THE BIOSTRATIGRAPHY OF THE UPPER ORDOVICIAN AND LOWER SILURIAN OF SOUTH-WEST DYFED, WITH COMMENTS ON THE *HIRNANTIA* FAUNA

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ABSTRACT. Late Ordovician and early Silurian beds around Haverfordwest, South-west Dyfed (Pembrokeshire), Wales, are remapped and their faunas reviewed. Five formations are defined, representing a fairly continuous succession from mid Ashgill (Cautleyan) to late Llandovery (Telychian). New faunal evidence places the local Ordovician–Silurian boundary higher than has been previously suggested, within the Haverford Mudstone Formation. The world-wide late Ashgill *Hirnantia* fauna is reviewed, and the conclusion reached that it represents a diachronous animal life assemblage and that it need not necessarily represent the latest local Ordovician fauna.

ROCK successions spanning the Ordovician–Silurian boundary are not common and with the current world-wide reassessment of late Ordovician and early Silurian rocks, their correlation, faunas, and ecology, it is desirable to review and evaluate the more important sections available.

One such section occurs in South-west Wales. Here a series of large thrust-faults separate blocks of various Palaeozoic ages and the upper Ordovician and lower Silurian are exposed together within one of these blocks around the town of Haverfordwest. Our field-work there, together with work on museum collections, provides new faunal and stratigraphical evidence in the light of which earlier accounts of late Ordovician and early Silurian strata in Pembrokeshire need revision. We attempt also to rationalize the stratigraphical terminology and we review the position of the Ordovician–Silurian boundary within the area.

PREVIOUS WORK

Marr and Roberts (1885) first recognized and determined a detailed succession within Ordovician and Silurian rocks in the neighbourhood of Haverfordwest. They regarded the 'Slade Calcareous Shales' (the highest unit of the '*Trinucleus seticornis* Beds' of their succession) as forming the summit of the Ordovician System. These shales were succeeded by their 'Conglomerate Series', represented at Haverfordwest by the unit to be subsequently designated the Cethings Sandstone, and elsewhere by conglomerate or grit or both. The relationship of the Conglomerate Series to higher horizons was not entirely clear to them, but in the Cethings railway cutting at Haverfordwest the sandstone mentioned above was succeeded by strata which graded upwards into the fossiliferous horizons near Haverfordwest gasworks, which they regarded as of definite lower Llandovery age. Outcrop patterns elsewhere supported this relationship. Provided the position of the Conglomerate Series was as this evidence suggested, they argued (1885, p. 489) that it formed 'a satisfactory base to

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the Silurian rocks of this area' and that it should be included within the lower Llandovery. The horizon was lithologically compared with the Mulloch Hill Conglomerate (now Lady Burn Conglomerate, Cocks and Toghill 1973) of the Girvan district, Scotland (Lapworth 1882).

The Geological Survey (Strahan *et al.* 1914) accepted this conclusion and followed Marr and Roberts in regarding the Slade (and Redhill) Beds as the youngest of the Ordovician formations. The succeeding strata the Survey termed the 'Basement Beds', comprising at Haverfordwest the Cethings Sandstone (named for the first time) with shale units above and below it. Elsewhere conglomerates were variably developed within or at the base of the shales beneath the sandstone.

For Strahan and his colleagues the problem of delimiting the local Ordovician–Silurian boundary was primarily one of mapping the junction between the Basement Beds and the Slade and Redhill Beds, a task in which the Cethings Sandstone played an important part as a marker horizon. It was on this basis that the rich faunas collected by V. M. Turnbull from localities near St. Martin's Cemetery, Haverfordwest, were placed within the Silurian (Reed 1906), even though Reed (1905, pp. 98, 103) had earlier regarded them as of 'Upper Bala' age. There was some palaeontological evidence for the lower Silurian age, mainly from the misidentifications of graptolites found in the succession (see p. 714), but it is clear, particularly from the accounts written by Cantrill (1907 and *in* Strahan *et al.* 1914, p. 101), that the chief reason for reconsidering the age of the St. Martin's Cemetery faunas was their occurrence *above* the Cethings Sandstone marker horizon. Strahan *et al.* (1914) also comprehensively described the succeeding Silurian horizons.

Since the publication of the Survey Memoir, and also following Jones (1925, p. 354), the horizon yielding the St. Martin's Cemetery fauna has been widely regarded as of lowermost Llandovery age. Recently, however, Ingham and Wright (1970, p. 240) recognized elements of the *Hirnantia* fauna amongst the brachiopods and trilobites recorded from this horizon and suggested for it a Hirnantian age.

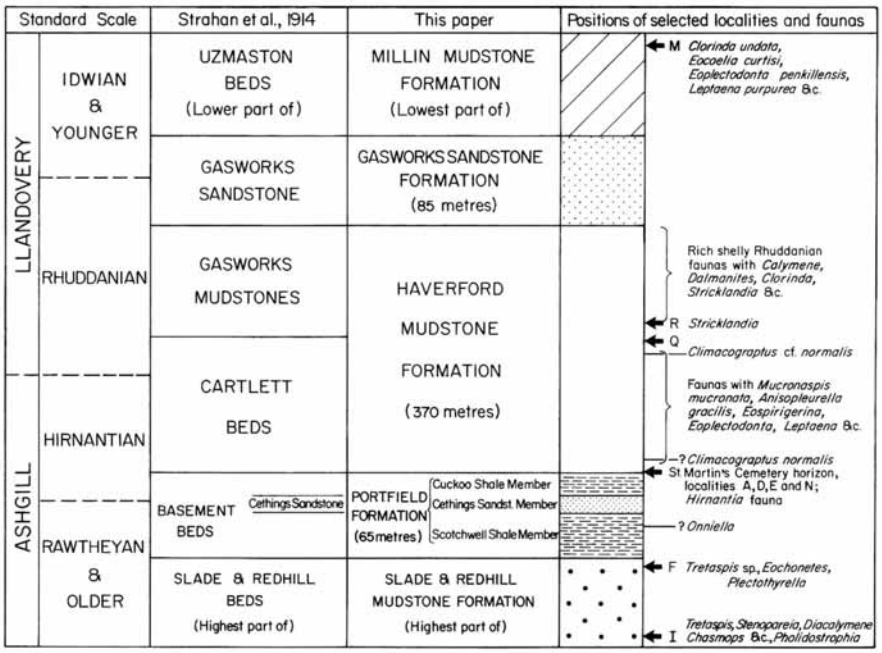
STRATIGRAPHY AND FAUNAS

Due to various palaeontological and stratigraphical misconceptions, outlined below, the previous rock terminology is in several parts unsatisfactory and we have found it necessary to present a revised succession for the Haverfordwest area (Table 1). Geological maps of the area are shown in text-figs. 1 and 2. Each rock unit and its fauna is now reviewed in turn.

Slade and Redhill Mudstone Formation

Lithostratigraphy. The 'Redhill Shales' and 'Slade Calcareous Shales' of Marr and Roberts (1885) were grouped by the Geological Survey into a single formation, their 'Slade and Redhill Beds', since in certain developments of their 'northern type' (Strahan *et al.* 1914, pp. 55–56) they had been unable to map the two divisions separately. Price (1973) has considered these beds in part and also found that distinctions between various levels within them are not consistent over any area and that even where broad lithological distinction between an upper and a lower level can be made, the boundary region is very vague. We therefore propose that these

TABLE 1. Stratigraphical terminology within the Haverfordwest area.



horizons should be regarded as a single formation formally designated the Slade and Redhill Mudstone Formation. The type development should be taken as the outcrop strip immediately north-west of Haverfordwest, which includes both Marr and Roberts original localities along the B4330 road and also the outcrops along the A487 road between St. Martin's Cemetery and the school near Pelcomb Cross, which are much more continuous and include exposures near both base (Grid Ref. SM 9140 1820, loc. 1 of Price 1973) and summit (Grid Ref. SM 9463 1575, see text-fig. 2) of the formation.

Fauna. Price (1973) has dated the lower parts of the formation, which is diachronous within the Cautleyan Stage at its base, and reviewed the trilobite fauna. In this paper we consider only the youngest part of the formation. The stratigraphically highest diagnostic fauna from the Slade and Redhill Mudstones known so far comes from locality I on text-fig. 2, a disused quarry on the west bank of the Western Cleddau (Grid Ref. SM 953 162). As well as brachiopods (pp. 706, 709) and other shelly fossils, the following trilobites occur:

Calyptaulax sp. (Pl. 81, fig. 6), *Chasmops* cf. *marri* (Reed, 1894) (Pl. 81, fig. 4), '*Diacalymene*' cf. *marginata* Shirley, 1936 (Pl. 81, figs. 1–3) (for discussion of the genus see Temple 1975, pp. 146–149), *Remopleurides* sp. (Pl. 81, fig. 5), *Stenopareia bowmanni* Salter, 1848 (Pl. 81, fig. 7), *Tretaspis* cf. *hadelandica* Størmer, 1945 *brachystichus* Ingham, 1970 (Pl. 81, figs. 8, 9).

Tretaspis hadelandica brachystichus ranges up to Rawtheyan Zone 6 in the north of England (Ingham 1970) and its probable descendant, *T. latilimbus* (Linnarsson) *distichus* Ingham, appears in Zone 7. When histograms of fringe characters are plotted separately for forms from Zones 5 and 6 (Ingham 1970, text-fig. 10) there are differences indicating a gradual change towards *T. l. distichus*. The fringe characters of the Slade and Redhill Mudstone specimens are like those of the Cautley forms from Zone 5 and also like those of specimens from the highest part of the underlying Sholeshook Limestone (probably Cautleyan Zone 3), but it is not known whether the changes in Welsh populations exactly paralleled those seen in the north of England. All that can yet be said is that the Slade and Redhill specimens are earlier than Zone 7 and most likely to be low to mid Rawtheyan, an age consistent with the rest of the fauna.

Cocks (1968, p. 304) reported a specimen of *Tretaspis* from a temporary exposure near St. Martin's Cemetery (locality F on text-fig. 1, Grid Ref. SM 9434 1570), in an area marked on the Survey map as early Silurian. The specimen (BM It. 13243) is certainly a *Tretaspis*, although it is too incomplete to allow specific determination, but our recent remapping, with the aid of many new exposures in the foundations of a housing estate, shows the locality to be unequivocally within the highest Slade and Redhill Mudstones. Thus, as far as is known, there is still no authenticated record of *Tretaspis* from rocks of Silurian age.

The brachiopod faunas of the Slade and Redhill Mudstone Formation are much in need of exhaustive collecting and systematic revision. The assemblages differ much from place to place. The temporary exposure mentioned above (locality F) just west of St. Martin's Cemetery, was dominated by *Eochonetes* aff. *advena* Reed, 1917 (Pl. 83, figs. 7, 9, 12), a genus hitherto unknown outside its type area at Girvan, Scotland, which was in late Ordovician time on the further side of the Iapetus Ocean. *Eochonetes* made up of 84% of the collection (n = 287), with *Plectothyrella* at 8% the next most common element. (The method of calculating percentages follows Ziegler *et al.* 1968, p. 4.) Topographically close, but over 50 m lower in the formation, a temporary exposure at SM 942 158 (locality G on text-fig. 2) yielded a quite different assemblage dominated by *Eostropheodonta* (43%, n = 181), amongst thirteen different

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EXPLANATION OF PLATE 81

Figs. 1–3. '*Diacalymene*' cf. *marginata* Shirley, ×3. 1, SM A53047a, internal mould of enrolled exoskeleton, dorsal view of anterior part. 2, SM A85288a, internal mould of distorted enrolled specimen, cranidium in dorsal view. 3, SM A31207, internal mould of cranidium in dorsal view.

Fig. 4. *Chasmops* cf. *marri* (Reed). SM A30961, internal mould of incomplete pygidium, dorsal view, ×2.

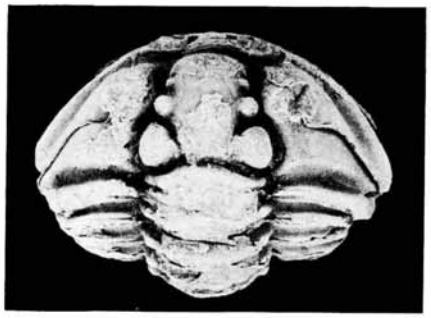
Fig. 5. *Remopleurides* sp. SM A30966, internal mould of pygidium, dorsal view, ×8.

Fig. 6. *Calyptaulax* sp. SM A30960b, cast from external mould of right free cheek, dorso-lateral view, ×3.

Fig. 7. *Stenopareia bowmanni* (Salter). SM A30943, internal mould of incomplete cranidium, dorsal view, ×2.

Figs. 8, 9. *Tretaspis* cf. *hadelandica* Størmer *brachystichus* Ingham. SM A53049a, b, internal mould and cast from external mould of cephalon, dorsal views, ×5.

All specimens from the high Slade and Redhill Mudstones of locality I on text-fig. 2. Originals of figs. 1, 8, and 9 collected by Mrs. M. R. Cave, originals of figs. 2 and 4–6 collected by V. M. Turnbull, original of fig. 3 collected by D. P., original of fig. 7 collected by J. E. Marr.



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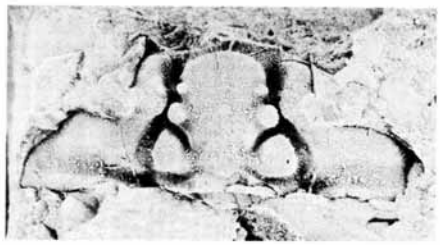

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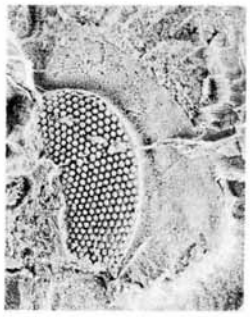

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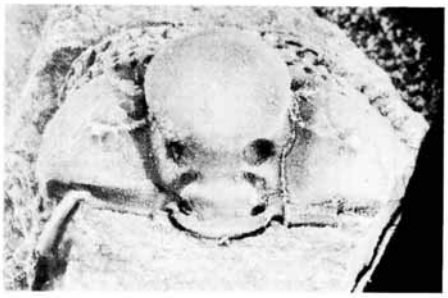

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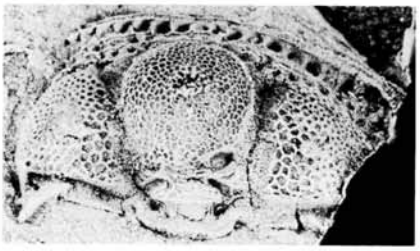

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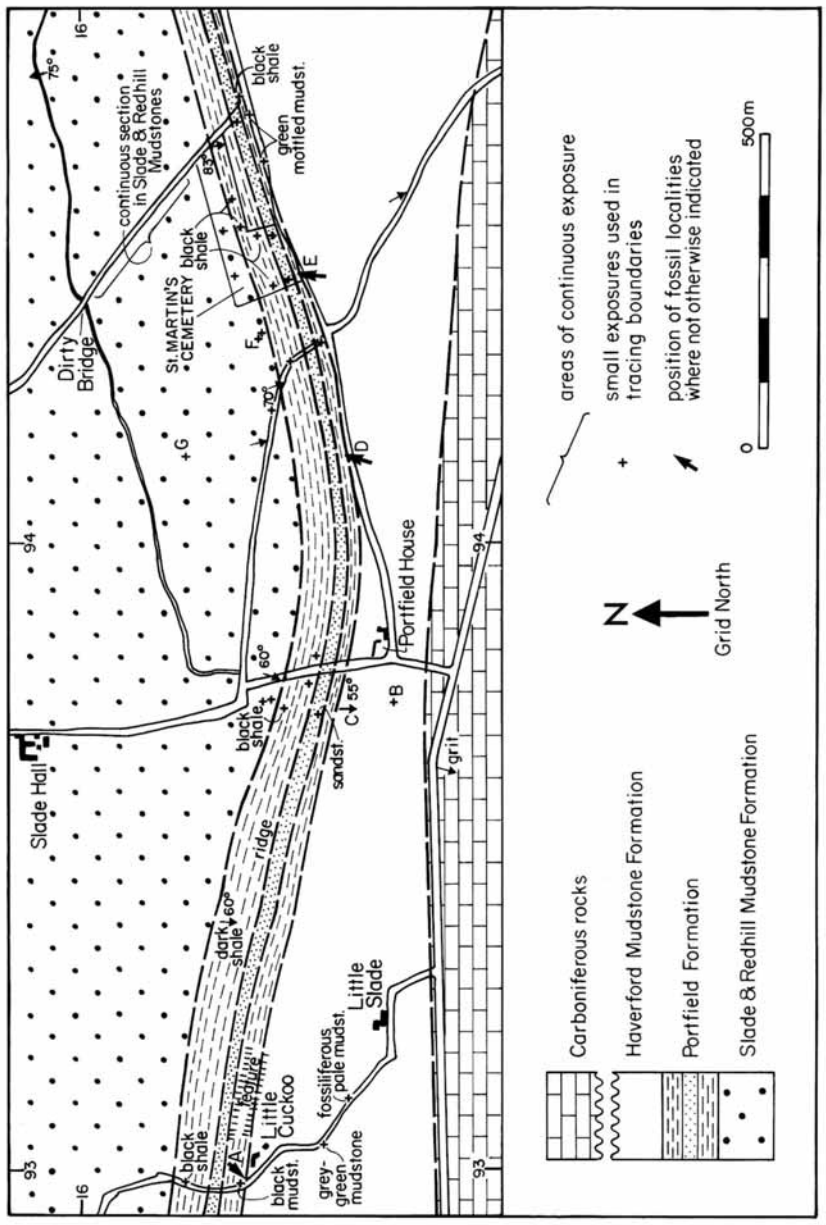
COCKS and PRICE, Ordovician trilobites



TEXT-FIG. 1. Geological map of the area between Little Cuckoo and St. Martin's Cemetery, west of Haverfordwest. Lettered localities are those referred to in the text.

brachiopods and nine species of other groups. The *Sowerbyella* present here at 3% is of interest in that it appears morphologically indistinguishable from the *Eochonetes* mentioned above from higher strata, apart from the lack of perforations along the hinge-line, and suggests an ancestor for the aberrant *Eochonetes* stock. Another assemblage, from the old quarry near the Western Cleddau (locality I), yielded a fauna in which *Pholidostrophia* (*Eopholidostrophia*) *matutinum* (Lamont, 1935), a species previously recorded only from the Cautleyan of the Girvan area and of Cautley itself, occurs commonly (BM BB 69611–69614). A further exposure in the formation south of Little Clerkenhill, 9 km west of Haverfordwest (Grid Ref. SN 045 150) also yielded *Eochonetes* (26%, n = 173) and *Plectothyrella* (13%), but the most common brachiopod (at 39%) was an enteletacean probably related to *Resserella*. In no part of the Slade and Redhill Formation, however, do we consider a *Hirnantia* fauna to be present, although several of its constituents occur at different localities and horizons within the formation.

Portfield Formation

Lithostratigraphy. The name 'Portfield Formation', after the region of Haverfordwest known as Portfield (see Portfield House on text-fig. 1), is proposed for the unit designated 'Basement Beds' by Strahan *et al.* (1914)—an unsatisfactory term because of its erroneous assumption about the position of the unit in relation to the Ordovician–Silurian boundary, as well as its lack of a local name. The Portfield Formation is divided into three members, two of shale with an intervening sandstone.

The type section is in the railway cutting at Cethings (see text-fig. 2; Grid Ref. SM 966 161). At the north-east end of this cutting is exposed the unit which we propose to designate the Cethings Sandstone Member; here a thickness of about 8·5 m of well-sorted, fine-grained grey to buff sandstone dipping at 62° to the south. Below the sandstone, dark sooty shales of the Scotchwell Shale Member (named after Scotchwell, see text-fig. 2) are poorly exposed in a shallow ditch on the east side of the railway line. Their thickness was estimated by Strahan *et al.* (1914, p. 89) as at least 46 m. Shales of similar aspect form the Cuckoo Shale Member (named after Little Cuckoo, text-fig. 1), exposed to a thickness of about 9 m above the sandstone and grading up over a distance of about 1 m in bioturbated beds into the greener mudstones of the overlying Haverford Mudstone Formation. From regional mapping the shales of the lowest member appear to be conformable with the underlying Slade and Redhill Mudstone Formation, but the junction is nowhere exposed.

The sequence in the Cethings railway cutting applies over a region from about 7 km west of Haverfordwest to about 4 km to the east. Further to the east conglomerates are locally and variably developed at or near the base of the formation, one of the most prominent forming the hill at Robeston Wathen (Grid Ref. SN 081 158); further details are given in Strahan *et al.* 1914, pp. 83–101. The Cethings Sandstone Member, although in places attenuated and locally containing some intercalated shale bands, is persistent in the sequence at least as far east as Narberth and Lampeter Velfrey and forms a valuable mapping horizon.

Fauna. The Portfield Formation is largely barren of fossils. We have found none and the only known specimen (SM A32094) was collected by V. M. Turnbull from the

Scotchwell Shale Member in the Cethings railway cutting; it comprises the conjoined valves of an enteletacean brachiopod, perhaps referable to *Onniella*.

The St. Martin's Cemetery Horizon

Lithostratigraphy. V. M. Turnbull made painstaking collections, now in the Sedgwick Museum, from two fossiliferous localities (D and E on text-fig. 1) at the roadside west of St. Martin's Cemetery. Because the fossils were described (Reed 1905, 1906, 1907) before the complete survey of the area (Strahan *et al.* 1914), a stratigraphical name, variously the St. Martin's Mudstone or the St. Martin's Cemetery Beds or Formation has been applied to the rocks from which Turnbull's fossils came.

The original localities, though no longer exposed, can be accurately located and lie at the junction of the Portfield Formation and the Haverford Mudstone Formation; the fossiliferous horizon involved was almost certainly that also seen in the Cethings railway cutting. There a fossiliferous band about one metre in thickness occurs at the same junction (locality N on text-fig. 2), fossils from its lowest part having a dark shaley matrix and those from the upper part a light, more silty one. Most specimens from the St. Martin's Cemetery localities have either a light siltstone or olive-green mudstone matrix which, as at Cethings, is often bioturbated. Elements of the same fauna, in a matrix similar to that from the St. Martin's Cemetery localities, are known from Little Cuckoo (locality A, text-fig. 1), suggesting that there is a constant band from Little Cuckoo, through St. Martin's Cemetery to Cethings railway cutting, a distance of approximately 4 km.

This fossiliferous band, because of its thinness and because its dominant lithology is more similar to the rocks above rather than below it, we include within the basal part of the Haverford Mudstone Formation. We refer to the band informally as the St. Martin's Cemetery horizon and recommend that the designation 'St. Martin's Cemetery' should not again be used as a separate formal stratigraphical name for a formation or member.

EXPLANATION OF PLATE 82

Figs. 1, 2. *Lichas* cf. *laciniatus* (Wahlenberg), ×2. 1, SM A32014, internal mould of cranidium, dorsal view. 2, SM A4650, internal mould of pygidium, dorsal view.

Figs. 3–8. *Otarion* cf. *megalops* (M'Coy). 3, SM A85575, internal mould of left free cheek, dorsal view, ×6. 4, SM A4648, internal mould of cranidium, dorsal view, ×8. 5, 6, SM A32068, internal mould of cranidium, right-lateral and dorsal views, ×8. 7, SM A85576a, internal mould of cranidium, dorsal view, ×8. 8, SM A4647b, internal mould of cranidium, dorsal view, ×8.

Fig. 9. *Brongniartella* sp. GSM Pg 17, cast from external mould of incomplete pygidium, dorsal view, ×2.

Figs. 10–13. *Diacanthaspis sladensis* (Reed), ×10. 10, SM A4646b, lectotype (selected Temple 1969, p. 203), cast from external mould of cranidium, dorsal view. 11, 12, SM A4644a, b, internal mould and cast from external mould of cranidium, dorsal views. 13, SM A32010, internal mould of small pygidium, dorsal view.

Figs. 14, 15. cf. *Leonaspis girvanensis* (Reed), ×10. 14, SM A88536, internal mould of pygidium, dorsal view. 15, SM A32021, internal mould of partial pygidium, dorsal view.

All specimens from St. Martin's Cemetery horizon (basal Haverford Mudstone Formation); collected by V. M. Turnbull. Figs. 1, 2, 4, 6–15 from either of localities D and E on text-fig. 1. Fig. 3 from the Cethings railway cutting, locality N. Fig. 4 from Little Cuckoo, locality A.

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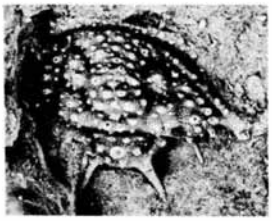

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COCKS and PRICE, Ordovician trilobites

Fauna. The fauna in Turnbull's collections was listed by Reed (1906, p. 537). We have reidentified the trilobites and brachiopods in these collections in addition to those collected subsequently from all localities at this restricted horizon (an asterisk denotes species originally described from the horizon):

Trilobites. *Brongniartella* sp. (Pl. 82, fig. 9), **Diacanthaspis sladensis* (Reed, 1905) (Pl. 82, figs. 10–13), cf. *Leonaspis girvanensis* (Reed, 1914) (Pl. 82, figs. 14, 15), *Lichas* cf. *laciniatus* (Wahlenberg, 1818) (Pl. 82, figs. 1, 2), *Mucronaspis mucronata* (Brongniart, 1822) (Pl. 83, figs. 1–4), *Otarion* cf. *megalops* (M'Coy, 1846) (Pl. 82, figs. 3–8).

Brachiopods. *Lingula* sp., *Orbiculoidea concentrica* (Wahlenberg, 1821) (Pl. 83, fig. 5), *Philhedra* sp., *Craniops* sp., *Skenidioides* sp., **Giraldiella giraldi* Bancroft, 1949, **Dalmanella*? *biconvexa* Williams, 1951, *Dalmanella* aff. *testudinaria* (Dalman, 1828) (Pl. 83, fig. 11), *Hirnantia sagittifera* (M'Coy, 1851) (Pl. 83, figs. 13, 14) of which **Orthis porcata sladensis* Reed, 1905 is a junior synonym, *Chonetoidea* cf. *papillosa* (Reed, 1905), **Leptaena martinensis* Cocks, 1968 (Pl. 83, fig. 6), **Eostropheodonta whittingtoni* Bancroft, 1949 (Pl. 83, figs. 6, 8) of which **Eostropheodonta hirnantensis delicatula* Bancroft, 1949 is a junior synonym, **Cliftonia lamellosa* Williams, 1951 which may be a junior synonym of *Cliftonia psittacina* (Wahlenberg, 1821) (see Bergström, 1968, p. 11), *Cryptothyrella crassa* (J. de C. Sowerby, 1839) *incipiens* (Williams, 1951) (Pl. 84, fig. 3).

Diacanthaspis sladensis, together with forms very similar to *Otarion* cf. *megalops* and *Lichas* cf. *laciniatus*, is known from limestone bands immediately overlying the Keisley Limestone of Westmorland (Temple 1969), an horizon which Temple considered to be lowest Silurian in age, but which Ingham and Wright (*in* Williams *et al.* 1972, p. 47) more recently considered to be Hirnantian. The type material of *Leonaspis girvanensis* is from the upper Drummuck Group of Girvan which is late Rawtheyan in age (Ingham 1966, p. 495). In addition, a pygidium (SM A43243) very similar to that figured here as Plate 82, fig. 14 is known from the '*Mucronatus* Beds' west of Troutbeck in the Lake District, another late Rawtheyan horizon. In what can be seen of its ornamentation, the Welsh pygidium shows more affinity with these two forms than with the species from the basal Silurian of Watley Gill, Cautley, mentioned

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EXPLANATION OF PLATE 83

Figs. 1–4. *Mucronaspis mucronata* (Brongniart). 1, 2, BM It 13246a, b, internal mould and cast from external mould of pygidium, dorsal views, ×6. 3, BM It 13247, internal mould of cephalon, dorsal view, ×4. 4, SM A32020, internal mould of cephalon, dorsal view, ×4.

Fig. 5. *Orbiculoidea concentrica* (Wahlenberg). SM A31850a, brachial valve, ×2.

Figs. 6, 8. *Eostropheodonta whittingtoni* Bancroft. 6, SM A30039a, pedicle valve with brachial valve of *Leptaena martinensis* Cocks, ×1·4. 8, SM A32035, pedicle valve, ×1·5.

Figs. 7, 9, 12. *Eochonetes* aff. *advena* Reed. 7, BM BB 31678–31679, internal moulds of pedicle valves, note perforated hinge-lines, especially on top left-hand specimen, ×1·3. 9, BM BB 32230, brachial valve, ×1·5. 12, BM BB 31683, brachial valve, ×3.

Fig. 10. *Anisopleurella gracilis* (Jones). GSM 37555, internal mould of brachial valve, ×5.

Fig. 11. *Dalmanella* aff. *testudinaria* (Dalman). SM A31899, internal mould of large brachial valve showing musculature, ×2.

Figs. 13, 14. *Hirnantia sagittifera* (M'Coy). 13, SM A31908, pedicle valve, ×1·4. 14, SM A31912, brachial valve, ×2.

Figs. 1–3 and 10 from lower Haverford Mudstones, locality K; 1–3 collected by L. R. M. C., 10 collected by O. T. Jones. Figs. 4–6, 8, 11, 13, and 14 from St. Martin's Cemetery horizon (basal Haverford Mudstones), 4–6, 11, 13, and 14 from either of localities D and E, 8 from locality N; all collected by V. M. Turnbull. Figs. 7, 9, and 12 from upper Slade and Redhill Mudstones, locality F; collected by L. R. M. C.


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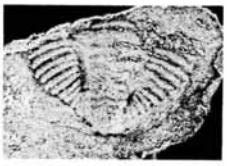
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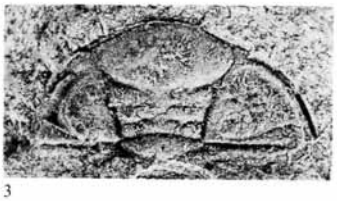
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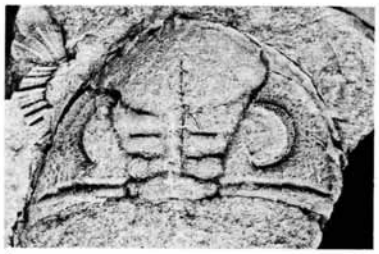
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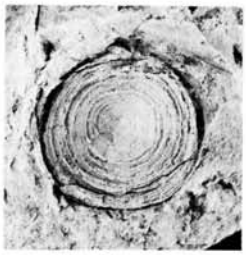
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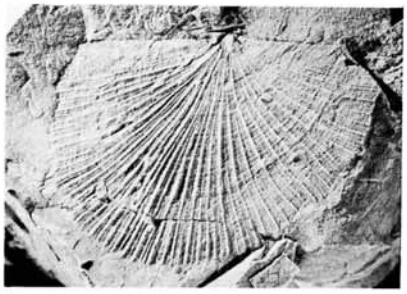
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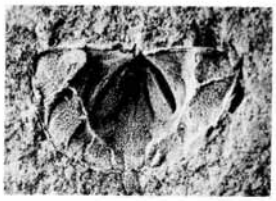
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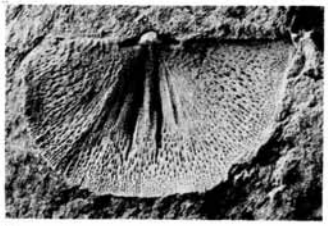
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14

COCKS and PRICE, Ordovician trilobites and brachiopods

by Temple (1975, p. 158). Similarly, the Welsh material of *Mucronaspis mucronata* does not appear to belong to the subspecies *M. m. brevispina* which at Watley Gill also occurs in the basal Silurian (Temple 1952). *Brongniartella* is known in the fauna only from two pygidia, the better of which is figured here (Pl. 81, fig. 1), and one poor, very small (?holaspid) cranidium (SM A85611). Although what features can be seen from this material are similar to the upper Ordovician *B. platynota* (Dalman, 1828), adequate comparison is not really possible.

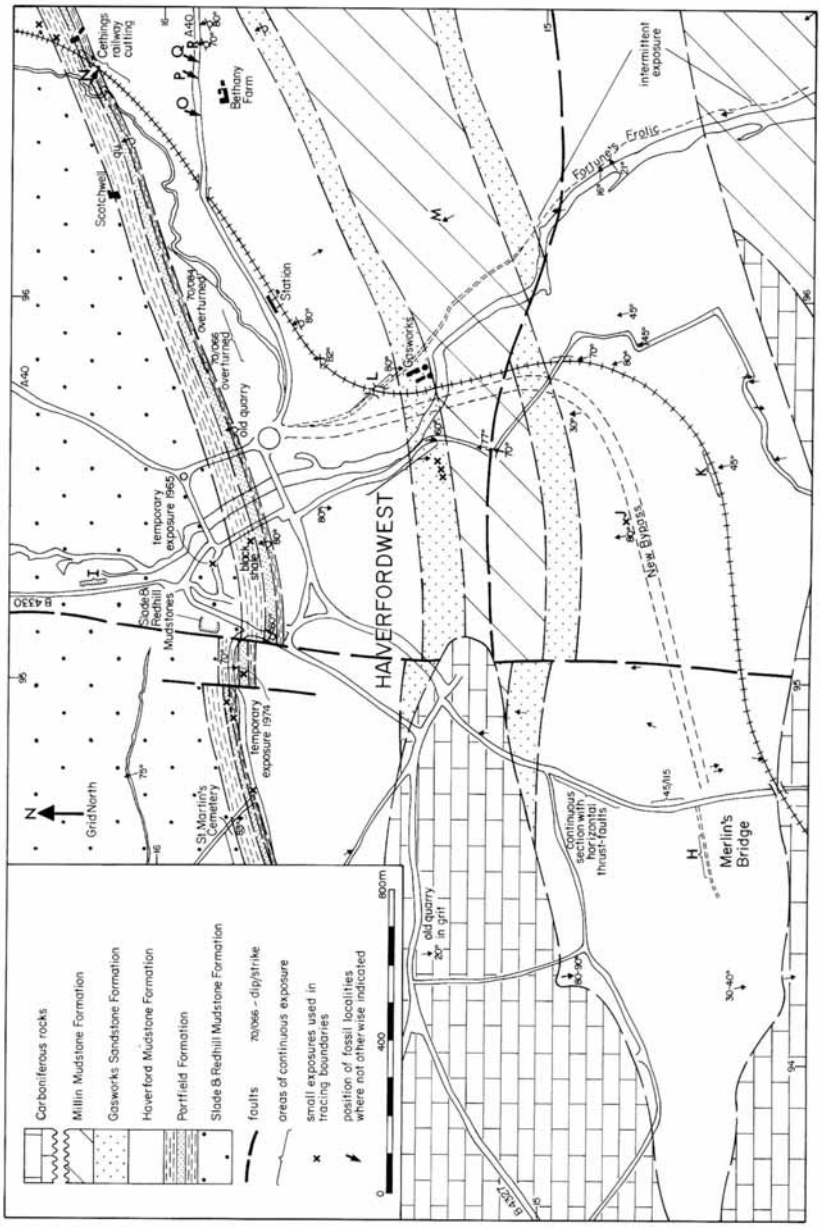
There are only two graptolite specimens known from the St. Martin's Cemetery horizon, one collected by Turnbull from the Cemetery localities and one by Pringle from the Cethings cutting. Both were identified at Cambridge, the first by Miss Elles as *Diplograptus* cf. *modestus* Lapworth (Reed 1907, p. 537) and the second by her colleague Mrs. Shakespeare (Miss Wood) as *Diplograptus modestus*? Lapworth (Strahan *et al.* 1914, p. 101). Unfortunately the Turnbull specimen is now lost, but the Pringle specimen (GSM Pg. 54) has been kindly re-examined for us by Dr. R. B. Rickards who states that, while the specimen superficially resembles *D. modestus*, it is definitely not that form and represents an undescribed diplograptid species. It seems reasonable to assume that the lost Turnbull specimen was probably of the same form (particularly in view of its 'cf.' identification) so that these graptolites are at present of little use in any determination of the detailed age of the St. Martin's Cemetery horizon. This fact is important since the original '*D. modestus*' determination was one of the main palaeontological factors in the decision by Reed and the Survey Officers to assign the horizon to the Silurian.

The shelly fauna from the St. Martin's Cemetery horizon we interpret as a *Hirnantia* fauna of late Ashgill age; it is further discussed at the end of this paper.

The Haverford Mudstone Formation

Lithostratigraphy. Although in their vertical sections (e.g. Strahan *et al.* 1914, fig. 12) the Survey workers distinguished between their 'Cartlett Beds' and 'Gasworks Mudstones', they made no attempt to map these as separate divisions. This is consistent with the experience of the present authors who have reached the conclusion that it is only the presence of distinctive shelly faunas at certain localities that enables them to be classed as developments of Gasworks Mudstones rather than Cartlett Beds; lithologically there is no clear distinction. Although there is a gradual increase in the number of thin sandstone beds upwards and also an increase in faunal content, there is no sharp change that could be used to separate two formations. We therefore group the Survey's Cartlett Beds and Gasworks Mudstones together as a single formation for which we propose the name Haverford Mudstone Formation—taking the name used by the Survey workers for the lowest stage (what would today be termed a group) of their Silurian succession.

There is no one section through which the entire formation may be followed. Many excellent localities, however, have become temporarily available for periods over the last ten years, including those due to the building of the Haverfordwest bypass, improvements along the A40 road to the east of the town, and the construction of a series of housing estates to the west of the town. The most important permanent sections in the formation are the Cethings railway cutting (text-fig. 2), where the contact with the underlying Portfield Formation is seen (locality N), the



TEXT-FIG. 2. Map of the solid geology of the Haverfordwest area. Lettered localities are those referred to in the text. The Carboniferous outcrop boundary is taken from the Geological Survey six-inch map (Pembrokeshire 27 NE.) and some of the fossil localities shown are Geological Survey localities. There are more strike-faults and minor local folds than are shown.

sections in the railway cuttings south-west of Haverfordwest Station (locality K), and the classic section running from New Road to opposite the entrance of Haverfordwest gasworks (Strahan *et al.* 1914, pp. 89–91) (locality L), where the contact with the overlying Gasworks Sandstone Formation is exposed.

The structure of the outcrop area (text-figs. 1 and 2) is complex and the exposures restricted; there are certainly more strike faults than we have shown on our maps, as well as many minor local folds.

Fauna. The Haverford Mudstone Formation is estimated to be between 350 and 390 m in thickness and is divided faunally into three parts. The basal metre includes the St. Martin's Cemetery horizon which carries a *Hirnantia* fauna, the next 210 to 250 m carries a sparse fauna discussed further below, and the uppermost 140 m contains a rich shelly fauna of typical lower Llandovery (Rhuddanian) aspect, best known through the classic exposures opposite the gasworks at Haverfordwest.

The fauna of the St. Martin's Cemetery horizon has been discussed above. The next division of the formation is largely barren of macrofauna but it has yielded fossils in four areas:

(i) 9 m above the base of the formation in the Cethings railway cutting a single graptolite was collected by Strahan *et al.* (1914, p. 89) and identified by them as ?*Diplograptus modestus parvulus* (H. Lapworth). Dr. R. B. Rickards reidentifies the specimen as ?*Climacograptus normalis* Lapworth, although he reports a hint of apertural spines recalling the *C. innotatus* group. In either case the stratigraphical significance is doubtful.

(ii) A series of exposures in the railway cutting south of Haverfordwest (locality K, Grid Ref. SM 955 146), where dark-green micaceous mudstones have yielded a shelly fauna dominated (80% in one collection, n = 103) by the small brachiopod *Anisopleurella gracilis* (Jones, 1925) (Pl. 83, fig. 10; Cocks 1970, pl. 16, figs. 1–9), with subsidiary *Mucronaspis mucronata* (Pl. 83, figs. 1–4), *Leptaena*, *Eoplectodonta*, *Lingula*,

EXPLANATION OF PLATE 84

Figs. 1, 2, 5, 6. *Hirnantia sagittifera* (M'Coy). 1, 2, BM BB 68722 and BM BB 68709, internal moulds of large brachial valves, ×2·5. 5, BM BB 38699, pedicle valve, ×2. 6, BM BB 68720, internal mould of small brachial valve, ×2.

Fig. 3. *Cryptothyrella crassa incipiens* (Williams). SM A31930, internal mould of conjoined valves, posterior view, ×2.

Figs. 4, 7. *Eostropheodonta whittingtoni* Bancroft. 4, SM A30041a, brachial valve, ×1·4. 7, SM A31884, pedicle valve, ×1·5.

Figs. 8, 10. *Eostropheodonta hirnantensis* (M'Coy). 8, BM BB 38634, brachial valve, ×1·5. 10, BM BB 38660, pedicle valve together with *Hirnantia sagittifera* brachial valve, ×1·7.

Figs. 9, 13. *Stricklandia lens lens* (J. de C. Sowerby), brachial valves. 9, BM BB 69607, ×2. 13, BM BB 69608, ×1·5.

Figs. 11, 12. *Katastrophomena* aff. *scotica* (Bancroft). 11, BM BB 69610, pedicle valve, ×2. 12, BM BB 69609, brachial valve, ×1·6.

Figs. 1, 2, 5, 6, 8, and 10 from Hirnant Quarry, south-east of Bala, Merionethshire (Gwynedd), Grid Ref. SH 945 285; collected by L. R. M. C. Figs. 3, 4, 7 from St. Martin's Cemetery horizon (basal Haverford Mudstones), localities D and E; collected by V. M. Turnbull. Figs. 9, 13 from upper Haverford Mudstones, locality J; collected by L. R. M. C. Figs. 11, 12 from upper Haverford Mudstones, locality H; collected by L. R. M. C.

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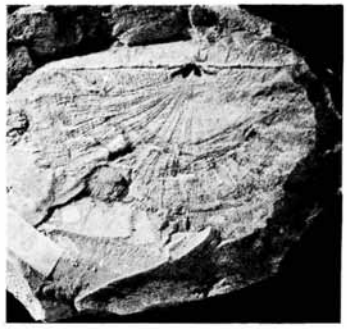

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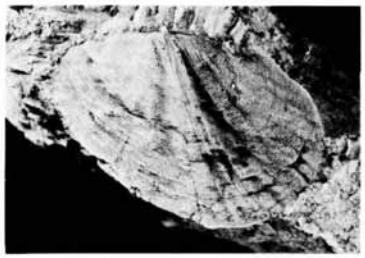

13

COCKS and PRICE, Ordovician and Silurian brachiopods

Eospirigerina, and two undetermined species of enteletacean brachiopod. Unfortunately the exact stratigraphical horizon of this locality within the formation is difficult to determine, since it lies on the southern limb of a syncline when compared with other localities (text-fig. 2).

(iii) Several temporary exposures in the foundations of new houses in the area around Portfield House (text-fig. 1). At one locality (locality B, Grid Ref. SM 9375 1550) *Anisopleurella gracilis* occurred in some quantity, and 60 m north of this (SM 9374 1556, locality C) an indeterminate graptolite fragment. The former locality is an estimated 45 m from the base of the formation, the latter about 20 m.

(iv) A series of exposures, mainly temporary, along the main A40 road just north of Bethany Farm (text-fig. 2). At locality P (Grid Ref. SM 9653 1590) *A. gracilis* occurred as many specimens on a single bedding plane and *Orbiculoidea*, *Eospirigerina*, *Leptaena*, *Eoplectodonta*, *Skenidioides*, and *Resserella* (BM BB 70622–70631) as scattered single specimens. This is near a locality (O on text-fig. 2) termed Eλ 23 by the Survey, which yielded to them, as well as *A. gracilis*, a graptolite (GSM TCC 1876/7) which Dr. Rickards identifies as *Climacograptus* cf. *normalis* Lapworth. From a stratigraphically slightly higher horizon (locality Q, Grid Ref. SM 9661 1589), no longer exposed, the Survey (their locality Eλ 24) recovered single specimens of *Cryptothyrella*, *Leangella scissa* (Davidson, 1871), *Eospirigerina*, ?*Clorinda*, *Eostropheodonta*, and ?*Anisopleurella* and three specimens of *Resserella*, a fauna which, although not fully diagnostic, suggests for the first time in the formation a positive Llandovery, rather than an Ashgill, age. Within 15 m above this (locality R, Survey loc. Eλ 28, Grid Ref. SM 9666 1591) a typical Llandovery fauna, including *Stricklandia*, occurs.

Thus the age of this central division of the Haverford Mudstone Formation remains equivocal. Below it there is a definite Hirnantian horizon and above it a definite Rhuddanian horizon. Where within this division the boundary limit between these Stages, and hence between the Ordovician and Silurian, should be drawn is uncertain. There seems a good case for putting the highest 15 m of the division (locality Q and above) into the Rhuddanian, but the underlying 235 m with its sparse *Anisopleurella* fauna and *Mucronaspis mucronata* could just as well be Hirnantian; we do not regard the presence of *Mucronaspis* as being necessarily diagnostic in this respect. It is hoped that more graptolites may be recovered from these horizons in the future, although even graptolite faunas near the Ordovician–Silurian boundary still await a definitive study.

The fauna of the uppermost 140 m of the formation is one of the richest in the Rhuddanian of Britain. Temple (1975) has reviewed the trilobites and redescribes *Calymene crassa* (Shirley, 1936), *Calymene* sp. A, *Brongniartella* sp., *Hadromeros elongatus* (Reed, 1931), *Acernaspis* sp., *Dalmanites* sp., *Stenopareia* sp., and an indeterminable odontopleurine. The faunas, however, are numerically dominated by brachiopods, of which only the strophomenides have yet been redescribed (Cocks 1968, 1970), although many of the forms described by Temple (1970) from Meifod also occur in the Haverfordwest area. The chief localities are:

(i) The lane leading from New Road to the gasworks, Haverfordwest (locality L, Grid Ref. SM 9622 1500 to SM 9582 1537; Strahan *et al.* 1914, pp. 90–91).

(ii) Along the path known as Fortune's Frolic (text-fig. 2) on the east bank of the Western Cleddau (Grid Ref. SM 9622 1500 to SM 9647 1461; Strahan *et al.* 1914, pp. 92–96), where the succession is repeated by local folding and faulting.

(iii) The area around Priory Mill (Grid Ref. SM 959 149), including some large temporary exposures made during the construction of the southern bypass in 1974, from locality J (SM 9540 1478) eastwards.

(iv) The area around Merlin's Bridge (text-fig. 2) where there are several isolated exposures. Jones (*in* Strahan *et al.* 1914, pp. 96–99) was concerned that the faunal aspect of these '*Pentamerus undatus* beds', as he called them, was not the same as that of those opposite the gasworks entrance. We have examined the material collected by the Survey and made new collections from several localities, in particular an old quarry west of Merlin's Bridge (locality H, Grid Ref. SM 946 146), and there is no doubt that the exposures fall within the uppermost part of our Haverford Mudstone Formation.

There are three different main brachiopod assemblages present in the upper division:

(i) Faunas dominated by *Clorinda undata* (J. de C. Sowerby) and *Eoplectodonta duplicata* (J. de C. Sowerby), and typical of most of the exposures in the Merlin's Bridge area. A collection from locality H yielded *Clorinda undata* (23%), *Eoplectodonta duplicata* (18%), *Resserella llandoveriana* Williams (10%), *Skenidioides woodlandiense* (Davidson) (9%), nine other species of brachiopod, and eight species of other groups (n = 122).

(ii) Faunas dominated by *Stricklandia lens*, very often in nearly monospecific assemblages covering single bedding planes, with some specimens even in position of growth (Ziegler *et al.* 1966). The subspecies present is chiefly *S. lens lens* (J. de C. Sowerby), but some populations and individuals are morphologically closer to *S. l. prima* Williams, whose type horizon and locality (Williams 1951) is A_{2-3} Beds at Llandovery itself, and which is the earliest Silurian stricklandiid form. These *Stricklandia*-dominated assemblages are widespread, extending well outside the area to such localities as that north of Woodford Cottage, south of Robeston Wathen (Grid Ref. SN 0848 1504).

(iii) Diverse faunas without common pentamerids, the best examples coming from the exposures opposite the entrance to the gasworks at Haverfordwest (locality L). In a large collection from a band approximately 14 m below the top of the formation, brachiopods dominated the assemblage, with twenty different species, including *Eoplectodonta duplicata* (18%), *Resserella llandoveriana* Williams (9%), *Leangella scissa* (8%), *Eopholidostrophia sefinensis ellisae* Hurst (5%), *Eostrophonella eothen* Bancroft (3%), and *Schizonema sowerbyiana* Davidson (2%) (n = 658), but the collection also contained at least seventeen species of other phyla, including a thick stick bryozoan, possibly *Hallopora* (15%), *Tentaculites* (10%), the dasyclad alga *Mastopora fava* Salter (5%), a thin stick bryozoan (4%), and a compound bryozoan (3%), one species of orthoceratid, three species of gastropod, one of bivalve, two species of coral, much crinoid debris, and four different trilobites (*Calymene crassa*, an odontopleurine—probably *Leonaspis*, a phacopid, and an encrinurid). Another, much smaller, collection from the railway cutting 40 m NE. of the railway bridge

(Grid Ref. SM 9579 1551) was from a single thin band and was very much less diverse, being dominated by *Katastrophomena scotica* (Bancroft) (59%), with the next most common taxa each at 7% (*Resserella llandoveriana* and a bryozoan). A notable feature of this faunal group is the variety of assemblages encountered, with particular abundances of groups other than brachiopods, and an unusual absence of pentamerids.

The interpretation of the first two of these upper division assemblages is that they can be identified with the *Clorinda* and *Stricklandia* Communities defined in the upper Llandovery of the Welsh Borderland (Ziegler *et al.* 1968). However, the interpretation of the third group, which is both varied and diverse, presents more of a problem. Perhaps the most likely solution is that assemblages are represented which ecologically parallel a typical *Clorinda* Community, but from an environment locally unsuited to *Clorinda* itself or other pentamerids; the abundance of bryozoa and *Mastopora* are also unusual. Whether or not the deposition was unusual is uncertain. Sanzen-Baker (1972, p. 152) suggests that the upper parts of the Haverford Formation were partly deposited from turbidity currents, and the jumbled nature of many of the third assemblage occurrences would be explained by this. On the other hand, the fact that many of the brachiopods are found with conjoined valves, and that the fragile calcareous algae are found at all, implies that the amount of pre-depositional disruption was not great. In any case a Rhuddanian age for the upper part of the Haverford Mudstone Formation is quite certain.

Gasworks Sandstone and Millin Mudstone Formations

Lithostratigraphy. Detailed discussion of these later formations is outside the scope of this paper. Sanzen-Baker (1972) has described the turbidites of the Gasworks Sandstone Formation, which succeed the Haverford Mudstone Formation apparently conformably. Above the Gasworks Sandstone there are thick mudstones which Strahan *et al.* (1914) divided into lower Uzmaston Beds and upper Canaston Beds. The Survey workers were not able to map these two divisions separately, and the present authors treat them as one formation, the Millin Mudstone Formation, whose name is taken from the Survey's 'Series' name.

Fauna. Fossils, chiefly brachiopods, occur sporadically within the Gasworks Sandstone Formation, but their age is not diagnostic. The Millin Mudstone Formation is more fossiliferous, yielding late Llandovery faunas chiefly representing the *Clorinda* Community. These beds may be dated by stricklandiids and *Eocoelia* to a variety of ages within the Fronian and Telychian stages; a representative locality occurring on our map (locality M, Survey loc. Eλ 25, Grid Ref. SM 9620 1525) included *Anthirhynchonella linguifera* (J. de C. Sowerby), *Eoplectodonta penkillensis* (Reed), *Clorinda undata* (J. de C. Sowerby), *Leptaena purpurea* Cocks, *Atrypa reticularis* (Linnaeus), and *Eocoelia curtisi* Ziegler, indicating a Telychian age at approximately 90 m above the base of the Millin Mudstone Formation.

THE *HIRNANTIA* FAUNA

For many years a fauna has been known, typified by the association of the enteletacean *Hirnantia sagittifera* (M'Coy) and the strophomenide *Eostropheodonta hirnantensis*

(M'Coy), from near the Ordovician–Silurian boundary. The type area is at Aber Hirnant, south-east of Bala, North Wales, where the beds were often regarded as post-Ashgill (Elles 1922; Bancroft 1933, p. 4), although more recently these beds at Hirnant were revised to form the type Hirnantian, the highest stage within the Ashgill Series (Ingham and Wright 1970). It is perhaps unfortunate that the name of the fauna and the name of the stratigraphical time division should be so similar; although this misfortune has since been compounded into error, for example by Lespérance (1974), who even explicitly equates the two terms, resulting in an erroneous hybrid 'Hirnantian fauna', which Lespérance identifies, as if by definition, with the Hirnantian time horizon (Stage).

The beds around Aber Hirnant await modern redescription, but a collection from Hirnant Quarry yielded the following seven brachiopods: *E. hirnantensis* (30%, n = 153), *H. sagittifera* (21%), *Plectothyrella crassicosta* (Dalman, 1828) (10%), *Kinnella kielanae* (Temple, 1965) (9%), *Dalmanella* sp. (9%), *Bancroftina? bouceki* (Havlíček, 1950) (8%), and *Skenidioides* sp. (1%). The only representatives of other phyla were a few crinoid ossicles, some compound bryozoa, and some borings, presumably of sponges, into the brachiopod shells. These data are comparable with the percentages (of brachiopods only) from the same locality recorded by Temple (1965, p. 419), and consist of the same species, with the addition only of the uncommon *Skenidioides*. The lithology of Hirnant Quarry is variable, but includes a pisolitic oolite not seen elsewhere.

This *Hirnantia* fauna is very comparable in composition and diversity with others from near Llangollen, North Wales, and from Hol Beck (Temple 1965, p. 418) and Cautley (Wright 1968, p. 361), both in northern England. These *Hirnantia* faunas, however, are less diverse than others which possess the same basic elements but with the addition of other taxa. One such is from the St. Martin's Cemetery horizon, described above. Another, from Stawy, Poland, contains three inarticulate and seven articulate species of brachiopod as well as 'trilobites, ostracods, bryozoans, worm tubes, a hyolithid and crinoid and graptolite fragments' (Temple 1965, p. 380). A further fauna, from the Kildare Limestone, Ireland (Wright 1968) consisted of *Cyptothyrella crassa incipiens* (35%), *Cliftonia oxoplecioides* (28%), *Plectothyrella platystrophoides* (19%), dalmanellids (including *Dalmanella*) (12%), cf. *Leptaenopoma* (4%), *H. sagittifera* (3%), and *Eostropheodonta* sp. (less than 1%). Rare trilobites included *Dalmanitina* sp. and an odontopleurid. It is of great interest that Wright records that these Kildare Beds, which include the *Hirnantia* fauna elements, are actually interbedded with reef limestones with a rich and diverse fauna including *Cliftonia*, *Streptis*, *Triplesia*, *Anisopleurella*, *Leptaena*, and *Christiania*, as well as *Sphaeroxochus*, illanenids and other trilobites, ostracodes, byrozoans, and algae; and it is also interesting to note the records of fragmentary trinucleids from beds above those with the *Hirnantia* fauna.

Bergström (1968) gives valuable data on the brachiopod fauna of the *Dalmanitina* Beds in Västergötland, Sweden. Of the eighteen localities from which he records brachiopods, seven (his fig. 4 locality nos. 1, 3, 6–7, 8, 10, 14, and 28) are typical, fairly restricted, *Hirnantia* assemblages, four (his localities 18 and 22–24) are not *Hirnantia* assemblages, and the rest are diverse assemblages which include *Hirnantia* fauna elements to greater or lesser extents. His most prolific exposure (his locality 5)

yielded an interesting assemblage consisting of (percentages calculated from his fig. 4 of brachiopods only): *Coolinia dalmani* (43%) (n = 625), *H. sagittifera* (9%), *K. kielanae* (9%), *E. hirnantensis* (7%), *P. crassicosta* (6%), *Cliftonia psittacina* (5%), *Horderleyella fragilis* (4%), *Aphanomena schmalenseei* (4%), *Leptaenopoma trifidum* (3%), *Leptaena rugosa* (3%), *Orbiculoidea concentrica* (2%), *Drabovia westrogothica* (1%), *Giraldiella bella* (1%), *Dalmanella testudinaria* (1%), *Draborthis caelebs* (1%), *Titanomena grandis* (1%), and rare *Dalmanella pectinoides* and *Petrocrania aperta*, a total of eighteen brachiopod species, which is quite diverse. Bergström also records (1968, p. 5) *Hirnantia* fauna elements from Jämtland, northern Sweden, occurring in the same beds as *Dalmanitina mucronata*, *Brongniartella platynota*, and also *Tretaspis*.

Marek and Havlíček (1967) described comparable assemblages from the Kosov Formation of Bohemia in which *Hirnantia* fauna elements—*Hirnantia*, *Kinnella*, *Dalmanella testudinaria*, *Cliftonia*, *E. hirnanentensis*, *Leptaena rugosa*, *Cryptothyrella*, and *Plectothyrella* occur with other forms—*Giraldiella subsilurica*, *Comatopoma sororia*, *Drabovia agnata*, *Draborthis caelebs*, *Onniella rava*, *Aegiromena ultima*, *Rafinesquina urbicola*, *R. ultrix*, *Leptaenopoma trifidum*, *Bracteoleptaena polonica*, *Fardenia comes*, and *Zygospira fallax*. Although a few of these latter species have been recorded with *Hirnantia* fauna elements elsewhere (e.g. Bergström 1968), most of them are not found in the strict *Hirnantia* fauna at all.

Havlíček (1971) also described a comparable fauna from the Deuxième Bani of the Anti-Atlas, Morocco. Here, in addition to *Hirnantia*, *Eostropheodonta*, and *Plectothyrella*, he described another ten brachiopod species not so far recognized elsewhere. *Hirnantia* aff. *sagittifera* and endemic species of *Plectothyrella* have also been described from the Memouniat Formation of Libya (Havlíček and Massa 1973).

Lespérance (1974, tables 1 and 2) reports a fauna from Percé, Canada, consisting of *Brongniartella* sp., *M. mucronata*, *M. olini*, *Philipsinella parabola*, two other endemic trilobites, *Dalmanella*?, *E. hirnantensis*, *Hirnantia*?, *Kinnella kielanae*, and *Plectothyrella*, but he does not give relative abundances, or state whether the fauna was all collected from the same horizon. From the Portage River area, 17 km away, Lespérance records a fauna (without brachiopods) in which the trilobites *M. mucronata*, *M. olini*, *Brongniartella*, *Portaginus*, and *Cryptolithus* occur together with what he records as *Climacograptus rectangularismedius*, the latter suggesting an early Silurian age. However, Dr. Rickards (pers. comm.) believes that these graptolites probably represent an earlier climacograptid stock, perhaps evolved from *C. normalis*, and that their age, although uncertain, is more probably late Ordovician.

The situation in Kazakhstan, U.S.S.R., requires further clarification: Nikitin (1971, p. 339) records *M. mucronata* and *M. olini* from the upper Tolen Beds in association with *Glyptograptus persculptus*, but a *Hirnantia* fauna as such does not seem to be present, the only brachiopod recorded being '*Conchidium*' *munsteri*.

Thus the *Hirnantia* fauna assemblages are widely variable; sometimes restricted to a mere two genera, at other times consisting of the basic half-dozen *Hirnantia* fauna elements with up to twelve associated cosmopolitan or endemic brachiopods. Sometimes no trilobites are present; at other times one or more representatives of the '*Dalmanitina*' fauna with or without other cosmopolitan or endemic forms. We believe that the *Hirnantia* fauna is best interpreted as representing an animal com-

munity comparable with those described by Ziegler *et al.* (1968), rather than as a single time assemblage zone, and that its occurrence is therefore *a priori* as likely to be diachronous as synchronous. As Wright (1968, p. 365) suggested, the *Hirnantia* Community, at least in its restricted form, suggests original deposition under relatively shallow water; but perhaps the more diverse *Hirnantia* assemblages could reflect deposition under slightly deeper water.

Spectacular evidence for a late Ordovician–early Silurian glacial event has been accumulating from many parts of the world for some years, and this event is probably connected with the faunal changes seen across the Ordovician/Silurian boundary. Obviously near the then poles this glacial event would have been more prolonged than in equatorial regions, but to what extent the *Hirnantia* Community is a direct reflection of cold-water conditions is as yet uncertain. In the same way the degree to which this glaciation coincides with the extent of the Hirnantian Stage remains unknown.

The age range of the *Hirnantia* Community also remains uncertain. *Eostropheodonta* ranges from Cautleyan up to the Wenlock, *Hirnantia* itself is known from the early Ashgill to late Llandovery (Walmsley *et al.* 1969, p. 515), *Cryptothyrella* from the early Ashgill to the Wenlock, *Dalmanella* s.s. from the Caradoc to the Llandovery, and *Plectothyrella* from the Ashgill to the Llandovery. Of the typical *Hirnantia* Community forms only *Kinnella* appears to be confined to the late Ashgill, and that enteletacean has only been recognized comparatively recently (Bergström 1968) as a separate genus; its range is not definitively known. Sometimes the *Hirnantia* Community occurs below tretaspid trilobites, at other times in the same beds, and at yet other times apparently later than the last local tretaspid fauna. In a similar fashion the ranges of the trilobites that make up the '*Dalmanitina*' fauna also vary and their occurrences should be assessed separately from those of the whole *Hirnantia* Community. Very often the two occur together in a single assemblage, but at other times each is found separately. Thus to conclude that the *Hirnantia* Community occurrences are all of the same age appears to us to be a dangerous assumption.

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