British Cambrian to Ordovician Stratigraphy

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Chapter 8

Arenig to Ashgill in South Wales

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INTRODUCTION

In South Wales, rocks of the Arenig to Ashgill Series extend in a broad and complex tract about 160 km long, from Ramsey Island off the north-west coast of Pembrokeshire eastwards to Llandeilo (Figure 8.1), and thence north-east along the Tywi Lineament to Abbeycwmhir, north of Builth. This classic area of British geology, which includes the localities Llanvirn, Llandeilo and Llandovery, has long been studied and has influenced the development of the stratigraphy and nomenclature of both the Ordovician and the Silurian systems.

The southern margin of this tract, throughout its length, lies close to the break in slope between the Welsh Basin to the north and west and the shallow marine shelf bordering the Midland Platform to the east and south. Sporadic movement along the Tywi Lineament during the Ordovician seems to have maintained the shelf-to-basin slope (Bevins *et al.*, 1992; Cave and Rushton, 1996), and in consequence the rocks show a variety of lithofacies and biofacies. Fortey and Cocks (1986) indicated that deposition in south-central Wales (e.g. the area around Carmarthen), although not outstandingly thick, was demonstrably more continuous than elsewhere in Wales. In broad outline, arenaceous deposits of shallow-water origin accumulated during the early Arenig transgressive episode and were succeeded by later Arenig and early Llanvirn graptolitic mudstones deposited in deeper water. The later Llanvirn to early Caradoc saw the formation of calcareous and sandy strata of the Llandeilo Flags along the shelf margin, again overlain during the later Caradoc by dark graptolitic mudstones, whilst the contemporaneous basinal rocks to the north consist of turbiditic sandstones with graptolitic mudstone interbeds. Along the shelf margin the Ashgill consists of shelly mudstones and limestones of various lithologies, whereas the contemporaneous basinal beds consist of rapidly deposited sandstones, mudstones and mass-flow deposits.

Although volcanism in South Wales was less extensive and prolonged than in North Wales, there was activity particularly during the Llanvirn (Bevins *et al.*, 1992) and also in the early Caradoc (Cave and Rushton, 1996), and at Builth the volcanic edifice was of sufficient relief to create rapid lateral changes from shelly to graptolitic facies (Jones and Pugh, 1949). The localities are shown in Figure 8.1.

Fortey and Owens (1987) proved that South Wales has the fullest Arenig succession in Wales and used the faunal succession there to propose the Moridunian, Whitlandian and Fennian stages. The basal Arenig is displayed in the west

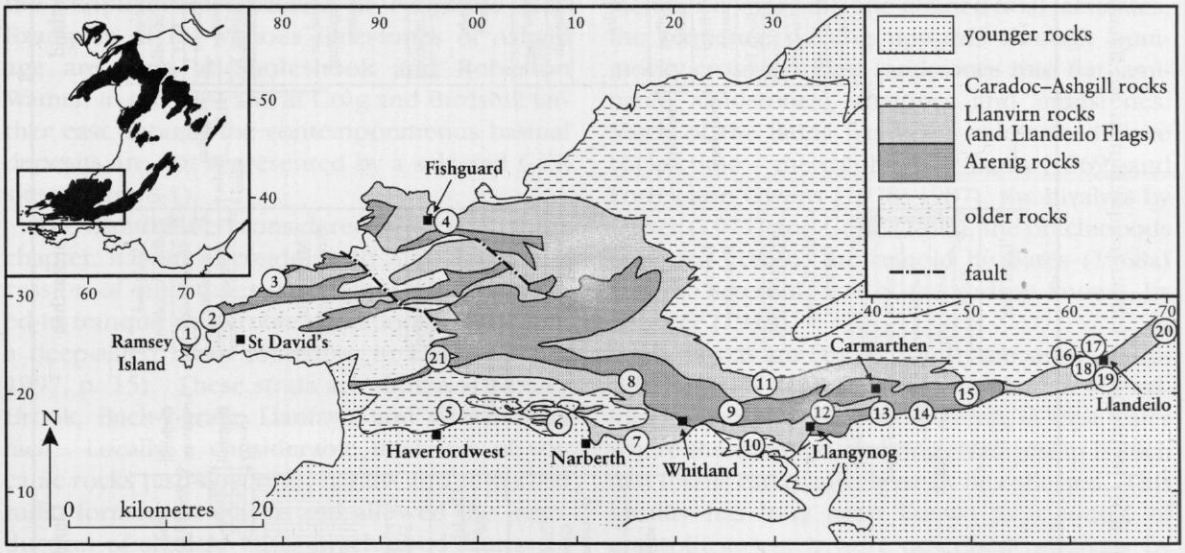

Figure 8.1 Distribution of Ordovician (Arenig to Ashgill) rocks in south-west Wales, after British Geological Survey (1994c). Locations of GCR localities as follows: 1, Ogof Hên and Road Uchaf; 2, Pwlluog; 3, Abereiddi Bay; 4, Abergwaun; 5, Sholeshook; 6, Robeston Wathen; 7, Bryn-banc; 8, Llanfallteg; 9, Pontyfenni; 10, Mylet Road; 11, Meidrim; 12, Dan-lan-y-castell; 13, Glan Pibwr; 14, Allt Pen-y-coed; 15, Cwm yr Abbey; 16, Birdshill; 17, Crûg; 18, Dynevor Park; 19, Ffairfâch; 20, Talar Wen. Also 21, Treffgarne Bridge (Upper Cambrian, see Chapter 4).

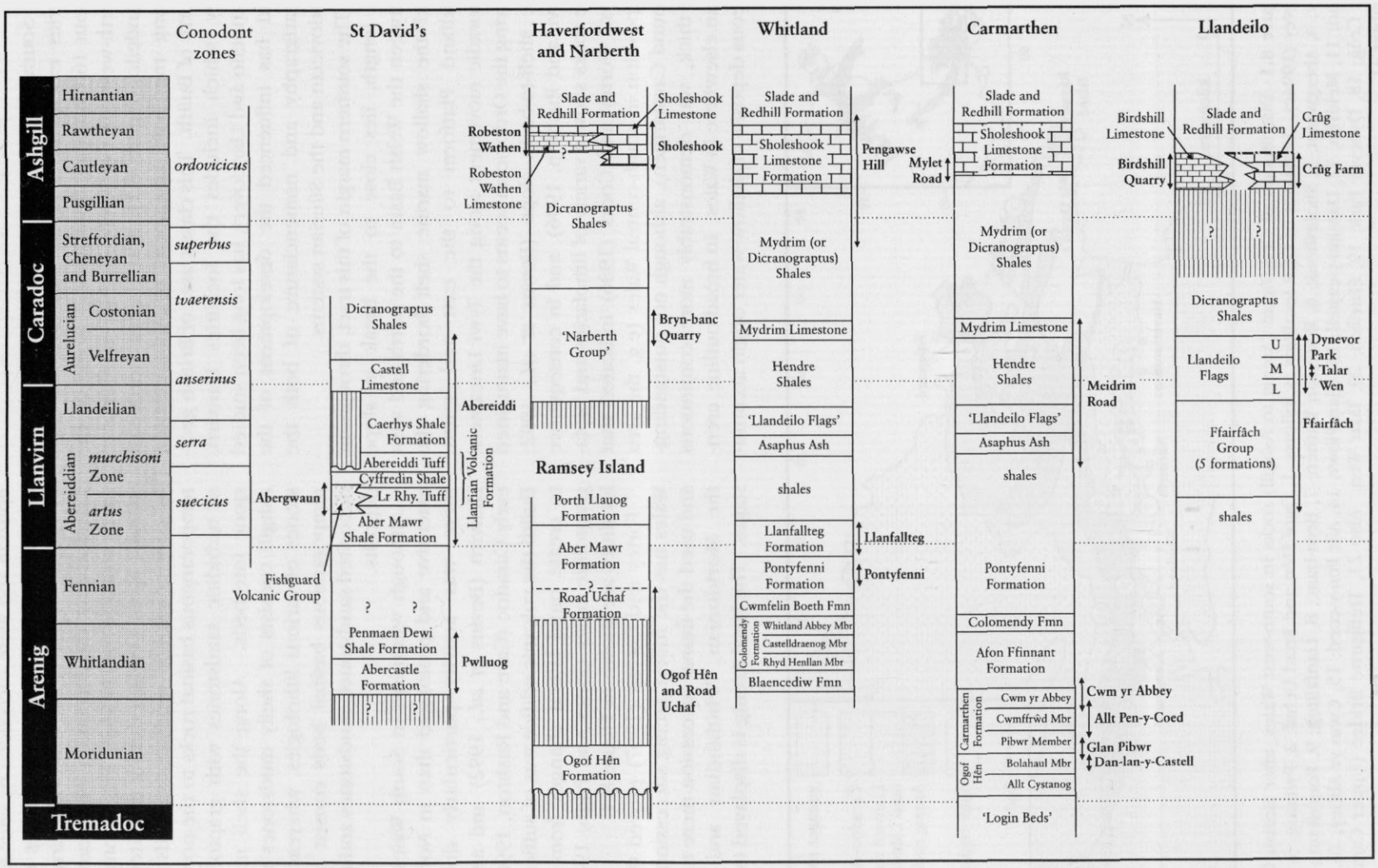

Figure 8.2 Correlation of the principal Arenig to Ashgill successions in south-west Wales, showing the stratigraphical ranges of individual GCR sites. Note that the upper Caradoc stages are not separately distinguished in this figure.

at Ogof Hên and in the Carmarthen area at Danlan-y-castell, where the Bolahaul Member contains a particularly significant shallow-water fauna. In the Carmarthen area, the overlying Carmarthen Formation contains a succession of Moridunian trilobite faunas that inhabited an oxygen-poor environment in a postulated graben (Fortey and Rushton, fig. O4b, in Bevins *et al.*, 1992). This succession is exemplified at Glan Pibwr, Allt Pen-y-coed and Cwm yr Abbey. The Whitlandian is seen at Pwlluog, the Fennian at Pontyfenni and Road Uchaf, and the passage up into the Llanvirn at Llanfallteg (Figure 8.2).

The Llanvirn Series (Abereiddian and Llandeilian stages) is exemplified by the Abereiddi Bay site, which includes Llanvirn itself, and the volcanic pile is biostratigraphically dated at Abergwaun. Farther east the upper Abereiddian is developed in a shallow-water facies and passes up into the Llandeilian at Ffairfâch, the typical Llandeilo Flags being seen at Dynevor Park and Talar Wen. The passage from Llandeilian to Aurelucian (lower Caradoc Series) is shown in a mixed shelly and graptolitic facies at Meidrim and an important calcareous development of the Aurelucian at Bryn-banc Quarry.

Much of the higher Caradoc is developed in dark-coloured graptolitic mudstones. These pass up into the Sholeshook Limestone at Mylet Road, and the same sequence is clearly seen at the supplementary section at Pengawse Hill. Examples of the various limestones of Ashgill age are seen at Sholeshook and Robeston Wathen in the west and at Crûg and Birdshill farther east, though the contemporaneous basinal deposits are not represented by a selected GCR site (Figure 8.1).

The Builth Inlier, considered at the end of this chapter, has an Abereiddian to Aurelucian succession of mudstones (see Figure 8.25) deposited in tranquil dysaerobic conditions, possibly in a deep-silled basin (Sheldon, in Davies *et al.*, 1997, p. 15). These strata are shown at Howey Brook, Bach-y-graig, Llanfawr and Gwern yfed fâch. Locally, a considerable thickness of volcanic rocks (ash-flow tuffs, basalts and reworked tuffs) formed an edifice and allowed the introduction of shallow-water brachiopod faunas to the basin. These are found at the Newmead site, where Jones and Pugh (1949) described an Ordovician shoreline and contemporaneous subaerial erosion of the volcanic pile, and also at Howey Brook.

OGOF HÊN (SM 7060 2508–SM 7085 2522) AND ROAD UCHAF (SM 7052 2434)

Introduction

The coastal section around Ogof Hên includes the type locality for the early Arenig Ogof Hên Formation and is the best representation in South Wales of the transgressive base to the Arenig Series. The fauna from Ogof Hên was described by Hicks (1873), who recognized new species of trilobite, bivalve, hyolithid, crinoid and asteroid. He believed it to be of Tremadoc age. Pringle (1911) demonstrated that the fauna was of Arenig age and later (Pringle, 1930) subdivided the Arenig rocks at Ogof Hên, employing divisions first described by Cox (1915) at Abercastle on the north side of the St David's peninsula, namely the Abercastle Beds (beneath) and Porth Gain Beds (above). Bates (1969) was unable to recognize these divisions, however, and introduced the term Ogof Hên Formation for the entire early Arenig sequence. Kokelaar *et al.* (1985), like Pringle, distinguished two units: a lower Sandstone Member and an upper Mudstone Member, which correspond lithologically to the Abercastle and Porth Gain Beds but are not correlatives of those units at Abercastle. Traynor (1988, p. 280) analysed and described the sedimentary facies, the basal sandstone member comprising fine grained tidal laminates, the sequence passing upwards through hummocky cross-stratified sandstones into flat laminated sandstones, siltstones and mudstones. Much of the fauna has been redescribed since Hicks' time – the trilobites by Bates (1969) and Fortey and Owens (1978, 1987), the bivalves by Carter (1971) and Cope (1996), the brachiopods by Bates (1969), the crinoid by Bates (1968a) and the asteroid, one of the earliest known, by Spencer (1918).

About 0.8 km farther south, the small, steep-sided inlet of Road Uchaf is one of the few localities in the upper part of the Arenig in west Wales where the cleavage–bedding relationship is such that fossils can relatively easily be collected. This locality has long been known as a source of graptolites, which were described originally by Hopkinson and Lapworth (1875), and is the type locality for several of Hopkinson's species, of both graptoloids and dendroids. Some of these have been revised subsequently by Elles and Wood (1901), Bulman (1927–1967), Jenkins

(1982) and Fortey and Owens (1987). Comparatively deep-water conditions have been inferred for the deposition of the Road Uchaf Formation, typically developed here; it is one of the few horizons in the Arenig of Wales to have yielded isograptid graptolites, which are valuable for long-distance correlation.

Description

The Ogof Hên Formation crops out extensively on the cliff-tops of the north-east tip of Ramsey Island (Figure 8.3). The sequence is 190 m thick and is predominantly of siltstones and fine sandstones with silty mudstones and shales that dip between 60° and 80° to the north-west; the lower part comprises laminated fine sandstones and silty mudstones, the upper, silty mudstones and dark mudstones. It overlies the '*Lingula* Flags' (Ogof Velvet Formation of Kokelaar *et al.*, 1985) with a slight angular unconformity (around 7085 2518). At the base of the Ogof Hên Formation a discontinuous pebbly sandstone up to 20 cm thick contains whole and fragmented phosphatic oncoliths (formerly described as the bryozoan *Bolopora undosa* Lewis). The Sandstone Member comprises laminated, well-sorted fine sandstones and silty mudstones with cross-lamination, burrows and *Cruziana*-type trails. The blue-grey silty mudstones of the Mudstone Member are 100 m thick and lack the abundant bioturbation and well-defined lamination of the Sandstone Member. They are richly fossiliferous, some bands being charged with brachiopods and trilobites. Most of the fossils have suffered such distortion that Hicks discriminated several species that are now considered synonyms. According to Bates (1969, p. 6), most of the fauna occurs between about 15 m and 25 m above the base of the Mudstone Member, with the brachiopod *Paralenorthis alata* (J. de C. Sowerby) ranging throughout much of the succession. This species, the trilobites *Merlinia murchisoniae* (Murchison) and *Neseuretus ramseyensis* Hicks and the crinoid *Ramseyocrinus cambriensis* Hicks are also known from the Ogof Hên Formation in the Carmarthen district, although the fauna is not as diverse as that at Dan-lan-y-castell (see site report).

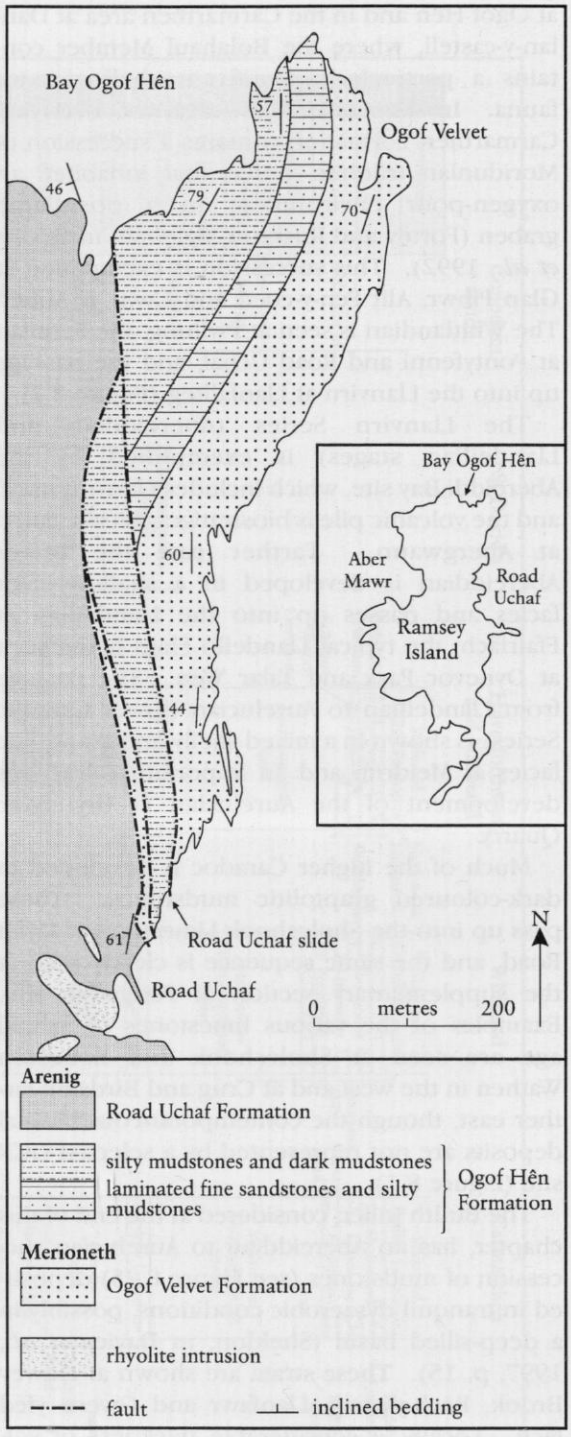

Figure 8.3 Geological map of Ogof Hên and Road Uchaf, including the type section of the Ogof Hên Formation, after Kokelaar *et al.* (1985).

At Road Uchaf (Figure 8.3) the Ogof Hên Formation is overlain by black, strongly cleaved mudstones of the Road Uchaf Formation, whose fauna indicates an early Fennian age. The absence on Ramsey Island of any intervening late Moridunian and Whitlandian strata has been explained through their removal by penecontemporaneous (Llanvirn) wet-sediment sliding

(Kokelaar *et al.*, 1985, p. 594). In the outcrops in Road Uchaf, cleavage and bedding are more or less coincident, and an extensive fauna of graptolites has been obtained; this is the type locality for the following of Hopkinson's species: *Didymograptus* (*Expansograptus*) *sparsus*, *Pseudisograptus stella*, *Ptilograptus hicksii*, *P. cristula*, *Dendrograptus flexuosus*, *D. arbusculus*, *D. divergens*, *D. diffusus*, *Dictyonema homfrayi* and *Callograptus radicans*.

Interpretation

On Ramsey Island, as elsewhere, the Ogof Hên Formation represents a shallow-water transgressive sequence, and the present site is valuable for showing the unconformable base on the underlying Cambrian. Care is needed in interpreting the basal contact: Bates (1969) erroneously included the lowest 40 m of the Ogof Hên Formation, that is, the Sandstone Member of Kokelaar *et al.* (1985), in the '*Lingula* Flags' (Kokelaar *et al.*, 1985, p. 594), and his '*Bolopora*' horizon was identified by the latter authors as weathered-out carbonate nodules. The upwardly fining sequence suggests deepening of the marine environment (Kokelaar *et al.*, 1985, p. 594), although no great depth is implied for the whole succession. On the basis of his analysis of the sedimentology, Traynor (1988, p.281) reached a similar conclusion, with the sequence indicating progressive deepening from tide-dominated to storm-dominated deposits, through a wave-influenced water column.

The fauna is of early Arenig (Moridunian) age and is correlated with the Bolahaul Member of the Carmarthen Formation (Fortey and Owens, 1987, p. 93). It represents a typical *Neseuretus* community (Fortey and Owens, 1978, p. 238), though the absence of many of the taxa found at Dan-lan-y-castell may reflect a slightly different environment or, alternatively, poorer preservation and less intensive collecting. Similar *Neseuretus* community faunas of Moridunian age occur in the Mytton Flags Formation of Shropshire and in the Henllan Ash of the Arenig district, but different species are present, because of differences in either age, or environment, or both.

The Road Uchaf Formation represents a significantly deeper-water environment, and the presence of the isograptid graptolites *Pseudisograptus stella* and *Isograptus caduceus* (Salter) indicates the presence of the offshore isograptid biofacies. The association of *Pseudisograptus* and *I. caduceus* is restricted to the Upper Castlemainian (Ca3) and Yapeenian of Australia (Cooper, 1973) and thus affords a valuable intercontinental correlation datum. The total graptolite fauna shows that the Road Uchaf Formation is of late Arenig (Fennian) age. It probably belongs to the earlier part of the stage, for higher strata on the west side of Ramsey Island, at Aber Mawr (Kokelaar *et al.*, 1985, p. 595), have yielded a fauna similar to that of the Fennian at Pontyfenni (see site report for Pontyfenni).

Conclusions

Ogof Hên has the best exposure in South Wales of the transgressive base of the Arenig succession. The Ogof Hên Formation rests unconformably on the Cambrian and contains a historically and stratigraphically important fauna of shelly fossils that allow correlation with the succession in the Carmarthen area. The Road Uchaf Formation is the only known example in the Arenig of South Wales of the isograptid biofacies and is thus important from a palaeobiogeographical point of view.

DAN-LAN-Y-CASTELL (SN 3640 1639)

Introduction

The quarry at Dan-lan-y-castell is of special importance on account of the diverse fauna obtained there. The locality lies in the northern part of the Llangynog Inlier of Precambrian to Arenig rocks (Cope, 1982) and exposes early Arenig (Moridunian Stage) siltstones and mudstones belonging to the Bolahaul Member of the Ogof Hên Formation. It was noted by Cantrill and Thomas (1906, p. 227) and Thomas (in Strahan *et al.* 1909, p. 16), who listed a meagre fauna and assigned the rocks to the 'Tetragraptus Beds'. Exhaustive collecting by Dr J.C.W. Cope from over 20 tonnes of rock has afforded the largest and most diverse early Arenig fauna known in Britain. Especially important and dominant is the large bivalve fauna, among which are the earliest known representatives of several major groups.

Description

A small disused quarry 500 m SSE of Dan-lan-y-castell Farm shows interbedded siltstones and mudstones of the Bolahaul Member (Arenig, Moridunian Stage), overlying conglomerates of the Allt Cystanog Member of the Ogof Hên Formation. Thin stringers of conglomerate and occasional pebbles occur within the Bolahaul Member, and bioturbation is widespread.

The fauna includes the stratigraphically important trilobites *Merlinia murchisoniae* (Murchison), *Ampyx cetsarum* Fortey and Owens and *Neseuretus ramseyensis* Hicks (see Fortey and Owens, 1978, 1987), along with the brachiopod *Paralenorthis alata* (J. de C. Sowerby). Especially interesting is the rich bivalve fauna (Figure 8.4a), described by Cope (1996), and comprises abundant actinodontoids together with palaeotaxodonts, rarer modiomorphoids, and the earliest representatives of the anomalodesmatans, cyrtodontoids, solemyoids and pterioids. Many of the taxa were recognized for the first time from this locality, including 12 species and nine genera, two families, two superfamilies and one order, and the fauna forms the basis of Cope's major reassessment of the early history, diversification and high-level classification of the Class Bivalvia. In addition, the fauna includes the earliest known bryozoan from Britain (Taylor and Cope, 1987) and a parablastoid (Paul and Cope, 1982), orthoconic nautiloids, gastropods, monoplacophorans, a rostroconch, dendroid graptolites, conulariids, hyolithids and several other groups (Cope, 1996). Riding *et al.* (1998) described *Arenigiphyllum*, the oldest definite example of a calcified red alga, from this quarry.

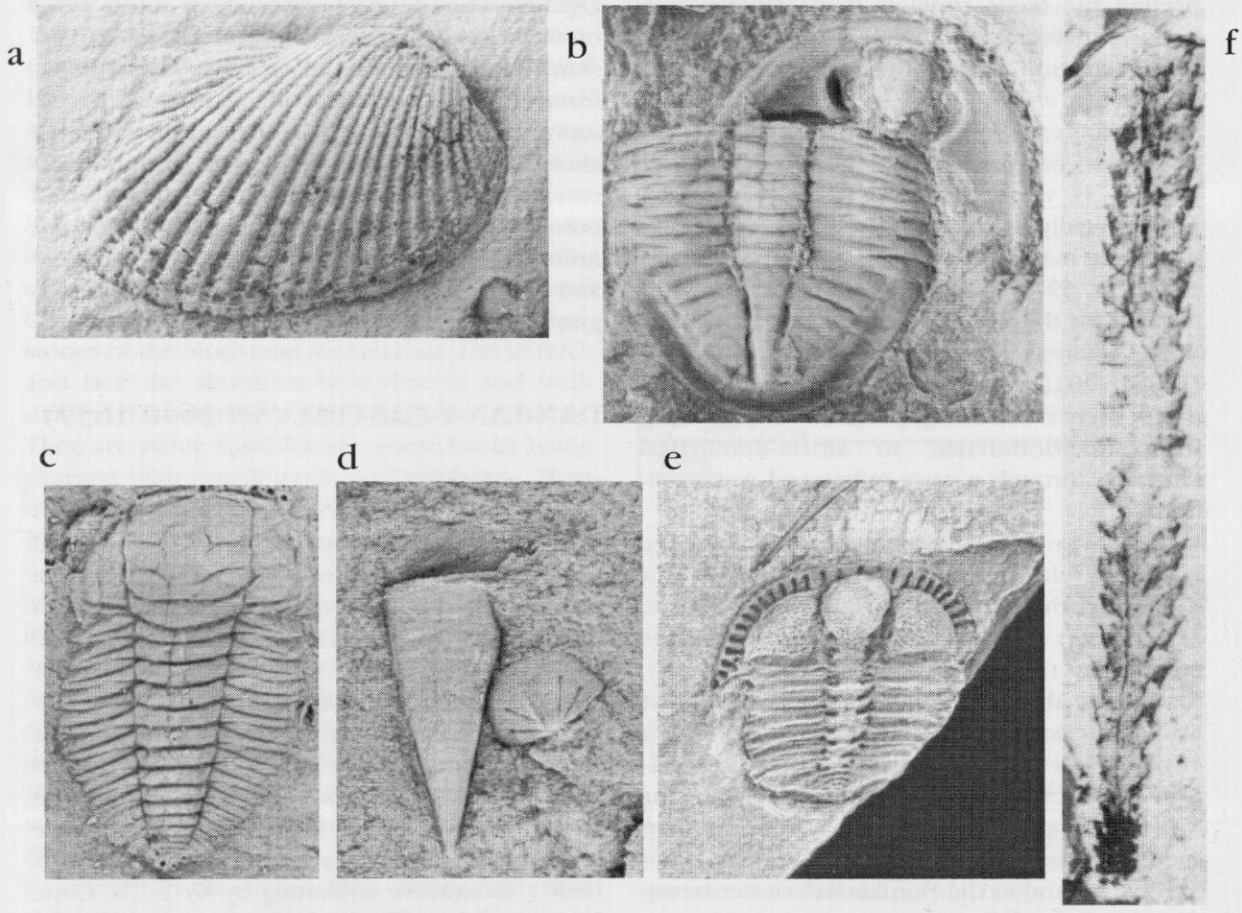

Figure 8.4 Fossils from Arenig and Llanvirn sites in South Wales. (a) *Falcatodonta costata* Cope, ×4.5, from the Bolahaul Member (Moridunian) at Dan-lan-y-castell. (b) *Merlinia selwynii* (Salter), ×2.5, Pibwr Member (Moridunian), Glan Pibwr. (c) *Porterfieldia punctata* (Crosfield and Skeat), ×8, Cwm yr Abbey Member (Moridunian), Cwm yr Abbey. (d) Hyolithid conch and operculum, ×5, and (e) *Bergamia rushtoni* Fortey and Owens, × 3.5, both from the Pontyfenni Formation (Fennian), Pontyfenni. (f) *Undulograptus austrodentatus* (Harris and Keble), ×6, Llanfallteg Formation (basal Abereiddian), Llanfallteg.

Interpretation

The Ogof Hên Formation is interpreted as being deposited in a transgressive inshore, shallow-water environment, the fauna of which was described as the *Neseuretus* community by Fortey and Owens (1978). The early Arenig age of the sediments is determined by the species of the trilobites *Merlinia, Ampyx* and *Neseuretus*, most of which are common to several localities in the Ogof Hên Formation of the Carmarthen district and in Pembrokeshire. The diverse bivalve fauna is known only from Dan-lan-y-castell. Cope (1996) considered that exceptional diversity occurs here because the sediments were deposited in an environment close inshore, such as is not often preserved in the geological record, and that it may represent a habitat where major evolutionary change was occurring.

Conclusions

Dan-lan-y-castell is a site of international palaeontological significance because it provides a unique 'window' on a close-inshore facies, such as is not commonly preserved. The Arenig shelly fauna is uniquely rich and includes the earliest species of certain animal groups and, especially, a rich bivalve fauna that has an important bearing on the early evolution of the Class Bivalvia.

GLAN PIBWR (SN 4162 1794–SN 4189 1798)

Introduction

This section supplements the larger exposure at Allt Pen-y-Coed because it displays the lower part of the Pibwr Member, which is not exposed there; it furnishes the basal stratotype of the Pibwr Member of the Carmarthen Formation. Glan Pibwr has yielded the best-preserved trinucleid trilobites from this unit and the only graptoloid graptolites from the Carmarthen Formation.

The section was described briefly by Crosfield and Skeat (1896), who identified the common asaphid trilobite as '*Ogygia marginata*'; Stubblefield (1933) applied the name '*Ogygia marginata* Beds' for the Arenig mudstones at Glan Pibwr and elsewhere in the Carmarthen district. These were later formally described as the Pibwr Member of the Carmarthen Formation by Fortey and Owens (1978), and they synonymized *Ogygia marginata* with *Merlinia selwynii* (Salter), a species that occurs also in the early Arenig of North Wales. Glan Pibwr is effectively the type locality for Stubblefield's '*Ogygia marginata* Beds' and is the only permanent section in which the lower part of the Pibwr Member is exposed.

Description

Exposures occur on the floor of and along the side of an old lane to the south and south-west of Glan Pibwr Cottage (Figure 8.5). The base of the Pibwr Member is drawn at the lowest beds exposed in the lane (4169 1798) (Fortey and Owens, 1978, p. 234), overlying 5–6 m of shales that are transitional in character from those of the underlying Bolahaul Member of the Ogof Hên Formation. The succeeding black mudstones typical of the remainder of the Pibwr Member are well-seen in the bank exposure at SN 4162 1794. The lowest beds have yielded asaphid trilobites (*Merlinia selwynii*, Figure 8.4b), well-preserved trinucleid trilobites (*Myttonia* cf. *fearnsidesi* Whittington) and graptolites (*Phyllograptus* cf. *densus* Törnquist and *Pseudophyllograptus* aff. *angustifolius* (Hall)). The higher mudstones are rich in *Merlinia selwynii* and infaunal bivalves (nucluloids and

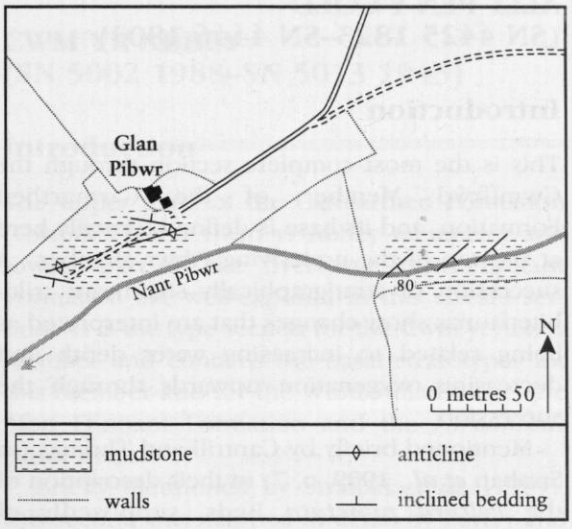

Figure 8.5 Location of exposures in the lower part of the Pibwr Member, after Fortey and Owens (1978, fig. 4). The base of the Pibwr Member and of the Carmarthen Formation are taken here.

'*Actinodonta*' aff. *naranjoana*), with occasional raphiophorid trilobites (*Ampyx cetsarum* Fortey and Owens, for which this is the type locality).

Interpretation

The Pibwr Member is interpreted by Fortey and Owens (1978) as an upwardly deepening sequence. The fauna, although locally abundant, is restricted in diversity, and there is a lack of surface-living sessile benthos such as characterizes the underlying Ogof Hên Formation. Instead, infaunal bivalves are frequent, especially in the lower part, attesting to a soft but not anaerobic substrate. The morphology of the trilobites is regarded as an adaptation to soft sediments. The trilobite association of the Pibwr Member was named the Raphiophorid community by Fortey and Owens (1978).

Conclusions

This locality is significant in affording exposures of the lowest division of the Arenig Carmarthen Formation and is the only one known from this part of the sequence to yield well-preserved trinucleid trilobites, graptoloid graptolites and infaunal bivalves. It also complements the Allt Pen-y-Coed site in having exposures of horizons lower in the Pibwr Member than any seen there.

ALLT PEN-Y-COED (SN 4425 1823–SN 4446 1803)

Introduction

This is the most complete section through the Cwmffrŵd Member of the Carmarthen Formation, and its base is defined formally here at the top of the underlying Pibwr Member. A succession of stratigraphically significant trilobite faunas show changes that are interpreted as being related to increasing water depth and decreasing oxygenation upwards through the succession.

Mentioned briefly by Cantrill and Thomas (in Strahan *et al.*, 1909, p. 7) in their description of the *Peltura punctata* Beds, supposedly of Tremadoc age, this section was discussed in detail by Fortey and Owens (1978, p. 234), who mapped the succession and figured the characteristic trilobite fauna; they recognized the two lower members of the Carmarthen Formation, which are particularly well-exposed here. It is the only section that shows well the upward passage from the Pibwr Member into the Cwmffrŵd Member and is thus one of the key localities in the interpretation of the stratigraphy and palaeoenvironments of the early Arenig in South Wales.

Description

Allt Pen-y-Coed is a steep-sided wooded dingle that runs parallel to a minor road a short distance to the south of the A48 trunk road 0.8 km WSW of Nant-y-Caws. The section is some 320 m long, with more or less continuous exposure (Figure 8.6). The succession youngs to the south-east, dipping generally south to south-east at 60–70° (Fortey and Owens, 1978, fig. 5, p. 235). In the northern part of the section the upper part of the Pibwr Member crops out as a monotonous series of black, well-bedded mudstones, in beds 5–15 cm thick, weathering to show an iridescent dark purplish or umber film. Asaphid trilobites (*Merlinia selwynii* (Salter)) are the commonest fossils; nuculoid bivalves, very common in the lower part of the Pibwr Member at Glan Pibwr (see site report), are present here, but become progressively rarer up the succession. Rare olenid (*Bienvillia praecalva* Fortey and Owens) and trinucleid (*Myttonia* cf. *fearnsidesi* Whittington) trilobites also occur.

Approximately midway along the section the mudstones of the Pibwr Member give way to the sequence of alternating turbidites and shales of the Cwmffrŵd Member; its base is drawn formally at the base of the lowest turbidite exposed in Allt Pen-y-Coed at 4437 1809. The turbidites vary from a few centimetres to over a metre thick and are generally separated by an equal or slightly greater thickness of dark-grey or black mudstones or shales. The turbidites are generally well-graded, with quartz and feldspar clasts in a dark siliceous matrix. Towards the mid part of the Cwmffrŵd Member the turbidites increase greatly in thickness (up to 2 m) at the expense of the shales and in Allt Pen-y-Coed give rise to a series of waterfalls where the stream runs through a steep-sided gorge. Fossils are confined to the shales and mudstones and include *Bienvillia praecalva* (in greater abundance than in the Pibwr Member), *Merlinia rhyakos* Fortey and Owens (common) and a rare olenid *Hypermecaspis venerabilis* Fortey and Owens, for which this is the type locality.

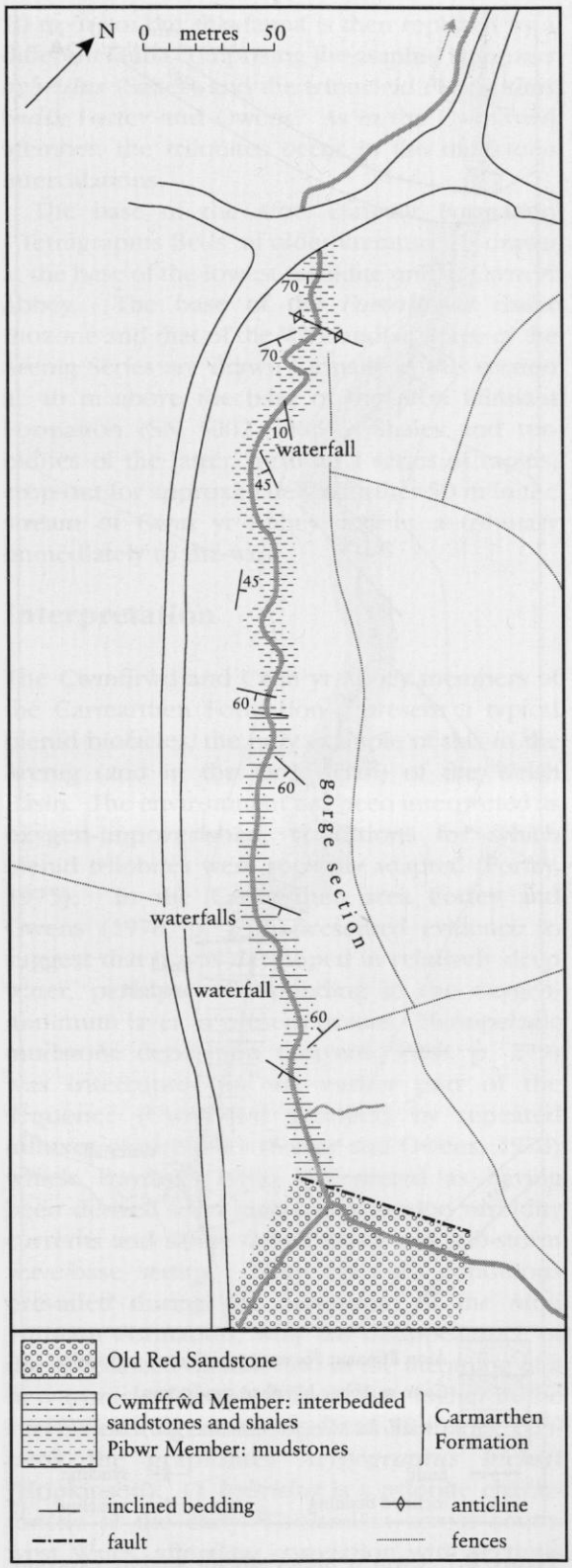

Figure 8.6 Allt Pen-y-coed stream section, exposing the basal stratotype of the Cwmffrŵd Member, the middle member of the Carmarthen Formation, after Fortey and Owens (1978, fig. 5).

Interpretation

Fortey and Owens (1978) presented evidence for an upwardly deepening sequence in the lower Arenig of the Carmarthen district, on the basis of changing lithologies and faunas. The Pibwr Member contains what they termed the Raphiophorid community, including trilobites of low convexity with a high ratio of ventral surface area/volume (e.g. *Merlinia*) or with long genal spines (*Myttonia*): these and the associated infaunal bivalves show adaptations to soft-surface sediments.

High in the Pibwr Member, at Allt Pen-y-Coed, small numbers of the first olenids (*Bienvillia praecalva*) appear, but in the overlying Cwmffrŵd Member these become dominant; this trilobite has been interpreted as being adapted to oxygen-poor and relatively deep water and characterizes the Olenid Community.

Conclusions

With its long sections through part of the Arenig Carmarthen Formation, Allt Pen-y-Coed demonstrates the zones and local environmental changes during the early Arenig. It is a key section for interpreting the biostratigraphy and facies distribution and is a locality that shows well the olenid biofacies, whose occurrence in the Arenig is limited to this part of the Welsh Basin.

CWM YR ABBEY (SN 5002 1988–SN 5013 1943)

Introduction

The upper parts of the Carmarthen Formation (Cwmffrŵd and Cwm yr Abbey members) and lowest part of the overlying Afon Ffinnant Formation are well-exposed in this stream section. It is the type section for the Cwm yr Abbey Member and contains the basal stratotypes for this member and for the Whitlandian Stage, the Afon Ffinnant Formation and the *Furcalithus radix* Zone.

Briefly mentioned by Strahan *et al.* (1909), this section was mapped in detail by Fortey and Owens (1978, fig. 5, p. 235), who demonstrated the presence here of the upper part of the Carmarthen Formation and its passage upwards into the Afon Ffinnant Formation (Fortey and Owens, 1987, p. 96). The good and mostly con-

tinuous exposure makes this an ideal section in which to demonstrate these relationships in an area where natural outcrops are few and generally small; it has afforded sufficient fossils (trilobites) to establish the biostratigraphical framework. The facies exposed here were used in the regional analysis of Arenig sedimentology by Traynor (1988).

Description

Cwm yr Abbey, a deep, wooded dingle that flows northwards into the Tywi (Figure 8.7), has long exposures interspersed at intervals with short stretches of non-exposure. The strata generally dip north at about 60°, although there is a good deal of minor folding and faulting. The oldest strata, the upper part of the Cwmffrŵd Member, crop out for about 100 m along the southernmost part of the dingle. As elsewhere, the Cwmffrŵd Member here comprises alternating mudstones and turbidites, the latter ranging in thickness from a few centimetres to over one metre; commonly they show graded bedding that confirms the northward younging of the succession. Fossils are restricted to the mudstone bands and include the asaphid trilobite *Merlinia rhyakos* Fortey and Owens, for which this is the type locality, and the olenid trilobite *Bienvillia praecalva* Fortey and Owens. Near the top of the Cwmffrŵd Member, a different olenid, *Porterfieldia punctata* Crosfield and Skeat (Figure 8.4c), replaces *B. praecalva.*

The base of the Cwm yr Abbey Member (the uppermost unit of the Carmarthen Formation) is drawn formally at the top of the uppermost turbidite unit (5010 1952). Characterized by grey, irregularly fracturing mudstone, the Cwm yr Abbey Member represents the '*Peltura punctata* Beds' *sensu stricto* of older literature. The characteristic olenid trilobite *Porterfieldia punctata* is common throughout the member, accompanied by less frequent *Merlinia rhyakos*, orthoconic nautiloids and the dendroid graptolite *Callograptus* cf. *tenuis* Bulman. The uppermost beds of the Cwm yr Abbey Member are exposed for some 10 m downstream from the road bridge (B4300) and become progressively more shaly and conspicuously micaceous, passing upwards into the Afon Ffinnant Formation.

Lithologically the alternating shales and turbidites of the Afon Ffinnant Formation are indistinguishable from those of the Cwmffrŵd Member, and *P. punctata* occurs in the lowest

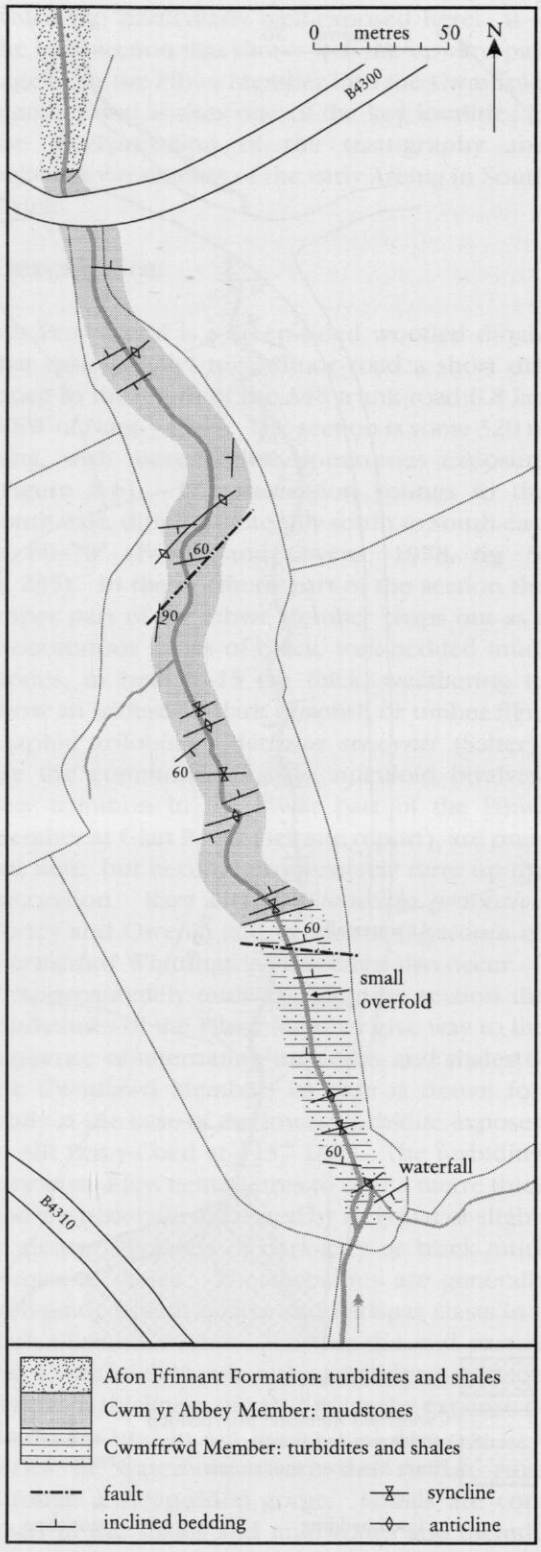

Figure 8.7 Cwm yr Abbey stream section, exposing the type section of the Cwm yr Abbey Member of the Carmarthen Formation and the stratotype base of the Whitlandian Stage, after Fortey and Owens (1978, fig. 5).

10 m or so; but this fauna is then replaced by a different fauna comprising the asaphid *Ogyginus hybridus* (Salter) and the trinucleid *Furcalithus radix* Fortey and Owens. As in the Cwmffrŵd Member, the trilobites occur in the mudstone intercalations.

The base of the Afon Ffinnant Formation ('Tetragraptus Beds' of older literature) is drawn at the base of the lowest turbidite unit at Cwm yr Abbey. The base of the *Furcalithus radix* Biozone and that of the Whitlandian Stage of the Arenig Series are drawn formally in this section at 40 m above the base of the Afon Ffinnant Formation (SN 5002 1985). Shales and turbidites of the latter, forming a series of rapids, crop out for approximately a further 50 m in the stream of Cwm yr Abbey and in a tributary immediately to the west.

Interpretation

The Cwmffrŵd and Cwm yr Abbey members of the Carmarthen Formation represent a typical olenid biofacies, the only example of this in the Arenig (and in the Ordovician) of the Welsh Basin. The environment has been interpreted as oxygen-impoverished, conditions for which olenid trilobites were specially adapted (Fortey, 1975). In the Carmarthen area Fortey and Owens (1978, p. 238) presented evidence to suggest that it was developed in relatively deep water, perhaps corresponding to the oxygen-minimum layer in present oceans. Hemipelagic mudstone deposition (Traynor, 1988, p. 279) was interrupted in the earlier part of the sequence (Cwmffrŵd Member) by repeated influxes of turbidites (Fortey and Owens, 1978) which Traynor (1988) interpreted as having been derived from high concentration turbidity currents and sandy debris flows in a sub-storm wave-base setting. More open-sea conditions prevailed during the deposition of the Afon Ffinnant Formation, with the disappearance of the specialized olenids and in the incoming of a new trinucleid–asaphid fauna that, higher in the succession (e.g. at nearby Cwm Ffinnant), contains the graptolites *Azygograptus hicksii* (Hopkinson). *O. hybridus* is a trilobite characteristic of the early Whitlandian across south-west Wales, affording correlation with sections in the Whitland district to the west. The olenid biofacies is restricted to the Carmarthen district, rendering correlation outside that area rather imprecise.

Conclusions

The section at Cwm yr Abbey shows lithological and faunal changes that reflect an environmental shift from the poorly oxygenated conditions of the Olenid biofacies to better-oxygenated conditions characterized by trinucleid-asaphid faunas. The latter are typical of the Whitlandian Stage whose base is defined in this section.

PWLLUOG (WHITESAND BAY) (SM 7319 2734–SM 7302 2759)

Introduction

Pwlluog, an inlet at the northern end of Whitesand Bay, affords the best and most accessible exposure of strata of mid-Arenig (Whitlandian) age in south-west Wales. It has for over a century been renowned as a source for dendroid graptolites and has also yielded numerous trilobites; it is the type locality for several species of each.

The section was described originally by Hicks (1875a), who differentiated 'Lower' and 'Middle' Arenig strata here, representing the first identification of rocks of this age in south-west Wales; Hicks' 'Upper Arenig' is now included largely within the Llanvirn Series and is not exposed in Pwlluog. With Hicks' and Hopkinson's investigations in the early 1870s, rich faunas of graptolites and trilobites were found, and the former were described by Hopkinson and Lapworth (1875); the trilobites had been described some years earlier by Salter (1866b, 1864–1883). The entire trilobite fauna was revised by Fortey and Owens (1987) and parts of the graptolite fauna by Bulman (1927–1967) and by Beckly and Maletz (1991).

The term 'Penmaen Dewi Shale Formation' was used for Hicks' 'Lower' and 'Middle' Arenig in a field guide (Hughes *et al.*, 1982). On the basis of its fauna, Fortey and Owens (1987) were able to correlate the Penmaen Dewi Formation at Pwlluog with the Whitlandian. It is the type locality for several fossils diagnostic of this stage, such as the trilobites *Gymnostomix gibbsii* (Salter), *Bohemopyge scutatrix* (Salter), *Cyclopyge grandis grandis* (Salter) and *Cnemidopyge salteri* (Salter) and the graptolite *Azygograptus hicksii* (Hopkinson). Whilst the Penmaen Dewi Formation is well exposed at Pwlluog, its base is a faulted contact there, and the base is defined formally at Porth Gain (Fortey

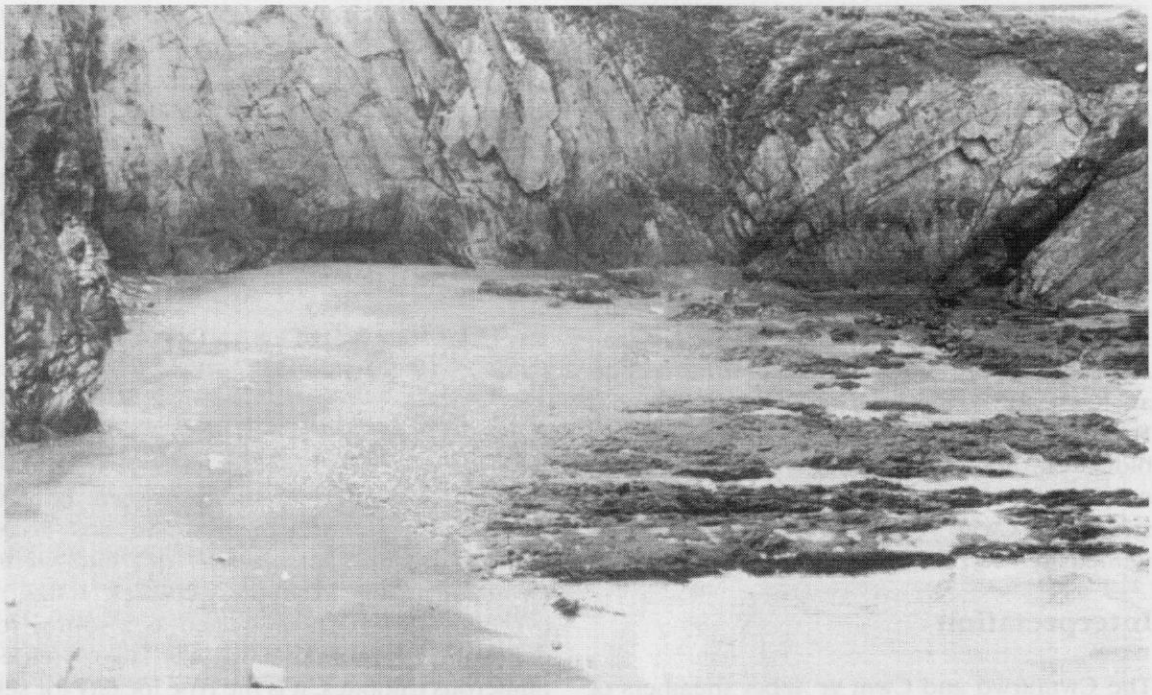

Figure 8.8 Pwlluog, St David's, south-east corner. To the extreme left and on the foreshore are dark, almost vertical, shales of the Penmaen Dewi Formation. In the background, on the northern side of Trwynhwrddyn, are grey, silty sediments probably referable to the Abercastle Formation, faulted against the Penmaen Dewi Formation in the corner of the inlet. (Photo: R.M. Owens.)

and Owens, 1987, p. 96). However, Pwlluog is regarded as the body stratotype of the Penmaen Dewi Formation and is the only locality at which the succession and faunas can readily be examined. Following the revision of the stratigraphy by Fortey and Owens (1987), Traynor (1988) used this as one of the sections for his analysis of the sedimentology of the Arenig in south-west Wales.

Description

The promontory of Trwynhwrddyn forms the southern end of the inlet of Pwlluog, which itself is divided by a smaller promontory into northern and southern parts. Much of Trwynhwrddyn is formed of Upper Cambrian 'Lingula Flags', which on its southern side contains occasional bands crowded with *Lingulella* sp. or with *Hymenocaris*. The nature of the junction with the Arenig has been controversial (Jones, 1940; Evans, 1948), but the presence of a thin conglomerate on the neck of the promontory (around 7320 2735) suggests that it is unconformable. The sandy and silty Arenig sediments on Trwynhwrddyn itself have been assigned to the Ogof Hên Formation, of early Arenig (Moridunian) age, although nowhere have they yielded any trace of the rich brachiopod–trilobite fauna characteristic of this formation on nearby Ramsey Island (Bates, 1969) and in the Carmarthen district (Fortey and Owens, 1978, 1987). Lithologically they closely resemble the Abercastle Formation at Abercastle (Fortey and Owens, 1987, p. 94), which is where they were included by those authors, although this correlation remains to be proved.

In Pwlluog, some 600 m of dark-coloured shales and slates dip north between 60° and 90°. The lowest beds of the Penmaen Dewi Formation are faulted against the supposed Abercastle Formation in the south-east corner (7327 2738) (Figure 8.8), but how much of the succession is missing is not known. Steeply dipping bedding planes in the cliffs between 10 m and 15 m north of the fault have yielded *Callograptus*, poorly preserved trinucleid trilobites (probably *Furcalithus*), small lingulate brachiopods, orthoconic nautiloids and occasional articulate brachiopods; none of this fauna is age-diagnostic. From about 25 m north of the fault and as far as the small promontory in the centre

of Pwlluog, volcaniclastic sandstones in beds up to 50 cm thick are prominent, especially on the wave-washed platform on the beach. They commonly show grading and may contain scattered mudstone clasts. The sediments are invaded by occasional thin intrusions of intermediate composition. On the south side of the small promontory (around 7321 2746), dendroid graptolites and lingulate brachiopods occur. The promontory marks the approximate boundary between Hicks' 'Lower' and 'Middle' Arenig, and that part of Pwlluog to the south of it is the type locality for several of Hopkinson's dendroid graptolite species (Hopkinson and Lapworth 1875), for example *Dendrograptus arbusculus, Callograptus radiatus* and *Dictyograptus cancellatus*, but the precise levels from which these originated is not known.

On the north side of the promontory (7318 2748) a nearly vertical bedding plane facing a prominent stack of thick, slightly graded silicic tuff has long been known as a source of both graptoloid and dendroid graptolites, including *Tetragraptus* spp., *Azygograptus hicksii* and *Callograptus*. The type locality for *A. hicksii* and *Aspidograptus implicatus* Hopkinson must lie hereabouts.

The mudstones and shales of the northern part of Pwlluog are Hicks' 'Middle Arenig', and they contain fewer volcaniclastic sandstone beds and a few intermediate intrusions; one of these stands slightly proud of the softer Arenig shales (7318 2755). The cliff top (around 7315 2760) is probably the site of the 'slate quarry' referred to by Hicks (1875a) as a source for much of the trilobite fauna from Pwlluog. In the cliffs hereabouts some bands are crowded with mostly disarticulated trilobites, including *Gymnostomix gibbsii* (Salter), *Furcalithus sedgwickii* (Salter), *Cyclopyge grandis grandis* (Salter) and *Cnemidopyge salteri* (Salter), together with occasional articulate brachiopods, hyolithids and dendroid graptolites. Similar horizons crop out at the beach level (e.g. around 7310 2758), where the above fauna and *Shumardia gadwensis* Fortey and Owens occur; the latter has also been reported from shales metamorphosed by a nearby gabbro intrusion, on the north side of Craig y Creigwyr (7302 2759).

Interpretation

In general, the monotonous muddy sedimentation in the lower part of the succession is dominated by a dendroid graptolite fauna, accompanied by occasional lingulate brachiopods and trilobites. The repeated influxes of volcaniclastic sandstone and the silicic tuff of the stack in the centre of Pwlluog are evidence of volcanic activity in the general vicinity (e.g. Traynor, 1988, p. 282), although the location of the volcanic centre is not known. The presence of trilobite faunas comprising cyclopygids and small-eyed and blind taxa indicates the presence of the cyclopygid biofacies and an atheloptic fauna, suggestive of deep, offshore conditions (Fortey and Owens, 1987; Traynor, 1988, p. 282). It is possible that the whole succession at Pwlluog represents gradual deepening upwards, and higher beds in the Arenig sequence exposed elsewhere (see Road Uchaf site report) were certainly deposited in a deep, offshore environment. *Azygograptus hicksii,* however, may be a comparatively inshore species (Beckly and Maletz, 1991), suggesting that the lower half of the sequence may have been deposited in relatively shallower waters.

Gymnostomix gibbsii, Shumardia gadwensis, Bohemopyge scutatrix and *Cyclopyge grandis grandis* are widespread indicators of Whitlandian strata, being reported farther eastwards in South Wales (Fortey and Owens, 1987) and in North Wales (Beckly, 1988).

Conclusions

Pwlluog is the best locality in South Wales for the Whitlandian fossils that are used to characterize the middle division of the Arenig Series.

PONTYFENNI, WHITLAND (SN 2379 1690–SN 2381 1693)

Introduction

The dark, blocky mudstones exposed at Pontyfenni are the type development of the Pontyfenni Formation of late Arenig (Fennian) age, and this locality is internationally important, having yielded by far the richest Fennian fauna. Prolonged collecting has yielded a diverse, though not abundant, fauna, chiefly of trilobites and graptolites. The trilobites are palaeontologically significant: they include the earliest known representatives of several genera. Many specimens are well preserved, and a high proportion are articulated. It is on the basis of

fossils recovered from Pontyfenni that Fortey and Owens (1987, p. 107) recognized the cyclopygid biofacies and atheloptic trilobite association.

This locality was noted by Evans (1906, p. 612) and by Strahan *et al.* (1909, p. 20) as exposing the 'Tetragraptus Beds', and both gave brief faunal lists that included graptolites and cyclopygid trilobites. However, extensive collections made by Fortey and Owens in the late 1970s greatly increased the number of taxa present, particularly among the trilobites, and Pontyfenni has become the source of some of the most diverse and well-preserved late Arenig faunas from Britain. It is one of the few localities that demonstrate the peripheral position of Wales on the edge of the palaeocontinent Gondwana.

Description

A long-disused quarry on the east bank of Afon Fenni, immediately east of Pontyfenni, shows strata dipping NNW at about 60°; these lie either on the northern limb of a subsidiary fold of the anticlinal area to the north of Whitland (Fortey and Owens, 1987) or on an overturned southern limb of the latter. This is effectively the type locality for the Pontyfenni Formation and the best at which to examine its typical development, which is a sequence of dark-grey, blocky mudstones that break conchoidally rather than along the bedding. Exposed surfaces exhibit a dark-brown film, and a weathering pattern of concentric rings is typically developed. Black siliceous nodules, usually up to 3–4 cm across, occur sporadically throughout the succession, and some enclose well-preserved fossils (Fortey and Owens, 1987, p. 81).

Fossils are rather sparse but are well preserved and undistorted, and hours of patient collecting is required to acquire a representative fauna. The commonest fossils are the extensiform graptolites *Didymograptus (Expansograptus?) uniformis lepidus* Ni and *D.(E.) hirundo* Salter, cyclopygid trilobites such as *Pricyclopyge binodosa eurycephala* Fortey and Owens, phyllocarid crustaceans *(Caryocaris)* and hyolithids, but many further taxa are known from this locality. Other graptolites include *Pseudotrigonograptus ensiformis* (Hall) and *Undulograptus cumbrensis* (Bulman). Among the trilobites are cyclopygids such as *Cyclopyge grandis brevirhachis* Fortey and Owens, *Degamella evansi* Fortey and Owens, *Microparia (M.) broeggeri* (Holub), and other inferred pelagic forms *(Bohemilla (Fenniops) sabulon* Fortey and Owens, *Girvanopyge* sp.), as well as a series of small-eyed and blind species such as *Shumardia (Conophrys) crossi* Fortey and Owens, *Dindymene saron* Fortey and Owens, *Placoparia cambriensis* Hicks, *Illaenopsis harrisoni* (Postlethwaite and Goodchild), *Bergamaia rushtoni* Fortey and Owens (Figure 8.4e), *Ampyx linleyoides* Fortey and Owens, *Colpocoryphe taylorum* Fortey and Owens and *Ormathops nicholsoni* (Salter). The remainder of the fauna includes hyolithids (Figure 8.4d), orthoconic nautiloids, bivalves, gastropods, calcichordates, ostracods and small lingulate brachiopods.

Interpretation

On the basis of the graptolite fauna, the age of the mudstones at Pontyfenni is late Arenig. *Undulograptus cumbrensis* (*'Glyptograptus' dentatus* of Fortey and Owens, 1987), the oldest diplograptoidean recorded from Wales (Mitchell and Maletz, 1995, p. 324), indicates the presence of the *U. sinicus* Subzone of the *U. austrodentatus* Biozone and falls within the uppermost part of the range of *D.(E.) hirundo*, which also occurs here. *Pseudotrigonograptus ensiformis* is another late-Arenig indicator. Trilobites such as *Placoparia cambriensis* and *Selenopeltis buchii macrophthalma* also support a late-Arenig age and are taxa that range upwards into the Llanvirn.

That Pontyfenni occupied a peripheral position on the margin of the Gondwanan palaeocontinent is inferred from both its palaeogeographical occurrence and the fauna, which is made up of pelagic organisms (graptolites and cyclopygid trilobites) and a benthic fauna adapted to conditions of low illumination, such as might be expected on a continental margin. The occurrence here of pelagic trilobites and graptolites with the atheloptic association of small-eyed and blind trilobites led Fortey and Owens (1987, p. 106) to suggest accumulation at a water depth of 300 m or more, perhaps just below the critical depth for the penetration of light.

Conclusions

The site at Pontyfenni is the most important exposure of the Upper Arenig Pontyfenni

Formation and is palaeontologically of international significance. It has yielded a large fossil fauna and is the type locality for many of the species that characterize the Fennian Stage, the upper division of the Arenig Series.

LLANFALLTEG CUTTING (SN 1575 2020–SN 1571 2013)

Introduction

Llanfallteg railway cutting is a nationally, and potentially internationally, important section that shows the base of the Llanvirn Series. The cutting exposes a 70-m-long section through sediments of latest Arenig and earliest Llanvirn strata that are richly fossiliferous throughout; the base of the Llanvirn is marked by an influx of pendent didymograptid graptolites. It offers a much more satisfactory section at which to define the Arenig–Llanvirn boundary (Fortey and Owens, 1990b) than does the historical type locality at Llanvirn, where the section is discontinuous and the late Arenig is cleaved and altered and practically devoid of fossils.

Although Strahan *et al.* (1914, pp. 20, 28) noted the continuous section at Llanfallteg passing from the Arenig into the Llanvirn, its significance as an alternative to the unsatisfactory section at Llanvirn was overlooked until reported by Fortey and Owens (in Rushton *et al.*, 1979). It was described in detail by Fortey and Owens (1987, p. 90), who logged the faunal content of 40 m of strata spanning the boundary. Llanfallteg has become the effective boundary stratotype and has featured in discussion of the base of the Llanvirn Series at an international level (e.g. Fortey *et al.*, 1990, 1991, 1995; Mitchell, 1992; Mitchell and Maletz, 1995). Although international agreement on the base of the Llanvirn has yet to be reached, this section will remain the prime reference, important at least at a national level.

Description

The cutting along the abandoned Whitland to Cardigan railway on the east bank of the Afon Tâf is immediately north of the hamlet of Llanfallteg. A 70-m-long section was cleared by the Nature Conservancy Council in November 1978 (Rushton *et al.*, 1979) to give continuous exposure of the uppermost 30 m of the Arenig Series and the basal few metres of the overlying Llanvirn. This is a sequence of soft, light-grey mudstones and shales, the surface of which takes on a characteristic vermilion colour on weathering. Fortey and Owens (1987, p. 82) named these beds the Llanfallteg Formation; no change in lithology occurs at the Arenig–Llanvirn boundary, which can be recognized only on palaeontological grounds, with the influx of the pendent 'tuning fork' graptolites *Didymograptus artus* Elles and Wood and *D. spinulosus* Perner (Figure 8.9).

The oldest beds seen crop out in the core of a small anticline (1575 2020), and most of the section is occupied by mudstones belonging to the *Dionide levigena* Zone, the uppermost trilobite zone in the Fennian Stage of the Arenig Series. These dip south at 30–50° and are fossiliferous throughout. Distal stipes of *Acrograptus acutidens* (Elles and Wood) are the commonest fossils. Other graptolites include the biserial forms *Undulograptus austrodentatus* (Harris and Keble) (Figure 8.4f), *U. cumbrensis* (Bulman) (recorded in part as '*Glyptograptus*' *dentatus* by Fortey and Owens (1987) and redetermined by Mitchell (1992)), *Glossograptus acanthus* (Elles and Wood) and *Oelandograptus* cf. *oelandicus* (Bulman). Trilobites are common, especially *Ectillaenus perovalis* (Murchison), *Barrandia homfrayi* Hicks, *Stapeleyella inconstans* Whittard, *Dionide levigena* Fortey and Owens, *Placoparia cambriensis* Hicks, *Ampyx linleyensis* Whittard and *Microparia teretis* Fortey and Owens. The fauna also includes abundant hyolithids and gastropods.

The Llanvirn portion of the Llanfallteg Formation crops out only in a small quarry at the southern end of the cutting (1571 2013). Most of the fauna listed above (with the exception of *U. cumbrensis*) ranges into the Llanvirn, where it is accompanied by the incoming of the pendent didymograptids that mark the base of the *artus* graptolite zone (Figure 8.9). Thin bentonites occur in the quarry, offering potential for radiometric age determination at this important level.

Interpretation

The Llanfallteg Formation here and elsewhere contains faunas that contrast with those of the underlying Pontyfenni Formation, the changes being attributed to a world-wide regression (possibly eustatic in origin) occurring at the end of Arenig time (Fortey and Owens, 1987, p. 105; Fortey *et al.*, 1990, p. 122). Although cyclopy-

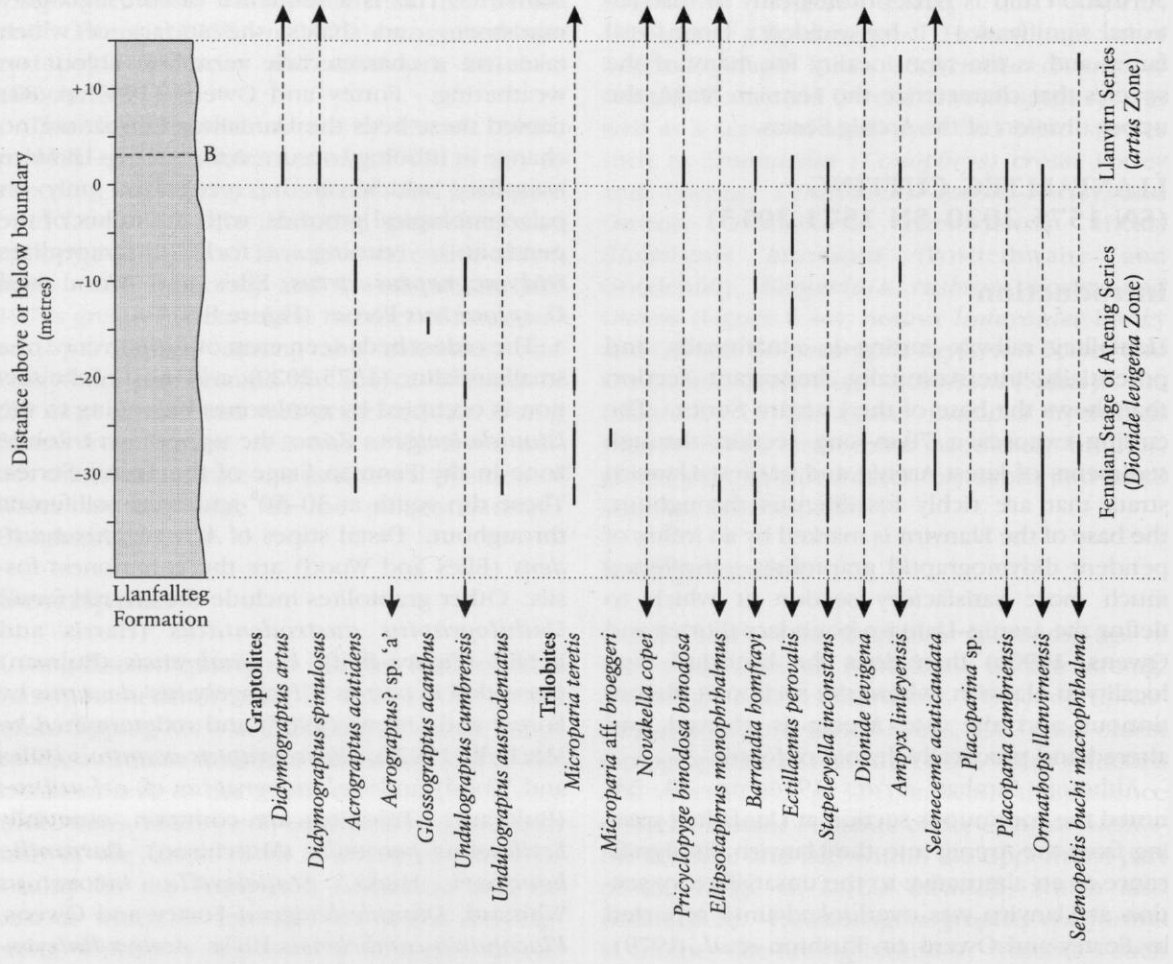

Figure 8.9 Fossil distribution across the Arenig–Llanvirn boundary in the Llanfallteg section, after Fortey and Owens (1987, fig. 9). 'B' shows the approximate level of the thin bentonite beds. The range of *U. cumbrensis* is from Mitchell (1992, fig. 7).

gids persist into the Llanfallteg Formation, much of the atheloptic fauna that characterizes the Pontyfenni Formation, notably at Pontyfenni (see site report), disappears, to be replaced by species with normally-developed eyes, such as *Barrandia homfrayi* Hicks.

Fortey and Owens (1987) and Fortey *et al.* (1990) have argued that the base of the *D. artus* Zone should be adopted as an international standard for the base of the Llanvirn Series, and this section takes on importance for this reason. The *artus* Zone can be recognized over much of the Gondwanan region, including South China and Australia, but because the diagnostic fauna belongs to a relatively inshore biotope, as described by Cooper *et al.* (1991), Mitchell and Maletz (1995) considered it unsuitable as an international standard, for which they preferred the use of pandemic biserial graptolites (*Undulograptus austrodentatus* and others) to characterize an earlier horizon, within the Fennian. Although biserial graptolites are abundant at Llanfallteg, all belong to the upper part of the *U. austrodentatus* Biozone of Mitchell and Maletz (1995). Whichever level is eventually preferred, the Llanfallteg section will remain critical for understanding the regional geology and as a datum for peri-Gondwanan areas.

Conclusions

Llanfallteg Cutting is internationally important because it provides the best section at which to define the base of the Llanvirn Series and of the *artus* Zone at the base of the Abereiddian Stage. This level can be recognized internationally in the peri-Gondwanan areas. The presence of bentonite beds holds promise that an accurate

radiometric date will be obtained for this level.

ABEREIDDI BAY (SM 7966 3164–SM 7980 3076)

Introduction

As the stratotype area for the Llanvirn Series, this is a historic section of international significance. It exposes sandstones, shales and a thin, impure limestone and contains mixed trilobite–graptolite faunas ranging in age from early Llanvirn to early Caradoc. Contemporaneous extrusive igneous rocks occur in the lower part of the succession, and zircon crystals taken from an indurated tuff at a level low in the *D. murchisoni* Zone have given a U-Pb radiometric age of 465 Ma (see below).

The geology and faunas of Abereiddi were first described by Hicks (1875a), who placed the shales exposed there in the Arenig and Llandeilo groups. Shortly afterwards, because he considered the fauna of his 'Upper Arenig' to be so distinct from that of the 'Middle Arenig' as exposed, for example, at Pwlluog (see site report), Hicks (1881b) proposed the 'Llanvirn Group' to accommodate the 'Upper Arenig', together with the lower portion of his Llandeilo Group at Abereiddi. These now include, respectively, shales of the lower Abereiddian *artus* Zone and of the upper Abereiddian *murchisoni* Zone. The stratigraphy was refined and described fully by Cox (1915), whose scheme was widely used until modern reassessment. The structure at Abereiddi has been the subject of debate and was only relatively recently elucidated (see Hughes *et al.* (1982), following Jenkins' (1979) unpublished proposals). The oft-cited Llanvirn Quarry, a short distance inland from Abereiddi, is the source of the type material for many of the trilobites and other shelly fossil species described by Hicks (1875a) and is particularly important in descriptions of lower Llanvirn trilobites (Whittard, 1955–1967; Fortey and Owens, 1987; Kennedy, 1989). Although most of the fossils there are tectonically distorted to some degree, Abereiddi is the most renowned source for the 'tuning-fork' graptolite *Didymograptus murchisoni* (Beck), which occurs in great abundance at the southern end of the bay.

Description

The main structure of Abereiddi Bay is the Llanrian Syncline, the axis of which runs through the centre of the bay, with the northern limb being overturned. Details of the succession on the two limbs differ, though the same sequence has now been identified in each (Hughes *et al.*, 1982). The section is described from north to south (Figure 8.10).

The oldest sedimentary rocks exposed on the north side of the bay, on the north side of the promontory of Trwyn Castell, comprise a massively bedded black shale unit 2 m thick with matrix-supported angular volcanic debris that occurs within the tuffs of the Llanrian Volcanic Formation between two gabbros in the vicinity of the Carn Llwyd (7966 3164). These rocks have yielded no fossils, and it is not known whether they belong to the *artus* Zone or to the *murchisoni* Zone.

An old tramway cutting above the north-west corner of Porth Gain Slate Quarry (7955 3156) exposes the Llanrian Volcanic Formation. Shales of the Cyffredin Shale Member, tuffaceous near their base, overlie the 'Lower Rhyolitic Tuffs' and contain a fauna indicative of the *murchisoni* Zone, including *Didymograptus murchisoni* (Beck), *Cryptograptus latus* Bulman, *Diplograptus* sp., *Lasiograptus* sp. nov., *Cnemidopyge* cf. *nuda* (Murchison) and species of *Segmentagnostus* and *Protolloydolithus*. Nearby, the Cyffredin Shale Member is overlain by fine, grey, vitric-lithic crystal tuffs with a vesicular keratophyre intrusion; these are correlated with the Abereiddi Tuff Member, which crops out on the south side of the bay. The upper part of the Abereiddi Tuff Member can be seen on the raised bench in the quarry (at 7954 3150).

The main part of Porth Gain Quarry exposes shales of the overlying Caerhys Shale Formation, which incorporates the upper part of the *murchisoni* Zone and the overlying *teretiusculus* Zone. No significant lithological change differentiates the two, but they can be recognized on faunal grounds. The lower fauna is similar to that of the Cyffredin Shale Member, with *D. murchisoni, C. latus* and *Lasiograptus* sp. nov., whilst the upper lacks pendent didymograptids and has the trilobites *Protolloydolithus* sp., *Segmentagnostus* sp., *Ogygiocarella* cf. *angustissima* (Salter) and *Platycalymene* cf. *tasgarensis simulata* Hughes, plus lingulate brachiopods, gastropods (*Modestospira*) and bivalves.

The Caerhys Shale Formation is tuffaceous near the base and becomes more silty towards

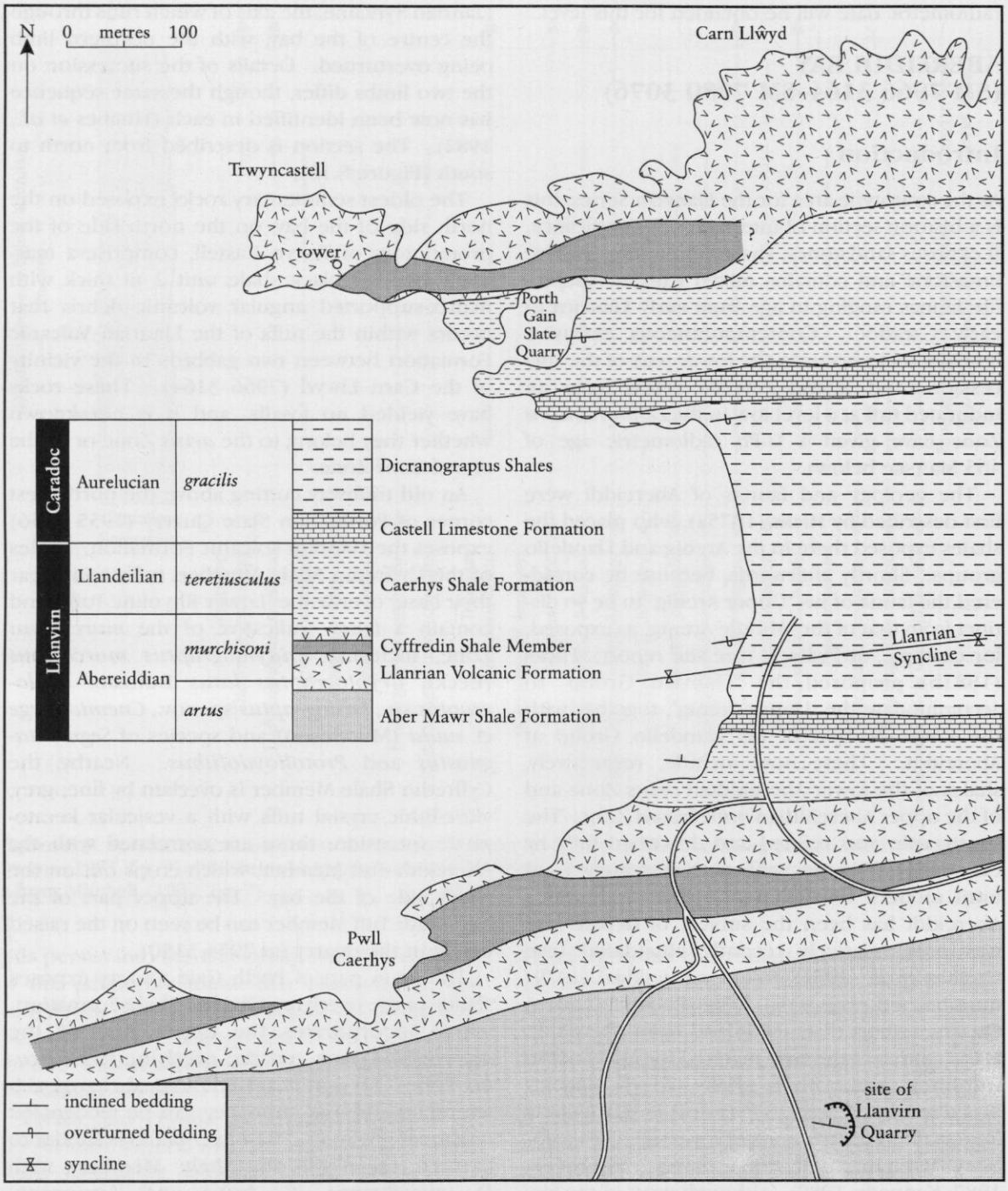

Figure 8.10 Sketch-map of the geology around Abereiddi Bay and Llanvirn, after Hughes *et al.* (1982, figs 5, 6). This is the historical type area for the Llanvirn Series.

the top. It includes a prominent graded-tuff horizon, probably an ash-fall deposit, about 9 m above the base and another similar tuff about 3 m below the top, where it passes upwards into interbedded shales and calcareous beds – the Castell Limestone Formation. The basal part of the Castell Limestone, exposed near the entrance to Porth Gain Quarry (7952 3142) (Figure 8.11), has yielded trinucleid trilobites, graptolites (*Dicellograptus* cf. *sextans* (Hall), *Pseudoclimacograptus riddellensis* (Harris), *Orthograptus* cf. *acutus* Elles and Wood and

Figure 8.11 Abereiddi Bay, looking north-west to Trwyncastell. To the right, the low black cliff near sea level is the Castell Limestone (basal Caradoc), sub-vertical but slightly overturned, with the Caerhys Shale (mainly Llandeilian) behind it and extending farther to the left, beyond the ruined black buildings. The paler cliffs behind and Trwyncastell (the headland with the tower) are made up of Llanrian Volcanic Formation (upper Abereiddian, *murchisoni* Zone). (Photo: R.M. Owens.)

Isograptus sp.), beyrichiocope ostracods *(Vitella fecunda* Siveter, *Ceratopsis* sp., *Conchoprimitiella* sp., *Laterophores* sp. and *Pseudulrichia*) and the conodonts *Amorphognathus tvaerensis* Bergström, *Drepanoistodus suberectus* (Branson and Mehl), *Phragmodus* sp., cf. *Icriodella* sp. and *Plectodina flexa* (Rhodes). The conodont assemblage suggests a low level in the *tvaerensis* conodont zone and is like that of the upper Llandeilian at Llandeilo (Bergström *et al.*, 1987). In shales immediately above the top of the Castell Limestone Formation (7963 3038), a fauna with the graptolites *Nemagraptus* sp. and *Diplograptus foliaceus* (Murchison) and the trilobites *Trinucleus fimbriatus* Murchison, *Telaeomarrolithus* cf. *intermedius* Hughes and *Cnemidopyge* sp. indicates the *gracilis* Zone.

The central part of Abereiddi Bay is low-lying and covered by alluvium, and the outcrops on the south side essentially repeat the succession in the north, the axis of the Llanrian Syncline passing through the bay (Figure 8.10). Inverted shales immediately north of the axis of the syncline have yielded poorly preserved *Dicranograptus* sp. (Rickards, 1973). Jenkins (in Hughes *et al.*, 1982) demonstrated the presence of the Castell Limestone Formation on the south side of the bay, where formerly it had been thought to be absent. It is much thinner than in the north, being represented by 9 m of calcareous and decalcified beds, including 2 m of micritic limestone in the cliff just south of a small cave (7970 3112); this is stratigraphically immediately beneath the shales at the centre of the syncline. The Castell Limestone hereabouts has yielded fragmentary *Trinucleus*, *Telaeomarrolithus* and bryozoans.

As in the Porth Gain Slate Quarry, the southern outcrop of the Caerhys Shale Formation yields a lower Llandeilian fauna near the top and an upper Abereiddian one closer to the base. The southernmost corner of the bay (7965 3104) is the classic locality for the 'tuning fork' graptolite *Didymograptus murchisoni* (Figure 8.12); one reason it is easy to collect here is that the bedding and cleavage are practically coincident. The large size of the specimens has been attributed partly to tectonic deformation (Jenkins, 1987). The lowest 1–2 m of the Caerhys Shale

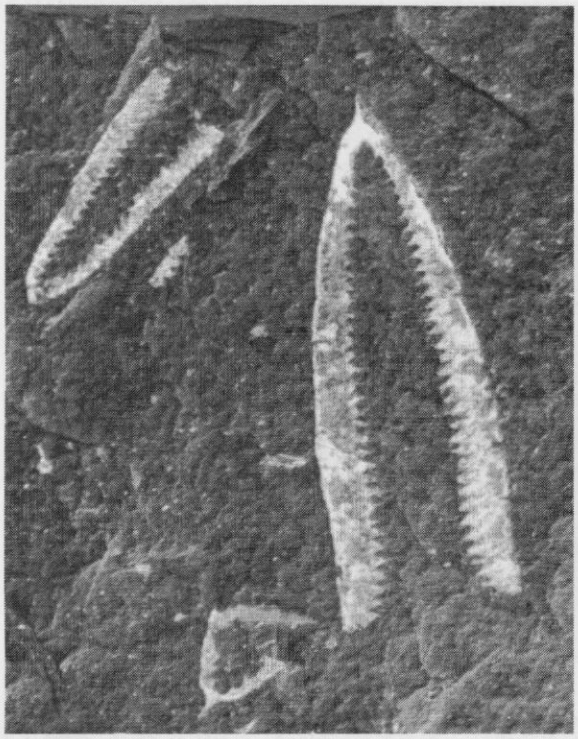

Figure 8.12 *Didymograptus murchisoni* (Beck), ×2, from the Caerhys Shale Formation at the southern end of Abereiddi Bay.

Formation is tuffaceous, with a number of 1–2 cm thick redeposited tuff bands and some more massive beds up to 20 cm thick. Bentonites have been identified at levels 3 m above the base and 2 m below the top of the Caerhys Shale, and pyritous nodules are frequent in the lowest 5 m of the formation, on occasion yielding pyritized *D. murchisoni*.

The Llanrian Volcanic Formation occupies the cliffs on the south side of Abereiddi Bay. The succession differs in detail from that seen around Trwyncastell: the Abereiddi Tuff Member (the '*Murchisoni* Ash' of Cox, 1915) is a coarse, pumiceous lapilli tuff 28 m thick; it is well exposed to the north of Melin Abereiddi. The underlying Cyffredin Shale Member is exposed in Melin Abereiddi Quarry (7960 3095) and farther west along the coast path at Pwll Caerhys (792 308), and has yielded a fauna of the lowest upper Abereiddian, like that in the cutting above Porth Gain Quarry. The lowest unit of the Llanrian Volcanic Formation comprises about 12 m of crystal tuff, well-seen from the cliff path at Pwll Caerhys (7930 3083).

Lower horizons of the Llanvirn Series within the *D. artus* Zone are not exposed in the coastal section of Abereiddi, and the '*bifidus* Shales' of earlier authors (now the Aber Mawr Shale Formation) occupy a belt of country inland of the southern cliff line of Abereiddi Bay, being exposed in the classic locality of Llanvirn Quarry (7980 3076) (Figures 8.10 and 8.13). Although this locality is now largely overgrown, collections have been made from spoil heaps to the west of the lane. The blue-grey, buff- and orange-weathering shales from this locality yielded the large trilobite-dominated fauna that Hicks (1875a) included in his 'Upper Arenig' and upon which, together with the *D. murchisoni*-bearing shales above, Hicks (1881b) based his 'Llanvirn Group'; effectively Abereiddi is the type area for the Llanvirn Series. Llanvirn Quarry is the type locality for several species, e.g. the trilobites *Barrandia homfrayi* Hicks, *Ormathops llanvirnensis* (Hicks) and *Placoparia cambriensis* Hicks, plus the brachiopod *Dinobolus hicksii* Davidson, the bellerophontid *Modestospira llanvirnensis* (Hicks), the hyolithid '*Theca*' *caereesiensis* Hicks and the graptolite *Acrograptus nicholsoni* (Lapworth). Much of this fauna is, however, better preserved and more readily obtained from localities to the east (see site report for Llanfallteg).

Interpretation

Although the sections at Abereiddi Bay have often been studied, the stratigraphy and structure are not readily elucidated. Hicks (1875a) read the succession as generally younging northwards. Cox (1915), recognizing the presence of pendent *Didymograptus* north of the Castell Limestone, inferred that the Llanvirn (Abereiddian of this account) was repeated by an overthrust at Porth Gain Quarry; this was a reasonable hypothesis for the time, thrusting being fashionable and way-up criteria little known. The stratigraphical repetition across the Llanrian synclinal structure was made evident when Waltham (1971) adduced new structural evidence and Black *et al.* (1971) reported faunal and sedimentological details. The position of the synclinal axis was established by Rickards (1973), who demonstrated by bedding–cleavage relationships that, in their most northerly outcrop in the south of the bay (7970 3116), the shales are inverted, as Waltham (1971) had shown for the sequence in the north. Passing southwards within the same shale unit, the bedding–cleavage relationship reverses on crossing

Figure 8.13 Llanvirn Quarry, south of Abereiddi Bay, looking south-east, photographed in 1932. The Aber Mawr Formation (lower Abereiddian, *artus* Zone) dips steeply north, the cleavage here being nearly coincident with bedding. (Photo: British Geological Survey photographic collection, A6108.)

a prominent fault on the axis of the Llanrian Syncline, whose southern limit is the right way up. The sequence around the fold axis is cut by closely spaced faults that commonly form gullies in the wave-cut platform; many show well-exposed fault breccias. The shales concealed by the alluvium-covered central part of Abereiddi Bay are presumably of early Caradoc age.

Jenkins (1987) studied the several morphs of pendent *Didymograptus* found at the south-east corner of Abereiddi Bay and concluded that the only species present is *D. murchisoni*, all the other reported taxa being merely tectonically deformed morphs. He was also able to calculate a three-dimensional strain-ellipse for the slates at Abereiddi. Samples taken from immediately below the Cyffredin Shale Member of the Llanrian Volcanic Formation on Trwyn Castell (7940 3150), have given a radiometric age of 464.6 ± 1.8 Ma (Tucker *et al.*, 1990; Tucker and McKerrow, 1995).

Conclusions

Abereiddi Bay and its immediate environs is a classic and important site: it is the historical type area for the definition of the Llanvirn Series and is significant for research into sediments and faunas of this time-interval. Volcanic ashes that are stratigraphically well-controlled have given a radiometric age showing that they are about 464 million years old. The area is excellent for teaching at various levels. It affords good sections for demonstrating aspects of structural geology, especially cleavage–bedding relationships and their significance, and also shows very clearly the influence on coastal morphology of various rock types and their distribution and structure.

ABERGWAUN (FISHGUARD OLD HARBOUR) (SM 9600 3727–SM 9598 3735)

Introduction

Exposures in the cliffs on both shores of Fishguard Old Harbour contain graptolite faunas of Llanvirn age that constrain the age of both the base and the top of the Fishguard Volcanic Group, thereby affording correlation with suc-

Figure 8.14 Abergwaun, immediately east of Fishguard, looking north. The Afon Gwaun provides a dip-section across the southern limb of the Goodwick Syncline. The foreground is underlain by Abereiddian slates. The acidic and basic lavas of the Fishguard Volcanic Group form bluffs at the mouth of the inlet. In the distance the cliffs are of acid tuffs on the northern limb of the Goodwick Syncline. (Photo: British Geological Survey photographic collection, A6129.)

cessions elsewhere in South Wales. These are the only sections so far identified that have yielded identifiable faunas in association with the Fishguard volcanic rocks.

In the first detailed description of the geology of the Fishguard district, Reed (1895) included the volcanic rocks of the area within the 'Bala' and 'upper Llandeilo', whilst Cox (1930, p. 285) recognized that '*Didymograptus bifidus* Shales' occur below the volcanic rocks, and included all within the Llanvirn Series. Thomas and Thomas (1956) concentrated upon the mapping and petrography of Fishguard Volcanic Group but noted the presence of a graptolite fauna at the top of the volcanic succession (1956, p. 314), to which they ascribed a '*D. bifidus*' zonal age. Unpublished work by C.J. Jenkins has refined the biostratigraphical information, and diagnostic faunas have been recognized in shales at both the base and the top of the volcanic rocks in Fishguard Old Harbour.

Description

Graptolite faunas have been recovered from three points in the cliff exposures in Fishguard Old Harbour (Figure 8.14), two on the west side from below the Fishguard Volcanic Group and one on the east side above it.

At Aber Bach (9600 3727), cleaved grey-black slates, where the cleavage (the orientation of which varies in this section) and bedding are coincident, contain *Acrograptus* cf. *nicholsoni* (Lapworth). About 15 m below the base of the volcanics south of Lampit Bach (9598 3735), Jenkins reported well-preserved *Didymograptus artus* Elles and Wood in hornfelsed slates. Both these occurrences are referred to the lower Abereiddian *artus* Zone.

On the west side of the old harbour, about 100 m south of Castle Point, some 10 m of blue-black fissile shales with thin tuff bands crop out in a little inlet (see Thomas and Thomas, 1956, figs 6 and 7). These yielded a graptolite fauna that Thomas and Thomas (1956, p. 314) considered to indicate the topmost horizons of the *bifidus* (now *artus*) Zone. Jenkins' unpublished work, however, suggests that the fauna, in which he reported *Didymograptus murchisoni* (Beck) and *Diplograptus* cf. *caelatus* (Lapworth),

instead indicates a level low in the upper Abereiddian, equating approximately with the Cyffredin Shale Member at Abereiddi (see site report). On the basis of these faunas, the extrusion of the Fishguard Volcanic Group can be dated as having taken place close to the lower-upper Abereiddian boundary.

Above the shales south of Castle Point there is a thickness of bedded rhyolitic tuffs. According to Thomas and Thomas (1956, fig. 6), these are in faulted contact with a succession of calcareous flags that crop out on Castle Point and on the west side of the harbour. Jenkins' unpublished work, however, suggests that the junction is an unconformity (seen at 9618 3778). On the basis of lithology and fauna, he suggested comparison with the Castell Limestone at Abereiddi (see site report) and with the Ffairfâch Group and Llandeilo Flags at Llandeilo.

Interpretation

The Fishguard Volcanic Group represents an important volcanic event in the early Ordovician of south-west Wales, and the dating of the onset and termination of volcanism is critical in placing it in its wider palaeogeographical context. The sediments above and below the igneous rocks tend to be poorly exposed, and even where they are exposed, unfavourable cleavage–bedding relationships make fossils difficult to find and commonly render them too badly preserved for identification. Therefore the three graptolite occurrences in the Old Harbour at Fishguard are important since they occur close to the base and summit of the volcanic sequence and, moreover, are sufficiently well preserved to show that the Fishguard Volcanic Group was erupted above the lower part of the *artus* Zone and below the lower part of the *murchisoni* Zone. If Jenkins' interpretation of the correlation of the calcareous flags at the top of the succession is correct, then the equivalents of the Caerhys Shale Formation of Abereiddi are missing at Fishguard.

Conclusions

The fossil localities at Abergwaun (Fishguard Old Harbour) are important because they provide the only reliable biostratigraphical evidence that constrains the age of the Fishguard Volcanic Group to a mid-Abereiddian age.

FFAIRFÂCH RAILWAY CUTTING AND AFON CENNEN (SN 6307 2142–SN 6220 2003)

Introduction

The railway cutting just south of the village of Ffairfâch and the outcrops in railway cuttings and in the banks of the Afon Cennen to the south are the standard sections respectively for the Ffairfâch Group and Llandeilo Flags, as defined by Williams (1953); together they afford the most complete section through the upper Abereiddian and Llandeilian in the Llandeilo district. The section is the best succession within the type Llandeilo area, and although exposures are more numerous in nearby Dynevor Park (see site report), faulting and folding there make the succession more difficult to determine.

The geology of the area around Llandeilo was first described by Murchison (1835, 1839), who named the calcareous flags exposed there the 'fourth formation of the Silurian System' and considered the grits (i.e. the Ffairfâch Group) stratigraphically underlying the flags as representing an 'attenuated remnant of the Caradoc Sandstones'. De la Beche (1846) and Aveline (1857) revised Murchison's interpretations and these were then incorporated by Murchison (1867) into the basis of the succession as it is understood today.

Strahan *et al.* (1907) gave a full description of the area for the Geological Survey, and this formed the basis for Williams' (1953) work, in which he offered a detailed lithological and biostratigraphical subdivision of his newly introduced 'Ffairfâch Group' and the Llandeilo Flags. He also described the stratigraphically important trinucleid trilobites and brachiopods (Williams, 1948, 1949). From its position between the lower Llanvirn shales beneath and Llandeilo Flags above, Williams suggested that the Ffairfâch Group was a facies of the *murchisoni* Zone, and this interpretation has generally been followed. On the basis of conodonts, however, Bergström *et al.* (1987) proposed that the upper part of the Ffairfâch Group correlated with part of the *teretiusculus* Zone, implying that only the lower part belonged to the *murchisoni* Zone.

More recent work has also focused on facies, faunas and palaeocommunities in the Ffairfâch Group (Williams *et al.*, 1981) and in the type Llandeilo (Wilcox and Lockley, 1981). The brachiopod faunas were revised by Lockley and

Williams (1981) and the ostracods were described by Jones (1986–1987).

Discussions on the status of the Llandeilo Series have necessarily involved this section (e.g. Williams *et al.*, 1972; Ross *et al.*, 1982; Whittington *et al.*, 1984; Fortey *et al.*, 1991, 1995; Bassett and Owens, 1996). Even if the Llandeilo is relegated to the status of a stage, as proposed by Fortey *et al.* (1995) and followed in this account, it is the present site that will act as its standard.

Description

The main part of this section comprises exposures, railway cuttings and small quarries over a distance of 1.4 km upstream along the Cennen Valley SSW from the level crossing at Ffairfâch (Figure 8.15). To the north of the level crossing there are small exposures of shales of the *artus* Zone, for example on the east bank of the Cennen (6307 2142 and 6309 2132), where soft, black shales dip steeply (70–73°) to the south and have yielded graptolites, including *Didymograptus artus* Elles and Wood, and the trilobites *Protolloydolithus ramsayi* (Hicks). These shales pass upwards into grey, ashy shale with irregular bioturbated beds that, immediately below the base of the Ffairfâch Grit at the level crossing (6287 2122), yield the heterorthid brachiopod *Tissintia prototypa* (Williams). The type section of the Ffairfâch Group extends for 110 m south-west of the railway, in cuttings and an adjacent overgrown quarry (between 6287 2122 and 6280 2112). Williams (1953) recognized five units within the Ffairfâch Group, and these were given formational status by Lockley and Williams (1981) and described in detail by Williams *et al.* (1981) as follows.

1. The lowest, the Ffairfâch Grit, up to 26 m thick, consists of massively bedded, clean-washed arkosic grits, with individual beds on average about 1 m in thickness; thin shales occur in the upper part. *Tissintia prototypa* has been found in the upper part of the Ffairfâch Grit, and a few other brachiopods and other fossils from one of the shale bands.
2. The succeeding Pebbly Sands (35 m thick) crop out in the back wall of the quarry; the transition is seen in the northern face of the quarry, where the grits are replaced by a succession of bioturbated flaggy sandstone beds overlain by pebbly grits.
3. The overlying Flags and Grits (46 m thick) exposed in the south of the quarry and along the adjacent cutting comprise seven mainly intergrading lithological units, including fine calcareous siltstones, flaggy calcareous siltstones, sandstones and conglomeratic grits; the uppermost 15 m of the unit consists of calcareous sediments with shelly, crystalline limestones and siltstones, rubbly calcareous shales, impure limestones and a number of thin bentonites.

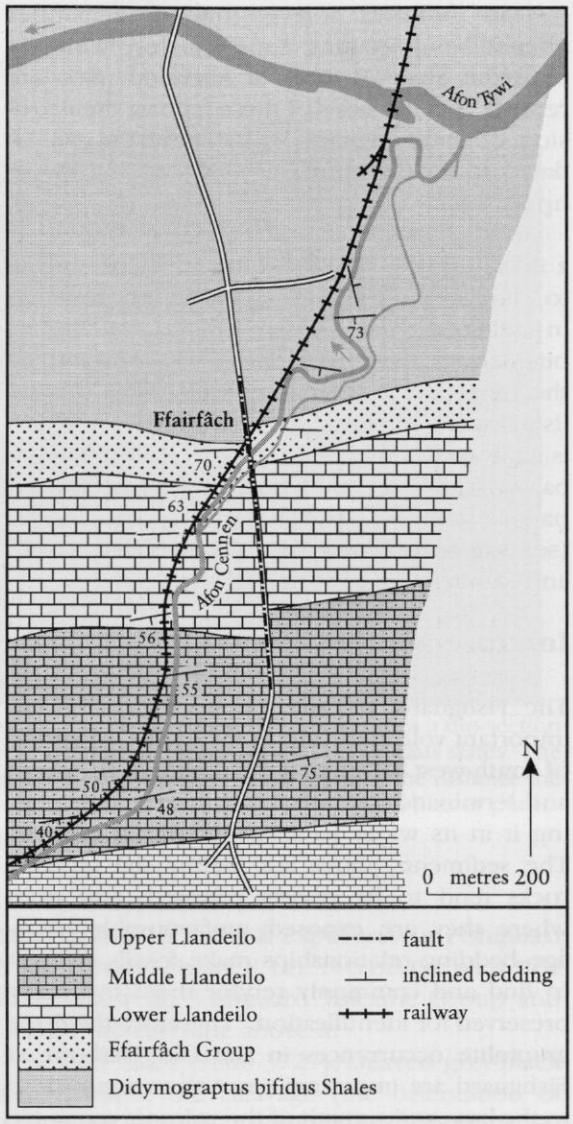

Figure 8.15 The geology around Ffairfâch and Afon Cennen, after Williams (1953) and Wilcox and Lockley (1981). The Cennen section is historically the type section for the Llandeilo Series (now Llandeilian Stage).

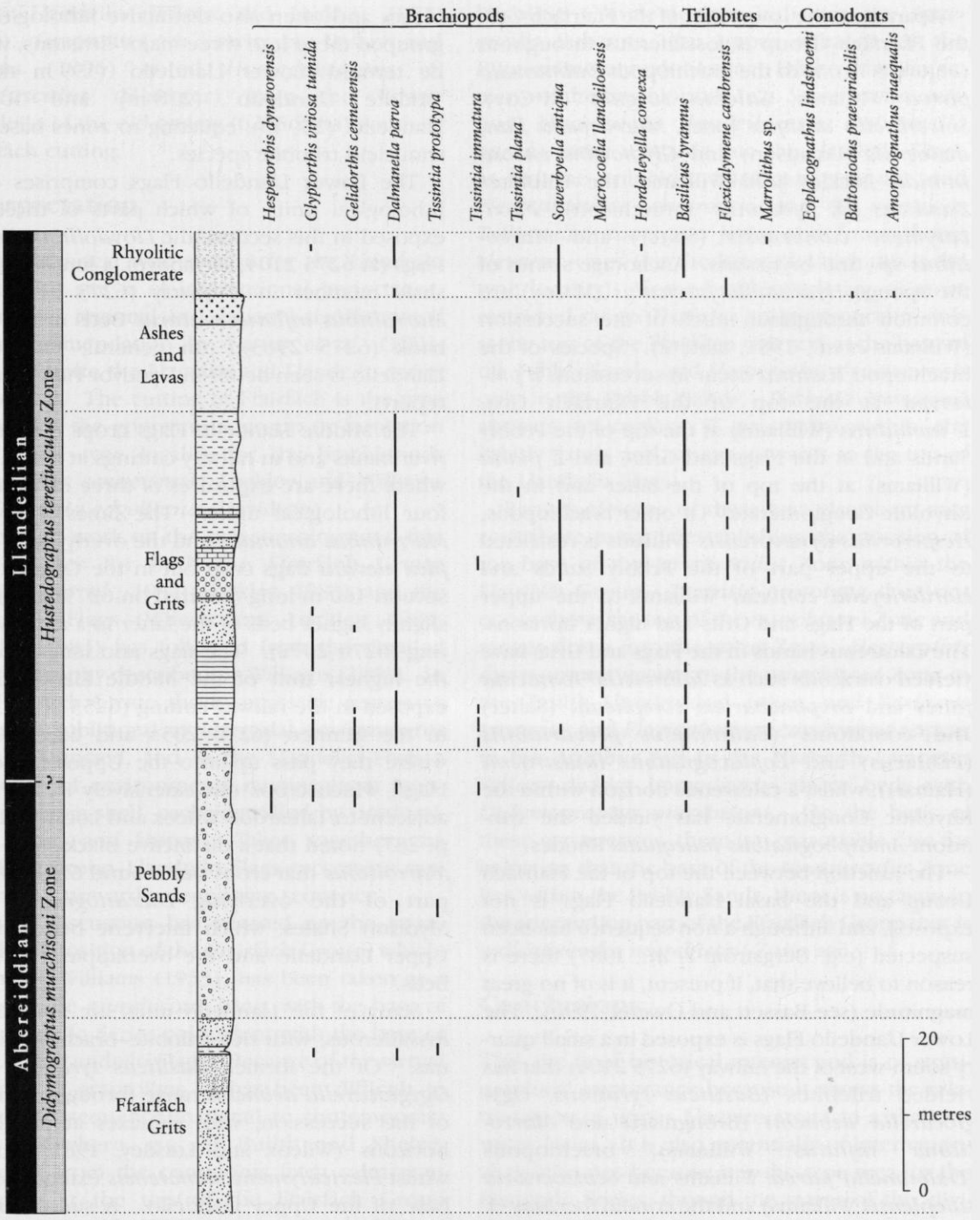

Figure 8.16 Lithological and faunal succession in the type section for the Ffairfâch Group, after Williams *et al.* (1981).

4. The Ashes and Lavas are poorly exposed here; they are about 15 m thick, consisting of crystal tuffs with arenaceous and pyroclastic horizons.
5. The ashy facies is succeeded abruptly by Rhyolitic Conglomerate – about 8 m of variable conglomeratic sandstones forming the topmost component of the Ffairfâch Group; it includes fine argillaceous partings and shaly calcareous horizons.

Apart from the lower part of the Ffairfâch Grit, the Ffairfâch Group is fossiliferous throughout (Figure 8.16), with the brachiopods *Dalmanella parva* Williams, *Salopia turgida* (M'Coy), *Sowerbyella antiqua* Jones, *Macrocoelia llandeiloensis* (Davidson) and *Glyptorthis viriosa tumida* Lockley and Williams, the trilobites *Basilicus* cf. *tyrannus* (Murchison), *Flexicalymene cambrensis* (Salter) and *Marrolithus* sp., and bryozoans. Anchorage spines of the sponge *Hyalostelia fasciculus* (M'Coy) are common throughout much of the succession (Williams *et al.*, 1981, table 2). Species of the brachiopod *Tissintia* occur in succession: *T. prototypa* at the top of the Ffairfâch Grit, *T. immatura* (Williams) at the top of the Pebbly Sands and in the Flags and Grits, and *T. plana* (Williams) at the top of the latter and in the Rhyolitic Conglomerate. Of other brachiopods, *Hesperorthis dynevorensis* Williams is restricted to the upper part of the Pebbly Sands and *Horderleyella convexa* Williams to the upper part of the Flags and Grits and higher horizons. The calcareous bands in the Flags and Grits have yielded ostracods such as *Tallinnella? tomacina* Jones and *Brephocharieis complicata* (Salter) and conodonts (*Baltoniodus prevariabilis* (Fåhraeus) and *Eoplacognathus lindstroemi* (Hamar)), whilst a calcareous horizon within the Rhyolitic Conglomerate has yielded the conodont *Amorphognathus inaequalis* Rhodes.

The junction between the top of the Ffairfâch Group and the basal Llandeilo Flags is not exposed, and although a non-sequence has been suspected (e.g. Bergström *et al.*, 1987) there is reason to believe that, if present, it is of no great magnitude (see Bassett and Owens, 1996). The Lower Llandeilo Flags is exposed in a small quarry south-west of the railway (6275 2104) that has yielded trilobites (*Basilicus tyrannus, Ogygiocarella debuchii* (Brongniart) and *Marrolithus inflatus* Williams), brachiopods (*Dalmanella parva* Williams and *Schizocrania salopiensis* Williams) and the crinoid *Iocrinus* cf. *pauli* Donovan and Gale (Donovan, 1986–1995).

The most complete exposures of the Llandeilo Flags lie southwards along the Cennen Valley, which Williams (1953, p. 188) regarded as the type section. Wilcox and Lockley (1981) estimated a total thickness of 716 m of sediments, with 63% of the succession exposed. Williams (1953) recognized a local succession comprising 13 units characterized by distinctive fossil assemblages and often also distinctive lithologies; he grouped these into three major divisions, which he termed 'Lower Llandeilo' (199 m thick), 'Middle Llandeilo' (278 m) and 'Upper Llandeilo' (239 m), equating to zones based on trinucleid trilobite species.

The Lower Llandeilo Flags comprises eight lithological units, of which parts of three are exposed in this section: the *Lloydolithus lloydii* Flags (at 6275 2104, see above), a limestone and shale member in a quarry (6273 2102) and *Marrolithus inflatus maturus* Beds in the river bank (6275 2903). In general, the Lower Llandeilo is seen better in Dynevor Park (see site report).

The Middle Llandeilo Flags crops out on the river banks and in railway cuttings at five places, where there are exposures of three of Williams' four lithological units. The limestones with *Marrolithus anomalis* and the overlying *M. simplex elevata* flags crop out in the Cennen in a section 160 m long (centred on 6275 2078) and slightly higher beds of the latter in a railway cutting (6270 2072). The flags and limestones of the highest unit of the Middle Llandeilo are exposed in the railway cutting (6253 2050), and in the Cennen (6270 2054 and 6230 2037), where they pass up into the Upper Llandeilo Flags, which crops out extensively in the river adjacent to Talhardd. Wilcox and Lockley (1981, p. 287) noted that a distinctive black shale with *Marrolithus* that crops out around 6222 2004 is part of the overlying *Dicranograptus* (or Mydrim) Shales, which intervene between the Upper Llandeilo and the overlapping Wenlock beds.

Many of the Llandeilo units are abundantly fossiliferous, with rich trilobite–brachiopod faunas. Of the former, *Basilicus tyrannus* and *Ogygiocarella debuchii* range throughout much of the succession, with climaxes at particular horizons (Wilcox and Lockley, 1981, fig. 6), whilst *Flexicalymene cambrensis* extends to the base of the Upper Llandeilo. A succession of trinucleids (*Lloydolithus lloydii* and species of *Marrolithoides* and *Marrolithus*) are the basis of the zonal scheme erected by Williams (1948), with small refinements by Wilcox and Lockley (1981). Articulate brachiopods (e.g. *Sowerbeyella antiqua* Jones, *Dalmanella parva* Williams and *Horderleyella* sp.) are dominant in the Lower and parts of the Middle Llandeilo, whilst lingulates, craniates and *Tissintia immatura* predominate in the Middle and

Upper Llandeilo (Wilcox and Lockley, 1981, fig. 6). Graptolites are a rarity, but Bassett and Owens (1996) noted *Hustedograptus* cf. *teretiusculus* (Hisinger) from the Lower Llandeilo of the old quarry (6275 2104) south of Ffairfâch cutting.

Interpretation

As the historical type section for the Llandeilo Series, this site is of international importance, and retains regional and national significance if the recommendation by Fortey *et al.* (1991, 1995) to unite the Llanvirn and Llandeilo series is adopted. The cutting at Ffairfâch is the type locality for the eponymous group or formation and is the type locality for the brachiopods *Gelidorthis cennenensis* Lockley and Williams and *Triplesia edgelliana* (Davidson).

Detailed work on the palaeoecology and faunal changes for both the Ffairfâch Group (Williams *et al.*, 1981; Lockley, 1983) and the Llandeilo Flags (Wilcox and Lockley, 1981; Lockley, 1983) has followed from the detailed biostratigraphy described by Williams (1953). In the Ffairfâch Group three successive regressive cycles in sublittoral to intertidal environments were recognized, and in the Llandeilo Flags a sequence of environments ranging from intertidal to open-shelf, each identified by predominant facies and faunas. Taken together, the Ffairfâch Group–Llandeilo Flags succession represents an upwardly deepening sequence.

Much discussion has centred on the stratigraphical position of the Ffairfâch Group, which, following Williams (1953), has been taken as a facies of the *murchisoni* Zone, with the base of the Llandeilo Series coincident with the base of the Lower Landeilo Flags. Because of the virtual absence of graptolites, it has been difficult to relate this sequence in detail to contemporary ones elsewhere, e.g. at Builth and Shelve. Evidence from the conodonts from calcareous horizons at the top of the Ffairfâch Group (Bergström *et al.*, 1987) suggests that the base of the *teretiusculus* Zone is well below the base of the Llandeilo Flags: *Baltoniodus prevariabilis* and *Eoplacognathus lindstroemi* from the Flags and Grits are indicative of a level in the *Amorphognathus kielcensis* Subzone of the *Pygodus anserinus* conodont zone that correlates with a level high in the *teretiusculus* Zone (Bergström *et al.*, 1987, p. 298), whilst the presence of *Amorphognathus inaequalis* in the Rhyolitic Conglomerates indicates the *inaequalis* Subzone, the upper subzone of the *P. anserinus* conodont zone. Of the other fauna, many of the brachiopods (e.g. *Sowerbyella antiqua*, *Macrocoelia llandeiloensis*, *Dalmanella parva*) range upwards into the Llandeilo Flags, as do the trilobites *Basilicus tyrannus* and *Flexicalymene cambrensis*, and the ostracods *Tallinnella? tomacina* Jones and *Laterophores elevatus* Jones (for the latter of which this is the type locality). Some brachiopods are of more restricted range: *Tissintia prototypa* occurs only at the top of the Ffairfâch Grit and at the base of the Pebbly Sands, and *Hesperothis dynevorensis* only in the Pebbly Sands. *Tissintia immatura* appears to replace *T. prototypa* within the Pebbly Sands and ranges upwards to the top of the Llandeilo Flags.

Ranges of some of these taxa elsewhere may contribute towards establishing the position of the base of the *teretiusculus* Zone within the Ffairfâch Group. *Tissintia prototypa* does not occur above the top of the *murchisoni* Zone and ranges down into the *artus* Zone. *Hesperothis dynevorensis* occurs in the *murchisoni* Zone in the Builth–Llandrindod Inlier, and *Basilicus tyrannus* and *Flexicalymene cambrensis* appear in the *Asaphus* Ash in the Narberth–Lampeter Velfrey district immediately above beds with *Didymograptus murchisoni*. On the basis of these occurrences, there is a reasonable case for believing that the base of the *teretiusculus* Zone lies within the Pebbly Sands; there is no taxon in the succeeding part of the Ffairfâch Group that is indicative of a *murchisoni* Zone age.

Conclusions

This site is of historical interest and is of stratigraphical importance because it shows the relationships of upper Llanvirn strata in a shallow-water facies. It is also potentially of international significance because it is the type area for the Llandeilo Series, though the status of this division is under debate.

DYNEVOR PARK (SN 61 22)

Introduction

Dynevor Park is one of Murchison's (1835; 1839, p. 356) original localities for the Llandeilo Flags. Together with the Cennen section (see Ffairfâch site report), it represents the Llandeilo Series as

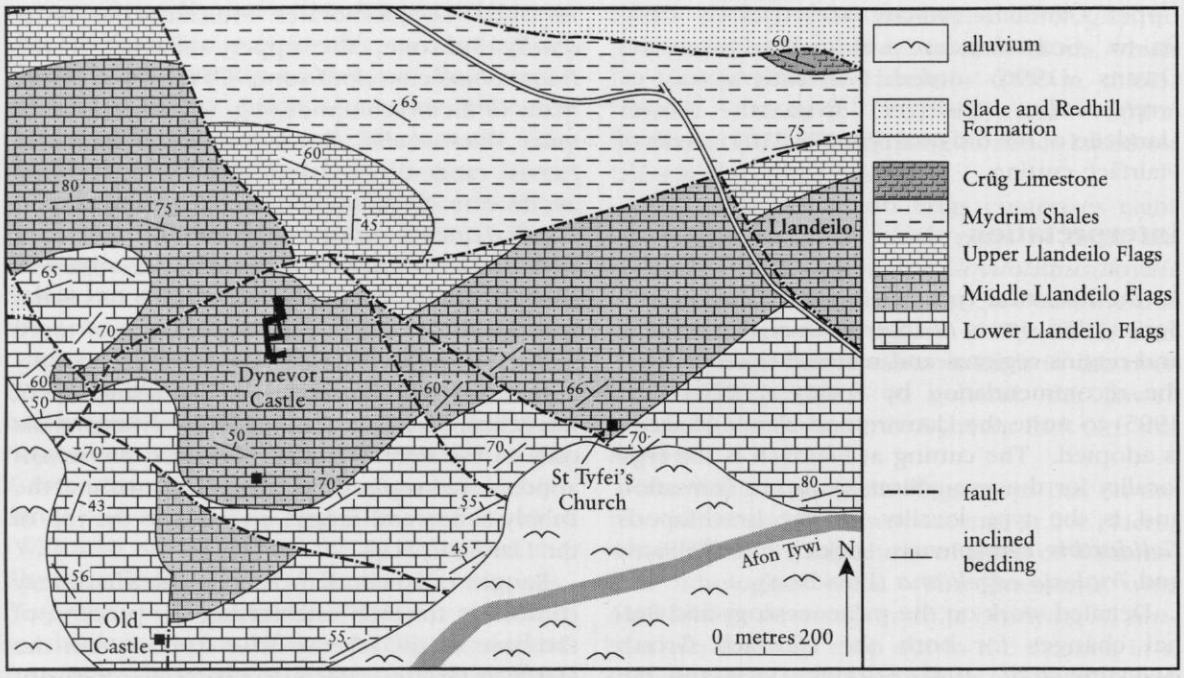

Figure 8.17 Geological map of Dynevor Park, after Williams (1953).

understood by Williams *et al.* (1972) and Wilcox and Lockley (1981). The area was mapped in detail by Williams (1953), who recorded the same succession of Llandeilo Flags as that seen in the Cennen, but it complements it particularly in showing better the various horizons of the Lower Llandeilo and in being generally more easily accessible. Information from the sections in Dynevor Park was used in the palaeoecological analyses of Wilcox and Lockley (1981), and Lockley (1983). Trilobites from this section were described by Williams (1948), Owens (1973) and Fortey (1980), brachiopods by Williams (1949) and by Williams and Lockley (1981) and ostracods by Jones (1986–1987). It is the type locality for brachiopod species including *Hesperorthis dynevorensis* Williams, *Pseudolingula granulata* (Phillips) and probably *Sowerbyella antiqua* Jones, and for the trilobites *Marrolithoides simplex elevatus* (Williams), *Basilicus peltastes* Salter, *Ogygiocarella debuchii* (Brongniart) and probably *B. tyrannus* (Murchison).

Description

Although the full development of Llandeilo Flags is exposed in Dynevor Park, the divisions are not in sequence, as they are in the Cennen Section, but are disposed in a NE-plunging anticline and syncline that are considerably faulted (Figure 8.17). There are good exposures of the basal units of the Lower Llandeilo Flags in an old quarry in Castle Wood east of the old castle (6150 2171); faunas include common *Basilicus tyrannus* and *Dalmanella parva* Williams. The succeeding *Lloydolithus lloydii* Flags are exposed both in the north face of the quarry and east of the old castle (for example around 6156 2176, 6160 2180 and 6167 2187). They contain an abundance of *L. lloydii* and *Ogygiocarella debuchii* (Brongniart), together with smaller numbers of other trilobites and articulate and lingulate brachiopods. Well-bedded limestones and calcareous siltstones of the *Sowerbyella* Beds are well exposed along the road running north-west from the lake at the western end of the Deer Park (around 6088 2226). Here the brachiopod *S. antiqua* is abundant and is accompanied by other brachiopods such as *Dalmanella parva* Williams, *Horderleyella* sp. and *Palaeoglossa attenuata* (J. de C. Sowerby) and the trilobites *Basilicus tryannus* and *Flexicalymene cambrensis* (Salter). Ostracods, including *Brephocharieis complicata* (Salter), *Homeoceratopsis jubata* Jones, *Gunnaropsis cristata* Spjeldnaes and *Vittella fecunda* Siveter, have been recovered from silicified horizons at this locality and elsewhere in Dynevor Park

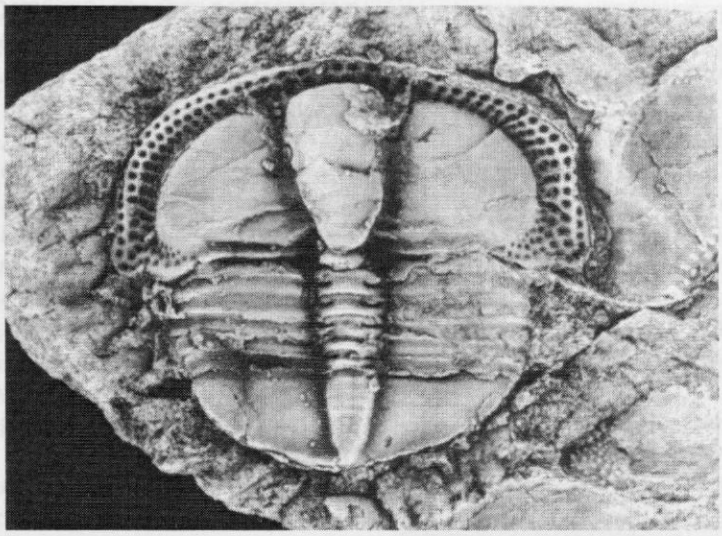

Figure 8.18 *Marrolithoides simplex* (Williams), ×4, from the Middle Llandeilo Flags, Talar Wen, Bethlehem.

(Jones, 1986–1987). The succeeding *Corineorthis* Flags, a series of poorly bedded calcareous flags with intercalations of massive limestones, can be seen in a quarry south-east of St Tyfei's church (6224 2217), where the brachiopod *Corineorthis pustula* Williams is common; it is restricted to this horizon. Other fauna includes *Basilicus tyrannus* and *Flexicalymene cambrensis* and the brachiopod *Horderleyella* sp..

Middle Llandeilo horizons are well exposed at the side of the old road north-east of St Tyfei's church (6208 2232) and immediately north of the Keeper's Lodge (between Dynevor Castle and the old castle), and in the quarry 60 m to the north-west (6133 2219), where shaly flags and limestones crop out; the trilobites *Ogygiocarella debuchii* and *Marrolithoides simplex* (Williams) are common. Richly fossiliferous Upper Llandeilo limestones and flags with abundant trilobites (*Ogygiocarella debuchii* and *Marrolithus favus* (Salter), and brachiopods (*Tissintia immatura* Williams and *Dalmanella* sp.)) are exposed in a small quarry in woods about 250 m north-east of the Dynevor Castle (6161 2272).

Interpretation

This area is of historical importance, being a well-known source of fossils since Murchison's time – and well before, because some of Lhwyd's (1699a,b) trilobite specimens originated from here. The geology of the area has been well documented since Williams' (1953) description; it provides important evidence in the interpretation of the stratigraphy and palaeoenvironments of the Llandeilo Flags and hence the type 'Llandeilo Series' of authors. The environment of deposition, as inferred by Wilcox and Lockley (1981), is discussed in the Ffairfâch and Afon Cennen site report.

Although the succession of Llandeilo Flags is more completely exposed in the Afon Cennen, Dynevor Park complements it in affording outcrops of Lower Llandeilo horizons not seen there and in having more readily accessible sections in the Middle and Upper Llandeilo. Thus, the Cennen Valley and Dynevor Park between them have exposures essential to understanding the stratigraphy of the Llandeilo Flags in the type area and have yielded the type specimens of many of the characteristic fossils.

Conclusions

Dynevor Park is a classic section in fossiliferous Llandeilo Flags. It complements the Afon Cennen section by making-good deficiencies in the exposure there.

TALAR WEN (SN 7012 2660)

Introduction

This small quarry is a valuable source for

Llandeilian fossils, in particular trilobites, and is the type locality for the trinucleid *Marrolithoides simplex* (Williams). It was given by Williams (1948, p. 79) as 'quarry 300 yards W of Wernellyn farm, 1 mile SSE [*sic* – should read SSW] of Llangadock'. The section is supplementary to those seen in Dynevor Park, at Ffairfâch and in the Meidrim Road section.

The area in which this quarry lies is included on Williams' (1953) map, and it falls within the outcrop of the Middle Llandeilo Flags. It has featured in excursion guides (e.g. Bassett, 1982), but until recently much of the face was obscured by talus. The section was cleared in a joint operation by the Countryside Council for Wales and Cwmdeithas Edward Lhwyd in early 1997, and its condition is now (1999) far better than it has been for many years.

Description and interpretation

The roadside quarry shows the following section:

Thickness	
10 m+	Soft shales
6 m	Dark, calcareous flags
2 m	Massive, calcareous sandstones

Fossils are particularly abundant in the calcareous flags and include articulated and fragmentary specimens of the trilobites *Ogygiocarella debuchii* (Brongniart) and *Marrolithoides simplex* (Williams) (Figure 8.18), together with lingulate brachiopods (*?Palaeoglossa*). This assemblage is typical of the *Marrolitoides simplex* Beds, the lowermost division of the Middle Llandeilo Flags of Williams (1953, p. 193), and are interpreted as having accumulated in relatively shallow-water conditions.

Conclusions

Acting as a complementary section to others at this horizon, Talar Wen is useful in that it is one of the most accessible and fossiliferous localities at which to study the fauna of the Middle Llandeilo Flags and is certainly the best locality to see the *Marrolithoides simplex* Beds. It is the type locality for the eponymous trilobite.

MEIDRIM ROAD SECTION (SN 287 203–SN 289 208)

Introduction

Pant-yr-hendre Quarry and the road extending 500 m northwards to the village of Meidrim (Mydrim) provides a section in which horizons from the top of the *murchisoni* Zone to the *gracilis* Zone are exposed. Much of the succession is in a more distal (graptolitic) facies than that cropping out at Dynevor Park, Llandeilo (see site report), and the lower part contains a mixed shelly-graptolite fauna affording correlation between these two facies.

Early descriptions of this section were given by Evans (1906) and by Strahan *et al.* (1909), who recognized the succession, established its nomenclature and listed characteristic fossils. No further descriptions, apart from a brief mention by Evans and Jones (1926), were given until Toghill (1970a) discussed the graptolite fauna and commented on correlation with the Llandeilo sequences at Llandeilo, Builth and Shelve. He noted the abundant occurrence of *Glyptograptus* (now *Hustedograptus*) *teretiusculus* (Hisinger) in the basal Hendre Shales, with sparser occurrences higher in the sequence, and the presence of *Nemagraptus gracilis* (Hall) in the Mydrim Limestone; Toghill rebutted earlier reports of *N. gracilis* within the Hendre Shales. Morris (in Toghill, 1970a, p. 122) suggested that the trilobite association appeared to be from 'the upper part of the Llandeilo Series'. Addison (in Williams *et al.*, 1972, p. 35), having re-examined the trilobites, ascribed an early Llandeilo age to this fauna and also noted that *N. gracilis* had been identified by Toghill in his collections from exposures of the Hendre Shales near Ty Newydd Farm, 5 km WNW of Carmarthen, at horizons well below the level of the Mydrim Limestone, in association with the trilobite *Lloydolithus lloydii* (Murchison). The latter is characteristic of the Lower Llandeilo Flags of the Llandeilo area. As a consequence, it was considered that much of the type Llandeilo at Llandeilo was of *gracilis* Zone age, as discussed further by Bergström *et al.* (1987, p. 303). The Ty Newydd occurrence of *N. gracilis* has been confirmed recently by Dr R. Bettley, who notes (pers comm., March 1998) that equivalent strata in the Meidrim Road section suffer from a very strong cleavage, which makes all the fauna difficult to identify, although thin graptolite stipes do occur. He states that

'correlation of the identifiable shelly species at Meidrim with those at Ty Newydd indicates very strongly that *N. gracilis* occurs in the middle Hendre Shales'. Thus, Toghill's (1970a) contention that *N. gracilis* does not occur below the Mydrim Limestone is now considered incorrect.

As well as having a mixed shelly–graptolitic fauna, the section in Pant-yr-hendre Quarry and adjacent exposures shows a continuous late Llanvirn–early Llandeilo sequence and is therefore a potential stratotype for the definition of the base of the latter (Fortey *et al.*, 1991, p. 16), whether it is regarded as a series or, as in this work, adopted as a stage (see Fortey *et al.*, 1991, 1995).

Description

In Pant-yr-hendre Quarry, the beds dip north at about 45° (Figure 8.19). The oldest strata are present at the south of the quarry, where a bedding plane of the *murchisoni* Shales crops out immediately below the Asaphus Ash, a variably silicified ashy deposit 21 m thick, which is the horizon in which the quarry was opened. The ash has yielded abundant specimens of the asaphid trilobite *Basilicus tyrannus* (Murchison), from which it takes its name.

At the northern edge of the main quarry, the ashes pass up into a similar thickness of flaggy, bedded siltstones and shales, which have been called 'Llandeilo Flags'. They have yielded trilobites including *Basilicus* sp., *Whittardolithus* cf. *inopinatus* (Whittard) and *Marrolithus* sp., but according to Dr R. Bettley (pers. comm., March 1998) they are not equivalent to the Lower Llandeilo Flags at Llandeilo since they do not contain *Lloydolithus lloydii*; they are probably equivalent to the Ffairfâch Grits. These beds in turn pass upwards into the basal Hendre Shales, dark-grey shales with sporadic ashy siltstone horizons that have yielded abundant graptolites dominated by *H. teretiusculus* and trilobites including *W. inopinatus*, *Cnemidopyge* sp., *Marrolithus inflatus* Williams and *Spirantyx calvarina* Whittard. Younger horizons in the Hendre Shales are exposed in the road section to the north of the quarry. The lower 40 m have yielded *Lloydolithus lloydii* (e.g. at 2882 2052), suggesting correlation with the Lower Llandeilo Flags, and higher beds (e.g. at 2887 2060) contain *Marrolithus* and *Marrolithiodes* species, indicating correlation with the Middle Llandeilo Flags.

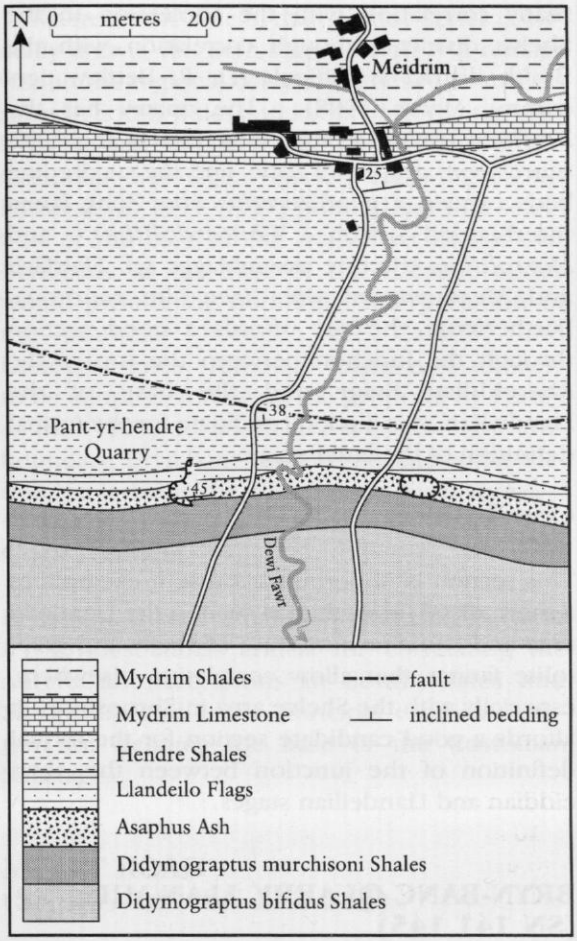

Figure 8.19 Geological map south of Meidrim, after Addison (in Bassett *et al.* 1974, fig. 6).

The contact between the Hendre Shales and Mydrim Limestone occurs at some level beneath the road at the cross-roads in Meidrim (Figure 8.19). The Mydrim Limestone is underlain by buff shales with abundant *Leptograptus validus* Elles and Wood and thin calcareous bands (Dr R. Bettley, pers. comm., March 1998). The Mydrim Limestone itself crops out in the side of the road near the post office in Meidrim; it is very impure, rather flaggy and not here very fossiliferous, but it has yielded trinucleid trilobites, namely *Marrolithus favus* (Salter) at the base and *Telaeomarrolithus* near the top.

Interpretation

The facies present in this section is of a more distal origin than that seen in the Llandeilo area, and the trilobite and graptolite faunas afford

ready correlation with the succession in the Shelve district, although correlation with the Builth district is difficult (Dr R. Bettley, pers comm., March 1998). The quarry has the *Basilicus tyrannus* fauna immediately above the *murchisoni* graptolite zone, and the succeeding beds contain a good *teretiusculus* Zone fauna interbedded with *Whittardolithus* and *Marrolithus* trilobite assemblages (cf. Ffairfâch and Meadowtown sites (see site reports)). Furthermore the site affords a good section through the junction between the top of the Abereiddian Stage and the base of the Llandeilian; it is a good candidate for the formal definition of the latter stage.

Conclusions

This section is important because it exemplifies a more distal facies than is seen in the Llandeilo area and contains a mixture of shelly and graptolite faunas that allow correlation elsewhere, especially with the Shelve area in Shropshire. It affords a good candidate section for the formal definition of the junction between the Abereiddian and Llandeilian stages.

BRYN-BANC QUARRY, LLAN-MILL (SN 141 145)

Introduction

The limestones and flags exposed here form part of the 'Narberth Group' of Addison, and until his work in the early 1970s (largely unpublished), they were considered to be wholly of Llandeilian age. In the upper part of the sequence Addison recognized trilobite faunas with taxa common to the Costonian Stage of the Caradoc of south Shropshire (see Coston site report). This section has thereby acquired national importance as one that shows the relationship of the type Llandeilo sequence of South Wales with that of the Caradoc of Shropshire in a continuous succession in the shelly facies. Its significance has been enhanced by more recent work on other groups, such as conodonts and ostracods.

The limestones of the Narberth Group were long quarried in the vicinity of Llan-Mill and Lampeter Velfrey (Strahan *et al.*, 1914, p. 32), and a composite succession can be constructed from the numerous disused quarries in the area. Murchison (1839, p. 396) recognized their Llandeilo age, and Strahan *et al.* (1914) also included them within the Llandeilo Series. However, the faunas were little studied until Spjeldnaes (1963) described silicified fossils (trilobites, bryozoans and ostracods) from a slab of limestone from an unspecified locality at Llan-Mill. On the basis of the trilobites and unsilicified brachiopods he suggested a late Llanvirn or early Llandeilo age (now Abereiddian–Llandeilian) but noted that the ostracods and bryozoans resembled more those from the Caradoc. Addison (1974) described the geology of the area in detail in an unpublished PhD thesis, although his main conclusions were published as a note in Williams *et al.* (1972, p. 36) and reported in Bassett *et al.* (1974, p. 13), who reproduced Addison's geological map of the area. Addison recognized the presence at Bryn-banc of trilobites like those from the lowest Caradoc Sandstone (Costonian Substage) of south Shropshire. Thus this section affords a critical link between Shropshire and South Wales, and along with other sections nearby (see below) demonstrates in a shelly facies the passage from the classic Llandeilo into the Caradoc, whose base is unconformable in Shropshire.

The importance of Addison's work at Bryn-banc and nearby localities has been emphasized by subsequent work on, for example, the conodonts by Bergström *et al.* (1987) and the ostracods by Jones (1986–1987), and on its potential as a boundary stratotype by Whittington *et al.* (1984), and Fortey *et al.* (1991 and 1995). If the recommendations of the latter are accepted, the base of the Caradoc Series will be drawn formally at the base of the *gracilis* Zone, a level well down in the Llandeilo succession in South Wales. However, Bryn-banc remains the prime candidate to define the base of the Costonian, which, on the recommendations of Fortey *et al.* (1995) becomes the upper substage of the Aurelucian Stage.

Description

Some 70 m of argillaceous limestones and flags, faulted in places, are exposed at Bryn-banc Quarry and have yielded a diverse fauna of trilobites, brachiopods, ostracods, conodonts and bryozoa. From beds near the top of the sequence, Addison (in Williams *et al.*, 1972; in Bassett *et al.*, 1974) reported the trinucleid trilobite *Costonia elegans* Dean and also other undescribed marrolithine trinucleids that are differ-

ent from any from the Llandeilo Flags at Llandeilo. *C. elegans* occurs in the Costonian of south Shropshire, whilst an undescribed marrolithine resembles *Marrolithus ventriculatus* Whittard, which occurs in the Costonian Spy Wood Grit in the Shelve area (see site reports for Spy Wood and Aldress dingles). Dr R. Bettley (pers. comm., March 1998) has recovered *Orthograptus apiculatus* Elles and Wood from the upper part of the quarry; he notes that the presence of this species also affords correlation with the Spy Wood Grit and is a good indicator for the top of the *gracilis* Zone (see also Hughes, 1989, p. 67). Further, an undescribed species of *Marrolithoides* from the middle of the Bryn-banc sequence occurs at the top of the Llandeilo Flags at Llandeilo.

Bergström *et al.* (1987) provided data which suggest that the base of the *Amorphognathus tvaerensis* conodont zone lies in the middle to upper part of the Bryn-banc sequence; the position in the evolutionary range of specimens of *Eoplacognathus elongatus* (Bergström) from this locality places them within the lower part of the *Baltognathus variabilis* Subzone, which is coeval with the middle part of the *gracilis* graptolite zone. The ostracods contain species that range throughout the sequence (e.g. *Gunnaropsis narberthensis* Jones and *Latebina pseudantra* Jones) or are confined to the 'Costonian' part (e.g. *Varilatella* (*Redacta*) *coronata* Jones and *Conchoprimitiella papilalata* Jones) (Jones, 1986–1987). Although these species have not been reported outside South Wales, *Piretopsis* (*Protallinnella*) *salopiensis* (Harper), which occurs in the Narberth Group at Lampeter Velfrey at the same horizon as that exposed in Bryn-banc, has been recorded from the Costonian Stage in the Shelve and south Shropshire areas.

Interpretation

Taken together, the trilobite, conodont and ostracod evidence indicates firmly the presence of correlatives of the Costonian Stage at Bryn-banc. Together with nearby sections at Henllan (SN 131 160) and Lampeter Velfrey, Bryn-banc Quarry affords a composite section through the Narberth Group; between them these localities have yielded faunas diagnostic of the Upper Llandeilo Flags at Llandeilo and the lowest Caradoc of Shropshire.

Wherever the base of the Caradoc Series is formally drawn, the Bryn-banc section will remain vital in the regional correlation between successions in South Wales and in Shropshire; it is likely to become the stratotype for the base of the Costonian Substage. Bassett and Hughes (in Fortey *et al.* 1991, p. 17) pointed out that selection of the base of the *tvaerensis* Biozone at Bryn-banc as the base of the Caradoc Series would protect the traditional interpretation of the boundary between the Caradoc and Llandeilo series. Although this is now unlikely to be adopted, following the proposal by Fortey *et al.* (1995) to adopt a lower level for this boundary, Bryn-banc remains an important section for securing the correlations given above.

Conclusions

Bryn-banc Quarry is nationally valuable because it provides faunas critical for correlating the Aurelucian successions in South Wales and Shropshire and is the principal candidate section for defining the base of the Costonian Substage.

MYLET ROAD (SN 269 144–SN 272 145)

Introduction

This locality is of historical importance for showing the stratigraphical and zonal relationships around the Caradoc–Ashgill boundary in South Wales. The exposure is, however, less good than the more recently exposed section at Pengawse Hill, near Whitland.

The Mylet Road section shows one of the best tectonically-undisturbed sections through the upper part of the Mydrim Shales in their entire area of outcrop, together with the lower part of the overlying Sholeshook Limestone Formation. It was described initially by Cantrill (in Strahan *et al.*, 1909, p. 51, 56), and later by Price (1973a, p. 234), who recognized the presence there of the trinucleid trilobite *Tretaspis moeldenensis moeldenensis* Cave in the basal Sholeshook Limestone, giving an important age datum to this horizon. The type locality for this stratigraphically significant trilobite is about 800 m to the ESE (2758 1424) at Moldin (Cave, 1960), where it occurs at the same horizon in the lowermost Sholeshook Limestone Formation (see

Figure 8.20 Road section at Pengawse Hill, west of Whitland. Black Mydrim Shales dipping uphill are overlain conformably by paler Sholeshook Limestone. The transition is marked by alternations of shale with layers of calcreous nodules and thin beds of limestone. (Photo: J.A. Zalasiewicz.)

also Price, 1973a, p. 234, locality 25). Price's (1973a) work on the trilobite faunas of the Sholeshook Limestone Formation has enabled its base to be correlated firmly with the early Cautleyan here; there has, however, been no modern assessment of the graptolite faunas of the underlying Mydrim Shales, although Cave (1960, p. 334) compared the graptolites of the highest beds to those of the Nod Glas in the Welshpool district, and on this basis suggested an Onnian age for them. Thus Price (1973a, p. 243) proposed that there was a hiatus beneath the base of the Sholeshook Limestone embracing part of the Onnian Stage, the Pusgillian Stage and part of Zone 1 of the Cautleyan Stage. Cantrill (in Strahan *et* al. 1909, p. 51) has also noted that the graptolites at the top of the Mydrim Shales indicate the base of the *Pleurograptus linearis* Zone, which level correlates broadly with the mid-Onnian Stage.

A new section that has become available only in recent years lies a few kilometres to the west, at Pengawse Hill, west of Whitland (Figure 8.20). There, essentially the same sequence as is seen at Mylet Road is exposed, but more completely. A preliminary report on the biostratigraphy of this section, including a range-chart of the graptolites, was given by Zalasiewicz *et al.* (1995). They demonstrated a continuous passage from the Mydrim Shales into the Sholeshook Limestone and, on the basis of graptolite and trilobite faunas, inferred that there is no late Caradoc–early Ashgill hiatus. The same situation is likely to obtain also at Mylet Road.

Description

The oldest horizons seen in the Mylet Road section crop out in an old roadside quarry (2694 1439) on the south side of the road 350 m southwest of Mylet. Black shales dip a little west of south at 45° and are affected by a nearly horizontal cleavage. They have yielded *Diplograptus* species and are attributed to the '*Mesograptus* Beds' of Strahan *et al.* (1914), although without a reappraisal of the graptolites their biostratigraphical correlation is unclear. Some 150 m

south-west along the road from the quarry (2681 1435) there is a bed full of the graptolite *Dicellograptus morrisi* Hopkinson, a species reported by Zalasiewicz *et al.* (1995, p. 614) at a similar (and probably correlative) level at Pengawse Hill. To the south-west, on the south-east side of the road (2681 1431), between 24 m and 27 m below the base of the Sholeshook Limestone, there is a 3.6 m-thick unit of black, yellow-weathering shales alternating with thin calcareous bands from 5 cm to 30 cm thick, one of which is rich in ostracods.

The topmost beds of the Mydrim Shales are sandy and pale-weathering and may have been calcareous (Cantrill, in Strahan *et al.*, 1909, p. 51), with the highest graptolite-bearing horizons at 3 m below the base of the Sholeshook Limestone, the lowest 8 m of which is represented by hard, calcareous mudstones. The passage upwards from the Mydrim Shales is gradual, and Cantrill (in Strahan *et al.*, 1909, p. 56) took the base of the Sholeshook Limestone at the bottom of the lower of two horizons of black phosphatic nodules. The horizons are about 15 to 20 cm thick and about 3.5 m apart, the nodules ranging from 1.5 cm to 9 cm in diameter. Price (1973a, p. 234) placed the base of the limestone lower than Cantrill, at 2 m below the lower band of nodules. He noted that there were traces of phosphatization throughout the basal 2 m of the Sholeshook Limestone. The lowest part of the formation is exposed around 2680 1424, where *Tretaspis moeldenensis moeldenensis* Cave occurs 5–6 m above the base. Above 9 m it is replaced by *Tretaspis* cf. *radialis* Lamont. Other trilobite taxa occurring with *T. moeldenensis moeldenensis*, such as *Ceraurinella intermedia* (Kielan) and *Encrinuroides sexcostatus* (Salter), range higher in this section and elsewhere (Price, 1973a, table 4). The calcareous mudstones exposed at Moldin (2758 1424) appear to correlate with a horizon between the phosphatic nodule bands exposed in the road section, probably about 4–5 m above the base of the Sholeshook Limestone Formation (Price, 1973a, p. 234). The top of the Sholeshook Limestone is not exposed at Mylet but can be seen at Pengawse Hill; there it includes an upward passage into the Slade and Redhill Mudstone Formation, which has yielded a rich bryozoan fauna (Buttler, 1991; cf. Figure 8.23b). The upper limit of the Sholeshook Limestone is seen also at Robeston Wathen and Sholeshook (see site reports).

Interpretation

Zalasiewicz *et al.* (1995, p. 613) showed that, at Pengawse Hill, Whitland, there is a continuous and gradual passage from the Mydrim Shales into the Sholeshook Limestone (Figure 8.20) and presented biostratigraphical evidence to demonstrate that there is no break in the sequence, as had formerly been supposed (e.g. Price, 1973a). From graptolite evidence they proved the presence of both divisions of the *clingani* Zone (*caudatus* Subzone below and *morrisi* Subzone above) and inferred an equivalent to the *linearis* Zone (their '*Normalograptus* proliferation interval'), and reported *Tretaspis* cf. *moeldenensis moeldenensis* from the basal Sholeshook Limestone. The pit-count on the fringe of the latter is similar to that of the lower Pusgillian taxon *T. moeldenensis colliquia* Ingham, suggesting a Pusgillian age for the base of the Sholeshook Limestone at Pengawse, thus possibly slightly older than at Mylet Road and elsewhere (Zalasiewicz *et al.*, 1995, p. 615). Because the section at Mylet Road shows an apparent continuous passage upwards from the Mydrim Shales, by analogy with Whitland there is likely to be no stratigraphical gap. New work on the graptolite faunas of the Mydrim Shales at Mylet Road, and also on those from elsewhere, is needed to establish whether locally (e.g. at Sholeshook – see site report) there is a hiatus.

The Mydrim Shales are thought to have been deposited under dysaerobic bottom-conditions (Temple and Cave, 1992; Zalasiewicz *et al.*, 1995) from a sea with high surface productivity that supported a diverse graptolite fauna. Upwards there is a reduction in diversity, which seems to be related to decreasing water depth and perhaps lowered temperatures; the onset of carbonate-rich sediments of the Sholeshook Limestone may be linked to both these factors (Zalasiewicz *et al.*, 1995).

Conclusions

Mylet Road is important in exposing the Mydrim Shales–Sholeshook Limestone transition; it also shows a biostratigraphically significant succession of *Tretaspis* species. Pengawse Hill, near Whitland, offers a much more complete and better-exposed section, but as yet it is unstudied in full. The Mylet Road section should therefore be used in tandem with that at Whitland.

SHOLESHOOK (SM 966 171 AND SM 968 172)

Introduction

Sholeshook railway cutting is of regional and national significance palaeontologically and biostratigraphically. It is the type section of the Sholeshook Limestone Formation of Cautleyan–Rawtheyan age, which has long been known for its diverse trilobite and echinoderm faunas. It is the type locality for many species of trilobites, a craniate brachiopod and several echinoderms (cystoids, pelmatozoans and a coronate).

The Sholeshook Limestone, like the Robeston Wathen, Birdshill and Crûg limestones (see site reports), is part of a series of early to mid-Ashgill carbonate or carbonate-rich developments that occur between Haverfordwest and Llandeilo. Each has its own distinct faunal and facies characteristics, and precise correlation between them is difficult. Most fall within the Cautleyan Stage, although the Sholeshook Limestone has been shown to extend upwards into the Rawtheyan (Price, 1980) and, probably, downwards into the Pusgillian (Zalasiewicz *et al.*, 1995).

As with the other Ashgill limestones in southwest Wales, the Sholeshook Limestone was included by Murchison (1839, p. 397) within his Llandeilo Limestone and Flags division. Phillips (1848, p. 322) described the limestone as 'subcalcareous and sandy beds, with Cystidea etc.', and in the appendix of the same work Salter described trilobite species. In the same year Forbes (1848) described several of the cystoids. The first detailed account of the site was by Marr and Roberts (1885, p. 480), who introduced the term 'Sholeshook Limestone' and listed the fossils present. Some trilobites and a brachiopod were described by Reed (1904, 1905, 1908), based on specimens from the Turnbull Collection in the Sedgwick Museum, Cambridge. Cantrill (in Strahan *et al.*, 1914, pp. 59–64) presented the first detailed map of the railway cutting and adjacent area and gave a long faunal list. Marr (1907, p. 68) placed the Sholeshook Limestone at the base of his then newly proposed Ashgill Series, with the underlying Robeston Wathen Limestone at the top of the Caradoc. Many later authors (e.g. Whittington, 1965, p. 41) considered the age to be middle Ashgill, but in a series of papers on the stratigraphy and trilobite faunas Price (1973a, 1974, 1977, 1980a,b) showed that the age at Sholeshook ranges from Cautleyan Zone 2 to Rawtheyan Zone 5. The cheirurid trilobites were redescribed by Lane (1971) and the important cystoid fauna by Paul (1973–1997), who described the succession at this locality and noted (1973, p. 4) that this is 'probably the richest site for cystoids in Britain'. Donovan and Paul (1985) described coronate blastozoan echinoderms, and Donovan (1986–95) described the pelmatozoan columnals.

Description

About 57 m of strata are exposed in the railway cutting (Figure 8.21), dipping at between 20° and 30° to the NNW (Figure 8.22). The junction with the underlying Mydrim Shales is not exposed here, but according to Price (1973a, p. 227) the lowest beds seen, on the west side of the south end, must lie only a short distance above it. The contact can be seen, however, in a rather poor exposure some 30 m upstream from the bridge over Cartlett Brook (9653 1694), where shales pass abruptly up into the limestone (Figure 8.21). The horizon represented by the

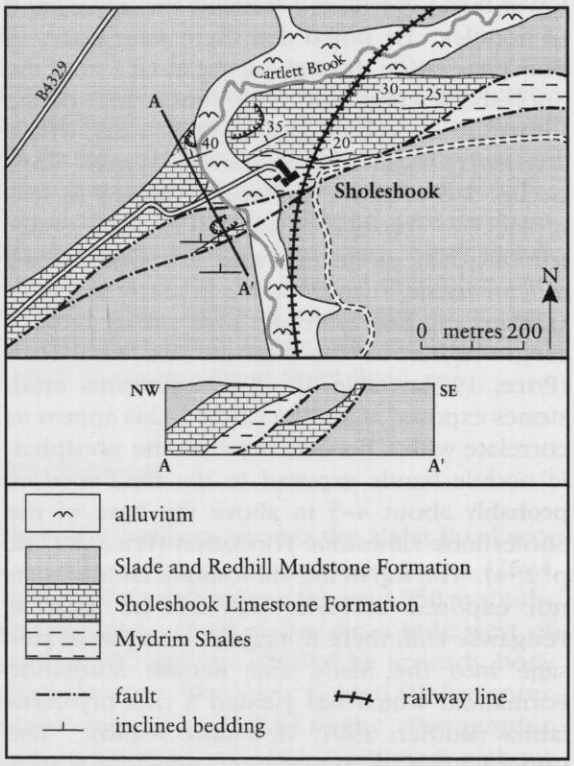

Figure 8.21 Geological sketch-map and cross section around Sholeshook, after Price (1973a).

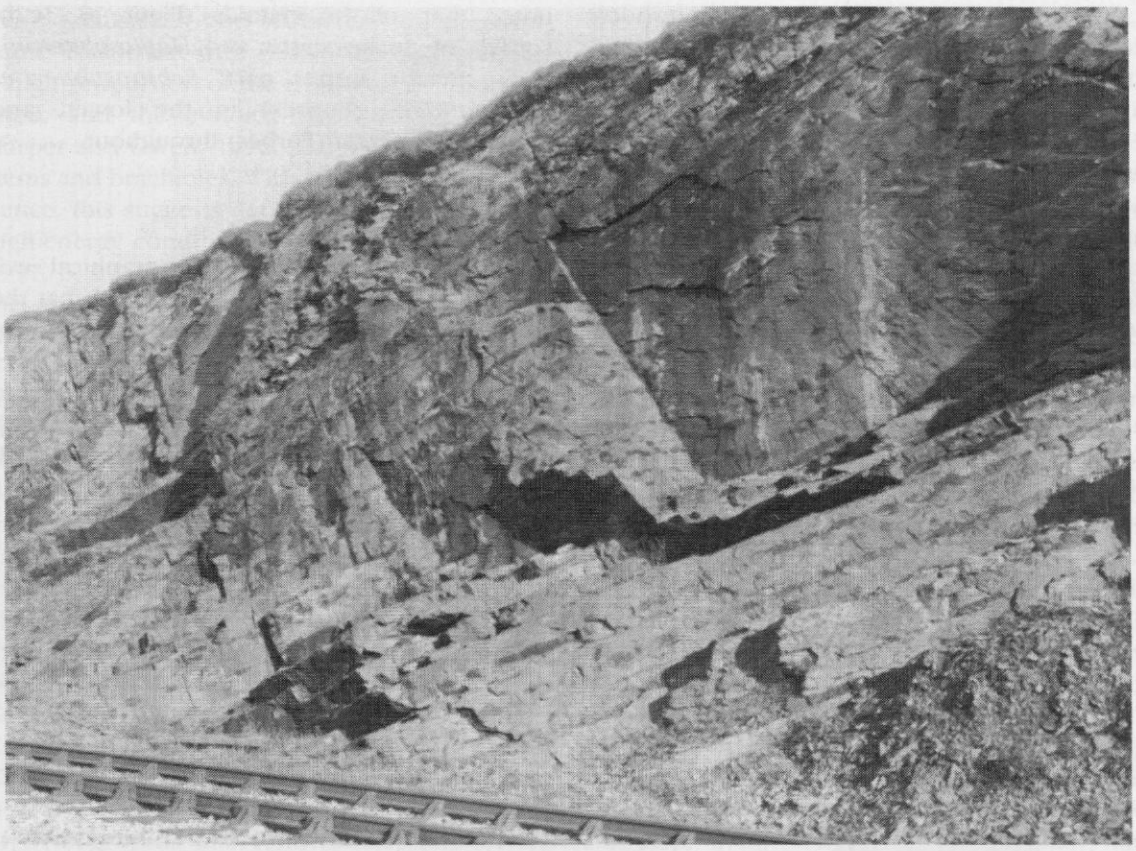

Figure 8.22 Sholeshook railway cutting, north-east of Haverfordwest. Photograph taken in 1909, looking east, showing northward-dipping Sholeshook Limestone in its type development. (Photo: British Geologcial Survey photographic collection, A892.)

shales is not known, but Price (1973a, p. 243, fig. 6) implied that there is a gap in the succession embracing the upper Caradoc and lower Ashgill; however, by analogy with the section at Pengawse Hill (Zalasiewicz *et al.*, 1995), it is possible that the succession is more complete than had been supposed (see Mylet Road site report).

The lower half of the Sholeshook Limestone exposed in the railway cutting comprises beds of tough, compact, dark blue-grey limestone, ranging in thickness from 6 cm to 20 cm and separated by units of light blue-grey, thinly bedded, fissile calcareous siltstone ranging from 30 cm to more than 200 cm thick. The limestone horizons are extremely fine-grained and weather rusty-brown. The thicker of these beds have gently undulating upper and lower surfaces and are probably the developments of 'nodular limestones' referred to in earlier accounts. Higher in the succession, the beds above about 25 m from the base lack these 'nodular limestones', and the uppermost 3–4 m are more argillaceous, greenish and bioturbated. These latter beds are well seen in a small exposure just west of the north end of the railway cutting (9683 1712) (Price, 1973a, loc. 9f). The highest beds exposed in the cutting were estimated by Price (1973a, p. 227) to be some 4–5 m below the top of the Sholeshook Limestone; the junction with the overlying Slade and Redhill Mudstone Formation can be seen in the south-east side of a quarry (9657 1683) downstream from the bridge over Cartlett Brook at Sholeshook (Price, 1973a, loc. 9d), within a small, fault-bounded thrust slice to the south of the main outcrop of the Sholeshook Limestone. An old quarry (968 172) 100 m north-west of Sholeshook Farm (Price, 1973a, loc. 9e) offers a confirmatory section that lies approximately half-way up the Sholeshook Limestone (Price, 1973a, table 2) and is important in having yielded specimens of the only graptolite from the formation, recently redetermined by Zalasiewicz *et al.*, (1995, p. 615) as *Orthograptus abbreviatus* Elles and Wood.

Fossils occur throughout the Sholeshook Limestone Formation in the railway cutting, although both trilobites and cystoids are more diverse in the upper part of the sequence (Price, 1973a, table 2; Paul, 1973–1997, p. 6, text-fig. 5). Of the former, *Tretaspis* cf. *radialis* Lamont, *Ceraurinella intermedia* Kielan, *Pseudosphaerexochus tectus* Ingham, *Encrinuroides sexcostatus* (Salter), *Atractopyge* aff. *scabra* Dean, *Flexicalymene cavei* Price and *Platylichas noctua* Price are common throughout and are joined in the upper half by such taxa as *Stenopareia bowmanni* (Salter), *Pseudosphaerexochus juvenis* (Salter), *Staurocephalus clavifrons* Angelin and *Calyptaulax planiformis* Dean (Price, 1973a, 1980b). Paul (1973–1997) noted that, of the cystoids (Figure 8.23c,d), species of *Archegocystis* and *Haplosphaeronis* occur in the upper part, *Echinosphaerites arachnoideus* (Forbes) in the lower, and *Sphaeronites litchi* (Forbes) throughout.

Interpretation

On sedimentological and stratigraphical evidence, Price (1980b, p. 882) suggested that the Sholeshook Limestone Formation probably represents an environment in the middle to upper part of the slope, between the platform edge and basin. The association of trilobite genera, with elements of deeper-water mudstones and shallow-water carbonate accumulations, supports

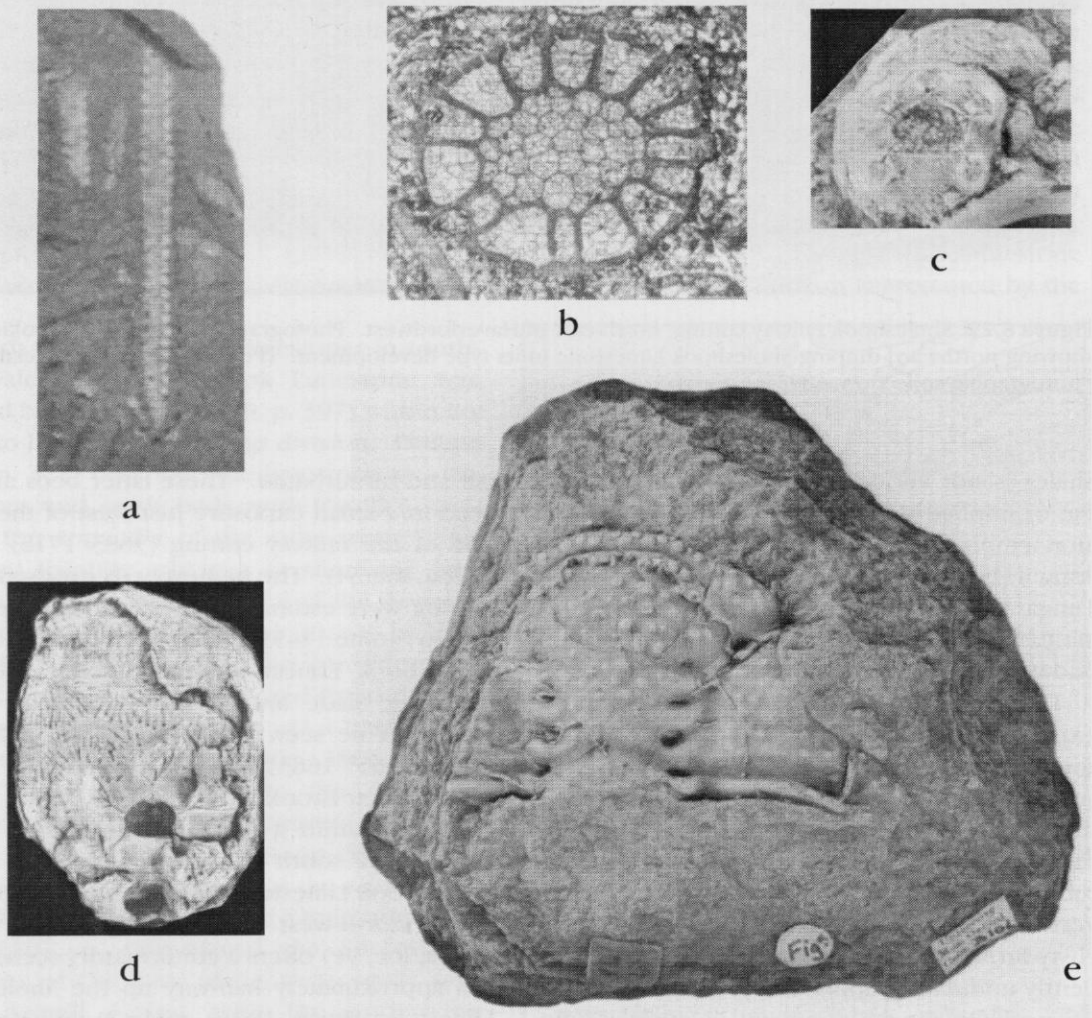

Figure 8.23 (a) *Normalograptus* sp., ×3, a typical graptolite that proliferates in the upper beds of the Mydrim Shales at Pengawse Hill. (b) Transverse section of the bryozoan *Kuckersella borealis* (Bassler), ×30, Slade and Redhill Beds, Pengawse Hill. (c) *Eucystis pentax* Paul, ×4, Sholeshook Limestone, Sholeshook. (d) *Archegocystis stellulifera* (Salter), ×2, Sholeshook Limestone, Sholeshook. (e) *Atractopyge verrucosa* (Dalman), holotype cranidium, ×1.5, from the Crûg Limestone, Crûg.

this conclusion. The sediments are predominantly clastic but with some carbonate content. A high proportion of the trilobites are disarticulated, and the cystoids (Donovan *et al.*, in Harper and Owen, 1996, p. 202) have lost their stems and brachioles. With sedimentological evidence, this suggests deposition under relatively high-energy conditions. However, Paul (1973–1997, p. 29) inferred that conditions just below the water–sediment interface were at times anaerobic.

The trilobite fauna shows greatest similarity to that of the Cautleyan parts of the Cautley Mudstones in northern England, with a large number of species in common (Price, 1980b, p. 881), making precise correlation possible. Of these, species of the trinucleid trilobite *Tretaspis* have been particularly important in establishing the age of the Sholeshook Limestone (Price, 1973a, p. 238; Zalasiewicz *et al.*, 1995, p. 615), the base apparently being diachronous, with a possible Pusgillian age established at Whitland, a Cautleyan Zone 1 age at Llanddowror, and Cautleyan Zone 2 at Sholeshook. The mid-Cautleyan age of the middle part of the succession at Sholeshook is supported by the presence of *Orthograptus abbreviatus* Elles and Wood, which is suggestive of an *anceps* Biozone age (Zalasiewicz *et al.*, 1995, p. 615). Revision of *Tretaspis* species by Price (1977) demonstrated that the top of the formation extends into the Rawtheyan Stage, Zone 5 (Price, 1980a), and the diagnostic subspecies *Tretaspis hadelandica brachystichus* Ingham was reported from several localities, including from the quarry downstream of the bridge at Sholeshook (Price, 1973a, loc. 9d, see above), and from Robeston Wathen (see site report). The limestone at Sholeshook itself apparently does not extend downwards into horizons with *Tretaspis moeldenensis moeldenensis* Cave, but these are seen at Mylet Road (see site report) and in the Whitland section (Zalasiewicz *et al.*, 1995, p. 615).

Conclusions

Sholeshook is an important locality regionally and nationally, being the type locality of the Sholeshook Limestone. This formation is stratigraphically and palaeontologically the most important of the Ashgill limestones in South Wales; it is the type stratum for several species of trilobites and cystoid echinoderms, including species of stratigraphical value.

ROBESTON WATHEN (SN 084 161)

Introduction

Robeston Wathen is an important locality for showing the stratigraphical and age relationships of the Robeston Wathen Limestone (one of the few coral-rich units in the Anglo-Welsh Ordovician) to other divisions in the Ashgill of Wales.

This is the type locality for the Robeston Wathen Limestone. The formation had been noted by Murchison (1839, p. 397), who described it as 'beds of black limestone two, three and five feet thick alternating with dark grey shale, passing upwards into sandy flags', and attributed it to the Llandeilo Flags. Lonsdale (in Murchison, 1839, p. 687, pl. 16*bis*, fig. 12) described and figured the coral '*Porites*' (now *Heliolites*) *inordinatus* from this locality, later redescribed in Milne Edwards and Haime's monograph (1855, p. 253, pl. 57, figs 7 and 7a). *Halysites catenularius* (Linnaeus) was also noted from here (Milne Edwards and Haime, 1855, p. 270). Phillips (1848, p. 220), like Murchison, mentioned black limestone with corals and fossiliferous shales at Robeston Wathen.

The first detailed description and section of the site was by Marr and Roberts (1885, p. 479, pl. 15, fig. 3), who proposed the name 'Robeston Wathen Limestone'; they considered it to be a calcareous development at the top of the *Dicranograptus* (now Mydrim) Shales, directly overlain by the Sholeshook Limestone. A fuller description was given by Jones (in Strahan *et al.*, 1914, p. 57), who evidently believed it to succeed the *Dicranograptus* Shales. A modern reassessment by Price (1973a, p. 232) described the succession and gave vertical sections through the Robeston Wathen Limestone and succeeding Sholeshook Limestone (Figure 8.24). He showed that the latter formation, following Marr and Roberts (1885), directly overlies the Robeston Wathen Formation in a calcareous mudstone facies. On the basis of the trilobite faunas, Price (1973a, fig. 6) correlated the Robeston Wathen and Sholeshook limestones at this locality with the Cautleyan Stage. This assessment was supported by Orchard (1980, p. 13) and by Savage and Bassett (1985, p. 680) on the basis of conodont

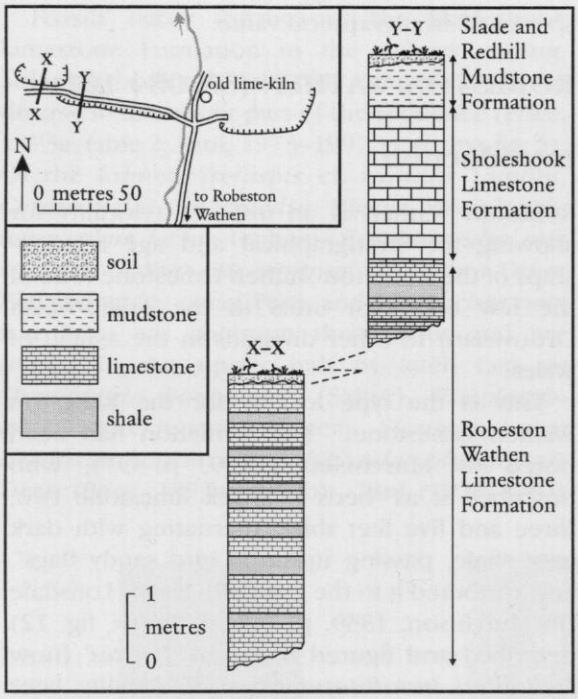

Figure 8.24 The geological succession north of Robeston Wathen, after Price (1973a).

faunas from the Robeston Wathen Limestone. Having re-examined the trilobite fauna (Price, 1974, 1977, 1980b), Price (1980a) revised the age of the top of the Sholeshook Limestone at Robeston Wathen as Rawtheyan Zone 5.

Description

A succession extending from the Robeston Wathen Limestone Formation through the Sholeshook Limestone Formation and the Slade and Redhill Mudstone Formation is exposed in old quarries and the adjacent dingle north of Robeston Wathen church (Figure 8.24). The strata dip SSW at 35–40°. The junction between the base of the Robeston Wathen Limestone and the underlying Mydrim Shales is not exposed, but a small outcrop of the latter (0844 1622) was noted by Jones (in Strahan *et al.*, 1914, p. 45, Geological Survey locality 29NW λ2) 46 m north of the quarry. Smooth, flaggy black shales here yielded graptolites, including *Diplograptus multidens* Elles and Wood, *Climacograptus* and *Dicranograptus*. It is not known whether the succession below the Robeston Wathen Limestone is complete or if there is a break (for discussion of this interval at Pengawse Hill, Whitland, see Zalasiewicz *et al.*, 1995).

The Robeston Wathen Limestone Formation is exposed in two disused quarries (0837 1618 and 0847 1615) on either side of the dingle about 400 m north of Robeston Wathen; that on the east side is the one referred to by Marr and Roberts (1885, p. 479) when they proposed the name. The sequence comprises some 8 m of alternations of thick beds of tough, dark-coloured, medium- to coarse-grained limestone with generally much thinner beds of dark-coloured calcareous shale (Price, 1973a, p. 232). The limestone beds are particularly rich in halysitid corals, with subordinate numbers of other tabulate corals and brachiopods. Conodonts include *Amorphognathus ordovicicus* Branson and Mehl (Savage and Bassett, 1985) and species of *Plectodina*, *Birksfeldia* and *Walliserodus* (Orchard, 1980).

The Robeston Wathen Limestone passes upwards gradationally into about 4 m of deeply-weathered calcareous mudstones and silty rottenstones that are richly fossiliferous and are considered to be a development of the Sholeshook Limestone (Figure 8.24), this conclusion being based on stratigraphical, lithological and faunal grounds (Price, 1973a, p. 233). The trilobite fauna includes the trinucleid *Tretaspis hadelandica brachystichus* Ingham, which is diagnostic of the Rawtheyan Stage in northern England, and its presence is taken as evidence for that stage at this locality (Price, 1980a). These beds are well exposed in the steep bank between the western of the two quarries and the stream.

The junction with the overlying Slade and Redhill Mudstone Formation is a sharp plane of contact, seen in the section about 10 m south-east of the western quarry. Immediately above is a very thin and inconstant conglomeratic horizon, and Price (1973a, p. 233) suggested that together these features indicate the possibility of at least a slight stratigraphical break. However, the presence of *Flexicalymene cavei* Price in the basal mudstone above the contact suggests that the break, if present, is of no great magnitude, for that species ranges no higher than Rawtheyan Zone 5 (Price, 1980a, p. 486), the age of the top of the underlying Sholeshook Limestone here. There are further outcrops of the Slade and Redhill Mudstone Formation in the sides of the dingle to the south (e.g. 0843 1605, 0843 1601 and 0845 1588), and Jones (in Strahan *et al.*, 1914, p. 69) estimated a thickness

of 137 m of strata between the top of the Robeston Wathen Limestone and the base of the Llandovery. Little work has subsequently been done on the Slade and Redhill strata. The sequence is essentially blue-grey mudstones with thin micaceous bands in the lower part, and hard bands of predominantly grey and brown sandstones in the upper (Jones, in Strahan *et al.*, 1914, p. 70), in which fossils are more abundant and include trinucleid and calymenid trilobites. These have not been studied, although all of this succession is probably of Rawtheyan age, including, according to Cocks and Price (1975, p. 709), the highest beds of the formation.

Interpretation

The transition from the black graptolitic Mydrim Shales into the carbonates and calcareous mudstones of the Robeston Wathen and Sholeshook limestone formations probably relates to a general shallowing and perhaps a cooling event (see Mylet Road site report; Zalasiewicz *et al.*, 1995, p. 616); whether there is a break in succession is not known. The Robeston Wathen Limestone is a locally developed carbonate facies, rich in corals, that is particularly well developed and well known at this locality but is reported to crop out elsewhere (Strahan *et al.*, 1909, 1914). It appears that locally, as here, conditions favourable to corals prevailed, although nowhere do they form reefs. Several taxa are common to coeval horizons elsewhere, such as the Portrane Limestone in eastern Ireland (Somerville, in Harper and Owen, 1996, pp. 40, 46). The Sholeshook Limestone equivalents and the overlying Slade and Redhill Mudstone are all generally shallow-water platform deposits with rich shelly faunas.

The special significance of this section lies in the abundance of corals in the Robeston Wathen Limestone (an unusual feature in the British Ordovician), the demonstration of the stratigraphical relationship between the Robeston Wathen and Sholeshook limestones, and the presence at the top of the latter of trilobites indicative of a Rawtheyan age, demonstrable at only a few other localities. Potentially it may be possible to show here whether the succession below the Robeston Wathen Limestone is conformable with the underlying Mydrim Shales, as is apparently the case below the Sholeshook Limestone at Pengawse Hill (Zalasiewicz *et al.*, 1995, p. 616).

Conclusions

Robeston Wathen is, stratigraphically and palaeontologically, an important locality. It is the type locality for the Robeston Wathen Limestone, an unusual coral-rich facies of the Ordovician in Britain, and is one of the few localities where the stratigraphical relationships and age of the Upper Ordovician limestones of South Wales can be discerned.

CRÛG FARM (SN 627 231)

Introduction

Crûg Farm is of regional and palaeontological importance, being the type locality of the Crûg Limestone, a conodont-rich limestone facies in the Ordovician of Wales. It is the type locality for certain trilobite and conodont species.

A small outcrop of fossiliferous shelly limestone at Crûg Farm, 0.6 km NNW of Llandeilo (Figure 8.17), is the type locality for the Crûg Limestone. This limestone was reported by Murchison (1839), who described the rocks as being the 'oldest calcareous beds' of his 'Llandeilo Flags Formation'. Phillips (1848, p. 324) described it as a limestone with large trilobites and also attributed it to the Llandeilo Series. Salter (1853) initially followed this view in describing *Phacops* (now *Toxochasmops*) *amphora*, but later (Salter 1864–1883, p. 42) described it as 'Caradoc Limestone'. Cantrill (in Strahan *et al.*, 1907, p. 31) included it within the 'Bala Limestone'.

The Crûg Limestone was named by Williams (1953, p. 194), who, on the basis of the shelly fauna, regarded it as being referable to the Longvillian to Marshbrookian stages of the Caradoc. He suggested that it was probably equivalent to the upper Cheney Longville Flags of Shropshire and the Robeston Wathen Limestone of Pembrokeshire. Following Williams' (1953) description, which remains the only detailed account, there has been a good deal of palaeontological debate on the age of the limestone, centred particularly upon the rich conodont fauna that was first described from here by Lindström (1959); he followed Williams' age assessment. A similar age, within the *Amorphognathus superbus* conodont Zone, was supported by Bergström (1964, 1971) on the basis of further studies on the conodont fauna. Orchard (1980) made new conodont collections

from the Crûg Limestone and noted similarities between these and those of the low Ashgill of the Howgill Fells, and he suggested that it may, at least in part, be of early Ashgill age, possibly close to the *superbus–ordovicicus* zonal boundary. From the occurrence of the trilobite *Decoroproetus piriceps* (Ingham), known from Cautleyan strata in northern England, Owens (1973, p. 48) suggested that the Crûg Limestone may fall within the Cautleyan; McNamara (1980, fig. 2), who redescribed *Toxochasmops amphora* (Salter), gave a similar range for that species. Price (1984, p. 103) concluded that the age was early in the Cautleyan Stage. New collections of conodonts made by Savage and Bassett (1985, p. 683) lacked any *A. superbus* but included numerous specimens of *Amorphognathus ordovicicus* Branson and Mehl, on the basis of which they placed the Crûg Limestone firmly within the *A. ordovicicus* Zone and as a consequence placed the *superbus–ordovicicus* boundary within the late Caradoc, removing an otherwise anomalous extension of the top of the *superbus* Zone well into the Ashgill. Trilobite and conodont evidence, therefore, now both indicate an early Ashgill, probably Cautleyan, age for the Crûg Limestone.

Historically, the quarry at Crûg Farm is of some interest in that it is very likely the type locality for the trilobite *Atractopyge verrucosa* (Dalman) (Figure 8.23e); the type specimen of this species is almost certainly the original of one of Lhwyd's (1699a) figures (see Dean, 1974, p. 97), which is one of the earliest illustrations of a trilobite ever published; his woodcut is clearly recognizable as a mirror image of the type specimen at Oxford University Museum (Owens, 1984, p. 4). The same specimen was illustrated by Brongniart (1822, pl. 4, fig. 11). Crûg is the type locality for several conodonts, including *Aphelognathus rhodesi* Lindström and *Ozarkodina? pseudofissilis* (Lindström).

Description

The exposures at Crûg Farm are generally poor and disjointed, and there is no continuous section through the sequence. The largest exposure is in a disused quarry at the eastern end of the field immediately adjacent to the farmhouse. The remainder of the outcrop is seen poorly exposed in a series of hummocks in the same field and along the northern bank of a disused track running along the southern boundary of the field. Approximately 20 m of limestone are exposed. It is dark-grey, coarsely crystalline, with remarkably little siliciclastic material, and is richly fossiliferous. A considerable amount of the calcium carbonate is composed of bioclastic, sand-sized particles, predominantly comminuted brachiopod and echinoderm fragments. Approximately half-way up the succession occur two horizons rich in phosphate nodules, each horizon about 20 cm thick and separated by 1.8 m of limestone, 13 m above the base of the exposed beds. The limestone outcrop is a fault-bounded lenticle, dipping at 60° to the north. Shales with *Nemagraptus gracilis* crop out to the south and cleaved 'upper Bala' mudstones, presumed to be referable to the Slade and Redhill Formation, to the north.

Interpretation

Williams (1953, p. 203) described the Crûg Limestone as being of shallow-water origin. Lindström (1959) considered it to be a reworked deposit, with the greatest abundance of conodonts in the lower part and those from the upper part fragmentary and corroded. This claim was supported by Orchard (1980, p. 13), who believed that the conodont association reflected a degree of reworking and condensation. Both the conodont and trilobite faunas support an early Ashgill age (probably Cautleyan Stage), and they show more differences than similarities to the older (Caradoc) faunas, with which the Crûg Limestone had formerly been correlated, as discussed above.

Conclusions

Crûg Farm is the only place where the Crûg Limestone, a unique conodont-rich limestone facies in the Ordovician of Wales, is exposed. It is the type locality for certain species of trilobites and conodonts.

BIRDSHILL QUARRY (SN 6014 2312)

Introduction

This locality, about 3 km west of Llandeilo, is of historical significance, and important because it is the only place where the Birdshill Limestone, a unique limestone facies in the Ordovician of Wales, is exposed. Recognized by Murchison (1839) and Phillips (1848), the locality has long

been known for its abundant shelly fossils.

The term 'Birdshill Limestone' was first applied by Thomas (in Strahan *et al.*, 1907, p. 31), who gave an extensive list of trilobites, brachiopods and other fossils from the quarries. Like the Crûg Limestone (see Crûg Farm site report), it has yielded a rich conodont fauna, first described by Bergstöm (1964, 1971), who recognized 18 species here. He considered it to be the lateral equivalent of the Sholeshook Limestone, as did Shirley (1936) and George and Pringle (1948). Price (1973b, 1984), on the basis of the trilobite fauna, argued for a low Ashgill (Cautleyan) age but noted that the different facies made exact correlation with the Sholeshook Limestone difficult. More recent work on the conodonts by Orchard (1980) supported a low Ashgill age, within the *superbus* conodont zone, and he suggested, contrary to many earlier opinions, that the Birdshill Limestone might be slightly older than the Crûg Limestone. Latterly, Savage and Bassett (1985) made extensive new conodont collections, with abundant specimens of *Amorphognathus ordovicicus,* and placed the Birdshill Limestone in the *ordovicicus* Zone; they found no evidence for a *superbus* age and concurred with earlier assessments for a late Pusgillian–early Cautleyan age.

Birdshill Quarry is the type locality for the brachiopods *Retrorsirostra retrorsa* (Salter) and *Hebertella llandeiloensis* Foerste (the latter considered by Cocks (1978, p. 52) to be the brachial valve of the former), the bivalve *Ambonychia triton* (Salter) and the trilobite *Gravicalymene convolva* Shirley.

Description

The Birdshill Limestone is exposed in disused quarries 3 km west of Llandeilo, along the side of a track 200 m north-west of Birdshill Farm. It lies in a fault-bounded area WNW of Dynevor Park, and according to the map by Thomas and Pringle (fig. 11 in Pringle and George, 1948) is underlain by Mydrim Shales and succeeded by the Slade and Redhill Formation. The limestone, like that at Crûg, is shelly and coarse-grained but differs in being a much paler grey. It has yielded trilobites including *Decoroproetus piriceps* (Ingham), *Harpidella tridens* (Ingham), *Acidaspis magnospina* Stubblefield, *Atractopyge* cf. *verrucosa* (Dalman) and a *Tretaspis* that is probably *T. moeldenensis moeldenensis* Cave; this association is indicative of a late Pusgillian or Cautleyan age (Price, 1984, p. 103). The conodont fauna, dominated by *Amorphognathus ordovicicus* Branson and Mehl with common *Prioniodus* sp. and *Rhodesognathus elegans* (Rhodes), supports this age. No modern account of the brachiopods has been given.

Interpretation

Like Crûg Quarry, Birdshill has yielded a rich conodont fauna, one of the few horizons of this age in Britain to have done so. Having elements in common, the Birdshill and Crûg limestones are evidently of about the same age, although the latter has a richer conodont fauna, including *Aphelognathus rhodesi* (Lindström), which is lacking in the Birdshill Limestone and which is possibly a useful index of the Pusgillian Stage (Savage and Bassett, 1985, p. 690). The faunal differences may be a result of slightly different age or facies. Both deposits may correlate with the lower part of the Sholeshook Limestone, which is in a more argillaceous facies. Like the Crûg, the Birdshill Limestone was probably deposited in shallow water.

Conclusions

This site is unique, being the only exposure of a limestone facies that complements that at Crûg Farm. It is an early Ashgill conodont-rich horizon, of which there are few other examples in Britain. It also has a rich shelly fauna showing striking contrasts with that of the approximately coeval Sholeshook Limestone.

BUILTH–LLANDRINDOD INLIER

The inlier of Ordovician rocks between Builth Wells and Llandrindod Wells in mid-Wales (Figure 8.25) represents an uplifted local basin of Llanvirn to early Caradoc rocks some 10 km to the south-east of the axis of the Tywi Lineament. It lies about mid-way between the Llanvirn outcrops of the Llandeilo area (see Fairfâch Railway Cutting site report) and the Shelve area, described in Chapter 7, and differs from each of those areas – from Llandeilo in showing finer clastics deposited in a deeper, more dysaerobic environment, and from Shelve in that the chief volcanic eruptions occurred in late rather than early Abereiddian times. From the time of

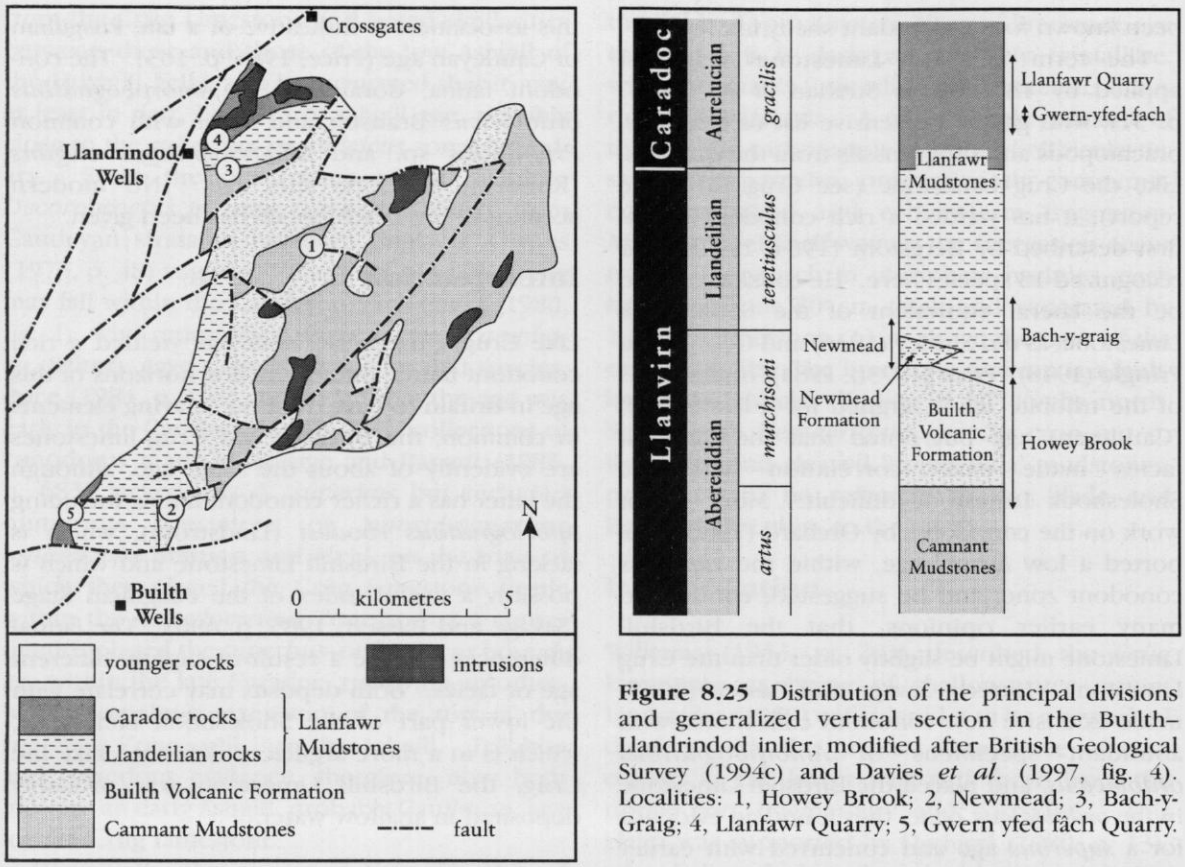

Figure 8.25 Distribution of the principal divisions and generalized vertical section in the Builth–Llandrindod inlier, modified after British Geological Survey (1994c) and Davies *et al.* (1997, fig. 4). Localities: 1, Howey Brook; 2, Newmead; 3, Bach-y-Graig; 4, Llanfawr Quarry; 5, Gwern yfed fâch Quarry.

Murchison (1839) the area has attracted researchers, for both the spectacular volcanic rocks and the well-preserved and prolific fossil faunas.

HOWEY BROOK (SO 087 591–SO 095 589)

Introduction

Exposures in Howey Brook provide sections through the lower part of the *Didymograptus murchisoni* Zone of the Builth–Llandrindod inlier, which includes the type locality for *Didymograptus murchisoni* itself. The brook affords a sequence of shales and flags, with contemporaneous igneous rocks that represent the attenuated northern part of the outcrop of the Builth Volcanic Formation; it provides a good example of the succession that occurs in this part of the inlier, as follows:

Builth Volcanic Formation (with Llandrindod Tuff at base, overlain by reworked tuffs)
Camnant Mudstones Formation

Both the shales and some horizons within the tuffs are richly fossiliferous; they include the type localities for several trilobite, brachiopod and graptolite species.

Historically this site is of interest since it was described in detail by Murchison (1839, p. 325), who logged and illustrated the sequence exposed in a ravine (the 'Cwm-re') through which a large tributary of the Howey flows; he referred to it as the 'chief feeder' (later, following Elles (1940), referred to as the 'main feeder'). Murchison described an alternating sequence of flags, shales and ashes and inferred that the volcanics were erupted in a submarine environment. He noted the presence of both trilobites and graptolites, the latter in his bed 'f', where there were abortive workings for coal (the adit may be the 'cave' indicated on the 1:25 000 topographical map). It is probable, by inference from Murchison (1839, pp. 326, 694), that this is the horizon with the calcareous concretion that contains the type specimens of *Didymograptus murchisoni* (Beck), the type species of *Didymograptus*. These specimens were redescribed and refigured by Elles and Wood

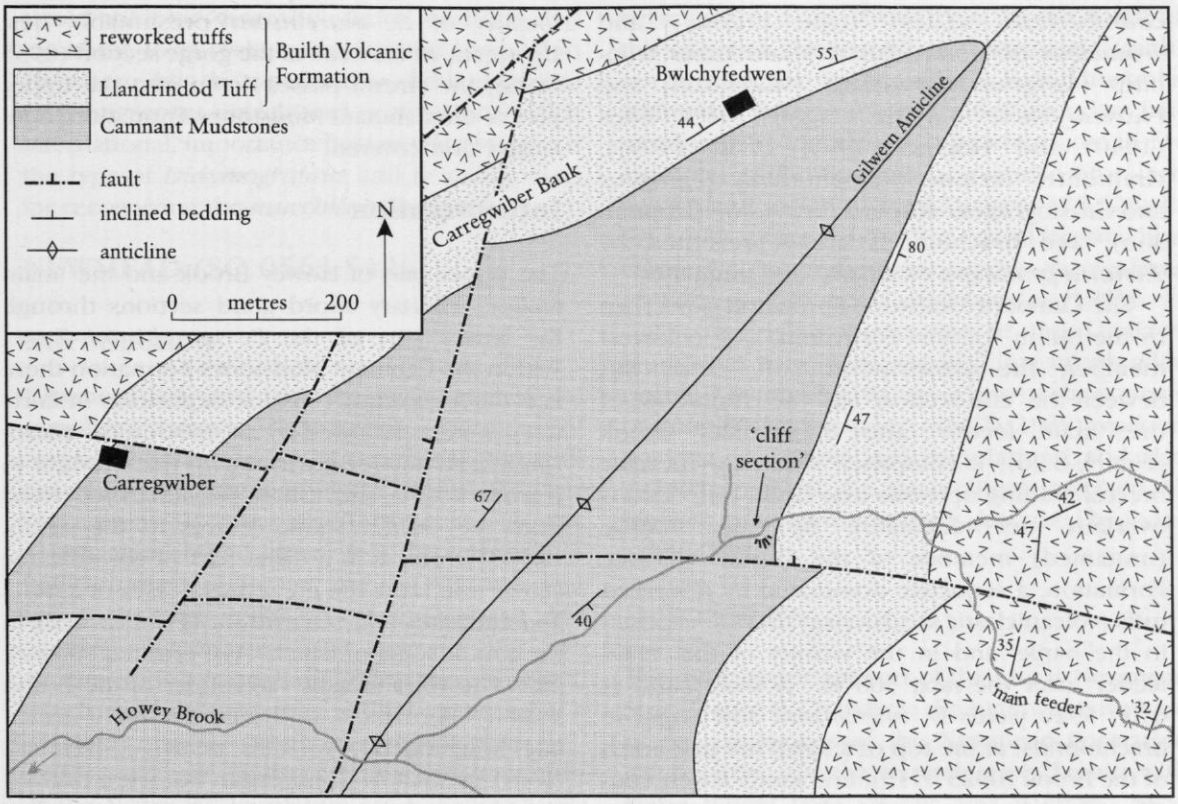

Figure 8.26 Geological map of the Gilwern Anticline and Howey Brook including the 'main feeder' tributary, after Davies *et al.* (1997, fig. 5).

(1901), Strachan and Khashogji (1984) and Jenkins (1987), and Lapworth (1879b, p. 197) used this name when he established the *murchisoni* graptolite zone, albeit in a wider sense than that employed today.

Elles (1940, pp. 395, 401) gave the only detailed description of the section since that of Murchison and presented a sketch-map of the 'main feeder' and adjacent part of Howey Brook. Jones and Pugh (1949, p. 85) used this section, among others, to infer sequences of events from which they derived their picture of Ordovician palaeogeography in the Builth district (see Newmead site report). The area of Howey Brook appears on the 1:25 000 British Geological Survey map of the Builth–Llandrindod inlier (Earp, 1977); much of this map was based on the mapping of Jones and Pugh, who offered a modification to the interpretation given by Elles. Part of Earp's map, including this site, has subsequently been revised by Davies *et al.* (1997), and their version is followed here. The sections in the upper part of Howey Brook and the 'main feeder' have yielded trilobites (described by Elles (1940) and Hughes (1969, 1971, 1979)), graptolites (Jenkins, 1987) and brachiopods (Lockley and Williams, 1981; Williams *et al.*, 1981).

Description

The upper reaches of Howey Brook cross the southern limb of the Gilwern Anticline, in the core of which the Camnant Mudstones crop out (Figure 8.26). Although most of the outcrop is drift-covered, resistant tuffs of the overlying Llandrindod Tuff, the lowest member of the Builth Volcanic Formation, form scarps running NNE from the brook (089 592) on the south-east limb of the anticline and along Carregwiber Bank on the north-west limb. Black, richly fossiliferous silty shales of the upper part of the Camnant Mudstones lying in Elles' (1940) *'Didymograptus speciosus* and *Cryptolithus gibbosus* Subzone' (now considered to be at the base of the *murchisoni* Zone – see Davies *et al.* (1997, p. 11)) are exposed on the south bank of the brook (089 592). They dip south-east under the tuffs at about 55° in the 'cliff section', famous for its abundant trinucleids (*Bettonolithus*

chamberlaini (Elles) (type locality) and *Trinucleus abruptus* Hughes) and other trilobites (*Ogyginus corndensis* (Murchison) and *Flexicalymene aurora* Hughes) (see Elles (1940) and Hughes (1969, 1971, 1979)). Graptolites include pendent *Didymograptus* and *Glossograptus hincksii fimbriatus* (Hopkinson), and brachiopods are represented by *Tissintia prototypa* (Williams) and lingulates.

The Camnant Mudstone Formation is overlain by the Builth Volcanic Formation, and its lowest member, the Llandrindod Tuff, crops out beween the 'cliff section' and the confluence of the 'main feeder' and the Howey Brook (Figure 8.26); it comprises a basal pyroclastic breccia grading upwards into lapilli tuff. This is overlain unconformably by the middle (unnamed) member of the Builth Volcanic Formation, a sequence dominated by reworked tuffs (volcaniclastic sandstones) that are exposed in the banks and in the vicinity of the 'main feeder' over the next 300 m. A shale band at 0909 5920 yields *D. murchisoni* and lingulate brachiopods; at the top of a small hill just north of the brook (0925 5915), fine sandy ashes, considered to belong to the Cwm-amliw Tuff by Earp (1977), have afforded a diverse brachiopod fauna in association with abundant bryozoans and subsidiary numbers of trilobites, molluscs, graptolites and other fossils (Lockley and Williams, 1981; Williams *et al.*, 1981). This is the type locality for the brachiopods *Christiania elusa* Lockley and Williams and *Macrocoelia llandeiloensis elongata* Lockley and Williams; the latter and *Dalmanella parva* Williams are numerically the most abundant, with *Hesperorthis dynevorensis* Williams and *Glyptorthis* cf. *viriosa* Williams also common.

The remainder of the section in the 'main feeder' also exposes the reworked tuffs of the Builth Volcanic Formation. It is part of this that was illustrated by Murchison (1839, p. 325), and a map of the whole section was given by Elles (1940, p. 402). Tuffs, flags and shales crop out, dipping downstream at between 30° and 35°; the more resistant tuff and ash bands give rise to the series of waterfalls in the ravine section. Many of the shaly and flaggy horizons are fossiliferous; at 9013 5913 they have yielded *Diplograptus priscus* Elles and Wood, and below the main waterfall (0917 5906) *Amplexograptus confertus* (Lapworth), pendent *Didymograptus* and dalmanellid brachiopods (C.J. Jenkins, unpublished). It is within this stretch that the type locality of *D. murchisoni* presumably lies. Upstream, at the head of the gorge section (0935 5898), the stream passes down into the upper part of the Camnant Mudstones Formation, here largely drift-covered.

Interpretation

The upper part of Howey Brook and the 'main feeder' tributary afford good sections through the lower part of the *D. murchisoni* Zone. Within the Camnant Mudstones Formation there is evidence for quiet marine deposition in fairly deep waters, followed by an episode of volcanism in a submarine environment that brought in pulses of tuffs and ashes, presumably derived from the main volcanic centres to the south. Howey Brook is in a distal part of the volcanic centre and lacks the great thicknesses of basalts and andesites that occur towards Builth Wells in the south, some of which were erupted subaerially. The volcaniclastic sandstones of the Builth Volcanic Formation, with their abundant articulate brachiopods (Williams *et al.*, 1981), are clearly of shallow-water origin but were derived into a deeper-water setting by gravity flow (Davies *et al.*, 1997, p. 15).

Besides providing palaeogeographical and stratigraphical evidence for this part of the Builth sequence, Howey Brook is the type locality for several species, most notably the zonal graptolite *Didymograptus murchisoni*. Redescription of the type material has not stilled controversy over the interpretation of this species (Strachan and Khashogji, 1984; Jenkins, 1987; Strachan, 1996), and it may require new material from the type locality to resolve certain problems. A solution is desirable because *D. murchisoni* is used to effect correlation with sections in North and South Wales, in the Shelve area and many other places as far afield as continental Europe, North and South America, and China, whilst the zonal name is recognized globally. Among the trilobites, *Bettonolithus chamberlaini* is known in the Camnant Mudstones elsewhere in the Builth Inlier and also occurs in the contemporaneous Betton and Weston Beds at Shelve.

Conclusions

The Howey Brook site is valuable for displaying the biostratigraphical succession of the lower part of the *murchisoni* Zone in a fairly uniform

mixed trilobitic–graptolitic facies, enabling dating of the local rock succession and correlation elsewhere; but the type locality of the graptolite *Didymograptus murchisoni* is of national, even international, importance because that species is the type of *Didymograptus* and is widely used for recognizing the *murchisoni* Zone.

NEWMEAD (SO 0563 5426)

Introduction

Newmead Scar and outcrops in the vicinity are significant because they expose examples of coarse shallow-water sediments associated with the main development of the Builth Volcanic Formation in the southern part of the Builth–Llandrindod inlier. It is the relationship between these sediments and the volcanics that led Jones and Pugh (1949), by careful and detailed mapping on a large scale, to their classic description of an early Ordovician shoreline, which must be one of the earliest examples of a detailed palaeogeographical reconstruction.

The epiclastic sandstones and conglomerates of the Newmead Formation are a shallow-water facies of the *murchisoni* Zone that crops out between Coed-cae, about 1 km to the north of this site, and Llanelwedd, at the extreme southern end of the Builth Inlier. Some horizons within this formation have yielded abundant faunas dominated by articulate brachiopods, as, for example, at Tan-Lan, near Newmead Scar (see below) and at Tan y Graig Quarry (475 528) to the south. These and other coeval benthic brachiopod communities were used in the analyses of Williams *et al.* (1981) and Lockley (1983).

The overlying mudstones of the Llanfawr Mudstones Formation, exposed in a stream adjacent to Newmead Lane, were one of the sources of trilobites for Sheldon's (1987a, 1988) work on phyletic gradualism and populations, and also yielded some of the graptolites described by Hughes (1989) and ostracods described by Jones (1986–1987).

Description

The most important part of this site is Newmead Scar (Figure 8.27), where the highly erosive base of the sandstones of the Newmead Formation can be seen. Here, a vertical face of basalts with some pillow lavas (Baker and Hughes, 1979, p. 71) is capped by some 3 m of grey feldspar

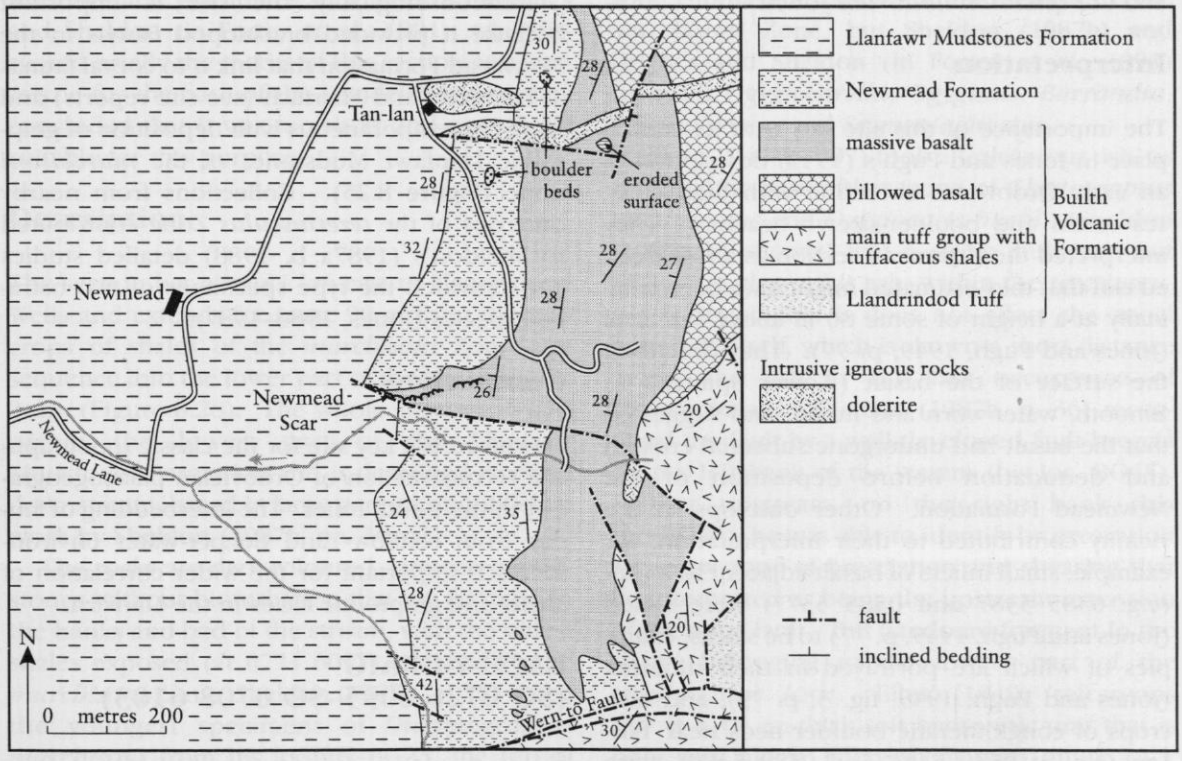

Figure 8.27 Geological map of the area around Newmead, after Jones and Pugh (1949) and Earp (1977). The massive basalt forms small inliers, interpreted by Jones and Pugh as stacks that protrude through the Newmead Formation.

sands. The junction is irregular but sharply defined, and the sandstones penetrate some fissures and cavities; in places small patches of sandstone can be seen cemented to the face.

Near Tan-Lan (near 057 547), current-bedded epiclastic sandstones (pyritous feldspar sands) have yielded a shelly fauna dominated by the strophomenoid brachiopod *Macrocoelia llandeiloensis* (Davidson) and abundant anchoring spines of the sponge *Hyalostelia fasciculus* (M'Coy). Nearby, flinty mudstones overlying these sandstones form the top of the *murchisoni* Zone and the base of the Llanfawr Mudstones Formation. Dark mudstones with bentonite and tuff horizons belonging to the succeeding *teretiusculus* Zone are exposed in the stream adjacent to Newmead Lane (0488 5422–0515 5422) and have yielded a mixed fauna including species of the trilobites *Ogygiocarella, Ogyginus, Cnemidopyge, Bergamia* and *Whittardolithus* and the graptolites *Diplograptus foliaceus* (Murchison), *Hustedograptus* cf. *teretiusculus* (Hisinger) and *Climacograptus sheldoni* Hughes. From this section Jones, (1986, 1987) reported the ostracods *Schallreuteria builthensis* Jones (type locality), *Cymabolbina acanthodes* Jones (type locality) and *Conspicillum ululatum* Jones.

Interpretation

The importance of this site lies with its central place in Jones and Pugh's (1949) description of an early Ordovician shoreline with high cliffs, sea stacks and boulder-strewn beaches. They interpreted the Newmead section as a resurrected cliff that they estimated might have been originally at a height of some 80 m above sea level (Jones and Pugh, 1949, p. 77). They described the surface of the basalt ('Lower Spilites') as 'smooth, water-worn and fluted' and suggested that the basalt had undergone subaerial erosion and denudation before deposition of the Newmead Formation. Other outcrops in the vicinity contributed to their interpretation; for example, small inliers of basalt adjacent to a wall (e.g. 0585 5387 and 0585 5377) were stated (Jones and Pugh, 1949, p. 77) to be stacks, examples of which are portrayed in their diorama (Jones and Pugh, 1949, fig. 3, p. 79), and outcrops of conglomeratic boulder beds near Tan-Lan (e.g. at 0580 5464 and 0589 5480) were taken to be beach deposits. An eroded surface of basalt (0598 5468) (an outlier of which lies a short distance to the west (0595 5467)) that in parts shows cross sections of pillows has abundant relics of grey feldspar sands adhering to it; it was believed by Jones and Pugh (1948, p. 80) to be a wave-worn surface. Furnes (1978), in an unpublished PhD thesis, reinterpreted some of the Newmead Formation sandstones as being deposited rapidly by a debris-flow or submarine fan, because many of them are structureless, but allowed that some of the rounded boulders probably originated from beach deposits. An onshore source for them is likely (see Lockley, 1983, p. 117) and the Newmead Formation sandstones and conglomerates are the product of constant and rapid erosion and the transport of sediment probably originating from uplift of an active volcanic centre within a marginal basin. The presence of articulate brachiopods belonging to Lockley's (1983) *Hesperorthis* palaeocommunity attests to derivation from an onshore intertidal or shallow subtidal source.

The deposition of the Newmead Formation followed the closing phase of the Builth volcanism, after which the area was subjected only to occasional fine ash falls from a distant centre, as shown by the tuffs and bentonites in shales of the *teretiusculus* Biozone.

Palaeontologically the site is important because it provided brachiopod faunas in the Newmead Formation that link it to coeval faunas at Llandeilo and Ffairfâch (see site reports) and were contemporaneous with deposition of graptolitic Llanfawr Mudstones of the *murchisoni* Zone (Figure 8.25). Collections from nearby outcrops of the *teretiusculus* Zone contributed to Sheldon's (1987a, b, 1988) detailed studies and provided the type specimens of two ostracod species (Jones, 1986–1987).

Conclusions

Newmead is a key site for the classic topographical reconstruction of Ordovician palaeogeography in the Builth Inlier. The interbedding of faunas from shallow- and deeper-water environments is important for the wider correlation of shelly and graptolitic facies in the Llanvirn.

BACH-Y-GRAIG (SO 0726 6095–SO 0708 6103)

Introduction

This section is the only one in the Builth–

Llandrindod inlier in which the boundary between the graptolite zones of *Didymograptus murchisoni* and *Hustedograptus teretiusculus* is exposed. A radiometric U-Pb age of 460.4 ± 2.2 Ma (Tucker and McKerrow, 1995) was obtained from zircon crystals from a tuff close to the boundary (Sheldon, in Ross *et al.*, 1982), making it the oldest of several sections collected exhaustively by Sheldon (1987b) during his work on gradualistic evolution and populations in trilobite lineages in the Builth area.

Bach-y-graig was described in detail by Elles (1940), who recognized the *murchisoni–teretiusculus* zonal transition here. She believed (p. 407) that the section was unfaulted, but this opinion was challenged by Jones and Pugh (1949, p. 87), who stated that a strike fault crosses the stream at the position of the boundary. The presence of a fault was confirmed by Sheldon (in Ross *et al.*, 1982, p. 142), but it was considered to cut shales of the *teretiusculus* Zone 4 m above the zonal boundary. R.A. Hughes (1989, p. 16) logged graptolite ranges in the *murchisoni* Zone and in the basal *teretiusculus* Zone as far as the fault, whilst C.P. Hughes (1969, 1971, 1979) described trilobites from this section. Ranges for both the trilobites and graptolites were given by Hughes and Sheldon (in Fortey *et al.*, 1991), who discussed briefly the merits of this section as a stratotype for the base of the Llandeilo Series; they concluded that it was too short and not wholly suitable for this purpose.

Description

The section lies about 1 km east of Llandrindod Wells and extends for some 90 m from the outcrops of shales of the *murchisoni* Zone, upsequence into the lower part of the *teretiusculus* Zone (Figure 8.28). The whole succession falls within the lowest part of the Llanfawr Mudstones Formation and is described working downstream, based in large part on unpublished work by Sheldon (1987b, pp. 30–42).

The rocks are dark-coloured, laminated mudstones without bioturbation that are exposed in the banks and bed of the stream, with the oldest shales exposed (at 0724 6097) assigned to the *murchisoni* Zone. Sheldon (1987b, p. 37) noted the youngest specimens of *Didymograptus murchisoni* from his locality BG23, the top of which is 19 cm below the 'calcareous ash' at which Elles (1940) drew the zonal boundary.

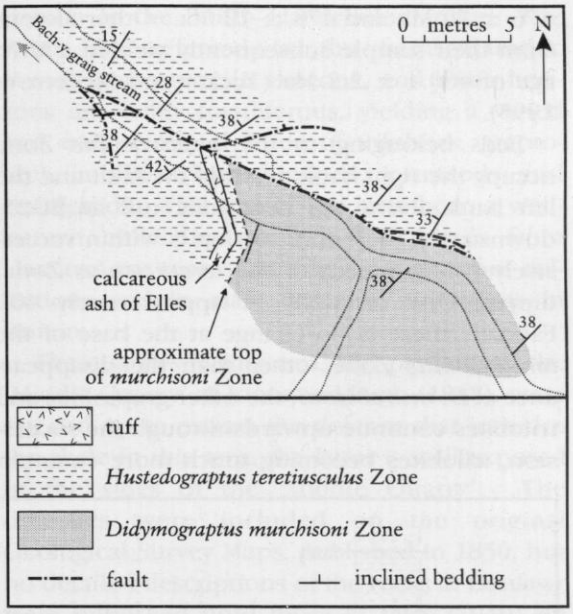

Figure 8.28 Sketch-map of the Bach-y-graig stream section, from Sheldon (1987b, unpublished).

Shales of the *murchisoni* Zone have also yielded *Cryptograptus* ex gr. *tricornis* (Carruthers), *Pseudoclimacograptus angulatus sebyensis* Jaanusson and *Diplograptus? decoratus* (Harris and Thomas). Trilobites are scarce in the *murchisoni* Zone, but Sheldon (1987b) and Hughes and Sheldon (in Fortey *et al.*, 1991) reported *Ogygiocarella*, *Ogyginus*, *Barrandia*, *Platycalymene* and *Segmentagnostus*.

Elles (1940, p. 407) took a 'calcareous ash' as marking the base of her 'zone of *Glyptograptus teretiusculus* and *Ogygiocaris buchi*'. Sheldon (1987a, b) showed that a strike fault cuts out strata 4 m above this ash, within the *teretiusculus* Zone, so that it does not affect the zonal boundary itself, which is drawn a short distance below the ash at the last occurrence of *D. murchisoni*. Sheldon (1987b, p. 36) recognized the fault by a well-developed fault breccia on the left bank of the stream (his loc. BG45). Farther upstream, on the right bank (his loc. BG46), he was able to identify by excavation a narrow zone of brecciation and shearing that he interpreted as being the upstream extension of the same fault. Tuff bands are frequent in the shales belonging to the lowest part of the *teretiusculus* Zone. Elles' (1940) 'calcareous ash' is a 14 cm-thick soft bentonitic unit that is only very mildly effervescent with dilute HCl. Using zircon crystals from this unit, Ross *et al.* (1982) obtained fission-track ages of

476 ± 10 Ma and 478 ± 12 Ma. Other zircons from their sample subsequently yielded a U-Pb age of 460.4 ± 2.2 Ma (Tucker and McKerrow, 1995).

Beds belonging to the *teretiusculus* Zone occupy the right bank north of the fault and the left bank above the bentonitic tuff at BG25; downstream the entire section is within successively younger beds of the *teretiusculus* Zone, dipping NW or WNW at approximately 40°. Faunally there is no change at the base of the *teretiusculus* Zone, other than the disappearance of *D. murchisoni*; the other graptolites and trilobites continue upwards through the succession, trilobites becoming much more common (Figure 8.29). Small lingulate brachiopods, including *Lingulella* cf. *displosa* Williams, occur throughout.

The trilobites listed above are joined by other taxa in the *teretiusculus* Zone, and the type localities for *Cnemidopyge parva* Hughes, *Protolloydolithus reticulatus* (Elles), *Barrandia expansa* Hughes and *Rorringtonia kennedyi* Owens are all in the Bach-y-graig section, many from points between 35 m and 45 m from where the footpath enters the western end of the wood. A few cyclopygid trilobites, rare in the Builth Inlier, have been found in this section: *Emmrichops? extensus* Hughes and *Microparia lusca* Marek.

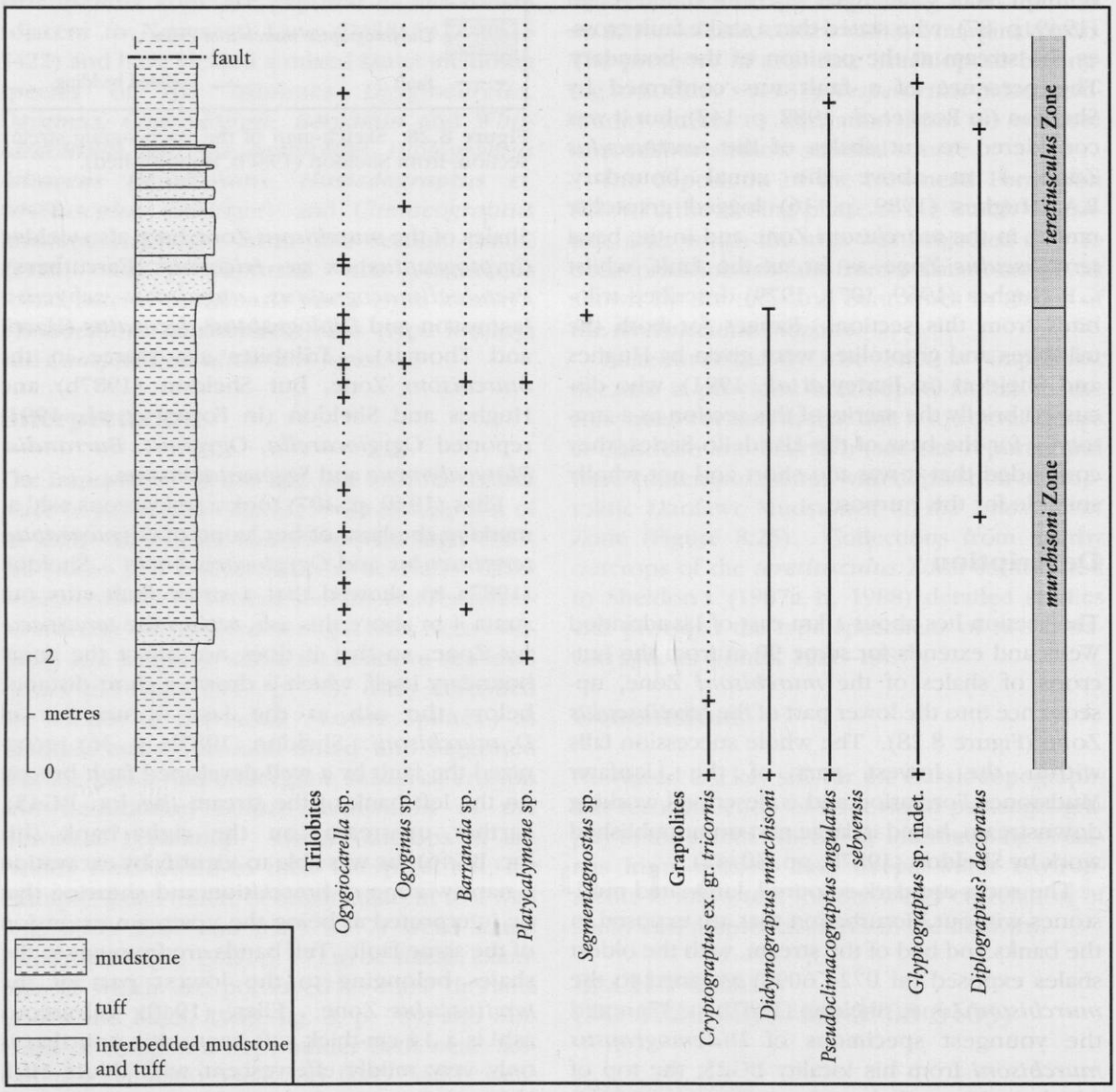

Figure 8.29 Faunal distribution about the base of the *teretiusculus* Zone at Bach-y-graig, after Hughes and Sheldon (in Fortey *et al.*, 1991, fig. 5).

Interpretation

Sheldon (1987b, p. 41) interpreted the environment of deposition of the well-laminated and unbioturbated Llanfawr Mudstones Formation at Bach-y-graig as being of low energy in poorly oxygenated water, with intermittent influxes of volcanic ash. He inferred that any currents were weak, since the graptolites are not aligned and the tuffs are undisturbed, the latter having been produced by distant volcanic eruptions (see also site report for Llanfawr Quarry).

Biostratigraphically, the importance of this section lies in the presence of the *murchisoni–teretiusculus* zonal boundary, recognized by the disappearance of the widespread species *Didymograptus murchisoni*. Palaeontologically it is significant on three counts: first, for being the type locality for four trilobite species; secondly for furnishing two of the sections from which Sheldon (1987a, b, 1988) collected large numbers of specimens during his work on gradualistic evolution and population structure in trilobites (these are the lowest of seven sections that contributed to his analysis); and thirdly in yielding graptolites that afford correlation of part of the *teretiusculus* Zone of the Builth sequence to areas outside Britain: *Pseudoclimacograptus angulatus sebyensis* Jaanusson known from Scandinavia and *Diplograptus? decoratus* (Harris and Thomas) from Australia were both reported for the first time from Britain by Hughes (1989).

Conclusions

This section is nationally important because it is possible to identify there the base of the internationally recognized *teretiusculus* Zone in a single succession of uniform facies (contrast the Newmead site); this base has been dated accurately by means of radioactive isotopes. Bach-y-graig is also the original site for four species of trilobites and for certain large trilobite populations used in the study of their evolution.

LLANFAWR QUARRY (SO 066 617)

Introduction

Llanfawr Quarry, east of Llandrindod ('4' in Figure 8.25), is important stratigraphically and palaeontologically because it exposes the youngest well-dated beds of the Ordovician succession in the Builth–Llandrindod Inlier. The strata are referred to the basal Caradoc *Nemagraptus gracilis* Biozone, and some horizons are richly fossiliferous, yielding a varied and well-preserved fauna of trilobites, graptolites, molluscs, brachiopods, ostracods and conulariids. This quarry has long been a well-known collecting ground, and fossils from Llanfawr are represented in most museum collections and in many teaching collections in Britain.

The quarries in this area, and particularly the 'Middle Quarry' of Jones and Pugh (1948), were opened up to extract the dolerite that intrudes the shale in this area; the latter is well exposed in the sides of the 'Middle Quarry'. The dolerites were included on the original Geological Survey Maps, published in 1850, but no detailed descriptions of the rocks at Llanfawr were published until those of Elles (1940) on the sedimentary rocks and of Jones and Pugh (1948) on the dolerites. Elles listed the fossils present and described a new trilobite species, *Ampyx* (now *Cnemidopyge*) *bisectus*. In more recent years, the trilobites (C.P. Hughes, 1969, 1971, 1979), graptolites (R.A. Hughes, 1989), ostracods (Jones, 1986–1987), brachiopods (Lockley and Williams, 1981) and cephalopods (Evans, 1994) have been revised. The geology was described briefly by Baker and Hughes (1979) and is included on the British Geological Survey (BGS) 1:25 000 map of the Llandrindod Wells Ordovician inlier (Earp, 1977) and the 1:50 000 Rhayader sheet (BGS, 1993). On the latter, the BGS introduced the lithostratigraphical term 'Llanfawr Mudstones Formation' to supersede the *N. gracilis* shales, *H. teretiusculus* shales and the topmost *D. murchisoni* shales in the Builth–Llandrindod inlier; this term was formally defined in the accompanying memoir (Davies *et al.*, 1997).

Description

Quarry working at Llanfawr ceased long ago. In the Middle Quarry, the largest of the three originally present, the lowest (easternmost) leaf of dolerite is overlain and underlain by shales. Removal of the dolerite has exposed, on the south-east side of the quarry, a large dip surface of the underlying shales that is inclined at 32° to the WNW. The shales overlying the dolerite can be seen near the track of the old tramway near the mouth of the quarry, where they have been

baked and metasomatized for up to a metre above the contact, and the dolerite shows a chilled margin. Near the centre of the south-east face of the quarry there is a small plug of dolerite that Jones and Pugh (1948) interpreted as a feeder to the dolerite laccolith.

The dark-coloured, flaggy shales and blocky mudstones exposed on the south-east face are richly fossiliferous and have yielded abundant well-preserved fossils, of which the commonest is the trilobite *Trinucleus fimbriatus* Murchison. Other trilobites include *Homalopteon radians* (M'Coy), *Platycalymene duplicata* (Murchison), *Ogygiocarella debuchii* (Brongniart), *Nobiliasaphus powysensis* Hughes (type locality), *Cnemidopyge bisecta* (Elles) (type locality) and *Telaeomarrolithus intermedius* Hughes (type locality). Revision by R.A. Hughes (1989) of the extensive list of graptolites given by Elles (1940) led to a substantial reduction in their number: Hughes listed *Nemagraptus gracilis* (Hall), *N.* cf. *subtilis* Hadding, *Dicellograptus cambriensis* Hughes, *D. salopiensis* Elles and Wood, *Dicranograptus brevicaulis* Elles and Wood, *Normalograptus brevis brevis* (Elles and Wood), *Cryptograptus* ex gr. *tricornis* (Carruthers) and *Glossograptus hincksii fimbriatus* (Hopkinson). Other fossils include brachiopods (*Tissintia* sp. and lingulates), bellerophontid gastropods, the orthoconic nautiloid *Allumetcoceras oneratus* Evans (type locality) and the ostracod *Conspicillum bipunctatum* (Jones and Holl).

Interpretation

This quarry shows the highest exposed parts of the Llanfawr Mudstones and is the type locality of the formation. The strata represent the youngest dated part of the Ordovician succession in the Builth–Llandrindod Inlier, the basaltic Trelowgoed Volcanic Formation that overlies it being undated. The *gracilis* Zone is well represented by the large mixed trilobite–graptolite fauna. The graptolites include species characteristic of the lower half of the zone: *Dicellograptus salopiensis, Dicranograptus brevicaulis, D. irregularis* and *Nemagraptus subtilis*. Higher levels in the *gracilis* Zone, such as are developed in the Spy Wood section (see site report) in the Shelve area, are apparently not represented. The trilobite fauna includes several species that are larger than, and differ from, those from the Rorrington Formation in the Spy Wood section. *Telaeomarrolithus intermedius*, whose type locality is at Llanfawr, has been identified in the Gilfach Borehole, Llanwrtyd, where it is in the lowest representative of the *gracilis* Zone in the succession (Cave and Rushton, 1996, pp. 53, 56, fig. 6a).

Elles (1940) considered the *N. gracilis* shales at Llanfawr to represent relatively deep, quiet-water, offshore conditions, comparable to those inferred at Bach-y-graig (see site report). Evans (1994), who reached similar conclusions, considered the fauna at Llanfawr to be indicative of the Raphiophorid Community of Fortey and Owens (1978). Sheldon (1987b) suggested that the Llanfawr Mudstones were deposited in a silled basin that was deep and poorly oxygenated, though the interpretation of depth was doubted by Davies *et al.* (1997, p. 15), who favoured a distal shelf setting in somewhat shallower water.

Conclusions

Llanfawr Quarry is an important locality. It is the most instructive locality in the Builth–Llandrindod inlier at which to examine the sediments and fauna of the *gracilis* Zone; the outcrop in the quarry is readily accessible and fossils are easy to obtain, so it is better suited for educational purposes than Gwern yfed fâch, which forms a complementary section.

GWERN YFED FÂCH, BUILTH ROAD (SO 0298 5259)

Introduction

Stratigraphically, this section at the extreme south-west corner of the Builth–Llandrindod inlier ('5' in Figure 8.25), repeats that seen at Llanfawr Quarry but is less well exposed. It is thus to be regarded as a complementary site but is interesting historically since it is one of the localities listed by Murchison (1839, as 'Gwern y fad') as exposing Llandeilo rocks. Palaeontologically it is the type locality for the original trinucleid trilobite *Trinucleus fimbriatus* Murchison, which typifies the Suborder Trinucleina. Elles (1940) discussed the biostratigraphy and faunas, and Jones and Pugh (1946) mentioned this locality in the context of the dolerite intrusions of the Builth–Llandrindod Inlier.

In more recent work on the fauna,

C.P. Hughes (1971, 1979) described and illustrated the trilobites (including *Homalopteon murchisoni* Hughes, for which this is the type locality), Lockley and Williams (1981) described the brachiopods and R.A. Hughes (1989) described the graptolites. A brief description of the quarry was given by Baker and Hughes (1979).

Description

This is an old quarry in two dolerite sills, numbers 49 and 52 of Jones and Pugh (1946), the highest and westernmost that they recognized. The quarry is, at the time of writing, much degraded and largely obscured, although the contact between the shales and the upper sill is exposed along the side of the A470 road where it has been widened, and in the adjacent old railway cutting. Some 12 m of shales were formerly exposed in the quarry, comprising a sequence of hard, black, flaggy and pyritic shales that dip north-west at 43–53°. Some horizons show iridescent and rusty weathering. The sediments are intensely jointed, and baked and hardened when in contact with the dolerite, where they are often bleached, weathering to a greyish-white colour, as noted by Murchison.

As at Llanfawr, these shales of the Llanfawr Mudstones Formation belong to the *gracilis* Zone. The presence of *Husteodograptus* cf. *teretiusculus* (Hisinger) suggests the lower part of that zone, by comparison with ranges noted at nearby Penddol Rocks by Hughes (1989). Gwern yfed fâch is the type locality of the graptolite *Normalograptus* (*Climacograptus*) *brevis brevis* (Elles and Wood), and other graptolites include *Nemagraptus gracilis* (Hall), *N.* cf. *subtilis* Hadding, *Dicellograptus intortus* Lapworth, *Dicranograptus brevicaulis* Elles and Wood and *Cryptograptus* ex gr. *tricornis* (Carruthers). The trilobite fauna is like that at Llanfawr and includes *T. fimbriatus, Platycalymene duplicata* (Murchison), *Ogygiocarella debuchii* (Brongniart), *Nobiliasaphus powysensis* Hughes, *Cnemidopyge bisecta* (Elles) and a rare *Rorringtonia*. Brachiopods are restricted to the lingulates *Schmidtides? micula* (M'Coy) and *Monobolina crassa* Lockley and Williams.

Interpretation

This site is significant for its historical context and as the type for trilobite and graptolite species, especially *Trinucleus fimbriatus*. It is also the principal locality in the Builth Inlier for *Dicellograptus intortus* (Elles and Wood, 1904, pl. 20, figs 4c–f). Although cautiously referred to by Hughes (1989) as *D.* cf. *intortus*, this species is a valuable indicator of the *gracilis* Zone and is nearly as widely distributed as *N. gracilis* itself, being known from North America, Russia, China and Australia (Strachan, 1997).

As at Llanfawr, the shales are intruded by dolerite sills, presumably during the same episode, although the shales at Gwern yfed fâch may be a little older, being near the base of the *gracilis* Zone. Conditions of deposition were presumably similar to those inferred for Llanfawr Quarry.

Conclusions

This is the type locality of the nomenclatorially important trilobite *Trinucleus fimbriatus* and the source of other fossils. Stratigraphically it is a useful complementary section to Llanfawr Quarry.