# *British Cambrian to Ordovician Stratigraphy*

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# Chapter 7

# Tremadoc Series in Wales and England

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## INTRODUCTION

The Tremadoc Series stems from the lithostratigraphically conceived Tremadoc Group of Sedgwick (1852), who named it after the village (now Tremadog) in North Wales. This group of strata was characterized palaeontologically by Salter (1866b), who recognized the significance of the fauna as forming a transition between the 'primordial' (Cambrian) and 'lower Silurian' (Ordovician) faunas. Whittard (1960) discussed in detail the historical development of the Tremadoc Series.

The Tremadoc Series, though formerly often treated as the uppermost part of the Cambrian, is now internationally accepted as one of the designations of the lowest series of the Ordovician System. The base of the Ordovician and the definition of the primary divisions of the system are under international debate, and the Cambrian–Ordovician Working Group has recommended a stratotype for the base at a level close to the base of the Tremadoc Series as recognized in Wales. Whether the Tremadoc is to be adopted as the lowest primary international series division of the Ordovician or merely a secondary (regional) series, it remains of worldwide significance, and the sites that exemplify it are accorded corresponding importance.

In Britain the Tremadoc is divided biostratigraphically into a composite sequence of zones (see Figure 6.2) derived mainly from the Tremadoc successions in Shropshire, though the lower and upper limits are better defined in Welsh and northern English sites. Fortey *et al.* (1995) divided the Tremadoc Series into two stages. The lower Cressagian Stage encompasses the *flabelliformis* and *tenellus* graptolite zones and the overlying poorly characterized interzone. This stage approximates to Cooper's (1979) Graptolite Assemblages 1–3 and corresponds to Salter's (1866b, p. 253) 'Lower Tremadoc' and 'Passage Beds'. The Migneintian Stage is defined at the base of the *salopiensis* trilobite zone and extends upwards through the *sedgwickii* Zone and the overlying strata of pre-Arenig age. It corresponds to Salter's 'Upper Tremadoc', together with overlying strata of which he had no knowledge.

The Tremadoc is developed in two main settings: the Welsh Basin, particularly in North Wales, and the English cratonic area, especially the Welsh Borderland.

## WALES

In the North Wales basin there are cleaved mudstones with significant but only locally developed sandstone units, of total thickness up to about 500 m. Many stratigraphical terms have been applied in the past (Cowie *et al.*, 1972, pl. 3), and those employed by Fearnsides (1905, 1910) are listed here because they remain useful labels for local lithostratigraphical divisions in the Arenig and Tremadog (or Ynyscynhaiarn) areas. However, wider mapping of Fearnsides' units has proved impracticable, and recent work refers all the slaty mudstones of Tremadoc age in North Wales to the Dol-cyn-afon Formation (Pratt *et al.*, 1995, p. 14) and leaves the sandstone divisions as unnamed members (Howells and Smith, 1997). The divisions may be correlated approximately as given in Table 7.1.

The whole sequence was laid down in a fairly shallow open marine setting with some divisions showing striking local changes in thickness

**Table 7.1** Divisions of the Tremadoc in Wales, showing their approximate correlation

| **Fearnsides (1910)** (Tremadoc or Ynyscynhaiarn) | **Howells and Smith (1997)** | **Fearnsides (1905)** (Arenig area) | |
|---|---|---|---|
| Garth Hill Beds<br>Penmorfa Beds | Upper Mudstone | —<br>Amnodd Beds | Migneintian |
| Portmadoc Flags<br>Moel-y-gest Beds<br>Tyn-llan Beds | Upper Sandstone<br>Lower Mudstone<br>Lower Sandstone | Tai-hirion Flags<br>Nant-ddu Beds<br>Niobe Beds | Cressagian |
| (Dolgelly Beds | Dolgellau Formation | Dolgelly Beds | Merioneth) |

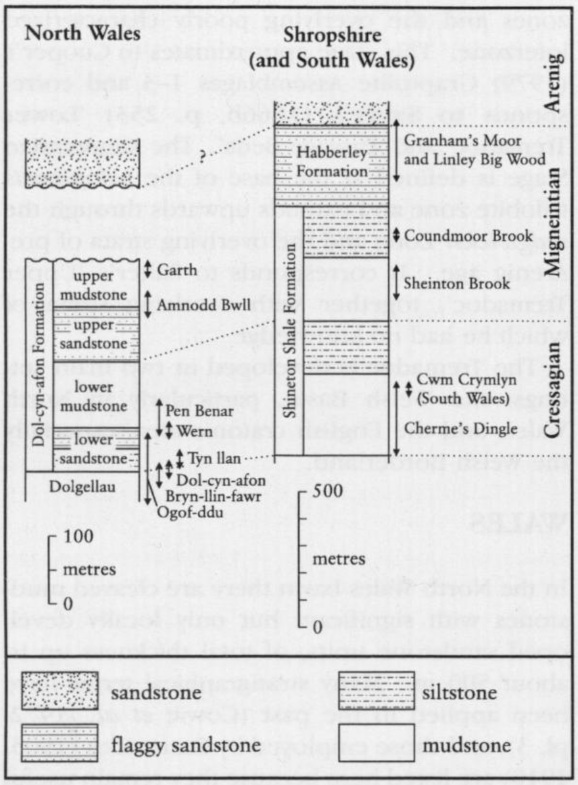


**Figure 7.1** Generalized sequences of Tremadoc rocks in North Wales and Shropshire, showing stratigraphical ranges of individual GCR sites. For locations of sites see Figures 3.2, 7.9, 9.1 and 10.1.

across synsedimentary faults (Howells and Smith 1997).

The succession follows the Cambrian conformably, or locally with slight non-sequence, and the boundary is marked by a subtle change in sedimentation linked to oceanic changes such as an increase in marine oxygenation. The stratigraphical succession in North Wales is nearly complete, from the lowest part of the *flabelliformis* Zone where it overlies the highest Cambrian Zone of *Acerocare* to the *sedgwickii* Zone; however, the top of the latter is not seen and there is a hiatus of uncertain magnitude between the youngest Tremadoc and the oldest Arenig in North Wales.

The sites that exemplify the North Welsh Tremadoc succession are indicated in Figure 3.2 and their stratigraphical positions are shown in Figure 7.1. The lower parts of the Tremadoc are represented at Ogof Ddû (Rhiw-for-fawr), which is principally in the Merioneth Series but extends up from the Dolgellau Formation, through a putative non-sequence, into the

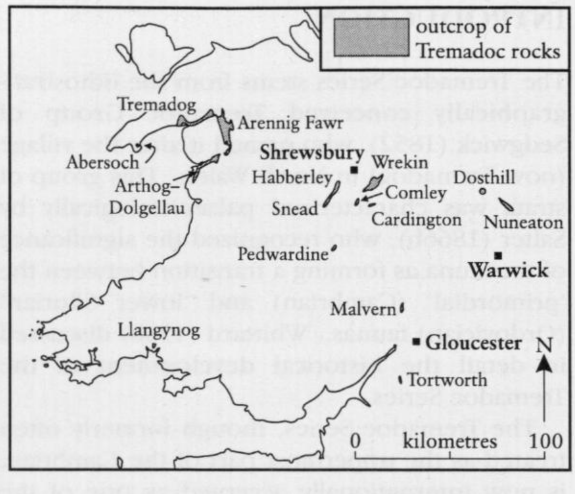


**Figure 7.2** Outcrops of Tremadoc rocks in Wales and central England, after Bulman and Rushton (1973).

Lower Sandstone Member of the Dol-cyn-afon Formation (Tremadoc), for which it is the best lithostratigraphical section. Bryn-llin-fawr shows a biostratigraphical succession from the *Acerocare* Zone to the designated base of the Cressagian Stage at the base of the *flabelliformis* Zone and is the best locality in Britain at which to define the base of the Tremadoc Series, whereas Dol-cyn-afon shows more clearly the lithological transition from the Dolgellau to the Dol-cyn-afon formations, though with less good biostratigraphical control. Biostratigraphically the Lower Sandstone Member is best served by Tyn-llan, which is a classic site for lower Tremadoc trilobites, and the Lower Mudstone Member by the Wern Road section. Besides these, the more westerly site at Pen Benar shows a sand-rich development of Cressagian rocks in a position closer than any other to the putative Irish Sea positive area (see Figure 9.1).

The lithology and palaeontology of the upper parts of the Tremadoc succession are exemplified by Amnodd Bwll, which shows the Upper Mudstone Member and includes the intended base of the Migneintian Stage, and Y Garth, which exemplifies a different facies of the Upper Mudstone Member. The Upper Sandstone Member exposed at the coast around Porthmadog and inland at Tan-y-Grisiau is not yet represented by a GCR site.

The Tremadoc rocks of South Wales have been described only relatively recently (Owens *et al.*, 1982; Cope and Rushton, 1992). They somewhat resemble the Shineton Shales of the Welsh

Borderlands, though the full succession and its aggregate thickness are unknown. The site at Cwm Crymlyn near Llangynog (Figure 7.2) shows the lithology and displays the fauna of the *tenellus* Zone better than elsewhere in Wales.

## BRYN-LLIN-FAWR (SH 7904 3068)

### Introduction

The forestry road section by Afon Bryn-llin-fawr is the best place in Britain to identify the Merioneth–Tremadoc series boundary and the base of the Cressagian Stage. Mudstones at the top of the Dolgellau Formation containing a fauna of the *Acerocare* Zone pass up into silty mudstones at the base of the Dol-cyn-afon Formation that contain early subspecies of *Rhabdinopora flabelliformis*. The faunas include taxa known from many other regions (Scandinavia, North and South America and China), making this a key site, regionally and internationally, for the correlation of the base of the Tremadoc Series in the graptolitic and olenid biofacies and for the evidence it contributes to the definition of the Cambrian–Ordovician boundary. A volcaniclastic sandstone lying at the base of the Tremadoc can be dated radiometrically.

Faunas of the *Peltura* Zones are widely recognized in Britain (Thomas *et al*., 1984, fig. 6), and the early Tremadoc *Rhabdinopora flabelliformis* is even more widely distributed (Erdtmann, 1982, p. 19). The contacts described by Stubblefield (1956) between units containing these faunas indicate a non-sequence, because the faunas of the uppermost Cambrian *Acerocare* Zone, known to lie above the *Peltura* Zones and below *Rhabdinopora flabelliformis* in Scandinavia, were unknown in Britain. However, the British Geological Survey detected faunas of the *Acerocare* Zone at several places east and north of Rhobell Fawr (Allen *et al.*, 1981) and identified two sections, Bryn-llin-fawr and Dol-cyn-afon (see site report below), where a passage up into the *flabelliformis* Zone could be seen. Whereas Dol-cyn-afon displays the lithological succession well and provides the basal stratotype of the Dol-cyn-afon Formation, the faunal succession at Bryn-llin-fawr provides the more satisfactory correlation with the Cambrian–Ordovician boundary as recognized

**Figure 7.3** Bryn-llin-fawr, as excavated in 1978, looking south. The figure on the left is working at the *Rhabdinopora* beds at the base of the Dol-cyn-afon Formation which dip to the left and strike towards the viewer. The next figure stands near the volcaniclastic sandstone beds that lie close to the boundary between the Merioneth and Tremadoc series. The other figures stand near the top of the Dolgellau Formation, on the beds with the *Acerocare* Zone fauna. (Photo: A.W.A. Rushton.)

in Scandinavia and includes a number of taxa identical with, or closely related to, those known from North America (Newfoundland, New Brunswick, Vermont, Mexico), South America (Argentina) and northern China (Nei Monggol).

## Description

The Bryn-llin-fawr section occurs by the forestry road on the south side of Afon Bryn-llin-fawr, 9.5 km south-east of Trawsfynydd. After early studies had shown its potential, the Nature Conservancy Council arranged for excavation over about 500 m of the roadside to improve exposure (Figure 7.3), especially at the critical Merioneth–Tremadoc boundary interval (Rush ton *et al.*, 1979). The section was measured by reference to an arbitrary datum and fossils collected systematically at intervals of about 0.5 m. The faunal succession was described by Rushton (1982), with revisions in Fortey *et al.* (1991). The section was sampled for microflora, and poorly preserved acritarchs are known to be present, but they have not yet been studied in detail. Further details of the geology are given by Allen *et al.* (1981) and Allen and Jackson (1985). The succession is illustrated in Figure 7.4.

**162–165 m from datum:** The lowest beds in the principal part of the section are cleaved but have nevertheless yielded numerous fossils, including the conodont *Cordylodus proavus* Müller (*sensu lato*), *Parabolinella contracta* Lu and Zhou and several fragments of *Hysterolenus* sp.. These beds terminate at a small fault trending at 160°.

**165–177 m:** These weakly cleaved strata contain abundant fossils, including the conodont *Phakelodus tenuis* (Müller) and ten species of trilobites, among which *Parabolina heres heres* Brögger ranges through much of the unit and *Parabolina (Neoparabolina) frequens* occurs near the top.

**177–180 m:** Here occur pale beds in which fossils are scarcer, though a fragment of *Parabolina acanthura* (Angelin)? was found near the top. At 180 m two sandstone beds about 30 cm apart dip eastwards at 74°. They are pyritic tuffaceous sandstone with euhedral quartz grains (Allen *et al.*, 1981, p. 313). Each bed is 10 cm thick, but within the space of about 1 m the upper one is seen to thin out. For about 0.4 m above the upper sandstone bed the shales are disturbed and slightly brecciated, suggesting minor faulting.

**180.4–184 m:** These strata consist of black mudstones with *Phakelodus* and fragmentary trilobites including *Parabolina heres*, followed by more massive siltstone. The siltstone has been taken as the local base of the Dol-cyn-afon Formation.

**184–187.5 m:** These beds comprise grey mudstones, in which a 15-cm ochreous-weathering bed 20 cm above the base has yielded a fragmentary *Rhabdinopora flabelliformis* (subsp. indet.). A bed 2 m above the base (185.80–186.20 m) yields several *Rhabdinopora flabelliformis* (Eichwald), including specimens compared by Prof. Ph. Legrand (unpublished report, 1980) with the subspecies *desmograptoides* (Hahn), *parabola* (Bulman) (Figure 7.5) and *socialis* (Salter). Rushton (1982) took the base of the Tremadoc Series at 184.20 m, i.e. the base of the ochreous-weathering mudstone.

**187.5–195 m:** Striped silty mudstone with sparse trilobites occurs here; *Boeckaspis hirsuta* (Brögger) was collected at the base of this unit, and the brachiopod *Eurytreta sabrinae* (Callaway) appears near the top. This unit terminates at a fault.

**195–199 m:** These are massive beds, sparingly fossiliferous, dipping southwards and cleaved at a high angle to bedding.

Above this unit the section is less well-exposed, but collections were made at several places and include *Euloma (Proteuloma)* cf. *geinitzi* (Barrande) at 7908 3074, *Boeckaspis mobergi* (Wiman) and *Anacheirurus*? at 7915 3081, and *Rhabdinopora flabelliformis flabelliformis,* identified by Prof. Legrand as transitional to *R. f. anglica* (Bulman), at 7917 3083.

## Interpretation

The importance of Bryn-llin-fawr is primarily as a representative section for the base of the Tremadoc Series in North Wales. However, the recommendation to place the base of the Ordovician in the Green Point section in north-west Newfoundland (Webby, 1998), at the level at which a species of *Iapetognathus* appears and immediately below the first appearance of *Rhabdinopora flabelliformis* subspecies, makes the corresponding level at Bryn-llin-fawr valuable as a parastratotype for the base of the Ordovician in Europe, especially in the historical

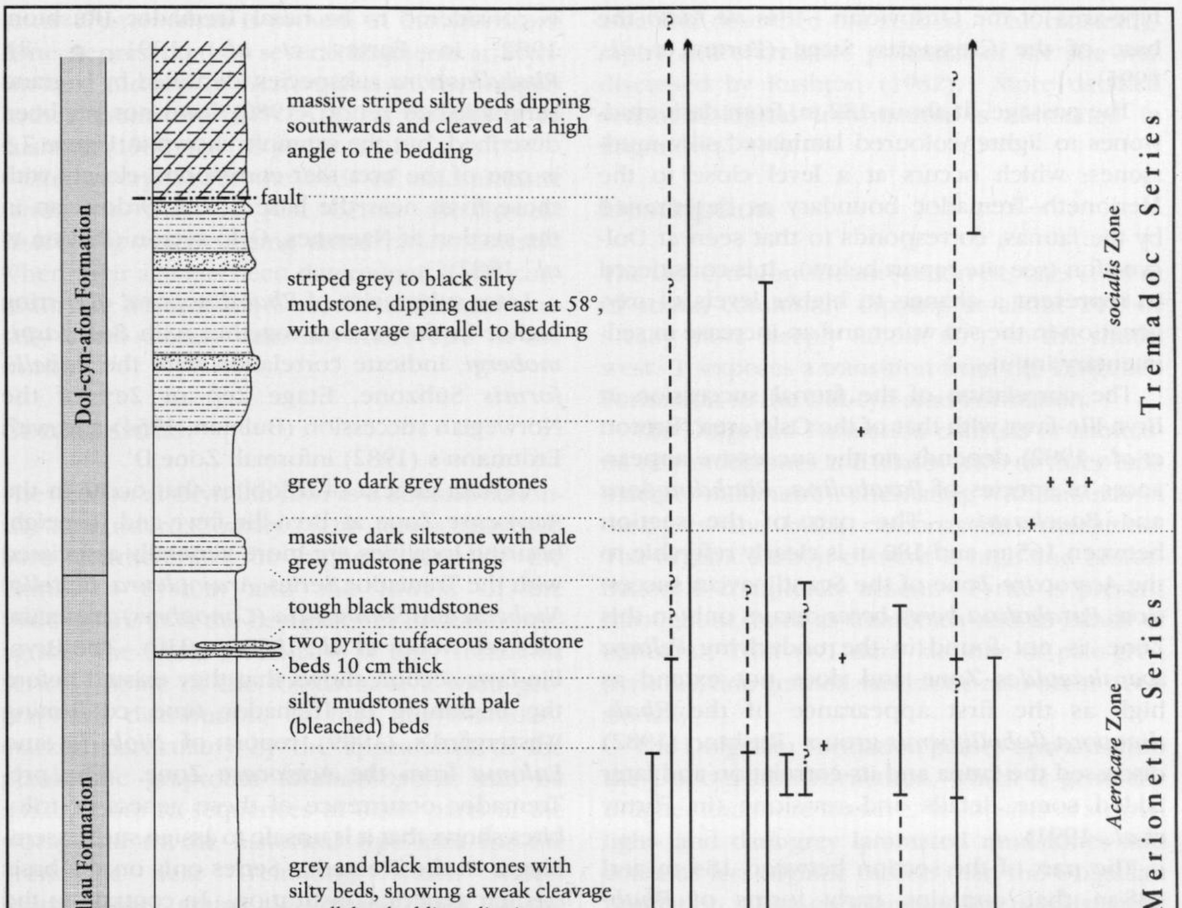


**Figure 7.4** Section at Bryn-llin-fawr, as measured in 1978 by S.P. Tunnicliff, with fossil distribution from Rushton (1982, fig. 3) and Fortey *et al.* (1991, fig. 1).

type-area of the Ordovician. It is *de facto* the base of the Cressagian Stage (Fortey *et al.*, 1995).

The passage, at about 182 m, from dark mudstones to lighter-coloured laminated silty mudstones, which occurs at a level close to the Merioneth–Tremadoc boundary as determined by the faunas, corresponds to that seen at Dolcyn-afon (see site report below). It is considered to represent a change to higher levels of oxygenation in the sea water and an increase in sedimentary input.

The correlation of the faunal succession at Bryn-llin-fawr with that of the Oslo area (Bruton *et al.*, 1982) depends on the successive appearances of species of *Parabolina*, *Rhabdinopora* and *Boeckaspis*. The part of the section between 165 m and 180 m is clearly referable to the *Acerocare* Zone of the Scandinavian succession: *Parabolina heres heres* occurs only in this Zone, is not found in the underlying *Peltura scarabaeoides* Zone and does not extend as high as the first appearance of the *Rhabdinopora flabelliformis* group. Rushton (1982) discussed the fauna and its correlation and later added some details and revisions (in Fortey *et al.*, 1991).

The part of the section between 184 m and 188 m that contains early forms of *Rhabdinopora flabelliformis* and *Boeckaspis hirsuta* is considered to be basal Tremadoc (Rushton, 1982; in Fortey *et al.*, 1991, p. 8). *Rhabdinopora* subspecies identified by Legrand (unpublished report, 1980) have not yet been described, but the example shown in Figure 7.5 is one of the taxa that correspond closely with those from near the base of the Ordovician in the section at Naersnes, Oslo region (Bruton *et al.*, 1982).

Later subspecies of *Rhabdinopora*, occurring higher in the section together with *Boeckaspis mobergi*, indicate correlation with the *flabelliformis* Subzone, Etage 2eβ or 2eγ of the Norwegian succession (Bulman, 1954) and with Erdtmann's (1982) informal 'Zone D'.

Certain genera of trilobites that occur in the *Acerocare* Zone at Bryn-llin-fawr and in neighbouring localities are more generally associated with the Tremadoc Series: *Araiopleura, Beltella, Niobella* and *Shumardia (Conophrys)* are examples (cf. Webby *et al.*, 1988, p. 930). The Bryn-llin-fawr section shows that they existed before the beginning of Tremadoc time, confirming Westergård's (1909) report of *Niobella* and *Euloma* from the *Acerocare* Zone. The pre-Tremadoc occurrence of these genera of trilobites shows that it is unsafe to assign such assemblages to the Tremadoc Series only on the basis of their generic constitution. In contrast to the assumptions of Webby *et al.* (1988, p. 930), the

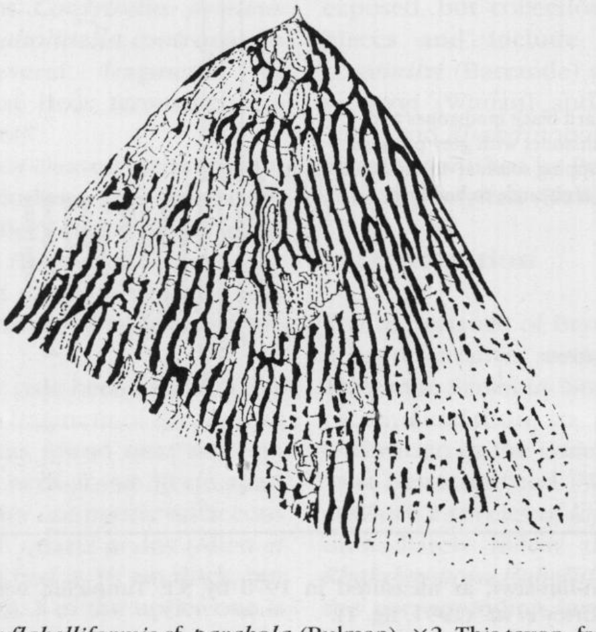

**Figure 7.5** *Rhabdinopora flabelliformis* cf. *parabola* (Bulman), ×2. This taxon, from the basal beds of the Dolcyn-afon Formation at Bryn-llin-fawr, is characteristic of the lowest Tremadoc. (Drawing by Dr P. Legrand, published with his permission.)

genus *Hysterolenus* is present in the *Acerocare* Zone, represented by several fragments at Bryn-llin-fawr and also by *Hysterolenus* cf. *toernquisti* farther south (SH 7947 2873), at 'Locality B' of Rushton (1982, fig. 1B and p. 44).

Zircon crystals in the beds of volcaniclastic sandstone that lie just below the lowest *Rhabdinopora* are being dated radiometrically. When their age has been determined it will constrain the base of the Ordovician chronometrically more closely than anywhere else in the world.

## Conclusions

The section at Bryn-llin-fawr is a key site nationally and internationally. The fossils recorded here characterize the highest zone of the Cambrian System and the lowest of the Ordovician. It is the best place in Britain to recognize the basal boundary of the Tremadoc Series. Some of the fossils have a wide geographical distribution, so that this boundary, marked particularly by the appearance of the planktonic graptolite *Rhabdinopora*, can be related both to sequences in other parts of the world and to the historical type area for the Tremadoc near Tremadog, North Wales. Furthermore, grains of volcanic rock at the boundary enable the age of the base of the Ordovician System to be determined in millions of years.

# DOL-CYN-AFON (SH 7941 2873)

## Introduction

The stream section at Dol-cyn-afon is the basal stratotype locality for the Dol-cyn-afon Formation and one of the best sites exposing the transition from the Dolgellau Formation (Merioneth Series, Upper Cambrian) to the Dol-cyn-afon Formation (Tremadoc Series, Lower Ordovician). The *Acerocare* Zone is overlain by a low Tremadoc assemblage including *Rhabdinopora flabelliformis*.

The lithological change across the Merioneth–Tremadoc boundary from black mudstones to dark-grey, silty mudstones has long been recognized, and the transitional section in the Dol-cyn-afon stream was discovered during the British Geological Survey's resurvey of the area (Allen and Jackson, 1985). Allen *et al.* (1981) gave an account of the geology of the area and described the section. The biostratigraphy and correlative potential of the site was discussed by Rushton (1982). More detailed sedimentological information is contained in Prigmore (1994).

## Description

The Dol-cyn-afon stream section exposes *c.* 80 m of strata, commonly dipping at about 20°, or locally more steeply (about 60°), to the southwest. It exposes a transition from the Dolgellau Formation to the Dol-cyn-afon Formation.

The Dolgellau Formation consists of laminated silty mudstones and shales (two or three laminae per millimetre), alternating with laminae of dark-grey and black carbonaceous mudstone. The organic carbon content is high and bioturbation is completely absent. Pyrite is present throughout, both as framboids and as bands of euhedra. Thin (<1 mm) laminae of pale-grey, pyritous, fine-grained sandstone also occur occasionally.

The Dolgellau Formation passes upwards into the Dol-cyn-afon Formation, which is generally tougher and more massive. It consists of striped light- and dark-grey laminated mudstones and contains less organic carbon than the Dolgellau Formation. Dark-grey laminae are usually about 1 mm thick, whereas light-grey laminae are 2–3 mm thick; black laminae are generally absent. Bioturbation is present sparingly and causes some disruption of the lamination. Phosphate nodules and pyrite layers and lenses are common.

In the transition beds, packets of Dolgellau Formation lithology are interbedded with intervals of Dol-cyn-afon type rocks through a thickness of approximately 10–20 m, so the lithostratigraphical boundary is not sharply defined. Allen *et al.* (1981) chose an arbitrary boundary for the base of the Dol-cyn-afon Formation (originally defined as a Member), at the base of a banded dark-grey mudstone 47 cm thick that broadly separates the carbonaceous mudstones below from the less organic-rich silty mudstones of the transitional zone, here some 30 m thick.

The upper part of the Dolgellau Formation yields fossils of the *Acerocare* Zone (including some rarities such as *Acanthopleurella* and *Dichelepyge*). The zonally significant trilobite *Parabolina heres* Brögger (*sensu lato*) extends to within about 4 m of the top of the formation. The lowest *Rhabdinopora* occurs about

10–12 m above the base of the Dol-cyn-afon Formation, but the species is undeterminable. *Rhabdinopora flabelliformis socialis* occurs, with sponge spicules, *Eurytreta sabrinae* (Callaway), hyolithids, *Beltella* sp. and *Niobella homfrayi* (Salter), 37 m higher in the section and ranges up for 12 m. Above this the section is disturbed by folding and faulting.

## Interpretation

The Dol-cyn-afon section shows changes in patterns of sedimentation across the Merioneth–Tremadoc boundary. The section at Brinllin-fawr is clearer biostratigraphically, but at Dol-cyn-afon the lithological changes around the basal stratotype of the Dol-cyn-afon Formation are more clearly seen. The subtle colour change from black to dark-grey mudstones across this boundary may be related to the loss of conditions suitable for the preservation of organic carbon in large quantities. The black mudstones of the Dolgellau Formation were deposited in quiet, restricted environments, with little sedimentary input. The preservation of lamination and absence of bioturbation suggest that anoxic conditions prevailed. Conditions changed slightly as deposition of the Dol-cyn-afon Formation began. Signs of bioturbation indicate that levels of oxygenation were rising, and an increased supply of muddy sediment reflects the development of more open marine conditions. Changes in style of sedimentation in many parts of the world at this horizon have been linked to a eustatic sea-level rise. There is evidence from around the world for a eustatic sea-level fall at the top of the Cambrian, followed by an early Tremadoc sea-level rise (e.g. Erdtmann and Miller, 1981; Fortey, 1984). This event, enhanced by local tectonic controls, was probably responsible for the change in sedimentation seen here.

## Conclusions

The Dol-cyn-afon stream section is the type locality for the Dol-cyn-afon Formation and contributes to the recognition and correlation of the Cambrian–Ordovician boundary in Wales and elsewhere. The section shows a subtle colour change in the rocks near this boundary; this can be related to increasing levels of oxygen in the water and may be linked to a global contemporary rise in sea level.

# TYN-LLAN (SH 5415 4044)

## Introduction

The stream section and adjacent outcrops at Tyn-llan expose fossiliferous representatives in the type Tremadog area of the lower beds of the Dol-cyn-afon Formation, equivalent to the Tynllan Beds of Fearnsides (1910). It has long been known for its fossils (Salter, 1866b, p. 253) and has the best-preserved Cressagian trilobite faunas in the region.

Salter (1866b) summarized early biostratigraphical work, but the most detailed study was that of Fearnsides (1910), who distinguished the Tynllan or *Niobe* Beds as the lowest division of the Tremadoc Series and listed fossils found at the present site. In their resurvey of the Tremadog area, Howells and Smith (1997) subsumed the Tynllan Beds within their informal 'Lower Sandstone Member' of the Dol-cyn-afon Formation. Detailed sedimentological descriptions of the unit are contained in Prigmore (1994).

## Description

The mudstones exposed in the stream section at Tyn-llan dip north-east at about 30°. They are similar to lower Tremadoc strata seen elsewhere in North Wales, such as at Ogof Ddû (see site report) and consist of thin- to medium-bedded, fairly massive, dark-grey silty mudstones. Cleavage, although present, is not well developed. Faint lamination can be seen in places. Paler-grey laminae show signs of disruption and bioturbation, producing mottled textures. Pyrite is common as layers and lenses 1–2 mm thick. Pale-grey quartz-rich and pyritic silt beds, usually less than 1 mm thick but occasionally reaching 1 cm, occur throughout. Phosphate nodules are common. Some beds contain trilobites, especially *Psilocephalinella innotata* (Salter) but also *Beltella depressa* (Salter), *Niobella homfrayi homfrayi* (Salter) and *Shumardia* (*Conophrys*?) sp., together with brachiopods (*Eurytreta sabrinae* (Callaway) and *Lingulella* sp.), hyolithids, sponge spicules and other taxa.

## Interpretation

The lower Tremadoc rocks exposed at Tyn-llan are assigned to the Lower Sandstone Member of the Dol-cyn-afon Formation (Howells and Smith, 1997), and are referable to the *flabelliformis* Zone. Because the cleavage is weak, it is the best locality at which to examine the trilobite fauna, some species of which are restricted to this division of the lower Tremadoc. They allow correlation with similar beds exposed in North Wales and elsewhere, for example the Breadstone Shales of Gloucestershire (Cave, 1977, p. 11) and Random Island, south-east Newfoundland (Fortey and Owens, 1991a).

## Conclusions

The stream section and adjacent exposures at Tyn-llan are of importance as they show the best fossiliferous exposures of the lowest member of the Tremadoc sequence in North Wales.

# PEN BENAR (SH 315 283)

## Introduction

Pen Benar shows the most north-westerly outcrop of Tremadoc rocks in Wales. The lower Tremadoc *flabelliformis* and *tenellus* zones are proved, but the lithofacies present are coarser-grained than those of contemporaneous strata seen elsewhere in North Wales. Palaeogeographically the site is of regional significance, as it represents a position near the north-west margin of the Welsh Basin.

In the area of St Tudwal's Peninsula, the Dol-cyn-afon Formation of the Tremadoc is exposed only adjacent to the Sarn-Abersoch Thrust and north of Abersoch. The formation is strongly deformed. Pen Benar provides the best section, but tight folding and abundant minor faulting obscure details of the succession. Nicholas (1915) described the exposures and recorded the faunas. The rocks in this area were subsequently re-examined by Crimes (1969), and geological excursion guides to the section are included in Roberts (1979) and Cattermole and Romano (1981).

## Description

The oldest beds exposed, assigned to the *flabelliformis* Zone, are thrust up approximately 30 m west of the old landing place (3152 2836), where they dip steeply westwards. They consist of rusty-weathering, dark-grey, laminated and mottled mudstones, similar to other Welsh lower Tremadoc rocks. Pale-grey mudstones, up to 10 cm thick and often showing microfaulting, occur occasionally; they have sharp bases and become darker upwards, indicating an origin from waning-flow events. *Rhabdinopora flabelliformis* (Eichwald) can be found. West-dipping thrusts imbricate this lower part of the sequence, and minor folds that verge south-east plunge at about 25° to the NNE. To the west (3149 2836), mottled and structureless dark-grey mudstones yield *Adelograptus tenellus* (Linnarsson). These mudstones extend westwards and include a bed of feldspathic sandstone, suggestive of volcanic activity nearby.

Above this horizon the rocks become more arenaceous, with thin beds of grey-green siltstone and fine sandstone (Figure 7.6) that are planar and laterally continuous or else may become lenticular and preserve ripple cross-lamination. Bioturbation is common. Large (1.5 m) sideritic concretions are commonly associated with the coarser horizons. These arenaceous beds are also exposed beneath the thrust associated with the *Rhabdinopora*-bearing strata and can be traversed eastwards beyond the old landing place, where there is an anticlinal hinge. At the eastern edge of the site a vertical fault introduces Arenig strata that are folded into a syncline and which, farther east, rest once again on strata of Tremadoc age, as described by Nicholas (1915, p. 120).

## Interpretation

The lowest strata at Pen Penar are assigned to the lower Tremadoc *flabelliformis* and *tenellus* zones and lithologically resemble Fearnsides' '*Dictyonema* band'. The sandstones and graded mudstones higher in the sequence indicate deposition from waning-flow events, such as turbidite or storm events. These coarser beds overlie beds with *Adelograptus tenellus* and have been placed in the *tenellus* Zone (Nicholas, 1915), though faunal proof is lacking. If Nicholas' assignment is correct, it indicates that coarser lithofacies developed earlier in St Tudwal's Peninsula than in other parts of Wales, suggesting that uplift or shallowing occurred earlier there than elsewhere: in the rest of North Wales the Upper Sandstone Member is developed in the upper Tremadoc, whereas the sandstones of Pen Benar appear to correlate with the lower Mudstone Member. If this is confirmed, it may be due to the proximity

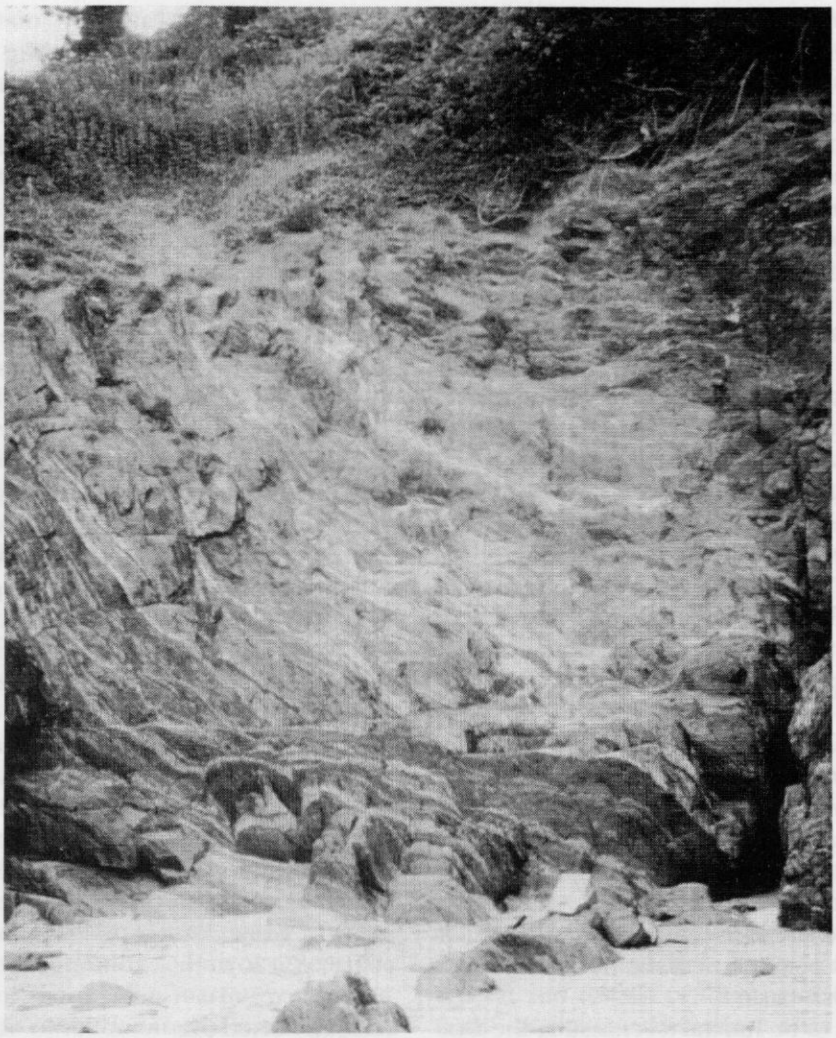

**Figure 7.6** Pen Benar, Abersoch. Laminated sandstone units in mudstones of the lower part of the Dol-cyn-afon Formation, such as are not commonly developed in the *flabelliformis* and *tenellus* zones. (Photo: J.K. Prigmore.)

of the positive Anglesey–Wexford axis. It remains possible, however, that there is a hiatus in the Pen Benar sequence and that the sandstone beds there correlate with the similar unfossiliferous Upper Sandstone Member of the Tremadog area.

## Conclusions

The locality at Pen Benar is the most north-westerly outcrop of Tremadoc rocks in Wales. The fossils allow correlation with lower Tremadoc rocks elsewhere in Wales and Shropshire. However, the rocks here differ from those elsewhere in containing many sandy beds, suggesting that the water depth here may have been less than in other early Tremadoc strata in Britain.

# WERN ROAD (SH 544 396)

## Introduction

The road cutting at Wern exposes part of the lower Tremadoc (Cressagian) sequence in the historical type area. The section passes from the upper Tynllan Beds of Fearnsides (1910) through the '*Dictyonema* Band' into the Moelygest Beds, which, though commonly poorly fossiliferous, have here yielded an assemblage of fossils.

When Salter (1866b, p. 250) described the palaeontology of the 'Tremadoc Slates', he char-

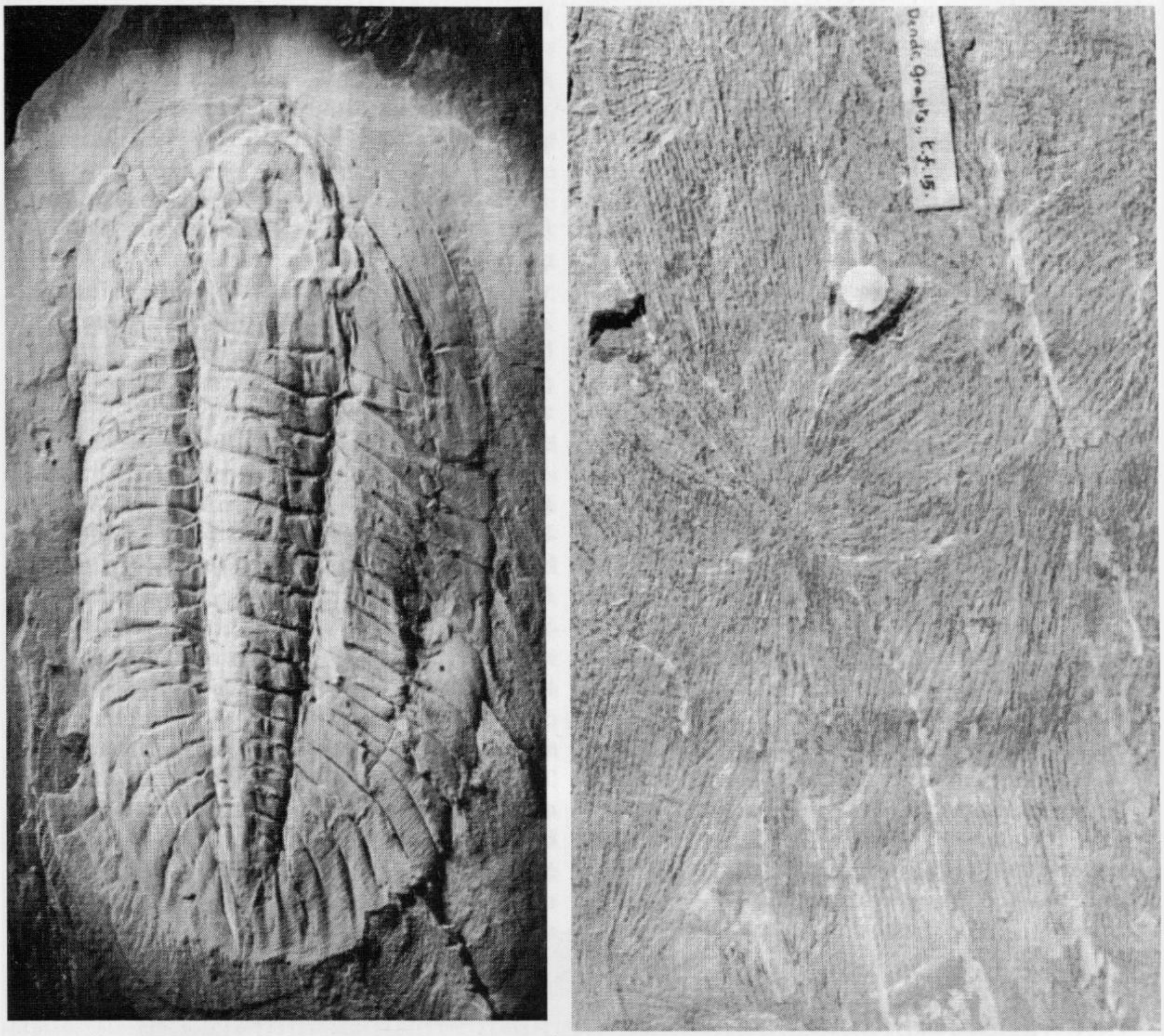

**Figure 7.7** Tremadoc fossils from the site at Wern. (a) *Niobella homfrayi smithi* Stubblefield, ×0.65. (b) *Rhabdinopora flabelliformis socialis* (Salter), ×1.5, paralectotype from Cefn Cyfanedd.

acterized a 'lower' and an 'upper' division and recognized 'Passage Beds' between them, principally at Llanerch (2 km south-east of Wern) (Salter 1866b, p. 253), though the stratigraphy there is evidently affected by faulting. Fearnsides (1910) mentioned rocks in the vicinity of Wern, although the road cutting itself had not then been made. He stated that the '*Dictyonema* Band' was very fossiliferous, and that by the road from Wern to Bron y foel near Cefn Cyfanedd was a wall 'every piece of which, when broken open, is fit for preservation in a museum' (Figure 7.7b). The area was resurveyed by Howells and Smith (1997), who referred the '*Dictyonema* Band' and Moelygest Beds to their 'Lower Mudstone Member' of the Dol-cyn-afon Formation, but the site owes much of its importance to the unpublished discoveries of S. Jusypiw (see Interpretation, below).

## Description

The section extends along the A497 Porthmadog to Criccieth road. It exposes some 40 m of strata dipping north-east at about 25° and exhibiting a spaced cleavage dipping at 65° to the NNE. The beds consist of well-bedded dark-grey mudstones. Lamination occurs in places, with darker- and lighter-grey laminae giving the rock a characteristic ribbed appearance. However, disruption is common, and there is evidence of bioturbation. Pyrite is common as layers, lenses and euhedra; white-weathering phosphate nodules are ubiquitous in layers parallel to bedding.

The site has yielded faunas that span the top of the Lower Sandstone Member and the lower part of the Lower Mudstone Member of the Dol-cyn-afon Formation. East of the track to Bron y foel (SH 5436 3966) are numerous *Rhabdinopora flabelliformis* (Eichwald) *sensu lato*, and these indicate Fearnsides' '*Dictyonema* Band'. Farther to the east an outcrop (not now exposed) has yielded a fossil assemblage including the brachiopods *Eurytreta sabrinae* (Callaway), *Lingulella lepis* Salter, the bellerophontid *Oxydiscus*? *multistriatus* (Salter), the nautiloid *Dakeoceras praecox* (Salter) and the trilobites *Asaphellus homfrayi* (Salter), *Platypeltoides croftii* (Callaway), *Proteuloma* cf. *geinitzi* (Barrande) and large *Niobella homfrayi smithi* Stubblefield (Figure 7.7a) (Howells and Smith, 1997, p. 22).

## Interpretation

The Dol-cyn-afon Formation at Wern Road typifies the succession from the top of the Lower Sandstone Member through the lower part of the Lower Mudstone Member. Sedimentological features generally indicate deposition in open marine conditions, with sediment influx of low-concentration muddy turbidity flows (see site report for Ogof Ddû). Palaeontologically this site has provided a fauna for part of the Dol-cyn-afon Formation above the *flabelliformis* Zone and (following mapping of the area) is assigned by Howells and Smith (1997) to the *tenellus* Zone, though the zonal graptolites have not yet been found there. It corresponds to the fauna of Salter's (1866b, p. 254) 'Passage Beds', as identified by him at Llanerch, in which the ranges of the Lower Tremadoc *Niobella* and the Upper Tremadoc *Asaphellus homfrayi* overlap. The principal components of the fauna were collected by S. Jusypiw, but while he was preparing a description his collection was damaged in a fire, though such material as survives is now housed in the National Museum of Wales.

## Conclusions

The Wern Road section covers outcrops representative of the middle part of the Tremadoc sequence and has yielded (from what is generally a poorly fossiliferous part of the succession) the best assemblage of fossils that characterize this horizon.

# AMNODD-BWLL (SH 806 367)

## Introduction

The stream section north-east of the abandoned farm Amnodd-bwll exposes upper Tremadoc deposits (Amnodd Shales of Fearnsides, 1905) with the best-preserved fauna of the *salopiensis* Zone in Wales. The locality is designated as the basal stratotype of the Migneintian Stage and provides representatives of equivalent strata that are no longer visible in the historic Tremadoc sequence at Penmorfa, near Tremadog.

The first definitive study of the area was by Fearnsides (1905), who described the 'Amnodd Beds' and mentioned the stream at Amnodd-bwll as a good locality for the '*Shumardia pusilla*' fauna (now referred to the *salopiensis* Zone). Subsequently Zalasiewicz (1984b, p. 111) re-mapped the area and reported that the section had been examined systematically between 8054 3670 and 8081 3690 by P.H. Whitworth (1970), whose work, however, remains unpublished. The shelly fossils Whitworth collected indicated a local base for the *salopiensis* Zone, and this feature is the reason for placing the base of the Migneintian Stage there. He also recognized that acritarch microfloras are present, though these have not been described.

## Description

The section is in a small gorge cut by a tributary of the Afon Amnodd-bwll (8042 3657–8066 3684). The rocks consist of monotonous dark-grey silty mudstones with rusty-weathered joint surfaces, dipping at about 45° towards the north-east. They are mostly structureless but sometimes mottled, with abundant evidence of disruption and bioturbation. The upstream reaches of the section are rather poorly fossiliferous but yield *Asaphellus homfrayi* (Salter). Downstream, at about 8075 3687, a diverse fauna is found, its appearance marking the base of the *salopiensis* Zone and the Migneintian Stage. Details of the section have yet to be published, but Fearnsides (1905, p. 617) listed the fauna of the Amnodd Shales as a whole, and recent work has confirmed the following from Amnodd-bwll: acrotretid brachiopods and *Lingulella*; molluscs, including bellerophontids such as *Peelerophon? arfonensis* (Salter), and hyolithids; the trilobites

*Apatokephalus sarculum* Fortey and Owens, *Asaphellus homfrayi*, *Platypeltoides croftii* (Callaway), *Pseudokainella impar* (Salter), *Shumardia* (*Conophrys*) *salopiensis* (Callaway), *Skljarella cracens* Fortey and Owens, and species of *Orometopus* and agnostids; and the cystoid *Macrocystella mariae* Callaway. The good preservation is shown in Whitworth's (1969) illustrations of *P. impar*, Fortey and Owens' (1991, figs 8m, n) of *S.* (*C.*) *salopiensis*, and Paul's (1973–1997, pls 12, 13) of *M. mariae*.

## Interpretation

The mudstones exposed in the Amnodd-bwll stream section are typical of Migneintian rocks of the Upper Mudstone Member elsewhere in North Wales (Howells and Smith, 1997) and represent deposition under normally-oxygenated conditions in an open marine environment. These beds generally occur above pockets of significantly coarser sediment (the Upper Sandstone Member) that are not evident in the present section, although Fearnsides (1905) mapped their local equivalent, the 'Tai-hirion Flags', in the area.

The fossils are the best-preserved representatives of the *salopiensis* Zone to have been found in Wales, and Amnodd-bwll is the clearest place at which to observe the base of the zone, and hence the Migneintian. The faunas are directly comparable to those found at Penmorfa and other places in North Wales. There are several species in common with the typical development at Sheinton Brook and Coundmoor Brook (see site reports), allowing regional correlation, and there is also potential for acritarch zonation.

## Conclusions

The stream section at Amnodd-bwll is an important site nationally because it exposes rocks of the base of the Migneintian Stage of the Tremadoc Series and contains abundant fossils that allow correlation between the historic type area of Tremadog in North Wales and the stratigraphical standard furnished by the Shineton Shales of Shropshire.

# Y GARTH (SH 595 393)

## Introduction

The hill known as Y Garth is the type locality for the highest division (Upper Mudstone Member) of the Tremadoc Series in the type area around Tremadog. The rocks contain faunas of the

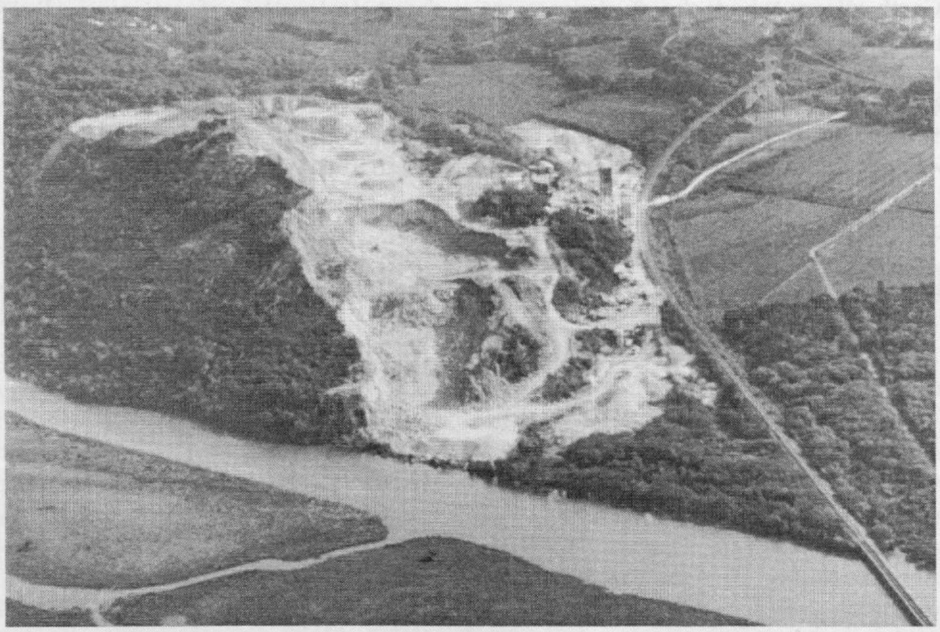

**Figure 7.8** Y Garth Quarry, west of Penrhyndeudraeth, seen from the west. The quarry exploits a dolerite intrusion into the Upper Mudstone Member (or 'Garth Hill Beds') of the Dol-cyn-afon Formation. The Upper Mudstone dips north (to the left), making weak features on the wooded hillside between the quarry and river (Afon Glaslyn). (Photo: Cambridge University Collection of Air Photographs, 70Kn EN59: copyright reserved.)

*Angelina sedgwickii* Zone and provide a reference section for the correlation of the youngest Tremadoc (Migneintian) rocks in Wales.

Y Garth was known to early collectors (Salter, 1866b, p. 252), and many museums have specimens of *Angelina sedgwickii* from there. The Tremadog area was studied by Fearnsides (1910), who mapped six subdivisions within the 'Tremadoc Slates', of which his highest division, the 'Garth Hill Beds', is found at Y Garth. The site was described by Fearnsides and Davies (1944), who stated that the 'famous collecting ground, the slabs along the Glaslyn river frontage north of Y Garth, has been cleared and almost devastated by collectors'. The Tremadog area was resurveyed by Howells and Smith (1997) and the term 'Garth Hill Beds' rejected, the division being informally designated the 'Upper Mudstone Member' of the Dol-cyn-afon Formation. In the Porthmadog area the member is up to 60 m thick beneath the basal Arenig unconformity. Detailed sedimentological information is contained in Prigmore (1994).

## Description

The mudstones exposed on the hillside at Y Garth dip north or north-east at about 40° (Figure 7.8) and show a cleavage that dips more steeply to the north-west. The best exposures are in Y Garth quarry, where the mudstones are intruded by a dolerite sill. Some 5–10 m of mudstones are exposed; in part they are strongly affected by contact metamorphism, which highlights the structures in the mudstones.

The rocks generally consist of dark-grey, structureless, mottled, silty micaceous mudstones. Usually, bioturbation is intense and no internal structure is preserved, but occasional beds are well laminated. At intervals there are pyritous siltstone and fine sandstone laminae that cause the rock to weather with a ribbed appearance. The siltstones often show wavy and lenticular bedding, and sandstone lenses may preserve cross-lamination, parallel lamination and wave-ripple structures. Trace fossils include horizontal and sub-horizontal sandstone-filled burrows up to 5 mm across, and rare, coarse-filled vertical burrows disrupting the coarser horizons. Large cone-in-cone carbonate concretions are associated with the sandstones.

The mudstones contain lingulellid brachiopods, rare mollusca, and trilobites, among which *Angelina sedgwickii* Salter, *Peltocare olenoides* (Salter) and *Niobina davidis* Lake are the main constituents; it is the type locality for the two former species. Further faunal details can be found in Fearnsides and Davies (1944) and Howells and Smith (1997). Specimens are tectonically distorted and are suitable for the study of tectonic strain (Rushton and Smith, 1993).

## Interpretation

The bioturbation, intense in places, indicates normal oxygenation, and wave-ripples in the sandstones indicate that they were formed above wave base. The preservation of vertical burrows in some sandstones may indicate fairly energetic environments. Although olenids commonly indicate dysaerobic conditions characterized by weakly bioturbated textures, the dominance of the olenid trilobite *Angelina* suggests that it could thrive in relatively well-oxygenated water.

Upper Tremadoc sediments in this area are relatively coarse and show significant facies and thickness changes, which indicate fault-controlled deposition in grabens and half-grabens with south-east-facing palaeoslopes (Howells and Smith, 1997). The *Angelina*-bearing beds are developed where fault-controlled highs occurred in the coarser beds below. They thus represent restricted, possibly lagoonal, shallow-water conditions that are thought to represent the culmination of an upwardly shallowing trend. *Angelina sedgwickii* has been found in part of the upward-shallowing sequence of the Habberley Formation (Fortey and Owens, 1992) of the Welsh Borderland (see site report for Granham's Moor).

## Conclusions

The hillside of Y Garth provides a stratigraphical reference for the highest Tremadoc rocks in the historical type area. The strata were deposited in fairly shallow water, possibly lagoons, and contain *Angelina sedgwickii* and other fossils, possibly adapted to a high-stress environment, yet of value for correlation. The site has been subject to over-collection of fossils, and its future conservation is a matter of importance.

# CWM CRYMLYN (SN 3477 1735)

## Introduction

The quarry at Cwm Crymlyn is the best exposure of Tremadoc rocks in South Wales and is important as a record of the presence of Tremadoc rocks in the Llangynog area (Figure 7.2). It yields a rich and well-preserved fauna of the *Adelograptus tenellus* Zone. Some trilobites from here are not recorded elsewhere in Britain but are comparable with forms found in South America and indicate continuity of a distal detrital biofacies from Avalonia to western Gondwana.

Until relatively recently the oldest rocks in the Llangynog area of South Wales were thought to be of Arenig age, following Strahan *et al.* (1909). However, detailed mapping of the area south-west of Carmarthen revealed several localities with Tremadoc rocks (Cope *et al.*, 1978), notably the site at Cwm Crymlyn, which was described in detail. Further sites for Tremadoc rocks were reported by Owens *et al.* (1982), and faunas were described from many localities. The stratigraphy of Upper Cambrian and Tremadoc rocks in the area was summarized by Cope and Rushton (1992), and sedimentological details are contained in Prigmore (1994).

## Description

The roadside quarry at Cwm Crymlyn exposes a few metres of north-dipping, dark greyish-blue mottled mudstones with occasional thin, silty bands. They contain phosphate nodules. Lithologically they are typical of Tremadoc mudstones that have been slightly metamorphosed, and they show a marked metamorphic lineation, seen as fine striae on the bedding planes.

A rich fauna was listed by Owens *et al.* (1982, fig. 2, locality 1), some of the fossils being well preserved; they include brachiopods, notably *Palaeobolus quadratus* (Bulman), along with hyolithids and sponge spicules and anchorage-spines. Graptolites recorded include *Adelograptus tenellus* (Linnarsson) (Figure 7.9a), and the trilobites include *Parabolinella argentinensis* Kobayashi and species of *Platypeltoides*, *Dichelepyge*, *Leiagnostus* and *Niobella*.

## Interpretation

The dark greyish-blue colour of the mudstones at Cwm Crymlyn contrasts with the grey or grey-green of other mudstone exposures in the district. The dark colour appears to be due to metamorphic alteration, and the hardness this confers on the rocks explains the presence of this, the only quarry in the area.

The graptolites found at Cwm Crymlyn were assigned by Owens *et al.* (1982) to four taxa, all of which Maletz and Erdtmann (1987) considered conspecific with *Adelograptus tenellus* (Linnarsson). This species is characteristic of the *tenellus* Zone. The trilobites show links with South American faunas (Owens *et al.*, 1982): *Dichelepyge phylax,* originally described from the Shineton Shales at Cardington (Hutchison and Ingham, 1967), is related to *D. pascuali* Harrington from the *Kainella meridionalis* Zone, a similar horizon of the lower Tremadoc in Salta Province, Argentina (Harrington and Leanza, 1957). The genus *Pseudohysterolenus* was recorded for the first time outside its type

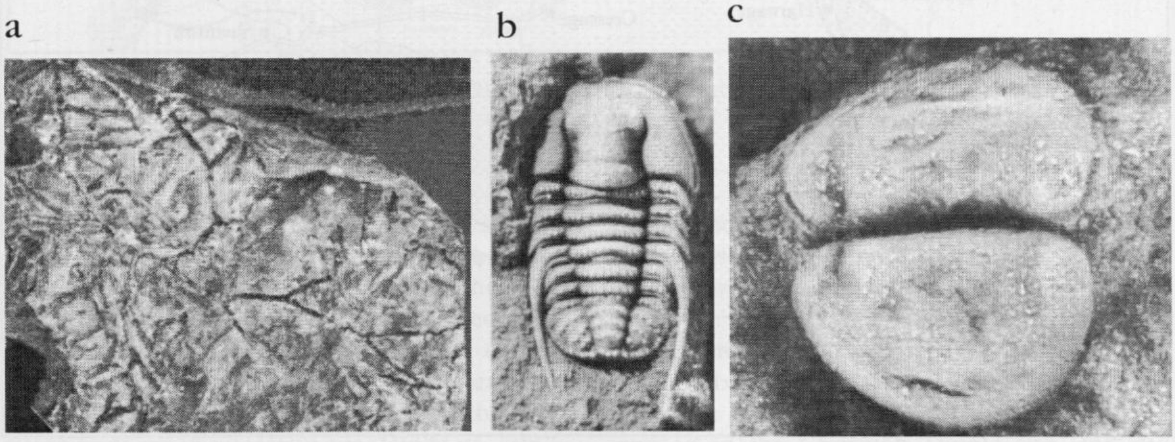


**Figure 7.9** Fossils from Tremadoc sites. (a) *Adelograptus tenellus* (Linnarsson), ×3, Cwm Crymlyn. (b) *Shumardia* (*Conophrys*) *salopiensis* Callaway, ×12, Sheinton Brook. (c) *Beyrichona triceps* Matthew, × 25, Coundmoor Brook, Evenwood.

locality in Argentina. *Parabolinella argentinensis* is also known from Argentina, and the forms of *Leiagnostus* and *Pharostomina* are comparable to South American forms. These faunal similarities indicate that during the earlier part of the Tremadoc, trilobites were able to migrate far along latitudinal facies-belts on the outer margins of Gondwana and Avalonia (Whittington and Hughes, 1974, fig. 4). However, the small differences in the faunas of the *tenellus* Zone as represented at Cwm Crymlyn and in Sheinton Brook (see site report, and see Stubblefield and Bulman, 1927, p. 111) may indicate that slightly different horizons or biofacies are present in the two areas.

## Conclusions

The quarry at Cwm Crymlyn is the best outcrop of Tremadoc rocks in South Wales and has the richest representative of the *tenellus* Zone in the Welsh Basin. Its international importance is highlighted by the presence of certain fossils, namely some trilobites that have not been found elsewhere in Britain but which closely resemble forms found in South America.

## ENGLAND

The Tremadoc of the Welsh Borderland and the English Midlands is represented mainly by the Shineton Shale Formation and its equivalents, to which several local names have been given (Cowie *et al.*, 1972, pl. 1). These are unmetamorphosed mudstones and siltstones deposited across the Midlands microcraton, partly in grabens or half-grabens associated with local rifting, in which their thickness may be 2000 m or

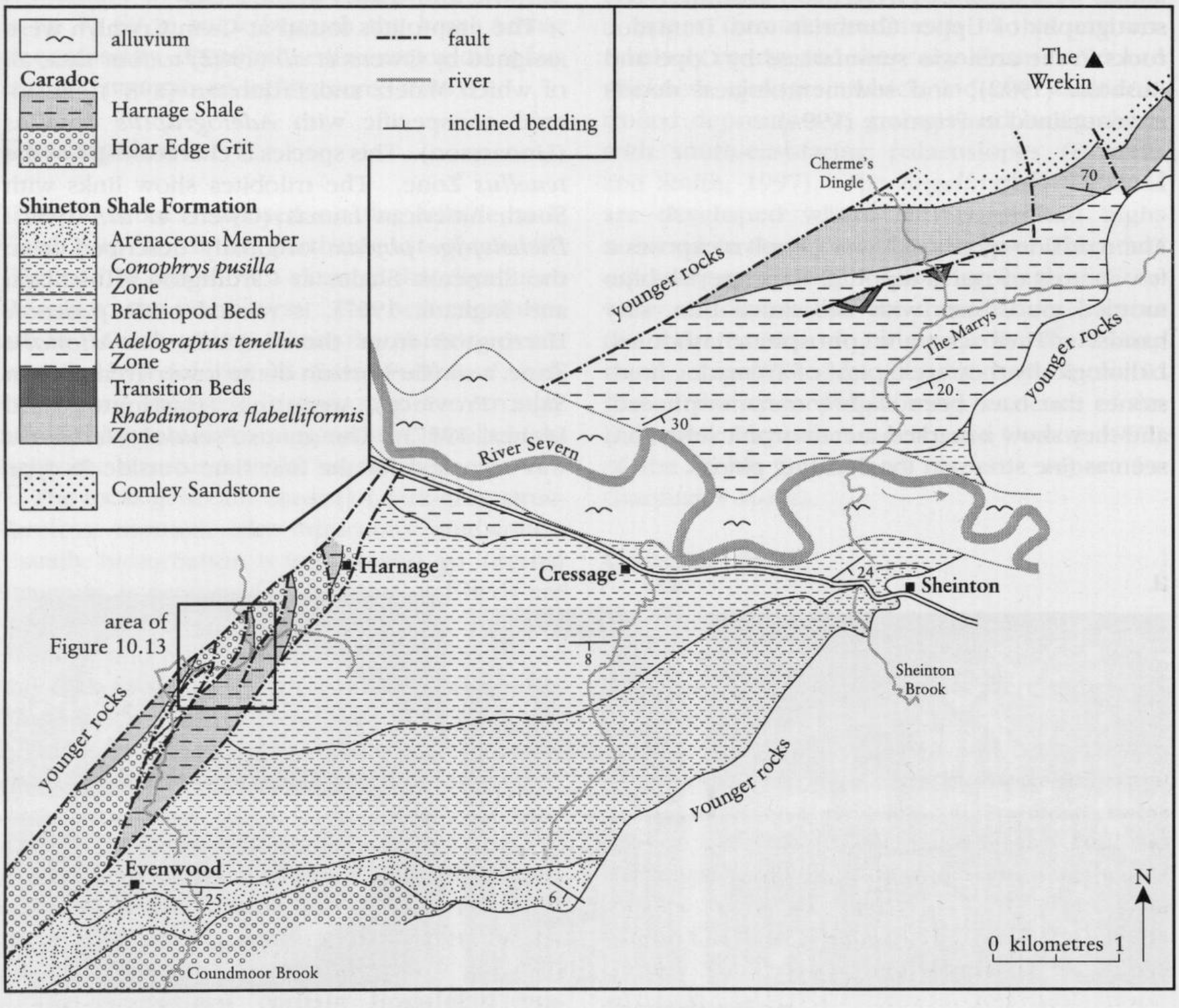


**Figure 7.10** Geological map of the Shineton Shales of the Wrekin district, after Stubblefield and Bulman (1927, pl. 5). Coundmoor Brook includes the Tremadoc GCR site south-east of Evenwood and the type Harnage Shale locality south-west of Harnage (Chapter 10).

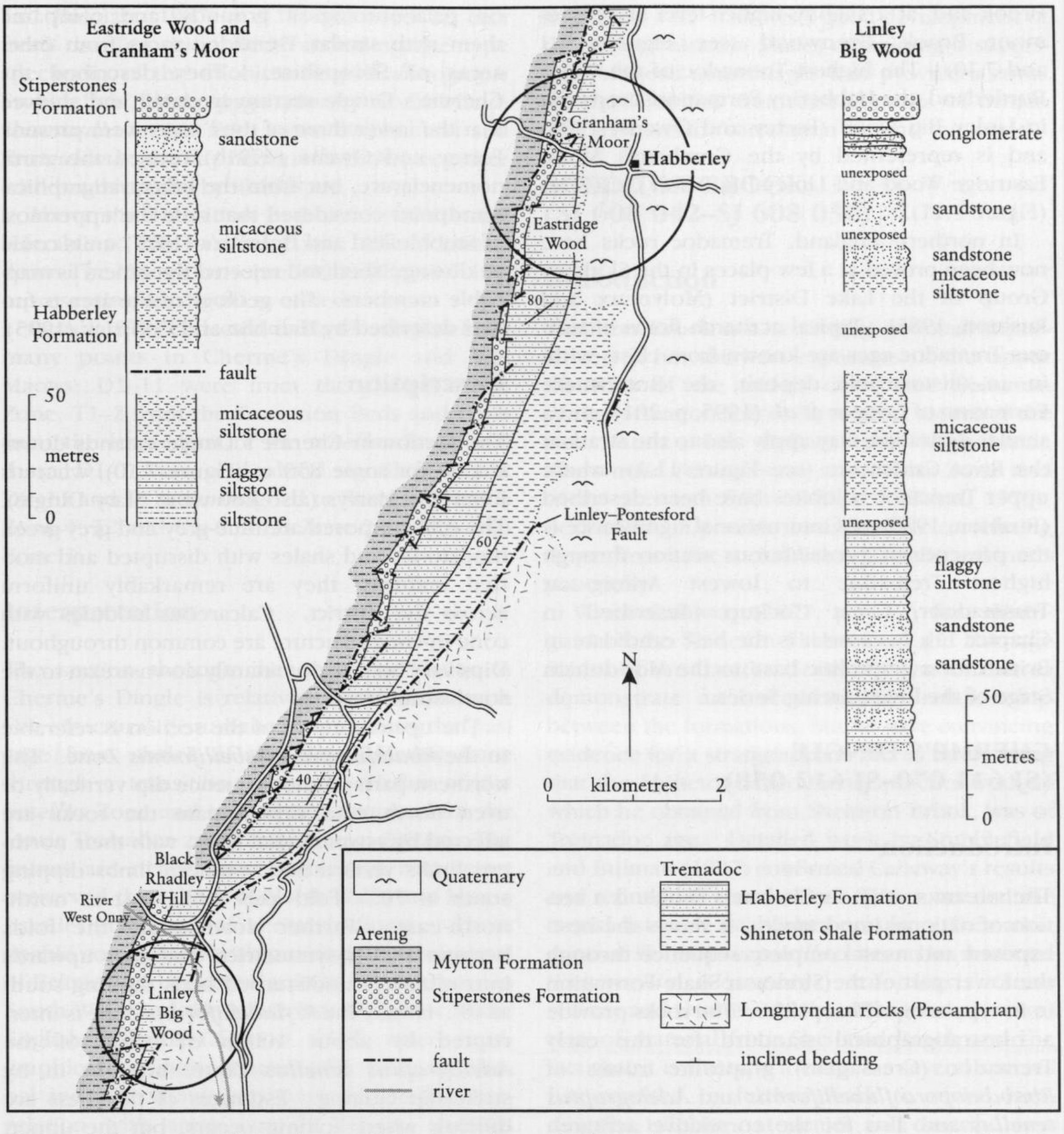


**Figure 7.11** Geological sketch-map of the Tremadoc rocks from the area of Granham's Moor to Linley Big Wood, with vertical sections exposed in each area, after Fortey and Owens (1992, fig. 1).

more (Smith and Rushton, 1993). The succession is generally incomplete at the base, because of either non-sequence or (as at Cherme's Dingle) faulting. Even where there is sedimentary continuity, as in the subcrop in central England, faunas of the topmost Merioneth and lowest Tremadoc remain unproved and the transition beds are of uncertain age (Old *et al.*, 1987; Bridge *et al.*, 1998). At the top of the Shineton Shale Formation there is widespread erosion and an unconformity with overlying beds. Only in the Shelve area is there an approach to continuity between the Tremadoc and the overlying Arenig.

The Shineton Shales are generally poorly exposed, but much of the Cressagian, represented by the *flabelliformis* and *tenellus* zones, is exposed in the Cherme's Dingle site, and the lower parts of the Migneintian, namely the *salopiensis* Zone, are exposed in Sheinton

Brook and, at a slightly higher level at Coundmoor Brook, Evenwood (see Figures 7.1 and 7.10). The highest Tremadoc of the Welsh Borderland, the Habberley Formation, crops out in Linley Big Wood (Fortey and Owens, 1992) and is represented by the Granham's Moor, Eastridge Wood and Linley Big Wood GCR sites (Figure 7.11).

In northern England, Tremadoc rocks have now been proved at a few places in the Skiddaw Group of the Lake District (Molyneux and Rushton, 1985). Typical acritarch floras of various Tremadoc ages are known from clasts within an olistostrome deposit, the Buttermere Formation of Cooper *et al*. (1995, p. 201), and a similar derivation may apply also to the strata at the River Calder site (see Figure 11.1), where upper Tremadoc trilobites have been described (Rushton, 1988). Of international significance is the presence of a fossiliferous section through highest Tremadoc to lowest Arenig at Trusmadoor, Great Cockup (described in Chapter 11), because it is the best candidate in Britain for a graptolitic base to the Moridunian Stage of the lower Arenig Series.

## CHERME'S DINGLE (SJ 611 070–SJ 612 058)

### Introduction

The stream section in Cherme's Dingle is a section of national importance. It shows the best-exposed and most complete sequence through the lower part of the Shineton Shale Formation in its type area of Shropshire. The rocks provide a biostratigraphical standard for the early Tremadoc (Cressagian) graptolite zones of *Rhabdinopora flabelliformis* and *Adelograptus tenellus* and also for the correlative acritarch microfloral succession. Cherme's Dingle shows the only exposure of the Transition Beds between these graptolite zones and is the type locality for species of trilobites and other taxa of importance in the correlation of lower Tremadoc sequences, both in Britain and abroad.

In 1877 Callaway showed that the Shineton Shales of the Wrekin area of Shropshire were of Tremadoc age and distinguished them from the Harnage Shales, of Caradoc age. A more detailed account of the Shineton Shales was given by Stubblefield and Bulman (1927), who subdivided the formation into six units, mostly on palaeontological grounds, and compared them with similar Tremadoc rocks from other areas of Shropshire. They described the Cherme's Dingle section in detail and showed that the lower three of their units were present. Fortey and Owens (1991b) revised the zonal nomenclature, but from the lithostratigraphical standpoint considered that only the uppermost of Stubblefield and Bulman's (1927) units could be distinguished and rejected the others as mappable members. The geology of the area is further described by Hamblin and Coppack (1995).

### Description

The section in Cherme's Dingle extends downstream for some 850 m (Figure 7.10), where it joins The Marrys (also known as Mary Dingle). The rocks exposed are blue-grey and grey-green mudstones and shales with disrupted and mottled textures; they are remarkably uniform across the district. Calcareous nodules with cone-in-cone structure are common throughout. Dips vary but are dominantly downstream to the south-south-east.

The upstream part of the section is referable to the *Rhabdinopora flabelliformis* Zone. The northern parts of the sequence dip vertically or even north, and downstream the rocks are affected by asymmetrical folds, with their northern limbs vertical and southern limbs dipping south at 70°. Fold axes strike east to north-north-east. Farther downstream the folds become almost symmetrical and pass upwards into relatively undisturbed beds dipping south at 40°. Locally the *R. flabelliformis* Zone is interrupted by about 100 m of strata of the *Adelograptus tenellus* Zone, brought in by strike-slip faulting. Estimates of thickness are difficult where folding occurs, but the upper, less disturbed, mudstones are about 100 m thick.

*Rhabdinopora flabelliformis* (Eichwald) is abundant throughout the section; Stubblefield and Bulman (1927) state that 'in 210 feet of shale exposed in the stream bed, 119 localities spaced well over the length of the section have yielded *Dictyonema flabelliforme*'. Shales of the *flabelliformis* Zone pass upwards into the 'Transition Beds' (Figure 7.10), some 15 m thick, in which shales with faunal assemblages from the *tenellus* Zone, characterized by *Adelograptus tenellus* (Linnarsson) itself, alternate with layers with *R. flabelliformis*. Stubblefield and Bulman (1927, p. 118) recorded 22 taxa from the Transition Beds, including the type specimens of the trilobites *Hospes clonograpti* Stubblefield, *Macropyge chermi* Stubblefield, *Shumardia* (*sensu lato*) *curta* Stubblefield and *Proteuloma monile praemonile* (Lake), together with brachiopods, hyolithids etc..

Above the Transition Beds are similar strata referable to the *tenellus* Zone. These extend down The Marrys for some 500 m (Figure 7.10), representing maybe 60 m of beds.

Rasul (1979) collected acritarch samples from many points in Cherme's Dingle and The Marrys; D1–11 were from the *flabelliformis* Zone, T1–2 from the Transition Beds and C1–8 from the lower part of the *tenellus* Zone. Of these, D1–7 were of doubtful significance, but D8–11 and T1 were assigned to Rasul's acritarch Zone 1, T2 and C1–6 to his Zone 2 and C7–8 to Zone 3.

## Interpretation

The section through the Shineton Shales in Cherme's Dingle is relatively continuous, with few structural disturbances. It shows the passage from shales of the *flabelliformis* Zone through a transition zone into shales of the *tenellus* Zone and is used as a standard for the lower Tremadoc zonal sequence in Britain. The faunas are richer, more numerous and better preserved than those of North Wales and have a parallel sequence of acritarch floras. These enable comparison with outcrops in other areas of Britain and in particular help to date those in South Wales and the subsurface Tremadoc of the English Midlands (Old *et al.*, 1987), where stratigraphical continuity is not readily seen. The faunal and microfloral succession also enables correlation with areas outside Britain, such as Estonia, Belgium, Newfoundland and South America.

The lower Shineton Shale Formation is very similar to correlative strata in many parts of eastern Avalonia (cf. Landing, 1996). In some areas the sequences are very thick, reflecting active fault-controlled rifting in the Tremadoc. Smith and Rushton (1993) showed that deposition occurred in half-grabens, with some divisions thickened locally against syndepositional faults.

## Conclusions

The section in Cherme's Dingle is a nationally important site. It shows a good development of the lower Shineton Shales containing a succession of fossil assemblages that provide a zonal standard for the Tremadoc deposits of Britain and are used for correlation around the world.

# SHEINTON BROOK (SJ 608 042–SJ 608 036)

## Introduction

Sheinton Brook is a section of national importance. It has the best exposures of the upper divisions of the widely distributed Shineton Shale Formation and is the original source of the rich fauna that defines the Migneintian *Shumardia (Conophrys) salopiensis* Zone and of the acritarch flora of Zone 7 (Rasul, 1979), both of which provide a standard for correlating upper Tremadoc rocks both regionally and internationally.

When Callaway (1877, p. 657) first distinguished the Shineton Shales from the Harnage Shales of the Caradoc Series, he was unable to demonstrate an unconformable relationship between the formations, but he gave convincing evidence for a stratigraphical hiatus by showing that the Shineton Shale fauna, practically all of which he obtained from Sheinton Brook, was of Tremadoc age. Detailed work by Stubblefield and Bulman (1927) confirmed Callaway's results and refined his correlations. They extended the faunal lists and established an upper Tremadoc zone of *Shumardia pusilla*, later to be renamed '*Shumardia* (*Conophrys*) *salopiensis*' Zone (Fortey and Owens, 1991b). The good preservation of material from Sheinton Brook and the fact that it is the type locality for several species has resulted in further work to revise taxa, describe trilobite ontogenies and describe new forms. Rasul (1979) used samples from the macrofaunally-controlled succession in Sheinton Brook to establish part of his acritarch zonation for the Shineton Shales.

## Description

The section in Sheinton Brook traverses the strike of the Shineton Shale Formation for some 400 m (Figure 7.10). The downstream end of the section exposes grey, silty mudstones with cone-in-cone concretions, dipping at about 24° to the south-east. These are assigned to Stubblefield and Bulman's 'Brachiopod Beds'.

South of the Cressage to Sheinton road bridge the Brachiopod Beds pass up into finer-grained blue-grey shales with fewer concretions. These beds, which weather to a greenish-grey tint, are referred to the *salopiensis* Zone; they are exposed sporadically in the stream bed and banks for more than 300 m across strike and dip at 20° to 45° to the south-east. The principal exposures are at the large meanders towards the southern end of the site, and there Stubblefield and Bulman (1927, p. 112) recorded a section through about 90 m of beds. They divided the succession into seven units and tabulated the distribution within them of 28 taxa of fossils, in effect the whole fauna of the '*Shumardia pusilla* Zone', as known to them.

The brachiopods *Eurytreta sabrinae* (Callaway) and **Lingulella nicholsoni* Callaway (illustrated by Owens *et al.*, 1982) range throughout the succession and are the only species recorded in the uppermost division (* signifies a species whose type locality is Sheinton Brook). Hyoliths, bellerophontids, smooth ostracods (Williams and Siveter, 1998) and the cystoid **Macrocystella mariae* Callaway, redescribed by Paul (1973–1997), are common in places, but the priapulid-like **Palaeoscolex piscatorum* Whittard (1953) is rare (Conway Morris, 1997). The trilobite fauna includes some 20 taxa, of which the commonest are *Asaphellus homfrayi* (Salter), **Shumardia (Conophrys) salopiensis* Callaway (Figure 7.9b), **Geragnostus callavei* (Raw, in Lake) **Platypeltoides croftii* (Callaway), **Proteuloma monile monile* (Salter), **Parabolinella triarthra* (Callaway) and **Leptoplastides salteri* (Callaway). These, which form the basis of the fauna of the *salopiensis* Zone, were described by Lake (1906–1946), and some have since been revised by Fortey and Owens (1991b) and Owens *et al.* (1982). The rare **Cyclopyge genatenta* Stubblefield was revised by Fortey (1981) and made the type species of *Prospectatrix*, and Fortey and Rushton (1980) described the shumardiid **Acanthopleurella stipulae*.

In compiling his acritarch zonation for the Shineton Shales, Rasul (1979) drew his highest samples of Brachiopod Beds, B1–B3, from the downstream end of Sheinton Brook. These are referred to the upper part of his zone 6. He took samples S1–S5 from Stubblefield and Bulman's exposures of the *salopiensis* Zone farther upstream, and used the appearance there of *Acanthodiacrodium crinitum* Rasul, *A. ovatum* Rasul *A. tremadocum* Górka, *Stelliferidium trifidum* (Rasul) Fensome *et al.* and *Tectitheca decorata* Rasul to characterize his zone 7.

## Interpretation

Exposures in Sheinton Brook reveal a south-east-younging succession representing a part of the upper Shineton Shales succession. Although the sedimentology of the silty lower beds (the Brachiopod Beds) has not been studied, it is thought that they may have been deposited in quiet (but oxygenated) conditions (Stubblefield and Bulman, 1927, p. 111). The overlying mudstones of the *salopiensis* Zone were likewise deposited in quiet conditions, as shown by the presence of undisturbed trilobite exoskeletons showing moulting configurations.

The fauna of the *salopiensis* Zone in Sheinton Brook is an important reference for the correlation of the upper Tremadoc rocks in the UK. It has yielded a large fauna, mainly of trilobites, many of which have been found in Upper Tremadoc rocks in other parts of Britain: North and South Wales (Fortey and Owens, 1991b; Owens *et al.*, 1982), the central England subcrop (Bulman and Rushton, 1973) and the Lake District (Rushton, 1988). The correlation of these is summarized by Cowie *et al.* (1972) and Fortey and Owens (1991b). The value of the acritarch assemblages of the *salopiensis* Zone in Sheinton Brook was confirmed by the work of Molyneux (in Pratt *et al.*, 1995, p. 16) and when Rasul (in Bulman and Rushton, 1973, p. 7–8) gave evidence that the Tremadoc beds of the Deanshanger Borehole (Buckinghamshire) should be assigned to the *salopiensis* Zone, contrary to the evidence suggested by '*Dictyonema*' (=*Rhabdinopora*) but in keeping with the trilobite evidence.

The good preservation of certain fossils in the shales of Sheinton Brook is epitomized by the delicate details visible in the type and other material of *Palaeoscolex piscatorum* Whittard (1953), which shows the jaw apparatus, the gut, and 'papillae' on the skin. Conway Morris (1997) has shown that the papillae are exoskeletal elements akin to *Hadimopella*.

Some beds contain abundant moulted exoskeletons of juvenile trilobites, allowing observations on the ontogeny of various species, for example *Asaphellus* and *Acanthopleurella*. However, the most significant is the complete suite of growth stages of *Shumardia*

*(Conophrys) salopiensis*, which Stubblefield (1926) described (as *S. pusilla*) and from which he drew important general conclusions about growth in trilobites. The ontogeny of *Leptoplastides salteri* was likewise described by Raw (1925), and although he, too, drew far-reaching conclusions from his studies, they have not in general been accepted by later workers.

## Conclusions

Sheinton Brook is of international importance because it has yielded fossil faunas typical of the upper Tremadoc Series, for which it remains a prime reference section. The faunas include the original specimens of several species, many of which have biological, taxonomic and historical significance.

# COUNDMOOR BROOK, EVENWOOD (SJ 5549 0152)

## Introduction

This site is the only locality at which the Arenaceous Beds Member of the Shineton Shale Formation is substantially fossiliferous and its reference to the *salopiensis* Zone can be established.

In their account of the Shineton Shales, Stubblefield and Bulman (1927, p. 114) described the highest division that they recognized as the 'Arenaceous Beds'. They found very few fossils, but inferred that the unit correlated with the *sedgwickii* Zone of the highest Tremadoc Slates in North Wales (see site report for Y Garth) and with the *Apatokephalus serratus* Zone in Scandinavia. They considered that the Arenaceous Beds showed evidence of shallowing of the Shineton Shale basin of deposition.

In 1991, however, Fortey and Owens announced the finding of a new fauna from the Arenaceous Beds (which they treated as a member of the Shineton Shale Formation) and showed that, although it differs from the fauna from Sheinton Brook, it is likewise referable to the *salopiensis* Zone.

## Description

The best section of the Arenaceous Beds Member is in the banks of Coundmoor Brook, south of Bullhill Cottage, Evenwood (Figure 7.10). At the downstream end of the section the base of the Arenaceous Beds is taken at a sandstone bed that overlies shales typical of the Shineton Shales Formation. Passing upstream over a gap in the section, the principal exposure of the Arenaceous Beds consists of sandstones and mudstones dipping south at 20–25°, which, after another gap in the succession, are inferred to dip under the basal unconformity of the Hoar Edge Grit of the Caradoc Series (see site report for Coundmoor Brook, Harnage, Chapter 10).

According to Fortey and Owens (1991b), the sandstone beds include turbidites up to 10 cm thick, some of which show complete Bouma cycles; the bases may show flute marks and the basal divisions may be graded. Other sandstones are cross- or parallel-laminated and some are micaceous. Bioturbation is prevalent. The mudstone interbeds are silty or shaly and resemble beds typical of lower divisions of the Shineton Shales.

Certain shaly intervals contain a well-preserved fauna of lingulate brachiopods, the bradoriid arthropod *Beyrichona* cf. *triceps* Matthew (Figure 7.9c; see Williams and Siveter, 1998), an eocrinoid, five genera of 'carpoid'-like animals, of which one, the cornute *Prochauvelicystis semispinosa,* was described by Daley (1992a); and Fortey and Owens (1991b) described nine species of trilobites, including *Geragnostus callavei* (Raw), *Litagnostus meniscus* Fortey and Owens, *Asaphellus homfrayi* (Salter), *Leptoplastides salteri* (Callaway), *Skljarella cracens* Fortey and Owens, *Apatokephalus sarculum* Fortey and Owens, *Pseudokainella impar* (Salter) and *Shumardia* (*Conophrys*) *salopiensis* Callaway.

## Interpretation

Fortey and Owens (1991b, p. 439) argued that the Arenaceous Beds show no evidence of substantial shallowing towards the top of the Shineton Shales Formation, and in this respect the unit differs from the Habberley Formation, which overlies the Shineton Shales in the Shelve area (see Graham's Moor site report). The presence of undisturbed moults of trilobites and articulated 'carpoids' in the shaly beds indicates that deposition continued in quiet conditions below wave base. The sea floor was normally-oxygenated and the prevailing substrate was soft mud.

The development of turbidites does, however, indicate a change in sedimentary environment compared with the underlying divisions and may account for the differences in the fauna: the presence of the 'carpoids' and echinoderms and the abundance of trilobite genera that are rare or unknown from Sheinton Brook.

The trilobite fauna has species in common with that of the *salopiensis* Zone and is referred to the same zone: *S.(C.) salopiensis* itself, *A. homfrayi, L. salteri* and *G. callavei* are well known from Sheinton Brook, and *Pseudokainella impar*, though not previously recorded from the Shineton Shales, is known from the *salopiensis* Zone in North Wales. *Leiagnostus* and *Skljarella* are common at Coundmoor Brook, yet neither is recorded from lower in the Shineton Shales.

## Conclusions

This site uniquely shows a rich fauna in the uppermost division of the Shineton Shales. Palaeogeographically it shows that the depositional basin of the Shineton Shales continued to be deep in the Wrekin area almost to the end of the Tremadoc epoch.

# GRANHAM'S MOOR AND EASTRIDGE WOOD (SJ 392 00374–SJ 3888 0360) AND LINLEY BIG WOOD (SJ 3400 9496–SJ 3422 9482)

## Introduction

These two nationally significant localities are complementary and were selected to show the appearance of a conformable passage from the Tremadoc into the Arenig. Unlike the graptolitic passage beds at Trusmadoor in the Lake District, here the passage is in shallow-water facies at these localities. Until recently it had been thought that there was a break in the succession at Granham's Moor between the Tremadoc Habberley Formation and the Arenig Stiperstones Quartzite Formation, but now new work indicates that, if present, this is of insignificant duration.

The Habberley Formation, whose type area is in Habberley Brook immediately to the east of the present site, was introduced (as Habberley Shales) by Lapworth (1916, p. 37). However, the rocks had been noted long before, by Murchison (1872, p. 37), who described them as 'black schists' of '*Lingula*-Flags age', and by Callaway (1878, p. 333), who inferred, on the basis of their lithology and stratigraphical position, that their age was equivalent to the Shineton Shales of the Wrekin district. Although the term 'Habberley Shales' was retained by Watts (1925) and in earlier publications by Whittard (e.g. 1931a, 1955), Whittard later (1960, p. 144; 1979, p. 10) concluded that they were synonymous with the Shineton Shales. Stubblefield and Bulman (1927, p. 116) recorded *Rhabdinopora flabelliformis* (Eichwald) and *Adelograptus tenellus* (Linnarsson) from lower horizons, whilst Whittard (1931b, p. 344) reported the identification by Stubblefield of the trilobite '*Shumardia pusilla*' (now referred to *Shumardia (Conophrys) salopiensis*) in a trench (3894 0370) that had been excavated to expose the Tremadoc–Stiperstones Quartzite junction. The identification of that species in shales immediately below the Stiperstones Quartzite suggested the presence of the *pusilla* Zone of the Tremadoc and, by inference, the absence of later Tremadoc strata such as occur above it in North Wales. Whittard (1931a, p. 324, fig. 45) considered the unconformity to be marked by a conglomerate at the base of the Stiperstones Quartzite. Whitehead (in Pocock *et al.*, 1938, p. 72), however, believed that the junction could be conformable though 'not necessarily without a break in deposition', and because the dips of the quartzite and underlying siltstones are concordant, Whittard (1979, p. 10) described the junction as being disconformable.

Reinvestigation by Fortey and Owens (1992) of the Granham's Moor site, and of Linley Big Wood to the south (Figure 7.11), has shown that a far more complete succession of Tremadoc strata is present than was formerly supposed, and they revived the name 'Habberley Formation' for the higher, more arenaceous, part of the succession. By collecting the olenid trilobites *Angelina sedgwickii* Salter and *Peltocare olenoides* (Salter) they demonstrated the presence of the *sedgwickii* Zone in strata underlying those that had yielded the supposed *Shumardia* exposed in Whittard's trench; re-examination of the latter specimen by Rushton revealed that it is not a trilobite, but the bradoriid crustacean *Beyrichona* cf. *triceps* (Matthew) (compare Figure 7.9c; see Williams and Siveter, 1998), thereby removing evidence for the *salopiensis* Zone at that locality. Above the shales

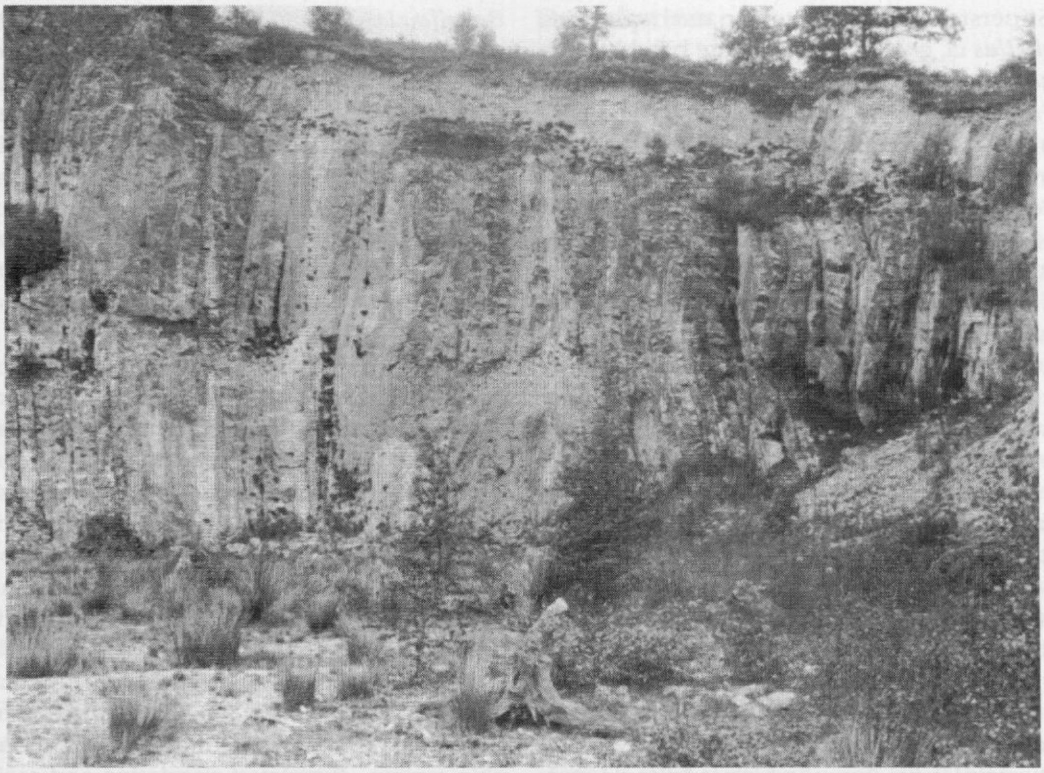

**Figure 7.12** Granham's Moor Quarry, 1 km east of Habberley (SJ 3886 0350). The vertical beds of the Stiperstones Quartzite Formation (Arenig) strike SSW. The underlying flaggy beds of the uppermost Habberley Formation (Upper Tremadoc) are just beyond the left edge of the photograph. (Photo: British Geological Survey photographic collection, A4808.)

with *Angelina* and below the Stiperstones Quartzite, Fortey and Owens (1992) described a sequence of micaceous siltstones and flags with the trilobite *Asaphellus* cf. *graffi* (Thoral), which characterizes a level not seen in North Wales, in which the *sedgwickii* Zone is overlain unconformably by the Arenig Garth Grit. They demonstrated a similar sequence along the length of the outcrop, and the fine section in Linley Big Wood repeats that seen at Granham's Moor and includes a more complete succession. Fortey and Owens could find no evidence for any unconformity or disconformity, and they concluded that there was likely to be no break in the succession. The Linley Big Wood section was considered as a candidate for definition of the base of the Arenig Series in Britain (Fortey *et al.*, 1991, p. 10).

## Description

### *Granham's Moor*

The lowest beds of the Habberley Formation are seen along the north side of a forestry road leading from Habberley into Eastridge Wood (Figure 7.11), where some 50 m of black shales with thin turbidites, dipping at 80° to the west, crop out around 3913 0373. In the lane to the east (3920 0374) these beds pass downwards into buff, micaceous shales lithologically not unlike those of the highest Shineton Shales, but here they have not proved fossiliferous. They demonstrate the lithological difference between the Shineton Shales (restricted) and the Habberley Formation. Beds some 20 m above the base of the Habberley Formation have yielded rare trilobites, including *Angelina sedgwickii* and *Peltocare olenoides,* and an orthoconic nautiloid, *Anguloceras sericeum* (Salter), all of them forms typical of the *sedgwickii* Zone in North Wales. These beds pass up into black, buff-weathering shales with siliceous nodules. Whittard's (1931b) trench (3894 0370) is still visible, although rather degraded. A forestry road immediately to the west is more instructive in showing the uppermost Habberley Formation. At several points between 3 m and 70 m below the Stiperstones Quartzite, sparse trilobites (*Asaphellus* cf. *graffi*) and lingulate brachiopods (*Lingulella bella* Walcott) have been recovered from a sequence of black, micaceous, rusty-weathering flags and silty shales. These are overlain by well-bedded sandstones that are characteristically green when freshly fractured, owing to the presence of a chloritic cement. Immediately below the Stiperstone Quartzite are about 2–3 m of black shales with flaser bedding picked out by paler, silty seams; these are seen near the entrance to a quarry. These shales yielded the *Asaphellus* and the *'Shumardia'* in Whittard's trench. The Stiperstones Quartzite Formation, as exposed in, for example, the quarry centred on 3888 0360, is typified by massive, compact, moderately well-bedded pale quartzite (Figure 7.12), which at some localities yields *Skolithos* tubes perpendicular to the bedding and other trace fossils. The only body fossils to have been recovered from the Stiperstones are poorly preserved lingulate brachiopods (Williams, 1974, p. 11) and two specimens of the characteristically Arenig trilobite *Neseuretus ramseyensis* Hicks, one of which is from a loose block at Upper Vessons, about 1.5 km south of this site.

### *Linley Big Wood*

A more extensive section through the Habberley Formation, also showing its upward passage into the Stiperstones Quartzite, was cleared by English Nature along a forestry road (SJ 3400 9496–3422 9482) in Linley Big Wood, south of Black Rhadley Hill, at the southern end of the outcrop (Figure 7.11); this section complements the Granham's Moor site, and between them they expose most of the Habberley Formation succession (Fortey and Owens, 1992). The lower part of the section (3418 9442) shows turbiditic sandstones interbedded with shales, dipping west at about 60°; Fortey and Owens (1992) correlated these with the uppermost division of the Shineton Shale Formation. The base of the Habberley Formation is taken at the overlying black, flaggy, micaceous siltstones. The mid-part of the Habberley Formation, faulted out at Granham's Moor, is present at Linley Big Wood and consists of 150 m or more of black flags. It is almost unfossiliferous but nearby, at Nipstone Rock, has yielded a single specimen of *Angelina sedgwickii*. The upper beds of the formation comprise shales with rare olenids (*Angelina, Beltella, Leptoplastides*), overlain by bioturbated flaggy sandstones and shales with *Lingulella bella* and *Asaphellus* cf. *graffi*. These beds underlie the Stiperstones Quartzite, which is taken as the local base of the Arenig, and lithologically they much resemble the Mytton Formation, which overlies that formation. Further details of the section are recorded in Cave and Hains (in press).

## Interpretation

In other outcrops of the Tremadoc Series in the Welsh Basin there is a break at the top of the succession prior to the deposition of the earliest Arenig sediments. It is possible that deposition became restricted later in the Tremadoc Epoch, and conditions possibly became dysaerobic at times, since an olenid trilobite biofacies, indicative of such conditions, became established both here and in North Wales. Some horizons of flaggy beds near the top of the Habberley Formation well-seen in Linley Big Wood are virtually unfossiliferous, perhaps signalling a completely anaerobic regime. Restricted circulation and regional unconformity may both be a result of basin inversion or of local tectonics. A barrier to the open sea to the west may have produced a largely stagnant basin. The presence near the top of the Habberley Formation of bioturbation and of a restricted fauna (*Asaphellus* and *Lingulella*) suggests a return to more normal oxygenation. Most of the Habberley Formation sequence was interpreted by Fortey and Owens (1992) as a shallowing-upwards sequence, possibly related to a regression event at the end of the Tremadoc. There may be a slight hiatus below the overlying Stiperstones Quartzite Formation that represents prograding sands deposited at the initiation of the subsequent transgression. The presence of *Skolithos* 'pipe-rock' in the overlying Stiperstones indicates deposition in shallow water (Droser, 1991).

Although the fauna of the Habberley Formation is sparse, the presence of the trilobites *Angelina sedgwickii* and *Peltocare olenoides* is crucial in affording correlation with the uppermost Tremadoc rocks seen in the North Wales sequence; this constrains the age of the upper part of the Habberley Formation, which has so far afforded no fossils diagnostic for correlation, as *Lingulella bella* seems to have quite a long range in Newfoundland (Rushton, in Fortey and Owens, 1992), and the specimens that Fortey and Owens (1992, p. 563) assigned to *A.* cf. *graffi* show differences from the Lower Arenig species *A. graffi*.

The stratigraphical position of the Habberley Formation may well correspond, at least in part, to the Hunnebergian Stage in Scandinavia (Fortey and Owens, 1992). It is also homotaxial with the Watch Hill Formation and the base of the Hope Beck Formation in the Lake District (see site report for Trusmadoor), but there the strata are graptolitic and can be correlated only indirectly with the Habberley Formation.

## Conclusions

Granham's Moor and Linley Big Wood are of national importance, being the only places in Wales and the Welsh Borderland showing a transition from the Tremadoc to the Arenig series and the only sites in which this transition can be seen in a trilobite-bearing facies.

# RIVER CALDER, LATTER BARROW (NY 0687 1178)

## Introduction

Exposures in the River Calder yield a distinctive late-Tremadoc acritarch flora and the only essentially trilobitic fauna known from the Skiddaw Group. The source rock may be an olistolith of Tremadoc strata derived into the Buttermere Formation.

Having described the graptolite fauna of the Skiddaw Group, Elles (1898) considered that part of it was of Tremadoc age, but subsequent revision did not uphold her conclusions, and for some years the Skiddaw Group was believed to be no older than Arenig (Jackson, 1962). In 1985, however, Molyneux and Rushton reported late Tremadoc acritarchs and trilobites from the Calder River north-west of Latter Barrow hill and also from other areas of the Skiddaw Group outcrop. Allen and Cooper (1986) reviewed the geological investigations in the area of Latter Barrow and produced a geological map. In 1988, Webb and Cooper described an olistostrome deposit in the Buttermere area; subsequently Cooper *et al.* (1995) formalized this as the Buttermere Formation and extended its outcrop to include the area of the Calder River, so the Tremadoc rocks there may represent an olistolith within the Buttermere Formation.

## Description

The Skiddaw Group is exposed in the River Calder to the west of Latter Barrow hill, 6 km east of Egremont (see Figure 11.1). The exposures are mainly in the east bank of the river, 70–200 m upstream of the place where the base of the unconformably overlying Latterbarrow Sandstone Formation crosses the river (Allen and Cooper, 1986). The Skiddaw Group consists mainly of grey, silty mudstones with sandstone laminae and thin turbiditic beds of fine- to medium-grained sandstone, generally dipping at 20–30° to the west or north-west. A flat-lying slump-fold of the Skiddaw Group is exposed at the northern end of the outcrop.

Acritarchs were detected in six samples collected from these exposures, and detailed analysis showed that their age lies between the base of the *Shumardia (Conophrys) salopiensis* (= *pusilla*) Zone and the top of the *Tetragraptus approximatus* Zone and is probably late-Tremadoc (Molyneux and Rushton, 1985). Ten species of trilobites, together with a few other shelly fossils, were collected from three places on the east bank, and one trilobite is recorded from the right bank (Rushton, 1988). The trilobites include *Niobina davidis* (Lake) and *Peltocare olenoides* (Salter), both known from Y Garth in the Porthmadog area of North Wales (see site report for Y Garth); they also indicate a late-Tremadoc age and were correlated with the *Angelina sedgwickii* Zone of the Welsh Tremadoc succession (Rushton, 1988). The fauna also includes *Parabolinella triarthroides* Harrington, described from the upper Tremadoc of Argentina, and at least two new endemic species.

## Interpretation

The Tremadoc age of the exposures in the River Calder contrasts with Arenig faunas (*Isograptus gibberulus* Zone?) from Ya Gill, 1 km to the north-east, and Beck Grains, 1 km to the south-east, and its discovery contributed to the identification of an unconformity at the base of the overlying Latterbarrow Formation (Allen and Cooper, 1986). However, identification of the Buttermere Formation as an olistostrome suggests that all the Tremadoc localities are within a large olistolith of a pre-existing Tremadoc formation and derived into the Buttermere formation by major slumping, inferred by Cooper *et* *al.* (1995, p. 202) to have occurred during late Arenig times.

Although acritarch floras are very widely distributed throughout the Skiddaw Group, the present locality has the only essentially trilobitic fauna in the group; indeed, it has yielded more trilobites than all the rest of the Skiddaw Group below the Llanvirn. Late-Tremadoc trilobite faunas are uncommon, presumably partly on account of the end-Tremadoc eustatic regression, and elsewhere in Britain they are restricted to North Wales and the Shelve area of Shropshire (Fortey and Owens, 1992). The Calder fauna appears to be an outer-shelf benthic association that inhabited cool water (Rushton, 1988).

## Conclusions

This site is unique in the Lake District in exposing a rarely found benthic trilobite fauna of late-Tremadoc age. It is probable that the fossiliferous strata slipped into their present place in a giant chaotic submarine mud-slide.