ABSTRACT.

The stratigraphy of the Arenig Series in North Wales is revised using the three fold division, based on shelly faunas, recognised in South Wales. Sequences are described, with the aid of sedimentary logs, for ten areas: Anglesey, Caernarfon-Bangor, Aber-Betws Garmon, northern Llyn, western Llyn, St.Tudwal's Peninsula, Criccieth, area bounding Harlech Dome, Arans, and Tywyn- Cader Idris. Each is thought to represent a separate structural unit, this being reflected in their differing stratigraphies.

The traditional view of the complete series being developed throughout North Wales is shown to be wrong: only in the western Llyn have all three divisions been recognised. A new lithostratigraphy is proposed for this area and previously unrecognised structural complexities are identified. Elsewhere, the Series is incomplete; the lower and middle Arenig being restricted in development whilst the upper is widespread. In the Arenig ("type") area only the lower and upper Arenig are present.

The development of the basin is thought to have been controlled predominantly by penecontemporaneous normal faulting and various sedimentary evidence of tectonic instability is described. Regional development of an ironstone and associated condensed facies is recognised at the Arenig - Llanvirn boundary.

Graptolite faunas are comprehensively described. New topotype material of the type species of Acrograptus is described and the genus Azygograptus is reviewed. Extensiform graptoloids are described under a number of species groupings based on proximal development. A number of 'Pacific' province graptolites are recognised from Britain for the first time.

Trilobites not recorded in South Wales are briefly discussed. A new shallow water (Neseuretus community type) fauna is described from the Bangor area and includes four new species. A number of other new species are briefly described.
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CHAPTER 1: Introduction.

1.1 Introduction

The Arenig Series as now used bears little comparison to the "Arenig slates and porphyries" of Sedgwick (1852) that first brought the name into use. Indeed the subsequent evolution of the chronostratigraphic unit has been based on evidence from widely separated areas (Whittard 1960) and the name remains because of historical precedent rather than the geological suitability of the area in North Wales from which it derives (Zalasiewicz 1984). It was in the same area that Lapworth (1879) defined the Ordovician System, taking the base at that of the Arenig Series. The question of the inclusion of the Tremadoc Series within the Ordovician System is not yet resolved, but need not be considered further here, as it was the presence of a stratigraphic break at the base of the Arenig that caused Lapworth to select the horizon he did. Of far greater relevance to this study is that this stratigraphic break probably marks a change in the tectonic setting of the Welsh Basin (Bevins et al 1984).

The only previous regional examination of the Arenig Series in North Wales was by Elles (1904) in which it was divided into three biozones: D. extensus, D. hirundo and D. bifidus, though the last was subsequently incorporated into the Llanvirn Series. Despite the recognition of a four fold zonation in the Lake District, (Jackson 1962), only a two fold division was employed in the Ordovician Correlation Chart for Wales (Bassett in Williams et al 1976 Fig.6) (see Table 1.1)

Table 1.1: The Arenig Series in North Wales as shown in the Ordovician Correlation Chart (from Williams et al 1976 Fig.6)
Fig. 1.1 Map showing distribution of previous regional studies. (10 km grid squares also marked)

The majority of previous work is contained in regional studies, and these, along with the small number of palaeontological papers, are summarised in Fig. 1.1. These contributions will be considered in greater detail in the
discussions of the areas to which they pertain. However, the simple view shown in Table 1.1, of a basal sandstone overlain by a complete Arenig succession accurately summarises the previous interpretations of the series’ development in North Wales, though Zalasiewicz (1984) appreciated the possibility that the Series was incomplete in the Arenig area itself.

1.2 Aims of Thesis.

Work over the past ten years in South Wales (Fortey & Owens 1978, Fortey in Whittington et al 1984; Fortey & Owens in press) has resulted in a new biostratigraphic division of the Arenig Series, which places greater emphasis on the shelly faunas and in particular trilobites. Though a finer zonal scheme may be applicable there, it is only proposed to employ here the published informal three-fold division (Fortey in Whittington et al 1984) into lower, middle and upper which will ultimately form the basis of formal stages (Fortey & Owens in press). The faunal basis of the divisions is summarised by Fortey (in Whittington et al 1984); the same assemblages can be recognised in North Wales. This study has three main aims:

1. To revise the regional stratigraphy on the basis of the new correlation.
2. To use the mixed shelly and graptolitic faunas of North Wales to refine the correlation between the three-fold division and the graptolite zonation of the Lake District.
3. To refine existing models for the structural and tectonic evolution of North Wales in the early Ordovician.

1.3 Methods.

The recent geological mapping done in North Wales (see Fig.1.1) has negated the need for such work and consequently the formal proposal of new lithostratigraphic units is avoided. The exception is the Aberdaron area, where some mapping was carried out owing to the unavailability of the work by Tegerdine (in prep). In addition some rationalisations are suggested to existing units where it is felt their limits reflect more the boundaries of the area investigated than the regional geology.

The main emphasis of field work has been the examination of the best exposed sections in the various areas of Arenig outcrop as identified by the previous
mapping. Where possible, sedimentary logs were measured. The symbols used in the illustration of these are summarised in Appendix 1, and unless otherwise stated the scale bars represent 1m. Owing to the presence of mica flakes in the argillaceous lithologies, these are referred to as siltstones, though some, in particular the Maen Gwenonwy Member of the Western Llŷn, might be termed mudstones by others. All fossil localities recorded in the literature were revisited and a number of new ones identified.

Fig. 1.2 Map of area divisions used in following discussion. 1: Anglesey (Chap.7); 2 Caernarfon-Bangor Area (Chap.4); 3: Aber-Betws Garmon (Chap.6) 4: Northern Llŷn (Chap.5); 5: Aberdaron-Sarn Area (Chap.3) 6: St. Tudwal's Peninsula (Chap.7); 7: Criccieth Strip (Chap.5) 8: Area bounding Harlech Dome (Chap.2) 9: Arans (Chap.7) 10: Tywyn-Cader Idris (Chap.7)
This work has shown that there are substantial regional variations in stratigraphy and each area is therefore described in turn. In the case of the Aberdaron-Sarn area, the extensive revision of the litho-stratigraphy has identified a number of previously unrecognised structural complexities. The area divisions are shown in Fig.1.2.

The lithostratigraphic terminology employed in the following chapters is summarised in Table 1.2. In brief, the lower and middle Arenig are restricted in distribution which contrasts with the widespread development of the upper Arenig.

Table 1.2: Main lithostratigraphic terminology employed in text. (Asterisks indicate new terms or revised usage)

In addition to the faunas collected during my field work, those in previous collections were examined. The abbreviations used to indicate the repositories of the specimens are as follows:

B.M. British Museum (Natural History)
N.M.W. National Museum of Wales.
B.U.M. Birmingham University Museum.
I.C.T.C. Imperial College Teaching Collection.
B.G.S. British Geological Survey Collection.

The restricted development of the lower two Arenig divisions, and problems in the taxonomy of extensiform
graptolites, have proved limiting factors in the completion of wider correlation. However, since some biostratigraphically important species have been found from the upper Arenig for the first time in the British Isles, and the other species may prove useful in future correlation, the graptolites are comprehensively described.

The trilobites, on which the biostratigraphy is largely based, are not described in detail as this would extensively duplicate the work now being done in South Wales. However there are a few species that have not been recorded in South Wales, and these are described here; they include a number of new species.
Chapter 2: The Area Bounding the Harlech Dome.

2.1 Introduction.

A nearly continuous strip of Arenig age rocks has been mapped from Moel Offrwm to Porthmadog bordering the Harlech Dome, and includes the area which gave its name to the Series. Considering the incompleteness of the Series in the area of Arenig Fawr as discussed below, it is considered inadvisable to refer to it as the type area for the Series. Throughout the area the Arenig rests with varying disconformity on Tremadoc siltstones, and an angular discordance can be recognised with the Rhobell Volcanic Group (Kokelaar 1979). Lynas (1973 p500) stated:

'The formation (Carnedd Iago) was apparently conformable on the Cambrian in the west (ie Croes y ddwy afon and Bryn Glas quarries) though unconformable to the east of the Ffynnon Eida Fault.'

Bassett (in Williams et al 1976 p.19) quoted Lynas (1970) as considering the contact to be gradational. Bromley (1963) likewise considered conformity to exist just east of the Cwm Bowydd fault and the base then to cut down sequence to south and east (see Fig.2.1). The description of the sequence in question (Lynas 1973 p485) records a 40cm basal coarse unit overlain by an alternating sequence of sandstones and mudstones giving way gradationally to the typical massive, current bedded sandstone. Coarse units have also been noted in the top of the Tremadoc at Rhyd (Bromley 1963 p13) as has the presence of the phosphatic oncinite Bolopora undosa, (Bates 1969a) long thought to be characteristic of the basal Arenig. Such gradational sequences may be compared with that shown in Fig.2.3 and it is possible that the supposed sandy beds of Tremadoc age may occur in the base of the Arenig.

Despite these difficulties the facies change is sufficient to have allowed the consistent recognition of the base throughout, though opinions have differed on the chronostratigraphy of the overlying sequence. (see Table 2.1). Major N-S lineaments have been shown to affect the stratigraphy (Bromley 1963, Lynas 1973) and this could be invoked to explain the lateral variations but it is felt more likely the these have been exaggerated by erroneous stratigraphic placement in the absence of faunal control, eg it is suggested below that the Llanvirn may be present SW of
Fig. 2.1: Annotated map of Arenig strip bounding Harlech Dome
Blaenau Ffestiniog.

Table 2.1 Lithostratigraphies of previous authors.

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Table 2.2: Lithostratigraphy employed.

Only two sequences have been examined in detail; that of the Arenig Area from Carnedd Iago to Moel Llyfnant and that above Tan-y-Grisiau, near Blaenau Ffestiniog. Despite the variations noted above, these two sequences are considerably alike and it is possible that a single lithostratigraphy can be recognised throughout the strip, at least for the lower portions of the sequence. However, the restriction of the fossils to the eastern part of the area means that the intra-Arenig placement of the sequences in the west depends on lithostratigraphy alone and the units could be diachronous.

The stratigraphy employed here is based on the Arenig area itself where there is the best
Fig. 2.2: Sedimentary log of Llyfnant member on Moel Llyfnant (SH 812357)
1: Pl.1 Fig. 4
2: Pl.1 Fig. 3
3: see Fig. 2.5
Fig. 2.3: Sedimentary log of Garth Grit and Llyfnant Members above Tan-y-Crisiau. Section along incline at SH 679452. For notes see Fig. 2.4.
Fig. 2.4: Detail of cross-bedded unit and overlying beds at top of Tan-y-Grisiau section, Fig. 2.4. Exposed beside road to Stwlan Dam where crossed by incline. Palaeocurrent rose-diagram shown for cross bedded unit.
(Cross-bedded unit shown in Pl.1 Fig.6)

Notes to Fig. 2.3
1: Pl.2 Fig.9
2: Pl.1 Fig.2
3: Pl.2 Fig.10
4: Pl.2 Figs.5-8 over this interval.
5: Pl.2 Figs.1 & 2
6: Pl.2 Figs.3 & 4
Biostratigraphic control and the lithostratigraphic terminology is mainly that proposed by Lynas (1973) for the Mignient region, and adopted by Zalasiewicz (1984) for the Arenig area. The only change is the proposal of the Olchfa member. This is not equivalent to the Olchfa Shales of Fearnside (1905), which are Llanvirs in age, but represents part of his Filltirgerig Beds. Stratigraphy is summarised in Table 2.2.

2.2 Garth Grit Member (Carnedd Iago Formation)

The Garth Grit is distinguished from the underlying Tremadoc and overlying Llyfnant Member by the dominance of coarse quartzose sandstone, though the gradational junction with the beds above makes its upper limit ill-defined. Despite its lenticularity, thicknesses of 0-70m recorded (Lynas 1973), the member has been recognised throughout the strip. Lateral variations recognised by previous workers are summarised in Fig.2.1.

Of the two areas examined in detail, only that above Tan-y-Grisiau provides good sections through this member, the Tremadoc - Arenig boundary being complicated by a dolerite sill in the Arenig area (Zalasiewicz 1984). The best exposed sedimentary sequence is that shown in Fig.2.3, where the base is marked by a thin gravelly bed (Pl.2 Fig.9), followed by 2.5m of interbedded sandstone and siltstone (Pl.1 Fig.2) with some evidence of bioturbation. In the absence of the distinct basal bed, this junction could have been considered gradational. Two other features may be noted in this section. First, the presence of coarser material, up to small pebble size, well above the base and this is apparently typical, and second the large isolated ripples (Pl.2 Fig.10) that highlight the difficulty in defining a junction with the Llyfnant Member.

This outcrop of the Garth Grit Member can be followed almost continuously to the SW for 1.5km until it lenses out at SH 66954402 where in the last exposure it is little more than 1m thick. Whilst remaining quartz-dominated there is some change in lithology, being distinctly more heterolithic and poorly sorted than to the N.E.. Clasts include angular fragments up to 1cm long of a khaki - coloured siltstone and pale volcanogenic clasts, possibly comparable to the rhyolitic clasts recorded elsewhere (Lynas 1973, Bromley...
1963). A thin section shows there to be plagioclase crystals present, the quartz clasts to be dominantly polycrystalline and the matrix to be composed of fine grained quartz with some interstitial chlorite. The larger quartz clasts are well rounded whilst the matrix is more angular. This facies change, and that seen at Bryn Glas Quarry (see Fig.2.1) are both associated with the lenticularity and suggests the latter may be deposition in origin.

No fossils have been recorded from this member.

2.3 Llyfnant Member (Carnedd Iago Formation)

The original term of Fearnside (1905), the Llyfnant Flags, conveys well the nature of this unit. Characterised by a prominent parallel-banding in outcrop (Pl.1 Fig.5), developed between siltstone and fine sandstone, the lithology of the unit appears relatively uniform apart from some variation in the proportions of the grain sizes and the sedimentary structures present. In the area of its type locality, Moel Llyfnant, it breaks into distinctive rectangular blocks which furnish evidence of the finer-scale sedimentary structures, described below.

A restricted graptolite fauna is present in this member. *D. cf. infrequens* (Kraft), *Azygograptus cf. eivionicus* Elles and *D. aff deflexus* Elles & Wood. The material of the last two species, recorded by Zalasiewicz (1984), has not been re-examined.

2.3a Field Occurrence.

In its type area, the Llyfnant Member is bounded by the Garth Grit Member below and the Henllan Ash Member above. Regionally it may not be possible to separate the Olchfa Member from the Llyfnant Member in the absence of the intervening Henllan Ash Member, despite the evidence for there being a stratigraphic break between (see below). Taking the restricted view, thicknesses up to 160m (Lynas 1973) are indicated, though at the type locality (Fig.2.2) it seems somewhat less (70m).

The junction with the Garth Grit Member is gradational, and scattered coarser material is present in the lower part of the Llyfnant Member and in occasional bands up to 40m above the base (see Fig.2.2). Cross lamination is more common than was implied by Zalasiewicz (1984 fig.6), is generally on a fairly small scale, with cosets <5cm. thick,
though occasional thicker examples are present. The cross-bedding is predominantly simple, with some reactivation surfaces being developed, and occurs as both fairly continuous tabular units or in more isolated lenses.

Slumping has been recorded previously in the Blaenau Ffestiniog area (Bromley 1963) and is noted here in the Arenig area for the first time, two possible examples having been found in the section on Moel Llyfnant (Fig. 2.2). The lower occurs approximately in the middle of the section overlying an homogeneous fine sandstone bed of comparable thickness to it. There is no clear evidence of lateral movement in this unit and the convolute structures could result from in-place disturbance. However, the upper, thicker, example appears to cut down about 1m into the underlying beds at its NW end, almost certainly indicating lateral motion (See Fig. 2.5). Below this unit there is a cross-cutting structure (Pl. 1 Fig. 4) also suggestive of lateral movement of material, but much better examples of this are present above Tan-y-grisiau. These slide surfaces (Pl. 2 Figs. 5-8) can be seen below the major slumped unit which itself has a well developed example at its base (Pl. 2 Fig. 2), inclined at 37° to 190° (when compensation is made for the regional dip). Slump
structures can be seen at a number of other places in the good exposure below the Moelwyns. In the context of the instability suggested by these features, the presence of a 1m tuff band towards the top of the Llyfnant Member at Hafotty Ffilltirgerig (SH 81743868) is noteworthy (Zalasiewicz 1984)

2.3b Detailed Lithology.

Though the small scale laminae possess a parallelism comparable to that seen in outcrop, their lateral continuity is generally very limited, the flaggy appearance hence being the combined effect of a large number. Typically the siltstone fraction is dominant but occasional sandstone dominated horizons occur, the siltstone being reduced to irregular streaks. Such extremes as this usually can also be distinguished in outcrop. However, within the siltstone dominated lithologies, there is considerable variation in the nature of lamination, with which there appears to be some correlation in the nature of the bioturbation. There are two main end members:  
1) Very finely interlaminated siltstone and sandstone with densities up to 20 laminae/cm. These laminae are more laterally continuous (>20cm) than the thicker examples and the bioturbation is dominantly parallel to bedding.  
2) Moderately widely spaced lenses of sandstone that sometimes grade into thinner laminae laterally though these are still of the order of 1mm in thickness. The thicker sandstone lenses are usually less than 1cm thick and quite commonly show mud-draped cross lamination, and are therefore best regarded as starved ripples. Occasionally more continuous sandstone bands of approximately the same thickness occur but these show little internal structure and may represent the amalgamation of lenses. Vertical spreite filled burrows 2-3cm long appear to be preferentially associated with such bands, and probably indicate a higher energy depositional environment.

The member contains a complete spectrum of variation between these two extremes as well as variation in proportions of the two components. The siltstone is usually medium - grey in colour and moderately micaceous with some surfaces coated with abundant mica flakes. The sandstone is characteristically pale in colour and consists of varying
proportions of poorly rounded feldspar and quartz (Zalasiewicz 1984).

2.4 Henllan Ash Member. (Carnedd Iago Formation.)

Zalasiewicz (1984) reviewed the lithological variation of this member in the Arenig area and recognised three facies:

1) Henllan Facies: A clean washed feldspatic sandstone locally showing prominent cross-bedding.
2) Erwent Facies: Mixed siltstone and feldspatic sandstone strongly bioturbated.
3) Mudflow facies: Recognised at only one locality, consisting of blocks of feldspatic sandstone (up to 1m) in a feldspatic sandstone to mudstone matrix.

The member attains a maximum thickness of 190m (Zalasiewicz 1984). It can be recognised to the south, forming the summit of Rhobell Fawr and may be equivalent to the volcanic sandstone around Moel Offrwm, but seems to die out quite rapidly to the north-west, at SH 779417, just east of the Dernant Fault.

The trilobite fauna from this member was described in detail by Whittington (1966) and contains: *Merlinia selwynii* (Salter), *H. murchisonia* (Murchison), *Neseuretus parvifrons* (M'Coy), *H. murchisoni* (Salter), *Myttonia fearnsidesi* Whittington and *Apxy cetsarum* Fortey & Owens. Fortey and Owens (1978) noted the equivalence of this to their lower Arenig assemblage. The only graptolite recorded from this member is *Azygograptus* cf. *eivionicus* Elles (Zalasiewicz 1984, p.116). The siltstones from which Zalasiewicz (1984) recorded *Didymograptus* cf. *praenuntius* Törnquist and *Tetragraptus reclinatus* Elles & Wood are here placed in the Olchfa Member rather than the Henllan Member as he proposed.

The origin of the member is less clear. The presence of the mudflow facies, the tuff within the top of the Llyfnant Member and tectonic instability indicated by the slumping all tend to support the interpretation of its being a reworked tuff (Fearnside 1905, Lynas 1973). Zalasiewicz (1984) suggested that a detrital origin from a pre-existing igneous source was more likely. No critical evidence on this problem has been discovered from within the area during this study, but the presence of a volcanic horizon at
2.5 Overlying Sequence

Only in the Arenig area is there biostratigraphic control on the higher part of the sequence, as discussed below. This shows that the Arenig Series is incomplete here; the possibility remains for significant regional variation, which might be obscured by lithostratigraphy alone.

2.5a Arenig Fawr Area: Olchfa Member (Serw Formation).

Zalasiewicz (1984) did not recognise Fearsides (1905)
Filltirgerig Beds, favouring the re-distribution of this unit between the underlying Henllan Ash Member and overlying Serw Formation. There is little doubt that the Serw Formation, as used by previous authors, is of Llanvirn age (Zalasiewicz 1984, Lynas 1973), but there was some doubt as to the intra-Arenig position of the portion assigned to the Henllan Member. The fauna recorded from these beds at Hafotty Filltirgerig (Zalasiewicz 1984) is the same as that from Nant yr Olchfa (SH 7849) recorded by Lynas (1973 p486). The faunal list for the latter locality has been extended by collecting during this study (see Table 2.3) and the discovery of *Pseudotrigonograptus minor* (Mu & Lee) and *Cryptograptus tricornis schaeferi* Lapworth has shown the sequence is probably upper Arenig in age. This therefore explains the presence of *Ampelxograptus cf. confertus* Lapworth noted by Zalasiewicz (1984). As both here and at Hafotty Filltirgerig this siltstone rests directly on the Henllan Member there is clearly a significant break representing the middle Arenig and probably also including parts of the lower and upper Arenig. For this reason it seems inappropriate to place these beds within the Carnedd Iago Formation and it may be best to consider them basal to the Serw Formation.

The member is extremely variable in thickness, being very thin at Hafotty Filltirgerig (Zalasiewicz 1984) and probably absent locally. The variable thicknesses recorded by Lynas (1973 Fig.4) are greater, but since there is evidence of folding of the unit (Fig.2.6) these may be slightly overestimated. A thickness of 90m is estimated for the Olchfa section (see Fig.2.6).

The dominant lithology of the member is a laminated siltstone, which, though producing large slabs, is less sandy and with less marked sandstone lamination than the Llyfnant member. However, as is indicated in Fig.2.6 there is considerable variation in the lithologies of the Nant yr Olchfa section with similar variation being apparent in the Afon Serw section (Fig.2.7), which Lynas (1973) considered transitional between the top of the Carnedd Iago Formation and the base of the Serw Formation.

Particularly interesting is the oolitic mudstone and lithologies associated with it seen in Nant yr Olchfa.
Underlying the oolitic mudstone are typical siltstones of the Olchfa Member, but there is no exposure above. The ooliths are about 1mm in diameter, distributed as irregular patches within a dark homogeneous siltstone. The oolitic patches are extremely well sorted and are elongated parallel to bedding, but other clastic material of comparable size is absent. However in the associated non-oolitic siltstone, are concentrated bands of fragmented biogenic phosphatic material, with occasional complete valves of an inarticulate brachiopod. Though no sand grade quartz is present in these bands, rectangular crystalline patches up to 2mm in length are relatively common. These could either represent an authigenic mineral growth or altered volcanogenic feldspars, the latter being favoured by the composition of the sandstones in the sequence, and the volcanogenic nature of the Serw formation.

Fig.2.7: Annotated sketch map of Afon Serw at SH 776423
Despite the phosphatic and oolitic material generally being mutually exclusive two associations of them together have been noted. One is a large phosphatic nodule (2cm across) that contains quite abundant ooliths in its outer portion though none are present in the surrounding matrix. In the other case, the matrix to the phosphatic bands is not a normal siltstone but has a texture suggestive of a very fine oolite and this may represent an early stage in the genesis of the coarser oolitic material. The phosphate-rich horizon present in the Afon Serw Section (Fig.2.7) may be laterally equivalent, and the occurrence of *Neseuretus* sp. suggests a possible shallowing. The only other fossils from this locality are *Monobolina plumbea* (Salter) (also common in Nant yr Olchfa), lingulids, an indeterminate asaphid and graptolite fragments. Though phosphatic nodules are common at other points especially at Loc. C of Nant yr Olchfa (see Fig.2.6), those in the Serw Section are notable for containing abundant sponge spicules and other biogenic material including a gastropod and graptolite fragments. Such nodules have not been seen elsewhere within the area but sponge spicules are very common on some bedding planes of the siltstone underlying the oolitic mudstone in Nant yr Olchfa (Loc.B).

2.5b Regional Development.

To the south, on Moel Offrwm, a thin shale band 'not more than 15ft thick' has been recorded, resting on the basement group and which was considered equivalent to the " Hirundo Shales" (Wells 1925). This occurrence is interesting because of the presence of 'a pisolitic iron ore' strongly suggesting comparison with the latest Arenig in Nant yr Olchfa. Kokelaar (1979) recorded an oolitic mudstone at the same horizon and noted that it had suffered soft-sediment deformation associated with the emplacement of overlying volcanics.

SW of Blaenau Ffestiniog the Arenig Series has been considered thicker than elsewhere, with the Caradoc being thought to rest directly on it. Owing to the thermal and regional metamorphism, biostratigraphic control is minimal. Arenig graptolites from the Moelwyn Slate quarry (SH 662438) (Fearnside 1910a) cannot be traced and can hardly be relied upon. This leaves only the Caradocian shelly fauna
from Cresiliau Dwon (Bromley 1965). Emphasis therefore has to be placed on lithostratigraphy. The supposed absence of the Llanvirn is puzzling, since this series is recognised to the east of Blaenau Ffestiniog (Lynas 1973) and in the Criccieth area to the west (Fearnside 1910, Roberts 1967), though new graptolite evidence obtained during this study (see Chapter 5) does raise questions as to the thickness of Llanvirn present at the latter locality. Furthermore below Moel-yr-rhyd (SH 678451) a slate horizon outcrops above typical Llyfnant Member flags, and contains significant volcanic material, mostly fine grained tuffs, but including also crystal tuffs and bands of accretionary lapilli. These rocks bear little resemblance to any of known Arenig age but are closely comparable to those of the Llanvirn. (eg Serw Formation of Arenig area).

Tracing the junction between the slate and flags shows a cross-bedded sandstone to be present (Figs.2.3 & 2.4; Pl.1 Fig.6) suggestive of a significant shallowing that may represent either that of the Henllan Member or that suggested by the fauna at the top of the Olchfa Member. The feldspathic composition of the sandstone may favour equivalence with the Henllan Member, but the apparent gradation with the overlying sequence suggests closer association with the younger rocks. Laterally the slate grades into flaggy lithologies more difficult to separate from the Arenig. The considerable thickness of beds assigned to the Arenig on Craig Nyth y Gigfran and named after the locality (Bromley 1963), was divided into Upper and Lower units by a slate band and it is the Upper part that is noted as containing significant volcanic material, clearly suggesting comparison with the situation below Moel-yr-rhyd.

Further to the south-west around Penrhyndeudraeth and Porthmadog there are a couple of other occurrences requiring discussion. Graptolites of Arenig age, Azygograptus lapworthi Nicholson and Pseudophyllumgraptus cf angustifolius (Hall) have been described from the old Copper Mine at Penrhyndeudraeth (Fearnside and Davies 1943 p253) and which were considered to be derived from beds overlying the typical Arenig Flags; termed the Pant-y-Wrâch beds. The original specimens are not available, but material of the azygograptid has been examined and though poorly preserved
does appear to be *A. lapworthi*. This (see Chap.11 for discussion of *Azygograptus*) therefore tends to support an upper Arenig age and though the fauna is different, approximate equivalence with the Olchfa Member is likely.

Within this area the Caradoc has been mapped as being faulted against older parts of the sequence (Fearnside 1910, Fearnside & Davies 1943) but on the Snowdonia 1:25000 sheet (IGS 1972) the exposures just north of Porthmadog (SH 56653930) are shown as being Llanvirn. The evidence for this stratigraphic placement is unknown, especially since Fearnside (1910), on whose work the map was based, recorded graptolites suggestive of the Caradocian. A well developed ironstone /oolitic mudstone is present at the locality and contains the phosphatic nodules and oncolites seen in other lower Llanvirn ironstones eg Betws Garmon. However, within the immediate vicinity are a number of occurrences of Caradocian ironstones (Fearnside 1910 p170-3, Fearnside & Davies 1943 p 265-6) and therefore the presence of an ironstone alone does not indicate a single stratigraphic horizon.
Figs. 1 & 7: Blocks of Llyfnant Member flags showing fine scale lenticular laminae. Cross-lamination can be distinguished in some of the sandstone lenses.

Fig.2: Finely interbedded coarse sandstone and siltstone at the base of the Tan-y-Grisiau section (Note 2 Fig.2.3). Garth Grit Member

Fig.3: Thicker sandstone beds in typical flags of the Llyfnant Member, Moel Llyfnant. (Note 2 Fig.2.2). Note low angle cross-lamination in sandstone bed level with hammer head.

Fig.4 Cross cutting unit just below major slumped unit in Moel Llyfnant section (Note 1 Fig.2.2).

Fig.5 Typical field appearance of Llyfnant Member. Exposure below Moelwyns (SH 44126711)

Fig.6 Cross bedded unit between Llyfnant Member and overlying slates with volcanics, Tan-y-grisiau section. (Fig.2.4)

Fig.8 Detail of upper slumped unit, Moel Llyfnant. Position indicated on Fig.2.5.
PLATE 2

Details of Tan-y-Grisiau section, Fig.2.3 (Notes refer to this.)

Figs. 1-4 major slumped unit: relative positions of Figs.2-4 indicated on Fig.1. Figs.1,2 & 4 looking NE; Fig.3 looking SW. Fig.2: basal slide surface of slump unit (Note 5). Figs.3 & 4: slumped unit with complex folding. (Note 6)

Figs.5-8: Small scale slides below major slumped unit (Note 4)

Fig.9: Basal disconformity. Basal gravel band at top of compass clinometer. (Note 1)

Fig.10 Large scale isolated ripples at transition from Garth Grit Member to Llyfnant Member. (Looking SW) (Note 3).
CHAPTER 3: Aberdaron – Sarn Area, Western Llŷn.

3.1 Introduction.

The area around Aberdaron and extending north to Sarn Meyllteyrn (termed Sarn hereafter) contains some 12km² of solid mapped Arenig strata, and is the only area in North Wales in which all three divisions have been recognised. Throughout the area the Arenig rests unconformably on crystalline rocks, though much of the contact may be faulted. Rb-Sr ages for the Sarn Granite and gneisses of the Mona Complex are 549+19Ma and 542+17Ma respectively indicating intrusion and metamorphism in early Cambrian times (Beckinsale et al 1984). The age of the Penmynydd schists is more problematic (Gibbons & Mann 1983). They are believed to be younger than the Sarn Granite (Gibbons 1983), but are clearly separated from the Arenig by a significant metamorphic event (Roberts 1981).

Despite the relatively small distances involved, less than 10km N–S or E–W, no single stratigraphy seems Table 3.1 Lithostratigraphic terminology proposed for the Aberdaron–Sarn area.

<table>
<thead>
<tr>
<th>ABERDARON AREA</th>
<th>SARN AREA</th>
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<tbody>
<tr>
<td><strong>W. of Wig fault</strong></td>
<td><strong>E. of Wig fault</strong></td>
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<tr>
<td>Carw Tuff Fm.</td>
<td>Carw Tuff Fm.</td>
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<tr>
<td><strong>Llanvirn</strong></td>
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<tr>
<td><strong>upper</strong></td>
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<tr>
<td>Porth Meudwy Member</td>
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<tr>
<td><strong>Arenig</strong></td>
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<tr>
<td>middle</td>
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<tr>
<td>Aberdaron Fm.</td>
<td>Aberdaron Fm.</td>
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<td>Sarn Fm. ?</td>
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<td><strong>lower</strong></td>
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Fig. 3.1 Geological map of Aberdaron-Sarn area
appropriate for the entire area. In the north around Sarn, there is evidence that the succession is entirely of upper Arenig age resting directly on the Sarn Granite. In the south the succession is thicker and all three divisions can be recognised between Wig and Llanfaelrhys, though west of the Wig fault no rocks of lower Arenig age have been proved and the unconformity could be middle Arenig in age. The suggested stratigraphy is summarised in Table 3.1. Only one unit, the Carw Tuff Formation, a volcanic marker horizon approximating closely to the Arenig / Llanvirn boundary, can be recognised throughout the area, but the facies of the Sarn Formation and Porth Ysgo Sandstone Member are closely comparable and they can only be separated on the basis of their associated sequence$.

3.1a Previous Work.

The main papers on the area are those of Matley (1928 & 1932) and references to earlier works are contained therein. The stratigraphic sequence he proposed has survived largely unaltered in subsequent works but the proposed intrusive contact of the Sarn Granite has been reinterpreted as an unconformity (Matley & Smith 1936) and Shackleton (1956) challenged the concept of the "boundary thrust" separating the Mona Complex from the Arenig, favouring an unconformity.

Extensive work carried out during the last war on the manganese mines of Nant y Gadwen and Rhio (Groves 1947 & 1952) has been largely overlooked in other studies which, apart from the ichnofacies analysis of Crimes, (1970) have been mainly concerned with the intrusives (Hawkins 1965 & 1970, Cattermole 1976), the structure (Hawkins 1983) and the metamorphism (Roberts 1981). Recent work has involved remapping and sedimentological examination of the lower Palaeozoic sequence (Tegerdine in prep). The map shown in Fig.3.1 is based both on previous work and personal observation and uses the refined stratigraphy. Two recent geological guides have described localities in this area (Roberts 1979 & Cattermole & Romano 1981).

3.2 Lower Arenig.

The lower Arenig may be somewhat restricted in distribution, and for this reason, of the four exposures of the basal unconformity described, only two can be assigned to the lower Arenig with any confidence, though even in
these the age is not proved within an unfaulted sequence.

1) Penrhyn Mawr (SH 190261).

The exposure originally described (Shackleton 1956 p.409) no longer appears to be exposed (Hawkins 1983) but is recorded as consisting of 30cm of conglomerate resting on gneiss and overlain by shale. Though the latter is clearly folded, a thickness of up to 40m is indicated by the present exposures.

2) Wig Headland (SH 18582581) (see Fig 3.2 P1.3 Figs.6 & 8)

This exposure has also been described recently, though wrongly, as no longer exposed (Hawkins 1983 p.179), the error no doubt resulting from a change in the nature of the outcrop. It was originally described as occurring at the base of a rain washed gully (Matley 1932 p.241) but is now isolated at the top of the schist cliff, presumably as a result of the erosion of the northern side of the gully. A log of the sequence is shown in Fig.3.2A. The basal conglomerate contains well rounded cobbles up to 25cm in diameter and though the grey 'chert' noted by Matley is abundant there are also conspicuous amounts of jasper present providing a closer comparison with the local basement. The matrix to these larger clasts is a quartzose sandy gravel which itself has a silty matrix. The deposit appears to be clast supported and therefore the variety of grain sizes may well be a secondary infilling of interstices. The conglomerate is overlain by coarse quartzose sandstones, friable and rusty weathering in places and displaying parallel lamination, very faint mud streaking and shale partings between the beds.

The bed separating the sandstones and shales is slightly enigmatic. It has clearly suffered some shearing but its clastic content of gravel grade quartz, phosphatic nodules and possible larger siltstone clasts set in a silvery siltstone matrix is thought to indicate a primary deposit rather than some form of fault rock. The overlying siltstone has hard siliceous bands, that may well have nucleated on sandstone laminae, and diffuse bands of phosphatic nodules.

Fig.3.2: (see overleaf) Geological map and drawing of Wig headland with sedimentary log of sequence overlying basal unconformity. 

dashed ornament: Maen Gwennonw Siltstone Member

circle ornament: Porth Ysgo Sandstone Member

cross ornament: Penmynydd Schists
Fig. 3.2:
Vig Headland
(caption on previous page.)
The sandstones described by Matley as occurring above this may belong to the sequence to the east of the Wig Fault but are no longer exposed in the gully.

3.2a Wig Formation.

This unit represents the beds that may confidently be placed in the lower Arenig as developed in the area. Two main members have been recognised; a lower Porth Ysgo Sandstone Member and an upper Maen Gwenonwy Siltstone Member. The base of the formation is taken at the basal unconformity and hence the beds directly overlying it are included within the formation. The relationship of these to the Porth Ysgo Sandstone Member is not clear, and, as noted for the Penrhyn Mawr exposure of the basal unconformity, there may be a significant siltstone sequence present at the base.

3.2b Porth Ysgo Sandstone Member.

This is exposed at three localities: Wig Headland (SH 186257), the Mainland opposite Maen Gwenonwy (SH 19812598 to SH 20072621) and Porth Ysgo (SH 207264) the last two being structurally equivalent in overlying the Gallt-y-Mor Sill.

The dominant lithology is a sand streaked, bioturbated, siltstone. The sandstone laminae are very thin and discontinuous, the thicker examples probably being composite in nature. Isolated ripples occur in the thin laminae and rippled surfaces are present on some of the thicker bands. The bioturbation is predominantly parallel to bedding allowing the preservation of a prominent bedding-parallel fabric.

Within this lithology are distinct sandstone units, often representing a marked change in facies (see Pl.3 Fig.3). These units can include coarse sandstones up to 25cm thick, characteristically lenticular and occasionally showing tabular cross-bedding though this may be more usual than can be recognised from the exposures. Phosphatic nodules and rip-up clasts of siltstone commonly occur within the thicker sandstone beds whilst some thinner examples, eg those of Pl.3 Fig.4 appear to have a concentration of phosphatic nodules on their upper surface, possibly representing slight development of a lag deposit. The abundant trace fossils are dominated by those of the Fodinichnia facies (Crimes 1970).

This sandier facies appears to dominate in the exposure
Fig. 3.3: Sedimentary log of Porth Ysgo Sandstone Member at Maen Gwenonwy (NH 19812598 to 19982602). 1: Sandstone dominated lower portion, Pl. 3 Fig. 7; 2: Distinct 'packet' of sandstones, Pl. 3 Figs. 1 & 3.
at Wig and is more prevalent towards the base of the section at Maen Gwenonwy (Pl.3 Fig.7). In the case of the latter the section is juxtaposed against the dolerite sill by a bedding parallel fault at its western end but an adjacent patch of thermally metamorphosed sandstone, resting directly on the sill, confirms the contact as intrusive.

Overlying the bedding parallel fault, just above sea-level, is an isolated zone of complex folding (see Pl.5 Figs.1 & 4) in an otherwise parallel bedded sequence. The restricted and complex nature of this folding is suggestive of soft-sediment deformation and this is the interpretation taken here, the proximity to the fault being considered coincidental.

3.2c The Junction of the Porth Ysgo and Maen Gwenonwy Members.

This is only seen in the sequence at Wig Headland (see Fig 3.2) where it is repeated by faulting and locally complicated by folding. However all the field relationships can be explained as a single bed across which there is a dramatic change in facies (Pl.3 Fig.9). The bed is approximately 20cm thick, a somewhat rusty weathering coarse quartzose sandstone with a significant amount of silty material, both in distinct streaks and as a more diffuse element of the matrix, but the most significant feature is a concentration of phosphatic nodules. A thin section has shown: the presence of quite abundant carbonate as a matrix material and cement; the quartz to be quite angular and generally strain recrystallised and polycrystalline; apparently diffuse margins to the phosphatic nodules to be the result of concentration of impurities, possibly as a result of pressure solution, and the phosphatic nodules to contain a significant clastic fraction. This clastic fraction in the nodules is generally quartz, suggesting an origin by phosphatisation of sediment, which is supported by the presence of graptolite fragments within them also. These appear to be preserved in relief as the section cuts longitudinally through a segment three thecae long. The low inclination of the thecae suggests *Azygograptus*, which would be compatible with the facies. The carbonate present does not react readily with acid, but will do so when powdered and is therefore probably dolomite.
3.2d Mean Gwenonwy Siltstone Member.

This is the most widespread and fossiliferous Member of the Wig Formation. A thickness slightly over 50m is indicated at Wig, and though the widespread occurrence of these beds in the Rhiw area suggests more, this may reflect structural duplication. It generally appears as a massive, blocky, slightly micaceous, homogenous siltstone to mudstone. However at Wig occasional composite, bioturbated sandstone laminae occur as do diffuse bands of phosphatic nodules (see Pl.3 Fig.2) though these features may be restricted to the lower part of the member. Inland, the siltstone weathers to a grey green colour, is somewhat softer and has a concentric fracture. At Benallt Mine, Rhiw it becomes nearly white in places, though this may reflect the metasomatism associated with the local mineralisation.

The fauna is summarised in Table 3.2. Azygograptus eivionicus and Merlinia selwynii are dominant, the other elements only occurring rarely. The abundance of Azygograptus and virtual absence of other graptolites is typical of the genus and is taken to indicate a relatively shallow graptolitic enviroment.

Table 3.2: Lower Arenig faunas of the Aberdaron-Sarn area.

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<tr>
<td>Trilobites</td>
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<tr>
<td>Merlinia selwynii (Salter)</td>
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<td>Hanchangolithus primitivus (Born)</td>
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<td>trinucleid 1 (aff Ryttonia)</td>
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<tr>
<td>Graptolites</td>
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<tr>
<td>Didymograptus praecucius Törnquist</td>
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<tr>
<td>Azygograptus eivionicus Elles</td>
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<tr>
<td>Azygograptus indet.</td>
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</table>

1: Benallt Mine. Number of localities given in Section 3.6.
2: Maen Gwenonwy. SH 20042598
3: Nant y Gadwen (see Fig.3.13)
4: Wig Headland (see Fig.3.1)

At all the localities the presence of dolerite bodies showing features suggestive of intrusion into partially lithified sediment has been observed. On the western side of Penrhyn Headland (SH 18582645) these take the form of thin
Fig. 3.4: Drawings of soft sediment intrusion on west side of Penrhyn Headland (SH 18582654); based on field sketches and slides. Intrusive in white; siltstone in black.
A: shows detail of contact.
B: shows irregular form of dykes.

Dykes that are extremely irregular and show lobate interdigitation with the sediment at their margins (see Fig 3.4). A similar irregular intrusive occurs at the northern end of Nant y Gadwen, although it is extremely weathered there and appears more coarsely crystalline and vesicular. The vesicularity could result from the dissolution of calcite filled vesicles which are common in the Maen Gwenonwy example. Here a thick sill has a very irregular base (Pl.4 Fig.1) with evidence of folding of the immediately underlying sediments, which, close to the junction, have been bleached white and calcitised. Locally intermixing of the dolerite and sediment has occurred (see Pl.4 Fig.3). A vertical structure intruding into the base of the sill (Pl.4 Fig.2) is interpreted as some form of fluid escape structure. Though there is no evidence of such features in the outcrop at Rhiw, they have been recognised underground. Groves (1952) recorded a number of small basalt bodies ranging up to 1m thick, and examples in the core material (Pl.9 Fig.5), are clearly comparable with the features seen at Wig.

3.3 Middle Arenig.

This division has only been recognised in the south of the area where it forms a major part of the Aberdaron Formation. The absence of proven lower Arenig west of the
Wig Fault, means the accepted view of the base being an unconformity (Shackleton 1956) needs to be reassessed. For this reason the base will be considered separately for either side of the fault.

3.3a The base of the Aberdaron Formation.

A) West of the Wig Fault.

Matley (1928) proposed that the Mona Complex was thrust over the Arenig, therefore interpreting the junction as being faulted throughout. (Fig.3.5a). However Shackleton (1956), on the basis of the four exposures of a basal unconformity, only one of which lies west of the Wig fault, interpreted this to be the more typical nature of the junction, a view that has been followed subsequently (Crimes 1970, Hawkins 1983) (see Fig.3.5b).

Fig. 3.5 Previous interpretations of the geology of the Aberdaron area. a: based on Matley (1928); b: Based on Hawkins (1983). Letters on b refer to localities discussed in text below.

There are a number of localities important in the assessment of these two views. (Localities are shown on Fig.3.5b).

a) Parwyd Bay (SH 15492436). Basal unconformity noted and figured by Matley (1926 p488 Pl.XXXI Fig.2) consisting of a thin sequence of parallel laminated arenaceous beds overlain by shales and resting on a fault-bounded block of gneiss. The outcrop is inaccessible and provides no evidence as to the local age of the unconformity. Apart from this exposure all Mona Complex / Arenig junctions in Parwyd Bay are clearly faulted.

b) Ty-tan-yr-allt (SH 16522625). This locality was specifically mentioned by Matley (1928 p496) as showing
Arenig slates underlying Mona Complex the junction being inclined at 30°. Present exposures are poor but a faulted junction would seem most likely. Shackleton (1956) did not mention this locality but mapped the junction as an unconformity.

c) Dwyrhos Quarry (SH 16752650). A large exposure of laminated siltstone yielding an abundant middle Arenig fauna and lying just 30m SE of an exposure of spilitic basement. The trilobites indicate the raphiophorid community type (Fortey & Owens 1978) and therefore a significant water depth not ideally compatible with such close proximity to a basal unconformity and perhaps makes a fault more likely.

d) Afon Cyllfelin. (SH 17272752). The small exposures of siltstone here are mapped as occurring in the corner of the Arenig outcrop, being unconformable on the schists to the NW and faulted against them to the W. The lithology is identical to that of the middle Arenig as seen elsewhere and has yielded a small number of Pseudophyllograptus cf. densus though these are not age-diagnostic. However there is no evidence for considering an unconformity to be present. To the NE, around Hendre Uchaf (SH 179279) sandier lithologies are exposed close to the same supposed unconformity. Approximately 200m NW of the farm (SH 18152806) is an outcrop of bioturbated sandstone and siltstone. The sandstone fraction is pale in colour and though still relatively fine grained, is distinctly coarser than the siltstone. The other exposure is 100m SE of the farm, where thin, 1cm thick laminated sandstones, with some cross-cutting laminae occur in otherwise typical laminated siltstones of the Aberdaron Formation. These sandstone bands also display small scale syn-sedimentary deformation features, the example figured (Pl.5 Fig.6) clearly indicating compressional deformation.

However, again there is no good evidence for assuming an unconformity. Bedding orientation is highly variable with a fold axis being exposed in the NE corner of the farm-yard, and since there is no clear evidence of the sandy beds paralelling the junction, a fault seems more likely.

e) Mynydd Ystum. (SH 187285). This is the only place in which a sandy facies compatible with a basal unconformity is seen. The best exposure is on the roadside to the SE (SH
Fig. 3.6: Roadside exposure of sandy beds (Sarn Formation) SE of Mynydd Ystum (SH 187285). and a log through this is shown in Fig. 3.6. The siltier lower portion contains somewhat bioturbated medium to fine sandstone laminae of variable lenticularity though generally fairly continuous. The sandier upper portion is mud-streaked and bioturbated but has some quite coarse grained beds ranging from quartz dominated to distinctly heterolithic with numerous mud clasts averaging about 1cm across. This exposure is not closely associated with any others either above or below but higher on the hillside at SH 18392829 there is an exposure of similar coarse beds very close to the Mona Complex. The nearest exposure of the siltstones is 80m to the SW at SH 18432922, and though this has not yielded any diagnostic fossils the lithology, and the presence of a cyclopygid eye are suggestive of the middle Arenig.

However as was noted in the introduction, the facies of the Porth Ysgo Sandstone Member (lower Arenig) and the Sarn Formation (upper Arenig) are extremely similar. The sequence at Mynydd Ystum is compatible with both and since a similar facies might be expected above a middle Arenig unconformity, the age is unresolved. The presence of middle Arenig might be taken to indicate that an unconformity is necessarily older, but on the possibility that the upper Arenig may overlap older parts of the series, this cannot be assumed.

From the above it is therefore suggested that the Arenig/Mona Complex junction is dominantly faulted. There is the possibility of an unconformity in the vicinity of Mynydd Ystum, ironically one of the few junctions those advocating an unconformity mapped as a fault, but its age is uncertain. However the recognition of the sandy beds at a possible lower horizon calls into question the Arenig that has been consistently mapped along the east flank of Mynydd Ystum. This appears to be based entirely on feature mapping with no
supporting outcrop evidence and therefore does not pose such a significant problem.

B) East of Wig Fault.

At one locality, on the west side of Penrhyn Headland (SH 18572538), a gradational junction at the top of the Wig Formation is exposed. Sandstone laminae appear, initially widely spaced, interbedded with the siltstone, but within about 6m they become abundant, and the matrix coarser and paler in colour than the siltstone of the Maen Gwensonwy Member. Above this the lithology may be considered a fine sandstone but remains finely laminated, the intermediate nature of the matrix allowing both darker, finer and coarser, lighter laminae to be distinguished. These laminae show little or no internal structure other than finer parallel lamination, and though there is banding on a coarser scale, this is formed of individual laminae at most 2mm thick. Individual laminae can be lenticular but more typically have significant lateral continuity. Some bioturbation is present and though there are occasional short vertical burrows these are not sufficient to destroy the lamination. Above these beds is a sequence of silicified tuffs 3.5 - 4.0m thick, (discussed later) but thought to represent a distinct horizon either in the top of the lower Arenig or base of the middle. The total thickness of beds between the top of the Wig Formation, taken at the first sandstone lamina, and the tuffs is approximately 35m, but as no fossils have been recovered from these the exact position of the lower/middle boundary is conjectural and has arbitrarily been taken at the top of the Wig Formation.

3.3b Lithology of the middle Arenig.

With the exception of Parwyd Bay all the middle Arenig fossil localities (see Table 3.3) and their associated sequences are developed in dark laminated siltstone. The cliff exposures on Penrhyn Headland and the western side of Aberdaron Bay, developed in this lithology, both have bedding planes extending the entire height of the cliffs. However the differences between beds are slight, representing only variation in the development of lamination and degree of bioturbation. This rock, when fresh, is dark grey in colour the laminae only being picked out by subtle variations of shade. However, when weathered, it becomes
**Table 3.3 Middle Arenig fauna of the western Liýn.**

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<td>Bergmania gibbsii (Salter)</td>
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<td>Ampyx indet</td>
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<td>Ellsaspis cf. elliptica Rasetti</td>
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<td><strong>Graptolites</strong></td>
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<td>Didymograptus aff. praenustius Fora A</td>
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<td>Pseudophylograptus cf. densus (Tornquist)</td>
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1: Dwythos Quarry, Aberdaron; SH 16722649.
2: Nant y Gadwen; (see Fig.3.13).
3: Ogof Lleuddad, at top of cliff; SH 19032557.
4: Back of Parwyd Bay; SH 15422439.
5: Outcrop at end of track c.200m WSW of Deuglawdd; SH 17272753.
6: Lay-by just outside Aberdaron; SH 18452766.

* described from South Wales (Fortey & Owens in press)
somewhat paler, this being accentuated along the fracture cleavage and certain laminae. Often the laminae are only partially highlighted by lenticular diffuse pale bands but in some cases the pale laminae are more sharply defined.

This is true of the lithology at the top of the bank just south of Dwyrhos quarry (SH 16702649), where it is also associated with a more flaggy fissility that tends to set it apart from the typical siltstone. This rock is highly fossiliferous, including an anomalous proportion of complete trilobites suggesting the depositional mechanism may have been responsible for the fatalities. However the laminae are still very thin, only 0.5cm, so if smothering is the mechanism, and there is no evidence of the specimens having been transported, considerable compaction is indicated, possibly of tuffaceous bands. This lithology is closely comparable to some associated with the volcanics of the Carw Formation.

Apart from this example, there is very little variation from the laminated siltstone in rocks of known middle Arenig age. The sandy beds around Hendre Uchaf (see d above) may be middle Arenig, but the only place sandy units of this age have been proved is Parwyd Bay (SH 15442439). Even here the sandy bands are still thin (about 1cm), but contain concentrations of fossil material in some cases, and occasionally show cross-lamination. In addition these beds are associated with very large (up to 1m diameter) nodules that display a septarian like core. These contrast from the concretions seen elsewhere, eg Porth Simdde (SH 16542623) and Porth Meudwy (SH 16382559), which have a cone-in-cone internal structure. However, the entire sequence exposed in Parwyd is not easily correlated with any other in the area, and will therefore be discussed separately.

Though the Aberdaron formation probably includes a significant thickness of upper Arenig it seems likely that the laminated siltstone is characteristic of the middle Arenig. 50m of such beds can be recognised in the valley west of Porth Meudwy and whilst 100m+ could be present in the section of Penrhyn Headland, its inaccessibility renders this estimate unreliable.

3.4 Upper Arenig

The recognition of the Carw Tuff Formation as a marker
horizon approximating very closely to the Arenig/Llanvirn boundary, and developed throughout the area, has considerably aided distinction of the upper Arenig. This is particularly significant in that it has highlighted considerable regional facies variation.

In the north, the Sarn Formation may well be entirely of upper Arenig age and rests directly on the Sarn Granite. In the south the division is more poorly characterised, the majority of biostratigraphical control being associated with the Carw Tuff Formation itself. The Aberdaron Formation is taken to include the entire sequence between the Wig Formation and the Carw Tuff Formation, and therefore the majority of the upper Arenig. However in the only section where the sequence can be examined in detail, Porth Meudwy (see below), rocks of this age do appear to be distinctive. No other significant sequence of known upper Arenig age has been identified south of Mynydd Rhiw, and therefore it is not proposed as a separate formation since lateral equivalents may be lithologically identical to the middle Arenig.

Because of the significant lateral variation the division will be considered separately in each area for which there is a distinctive sequence.

3.4a Porth Meudwy (SH 164255) to Pen y Cil (SH 156242).

Fig. 3.7: Annotated sketch of Porth Meudwy as seen from the south.

The best exposed section in this area is that of Porth
Meudwy and the valley to the west. The sequence in the valley is not well exposed and that of the bay is of much greater interest. Faulting is obvious, the offsets being shown by distinctive marker horizons (see Fig.3.7). The bedding parallel fault exposed in the cliffs on the north side (marked on Fig.3.7) apparently terminates against, or is offset by, the EW vertical faults since it cannot be found developed in the wave-cut platform of the bay. However there is a suggestion that the sequence of siltstones exposed in the cliff is thicker than that in the apparently unfaulted section, but this may reflect duplication in the lower part of the sequence close to the bedding parallel fault.

The sequence in the bay may be summarised as follows.

Dolerite Sill

5 Tuffs & interbedded sediments 10m Carw Tuff Formation.

4 Sandstone and siltstone 7m

3 Mass Flow conglomerates 22.5m Porth Meudwy Member.

2 Siltstone with sandstones 25m

1 Bioturbated sandstone & siltstone 36m

Up to 50m of sandy siltstone comparable to that of the lower part of the sequence may be present in the valley to the west. The presence of *Tetragraptus reclinatus* s.l. Elles & Wood in the lowest exposure of this lithology is suggestive of the upper Arenig though cannot as yet be considered diagnostic. Sedimentary logs of the lower and upper parts of the sequence are shown in Figs. 3.8 and 3.10 respectively.

1) Bioturbated Siltstone and Sandstone.

Normal weathering gives this unit a massive thick bedded appearance with a slightly rusty surface, seen developed in the valley and the upper parts of the bay’s cliffs. The bedding appears to reflect varying homogeneity, apparent in wave polished surfaces, ranging between very distinct light–dark banding to a fairly homogeneous appearance with only diffuse streakings of both darker and lighter material. Even in the well banded lithologies the variation in grain size does not appear very great, the darker lithology being a coarse siltstone with the paler a fine sandstone. In the more homogeneous units the dominant lithology is a dirty
Fig. 3.8 Sedimentary log of lower part of Porth Meudwy section measured along north side of bay (Aberdaron Formation.) Notes: 1: Soft-sediment deformed unit, Pl.6 Figs.1, 3, & 7; Pl.7 Fig.7; 2: Tuff Bed, Pl.6 Fig.3; 3: Pl.7 Fig.3; Pl.8 Fig.5; 4: Pl.6 Fig.4; 5: Pl.6 Fig.6; 6: Pl.6 Fig.5; 7: Pl.7 Fig.5; 8 Pl.8 Fig.7; 9: Pl.6 Fig.8; 10: Fig.3.9; 11: Pl.8 Fig.8 of silt dominated sequence.

Fine sandstone, the streaks reflecting only a variation in proportions of the dark and pale fractions within this.

Whilst there may be some variation in the primary mode of deposition it is thought that bioturbation is a significant factor in the homogenisation.

The trace fossils present have not been studied in detail but some comment seems necessary since variation appears to be correlated with homogeneity of the lithology. In the units displaying clear banding the vertical element of the bioturbation is represented by relatively short (2cm) burrows that may or may not be spreite filled. In some cases
silt-filled examples only penetrate the upper part of a sandstone bed indicating a single depositional event. In one example two such beds converge, but the silt filled burrows remain present in the lower suggesting the erosion of an intervening silt layer. The more homogeneous units show more complex bioturbation and this is characterised by long (30cm) spreite filled 'burrows' both perpendicular and oblique to bedding. Since these are only seen in section, their three dimensional form is uncertain, and they may therefore be related to another structure present. This consists of irregular 'laminated' patches, the lamination being inclined to bedding. These could be interpreted as relict cross-lamination, but in neither form nor scale are they compatible with the primary lamination recognised, though are closely comparable with other examples of spreite. Horizontal bioturbation is also present, and is locally dominant over the vertical.

Primary sedimentary structures are uncommon. Loading is prevalent where banding is distinct, and flame structures are developed in some examples (see Pl.6 Fig.6). The irregularity of the upper surfaces of the sandstone bands may result solely from bioturbation, but their overall form suggests some degree of fluid behaviour by both silt and sand fractions. No certain examples of cross-bedding have been observed in outcrop but in fallen blocks associated with the bedding plane fault is one that appears to contain sigmoidal cross-bedding and another suggestive of hummocky cross-stratification. However these also appear to be associated with some form of soft sediment deformation and will be considered further under that heading.

Within the sequence there is a 2m thick tuff bed that is the means of correlation across one of the faults. This appears to be slightly finer at the base, which is parallel laminated, whilst the main body is massive and has a medium grade sandstone appearance. The massive part has a distinctive curving fracture pattern picked out by weathering (see Pl.8 Fig.3) whilst the presence of siltstone rip up clasts suggests aqueous deposition.

Syn-sedimentary deformation.

This divides into two distinct types: examples in which the sediment has undergone precompactional brittle failure,
and examples where the sediment has behaved in a soft, fluidised manner, possibly synchronous with deposition. However the two elements are not mutually exclusive.

A: Soft sediment glides. These are by far the most difficult structures to interpret especially since they commonly have an appearance comparable to cross-bedding and may even be associated with this. The examples most readily interpreted as slides occur along a single horizon approximately 10m below the tuff. This can be traced laterally for 10m but no sedimentary termination is seen, and it is c.1.5m thick. The units affected show less bioturbation than is typical of the sequence but some parts do contain burrows.

The base of the unit appears to be approximately horizontal, with no clear evidence of cross-cutting either parallel or perpendicular to strike. It consists of a series of ‘packets’ of sediment that cross-cut each other or are separated by zones of homogenisation. Within a given ‘packet’ the internal laminae appear to parallel the lower surface, which is usually curved and cuts across the laminae below, whilst at the upper surface they are truncated. There does not usually appear to be significant internal deformation of the units but some examples of this are present. Most problematic are the zones of homogenisation. These appear to both separate ‘packets’ and to cross-cut them also. Since there is evidence of relic lamination within these homogenous bands that is continuous with that of the bounding units, some form of in-place homogenisation seems most likely. These structures may therefore result from the expulsion of fluid and its subsequent movement through the sediment, both carrying material with it and homogenising that through which it passes.

The blocks associated with the bedding plane fault superficially resemble the structures just described but in these there appears to be clear evidence of the association with cross-bedding. The best example of this is shown in Pl.6 Fig.3 which appears only explicable as sigmoidal cross-bedding but there are also rapid lateral changes in thickness that seem to be associated with cross-cutting relationships. The presence of excess fluid is once again indicated by the load structure and may be associated with
fluid escape, possibly along the line of cross-cutting. Another block appears to have clear evidence of synsedimentary deformation in the lower half whilst the upper half has cross-cutting relationships most compatible with hummocky cross stratification.

It is possible that the unit described first results from the more extensive fluidisation of a cross bedded sequence like that seen in the blocks. This would easily account for the restricted thickness in which these structures are developed but it is doubtful that cross-bedding alone could account for all the cross cutting relationships seen, and therefore some lateral transport of very soft sediment seems likely, with associated fluidisation. It may be noted that brittle fractures, comparable to those discussed below, offset structures within the unit clearly showing they post date the soft-sediment deformation.

B: Brittle failures. These are sharp lines of displacement, with the rocks on either side showing no evidence of deformation. There appear to be two modes of occurrence:

a) As isolated lines in relatively undeformed sequences (Pl.6 Fig.6).

b) As pervasive fractures throughout a volume of rock (Pl.7 Fig.3).

These structures are closely comparable in scale to those described from the Helmsdale fault area (Pickering 1983) and the Muschelkalk (Schwarz 1975). The rotation across the isolated fractures is minimal, but can be extreme in some of the pervasively faulted material. This could be accounted for by brittle fracturing of a slump fold (eg Schwarz 1975 p.53 Fig.19a) but the only example in the sequence (see below) shows no evidence of faulting. A second and more likely origin is the internal fracturing of a rotated block, an example of which has been recognised (Pl.7 Fig.5). This would appear to have been a superficial process and the pervasive fracturing observed would be compatible with the incipient formation of a breccia. The isolated faults are likely to be the lines along which the blocks separated and the origin of these faults could either be in response to a slope or hydrodynamic fracturing. The apparent presence of abundant water has already been emphasised above, and to
this may be added an example of fluidisation which underlies banded rocks showing significant brittle failure. (Pl.6 Fig.5). The fluidised band appears to have significant lateral continuity, and shows various flow structures throughout. It may either represent a neptunian intrusion or the base of a larger scale slump structure.

The majority of synsedimentary fractures associated with deformation of this part of the sequence appear to be extensional, with both normal and listric faults being recognisable.

C: Slump folding. Only one example of this has been seen (Pl.6 Fig.4). It affects a 50cm thickness of sediment, and appears to have a truncated lower limb. Though it occurs in an horizon that shows brittle fracture (see 3 below) there is no evidence of this affecting the fold structure. The slump fold may represent an earlier phase of precompactional deformation though the absence of fractures suggests the possibility that it represents a body of sediment that underwent plastic rather than brittle deformation.

The abundant vertical spreite-filled burrows and various evidence for a high fluid content of the sediment both suggest rapid deposition. The synsedimentary deformation could result from hydrodynamic fracturing but it is suggested that a more likely mechanism is instability induced by fault movement. The extensional nature of the fracturing suggests a position on the upper part of the slope down which sediment was moving.

2) Siltstone with thin Sandstones.

The junction with the overlying sequence is relatively sharp with a dramatic increase in the proportion of siltstone but sandstone bands are slightly more abundant at the base of this unit than is typical of the lower part as a whole. The sequence is dominated by siltstone with thin sandstones interbedded, the latter increasing in abundance towards the top, almost to dominance.

The sandstone bands appear to be fairly laterally continuous, though lenticular terminations can be found. The thicker examples (3-5cm) can be distinctly coarse grained, containing occasional gravel grade clasts and phosphatic nodules, with the dominant grain size being a coarse sandstone. Thinner examples often tend to be somewhat finer.
The internal structure of the sandstones is not clear. Both normal and inverse grading appear to be developed, along with occasional parallel lamination. The upper and lower surfaces of the sandstones tend to be extremely irregular, resulting from both loading and bioturbation. In some cases loading has resulted in the fragmentation of the sandstone beds (Pl. 8 Fig. 7).

Syn-sedimentary deformation.

The major difficulty in recognising any synsedimentary deformation in this unit is that it displays numerous structures associated with broadly E-W faults and shear zones. However, because of this association with the fractures such structures tend to occur in elongate zones perpendicular to the strike. Ignoring these, a number of structures remain that are probably of syn-sedimentary origin. These differ from those seen in the underlying sequence in that they appear to be dominantly compressional in nature, with sandstone beds being folded (see Pl. 6 Fig. 8) and faulted. The latter is dominantly reverse faulting (Fig. 3.9a) and there are a number of examples of sandstone bands riding over-themselves, producing significant duplication (Fig. 3.9b).

These structures can only be observed in the lower part of the sequence but probably extend throughout. It is not entirely clear at what point in the succession the change from extensional to compressional deformation occurs. The sandier basal part of the siltstone sequence does appear to be slightly faulted and this is probably extensional. The change therefore appears to occur just above this, and hence the change in facies probably also represents a change in the syn-sedimentary structural position, from an up-slope to
down-slope environment.

The change to the facies represented by the Porth Meudwy Member is very sharp. The base of this sequence appears to cross-cut the underlying sandstone bands, whilst at the same time being planar and parallel to bedding. The interpretation suggested is that the beds underlying the debris flow were deformed by its passage hence producing the cross-cutting. This tends to be supported by the attitude of the truncated sandstone beds which is not parallel to the normal bedding.

3) Porth Meudwy Member.

This is a mass flow dominated sequence (see Fig.3.10) exposed on both the north and south sides of bay and on Pen y Cil. However, neither comparable beds nor likely lateral equivalents have been recognised away from the above except possibly in Parwyd Bay. Despite this very restricted distribution there is relatively close comparison between the various exposures especially with regard to the basal bed (Pl.7 Fig.4). This is distinct from the rest of the sequence in consisting almost entirely of siltstone blocks, up to 30cm across, comparable to the lithology of the underlying sequence, in a gravelly silt matrix, the finer fraction of which is identical to that forming the clasts. The overlying bed is also distinct from the rest of the sequence in containing relatively little silt grade material and is dominated by angular schist clasts about 2-5cm in length. A similar dominance of schist clasts has also been observed in the bases of several other beds. These display a graded lower portion developed by the schistose material below an equally thick part of finer material but containing synsedimentary clasts that are significantly larger than any seen in the basal part (Pl.7 Fig.2; Pl.5 Fig.7) The mechanism of deposition of such units is! not clear and appears to be a mixture of turbiditic and debris flow processes.

The majority of beds are more massive and appear to be typical of debris flows, the matrix being a muddy gravelly sandstone containing large, deformed, synsedimentary clasts (Pl.7 Fig.6). Large clasts of extraformational origin are less common; the largest schist clast seen is angular and <10cm, but a rounded sandstone clast 15cm across may be
Fig. 3.10: Sedimentary log of Porth Meudwy Member, Porth Meudwy, (north side).
1: Pl.7 Fig.4
2: Pl.7 Fig.2
3: Pl.7 Fig.6
* star: Fossiliferous siltstone.
considered to belong to this category.

As can be seen from the log (Fig. 3.10), in the lower part of the sequence there are lenticular conglomeratic bands with evidence of finer sediments being interbedded whilst in the upper part the debris flows appear to rest directly on one another except at the very top. Despite the chaotic internal nature of many of the beds the sequence retains a well bedded appearance in outcrop and no evidence has been seen of the washouts mentioned by Crimes (1970).

One further feature of note is the presence of phosphatic oncolites associated with a mass flow deposit exposed in a field to the south of the bay (SH 16302522). Since these appear to be in a siltstone matrix overlying a conglomerate they may be contained in an interbedded finer sequence rather than a mass flow. However massive phosphatic clasts do occur in the mass flow units.

4) Sandstone and siltstone.

These are in many respects comparable to the lower beds of the bay displaying bioturbation etc., and do not warrant further comment except that their weathered character appears finely bedded rather than massive.

5) Tuffs: Carw Formation.

The recognition of the tuffs in this section is more difficult than elsewhere because they are altered by the dolerite sill. However, a typical example of the tuff is seen in the bed directly below the sill; this has the normal pale weathering colour and shows ripple, convolute and parallel lamination. There appears to be a much higher proportion of interbedded sediment in this section than elsewhere and fossils have been collected, during this study, from the siltstone 5m below the dolerite. Only three species have been identified Cryptograptus tricornis schaeferi Lapworth, D. aff nicholsoni Lapworth and Pseudoclinaco-graptus sp., but these are adequate to indicate an uppermost Arenig to lower Llanvirn age; the former being favoured by the common apperance elsewhere of pendents directly above the tuffs.

3.4b Afon Daron. (SH 190274)

Though it is suggested that upper Arenig strata may be absent in this section, it is considered here because Matley (1928) correlated what he termed the Daron Cherts (SH
with the tuffaceous beds of Porth Meudwy. However he considered the overlying shales seen in the Afon Daron section to be lower Arenig in age, whilst if his correlation of tuff beds is accepted, the new evidence from Porth Meudwy would suggest these shales are Llanvirn. To test this an attempt was made to collect a fauna from the previously barren shales. The discovery of *Platycalyxene* sp. with biserial and pendent graptolites (SH 18982741) confirmed the predicted Llanvirn age. On closer examination the tuffs in Afon Daron were found to be generally coarser than is typical of the Carw Tuff Formation and it is thought more likely that they are somewhat younger, tuffs of Llanvirn age occurring elsewhere in the area (see Sectn.3.5). It is therefore tentatively suggested that the siltstones to the north, underlying the tuffs, are also Llanvirn in age though as yet there is no biostratigraphic evidence to support this. The lithology of these beds favours this interpretation, being similar to Llanvirn, but unlike any upper Arenig age strata identified.

3.4c Nant y Gadwen. (SH 210265 to SH 212268)

This valley contains two thin fault-bounded sequences of upper Arenig age, but these are important because of their prolific fauna. Whilst exhibiting distinct differences in both fauna and lithology, they do share important elements of the former and both are probably best placed within the Carw Formation. A map of the valley is shown in Fig.13.14 (Sectn.3.6).

a: West side of Valley.

This sequence consists of flaggy sandstones overlying typical silicified tuffs of the Carw Formation on which criterion the sediments are included therein. The sediments are grey in colour and parallel laminated, with the laminae ranging from dark to pale and occasionally almost white. There appears to be little variation in the grain size, which is typically a fine sandstone, distinctly coarser and harder than the siltstones seen elsewhere. These beds contain abundant graptolites, including a range of isograptids, indicative of a significant water depth open to the ocean (Fortey 1984). Graptolites are often preserved as pyritic internal moulds, though flattened periderm preservation is also present. The fauna is summarised in
Table 3.4 with a more detailed distribution given in Table 3.5. The beds strike parallel to the valley side thus exposing only a small thickness, though the evidence to the west suggests that it is also restricted by faulting.

Fig.3.11: Linear load structure from west side of Nant y Gadwen. Found in loose block, therefore way-up interpreted. Pale, ?coarser band stippled.

Sedimentary structures are rare apart from the parallel lamination, but the presence of occasional parallel aligned graptolite lags, comparable to those described by Williams & Rickards (1984 p162), and a linear lode structure suggest some current activity. The linear lode structure (Fig.3.11) appears to have resulted from differential loading initiated by thickness changes in the upper band as indicated by 'steps' in the top surface, the material having moved from the thicker parts of the layer under thinner. Since this feature was observed in a loose block the way up had to be inferred, and this was based largely on the above interpretation, supported by the downwarping of the underlying laminae. The only internal structures of the loaded band is parallel lamination, somewhat convoluted where associated with the loading. The way up and absence of cross lamination set this structure apart from the superficially similar load casted ripples figured by Allen (1982 p.376 Fig.9.22).

B: Northern end of Valley.

This sequence consists of a vitric tuff just under 5m thick within a sequence of strongly parallel laminated siltstones, about 10m being exposed below and 3m above. The siltstone has a marked differential colouring of the laminae, some pale laminae having diffuse margins as a result of reduction of the bounding dark laminae. It is likely there is a significant volcanic influence in this
Table 3.4 Upper Arenig fauna of the western Llŷn.

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<td>Pseudisograptus cf duموسus (Harris)</td>
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<td>Brachiograptus cf etaformis Harris &amp; Keble</td>
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<td>Pseudocliaacograptus sp</td>
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* described from South Wales (Fortey & Owens in press)

1: West side of Nant y Gadwen
2: Northern end of Nant y Gadwen
3: Nant y Gadwen, position uncertain.
4: Benallt Mine
5: Porth Meudwy (+ track to west in brackets)
6: Bryncroes (Sarn area in general)
banding. The beds overlying the tuff are highly fossiliferous see Table 3.5.

3.4d Benallt Mine and Mynydd Rhiw (SH 2228 to 2330)

Few sediments are exposed in this region but it is of importance because at least one thick pillow lava associated with the Carw Tuff Formation is exposed there. The pillows are best seen on the western slopes of Mynydd Rhiw (SH 22652915), where silicified tuffs rest directly on this lava (SH22782947 & SH 22312809). The presence of a second lava (Matley 1932) has not been confirmed, but considering the similarity of the massive portions of the lava to supposed dolerite sills, and their comparable spilitic composition (Hawkins 1967), confusion of the two is quite possible. One other point of note is the presence of the ignimbrite recognised by Hawkins (1967) on the eastern slopes of Mynydd Rhiw (eg SH 23342963). These features possibly suggest closer proximity to the volcanic source.

There is a small fossiliferous exposure of the Carw Formation in the west face of the lower quarry of Benallt Mine (SH 22172818) with a continuation in the rubbish filled quarry to the south (SH 22172804). The thin sequence exposed is developed in pale weathering, somewhat cherty, tuffs with intercalated laminated siltstones that vary from pale cream to dark grey in colour, though the former colouration is probably secondary in origin. The fauna from this locality is given in Table 3.4. These exposures are separated from the pillow lava by a thickness of the lower Arenig Maen Gwenonwy Siltstone Member.

The manganese ore of Benallt Mine and Nant-y-Gadwen has generally been taken as a stratigraphic marker horizon (Matley 1932). The biostratigraphic evidence obtained during this study suggests a more probable association with faulting. Doliths and other primary structures are present, and appear to have been the basis of the sedimentary interpretation. These may well be of upper Arenig age but will be considered further in the context of the mining belt as a whole.

3.4e Sarn Area. (SH 2332)

Basal Unconformity.

On recognition of the Sarn Granite / Arenig junction as an unconformity (Matley & Smith 1936) it was suggested that
it might lie at a higher horizon than to the south. There is a considerable reduction in the thickness of the Arenig in this area and neither the lithologies nor the fossils characteristic of the lower and middle Arenig to the south have been found. Secondly, even when the termination of the Ty Ruttan sill is taken into consideration, the pillow lava approaches closer to base of the series in the north (SH 23453324) than it does in Nant y Carw (SH 23373238). This may indicate the presence of two flows but more probably reflects further northward thinning.

The only exposure of the base is at Mountain Cottage Quarry (SH 23003470) (Matley & Smith 1936). Owing to the deterioration of the exposure little can be added to their original description. The basal bed is thin, usually less than 10cm thick, with clasts >1cm being rare and though Matley & Smith recorded a clast approaching 8cm they implied that this was an isolated occurrence. The dominant lithology is a coarse arkosic sandstone with scattered gravel clasts. Gibbons (1980) notes a dominance of granite clasts but also recognises fragments of Penmynydd Schist and pyroclastic debris. Overlying the basal bed is 1-40m of grey green mudstone that then gives way to the more sandy lithologies typical of the Sarn Formation.

**Sarn Formation.**

The base of the Sarn formation is taken at the unconformity, includes all the sequence to the base of the Carw tuff Formation and is dominated by sand streaked siltstone though there is considerable variation in the range of grain size of both fractions; the finer from mudstone to fine sandstone and the coarser from fine to coarse sandstone. The coarsest grain size appears to be associated with sandstone dominated portions and thicker sandstone beds. Such are seen close to the base in Mountain Cottage Quarry and in the base of the lane at SH 23253263. Coarser sandstone material is also seen higher in the section directly underlying the Ty Ruttan sill (SH 22963212). Here a thin, sandstone-dominated sequence is present including a 5cm thick bed apparently showing inverse grading and abundant mud clasts up to 3cm in length. Associated lithologies include thin medium-coarse sandstones separated by shale laminae.
The more characteristic lithology is shown in Pl.5 Fig.10; Pl.7 Fig.8 and consists of irregular sandstone lenses and laminae in a finer matrix. Mud drapes pick out cross-sets in some of the lenses and some loading may be present. However the latter is difficult to distinguish from the bioturbation that is present in all but the thicker sandstone beds. Though vertical burrows are present, horizontal examples are more common, their circular cross-section showing them to be infaunal.

Azygograptids and lingulids have been recovered from the finer laminae at three localities; SH 23053327, SH 23173150 & SH 22853114. A specific identification, *Azygograptus lapworthi* Nicholson, can only be made on the specimens from the second locality, but this supports an upper Arenig age for the sequence (see Chap.11).

A pillow lava occurs within the formation, and is best exposed in Nant y Carw (SH 23383238) and in the quarry on the north side of the road (SH 23423245). It appears to thin and disappear quite rapidly to the south, and though it cannot actually be traced to the north, outcrops at SH 23583301 & SH 23553324 appear to represent a continuation there, with the latter approximating to the northerm termination. Pillows are moderately well displayed in Nany Y Carw and the associated quarry, often picked out by interstitial cherty material.

Directly overlying the lava are lithologies that may reflect the topographic change produced by the flow, and are probably associated with the formation of an ironstone. They can be seen at both the basalt exposures, though the northern sequence is somewhat coarser and contains a higher proportion of matrix. These beds are at most 1.8m thick, and are coarse sandstone with clasts ranging upto gravel grade. The arenaceous material is dominated by highly strained quartz, presumably derived from the Mona Complex, with subsidiary plagioclase, collophane nodules (containing no clastic material), siltstone clasts and possible schist clasts. In some cases the apparent clastic fraction is exaggerated by the presence of abundant authigenic quartz. The incipient development of an ironstone is indicated by the presence of scattered ooliths, often spastolithic, and the rusty weathering. The former represent an additional
clastic element and are rarely dominant, but the matrix occasionally has a very bright green colour in thin section, suggestive of chamosite, which may well be the main source of the iron.

There is no exposure above these beds in Nant y Carw but to the south, near Ty Fair (SH 233316), there is evidence that typical Sarn Formation facies continue to the base of the Carw Formation.

**Carw Tuff Formation.**

This is well exposed in Nant y Carw (SH 23553231) and to the south near Melin Trygarn (SH 23503175). At their type locality the tuffs are about 15m thick and are dominated by pale weathering, hard siliceous lithologies. These will be discussed further under the volcanics. The top of the tuffs in Nant y Carw is intruded by a dolerite sill but resting on this are parallel laminated siltstones closely comparable to those seen at the northern end of Nant y Gadwen. Pendent graptolites are present in the siltstone above this (SH 23513228) confirming again the stratigraphic position of the Carw Formation.

The stream section near Melin Trygarn appears to have an uninterrupted section across the boundary part of the sequence, though, as a result of thermal metamorphism, the only fossils found are in the Llanvyrn. This sequence adds little lithological detail other than showing there to be a 10m thickness of siltstone between the tuffs and rocks of proved Llanvyrn age. These contain sandy laminae in the top 2m.

Though the Llanvyrn can be proved to the north of Sarn in the valley of Afon Soch (SH 23843343 to SH 23833328), the Carw Formation has not been identified with certainty there.

3.4f Parwyd Bay (SH 153241)

The lithologies mentioned in the description of the middle Arenig occur at the back of the bay and the fossils these contain provide the only biostratigraphic control for the 60m+ sequence exposed along the west side. This therefore indicates that the entire sequence occurs above beds of late middle Arenig age, on the basis of the presence of the trinucleid *Bergania gibbsii*. The sequence divides into two main elements: a lower siltstone with sandstone interbeds and an upper packet of thicker bedded sandstones
that appears to continue into the much faulted sequence terminating the exposure. The two units are readily apparent in Pl.8 Fig.4.

In the NW corner of the bay, just above known middle Arenig, sandstone beds are quite abundant and up to 10cm thick (Pl.8 Fig.1). Despite the extensive tectonic faulting of this unit, some of the fractures have a suggestion of being syn-sedimentary (see Pl.7 Fig.1 also). Just above this, sandstone beds become less abundant being only about 1cm thick and on average 15cm apart. However within 18m they start becoming thicker (5cm-20cm) and more closely spaced, after which they remain abundant to the base of the sandstone dominated unit. The only sedimentary structure these sandstones display is parallel lamination, and though some, especially the thicker examples, are graded, none reach more than medium sandstone. The sandstones are sharp based with only very fine scale loading apparent, whilst the upper surfaces may merge with the siltstone or be sharp depending on the extent of grading. Bioturbation is virtually absent.

The incoming of the packet of sandstones is exaggerated by the faulting, but considering the comparability of facies with the beds below, movement is probably not great. The sandstones are 10-50cm thick, and only separated by thin siltstone bands. Internally they show only parallel lamination and no evidence of grading. As below, the maximum grain size is a medium sandstone, though coarse sandstones are present in the highly fractured zone above.

Though the obvious correlation of these beds is with the sequence seen in Porth Meudwy, the lithological comparison is slight and therefore the equivalence of the units is uncertain. In addition, a sequence the same as that of Porth Meudwy is seen on Pen y Cil just 250m to the east, and even allowing for the extensive faulting this still represents a dramatic facies change for the separation. Since graptolite fragments have been found just below the sandstone dominated unit, detailed collecting may provide biostratigraphic control on the sandstone packet, at which time a more detailed correlation might be possible.

3.5 Volcanics

The usefulness of volcanics, both as stratigraphic
markers and in the interpretation of the broader plate tectonic setting is dependent on the accuracy with which they can be placed within the sequence. As noted, the Carw Tuff Formation forms a useful stratigraphic marker, but in nearly all cases the confident recognition of this horizon is based on corroborative biostratigraphic evidence. However there are a significant number of additional volcanic units in the western Llyn of less certain stratigraphic position and correlation.

The main problem in correlation of the volcanic horizons in this area is that faulting and poor exposure, associated with lateral facies changes, precludes the recognition of a continuous stratigraphic section, so that the number of volcanic horizons present is uncertain. The lithological variation apparent offers a potential means of correlation but two factors reduce the reliability of this: the potential for rapid lateral variation and features resulting from secondary alteration.

Secondary alteration commonly affects the tuffs. Though silicification is often associated with intrusions, does not appear to result from thermal metamorphism (Matley 1932 p267) and as it seems to affect the Carw Formation in particular it may partly be a primary lithological character. The low grade regional metamorphism is the other main mode of alteration and makes distinction of crystal, lithic and vitric tuffs difficult. Thin sections do allow at least some separation of these lithologies but the following discussion is based mainly on macroscopic observations.

The main occurrences of pyroclastic rocks are recorded below, being treated for different stratigraphic intervals in turn. Considering the uncertainty of the stratigraphic horizon in a number of cases, the assignment is often tentative, and the main evidence is therefore indicated.

3.5a Lower to middle Arenig.

The best evidence for a tuffaceous unit in the lower part of the succession comes from the sequence at Penrhyn Headland (see Sectn.3.3aB). These tuffs form a bedded sequence about 3.5-4.0m thick. The dominant lithology is pale both on the weathered surface and internally, almost approaching white. Though generally fine grained the variation in texture may reflect some differences in grain
size. The closely comparable tuff sequence exposed in the cliff NNW of Bodernabwy (SH17332736) may be equivalent, but there is no direct faunal control, and considering the uncertainty in the structure of that area, extrapolation is unreliable.

A couple of other isolated occurrences of tuffaceous lithologies of possible middle Arenig age occur in the Aberdaron area, and both are very small. The more exotic occurs 300m W of the exposure near Bodernabwy, at SH 17652743, and consists of pale grey, fine grained, angular clasts up to 2cm across in an otherwise normal siltstone matrix (Pl.3 Fig.5). A thin section of this rock is difficult to interpret, but the presence of small idiomorphic plagioclase crystals in the clasts tends to support a volcanic origin. The other tuffaceous bed occurs in the track at Hendre Uchaf (18042804) and is a homogeneous buff-grey fine grained hard lithology. A couple of other similar beds are also present and these are all interbedded with moderately dark siltstone.

3.5b Upper Arenig (sub Carw Formation).

The only example that can confidently be placed in this stratigraphic position is the tuff bed of Porth Meudwy (see Fig.3.8). This consists of a parallel-laminated and paler lower 20cm overlain by a more massive unit, the total thickness being approximately 2m. This bed is comparable to that of known upper Arenig age at the northern end of Nant y Gadwen. In hand specimen the latter has a rusty brown colour and massive appearance, with a poorly developed parallel fabric apparent on the cut surface, whilst in thin section glass shards can be recognised. However it may be noted that the strongly parallel laminated unit within which this bed occurs is distinctly different to the bioturbated siltstones of the Porth Meudwy example.

3.5c Carw Tuff Formation.

This has been the most widely recognised volcanic horizon in the area. Traceable aTong strike to the SE of its type locality it is probably the same horizon that is interbedded with the basalts on Mynydd Rhiew and though the tuffs seen in the mine workings themselves are somewhat softer and paler in colour, they are probably referable to this horizon. Further correlated exposures occur on the west
side of Nant y Gadwen and in Porth Meudwy, but as has been noted, the tuffs of Afon Daron thought to be equivalent to those of Porth Meudwy (Matley 1928), may be at a slightly higher horizon and are therefore discussed below.

The main feature of this formation is the very pale weathering surface, often associated with a very dark internal colour, though this is somewhat variable. The lithologies are extremely hard, very fine grained and often develop a very angular jointing this producing flat faced blocks. Coarser grained tuff varieties are virtually absent. Internal structures are only apparent on the weathered surface and include parallel, ripple and convolute lamination, complex examples of the latter being suggestive of flow banding (Pl.5 Fig.8), though the others indicate subaqueous reworking and deposition.

3.5d Llanvyrn: Post Carw Formation.

Only one occurrence of known Llanvyrn age has been recognised, this lying between the dolerite sills E of Nant-y-Gadwen (SH 21152626) from which Matley (1932) recorded pendent graptolites. These tuffs are much coarser grained than those of the Carw Formation and are probably predominantly lithic.

Other examples assigned to the Llanvyrn are more conjectural. The regional criteria on which the Afon Daron sequence (SH 19082746) may be considered such have already been mentioned. The lithologies of the volcanics themselves also seem to support this, in that, though pale fine grained types are present many of these dust tuffs remain quite dark even on the weathered surface, and the upper part of the sequence contains a significant proportion of crystal, lithic and vitric tuffs.

Coarser grained tuffs are also seen in the quarry above Ebolion (SH 18872523), though it must be pointed out that this horizon is close to a 'chert' band noted by Matley (1932 Fig.1 p243) in the cliff section, that could represent the Carw Formation. The lithologies present in the quarry include a very coarse clastic rock (Pl.5 Fig.9) of dark angular, somewhat imbricated clasts within a pale matrix that appears coarse on the weathered surface, though this texture may not be a true reflection of the actual grain size. Other lithologies present include scattered crystals
and patches of very pale sandstone within siltstone, the latter being comparable to lithologies seen N of Sarn (SH 23783372). It may be noted that though the Carw Formation has not been recognised north of Sarn but the volcanogenic lithologies seen probably approach closely to that horizon, which extends the comparison with those seen above Ebolion.

In summary, therefore, volcanism is probably more stratigraphically widespread in the area than has previously been thought, but this limits the use of the deposits as stratigraphic markers at the present level of understanding.

3.6 The Manganese ore of Rhiw and Nant y Gadwen.

Until now this ore has been considered stratiform in nature and has been taken as a marker horizon within beds of \textit{D. hirundo} biozone age, ie upper Arenig. (Matley 1932, Crimes 1970). This was despite the recognition that:

1) The ore has clearly been produced by alteration of other lithologies. (Matley 1932 p263)

2) The ore deposits display considerable structural complexity, eg Matley (1932) said of the ore at Nant y Gadwen:

"This bed has been so greatly affected by earth movements that it tends to occur in wedges and lenticles surrounded by highly sheared and slickensided soft shale."

and Groves (1944), commenting on the wartime workings at Rhiw said:

"As the modern mine developed, Benallt was found to have perhaps the most complex structural geology of any British metalliferous mine now operating."

Considering this the stratigraphic interpretation is slightly surprising, but there appear to have been two main factors leading to such a conclusion. First; a consistent stratigraphic position. Nant y Gadwen had been considered a normal sequence younging east across the \textit{extensus-hirundo} junction (Elles 1904) and Matley (1932 p260-1) listed fossils from both Nant y Gadwen and Rhiw (identified by Elles) as indicating the \textit{hirundo} biozone. Second; there is the pisolitic and oolitic nature of the ore that suggests comparison with other sedimentary ores.

This study has shown the claimed stratigraphic correlations to be a oversimplification, and this will be considered prior to any examination of the petrographic evidence. Two references may be noted at this stage. The first, Groves 1952, deals with the geology of the mines in
some detail whilst the second, Down 1976, contains greater
detail on the actual workings themselves.

3.6a Benallt Mine, Rhiw.

As was noted by Groves (1947 & 1952) the ore is
contained in a siltstone lying between the Lower Clip Lava
to the east and the largely unexposed Footwall sill to the
west. Only dolerite is exposed to the west of the sill
and therefore the age and nature of the underlying sequence
are unknown. Resting directly on the Lower Clip Lava, as
noted above, are exposures of the Carw Tuff Formation of
upper Arenig age. The only exposures of the ore belt itself
are those of the previous opencast workings and a couple of
adits. However these are sufficient to provide some
important biostratigraphic evidence.

The dominant lithology is a pale to medium grey-green
weathering siltstone in outcrop, with loose blocks from the
workings, showing a much harder, darker and blocky nature
typical of the lower Arenig Maen Gwenonwy Siltstone Member.
Faunas confirming this age have been recovered from:
1) Loose material associated with a small scrape below Clip
y Gylfinhir, (SH 22322847)
2) A small adit SSW of 1. (SH 22252822)
3) A number of places in the main opencast workings (SH
   22212812 to 22182828)
4) Loose blocks throughout the area of the mine workings.

The full fauna is given in Table 3.2.

A possible extension of the outcrop of the siltstone has
been recognised on lithological criteria in the old workings
east of Tyddyn Meirion (SH 22192762).

The presence of lower Arenig contrasts with the quoted
upper Arenig age, but rocks of this age are exposed in the
ore belt, in a structural position that underlies the lower
Arenig siltstone.

The upper Arenig exposure forming the west face in the
southern quarry of the northerly opencast workings (SH
22182820) shows signs of alteration associated with the
formation of the ore, and a lozenge shaped body of ore can
be seen at the northern end of the cliff (see Pl.9 Fig.4).
Though a continuation can be followed to the south (Sectn.
3.4), this outcrop of upper Arenig does not appear to be
continuous along strike to either north or south and
Therefore it seems likely that it is a lenticular unit. Whether it rests directly on the Footwall Sill or is underlain by other sediments cannot be stated with certainty on the outcrop evidence, but the former is probably more likely considering the proximity of the intrusion. It is this unit that has been described as a chert bed within the shales (Matley 1932).

![Diagram](image)

**Fig. 3.12**

Distribution of ore bodies in Benallt Mine. Boundaries of Dolerite Sill and Pillow Lava shown for 130' Level of Mine. Sections: True Scale. (Based on Groves 1952 Figs. 38 & 39)

Therefore on the outcrop evidence alone, lower Arenig sediments appear to be intercalated between upper in a superficially simple easterly dipping sequence. Thrusting can be invoked to explain this, which is supported by the mode of occurrence of the ore. Groves (1952 p306) stated:
"The upper and lower surfaces of the lenticular ore bodies are sharply defined and are more often than not bounded by over-thrust faults or small scale thrusts."

Also commonly noted has been the imbricate stacking of the ore bodies (Matley 1932, Groves 1947 & 1952) which, like the enclosing strata, dip east (see Fig.3.12). This subsurface structural detail was based on both the mine workings and extensive coring at the 130ft. level (Groves 1952). Some of this core material has been traced and is now contained in the collections of the Mineralogy Dept. B.M. (N.H.). There is not sufficient to map out the structure, but the lithologies present are extremely varied and suggest even greater structural complexity. The lower Arenig is represented by dark siltstone but soft sediment intrusions are present that are not seen in outcrop (Pl.9 Fig.5). Tuffaceous lithologies showing varying degrees of alteration and ranging from white to a deep reddish-brown (Pl.8 Fig.2) may be compared to the upper Arenig exposed and are probably of this age. It is also suggested that the most exotic lithology present is upper Arenig in age (Pl.9 Fig.3) and is thought to be a development of the "chamositic mudstone" (Groves 1952). This will be discussed under petrography. The bioturbated sandy siltstone (Pl.9 Fig.2) and the phosphatic dominated units (Pl.5 Fig.5) are of uncertain age.

3.6b Nant y Gadwen (Nant Mine).

This small valley is the most fossiliferous locality of Arenig age in North Wales with faunas of all three divisions. Refinement of the distribution of the three divisions could probably be achieved with further collecting but this has been precluded by restricted access. The fossil localities are shown in Fig.3.13 and a map of this valley and that immediately to the west is shown in Fig.3.14. The extreme structural complexity recognised on the basis of the biostratigraphy during this study is in marked contrast to the simple easterly younging succession of previous interpretations (Elles 1904, Matley 1932). The lithologies present at this locality have been considered already and the emphasis here is on the structural relationships. As with the Rhiw area, the relationships are best explained by Fig.3.13 (overleaf). Map of Faunal Localities in Nant y Gadwen used in Table 3.5. Detail Map of Ore Body (stippled): from Groves 1952 Fig.41. Sections: True Scale.
Fig. 3.13: Nant y Gadwen. (caption on previous page).
Fig. 3.14: Geological map of Llanfaelrhys (Nant y Gadwen and Porth Ysgo) Around SH 210265.
Table 3.5 Faunas of Nant y Gadwen.

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* described from South Wales (Fortey & Owens in press)

Localities given in Fig.3.13; Column X: locality uncertain.
westerly directed thrusting producing an easterly dipping stack of slices. The presence of a thrust close to the base of the sill exposed at the south-eastern end of the valley is not certain, but there does appear to be a change in dip across a zone of disturbance and quite a marked change in facies, the beds above the thrust being distinctly sander.

A comparable fault has been recognised in the quarry on the east side (Groves 1952 see Fig.3.13 Section A).

Again thrusting is compatible with the structural interpretation of the ore (Groves 1952) (see Fig.3.13). The ore body only reaches the surface in the quarry (SH 21192672) and dips eastward at an angle of 40°-45°. and on the basis of mapping would lie within the middle Arenig. However as can be seen from the sections (Fig.3.13), the upper and lower surfaces of the ore are considered to be formed by thrusts, the body as a whole being truncated to the east by a high angle fault. The beds at the northern end of the valley are structurally distinct from the rest in having a south westerly dip. This has usually been explained with a major NW-SE fault cutting across the valley, but from the map it can be seen that the east side only is affected by a change in bed orientation. A fault cutting the eastern side alone therefore seems to be necessary.

3.6c Area between Nant y Gadwen and Rhiw.

There is little doubt that the southern margin of the Rhiw mining area is marked by the NE-SW trending Rhiw fault, whilst Nant-y-Gadwen is isolated by a structural complexity that invalidates extrapolation. Apart from the outcrop of pillow lava at SH 21672698 the area is drift covered and therefore the evidence yeilded by the boreholes drilled in 1942 is important. (Groves 1952 p 315-318). (Specimens of these may be held by the B.G.S. but have not been traced.)

The sections indicated by these are shown in Fig.3.15. These have been recalculated to actual thickness assuming a dip of 45°, this being the value quoted by Groves (1952). As might be expected from the structural complexity seen at both Nant y Gadwen and Benallt mine, no consistent sequence is seen. The Lower Clip Lava was claimed for BH's 1, 5 & 6, all of which were drilled close to the outcrop of the lava. However, even in these three sections there is significant variation. In two there is a chamositic politic-pisolitic
mudstone directly underlying the lava whilst in the other, cherty lithologies were recorded in this position, suggesting comparison with the Carw Tuff Formation. The other main elements were simply recorded as mudstone or interbedded basalt and mudstone and therefore little comment can be made as to the age of the argillaceous rocks.

3.6d Petrography.

The intended paper on this subject resulting from the wartime workings (cf. Groves 1952 p310) was never published and therefore the only detailed work (Woodland 1939) was done prior to the reopening and based on specimens from the rubble piles. The mineralogy of the ore is extremely complex, (Woodland 1939, Cambell Smith 1948, Cambell Smith et al 1944, 1946, 1947, & 1949 & Bannister et al 1955) with a metasomatic origin being generally accepted.

Such aspects are outside the scope of this study, but of interest are the primary sedimentary features of the ore. Groves (1952) stated that the ore was the metasomatic alteration product of a chamositic mudstone, whilst Woodland (1939) considered its precursor to have been tuffaceous. However some of the tuff lithologies are fragmental with the matrix containing ooliths, pisoliths and stromatoliths, features also seen in the chamositic mudstone, so the two are probably not unrelated. Though Woodland (1939 p215) compared the stromatoliths to the phosphatic organic structure *Bolopora undosa* he considered the absence of internal structures to indicate an inorganic origin. However comparison with the occurrences of the northern Llyn suggests a likely algal origin for these structures.

The core material taken to be the chamositic mudstone is clearly a clastic rock with abundant ooliths present but also numerous larger clasts, the largest examples being up to 6cm across. Some of these appear phosphatic though others appear to be siltstone. The most obvious clastic fraction is only of gravel grade, relatively angular and very pale in colour. This is almost certainly reworked volcanic material, and confirms the association of the two lithologies. A thin section of the chamositic mudstone, with neither hand specimen nor detailed source, is indeed an oolitic rock with both abundant ooliths and larger pisolitic to oncolitic bodies also present. All these are developed in a bright
Fig. 3.15: Logs of boreholes drilled east of Nant y Gadwen. (recalculated to true thickness) 1-5 vertical; 6 perpendicular to bedding. BH1: SH 21482697; BH2: SH 21422675; BH3: SH 21602697; BH4: SH 21352681; BH5 & BH6: SH 21662698 (details from Groves 1952).

Green material, and therefore reasonably termed chamosite, but in addition there is a significant number of rounded clasts of polycrystalline strained quartz, along with occasional phosphatic nodules.

Phosphatic nodules are extremely abundant in some of the deposits of Benallt, and these contain organic fragments, most commonly sponge spicules. The association of these nodules with pisolitic and oolitic structures is similar to that seen in Nant y-r Ochfa in the Arenig Fawr area. (see Section 2.5a). Phosphatic shell fragments were noted in some of the detrital tuff beds, confirming their sedimentary origin, but quartz clasts were stated as being rare (Woodland 1939 p.212). There may therefore be a wide
variety of lithologies developed at this horizon.

3.6e Stratigraphic significance.

It seems a remarkable coincidence if the above primary sedimentary characters, especially the presence of oolits and pisoliths, occurred in both lower and middle Arenig beds along this belt and yet are seen nowhere else. The suggestion made here therefore is that these characters are infact representative of the upper Arenig, and that rocks of this age have been intercalated with older rocks by the thrusting. No proof can be claimed for this but the following tend to support the hypothesis.

1: The upper Arenig is the only division seen at both the localities.

2: At three localities the chamositic mudstone has been described as conformably overlain by the Lower Clip Lava: Boreholes 5 & 6 Fig.3.15 and the Maclellan shaft, Benallt Mine (Groves 1952). This could have been influenced by the interpretation of the belt being a specific horizon but Groves (1952 p303) stated that this is only true in a regional sense. This may therefore be the true stratigraphic position of the chamositic mudstone and the Lower Clip Lava is probably upper Arenig in age.

3: The involvement of tuffs with the other primary features suggests comparison with the Carw Formation and rocks of this type are present at both localities.

Though the comparison of this deposit with the other occurrences of upper Arenig age seen in North Wales is tempting it is not unequivical. The nature of this regional development will be considered in greater detail elsewhere.  

3.7 Structural Reinterpretations.

Considering the previous lithostratigraphy was derived largely from inferred structural relationships, it is not surprising that an independently derived stratigraphy necessitates some alterations.

3.7a The Aberdaron Area.

Inadequate exposure is the major limitation in the structural interpretation of this area, and Roberts (1983) in a structural review, concluded that there was no evidence to support the previously proposed south-westerly plunging syncline (Matley 1928, Shackleton 1956), favouring a broadly south-easterly dipping succession. This view is supported by
the limited faunal evidence available, the Daron Section now known to be, at least in part, Llanviri whilst middle Arenig has been confirmed to the NW (SH 18152749), these two localities occurring above and below a supposed dolerite sill respectively. However, there is serious doubt that the sill occurs throughout the area.

In the immediate vicinity of Aberdaron there is good evidence for there being a doleritic body. Occurrences at Bodernabwy (SH 17432720) and Pendref (SH 17482690) have been taken to be the lower and upper boundaries respectively of a NE trending sill. An intervening exposure, (SH 17272704) though badly weathered is coarsely crystalline, compatible with a central position in the body. However there is no clear evidence for its continuation to the NE. Much discussion has centred on the supposed occurrence in the track at Bodwrdda (SH 189274) (Matley 1928, Shackleton 1956, Hawkins 1983), but no mention has been made of the badly weathered dolerite exposed in the river itself, (SH 19022743) which has approximately the same NW-SE stike as the tuff beds c.70m upstream. This could easily be a continuation of the body exposed in the track and is clearly not thick enough to be automatically considered equivalent to the southern body.

It is therefore concluded that, considering the prevalence of faulting elsewhere and the different strike of the competent beds in the Daron section, the nature of the drift area cannot be reasonably inferred.

3.7b The Base of the Arenig East of Wig.

Previous maps have all shown a fault trending NNW from Ogof Lleuddad (SH 190255), down throwing to the east. The interpretation suggested here is that the fault trends NNE parallel to the west side of Penrhyn headland and down throws to the west. A number of points support this.

1) The dolerite sill that forms the cliffs to the east of this fault is overlain by lower Arenig rocks whilst immediately east of the fault a middle Arenig fauna has been recovered. Though there is evidence of reverse faulting at the eastern contact of the sill and sediments opposite Maen Gwenonwy (SH 19812587) baked sandstones are associated and a definite thermally metamorphosed contact can be seen at Porth Ysgo (SH 20712650).
2) At the cliff top above Dgof Lleuddad, sediments can be seen in a position (SH 19082562) that would underlie the sill on the basis of the NNE fault trend but are lithologically comparable to the middle Arenig.

3) The dolerite sill that can be seen on Carreg Gybi (SH 19022528) is correlated with that on Maen Gwennonwy (SH 200259). (This could easily be proved if the underlying sediment is the Maen Gwennonwy Member).

The implication of this evidence is that the sill is intruded close to the basal unconformity and that therefore the thickness of sediment previously inferred to underlie it is probably wrong.

The nature of the unconformity between the coast and the Bryncroes fault is somewhat conjectural especially towards the southern end. There appears no good reason to question the relatively continuous N-S strike of beds in this area which makes a regional interpretation of the complex structures of the mining belt very difficult. These raise an additional problem, concerning the basal unconformity in that the most northerly exposure of sub-upper Arenig is contained within the complex. Considering the difference in the upper Arenig facies between north and south, both lithologically and faunally, there does appear to be a genuine deepening to the south. However, the possibility must be borne in mind that the Sarn Formation extends further to the south and overlaps lower parts of the Arenig succession.
PLATE 3

Figs. 1 & 3. Porth Ysgo Sandstone Member at Maen Gwenonwy. Fig. 3 shows abrupt facies change from siltstone dominated sequence to sandstone dominated. Fig. 1 shows sandstones in more detail. (Note 2 Fig. 3.3).

Fig. 2 Loose block of Maen Gwenonwy Siltstone Member at Wig. Note bioturbated sandstone bands to right and diffuse bands of phosphatic nodules to left.

Fig. 4 Thin bedded bioturbated sandstones with intervening siltstones, Porth Ysgo Sandstone Member, mainland opposite Maen Gwenonwy.

Fig. 5 x1. Pale angular ?volcanogenic clasts in siltstone of the Aberdaron Formation. (SH 17652743)

Figs. 6 & 8 Basal unconformity at Wig. Fig. 6 is detail of Fig. 8. Position of unconformity shown in Fig. 3.2.

Fig. 9 Hammer resting on phosphatic junction bed between the Porth Ysgo Sandstone Member and the Maen Gwenonwy Siltstone Member.
PLATE 4

Fig. 1 Dolerite sill on Maen Gwenonwy overlying Mean Gwenonwy Silstone Member. Junction dotted in. Positions of Figs. 2-4 indicated.

Fig. 2 Fluid escape structure intruding into base of dolerite. Viewed approx. perpendicular to Fig. 1

Fig. 3 Intermixed basalt and mudstone.

Fig. 4 Soft sediment folding in siltstone directly below sill.
PLATE 5

Figs.1 & 4 Complex, ?soft-sediment, folding of Porth Ysgo Sandstone Member at western end of outcrop opposite Maen Gwenonwy. Fig.1 is detail of 4.

Figs.2 & 3 Cut hand specimens of Porth Ysgo Sandstone Member. Fig.2 from Porth Ysgo; Fig.3 from Maen Gwenonwy.

Fig.5 Phosphatic material from borehole at Benallt Mine. Left: B.M. 1944.62.59. from borehole A29 at 40’, possibly of lower Arenig age. Right: Borehole A17 at 9’ 6”; contains high proportion of volcanogenic material and may be upper Arenig in age. (Borehole Numbers: Groves 1952 Fig.40).

Fig.6 Compressional soft-sediment deformation of sandstone bands; Aberdaron Formation, near Hendre Uchaf.

Fig.7 Graded bed from Porth Meudwy Member, Porth Meudwy. Note angularity of schist clasts.

Fig.8 Convolute lamination in tuff from Carw Tuff Formation, Nant y Carw.

Fig.9 Volcanogenic rock from quarry above Ebolion. Angular fine grained cherty clasts in pale ?coarser matrix. (Way up inferred).

Fig.10 Typical sand streaked siltstone of the Sarn Formation from east of Bryncroes.
PLATE 6

Plates of lower part of Porth Meudwy sequence. (See Fig. 3.8 Notes refer to this Fig.)

Figs. 1, 2 & 7 Synsedimentary soft-sediment glides. (Note 1.)

Fig. 3 Loose boulder from area of bedding parallel fault showing sigmoidal cross lamination (to left) and loading/fluid escape structure. (Approx. centre of photo.)

Fig. 4 Slump fold closure (Note 4)

Fig. 5 'Fluidised' bed at base of fractured zone (Note 6)

Fig. 6 Parallel banded unit showing isolated fractures eg just above tape. Note flame structure just above centre of photo.

Fig. 8 Synsedimentary folding in base of siltstone dominated sequence. (Note 9).
PLATE 7

Fig. 1 Precompactional faulting in lower part of sequence along west side of Parwyd Bay.

Fig. 2 Porth Meudwy Member. Graded units dominated by schist fragments overlain by siltier portions containing larger intraformational clasts. Main bed approx. 30cm thick. (Note 2 Fig. 3.10), Porth Meudwy.

Fig. 3 Pervasive pre-compactional fracturing (Fig. 3.8 Note 3). Porth Meudwy.

Fig. 4 Basal bed of Porth Meudwy Member. (Fig. 3.10 Note 1), Porth Meudwy.

Fig. 5 Isolated lozenge-shaped mass of sediment. (Fig. 3.8 Note 7), Porth Meudwy.

Fig. 6 Chaotic, debirs flow unit, Porth Meudwy Member (Note 3 Fig. 3.10), Porth Meudwy.

Fig. 7 Cross-cutting bands towards top of soft sediment glide horizon, (Note 1 Fig. 3.8), Porth Meudwy.

Fig. 8 Cut hand specimen of sand-streaked siltstone from Nant y Carw, Sarn Formation.
PLATE 8

Fig. 1 Fine scale tectonic plus ?precompactional fractureing at base of sequence along west side of Parwyd Bay.

Fig. 2 Partially mineralized tuff units in core material from Benallt Mine. left: Borehole A2 at 7'; right: B.M.: 1944.62.15, Borehole A20 at 56'. (Borehole Numbers refer to Groves 1952 Fig.40.

Fig. 3 Tuff bed Porth Meudwy (Note 2 Fig.3.8)

Fig. 4 Sequence along west side of Parwyd Bay.

Fig. 5 Pervasive precompactional fractureing, Porth Meudwy. (Note 3 Fig.3.8)

Fig. 6 Large, soft deformed clast in debris flow, Porth Meudwy Member, Porth Meudwy.

Fig. 7 Loaded sandstone bed in lower part of siltstone dominated sequence Porth Meudwy (Note 8, Fig.3)

Fig. 8 Siltstone dominated sequence below Porth Meudwy Member, showing increase in sandstone beds towards the top, north side of Porth Meudwy. (Note 11 Fig.3.8)
Benallt Mine. All borehole numbers refer to Groves 1952

Fig. 40.

Fig. 1 Open-cast workings seen from south. Cliff of upper Arenig, Carw Tuff Formation, just left of centre; rest of exposure Maen Gwenonwy Siltstone Member, lower Arenig.

Fig. 2 Bioturbated silty sandstone; B.M.: 1944.62.1, Borehole A18 at 228’. This lithology is not seen in outcrop at Benallt, Age uncertain.

Fig. 3 ?Chamositic Mudstone, contains ooliths but also abundant volcanogenic material. B.M.: 1944.62.29-32. Borehole A21, from left to right at: 177’, 182’, 185’ & 187’.

Fig. 4 Lens of manganese ore within outcrop of Carw Tuff Formation. (Looking south).


Fig. 6 Volcanogenic sandstone, probably upper Arenig. Borehole 13, left at 109’ 6”, right at 114’.
CHAPTER 4: Caernarfon – Bangor Area.

4.1 Introduction.

Lying between the Aber-Dinlle fault and the Menai Straits, the Caernarfon-Bangor area forms a low lying region that is topographically more comparable with Anglesey than the high relief of Snowdonia. The major Arenig strip runs from Caernarfon to Bangor, being duplicated by the Bangor Fault at the northern end. The small exposure on the Menai Straits (the Straitside Inlier) lies to the west of the Dinorwic fault and is lithologically distinct from the main strip.

Much of the area has recently been remapped by the B.G.S. (as yet unpublished) the only previous regional work being that of Greenly (1944). This work has shown there to be a major sub-Arenig unconformity that cuts down sequence from north to south (see Reedman et al. 1984 fig.1). The early description of the Afon Seiont section, Caernarfon (Elles 1904) is significant as a continuous section through the extensus, hirundo and bifidus biozones was claimed and subsequently accepted in acritarch work (Booth 1979).

The fauna from the basal sandstone, found during this study, is of uncertain age (see below), but is unlikely to be lower Arenig, whilst the only age diagnostic fossils found in the overlying siltstones are of upper Arenig age. The use of the lithostratigraphic terminology of the Aber-Betws Garmon area in the Caernarfon – Bangor strip (Reedman et al. 1983) is questionable. Not only are the two areas separated by the penecontemporaneously active Aber-Dinlle fault (Webb 1983), but in the case of the basal sandstones, closer lithological and faunal comparison can be made with the Carmel Formation of Anglesey. However no fewer than four other names have been used for intervening outcrops of basal sandstones on Anglesey (Bates 1972) and unless all are placed in a single lithostratigraphic unit there appears no alternative but to erect a new name in the Caernarfon Bangor area. To minimise the proliferation of names it is recommended that the Maes y Geirchen Quartzite Member

Fig.4.1: (Overleaf) Map of Bangor Foreshore area with detail map of Garth Point. Localities indicated: A: West of Bangor Pier (Figs. 4.2 & 3); B: Garth Point; C: University College Cliff; D: Basal Unconformity shown in Fig.4.4; E: 'Boundary section', Fig.4.7.
Reedman et al. 1983) be changed to the Maesgeirchen Sandstone member and extended to include the entire basal sandstone sequence. The overlying siltstone sequences are more difficult to characterise and have not generally been named. For this reason the use of the Nant Ffrancon Formation is tentatively retained.

4.2 Maesgeirchen Sandstone Member.

Three exposures of the basal unconformity and associated sandstones have been examined.
1: The section on the Bangor Bypass (A5) at Cearhun (SH 575692) examined whilst road still under construction. (Fig.4.5)
2: The basal sandstones just west of the pier, Bangor (SH 583732). (Fig.4.2 & 3; Loc.A Fig.1)
3: Small exposure just inland from University College cliff (Greenly 1944 p80 fig 2) SH 59017247. (see Fig.4.4; Loc.D Fig.4.1)

Despite lying either side of the Bangor fault, the two Bangor localities are similar and will be described separately from the somewhat different Bangor Bypass Section 4.2a Bangor area.

The positions of the various localities associated with the Bangor foreshore are shown on Fig.4.1. Faulting has removed the possibility of a continuous section but the main features of the succession can be inferred in the area around Bangor Pier (see Fig.4.2 & 3).

Despite a measurable angular unconformity, bedding below 229° 28°SE, bedding above 233° 18°SE, the similar strike parallel to the trend of the cliff tends to make it difficult to recognise. This is furthur compounded by some of the underlying volcanics having a distinctly arenaceous nature, the first appearance of quartz being important in the recognition of the base. The coarse basal unit gives way upwards to silty sandstones with some thicker arenaceous beds and thence to flaggy sandstones. The area of University College Cliff (Loc.C Fig.4.1) shows a repetition of the sequence. A previously undescribed exposure of the basal unconformity has been found just inland (see Fig.4.4) and like that west of the Bangor fault, is developed in quite coarse clastics.

A number of features may be recognised in the basal...
Fig. 4.2: Cliff section west of Bangor Pier. (Loc. A Fig. 4.1)
Sections shown in Fig. 4.3
Fig. 4.3: Sedimentary logs of the Maesgeirchen Sandstone Member west of Bangor Pier. Positions of sections shown in Fig. 4.2.

1: Pl. 10 Fig. 2

Star: Horizons in which shell material found including Calymenella sp. A
sandstone beds.

1: There are two main types of coarse unit.
   a) Fairly well sorted coarse sandstone to gravel grade quartzose arenaceous beds.
   b) Scattered larger clasts up to small pebble size in medium grained highly micaceous and quartzose sandstone (Pl.10 Fig.2). The larger clasts are lithologically variable but are dominantly of quartzite and the underlying volcanics with some jasper clasts also possibly present. Strings of gravel grade clasts often pick out inclined planes suggestive of cross sets. In addition beds of this type have yielded a number of poorly preserved fossils adequate to indicate a fauna equivalent to that collected from the Bangor Bypass (see Pl.24 Figs.7 & 16). Both the immaturity of the matrix and the diffuse nature of the coarser fraction indicate rapid deposition.

2) Current activity is indicated by cross-bedding in both of the above types of bed and appears to be predominantly tabular. Irregular wavy surfaces are also present but are not exposed in sufficient detail to show whether they result from the depositional event or subsequent reworking.

3) The coarser beds show rapid lateral variation in thickness both as a result of channeling and the development of lenticular units. An example of the former is shown in Pl.10 Fig.7 where the bifurcation of the coarse unit at the margin indicates infilling of the eroded area prior to the deposition of the overlying bed.

Section 2 Fig.4.3 gives some indication of the nature of the transition into the overlying silty sandstones. The flaggy silty sandstones seen at Garth Point (Fig.4.1) are probably not greatly different to the lithologies seen in section 3 but may well represent a somewhat higher horizon since they contain no bedded sandstone sequences as seen at the top of Section 3. However occasional coarse beds are
present at Garth Point, usually attaining gravel grade, quartzose in composition, but with abundant to dominant rounded phosphatic clasts. These appear to occur either as isolated bands or composite thicker units, and when phosphatic material is dominant the bedding is typically thin (c.10 cm). As indicated in Fig. 4.1 there are a number of these coarse units at Garth Point, but some may reflect structural repetition. It is appropriate at this point to note the occurrence of very similar beds to the east of Bangor fault also; on the hill of Maesgeirchen at SH 58427148 and also in the bypass section within 20 m of the top of the section shown in Fig. 4.5 (see Pl. 10 Fig. 1).

The flaggy beds themselves are fairly typical of this lithology as seen elsewhere in the Arenig of North Wales and it seems to be a facies of no particular age association. Azygograptids are confined to horizons where the lithology splits to give very smooth bedding planes whilst the more normal surface is rather rough and knobbly. This reflects greater bioturbation, predominantly bedding parallel, and loading possibly associated with somewhat greater sand content. The azygograptid–yielding beds at University College Cliff may be a slightly lower horizon than those of Garth Point as they are closely associated with thicker sandstone beds.

4.2b Bangor Bypass Section.

one of the more significant differences from the sequence at Bangor itself is the nature of the beds directly overlying the unconformity, as gravel grade material is absent till some 5 m above the base and even then the amount is fairly insignificant. The top of the underlying Minffordd Formation (Reedman et al. 1984) is dominated by gravel grade intraformational breccias associated with lithic sandstone, both composed entirely of Arvonian detritus. The base of the Maesgeirchen Member, and hence the Arenig, is marked by the first appearance of a medium grade micaceous quartzose sandstone with no evidence of any coarser quartzose material, though some angular fragments of the underlying Arvonian do occur. These were only seen in a loose block associated with the basal beds, the breccia material occurring approximately in the middle portion of the associated sand bed, therefore giving no reason to assume
that it is the basal bed that is represented. The overlying sequence, constituting the basal sandstones, can be approximately divided into three (see Fig. 4.5).

1: Lower Sandstones.

These are 30 to 35m thick and are dominated by sands very similar to those seen at the base, i.e. though quartzose, containing a very high proportion of mica. These sandstones are well bedded, but monotonous, showing little in the way of sedimentary structures. They are hard, and mostly grey in colour, though occasional rusty weathering is present. After the incoming of the first coarser material, about 5m above the base, the sequence is somewhat more variable, though the area of poor exposure at the top of the first column is dominated by lithologies very similar to those that form the basal 7m, with possibly slightly greater rusty colouration. The most important part of the sequence occurs just above this area (base of second column) where overlying a fairly massive coarse bed are about 5m of slightly more muddy and rusty weathering sandstones, containing abundant fossil material.

Scattered fossils do occur below this, as indicated on the section, but these are rare. Though some specimens were collected in situ, the majority came from loose blocks produced during road construction. It is thought that most of these blocks were from the higher, more fossiliferous beds (base of column 2).
Three main faunal elements are present; trilobites, brachiopods and bivalves. The first and last appear to be almost mutually exclusive with distinct modes of occurrence, whilst brachiopods occur with both and are occasionally dominant, usually when fossil material is relatively sparsely scattered.

The trilobite material is totally disarticulated (see Pl.10 Fig.8). Though some fragments appear broken, there is no evidence of significant abrasion, eg genal spines still run to a point. The most common mode of occurrence is in beds that are very slightly graded from medium-coarse to medium sandstone which is of the typical quartz-mica type, towards the tops of which there is some evidence of mud flasers. The trilobite material occurs in the top half of the beds predominantly parallel to bedding. The incoming of this often seems to be marked by a concentrated band, the fragments above being more scattered, though concentrations can occur at virtually any point in the upper half, sometimes forming a nearly continuous surface of fragments. The absence of shell material from the lower half is fairly consistent.

Bivalves occur as distinct bands of both single and articulated valves within a sandstone bed and are often associated with gravel clasts of a comparable size. (see Pl.10 Fig.6) Such bands can be quite widely spaced or concentrated into a ‘roach’ like lithology. Occasional scattered specimens do occur between such bands but represent an insignificant proportion of the total number of specimens present.

The trilobite fauna is largely endemic; Annamitella sp. A, Megalaspidella cf graffi, Meseuretus sp. A, Calycemella sp. A, Calycemella sp. B, and is therefore of limited biostratigraphic use. The chronostratigraphic position of these basal beds within the Arenig is discussed in more detail in Chapter 8 where it is concluded they are most probably of early middle Arenig age.

2: Muddy Sandstones.

Though sandstone is still dominant there is significantly more silt present in this part of the sequence than is seen in the sandstones either above or below. The silt fraction is present as mud flasers often very irregular
in shape, a character emphasised by bioturbation. Bioturbation is also thought to be responsible for the more homogeneous silty sandstones, two observations tending to support this. First, occurring in the silty sandstones are patches of cleaner sandstone within which mud flasers can be recognised, though they are apparently absent from the surrounding lithology. It is thought that these patches represent regions of sediment that have escaped bioturbation. Second, two beds are present that show mud flasers in the cleaner sand of the lower half but are a more homogeneous silty sand in the upper. This would be compatible with biological reworking of a single depositional package.

3: Upper Sandstones.

These differ from the lower sandstones in being distinctly paler in colour, compositionally closer to quartzite and showing evidence of cross-bedding. The contact with the underlying muddy sandstones is somewhat gradational. The clearest examples of cross-bedding are tabular cosets occupying the bed thickness, but there are suggestions of trough cross-bedding also being present. However it seems likely that the weathering was insufficient to pick out such features reliably and therefore cross-bedding may be more common than is shown on the log. The combination of large scale cross-bedding with more mature sediment composition suggests a higher energy environment than that in which the lower part of the sequence was deposited.

Other differences from the lower sandstones include the generally greater grain size, and the presence of mud clasts that can reach up to 8cm in length. Some bioturbation is indicated by vertical muddy streaks but many of these beds are massive and featureless.

The transition into the overlying shale-dominated sequence is dramatic and an interesting rudaceous component is associated with this transition. The dominant fraction is gravel grade, distinctly coarser than the lithologies below, but the abundant matrix is silt dominated. It would seem likely that the concentration of coarser material has a genetic association with the change in facies and may represent some form of starved, lag deposit.
4: Siltstone sequence.

Though some distinctly sandy horizons occur in the basal part of the sequence, this including that shown in the log and a significant thickness above, the majority is developed in a laminated siltstone (see below). These sandier lower portions may, at least in part, be equivalent to the flaggy beds seen on the Bangor foreshore but appear to be somewhat less sandy. There is considerable variation in the proportions of sand and silt with both occurring as lenses and laminae within the other. Bioturbation is present and appears to be dominantly bedding parallel and phosphatic conglomerates comparable to those seen at Bangor are also present. The lower sand content may be a factor in the Bypass lithologies having a better developed cleavage and no fossils have been recorded from the siltstones in this section.

4.4 Siltstone Member. (Nant Ffrancon Formation).

In two sections:

1) The Penrhyn Park Foreshore : SH 59937295 to 60357304. (Described by Greenly 1944)

2) Seiont River Section, Caernarfon : SH 47886247 to 48036181. (Described by Elles 1904)

there is a continuous passage between the Arenig and Llanvyrn, and in both cases some 300m of the underlying sequence are exposed. Elles (1904) considered this sequence at Caernarfon to represent an almost complete section through the Arenig but it is now clear that only the youngest part of the Series is represented. The thickness estimates seem reasonable despite the presence of significant faulting in both sections. The nature of the faulting in the Penrhyn Foreshore section in not clear since faults are only represented by gullies in the wave-cut platform. However in the Seiont Section only the vertical profiles are visible and this suggests the presence of quite common small-scale, low angle faulting and jointing which in some cases have developed duplex-like structures. To calculate the approximate thicknesses of the sequences their apparently small effect has been ignored.

As noted above, the exposure of both these sections is from the Llanvyrn downwards rather than upwards from the Maesgeirchen Sandstone Member. The lower part of the Seiont
section turns over into the other limb of an anticline which forms the seaward dipping exposures that outcrop below Caernarfon Castle. The sequence is then faulted against the River's Mouth Formation of uncertain age (Greenly 1943). The Penrhyn Foreshore section is separated from the exposures of the basal sandstones at University College Cliff by about 850m of non-exposure. If this area contains a simply dipping sequence comparable to that seen above and below, then some 500m could be represented. This would give a total thickness of c.800m for the siltstones, a figure not incompatible with that suggested by the cuttings on the Bangor Bypass, though the top of the Arenig is less reliably defined there and the middle part of the section is again not exposed. That a significant thickness of siltstones of uncertain age may be present is important when considering the possible age of the Maesgeirchen Sandstone Member, because the upper 300m on the Afon Seiont section are entirely upper Arenig in age.

4.4a Lithology.

With variations in the streaky sandstone content the sequence is dominated by a coarse dark micaceous siltstone. In the Bangor area this lithology has taken a significant cleavage and very few fossils are known. By contrast, fossils are relatively abundant in the Seiont section. However, deformation makes the determination of graptolites difficult, and apart from the abundant occurrence of Pricyclopyge binodosa subsp nov Fortey (1985) trilobites are known only from isolated specimens limiting the value of the section in determining ranges. The total fauna recognised is: Didymograptus hirundo Salter, D. aff. praenuntius s.l., Tetragraptus reclinatus s.l. Elles & Wood, Pseudisograptus manubriatus subsp. 1 (T.S.Hall) (loc.3), Eoharpes sp A (loc.3), Dindymene sp. (loc.1), Ectillaenus sp. (loc.2), Selenopeltis ?inermis macrothalmus (Klouček) (loc.4), Placoparia sp. (loc.4), ?Illaenopsis (loc.4), ?Emrichopsis and ?Microparia. The localities of the most significant specimens are shown in Fig.4.6.

The preservation of the fossils confirms a somewhat concretionary cementation of the siltstone in addition to the frequent occurrence of specimens wholly or partially contained in small phosphatic nodules. There are parts of
Fig. 4.6: Map of Afon Seiont, Caernarfon showing localities of the most significant fossils found. (see faunal list in text).
the section where the sandstone fraction is more significant, and these parts take on the appearance of a fine sandstone, though in fact there appears to be little true variation in grain size between the siltstone and sandstone fractions, the main difference being the colour. The most marked incursion of sandy material is at the top of the Arenig and this is considered below.

4.5 The Arenig / Llanvyrn Junction.

In contrast to the underlying lithologies it has been the exposures at the top of the Penrhyn Foreshore section that have proved the most fossiliferous and informative in this context, though some additional information has been obtained from the Seiont Section. At the latter locality the top is poorly exposed at river level, opposite the sewage works, but can be seen in the tramway above the south bank. This is dominated by sandy, somewhat bioturbated silty lithologies that have yielded a few fossils, most notably specimens of *Glyptograptus* one specimen determinable as *G. austrodentatus* Harris & Keble. The top of the series itself is difficult to define biostratigraphically and may be slightly faulted. The thickness of sandy beds exposed below the likely junction is some 75m whilst on the Penrhyn Foreshore the thickness of similar beds appears to be c.50m and the sedimentary details are much better exposed.

The sandy units can be seen to occur as distinct packets of fairly thin beds, in general showing a thinning upward sequence and variable bioturbation (see Pl.10 Fig.5a). The junction itself is exposed in a monocline at the top of the section (shown in Fig.4.7) and, as can be seen from this, the lithologies divide in two along a distinct horizon, which, though not exactly on the boundary is extremely close to it. The lower part represents the top of the sandy sequence, which, just below the junction, may reasonably be termed a sandstone. The dramatic return to a siltstone facies is all the more exaggerated for being associated with a band of pyritic nodules and matted graptolite material. Though the majority of the graptolite material is too tightly packed to be determinable, two points emerge. Among the debris are specimens of isograptids and sigmagraptines, the only occurrence of these truly oceanic forms (Fortey 1984) in the main Caernarfon-Bangor strip,
Fig. 4.7: Arenig-Llanvirn boundary exposed on foreshore of Penrhyn Estate. (loc E Fig. 4.1).

1: *Ornatops nicosoni* (Salter);  
*Barrandia* cf *homfrayi* Hicks  
biserial graptolite (indet).

2: *Didymograptus* cf *linearis* Monsen

3: *Priscyclopyge* *binodosa* subsp nov Fortey  
*Pseudisograptus* sp.  
*Brachiograptus* cf *etaformis* Harris & Keble.  
*Tetragraptus reclinatus* sl E. & W.  
*Didymograptus* aff *praenuntius* ?Form C  
associated with band of pyritic nodules

4: Pendent graptolites.

5: Pl. 10 Fig. 3
apart from the single specimen of *Pseudisograptus manubriatus* in the Seiont section. Secondly, despite the fact that a biserial has been found in the sandy beds below none have been seen among the graptolite mats and the characteristic morphology should make even a small fragment obvious. As is shown in Fig.4.7 pendants are found shortly above, thereby indicating the Llanvirn.

In view of the nature of this junction, the description given of the Llandegai ironstone is interesting:

6 Black Shale (elsewhere at least 12ft.) 5ft. 0ins.
5 Red pisolitic ore 11ft. 3ins
4 Flaggy shale alternating with black pisolitic ore. 9ins
3 Black pisolitic iron ore 2ft. 0ins.
2 Black mudstone with nests and balls of iron pyrites. 11ins.
1 Shales, mudstones etc.

(Cantrill & Sherlock in Strahan et al 1920)

The character of the basal pyritic horizon clearly suggests comparison with the boundary section, and recently a lower Llanvirn age has been claimed for this ironstone on the basis of acritarchs (Howells et al 1983, Molyneux pers comm). This contrasts with the Llandeil-o age claimed on the basis of graptolites (Greenly, 1944 p77). The old mine workings have now been completely filled in during the construction of the bypass, and since it has not been possible to examine Greenly's original material, the validity of the graptolite age remains in doubt. It may be further noted that within the lower part of the Llanvirn on the foreshore section (Fig.4.6) are some coarse beds, the thickest of which contain abundant phosphatic nodules and occasional oolites (see Pl.10 Fig.3), further supporting the correlation of the ironstone with the boundary interval.

4.6 Menai Straits Inlier.

The small area of Arenig shales exposed on the Menai Straits was first recognised by Greenly (1898) and the fauna was further described by Elles in 1904.

The siltstones emerge from below the Carboniferous at SH 55657728 and the majority of the shales are stained red. However, towards the south-western end of the exposure, at SH 55107728, the siltstones are exposed to greater depth
below the unconformity and are unstained. It is from this locality that an upper Arenig fauna has been recorded: *Didymograptus* aff. *praenuntius* form C, *Pseudisograptus menaiensis* Jenkins, *Tetragraptus reclinatus* s.l. Elles & Wood, *Pricyclopyge binodosa* subsp indet, *Ormathops* sp and a penatulacean.

The lithology is a uniform dark grey, fissile, fine siltstone differing from those of the Afon Seiont in the absence of any coarser fraction. Despite the staining, it is clear that the same primary lithology made up the entire outcrop, and though an accurate estimate of the thickness is not possible because of folding it is adequate to indicate the differences from the main Caernarfon-Bangor strip are not the result of chance sampling of a limited part of the section.
Plate 10

Fig. 1: Phosphatic conglomerate bands in sand-streaked siltstone from within 30m of the top of the Maesgerichen Sandstone Member, Bangor Bypass. Note load-casted ripples towards top.

Fig. 2: Coarse unit from basal sequence of Maesgeirchen Sandstone Member west of Bangor Pier (Note 1 Fig. 3.3). Suggestion of gravel draped cross-sets to left.

Fig. 3: Coarse unit in base of Llanvirn, Penrhyn Park Foreshore (Note 5 Fig. 4.7) containing abundant phosphatic nodules and occasional ooliths. Scale bar: 5cm.

Fig. 4: Complex intermixed sandstone and siltstone, Maesgeirchen Sandstone Member, Bangor Bypass section (Note 1 Fig. 4.5)

Fig. 5a & b. Nant Ffrancon Formation as exposed on Penrhyn Park Foreshore. a: thinning upwards packet of sandstones from sandier sequence towards top of Arenig. b: More typical parallel laminated sandy siltstone.

Fig. 6 & 8: Coquina bands from the Bangor Bypass Section. Fig. 6 dominated by bivalves; Fig. 8 dominated by trilobite fragments.

Fig. 7 Channelised sandstone in basal Maesgeirchen Sandstone Member, west of Bangor Pier. (Between sect'ns 1 & 2 Fig. 4.2). Note gravel band just below hammer merges, to the right, with that running along the bottom of the channel.
CHAPTER 5: Criccieth and Northern Llŷn.

Though the two following areas are widely separated, both occur on the margins of the Llŷn Peninsula, intervening between major areas of exposure.

5.1 Criccieth.

5.1a Introduction.

Extending NNE of Criccieth for just under 3km is a coarse unit resting on Tremadoc slates, with little evidence of unconformity, which has been consistently mapped as Arenig along with varying proportions of the overlying slates (Fearnside 1910, Roberts 1967). The only fossils recorded from this strip are an asaphid, a neseuretid and inarticulate brachiopods (Fearnside 1910 p164), and though no more shelly fossils have been found during this study, new graptolite localities are recorded.

5.1b Sequence.

Indifferent exposure compounded by apparent rapid lateral variation makes an overall interpretation of the sequence difficult. The most informative area is that just north of Pen-ystumllynn (SH 509389) illustrated in Fig.5.1.

Though the contact with the Tremadoc is not actually exposed the base of Section A appears to approach quite closely, with a clean washed, well sorted feldspathic quartzose coarse sandstone at the base. This gives way rapidly to thin and irregularly bedded, muddy, medium to fine sandstones with quite abundant bioturbation and clear evidence of cross lamination. These mud streaked sandstones then appear to fine further, possibly by increased mud content, taking a cleavage, and occupy a thickness of c.20-25m. Above these at SH 51243954 occurs a second coarse unit that can be followed along strike (Section B) before being faulted against the Tremadoc (SH 51413991). Though this upper unit contains some very muddy, poorly sorted coarse sandstone units giving a superficially different appearance to the lower arenaceous unit, both contain lithologies comparable with those dominant in the other, and therefore the entire sequence is treated as a single basal unit. Such a unit with comparable lithological variation can be traced northwards until it disappears at SH 51424088 though there appears to be no consistent
Fig. 5.1: Map and sedimentary logs of area just north of Pen-ystumllyn. Star indicates horizon from which graptolite fragments obtained.

relationship between the various lithologies.

From Pen-ystumllyn south the sequence is much less clear, and includes a group of curious lithologies exposed in the track leading to Pen-ystumllyn (SH 51093894). These include a red laminated siltstone interbedded /laminated with medium sandstone varying from relatively pure quartzose to quite muddy, with a significant pale flecking. The sandstones are burrowed into the siltstone and clasts of the latter occur within the sandstone suggesting that the colouration may be syndepositional. However, above these beds are sandy siltstones, comparable to those seen to the north, which intern grade rapidly into the overlying siltstone.

It is from two localities in this southern part of the
area that graptolites have been found for the first time and
details of these localities are given below.

1) SH 50783878; Diplograptus sp and Dicellograptus sp. were
collected from laminated siltstones on the NE side of a
small gully, the rocks below being pale weathering
siltstones, commonly laminated, with thin lenticular laminae
of fine sandstone.

2) SH 50833858; Specimens of Pseudoclímacograptus
?scharenbergi (Lapworth) were recovered from siltstones and
sandy siltstones associated with some ‘cherty’, possibly
volcanic, bands outcropping in the low bank on the west side
of a track. In the base of the track (SH 50713855) there
is an outcrop of coarse muddy sandstone containing a very
high proportion of pale weathering clasts. These were
described as kaolinised feldspars by Fearsides (1910)
though this rock looks little different in thin section to
the muddy sandstones to the north (sect B Fig.5.1), which
show little evidence of pale flecking on the surface. The
suggestion of a volcanic origin for these pale clasts
(Fearsides 1910 p165) is compatible with the tuffaceous
appearance of beds above.

Both these localities appear to occur low in the the
slate sequence, and at least the second could be gradational
with the basal unit.

Graptolite fragments were also found in the area to the
north (Sect B, Fig.5.1) but these are only determinable as
dichograptid, probably of an extensiform, with relatively
low thecal inclination.

4.1c Correlation.

The fossils previously collected came from a locality
75yrd NE of Tan-y-rhiwiau, which now lies within a housing
estate, and it has not proved possible to trace the original
specimens. The specific names given; selwynii (asaphid) and
parvifrons (neseuretid) would indicate a lower Arenig age,
but the identifications cannot be relied upon since the
names as then used encompass a number of separate species
subsequently recognised.

Acritarchs, recovered from the basal unit at SH 51273951
indicate a lower Arenig age also but do not preclude a
higher division of the Arenig (Molyneux pers comm. 1984),
whilst Llanvirn acritarchs have been recorded from SH
51484176, 5143947 and 51074003, all to the north of Pen-y-stumlllyn. In this area therefore the Llanvirn rests on a very thin sequence of Arenig. It is possible that the duplication of coarse units indicated in Fig.5.1 reflects two periods of transgression, one lower Arenig the other upper Arenig–Llanvirn. Locally the younger interval may overstep onto the Tremadoc.

The new graptolite evidence from the second locality described above could be explained by a similar sequence, this being compatible with the pendent graptolites recorded by Fearnside (1910 p.165) from Ceunant Ddu a little to the west. However the fauna from the first locality described suggests a higher horizon, at oldest uppermost Llanvirn. The finer laminated lithology also suggests a different horizon and the outcrop may either be the result of faulting or, possibly more likely, overlap by a higher transgressive sequence.

4.2 Northern Llyn

Lower Palaeozoic rocks are exposed along the northern coast of the Llyn Peninsula to the NE of Nefyn, but the succession is complicated by intrusives; the sediments are generally drift covered, and the biostratigraphic control is limited by a strongly developed cleavage. In the SW the overall structure has been interpreted as the NW limb of a syncline producing a simple SSE younging succession, with the oldest rocks considered to be those exposed at Trwyn-y-tâl (SH 3649) (Tremlett 1962). Towards Snowdonia the Ordovician is faulted against the Pre-Cambrian/Cambrian of the Vale of Nantlle, and the structure is complicated by the Llwyd Mawr Syncline (Roberts 1967). (see Fig.5.2).

With the possible exception of loc 5 (see Fig.5.2), which may be topmost Arenig in age, no sub-Llanvirn faunas have been previously identified in this region. However, Roberts (1967 p374) recorded a cyclopygid fauna from Foel Quarry (SH 457507) thought to be Llanvirn in age, but Fortey (pers. comm.) reidentified the limited material as Cyclopyge grandis grandis Salter, indicative of the middle Arenig. Additional collecting yielded plentiful material of this species but no other, the only other element being distal dichogaptid fragments, probably of extensiforms.

The value of this locality is reduced by the uncertainty
Fig. 5.2: Geological map of Northern Llyn.
of its structural position and relationship to the other exposures on Foel Hill. The quarry itself demonstrates the variability of bedding, the fossils being preserved on the SE face as a result of bedding/cleavage parallelism, but on the N side bedding strikes almost perpendicular to the near vertical NE-SW cleavage. A cleavage of this orientation occurs throughout the area generally obscuring bedding. The structural interpretation must therefore be based on mappable lithological differences, on which basis a south-westerly plunging anticline cored by rocks of Ffestiniog age has been interpreted (Roberts 1967), but is rejected here.

Along the NE side of the hill are a couple of exposures of buff coloured, bioturbated, sandy siltstone, one of which indicates a shallow SW dip, and a strike parallel to the hill-side. The lithology of the quarry, which is also on the NW side of the hill is a pale grey to buff, parallel banded siltstone and is therefore more closely comparable to the other outcrops on this side of the hill than the medium to dark grey slate that characterises the rest. However at three localities (SH 44785079, 45075065 and 45015015) an ironstone has been noted for the first time.

The ironstone is best developed at the first two localities towards the top of the hill. It is a much darker denser rock than the slate, contains fairly abundant quartz but is most noteworthy for the presence of numerous phosphatic oncolites (see Pl.11 Fig.1). Ooliths are not apparent in outcrop but can be seen in thin section showing them to have been smeared out by the cleavage. In addition the thin section shows the quartz to be unstrained and almost certainly authigenic in origin, the only detrital material being occasional siltstone and phosphatic clasts. At the third locality the ironstone is recognised on the basis of a phosphatic oncolite, interpreted as representing a less well developed lateral equivalent of the same horizon. The positions of the localities are compatible with an overall SSW dip, and as it is likely that the ironstone is younger than middle Arenig (see below) the sequence supports this.

The ironstone is of additional significance in that it may be compared with the better known mined ore of
Trwyn-y-tâl. This consists of a 2.5m thickness of relatively well sorted pisolitic material (Pl.11 Fig.2), bounded to the north by a dark, oolitic lithology containing numerous phosphatic nodules (see Pl.11 Fig.3). These are typically massive with included pisoliths and ooliths (Pl.11 Fig.4), but oncolitic examples are also present and rare mixed examples show the banded form overgrowing the massive (Pl.11 Fig.5). Occasional nodules are present to the south of the pisolitic ore but give way much more rapidly to the pale grey slate of the country rock than on the northern side. The younging direction is not clear, bedding being almost vertical. The pisolitic facies is almost certainly restricted, and the other lithologies are closely comparable to those of Foel Hill.

A basal Llanvirn age is favoured for this ironstone. Regionally there appear to be two main periods of ironstone development (see Sectn.8.5), one at the top of the Arenig / base of the Llanvirn and the other at the base of the Caradoc. The presence of a Llanvirn succession proved to the south (see Fig.5.2) favours the former. Since the two localities where the ironstone has been recognised are a considerable distance apart, it may provide a important marker horizon if it can be mapped between.
Plate 11

Ironstones and phosphatic nodules.

Fig. 1 Laminated phosphatic nodules on Foel Hill, northern Llyn.

Fig. 2 Pisolitic iron ore, Trwyn-y-tâl.

Fig. 3 Abundant phosphatic nodules with included ooliths in oolitic mudstone, north side of pisolitic ore of type shown in Fig. 2, Trwyn-y-tâl.

Fig. 4 Massive phosphatic nodule with included ooliths, Trwyn-y-tâl.

Fig. 5 Weathered section across spherical, concentrically laminated phosphatic nodule, Porthmadog (SH 566393).

Figs. 6 & 8 Massive nodules containing ooliths with elongate laminated overgrowths, Trwyn-y-tâl.

Fig. 7 Reworked broken fragment of laminated phosphatic nodule, Porthmadog (SH 566393).

Fig. 9 Small phosphatic nodules (pisoliths), Betws Garmon.
CHAPTER 6: Aber to Betws Garmon.

6.1 Introduction.

Resting on late Cambrian and separated from the Caernarfon-Bangor area by the Aber-Dinlle fault, this strip forms a distinct entity which does not necessarily have a one-for-one lithostratigraphic correlation with any other. The strip itself strikes NE-SW for some 15km with complex regional folding at either end and an apparent increase in cleavage development from NE to SW with even the sandstones developing a fracture cleavage at Nant Peris.

6.2 Previous Work.

Early work on this area has been superseded by recent mapping (Reedman et al. 1983). This has shown that the Plas-y-Nant beds of the Snowdon area (H. Williams 1927) were an inconsistent combination of Arenig and Cambrian strata whilst between Nant Ffrancon and Nant Peris (D. Williams 1930), what is now known to be Arenig was included within the Ffestiniog Grits, against which the Llanviri slates were thought to be faulted. Though a temporal break was shown by the absence of the Tremadoc, the basal unconformity has only recently been described in detail (Reedman et al. 1983)

6.3 Basal Unconformity.

No clear basal conglomerate has been seen at any point and the base of the Arenig is developed in a variable muddy sandstone facies which is locally absent, causing the overlying slates to rest directly on the Cambrian. Throughout the strip the change in level on the underlying Cambrian appears to be no more than 100m, though a significant down cutting has been claimed towards the Aber-Dinlle fault. (Reedman et al. 1983)

The best and most reliable exposure of the basal unconformity is in Cwn Graianog (SH 623634) (see Pl.12 Fig.8), where there is a slight though obvious angular discordance. However, close to (Pl.12 Fig.6), the break is much less easy to recognise, especially where the Arenig oversteps onto the finer-grained Marchlyn Formation.

At the localities of the other two sections shown (Figs. 6.2 & 3) the situation is less straightforward. The junction on the south side of Nant Peris was figured by Reedman et al. (1983 Pl.2) as an unconformity. This has a very irregular
Fig. 6.1: Sedimentary log of Graianog Sandstone Member Cwm Graianog.
1: Basal unconformity (Pl. 12 Fig. 6).
2: Pl. 12 Fig. 7
Fig. 6.2: Sedimentary log of Graianog Sandstone Member exposed along SW side of Bwlch ym Mhwll-1e.
Stars indicate horizons from which graptolites have been recovered (D. aff. Infrequens (Kraft)).

Trend and cuts down markedly into the Cambrian. The Arenig strata also appear to trend into the junction rather than paralleling it, though this may be the result of the visible strike being that of the cleavage and not bedding. The junction itself can be seen at the base of the gully where c.1m of grey-green sheared slate intervenes between the Carnedd y Filliast grit of the Cambrian and the basal Graianog Sandstone Member of the Arenig. Considering the extensive faulting in this area it is probable that there has been some movement along the contact especially regarding the competence difference between the two groups. The unconformity has therefore probably been modified by tectonic movement.

The base at Bwlch ym Mhwll-1e is almost certainly faulted, but has been mapped as a normal junction (B.G.S. Standards)

6.4 The Arenig Succession.

This has been mapped as the Nant Ffrancon Formation with the Graianog Sandstone Member generally present at the base and locally forming a multiple unit separated by siltstones typical of the higher parts of the formation. The formation extends into the Llanvîn, and though the Graianog Sandstone Member has been mapped to the west of the Aber–Dinlle fault, it is thought best to restrict its use to the type area east of the fault (see Sectn. 4.1).

The Graianog Sandstone member is dominated by medium to fine micaceous sandstones containing a significant mud fraction both as a diffuse matrix element and as distinct
streaks. A continuous source of coarser material is indicated by the presence of scattered gravel grade quartz clasts. As can be seen from the logs some cleaner sandstone beds are present, a distinctive example being shown in Pl.12 Fig.7 where they are interbedded with flaggy arenaceous units, both being coarser grained than is typical of the section. The cleavage only allows division of the sequence at Nant Peris into lithological units of the order of 10m thick (Fig.6.3); a couple of sandstone beds, up to 20cm thick can be seen in the upper part of the basal muddy sandstone unit, which is heavily bioturbated and locally quite coarse grained. Distinctly coarser sandstones occur in the upper half of the Bwlch ym Mhwll-le section (Fig.6.2). The first of these sandstones are distinctly muddy and heterolithic in nature and fairly poorly sorted, but those higher are better sorted and more quartzose, with examples of thinning-upward cycles, up to 2.5m thick, resulting from increased mud streaking. In all the sections there appears to be a distinct coarsening of the sandstone prior to the incoming of a siltstone-dominated sequence.

Apart from the bioturbation and variations in the mud content, few sedimentary structures are apparent. The only cross-beding seen is that in Cwm Graianog 9m above the base (Fig.6.1), the cosets being tabular, laterally continuous, at least bimodal, and containing numerous small mud flakes. Ripple lamination is also indicated by mud drapes within coarse sandstone lenses present in the siltstone dominated facies at the top of the Bwlch ym Mhwll-le section (Fig.6.2). Such small scale cross-lamination may be more widespread than has been recognised. No structures are apparent within the sandstones of this section but the upper
surface of the lowest muddy sandstone is rippled on a wavelength of 30cm, this being paralleled by the sandstone laminae in the siltstone above. Though this could be the result of compaction, a draping of the surface by sediment from the same depositional event is favoured.

The upper part, and greater thickness of the Nant Ffrancon Formation is dominated by dark grey siltstone with occasional lenticular sandstone laminae of variable abundance. Within the siltstone interbedded in the Graianog Member of Cwm Graianog is a volcanic band 40 cm thick. The lithology is pale buff grey in colour with darker flecks, and has a platy texture. A thin section suggests this unit was originally a lithic / crystal tuff.

The other lithology of note is the ironstone of Betws Garmon, dated as lower Llanvirn on the basis of mapping (Reedman et al 1983 p8) and only about 150m above the Cambrian. The fissure style workings of this ore strike in straight line for over 1km, with only minor offset by faulting (see Pl.13 Fig.7) The ore is lithologically comparable to that seen elsewhere at this interval (see Sectn.8.5), being about 3m thick, dominated by a well sorted oolite with local concentrations of phosphatic nodules. The latter are dominantly massive with included oolits, one example being found in otherwise non-oolitic siltstone. Laminated, oncolitic forms are present and appear to be associated with the sparse developments of pisoliths, suggesting a possible genetic association.

6.5 Correlation

The first graptolites from the strip, Didymograptus aff. infrequens (Kraft) were found during this study in the Bwlch ym Mhwall-1e section, though neither these nor the acritarchs previously found (Molyneux pers comm) are adequate to determine its position in the Arenig. Considering the continuity of the Nant Ffrancon Formation across the Arenig-Llanvirn boundary it is possible that the sequence is entirely upper Arenig in age, but the succession in the Arenig area shows this can be misleading and the basal part could be lower or middle Arenig in age. Since the Nant Ffrancon Formation is continuous across the Series' boundary there is the additional problem of estimating the true thickness of the Arenig. The ironstone at Betws Garmon
probably approaches close to the Series' boundary and offers the best approximation. The sequence is therefore considerably thinner than that of the Caernarfon-Bangor area, though it may thin towards the south, especially if the Criccieth strip represents its southerly continuation.
CHAPTER 7: Other Areas.

These areas; Anglesey, St. Tudwal's Peninsula and Dolgellau, have either been recently described elsewhere or present particular problems, and have not been examined in the same detail by me as those already covered. However each was examined in the field and brief mention needs to be made of them to complete the description of the Series in North Wales.

7.1 Anglesey.

The stratigraphy and shelly faunas of this island have already been described in detail (Greenly 1919, Bates 1968 & 1972, and Neuman & Bates 1978) and this information is only reviewed here. Unfortunately Greenly's graptolite collections were not available during this study, as these may have repaid examination.

Bates (1972) divided Anglesey into a number of structural blocks separated by faults, within each of which he recognised a different lithostratigraphy. The three easterly blocks,

1: Llangwylllog Area (Bates 1972 pp36 & 42, Greenly 1919 pp436-9)

2: Berw Fault Complex (Bates 1972 pp.36-7 & 44, Greenly 1919 pp434-6)

3: Llangoed area (Bates 1972 pp.37 & 44, Greenly 1919 pp432-4)

are all poorly exposed though display an essentially comparable sequence of a basal coarse unit overlain by siltstones, with evidence in the Berw Fault complex of an intervening turbidite unit: the Dryll Formation. Two occurrences have been quoted where the shales overlap onto the Mona Complex. That in the lane at Pen Rallt (SH 576803) (Greenly 1919 p434) shows a vertical contact that may well be faulted and the second, at Dragon Farm (SH 505746), is now obscured by farm buildings. An ironstone occurs in two of the blocks, the Ty'n yr Onen Ironstone in the Llangwylllog area and that of Bryn-celyn in the Llangoed area. The former appears to occur at the base of the Caradoc (Greenly 1919p 438) whilst the latter was shown as lying between the Arenig and Llanvirn by Bates (1972.p31 Fig2). It probably lies within the Llanvirn, being interbedded with siltstones.
yielding pendent graptoloids (T. Young pers. comm.) but this need not preclude it from being an example of the regional development in the lower Llanvyrn. In all three areas the contact with the Mona complex appears to be in general faulted. (Bates 1972).

The exposures at Garth Ferry (SH 580740) are included within the Llangogoed area and provide a comparison with the basal beds that lie directly across the Menai Straits, less than 1km away. The structural setting is closely comparable, the basal sandstones being faulted against schists along a trend parallel to the shore, and are locally unconformable on them. The Garth Ferry beds are coarse quartzose sandstone with occasional grit and muddy bands, and are not significantly different from the basal unit of the Bangor area. The absence of the Arfon Group may be explained in part by the bounding of the depositional basin by the Dinorwic fault (Reedman et al 1984) or its subsequent erosion from Anglesey, but in either case a marked change in stratigraphy occurs across the Dinorwic fault. As already noted it is likely that the Menai Straits inlier should be grouped with Anglesey rather than the Caernarfon -Bangor area, and this gains some support from the fact that the only graptolite recorded from the Llangogoed area is an isogaptid (Greenly 1919 p432), a group virtually absent from the Caernarfon-Bangor area but relatively abundant in the Menai Straits inlier.

The biostratigraphic control in all three blocks is somewhat limited. The upper Arenig isogaptid occurs close to the junction with the Mona Complex but this is faulted and the succession could extend below the later Arenig in the Llangogoed area. In the Berw Fault complex there is no exposure of a basal unconformity (Bates 1972). In this area, brachiopods have been recorded from three localities (Bates 1972) but their stratigraphic position is confused by the extensive faulting. The only graptolite, from Rhyd-yr-arian (SH 498735) is recorded as *D.hirundo*. The best evidence for the base being high in the Arenig comes from the Llangwyllog area, where a small pendent graptoloid from Tydynn Farm (SH 419797) and biserial graptoloids from the railway cutting SW of Llangwyllog (SH 432796), recorded as *Glyptograptus dentatus*, both occur a short distance above the unconformity
1 Carmel Fm
2 Treiorwerth Fm
3 Nantannog Fm.
4 Foel Fm.
5 Dulas Fm.
6 Porth Cynfor Conglomerate
7 Torllwyn Fm.
8 Llangwylllog Grits
9 Berw Uchaf Grits
10 Dryll Fm.
11 Glanmorfa Shales
12 Garth Ferry Grits

Carmel Head Thrust
Ogof Goch Fault.
Ceidio Fault
Berw Fault

Legend:
siltstone with breccia beds
turbidites
conglomerates
sandstones
siltstone

500m
and indicate lower Llanvirn and ?Upper Arenig age. There is no evidence for lower or middle Arenig in any of these areas and it is thought that they are probably absent.

The two remaining areas; the "Principal" area of Greenly, and the Gynfor outliers both contain proximal mass-flow deposits, but because of the intervening Carmel Head thrust are best considered separately.

7.1a The "Principal" area.

(Bates 1972 pp 34-6 & 37-42; Greely 1919 pp439-451

The basal units; the Carmel and Foel Formations, west and east of the Ceido fault respectively, are not dissimilar lithologically from the basal Arenig beds seen elsewhere apart from their expanded thickness. The Carmel Formation may be divided into two; a lower bedded, pebbly sandstone unit with occasional coquina bands and some current bedding and an upper multimodal cross-bedded sandstone (Pl.12 Fig.5, better sorted than the lower unit and containing sparser coquinas. The coquinas are dominated by articulate brachiopods, but include some trilobite material: Heseuretus monensis (Shirley), Annamitella perplexa (Bates) and an asaphid, indicative of the same biofacies as the Maesgeirchen Sandstone Member of the Caernarfon-Bangor area, and the ferruginous, micaceous sandstone is closely comparable to the most fossiliferous beds of the Bangor Bypass. The Foel Formation is somewhat coarser and contains a higher proportion of silt grade material separating bedded sandstones.

These formations are overlain by rocks placed in three different formations: Treiorwerth, Nantannog and Dulas. The Treiorwerth Formation is a very thick, mass flow dominated sequence that gives way laterally to the Nantannog Formation which is dominated by siltstones, though contains isolated beds comparable to those of the Treiorwerth Formation (see Pl.1.12 Fig.1). The coarsest beds of the Treiorwerth Formation appear to be in the south of the area near Rhosneiger (see Greenly 1919 Pl XXVII, facing p.404) and some cobble grade beds in this area become almost clast supported. However, in general, the formation is somewhat finer, pebble grade extraformational material being typical, though larger intraformational clasts do occur.

The Nantannog formation locally contains abundant
sandstone beds, eg at Rhosneiger, where there is a suggestion that this facies may partly underlie the Treiorwerth Formation though this is not indicated on Bates' sequences (see Fig.7.1). The Dulas Formation is restricted to the east of the area and is, at least in part, laterally equivalent to the Nantannog Formation. At its type locality it shows considerable evidence of syn-sedimentary deformation (see Fig.7.2), and though no macro-fossils have been found it is thought to underlie beds of known Llanvirn age.

Fig.7.2: Slumping in the Dulas Formation, Dulas Bay. (SH 486894)

A number of graptolite faunas have been obtained from the siltstones throughout this area, and all appear to indicate the topmost Arenig and basal Llanvirn, containing biserial and pendent graptoloids respectively. The shelly faunas of the Carmel and Treiorwerth formations (Bates 1969, Neuman & Bates 1978) tend to be endemic at the species level and are of little use in finer scale correlation. Acritarchs and chitinozoa have been recorded from Dulas Bay (Fenton 1976) and these are thought to indicate a lower Llanvirn age for the Dulas Formation. This suggests that the base of the Dulas formation may be slightly younger though both the Treiorwerth and Nantannog Formations certainly extend into the Llanvirn and may even be dominantly of that age.

7.1b The Gynfor Outliers.
(Bates 1972 pp32-4 & Greenly 1919 pp. 472-7)

At Ogof Gynfor (SH 378948), the Torllwyn Formation rests directly on the Gwna melange, is only 25m thick and is dominated by poorly sorted conglomerate with clasts of quartzite up to 2m across (see Pl.12 Fig.2). Despite the poor
sorting of the unit, weathering picks out thin parallel bedding in much of it. Just over 2km east the formation has increased in thickness to about 140m, and is more arenaceous though rudaceous units are still abundant, including lenticular conglomerates one example thinning from 2m to 50cm in only 4m with a strongly convex upper surface.

The purple Porth Cynfor Conglomerate (Pl.12 Fig.3) underlies the Torllynwyn Formation in the east and reaches a thickness of 55m. In facies it is closely comparable the overlying beds and Bates considered the Torllynwyn Formation to overlap this unit. However he also noted that folds in the Porth Cynfor Conglomerate were truncated by the Torllynwyn Formation and this suggests the relationship may involve overstep.

The age of the Porth Cynfor Conglomerate is unknown but brachiopods from the Torllynwyn (Bates 1968 & Greely 1919) are comparable to those of the Carmel Formation.

7.2 Dolgellau Area.

Three areas of Arenig exposure occur in the Dolgellau area:

1) The outliers of Foel Offrwm and Rhobell Fawr.

2) A strip along the western flank of the Aran Mountains.

3) A strip extending from Tywyn to Cader Idris via Fairbourne.

The sequences of these areas have all been grouped in a single, variously named, formation at the base of the Aran Volcanic Group; Pared- yr- Ychain Formation (Ridgway 1975) and Allt Lwyd Formation (I.G.S. 1982). However there are distinct differences in the three sequences. As already noted the sequence on Rhobell Fawr and Foel Offrwm is closely comparable to the Carnedd Iago Formation of the Arenig area and is probably best included therein. Though not separated from these exposures by any structural lineament the sequence exposed between Tywyn and Cader Idris has a uniform lithostratigraphy that is different. By contrast, the Aran Mountains lie to the SE of the Bala fault and show a sequence different from both the above and are therefore also treated separately.

In neither of the areas discussed below have Arenig faunas been collected and their position within the Arenig is unknown. The strong cleavage, especially in the Arans,
makes recognition of sedimentary structures difficult, whilst south of Dolgellau obtaining access is a problem. Both areas warrant further study, particularly mapping, since no recent maps have been published.

7.2a Tywyn - Cader Idris.

The sequence broadly divides into two; a lower clastic unit, termed the "Basement Group" (Cox & Wells 1920), and an upper volcanic group, the latter divided in two by a slate horizon yielding pendent and extensiform graptoloids that has been taken as approximately indicating the Arenig/Llanvirn junction (Jones 1933 p159, Cox & Wells 1920 p271-2). Though extensiform graptoloids remain relatively abundant well into the Llanvirn this age determination is probably not unreasonable.

The basal unconformity rests on Tremadoc slates with one exception. To the south of the Llanegryn fault the Tremadoc is cut out and the Arenig rests directly on Dolgellau beds. The "Basement Group" thickens towards the south, being about 45-60m south of Dolgellau; 200-250m between Fairbourne and the Llanegryn fault; and about 450m on Beacon Hill above Tywyn, south of the fault (Cox & Wells 1920, Jones 1933).

The facies of the "Basement Group" is like basal parts of the Arenig sequence as seen elsewhere in North Wales. A log through the sequence south of Llyn Wylfa (SH 672162) is shown in Fig.7.3 and is dominated by flaggy beds in the lower part overlain by cross-bedded, somewhat arkosic, sandstones. Jones (1933 p155 Fig2) presented logs of the "Basement Group" at three points between Fairbourne and the Llanegryn fault. Again, the sequence is dominated by flaggy beds with less evidence of the cross-bedded sandstones.

Above Hafotty (SH 62211182), a lenticular conglomerate occurs in the mid-part of the sequence. Approximately 10m thick, it is dominated by well rounded clasts up to 45cm across of a vesicular igneous rock (See Pl.13 Fig.4). This unit is very like the Aran Boulder Bed (see below). At the top of the same section concentrically laminated phosphatic nodules have been recorded from shales interbedded with tuffs. The sequence on Beacon Hill, despite its greater thickness, appears to be dominated by flaggy beds with occasional coarser units, most notable at the base.

The overlying volcanic rocks have been placed in the
Fig. 7.3: Sedimentary log of "Basement Group" south of Llyn Wylfa, SH 672162.

Mynydd-y-Gader Acid Formation (Ridgway 1975), the portion below the slate band being dominated by ignimbrites. Cox & Wells (1920) described this sequence in detail and noted a thinning from east to west away from Cader Idris.
7.2b The Arans.

No detailed map has been published of the area, and only two papers provide any significant information about it (Dunkley 1979 & Ridgway 1975). Both are mainly concerned with the Aran Volcanic group and therefore treatment of the Arenig is brief.

The sequence in the south, around Bryn Gwynion (SH 8120) and Bryn Mawr (SH 8220) is dominated by volcanic sandstone with some evidence of cross bedding and local mud streaking giving a flaggy appearance. At the top of the sequence is the remarkable Aran Boulder Bed (see Pl.13 Fig.6) that may reach up to 66m in thickness (Ridgway 1975). Above this occur multimodal cross-bedded sandstones followed by mudstone. In the central part of the Arans (SH 851229) the sequence is dominated by immature breccio-conglomerates. The total thickness of 450m indicated by Ridgway (1975) is probably an overestimate, but a considerable thickness is certainly present. To the north Ridgway shows the sequence as becoming more arenaceous whilst Dunkley (1979) showed the sequence in the NE Arans as dominated by conglomerate.

7.3 St. Tudwal’s Peninsula.

St. Tudwal’s Peninsula is dominated by a near horizontal Arenig sequence resting on a thick Cambrian succession with marked angular unconformity (see Pl.13 Figs.1 & 3). No account of this area has been published since that of Nicholas (1915) but it has recently been reexamined in detail during a PhD project (Tegerdine in prep) and duplication of this work has been avoided.

Nicholas (1915 p109 fig 5 & p.113) divided the Arenig succession into the Tudwal’s Sandstone, just under 100m in thickness, overlain by the Llanengan Mudstone, about 75m thick. The junction was supposedly gradational, “Transition Beds” being recognised, but at Penrhyn Dû (SH 320264) a phosphatic lag is developed between the two units (see Pl.13 Fig.5). Though much of the Tudwal’s Sandstone is dominated by quite thick sandstones (Pl.13 Fig.1) very silty portions are present.

Above the Llanengan Mudstones is an ironstone, which Nicholas considered to lie along the sole of a thrust, though Tegerdine (pers comm) favours a normal sequence. Directly overlying this ironstone are beds of Caradoc age.
(Molyneux pers comm & Nicholas p123), dramatically different to the sequence north of the Peninsula where the Llanvirn is well-developed (Matley 1938). A basal Caradocian unconformity seems most likely from the distribution shown in Nicholas' Map (Pl.XIII) and therefore the complex zone of Pen Benar (SH 316282), which includes Tremadoc rocks (Nicholas 1915 p118 Fig7) probably indicates the structural lineament separating the two areas. This zone shows a steep metamorphic gradient that is considered to indicate high strain (Roberts & Merriman 1985).

The area to the north, which has a supposed strip of Arenig rocks running from WNW of Bottwnog to the coast N of Abersoch (Matley 1938 Pl. L) is very poorly exposed, and the only comments made here concern the fossils recorded.

A number of graptolites have been recorded from the Peninsula itself but this material was not available and only additional material of the azygograptid from the "Transition Beds" was collected. This is assigned to Azygograptus lapworthi, and is taken to indicate an upper Arenig age. The same species is present at Castellmarch Farm (SH 31452980) and due west of this locality at SH 30792976 Pseudophyllograptus angustifolius subsp. 1 is present, first noted by M. Bedrock (pers. comm.), but collected in greater numbers during this study. This species may prove to be biostratigraphically useful when the group is better understood.
Plate 12
Anglesey and Aber-Betws Garmon strip.

Fig.1 Mass flow unit in Nantannog Formation, Llanerchymed Station (SH 417842).

Figs. 2 & 4 Torllwyn Formation, Ogof Gynfor. SH 378948.
Fig.4 shows basal unconformity; Fig.2 large quartzite block (about 2mm across).

Fig.3 Porth Cynfor Conglomerate, just east of Ogof Gynfor.

Fig.5: Upper, cross-bedded part of Carmel Formation, Tan-y-bryn SH 357787.

Figs. 6 & 8 Basal unconformity of Graianog Sandstone Member, Cwm Graianog. Fig.6; resting on Marchlyn Formation; Fig.8 shows clear angular discordance with Carnedd y Filliast Grit, to right.

Fig.7 Interbedded flaggy and massive sandstones, Graianog Sandstone Member, Cwm Graianog. (Fig.6.1 note 2)
Plate 13

Fig. 1: St. Tudwal's Sandstone, east side of Penrhyn Du (SH 324265).

Figs 2 & 3: Basal unconformity of St. Tudwal's Sandstone, Trwyntllech-y-doll.

Fig. 4: Cobble conglomerate above Hafotty, Fairbourne (SH 62211182).

Fig. 5: Phosphatic band between St. Tudwal's Sandstone (Transition Beds) and Llanengan Mudstone, west side of Penrhyn Du.

Fig. 6: Aran Boulder Bed, Bryniau Gwynion (SH 815205)

Fig. 7: Ironstone workings at Betws Gwanon.
CHAPTER 8: Overview.

8.1 Introduction.

In the following chapter an attempt is made to integrate the sequences seen in the different areas into an overall picture of North Wales during the Arenig. Though the biostratigraphic scheme employed during this study has allowed considerable refinement in the chronostratigraphic division of the Series, there are still serious limitations in its ability to allow precise correlation. Firstly, there are large areas that have either not yielded fossils or are without stratigraphically diagnostic species, and even in areas where such forms are present they are often localised in the sequence, leaving parts of the section without temporal control. As a result much inevitably still depends on lithostratigraphic correlation, although it is as well to recall that the previous applications of this have proved unreliable. Furthermore, indifferent exposure often obscures the finer-scale sedimentary structures of the more argillaceous lithologies, and the description of such rocks is often limited to such terms as flaggy-beds or sand streaked siltstone when sporadic exposures show the complexity to be considerably greater. In spite of the difficulties in detailed environmental interpretation it is likely that throughout the majority of the Arenig North Wales was a patchwork of shelf environments of varying depths, the best indicator of which is probably the biofacies. Both graptolites and trilobites have been shown to be affected by environment (Fortey & Owens 1978, Fortey 1984, Fortey & Cocks in press) and the main communities are shown in Fig.8.1. The strongly diachronous development of these biofacies in North Wales is a further limitation on the biostratigraphic correlation.

REGIONAL CORRELATION & ENVIRONMENTAL INTERPRETATION.

The sequences seen in the various areas are summarised in Fig.8.2 with suggested correlations.

8.2 Lower Arenig.

The lower Arenig has only been proved in the Arenig area and east of Aberdaron, although the former may reasonably be extrapolated around the Harlech Dome. In the Aberdaron area the basal conglomerate rests on the Mona
complex, including the supposedly youngest Penmynydd schists (Gibbons 1983). In total contrast, around the Harlech Dome the underlying rocks are of Tremadoc age, and locally, the two series even appear conformable (Lynas 1973). However, there is also considerable evidence of disconformity between the two. Lynas (1973 p500) noted that subsequent to the deposition of the Tremadoc uplift occurred along NS fault lines (see Fig.2.1) resulting in some erosion, and the late Tremadoc Rhobell Volcanic group was 'folded, faulted and deeply eroded before being unconformably over lain by the basal Arenig' (Kokelaar et al 1984). There is therefore, very probably a significant stratigraphic break below the Garth Grit, even where there is apparent conformity with the underlying Tremadoc.

The lenticular nature of Garth Grit has been taken to suggest distributary channels of a delta (Lynas 1973) but this implies that the underlying Tremadoc siltstones of the Afon Gam Formation represent deltaic deposits themselves. The stratigraphic break between the two Series makes this unlikely and it is more reasonable to regard the Garth Grit as remnants of a transgressive sandstone, an alternative noted by Lynas and favoured by Zalasiewicz (1984). The lenticularity could result from either erosion or restricted deposition in depressions, the latter being favoured by the
Fig. 8.2: Summary diagram of the Arenig Series in North Wales showing distribution of the three divisions and the facies developed.
correlation of facies variation with the lenticularity. This model is also more compatible with the presence of metamorphic clasts in the Garth Grit; the clearly shallow marine environment of the overlying Llyfnant Member and the presence of phosphatic oncrites is suggestive of a period of slow deposition. The restricted fauna of the Llyfnant Member (Zalasiewicz 1984) suggests no great water depth but the larger scale cross-bedding and *Neseuretus* trilobite community type of the Henllan Ash Member suggest this was deposited in more energetic, and probably shallower environment still.

The flaggy facies of the Llyfnant member is one that occurs throughout the Arenig of North Wales and is not restricted to a single stratigraphic interval. Zalasiewicz (1984) noted the difficulty in defining the environment of such beds and favoured "a shallow though subtidal environment". Pedersen (1985) recently described storm layers from a muddy shelf sequence of Jurassic age, which develop facies very similar to those seen in the flaggy beds of North Wales. Such lithologies were considered to extend onto the outer shelf, and though the majority of the North Wales examples are probably shallower than this, the environment need not be as restricted as that implied by Zalasiewicz.

The depositional environment of the Wig Formation in the Aberdaron area is not thought to have been substantially different from that of the Arenig area. The siltier portions of the Porth Ysgo Sandstone Member are very similar in facies to the Llyfnant member and the trace fossils present indicate a relatively shallow environment (Crimes 1970, cf Crimes 1969). The greater current activity indicated by the sandstone beds and common rippled surfaces of the thinner sandy laminae suggest slightly shallower water than is characteristic of the Llyfnant member, and the coarse basal conglomerate containing clasts of the Mona Complex, greater proximity to the source area.

The more argillaceous nature of the overlying Maen Gwemonwy Member may indicate somewhat quieter deposition, though the dominance of *Azygograptus eivionicus* and *Merlinia selwynii* and rarity of extensiform graptolites in the fauna suggests that the depth is not significantly different. The facies change may therefore, at least partly, reflect a
change in sediment input, this being supported by the development of a probable condensed bed at the facies change.

Nowhere in North Wales has the upper part of the lower Arenig, characterised by *Merlinia rhyakos* Fortey & Owens (1978) in South Wales, been recognised. Since *M. selwynii* and *M. rhyakos* form a single phyletic lineage the absence of the latter cannot be facies controlled. As the Olchfa Member rests directly on the Henllan Ash Member the upper part of the lower as well as the middle Arenig is absent in the Arenig area. In the western Llyfn may appear to be a continuous section but this is barren of fossils and therefore the boundary cannot be accurately positioned.

In the context of the stratigraphic break at Arenig, the evidence of tectonic instability in the lower Arenig is significant, and it is tempting to suggest that the slumping seen in the Llyfnant Member on Moel Llyfnant and above Tan-y-Grisiau reflects earth tremors associated with fault controlled basin shallowing. However there is no evidence of shallowing in the Tan-y-Grisiau section, the lithology overlying the slumped unit being more argillaceous than those below and the cross-bedded sandstones at the top appear continuous with the overlying slate succession.

The tectonic activity may be associated with the volcanics which have been identified. A primary volcanogenic origin for the Henllan Ash Member has been questioned, but a tuff band is present towards the top of the Llyfnant Member (Zalasiewicz 1984). Though the tuff horizon recognised here in the western Llyfn may be stratigraphically slightly higher, it almost certainly reflects the same broad episode. Therefore there appears to be good evidence of minor tectonic disturbance within the upper part of the lower Arenig.

Throughout the Aberdaron area the Maen Gwenonwy Siltstone Member shows evidence of interaction between soft sediment and intruded magma, and on Rhobell Fawr, soft sediment slumping has occurred in the Llyfnant Member where this unit has been tilted in response to the intrusion of a sill (cf.Wells 1925 p.498 Fig.8). Since such features can occur at considerable depths of burial (Kokelaar 1982) the age of intrusion may well be somewhat later, but evidence of
soft sediment intrusion has not been noted in younger parts of the Arenig sequence; therefore it is possible that these features also reflect the late lower Arenig volcanic episode. Development of such shallow level sills is typical of the Welsh Basin (Kokelaar et al. 1984).

The best biostratigraphic correlation is with the sequence in South Wales (Fortey & Owens 1978) because there is a comparable sequence of facies and biofacies developed there in a transition from a coarse transgressive base to siltstones. There is no clear evidence in North Wales for the uppermost part of the lower Arenig as defined in South Wales where it is a series of mudstones deposited under low oxygen conditions and including an olenid trilobite biofacies. It is possible that part of the Trefgarn Volcanic Group could be lower Arenig in age since it is only known to be overlain by middle Arenig though this could reflect overlap.

The occurrence of *Hanchungolithus primitivus* in SE Ireland and Montagne Noire, Southern France is noted under the discussion of the species (see Chapter 12). Its occurrence at the top of the exposed Arenig section in the Landeyran Valley does raise the possibility that lowermost Arenig beds are not developed in North Wales, though it is not possible to estimate the time period represented by the basal coarse units; the Garth Grit Member and the Porth Ysgo Sandstone Member.

There is a major problem in correlating accurately with the graptolitic sequence in the Lake District. The recent discovery of a Lancefieldian graptolite (Rushton 1985a) from the Uldale Fells in a section continuous with Frozen Fell Gill from which Jackson (1979) recorded *Didymograptus protobalticus* Monsen, indicates that the Arenig sequence is developed entirely within graptolitic facies. *D. deflexus* has been recorded from the Llyfnant Member (Zalasiewicz 1984) but is less abundant than *D. aff simulans* which suggests closer comparison with Barf and the *D. nitidus* biozone. Considering the restricted nature of the Llyfnant Member fauna, and the absence of any deflexed graptolites in the Maen Gwenonwy Member, their distribution may be significantly facies controlled and in this case they could range through much of the Arenig. *Didymograptus praenuntius* recorded from the western Llyn does not assist
in the resolution of this problem.

8.3 Middle Arenig.

This division, like the lower Arenig, is very restricted in distribution and has only been proved on the Llŷn. The best development is again in the Aberdaron area, where it is developed in parallel laminated dark siltstone. Though *Cyclopyge grandis grandis* is very common, the fauna is best assigned to the raphiophorid community type of Fortey & Owens (1978) since raphiophorids and asaphids are abundant among a diverse trilobite assemblage. This suggests a somewhat deeper shelf environment than in the lower Arenig. The fauna of Foel Quarry in the northern Llŷn is almost totally dominated by the pelagic trilobite *C. grandis grandis* (Salter). This may indicate a deeper depositional environment, though a single fauna is not enough for further palaeogeographic speculation.

Sandy beds occur in the Aberdaron Formation at Parwyd and Hendre Uchaf, both west of the Wâg fault. Those of Parwyd contain clear cross-lamination and there are suggestions of cross-cutting laminae also at the latter locality. The soft-sediment deformation described above suggests some degree of instability along the fault bounding the outcrop of the Mona Complex, presaging the more obvious instability of the later Arenig.

It is possible that the Maesgeirchen Sandstone Member of the Caernarfon–Bangor area is middle Arenig in age (see below). That these beds are of shallow water origin is indicated both by the sediments and the presence of the inshore neseuretid community type. The coarser basal beds of the Bangor area suggest a source area in that direction with the gravel draped cross-bedding and channelling both indicating a high energy depositional environment, probably above the normal wave base. Their micaceous composition and poor sorting both suggest fairly rapid deposition of immature sediment. The parallel bedding in the Bangor Bypass section of the Maesgeirchen Member, suggests individual depositional events and though storm processes would seem most likely, the distribution of the fossil fragments is not entirely typical of tempestites (cf Kreisa 1981, Brenner & Davies 1973).

In modern storms the transport of shells is reported as
insignificant in all but the very near shore environs. Shell lags are therefore generated by the winnowing of the surrounding sediment, the subsequent deposition of which forms a couplet with the coquina (Kreisa 1981). However, in ancient sedimentary sequences interpreted as storm dominated the movement of shelly material has been proposed (Brenner & Davies 1973, Brenchley & Newall 1982). Though somewhat thinner than the beds in North Wales, examples have been described from the Welsh Borders where shell concentrations occur in the middle parts of the bed (Brenchley & Newall 1982; Benton & Gray 1981). Such occurrences indicate that shell transport has occurred, at least in the early stages of the storm, presumably in fairly close proximity to the shoreline. The bivalve-dominated bands in North Wales are closely comparable to winnowed lag deposits, and though the concentrated bands of trilobite fragments may be comparable, these appear to have been light enough to continue being transported until late in the depositional event. Such a complex depositional sequence suggests interaction between deposition and winnowing within a single bedding-unit and may reflect longer periods of storm activity.

The middle Arenig is probably absent elsewhere in North Wales, as it certainly is in the Arenig area. The biostratigraphic correlation of the Llyn sequences with those of South Wales is well established as they share a large number of trilobite species, most notably Cyclopyge grandis grandis, Bohemopyge scutatrix and Ampyx salteri. Though comparison might be expected between the fauna of the Maesgeirchen Member and the Mytton Flags of Shropshire none of the species are in common. Megalaspisella cf. gralli, compares with the species described originally from the Arenig of Montagne Noire, and though none of the other trilobites figured serve to define the horizon more accurately the graptolite fauna given does suggest the lower half of the Arenig (Thoral). Azygograptus eivionicus which occurs in the beds directly overlying the Maesgeirchen Sandstone Member is known from the base of the middle Arenig as defined in South Wales (Fortey & Owens in press) and since the trilobite fauna does not compare with that of the same biofacies described from the Henllan Ash Member (Whittington 1966) and of lower Arenig age, a basal middle
Arenig age is favoured for the Maesgeirchen Member fauna. As with the lower Arenig, the paucity of graptolites precludes accurate correlation with the Lake District.

8.4 Upper Arenig.

This is the most widespread of all three divisions and shows the greatest evidence of tectonic instability, though it may be locally absent in the area around the Harlech Dome. For the reasons outlined above certain sequences where the age is uncertain, for example Aber- Betws Garmon, the Arans and S. of Dolgellau, are considered to be at least in part of upper Arenig age if not dominantly so. The regressive-transgressive interval at the top of the Arenig (Fortey 1984) may be reflected by the increased coarseness of the beds towards the top in the Caernarfon-Bangor area and the regional development of an ironstone discussed below.

The most dramatic founding of a previously positive area was in Anglesey, and the "Principal Area" in particular, where the thickest Arenig sequence in North Wales appears to be totally restricted to the upper part, though it should be noted that the base of the Llanvirn is ill-defined. Bates (1972) considered the Treiorwerth Formation to be of westerly derivation from fault bounded Mona Complex. In this context comparison may be made with the Porth Meudwy Member and underlying synsedimentary deformation seen in the Aberdaron area, which may also have been derived from an upfaulted area of Mona Complex just to the west.

It is suggested from indirect evidence that the Arenig sequence SE of the Bala fault is dominantly upper Arenig in age. Whether or not this is the case the question of the sense of vertical movement on the Bala fault remains. Ridgway (1976) and Rast (1969) both favoured downthrow to the SE; Dunkley (1979), the opposite sense of movement mainly on the basis of shallow water facies to the SE side: a feature recognised by Ridgway but explained by sedimentation out-stripping subsidence. Dunkley's interpretation does not appear tenable on the basis of the facies change that is apparent across the Bala fault, with fan type deposits, whether sub-marine (Ridgway) or alluvial (Dunkley), being restricted to the SE side. Considering the close approach these deposits now make to the line of the
Bala fault, their restriction to the SE must indicate ponding by a SE facing fault scarp, and this sense of movement would also be more compatible with the thickness changes observed (Ridgway 1975). This is not incompatible with either of the proposed source directions; from the north (Ridgway 1976) or south east (Dunkley). The restriction of shallow water clastic facies to the SE side may well reflect bounding of the depositional basin, since if an upper Arenig age interpretation is correct, a condensed oolitic mudstone horizon was developing in the circum-Harlech Dome area.

The tectonic instability and fault activity of the upper Arenig are associated with some volcanism which presages the more widespread activity in the Llanvirn. The Carw Tuff Formation of the Aberdaron area lies on the Arenig/Llanvirn boundary and there is evidence in the Sarn area of the extrusion of a pillow lava within the upper Arenig. It is tempting to equate this activity with the Mynydd-y-Gader Acid Formation of the Dolgellau area. The graptolitic slate band interbedded with these volcanics, and believed to indicate the Arenig-Llanvirn boundary, tends to support this interpretation.

The distribution of biofacies is complex at this time. The presence of an isogaptid graptolite biofacies, indicative of a marginal environment open to the ocean (Fortey & Cocks in press), suggests a deeper water environment in the southern part of the Aberdaron area (Nant y Gadwen); west of the Dinorwic fault; and in the Caernarfon - Bangor area subsequent to the "basal Llanvirn" transgression. A single specimen of *Pseudisograptus* has been recorded from the Afon Seiont section, but is not typical. The more restricted nature of the fauna in the Caernarfon - Bangor area suggests it may have been somewhat shallower than that to the west of the Dinorwic fault and this may indicate a reversal in fault movement from earlier times.

Relatively inshelf graptolite faunas are indicated by the presence of *Azygograptus*, notably at a number of localities on the Llyn, and the neseuretid community of the basal Carmel Formation on Anglesey. A single specimen of *Neseuretus* has been found in the St Tudwal's Sandstone (Tegerdine pers comm.). The shelly faunas contained in the
Treiwrwrth Formation of Anglesey are probably derived from a nearby area that continued to be positive.

Correlation with other areas is generally well founded for the upper Arenig, because graptolite taxa are widespread and distinctive and the facies was more uniform throughout the British Isles. The trilobite species of the Carmel Formation are again endemic, but the overlying sequence suggests an upper Arenig age. Volcanism appears to have become prevalent in all areas of southern Britain at the base of the Llanvirn.

8.5 Ironstones.

Circular argument has to be avoided in correlating the development of ironstones with a particular time horizon, especially when biostratigraphic control is limited. Thus it was that Weinberg (1973) suggested that all the ironstones in North Wales correlated with the basal Caradoc transgression. Although ironstones were extensively developed at that time there is good evidence that there was also a significant development at the Arenig – Llanvirn boundary. (Numbers refer to Fig.8.3)

1) The ironstone at Llandegai (4) has been shown to be lower Llanvirn on the evidence of acritarchs (Molyneux pers comm.), and correlated with that at Betws Garmon (Howells et al 1983).

2) The chamositic mudstone of Rhiw (1) (Groves 1952) is closely associated with the Carw Tuff Formation, which has been shown here to correlate closely with the Arenig–Llanvirn boundary.

3) The oolitic mudstone of Nant yr Olchfa (6) occurs at the top of a thin sequence of siltstones yielding upper Arenig graptolites. This may reasonably be correlated with the similar lithology on Foel Offrwm (7), which is intimately associated with overlying volcanics dated as lower Llanvirn (Kokelaar 1979).

4) On the basis of regional structure the ironstone at Trwyn–y-Tâl (2) has been considered Arenig (Tremlett 1962), and the ironstone discovered on Foel Hill (3), which probably overlies the known middle Arenig, may be reasonably correlated with it.

5) Ironstones occur in Europe at the Arenig – Llanvirn Boundary.
Fig.8.3: Distribution of upper Arenig-lower Llanvirn Ironstones and related facies. 1 Rhiw; 2: Trwyn-y-Tal; 3: Foel Hill; 4Llandegai; 5: Betws Garmon; 6: Nant yr Olchfa; 7: Foel Offrwm.

a) Ironstones occur at the base of the Llanvirn Sarka Formation of Bohemia (Boucek 1973 p.139)
b) Ironstones in Northern Normandy have been placed at the base of the Llanvirn, while those a little further south and in Brittany have been placed in the upper part of the Arenig. (Robardet 1981 p.83 Fig.26)

The Wabana ore of Newfoundland is of uncertain age, though appears to be at least in part Arenig (Bergstrom 1976 p.1616). Subsequent work may prove some of the supposed higher Ordovician ironstones to be at this horizon, particularly in the Iberian peninsula and Morocco.

A genetic relationship between ironstones and regressive
transgressive intervals has been generally recognised (cf. Van Houten & Bhattacharyya 1982) and such an interval has been identified at the Arenig – Llanvirn boundary (Fortey 1984). The effects of this as represented on the Bangor foreshore have already been described, along with the comparison this shows with the sequence of the Llandegai Ironstone. This clearly suggests that the ironstone occurs at the base of the transgression rather than the top of the regression, both modes having been recognised (Van Houten & Bhattacharyya 1982). In either case, the ironstones tend to represent condensed sequences, and this is compatible with a common association with phosphatic nodules.

![Diagram of phosphatic nodules and evidence of reworking](image)

**Fig. 8.4**: Types of phosphatic nodules and evidence of reworking. 1: Oolitic mudstone. 2: Massive nodule in siltstone. 3: Laminated (oncolitic) nodule in oolitic mudstone. 4: Massive nodule with included ooliths in oolitic mudstone. 5: As 4 but with laminated overgrowths on nodule. 6: Massive nodule with included ooliths in siltstone. 7: Broken laminated nodule. (Actual examples shown in Plate 11.

Phosphatic nodular horizons are common throughout the Arenig of North Wales at periods of reduced sedimentation, with the widespread recognition of laminated phosphatic nodules, often referred to as *Bolopora undosa*, those in the Garth Grit member being a good example. The laminar nature is probably algal in origin (Hofmann 1975), and though the presence of such nodules in the ironstones was dismissed as being of no significance by Weinberg (1973) there does appear to be a correlation with their presence and the development of the larger pisoliths particularly at Trwyn-y-Tâl and Betws Garmon and they may also be algal in origin. The variety of nodules present is summarised in Fig.8.4 along with the evidence that indicates that their development was contemporaneous with that of the ooliths and
that they were reworked on the sea-floor. Mixed nodules are not very common but do occur to show that all the nodule types were capable of developing together. The association of sponge spicules with the development of ironstones has been recognised (Pulfrey 1933 & 1933a, Woodland 1939 & 1939a); such spicules are often included in more massive nodules.

There is some evidence that the Arenig-Llanvirn ironstone interval is locally represented by phosphatic nodular horizons eg.

1) The presence of both massive and oncolitic phosphatic nodules in the Porth Meudwy Member, Aberdaron, presumably derived from the "high" of the source area.

2) An horizon of *B.undosa* was recognised at the top of the "Basement Group" above Fairbourne. (Jones 1933)

3) Phosphatic nodules, some with abundant sponge spicules, occur towards the top of the Arenig in the Afon Serw section (see Fig.2.7).

One ironstone remains, the genesis of which does not appear to be related to those described above. It appears to have developed on the pillow lava that outcrops north and south of Sarn and is probably at an horizon well below the Series' boundary. It is suggested that it results from shoaling associated with the topographic effect of the lava in relatively shallow water. It differs from other examples in having a significant clastic component which probably results from a winnowed concentration of the scattered coarser clasts present in the Sarn Formation. The petrography of this ore is extremely complex and worthy of further study. It is possible that there may also have been some chemical effect by the underlying lava. The Rhiw chamositic mudstone (1) also has a coarse clastic component and may have a somewhat intermediate origin, reflecting a lag deposit close to the Series' boundary. These two examples may represent the regressive rather than transgressive mode of development.

PALAEOGEOGRAPHY & PLATE TECTONIC SETTING.

8.6 Palaeogeography.

The examination of a short period in the evolution of a limited area does not provide the basis for a regional plate tectonic model, but it can enhance or detract from existing
hypotheses.

Before the wider palaeogeographic setting can be assessed it has to be decided how the relative positions of the structural blocks today compares with their disposition during the Arenig. This is particularly pertinent in view of the controversial proposal by Nutt & Smith (1981) that the areas exposing the Mona Complex have undergone 100km. of post Carboniferous dextral strike slip displacement, from an original position off SE Ireland. The following are considered sufficient to show that the present and Arenig positions of Anglesey relative to North Wales were much the same, a conclusion reached by Reedman et al (1984) on the basis of the first point.

1: Reedman et al (1984) support Greenly's claim that the Arfon Group is present on Anglesey, and correlate the units seen with those of the Caernarfon-Bangor area. On this basis they reject the occurrence of any transform movement between the two areas either during or after deposition.  

2: Nutt & Smith rejected the evidence of clasts derived from the Mona Complex occurring in the Lower Palaeozoic Welsh Basin. Such a dismissal of the following examples is not thought to be justified, especially in the context of the proposed position of the Lake District their model advocates.

a) Highly strained quartz clasts compatible with a metamorphic source area occur in the Garth Grit Member (Lynas 1973 & personal observation)

b) Greenly (1943) described a conglomerate bed resting on the Twt Hill granite at Caernarfon composed of abundant schist clasts which he compared to the Penmynydd Zone of the Mona complex. Though the unconformity on the Twt Hill Granite does not now appear to be exposed, the description is significant in that it was not just isolated clasts that were claimed.

c) Gibbons (1983) confirms Greenly's claim that Penmynydd Schists are present in the Cambrian Cilian grit of the St Tudwals.

d) Greenly (in Nicholas 1915) identified a variety of clasts in the basal Arenig conglomerate of St Tudwal's Peninsula as being compatible with a source area of the Mona Complex, and including numerous jaspers.
3) This study has demonstrated the following pertinent facts in the development of the Arenig: (cf Nutt & Smith 1981)
   a) A very close comparison both faunally and lithologically between the Carmel Formation of Anglesey and the Maesgeirchen Member of the Caernarfon-Bangor area.
   b) There are significant differences between the sequences in the Aberdaron Area and on St Tudwal's (cf Tegerdine et al 1981). However St Tudwal's Peninsula appears to be isolated by a broadly east-west lineament (see Sectn.7.3) and not the north-south fault advocated by Nutt & Smith.

   The above points also relate to the suggestion that Anglesey was an island in the lower Ordovician (Neuman 1984). Apart from the evidence of an Anglesey-like area having contributed material to the Welsh Basin since the Cambrian, the sequence of the Aberdaron area is significant in that it is unconformable on the Mona Complex and contains faunas, particularly in the lower Arenig exactly comparable to South Wales at the species level. The deeper water faunas of the middle and upper Arenig are less reliable as indicators of isolation (cf Cocks & Fortey 1982). The endemic nature, particularly of the Treiorwerth Formation fauna, probably results from the founding of much of the rest of North Wales in the late Arenig to early Llanvirn that left isolated highs in an otherwise deeply submerged continental shelf. The Tagoat fauna of SE Ireland probably represents a comparable setting accounting for the similarities recorded by Neuman (1984).

   Therefore though Anglesey and associated parts of the Irish Sea horst may have behaved as marginal islands during certain periods they were unlikely to have been separated from the mainland by oceanic crust, and were probably in a relative position little different from that seen today.

8.7 Arenig Plate Tectonic setting of North Wales.

   There now appears to be some consensus that during the Ordovician, North Wales was the site of a back-arc ensialic marginal basin with the subduction zone somewhere to the north-west of the Lake District-Leinster arc. (Kokelaar et al 1984). It has been suggested that the Arenig "transgression" was initiated by the cessation of the subduction represented by the late Tremadoc Rhobell and
Trefgarn Volcanic groups. (Bevins et al 1984). However, the major foundering of the basin did not occur until the upper Arenig and was quickly followed by the early Llanvyrn volcanism that suggests the initiation of a new subduction zone. It is therefore more likely that the lower to middle Arenig was a relatively quiescent period in North Wales between the cessation of subduction and the initiation of the back arc basin.

The distribution of both volcanic activity and sedimentation appears to have been influenced by long lived, probably basement controlled, faults. Some of these were active at least as early as the Cambrian eg Dinorwic (Reedman et al 1984) and Aber - Dinlle (Webb 1983) faults and most appear to have some pre-Arenig expression, eg Ffynnon Eida fault (Lynas 1973) and Llanegryn fault (Jones 1933). The most significant dispute in the evolution of the basin concerns the nature of the movement on these faults, whether strike- slip or dip- slip. Reedman et al (1984) have argued that there has been no transform movement on any of the faults bounding the Arfon basin during or since deposition of the Arfon Group. However Woodcock (1984) has argued for the importance of transform faulting, but all the examples of strike- slip movement he gives are either on or to the south east of the Bala Fault, and the majority appear to have a lower age limit in the Silurian. The only evidence he quotes from the lower Palaeozoic to the north west of the Bala fault is the nature of the fault controlled basins on Anglesey.

It must be acknowledged that the features of small basins with rapid lateral facies variations and fault controlled margins does tend to support the idea of transform controlled development (cf Reading 1980 & Woodcock 1984 Fig.5). This is particularly true of the Aberdaron area which appears to have had a rapid deepening to the south and active faulting along its western margin. It may also be argued that the enigmatic juxtaposition of blocks in the Rhiw- Llanfaelrhys mining belt is best explained by a transform fault zone. However, a major problem is the absence of any proven contemporaneous strike slip movement. In the case of Anglesey, and in particular the "Principal Area", which was the most active basin, a close correlation
has been recognised between the clastic composition and the local source area, notably around Bodedern (Bates 1973, Greenly 1919), and there is no evidence of displaced source areas in the Aberdaron area either, since the Penmynydd Schists are still juxtaposed with the Porth Meudwy Member. The only evidence of transform movements are derived from structural criteria (Campbell et al 1985) and are seen on the Nantmoor and Bala faults. The movements are opposite and increase to the SW, indicating a northward movement of the Harlech Dome block and the association with the cleavage indicates the timing to be during the end Silurian deformation. The direction and extent of movement, are compatible with the 5-7km of dextral movement Ridgway (1976) proposed to account for the distribution of Arenig sediments in the Arans.

Both the "Principal Area" of Anglesey and the Aberdaron-Sarn area show evidence of the southward tilting of fault blocks, recognised by Dunkley (1979) in the Dolgellau area. Such tilting of grabens controlled by normal faulting would cause some of the facies variations observed and would also account for increased activity on the bounding faults in that direction. It is concluded that in the absence of clear evidence of penecontemporaneous transform movements the development of the Arenig basin was controlled predominantly by normal faulting.

The proposed comparison with the back arc marginal basin of North Island, New Zealand made by Reedman et al (1984) is particularly interesting in this context. The importance of strike slip movement in the development of New Zealand is well known (cf. Spörli 1980), and yet the faulting that has controlled the development of the onland Taupo- Rotura depression is entirely normal though affected by its transform setting. (Cole 1984). By contrast, the offshore expression of the same marginal basin in the Bay of Plenty does show features that are suggestive of significant strike slip displacement (Lewis & Pontin 1984). The juxtaposition of the basin with a schistose shear zone suggests some comparison with the proposed transform origin of the Penmynydd Metamorphic Zone (Gibbons 1983), and the prevalent strike slip setting could account for the importance of such features in the later stages of ocean closure and in the
development of the Welsh Borders. (Woodcock 1984)

The distribution of the Arenig faunas has recently been reviewed with regard to the palaeogeographic position of the British Isles relative to other continental plates (Cocks & Fortey 1982). It was concluded from this that in addition to the well accepted separation of Laurentia and Gondwana by the Iapetus ocean, the Scandinavian and Armorican-Iberian platforms lay either side of a significant oceanic area in the early Ordovician: Tornquist's Sea. Support for this has now come from palaeomagnetic studies (Perroud et al 1984), though they favour Baltica being latitudinally closer to Laurentia rather than at intermediate latitude as suggested by Cocks & Fortey (1982). Such a close position between the two continents is not easy to reconcile with the faunal provincialism and it is likely that there is some latitudinal separation between them.

The faunas from North Wales serve to confirm its marginal Armorican position during the Arenig (cf Cocks & Fortey 1982 Fig.3). Heseuretus is present in the Henllan Ash Member, Maesgeirchen Sandstone Member and Carmel Formation, and Selenopeltis occurs in the Afon Seiont section. In addition to these characteristic genera, a number of Armorican and Gondwanan taxa have been recorded here for the first time from Wales: Eoharpes, Hanchungolithus and Calypsenella.

There are two general points about the graptolite faunas with regard to palaeogeography. Firstly Azygograptus has been considered a genus typical of Gondwana, its occurrence in Baltica being part of the evidence for an intermediate "province". On the evidence from North Wales I agree with Fortey (1984) that Azygograptus is the most inshelf graptolite, being consistently the first graptolite to appear in upward-deepening sequences, usually as a monospecific assemblage. However, there is a chance that the inner-shelf forms from Wales may be distinct from representatives of the genus in Scandinavia, and if the genus is polyphyletic then its provincial importance decreases. The closest comparison with A. suecicus is the population from Barf, and like the Oslo population, but unlike the monospecific Welsh assemblages, occurs as part of a diverse graptolite fauna. This suggests a different
ecology and even if the genus is monophyletic the widespread occurrence of deeper water forms is less significant than that of shallower.

The presence of pandemic graptolites, in particular Didymograptus distinctus, Pseudisograptus manubriatus and P. cf. dumosus clearly indicates the marginal position of Wales, especially since these forms occur in sections overlying typical Armorican trilobites. This contrasts with the review of British isograptids by Jenkins (1982) in which none of the forms he described from Wales have been recognised elsewhere in the world.
Chapter 9: Graptolite Taxonomy

The greater abundance of graptolites in North compared with South Wales, might be expected to allow more accurate correlation between the shelly based biostratigraphy of South Wales and the graptolite zonation of the Lake District. However, taxonomic problems and the restricted nature of the lower and middle Arenig graptolite faunas have limited this cross-correlation. Despite this it is worthwhile to describe the graptolite fauna in detail as this extends the graptolite assemblages of the South Wales divisions. The faunas of St. Tudwal's and Anglesey were not examined in detail as previous collections were not available.

9.1 Methods of Measurement

All measurements were made on camera lucida drawings at magnifications of 12, 25 and 50. The actual magnification of the drawing is dependent on the height of the camera lucida mirror and is hence variable. Since the diameter of the field of view remains constant, an accurate magnification was obtained using a calibrated scale placed under the camera lucida to measure the field of view. The majority of measurements were made at x12, in reality x13 - x14 and measurements are given to the nearest 0.05mm.

Parameters specific to a given group are briefly discussed at the beginning of the section to which they are relevant.

9.1a Thecal count.

A variety of techniques have been proposed for the measurement of thecal spacing; eg two theca repeat distance (2TRD) (Howe 1983); thecal density (Bouček 1973); the distance between specified thecae eg th.5 and th.15 (Fortey and Owens in press) and the more conventional number of thecae per 10mm (eg Elles and Wood 1901). A variety of techniques have been employed during this study, largely in relation to specific groups; thecal spacing for individual thecae was employed in the azygograptids, 2TRD for the simulans plexus of extensiforms and in the case of the majority of extensiforms the distance over 10 thecae intervals from th.5 eg th.5-15, 15-25 etc. For groups where only a limited part of the rhabdosome is measurable, eg
phylograptids and isograptids, the distance between two thecae a known number apart was measured, as long as the straight line between the two points did not represent a significant deviation from the margin of the rhabdasome. Despite this variety of measurement, all can be expressed as a thecal count in units of th/10mm. In all cases this is a recalculated value and in no specimen has the number of thecae actually in a 10mm interval been used as a measure. The advantage of using different techniques is that it tends to remove variation due to stipe curvature.

9.1b Stipe Width

This has been measured at each reasonably preserved thecal aperture, along a line perpendicular to the dorsal stipe margin. The main exception to this is the phylograptids where only maximum rhabdosome width has been measured. Following the technique of Cooper and Fortey (1982) the variation in stipe width with growth is illustrated using stipe expansion diagrams. On well preserved material such as used by Cooper and Fortey the results obtained are objective. In North Wales the indifferent perservation introduces a degree of subjectivity in the selection of thecal apertures adequately preserved to give a reliable measurement of stipe width. This has been standardised by taking the upper envelope of the scatter of points, in the case of extensiforms, for both stipes together (see Fig.9.1). Though this means that a curve is often determined by only a few points, (only these are shown on the figures) it does provide consistent results and appears to effectively group specimens. In cases where there is good evidence that this technique may obscure the true form of the stipe expansion curve, eg Didymograptus aff praenuntius Form D, this has been pointed out. The curves

Fig.9.1 : Method of plotting stipe expansion diagrams for extensiforms. Solid and open circles represent measurements made on the two stipes. Solid line taken as stipe expansion curve.
have been drawn on the principle that a distal decrease in width may be a real feature.

9.1c Illustration.

An attempt has been made to standardise the magnifications of figures and plates on the following scale 0.5, 1, 2.5, 5, 10, 15, 20, 25, 50. Where appropriate the lineation is indicated by a dashed or solid line.

9.2 Deformation.

The extensive use of quantitative characters in graptolite taxonomy makes identification very difficult when there is any significant deformation. The deformation in North Wales is highly variable and sometimes elusive, eg Didymogratus cf infreques from Hafotty Filltirgerig, though in other cases it is obvious and associated with prominent lineation, eg Afon Seiont.

Added to this there is considerable inhomogeneity in deformation especially when pyritised internal moulds are present. Good examples of compressional and extensional deformation of these are shown in Figs.9.2a & c whilst the break up of periderm is shown in Fig.9.2a of a specimen from Afon Seiont. In general, however the deformation of relief material is much less than for completely flattened specimens and hence provides the most reliable measurements. One important point may be noted from the specimen shown in Fig.9.2a and that is that the lineation often visible in the chlorite envelope of graptolites trends perpendicular to the line of extension and hence perpendicular to the lineation.

![Fig.9.2: Brittle deformation of graptolites. Triple dashed lines indicate lineation. a: (x10) Afon Seiont Caernarfon; solid ornament: upper periderm surface; stippled ornament: lower periderm surface; irregular short dashed lines: lineation in chlorite. b & c: (x5) compressional and extensional deformation respectively of pyritised specimens, Nant-yr-Olchfa. (hatched areas in c indicate chlorite infilled cracks).](image-url)
When a lineation is not apparent on the surrounding rock surface this foliation could be mistakenly taken to represent it. There are two aspects of the deformation that need to be considered. Firstly the separation of an assemblage into constituent species and secondly the determination of the undeformed parameters of the species.

Throughout this study deformation has been treated as an equal area deformation of the bedding plane and no attempt has been made to obtain the strain ellipsoid.

9.2a Subdivision of an assemblage.

This has been achieved by plotting stipe width at a given thecal number eg th.15 against thecal count. Assuming equal area deformation these two parameters maintain a linear relationship and therefore members of a given species should plot along this line. The main purpose this serves is to indicate the likelihood that a variant is taxonomically distinct rather than resulting from deformation. Such a plot was not effective on the Afon Seiont assemblage and may indicate that the assumption of equal area deformation is not justified for that locality.

9.2b Estimation of deformation

i) Using sponge spicules.: Undeformed these usually form a cross. The change in angle of a spicule in which the lineation bisects one of the angles may be used to estimate the deformation (see Fig.9.3).

The only locality where this method is feasible, Nant yr Olchfa, it is of little value since the pyritised preservation of the graptolites makes the deformation inhomogeneous, the sponge spicules being preserved as a dark film.

ii) Thecal count v angle to lineation.: In a small locality the lineation is likely to maintain a consistent orientation to bedding as long as there is no significant folding. Using this the orientation of a number of specimens on separate slabs can be measured and a radial plot of thecal count at the angle relative to the lineation produces an ellipse. Since thecal count decreases with extension such an ellipse is orientated perpendicular to the strain ellipse. The lineation defines one axis of the ellipse so plots can be made in a 90° sector. Inhomogeneous deformation resulting from differing preservation causes points to scatter off the
Fig. 9.3: Deformation of a sponge spicule. Ratio of sides of rectangle (same as that of ellipse's axes) can be calculated from angle of intersection.

ellipse.

iii) Thecal count v arbitrary grid. : In the absence of a lineation only a single slab can be used in order to have a consistent relative orientation. Stipe orientation is then measured relative to an arbitrary set of parallel lines and plotted in the same way as for ii) but the angle needs to be measured through 180° since an axis of the ellipse is not defined.

9.3 Problems in Taxonomy.

Cooper & Fortey (1982 p180-182) concluded that the recognition of phylogenetic lineages was crucial to a reliable classification of the Dichograptidae. They considered the nature of the proximal development to be the character with greatest potential for achieving this, and on which basis the phyllograptids were subdivided at the generic level for the first time and Xiphograptus distinguished as an extensiform genus characterised by a virgella and hence related to their restricted view of Phyllograptus.

However the generic classification of the extensiform didymograptids remains a major problem. Of the four proposed genera Cooper & Fortey (1982) employed Expansograptus Bouček & Přibyl 1951 and Corymbograptus Obut & Sobolevskaya 1964 as sub-genera of Didymograptus s.l. but considered Acrograptus Tzaj 1969 and Aulograptus Skevington 1965 to be true genera; the former being placed in their new subfamily Sigmagraptinae. The identity of Acrograptus is reviewed below and since the climacograptid thecae of Aulograptus are not seen in Arenig extensiforms only Expansograptus and Corymbograptus remain available.

The outstanding question remains the proximal development of Didymograptus v-fractus (Salter), the type species of Corymbograptus, and until such time as this is known the use of this genus/subgenus may result in misleading groupings whilst at the same time compromising
the erection of new genera. Since only *Expansograptus* remains available, and even the extent of variation in proximal development this should encompass is uncertain, it is not proposed to attempt any generic separation of the extensiforms and they are all placed in *Didymograptus* s.l.

Considering these difficulties in extensiform taxonomy and their prevalence in the Arenig faunas of the Atlantic province, they are treated in a separate chapter from the other morphotypes. The only exception is *Xiphograptus* Cooper & Fortey 1982 which is retained under the Phyllograptidae.

9.3a Identity of *Acrograptus*.

The type species of *Acrograptus* is *Didymograptus affinis* Nicholson (1869), for which Elles & Wood (1901 p25) selected one of the specimens they figured (Pl.II fig.1b) as the "type" (lectotype) and gave the locality as being Outerside in the Lake District. This is not one of the localities given in Nicholson's original description, and has in fact been misquoted. The locality given on the label, is Eggbeck near Pooley, now renamed Aik Beck. Benton (1979) correctly recognised this but treated the two numbers given to this specimen as being separate. The details, therefore, of *D. affinis* are:

1) Type Specimen: (Lectotype selected by Elles & Wood 1901 p24). BM: Q3108 (The original number on the specimen was P1858). Figured: Elles & Wood 1901 Pl.II fig.1b

   Cooper & Fortey 1982 p271 fig.66a

2) Type Locality: Aik Beck (NY4722) just SW of Ullswater in the eastern Lake District.

On recognition of the above, an attempt was made to collect toptype material. The exposure extends for over 1km and graptolites can be recovered throughout. The lower part of the succession (downstream end) may be upper Arenig in age but the majority is clearly Llanvirn and it was from strata towards the top of the section (NY473222) that specimens referable to *D. affinis* were found. The majority of the material from this locality is badly deformed, but the specimen described below is in partial relief and appears to have suffered negligible deformation.

9.3b Proximal development of *D. affinis*

This is based on a single specimen preserved with only obverse side visible, though there is a suggestion that some
of the relief may represent features of the reverse side pressed through (see Fig.9.4). The sicula aperture is incomplete but a minimum length of 0.5mm is indicated for the sicula and is unlikely to be significantly greater. Th.1\textsuperscript{i} originates high on the left side of the sicula, indicating dextral development, and grows down onto of, and slightly to the side of, the sicula. It turns away abruptly at the base of the sicula as preserved. The origin of th.1\textsuperscript{2} on th.1\textsuperscript{i} is not clear, but is probably fairly low. The ventral wall of th.1\textsuperscript{2} emerges from behind the sicula approximately level with that of th.1\textsuperscript{i}, proximal development therefore being approximately symmetrical. A very thin canal appears to run along the dorsal margin of th.1\textsuperscript{i} to th.2\textsuperscript{i} thereby suggesting isograptid development.

![Fig.9.4 : D. affinis Q5858 (x25), toptotype, Aik Beck, Ullswater (Dashed line indicates lineation).](image)

9.3c Significance of Acrograptus.

Cooper and Fortey (1982 p.270-1) placed Acrograptus in their subfamily Sigmagraptinae. Though the slender stipes may be taken to support this placement the squaform of the sicula and the symmetrical nature of the proximal end are not compatible with this classification and the genus is best left in the Dichograptinae for the present. They also discussed the possibility that members of the genus exhibited artus development mode, and concluded that it may have evolved in later members of the lineage. Since the type species has now been shown to be Llanvyrn this becomes less likely. It has also emerged that there is a distinct group, here referred to as the D.simulans plexus, which do appear to have artus mode development associated with marked proximal asymmetry (Fig.10.1b) and which have been referred to Acrograptus (Kraft 1977).
Chapter 10: Grpatolite Systematics; Extensiforms.

As noted at the end of chapter 9, no generic/subgeneric classification is attempted for the extensiform didymograptids. However, a number of groups have been recognised on the basis of proximal development (see Fig. 10.1). The extent to which these groups should be subdivided, and the names that should be given to the forms recognised, is often unclear. Considering the large number of names available it is thought unwise to erect any new specific names until such time as the characters of those already proposed are better understood and for this reason a number of forms are described under open nomenclature.

Some groups, eg. the Didymograptus aff. praenuntius plexus, can be recognised in all three divisions, and in a number of cases the differences between the stratigraphically separated forms are slight and of questionable taxonomic significance. Despite this, forms found in different chrono-divisions are described separately to emphasise the stratigraphic distribution.

Order GRAPTOLOIDEA Lapworth, 1875
Family DICHOGRAPTIDAE Lapworth, 1873
Subfamily DICHOGRAPTINAE Lapworth, 1873
Genus DIDYMGRAPTUS M'Coy, 1851

10.1 Didymograptus aff. simulans plexus.

This plexus is characterised by a prominent asymmetry of the proximal end (Fig. 10.1b). In the case of D. aff. infrequens (Kraft), described below, this is associated with an artus mode development and metasicular origin of th.1', features that may ultimately prove to be characteristic of the plexus. Thecal inclination is typically low. Species that may reasonably be placed in this plexus are: D. simulans
Elles & Wood (1901); D. deflexus Elles & Wood (1901) and D. infrequens (Kraft 1973).

The presence of artus mode development in a graptolite of known lower Arenig age is important since Cooper & Fortey (1983) argued that this is not generally observed until the Llanvirn.

*Didymograptus cf. infrequens* (Kraft)

Fig.10.1 b, Fig.10.3 a-e. Pl.14 Figs.3, 8 & 10.

*cf. 1977 Acrograptus infrequens* Kraft; Kraft pp.17-18; Pl.9 Figs.3-4.

1984 *Didymograptus aff. simulans* Elles & Wood;

Zalasiewicz p245 Figs.2a-d

**Material.**

B.M.: Q5861, Q5893-4; N.M.W.: 85.166.76-7; S.M.: A17512-38 from Hafotty Fillitirgerig. Age: lower Arenig. Generally preserved as flattened carbonaceous film but a few pyritised internal moulds are present. Superficially there appears to be little deformation and no lineation is present, but detailed examination often shows differences in the parameters measured on the two stipes of a rhabdosome. Using an arbitrary orientation on a slab with numerous specimens a strain ellipse was calculated from values of thecal spacing,

**Fig.10.2:** Deformation of *D. cf. infrequens* from Hafotty Fillitirgerig. Plotted strain ellipse shown with implied lineation. (Scale bar: 5mm). N.B. Synrhabdosome at top. B.M.: 05893a.
and confirmed a deformation to be present. (see Fig.10.2).

Axial ratio of ellipse: 1 : .73.

Description.

![Diagram of stipes and sicula](image)

Fig.10.3 : *Didymograptus* cf *Infrequens* (Kraft) from Hafoty Fillitirgerig. a-d x2.5; e x20. a: S.M.: AI7515; b & e: S.M.: AI7519; c: S.M.: AI7512b; d: B.M.: 05861

Stipes moderately deflected enclosing an angle of 110°-120° at their origin, this increasing distally until stipes become straight and declined. Longest stipe: 15.5mm reaching th.20. Stipes have a uniform width of c.0.7mm and even without compensation for the deformation the coefficient of variation (c. of v.) is only 8.6% and the total range of means 0.62-0.88mm. Thecal spacing was measured as 2TRD; the value suggested by the strain ellipse being 1.48mm whilst the mean for the population was 1.52mm. C. of v. 6.84%; range 1.34 to 1.72mm. Using the standard deviation the recalculated thecal count has a range 12-14 th/10mm.

Two specimens, A17503 and A17519, have semi-relief proximal ends, and these indicate artus mode development (see Fig.10.3, Pl.14 Fig.3a & 8). Th.1-originates just over half way down the sicula and almost immediately curves away sharply. The origin of th.1-is from the proximal portion of th.1-approximately at the point of flexure. It then grows down across the sicula, crossing its dorsal margin just above the aperture. There is no evidence of any crossing canal connecting th.2-to th.1-and hence artus development has been interpreted. Sicula length has a c. of v. over 15% and this probably reflects the lack of an averaging effect with respect to the deformation, and incomplete preservation. Considering the pyritised material to be the least deformed and also some of the best preserved a value
of 1.55-1.6mm is indicated.

Synrhabdosomes have been recorded from this population (Zalasiewicz 1984a)

**Discussion.**

One interesting aspect of this population is that the c. of v. for stipe width and 2TRD measured for each theca of a single rhabdosome is often greater than that for the population. This probably reflects the deformation, the effects of which are somewhat compensated for by the calculation of a mean.

The above material is closely comparable to *D. similans* Elles & Wood (1901 p.33 text.figs.19a-c Pl.II Figs.6a-b). A detailed comparison has been made between the two populations (Zalasiewicz in prep) but one parameter not examined, stipe expansion, does separate the two; *D. similans* showing a marked expansion (see Fig.10.4) compared to the uniform width of the North Wales specimens. In this character closer comparison can be made with the Bohemian species *D. infrequens* (Kraft), though the thecal count; 14-17 th/10mm, is somewhat higher in that species.

**Fig.4:** Stipe expansion curves for type population of *D. similans* Elles & Wood; Barf, Lake District.

**Didymograpthus aff. infrequens** (Kraft)

**Fig.10.5a-d; Pl.14 Fig.2,**

**Material:**

N.M.W.: 85.166.11-13 from Bwlch ym Mhwll-le, above Bethesda (SH 63666827), Graianog Sandstone Member. Age uncertain. Significant cleavage present but is oblique to bedding in the case of the above specimens and therefore may not be causing significant deformation.

**Description and Discussion.**

Though neither rhabdosome is well preserved these, and another sicula, show the asymmetrical proximal end typical of the *simulans* plexus. Stipe width uniform at approximately 0.7mm like *D. infrequens* but the thecal count is somewhat
lower, approximately 9-10 th/10mm, and thecae are inclined at about 20°. The stipes are also somewhat less deflexed the angle between the proximal dorsal walls being 134°-146° whilst the distal parts are almost horizontal.

10.2 Didymograptus aff. praenuntius plexus

This is a group with distinctive proximal development (see Fig. 10.1a) characterised by an elongate sicula (c.2mm

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**Fig. 10.5**: Didymograptus aff. infrequens (Kraft). a & b \( \times 2.5 \)
c & d \( \times 20 \). a & d: N.M.W.: 85.16G.11; b: N.M.W.: 85.16G.12;
c: N.M.W.: 85.16G.13. All from Bwlch ym Mhwll-1e.

---

**Fig. 10.6**: Plot of stipe width at th.15 vs. thecal count for the D aff. praenuntius plexus. Open triangles: lower Arenig, Maen Gwennow Member; solid circles: Dwyhos Farm, middle Arenig; rest upper Arenig, open squares: Benallt Mine; solid squares: Nant yr Olchfa; open circles: Menai Straits Inlier. Solid lines represent trends for equal area deformation.
long) of which a major proportion is supradorsal along with the proximal part of th.1\(^1\). Thecae 1\(^1\) and 1\(^2\) are both predominantly pendent, the former flexing away from the ventral wall of the sicula. The aperture of the sicula is turned away from th.1\(^1\), the dorsal wall of which is completely overgrown by th.1\(^2\). The ventral part of the sicula appears as a small denticle between the proximal thecae. The proximal region is usually slightly deflexed. Development mode isogaptid.

This plexus can be recognised throughout the Arenig, but is most abundant and diverse in the upper, the forms from the lower and middle each being represented by a single population. The separation of the upper Arenig assemblage has been achieved by a plot of thecal count vs. width at th.15 (Fig.10.6). However this has not proved effective in the separation of the Afon Seiont fauna (Fig.10.7), which probably contains at least two forms.

Fig.10.7: Didymograptus aff. praenuntius plexus from Afon Seiont, undivided. All x2.5 except b' which is x10. a, N.M.W.: 85.166.31; b, B.M.: 05887; c, N.M.W.: 85.166.27; d, N.M.W.: 85.166.28; e, N.M.W.: 85.166.28; f, S.M.: A16977; g, B.M.: 05890; h, N.M.W.: 85.166.30; i, N.M.W.: 85.166.31; j, B.M.: 05888; k, B.M.: 05889; l & m, N.M.W.: 85.166.31.
There are a number of names available which appear to be compatible with this plexus, but in view of the variation apparent from the North Wales specimens open nomenclature is employed and comparison with previous descriptions made in the discussions.

The forms recognised from the upper Arenig are distributed between the populations as follows:

1) Nant yr Olchfa, Forms B & C
2) Benallt Mine, Forms B & D
3) Menai Straits, Form C, though one specimen approaches Form B.
4) Nant y Gadwen, Immature specimens only: a single specimen from the west side referred to Form D and a population from the northern end tentatively to Form B.

*D. hirundo* is similar to this plexus in most features of proximal development, except the supradorsal portion of the sicula and the 1 is much less prominent.

**Didymograptus praenuntius** Törnquist.

Fig.10.8 a & b; Pl.14 Figs.7 & 9.

1901 *Didymograptus praenuntius* sp.nov; Törnquist : 17; Pl.2, figs.7-12.

**Material.**

B.M.: Q5721; N.M.W.: 85.166.75 from Mean Gwennonwy SH 20052598. B.M.: Q5722 from loose rubble at Benallt mine, Rhiv SH 22232803. Both are preserved as flattened periderm.

Q5721 may be affected by a slight lineation. Age: lower Arenig.

**Description.**

Rhabdosome straight with slightly deflexed proximal portion, affecting at most four thecae on each stipe. Longest stipe: 34mm. Development not clear; probably isograptid. In neither specimen is the sicula complete but a minimum length of 1.92mm is apparent with a significant supradorsal development. Stipe characters differ in the two specimens

<table>
<thead>
<tr>
<th></th>
<th>Q5721</th>
<th>Q5722</th>
</tr>
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<tbody>
<tr>
<td>Proximal stipe width (mm):</td>
<td>1.25</td>
<td>0.9</td>
</tr>
<tr>
<td>Distal stipe width (mm):</td>
<td>1.85</td>
<td>1.65</td>
</tr>
<tr>
<td>Theecal count (th/10mm)</td>
<td>11.4</td>
<td>10.5</td>
</tr>
<tr>
<td>Theecal inclination:</td>
<td>60°</td>
<td>42°</td>
</tr>
</tbody>
</table>

In Q5722 the thecae can be seen to be curved with a proximal inclination of about 25° and thecal length about
2mm. Much of the variation in the above table may be accounted for by the difference in thecal inclination which may in part be the result of the lineation affecting 05721.

Stipe expansion curves are shown in Fig. 10.9

![Stipe expansion curves for Didymograptus praenuntius](image)

**Fig. 10.8:**
*Didymograptus praenuntius*
Törnquist. x2.5. From Maen Gwenonwy Member, lower Arenig.
- a, B.M.: 05722, Benallt Mine.
- b, B.M.: 05721, Maen Gwenonwy.

**Fig. 10.9**
Stipe expansion curves for *D. praenuntius* Törnquist.

**Discussion.**

Apart from slightly higher thecal count, the N. Wales specimens match closely Törnquist's original description. They differ from the material assigned to this name by Monsen (1937 P118-19 PL.1 figs.27 & 29) in their greater stipe width, and that by Cooper & Fortey (1982 p.235-6 Fig.43a,b; P1.4 Fig.12) in less marked proximal expansion.

*Didymograptus aff praenuntius Form A*

- Fig.10.11 a-d; P1.17 Figs.4 & 17.

**Material:**


**Description:**

Known from only four specimens that form a distinct cluster on a plot of width at th20 against th/10mm (Fig.10.10) despite their varying orientation relative to the lineation: 25°-77°. Description therefore based on the actual measurements made with no compensation for deformation.
Fig.10.10: Plot of stipe width at th. 20 vs. thecal count for Dwyrhos Quarry extensiform assemblage. Specimens ringed by dotted line assigned to *D. aff. praenuntius* Form A. Solid line indicates trend for equal area deformation.

Rhabdosome dominantly horizontal with slight flexure in the proximal region. Longest stipe is 33mm. Details of the proximal development are not clear. In none of the specimens is the sicula complete but a minimum of 1.5mm is indicated, with a moderate supradorsal development. The initial thecae appear to grow downwards producing an excavated appearance below the sicula. The proximal width is difficult to estimate in that the proximal flexure causes a different orientation relative to the deformation.
compared with the rest of the stipe. This effect is most clearly seen in the stipe expansion curve for O5732, (see Fig.10.12) where there is a distinct jump in the curve between th.5 and th.6, either side of the point of flexure. This specimen provides a minimum estimate for the proximal width of 1mm, the maximum seen being 1.3mm. Width at th.20 is 1.70 to 1.95mm and though O5732 is significantly longer, 1.95mm is still the maximum width reached. Thecal count is high: 14.8 to 15.7 th/10mm.

Thecae are inclined at about 50° - 60° and the apertural angle is distinctly acute in all specimens, being about 48°. Thecae are somewhat curved though the true extent of this is not apparent and about 0.7mm of the distal ventral wall of each theca is exposed.

Discussion:

The most similar specimens come from the upper Arenig and are described under Form D, though in stipe width the Dwyrhos specimens approach Form B. The closest named species is \textit{D. enshiensis} Ni (in Mu et al 1979 p.88 Figs.15 & 16) which also has a high thecal count (13-14 th/10mm) but is somewhat narrower.

\textbf{Didymograptus aff. praenuntius Form B}

Figs. 10.13-10.15; P1.15 Figs.1 & 2; P1.16 Fig.8•

\textbf{Material:}


\textbf{Description.}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
\textbf{Locality} & \textbf{Length of Stipe} & \textbf{Th/10mm} & \textbf{Prox. Width} & \textbf{Dist. Width} & \textbf{Thecal Incl' n.} \\
\hline
Benallt Mine & 1.93 -2.00 & 174-17.7 & 1.10-1.40 & 1.80-1.90 & 50°-70° \\
Carnedd Iago & 2.22 -2.47 & 11.2 -12.1 & 1.20-1.45 & 1.90-1.95 & 50°-70° \\
\hline
\end{tabular}
\caption{Parameters of \textit{D. aff. praenuntius} Form B.}
\end{table}

The longest specimen is from the Nant yr Olchfa section, with one stipe measuring 98mm. Rhabdosome morphology is predominantly straight with a slight flexure in the proximal region. The major difference between the two populations of mature individuals (see Table 10.1) is in the thecal count and apart from this their overall appearance is identical.
In both cases the thecae are curved, the variation in distal inclination being the result of differing preservation of the ventral wall of the thecal aperture. When this is fully developed the apertural angle is about 50° though when incomplete it increases to about 70° compensating for the decrease in the distal inclination.

**Fig. 10.13:** Didymograptus aff. praenuntius Form B from Nant yr Olchfa. (a-c x2.5; d x10). a & d, B.M.: 05728; b, S.M. A74923; c, S.M.: A74932a.

**Fig. 10.14:** Didymograptus aff. praenuntius Form B from Benallt Mine. (all x2.5). a, B.M.: 05742; b, B.M.: 05744; c, B.M.: 05743.

**Fig. 10.15:** Didymograptus aff praenuntius from Nant y Gadwen. (All x2.5) a-d Form B: a, N.M.W.: 85.166.24; b, B.M.: 05738; c, B.M.: 05870; d, N.M.W.: 85.166.25 e Form D, B.M.: 05863.

Proximal development is typical of the plexus being best preserved on 05278 (Fig.10.13d). A web of periderm partially infills the gap between the sicula and th.1 on this specimen.

**Discussion.**

The stipe width, and hence the stipe expansion diagrams (Figs.10.16 & 10.17) serve to distinguish this form from the others recognised in this plexus from North Wales. The only
specimen that approaches this width and is not included is one from the Menai Straits, which is retained in form C since it is the end member of a continuous range of variation.

![Graph](image)

**Fig. 10.16**: Stipe expansion curves for *D. aff. praenuntius* Form B from Nant yr Olchfa.

![Graph](image)

**Fig. 10.17**: Stipe expansion curves for *D. aff. praenuntius* Form C from Benallt Mine.

The most comparable previously described material is that of *D. patulentis* Chen (in Mu et al 1979 pp.105-6; Pl.36 Figs.5,20,21; Pl.37. Fig.1). Cooper and Fortey (1982 p292) considered this species to belong to *Xiphograptus* but such an assignment is not clear cut.

Though *D. patulentis* was an upgrading of the material Tornquist (1901 Pl.2 Figs.1-6) referred to as *D. patulus*
Hall, a Chinese holotype is selected for the species, and therefore it is the characters of this that determine those of the species and not those described by Törnquist (cf. Cooper & Fortey). There is the suggestion that a virgella may be present on one of the figured Chinese specimens but this needs to be confirmed by closer examination of the material. In addition, the proximal development of the Chinese forms is different from that of the specimens Cooper and Fortey referred to this species, in which the proximal thecae turn away sharply from the sicula. That of the Chinese form is typical of the praenuntius plexus as described here.

*D. patulentis* also compares favourably with the North Wales specimens described above in all other characters except sicula length, given as 1.5mm. However that quoted for the very similar *D. alatus* is 2mm. It is thought that *D. patulentis* provides the best available name for form B from North Wales.

**Didymograptus aff. praenuntius form C**

Figs.10.8 & 9; Pl.15 Figs.6, 8 & 9; Pl.16 Fig.3.

**Material:**


**Description:**

Table 10.2: Parameters of *D. aff. praenuntius* Form C.

<table>
<thead>
<tr>
<th>Locality</th>
<th>Length of Sicula</th>
<th>Th/10mm</th>
<th>Proc. Width</th>
<th>Dist. Width</th>
<th>Thecal Incl'n.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Menai Straits</td>
<td>1.92 -2.47</td>
<td>9.9 -11.2</td>
<td>0.95-1.40</td>
<td>1.45-2.00</td>
<td>35°-45°</td>
</tr>
<tr>
<td>Carnedd Iago</td>
<td>1.75 -1.96</td>
<td>10.2 -10.7</td>
<td>1.0</td>
<td>1.4</td>
<td>35°-45°</td>
</tr>
</tbody>
</table>

(all lengths in mm)

There is a considerable difference in the range of variation seen at the two localities. This is probably to some extent the result that the Carnedd Iago assemblage can be divided into two (see discussion of plexus) whilst the Menai Straits assemblage shows more continuous variation. However, one specimen, Q5731, considerably extends the range of the Menai Straits assemblage being comparable to *D. aff. praenuntius* form B. It is likely that the majority of specimens from Afon Seiont, Caernarfon are best assigned to this form.
Fig. 10.18 Didymograptus aff. praenuntius Form C from Nant yr Olchfa. (a-c x2.5, d x20) a, B.M.: 05730; b, B.M.: 05854; c & d, B.M.: 05729.

Fig. 10.19 Didymograptus aff. praenuntius Form C from the Menai Straits Inlier. (A11 x2.5) a, B.M.: 05731; b, S.M.: A17004; c, B.U.M.: 72b; d, B.M.: 05898; e, B.M.: 05853; f, S.M.: A16930b; g, N.M.W.: 85.1.6.120; h, B.G.S.: DJ2917.

The proximal development is shown by 05729 and 05857 see Figs. 10.18d & 10.7b and is typical of the plexus. Th.1 turns away from the sicula just below the origin of th.1², leaving 0.5mm of the dorsal margin of the sicula free. The sicula aperture is turned away from th.1¹, the apertural angle being 55°. Th.1² grows down across the sicula to obscure the ventral corner of the aperture. Development mode isograptid. The Menai Straits specimens do not show equivalent detail of the proximal development, but seem to differ in having a narrower and more prominent supradorsal development of the sicula/th1¹ pair, and in the initial thecae being slightly more pendent, though this character is quite variable.

The stipe characters are closely comparable though the Menai Straits specimens appear to be more flexed proximally. The thecal count and thecal morphology are similar in the two populations, the latter being distinctly
curved ranging from 10° to 45° relative to the stipe margin with an apertural angle of 70°. Thecal apertures are slightly concave.

Fig. 10.20
Fig. 10.21

Fig. 10.20 Stipe expansion curves for *D. aff praenuntius* Form C from Nant yr Olchfa.
Fig. 10.21 Stipe expansion curves for *D. aff praenuntius* Form C from Menai Straits Inlier.

Discussion.

The comparison with *D. holubi* (Kraft 1977 p. 19–20 Pl. 11 Fig. 1–3) is reasonable, the two main differences being the somewhat greater distal stipe width (1.8 mm) and the depth of the proximal deflexed portion, only a minority of the Menai Straits specimens being comparable. *D. uniformis* and *D. cf. uniformis* Elles & Wood 1901 are both much thinner proximally and have a higher thecal count (13 th/10 mm).

**Didymograptus aff praenuntius** Form D.

Fig. 10.22; Pl. 15 Figs. 3–5 & 7.

Material:


Description:

Rhabdosome with prominent proximal deflexed portion involving about 5 thecae on each stipe. Subsequent growth horizontal. The point of flexure is sharp.

Proximal development not clear. Significant supradorsal development of the sicula/th.1° pair, though length of sicula is quite variable, 1.41 – 2.20 mm. The smaller values may result from incomplete preservation and
a value of c.2mm seems most reliable. Proximal thecae grow addressed to the sicula initially and are distinctly pendent, their ventral walls approaching parallel in some cases. From early development stages at Benallt Mine and the specimen from Nant y Gadwen it can be seen that th.1° originates very high on the sicula, probably at the base of the prosicula.

**Fig. 10.22** *Didymograptus aff praenuntius* Form D from Benallt Mine. (All x2.5) a, N.M.W.: 85.166.109; b, B.M.: 058852a; c, N.M.W.: 85.166.109; d, B.M.: 05745a; e, B.M.: 05851b; f, N.M.W.: 85.166.110.

**Fig. 10.23** Stipe expansion curves for *D. aff praenuntius* Form D.

Thecal count is high, 14.2 to 15.9 th/10mm. Proximal stipe width 0.85 to 1.15mm rising rapidly over the first few thecae. In a couple of specimens there is a suggestion that it is wider at the flexure than in the proximal part of the horizontal portion of the stipe, but considering the quality of the specimens this is not totally reliable. This is not indicated in the stipe expansion curves (Fig.10.23). The horizontal portion of the stipe expands only very slowly nearing a value of 1.4mm at th.20. Thecae are slightly curved, their distal inclination being 40°-50°. Apertural angle acute: about 60°.

**Discussion:**

This form differs from form B, with which it is associated at Benallt Mine, in higher thecal count, narrower stipes and more prominent proximal deflexed portion. There
are a number of species with comparable rhabdosome form described from the deflexus zone of China (Mu et al. 1979) but the nature of the proximal development excludes many from comparison with the above specimens, in that they have a more isolated sicula with the initial growth of the first thecae perpendicular to the sicula before turning pendent. This contrasts sharply with the adpressed form of the praenuntius plexus. Apart from this difference a very close comparison could be made with D. kummigensis Ni (Mu et al. 1979 p83 P1.32 figs.14 - 18). Two forms which have comparable proximal developments are D.enshiensis Ni (in Mu et al. 1979 p.88 P1.30 Figs.15 & 16) and D.mundus T.S.Hall (Mu et al 1979 p83 P1. figs 18 -28). The former has a slightly larger deflexed portion and lower thecal count but is otherwise closely comparable with the Benallit specimens. D.mundus from its type locality (T.S.Hall 1914 p.107 P1.17 Fig.9) still retains some comparability but has a much lower thecal count (9 th/10mm), as also does the chinese form referred to this species, and is significantly older, being recorded form the Bendigonian of Australia.

**Didymograptus hirundo** Salter.

Fig.10.24e-h; P1.14 Figs.4, 5 & 6; P1.16 Figs. 1, 2 & 5.

1863 **Didymograptus hirundo** sp. nov : Salter p.138 Fig.13f.
1901 **Didymograptus** hirundo Salter; Elles & Wood p.15-17
Text Figs.9a-c P1.1 Figs.5a-c.
1933 **Didymograptus** hirundo Salter; Elles p.111 Fig.12.
1934 **Didymograptus** hirundo Salter; Hsu p.26-8 PL.11
Fig.8a-d Text Fig.2.
1936 **Didymograptus** hirundo Salter; Bulman p.76 Fig.25f.
1937 **Didymograptus** hirundo Salter; Monsen p.120-121 P1.15
Figs.8 & 12.
1953 **Didymograptus** hirundo Salter; Spjeldnaes p.178-180
Text figs.2B-E.
1985 **Didymograptus** hirundo Salter; Rushton p.197-8 Text
Figs.1-3.

**Fig.10.24** (see next page.) All x2.5

**Fig.10.24a, Didymograptus** aff suecicus Form C, O5709 from Nant y Gadwen (west side).
**Fig.10.24b-d, Didymograptus** aff suecicus Form A. b, B.G.S.: AW22; c, B.G.S.: AW19; d, B.G.S.: AW25. All from Nant y Gadwen.
**Fig.10.24e-h Didymograptus** hirundo Salter. e, B.M.: O5707; g, S.M.: A15944; h, S.M.: A22611; from Nant y Gadwen. f, B.M.: O5891; from Afon Seiont, Caernarfon.
Material:

Description:

Fig.10.25 Proximal development of Didymograptus hirundo Salter (both x15). a, B.M.: Q5707b from Nant y Gadwen (west side); b, B.M.: Q38 Skiddaw Slates, Lake District. (Fig'd. Elles & Wood 1901 Text Fig.9a Pl1 Fig.5a).

Broad stipes slightly reclined; proximal end with low supradorsal expression. Proximal development apparently isograptid (see Fig10.25). The sicula can only be reliably measured on Q5707, and is 2.67mm, the supradorsal expression being about 1mm. Th.11 originates above the dorsal stipe margins and the isograptid arch is also apparently high on the sicula approximately at the level of the dorsal stipe margins. Th.11 grows down with the sicula for approximately 2/3 of the sicula length and then they separate, th.11 growing down further than the sicula aperture, and only being slightly shorter than th.21. The angle between Th.11 and the sicula is partially infilled with a web of periderm.

Stipe width quite variable (see Fig.10.26) proximal width being of the order of 2mm, with relatively rapid rise to 3mm by th.30 and then slower increase subsequently. Specimen A16944 (Fig.10.24 Pl.14 Fig.6) is somewhat different showing a much steeper increase in width proximally, to over 4mm by theca 30 and then decreases dramatically. Thecal count: 12.0-14.6 th/10mm.

Discussion:
The North Wales specimens are broadly comparable to the lectotype (Rushton 1985), especially in stipe expansion, but have a somewhat higher thecal count (lectotype 11.3 th/10mm). Values for the lectotype measured from Rushton's
Fig. 10.26 Stipe expansion curves for D. hirundo Salter.

Fig. 1a. The distal decrease in stipe width shown by Al6944, may be either a real feature or the result of preservation, though such stipe forms do occur eg D. pennatulus, Hall.

Elles and Wood (1901 p.16 Figs. 9a & b) figured two modes of proximal development, the filled in type (Fig. 9a) being different to that of the lectotype, and which Rushton (pers comm) feels may be adequate to justify its exclusion from
The species. Bulman (1936 p.76 Fig.25f) figured the proximal end of A16944 from Nant-y-Gadwen, but this is not well enough preserved to justify the interpretation illustrated. The fused growth of th.1 and th.2, that Spjeldnaes (1953) was unable to recognise, does not appear to be present. The best preserved proximal end from Nant-y-Gadwen is shown in Fig.10.25a and though having a marked ventral embayment, is clearly comparable to that with infilled proximal end figured by Elles and Wood (Fig.10.25b). Both forms were illustrated by Monsen (1937): P1.15 Fig.8: open proximal end; P1.5 Fig.12: infilled proximal end. It is therefore suggested that both types be encompassed within the species as it is possible the variation reflects continued or variable growth of the sicula and th.1.

10.3 D. cf linearis / D. uniformis lepidus plexus

The specimens included in this plexus show extensive correlated variation between rhabdosome morphology and thecal count (Fig.10.27) and thecal count and sicular length (Fig.10.28). The variation observed could be taken to suggest deformation, the lineation of which would change from parallel to perpendicular relative to the specimens in going from bottom to top of Fig.10.27. Though a slight deformation can be recognised it is unlikely that it can account for the variation seen, considering the symmetry of 05696 (Fig.10.27a) and the equivalent behaviour of the pyritised specimens.

![Plot of sicular length against thecal count for D. cf. linearis / D. uniformis lepidus plexus. Solid circles: west side of Nant y Gadwen; open circles: northern end of Nant y Gadwen. Arrows indicate plots based on damaged siculae.](image)
There is no obvious taxonomic subdivision of such a plexus, and the interpretation adopted has been to indentify two species based on the end members, whilst recognising that some of the intermediates, partiucally AW26.
and Q5702 (Fig.10.27 f & j) could represent a third.

*Didymograptus* sp A from the middle Arenig is best considered as belonging to this plexus.

**Didymograptus cf. linearis** Monsen

Fig.10.27 g,m,o-s; Fig10.30; Fig.10.32-34; Fig.10.35c

Pl.1 Figs.1 10 & 11

1898 *Didymograptus extensus* Hall; Elles p.504

1933 *Didymograptus extensus* Hall; Elles p.111 figs.6 & 7

1936 *Didymograptus extensus* Hall; Bulman p.76 fig.a

P115-7 P1.1 figs.41 & 47 P1.7 figs.17 & 20.

P11937 *Didymograptus extensus linearis* subsp. nov.; Monsen

P115-7 P1.1 figs.41 & 47 P1.7 figs.17 & 20.

P11962 *Didymograptus extensus* Hall; Blake p.229 P1.1

Fig.10 P1.2 figs 10 & 11

**Material:**


**Description.**

Fig.10.29: Stipe expansion curves for *D. cf. linearis.*

Rhabdosome variable from straight to gently deflexed in the proximal area, becoming declined distally in the longest specimen. Deflexed forms can become slightly reclined distally. Isograptid mode of proximal development. Sicula: 0.83 - 1.09 mm. Stipe expansion curves are shown in Fig.10.29, the proximal width being 0.40 - 0.65mm; distal width variable but generally less than 1.25mm. Thecal count: 12.3-14.2 th/10mm. Thecal inclination is usually about 28° proximally, remaining constant in some specimens but in others increasing distally to a maximum of 42°.
Thecal length appears to range from 1.0 - 1.5mm, being slightly shorter proximally. Apertural angle: c.90°.

Discussion.

In subdividing a plexus such as that from the west side of Nant y Gadwen shown in Fig.10.27 the major problem is in the placing of the intermediate forms into one or other of the end member species. The majority of intermediate forms in this assemblage (ie with 13-14 th/10mm) are placed in D. uniformis lepidus on the basis of sicula length and stipe expansion. However two intermediates are retained in D.linearis: Q5712, (14.2 th/10mm) because it has a stipe expansion identical to that of Q5711 associated with an apparently short sicula, and Q5692 (13.3 th/10mm) on sicula length (0.98mm).

Fig.10.30: Didymograptus cf. linearis Monsen from northern end of Nant y Gadwen. (a-f & i x2.5; h & g x20). a & h, B.M.: 05719; b & g, B.M.: 05710; c, B.M.: 05718; d, B.M.: 05718; e, B.M.: 05862; f, B.M.: 05716; i, B.M.: 05717

In contrast to the continuous variation seen in the assemblage from the west side, the population assigned to D. cf. linearis from the northern end of Nant y Gadwen is quite distinct from other members of the assemblage.

Fig.10.31: Stipe expansion curves for D. cf. linearis from northern end of Nant y Gadwen.

Comparison of the two populations shows no overlap of sicula length, that of those from the northern end being <0.9mm whilst >0.9mm on specimens from the western side.
Additionally 05711, 05691, 05712 and 05719 form a small separate group on the basis of stipe expansion and on which character they may be distinguished more easily from *D.u.lepidus* than may be the other forms assigned to *D.cf linearis* (Figs 10.29 & .31). The variant shown in Fig.10.32 would also appear to belong to this group. It was not included in the description because damaged. Thecal counts on the two figured specimens are 13.7 & 14.2 th/10mm.

Fig.10.32 Straighter form of *D. cf linearis* from west side of Nant y Gadwen; N.M.W.: 85.166.33.

Outside Nant y Gadwen a single specimen from the Nant yr Olchfa section, Arenig area (10.33), and a small population from the boundary section on the Bangor foreshore (Fig.10.34) are also assigned to this species. In both cases the specimens are deformed and therefore, considering the small number available, their placement here is only tentative. Despite the deformation a well preserved proximal end is available from each locality. The Nant yr Olchfa specimen has a squat supradorsal development suggestive of a th.1¹ sicula pair with a high origin of the former. This is compatible with the best preserved specimens from the northern end of Nant y Gadwen (Fig.10.30 g & h; 10.35c). However the Bangor foreshore specimen appears to have a lower origin of th.1¹ giving a more isolated apex to the sicula. This difference would require taxonomic recognition if shown to be true at the population level, but the material available is not adequate to justify this.

No described species matches the above material exactly. It seems likely that equivalent specimens from the Lake District have been placed in *D.extensus* since many of the localities given for this species in Elles & Wood (1901) are upper Arenig in age. However, the rigid form of the rhabdosome in the type series of *D. extensus* (Cooper & Fortey 1982 pp.231-4), invalidates its use for the above specimens. The most appropriate name found is *D.extensus linearis*, the flexuous nature of which is incompatible with *D.extensus* and hence the elevation to a species.
In the original description (Monsen 1937) the sicula (1.3-1.5mm) and thecae (2-2.5mm) are considerably longer and distal stipe width is greater (1.3 - 1.5 mm) than in the North Wales specimens, but thecal spacing (12-13 in 10mm) and range of rhabdosome morphology are similar. Comparison may also be made with the *D. extensus* described from the Bogo shale (Blake 1962 p 229) a significant feature being the comparable size of the sicula (1.0 - 1.2mm) though most of the other characters, except stipe form, are different. The rhabdosome form of *Didymograptus* sp. Cooper (1979 Pl.12 Fig.a) is very similar to that shown by Q5711, and though there is no description given of the New Zealand specimen it appears to be somewhat wider and have greater thecal spacing.

*Didymograptus uniformis lepidus* Ni

1979 *Didymograptus lepidus* sp. nov. : Ni in Mu et al. pp.99

Material.

B.M.: Q5690, Q5693-4, Q5696-8, Q5700-3, Q5714; B.G.S.: AW26, from west side of Nant y Gadwen. Preservation variable: flattened periderm; pyritic internal moulds;
carbonised films and external moulds. Age: upper Arenig.

Description.

Fig. 10.35: Proximal ends of D. cf linearis / D. uniformis lepidus plexus. (All X20). a, b & d D. uniformis lepidus Ni a, B.M.: 05696a; b, B.M.: 05690a; d, B.G.S.: AW26. c D. cf linearis Monsen c, B.M.: 05691.

Rhabdosome variable from gently flexed proximally to a distinct deflexed portion occupying up to ten thecae either side of the sicula. Development mode isograptid (see Fig.10.35a). Sicula 1.15 - 1.46mm long with a long thin supradorsal expression. Th.1 has a high origin on the sicula but does not expand significantly until close to the dorsal stipe margin. Stipe expansion curves are variable (Figs.10.36-37), the 'typical' lepidus forms showing a steady increase. Proximal width: 0.45 - 0.65mm; width at th.20: 1.05 - 1.60mm. Thecal count: 13.3 - 15.9 th/10mm. Thecal inclination variable: 25°-48°. Gently flexed forms often show a marked increase in inclination away from the proximal end that can occupy nearly the entire range of variation whilst the strongly deflexed forms usually have higher values proximally and show smaller or no increase. Apertural angle c.90°.

Discussion.

D.u.lepidus Ni is the other end member of the assemblage from the west side of Nant y Gadwen discussed under D. cf. linearis Monsen. However further comment needs to be made here on the 'intermediate forms', the stipe expansion curves for which are shown in Fig.10.37. When contrasted with the curves for 'typical' lepidus (Fig.10.36) they can be seen to be generally narrower, the exceptions
being 05702 and AW26 which also have more rigid stipes.

**Fig. 10.36**: Stipe expansion curves for typical D. uniformis lepidus.

**Fig. 10.37**: Stipe expansion curves for forms intermediate between D. cf linearis and D. uniformis lepidus, assigned to latter species.

The deflexed proximal region is comparable to D. uniformis (Elles & Wood 1901 Pl. Fig.4) but the specimens described above have a higher thecal count and are narrower than that species (cf. Fig.10.38). The same is also true of the specimen Elles & Wood referred to as D. cf. uniformis (Pl.1 Fig.3). D. lepidus Ni has a quoted thecal count of 15–17 th/10mm but measurement from the illustrations suggests it may range down to 13.5 th/10mm. The moderately deflexed nature and wide range of thecal count compares favourably with the North Wales specimens. This is placed as a subspecies of D. uniformis following Fortey & Owens (in press).

D. nitidus Hall, to which these specimens have been previously referred is distinctly wider (see Fig.10.38).
**Didymograptus sp. A**

Fig.10.39; Fig.10.40; Pl.17 Figs.9, 12, 13 & 15.

**Material:**

B.M.: H487-8, H490, 05741; B.G.S.: Z4187; N.M.W.: 85.166.20; S.M.: A16857-16861 from Dwyrhos Quarry, Aberdaron. Majority of specimens are totally flattened but some have slight relief. Deformation prevalent, and in some specimens can be correlated with orientation to the lineation (Fig.10.39). However, this is not the case with those in relief (S.M. specimens) and therefore description is based mainly on these. Age: middle Arenig.

**Description:**

Fig.10.39: Didymograptus sp A from Dwyrhos Quarry Aberdaron. Radial plot of thecal count along angle to lineation. Strain ellipse dotted in. Drawings x2.5. a, N.M.W.: 85.166.20; b, B.G.S.: Z4187; c, B.M.: H488; d, B.M.: H480; e, B.M.: 05741; f, B.M.: H487.

Rhabdosome predominantly horizontal with slight proximal deflexed portion. Longest stipe 33mm. Stipe expansion diagram shown in Fig.10.41. Proximal width 0.5-0.75mm; width at th30 c.1.3mm. Thecal count average:
15.3 th/10mm (14.9-15.9 th/10mm). Value from strain ellipse somewhat higher. Thecal inclination 45° - 50°.

Fig. 10.41: Stipe expansion curves for Didymograptus sp A.

Proximal development unclear. Length of sicula c.1.5mm.

Discussion:

Stipe expansion curve is closely comparable to that of the D. cf. linearis / D. uniformis lepidus plexus and the middle Arenig specimens are similar to this group in the majority of other parameters also. It is therefore questionable whether separation from the upper Arenig plexus is possible and the above material is only described separately in that it is of known middle Arenig age and the poor preservation may obscure diagnostic characters.

10.4 Didymograptus aff suecicus plexus

The following three forms are grouped in a plexus due to their similar stipe expansion curves (see Fig. 10.42). Form B has a well preserved proximal development on which basis
comparison is made with *D.suecicus* Tullberg (Monsen 1937 Pl.1 Fig.36) but other features differ markedly. No published name has been found that is suitable. The proximal ends of forms A and C are not well known and though possibly comparable with form B, this is not certain.

**Didymograptus aff suecicus Form A.**  
Fig.10.24 b-d; Pl.17 Figs. 7 & 16

**Material.**  

**Description.**  
Rhabdosome straight to slightly reclined. Longest stipe 41mm. Development uncertain, probably isograptid mode. Sicula damaged in all specimens, a minimum length being 1.16mm, and it seems that the sicula was short forming a squat supradorsal triangle with th.1°. Stipe expansion curve is distinctive (see Fig.10.42); proximal width being about 0.9mm, rises steeply for first ten thecae and though flattening by th20 – th30, continues to rise significantly giving a width at th.50 of 1.95 - 2.25mm. Thecal count: 15.5 - 16.8 th/10mm. Thecal inclination 55° - 60°, though relief material shows the thecae to be curved with a proximal inclination of about 25°. Thcae increase in length along the stipe. Apertural angle about 45° producing a denticulate appearance.

**Discussion.**  
All the specimens appear slightly crenulated, but the pyritised portion of AW25 indicates the width and thecal count to be genuine. In gross form some comparison can be made with AW26 but the proximal development of that specimen appears more compatible with its placement in the *D. cf. linearis - D.u.lepidus* plexus. No described species has been found that shows the distinctive expansion associated with high thecal count and these features may therefore be considered diagnostic.

**Didymograptus aff. suecicus Form B**  
Fig 10.43;

**Material:**  
BM: H472, H493. from Nant y Gadwen. Pyritic internal
moulds and external moulds. Age: upper Arenig.

Description:
Stipes horizontal with slight proximal deflexed portion. Longest stipe: 15.4mm. Stipe expands from a proximal width of 0.75mm to 1.4mm by th.20; the stipe expansion curve is almost linear (see Fig.10.42). Thecal count: c.13 th/10mm. Thecae curved; inclination increasing from 30° to 50°. Apertural angle c.90°.

Proximal development well shown by one specimen (Fig.10.43e). Sicula 1.5mm long. Origin of th.1 not clear but probably high on sicula. Grows down largely ontop of the sicula before turning away to leave about 1/4 of the ventral wall of the sicula exposed. Th.12 originates high on th.11 and grows across the sicula as a narrow crossing canal before growing down its dorsal wall. Th.21 originates from the crossing canal of th.12 almost on the dorsal side of the sicula and grows across the latter approximately half way along its length. Thecae 11 and 12 enclose an angle of 60°-70°.

Fig.10.43: Didymograptus aff suecicus Form B (a-d x2.5, e x20). All from Nant y Gadwen a, c, & e, B.M.: H483; (e = detail of a); b, B.M.: H472; d, B.M.: H474.

Discussion.
This form compares with form A in rhabdosome shape and form C in thecal count. The proximal development is similar to D. suecicus Tullberg as figured by Monsen (1937 Pl.1 Fig.36) though differs from this species in most other characters. Like form A the stipe expansion diagram appears to set this form apart from previously described species.

Didymograptus aff suecicus Form C
Fig.10.24a; Pl.16 Fig.9

Material.
B.M. 85709 from west side of Nant y Gadwen. Preserved as flattened periderm. Age: upper Arenig.
Description.

Stipe declined, enclosing an angle of 155° proximally, apparently decreasing distally as stipes flex down. Longest stipe 80mm. Proximal development appears to be almost identical to that of D. aff. suecicus Form A, with damaged sicula indicating a minimum length of 1.22mm. Stipe expansion curve very similar also, and lying along the lower range of form A (see Fig.10.43). Thecal count: 13.9 th/10mm. Thecal inclination 40°-50° and thecae are approximately straight. Apertural angle: 55°.

Discussion.

The declined stipes and lower thecal count distinguish form C from form A. The lower Arenig species D. protobalticus Monsen (1937 p.138-140 Pl.3 Figs.2, 3, & 40; Pl.9 Fig.5) has comparable stipe attitude but is wider proximally, has lower thecal count and shows less marked stipe expansion.

10.5 Other extensiforms

The following two species are not described in the context of a plexus, though it is likely D. aff. nicholsoni does belong to a larger group. However D. distinctus, as its name implies, is readily separated from other species, and is not easily grouped with other extensiforms except possibly some species of Janograptus.

Didymograptus aff. nicholsoni

Material:

N.M.W. : 85.16G.14-16 from Porth Meudwy. Age: uppermost Arenig or lowermost Llanvirn

Description:

Only in the largest specimen, stipe length 9mm reaching th.12, does periderm indicate the presence of a second stipe, and the poor preservation reduces the certainty with which stipe characters can be given. In no specimen is the.
proximal development clear.

It seems that the initial thecae are declined away from a thin upstanding sicula. Stipes rigid, enclosing an angle of 110° or less. Though the sicula is incomplete in both specimens, a minimum length of 0.85mm can be given, so the complete sicula probably has a length of the order of 1mm.

The stipes are extremely thin, the width at the aperture of the first theca being only 0.25mm, but this widens to 0.45mm by theca 4 or 5 and remains at this value to the most distal theca measured; th10. Increase in width appears to reflect: increase in thecal inclination from 11° to 22°; and increase in thecal overlap from approximately zero to about 1/3.

Insufficient measurements can be made to ascertain the presence of any variation in the values of 2TRD along the stipes but the measurements made suggest a range of 1.3 to 1.5mm (13-15 th/10mm).

A stipe fragment (Fig.10.4c) is tentatively assigned to this species and indicates that distally the stipe width may reach 0.7mm and thecal overlap about 1/2. The thecal count of 14.9 th/10mm is not incompatible with that measured proximally.

Discussion:

The thin, rigid, declined stipes suggest comparison with both D.affinis Nicholson and D.nicholsoni Lapworth. The former may be eliminated on the basis of its very short sicula (see Sectn.9.3b). Though Elles & Wood (1901) claimed a sicular length of 1.8mm for D.nicholsoni, Bouček (1973 p69) states that examination of the holotype indicates a length of only 1.2mm. The thin nature of the sicula compares favourably with the available evidence of the Forth Meudwy specimens. Stipe width is also comparable, but thecal count is somewhat higher.

Didymograpthus distinctus Harris & Thomas

1935 Didymograpthus distinctus sp. nov.; Harris & Thomas p.292 Figs.1,3 & 2,10

1984 Didymograpthus distinctus Harris & Thomas; Carter & Tailleur p.45 Fig.5c

Material:

B.M.: Q5704 from northern end of Nant y Gadwen. B.M.: Q5705-6 from west side of Nant y Gadwen. All specimens
flattened. Age: upper Arenig.

**Description:**

![Diagram of Didymograptus distinctus](image)

**Fig. 10.45** *Didymograptus distinctus* Harris & Thomas. (a-c x5, d x20), a, B.M.: 05704a; b, B.M.: 05704b from northern end of Nant y Gadwen. c, B.M.: 05706; d, B.M.: 05705 from west side of Nant y Gadwen

Rhabdosome straight, longest specimen 1.5cm, reaching th. 8. Despite the short length of the specimens, the presence of a proximal end on all three suggests that the species did not grow to any great length. Proximal development clearest on 05704, the only specimen showing definite evidence of a sicula. Assuming that the supra-dorsal expression is not damaged, it is represented by a squat triangle 0.24mm in height. The ventral expression of the sicula is also triangular with an apertural angle 36°. Total sicular length 1mm. Sicula is asymmetrically placed between th. 1 and th. 12, the dorsal wall of the sicula being approximately perpendicular to the dorsal stipe margin. First two thecae enclose an angle of 65°-100°. On specimen 05706 th. 2 on the left stipe (presumably 22) appears to pass behind th. 1 (17) suggesting isograptid development mode.

There appears to be little variation in width along the stipes though 05704, at 1mm is noticeably wider than the other two specimens at 0.7mm. Thecal spacing is estimated at 9-10 thecae in 10mm. Thecal morphology is distinctive, the common canal being extremely thin, the initial width of the thecae being c.0.07mm, with the ventral wall forming an angle of 6° with the dorsal stipe margin whilst the distal ventral margin forms an angle of 41°, the apertural width being 0.65mm. Thecal overlap is just less than 1/2 on 05704 but may be a little less on the other two specimens.

**Discussion:**

Apart from the greater thecal overlap and possibly a
slightly more prominent sicula, Q5704 is closely comparable to the original description from Australia. The thinner stipes of the two specimens from the west side of the valley compare with the measurements given for the Alaskan specimens (Carter & Tailleur 1984). The apparent absence of a sicula is a common character in the species and its reduced nature combined with the thecal form suggest it may be ancestral to at least some species of Janograptus.
Plate 14

Fig. 1 Didymograptus aff. praenuntius Form C
B.M.: Q5730 x2.5. Olchfa Member (upper Arenig), loc.B
(Fig. 2.6) Nant yr Olchfa.

Fig. 2 Didymograptus aff. infrequens (Kraft).
N.M.W.: 85.166.11 x2.5. Graianog Sandstone Member, Nant Ffrancon Formation. Bwlch ym Mhwtle-1e.

Fig. 3, 8, & 10 Didymograptus cf. infrequens (Kraft)
Llyfnant Member (lower Arenig), Carnedd Iago Formation. Hafotty Ffilltirgerig.
Fig. 3: S.M.: A17519 x5 Fig. 3a x20 Detail of partially pyritised proximal end; reverse view.
Fig. 8: S.M.: A17529 x20 Partially pyritised proximal end; obverse view.
Fig. 10: S.M.: A17512b x2.5.

Fig. 4, 5, & 6 Didymograptus hirundo Salter. Carw Tuff Formation (upper Arenig) Nant y Gadwen.
Fig. 4: S.M.: A22611 x1
Fig. 5: B.M.: Q5707 x2.5.
Fig. 6: S.M.: A16944 x2.5.

Fig. 7 & 9 D. praenuntius Törnquist Maen Gwenonwy Siltstone Member, Wig Formation.
Fig. 7: B.M.: Q5722 x2.5 Benallt Mine, Rhiw.
Fig. 9: B.M.: Q5721 x2.5 Maen Gwenonwy.
Plate 15

Fig. 1 & 2 Didymogaptus aff. praenuntius Form B
Fig. 1: B.M.: Q5728 x2.5, Fig. 1a x15 detail of proximal end.
Olchfa Member, (upper Arenig), Serw Formation. Loc.B
(Fig. 2.6) Nant yr Olchfa.
Fig. 2: B.M.: Q5742 x2.5. Fig. 2a x10. Carw Tuff Formation
(upper Arenig), Benallt Mine.

Fig. 3, 4, 5 & 7 Didymogaptus aff. praenuntius Form D Carw
Tuff Formation, upper Arenig.
Fig. 3: B.M.: Q5860 x2.5 Benallt Mine.
Fig. 4 & 7: (part & counterpart) B.M.: Q5851 (upper), Q5852
(lower) x2.5 Benallt Mine.
Fig. 5: B.M.: Q5863 x5. Nant y Gadwen (west side).

Fig. 6, 8 & 9 Didymogaptus aff. praenuntius Form C
Fig. 6: S.M.: A17012a x5, (upper Arenig) Menai Straits
Inlier.
Fig. 8: B.M.: Q5729 x2.5., Fig. 8a x15. Olchfa Member, (upper
Arenig) Serw Formation. Loc.B (Fig. 2.6), Nant yr Olchfa.
Fig. 9: B.G.S.: DJ2917, x2.5, (upper Arenig) Menai Straits
Inlier.
Plate 16

Fig. 1, 2 & 5 Didymograptus hirundo Salter
Fig.1: B.M.: Q5708 x1. Carw Tuff Formation (upper Arenig), Nant y Gadwen (west side) Specimen preserved slightly oblique to bedding.
Fig.2: S.M.: A16936 x2.5. Nant Ffrancon Formation (upper Arenig), Afon Seiont, Caernarfon.
Fig.5: B.G.S.: AW27 x2.5. Carw Tuff Formation, (upper Arenig), Nant y Gadwen (west side). Distal, partial relief proximal end.

Fig. 3 Didymograptus aff praenuntius Form C
B.M.: Q5887 x2.5; Fig.3a x10. Nant Ffrancon Formation, (upper Arenig) Afon Seiont, Caernarfon.

Fig. 4 & 8 Didymograptus aff praenuntius Form B
Fig.4: B.M.: Q5155 x1, Olchfa Member, Serw Formation, Loc.B (Fig.2.6) Nant yr Olchfa.
Fig.8: B.M.: Q5743 x2.5, Carw Tuff Formation, (upper Arenig) Benallt Mine.

Fig. 6, 7 & 10 Didymograptus distinctus Harris & Thomas
Carw Tuff Formation (upper Arenig) Nant y Gadwen
Fig.6: B.M.: Q5706 x5. west side.
Fig.7 & 10: (part and counterpart), B.M.: Q5704 x5. northern end.

Fig. 9 Didymograptus aff. suecicus Form C
B.M.: Q5709 x2.5, Carw Tuff Formation (upper Arenig), Nant y Gadwen.
Plate 17

Fig. 1, 10 & 11 *Didymograptus* cf. *linearis* Monsen.
Carw Tuff Formation (upper Arenig), Nant y Gadwen.
Fig.1: B.M.: 05691 x2.5
Fig.10: S.M.: A13590 x2.5
Fig.11: B.M.: 05690a x1

Fig. 2, 3, 6, 8 & 14 *Didymograptus* *uniformis* *lepidus* Ni
Carw Tuff Formation (upper Arenig) Nant y Gadwen.
Fig.2: B.M.: 05701 x2.5
Fig.3: B.M.: 05696 x2.5
Fig.6: B.G.S.: AW26 x2.5 Fig.6a x10
Fig.8: B.M.: 05690b x2.5
Fig.14: B.M.: 05690 x5?

Fig. 4 & 17 *Didymograptus* aff. *praenuntius* Form A
Aberdaron Formation (middle Arenig), Dwyros Quarry.
Aberdaron.
Fig.4: B.M.: 05732 x2.5
Fig.7: B.M.: 05733 x2.5

Fig. 5 *Didymograptus* aff. *praenuntius* ? Form B
B.M.: 05870 x7.5 Carw Tuff Formation (upper Arenig) Nant y Gadwen (northern end)

Fig. 7 & 16 *Didymograptus* aff *suecicus* Form A
Carw Tuff Formation, (upper Arenig) Nant y Gadwen.
Fig.7: B.G.S.: AW22 x2.5
Fig.16: B.G.S.: AW25 x2.5

Fig.9, 12, 13 & 15 *Didymograptus* *sp.* A
Aberdaron Formation (middle Arenig) Dwyros Quarry.
Fig.9: B.M.: H488
Fig.12: S.M.: A16858 x2.5
Fig.13: S.M.: A16861 x2.5
Fig.15: B.M.: 05741 x2.5
Chapter 11: Graptolite Systematics: non-extensiforms

Order GRAPTOLOIDEA Lapworth, 1875
Family DICHOGRAPTIDAE Lapworth, 1873
Subfamily DICHOGRAPTINAE Lapworth, 1865
Genus TETRAGRAPTUS Salter 1863
Type Species: Fucoides serra Brongniart 1828.

Tetragraptus (Tetragraptus) reclinatus s.l. Elles & Wood
Fig. 11.1a-u.

Synonymy See Cooper & Fortey 1982 p203

Material

Age: upper Arenig.

Description
Rhabdosome morphology extremely variable from gently to strongly reclined with a number of specimens preserved in 'quadribrachiate' mode. Apart from the proximal flexure the stipes are relatively straight reaching a length of 47mm in a specimen from Benallt Mine.

In the few specimens where the sicula is preserved, a length of about 2.0mm is characteristic, the one notably larger example (2.5mm) probably being tectonically elongated. The proximal development is not clear in any of the specimens, but in those preserved in 'quadribrachiate' mode the 1st order stipes can be seen to form a funicle about 2.0mm long.

The maximum stipe width ranges from 1.5-2.7mm, (no compensation made for deformation) the variability probably being enhanced by differences in stipe orientation relative to the bedding. The thecae are slightly curved, the main part usually being inclined at 40°-50° to the dorsal wall, with the free ventral surface forming an angle about 20° greater. A ventral denticle is normally developed. Thecal count typically 13 th/10mm but in some specimens reaches 15 th/10mm though this may in part reflect deformation.

Discussion
Considerable variation has been encompassed under a
Fig. 11.1 *Tetragraptus reclinatus* s.l. Elles & Wood.
(A11 x2.5)

a–c Porth Meudwy: a, B.M. Q5752; b, B.M.: Q5753; c, B.M. Q5754.
f–i Menai Straits: f, B.M.: Q5757; g, B.M.: Q5768; h, B.M. Q5766; i, B.M.: Q5761.

Single name largely in the absence of any reliable criterion for separation. One of the most significant differences between populations is in the proportions of the preservational orientation. Both Benallt Mine and Nant y Gadwen are almost completely dominated by forms showing 'quadribrachiate' mode, and the few that are preserved in 'serra' mode have a relatively small reclinatio of the second order stipes. This contrasts with the dominance of
'serra' mode preservation in the Afon Seiont and Porth Meudwy populations and to a lesser extent those of the Menai Straits inlier and Nant yr Olchfa. There is some evidence that this may partly reflect the depositional environment as well as the original stipe orientation it that the lithologies of Afon Seiont and Porth Meudwy both suggest rapid deposition of immature sediment and in specimens where the second stipe pair is visible the two pairs are separated by a distinct thickness of sediment. This contrasts with the very finely laminated beds of Nant y Gadwen, where graotolites clearly settled on the surface, and it may be that in the former cases the graotolites were actually caught up in the sediment and deposited with it. Specimens from Nant yr Olchfa and the Menai Straits show a wide range of stipe reclination.

The main criteria for grouping all the material under *T. reclinatus* are the maximum stipe width and thecal form. It could be argued that the Nant y Gadwen and Benallt populations represent a less reclined form and that they should be compared to *T. amii*. Though the maximum stipe width of this species does range down to 2.4mm (Cooper & Fortey 1982 p 198) it appears to be characteristically greater than in these specimens as is also true of *T. serrata* (Cooper & Fortey 1982 pp. 191-195)

Though many of the specimens may be compared fairly closely to *T. reclinatus* Elles & Wood (Cooper & Fortey 1982 pp203-4 Fig 24) some of the thinner examples approach more closely to the other subspecies *T. r. toernquisti* Monsen (Cooper & Fortey 1982 pp 207-210 Fig 28) and *T. r. abbreviatus* (Bouček 1973 pp22-23). The material assigned by Bouček (1973 pp 20-2 Fig.3 e-g) to *T. pseudobigbsbyi* Skevington has a maximum stipe width of 1.0-2.5mm as compared with that stated for the holotype of 2.9 to 3.2mm (Skevington 1965 pp 8-9), though is comparable to *T. cf T. pseudobigbsbyi* Skevington (1965 pp 9-10). The specimens described by Bouček tend to fall within the range seen in the North Wales material, apart from having a larger sicula, and these specimens are associated with *T. r. abbreviatus*, giving an overall variation for the 'population' comparable to that described above.
**PSEUDOPHYLOGRAPTUS** Cooper & Fortey 1982

**Type Species:** *Phylograptus angustifolius angustifolius* Hall 1858

*Pseudophylograptus angustifolius* aff. *regularis* (Monsen)

Fig. 11.2; Pl. 18 Fig. 5.

aff 1937 *Phylograptus angustifolius regularis* subsp nov; Monsen p214, Pl 18 Fig 4.

1928 *Phylograptus typus* Hall; Matley p 488

1928 *Phylograptus angustifolius* Hall; Matley p488

**Material**

Numerous specimens on a number of slabs from Parwyd Bay.

BGS: Z4365-77; SM: A17398-9. All are preserved as flattened periderm often coated with a rusty stained layer of chlorite. Age: uppermost middle Arenig.

**Description.**

![Figure 11.2](image)

*Fig.11.2 Pseudophylograptus angustifolius aff. regularis* (Monsen) from Parwyd Bay. (all x2.5). a, B.G.S.: Z4368; b, B.G.S.: Z4376; c & d, B.G.S.: Z4373; e, B.G.S.: Z4370; f, B.G.S.: Z4372; g, B.G.S.: Z4376; h, S.M.: A17398-9; i, B.G.S.: Z4375.

Maximum rhabdosome width seen: 10.8mm in an incomplete specimen. Largest complete specimen: 9.2mm maximum width, length 39.7mm. Rhabdosome ovate, somewhat parallel sided, with distal end more rounded than proximal. Variation of
Fig. 11.3

Plot of length vs. width: length ratio for *Pseudophyllograptus*. Examples from literature: 1, *P. a. angustifolius* (Hall) (Cooper & Fortey 1982 Fig. 48 e & f); 2, *P. a. chors* Cooper & Fortey (1982 Fig. 48 a-c); 3, *P. a. subsp 1* Cooper & Fortey (1982 Fig. 48d); 4, *P. a. regularis* Monsen (1937 Pl. 18 Fig. 14); 5, *P. a. tenuis* Monsen (1937 Pl. 19 Fig. 8).

width : length ratio summarised in Fig.11.3 and discussed below.

Thecae are significantly curved, from as little as 35°
close to the axis to a perpendicular ventral free margin. Slight ventral denticle. Thecal count, measured in middle of rhabdosome, ranges from 11.5 - 14.5 th/10mm (Avg.12.6), and shows some correlation with orientation to lineation, correction for which gives a value of 12.8 th/10mm.

Details of the proximal development are unknown.

Discussion.

This material is placed in *Pseudophyllum* on the basis of the relatively rounded proximal end and parallel sided shape of the rhabdosome (Cooper & Fortey 1982 p.241), this also being true of the other two North Wales populations. *P.angustifolius*, sensu lato extends throughout the Arenig and into the Llanvirn (Cooper & Fortey 1982 p161 Fig.1). Though sub-species may be distinguished by proximal development, e.g. *P. a. chors* Cooper & Fortey (1982 p.247) such criteria are rarely visible on flattened material and features such as thecal count, *P. a. elongatus* (Bulman 1936 p46); thecal curvature, *P. a. subsp. 1 nov.* Cooper & Fortey (1982 p.247); and rhabdosome shape (Mu et. al. 1979 Pl.41 Figs. 11,12 & 16) have to be relied upon.

The use of the last character is complicated by astogenetic changes, and the consequent difficulty in quantifying this feature. It is likely that in the quoted example the three species recognised are different growth stages of a single species, as all occur on a single slab. A parameter that has been quoted is the width : length ratio (or its inverse) but is of little use since it changes with size. However a simple length vs width : length ratio plot was found to produce an apparently linear relationship, that varies between populations. A number of populations and individuals measured from illustrations in the literature are shown in Fig.11.3. Of the populations only that from Graptolite Valley is not deformed, but correction for this in the two larger North Wales populations did not significantly alter the line. The scatter seen is no more than might be expected from biological variation and the vagaries of preservation.

Of the North Wales populations, that dominated by small individuals (*P. sp. A*) illustrates one shortcoming of the method in failing to distinguish diminutive forms and populations of juveniles, since they lie in the region of
overlap of the majority of lines. However, the two other populations are clearly separated, though *P. a.* Subsp. 1 lies among both the Barf and Graptolite Valley populations. That from Parwyd Bay, described above, lies on a distinctly lower line, close to which the holotypes of *P. a.* regularis Monsen (1937 Pl.18 fig.14); *P. a.* tenuis Monsen (1937 Pl.19 fig.8) and *P. a.* subsp. 1 Cooper & Fortey (1982 Fig 48d) plot. For this reason, though the thecal count quoted in the type description is somewhat less, the Parwyd material is tentatively assigned to *P.a.*regularis, though clearly more plots of the type material would be required to make this more reliable.

There are a couple of other significant points that emerge from the plot. Firstly, *P. a.* chors, that was recognised on the basis of proximal development lies well away from *P. a.* angustifolius on this plot. However, in contrast, the populations from Barf and Graptolite Valley lie very close whilst coming from widely separated stratigraphic horizons.

*Pseudophyllum* graptus angustifolius Subsp. 1

**Fig.11.4**

**Material.**

BM 05770-83 from W. of Castellmarch Farm (SH 31452980). Significant number of variably flattened and deformed specimens. These specimens appear to have been preserved with the stipes perpendicular to bedding not completely crushed, i.e. they are found tilted over to one or other side and separated from the other stipe pair by a distinct thickness of sediment. Age: probably upper Arenig.

**Description:**

Elongate, distinctly parallel sided rhabdosome, maximum length and width observed 31mm and 8.6mm respectively. However these are not seen on the same specimen and are probably exaggerated by deformation, though the length vs width : length plot gives a straight line that is little different if corrected for deformation. (Uncorrected values are plotted.) Thecae tend to rotate into parallel with the lineation making measurement of the inclination difficult. The most reliable evidence comes from a specimen lying parallel to the lineation (Fig.11.4a) which shows a rotation from 45° axially to 90° at the margin relative to the long
Thecal count ranges from 11.1 – 17.7 th/10mm (Avg. 14.6). There is some correlation with orientation to the lineation, correction for which gives a value of 13.6 th/10mm, though the highest value of 17.7 th/10mm occurs in a specimen inclined at 45° to the lineation.

Details of the proximal development are not known since interthecal walls are rarely observed in this region. In view of the preservation of all four stipes an attempt was made to cut across one rhabdosome but did not provide any clear evidence on the internal structure of the axis. However, a v-shaped closure visible along the axis of one specimen is compatible with the structure of *Pseudophyllumgraptus* (Cooper & Fortey 1982 p246 Fig 51).

Discussion

See discussion under *P. a. aff. regularis*. As can be seen from Fig.11.3 these specimens plot in an area equivalent to a number of other populations for which the correct name is unclear. For this reason, no sub-specific name is given.

*Pseudophyllumgraptus cf. densus* (Törnquist)

Material

BM: Q5784-9 from a small quarry at SH 17272753, NNW of Aberdaron. The material is not totally flattened and in at
least a couple of specimens all four stipes are preserved oblique to bedding and separated by a thin layer of sediment. Age: ?middle Arenig.

**Description**

*Fig. 11.5: Pseudophyllograptus cf densus* (Törnquist). (All x2.5) a, B.M.: Q5786; b, B.M.: Q5784; c, B.M.: Q5787; d, B.M.: Q5789.

All specimens are small and strongly ovate though the longest specimen is more parallel sided. Proximal end rounded. Largest specimen is incomplete, with a minimum length of 13.4mm and maximum width of 7.4mm. Thecal count is very high: 20.5, 18.8 & 18.4 th/10mm in the three specimens where measurable. The thecal curvature is only visible in one specimen, and is limited, with an inclination of 53° to the axis going to perpendicular at the margin.

**Discussion**

The rhabdosome shape clearly indicates *Pseudophyllograptus*, but as a result of the small size is of limited value in distinction from other species. Since only small specimens have been found this may be a genetic character of the population. The most distinctive feature is the very high thecal count, apparently greater than in all previously described species. The most similar is *P. densus* (Törnquist) for which 16-17 th/10mm was quoted in the original description (1879 p.447). However the rhabdosome tends to be more elongate than in the material described above, and in the specimens he assigned to this species in 1904 are forms with a morphology comparable to *P. angustifolius* and much lower thecal counts. In shape there is possibly a closer comparison with *P. d. opulentus* (Monsen 1937 p20 Pl.18 Fig.4) but the thecal count quoted for this subspecies is again much lower than in the North Wales specimens.

*Pseudophyllograptus aff. cor* (Strandmark)

*Fig. 11.6.*

**Material**

BM: Q5750-1 from Loc-B (Fig.2.6), Nant yr Olchfa. Poorly
preserved, flattened and deformed. Age: upper Arenig.

Discussion

Neither of these specimens is well enough preserved to be sure that stipe fusion has occurred, but is thought to be more likely than stipe overlap. P. cor (Strandmark) has recently been redescribed (Cooper & Lindholm 1984) and is typically wider than the specimens from North Wales, in which a maximum width of 4.2mm was measured on the specimen orientated perpendicular to the lineation. Though not clear it also seems likely that the point of fusion is slightly more proximal. The details of the proximal end are not clear but it is possible that the specimens compare more closely with the related form Cooper & Lindholm recognise (p 285 Fig3 c-d) which is of comparable size and has a similar rhabdosome form.

Cooper & Lindholm (1984) have shown this species to be topmost Arenig/ basal Llanvirn in age, being associated with Glyptograptus austrodentatus. In view of this the suggestion may be made that the two specimens figured from Troutbeck by Elles & Wood as Tetrograptus bigsbyi (1902 Pl.VI Figs 6 d & e) may also be proximal portions of P. cor.

AZYGOGRAPTUS Nicholson & Lapworth 1875

Type Species Azygograptus lapworthi Nicholson 1875

Diagnosis.

Rhabdosome of single pendent to reclined stipe with a metasicular origin. None to slight parallel growth of sicula and th.1. Thecae; simple, elongate, conical and inclined at low angle to the dorsal stipe margin.

Discussion

On the basis of the above diagnosis the following described species are retained in the genus: A. lapworthi Nicholson 1875 (Oct); A. hicksii (Hopkinson 1875); A.
suecicus Moberg 1892; A. eivionicus Elles 1922; A. undulatus Chen & Xia 1974, A. flexilis Chen & Xia (in Mu et al 1979) and A. fluitans Ge (in Mu et al 1979). The following may also be included but the published illustrations are inadequate to be certain: A. validus Törnqvist 1904; A. ellesi Monsen 1937 and A. gronwalli Monsen 1937.

Obut and Sennikov (1984) recognised four subgenera of Azygograpthus: A. (Azygograpthus), A. (Eozygograpthus), A. (Metazygograpthus) and A. (Pseudazygograpthus). The last was a down grading of the genus recognised by Mu et al. (1960) whilst the others are new and were based on the three groups noted by Elles & Wood (1902 p.93), and distinguished on the same criteria. Since the high origin of th.1 on the sicula excludes A. coelebs Lapworth 1880 from Azygograpthus on the above diagnosis, Eoazygograpthus may have some validity if this species cannot be accommodated elsewhere. Pseudazygograpthus contains species with different thecal morphology and therefore should remain a distinct genus. However, the concept of A. (Metazygograpthus) based on A. suecicus is not valid on the criteria proposed, in that the main distinguishing feature is taken to be the low origin of th.1 on the sicula which is also true to a greater or lesser extent of the species included in A. (Azygograpthus).

The genus is therefore retained undivided, a number of species previously included being considered part of a phyletically separate radiation in the Llanviri, characterised by different thecal morphology and proximal development, and possibly best placed in Eoazygograpthus, as a distinct genus.

The following descriptions are of species that have been previously recognised in the British Isles, and all but A. suecicus were described originally from British specimens. Since the features considered important in the recognition of these species are generally not visible on figured specimens, and rarely contained in accompanying descriptions, such material is not included in the synonymy lists. The recognition of six species from the A. suecicus zone of China (Mu et al 1979) probably either represents over splitting of one or two species, or the grouping of all azygogaptids in that zone on the presumption that the genus is restricted to it.
Parameters used in the following descriptions

1) Basal free length of sicula. The distance between an imaginary line tangential to the sicular aperture and the line parallel to this that cuts the dorsal margin at the point of divergence of the stipe. (A on Fig.11.7)

2) Stipe Divergence Angle. Angle between dorsal wall of sicula and dorsal wall of basal part of stipe. (B on Fig.11.7)

3) Origin of th.1 is given as a fraction of the length of the sicula measured away from the apex. (x/y on Fig.11.7)

Fig.11.7: Sicula parameters used in description of *Azygograptus*. (see above text for explanation)

*Azygograptus lapworthi* Nicholson

Fig.11.9a-d,h-s

1875 *Azygograptus lapworthi* sp. nov.; Nicholson p270 P1.VII Figs.2-2c.

1898 *Azygograptus lapworthi* Nicholson; Elles p.513

1902 *Azygograptus lapworthi* Nicholson; Elles & Wood, p.93, Text Fig.54, Pl.13 Figs.1 a-b.

1915 *Azygograptus lapworthi* Nicholson; Nicholas, p.112 & p.121

1938 *Azygograptus eivionicus* Elles; Matley p.559

1984 *Azygograptus lapworthi* Nicholson; Zalasiewicz p.427 Figs.2e & f.

Diagnosis.

*Azygograptus* with significant basal free length of the sicula and prominent ventral lip on sicular aperture. (Both these features may be dependent on the maturity of the rhabdosome).

Type Material.

Type slab figured by Nicholson from Dover's collection has not been traced. No lectotype has been designated.
Type Locality.


Description of Topotype Material. (fig.11.9, a-d)

Flattened specimens in flaggy micaeous sandstones. Deformation does not appear significant.

Short sicula, 0.89-1.33mm, with squat appearance. When well preserved there is a very prominent, broad, ventral lip on the sicula aperture. Stipe originates at approximately 0.7 of the sicula length, and diverges immediately at an angle of 87°-155°, 140° being typical. Basal free length of sicula prominent: 0.07-0.45mm, >0.2mm typically.

Stipes moderately flexed with up to 53° rotation. Maximum stipe length 30mm. Stipe width stabilises around 0.8mm after first few thecae. Recalculated thecal count: 6-8.5 th/10mm. Thecal inclination: 10°-12°.

Synrhabdosome has been described. (Zalasiewicz 1984a)

Discussion of Topotype material.

This species is distinguished by the sicula characters given in the diagnosis, with stipe characters little different from other species. In the original description, and that of Elles & Wood, emphasis is placed on the angle of divergence of the stipe being close to perpendicular. As shown in Fig.11.8 the range is infact somewhat greater, and considering the susceptibility of angular measurements to deformation, does not provide a reliable character on which to distinguish the species. Variation of this parameter combined with differences in stipe flexure produces a wide range of stipe morphology from moderately declined (Fig.11.9b) to somewhat reclined (eg specimens on original figured slab).

Elles & Wood (1902) quoted the length of the sicula as being 1.5mm, ie outside the range quoted above, but Nicholson (1875) and Elles (1898) gave values of 1.05mm and 1.26mm respectively, well within the range observed here.

North Wales Material (Fig.11.9 h-s Pl.18 Fig.1 & 6)

Populations from four localities are placed in this species:

1) Castellmarch Farm, 1.5km N of Abersoch (SH 31452980). A strong lineation is present but deformation does not appear to be very bad.
2) Penrhyn Dû, 1.5km SSE of Abersoch (SH 31742653)
Localities ης & ηα of Nicholas 1915 Pl XIII.
3) Small Valley 400m west of Bryncroes (SH 23173150)
4) Copper Mine of Penrhyndeudraeth (SH 616401)

Fig. 11.8: Histograms of thecal count, maximum stipe width and stipe divergence angle for A. lapworthi.

Description and Discussion.

The main criterion for including these populations in A. lapworthi is that the basal free length of the sicula typically ranges above 0.2mm. Like the topotype population, that from Bryncroes has a wide range in this parameter but differs from it in having the distribution skewed more heavily to values less than 0.2mm. However, these values tend to occur in immature specimens, i.e. with less than five thecae, and most notably those associated with a synrhabdosome (Fig. 11.12; Pl. 18 Fig. 6). This synrhabdosome differs from that described from Hodgson How (Zalasiewicz Fig. 11.10 (overleaf). Details of sicular apertures of Azygograptus (orientated with stipe to left) and histograms of basal free length of sicula.
Oslo (A. ct. suecicus)

Whitesand Bay (A. hicksi)

Penryn Deudraeth

Bryncoes

Penryn Du

Hodgson How Quarry, (A. lapworthi)

Barf

Rhiw & Maen Gwenonwy

Bangor (A. elvionicus)

sicular apertures x20

Fig.11.10; caption: previous page.
Fig 11.9. (rhabdosomes x5, siculae x20, detail of n x10)

a-d & h-r: Azygograptus lapworthi Nicholson.
e-g: Azygograptus hicksii (Hopkinson); Whitesand Bay; e, S.M.: A17392;
f & g, S.M.: A17933.
Oslo (A. cf. suecicus)

Whitesand Bay (A. hicksii)

Penrhyndeudraeth

Bryncroes

Penrhyn Dû

Hodgson How Quarry (A. lapworthi)

Rhiw & Maen Gwenonwy

University College Cliff Bangor

Garth Point, Bangor (A. elvlonicus)

Fig. 11.11: Histograms of origin of th.1 along sicula and length of sicula, for Azygograpthus 1984a) in that it appears to be composed of juvenile individuals with much longer nemas. The intriguing inflation at the end of one of these may be a poorly preserved prosicula, but would be the only rhabdosome pointing in this direction, though the unidirectional nature of the assemblage contrasts with the radial arrangement typical of synrhambdosomes. The Penrhyn Dû and Penrhyndeudraeth populations have basal free lengths restricted to values greater than 0.2mm. In the case of the former this may reflect greater maturity of the population, but a similar
explanation seems less appropriate for the latter and both populations show differences in stipe character from the toptotypes.

Fig. 11.12 Synrhabdosome (B.M.: Q5878) of juvenile *A. lapworthi* from Bryncroes. (x5. a x10)

The very prominent ventral lip is less well developed in all the North Wales populations with the exception of the specimens from Castellmarch Farm. Only three siculae are known from this locality and all show a prominent ventral lip. Slight relief on one of these confirms the interpretation as a lip rather than a finer process and the very broad process on one specimen probably results from this lip having been preserved in a more plan view, and could be mistaken for a vestigial theca. Measurements taken from the semi-relief specimen: 1.0mm in length; basal free length of 0.21mm and prosicula 2.7mm in length. The stipe originates at 0.64 of the length and diverges immediately at an angle of 126°.

Of the other parameters, all summarised in Figs.11.8 & 11.11, only stipe width appears to show significant variation between the populations. The Bryncroes population has values concentrated around 0.7-0.8mm and is therefore the most similar to the Hodgson How population, though possibly on average is slightly thinner. The Penrhyn Dû population is the only one other than the type population of *A. hicksii* to range significantly over 1mm. The extreme length of some specimens in this fauna, an incomplete distal fragment reaching 38mm, may explain this if there is a very slow stipe expansion not apparent in shorter individuals. It differs from *A. hicksii* in having a normal thecal count of 5.7-8.4 th/10mm.

The Penrhynedendraeth population is noticeably thinner than is typical, even though a maximum length of 32mm is reached. This could be explained by the deformation, but
stipe width appears to remain lower even in specimens lying perpendicular to the lineation. In addition specimens on BGS: Z1672 show evidence of the dorsal wall of the thecae becoming separated at their apertures by a notch 0.3mm deep (see Fig.11.9n). This feature is only seen in specimens on this one slab, and is not consistently visible even along a single rhabdosome. It is therefore considered to simply represent an anomalous, variant population, but since this feature has not been seen in any other species, would clearly justify taxonomic separation if consistently present.

Horizon

No biostratigraphically significant fossils are associated with any of the North Wales populations, but Lake District occurrences are from the upper Arenig (cf. Rushton 1985). There is independent lithostratigraphic evidence that the Bryncroes locality is upper Arenig in age.

*Azygograptus hicksii* (Hopkinson)

Fig.11.9 e-g.

1875 *Tetragraptus hicksii* sp. nov.; Hopkinson (in Hopkinson & Lapworth) p 651-2 Pl.XXIII Figs 12a-d.

1902 *Azygograptus hicksii* (Hopkinson); Elles & Wood p.94-5 Text. Figs 55a-b, Pl.XII Figs. 2a-e.

(Full synonymy contained in Fortey & Owens in press)

Discussion

This species is being described fully in the above paper but is mentioned here for the sake of completeness. The type locality at Whitesand Bay is in the upper part of the middle Arenig, and the species is only known from here. Characterised by its large size (see Figs.11.9 e-g) and the elongate ventral process of the sicural aperture (Fig.11.11) it is easily distinguished from other species.

It has been suggested (Jenkins 1979) that this species is a junior synonym of *A. lapworthi*, the larger size being explained by tectonic expansion resulting from the bedding parallel cleavage. However there is no evidence of this affecting other elements of the fauna at the type locality (Fortey pers comm), and the discovery of a transitional fauna between *A. eivionicus* and *A. hicksii* (Fortey & Owens in press) confirms its recognition as a distinct species.
Azygothrustus eivionicus Elles

1915 Azygothrustus lapworthi Nicholson; Nicholas 1916 p113
1922 Azygothrustus eivionicus sp. nov.; Elles p299-301 Figs 1-3

1932 Azygothrustus suecicus Moberg; Matley p 261 locs 3-6

Type material: Holotype SM: A17372; Syntypes SM: A17373-4
(Strachan 1971 p.19 listed all these specimens as syntypes, though in the original description a type specimen is clearly designated.)

Type locality: Valley SE of Nant, St. Tudwal’s Peninsula.
Loc. β of Nicholas (1915 Pl. XIII) SH 297253

Description of Type Material. (Fig.11.13, Pl.18 Fig.7)

Fig.11.13: Type specimens of Azygothrustus eivionicus Elles. a: Elles’ original drawings (1922) quoted as x5. b: same specimens redrawn at x10. 1: S.M.: A17372 (holotype); 2: S.M.: A17373; 3: S.M. A17374.

Material is flattened, matted, fragmentary and strongly deformed. The three specimensfigured by Elles are shown in Fig.11.13 against her original drawings, which can be seen to be inaccurate. This is most significant in the case of the holotype, there being no proof of the sicula indicated and it is possible that the proximal end is not even reached.

There are very few proximal ends among the material and only one complete sicula; A 17373. This is 1.1mm long with a basal free length of 0.08mm. The basal free lengths in two other measurable specimens are 0.05 & 0.09mm. None of these are associated with more than a couple of thecae and
therefore all may be immature. In figuring A17373 (Fig.11.13/2), Elles showed th.1 as originating in the mid-part of the sicula and growing adpressed to it for a short distance. There is no evidence for the shoulder this produces and the stipe diverges abruptly at 0.8 of the length. There is a slight inflation of the sicula approximately at its mid-point, but this is also developed on the ventral side and probably represents the expansion at the base of the metasicula. The stipe divergence angles measurable on two specimens are 138° and 144°. (No correction made for deformation.)

Stipe characters are difficult to quantify because of the deformation but are probably most reliable on the holotype which lies almost parallel to the lineation. This has a stipe width of 0.6mm and a recalculated thecal count of 7.4 th/10mm. Stipes are gently flexed.

Discussion

The above is not adequate to characterise the species and it has not proved possible to obtain additional topotype specimens. It is therefore proposed to characterise the species on the basis of the other two localities given in the original description: University College Cliff and Garth Point, Bangor. However there are problems in this.

The type material comes from the Llanengan Mudstones, which cannot be accurately placed within the Arenig. Azygograptids are common at the junction between the St. Tudwal's Sandstone and the Llanengan Mudstone in what were termed the Transition Beds by Nicholas (1915). This material was described above and is considered to belong to *A. lapworthi*. Since there is now evidence that *A. eivionicus*, as characterised here, is older than *A. lapworthi*, the possibility exists that the type specimens should in fact be placed in the former species. As this cannot be proved on the evidence of the specimens themselves the name is retained for material as diagnosed below, accepting that it may have a longer range than is currently proved.

Description of Bangor Material (Fig. 11.14)

Diagnosis Short basal free length of sicula, 0.1-0.2mm. Slight to moderate development of ventral lip of sicula

Material Abundant material collected from localities shown in Fig.4.1. B.M.: 05880-3, 05886, 05895; N.M.W.:
Preservation varying from flattened to slight relief. Distinct lineation present at University College Cliff.

Description

Fig. 11.14 Azygograptus eivionicus Elles from Bangor. (a-d x5, f & g x20) a, B.M.: Q5881; b, e, f, & g, B.M.: Q5880; c, B.M.: Q5883; d, B.M.: Q5882.

Stipe moderately flexed: maximum rotation seen: 65° in stipe 2.0cm; minimum: 33° in stipe 1.7mm. Variation is slightly greater in the University College Cliff fauna and probably reflects the greater deformation. Since this extends to the other parameters also the following description is based mainly on the Garth Point material. Variation for both localities is shown in Figs. 11.10, 11 & 15.

Siculc length: 1.13-1.62mm. Even allowing for deformation the values from University Cliff are slightly lower. A slab from this locality Q5886 is coated with abundant siculæ preserved in relief showing a prosicula 0.3mm long with 6-7 "bands" of the spiral visible. Stipe originates abruptly from the sicula 0.71-0.89 along its length and diverges at an angle of 120°-160°. Basal free length of the sicula short; typically 0.1-0.2mm, total range: 0.03-0.22mm. Development of ventral sicular lip is variable but is moderate in over 50% of the specimens (see Fig. 11.10). A couple of specimens also have a suggestion of a dorsal lip being developed but this is probably not typical.

Stipe width and thecal spacing vary significantly on any one stipe but both show a change over the first five thecae. Thecal spacing falls from as much as 2.5mm (4th/10mm) to the more typical value of 1.5-1.7mm (6-7th/10mm); stipe width increases from 0.4-0.6mm at the aperture of th.1 to
Fig. 11.15: Histograms of thecal count, maximum stipe width and stipe divergence angle for *Azygograptus*.
0.7–0.8mm in the more distal stipe. Thecal inclination low 8°–10°. Thecae fairly straight, conical with slight ventral concave curvature. Thecal overlap about 2/5ths. It is likely that the proximal variation results mainly from increasing overlap.

**Horizon:** Both localities occur in the flaggy beds at the top of the Maesgeirchen Sandstone Member as it passes up gradationally into the siltstones of the Nant Ffrancon Formation. The University College Cliff locality is slightly closer to the unconformity and therefore probably a little lower. The only potential independent biostratigraphic control is the trilobite fauna of the sandstones and this has been discussed (see Chap. 8)

**Population from the western Llyn**
(Fig. 11.16 Pl. 18 Figs. 3, 8 & 10; Pl. 19 Fig. 5.)

**Material**

**Description**

**Fig. 11.16:** *Azygograptus eivionicus* Elles from Maen Gwenonwy Member. (a–e x5, f–h x20). a, B.M.: Q5871; b, B.M.: Q5872; c, B.M.: Q5874; d, B.M.: Q5884; e, B.M.: Q5875; f, B.M.: Q5873; g, N.M.W.: 85.166.103.

Stipe flexure: 35°–48° in specimens 22mm in length. Maximum length seen 36mm without proximal end. Sicula length 1.04–1.44mm, origin of stipe 0.58–0.80 along sicula, diverging at angle of 110°–160°. Basal free length strongly unimodal: 0.1–0.2mm. Sicula aperture concave with minimal development of dorsal or ventral lip.
Stipe width increases from 0.4—0.5 mm at th.1 to 0.7 mm distally. Typically this occurs over the first five thecae but a couple of specimens show such a trend over the first ten thecae. Thecal spacing falls in a manner comparable to the Bangor material, and relief material clearly shows increased overlap to be a factor. Recalculated thecal count 6.4—8.0 th/10 mm. Thecal inclination 8°-10°. Prothecal folds variably developed but quite prominent in some specimens.

Discussion.

_A. eivionicus_ may be distinguished from other species as follows: from _A. lapworthi_ by the restricted basal free length of the sicula and less pronounced ventral lip on the sicular aperture; from _A. suecicus_ by the more prominent sicular lip and slightly thicker stipes with greater thecal overlap and from _A. hicksii_ by the much greater size of that species. However the presence of a transitional population between _A. eivionicus_ and _A. hicksii_ (Fortey & Owens in press) suggests a possible phyletic relationship between the two.

The material from the western Llŷn differs from the Bangor population in having a much less well developed ventral process on the sicula and a slightly higher thecal count. The former may be a means of recognising what is probably an earlier form. Material from the lower part of the middle Arenig of South Wales (Fortey & Owens in press) is comparable in all features except that the ventral lip of the sicula turns more strongly away from the line of the ventral wall of the sicula. This feature is taken to the extreme in _A. hicksii_ Hopkinson (see Fig.11.10). The presence of prothecal folds raises questions as to the validity of the distinction of _A. undulatus_ Chen & Xia on this feature.

_A. eivionicus_ has not been recognised from the Lake District.

_Azygograptus cf suecicus_ Moberg

Fig.11.17

cf 1892 _Azygograptus suecicus_ sp.nov.; Moberg pp.342-3 Pl.8 figs 1-2.

cf 1904 _Azygograptus suecicus_ Moberg ; Törnquist pp.26-7 Pl.IV Figs. 6-11.

1937 _Azygograptus cf suecicus_ Moberg ; Monsen pp204-5
Discussion

No revision of this species is attempted since topotype material has not been examined and the following discussion is based on measurements taken of a population from Slemmestad, Nr. Oslo (Zone 3b). On the basis of this *A. suecicus* may be distinguished from other species by the absence of a ventral sicula lip; the greater length of the sicula and the much more slender and straight stipe. There is some suggestion that th.1 originates slightly higher on the sicula than its point of divergence and grows adpressed to the sicula for a short distance (Fig.11.17a,b). In most features there is a close comparison with the description of topotype material by Törnquist (1904) but he gave the sicular length as only 1.5mm and showed th.1 as diverging from the sicula immediately at its origin. Hence there is some doubt that this material is exactly con-specific with true *A. suecicus*.

*A. suecicus* has been the most widely recognised species of the genus. eg. China (Lee 1961, Mu et al 1979); Bohemia (Bouček 1973); U.S.S.R. (Obut & Sennikov 1984) and Great Britain (Elles & Wood 1902). However, in some cases, the identifications are questionable. The most similar material from the British Isles is from Barf and is described below. The presence of a ventral lip on the sicula of the specimen figured by Mu et al (1979 Pl.38 Fig.2) almost certainly excludes it from this species, and suggests it belongs to *A. eivionicus*. However this feature is rarely apparent in figures. A similar sicular length to the Oslo material is,
however, quoted for the Bohemian specimens (Bouček 1973 p107–8, Kraft 1977 p22).

*Azvyograpthus aff suecicus* Moberg

Fig. 11.18

1898 *Azvyograpthus suecicus* Moberg; Elles pp.514–5 Fig.29

1902 *Azvyograpthus suecicus* Moberg; Elles & Wood pp. 95–6, Text Fig 56, P13 figs 3a–b

Material


Description.

Fig.11.18 *Azvyograpthus aff. suecicus* Moberg from Barf, Lake District. (a & b x5, c & d x20.) a, B.M.: P7216; b, B.M.: H948; c & d, B.M.: P2010.

Sicula 1.2–1.5mm long with simple concave aperture and no significant ventral lip. Stipe originates about 0.6 along sicula and grows adpressed for 0.3–0.5mm before diverging at an angle of 118°–148°, leaving a basal free length of 0.20–0.25mm. The stipe is gently flexed and somewhat more delicate than in *A. eivionicus* with a characteristic width of 0.6mm and a thecal count of 7.2–9.2 th/10mm, the range of this probably being somewhat extended by deformation. Thecal overlap just less than 1/2. Thecal inclination, 5°–10°. Thecae slightly expanded at aperture giving concave ventral margin.

Discussion:

The simple sicular aperture, and adpressed growth of th. 1 compare closely with *A. cf suecicus* though the latter feature is more obvious than in that material. The clearness with which the higher origin of th.1 is visible in a number of specimens tends to confirm the absence of this in the material, other than *A. cf suecicus*, described above, and
serves as a distinguishing feature.

The Barf specimens differ from the Slemmestad material in having a much shorter sicula, but as noted the length quoted for topotype material of *A. suecicus* is only 1.5mm. However, there is no evidence for the adpressed growth of th.1 in those specimens (Törnquist 1904) and the stipes are less flexed and slightly narrower.

Genus *Pseudotrigonograptus* Mu & Lee 1958

Type Species: *Graptolithus ensiformis* Hall 1865

*Pseudotrigonograptus minor* (Mu & Lee 1958)

Fig.11.19; Pl.18 Fig.9

Synonymy: see Cooper & Fortey 1982 p.250

Material:

B.M.: Q5859 from Benallt Mine; N.M.W.: 85.166.1 from Nant yr Olchfa (Loc. B Fig.2.6). Both specimens preserved as impressions with slight relief. Age: upper Arenig.

Description and Discussion

![Fig.11.19 Pseudotrigonograptus minor (Mu & Lee) (x5) a. B.M.: Q5859 from Benallt Mine; b. N.M.W.: 85.166.1 from Nant yr Olchfa.](image)

Both specimens are preserved in the typical flattened appearance of the species (cf. Fortey 1971). They are assigned to the above species on the basis of the narrow rhabdosome (1.5 & 1.8mm) and the thecal counts, 13 & 17 th/10mm, compare favourably with the 14-12 th/10mm given in the original description (Mu & Lee 1958 p.46). The thecal count of *P. ensiformis* (Hall) is lower 10-11 th/10mm (Cooper & Fortey 1982 p248). Cooper & Fortey employ *P. minor* as the name for the triserial form (cf Fortey 1971) but there is no evidence available on the number of stipes in the North Wales specimens.
Subfamily ISOGRAPTINAE Harris 1933

In a recent review of this group in England and Wales (Jenkins 1982), three species; Pseudisogruptus angel Jenkins, P. menaiensis Jenkins and P. spp B were recorded from North Wales, the first two from the Menai Straits Inlier and the last from the upper Arenig of Nant y Gadwen. Isogruptids are of particular stratigraphic importance, and new material, meriting description, has been found during this study, as well as the group being recorded from two more localities, the Seiont river section, Caernarfon, and the foreshore at Bangor. Three species of isogruptid have now been recognised from Nant y Gadwen. The specimens from the Bangor Foreshore (Fig.11.20) are too poor to warrant description and may only tentatively be placed in Pseudisogruptus.

![Fig.11.20. Pseudisogruptus from boundary section of Bangor Foreshore. (x5)](image)

Genus ISOGRAPTUS Moberg, 1892

**Type Species:** Didymograptus gibberulus Nicholson 1875.

*Isograptus caduceus gibberulus* (Nicholson)

Fig.11.21; Pl.19 Figs. 6 & 7.

**Synonymy:** See Jenkins (1982 pp.224 &226)

**Material:** B.G.S.: AW 25i & ii; B.M.: 05746 from upper Arenig of Nant y Gadwen. All preserved as flattened periderm and possibly slightly deformed.

**Description**

**Table 11.1. Parameters of I.c.gibberulus.** (Type measurements taken from Jenkins 1982.)

<table>
<thead>
<tr>
<th></th>
<th>AW 24(i)</th>
<th>AW 24(ii)</th>
<th>Q 5746</th>
<th>I.c.gibberulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sicular Length (mm)</td>
<td>3.3</td>
<td>3.5</td>
<td>2.8</td>
<td>3.5</td>
</tr>
<tr>
<td>Proximal free length of sicula (mm)</td>
<td>0.9</td>
<td>1.2</td>
<td>0.8</td>
<td>1.25</td>
</tr>
<tr>
<td>Depth of notch between sicula &amp; th 1st (mm)</td>
<td>0.9</td>
<td>0.5</td>
<td>1.0</td>
<td>0.4-0.5</td>
</tr>
<tr>
<td>No. of Pendent thecae</td>
<td>8</td>
<td>9</td>
<td>9/10</td>
<td>6-9</td>
</tr>
<tr>
<td>Angle between stipes</td>
<td>20°</td>
<td>21°</td>
<td>53°</td>
<td>30°-50°</td>
</tr>
<tr>
<td>Stipe length (mm)</td>
<td>18.2</td>
<td>15.5</td>
<td>---</td>
<td>30</td>
</tr>
<tr>
<td>Thecae / 10mm</td>
<td>12.2-14.3</td>
<td>11.7-14.5</td>
<td>---</td>
<td>9.5-13.5</td>
</tr>
<tr>
<td>Thecal inclination</td>
<td>---</td>
<td>25°</td>
<td>---</td>
<td>25°-35°</td>
</tr>
</tbody>
</table>
Stipe Width: see stipe expansion diagrams (Fig. 11.22)

Though there might be a slight proximal asymmetry in the shoulder of the stipes, with that on the side of th.1¹ being slightly depressed, this has probably been exaggerated by a mild deformation, despite the absence of any lineation. This would also account for the asymmetry in the stipe expansion diagrams, though the values still fall within the quoted range of *I.c.gibberulus* (Jenkins 1982 p226).

![Stipe Diagram](image)

Fig. 11.21: *Isograpthus caduceus gibberulus* (Nicholson) from Nant y Gadwen. (x5). a, B.M.: Q5700; b, B.G.S.: AW24ii; c; B.G.S.: AW24i; d, B.M.: Q5746.

A couple of details of the proximal development are apparent from Q5746, there being clear evidence for the origin of th.1¹ very high on the sicula, and for a small web of periderm partially infilling the notch between the sicula and th.1¹. (see Fig. 11.21d).

**Discussion.**

The material closely resembles *I.c.gibberulus* as redescribed by Jenkins (1982 pp 226-8). The above specimens are easily distinguished from *P.menaiensis* Jenkins (1982 pp234-8), by the stipes diverging distally rather than converging as in that species.

The above material is insufficient to warrant any comment on the placement of *gibberulus* as a subspecies of *I.caduceus*. 
Fig. 11.22: Stipe expansion curves for *I.c.gibberulus*. Two stipes plotted separately.

Genus *PSEUDISOGRAPTUS* Beavis, 1972

**Type Species:** *Didymograptus caduceus var. manubriatus* T.S.Hall 1914

*Pseudisograptus angel* Jenkins

Fig. 11.23, Pl. 19 Figs. 2, 9, 10 & 11.

**Synonymy:** see Jenkins 1982 p238

**Material**

N.M.W. 27110 G 237-9; B.M.: Q5747 from upper Arenig of Nant y Gadwen. None are complete and most appear immature. However the pyritised preservation allows fairly detailed description of the proximal development.

**Description.**

The supradorsal portion of the sicula is only preserved in one specimen (Fig.11.23c), which indicates a minimum length of 2.9mm for the sicula which is incomplete. The initial stipe width of 2.0mm is the maximum seen with the stipes narrowing gradually proximal to the shoulders but dramatically across the bend. The shoulders of the stipes are horizontal and have an internal width (between dorsal margins) of 2.2mm. The stipes turn sharply through 90° across the shoulders and the stipes are parallel to slightly convergent distal to them.

**Proximal development:** The height of the origin of th.1 on the sicula is not preserved but is presumably high. The
ventral wall of th.1\textsuperscript{1} slightly overlaps that of the sicula on the reverse side, the two diverging distally at an angle of 20° to 44° leaving a notch between 0.8–1.0mm in depth. Th.1\textsuperscript{2} originates about 0.5mm down th.1\textsuperscript{1} but the origin of th.2\textsuperscript{1} is not preserved. Thecae 1\textsuperscript{2} and 2\textsuperscript{1} grow down over the reverse sides of the sicula and th.1\textsuperscript{1} respectively, diverging fractionally proximal to the earlier pair at an angle of 78°–93°. The change of growth direction in both pairs is marked by a geniculation, but the subsequent thecae are added laterally following the line with a more gradual curvature. 10 pendent thecae are present.

Discussion.

The specimens are identical to the type material of P.\textit{angel} (Jenkins 1982 p238–9 Pl.16 fig 4). Preparation of the small specimen he referred to \textit{Pseudisograptus} n. sp B (p. 240 Fig 5D) has revealed a significant proximal free length of the sicula and th.1\textsuperscript{1} 0.5mm in height. Though not well preserved the curvature of the thecae suggests a development comparable to that described above rather than \textit{P. cf dumosus} (see below). It is therefore suggested that this specimen is best placed within \textit{P.angel} until such time as new material confirms a distinct identity.

\textit{Pseudisograptus cf dumosus} (Harris) 1933

Fig.11.24; Pl.19 Figs.1,3 & 4.

Synonomy.

See Cooper 1979 p77

1981 \textit{Arienigraptus jiangxiensis} Yu & Fang pp 29–30, Fig.3; Pl.1 Figs 1–2
Material.
H480 & Q5748 from Nant y Gadwen. The former is preserved as an incomplete impression but the latter is preserved in relatively high relief, though there is a dorsal-ventral fracture in the proximal region displacing the two stipes relative to each other. When the rock was originally split the two halves of the specimen separated along the fracture. To obtain a complete view of one side, (the obverse) the powdery material preserving the specimen was dug out and a latex taken of the external mould.

Description.

The dimensions of both specimens are almost identical. The rhabdosome is about 4.0mm wide and 3.3mm in height. In both specimens the entire height is occupied by the sicula which has a proximal free portion 0.7-0.9mm in length. The ventral curvature of the rhabdosome is elliptical, narrowing in width steadily towards the portion of stipe distal to the shoulder, which may be as little as 0.7mm in width though is poorly preserved in both specimens. The shoulders are undulose and asymmetrically declined, but do not deviate significantly from the horizontal. The stipes turn through almost 90° at the shoulders and the distance between the ventral walls across the shoulders is 1.7-1.8mm.

The development appears to be comparable to that of *P.angel* in that thecae 1² & 2¹ rest on the sicula and th.1¹. In both specimens there is a suggestion of differing curvature of thecae in the two stipes but since this is correlated with the asymmetry of the shoulder it may reflect a slight deformation. Three to four thecae lateral to the two initial superposed pairs have a proximal pendent growth before turning through a sharp angle that increases towards
the shoulders but averages about 90°.

**Discussion.**

These specimens differ from those of *P.angel* in being smaller and the proximal thecae showing greater curvature lateral to the th.1₂ and th.2¹ pair rather than less. The rhabdosome shape compares closely with *P.dumosus*, the dimensions being almost identical to the form A recognised by Cooper (1973 p78-82 Text fig 18 k-n,p.) from the upper Ca3 zone of New Zealand. The most significant difference is the much more declined attitude of the shoulders in the New Zealand specimens.

The two species described under the generic name *Arienigraptus* Yu & Fang 1981 are probably different growth stages of a single species. The dimensions of this are comparable to those described above, and the disposition of the thecae are the same, though the interpretative illustration of the proximal development (Fig.1c) shows th.1₂ originating proximal to th.2¹ on a dicalycal th.1₂. This is unlike isograptid development but may not be an accurate interpretation. Considering the obscurity of this feature in most specimens it is not considered to preclude the suggested synonymy. Of possibly greater significance in this context is the virtual absence of a proximal free portion to the sicula and the horizontal attitude of the shoulders, but in the absence of such differences being shown to hold throughout a population, a new name is not valid and a subspecific separation is probably all that could be justified.

*Pseudisograptus manubriatus* (T.S.Hall) subsp.1

**Material:**

B.M.: Q5749 from Afon Seiont, Caernarfon. The manubrium and proximal free portions of the sicula and th.1¹ are preserved in relief, though the latter are now only present as external moulds. The apertural parts of the thecae are preserved in falttened periderm.

**Description**

The manubrium is extremely prominent, wedge shaped, 2.0mm in length, 1.9mm wide and with a manubrial angle of 33° (parameters are those of Cooper 1973). Including the spinose appertural processes (see Fig.11.25), the sicula is
5.6mm in length with a proximal free portion of 1.2mm. Th.1 originates approximately at the mid-point of this and there is some suggestion that the sicula proximal to the origin is the prosicula (0.6mm long). A short nema, 0.4mm long, is present.

**Fig.11.25:**
*Pseudisogruptus manubriatus* (T.S.Hall) subsp 1
from Afon Seiont, Caernarfon (x25)
(B.M.: Q5749)
a: interpretative drawing.

The proximal development is not easily inferred from this specimen but may readily be interpreted by analogy with material preserved in relief from the Ningkuo shale of China (Cooper & Ni in press). An interpretation of the proximal development is shown in Fig.11.25a with the crumpled appearance of the manubrium resulting from the presence of prothecal folds.

**Discussion**

Cooper & Ni (in press) have reviewed the manubriate isograptids and recognise a number of sub-species of *P. manubriatus*. They consider the proximal development described by Bulman (1968) from a Texan specimen to be different from the Australian types, but the new Chinese material they describe is thought to be comparable to the
types and indicates a more symmetrical proximal development. The North Wales specimen is very similar to the Chinese material apart from being a little smaller.

Subfamily: SIGMAGRAPTINAE Cooper & Fortey, 1982
Genus: BRACHIogrAPTUS Harris & Keble, 1932
Type Species: Brachiograptus etiformis Harris & Keble 1932

Discussion:

The generic assignment of the following material is questionable in that none of the specimens show sufficient branching for there to be certainty as to the form of the mature rhabdosome. Taking the most complete specimen (Q5869 Fig.11.26f) a branching pattern can be inferred that produces 12 "lateral stipes": 4 third order and 8 fourth order. This is exactly the morphology proposed by Bulman (1931 p.26 Text Fig.6c) for the material he termed Loganograptus longi var. boliviensis and which Harris & Keble (1932) implied belonged to their new genus Brachiograptus. On this basis the following material is also included in that genus.

Brachiograptus cf. etiformis Harris & Keble

Fig.11.26

Material


Description:

A maximum of 10 stipes has been recognised in a single specimen (Q5869) and a minimum of 12 are inferred. Stipes undergoing dichotomy are one theca in length and are 1.3-1.4mm long. A strong lineation makes the angular
relationships of the stipes unreliable.

Siculic length is c.1mm, measured values being 0.9mm at
45° to the lineation and 1.3mm parallel to it. Thecae are
rarely visible but a short section (Fig.11.26f) indicates
8-9 th/10mm and a stipe width of 0.7mm for the forth order
stipes and the latter is comparable with that measured
proximally on Q5866 (Fig.11.26a). Thecae elongate with
slight ventral concave curvature and very small overlap.

Discussion:

The specimen from Benallt Mine appears slightly smaller
and the first and second order stipes are only 1.1mm in
length. Though there are no fourth order stipes apparent, it
is thought likely that this specimen belongs to
Brachiothegraptus and is retained in the above species because
the preservation is inadequate to confirm or refute
equivalence.

In the absence of any well preserved fourth order
stipes exact comparison with B. etaformis is not possible, but
many of the measurable stipe characters as listed in the
original description and by Berry (1966) are comparable.
However, the features of the South American form (Bulman
1931) which has the same inferred branching pattern are less
similar, especially the very short (0.5mm) sicula length and
narrower stipes.

Family PHYLLOGRAPTIDAE Lapworth, 1873
Genus XIPHOGRAPTUS Cooper & Fortey 1982

Type Species: Didymograptus formosus Bulman 1936

Xiphothegraptus aff delicatus (Braithwaite)
Fig.11.27; Fig.11.28; Pl.18 Figs.2 & 4.

aff. 1976 Didymograptus delicatus sp nov.: Braithwaite

Material.

BGS: Z4181; B.M.: Q5723, Q5725-7, Q5736-7, H493 from
Dwyrhos Quarry, Aberdaron. All flattened and deformed. Age:
middle Arenig.

Description.

The deformation is readily apparent from Fig.11.27, though
only thecal spacing appears to correlate significantly with the lineation, this giving the strain
ellipse shown. All specimens are short, the longest being
2.3cm with a maximum of 16 thecae being seen on a stipe. The
stipes are thin, this being somewhat exaggerated by many
specimens lying parallel to the lineation, these forms also appearing straighter than those lying at an angle to the lineation, which show some flexure. Thecal count, as measured, ranges from 13.3 - 23.0 th/10mm, though on the basis of the strain ellipse, 18 th/10mm can be suggested as the true value. Measured proximal stipe width varies from .45 to .55mm, distal width .75 to .95mm and undeformed the maximum was probably only about 1mm. Thecal inclination does show variation that can be correlated with the deformation, the total observed range being 25° - 52°, with c.40° being a likely original value. The thecae seem to be simple, with an overlap of c.1/2 and an apertural angle just less than 90°.

![Fig. 11.27: Radial plot of thecal count along angle to lineation for Xiphograptus aff. delicatus (Braithwaite) (x2.5) a: N.M.W.: 05.166.125; b, B.M.: 05725; c, B.M.: 05726; d, B.M.: 05737; e, B.M.: 05736; f, B.M.: 05723; g, B.M.: H493](image)

Sicular length as measured ranges from .93mm to 1.08mm, an original value of about 1mm being likely. On two specimens a virgella can be seen, (05725 & 05727) (Fig.11.28) the longer one being about .4mm. Both the specimens showing this feature are at an angle to the lineation and this may be significant in its preservation though the only nema seen (0.8mm long on 05723) is on a specimen almost parallel to the lineation. Specimen 05724 is the easiest on which to interpret the proximal development. Th.1 appears to originate approximately a fifth of the way down the sicula, grows down beside it as quite a broad
development turning away more sharply distally, leaving .13mm of the dosal siculic wall free. The aperture of the sicula is turned in the opposite direction, ie towards the virgella which is the only expression of the ventral part of the sicula aperture.

Fig.11.28: Proximal ends of X. aff. delicatus showing virgella. (x20)
a, B.M.: 05725
b, B.M.: 05727

Discussion.

Some comparison can be made with the thinner forms of the genus already recognised (Cooper & Fortey 1982) especially in the manner of the proximal development. However the proportion of the dorsal siculic wall left free may be significant, being somewhat greater in X.elongatus (Harris & Thomas) (Cooper & Fortey 1982 p289-291 Fig 83) which is the only species described from rocks older than upper Arenig. However the major difference from the previously described forms is in the thecal count which is comparable only in X. delicatus (Braithwaite) from the Llanvirn of Utah, with 16 th/10mm in distal parts of the stipe. This species is somewhat thinner, though it may be noted that it is characteristically short and shows similar variation in stipe curvature.

Suborder GLOSSOGRAPTINA Jaanusson, 1960
Family CRYPTOGRAPTIDAE Hadding 1915
Genus CRYPTOGRAPTUS Lapworth
Type Species: Diplograptus tricornis Carruthers 1859
Cryptograptus tricornis schaeferi Lapworth
Fig.11.29

Synonymy: see Skevington 1970 p.418

Material:
NMW: 85.166.2 & 3 from Nant yr Olchfa (Loc.B. Fig.2.6)
N.M.W.: 85.166.4 from Porth Meudwy. 85.166.2 partially pyritised with some relief. Age: upper Arenig (?basal Llanvirn).
Description and Discussion.

Fig.11.29 Cryptogaptus tricornis schaeferi Lapworth. (x2.5)
detail of proximal ends (x5)
a-c: from Nant yr Olchfa. a & b: N.M.W.: 85.16G.2a,b; c, N.M.W.: 85.16G.3.
d & e from Porth Meudwy, 85.16G.4a,b

The Nant yr Olchfa specimens are broad (2.05 & 2.9mm) and are preserved in lateral to slightly oblique view, though the proximal part of 85.16G.2 is preserved in scalariform view. The Porth Meudwy specimen is preserved entirely in scalariform view and is only 1.5mm in width. Skevington (1970) only quotes widths for the scalariform view; 1.2-2.2mm. Thecal form is not clear but appears to compare more closely with C. t. schaeferi than C. t. tricornis since the supragenicular wall is clearly not parallel to the long axis. Thecal count in proximal region (17 & 13.6 th/10mm) compares with the 13-15th in the first 10mm given by Skevington.

The proximal spines are much more prominent in 85.16G.2, 2.25mm in length, than in the Porth Meudwy specimen where they are only 0.95mm long. In both cases there are two elongate pendent spines with a shorter more triangular one between. In both the above specimens a virgula is also present. That of 85.16G.4 is very delicate whilst that of 85.16G.2 is broad comparing with the expanded examples noted by Skevington.

Suborder DIPLOGRAPTINA Lapworth, 1880
Family DIPLOGRAPTIDAE Lapworth, 1873
Genus GLYPTOGRAPTUS Lapworth

Type Species: Diplograptus tamariscus Nicholson 1868

Glyptogaptus australodontatis s.l. Harris and Keble

Fig.11.30
Material:

B.G.S. Z4383 from Benallt Mine, Rhiw; exact locality unknown. N.M.W.: 85.166.5 from the sandy beds of the Tramway section, Afon Seiont.

Discussion:

Fig. 11.29 Glyptograptus austrodentatus s.l. Harris & Keble. (x2.5)

a, N.M.W.: 85.166.5 from tramway section, Afon Seiont.
b; B.G.S.: Z4183/4 from Benallt mine.

The above two specimens are the only ones found in which a proximal end is preserved. The blunt nature of this is adequate to indicate placement in the G. austrodentatus group but deformation precludes recognition of the subspecies described by Bulman (1963).

Genus PSEUDOClimacograptus Pribyl
Type Species: Climacograptus scharenbergi Lapworth 1876

Pseudoclimacograptus sp. indet

Fig. 11.31


Discussion:

Specimen not well preserved and is a distal fragment only, but the thecal form and suggestion of zig-zag median septum tend to indicate placement in the above genus.

Fig. 11.31: Pseudoclimacograptus sp (x2.5)
Plate 18

Fig. 1 & 6 Azygograptus lapworthi Nicholson.
Fig.1: S.M.: A55166a x20, Castellmarch Farm. Abersoch.
Fig.6: B.M.: Q5878 x10, Sarn Formation (upper Arenig), Bryncroes. Synrhabdosome.

Fig. 2 & 4 Xiphograptus aff. delicatus (Braithwaite) Aberdaron Formation (middle Arenig), Dwyrhos Farm, Aberdaron.
Fig.2: B.M.: Q5736 x2.5
Fig.4: B.M.: Q5725 x20

Fig. 3, 7, 8 & 10 Azygograptus eivionicus Elles
Fig.3 B.M.: Q5876 x20. Maen Gwenonwy Member, Wig Formation (lower Arenig), Clip y Gylfinhir, Rhiw.
Fig.7: A17372a x2.5, Llanengan Mudstones, Nant Valley, St. Tudwal's. Type slab.
Fig.8: B.M.: Q5885 x1, Maen Gwenonwy Member, Wig Formation. Maen Gwenonwy.
Fig.10 S.M.: A22601 x5. As for Fig.3.

Fig.5 Pseudophyllograptus aungustifolius aff regularis Monsen
B.G.S.: A17372a x2.5. Aberdaron Formation, (uppermost middle Arenig), Parwyd Bay.

Fig.9 Pseudotrigirnigraptus minor (Mu & Lee)
B.M.: Q5859 x15, from Carw Tuff Formation, Benallt Mine.; upper Arenig.
Plate 19

Fig. 1, 3 & 4 *Pseudisograptus cf. dumosus* (Harris
Carw Tuff Formation, (upper Arenig), Nant y Gadwen.
Fig.1: B.M.: Q5748 x10. (latex)
Fig.3: B.M.: H480 x5
Fig.4: B.M.: Q5748 x5

Fig. 2, 9, 10 & 11 *Pseudisograptus angel* Jenkins
Carw Tuff Formation, (upper Arenig), Nant y Gadwen.
Fig.2: B.M.: Q5747b x10
Fig.9: N.M.W.: 27.1106.328 x15
Fig.10: N.M.W.: 27.1106.329 x15
Fig.11: N.M.W.: 27.110g.327 x10

Fig. 5 *Azygograptus eivionicus* Elles.
B.M.: Q5897 x10. Maen Gwenonwy Member, Wig Formation
(lower Arenig). Clip y Gylfinhir, Rhiw. First theca known
to be th.1 as sicula originally present.

Fig. 6 & 7 *Isograptus caduceus gibberulus* (Nicholson)
Carw Tuff Formation, (upper Arenig), Nant y Gadwen.
Fig.6: B.G.S.: AW24ii x2.5
Fig.7: B.G.S.: AW24i x2.5

Fig.8 *Pseudisograptus manubriatus* (Hall) subsp. 1
B.M.: Q5749 x20, Nant Ffrancon Formation, (upper Arenig),
Afon Seiont.
CHAPTER 12: Arenig Trilobites of North Wales.

Trilobites are in general less abundant and diverse than in South Wales, and the majority of the species are the same. However some species have been found during this study that have not been recorded in South Wales though the majority are known from single specimens only. Where the material is adequate these species are described, whilst in other cases generic identification is given along with figures.

Dr. R. M. Owens has examined the trinucleids, other than Hanchungolithus primitivus, and though similar to species known from South Wales (Fortey & Owens in press), none are conspecific, with the possible exception of Bergasia gibbsii (Salter) from Parwyd Bay, though no well preserved fringes are available of this species. Since the descriptions of the South Welsh species are not yet published only H. primitivus is described.

The lower Arenig fauna of the Henllan Ash Member was described by Whittington (1966) and does not require redescription. The fauna of the Maen Gwenonwy Siltstone Member of the western Llŷn is dominated by Merlinia selwynii (Salter), a species most recently revised by Fortey & Owens (1978), but rare trinucleids are also present including Hanchungolithus primitivus (Born) (described).

The endemicity of the Bangor Bypass fauna leaves its age in some doubt, as discussed above, but it is most likely near the lower-middle Arenig boundary. This fauna is described in detail.

A diverse trilobite assemblage of middle Arenig age is known from two localities: Dwyrhos quarry and the east side of Nant y Gadwen, both in the Aberdaron area. The most abundant species is Cyclopyge grandis grandis (Salter), which along with, Shumardia sp. nov., Ampyx salteri Hicks, Segmentagnostus hirundo (Hicks) and Bohemopyge scutatrix (Salter) are confined to the middle Arenig of South Wales (Fortey in Whittington et al 1984). In addition a number of genera are present in North Wales which are not found in South Wales until the upper Arenig: Psilacella sp. (described), Ellisaspis aff. elliptica Rasetti (described), Girvanopyge sp. (Pl.22 Fig.11), Bohemilla sp. (Pl.22
Fig. 10), *Ellipsotaphrus* sp. (Pl.22 Fig.8), *Leioshumardia* sp (Pl.20 Fig.14) and an indeterminate asaphid with a pygidium similar to *Bohemopyge scutatrix* but lacking interpleural furrows (Pl.22 Fig.9).

Trilobites of upper Arenig age have been recorded from a number of localities: the Bangor Foreshore, Benallt Mine, and the Menai Straits inlier. These are recorded in the appropriate faunal lists. In the Arenig area juvenile specimens of *Pricyclopyge* and a nileid have been found in Nant yr Olchfa along with indeterminable fragments of an asaphid; *Neseuretus* sp. has been found in the Serw Section. The two main localities for upper Arenig trilobites are Nant y Gadwen in the western Llyn and Afon Seiont, Caernarfon. The latter is dominated by *Pricyclopyge binodosa* subsp. nov (Fortey 1985) with other species mostly being represented by single specimens, the most significant of which is the earliest record of *Eoharpes* (described). The full fauna is given in chapter 4.

By contrast the fauna from Nant y Gadwen is more diverse and with a more uniform abundance of species. A number of cyclopygids are present: *Microparia broeggeri* (Holub), *Microparia* sp. nov. (known from South Wales), *Degasnella* sp. (Pl.22 Fig.5) and cyclopygid indet (Pl.20 Fig.9). Other elements include: a trinucleid, *Shumardia* sp. nov. (known from South Wales), ?*Megalaspidella* sp. (described), *Ectillaenus* sp. (Pl.22 Fig.14), *Ellsaspis* sp. A (described), agnostid indet, niobine asaphid (Pl.22 Fig.13), to which species an indeterminate pygidium may belong (Pl.22 Fig.14), and an indeterminate specimen with a terminal pygidial spine (described).

**Systematic descriptions.**

Terminology follows that of the *Treatise on Invertebrate Palaeontology, Part 0, Arthropoda 1* (Harrington, Moore, & Stubblefield, in Moore 1959). Glabella is usually understood to include the occipital ring. Systematic order is by family as they appear in the Treatise.

**Family LEIOSTEGETIIDAe Bradley, 1925**

**Genus ANNAMITELLA** Mansuy, 1920

**Type Species:** *Annamitella asiatica* Mansuy, 1920

**Discussion.**

In the recent review of this genus by Fortey &
Shergold (1984 p323) a number of genera were considered to be junior synonyms, including Monella, the type species of which is A. perplexa (Bates 1968) from Anglesey. However it was suggested that Monella might be a junior synonym to a possibly separate genus Proetiella Harrington & Leanza 1957 (Fig 59; 3-7) based on the presence of a 3P glabellar furrow.

The material described below is similar to A. perplexa in having a flat pygidial border and anterior cranidial border that is not incorporated into the glabella. Neither of these characters is shared by Proetiella and therefore this grouping does not seem valid. A. guizhousensis Yin 1978 (Pl.183 Figs.4-7) shares the cranidial characters of A. perplexa in having a 3P furrow and separate anterior border, but has a pygidium typical of other members of Annamitella. Therefore if Monella is to be recognised as a separate genus, the distinguishing characters must be those of the pygidium (flat border and less prominent development of axial rings and pleural furrows), though for the time being the two North Wales species are retained in Annamitella.

Annamitella sp. A sp. nov.

Fig.12.1 b, Pl.20 Figs.1-8

Diagnosis: Effaced species of Annamitella with no evidence of lateral glabellar furrows. Suggestion of anterior border present. Pygidium with fairly broad, flat, sloping border.

Type Locality: Cutting on Bangor Bypass (A5) about 100m E. of the flyover at Caerhûn (SH 575692)


Age & Occurrence. Known only from its type locality. Maesgeirchen Sandstone Member; Arenig age, though position within series uncertain; possibly close to lower-middle boundary.

Description.

Cranidium: Dominated by rectangular glabella defined by broad, deep axial furrows that are subparallel posteriorly but diverge anteriorly giving glabellar sides a concave form. Transverse profile moderately convex, glabella standing well above fixed cheeks which are at approximately
half the total height of cranidium. Sagittal profile also convex, with glabella curving steadily down from its highest point immediately anterior to the occipital furrow.

Fig.12.1  a: Annamitella perplexa (Bates), (with free cheek replaced); b: Annamitella sp. A (both circa x3)

Occipital furrow, broad and slightly concave posteriorly causing axial widening of the occipital ring. On the exterior of exoskeleton this furrow would probably be narrower, and more sharply defined (cf. Fortey & Shergold 1984 Pl.38 Figs.3 & 5). This is probably also true of the axial furrows.

Apart from the prominent occipital furrow and slight evidence of an anterior border, glabella is totally effaced with no indication of any lateral glabellar furrows.

Fixed cheeks dominated by elongate sub-parallel sided inflated lobes about quarter the width of the glabella, but expanding inside the palpebral lobe to about 0.45x the width of the glabella. In addition there is some suggestion of depressed areas both anterior and posterior to this major ridge on the fixed cheeks, but the form of these is not clear.

Palpebral lobes prominent: slightly below level of fixed cheeks from which they are separated by shallow furrow; slightly curved and about a third of the width of the expanded cheek adaxial to them and about a third the total length of the cranidium, extending from 0.26 – 0.58 of cranial length (sag.).

Pygidium: Semi-circular to slightly triangular in outline with prominent, slightly tapering, subparallel sided axis with well rounded terminal axial piece. Axial furrows poorly developed, axis standing well above pleural fields
and is approximately semi-circular in transverse section. Articulating half ring not clear on any of the specimens. Only three to four axial rings and pleural ribs developed, first axial ring being much more obvious than others.

Moderately wide border (approx 1/4 length of axis) present that slopes fairly steeply but is flat, and of even width throughout: axis extends a short distance onto it. Double ring corresponds in position to the border and is quite strongly concave on dorsal surface.

Discussion:

As noted in discussion of the genus, this species may be separated from all other members of the genus and grouped with *A. perplexa* (Bates) on the basis of the broad, flat pygidial border. It may easily be distinguished from *A. perplexa* by its effaced cranidium, a character also not seen in any other members of the genus.

Family ASAPHIDAE Burmeister, 1843
Subfamily ISOTELINAE Angelin, 1854
Genus *MEGALASPIDELLA* Kobayashi, 1937.

*Type Species:* *Megalaspidella kayseri* Kobayashi, 1937

*Megalaspidella cf graffi* (Thoral)

Fig. 12.2; Pl.21 Figs.1-16.

cf. 1946 *Plesio* *megalaspis graffi* sp. nov.; Thoral pp61-68;
Pl.VI figs.1 & 2; Pl.VIII fig.1; Pl.IX fig.1;
Pl.X; Pl.XI fig.3; Pl.XII; Pl.XIII fig.1; Pl.XIV fig.1a-b; Pl.XV fig.4; Pl.XVI fig.4.

*Diagnosis:*

Preocular sutures slightly divergent and eye placed well back in posterior half of cranidium. Glabella inflated, but has gently sloping margins. Pygidella semi-circular, flattened postaxially. Pygidium effaced with only 2-3 axial rings and pleural furrows developed.

*Material:* All following B.M. numbers prefixed by IT198 eg. IT19821


Additional material: N.M.W.: 85.166.34-43, & 85.166.46

*Locality, Age etc.* As for *Annamitella* sp. A

*Description:*

Species attained moderate size the largest cranidium
being 23mm wide anteriorly, allowing an estimate of cranidial length of c.34mm, whilst largest free cheek suggests a cranidial length of over 40mm. Largest pygidium is 45mm wide anteriorly.

**Fig. 12.2**: *Megalaspidella cf. graffi* (Thoral). (c.x1) a: cranidium with free cheek replaced; b: free cheek in plan view. c: hypostome; d: pygidium.

Cranidium: Preocular sutures slightly divergent (range 49° to 22° enclosed angle), those of the larger cranidia more nearly parallel. Anterior of the cranidium is pointed, the anterior sutures enclosing an angle of 132° to 145°. Anterior sutures are intramarginal as confirmed by the free cheeks (see below).

On only one specimen, 2cm in length, can the position of the eye be seen clearly and is placed well back in the posterior half, the palpebral lobe extending from .23 to .40 along the sagittal length of the cranidium. Though not easy to judge exactly from the free cheeks it appears that even in the larger cranidia the length posterior to the eye would still be less than 1.5 times the length of the palpebral lobe. In the largest specimen the post-palpebral length appears to be 1.35x the length of the palpebral lobe. Palpebral lobe semi-circular in outline and is only just below the maximum elevation of the glabella.

Glabella effaced, slopes gently down on all sides with
no development of distinct axial or preglabellar furrows. Front of glabella slopes down into an anterior border that is still slightly sloping but at a lower angle. This produces a concave profile to the anterior of the cranidium. Anterior border widest at the antero-lateral corners of the cranidium where it reaches 1/4 of the maximum preocular width (tr.) of the cranidium; narrows towards the midline.

Though poorly preserved there is no evidence of any occipital furrow, and only slight evidence of a posterior border furrow.

**Free Cheek:** The external margin is gently curved and extends posteriorly into a pronounced genal spine that becomes somewhat broader in the larger specimens and more truncated. Both the preocular and postocular sutures are fairly straight for the majority of their length and strongly curved at their abocular ends. In the postocular suture this curve turns the suture through about 90° so that it is perpendicular to the immediately adjacent part of the genal spine and hence also the posterior margin of the cranidium. The preocular suture curves to become parallel with the front margin of the cranidium, and there is a thin extension of the dorsal exoskeleton continuing the external curvature of the free cheek. The two sutures converge at an angle just less than 90° in plan view and are of approximately equal length.

In plan view a broad concave border occupies just less than half the maximum width. Doublure is co-extensive and slighty more concave in profile. Terrace lines faintly developed on doublure.

A panderian opening is present on IT19838 just interior to the paradoublural line and close to the posterior margin.

**Hypostome:** Oval in outline, with posterior broader. Anterior margin formed by median body; no anterior border preserved. Median body occupies about .9 of the length (sag.), with a posterior lobe that is 1/4 the length (sag.) of the anterior lobe, and separated from it by a pair of prominent maculae. Little evidence of a border furrow but the maculae are joined by a slight furrow extending around the rear of the posterior lobe. Overall shape of median body is elliptical.

Prominent lateral border starts at approximately half
the length of the anterior lobe, the margin initially being straight and tangential to the anterior curvature of the lobe. Maximum width opposite maculae. Posterior to this the margin curves sharply inwards, border narrowing into the posterior border, the posterior margin a smooth curve parallel to the border furrow of the posterior lobe.

Pygidium: Broadly semi-circular in outline though slightly straightened postaxially. Length: breadth ratio 1:1.5-1.6 in the largest pygidia. Transverse profile strongly convex. Border broad, ≈1/3 of the length (sag.) of the axis at its widest, and steeply sloping, flat to slightly concave. Narrows post axially with a suggestion of increased concavity.

Axis only slightly inflated with faint axial furrows concave abaxially. Maximum width of axis less than 0.3x maximum width (tr.) of pygidium, with posterior well rounded and extending very short distance onto the border. At most three axial rings are apparent and a similar number of pleural furrows. Only the first of each is clearly defined. Narrow articulating half ring present.

Doubleur approximately corresponds to the border, and is more strongly concave than the border. Narrows post-axially giving a distinct v-shape to the interior doublural margin though details of this margin are not well preserved.

Discussion

The main problem in comparing the Welsh material with that of *M. graffi* (Thorvald) is the generally larger size of the latter. If the larger specimens of the Welsh population are fully mature then this size difference may be a taxonomic difference in itself, but is more likely to reflect ecophenotypic variation. There is a small difference between the two populations in the development of the genal spines. These become blunter in larger specimens of both populations, but in the case of the type material of *graffi* the spine is still pointed in specimens with a cranial length of 45mm; Welsh specimens of this size already have blunt spines.

There are a number of other minor differences that can be recognised.

1) The eye in the Welsh specimens is more posterior in position. Eye in *M.graffi* is positioned between about 0.3 and
0.5 of the cranidial length (sag) whilst that of the Welsh specimens is between 0.2 and 0.4.

2) The line of the postocular suture has a much sharper curvature in *M. cf. graffi*.

3) The pygidial border appears to narrow postaxially in *M. cf. graffi* whilst being of constant width in *M. graffi*. The ratio of the postaxial length against axial length is <0.25 in the Welsh specimens, and >0.25 in the French specimens, but evidence is limited to two and three specimens respectively.

4) The posterior margin of the posterior lobe of the hypostome is smoothly rounded in the Welsh specimens whilst there is a distinct pointed posterior axial extension to the lobe in *M. graffi*.

The asaphid described from the Carmel formation on Anglesey (Bates 1968 P1.12 figs.1-6) has more divergent preocular sutures and centrally placed eye, whilst *M. whittardi* Bates 1969 has a much more strongly furrowed pygidium (Whittard 1963 P1 XXXVIII figs.10-13). The specimens figured as *M. graffi* by Gigout (1951 P1.II figs.1-5) from Morocco are probably better referred to *M. whittardi* than *M. graffi*.

*Megalaspis bella* sp.

Material: B.M. : IT19864-5: nearly complete specimens. B.M. IT19863 small cranidium. All from west side of Nant y Gadwen; upper Arenig.

**Description**

*Cranidium*: In larger specimens width across palpebral lobes 8mm; width across posterior border 14mm. Form of preocular sutures not clear in any of the specimens. Postocular sutures subparallel to the posterior border anteriorly, turning sharply to be perpendicular abaxially. Glabella weakly defined laterally with no evidence of axial furrows, but is delimited by steeply sloping sides anterior to the palpebral lobes. No preglabellar furrow present. Glabella effaced. Posterior border furrow weakly developed. Palpebral lobes 1.5mm long; separated from posterior border by just over 1.5x their length.

*Thorax*: 2.6 and 2.7 times as broad (tr.) as long (sag.). Eight uniform segments just under 1mm long (sag.). Axial
region about 1/4 total width (tr.) Pleural furrows quite prominent laterally.

Pygidium: Estimated length : width ratio of 1 : 2.42. Axis narrows uniformly and is straight sided. Border unknown. Effaced; no furrows bounding axis and only first pleural furrow apparent.

Discussion:

These specimens are tentatively placed in *Megalaspidella* on the basis of the postocular suture turning perpendicular to the posterior margin. Comparison with other species is not possible in the absence of clear evidence on the form of the preocular facial suture and a well preserved pygidium. The very broad overall outline may prove distinctive.

Family CYCLOPYGIDAE Raymond, 1925
Genus *PSILACELLA* Whittard, 1952

*Type Species:* *Psilacella trirugata* Whittard, 1952

*Psilacella* sp. A

Pl.22 Figs.3,6 & 7.

Material:

Two cranidia B.M.:IT19866 & IT19867; one pygidium B.M.:IT19868. All from Dwyrhos Quarry; middle Arenig.

Description:

Both cranidia the same size; 5.5mm wide (tr.), 4.5mm long. Semi-circular to trapezoidal in outline. Both specimens appear crumpled, but the close similarity in the pattern of rugae indicates this to be a primary sculpture and not a product of deformation.

The rugae are interrupted by three pairs of lateral glabellar furrows and terminate against a posterior furrow that may be occipital. 1P furrows appear joined into a transglabellar furrow. This may be the result of the furrows being linked by the axial ornament, which is perpendicular to the sagittal line. The three pairs of furrows are sub-parallel, inclined forward towards the sagittal line, with which they make an angle of about 70°. Lines joining adaxial terminations of furrow pairs cross sagittal line at about 0.3, 0.45-0.5, and 0.6 of the total cranidial length.

The posterior furrow and 1P furrows appear to merge laterally, with a single furrow continuing across a small depressed area that is taken to be the remnant fixed cheek.
Sculpture divided into two zones: an outer concentric series of rugae and an axial zone with sculpture dominantly perpendicular to the sagittal line. The inner zone expands anteriorly and the two zones are most clearly defined in the area between the posterior furrow and the 1P furrow pair. The area behind this (?) occipital ring) has a much finer, dominantly transverse, rugose sculpture.

Pygidium: Outline semi-circular; .23cm long (sag.) .41cm wide (tr.); length : width ratio 0.56. Axis triangular; .13mm long (sag.) and .13mm wide anteriorly. Axial furrows, 4 axial rings and terminal piece all well defined though furrows decreasing in depth posteriorly. 3 pleural furrows decreasing in definition posteriorly. Short interpleural furrow apparent on second pleura. Narrow border faintly developed.

Discussion:

The presence of three pairs of lateral glabellar furrows suggests assignment to either Novakella Whittard 1960 or Psilacella Whittard 1952. The latter is favoured in that the lateral glabellar furrows are not isolated in the glabella as in Novakella and the pygidial segmentation is more similar to Psilacella. (eg type species, Whittard 1952 Pl.32 Figs.1-5)

The additional posterior furrow is not present in other members of the genus and may be a primitive feature. The coarse cranidial sculpture distinguishes the Welsh material from other described species.

Family HARPETIDAE Hawle & Corda, 1847
Genus EOHARPS Raymond, 1905
Type Species. Harpes primus Barrande, 1872

Eoharpes sp. A
Pl.22 Fig.4

Material B.M.: IT19859 from Afon Seiont, Caernarfon; upper Arenig. Only fringe well preserved but thoracic segments suggest individual may have been preserved complete.

Description.

Terminology follows Whittington 1950 Fig.1

Cephalon horse-shoe shaped: 16mm long. Maximum width across posterior border: 12mm. Part (not figured) indicates prolongations just under half total length. Details of prolongation not clear. Prolongation of rim broad and of
comparable width to that anterior. Cheek-roll prolongation not preserved.

Glabella poorly preserved: probably about 3mm long and narrow. Alae not preserved. Right cheek seems to be preserved and appears to have a very fine sculpture. No evidence of eye-tubercle or eye-ridge, though may reflect the poor preservation rather than true absence. Preglabellae field very narrow.

Fringe with prominent girder. Circular pits randomly distributed, closely spaced and of uniform size on both rim and cheek-roll. Rim of uniform width (2mm) with about 8 pits radially. Cheek-roll twice as wide anteriorly (5 pits radially) as lateral to glabella (2-3 pits radially). Narrow external rim apparent on part.

Discussion.

Hitherto the earliest described member of the genus was *E. primus* (Barrande) from the Llanvirn of Bohemia. This is the type species and was redescribed by Whittington (1948 p228 Pl.XI figs.1-4). The pitting of the fringe in this species is on much the same scale as in the specimen described above, but even allowing for the flattening its cheek-roll is wider and the cheeks narrower than in *E. primus*.

No other described species offers a closer match, though adequate comparison is not possible in the absence of details of the glabella and cheeks.

Family TRINUCLEIDAE Hawle & Corda, 1847
Subfamily HANCHUNGOLITHINAE Lu, 1963
Genus HANCHUNGOLITHUS Lu, 1954
Type Species: Cryptolithus multiserialis Endo, 1932
Hanchungolithus primitivus (Born)
P1.20 Fig.15
Material: B.M.:IT19861 from loose rubble below Clip y Gylfinhir. Only lower lamella well preserved
Synonymy: see Dean 1966 p281

Description & Discussion.

No lower lamella has previously been figured of this species but the extremely close comparison between the pitting on the North Wales specimen and that of the dorsal fringe surface in the specimens figured by Whittard 1957 and Dean (1966 P1.15) allows confident placement in this
species.

*H. primitivus* is the guide fossil of the Couches du Landeyran superieures which forms the top of the Arenig succession in the Landeyran Valley of Montagne Noire, but is unconformably overlain by Devonian and Carboniferous. The species has also been recorded from the Ribband Group of S.W. Ireland (Brenchley et. al. 1967).

Family RAPHIOPHORIDAE Angelin, 1854
Subfamily ENDYMIONIINAE Raymond, 1920
Genus *ELLSASPIS* Rasetti, 1945
**Type species:** *Ellsaspis elliptica* Rasetti, 1945
*Ellsaspis cf. elliptica* Rasetti
P1.22 Fig.2

cf. 1984 *Ellsaspis elliptica* Rasetti; Landing & Ludvigsen p.1488 Fig.2 A-E.

**Material:** B.M.: IT19862. Crushed cranidium from Dwyrhos Quarry. Age: middle Arenig.

**Description:** Cranidium 3.6mm wide (tr.), 2.1mm long (sag.), semi-circular in outline. Glabella over half total width and 3/4 of total length (sag.). Glabellar outline not clear but appears parallel sided and rounded anteriorly. Prominent anterior and posterior border furrows. Finer details not clear.

**Discussion** See under *Ellsaspis* sp. A

*Ellsaspis* sp. A
P1.22 Fig.15

**Material:** B.M.: IT19872 cranidium from west side of Nant y Gadwen. Age: upper Arenig.

**Description:** Cranidium 10mm wide (tr.), 6mm long (sag.). Semi-circular outline. Glabella sub-circular; 4mm long (sag.). Narrow anterior border just preserved on left anterior of specimen. Posterior border furrow visible on right side.

**Discussion:**

In neither specimen are details of the glabella apparent but they are placed in *Ellsaspis* on the presence of an anterior border (cf Landing & Ludvigsen 1984 p.1487). The overall shape and broad anterior border of the middle Arenig specimen are closely comparable to *E. elliptica* Rasetti from the middle Arenig of Canada (Landing & Ludvigsen 1984). The upper Arenig specimen is more rounded than this species and
its sub-circular glabella is more similar to that of *E. extensa* (Fortey 1975 p93 P133 figs.1-3), though the cranial outline of this species is more triangular.

Family CALYMNIDAE Burmeister, 1843
Subfamily REEDOCALYMENINAE Hupe, 1955

**Genus** NESEURETUS Hicks, 1873

**Type Species:** *Calymene parvifrons var. murchisoni* Salter, 1865

**Heseuretus sp. A. sp. nov.**

Fig.12.3; P1.20 Fig.11; P1.23 Figs.1-21; P1.24 Figs.1-3, 5-6.

**Diagnosis:**

*Heseuretus* species with distinctly oblique trend of eye ridges and long (sag.) anterior area (>0.62x preoccipital glabellar length (sag.)). Anterior border furrow slightly developed, marking off approximately horizontal border. Hypostome has distinct anterior and posterior lobes of the median body, the posterior lobe crossing the border furrow into an inflated anterior part of the lateral border. Posterior of hypostome smoothly rounded.

**Type Locality:** As for *Annamitella* sp. A

**Holotype:** B.M. IT19800. Well preserved cranidium.

**Other Material:** All following B.M. specimens with numbers beginning IT198


**Additional material:** N.M.W.: 85.16G.51-63

**Age & Occurrence:** As for *Annamitella* sp. A. An indeterminable *Heseuretus* (N.M.W. 85.16G.47) from the Maesgeirchen Sandstone Member west of Bangor Pier is likely to be this species.

**Description:**

Cranidium. A number of cranidia are known ranging in size up to 30mm wide (tr.) and 18mm long (sag.), the two best preserved being of the maximum size, and it is on these that the description is mostly based. The shape of the cranidium is approximately sub-trapezoidal, with significantly rounded anterior, preocular sutures converging slightly but the anterior width (tr.) remaining greater than the posterior width (tr.) of the glabella.

Glabella approximately trapezoidal and moderately
inflated, well defined by axial and preglabellar furrows. Three pairs of lateral glabellar furrows are present. The 1P furrow trends backwards towards the sagittal line and forms an angle of c.50° with it. At its inner termination this furrow turns perpendicular to the sagittal line and may even be inclined slightly anterior in some cases. A fifth of the glabellar width (tr.) is not cut by this pair of furrows. 2P furrow is straight and approximately perpendicular to the sagittal line. On the holotype it is perched but this does not appear to be the normal situation. The 3P furrow is very faint, but can be seen on the holotype and lies approximately mid-way between the 2P furrow and the anterior of the glabella. An axial ridge is apparent on well preserved specimens which broadens and merges with the anterior lobe. The 1P lobe narrows considerably adaxially, whilst the 2P expands in this direction by a compensating amount.

The occipital furrow is approximately straight and of fairly even development apart from a slight fading over the axis. There appears to be a constriction of the furrow either side of the glabella. In one specimen the axial part of the furrow has a slight anterior curvature. Axial furrows are expanded into crescentic depressed areas posterior to the palpebral lobes and anterior to this area are only slightly developed. The preglabellar furrow is moderately well developed with fossulae present at its junction with the axial furrows.

The palpebral lobes are prominent and the line joining their posterior margins crosses the glabella at, or just anterior to, the 1P furrow. They are separated from the glabella by half the glabellar width as measured along the same line. The line joining the anterior margins of the palpebral lobes runs just posterior to the 3P furrow. Eye ridges trend anteriorly from the palpebral lobes, the pair enclosing an angle of 144°-154°, and cross the axial furrow just posterior to the fossulae.

The anterior area, i.e. anterior border and preglabellar field, is large ranging in length (sag.) from 0.63-0.79 times the preoccipital length of the glabella. Though the posterior part of the preglabellar field is somewhat domed, the preocular fixed cheeks are more raised producing the
appearance of slight furrows diverging anteriorly. Anterior border furrow is moderately developed with the anterior border horizontal in profile.

Fig. 12.3 *Heseuretus* sp. A. (c. x2); a: cranium with free cheek replaced; b: plan view of free cheek; c: hypostome; d: reconstruction of lateral view of cephalon.

**Free Cheek:** In plan view the two sutures converge at about 90°, the preocular suture length being 2/3 of the postocular. A moderately inflated border is present and occupies a quarter of the width opposite the eye. The border widens a little posteriorly whilst the doublure narrows as a result of being turned to a higher angle relative to the plan view. No sculpture is seen on the border, though this may reflect the mode of preservation. There is a significant length of doublure extending from the front of the free cheek, confirming the wide separation of the anterior sutures.

**Hypostome:** Only one complete specimen is known and this is quite large being 9mm long; it is represented by both internal and external moulds. The depressed anterior area, typical of the *Heseuretus* hypostome, is well developed, occupying just less than 1/3 of the total length (sag.). The median body is divided into distinct anterior and posterior lobes which are separated by a crescent shaped depression. The anterior lobe is oval, the narrower end being posterior, each end grading down into the depressed areas, and laterally bordered by deep furrows. The posterior lobe is crescent shaped, the posterior edge of which is steeper than the anterior. This lobe extends across the line of the border furrow dividing it in two and causing an inflated portion of the lateral border alongside the anterior lobe. The border furrow behind the posterior lobe follows the curvature of the latter, before being truncated by the extension of the lobe and there is some suggestion of
deeper at the anterior ends though the depth of the furrow appears more even on the internal mould. The anterior part of the border furrow shallows posteriorly, grading into the depressed area separating the two lobes of the median body. The posterior margin of the hypostome is smooth and follows the curvature of the posterior border furrow.

Posterior border narrow. Lateral border is continuous with the posterior border and merges with the extension of the posterior lobe into a broader and more elevated anterior portion, that curves down gently to the lateral margin.

Pygidium: The pygidia assigned to this species fall into two size groupings greater and less than 10mm in length (sag.). There are two well preserved specimens of the larger size and these have different outlines, one being distinctly triangular whilst the other is well rounded posteriorly. Both have a funnel shaped axis, axial furrows converging at 35° till just posterior to the fifth axial ring and thereafter continuing subparallel. Nine axial rings are present on one specimen and show slight constrictions forming small tubercular inflations at their lateral terminations. On the other specimen only six axial furrows are apparent and there is no evidence of the tubercular terminations; this may reflect the coarser preservation. Posterior of axis inflated in sagittal profile. Six pleural furrows are present on the best preserved specimen, short interpleural furrows being developed in the steeply down-turned sides of the pleural field. A fine tuberculate sculpture covers the pygidium.

The smaller pygidia are grouped with this species on the basis of the posterior inflation of the axis. However they differ in being somewhat effaced, with the axial furrows only shallowly developed and fading posteriorly, and three to four axial and pleural furrows indistinctly developed. A prominent articulating half ring is present in two specimens that is longer (sag.) than the first axial ring. This character is not preserved in either of the larger specimens.

Discussion:

Since the various skeletal elements described under the above species are derived from an assemblage of disarticulated fragments, there is no direct evidence that
they all belong to the same species. However it is only for the pygidium that this is questionable and these have been separated into two groups on the presence or absence of the posterior inflation of the axis, those not showing this being assigned to *Calymenella* sp. nov. A. The development of a post axial ridge, considered characteristic of *Neseuretus* (Hammann 1983 p.40 fig.17) is seen in a couple of the pygidia (eg P1.24. Fig.2) and the posterior inflation of the axis is also shown by other members of the genus (eg. *N. parvifrons* (M'Coy) Whittington 1966 P1.4 fig.12).

In only four other species of *Neseuretus* has the hypostome been described; *N. parvifrons* (M'Coy) (Bates 1969 p.26 P1.9 figs.4 & 10; Whittington 1966 p.501-2, P1.5 figs.5 & 8); *N. tristani* (Brongraiart) (Henry 1980 P1.10 figs.4 a-b,P1.11 Figs.2 & 5; Hammann 1983 P1.6 Figs.61 & 64); *N. avus* Hammann (Hammann 1983 P1.4 Fig.46 and *N. henkei* Hammann (Hammann 1983 P1.7 Fig.74). Henry (1980) considers there to be considerable intraspecific variation in the form of the hypostome (p.71 Fig.25) but since each of the specimens comes from a different locality it seems more likely that the variation may be indicative of sub-species as recognised by Hammann (1983). This would therefore suggest that the hypostome may be a significant taxonomic feature, its limitation being rare preservation.

The hypostome described above is quite distinct from those previously described in that the border furrow is not continuous. However, there is some similarity to that of *N. parvifrons*, in the form of the anterior and posterior lobes, and the hypostome of *Neseuretus* sp.A could easily be derived from this by the extension of the posterior lobe. There is no evidence of the maculae seen in *N. tristani*.

The form of the lateral glabellar furrows, in which there is a marked adaxial divergence of the 1P and 2P with the 2P furrow approximately perpendicular to the sagittal line, may be considered typical of *Neseuretus* as it is also seen in the type species *N. murchisoni* (Salter 1865). The combination of this associated with the oblique form of the eye ridges, which are more normally perpendicular to the sagittal line (cf. Whittard 1959 Pls.XIX & XX), separates the above species, along with *N. monensis* (Shirley 1936 p.401-2 P1.XXIX Figs.1-4), from other members of the genus.
The oblique form of the eye ridge results from the posterior position of the eye, approximately opposite the 2P lobe, a feature Shirley (1936 p.402) noted as being diagnostic of *H. monensis*. The Bangor species may be distinguished from *H. monensis* in having a longer anterior area and obvious anterior border.

Genus *CALYMENELLA* Bergeron, 1890  
**Type Species:** *Calymenella boiselli* Bergeron, 1890  
*Calymenella* sp. A sp. nov.  
Fig.12.4; Pl.24 Figs.4, 7-16

**Diagnosis:**
*Calymenella* very similar to type species in having elongate sub-triangular anterior area, but differing from this and other species in having less strongly developed lateral, preglabellar and occipital furrows. Glabella is of a rounded pentagonal form. Posterior of pygidial axis is ill defined.

**Type locality** As for *Annamitella* sp. A  
**Other Material:** All B.M. numbers beginning IT198  
Cranidia: 02, 12, 21, 34, 44. Pygidia: 15, 17.  
Free-Cheeks: 03, 26, 32, 37, 55.  
**Age and Occurrence** As for *Annamitella* sp.A with the addition of a single specimen from the Maesgeirchen Sandstone Member west of Bangor Pier (IT19844)  
**Description:**
Cranidium: Three well preserved specimens are known, all of which are about 15mm long. Poorly preserved specimens are difficult to distinguish reliably from the neseuritid in the fauna. Cranidium is strongly triangular, with slightly truncated, rounded anterior. The glabella occupies approximately 3/5 of the preoccipital length (sag) of the cranidium and has a rounded, sub-pentagonal outline. At least two pairs of shallow and broad, indistinctly developed lateral furrows are present, the 1P lobe being moderately well defined. The 1P furrow is inclined gently backwards, causing the 1P lobe to narrow adaxially. The furrow is also slightly curved, being approximately perpendicular to the axis at its inner termination. An axial unfurrowed area is present that is approximately the same width as the shallower portion of the occipital furrow. The 2P furrow is
very poorly defined and is little more than a shallow depressed area, the orientation of which is not clear, but appears to be elongate perpendicular to the axis. Axial and preglabellar furrows are poorly developed, being little more than depressions separating the glabella from the fixed cheeks and the inflated anterior area respectively. The absence of marked furrows means the glabella is less well defined in plan view than is apparent from the profile. Palpebral lobes quite large, their posterior margin being approximately level with the 1P furrow, and the anterior only slightly behind the anterior of the glabella. Eye ridge present; inclined slightly forward towards the sagittal line.

Preocular sutures straight in dorsal view and converge sharply towards the anterior enclosing an angle of 65°. These sutures margin an area that is slightly elevated just anterior to the preglabellar furrow, and then sloping down with concave curvature into an ill-defined anterior border, hardly apparent in dorsal view. The anterior of the cranidium is narrower than the posterior width of the glabella. Occipital furrow deepest at margins of glabella, fading over the axis, and curving slightly forward. Posterior border furrow is well developed curving slightly forward abaxially. The occipital ring is well-defined laterally but almost merges into the preoccipital portion of the glabella at the axis. The posterior border widens laterally as a result of the anterior curvature of the posterior border furrow.

Fig. 12.4 Calymenella sp. A. (c.3) a: Cranidium with free cheek replaced; b: free cheek in plan view; c: lateral view of reconstructed cephalon.

Free Cheek: In plan view sutures converge at about 120°. Preocular suture is slightly longer than post-ocular. Genal angle rounded. Doublure occupies just under 1/4 of width of free cheek opposite eye, and in plan view narrows towards
the genal angle apparently as a result of being more steeply inclined to the surface of the free cheek. Slightly elevated border on dorsal surface is approximately the same width as the doublure.

**Pygidium:** Both pygidia assigned to this species are known only from internal moulds the external that exists for one of them being too poor to warrant description. Both are small; only 6-7mm long (sag.), approximately 1.25 times as wide as long and rounded posteriorly. Axis occupies 1/3 of the maximum width anteriorly and tapers posteriorly, the margins being defined by prominent axial furrows that converge to enclose an angle of 20°. 6-7 axial rings present.

5-6 pleural furrows developed; no interpleural furrows have been observed though this may be a result of the coarse preservation. Posterior of axis is ill-defined and appears to grade into the post axial area, which is supported by the lateral profile which shows an almost continuous curvature between the two.

Articulating half-ring narrow.

**Discussion:**

The pygidia assigned to this species are distinguished from those of the *Meseuretus* in the fauna by the absence of a posterior inflation of the axis and the more prominent axial and pleural furrows in specimens of equivalent size.

*Calymenella* has previously been considered restricted to the Caradoc and *?Angill* (Hammann 1983 p72) and therefore the material described here represents a significant extension of the range. In view of this the North Wales specimens bear a remarkably close resemblance to the type species of the genus, *C. boisseli* Bergeron. It is of interest as the later members of the genus have a typically Gondwanan distribution: Armorica (Henry 1980), Iberia (Hammann 1983) and Turkey (Dean 1983).

The only other species that shows a comparable convergence of the preocular sutures is *Calcantarae* Hammann & Henry 1978, but in both this and the type species the palpebral lobe is smaller than in the Welsh specimens causing the eye ridges to be oblique. In addition the furrows bounding the glabella tend to be more prominent in *Calcantarae*. 
The posterior of the pygidial axis is less clearly defined than is typical of the genus (see Hammann 1983 p.38 fig.16).

*Calymenella* sp. B.
Pl.20 Figs.13, 16 & 17.

**Diagnosis.**

Very rounded cranidial outline, semi-circular inflated glabella with 1P lobes developed but 1P furrow faint. Palpebral lobes only slightly separated from glabella, and at level of its base; approx. half the height of the cranidium. Crescent shaped preglabellar field with horizontal posterior portion and steeply sloping anterior.

**Locality etc.** As for *Annamitella* sp.A

**Material B.M.:** IT19814 External mould of cranidium.

**Description:**

Dimensions of cranidium: 22mm long (sag.), 34mm wide (tr.) and 13mm high.

Outline of cranidium well rounded, semi-circular to slightly triangular. Glabella outline similar to that of cranidium, highly domed; occupies half the total height of the cranidium. Maximum elevation just anterior to the occipital furrow and in profile curves down smoothly to the anterior. Glabella featureless except for occipital furrow and faint 1P furrow that forms an approximately straight depression from the axial posterior of the glabella to the palpebral lobe. Separates off a somewhat inflated 1P lobe. Occipital ring widens axially and is poorly developed behind the 1P lobes.

Preglabellar field occupies .29 of the total cranidial length (sag.) and is approximately half the preoccipital length (sag) of the glabella. Neither preglabellar nor axial furrows clearly developed, the margins of the glabella being marked by sharp changes of slope. The posterior two-thirds of the preglabellar field slopes gently downwards whilst the anterior third is sharply curved down. The gently sloping area appears to narrow slightly as it curves towards the palpebral lobes whilst the steeply sloping portion remains approximately the same width when viewed dorsally.

Palpebral lobe only slightly separated from glabella and in profile can be seen to be at approximately the level of the base of the glabella. It lies between .49 and .59 along
the sagittal line of the cranium, i.e. just over half way, and is only slightly elevated above the fixed cheeks. Posterior to the palpebral lobe there is a gently sloping area of fixed cheek widening posteriorly. Posterior border furrow only faintly developed though the posterior border is quite strongly inflated and widens quite significantly abaxially.

In lateral view the facial sutures indicate a relatively small free cheek, the preocular suture not extending anterior of the glabella.

Discussion:

The generic placement of this specimen has proved difficult. It is included in Caymenella because a single cranium is inadequate basis for the erection of a new genus. In plan view the specimen bears some resemblance to Platycorophe heberti (Lebesconte) (see Henry 1980 PI.15. Fig.1). Platycorophe belongs to the Homalonotidae and there is no suggestion in the North Wales specimen of the concave lateral margin of the IP lobe typical of this family.

INCERTAE SEDIS
Gen. et Sp. indet.
Pl.22. Fig.12

Material: B.M. IT19869 from upper Arenig at northern end of Nant y Gadwen. Pygidium and fragments of thoracic segments.

Description: Pygidium 4.2mm wide (tr.); 3.3mm long including terminal axial spine 1.4mm long (sag.). Overall outline triangular. Prominent articulating half-ring. Fine sculpture of widely spaced terrace lines.

Fragments of thorax indicate a width of 8mm. Broad pleural spines developed on all segments preserved.
Plate 20

*Annamitella* sp A, from Bangor Bypass Section.
Fig.3: B.M.: IT19818 x5: Dorsal view of internal mould of cranidium. Note anterior border.
Fig.4 B.M.: IT19837 x5 Internal mould of pygidium.
Figs.5,6 & 7: B.M.: IT19840 (x3) dorsal and oblique views of internal mould of pygidium. Note flat border and concave doublure.
Fig.8: B.M.: IT19817a x5. Dorsal views of internal mould of pygidium.

*Cyclopygid* indet, from west side of Nant y Gadwen; upper Arenig.
Fig.9: Dorsal views of internal mould of pygidium and thorax.

*? Megalaspidella* sp. from west side of Nant y Gadwen; upper Arenig.
Fig.10: B.M.:IT19864 x3. Internal mould.
Fig.12: B.M.:IT19865 x3. Latex of external mould.

*Neseuretus* sp A from Bangor Bypass Section (?basal middle Arenig)
Fig.11: B.M.: IT19809 x2.5 Plan view of internal mould of free cheek showing doublure.

*Calymenella* sp B from Bangor Bypass Section (? basal middle Arenig.
Figs.13, 16 & 17: B.M.:IT19814 x2: lateral, dorsal and frontal.

*Leioshumardia* sp from Dwyrhos Quarry, middle Arenig.
Fig.14: B.M.: IT19870 x20: Dorsal view of cranidium

*Hanchungolithus primitivus* (Born) from Clip y Gylfinhir, lower Arenig.
Fig.15: B.M.: IT19861 x10. Latex of lower lamella.
Plate 21

*Megalaspidella cf graffi* (Thoral) from Bangor Bypass Section; ? basal middle Arenig.

Fig. 1: B.M.: IT19805 x2. Internal mould of cranidium.
Fig. 2: B.M.: IT19843 x2. As 1.
Fig. 3: B.M.: IT19813d x2. As 1.
Fig. 4: B.M.: IT19843 x2.7. As 1.
Figs. 5 & 7: IT19813c. Dorsal and lateral views of internal mould of cranidium.
Fig. 6: B.M.: IT19831 x7.5. Latex of external mould of hypostome.
Fig. 8: B.M.: IT19803 x1.25. Latex of external mould of free cheek.
Fig. 9: B.M.: IT19827 x1.25. Latex of external mould of pygidium.
Fig. 10: B.M.: IT19822 x2. Poor internal mould of pygidium but showing doubture.
Fig. 13: B.M.: IT19838 x1.25: Internal mould of free cheek. Note panderian opening just interior to paradoubural line.
Fig. 14: B.M.: IT19820 x7.5. Internal mould of hypostome.
Fig. 15: B.M.: IT19829 x3. Latex of external mould of broken hypostome.
Fig. 16: B.M.: IT19833 x1.25. Latex of external mould of free cheek.
Plate 22

Fig. 1: Ectillaenus from west side of Nant y Gadwen, upper Arenig. B.M.: IT19871 x3. Latex.

Fig. 2: Elysaspis cf elliptica Rasetti. Dwyrhos Quarry, Aberdaron; middle Arenig. B.M.: IT19862 x10. Internal mould of pygidium.


Fig. 7: B.M.: IT19866 x7.5. As for fig. 6

Fig. 4: Eoharpes sp. A from Afon Seiont section, Caernarfon; upper Arenig. B.M.: IT19859 b latex of external mould.

Fig. 5: Degamella sp. from west side of Nant y Gadwen, upper Arenig. N.M.W.: 85.166.68 x3 Internal mould.

Fig. 8: Eelisotaphrus sp. from Dwyrhos Quarry, Aberdaron; middle Arenig. N.M.W.: 85.166.69a x10. Internal mould.

Fig. 9: Asaphid indet from Dwyrhos Quarry, Aberdaron; middle Arenig. B.M.: IT14285 x2. Latex of pygidium.

Fig. 10: Bohemilla sp. from Dwyrhos Quarry, Aberdaron; middle Arenig. N.M.W.: 85.166.65 x10. Latex of external mould of cranidium.

Fig. 11: Girvanopyge sp. from east side of Nant y Gadwen, middle Arenig. B.M.: IT19860 x10 internal mould of pygidium.

Fig. 12: Incertae sedis. from northern end of Nant y Gadwen; upper Arenig. B.M.: IT19869 b x10. Note posterior pygidal spine apparently continuous with the axis and the pleural spines in top left of plate.

Niobine asaphid from west side of Nant y Gadwen, upper Arenig.

Fig. 13: B.G.S.: 24080 x3. Latex of external mould of free cheek. Note rounded genal angle.

Fig. 14: N.M.W. 85.166.67a x3 Internal mould of pygidium.

Fig. 15: Elysaspis sp. A from west side of Nant y Gadwen; upper Arenig. B.M.: IT19872 x4. Latex of external mould.
Plate 23

*Neuretus* sp. A from Bangor Bypass Section, ?basal middle Arenig.

Figs. 1, 2, & 5: B.M.: IT19800 x2. Dorsal, lateral and anterior views of latex of external mould of cranidium.

Fig. 3: B.M.: IT19813 x2. Internal mould of cranidium.

Figs. 4, 8 & 10: B.M.: IT19839 x2. Lateral, dorsal and anterior views of latex of external mould.

Fig. 6: B.M.: IT19835 x2.5. Internal mould of cranidium.

Fig. 7: B.M.: IT19803 x2.5. Plan views of latex of external mould of free cheek.

Fig. 9: B.M.: IT19819 x5. Internal mould of cranidium.

Fig. 11: B.M.: IT19809 x3. Latex of external mould of free cheek.


Figs. 16 & 18: B.M.: IT19811 x5 External (latex) and internal moulds respectively of hypostome.


Figs. 18 & 20: B.M.: IT19807 x2.5 & x 7.5. Internal mould of pygidium. Note constrictions on lateral parts of axial rings giving a tubercular appearance and on detail, short interpleural furrows and fine tubercular sculpture.
All material from Bangor Bypass section of the Maesgeirchen Sandstone Member, except IT19844 which comes from the same unit exposed west of Bangor Pier (see Figs.4,2 & 3).

_Heseuretus_ sp. A

Fig.1: B.M.: IT19832 x5. Dorsal and lateral views of internal mould of pygidium.

Fig.2: B.M.: IT19801 x3. as for fig.1. Note postaxial ridge.

Fig.3: B.M.: IT19805 x5. as for fig.1

Fig.5: B.M.: IT19830 x5. Dorsal and lateral views of latex of external mould of pygidium.

Fig.6: B.m.: IT19829 x3. As for fig.1

_Calyxemella_ sp A

Fig.4: B.M.: IT19817 x5. As for fig.1

Fig.7, 16 & 17. IT19844 x2.5. Dorsal view of latex of external mould of glabella; dorsal view of internal mould of cranidium and lateral view of internal mould of cranidium respectively.

Figs.9 & 12: B.M.: IT19815 x5. Dorsal and oblique posterior views of internal mould of pygidium.

Figs.10, 13 & 14: IT19834 x2.5. Lateral, anterior and posterior views of latex of external mould of cranidium.

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Appendix 1

Symbols used in sedimentary logs

The symbols employed in the sedimentary logs are not intended to be schematic, but rather to convey an impression of the sequences as they are exposed in the field. In this respect the plates indicated in the sections serve better than any descriptive explanation that could be given here and the following is only intended to supplement this where necessary.

One result of this technique that needs to be noted is that differing modes of exposure convey a different appearance. Thus it is likely that if the flaggy beds of the Harlech Dome area were exposed on the coast they would be shown as silt-streaked sandstones etc. Such variations are generally emphasised in the text.

Grain size scale.

<table>
<thead>
<tr>
<th>Grain size scale</th>
<th>a: clay</th>
<th>b: silt</th>
<th>c: fine sand</th>
<th>d: medium sand</th>
<th>e: coarse sand</th>
<th>f: gravel</th>
<th>g: pebble</th>
<th>h: cobble</th>
<th>i: boulder</th>
</tr>
</thead>
</table>

Vertial Scale.

Unless otherwise stated scale bars are one metre throughout.

1) Gap with break in vertical scale indicates probable fault.
2) Gap with no break in scale bar indicates area of non-exposure.

'Flaggy lithologies':

As exposed around Harlech Dome: increasing siltstone fraction from left to right.

Finer scale exposure.

Increasing bioturbation from left to right.
Increasing sand content from bottom to top.
(fine stippling indicates diffuse mud content.)
**Lamination**

- parallel lamination
- ripple lamination
- tabular cross-lamination
- trough cross-lamination
- convolute lamination / slumping

**Clasts.**

- shell fragments
- scattered pebbles, cobbles etc.
- angular mudstone clasts
- angular extraformational clasts
- intraformational blocks, deformed
- phosphatic nodules: need not be derived

**Volcanics**

**Tuffs.**

**Bedding Surfaces.**

- sharp, planar
- wavy / rippled
- irregular
- convex up
- concave up (channelised)

**Cherty Tuffs**