British Cambrian to Ordovician Stratigraphy

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Chapter 9

Arenig to Ashgill of North Wales

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INTRODUCTION

In North Wales the Ordovician occupies a broad tract surrounding the Cambrian of the Harlech Dome and extends eastwards to the Bala area and westwards over most of Llŷn (the Lleyn Peninsula). In addition, the lower parts of the Ordovician are preserved on Anglesey and the upper parts are well developed in the Berwyn Hills (Figure 9.1). All these strata formed part of Sedgwick's concept of the Cambrian System (Sedgwick and Murchison, 1835), and when Lapworth (1879a) proposed the Ordovician they became part of the type Ordovician System.

In outline, the Ordovician of the North Welsh Basin consists of mudstones, siltstones and sandstones of great aggregate thickness deposited in oxygenated waters commonly of no great depth (above wave base). Basin subsidence was roughly balanced by deposition, except perhaps during parts of the Caradoc, when Prigmore *et al.* (1997) considered subsidence at a maximum. The stratigraphical sequences are fairly complete, although there are breaks below and within the Arenig, there is generally no evidence for the Llandeilian Stage and the Pusgillian Stage is proved only locally in the Berwyn Hills. All the rocks in Wales from the sub-Arenig unconformity to the hiatus below the Ashgill fall within the Gwynedd Supergroup (Woodcock, 1990).

The stratigraphy of North Wales is complicated by the interfingering of deposits from local volcanic centres with the marine clastic deposits accumulating in the unstable Welsh Basin. Many local successions have been described and more than 100 formational names proposed. Rushton and Howells (1998) synthesized a stratigraphical framework for the Tremadoc to Caradoc of Snowdonia, though they did not review the Ashgill Series, nor the areas of Anglesey and the Berwyn Hills. They distinguished as volcanic 'groups' the products of each volcanic centre. For the marine sequence that envelops the volcanic groups of North Wales, Rushton and

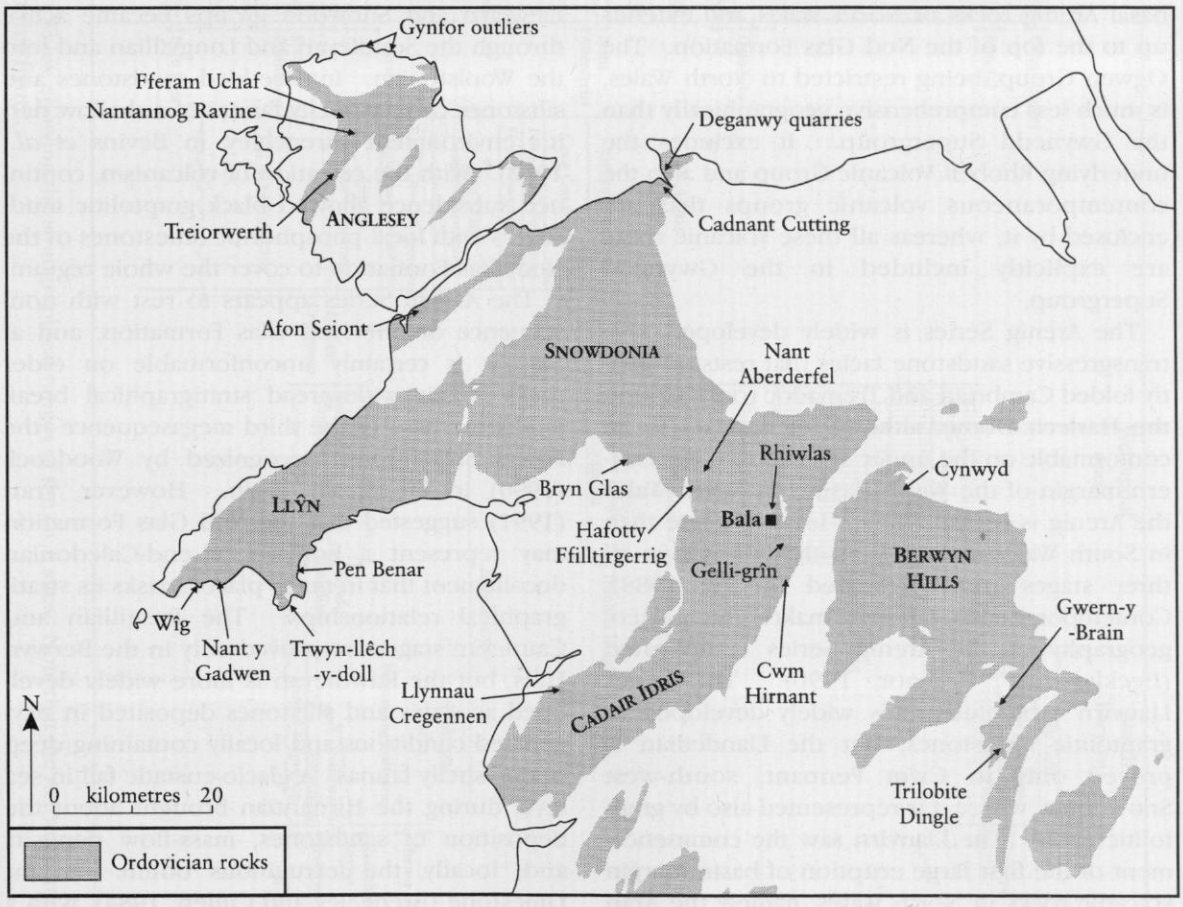


Figure 9.1 Distribution of Ordovician (Arenig to Ashgill) rocks in North Wales, after British Geological Survey (1994c), showing the location of GCR sites. For the Tremadoc site at Pen Benar, see Chapter 7.

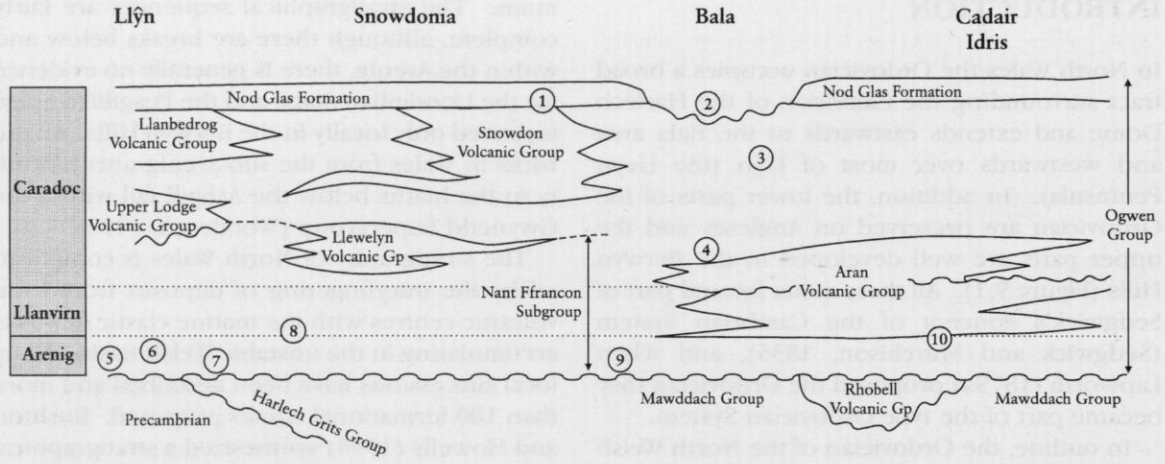


Figure 9.2 Schematic section to show the general stratigraphical relations of the main divisions that make up the Ogwen Group in North Wales, after Rushton and Howells (1998). The positions of GCR sites are shown as follows: 1, Cadnant Cutting; 2, Rhiwlas; 3; Gelli-grîn; 4, Nant Aberderfel; 5, Wîg; 6, Nant y Gadwen; 7, Trwyn Llêch-y-doll; 8, Afon Seiont; 9, Bryn Glas and Hafotty Ffilltirgerig; 10, Llynnau Cregennen.

Howells (1998) proposed the new term 'Ogwen Group' (Figure 9.2), which commences with the basal Arenig rocks of North Wales and extends up to the top of the Nod Glas Formation. The Ogwen Group, being restricted to North Wales, is much less comprehensive geographically than the Gwynedd Supergroup. It excludes the underlying Rhobell Volcanic Group and also the contemporaneous volcanic groups that are enclosed by it, whereas all these volcanic rocks are explicitly included in the Gwynedd Supergroup.

The Arenig Series is widely developed as a transgressive sandstone facies that rests on gently folded Cambrian and Tremadoc rocks around the Harlech Dome, although it appears to be conformable on the upper Tremadoc at the eastern margin of the Welsh Basin. In North Wales the Arenig is typically much less complete than in South Wales (Figure 9.3), though in Llŷn all three stages are represented (Beckly, 1988). Contemporaneous faulting makes the palaeogeography of the Arenig Series complicated (Beckly, 1987; Traynor, 1990). The lower Llanvirn (Abereiddian) is widely developed as graptolitic mudstones, but the Llandeilian is proved only in Cwm Pennant, south-west Snowdonia, where it is represented also by graptolitic rocks. The Llanvirn saw the commencement of the first large eruption of basin margin volcanic rocks in North Wales, namely the Aran Volcanic Group.

During the Caradoc the Aran volcanic activity ceased at about the beginning of the Harnagian, and farther north new volcanic centres of the Llewelyn and Snowdon groups became active through the Soudleyan and Longvillian and into the Woolstonian. Interbedded sandstones and siltstones contain shelly faunas of a shallow neritic environment (Brenchley, in Bevins *et al.*, 1992). With the cessation of volcanism, continued subsidence allowed black graptolitic mudstones with local phosphoritic limestones of the Nod Glas Formation to cover the whole region.

The Ashgill Series appears to rest with nonsequence on the Nod Glas Formation, and at Bala it is certainly unconformable on older rocks. This widespread stratigraphical break marks the base of the third megasequence (the Powys Supergroup) recognized by Woodcock (1990) in the Welsh Basin. However, Pratt (1991) suggested that the Nod Glas Formation may represent a horizon of end-Caledonian decollement that in many places masks its stratigraphical relationships. The Pusgillian and Cautleyan stages are proved only in the Berwyn Hills, but the Rawtheyan is more widely developed as slates and siltstones deposited in oxygenated conditions and locally containing deep neritic shelly faunas. A glacio-eustatic fall in sea level during the Hirnantian brought about the deposition of sandstones, mass-flow deposits and, locally, the ferruginous oolitic Hirnant Limestone (Brenchley and Cullen, 1984), with a low-diversity brachiopod fauna, the *Hirnantia* Fauna.

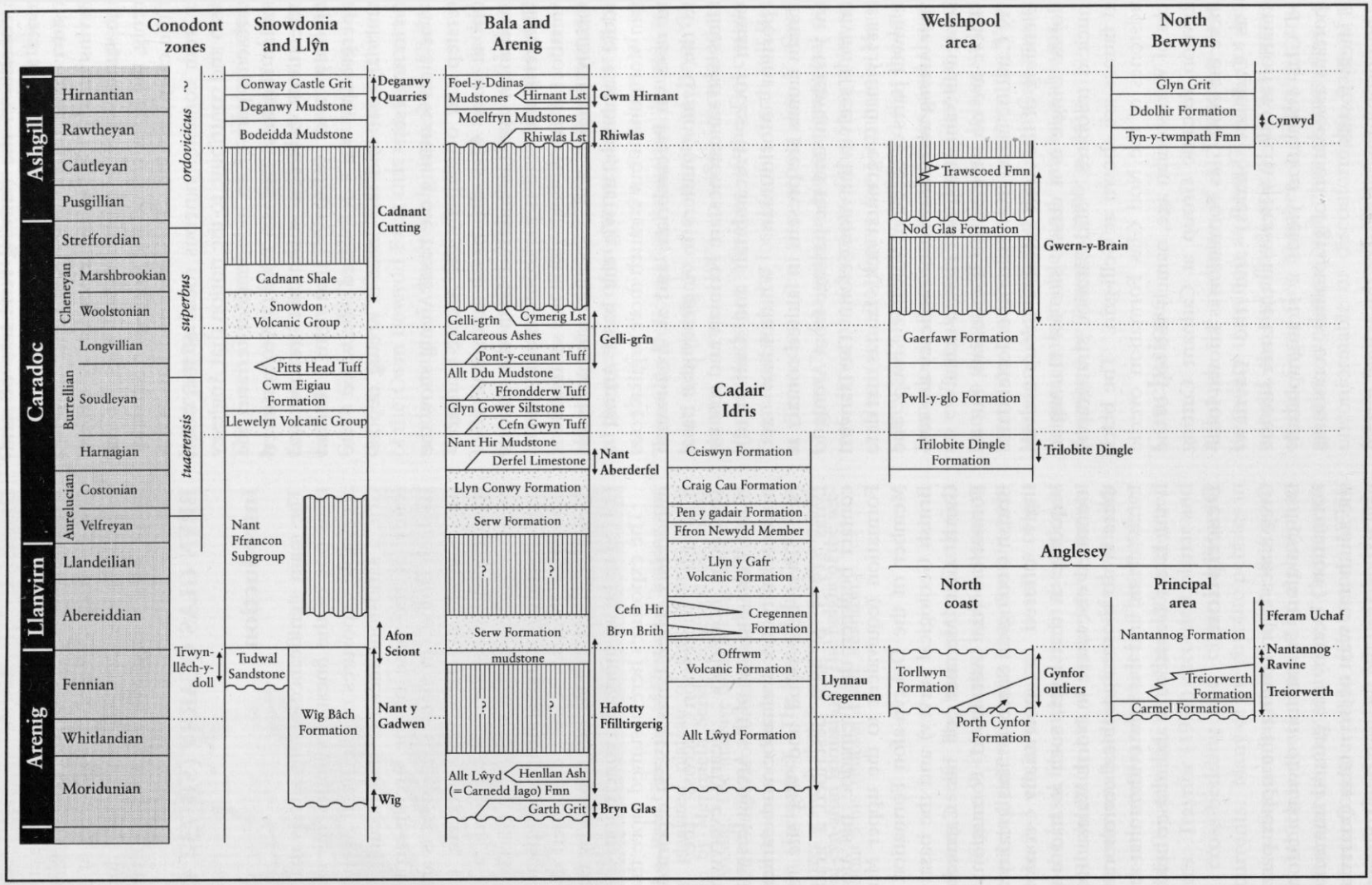


Figure 9.3 Correlation of the principal Arenig to Ashgill sites in North Wales, showing the stratigraphical ranges of the GCR sites. Note that the Actonian and Onnian substages of the Streffordian Stage are not separately distinguished in this figure.

The Ordovician of Anglesey is rather different. It consists of the outlying remnants of sandstones and shales deposited on the prevailingly positive area of the Irish Sea horst complex (Bevins *et al.*, 1992) during periods of marine high-stand, namely the Fennian Stage of the Arenig, the Llanvirn and the Costonian Substage of the early Caradoc. The facies and faunas differ from contemporaneous rocks of the Welsh Basin and contribute to the notion that Anglesey represents part of an independent terrane, the Monian Terrane. Tietzsch-Tyler (1996) reviewed correlations between south-east Ireland and Anglesey and inferred that the Monian Supergroup was deformed between late Cambrian time and the onset of Arenig deposition in Anglesey.

The sites featuring the basal Arenig show the overstep and overlap by the Arenig transgression: at Bryn Glas the basal sandstone is of Moridunian age (as inferred from the Hafotty Ffilltirgerig site) and is paraconformable on the Tremadoc; at Trwyn-llêch-y-doll the sandstone is probably Fennian and rests unconformably on Middle Cambrian; at Wîg the basal Arenig is again Moridunian but is much more argillaceous and rests on Precambrian; and at Treiorwerth and the Gynfor outliers in Anglesey the basal rudites and sandstones are Fennian and rest on Monian rocks (Precambrian and Cambrian?). Important Moridunian, Whitlandian and Fennian faunas are present in faulted contact at Nant y Gadwen, and the passage from Arenig to Llanvirn is seen in the Afon Seiont. The Llanvirn site at Llynnau Cregennen yields faunas that date the lower parts of the Aran Volcanic Group. The upper Arenig and Llanvirn of Anglesey are represented at Nantannog and Fferam-uchaf.

There are no sites in the Llandeilian, but an early Caradoc fauna from Nant Aberderfel dates the ending of the Aran Volcanic Group activity. Trilobite Dingle is a classic site for Harnagian trinucleid trilobites. Mid-Caradoc stratigraphy and faunas are shown at Gelli-grîn. The black mudstones of the Nod Glas Formation overlie rocks of Woolstonian age, namely the top of the Snowdon Volcanic Group at Cadnant Cutting (where the Nod Glas Formation is known locally as Cadnant Shales) and the Gaerfawr Formation at Gwern-y-Brain; at the latter site the Nod Glas Formation yields a stratigraphically important association of graptolites, conodonts and shelly fossils.

The unconformable base of the Ashgill is seen at Rhiwlas in the Bala area, where the Rhiwlas Limestone of Rawtheyan age rests on Woolstonian strata; Cynwyd in the northern Berwyn Hills is a classic site for later Rawtheyan faunas. The sedimentological effects of the end-Ashgill glacio-eustatic fall in sea level are shown by the sites at Deganwy and Cwm Hirnant.

BRYN GLAS QUARRY (SH 732 421)

Introduction

The main significance of this site is that it contains one of the finest developments and most accessible exposures of the basal Arenig Garth Grit, a sandstone member that occurs impersistently at the base of the Arenig around the Harlech Dome. In many sections it is absent, as for example at Hafotty Ffilltirgerig (see site report), and thus Bryn Glas affords a complementary section to that site. Bryn Glas is also the type locality for the phosphatic pseudofossil '*Bolopora undosa* Lewis', described as a bryozoan by Lewis (1926) but shown by Hofmann (1975) to be an inorganic concretion.

The exposures here assumed more than local importance when Lynas (1973) reported a conformable succession across the Arenig–Tremadoc boundary. Nearly everywhere in North Wales the base of the Arenig lies with clear unconformity on Tremadoc and earlier rocks (see Trwyn-llêch-y-doll and Wîg site reports). Lynas (1973, p. 485) described a gradational contact between the Tremadoc, his Afon Gam Formation (equivalent to the upper Mudstone Member of the Dol-cyn-afon Formation of the British Geological Survey) and the basal Arenig Garth Grit Member of his Carnedd Iago Formation (the Allt Lŵyd Formation of the British Geological Survey). This locality accordingly offered a potentially conformable sequence at that level, such as had not been identified elsewhere in North Wales. However, there is no biostratigraphical corroboration for Lynas' claim, and it is now evident that regionally the latest Tremadoc is absent (see below).

Description

Grey slates representing the upper part of the Dol-cyn-afon Formation (Lynas' 'Afon Gam Formation') occupy the ground immediately to the south and west of Bryn Glas Quarry and are well exposed in the western and southern parts

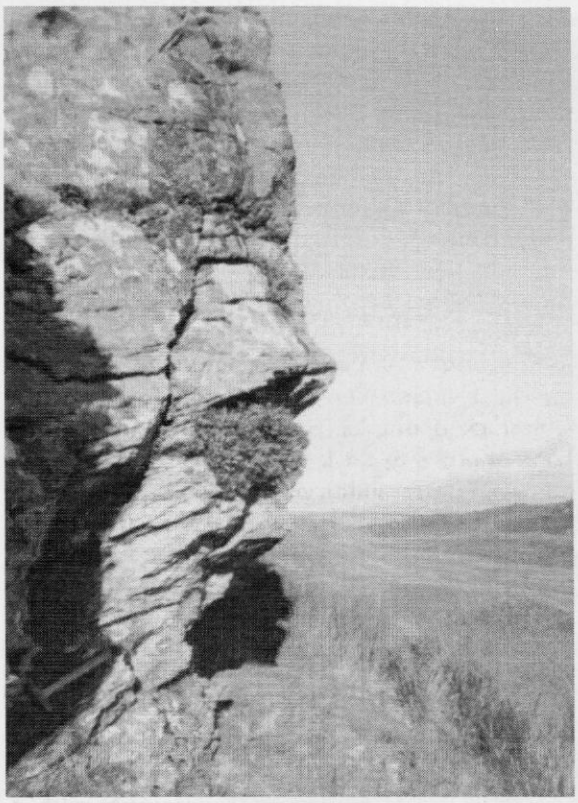


Figure 9.4 Bryn Glas, east of Ffestiniog, looking east over the glaciated plateau of the Migneint (here underlain by Merioneth Series, repeated by faults) towards Arenig. The massive basal Arenig sandstones of the Garth Grit paraconformably overlie silty slate of the Upper Mudstone Member of the Dol-cyn-afon Formation (Tremadoc). The base of the Garth Grit juts out over a shrub that is growing on the top bed of the Dol-cyn-afon Formation. The height of the section is about 3 m. (Photo: A.W.A. Rushton.)

of the quarry itself. The base of the Garth Grit Member (Figure 9.4) is marked by the incoming of coarse conglomeratic grits that contain pebbles up to 2–3 cm in diameter. A series of grit units in the basal few metres are in the order of 40 mm thick; each has a sharp lower surface (possibly erosional) and is interbedded with silty and dark-coloured sandy shales. This sequence is overlain by tabular, cross-bedded grey-green quartzites. Traynor (1990) recorded planar and trough cross-bedding and observed bipolar palaeocurrents. Many of the rhyolite pebbles in the basal units are encrusted with '*Bolopora undosa*', which is now known to be a phosphatic oncolitic accretionary structure of chemogenic and/or bacteriogenic origin (Hofmann, 1975). At 70 m thick, the Garth Grit Member here reaches its greatest thickness in the sector east of the Cwm Bowydd Fault (Howells and Smith, 1997, p. 26). All beds dip at 30–34° to the north-east and ENE; they are overlain in the eastern part of the quarry by the Llyfnant Member, which is better seen at Hafotty Ffilltirgerig (see site report).

Interpretation

The Garth Grit Member in general forms a clearly transgressive base to the Arenig and was deposited in turbulent, very shallow marine conditions. Traynor (1990, p.18) interpreted the Garth Grit at this locality as a transgressive tidal deposit, part of a fluviodeltaic system to the east of the Cwm Bowydd Fault that was transporting sandy material southwards into his 'Rhobell Trough' (Traynor 1990, fig.11).

Biostratigraphical evidence of age is lacking but, by association with the overlying Lyfnant Member, is assumed to lie above the base of the Moridunian (see Hafotty Ffilltirgerig). In the Migneint area, Lynas (1973, p. 484) demonstrated the presence of an overstep from west to east by the Garth Grit upon members of the Tremadoc Dol-cyn-afon Formation, but this is of least magnitude in the vicinity of Bryn Glas Quarry. Lynas (1973, p. 484) correlated the Upper Mudstone Member of the Dol-cyn-afon Formation with the fossiliferous Garth Hill Beds at Tremadoc (see site report for Y Garth, Chapter 7), but without biostratigraphical control. From consideration of the Shropshire succession (see site report for Granham's Moor), Fortey and Owens (1992) showed that the latest Tremadoc is absent in North Wales, and there is no evidence known from Bryn Glas that is contrary to this general conclusion. It is most likely, therefore, that the junction between the Upper Mudstone Member and the Garth Grit Member is paraconformable and masks a hiatus, as described by Traynor (1990, p. 24).

Conclusions

Although the promise of a Tremadoc–Arenig boundary transition at Bryn Glas has not been upheld, the site affords one of the best sections of the Garth Grit Member, a distinctive transgressive sandstone unit that characterizes the unconformable or disconformable base of the Arenig Series in North Wales.

HAFOTTY FFILLTIRGERIG AND AMNODD-WEN (SH 8167 3844–SH8161 3860 AND SH 8202 3703)

Introduction

This locality is of historical importance as it exemplifies the Arenig Series in its type area. It was used by Sedgwick (1852) to establish his subgroup of 'Arenig slates and porphyries'.

Elles (1904) gave a brief and rather inaccurate description of a section at Hafotty Ffilltirgerig, but the first detailed account was that of Fearnsides (1905), who named the basal Llyfnant Flags, overlain by the Henllan Ash and Ffilltirgerig Beds. Subsequently little attention was paid to this locality, until Whittington (1966) described the trilobites of the Henllan Ash and correlated the fauna with the lower one-third of the Mytton Flags of Shropshire and Skevington (1969) assigned the graptolites from the Llyfnant Flags to the *deflexus* Subzone. Fortey and Owens (1978) noted that the trilobite fauna has species in common with the lower Arenig Carmarthen Formation in South Wales. Zalasiewicz (1984b) gave the first modern account of the sequence and biostratigraphy and concluded that much of the later Arenig was absent; he adapted the lithostratigraphy introduced by Lynas (1973) for the Migneint area to the north. Beckly (1987) confirmed most of Zalasiewicz's conclusions but on the basis of graptolites suggested that the later Fennian was present, resting disconformably upon Moridunian strata.

Description

There are exposures in crags on the hillside (Figure 9.5), but the best section is in a stream section 400–500 m south-east of Hafotty Ffilltirgerig (Zalasiewicz, 1984b, fig. 8), which extends through the Arenig Carnedd Iago Formation of Lynas (= Allt Lŵyd Formation of Traynor, 1990, and Howell and Smith, 1997) into the lower part of the Serw Formation, of Llanvirn age. The basal unit of the Allt Lŵyd, the Garth Grit Member, is not developed here but is seen to advantage at Bryn Glas Quarry (see site report). The oldest division here is the Llyfnant Member, a sequence of predominantly flaggy, laminated siltstones and mudstones, interbedded with graded sandstones that sometimes show low-angle cross-lamination; these beds are considered to have been deposited from waning turbidity currents (Traynor, 1990). Bioturbation, including *Teichichnus* and *Chondrites* burrows, is common throughout. A level near the base of the member is exposed in small quarries south of Hafotty Ffilltirgerig (8167 3844) and the middle part of the member south-east of Amnodd-wên (8202 3703); both have yielded the graptolite *Didymograptus* aff. *simulans* Elles and Wood.

Ross *et al.* (1982) gave an age of 478 ± 27 Ma for the Llyfnant Member, derived from the fission-track dating of zircons from a tuffaceous band about 1 m thick within this unit, exposed above Hafotty Ffilltirgerig (8174 3868), and Compston and Williams (1992), using the SHRIMP ion-probe technique on the same sample, refined this date to 471 ± 3 Ma.

The overlying Henllan Ash Member comprises various lithologies, ranging from massive, blocky feldspathic sandstones with little trace of bedding (the 'Henllan Ash' of Fearnsides, 1905, and the 'Henllan facies' of Zalasiewicz, 1984b) to muddy, strongly bioturbated feldspathic sandstones or sandy mudstones, commonly with a shelly fauna (which Fearnsides, 1905, called the 'Erwent Limestone', though it is not limestone, and the 'Erwent facies' of Zalasiewicz, 1984b). The latter is exposed in and adjacent to the stream to the south-east of Hafotty Ffilltirgerig and at 8161 3860 has yielded the graptolite *Azygograptus* cf. *eivionicus* Elles (see Zalasiewicz, 1984a). Whittington (1966) described a trilobite fauna from exposures in the same general area (818 387) that included *Merlinia selwynii* (Salter), *Neseuretus parvifrons* (M'Coy) and *Ampyx cetsarum* Fortey and Owens, accompanied by brachiopods (*Paralenorthis*). Displaced blocks of dark-coloured, bioturbated mudstone from trenches excavated by the then Nature Conservancy Council at SH 816 386 yielded (on different blocks) *Expansograptus* cf. *praenuntius* Törnquist and *Amplexograptus confertus* (Lapworth); the blocks apparently originate from the top of the Carnedd Iago Formation (Zalasiewicz, 1984b, p. 119). The former species was also identified by Zalasiewicz among specimens collected by Fearnsides from Hafotty Ffilltirgerig and labelled as '*Didymograptus hirundo*'. On lithological grounds, Zalasiewicz (1984b, p. 119) believed these to originate from the Serw Formation. Farther south, to the south-

Figure 9.5 Hafotty Ffilltirgerig, north-west flank of Arenig Fawr. Sandstones with mudstone laminae of the Allt Lŵyd Formation (Llyfnant Flags of Fearnsides), dipping eastwards, away from the observer. Such sandstones are typical of the lower Arenig and are developed widely around the Harlech Dome. (Photo: A.W.A Rushton.)

east of Amnodd-wen, the 'Henllan facies' crops out.

The base of the succeeding Serw Formation, a series of mudstones, crystal tuffs and minor ignimbrites of early Llanvirn age, crops out a short distance upstream from the Henllan Member south-east of Hafotty Ffilltirgerig, and loose blocks from the vicinity of 8184 3850 have yielded *Didymograptus* cf. *artus* Elles and Wood, *Amplexograptus* sp. and *Lasiograptus* sp. Further specimens recorded by Fearnsides (1905) from 'Hafotty Ffilltirgerig' were redetermined by Zalasiewicz (1984b) as *D.* cf. *artus* Elles and Wood, *Aulograptus cucullus* (Bulman), *Cryptograptus tricornis schaeferi* Lapworth and '*Didymograptus*' cf. *acutidens* Elles and Wood. Zircons from the Serw Formation (8185 3856) yielded an age of 465.7 ± 2.1 Ma to Tucker *et al.* (1990).

Interpretation

Zalasiewicz (1984b, p. 120) argued on the basis of the sedimentology that a shallow, subtidal

marine environment was most likely for the deposition of the Llyfnant Member, although Traynor (1990, p. 18) thought that deposition was predominantly below storm wave-base. Zalasiewicz proposed that the clean-washed, in places strongly cross-bedded, arenaceous feldspathic sandstones that form the 'Henllan facies' were deposited in turbulent, probably shallow, water; they were derived perhaps by rapid erosion of the Rhobell Volcanic Group (Traynor, 1990). The muddy bioturbated 'Erwent facies' represents quieter water, with well-aerated bottom conditions favourable for a benthic fauna.

There is likely to be an unconformity or disconformity at or near to the top of the Carnedd Iago Formation, for definitive post-Moridunian faunas have not been identified at the present site and the base of the overlying Serw Formation has yielded a *D. artus* Zone graptolite fauna (Zalasiewicz, 1984b, p. 121). Beckly (1987), however, placed faunas with the graptolites *Cryptograptus tricornis schaeferi* Lapworth, *Pseudotrigonograptus minor* (Mu and Lee) and *Pseudophyllograptus cor* (Strandmark) in the late Fennian, these originating from the Arenig area, though locality details and discussion were not given.

What is clear from the sections at Hafotty Ffilltirgerig and elsewhere in the Arenig district is that a large part of the Arenig Series, as represented in its fullest development in South Wales, is absent from the type area (Zalasiewicz, 1984b; Fortey and Owens, 1987; Beckly, 1987). Such graptolites as are present do not permit precise correlation with sections elsewhere (Zalasiewicz, 1984b, 1986), although the trilobites from the Henllan Member (Whittington, 1966; Fortey and Owens, 1978) include species common to the Moridunian Stage in South Wales (see site reports for Glan Pibwr and Allt Pen-y-Coed, for example) and to the lower third of the Mytton Flags (see Mytton Dingle site report).

The refined radiometric age of 471 ± 3 Ma obtained from the Moridunian part of the succession and that of 466 ± 2 Ma from the lower Llanvirn are important ties between the British standard series and the geochronological timescale.

Conclusions

This site is of historical importance as it shows the Arenig Series in the area in which it was originally conceived, and the scope there of the Series as now understood. Compared with the Arenig of South Wales and as recognized in the graptolitic sequence, the historical type area shows only the upper parts of the Moridunian and Fennian stages, and the present site is significant for identifying the gaps in the succession.

TRWYN-LLÊCH-Y-DOLL (SH 302 235)

Introduction

This section shows particularly well the unconformable base of the Arenig and the facies and trace fossils of the transgressive sandstone unit above the unconformity.

In the little inlet immediately west of the headland of Trwyn-llêch-y-doll, Arenig sediments can be seen unconformably overlying Middle Cambrian mudstones. Ramsay (1881, p. 209, fig. 76) described the section as having the 'appearance of an unconformity' but considered it more likely to be a 'case of false bedding' (Figure 9.6). It was described in detail by Nicholas (1915), who confirmed the presence of the unconformity and who considered the 'Arenig Tudwal Sandstone' (a term he introduced) to be of early Arenig (*extensus* Zone) age. This assessment of age was followed by Crimes, who used the section when describing ichnofacies and trace fossils in North Wales (Crimes 1968, 1969, 1970c, d), but more recently Beckly (1987) revised the age and regarded the entire Arenig sequence on St Tudwal's Peninsula as being of late Arenig (Fennian) age.

Description

The Tudwal Sandstone forms an almost vertical cliff some 36 m high. The Middle Cambrian Ceiriad Formation (Young *et al.*, 1994) crops out at the base of the cliff and on the beach, dipping ESE at 30°. The plane of unconformity is seen at the base of the cliff dipping east (Figure 9.6), disappearing below beach level before the headland of Trwyn-llêch-y-doll is reached.

The Arenig sediments dip at a lower angle (14°) to the ENE. The base of the succession is marked by a thin conglomeratic unit with large pebbles of Gwna Quartzite and jasper derived from the Monian Supergroup. Nicholas (1915, p. 106) noted the apparent absence of clasts

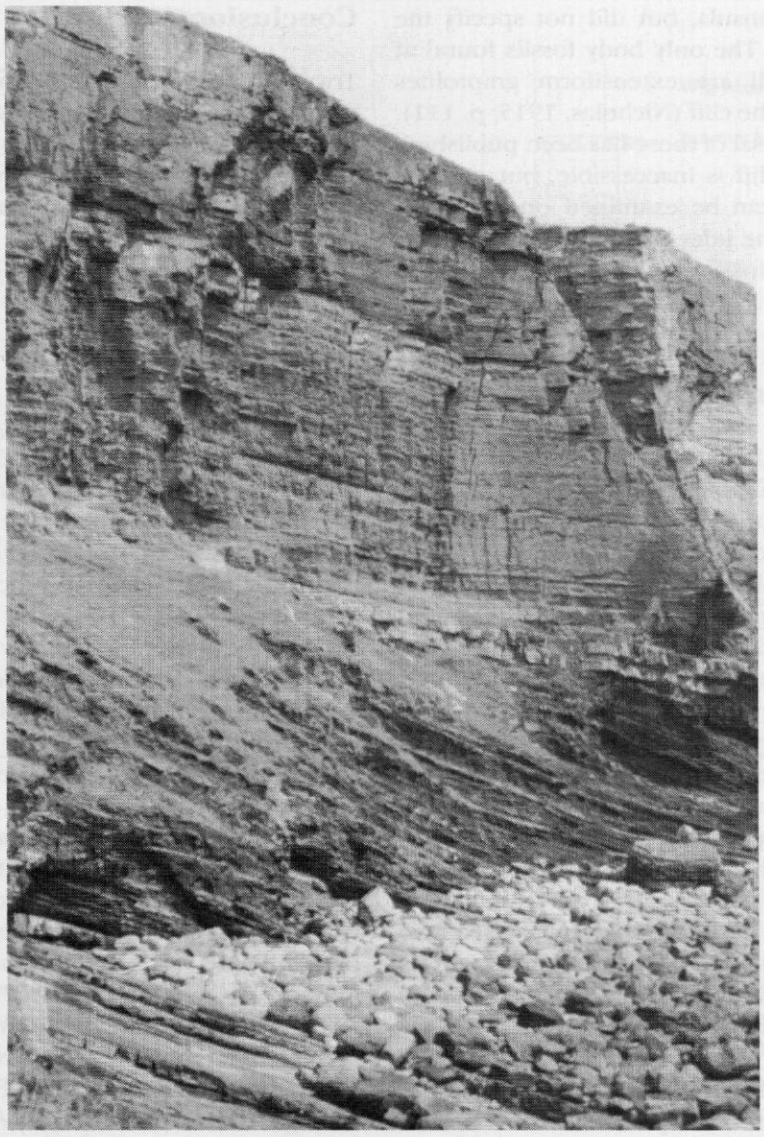


Figure 9.6 Trwyn-llêch-y-doll, St Tudwal's Peninsula, looking north-east. Bioturbated sandstones of the Tudwal Sandstone Formation (Arenig, probably Fennian) form a vertical cliff and overlie the basal beds of the Ceiriad Formation (Cambrian, probably St David's Series) with unconformity. The total height of the cliff is about 45 m. (Photo: A.W.A. Rushton.)

derived from the underlying Cambrian. The conglomerate is overlain by a thin, coarse-grained, current-bedded sandstone, described by Crimes (1970d) as a *Cruziana* Sandstone Facies, from the common occurrence within it of the trace fossil *Cruziana furcifera* (d'Orbigny), believed to be a trilobite track. Nicholas (1915, p. 106) recognized a coarse basal grit, divided into two units 0.75 m thick, separated by a soft, shaly band. It is overlain by some 9 m of bluish rusty-weathering sandstone (the 'streaky sandstone' of Nicholas, 1915, p. 110) that Crimes (1970d) placed in his Fodinichnia shaly sandstone facies, feeding burrows being abundant. The streaky appearance is due to thin laminae of argillaceous material. Higher in the succession the *Cruziana* Sandstone Facies reappears at intervals, but much of the thickness of strata is in Nicholas' 'streaky sandstones'. Beckly (1987) included all this sequence within the *Neseuretus* sandstone facies, and reported that the eponymous trilobite had been recorded from the

St Tudwal's Peninsula, but did not specify the precise locality. The only body fossils found at Trwyn-llêch-y-doll are extensiform graptolites from the top of the cliff (Nicholas, 1915, p. 111). No recent appraisal of these has been published.

Most of the cliff is inaccessible, but parts of the succession can be examined on the steep slope down to the inlet, and sedimentary structures and trace fossils can be studied in fallen blocks.

Interpretation

The Tudwal Sandstone is a typical transgressive sequence, deposited in an inshore environment. With its coarse sandstones and large-scale tabular and trough cross-bedding, with large-scale symmetrical ripples, Crimes (1970d) considered the *Cruziana* Sandstone Facies to be deposited under conditions of relatively high current velocity and probably oscillatory water movement. He believed that the inorganic and biogenic sedimentary structures together suggested deposition above wave-base, but in the sublittoral zone. Because the Fodinichnia shaly sandstone facies comprises fine sandstones and siltstones, commonly with small-scale cross-stratification, whereas large-scale cross-stratification and ripple marks occur more rarely, it is likely to have been deposited in quieter, deeper waters than the *Cruziana* Sandstone Facies, possibly in the sublittoral zone near or below wave base and out of reach of tidal scour (Crimes, 1970d). Coarser beds within the Fodinichnia shaly sandstone facies, generally adjacent to the *Cruziana* sandstone facies, with the trace fossil *Phycodes circinatum* Mägdefrau, might have been deposited in a higher energy, possibly slightly shallower-water environment than the finer beds with *Teichichnus*.

In the northern part of St Tudwal's Peninsula, Beckly and Maletz (1991) recorded *Azygograptus lapworthi* Nicholson from the 'Transition Beds' that succeed the Tudwal Sandstone. The occurrence of this species allows correlation into the Lake District sequence, and provides some biostratigraphical control for the higher part of the sequence in the mid- to late Fennian. On Beckly's (1987) palaeogeographical model, St Tudwal's Peninsula remained an emergent area until the early Fennian, during which time the Arenig sediments at Trwyn-llêch-y-doll were deposited.

Conclusions

Trwyn-llêch-y-doll affords a clear section through the Tudwal Sandstone, a transgressive shallow-water sandstone at the local base of the Arenig Series, and shows an admirable section of the basal unconformity. The unconformity is seen to be much more profound than at Bryn Glas, but less so than at Wîg.

WÎG (SH 186 258)

Introduction

Wîg is the most accessible locality to show the overstep of the Lower Arenig onto the Precambrian of the Aberdaron area of Llŷn. It includes the basal stratotype of the Wîg Bâch Formation and is the type locality for the Wîg Member.

From the Harlech Dome towards the Irish Sea positive area the Arenig rocks transgress the Tremadoc and the whole Cambrian (see Trwyn-llêch-y-doll), to overstep onto the Precambrian of western Llŷn, where, however, most of the basal Ordovician contacts are faulted. Matley (1928, 1932) considered that the Ordovician was predominantly thrust against the Precambrian, but Shackleton (1956) detailed unconformable contacts and inferred that the Ordovician was primarily unconformable on the Precambrian.

Beckly (1988) described the Ordovician stratigraphy of south-west Llŷn, with emphasis on biostratigraphy; he reconstructed the palaeogeography of the area, which is complicated through the interaction of a marine transgression across contemporaneously faulted blocks (Beckly, 1987). Gibbons and McCarroll (1993) described the geology of the Aberdaron area and revised the stratigraphy of the Ordovician, though part of their terminology is emended in Rushton and Howells (1998).

Description

A sea-cliff at Wîg shows exposures of Precambrian mylonitic rocks of the Sarn Complex in the Llŷn Shear Zone and Ordovician sedimentary rocks of the Wîg Bâch Formation. The critical exposure is a small faulted sliver caught between faulted mylonites on the west and the Wîg Fault on the east. Resting on mylonites are about 3 m of local basal Ordovician rocks (Figure 9.7), showing a clear

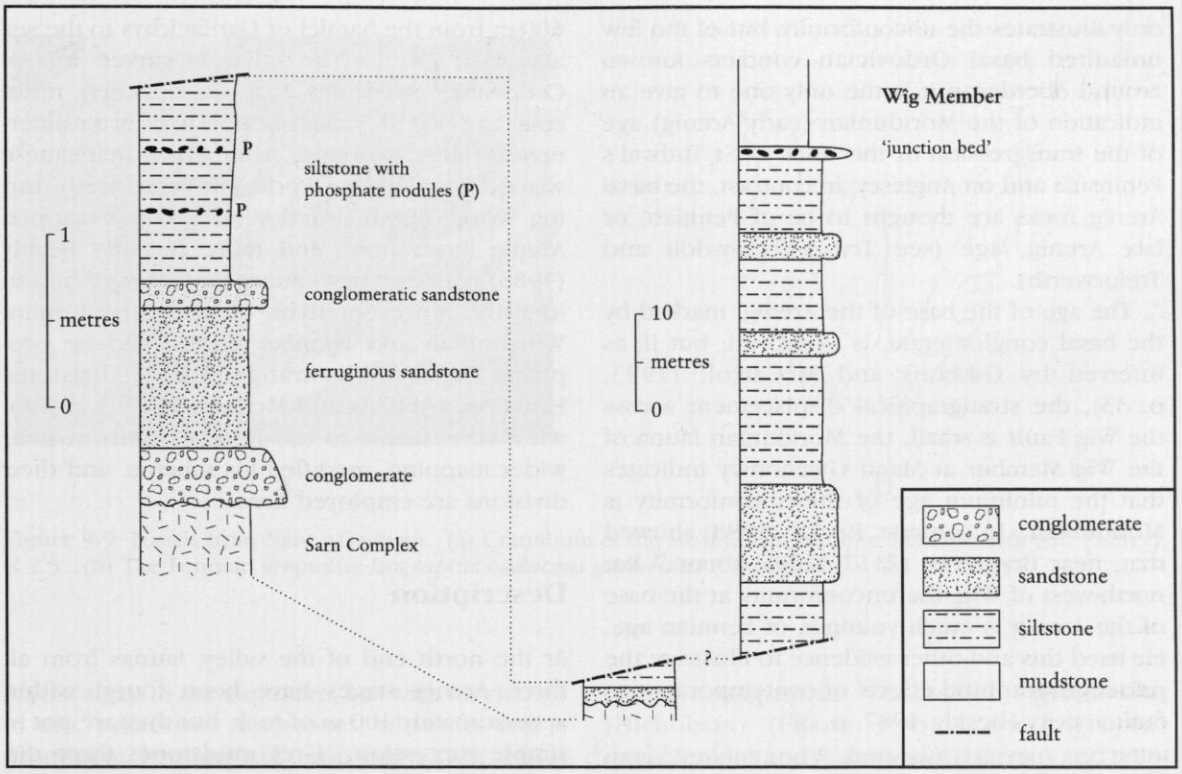


Figure 9.7 Stratigraphical section through the base of the Wig Bâch Formation at Wîg, with an enlargement (left) of the basal unconformity on the Sarn Complex (Precambrian). The base of the mudstones of the Wîg Member appear above the 'junction bed'. After Beckly (1985, unpublished).

plane of unconformity dipping ESE at about 55°. The conglomeratic base is 30 cm thick and includes cobbles of grey chert and pebbles of jasper. It is overlain by ferruginous sandstones interbedded with thin mudstones; and these are overlain by a 13 cm bed of conglomeratic sandstone containing ferruginous, commonly phosphatized, ooids, that is thought to represent a sediment-starved condensed unit (Gibbons and McCarroll, 1993). Above is an abrupt change to dark-grey siltstones with fine sandy laminae and phosphate nodules, seen for about 1 m, above which the succession is truncated by the Wîg Fault.

On the east side of the Wîg Fault is a succession in which the lowest beds resemble the siltstones to the west of the fault (Figure 9.7); these pass up into bioturbated sandstones and are capped by Beckly's 'junction bed' of indurated and bioturbated pebbly phosphatic sandstone, which Gibbons and McCarroll interpreted as a hardground formed during a period of non-deposition. The Wîg Member, consisting of 30 m of dark-grey mudstone and siltstone with phosphatic nodules, overlies the 'junction bed' and has its type locality here, at Wîg Bâch. Poorly preserved *Merlinia* and *Azygograptus* have been found at Wîg Bâch, and numerous *Merlinia* at Ogof Ddeuddwrs (1868 2550) to the south, but the best evidence for the Moridunian age of the Wîg Member is the presence of *Merlinia selwynii* (Salter) and *Azygograptus eivionicus* Elles in correlative beds at Maen Gwenonwy (2007 2599) (Beckly, 1988; Gibbons and McCarroll, 1993, p. 29).

Interpretation

The hiatus beneath the base of the Arenig increases in magnitude from the Harlech Dome north-west towards Anglesey: at Bryn Glas it rests on the Tremadoc (see site report), at Trwyn-llêch-y-doll on St Tudwal's Peninsula it oversteps the Cambrian, and in the Aberdaron area it rests on Precambrian. The site at Wîg not

only illustrates the unconformity, but of the few unfaulted basal Ordovician contacts known around Aberdaron it is the only one to give an indication of the Moridunian (early Arenig) age of the transgression in this area; at St Tudwal's Peninsula and on Anglesey, in contrast, the basal Arenig rocks are thought to be of Fennian, or late Arenig, age (see Trwyn-llêch-y-doll and Treiorwerth).

The age of the base of the Arenig, marked by the basal conglomerate, is unproved; but if, as inferred by Gibbons and McCarroll (1993, p. 33), the stratigraphical displacement across the Wîg Fault is small, the Moridunian fauna of the Wîg Member at Maen Gwenonwy indicates that the minimum age of the unconformity is Moridunian. In contrast, Beckly (1988) showed that, near Bryncroes (2317 3150), about 7 km north-west of Wîg, the unconformity at the base of the Arenig is much younger, of Fennian age. He used this and other evidence to illustrate the palaeogeographical effects of contemporaneous fault activity (Beckly, 1987, p. 28).

Conclusions

Wîg is an important site for interpreting Ordovician stratigraphy and palaeogeography of Llŷn. It shows the basal unconformity on the Precambrian and is the type area for the Wîg Member, whose fossils from a nearby locality demonstrate the early Arenig age of the marine transgression in this area.

NANT Y GADWEN (SH 2122 2685–SH 2108 2661)

Introduction

This site is important in exemplifying the biostratigraphy of the Arenig succession as developed in southern Llŷn, and is the only place where Moridunian, Whitlandian and Fennian faunas are all present. It is also significant in that the graptolites afford correlation with the Lake District succession (Jackson, 1962; Cooper *et al.*, 1995) and the trilobites with that in South Wales (Fortey and Owens, 1987), thereby offering a significant link in the correlation between these two important areas.

Nant y Gadwen is a narrow valley occupied by an underfit stream that may have formed subglacially (Gibbons and McCarroll, 1993, p. 61), and which runs south-south-west for some 600 m from the hamlet of Llanfaelrhys to the sea at Porth Alwm. The valley is carved out of Ordovician siltstones that lie between more resistant dolerite intrusions. There are numerous old mine workings from which manganese was extracted before World War I and briefly during World War II. Matley (1932) first mapped Arenig strata here, and more recently Beckly (1988) collected new faunas that allowed him to identify representatives of the Moridunian, Whitlandian and Fennian stages, and he proposed new lithostratigraphical divisions. However, Gibbons and McCarroll (1993, p. 28), who were unable to use Beckly's units in their wider mapping, modified his scheme, and their divisions are employed here.

Description

At the north end of the valley, faunas from all three Arenig stages have been found within approximately 100 m of rock, but they are not in simple succession. Grey mudstones there dip south to south-west at 28–50° (Figure 9.8). The trilobite *Merlinia selwynii* (Salter) (Figure 9.9a), indicative of the Moridunian Stage in South Wales and in the Harlech Dome, occurs commonly in mudstones exposed on the east side of the valley (2122 2685), above a dolerite sill.

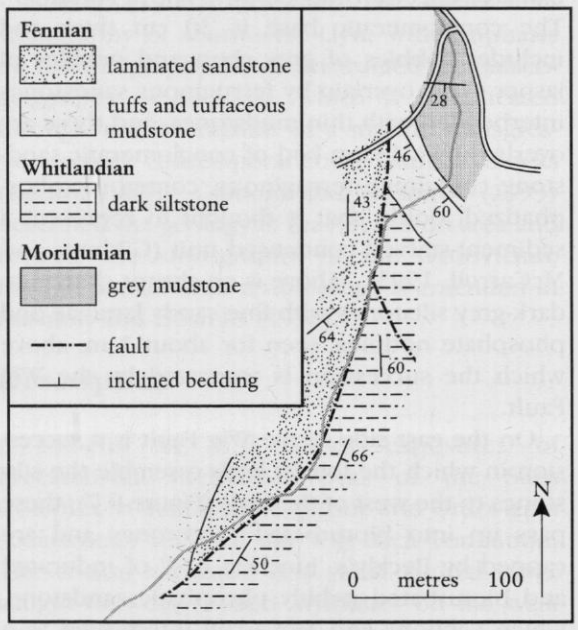
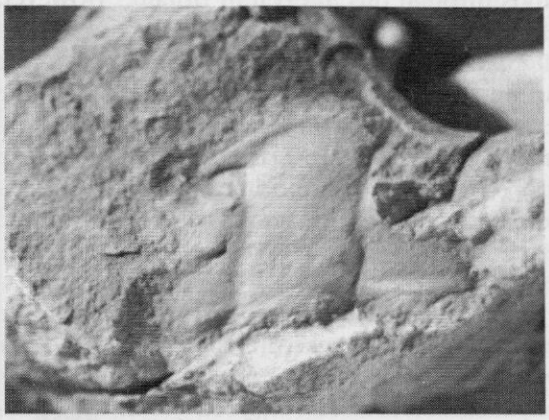
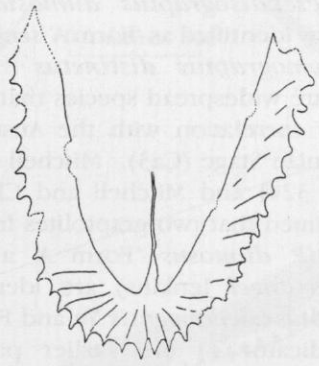


Figure 9.8 Distribution of rocks of the three stages of the Arenig Series in Nant y Gadwen, after Beckly (1985, unpublished).



a



b

Figure 9.9 Fossils from Nant y Gadwen. (a) Cranidium of the Moridunian trilobite *Merlinia selwynii* (Salter), × 2.5. (b) The Fennian graptolite *Isograptus caduceus gibberulus* (Nicholson), × 4.

Across a gap in the exposure, but with no change in dip, tuffaceous mudstones, siltstones and a prominent bedded tuff crop out (2122 2684) and yield trilobites and graptolites, including *Didymograptus distinctus* Harris and Thomas, *Expansograptus* cf. *extensus linearis* Monsen and *Pseudisograptus* cf. *dumosus* (Harris), which are indicative of a Fennian age. To the south-west, also dipping south and apparently overlying the Fennian strata, are manganese-stained laminated siltstones that have yielded a Whitlandian fauna which includes the diagnostic trilobites *Bohemopyge scutatrix* (Salter) and *Cyclopyge grandis grandis* (Salter). Clearly this succession is affected by local faulting, the details of which are unknown.

These SW-dipping beds are truncated by a NW-trending fault, and the beds that crop out on both sides of the valley to the south dip to the south-east at about 60–65° on the west side and about 30° on the east side according to Matley (1932, p. 244), though Beckly (1985, unpublished) gave higher values (Figure 9.8). All the strata are referred to the Wîg Bâch Formation of the Aberdaron Bay Group, and comprise dark-grey laminated mudstone and siltstone. Beckly (1988) recorded Fennian faunas from the west side and Whitlandian ones from the east, indicating that there is not a simple succession here (Figure 9.8). From the west side of the valley (2108 2661) he recorded abundant *Didymograptus uniformis lepidus* Ni, together with other graptolites (*Expansograptus hirundo* Salter, *Isograptus caduceus gibberulus* (Nicholson) (Figure 9.9b), *Pseudisograptus angel* Jenkins and *P. dumosus* (Harris)) and trilobites (*Microparia (M.) broeggeri* (Holub) and *Pricyclopyge binodosa eurycephala* Fortey and Owens). In collections from the east side of the valley (2119 2679) a trilobite fauna with *Cyclopyge grandis grandis* (Salter), *Furcalithus* aff. *sedgwickii* (Salter), *Shumardia gadwensis* Fortey and Owens (type locality) and *Bohemopyge scutatrix* (Salter) is firmly indicative of the Whitlandian Stage.

Interpretation

Nant y Gadwen is one of the few inland exposures of Arenig strata in south-western Llŷn. The laminated siltstones and mudstones of the Aberdaron Bay Group seem to have been deposited in relatively quiet, deep water over a period of about 10 million years, during much of the Arenig epoch. It is probable that deposition of this kind took place continuously, although because of local faulting and lack of exposure only parts of the succession can be seen at Nant y Gadwen and elsewhere.

Biostratigraphically the faunas from Nant y Gadwen are important in affording correlation within the British Isles and internationally. The *Isograptus* and *Pseudisograptus* from the west side of the valley indicate the development of the widespread deep-water Isograptid Biofacies of Cooper *et al.* (1991). Fortey *et al.* (1990)

pointed out that of the graptolites from this locality, *Pseudisograptus dumosus* (Harris) (which they identified as 'Form A' *sensu* Cooper) and *Didymograptus distinctus* Harris and Thomas, are widespread species that afford evidence for correlation with the Australian late Castlemainian Stage (Ca3). Mitchell and Maletz (1995, p. 324) and Mitchell and Chen (1995, p. 83) claimed that two graptolites from Nant y Gadwen (*P. dumosus* 'Form A' and *Pseudisograptus angel* Jenkins) are identical with *Arienigraptus zhejiangensis* Yu and Fang, which is an indicator of the earlier part of the *Undulograptus austrodentatus* Zone, a horizon that they recognize worldwide. The occurrence at Nant y Gadwen, therefore, pins part of the British succession into their scheme. Correlation with the *U. austrodentatus* Zone indicates a Darriwilian, not Castlemainian age, and Mitchell and Maletz (1995, p. 325) suggested that *D. distinctus* may have a longer range here, since elsewhere it does not range above the Castlemainian.

Conclusions

Nant y Gadwen is a site of national importance. It contains trilobite and graptolite faunas from all three stages of the Arenig Series, and these contribute to the correlation of the trilobite-bearing sequence in South Wales with the sequence in the Lake District, which serves as a graptolitic standard (see Chapter 11).

AFON SEIONT (SH 4788 6247–SH 4809 6169 AND SH 483 617)

Introduction

The Afon Seiont exposes an important local section through the upper part of the Arenig Series, furnishing some of the best palaeontological evidence for the Fennian and lower Llanvirn strata in the Nant Ffrancon 'Formation' (now Subgroup), whose outcrop extends north-east to Bangor and is widespread in Snowdonia.

The Arenig age of rocks in this section was recognized by Hicks (in Marr, 1876, p. 126) and by Ramsay (1881, p. 197). Elles (1904, pp. 200–203), who identified on the basis of graptolite faunas the presence of the *extensus, hirundo* and *bifidus* zones, was of the opinion that most of the Arenig was represented, suggesting that it is one of the few continuous sections through this interval in Britain. However, Beckly (1987) re-collected these exposures and demonstrated that only the upper part of the Arenig (Fennian Stage) and lower part of the Llanvirn (Abereiddian Stage) can be proved. Although the Arenig–Llanvirn boundary itself crops out here, it is poorly exposed, and is better exposed on the shore at Penrhyn Park, Bangor (SH 6035 7304) (see Fortey *et al.*, 1990, p. 126).

Afon Seiont is the type locality for the trilobite *Aeglina hughesii* Hicks (in Marr, 1876) (a junior synonym of *Pricyclopyge binodosa*) and for the phyllocarid crustacean *Caryocaris marrii* (a junior synonym of *C. wrightii* Salter). The faunas here are mixed graptolitic–shelly facies, and afford correlation between South Wales and the Lake District.

Description

The section is described from north to south, up sequence (Figure 9.10). The oldest Arenig strata are seen just south of the quay (at 4788 6247), near the core of an anticline which, on the basis of Elles' (1904, p. 201) map, runs approximately NE–SW through the quay itself. A short distance to the north, near the castle, the Arenig is faulted against the Monian Supergroup (Precambrian). Much of the section in exposures to the south of the quay on the left bank (as far as 4799 6183), over a distance of some 800 m, exposes grey micaceous siltstone with discontinuous fine sandstone laminae, dipping south-east variously at 25–65°. Fortey *et al.* (1990, fig. 3, p. 126) measured some 275 m of strata here. The northernmost exposures, south of the quay, have yielded the trilobite *Dindymene* sp. at 4782 6240, the trilobite *Eoharpes* sp. with a specimen of the graptolite *Pseudisograptus manubriatus koi* Cooper and Ni at 4801 6233, and a trilobite *Selenopeltis* sp. at 4804 6219. *Pricyclopyge binodosa eurycephala* Fortey and Owens, which (along with deformed extensiform graptolites) dominates the fauna, ranges between the last two points. Elles (1904, fig. 1, p. 201) placed all this part of the section in the *D. extensus* Zone.

The highest part of the Arenig is exposed in outcrops to the south, alongside the path of an old tramway. Here, the topmost 75 m is much sandier and is poorly fossiliferous but has yielded biserial graptolites, including *Undulograptus austrodentatus* (Harris and Keble) at 4800 6180. Bluish-black siltstones overlying these sandier

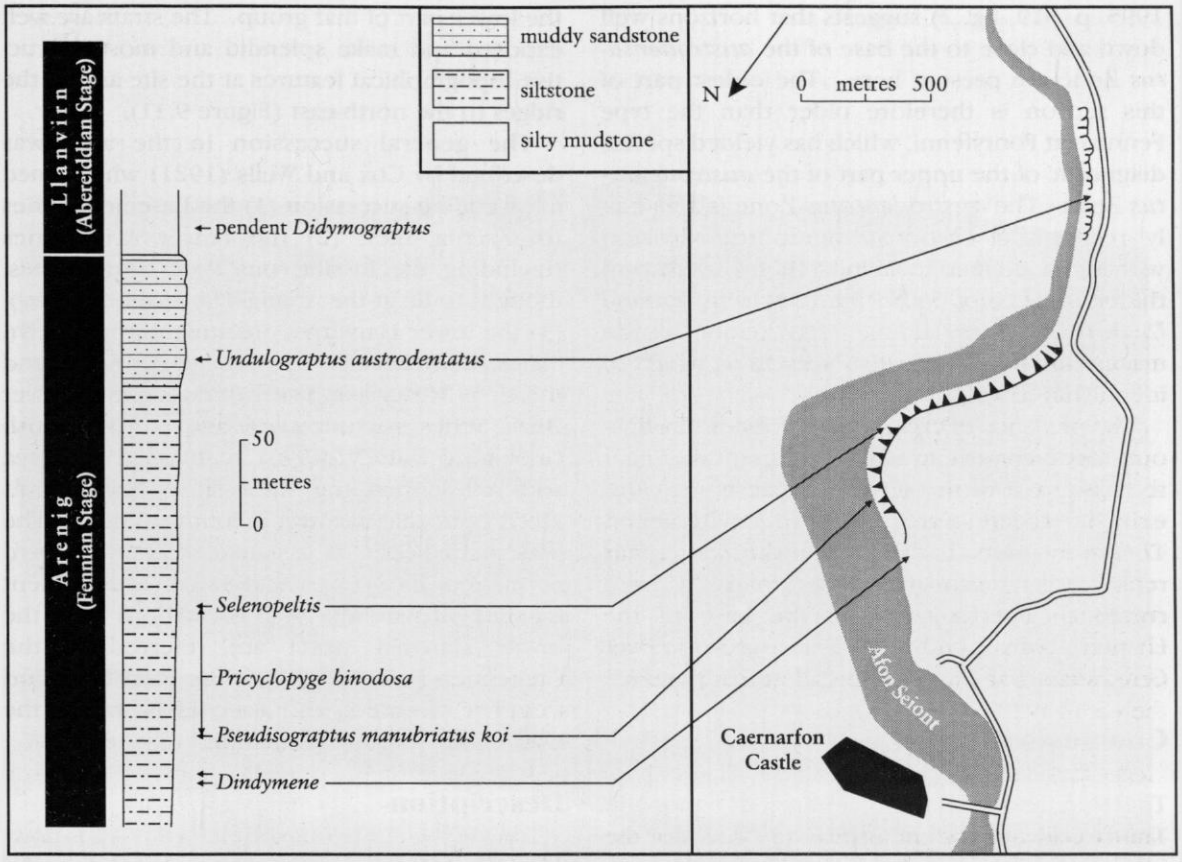


Figure 9.10 Stratigraphical succession showing the Arenig to Llanvirn succession along Afon Seiont, after Fortey *et al.* (1990, fig. 3).

beds are characterized by abundant pendent ('tuning fork') graptolites, indicative of the *D. artus* Zone. The junction is poorly exposed at 4803 6181, and the lower Llanvirn crops out over a distance of some 150 m south-east of this point. Besides the graptolites, some of which are preserved in full relief (Jenkins, 1979, unpublished), trilobites (e.g. *Placoparia* sp. and *Pricyclopyge binodosa binodosa* Salter), phyllocarids and lingulate brachiopods occur. This stretch probably includes the type localities for *Aeglina hughesii* and *Caryocaris marrii.*

On the opposite bank of the Seiont, near the gates to Eryri Hospital, blue-black cleaved shales, commonly iron-stained, are exposed to the north of a dolerite intrusion (around 483 617) and have yielded graptolites including abundant pendents, together with *Amplexograptus confertus* (Lapworth), *Eoglyptograptus dentatus* (Brongniart) and *Pseudoclimacograptus scharenbergi* (Lapworth). Jenkins (1979) collected 'forms close to *Didymograptus murchisoni* (Beck)' from this locality and therefore considered it to lie low in the *murchisoni* Zone.

Interpretation

Although Beckly's (1987) work has shown that less of the Arenig is present here than was formerly supposed, the locality does afford a useful section through the late Arenig and early Llanvirn, and confirms the presence in North Wales of the general sequence described in South Wales by Fortey and Owens (1987). Perhaps most significant is the presence of the graptolite *Pseudisograptus manubriatus koi*, which is widespread globally, and in Australia is restricted to the Yapeenian Stage (Fortey *et al.*, 1990, p. 127). The presence of this species immediately below and in the basal part of the *U. austrodentatus* Zone (Mitchell and Maletz,

1995, p. 319, fig. 2) suggests that horizons well down and close to the base of the *austrodentatus* Zone are present here. The oldest part of this section is therefore older than the type Fennian at Pontyfenni, which has yielded species diagnostic of the upper part of the *austrodentatus* Zone. The *austrodentatus* Zone is a globally recognized chronostratigraphical division with a base defined in China (Webby, 1998), and the occurrence of both *P. manubriatus koi* and *U. austrodentatus* in the Afon Seiont section makes this the best British section at which to identify its base.

The presence of cyclopygid trilobites throughout, together with an isograptid graptolite near the basal part of the section, suggests the presence of a deep-water, offshore environment. The sandy interval at the top of the Arenig may represent a regressive phase, followed by a return to deeper water at the base of the Llanvirn, corresponding to a transgression over Gondwana that was widespread at this time.

Conclusions

The Afon Seiont section is important nationally. The faunas allow identification in Britain of the internationally recognized *Undulograptus austrodentatus* Zone, and they include both trilobites and graptolites that aid correlation between the upper Arenig succession in South Wales with that in the English Lake District. Regionally the section provides biostratigraphical evidence for the age of the lower part of the Nant Ffrancon Subgroup, which, though thick and widespread, rarely reveals fossiliferous beds in such good stratigraphical succession.

LLYNNAU CREGENNEN (SH 652 148–SH 658 144)

Introduction

The outcrops to the north-west of Llynnau Cregennen display a partial section through the lower part of the Aran Volcanic Group from the local base of the Arenig up to fossiliferous Llanvirn strata which serve to date the lower parts of the Aran Volcanic Group.

Ridgway (1975) proposed the term Aran Volcanic Group for the major complex of volcanic rocks that girdle the south and east of the Harlech Dome, and the area of the Cregennen site shows a representative succession through the lower part of that group. The strata are well exposed and make splendid and most instructive topographical features at the site and in the ridges to the north-east (Figure 9.11).

The general succession in the area was described by Cox and Wells (1921) who named in ascending succession (1) the Basement Series (of Arenig age), (2) the Lower Acid Series (including the fossiliferous Pont Kings Slates, thought to lie at the Arenig–Llanvirn boundary), (3) the lower Llanvirn, consisting of the Moelyn Slates, Bryn Brith Ashes, Croegenen Slates and the Cefn Hir Ashes, overlain by (4) the Lower Basic Series (of uncertain age). The British Geological Survey (1995) re-mapped the area and redescribed the succession (Pratt *et al.*, 1995), and that account is followed here. The 'Basement Series' is assigned to the Allt Lŵyd Formation, the 'Lower Acid Series' is equivalent to the Offrwm Volcanic Formation, and the lower Llanvirn strata are referred to the Cregennen Formation (with the Bryn Brith and Cefn Hir members) and are overlain by the the Llyn y Gafr Volcanic Formation.

Description

The Allt Lŵyd Formation rests sharply on the Dol-cyn-afon Formation (Tremadoc) near Pant-y-cae (6535 1482). It is composed of thickly bedded sandstones showing cross-lamination and bioturbation. Macrofossils are not known, but, from localities to the north-east, Molyneux (in Pratt *et al.*, 1995, p. 20) recorded acritarch floras of Arenig age that indicate the presence of both Moridunian and Fennian strata.

The Offrwm Volcanic Formation consists of 100 m of acid tuffs and intercalated mudstones. Pratt *et al.* (1995, fig. 12) gave a log. The succession is interrupted by a thick, intrusive dolerite sill. No fossils are recorded here, but graptolites of early Llanvirn age (*Amplexograptus confertus* (Lapworth), *Didymograptus* cf. *miserabilis* Bulman) were found about 1 km to the north-east (Pratt *et al.*, 1995, p. 24), in strata that Cox and Wells (1921, pl. 20) mapped as 'Pont Kings Slate'.

The stream that drains Llynnau Cregennen exposes mudstones representative of the type area of the Cregennen Formation, together with a thin development of the Bryn Brith Member, both dipping south-east at about 60°. The Cregennen Formation consists mainly of dark-coloured graptolitic mudstone with numerous

Figure 9.11 Llynnau Cregennen, viewed from Barmouth, looking ESE towards Cadair Idris (the highest ridge). The dark scarp below and to the right of Cadair Idris is Tyrrau Mawr, made up of Aran Volcanic rocks intruded by microgranite. The lakes Llynnau Cregennen appear as dark expanses directly below the summit of Cadair Idris; and, below them, steep wooded slopes around the settlement of Arthog are mostly of Dol-cyn-afon Formation (Tremadoc). The ground left of Llynnau Cregennen and Arthog is well featured, showing successively higher ridges of the Dol-cyn-afon (quarried for slate), Allt Lŵyd Formation (Arenig), Offrwm Volcanic Formation (Arenig–Llanvirn), and the Bryn Brith and Cefn Hir members of the Cregennen Formation (Llanvirn). (Photo: Cambridge University Collection of Air Photographs, BMZ 22: copyright reserved.)

thin beds and layers of feldspar crystals and fragments of volcanic rocks. Cleavage is strong, and bedding may (in the absence of tuffaceous layers) be difficult to discern. Pendent didymograptids typical of the lower Llanvirn *artus* Zone have been collected, including *Didymograptus* (*D.*) cf. *spinulosus* Perner west of Llynnau Cregennen (6578 1437) and at other localities to the north-east (Pratt *et al.*, 1995, figs. 14i, j).

The Bryn Brith Member consists of coarse-grained basic tuffs with mudstone interbeds, together forming a steep ridge that stands above the ground occupied by the softer slates. Pratt *et al.* (1995, fig. 13) gave a log and recorded trilobites, including *Stapeleyella murchisonii* (Salter), from a mudstone interbed immediately north of the site (6581 1486) (Pratt *et al.*, 1995, p. 29, pls 9h, l). The overlying Cefn Hir Member consists of basic and acid tuffs and tuffites that, with a microgranite intrusion, form another striking ridge (Figure 9.12). South of Llynnau Cregennen the formation is overlain in turn by the Llyn y Gafr Volcanic Formation. South of Arthog (6467 1334) mudstones between the Cefn Hir and Llyn y Gafr divisions contain Llanvirn graptolites, but their zone is uncertain (Pratt *et al.*, 1995, p. 30).

Interpretation

The Allt Lŵyd Formation represents shallow-water sandstones deposited under the influence

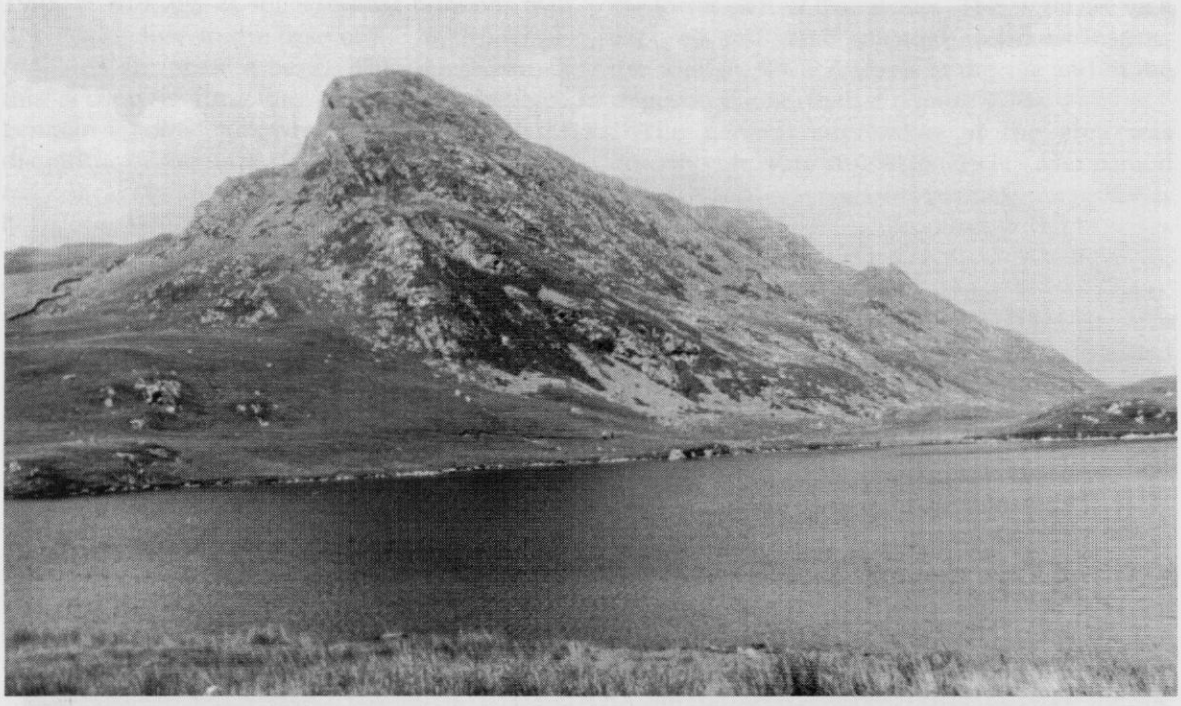


Figure 9.12 Llynnau Cregennen, looking north-east towards Pared y Cefn Hir. The lower ground to the left is occupied by fossiliferous Llanvirn slates of the Cregennen Formation, overlain by basic and acid tuffs of the Cefn Hir Member dipping to the right, with debris from a microgranite intrusion littering the dip-slope. (Photo: R.M. Owens.)

of storms. According to Pratt *et al.* (1995, p. 20), deposition of coarse sandstone commenced to the south-west in Tremadoc to early Arenig times and transgressed towards an uplifted area in the north-east, where some of the sandstones yield probable Llanvirn acritarch floras. The present site lies in an intermediate position in this transect. Traynor (1990, fig. 11) showed deposition of deltaic fans forming on the downthrow side of the active fault scarp that marks the southerly margin of his 'Fairbourne Trough' to the south of the Harlech Dome.

After uplift and erosion the tuffs of the Offrwm Volcanic Formation were deposited subaqueously. Intercalated mudstones contain early Llanvirn graptolites referred to the *artus* Zone, but Cox and Wells' (1921) record of Arenig graptolites was discounted by Rushton (in Pratt *et al.*, 1995, p. 24), and all the known faunas associated with the Offrwm Volcanic Formation are regarded as basal Llanvirn in age.

The Cregennen Formation represents background deposition of fine-grained detritus in poorly oxygenated conditions and is typical of graptolitic Llanvirn mudstones in much of Wales. It includes periodic influxes of volcanic material by mass-flow from a volcanic centre somewhere nearby; the Bryn Brith and Cefn Hir members show the most substantial of these flows. Although the location of the centre is uncertain, Pratt *et al.* (1995, p. 30) considered it may have lain to the north-east. All the identifiable faunas indicate the *artus* Zone and set a maximum age for the Llyn y Gafr Formation, which underlies strata of the *multidens* (and possibly *gracilis*?) Zone, but is otherwise of uncertain age (Pratt *et al.*, 1995, p. 32).

Conclusions

Llynnau Cregennen provides an admirably featured and instructive transect of the stratigraphy of the lower part of the Aran Volcanic Group. Faunas from the vicinity demonstrate better than those from elsewhere around Cadair Idris the Llanvirn age of the first stages of volcanic activity of the Aran Volcanic Group.

TREIORWERTH AND TY-HÊN (SH 3552 7872–SH 3625 7952 AND SH 3570 7992)

Introduction

This site is important because it is the type section for the Treiorwerth Formation, a major fossiliferous representative of the Arenig transgression in North Wales, and because it includes the type localities for a large number of the brachiopod taxa described by Bates (1968b).

Inshore, transgressive facies of late Arenig (Fennian) age are well developed in the Anglesey succession, and this site, together with Ogor Gynfor to the north (Figure 9.13) affords good examples. The outcrops and their faunas were reported by Greenly (1919) and were described in detail by Bates (1972) and by Neuman and Bates (1978). Although the Fennian age is not proved, Beckly (1987) has presented evidence to demonstrate that such an age is likely, especially in terms of local palaeogeography and because the local species of the trilobite *Neseuretus* is different from those characterizing earlier Arenig horizons in other parts of the Welsh Basin.

The brachiopod faunas in particular formed part of the basis of the 'Celtic Province' of Williams (1973), and were believed by Neuman and Bates (1978) to represent 'island faunas' (see below).

Description

There are three areas of outcrop to the south and south-east of Treiorwerth House in which the Carmel and Treiorwerth Formations are exposed. By the roadside 200 m north-west of Ty-hên (SH 3552 7872), sandstones of the Carmel Formation, some cross-bedded and with conglomerate bands and shelly lenses, have yielded brachiopods including *Paralenorthis proava* (Salter) and *Hesperonomiella carmelensis* Bates, together with scarce trilobites (*Neseuretus monensis* (Shirley), *Annamitella perplexa* (Bates) and *Ogyginus*? sp.). The Monian Supergroup crops out a short distance to the south, but the unconformable junction is not exposed here; it can be seen just north of Prys-Owain-bâch cottage, 6 km to the north-east (3986 8282).

The junction between the Carmel Formation and the overlying Treiorwerth is not exposed, although Bates (1968b, p. 134) regarded the lowest horizons of the latter, seen in a number of small natural exposures and quarries 350 m south-east of Ffynnon-y-mâb (centred on SH 3625 7952), to be not far above the base. Here the beds dip at 50–65° to the north-west; the lowest are grey-green siltstones with coarse micaceous shale partings, which pass upwards

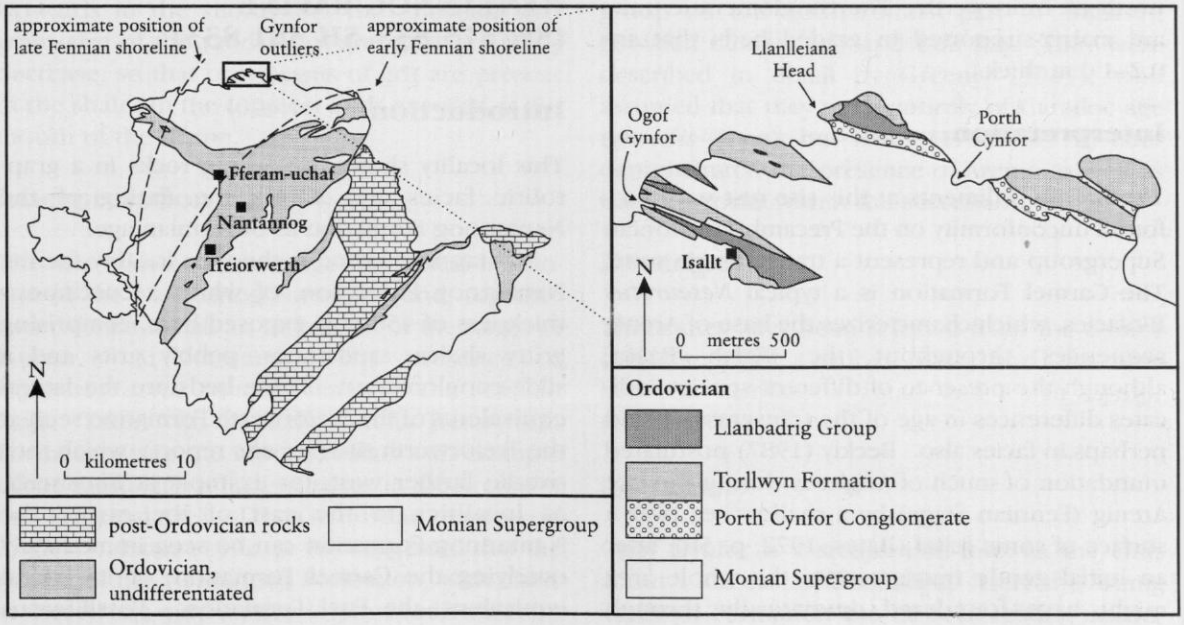


Figure 9.13 Distribution of Ordovician rocks on Anglesey, from British Geological Survey (1994b), with details of the Gynfor inliers from Bates (1972).

through 106 m of siltstones and sandstones into the coarse grits and conglomerates that are typical of much of the formation. The sandstones have yielded fragments of the graptolite *Tetragraptus headi* (Hall)?, and water-sorted shelly lenticles have yielded a rich brachiopod-dominated fauna, including *Tritoechia pyramidalis* (Bates), *'Orthambonites'* sp., *Monorthis typis* Bates, *Productorthis* sp., *Ffynnonia costata* (Bates), *Rhynchorthis rotunda* Bates, *Rectotrophia globularis* Bates, *Reinversella monensis* Bates and *Treioria chaulioda* Neuman and Bates. This is the type locality for all these species. Bryozoans are the next commonest group of fossils after the brachiopods, and smaller numbers of other fossils occur: trilobite fragments including an agnostid, pelmatozoan plates including the parablastoid *Blastoidocrinus antecedens* Paul and Cope, and a gastropod *Matherella? acuticostata* Bates (1963), for which this is the type locality.

Sediments that are regarded as being more typical of the Treiorwerth Formation are exposed in an old quarry on the south side of the road 350 m south-east of Treiorwerth (3570 7992), just west of Pont Rhyd-Iorwerth. Thick-bedded conglomerates exposed here dip at about 70° to the north-west and contain a variety of subangular pebbles and cobbles of green and purple schists and jasper derived from the Monian Supergroup that can be seen *in situ* around Presaddfed (351 809), not far to the north of Treiorwerth. The conglomeratic units are matrix-supported in graded beds that are 0.2–1.0 m thick.

Interpretation

The Arenig sediments at this site rest with profound unconformity on the Precambrian Monian Supergroup and represent a transgressive suite. The Carmel Formation is a typical *Neseuretus* Biofacies, which characterizes the base of Arenig sequences throughout the Welsh Basin, although the presence of different species indicates differences in age of the transgression and perhaps in facies also. Beckly (1987) postulated inundation of much of Anglesey during the late Arenig (Fennian Stage) by a shallow sea over a surface of some relief (Bates, 1972, p. 56); after an initial gentle transgression, the whole area might have foundered dramatically through fault-controlled subsidence, and the conglomeratic facies that typifies much of the Treiorwerth Formation comprises up to 650 m of rudaceous mass debris-flow deposits that were banked up against an east dipping fault scarp (Beckly, 1987, p. 28) and probably derived from the west (Bates, 1972, p. 56). The abundant brachiopod fauna at Ffynnon-y-mâb comprises disarticulated valves of robust, thick-shelled coarsely ribbed species that accumulated in lenses and clearly were transported from their original habitat. Neuman and Bates (1978, p. 577) noted a generic similarity between this fauna and those from the Tagoat Beds in south-east Ireland and from broadly contemporaneous horizons in eastern North America. They proposed (p. 578) that these 'Celtic Province' brachiopods may have occupied a group of islands, with Anglesey and the Irish Sea Horst in late Arenig times separated from the Welsh Basin by a wide expanse of ocean. However, this interpretation was challenged by Beckly (1987) and others (e.g. Fortey and Rushton, in Cope *et al.*, 1992), and most authorities maintain Anglesey as an integral part of the Welsh Basin.

Conclusions

This site is critically important in affording evidence for both the palaeogeography of Anglesey and shallow-water fossil assemblages in the late Arenig and has yielded one of the most diverse brachiopod faunas of this age in Britain.

NANTANNOG RAVINE (SH 375 838–SH 381 833)

Introduction

This locality shows the Arenig rocks in a graptolitic facies and allows the dating of the Nantannog Formation as of Fennian age.

Nantannog Ravine is the type locality for the Nantannog Formation, of which a continuous thickness of 450 m is exposed here, comprising gritty shales, sandstones, pebbly grits and a slide-conglomerate. These beds are the lateral equivalents of the Treiorwerth Formation seen at the Treiorwerth site (see site report), which they overlie farther west, for example at Rhosneigr. At localities to the east of the ravine the Nantannog Formation can be seen immediately overlying the Carmel Formation, or its lateral equivalent, the Foel Formation. Fossiliferous horizons within the Nantannog Formation show that it has an age ranging from late Arenig

(Fennian) to mid-Llanvirn (Abereiddian). At Nantannog Ravine the succession is of Arenig age, whereas examples of younger horizons in this facies can be seen at Fferam-uchaf (see site report).

Description

Mentioned briefly by Greenly (1919, p. 441), this locality was described more fully by Bates (1972, p. 38), who provided a map (Bates, 1972, p. 38, fig. 5). The section is almost 1 km long, and the beds dip at 45–75° to the north-west or NNW. The oldest horizons crop out south of the road bridge (3797 8344), where slightly gritty shales have yielded the only fauna reported from this locality (at 3808 8332), a cyclopygid trilobite and *Expansograptus hirundo* (Salter). Similar gritty shales crop out over a distance of 360 m downstream from the bridge. At this point, at a sharp bend in the stream, a 20-m-thick slide-conglomerate is exposed, well seen on the north bank of the ravine (3779 8376). It contains blocks reaching 0.6 m in size that are are generally subangular and comprise predominantly phyllites and schists together with quartzite, granites, jaspers, gneiss and sandstones set in gritty pelite. The clasts are derived from the Monian Supergroup, and possibly also from the Lower Palaeozoic. Downstream from the slide-conglomerate the succeeding beds are sandstones and pebbly grit showing grading and alternating with shales. Upwards in the succession, the thickness and grain size of the sandstones and grits gradually decrease, so that only seams of grit are present in the shales in the topmost beds exposed at the mouth of the ravine.

Interpretation

This site shows to advantage the typical lithologies of the Nantannog Formation and, together with Fferam-uchaf, an indication of the range of faunas. At Nantannog the presence of *Expansograptus hirundo* indicates the Fennian Stage. Taken with the shallow-water Treiorwerth Formation (see site report) it shows an example of the rapid lateral facies change in the Arenig of the 'Principal Area' of the Ordovician outcrop on Anglesey. Bates (1972, p. 56) suggested that the nature of the Nantannog Formation, with clasts scattered in a mud matrix, implied redistribution of an already deposited sediment, probably by slumping into deeper water of material from the area of deposition of the Treiorwerth Formation. The clasts of Monian Supergroup rocks within the Nantannog Formation were believed by Bates (1972, p. 56) to be derived from the west.

Conclusions

The Nantannog Ravine is an important locality at which to observe deeper-water facies of the Arenig rocks in Anglesey. Taken with Treiorwerth, Gynfor and other localities, it exemplifies the complicated palaeogeography of the late Arenig transgression in north-west Wales.

THE GYNFOR OUTLIERS (SH 378 948, SH 383 945, SH 387 952–SH 396 948)

Introduction

The Gynfor outliers (Figure 9.13) are of particular interest for the interpretation of Arenig stratigraphy and palaeogeography in Anglesey; and that at Ogof Gynfor, especially, provides an excellent example of the structural relationships between and within Monian and Ordovician rocks, as described by, for example, Bates (1974) and Barber and Max (1979).

A number of small fault-bounded outliers of Ordovician sediments occur within the late Precambrian–early Cambrian Monian Supergroup on the northernmost part of Anglesey, between Camaes Bay and Bull Bay. They were described in detail by Greenly (1919), who assumed that they were entirely of Caradoc age (*gracilis* Zone), but Bates (1968b, 1972) later demonstrated the presence of Arenig as well as Caradoc rocks within the succession.

Description

Three sites have been selected from the Gynfor outliers: Ogof Gynfor, Isallt, and the area between Llanlleiana Head and Porth Cynfor (Figure 9.13).

Ogof Gynfor

Ogof Gynfor is a steep-sided inlet in the cliffs about 1 km east of Llanbadrig. Here the Arenig Torllwyn Formation can be seen resting unconformably on the Gwna Melange of the Monian Supergroup. In turn, the Caradoc Llanbadrig

Group lies disconformably on the Torllwyn Formation. The section has been described and illustrated in a number of publications, for example by Blake (1888, fig. 21, p. 519), Greenly (1919, p. 475, fig. 220, pl. 29), Bates (1974, p. 50, fig. 5A) and Barber and Max (1979, p. 417, fig. 7). Bates (1974, p. 50) described part of this section as 'a classic example of the interrelationships that can obtain between folding and faulting'. Not all of the section can easily be seen from the cliffs, and it is best examined from a boat.

The unconformity between the Gwna Melange and Torllwyn Formation is well seen in the deep chasm (Figure 9.14; Greenly, 1919, pl. 29). Barber and Max (1979, p. 417) noted that both the Gwna Melange and Ordovician show a simple, steeply dipping cleavage, indicating that they were deformed together. The Torllwyn Formation is 25 m thick at Ogof Gynfor and comprises dominantly pale, brown-weathering conglomerates containing quartzite blocks up to 1.7 m across (Figure 9.14), with subordinate partings of shales, siltstones or fine grits. These finer beds have yielded most of the fossils here, predominantly brachiopods including *Ahtiella quadrata* Bates (type locality) and *Rhynchorthis rotunda* Bates, together with pelmatozoan and bryozoan fragments.

Farther north, around the headland from north of the inlet and about 100 m from the unconformity described above, there is a faulted syncline, in the core of which Caradoc (*N. gracilis* Zone) sediments – the Gynfor Shales of the Llanbadrig Group – are exposed. The northern limb of the syncline is cut by fairly steep reverse faults, whilst those on the southern limb are more or less vertical. The Torllwyn Formation is exposed on both limbs of the fold, and the north limb is truncated by a fault that brings it into contact with the Gwna Melange, which is the northern limit of the Ogof Gynfor outlier.

Isallt

Inland, along the same fault complex, Ordovician rocks crop out as far as Isallt (383 945). Behind and to the south of this point the unconformity at the base of the Arenig can be seen, where it dips at a low angle, and quartzite

Figure 9.14 Cliffs of Ogof Gynfor viewed from the sea. On the extreme right, surmounted by pale-weathering quartzite, is the Gwna Melange of the Mona Supergroup. It is overlain unconformably by thick sandstones and conglomeratic horizons of the Torllwyn Formation (Arenig), which are disposed in a faulted syncline; within this is a faulted wedge of dark cherty shales of early Caradoc age. The left-hand fault is vertical, whereas the right-hand one is an overthrust. (Photo: D.E.B. Bates.)

breccia at the base of the Torllwyn Formation is exposed on crags of Gwna Quartzite. The contact is irregular, and small stacks of quartzite can be seen, surrounded by breccia (Bates, 1972, p. 33, fig. 3).

Llanlleiana Head to Porth Cynfor

In the outlier of Llanlleiana Head to Porth Cynfor a conglomerate intervenes between the Torllwyn Formation and the Gwna Quartzite. This, the Porth Cynfor Conglomerate Formation, is overlapped by the Torllwyn Formation to the west, as at Ogof Gynfor. The Porth Cynfor Formation rests unconformably upon an irregular surface of Gwna Quartzite, with a 3-m-thick quartzite breccia at the base. This is overlain by 5 m of lavender-coloured and cream-grey shales, alternating with sandstone and conglomerate, and includes a 13 cm band of brown-weathering limestone. Succeeding these beds are 20 m or more of massive purple conglomerates, with white and red quartz and jasper cobbles and boulders, set in a matrix of purple sand and shale, which in some outcrops are altered to a phyllite (Bates, 1972, p. 32). Between Llanlleiana Head and Porth Cynfor the Porth Cynfor Formation is faulted against the Llanbadrig Group and Torllwyn Formation to the north, with the unconformable base forming the southern margin of its outcrop. On the eastern side of Porth Cynfor the Torllwyn Formation conformably overlies the Porth Cynfor Formation. The outcrops on either side of Porth Cynfor represent the type locality for the Porth Cynfor Formation (the 'Hell's Mouth conglomerate' of Bates (1968b, p. 137)).

Interpretation

The Porth Wen Group, comprising the Porth Cynfor and Torllwyn formations, consists predominantly of coarse clastics belonging to a transgressive sequence. Bates (1968b, 1972) attributed to it an *extensus–hirundo* Zone age, but Beckly (1987) argued for a late Arenig (Fennian) age for the entire Anglesey sequence, suggesting that the transgression took place wholly during the Fennian and did not reach northern Anglesey until the middle of the late Fennian. If this is the case, the local base of the Arenig is diachronous, with the oldest sediments being the Carmel and Foel formations of the 'Principal Area'. The Porth Wen Group, on Beckly's model, is approximately coeval with the Treiorwerth and lower part of the Nantannog formations. This correlation appears to be supported by the common occurrence in the Treiorwerth and Torllwyn formations of the brachiopod *Rhynchorthis rotunda* Bates. As in the Treiorwerth Formation, the brachiopods of the Torllwyn are mainly coarse-ribbed, robust shallow-water forms (see Treiorwerth site report). No Llanvirn sediments are preserved in the Gynfor outliers, due either to non-deposition (perhaps the area remained under very shallow water or was positive), or subsequent erosion prior to the early Caradoc transgression. Similar cleavage affects the Monian rocks and the Ordovician Porth Wen and Llanbadrig groups, indicating that deformation occurred after the mid-Ordovician.

Conclusions

These localities provide components for the palaeogeographical interpretation of north-west Wales during the Arenig. The rocks were formed in shallow water, like those in the Treiorwerth–Ty Hen area, but deposition began later here, illustrating the diachroneity of the unconformity at the base of the Ordovician on Anglesey.

FFERAM-UCHAF (SH 3617 8668, SH 3618 8655 AND SH 3650 8657)

Introduction

An exposure south-west of Fferam-uchaf is of significance because it is one of only two localities on Anglesey from which the *murchisoni* Zone has been recognized. It was reported by Greenly (1919, p. 452), who also noted two outcrops nearby that yielded graptolite faunas indicative of the underlying *D. artus* Zone. All three exposures are within the topmost part of the Nantannog Formation and lie at the north-westerly extremity of its outcrop.

Description

West of the road, at the bend 180 m west of Fferam-uchaf farm (3617 8668), are shales, fine gritty beds with fragments of grey mudstone and thin ribs of fine sandstone that dip north at 30–50°. Bates (1972, p. 40) redetermined Greenly's collection from here as follows:

Didymograptus 'bifidus' (Hall) (probably = *D. artus* Elles and Wood), *D. (Expansograptus) hirundo* Salter, *Orthambonites?* sp. and *Paterula? balclatchiensis* (Davidson). More or less along strike, 170 m south-east of the farm (3650 8657), similar beds yielded a shelly fauna including brachiopods (*Dactylogonia* sp., *Ptychopleurella* sp., *and Skenidioides* sp.), bryozoans and pelmatozoan columnals. To the south-west of the farm (3618 8655), shales and fine sandstones yielded the graptolite *Didymograptus murchisoni* (Beck), trilobites (*Bergamia?* sp., *Cyclopyge?* sp., *Placoparia* sp., and *Illaenus (sensu lato)* sp., an orthid brachiopod and a bivalve.

Interpretation

The mixed shelly–graptolitic faunas from the top of the Nantannog Formation here are probably indicative of fairly shallow-water conditions. The presence of rock fragments within the matrix implies redistribution of an already deposited sediment (Bates, 1972, p. 56). Because beds assigned to the *murchisoni* Zone crop out to the south of those of the *artus* Zone in a north-dipping sequence, the former are either downfaulted or folded into their present positions (Bates, 1972, p. 40). At Fferam-uchaf itself, the Fferam ironstone and overlying graptolite shales to the north belong to the Llanbabo Formation (basal Caradoc, *gracilis* Zone). Although the contact with the Llanvirn is not exposed, it is presumably unconformable or faulted, and there is no evidence for the intervening *teretiusculus* Zone.

Conclusions

The outcrops at Fferam-uchaf are important in providing fossiliferous exposures of both the Abereiddian (Llanvirn) graptolite zones, *artus* and *murchisoni*, in a mixed shelly–graptolite facies. They are complementary to the larger exposures in Nantannog Ravine (see site report).

TRILOBITE DINGLE (SJ 221 080)

Introduction

The abundance of trinucleid trilobites in Bron-y-buckley Wood, near Welshpool ('2' in Figure 10.1) led Murchison (1839, p. 303) to call this locality 'Trilobite Dingle'. It is the historically important type locality for *Salterolithus caractaci*, the type species of a trinucleid trilobite genus that, together with the closely related *Broeggerolithus*, plays a vital part in Anglo-Welsh Caradoc correlation. The abundant trinucleids from this site enable close correlation with the somewhat shallower-water succession of the type Harnagian Substage of the Burrellian Stage in Shropshire. They also provide valuable insights into the evolution of this group of trilobites. The co-occurrence in Trilobite Dingle of the planktonic graptolites with shelly fossils is potentially important for global correlation of this division of the Ordovician.

Wade (1911, p. 422) described the section, listed the faunas and termed the Ordovician rocks here the 'Trilobite Dingle Shales'. Cave (1957) redescribed populations of the trinucleids, including topotypic *Salterolithus caractaci* (Murchison) (Figure 9.15). He provided a sketch-map of the site, as did Cave and Dixon (1993, p. 64, fig. 6).

Description

Green-grey micaceous shales and nodular mudstones of the Trilobite Dingle Formation crop out intermittently for some 300 m in the bed and banks of the stream in Bron-y-buckley Wood (Figure 9.16). The beds dip north-west fairly steeply (50–60°) along most of the stream, but at the northern end the dip is gentler (25°) and

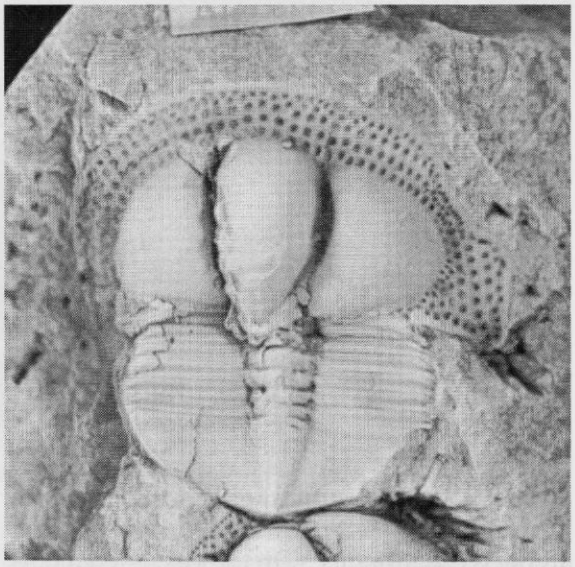


Figure 9.15 *Salterolithus caractaci paucus* Cave, ×3, showing healed injury on the right-hand side of the fringe. Trilobite Dingle.

almost due west. Dr J.K. Ingham suggests (pers. comm., September 1996) that this reflects the presence of a fault striking approximately east, with a southerly downthrow, between Cave's localities λ36 and λ35. Beds immediately south of this putative fault are stained red, probably as a result of pre-Triassic emergence and the flow of oxidizing fluids along the fault. About 50 m to the north of the last outcrop of the Trilobite Dingle Formation, a small quarry exposes red Llandovery conglomerates dipping east at about 50°.

Interpretation

The Trilobite Dingle Formation is the lowest Ordovician unit exposed in the Welshpool area. Wade (1911) considered it to be 'Llandeilo' in age, but Bancroft (1929a) assigned it to his newly established Girvanian and Harnagian stages of the lower Caradoc. In 1933, when Bancroft replaced the name 'Girvanian' by 'Costonian', he restricted the beds in Trilobite Dingle to the Harnagian. This view was subsequently endorsed by Cave (1957), and a correlation to the Harnagian Substage of the Burrellian Stage (of Fortey *et al.*, 1995) is now well established. The abundance of trinucleid trilobites enabled Cave (1957) to undertake a detailed analysis of populations. A more wide-ranging statistical analysis of the taxonomy and evolution of *Salterolithus* and the closely allied *Broeggerolithus* in the Caradoc of the Welsh Basin is being carried out by Ms A. Bowdler-Hicks of Glasgow University; her work shows that, whilst the samples from south of the putative fault in Trilobite Dingle belong in the upper Harnagian taxon *Salterolithus caractaci,* those from north of the fault are closest to lower Harnagian forms seen also in the type Caradoc of South Shropshire.

In addition to the abundant trinucleid trilobites, the Trilobite Dingle Formation is the type locality for the asaphid trilobite *Parabasilicus powisii* (Murchison), which also facilitates correlation with the somewhat shallower-water Harnagian of Shropshire. Brachiopods, molluscs and several graptolite species are also known (Wade, 1911). The graptolites belong in the *multidens* Zone and are in need of modern re-identification, but the association of graptolites and shelly fossils provides a rare opportunity to enhance the wider correlation of the lower part of the Burrellian Stage.

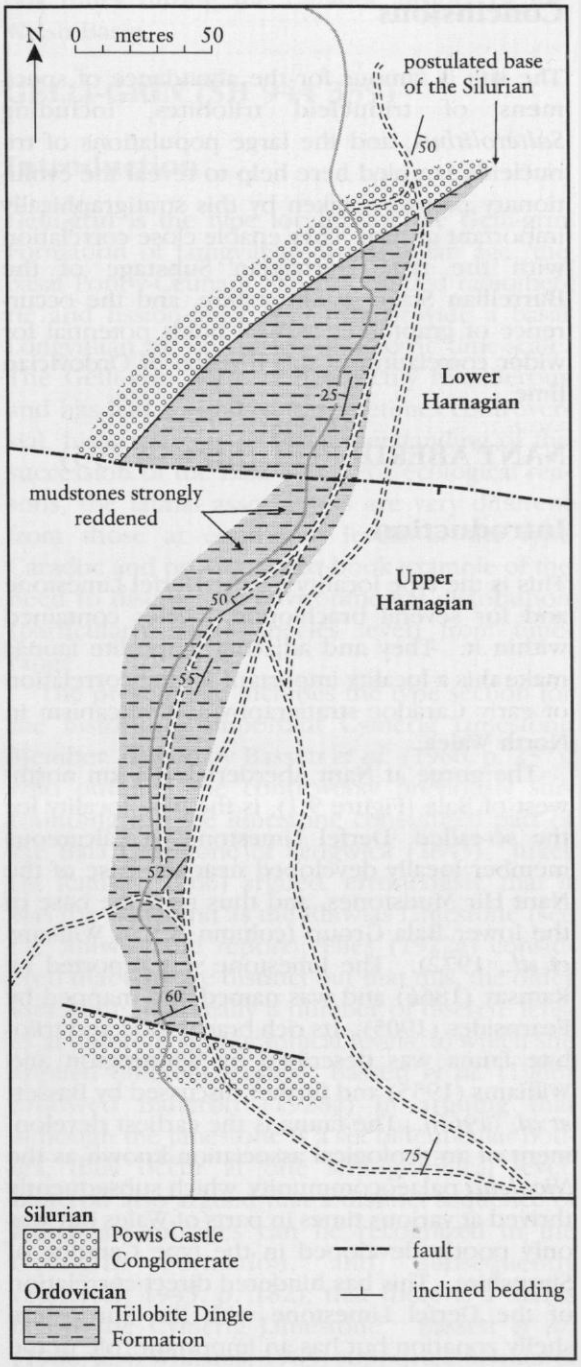


Figure 9.16 Sketch map of the Trilobite Dingle Formation in Bron-y-buckley Wood, Welshpool, based on Cave (1957, fig. 1) and including an east-west fault suggested by Dr J. K. Ingham (pers. comm., 1996) that separates the Lower Harnagian mudstones at the northern end of the section from Upper Harnagian strata farther south.

Conclusions

The site is famous for the abundance of specimens of trinucleid trilobites, including *Salterolithus*, and the large populations of trinucleids sampled here help to reveal the evolutionary pathways taken by this stratigraphically important group. They enable close correlation with the type Harnagian Substage of the Burrellian Stage in Shropshire, and the occurrence of graptolites as well holds potential for wider correlation of this division of Ordovician time.

NANT ABERDERFEL (SH 850 395)

Introduction

This is the type locality for the Derfel Limestone and for several brachiopod species contained within it. They and adjacent graptolite faunas make this a locality important for the correlation of early Caradoc stratigraphy and volcanism in North Wales.

The gorge at Nant Aberderfel, 8.5 km northwest of Bala (Figure 9.1), is the type locality for the so-called 'Derfel Limestone', a calcareous member locally developed near the base of the Nant Hir Mudstones, and thus near the base of the lower Bala Group (column W.5 in Williams *et al.*, 1972). The limestone was reported by Ramsay (1866) and was named and mapped by Fearnsides (1905). Its rich brachiopod and trilobite fauna was described by Whittington and Williams (1955) and further discussed by Bassett *et al.* (1966). The fauna is the earliest development of an ecological association known as the *Nicolella* palaeocommunity, which subsequently thrived at various times in parts of Wales but was only poorly developed in the type Caradoc of Shopshire. This has hindered direct correlation of the Derfel Limestone with the Shropshire shelly zonation but has an important role in the analysis of the changing environmental patterns of the basin. Zalasiewicz (1992) described graptolites of the *multidens* Zone from strata just above and just below the Derfel Limestone.

Description

As described by Bassett *et al.* (1966, p. 229), the type Derfel Limestone at Nant Aberderfel comprises 1–2 m of blue-black, pyritous, slightly calcareous mudstones in the west wall of the gorge. Lockley (1980a, p. 25) noted that the gorge was subsequently partly flooded by Llyn Celyn, and when the water level is low it is seen that the 'limestone' (something of a lithological misnomer) is separated from the underlying Aran Volcanic Group by 15 m of mudstones with ashy intercalations. Lynas (1973), however, noted lenses of beds similar to the Derfel Limestone within the topmost division of the Aran Volcanic Group, the Llyn Conwy Formation. Bassett *et al.* (1966, p. 229) considered correlatives of the Derfel Limestone in the Bala area to include fossiliferous silty mudstones in Afon Serw, and blocky mudstones at Pistyll Gwyn in Nant Hir. The Nant Hir Mudstones, of which the Derfel Limestone forms an impersistent basal member, may be in excess of 1000 m thick.

The Derfel Limestone is richly fossiliferous; a 10 kg bulk sample analysed by Lockley (1980b, p. 173) yielded 173 specimens belonging to at least 28 taxa, in a fauna dominated by brachiopods and bryozoans but also including trilobites and a few echinoderms, ostracods and machaeridians. A total of 19 species of brachiopod and 9 of trilobite are known from the member (Whittington and Williams, 1955; Williams, 1963; Lockley, 1980b), with 10 of the brachiopod species or subspecies having this as their type horizon.

Interpretation

The faunal association in the Derfel Limestone was originally termed the '*Kullervo–Palaeostrophomena–Nicolella* association' by Williams (in Whittington and Williams, 1955) but was subsequently renamed the '*Nicolella* association' (Williams, 1963, 1973). Williams noted similarities to some of the faunas of the Gelligrîn Formation (see site report for Gelli-grîn) and the significant component of stocks of Baltic origin. Lockley (1980b), who made a quantitative assessment of the faunas of the Bala area and subsequently the Arenig to Caradoc of the Welsh Basin as a whole (Lockley, 1983), considered that what he termed the '*Nicolella* palaeocommunity' was derived from the earlier 'mixed *Dalmanella* palaeocommunity' and that it typified fine-grained calcareous siliciclastic rocks and limestone. In addition to the Derfel Limestone in the Bala area, Lockley recognized the palaeocommunity in much of the Gelli-grîn Formation of Longvillian–Woolstonian age and, in the intervening succession, in part of the Glyn

Gower Siltstone. It is also developed in the Longvillian of the Berwyns, the lower Caradoc of Anglesey and the Soudleyan of the Shelve area, but not to any significant extent in the type Caradoc of Shropshire.

The development of the *Nicolella* palaeocommunity in the Derfel Limestone marks its earliest occurrence, but its precise age there is uncertain because of palaeoecological problems of direct correlation with the type Caradoc. Elles (1922) assigned to the *Nemagraptus gracilis* Zone a graptolite fauna that she considered to be from a level between the Derfel Limestone and the underlying volcanic formation. However, Zalasiewicz (1992) extracted graptolite faunas from above the Derfel Limestone at Nant Aberderfel (his Locality 3) and from immediately above the base of the Nant Hir Formation at his Locality 4 near Castell Carndochan (8357 3033) and assigned both to the *multidens* Zone (renamed '*foliaceus* Zone' in Fortey *et al.*, 1995). These faunas date the cessation of Aran Volcanic Group activity to within the *multidens* Zone.

Williams (1963) and Bassett *et al.* (1966) drew attention to similarities between the Derfel Limestone brachiopod fauna and faunas from Anglesey that include *N. gracilis* Zone graptolites (Bates, 1968b), suggesting correlation with the Costonian of Shropshire, whilst Rushton and Howells (1998) and Howells and Smith (1997) placed the Derfel Limestone near the Costonian–Harnagian boundary. Of the trilobites known from the Derfel Limestone, only one, *Broeggerolithus* cf. *harnagensis* (Bancroft) of Whittington (in Whittington and Williams, 1955; Whittington, 1968) allows any direct correlation with south Shropshire. Though Dean (1960, p. 105) considered it similar, but not identical, to Bancroft's species from the type Harnagian, its occurrence is consistent with the revised graptolite zonation.

Conclusions

This is the type locality for the Derfel Limestone, which contains a rich, shelly fauna dominated by brachiopods, some ten taxa having their type locality there. This fauna, taken with the graptolites, provides a regionally important horizon for dating the end of the Aran Volcanic Group volcanism. The shelly fauna is the earliest development of an ecological assemblage, the *Nicolella* palaeocommunity, that thrived at various times during the Caradoc history of the Welsh Basin.

GELLI-GRÎN (SH 944 339)

Introduction

Gelli-grîn is the type locality for the Gelli-grîn Formation of Longvillian–Woolstonian age; the basal Pont-y-Ceunant Ash has yielded radiometric and fission-track ages that provide a basal Longvillian tie on the chronometric time-scale. The Gelli-grîn Formation is richly fossiliferous and has had a significant, sometimes controversial, historical role in the understanding of the succession of the Bala area. For ecological reasons, the faunal associations are very different from those at equivalent levels in the type Caradoc and provide a text-book example of the need to disentangle environmental distribution (particularly above species level) from time-range.

The present site includes the type section for the historically important Cymerig Limestone Member, named by Bassett *et al.* (1966, p. 237), who outlined the controversy previously surrounding it. The limestone constituted part of the Bala Limestone of Sedgwick (1845). Jukes (in Ramsay, 1866) argued, erroneously, that it was the same unit as the Rhiwlas Limestone (see the Rhiwlas site report); Elles (1922a) considered that they are distinct but that this, the older limestone, was really a number of discrete lenses at different stratigraphical levels, to which she applied different names. Bassett *et al.* (1966) followed Bancroft (1928a) in arguing that although the limestone is a set of lenticular bodies, they occur at one stratigraphical level. Bancroft also argued that a distinct sequence of faunal assemblages can be recognized in the Gelli-grîn Formation, and, subsequently (Bancroft, 1945, p. 182), that there is a hiatus below the Cymerig Limestone. Bassett *et al.* (1966; also Williams, 1963) supported neither of these contentions, but argued (1966, p. 258) that the strong ecological control at generic level had hindered correlation with the type Caradoc of Shropshire and resulted in some earlier misconceptions about the age of the formation.

The rich faunas have an important role in the understanding of both biofacies distribution and biostratigraphy in the Caradoc of the British Isles and include the type material of several species of brachiopod. Lockley's (1980b, 1983) quanti-

tative analyses of the shelly faunal changes through the formation here and at several other localities showed that a sequence of lithofacies-related assemblages is recognizable and can be fitted into the overall pattern of recurring biofacies in the Caradoc of Wales and the Welsh Borderland. Furthermore, the Cymerig Limestone Member contains an abundant conodont fauna, including, at a nearby locality, the type material of the zonal species *Amorphognathus superbus*. The interpretation of that species is critical in the international definition of the base of the succeeding *A. ordovicicus* Zone and its relation to the base of the Ashgill Series.

Description

Natural outcrops and old quarries west of Gelli-grîn farm (Figure 9.17) reveal that the Gelli-grîn Formation is almost 60 m thick in its type development. Bassett *et al.* (1966), who considered the Gelli-grîn Formation to be the most recognizable formation in the Bala district, provided logs through the formation here. Lockley (1980b) did likewise, showing more explicitly the significant gaps in exposure in the middle part of the unit that make estimates of thickness somewhat uncertain. The formation dips SSE at about 30°, but locally somewhat more steeply, and the outcrop is offset by faults (Figure 9.17).

The Gelli-grîn Formation overlies the dark-blue, silty mudstones of the Allt Ddu Mudstone Formation and its base is marked by the 3 m thick Pont-y-Ceunant Ash Member. Schiener (1970) described the sedimentology and petrography of this coarse, water-lain vitric tuff. It has an irregular base and its lower parts contain mudstone clasts derived from the underlying formation. It thickens to over 6 m at Y Garnedd (945 354) and its development elsewhere is intermittent. Ross *et al.* (1982) obtained fission-track ages of 460 ± 14 Ma and 469 ± 12 Ma from the Pont-y-Ceunant Ash at Gelli-grîn and, more recently, radiometric ages of 448 ± 4 Ma, 454 ± 8 Ma and 457 ± 2.2 Ma were obtained using U–Pb isotopic techniques (Tucker and McKerrow, 1995, p. 375).

The ash is succeeded at Gelli-grîn by about 8 m of tuffaceous mudstone, 2 m of sandstone and almost 6 m of mudstone before the reappearance of a significant volcaniclastic component, with perhaps 25 m of calcareous tuffaceous mudstones and siltstones intermittently exposed. These are overlain by the Cymerig Limestone Member, which has its type locality in the abandoned quarry near the western end of the site. It is about 4.5 m thick, comprising several horizons of dark-blue crystalline limestone, nodular limestones and calcareous and ashy mudstones, and is overlain by about a metre of calcareous mudstones with rare limestone nodules, which pass up into some 8 m of calcareous and tuffaceous mudstones. The formation is overlain with slight angular unconformity by mudstones of the Ashgill Moelfryn Mudstone, which here lacks the Rhiwlas Limestone at its base. Shelly fossils occur in all the lithologies of the Gelli-grîn Formation (Figure 9.18) and are abundant at some horizons. Abundant conodonts have been extracted from the Cymerig Limestone Member (Savage and Bassett, 1985).

Bassett *et al.* (1966) described other outcrops of the Gelli-grîn Formation in the Bala area and Lockley (1980b) sampled through the formation at several localities for 14 km along-strike to the SSW. His suggestion that the upper part of the formation passes laterally into the Nod Glas Formation, when traced farther in that direction (Lockley, 1980a), has yet to be verified. His faunal analysis at Gelli-grîn and other localities at

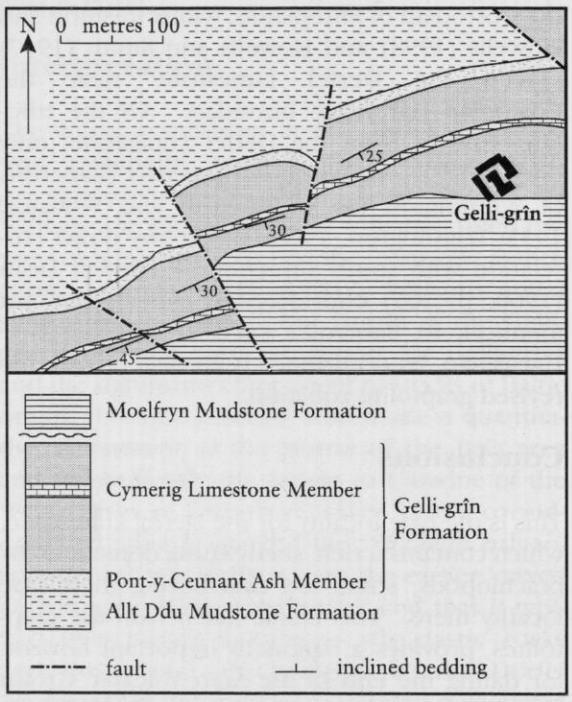


Figure 9.17 Geological map of the type development of the Gelli-grîn Formation west of Gelli-grîn Farm, from Bassett *et al.* (1966, fig. 4).

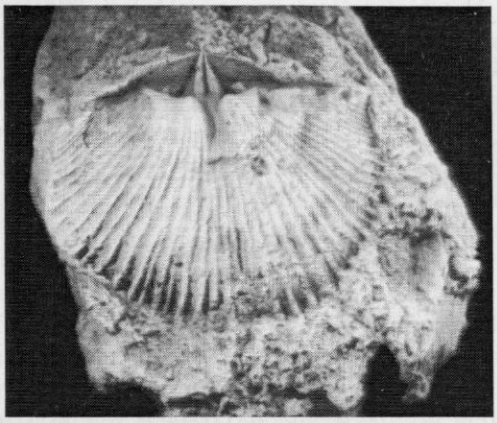


Figure 9.18 Dorsal valve of *Dolerorthis duftonensis prolixa* Williams, ×2, Gelli-grîn.

the northern end of the outcrop showed three successive faunas, with a *Howellites–Kloucekia* Association sandwiched between variants of the *Nicolella–Onniella* Association. These were subsequently included in his wider analysis of palaeocommunity distribution in the Arenig to Caradoc of the Welsh Basin (Lockley, 1983).

Interpretation

The Gelli-grîn Formation has yielded over 30 species of brachiopod (e.g. Figure 9.18) (Williams, 1963; Bassett *et al.,* 1966; Lockley, 1980b) and 19 of trilobite (Whittington, 1968; Lockley, 1980b), together with molluscs, conulariids, tentaculitids, bryozoans, ostracods and echinoderms. Many of these occur at the type locality and several species have their type material there. The faunal associations differ considerably from those at equivalent levels in the type Caradoc of Shropshire, and this led to correlation problems by several workers that were largely resolved by Williams (1963) and Bassett *et al.* (1966, p. 258). Of the brachiopods, only the appearance of *Howellites antiquior* (M'Coy) in the Pont-y-Ceunant Ash indicates a correlation with the base of the Longvillian, and the appearance of *Bancroftina* sp. in the beds above the Cymerig Limestone suggests a correlation with the Woolstonian Stage. Although trilobites are not known from the Pont-y-Ceunant Ash or the Cymerig Limestone, the intervening strata have nine species in common with Longvillian strata in Shropshire and the north of England, including the trinucleid *Broeggerolithus nicholsoni* (Reed). The beds above the Cymerig Limestone yield *Estoniops alifrons* (M'Coy), which characterizes Woolstonian (= 'Upper Longvillian' of earlier authors) in northern England.

The Cymerig Limestone contains a rich conodont fauna at several localities, including Gelli-grîn (Bergström and Orchard, 1985; Savage and Bassett, 1985). These all belong to the *Amorphognathus superbus* Zone, and this is the type horizon for *A. superbus* itself, with a type locality at Y Garnedd, 1.5 km ENE of Gelli-grîn. Its understanding is vital to the debate on the definition of the base of the succeeding *A. ordovicicus* Zone and international correlation at this level (see site report for Gwern-y-brain).

Conclusions

The type locality of the Gelli-grîn Formation has great historical significance in the understanding of the geology of the classic Bala area. It is the type locality for several fossil species, including a zonally significant conodont used in international correlation. Because of environmental factors, the fossil associations are significantly different from coeval ones that lived on the edge of the Welsh Basin, and this has led to difficulties in correlation. These have now been surmounted but provide a text-book example of the need to disentangle environmental range from time-range of fossil organisms. The Pont-y-Ceunant Ash at the base of the Gelli-grîn Formation has been dated in the range 448 ± 4 to 457 ± 2.2 million years, providing a tie between the chronometric and biostratigraphical Ordovician time-scales.

CADNANT CUTTING (SH 776 778–SH 779 776)

Introduction

This section is important both historically and for regional correlation. It provides a thick and undeformed section through the graptolitic Cadnant Shale Formation, the northernmost equivalent of the Nod Glas Formation that extends over a large area of North Wales. Although the site is effectively the type (or at least the original) section for the *D. multidens* Zone, there are now severe doubts as to whether that zone is actually present in the section.

The railway cutting in the Cadnant area of

Conwy exposes a complete sequence from the upper part of the Snowdon Volcanic Group, namely the undifferentiated middle to upper Crafnant Volcanic Formation of Caradoc age, through the richly graptolitic Cadnant Shale Formation, to the lower part of the Ashgill Bodeidda Mudstone. The site provides a fairly undisturbed section through a shale unit that is a direct correlative of at least part of the Nod Glas Formation, which crops out extensively farther south (Cave, 1965) and which is generally disturbed tectonically. It was for part of the Cadnant Shales that Elles (1909) first coined the term 'zone of *Diplograptus multidens* and *Dicranograptus brevicaulis*', the forerunner of the *D. multidens* Zone. However, Strachan (in Wood and Harper, 1962) concluded that the graptolites of the entire section may all belong in the *Dicranograptus clingani* Zone. Evidence from elsewhere in the Conwy area shows that the Bodeidda Mudstone, which unconformably overlies the Cadnant Shale, is Rawtheyan in age, and that there is a widespread latest Caradoc to early Ashgill hiatus at this boundary.

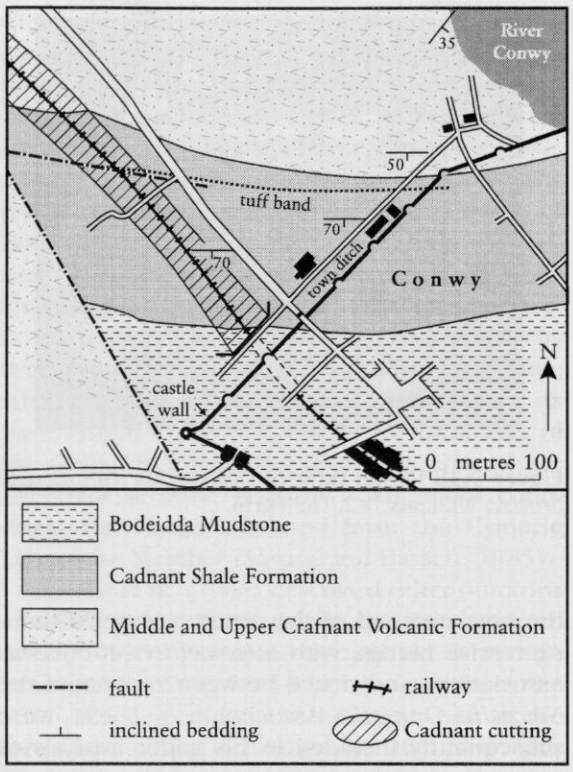


Figure 9.19 Geological map showing the Cadnant Shale Formation and contiguous units in Cadnant railway cutting, and the eastward extension of the lower part of the succession in the temporary road section documented by Wood and Harper (1962, fig. 1).

Description

The cutting exposes some 155 m of south-dipping black graptolitic Cadnant Shale. Though affected by a minor fault in the lower part of the section (Figure 9.19) and locally overturned near the top, the shales are otherwise undisturbed. They are underlain by about 8 m of unfossiliferous calcareous tuffs with thin chert layers and a distinct band of pyrite nodules 1.5 m above the base. The lithological change to the Cadnant Shale is abrupt and conformable and there is only one, thin, tuff band within the shales at about 15 m above the base of the formation. The Cadnant Shale is overlain unconformably by the Bodeidda Mudstone. Wood and Harper (1962) described a section through the lower part of the shales and the top of the underlying tuffs in a temporary road cutting 800 m to the east, but there the Cadnant Shale was estimated to be only about 125 m thick. Trilobites and brachiopods from the underlying unit in the road section indicated a Woolstonian age (Upper Longvillian of Wood and Harper).

The Bodeidda Mudstones at the top of the railway section are unfossiliferous, but shelly faunas from elsewhere in the Conwy area indicate a Rawtheyan age for the formation (Price, 1984, p. 103), despite some suggestions of an earlier Ashgill or even latest Caradoc age for parts of the unit (e.g. Howells *et al.*, 1981). There is thus a considerable hiatus between this and the underlying Cadnant Shale.

Interpretation

Lapworth (1879b) placed the graptolites from the Cadnant Shale of the railway cutting in the *Dicranograptus clingani* Zone, whereas Elles (1909) considered a much longer sequence of zones to be present and assigned the graptolites to the zones of *Climacograptus peltifer*, *Diplograptus multidens* and *Dicranograptus brevicaulis* and *Dicranograptus clingani*. This was the first time that the names '*multidens*' and '*brevicaulis*' had been used zonally, and thus, historically, Cadnant Cutting is the type section for what became the *multidens* Zone (=*foliaceus* Zone in Fortey *et al.*, 1995). However, Strachan (in Wood and Harper, 1962, p. 184)

concluded that there is no significant change in the graptolite faunas through the whole of the Cadnant Shale in the section and that little or none of the *multidens* Zone is present. The presence of *D. clingani* itself in the fauna suggests that the whole formation belongs in the lower part of the *clingani* Zone; but the fauna needs to be reassessed in the light of recent work by Zalasiewicz *et al.* (1995) on the zone in South Wales and Scotland.

Strachan's re-interpretation of the graptolite fauna throws considerable doubt on whether any of the '*multidens*' Zone is present in this its historical type section but agrees with the general conclusion of Rushton and Howells (1998) that the Cadnant Shale and Nod Glas Formation are of lower *clingani* Biozone age where they overlie the Snowdon Volcanic Group of Woolstonian age; they recommended that the term 'Nod Glas Formation' should replace the term 'Cadnant Shales' and several other local names for similar upper Caradoc black shales of this age. On a regional scale, the development of lower *clingani* Zone black shales at Conwy is compatible with the development of the Nod Glas Formation over a large part of North Wales (Pratt *et al.*, 1995; Howells and Smith, 1997), although in places the shales extend to higher levels in the upper Caradoc (see site report for Gwern-y-Brain).

Price (1984, p. 103) noted considerable fossil evidence that all the basal Ashgill rocks in North Wales from Towyn to Conwy are Rawtheyan in age, indicating a latest Caradoc to early Ashgill hiatus that was termed the 'sub-Powys unconformity' by Woodcock (1990), although Pratt (1991) suggested that the Nod Glas Formation may later have acted as a decollement horizon in the deeper parts of the basin, and deposition may accordingly have continued locally across the Caradoc–Ashgill boundary. Cadnant Cutting provides an excellent section through the most northerly extent of this widespread hiatus, which probably reflects basin tectonics rather than global sea-level change.

Conclusions

Cadnant Cutting shows a thick and relatively undeformed section through the Cadnant Shale, a lateral equivalent (or synonym) of the Nod Glas Formation elsewhere in North Wales. It thus helps demonstrate a very extensive consistency in depositional pattern in the northern part of the Welsh Basin, with a major deepening event followed in many areas by an episode of uplift and erosion.

GWERN-Y-BRAIN (SJ 2180 1265–SJ 2180 1285)

Introduction

This nationally important site includes a relatively shallow-water development of the laterally persistent Nod Glas Formation. Its lithologies and graptolite, trilobite and conodont faunas provide important evidence for regional basin topography and global biostratigraphical correlation.

The upper Caradoc Nod Glas Formation can be traced over large parts of central and North Wales and the exposures in the Gwern-y-Brain stream, 1 km north of Guilsfield near Welshpool (see '1' in Figure 10.1), marks its most south-eastward extent. This is the only section in the formation to contain shelly fossils and conodonts as well as graptolites and thus provides an important link between the shelly and graptolitic zonal schemes in the Welsh Basin. The conodonts provide key evidence concerning the relative positions of graptolite and conodont biozonal boundaries and the base of the Ashgill Series.

Cave (1965) gave a detailed description, map and log of the section through the Nod Glas Formation and contiguous formations in Gwern-y-Brain. It was put into a wider stratigraphical context by Cave and Price (1978), who included a geological map of the area to the west and north of Guilsfield (Figure 9.20a) and formally corrected some major misconceptions made by other workers over the age-range of the Nod Glas Formation. The section is also covered in an excursion guide by Cave and Dixon (1993).

Description

Intermittent outcrops in the bed and banks of the stream expose 2 m or so of phosphatic limestone (the Pen-y-garnedd Phosphorite Member) that is nodular in its uppermost part and overlain by about 6.5 m of dark-coloured shale with a few thin seams of phosphatic mudstone (the Pen-y-garnedd Shale Member). This upper member yields graptolites and shelly fossils including the trilobites *Flexicalymene onniensis* (Shirley) and *Onnia gracilis* (Bancroft). The for-

mation is overlain unconformably at the northern end of the site by the lower Llandovery Powis Castle Conglomerate (Figure 9.20). The beds of the Nod Glas Formation dip north-west at about 25°, and although the base is not exposed, calcareous siltstones and limestones of the underlying Gaerfawr Formation crop out within a few metres of the lowest phosphatic limestone and are further exposed to the south. Cave (1965) equated the uppermost part of the Gaerfawr Formation with the upper Gelli-grîn Formation (see site report for Gelli-grîn).

Cave and Price (1978, p. 190) estimated that the uppermost 6 m or so of the Pen-y-garnedd Shale Member (and thus the Nod Glas Formation) is missing in Gwern-y-Brain. They estimated that, immediately to the south-west, the upper member is about 12.5 m thick; it is overlain by up to 38 m of homogeneous mudstones, termed the 'Trawscoed Mudstone Formation' and containing a Cautleyan (mid-Ashgill) shelly fauna. This in turn is overlain by the Powis Castle Conglomerate, the base of which thus lies on progressively older units as it is traced northwards.

Interpretation

The Nod Glas Formation occurs widely in central and North Wales and marks the top of the Ogwen Group, representing a late Caradoc deepening event in the Welsh Basin. It was originally named by Pugh (1923) for black graptolitic shales between Corris and Aberllefenni in Gwynedd. That facies is typical of the unit in the deeper parts of the basin such as Cadair Idris (Pratt *et al.*, 1995, p. 48), and Cave (1965) considered the development with phosphatic limestones in the southern Berwyn Hills, as at Gwern-y-Brain, to represent a large submarine high (see also Temple and Cave, 1992, fig. 1). In the area north of Dinas Mawddwy, Pugh (1928)

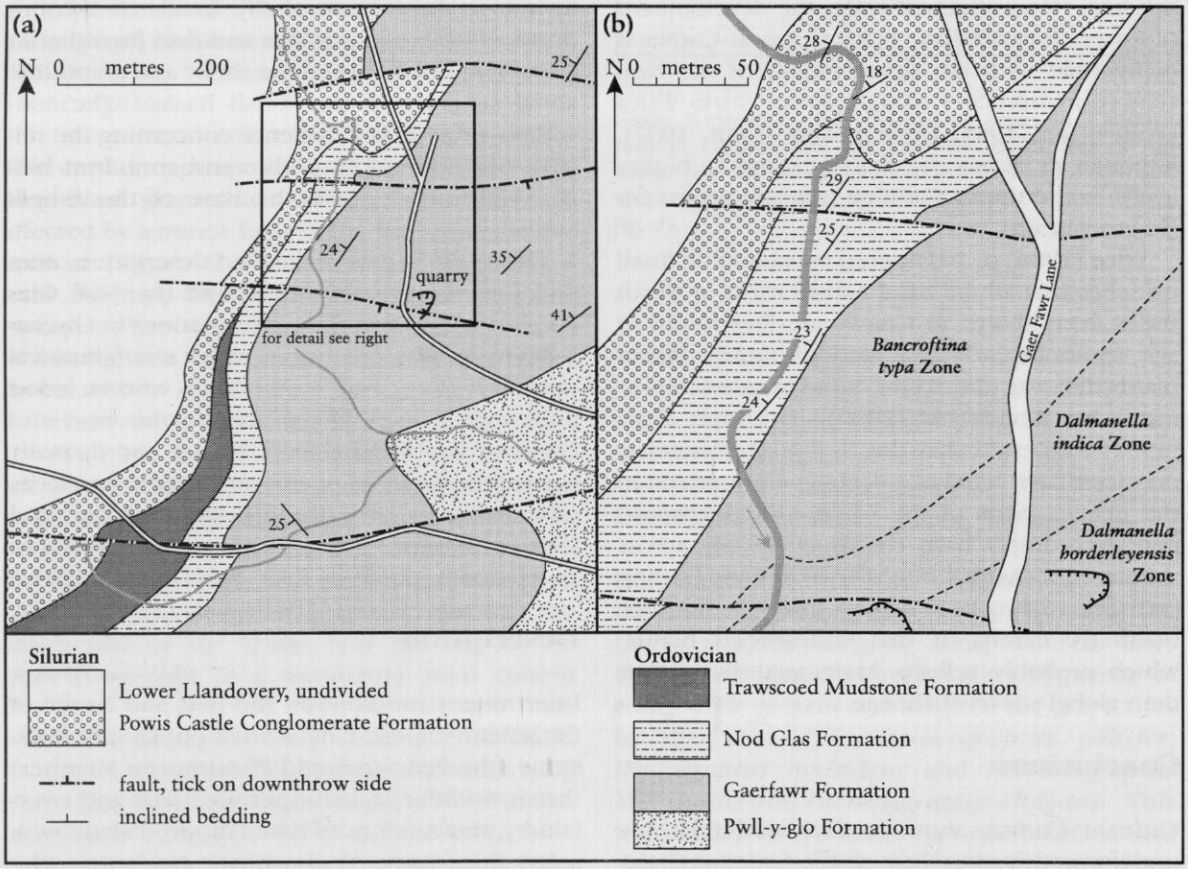


Figure 9.20 (a) Geological map showing the occurrence of the Nod Glas Formation and the overlying Trawscoed Formation (Ashgill) to the south of the Gwern-y-brain site, from Cave and Price (1978, fig. 3); (b) more detailed map of the Nod Glas Formation and contiguous units in the Gwern-y-brain section, after Cave (1965, fig. 3).

noted that part of the graptolitic facies passes into nodular limestones which Lockley (1980a, p. 39) considered to be equivalents of the Woolstonian Cymerig Limestone Member of the Gelli-grîn Formation. This represents a lower level than is inferred for the typical Nod Glas Formation elsewhere (Pratt *et al.*, 1995) and is certainly older than the development in Gwern-y-Brain.

The various fossils recovered from the Nod Glas Formation at Gwern-y-Brain have an important, but as yet not fully resolved, bearing on the relative positioning of graptolite and conodont biozonal boundaries and the base of the Ashgill Series. The graptolites from the Pen-y-garnedd Shale Member represent the *clingani* Zone (Cave, 1965). Elsewhere, both lower and upper subzones of the *clingani* Zone may be present (Pratt *et al.*, 1995), and the *Pleurograptus linearis* Zone faunas may be present locally, as near Llanystwmdwy (Price, 1984, p. 104). The boundary between the *clingani* and *linearis* biozones lies within the uppermost Caradoc Series (Fortey *et al.*, 1995). The occurrence of the trilobites *Flexicalymene onniensis* and *Onnia gracilis* in the Pen-y-garnedd Shale at Gwern-y-Brain is taken to indicate the Onnian Substage at the top of the Caradoc and is supported by an ostracod assemblage recorded at Welshpool by Jones (1986–1987, p. 108) that is similar to that from the middle of the type Onnian. If this age is applied to the whole of the Nod Glas Formation at Gwern-y-Brain, a hiatus is indicated at the base as well as the top of the formation (Cave and Price, 1978, fig. 2), because the underlying beds are of Woolstonian age (= 'upper Longvillian' of older usage).

Savage and Bassett (1985, p. 683) extracted two conodont faunas from the Pen-y-garnedd Phosphorite Member in Gwern-y-Brain. The lower, from the basal part of the member, included fairly abundant *Plectodina bullhillensis* Savage and Bassett, a species occurring only in samples from the Costonian to Woolstonian of the type Caradoc. If these conodonts are not long-ranging or reworked they raise the possibility that the base of the Phosphorite Member is as old as Woolstonian, which is the age of the underlying Gaerfawr Formation. The second sample, from immediately below the nodular bed at the top of the member, contained conodonts which they ascribed to *Amorphognathus ordovicicus*, suggesting that the base of the *ordovicicus* Zone lies within the Phosphorite Member. Compared with the graptolite and trilobite evidence from the site, this conodont zonal boundary seems to be at a substantially lower horizon than the level within the Ashgill at which it is reported elsewhere (see Fortey *et al.*, 1995, p. 23). The resolution of this difference has important consequences for any international agreement on the base of an acceptable chronostratigraphical unit at or about this level in the upper Ordovician.

Conclusions

The rocks in the Gwern-y-Brain section include a relatively shallow-water development of the Nod Glas Formation, which extends widely through central and north Wales. The locality is unique in that graptolites, shelly fossils and conodonts are associated in the unit, and these have an important bearing on international correlation and definition of the base of the Ashgill Series.

CYNWYD (SJ 092 399)

Introduction

At this site (Figure 9.1) 19th century collectors found one of the most diverse and best-preserved Rawtheyan faunas in the Welsh Basin; it is the type locality for several species, especially trilobites. The site was effectively lost for almost a century, but recent excavations hold the prospect of both clarifying the stratigraphical setting of the highly diverse historical collections and providing new material of equally good preservation.

In the second half of the 19th century, various collectors, most notably Champernowne, Lee, Parrott and Ruddy, made large collections of well-preserved fossils from the Ddolhir Formation. Whittington (1962–1968, p. 123) noted that in the Natural History Museum and British Geological Survey these collections are variously labelled 'Cynwyd', 'Bwlch-y-Gaseg west of Moel Fena' and 'Cerrig Coedog, south base of Moel Ferna', but it is likely that all represent the same locality. Some of the faunas were listed by Ruddy (1879, 1885) and include specimens that subsequently became the types of various species. Whittington (1962–1968) listed some 16 species of trilobite from Cynwyd, including two for which this is their type locality, to which can be added *Gravicalymene arcuata* Price, 1982 (Figure 9.21), which was partially based on

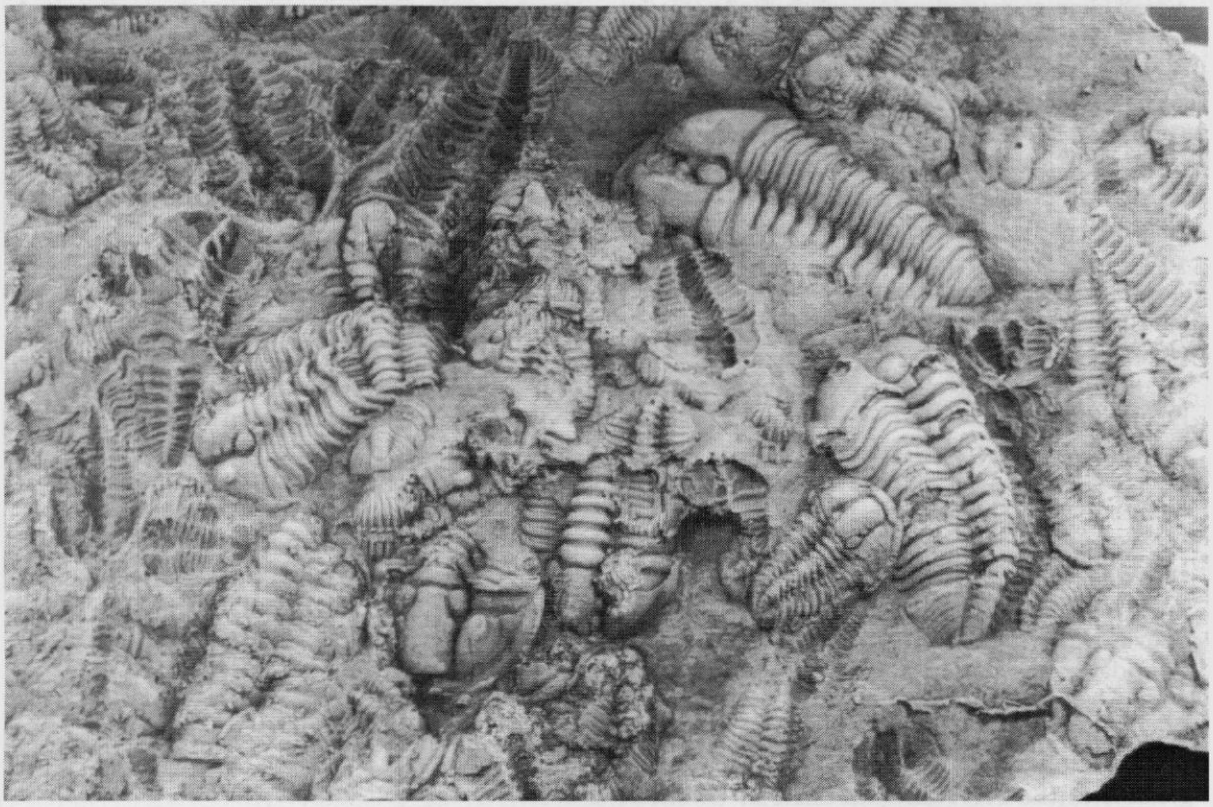


Figure 9.21 'Graveyard' of *Gravicalymene arcuata* Price, ×5, Cynwyd.

material from the rediscovered Cynwyd site. Other elements of the fauna present in 19th century and more recent collections include cystoids (Paul, 1973–1997), crinoids (Donovan, 1986–1995), bryozoans, brachiopods (Cocks, 1978) (Figure 9.22a, b), bivalves, cephalopods, conulariids, sponges and corals.

Description and Interpretation

The site was re-excavated by Forest Enterprise in 1996. Dr R.J. Kennedy of Birmingham City Museum reports (pers. comm., 1997) that some 38 m of rock were cleared, approximately across strike and parallel to the existing forestry track. The beds are assigned to the Ddolhir Formation and dip (and young) to the north-east at 35–40° at the northern end of the section and a little more gently (30°) at the southern end. There are small-scale normal faults with slickensides and minor rotation of the bedding at various levels. The lithology does not vary greatly and is generally a hard, buff, grey or dark-blue mudrock, commonly with limonitic replacement of fossils, especially in the lower 12 m of the section. The fossil fauna was sampled both *in situ* and from loose material and includes complete trilobite exoskeletons, including juveniles. There are also beds composed almost entirely of branching and filamentous bryozoans and rarer sponges preserved in limonite. The detailed site report and analysis of the fauna are still awaited.

Price (1977, pp. 785, 790) reassigned to *T. sortita* (Reed) trinucleid trilobite specimens that Whittington had ascribed to *Tretaspis* cf. *kiaeri* Størmer, thus indicating a late Rawtheyan age for the Ddolhir Formation at Cynwyd (see also Ingham, 1970, p. 43). The whole formation probably has a much longer range, extending down into the middle Cautleyan (Williams *et al.*, 1972; Hiller, 1980, 1981).

Conclusions

This site is palaeontologically significant, having in the past yielded one of the most diverse and

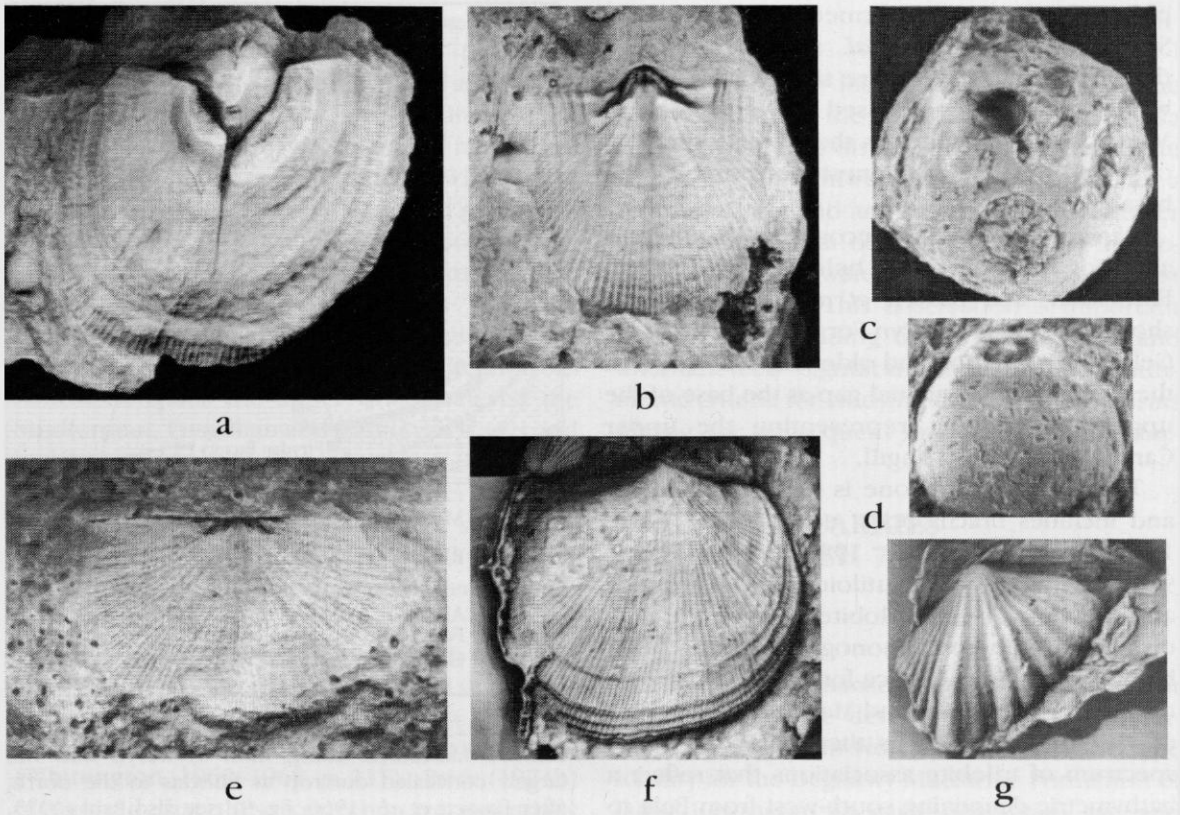


Figure 9.22 Ashgill fossils from sites in North Wales. (a, b) Ventral and dorsal valves of *Vellamo* sp., ×1.5, Cynwyd. (c, d) *Tetraeucystis munita* (Forbes), ×4, Rhiwlas. (e–g) Brachiopods of the *Hirnantia* Fauna, Hirnant Limestone of Aber Hirnant: (e) Dorsal valve of *Eostropheodonta hirnantensis* (M'Coy), ×1.5; (f) Dorsal valve of *Hirnantia sagittifera* (M'Coy), ×1.5; (g) Ventral valve of *Plectothyrella crassicostis* (Dalman), ×2.

best-preserved Rawtheyan (late Ashgill) fossil faunas in the Welsh Basin, and includes specimens subsequently included amongst the type material for several species. Recent excavations at the site will clarify the setting from which these faunas were collected and may provide further important material of high quality.

RHIWLAS (SH 921 367 AND SH 923 369)

Introduction

The site at Rhiwlas is the type locality for the Rhiwlas Limestone, which locally marks the base of the upper Bala Group. It played an important part in the understanding of the classic Bala district, particularly in the recognition and interpretation of the major hiatus at the base of the upper Bala Group (column W.5 in Williams *et al.*, 1972, fig. 5). The trilobite fauna of the Rhiwlas Limestone is the most diverse in the district and is of significance both taxonomically and palaeoecologically.

Exposures south of Rhiwlas form the type locality for the Rhiwlas Limestone of Ashgill (Rawtheyan) age. The limestone was named by Sedgwick (1843) and formed the middle of his three limestone units in the Bala succession. He considered it to lie well below the 'Bala Limestone' (now termed the Cymerig Limestone), being unaware that the succession was duplicated on either side of the Bala Fault, and hence that the Rhiwlas Limestone was the younger unit. Jukes (in Ramsay, 1866) and Ruddy (1879) considered the Rhiwlas and Cymerig limestones to be the same unit, although Salter (in Ramsay, 1866) expressed a contrary view on the basis of lithological and faunal differences. Marr and Roberts (1885) considered the two limestones to be separate, a view confirmed by Elles (1922a). Elles used the term 'Rhiwlas Beds' or 'Rhiwlas Mudstone and Limestone' to include the overlying succession,

part of which she termed the 'Moel-fryn Sandstone'. Bassett *et al.* (1966) recognized that these coarser beds are simply interbedded with the mudstones and used the term 'Moelfryn Mudstones' to encompass the whole formation, of which the Rhiwlas Limestone forms a local basal member.

Bancroft (1928a) first recognized that there is a major unconformity below the Moelfryn Formation, and Bassett *et al.* (1966, p. 242) showed that the Moelfryn Formation overlies the Gelli-grîn Formation and older deposits and that there is thus a substantial gap at the base of the upper Bala Group, representing the upper Caradoc and lower Ashgill.

The Rhiwlas Limestone is richly fossiliferous and includes brachiopods, echinoderms (Paul, 1973–1997; Donovan, 1986–1995) (Figure 9.22c, d), ostracods, nautiloids and gastropods and the most diverse trilobite fauna in the Bala district, Whittington's monograph (1962–1968) being a standard reference for upper Ordovician trilobite studies. Price and Magor (1984) regarded the Rhiwlas fauna as the shallow end of a spectrum of trilobite associations that reflect a bathymetric deepening south-west from Bala to Corris.

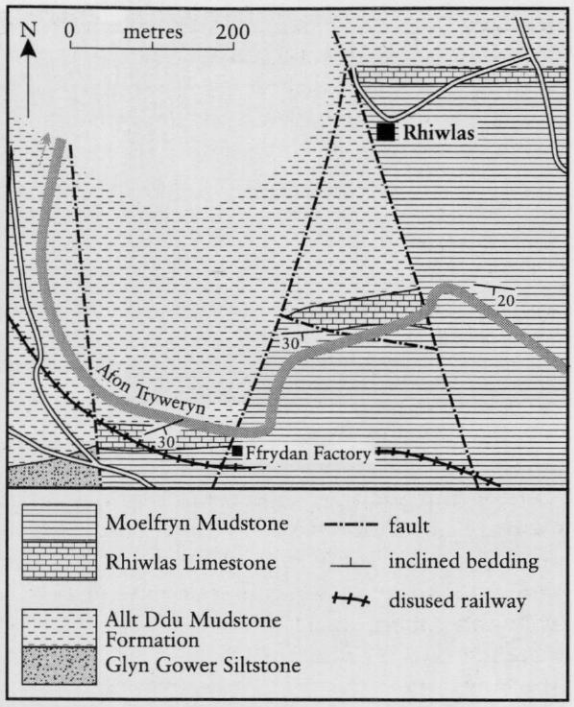


Figure 9.23 Geological map of the type locality of the Rhiwlas Limestone along Afon Tryweryn and the largely concealed outcrop at Rhiwlas to the north, after Bassett *et al.* (1966, fig. 9); see also Paul (1973, fig. 7).

Description

The type locality for the Rhiwlas Limestone comprises two exposures on the banks of the Afon Tryweryn, 1 km north of Bala (Figure 9.23), as described by Bassett *et al.* (1966). That on the north bank probably provided the early shelly fossil collections labelled 'Rhiwlas'. That on the south bank shows the S-dipping limestone resting on siltstones of the Allt Ddu Formation; about 2 m of unfossiliferous crystalline limestone are followed by 25 cm of black shale with pyrite nodules, then 30 cm of grey mudstones containing black pebbles of the underlying bed, and finally a little over 3.5 m of pale-grey, well-bedded fossiliferous limestone. The Rhiwlas locality has been sampled unsuccessfully for conodonts, but elsewhere the member has yielded sparse assemblages of the *Amorphognathus ordovicicus* Zone (Bergström and Orchard, 1985; Savage and Bassett, 1985).

The Rhiwlas Limestone is only sporadically developed at the base of the Moelfryn Mudstone Formation, which achieves a maximum thickness of about 760 m (Bassett *et* al., 1966). Price and Magor (1984, p. 192) and Lockley (1980a, figs 1 and 6) noted that the Rhiwlas Limestone can be traced southwards to Llechwedd-du, 6.6 km south of Bala, beyond which it passes into distinctive calcareous silty mudstones. Bassett *et al.* (1966) demonstrated that south of the Bala Fault the Moelfryn Formation generally rests on various levels within the Gelli-grîn Formation, the top of which is Woolstonian in age (see Gelli-grîn site report). To the north of the Bala Fault the Gelli-grîn Formation is cut out (except at the extreme eastern end of the exposure), as is an increasing amount of the underlying Allt Ddu Formation, as the unconformity is traced westwards. On both sides of the Bala Fault the depth of erosion below the top of the Gelli-grîn Formation increases westwards, particularly to the north of the fault, where it may exceed 100 m. Bassett *et al.* (1966) attributed this to the effects of both the NE–SW Bala Fault and local N–S faults prior to deposition of the Moelfryn Formation.

Interpretation

The age of the Rhiwlas Limestone has been

debated (Bassett *et al.*, 1966), being variously assigned to the Actonian–Onnian (Bancroft, 1933), Pusgillian (Bancroft, 1945) and lower Ashgill (Dean, 1959a). A middle Ashgill (i.e. Rawtheyan) age was favoured by Bassett *et al.* (1966) and was confirmed by Whittington (1962–1968, p. 117), who recognized an equivalence to Zones 5–7 of Ingham's (1966) subdivision of the Ashgill of the Cautley area, which subsequently formed the basis for the Rawtheyan Stage (Ingham and Wright, 1970). Thus the minimum hiatus below the Rhiwlas Limestone spans the upper Cheneyan and the Streffordian, Pusgillian and Cautleyan stages and locally extends well down into the Burrellian. The unconformity can be traced over much of North Wales and was termed the 'sub-Powys unconformity' by Woodcock (1990), who considered it to be tectonically rather than eustatically controlled.

Some of the problems in assigning an age to the limestone hinge on the ascription of its trilobite fauna to either the *Phillipsinella parabola* 'Zone' or the *Staurocephalus clavifrons* 'Zone' (Whittington, 1962–1968, p. 117). Price (1973b) recognized that these concepts are essentially ecologically based and have little biostratigraphical significance. At species level there is strong evidence for correlation with the Rawtheyan Stage. Given the great thickness of the Moelfryn Formation above it and the Hirnantian age of the Foel-y-Ddinas Mudstone above that (see Cwm Hirnant site report), an early Rawtheyan age seems most probable (see also Price and Magor, 1984).

Price and Magor (1984) quantitatively documented a spectrum of trilobite faunas, ranging from their *Ceraurinella–Encrinuroides* Association in the Rhiwlas Limestone of Bala, through the *Nankinolithus–Opsimasaphus* Association, to the *Novaspis*–cyclopygid Association in equivalent strata about 30 km to the south-west at Corris. This represents a bathymetric deepening from fairly shallow-shelf to upper-slope depths during one time interval and is the most complete such spectrum of trilobite biofacies in the Ordovician of the British Isles. It provides not only information on basin geometry but also a database on trilobite depth distributions. The latter was used by Owen *et al.* (1991) and Owen and Robertson (1995) in analyses of the fate of Rawtheyan trilobite genera from different ecological settings during the end-Ordovician extinction event.

Conclusions

Rhiwlas is a key locality for recognizing the unconformity at the base of the upper Bala Group in the Bala district. The diverse trilobite faunas of the Rhiwlas Limestone indicate a Rawtheyan age and are viewed as the shallower end of a spectrum of faunas that lived in progressively deeper waters when traced south-west towards Corris. This observation is important for the understanding of the Welsh Basin and internationally significant in providing bathymetric criteria for studying the fate of organisms during the subsequent end-Ordovician extinction event.

DEGANWY QUARRIES (SH 786 791–SH 788 792)

Introduction

The Deganwy Quarries site is important for understanding the development of the uppermost Ordovician in North Wales. It is the type locality for the Deganwy Mudstone Formation of latest Rawtheyan or early Hirnantian age and provides the best exposures of the Hirnantian Conway Castle Grits. The latter reflects the late Ordovician glacio-eustatic fall in sea level, which gave rise to a large submarine fan that brought coarse sediment into a deep part of the Welsh Basin.

Both the Deganwy and Conway Castle Grit formations were named by Elles (1909) in her account of the geology of the Conwy district, which included a map of the area. Conwy Castle, 1.5 km SSW of Deganwy, is built on the formation to which it gives its name. Elles (1909, p. 182) provided brief descriptions of the units in Deganwy Quarries and listed faunas from both formations. She confirmed the correlation originally made by Jukes (1871) of the Conway Castle Grits with the Hirnant Limestone in the Bala area (see the Aber Hirnant site report), although, as she noted (1909, p. 170), Jukes subsequently suggested correlation with a lower horizon in the Bala sequence.

James and James (1969, p. 579) briefly outlined the sedimentology of the Conway Castle Grits in the Deganwy Quarries and recognized that its base represents a large-scale erosion surface. An account of the formation, including sedimentary logs, was given by Cullen (1986, unpublished), and the succession in the Conwy

area was shown schematically by Brenchley and Cullen (1984), who discussed the significance of the faunas from Deganwy.

The Deganwy and Conway Castle formations and their equivalents have also been described in areas west of the River Conwy and south of Deganwy (Stevenson, 1971; Roberts, 1979; Warren *et al.*, 1984). The underlying Bodeidda Mudstone Formation (not exposed in Deganwy Quarries) contains a shelly fauna that indicates a Rawtheyan age (Brenchley and Cullen, 1984, p. 117, table 2; Price, 1984, p. 101), and there is thus a significant hiatus above the upper Caradoc (*Dicranograptus clingani* Zone) Cadnant Shale Formation (see the Cadnant Cutting site report).

Description

The Deganwy Quarries provide about 40 m of vertical exposure on the two main faces, which are orientated NW–SE, and over 300 m of lateral exposure in these and two faces at right angles to them. The succession dips south at about 65°. Some 5.5 m of bioturbated, cleaved mudstones of the Deganwy Mudstone Formation are exposed in the south-west face of the main quarry. Their colour varies upwards from light-grey to dark-grey immediately below the overlying Conway Castle Grits, and there is a band of small, highly fossiliferous phosphatic nodules 2 m below the top. The erosional base of the Conway Castle Grits is well seen in this section (Figure 9.24), and the coarse calcarenites at various levels in the formation contain lithoclasts of the underlying mudstone unit. At Llanros, to the north, the Deganwy Mudstones were completely removed prior to deposition of the Conway Castle Grits, which there lies on the underlying Bodeidda Mudstone Formation. About 38 m of the Conway Castle Grits are exposed in the south-west face of Deganwy Quarries, and Cullen's (1986) detailed sedimentary log of the section there is simplified here as Figure 9.24. Cullen also produced a log of the north-east end of the quarry, where some 18 m of the formation is seen. The overlying Gyffin Shales (Llandovery) are not exposed.

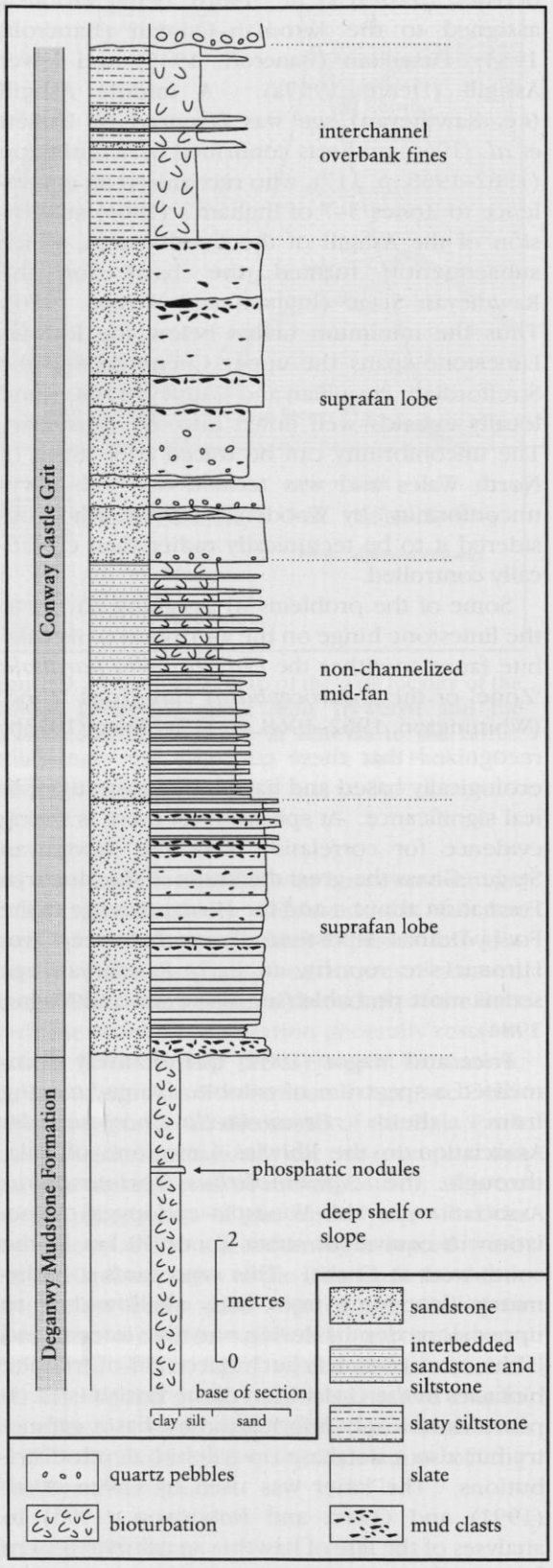


Figure 9.24 Simplified sedimentary log of the uppermost part of the Deganwy Mudstone Formation and the lower half of the Conway Castle Grits at the south-west end of Deganwy Quarries, after Cullen (1986, unpublished).

The Conway Castle Grits contain three main facies, interpreted by Cullen (1986) as representing different parts of a submarine fan (Figure 9.24), much of the sediment having been transported by turbidity currents. Most of the section comprises channel deposits of coarse, generally thickly bedded calcarenites. Between 10 m and 14 m above the base of the formation in the south-west section, more thinly bedded, generally finer deposits represent the mid-fan, and at various levels above 19 m siltstones represent the deposition from suspension of interchannel overbank fines.

Interpretation

Elles (1909, p. 183) recorded *Orthograptus truncatus abbreviatus* from the lowest exposed part of the Deganwy Mudstones in the Deganwy Quarries, and Williams *et al.* (1972, p. 22) took this to indicate the *D. anceps* Zone. Elles also recorded the trilobite *Mucronaspis mucronata* (as *Phacops (Dalmanites) mucronatus*) in the uppermost 1.5 m or so of the mudstones, together with brachiopods, orthocones, bivalves and other shelly fossils. This has been confirmed by more recent collecting (BGS unpublished internal report; Brenchley and Cullen, 1984; Cullen, 1986). Williams *et al.* (1972, p. 22) considered the presence of *M. mucronata* to indicate that the Deganwy Formation extends up into the Hirnantian. However, the appearance of the species in the latest Rawtheyan of northern England (see the Ashgill Quarry site report) makes such a correlation somewhat doubtful.

The Conway Castle Grits is interpreted as a slope-base channel-fill (Cullen, 1986). The age of the formation has been the subject of some controversy (see Williams *et al.*, 1972, p. 22), but a correlation with the Hirnantian now seems well established on the basis of elements of the *Hirnantia* fauna at various levels in the unit at Deganwy and elsewhere (Elles, 1909, p. 183; Brenchley and Cullen, 1984, p. 118; Cullen, 1986). The faunas are locally diverse (unpublished BGS internal reports) but are clearly allochthonous; together with abundant bioclasts at some levels (Cullen, 1986), they indicate a carbonate source-area in addition to the source of the siliciclastic sediment. Locally, solitary rugose corals form a significant proportion of the bioclasts. The presence of lithoclasts derived from the underlying Deganwy Mudstones leaves open the possibility that some of the faunal elements may be reworked from that formation. Brenchley and Cullen (1984, p. 118, fig. 3) suggested that the *Mucronaspis* (formerly *Dalmanitina*) fauna of the Deganwy Mudstones represented the indigenous deep-shelf fauna, the shallower-water *Hirnantia* faunas being introduced from the west within a submarine fan. The development of the latter resulted from the Hirnatian glacio-eustatic fall in sea-level.

Conclusions

This site is important in providing the best exposures of the Conway Castle Grits, the deposition of which reflects the late Ordovician global fall in sea level; this fall resulted in the development of a large submarine fan bringing coarse sediment into a part of the Welsh Basin that had previously been the site of deep-water muds.

CWM HIRNANT (SH 951 296)

Introduction

Cwm Hirnant gives its name to the latest Ordovician stage, the Hirnantian, and is the type locality for two of the core elements of the latest Ordovician *Hirnantia* brachiopod fauna, *Hirnantia sagittifera* and *Eostropheodonta hirnantensis*. The site thus has global importance because these taxa, the *Hirnantia* brachiopod fauna generally and the Hirnantian Stage figure prominently in the understanding of one of the major mass extinction events, namely that at the end of the Ordovician.

The mudstones and oolitic limestone known as the 'Hirnant Limestone Member' of the Foel-y-Ddinas Mudstone Formation at Cwm Hirnant were the first beds from which the so-called *Hirnantia* brachiopod fauna was recognized. The unique character of this fauna, which contrasts with the less remarkable compositions of the faunas that preceded and followed it, gave rise to considerable controversy as to the age of the 'Hirnant Beds'. Sedgwick (1845) considered the Hirnant Limestone to be the third and highest limestone in his 'Bala Group'. Ruddy (1879) referred the beds to the lower Silurian, as did Elles (1922b, 1923), who first drew attention to their unusual brachiopod fauna, whereas Jones (1923) argued for an Ordovician age. The term 'Hirnantian', introduced by Bancroft (1933, 1945) for the highest part of the Ordovician, was

put on a more formal footing by Ingham and Wright (1970); it has since developed considerable international currency, although a stratotype section and basal boundary definition have yet to be designated. Bassett *et al.* (1966) described the rocks of Cwm Hirnant and placed them in stratigraphical and historical context.

Temple (1965) recognized the fact that the brachiopod association of Cwm Hirnant (Figure 9.22e–g) had a wider than local distribution and introduced the term '*Hirnantia* fauna'. He was followed by various workers, who extended the geographical range of the fauna and interpreted its development. The *Hirnantia* fauna is now understood to have an almost world-wide distribution (Rong and Harper, 1988) and is the means by which the uppermost stage of the Ordovician, the Hirnantian, is recognized in shelly facies. Its origin and fairly swift demise are an important facet of the latest Ordovician mass extinction event (Owen *et al.*, 1991, Harper and Rong, 1995), one of the largest extinctions in Earth history. The faunas from Cwm Hirnant provided the starting point for the recognition and understanding of that event.

Description

The site is a small abandoned quarry on the western side of Cwm Hirnant. The rocks dip at about 75° to the ESE; Bassett *et al.* (1966, p. 254) gave a measured section through the Foel-y-Ddinas Mudstone Formation there. The section is about 22.5 m thick and comprises cleaved blue mudstones and silty mudstones, with the 1.8 m thick Hirnant Limestone Member 3 m from the top. The dark-coloured limestone is pisolitic (possibly originally oolitic), with ellipsoidal grains up to 3 mm in diameter, flattened in the plane of cleavage and set in a black matrix that owes its colour to the presence of carbon. Brenchley and Cullen (1984, p. 117) interpreted the limestone as a channel-fill sediment, into which shells were washed from the adjacent muds during the deposition of the limestone.

Bassett *et al.* (1966) estimated the whole of the Foel-y-Ddinas Mudstone Formation to be about 120 m thick, the section at Cwm Hirnant lying in the upper half. They equated the thin Calettwr Quartzite some 6 km to the NNE with the Hirnant Limestone and recorded shelly fossils from both of these members, as well as from mudstones at Cwm Hirnant and elsewhere.

Interpretation

Sedimentologically, the occurrence of oolitic/pisolitic limestone in a channel-fill at Cwm Hirnant reflects the glacially induced Hirnantian sea-level fall, even in what was a fairly distal shelf setting (Brenchley and Cullen, 1984, figs 2 and 3). The brachiopod-dominated shelly fauna is the same in both the mudstones and the limestone and was listed and partly described by Temple (1965), in conjunction with similar faunas from the north of England and from Poland (see also Brenchley and Cullen, 1984, table 1). It is dominated by the brachiopods *Hirnantia sagittifera* (M'Coy) and *Eostropheodonta hirnantensis* (M'Coy) (Figure 9.22d, e), both of which have their type locality here, and *Horderleyella* sp. nov. of Havlíček (1977) (= *Bancroftina*? cf. *bouceki* of Temple, 1965), with rarer specimens of *Dalmanella*, *Kinnella* and *Plectothyrella* (Figure 9.22f). Most of these genera are core members of the globally widespread *Hirnantia* fauna (Rong and Harper, 1988). Bryozoans, conulariids and the almost cosmopolitan trilobite *Mucronaspis mucronata* (Brongniart) also occur.

In its widest sense, the *Hirnantia* fauna comprises several different communities that lived at a variety of water depths and show a latitudinal provincialism (Rong and Harper, 1988; Owen *et al.*, 1991). At high latitudes, the Bani province comprised low-diversity *Hirnantia* faunas, whereas the subtropical and temperate Kosov province (which included the Anglo-Welsh area) had more diverse *Hirnantia* faunas. The equatorial belt was typified by the Edgewood province, which contained several endemic elements. The *Hirnantia* fauna developed from a mixture of existing genera and newly evolved forms during a time of global mass extinction. It reflects a short-lived reorganization of the brachiopod communities and disappeared as a recognizable suite of ecological units before the end of the Hirnantian (Harper and Rong, 1995; Owen and Robertson, 1995).

Conclusions

This site was the first at which the distinctive and short-lived but widely distributed *Hirnantia* association of brachiopods was recognized; the association represents an episode of fundamental change in benthic community structure during one of the most profound mass-extinction

episodes in Earth history. The site gives its name to this association and is the type locality for two of its brachiopod species. It also gives its name to the latest stage of the Ordovician, the Hirnantian, which is typified by the *Hirnantia* fauna in many parts of the world.