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Mid-Wenlock acritarchs from a Silurian inlier in the Cheviot Hills, NE England.

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SYNOPSIS

Six samples from the SE margin of the Greyhound Law Inlier on the southern slopes of the Cheviot Hills yielded diverse, moderately well preserved middle Silurian palynomorph assemblages. The taxa present suggest a mid- to late Sheinwoodian or earliest Homerian age, which is in agreement with new graptolite collections of *Cyrtograptus ellesae* to *Cyrtograptus lundgreni* Zone age. Thick-walled *Leiosphaeridia*, suggestive of deposition in a hemipelagic environment, are common in the assemblages and are associated with diverse non-sphaeromorph acritarchs and some miospores that were derived from shelf areas by turbidity currents. Acritarch and spore colours are consistent with low thermal maturation, with palaeotemperatures probably in the region of 60 - 130°C.

Running head: H.F. BARRON

WENLOCK ACRITARCHS FROM THE CHEVIOT AREA

INTRODUCTION

The inlier here termed the Greyhound Law Inlier is situated between Catcleugh Reservoir and Fulhope in Northumberland, and Leithope Forest in the Borders Region of Scotland (Fig.1). It is the most southeasterly of several Silurian inliers that lie between Jedburgh and the Cheviot Hills and which are assigned to the Southern Belt of the Southern Uplands. Peach and Horne (1899) considered that the Southern Belt deposits, or Riccarton Group, consisted entirely of Wenlock strata; they recorded a Wenlock graptolite fauna from the Greyhound Law Inlier and this age was confirmed by Warren (1964, p.208). Clarkson et al.(1975) proposed a mid- to late Llandovery age for parts of the group. However, subsequent work by Kemp and White (1985) on new graptolite collections found no evidence for a Llandovery age and confirmed the original interpretation of Peach and Horne. Kemp (1986) proposed a revised stratigraphy for the Riccarton Group and divided it into a lower Ross Formation and an overlying Raeberry Castle Formation.

The strata comprise steeply dipping alternating turbiditic greywackes, siltstones and mudstones, associated with graptolitic argillaceous siltstone beds of hemipelagic origin.

This paper describes palynomorph assemblages recovered from samples obtained from recent graptolite collections, supplemented with relevant new graptolite data supplied by Dr D.E. White.

Fig. 1 approx. here

SAMPLE DETAILS

Six samples were collected approximately along strike, from the headwaters of the River Coquet, a few kilometres SW of Fulhope, to the Ramshope Burn north of the Catcleugh Reservoir (Fig.1). Seven preparations (British Geological Survey registered numbers MPA 24430 - 24435, 28225) were made from this material. Sample descriptions and details are given below in geographical order from NE to SW; colour descriptions are based on the Geological Society of America "Rock Color Chart" (1980).

1. MPA 24430. Greenish grey (5GY 6/1) turbidite mudstone associated with light olive grey (5Y 5/2) argillaceous graptolitic siltstone; SE bank of the River Coquet, 0.9km WSW of Fulhope [NT 8105 0988].

2. MPA 24435. Dominantly light olive grey (5Y 5/2) argillaceous graptolitic siltstone with minor greenish grey (5GY 6/1) turbidite mudstone; SE bank of the River Coquet opposite Makendon Farm [NT 8038 0930].

3. MPA 24434 and 28225. Greenish grey (5GY 6/1) turbidite mudstone with light olive grey (5Y 5/2) argillaceous graptolitic siltstone partings; east bank of the River Coquet, 0.5km SSW of Makendon Farm [NT 8018 0891].

4. MPA 24433. Light olive grey (5Y 5/2) argillaceous graptolitic siltstone; storm gully, 1.2km SW of Makendon Farm [NT 7950 0843].

5. MPA 24431. Dominantly medium grey (N5) argillaceous graptolitic siltstone; south bank of tributary of the Ramshope Burn, 1.4km north of Catcleugh Reservoir [NT 7408 0483].

6. MPA 24432. Medium grey (N5) argillaceous graptolitic siltstone associated with greenish grey (5GY 6/1) turbidite mudstone; east bank of the Ramshope Burn, 0.6km north of Catcleugh Reservoir [NT 7328 0442].

PALYNOLOGY

Samples were prepared using standard palynological techniques. The residues recovered were sieved through 75um, 20um and 5um mesh sizes; all yielded moderately well preserved acritarchs and spores, and three samples also yielded sparse, poorly preserved chitinozoa. Samples from the Fulhope - Makendon area contain richer palynomorph assemblages than those collected from Ramshope Burn. Most acritarchs are pale yellow to orange/brown in colour; the spores are orange-brown and the chitinozoa black. Palynomorphs present are listed below; for acritarch taxonomic references see Turner (1984) and Priewalder (1987). Figures in brackets refer to the occurrence of the species in the samples listed above.

Acritarchs:

<u>Alveosphaera</u> spp. (1,3)

<u>Ammonidium</u> <u>microcladum</u> (Downie 1963) Lister 1970 (3)

Ammonidium waldronense (Tappan and Loeblich 1971) Wicander 1974 (3)

Cymatiosphaera heloderma Cramer and Díez 1972 (1,3)

Cymatiosphaera octoplana Downie 1959 (1,3,4)

Cymatiosphaera cf. pentagonalis Kirjanov 1978 (3)

Diexallophasis denticulata (Stockmans and Willière 1963) Loeblich 1970 ((3)

Diexallophasis granulatispinosa (Downie 1963) Hill 1974 (1-4)

Diexallophasis pachymura (Hill 1978) Dorning 1981a (1-3)

Estiastra barbata Downie 1963 (3)

Gracilisphaeridium encantador (Cramer 1970) Eisenack, Cramer and Díez 1973 (3)

Leiosphaeridia spp. (1-6)

Lophosphaeridium parverarum Stockmans and Willière 1963 (1,3)

Micrhystridium inflatum (Downie 1959) Lister 1970 (1)

Micrhystridium stellatum Deflandre 1945 (3)

Multiplicisphaeridium arbusculum Dorning 1981a (1,3,4)

Multiplicisphaeridium cladum (Downie 1963) Eisenack 1969 (3)

Multiplicisphaeridium aff. cymulum (Cramer and Díez 1972) Eisenack, Cramer and Díez 1973 (3)

Multiplicisphaeridium paraguaferum (Cramer 1964) Lister 1970 (3)

Multiplicisphaeridium sp. (3)

Oppilatala frondis (Cramer and Díez 1972) Dorning 1981a (3)

Salopidium granuliferum (Downie 1959) Dorning 1981a (1,3)

Schismatosphaeridium rugulosum Dorning 1981a (1,3)

Tylotopalla cellonensis Priewalder 1987 (3)

Tylotopalla aff. *digitifera* Loeblich 1970 (3)

Tylotopalla robustispinosa (Downie 1959) Eisenack, Cramer and Díez 1973 (1-4)

Tylotopalla wenlockia Dorning 1981a (1-4)

Tylotopalla sp. (3)

Veryhachium rhomboidium Downie 1959 emend. Turner 1984 (3,4)

Veryhachium trispinosum (Eisenack 1938) Deunff 1954 ex Downie 1959 (1,5)

Visbysphaera brevifurcata (Eisenack 1954) Lister 1970 (3)

Chitinozoa:

Ancyrochitina spp. (3,6)

Conochitina proboscifera (Eisenack 1937) forma *truncata* Laufeld 1974 (3)

Conochitina spp. (2,3)

Miospores:

Ambitisporites avitus Hoffmeister 1959 (2,3,5,6)

Ambitisporites dilutus (Hoffmeister 1959) Richardson and Lister 1969 (2,3,5,6)

Archaeozonotriletes chulus var. *nanus* Richardson and Lister 1969 (1)

Dyadospora murusdensa Strother and Traverse 1979 (6)

cf. *Synorisporites verrucatus* Richardson and Lister 1969 (1,3,4,6)

Tetrahedraletes medinensis Strother and Traverse 1979 (2,3,5)

Relative abundances of the components of the palynomorph assemblages are illustrated in Fig.2; Leiosphaeridia, Tylotopalla and Diexallophasis are generally dominant but Alveosphaera, Ammonidium, Cymatiosphaera and Multiplicisphaeridium are common in some preparations, especially MPA 24434 and 28225. The wide variations in palynomorph yield are due mainly to differences in lithology, with turbidite mudstone dominated samples (MPA 24430 and 24434/28225) containing more abundant and diverse assemblages than graptolitic siltstones (MPA 24435, 24433, 24431 and 24432).

Fig. 2 approx. here

Taxonomic notes

Ammonidium waldronense (Tappan and Loeblich 1971) Wicander 1974

Fig.3a

Remarks: The specimens are very similar to those described by Tappan and Loeblich (1971). Under the light microscope the furcate process tips often appear as very small capitate terminations; the aculeate branches are normally only resolved with the SEM.

Dimensions: Vesicle diameter 25(29)32µm, process number 40-50, process length 5-10µm, process width at base 1.5-2.0µm; 8 specimens measured.

Other occurrences: late Wenlock Waldron Shale, Indiana (Tappan and Loeblich 1971); Coalbrookdale Formation to Elton Beds (mid-Wenlock to early Ludlow) of Shropshire

(Dorning 1981a); latest Llandovery to earliest Wenlock of the Cellon section, Austria (Priewalder 1987), and the latest Llandovery of Bohemia (Dufka and Pacltová 1988).

Cymatiosphaera heloderma Cramer and Díez 1972

Fig.3d

Remarks: The specimens found most closely resemble those illustrated by Kirjanov (1978) but are generally larger, with dimensions similar to the type material described by Cramer and Díez (1972).

Dimensions: Vesicle diameter 25(31)38µm, total diameter 40(52)63µm, number of polygonal fields 6-10; 11 specimens measured.

Other occurrences: latest Llandovery Alger Shale, Ohio (Cramer and Díez 1972); latest Llandovery to top Wenlock of Podolia in the Ukraine (Kirjanov 1978), Shropshire (Dorning 1981a) and Ringerike, Norway (Smelror 1987); early Wenlock of Gotland (Cramer *et al*. 1979; Le Herisse 1984).

Cymatiosphaera cf. *pentagonalis* Kirjanov 1978

Fig.3e

Remarks: The individuals found are slightly larger than the specimens of *C*. *pentagonalis* illustrated by Kirjanov (1978). *Cymatiosphaera* cf. *pentagonalis* is similar in form and size to *C*. *heloderma* but lacks the foveolate sculpture seen on the vesicle of the latter, and commonly has an irregularly pentagonal outline.

Dimensions: Vesicle diameter 30(32)37µm, total diameter

50(53)55μm, number of polygonal fields 6-10; 9 specimens measured.

Other occurrences: latest Llandovery to top Wenlock of Podolia, Ukraine (Kirjanov 1978). Apparently identical specimens occur in the late Sheinwoodian of the Welsh Borderlands (Paul Swire, Nottingham University, verbal comm.).

Fig. 3 approx here

Estiastra barbata Downie 1963

Remarks: One fragmented specimen is appproximately 80μm in total diameter with four processes ranging from 30-35μm in length. On the distal part of the processes, the ornament consists of proximally hollow spines up to 2μm in length; towards the process bases these decrease in size to become a granulate ornament. Dorning (1981a, p.182) stated, incorrectly, that Eisenack et al.(1973) transferred this species to Tylotopalla Loeblich. The species is here retained in Estiastra Eisenack 1959, as the central portion of the test is formed from the bases of the processes, unlike Tylotopalla where the processes are differentiated from the circular to subcircular central body.

Other occurrences: Wenlock of Wenlock Edge (Downie 1963); latest Llandovery to earliest Wenlock of Belgium (Martin 1966,1968), Podolia, Ukraine (Kirjanov 1978), Shropshire (Dorning 1981a) and Wenlock Edge (Mabillard and Aldridge 1985).

Gracilisphaeridium encantador (Cramer 1970) Eisenack, Cramer and Díez 1973

Fig.3c

Remarks: The single specimen found is 35μm in diameter, has approximately 25 processes, which are 10-15μm in length and the process loops are generally 2-3μm in length. This specimen is similar to the "short forms" of *G. encantador* described from Gotland (Cramer *et al*. 1979).

Other occurrences: very latest Llandovery of Ohio and Kentucky (Cramer and Díez 1972); late Llandovery to early Wenlock of Wales and the Welsh Borderland (Dorning 1981a; Mabillard and Aldridge 1985); early Wenlock of Gotland (Cramer *et al*. 1979; Le Herisse 1984). K.J. Dorning (written comm.) has observed the "short forms" to range up to the mid-Wenlock.

Multiplicisphaeridium sp.

Fig.3g

Remarks: The single poorly preserved specimen recovered has a subspherical, laevigate vesicle 25μm in diameter with 7 flattened processes, 15 to 24μm long and 5 to 6μm wide at the base tapering to sharp points and branching up to the third order. The flattened processes are similar to those of *Leptobrachion* Dorning 1981a; however, a double walled vesicle was not observed and the specimen is therefore retained in *Multiplicisphaeridium*.

Fig. 4. approx. here

Multiplicisphaeridium aff. *cymulum* (Cramer and Díez 1972) Eisenack, Cramer and Díez 1973

Fig. 4a

Remarks: The specimens recorded from the Greyhound Law samples are smaller and have fewer processes than the type material described by Cramer and Díez (1972). However, the relative process length, branching type and vesicle ornament are very similar.

Dimensions: Vesicle diameter 28(31)33µm, process number 9-12, process length 15-30µm, process width at base 4-6µm; 7 specimens measured.

Other occurrences: Upper Llandovery to late Wenlock of eastern USA (Cramer and Díez 1972); late Wenlock to early Ludlow of Shropshire (Dorning 1981a).

Oppilatala frondis (Cramer and Díez 1972) Dorning 1981a

Fig. 4b

Remarks: The examples found are similar in vesicle size and process length to the type material (Cramer and Díez 1972) though they have fewer processes. All specimens have a granulate ornament on the vesicle surface.

Dimensions: Vesicle diameter 30(35)40µm, process number 10-15, process length 15-30µm, process width at base 2-3µm; 6 specimens measured.

Other occurrences: Upper Llandovery of Kentucky (Cramer and Díez 1972); late Llandovery to mid-Wenlock of Shropshire (Dorning 1981a) and Austria (Priewalder 1987).

Fig. 5 approx here

Tylotopalla cellonensis Priewalder 1987

Fig.4f

Remarks: Similar to type material described by Priewalder (1987), though the process ornament is often not as prominent on the Greyhound Law specimens.
Dimensions: Vesicle diameter 25(30)34µm, process number 8-10, process length 8-18µm, process width at base 5-12µm; 5 specimens measured.
Other occurrence: latest Llandovery to mid-Wenlock of the Cellon section, Austria (Priewalder 1987).

Tylotopalla aff. digitifera Loeblich 1970

Fig.4g

Remarks: The specimens recovered resemble the type material of T. digitifera Loeblich 1970, but are much larger, with some specimens having more numerous processes. As in T. digitifera, the process morphology is variable and includes simple and bifurcate forms.
Dimensions: Vesicle diameter 36(39)45µm, process number 20(23)33, process length 6-13µm, process width at base 4-8µm; 6 specimens measured.
Other occurrences: Late Llandovery of New York (Loeblich 1970) and Shropshire (Dorning 1981a).

Tylotopalla wenlockia Dorning 1981a

Fig.5b,c

Remarks: Tylotopalla wenlockia is part of the complex which includes *T. cellonensis*, *T. robustispinosa* and *T. tappanae* Kirjanov 1978. The last named appears very similar to *T. wenlockia*, but examination of the Russian material would be necessary before establishing synonymy. *Tylotopalla wenlockia* is common in the River Coquet samples, constituting 27% of the non-sphaeromorph acritarch population in MPA 24434 and 28225.

Dimensions: Vesicle diameter 25(28)40μm, process number 10(14)20, process length 13-28μm, process width at base 3-7μm; 15 specimens measured.

Other occurrences: Late Llandovery to late Wenlock of Podolia, Ukraine (Kirjanov 1978); early Wenlock to early Ludlow of Shropshire (Dorning 1981a) and the Linkim Beds (early Wenlock) of the Southern Uplands (Molyneux 1987). Forms which are very similar, but have a more pronounced echinate ornament on the processes, have been observed by the author in assemblages from the Telychian (*Monoclimacis griestoniensis* Zone) of central Wales and the Telychian of the Kirkcudbright coast.

Fig. 6 approx. here

BIOSTRATIGRAPHY

On the basis of a graptolite collection from the banks of the River Coquet near Fulhope (Fig.1), Warren (1964) suggested a correlation of the beds there with the Caddroun Burn Beds of the Hawick area, which range from the *Cyrtograptus rigidus* (late Sheinwoodian) to the *Cyrtograptus lundgreni* Zone (earliest Homerian) in age. Graptolite faunas present at the palynological sample localities are listed below, with their attributed age, from NE to SW; determinations were made by Dr D. E. White.

MPA 24430. ?*Diversograptus gracilis* (Bouček) or *Cyrtograptus ellesae* Gortani (proximal end), *Monoclimacis flumendosae* cf. *kingii* Rickards, *Monograptus flemingii* Salter, *Pristiograptus dubius* cf. *pseudolatus* Rickards and *P*. cf. *pseudodubius* (Bouček).
Age: *Cyrtograptus ellesae* or *Cyrtograptus lundgreni* Zone.

MPA 24435. ?*Monoclimacis flumendosae* Gortani *s.l.* and *Monograptus flemingii*.
Age: *Cyrtograptus rigidus* to *C*. *lundgrenii* Zone.

MPA 24434/28225. ?*Pristiograptus pseudodubius*.
Age: not determinable.

MPA 24433. *Monoclimacis* sp. and *Pristiograptus pseudodubius*.
Age: *C*. *ellesae* or *C*. *lundgreni* Zone.

MPA 24431. *Monoclimacis flumendosae s.l.* and *M*. *flumendosae* cf. *kingii*.
Age: *C*. *ellesae* to *C*. *lungreni* Zone.

MPA 24432. *Monoclimacis flumendosae s.l.*, *Monograptus flemingii* and *Pristiograptus pseudodubius*.
Age: *C*. *ellesae* to *C*. *lundgreni* Zone.

Data on acritarchs from the Wenlock of the Southern Uplands is at present limited to the impoverished assemblage from the Linkim Beds on the Berwickshire coast (Molyneux 1987). Several of the longer ranging Greyhound Law taxa are also present in the early Wenlock Knockgardner Formation of the Midland Valley, Ayrshire (Dorning 1982). The nearest comparable Wenlock sections are, however, in Wales and the Welsh Borderlands. The known ranges, based upon records in the literature, of the acritarch taxa from the Greyhound Law Inlier, are shown in Fig.7; many span the Llandovery - Wenlock Series boundary, from the D. monospinosa to the C. pavimenta Biozone (Dorning and Bell 1987). On acritarch evidence alone, the presence of Ammonidium waldronense, Diexallophasis pachymura, Oppilatala frondis, Schismatosphaeridium rugulosum and Tylotopalla wenlockia suggest a mid- to late Sheinwoodian or possibly earliest Homerian age. The absence of Domasia species, which are particularly common in the late Llandovery to early Wenlock of the Central and Southern Belts of the Southern Uplands (author, BGS unpublished data) indicates a post D. brevifurcata Biozone age. Dorning (1981a) recorded the acme of T. wenlockia within the C. pavimenta Biozone; this species is also a common feature of the Greyhound Law assemblages.

Fig. 7. approx here

DEPOSITIONAL ENVIRONMENTS

Sedimentological work by Warren (1963) on the Riccarton Group of the Hawick area (Fig.1) indicates probable water depth in excess of 200m. More recently Kemp (1987) has proposed a mid- to ?late Wenlock depositional model for the Southern Uplands margin that invokes canyons cutting a trench slope and supplying sediment to basinal overlapping depositional lobes with associated meandering submarine channels and levee complexes. Casey and Oliver (in Oliver et al. 1984) envisage a similar trench-slope basinal environment for the deposition of the early Wenlock Linkim Beds on the east coast near Eyemouth (Fig.1).

Dorning (1981b) examined the late Silurian of the Welsh Borderlands and recognised three main acritarch assemblages which he related to water depth and distance from the shoreline; these were a nearshore, an offshore shelf and a deep water assemblage. In comparison with this model, the moderately high acritarch diversity (at least 31 species) and the predominance of thick-walled Leiosphaeridia in the Greyhound Law samples suggests affinity with the offshore shelf and the deep water environments. Although discrete lithologies were not isolated and processed separately, it would appear that turbidite mudstones contain a greater abundance and diversity of acritarchs, and the hemipelagic graptolitic siltstones yield sparse assemblages with a greater relative proportion of sphaeromorphs. This implies that turbidity currents transported acritarch and miospore assemblages from the offshore shelf and deposited them intermittently in a hemipelagic setting. In parts of the Welsh Basin and the Irish Silurian, miospores are more common in deep water offshore areas than in the nearby shelves, suggesting transport by turbidity currents or subsea canyons from river mouths (K.J. Dorning, written comm.)

THERMAL MATURATION

It is widely accepted that fossil organic material generally shows progressive colour changes that result from irreversible catagenetic processes associated with increasing temperature. In palynomorphs these colour changes are generally from pale yellow through brown to black and are particularly useful for determining palaeotemperatures of up to around 200°C, especially when calibrated with reflectance studies and geochemical techniques. Using selected species of Leiosphaeridia, Legall et al. (1981) have proposed acritarch alteration indices (AAI) on a scale of 1-5 and calibrated these with conodont colour alteration indices. In the Greyhound Law samples, sphaeromorphs are generally yellow to orange brown depending on wall thickness, and the remaining acritarchs are pale to deep yellow or occasionally orange-brown, suggesting AAI indices of 2-4. This would correspond with an approximate temperature range of 60°-90°C. Dorning (1986) stated that acanthomorph acritarchs show much the same progressive colour changes at significantly higher temperatures than the sphaeromorphs studied by Legall et al. (1981). Comparison of the Greyhound Law palynomorphs with the thermal index of dispersed exinite of Staplin (1982) suggests a temperature range of 65°-120° C, and the orange to brown miospores correlate with a temperature of 60°-130° C in the spore coloration scheme of Kantsler et al. (1978). Thus the sediments sampled have probably attained a maximum palaeotemperature of between 60° and 130° C.

Preliminary results of a survey of white mica crystallinity in pelitic rocks of SW Scotland, forming part of the BGS Southern Uplands Regional Geological Survey, show a general trend of increasing metamorphic grade from the NW towards the SE; a maximum is reached at the SE edge of the Central Belt and followed by a marked decrease in the Southern Belt (R.J. Merriman, BGS, verbal comm.). Kemp et al. (1985) recorded middle anchizone conditions (prehnite-pumpellyite facies) in the Langholm area (Fig.1) and advanced diagenetic zone (zeolite facies) to anchizone conditions at Kirkcudbright Bay. The mid-Wenlock sediments of the Greyhound Law Inlier therefore appear to represent diagenetic zone conditions, probably towards the lower end of the range, and are possibly the least thermally altered Silurian rocks of the Southern Uplands.

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Figure Captions

Fig.1. Sample locations and geological map of the Greyhound Law Inlier compiled from BGS 1:250000 Borders sheet, 1:50000 sheets 5 (England and Wales) and 17E (Scotland), and 1:63360 sheet 8 (England and Wales). Inset: Geological map showing the Silurian of the Southern Uplands and location of main map. K: Kirkcudbright Bay, L: Langholm area, H: Hawick area, J: Jedburgh, E: Eyemouth.

Fig.2. Abundance and distribution of acritarchs, chitinozoa and miospores in the Greyhound Law samples. Counts based on total number of palynomorphs in three slides from each sample, except MPA 28225 where four slides were used.

Fig.3. Acritarchs from the Greyhound Law Inlier. Specimens illustrated in Figs. 3-6 are held in the palynological collections of the British Geological Survey, Keyworth, and are registered in the MPK series (MPK 5805-31). All specimens x1000.
a, Ammonidium waldronense. MPA 24434/2, MPK 5805. b, Ammonidium microcladum. MPA 24434/2, MPK 5806. c, Gracilisphaeridium encantador. MPA 28225/2, MPK 5807. d, Cymatiosphaera heloderma. MPA 28225/2, MPK 5808. e, Cymatiosphaera cf. pentagonalis. MPA 24434/3, MPK 5809. f, Diexallophasis pachymura. MPA 24430/3, MPK 5810. g, Multiplicisphaeridium sp. MPA 24434/3, MPK 5811.

Fig.4. Acritarchs from the Greyhound Law Inlier. All specimens x1000.

a, Multiplicisphaeridium aff. cymulum. MPA 28225/3, MPK 5812. b, Oppilatala frondis. MPA 28225/3, MPK 5813. c, Multiplicisphaeridium cladum. MPA 24434/3, MPK 5814. d, Multiplicisphaeridium arbusculum. MPA 24434/3, MPK 5815. e, Schismatosphaeridium rugulosum. MPA 28225/4, MPK 5816. f, Tylotopalla cellonensis. MPA 28225/3, MPK 5817. g, Tylotopalla aff. digitifera. MPA 28225/2, MPK 5818.

Fig.5.Acritarchs from the Greyhound Law Inlier. All specimens x1000.

a, Tylotopalla robustispinosa. MPA 24435/2, MPK 5819. b,c, Tylotopalla wenlockia, b, MPA 28225/2, MPK 5820. c, MPA 24434/2, MPK 5821. d, Veryhachium rhomboidium. MPA 24434/3, MPK 5822. e, Tylotopalla sp. MPA 24434/3, MPK 5823. f, Veryhachium trispinosum. MPA 24430/1, MPK 5824. g, Visbysphaera brevifurcata. MPA 24434/2, MPK 5825.

Fig.6. Spores from the Greyhound Law Inlier. All specimens x1000.

a, Ambitisporites avitus. MPA 24432/1, MPK 5826. b, Ambitisporites dilutus. MPA 28225/1, MPK 5827. c, cf. Synorisporites verrucatus. MPA 24430/1, MPK 5828. d, Tetrahedraletes medinensis. MPA 24435/1, MPK 5829. e, Archaeozonotriletes chulus var. nanus. MPA 24430/1, MPK 5830. f, Dyadospora murusdensa MPA 24432/1, MPK 5831.

Fig.7. Published stratigraphical ranges of acritarch species recorded from the Greyhound Law Inlier.

Wales and the Welsh Borderland: a, Downie 1963. b, Hill 1978. c, Aldridge _et al_. 1981. d, Dorning 1981a. e, Hill and Dorning 1984. f, Mabillard and Aldridge 1985.

Southern Uplands: g, Molyneux 1987.

Midland Valley: h, Dorning 1982.

Ringerike, Norway: 1, Smelror 1987.

Gotland, Sweden: 2, Cramer _et al_. 1979. 3, Le Herisse 1984.

Podolia, Ukraine: 4, Kirjanov 1978.

Carnic Alps, Austria: 5, Priewalder 1987.

Eastern USA: 6, Loeblich 1970. 7, Tappan and Loeblich 1971. 8, Cramer and Díez 1972.

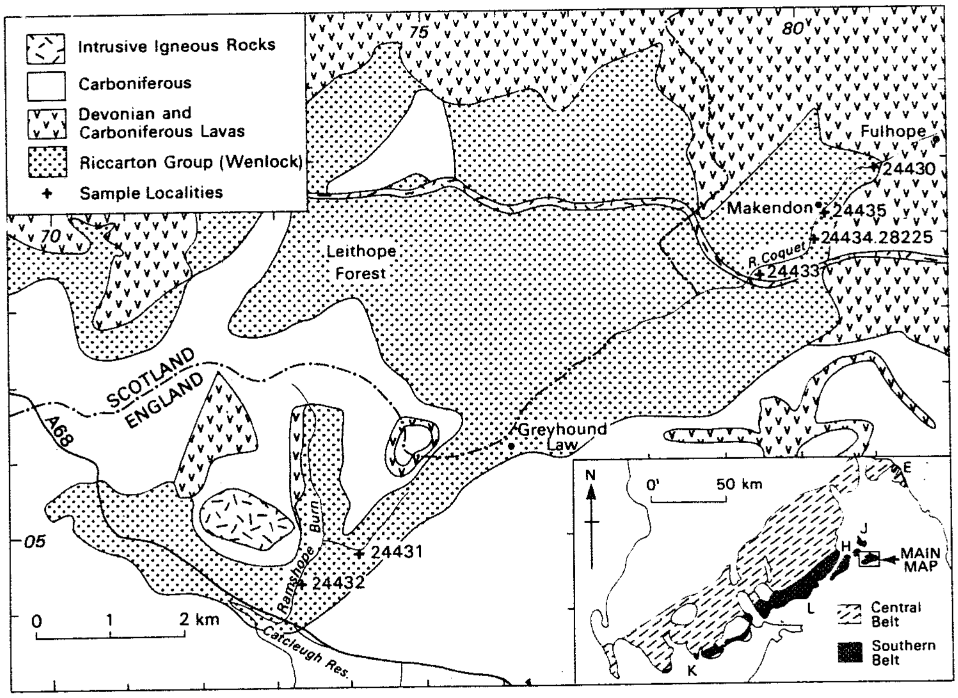

Fig. 1

ACRITARCH GENERA / PREPARATION NUMBER	*Alveosphaera*	*Ammonidium*	*Cymatiosphaera*	*Diexallophasis*	*Estiastra*	*Gracilisphaeridium*	*Leiosphaeridia*	*Lophosphaeridium*	*Micrhystridium*	*Multiplicisphaeridium*	*Oppilatala*	*Salopidium*	*Schismatosphaeridium*	*Tylotopalla*	*Veryhachium*	*Visbysphaera*	CHITINOZOA	MIOSPORES
MPA 24430	8		5	6			38	1	3	1		1	2	37	1			18
MPA 24435				2			48							7			1	3
MPA 24434 / 28225	4	16	35	56	1	2	1000+	1	1	20	6	6	1	192	6	1	6	32
MPA 24433			2	7			30			1				14	1			4
MPA 24431							6								1			9
MPA 24432							61										1	10

Fig. 2

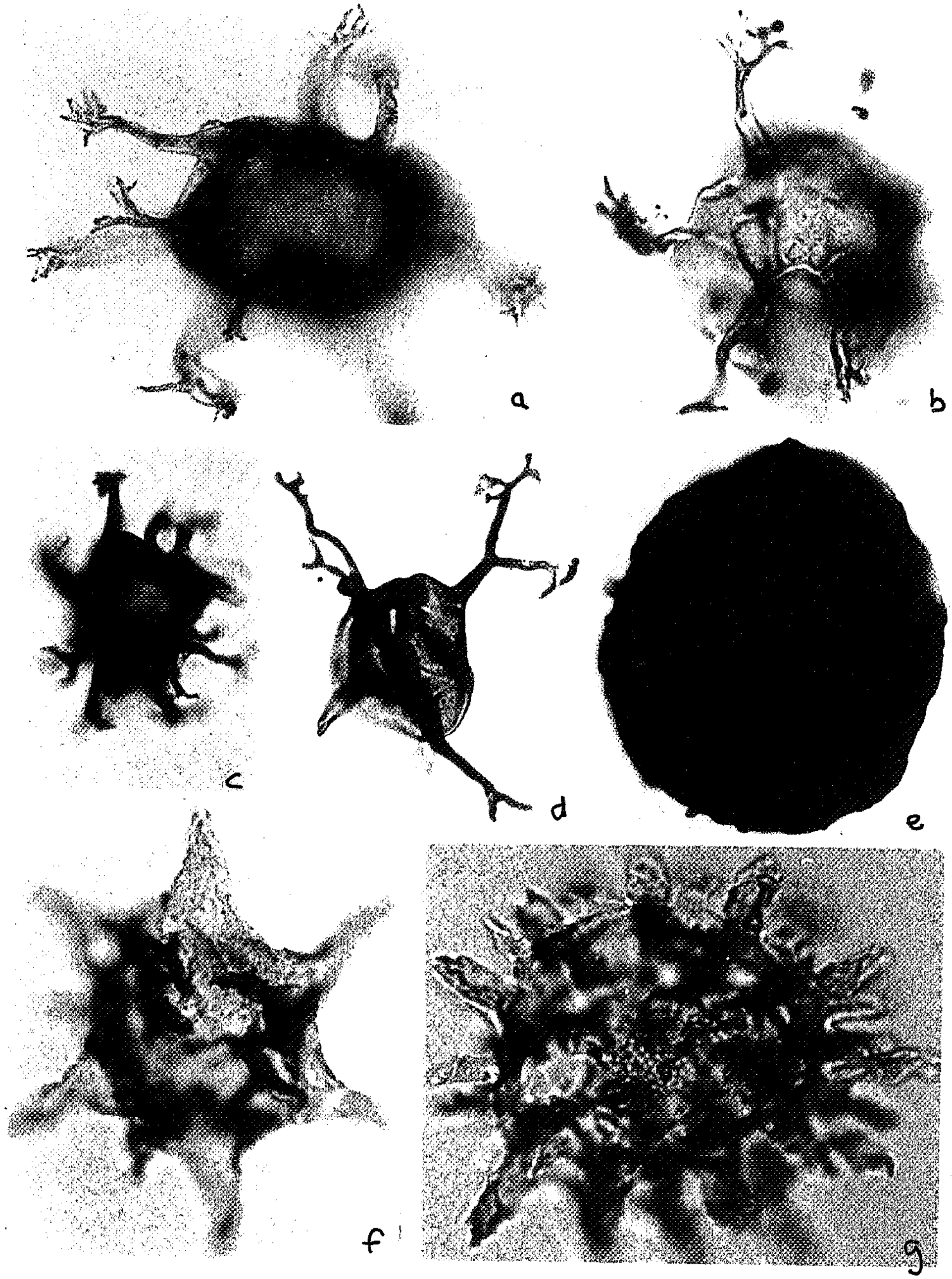

Fig 4

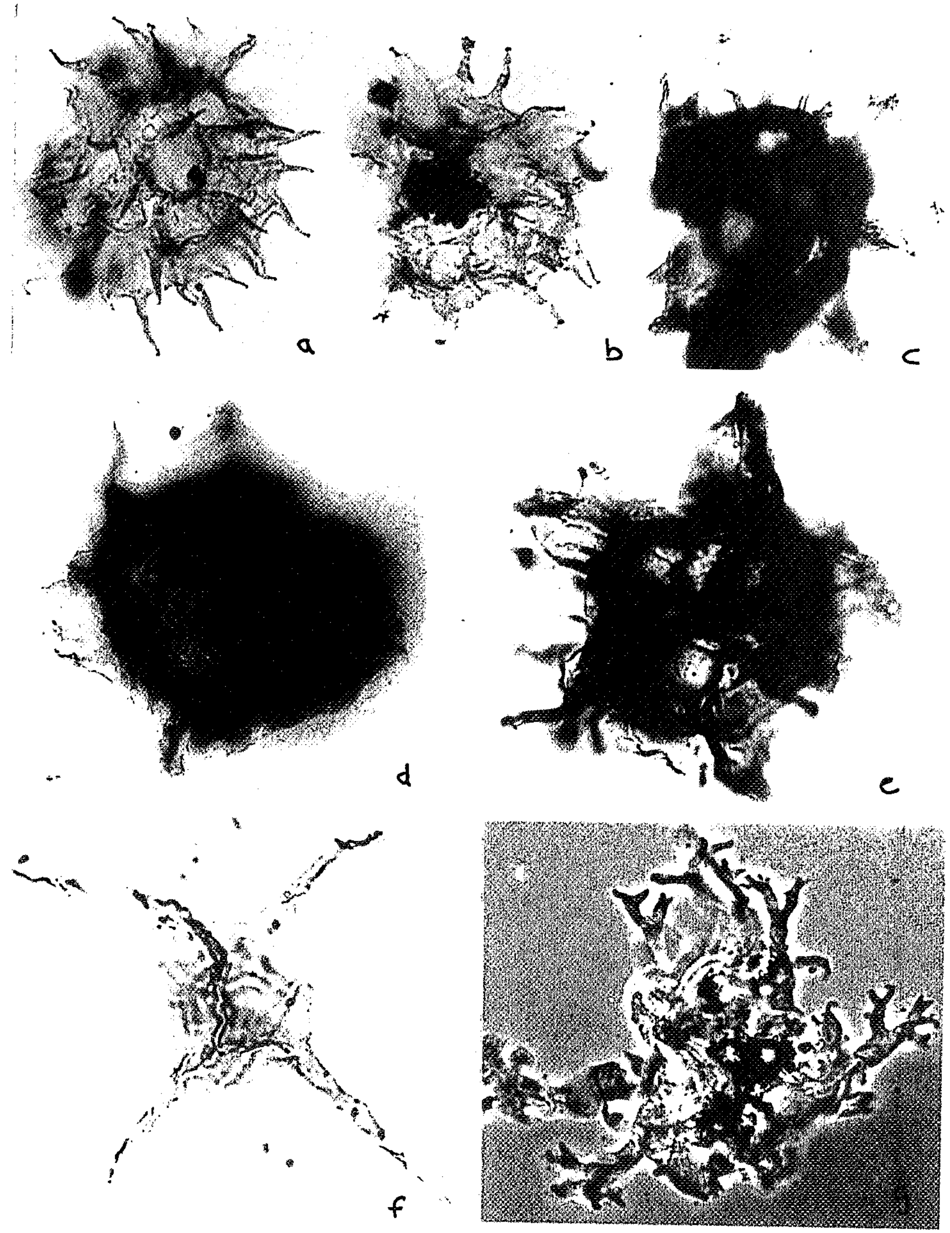

Fig. 3

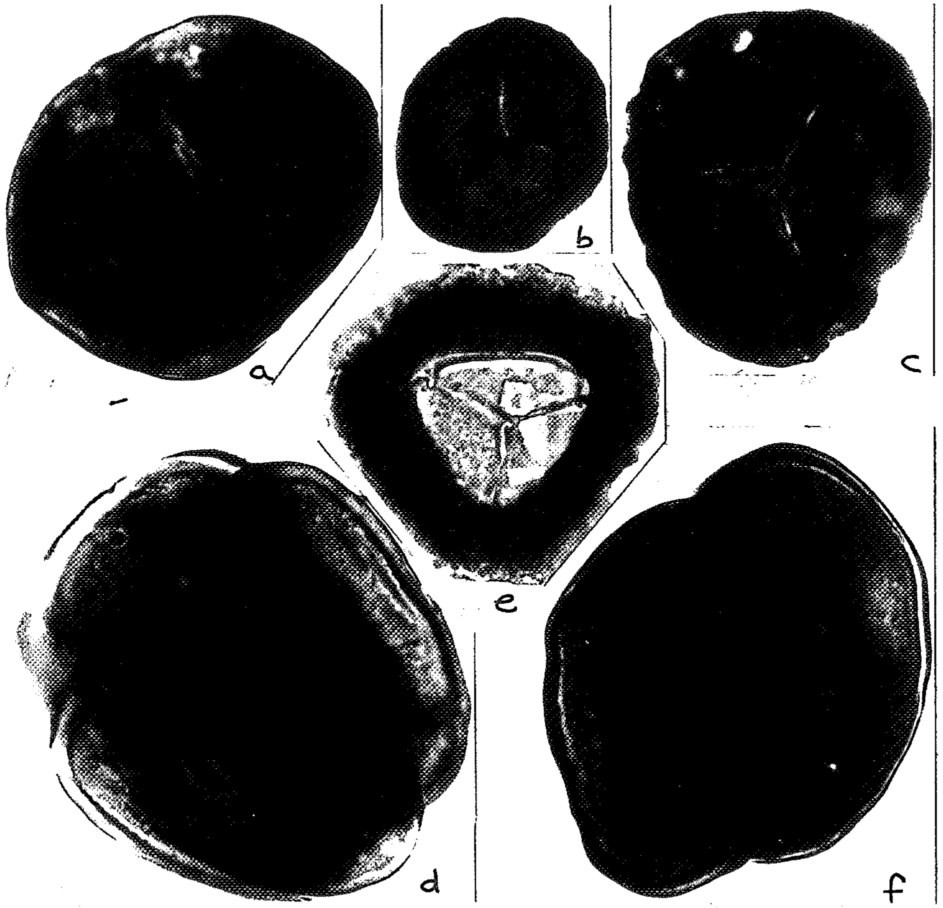

Fig. 6

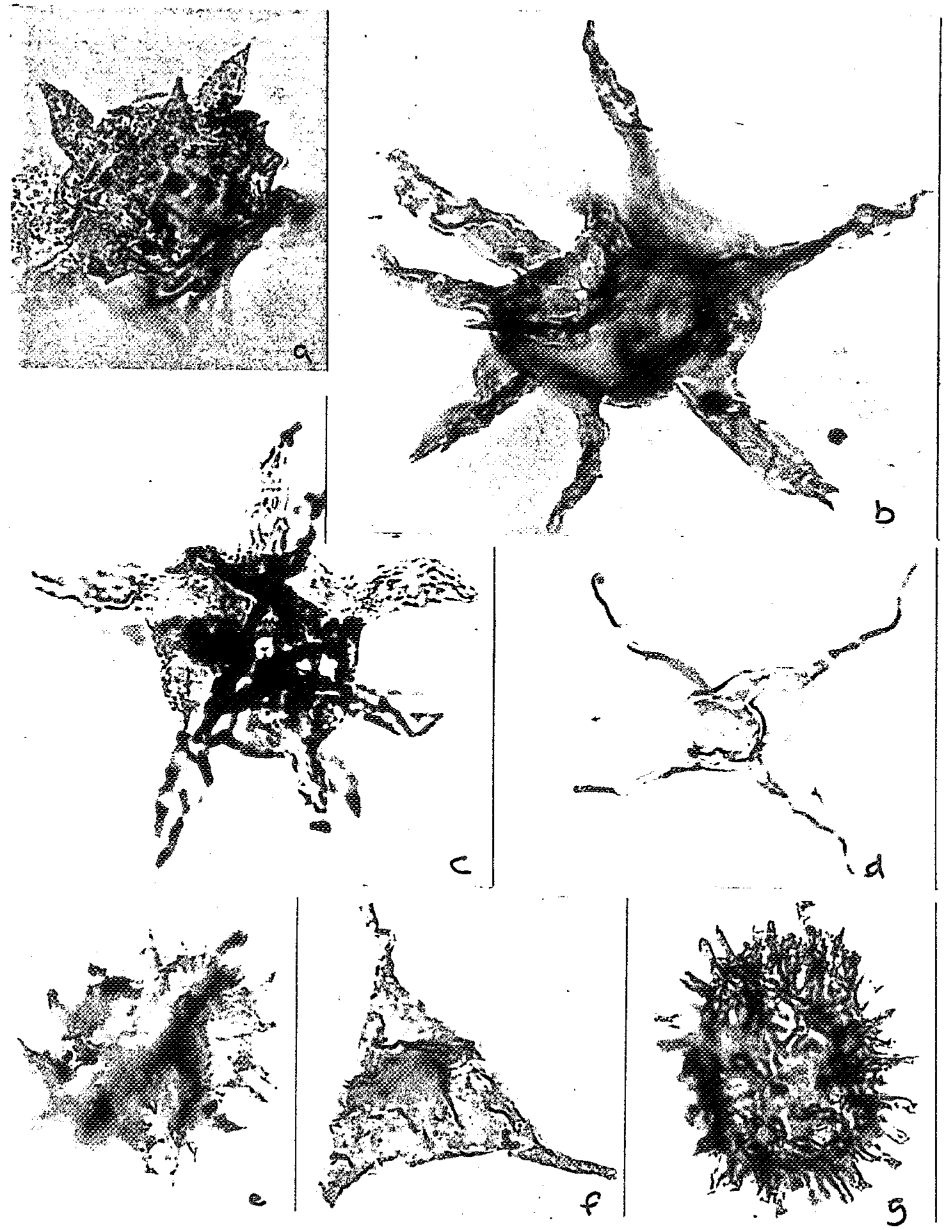

Fig. 5

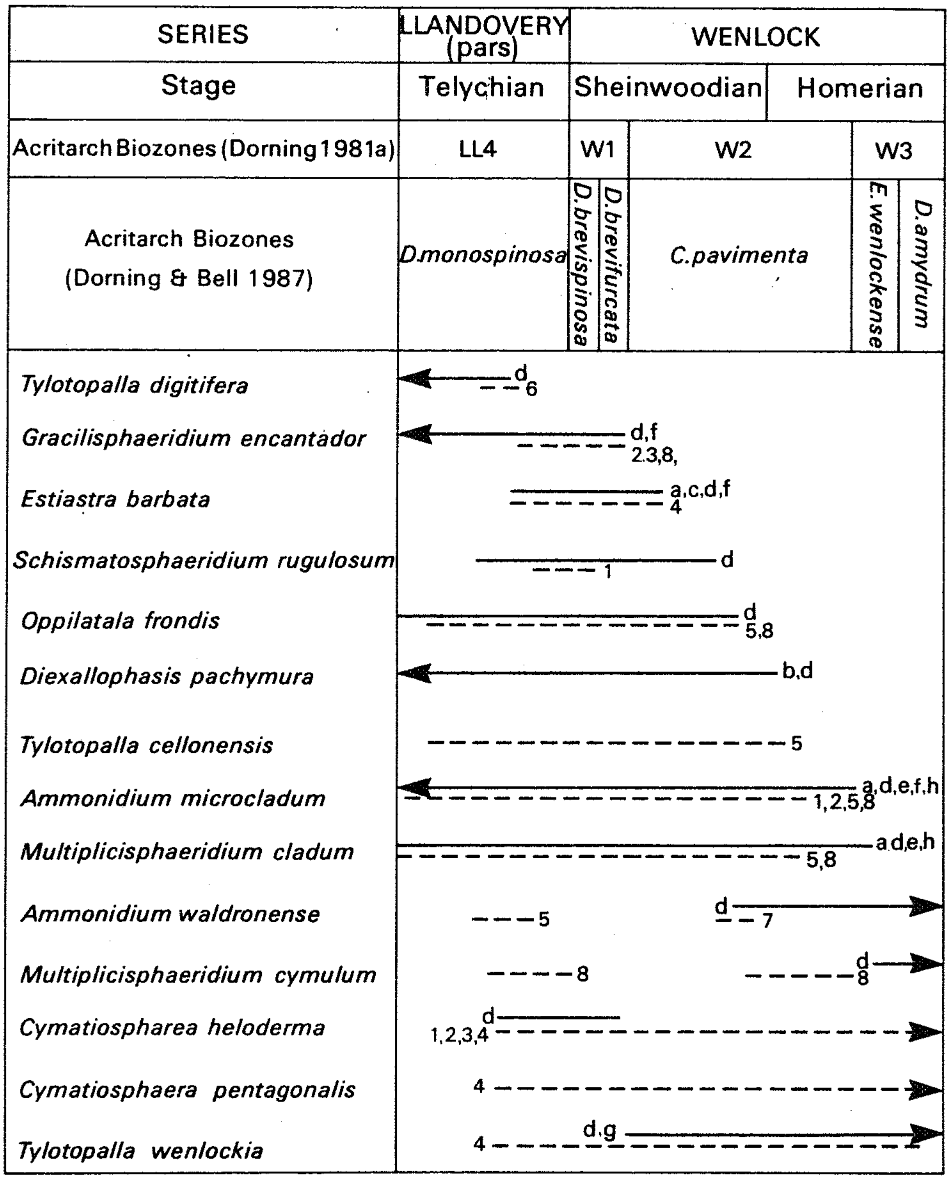
SERIES
LLANDOVERY (pars)
WENLOCK
Stage
Telychian
Sheinwoodian
Homerian
Acritarch Biozones (Dorning 1981a)
LL4
W1
W2
W3
Acritarch Biozones (Dorning & Bell 1987)
D.monospinosa
D.brevispinosa
D.brevifurcata
C.pavimenta
E.wenlockense
D.amydrum
Tylotopalla digitifera
d
6
Gracilisphaeridium encantador
d,f
2.3,8,
Estiastra barbata
a,c,d,f
4
Schismatosphaeridium rugulosum
1
d
Oppilatala frondis
d
5,8
Diexallophasis pachymura
b,d
Tylotopalla cellonensis
5
Ammonidium microcladum
a,d,e,f,h
1,2,5,8
Multiplicisphaeridium cladum
a,d,e,h
5,8
Ammonidium waldronense
5
d
7
Multiplicisphaeridium cymulum
8
d
8
Cymatiosphaera heloderma
d
1,2,3,4
Cymatiosphaera pentagonalis
4
Tylotopalla wenlockia
4
d,g

Fig. 7