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Cambrian stratigraphy of St Tudwal's Peninsula, Gwynedd, northwest Wales

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Abstract – Lithostratigraphic units of early to late Cambrian age established by T. C. Nicholas in 1915 in the St Tudwal's Peninsula are revised. They comprise, in ascending order: Hell's Mouth Formation (> 190 m); Trwyn y Fulfran Formation (37 m); Cilan Formation (400 m); Ceiriad Formation (40 m seen); Nant-y-big Formation (> 110 m seen); Maentwrog Formation (in part, 50 m seen, an estimated 250 m concealed); Ffestiniog Flags Formation (in part, *c.* 120 m seen). The 'calcareous grit' at the top of Nicholas's Nant-pig Mudstones spans the unconformable boundary between the Nant-y-big and Maentwrog formations. Previously described limestone clasts in the 'grit' are probably erosional remnants of an *in situ* bioclastic limestone bed; their contained trilobites include genera and species found in the Andrarum Limestone (late Middle Cambrian) of Scania, Sweden. Acritarchs are documented and compared particularly with those from eastern Newfoundland. Those from the highest part of the 'calcareous grit' include *Cymatiogalea* sp. and are of late Cambrian age. One new species, *Heliosphaeridium? llynense* Martin, comes from the lower part of the Nant-y-big Formation (middle Middle Cambrian), where it appears a little earlier than the *Adara alea* Biozone.

1. Introduction (T.Y., W.T.D., F.M.)

St Tudwal's Peninsula and adjacent small islands form the southeastern tip of the Llŷn Peninsula, at the northern end of Cardigan Bay, northwest Wales (Fig. 1). Cambrian rocks and fossils were recognized there during the nineteenth century, but the first detailed account was that of Nicholas (1915, 1916), which formed the basis of subsequent interpretations. The relatively small Cambrian outcrop is important in Welsh Lower Palaeozoic stratigraphy as it lies near the northwest margin of the Welsh Basin. The succession (Fig. 2), broadly comparable with that of the Harlech Dome, 30 km to the east, is some 1400 m thick but the base is not seen. The Harlech Grits Group (Lower–?Middle Cambrian) consists largely of arenaceous turbidites; mudstones and siltstones are dominant in the overlying Ceiriad and Nant-y-big formations (Middle Cambrian). Above an unconformity the Maentwrog and Ffestiniog Flags formations (Upper Cambrian) correspond to a shelf environment, with indicators of storm-dominated depositional processes. The highest parts of the succession are not well seen at St Tudwal's, but north of the Sarn–Abersoch Fault, Tremadoc (Ordovician) strata crop out, represented by the Dol-cyn-afon Formation. Revised terminology of the Cambrian rocks used in the BGS Pwllheli Memoir (Young, Gibbons & McCarroll, in press) and followed here forms part of the mapping of Sheet 134 (Pwllheli) under NERC contract F60/G2/28 awarded to the Department of Geology, University of Wales College of Cardiff. All map references refer to National Grid square SH.

Macrofossils are generally scarce in the Cambrian of St Tudwal's, and apart from the discovery of late Lower Cambrian trilobites in the highest Hell's Mouth Formation in 1960 (Bassett & Walton, 1960; Bassett, Owens & Rushton, 1976) there have been no significant additions to the collection made by the late T. C. Nicholas and reviewed both by Rushton (1974) and herein. Most of the macrofossils are Middle Cambrian trilobites, particularly agnostids or eodiscids, of which the former provide zonal indices for most of the classic 'reference' sections in Sweden (Westergård, 1946) and were widely distributed, though with a distinct preference for deeper marine environments. A few Upper Cambrian trilobites at one level in the Maentwrog Formation indicate, probably, the *Olenus* Biozone; the lower part of the *Parabolina spinulosa* Biozone is possible but unlikely.

A pioneer study on the Cambrian acritarchs of North Wales by T. L. Potter in a Ph.D. thesis of 1974 remains unpublished except for a short note (Potter, 1974). The present palynological investigation permits a partial comparison with results obtained in eastern Newfoundland (Martin & Dean, 1981, 1983, 1984, 1988), where biostratigraphic control based on trilobites is often better and macrofossils, which have many species in common with those of Scandinavia

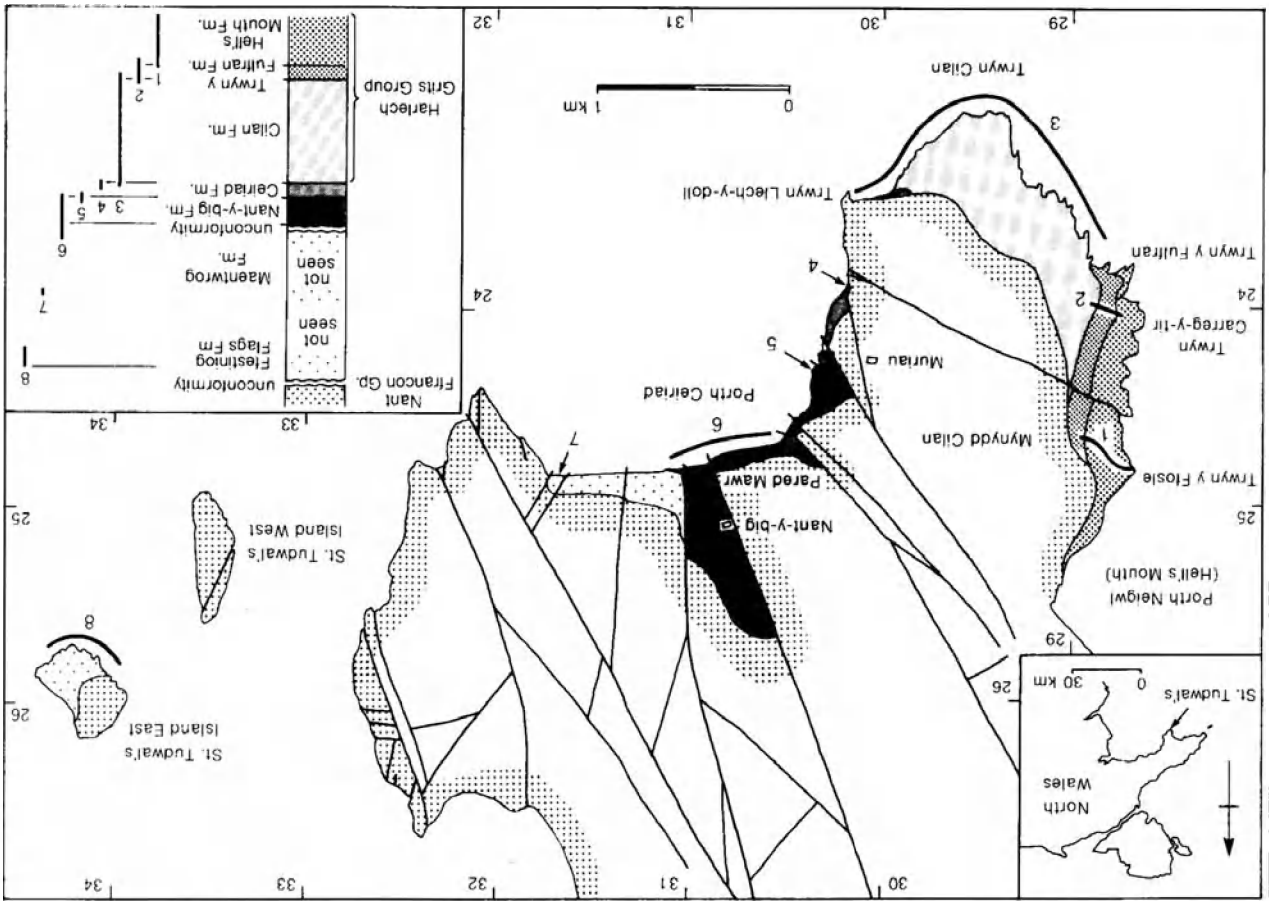

Figure 1. Outline maps of North Wales (inset), St Tudwal's Peninsula and adjacent islands, showing locations of sections mentioned in the text. Geology after British Geological Survey (BGS) 1:50000 Sheet 134, Pwllheli (in press). Course of faults inland partly uncertain. Section number as follows: (1) type section for Hell's Mouth Formation; (2) type section for topmost Hell's Mouth Formation, Trwyn y Fulfran Formation and base of Cilan Formation; (3) type section for body of Cilan Formation and base of Ceiriad Formation; (4) fault bounded type section for middle of Ceiriad Formation; (5) base of Nant-y-big Formation; (6) type section for Nant-y-big Formation and section through lower part of Maentwrog Formation; (7) isolated section in Maentwrog Formation; (8) section through part of Ffestiniog Flags Formation.

and Wales, are more readily collected. A few selected trilobites and acritarchs are published elsewhere by Young, Gibbons & McCarroll (in press). Present illustrations of macrofossils are confined to material from Porth Ceiriad, in the so-called 'calcareous grit' of Nicholas (1915), which spans the boundary between the Nant-y-big and Maentwrog formations, and at a higher level in the Maentwrog Formation. Characteristic acritarchs illustrated here range from the upper part of the Hell's Mouth Formation at Trwyn y Ffosle to the Maentwrog Formation at Porth Ceiriad, and from the lower part of the Ffestiniog Flags Formation outcrop on St Tudwal's Island East.

Palaeontological specimens with prefix SM are from the Sedgwick Museum, Cambridge, and those with the prefix IRScNB from the Institut royal des Sciences naturelles de Belgique, Brussels.

2. Dyfed Supergroup (T.Y.)

The Cambrian succession at St Tudwal's forms part of the Dyfed Supergroup (Woodcock, 1990), the base of which is not seen here. In the area of Mynydd Rhiw and Sarn, 6 km northwest of St Tudwal's, the succeeding Gwynedd Supergroup (Ordovician, Arenig) rests unconformably on the late Precambrian Sarn Complex. In the Harlech area, 30 km to the east, the base of the Dyfed Supergroup was seen in the Bryn-teg borehole, where the Dolwen Formation lies unconformably on the Bryn-teg Volcanic Formation of probable late Precambrian age (Allen & Jackson, 1985).

The base of the Gwynedd Supergroup was defined (Woodcock, 1990) as the base of the transgressive succession of Ordovician (Arenig) age over most of North Wales, but locally as the base of the Rhobell Volcanic Complex. It is marked in the current area by the unconformity below the Nant Ffrancon Group (Arenig). The latter group rests on the Dol-cyn-afon Formation (Ordovician, ?lower Tremadoc) to the north of St Tudwal's Peninsula near Abersoch, and on the peninsula itself, on progressively older parts of the Cambrian succession from the Ffestiniog Flags Formation in the east to the Hell's Mouth Formation in the west. The unconformity becomes more angular from east to west.

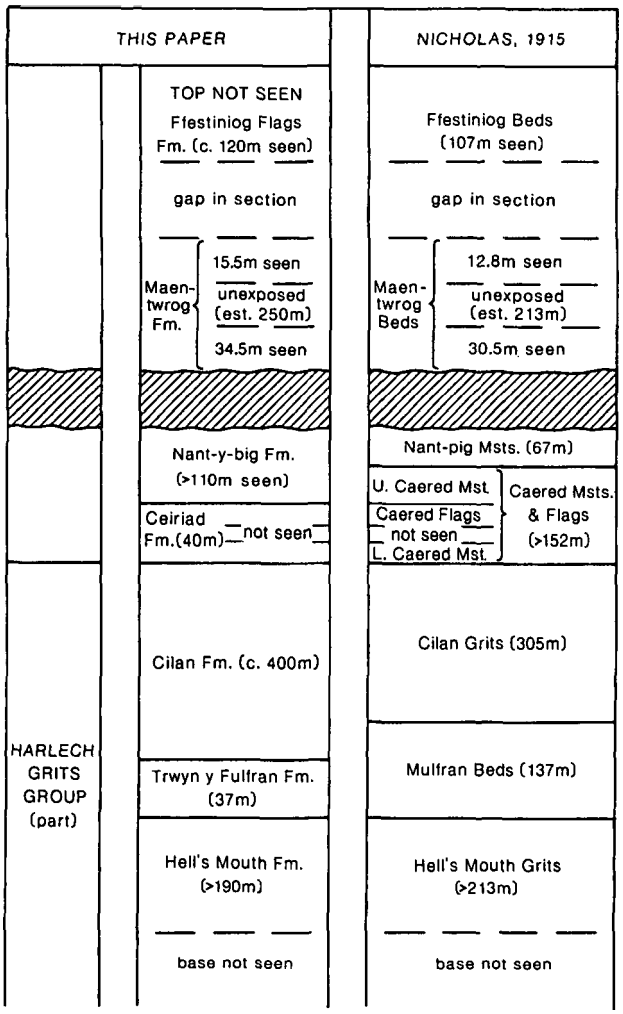

Figure 2. Cambrian lithostratigraphic succession at St Tudwal's Peninsula and St Tudwal's Island East. For chronostratigraphic ages of formations see Figure 8.

2.a. Harlech Grits Group (T.Y.)

The group is typified by a succession dominated by sand-grade, or coarser, thickly-bedded turbidites. The base of the overlying Ceiriad Formation is marked by a significant, abrupt decrease in sediment grain size. The Harlech Grits Group of St Tudwal's Peninsula includes two thick, turbidite-dominated formations (Hell's Mouth and Cilan) separated by an interval characterized by finer-grained sediments, particularly manganiferous siltstones (Trwyn y Fulfran Formation).

In its type area the Harlech Grits Group (Allen, Jackson & Rushton, 1981) includes the Dolwen, Llanbedr, Rhinog, Hafotty, Barmouth and Gamlan formations. None of these is lithostratigraphically equivalent to any of the formations at St Tudwal's, but there is broad similarity between the Rhinog, Hafotty and Barmouth formations on the one hand, and the Hell's Mouth, Trwyn y Fulfran and Cilan formations on the other.

The base of the group is not seen at St Tudwal's, where the observed succession is over 630 m thick. Comparison with the sequence in the Harlech area suggests that a considerable thickness of Cambrian strata (equivalent to the lower Rhinog, Llanbedr and Dolwen formations, totalling 1500 m at Harlech) might be concealed beneath the sea in the Hell's Mouth area.

2.b. Hell's Mouth Formation

2.b.1. Lithostratigraphy (T.Y.)

The unit, equivalent to the 'Hell's Mouth Grits' of Nicholas (1915), comprises laterally persistent, coarse- to medium-grained, graded green sandstone beds (< 4 m thick), interbedded with thinner (< 0.5 m) green and grey siltstones. Some 190 m of the Hell's Mouth Formation are seen, but the base is not exposed and the oldest visible beds are those near sea-level on the west side of St Tudwal's Peninsula.

Type Section. At Trwyn y Ffosle, where a relatively complete succession can be traced from sea-level [2868 2482] to the manganese trials marking the line of outcrop of the overlying Trwyn y Fulfran Formation [2894 2464]. The upper part of this section is not well exposed, so the section above Trwyn Carreg-y-tir [2876 2402] has been used to define the base of the Trwyn y Fulfran Formation (Fig. 3).

Description. The sandstones have sharply defined bases which often bear sole structures and may be loaded. Sandstone dykes cut down from the bases of some beds and extend through up to 0.6 m of underlying siltstones. The body of the sandstone beds is usually structureless but often shows a bedding-parallel jointing. The beds are typically crudely graded, with the basal layers of coarse sand grade, sometimes as coarse as granule grade; they are generally dominated by medium- to coarse-grade sand. The upper parts of the beds fine upwards to silt grade, are usually parallel laminated, but may show ripple lamination at the very top, which is typically gradational into the overlying siltstone. The sandstones may form sheets up to 4 m thick, though a bed thickness of up to 1 m is more usual, and they have been interpreted as turbidites deposited by currents from the northeast (Bassett & Walton, 1960). Background sediments include siliceous mudstones with beds of micaceous siltstone, together with thin beds and lenses of coarse sand to granule grade. The lenses suggest some reworking or winnowing of the sediments between major depositional events.

2.b.2. Biostratigraphy: macrofossils (W.T.D., A.W.A.R.)

Trilobites, including *Hamatolenus* (*Myopsolenus*) *douglasi* and *Kerberodiscus succinctus*, were described by Bassett, Owens & Rushton (1976) from a level 16.5 m below the base of the overlying Trwyn y Fulfran Formation at Trwyn Carreg-y-tir [2875 2404],

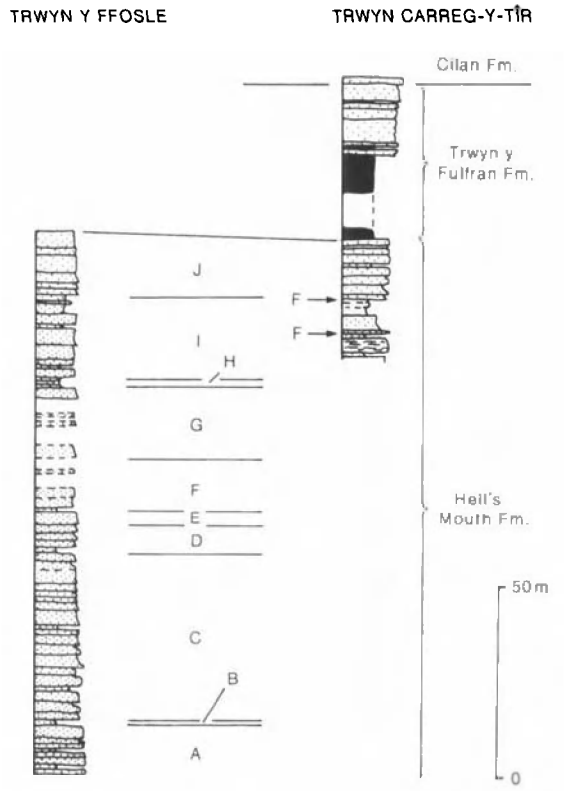

Figure 3. Log of sections through the lower part of Harlech Grits Group (Fig. 1, sections 1, 2). Left: type section of Hell's Mouth Formation, Trwyn y Ffosle section [2873 2480] to [2888 2472]. Right: type section of Trwyn y Fulfran Formation and basal Cilan formation; Trwyn Careg-y-tir section [2872 2403] to [2887 2390]. A–J = lithofacies divisions; F = fossil localities of Bassett & Walton (1960). Strata shaded black denote manganiferous beds.

on the southwest margin of St Tudwal's Peninsula. The former species, a protolenid, belongs to a genus known from the Lower and lowest Middle Cambrian of the Anti-Atlas Mountains, Morocco; the latter is one of a number of eodiscids widespread in only the highest Lower Cambrian of what is now Europe and eastern North America, regions that formed part of the Gondwana 'supercontinent' during early Palaeozoic times. A single pygidial fragment identified by Bassett, Owens & Rushton (1976, p. 629) as '*Serrodiscus ctenoa*? Rushton' (1966, p. 14) refers to a species from late in the *Protolenus* Zone of Warwickshire. Cowie, Rushton & Stubblefield (1972) introduced a 'Protolenid–Strenuellid' Biozone to designate the topmost zone of the Lower Cambrian, or Comley Series (named after rocks in the Church Stretton area, Shropshire), and the assemblage from the Hell's Mouth Formation is of this age. No macrofossils useful for delimiting the Lower–Middle Cambrian boundary in the St Tudwal's Peninsula are yet known. Geyer (1990) has assigned the 'Protolenid–Strenuellid' Biozone to the earliest Middle rather than the latest Lower Cambrian on the basis of evidence cited from Morocco; this raises wider problems for defining the Lower–Middle Cambrian boundary in the Cambrian type area and elsewhere, but for present purposes the traditional interpretation is followed.

2.b.3. Biostratigraphy: microfossils (F.M.)

East of Trwyn y Fossle acritarchs from the upper part of the Hell's Mouth Formation are often numerous but, at best, moderately well preserved. Only *Skiagia scottica* Downie, 1982 (Figs. 10m, r, t–v), abundant in the upper part of the formation, and *Skiagia insignis* (Fridrichsone) Downie, 1982 (Fig. 10p) and *Peramorpha manuelsensis* Martin in Martin & Dean, 1983 (Fig. 10n), both very rare at a level 66 m below the top, are limited to the Lower Cambrian in the Llŷn Peninsula. According to Downie (1982) *S. scottica* is known from the Lower Cambrian in the *Holmia* Shales of Norway, the Bastion Formation in Greenland and the Fucoid Beds in northwest Scotland. In the first of these regions its age is middle Lower Cambrian, and is the oldest record based on direct, independent age control. According to Cowie (1974, pp. 145, 148) the Bastion Formation and the Fucoid Beds are of the same age, and both contain the *Olenellus* Biozone of North America, correlated by Fritz (1972, p. 4) with the '*Protolenus* Biozone' of Europe and eastern Canada, itself equivalent to the 'Protolenid–Strenuellid' Biozone of Cowie, Rushton & Stubblefield (1972). All the type specimens of *S. scottica* illustrated by Downie (1982) came from the Fucoid Beds and their age is late Lower Cambrian. *Skiagia scottica* has a vast geographic distribution, including the East European Platform and east Spitsbergen (references in Moczydłowska, 1991), and the South China Platform (Zang, 1992), and is known only from deposits attributed to the Lower Cambrian. On the other hand, *Skiagia insignis* is not typical of the series and was first described from the Kibertai Horizon, early Middle Cambrian, of the East European Platform (Volkova *et al.* 1979). *Peramorpha manuelsensis* is known from the Brigus Formation, late Lower Cambrian, in eastern Newfoundland (Martin & Dean, 1983), at a level dated as '*Catadoxides* Biozone', correlated by Hutchinson (1962) with the '*Protolenus*' Biozone and by Bengtson & Fletcher (1983, fig. 5) with a level about the middle of that division.

Cymatiosphaera capsulara Jankauskas *in* Jankauskas & Posti, 1976 (Fig. 10o) and *Cymatiosphaera ovillensis* Cramer & Diez, 1972 (Fig. 10j, q) are variably abundant in the upper part of the Hell's Mouth Formation and rare in the Ceiriad Formation, the age of which is imprecise owing to the lack of macrofossils. Data concerning the distribution of the former species in the Baltic area (Hagenfeldt, 1989*a*) and East European Platform (Volkova *et al.* 1979), and of the latter species in northeast Spain (Fombella, 1978) do not permit Lower Cambrian to be distinguished from basal Middle Cambrian.

Multiplicisphaeridium dendroideum (Jankauskas) Jankauskas & Posti, *in* Volkova *et al.* 1979 (Fig. 10a), also recorded from the Hell's Mouth Formation by Downie (1982, p. 262), was very rare 66 m below the top of that unit and at a level 18.5 m above the base of the Nant-y-big Formation. The species is unknown after the Middle Cambrian, and its oldest recorded occurrence is close to the *Holmia kjerulfi* Biozone in the East European Platform (Moczydłowska, 1991).

Annulum squamaceum (Volkova) Martin *in* Martin & Dean, 1983 (Fig. 10s), *Comasphaeridium* sp. *in* Albani, Massa & Tongiorgi, 1991 (Fig. 10f), *Dichotisphaera gregalis* (Hagenfeldt) Vanguestaine, 1991 (Fig. 10l), *Eliasum llaniscum* Fombella, 1977 (Fig. 10h, k), *Retisphaeridium dichamerum* Staplin, Jansonius & Pocock, 1965 (Fig. 10c, i), *R. howellii* Martin *in* Martin & Dean, 1983 (Fig. 10b), *Synsphaeridium* sp. 1 *in* Cramer & Diez, 1972 (Fig. 10e) and several undeterminable species of *Skiagia* Downie, 1982 are common between 99.5 m and 5 m below the top of the formation, particularly at and above the richest level at 66 m. They are not restricted to the Lower Cambrian but range within the Middle Cambrian (*Tomagnostus fissus* Biozone), in the lower Nant-y-big Formation up to at least 22.65 m above a datum level marked by the pair of small faults indicated by Nicholas (1915, p. 96, fig. 3).

2.c. Trwyn y Fulfran Formation (new term, T.Y.)

2.c.1. Lithostratigraphy (T.Y.)

The relatively thin (37 m) unit comprises finer-grained strata between the coarser sandstone turbidites that characterize both the Hell's Mouth and Cilan formations. It is dominated by dark, manganiferous siltstones, which become interbedded with fine- to medium-grained sandstones in the upper part. The lower part is easily traced along strike because of the almost continuous trial trenching for manganese along the line of outcrop. The new formation is broadly equivalent to the 'Mulfran Beds' (137 m) of Nicholas (1915) but the thickness as now interpreted is considerably less, for reasons given below.

Type section. Above Trwyn Carreg-y-tir, from the old manganese trials [2877 2402] onto the poorly exposed slopes above [2885 2394]. The formational base corresponds to that of Nicholas's 'Mulfran Beds' and is drawn at the base of the first significant manganiferous siltstone bed. The appearance of the latter lithology coincides with the disappearance of the typical thick sandstone beds of the Hell's Mouth Formation, and the boundary of the two formations is sharp. Nicholas (1915) chose the disappearance of manganiferous shales as the criterion for the base of the succeeding 'Cilan Grits'; but this is problematic, for manganiferous siltstones occur sporadically throughout the Harlech Grits Group. Instead, the appearance of very coarse-grained sandstones has been chosen to define the base of the Cilan Formation, and on this criterion the thickness of the Trwyn y Fulfran Formation is significantly less than that of Nicholas's 'Mulfran Beds'.

Description. The lower part of the formation includes approximately 20 m of manganiferous siltstone with occasional medium-grained sandstone beds, generally less than 10 cm thick, forming 15% of the thickness. The upper part is very poorly exposed, apart from the inaccessible cliff section southeast of Trwyn y Fulfran, but the sandstone component forms at least 80% of the succession. The sandstone beds show an overall increase in thickness and grain size upwards through the upper part of the formation into the lower part of the Cilan Formation.

2.c.2. Biostratigraphy: Trwyn y Fulfran and Cilan formations (W.T.D., F.M.; see also Section 2.d.2)

No trace of macrofossils was found in either unit. Along the coast between Trwyn Carreg-y-tir and a point 0.5 km northeast of Trwyn Cilan, the acritarchs of both formations are badly preserved, but sporadically observed up to 68 m above the base of the Cilan Formation. All are forms already present in the Hell's Mouth Formation, except for *Pterospermella solida* (Volkova) Volkova *in* Volkova *et al.* 1979 (Fig. 10d), which was recognized only in the Cilan Formation. None provides evidence for deciding whether the age is late Lower or Middle Cambrian.

2.d. Cilan Formation (new term, T.Y.)

2.d.1. Lithostratigraphy (T.Y.)

The formation, a thick (approximately 400 m) succession of dominantly coarse-grained thickly bedded turbidites, is broadly equivalent to the 'Cilan Grits' of Nicholas (1915), but the base is drawn about 100 m lower.

Type section. Formed by the cliffs around Trwyn Cilan which, though clearly visible from the sea, are largely inaccessible; farther east, limited access to the upper part of the section is available, but inland exposure is poor. The formational base is well exposed in the sea cliffs, but as it can be reached only by boat, the boundary has been defined on the poorly exposed slopes above the cliffs [2885 2394]. The top of the formation is the abrupt contact with markedly finer-grained lithologies at Trwyn Llech-y-doll [2995 2340].

Description. The formation is marked by the typically coarser grain size of the sandstone beds compared with that in the Hell's Mouth Formation. The bases of individual beds are generally of granule grade and sometimes pebble grade. Some sandstones up to 1 m thick may be of very coarse sand grade throughout and often, particularly in the uppermost 30 m of the

formation, contain ripped-up clasts of mudstone and siltstone, usually up to 0.8 m in length, but in some cases exceeding 3 m. The coarse-grained sandstone beds typically show fewer sole structures than the finer-grained sandstones of the Hell's Mouth Formation. Rippled top surfaces with trough-cross lamination in the upper part of the formation indicate palaeocurrents from 060° to 085°. Between 70 and 30 m below the top of the formation there is a markedly finer-grained interval dominated by red and green mudstones and siltstones. These bear examples of the trace fossils *Diplocraterion parallelum*, *Planolites* isp., *Phycodes* isp. and *Cruziana* isp. (R. Goldring, pers. comm.), which are usually considered indicative of the shallow water *Cruziana* ichnofacies.

2.d.2. Biostratigraphy: see Section 2.c.2

3. Middle Cambrian formations above the Harlech Grits Group (T.Y.)

These comprise markedly finer-grained deposits that are seen in the northwestern part of Porth Ceiriad. The sediments include many previously interpreted as turbidites, but these are of siltstone grade rather than the coarse sandstones considered by Allen, Jackson & Rushton (1981) to typify the Harlech Grits Group. Some of the siltstones contain a shelly macro-benthos, mainly trilobitic; acritarchs have been found in most of the sequence, excluding the upper portion of the Nant-y-big Formation (corresponding to the Nant-pig Beds of Nicholas, 1915). The higher part of the section shows evidence of current or storm reworking of the sediments. Owing to incomplete exposure the total thickness could not be determined accurately but is at least 150 m and probably about 170–200 m.

3.a. Ceiriad Formation (new term) (T.Y.)

3.a.1. Lithostratigraphy (T.Y.)

The unit, which corresponds to the combined 'Lower Caered Mudstones' and 'Caered Flags' of Nicholas (1915), comprises red, brown and green siltstones with subsidiary sandstones of similar colour. Exposure is incomplete, but at least 40 m are seen (Fig. 4).

Type section. The basal part of the formation is exposed at Trwyn Llech-y-doll [299 233] and a little farther north [3018 2387]. The upper beds are exposed along the northern part of the west side of Porth Ceiriad ([3033 2425] to [3056 2469]). These sections are separated by significant faults and their exact stratigraphic relationship is not known, but it is assumed that only a small thickness of strata is not seen.

Description. Nicholas (1915) divided the 'Caered Mudstones and Flags' into 'Lower Caered Mudstones' below the break in exposure, with 'Caered Flags' and 'Upper Caered Mudstones' above. Because of the similar facies of the two lowest divisions they are united here as Ceiriad Formation. The 'Upper Caered Mudstones' are similar to Nicholas's 'Nant-pig Mudstones' and are incorporated here within the Nant-y-big Formation (see Section 3.b.1).

The Ceiriad Formation consists mainly of red and brown siltstones and very fine sandstones bedded on a 2–50 cm scale. Its base is marked by a cherty bed with diffuse cross-laminae of sandstone containing intraclasts; the top of the bed is strongly sulphide mineralized. Included within the unit are many thin, pale horizons which may be metabentonites, such as are recorded from what is now the Nant-y-big Formation. The Ceiriad Formation is seen at Trwyn Llech-y-doll, where 40 m are exposed, and again to the west of Porth Ceiriad, where at least 12 m of red, green and purple sandstones are visible. Finer-grained interbeds in this upper part of the formation are similar to the dominant lithologies in the lower part at Trwyn Llech-y-doll. The sandstones, dominantly very fine-grained lithic arkoses, are moderately to well sorted and contain the same clast assemblage as seen in the Hell's Mouth Formation, i.e. quartz (dominant), plagioclase, alkali feldspar, biotite (minor but prominent), muscovite and trachytic volcanic fragments; one thin section shows detrital green tourmaline. The uppermost beds of the formation in the northwestern angle of Porth Ceiriad are siliceous siltstones and sandstones which often contain large pyrite cubes and closely resemble the basal beds.

Despite showing some lithological similarity to the Gamlan Formation of the Harlech district, the Ceiriad Formation has been excluded from the Harlech Grits Group because of the complete absence of sand-grade turbidites coarser than very fine sand grade. Instead, the dominance of silt grade turbidites is a feature in common with the succeeding Nant-y-big Formation.

3.a.2. Biostratigraphy: macrofossils (W.T.D.)

The only report of a macrofossil is that of a complete agnostid trilobite (Matley, Nicholas & Heard, 1939, p. 85) about 30 m above the formation base, which remains unconfirmed (Bassett, Owens & Rushton, 1976, p. 639).

3.a.3. Biostratigraphy: microfossils (F.M.)

Acritarchs are of variable abundance and preservation between 3.1 m and 23 m above the formation base at Trwyn Llech-y-doll. Specimens of *Cymatiosphaera* sp. exhibiting wide variation are usually very numerous. *Cristallinium cambriense* (Slavíková) Vanguestaine, 1978 (Fig. 11i) is the only index taxon and appears 6.5 m above the base. It is accepted here as indicating a Middle Cambrian age, precise horizon unknown but older than the first level containing the *Tomagnostus fissus* Biozone in the lower part of the Nant-y-big

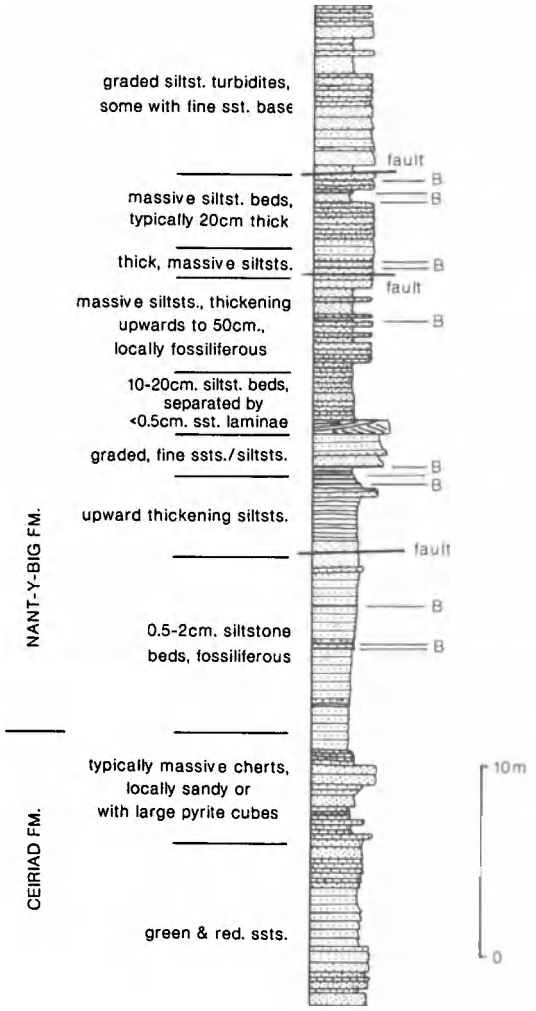

Figure 4. Log of upper part of Ceiriad Formation and lower part of Nant-y-big Formation (Fig. 1, section 6), northwest corner of Porth Ceiriad [305 247]. B = metabentonite beds.

Formation. No convincing specimen of the species has been illustrated from deposits assigned to the Lower Cambrian by means of macrofossils (references in Albani, Massa & Tongiorgi, 1991). The first appearance of *C. cambriense* has been dated as middle Middle Cambrian; in eastern Newfoundland (Martin & Dean, 1988) the level belongs to the *Ptychagnostus atavus–Tomagnostus fissus* Biozone, and in Bohemia (Vavrdová, 1976, p. 61) to the *Eccaparadoxides pusillus* Zone.

A single level 3.8 m below the top of the formation in the eastern part of Porth Ceriad yielded rare, badly preserved acritarchs, including *C. cambriense*.

3.b. Nant-y-big formation (new term, T.Y.)

3.b.1. Lithostratigraphy (T.Y.)

The formation comprises > 110 m of dark grey siltstones with subordinate thin beds of pale sandstone/quartzose siltstone in the upper part, and is equivalent to the 'Upper Caered Mudstones' and 'Nant-pig Mudstones' of Nicholas (1915), which units are separated in Porth Ceiriad by a poorly exposed fault zone at the east end of the prominent cliff of Pared Mawr. Nicholas claimed there was a stratigraphic gap between the highest 'Upper Caered Mudstones' west of the fault and the lowest 'Nant-pig Mudstones' east of it. This is impossible to verify on current evidence, nor has any exposure of the contact between the two units been found inland, and as they are of similar facies they are formalized here as a single formation. The eponymous farm is the same as that used by Nicholas for his higher unit but the current spelling is adopted.

Type section. This extends along the coast in Porth Ceiriad, below Pared Mawr (Fig. 4). The formation base is well exposed in the northwestern angle of the bay [3056 2469], where red and green siliceous siltstones of the Ceiriad Formation pass upwards rapidly into darker green siltstones of the Nant-y-big Formation. The base is defined at a thin (4 cm) ferruginous sandstone bed, locally with granule-grade clasts, which lies above the highest green siliceous siltstone and below the first of the thinly bedded brown siltstones characteristic of the lower Nant-y-big Formation. This horizon lies 5.04 m above the prominent bedding plane at the base of the small waterfall. The middle part of the formation is cut by the major fault referred to above; the top is well exposed in the sea cliffs east of the fault.

Description. The contact between the Ceiriad and Nant-y-big formations is exposed in the northwestern corner of Porth Ceiriad. The lower parts of the Nant-y-big Formation are well seen at beach level, where they are dominated by massive to crudely graded siltstones, interbedded with more laminated siltstones; the thicker (2–30 cm) beds are probably turbidites. Some parts of the succession, for instance the basal 6 m of the formation where background laminated siltstones are dominant, contain shelly macrofossils, mostly trilobites. At various horizons, particularly noticeable about 12 m above the base, there are abundant metabentonite horizons. They were described by Bennett (1989), who attributed the origin of coticules in the Harlech area to diagenesis and metamorphism of such horizons, and by Roberts & Merriman (1990). The middle part of the formation is exposed high in the cliffs below Pared Mawr, where the mudstones are more weathered.

The succession is cut by a major fault that coincides with the boundary between Nicholas's 'Upper Caered Mudstones' and 'Nant-pig Mudstones'; the latter were distinguished on the basis of their supposedly typically greyer colour, but the sedimentary facies of the two units are closely linked. The lower part of the succession east of the fault (Nicholas's 'Nant-pig Mudstones') comprises also 10–20 cm beds of graded, internally structureless, grey-brown siltstones with darker, laminated siltstones. The siltstone beds often

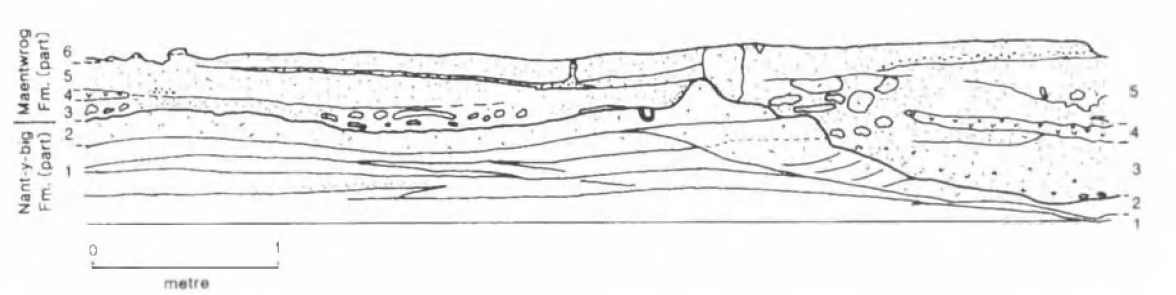

Figure 5. Section of 'calcareous grit' at contact of Nant-y-big and Maentwrog formations exposed at base of cliff in Porth Ceiriad [3106 2482] (Fig. 1, eastern end of section 6). Vertical scale is equal to horizontal scale. Numbered units as follows, in ascending stratigraphic order: 1, fine-grained siltstone with bedding picked out by phosphatic? horizons; 2, fine-grained buff, calcareous?, probably diagenetically cemented top to unit 1; 3, brown, medium- to very coarse-grained sandstone with large clasts of unit 2 (possibly including those from which late Middle Cambrian trilobites were obtained by Nicholas), and much phosphatic debris; 4, hard, green, fine-grained bentonite?; 5, pale, hard, fine- to medium-grained sandstone containing Upper Cambrian acritarchs and irregular horizons of very coarse sandstone with black matrix; 6, erosional remnants of bioclastic limestone. The formational boundary is between levels 2 and 3.

have sand-grade bases which may show the development of diagenetic or metamorphic sulphides. These graded beds are similar to the silty turbidites described above from the basal part of the formation.

Silty turbidites become progressively less important upwards through the formation, eventually being subordinate to laminated interbeds, a facies that indicates reworking and sorting of the sea-floor sediment into a more bimodal sediment assemblage. Towards the top of the formation, the coarse-grained laminae become thicker, often forming trains of starved ripples that are frequently mineralized by sulphides. The uppermost 15 m of the formation mark the appearance of some thicker (< 20 cm) sandstone beds upon which large carbonate concretions have often nucleated. The dark background siltstones may be fossiliferous.

The top metre of the Nant-y-big Formation is formed of siltstones with large wavelength but low amplitude cross-lamination, picked out by seams of darker (phosphatic?) material that is also reworked as intraclasts. This lithology becomes increasingly concretionary upwards and is highly indurated for 20 cm below the major hiatus within the 'calcareous grit' (Fig. 5) of Nicholas (1915, p. 102), a unit now considered to span the boundary between the Nant-y-big and Maentwrog formations at Porth Ceiriad.

As a whole the formation shows the waning influence of turbidity currents, the increasing importance of reworking, probably due to wave or storm action, and a decrease in sedimentation rate, evidenced by the significant diagenetic carbonate and phosphate concretions.

3.b.2. Stratigraphic levels of Nicholas's fossil localities (T.Y.)

Although the relative positions of most localities listed by Nicholas (1915, 1916) for the 'Upper Caered Mudstones' and 'Nant-pig Mudstones' are correct, his given distances above the base and below the top of what is now the Nant-y-big Formation require some revision. Localities are shown below in descending stratigraphic order:

Locs. α14 (beach level), α16 (top of cliff): 3–6 m below top of formation.
Loc. α9: < 5 m (est.) below top of formation, top of cliff at Porth Ceiriad.
Loc. α8: 50–60 m (est.) above base of formation, high on cliff slope below Pared Mawr.
Loc. α7: 50 m (est.) below top of formation; lowest part of continuous section in cliff, Port Ceiriad.
Locs. α10, α12 (close to α10): include at least 20 m of strata, up to 22.7 m above formation base; near old adit at west end of bay, Porth Ceiriad.
Loc. α11: fallen blocks; not closely located, and cover at least 20 m of strata near base of formation; west of fault zone in northwest corner of Porth Ceiriad [3042 2454].

3.b.3. Biostratigraphy: macrofossils (W.T.D., A.W.A.R.)

Nearly all macrofossils from the lower part of the formation, corresponding to Nicholas's (1915, 1916) 'Upper Caered Mudstones', are trilobites, mostly agnostids; the majority came from the lowest part of the unit and a selection is illustrated in Young, Gibbons & McCarroll (in press). Nicholas's list, revised, includes: *Eodiscus punctatus* (Salter, 1864), *Peronopsis scutalis* (Hicks, 1872), probably subsp. *exaratus* (recorded as *Agnostus exaratus* Grönwall, 1902), *Ptychagnostus longifrons* (Nicholas, 1916) and *Pt. typicalis* (Nicholas, 1916) (for both of which this is the type locality and horizon), *Tomagnostus fissus* (Linnarsson, 1879) and the paradoxidid *Plutonides hicksii* (Salter, 1866). As noted by Rushton (1974, p. 72) the assemblage indicates the *T. fissus* Biozone of the Middle Cambrian. *P. hicksii*, based on material from the Mawddach valley, east of Barmouth (Allen & Jackson, 1985, p. 17), is a widespread species, recorded also from south Wales, the English Midlands,

eastern Canada (especially eastern Newfoundland), Scandinavia and Siberia.

The remainder of the Nant-y-big Formation, corresponding to Nicholas's (1915, 1916) 'Nant-pig Mudstones', is variably fossiliferous (Fig. 10). The lower half of the exposed section contains many fewer trilobites than the upper half, and only *Peronopsis scutalis*, *Plutonides hicksii*, *Eodiscus punctatus* and *Parasolenopleura applanata* (Salter *in* Salter & Hicks, 1869) are recorded (Rushton, 1974, p. 72). *P. scutalis* ranges from the *P. gibbus* Biozone to the *P. punctuosus* Biozone; *P. hicksii* occurs in the *P. gibbus* and *T. fissus* biozones; and the remaining two species are not recorded below the *T. fissus* Biozone, to which the assemblage is considered to belong.

The more diverse fauna in the upper part of the section at Porth Ceiriad includes agnostids such as *Peronopsis scutalis scutalis*, *Ptychagnostus punctuosus* (Angelin, 1851), *Phalagnostus* sp. and *Pleuroctenium scanense* Westergård, 1946, together with *Eodiscus punctatus*, *Meneviella venulosa* (Salter *in* Hicks, 1872), *Centropleura pugnax* Illing, 1916, *Agraulos longicephalus* (Hicks, 1872) and *Corynexochus cambrensis* Nicholas 1916 (for which this is the type locality and horizon). The assemblage indicates the *Hypagnostus parvifrons* Biozone of the Middle Cambrian, in spite of the record of *Pt. punctuosus*, a species that can occur below its nominal zone (Thomas, Owens & Rushton, 1984, p. 11). Nicholas's (1916) questioned record of *Paradoxides* [now *Plutonides*] *hicksii* is not confirmed. His listing of '*Solenopleura variolaris* (?)' (Salter, 1864), a species now assigned to *Solenopleuropsis* (a genus of zonal value in the Mediterranean region), from two levels in the highest 10 m of the Nant-y-big Formation suggests a possibly younger horizon, the *P. punctuosus* Biozone. But the record is not confirmed and may refer to *Parasolenopleura* cf. *applanata*, resembling a long ranging species that occurs, *inter alia*, in the *H. parvifrons* Biozone. There is no evidence at St Tudwal's of *Paradoxides davidis* Salter, 1863, a very large trilobite conspicuous in the Menevian Beds of St David's, south Wales, and in the Clogau Formation of the Harlech Dome (Rushton, 1974, pp. 62, 90; Allen & Jackson, 1985) in strata that belong to the *Pt. punctuosus* Biozone. As noted by Nicholas, a significant stratigraphic break occurs between the Nant-y-big and Maentwrog formations, and is confirmed by both palaeontological and sedimentological evidence.

3.b.4. Biostratigraphy: microfossils (F.M.)

Acritarchs are of variable abundance and preservation in the lower part of the Nant-y-big Formation (= Upper Caered Mudstones of Nicholas) at the beach-side outcrop [306 247] in western Porth Ceiriad, where they become determinable upwards from a level 18.5 m (sample NAN-11) above the formational base. At this level numerous specimens of Acritarch gen. et sp. nov. Martin *in* Martin & Dean, 1984 (Fig. 11e), known only from the middle Middle Cambrian in eastern Newfoundland, and rare *Heliosphaeridium? llynense* Martin sp. nov. (Fig. 11b, g, h, j, k, o, q) are present and mark a contrast with subjacent assemblages from the Ceiriad Formation. *H.? llynense* is better represented in strata at Nicholas's locality α10 (*T. fissus* Biozone), in sample NAN-12, approximately 27.50 m above the base of the formation, and at several levels in the succeeding 29.15 m of the same unit. *Comasphaeridium longispinosum* Hagenfeldt, 1989*b* (Fig. 11f, l) occurs first in this section in sample NAN-13, 33.90 m above the formation base. The only other illustrated records (Hagenfeldt, 1989*b*, figs 5, 6) of the species, the processes of which are very fragile, are from boreholes in Sweden, the south Bothnian Sea and Gotland. The strata were correlated, on the basis of acritarch evidence, with the *Acadoparadoxides oelandicus* Biozone (sometimes *Paradoxides oelandicus* 'Stage'), generally taken as lowest subdivision of the Middle Cambrian in Scandinavia but younger than the lowest biozone in the Mediterranean region according to Geyer (1990, p. 66).

The first occurrence of *Adara alea* Martin *in* Martin & Dean, 1981 (Fig. 11m, n, p), also in the *T. fissus* Biozone, is in sample NAN-17, a level 45.45 m above the base of the formation and 11.55 m above the first record of *Comasphaeridium longispinosum*. This is the youngest assemblage containing both the latter taxon and *Annulum squamaceum*, assuming there is no reworking. The *Adara alea* Biozone, defined by the range of the eponymous taxon, was found in the succeeding 6.50 m of the middle part of the Nant-y-big Formation; the overlying 24.50 m were not sampled. In eastern Newfoundland (Martin & Dean, 1988) its lower limit is the upper part of the '*Paradoxides hicksii* Zone' (of Hutchinson, 1962), which is correlated with the *T. fissus* Biozone. Its upper limit, though less precise, is close to the base of the '*Paradoxides davidis* Zone', corresponding to about the top of the *Hypagnostus parvifrons* Biozone. Its range in Öland (Bagnoli, Stouge & Tongiorgi, 1988), western Libya (Albani, Massa & Tongiorgi, 1991) and southeastern Turkey (Erkmen & Bozdoğan, 1981) has not been verified by means of macrofossils.

All acritarchs from the higher part of the Nant-y-big Formation, corresponding to the Nant-pig Mudstones of Nicholas (1915), were very fragmentary, black and undeterminable.

4. Formations of Upper Cambrian age (T.Y.)

The base of the section is well exposed in Porth Ceiriad, where it lies unconformably on the Nant-y-big Formation, and the succession closely resembles part of the Maentwrog Formation in the Harlech area. Following a break in exposure, equivalent to an

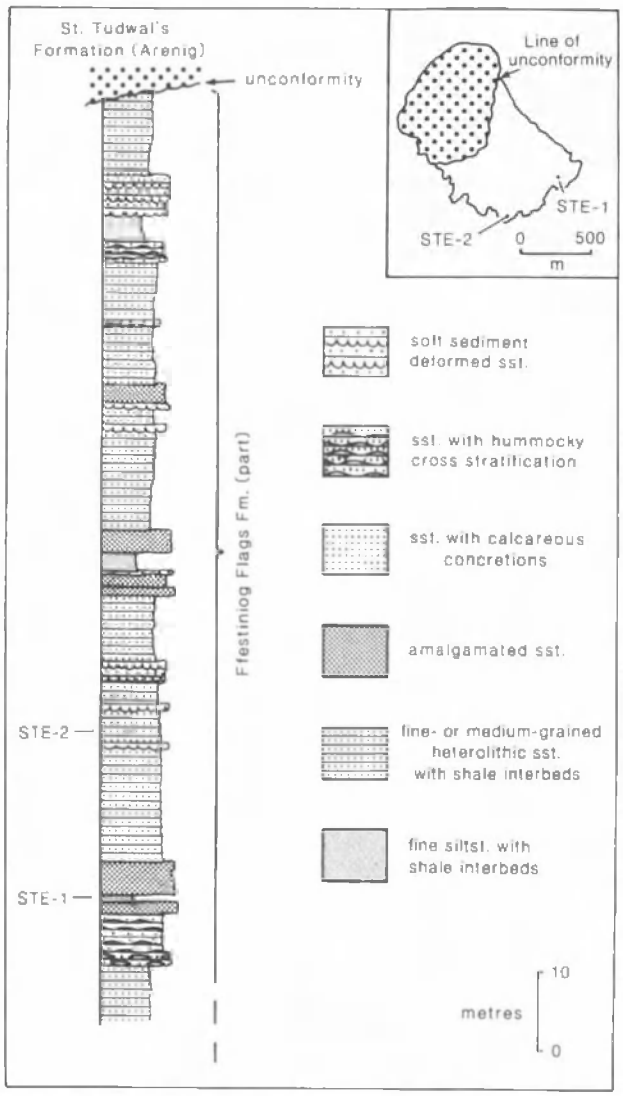

Figure 6. Log of the Ffestiniog Flags Formation as exposed on St Tudwal's Island East (Fig. 1, section 8). STE-1 and STE-2 indicate microfossil localities.

estimated thickness of 250 m, a very small area of Maentwrog Formation occurs at the eastern end of the beach in Porth Ceiriad. Still farther eastwards, there is a stratigraphic gap that Nicholas (1915, p. 105) described as 'very considerable' before the Ffestiniog Flags Formation is seen on St Tudwal's Island East (Fig. 6).

Elsewhere in southern Llŷn, rocks of Ordovician (Tremadoc) age ascribed to the Dol-cyn-afon Formation are exposed outside the limits of the present paper, in the area between Abersoch and Sarn. The sediments of the Dol-cyn-afon Formation are the oldest seen north of the Sarn–Abersoch Fault, and their relationship to the Cambrian rocks now discussed is unknown.

4.a. Maentwrog Formation

4.a.1. Lithostratigraphy (T.Y.)

The rocks consist of beds of coarse siltstone to fine sandstone, up to 40 cm thick, interbedded with thinner levels of dark mudstone and siltstone with fine sandstone laminae.

Type section. Defined and described by Allen, Jackson & Rushton (1981), and located downstream from Vigra Bridge in the Hirgwm [6682 1922], on the southern side of the Harlech Dome, where the formation is 700–1200 m thick. The basal 34.5 m are seen only in the cliffs in the centre of Porth Ceiriad, followed by an unexposed interval between them and the small exposures at the eastern end of the beach.

Description. The boundary between the Nant-y-big and Maentwrog formations lies within the 'calcareous grit' of Nicholas (1915), later named the 'Dorypyge Limestone' by Shergold & Brasier (1986). The majority of this bed is not, however, limestone and the trilobite *Dorypyge* is very rare; this name is not used here. Indeed, because of the presence of at least one major unconformity within the bed, it has not been accorded a formal lithostratigraphic status in this study. This bed, with a total thickness about 0.6–1 m, is a complex unit; it is subdivided into six numbered layers (Fig. 5) and embraces the concretionary top of the Nant-y-big Formation together with the coarse conglomeratic sandstones at the base of the Maentwrog Formation. The erosion surface within the bed (between layers 2 and 3) has significant relief, with associated boulders of > 30 cm diameter; fragments of stromatolitic crust are seen lying on the surface. The top of the bed is irregular, and the prominences on the surface preserve erosional remnants of a bioclastic limestone (layer 6) indicating a second erosional event at this higher level. This complicated history of low sedimentation rates and erosion means that the biostratigraphic data must be treated with extreme caution, especially in the case of old collections whose precise location within the bed is unknown.

The lowest 34.5 m of the Maentwrog Formation, exposed in the cliff section in the centre of Porth Ceiriad, are characterized by beds up to 40 cm thick of calcite-cemented, very fine sandstone and coarse siltstone. Thinner sandstone beds commonly comprise complex amalgamated ripple sets while thicker beds show parallel lamination in the body of the bed, wave rippled tops, and sole structures. An important feature of the formation is the common occurrence of structures attributable to soft sediment deformation; these include convolute beds, and beds exhibiting ball and pillow structure. The interbeds consist of laminated siltstone with rippled sandstone laminae and starved ripple trains. The thickness ratio of sandstone beds to the mudstone-dominated background sediment is about 2:1 according to Bose (1983), who considered the sediments to be typical shallow marine sandstones deposited under the influence of storm action.

Most of the northeastern shore of Porth Ceiriad is occupied by beach sand, bordered by low cliffs of Drift material, and there is an unexposed horizontal

interval of 570 m, corresponding to an estimated thickness of 250 m. This is followed by a very small outcrop of Maentwrog Formation at the northeastern corner of Porth Ceiriad [3172 2490] which shows about 15.5 m of laminated siltstones with sandstone laminae below the unconformity at the base of the St Tudwal's Formation (Ordovician, Arenig).

4.a.2. Biostratigraphy: macrofossils (W.T.D., A.W.A.R.)

Nicholas's (1915, 1916, locality α15) description of the 'thin calcareous grit' (Fig. 5) that spans the junction of the Nant-y-big and Maentwrog formations near Nant-y-big [3106 2482] as 'a most disappointing bed' is an understatement. Nevertheless, he obtained a small number of fragmentary trilobites preserved in supposed limestone clasts, a lithology otherwise unknown at this level in north Wales, and the unit has been cited as a calcareous conglomerate, the age of which approximates to the *Paradoxides forchhammeri* 'Stage', late Middle Cambrian (Rushton, 1974, p. 72; Thomas, Owens & Rushton, 1984, p. 12). Nicholas's principal specimens are figured here (Fig. 9a–o), some for the first time. As now revised the faunule includes *Bailiaspis glabrata* (Angelin, 1854), *Dolichometopus* cf. *svecicus* (Angelin, 1854), *Dorypyge* sp., *Linguagnostus aristatus* Fedjanina, 1977, *Acrocephalites?* sp., *Solenopleura* sp. and *Centropleura* sp. Although specific identification is only partly possible, the assemblage has elements in common with that of the Andrarum Limestone in Scania, Sweden, correlated with the *Solenopleura brachymetopa* Biozone by Westergård (1953, p. 37) or, in the case of *L. aristatus*, corresponding strata in Siberia.

The level (or levels) within the 'calcareous grit' from which the material was obtained remains uncertain, but judging from the new detailed section (Fig. 5) level 6 is unlikely, as level 5 contains Upper Cambrian acritarchs; level 3 seems more probable. If this is the case, the 'clasts' were probably produced by erosion of a late Middle Cambrian limestone unit, unknown elsewhere in north Wales, and incorporated into a transgressive sequence of early Upper Cambrian rocks. In the Harlech Dome it has been suggested (Allen, Jackson & Rushton, 1981) that a fossiliferous bed approximately 25 m above the base of the Maentwrog Formation may be of late Middle Cambrian age.

The small collection of trilobites from the highest beds of the incomplete section of Maentwrog Formation exposed in the low cliff at Nant-y-big beach [3112 2487] is still the only one available from the St Tudwal's area. The specimens were listed (Nicholas, 1915, p. 104; 1916, locality α17) as *Agnostus pisiformis* var. *obesus* Belt, 1867 and *Olenus* sp., and considered by him as indicative of the *Olenus* Biozone, early Upper Cambrian. Some of the less imperfect material is illustrated herein (Fig. 9p–s) as *Homagnostus* cf. *obesus* and olenid? genus and species undetermined. By comparison with the Maentwrog Formation in the Harlech Dome (Allen, Jackson & Rushton, 1981) the age is probably *Olenus* Biozone.

4.a.3. Biostratigraphy: microfossils (F.M.)

Various levels within the 'calcareous grit' were sampled for acritarchs but only the uppermost part of level 5 (Fig. 5) yielded determinable specimens. Among them were *Izhoria* sp. (Fig. 11a), *Cymatiogalea* sp. (Fig. 11c, d) and *Timofeevia lancarae* (Cramer & Diez) Vanguestaine, 1978, all of which range higher in the Upper Cambrian rocks of the area. The first two taxa permit level 5 to be attributed to the Upper Cambrian. They are known only from that series in the East European Platform (Volkova & Golub, 1985; Volkova, 1990) and in the Baltic region, at Öland (Di Milia, Ribecai & Tongiorgi, 1989); *Cymatiogalea* is known from the Upper Cambrian in eastern Newfoundland, but *Izhoria* has not been determined there (Martin & Dean, 1988).

Acritarchs from the cliff exposures of Maentwrog Formation at the western and eastern ends of Nant-y-big beach are very abundant and variably preserved; they were studied from thicknesses of 32.30 and 14.00 m respectively at the two sections. Comparison with the zonation in eastern Newfoundland (Martin & Dean, 1981, 1988) and in the Eastern European Platform (Volkova, 1990) is as follows.

1. *Timofeevia microretis* Martin *in* Martin & Dean, 1981, rare at levels 10 cm and 3.85 m above the top of the 'calcareous grit' at the base of the section, could indicate, with reservations, the middle of the upper part of microflora A2 which, in eastern Newfoundland, ranges from the *Agnostus pisiformis* Biozone into strata without trilobites that underlie the *Olenus* Biozone.

2. If the above assessment is correct, and if the trilobite-bearing horizon 30 m higher in the same section at Nant-y-big beach belongs to the *Olenus* Biozone (which is not totally certain; see Section 4.a.2), the species of *Stelliferidium* Deunff, Górka & Rauscher, 1974 and *Cymatiogalea* Deunff, 1961 emend. Górka & Rauscher, 1974 may appear earlier in the Upper Cambrian than previously recognized. In eastern Canada the former genus appears in the poorly preserved upper part of microflora A2, dated as *Olenus* Biozone, and the latter among the more determinable specimens in microflora A3a, contemporaneous with the *Parabolina spinulosa* Biozone. In the East European Platform, and in the absence of trilobites and conodonts, the appearance of *Cymatiogalea* and *Stelliferidium* in assemblage VK2 is correlated with the *P. spinulosa* Biozone on the basis of palynological comparison with eastern Newfoundland (Volkova, 1990, pp. 42, 43, who indicated that her figure 3 should be modified).

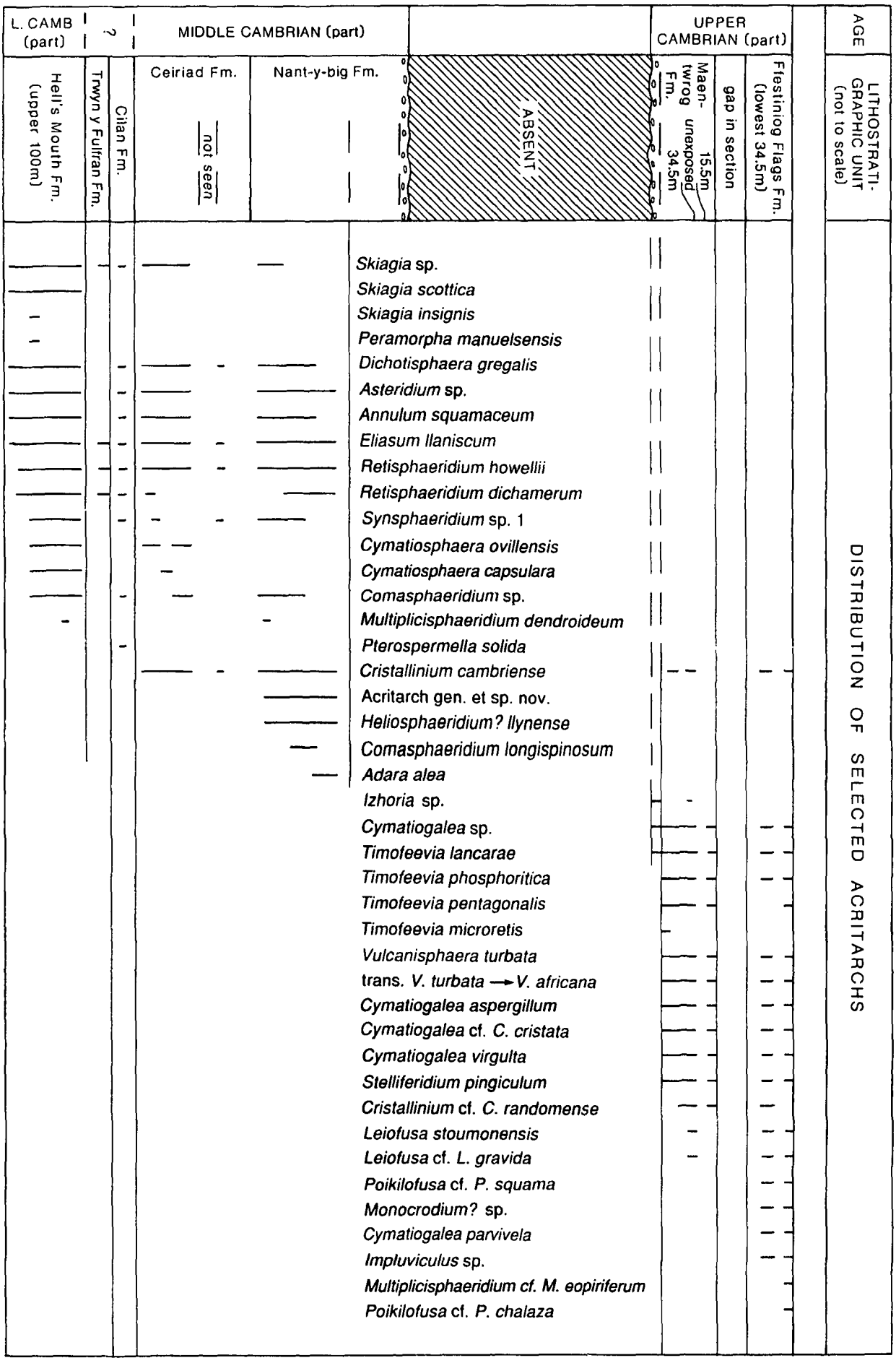

Figure 7. Range chart of selected Cambrian acritarchs at St Tudwal's Peninsula and St Tudwal's Island East. Selected species are illustrated in Figures 10, 11, 12.

3. *Timofeevia lancarae* (Fig. 12u), *T. phosphoritica* Vanguestaine, 1978 (Fig. 12q), *Cymatiogalea aspergillum* Martin *in* Martin & Dean, 1988 (Fig. 12r), *Cymatiogalea virgulta* Martin *in* Martin & Dean, 1988 (Fig. 12c), *Cymatiogalea* cf. *C. cristata* (Downie) Rauscher, 1974 (Fig. 12f), *Stelliferidium pingiculum* Martin *in* Martin & Dean, 1988 (Fig. 12y), *Vulcanisphaera turbata* Martin *in* Martin & Dean, 1981 (Fig. 12t) and transitions from *V. turbata* to *V. africana sensu* Martin *in* Martin & Dean, 1988 (Fig. 12v) are abundant. *Timofeevia pentagonalis* (Vanguestaine) Vanguestaine, 1978 (Fig. 12k) and *Cristallinium cambriense* are rare in the Maentwrog Formation from 10 cm upwards above the 'calcareous grit'. Numerous incompletely preserved *Cristallinium* cf. *C. randomense* Martin *in* Martin & Dean, 1981 emend. Martin *in* Martin & Dean, 1988 (Fig. 12d) were determined from 3.85 m upwards above the 'calcareous grit'. *Leiofusa stoumonensis* Vanguestaine, 1973 (Fig. 12h) and *Leiofusa* cf. *L. gravida* Pittau, 1985 (Fig. 12n–p) are present 27.20 m above the same level. All the above taxa from the Maentwrog Formation, except *Timofeevia microretis*, have been identified in the Llŷn Peninsula up to the lower part of the Ffestiniog Flags Formation at St Tudwal's Island East. All except *Leiofusa* cf. *L. gravida* and *Cymatiogalea* cf. *C. cristata* are known in eastern Newfoundland from the summit of microflora A2 and from microflora A3a; they do not permit a distinction to be made between the upper part of the *Olenus* Biozone and the lower part of the *Parabolina spinulosa* Biozone.

It should be noted that *Veryhachium dumontii* Vanguestaine, 1973 has been found neither in the Maentwrog Formation at Nant-y-big beach nor in the lower part of the Section in Ffestiniog Flags Formation at St Tudwal's Island East. The species enters in strata without macrofossils located between the *Olenus* and *Parabolina spinulosa* biozones, a little below the base of microflora A3a in eastern Newfoundland. It appears at the base of assemblage VK2 in the East European Platform. In north Wales it is abundant in the Ffestiniog Flags Formation at Llŷn Carreg-Wen, west of Portmadoc (F.M., personal observation).

4. Acritarch assemblages from 14.00 m of the Maentwrog Formation at the eastern end of Nant-y-big beach differ from those in the topmost 18 m of the formation at the western end of the same beach only in the absence of *Leiofusa stoumonensis* and *L.* cf. *gravida*. They do not permit any reliable age distinction to be made between the strata at the two sections.

4.b. Ffestiniog Flags Formation (T.Y.)

The highest part of the Cambrian succession at St Tudwal's was referred by Nicholas (1915) to the 'Ffestiniog Flags', a correlation followed here as the succession shows many similarities to that described in the Harlech district (Allen, Jackson & Rushton, 1981; Allen & Jackson, 1985). The formational name was formalized by Allen, Jackson & Rushton (1981), who defined the stratotype as near Bryn-y-gath, in a tributary of the Afon Mawddach [7492 2947].

4.b.1. Lithostratigraphy (T.Y.)

The Ffestiniog Flags Formation is well exposed on St Tudwal's Island East (Figs 1, 6), where the sedimentary facies are very similar to those of the underlying Maentwrog Formation but generally finer grained. Packets of fine-grained sandstone with soft sediment deformation features similar to those of the Maentwrog Formation occur throughout the observed succession but are rarely more than a few metres thick, separated by tens of metres of finer-grained rocks. Between the packets of thick, storm-generated sandstone beds, the formation consists of bioturbated heterolithic facies with variable preservation of the original bedding fabric. Approximately 120 m of the formation are seen on St Tudwal's Island East, but there is no evidence for the total thickness in the district as the base is not seen and the highest strata are overlain unconformably by the St Tudwal's Formation (Arenig).

4.b.2. Biostratigraphy: macrofossils (W.T.D., A.W.A.R.)

Nicholas (1915, p. 105) recorded distorted examples of *Lingulella davisii* (McCoy, 1851) from a bed in the section on St Tudwal's Island East and several specimens were found during the present work. Nicholas correlated the horizon with the '*Lingulella* Band' at the top of the Lower Ffestiniog 'Series', part of the '*Lingula* Flags' in the Harlech Dome. The usefulness in correlation of a facies-controlled species such as *L. davisii* is limited, and although it is typical of the Ffestiniog Flags Formation in north Wales, the age of the '*Lingula* Flags' may vary significantly in other parts of the Welsh Basin (review in Rushton, 1974, pp. 63, 90). No other macrofossils were recorded in the St Tudwal's area.

4.b.3. Biostratigraphy: microfossils (F.M.)

In the lower part of the section at St Tudwal's Island East acritarchs are abundant and relatively well preserved at levels 130.50 m and 82.50 m below the angular unconformity at the base of the St Tudwal's Formation (Figs 7, 8). In addition to acritarchs known earlier from the Maentwrog Formation, several taxa are recognized. *Cymatiogalea parvivela* Di Milia, 1991 (Fig. 12j) is abundant. *Monocrodium?* sp. (Fig. 12s), *Impluviculus* sp. (Fig. 12m) and *Poikilofusa* cf. *P. squama* (Deunff) Martin, 1973 (Fig. 12l, w, x) are rare. A few poorly preserved *Multiplicisphaeridium* cf. *M. eopiriferum* Fombella, 1978 (Fig. 12a) and *Poikilofusa* cf. *P. chalaza* Rasul, 1979 (Fig. 12g) were determined only in the higher sample. Such an

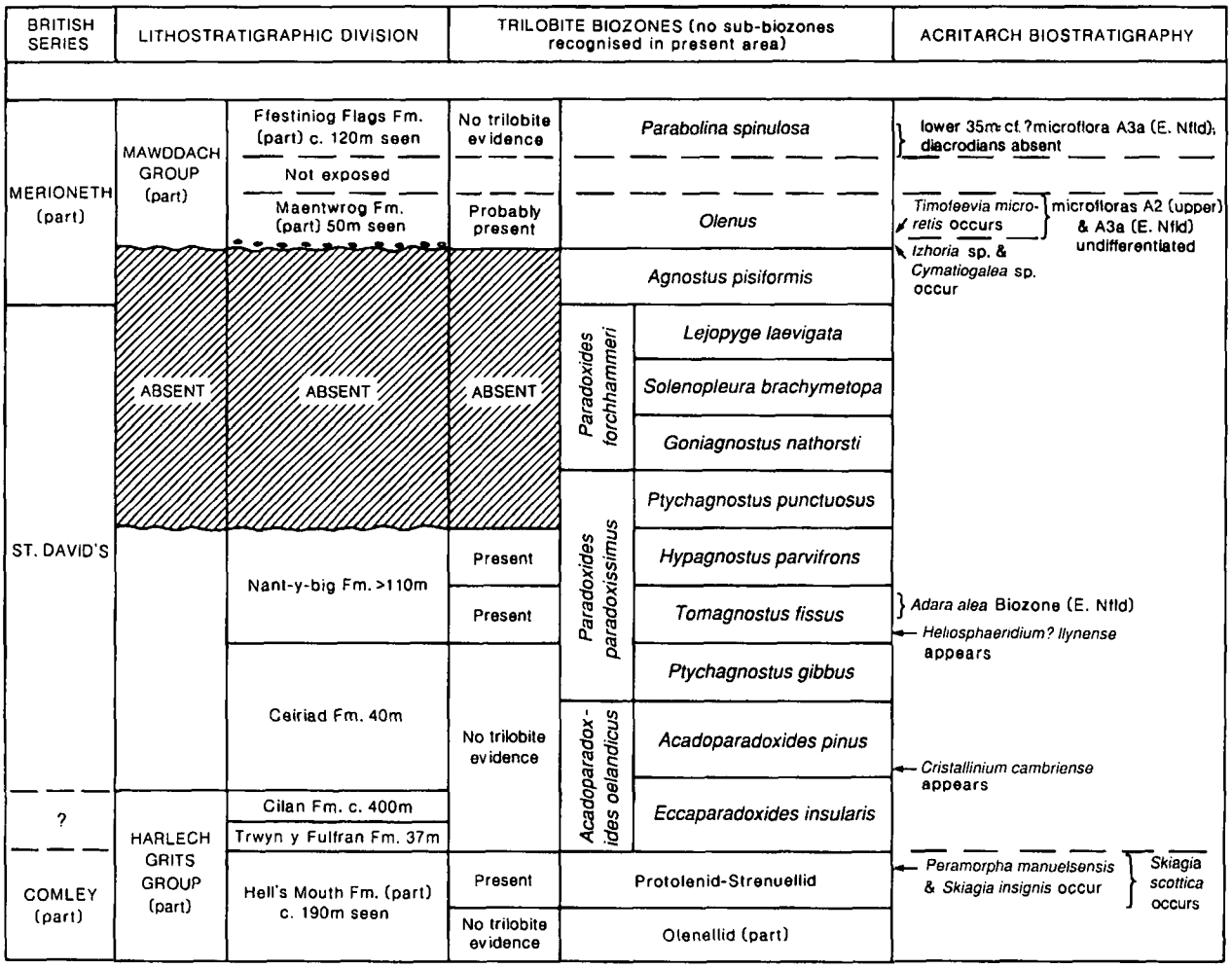

Figure 8. Correlation of Cambrian lithostratigraphic units at St Tudwal's and St Tudwal's Island East with trilobite biozones and selected acritarchs.

assemblage is as yet unknown elsewhere. Because of the absence of diacrodians it may be compared, with reservations, with microflora A3a in eastern Newfoundland, which ranges from strata lacking macrofossils between the *Olenus* and *Parabolina spinulosa* biozones, to the lower part of the *P. spinulosa* Biozone. The association of *Cymatiogalea parvivela*, *Leiofusa* cf. *L. gravida*, *Timofeevia lancarae*, *T. phosphoritica* and *T. pentagonalis*, and the lack of diacrodians are known from part of the Solanas Sandstone Formation, which crops out in the Riu Araxisi, central Sardinia. The latter unit is attributed (Di Milia, 1991), on the basis of acritarch data, to the middle Upper Cambrian, from the summit of the *Olenus* Biozone to the middle part of the *Parabolina spinulosa* Biozone.

5. Palaeontological notes (W.T.D., F.M., A.W.A.R.)

5.a. Trilobites from the Maentwrog Formation (W.T.D., A.W.A.R.)

5.a.1. Trilobites from the 'calcareous grit' at locality α15

Bailiaspis glabrata (Angelin, 1854)
Figure 9g, k, m?, n

A large, incomplete cranidium and associated pygidium (SM A.15630) were listed by Nicholas (1915, p. 102) as '*Conocoryphe* cf. *dalmanni* [sic = *dalmani*] Angelin' and later described briefly, but not illustrated (Nicholas, 1916, p. 461). The material was listed by Resser (1936, p. 14) as a new species, *Bailiaspis nicholasi*, but no diagnosis was given and the taxon remained a *nomen nudum* until described and illustrated by Lake (1940, p. 286, pl. 41, figs 1–4), who must be considered the author. Westergård (1950, p. 31) noted that the material 'seems to agree with [*Bailiaspis*] *glabrata* (in particular our fig. 8)'; he apparently found significant Lake's description of a granulate test in the Welsh cranidium, even though he recorded that of *B. glabrata* as being 'finely granulate'. The Welsh specimen is slightly distorted but closely resembles the type and other material of *B. glabrata* from the Andrarum Limestone of Scania illustrated by Westergård (1950, pl. 6, figs 6–8) and is considered conspecific. The pygidium of *B. glabrata* has not been described, and the example (Fig. 9m) associated with the Welsh cranidium is assigned questionably to the species; it is of general conocoryphid type with three axial rings, progressively less well defined from first to third, and two and a half pairs of pleural ribs. Further

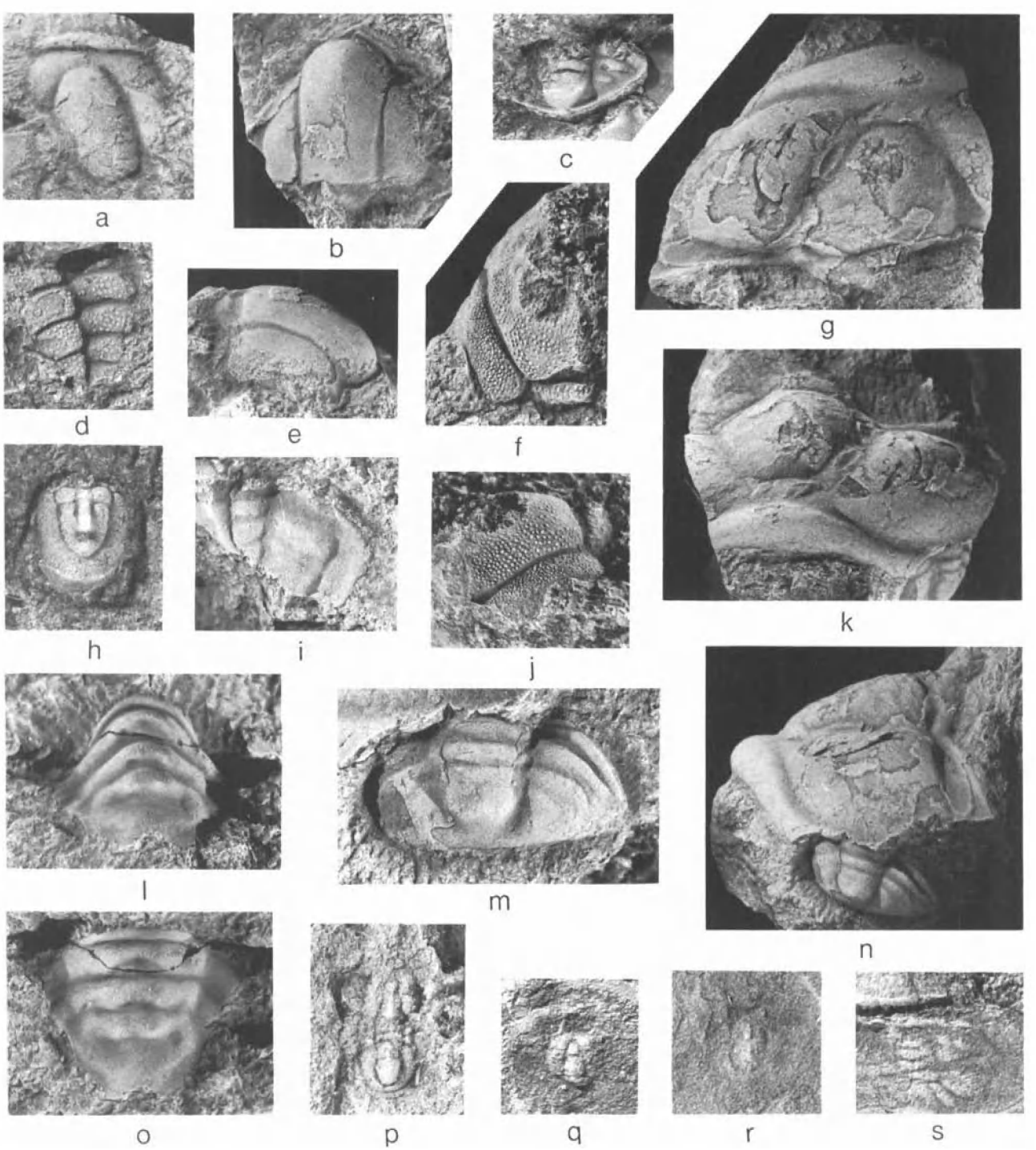

Figure 9. Trilobites in T. C. Nicholas Collection from Maentwrog Formation at Porth Ceiriad: (a–o) from the 'calcareous grit', locality α15 of Nicholas (1915); (p–s) from siltstones 30 m (est.) above the 'calcareous grit', at locality α17 of Nicholas (1915). (a) *Solenopleura* sp. Incomplete cranidium, SM X.23265 (× 3). (b, e, i) *Dolichometopus* cf. *svecicus* Angelin, 1854. (b, e) dorsal and oblique right lateral views of exfoliated cranidium, SM A.10800 (× 2.5); (i) fragment of pygidium, SM X.23266 (× 4). (c) *Acrocephalites?* sp. Incomplete pygidium, SM A.54671 (× 4), listed Nicholas (1915, p. 102) as '*Solenopleura* sp.' (d, f, j) *Dorypyge* sp. (d) fragment of pygidium, SM A.54230 (× 4); (f, j) incomplete cranidium, SM A.263a (× 3), figured Nicholas (1916, pl. 39, fig. 10) as '*Dorypyge* cf. *richthofeni* Dames'. (g, k, m?, n) *Bailiaspis glabrata* (Angelin, 1854). (g, k, n) dorsal, anterior and left lateral views of incomplete, large, slightly distorted cranidium SM A.15630 (× 1.5), figured Lake (1940, pl. 41, figs 1–4) as *Bailiaspis nicholasi*; (m) associated pygidium assigned questionably to the same species (× 2.5). (h) *Linguagnostus aristatus* Fedjanina, 1977. Incomplete pygidium, SM A.245 (× 7), figured by Nicholas (1916, pl. 39, fig. 3) as '*Agnostus kjerulfi*' Brögger. (l, o) *Centropleura* sp. Fragmentary pygidium, SM A.10801 (× 3), listed Nicholas (1915, p. 102) as '*Centropleura salteri* (?)'. (p, q, r) *Homagnostus* cf. *obesus* (Belt, 1867). (p) latex cast of almost complete exoskeleton, SM A.243 (× 6); (q) incomplete cephalon, SM A.1180 (× 5); (r) fragmentary pygidium, SM X.24556 (× 6). (s) Olenid genus and species undetermined. Fragment of poorly preserved cranidium, SM A.54224 (× 5); cited Nicholas (1915, p. 104) as '*Olenus* sp.'.

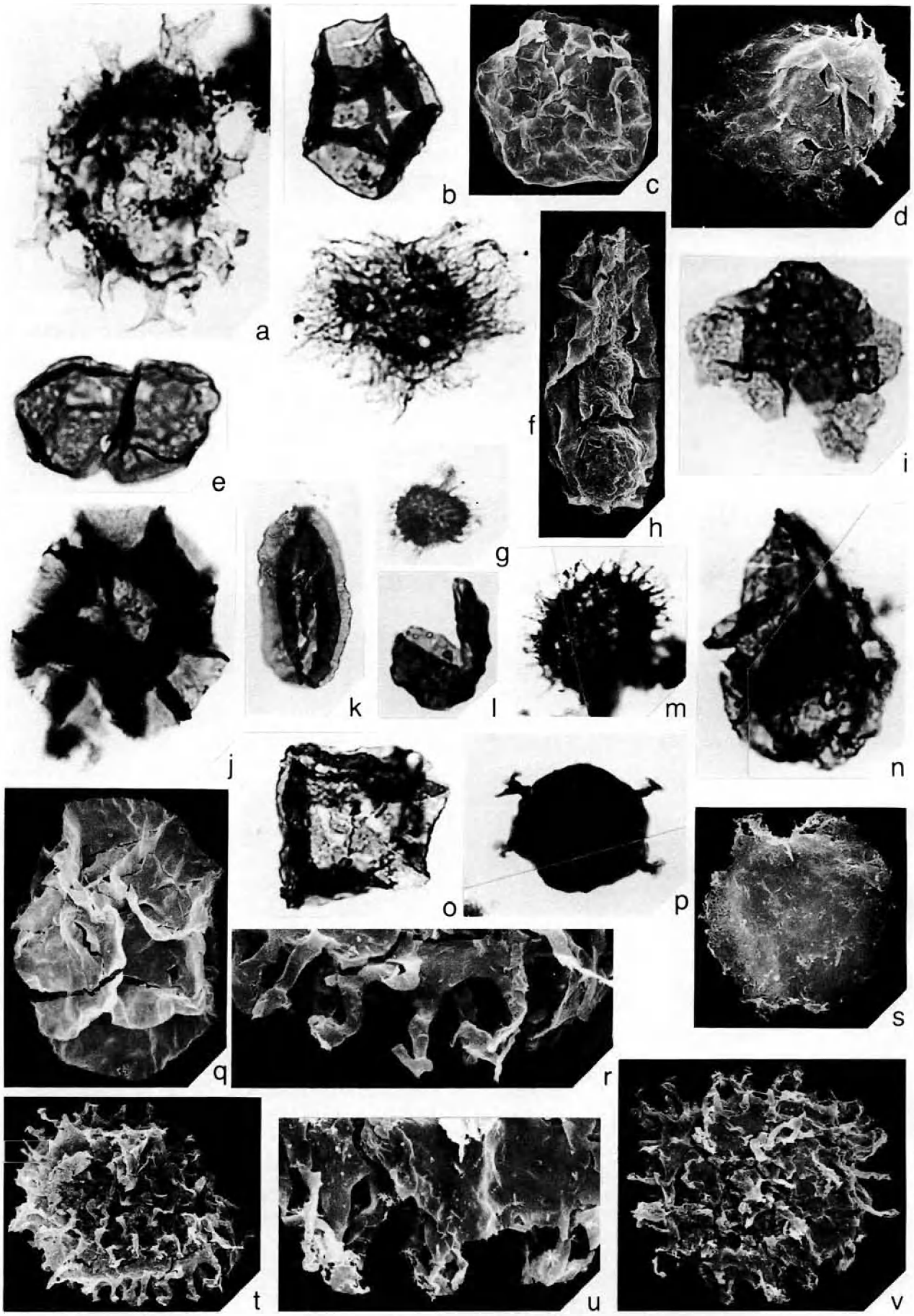

Figure 10. For legend see facing page.

comparison may be made with material from the Bergleshof-Schichten, late Middle Cambrian, of Germany described as *Bailiella? glabrata* by Sdzuy (1966, p. 74, pl. 9, figs 16–24).

Dolichometopus cf. *svecicus* Angelin 1854
Figure 9b, e, i

Type material is from the Andrarum Limestone of Andrarum, Scania, and the species was redescribed, as *D. suecicus* [sic], by Westergård (1948, p. 11, pl. 3, figs 12–16). Particularly distinctive are the glabellar outline, mostly subparallel-sided but widening slightly near the extremity of the flat anterior border, and the long, narrow palpebral lobe, continuous with an eye ridge that meets the glabella at its widest point. Small differences in convexity are probably due to preservation. So far as it goes the pygidial fragment illustrated agrees with Westergård's figures of the species.

Dorypyge sp.
Figure 9d, f, j

Recorded by Nicholas (1915, p. 102) as *Dorypyge* sp. and later (Nicholas, 1916, p. 465, pl. 39, figs 10, 11) as '*Dorypyge* cf. *richthofeni* Dames' (1883). Figured as *Dorypyge* sp. by Lake (1938, pl. 37, fig. 13), who suggested that it might be identical with *Dorypyge aenigma* (Linnarsson, 1869) from the Andrarum Limestone of Scania. In his redescription of *D. aenigma* Westergård (1948, p. 7) agreed that it resembled the Welsh form 'as far as a comparison is possible', but cautioned that the latter seemed to occur at a considerably lower horizon, a negative argument that cannot now be sustained. The Welsh material is too fragmentary for full comparison but granules on the surface of the cranidium, in particular, appear smaller and denser than those of *D. aenigma*.

Linguagnostus aristatus Fedjanina, 1977
Figure 9h

This single incomplete pygidium was recorded by Nicholas (1915, p. 102) as '*Agnostus kjerulfi* Brögger' (1878), and described (Nicholas, 1916, p. 459, pl. 39, fig. 3) under the same name, but according to Westergård (1946, p. 64) the Welsh pygidium could not be safely identified from Nicholas's illustration. Although incomplete, it differs from the lectotype pygidium of *L. kjerulfi* in having the breadth 1.05 times the length, compared with 1.28. The axis is subparabolic in outline, 1.2 times longer than wide, in contrast to the squat, subpentagonal outline, as wide as long, in the lectotype.

Linguagnostus aristatus Fedjanina (1977, p. 145, pl. 19, figs 1–4) was described from Siberian strata correlated with the Andrarum Limestone of Sweden; three type specimens are compressed or slightly distorted, but an apparently undeformed paratype pygidium (Fedjanina, 1977, p. 145, pl. 19, fig. 4) agrees closely with that from Porth Ceiriad. Both have a parabolic axis with breadth and length respectively about 0.52 and 0.63 those of the pygidium (compared with 0.46 and 0.58 in *L. kjerulfi*); and segment M2 (terminology from Shergold, Laurie & Sun, 1990, p. 18) is almost undefined, whereas in *L. kjerulfi* it is bounded by a deep F2 furrow. *L. aristatus* and the Scandinavian species have a conspicuous, rectangular axial node with a deep, transverse depression behind the tip; the node occupies 0.68 of the length of the axis in the former species, but only 0.59 in the latter.

Solenopleura sp.
Figure 9a

Rushton (*in* Taylor & Rushton, 1972, p. 8) noted that the type species of *Solenopleura* is *S. holometopa* (Angelin, 1851) and not *S. canaliculata* (Angelin, 1851) or *S. brachymetopa* (Angelin, 1851) as is sometimes claimed. The slightly deformed and compressed cranidial fragment now illustrated resembles *S. holometopa* (Angelin, 1851), from the *S. brachymetopa* Zone of Scania and redescribed by Westergård (1953, p. 14, pl. 4, figs 1–8), in the glabellar outline and the length (sag.) and form of the preglabellar field and anterior border. The palpebral lobe is not preserved but may have been located only slightly in

Figure 10. Magnification × 1000 unless otherwise stated. (a, b, e, g–i, k, l): lower part Nant-y-big Formation (formerly Upper Caered Mudstones). (c, d, s): Cilan Formation (formerly Cilan Grits). (h, q): lower part of Ceiriad Formation (formerly Lower Caered Mudstones). (j, m, o, p, r, t–v): Hell's Mouth Formation (formerly Hell's Mouth Grits). (a) *Multiplicisphaeridium dendroideum* (Jankauskas) Jankauskas & Kirjanov *in* Volkova *et al.* 1979. NAN-11, IRScNB b2612. (b) *Retisphaeridium howellii* Martin *in* Martin & Dean, 1983. NAN-18. IRScNB b2622. (c, i) *Retisphaeridium dichamerum* Staplin, Jansonius & Pocock, 1965. (c) CIL-2, IRScNB b2620; (i) NAN-59, IRScNB b2621. (d) *Pterospermella solida* (Volkova) Volkova *in* Volkova *et al.* 1979. CIL-2, IRScNB b2619. (e) *Synsphaeridium* sp. 1 *in* Cramer & Diez, 1972. NAN-58, IRScNB b2634. (f) *Comasphaeridium* sp. *in* Albani, Massa & Tongiorgi, 1991. NAN-51, IRScNB b2593. (g) *Asteridium* sp. NAN-15, IRScNB b2590. (h, k) *Eliasum llaniscum* Fombella, 1977. (h) TRW-2, IRScNB b2604; (k) NAN-64, IRScNB b2605, × 500. (j, q) *Cymatiosphaera ovillensis* Cramer & Diez, 1972. (j) HMG-4, IRScNB b2600; (q) TRW-1, IRScNB b2601. (l) *Dichotisphaera gregalis* (Hagenfeldt) Vanguestaine, 1991. NAN-18, IRScNB b2603. (m, r, t–v) *Skiagia scottica* Downie, 1982. (m) HMG-2, IRScNB b2630, × 500; (r, t) HMG-2, IRScNB b2631; (r) = enlargement, × 3000, of lower right part of (t); (u, v) HMG-1, IRScNB b2632; (u) = enlargement, × 3000, of lower right part of (v). (n) *Peramorpha manuelsensis* Martin *in* Martin & Dean, 1983. HMG-4, IRScNB b2615. (o) *Cymatiosphaera capsulara* Jankauskas *in* Jankauskas & Posti, 1976. HMG-4, IRScNB b2602, × 750. (p) *Skiagia insignis* (Fridrichsone) Downie, 1982. HMG-4, IRScNB b2623. (s) *Annulum squamaceum* (Volkova) Martin *in* Martin & Dean, 1983. CIL-2, IRScNB b2573, × 1500.

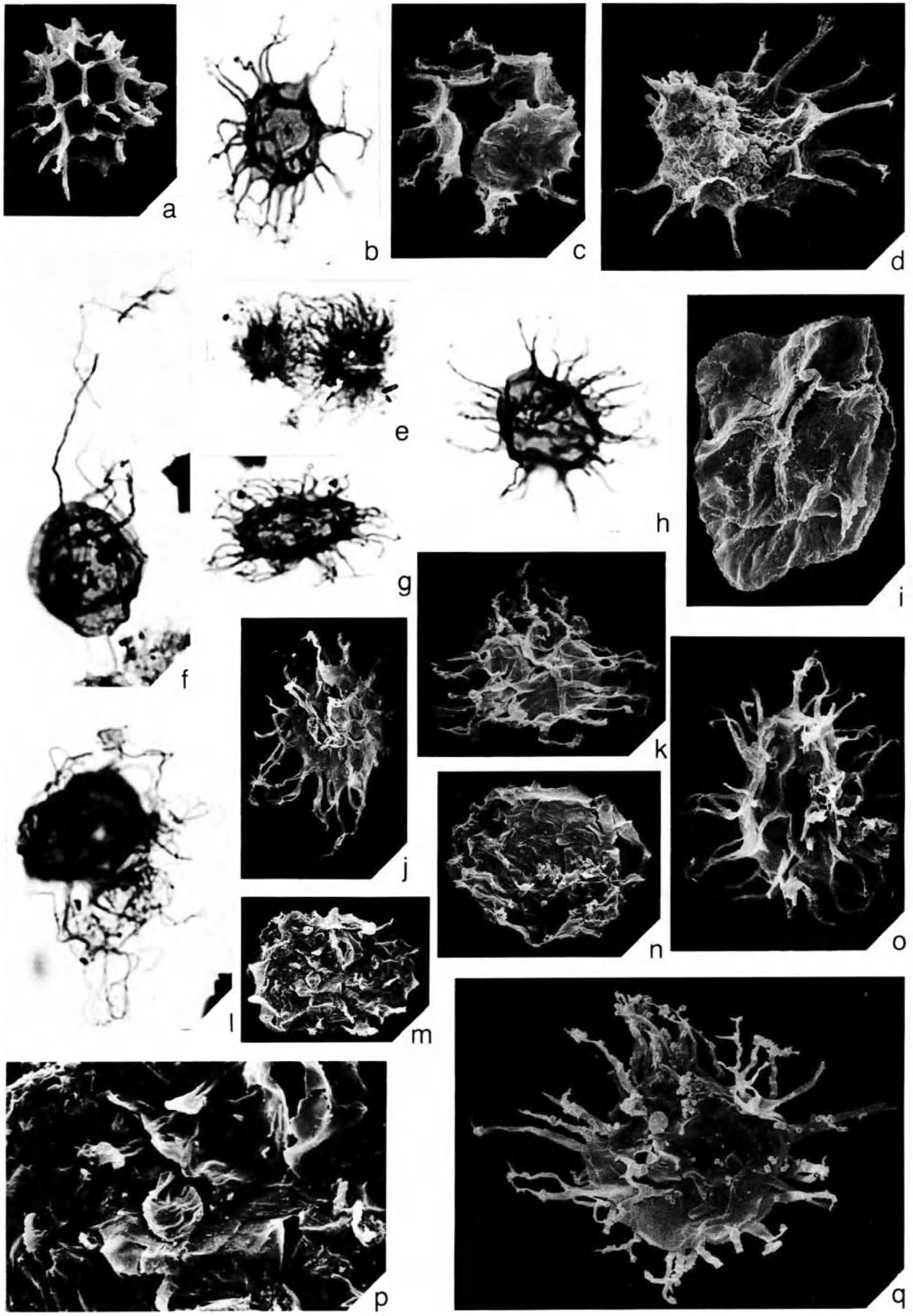

Figure 11. For legend see facing page.

front of a line through the centre of the glabella, judging from a remnant of the eye ridge. In this respect it resembles the lectotype of *S. holometopa* (Westergård, 1953, pl. 4, fig. 1 a), though other cranidia of the species illustrated by Westergård have the eye set farther forwards.

Acrocephalites? sp.
Figure 9c

A single, incomplete pygidium listed by Nicholas (1915, p. 102) as '*Solenopleura* sp.' resembles that of *A. stenometopus* (Angelin, 1851), from the *Lejopyge laevigata* Zone (slightly above the Andrarum Limestone) in Scania and redescribed by Westergård (1948, p. 19, pl. 2, figs 11, 12). Both have a similar outline with marginal rim and, probably, two and a half pairs of pleural ribs. The Welsh specimen may have two axial rings, rather than one as in the Swedish species, but is too poorly preserved for detailed comparison and also lacks the exoskeleton, which is granulose in *A. stenometopus*.

Centropleura sp.
Figure 9l, o

Listed by Nicholas (1915, p. 102) as '*Centropleura salteri* (?)', described as *Anopolenus Salteri* Hicks (*in* Salter & Hicks, 1865, p. 478) from south Wales and placed in synonymy with *A. henrici* Salter, 1864 by Lake (1934, p. 189). The specimen comprises only a strongly convex, gently tapered pygidial axis, slightly wider than long, with part of the adjacent right pleural region. There are three large axial rings, bounded by sinuous inter-ring furrows that curve forward medially and distally around a pair of lobe-like swellings. Comparable structures are seen in some illustrations of *Centropleura phoenix* Öpik (1961, pl. 8, fig. 2a, b) from the upper Middle Cambrian (*Lejopyge laevigata* Zone) of Australia. In his redescription of the type species of *Centropleura*, *C. loveni* (Angelin, 1851) from the *Solenopleura brachymetopa* Zone of Scania, Westergård (1950, p. 4, pl. 1, fig. 4) included tentatively a pygidium in which the axis is relatively narrower than that of the Welsh specimen. In both the Swedish pygidium, and in another referred probably to the associated *C. angelini* Westergård (1950, pl. 1, fig. 10a), the well-defined axial rings show little evidence of lobe-like structures.

5.a.2. Trilobites from the higher Maentwrog Formation

'Very badly preserved' specimens of *Olenus* sp. and *Agnostus pisiformis* var. *obesus* Belt, 1867 from locality α17, 30 m above the base of the Maentwrog Formation at Porth Ceiriad, were noted by Nicholas (1915, p. 104; 1916, p. 470) but not illustrated; no additional specimens have been found. The agnostid is represented by a few, poorly preserved cephala and pygidia (Fig. 9q, r) and a small, almost complete dorsal exoskeleton (Fig. 9p) referred here to *Homagnostus* cf. *obesus*. The lectotype of *H. obesus* from Wales was figured by Allen, Jackson & Rushton (1981) and variation in English material figured by Rushton (1983). The species is accepted as indicative of the *Olenus* Zone in the Welsh Basin and Scandinavia (see, for example, Henningsmoen, 1958). A subspecies from the lower half of the overlying *Parabolina spinulosa* Zone in Scania was described as *Agnostus* (*Homagnostus*) *obesus laevis* Westergård (1947), and differs only in the presence of a broader marginal furrow and the absence of a median preglabellar furrow on the cephalon, characters that are difficult to evaluate in poorly preserved or compressed material. Evidence from the present specimens suggests that a median preglabellar furrow is present, and the resemblance to *H. obesus* is evident.

Identification of the other trilobite is equivocal and one of the better specimens (Fig. 9s) cited as *Olenus* sp. by Nicholas cannot be assigned confidently to that genus, though it is of olenid type. On present evidence, the trilobites from the Maentwrog Formation of Porth Ceiriad are more likely to belong to the *Olenus* Zone, as in the Maentwrog Formation of the main outcrop. The lower half of the *P. spinulosa* Zone cannot be altogether excluded, but is less likely.

5.b. Description of acritarchs (F.M.)

Genus *Cristallinium* Vanguestaine, 1978

Type species. Cristallinium cambriense (Slavíková) Vanguestaine, 1978, by original designation.

Cristallinium cambriense (Slavíková) Vanguestaine, 1978
Figure 11i

1968. *Dictyotidium cambriense* n. sp. Slavíková, p. 201, pl. 2, figs 1, 3.

Figure 11. Magnification × 1000 unless otherwise stated. (a, c, d): level 5 of 'calcareous grit' at base of Maentwrog Formation. (b, e–q): lower part of Nant-y-big Formation (formerly Upper Caered Mudstones). (a) *Izhoria* sp. NAN-33c, IRScNB b2468. (b, g, h, j, k, o, q) *Heliosphaeridium? llynense* Martin sp. nov. (b) NAN-55, IRScNB b2624; (g) NAN-16, IRScNB b2625; (h) NAN-15, holotype, IRScNB b2626; (j) NAN-51, IRScNB b2469; (k) NAN-15, IRScNB b2627, × 1500; (o) NAN-14, IRScNB b2628, × 2000; (q) NAN-51, IRScNB b2629, × 2000. (c, d) *Cymatiogalea* sp. NAN-33c. (c) IRScNB b2467; (d) IRScNB b2466. (e) Acritarch gen. et sp. nov. Martin *in* Martin & Dean, 1984, NAN-11, IRScNB b2586. (f, l) *Comasphaeridium longispinosum* Hagenfeldt, 1989*b*. (f) NAN-13, IRScNB b2591; (l) NAN-14, IRScNB b2592. (i) *Cristallinium cambriense* (Slavíková) Vanguestaine, 1978, NAN-67, IRScNB b2594, × 1500. (m, n, p) *Adara alea* Martin *in* Martin & Dean, 1981. NAN-17. (m, p) IRScNB b2587; (p) = enlargement, × 4000, of central part of (m); (n) IRScNB b2588.

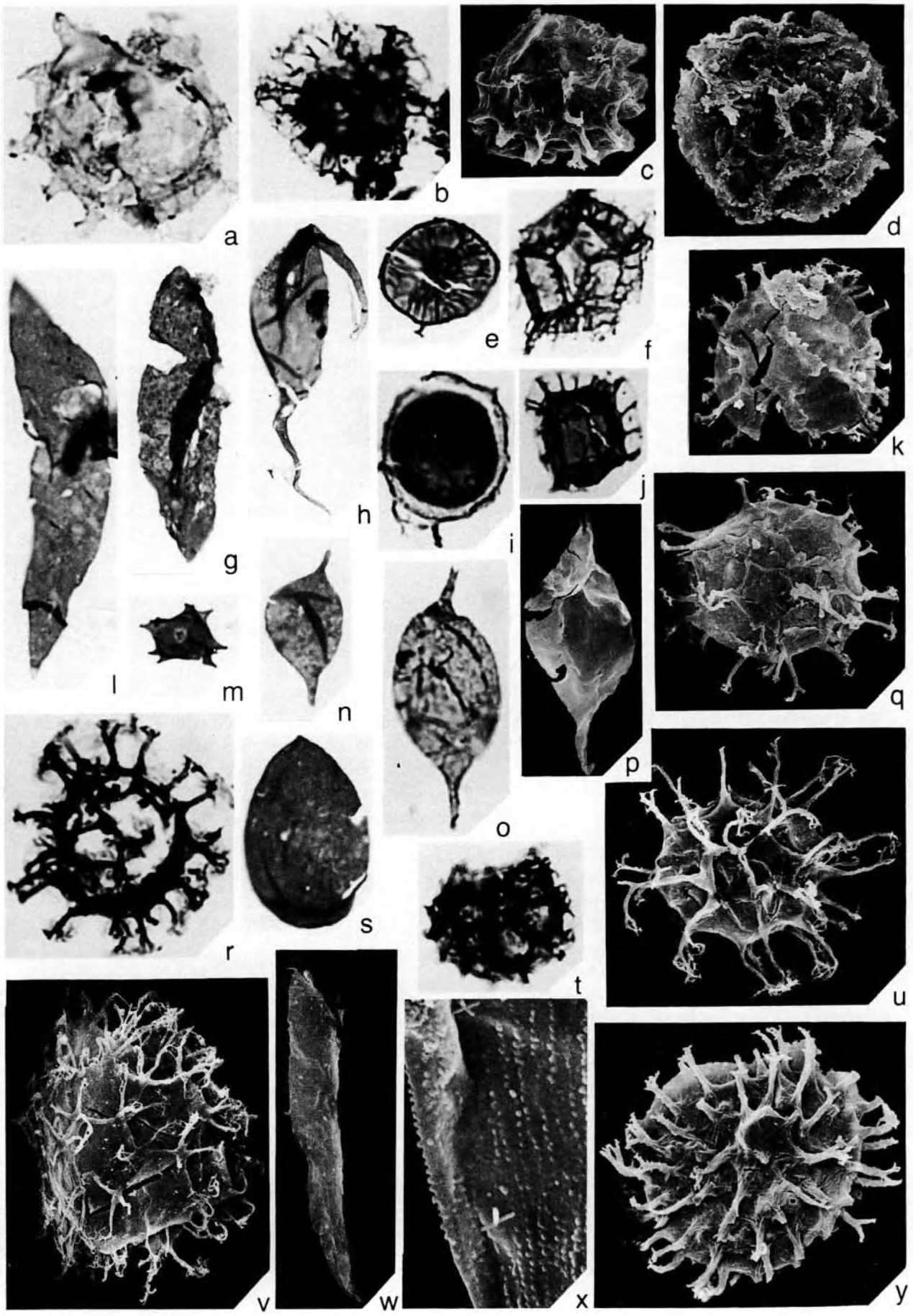

Figure 12. For legend see facing page.

1978. *Cristallinium cambriense* (Slavíková) Vanguestaine nov. comb., p. 271, pl. 2, figs 16, 17; pl. 3, figs 16, 26.
1991. *Cristallinium cambriense* (Slavíková) Vanguestaine, 1978. Albani, Massa & Tongiorgi, pp. 266, 268, pl. 1, figs 3–5. Includes references.

Occurrence. Rare in the Ceiriad Formation, where its oldest record is 6.5 m above the base of the unit; in the Maentwrog Formation; and in the lower part of the Ffestiniog Flags Formation.

Discussion. In her original description of the species Slavíková (1968, pl. 2, figs 1, 3) illustrated two specimens; the one designated as holotype, with diameter 32 μm, is clearly that in pl. 2, fig. 1, and not in pl. 1, fig. 11 as stated erroneously in one of her three references to the illustrations. The genus and species are widely used in Cambrian palynological literature and there is no doubt as to the holotype, which was correctly indicated by Vanguestaine (1978) as that of the type species of *Cristallinium*. It seems to me confusing to follow the proposal of Fensome *et al.* (1990, p. 160) who, on the basis of what is no more than a misprint by Slavíková, designated *Cymatiosphaera ovillensis* Cramer & Diez, 1972 as type species of *Cristallinium*. Furthermore, the holotype of *Cymatiosphaera ovillensis* illustrated by Cramer & Diez (1972, pl. 2, fig. 4) appears to belong to that prasinophyte genus on the basis of the relative importance of the muri; *C. ovillensis* is figured herein (Fig. 10j, q).

Genus *Heliosphaeridium* Moczydłowska, 1991

Type species. Heliosphaeridium dissimilare (Volkova) Moczydłowska, 1991, by original designation.

Heliosphaeridium? llynense Martin sp. nov.
Figure 11 b, g, h, j, k, o, q

In press. *Skiagia* sp. nov. Martin *in* Young, Gibbons & McCarroll, pl. 1, fig. 5.

Holotype. IRScNB b 2626 (Fig. 11 h). Vesicle diameter: 18 μm; trunk of processes: 11 to 15 μm long, with basal breadth 0.7 to 1.5 μm; distal divisions of processes: up to 6.5 μm long.

Type locality. Lower part of Nant-y-big Formation, Loc. NAN-15, 15.85 m above the pair of small faults used as datum point at the section along the northwest shore of Porth Ceiriad.

Derivation of name. Latin (substantive in the genitive), for the Llŷn Peninsula.

Diagnosis. Based on 150 specimens. Single-walled, psilate acritarch. Vesicle originally spherical, clearly distinct from processes. About fifteen to forty slender processes, the hollow internal cavity of which communicates with that of the vesicle. The length of the proximal portion, slightly conical basally, varies from one-quarter to 1.0, but most often two-thirds, of the vesicle diameter. The distal extremity is divided dichotomously, up to the fourth order, into 'straps' which anastomose with those of adjacent processes.

Dimensions. Based on 60 specimens. Diameter of vesicle: 14–23 (average 18) μm; length and basal width of proximal part of processes: 4–12 μm and 1–2.5 μm; total length of distal divisions of processes: 5–14 μm; maximum thickness of vesicle wall: less than 0.35 μm.

Occurrence. Rare to abundant in the lower Nant-y-big Formation. Locs., in ascending order, NAN-11, -12, -50, -51, -55, -13, -56, -57, -58, -14, -59, -15, -61, -62, -16, -17, -64 and -67.

Discussion. Frequent breakage of the distal extremities of the processes produces artificially a funnel-like aspect such as is indicated in the diagnosis of *Skiagia* Downie, 1982. The generic attribution is doubtful as coalescence of the distal divisions of the processes is not mentioned in the diagnosis of *Heliosphaeridium*. Incomplete specimens recall those determined by Vanguestaine & Van Looy (1983, p. 73, pl. 1, figs

Figure 12. Magnification × 1000 unless otherwise stated. (a, e, g, h, j, l–n, s, v, w, x): Ffestiniog Flags Formation (formerly Ffestiniog Beds). (b–d, f, i, k, o–r, t, u, y): Maentwrog Formation (formerly Maentwrog Beds). (a) *Multiplicisphaeridium* cf. *M. eopiriferum* Fombella, 1978. STE-2, IRScNB b2613. (b) *Timofeevia microretis* Martin *in* Martin & Dean, 1981. NAN-34, IRScNB b2635. (c) *Cymatiogalea virgulta* Martin *in* Martin & Dean, 1988. NAN-36, IRScNB b2599. (d) *Cristallinium* cf. *C. randomense* Martin *in* Martin & Dean, 1981. NAN-39, IRScNB b2595. (e, i) Isolated opercula of *Stelliferidium* sp. or *Cymatiogalea* sp. (e) STE-1, IRScNB b2580; (i) NAN-42, IRScNB b2614. (f) *Cymatiogalea* cf. *C. cristata* (Downie) Rauscher, 1974. NAN-42, IRScNB b2597. (g) *Poikilofusa* cf. *P. chalaza* Rasul, 1979. STE-2, IRScNB b2616, × 500. (h) *Leiofusa stoumonensis* Vanguestaine, 1973. STE-2, IRScNB b2610, × 750. (j) *Cymatiogalea parvivela* Di Milia, 1991. STE-1, IRScNB b2598. (k) *Timofeevia pentagonalis* (Vanguestaine) Vanguestaine, 1978. NAN-42, IRScNB b2636. (l, w, x) *Poikilofusa* cf. *P. squama* (Deunff) Martin, 1973. STE-2. (l) IRScNB b2617; (w, x) fragment, IRScNB b2618; (x) = enlargement, × 8000, of lower left part of (w). (m) *Impluviculus* sp. STE-1, IRScNB b2606. (n–p) *Leiofusa* cf. *L. gravida* Pittau, 1985. (n) STE-2, IRScNB b2607; (o) NAN-43, IRScNB b2608; (p) NAN-42, IRScNB b2609. (q) *Timofeevia phosphoritica* Vanguestaine, 1978. NAN-39, IRScNB b2637. (r) *Cymatiogalea aspergillum* Martin *in* Martin & Dean, 1988. NAN-37, IRScNB b2596. (s) *Monocrodium?* sp. STE-1, IRScNB b2611. (t) *Vulcanisphaera turbata* Martin *in* Martin & Dean, 1981. NAN-44, IRScNB b2638. (u) *Timofeevia lancarae* (Cramer & Diez) Vanguestaine, 1978. NAN-42, IRScNB b2575. (v) Transition *Vulcanisphaera turbata* to *V. africana sensu* Martin *in* Martin & Dean, 1988. STE-2, IRScNB b2639. (y) *Stelliferidium pingiculum* Martin *in* Martin & Dean, 1988. NAN-36, IRScNB b2633.

16–19; text-fig. 4) as *Micrhystridium* aff. *M. coniferum* Downie, 1982, from deposits they considered as Middle Cambrian in the Moroccan High Atlas.

Genus *Leiofusa* Eisenack, 1938 emend. Combaz, Lange & Pansart, 1967

Type species. Leiofusa fusiformis (Eisenack) Eisenack, 1938 by original designation.

Leiofusa cf. *L. gravida* Pittau, 1985
Figure 12n–p

1985. *Leiofusa* sp. Albani, Di Milia, Minzoni & Tongiorgi, pl. 1, figs 7, 8.
1991. *Leiofusa stoumonensis* Vanguestaine, 1973. Di Milia, p. 142, pl. 2, figs 1?, 2–4.

Dimensions. Based on 22 specimens. Length and width of vesicle: 24–40 μm and 16–22 μm. Length and basal width of processes: 7–13 μm and 2–4 μm respectively.

Occurrence. Rare in the upper part of the Maentwrog Formation (Locs. NAN-41, -42, -43 and -44); rare to common in the lower part of the Ffestiniog Flags Formation (Locs. STE-1, STE-2).

Discussion. Based on 45 specimens. *Leiofusa* cf. *L. gravida* differs from *L. stoumonensis* in the dissimilar processes and asymmetric swelling of the vesicle; and from *L. gravida* in the much shorter processes. One complete process has a length between one-quarter and one-half that of the vesicle; the other, of approximately similar length, is always broken and gaping. Vesicle and processes are weakly and irregularly granulate.

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References

ALBANI, R., DI MILIA, A., MINZONI, N. & TONGIORGI, M. 1985. Nuovi dati palinologici e considerazioni geologiche sull'età delle Arenarie di Solanas (Cambro-Ordoviciano), Sardegna Centrale. *Atti della Società Toscana di Scienze Naturali, Memoria* **A 91**, 1–20.

ALBANI, R., MASSA, D. & TONGIORGI, M. 1991. Palynostratigraphy (Acritarchs) of some Cambrian beds from the Rhadames (Ghadamis) Basin (Western Libya – Southern Tunisia). *Bolletino della Società Paleontologica Italiana* **30**, 255–80.

ALLEN, P. M. & JACKSON, A. A. 1985. *Geology of the country around Harlech. Memoir for 1:50000 geological sheet 135 with part of sheet 149 (England and Wales).* British Geological Survey, 112 pp.

ALLEN, P. M., JACKSON, A. A. & RUSHTON, A. W. A. 1981. The stratigraphy of the Mawddach Group in the Cambrian succession of North Wales. *Proceedings of the Yorkshire Geological Society* **43**, 295–329.

ANGELIN, N. P. 1851–78. *Palaeontologia Scandinavica: Academiae Regiae Scientiarum Suecanae (Holmiae); Pars I. Crustacea formationis transitionis*, pp. 1–24 [1851]; *Pars II*, pp. i–ix, 25–92 [1854]; republished in revised and combined form (ed. G. Lindström, pp. x + 96 [1878].

BAGNOLI, G., STOUGE, S. & TONGIORGI, M. 1988. Acritarchs and conodonts from the Cambro-Ordovician Furuhäll (Köpingsklint) Section (Öland, Sweden). *Rivista italiana di Paleontologia e Stratigrafia* **94**, 163–248.

BASSETT, D. A. & WALTON, E. K. 1960. The Hell's Mouth Grits: Cambrian greywackes in St Tudwal's Peninsula, North Wales. *Quarterly Journal of the Geological Society, London* **116**, 85–110.

BASSETT, M. G., OWENS, R. M. & RUSHTON, A. W. A. 1976. Lower Cambrian fossils from the Hell's Mouth Grits, St Tudwal's Peninsula, North Wales. *Journal of the Geological Society, London* **132**, 623–44.

BELT, T. 1867. On some new trilobites from the Upper Cambrian rocks of North Wales. *Geological Magazine* **4**, 294–5.

BENGTSON, S. & FLETCHER, T. E. 1983. The oldest sequence of skeletal fossils in the Lower Cambrian of southeastern Newfoundland. *Canadian Journal of Earth Sciences* **20**, 525–36.

BENNETT, M. A. 1989. Quartz-spessartine metasediments (coticules) and their protoliths in North Wales. *Geological Magazine* **126**, 435–42.

BOSE, P. K. 1983. A reappraisal of the conditions of deposition of the Maentwrog Beds (Upper Cambrian) at Porth Ceiriad, North Wales. *Geological Magazine* **120**, 73–80.

BRITISH GEOLOGICAL SURVEY (in press). *Pwllheli, Sheet 134, 1:50000 Geological Series (England & Wales).* Keyworth.

BRÖGGER, W. C. 1878. Om paradoxidesskifrene ved Krekling. *Nyt Magazin for Naturvidenskaberne* **24**, 18–88.

COMBAZ, A., LANGE, F. W. & PANSART, J. 1967. Les "Leiofusidae" Eisenack, 1938. *Review of Palaeobotany* **1**, 291–307.

COWIE, J. W. 1974. The Cambrian of Spitzbergen and Scotland. In *Cambrian of the British Isles, Norden and Spitsbergen; Lower Palaeozoic of the World, Volume 2* (ed. C. H. Holland), pp. 123–55. J. Wiley & Sons.

COWIE, J. W., RUSHTON, A. W. A. & STUBBLEFIELD, C. J. 1972. *A correlation of Cambrian rocks in the British Isles.* Geological Society of London, Special Report no. 2, 40 pp.

CRAMER, F. H. & DIEZ, M. D. C. 1972. Acritarchs from the upper Middle Cambrian Oville Formation of León, northwestern Spain. *Revista Española de Micropaleontología. Número extraordinario, XXX Aniversario E. N. Adaro*, pp. 39–50.

DAMES, W. 1883. Kambrische Trilobiten von Liau-Tung. In *Ergebnisse iegener Reisen und darauf gegundete Studien, Vol. 4. Paläontologie* (ed. F. F., von Richthofen), pp. 3–33. Berlin: D. Reimer.

DEUNFF, J. 1961. Un microplancton à Hystrichosphères dans le Tremadoc du Sahara. *Revue de Micropaléontologie* **4**, 37–52.

DEUNFF, J., GÓRKA, H. & RAUSCHER, R. 1974. Observations nouvelles et précisions sur les acritarches à large ouverture polaire du Paléozoïque Inférieur. *Geobios* **7**, 5–18.

DI MILIA, A. 1991. Upper Cambrian acritarchs from the

Solanas Sandstone Formation, Central Sardinia, Italy. *Bollettino della Società Paleontologica Italiana* **30**, 127–52.

DI MILIA, A., RIBECAI, C. & TONGIORGI, M. 1989. Late Cambrian acritarchs from the *Peltura scarabaeoides* Trilobite Zone at Degerhamm (Öland, Sweden). *Palaeontographica Italica* **76**, 1–56.

DOWNIE, C. 1982. Lower Cambrian acritarchs from Scotland, Norway, Greenland and Canada. *Transactions of the Royal Society of Edinburgh, Earth Sciences* **72** (1981), 275–85.

EISENACK, A. 1938. Hystrichosphaeriden und verwandte Formen im baltischen Silur. *Zeitschrift für Geschiebeforschung und Flacklandschegeologie* **14**, 1–30.

ERKMEN, U. & BOZDOĞAN, N. 1981. Cambrian acritarchs from the Sosink Formation in southeast Turkey. *Revista Española de Micropaleontología* **13**, 47–60.

FEDJANINA, E. S. 1977. Trilobites of the Orlinogorski Formation (Orlinaya Mountains, northeast Salair). *Trudy Instituta Geologii i Geofiziki. Sibirskoe Otdelenie. Novosibirsk* **313**, 145–52 (in Russian).

FENSOME, R. A., WILLIAMS, G. L., BARSS, M. S., FREEMAN, J. M. & HILL, J. M. 1990. *Acritarchs and fossil prasinophytes: an index to genera, species and infraspecific taxa.* American Association of Stratigraphic Palynologists Foundation. Contributions Series no. 25, 771 pp.

FOMBELLA, M. A. 1977. Acritarcos de edad Cámbrico Medio-Inferior de la Provincia de León, España. *Revista Española de Micropaleontología* **9**, 115–24.

FOMBELLA, M. A. 1978. Acritarcos de la Formación Oville, edad Cámbrico Medio – Tremadoc, Provincia de León, España. *Palinología, Número Extraordinario* **1**, 245–61.

FRITZ, W. H. 1972. *Lower Cambrian trilobites from the Sekwi Formation type section, Mackenzie Mountains, northwestern Canada.* Geological Survey of Canada, Bulletin no. 212, 58 pp.

GEYER, G. 1990. Revised Lower to lower Middle Cambrian biostratigraphy of Morocco. *Newsletters on Stratigraphy* **22**, 53–70.

GRÖNWALL, K. A. 1902. Bornholms Paradoxideslag og deres Fauna. *Danmarks geologiske Undersøgelse* **2** (13), 1–230.

HAGENFELDT, S. E. 1989*a*. Lower Cambrian acritarchs from the Baltic Depression and south-central Sweden, taxonomy and biostratigraphy. *Stockholm Contributions in Geology* **41**, 1–176.

HAGENFELDT, S. E. 1989*b*. Middle Cambrian acritarchs from the Baltic Depression and south-central Sweden, taxonomy and biostratigraphy. *Stockholm Contributions in Geology* **41**, 177–250.

HENNINGSMOEN, G. 1958. The Upper Cambrian faunas of Norway. With descriptions of non-olenid invertebrate fossils. *Norsk Geologisk Tidsskrift* **38**, 179–96.

HICKS, H. 1872. On some undescribed species from the Menevian group. *Quarterly Journal of the Geological Society of London* **28**, 173–83.

HUTCHINSON, R. D. 1962. *Cambrian stratigraphy and trilobite faunas of southeastern Newfoundland.* Geological Survey of Canada, Bulletin no. 88, 156 pp.

ILLING, V. C. 1916. The Paradoxidian Fauna of a part of the Stockingford Shales. *Quarterly Journal of the Geological Society of London* **71**, 386–448.

JANKAUSKAS, T. V. & POSTI, E. 1976. New Cambrian acritarchs from the East Baltic area. *Izvestiia Akademii Nauk Estonskoii SSR, Geologia* **22**, 145–51 (in Russian).

LAKE, P. 1906–46. *A Monograph of the British Cambrian Trilobites.* Palaeontographical Society [Monographs], 350 pp.

LINNARSSON, J. G. O. 1869. Om Vestergötlands Cambriska och Siluriska aflagringar. *Kungliga Svenska Vetenskapsakademiens Handlingar* **8** (2), 1–89.

LINNARSSON, J. G. O. 1879. Om faunan i kalken med *Conocoryphe exsulans* ('coronatuskalken'). *Sveriges Geologiska Undersökning* **C 35**, 1–31.

MARTIN, F. 1973. Les Acritarches de l'Ordovicien inférieur de la Montagne Noire (Hérault, France). *Bulletin de l'Institut royal des Sciences naturelles de Belgique* **48** (1972), *Sciences de la Terre* no. 10, 61 pp.

MARTIN, F. & DEAN, W. T. 1981. *Middle and Upper Cambrian and Lower Ordovician acritarchs from Random Island, eastern Newfoundland.* Geological Survey of Canada, Bulletin no. 343, 43 pp.

MARTIN, F. & DEAN, W. T. 1983. Late Early Cambrian and early Middle Cambrian acritarchs from Manuels River, eastern Newfoundland. In *Current Research, Part B*, pp. 353–63. Geological Survey of Canada, Paper no. 83-1B.

MARTIN, F. & DEAN, W. T. 1984. Middle Cambrian acritarchs from the Chamberlains Brook and Manuels River formations at Random Island, eastern Newfoundland. In *Current Research, Part A*, pp. 429–40. Geological Survey of Canada, Paper 84-1A.

MARTIN, F. & DEAN, W. T. 1988. *Middle and Upper Cambrian acritarch and trilobite zonation at Manuels River and Random Island, eastern Newfoundland.* Geological Survey of Canada, Bulletin no. 381, 91 pp.

MATLEY, C. A., NICHOLAS, T. C. & HEARD, A. 1939. Summer field meeting to western part of the Lleyn Peninsula. *Proceedings of the Geologists' Association* **50**, 83–100.

MCCOY, F. 1851. On some new Cambro-Silurian fossils. *Annals and Magazine of Natural History* (2) **8**, 387–409.

MOCZYDŁOWSKA, M. 1991. *Acritarch biostratigraphy of the Lower Cambrian and the Precambrian–Cambrian boundary in southeastern Poland.* Fossils and Strata no. 29, 127 pp. Oslo: Universitetsforlaget.

NICHOLAS, T. C. 1915. The geology of the St. Tudwal's Peninsula (Carnarvonshire). *Quarterly Journal of the Geological Society of London* **71**, 83–141.

NICHOLAS, T. C. 1916. Notes on the trilobite fauna of the Middle Cambrian of the St. Tudwal's Peninsula (Carnarvonshire). *Quarterly Journal of the Geological Society of London* **71**, 451–71.

ÖPIK, A. A. 1961. The geology and palaeontology of the headwaters of the Burke River, Queensland. *Bureau of Mineral Resources, Geology and Geophysics, Bulletin* **53**, 1–249.

PITTAU, P. 1985. Tremadocian (early Ordovician) acritarchs of the Arburese unit, southwest Sardinia (Italy). *Bolletino della Società Paleontologica Italiana* **23** (1984), 161–204.

POTTER, T. L. 1974. British Cambrian acritarchs – a preliminary account. *Review of Palaeobotany and Palynology* **18**, 61–2.

RASUL, S. M. 1979. Acritarch zonation of the Tremadoc Series of the Shineton Shales, Wrekin, Shropshire, England. *Palynology* **3**, 53–72.

RAUSCHER, R. 1974. *Recherches micropaléontologiques et stratigraphiques dans l'Ordovicien et le Silurien en*

France. Étude des Acritarches, des Chitinozoaires et des Spores. Université Louis Pasteur de Strasbourg, Sciences géologiques, Mémoire no. 38 (1973), 224 pp.

RESSER, C. E. 1936. Second contribution to nomenclature of Cambrian trilobites. *Smithsonian Miscellaneous Collections* **95** (4), 1–29.

ROBERTS, B. & MERRIMAN, R. J. 1990. Cambrian and Ordovician metabentonites and their relevance to the origins of associated mudrocks in the northern sector of the Lower Palaeozoic Welsh marginal basin. *Geological Magazine* **127**, 31–43.

RUSHTON, A. W. A. 1966. *The Cambrian Trilobites from the Purley Shales of Warwickshire.* Palaeontographical Society (Monographs), 55 pp.

RUSHTON, A. W. A. 1974. The Cambrian of England and Wales. In *Cambrian of the British Isles, Norden and Spitzbergen* (ed. C. H. Holland), pp. 43–121. John Wiley & Sons.

RUSHTON, A. W. A. 1983. Trilobites from the Upper Cambrian *Olenus* Zone in central England. *Special Papers in Palaeontology* **30**, 107–39.

SALTER, J. W. 1863. On the discovery of *Paradoxides* in Britain. *Quarterly Journal of the Geological Society of London* **19**, 274–7.

SALTER, J. W. 1864. On some new fossils from the Lingula-flags of Wales. *Quarterly Journal of the Geological Society of London* **20**, 233–41.

SALTER, J. W. 1866. On the fossils of North Wales. In *The Geology of North Wales* (ed. A. C. Ramsay), pp. 239–381. Memoirs of the Geological Survey of Great Britain no. 3.

SALTER, J. W. & HICKS, H. 1865. On some additional fossils from the Lingula-flags. With a note on the genus *Anopolenus*. *Quarterly Journal of the Geological Society of London* **21**, 476–82.

SALTER, J. W. & HICKS, H. 1869. On some fossils from the 'Menevian Group'. *Quarterly Journal of the Geological Society of London* **25**, 51–7.

SDZUY, K. 1966. Das Kambrium des Frankenwaldes. 2. Die Bergleshof-Schichten und ihre Trilobiten-Fauna. *Senckenbergiana Lethaea* **47**, 57–86.

SHERGOLD, J. H. & BRASIER, M. D. 1986. Chapter 23. Proterozoic and Cambrian phosphorites – specialist studies: biochronology of Proterozoic and Cambrian phosphorites. In *Phosphate Deposits of the World. Volume 1, Proterozoic and Cambrian Phosphorites* (eds P. J. Cook and J. H. Shergold), pp. 295–326. Cambridge University Press.

SHERGOLD, J. H., LAURIE, J. R. & SUN XIAOWEN 1990. *Classification and review of the trilobite order Agnostida: an Australian perspective.* Bureau of Mineral Resources, Geology and Geophysics Report no. 296, iii + 1–93 pp.

SLAVÍKOVÁ, K. 1968. New finds of acritarchs in the Middle Cambrian of the Barrandian (Czechoslovakia). *Věstnik Ústředního ústavu geologického* **43**, 199–205.

STAPLIN, F. L., JANSONIUS, J. & POCOCK, S. A. J. 1965. Evaluation of some acritarcheous Hystrichosphere genera. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* **123**, 167–201.

TAYLOR, K. & RUSHTON, A. W. A. 1972. *The pre-Westphalian geology of the Warwickshire Coalfield with a description of three boreholes in the Merevale area.* Bulletin of the Geological Survey of Great Britain no. 35, vii + 150 pp. [dated 1971].

THOMAS, A. T., OWENS, R. M. & RUSHTON, A. W. A. 1984. *Trilobites in British stratigraphy.* Geological Society of London, Special Report no. 16, 78 pp.

VANGUESTAINE, M. 1973. New acritarchs from the Upper Cambrian of Belgium. In *Microfossils of the oldest deposits* (eds T. F. Vozzhennikova and B. V. Timofeev), pp. 28–30. Proceedings of the Third International Palynological Conference, Academy of Sciences of the USSR, Siberian Branch, Institute of Geology and Geophysics. Moscow: Nauka.

VANGUESTAINE, M. 1978. Critères palynostratigraphiques conduisant à la reconnaissance d'un pli couché revinien dans le sondage de Grand-Halleux. *Annales de la Société géologique de Belgique* **100** (1977), 249–76.

VANGUESTAINE, M. 1991. Datation par acritarches des couches cambro-trémadociennes les plus profondes du sondage de Lessines (bord méridional du Massif du Brabant, Belgique). *Annales de la Société géologique de Belgique* **114**, 213–32.

VANGUESTAINE, M. & VAN LOOY, J. 1983. Acritarches du Cambrien Moyen de la vallée du Tacheddirt (Haut-Atlas, Maroc) dans le cadre d'une nouvelle zonation du Cambrien. *Annales de la Société Géologique de Belgique* **106**, 69–85.

VAVRDOVÁ, M. 1976. Excystment mechanism of Early Palaeozoic acritarchs. *Časopis pro mineralogii a geologii* **21**, 55–64.

VOLKOVA, N. A. 1990. *Middle and Upper Cambrian acritarchs in the East-European Platform.* Academy of Sciences of the USSR, Transactions no. 454, 116 pp. (in Russian).

VOLKOVA, N. A. & GOLUB, I. N. 1985. New acritarchs of Upper Cambrian Leningrad district (Ladoga Formation). *Palaeontologischeskij Zhurnal, Akademia Nauk SSSR* **4**, 90–8 (in Russian).

VOLKOVA, N. A., KIRJANOV, V. V., PISKUN, L. V., PASKEVICIENE, L. T. & JANKAUSKAS, T. V. 1979. [English translation, 1983]. Plant microfossils. In *Upper Cambrian and Cambrian palaeontology of the East European Platform* (eds A. Urbanek and A. Yu. Rozanov), pp. 7–46. Warsaw: Wydawnictwa Geologiczne.

WESTERGÅRD, A. H. 1946. Agnostidea of the Middle Cambrian of Sweden. *Sveriges Geologiska Undersökning* **C 477**, 1–141.

WESTERGÅRD, A. H. 1947. Supplementary notes on the Upper Cambrian trilobites of Sweden. *Sveriges Geologiska Undersökning* **C 489**, 1–35.

WESTERGÅRD, A. H. 1948. Non-agnostidean trilobites of the Middle Cambrian of Sweden. I. *Sveriges Geologiska Undersökning* **C 498**, 1–33.

WESTERGÅRD, A. H. 1950. Non-agnostidean trilobites of the Middle Cambrian of Sweden. II. *Sveriges Geologiska Undersökning* **C 511**, 1–57.

WESTERGÅRD, A. H. 1953. Non-agnostidean trilobites of the Middle Cambrian of Sweden. III. *Sveriges Geologiska Undersökning* **C 526**, 1–59.

WOODCOCK, N. H. 1990. Sequence stratigraphy of the Palaeozoic Welsh Basin. *Journal of the Geological Society, London* **147**, 537–47.

YOUNG, T. P., GIBBONS, W. & MCCARROLL, D. (in press). *Geology of the country around Pwllheli. Memoir for 1:50000 geological sheet 134.* British Geological Survey.

ZANG, W. L. 1992. Sinian and Early Cambrian floras and biostratigraphy on the South China Platform. *Palaeontographica* **B 224**, 75–119.

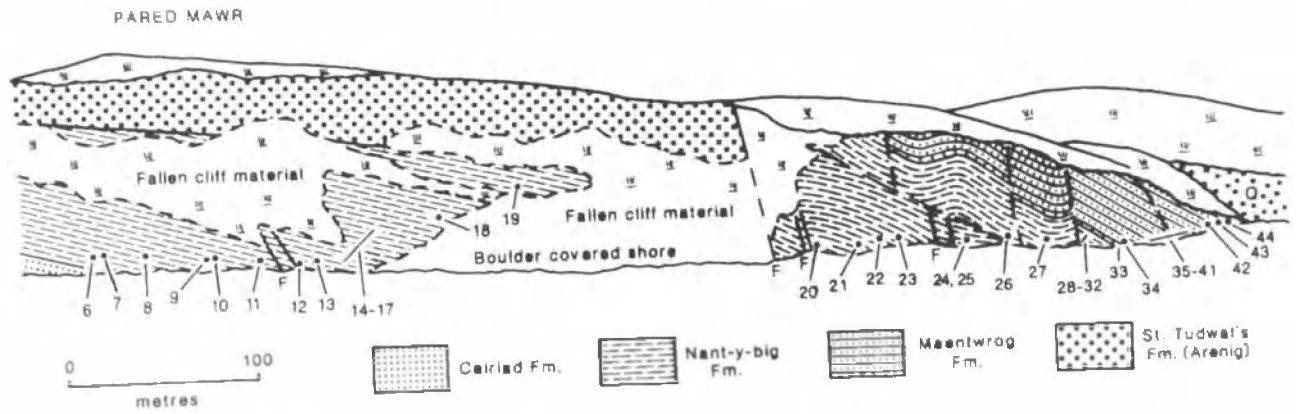

Figure 13. Sketch (adapted from Nicholas, 1915, fig. 3) of cliff section at west end of Porth Ceiriad showing lithostratigraphic boundaries and selected microfossil localities (locality numbers carry the prefix NAN- in the text). Q = Quaternary sediments seen in distance at east end of Porth Ceiriad.

Appendix. Location of microfossil samples (F.M., W.T.D., T.Y.)

(a) acritarchs present; (o) acritarchs absent or undeterminable.

A1. Ffestiniog Flags Formation

St Tudwal's Island East (*c.* 120 m seen)

STE-2: 82.50 m below Arenig unconformity (a)
STE-1: 103.50 m below Arenig unconformity (a)

A2. Maentwrog Formation

Northeastern shore of Porth Ceiriad (15.5 m seen)

(1.50 m to base of Arenig unconformity)
NAN-48: 14.00 m above base of section (a)
NAN-47: 11.00 m above base of section (a)
NAN-46: 8.10 m above base of section (a)
NAN-45: 6.80 m above base of section (a)
(gap in section at Nant-y-big beach)

Northwestern shore of Porth Ceiriad (34.5 m seen)

(*c.* 2.00 m exposed above NAN–44)
NAN-44: 32.30 m above base of unit (a)
NAN-43: 27.20 m above base of unit (a)
NAN-42: 22.30 m above base of unit (a)
NAN-41: 16.20 m above base of unit (a)
NAN-40: 10.40 m above base of unit (a)
NAN-39: 9.00 m above base of unit (a)
NAN-38: 6.90 m above base of unit (a)
NAN-37: 5.65 m above base of unit (a)
NAN-36: 3.85 m above base of unit (a)
NAN-35: 0.95 m above base of unit (a)
NAN-34: 0.10 m above base of unit (a)

A3. 'Calcareous grit'

Base of cliff, Porth Ceiriad (Fig. 5; levels 1, 2, Nant-y-big Formation; levels 3–6, basal Maentwrog Formation).
NAN-33c: level 5 (a)
NAN-33b: level 3 (o)
NAN-33a: level 1 (o)

A4. Nant-y-big Formation, upper part (67 m seen)

Northwestern shore of Porth Ceiriad (Fig. 13)

NAN-32: 0.25 m below top of unit (o)
NAN-31: 0.90 m below top of unit (o)
NAN-30: 1.70 m below top of unit (o)
NAN-31: 3.70 m below top of unit (o)
NAN-30: 4.70 m below top of unit (o)
NAN-29: 7.70 m below top of unit (o)
NAN-28: 8.70 m below top of unit (o)
NAN-27: 14.00 m below top of unit (o)
NAN-26: 3.50 m above fault plane datum (o)
NAN-25: 2.80 m above lowest bed in triangular block of faulted strata (o)
NAN-24: 2.60 m above lowest bed in triangular block of faulted strata (o)
NAN-23: 14.00 m above fault/shore datum (o)
NAN-22: 12.30 m above fault/shore datum (o)
NAN-21: 7.30 m above fault/shore datum (o)
NAN-20: 3.50 m above fault/shore datum (o)
(Base not seen)

A5. Nant-y-big Formation, lower part (> 120 m; previously Upper Caered Mudstones)

NAN-19: 53.65 m above fault datum (o)
NAN-67: 29.15 m above fault datum (a)
NAN-66: 27.80 m above fault datum (a)
NAN-18: 27.65 m above fault datum (a)
NAN-65: 26.75 m above fault datum (a)
NAN-64: 25.20 m above fault datum (a)
NAN-17: 22.65 m above fault datum (a)
NAN-16: 20.05 m above fault datum (a)
NAN-63: 17.85 m above fault datum (o)
NAN-62: 16.80 m above fault datum (a)
NAN-61: 15.90 m above fault datum (a)
NAN-15: 15.85 m above fault datum (a)
NAN-60: 15.30 m above fault datum (a)
NAN-59: 14.00 m above fault datum (a)
NAN-14: 13.85 m above fault datum (a)
NAN-58: 12.60 m above fault datum (a)
NAN-57: 12.00 m above fault datum (a)
NAN-56: 11.30 m above fault datum (a)
NAN-13: 11.10 m above fault datum (a)
NAN-55: 10.90 m above fault datum (a)
NAN-54: 10.00 m above fault datum (a)

NAN-53: 9.40 m above fault datum (o)
NAN-52: 8.70 m above fault datum (o)
NAN-51: 8.30 m above fault datum (a)
NAN-50: 7.60 m above fault datum (a)
NAN-12: 4.70 m above fault datum (a)
(pair of small, parallel faults used as datum point; at beach level, the easterly fault is 22.80 m above formation base)
NAN-11; 18.50 m above base of unit (a)
NAN-10: 12.60 m above base of unit (o)
NAN-9: 10.55 m above base of unit (o)
NAN-8: 6.85 m above base of unit (o)
NAN-7: 1.85 m above base of unit (o)
NAN-6: 1.65 m above base of unit (o)

A6. Ceiriad Formation (upper > 35 m; previously Caered Flags)

NAN-5: 0.40 m below top of unit (o)
NAN-4: 3.80 m below top of unit (a)
NAN-3: 7.30 m below top of unit (o)
NAN-2: 8.85 m below top of unit (o)
NAN-1: 11.65 m below top of unit (o)

A7. Ceiriad Formation (lowest 34 m; previously Lower Caered Mudstones; Trwyn Llech-y-doll)

TRW-6: 23.00 m above base of unit (a)
TRW-5: 20.10 m above base of unit (a)
TRW-4: 15.70 m above base of unit (o)
TRW-3: 11.10 m above base of unit (a)
TRW-2: 6.50 m above base of unit (a)
TRW-1: 3.10 m above base of unit (a)

A8. Cilan Formation (*c.* 400 m; Trwyn Cilan and Trwyn Carreg-y-tir)

MUL-3: 68.00 m above base of unit (a)
CIL-2: 64.00 m above base of unit (a)
CIL-1: 28.50 m above base of unit (o)

A9. Trwyn-y-Fulfran formation (37 m; section between Trwyn Cilan and Trwyn Carreg-y-tir)

MUL-4: 37.00 m above base of unit (a)
MUL-2: 28.50 m above base of unit (a)
MUL-1: 26.50 m above base of unit (a)

A10. Hell's Mouth Formation (> 190 m; south of Trwyn y Ffosle)
HMG-6: 5.00 m below top of unit (a)
HMG-5: 45.00 m below top of unit (a)
HMG-4: 66.00 m below top of unit (a)
HMG-3: 70.50 m below top of unit (a)
HMG-2: 92.00 m below top of unit (a)
HMG-1: 99.50 m below top of unit (a)
(Base not seen)