation would have to be undertaken before the locality could be restudied.

MOCKTREE QUARRIES (SO 4130 7520–SO 4170 7536)

Introduction

These small, disused quarries occur on the north side of the A4113 Bromfield to Leintwardine road in the Mocktree area, about 1.5 km northeast of Leintwardine, Herefordshire (Figures 5.27, 5.31). The site displays a sequence through the middle part of the Ludlow Series, from Lower Bringewood to Lower Leintwardine formations (late Gorstian to early Ludfordian).

The first account of the rocks in the vicinity of Leintwardine was in Murchison's (1839) *Silurian System*. He noted, for example, that fine exposures of the 'Aymestry' (= Upper Bringewood) limestones are exposed at 'Mocktree Hayes' and along, 'The new road from Ludlow to Leintwardine...'. The strata are part

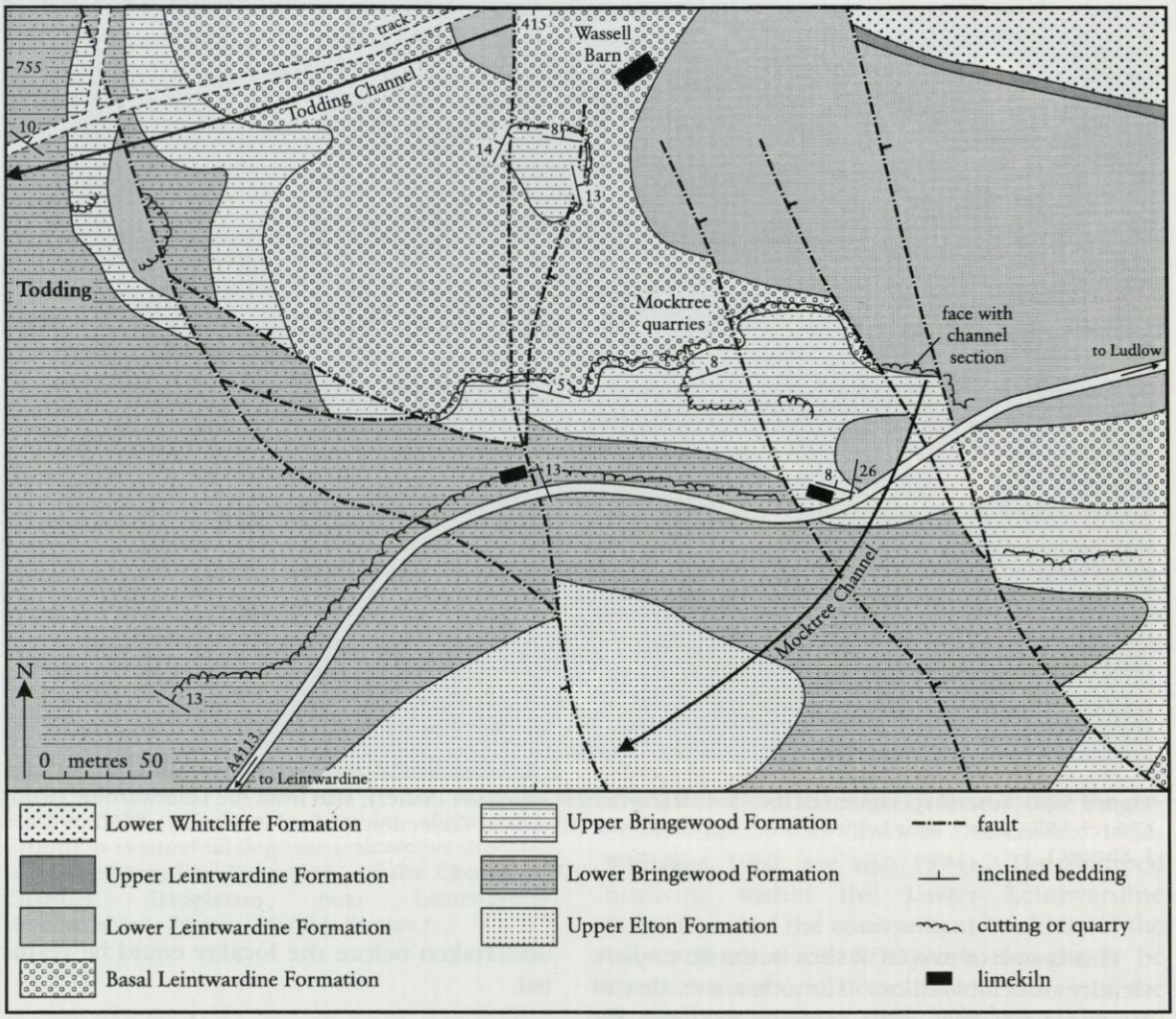


Figure 5.31 The geology of the vicinity of Mocktree Quarries near Leintwardine, Herefordshire (after Whitaker, 1962).

of the gently dipping northern limb of the asymmetrical Downton Syncline. The overall succession, comprising about 1100 m of Wenlock to Přídolí sediments, is similar to that at Ludlow 10 km to the east, but is thicker, generally less calcareous and shows larger-scale evidence of submarine erosion. Whitaker provided the seminal modern account of the geology of the Leintwardine region and its environmental setting (1962); Cherns (1988) made a specialized study of the local Leintwardine Group strata; and Siveter *et al.* (1989, locality 3.8) summarized the Silurian geology of Mocktree.

Early indications that the site contained a shallow erosive feature (Lightbody, 1863; Marston, 1865; Woodward and Dixon, 1904; see Figure 5.32) were confirmed when detailed mapping recognized the so-called Mocktree Channel as one of six, small-scale, NE–SW trending canyon heads in the vicinity of Leintwardine (Whitaker, 1960, 1962, 1994; see also Alexander, 1936 and Figures 5.27–5.33). About 170 m north-west of Mocktree Quarries exposures along the trackway from near Wassell Barn to Martin's Shell demonstrate the adjacent Todding Channel. This is part of a rare, important example (e.g. see Pickering *et al.*, 1989) of an ancient submarine canyon system, characterized in part by the fauna of the channels themselves.

Description

About 30 m from the road a face of the main quarry shows a section across the Mocktree

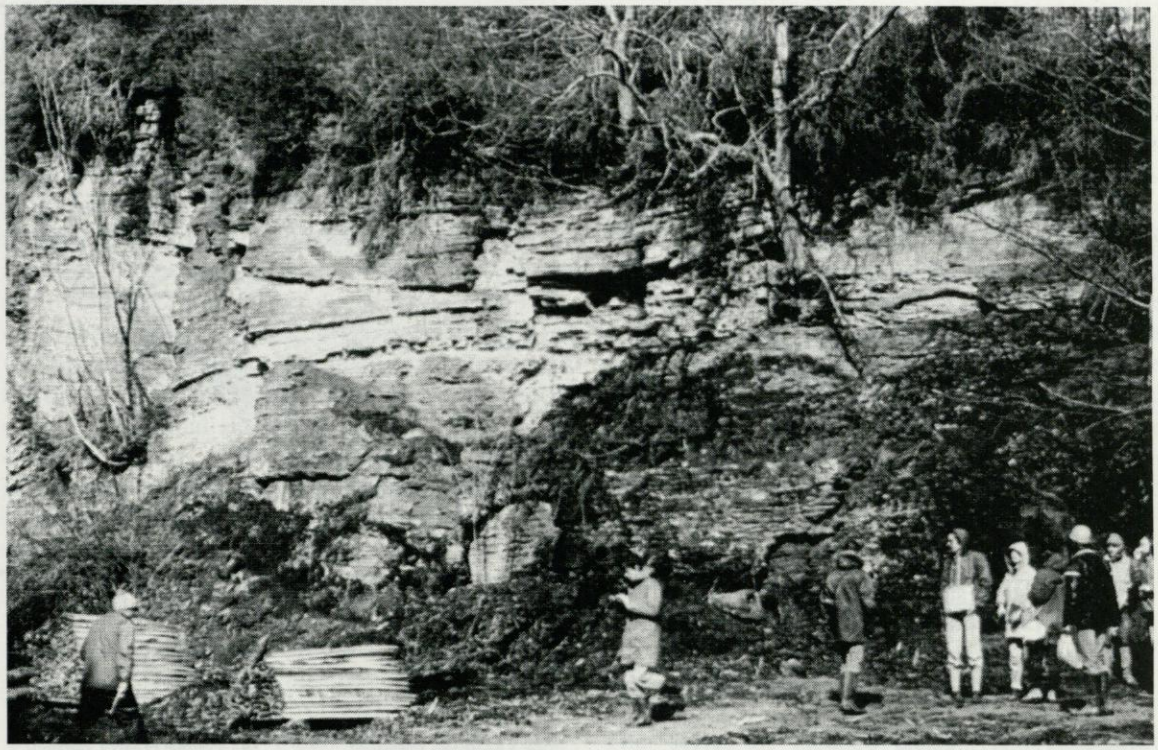


Figure 5.32 South-east face of Mocktree Quarries, near Leintwardine, Herefordshire, displaying Lower Leintwardine siltstones infilling the Mocktree submarine channel. This channel down-cuts, with a broad, gently curved base, into Basal Leintwardine Formation siltstones (0.7 m remaining in the centre of the channel), which lie above the Upper Bringewood Formation limestones occupying the lower part of the section (from below base of tree at centre right). Person at bottom left is J.H.McD. Whitaker. (Photo: David J. Siveter.)

Channel (SO 4167 7537). The lower part of this section and virtually all of the main part of the same quarry consist of hard, fairly massive and sometimes nodular, biocalcarenitic argillaceous limestones of the Upper Bringewood Formation. They contain crinoids, stromatoporoids, small discrete compound rugose and tabulate corals such as *Heliolites* and *Favosites* and brachiopods such as *Atrypa reticularis* and *Kirkidium knightii*. Some of the colonies are inverted, suggesting energetic water conditions. A broad, gently curved channel, 27 m across with an infill of calcareous siltstones of the Lower Leintwardine Formation, is eroded into calcareous siltstones of the Basal Leintwardine Formation that lie above the Bringewood limestones. The Basal Leintwardine of the area is normally about 18 m thick, but at the axis of the channel at Mocktree only 0.7 m survives.

The olive-grey Leintwardine strata contain many fossil-rich bands, yielding typical mid-Ludlow brachiopods *(Atrypa, Leptaena* and especially *Dayia)*, disarticulated trilobites such as *Alcymene lawsoni* (see Siveter, 1983; Ramsköld *et al.*, 1994), ostracods and, in former times, some of the unusual faunal elements (e.g. star fish, phyllocarids, eurypterids) supposedly occupying the channel (see GCR site report for Church Hill Quarry and Figure 5.28). Nearer the road from the channel face, these beds are faulted down to ground level, but are currently largely obscured by scree debris. Elsewhere, much of the quarry top is surrounded by Leintwardine siltstones, pieces of which litter the foot of the quarry face; they contain the ostracod *Neobeyrichia lauensis*, indicating the previously unrecorded presence of Upper Leintwardine strata here (David Siveter, pers. observ.).

The existence of the Mocktree Channel is also indicated by a tiny, mostly overgrown but very informative outcrop on the bend of the A4113 road, about 50 m south of the entance to Mocktree Quarry (SO 4163 7531), immediately east of an old lime kiln. This outcrop demonstrates a steep canyon head margin, with Lower Leintwardine channel fill resting with an original

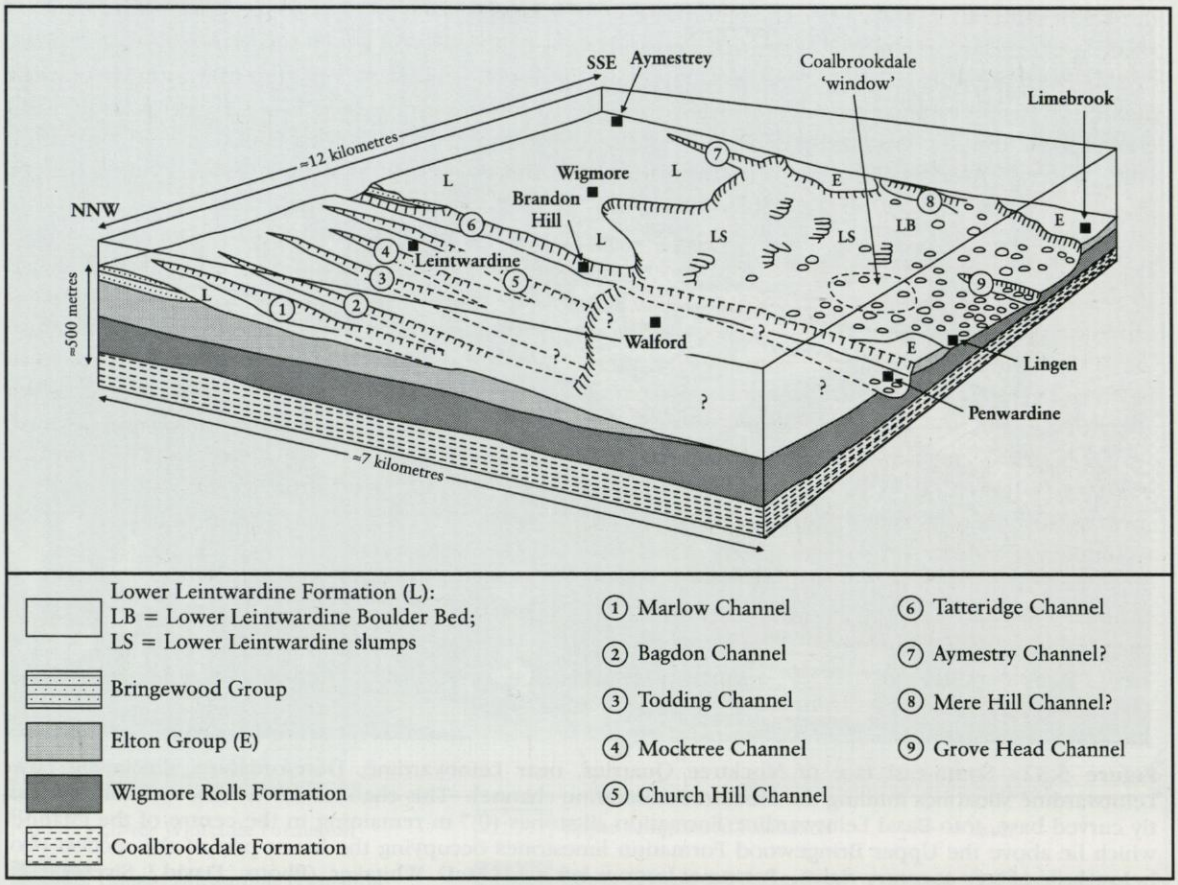


Figure 5.33 Block diagram, not to scale, illustrating the possible shelf edge and Welsh Basin slope in the Lentwardine–Lingen area at the beginning of Ludfordian time (after Whitaker, 1994). In the south-west, where the boulder bed is developed as a debris flow downslope from the postulated slide scar, places where Elton beds are not fully stripped off are not necessarily in their correct positions, nor is the Coalbrookdale 'window' where Lower Leintwardine erosion has cut right through the Wigmore Rolls Formation into the top of the Coalbrookdale Formation.

high dip of 26° against north-east dipping Upper Bringewood limestones that form the channel wall. Thus in a very short lateral distance the channel has cut down deeper and has completely eroded out the basal Leintwardine strata.

Across a fault just south of the lime kiln, the thickly bedded, tough, grey calcareous siltstones of the Lower Bringewood Formation occur. They are exposed for over 300 m westwards in bluffs on the north side of the A4113 road, beyond another lime kiln, to an old quarry near Lower Todding (SO 4135 7520; Figure 5.31). Occasional bentonitic clays are present. Common macrofossils include particularly large strophomenid brachiopods such as *Strophonella euglypha* and *Leptaena depressa,* together with *Atrypa reticularis, Gypidula,* bryozoans, crinoidal debris and the trilobite *Dalmanites*. This roadside section has also yielded many chitinozoan assemblages (Sutherland, 1994).

Interpretation

The sediments of this site were deposited along the western shelf edge of the Midland Platform, on the south-eastern margin of the Welsh Basin (see Siveter *et al.*, 1989, fig. 10; Bassett *et al.*, 1992, figs S4b, S5a; Figure 5.47).

The *Kirkidium* accumulations in the Bringewood strata were formed in moderate to high energy conditions (Watkins and Aithie, 1980). The Mocktree Channel is interpreted as one of several locally developed, parallel, submarine canyon heads trending from the shelf towards

the basin (Whitaker, 1962, 1994). Near source, as at Mocktree, these channels take out only part of the Basal Leintwardine Formation. At their maximum axial gradient they erode into Middle Elton beds, thus eliminating over 230 m of Ludlow strata (see GCR site report for Church Hill Quarry). Cut in earliest Ludfordian times, the channels were filled shortly afterwards, during the deposition of the Lower and Upper Leintwardine sediments. Elements of this canyon system can be traced south-westwards to the basin slope in the Wigmore Rolls area and beyond which, as evidenced by the occurrence of wide erosional slide scars, witnessed considerable instability at the same time as the channels were cut (Whitaker, 1994). The fauna of the canyon fill sediments may be indigenous (Whitaker, 1962) or transported into the channels (Goldring and Stephenson, 1972).

Many GCR sites in the central and southern parts of the Welsh Borderland (e.g. Wigmore Road, Deer Park Road, Sunnyhill, Perton Road, Longhope Hill) and in southern Wales (Sawdde Gorge) and northern Wales (Dinas Brân) have sequences containing a similar stratigraphical interval to that at Mocktree. Locally, GCR sites at View Edge at Craven Arms to the north, Aymestrey Quarries to the south and Bow Bridge to the west, also have Bringewood carbonates that accumulated in a similar, shelf-edge setting to those along strike at Mocktree. The nearby GCR site Church Hill Quarry contains evidence of the same submarine channel system as that manifest at Mocktree.

Conclusions

This site displays a complete and fairly continuous exposure of the fossiliferous middle Ludlow sequence in the Leintwardine area. However, its chief significance stems from the evidence it contributes for the existence of a regionally important submarine canyon-head system. Examples of the latter are very rare in the Phanerozoic and no other comparable feature is known in the British Silurian. The unusual, channel-fill fauna gives added, palaeontological significance to the site. Of great value to teachers and researchers, the exposures illustrating the anatomy of the Mocktree Channel are particularly important and should be rigorously preserved.

AYMESTREY QUARRIES (SO 4248 6547–SO 4210 6553)

Introduction

This series of disused quarry and associated pathside exposures occurs between Beechenbank Wood and the nearby Riverside (formerly the Crown) Inn at the A4110 road bridge over the River Lugg at Aymestrey, Herefordshire (Figure 5.34). The main quarry is sometimes referred to as Rockhall Quarry (e.g., Cleal and Thomas, 1995). The outcrops lie at the western end of the southern limb of the Ludlow Anticline and form a contiguous geographical and stratigraphical link with the type Ludlow Series

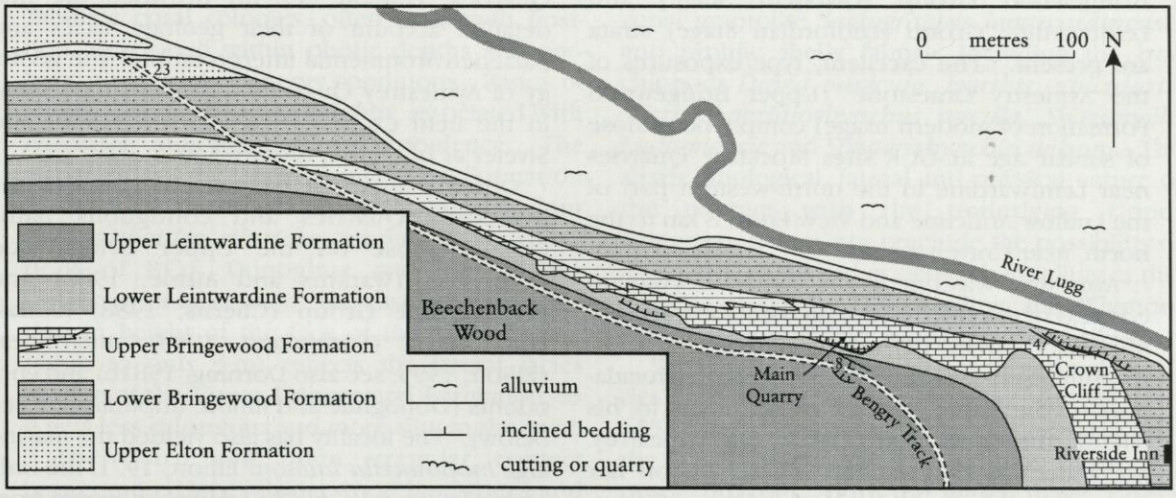


Figure 5.34 The geology of Aymestrey Quarries, Beechenbank Wood, Aymestrey, Herefordshire (after Lawson, 1973b; modified from Siveter *et al.*, 1989).

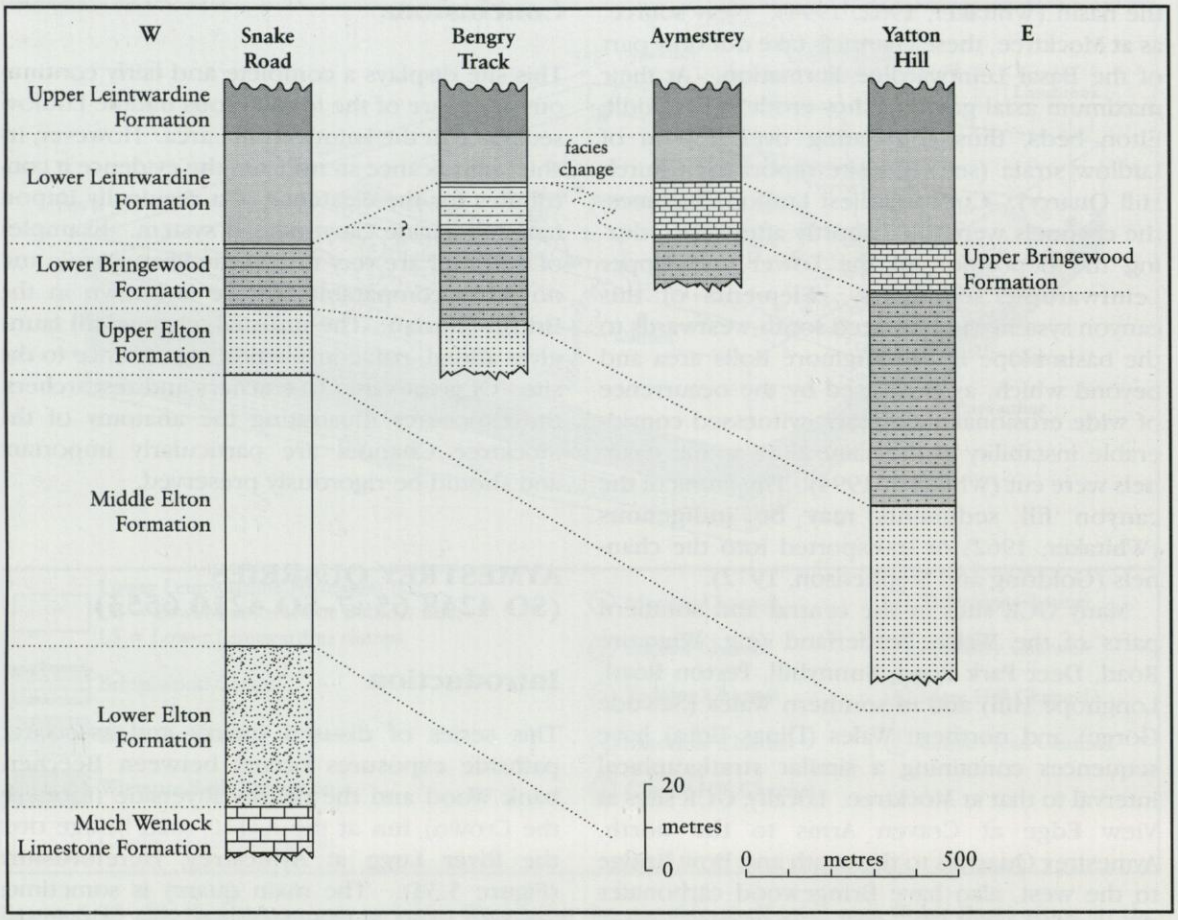


Figure 5.35 Comparative vertical sections in the Aymestrey area, to show east–west changes in facies and thickness of the Upper Bringewood Formation (after Lawson 1973b; modified from Siveter *et al.*, 1989).

(Holland *et al.*, 1963). Gently dipping Bringewood Group (Gorstian Stage) and Leintwardine Group (Ludfordian Stage) strata are present. The excellent, type exposures of the 'Aymestry Limestone' (Upper Bringewood Formation of modern usage) complement those of similar age at GCR sites Mocktree Quarries near Leintwardine in the north-western part of the Ludlow Anticline and View Edge, 8 km to the north, near Craven Arms.

Aymestrey was one of the earliest documented areas of the British Silurian, being featured by Murchison (1833, 1834, 1939) and Lyell (1841). As Murchison indicated (1839, p. 201), elucidation of the local geology owed much to his friend the Rev. T.T. Lewis of Aymestrey. Alexander (1936) included the region on her map of 'the Aymestry Limestone of the main outcrop', but gave no further information. Following Newell's (1966) lithological and palaeoecological studies on the Aymestrey Quarries, Lawson (1973b) provided the first detailed account of their geology, facies and palaeoenvironmental interpretation. The geology of Aymestrey Quarries was also summarized in the field excursions of Lawson (1960) and Siveter *et al.* (1989, locality 3.9).

Other analyses of the palaeontology of the Aymestrey Quarries and contiguous paths include those on the Upper Bringewood Formation (Watkins and Aithie, 1980) and Leintwardine Group (Cherns, 1988) faunas, chitinozoans (Sutherland, 1994), microfloras (Elliott, 1995; see also Dorning, 1981b) and conodonts (Donoghue and Elliott, unpublished, see below). The locality has also yielded the marine alga *Inopinatella lawsoni* Elliott, 1971, the only example of a non-calcified dasyclad known from the Palaeozoic worldwide (see Cleal and Thomas, 1995).

Description

Marked east–west facies changes of the Upper Bringewood beds occur over a distance of a few hundred metres in the Beechenbank sector of the Aymestrey area (Lawson, 1973b; see Figures 5.34, 5.35). Stratigraphically the section begins at Crown Cliff (SO 4248 6547), where the lower part of the pathside exposure displays about 10.5 m of the Lower and Upper Bringewood formations. Here shaly and flaggy calcareous siltstones, with a few bands of calcareous nodules, show an upward increase in carbonate content. The dominant macrofauna in the Lower Bringewood strata are brachiopods, including *Aegiria grayi, Atrypa reticularis, Shagamella ludloviensis* and *Sphaerirhynchia wilsoni,* together with the trilobite *Dalmanites.* The base of the Upper Bringewood Formation is drawn at the first appearance of *Favosites* tabulate coral colonies and of several bands of the large pentamerid brachiopod *Kirkidium knightii.*

The so-called Main Quarry (SO 4234 6548; Figure 5.36), about 40 m west of Crown Cliff, is the type locality for Murchison's (1833, 1834, 1839) Aymestry Limestone (Upper Bringewood Formation). Here the unit consists of nodular silty limestones containing three palaeoecological assemblages, which are perhaps arranged in two to three cycles, each of which reflects an increase in energy conditions (Newall, 1966; Lawson, 1973b). The relatively sparsely fossiliferous parts of the sequence have *Atrypa–Strophonella* assemblages, which possibly accumulated in relatively quiet water conditions. Tabulate coral colonies, often in growth position, developed within photic depths and perhaps under higher energy conditions. Bands of mainly disarticulated *K. knightii,* associated with *Favosites,* indicate increased turbulence. The upper part of the Upper Bringewood Formation has yielded the important biozonal conodont *Polygnathoides siluricus* (unpublished collections of P.C.J. Donoghue and R.E. Elliott, University of Leicester). The east to west reduction in height of the face of the Main Quarry (12 m to only 3 m) reflects the lateral facies change of the Upper Bringewood Formation, as it gets less calcareous and more silty to the west.

The sharp and often irregular contact between the Upper Bringewood limestones and the overlying, partly laminated, flaggy Lower Leintwardine Formation siltstones is traceable

Figure 5.36 The Main Quarry at Aymestrey, Herefordshire, exposing limestones of the Upper Bringewood Formation and, near the top of the section, the flaggy calcareous siltstones of the overlying Lower Leintwardine Formation. (Photo: David J. Siveter.)

westwards for 120 m along the face of the Main Quarry. About 3 m below the top of the limestones there is a distinctive shale band. The Leintwardine siltstones have ENE–WSW scour channels and contain the basal Ludfordian biozonal graptolite *Saetograptus leintwardinensis* and prolific shelly faunas, including the brachiopods *Dayia navicula, Isorthis orbicularis, Microsphaeridiorhynchus nucula, Shagamella Ludloviensis* and *Sphaerirhynchia wilsoni.* The sharp lithological, faunal and physical nature of the contact with the underlying Upper Bringewood does not preclude the possibility of an erosive break and possible channelling at this level as at nearby Leintwardine and Wigmore Rolls (Lawson, 1973b; Whitaker, 1962, 1994).

West of the Main Quarry are three small quarries (SO 4220 6550; SO 4214 6552; and SO 4210 6553), the easternmost of which exposes only the Lower Leintwardine Formation. At the two other quarries, both of which have Upper Bringewood and Lower Leintwardine formations, the Bringewood limestone is comparative-

ly muddy and yields shell debris. West of the westernmost quarry, which has about 4.5 m of Lower Leintwardine strata above 2.5 m of Upper Bringewood Formation, the limestone is not seen again. Evidence provided by a change of slope and from now overgrown small excavations along the riverside path strongly suggests a lateral passage of the limestone into siltstones from its base upwards (Lawson, 1973b).

Apart from a small quarry (SO 4234 6544), which exposes the Upper Leintwardine Formation, little outcrop remains of the section along Bengry Forestry Track, which was excavated in 1965–1966 across Beechenbank Wood above the Main Quarry. This track once exposed a virtually continuous, richly fossiliferous sequence from the Upper Elton Formation to the Upper Leintwardine Formation. The palynomorph assemblages of the Leintwardine Group of Bengry Track and of some of the quarries at Aymestrey have been detailed by Elliott (1995).

Interpretation

In mid-Ludlow times Aymestrey was situated at the western edge of the Midland Platform shelf area, on the eastern margin of the Welsh Basin (Siveter *et al.*, 1989, fig. 10; Bassett *et al.*, 1992, figs S4b, S5a; Figure 5.47). Relatively minor lithological, faunal and thickness variations of the Ludlow successions westwards, across the Ludlow Anticline towards Aymestrey and Leintwardine, in part reflect a proximal to distal transect across this shelf.

The facies at Aymestrey and their westward lateral changes signal a palaeogeographical position at the hinge between shelf and basin (Lawson, 1973b; see also Holland and Lawson, 1963, fig. 16; Cherns, 1988, text-fig. 14a). Here the Much Wenlock Limestone Formation becomes an alternation of carbonates and mudstones; the Upper Elton and the Bringewood beds become thinner (due to erosion on a ridge at the hinge ?); the Leintwardine Group thickens, shows slumping, and has faunas of more basinal affinity; the Whitcliffe Group also thickens but consists essentially of shallow-water deposits; and, most notably, the Upper Bringewood carbonates change rapidly into siltstones. The *Kirkidium* banks and biocalcarenites of the Upper Bringewood beds at Aymestrey accumulated in a narrow, relatively high energy shelf-edge zone (Facies 5 of Watkins and Aithie, 1980; see also Aymestry Limestone facies of Cherns, 1988). A water depth of less than 30 m is suggested by the presence of the alga *Inopinatella lawsoni* in a shale in these limestones (SO 4214 6552).

Other GCR sites on the same flank of the Welsh Basin that also have Bringewood and/or Leintwardine strata and are of shelf aspect occur at Wigmore Road, Goggin Road, the Whitcliffe, Deepwood and Deer Park Road in the Ludlow Anticline, Mocktree Quarries and Bow Bridge in the Downton Syncline, View Edge near Craven Arms, Turner's Hill in the West Midlands and Woodbury Quarry, Perton Road, Wood Green and Linton Quarry in the southern Welsh Borderland inliers. This stratigraphical interval is also present at the Sawdde Gorge in south Wales, but mostly in a more basin margin setting.

Conclusions

This internationally known, frequently visited site has historical, stratigraphical, palaeontological and palaeogeographical importance. It features in some of the earliest geological literature about the Silurian System; it contains the type sections for the 'Aymestry Limestone' of former usage; its rich, dominantly shelly biota includes a globally unique occurrence of an early non-vascular marine plant; and its facies patterns indicates that it was a pivotal, shelf edge locality. A high conservation value should be given to this site.

VIEW EDGE (SO 4260 8075)

Introduction

This disused quarry complex is sited at the crest of the wooded scarp of View Edge, about 2.2 km SSW of Craven Arms and 150 m south-west of View Edge Farm on the minor road from Onibury to Rowton, Shropshire (Figure 5.37). The site falls within the SSSI named Stoke Wood and View Edge Quarries. The exposures belong to the Upper Bringewood Formation (Figure 5.38), which is equivalent to part of the 'Aymestry Limestone' (Murchison, 1839, see also Alexander, 1936) of former usage. This very fossiliferous, late Gorstian age formation (see Holland *et al.*, 1963) occurs widely in the central Welsh Borderland.

View Edge lies between the Silurian of the Craven Arms to Much Wenlock area that occurs along strike to the north-east (Shergold and

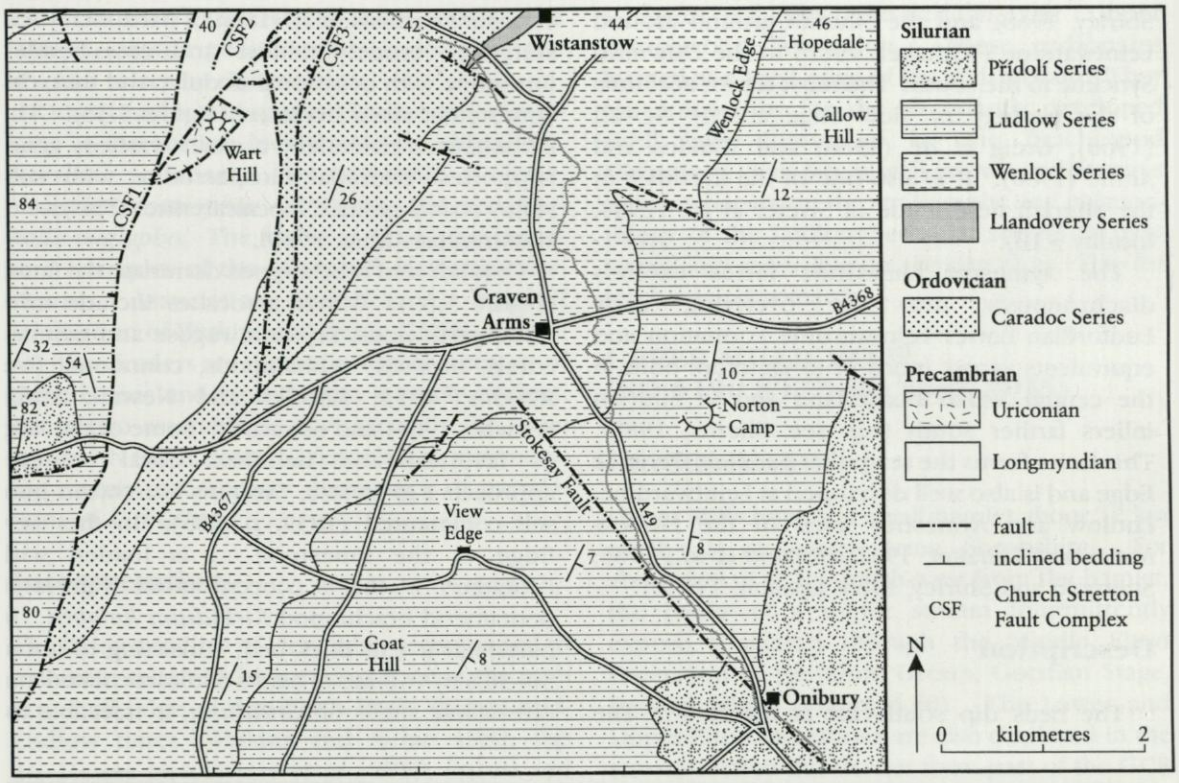


Figure 5.37 The geology of the Craven Arms area, Shropshire, showing the location of View Edge (after Siveter *et al.*, 1989).

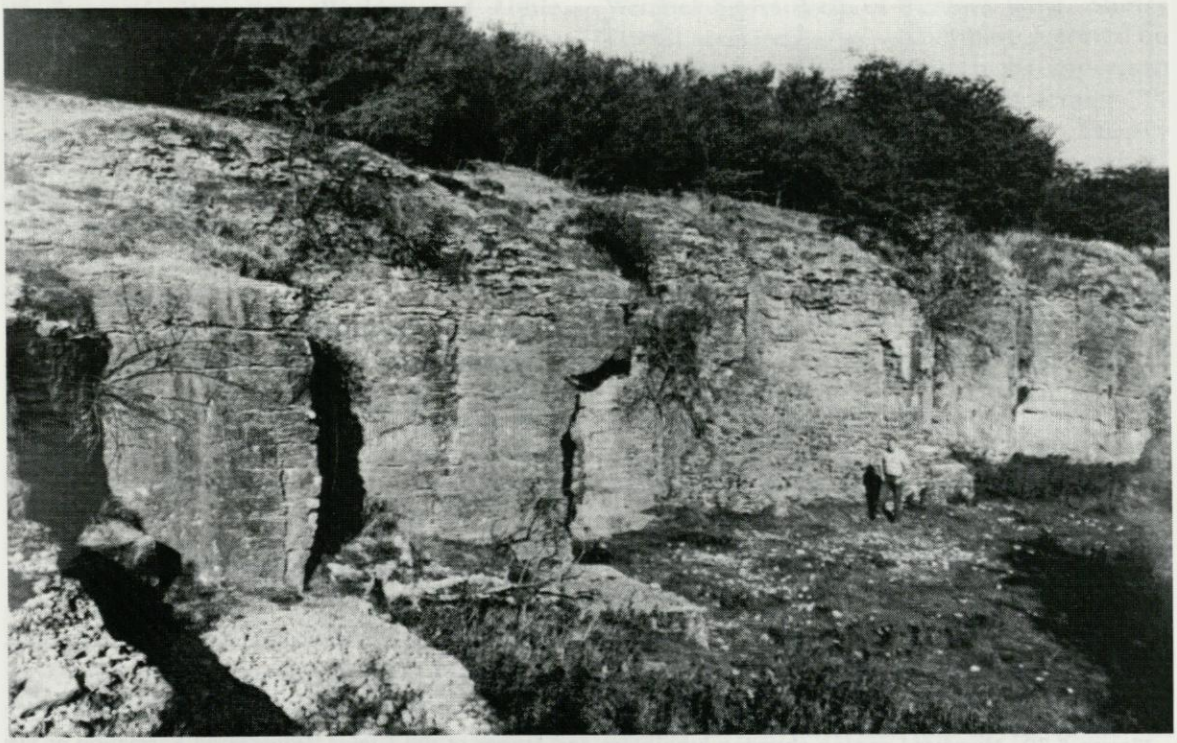


Figure 5.38 The quarries at View Edge, near Craven Arms, Shropshire: Upper Bringewood Formation carbonates containing abundant shell lags of the brachiopod *Kirkidium knightii*. (Photo: David J. Siveter.)

Shirley, 1968) and the Silurian ground around Leintwardine (Whitaker, 1962) in the Downton Syncline to the south. The most recent accounts of the geology of View Edge are by Newell (1966), Greig *et al.* (1968) and Watkins and Aithie (1980). It is also one of the localities in the Silurian field guide of Siveter *et al.* (1989, locality 3.10).

The Aymestry Limestone facies extends diachronously into the overlying early Ludfordian Lower Leintwardine Formation and equivalents across much of its outcrop, both in the central Welsh Borderland and in Silurian inliers farther south (e.g. see Cherns, 1988). This facies forms the scarp that parallels Wenlock Edge and is also well developed at Leintwardine, Ludlow and Aymestrey itself in the Ludlow Anticline (Whitaker, 1962; Holland *et al.*, 1963; Shergold and Shirley, 1968; Lawson, 1973b).

Description

The beds dip south-east at about 4°. The exposure consists of 10–11 m of hard, richly fossiliferous, crudely tabular and cross-bedded limestone with occasional nodular and thin, discontinuous shale horizons (Figure 5.38). The carbonate is essentially a clean washed, grain-supported crinoidal biosparrudite with subsidary coarse-grained biocalcarenites (Facies 6 of Watkins and Aithie, 1980).

Crinoids and brachiopods dominate the fauna (Figure 5.39). Minor associates include trilobites, gastropods, bryozoa, rugose and tabulate corals, bivalves, cephalopods, conodonts (see Rhodes, 1953; Rhodes and Newall, 1963; Schwab, 1969) and ostracods. Some of the larger favositid and heliolitid coral colonies approach 1 m in size. Also, as Murchison himself commented (1839, p. 203), 'In the View Edge ... the limestone ... is loaded with Pentameri ...', that is, concentrations of the large pentamerid brachiopod *Kirkidium knightii*. In particular a 1 m thick bed, consisting of about 30–50% by volume of banks of disarticulated and rare whole shells of *Kirkidium*, is traceable for

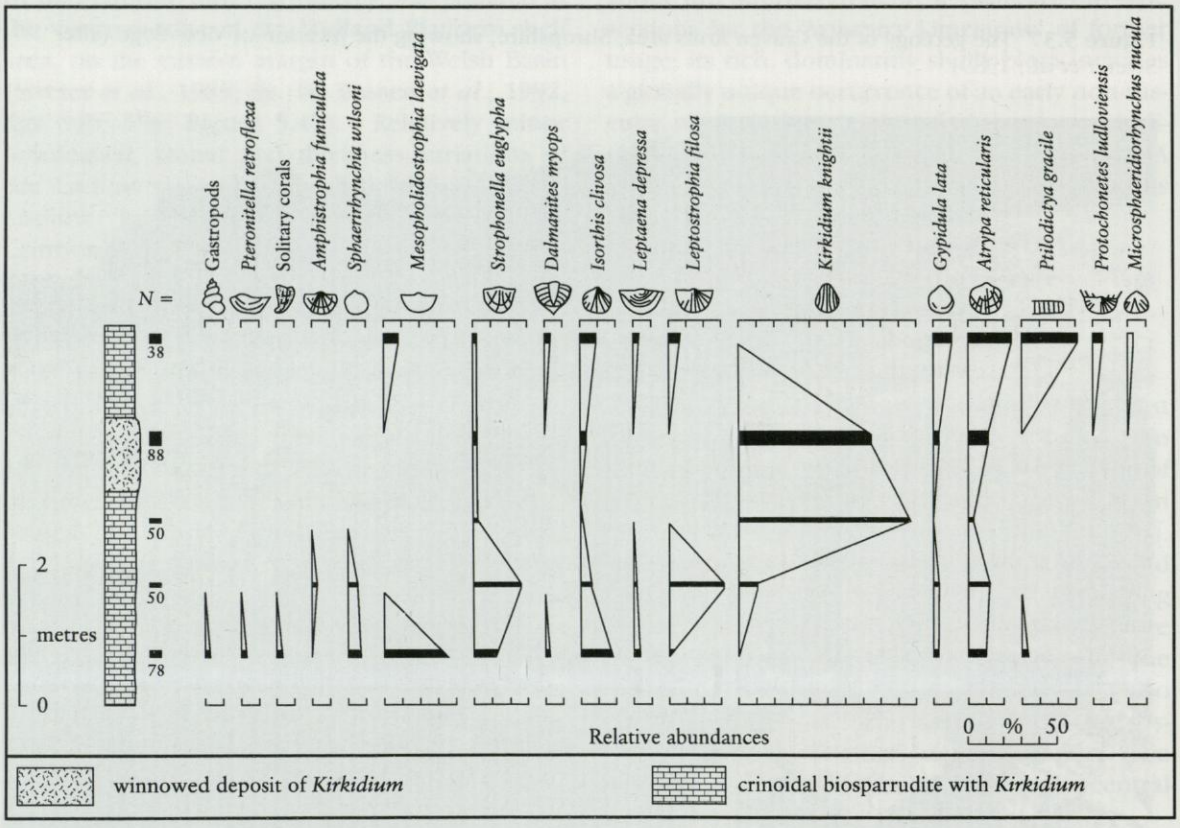


Figure 5.39 Measured section showing lithologies and faunas of the Upper Bringewood Formation at View Edge (after Watkins and Aithie, 1980).

230 m laterally (Watkins and Aithie, 1980). The heavier, convex pedicle valves outnumber the brachial valves by eight to one.

Other brachiopod species that are quite abundant in the section include *Atrypa reticularis*, *Isorthis clivosa*, *Leptostrophia filosa*, *Mesopholidostrophia laevigata* and *Strophonella euglypha*. The fossils at View Edge represent examples of the *Mesopholidostrophia laevigata* Association and the *K. knightii* Association of Watkins and Aithie (1980); epifaunal filter feeders are the main trophic category of these faunas and bioturbation is rarely evident. These two assemblages have virtually the same taxa, with the *K. knightii* Association representing merely a temporary dominance of populations of *Kirkidium*.

Interpretation

The biosparrudites of View Edge accumulated in a narrow, relatively high energy zone at the eastern shelf edge of the Welsh Basin during mid-Ludlow times (Watkins and Aithie 1980, figs 14–16; see also Siveter *et al.*, 1989, fig. 10 and Bassett *et al.*, 1992, fig. S4b). They are a representation of one of three parallel, north–south linear, carbonate facies belts of the Upper Bringewood Formation (Watkins and Aithie, 1980). This particular belt, a bank area of low topographical relief, supported high species diversity, especially dense stands of crinoids and brachiopods. Winnowing out of the fine sediment from the populations of *Kirkidium* produced shell lag deposits at or close to the site where the brachiopods lived. In general the inner shelf area to the east witnessed lower energy conditions.

The various facies of the Bringewood Group are traceable to the south and south-east from Craven Arms. The Upper Bringewood carbonates of the Leintwardine and Aymestrey areas (GCR sites at Mocktree Quarries, Bow Bridge and Aymestrey Quarries) are a continuation of the north–south shelf edge zone, but in the Ludlow area (GCR sites at Sunnyhill, Goggin Road, Deer Park Road and Deepwood) they reflect a more sheltered, inner shelf environment (Watkins and Aithie, 1980; Cherns, 1988).

Conclusions

View Edge is significant as it contains excellent, highly fossiliferous exposures of rocks typical of a facies of the mid-Ludlow age Upper Bringewood Formation. These carbonates formed at a shelf edge of the Welsh Basin. They are noteworthy for the abundantly developed shell lags dominated by the brachiopod *Kirkidium*. This site is well known and features in many papers on the stratigraphy and palaeontology of the Ludlow Series; it should be preserved and accessible on account of its value for teaching and research.

UPPER MILLICHOPE (SO 5190 8977–SO 5213 8935)

Introduction

Upper Millichope is a small hamlet about 12 km north-east of Craven Arms, Shropshire. For about 500 m to the north-west from the hamlet, the banks of a minor stream intermittently expose a section through the Middle Elton Formation of the Elton Group, Gorstian Stage, Ludlow Series (Figure 5.40). The Lower and Upper Elton formations are also displayed in the stream section but do not form part of the GCR site.

Upper Millichope is situated just to the south-west of the central part of the dip slope of the Wenlock Series scarp of Wenlock Edge. Shirley (1952) and Greig *et al.* (1968) have reported on the geology of the locality, which also appears in the field guides of Whittard (1958, locality 79) and Siveter *et al.* (1989; locality 2.9). The key studies of the section are the PhD work of Shergold (1967) and the findings of Shergold and Shirley (1968). Upper Millichope is chiefly celebrated as a richly fossiliferous locality; in particular, its trilobite faunas have long been prized. Its macrofaunal assemblages (Watkins, 1978a, 1979, p. 258, section 1E, fig. 22) and palynomorphs (Lister, 1970, text-figs 8, 11, 12) have received detailed attention.

Description

The Lower Elton Formation consists of shaly, shelly-dominated siltstones. The junction with the Middle Elton Formation is drawn at the change to more compact, blue- and olive-grey, brown-weathering, blocky calcareous siltstones and silty mudstones, which here are approximately 100 m thick and dip at 10–12° to the south-east (Shergold and Shirley, 1968). The Middle Elton beds characteristically show irregu-

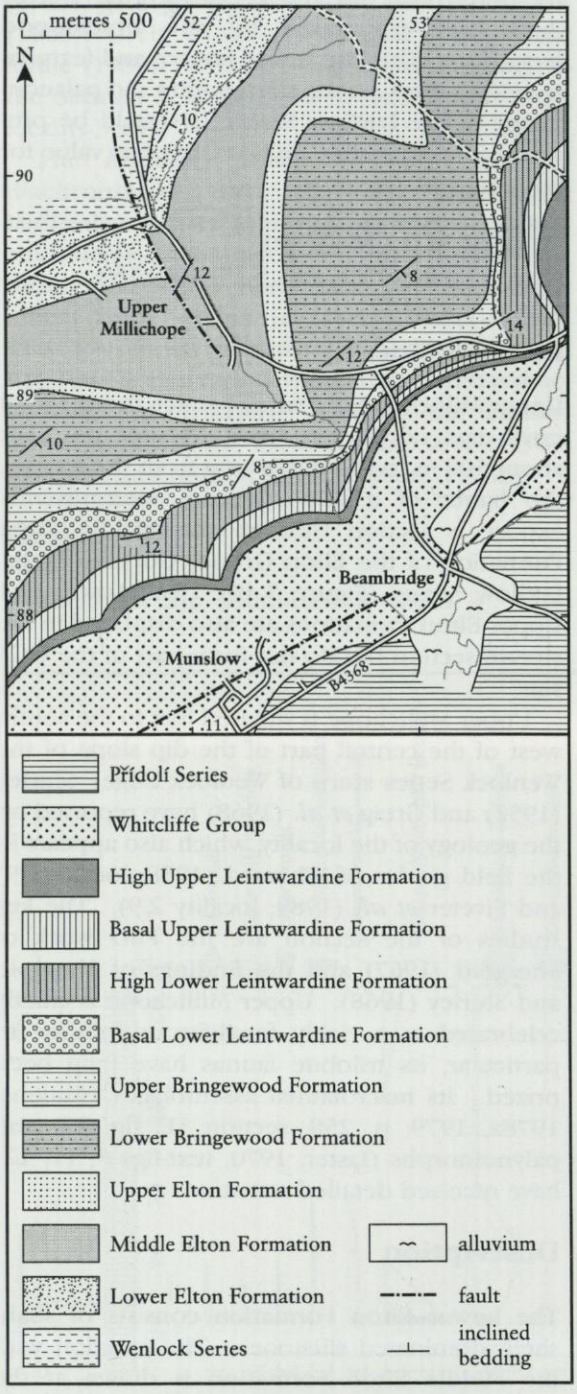


Figure 5.40 The geology of the Upper Millichope area, Shropshire (modified from Shergold and Shirley, 1968).

lar or conchoidal fracture; layers of argillaceous carbonate nodules are common in the formation, which also has about 15 bentonite layers.

Several of the shelly species found in the Lower Elton Formation, for example the brachiopod *Dicoelosia biloba* and the trilobite *Dalmanites myops*, range up into the basal 3–10 m of the Middle Elton. The lithological change from Lower to Middle Elton in the sequence coincides with the introduction of graptolites of the combined biozones of *Neodiversograptus nilssoni* and *Lobograptus scanicus*, with no less than 14 graptolite species recorded (Shergold and Shirley, 1968). *Saetograptus varians* and *N. nilssoni* are common, *Colonograptus colonus colonus*, *Saetograptus chimaera chimaera*, *Monograptus uncinatus uncinatus*, *Monoclimacis micropoma*, *Saetograptus roemeri*, *Spinograptus spinosus*, *Pristiograptus dubius*, *Bohemograptus bohemicus*, *Saetograptus incipiens* and *Pristiograptus* aff. *tumescens* also occur. The trilobites *Leonaspis*, *Ananaspis*, *Rhaphiophorus* and *Dalmanites* are also well represented. Several brachiopod taxa are present (e.g. *Glassia, Aegiria* and *Isorthis*), as are acritarchs and chitinozoans (Lister, 1970), rarer orthoconic and cyrtoconic nautiloids, bivalves, gastropods and solitary corals and a largely undescribed fauna of ostracods (see Shergold and Shirley, 1968; Watkins, 1979). Watkins (1979) collected a faunal assemblage from 15.8 m of Middle Elton strata at Upper Millichope and assigned it to his *Glassia obovata* Association (Figure 5.41).

Interpretation

The early Gorstian was a time of possible (eustatic) sea-level rise (e.g. see Hurst, 1975b; Bassett, 1976; Dorning, 1981a; Siveter *et al.*, 1989; Johnson *et al.*, 1991). The fine clastics of the Elton Group of Shropshire, which succeed late Wenlock bedded limestones and reefs, accumulated on the outer parts of the marine shelf (/shelf slope ?) of the Midland Platform area bordering the eastern margin of the Welsh Basin (see Siveter *et al.*, 1989, figs 8–10; Bassett *et al.*, 1992, fig. S4a). The volcanic centre for the source of the bentonites present at Upper Millichope and at other nearby Wenlock and Ludlow localities is unknown.

Though pelagic faunal elements (graptolites, nautiloids) are present in some numbers in the sequence at Upper Millichope, the co-occur-

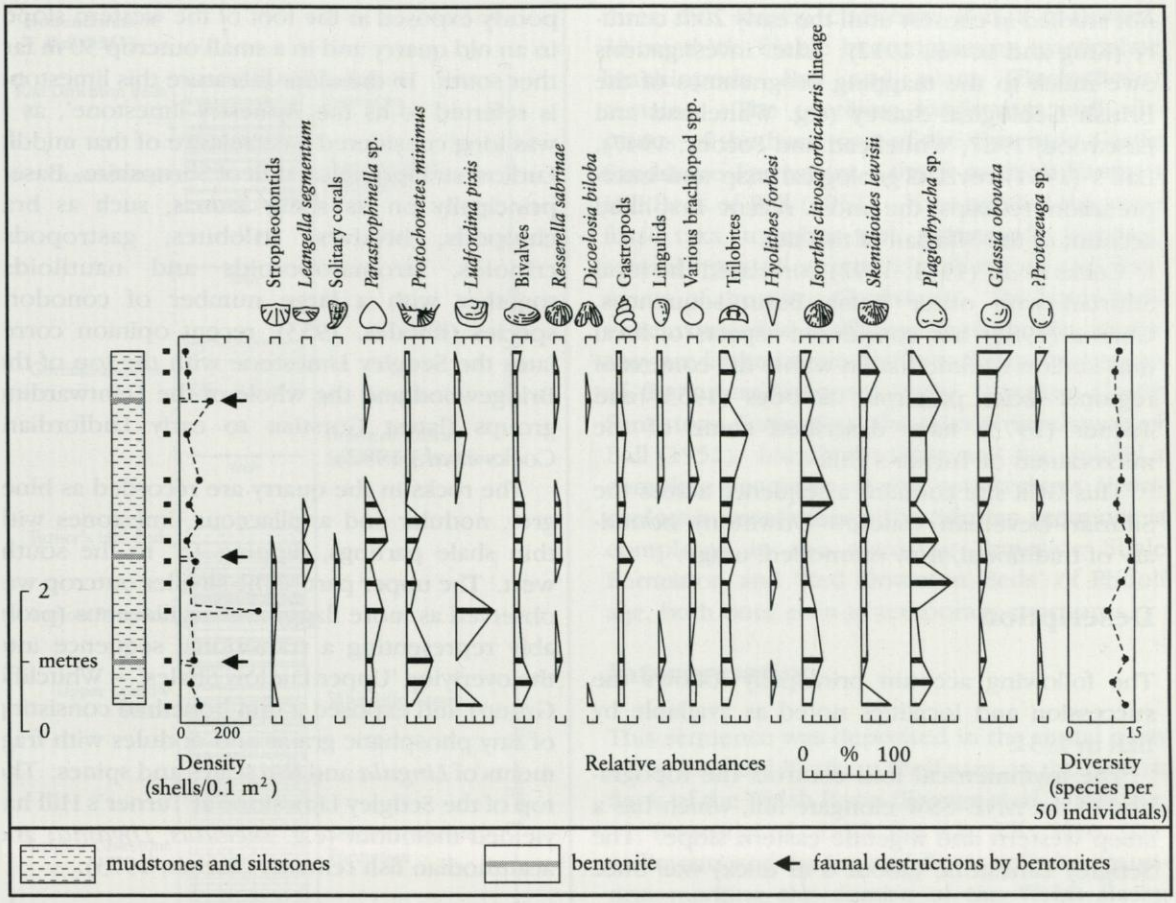


Figure 5.41 Faunal profile of 15.8 m of Middle Elton Formation strata at Upper Millichope, Shropshire (modified from Watkins, 1979): the *Glassia obovata* Association of Watkins (1979).

rence of brachiopods and characteristically disarticulated but nevertheless relatively locally derived (see Siveter *et al.*, 1989) trilobites and other associates indicates that bottom conditions were conducive to benthic life at such periods.

There are other GCR sites in the region that also have Middle Elton strata and are of like facies, such as Goggin Road, Burrington Farm Stream Section, Wigmore Road and Elton Lane in the Ludlow Anticline to the south.

Conclusions

This is a well-known site that provides a long, notably fossiliferous section through the Elton beds in ground contiguous with that of the type Wenlock Series. Its capacity to yield high numbers of finely preserved fossils is well documented; unfortunately, indiscriminate and excessive collecting has resulted in damage to the exposure. Its scientific value remains high, but access to the locality is granted only by special permission of the land owners and is strictly limited to small parties of *bona fide* researchers.

TURNER'S HILL (SO 910 919)

Introduction

This locality is about 2 km north-west of Dudley in the West Midlands (Figure 5.42). It once afforded exposures of Ludlow through into Přídolí beds (Figure 5.43).

Turner's Hill is one of several faulted, N–S to NNE–SSW aligned, anticlinal Silurian inliers arranged en echelon between Dudley, Sedgley and nearby Wolverhampton to the north. Though Murchison originally discussed this locality as early as 1839 (p. 482), its rocks were

not studied in earnest until the early 20th century (King and Lewis, 1912). Later investigations owe much to the mapping programmes of the British Geological Survey (e.g. Whitehead and Eastwood, 1927; Whitehead and Pocock, 1947). Ball's (1951) revised geological map and interpretation remains the most recent first-hand account of the Silurian of the site.

Cocks *et al.* (1971, 1992) correlated the local Silurian with other Welsh Basin sequences. Cherns (1988) has considered aspects of local mid-Ludlow sedimentation within the context of regional facies patterns. Rhodes (1953) and Turner (1973) have described some of the microfaunas of Turner's Hill.

This GCR site contains a sequence across the Silurian–Devonian (Ludlow–Downton) boundary of traditional, now outmoded, usage.

Description

The following account principally follows the succession and localities noted as available by Ball in 1951.

The asymmetrical fold controls the topography of the NNE–SSW elongate hill, which has a steep western and a gentle eastern slope. The Sedgley Limestone (about 8 m thick) was once poorly exposed at the foot of the western slope, in an old quarry and in a small outcrop 50 m farther south. In the older literature this limestone is referred to as the 'Aymestry limestone', as it was long considered a correlative of that middle Ludlow stratigraphical unit of Shropshire. Based principally on its shelly faunas, such as brachiopods, bivalves, trilobites, gastropods, crinoids, stromatoporoids and nautiloids, together with a large number of conodont species (Rhodes, 1953), recent opinion correlates the Sedgley Limestone with the top of the Bringewood and the whole of the Leintwardine groups (latest Gorstian to early Ludfordian; Cocks *et al.*, 1992).

The rocks in the quarry are recorded as blue-grey, nodular and argillaceous limestones with thin shale partings, dipping 15° to the south-west. The upper part of the smaller outcrop was observed as more flaggy and argillaceous (probably representing a transitional sequence into the overlying 'Upper Ludlow Shales' = Whitcliffe Group) and exposed a thin bone bed consisting of tiny phosphatic grains and nodules with fragments of *Lingula* and fish scales and spines. The top of the Sedgley Limestone at Turner's Hill has yielded thelodont (e.g. *Thelodus*, *Logania*) and acanthodian fish remains (Turner, 1973).

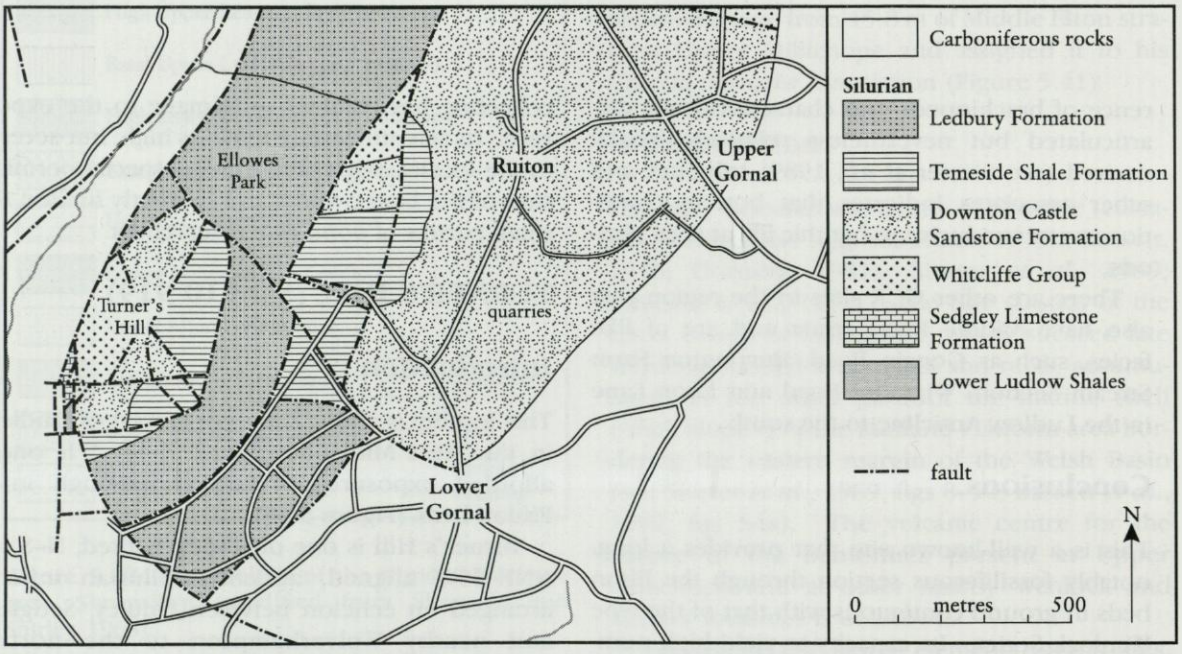


Figure 5.42 The geology in the vicinity of Turner's Hill, West Midlands (modified from Ball, 1951). Location of roads, buildings and quarries are shown as in 1951.

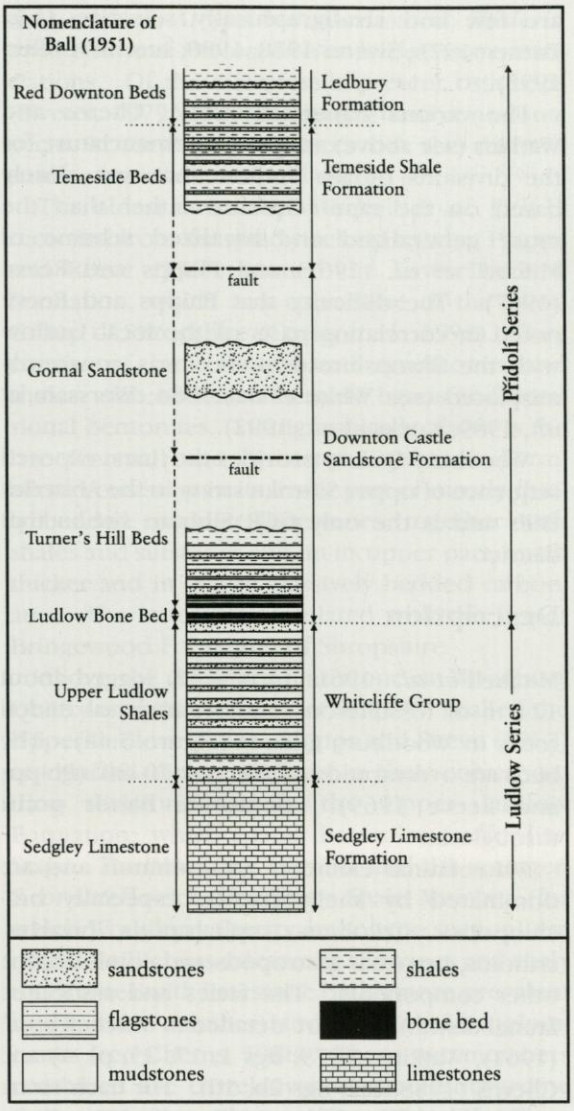


Figure 5.43 The Silurian succession at Turner's Hill, West Midlands (modified from Ball, 1951).

Fossiliferous Whitcliffe Group strata (about 9 m) were exposed along the western flanks of the hill north of the Sedgley Limestone outcrops. In general they have an upward transition from westerly dipping, argillaceous flaggy limestones through olive-buff shales, to horizontal and south-easterly dipping silty sandstones at the top of the Ludlow Series succession at the crest of the hill.

The Ludlow Bone Bed, at the base of the Přídolí Series Downton Castle Sandstone Formation, was once well exposed at the crest of the hill. In some places it consists of two or three thin lenses; elsewhere it is a coalesced, 38 cm thick, friable bed containing inarticulate brachiopods, fish and plant (*Pachytheca*) remains. The overlying sandstones and siltstones of the basal part of the Downton Castle Sandstone Formation – the 5 m thick Turner's Hill Beds of Ball (1951) – have yielded the same fossil taxa, together with gastropods, bivalves, several types of eurypterid arthropods and fragments of the plant *Cooksonia*. The latter beds were exposed in a hill crest road section, where they are faulted against yellow, flaggy sandstones of the succeeding part of the Downton Castle Sandstone Formation, the Gornal Sandstone of Ball (1951). Locally the latter unit has yielded a complete specimen of the ostracoderm *Hemicyclaspis murchisoni.* The Silurian sequence is completed in the overlying Temeside Shale Formation and 'Red Downton Beds' of Přídolí age, both once seen in temporary exposures.

Interpretation

This sequence was deposited in the cental parts of the Midland Platform shelf area on the eastern flank of the Welsh Basin (Siveter *et al.*, 1989, fig. 11; Bassett *et al.*, 1992, figs S5a, S5b, S8b). The sediments and faunas and floras reflect a transition marking the demise of the Welsh Basin, from fully marine, shallow-water conditions in the Ludlow to shallower, more marginal marine and, ultimately, terrestrial conditions in the late Přídolí (Allen and Tarlo, 1963; Allen, 1974, 1985; Bassett *et al.*, 1982; Miller, 1995). Land was never very far away from this locality.

The many GCR sites that display a Ludlow through to Přídolí sequence (see list under Ludford Lane and Ludford Corner) all reflect similar changes in palaeoenvironments. Of these Turner's Hill and the nearby locality at Brewin's Canal, just south of Dudley, are the most eastern, proximal shelf sites.

Conclusions

This site has the local equivalent of the former, unofficial Silurian–Devonian boundary level. It has palaeontological, palaeoenvironmental and palaeogeographical significance in containing several bone beds, including one in the Ludlow Series. It is also the type locality of several species of fossils. In addition it has historical value, featuring in *The Silurian System* of Murchison (1839). Unfortunately, because of

natural degradation and building development many of the former outcrops are no longer available.

WOODBURY QUARRY (SO 7430 6370)

Introduction

Woodbury Quarry lies about 1 km ENE of the hamlet of Shelsley Beachamp, Worcestershire. The Ludow and basal Přídolí strata here form part of the Abberley Hills, which are essentially a northerly continuation of the Silurian of the Malvern Hills and the contiguous area around Ledbury to the west.

Murchison (1839) and then Phillips (1848) gave the primary accounts of the Silurian geology of the Malvern and Abberley Hills. A 'Woodbury Hill' is mentioned in Murchison's account (1839, p. 410) of the 'Ludlow rocks in the Abberley Hills'. Groom (1899, 1900, 1910) also added significantly to our understanding of the local Silurian. Following the work of Holland *et al.* (1963) on the type Ludlow Series of Shropshire, Phipps and Reeve (1967, 1969) made what continues to be the standard study of the Silurian stratigraphy and structural geology of the Malverns and Abberley area.

The maps and overview of Phipps and Reeve lacked details of the stratigraphy of Woodbury Quarry itself. Such data was furnished in the British Geological Survey Droitwich Memoir (Mitchell *et al.*, 1961), which records the entire sequence, and by Watkins and Aithie (1980), Cherns (1988) and especially by Watkins (1978a, 1979), in their research on Ludlow facies and faunal communities of the Welsh Basin. Accounts of microfossils from Woodbury Quarry are few and stratigraphically selective (e.g. Turner, 1973; Siveter 1978, 1980; see also Miller, 1995).

The various papers of Aithie, Cherns and Watkins (see above) adopted a nomenclature for the divisions of the Ludlow that was closely based on the type sequence rather than the more generalized and localized scheme of Mitchell *et al.* (1961) and Phipps and Reeve (1967). The difficulty that Phipps and Reeve noted in correlating parts of the local Ludlow with the Shropshire sequence was apparently misplaced (see White *et al.*, 1984; Worssam *et al.*, 1989; Cocks *et al.*, 1992).

Woodbury Quarry provides the finest exposed sequence of upper Silurian strata in the Abberley Hills and is the only GCR Silurian site in that district.

Description

Mitchell *et al.* (1961, pp. 45, 46) logged about 124 m of fossiliferous Ludlow to basal Přídolí rocks in Woodbury Quarry (Figure 5.44). The beds are overturned and dip east 70–80° (Phipps and Reeve 1969). Bentonite bands occur throughout.

Macrofaunal elements are common and are dominated by shelly fossils, especially brachiopods. Trilobites, cephalopods, bivalves, crinoids, bryozoa, gastropods and corals are the other components. The facies and associated faunal distributions are detailed in Mitchell *et al.* (1961), Watkins (1979, figs 1, 17, 25, pl. 4) and Cherns (1988, text-figs 2b, 10). For each stratigraphical unit of the Ludlow at Woodbury Quarry, Watkins (1979) recognized a separate benthic faunal association, namely the *Mesopholidostrophia laevigata*, *Sphaerirhyn-*

Figure 5.44 Ludlow Series (Bringewood, Leintwardine and Whitcliffe groups) to basal Přídolí Series, Woodbury Quarry, Abberley Hills, Worcestershire; the strata young from right to left, are overturned to the east and dip 70°–80°. (Composite photo: David J. Siveter, 1970.)

chia wilsoni, *Atrypa reticularis*/coral, *Shaleria ornatella* and *Protochonetes ludloviensis* associations. Of the microfossils present ostracods (Siveter, 1979, 1980), acritarchs and conodonts occur in varying abundances but the relevant studies are mostly unpublished.

The oldest strata that Mitchell *et al.* (1961) recorded from the quarry belong to what Phipps and Reeve (1967) termed the Lower Ludlow Formation, which is a correlative of the Elton Group of Shropshire (Cocks *et al.*, 1992). They consist of buff, bioturbated mudstones and shales, with nodular limestone bands and occasional bentonites. Stratigraphically above is the late Gorstian age Aymestry Limestone Formation, consisting in its lower part of mostly thinly bedded, nodular limestones, together with shales and siltstones and, in its upper part, much thicker and in places massively bedded carbonates. The latter are correlated with the Upper Bringewood Formation of Shropshire.

Above the Aymestry Limestone at Woodbury Quarry are what Mitchell *et al.* (1961) called the Upper Ludlow Shales. Phipps and Reeve (1967) recognized three members in their corresponding division, namely the Upper Ludlow Formation, which spans the entire Ludfordian Stage. The Mocktree Member and the younger, *S. ornatella*-rich Woodbury Shale Member (for which Woodbury Quarry is the type section) are quite fossiliferous calcareous siltstones and shaly mudstones with limestone beds (more prevalent in the older member) and occasional conglomerates (see Cherns, 1988). These two members combined are correlatives of the Leintwardine Group of Shropshire. The Whitcliffe Flags Member, consisting essentially of flaggy calcareous silstones, is coeval with the type Whitcliffe Group (Cocks *et al.*, 1992). Mitchell *et al.* (1961) recorded about 1.6 m of 'Downton' strata at the top of the Woodbury Quarry succession. These assumed Přídolí age deposits consist of greenish-grey sandstone and shale containing inarticulate brachiopods and black carbonaceous and phosphatic debris and an exposure of the Ludlow Bone Bed (Mitchell *et al.*, 1961). Turner (1973) records several thelodont fish genera from these Přídolí sediments, including *Thelodus* and *Logania*.

Interpretation

These deposits accumulated on the Midland Platform on the south-eastern flank of the Welsh Basin (see Siveter *et al.*, 1989, figs 10, 11; Bassett *et al.*, 1992, figs S5a, S5b, S8b). The Ludlow Series reflects shallow-water marine sedimentation. During the time of deposition of its middle Ludlow carbonates and calcareous clastics the locality was sited on the relatively sheltered, back barrier, inner part of the shelf (Watkins and Aithie, 1980, fig. 15; Cherns,1988, text-fig. 14a; Figure 5.47). The much more faunally restricted fish and plant-bearing Přídolí sandstones bear evidence of the late Silurian regressive event which, as the remnant Welsh Basin finally silted up, established marine influenced mudflats and later terrestrial conditions over central England and Wales (see Bassett *et al.*, 1982; Allen, 1985).

Woodbury Quarry is one of many Welsh Borderland sites in the GCR network that shows Ludlow shelf facies succeeded by the overlying Přídolí Series (see list under Perton Road and Quarry). Gullet Quarry (Llandovery Series) in the Malverns and Gurney's Quarry (Wenlock and Ludlow Series) in the adjacent Ledbury area are the only other GCR sites in the Malvern, Abberley and Ledbury Hills region.

Conclusions

This site is the most stratigraphically complete section of the Ludlow to Přídolí series of the Abberley, Malvern and Ledbury region. It provides the standard reference sequence for a local stratigraphical unit of the Ludlow Series and is the type locality for a number of macro- and microfossils. Woodbury Quarry is cited in many research papers and, not least because of its excellent exposures, has good potential for use in teaching.

GURNEY'S QUARRY (SO 7170 3840)

Introduction

This large, abandoned quarry lies just west of the A449 road, about 1 km north-east of Ledbury, Herefordshire, in the central part of the Welsh Borderland. The locality is also known as County Quarry, Ledbury Quarry and Lower Hall Farm Quarry. It exposes a section across the Wenlock–Ludlow boundary (Figure 5.45).

This GCR site is part of the Silurian of the Malvern–Abberley–Ledbury Hills area. Originally studied by Murchison (1839) and Phillips

Figure 5.45 Gurney's Quarry, Ledbury, Herefordshire: Much Wenlock Limestone Formation and the calcareous mudstones and siltstones of the overlying Lower Ludlow Formation. (Photo: Derek J. Siveter.)

(1848) and later by Groom (1899, 1900, 1910), the Silurian litho- and chronostratigraphy and structure of this ground was mapped in modern times by Phipps and Reeve (1967, 1969). The Silurian stratigraphy of the south Malverns–Ledbury district is also summarized in the British Geological Survey Memoir for the country around Tewkesbury (Worssam *et al.*, 1989). Cocks *et al.* (1971, 1992) showed correlation of the Silurian here with the type and other sequences of Shropshire.

Several of the local Silurian localities have appeared in two field guides to the area (Penn and French, 1971; Bullard, 1989), of which the former briefly mentions Gurney's Quarry. Phipps and Reeve (1967) recorded the local Silurian faunas. Fossils from the quarry that have featured in specialist studies include trilobites (Thomas, 1978), brachiopods (Bassett, 1970a) and the microflora (Dorning, 1981b).

In the Welsh Basin Gurney's Quarry shows one of the best outcrops of the Wenlock–Ludlow junction outside the Ludlow area. It was one of the sections selected by Corfield *et al.* (1992) in their carbon isotope studies of that boundary.

Description

The quarry occurs more or less along the axis of a minor, NE–SW trending anticline and about 0.5 km east of the north–south aligned Ledbury Fault (Phipps and Reeve, 1969). The long, mostly vertical exposure shows gently dipping Much Wenlock Limestone Formation (late Homerian, Wenlock Series) overlain conformably by the Lower Ludlow Formation (early Gorstian, Ludlow Series). These Lower Ludlow beds are equivalent to the lower part of the Lower Elton Formation of Shropshire.

The Much Wenlock Limestone Formation is a grey, bedded, nodular and bioclastic carbonate; argillaceous partings and interbeds are common. In the Malverns area this stratigraphical unit has a varied fauna of brachiopods, corals, bryozoans, algae, stromatoporoids, crinoids and trilobites; gastropods, cephalopods and bivalves are rarer (Phipps and Reeve, 1967). Bioherms are not recorded from the limestone at Gurney's Quarry but very rare examples are known locally (Penn, 1971). Lawson (1954) used the characteristics of the Much Wenlock Limestone at

Gurney's Quarry in determining a late Wenlock age for the Gorsley Limestone of the Gorsley Inlier some 13 km to the south-east.

The Lower Ludlow Formation exposed consists predominantly of grey calcareous mudstones and siltstones. Locally this unit contains a varied, much comminuted shelly fauna dominated by small brachiopods; colonial organisms are virtually absent (Phipps and Reeve, 1967). Well-preserved microfloras, assignable to the *Leptobrachium longhopense* acritarch Biozone, have also been recovered from these clastic rocks (Dorning, 1981b, and unpublished data).

Interpretation

The late Wenlock to early Gorstian deposits represented at Gurney's Quarry accumulated on the outer shelf of the eastern, Midland Platform to the Welsh Basin (see Siveter *et al.*, 1989, figs 8–10; Bassett *et al.*, 1992, figs S3b, S4a; Figure 5.47). The lithological changes across the series boundary, from carbonates to fine clastics, possibly reflect a sea-level transgression (e.g. see Hurst, 1975b; Bassett, 1976; Dorning, 1981a; Siveter *et al.*, 1989; Johnson *et al.*, 1991). Shifts in climatic and associated oceanic states provide another possible explanation for such lithofacies changes (Jeppson, 1990; Jeppson *et al.*, 1995).

Gurney's Quarry and Woodbury Quarry, about 28 km to the north, are the only GCR sites that display Ludlow strata in the Malvern–Abberley–Ledbury Hills area. The only other GCR site in that area is Gullet Quarry (Llandovery Series), at the southern end of the Malvern Hills. Gurney's Quarry is one of several sites that show the Ludlow–Wenlock boundary in the Welsh Basin (see list under 'Pitch Coppice'). Like the sequence at Gurney's Quarry the boundary stratotype at Pitch Coppice in Shropshire reflects a shallow marine setting. Coeval localities representative of a range of depths in the Welsh Basin all show a marked carbon isotope depletion in the latest Wenlock, which in part is related to a decline in graptolite diversity (Corfield *et al.*, 1992).

Conclusions

This locality contains sediments indicative of a marine platform environment of the Welsh Basin. The site is readily accessible and is important because it displays a well-exposed Wenlock–Ludlow boundary sequence containing rich macro- and microfaunas and floras; moreover, it is the type locality for several species. The site is referred to in many research papers and should be conserved.

LINTON QUARRY (SO 6770 2570)

Introduction

This former working quarry lies 300 m south of the B4221 Newent to Ross-on-Wye road, in the village of Gorsley, Herefordshire (Figure 4.11). The Gorsley area contains the smallest of the Silurian inliers in the Welsh Borderland. Linton Quarry provides the most accessible and most complete local Silurian sequence, exposing Wenlock, Ludlow and Přídolí strata. The rocks of the latter two series are described here; the deposits of Wenlock age of the site are described separately in this volume.

The geology of the Gorsley area was first described in 1839 by Murchison. Phillips (1848), Symonds (1872) and Pocock (1950) have also discussed its stratigraphy. The most recent first-hand account of the rocks and fossils of Linton Quarry is by Lawson (1954; Figures 4.11, 4.12, 5.46). The stratigraphy of the Gorsley Inlier, and in particular that of Linton Quarry, is also reviewed in correlation charts, field excursion guides and British Geological Survey memoirs (e.g. Holland *et al.*, 1963; Squirrell and Tucker, 1967, 1982; Cocks *et al.*, 1971, 1992; Worssam *et al.*, 1989).

The Wenlock or Ludlow age of the Gorsley Limestone, the lowest stratigraphical unit exposed in Linton Quarry, has attracted debate for more than 150 years (see discussion of Linton Quarry, a Wenlock site, this volume). In addition to Lawson's (1954) survey of the faunas of Linton Quarry, Richardson and Lister (1969) and Richardson and Rasul (1990) have documented its palynomorphs. The topographical, bathymetric and palaeogeographical implications of the condensed Ludlow sequence of Linton Quarry have been graphically represented in several papers (e.g., Holland and Lawson, 1963; Cherns, 1988; Siveter *et al.*, 1989; Bassett *et al.*, 1992; see Figure 5.47).

Description

The Ludlow Series (Lawson, 1954; see Figures

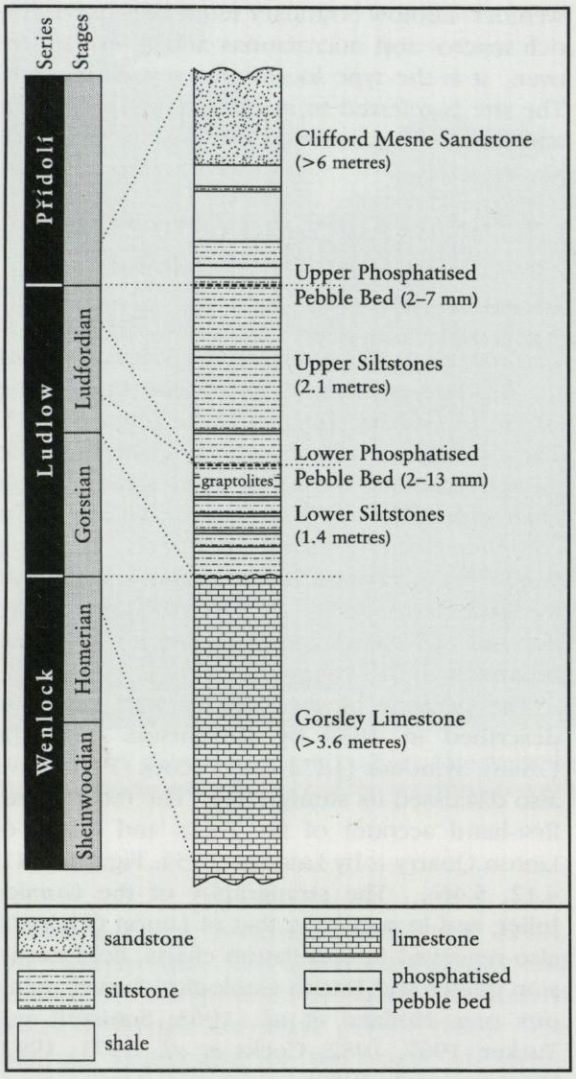


Figure 5.46 Succession and correlation of the Silurian strata at Linton Quarry, Gorsley Inlier, Herefordshire (after Lawson, 1954; see also Cocks *et al.*, 1971, 1992).

4.12, 5.46) consists of approximately 3.5 m of strata lying above a hard, massive carbonate, the Gorsley Limestone (*c.* 3.6 m seen). This limestone is generally thought to be a correlative of the Homerian Stage Much Wenlock Limestone Formation (Lawson, 1954; Bassett, 1974a; Cocks *et al.*, 1992; cf. Hurst *et al.*, 1978). Although no angular discordance is detectable in the section (all beds dip approximately 5° to the south-west), several unconformites are inferred.

The oldest rocks assigned to the Ludlow Series comprise 1.4 m of bluish-grey, shaly calcareous siltstones, the 'Lower Siltstones' of Lawson (1954). They yield a shelly fauna in which the brachiopods *Protochonetes ludloviensis*, *Isorthis orbicularis*, *Dayia navicula* and *Sphaerirhynchia wilsoni* are common. The bivalves *Fuchsella* and *Pteronitella* and the graptolite *Saetograptus leintwardinensis* also occur. The presumed early Ludfordian age of these siltstones implies that the entire Gorstian Stage is absent in the Gorsley Inlier.

The Lower Siltstones are separated from a 2.1 m sequence of siltstones above, in which current bedding is more prominently developed, by a 2–13 mm thick phosphatized pebble bed. These lightish coloured, shaly calcareous Upper Siltstones contain the brachiopods *Protochonetes ludloviensis* and *Microsphaeridiorhynchus nucula* and the bivalve *Pteronitella retroflexa* as common elements, together with *Orbiculoidea*, *Isorthis*, *Goniophora* and the tube-dwelling worm *Serpuloides longissimus*. *Isorthis orbicularis*, *Dayia navicula* and *Sphaerirhynchia wilsoni* are absent. Both the Lower and Upper Siltstones have well-preserved acritarchs, such as *Visbysphaera* and *'Dictytidium'*, and spores (Richardson and Lister, 1969; Richardson and Rasul, 1990). The Upper Siltstones are correlated with the Upper Whitcliffe Formation of Shropshire, thus indicating a local unconformity that spans some of the lower and middle part of the Ludfordian Stage.

The Upper Siltstones are succeeded by a thin (2–7 mm), unfossiliferous Upper Phosphatised Pebble Bed, above which is the Clifford's Mesne Sandstone (at least 6 m). The latter stratigraphical unit here consists of a lower part of yellowish-brown, shaly siltstones (1.4 m) containing eurypterid and plant fragments and the brachiopod *Lingula minima*, and an upper part comprising a very pale orange, unfossiliferous sandstone (about 4.6 m). Lithological, palaeontological and general stratigraphical evidence suggest that the Upper Phosphatised Pebble Bed and the Clifford's Mesne Sandstone are the local correlatives of the Ludlow Bone Bed Member and Platyschisma Shale–Sandstone members respectively of the main outcrop of the Přídolí Series Downton Castle Sandstone Formation of Shropshire. Analysis of palynomorphs present across the Ludlow–Přídolí boundary of Linton Quarry in general shows a decrease in inner-shelf marine microflora and a corresponding marked increase in land-derived material (Richardson and Lister, 1969; Richardson and Rasul, 1990).

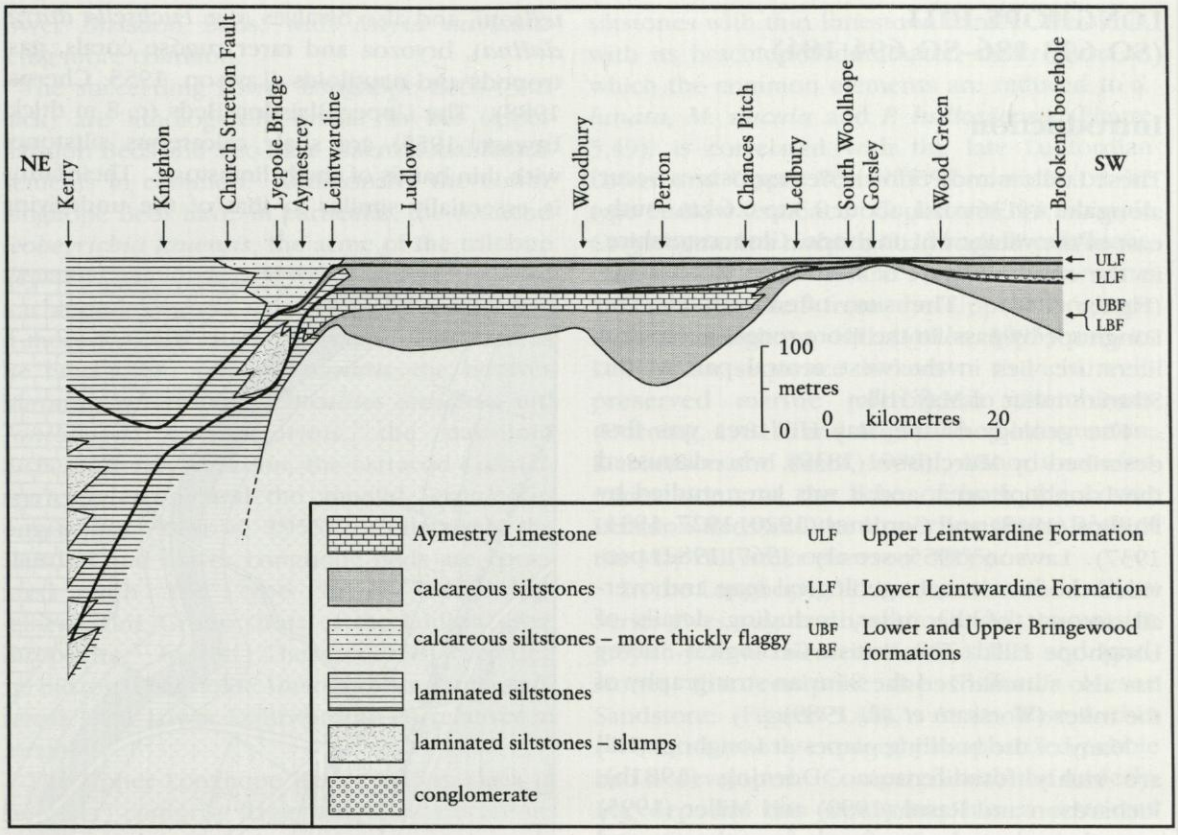


Figure 5.47 The concept of the 'Gorsley topographical high' of the Welsh Basin, as illustrated in the facies and thickness variations of the Leintwardine Group (early Ludfordian Stage) in a general south-west to north-east transect from the region of the Brookend Borehole, Gloucestershire, to Kerry, Powys (after Cherns, 1988).

Interpretation

The very thin, incomplete and unconformable nature of the sequence of Ludlow rocks at Gorsley suggests that the area was probably the site of a syndepositional axis of uplift (Lawson, 1954; Figure 5.47). Isopachyte maps (Holland and Lawson, 1963) support the existence of this submarine topographical feature, the so-called 'Gorsley High', which was part of the Midland Platform shelf area in the south-eastern part of the Welsh Basin and proximal to the southern landmass of Pretannia (see Siveter *et al.*, 1989, fig. 10; Bassett *et al.*, 1992, figs S4b, S5a).

Palaeoenvironmentally, the sequence at Linton Quarry charts a transition from open marine shelf (Wenlock and Ludlow series) to marginal marine–coastal mudflat conditions (Přídolí Series; see Bassett *et al.*, 1982 and Allen, 1985). These changes herald the onset, across central Britain, of thorough-going continental conditions of Devonian times.

Linton Quarry (see also under Wenlock sites) is the only GCR site in the Gorsley Inlier, although several others occur in the nearby May Hill and Woolhope inliers. The Sawdde Gorge in South Wales is the only other GCR Ludlow site that has exposures of the three latest of the four Silurian series, but the sequence there is not condensed.

Conclusions

Linton Quarry is an important site for determining the geology of the region and should be conserved. It contains the most complete succession of Silurian rocks in the Gorsley Inlier. The locality and the inlier are unique within the Welsh Basin in having a very condensed Ludlow sequence, thus implying the existence of a local topographical high. The locality also contains the local Ludlow–Přídolí series boundary.

LONGHOPE HILL (SO 693 186–SO 694 184)

Introduction

These Ludlow and Přídolí series exposures occur along the A4136 road, about 0.3 to 0.6 km south-east of the village of Longhope, Gloucestershire, in the southern part of the Welsh Borderland (Figure 5.48). The site, often termed 'The Longhope by-pass' in the more recent geological literature, lies in the west central part of the Silurian inlier of May Hill.

The geology of the May Hill area was first described by Murchison (1839), who discussed the Longhope area, and it was later studied by Phillips (1848) and Gardiner (1920, 1927, 1934, 1937). Lawson (1955; see also 1967, 1982) provided the most recent geological map and overall account of the inlier, including details of Longhope Hill. The British Geological Survey has also summarized the Silurian stratigraphy of the inlier (Worssam *et al.*, 1989).

Many of the bedding planes at Longhope Hill are richly fossiliferous. Dorning (1981b), Richardson and Rasul (1990) and Miller (1995) recorded selected microfossils from the site and Cherns (1988, fig. 7b) has logged its faunas of Leintwardine Group age. The nomenclature of the units that Lawson (1955) established for the May Hill Inlier has been used unchanged in almost all of the standard papers on British Silurian correlation (Holland *et al.*, 1963; Cocks *et al.*, 1971, 1992). An exception is Lawson's field excursion guide to the area (1967, 1982), in which the names of the type Ludlow stratigraphical units were used in tandem with the original names of the units.

Longhope Hill contains good reference sections of the Ludfordian to basal Přídolí stratigraphical divsions of the inlier.

Description

The beds dip between 20° and 30° to the south-west and young to the north-west down Longhope hill (Figure 5.48). The Lower Blaisdon Beds consist of less than 1 m of conglomeratic limestone bands containing shelly faunas and evidence of hardgrounds (Lawson, 1955; Cherns, 1980). Fossils chiefly include brachiopods such as *Atrypa reticularis, Microsphaeridiorhynchus nucula, Protochonetes ludloviensis* and *Sphaerirhynchia wilsoni*, and also bivalves (e.g. *Fuchsella amygdalina*), bryozoa and rarer rugose corals, gastropods and nautiloids (Lawson, 1955; Cherns, 1988). The Upper Blaisdon Beds (*c.* 8 m thick; Lawson 1955) are shaly calcareous siltstones with thin bands of shelly limestone. Their fauna is essentially similar to that of the underlying

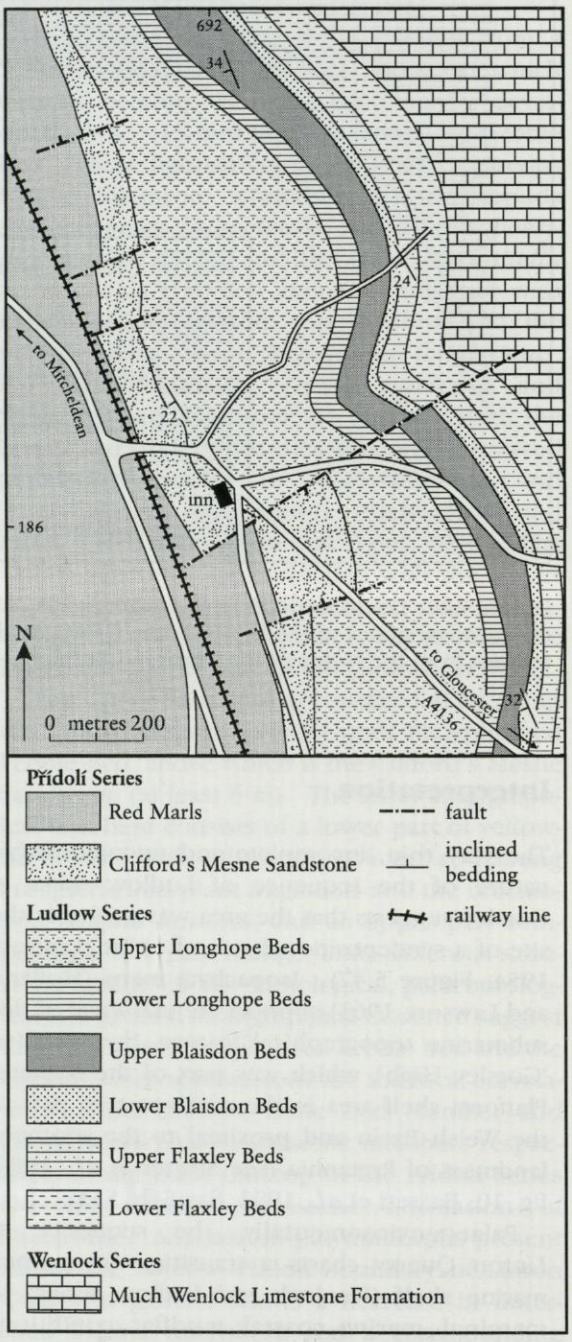


Figure 5.48 The geology of the A4136 road section and adjacent area, near Longhope, Gloucestershire (after Lawson, 1955).

Lower Blaisdon Beds, with *Dayia navicula* being more common.

The succeeding Lower Longhope Beds (3 m thick) are lithologically similar to the Upper Blaisdon Beds and also have macrofaunal faunal elements in common. Additionally, the Lower Longhope Beds have, in particular, the ostracod *Neobeyrichia lauensis*, the acme of the trilobite *Alcymene puellaris* and of the strophomenid brachiopod *Shaleria ornatella* and a selection of more typically late Ludfordian forms such as the brachiopod *Salopina lunata*, the bivalves *Pteronitella retroflexa*, *Nuculites antiquus* and *Goniophora cymbaeformis*, the nautiloid *Michelinoceras bullatum*, the ostracod *Calcaribeyrichia torosa* and the annelid *Serpuloides longissimus* (Lawson, 1955). Collectively the Blaisdon and Lower Longhope beds are correlated with the type lower Ludfordian Leintwardine Group strata of the Ludlow area, Shropshire. Indeed, Cherns (1988) recorded the biozonal graptolite *Saetograptus leintwardinensis* from Lower Leintwardine correlatives at Longhope.

The Upper Longhope Beds (3–15 m thick in the inlier) comprise flaggy and shaly calcareous siltstones with thin limestone bands. This unit, with its brachiopod-dominated shelly fauna in which the common elements are reduced to *S. lunata*, *M. nucula* and *P. ludloviensis* (Figure 5.49), is correlated with the late Ludfordian Lower and Upper Whitcliffe formations of the type Ludlow sequence. Conodonts, for example *Coryssognathus dubius*, *Ozarkodina confluens*, *Ozarkodina excavata* and *Panderodus serratus* are also recorded from the Upper Longhope Beds of Longhope Hill (Miller, 1995) and its Ludfordian sequence is known to yield well-preserved marine microfloral assemblages (Dorning, 1981b, and unpublished information; Richardson and Rasul, 1990). Minor unconformities occur at the base of both the Lower Blaisdon Beds and the Upper Longhope Beds of the May Hill Inlier (Lawson, 1955).

In the Longhope Hill road section the Ludlow Series gives way, north-west of a fault, to massive greyish-yellow, micaceous silts, shales and sandstones that comprise the Clifford's Mesne Sandstone (Figure 5.48). At its base a thin (< 0.2 m), poorly exposed phosphatized pebble bed is developed. Compared with the underlying deposits this sandstone has a restricted

Figure 5.49 Calcareous siltstones with shelly fauna dominated by brachiopods (e.g. *S. lunata*, *M. nucula* and *P. ludloviensis*), Upper Longhope Beds, Longhope Hill (A4136 road), Gloucestershire. (Photo: David J. Siveter.)

fauna, which nevertheless includes a substantial increase in land-derived spores (Richardson and Rasul, 1990), together with inarticulate brachiopods, ostracods, bivalves, gastropods and eurypterid and plant fragments. The Clifford's Mesne Sandstone is correlated with the basal Přídolí Downton Castle Sandstone Formation of Shropshire (see Bassett *et al.*, 1982), the Pebble Bed being the local equivalent of the Ludlow Bone Bed. The occurrence of the latter, containing thelodont scales, was recorded from the Blaisdon area, 2 km to the south, as early as the mid-19th century (Strickland, 1853).

Interpretation

The Ludlow Series in the May Hill Inlier is only a quarter of the thickness of that at the nearby Woolhope and Malverns areas to the north and is more than ten times the thickness of the extremely condensed Ludlow sequence at the neighbouring Gorsley Inlier (Lawson, 1955). Both sucessions are believed to have formed on a topographical rise of the Midland Platform (Holland and Lawson, 1963; Cherns, 1988) of the Welsh Basin (see Siveter *et al.*, 1989, figs 10, 11; Bassett *et al.*, 1992, figs S4a, S4b, S5a).

The Ludfordian rocks at Longhope Hill represent deposition on a shallow marine shelf, with the unconformities in the sequence at May Hill marking periods of local relative uplift and, or, non-deposition. As the Welsh Basin gradually silted up, the Clifford's Mesne Sandstone accumulated under shallower, more restricted marine conditions that preceded the onset of non-marine red bed deposition in latest Silurian–Devonian times.

Together with the Wood Green GCR site, Longhope Hill is a prime locality at which to demonstrate shelf deposits characteristic of the Ludlow Series of the May Hill Inlier. Furthermore, like the Tites Point, Brook House and Linton Quarry sites, of the nearby Tortworth, Usk and Gorsley inliers respectively, that at Longhope Hill contains a sequence across the Ludlow–Přídolí series boundary. The only other GCR site in the May Hill Inlier is that of late Wenlock age at Hobbs Quarry.

Conclusions

This is one of the best localities at which to examine all of the Ludfordian stratigraphical units within the May Hill Inlier. It is in the type area of the Lower and the Upper Longhope beds and it also contains the junction between the Ludlow and the Přídolí series. Though, in recent years, its potentially relative ease of access and fossil-rich reputation has lead to some overuse by geological visitors, undeniably its outcrops still have high value for both both teaching and research purposes.

WOOD GREEN (SO 6952 1658–SO 6935 1671)

Introduction

Wood Green is situated about 1 km WSW of Blaisdon village, Gloucestershire, near the southern end of the Silurian inlier of May Hill in the southern Welsh Borderland (Figure 5.50). The site consists of a roadside quarry, an old railway cutting and a stream section. It has a complete sequence of the Ludlow Series and the early part of the Přídolí Series of the inlier and is a locally important reference section for the stratigraphical units it contains.

The May Hill Inlier was mapped by Lawson, who detailed the stratigraphy and palaeontology of Wood Green and later wrote a field excursion guide to the area (1955, 1967, 1982). In connection with mapping in the vicinity of Tewkesbury, the British Geological Survey presented a summary of the Silurian stratigraphy of the inlier (Worssam *et al.*, 1989). Murchison (1839), Phillips (1848) and Gardiner (1920, 1927, 1934, 1937) provided earlier accounts of the geology of the region. Aspects of the microflora (Dorning, 1981b) and faunas of Leintwardine age (Cherns, 1988) of Wood Green have also been documented. The Ludlow Series of May Hill contains unconformities but in general is easily correlated with the international standard sequence (Holland *et al.*, 1963; Cocks *et al.*, 1971, 1992).

Description

Mudstones and siltstones dominate the six stratigraphical units of the Ludlow of the May Hill Inlier, which lacks the ('Aymestry') limestone so characteristic of the upper Gorstian of many Welsh Borderland Silurian sequences. All six units, established using a combination of macrofaunal and lithological criteria (Lawson, 1955), are present at Wood Green, where they strike

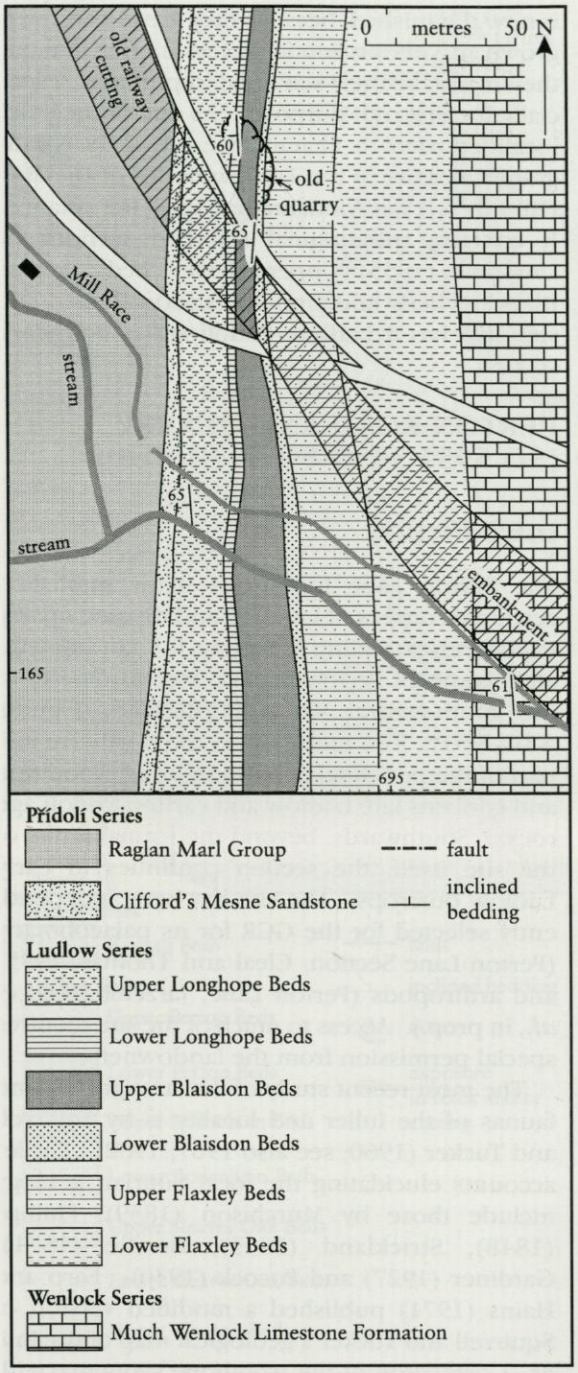


Figure 5.50 The geology of the Wood Green area, Gloucestershire (after Lawson, 1955).

due north and dip 60°–65° to the west (Figure 5.50). Lawson (1955) noted that the Lower Flaxley Beds (*c.* 35 m thick) were visible only in the banks of the small stream at the southern end of the locality; the Upper Flaxley Beds (*c.* 17 m) and the succeeding Lower and Upper Blaisdon and Lower Longhope beds (collectively totalling *c.* 15 m) and the Upper Longhope Beds (*c.* 17 m) were seen in the roadside quarry and were also intermittently and in some cases better exposed in the nearby railway cutting. The latter section also originally displayed the overlying Ludlow Bone Bed (Strickland, 1853), a division that was also once visible at the bend in the stream section (Lawson, 1955, fig. 1, locality C).

The Lower Flaxley Beds consist of fossil-rich, olive calcareous siltstones with occasional thin, impure carbonate bands. *Dicoelosia biloba*, *Skenidioides lewisi, Aegiria grayi, Howellella elegans, Atrypa reticularis* and other small brachiopods are common, as is the trilobite *Dalmanites*. Corals and molluscs are much less abundant and graptolites are very scarce. In the thinner, more silty, Upper Flaxley Beds brachiopods are generally larger (strophomenids such as *Strophonella* are normally abundant), corals are more common (e.g. *Favosites*, *Heliolites* and *Halysites*) and molluscs are quite scarce. The characteristics of the succeeding Blaisdon and Longhope beds are as given in the description of the nearby Longhope Hill GCR site, to which must be added Cherns' (1988) data on lower Ludfordian faunas from Wood Green, including the record of the biozonal graptolite *Saetograptus leintwardinensis*. The Wood Green sequence has also yielded diverse palynomorph assemblages and is the type locality for several acritarch species (Dorning, 1981b).

The Ludlow sequence at May Hill contains several stratigraphical breaks in which much of the Gorstian Stage and parts of the Ludfordian Stage are missing (Lawson, 1955, 1982; Worssam *et al.*, 1989; Cocks *et al.*, 1992). The Lower Flaxley Beds, which succeed the Much Wenlock Limestone Formation without a discernible break, are considered to be of earliest Gorstian age (*Neodiversograptus nilssoni* Biozone). The unconformably overlying Upper Flaxley Beds (late Gorstian: *Pristiograptus tumescens* Biozone) are correlated with the Lower, and the basal part of the Upper Bringewood formations of Shropshire. The Lower and Upper Blaisdon beds and Lower Longhope Beds are collectively correlated with the type Leintwardine Group of Ludfordian *Saetograptus leintwardinensis* Biozone age. The Upper Longhope Beds rest with minor unconformity on the Lower Longhope Beds and are correlatives of the late Ludfordian type Whitcliffe Group.

The local equivalent of the basal Přídolí Ludlow Bone Bed Member of Shropshire is the phosphatized pebble bed (25 mm thick) containing thelodonts and brachiopod fragments. At Wood Green it is overlain by about 3 m of grey sandy siltstones – the Clifford's Mesne Sandstone (Figure 5.50) – which have yielded a restricted fauna of inarticulate brachiopods, bivalves, ostracods and eurypterid and plant remains. Locally there follows a considerable thickness of red marls of the mid- and late Přídolí age Raglan Marl Group.

Interpretation

The Silurian deposits at May Hill seemingly accumulated on a marked topographical high (Holland and Lawson, 1963; Cherns, 1988; Figure 5.47) of the Midland Platform and in the south-eastern part of the Welsh Basin (see Siveter *et al.*, 1989, figs 10, 11; Bassett *et al.*, 1992, figs S4a, S4b, S5a, S5b). The Ludlow Series in the May Hill Inlier (40–80 m) is much thicker than the very attenuated Ludlow sequence at the adjacent Gorsley Inlier but is substantially thinner than the Ludlow at the Malverns and Woolhope Welsh Borderland areas to the north (Lawson, 1955). The several gaps in the Ludlow sedimentary sequence at May Hill denote local non-deposition and, or, relative uplift.

The fossil-rich, Ludlow strata of Wood Green reflect sedimentation on a shallow marine shelf. Faunal and lithological changes in the latest Ludlow to early Přídolí indicate changes in sea level and sea chemistry. They represent the gradual onset of shallower, perhaps reduced salinity conditions, thus heralding the non-marine red bed deposition which signifies the final, latest Silurian–Devonian demise of the Welsh Basin (see, for example, Bassett *et al.*, 1982).

Both Wood Green and, 2 km to the north, Longhope Hill exemplify the shelf facies of the Ludlow Series and are the only GCR sites in the May Hill Inlier. Other sites in nearby inliers that also contain a Ludlow–Přídolí series boundary sequence include Tites Point at Tortworth, Brook House at Usk and Linton Quarry at Gorsley.

Conclusions

Though accessibility to these fossil-rich sections is now diminished, because they are in part overgrown and permission for access is often denied, they maintain their scientific importance, especially for research purposes. As one of the chief localities used to characterize all of the stratigraphical units of the Ludlow Series of the May Hill Inlier, it has fundamental, local importance. It contains the original standard sections of Lawson's (1955) Upper Flaxley Beds, Lower Blaisdon Beds and Upper Blaisdon Beds. The site also has a Ludlow–Přídolí series boundary section.

PERTON ROAD AND QUARRY (SO 5951 3990–SO 5970 4040)

Introduction

The Perton Lane locality of many published accounts consists of laneside and disused quarry exposures extending for about 0.5 km immediately south of Perton hamlet, Herefordshire, in the south-central Welsh Borderland (Figures 4.10, 5.51). The locality is in the northernmost part of the periclinal Silurian inlier of Woolhope and contains late Ludlow and earliest Přídolí age rocks. Southwards, beyond the formal limits of the site itself, the section continues in early Ludlow outcrops. The site has been independently selected for the GCR for its palaeobotany (Perton Lane Section, Cleal and Thomas, 1995) and arthropods (Perton Lane, Jarzembowski *et al.*, in prep.). Access to much of the site requires special permission from the landowners.

The most recent study of the stratigraphy and faunas of the inlier and locality is by Squirrell and Tucker (1960; see also 1967, 1982). Earlier accounts elucidating the local Silurian geology include those by Murchison (1839), Phillips (1848), Strickland (1853), Brodie (1871), Gardiner (1927) and Pocock (1930). Earp and Hains (1971) published a modified version of Squirrell and Tucker's geological map of the inlier. Correlation of the Woolhope sequence with the standard Silurian is reviewed in Cocks *et al.* (1971, 1992) and Butler *et al.* (1997) drew the extent of the Woolhope Basin based on subsurface mapping.

The abundant, well-preserved fossils at Perton Lane have attracted many specialist studies. Amongst them are papers documenting eurypterids (Brodie, 1871; Kjellesvig-Waering, 1951, 1961), microfaunas (Aldridge, 1985; Miller and Aldridge, 1993, 1997; Miller, 1995), shelly

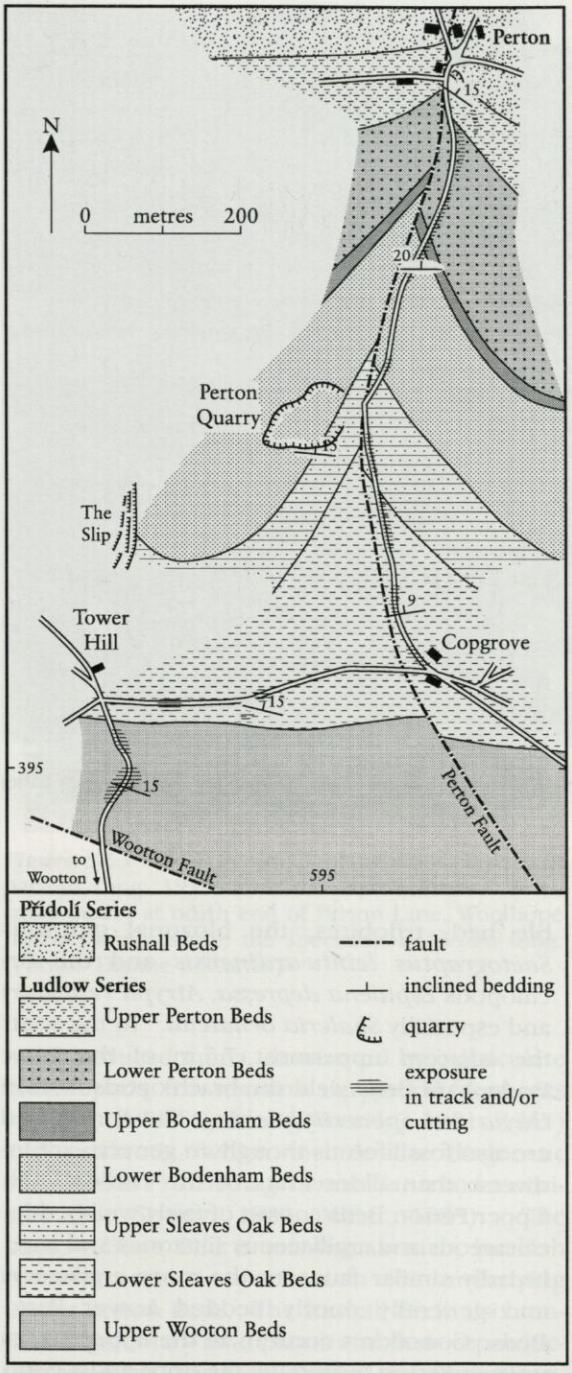


Figure 5.51 The geology of the area south of Perton, Woolhope Inlier, Herefordshire (after Squirrell and Tucker, 1960).

macrofaunas (Watkins, 1978a, 1979; Watkins and Aithie, 1980; Cherns, 1988) and micro- and macrofloras (Brodie, 1871; Lang, 1937; Richardson and Lister, 1969; Edwards, 1979; Edwards *et al.*, 1979, 1996; Dorning, 1981b; Fanning *et al.*, 1988, 1990, 1991a, 1991b; Burgess and Edwards, 1988; Richardson and Rasul, 1990; Edwards and Richardson, 1996; see also review by Cleal and Thomas, 1995).

Perton Lane is the longest, largely continuous section through the late Silurian of the Woolhope Inlier and it includes the Ludlow–Přídolí series boundary. As Phillips remarked (1848, p. 175), 'At Perton ... the sides of the valley offer an intelligible section from the Aymestry limestone to the Old Red.' Its fossil assemblages include world famous collections of early land plants.

Description

The Ludlow of the Woolhope Inlier consists of eight stratigraphical units, each based on faunal and, to a lesser degree, lithological distinctions (Squirrell and Tucker, 1960). The divisions reach maximum thickness in the north crop, at Perton, where they young and dip 15°–20° to the north (Figure 5.51). Rich and diverse macrofaunas, for which Watkins (1979) has recognized at least seven shelly benthic associations, occur throughout the Ludlow at Perton. They include corals, bryozoans, crinoids, bivalves, gastropods, cephalopods, graptolites, trilobites and especially brachiopods.

The disused Perton Quarry (SO 5954 3995; Figure 5.52), at the southern end of the site, exposes the uppermost Upper Sleaves Oak Beds below the lower part of the Lower Bodenham Beds. These divisions are correlated with the Upper Bringewood Formation (latest Gorstian) and Lower Leintwardine Formation (earliest Ludfordian) of Shropshire. To the south of Perton Quarry, towards Tower Hill, the sequence continues through early Ludlow and into Wenlock rocks.

In the Perton area the Upper Sleaves Oak Beds are 32 m thick, predominantly olive-blue, nodular argillaceous limestones with thin interbeds of silty mudstones and some bentonite bands. At Perton Quarry the Upper Sleaves Oak Beds consist of various calcilutite and biocalcarenite facies with very diverse shelly faunas (Watkins and Aithie, 1980), especially corals, crinoids and brachiopods such as *Kirkidium knighti*, *Protochonetes ludloviensis*, *Atrypa reticularis*, and species of *Gypidula*, *Leptaena* and *Strophonella*. The Lower Bodenham Beds (*c.* 40 m thick in the area), logged in detail by Cherns (1988), are mostly fine siltstones and thin, shelly and argillaceous limestones contain-

Figure 5.52 Upper Sleaves Oak Beds and Lower Bodenham Beds, Perton Quarry, Woolhope Inlier, Herefordshire. (Photo: David J. Siveter.)

ing, particularly in their lower part, fossil-bearing, calcareous siltstone intraformational conglomerates. They contain the bryozoans *Ptilodictya* and *Orbignyella* and about 20 brachiopod species such as *Shagamella ludloviensis* and *Shaleria ornatella*. The trilobite *Alcymene puellaris* (see Siveter, 1983), the brachiopod *Salopina lunata*, and the worm tube *Serpuloides longissimus* are introduced into the Ludlow sequence in the Lower Bodenham Beds.

On the east side of the lane north of Perton Quarry Squirrell and Tucker (1960, 1967, 1982) recorded sequences showing: the 4.5 m thick Upper Bodenham Beds (SO 5963 4018) and their junction with both the Lower Bodenham Beds below and the overlying Lower Perton Beds; a fairly continuous, 100 m exposure of Lower Perton Beds (*c.* 30 m thick) to its junction with the 15 m thick Upper Perton Beds (SO 5969 4031); and the junction between the latter unit and the overlying basal Přídolí Rushall Beds, in the small quarry (SO 5970 4040) on the corner of the lane immediately south of Perton hamlet.

The thinly bedded, calcareous siltstones of the Upper Bodenham Beds contain a thin pebble bed, trilobites, the biozonal graptolite *Saetograptus leintwardinensis* and the brachiopods *Leptaena depressa*, *Atrypa reticularis* and especially *Shaleria ornatella*. To the south, the adjacent uppermost 7.5 m of the Lower Bodenham Beds yield the brachiopods *Isorthis*, *Dayia* and *Sphaeriryhnchia*. The Perton beds are also fossiliferous though, in general, are less diverse than older units of the Ludlow. The Upper Perton Beds consist of fairly well-bedded, calcareous and argillaceous siltstones and have a broadly similar fauna to the more argillaceous and generally poorly bedded Lower Perton Beds. Conodonts occur in all the upper Ludlow units at Perton, especially the uppermost Perton beds (Squirrell and Tucker, 1960; Aldridge, 1985; Miller and Aldridge, 1993, 1997; Miller, 1995). The Upper Bodenham, Lower Perton and Upper Perton beds are correlated with the Ludfordian Lower Leintwardine and Lower and Upper Whitcliffe formations respectively of Shropshire.

The Rushall Beds here are fine-grained siltstones and mudstones and massive sandstones. Compared to the Ludlow strata this unit has a

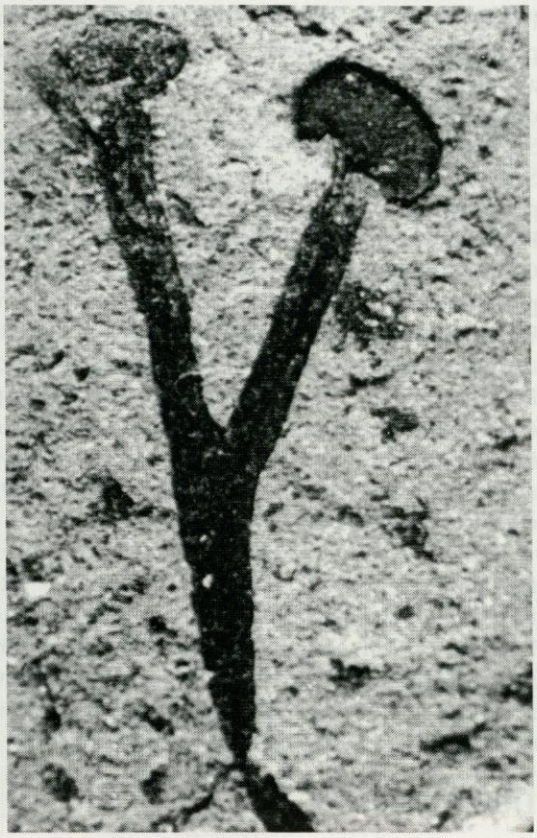


Figure 5.53 The early vascular land plant *Cooksonia pertoni* Lang, 1937, from the Přídolí Rushall Beds, small quarry at north end of Perton Lane, Woolhope Inlier, Herefordshire; the specimen is 15 mm long. (Photo: Dianne Edwards.)

much reduced fauna, dominated by inarticulate brachiopods, fish remains, eurypterid fragments (Brodie, 1871; Kjellesvig-Waering, 1951, 1961) and ostracods, which include the diagnostic early Přídolí *Frostiella groenvalliana* and associates (see Siveter, 1989; Miller, 1995). The Ludlow Bone Bed is missing as such, but fish remains occur in pockets in the underlying Upper Perton Beds. The Rushall Beds also contain fragmentary land plants and their reproductive products, and have yielded the type material of *Cooksonia pertoni* (Figure 5.53), widely considered as the most primitive known vascular plant (Lang, 1937; Richardson and Lister, 1969; Edwards, 1979; Edwards *et al.*, 1979, 1996; Fanning *et al.*, 1988, 1990, 1991a, b; Richardson and Rasul, 1990; Edwards and Richardson, 1996). Plant associates include *Caia* and the enigmatic *Actinophylum*, both of which are only known from this locality (see Cleal and Thomas, 1995).

Interpretation

In the upper Silurian this locality was sited on the Midland Platform, which formed the east and south-eastern flank of the Welsh Basin (Siveter *et al.*, 1989, figs 10, 11; Bassett *et al.*, 1992, figs S5a, S5b, S8b). The rocks and fossils of Perton imply an overall regressive sequence, from the relatively shallow, open marine shelf deposits of the Ludlow to a more restricted and ultimately land influenced, alluvial plains environment in the Přídolí (e.g. see Bassett *et al.*, 1982; Allen, 1985). The middle Ludlow calcareous silts and carbonates of Perton accumulated in a sheltered area behind the higher energy shelf edge zone to the west (Watkins and Aithie, 1980; Cherns, 1988; Figure 5.47). Compared to Ludlow–Přídolí sequences in the basin proper that at Perton is not very thick; nevertheless, it represents the thickest succession of that age from anywhere in the Woolhope Inlier or the Gorsley and May Hill inliers to the south (Squirrell and Tucker, 1960). Perton was apparently positioned just to the north-west of the Gorsely topographical high and therefore in somewhat deeper shelf waters (Cherns, 1988).

This is the only GCR site that contains a Ludlow–Přídolí boundary sequence in the Woolhope Inlier. Comparable shelf sections occur at Welsh Borderland sites at May Hill (Longhope Hill and Wood Green), Gorsley (Linton Quarry), Usk (Brook House), the Abberleys (Woodbury Quarry) and the Tortworth area (Tites Point), and elsewhere in the central Welsh Borderland at Ludlow (Ludford Lane and Ludford Corner) and the English West Midlands (Brewin's Canal and Turner's Hill). Other Welsh Basin sites displaying Ludlow–Přídolí rocks are the Sawdde Gorge in southern Wales and, in a more basinward setting, Lower Wallop Quarry, in the Long Mountain in Shropshire. Little Hill and Scutterdine Quarry are the two Wenlock GCR sites in the Woolhope Inlier.

Conclusions

This site has regional stratigraphical and international palaeontological significance and is also a valued teaching resource. It is part of an unequalled sequence through the entire Ludlow and into the Přídolí Series of the Woolhope Inlier and is the fundamental reference section for the Lower and Upper Perton beds of the inlier. Fossils are abundant and it is the type locali-

ty for many species of micro- and macrofauna and flora. It is internationally renowned for its important early plant remains. High value should be placed on conserving the site.

TITES POINT (SO 685 042–SO 689 046)

Introduction

This site lies 300–400 m WSW of the breakwater at Tites Point, on the southern foreshore of the Severn Estuary, near Purton, Gloucestershire (Figure 5.54). Full exposure is visible only at low water and varies with the continual movement of deposits of mud. Except for localities in the Mendips, Tites Point represents the most southerly exposure of the Silurian in England. The outcrop, consisting of late Ludlow and early Přídolí age strata (Figure 5.55), is at the northernmost part of the northern strip of two, mostly Silurian areas that make up the Tortworth Inlier.

The geology of the Tortworth Inlier, including its anticlinal fold at Purton, was discussed as early as 1819 in a landmark paper read before the Geological Society by Thomas Weaver (1824), a supporter of the Wenerian School. Curtis (1955a) has noted that this was, 'the first detailed study to be made of any area of Lower Palaeozoic rocks in the British Isles, and was probably the first stratigraphical work on these ancient rocks, for he discussed the fossils and compared them with those of May Hill' (the Silurian inlier just to the north of the River Severn). Later, Murchison demonstrated the presence of Ludlow rocks locally (1839) and Phillips, in a memoir to accompany the one-inch Geological survey map of the area (sheet 35), provided a detailed account of the Lower Palaeozioc rocks, including a map and a description of the Silurian strata of the so-called 'Pyrton Passage' (1848). Murchison (1839) and Phillips (1848) also noted the occurrence of fish remains in the sequence, as did Huxley and Salter (1856) and Turner (1973); Dineley and Metcalf (1999) reviewed the fish finds from this site.

Cave and White (1971) give the most recent first-hand account of the succession at Tites Point and its correlation with the standard Ludlow–Přídolí sequence of Welsh Borderland areas to the north. Other stratigraphical reviews are in Curtis (1955b, 1967, 1972, 1982), Holland *et al.* (1963) and Cocks *et al.* (1992).

Description

The Silurian Rocks at Tites Point occur in the core of a small, plunging anticline (Cave and White, 1971; see Figure 5.54). In the western

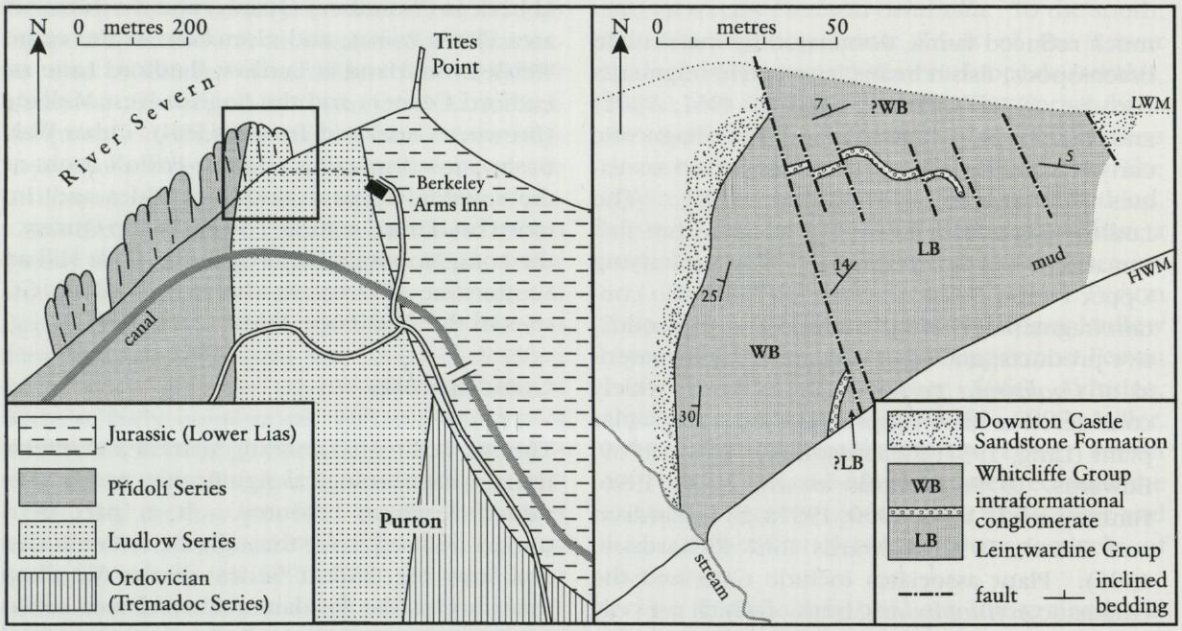


Figure 5.54 Sketch maps showing the Silurian geology (upper Ludlow to lower Přídolí) of the foreshore at Tites Point, near Purton, Gloucestershire (after Cave and White, 1971; Curtis, 1982).

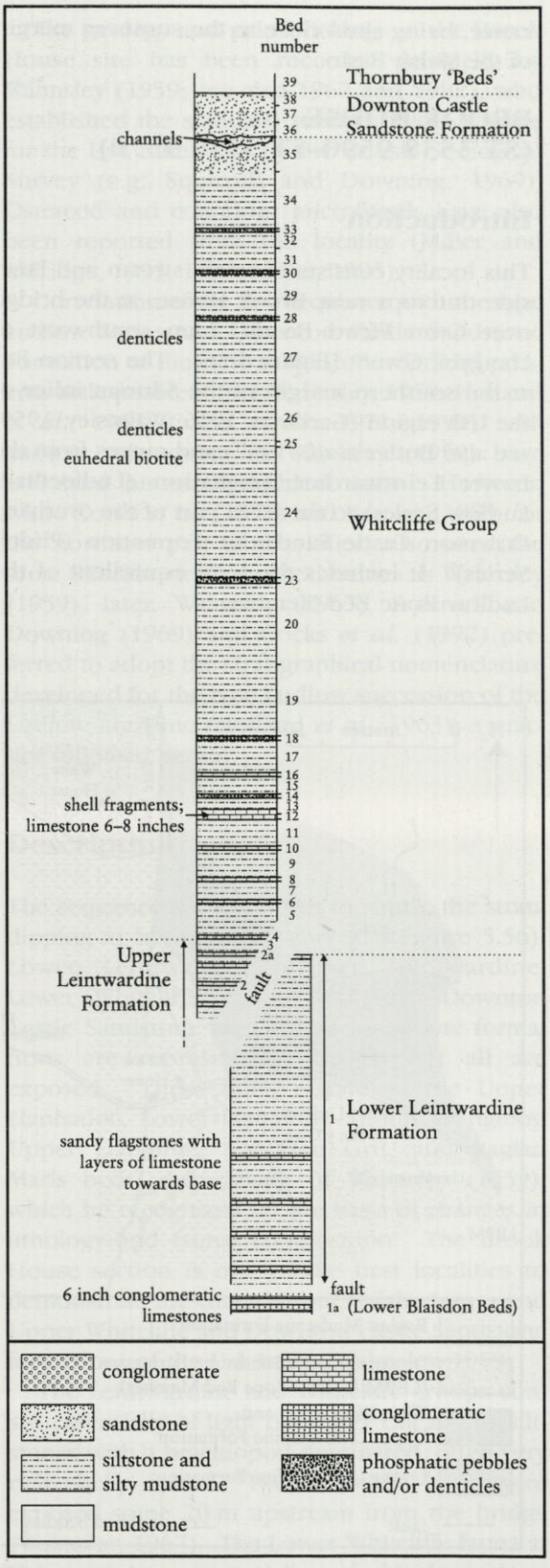


Figure 5.55 The stratigraphy of the Ludlow to early Přídolí series at Tites Point, near Purton, Gloucestershire (after Cave and White, 1971).

part of the foreshore, where the Přídolí conformably succeeds the Ludlow, strata dip west and north-west. In the northern part of the outcrop, the Ludlow dips north and in the east it dips to the east. This sequence of Ludlow and Přídolí series (Figure 5.55) is disrupted and complicated by numerous NNE–SSW trending faults. The succession is difficult to trace laterally for any distance.

The lowest strata observed by Cave and White (1971) consist of 2.13 m of conglomeratic limestones containing the brachiopods *Dayia navicula*, *Protochonetes ludloviensis*, *Sphaerirhynchia wilsoni* and *Whitfieldella canalis* (SO 6886 0458). The beds are thought to be the correlatives of the Lower Blaisdon Beds of May Hill (Lawson, 1955) and the lower part of the Lower Leintwardine Formation of the central Welsh Borderland. The stratigraphically succeeding beds consist of about 9.1 m of sparsely fossiliferous sandy flagstones with limestone layers near the base (Cave and White, 1971, Bed 1), forming what is considered to be the local upper part of the Lower Leintwardine Formation. These are overlain by mudstones and silty limestones with a shelly fauna including brachiopods and trilobites (Beds 2, 2a, 3; total 2.2 m); these beds are provisionally assigned to the Upper Leintwardine, although the fauna typical of that formation is unknown from Tites Point.

A 10 cm thick conglomerate (Bed 4) is taken as the base of the local Whitcliffe Group, which consists of about 21.8 m of silty mudstones with layers of siltstone and limestone. Macrofossils in the Whitcliffe Group (Beds 4–35) include brachiopods (e.g. *Schizocrania striata*, *Salopina lunata*, *Dayia navicula*, *Protochonetes ludloviensis*), bivalves (e.g. *Nuculites antiquus*, *Goniophora cymbaeformis*, *Fuchsella amydalina*) and nautiloids (*Michelinoceras bullatum*, *Kionocereas angulatum*). The thin limestones often contain concentrations of fragments of conodonts (fauna detailed in Miller, 1995; see also Aldridge, 1985 and Miller and Aldridge, 1993, 1997), horny brachiopods, chitinous worm tubes, fish denticles and small phosphatic pebbles. Such deposits probably represent the Ludlow age bone beds identified by Phillips (1848). Indeed, Turner (1973) recognized an abundant *Thelodus parvidens* thelodont fauna from the Upper Whitcliffe at Tites Point.

The Whitcliffe beds are overlain by 1.7 m of sandstone, which is considered to be the local equivalent of the Přídolí Downton Castle

Sandstone Formation. This in turn is succeeded, in an obscured contact, by soft red mudstones of the Thornbury Beds. Channels in the sandstone cut down into the top Whitcliffe beds, and have associated concentrations of heterostracan and acanthodian fish (*Cyathaspis banksi*, *Onchus* sp.) and plant fragments (*Pachytheca*?) in an horizon indicative of the Ludlow Bone Bed (Cave and White, 1971, p. 244).

Interpretation

Contrary to inferences made on the basis of the isopachyte evidence (Holland and Lawson 1963), all units of the Ludlow Series in the southern part of the Welsh Borderland, from the May Hill Inlier to Tites Point and the nearby Brookend borehole (Cave and White, 1968; see Figure 5.47), thicken southwards (Cave and White, 1971; Cherns, 1988). This may indicate the presence of a minor trough, to the south of the Gorsley topographical high, in the southern part of the Welsh Basin (Curtis, 1972). During the late Ludlow and early Přídolí, Tites Point was a shelf area just north of Pretannia, a probable alluvial plain landmass that bordered the Welsh Basin on its southern flank (see Cope and Bassett, 1987; Siveter *et al.*, 1989, figs 10, 11; Bassett *et al.*, 1992, fig. S5b).

The Ludlow succession represents an invertebrate-rich, shelf sea environment, which is transitional to the shallower, but still marine-influenced conditions of Downton Castle Sandstone times (e.g. see Bassett *et al.*, 1982; Allen, 1985). As in its main outcrop in Shropshire, the local representative of the Ludlow Bone Bed probably represents an organic-rich lag concentrate deposited close to land.

Other GCR sites in the Tortworth Inlier are of Llandovery (Damery Bridge and Cullimores Quarry) and Wenlock (Brinkmarsh Quarry, and Buckover Road Cutting) age. Tites Point is one of many sites in the Welsh Basin that have a Ludlow–Přídolí sequence (see list under Ludford Lane and Ludford Corner site report).

Conclusions

This locality has historical importance, in the development of studies on Lower Palaeozoic and especially Silurian stratigraphy in Britain. The sequence contains the Ludlow–Přídolí boundary and its faunas include several species of fish. It also has palaeogeographical significance, being sited close to the southern margin of the Welsh Basin.

BROOK HOUSE (ST 3538 9590–ST 3550 9570)

Introduction

This locality consists of small, stream and lane-side outcrops near Brook House, at the bridge over Cwm Ffrwd Brook, 2 km south-west of Llangybi, Gwent (Figure 5.56). The section lies at the southern margin of the Silurian inlier of the Usk region (Gardiner, 1916; Walmsley, 1959; see also Butler *et al.*, 1997) and ranges from the Lower Leintwardine Formation (Ludfordian, Ludlow Series) to the basal part of the overlying Downton Castle Sandstone Formation (Přídolí Series). It includes the local equivalent of the Ludlow Bone Bed Member.

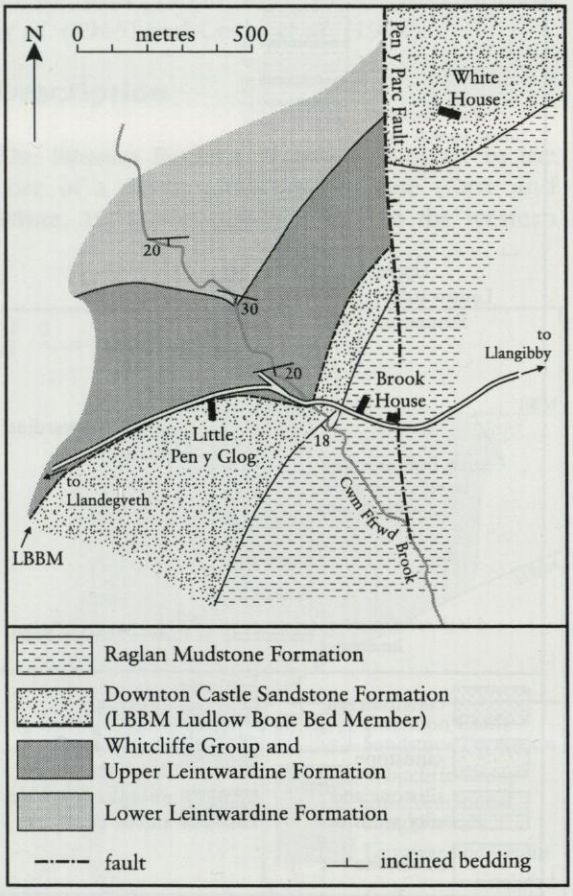


Figure 5.56 The geology in the vicinity of Brook House, near Llangybi, in the Usk Inlier, Gwent (after Walmsley, 1959).

The geology and palaeontology of the Brook House site has been recorded primarily by Walmsley (1959; see also 1967 and 1982), who established the standard stratigraphical scheme for the Usk Inlier, and by the British Geological Survey (e.g. Squirrell and Downing, 1969). Ostracod and conodont microfossils have also been reported from the locality (Miller and Aldridge, 1993, 1997; Miller, 1995).

Correlation of the Usk sequence with the type Ludlow Series and Downton Castle Sandstone Formation of the central Welsh Borderland presents little problem (see Walmsley, 1959; Holland *et al.*, 1963; Cocks *et al.*, 1971, 1992). All authors subsequent to Walmsley (1959) have endorsed his stratigraphical units. However, while Cocks *et al.* (1971) and Barclay (1989; for the northern part of the inlier) also used the same Silurian stratigraphical names as Walmsley (1959), later, Walmsley (1967), Squirrell and Downing (1969) and Cocks *et al.* (1992) preferred to adopt the stratigraphical nomenclature developed for the type Ludlow succession of the Ludlow Anticline (Holland *et al.*, 1963), a practice followed herein.

Description

The sequence youngs north to south, the strata dipping at between 14° and 30° (Figure 5.56). Lower Leintwardine, Upper Leintwardine, Lower Whitcliffe, Upper Whitcliffe, Downton Castle Sandstone and Raglan Mudstone formations are represented, though not all are exposed. These units equate to the Upper Llanbadoc, Lower Llangibby, Middle Llangibby, Upper Llangibby, Speckled Grit, and Raglan Marls beds, respectively, of Walmsley (1959), which he recognized on the basis of changes in lithology and faunal composition. The Brook House section is one of the best localities to demonstrate the characteristics of the Lower and Upper Whitcliffe and Downton Castle Sandstone formations of the Usk Inlier (Walmsley, 1959).

The Leintwardine and Whitcliffe groups consist essentially of light olive-grey calcareous siltstones with a brachiopod-dominated, often very rich shelly fauna. The Whitcliffe beds were exposed some 20 m upstream from the bridge (Walmsley, 1967). The Lower Whitcliffe fauna at Usk consists essentially of bivalves (e.g. *Fuchsella amygdalina, Goniophora cymbaeformis*, *Pteronitella retroflexa*), cephalopods (e.g. *Kionoceras angulatum, Michelinoceras bullatum*) and especially brachiopods (such as *Microsphaeridiorhynchus nucula*, *Protochonetes ludloviensis* and *Salopina lunata*) rare gastropods and trace fossils also occur.

The Upper Whitcliffe beds of Usk have a reduced version of the Lower Whitcliffe fauna. They consist of an alternation of unfossiliferous olive-grey siltstones, unfossiliferous and in part irregularly laminated and rippled siltstones, and lenses of highly fossiliferous calcareous siltstone that are partly decalcified to rusty-brown 'rottenstone' full of moulds of *Loxonema*. Bands of this gastropod occur in the Upper Whitcliffe in the stream section near the bridge at Brook House (Walmsley, 1967), as do the ostracods *Hemsiella* cf. *H. maccoyiana* and *Calcaribeyrichia torosa* and a fragmentary conodont fauna characterized by *Ozarkodina excavata*, *Ozarkodina confluens*, *Ozarkodina snajdri*, *Ozarkodina remscheidensis baccata* and *Coryssognathus dubius* (Miller and Aldridge, 1993, 1997; Miller, 1995). Squirrell and Downing (1969, p. 25) report the occurrence of a thin bone bed containing thelodont denticles in the upper 3 m of the Whitcliffe strata at Brook House.

The low bank approximately 12 m west of the bridge, on the south side of the lane (ST 3456 9570), has yielded fish and other faunal fragments that indicate the presence of the local equivalent of the Ludlow Bone Bed Member of the base of the Downton Castle Sandstone Formation (Walmsley, 1959, 1967, 1982; Squirrell and Downing, 1969). The overlying, sandy beds of that formation contain a sparse conodont fauna (Miller, 1995) and can be traced in tiny exposures in the lane-side and also downstream from the bridge, where they are succeeded by the Raglan Mudstone Formation (Red Marls of Walmsley, 1959, 1967).

Interpretation

This sequence accumulated close to the southern margin of the Welsh Basin (see Siveter *et al.*, 1989, fig. 11; Bassett *et al.*, 1992, fig. S5b). The facies present infer a gradual change from relatively shallow, open sea shelf environments of Leintwardine and Lower Whitcliffe times to restricted marine and then marine and river influenced, perhaps coastal mudflat conditions in the red beds of Přídolí times (see Bassett *et*

al., 1982; Allen, 1985). The bone bed lag deposits and associated sand shoals represent an intermediate stage in this overall regressive cycle.

Within the Usk Inlier Brook House represents the best locality in which to examine the Ludlow Bone Bed Member and one of the few in which the late Ludlow–Přídolí series transition can be demonstrated. Other GCR sites in the Welsh Basin that display a coeval stratigraphical sequence involving the Ludlow Bone Bed Member or its local equivalent are: Turner's Hill and Brewin's Canal in central England; Woodbury Quarry and Ludford Lane and Ludford Corner in the central Welsh Borderland; Perton Road and Quarry, Linton Quarry, Longhope Hill, Wood Green and Tites Point in the southern Welsh Borderland; and Lower Wallop Quarry in Shropshire. The GCR sites at Sawdde Gorge and Capel Horeb Quarry in west-central Wales also display late Ludlow and Přídolí age strata, but there the contact between the two series is an unconformable one. Cwm-Ton and Cilwrgi, both of Wenlock age, are the other GCR sites in the Usk Inlier.

Conclusions

The Brook House site has regional stratigraphical importance and should be conserved. Outcrops are small, intermittent and mostly overgrown. Nevertheless, in the Welsh Basin, Brook House represents the most southerly GCR locality with a Ludlow–Přídolí series boundary sequence that also includes the basal Přídolí Ludlow Bone Bed Member. It is also one of the rare localities where this member is documented from the Usk Inlier. It is a productive locality for faunal and correlation studies of this important stratigraphical horizon.

MEETING HOUSE QUARRY (SO 1372 6407)

POTENTIAL GCR SITE

Introduction

This small disused hillside quarry is on the north side of a lane 80 m west of the Friends' Meeting House ('The Pales'), about 1 km north of Llandegley, on the western margins of the Radnor Forest area of Powys. It is located on the Pontesford Lineament, a component of the NE–SW trending Welsh Borderland Fault System (Woodcock and Gibbons, 1988; Figures 5.57, 5.58) and is a very instructive exposure of off-shelf, basin margin facies and faunas of the Ludlow Series of the Welsh Basin. All of the rocks exposed in the quarry belong to the upper part of the Llanbadarn Formation (of Dimberline

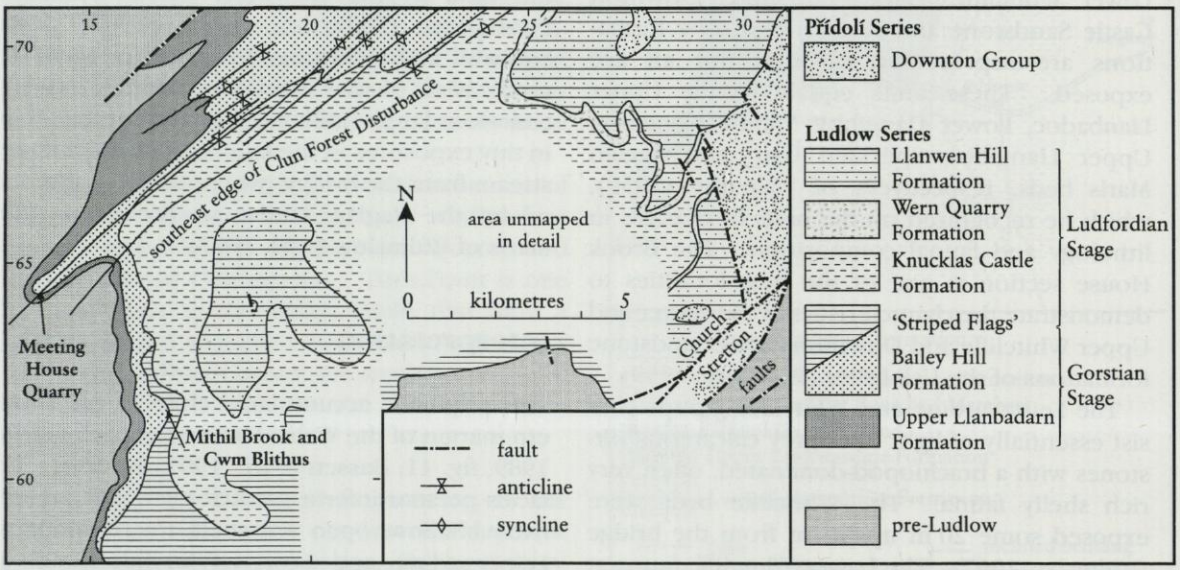


Figure 5.57 Geological map of the Radnor Forest area, Powys, showing the location of GCR sites Meeting House Quarry and Mithil Brook and Cwm Blithus (after Woodcock and Tyler, 1993; based partly on Kirk, 1947, and Holland, 1959).

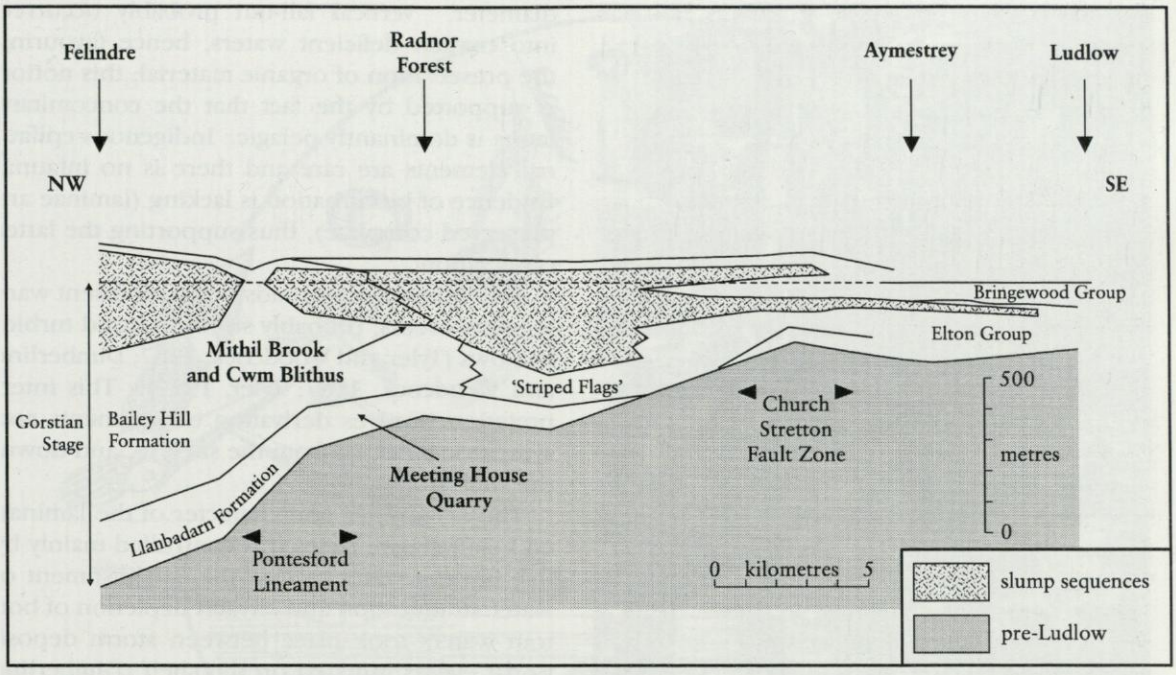


Figure 5.58 Position of Meeting House Quarry and Mithil Brook and Cwm Blithus, Powys, on a platform-basin transect showing lithostratigraphical formations of Gorstian age (after Woodcock and Tyler, 1993).

and Woodcock, 1987) of the Gorstian Stage (Figure 5.58).

The overall geology of this region, the 'Brecon anticlinal' area that was researched by Kirk (1947, 1951b; see also Bailey, 1964), still awaits comprehensive modern documentation. Nevertheless, Meeting House Quarry has featured in detailed sedimentological studies of the area (Tyler, 1987; see also Dimberline and Woodcock, 1987, Tyler and Woodcock, 1987, Dimberline *et al.*, 1990), its fossils and their palaeoecological significance have been highlighted (Siveter 1984; Siveter *et al.*, 1987, 1991) and it is a recommended site for field excursions to the Silurian of the Welsh Basin (Siveter, 1988, stop 13; Siveter *et al.*,1989, locality 4.4; Woodcock and Tyler, 1993, locality 4).

Description

The gently north-easterly dipping strata consist of interbedded units of 1–25 mm thick, homogeneous silty mudstone and 1–25 mm thick intervals of laminated carbonaceous mudstone (Tyler, 1987; see also Siveter *et al.*, 1987, 1991 and Woodcock and Tyler, 1993; Figure 5.59). The so-called 'homogenous mudstones' may be weakly graded, or have a basal division of parallel-laminated or cross-laminated siltstone. Subtle grading is seen only in thin or polished section (Woodcock and Tyler, 1993). The carbonaceous mudstones comprise alternating quartz-rich laminae and carbon-rich laminae (3–4 per mm).

The fauna at Meeting House Quarry is sparse, dominantly pelagic, and scattered at very low densities through the sequence (Siveter, 1984, Siveter *et al.*, 1987, 1991; Figure 5.60). It consists mostly of the graptolites *Bohemograptus bohemicus*, *Cucullograptus scanicus*, *Pristiograptus dubius*, *Pristiograptus tumescens*, *Saetograptus chimaera semispinosus* and *Saetograptus varians*; orthoconic nautiloids with, rarely, small epifaunal pisocrinoids attached; and ostracods, especially *Parabolbozoe bohemica* but including at least three other species. The orthocones and the graptolites are in some cases current orientated. The graptolites indicate that at Meeting House Quarry the Llanbadarn Formation belongs to the *C. scanicus* Biozone. Bivalves (*Slava fibrosa* and *Cardiola* species amongst others), brachiopods (*Aegiria grayi*, *Lingula lata*) and phyllocarids are minor associates.

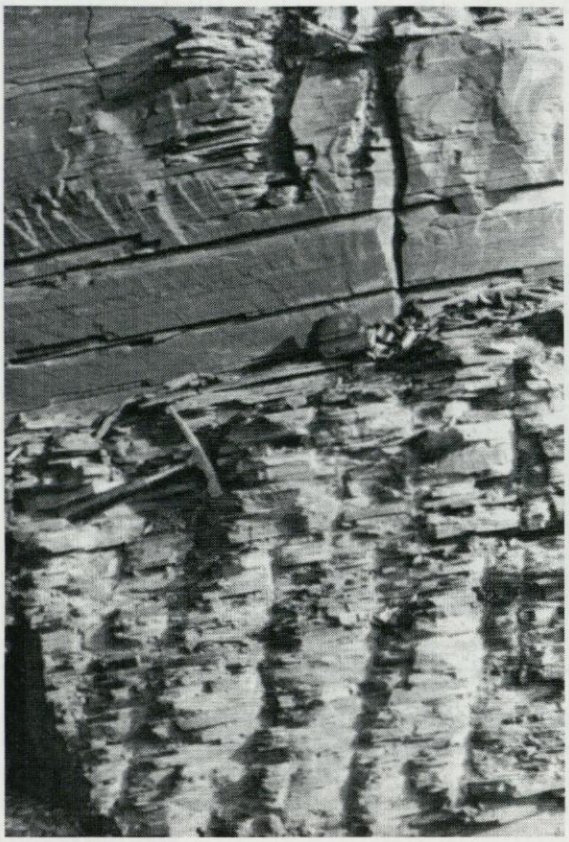


Figure 5.59 Laminated hemipelagites and homogeneous silty mudstones of the Llanbadarn Formation, Meeting House Quarry, Powys. (Photo: David J. Siveter.)

Interpretation

Based on sedimentological, palaeontological and palaeogeographical evidence this part of the Welsh Basin during Gorstian times is modelled as, probably, basin slope (see Siveter *et al.*, 1989, fig. 10, 1991, fig. 5; Dimberline *et al.*, 1990, fig. 6; Bassett *et al.*, 1992, fig. S4a). In broad terms it is transitional between the shelf area of the Midland Platform beyond the Church Stretton Fault to the south-east, and the deeper, axial part of the turbidite-dominated Montgomery Trough to the west.

The alternating quartz-rich laminae and carbon-rich laminae of the carbonaceous mudstones are considered to represent periodic, possibly annual couplets comprising silt influx and organic (plankton) background hemipelagic fall-out (Dimberline *et al.*, 1990). The silt layers often have a mottled appearance due to the presence of silt-clay aggregates of up to 2 mm diameter. Vertical fall-out probably occurred into oxygen deficient waters, hence favouring the preservation of organic material; this notion is supported by the fact that the concomitant fauna is dominantly pelagic. Indigenous epifaunal elements are rare and there is no infauna. Evidence of bioturbation is lacking (laminae are preserved complete), thus supporting the latter observation.

The 'homogenous mudstones' represent waning-flow events, probably storm induced turbidity flows (Tyler and Woodcock, 1987; Dimberline and Woodcock, 1987; Tyler, 1987). This interpretation involves derivation of sediments and sympatric bioclasts from the shelf to, and down, the shelf slope.

The occurrence and character of the laminated hemipelagite facies was controlled mainly by low bottom water oxicity; the establishment of water stratification and oxygen depletion of bottom waters took place between storm depositional events initiated on the shelf (Dimberline *et al.*, 1990). Such hemipelagites are an important element of basinal sequences of Wenlock and early Ludlow age of many basins flanking the former Iapetus Ocean (Kemp, 1991).

The faunal association represented at Meeting House Quarry was described, from Wales (see Watkins and Berry, 1977), initially from 'Radnorshire' (Kirk, 1947), and has subsequently been recognized elsewhere in the Welsh Basin (e.g. Long Mountain, Powys and Denbigh area,) and in many other countries such as France, Poland and the Czech Republic (Siveter 1984; Siveter *et al.*, 1987, 1991). This fauna, especially its representatives at Meeting House Quarry, is particularly important palaeoecologically as it provides evidence for the recognition of pioneer pelagic ostracods (myodocopes) in the stratigraphical record (Siveter, 1984; Siveter *et al.*, 1987, 1991).

Of the fauna at Meeting House Quarry, the bivalves are the only autochthonous, epibenthic element (Siveter *et al.*, 1987, 1991). Large bioclasts, in the form of generally disarticulated and current-orientated shells of typical shelf dwelling macro-invertebrates such as brachiopods, are confined to the graded, silty soles of the homogeneous mudstones. The less dense skeletons (e.g. graptolites) are generally found in the carbonaceous mudstones. Such fine distinctions between the lithological context of various (transported as opposed to *in situ*) faunal components of the sequence are crucial to its

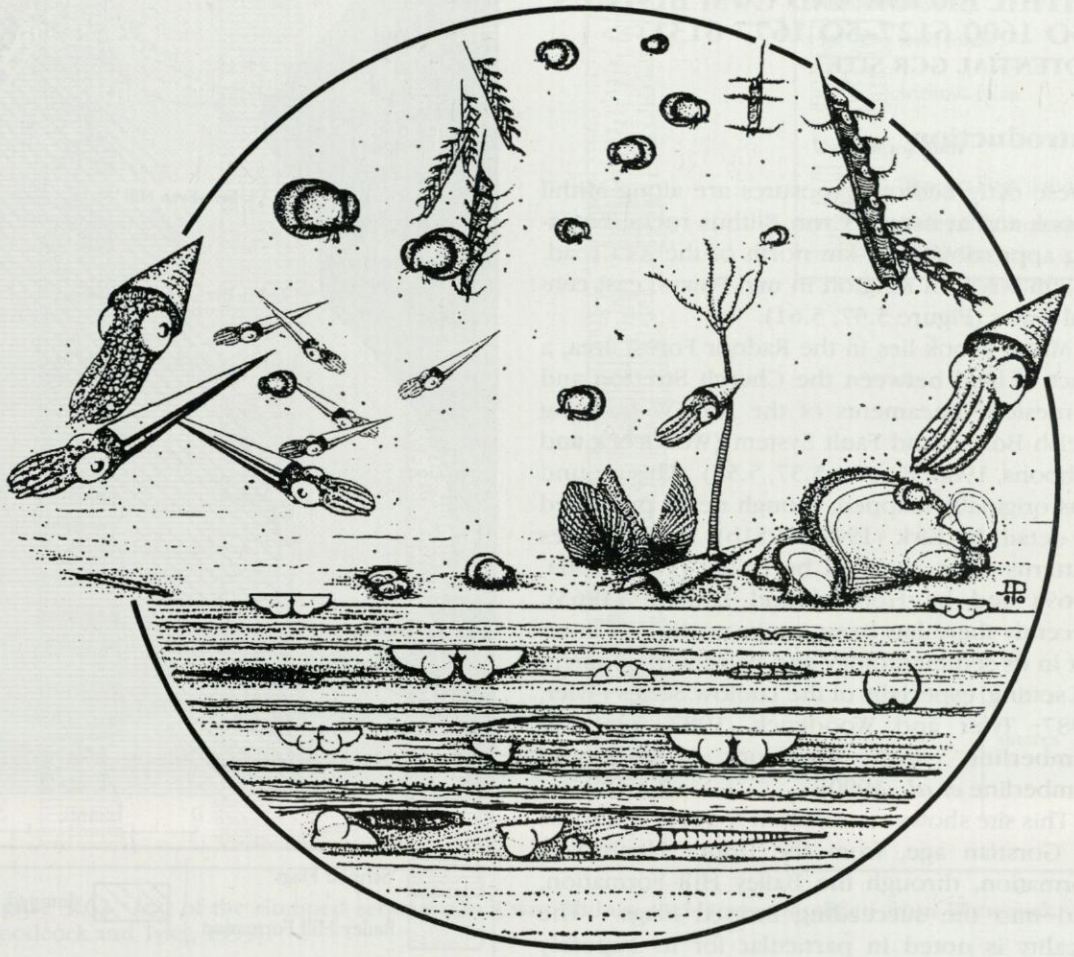


Figure 5.60 Reconstruction of the palaeoenvironment represented by the Ludlow Series Llanbadarn Formation at Meeting House Quarry, Powys (after Siveter *et al.*, 1991): an off-shelf, slope facies assemblage associated with laminated hemipelagites and dominated by pelagic organisms; bottom waters and sediments were mostly poorly aerated. In general order of abundance the fossil taxa illustrated are: orthoconic nautiloids, monograptids, myodocope ostracods, pterineid and cardiolid bivalves and pisocrinid crinoids.

interpretation. In off-shelf environments it appears that environmental stresses (?low oxygen–dysaerobic conditions and/or unsuitable substrates) prevented benthic brachiopods from becoming established. Certain bivalves, such as pterineids and cardiolids, were either especially adapted for such conditions or were more tolerant and opportunistic than the brachiopods.

Ludlow GCR sites of basin margin–slope aspect are relatively rare compared to those coeval sites situated on the shelf. In addition to Meeting House Quarry there are two others locally, namely Mithil Brook and Cwm Blithus in the Radnor Forest, and Beacon Hill in the Clun Forest area.

Conclusions

This is an excellent representative locality at which to study sediments and faunas characteristic of an early Ludlow basin margin environment of the Welsh Basin. The lithologies reflect an alternation of both backgound sedimentation and the results of discrete depositional events originating on the shelf. The rocks yield a dominantly pelagic fauna that has been used in developing the concept that the ostracods, a major invertebrate group, underwent the fundamental ecological shift of adopting pelagic lifestyles during the Silurian.

MITHIL BROOK AND CWM BLITHUS (SO 1600 6127–SO 1677 6131)
POTENTIAL GCR SITE

Introduction

These early Ludlow exposures are along Mithil Brook and at nearby Cwm Blithus rocks, beginning approximately 1 km north of the A44 road, 14 km WNW of Kington in mid-Powys, east central Wales (Figure 5.57, 5.61).

Mithil Brook lies in the Radnor Forest area, a tract of land between the Church Stretton and Pontesford lineaments of the NE–SW trending Welsh Borderland Fault System (Woodcock and Gibbons, 1988; Figures 5.57, 5.58). This ground was originally mapped, though never published in detail, by Kirk (1947, 1951b), and its facies patterns were analysed by Bailey (1962, 1964, 1969) and by Holland and Lawson (1963). Recently there has been a rejuvenation of interest in its sedimentology and palaeoenvironmental setting, especially of the Ludlow Series (Tyler, 1987; Tyler and Woodcock, 1987; see also Dimberline and Woodcock, 1987 and Dimberline *et al.*, 1990).

This site shows an excellent sequence of rocks of Gorstian age, from the Upper Llanbadarn Formation, through the Bailey Hill Formation, and into the succeeding Striped Flags. The locality is noted in particular for its superbly developed slumped horizons, documented in detail by Woodcock (1976a, b; Figures 5.62, 5.63). These outcrops are also described in the field guides of Bailey and Woodcock (1976), Siveter *et al.* (1989, locality 4.3) and Woodcock and Tyler (1993, locality 3).

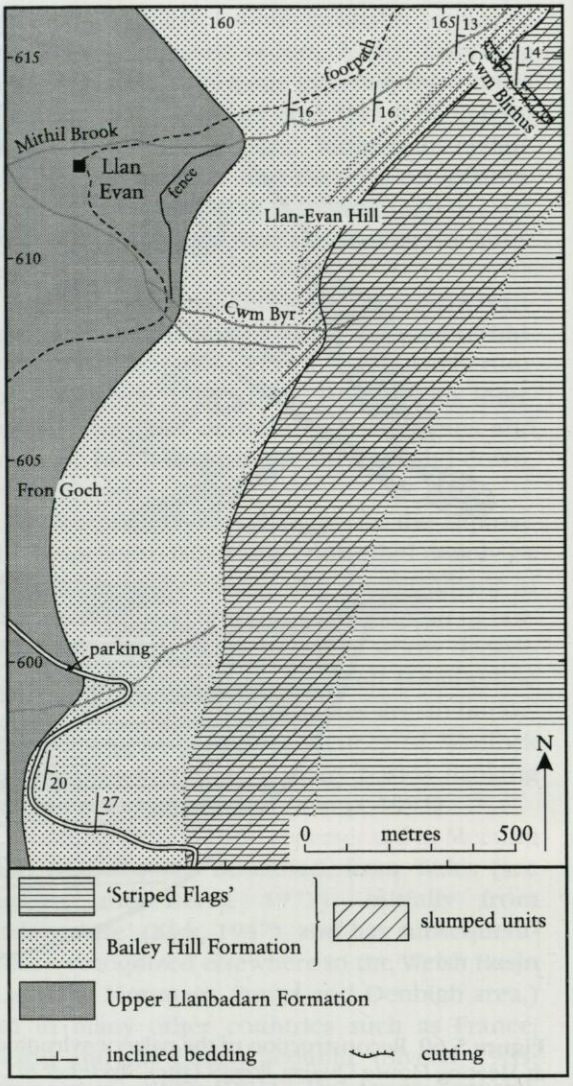


Figure 5.61 The geology in the vicinity of Mithil Brook and Cwm Blithus, mid-Powys (after Bailey and Woodcock, 1976; Siveter *et al.*, 1989; Woodcock and Tyler, 1993).

Description

Where a fence crosses Mithil Brook, some 350 m east of Llan-Evan farm, the upper part of the Llanbadarn Formation (of Dimberline and Woodcock, 1987) dips gently eastwards (SO 1600 6127). Such mudstone sequences locally consist of homogeneous silty mudstones and carbonaceous mudstones (for which see site report for Meeting House Quarry), reflecting different sedimentary processes within a single environment. The age of the Llanbadarn Formation at Mithil Brook is not yet known, but nearby oucrops of this formation yield graptolites of the upper part of the basal Gorstian *Neodiversograptus nilssoni* Biozone (Woodcock and Tyler, 1993) and at Meeting House Quarry, some 4 km to the north-west, the formation probably belongs to the succeeding *Cucullograptus scanicus* Biozone (Siveter *et al.*, 1987).

Just upstream there is a rapid lithological transition to the base of the Bailey Hill Formation, which is here represented by easterly dipping calcareous sandy siltstone beds, each 10–20 cm thick and characteristically with many allochthonous shells at their base. At a slightly younger horizon which crops out at a meander a short distance upstream, the Bailey Hill

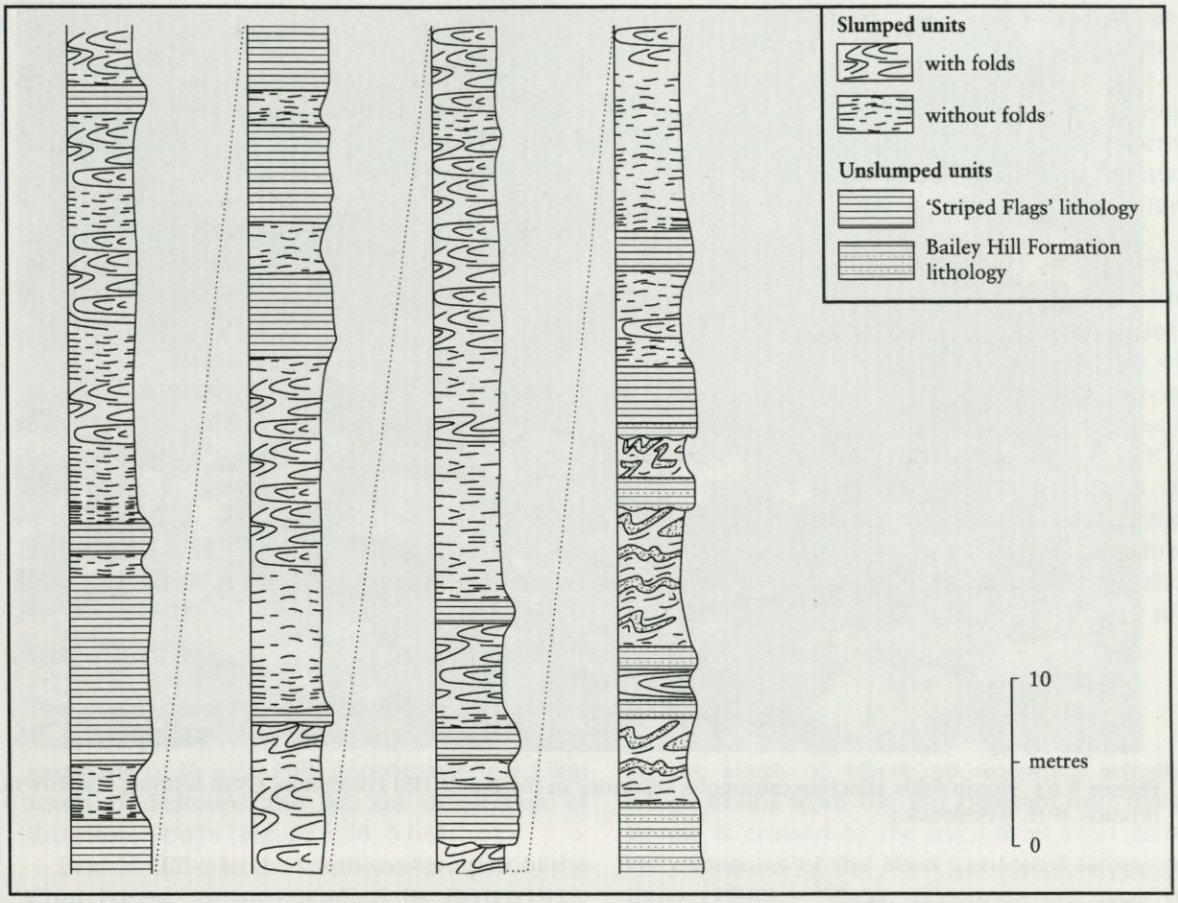


Figure 5.62 Log of the slumped sequence in Cwm Blithus, mid-Powys (modified from Woodcock, 1976a; Woodcock and Tyler, 1993).

Formation shows sole marks, convolute lamination and ripple cross-lamination in beds of 5 cm average thickness (SO 1618 6124). Sporadic exposures can be traced upstream to the base of the gully called Cwm Blithus (SO 1662 6153), which exposes a 200 m thick sequence of calcareous siltstones of the Bailey Hill Formation which at many horizons have suffered penecontemporaneous deformation to generate a magnificent array of slump and slide structures (Figures 5.62, 5.63).

Many of the more obvious slump structures are folds, mostly recumbent, with limb lengths of 10–80 cm, limb angles of 0–54°, NE–SW aligned hinges and in some cases eroded tops. Later formed, axial planar cleavage affects some of the folds. Direction of movement down the palaeoslope was from south-east to north-west, as indicated by the general north-westerly direction of overturning of the folds. Unslumped units punctuate the sequence throughout. They have lithologies characteristic of either the Bailey Hill Formation or, as seen especially in the upper part of the section in the upper reaches of Cwm Blithus, of the more finely laminated rocks included within the Striped Flags (of, for example, Kirk, 1947; Bailey, 1962). The latter is a regionally diachronous, often slump affected, hemipelagite-bearing facies unit that is coeval with much of the generally more distally formed Bailey Hill Formation (Tyler and Woodcock, 1987; Woodcock and Tyler, 1993).

Interpretation

The Bailey Hill sediments accumulated on a north-west dipping palaeoslope on the south-east margin of the Montgomery Trough (of Cummins, 1959b) in the Welsh Basin. This trough was a NE–SW trending, Wenlock to

Figure 5.63 Slump folds affecting calcareous siltstones in the Bailey Hill Formation, Cwm Blithus, mid-Powys. (Photo: N.H. Woodcock.)

Ludlow age turbidite-dominated depocentre (see Dimberline and Woodcock, 1987, fig. 4; Siveter *et al.*, 1989, fig. 10; Dimberline *et al.*, 1990, fig.1; Bassett *et al.*, 1992, figs S3b, S4a). By early Ludlow times its axis had migrated eastwards, so that its eastern margin coincided with the line of the Church Stretton Lineament. Thus in Gorstian times the Radnor Forest area represents a transition zone between shelf and the basin proper and an area that experienced extensive submarine slumping (see Woodcock and Tyler, 1993). Similar slumped horizons occur in the Ludlow of the adjoining districts of the Clun Forest to the north-west, north and north-east, such as Kerry (Earp (1938), south-west Clun (Earp, 1940) and the Knighton area (Holland,1959; see also Tyler and Woodcock, 1987).

The calcareous siltstones that dominate the Bailey Hill Formation were once considered to be turbidites (Cummins, 1959a; Holland and Lawson, 1963; Bailey, 1964, 1969; Woodcock, 1976b), but they have recently been re-interpreted as storm generated deposits that accumulated on the distal parts of the shelf and adjacent basin slopes (Tyler, 1987; Tyler and Woodcock, 1987). Furthermore, contrary to earlier opinions (Bailey 1964, 1969; Woodcock 1976b), the slump sheets are not synchronous with the start of 'turbidite' sedimentation of the Bailey Hill Formation, nor have they moved great distances (Woodcock and Tyler, 1993). They probably result from a mid-Ludlow reactivation of the Welsh Borderland Fault System, an event which precipitated slippage and deformation of sediments on local palaeoslopes (Tyler, 1987; see Tyler and Woodcock, 1987). Graptolite data tie the main movement to the late *scanicus–tumescens*–early *leintwardinensis* biozones, with an acme in the *tumescens* Biozone (Tyler and Woodcock, 1987), thus postdating deposition of most of the Bailey Hill Group.

Beacon Hill in Clun Forest and Meeting House Quarry in Radnor Forest are other sites containing Ludlow sediments indicative of the marginal slope of the Welsh Basin. Ty'n-y-Ffordd Quarry, in the Ludlow of northern Wales, is another site selected for the GCR network largely on the basis of its important submarine slumped horizons.

Conclusions

This site displays spectacular examples of soft sediment deformation structures that are characteristic of certain early and mid-Ludlow rocks over a wide region of this part of east central Wales. Such features are rare on a regional scale within the Silurian of the Welsh Basin, the other well-known area where they are developed being the Denbigh area in northern Wales. The site also has palaeogeographical importance. It defines the contemporaneous slope of the depositional basin and it represents one of the relatively few GCR sites of Ludlow age that have an off-shelf aspect.

BEACON HILL (SO 1808 7672)

POTENTIAL GCR SITE

Introduction

These old quarries occur between two paths, about 450 m WNW of Fron Rocks on the south-east flank of Beacon Hill, approximately 4.5 km south of Felindre and 12 km north-west of Knighton, Powys (Figure 5.58, 5.64).

Beacon Hill is in the south-western part of the Clun Forest, an area studied by Earp (1938; 1940). His 1938 paper centred on the Kerry district, but it also included an additional geological map (pl. 13) which focused on the distribution of the so-called 'Contorted Beds' (i.e. slumped beds) of an adjoining southerly region that contains Beacon Hill. In a subsequent paper he mapped the latter ground in greater detail and he included brief notes of the geology of the vicinity of Beacon Hill (Earp, 1940).

Holland *et al.* (1963) and Cocks *et al.* (1971, 1992) correlate the local basinal sequences with the standard Ludlow stratigraphy of Shropshire. The sedimentology of much of the Ludlow of Clun Forest and the contiguous Radnor Forest area to the south has recently been reassessed (Tyler, 1987; Tyler and Woodcock, 1987; Woodcock and Tyler, 1993). The research of Holland and Palmer (1974) demonstrated the palaeontological significance of the late Ludlow rocks exposed at Beacon Hill. The locality also featured in the field guide of Siveter *et al.* (1989).

Description

To the south of where an unnamed stream, which drains from the old quarries into Lawn Brook, is crossed by the track from Fron there are exposures of the Main Contorted Group of Earp (1940). These siltstones are part of slumped beds that here belong to the upper part

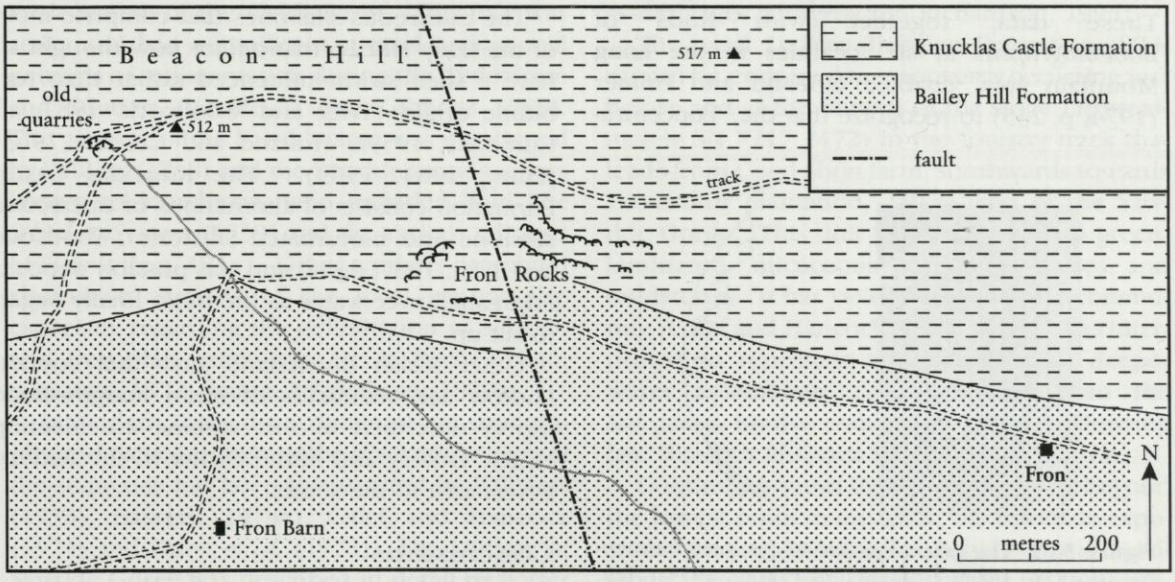


Figure 5.64 The geology of part of the south-east flanks of Beacon Hill, Powys (after Holland and Palmer, 1974).

of the Bailey Hill Formation (see Tyler and Woodcock, 1987).

Immediately below the track there is a change to the succeeding stratigraphical unit that Earp (1940) called the *Dayia navicula* Beds and which recently has been referred to as the Knucklas Castle Formation (see Woodcock and Tyler, 1993) after beds of that name in the Knighton area (Holland, 1959). Above the track the siltstones of this formation crop out sporadically in the gully of the unnamed stream and comprise the shallow quarried exposures of the site itself (Holland and Palmer, 1974). The formation contains the brachiopods *Dayia navicula* and *Aegiria grayi*, the ostracod *Neobeyrichia lauensis*, the bivalve *Cardiola interrupta* and, for some 65 m (= about 30 m of strata) in the gully north of the track, the graptolite *Saetograptus leintwardinensis* (Earp, 1940; Holland and Palmer, 1974). Throughout its distribution elsewhere in the Welsh Borderland the *A. grayi–N. lauensis* association is characteristic essentially of the Upper Leintwardine Formation (*Saetograptus leintwardinensis* Biozone).

The old quarries have a small thickness of thin, flaggy, calcareous siltstones that have yielded *A. grayi*, *C. interrupta* and several hundred, generally fragmentary specimens of the graptolite *Bohemograptus bohemicus tenuis* (Holland and Palmer, 1974; Figure 5.65). There is about 60 m thickness of strata between the last occurrence of the other graptolites (*S. leintwardinensis*) and the band containing *Bohemograptus*. These data, together with finds of *Bohemograptus* at six localities in the Long Mountain area, enabled Holland and Palmer (1974, p. 235) to recognize that the, 'concentration of *Bohemograptus* above and clearly separated from the *S. leintwardinensis* Zone justify correlation with the '*Bohemograptus* proliferation zone'... and thus reasonably indicate that much of the *Dayia navicula* Beds ... are ... post-Leintwardinian i.e. Whitcliffian in age'. Most importantly, the data proved that the *S. leintwardinensis* Biozone could no longer claim to be the youngest graptolite biozone in the British sequence.

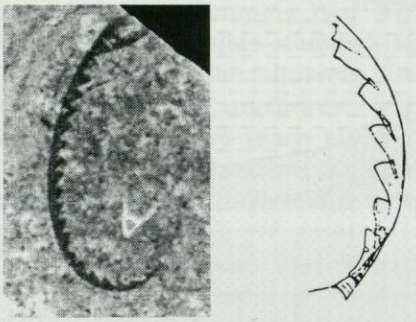


Figure 5.65 The graptolite *Bohemograptus bohemicus* (Boucek) (from Holland and Palmer, 1974): left, from the Long Mountain Siltstone Formation, Long Mountain, Powys (approximately × 2); right, from the Knucklas Castle Formation, Beacon Hill, Powys (× 6).

Interpretation

Palaeogeographically this locality lies within the approximately NE–SW trending Montgomery Trough of the Welsh Basin (Cummins, 1959a, 1959b and Bailey, 1969; see also Dimberline and Woodcock, 1987, fig. 4; Siveter *et al.*, 1989, fig. 10; Dimberline *et al.*, 1990, fig. 1). The Bailey Hill sediments and their associated slumped sequences (see Figure 5.58) accumulated mostly on a north-west dipping palaeoslope of the south-east margin of this depocentre. By the Ludlow, this margin essentially lay along the trend of the Church Stretton Fault Complex (Tyler and Woodcock, 1987). Beacon Hill, near Felindre, is sited between the two more outboard (Pontesford and Towy) lineaments of the Welsh Borderland Fault System (Woodcock and Gibbons, 1988), in the outer part of a broad transitional zone between platform and basin proper (Tyler and Woodcock 1987; Woodcock and Tyler, 1993).

The calcareous siltstones that comprise most of the Baily Hill Formation are now thought to have a shelf storm-influenced rather than turbiditic origin (Tyler and Woodcock, 1987; cf. Cummins, 1959a; Holland and Lawson, 1963; Bailey, 1964, 1969). The Knucklas Castle Formation consists of alternations of calcareous siltstone and bioturbated siltstone (Woodcock and Tyler, 1987, fig. 4) and was possibly deposited in shallower water as the basin finally began to silt up.

Other Welsh Borderland sites that contain Ludlow age sediments of basin margin–slope aspect described in this volume are Meeting House Quarry and Mithil Brook in the Radnor Forest area to the south.

Conclusions

This site is of prime palaeontological importance. It has yielded most of the material of the

last-known graptoloid species in the British succession. This find permits refinement of late Ludlow stratigraphical correlation both nationally and internationally. Beacon Hill also represents a relatively rare, off-shelf locality within the Ludlow sites of the GCR network.

SAWDDE GORGE (SN 715 260–SN 728 245)

Introduction

This internationally known locality displays all four Series of the Silurian. It consists of a major section along the narrow gorge of the Afon Sawdde, together with nearby trackside exposures and quarries, between 2.2 and 4.3 km SSE of Llangadog, on the southern side of the Tywi Valley, southern Wales (Figure 4.45). The almost continuous series of exposures, between Bont Fawr in the north-west and Pont-ar-Ilechau to the south-east, show late Telychian Llandovery Series to Přídolí rocks (Figure 5.66). Pont-ar-Ilechau – the 'Bridge on the tiles' – presumably refers to the 'tilestones' lithology of former usage relating to the Old Red Sandstone. The Ludlow and Přídolí part of the Sawdde Gorge sequence is described here; the Llandovery and Wenlock strata are detailed in the report of a Wenlock site of the same name in this volume.

The locality occurs on the south-east flank of the NE–SW trending Towy Lineament, an anticline within the so-called Welsh Borderland Fault System of the Welsh Basin. This fold was active and had a significant control on regional patterns of sedimentation during the Ordovician and Silurian (Woodcock and Gibbons 1988). The geology of the Sawdde area was mentioned by Phillips (1848) and the Sawdde sequence was known to Murchison, who included it in *The Silurian System* (1839) and the various editions of *Siluria* (e.g. 1854). Other workers presented alternative versions of the local stratigraphy, especially regarding the delimitation of Silurian and Devonian strata (e.g. De la Bêche, 1846; Symonds, 1872; Stamp, 1923; Straw, 1930).

In modern times the sedimentology, stratigraphy and palaeontology of the pre-Ludlow part of the sequence has been investigated by Williams (1953), Bassett (1974a), Calef and Hancock (1974) and Hurst *et al.* (1978). The Ludlow of Sawdde Gorge was described in detail by Potter and Price (1965) in their paper on the 'Ludlovian and Downtonian' in the Llandovery–Llandeilo region of southern Wales. As a key section in the Welsh Basin, Sawdde Gorge has also been referred to in several other stratigraphical and broad-scale facies analyses across the Silurian of the region (e.g. Holland and Lawson, 1963; Squirrell and White, 1978; Bassett *et al.*, 1982; Cherns, 1988). Richardson and Lister (1969) and Burgess and Richardson (1995) have reported about the microflora of the Sawdde Gorge. Summaries of the entire Silurian sequence at Sawdde Gorge, together with detailed itineraries, appear in the field guides of Bassett (1982b) and Siveter *et al.* (1989).

Description

The Ludlow is currently divided into six lithostratigraphical units and the overlying Přídolí is represented by two units (Potter and Price, 1965; Bassett, 1982b). All of the beds young to the SSE, with high dips of up to 70°. Macrofaunas are shelly and diverse (Figure 5.66) but in many cases are difficult to correlate precisely with the stratigraphical divisions of the type Ludlow sequence. The age determinations for the Ludlow units at Sawdde Gorge, as discussed below, follow Potter and Price (1965); however, it should be noted that, based on the nearby Cennen Valley and adjacent sections, Squirrell and White (1978) offer slightly revised correlations for these units. The Gorstian to early Ludfordian part of the Sawdde Gorge sequence yields high diversity cryptospore and miospore assemblages (Burgess and Richardson, 1995).

The basal Ludlow Tresglen Formation (90+ m) can be examined in exposures occurring just before and at the bottom of the slope (approximately SN 7217 2472) in the forestry track that leads from Coed Shôn farm, southwards towards Pen-Arthur plantation, 250 m west of the Sawdde Gorge. This unit consists of grey to green, laminated, micaceous siltstones, shales and mudstones. It has yielded a *Dicoelosia* community (Calef and Hancock, 1974), which was interpreted to represent a more offshore, deeper water assemblage (transgression) than the *Salopina*– bivalve community of the underlying late Wenlock Ffinnant Sandstone Formation.

Continuing south for a short distance, beyond the lowest point in the track, the trackside exposures chart an increase in shaly beds and sandstone units and the disappearance of an assemblage dominated by *Dicoelosia biloba*, thereby marking a gradual transition into the overlying

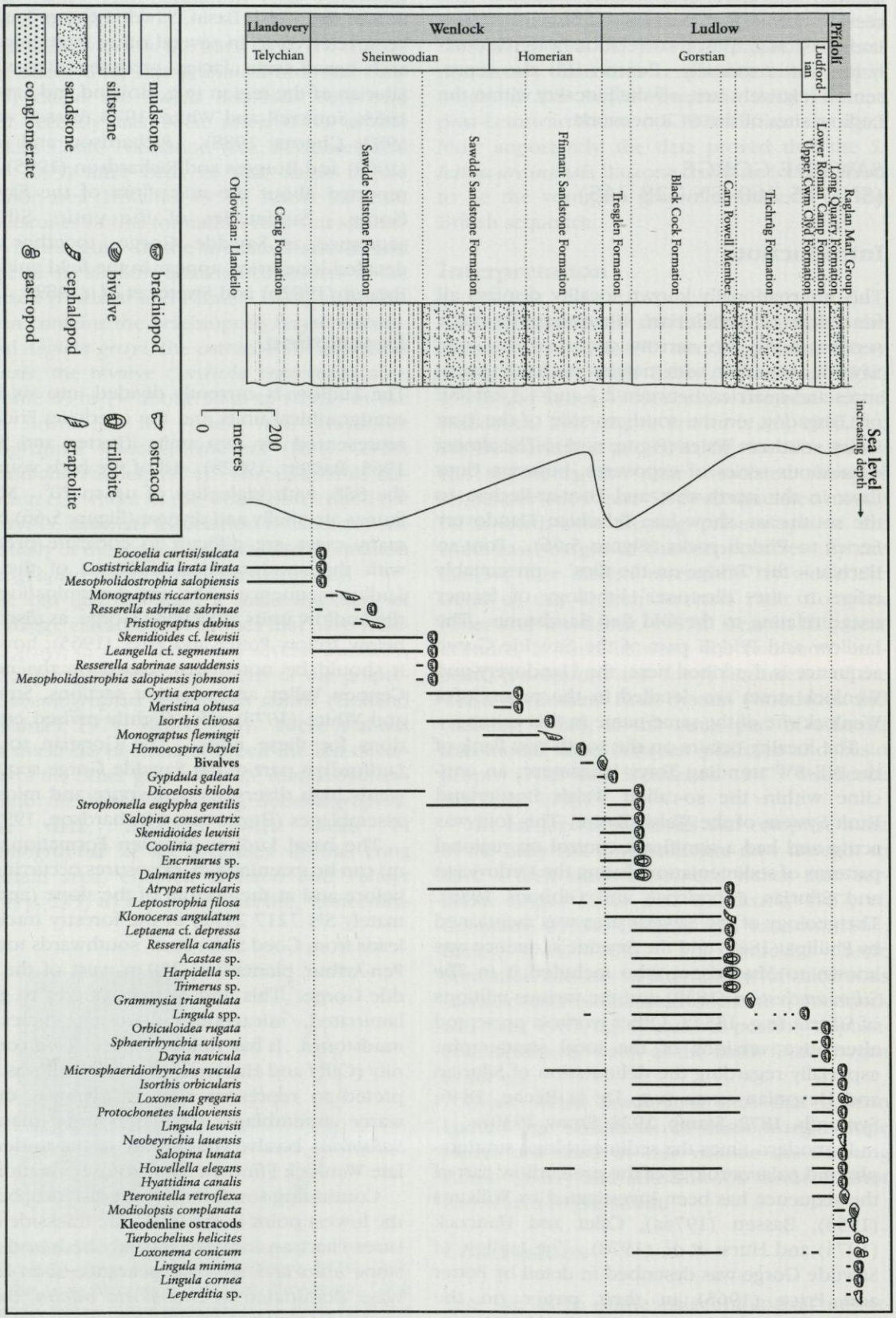


Figure 5.66 Silurian succession of the Sawdde Gorge, Carmarthenshire, showing lithologies, generalized sea-level curve and ranges of selected fossils (after Siveter *et al.*, 1989).

294 m thick Black Cock Formation. The base of the latter is defined at about 70 m upstream (SN 7239 2490) from the small former footbridge, about 100 m south of Ffinnant Farm, over the Sawdde Gorge. The lower part of the unit consists of grey to black calcareous shales and siltstones with medium-bedded sandstones; these lithologies are well displayed in the lower half of the quarry (SN 7225 2469) on the west side of the track to Pen Arthur and also around the bluff at southern entrance to that quarry. Bioturbation is common in these beds in the quarry, as are rottenstone bands with a diverse brachiopod (e.g. *Atrypa reticularis* and *Leptostrophia filosa*) and bivalve (e.g. *Grammysia*) fauna.

The upper part of the main (unnamed) member of the Black Cock Formation comprises more massive arenaceous shales and mudstones, with siltstones and sandstones, and is thought to be of mid- to late Gorstian age. At Cwar Glâs, about 300 m north of Pont-ar-Ilechau, the steeply dipping beds in the northernmost (SN 7263 2480) of the two large roadside quarries and the north-west face of the adjoining southern quarry are entirely in this upper part of the formation (Figure 5.67). These strata show a splendid array of ripple-mark structures and contain calcareous rottenstones and shelly coquinas dominated by bivalves (e.g. *Modiolopsis*, *Grammysia*) and gastropods (e.g. *Loxoconcha*), with brachiopod (e.g. *Isorthis*, *Microsphaeridiorhynchus*, *Howellella*) and trilobite (e.g. *Harpidella, Acaste, Trimerus*) associates.

The succeeding Carn Powell Member (*c.* 40 m total thickness) can best be examined in the east side of the southern quarry at Cwar Glâs (Figure 5.67), where the base of the member is defined. *Grammysia*-rich beds, which are seemingly faulted into the high part of the southern corner of the trackside quarry, west of the Sawdde Gorge, at SN 7225 2469, are also assigned to the Carn Powell Member. Characteristically, this member consists of flaggy-bedded purple and grey sandstones with subordinate thin beds of calcareous lenses, rottenstones and conglomerates.

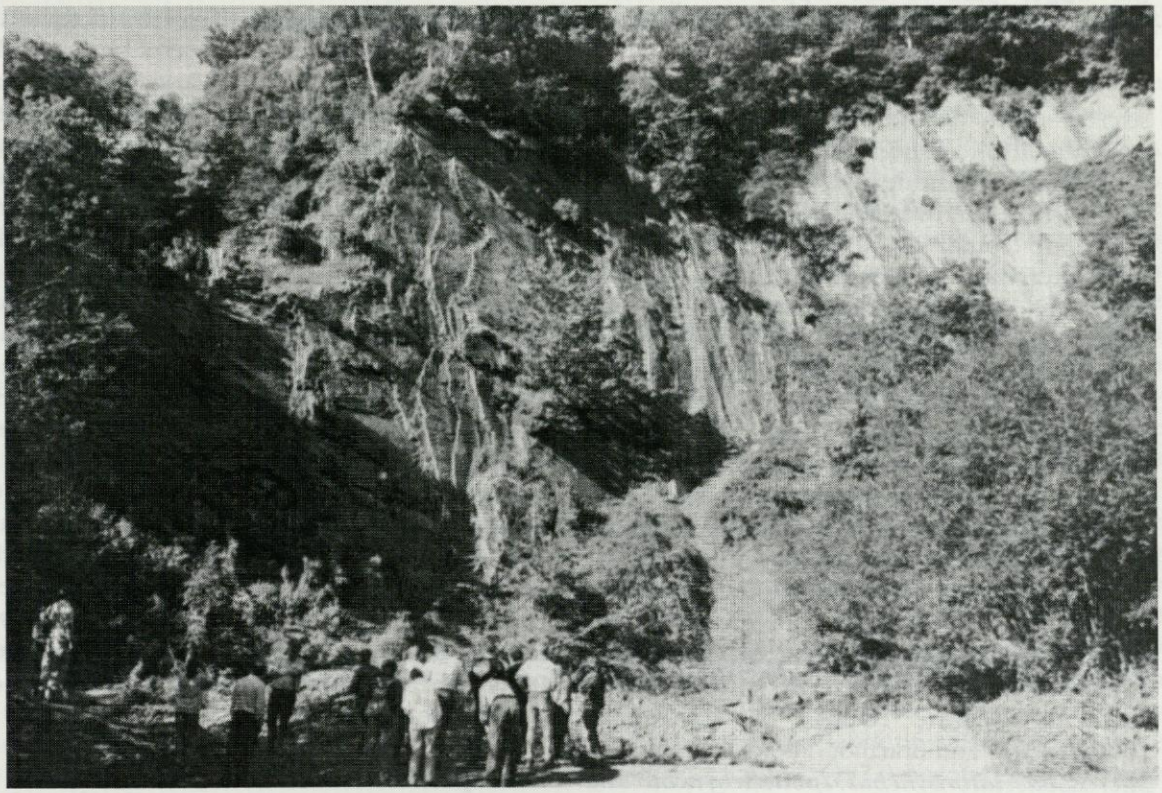


Figure 5.67 Steeply dipping, ripple-marked bedding planes of the highest beds of the Black Cock Formation (centre), overlain (upper right) by the Carn Powell Member, north side of the southern quarry at Cwar Glâs, Sawdde Gorge, Carmarthenshire. (Photo: David J. Siveter.)

The Trichrûg Formation (185 m) was assigned by some early workers to the Old Red Sandstone. Comprising red sandstones, pebbly sandstones, conglomerates and siltstones, its base is defined high in the south-east corner of the southern quarry at Cwar Glâs, where it overlies the Carn Powell Member. Immediately south-east of Cwar Glâs the formation forms a hummocky ridge in the hillside. The Trichrûg Formation can also be examined in the bed and banks of the Sawdde about 30–40 m downstream from its confluence with Afon Meilwch, at Pont-ar-Ilechau. It is also intermittently exposed for about 400 m along the track from immediately south of the quarry at SN 7225 2469, west of the Sawdde Gorge; for example, at the crown (SN 7262 2445) of the westerly bend in the track, coarse pebbly sandstones of the top part of the unit are displayed. Inarticulate brachiopods such as *Orbiculoidea* and *Lingula*, together with gastropods such as *Loxonema* and *Bucanopsis* are elements of the sparse, low diversity fauna of the Trichrûg Formation, which is thought to be the same age (late Gorstian) as the upper part of the Upper Bringewood Formation of the central Welsh Borderland (Potter and Price, 1965).

The Upper Cwm Clyd Formation (33 m) consists of green and grey flaggy laminated siltstones and mudstones with shell lenticles and subordinate sandstone and conglomeratic sandstone units. The overlying Lower Roman Camp Formation comprises about 54 m of grey to green-grey indurated mudstones with siltstone interbeds. Both formations are exposed along the westerly swinging track 200 m west of Pont-ar-Ilechau (SN 7260 2445) and, along strike, just north-west of Pont-ar-Ilechau in the banks and bed of the Sawdde Gorge itself. At the latter locality the base of the Upper Cwm Clyd Formation is clearly demarcated where greenish, flaggy to tabular bedded sandstones and siltstones, containing (near the base) subordinate coarse conglomeratic sandstones, succeed coarse red sandstones of the Trichrûg Formation. The upper part of the Upper Cwm Clyd Formation contains shelly lenticles with a restricted marine fauna of gastropods (*Loxoconcha*) and brachiopods such as *Isorthis*, *Microsphaeridiorhynchus*, *Sphaerirhynchia* and *Protochonetes*.

The base of the Lower Roman Camp Formation may be examined in the north bank of the Afon Meilwch, directly below the small bridge over its confluence with the Afon Sawdde (SN 7278 2452). There, the gradual incoming of somewhat darker grey and slightly thicker bedded units containing the biostratigraphically important (Upper Leintwardine) *Neobeyrichia lauensis* and other ostracods signifies the change from the underlying Upper Cwm Clyd Formation. The brachiopod *Salopina lunata* also enters the sequence in the Lower Roman Camp Formation but, in general, the shelly faunas of these two formations are similar. Potter and Price (1965) consider the Upper Cwm Clyd and Lower Roman Camp formations to be correlatives of the Lower and Upper Leintwardine formations (early Ludfordian) respectively of the central Welsh Borderland.

An unconformity (but with no angular discordance) at the top of the Lower Roman Camp Formation at Sawdde cuts out the Upper Roman Camp Formation (late Ludfordian), a unit which is present regionally to the north-east. The early Přídolí Long Quarry Formation (20 m), the so-called 'Tilestones' of earlier literature, oversteps the Ludlow strata from north-east to south-west across the region. The latter formation consists of green-grey, mica-rich, flaggy bedded sandstones with a limited assemblage of brachiopods (e.g. *Lingula minima*, *Protochonetes ludloviensis*, *Microsphaeridiorhynchus nucula*), bivalves (e.g. *Modiolopsis complanata*), gastropods (e.g. *Turbocheilus helicites*) and kloedinine beyrichiacean ostracods. The base of the Long Quarry Formation is seen in the river bed immediately north of the main bridge over the Sawdde at Pont-ar-Ilechau; exposures of the formation also occur in the small quarry behind the former Inn facing the main bridge (SN 7279 2446) and along the track (approximately SN 7232 2418) about 200 m south-east of Pen-Arthur-isaf, west of Sawdde Gorge.

The Lower Roman Camp Formation is succeeded regionally by conformable Přídolí Raglan Marl Group red sandstones, siltstones and marls of Old Red Sandstone facies. The restricted fauna includes gastropod taxa (*Loxonema conicum*, *T. helicites*), which are also found in older units, the brachiopods *Lingula cornea* and *L. minima* and leperditiid ostracods.

Interpretation

In general terms the various Silurian depositional facies at Sawdde Gorge mostly reflect nearshore shelf to shelf edge–basinal slope envi-

ronments, positioned on the southern flank of the Towy Lineament and near the southern margin of the Welsh Basin (see Siveter *et al.*, 1989, figs 10, 11; Bassett *et al.*, 1992, figs S3b, S4a, S4b, S5a, S5b, S8). To the south of this relatively shallow marine shelf was the northern margins of the landmass of 'Pretannia' (Cope and Bassett, 1987), which undoubtedly sourced much of the Silurian sediments of the Llandovery–Sawdde–Llandeilo region of southern Wales.

Apart from a brief transgression in the earliest Ludlow, as indicated by the occurrence of the offshore *Dicoelosia* community (Tresglen Formation), the Llandovery to Přídolí sequence at Sawdde demonstrates an overall shallowing upwards (Figure 5.66), transitional into non-marine environments in the Přídolí. Post-earliest Gorstian there is a return to shallower, nearshore conditions in the Black Cock Formation, as indicated by the bivalve and gastropod assemblages near the top of the unit. The dominant patterns of sedimentation in the Trichrûg Formation reflect the growth of a delta with associated estuarine and fluviatile facies (Potter and Price, 1965), which advanced northwards from Pretannia; bands with marine fossils in the Trichrûg Formation witness brief marine episodes. The shell-bearing Upper Cwm Clyd and Lower Roman Camp formations represent, overall, short-lived shallow marine re-incursions, which preceded the shallow to marginal marine and at times possibly lagoonal conditions signalled by the Přídolí Long Quarry Formation. Above, the younger red beds are of fluviatile aspect (see Bassett *et al.*, 1982 for a summary of the Přídolí of the Welsh Basin).

Like this Sawdde Gorge site, Capel Horeb Quarry, 15 km north-east along strike, also has Ludlow unconformably overlain by Přídolí strata. The GCR site at Wernbongham, along strike to the south-east, displays Wenlock overstepped by (disputed) Přídolí rocks. These sites network with the lower Silurian Sawdde Gorge site and the other, Llandovery and Wenlock sites in the Llandeilo to Llandovery area to provide a picture of the position and evolution of the shelf–shelf slope of the southern margin of the Welsh Basin during the Silurian.

Conclusions

Together with its sister site covering the lower Silurian of the Sawdde Gorge area this site presents one of the most complete successions through the Silurian of the Welsh Basin. It also exposes the standard reference section of many regionally important lithostratigraphical divisions. Furthermore, the facies here have significance for palaeogeographical and palaeoenvironmental interpretation. Its sediments and/or faunal assemblages can be used to demonstrate the existence of a regionally prominent deltaic system and associated southerly landmass and, hence, the position of the southern margin of the Welsh Basin. Its facies can also be used to chart the change from marine to fluviatile conditions as the Welsh Basin silted-up and shallowed during Ludlow into Přídolí times.

DINAS BRÂN (SJ 223O 4311)

Introduction

Dinas Brân is a steep-sided, conical hill 1 km north-east of Llangollen in northern Wales. The hill-top site consists of Ludlow strata in the vicinity of the remains of the ancient stronghold of Castell Dinas Brân (Figure 5.68); the Carboniferous scarp of Creigiau Eglwyseg lies to the north-east. This GCR site contains the type section of the fossiliferous Dinas Brân Beds.

Llangollen lies more or less on the principal, east–west axis of its eponymous synclinorium, north of the contiguous Berwyn Anticline (see Figure 5.70). Just to the south of Llangollen is the extensive, east-west trending, Llangollen fault. In essence the latter separates the simple flexured southern part of the synclinorium from the complexly folded northern part and, as a consequence of its northerly downthrow, introduces the youngest (Ludlow Series) beds of the local Lower Palaeozoic as outcrop on Dinas Brân.

The local Silurian stratigraphy, including the rocks of Dinas Brân, was first documented by Bowman (1841a, b) and was most recently reviewed by Cocks *et al.* (1971, 1992), Warren *et al.* (1984) and the British Geological Survey (Hains and Davies, 1991: 1:50 000 Wrexham Sheet 121). However, there has been hardly any published primary work on this sequence since Wills and Smith's (1922) account of the Lower Palaeozoic of the Llangollen area. In his unpublished thesis Bell (1990; Figures 5.68, 5.69) included new sedimentological observations on what he variously termed the Dinas Brân Beds or

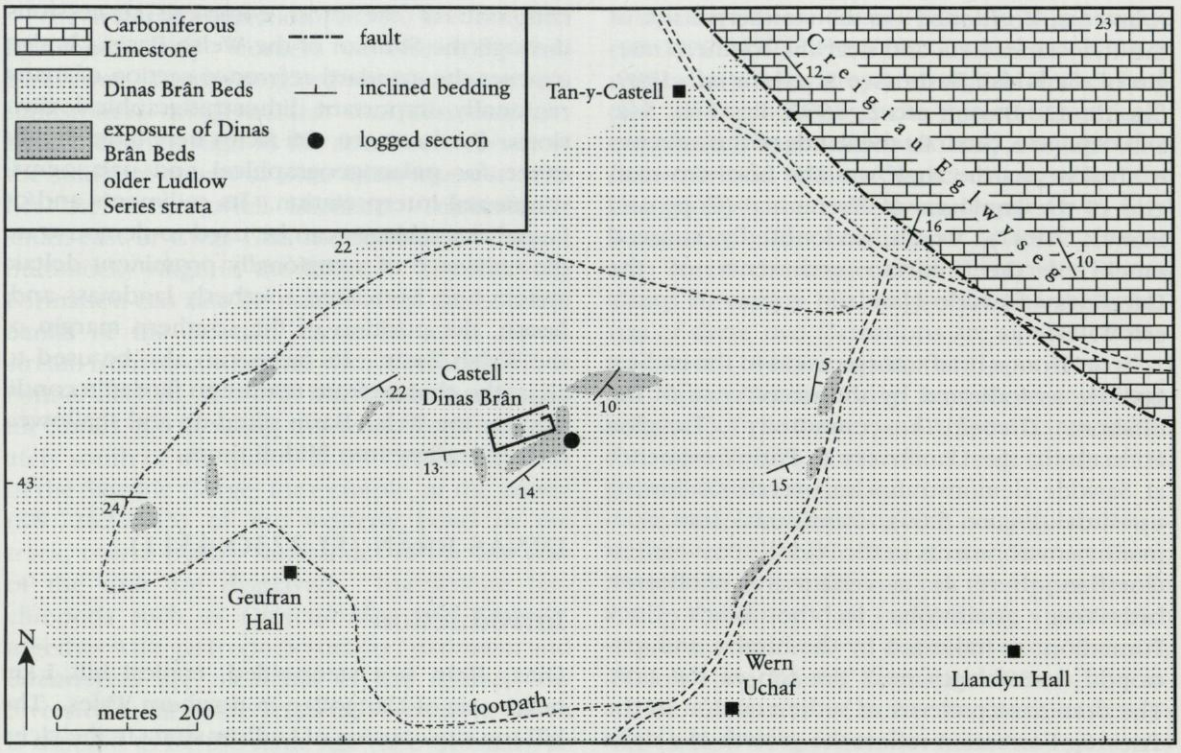


Figure 5.68 Distribution of the Dinas Brân Beds at Dinas Brân, near Llangollen (after Bell, 1990; with minor additions from Hains and Davies, 1991). For details of logged section see Figure 5.69.

the Dinas Brân Group and Dimberline *et al.* (1990) recognized late Wenlock–early Ludlow hemipelagite facies in the area. Swanson and Dorning (1977) described the palynomorphs of the Dinas Brân Beds. Earlier authors who mention Dinas Brân, particularly its fauna, include Sedgwick (1843a, b), Marr (1880b), Salter and Etheridge (1881), Lake (1895) and Wills (1920a, b). Sedgwick (1843b) featured the locality not only on a geological sketch cross-section but also on his geological map – one of the earliest of northern Wales – which accompanies his paper.

Description

The southerly dipping Dinas Brân Beds occur on the crown of the hill and its southern slopes (Wills, 1920a, fig. 1). They are uncleaved, thin- to medium-bedded, fossiliferous calcareous siltstones and subordinate fine micaceous sandstones, with a minimum total thickness of 250 m (Bell, 1990). The siltstones, in units 30–40 cm thick, are heavily bioturbated but preserve occasional parallel and low angle cross-lamination. The sandstone beds are lenticular, 4–11 cm thick and have planar bases and symmetrically rippled tops. They contain low angle cross-laminated, sand-draped symmetrical ripples and minor erosional surfaces. The diverse fauna consists chiefly of brachiopods, especially *Dayia navicula*, together with gastropods, bivalves, trilobites, corals, crinoids, phyllocarids and orthoconic nautiloids (e.g. Sedgwick, 1843a, b; Marr, 1880b; Lake, 1895; Wills and Smith, 1922). *Skolithus* type burrows are common at many horizons (Bell, 1990).

The Dinas Brân Beds are probably the youngest Silurian rocks in north Wales. Modern studies confirm that Dinas Brân hill is formed entirely of Ludlow rocks, as proposed by Bowman in his pioneer work (1841a, b). Cocks *et al.* (1971, 1992) thought that the Dinas Brân Beds are of Ludfordian age. Based on graptolite evidence and on lithological comparison with the succession in Denbigh to the west, Warren *et al.* (1984) proposed that the boundary of these beds with the underlying Vivod Group lies at no younger horizon than the base of the *Saetograptus leintwardinensis* Biozone (early

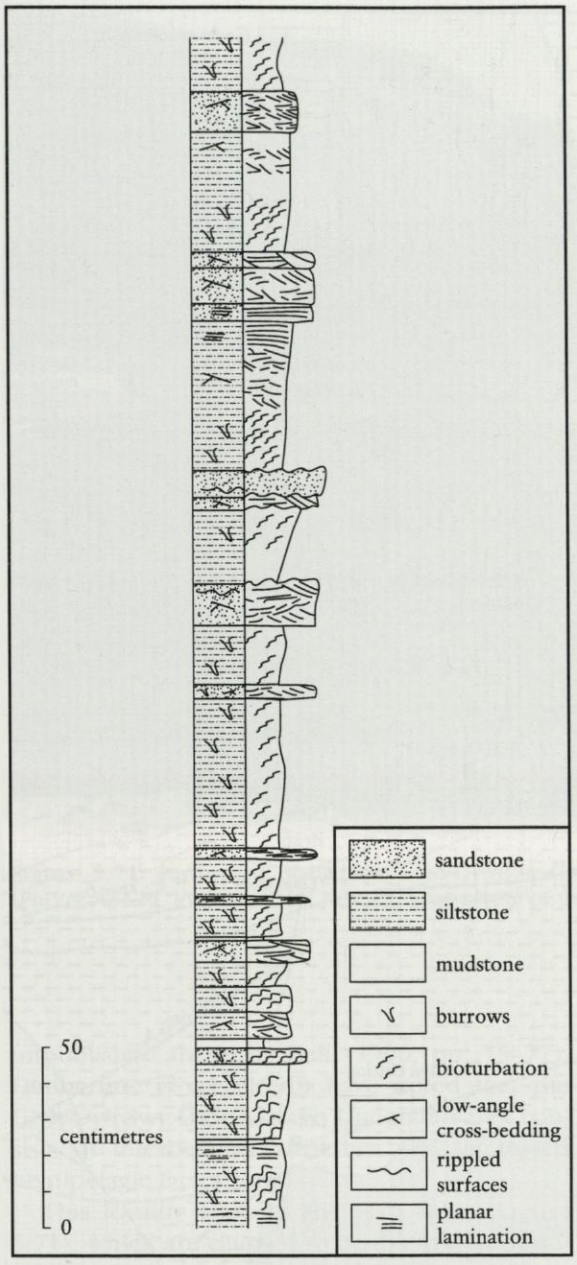


Figure 5.69 Log of the Dinas Brân Beds in the eastern moat of Castell Dinas Brân (see Figure 5.68), near Llangollen (after Bell, 1990): low-angle cross-bedded sandstones interbedded with bioturbated siltstones.

Ludfordian Stage) and that it may be as early as the base of the underlying *Saetograptus incipiens* Biozone (late Gorstian Stage). Swanson and Dorning (1977) identified Lower Whitcliffe Formation (Ludfordian) acritarchs and chitinozoans from the Dinas Brân Beds.

Interpretation

Throughout much of Silurian times the Llangollen area was situated in a relatively deep-water environment that was principally receiving turbidites and associated sediments in the northern part of the Welsh Basin (see Siveter *et al.*, 1989, figs 8–10; Dimberline *et al.*, 1990, fig. 1). During the Wenlock and early Ludlow the Llangollen area received sediments supplied from the south along the NNE–SSW aligned Montgomery Trough (Cummins, 1957). In mid- and late Ludlow times the Llangollen area was dominated by sediments from the west along the Denbigh Trough (Cummins, 1959a, b). The Dinas Brân Beds were, however, deposited above storm wave base, resulting in the suite of sedimentary structures (see above) in the sandstone beds (Bell, 1990). Siltstone units were strongly bioturbated between storm events.

Dinas Brân, Tyn-y-Ffordd and Clogau Quarry are the only GCR sites of Ludlow age in northern Wales. The latter two localities have a truly basinal rather than basin margin or shelf setting. For much of the Silurian the Dinas Brân vicinity shared a similar setting. However, the fact that the Dinas Brân Beds are characterized by shelly faunas and wave-formed structures reflects a shallowing of this part of the Welsh Basin in late Ludlow times.

Conclusions

This is a classic locality, which features in some of the earliest literature of the geology of Wales. It is also the type section for a locally developed, fossiliferous lithostratigraphical unit, the Dinas Brân Beds, which represents the youngest Silurian in northern Wales. The unit is characterized by a relatively shallow-water, shelly fauna, which is unusual for Silurian strata in this part of the Welsh Basin.

CLOGAU QUARRY (SJ 1850 4630)

Introduction

This large locality, termed Berwyn Quarry on some maps, is just south of the A542 road at the Horseshoe Pass on Maesyrychen Mountain, 6.5 km north-west of Llangollen, northern Wales (Figure 5.70). Formerly extensively worked for slate of probable Ludlow age, its large-scale

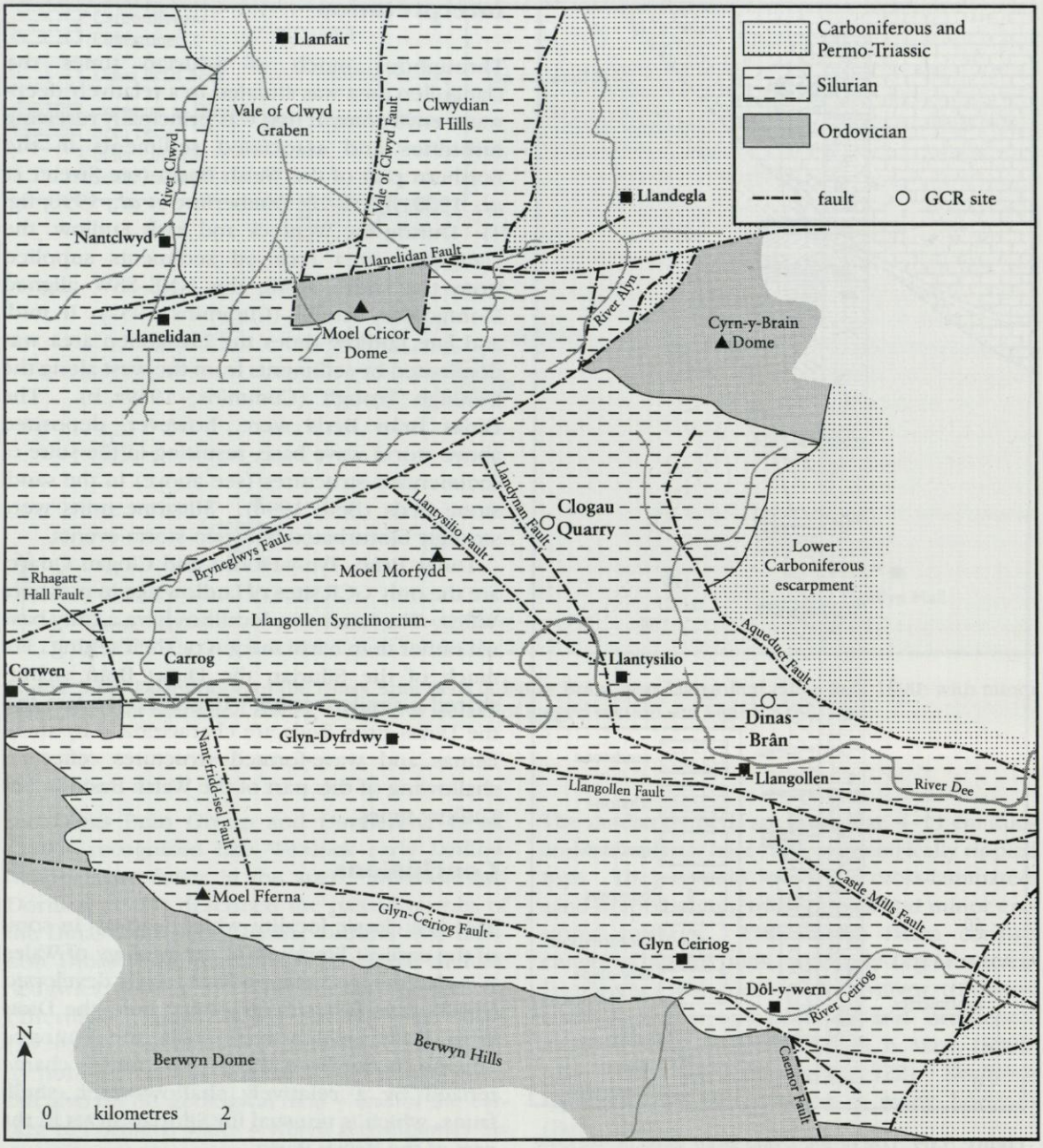


Figure 5.70 Geological map in the vicinity of Llangollen, showing the location of the GCR sites Clogau Quarry and Dinas Brân (after Wills and Smith, 1922, with minor additions to the fault pattern from Hains and Davies, 1991).

operations ceased perhaps more than 100 years ago. Substantial tips of rock waste litter the site.

Brief mention of the locality is made by Wills (1920a, p. 8; 1920b). It is situated in the complexly folded northern limb of the east–west trending Llangollen Synclinorium, in ground mapped by Wills and Smith (1922). There has been little subsequent first-hand study of the area, although Cocks *et al.* (1971, 1992) have summarized the succession and age of the local Silurian, as have British Geological Survey officers when compiling the 1:50 000 Wrexham Sheet 121 (Hains and Davies, 1991). The only new observations on the quarry are in the

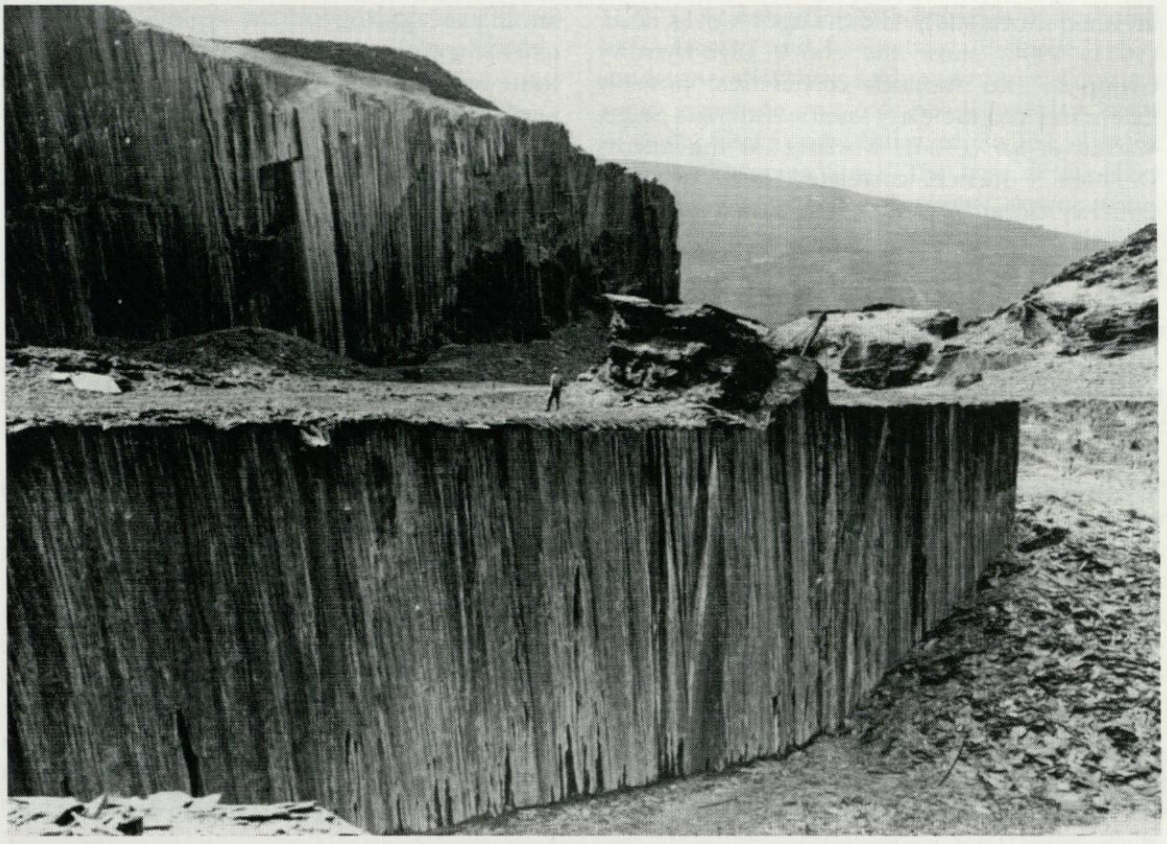


Figure 5.71 Part of the Slab Beds, Glyn-Dyfrdwy Group, Ludlow Series, at Clogau Quarry, near Llangollen. (Photo: A3125, looking NNW, July 1925; courtesy of the British Geological Survey.)

unpublished thesis by Bell (1990, pp. 75–77). Dimberline *et al.* (1990) have noted that the Glyn-Dyfrdwy Group of the Llangollen area consists of interbedded turbidites and laminated hemipelagic facies.

This locality exposes the Slab Beds (Figure 5.71), which are claimed to be the middle stratigraphical unit of the Glyn-Dyfrdwy Group (Wills and Smith, 1922) and a horizon that is 'traceable throughout the synclinorium with fairly constant lithological characters'. Wills and Smith (1922) placed the Slab Beds stratigraphically above the Pentre-Dwfr Slates in their Glyn-Dyfrdwy Group. Bell (1990) observed that the Slab Beds are lithologically identical to the adjoining Pentre-Dwfr Slates, the distinction being a structural one, of the angle of cleavage to the bedding. On the map compiled by Hains and Davies (1991) the 'Slab Horizon' is placed at the top of the Nantglyn Flags Formation, a unit that they state includes the Glyn-Dyfrdwy Group.

Description

The quarry lies in what appears to be tightly folded ground and its beds dip 70–75° to the north (Wills, 1920b; Wills and Smith, 1922). In 1919 it was estimated that (notwithstanding possible duplication due to folding) some 60–90 m of strata was exposed in the quarry (Wills, 1920b). The sediments of the Glyn-Dyfrdwy Group are a monotonous repetition of homogeneous silt-mud beds, between 1–40 mm thick, and laminated silt, in units 1–60 mm thick. The homogeneous silt-mud beds commonly have decalcified bases, usually graded and often with cross-laminaton (Bell, 1990).

The Slab Beds have yielded the crinoid *Scyphocrinites pulcher*, the nautiloid *Orthoceras primaevum* and a graptolite fauna containing '*Monograptus*' *nilssoni* (see Wills and Smith, 1922). Confirmation of the presence of the *Neodiversograptus nilssoni* Biozone would give

an unequivocal early Ludlow age. Cocks *et al.* (1971, 1992) show the entire Glyn-Dyfrdwy Group as late Wenlock correlatives, possibly extending into the early Ludlow Gorstian Stage. Warren *et al.* (1984), working on the nearby Denbigh sequence, correlated most of Glyn-Dyfrdwy Group, including the Slab Beds, with the basal Ludlow *nilssoni* Biozone. Hains and Davies (1991) state that, 'The 'slab horizon' (Wills and Smith, 1922) is the approximate equivalent of the Upper Nantglyn Flags of the Denbigh district', and indicate that the unit is of probable basal Ludlow age.

Interpretation

Turbidites and associated deep-water deposits were the dominant sediments throughout much of the Silurian in this northern part of the Welsh Basin (Siveter *et al.*, 1989, figs 8–10; Bassett *et al.*, 1992, fig. S4a; Dimberline *et al.*, 1990, fig. 1). During the Wenlock and early Ludlow the Llangollen area received distal turbidite sediments supplied from the south through the NNE–SSW aligned Montgomery Trough (Cummins, 1957). Later in the Ludlow the predominant sediment supply was from the west, along the east–west aligned Denbigh Trough (Cummins, 1959a, 1959b).

The homogeneous or graded silt–mud beds of the Glyn-Dyfrdwy Group at Clogau Quarry are interpreted as dilute turbidites (Bell, 1990). The intervening, well-displayed laminated silts are thought to be hemipelagites, formed by a fluctuating fall-out of organic carbon and terriginous silt (Bell, 1990; Dimberline *et al.*, 1990). Such hemipelagites form an important component of basinal Wenlock and early Ludlow sequences throughout the basins bordering the former Iapetus Ocean (Kemp, 1991).

Clogau Quarry, Ty'n-y-Ffordd Quarry and Dinas Brân are the only GCR sites of exclusively Ludlow age in northern Wales. Both Clogau Quarry and Ty'n-y-Ffordd Quarry are also relatively rare within the GCR network in that they are of truly basinal rather than basin margin or shelf setting. The basinal Wenlock site of Ty Mawr, also contains some early Ludlow strata.

Conclusions

This is a well-known site, important for determining the geology of the region. It displays extensive outcrop of a deep-water, basinal, graptolite-bearing lithostratigraphical unit of the Ludlow of the Welsh Basin.

TY'N-Y-FFORDD QUARRY (SH 8699 6525)

Introduction

This classic locality, an old quarry containing early Ludlow rocks, is on the north side of the A548 Abergele to Llanrwst road and about 2 km SSW of Llangerniew village in, northern Wales.

The site is situated in the Silurian of what was formerly the county of Denbighshire and in a region for which Warren *et al.* (1984) give a detailed modern study. Sedgwick (1843b), Ramsay (1866, 1882), McKenny Hughes (1879, 1885, 1894) and Strahan (1885) all contributed to the initial understanding and classification of Silurian stratigraphy of the Denbigh area, which embraced the contiguous Vale of Clwyd to the east. The early 20th century literature on the Silurian of the region is dominated in numbers and influenced by the work of Boswell (e.g. 1926, 1928, 1931, 1932, 1935a, b, 1937, 1942, 1943, 1953; Boswell and Double, 1934, 1938, 1940) and Jones (1937, 1940, 1943). Over a 40 year period Boswell produced 19 publications about the area (see Warren *et al.*, 1984). His 1932 paper deals with the geology of the vicinity of Llangerniew and his studies culminated in the publication of his 1949 book on the Silurian of northern Wales.

Evidence from this celebrated locality contributed to a famous, long-running and at times fierce geological debate, mainly between Boswell and Jones, concerning the genesis of so-called 'disturbed beds', which occur at many Wenlock and Ludlow horizons, affecting all rock types, in the Denbigh area. The resolution of the problem in favour of a syn-sedimentary slump origin was fundamental to the interpretation of the Silurian geology of the region. Specific mention of Ty'n-y-Ffordd Quarry occurs in, for example, Boswell, 1932, 1935a, b, 1937, 1942, 1949 ; Jones, 1937; and Warren *et al.*, 1984. More recently Maltman (1987) has studied Ty'n-y-Ffordd as part of his analysis of microstructures (shear zones), which he identified in the deformed sediments of the Silurian of the Denbigh Moors. Eva and Maltman (1994)

have estimated palaeoslope directions from slump folds, including data from Ty'n-y-Ffordd.

Description

This excellent exposure consists of 5–6 m of the Elwy Group above about 3 m of almost horizontal beds of the Upper Nantglyn Flags Group (Warren *et al.*, 1984; see Figures 5.72, 5.73). Here the latter are striped, regularly bedded and weakly cleaved silty mudstones, with sporadic thin sandy bands and ribbon-banded mudstones. Warren *et al.* (1984) define their ribbon-banded mudstone lithology as a regular alternation of three lithologies, which probably reflect different modes of formation within a similar environment (see below). Their striped silty mudstone rock-type comprises irregular alternations of silty mudstone and siltstone or fine sandstone.

The Elwy Group here are part of the locally distributed Llangerniew Disturbed Beds of Jones (1937). In the quarry this group is represented by contorted and fragmented (disturbed) silty mudstones that show folds and rolls and contain small ironstone and collophane pebbles, nests of shelly fossils and tabular decalcified siltstone blocks with graptolites. The base of the Elwy Group is irregular and shows downcutting, involving a progressive transgression of the bedding, totalling 1 m, across the exposure from west to east.

All rocks in the quarry are of early Ludfordian age (Warren *et al.*, 1984; see also Cocks *et al.*, 1992). The Upper Nantglyn Flags have yielded a fauna characteristic of the basal Upper *Neodiversograptus nilssoni* Biozone: *Saetograptus chimaera salweyi* (common), together with *Neodiversograptus nilssoni*, *Pristiograptus* cf. *frequens* and the bivalve *Cardiola interrupta*. The Elwy Group here contains the brachiopods *Atrypa reticularis*, *Hyattidina* (common), *Isorthis clivosa*, *Leptostrophia filosa*, *Microsphaeridiorhyncus* cf. *nucula* and *Pholido-*

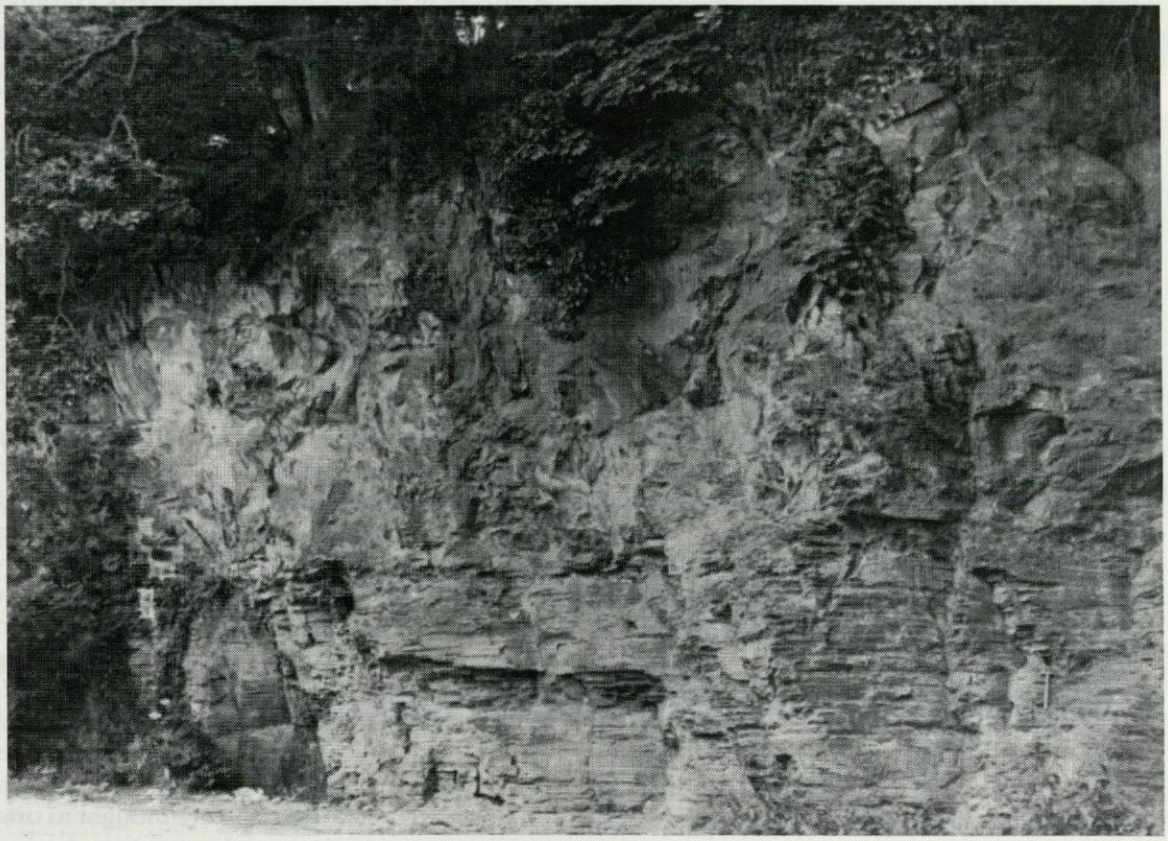


Figure 5.72 Ty'n-y-Ffordd Quarry near Llangerniew, showing contorted and fragmented (disturbed) beds of the Elwy Group cutting down into the silty mudstones and ribbon-banded mudstones of the Upper Nantglyn Flags Group; note hammer, at bottom right, for scale. (Photo: L1601, reproduced by kind permission of the Director, British Geological Survey, © NERC.)

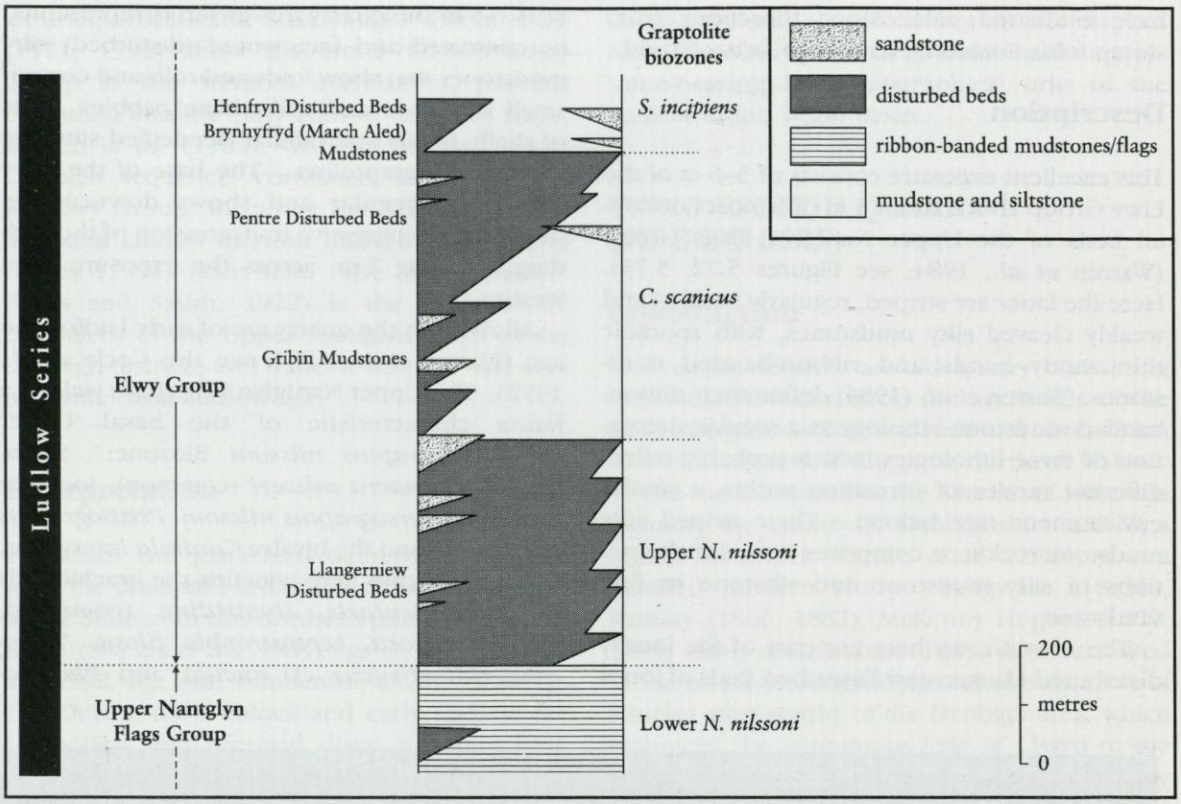


Figure 5.73 Generalized succession of the Elwy Group in the Llangerniew area (after Warren *et al.*, 1984). The local formations are after Jones (1937).

strophia, the nautiloid '*Orthoceras*' *undulocinctum*, the coral '*Syringopora*' *bifurcata* and the graptolites *Pristiograptus dubius, N. nilssoni* and *Monograptus uncinatus orbatus*. These Elwy Group graptolites are preserved in relief and are considered to be a derived fauna because they indicate a Lower *Neodiversograptus nilssoni* Biozone.

Interpretation

From Wenlock through to Ludlow times this area lay within the east–west aligned Denbigh Trough in the northern part of the Welsh Basin (Cummins 1957, 1959a, b; see also Siveter *et al.*, 1989, figs 8–10; Dimberline *et al.*, 1990, fig. 1). Sediment supply was mostly from the west and its western margin was probably along the line of the Conway Valley Fault.

The sandstones (greywackes) of the Elwy Group are interpreted as the distal products of turbidity currents (Warren *et al.*, 1984). The latter authors suggested (pp. 22, 46) that deposition of the three components of the ribbon-banded mudstone lithology (e.g. of the Nantglyn Flags) was by weak turbidity currents (silty mudstones), far-travelled turbidity currents (calcareous siltstones) and turbid suspensions (laminated muddy siltstones) in no great depths, largely lacking oxygen and well away from the basin margins. The origin of the laminated muddy siltstone component, with their relatively high carbon content, is especially controversial (Warren *et al.*, 1984). More recent studies have suggested that these laminated hemipelagites in the Upper Nantglyn Flags Group are the product of regular, perhaps annual, pulsing in plankton productivity and silt supply (Dimberline *et al.*, 1990). The striped silty mudstones are considered to be the lateral equivalents of the other beds in the area, such as the sandstones and ribbon-banded mudstones, and are thought to originate on a gentle slope as the distal products of tubidity currents and slump movements; a penecontemporaneous shelf source is indicated for their sporadically distributed shell-rich 'gin-

gerbread' horizons (Warren *et al.*, 1984).

Warren *et al.* (1984; see also Maltman, 1987) followed Jones (e.g. 1937, 1940, 1943) in regarding the disturbed beds of north-west Denbighshire as principally the result of penecontemporaneous, submarine, downslope, earthquake-generated slumping or sliding, rather than tectonic activity (e.g. Boswell, 1932, 1949, 1953). Eva and Maltman (1994) used slump fold orientations to show that the slump sheets at Ty'n-y-Ffordd moved south or south-east. The disturbed beds originated on the basin slope to the north, hence they mostly consist of striped silty mudstones (Warren *et al.*, 1984). The Ty'n-y-Ffordd example provided the clue to the interpretation, not only of the northern Wales slumped sequences, but also to more extensive examples in mid-Wales (Earp, 1938; Woodcock, 1976a, 1976b), such as at the GCR site of Mithil Brook and Cwm Blithus in Powys.

Of the GCR sites of exclusively Ludlow age in Wales the only ones representative of environments off the shelf and the shelf slope are Ty'n-y-Ffordd Quarry and Clogau Quarry in northern Wales. Ty Mawr, a GCR site consisting of an upper Wenlock and Ludlow sequence of basinal aspect, is also located in north Wales.

Conclusions

This site displays magnificent examples of post-depositional slumping and associated features that are so prominent in the local middle Silurian sequences and so critical for use in the interpretation of regional palaeogeography and palaeoenvironments. The importance of the locality is attested by its coverage in many key papers about the Silurian geology of Denbighshire. Its significance within the GCR network is that it represents one of only two sites with a truly basinal setting within the Ludlow of the Welsh Basin.

TEBAY CUTTINGS (NY 6079 0075–NY 6074 0140 AND NY 6090 0180–NY 6104 0239)

N. H. Woodcock

Introduction

This site consists of two of a number of substantial cuttings created where roads and a railway are confined within the narrow Lune Gorge, near Tebay village, about 16 km NNE of Kendal, Cumbria (Figure 3.49). The accessible cuttings border the west side of the A685 road, 2–4 km south of Tebay. They expose the Coniston Group (Windermere Supergroup), a thick lower Ludlow (Gorstian) sequence dominated by sand turbidites.

The history of study and nomenclature of the Coniston Group, including the primary work of Sedgwick (1845) and that of Marr (1927), has been detailed by Kneller *et al.* (1994). The upper boundary of Sedgwick's Coniston 'Grits' lies just up-section to the north from the Tebay cuttings.

The Coniston Group has two formations, the Latrigg and Moorhowe, dominated by laminated mudstones, separating three sandstone-rich formations, the Gawthwaite, Poolscar and Yewbank (Kneller *et al.*, 1994). King (1992) recognized the upper three formations at Tebay, the Poolscar in the southern roadcut, the Yewbank in the northern cut, and the intervening Moorhowe in the valley between them. However, new mapping by Soper (pers. comm., 1997) shows that the Moorhowe Formation thins eastward and disappears before reaching the Lune Gorge. The Coniston Group at Tebay does contain some intervals of laminated mudstones, but these do not correlate with the Latrig or Moorhowe formations, and they have not been given formal lithostratigraphical status. This uncertainty does not detract from the importance of the roadcuts as continuous sections through the main lithologies of the regionally extensive Coniston Group.

Description

The Coniston Group lies entirely within the *nilssoni-scanicus* biozones of the Gorstian Stage (Kneller *et al.*, 1994; Cocks *et al.*, 1992). However, this biostratigraphical assignment relies on regional correlation, as fossils are rare in the Tebay sections. Graptolites from the north end of the northern roadcut have indicated only a broadly Ludlow age (R.B. Rickards, pers comm., 1997).

The Coniston Group typically comprises four main lithofacies, interbedded in differing proportions in the sandstone-rich and sandstone-poor formations respectively (King, 1992). All four lithofacies (labelled B, C, D and E following the scheme of Pickering *et al.*, 1989) are inter-

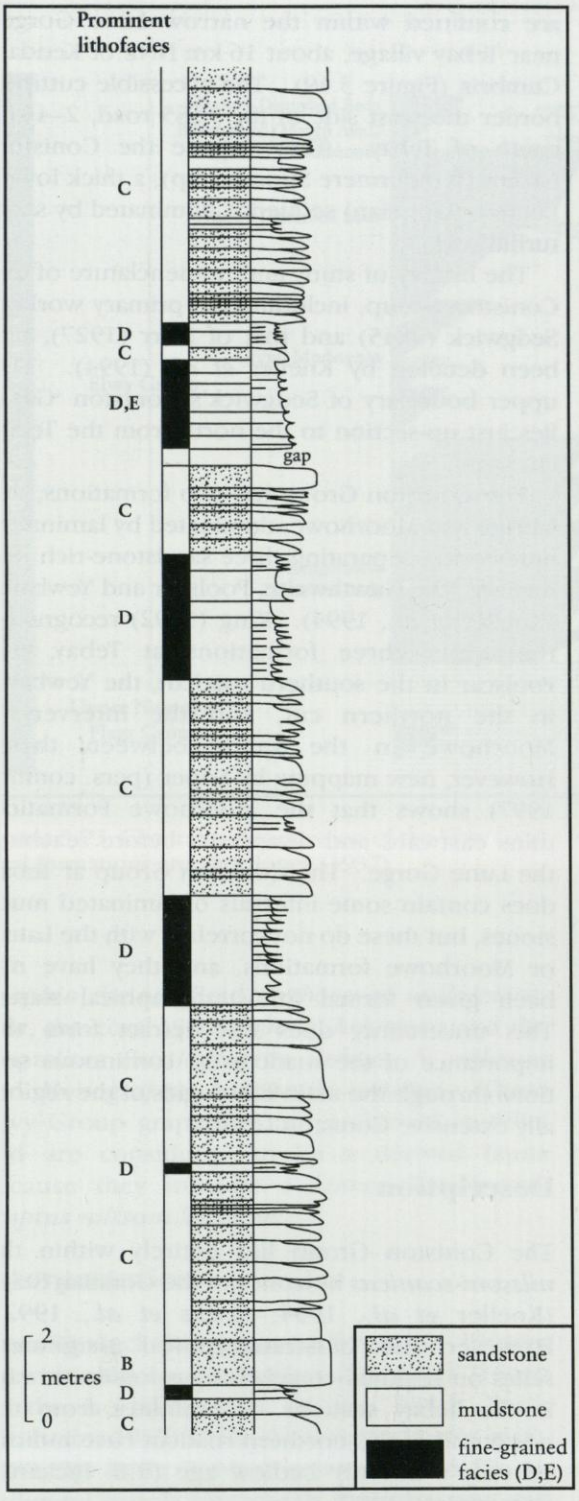


Figure 5.74 Lithological log of the Yewbank Formation, Coniston Group, in the northern Tebay roadcut, Cumbria, between numbered fence post 33 at NY 6098 0194 and post 66 at NY 6102 0206 (modified from King, 1992). The prominent lithofacies (B, C, D and E; see text) follow the scheme of Pickering *et al.* (1989).

preted as turbiditic or related deep-marine sediments and can all be observed in a 35 m thick section in the northern roadcut (Figure 5.74).

Facies B sandstones

Fine- to very fine-grained sandstone in medium to thick beds, but lacking the upward grading into mudstone that characterizes Facies C, occur sporadically throughout the section (e.g. at 1.5 m; Figure 5.74). Such beds are massive to cross-laminated, and usually eroded by the base of the succeeding sandstone bed.

Facies C sandstone–mudstone couplets

The predominant facies in the sandstone-rich intervals of the Coniston Group comprises medium to thick beds of fine- to very fine-sandstone grading up into mudstone (e.g. between 5 m and 7.5 m; Figure 5.74), deposited from high concentration turbidity flows. The beds typically preserve Bouma divisions T_a to T_d, with thin hemipelagic muds of division T_e sometimes discernible. The transition from sandstone to mudstone is usually rapid. Bed bases may preserve flutes and grooves, whose mean direction in the Tebay area indicates palaeoflow towards WSW. By contrast, ripple cross-lamination shows a mean southward palaeoflow. Divergence between flow indicators at the base and in the body of turbidite beds is common throughout the Coniston Group (Kneller *et al.*, 1991).

Facies D siltstone–mudstone couplets

About a third of the logged section (Figure 5.74) comprises thin to medium beds of siltstone or very fine-sandstone grading up to mudstone (e.g between 8 m and 9.5 m). This facies forms an important component, together with Facies E, of the sandstone-poor formations of the Coniston Group farther west such as the Moorhowe, and constitutes most of the Bannisdale Formation that overlies the Coniston Group. Cross-lamination, indicating mean southward palaeoflow, is common in the sandstone intervals of this facies but they may be also massive. The transition from sandstone to mudstone is often rapid, or proceeds through fading ripples of sand, grading down-current into mud. In the logged section (Figure 5.74) Facies D turbidites typically occur as intervals 0.5 m to 5 m thick between intervals of Facies C turbidites. Individual beds of Facies D also punctuate intervals of the hemipelagic Facies E (e.g. between 17 m and 19 m); see Figure 5.75.

Facies E mudstones

The characteristic facies of the sandstone-poor intervals of the Coniston Group is this dark grey, finely laminated, graptolitic, carbonaceous silty mudstone. This facies has been described extensively from other Lower Palaeozoic sequences, often by the term 'laminated hemipelagite' (e.g. Dimberline *et al.*, 1990; Kemp, 1991). The distinctive lamination is defined by alternation of carbonaceous laminae with silty mud laminae. The average thickness of each silty mud–carbon couplet in the Coniston Group is between 0.3 mm and 0.4 mm (King, 1992). However, this spacing increases to about 0.8 mm in the upper parts of the group, by increase in thickness of the silt-mud component. Intervals of this 'expanded' hemipelagite occur between 17 m and 19 m in the logged Yewbank Formation section (Figure 5.74). The hemipelagic mudstone is interbedded with isolated thin beds of Facies D turbidites (Figure 5.75).

Interpretation

The Tebay sections are interpreted in terms of sporadic turbidity currents advancing from the north-east or north over a marine basinal plain.

There are two conflicting hypotheses for forming the Facies E mudstones. Kemp (1991) said they represent very fine-grained turbidity flows that deposited discontinuous films of algal organic material in intimate association with clay and fine silt. In this hypothesis, a number of carbon and silty mud laminae are deposited during one event, and their continuity is then enhanced by later compaction. According to Dimberline *et al.* (1990) Facies E records the background lamina-by-lamina rain of fine-grained sediment that would have accumulated in the marine basin in the absence of direct input from turbidity flows. This background sedimentation was itself spasmodic, with the lamination reflecting fluctuation in either or both organic productivity and silt supply. An attractive hypothesis is that this fluctuation represents an annual climatic cycle of high warm-season productivity with high wet-season sediment run-off (Dimberline *et al.*, 1990) similar to that described from recent basins on the California Borderland (Thornton, 1984). Estimates of the lamination frequency in the Brathay Formation of the Lake District, using

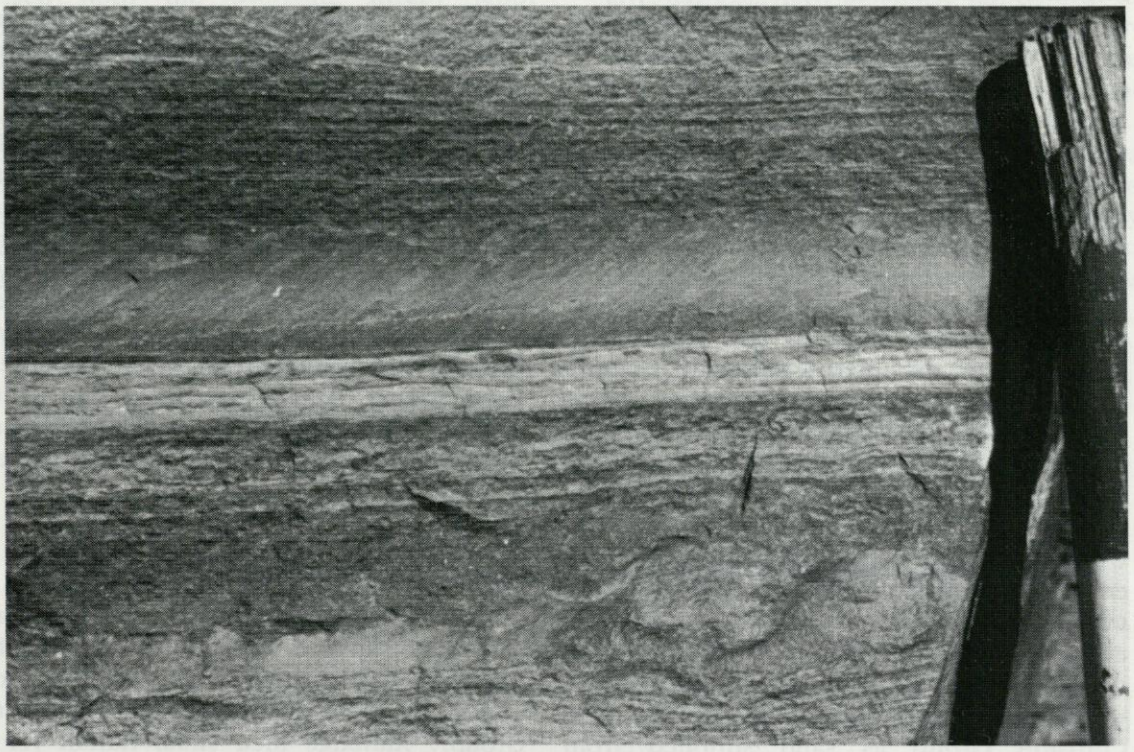


Figure 5.75 Coniston Group, Gorstian Stage, Tebay Cutting, Cumbria. The photograph shows laminated hemipelagic mudstones with intercalated turbidite, comprising a silt–mud interlaminated base overlain by homogenous mud; dark interval on staff = 10 cm. (Photo: N.H. Woodcock.)

graptolite biozonation and its chronometric calibration (King, 1992), suggest a periodicity of 3 or 4 years. A near-annual driving influence is not precluded by this observation, given the potential for erosion and non-preservation of laminae. A persuasive observation in favour of the hemipelagic rather than turbiditic origin of Facies E in the Coniston Group is the remarkable continuity and vertical regularity of the lamination, once it is expanded by thicker silt laminae (King, 1992). On either hypothesis, the lack of bioturbation in Facies E implies a sparse or absent benthic fauna, and probable dysaerobic to anaerobic bottom waters.

The remaining three facies are all uncontroversially interpreted as the products of intermittent deposition from turbidity currents. Facies D siltstone–mudstone couplets derive from low-concentration turbidity currents, flowing approximately southwards as they overwhelmed the Tebay area. These currents were intermittently active both during times of quiescent deposition of Facies E mudstones and during the more energetic periods of Facies C deposition. Facies C sandstone–mudstone couplets derive from high-concentration currents carrying mostly fine or very fine sand. Each flow probably originated north-east of the Tebay area, and initially flowed WSW, parallel to the mean direction of flute and groove marks. However, later parts of each flow tended to flow southward, as indicated by the ripple cross-lamination in the T_c divisions of the turbidite beds. A bounding slope to the north or north-west of the basin may explain this discrepancy, either by the influence of solitary waves relected off the slope (Kneller *et al.*, 1991; King, 1992), or by deflection of the whole flow by the slope, as suggested in the Welsh Basin (Clayton, 1993). The Facies B sandstones are also interpreted as the products of high-concentration turbidity flows. These beds are commonly amalgamated with overlying beds of Facies B or C, and they probably lack their muddy beds tops due to erosion by the succeeding current, rather than by non-deposition.

The Coniston Group turbidites were deposited during the collision of the Eastern Avalonian microcontinent, on which they rest, with the edge of the Laurentian continent represented by the Southern Uplands of Scotland to the north-west. Soper and Woodcock (1990) regarded the Coniston Group as sand supplied from Laurentia onto the underthrusting margin of the Avalonian continent. The increasing sediment accumulation rate during Windermere Supergroup deposition was interpreted by Kneller (1991) and Kneller *et al.* (1993) as the signal of flexural subsidence of the north-western edge of the Avalonian lithosphere, in a foreland basin due to thrust loading of Laurentia. Isotopic evidence implies that the source of the Coniston Group sediments may not have been locally from Laurentia, but from its collision zone with Baltica, some distance to the north-east (McCaffery and Kneller, 1996).

Locally, the Coniston Group turbidity flows seem to have been directed axially into the asymmetric foreland basin, with a relatively steep north-western slope and a more gentle slope on its south-eastern margin. Palaeocurrents in the Howgill Fells, to the south-east of Tebay, suggest the complication of an intrabasinal south-west facing slope here (King, 1992). Flows were deflected by, or reflected off, these bounding slopes to give the observed divergence of basal and intrabed flow indicators. Periods of high sand input, producing the three sandstone-rich formations, alternated with periods dominated by mud input, either controlled by sea-level variation or tectonic controls on sediment supply.

The Tebay GCR site typifies the turbidite deposition that accounts for the greatest thickness of Ludlow Series deposits in the Lake District Basin. It complements three sites in later Ludlow and Přídolí rocks of the Lake District, at Hills Quarry, Benson Knott and The Helm, which record the progressive shallowing of the basin when flexural subsidence waned in late Silurian time. The Ludlow Series turbidites at Tebay also offer an instructive comparison with the contemporaneous turbidites of the northern Welsh Basin (at GCR site Ty'n-y-Ffordd Quarry), with the storm-influenced deposits on the Welsh Basin margin (Mithil Brook and Cwm Blithus) and with the shallow marine deposits of the Midland Platform (e.g. sites in the Ludlow area).

Conclusions

This site is primarily of sedimentological and palaeogeographical significance. The Tebay roadcuts offer accessible, clean, continuous exposures of the mainly turbiditic Coniston Group. Although their strata cannot yet be dated precisely within the Gorstian, they superbly illustrate the typical turbidite and

hemipelagite facies deposited in the Lake District Basin during Ludlow time.

HILLS QUARRY (SD 5960 8803)
POTENTIAL GCR SITE

N. H. Woodcock

Introduction

The disused, roadside Hills Quarry, 2 km WSW of Killington, about 9 km south-west of Kendal, Cumbria (Figure 3.49), provides clean faces through the Underbarrow Formation, part of the Windermere Supergroup. The unit is up to 690 m thick and was erected as the Underbarrow Flags (Shaw, 1971a); it is approximately equivalent to the Passage Beds of Aveline and Hughes (1872, 1888). Moseley (1984) distinguished the Underbarrow Flags and the overlying Kirkby Moor Flags as members within a Kendal Formation (Figure 5.76), whereas Lawrence *et al.* (1986) recognized both members as full formations. Kneller *et al.* (1994) chose Hills Quarry as the body stratotype for the Underbarrow Formation and King (1994) included it within a Kendal Group that comprised both the overlying Kirkby Moor Formation and the underlying Bannisdale Formation (Figure 5.76).

Shaw (1971a, 1971b) recognized formal Lower and Upper divisions to the Underbarrow Formation based on biostratigraphy, but subsequently their lithostratigraphical use has been discontinued (Kneller *et al.*, 1994; King, 1994). However, the distribution of early and late Ludfordian faunas, corresponding to Shaw's Lower and Upper divisions, shows that both lower and upper boundaries of the formation are diachronous; they are older in the north, in Kentmere, and younger in the south, around Hills Quarry (Figure 5.77).

Description

Hills Quarry exposes about 30 m of strata; a typical section has three different lithofacies (King, 1992, 1994; see Figures 5.78, 5.79).

1. *Unbioturbated graded fine siltstones and sandstones* form beds 0.5 to 10 cm thick, grading up into mudstone. Bed bases are sharp, often with groove marks and load structures. Beds contain common unidirectional ripple cross-lamination, often arranged in fading ripple sets. Occasional intervals contain parallel or convolute lamination. This lithofacies also comprises most of the underlying Bannisdale Formation.
2. *Bioturbated graded fine siltstones and sandstones* represent beds of lithofacies 1 that have been variably affected by *Chondrites* bioturbation. Bioturbation is strongest in the mudstone top to each graded bed, where it gives an irregularly laminated appearance to the rock. The sandstone and siltstone intervals weather to a buff colour, reflecting the presence of a carbonate cement. This lithofacies dominates the Underbarrow Formation.
3. *Thin- to medium-bedded graded sandstones* occur in beds 5 to 30 cm thick. These beds are sharply based, and comprise moderately sorted, micaceous fine sand grading up into silt and clay. The sandstone intervals preserve

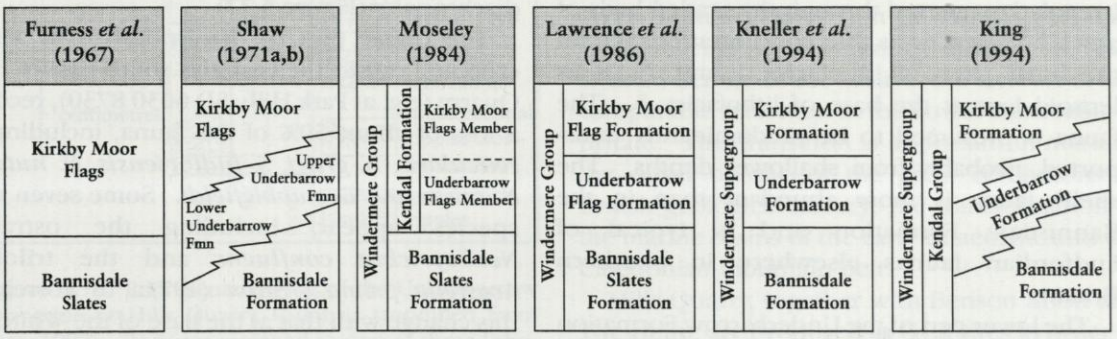


Figure 5.76 Evolution of lithostratigraphical nomenclature in the Kendal Group, upper part of the Windermere Supergroup (after Lawrence *et al.*, 1986). This nomenclature is relevant to Ludlow Series sites at Hills Quarry and Benson Knott, and to the Přídolí site at The Helm, Cumbria.

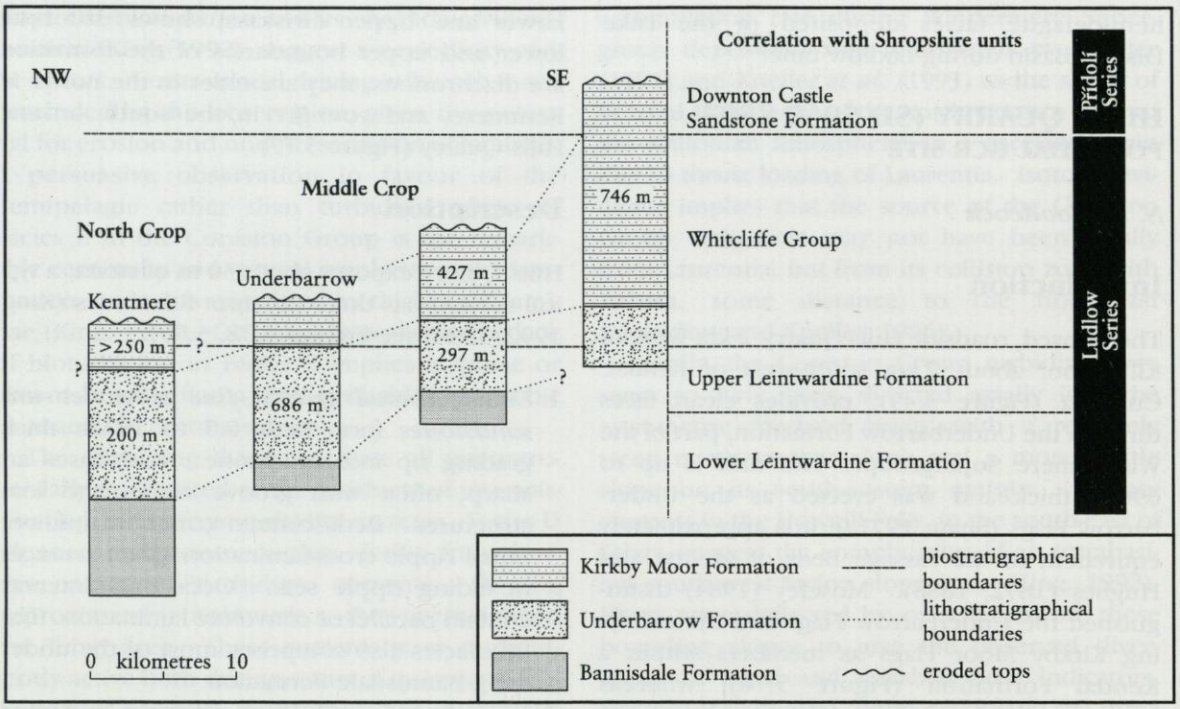


Figure 5.77 Diagram illustrating the diachroneity of the lithostratigraphical units of the Kendal Group (after King, 1994).

planar lamination, low-angle cross-lamination, ripple cross-lamination and occasional convolute lamination. The mudstone tops are often bioturbated. This lithofacies increases in frequency towards the top of the Underbarrow Formation.

Palaeocurrent data from this area of the Underbarrow Formation suggest south-east-directed flow based on grooves, and south-east to SSW flow based on ripple cross-lamination (King, 1994).

Fossils in the Underbarrow Formation occur irregularly scattered through the graded beds of any lithofacies; or as thin concentrations within the basal parts of lithofacies 1 and 2; or as lensoid lags at the base of lithofacies 3. The fauna is presumed to be predominantly transported, probably from shallower depths. The shelly fauna is more abundant than in the Bannisdale Formation and is typical of Ludfordian faunas elsewhere in southern Britain.

The lower part of the Underbarrow Formation in the Hills Quarry area is characterized by the brachiopods *Atrypa reticularis, Aegiria grayi, Shagamella ludloviensis, Dayia navicula* and *Isorthis clivosa,* the ostracods *Neobeyrichia lauensis, Neobeyrichia nutans* and *Nodibeyrichia scissa* and the trilobites *Encrinurus stubblefieldi* and *Proetus* spp. (Shaw, 1971a). Also recorded at this level are bryozoans, crinoid ossicles, starfish, bivalves, nautiloids, a conodont, a gastropod, a solitary coral and fish debris. Shaw (1971a, b) correlated this fauna with that of the Leintwardine Formation (*Saetograptus leintwardinensis* Biozone) of the Welsh Borderland. Elements of this fauna occur progressively higher in the Underbarrow Formation to the north, thus demonstrating its diachroneity (Figure 5.77).

The upper part of the Underbarrow Flags, cropping out to the east and south-east of Hills Quarry (e.g. at Park Hill: SD 6030 8730), records a loss of about 50% of the fauna, including *A. reticularis, A. grayi, S. ludloviensis, N. nutans, N. scissa* and *E. stubblefieldi.* Some seven new species appear, including the ostracod *Neobeyrichia confluens* and the trilobite *Acastella prima.* Shaw (1971a, b) correlated this change with that at the base of the Whitcliffe Formation in the Welsh Borderland. Faunas of this age become progressively restricted to the overlying Kirkby Moor Formation further north,

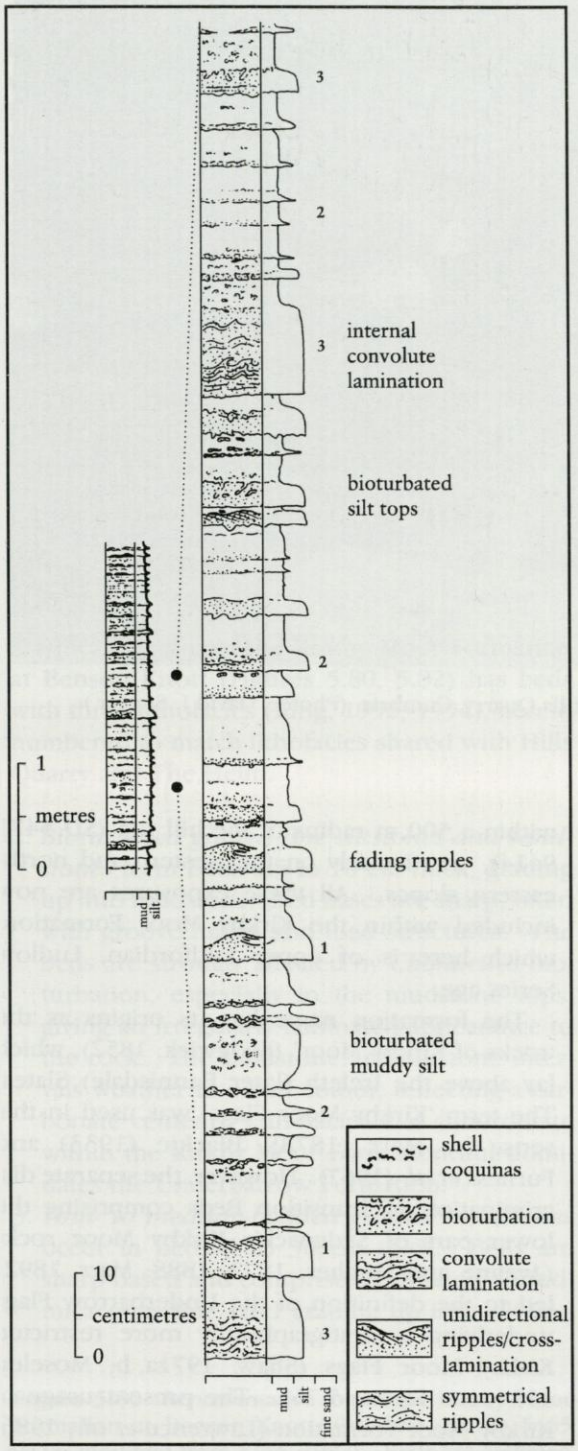


Figure 5.78 Representative log of the Underbarrow Formation at Hills Quarry, Cumbria (modified from King, 1992). Beds are assigned to one of three lithofacies (see text).

due to the diachroneity of the lithostratigraphical boundaries.

Interpretation

The graded beds of lithofacies 1 and 2 are interpreted as the products of deposition from dilute waning flows, probably turbidity flows generated by storm suspension of sediment (King, 1994). However, the absence of wave ripples or bi-directional cross-lamination in these beds precludes their deposition above storm wave base. They probably accumulated in an outer shelf or upper slope setting (Figure 5.81). The thin to medium-bedded sandstones (lithofacies 3) are transitional to those in the overlying Kirkby Moor Formation, where they show wave-generated features (see site report for Benson Knott). They represent more concentrated density flows, some probably deposited above storm wave base. The more abundant shelly fauna and bioturbation in the Underbarrow Formation indicates better oxygenated and probably therefore shallower water than the underlying Bannisdale Formation (King, 1994).

The diachroneity of the Underbarrow Formation implies that it was deposited between shallower water environments to the north, accumulating Kirkby Moor Formation, and deeper water environments to the south, accumulating Bannisdale Formation (Figure 5.81). These environments prograded rapidly southwards through late Ludlow and Přídolí time, as the Lake District Basin was transformed first into an alluvial plain, and, by the mid-Devonian time, into an upland area experiencing erosion.

Thus, the Underbarrow Formation represents an early stage in the shallowing and eventual uplift of the Lake District Basin (Shaw, 1971a; Ingham *et al.*, 1978; Lawrence *et al.*, 1986). The diachronous progradation of shallow and marginal marine environments during the late Silurian demise of the basin is the clearest of any comparable transition in the Lower Palaeozoic of Britain. This transition is important in marking the onset of one of the great revolutions in British geological history; the transformation of the marine basins of the early Palaeozoic into the Caledonian mountain belt.

Hills Quarry, together with Benson Knott and The Helm, are proposed as GCR sites in order to demonstrate stages in the late Silurian (–Devonian) demise of the Lake District marine basin.

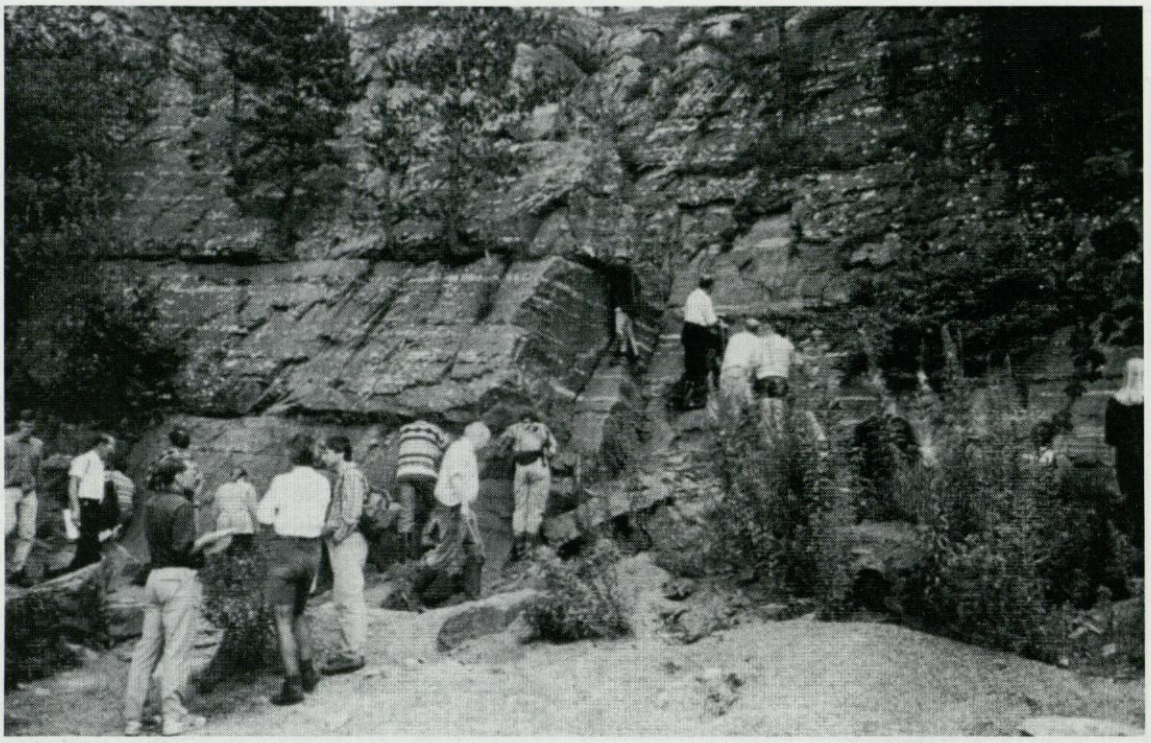


Figure 5.79 The Underbarrow Formation at Hills Quarry, Cumbria. (Photo: David J. Siveter.)

Conclusions

Hills Quarry provides good exposure of the type section of the Underbarrow Formation (Ludfordian Stage, Ludlow Series). This unit records the first phase of a regionally important late Silurian transition from the deep-marine Lake District Basin to shallow marine then marginal marine sedimentary rocks. Both bioturbation and shelly fossils are more common than in the underlying Bannisdale Formation, and turbidites give way progressively to coarser and more calcareous sediments. This locality has research potential for refining faunal and sedimentological parameters and their inter-relationship.

BENSON KNOTT (SD 5470 9414)
POTENTIAL GCR SITE

N. H. Woodcock

Introduction

Benson Knott is a hill 3 km north-east of Kendal, Cumbria (Figure 3.49). Outcrop is widespread within a 500 m radius of the hill top (SD 5470 9414), particularly on the western and north-eastern slopes. All these exposures are now included within the Kirkby Moor Formation, which here is of upper Ludfordian, Ludlow Series age.

The formation name has its origins as the 'rocks of Kirkby Moor' (Sedgwick, 1852), which lay above the Ireleth (later Bannisdale) Slates. The term 'Kirkby Moor Flags' was used in this sense by Marr (1878), Blackie (1933) and Furness *et al.* (1967). However, the separate discrimination of Transition Beds comprising the lower part of Sedgwick's Kirkby Moor rocks (Aveline and Hughes, 1872, 1888; Marr, 1892) led to the definition of the Underbarrow Flags underlying a stratigraphically more restricted Kirkby Moor Flags (Shaw, 1971a, b; Moseley, 1984; see Figure 5.76). The present usage of Kirkby Moor Formation (Lawrence *et al.*, 1986; Kneller *et al.*, 1994) therefore corresponds only to the upper part of Sedgwick's unit. The Underbarrow and Kirkby Moor units have been grouped as members within a Kendal Formation (Moseley, 1984) and, together with the Bannisdale Formation, as formations within a

Kendal Group (King, 1994).

Shaw (1971a) recognized a separate Scout Hill Flags unit above the Kirkby Moor Flags, on the basis of a Přídolí fauna and a reddening (which may, however, be secondary). On Benson Knott the lithofacies of the Scout Hill Flags is identical to that of the Kirkby Moor Formation, and Kneller *et al.* (1994) recommended disuse of the name Scout Hill Flags. However, a distinctive facies in the Scout Hill Flags at The Helm is given member status within the upper part of the Kirkby Moor Formation.

The Kirkby Moor Formation diachronously overlies the Underbarrow Formation (see Figure 5.77), represented at the Hills Quarry site (SD 5960 8803). The upper boundary of the Kirkby Moor Formation (as currently defined) is not preserved, but the formation is at least 1050 m thick.

Description

A typical section of the Kirkby Moor Formation at Benson Knott (Figures 5.80, 5.82) has beds with three lithofacies (King, 1992, 1994), herein numbered to match lithofacies shared with Hills Quarry and The Helm.

2. *Bioturbated graded fine siltstones and sandstones* form beds 0.5 to 10 cm thick, grading up into mudstone. Bed bases are sharp, often with groove marks and load structures. The beds are strongly affected by *Chondrites* bioturbation, especially in the mudstone tops, giving an irregularly laminated appearance to the rock. The sandstone and siltstone intervals weather to a buff colour, reflecting a carbonate cement. Lithofacies 2 is subordinate within the Kirkby Moor Formation but dominates the Underbarrow Formation.
3. *Thin- to medium-bedded graded sandstones* occur in beds 5 to 30 cm thick. Beds are sharp-based and comprise moderately sorted, micaceous fine sand grading up into silt and

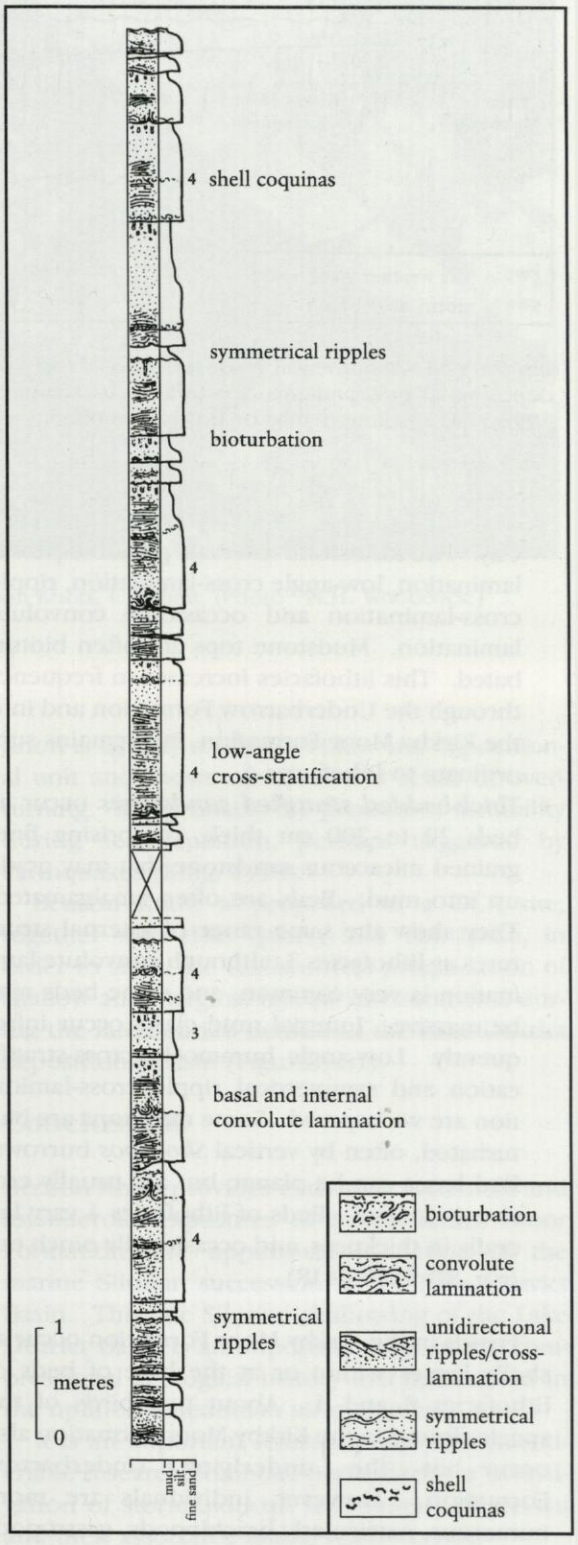


Figure 5.80 Representative log of the Kirkby Moor Formation at Benson Knott, Cumbria (at SD 5465 9418; modified from King, 1992). Beds are assigned to lithofacies 2 to 4 (see text); lithofacies 2 and 3 match similar facies in the Underbarrow Formation (see GCR site report for Hills Quarry). At Benson Knott lithofacies 3 and 4 are prominently developed but lithofacies 2 (which dominates in the Underbarrow Formation) is subordinate.

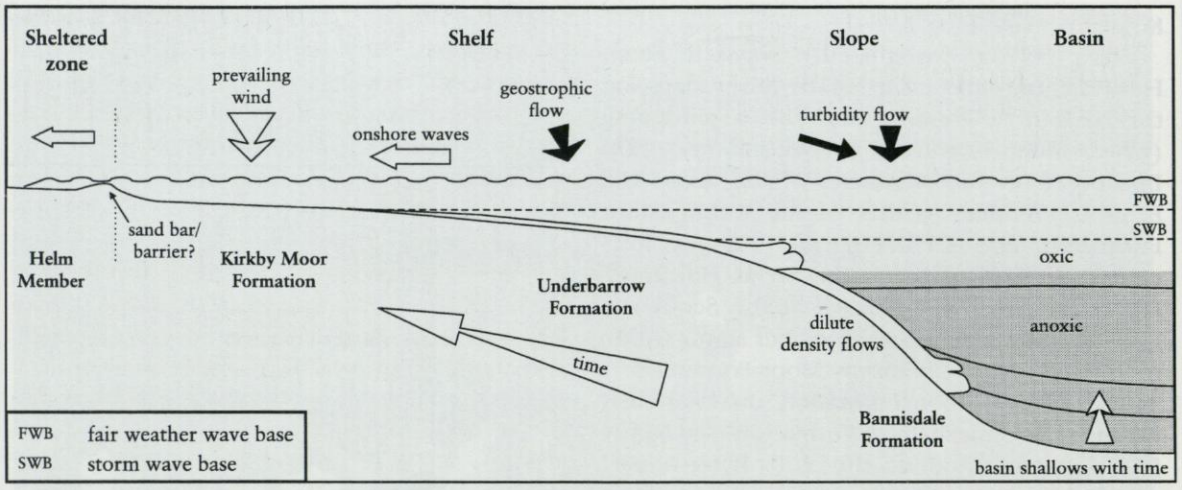


Figure 5.81 Hypothetical reconstruction of the northern margin of the Lake District Basin and its associated depositional environments, for formations spanning the Ludfordian–early Přídolí time interval (after King, 1992). No absolute depths or scale are implied.

clay. The sandstone intervals preserve planar lamination, low-angle cross-lamination, ripple cross-lamination and occasional convolute lamination. Mudstone tops are often bioturbated. This lithofacies increases in frequency through the Underbarrow Formation and into the Kirkby Moor Formation, but remains subordinate to lithofacies 4.

4. *Thick-bedded stratified sandstones* occur as beds 20 to 200 cm thick, comprising fine-grained micaceous sandstone that may grade up into mud. Beds are often amalgamated. They show the same range of internal structures as lithofacies 3, although convolute lamination is very common, and some beds may be massive. Internal mud clasts occur infrequently. Low-angle hummocky cross-stratification and symmetrical ripple cross-lamination are widespread. Some mud tops are bioturbated, often by vertical *Skolithos* burrows. Bed bases can be planar, but are usually erosive or loaded. Beds of lithofacies 4 vary laterally in thickness, and occasionally pinch out (e.g. SD 5465 9418).

Fossils in the Kirkby Moor Formation occur as shelly lenses within or at the base of beds of lithofacies 3 and 4. About two-thirds of the species found in the Kirkby Moor Formation also occur in the underlying Underbarrow Formation. However, individuals are more numerous, particularly brachiopods, gastropods and ostracods, and there is a marked increase in species of ostracods and bivalves. The fauna at Benson Knott includes the ostracod *Neobeyrichia confluens* and the trilobites *Acastella prima* and *Homalonotus knightii.* The rock is determined as of upper Ludfordian age, thus correlating with the Whitcliffe Group of the Welsh Borderland (Shaw 1971a, b). However, the base of the Kirkby Moor Formation is regionally diachronous, ranging down into the lower Ludfordian near Kentmere (Lawrence *et al.,* 1986) and rising well into the upper Ludfordian near Hills Quarry in the south-east (Shaw 1971a, b).

Interpretation

The Kirkby Moor Formation shows abundant sedimentological and faunal evidence of its shallow marine origin, thus contrasting with the deeper marine origin of the majority of the underlying sediments of the Windermere Supergroup. The diachroneity of the base of the Kirkby Moor Formation implies that it was deposited inboard of the outer shelf Underbarrow Formation and, in turn, the deeper water Bannisdale Formation (see Figure 5.81). These environments prograded rapidly southwards through late Ludlow and Přídolí time, as the Lake District marine basin was transformed first into an alluvial plain and, by the mid-Devonian, into an eroding upland.

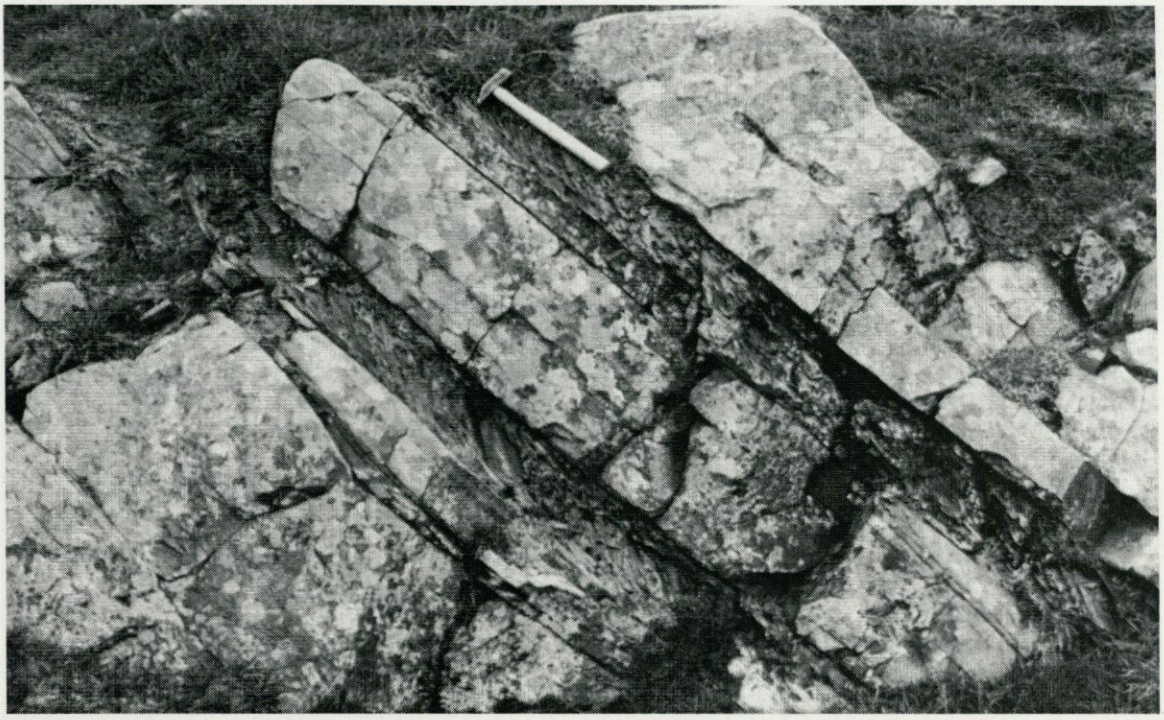


Figure 5.82 The Kirkby Moor Formation at Benson Knott, Cumbria. (Photo: N.H. Woodcock.)

The graded beds of lithofacies 2 are the product of deposition from dilute waning flows, probably turbidity flows generated by storm suspension of sediment (King, 1994). However, the abundant medium- to thick-bedded sandstones (lithofacies 3 and 4) suggest an environment of higher energy and greater sediment supply than the underlying Underbarrow Formation, where lithofacies 2 is dominant. Deposition of lithofacies 3 and 4 above storm wave base is suggested by the preservation of symmetrical ripples and associated cross-lamination. The hummocky cross-stratification typical of lithofacies 4 is the product of combined oscillatory and unidirectional flows generated by large storms (King, 1994). On this hypothesis, the graded beds of lithofacies 3 and 4 were formed by fallout of storm-mobilized sediment above storm wave base, probably on the mid- to inner shelf (see Figure 5.81). This environmental model is supported by the abundant shelly fauna and the nature of the bioturbation. The increase in abundance and diversity of gastropods and bivalves suggest shallower water than in the Underbarrow Formation (Shaw, 1971a, b).

Abundant convolute lamination at Benson Knott is usually confined within one depositional unit and shows no consistent sense of overturning. It is probably the product of instability during sedimentation, perhaps triggered by earthquakes (King, 1994).

Benson Knott is proposed as a GCR site, together with Hills Quarry and The Helm, in order to show the diachronous progradation of shallow and marginal marine environments during the late Silurian demise of the Lake District depositional basin (Figure 5.81).

Conclusions

Benson Knott provides extensive, accessible and fossiliferous exposures of typical Kirkby Moor Formation, the uppermost formation of the marine Silurian succession in the Lake District Basin. This late Silurian shallowing of the Lake District Basin is an important stage in the compressional geological history that culminated in the uplifted Caledonian mountain belt.

It is an important reference site with considerable research potential, particularly for investigation of storm-induced sedimentary processes and their associated faunal relationships.