Upper Ordovician and lowest Silurian graptolite biostratigraphy in southern Scotland.

(2 volumes)

Volume 1 (text)

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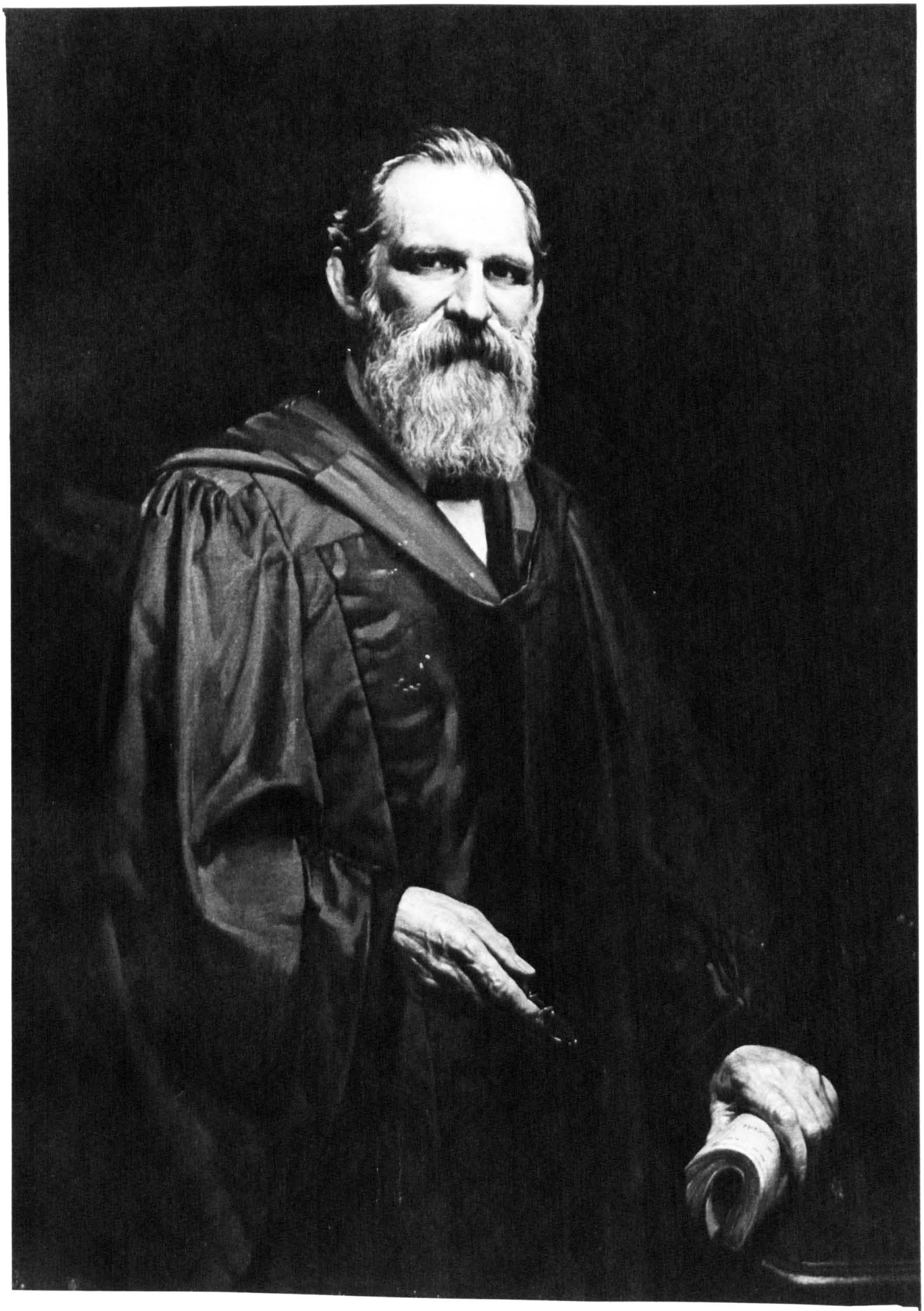
FRONTISPIECE

Professor Charles Lapworth

(from a painting in the Geology Department, Birmingham University)

"The discovery that organisms of such a lowly type as the Graptolites followed the same law of slow development, specific culmination, and extinction as that long acknowledged to be characteristic of the life-periods of the higher groups of animals ... has allowed us to unravel with comparitive ease the ascending sequence in one of the most complicated districts among the contorted strata of the Southern Uplands and has shaken the fashionable and mystifying doctrine of Colonies, as interpreted by British geologists, to its foundations".

(from: The Girvan succession, 1882)



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SUMMARY

In order to accurately define the late Ordovician to earliest Silurian graptolite zonal sequence of Britain detailed systematic collecting has been carried out at Dob's Linn near Moffat, southern Scotland from the top 9m of Lower Hartfell Shale (late *Dicranograptus clingani* and early-middle *Pleurograptus linearis* zones), the Complanatus, Anceps and Extraordinarius bands of the Upper Hartfell Shale and the basal 2.3m of Birkhill Shale (*Glyptograptus persculptus* and early *Orthograptus*? *acuminatus* zones). The *D. clingani*/*P. linearis* zonal boundary is defined accurately here for the first time. The five Anceps Bands are shown to belong to late *Dicellograptus anceps* Zone and are divided into two new internationally recognisable *Dicellograptus complexus* and *Paraorthograptus pacificus* subzones. The major extinction of typical late Ordovician graptolite faunas is demonstrated to occur at the boundary between the *P. pacificus* Subzone and the overlying *Climacograptus*? *extraordinarius* Zone. It is considered that this may have resulted from climatic changes related to the late Ordovician southern hemisphere glaciation. It is doubtful that the *C*? *extraordinarius*/*G. persculptus* zonal boundary can be recognised in any known section; in any event it is poorly defined on palaeontological grounds and commonly hinges on the recognition of poorly understood forms such as *C*? *extraordinarius* and *G. persculptus* which are often inadequately preserved for taxonomic distinction. The *G. persculptus*/*O*? *acuminatus* zonal boundary is marked by the first appearance of *Akidograptus* and *O*? *acuminatus* and is considered to be a synchronous and precisely correlatable horizon worldwide.

The distinctions between lithostratigraphy and biostratigraphy are stressed and the succession at Dob's Linn is compared with that at Girvan to demonstrate the inadequacy and incorrectness of equating the two on the basis of notional zonal boundaries which for the sake of stratigraphical 'tidiness' have commonly been taken to correspond with lithological boundaries by almost all previous workers on the Moffat Shale Group. An horizon in the Upper Whitehouse Group at Girvan with a mixed *P. linearis*/*Dicellograptus complanatus* zonal fauna is considered to lie close to the zonal boundary and to correlate with some part of the barren strata of the Upper Hartfell Shale below the lower Complanatus Band. The zonal sequence in southern Scotland is correlated with successions in North America, Russia,

Australia and China: Dob's Linn is evaluated as a possible international stratotype for the Ordovician/Silurian boundary.

Several non-graptolitic taxa are described from the Moffat Shale including a new genus of inarticulate brachiopod and stratigraphically useful conodonts which indicate a transition from the *Amorphognathus superbus* Zone to that of *Amorphognathus ordovicicus* just below the top of the Lower Hartfell Shale and show that all the graptolitic bands of the Upper Hartfell Shale lie within the *A. ordovicicus* Zone. All the non-graptolitic taxa are considered to have been planktonic although a number of bioturbated horizons in the pale grey mudstones and limestones of the Upper Hartfell Shale probably indicate a degree of oxygenation of bottom waters or sediments.

The diagnostic features which may be used in separating graptolite species in both flattened and three-dimensional material are assessed. Both critical examination of actual specimens and experimental work on models have been used and a number of detailed effects of diagenetic flattening have been discovered including differential lateral spread which commonly alters the apparent thecal style; flattening need not result in overall increase in stipe or thecal width although this does occur sometimes in rhabdosomes with a thin periderm.

Fifty graptolitic taxa are described in the systematic section including two new species, *Glyptograptus davisi* and *Plegmatograptus? craticulus*; several forms have not been recorded previously from outside Russia or China. The effects of astogenetic development on graptolite rhabdosomes are described, especially with regard to *Dicellograptus* species. These show proximal stipe thickening together with common development of axial membranes, probable resorption of the sicula and, depending on the species, either resorption or growth of basal spines. Both stipe torsion and proximal double curvature, commonly present in flattened specimens of *Dicellograptus*, are related to the original openly spiralled nature of most rhabdosomes referred to this genus. The details of the preserved form of flattened *Dicellograptus* specimens result from the direction of compression.

Appendix 1 summarises work carried out to date on the graptolitic fauna of the type section of the top Caradoc Onnian Stage along the River Onny in the Welsh Borderlands, which is expected to prove valuable for more precise cross-correlation between the shelly and graptolitic zonal schemes in conjunction with a detailed study of the trilobite faunas recently carried out by J.K. Ingham and A.W. Owen. A section through mixed shelly and graptolitic strata of partly similar age at Llanystumdwy near Criccieth, North Wales is shown to contain several major stratigraphical breaks and to be of little correlative value. Appendix 2 contains three published papers resulting from this thesis:- 'An excursion guide to Dob's Linn' (Williams 1980), 'Form and mode of life of Dicellograptus (Graptolithina)' (Williams 1981) and 'The restoration of flattened fossils' (Briggs & Williams 1981).

Chapter 1. Introduction.

1.1 Summary of previous research. The Moffat Shale Group of the Southern Uplands of Scotland was one of the first rock formations in which the use of fossils as precise stratigraphical indicators in structurally complex areas was recognised. The 'Silurian' graptolite faunas had been studied by Nicholson (e.g. 1867a), Carruthers (e.g. 1867b), Dairon (e.g. 1869) and Hopkinson (e.g. 1871) but the stratigraphical distinctiveness of this fossil group was not recognised before Lapworth found that each age of rock had its own characteristic assemblage of graptolite species. He gave a remarkably good early summary of his stratigraphical divisions of the Southern Uplands in 1872 which was followed by two mainly illustrative papers on the 'Silurian' graptolites of 'western' Scotland (1876) and Co. Down, Northern Ireland (1877) where a number of new species were figured. His major paper of 1878 on 'The Moffat Series' gave a thorough description of the Moffat Shale in several inliers of the Moffat region including Dob's Linn, Hartfell Spa and Glenkiln Burn and established graptolites as a major fossil group for use in Lower Palaeozoic correlation.

In 1879(a) Lapworth attempted to reconcile the opposing views of Sedgwick and Murchison on the boundary between the Cambrian and Silurian by proposing a new intervening 'Ordovician' system ranging from the base of the Arenig to the base of the Llandovery. In 1882 he utilised his discoveries from the Moffat Shale to produce a paper elucidating the stratigraphy and structure of the Girvan area. Lapworth's stratigraphical work was complimented by Peach & Horne's (1899) detailed systematic treatment of the Southern Uplands but his divisions were left unchanged. Elles & Wood (1901-18) produced their major monograph on British graptolites with Lapworth's assistance, which relied heavily on both Lapworth's and their own collections from the Upper Ordovician and Lower Silurian of the Southern Uplands, and this has remained the standard reference for graptolite workers both in Britain and abroad.

Meanwhile, elsewhere in Europe Holm (1895) and Wiman (1893) began working on three-dimensional material and reconstructing detailed graptolite morphology, the study of which was extended by Kraft (1926), Bulman (1945-47) and Kozlowski (1949). Unfortunately there has been little integration between detailed morphological and stratigraphical studies, largely because well preserved graptolites normally occur at rare, discreet horizons (e.g. limestones) in otherwise poorly fossiliferous sequences, while continuous graptolitic successions of stratigraphical use are almost always in black shale sequences with flattened fossils. Finney (1977, unpubl. thesis) has attempted to resolve this problem for some early Upper Ordovician graptolites by combining studies of three-dimensional and flattened material from the unusual variety of lithologies present in the Athens Shale of Alabama, North America.

Little descriptive work has been carried out on Upper Ordovician graptolites in Britain since the publication of Elles & Wood's monograph, although Davies (1929) described several new species from the late Ordovician and early Silurian of North Wales. Toghill (1968a, b) gave range charts and faunal lists for the lower Silurian of Dob's Linn and gave brief descriptions of some late Ordovician graptolites from the Hartfell Shale (1970). Rickards (1970) and Hutt (1974, 1975) described many lower Silurian graptolites from Northern England while Strachan (1974) described some isolated upper Ordovician material from Girvan. Eales (1978, unpubl. thesis) gave many graptolite descriptions mainly based on material from Craigmichan Scaurs near Moffat, but none have been published and most are superseded by the present work. In the introduction he did however give a useful summary of previous structural research on the Southern Uplands and discussed the presently accepted model of an accretionary prism above a subduction zone on the northern margin of the Lower Palaeozoic Iapetus Ocean. This hypothesis was published in a series of papers beginning with Mckerrow et al. (1977). Ingham has remapped both Dob's Linn and the Girvan foreshore in great detail and has given provisional summaries in Bassett et al. (1974) and Ingham (1978).

Further discussion of previous research in the fields of both stratigraphy and palaeontology is given in the relevant sections throughout the main body of this work.

1.2 Collection techniques. Throughout the development of geological research palaeontologists have recognised the importance of collecting from fossiliferous successions at several localities in order to allow for diachronism of both lithologies and species ranges. While this is

TEXT-FIGURE 1. Locality map of Dob's Linn (from Williams 1980).

Loc. 1. South Cliff - transition from Glenkiln to Lower Hartfell Shale.

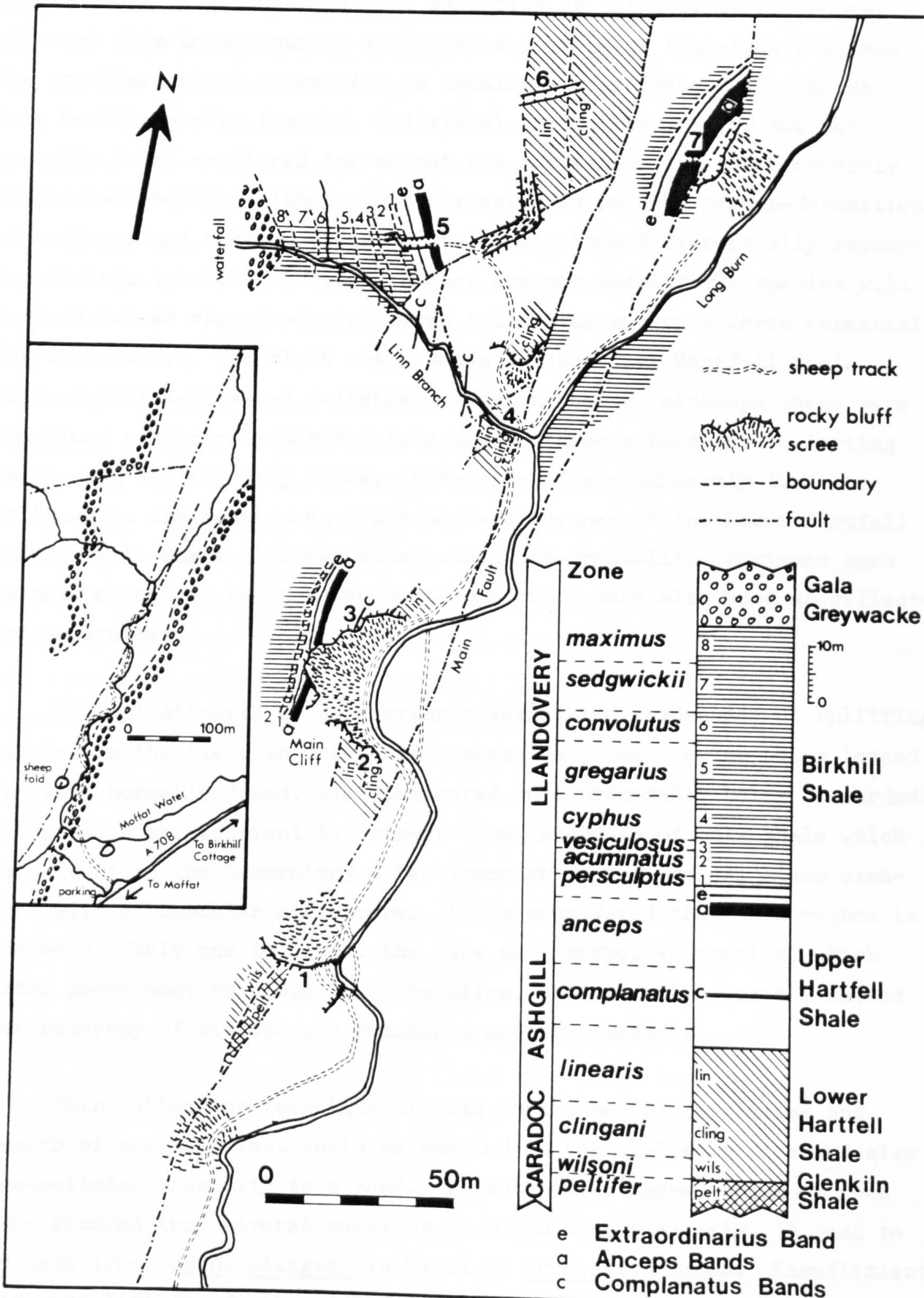
Locs. 2 and 3. Main Cliff - Lower Hartfell Shale and Complanatus Bands. Section through Upper Hartfell and Birkhill Shale.

Loc. 4. Linn Branch - Lower Hartfell Shale, Complanatus Bands just upstream (section with inarticulate brachiopods).

Loc. 5. Linn Branch trench - top Upper Hartfell to Birkhill Shale.

Loc. 6. North Cliff trench - top Lower Hartfell Shale with Complanatus Bands to the west.

Loc. 7. Long Burn trench - Anceps and Extraordinarius Bands.


N
waterfall
Linn Branch
Long Burn
Main Fault
Main Cliff
sheep track
rocky bluff
scree
boundary
fault
0 100m
sheep fold
Moffat Water
A 708
To Birkhill Cottage
parking
To Moffat
0 50m
Zone
LLANDOVERY
ASHGILL
CARADOC
maximus
sedgwickii
convolutus
gregarius
cyphus
vesiculosus
acuminatus
persculptus
anceps
complanatus
linearis
clingani
wilsoni
peltifer
Gala Greywacke
10m
0
Birkhill Shale
Upper Hartfell Shale
Lower Hartfell Shale
Glenkiln Shale
lin
cling
wils
pelt
e Extraordinarius Band
a Anceps Bands
c Complanatus Bands

essential for areas with complex lithological variation the field work time involved normally precludes total systematic collecting so sampling at regular intervals (e.g. 0.5m) is normally utilised. In black shale facies there is far less lateral variation in lithologies or faunas, although this does occur to a limited extent (e.g. text-fig. 5), and the stratigraphical succession is usually highly condensed. Unlike many benthic shelly fossils, individual graptolite species are not normally found scattered throughout the succession but occur commonly on discrete bedding planes, probably owing to periods of non-deposition of sediment and unknown environmental variations differentially favouring certain species. If these planes are not sampled the species will be recorded as absent so continuous collecting was considered essential for this study. The black shale bands in the Upper Hartfell Shale conveniently delineated suitable collecting units, although these were sometimes arbitrarily divided into two or three subsidiary collecting units when sufficiently thick. Intervals of approximately 10cm were utilised in the continuous black shale sequences of the Lower Hartfell and Birkhill Shale although conspicuous non-graptolitic horizons such as metabentonites and massive siliceous units were also used as collection separators.

Initial attempts at collecting revealed the inadequacy of splitting samples in the field to obtain specimens; only the species being looked for were normally found, the unexpected ones presumably being discarded. It proved more efficient to extract 10cm intervals of bulk shale which were split in the laboratory after thorough drying and all slabs examined with a binocular microscope. It is considered that this method is the most likely one to reveal the rare and unexpected species, which often prove most valuable in correlation, and the only feasible method for recovery of microscopic conodonts and scolecodonts.

This collection technique limited the number of localities and length of sections that could be sampled in the available time and also necessitated proximity to a road. In total over three tonnes of rock were removed from several sections at Dob's Linn (text-fig. 1) just to collect from top D. clingani to basal O? acuminatus zones. Insufficient time was left for further collecting other than general sampling in other parts of the succession at Dob's Linn and at other localities in the Moffat district and at Girvan (text-fig. 9). However, it is considered that the thoroughness of the method used largely compensates for the lack of collecting from comparative sections. It is hoped that detailed collecting from additional localities will be possible in the future.

1.3 Graptolite illustration techniques. The two alternative methods for graptolite illustrations are photographs and line drawings; as a 'camera lucida' was not readily available during this work photography was the predominant medium utilised. Whilst photographs lack the interpretative aspect of line drawings the methods developed during this study lose little detail and sometimes reveal features not easily visible under the microscope. The best technique for constructing a line drawing without a 'camera lucida' was found to be to trace onto a transparent acetate sheet overlying an enlarged photograph using a 'Rotring' pen. This has the advantage over the more commonly used method of drawing directly onto the photograph which is then bleached, in that no detail on the photograph is permanently obscured. If a critical interpretation of a specimen is required it may be studied under the microscope during construction of the line drawing. The final drawing was normally reduced by half for incorporation in a text-figure. Most photographs were taken on 'Ilford Pan F' film, rated at 15ASA to compensate for reciprocity failure and to increase contrast, and developed in 'ID 11'. Most prints were made on 'Ilfobrom grade 4' paper. Three photographic set-ups were employed, depending on the size and preservation of the specimen; all utilised a fibre-optics lamp as a light source.

(a) Normal 'macro' photographic set-up using camera body and standard lens with one to three extension tubes (text-fig. 2a), supported on a tripod with reversed centre column. The specimen was immersed in a dish of absolute alcohol and levelled on a 'bed' of glass beads. The light source was positioned far enough away to ensure even illumination and at the highest angle possible without causing reflection off the surface of the alcohol. The specimen was rotated until the optimum reflectance was obtained. A fragment of plastic ruler with a mm scale was included in every photograph to allow printing at an accurate magnification. This method was the one most commonly used and had the advantage of being a relatively fast procedure. Using this method most weathered and unweathered specimens and most sizes of graptolite could be dealt with satisfactorily. However, definition began to fall off when prints of more than x10 magnification were made.

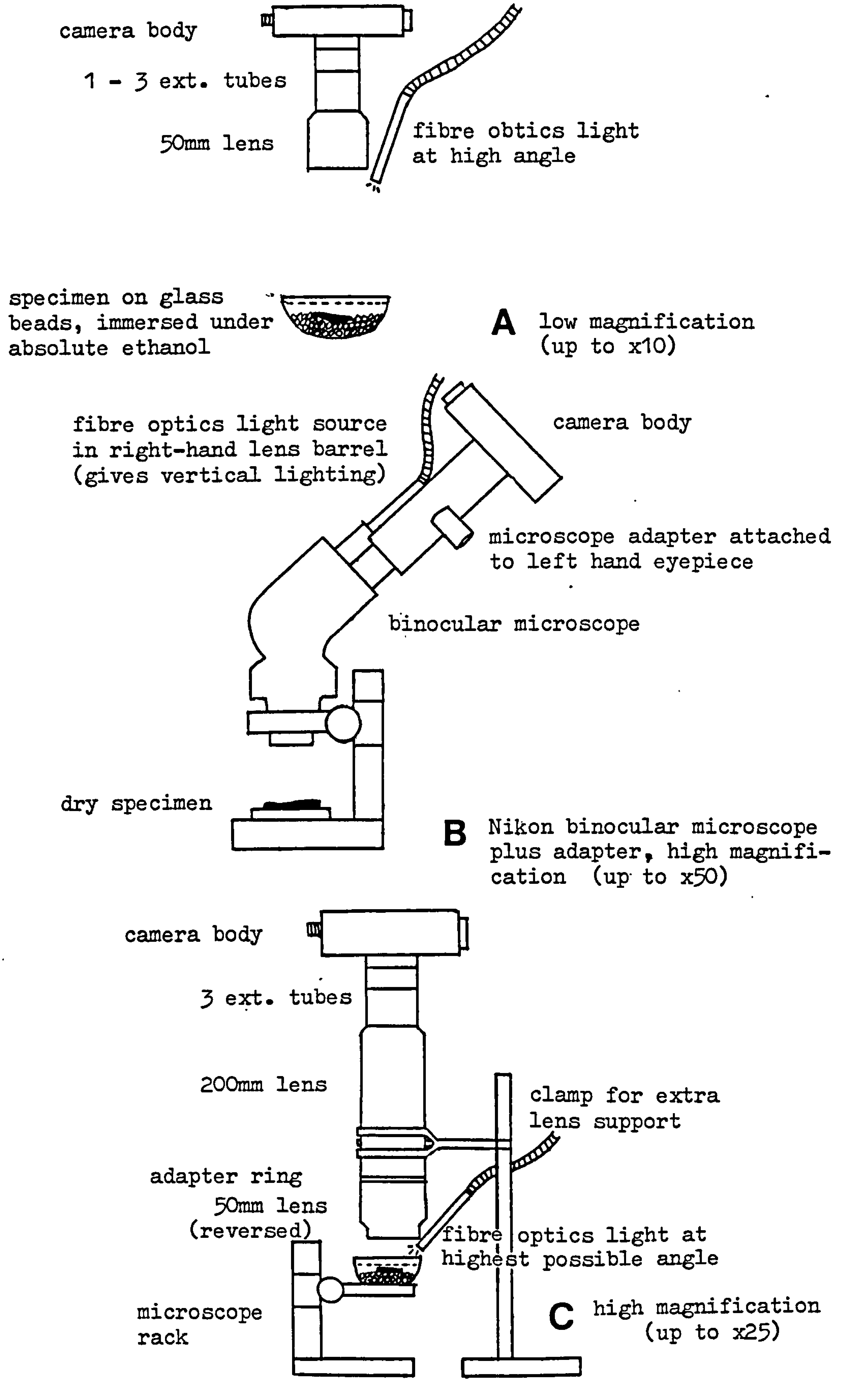
(b) 'Nikon' microphotographic equipment (text-fig. 2b). With this equipment a 'Nikon' microscope adaptor was fitted to one eyepiece of a binocular microscope and a camera body attached, while the other eyepiece was removed and a light source aligned down the tube. Positioning and focussing of the specimen was carried out using the adaptor eyepiece which utilised cross-hairs for critical focussing. Advantages of this method were the variable magnifications possible using the zoom objective and the vertical lighting which increased in intensity for higher magnifications. The main disadvantage was that the specimen could not be immersed when vertical lighting was employed. Thus only unweathered graptolites preserved as a silvery film on black shale produced good results. Also the depth of field was minute, necessitating a high degree of precision in levelling the specimen, especially when a composite photograph of a large rhabdosome was required. The limited depth of field also prevented use of this technique when the specimen was strongly three-dimensional.

(c) Microphotographic lens-stack technique (text-fig. 2c), based on Blaker (1977). This utilised a camera body attached to three extension tubes, a 200mm telephoto lens and a reversed 50mm standard lens, effectively building a microscope around the camera and providing the facility of a stoppable objective which no microscope is provided with. A double-screw reversing ring to connect the 200mm and 50mm lenses via their filter screw-threads and a rear-lens filter to protect the element from alcohol had to be specially constructed. The equipment had to be supported on both a tripod with reversed centre column and a separate clamp around the standard lens to prevent camera shake and over-stressing the camera tripod screw. It gave magnifications of up to x9 on the negative. The specimen to be photographed was levelled on glass beads and immersed under absolute alcohol as in method (a), but the dish was balanced on the column of a binocular microscope and focussing achieved by racking the specimen to the correct height rather than by adjusting the lenses. The light source had to be set at a low angle because of the small object to lens distance. The image was focussed using the camera viewfinder with the lens diaphragm of the standard lens fully open, which had to be stopped down fully prior to exposure. The diaphragm of the telephoto lens was kept open throughout the entire operation. The main disadvantage in this set-up as a microphotographic technique compared with that of the 'Nikon' was its lack of variable magnification, although for the present study the

TEXT-FIGURE 2 . Systems used for thesis macrophotography.

Monochrome: Ilford Pan F, rated 12 ASA.

Colour: Kodak Ektachrome Tungsten, rated 50 ASA.



resulting magnification proved ideal for most specimens. It was also not possible to use the high lighting angle preferable for most graptolite photographs. Its advantages were that small specimens could be photographed either dry or immersed (immersion normally produced better results) and it had a much greater depth of field when using the standard lens stopped down fully. Using an 'Olympus OM2' the length of exposure (normally 50 seconds to 4 minutes) could be controlled automatically and the set-up was portable and far cheaper than the custom made 'Nikon' equipment (c. £350 instead of £1400 at 1981 prices). Even so, there was little difference in resolution between photographs taken with the two systems when magnifications on the final prints did not exceed x25.

Examples of photographs produced by these techniques:-

Method (a). Most photographs in thesis with magnifications of x10 or less.
Method (b). Pl. 34, fig. 4, pl. 23, fig. 3.
Method (c). Pls. 5, 59, 61.

Chapter 2. Stratigraphy of the Moffat Shale Group at Dob's Linn.

2.1 Glenkiln Shale. The earliest formation of the Moffat Shale Group is the Glenkiln Shale. It is poorly represented at Dob's Linn but where it is well developed (e.g. Craigmichan Scaurs, Glenkiln Burn) the lowest parts are highly siliceous and commonly tuffaceous with only rare graptolitic shales. Black shales become more evident higher in the succession but the lithology remains siliceous and often poorly graptolitic throughout the unit. The lowest zone represented in the Glenkiln Shale is that of N. gracilis; only the upper zone of the Glenkiln Shale, the 'C. peltifer' Zone, is represented at Dob's Linn. The zone fossil was shown by Riva (1976, p. 595) to be a junior synonym of Climacograptus b. bicornis (Hall 1847); the name is however retained here to avoid confusion with the C. bicornis zones previously erected elsewhere (e.g. Carter & Churkin 1977). The C. peltifer Zone is exposed in the base of the South Cliff (text-fig. 1 , locality 1) and at the junction of the Linn Branch and Long Burn but yields only a sparse fauna of Climacograptus ex gr. bicornis, Dicranograptus spp., Dicellograptus spp., Corynoides sp. and a variety of early diplograptids. J.K. Ingham (pers. comm.) considers that there may be a succession in the South Cliff covering late C. peltifer, through C. wilsoni and into early D. clingani zones but it awaits excavation and detailed collecting.

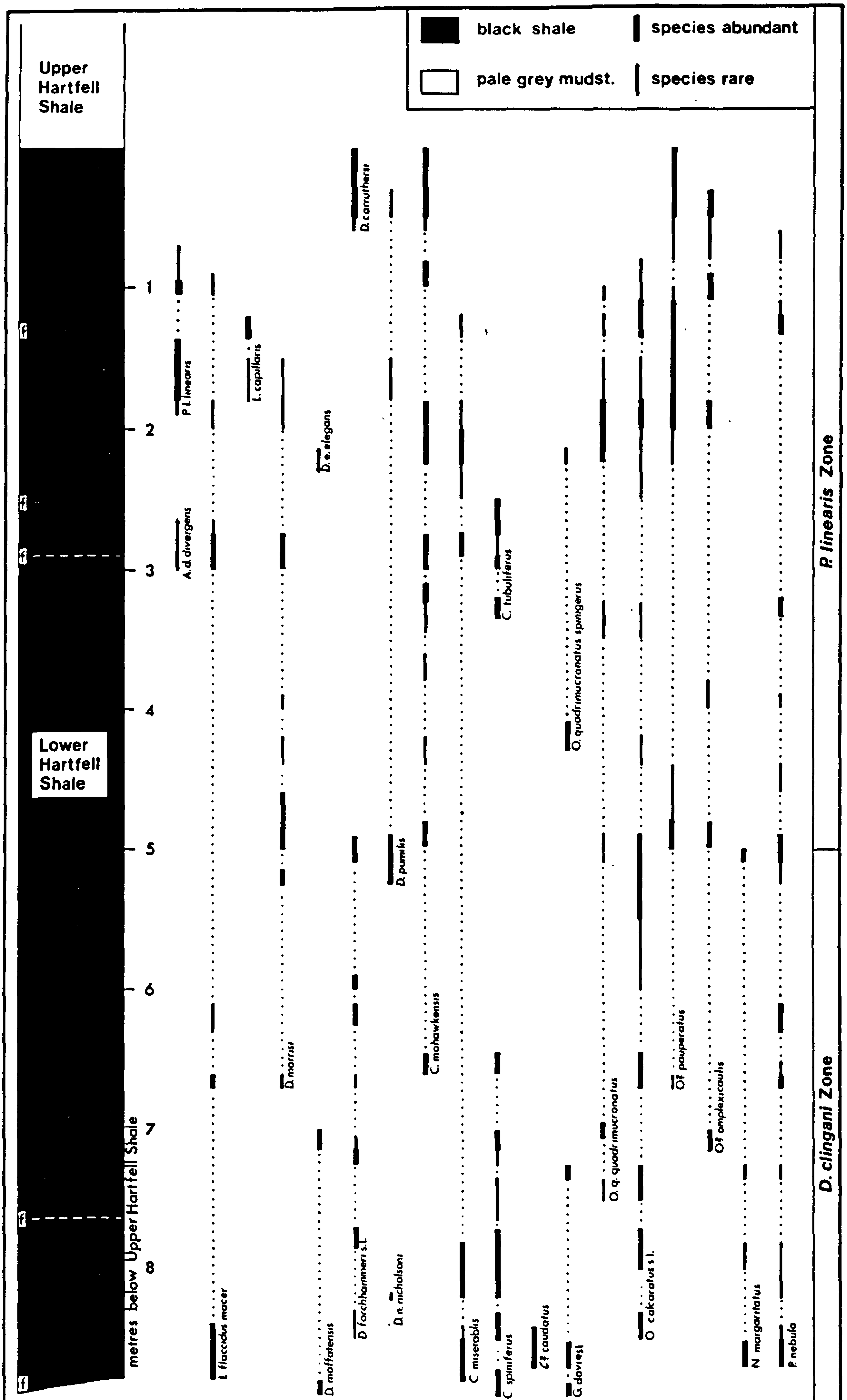
2.2 Lower Hartfell Shale. The Lower Hartfell Shale consists of over 20m of black, rather siliceous graptolitic shales at Dob's Linn. The cherty beds become thinner and less common in the higher parts of the succession; the youngest parts of the Lower Hartfell Shale, falling within the P. linearis Zone, have only rare siliceous horizons but contain more common laminae of metabentonite than the earlier parts of the unit. The transition into the pale grey mudstones of the Upper Hartfell Shale is a relatively sudden one, occurring above an interval of alternating pale and black laminations only about 3cm thick.

The lowest part of the Lower Hartfell Shale has been previously recorded as falling within the C. wilsoni Zone. At Dob's Linn it contains many pale grey cherty horizons and is usually sparsely fossiliferous. The C. wilsoni Zone is clearly seen only at the base of the South Cliff (text-fig. 1 , locality 1) and at the junction between the Linn Branch and Long Burn, where it forms a fault-bounded block between units belonging to the C. peltifer and D. clingani zones. The C. wilsoni Zone is not assessed in detail here; Elles & Wood (1901-18) gave a reasonable summary of its fauna but the ranges are rather vague and a thorough revision is needed. As with all the units of the Moffat Shale previous workers have confused lithostratigraphy and biostratigraphy, Elles & Wood (op. cit.) having equated the base of the C. wilsoni Zone with the base of the Lower Hartfell Shale. It is not clear exactly how they distinguished either between the top Glenkiln and basal Hartfell Shale or the C. peltifer and C. wilsoni zones. Here (p. 30) it is demonstrated that the boundary between the Lower and Upper Hartfell Shale does not lie at the P. linearis/D. complanatus zonal boundary as has been previously assumed (e.g. Elles & Wood 1901-18, Toghill 1970) and it is almost certain that a similar discrepancy exists at the Glenkiln/Lower Hartfell Shale boundary.

The C. wilsoni Zone is succeeded by the D. clingani Zone which is contained within a rather darker, less siliceous and more graptolitiferous lithology. It appears that the D. clingani Zone can be split into an earlier Dicranograptus-bearing division and a later post-Dicranograptus one. Only the higher division and the uppermost Dicranograptus-bearing part have been studied for this work; further detailed collecting of the earlier parts of the D. clingani Zone may allow the recognition of two distinct subzones.

The section collected in detail is situated high on the spur of the North Cliff which separates the gorge of the Linn Branch from that of the Long Burn (text-fig. 1 , locality 6). A trench has been excavated through a largely unfaulted section of the Lower Hartfell Shale which extends for 9m below the base of the Upper Hartfell Shale before a major fault is reached, forming a prominent gully and bringing representatives of probable earlier D. clingani Zone into juxtaposition with the later parts. Although minor bedding slips are present in the studied section they can be shown to have little or no dip-slip component while most of the apparently crumpled parts are demonstrably surface weathering effects. All measurements given in the following description of the section refer to the distance in metres below the defined base of the Upper Hartfell Shale.

TEXT-FIGURE 3. Species occurrences in the top Lower Hartfell Shale in the North Cliff trench (text-fig. 1, Loc. 6).
Dotted lines indicate ranges known from this section only (cf. the total known species ranges shown in text-fig. 4).



black shale
pale grey mudst.
species abundant
species rare
Upper Hartfell Shale
Lower Hartfell Shale
metres below Upper Hartfell Shale
1
2
3
4
5
6
7
8
P. linearis Zone
D. clingani Zone
P. l. linearis
A. d. divergens
L. capillaris
D. e. elegans
D. carruthersi
D. pumilus
D. morrisi
C. mohawkensis
C. tubuliferus
O. quadrimucronatus spinigerus
O. q. quadrimucronatus
O? pauperatus
O? amplexicaulis
L. flaccidus macer
D. moffatensis
D. forchhammeri s.l.
D. n. nicholsoni
C. miserabilis
C. spiniferus
C? caudatus
G. daviesi
O. calcaratus s.l.
N. margaritatus
P. nebula

The lowest part of the succession collected in detail is about 9m below the Upper Hartfell Shale and yields:

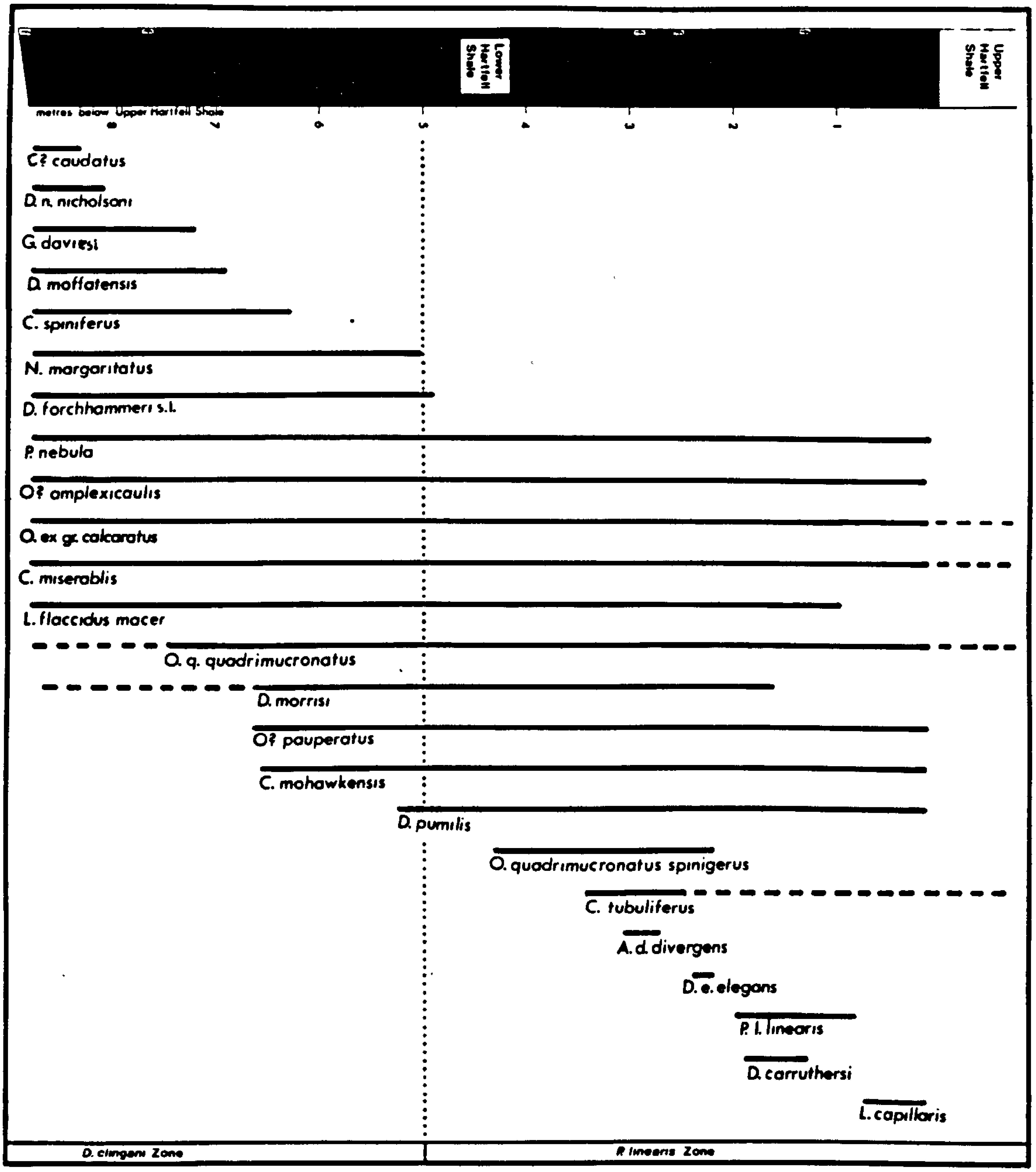
Leptograptus flaccidus macer Elles & Wood 1903
Dicellograptus moffatensis (Carruthers 1858)
D. forchhammeri (Geinitz 1852) s.l.
Climacograptus spiniferus (Ruedemann 1912)
C. miserablis Elles & Wood 1906
C? caudatus Lapworth 1876
Glyptograptus daviesi sp. nov.
Orthograptus ex gr. calcaratus
Neurograptus margaritatus (Lapworth 1876)
Plegmatograptus nebula Elles & Wood 1908

One specimen of Dicranograptus n. nicholsoni Hopkinson 1870 was found at 8.2m by Mr. K.A. Laurie on an excursion led by the writer. Dr. J.K. Ingham reports (pers. comm.) that several specimens have been discovered on the bedding planes forming the trench side of the fault gully which terminates the unbroken succession. Although the earliest specimens of Orthograptus q. quadrimucronatus (Hall 1865) and O? a. amplexicaulis (Hall 1847) were found at 7.5m and 7.2m respectively they are both known to occur at lower horizons. O. ex gr. calcaratus occurs throughout the section; although there appears to be some stratigraphical variation a more detailed study is required before any positive conclusions may be drawn but results to date are shown in text-fig. 27. The highest specimens of G. daviesi occur at 7.2m although one fragmentary specimen questionably referable to this species was found at 1.2m (P. linearis Zone). The highest specimens of D. moffatensis were found at 7.0m; specimens reported by Toghill (1970) and others from the P. linearis Zone all appear to be mature specimens of D. morrisi Hopkinson 1871 with thickened axils. D. morrisi, Climacograptus mohawkensis (Ruedemann 1912) (=C. minimus sensu Elles & Wood) and Orthograptus? pauperatus all first occur at about 6.5m. C. spiniferus last occurs at about 6.3m while D. forchhammeri s.l. and N. margaritatus last occur at 4.9m and 5.0m respectively. The species here considered to be restricted to the

D. clingani and lower zones are:

Dicranograptus n. nicholsoni Hopkinson 1870
(and all other Dicranograptus species)
Dicellograptus moffatensis (Carruthers 1858)
D. forchhammeri (Geinitz 1852) s.l.

(cont. over)



TEXT-FIGURE 4. Total known ranges of species in the top Lower Hartfell Shale, based on text-fig. 3 and additional data. Dotted lines indicate species to range longer than found in this section.

Climacograptus spiniferus (Ruedemann 1912)

C? caudatus Lapworth 1876

Glyptograptus davisi sp. nov.

Neurograptus margaritatus (Lapworth 1876)

As stated above, the highest Dicranograptus was found at about 8.2m, some 3m below the last occurrence of other species considered diagnostic of the D. clingani Zone. The last rare appearance of a single species is considered an unreliable criterion to use for a zonal boundary and until further work is carried out care should be taken not to overestimate its significance. Many poorly preserved Dicellograptus specimens which do not appear to belong to any previously described species occur in the late D. clingani Zone; more work on better preserved material is necessary before any taxonomic assessment can be given.

Species characteristic of the P. linearis Zone do not appear until 2 to 3m where Climacograptus tubuliferus Lapworth 1876, Dicellograptus e. elegans (Carruthers 1867a), Pleurograptus l. linearis (Carruthers 1858) and Leptograptus capillaris (Carruthers 1868) occur. In the interval from 5m to just over 3m no species appear or disappear with the exception of Orthograptus quadrimucronatus spinigerus (Lapworth 1876); additional knowledge concerning the zonal range of this subspecies is required before its stratigraphical usefulness can be assessed. Toghill (1970, p. 7) described a measured section through the Lower Hartfell Shale on the Main Cliff at Dob's Linn which is heavily strike faulted. He stated that on his evidence as much as 4.9m could be assigned to the P. linearis Zone. It is here considered that the best place to draw a boundary between the D. clingani and P. linearis zones in the unfaulted succession of the North Cliff is at 5.0m where all the diagnostic D. clingani Zone faunas have disappeared, except D. forchhammeri s.l. which last occurs at 4.9m. This horizon is followed by a rather sparse interval of some 2m before the first occurrence of typical P. linearis Zone faunas. The similarity to Toghill's postulated maximum thickness is considered fortuitous owing to the much faulted nature of his Main Cliff section.

Undoubted specimens of Dicellograptus pumilis Lapworth 1876 first appear at about 5.2m although some of the earlier indeterminate Dicellograptus specimens may belong to this species. C. tubuliferus was only found in the interval 3.5 to 2.5m; however, it is found in the lower Complanatus Band (p. 12) and has a similarly long range in Australia where it occurs in both the late Eastonian and early Bolindian stages (VandenBerg, pers. comm.). Although Amphigraptus d. divergens (Hall 1859) is restricted to 3.0 to 2.7m in this section it has been recorded from the N. gracilis Zone of North America (Ruedemann 1947). It is possible that this 'genus' may be a recurring mutation of a separate genus (e.g. Leptograptus) and is therefore of little stratigraphical value. D. e. elegans was only found in the interval 2.2 to 2.4m (text-fig. 3); although this may be its total range, this seems unlikely owing to its widely recorded occurrence, even when taking into account the many misidentifications which have been previously made. Judging from work abroad it appears that the species is however restricted to equivalents of the P. linearis Zone. A narrow form of O. ex gr. calcaratus approximating to O. c. basilicus sensu Elles & Wood (1907) occurs in the top 3.5m and appears to be restricted to the P. linearis Zone (text-fig. 27).

P. l. linearis, L. capillaris and Dicellograptus carruthersi Toghill 1970 are diagnostic of the latest P. linearis Zone as seen at Dob's Linn (i.e. below the Upper Hartfell Shale), although the P. linearis Zone is considered to extend some distance into the Upper Hartfell Shale (c.f. the Girvan succession, p. 30). In his stratigraphical summary Toghill (op. cit., p. 7) records P. l. linearis from the interval 1.5 to 2.1m although in his systematic description on p. 20 he records it to be restricted to 1.5 to 1.8m. Similarly he records D. carruthersi to be common in the top 0.3m of the Lower Hartfell Shale in his description (1970, p. 18) while recording it from the top 0.9m on p. 7. Recent work by the writer indicates that P. l. linearis occurs from 0.7 to 1.9m while D. carruthersi is restricted to the top 0.7m. Although Toghill (op. cit., p. 20) is considered correct in describing L. capillaris as typical of the later P. linearis Zone it appears to have a greater range than the single horizon at 0.9m recorded by him.

In summary the latest part of the P. linearis Zone seen at Dob's Linn (the top P. linearis Zone is only seen at Girvan) is characterised by P. l. linearis, D. carruthersi and L. capillaris in association with the longer ranging species:

Leptograptus flaccidus macer Elles & Wood 1903
Dicellograptus morrisi Hopkinson 1871
D. pumilis Lapworth 1876
Climacograptus mohawkensis (Ruedemann 1912)
C. miserablis Elles & Wood 1906
Orthograptus q. quadrimucronatus (Hall 1865)
O. ex gr. calcaratus
O? pauperatus Elles & Wood 1907
O? a. amplexicaulis (Hall 1847)
Plegmatograptus nebula Elles & Wood 1908

The lower part of the P. linearis Zone lacks P. l. linearis, D. carruthersi and L. capillaris but contains all the other listed species plus C. tubuliferus, A. d. divergens, D. e. elegans and O. quadrimucronatus spinigerus.

2.3 Upper Hartfell Shale. The Upper Hartfell Shale consists of some 28m of mainly pale grey, barren mudstone. There are however three intervals with graptolitic black shale bands named the Complanatus, Anceps and Extraordinarius Bands after their respective zonal faunas.

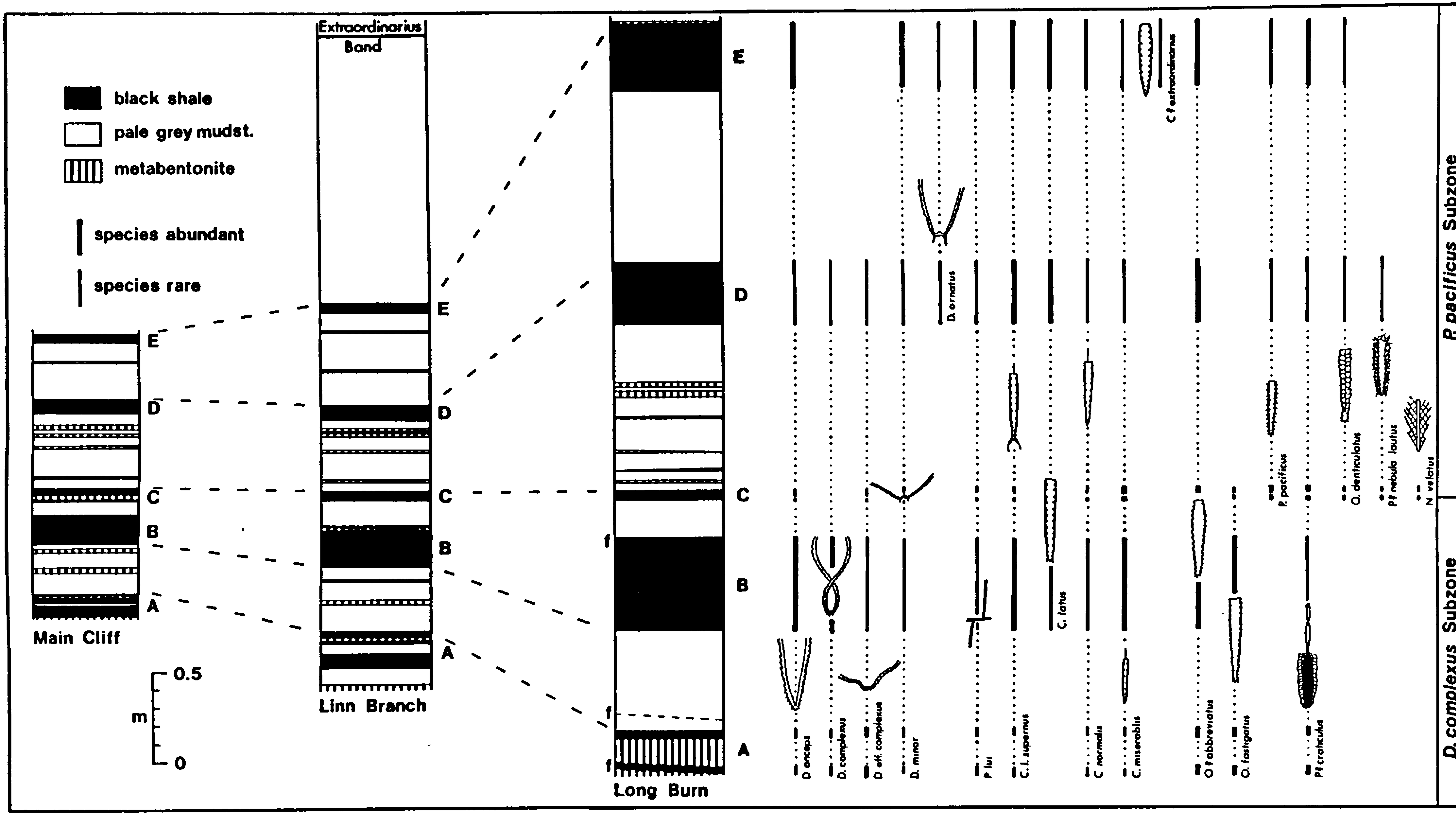
2.3.1 Complanatus Bands. The two Complanatus Bands, which occur just over 9m above the base of the Upper Hartfell Shale in the continuous North Cliff section, appear to be the first fossiliferous beds above the top of the Lower Hartfell Shale (P. linearis Zone). The lower band is about 4cm thick and yields abundant specimens of the zone fossil Dicellograptus complanatus Lapworth 1880 together with Climacograptus miserablis Elles & Wood 1906, Orthograptus? socialis (Lapworth 1880), Climacograptus tubuliferus Lapworth 1876 and Dicellograptus minor Toghill 1970 (one specimen). This is the Complanatus Band referred to in earlier literature. The upper band was discovered several years ago by J.K. Ingham (pers. comm.). It is 1cm thick and occurs about 0.4 m above the top of the lower; it yields D. complanatus and an inarticulate brachiopod Barbatulella lacunosa gen. et sp. nov. (p. 47) which continues into the first 0.7m of overlying laminated pale grey mudstone.

The lower Complanatus Band consists of three distinct black shale units, the lowest separated from the middle by a narrow interval of pale grey mudstone and the top by a metabentonite (pl. 1). The upper Complanatus Band is directly overlain by about 15mm of uniformly laminated pale grey mudstone which is succeeded by 13m of apparently unfossiliferous pale grey mudstone before the first Anceps Band is encountered.

The zonal boundaries between both the P. linearis and D. complanatus zones and the D. complanatus and D. anceps zones must lie in the barren mudstone succession. The earlier practise of drawing a zonal boundary at the base of a black shale band which contains a distinct fauna from the previous one involves the incorrect equating of lithostratigraphy and biostratigraphy, is inconsistent with modern stratigraphical method and should be discontinued. It can lead to gross misunderstanding in correlation, particularly when substantial thicknesses of intervening barren lithologies are present, as at Dob's Linn.

2.3.2 Anceps Bands. The Anceps Bands consist of alternating black shale and pale grey mudstone with thin metabentonite seams (text-fig. 5). They occur approximately 13m above the upper Complanatus Band and measure between 1.6m in the Main Cliff and 4.5m in the Long Burn. Excavations have been constructed through this interval on the southern part of the Main Cliff, the northern side of the Linn Branch and the western side of the Long Burn (text-fig. 1 , localities 2a, 5 and 7 respectively). The black shales have been divided into five bands or groups of bands A to E. The Anceps Bands at Dob's Linn have always been taken as the typical development of the D. anceps Zone following Elles & Wood's (1901-18) usage. Toghill (1970) did not recognise the lowest band and placed the base of the D. anceps Zone at the base of Anceps Band B. The lowest band was known by 1979 when Rickards produced his text-fig. 1 but he also confused lithostratigraphy and biostratigraphy by placing the base of the D. anceps Zone at the base of Anceps Band A. Recent work at Girvan by J.K. Ingham and comparison with foreign successions shows the Anceps Bands to belong to the late part of the D. anceps Zone and the boundary with the D. complanatus Zone should be placed accordingly in the barren mudstone succession well below the Anceps Bands (text-fig. 13). The variation in the thickness is a true sedimentary one and not due to tectonic stretching; different beds thicken by different amounts, some metabentonites are surprisingly discontinuous and the lithological characters of the black shale often vary, particularly in Bands D and E which are very silty in the Long Burn trench. The sequences

TEXT-FIGURE 5. Lithological variation and overall species ranges in the Anceps Bands at Dob's Linn. See text-fig. 1 for positions of measured sections. The Long Burn section is separated from the other two by a major thrust fault.



black shale
pale grey mudst.
metabentonite
species abundant
species rare
Main Cliff
Linn Branch
Long Burn
Extraordinarius Band
m
0.5
0
A
B
C
D
E
f
D. anceps
D. complexus
D. aff. complexus
D. minor
D. ornatus
P. lui
C. l. supernus
C. latus
C. normalis
C. miserabilis
C? extraordinarius
O.? abbreviatus
O. fastigatus
P. pacificus
P.? craticulus
O. denticulatus
P.? nebula lautus
N. velatus
P. pacificus Subzone
D. complexus Subzone

in the Main Cliff and Linn Branch sections are separated from the much thicker one in the Long Burn by the Main Fault; this is one of the imbricate thrusts described by McKerrow et al. (1977) and it is probable that the two sequences were deposited many miles apart.

Anceps Band A consists of four thin black shales, each between 1 and 5cm thick and separated by metabentonites with only a small quantity of pale grey mudstone. In the Long Burn trench Band A is in close proximity to the East Fault and consists of many fault-bounded slivers of black shale with a poorly preserved graptolite fauna on the bedding planes which are at an angle of about 45° to the faulted boundaries. A reasonable fauna has been recovered from Band A in the Main Cliff and Linn Branch sections including:

abundant	Orthograptus fastigatus Davies 1929
	O? abbreviatus Elles & Wood 1907
	Plegmatograptus? craticulus sp. nov.
less common	Dicellograptus anceps (Nicholson 1867a)
	D. aff. complexus
	D. minor Toghill 1970
	Pleurograptus lui Mu 1950
	Climacograptus longispinus supernus Elles & Wood 1906
	C. normalis Lapworth 1877
	C. miserablis Elles & Wood 1906
rare	Dicellograptus complexus Davies 1929

Band B is the thickest graptolitic black shale in the Anceps Bands, measuring between 17cm on the Main Cliff and just over 50cm in the Long Burn trench. In the Linn Branch trench a thin metabentonite seam occurs at the top of the band and is overlain by a black shale 1cm thick. Along strike the metabentonite narrows while in the Main Cliff and Long Burn sections it is absent. Sectioned slabs from the Linn Branch trench reveal a sharp boundary between the thick black shale and metabentonite and a gradational one from the overlying thin black seam into the pale shale. Sectioned slabs from the Main Cliff however reveal a thin orange seam just below the top of the band which would appear to be a greatly thinned representative of the metabentonite and a sharp boundary between the black and pale grey lithologies. The boundaries seem to be sedimentary rather than tectonic in all cases, being cohesive enough to withstand cutting without splitting, and it must be inferred that the variation in thickness of the metabentonite is an original sedimentary feature. Band B contains the most abundant and best preserved, although not the most diverse, graptolite fauna of the Anceps Bands and it was probably the source of most early collections from the D. anceps Zone at Dob's Linn. It yields:

abundant Dicellograptus anceps (Nicholson 1867a)
D. complexus Davies 1929
Climacograptus longispinus supernus Elles & Wood 1906
C. miserablis Elles & Wood 1906
Orthograptus fastigatus Davies 1929
O? abbreviatus Elles & Wood 1907

less common Dicellograptus minor Toghill 1970
Pleurograptus lui Mu 1950
Climacograptus latus Elles & Wood 1906
C. normalis Lapworth 1877
Plegmatograptus? craticulus sp. nov.

Band B is initially followed by fairly uniform laminated pale mudstone but some 2.7 to 3.0cm above the top is an horizon which on the Main Cliff contains abundant inarticulate brachiopod fragments, usually occurring in 'nests'. They are associated with pyritised fairly straight horizontal burrows several mm in diameter. This horizon is also seen in the Linn Branch section but contains only rare brachiopods and burrows. The brachiopods may have been fragmented either physically or biologically; both alternatives suggest partially oxygenated bottom conditions.

Band C is composed of two thin black shales; the lower is less than 1cm thick and is separated from the upper, which is about 2.5cm thick, by a 1.5cm thick metabentonite. The black shales are normally highly weathered, graptolites occurring as black films on the bleached shale which enhances preservation of fine spines and meshwork structures. The two black shales with their associated metabentonites and pale grey mudstones are approximately the same thickness in all three sections and give the most precise lithological correlation of all the Anceps Bands. Although extraction of graptolites from such thin seams is difficult they reveal a diverse fauna with:

TEXT-FIGURE 6.

Species abundance charts for the Anceps Bands at Dob's Linn.

A. Main Cliff.

B. Linn Branch trench.

C. Long Burn trench.

<u>Column width</u>

<u>Specimens per sample</u>

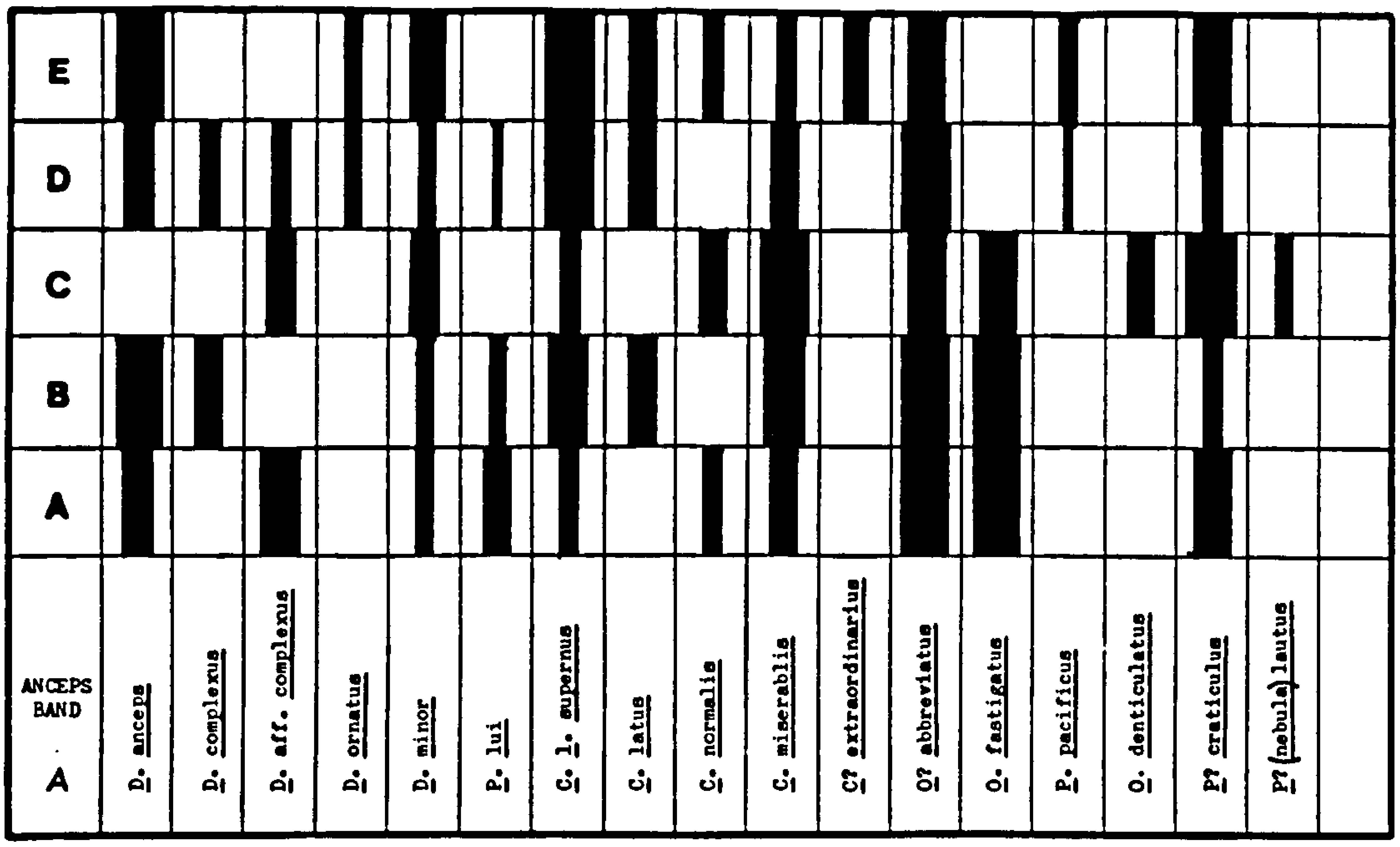
1

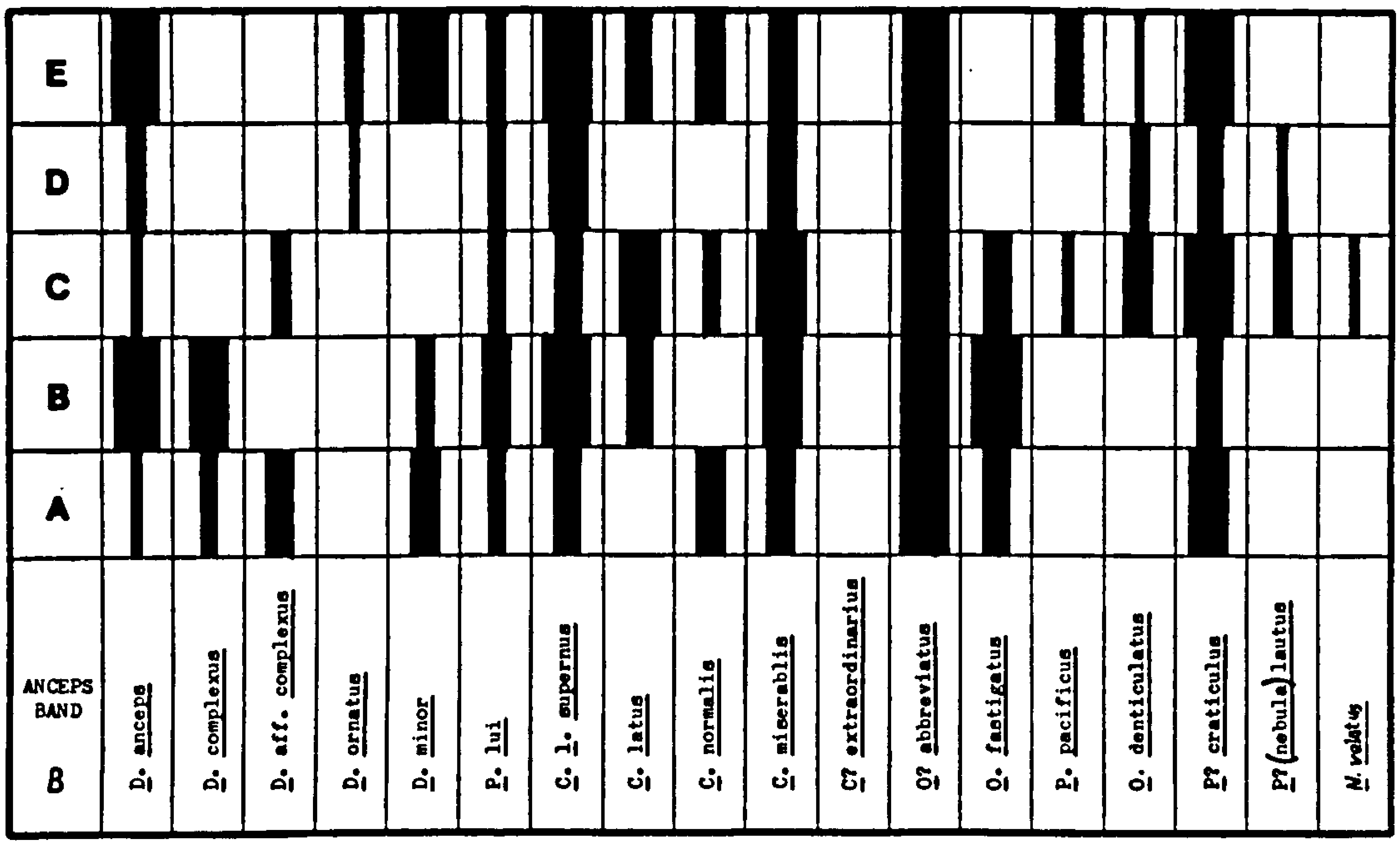
2 - 5

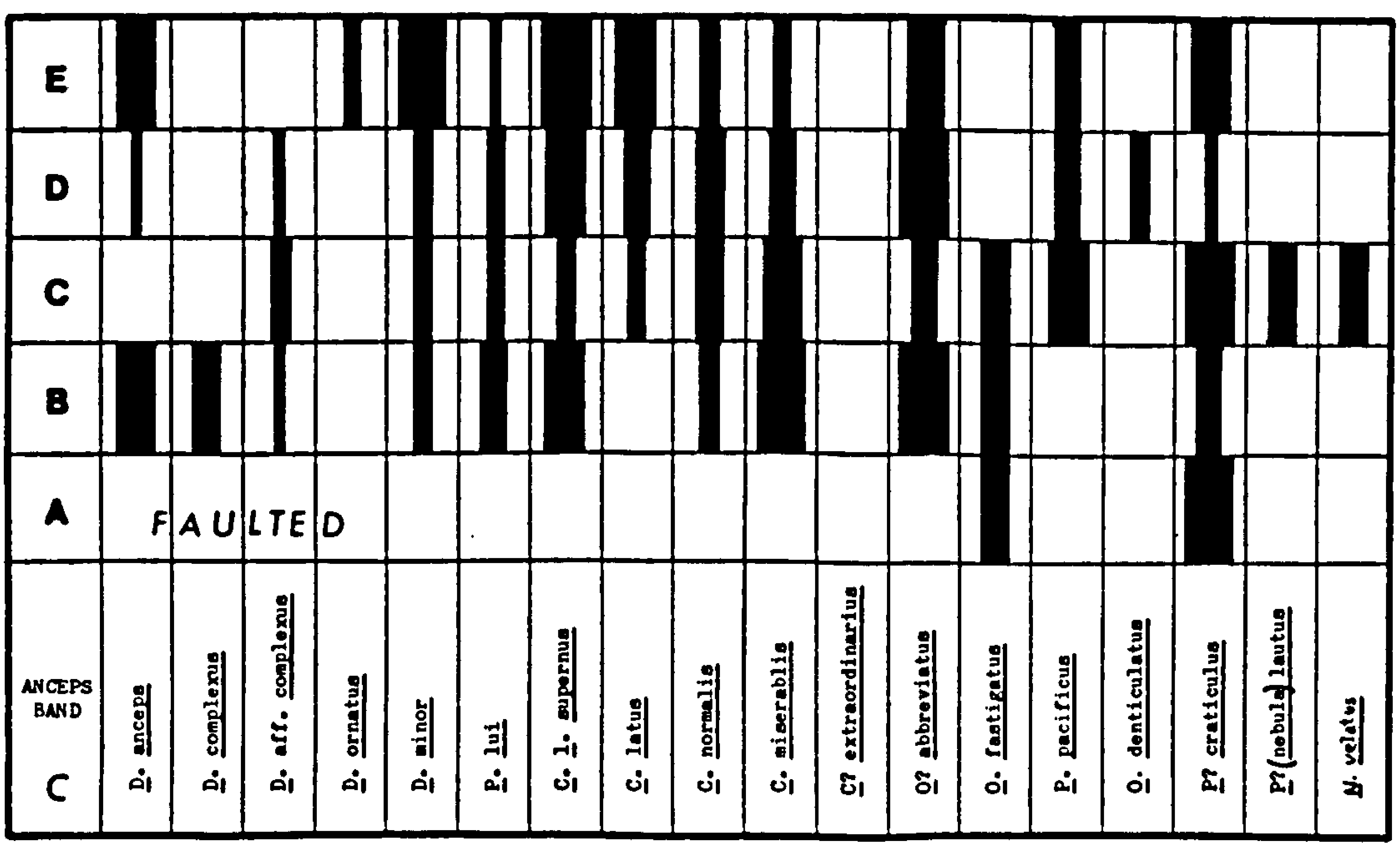
5 - 12

12 - 25

more than 25


ANCEPS BAND
A
A
B
C
D
E
D. anceps
D. complexus
D. aff. complexus
D. ornatus
D. minor
P. lui
C. l. supernus
C. latus
C. normalis
C. miserablis
C? extraordinarius
O? abbreviatus
O. fastigatus
P. pacificus
O. denticulatus
P? craticulus
P? (nebula) lautus


ANCEPS BAND
B
A
B
C
D
E
D. anceps
D. complexus
D. aff. complexus
D. ornatus
D. minor
P. lui
C. l. supernus
C. latus
C. normalis
C. miserablis
C? extraordinarius
O? abbreviatus
O. fastigatus
P. pacificus
O. denticulatus
P? craticulus
P? (nebula) lautus
N. velatus


ANCEPS BAND
C
A
B
C
D
E
FAULTED
D. anceps
D. complexus
D. aff. complexus
D. ornatus
D. minor
P. lui
C. l. supernus
C. latus
C. normalis
C. miserablis
C? extraordinarius
O? abbreviatus
O. fastigatus
P. pacificus
O. denticulatus
P? craticulus
P? (nebula) lautus
N. velatus

abundant	Climacograptus miserablis Elles & Wood 1906
	Orthograptus fastigatus Davies 1929
	O? abbreviatus Elles & Wood 1907
	Plegmatograptus? craticulus sp. nov.
fairly common	Dicellograptus aff. complexus
	D. minor Toghill 1970
	Climacograptus latus Elles & Wood 1906
	C. longispinus supernus Elles & Wood 1906
	C. normalis Lapworth 1877
	Paraorthograptus pacificus (Ruedemann 1947)
	Orthoretiograptus denticulatus Wang et al. 1977
rare	Pleurograptus lui Mu 1950
	Plegmatograptus? lautus Koren & Tzai 1980
	Nymphograptus velatus Elles & Wood 1908
one specimen	Dicellograptus anceps (Nicholson 1867a)

The faunal association of Band C and later Anceps Bands is here considered sufficiently distinctive to make Band C the lowest graptolitic horizon of a new subzone of the D. anceps Zone(text-fig. 5). This Paraorthograptus pacificus Subzone is characterised by P. pacificus, C. latus, O. denticulatus and P? lautus with only rare O. fastigatus and D. complexus which last occur in Band C and Band D respectively. The proposed new Dicellograptus complexus Subzone below it is characterised by common D. complexus (=D. szechuanensis Mu 1954) and O. fastigatus with rarer C. latus. It is considered that these two subzones are widely correlatable in all known top Ordovician graptolite sequences, the P. pacificus Subzone, for example, being equivalent to the P. pacificus Subzone of the north-eastern U.S.S.R. (text-fig. 13 ; Koren et al. 1979). Although Dicellograptus ornatus Elles & Wood 1904 is restricted to the top two Anceps Bands at Dob's Linn it appears to have a far longer range elsewhere and is not considered critical for precise correlation.

Anceps Band D consists of a single black shale 8cm thick in the Main Cliff and Linn Branch sections but thickening to about 30cm in the Long Burn where it contains a greater number of micaceous silty horizons. It yields a relatively rare but diverse P. pacificus Subzone fauna with:

common	Climacograptus longispinus supernus Elles & Wood 1906
	Orthograptus? abbreviatus Elles & Wood 1907
less common	Dicellograptus anceps (Nicholson 1867a)
	D. minor Toghill 1970
	Pleurograptus lui Mu 1950
	Climacograptus latus Elles & Wood 1906
	C. normalis Lapworth 1877
	C. miserablis Elles & Wood 1906
	Paraorthograptus pacificus (Ruedemann 1947)
	Plegmatograptus? craticulus sp. nov.
rare	Dicellograptus complexus Davies 1929
	D. aff. complexus
	D. ornatus Elles & Wood 1904
	Orthoretiograptus denticulatus Wang et al. 1977
	Plegmatograptus? lautus Koren & Tzai 1980

The change from pale mudstone to black shale at the base of Band D is a gradational one with mottling and bioturbation indicating partially oxygenated conditions.

Anceps Band E consists of a single black band, thickening enormously from 5cm in the Main Cliff and Linn Branch sections to almost 35cm in the Long Burn. It contains:

abundant	Dicellograptus anceps (Nicholson 1867a)
	D. minor Toghill 1970
	Climacograptus longispinus supernus Elles & Wood 1906
	Orthograptus? abbreviatus Elles & Wood 1907
	Plegmatograptus? craticulus sp. nov.
less common	Dicellograptus ornatus Elles & Wood 1904
	Climacograptus latus Elles & Wood 1906
	C. normalis Lapworth 1877
	C. miserablis Elles & Wood 1906
	Paraorthograptus pacificus (Ruedemann 1947)
rare	Pleurograptus lui Mu 1950
	Orthoretiograptus denticulatus Wang et al. 1977
	Climacograptus? extraordinarius (Sobolevskaya 1974)

There are several notable differences in the composition and astogenetic development of this band's fauna. It is the only band to consistently yield D. ornatus although even here it is fairly rare. Both this species and D. anceps from this band commonly possess well developed axial membranes which reach up to the fourth pair of thecae in D. anceps (text-fig.21i) and up to the seventh pair in D. ornatus (pl. 21, fig. 1). The latter species also develops extremely long and robust spines at this horizon (pl. 21, fig. 5). Rhabdosomes of C. longispinus supernus are common in Band E but never develop long thecal spines or anything more than the initial portions of a basal membrane, while sometimes the virgella is as long as the two thecal spines. All these unusual features occurring at one horizon may reflect changing, perhaps deteriorating, environmental conditions causing robust Dicellograptus to develop stronger axial regions and stunting the growth of C. longispinus supernus at a fairly early stage. Alternatively they may represent evolutionary trends, as the C. longispinus group appears to reduce the basal spine and membrane development during the late Ordovician (p. 128). The slender Dicellograptus minor is more abundant in Band E than any of the previous bands and C? extraordinarius makes its earliest known appearance, although to date it has only been found on the Main Cliff. Care has to be taken when collecting from this locality as the top two Anceps Bands and the Extraordinarius Band are repeated by strike faulting, but there is no doubt concerning the horizon from which the specimens of C? extraordinarius were collected. Conodonts are abundant in Band E, especially in coarser silty horizons, and one scolecodont (polychaete jaw) has been found (pl. 8 , fig. 1).

2.3.3 Extraordinarius Band. 1.5m above the last Anceps Band a dark brown seam occurs, half way through the otherwise pale grey mudstone which separates the black shale of Anceps Band E from the base of the Birkhill Shale. It yields occasional graptolites, especially in the Long Burn section, which have been identified as Climacograptus? extraordinarius (Sobolevskaya 1974), Climacograptus cf. normalis and Glyptograptus cf. persculptus by Rickards (1979) and the writer. This faunal assemblage identifies the top Ordovician C? extraordinarius Zone first described from Russia by Koren and others. Owing to the first occurrence of C? extraordinarius in Anceps Band E it is likely that the D. anceps/C? extraordinarius zonal boundary is best taken to be within the pale unfossiliferous mudstone a short distance above Anceps Band E. Intensive collecting from the interval between the top Anceps Band and the Birkhill Shale has failed to reveal any additional graptolitic laminae and should the base of the G. persculptus Zone be taken as the level at which the Ordovician/ Silurian boundary is placed by international agreement, then Dob's

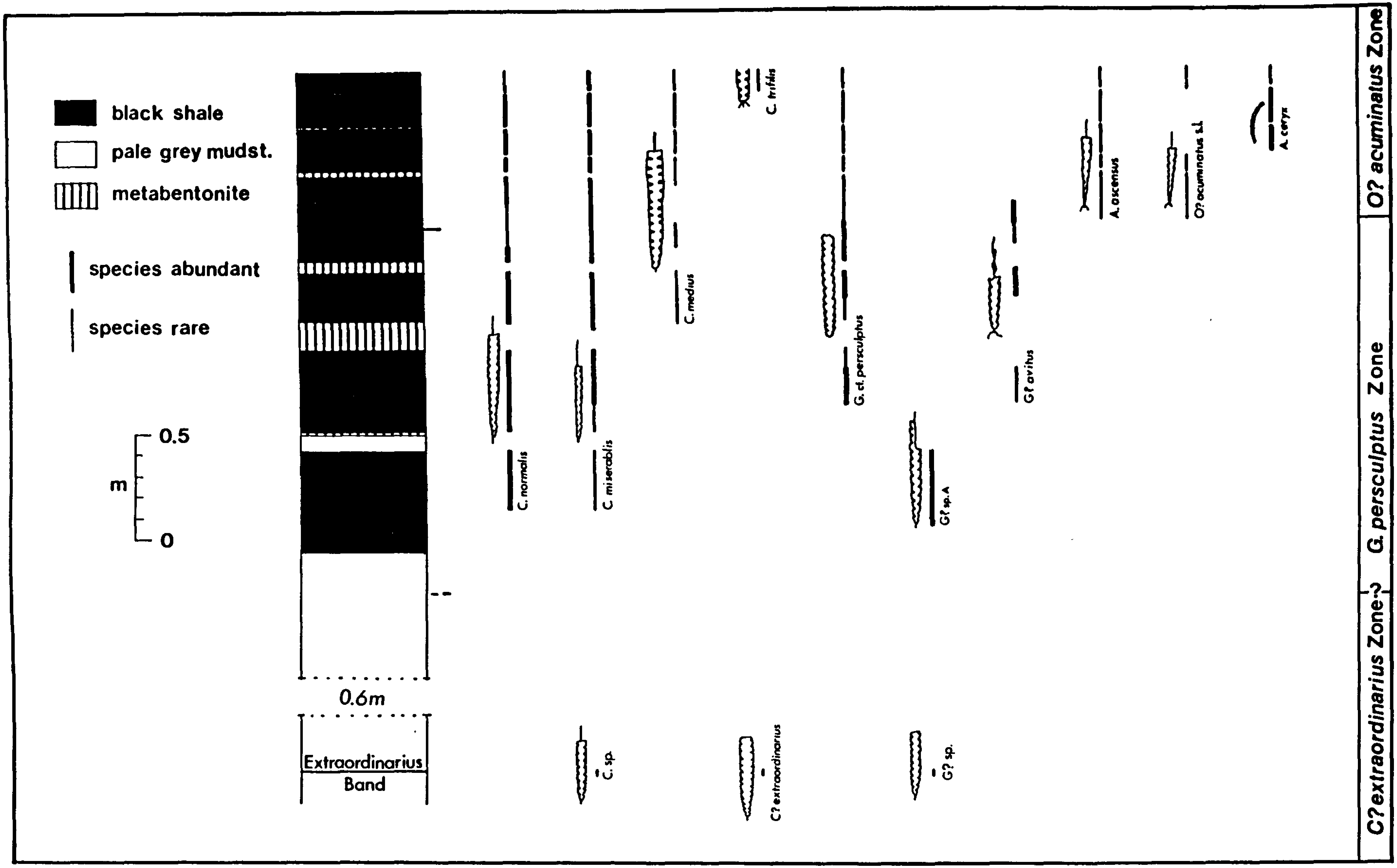
Linn would be unsuitable as an international stratotype.

N.H. Trewin and J.K. Ingham (pers. comm.) have discovered an horizon which yields trilobite, bivalve and nautiloid remains, especially in the Long Burn section. It is an interval about 10cm thick, lying from 5 to 15cm below the Extraordinarius Band. The trilobite is a blind dalmanitinine which evidently belongs to a new genus related to Mucronaspis and Dalmanitina. It is congeneric but not conspecific with the form described as Mucronaspis s.l. cellulana sp. nov. from the equivalent of the C? extraordinarius Zone in Co. Cavan, Eire by Siveter et al. (1980).

2.4 Birkhill Shale. The 43m of Birkhill Shale (Toghill 1968b) is composed predominantly of black graptolitic shale or mudstone which is less fissile and more heavily pyritous than the underlying Hartfell Shale. It also contains thin metabentonite seams which have commonly acted as planes of bedding slip, and occasional pale grey-green mudstones which become common in the M. convolutus and M. sedgwickii zones and dominant in the R. maximus Zone. The mudstones then give way transitionally into the Gala Greywacke Formation which at Dob's Linn begins within the R. maximus Zone.

The transition from the pale grey mudstone of the Upper Hartfell Shale to the black shales and mudstones of the Birkhill Shale is sharp and occurs 1.17m above the Extraordinarius Band in the Linn Branch section (text-fig. 7). The basal 15cm of black shale is unfossiliferous and coarse with a fine mottled appearance. It is followed by more typical graptolitic black shale although this again is mottled and contains common bands of fine silty material. This basal interval must be the one referred to by Elles & Wood (1906, p. 186) as the 'gingerbread' bed at the base of the Birkhill Shale which contains abundant Climacograptus normalis Lapworth 1877. 0.2m above the base typical black graptolitic shale is present, yielding a fairly abundant fauna of C. normalis and Glyptograptus? sp.A with rarer specimens of Climacograptus miserablis Elles & Wood 1906. At 0.46m there is a sharp reversal to pale grey-green mudstone, followed by 10cm of variously coloured and laminated mudstones (text-fig. 8). At 0.56m these are overlain by a metabentonite which is followed by a typical black graptolitic shale. G? sp. A last appears just below the pale mudstone unit while C. normalis and C. miserablis continue into the

TEXT-FIGURE 7. Lithological succession and species ranges of the top Upper Hartfell Shale and basal Birkhill Shale in the Linn Branch trench (text-fig. 1, Loc. 5).


black shale
pale grey mudst.
metabentonite
species abundant
species rare
m
0.5
0
0.6m
Extraordinarius Band
C. normalis
C. miserablis
C. medius
C. trifilis
G. cf. persculptus
G? sp. A
G? avitus
A. ascensus
O? acuminatus s.l.
A. ceryx
C. sp.
C? extraordinarius
G? sp.
C? extraordinarius Zone ?
G. persculptus Zone
O? acuminatus Zone

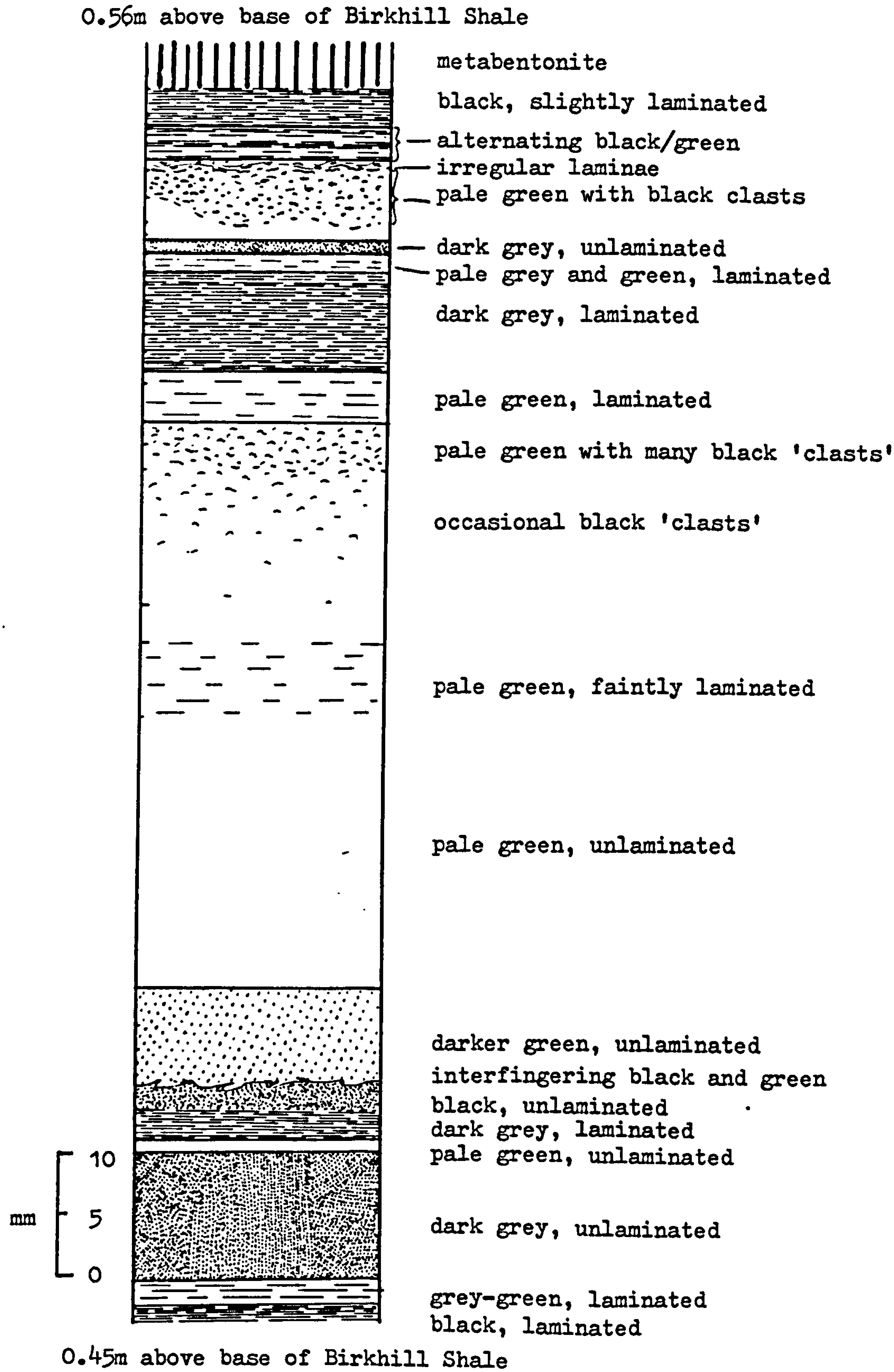
overlying black shale. At about 0.6m is a silty horizon containing beautifully preserved three-dimensional specimens of C. normalis. C. miserablis becomes abundant by about 0.7m and remains so throughout the rest of the collected interval, while Glyptograptus cf. persculptus (Salter 1865) and Glyptograptus? avitus Davies 1929 first appear at this horizon. Rare conodonts occur in the basal 1m of black shale but at present are inadequate for stratigraphical use (Chapter 5, p. 53).

A thick metabentonite occurs from 0.96 to 1.1m; it contains irregular slivers of black shale and evidently has acted as a plane of slip. It however appears to be concordant with the bedding and it is unlikely that it has had any significant effect on the succession. Possible specimens of Climacograptus medius Törnquist 1897 first appear just above the metabentonite but are rather narrow and may represent tectonically stretched specimens of C. normalis. C. medius s.s. appears soon after and occurs sporadically throughout the remainder of the collected interval. G? avitus first becomes abundant at 1.2m.

Another metabentonite is present from 1.32 to 1.38m but no significant faunal changes occur until 1.6m when Akidograptus ascensus Davies 1929 and Orthograptus? acuminatus (Nicholson 1867a)s.l. first appear and where G? avitus is last seen. The appearance of A. ascensus is considered by most lower Silurian graptolite workers to mark the base of the O? acuminatus Zone; while this effectively means that the G. persculptus/O? acuminatus zonal boundary is defined on the range of a single species it appears to be a reasonably synchronous cosmopolitan event when compared with other recorded graptolites and shelly faunas. It is suggested that the base of the O? acuminatus Zone should be placed at 1.6m above the base of the Birkhill Shale in the Linn Branch section at Dob's Linn (cf. the 1.06m of Toghill 1968a, b); if the current feeling of many researchers is adherred to in the future this horizon will become synonymous with the Ordovician/Silurian boundary (Chapter 4.3).

A. ascensus seems to occur consistently earlier and more commonly than O? a. acuminatus s.s. in the early O? acuminatus Zone (Davies 1929, p. 10; Toghill 1968b, p. 658; Hutt 1974, p. 6; Oradovskaya et al. 1979, field guide range chart). It is probable that the O? acuminatus Zone could be subdivided into a lower A. ascensus Subzone and a higher O? acuminatus s.s. Subzone after detailed collecting

TEXT-FIGURE 8. Detailed lithological log through the reversal to pale grey mudstone 0.46m above the base of the Birkhill Shale in the Linn Branch trench. See text-fig. 7 for stratigraphical horizon.


0.56m above base of Birkhill Shale
metabentonite
black, slightly laminated
alternating black/green
irregular laminae
pale green with black clasts
dark grey, unlaminated
pale grey and green, laminated
dark grey, laminated
pale green, laminated
pale green with many black 'clasts'
occasional black 'clasts'
pale green, faintly laminated
pale green, unlaminated
darker green, unlaminated
interfingering black and green
black, unlaminated
dark grey, laminated
pale green, unlaminated
dark grey, unlaminated
grey-green, laminated
black, laminated
mm
10
5
0
0.45m above base of Birkhill Shale

of the remainder of this zone at Dob's Linn.

The earliest monograptid Atavograptus ceryx (Rickards & Hutt 1970) is crowded on a few bedding planes from about 1.9 to 2.1m while occasional specimens occur in the remainder of the collected section. Monograptids have not been recorded previously before the C. vesiculosus Zone at Dob's Linn (Toghill 1968a, p. 48) although Rickards & Hutt (1970) and Hutt (1974) record A. ceryx from both the G. persculptus and O? acuminatus zones of the Lake District. Only one specimen of Climacograptus trifilis Manck 1923 was found during this study in the interval 2.19 to 2.31m; this species is considered to be restricted to the O? acuminatus Zone (Stein 1965, p. 168; Toghill 1968b, p. 658). The enigmatic fossil Dawsonia campanulata Nicholson 1873 occurs fairly commonly from 1.9 to 2.14m, although the affinity and stratigraphical range of this form is still unknown (Chapter 5.6).

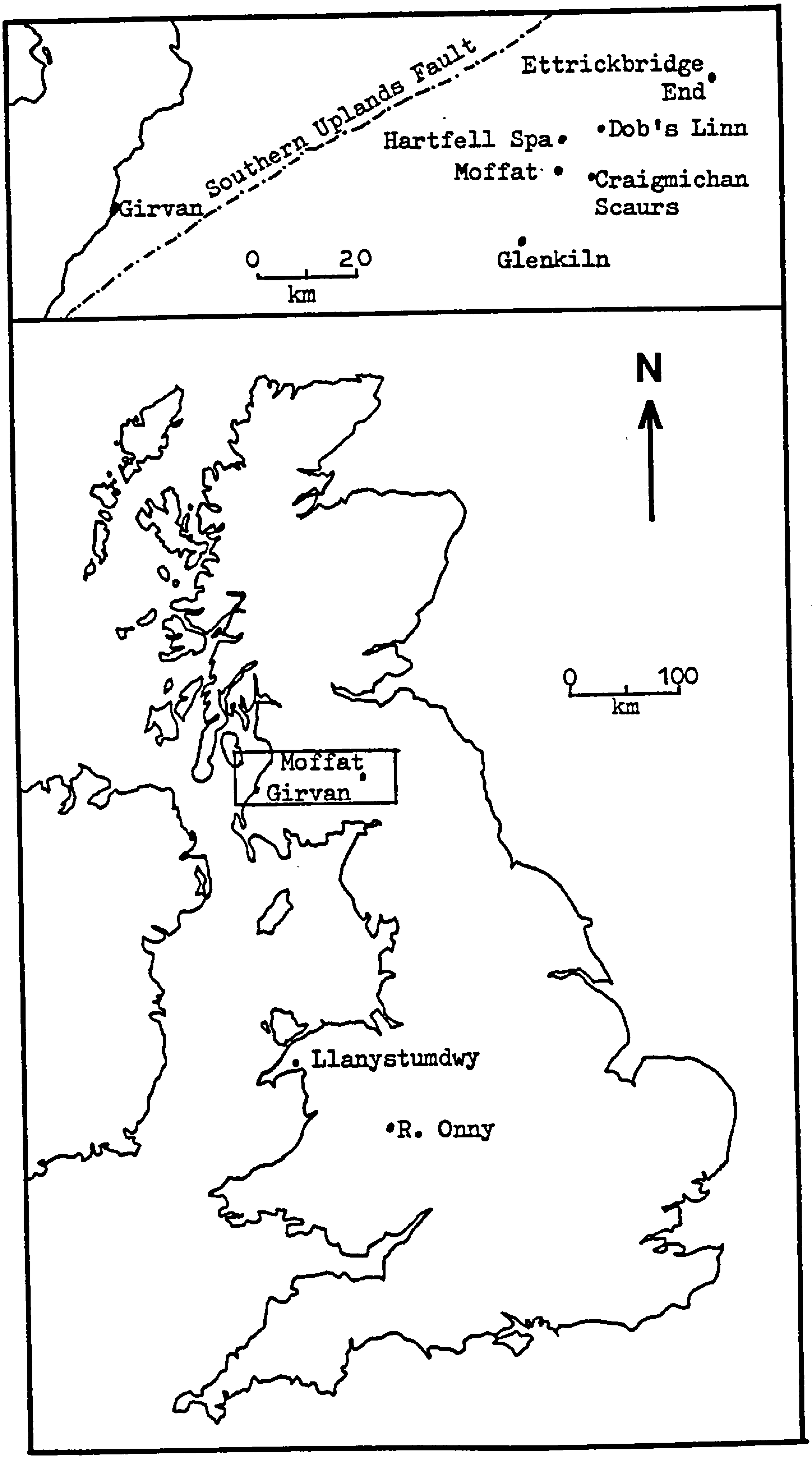
Chapter 3. Other important Upper Ordovician graptolite localities in southern Scotland.

3.1 Introduction. Although Dob's Linn has become the classical locality for the Moffat Shale Group owing to the presence of all four named formations and ease of access, many other inliers were found and described by both Lapworth (1878) and Peach & Horne (1899). These consist of commonly small faulted exposures varying from several metres to about one kilometre long and are located along major north east - south west faults. Both Lapworth and Peach & Horne considered them to be the cores of isoclinal anticlines but more recently Eales (1978) and others have shown them to consist of imbricate thrust slices.

Dob's Linn belongs to the Central Belt of the Southern Uplands and the localities described in the next section of this chapter all belong to this belt (text-fig. 9). In the Northern Belt greywacke deposition starts in the *D. clingani* Zone around Abington while in the Coulter-Noblehouse area it commences as low as the *N. gracilis* Zone and rests on cherts bearing only a fauna of conodonts which indicate a Llandeilo age (McKerrow *et al.* 1977). In the Southern Belt there is little, if any, recognisable Ordovician. The progressive southward younging of the succession, although each imbricate thrust slice youngs to the north, was considered by McKerrow *et al.* (*op. cit.*) to be due to the formation of an accretionary prism over a northerly dipping subduction zone. The localities described in Section 3.2 are restricted to those personally studied by the writer and constitute only a tiny minority of those known. Section 3.3 compares the Southern Uplands succession with that seen at Girvan.

3.2 Localities in the Central Belt of the Southern Uplands.

3.2.1 Craigmichan Scaurs. (centred at O.S. NT 162 061). This locality lies about 8km east of Moffat on the south-west flanks of Capel Fell and is perhaps the largest inlier of Moffat Shale in the Central Belt. Eales (1978) recently showed it to expose three thrust sheets and to contain considerably more Glenkiln Shale than Dob's Linn with tuffaceous and cherty lithologies which may extend down into the *N. gracilis* Zone. The Lower Hartfell Shale appears to be represented only by late *D. clingani* or low *P. linearis* zones and is mostly



TEXT FIGURE 9. Position of localities discussed in text.

sheared and poorly fossliferous. Although neither Lapworth nor Peach & Horne found any black graptolitic bands in the Upper Hartfell at Craigmichan Scaurs Eales (1978) and Ingham (pers. comm.) found the Complanatus Bands, represented by two thin veneers, at approximately the same distance above the Lower Hartfell Shale in the middle thrust slice as at Dob's Linn. The discovery of the Anceps Bands in the upper thrust sheet is even more significant; these occur high on the North Cliff at the head of the eastern tributary of Rae Grain in an exposure assumed to be part of the middle Llandovery R. maximus Zone by Lapworth and to be Birkhill Shale by Fyfe & Weir (1976). The Anceps Bands at Rae Grain appear to be composed of several thick black bands (weathered cream) with an abundant D. anceps Zone fauna. Unfortunately the succession has been tectonically confused and conclusions regarding the exact number and thickness of the bands may not be made until they have been mapped in greater detail than by Eales. The graptolites are preserved as black or grey films in weathered pale cream shale and are even more highly sheared than those at Dob's Linn. This makes them of little use for taxonomic work except for specimens of Paraorthograptus pacificus (Ruedemann 1947) and Plegmatograptus? craticulus sp. nov. which are best seen when preserved as black films in pale weathered shale. The writer has restudied Eales' material in addition to his own collections and has identified the following fauna from the top Anceps Band at Rae Grain:

Dicellograptus anceps (Nicholson 1867a)
D. minor Toghill 1970
Climacograptus normalis Lapworth 1877
C. miserablis Elles & Wood 1906
C. longispinus supernus Elles & Wood 1906 (some + long virgella)
C? extraordinarius (Sobolevskaya 1974)
Orthograptus? abbreviatus Elles & Wood 1907
Paraorthograptus pacificus (Ruedemann 1947)
Plegmatograptus? craticulus sp. nov.

These forms are similar to those found in Anceps Band E at Dob's Linn and the two must be approximately equivalent in age (late P. pacificus Subzone). The earliest graptolite bands contain species typical of the lowest Anceps Bands at Dob's Linn (D. complexus Subzone). It therefore seems that the Anceps Bands at Rae Grain do not cover a greater time span than those at Dob's Linn although Eales recorded them to occupy 20m of succession in contrast with the 2m of the Linn Branch and 4m of the Long Burn sections at Dob's Linn. He recorded a barren unit 2m thick above the last graptolitic band containing Dicellograptus before the occurrence of a normal G. persculptus Zone fauna; this presumably corresponds to the 3m of pale grey mudstone which lie between Anceps Band E and the base of the Birkhill Shale at Dob's Linn and contain the Extraordinarius Band. Eales recorded the first appearance of Akidograptus ascensus Davies 1929 2.4m above the base of the Birkhill Shale at Rae Grain. It therefore seems that extensive thickening of the Anceps Bands has occurred in comparison to Dob's Linn but that the top of the Upper Hartfell Shale above the last Anceps Band is if anything thinner and the basal Birkhill Shale belonging to the G. persculptus Zone is slightly thicker.

Eales (1978, text-fig. 9) also recorded a section through the Upper Hartfell Shale in the middle thrust sheet on the North Cliff;the overall thickness is similar but only the Complanatus Bands and two Anceps Bands seem to occur. The latter, measuring about 2cm thick each and separated by about 1m of pale mudstone, reveal only a rather poor D. anceps Zone fauna. He also recorded a black shale followed by a narrow pale band before entering continuous black Birkhill Shale. Although this superficially appears similar to the basal Birkhill succession at Dob's Linn he recorded only O? abbreviatus from the lowest black shale unit. Kearsley (pers. comm.) has recently shown the forms described as 'O. abbreviatus' from the lower Silurian by Hutt (1974) and others to be different from the late Ordovician amplexicaulis group diplograptids. The writer failed to find any specimens similar to O? abbreviatus in the basal Birkhill Shale at Dob's Linn and it appears that the Upper Hartfell to Birkhill Shale succession collected by Eales in the middle thrust sheet may therefore be a faulted one.

The substantial change in thickness of the Anceps Bands which occurs when crossing major thrusts at both Dob's Linn and Craigmichan Scaurs is impossible to explain without accepting an imbricate thrust model to bring originally widely separated areas into juxtaposition. The reasons for the variations in thickness remain however unknown; even more detailed collecting than has been carried out at Dob's Linn would be required from both the graptolitic black shale and pale mudstone lithologies of all known Anceps Band localities. It would also have to be certain that all tectonic effects on the successions had been recognised. The time that would be required to study this minute part of the Lower Palaeozoic succession may be prohibitive and it seems unlikely at the present time that the problem will ever be resolved.

3.2.2 Hartfell Spa. (centred at O.S. NT 097 116). This locality lies about 8km north of Moffat. Lapworth (1878, p. 295) stated that nowhere else is there "so magnificent an expanse of black flaggy beds of the middle division of the Moffat Series as is exhibited in the northern cliffs in the score at Hartfell Spa". He therefore named the middle division the 'Hartfell Shale' but recognised that there was little 'barren mudstone' (Upper Hartfell Shale) at this exposure. Both he (op. cit., text-fig. 23) and Peach & Horne (1899, text-fig. 24) considered the locality to be composed of a series of isoclinal folds with only a few steeply dipping faults, although Eales (1978, text-fig. 18) has recently shown it to consist of a series of imbricate thrust slices. All four Moffat Shale formations are represented but few continuous sequences with clear zonal transitions have been recognised, many of the faunal breaks observed by Eales and the writer seeming to occur at strike faults. However, both Eales (1978, pp. 50-51) and Peach & Horne (1899, p. 137) gave faunal lists from what they considered to be single zones which clearly indicate mixed zonal assemblages (see below). It is therefore possible that detailed collecting may reveal similar zonal transitions to the D. clingani/ P. linearis zonal boundary described for the North Cliff at Dob's Linn (p. 10).

The Glenkiln Shale is seen most clearly on the north bank of the stream running down Hartfell Score where it is faulted against Birkhill Shale, although it also crops out in several imbricate slices higher up on the northern valley side. It is composed predominantly of cherts and tuffaceous lithologies with subordinate interbedded shales. Neither Lapworth (1878, p. 296) nor Eales (1978, p. 44) found any identifiable graptolites in the Glenkiln Shale although Peach & Horne (1899, pp. 136-137) recorded fifteeen species including:

Dicranograptus ziczac Lapworth 1876
Nemagraptus explanatus pertenuis (Lapworth 1876)
Pseudoclimacograptus scharenbergi (Lapworth 1876)
Cryptograptus tricornis (Carruthers 1858)
Glossograptus hincksii (Hopkinson 1872)
Corynoides calicularis Nicholson 1867

This assemblage appears to belong to the C. peltifer Zone.

Eales (1978, pp. 45-47) recorded the C. wilsoni Zone to be represented at three different structural levels by black shales which were rather more carbonaceous and less siliceous than those typically found in the D. clingani Zone. Eales, Lapworth and Peach & Horne all recorded an abundant fauna from the C. wilsoni Zone which judging from the specimens in the Lapworth, Wood and Elles collections appear to be the most common and well preserved in the Central Belt of the Southern Uplands. The D. clingani and P. linearis zones are also abundantly fossiliferous and judging from the faunal lists given by Eales (1978, pp. 50-51) for the lower and second 'P. linearis thrust sheets' and by Peach & Horne (1899, p. 137) there may be some continuous sequences between the two zones. Eales listed many species from the 'P. linearis Zone' of the thrust sheets including:

Leptograptus capillaris (Carruthers 1868)
Pleurograptus l. linearis (Carruthers 1858)
Dicranograptus r. ramosus (Hall 1847)
Dicellograptus e. elegans (Carruthers 1867a)
D. pumilis Lapworth 1876
D. forchhammeri flexuosus Lapworth 1876
Climacograptus spiniferus Ruedemann 1912
'C'. caudatus Lapworth 1876
Orthograptus q. quadrimucronatus (Hall 1865)
O. c. calcaratus (Lapworth 1876)
O. calcaratus basilicus Elles & Wood 1907
O. p. pageanus Elles & Wood 1907

From the writer's recent detailed work at Dob's Linn it is clear that a sequence from fairly early D. clingani to middle or late P. linearis Zone is represented in what Eales considered to be a single tectonic unit.

The Upper Hartfell Shale is not certainly represented at Hartfell Spa; several knolls of pale grey mudstone crop out high on the northern slopes of Hartfell Score above the main exposures of Glenkiln and Lower Hartfell Shale. Intensive searching has however failed to reveal any black graptolitic laminae and the exposures may only be assigned tentatively to the Upper Hartfell Shale on purely lithological grounds.

The Birkhill Shale is found only on the south side of the major fault running along the valley bottom of Hartfell Score; it is highly shattered and convoluted near the fault but contains a fauna representative of the O? acuminatus and later zones and has not been studied for this thesis. Several small inliers of Birkhill Shale are found along the Auchencat Burn between the Permian New Red Sandstone unconformity and the confluence with the Spa Burn. Most are highly sheared and contain no identifiable graptolites although Peach & Horne (1899, p. 133) record faunas belonging to the C. gregarius Zone at the trial copper mine and at another exposure 300 yards upstream from this point.

3.2.3 Glenkiln Burn. (O.S. NY 008 895). This section is about 17km south-south-west of Moffat. Lapworth considered the Black Linn exposure of Glenkiln Burn to be the type section for his lowest Moffat Shale division. Instead of the pale cherts and tuffs characteristic of the Glenkiln Shale at Craigmichan Scaurs and Hartfell Spa it is here composed predominantly of dark shale with locally abundant graptolite faunas. Eales (1978, pp. 60-66) gave a full description of the locality which is summarised here in conjunction with Lapworth's and Peach & Horne's work. Eales gave revised geological maps of Glenkiln Burn but studies by the writer and in conjunction with members of the Southern Uplands Research Group do not give support to his structural interpretation.

The Black Linn locality probably shows the most fossiliferous development of the Glenkiln Shale in the Central Belt of the Southern Uplands. Diagnostic representatives of both the N. gracilis and C. peltifer zones are present although precise differentiation between these zones awaits a detailed study similar to the one carried out for this thesis on the top Lower Hartfell and bottom Birkhill Shale at Dob's Linn. A faulted block of Lower Hartfell Shale (P. linearis Zone) is present on the south bank of the stream where it bends sharply to the north; Peach & Horne (1899, p. 147) recorded Lower Hartfell Shale containing representatives of the C. wilsoni Zone including Climacograptus w. wilsoni Lapworth 1876 itself south-west of the confluence with the Lambfoot Linn but this has not been found by either Eales or the writer.

The northern faulted inlier of Moffat Shale is separated from the main Black Linn exposure by about 300m of greywacke and contains representatives of Glenkiln and Birkhill Shale. They are faulted into juxtaposition and highly shattered but Peach & Horne (1899, p. 149) recorded a fauna from the Birkhill Shale with representatives from at least the O? acuminatus to M. sedgwickii zones.

3.2.4 Ettrickbridge End. (O.S. NT 381 235). This locality is in the Ettrick Water about 10km south-west of Selkirk. Eales (1978, pp. 78-83) gave a full description and geological map of this locality which contains representatives of all four Moffat Shale formations. It is the most south-easterly Moffat Shale inlier of the Central Belt. Perhaps the most interesting, and certainly the most relevant division to this thesis, is the representative of the Upper Hartfell Shale which here consists of pale silty shales and grits instead of the normal 'barren mudstone' lithology. Eales recorded a black shale band within the grits which yielded:

Dicellograptus anceps (Nicholson 1867)
D. complexus Davies 1929
Climacograptus latus Elles & Wood 1906
C. longispinus supernus Elles & Wood 1906
Orthograptus amplexicaulis (Hall 1847)

This fauna is diagnostic of the D. anceps Zone. Elles & Wood's(1908) type specimens of Nymphograptus velatus appear to have come from this band; if this species is restricted to horizons equivalent to Anceps Band C (early P. pacificus Subzone) as suggested by the present work at Dob's Linn (text-fig. 5) it may well indicate an accurate correlation with this band, although additional fauna would be needed for this to be certain. Unfortunately the level of the River Ettrick has been too high to permit further collecting from the black shale when visited by the writer. The palaeogeographical significance of the change from typical pale grey mudstones to grits is uncertain but further demonstrates the great lateral facies variation at the level of the Upper Hartfell Shale.

3.3 The Girvan succession. The following description of the Upper Ordovician succession at Girvan is based on many valuable conversations with Dr. J.K. Ingham and on his published summary (1978). The stratigraphical names are mostly from an as yet unpublished manuscript by Ingham. The dominant trilobite faunas in the Myoch and parts of the Mill Formation of the Upper Whitehouse Group are Dionide/

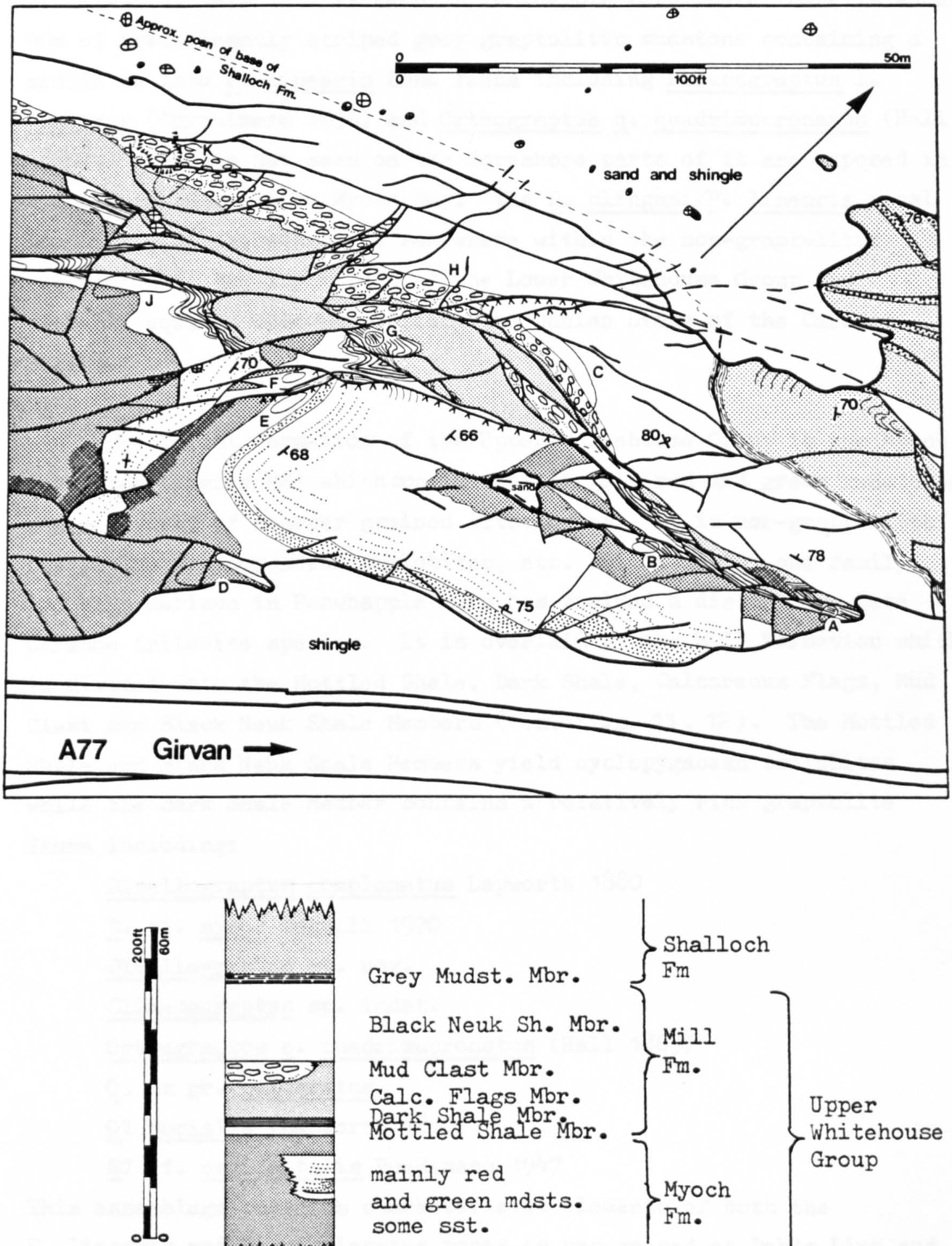
TEXT-FIGURE 10. General stratigraphy of the Girvan region (not to scale). Late Ordovician succession from Ingham (MS), Lower Silurian adapted from Cocks & Toghill (1973). Evidence for graptolite and shelly zonation given at stratigraphical positions where found.

STAGE	GRAPTOLITE ZONE	LITHOSTRATIGRAPHY			
	cyphus		Glenwells Shale		
late Rhuddanian			Mulloch Hill Ss.		
			Mulloch Hill Congl.		
		UNCONFORMITY			
Hirnantian			High Mains Ss.		CRAIGHEAD INLIER
mid-late Rawtheyan	anceps	Upper Drummuck Group			
mid-late Cautleyan		Lower Drummuck Group			
	anceps		Shalloch Fm.	shales, ss., etc.	
low Cautleyan /Pusgillian				detrital lsts.	
	complanatus			basal grey mdst.	
	complanatus	Upper Whitehouse Group	Mill Fm.	Black Neuk Shale Mbr.	GIRVAN FORESHORE
Pusgillian				Mud Clast Mbr.	
				Calc. Flags Mbr.	
	complanatus /linearis			Dark Shale Mbr.	
				Mottled Shale Mbr.	
Onnian			Myoch Fm		
	mid linearis	Lower Whitehouse Group	striped grapt. shale fm.		
			STRUCTURAL BREAK		
			finely laminated ss. flysch fm.		
Onnian/ Actonian			basal calc. flysch fm.		
	clingani	Ardwell Group	Cascade Grits		

Novaspis/cyclopygacean faunas while the brachiopods belong to the Foliomena association regarded by Sheehan (1973) to indicate a deep water environment. Ingham (1978) regards the late Ordovician succession at Girvan to have been deposited in an unstable down-slope basinal environment with deep sea fans.

The lowest stratigraphical unit relevant to this thesis is the Ardwell Group (text-fig. 10); in Penwhapple Burn the top of the Ardwell Group is represented by the Cascade Grits while on the Whitehouse Shore they are absent but probably represented by occasional thin sandstones. Both localities have associated dark grey, striped graptolitic mudstones. In his description of Ardwell Bay Lapworth (1882, p. 597) states, of what he refers to the Lower Whitehouse, that "the basal band of this subgroup is formed of striped grey and green somewhat carbonaceous shales much softer than the underlying Ardwell group ... [and]... contain abundant examples of Dicellograptus forchhammeri &c". However, in his description of Penwhapple Burn on p. 606 he states that the "Cascade Beds of the Ardwell group contain a variety of lithologies including dark shales and mudstones, striped with lines of carbonaceous matter and containing frequent bands and nodules of cementstones ... [and]... in mineralogical aspect the beds remind us of those found on the margins of Ardwell Bay, at the summit of the Ardwell Group; and their identity is placed beyond question by the fact that they contain all the peculiar fossils of that especial locality, viz.:- Dicellograptus forchhammeri, ...". Ingham has pointed out this clear contradiction to the writer and considers the dark graptolitic mudstone to belong undoubtably to the top of the Ardwell Group. He records only D. forchhammeri (Geinitz 1852) s.l. and Orthograptus? pauperatus Elles & Wood 1907 but Lapworth (1882, p. 606) lists several more species including 'Climacograptus' caudatus Lapworth 1876, Dicranograptus ramosus (Hall 1847) and 'Lasiograptus' (now Neurograptus) margaritatus Lapworth 1876, clearly indicating the D. clingani Zone.

On the foreshore the Lower Whitehouse Group commences with a basal calcareous flysch which is non-graptolitic but yields trilobite fragments including representatives of the Tretaspis ceriodes (Angelin) species group. This indicates a late Caradoc (late Actonian or Onnian age). It is followed by an unfossiliferous finely laminated sandstone flysch ('ribbon rock'). The succeeding lithological unit



TEXT-FIGURE 11. Geological map of Myoch Bay near Girvan by J.K. Ingham (MS). Loc. A = M1 and Loc. B = M2 of this thesis.

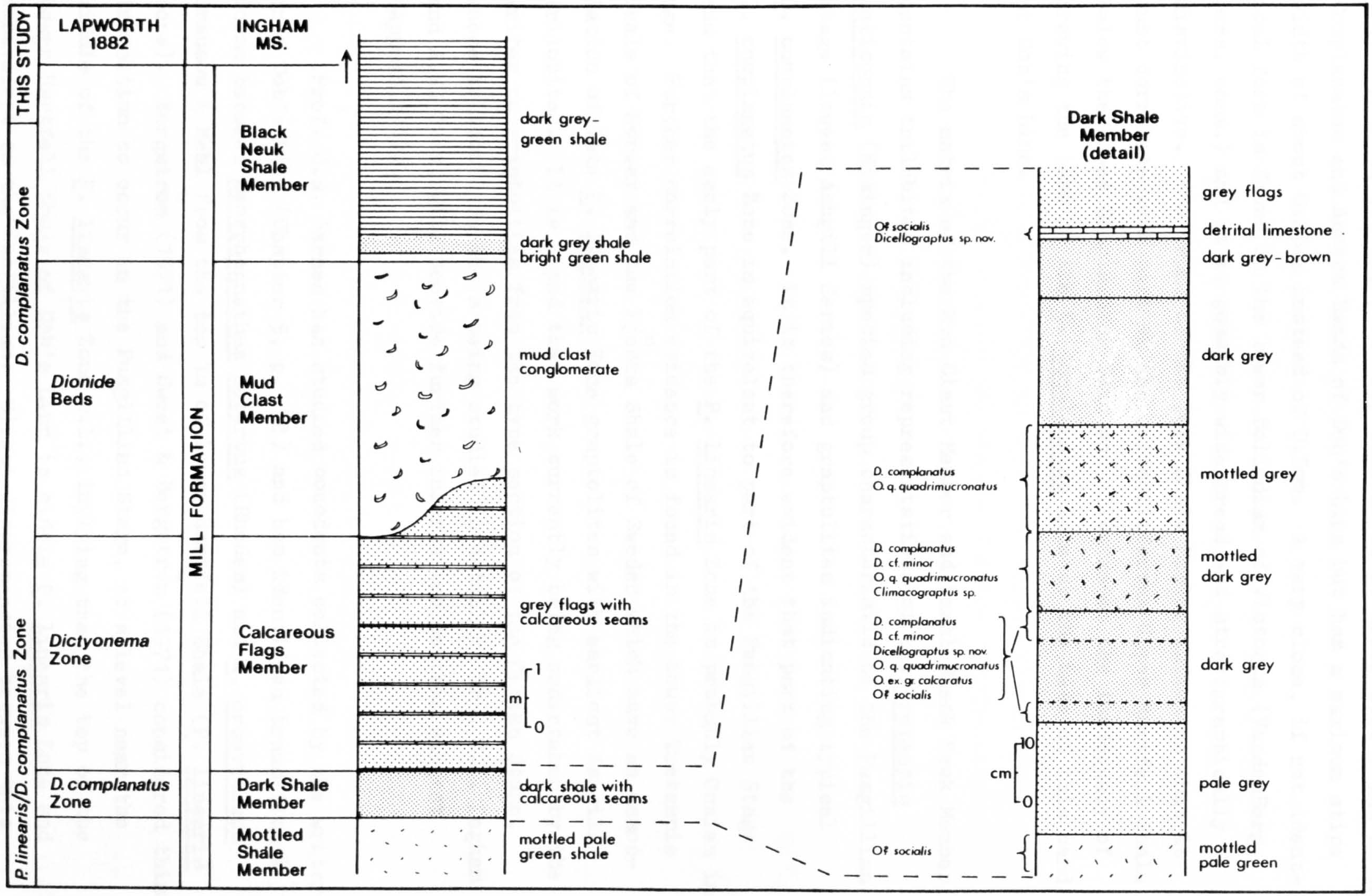
is not seen on the foreshore due to a structural gap. The maximum thickness of this unit is seen in Penwhapple Burn where there is about 90m of predominantly striped grey graptolitic mudstone containing a middle to late P. linearis Zone fauna including Pleurograptus l. linearis (Carruthers 1858) and Orthograptus q. quadrimucronatus (Hall 1865). Although not seen on the foreshore parts of it are exposed in Myoch Burn adjacent to Myoch Bay. The D. clingani/P. linearis zonal boundary must therefore lie somewhere within the non-graptolitic succession in the lower part of the Lower Whitehouse Group and probably equates somewhere within the Onnian Stage of the Caradoc Series.

The lowest formation of the Upper Whitehouse Group is the Myoch Formation (Ingham MS) which consists of largely red and green mudstones and a variety of coarser grained lithologies. It is non-graptolitic but yields cyclopygacean trilobites, etc. but of mostly one family. One high horizon in Penwhapple Burn has yielded a distinctive late Caradoc trilobite species. It is overlain by the Mill Formation which is divided into the Mottled Shale, Dark Shale, Calcareous Flags, Mud Clast and Black Neuk Shale Members (text-figs. 11, 12). The Mottled Shale and Black Neuk Shale Members yield cyclopygacean trilobites while the Dark Shale Member contains a relatively rich graptolite fauna including:

Dicellograptus complanatus Lapworth 1880
D. cf. minor Toghill 1970
Dicellograptus sp. nov.
Climacograptus sp. indet.
Orthograptus q. quadrimucronatus (Hall 1865)
O. ex gr. calcaratus
O? socialis (Lapworth 1880)
G? cf. occidentalis Ruedemann 1947

This assemblage contains characteristic elements of both the P. linearis and D. complanatus zones as recognised at Dob's Linn and it is considered that this horizon must lie close to the zonal boundary. If the distinctive zone fossil D. complanatus is taken to be restricted to its own zone the Dark Shale Member must be considered as early D. complanatus Zone. Although O. q. quadrimucronatus is taken as characteristic of earlier zones and does not range above the top of the Lower Hartfell Shale at Dob's Linn it is known to occur in equivalents of the early D. complanatus Zone elsewhere (e.g. the lower

TEXT-FIGURE 12. Stratigraphy of the Mill Formation (Upper Whitehouse Group) at Myoch Bay, south of Girvan. Detail of Dark Shale Member at Loc. M2 (see text-fig. 11) showing graptolitic faunas.


THIS STUDY
LAPWORTH 1882
INGHAM MS.
D. complanatus Zone
P. linearis/D. complanatus Zone
Dionide Beds
Dictyonema Zone
D. complanatus Zone
MILL FORMATION
Black Neuk Shale Member
Mud Clast Member
Calcareous Flags Member
Dark Shale Member
Mottled Shale Member
dark grey-green shale
dark grey shale
bright green shale
mud clast conglomerate
grey flags with calcareous seams
m
1
0
dark shale with calcareous seams
mottled pale green shale
Dark Shale Member (detail)
O? socialis
Dicellograptus sp. nov.
D. complanatus
O. q. quadrimucronatus
D. complanatus
D. cf. minor
O. q. quadrimucronatus
Climacograptus sp.
D. complanatus
D. cf. minor
Dicellograptus sp. nov.
O. q. quadrimucronatus
O. ex. gr. calcaratus
O? socialis
O? socialis
cm
10
0
grey flags
detrital limestone
dark grey-brown
dark grey
mottled grey
mottled dark grey
dark grey
pale grey
mottled pale green

Bolindian of Victoria, Australia, VandenBerg, pers. comm.). The form Dicellograptus cf. minor is very similar to D. minor s.s. found in the Complanatus and Anceps Bands of Dob's Linn but has a maximum stipe width of about 0.25mm instead of 0.5mm. A very close, if not identical form is found in the lower Bolindian of Victoria (VandenBerg, pers. comm.) and it is possibly widespread and stratigraphically distinctive. The fauna of the Dark Shale Member indicates that it must correlate with part of the unfossiliferous Upper Hartfell Shale below the lower Complanatus Band and illustrates the inadequacy of drawing the base of the D. complanatus Zone at the base of this band at Dob's Linn.

The matrix of the Mud Clast Member and basal Black Neuk Member contains trilobites including representatives of the Tretaspis seticornis (Hisinger) species group characteristic of the Pusgillian Stage (lowest Ashgill Series) and graptolites indicating typical D. complanatus Zone. It is therefore evident that part of the D. complanatus Zone is equivalent to part of the Pusgillian Stage and that the early part of the P. linearis Zone is probably Onnian in age. Further correlation evidence is found in the Lower Tretaspis Shale of Norway and the Fjäcka Shale of Sweden which have an association of late P. linearis Zone graptolites with earliest Ashgill trilobites. It is hoped that work currently being undertaken by the writer on graptolites from the type section of the Onnian Stage, whose trilobite fauna is being studied in detail by Drs. J.K. Ingham and A.W. Owen, will provide further information on this subject (Appendix 1).

Prof. C.R. Barnes has studied conodonts collected by the writer from Dob's Linn (Chapter 5, p. 52) and has identified transitional forms between Amorphognathus superbus (Rhodes) and A. ordovicicus Branson & Mehl from the top 1m of Lower Hartfell Shale (P. linearis Zone). Bergström (1971) and Sweet & Bergström (1971) considered this transition to occur in the Pusgillian Stage, at a level near the middle of the P. linearis Zone s.l., implying that the top of the Lower Hartfell Shale at Dob's Linn is middle P. linearis Zone and equivalent to the Pusgillian. Slight discrepancies between this correlation and that using trilobites is most likely to be due to innacurate usage of the P. linearis Zone which is accurately defined in this thesis for the first time.

The Upper Whitehouse Group is terminated abruptly by the widespread deposition of a basal unfossiliferous grey mudstone member defining the base of the overlying Shalloch Formation. The first fossiliferous horizons of the Shalloch Formation consist of detrital limestones some 9m above the base which yield D. complanatus Zone graptolites. Late Pusgillian or early Cautleyan trilobites occur in similar detrital limestones at a somewhat higher level. Dicellograptus anceps (Nicholson 1867a) is found at about 180m above the base of the formation.

The Shalloch Formation is overlain, probably conformably, by the Lower Drummuck Group in the Craighead Inlier which contains a middle to late Cautleyan shelly fauna towards its base. This implies that the base of the D. anceps Zone in the Shalloch Formation is equivalent to pre-middle Cautleyan. No further fossiliferous horizons are encountered until almost the top of the Upper Drummuck Group which yields a rich middle to late Rawtheyan shelly fauna with abundant Orthograptus? abbreviatus Elles & Wood 1907. Lapworth (1882) also recorded D. anceps from this horizon but this record has not been substantiated. The fauna indicates that the D. anceps Zone is still present and shows it to extend at least into beds of late Rawtheyan age. Because of their evidently high position in the D. anceps Zone the Anceps Bands of Dob's Linn almost certainly fall within the Rawtheyan Stage of the standard Ashgill classification.

The Upper Drummuck Group is overlain by the High Mains Sandstone which contains a rich Hirnantian shelly fauna with some American affinities (it lacks the trilobite genus Mucronaspis typical of Hirnantian faunas elsewhere). The Ashgill succession is terminated by a basal Silurian unconformity. In the Craighead Inlier the basal Mulloch Hill Conglomerate (= the Ladyburn Conglomerate of Cocks & Toghill 1973) overlies the High Mains Sandstone but a pronounced southerly overstep results in its laterally equivalent Craigskelly Conglomerate lying directly on the Shalloch Formation in the Girvan foreshore area. Cocks & Toghill (1973) recorded that the lowest fossiliferous horizons of the Mulloch Hill Formation belonged to the late Rhuddanian Stage of the Llandovery Series. The earliest graptolites occur in the overlying Glenwells Shale and indicate late C. cyphus Zone, demonstrating the existence of yet another major hiatus at the Ordovician/Silurian boundary.

Chapter 4. Comparison of the Scottish succession with others throughout the world.

4.1 Summary of recent international work on the top Ordovician and basal Silurian. Lapworth's and Elles & Wood's British Upper Ordovician and basal Silurian graptolite zones have remained unchanged except for the addition of the G. persculptus Zone by O.T. Jones (1909) which he recognised as a clearly distinguishable part of the O? acuminatus Zone sensu Elles & Wood in the Welsh succession, and the C? extraordinarius Zone by Rickards (1979). In this thesis it is shown that the D. anceps Zone is divisible into the D. complexus and P. pacificus subzones at Dob's Linn (p. 16) and suggested that upper and lower faunal assemblages may be recognised for the D. clingani, P. linearis and O? acuminatus zones (Chapter 2). Davies (1929) added to Elles & Wood's descriptions of the fauna of the Anceps Bands at Dob's Linn and described an apparent stratigraphical change in the position of the base of the median septum of G. persculptus and recognised the variation found in this species. Toghill (1970) gave brief faunal descriptions of the top Lower Hartfell and Upper Hartfell Shale and showed that P. l. linearis is restricted to the top of the P. linearis Zone as seen at Dob's Linn. He also published two papers (1968a, b) on the stratigraphical ranges of Birkhill Shale species.

During the past decade a new awareness of the stratigraphical importance of late Ordovician graptolites has been awakened in many countries. In North America Riva (1974a, b, c, 1976) produced a series of papers with thorough systematic descriptions of stratigraphically important American species and gave several correlation charts for the North American and British Upper Ordovician successions. Walters (1977) gave detailed collected sections and systematic descriptions of the graptolite fauna from the late Ordovician near Quebec and another correlation chart for North America and Britain. Carter & Churkin (1977) described detailed collections for the Phi Kappa Formation of Idaho and gave a world correlation chart for the whole of the Ordovician. Finney (1977) produced a major work on the graptolite fauna of the Athens Shale with highly detailed systematic descriptions utilising three-dimensional and flattened material and producing several range charts; it is however entirely restricted to the equivalent of the G. teretiusculus and N. gracilis zones of Britain and is of little relevance to this work.

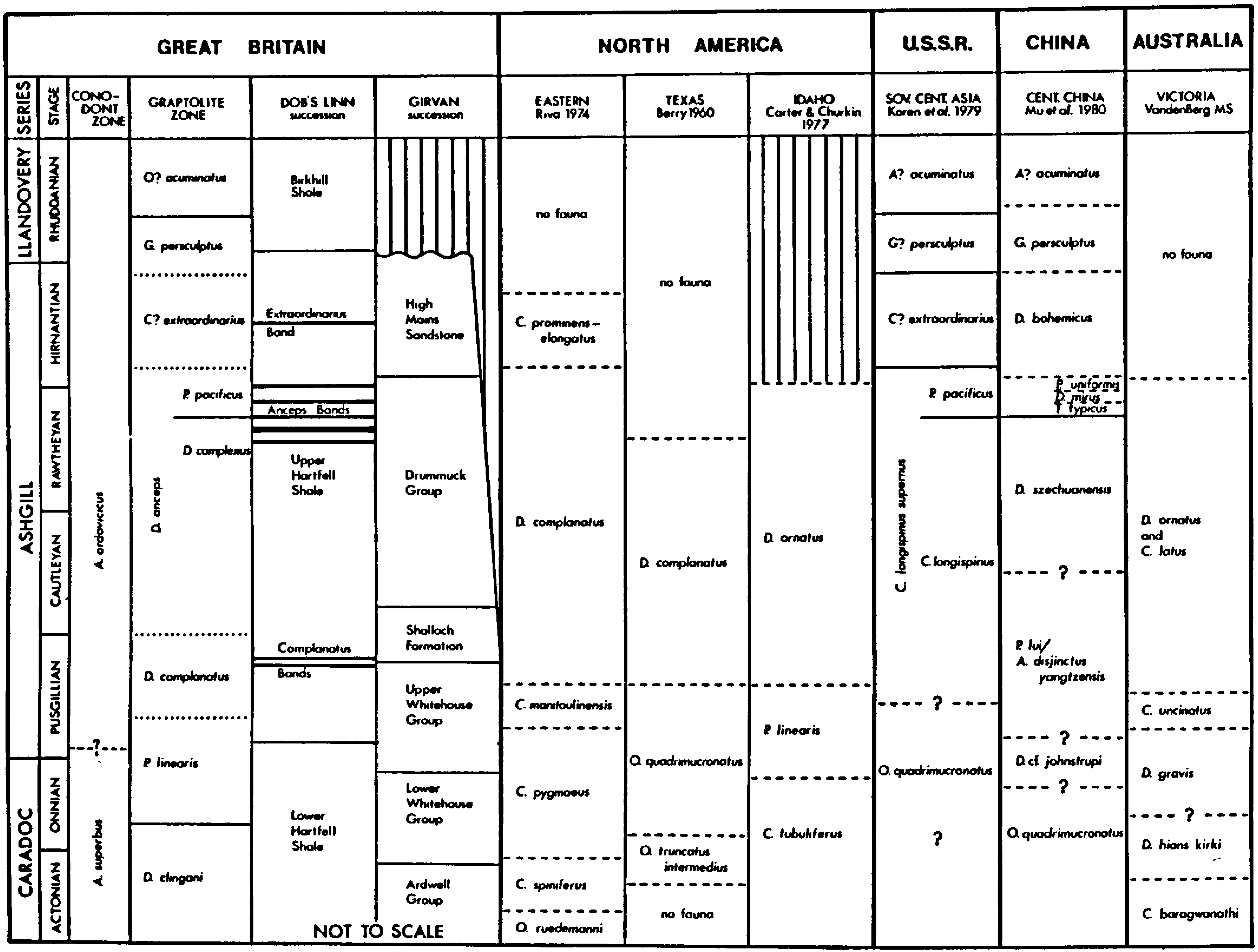
A great deal of research on the Upper Ordovician and basal Silurian has recently been carried out in Soviet Central Asia by Koren' and others; the stratigraphy is summarised in Koren' *et al.* (1979) while many species are systematically described in Koren' *et al.* (1980). Mu and others similarly have been involved in extensive collecting from the Ordovician and Silurian of south and central China and a series of monographs have been published (e.g. Wang *et al.* 1974, 1977, 1978). The Upper Ordovician stratigraphy is summarised in Mu *et al.* (1980) although Mu gives additional information and includes descriptions of the basal Silurian in his unpublished Report No. 43 of the Ordovician/Silurian Boundary Working Group of the I.U.G.S. Much work on the Upper Ordovician of Australia was carried out in the first half of this century and was summarised by Thomas (1960). VandenBerg is currently studying the Upper Ordovician of Victoria and his results currently await publication. His conclusions, summarised in the next section, are taken both from an unpublished manuscript and from detailed correspondence with the writer.

4.2 Discussion of international correlation chart (text-fig. 13).

The following section deals with the pertinent points used in constructing each column of the correlation chart, except for the correlation of the Dob's Linn and Girvan successions with the British graptolitic and shelly zonations which are discussed in the relevant sections of Chapters 2 and 3.3. Only the problems relevant to graptolite zonations of other countries are referred to here. To keep the account concise full generic names and authors of species will be omitted except in faunal listings and where they are not mentioned elsewhere in this thesis.

4.2.1 Conodont zonation. The conodont zone of *Amorphognathus ordovicicus* is indicated at Dob's Linn by platform elements of the zone fossil in association with simple cone conodonts in the Anceps and Complanatus Bands (p. 53). Conodonts are present in the basal Birkhill Shale but are rare and the writer has been unable to find a reference to a basal Silurian conodont zone approximately equivalent to the *G. persculptus* and *O? acuminatus* zones, although Prof. C.R. Barnes is currently studying conodonts from such horizons on Anticosti Island near Quebec (pers. comm.). The base of the *A. ordovicicus* Zone is normally assumed to correlate with middle *P. linearis* Zone (e.g. Bergström 1978) although Orchard (1980) implied that it

TEXT-FIGURE 13. International correlation chart.
Dotted lines for the British graptolite zonation indicate uncertain horizons for the zonal boundaries at Dob's Linn. Dashed lines for the other columns indicate uncertain correlation with the British zonation.


GREAT BRITAIN
NORTH AMERICA
U.S.S.R.
CHINA
AUSTRALIA
SERIES
STAGE
CONO-DONT ZONE
GRAPTOLITE ZONE
DOB'S LINN succession
GIRVAN succession
EASTERN Riva 1974
TEXAS Berry 1960
IDAHO Carter & Churkin 1977
SOV. CENT. ASIA Koren et al. 1979
CENT. CHINA Mu et al. 1980
VICTORIA VandenBerg MS
LLANDOVERY
ASHGILL
CARADOC
RHUDDANIAN
HIRNANTIAN
RAWTHEYAN
CAUTLEYAN
PUSGILLIAN
ONNIAN
ACTONIAN
A. ordovicicus
A. superbus
O? acuminatus
G. persculptus
C? extraordinarius
P. pacificus
D. complexus
D. anceps
D. complanatus
P. linearis
D. clingani
Birkhill Shale
Extraordinarius Band
Anceps Bands
Upper Hartfell Shale
Complanatus Bands
Lower Hartfell Shale
High Mains Sandstone
Drummuck Group
Shalloch Formation
Upper Whitehouse Group
Lower Whitehouse Group
Ardwell Group
NOT TO SCALE
no fauna
C. prommens-elongatus
D. complanatus
C. manitoulinensis
C. pygmaeus
C. spiniferus
O. ruedemanni
no fauna
D. complanatus
O. quadrimucronatus
O. truncatus intermedius
no fauna
D. ornatus
P. linearis
C. tubuliferus
A? acuminatus
G? persculptus
C? extraordinarius
P. pacificus
C. longispinus supermus
C. longispinus
?
O. quadrimucronatus
?
A? acuminatus
G. persculptus
D. bohemicus
P. uniformis
D. mirus
T. typicus
D. szechuanensis
?
P. lui/
A. disjinctus yangtzensis
?
D. cf. johnstrupi
?
O. quadrimucronatus
no fauna
D. ornatus and C. latus
C. uncinatus
D. gravis
?
D. hians kirki
C. baragwanathi

extends only into early D. anceps Zone but offers little supporting evidence. Discussion with Dr. M.J. Orchard and Prof. C.R. Barnes revealed that it is more likely that the A. ordovicicus Zone does extend down into the P. linearis Zone. Bergström (1978, p. 739) records A. ordovicicus from no higher than the O. truncatus intermedius Zone of Berry (1960) although Riva (1974a, table 1) considered Berry's zone to be equivalent to part of his C. spiniferus Zone; the faunal assemblages given by Berry uphold this correlation when compared with the succession at Dob's Linn. This means that either the conodont zone fossil A. ordovicicus ranges into the earlier A. superbus Zone or that the boundary between the two zones should be lowered to an horizon equivalent to late D. clingani Zone. However, Prof. Barnes has studied the conodonts collected by the writer from the Lower Hartfell Shale of Dob's Linn and concludes that while forms from the late D. clingani Zone are stratigraphically inconclusive, those from the top 1m of Lower Hartfell Shale are intermediate between A. ordovicicus and A. superbus and correlate with the forms described as middle late P. linearis Zone sensu Bergström (1971, 1978) and Sweet & Bergström (1971). It is therefore concluded that the conodont zonal boundary occurs just below the top of the Lower Hartfell Shale, at an horizon probably equivalent to the middle of the P. linearis Zone s.s.

It is clear that unless further refinement of the top Ordovician and basal Silurian conodont ranges can be achieved they are of little stratigraphical use in comparison with the graptolites and macro-shelly faunas. Barnes (pers. comm.) is however confident that his work on Anticosti Island will demonstrate an even more accurate stratigraphical scheme than the graptolite zonation.

4.2.2 Eastern North America. Although Riva (1974a) did not describe any collected sections with detailed range charts he gave detailed descriptions of the criteria he had used to differentiate his zones which were based on collections from New York State and eastern Canada. The lowest zone relevant to this thesis is the O. ruedemanni Zone which he separates from the preceeding C. americanus Zone by the absence of Corynoides. It is characterised by the presence of only a few species including Orthograptus ruedemanni (Gurley) and C. mohawkensis with rare specimens of N. margaritatus . The following C. spiniferus Zone contains Dicranograptus ramosus (Hall 1847), D. nicholsoni cf. minor Bulman 1945, 'C.' caudatus and C. spiniferus.

The presence of Dicranograptus implies a correlation with the earlier part of the D. clingani Zone, although this genus does seem to range somewhat later outside Britain. The early part of the succeeding C. pygmaeus Zone contains C. spiniferus and D. nicholsoni cf. minor but these disappear half way through the zone. Although not recorded from the previous two zones Corynoides makes its final appearance; typical O. quadrimucronatus first appears in this zone although varieties of this species occur earlier. The disappearance of C. spiniferus appears to be a relatively synchronous worldwide event while Dicranograptus seems to occur later in both North America and Australia than in Scotland. The base of the C. pygmaeus Zone therefore approximates with the latest horizons containing Dicranograptus at Dob's Linn and continues until towards the middle or top of the P. linearis Zone if Ruedemann's (1908, 1947) record of P. linearis in the Upper Utica Shale is correct.

The following C. manitoulinensis Zone contains an impoverished fauna with no stratigraphically important elements in common with Scotland. O. quadrimucronatus has its last appearance in this zone while C. miserablis is first seen. The boundary with the next D. complanatus Zone is marked by the appearance of O? abbreviatus, O? socialis and D. complanatus and also includes 'transients to D. anceps' and C. miserablis. Although the base of the D. complanatus Zone sensu Riva is probably fairly close to the base of the British D. complanatus Zone the early graptolitic portion is followed by a long interval with only rare graptolites. Riva states that the succeeding C. prominens-elongatus Zone, which has an extensive shelly fauna but only rare graptolites including Climacograptus prominens-elongatus (Barrass), O? abbreviatus and Glyptograptus sp., may correlate with the Dalmanitina Beds (Tömmarp Stage) of Scania and the "barren interval between the D. anceps and G. persculptus Zone of the Moffat region". Without further graptolitic evidence this correlation with the C? extraordinarius Zone remains tentative.

4.2.3 Texas. Berry (1960) gave faunal lists for each of his graptolite zones of Marathon, Texas although only the top three zones are relevant to this study. The O. truncatus intermedius Zone follows an unfossiliferous interval and contains a diverse fauna including:

Dicranograptus nicholsoni Hopkinson 1870

D. nicholsoni geniculatus Ruedemann & Decker 1934 (cont. over)

Dicellograptus forchhammeri flexuosus Lapworth 1876
Climacograptus spiniferus Ruedemann 1912
'*C.*' *caudatus* Lapworth 1876
Orthograptus quadrimucronatus vars.
O? '*truncatus*' *intermedius* Elles & Wood 1907

These species indicate a middle to late *D. clingani* Zone fauna, although the evidence given by conodonts from this horizon does not appear to agree (p. 53).

The next zone is that of *O. quadrimucronatus* which also contains a rich fauna including:

Dicellograptus forchhammeri (Geinitz 1852)?
D. pumilis Lapworth 1876
Climacograptus '*minimus*' (=*mohawkensis*)
'*C.*' *caudatus* Lapworth 1876
C. tubuliferus Lapworth 1876
Orthograptus q. quadrimucronatus (Hall 1865)

This indicates an interval corresponding from at least top *D. clingani* to middle *P. linearis* zone.

The succeeding *D. complanatus* Zone only contains species typical of the *D. complanatus* and *D. anceps* zones of Britain and it is likely that the *O. quadrimucronatus* Zone extends to a stratigraphical level equivalent to part of the *D. complanatus* Zone of Britain. Berry's *D. complanatus* Zone includes specimens of:

Dicellograptus complanatus Lapworth 1880
D. '*complanatus*' *ornatus* Elles & Wood 1904
Climacograptus hastatus Hall 1902
C. miserablis Elles & Wood 1906?
Orthograptus? *socialis* (Lapworth 1880)

This clearly equates with parts of the *D. complanatus* and *D. anceps* zones of Britain although the upper limit may not be deduced as *D. ornatus* appears to have a longer range in both North America and Australia than at Dob's Linn, where it is restricted to the *P. pacificus* Subzone.

4.2.4 Idaho. Carter & Churkin (1977) made detailed collections from the Phi Kappa Formation in the Trail Creek section of Idaho which extends in an apparently unbroken succession from the *Didymograptus protobifidus* Zone of the middle Arenig to the top Ordovician.

Unfortunately the boundary between the top Ordovician and Silurian has been faulted and locally thermally metamorphosed and the earliest Silurian exposed belongs to the M. convolutus Zone. The C. tubuliferus Zone follows a sparsely fossiliferous interval; it contains the latest Dicranograptus, a few Dicellograptus and several diplograptids including:

Climacograptus tubuliferus Lapworth 1876
'C.' caudatus Lapworth 1876
Orthograptus q. quadrimucronatus (Hall 1865)
O? pauperatus Elles & Wood 1907

This fauna suggests an interval correlating with late D. clingani to P. linearis zone. The overlying P. linearis Zone (sensu Carter & Churkin) includes:

Pleurograptus linearis (Carruthers 1858)
Climacograptus tubuliferus Lapworth 1876
C. cf. mohawkensis (Ruedemann 1912)
C? uncinatus Keble & Harris 1934

P. linearis occurs at only one horizon in the middle of the zone which may correlate with the top Lower Hartfell Shale at Dob's Linn. The total range of the zone must correlate with the British (middle?) P. linearis to middle D. complanatus zones. C? uncinatus is a very distinctive Australian species with long spines produced at a mid-point along the rhabdosome in a similar fashion to O. quadrimucronatus spinigerus. VandenBerg uses C. uncinatus as a zone fossil for the Victorian succession and this permits accurate correlation at this horizon between the Victoria and Idaho successions. The highest Ordovician recorded by Carter & Churkin belongs to the D. ornatus Zone. The lower part is characterised by Dicellograptus cf. minor, C. longispinus hvalross and C. hastatus and clearly correlates with latest D. complanatus or early D. anceps zone of Britain, while the upper part contains D. ornatus, O? abbreviatus and P. pacificus and must equate with part of the P. pacificus Subzone of Dob's Linn.

4.2.5 Russia. Koren' et al. (1979) gave a summary of the Upper Ordovician to basal Silurian graptolite biostratigraphy in the Central Asian part of the U.S.S.R. with detailed range charts for the C. longispinus supernus to 'A.' acuminatus zones. The O. quadrimucronatus Zone contains D. pumilis, C. styloideus and O. q. quadrimucronatus; although this assemblage is insufficient to allow certain correlation with the British zonation this zone probably equates at least in part with the P. linearis Zone. It is followed by the C. longispinus supernus Zone which is divided into a lower C. longispinus and upper P. pacificus subzone. The C. longispinus Subzone contains:

Dicellograptus complanatus Lapworth 1880
D. aff. complanatus
Climacograptus l. longispinus Hall 1902
C. longispinus supernus Elles & Wood 1906
C. ex gr. longispinus
C. hastatus Hall 1902
Orthograptus? ex gr. amplexicaulis (Hall 1847)

This indicates an interval approximately equivalent to the British D. complanatus and lower D. anceps zone although the exact correlation is uncertain. It is succeeded by the P. pacificus Subzone which contains a diverse fauna including:

Dicellograptus ornatus Elles & Wood 1904
Climacograptus longispinus supernus Elles & Wood 1906
C. hastatus Hall 1902
C. normalis Lapworth 1877
'Pacificograptus' pacificus subspp.
Plegmatograptus? 'nebula' lautus Koren'& Tzai 1980

These species indicate that the subzone is equivalent to the P. pacificus Subzone of Dob's Linn. It is followed by the C? extraordinarius Zone which yields only C? extraordinarius, C. normalis, C. angustus (=C. miserablis?) and Glyptograptus sp. in the lower part and only C. normalis and C. angustus with rare Glyptograptus spp. in the upper part. This zone correlates with the C? extraordinarius Zone of Dob's Linn where the Extraordinarius Band probably lies in the lower part of the zone. In Russia associated shelly faunas show that the C? extraordinarius Zone lies entirely within the Hirnantian Stage of Britain and that this stage also encompasses portions of the P. pacificus Subzone and G. persculptus Zone. The transition into the following G'?' persculptus Zone appears diffuse and seems to rely solely on the common occurrence of G. persculptus s.l. The succeeding 'A?' acuminatus Zone is defined by the first appearance of Akidograptus and a variety of Russian diplograptids not yet recognised in Britain. It seems that the first appearance of A. ascensus is an almost synchronous cosmopolitan event and that the base of the (O?) acuminatus Zones of Britain and Russia, which are both defined by the first appearance of Akidograptus, are equivalent.

4.2.6 China. Several papers giving the zonal scheme for the top Ordovician and basal Silurian of China have been published including a summary in English by Mu et al. (1980). The most detailed report in English is however given by Mu in Report No. 43 of the Ordovician/Silurian Boundary Working Group of the I.U.G.S., although this only gives faunal lists for the D. bohemicus and G. persculptus zones. Faunal lists for the three earliest late Ordovician zones of O. quadrimucronatus, D. cf. johnstrupi and P. lui/A. disjinctus yangtzensis have not been seen by the writer and their correlation is rather tentative. Wang et al. (1978) and other regional handbooks record the D. szechuanensis Zone as including D. szechuanensis (=D. complexus), C. longispinus supernus and O? abbreviatus and the top is almost certainly equivalent to the top of the D. complexus Subzone at Dob's Linn. The following three zones of Tangyagraptus typicus, Diceràtograptus mirus and Paraorthograptus uniformis seem to differ only by the occurrence of each zonal species, although the first two apparently belong to rather strange endemic Chinese dicranograptid genera. The three zones are considered here to merit only subzonal status. All three contain Paraorthograptus spp. (=P. pacificus of this thesis) and probably equate with most of the P. pacificus Subzone of Dob's Linn. Mu (unpubl. report) records the top Ordovician graptolite zone of Diplograptus bohemicus to contain:

Dicellograptus spp.
Climacograptus longispinus supernus Elles & Wood 1906
Glyptograptus spp.
Diplograptus bohemicus (Marek 1955)
D. orientalis Wang et al. 1974 (?=C? extraordinarius)
Paraorthograptus sp.
'Paraplegmatograptus' sp.

Mu (pers. comm.) considers D. orientalis to be close to or even conspecific with C? extraordinarius. If this is correct the faunal assemblage listed above is very similar to that of Anceps Band E at Dob's Linn and it seems likely that the D. bohemicus Zone of China correlates with the late P. pacificus Subzone and much of the C? extraordinarius Zone of Scotland. It is succeeded by the G. persculptus Zone which contains:

Climacograptus cf. normalis Lapworth 1877
C. miserablis Elles & Wood 1906
Glyptograptus persculptus (Salter 1865)
Akidograptus ascensus Davies 1929

The firm assertion of Mu (unpubl. report) to include the first occurrence of A. ascensus within his G. persculptus Zone differs from the ideas of Koren' and fellow Soviet workers, the writer, and most other workers. Mu combines the first occurrence of Akidograptus with the fact that monograptids first appear in the G. persculptus Zone, both in Britain (A. ceryx) and China (Rickards, pers. comm.), to argue that the G. persculptus Zone should be assigned to the basal Silurian. He also considers that the break between the Chinese 'Hirnantia' and Silurian 'Protatrypa' shelly assemblages occurs at the same horizon as the boundary between the D. bohemicus and G. persculptus zones.

4.2.7 Australia. VandenBerg (pers. comm., unpubl. MS) has given the writer a detailed account of the Upper Ordovician graptolite succession in Victoria from the Gisbornian to Bolindian. The Gisbornian is rather earlier than the stratigraphical unit studied for this thesis. The following Eastonian is divided into four graptolite zones; the earliest is the C. spiniferus lanceolatus Zone which is followed by the C. baragwanathi Zone. The fauna of the latter zone includes:

Dicranograptus nicholsoni Hopkinson 1870
D. ramosus (Hall 1847)
Climacograptus spiniferus Ruedemann 1912
'C.' caudatus Lapworth 1876
Orthograptus quadrimucronatus (Hall 1865) s.l.
Neurograptus margaritatus (Lapworth 1876)

This assemblage suggests a correlation with part of the D. clingani Zone. The succeeding D. hians kirki Zone is marked by the disappearance of Dicranograptus, except for the zone fossil, N. margaritatus and 'C.' caudatus while it contains C. tubuliferus and C. spiniferus throughout. It appears to correlate broadly with the late D. clingani and earliest P. linearis Zone, implying that C. tubuliferus must appear rather earlier and that C. spiniferus continues slightly later than they do in Britain. The D. hians kirki Zone is followed by the final Eastonian zone of D. gravis which appears to correlate broadly with the remainder of the P. linearis Zone. The lowest Bolindian zone is that of C. uncinatus. This is characterised by its distinctive zone fossil and also includes:

Dicellograptus morrisi Hopkinson 1871
Climacograptus l. longispinus Hall 1902
C. hastatus Hall 1902
C. tubuliferus Lapworth 1876

The *C. uncinatus* Zone evidently corresponds with part of the Idaho *P. linearis* Zone which also contains *C. uncinatus*, but the presence of *C. l. longispinus* and *C. hastatus* indicates a correlation with the *C. longispinus* Subzone of Russia. From this indirect evidence it is concluded that the *C. uncinatus* Zone of Victoria correlates with late *P. linearis* and at least part of the *D. complanatus* Zone of Britain. It may range as late as early *D. anceps* Zone but the presence of *C. tubuliferus* in both the *C. uncinatus* and (presumably part of) the following Australian zone implies a somewhat earlier boundary as the last recorded occurrence of *C. tubuliferus* in Britain is in the lower Complanatus Band at Dob's Linn. The final Upper Ordovician graptolite zone is that of *D. ornatus* and *C. latus*. This has not yet been refined to the same degree as top Ordovician zonal schemes in some other countries but contains all the characteristic species of the *D. complexus* and *P. pacificus* subzones of Dob's Linn, except *D. anceps*, including:

Dicellograptus complexus Davies 1929
D. ornatus Elles & Wood 1904
Climacograptus longispinus supernus Elles & Wood 1906
C. latus Elles & Wood 1906
Paraorthograptus pacificus (Ruedemann 1947)
Orthoretiograptus denticulatus Wang *et al.* 1977

The presence of both *C. tubuliferus* and *P. pacificus* indicates that the zone of *D. ornatus* and *C. latus* ranges from the (?late) *D. complanatus* Zone to *P. pacificus* Subzone of Dob's Linn. Unfortunately the upper part of the zone becomes progressively non-fossiliferous before any change into a *C? extraordinarius* Zone fauna, which means that the Victorian succession is of little help with the Ordovician/Silurian boundary problem.

4.3 Dob's Linn as a possible Ordovician/Silurian Boundary Stratotype.

The preceeding section demonstrates that the number of localities with suitable successions for an Ordovician/Silurian Boundary Stratotype is limited. The Ordovician/Silurian Boundary Working Group is currently debating this problem and a final decision is expected at the meeting in Moscow 1984. The three main topics to be decided are:

1. Which fossil group should be taken as stratigraphically definitive?
2. At which horizon should the boundary be placed?
3. Which area would provide the best stratotype?

A full discussion of all considerations is outside the scope of this thesis and only a summary of the relevant arguements is given here. Most members of the Working Group agree that graptolites hold considerable advantages over shelly faunas in having more cosmopolitan species and in being independant from benthic conditions and it is fairly certain that this phylum will be taken as the definitive one. The possible zonal boundaries which could be used for the Ordovician/Silurian boundary are the bases of the C? extraordinarius, G. persculptus and O? acuminatus zones. Although the clearest and most precisely correlatable change in graptolite fauna occurs at the base of the C? extraordinarius Zone, the successionsin Mirny Creek and other Soviet Central Asian localities show it to be entirely contained within the top Hirnantian Stage of the Ashgill Series and this zone is therefore considered to be Ordovician.

The base of the G. persculptus Zone has commonly been taken as the Ordovician/Silurian boundary in the past and this level has been taken as synonymous with the base of the Birkhill Shale at Dob's Linn (Cocks et al. 1970). Similar incorrect mixing of biostratigraphy and lithostratigraphy has been demonstrated to be inadequate for the P. linearis, D. complanatus and D. anceps zones (Chapters 2 and 3) and should be treated with great caution. The transition from the C? extraordinarius to G. persculptus zone is a poorly defined one with only a few changes at specific level of generically uncertain diplograptids. The earliest monograptid A. ceryx does however occur in the G. persculptus Zone (Rickards & Hutt 1970). The basal G? persculptus Zone of Russia contains an Hirnantian shelly fauna which indicates a top Ordovician age, although the G. persculptus Zone of China is recorded as occurring with an entirely Silurian shelly fauna.

The base of the O? acuminatus Zone in Britain and Russia is largely defined by the first appearance of Akidograptus although Mu (unpubl. report) includes this horizon within his G. persculptus Zone of China. This horizon appears to correlate accurately throughout the world; if it is taken as the Ordovician/Silurian bundary it has the disadvantage in being defined largely on the first appearance of a single species (A. ascensus). It would also require a change in the traditional placing of the boundary at the base of the G. persculptus Zone and would mean that the earliest monograptids were top Ordovician.

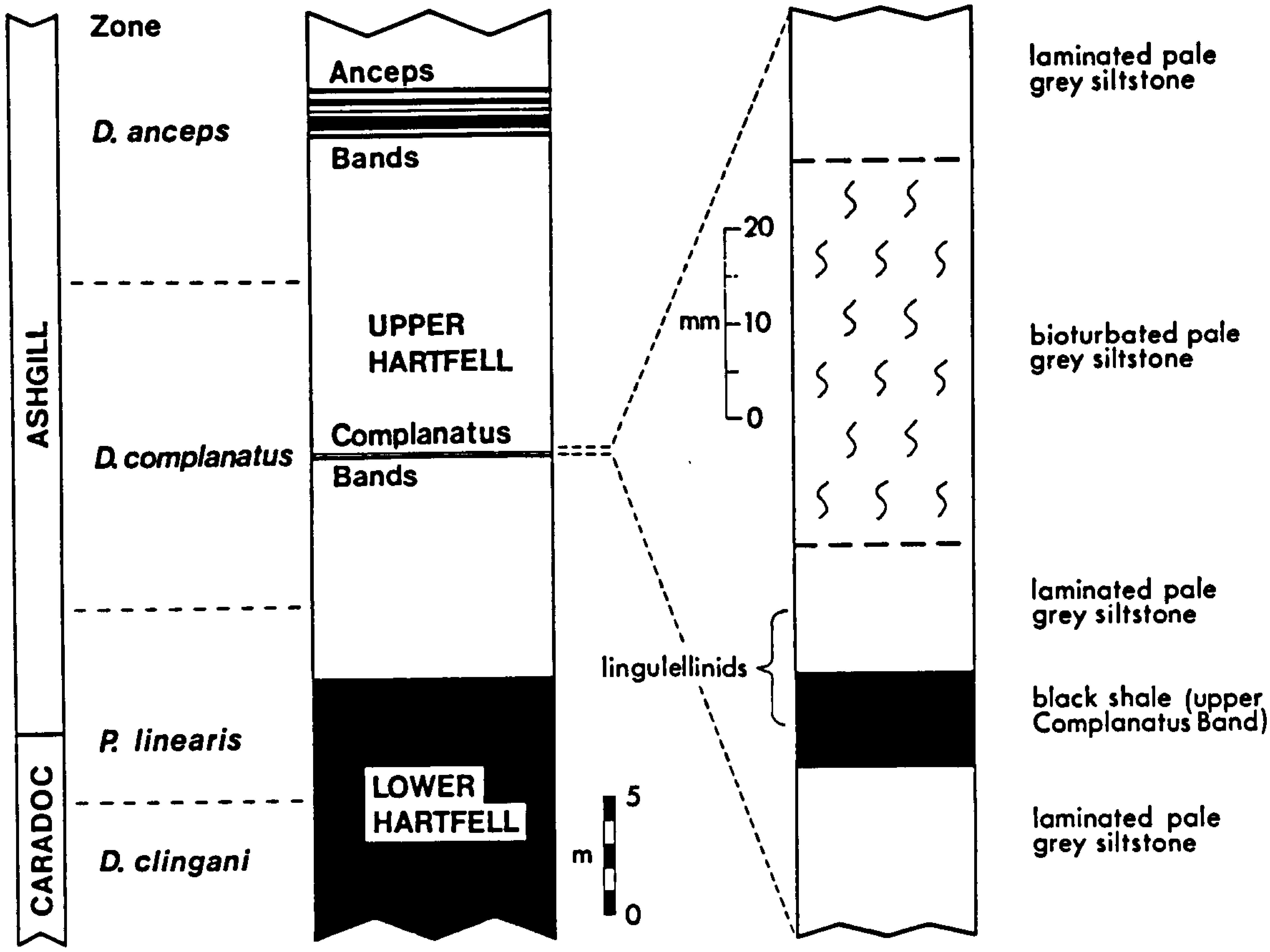
Only the advantages and disadvantages of Dob's Linn as a possible Ordovician/Silurian Boundary Stratotype will be discussed here owing to the complex variety of pros and cons being considered for each contender by the Boundary Working Group. The biggest advantage of Dob's Linn over several other localities is its physical and political accessibility. If the base of the O? acuminatus Zone is considered to be the best horizon for the Ordovician/Silurian boundary, Dob's Linn is a strong contender for the stratotype since it possesses a continuous graptolitic succession with an abundant and well preserved fauna. If the base of the G. persculptus Zone is considered to be the most appropriate position for the boundary the true base of this zone at Dob's Linn is probably in the unfossiliferous interval of Upper Hartfell Shale between the Extraordinarius Band and the base of the Birkhill Shale and no accurate position could be determined at this locality. However, few if any localities have a continuous graptolitic sequence at this level and Dob's Linn is probably not much more deficient in this respect than any other stratotype contender.

One argument against Dob's Linn as a stratotype is that it lacks a shelly fauna apart from a few rare and stratigraphically poorly understood forms, although it has now been shown (Chapter 5) to contain some stratigraphically useful conodonts. In the experience of the writer many localities with mixed shelly and graptolitic faunas tend to be less diverse in both faunas than at localities with only one type of fossil. When additional localities with representatives of both faunal components exist it seems permissible to elect a stratotype which possesses a good graptolitic fauna only. Dob's Linn is one of the few localities in the world to be given a potential Grade A rating by the Boundary Working Group; it is hoped that the work executed for this thesis will remove the possible arguement that the section has not been studied in sufficient detail to merit stratotype status.

Chapter 5. The non-graptolitic faunas of the Moffat Shale and their bearing on palaeoecology.

5.1 Introduction. Although the graptolites of Dob's Linn have been studied in detail by previous workers the remaining phyla from the Moffat Shale have rarely received more than a brief mention. Lapworth (1878, pp. 309, 313) recorded *Lingula*, *Siphonotreta micula*, *Discina*, *Acrotreta nicholsoni* and *Eurypterus*? sp. from the Lower Hartfell Shale. He also recorded *Dawsonia campanulata* and *Discinocaris* from the *C. vesiculosus* to *R. maximus* zones of the Birkhill Shale. Few other non-graptolitic fossils have since been listed; Lamont & Lindström (1957, pp. 65-66) recorded conodonts from the '?Glenkiln Shale' of the Main Cliff and recently Ingham & Trewin (pers. comm.) discovered an horizon just below the Extraordinarius Band at the top of the Upper Hartfell Shale which yields trilobite, bivalve and nautiloid fragments. The present work has revealed relatively common conodonts in the Anceps Bands including the top Ordovician zone fossil *Amorphognathus ordovicicus* and there are rare conodonts in both the Birkhill and Lower Hartfell Shale. One specimen of a scolecodont has been found in Anceps Band E. A narrow stratum in the pale grey mudstones just above the upper Complanatus Band has yielded common well preserved specimens of a new genus of inarticulate brachiopod here described as *Barbatulella lacunosa* gen. *et* sp. nov. Williams & Lockley. *Dawsonia campanulata* is common in the *O*? *acuminatus* Zone of the Birkhill Shale; it is here considered to be of algal affinity. Many unusual filamentous structures occurring in the Upper Hartfell and Birkhill Shale are presumed to be of algal origin although no fine structure is present.

5.2 Inarticulate brachiopods. Inarticulate brachiopods occur sporadically throughout the black shale at Dob's Linn but are usually found as poorly preserved organic films and are of indeterminate affinity. They are however common in the top half of, and just above, the upper Complanatus Band in the Linn Branch and are reasonably well preserved when found in the overlying pale grey mudstone. The stratum where they occur is finely laminated. Approximately 7mm above the last occurrence of the brachiopods a highly bioturbated unit is encountered; comparison with illustrations and descriptions in Byres (1979) who studied Devonian and Cretaceous enclosed basins in North America show the biogenic structures to compare closely with those



TEXT-FIGURE 14. Upper Ordovician stratigraphy of Dob's Linn showing detail of succession associated with the upper Complanatus Band.

characteristic of a dysaerobic environment (0.1-1.0ml O^2/litre sea water). Such an environment has sufficient oxygen to support a simple infauna such as polychaetes and aschelminths but not enough to sustain benthic shelly faunas.

It is therefore evident that although some of the pale grey mudstones and limestones of the Upper Hartfell Shale are bioturbated the interval containing the brachiopods just above the upper Complanatus Band is undisturbed. This suggests that they are unlikely to be in situ; they have been transported either from an environment where they were infaunal or from higher in the water column where during life they lived attached to the planktonic algae that are thought to have been present near the ocean surface. The only other pale grey mudstone horizon containing brachiopods is between Anceps Bands B and C; here they are fragmentary and of indeterminate affinity, occurring in a highly bioturbated unit with pyritised horizontal burrows. It is considered that these were also probably planktonic and were broken up by the infauna which produced the bioturbation.

The most distinctive feature of the inarticulate brachiopods associated with the upper Complanatus Band which prompted a detailed investigation with Prof. M.G. Lockley is a fine 'frill' around the commissure of some of the specimens. SEM examination reveals this to be a fine peripheral extension of the shell and also demonstrates the presence of internal pitting over the whole of the internal surface of the brachial valve and between two struts in the pedicle valve. One specimen collected by K.A. Davies, which almost certainly comes from the same horizon at Dob's Linn, also shows a proparea with closely spaced growth lines. These features indicate that the material belongs to a new lingulellinine genus and species which is here named Barbatulella lacunosa. The following systematic description and discussion is extracted from a manuscript prepared jointly with Prof. Lockley.

Class Inarticulata, Order Lingulida, Superfamily Lingulacea, Family Obolidae, Subfamily Lingulellinae, Genus Barbatulella nov.

Type species (by monotypy and original designation).
Barbatulella lacunosa gen. et sp. nov.

Diagnosis. Small elongately-oval, impunctate, thin shelled lingulellinine with well developed fine pitting concentrated in the posteromedian sectors of both valves and with spinose triangular projections forming a serrated commissure.

Barbatulella lacunosa gen. et sp. nov.
(pls. 2 - 4)

Derivation of name. From barbatullis (Latin) meaning with a slight beard and lacanosus (Latin) meaning full of hollows.

Proposed holotype. HM L14655a, b. Figd. Pl. 2 , figs. a-e. HM L14655b is preserved on an SEM stub.

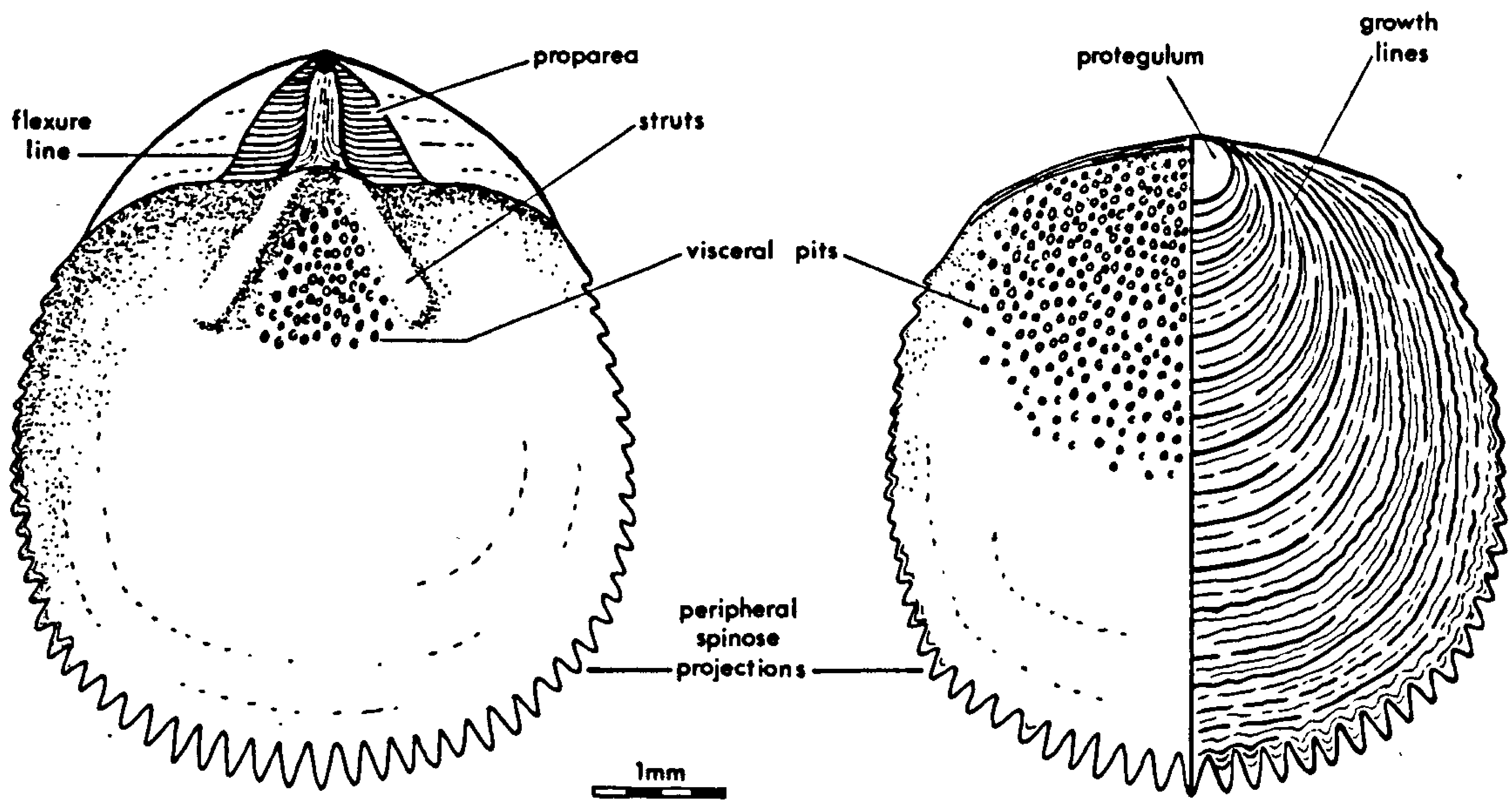
Material. 43 specimens were examined; of these, two were collected by K.A. Davies (University College of Wales, Aberystwyth collections), five by J.K. Ingham and P. Toghill (Hunterian Museum) and the remainder by the writer.

Horizons and localities. In and just above the upper Complanatus Band, Upper Hartfell Shale, *D. complanatus* Zone, Linn Branch, Dob's Linn.

Diagnosis. As for genus.

Description. Small subcircular to elongately oval thin shelled lingulelline averaging 85% as wide as long in 29 valves. Shell impunctate, laminar with maximum thickness (40µm) in the umbonal region tapering to about 10µm at the commissure at the 5mm growth stage. Ornamentation variable, consisting of an average of 2 low broad concentric growth rugae per mm between 2 and 5mm anteromedially of the umbones with fine, slightly scalloped, superimposed growth lines averaging about 8 per mm (range 5 - 12) at the 2mm growth stage. Sub-circular, smooth protegulum, about 0.6mm in diameter, visible in some specimens. Peripheral serrated frill at lateral and anterior commissure consists of divergent spinose projections which number about 50 around the entire commissure and are short and blunt laterally but more elongate at the anterior margins; they are equally spaced, average about 4 per mm at the 5mm growth stage, exhibit transverse growth lines numbering about 30 per mm and apparently project from the outer shell layer(s). Differentiated ventral interarea flanked laterally by propareas with finely spaced growth lines which bend posteriorly into longitudinal alignment, flexure lines prominent. Ventral interior with pair of radiating low struts extending anteriorly for about 1/3 of valve length and diverging for between 1/4 to 1/3 of its width to enclose a triangular posterior sector characterised by small subcircular pits about 15-20µm in diameter. Dorsal interior with numerous closely spaced pits covering the posteromedian visceral sector and thinning out to become sparse or absent beyond the 2 - 3mm growth stage. Relevant statistics for the length (l) and width (w) of 29 valves are l (var l) 4.3 (2.579), w (var w) 3.55 (2.382), r = 0.9238, a (var a) 0.9609 (0.00501).

Remarks. Although material described here displays morphological detail comparable with other obolid subfamilies the thin shell, outline, ornamentation, pseudointerarea and in particular the fine



TEXT-FIGURE 15. Reconstruction of the morphology of Barbatulella lacunosa gen. et sp. nov. showing the interior of the pedicle valve (left) and both internal and external portions of the brachial valve (right).

internal pitting of the visceral region is typical of lingulellinines (Rowell in Williams et al. 1965, figs. 161, 3a-d; Krause & Rowell 1975, p. 15) and the Dob's Linn material can be assigned unequivocally to this subfamily. However, known British Ordovician Lingulella (Williams 1962, 1963; Mitchell 1977; Hurst 1979; Lockley 1980) which have a generally sparse occurrence, differ from Barbatulella in internal morphology in that they lack ventral divergent struts (or septa) and commonly exhibit a dorsal median septum. The Dob's Linn species is sufficiently distinct from other British Lingulella, including the muscular Cambrian species L. davisii Salter (see Rowell in Williams et al. 1965) to warrant the erection of a new genus in which to accommodate it.

Although the struts in the pedicle valve of Barbatulella resemble those of Glottidia (Lingulidae) the genera differ in most other respects (see Paine 1963; Rowell in Williams et al. 1965, H263). The small size of Barbatulella shells and the prone peripheral spine-like projections are reminiscent of Spinilingula (Cooper 1956, p. 210) although the lack of 'spines' at all but the marginal growth stage distinguishes the Scottish material from Cooper's American species.

One of the most striking examples of a peripheral spinose frill similar to that noted in the Dob's Linn specimens is figured by Goryansky (1969, pl. 16, fig. 7a) for the Russian acrotretid Acrothele(?) barbata. Although the frill elements of this form, numbering about 7 per mm at the 5mm growth stage, closely resemble those described here the similarity does not reflect any close taxonomic relationship.

Interpreting the significance of the peripheral frill involves consideration of lingulacean shell structure which according to Rowell (in Williams et al. 1965, H75-76) is typically characterised by alternate thick organic and thinner mineral, phosphatic layers. According to Jope (in Williams et al. op. cit., H156-164) these layers are respectively composed of chitin and protein and calcium phosphate (i.e. 75-94% $Ca_3P_2O_8$) with the former organic components also comprising the periostracum and up to 52% of the whole shell.

Since the spinose elements of the Dob's Linn form apparently arise from the outer shell layer(s) they may have been chitinous flanges associated with the periostracum. Although their arrangement as a serrated peripheral frill might be considered an adaptation for burrowing it could equally well represent a mechanism to aid buoyancy. The spacing of each projection is also likely to reflect the frequency and configuration of marginal setae which may have been differentiated into principal and subsidiary elements (cf. Sudarson 1969).

The rare occurrence of sporadic internal raised 'pustules' about one order of magnitude larger than the smaller more regular pits (pl. 3, fig. d) is of no obvious morphological significance and is therefore perhaps an aberrant (?pathological) feature.

Discussion of implications on palaeoecology. The mode of life of fossil lingulids is rather uncertain and many conflicting views have been presented in recent literature. Paine (1970) and Plaziat et al. (1978) described infaunal modern Lingulidae (Lingula and Glottidia) which inhabit silty and fine sand substrates mainly in shallow to moderate water depth (i.e. 5 to 70m). However, species such as L. anatina and G. pyramidata respectively have been recovered from bathyal substrates at depths of 160 and 477m (Plaziat et al. op. cit, table 3).

Pickerill (1973) described infaunal Ordovician lingulids (Lingulasma) from inferred moderately deep water deposits. Percival (1978, p. 122) described various late Ordovician Australian Lingulida (Obolidae and Paterulidae) from "deeper-water (slope or rise)" deposits and reviewed literature concerning the inferred mode of life of such lingulides. He concluded that the Australian forms were atypical in being inferred to have had an epifaunal mode of life. His review shows that while many of the larger fossil lingulides are inferred to have had infaunal modes of life, like their modern relatives, numerous authors including Ruedemann (1934), Bulman (1964), Bergström (1968), Goryansky (1969), Thayer (1974), Popov (1975) and more recently Watkins & Berry (1977) have favoured the interpretation that small thin-shelled inarticulates (mainly obolids) were epiplanktonic and attached to algae. Cherns (1979) disputed the inferences of Watkins & Berry regarding the suggested mode of life of Lingula lata by demonstrating that the species is known to occur in a burrowing infaunal position. Krause & Rowell (1975, p. 13) concluded that whilst the mode of life of Ordovician Lingulella from the Meiklejohn mudmound, Nevada "is unknown ... there is seemingly nothing to have precluded an infaunal existence". It is worth noting that although a thin shell may be considered an epiplanktonic adaptation it is also a feature reminiscent of deep water articulate brachiopods (Cooper 1972, p. 6) and that small size may also indicate a deep water adaptation (cf. Cherns 1979). Similarly observations on the pedicles of populations of Recent articulates (Curry 1979, p. 246) suggest that they are highly variable and adaptable organs which develop differentially in response to immediate requirements and often bear no direct relationship to the morphology of the foramen. Indeed the diameter of Lingula pedicles are considerably more than those of the grooves (see Emig 1978, fig. 1); the same may therefore have been true for lingulelline and paterulid species whose respective pedicles need not necessarily have been 'threadlike' as suggested by Krause & Rowell (1975, p. 13) and Percival (1978, p. 123). Although the suggestions of these authors seem eminently reasonable for the taxa in question the inherent adaptibility of the brachiopod pedicle allows for considerable scope in such inferences. It is therefore evident that some fossil lingulides may have led an epiplanktonic mode of life and that Barbatulella lacunosa is a likely contender for such an existence.

5.3 Trilobites. Although Lapworth (1878, p. 331) recorded '*Asaphus* sp.' from the Glenkiln Shale of Craigmichan Scaurs [in fact, a specimen of the proetacean *Rorringtonia* (see Ingham *in* Bassett *et al*. 1974, p. 49)], the first specimen of a trilobite from the Upper Hartfell Shale of Dob's Linn was found a few years ago by an undergraduate on an excursion led by Dr. N.H. Trewin. Drs. Trewin and Ingham traced the trilobite-bearing horizon to a 10cm thick, conchoidally fracturing mudstone 5 to 15cm below the Extraordinarius Band. Over 100 specimens have now been collected, mostly from the Long Burn section which contains far more abundant specimens than the Linn Branch or Main Cliff sections. The band also yields bivalve and nautiloid fragments; it is uncertain if the trilobites are in life position or whether the assemblage is transported and it is considered that insufficient evidence is present to deduce the original palaeoenvironment. The trilobite material belongs to a new dalmanitinine genus, the most distinctive feature being the lack of eyes which in dalmanitids generally are typically schizochroal and well developed. The specimens are congeneric but not conspecific with *Mucronaspis* (s.l.) *cellulana* Siveter *et al*. 1980 from the top Ordovician (*C*? *extraordinarius* Zone) of Co. Cavan, Eire. The species from Dob's Linn is to be designated the type of the new genus which will also embrace *M*.(s.l.) *cellulana* (Ingham, pers. comm.).

5.4 Conodonts (pl. 5, figs. 1-17). This fossil group is normally considered to be of use only when found in calcareous lithologies, when specimens can be isolated from bulk samples by using acid extraction techniques. Conodonts are however relatively common in the black shale of Dob's Linn, especially in the Anceps Bands, where they are preserved in relief. Only one specimen has ever been found in the pale grey mudstone associated with the black Anceps Bands (by Dr. L.R.M. Cocks, from an horizon just above the top of Band D in the Long Burn section). Most specimens are of simple cone taxa but there are occasional ones of the more distinctive and stratigraphically useful amorphognathiform elements. Prof. C.R. Barnes has studied all specimens collected by the writer and has supplied the following summary.

> The identified conodont fauna of the late *D. clingani* Zone is:
> *Amorphognathus* sp.
> *Panderodus* cf. *P. gracilis* (Branson & Mehl)
> *Protopanderodus liripipus* Kennedy *et al.*

(cont. over)

Scabbardella sp.

The amorphognathiform elements of this collection cannot be identified to species level and P. liripipus ranges from lower Caradoc through Ashgill (Kennedy et al. 1979); it is therefore of little use for zonal determination. The top 1m of Lower Hartfell Shale yields:

Amorphognathus superbus (Rhodes)

A. cf. A. ordovicicus Branson & Mehl

The two elements of A. cf. A. ordovicicus appear to represent forms of the species transitional from A. superbus which Bergström (1971) and Sweet & Bergström (1971) considered to occur during the Pusgillian at a level near the middle of the P. linearis Zone (s.l.). It is therefore evident that the earlier conodonts belong to the A. superbus Zone while this fauna, from the middle or late P. linearis Zone, indicates a proximity to the boundary with the succeeding conodont zone of A. ordovicicus. This stratigraphical relationship is discussed further with respect to the Girvan succession in Chapter 3.3. The lower Complanatus Band yields:

Amorphognathus ordovicicus Branson & Mehl

A. cf. A. ordovicicus Branson & Mehl

Scabbardella cf. S. altipes (Henningsmoen)

Panderodus sp.

This fauna is referrable to the A. ordovicicus Zone, as is the slightly more diverse conodont fauna of the Anceps Bands which includes:

Amorphognathus ordovicicus Branson & Mehl

A. sp.

Panderodus? sp.

Protopanderodus liripipus Kennedy et al.

P. sp.

Pseudooneotodus mitratus Moskalenko

P. sp.

Scabbardella altipes (Henningsmoen)

S. sp.

cf. Walliserodus sp.

The sparse fauna from the basal Birkhill Shale (G. persculptus and early O? acuminatus zones) is zonally inconclusive, including:

Dapsilodus cf. D. obliquicostatus (Branson & Mehl)

?spathognathodiform element

N. gen. A

Most or all of the Upper Hartfell Shale is therefore referrable to the A. ordovicicus Zone while the conodont zonal identity of the basal Birkhill Shale remains unknown.

The biological affinity of conodonts is still a mystery and the mode of life of the conodontophorides uncertain. Barnes & Fåhraeus 1975 suggested that they were nektobenthonic and proposed a classification of depth control for the North Atlantic province from the Tremadoc to Ashgill series. They believed that while Amorphognathus was a relatively deep water form in the Arenig and Llanvirn it moved into a sub-littoral environment in the Llandeilo to Ashgill. Deep water faunas for the Ashgill were not recorded as the authors appeared to rely entirely on studies which utilised isolated material from relatively shallow water calcareous lithologies. Bergström & Sweet (1966, p. 311) suggested that Amorphognathus ordovicicus developed best in deep, quiet water environments while Seddon & Sweet (1971) recorded that Amorphognathus was best represented in deeper water sediments in the Ordovician of the Cincinnati region. Aldridge (1976, p. 98) concluded that it was quietness of environment, rather than water depth, that was the important factor in controlling the occurrence of Ordovician and Silurian Amorphognathus species. Aldridge also stated that the percentage of simple cone taxa in the total conodont fauna increased in deeper water environments. In conclusion, it appears that conodonts give no more evidence on palaeoecology than graptolites in that the genera occurring in black shales would seem to imply a relatively deep, quiet water environment. If the reason for all but one of the conodonts from Dob's Linn being found in graptolitic black shale is real, rather than being due to biased collecting, it does imply that the factors controlling the presence of black shale, graptolites and conodonts were intricately related. Although their usefulness as a palaeoecological indicator is limited, the occurrence of conodonts at Dob's Linn does however give it added importance as a possible international stratotype for the Ordovician/Silurian boundary.

5.5 Scolecodonts. Only one specimen of a scolecodont (polychaete jaw) has been found at Dob's Linn, from Anceps Band E (pl. 8, fig. 1); this phylum has not been recorded previously from this locality. Unfortunately the specimen is of uncertain affinity; M. Pye, S. Conway Morris and A. Brooks (pers. comms.) state that without further material it is not possible to assign it to a polychaete family or to be certain of the mode of life. During the present study scolecodonts have also been found associated with graptolites in the Upper Whitehouse Group at Girvan, the Onny Shale in the River Onny and the Hendre Shale at Meidrim, South Wales. It would appear that they probably belonged to planktonic polychaetes which, like the graptolites, were unaffected by substrate or bottom water conditions.

5.6 Dawsonia (pl. 6, figs. 1-15). This enigmatic fossil has caused confusion ever since it was first descibed as a genus by Nicholson (1873). All the specimens found at Dob's Linn may probably be assigned to the type(?) species Dawsonia campanulata; of his other species D. acuminata has a much more drawn out anterior(?) end while D. rotunda and D. tenuistrata appear to be inarticulate brachiopods. D. campanulata first appears just under 2m above the base of the Birkhill Shale at the same level as the earliest monograptid (A. ceryx) although this is assumed to be coincidental. Lapworth (1878, pp. 330-331) recorded it as occurring in the C. vesiculosus to R. maximus zones. Nicholson considered it impossible to assign Dawsonia to any known taxa but believed it to represent 'ovarian capsules' of graptolites. Rolfe (1969, R316) tentatively assigned this genus to the Ordovician crustacean Caryocaris Salter 1863 (order Archaeostraca) without comment.

Material collected during this study and from the Hunterian Museum (coll. R.B. Rickards) shows the anterior(?) neck to be well developed, often being preserved with some relief, but the posterior(?) margin to be always flattened, structureless and rather diffuse. One specimen (pl. 6, fig. 1) shows that Dawsonia was hollow with the neck closed, while the posterior margin was probably open, giving the body a 'crocus flower' type of appearance. Specimens range in size from 3 to12 mm long and 1 to 4 mm wide at the widest point although they maintain a similar shape throughout growth. The lack of internal structure and rather diffuse nature of preservation suggests an algal affinity to the writer, with which Rolfe (pers. comm.) would now tend to agree. It is possible that they were spore carrying algal bodies which grew in size before opening along the posterior margin to release the spores.

5.7 Other algae(?). Several enigmatic objects have been found in the graptolitic shales of the Anceps Bands and Birkhill Shale that are considered by the writer to be algal remains (pl. 7 , figs. 1-5). They lack well defined form and internal structures and have a rather diffuse, filamentous preservation. If the commonly accepted 'Sargasso Sea' type of environment postulated for the Moffat Shale by Lapworth and many later workers is correct it would be expected that occasional 'sea weed' or algae would sink and be preserved in the anoxic bottom waters prior to burial. It is perhaps significant that no similar remains occur in the Upper Hartfell pale grey mudstone lithology. This indicates either an original lack of carbonaceous material or a slightly better oxygenated environment which allowed decomposition of organic material prior to burial. Lapworth's specimen of an 'eurypterid' (pl. 8 , fig. 2) from the Lower Hartfell Shale has the same sort of preservation as these algal(?) remains and is here considered to be of similar origin, the apparent thoracic segments being purely coincidental.

Chapter 6. Philosophy of the graptolite species.

6.1 Graptolite affinity. The problem of graptolite affinity has been considered by many workers since they were first studied in detail in the early nineteenth century. Bulman (1970, V21 - 25) gave a reasonably full discussion of work up to the beginning of the last decade and only a brief summary is enclosed here. Graptolites have been variously assigned to inorganic remains (e.g. Linnaeus 1735), vegetable matter (Von Bromell 1727), cephalopods (e.g. Walch 1771), coelenterates (e.g. Hall 1865) and polyzoans (e.g. Salter 1866). Although Lapworth was primarily concerned, at least initially, with the stratigraphical use of graptolites he contributed much to the discussion with his more precise morphological understanding. It was largely his work that brought to a close the often trivial correspondance between Nicholson and Carruthers in the pages of the Geological Magazine in the 1860's (e.g Carruthers 1867b-d; Nicholson 1867 b-d).

The two workers who contributed most to the problem of graptolite affinity in the second quarter of the twentieth century were Bulman and Kozlowski; Kozlowski's 1949 summary of many years detailed work on isolated material represented a milestone in recognising the graptolites as an extinct class of the phylum Hemichordata by showing the similarity in microstructure between the graptolite periderm and that of extant pterobranchs. Since Kozlowski's publication most graptolite workers have accepted the affinity with hemichordates although little further evidence arose concerning the structure of the periderm or possible zooidal form until the advent of electron microscopy. This commenced with TEM work by Wetzel (1958) and Kraatz (1964, 1968) and was extended by the SEM work of Crowther & Rickards (1977), Andres (1977, 1980) and Urbanek (1978) while Bates & Kirk (1978) used the SEM to investigate retiolitid construction. A comprehensive review of microstructural work to date is given in Crowther's (1981) recently published major work on the fine structure of the graptolite periderm.

Crowther & Rickards (1977) were the first to realise the significance of what they termed 'cortical bandages' although these had been observed previously by Kraft (1926) using light microscopy, who called them 'chitinverdickungsbänder'. They suggest that the 'bandages' were deposited by a secretory 'cephalic shield' on a mobile zooid, in a similar manner to the extant hemichordate Cephalodiscus, giving further support for Kozlowski's assignment of the Graptoloidea to the phylum Hemichordata. Andres (1980) also shows excellent SEM photographs of cortical bandages, particularly of the radial disposition around thecal apertures. This author is in full agreement with Crowther & Rickard's inferences (op. cit.) of graptolite soft parts who consider them to have possessed mobile zooids living inside the thecal tubes. The problems surrounding the required complexity of cortical bandage secretion by wrinkled extrathecal tissue proposed by Urbanek (1978) are considered to demonstrate the inadequacy of his model.

Several workers have demonstrated recently the feasibility of studying pyritised graptolites using X-rays, either as an aid to accurate borehole logging when 100% of the entombed specimens may be observed (Crowther, in discussion of Bjerreskov 1978, pp. 469 - 470) or as a possible method to reveal the form of soft parts (Bjerreskov 1978, W. Stürmer, pers. comm.). Bjerreskov's paper illustrates the effects of pyrite concentration around the thecal apertures; while they may have been initiated by soft organic material they are not related to any original organic form. Stürmer can now produce X-radiographs with resolutions of about 2µm by using 15 hour, very low intensity exposures (pers. comm.) and is confident that such methods will eventually reveal the original nature of the graptolite zooid.

6.2 Criteria of species separation. Before proceeding with this discussion it must be stated that it is impossible to divide graptolites, or any other fossil group, into true species. Biological species definitions are based on genotypic criteria which are naturally lacking in fossils, so only phenotypic characters can be utilised. Once this restriction is recognised it is considered permissible by both palaeontologists and biologists to divide fossils into morphologically similar groups which for convenience are called 'species' although perhaps a term such as 'morphospecies' would be less ambiguous.

The graptolite rhabdosome has far less characters available for use in species diagnosis than many other invertebrate fossils. Using well preserved, isolated material graptolites may be divided on thecal style although the overall stipe form usually cannot be seen owing to the short length of most isolated fragments. Non-isolated material commonly reveals both thecal style (although this is not as clear as in isolated specimens) and overall stipe form. Difficulty has commonly arisen in identifying isolated fragments when original species descriptions were based on flattened material and vice versa; this problem has been discussed recently by Briggs & Williams (1981, see Appendix) who considered variation in thecal style of compressed rhabdosomes to result from differential lateral spread on flattening, controlled by the amount of support at each point along the thecae (thesis text-fig. 16). This was later investigated experimentally by the author and others for Dicellograptus complanatus Lapworth and Climacograptus normalis Lapworth which produced very similar results to those predicted (p. 62). In poorly preserved flattened material the overall rhabdosome form has sometimes been the only criterion used in erecting new species although this is now considered inadequate. Recently Crowther (1981) has attempted to use cortical bandage structure as an aid to classification but has so far produced few conclusive results.

The most reliable criterionfor graptolite species differentiation is thecal character; the tube which housed the zooid must have been closely related to its original soft parts. Ideally therefore it is necessary for all graptolites species to be defined utilising isolated material; as the vast majority of graptolite specimens are flattened or partially flattened in shales and siltstones this is unfortunately impossible. However these lithologies sometimes display a continuous range of preservation from full relief to flattened with an accompanying change in apparent thecal style. The drawback in being unable to observe specimens from all sides is compensated for commonly by observing material flattened in different orientations which, following allowance for effects of compression, may be used to reconstruct original three-dimensional structures. Such preservation also permits the original form of the rhabdosome to be recognised; Williams (1981) shows that flattening of the originally openly spiralled rhabdosome of D. complanatus results in a continuous normal distribution of axial angles from 0 to 130° while Finney (1977) considered several previously erected subspecies of Nemagraptus gracilis (Hall) to represent variably orientated flattened specimens of the branching spiralled rhabdosome of N. gracilis itself. While rhabdosome form alone is not reliable for species differentiation many graptolite species do have characteristic, fairly consistent overall forms (e.g. Dicellograptus elegans (Carruthers), D. complexus Davies, Pleurograptus linearis (Carruthers), Climacograptus tubuliferus Lapworth) which usefully can be utilised to identify poorly preserved specimens when associated with better preserved specimens of the same species (e.g. Dicellograptus morrisi Hopkinson vs. D. forchhammeri (Geinitz), when the rapid increase in stipe width of D. morrisi may be used to separate the two). However, new species should not not normally be defined on stipe form alone except in the case of consistent strikingly different specimens which differ significantly from all previously described species.

6.3 Effects of tectonic distortion. The appearance of specimens is commonly confused by tectonic stretching especially when the graptolites are preserved in black shale. Considerable change in both width and thecal style occurs as shown by the two distal fragments of Dicellograptus anceps (Nicholson) illustrated by Williams (1981, pl. 2, fig. 4) which are preserved parallel and perpendicular to a tectonic lineation. Jenkins (1980) recently demonstrated the construction of strain ellipsoids from specimens randomly orientated and showed that three species of Glyptograptus erected by Bulman (1963) were actually deformed specimens of one species of Undulograptus Bouček. At least a qualitative understanding of the range of deformation present in a collection is necessary when describing tectonically stretched graptolites although normally insufficient time is available to ascertain accurately whether variation in width is due to actual population or astogenetic variation, diagenetic lateral spread or tectonic deformation. This would require detailed measurement of several hundred specimens owing to the number of unknown parameters.

6.4 Changes during astogenetic development. Confusion in graptolite species differentiation has sometimes arisen due to morphological changes during the growth of the rhabdosome. One of the best known astogenetic effects is the common change in thecal style along the stipe, often changing from complex 'advanced' proximal thecae to more simple ones distally, although this situation is reversed in some monograptids such as Cucullograptus (see Urbanek 1966). This change is most clearly seen in the Monograptidae (e.g. Bulman 1970, text-fig. 47) and the Dicranograptidae. Urbanek (1960) suggested an hypothesis to account for the change which was clearly summarised by Bulman (1970, V66): "... morphogenic substances, some acting as stimulators and some as inhibitors, were transmitted from the siculozooid in steadily decreasing quantities through the asexually budded succession of zooids, and [that] when these fell below a certain threshold level they no longer exerted any effect. Proximal introduction of a character results from increasing activity of a morphogenetic stimulator, together with a lowering of the threshold level; distal introduction results from diminishing activity of an inhibitor and a rise in threshold level". However, it is uncertain whether such genetic change has been observed in any extant colonial organism.

The other astogenetic changes are those of secondary stipe thickening, commonly resulting in a more robust rhabdosome which deforms differently on flattening, and development of proximal structures. _Climacograptus longispinus supernus_ Elles & Wood clearly illustrates development of proximal spines (text-fig. 24) which commence as short, narrow projections on $th1^1$ and 1^2. These initially grow as narrow spines for several mm before a membranous undergrowth appears and grows along each spine throughout the life of the rhabdosome. Many diplograptids show similar astogenetic increase in size of spines (e.g. the _Orthograptus calcaratus_ group); Riva (1974b, 1976) made detailed studies of development in the _Climacograptus longispinus_ and _C. bicornis_ groups.

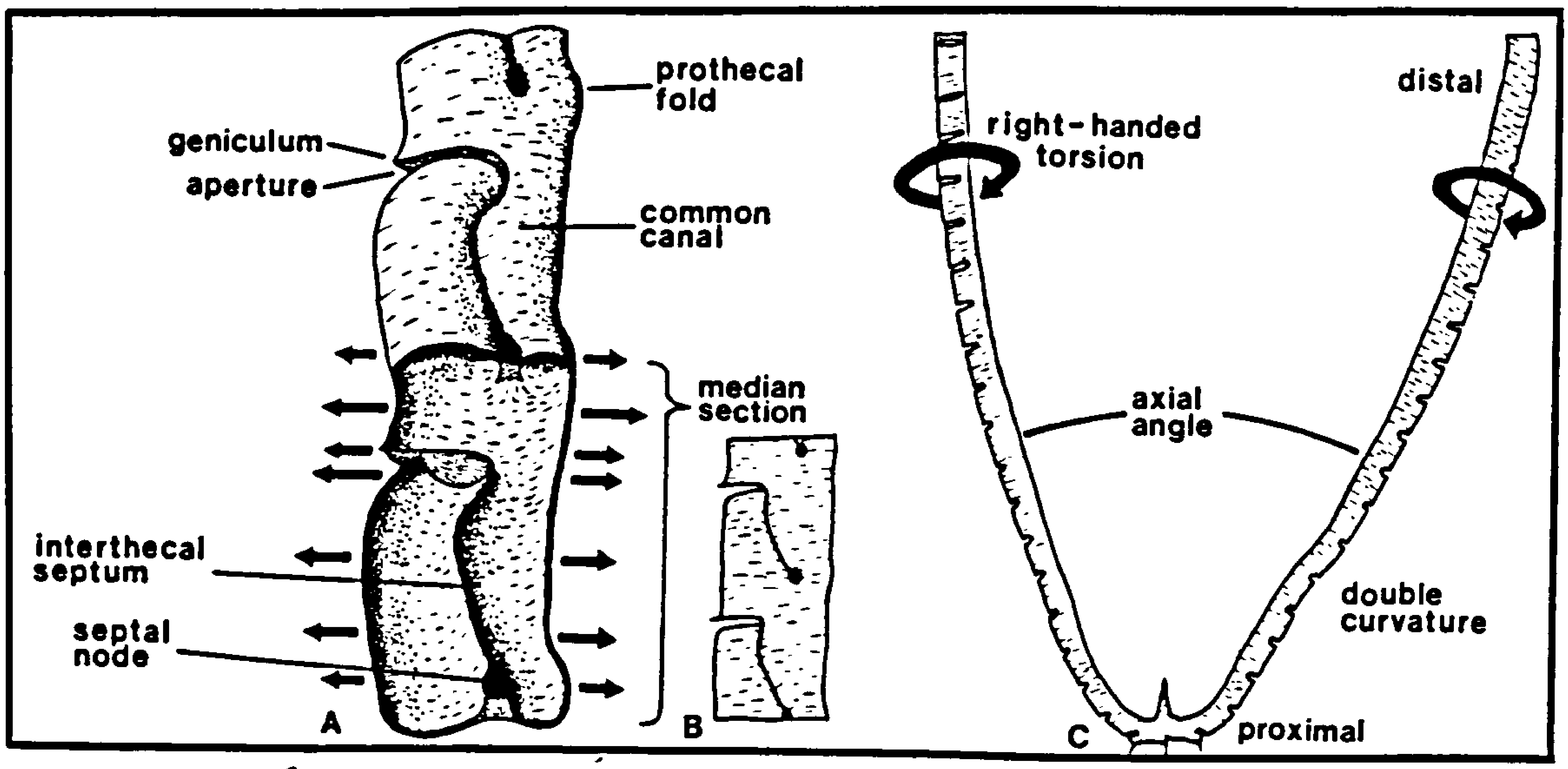
Most _Dicellograptus_ specimens show considerable thickening of proximal thecae which is accompanied sometimes by the development of an axial membrane (e.g. _D. moffatensis_ (Carruthers)) and commonly by the loss of the sicula; the sicula may have broken off during life, after death or during the preparation of the fossil specimen, or alternatively may have been resorbed during life. The fact that most juvenile specimens possess a sicula while mature ones commonly do not seems to indicate that the sicula was lost during life. If breakage had occurred one would expect the presence of the sicula to be fairly random; however, mature specimens of some species commonly possess a sicula (e.g. _D. anceps_ (Nicholson)) while others (e.g. _D. complanatus_ Lapworth) rarely exhibit one. It is therefore concluded here that the sicula was resorbed during life; Dr. I. Strachan (pers. comm.) suggests that if Finney's (1979) interpretation of a juvenile _Dicellograptus_ specimen with a flotation 'balloon' is correct, the presence or absence of the sicula may be related to the point at which a break occurred to release the flotation device. If it was released by severing the nema above the prosicula the sicula may have been retained intact, while if the breakage point was within the sicula (e.g. at the prosicula/metasicula junction) it would be reasonable to assume that the sicula had become functionless by this stage of astogeny and could have been resorbed without ill-effect to the rhabdosome.

Dicellograptus ornatus Elles & Wood and D. elegans (Carruthers) probably show the most pronounced and different effects of astogenetic development on Dicellograptus proximal spines. Juvenile specimens of D. ornatus (pl. 21, text-fig. 22) possess short slender spines on the first two thecae and have a similar appearance to species such as D. complanatus and D. complexus Davies. Throughout development of the rhabdosome of D. ornatus the spines grow, first in length and then in width, while the sicula is resorbed. Ultimately this gives a smooth rounded dorsal wall to the axil, which is sometimes filled by a membrane, and long robust spines which may be as thick as the stipes. On the other hand, juveile specimens of D. elegans (pl. 15, text-fig. 20) possess two long slender spines and sicula which are apparently resorbed during astogeny; this eventually results in proximal thecae with short spines or no spines and a rounded thickened axil lacking a sicula. The reasons for these astogenetic developments are unknown but may have been related to stability of the rhabdosome (Williams 1981).

6.5 The use of experimental palaeontology in determining the effects of diagenetic flattening on graptolites.

6.5.1 Introduction. An interest in the possibility of reproducing experimentally the effects of flattening on a graptolite rhabdosome was first aroused during the preparation of a paper with Dr. D.E.G. Briggs on the photographic imitation of compressional effects on stipe form and the possible extent of lateral spread of the stipes during flattening (Briggs & Williams 1981). Both authors discovered independently that apparent forms of a fossil species produced by variation in original orientation prior to flattening could be imitated by constructing a 'Plasticine' model and photographing it from a variety of angles. This was carried out for Dicellograptus complanatus Lapworth by Williams (1981) while Briggs & Williams (op. cit.) demonstrated the technique for a Middle Cambrian Burgess Shale arthropod Odaraia alata Walcott and the late Ordovician Dicellograptus complexus Davies. The hypothesis of Rickards & Palmer (1977, text-fig. 1) concerning lateral spread was considered over-simplistic; they postulated that the rhabdosome would spread laterally on compression with no other deformation such as fracture and infolding of the periderm. They also ignored the detailed effects of internal thecal structure and the lateral confining pressure imparted by the sediment.

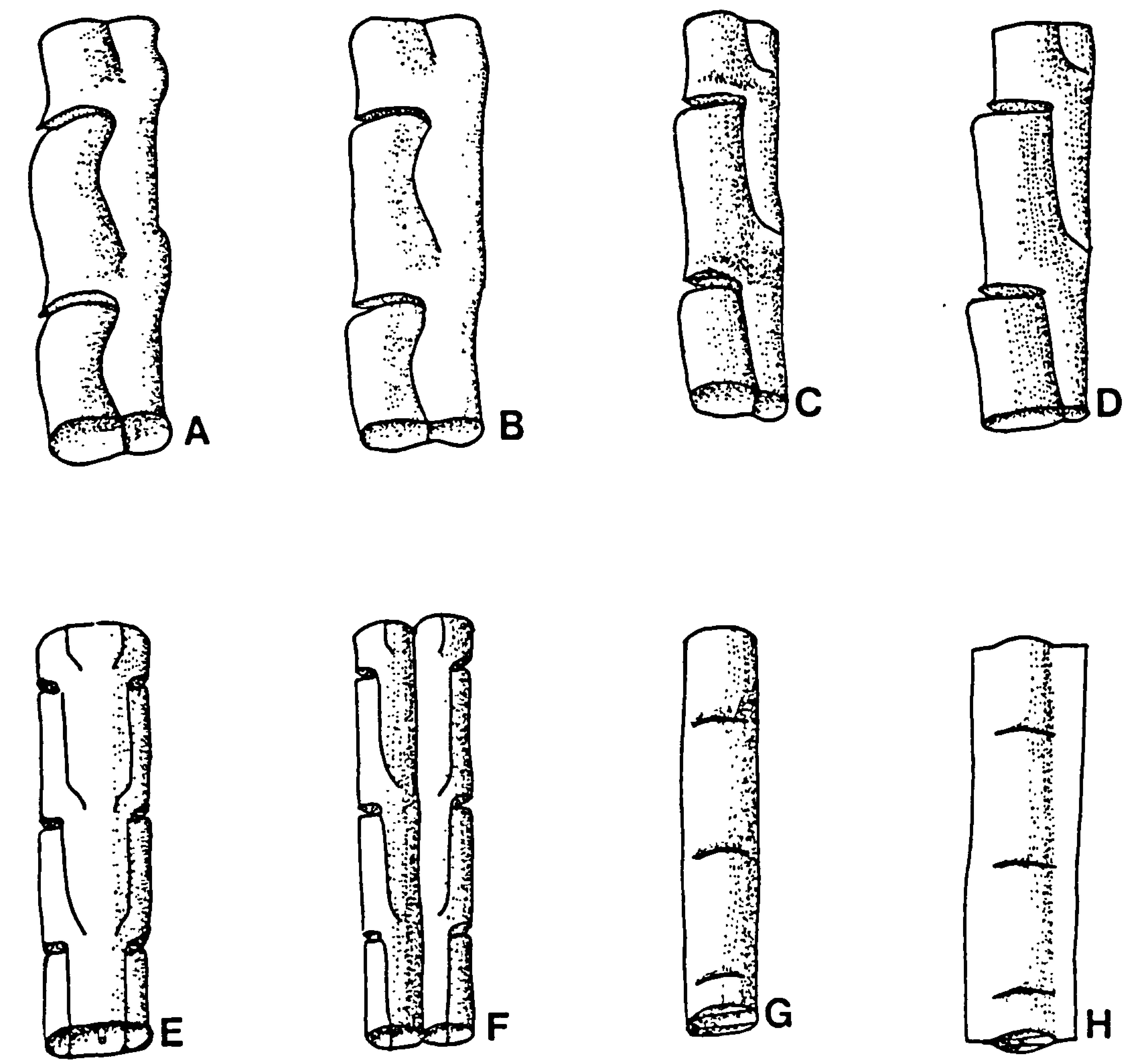
One problem that was unexplained prior to the joint study by Briggs & Williams is the lack of prothecal folds on the dorsal walls of most flattened Dicellograptus specimens, as they are normally conspicuous when specimens are preserved in relief (Briggs & Williams 1981, text-figs. 2a - c). It was proposed in this paper that the reason was due to the fact that stipes are not simple cylinders but composed of many complex tubes with variable degrees of overlap and thickening of walls. It was considered that on flattening lateral spread would be greatest in those parts of the thecae with least support. These regions would be at the apertures, as the weakest part of a cylinder is at the ends, and the area between the interthecal septal node (where the interthecal septum terminates) and the infrgenicular hood, where there is no central partition between the dorsal and ventral walls. A qualitative illustration was given by Briggs & Williams (op. cit., text-fig. 1a, thesis text-fig.16) indicating the expected relative amounts of lateral spread at different points along the thecae, the least amounts being around the interthecal septal node and at the infragenicular hood. This hypothetical effect would reduce greatly the prominence of prothecal folds and also account for the 'squaring up' of thecae noticed when comparing flattened specimens of D. complanatus with those preserved in relief.



TEXT-FIGURE 16 Dicellograptus complanatus Lapworth. A. Reconstruction of early thecae ca x40. Length of arrows indicate expected amounts of lateral spread on flattening. B. Flattened thecae showing apparent morphological simplification ca x15. C. Descriptive terms used for Dicellograptus in this thesis.

Many diplograptids possess a median septum which is clearly visible as a central groove when specimens are preserved in relief and may be straight (e.g. Climacograptus) or wavy (e.g. Glyptograptus). Some aseptate diplograptids (e.g. Orthograptus) also show an apparent 'median septum' when partially flattened (pl. 10, fig. 20); it is here proposed that this is due to the collapse of the periderm during diagenetic flattening with infolding along the central line running between the proximal (dorsal) ends of the interthecal septa. This is clearly seen in isolated, partially flattened specimens of Climacograptus typicalis Hall studied with the SEM by Dr. P.R. Crowther (pers. comm.). Illustrations of a hypothetical Climacograptus showing the development of a compressional 'median septum' are given in text-fig. 17E - F. Dr. C.J. Burton (pers. comm.) states that tentaculites commonly show a median groove which is an artefact of compression. Unlike the graptolites however it normally only occurs on the upper surface while the lower one is smooth; this may indicate partial lithification of the underlying sediment prior to diagenetic flattening (cf. graptolitic black shale).

When diplograptids are fully flattened in scalariform view they commonly show considerable overall lateral spread which may result in a lateral width greater than the compressed dorso-ventral width,(e.g. Climacograptus normalis Lapworth, pl. 10, fig. 19). This situation is the opposite to that normally occurring in Dicellograptus, whose stipes normally appear narrower in scalariform than in dorso-ventral view although they may appear wider when compressed obliquely. When diplograptids are preserved in scalariform view the apertures do not extend across the whole rhabdosome width and the outer margins lack any features formed by the curvature of the supragenicular wall or infragenicular hood. It is here proposed that the greatest lateral spread has occurred along the median line of the rhabdosome due to lack of retention by interthecal septa (text-fig. 17, G - H). Although this does seem to occur in septate diplograptids it is most pronounced in aseptate ones due to the lack of a median retaining wall (e.g. Diplograptus pristis (Hisinger) in Skoglund 1963, pl. 4, fig. 4). The lack of overall lateral spread in scalariform specimens of Dicellograptus is explained by the presence of median interthecal septa while the occasional increase in width when preserved in oblique orientation is due to the increased lateral spread at the apertures (text-fig. 17, C-D).



TEXT-FIGURE 17. A-D. Dicellograptus complanatus Lapworth ca x30. A. Reconstruction of early thecae in full dorso-ventral orientation. B. Appearance of thecae when partially flattened in full dorso-ventral view. C. Reconstruction of thecae in oblique orientation. D. Appearance of thecae when partially flattened in oblique orientation. E - H. 'Climacograptus sp.'. E. Aseptate rhabdosome in full dorso-ventral orientation. F. Hypothetical appearance of 'E' when partially flattened, showing development of a preservational 'median septum'. G. Rhabdosome in scalariform view. H. Hypothetical appearance of 'G' when partially flattened, showing extensive lateral spread along the centre of the rhabdosome but none towards the ventral walls where inter-thecal septa provide support.

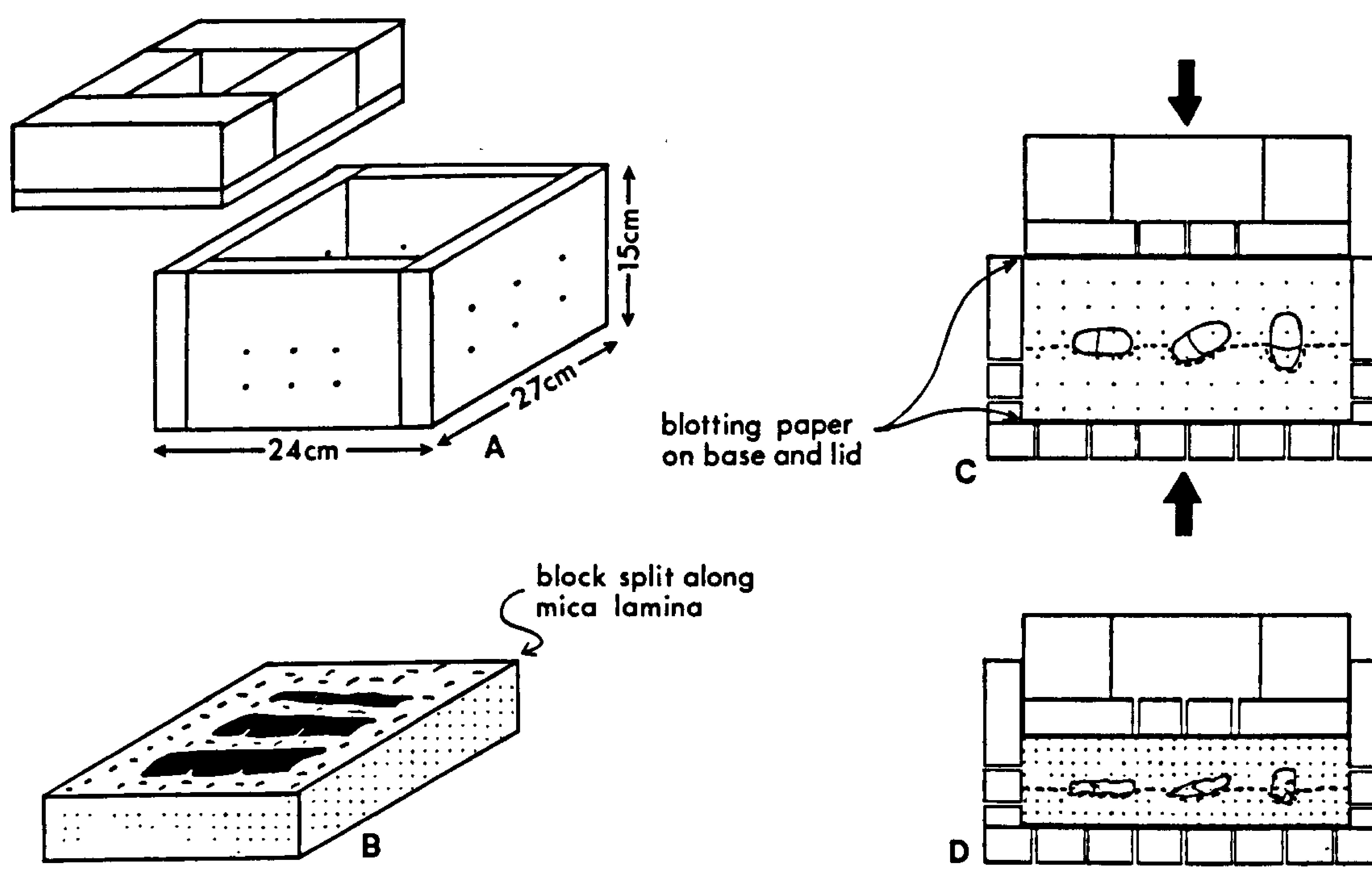
6.5.2 Experimental aims. Two experiments were carried out; the first was to discover whether cylinders made of several different materials would show lateral spread when compressed under conditions roughly approximating to those which must have been experienced by the graptolite rhabdosome during diagenetic flattening. The second was to see whether detailed models of D. complanatus would show the changes in apparent thecal morphology described in the previous section when compressed and whether models of an aseptate diplograptid would produce a preservational 'median septum' and any change in thecal morphology. Rather than follow the methods of Harris (1974) who experimentally compressed spheres between two hard surfaces to imitate compression of spores, it was considered necessary to compress the models in a soft matrix in a laterally restricted space. This would allow the projecting parts of the models to settle into the 'sediment' and would impart lateral confining pressures. It would therefore approximate more closely with the actual process undergone by diagenetically flattened graptolites. The matrix for the experiments was formed by finely sieved, loosely compacted, dry plaster which was compressed with the enclosed graptolite models in a strong wooden box.

6.5.3 Experiment 1. Twelve cylinders were constructed from a variety of materials (pl. 9 , figs. 9 - 20) with varying deformational properties from plastic to brittle. Some were filled with a coarsely-foamed polyurethane in a rough attempt to imitate the effects of interthecal septa while others were filled with loosely compacted plaster or left hollow. After accurate measurement of the cylinders at marked medial points they were placed in the box which had been half-filled with sieved plaster. The box was then filled with additional plaster, the lid fitted and then squashed down using a heavy duty vice until the plaster would compress no further. The lid was then screwed in place and the box immersed in water for several hours before dismantling it to remove the plaster block, now compressed to 55% of its original thickness. It was cut along three previously marked positions with a hack-saw and the revealed cross-sections were carefully drawn using a binocular microscope with a grid graticule.

The cylinders compressed as shown in pl. 9 , figs. 9 - 20. The resin cylinders deformed by fracture with little or no lateral spread. The plastic and paper cylinders showed lateral spread, the greatest occurring in the paper cylinders. When reinforced with resin lateral spread was reduced while brittle fracture and infolding occurred. This indicates that a degree of rigidity (mineralisation in fossil specimens) is necessary to prevent lateral spread even when lateral confining pressures are exerted. The presence of polyurethane foam had little apparent effect on deformation, probably because it lacked sufficient rigidity in comparison with the cylinders.

The degree of compression achieved in this experiment (approximately 1/2) was minute compared with what must have occurred in black shale (perhaps about x10); clear deformation was however achieved and is considered to provide a useful parallel with flattened graptolites, particularly in coarser lithologies which have suffered a lesser degree of compaction. When actual flattened specimens are observed (pl. 9, figs. 1 - 8) it is clear that although variable degrees of flattening and lateral spread occur even in one small slab, all specimens show a degree of brittle fracture and infolding of the periderm. However, compression of the figured graptolite sections is partially influenced by individual sediment grains owing to the fairly coarse silty lithology, which would be irrelevant to specimens in black shale or the plaster medium used for this experiment. Preservation in similar coarse, pale material is unfortunately the only lithology in which three-dimensional sections of graptolite rhabdosomes may be observed easily; sections of graptolitic shale rarely reveal sectioned graptolites owing to the lack of colour contrast between periderm and lithology. The sectioned slab of graptolites is important in revealing the highly variable amount of flattening in only a few rhabdosomes from undeformed (pl. 9, fig. 1) to almost completely flattened (pl. 9, fig. 8). The two factors affecting degree of compression in this case are the thickness of periderm (proximally well developed with secondary thickening but distally thin) and the degree of sediment fill in the rhabdosome prior to diagenetic flattening.

6.5.4 Experiment 2. This was carried out as an undergraduate project by Mr. I. Murray and Miss K. McManus, supervised by the writer and Dr. J.K. Ingham. Accurate scale models of stipe portions of D. complanatus and an aseptate diplograptid were constructed from acrylic resin. They were made by coating carved dental wax models with a thin resin layer, then melting the wax out in an oven. The resulting models were semi-brittle and were considered to possess relatively similar properties to actual graptolite rhabdosomes during diagenetic flattening. The three models of each type of graptolite were then painted with thin paint and photographed in accurately recorded dorso-ventral, oblique or scalariform orientation (pl. 10, figs. 1-15). A larger version of the box used previously was half filled with plaster as before followed by a very thin lamina of finely ground mica, which was sprinkled onto the surface to act as an artificial bedding plane. The models, themselves filled with sieved plaster, were then gently pressed into this surface in their photographed orientations. The box was filled with additional sieved plaster, compressed and immersed in water as before. The plaster block was split along the mica lamina, the compressed models remaining attached to the upper half (text-fig. 18). The proceedure was carried out twice to allow for compression of three models of each type.



TEXT-FIGURE 18. Experiment 2. A. Details of flattening box. B. Resulting compressed plaster block after splitting. C. Section through plaster filled box with models before compression. D. Section after compression.

The compressed models are shown in pl. 10, figs. 1,4,6; the model of D. complanatus in dorso-ventral orientation showed that differential lateral spread, but no overall increase in width, had occurred in exactly the manner proposed by Briggs & Williams (1981). The prothecal folds had disappeared and the ventral walls and apertures 'squared off'. The model in oblique orientation showed slight overall lateral spread but with greatest spread at the apertures, resulting in a 'stepped' ventral margin, as seen in actual flattened specimens of D. complanatus with obliquely preserved thecae (pl. 10, fig. 9). The model in scalariform orientation showed no apparent increase in width, as often found in Dicellograptus stipes preserved in this orientation (e.g. D. complexus, pl. 24, figs. 1, 3).

The diplograptid models proved less conclusive, although a slight median depression was formed; the rather irregular resulting deformation is very similar to that commonly found when graptolites are only partially flattened (A.T. Kearsley, pers. comm.). The reasons for the lack of a 'septum' in the model are probably an insufficient degree of flattening and too great a relative strength of the resin layer. It would be of interest to repeat the experiment using larger models and greater compression than the 45% achieved here.

6.6 The validity of graptolite species. It is evident from the previous sections of this chapter that causes of apparent morphological variation in graptolites are many and that specimens conforming strictly to a 'species' definition are likely to be exceptional. The characters used to separate species are commonly rather dubious and it is questionable whether the majority of graptolite species and subspecies recognised from the British late Ordovician and early Silurian are valid.

Certain morphological characters result in such obvious differences between species that there can be no question concerning their distinctiveness, for instance the two long basal spines and virgella of Climacograptus longispinus supernus Elles & Wood compared with the narrow proximal end and single virgella spine of C. normalis Lapworth. Once a distinct group of several previously named, similar species is recognised the inter-specific differences often become less clear, especially when separation relies largely on size criteria, such as in the grouping containing Climacograptus miserablis Elles & Wood (=C. angustus (Perner)?) and C. normalis Lapworth. Even though well preserved 'typical' specimens of these species are occasionally found which are obviously distinct, the majority are tectonically and diagenetically deformed and often appear intermediate between the two. This fact reinforces the previous statement (section 6.2) that all graptolite species ideally should be erected by studying a large number of three-dimensional, tectonically undeformed specimens where population variation may be assessed unequivocally. As this cannot be done with any of the material from Dob's Linn it is considered that the basic framework constructed largely by Elles & Wood (1901-18) cannot be much improved upon. It has therefore been decided to adhere to their commonly used framework for the purpose of this work but to give revised, less ambiguous diagnoses based on both the original and topotype material. More recently described British and foreign species have been incorporated into the basic framework and relevant synonymies included, although conclusions regarding the affinity and validity of many of the new species recently erected in Chinese and Russian literature have proved impossible in many cases owing to the lack of English translations or adequate illustrations.

6.7 Micro-evolutionary changes in graptolite species. Possible genetic reasons to account for the change in thecal style along the stipes of monograptids have been previously discussed (section 6.4). The genus Dicellograptus normally shows progressive simplification in thecal style distally, well shown in three-dimensional specimens of D. complanatus Lapworth (pl. 23, fig. 4). D. complexus Davies occurs stratigraphically higher; proximally the thecal style is identical to D. complanatus but the distal thecae do not appear to simplify and the rhabdosome has a tightly spiralled form as opposed to the original open spiral of D. complanatus. It is considered that both D. complexus and the more openly spiralled D. aff. complexus are evolved from D. complanatus which was probably a descendant of a Dicellograptus lineage with fairly simple thecae and almost straight supragenicular walls, such as is found in D. johnstrupi Hadding and D. carruthersi Toghill.

D. anceps (Nicholson) has complex, introverted proximal thecae with mesial spines on up to the first fifteen pairs. It has a similar thecal style proximally to D. morrisi Hopkinson but the complex thecae extend further up the stipes before simplifying into an almost Leptograptus thecal style and the rhabdosome is more tightly spiralled. D. anceps is thought to have evolved from the earlier D. morrisi via a number of forms such as occur in the equivalents of the P. linearis and D. complanatus zones in Australia (lower Bolindian).

Dicellograptus ornatus Elles & Wood and D. minor Toghill are erected to full specific status in this work owing to the extended stratigraphical range of D. minor and the different astogenetic development of its proximal spines (p. 121). D. minor exhibits a slight, but apparently cosmopolitan, evolutionary change; early specimens from the late P. linearis Zone at Girvan and lower Bolindian of Australia (VandenBerg, pers. comm.) remain consistently narrow throughout their length, while the specimens from the Complanatus and Anceps Bands, although identical in every other respect, gradually widen distally.

A clear evolutionary change in the late Ordovician diplograptids is the population shift in the maximum size and form of the basal spines of the Climacograptus longispinus group. The earliest representatives of this group are not found in Britain but are found in Australia, North America and Russia from equivalents of the D. complanatus Zone. Riva (1974b) figured mature rhabdosomes with up to two membranes below and one above the basal spines; he assigned them to C. l. longispinus Hall although VandenBerg (pers. comm.) states that many of Hall's types specimens do not possess such fully developed membranes. Riva (pers. comm.) no longer considers C. l. hvalross Ross & Berry and C. l. supernus Elles & Wood to represent Pacific and Atlantic province subspecies. There does however seem to be a stratigraphical change from the large, robust-spined rhabdosomes of C. l. longispinus (sensu Riva) to the small, narrow-spined forms of C. l. supernus (pls. 27 - 29) although both astogenetic development and population variability show the change to be a gradual evolutionary shift. Specimens of C. l. supernus in the top Anceps Band of Dob's Linn possess only small thecal spines without membranes while the virgella is of equal length; earlier specimens possess small virgellae distinctly subordinate to the two thecal spines in all but the most juvenile rhabdosomes.

Reasons for the described evolutionary changes are unknown; a tightly spiralled rhabdosome, as found in some Dicellograptus, may have been better suited to an environment with a high density of suspended food particles while a more openly spiralled rhabdosome may have filter-fed more efficiently in an environment with a lower food density. The development of axial membranes in D. anceps and D. ornatus in the top Anceps Band, together with the change in the basal spines of C. l. supernus, may represent an adaptation to a more hostile environment related to the late Ordovician glaciation as all three, together with most other P. pacificus Subzone species, became extinct at this time.

Mutations and growth failures are more easily seen in isolated material, although they may occasionally be observed in flattened rhabdosomes. The mutations observed in this study are restricted to diplograptids; perhaps the best example is the specimen of Climacograptus normalis Lapworth (BU 1142b, pl. 34, fig. 4) from the Birkhill Shale which splits distally to give a Dicranograptus-like appearance, although each half of the rhabdosome possesses a nema. The proximal part of the counterpart of this specimen was figured as a typical specimen of C. normalis by Elles & Wood (1906, text-fig. 119b)! A mutation or growth failure common in several diplograptid species is the development of a uniserial distal portion (e.g. Glyptograptus? sp. A from the basal Birkhill Shale, pl. 54); this normally extends for only a short distance although some are more than ten thecae long. Close examination of these specimens reveals the feature to be an original morphological feature rather than a breakage one.

Chapter 7. Introduction to systematic section.

7.1 Bibliographic problems. During construction of the taxonomic descriptions given in the following chapters several problems were encountered. One of the least resolvable was the use of Chinese, and to a lesser extent Russian, literature. In addition to the normally impossible task (to the writer) of understanding all but the simplest terminology the recent Chinese publications mostly consist of regional 'handbooks' published in Beijing (Peking) and Nanjing (Nanking). Translated title and contents pages reveal that the 'editor' is usually given as the Nanjing Institute of Geology and Palaeontology and that several authors are involved in the description of each fossil group. It is common for a new species to be described in these handbooks without clear reference to a specific author (e.g. '*Paraorthograptus typicus* gen. et sp. nov.' *in* a chapter written by Wang *et al.* 1974) but for consequent records of the species to be assigned to one, previously unmentioned, author (e.g. '*P. typicus* Mu' *in* Wang *et al.* 1977). Many other species are given manuscript authors in their first published descriptions (e.g. '*Paraorthograptus angustus* Mu & Lee (MS)' *in* Wang *et al.* 1977) who are then retained in future references. This turns out to be a courtesy device (Ingham, pers. comm.), the manuscript authors not realising that by allowing the results of their work to be mentioned in a monograph they have automatically lost the authorship of their species to the author(s) of the monograph in question. In similar fashion, many new species and subspecies described in the systematic graptolite section by Koren' *et al.* *in* Apollonov (ed.) 1980 are given only one or two of the several authors (e.g. '*Pacificograptus pacificus affinis* Koren' et Tzai subsp. nov.'). The authors listed in the following chapters for the synonymies of species which include recent Chinese and Russian references should therefore be recognised as possibly in at least partial error.

7.2 Problems with terminology. Many loosely defined morphological terms exist in graptolite literature and in this systematic section they are used as indicated in the next part of this chapter. Only family names may strictly be given the adjectival forms such as 'diplograptid' for 'Diplograptidae'. The loose usage that has been practised commonly in graptolite literature, utilising such terms as 'dicellograptid' to describe a feature found in the genus *Dicellograptus*, is incorrect and can be misleading. Such terminology is avoided in the following chapters and any reference to a form such as a 'diplograptid' refers to the whole family and not to one particular genus, with the exception of generic diagnoses unchanged from previous authors.

The following chapters are divided by families; each genus is given a separate title page with diagnosis and remarks, normally based on the Treatise diagnosis by Bulman (1970). Unpublished work carried out over the last few years on isolated material, especially by Dr. J. Rigby (*ex*-Cambridge University), has rendered many current graptolite generic diagnoses out of date. Many of the generic diagnoses given here are based on detailed knowledge only of flattened specimens and may therefore require subsequent modification. The stratigraphical range given for each genus corresponds to the total range, while the zonal range given in parentheses for each species in the 'species described' section refers to the range based on the present work and does not necessarily imply that this is the entire known range.

One or more idealised drawings, not to scale, of the features considered by the writer to be the most important in distinguishing taxa from other forms, are given at the beginning of each taxonomic description. The remainder of each description follows the standard format used in graptolite taxonomy. All species diagnoses are fully revised, and all stipe width measurements refer to the dorso-ventral width, unless otherwise stated. Where insufficient material of a species has been found to permit a full systematic description the 'Diagnosis' and 'Description' sections are omitted and comments are then included in the 'Remarks' section. All figured specimens are from the writer's collection (housed in the Hunterian Museum, Glasgow University) unless otherwise stated.

7.3 Definitions of morphological terms used (largely adapted after Bulman 1970, V8-12).

APERTURAL SPINE. Sharp projection originating on margin of aperture.

APERTURE. Distal opening of thecal tube.

ASEPTATE. Biserial rhabdosome lacking median septum.

AXIAL ANGLE. Angle between dorsal walls of reclined rhabdosome.

AXIL. Area between proximal dorsal walls of reclined rhabdosome.

BIFORM. Rhabdosome with proximal and distal thecae of conspicuously different style.

BISERIAL. Scandent rhabdosome with two series of thecae joined along dorsal margin, enclosing virgula.

BRANCH. See 'stipe'.

CLATHRIA. Skeletal framework of rods (lists) composing rhabdosome, in some supporting reticulum or attenuated periderm.

COMMON CANAL. Continuous cavity collectively formed by prothecae of rhabdosome.

CURVATURE (CONCAVE or CONVEX). Curve with respect to ventral wall of stipe or theca.

DECLINED. Rhabdosome with stipes hanging below the sicula, subtending an angle of less than 180° between their ventral walls.

DEFLEXED. Similar to declined but with distal extremities of stipes tending to horizontal.

DISTAL. Last formed part (of stipe, theca, etc.) farthest away from point of origin.

DORSAL. Side of stipe opposite thecal apertures.

EVERTED. Plane of aperture facing outward.

EXCAVATION. Hollow between aperture and infragenicular wall.

GENICULAR SPINE. Sharp projection originating on geniculum.

GENICULUM. Angular bend in ventral wall directly above excavation due to change in direction of growth of theca.

HORIZONTAL - STIPES. Rhabdosome with stipes perpendicular to axis of sicula.

- APERTURE. Aperture perpendicular to dorsal wall.

INFRAGENICULAR WALL. Ventral wall facing preceeding aperture and proximal to geniculum, normally within excavation.

INTERTHECAL SEPTUM. Peridermal membrane separating overlapping thecae, formed by parts of dorsal wall of one theca and ventral wall of succeeding theca.

INTROVERTED. Plane of aperture facing inward.

LACINIA. Delicate skeletal network, extraneous to rhabdosome proper, supported on spines.

LAPPET. Broad, rounded, lateral apertural process of theca.

LATERAL. Direction normal to plane of rhabdosome.

LIST. Skeletal rod strengthening periderm, an unit of clathria.

MEDIAN SEPTUM. Partition in biserial rhabdosome separating two sets of thecae.

MESIAL. Middle portion of supragenicular wall; hence mesial spine.

METASICULA. Distal portion of sicula composed of normal fusellar growth bands.

NEMA. Distal extension of virgula beyond thecal series.

OBVERSE. Aspect of rhabdosome (especially biserial forms) in which sicula is most clearly visible.

PERIDERM. Horny substance of scleroproteic composition forming skeleton comprising inner (fusellar) layer with growth bands and growth lines and outer (cortical) layer of finely laminated, bandaged tissue.

PROSICULA. Initially formed part of sicula with faintly marked spiral thread and secondary longitudinal fibres.

PROSOBLASTIC. Type of diplograptid development in which $th2^1$ and ultimately $th1^2$ grow upward (distally) from origin.

PROTHECA. Proximal portion of theca before differentiation of succeeding theca.

PROTHECAL FOLD. Inverted U-shaped curvature of protheca (usually initial portion) giving noded appearance to dorsal margin of stipe.

PROXIMAL. First formed portion (of rhabdosome, theca, etc.), nearest point of origin.

RETICULUM. Delicate network, usually supported on clathria, replacing continuous periderm in retiolitids.

REVERSE. Aspect of rhabdosome (especially biserial forms) in which sicula is least clearly visible.

RHABDOSOME. Sclerotised exoskeleton of entire graptolite colony.

SCALARIFORM. Preservational view presenting ventral (thecal) aspect of rhabdosome.

SCANDENT. Rhabdosome with stipes growing erect, enclosing virgula.

SCLEROTISED. Hardening due to secretion of scleroproteic substances by zooid(s).

SCOPULAE. Peculiar ramifying fibrous development from edges of median septum (as in lasiograptids) comparable with lacinia.

SICULA. Skeleton of initial zooid of colony, comprising conical prosicula and tubular distal metasicula.

STIPE. One branch of branched rhabdosome or entire colony of unbranched rhabdosome.

STREPTOBLASTIC. Type of diplograptid development in which significant portions of proximal parts of $th1^2$, $th2^1$ and even $th2^2$ grow downward.

SUPRAGENICULAR WALL. Ventral wall of theca lying distal to geniculum and proximal to aperture. For rhabdosomes with straight thecae, the ventral wall of the stipe lying between two successive apertures.

THECA. Sclerotised tube enclosing zooid of rhabdosome (other than sicula).

UNISERIAL. Rhabdosome or stipe consisting of single row of thecae.

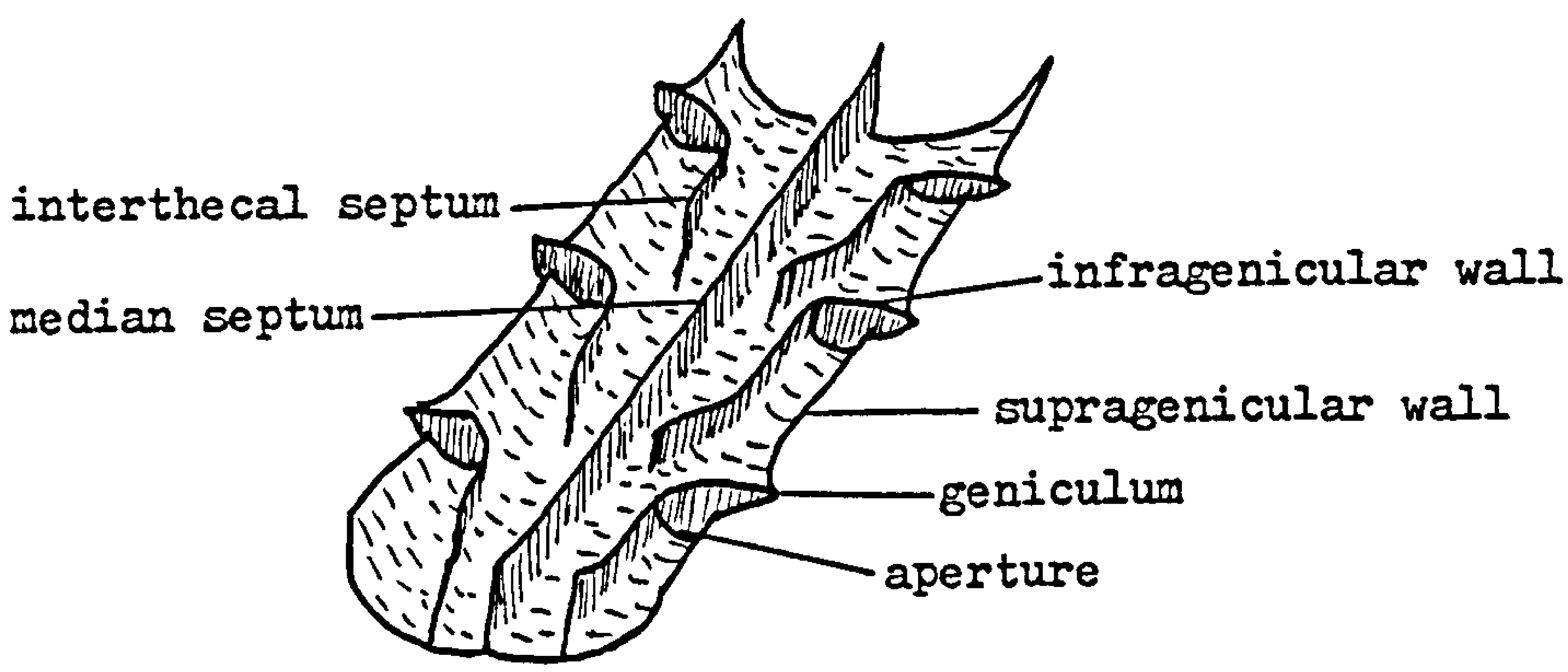
VENTRAL. Side of stipe on which thecal apertures are situated.

VIRGELLA. Spine developed during growth of metasicula, embedded in sicular wall and projecting freely from its apertural margin.

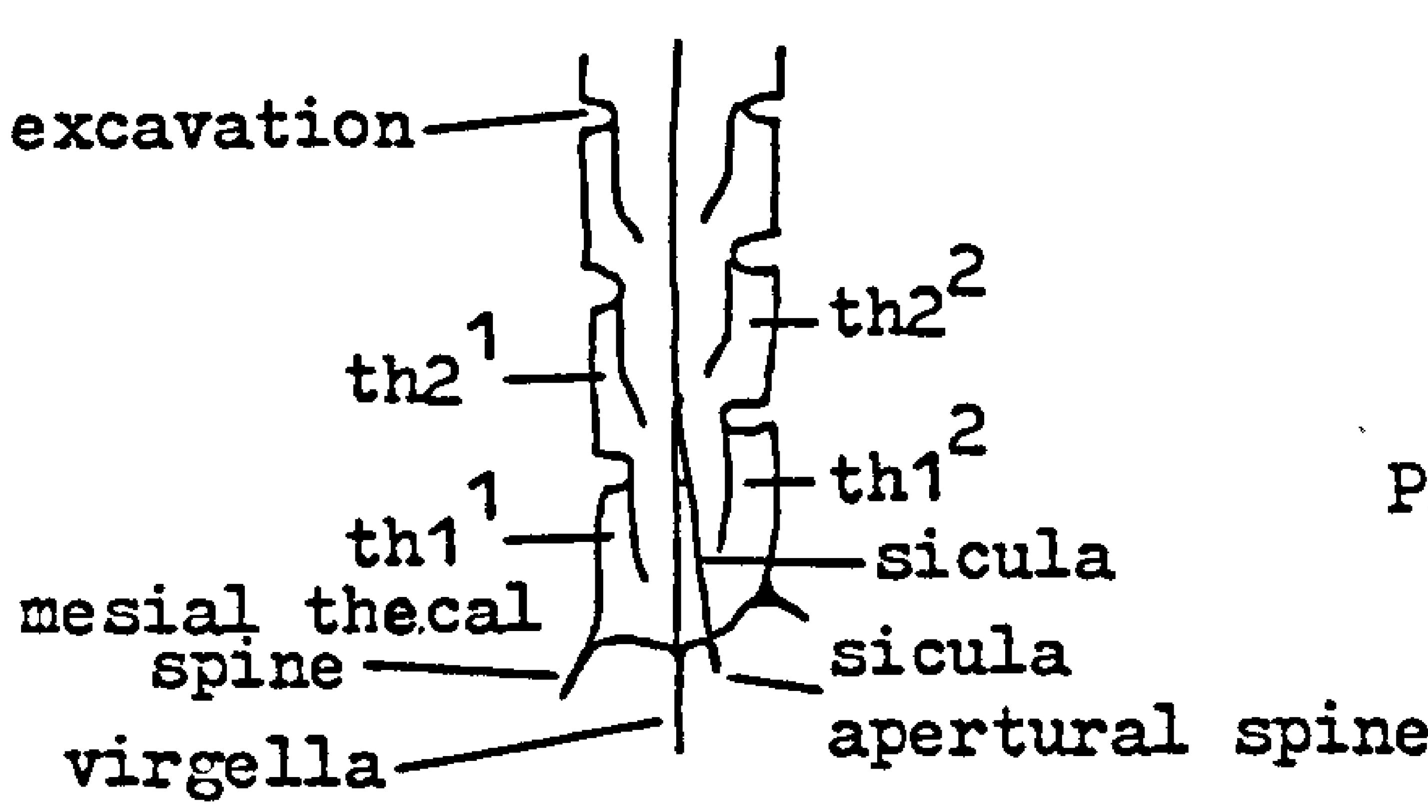
VIRGULA. Threadlike, cylindrical extension of apex of prosicula enclosed within two thecal series of scnadent (biserial) rhabdosome (cf. nema).

ZOOID. Soft-bodied individual inhabiting theca.

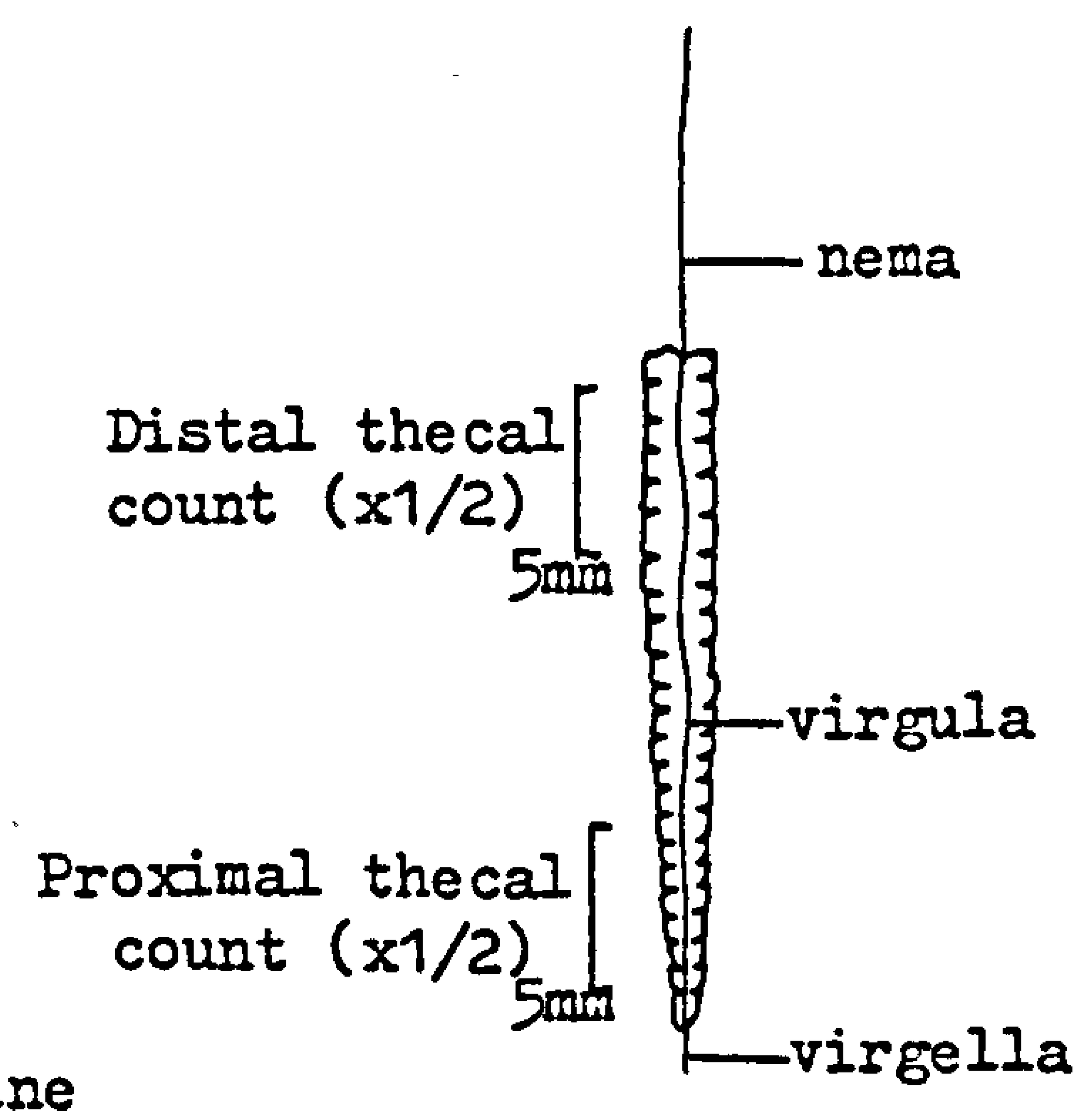
Idealised drawings of <u>Climacograptus</u> to illustrate morphological terms. (see text-fig. 16 for <u>Dicellograptus</u>)



<u>Idealised oblique section</u>

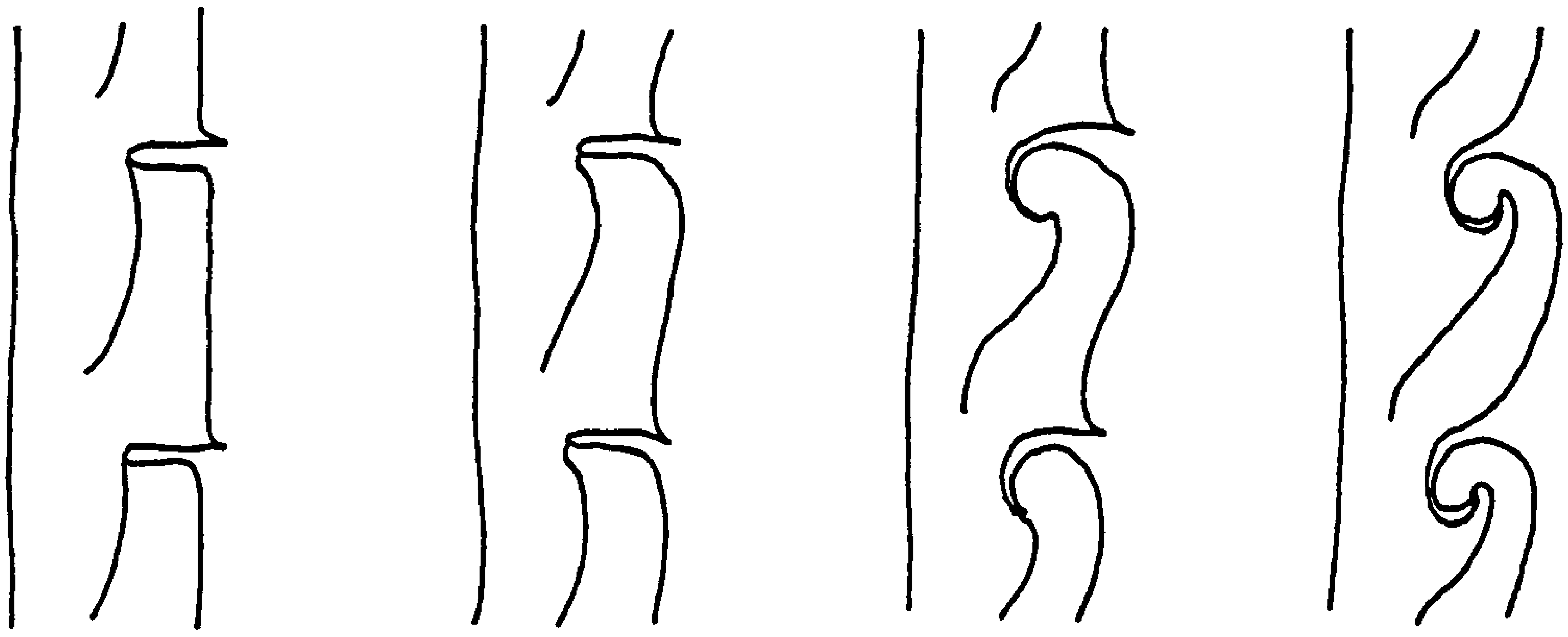


<u>Proximal development</u>



<u>Overall form</u>

Terminology of thecal style



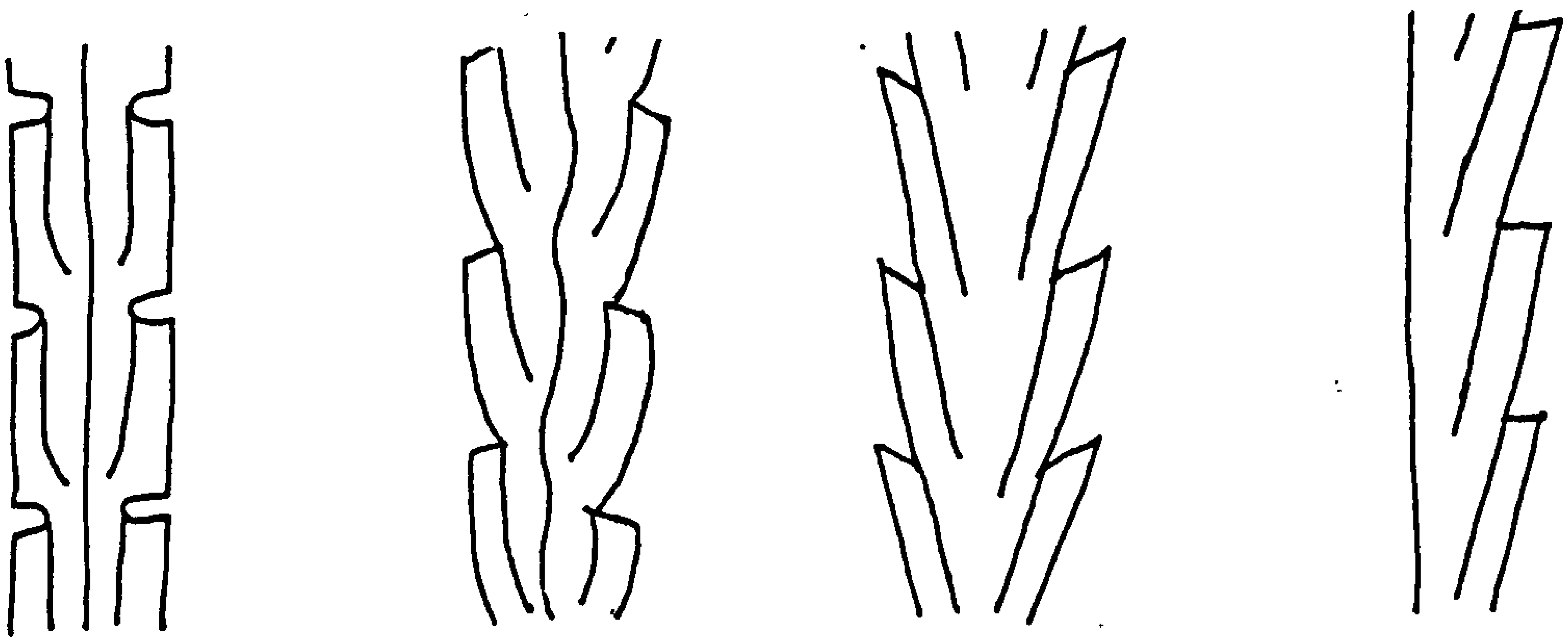
dicranograptid thecae

simple,
horizontal
geniculate

slightly
introverted,
geniculate

introverted,
geniculate

highly
introverted,
non-geniculate



diplograptid thecae

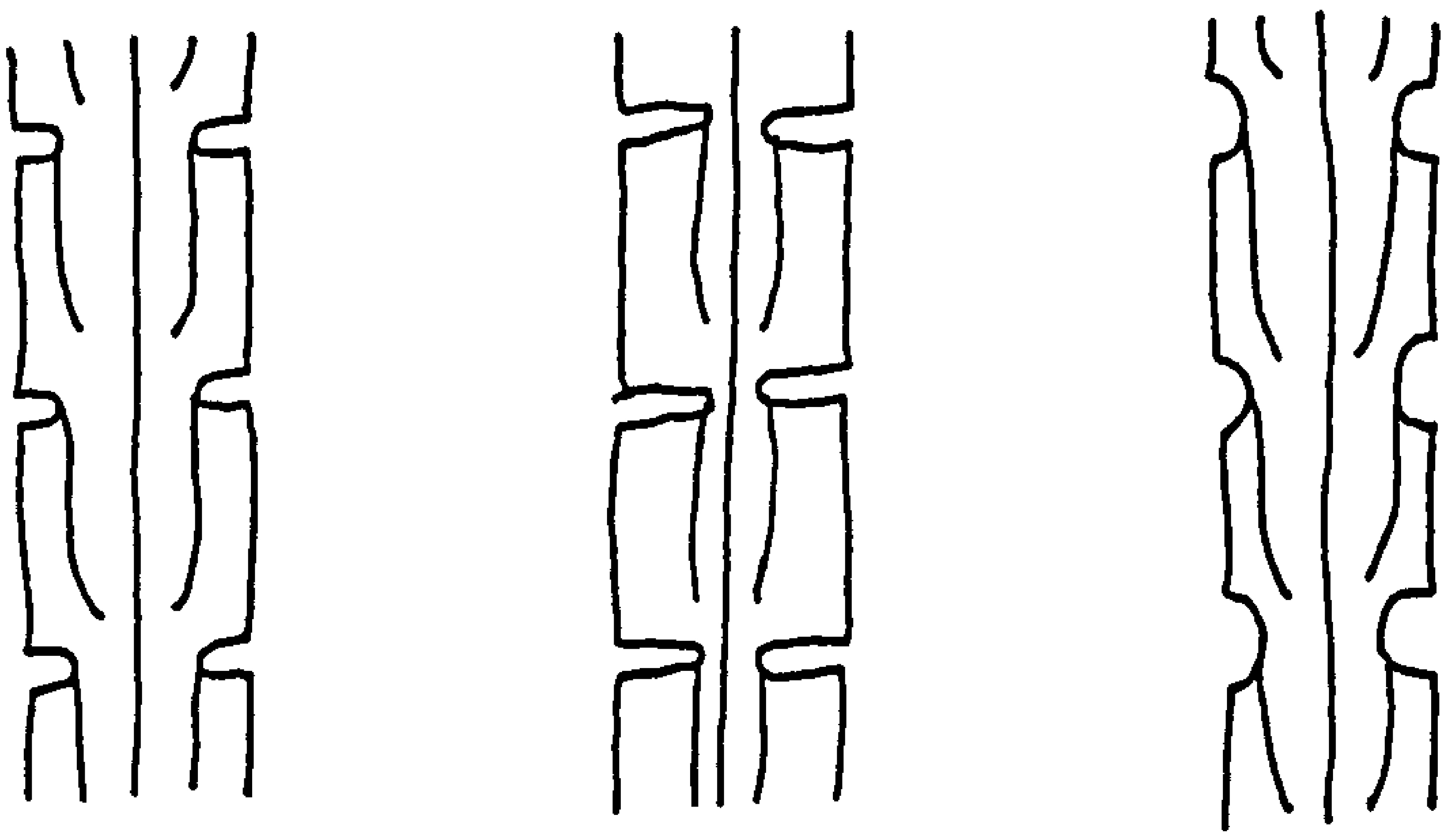
horizontal,
vertical
supragen.
walls

everted,
curved
supragen.
walls

introverted,
inclined
supragen.
walls

nemagraptid thecae

horizontal,
inclined
supragen.
walls



terminology of excavations

short,
shallow

short,
deep

long,
shallow

Chapter 8. Family NEMAGRAPTIDAE Lapworth (ex Hopkinson MS) 1873.

Diagnosis (adapted after Bulman 1970, V119). Uniserial, bilaterally symmetrical, with two slender flexuous stipes having a primary angle of divergence of about 180°; branches (if present) lateral, rarely paired, simple or compound; thecae elongate, inclined at low angles and almost straight, with simple apertures; development of "leptograptid type".

Remarks. Bulman recorded the thecae to have "well marked sigmoidal curvature". This is however more typical of the Dicranograptidae, most nemagraptids possessing simple thecae. Few, if any, nemagraptids possess spinose thecae and prothecal folds have never been recorded, while dicranograptids always exhibit proximal prothecal folds in well preserved material and possess spines on at least the first two thecae.

8.1 Genus *Leptograptus* Lapworth 1873

Type species (by original designation). *Graptolithus flaccidus* Hall 1865, p. 143, pl. 2, figs. 17-19.

Stratigraphical range. Upper Ordovician (*N. gracilis* to *P. linearis*)

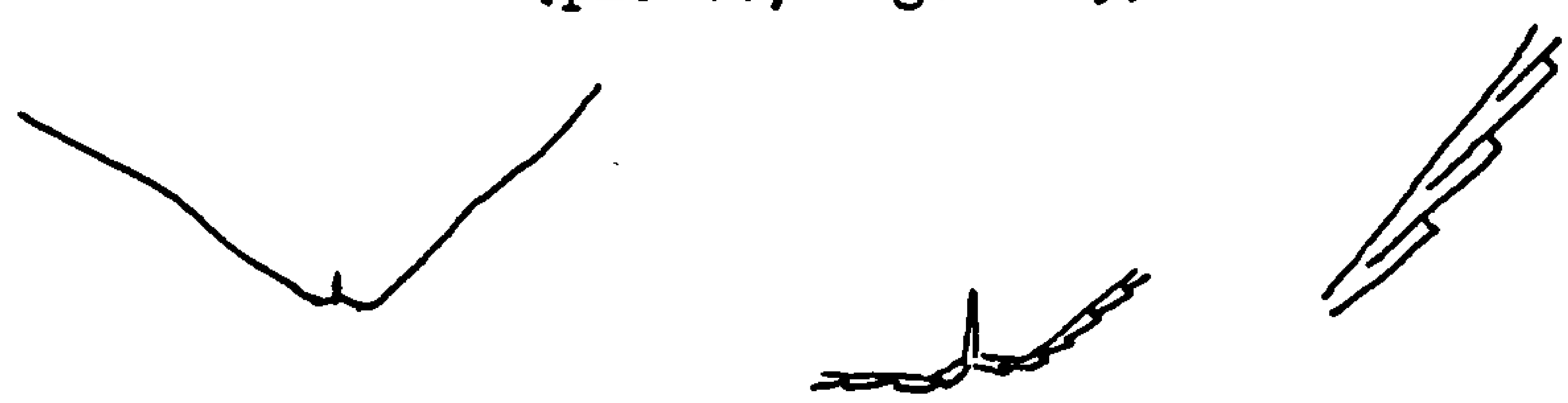
Diagnosis (from Bulman 1970, V121). Biramous, stipes slender, flexuous, slightly reclined, without secondary branches except in centribrachiate mutations.

Remarks. Confusion sometimes arises over the distinction between *Leptograptus* and *Dicellograptus* when the latter species possesses simple thecae. In addition to the difference in typical thecal style the two genera may normally be separated by the declined first two thecae and lack of prothecal folds or thecal spines in *Leptograptus*.

Species described.

L. flaccidus macer Elles & Wood 1903 (*D. clingani* and *P. linearis*)

Leptograptus flaccidus macer Elles & Wood 1903
(pl. 11, figs. 1-9)



1903 Leptograptus flaccidus var. macer var. nov.; Elles & Wood, pp. 110-111, pl. 15, figs. 2a-i.

1934 Leptograptus flaccidus Hall var. macer Elles & Wood; Ruedemann & Decker, p. 306, pl. 40, figs. 5-6.

?1963 Leptograptus cf. L. flaccidus var. macer Elles & Wood; Ross & Berry, p. 101, pl. 6, fig. 1.

Proposed lectotype. BU 1377. Figured by Elles & Wood 1903, pl. 15, fig. 2e and this thesis (pl. 11, fig. 1). From the Lower Hartfell Shale, P. linearis Zone, Hartfell Spa.

Material. Elles & Wood's figured specimens in the Wood Collection (Birmingham University) and numerous flattened specimens collected by the writer.

Horizons and localities. 8.8 to 0.8m below the top of the Lower Hartfell Shale, D. clingani and P. linearis zones, North Cliff trench, Dob's Linn. Elles & Wood's specimens from the Lower Hartfell Shale, P. linearis Zone of Hartfell Spa and Beldcraig Burn.

Diagnosis. Long slender stipes, straight or slightly curved, up to 70mm long and widening gradually from 0.2mm to a maximum 0.5mm. Axial angle 120 to 160°. Thecae long, narrow and straight, numbering 8-9 in 10mm. Apertures simple and everted.

Description. The stipes are very narrow and slightly flexuous, reaching up to 70mm long. They widen gradually from 0.15-0.3mm proximally to 0.5mm distally and have an axial angle of 120 to 160°. The thecae are rarely preserved but proximally number 9 in 10mm, reducing only slightly distally to 8 in 10mm. The sicula is commonly preserved and possesses a small inconspicuous virgella; in the specimens described here it is normally about 1mm long although Elles & Wood record it to be about 2mm. Th1^1 and 1^2 grow slightly downwards for most of their length; it is unclear whether they are spinose. Th2^1 and 2^2 grow downwards initially but slowly bend and point upwards at their apertures. The remaining thecae are straight, narrow and long with everted apertures which occupy about 1/2 the total width of the stipe. The thecae sometimes show slight spread at the apertures owing to differential lateral spread on diagenetic flattening.

Remarks. While there is no doubt in the identification of some material there are many specimens which appear intermediate in stipe width between L. flaccidus macer and other L. flaccidus subspecies described by Elles & Wood (1903). Much variation is probably due to diagenetic and tectonic deformation but some of the previously separated subspecies may be gradational forms. No secondary branches as figured by Elles & Wood (op. cit., pl. 15, figs. 2f and i) were seen in material collected by the writer and it is concluded that these are probably atypical for this subspecies.

L. flaccidus macer has been described from Oklahoma by Ruedemann & Decker (1934); the specimen figured as L. flaccidus cf. macer by Ross & Berry (1963) is rather wider proximally than the type material and is only questionably referrable to this subspecies.

8.2. Genus *Pleurograptus* Nicholson 1867d

Type species (by original designation). *Cladograpsus linearis* Carruthers 1858, p. 467, text-fig. 1.

Stratigraphical range. Upper Ordovician (*P. linearis* to *D. anceps*).

Diagnosis (adapted after Bulman 1970, V121). Main stipes somewhat flexuous, from which simple or compound branches are given off rather irregularly from either side; all thecae non-spinose.

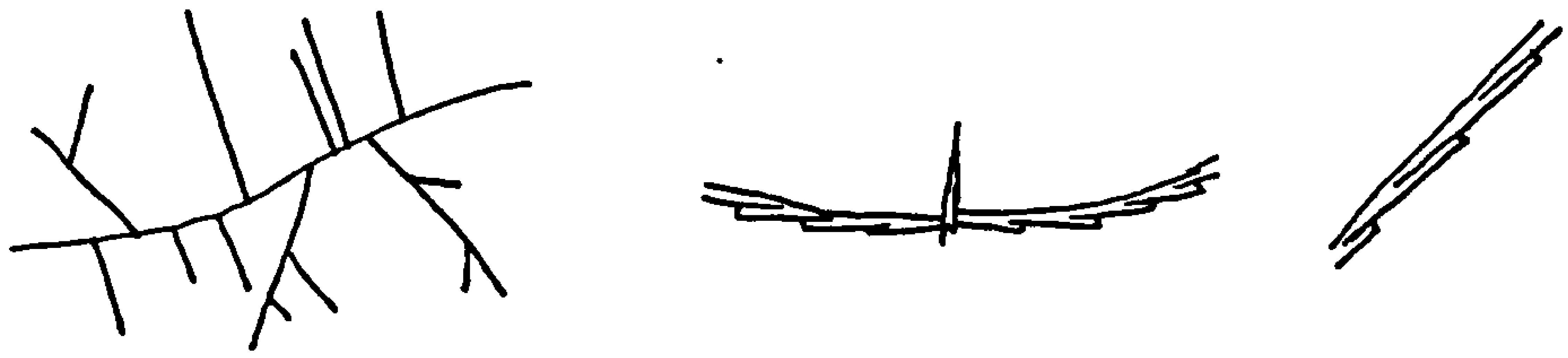
Remarks. This genus commonly possesses exceedingly long and narrow thecae. The sicula is broad and blunt and commonly gives rise to a branch in mature specimens.

Species described.

P. linearis linearis (Carruthers 1858) (?middle *P. linearis*)

P. lui Mu 1950 (*D. anceps*)

Pleurograptus linearis linearis (Carruthers 1858)
(pl. 12, figs. 1-8)



1858 Cladograpsus linearis sp. nov.; Carruthers, p. 467, text-fig. 1.

1859 Cladograpsus linearis Carruthers; Carruthers, p. 24, text-fig. 1.

1867d Pleurograpsus linearis Carruthers; Nicholson, p. 258, pl. 11, figs. 1-5.

1876 Pleurograptus linearis (Carruthers); Lapworth, pl. 3, fig. 69.

1903 Pleurograptus linearis (Carruthers); Elles & Wood, pp. 119-121, pl. 16, fig. 7, pl. 17, fig. 1.

1969 Pleurograptus linearis (Carruthers); Strachan, pp. 186-187, pl. 2, figs. 1-3, text-figs. 1a-c.

1970 Pleurograptus linearis (Carruthers); Toghill, p. 20, pl. 10, figs. 2, 4.

?1977 Pleurograptus linearis linearis (Carruthers); Carter & Churkin, p. 17, pl. 2, fig. 4.

Holotype. Q 848. The largest specimen on the slab figured by Carruthers 1858, text-fig. 1 and by Strachan 1969, pl. 2, fig. 1. Counterpart in the Royal Scottish Museum, Edinburgh (RSM 1858.10.4). From the Lower Hartfell Shale of Hartfell Spa.

Material. The holotype from the Carruthers Collection and specimens in the Nicholson and Toghill Collections (all British Museum, Nat. Hist.), the Lapworth Collection (Birmingham University) and many specimens, both flattened and in relief, collected by the writer.

Horizons and localities. 1.9 to 0.7m below the top of the Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn. Other specimens from the Lower Hartfell Shale of Hartfell Spa and Dob's Linn.

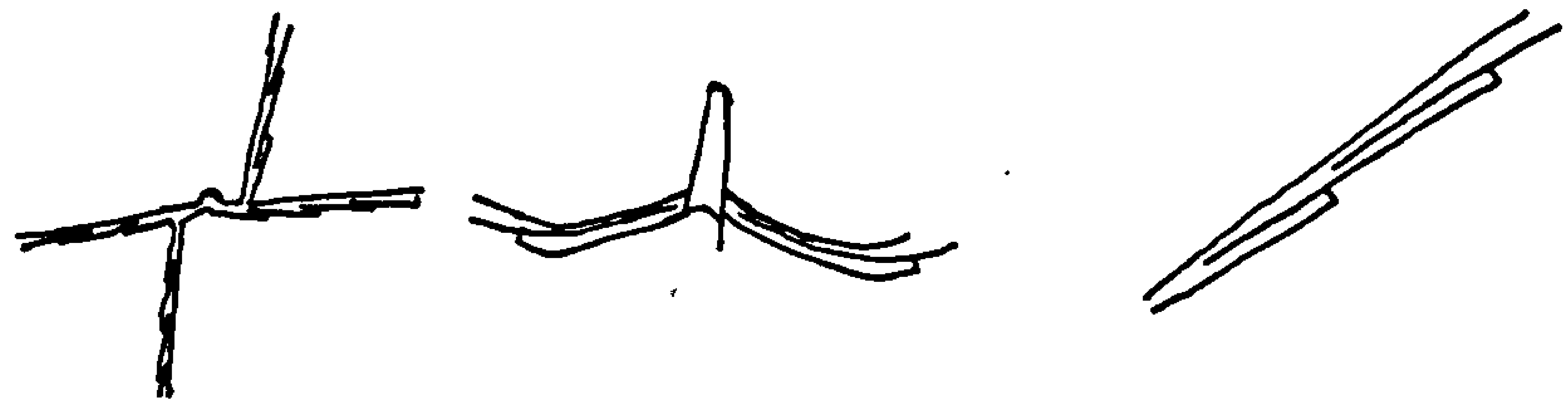
Diagnosis. Large rhabdosome consisting of two main stipes with secondary branches on one or both sides. Stipes up to 1mm wide. Thecae long and simple, numbering 8 in 10mm.

Description. Large rhabdosome with many long, gently curved stipes several hundred mm long (Carruthers records one specimen nearly three foot long). The two main stipes diverge horizontally or slightly upwards from the sicula and give rise to secondary and sometimes tertiary branching on one or both sides. The stipes occasionally reach 1mm wide distally although 0.7mm is the more common maximum width. The main stipes, which commonly possess a well thickened periderm in mature specimens, are only 0.2mm proximally and widen to 0.4mm in 5mm when flattened (less in three-dimensional specimens). The thecae number 8 in 10mm throughout the entire rhabdosome. The sicula is approximately 2mm long and bears an inconspicuous virgella. It apparently gives rise to a cladial branch which completely obscures it in mature specimens. $Th1^1$ and 1^2 grow horizontal or slightly downwards throughout their entire length and are non-spinose. The remaining thecae are long and thin, making only a slight angle with the dorsal wall. They are straight throughout their length and possess simple everted apertures which occupy 1/2 to 1/3 the stipe width.

Remarks. P. l. linearis is a very distinctive species; it is clearly different from Amphigraptus d. divergens (Hall 1859) which possesses only proximal secondary branching but is not necessarily distinct from P. l. simplex Elles & Wood 1903. This latter subspecies is recorded in the original description (Elles & Wood op. cit., p. 121) to be a variety "in which the main stipes have a much wider sweep and in which the secondary branches, which are simple, are few in number, generally only three on each main stipe... [which are] more regular than in the typical form, there being about 1.5cm between each branch". Although the spacing of the branches is closer than 1.5cm in the holotype of P. l. linearis it otherwise agrees more closely with this description than with Elles & Wood's description of P. l. linearis in having only four secondary branches and no tertiary ones. It is even possible that, if cladial branching may occur at any stage during astogeny, P. linearis simplex is merely an intermediate stage between the juvenile form of P. l. linearis which lacks any secondary branching and the mature form with a high density of secondary and tertiary stipes.

Mu (1950) described Pleurograptus linearis minor sp. nov. from the lower Wufeng Shale while VandenBerg (pers. comm.) reports P. linearis cf. linearis from the late Bolindian of Victoria (with an assemblage indicative of the *D. anceps* Zone of Britain). Both these forms seem similar but rather smaller than *P. l. linearis*. *Pleurograptus lui* Mu 1950, which has now been found in the Anceps Bands at Dob's Linn (p. 85), has similar long thecae but is a small narrow form with only two secondary branches. These species indicate that the genus *Pleurograptus* ranges long after the *P. linearis* Zone. Ruedemann (1908, 1947) described a specimen of '*P. linearis*' from the basal Utica Shale of New York State but its overall form does not agree closely with either *P. l. linearis* or *P. l. simplex*. Carter & Churkin (1977) described '*P. l. linearis*' from the Phi Kappa Formation of Idaho but their figured specimen appears closer to *P. l. simplex*. Thomas (1960) figured *P. l. simplex* from the Bolindian of Australia which appears similar to the specimen referred to *P. linearis* cf. *linearis* by VandenBerg.

Pleurograptus lui Mu 1950
(pl. 13, figs. 1-8)



1950 Pleurograptus lui sp. nov.; Mu, p. 3, text-figs. 2-4.
*1974 Pleurograptus lui Mu; Wang *et al*., p. 158, pl. 70, fig. 8.
*1977 Pleurograptus lui Mu; Wang *et al*., p. 308, pl. 94, fig. 9.
1978 Pleurograptus lui Mu; Wang *et al*., p. 626, pl. 197, figs. 7-8.
(* - these two figures are of the same specimen)

Holotype. G.S.C. 6624. The specimen figured by Mu 1950, text-figs. 2 and 4 (Geological Survey of China collections).

Material. Many flattened distal and a few proximal fragments collected by the writer. One almost complete specimen.

Horizons and localities. Rare specimens in all five Anceps Bands, Upper Hartfell Shale, *D. anceps* Zone, Dob's Linn.

Diagnosis. Small rhabdosome with two main and two secondary stipes which widen slowly from 0.15mm proximally to a maximum 0.5mm. Thecae straight and extremely long and thin, numbering 8-10 in 10mm.

Description. The stipes are straight and slender, reaching up to 20mm long. The main stipes are 0.3mm proximally but the secondary branches are initially only 0.15mm wide, increasing slowly throughout their length to a distal maximum of 0.5mm. The thecae number about 10 in 10mm proximally, reducing distally to about 8 in 10mm. The sicula is over 1.5mm long and stout (0.2mm wide near its aperture) with a small but conspicuous virgella up to 0.3mm long. Th1^1 and 1^2 are long, non-spinose, and grow slightly downwards for most of their length before bending slightly upwards just before their apertures. The distance between the apertures of th1^1 and 1^2 approaches 2mm. The thecae are simple, very slender and straight, narrowing slightly towards the apertures which open in shallow excavations occupying 1/2 the width of the stipe proximally and about 1/3 distally.

Remarks. This is the most slender graptolite found in the Anceps Bands at Dob's Linn. When tectonically deformed it may be confused with *Dicellograptus minor* Toghill 1970 but the two species differ in that the first pair of thecae of *P. lui* are non-spinose, the rhabdosome may possess secondary branches, the sicula is far stouter than that of any *Dicellograptus* and the thecae are more simple, being long and narrow and lacking introverted apertures and prothecal folds.

Pleurograptus linearis minor Mu 1950 is recorded from similar horizons in China (Mu 1950). VandenBerg records specimens of *Pleurograptus* from the late Bolindindian of Victoria, Australia (pers. comm.) and believes there to be little difference between the late Ordovician forms and the earlier *P. l. linearis* (Carruthers 1858). However, the writer considers that *P. lui* is very different from *P. l. linearis*, which is much more robust and has many secondary branches. The absence of any *Pleurograptus* species between the equivalents of the late *P. linearis* and *D. anceps* zones of Britain raises the problem of whether the species from the two horizons belong to the same lineage, but here they are accepted as congeneric. *P. lui* seems to occur earlier in China than in Britain as it is the zone fossil of the lowest zone of the Wufeng Shale, which is probably equivalent to the late part of the *D. complanatus* Zone of Britain. It does however range some time after this and was recorded in association with the succeeding zone fossil *Dicellograptus szechuanensis* Mu 1954 (=*D. complexus* Davies 1929) by Wang *et al.* 1974.

8.3 Genus *Amphigraptus* Lapworth 1873

Type species (by monotypy). *Graptolithus divergens* Hall 1859, p. 509, text-fig. 9.

Stratigraphical range. Upper Ordovician (*N. gracilis* to ?early *P. linearis*)

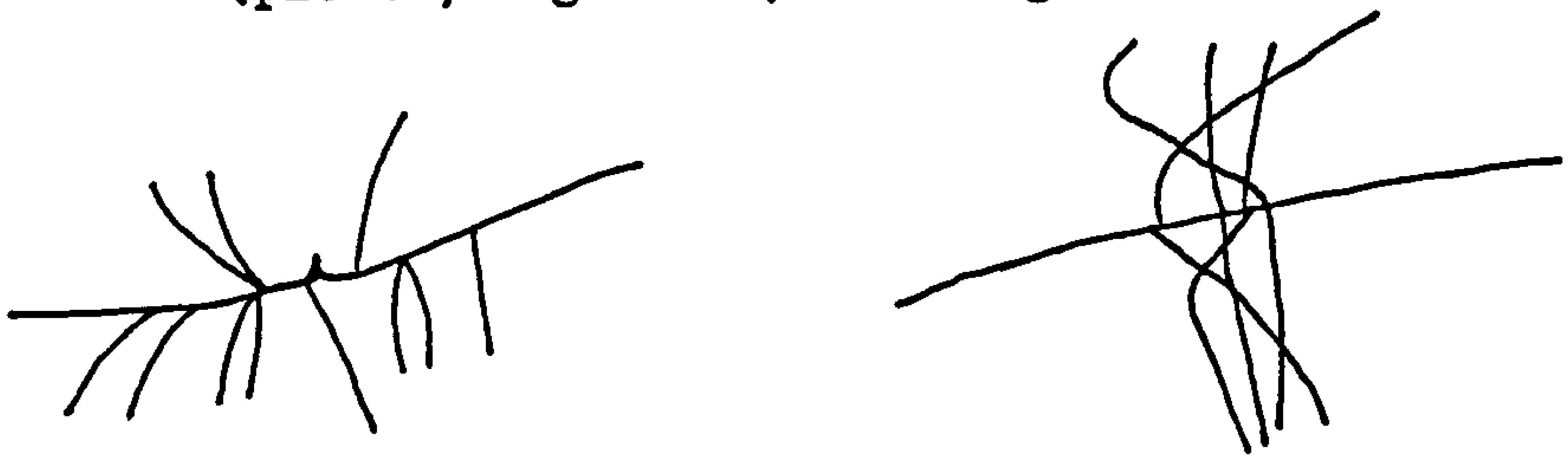
Diagnosis (from Bulman 1970, V121). Rhabdosome horizontal, composed of two straight main stipes with simple or compound, rigid lateral branches, typically produced in pairs.

Remarks. The early specimens of *Amphigraptus* are found in the equivalent of the *N. gracilis* Zone in North America, while apparently identical forms are found in the early *P. linearis* Zone of Britain, with few specimens recorded from the intervening interval. It is here considered that this 'genus' may represent a recurring *Leptograptus* mutation.

Species described.

A. divergens divergens (Hall 1859) (early *P. linearis*)

Amphigraptus divergens divergens (Hall 1859)
(pl. 14, figs. 1-4, text-figs. 19a-c)



*1859 Graptolithus divergens sp. nov.; Hall, p. 509, text-fig. 9.
*1859 Graptolithus divergens Hall; Hall, p. 57, text-fig. 9.
*1865 Graptolithus divergens Hall; Hall, pp. 12-13, text-fig. 11.
1868 Graptolithus (Coenograptus) divergens Hall; Hall, p. 179, text-fig. 12.
1876 Amphigraptus divergens (Hall); Lapworth, pl. 3, fig. 70.
1903 Amphigraptus divergens (Hall); Elles & Wood, pp. 122-123, pl. 18, fig. 1, text-fig. 73.
1908 Amphigraptus divergens (Hall); Ruedemann, pp. 271-272, text-figs. 187-190.
1947 Amphigraptus divergens (Hall); Ruedemann, pp. 372-373, pl. 59, figs. 27-32.
1977 Amphigraptus divergens (Hall); Walters, p. 950, pl. 1, fig. A.
(* - from Ruedemann 1947, not seen by writer)

Type specimen. Not traced. Hall's original specimens from the Normanskill Shale at Kenwood, New York State. Approximately N. gracilis Zone equivalent.

Material. Six flattened specimens collected by the writer.

Horizons and localities. 3.0 to 2.65m below the top of the Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn.

Diagnosis. Two long main stipes, horizontal or slightly reclined, with paired lateral branches proximally. Thecae long with simple apertures.

Description. Long primary stipes up to 30mm long with several paired secondary branches produced proximally, up to 60mm long. Most primary and secondary stipes are about 0.4mm wide proximally, widening extremely slowly to a maximum of about 0.8mm. The thecae are normally obscure but proximally number about 8-10 in 10mm. The base of the

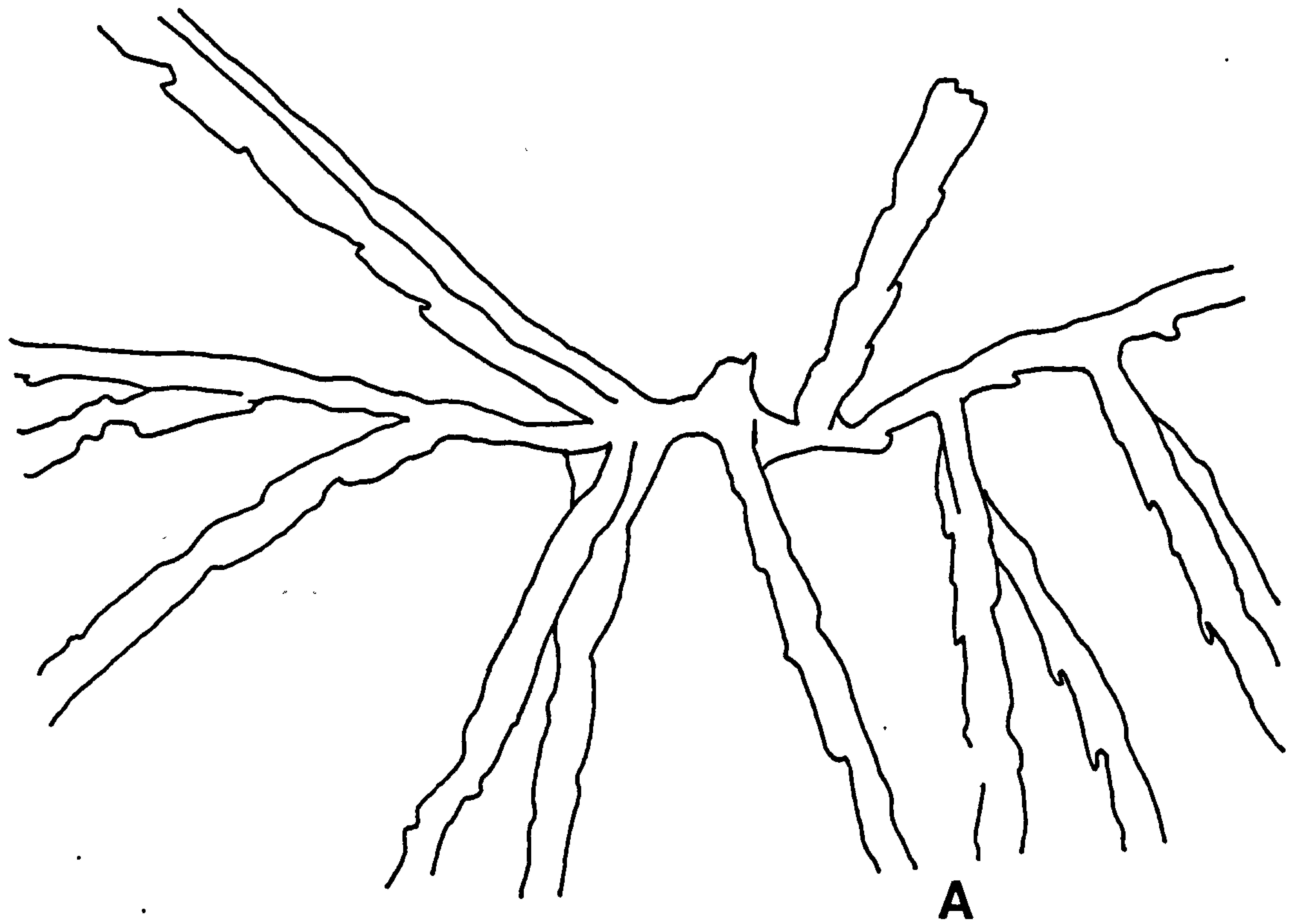
TEXT-FIGURE 19

<u>Amphigraptus</u> <u>divergens</u> <u>divergens</u> (Hall 1859).

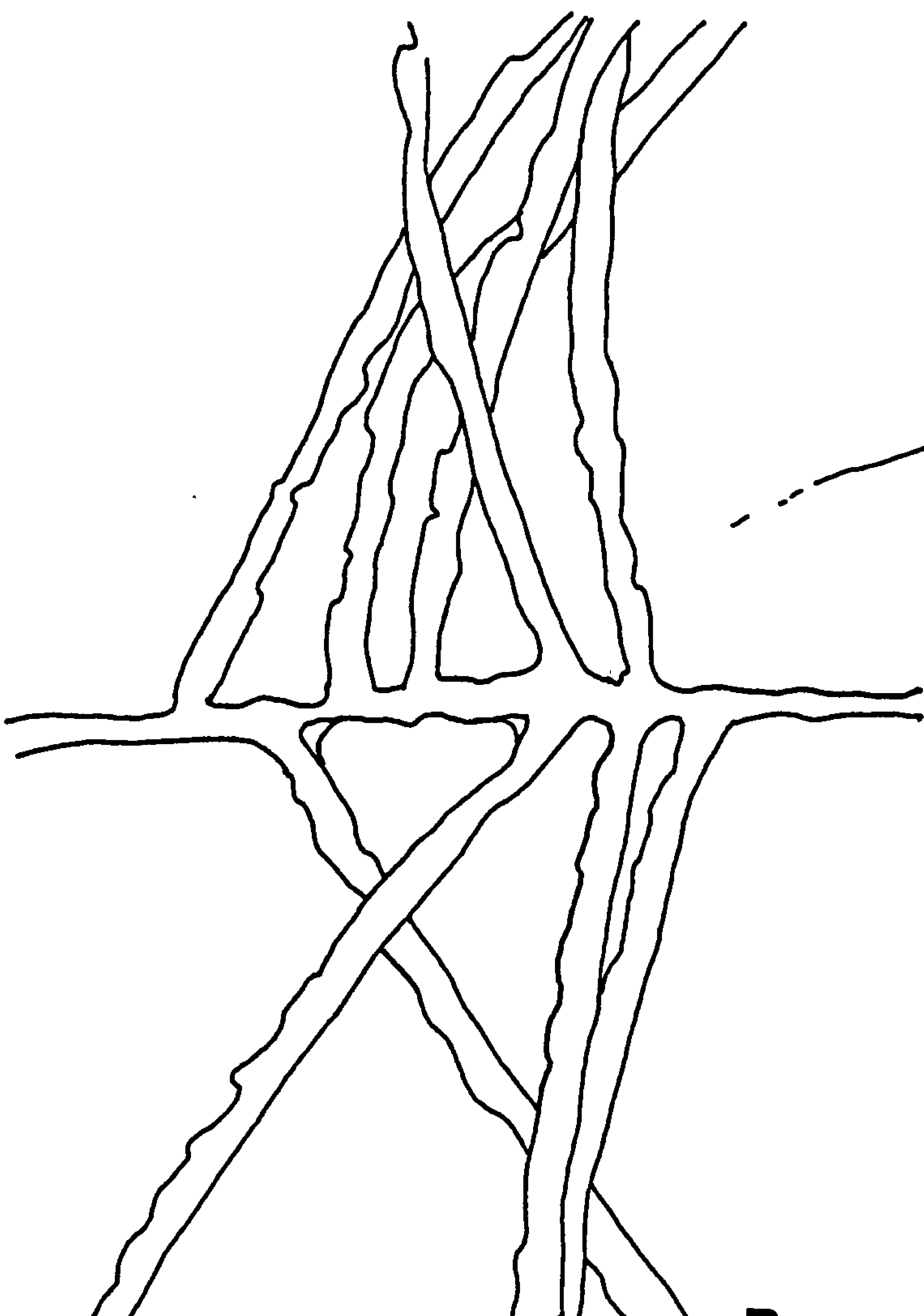
A. HM C14347a. Proximal detail showing (resorbed?) sicula, clearly paired secondary stipes and thecal style. 2.75 - 2.9m, Lower Hartfell Shale, <u>P.</u> <u>linearis</u> Zone, North Cliff trench, Dob's Linn. (x10)

B. HM C14348a. Proximal detail; central upper spine is probably produced by the sicula. 2.75 - 2.9m, Lower Hartfell Shale, <u>P.</u> <u>linearis</u> Zone, North Cliff trench, Dob's Linn. (x10)

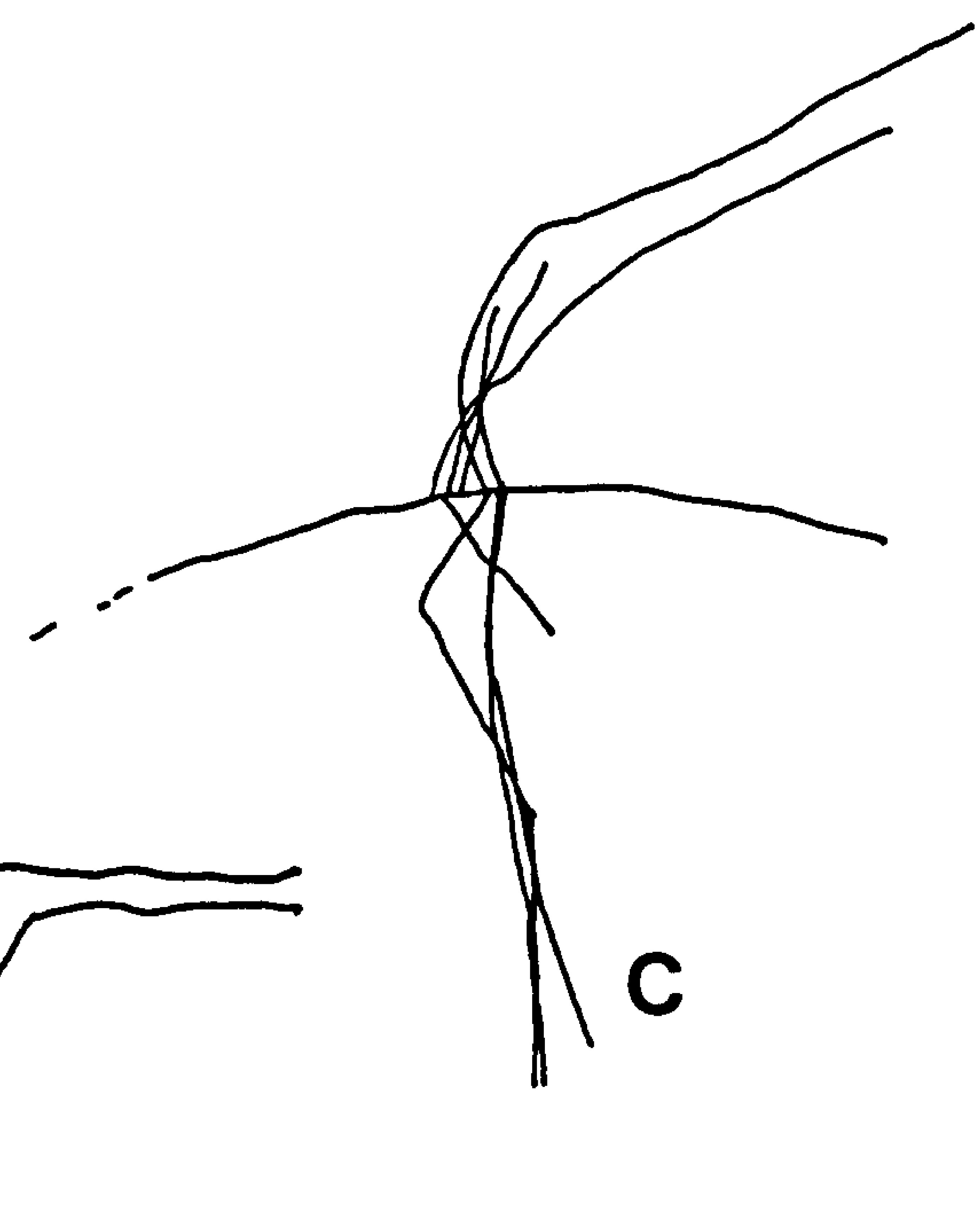
C. HM C14348a. Natural size showing overall form of rhabdosome.



A



B



C

sicula is seen in two specimens where it is apparently resorbed. The sicula of the specimen in text-figs. 19b and c apparently gives rise to a secondary stipe. The proximal development is obscured by secondary branches but seems similar to Leptograptus. The thecae are long and straight with simple apertures.

Remarks. All specimens of A. d. divergens from North America are from the equivalent of the N. gracilis Zone of Britain, while in Scotland this species appears to be confined to the P. linearis Zone (this study, Elles & Wood 1903). The remaining forms described by Elles & Wood (A. divergens radiatus Lapworth 1876 and A. distans Elles & Wood 1903) are restricted to the P. linearis and D. clingani zones. As there are no intervening occurrences it would seem highly unlikely that the American and British specimens belong to the same species, although they appear to be almost identical. It is possible that all the species of Amphigraptus are mutations of Leptograptus and should not have full generic and specific status. However, a great deal more work on well preserved specimens is needed before any further conclusions may be drawn.

Chapter 9. Family DICRANOGRAPTIDAE Lapworth 1873.

Diagnosis (adapted after Bulman 1970, V121). Uniserial or uni-biserial, reclined or initially scandent, without branches; thecae with conspicuous sigmoidal curvature and prothecal folds, introverted to a greater or lesser degree; development of "diplograptid type".

Remarks. All well preserved specimens studied by the writer possess proximal prothecal folds and it is here considered that they are always present in dicranograptids, although this is not the only family to exhibit them (e.g. Sinograptidae Mu 1957).

Genus Dicellograptus Hopkinson 1871

Type species (subsequently designated by Gurley 1896, p. 70). Didymograpsus elegans Carruthers 1867a, p. 369, pl. 2, fig. 16a.

Stratigraphical range. Latest Lower Ordovician to Upper Ordovician (G. teretiusculus to D. anceps).

Diagnosis (from Bulman 1970, V121). Rhabdosome of two reclined uniserial stipes, straight or curved.

Remarks. The thecal style of Dicellograptus is very variable from highly introverted to almost straight. Many rhabdosomes were originally spiralled to a greater or lesser degree.

Species described.

Introverted thecae with curved supragenicular walls:

D. elegans elegans (Carruthers 1867a) (P. linearis)

D. morrisi Hopkinson 1871 (D. clingani and P. linearis)

D. anceps (Nicholson 1867a) (D. anceps)

D. pumilis Lapworth 1876 (P. linearis)

Slightly introverted thecae with almost straight inclined supragenicular walls:

D. forchhammeri (Geinitz 1852) s.l. (D. clingani)

D. carruthersi Toghill 1970 (?middle P. linearis)

D. ornatus Elles & Wood 1904 (P. pacificus)

Slightly introverted proximal thecae with vertical, almost straight, supragenicular walls:

D. complanatus Lapworth 1880 (D. complanatus)

D. complexus Davies 1929 (D. anceps - D. complexus and early P. pacificus)

D. aff. complexus Davies 1929 (D. anceps - D. complexus and early P. pacificus)

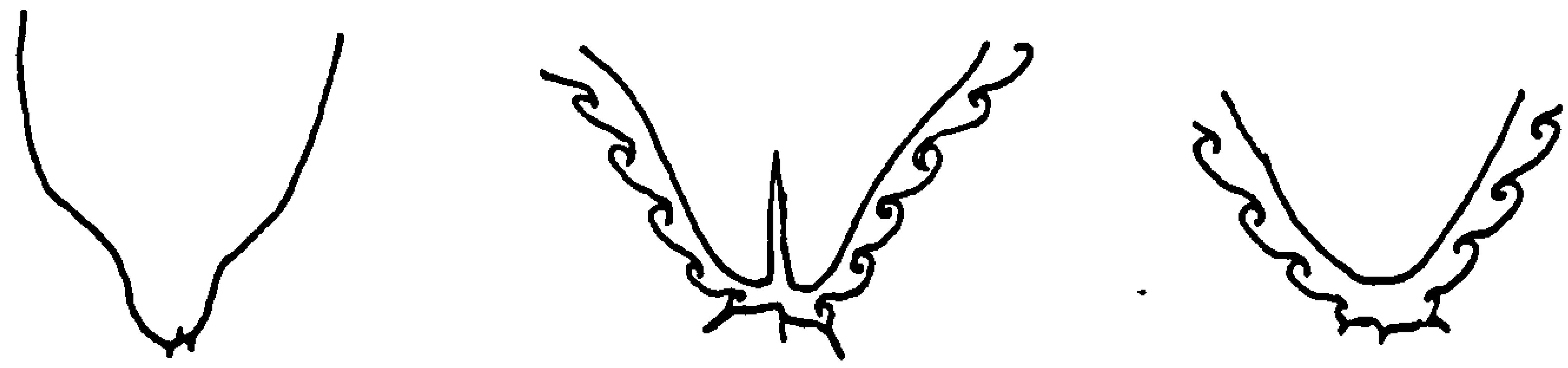
Long narrow slightly introverted thecae:

D. minor Toghill 1970 (late P. linearis/early D. complanatus to D. anceps)

Highly angular slightly introverted thecae:

D. sp. nov. (late P. linearis/early D. complanatus)

Dicellograptus elegans elegans (Carruthers 1867a)
(pl. 15, figs. 1-7, text-figs. 20a-g)



1867a Didymograpsus elegans sp. nov.; Carruthers, p. 369, pl. 2, fig. 16a.

1868 Didymograpsus elegans Carruthers; Carruthers (pars), p. 129, pl. 5, figs. 8a, ?d (non 8b, c).

1871 Dicellograpsus elegans Carruthers; Hopkinson, p. 24, pl. 1, fig. 3.

1876 Dicellograptus elegans Carruthers; Lapworth, pl. 4, fig. 87.

1877 Dicellograptus elegans Carruthers; Lapworth, p. 141, pl. 7, fig. 8.

1904 Dicellograptus elegans Carruthers; Elles & Wood, p. 159, pl. 23, figs. 2a-e, text-figs. 100a-d.

?1947 Dicellograptus elegans (Carruthers); Ruedemann, p. 380, pl. 63, fig. 1.

1954 Dicellograptus elegans (Carruthers); Sherrard, pl. 10, fig. 6.

1969 Dicellograptus elegans (Carruthers); Strachan, pp. 187-188, pl. 3, fig. 1, text-figs. 2a-b.

?1970 Dicellograptus cf. elegans (Carruthers); Toghill, pp. 19-20, pl. 9, figs. 1-3.

1977 Dicellograptus cf. D. elegans elegans (Carruthers); Carter & Churkin, pp. 19-20, pl. 2, fig. 2.

Holotype. Q 850. The specimen figured by Carruthers 1867a, pl. 2, fig. 16a, Elles & Wood 1904, pl. 23, fig. 2a and Strachan 1969, pl. 3, fig. 1, text-figs 2a, b. From the Lower Hartfell Shale, Dob's Linn.

Material. The holotype, several specimens in the Lapworth Collection (Birmingham University), several in a slab from Mount Benger Burn in the British Museum (Nat. Hist.) collections and several collected by the writer. All specimens flattened.

Horizons and localities. 3.0 to 2.5m below the top of the Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn. Other specimens from unknown horizons in the Lower Hartfell Shale of

Hartfell Spa and Mount Benger Burn, Moffat.

Diagnosis. Long fairly slender stipes normally 0.8mm wide with pronounced proximal double curvature and open axil. Thecae markedly introverted, numbering 10-12 in 10mm.

Description. The stipes are long and fairly slender, reaching over 120mm long, and with a pronounced proximal double curvature. They widen from 0.5mm at the aperture of $th1^1$ (0.6mm in mature specimens) to 0.7mm in 5mm and gradually increase to a maximum of 0.8-0.9mm distally. The axial angle varies from about 70° initially to a final angle of about 140°. Proximally the thecae number 10-12 in 10mm, reducing distally to 8-10 in 10mm. The sicula is long and slender, measuring about 2mm long when complete, with a small virgella. $Th1^1$ and 1^2 grow horizontal or slightly down throughout their length and possess sub-apertural spines up to 2mm long. $Th2^1$ and 2^2 bend gradually upwards after the apertures of the first thecal pair, giving a rounded open axil. During astogeny the sicula and thecal spines are apparently resorbed while the axil is thickened and the early apertures are almost closed, resulting in a rounded featureless proximal end in many mature rhabdosomes (text-fig. 20). All the thecae are highly introverted, opening into deep semicircular excavations which occupy 1/2 the stipe width, although distal thecae are normally obscure due to stipe torsion.

Remarks. Although both Elles & Wood (1904) and Strachan (1969) recorded the maximum stipe width as 1mm the present examination of both the type and Lapworth's specimens, together with recently collected ones, indicates a normal maximum width of 0.8mm, as recorded by Toghill (1970) for his specimens, and a rather higher maximum thecal count. The considerable astogenetic variation has not been described previously but is probably the best example of a Dicellograptus species showing resorption of both the sicula and basal spines (cf. D. ornatus Elles & Wood 1904 whose basal spines increase in size during astogeny).

The markedly introverted thecae separate D. e. elegans from many other Dicellograptus species. The only two species occurring in the P. linearis and D. clingani zones which resemble it closely are D. morrisi Hopkinson 1871 and D. moffatensis (Carruthers 1858) but these are both much stouter, have less strongly introverted thecae

TEXT-FIGURE 20

Dicellograptus elegans elegans (Carruthers 1867a) (all x5)

A. BU 1110. Juvenile specimen showing complete sicula and long thecal spines. Lower Hartfell Shale, Hartfell Spa. Lapworth Collection. Figd. Elles & Wood 1904, text-fig. 100b.

B. BU 1108. More mature specimen with slight proximal thickening and some resorption of thecal spines and sicula. Lower Hartfell Shale, Hartfell Spa. Lapworth Collection. Figd. Elles & Wood 1904, text-fig. 100a.

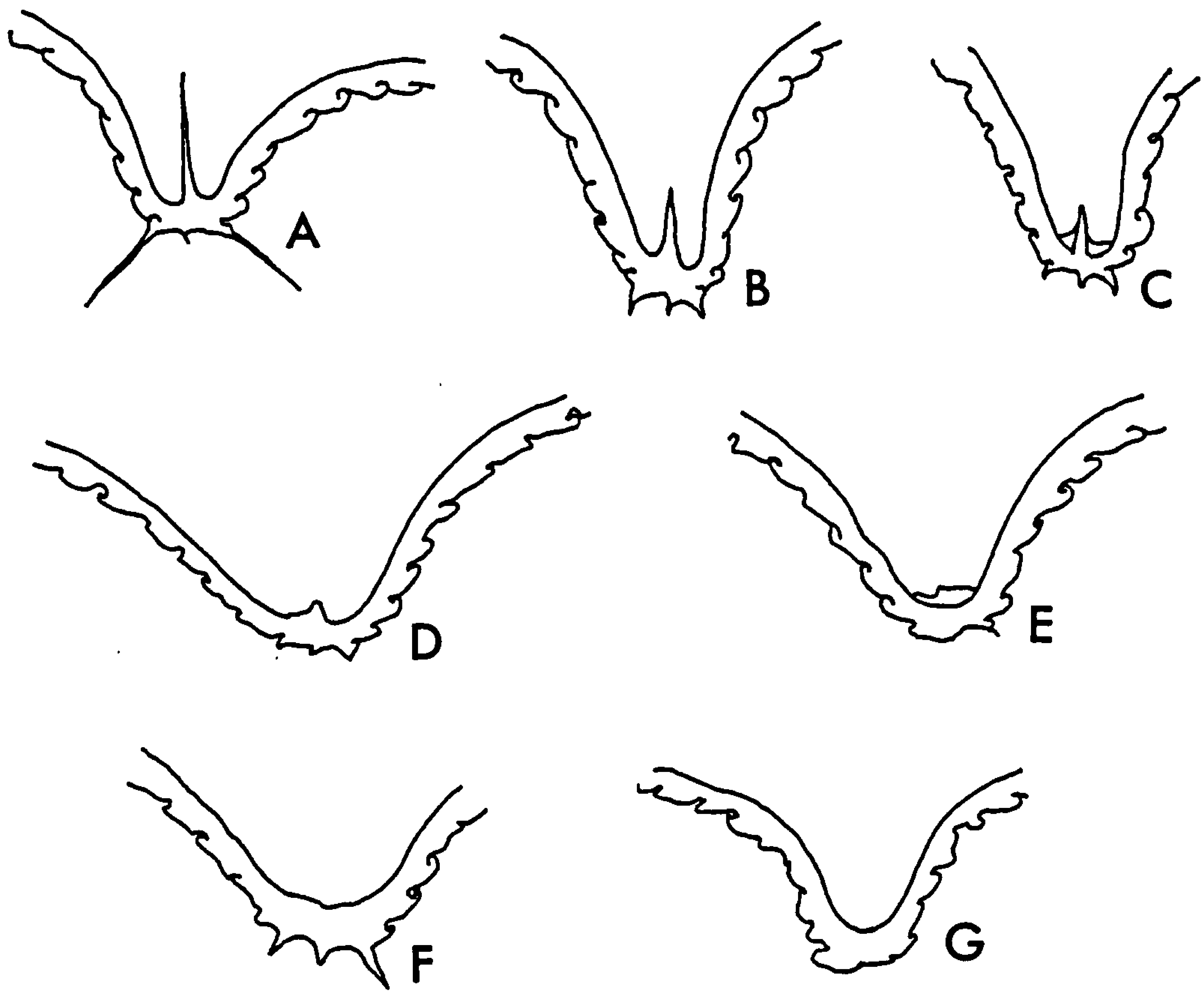
C. BU 1108. Specimen showing early development of membrane, partially resorbed sicula and thickened resorbed thecal spines. Lower Hartfell Shale, P. linearis Zone, Dob's Linn. Lapworth Collection.

D. BU 1108. Specimen with open axil and almost resorbed sicula and thecal spines. Lower Hartfell Shale, P. linearis Zone, Dob's Linn. Lapworth Collection. Figd. Elles & Wood 1904, pl. 23, fig. 2d.

E. BU 1108. Mature specimen with thickened proximal thecae, rounded dorsal wall without sicula and slight membrane. Lower Hartfell Shale, P. linearis Zone, Dob's Linn. Lapworth Collection.

F. BU 1110. Mature specimen with thickened rounded axil and reduced proximal apertures. Lower Hartfell Shale, Hartfell Spa. Lapworth Collection. (cpt. figd. Elles & Wood 1904, pl. 23, fig. 2e)

G. Q 714. Mature specimen with thickened rounded axil and proximal apertures almost completely filled. Mt. Benger Burn, Moffat. British Museum (Nat. Hist.) collections.



TEXT-FIGURE 20. (see opposite for description)

and narrower axils. Elles & Wood's (1904) subspecies D. elegans rigens lacks any sign of stipe curvature and would seem distinct from D. e. elegans although it is identical in every other respect. Elles & Wood (op. cit.) only recorded D. elegans rigens from Mount Benger Burn although Toghill (1970) assigned one of his specimens from Dob's Linn to this subspecies. Until the proximal double curvature of the rhabdosome has been explained in terms of the original three-dimensional form, further conclusions regarding the status of these two subspecies should not be drawn.

D. e. elegans s.s. does not seem to occur widely, although its range does not seem to be restricted to equivalents of the P. linearis Zone. Most Australian specimens referred to this species are other Dicellograptus with proximal curvature. VandenBerg has however collected specimens from Victoria which may be unequivocally assigned to D. e. elegans (pers. observ.). Carter & Churkin's (1977) specimens from the 'passage beds' of Idaho definitely belong to this species.

Dicellograptus morrisi Hopkinson 1871
(pl. 16, figs. 1-5)

?1867a *Didymograpsus flaccidus* Hall; Nicholson, pp. 110-111, pl. 7, figs. 1-3.

1868 *Didymograpsus elegans* Carruthers; Carruthers (*pars*), pl. 5, figs. 8b, c (non figs. 8a, d).

1871 *Dicellograpsus morrisi* sp. nov.; Hopkinson, p. 5, pl. 1, figs. 2a-h.

1876 *Dicellograptus morrisi* Hopkinson; Lapworth, pl. 4, fig. 85.

1877 *Dicellograptus morrisi* Hopkinson; Lapworth, pl. 7, fig. 6.

*1891 *Dicellograptus anceps* Hopkinson; Törnquist, p. 21, pl. 2, figs. 16-19.

1904 *Dicellograptus morrisi* Hopkinson; Elles & Wood, pp. 155-157, pl. 21, figs. 6a-d, text-figs. 98a-e.

1904 *Dicellograptus pumilis* Lapworth; Elles & Wood (*pars*), pl. 21, fig. 3c (*non* figs. a-b, d-f).

1963 *Dicellograptus morrisi* Hopkinson; Skoglund, pp. 31-32, pl. 1, figs. 1-2.

1970 *Dicellograptus morrisi* Hopkinson; Toghill, pp. 17-18, pl. 7, figs. 1-4, text-figs. 4d-f.

(* - from Skoglund 1963, not seen by writer)

Type specimen. Not yet designated.

Material. Numerous flattened specimens from the Hopkinson Collection (Sedgwick Museum), Lapworth and Wood Collections (Birmingham University), Gray, Toghill and other collections (British Museum, Nat. Hist.) and collected by the writer.

Horizons and localities. 6.7 to 1.5m below the top of the Lower Hartfell Shale, *D. clingani* and *P. linearis* zones, North Cliff trench, Dob's Linn. Specimens in the Gray Collection from the 'Ardmillan Series, Whitehouse Group', Shalloch Mill and Whitehouse Bay, Girvan (*P. linearis* Zone?). Specimens in the Lapworth Collection from an unknown locality in Sweden. Specimens in the British Museum (Nat. Hist.) collections, labelled '*D. elegans*' from an unknown locality in Victoria, Australia.

Diagnosis. Stipes over 90mm long, rapidly widening from 0.5mm to a maximum 1.2mm. Axial angle 30 to 60°, axil rounded. Thecae number 9-14 in 10mm, with curved supragenicular walls and introverted apertures.

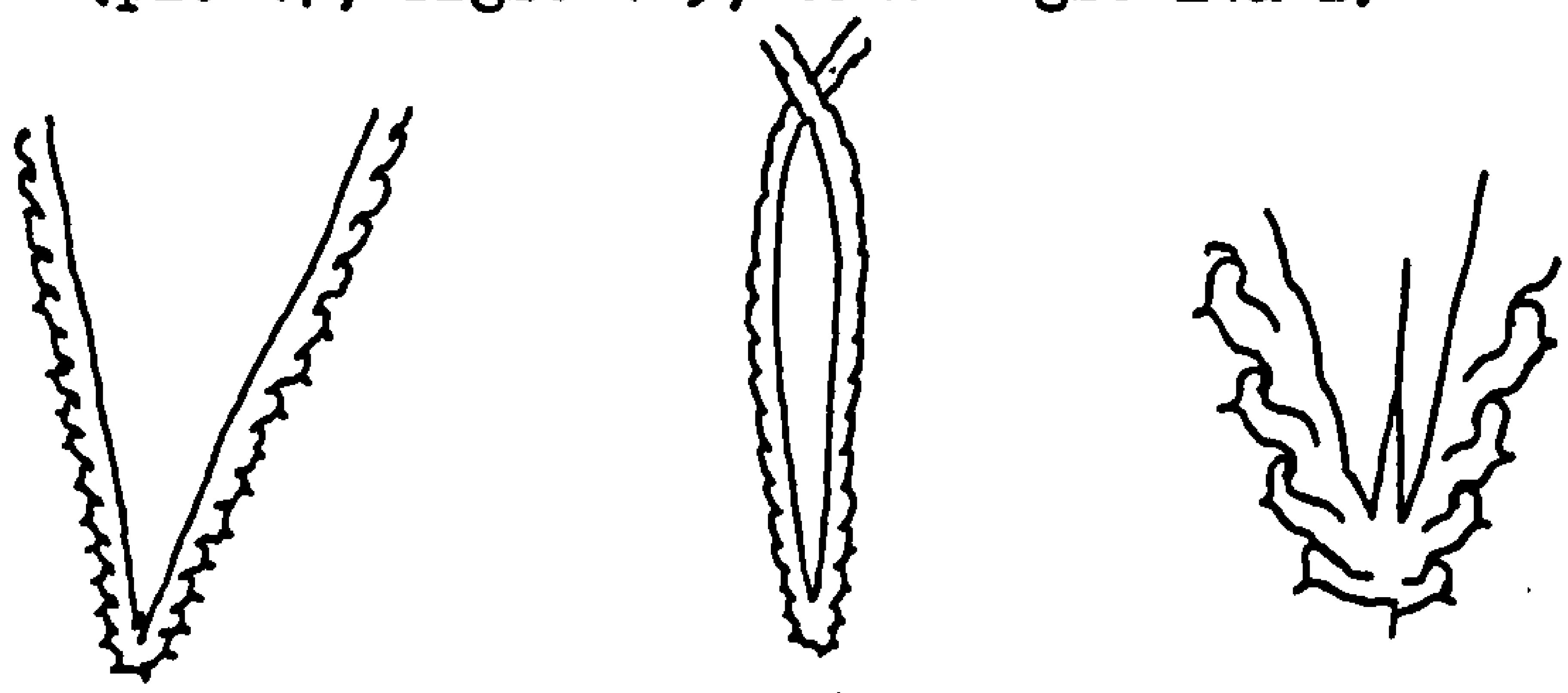
Description. The stipes are over 90mm long with a distal convex curvature and stipe torsion which may be right or left-handed. Slight proximal double curvature commonly occurs on one stipe only. The axial angle varies from 30 to 60° but is normally about 45°. The stipes are 0.5-0.6mm wide proximally, rapidly increasing to the maximum 1.2-1.3mm within 20mm which is then maintained. Proximally the thecae number 12-14 in 10mm, reducing distally to 9-10 in 10mm. The sicula is invariably missing in mature specimens, probably due to resorption. In immature specimens it measures 1.5mm long and possesses an inconspicuous virgella. $Th1^1$ and 1^2 grow horizontal or slightly downwards throughout their length and bear small sub-apertural spines. $Th2^1$ and 2^2 initially grow parallel to $th1^1$ and 1^2 but bend upwards after the first apertures, producing a rounded axil. The second and third thecal pairs sometimes bear mesial spines while Skoglund (1963) stated that these may occur on up to the eleventh pair of thecae. The later non-spinose thecae have slight genicula, curved supragenicular walls and moderately introverted apertures which open into semicircular excavations occupying 1/2 the total stipe width proximally but only 1/3-1/4 distally. Prothecal folds are commonly conspicuous in the proximal dorsal walls.

Remarks. *D. morrisi* appears very similar in thecal style to the later species *D. anceps* (Nicholson 1867a) although this has a greater number of spinose thecae, is rather more robust and normally has a narrower axil due to an originally more tightly spiralled rhabdosome. When the thecae are well preserved *D. morrisi* is easily separable from *D. forchhammeri* (Geinitz 1852) s.l. by the almost *Leptograptus* - like thecae of the latter species. However, most specimens of *D. morrisi* from the Lower Hartfell Shale have indistinct thecae; in this case the species may only be separated on the unreliable criteria of stipe width and form. *D. forchhammeri* has more slowly widening stipes, a

narrower maximum width (normally 0.9mm), more openly divergent stipes which apparently lack any torsion and commonly possesses a complete sicula in mature specimens. D. johnstrupi Hadding 1915 has a similar rhabdosome form to D. morrisi but has more simple thecae with straight supragenicular walls and only slightly introverted apertures.
D. carruthersi Toghill 1970 has similar thecae to D. johnstrupi and has more slender stipes than either this or D. morrisi. D. pumilis Lapworth 1876 differs from D. morrisi in having less introverted thecae and fairly short stipes which widen more gradually to a normal maximum width of 0.9mm. D. e. elegans (Carruthers 1867a) has highly introverted thecae and a conspicuous form that is readily separable from D. morrisi although some workers, especially in Australia, have identified specimens of D. morrisi and other Dicellograptus specimens as D. e. elegans owing to the slight proximal double curvature commonly found in this genus. This curvature is due to the flattening of an originally openly spiralled rhabdosome and is an unreliable criterion for taxonomic differentiation (Williams 1981). D. moffatensis (Carruthers 1858) has a broadly similar thecal style to D. morrisi but a much more robust form with a typical proximal width of 0.7-0.8mm and a maximum width of 1.3mm. The presence of an axilliary membrane is an unreliable taxonomic criterion as many mature Dicellograptus possess one (e.g. D. e. elegans, D. ornatus Elles & Wood 1904).

Although D. morrisi has not been widely recorded it definitely occurs in Scandinavia (Skoglund 1963, pers. observ.) and Australia (pers. observ.) and it appears that it may have been recorded under a variety of other species names elsewhere.

Dicellograptus anceps (Nicholson 1867a)
(pl. 17, figs. 1-9, text-figs. 21a-i)



1867a Didymograpsus anceps n. sp.; Nicholson, p. 110, pl. 7, figs. 18-20.
1870 Didymograpsus anceps Nicholson; Nicholson, p. 351, pl. 7, fig. 5.
1871 Dicellograpsus anceps Nicholson; Hopkinson, p. 26, pl. 1, figs. 5a, b.
1876 Dicellograptus anceps Nicholson; Lapworth, pl. 4, fig. 82.
1877 Dicellograptus anceps Nicholson; Lapworth, pl. 7, fig. 5.
1904 Dicellograptus anceps Nicholson; Elles & Wood, pp. 141-143, pl. 20, figs. 3a-e.
1970 Dicellograptus anceps (Nicholson); Toghill, pp. 10-12, pl. 2, figs. 1-7, pl. 3, figs. 2-7, text-figs. 2a-f, 4a.

Lectotype. Q 3047. The specimen possibly figured by Nicholson 1867a, pl. 7, fig. 19, from Dob's Linn. Designated by Toghill 1970, p. 10.

Material. Specimens from the Nicholson and Toghill collections (British Museum, Nat. Hist.), Lapworth Collection (Birmingham University), Ingham Collection (Hunterian Museum) and many specimens collected by the writer.

Horizons and localities. All five Anceps Bands, Upper Hartfell Shale, D. anceps Zone, Dob's Linn. Shalloch Formation, D. anceps Zone, Cautleyan Stage, Girvan. Cautley Mudstones, Rawtheyan Stage, River Rawthey, Cautley.

Diagnosis. Rhabdosome with narrowly divergent, originally openly spiralled stipes. Thecae introverted, numbering 9-11 in 10mm. Many early thecae with short mesial spines. Axil narrow and rounded, sicula commonly preserved.

Description. Distal fragments greater than 60mm long are known although no complete specimens of this size have been observed. The stipes are either straight or slightly curved with gentle left or right-handed torsion and may diverge continuously at an angle of 0 to 45° or cross distally, indicating the original openly spiralled form of the rhabdosome. In tectonically undeformed specimens the stipes are 0.6mm wide at the aperture of $th1^1$, increasing to 0.8-0.9mm in 5mm and gradually reaching the maximum width of 1.2mm within 15mm. The maximum width may vary between 0.9 and 1.5mm when tectonic deformation has occurred. Proximally the thecae number 11 in 10mm, reducing distally to about 9 in 10mm. The sicula is commonly seen in both juvenile and mature specimens; it is 1.7-2.0mm long with an inconspicuous virgella but prominent nema in immature specimens. It may lie either symmetrically between the stipes or attached to $th1^1$ and 2^1. $Th1^1$ grows horizontal or slightly downwards for most of its length before turning upwards after the mesial spine. $Th1^2$ initially grows horizontally but bends upwards before the mesial spine. $Th2^1$ and 2^2 grow upward for the whole of their length. This results in a very narrow but rounded axil with initially sub-parallel stipes. Specimens in Anceps Band E at Dob's Linn commonly develop an axial membrane which reaches up to the aperture of $th4^2$ (text-figs. 21h, i). Specimens from lower horizons only show the normal secondary proximal thickening common in Dicellograptus with no hint of a membrane. The proximal thecae are fairly introverted, opening into deep excavations which occupy about 1/2 the total width of the stipe and possess thickened genicular hoods. The supragenicular walls are divided into proximal dorsally sloping and distal ventrally sloping parts, separated by mesial spines in at least the first fifteen thecal pairs. The spines are however only visible when the thecae are preserved in full dorso-ventral orientation and are commonly not seen. They are formed during the initial development of the thecae and do not appear to change appreciably in size or number after the initial formation of the thecae. The interthecal septa are sigmoidally curved and terminate proximally in thickened nodes. Proximal thecae commonly show prothecal folds. The distal thecae are rarely seen in full dorso-ventral view owing to stipe torsion but are simpler in character with straight, dorsally inclined supragenicular walls, little introversion, narrow excavations and straighter interthecal septa.

Remarks. The proximal spinose thecae of D. anceps clearly separate it from all other coeval Dicellograptus species, while the thecal style shows it to belong to a different lineage from such species as

TEXT-FIGURE 21

Dicellograptus anceps (Nicholson 1867a) (all x7.5)

All specimens from the Anceps Bands, Upper Hartfell Shale, D. anceps Zone (D. complexus and P. pacificus subzones), Dob's Linn.

A. HM C13347a. Juvenile specimen showing complete sicula and sub-parallel stipes. Band B, Main Cliff.

B. HM C13332. Complete sicula with nema and dorsal wall with conspicuous prothecal folds. Band B, Main Cliff.

C. HM C13495a. Complete sicula with nema. Band D, Long Burn trench.

D. HM C13616a. Mature specimen with sicula and proximal membrane up to the aperture of $th2^1$. Band E, Linn Branch trench.

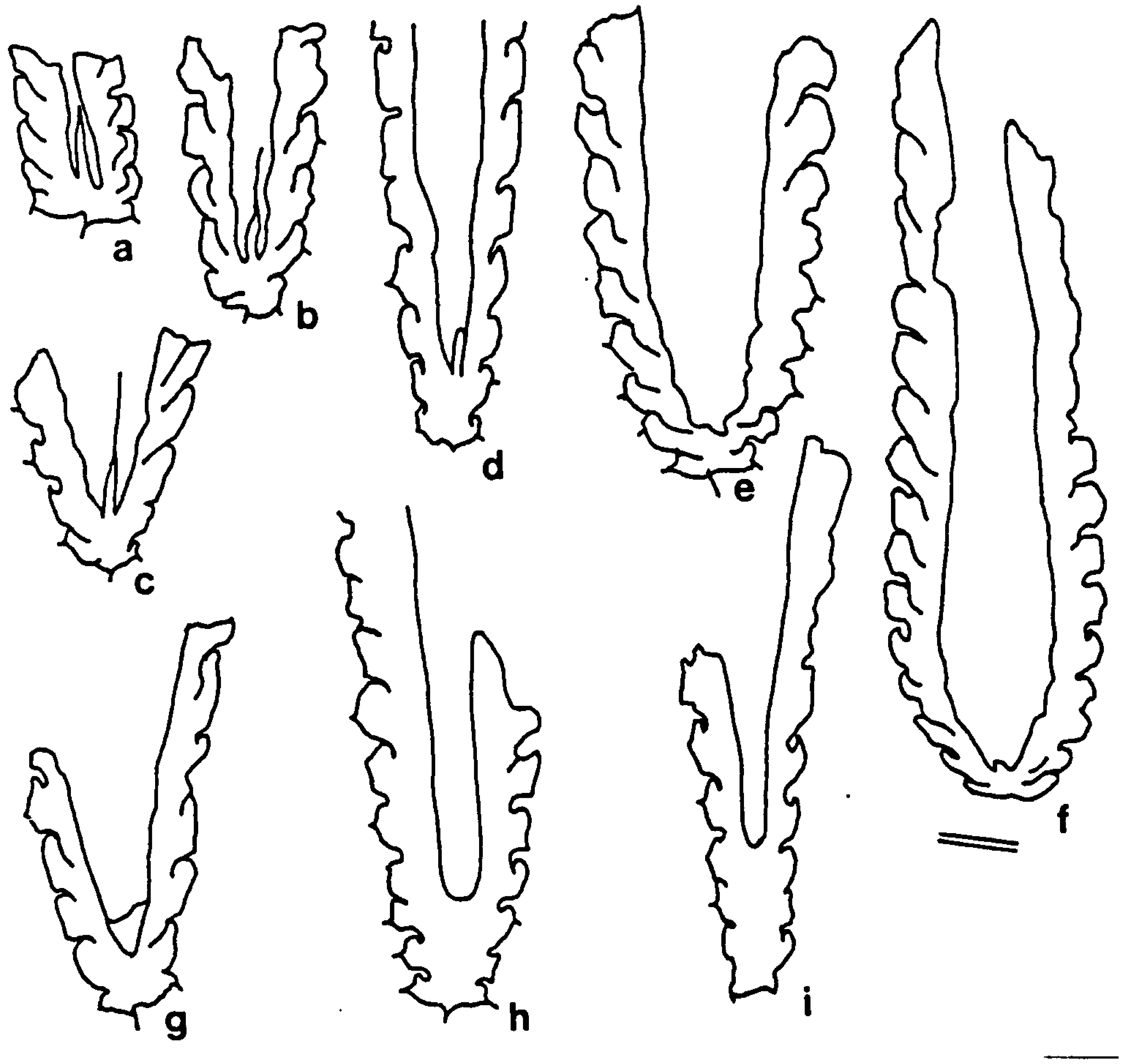
E. HM C13364a. Tectonically widened specimen with prominent thecal spines. Band B, Main Cliff.

F. HM C13315/1. Tectonically widened specimen (bar shows direction of lineation). Band B, Linn Branch trench.

G. HM-C13688. Specimen with basal membrane just beyond the aperture of $th2^2$. Band E, Main Cliff.

H. HM C13644a. Specimen with basal membrane up to the aperture of $th3^2$. Band E, Linn Branch trench.

I. HM C13625. Specimen with basal membrane up to the aperture of $th4^1$, giving 'Dicranograptus-like' appearance. Band E, Linn Branch trench.



TEXT-FIGURE 21. (see opposite for description)

D. complanatus Lapworth 1880, D. complexus Davies 1929 and D. ornatus Elles & Wood 1904. The thecae of D. anceps are most closely comparable with D. morrisi Hopkinson 1871 and it is suggested here that they may represent part of an evolutionary lineage, together with a possible intermediate form recently recorded from the Lower Bolindian (equivalent of part of the British D. complanatus Zone) of Victoria, Australia (VandenBerg, pers. comm.). The Australian form is almost identical to D. anceps but with fewer spinose thecae.

D. anceps is abundant in the D. anceps Zone of southern Scotland. It only occurs rarely in the Rawtheyan of northern England (Ingham & Wright 1970) and has been recorded from Wales (Jones 1909, Pugh 1923) and Northern Ireland (Clark 1902, Fearnsides et al. 1907). There are no certain occurrences recorded from outside Britain; Skoglund (1963, p. 32) considered that the specimens recorded as D. anceps by Törnquist (1879, 1891) were actually D. morrisi. Hall (1898) and Thomas (1960) recorded, but did not figure, specimens from Australia, as did Decker (1936) from North America. Several Chinese authors (e.g. Wang *et al.* 1978) have described and figured specimens as *D. anceps* but the plates are not sufficient to allow any conclusions regarding the validity of their identifications to be substantiated. *D. anceps* therefore appears to have a restricted geographical distribution in contrast to the majority of most other late Ordovician graptolite species.

Dicellograptus pumilis Lapworth 1876
(pl. 18, figs. 1-10)

1876 Dicellograptus pumilis sp. nov.; Lapworth, pl. 4, fig. 81.

1904 Dicellograptus pumilis Lapworth; Elles & Wood (pars), p. 149, pl. 21, figs. 3a, b, d-f, text-figs. 92a, b (non pl. 21, fig. 3c).

?1915 Dicellograptus pumilis Lapworth; Hadding, pp. 23-24, pl. 3, fig. 11.

?1964 Dicellograptus pumilis Lapworth; Obut & Sobolevskaya, p. 40, pl. 6, figs. 3-5.

Type specimen. No specimen corresponding with Lapworth's original figure has been found.

Material. Numerous flattened specimens in the Lapworth Collection (Birmingham University), the collections of the British Museum (Nat. Hist.) and collected by the writer.

Horizons and localities. 5.25m below to the top of the Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn. Specimens in the Lapworth and British Museum (Nat. Hist.) collections from the Lower Hartfell Shale of Hartfell Spa.

Diagnosis. Short stipes up to 25mm long, gradually widening from 0.4-0.5mm to a maximum of 0.6-0.9mm, axial angle 30 to 60°. Thecae with gently curved supragenicular walls and slightly introverted apertures, numbering 12 in 10mm.

Description. The rhabdosome is small with almost straight stipes up to 25mm long and an axial angle of 30 to 60°. The stipes widen almost imperceptibly from 0.4-0.5mm proximally to a maximum of 0.6-0.9mm in about 12mm which is then maintained. The thecae number an almost constant 12 in 10mm throughout the rhabdosome. The sicula is about 1.5mm long and is commonly preserved complete. Th1^1 and 1^2 grow horizontal initially but bend up just before their apertures while th1^1 and 2^2 grow upwards throughout their length, producing a rounded axil. The virgella and sub-apertural spines of th1^1 and 1^2 are normally inconspicuous but one specimen (pl. 18, fig. 8) possesses a thickened spine 0.5mm long. The thecae are normally poorly preserved; the geniculum is indistinct and the proximal portion of the supragenicular wall is straight and inclined while the distal portion bends inwards. This gives gently curved supragenicular walls and slightly introverted apertures which occupy 1/3 of the stipe width proximally. Prothecal folds are only occasionally visible in the proximal dorsal walls.

Remarks. Specimens of *D. pumilis* are normally poorly preserved without any clearly visible thecae. Identification therefore relies on the unreliable criteria of stipe width and form; the almost imperceptible widening distinguishes it from *D. morrisi* Hopkinson 1871, *D. forchhammeri* (Geinitz 1852) s.l. and other species occurring at similar horizons. There are many other slender *Dicellograptus* in the late *D. clingani* Zone of Dob's Linn which rarely have any clearly visible thecae; these have much longer, commonly crossing, stipes, indicating a fairly tight original spiral which *D. pumilis* does not appear to have possessed. *D. carruthersi* Toghill 1970 has similar stipe widths but the thecae are more simple than those of *D. pumilis* with straight supragenicular walls.

D. pumilis has been described from Scandinavia by Hadding (1915) and from Russia by Obut & Sobolevskaya (1964) but the illustrations are insufficient to allow confirmation of either identification. It has also been described, but not figured, by Berry (1960) from Texas and recorded by Thomas (1960) from Australia.

Dicellograptus forchhammeri (Geinitz 1852) sensu lato
(pl. 19, figs. 1-5)

?1852 Cladograpsus forchhammeri sp. nov.; Geinitz, p. 31, pl. 5, figs. 28-31.

1871 Dicellograpsus forchhammeri Geinitz; Hopkinson, pp. 4-5, pl. 1, figs. 1a-d.

1876 Dicellograptus forchammeri Geinitz; Lapworth, pl. 4, fig. 88.

1877 Dicellograptus forchammeri Geinitz; Lapworth, pl. 7, fig. 7.

1904 Dicellograptus forchammeri Geinitz; Elles & Wood, pp. 150-152, pl. 22, figs. 1a-d, text-figs. 94a-d.

Type material. Geinitz' original specimens from Bornholm were housed in Dresden and destroyed during the Second World War.

Material. Numerous flattened specimens in the Lapworth Collection (Birmingham University), Sedgwick Museum, British Museum (Nat. Hist.) and collected by the writer.

Horizons and localities. 8.5 to 4.9m below the top of the Lower Hartfell Shale, D. clingani Zone, North Cliff trench, Dob's Linn. Previous collections from the Lower Hartfell Shale of Dob's Linn, Hartfell Spa and Syart Law.

Diagnosis. Stipes over 100mm long, straight or gently curved, widening gradually from 0.4mm to 0.9mm maximum in 20mm. Axial angle 45 to 120°. Thecae simple, almost Leptograptus-like, numbering 9-12 in 10mm.

Description. The stipes are long, occasionally exceeding 100mm, and are straight or with a slight proximal concave and a distal convex curvature. They widen slowly from 0.4mm proximally to the maximum 0.9mm within about 20mm. The axial angle is very variable from 45 to 120°. Proximally the thecae number 12 in 10mm, reducing distally to 9-10 in 10mm. The sicula is often present in mature specimens and bears a small but conspicuous virgella. $Th1^1$ and 1^2 grow horizontal or slightly downwards throughout their length and possess conspicuous apertural spines. $Th2^1$ and 2^2 grow initially parallel to the first thecal pair but bend slightly upwards after the first apertures. Occasionally they also possess very small apertural spines. The remaining thecae have an almost Leptograptus-like appearance with straight inclined supragenicular walls and little or no genicula although the apertures are very slightly introverted, opening into excavations which occupy 1/2 to 1/3 the total stipe width. Prothecal folds are sometimes apparent in the proximal dorsal walls.

Remarks. Although the specimens agree well with Elles & Wood's figured material it is uncertain whether they belong to the same species as Geinitz' original material. Dr. M. Bjerreskov has recently collected topotype material (pers. comm.) but has not yet described it. As there has obviously been confusion in the past over both D. f. forchhammeri and D. forchhammeri flexuousus Lapworth 1876 owing to Geinitz' inadequate idealised illustrations (e.g. Dr. J. Riva (pers. comm.) considers that Hadding's 'topotype' material of D. f. forchhammeri described in 1915 could be a Leptograptus species) further discussion concerning the species is left until Bjerreskov has described her material.

Dicellograptus carruthersi Toghill 1970
(pl. 20, figs. 1-4)

1970 Dicellograptus carruthersi sp. nov.; Toghill, p. 18, pl. 7, figs. 5-6, text-fig. 4c.

Holotype. Q 2915. The specimen figured by Toghill 1970, pl. 7, fig. 6, text-fig. 4c. From the Lower Hartfell Shale, P. linearis Zone, Dob's Linn.

Material. Toghill's type collection (British Museum, Nat. Hist.) and about ten specimens collected by the writer.

Horizons and localities. 0.6m below the top to the top of the Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn.

Diagnosis. Stipes straight, up to 45mm long, gradually increasing from 0.4mm wide to a maximum 0.8mm. Axial angle normally 30°. Thecae with almost straight supragenicular walls, slightly introverted apertures and numbering 8-12 in 10mm.

Description. The stipes are straight and slender, gradually increasing in width throughout from 0.4mm proximally to a maximum 0.8mm. A slight degree of torsion is evident in the largest specimens. The axial angle is 30 to 45°. Proximally the thecae number 10-12 in 10mm, reducing distally to 8-10 in 10mm. The sicula has not been observed complete but bears a short inconspicuous virgella. Th1^1 and 1^2 grow initially horizontal or slightly down but bend upward before their apertures at the point where they produce small mesial spines, resulting in a narrow, rather angular axil. The remaining thecae have slight genicula and straight or slightly concave, sub-vertical supragenicular walls. The apertures are slightly introverted, opening into excavations which occupy 1/2 to 1/3 the total stipe width.

Remarks. The only species in equivalents of the *P. linearis* Zone with similar thecal style to *D. carruthersi* is *D. johnstrupi* Hadding 1915. It is possible that the two are related but *D. johnstrupi* (from Scandinavia) has more robust stipes up to 1.2mm wide and a greater degree of torsion and distal convex curvature, indicating an originally more tightly spiralled rhabdosome. Contrary to Toghill *D. carruthersi* has little resemblance to *D. morrisi* Hopkinson 1871 but the stipe widths are comparable to *D. pumilis* Lapworth 1876. Even when the thecae are not well preserved the narrow angular axil of *D. carruthersi* distinguishes it from the open rounded one of *D. pumilis*. *D. carruthersi* has not been recorded by any authors since Toghill's original description.

Dicellograptus ornatus Elles & Wood 1904
(pl. 21, figs. 1-7, text-figs. 22a-f)

1904 Dicellograptus complanatus var. ornatus var. nov.; Elles & Wood (pars), pp. 140-141, pl. 20, figs. 2a, b (non 2c), text-figs. 85a, b.

1906 Dicellograptus complanatus Lapworth var. ornatus Elles & Wood; Hall, p. 273, pl. 34, fig. 3.

1947 Dicellograptus complanatus Lapworth var. ornatus Elles & Wood; Ruedemann, pp. 377-378, pl. 62, figs. 16-20.

1960 Dicellograptus complanatus var. ornatus Elles & Wood; Berry, p. 74, pl. 20, fig. 3.

1963 Dicellograptus ornatus Elles & Wood; Churkin, pl. 3, fig. 40.

1963 Dicellograptus complanatus var. ornatus Elles & Wood; Ross & Berry, pp. 103-104, pl. 6, figs. 8, 12, 13, 17, 19.

1970 Dicellograptus ornatus Elles & Wood; Toghill, pp. 14-16, pl. 6, figs. 2-4, text-figs. 3a, b.

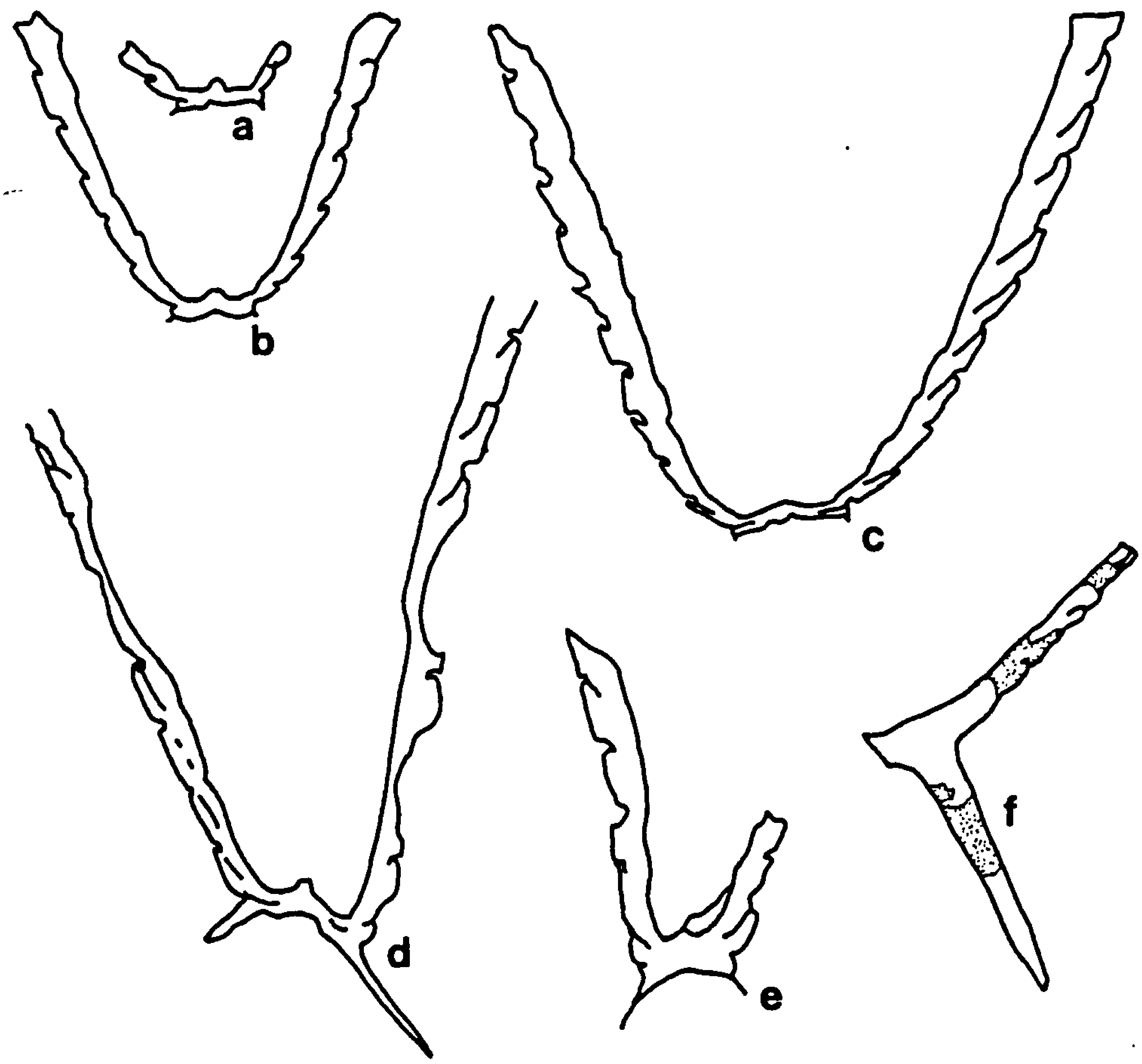
1978 Dicellograptus ornatus Elles & Wood; Wang et al., p. 629, pl. 203, fig. 17.

1980 Dicellograptus ornatus ornatus Elles & Wood; Koren et al., pp. 121-122, text-fig. 29e.

Lectotype. SM A19332. The specimen figured by Elles & Wood 1904, pl. 20, fig. 2b. From the Upper Hartfell Shale, D. anceps Zone, Dob's Linn. Designated by Toghill 1970, p. 14.

Material. The lectotype and two paralectotypes from the Elles Collection (Sedgwick Museum) and nineteen specimens collected by the writer.

Horizons and localities. Anceps Bands D and E, Upper Hartfell Shale, P. pacificus Subzone, Dob's Linn.



TEXT-FIGURE 22. Dicellograptus ornatus Elles & Wood 1904 (all x7.5) From the Anceps Bands, Upper Hartfell Shale, P. pacificus Subzone, Dob's Linn.

A. HM C13622. Juvenile specimen, Band E, Linn Branch trench.

B. HM C13666. Young specimen with small spines. Band E, Long Burn trench.

C. HM C13552a. Fairly large specimen but with small spines. Band D, Linn Branch trench.

D. SM A19331a. Mature specimen with large spines. Figd. Elles & Wood 1904, pl. 20, fig. 2a, text-fig. 85a; Toghill 1970, pl. 6, fig. 3, text-fig. 3b.

E. HM C13636. Fairly mature specimen with small spines but with beginnings of axial membrane. Band E, Linn Branch trench.

F. HM C13619a. Very robust spine and thickened proximal thecae. Band E, Linn Branch trench.

Diagnosis. Rhabdosome with large basal spines. Stipes usually straight or distally with slight convex curvature, widening from 0.3 to 0.8mm within 8mm, axial angle 30°. Thecae slightly introverted, numbering 8-13 in 10mm. Sicula rarely preserved.

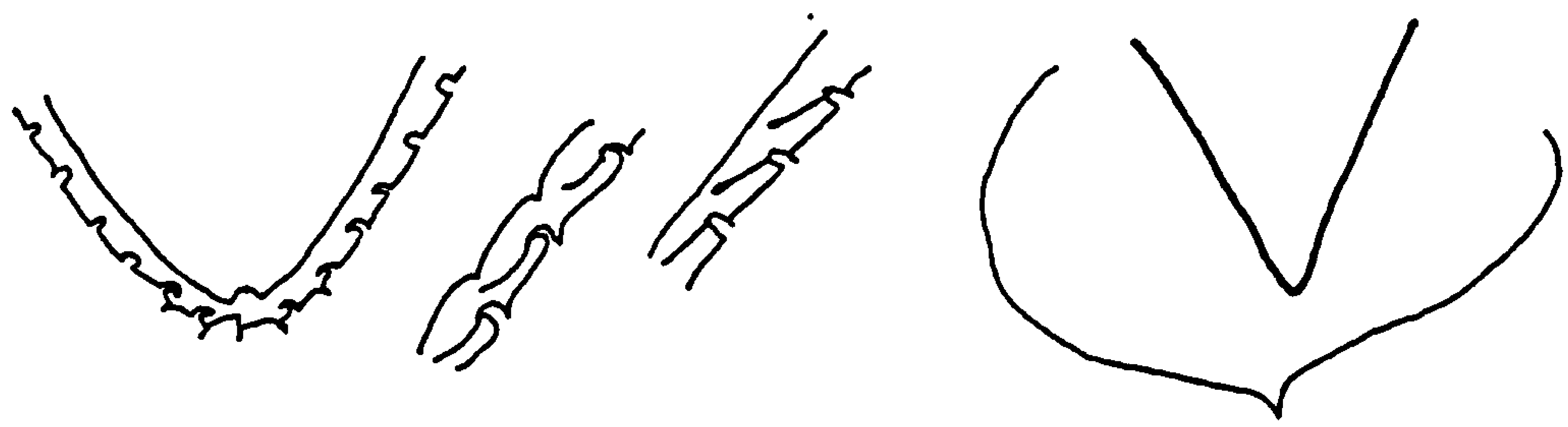
Description. The largest stipe fragment observed is 20mm long. They are normally straight but occasionally show slight proximal double curvature and are distally convex; they normally exhibit gentle torsion. The axial angle is commonly 30° but varies from 0 to 100°. The stipes are 0.3mm wide at the aperture of $th1^1$, widening to about 0.4-0.5mm in 5mm and reaching the maximum 0.7-0.8mm within 8mm. Proximally the thecae number 12-13 in 10mm, decreasing distally to 8 in 10mm. $Th1^1$ and 1^2 are slightly deflexed, $th2^1$ grows parallel to $th1^1$ before bending abruptly upwards while $th2^2$ grows upwards more steadily and is only slightly curved. Juvenile specimens have a round open axil with approximately 1.7mm between the spines of $th1^1$ and 1^2 but the axil appears narrower and more angular in mature specimens, the normal distance between the spines decreasing to about 1mm, and may be filled by a membrane reaching up to the aperture of $th6^2$ (pl. 21, fig. 1). No complete sicula has been observed. $Th1^1$ and 1^2 bear sub-apertural spines which are initially small but grow longer and stouter throughout astogeny to give a maximum width of 0.4mm and lengths in excess of 3.5mm. Proximal and distal thecae are similar in style with slight genicula and straight, gently inclined supragenicular walls. The apertures are slightly introverted, opening into narrow excavations which occupy approximately 1/3 the total width of the stipe. Interthecal septa are straight and slope at about 30° to the dorsal wall.

Remarks. The most distinctive feature of D. ornatus is the astogenetic change of the proximal region with the remarkable growth of the basal spines, pronounced secondary thickening of the early thecae and development of an axial membrane (text-figs. 22 a-f). While many Dicellograptus species show proximal thickening and resorption of the sicula and a few possess axial membranes in mature specimens (e.g. D. moffatensis (Carruthers 1858), D. anceps (Nicholson 1867a)) the extraordinary development of the basal spines is unique to D. ornatus. The reasons for the development is unknown but the growth of such long spines appears to pose a problem if the model of cortical secretion by mobile zooids (Crowther & Rickards 1977) is accepted owing to the required length of zooids. If well preserved, isolated material is available in the future investigation of the spines with the SEM should prove valuable.

The thecal style of D. ornatus is very different from D. complanatus Lapworth 1880 and Toghill's erection of this species to full specific status is here accepted. D. minor Toghill 1970 is however removed as a subspecies of D. ornatus owing to its different thecal style, the lack of astogenetic growth of its basal spines and its extended range from late P. linearis/early D. complanatus to D. anceps zones. D. ornatus is distinguished from D. complexus Davies 1929 by its more open axil, thecal style and basal spines, although juvenile specimens may appear similar when tectonically deformed.

The rarity and restricted range of D. ornatus at Dob's Linn and elsewhere in Britain is unusual when compared with other continents. Workers in North America (Ruedemann 1947, Churkin 1963, Ross & Berry 1963) and Australia (VandenBerg, pers. comm.) have used it as a zone fossil, regarding it to be reasonably abundant and with a longer range. It also occurs in the C. l. supernus Zone of Russia (Koren et al. 1980) and the D. szechuanensis Zone of China (Wang et al. 1978). Many of the foreign specimens appear to widen more rapidly than the Scottish ones to reach a maximum width of 0.9mm, although the spines are no longer and the well developed membrane seen in the specimens described here has not been previously recorded.

Dicellograptus complanatus Lapworth 1880
(pl. 22, figs. 1-6, pl. 23, figs. 1-6)



1880 Dicellograptus complanatus sp. nov.; Lapworth, pp. 160-168, pl. 5, figs. 17a-e.

1897 Dicellograptus complanatus Lapworth; Roemer & Frech, p. 618, text-fig. 183.

1904 Dicellograptus complanatus Lapworth; Elles & Wood, pp. 139-140, pl. 20, figs. 1a-d, text-figs. 84a-e.

?1935 Dicellograptus complanatus Lapworth; Decker, p. 702, text-figs. 1a-e, 2g.

1936 Dicellograptus anceps var. bornholmiensis var. nov.; Poulsen, pp. 57-58, text-figs. 2a-c.

?1938 Dicellograptus cf. complanatus Lapworth; Harris & Thomas, pl. 3, fig. 103.

1947 Dicellograptus complanatus Lapworth; Ruedemann, p. 376, pl. 62, figs. 4-10.

1947 Dicellograptus complanatus var. tenuis var. nov.; Ruedemann, p. 378.

1956 Dicellograptus complanatus Lapworth; Keller, p. 70, text-fig. 4.

1960 Dicellograptus complanatus Lapworth; Berry, p. 73, pl. 20, fig. 1.

?1963 Dicellograptus complanatus Lapworth; Churkin, p. 63, text-fig. 39.

1963 Dicellograptus complanatus Lapworth; Skoglund, pp. 33-36, pl. 1, fig. 3, text-figs. 10a-e.

1970 Dicellograptus complanatus Lapworth; Toghill, pp. 12-14, pl. 4, figs. 1-5, pl. 5, figs. 1-5, pl. 6, fig. 1, text-figs. 2g-l, 4b.

Lectotype. BU 1072b. The specimen figured by Elles & Wood 1904 pl. 20, fig. 1b from the lower Complanatus Band, Dob's Linn, Lapworth Collection. Selected by Toghill 1970, p. 13.

Material. Numerous specimens preserved flattened and in partial relief from the Lapworth Collection (Birmingham University), Ingham Collection (Hunterian Museum), Gray and Toghill Collections (British Museum, Nat.

Hist.), collections of the Sedgwick Museum (Cambridge University) and collected by the writer.

Horizons and localities. Lower and upper Complanatus Bands, Upper Hartfell Shale, D. complanatus Zone, Main Cliff, North Cliff and Linn Branch, Dob's Linn. Mill Formation, Upper Whitehouse Group and Shalloch Formation, D. complanatus Zone, Myoch Bay and Whitehouse shore, Girvan. Scania and Röstånger, collected by Tullberg 1879 (in the Lapworth Collection), horizon and locality unknown.

Diagnosis. Long slender stipes, straight or gently curved, up to 1mm wide and 160mm long and with an axial angle of 20 to 130°. Simple thecae with little introversion, pronounced genicula and straight supragenicular walls, numbering 8-14 in 10mm. Sicula rarely preserved, virgella conspicuous but short, first two (sometimes up to first six) thecae bearing short mesial spines.

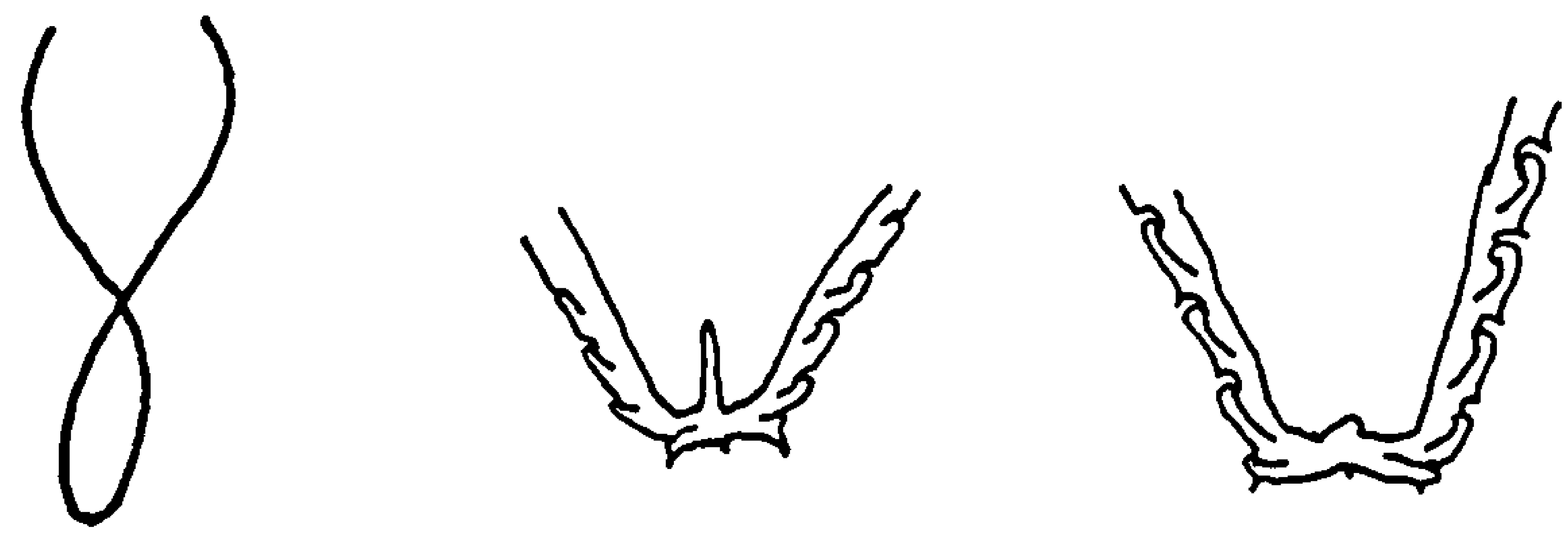
Description. The stipes are often very long, reaching up to 160mm, and may be straight or with a proximal concave and distal convex curvature. They normally exhibit gentle right or left-handed torsion. The stipes are 0.3-0.6mm wide at the aperture of $th1^1$, increasing to 0.5-0.7mm at the aperture of $th5^1$ and usually reaching the maximum width of about 0.9mm within 10mm. Some small specimens preserved in partial relief however only widen to a maximum of 0.5mm. Proximally the thecae number 11-14 in 10mm, decreasing distally to 8-11 in 10mm. $Th1^1$ and 1^2 diverge horizontally from the sicula; $th2^1$ grows horizontal initially thens bends abruptly up while $th2^2$ grows at a steady upward angle, resulting in a wide rounded axil with 1.1-1.7mm between the apertures of $th1^1$ and 1^2. The sicula, which is invariably missing in mature specimens, bears a virgella up to 0.3mm long. $Th1^1$ and 1^2 bear mesial spines 0.2mm long which divide the supragenicular walls into gently inward and outward sloping portions. Thecae up to $th3^2$ may also bear mesial spines. The proximal thecae have slightly introverted apertures that almost fill the semicircular excavations which normally occupy 1/2 the total stipe width. A prominent genicular hood is present on all thecae, occasionally giving an appearance of genicular spines in flattened material. When specimens are preserved in relief the proximal dorsal wall possesses conspicuous prothecal folds which bend around the thickened interthecal at about 20° to the dorsal wall, while the proximal portion bends almost perpendicular to it. The supragenicular walls remain curved until about $th8^1$ when they become straight and subparallel to the dorsal margin. The prothecal folds become less pronounced distally while the apertures lose their introversion, excavations become narrow and interthecal septa have a distal portion subparallel to the dorsal wall, gradually attaining an angle of about 30° proximally.

Remarks. The gentle torsion and curvature are remnants of original openly spiralled stipes (Williams 1981). The thecae are less introverted than any other Dicellograptus species, comparing only with D. complexus Davies 1929, D. johnstrupi Hadding 1915 and D. carruthersi Toghill 1970. The thecae of D. complexus are almost identical to the early ones of D. complanatus but the stipes are tightly spiralled, crossing several times, and usually have a maximum width of 0.5mm. Both D. johnstrupi and D. carruthersi have thecae with nearly straight supragenicular walls and moderately developed genicula but the supragenicular walls slope gently and the apertures are slightly more introverted. The axils are also rather narrower and stouter. The thecal form of D. complanatus is very different from D. anceps (Nicholson 1867) and the two are not closely related as suggested by some authors. Prothecal folds are prominent proximally when specimens are preserved in relief, a 'notch' sometimes being present at the top of the fold, but become less obvious when flattened owing to differential lateral spread (Briggs & Williams 1981, thesis text-fig. 16). It is considered here that prothecal folds are normal for the proximal thecae of Dicellograptus and are a response to the thickening of interthecal septal nodes.

In the Moffat area D. complanatus has been found at Dob's Linn and Craigmichan Scaurs. At Girvan it is found in the later part of the Upper Whitehouse Group; it initially appears in the Dark Shale Member of the Mill Formation (text-fig. 12) where it is associated with Orthograptus q. quadrimucronatus (Hall 1865), O. ex gr. calcaratus, O? socialis (Lapworth 1880) and Dicellograptus minor Toghill 1970, indicating an age intermediate between the P. linearis and D. complanatus zones sensu Dob's Linn. In higher beds it occurs with O? socialis alone, probably indicating an horizon equivalent to the Complanatus Bands of Dob's Linn and suggesting that they represent the later part of the D. complanatus Zone. D. complanatus has been recorded from Northern Ireland (Lapworth 1880, Fearnsides, Elles & Smith 1907) but not figured. Elsewhere in Europe it has been recorded from the Jonstorp Formation and the Upper Dicellograptus Shale of Sweden (Törnquist 1881, 1913, Tullberg 1882, 1883, Roemer & Frech 1897, Tornebohm & Henning 1904, Olin 1906, Moberg 1911, Glimberg 1961, Skoglund 1963) and in Bornholm (Poulsen 1936, as D. anceps var. bornholmiensis var. nov.). It has also been recorded from North America where it is apparently common and widely distributed (Decker 1935, Ruedemann 1947, Berry 1960, Churkin 1963, Riva 1969), the Bolindian of Australia, where it is referred to D. cf. complanatus (Sherrard & Keble 1937, Harris & Thomas 1938, Thomas 1960) and the Wufeng Shale of China (Mu 1954, Wang et al. 1974, Wang et al. 1978) where D. tenuis Mu et al. (a junior homonym of D. complanatus tenuis Ruedemann 1947), D. complanatus guizhouensis subsp. nov. and D. complanatus var. nov. are here tentatively referred to D. complanatus s.s. The only illustrated description of D. complanatus from Russia is by Keller (1956). Koren' et al. (1979) record it from the C. l. longispinus and P. pacificus subzones of the Kalyma River; while the earlier of these is probably D. complanatus the later occurrence is more likely to be D. aff. complexus owing to the associated faunal assemblage which is characteristic of the D. complexus Subzone of Dob's Linn.

Dicellograptus complexus Davies 1929

(pl. 24, figs. 1-5, pl. 25, figs. 1-5)



1929 Dicellograptus complanatus var. complexus nov.; Davies, pp. 3-4, text-fig. 9.

1954 Dicellograptus szechuanensis sp. nov.; Mu, p. ? , pl. 1, figs. 7, 8.

1965 Dicellograptus szechuanensis Mu; Mu & Chen, pl. 13, figs. 13a, b.

1970 Dicellograptus complanatus complexus Davies; Toghill, pl. 3, fig. 8. Text-fig. 3c (as D. ornatus minor subsp. nov.).

1974 Dicellograptus szechuanensis Mu; Wang et al., p. 159, pl. 70, figs. 4, 5.

1977 Dicellograptus szechuanensis Mu; Wang et al., p. 313, pl. 95, fig. 13.

1978 Dicellograptus szechuanensis Mu; Wang et al., p. 629, pl. 203, figs. 18, 19.

1980 Dicellograptus ornatus minor Toghill; Koren' et al., pp. 122-123, pl. 33, figs. 1, 2, text-figs. 29a-d.

(n.b. The specimens illustrated by Wang et al. 1974, pl. 70, fig. 4 and 1978, pl. 203, fig. 19 are counterparts of the same specimen)

Type material. The holotype SM A10008 from Dob's Linn appears to be mislaid. No further specimens of this species collected by Davies from the Anceps Bands at Dob's Linn appear to have been catalogued.

Material. One specimen with counterpart from the Toghill Collection (British Museum, Nat. Hist.) and numerous flattened specimens collected by the writer.

Horizons and localities. Anceps Bands A to D, Upper Hartfell Shale, D. anceps Zone (D. complexus and early P. pacificus subzones), Dob's Linn.

Diagnosis. Slender rhabdosome with tightly spiralled stipes 0.5mm wide and up to 60mm long. Thecae simple, numbering 10-14 in 10mm. Sicula rarely preserved, virgella inconspicuous, first two thecae with short mesial spines.

Description. The stipes are 60mm long with one or two crosses and strong, consistently left-handed, torsion caused by an originally tightly spiralled rhabdosome. The distance to the first cross is dependant on the orientation of the rhabdosome (Briggs & Williams 1981) but is normally less than 15mm. The stipes are initially 0.4mm wide, rapidly increasing to the maximum 0.5mm within a few mm, although the width is often varied due to the effects of both tectonic and diagenetic deformation. The thecae number 14 in 10mm proximally, decreasing to about 10 in 10mm distally. The sicula is usually missing; only three have been observed, about 1.5mm long and with an inconspicuous short virgella. Th1^1 and 1^2 are slightly declined while th2^1 and 2^2 grow horizontal intially before slowly bending up, giving a wide axil in juveniles but a more narrow one in mature specimens due to the normally oblique angle of compression. Immature specimens have characteristically asymmetrical proximal parts with two different widths (commonly 0.4 and 0.5mm) due, not to tectonic distortion, but to greater lateral spread at the apertures of thecae in oblique orientation to the bedding (pl. 25, fig. 3). Th1^1 and 1^2 bear narrow, sub-apertural spines up to 0.8mm long which apparently become shorter throughout astogeny. The distance between the spines varies from 1.2 to 1.8mm, depending on the orientation of the rhabdosome prior to compaction. All thecae have slightly introverted apertures, opening into short semicircular excavations which occupy 1/3 the total width of the stipe. They all have conspicuous genicula and slightly convex supragenicular walls, similar to early D. complanatus thecae, although the appearance of distal thecae is commonly confused due to stipe torsion. The interthecal septa slope ventrally just below the apertures, then turn sharply to slope at about 30° to the dorsal wall and proximally culminate in a high dorsal angle.

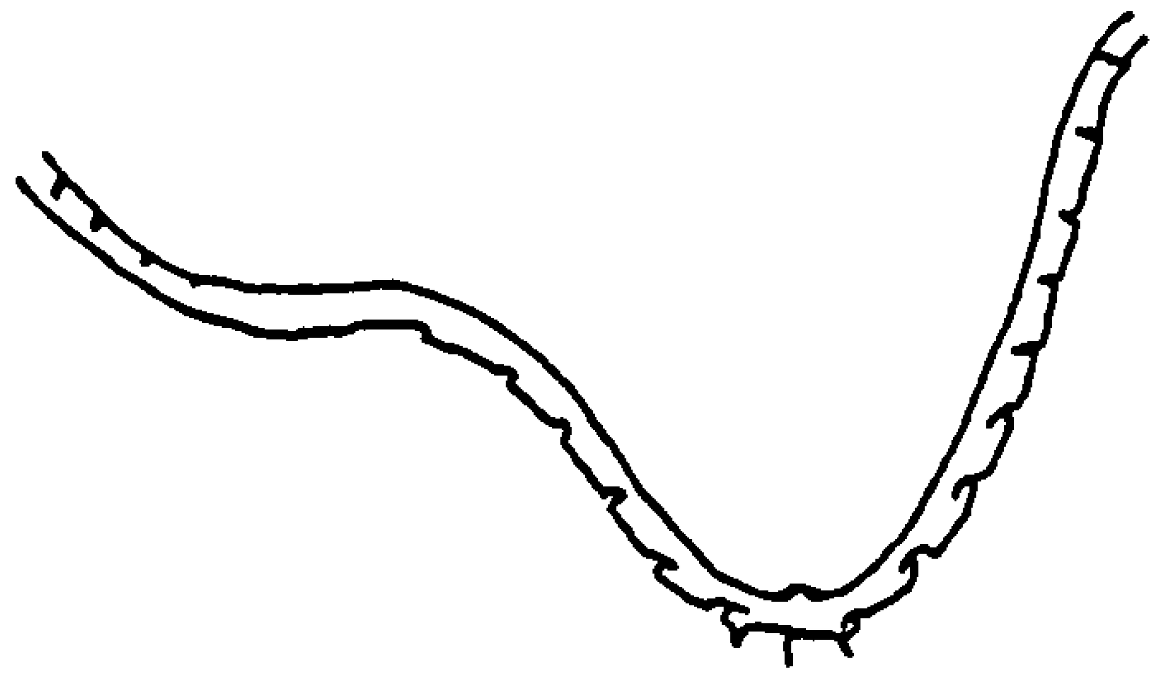
Remarks. The distinctive feature of this species is the tight spiral and accompanying strong, left-handed torsion which can be observed in both mature and juvenile specimens and separates it from all other late Ordovician Dicellograptus species. While most Dicellograptus possessed openly spiralled rhabdosomes (Williams 1981) only a few other species (e.g. D. caduceus Lapworth 1876, D. intortus Lapworth 1880) were spiralled tightly enough to produce a consistent 'figure of 8' form when flattened. It is suggested here that tight spiralling was a recurring homeomorphic evolutionary feature as D. complexus and the two other mentioned species have totally different thecal styles and belong to separate evolutionary lineages. It was also not necessarily a particularly late stage evolutionary feature as D. vagus Hadding 1913 from the G. teretiusculus Zone of Scandianavia sometimes shows a tightly spiralled form.

The thecae of D. complexus are similar to those of D. complanatus Lapworth 1880 but unlike this earlier species do not show any change in style along the stipe. It is considered here that D. complexus evolved from D. complanatus via a form such as D. aff. complexus which occurs abundantly in Anceps Band A at Dob's Linn. The Chinese late Ordovician zone fossil D. szechuanensis Mu 1954 (pl. 24, fig. 5) is here considered synonymous with D. complexus. Mu originally separated the two species because of the apparently more introverted thecae of D. szechuanensis than those described for D. complexus by Davies (1929) and for D. complanatus by Lapworth (1880) and Elles & Wood (1904). This study has however demonstrated that the thecae of both these species are somewhat introverted. If the photograph of D. szechuanensis preserved in relief given to the writer by Prof. Mu (pl. 24, fig. 5) is compared with D. complanatus preserved in relief (pl. 23, fig. 4) the proximal thecal style is almost identical. When tectonically deformed the thecae of D. complexus may appear similar to D. ornatus Elles & Wood 1904 and could also be confused with deformed D. minor Toghill 1970. D. complexus is most common in Anceps Band B but also occurs rarely in Bands A, C and D where it is associated with the more openly divergent forms possessing long, fairly straight stipes here referred to D. aff. complexus.

D. complexus has not been recorded commonly from outside Scotland. It is however found in several countries including Northern Ireland (Killy Bridge Beds, in the Tripp Collection, pers. observ.) and Russia, where it has been figured and described as 'D. ornatus minor' from the C. l. supernus Zone by Koren' et al. (1980, pp. 122-123). VandenBerg (pers. comm.) records D. cf. complexus from the late Bolindian (zone of D. ornatus and C. latus) of Victoria, Australia;

the writer has seen his camera lucida drawings and considers that his material may be referred to _D. complexus_ s.s. _D. szechuanensis_ (=_D. complexus_) is used in China as the second zone fossil for the Wufeng Shale (text-fig. 13).

Dicellograptus aff. complexus Davies 1929
(pl. 25, figs. 6-8)

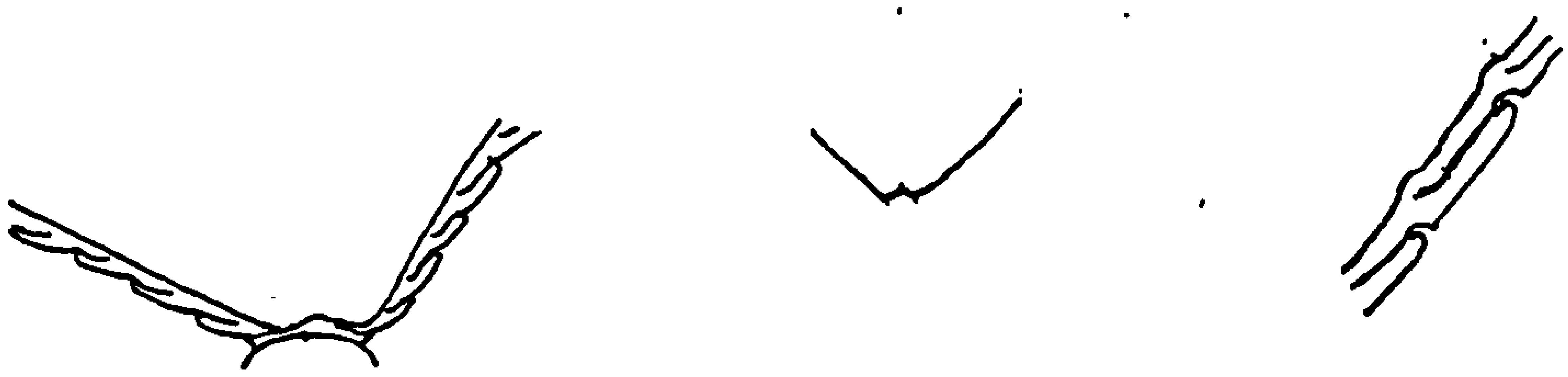


Material. Many flattened proximal and distal fragments collected by the writer.

Horizons and localities. Anceps Bands A to D, Upper Hartfell Shale, D. anceps Zone (D. complexus and early P. pacificus subzones), Dob's Linn.

Remarks. The specimens here assigned to D. aff. complexus are identical to D. complexus s.s. in every respect except that they possessed a more openly spiralled rhabdosome, resulting in a form with consistently divergent, asymmetrical stipes exhibiting proximal double curvature and strong torsion. Distal fragments are commonly almost straight. D. aff. complexus is common in Anceps Band A where there are only occasional specimens of D. complexus s.s., rare in Band B where D. complexus s.s. is more common, and is more abundant in Bands C and D where D. complexus s.s. is rare. It is possible that these specimens belong to D. complexus s.s. but are representatives of a population which possessed genetic variability in terms of the degree of tightness of the rhabdosome spiral.

Dicellograptus minor Toghill 1970
(pl. 26, figs. 2, 3, 6-12)



1904 Dicellograptus complanatus var. ornatus var. nov.; Elles & Wood (pars), pp. 140-141, pl. 20, fig. 2c (non pl. 20, figs. 2a, b, text-figs. 85a, b).

1970 Dicellograptus ornatus minor subsp. nov.; Toghill (pars), pp. 16-17, pl. 6, figs. 5-7, text-figs. 3d-g (non text-fig. 3c, =D. complexus Davies 1929).

non1980 Dicellograptus ornatus minor Toghill; Koren' et al., pp. 122-123, pl. 33, figs. 1,2, text-figs. 29a-d (=D. complexus).

Holotype. SM A19333. The specimen figured by Elles & Wood 1904, pl. 20, fig. 2c and Toghill 1970, pl. 6, fig. 5, text-fig. 3f. From the Upper Hartfell Shale, D. anceps Zone, Dob's Linn.

Material. Numerous specimens, mostly flattened but some in relief, from the Toghill Collection (British Museum, Nat. Hist.), Davies Collection (Sedgwick Museum) and collected by the writer.

Horizons and localities. All five Anceps Bands (very common in Band E) and the lower Complanatus Band (one specimen), Upper Hartfell Shale, D. complanatus and D. anceps zones, Dob's Linn. Specimens questionably referred to D. minor s.s. from the Dark Shale Member, Mill Formation, Upper Whitehouse Group, late P. linearis/early D. complanatus zone, Myoch Bay, Girvan.

Diagnosis. Very slender rhabdosome with only slightly introverted thecae, numbering 10-11 in 10mm. Stipes straight, gradually widening from 0.3 to 0.5mm throughout. Wide axial region, axial angle typically 110°. First two thecae with small but conspicuous subapertural spines.

Description. The stipes are straight and normally short in specimens possessing proximal ends but distal fragments of 40mm are not uncommon.

They show no torsion and normally diverge at an angle of about 110° although occasional specimens are found with smaller axial angles down to 60°. The stipes are 0.20-0.25mm wide at the aperture of $th1^1$, increasing to 0.3mm in 5mm and slowly widening to a maximum 0.5mm in distal fragments. The thecae number 11 in 10mm proximally, reducing only slightly distally to 10 in 10mm. The sicula is usually missing in mature specimens but measures 1.7mm long and bears a small, inconspicuous virgella. $Th1^1$ and 1^2 are slightly declined, $th2^1$ and 2^2 grow initially down before bending up, forming a wide, angular, symmetrical axial region with 1.5mm between the apertures of $th1^1$ and 1^2. $Th1^1$ and 1^2 bear small but prominent sub-apertural spines 0.4mm long in juveniles which become shorter during astogeny. All thecae are long and thin with rather less overlap than is normal in Dicellograptus. The proximal thecae possess slight genicula and straight supragenicular walls sub-parallel to the dorsal margin except for very slightly introverted apertures which open into shallow excavations occupying 1/3 the total width of the stipe. The interthecal septa are straight and inclined to the dorsal wall at about 10° except for a slight increase to about 30° in the proximal portion. Prothecal folds are prominent in the proximal thecae. Distally the thecae become almost Leptograptus-like with little or no introversion. The interthecal septa run without change of direction into the supragenicular walls which are straight and inclined at about 10° to the dorsal wall.

Remarks. Both the simple thecal style and wide open, non-spiralled nature of D. minor are reminiscent of a Leptograptus. The proximal thecae which show slight introversion and prominent prothecal folds are however clear indications of its generic position in Dicellograptus. D. minor is here raised to full specific status and separated from D. ornatus Elles & Wood 1904 owing to its greater range and different thecal style. The astogenetic development of the proximal spines is also the opposite to D. ornatus as the spines of D. minor become smaller (probably resorbed) instead of larger during growth. The other two narrow Dicellograptus species found in Britain, D. angulatus Elles & Wood 1904 and D. geniculatus Bulman 1932b, are both from much earlier horizons. Distal stipe fragments of D. minor and Pleurograptus lui Mu 1950 may be confused when tectonically deformed as both possess simple, rather elongate thecae and reach about 0.5mm wide. The proximal regions are however distinct, P. lui having a proximal width of only 0.15mm which widens extremely slowly and lacking any thecal spines.

Definite occurrences of D. minor seem to be restricted to Scotland. The early specimens from both Girvan and the Lower Bolindian of Australia (VandenBerg, pers. comm.) do not appear to widen to the same extent as those in the Complanatus and Anceps Bands at Dob's Linn; it is possible that they represent a distinct early form of this species and they are here provisionally referred to D. cf. minor (pl. 26, figs. 1, 4, 5). Specimens referred to D. minor by Toghill from the Belfast area have not been reexamined but he records them to be more slender than the typical forms and they may be representatives of the early form found at Girvan. The specimens of D. complanatus arkansasensis Ruedemann 1947 (1947, p. 377, pl. 62, figs. 11-15) referred to D. minor by Toghill do not appear to belong to D. minor, neither does the specimen figured by him from the Nicholson Collection (Toghill 1970, text-fig. 3c, Q3066) which was probably first figured by Nicholson (1867a, pl. 7, fig. 3) as 'Didymograpsus flaccidus'. This specimen is here considered to be a juvenile specimen of D. complexus Davies 1929, as are the specimens described and figured by Koren' et al. (1980) from the C. l. supernus Zone of Russia.

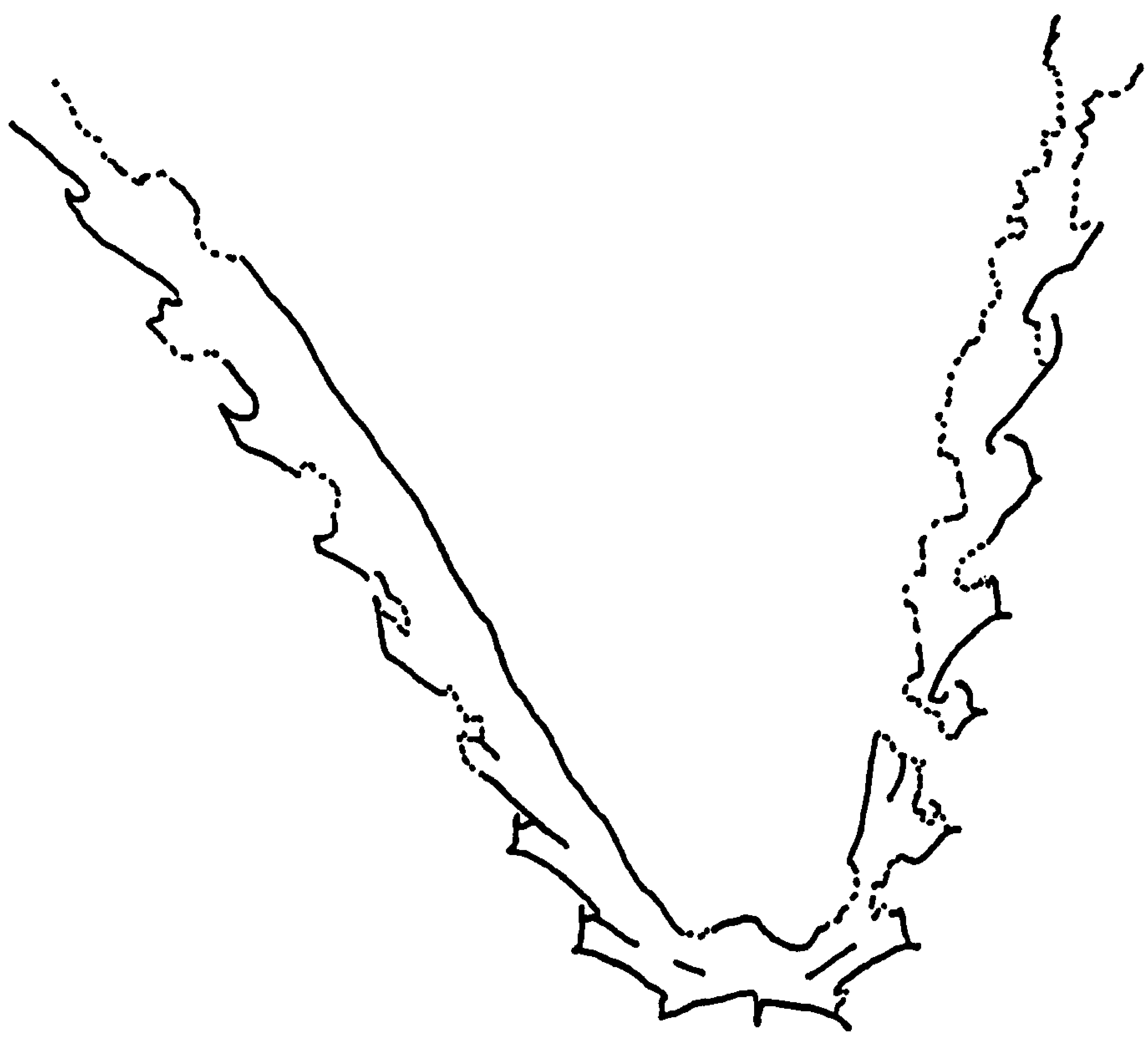
Dicellograptus sp. nov.

(text-fig. 23)

Material. One proximal specimen in the Rushton Collection (I.G.S. South Kensington) and several distal flattened fragments collected by the writer.

Horizons and localities. Dark Shale Member, Mill Formation, Upper Whitehouse Group, late P. linearis/early D. complanatus zone, Myoch Bay, Girvan.

Remarks. The thecal style of these specimens is very simple and distinct from all previously described species. The supragenicular walls are divided, in the proximal thecae, into proximally and distally sloping portions by mesial spines while the distal ones become straighter. The thecae are only slightly introverted and open into narrow, short excavations. The dorsal wall sometimes possesses slight prothecal folds, confirming the generic placing of this material. Unfortunately insufficient specimens have been found to permit the erection of a new species.



TEXT-FIGURE 23. Dicellograptus sp. nov. (x10)
RU 2966. Dark Shale Member, Mill Formation, Upper Whitehouse Group, Myoch Bay, Girvan. Rushton Collection (I.G.S. South Kensington).

Chapter 10. Family DIPLOGRAPTIDAE Lapworth 1873.

Diagnosis (adapted from Bulman 1970, V124-125). Rhabdosome biserial with or without complete or partial median septum; thecae straight or with sigmoidal curvature, early thecae may possess mesial spines, remaining ones normally non-spinose but apertural or genicular spines may occur throughout; periderm continuous, rarely attenuated or supported by lists; development "streptoblastic" or "prosoblastic".

Remarks. This is the most diverse upper Ordovician/lower Silurian graptolite family with a wide variety of thecal styles and rhabdosome forms. Bulman (1970, V131) considered *Akidograptus ascensus* Davies 1929 to belong to the Dimorphograptidae Elles & Wood 1908; it is here considered to lack a uniserial portion and to have a proximal development akin to *Petalograptus* Suess 1851 and *Cephalograptus* Hopkinson 1869, indicating it to be a member of the family Diplograptidae as suggested by Stein (1965).

10.1 Genus *Climacograptus* Hall 1865

Type species (by original designation). *Graptolithus bicornis* Hall 1847, p. 268, pl. 73, fig. 2.

Stratigraphical range. At least Lower Ordovician to Lower Silurian.

Diagnosis (from Bulman 1970, V125). Rhabdosome nearly circular in cross section, scalariform views consequently common; thecae strongly geniculate, with deep apertural excavations, supragenicular walls straight, parallel to axis of rhabdosome.

Remarks. The development of proximal structures is especially important in distinguishing members of this genus.

Specimens described.

First two thecae with long spines:

C. longispinus supernus Elles & Wood 1906 (*D. anceps*)

Sicula and $th1^1$ with conspicuous spines:

C. spiniferus Ruedemann 1912 (*D. clingani*)

Sicula. and first two thecae with small spines:

C. latus Elles & Wood 1906 (D. anceps - mostly P. pacificus)

Sicula with long and thickened virgula:

C. tubuliferus Lapworth 1876 (P. linearis to D. complanatus)

C? caudatus Lapworth 1876 (D. clingani)

Sicula with prominent virgella:

C. normalis Lapworth 1877 (D. anceps to O? acuminatus)

C. miserablis Elles & Wood 1906 (?D. clingani to O? acuminatus)

C. medius Törnquist 1897 (G. persculptus and O? acuminatus)

C. mohawkensis (Ruedemann) 1912 (D. clingani and P. linearis)

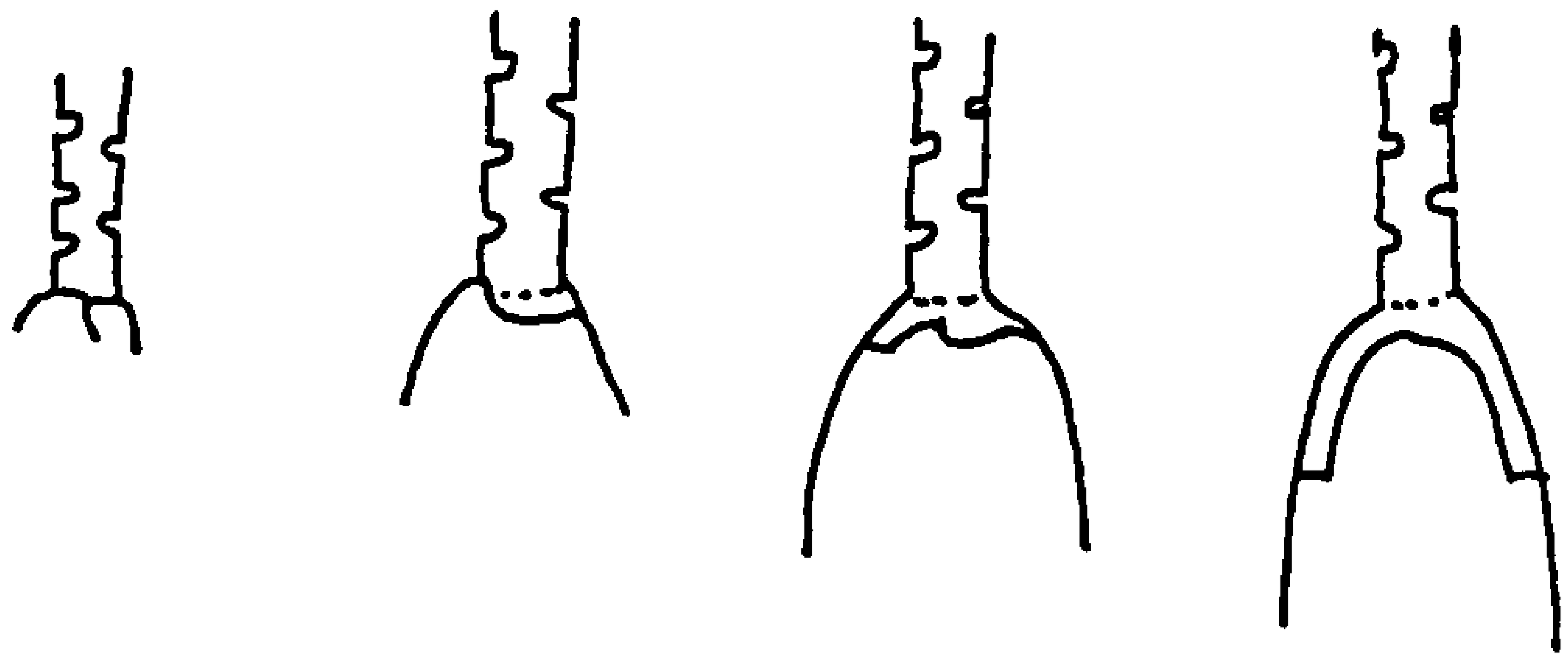
Sicula with virgella and two other spines:

C. trifilis Manck 1923 (O? acuminatus)

Sicula with virgella, thecae intermediate to Glyptograptus:

C? extraordinarius (Sobolevskaya 1974) (P. pacificus to C? extraordinarius)

Climacograptus longispinus supernus Elles & Wood 1906
(pls. 27 - 29, text-figs. 24a-o)



1906 Climacograptus supernus sp. nov.; Elles & Wood, pp. 196-197, pl. 26, figs. 11a-d, text-figs. 127a-d.

1933 Climacograptus supernus Elles & Wood; Sun, pp. 22-23, pl. 3, fig. 6.

1956 Climacograptus supernus Elles & Wood; Keller, p. 90, text-fig. 27.

1970 Climacograptus hvalross Ross & Berry; Toghill, p. 22, pl. 2, figs. 1-4, 7.

1970 Climacograptus supernus Elles & Wood; Toghill, p. 22, pl. 2, figs. 5, 6, 8-10.

1974b Climacograptus longispinus supernus Elles & Wood; Riva, pp. 120-125, text-figs. 8a-q.

1977 Climacograptus supernus Elles & Wood; Wang et al., p. 330, pl. 100, fig. 10.

1978 Climacograptus supernus Elles & Wood; Wang et al., p. 638, pl. 206, figs. 8, 9.

1980 Climacograptus longispinus hvalross Ross & Berry; Koren' et al., pp. 134-135, text-figs. 37a-d.

1980 Climacograptus longispinus supernus Elles & Wood; Koren' et al., pp. 135-137, pl. 38, figs. 1-6, text-figs. 38a-g.

Lectotype. BU 1167 (pl.28 , fig. 2). The specimen figured by Elles & Wood 1906, pl. 26, fig. 11c. From the Upper Hartfell Shale, D. anceps Zone, Dob's Linn. Designated by Riva (1974b, p. 120).

Material. Numerous flattened specimens from the Wood Collection (Birmingham University), Elles and Davies collections (Sedgwick Museum), Toghill Collection (British Museum, Nat. Hist.) and collected by the writer.

Horizons and localities. All five Anceps Bands, Upper Hartfell Shale, D. anceps Zone, Dob's Linn.

Diagnosis. Rhabdosome up to 35mm long, 0.6mm wide proximally, maximum 1.5mm, with two long basal spines from $th1^1$ and 1^2 possessing membranous undergrowths. Thecae number 10-13 in 10mm.

Description. The rhabdosome is up to 35mm long, widening from 0.4-0.6mm (0.6mm undistorted) at the aperture of $th1^1$ to 0.7-1.5mm (1.2mm undistorted) in 5mm and reaching the maximum 0.9-1.7mm (1.5mm undistorted) within 12mm which is then generally maintained. The width of the rhabdosome at the aperture of $th1^2$ is normally equal to, and sometimes slightly less than, that at $th1^1$. Some specimens show slight distal narrowing although this may be a function of the common, normally right-handed, stipe torsion and subsequent diagenetic flattening without lateral spread. The thecae number 11-13 in 10mm proximally, reducing to 10-11 in 10mm distally. The sicula is about 1mm long and bears a virgella which is normally short but occasionally reaches up to 1.5mm long in specimens from the higher Anceps Bands (text-fig. 24o). A spine is produced by the first two thecae at the point where they turn upwards. These are small in juvenile specimens but grow throughout astogeny, reaching a maximum 5mm long. Once the spines have reached about 1mm long a membranous growth commonly begins. The astogenetic phase when this development commences does however seem rather variable, starting at any time after the completion of eight pairs of thecae. The membrane appears to grow initially from the base of $th1^1$, growing across the sicula aperture and virgella so that the full thickness of basal membrane first appears under the spine on the side of $th1^2$. When this has reached below the supragenicular wall of $th1^2$ a membrane appears to be produced by $th1^2$ which crosses to the side of $th1^1$, sometimes producing a median 'step' (text-figs. 24b-e). The membranes, of an average 0.3mm wide, usually fill the 'step' in the lower margin to produce a rounded median region (text-fig. 24f) before growing along the underside of each spine for a maximum distance of about 3.5mm (text-fig. 24j). The thecae have straight, vertical supragenicular walls and open into small, rounded and shallow apertural excavations which occupy 1/3 of the total rhabdosome width proximally but only about 1/5 distally. Inclined supragenicular walls are occasionally found due to greater lateral spread at the thecal apertures, especially when the rhabdosome is preserved in oblique orientation (pl. 28, figs. 1, 5). Complete specimens invariably have a short nema preserved. As noted by Riva (1974b) the rhabdosome is aseptate, the often slightly wavy

TEXT-FIGURE 24 (cont.)

Climacograptus longispinus supernus Elles & Wood 1906. (all x10)

N. HM C13603. Specimen with virgella almost as long as thecal spines. Anceps Band D, P. pacificus Subzone, Main Cliff, Dob's Linn.

O. HM C13585. Specimen with virgella and thecal spines of equal length. Anceps Band D, P. pacificus Subzone, Long Burn trench, Dob's Linn.

TEXT-FIGURE 24

Climacograptus longispinus supernus Elles & Wood 1906. (all x10)

A. HM C13554/1. Juvenile specimen. Anceps Band D, P. pacificus Subzone, Linn Branch trench, Dob's Linn.

B. SM A19605. Juvenile specimen. Upper Hartfell Shale, D. anceps Zone, Dob's Linn. Elles Collection. Figd. Riva (1974b, text-fig. 8c).

C. HM C13559a. Fragmentary juvenile specimen. Anceps Band D, P. pacificus Subzone, Linn Branch trench, Dob's Linn.

D. HM C13584. Juvenile specimen. Anceps Band D, P. pacificus Subzone, Long Burn trench, Dob's Linn.

E. HM C13299/1b. Specimen with early membrane development showing 'step'. Anceps Band B, D. complexus Subzone, Linn Branch trench, Dob's Linn.

F. HM C13556a. Specimen with early but rounded membranes. Anceps Band D, P. pacificus Subzone, Linn Branch trench, Dob's Linn.

G. HM C13350. Specimen with long spines but fairly short membranes. Anceps Band B, D. complexus Subzone, Main Cliff, Dob's Linn.

H. HM C13528a. Specimen with thick membranes but with 'step' and prominent virgella. Anceps Band D, Long Burn trench, Dob's Linn.

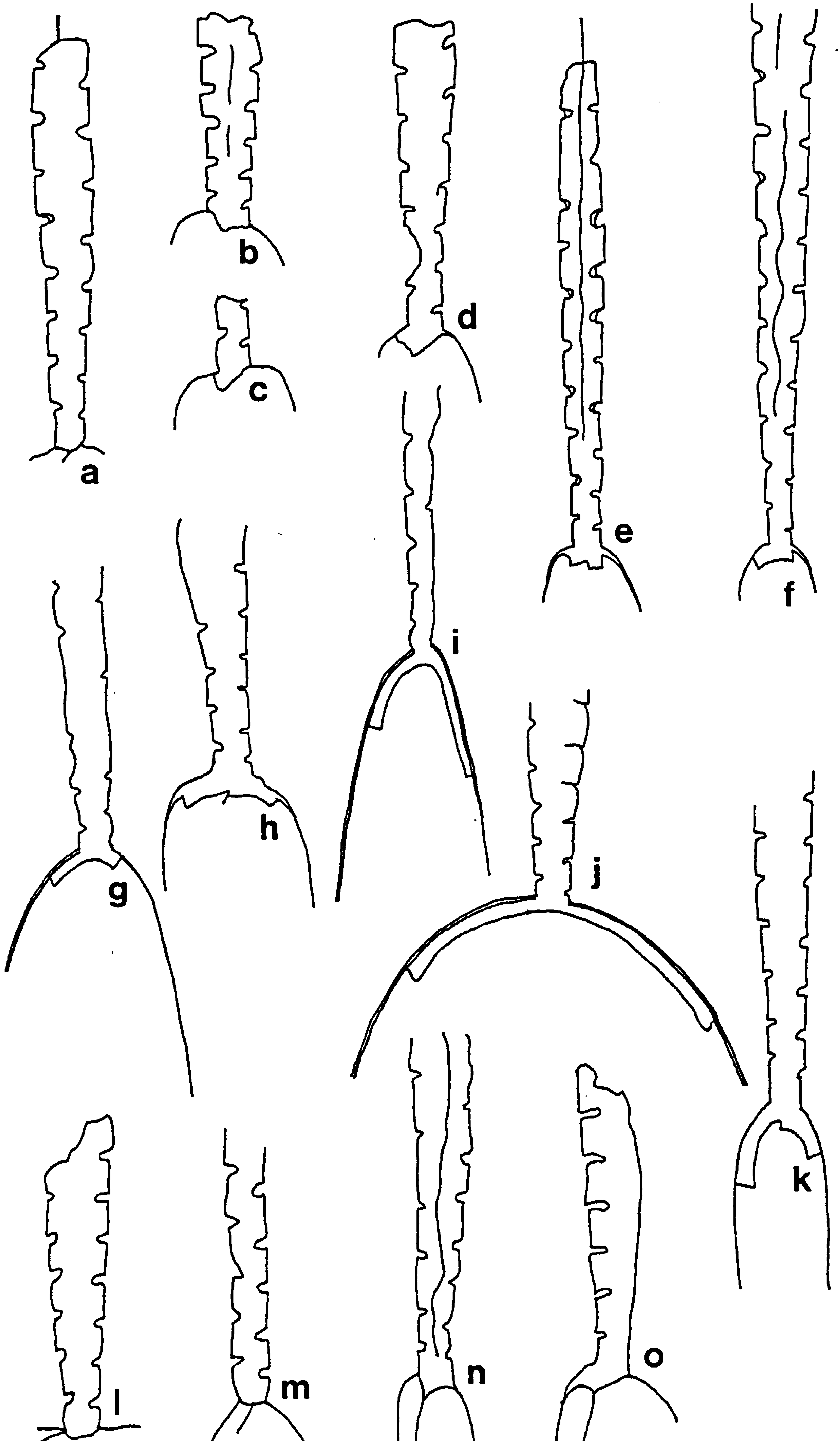
I. HM C13301a. Specimen with long 'droopy' spines and membranes. Anceps Band B, D. complexus Subzone, Linn Branch trench, Dob's Linn.

J. HM C13392b. Specimen with long 'rigid' spines and membranes. Anceps Band B, D. complexus Subzone, Long Burn trench, Dob's Linn.

K. HM C13549. Specimen with 'droopy' spines and very thick membranes. Anceps Band D, P. pacificus Subzone, Long Burn trench, Dob's Linn.

L. HM C13558. Specimen with small thecal spines but long virgella. Anceps Band D, P. pacificus Subzone, Linn Branch trench, Dob's Linn.

M. HM C13574. Spines as 'L'. Anceps Band D, P. pacificus Subzone, Long Burn trench, Dob's Linn.


a
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median line being formed by the virgula.

Remarks. This subspecies is distinct from all other Climacograptus from equivalent horizons in Britain. The main confusion arises when comparison is made with other C. longispinus group subspecies. Riva discussed these in 1974 but has since changed his ideas on the Pacific vs. Atlantic faunal provinces (pers. comm.). He did not study Hall's Australian type material of C. longispinus longispinus Hall 1902; VandenBerg believes that C. l. longispinus sensu Riva does not necessarily conform to Hall's type material and that some of these specimens are inseparable from C. l. supernus (pers. comm.). There also appears to be confusion over whether C. l. hvalross Ross & Berry 1963 is actually distinct from C. l. supernus. Full revision of this group would require careful study of all material from all known localities and is outside the scope of this thesis. The synonymies given here are therefore restricted to those specimens which in the opinion of the writer are undoubtably referrable to C. l. supernus using Riva's revision. It appears to the writer that the various subspecies of the C. longispinus group may represent an evolutionary lineage beginning with the large, multiple membrane forms figured as C. l. longispinus by Riva and ending with the small, narrow-spined forms which in some cases develop a long virgella, exemplified by the specimens of C. l. supernus from Dob's Linn.

The original form of the basal membrane is enigmatic owing to the compressed nature of all known material. Hsü (1959) stated that similar processes in C. venustus Hsü 1959 were hollow. Riva (1976) concluded that those found in association with spines of the Climacograptus bicornis group were webs or membranes although Bulman (1947) used serial sections to show that the initial parts of the spines were thecal tubes. The reason for the secondary development of the spines and membranes is unresolved; possibilities include stability and strengthening of the spines although the writer considers them to more probably have been a method of orientating the rhabdosome in a food-carrying current.

C. l. supernus is present in all the Anceps Bands at Dob's Linn but is most common in Bands B, D and E. It is found at equivalent horizons in all continents and is an extremely useful species for correlation.

Climacograptus spiniferus Ruedemann 1912
(pl. 30, figs. 1-8)

1847 Graptolithus bicornis sp.nov.; Hall (pars), pp. 268-269, pl. 73, figs. 2a, b (non 2c-s).

1908 Climacograptus typicalis Hall mut. spinifer nov.; Ruedemann, pp. 411-412, pl. 28, figs. 8-9, text-fig. 363.

1912 Climacograptus spiniferus Ruedemann; Ruedemann, p. 63 (footnote), p. 84.

1932a Climacograptus diplacanthus sp. nov.; Bulman, pp. 13-16, pl. 3, figs. 1-20, text-figs. 7, 8.

1947 Climacograptus spiniferus Ruedemann; p. 439, pl. 73, figs. 1-7.

1955 Climacograptus spiniferus Ruedemann; Clark & Strachan, pp. 692-693, text-figs. 3d, f.

1960 Climacograptus diplacanthus Bulman; Mu et al., p. 38, pl. 2, figs. 4-8, text-fig. 1.

1963 Climacograptus spiniferus Ruedemann; Ross & Berry, p. 130, pl. 9, fig. 12.

1969 Climacograptus spiniferus Ruedemann; Riva, p. 521, text-figs. 3k-p.

1969 Climacograptus cf. C. supernus Elles & Wood; Moors, pp. 266-267, fig. 3f.

1971 Climacograptus spiniferus Ruedemann; Berry, p. 637, pl. 73, fig. 5.

1974a Climacograptus spiniferus Ruedemann; Riva, pp. 11-17, pl. 1, figs. 4, 8, text-figs. 2-4.

1974 Climacograptus cf. spiniferus Ruedemann; Strachan, pp. 100-102, pl. 6, figs. 2, 3, 6, text-fig. 2d.

1976 Climacograptus spiniferus Ruedemann; Riva, pp. 608-613, text-figs. 11-14.

Lectotype. A.M.N.H. 1041/5. Designated and figured by Riva 1974a, p. 12, pl. 1, figs. 4, 8, text-fig. 4a. From the basal Utica Shale in the southern part of Ballston Spa, New York State (see Riva 1974).

Material. Numerous flattened, mostly poorly preserved, specimens collected by the writer.

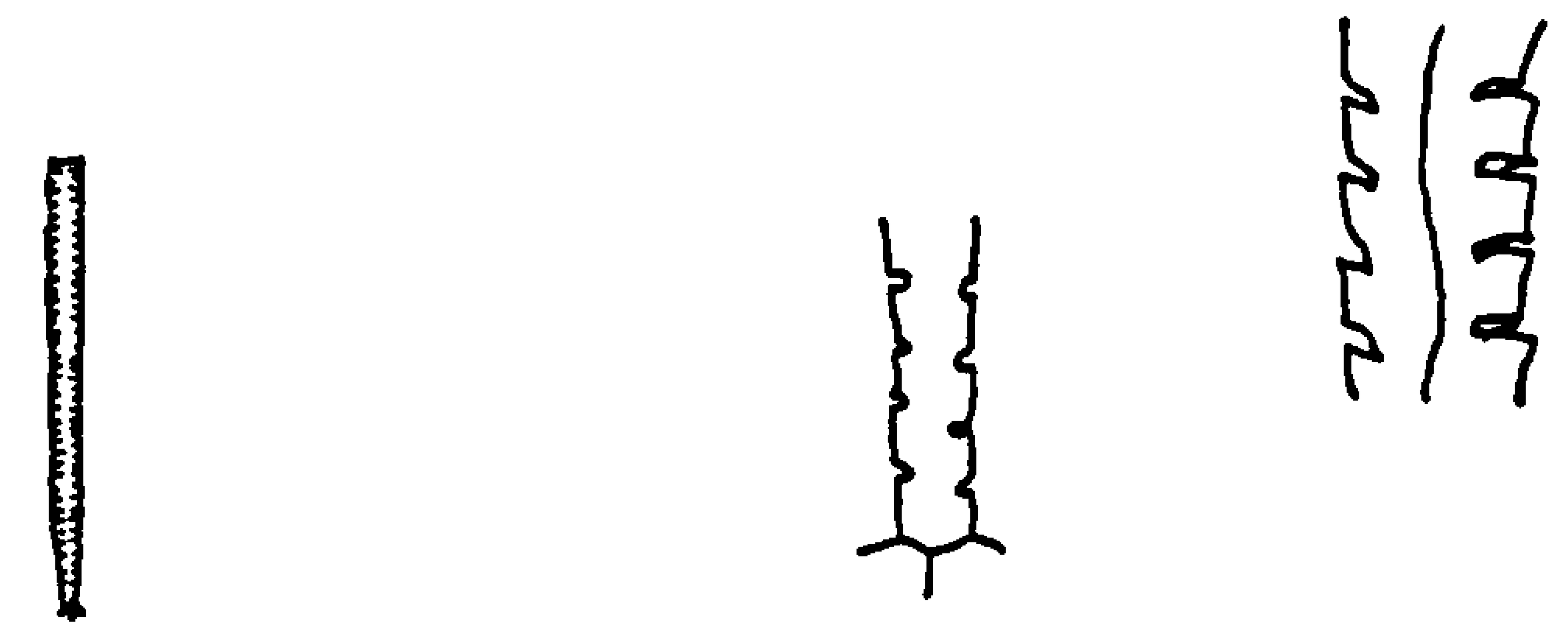
Horizons and localities. 8.9 to 6.4m below the top of the Lower Hartfell Shale, top *D. clingani* Zone, North Cliff trench, Dob's Linn.

Diagnosis. Rhabdosome up to 70mm long, gradually widening from 0.7mm to 1.9mm maximum. $Th1^1$ and sicula with conspicuous spines. Thecae number 10-14 in 10mm.

Description. The rhabdosome is up to 70mm long. It measures 0.6-0.8mm wide at the aperture of $th1^1$, widens to 1.3-1.5mm in 5mm and normally reaches the maximum width of 1.7-1.9mm within 12mm. Proximally the thecae number 14-12 in 10mm with only a slight reduction distally to 12-10 in 10mm. Neither the sicula nor any well preserved proximal regions are visible in the material from Dob's Linn. Riva (1974a) recorded that the two conspicuous basal spines are the virgella and a spine produced by $th1^1$ while $th1^2$ is non-spinose. The specimens described here possess only short but commonly thickened spines up to 0.7mm long which are occasionally connected by basal thickening in mature rhabdosomes (e.g. pl. 30, fig. 5). The spines do not appear to lengthen during astogeny. The thecae are typically *Climacograptus* in style with straight, vertical supragenicular walls and slightly thickened genicular hoods. The apertures are horizontal, shallow and short, occupying 1/5 to 1/6 the total width of the rhabdosome and 1/3 to 1/4 the ventral wall. The faint median line seen occasionally results from the virgula being pushed through the outer periderm, although it is rarely seen as a distally projecting free nema.

Remarks. The specimens from Dob's Linn seem intermediate between *C. spiniferus* s.s. and *C. dorotheus* Riva 1976. Their rhabdosome form is similar, but rather narrower, to that described for *C. spiniferus* by Riva (1974a, 1976) but their short spines are similar to those in *C. dorotheus*, although the latter species has a more rapidly widening rhabdosome. *C. spiniferus* has frequently been recorded from North America (see Riva 1974a, pp. 16-17) while *C. diplacanthus* Bulman 1932a (=*C. spiniferus*) has been figured by Mu *et al.* (1960) from China. Moor's specimens of '*C.* cf. *supernus*' from Australia (1969) and Strachan's (1974) specimens of '*C.* cf. *spiniferus*' from Girvan are both considered to belong to *C. spiniferus* s.s..

Climacograptus latus Elles & Wood 1906
(pl. 31, figs. 1-13)



1906 *Climacograptus latus* sp. nov.; Elles & Wood, pp. 204-205, pl. 27, figs. 3a-h, text-figs. 135a-d.

1929 *Mesograptus modestus* var. *intensus* nov.; Davies, p. 5, text-fig. 6.

1933 *Climacograptus latus* Elles & Wood; Sun, pp. 21-22, pl. 3, figs. 5a-d.

?1956 *Climacograptus latus* Elles & Wood; Keller, p. 86, pl. 3, figs. 1, 2.

1970 *Climacograptus latus* Elles & Wood; Toghill, p. 22, pl. 15, figs. 1, 2.

1977 *Climacograptus latus* Elles & Wood; Wang *et al.*, p. 330, pl. 100, fig. 12.

Type specimen. Not yet designated. Elles & Wood's material from the Upper Hartfell Shale, *D. anceps* Zone, of Dob's Linn.

Material. Several flattened specimens from the Wood Collection (Birmingham University) and Elles Collection (Sedgwick Museum) and numerous flattened specimens collected by the writer.

Horizons and localities. Anceps Bands B to E, Upper Hartfell Shale, *D. anceps* Zone, Dob's Linn.

Diagnosis. Large robust rhabdosome up to 60mm long and 2.6mm wide. Sicula and first two thecae with conspicuous spines, nema not commonly preserved.

Description. The rhabdosome is long and robust, up to 60mm long and widening from 0.8-1.1mm at the aperture of th1^1 to 1.2-1.9mm (average 1.6mm) in 5mm and reaching a maximum 1.8-2.6mm (commonly 2.2mm) in about 10mm which is normally maintained. The thecae number a uniform 14 in 10mm in tectonically undeformed specimens. Elles & Wood (1906,

p. 204) recorded the sicula to be obversely visible for 0.5mm but didnot record its length. The first two thecae produce spines at the point where they turn upwards; both these and the virgella are conspicuous, commonly measuring 0.5-0.8mm long. The thecae have straight, vertical supragenicular walls although these are commonly slightly inclined owing to greater lateral spread at the apertures, especially in distal thecae which would have possessed a less well thickened periderm. The apertural excavations are deep and occupy 1/3 to 1/4 of the total rhabdosome width proximally but only 1/5 to 1/6 distally. The rhabdosome is apparently aseptate although a wavy median line is normally formed by the virgula being pressed though the outer periderm. Only one specimen has been observed with a distally projecting nema.

Remarks. This species is readily separable from all coeval *Climacograptus* species providing that the proximal end is complete. The distal thecae of *C. latus* may be superficially confused with those of *Orthograptus fastigatus* Davies 1929 but closer examination shows them to lack the characteristic introversion of the latter species. Distal fragments may be confused with tectonically widened *C. longispinus supernus* Elles & Wood 1906 so that identification may only be made by using complete specimens. Contrary to Elles & Wood (1906) and Toghill (1970) *C. latus* occurs abundantly at Dob's Linn in all the Anceps Bands except A, although it is most characteristic of the later bands belonging to the *P. pacificus* Subzone.

The occurrence of *C. latus* seems to be more restricted than most other late Ordovician diplograptids. The specimens figured by Keller (1956) from Russia do not possess proximal parts so identification cannot be certain. Sun (1933) and Wang *et al.* (1977) both figured specimens from the *D. szechuanensis* Zone of China that appear to agree well with the type material. Although not previously recorded from Australia VandenBerg (pers. comm.) reports *C. latus* to be abundant and has utilised it as a zone fossil in the latest Bolindian of Victoria (zone of *D. ornatus* and *C. latus*).

Climacograptus tubuliferus Lapworth 1876

(pl. 32, figs. 1-13)

1876 Climacograptus tubuliferus sp. nov.; Lapworth, pl. 2, fig. 49.

1877 Climacograptus scalaris var. tubuliferus Lapworth; Lapworth, pl. 6, fig. 33.

1902 Climacograptus tubuliferus Lapworth; Hall, p. 55, pl. 13, fig. 5, pl. 6, fig. 33.

1906 Climacograptus tubuliferus Lapworth; Elles & Wood, p. 203-204, pl. 27, figs. 8a-d, text-figs. 134a-c.

1947 Climacograptus tubuliferus Lapworth; Ruedemann, p. 440, pl. 75, figs. 54-56.

1955 Climacograptus tubuliferus Lapworth; Harris & Thomas, p. 40, pl. 1, figs. 10-12.

1960 Climacograptus tubuliferus Lapworth; Berry, p. 85, pl. 19, fig. 5.

1963 Climacograptus tubuliferus Lapworth; Ross & Berry, p. 132, pl. 10, figs. 1-2.

1977 Climacograptus tubuliferus Lapworth; Carter & Churkin, pp. 23-24, pl. 7, fig. 5.

Type specimen. Lapworth's original specimen has not yet been recognised (Strachan 1971, p. 35.).

Material. Specimens in the Lapworth and Wood collections (Birmingham University) and numerous specimens collected by the writer.

Horizons and localities. 3.4 to 2.5m below the top of the Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn. Lapworth's and Wood's specimens from the Lower Hartfell Shale of Hartfell Spa and Beldcraig Burn, Moffat.

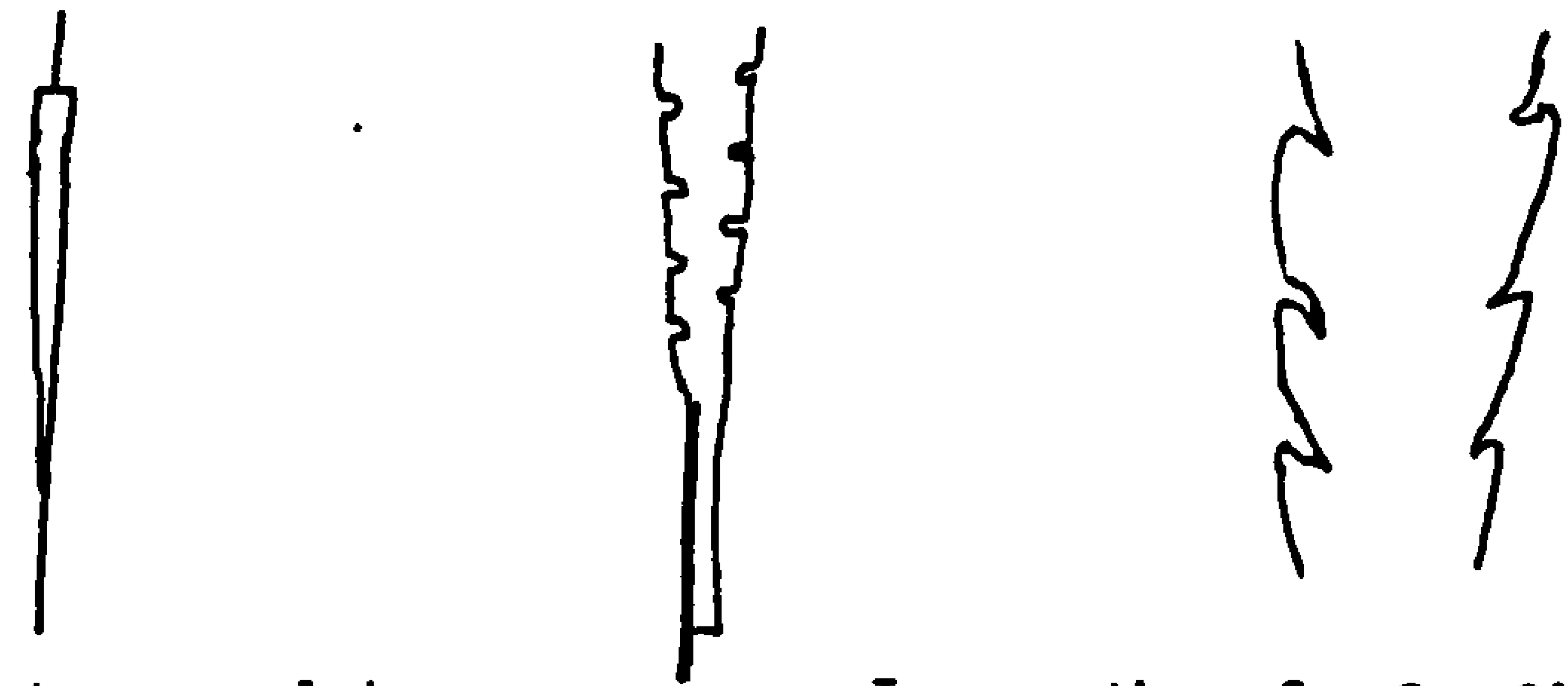
Diagnosis. Rhabdosome over 40mm long, gradually increasing from 0.8mm to the maximum 2.0mm in 20mm. Proximal end pointed. Thecae of typical Climacograptus style, numbering 8-13 in 10mm. Nema long and up to 1.5mm wide.

Description. The rhabdosome is over 40mm long excluding the nema. It increases from 0.8mm wide at the aperture of $th1^1$ to 1.4-1.6mm in 5mm and gradually attains the maximum width of 2.0-2.2mm in about 20mm which is then maintained. The thecae number 11-13 in 10mm proximally, reducing to 8-10 in 10mm distally. The sicula has not been observed but it possesses a conspicuous virgella which in some specimens (but not in the British ones) may reach 10mm long (Carter & Churkin 1977) and possess a thickened membrane on the side of $th1^1$ for several mm. $Th1^1$ and 1^2 appear to grow upwards throughout their length. The thecae are typically Climacograptus in style with straight, vertical supragenicular walls and horizontal apertures occupying 1/4 the total width proximally and about 1/5 distally. A characteristic long and wide nema is usually present, measuring up to 30mm long and 1.5mm wide. It is not clear whether this was originally a flat vane or cylindrical, but some specimens show the virgula to be thickened within the stipe (e.g. pl. 32, fig. 2). The nema is normally narrow in juvenile specimens but more material is required before any certain conclusions regarding the astogenetic development of the nema may be drawn.

Remarks. Some confusion has previously arisen in distinguishing C. tubuliferus from C? caudatus Lapworth 1876. Although the rhabdosomal forms are similar the thecal style of C? caudatus often appears intermediate between Climacograptus and Orthograptus and the nema is never thickened to the same extent as C. tubuliferus. The proximal regions of the two species could be confused but the characteristic long drawn-out virgella of C? caudatus which sometimes reaches several cm long is not found in C. tubuliferus. C? caudatus is only found in the D. clingani Zone while, if previous records are accurate, C. tubuliferus is found in both the D. clingani and P. linearis zones. Although it has not been previously recorded above the Lower Hartfell Shale the writer has found numerous, but poorly preserved, specimens in the lower Complanatus Band at Dob's Linn while VandenBerg (pers. comm.) records it to range as high as the Upper Bolindian in Victoria. C. tubuliferus has been recorded several times from Australia (Hall 1902, Harris & Thomas 1955) and North America (Ruedemann 1947, etc.).

Climacograptus? caudatus Lapworth 1876

(pl. 33, figs. 1-6)



1876 Climacograptus caudatus sp. nov.; Lapworth, pl. 2, fig. 48.

1877 Climacograptus scalaris var. caudatus Lapworth; Lapworth, pl. 6, fig. 34.

1906 Climacograptus caudatus Lapworth; Elles & Wood, pp. 202-203, pl. 27, figs. 7a-e, text-figs. 133a-d.

1908 Climacograptus caudatus Lapworth; Ruedemann, pp. 438-439, pl. 28, figs. 17-18, text-fig. 406.

?1913 Climacograptus caudatus Lapworth; Hadding, pp. 49-50, pl. 3, figs. 18-19, text-fig. 19.

?1934 Climacograptus caudatus Lapworth; Ruedemann & Decker, p. 319, pl. 43, figs. 1-1a.

1947 Climacograptus caudatus Lapworth; Ruedemann (pars), p. 424, pl. 72, figs. 57-65 (non pl. 71, figs. 51-52).

1955 Climacograptus caudatus Lapworth; Harris & Thomas, pp. 38-39, pl. 1, figs. 4-6.

?1963 Climacograptus caudatus Lapworth; Ross & Berry, pp. 119-120, pl. 8, figs. 11-12.

Type specimen. Lapworth's original figured specimen has not been found (Strachan 1971, p. 32).

Material. Specimens in the Lapworth Collection (Birmingham University) and about thirty flattened specimens collected by the writer.

Horizons and localities. 8.7 to 8.4m below the top of the Lower Hartfell Shale, late D. clingani Zone, North Cliff trench, Dob's Linn. Lapworth's specimens from the Lower Hartfell Shale of Glenkiln Burn and Hartfell Spa.

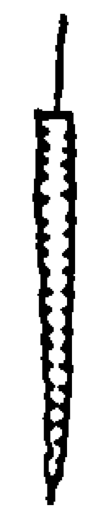
Diagnosis. Rhabdosome over 60mm long, widening from 0.6mm proximally to the maximum 2.0-2.5mm within 15mm. Thecae intermediate in style between Climacograptus and Orthograptus, numbering 9-12 in 10mm. Virgella up to 30mm long with an early membrane.

Description. The rhabdosome sometimes measures over 60mm long excluding the virgella, widening from 0.6-0.7mm at the aperture of $th1^1$ to 1.3-1.7mm in 5mm and reaching the maximum 2.0-2.5mm within 15mm. Proximally the thecae number 11-12 in 10mm, reducing distally to 9-10 in 10mm. The sicula is obscure but bears a long virgella up to 30mm long with a thickened membrane, commonly about 5mm long, on the side of $th1^2$. Development of $th1^1$ and 1^2 is unclear but the narrow pointed proximal end indicates continuous upward growth. The first few thecae are typically Climacograptus in style with straight, sub-vertical supragenicular walls and horizontal apertures but distally the supragenicular walls are somewhat inclined and straight or gently rounded. Proximally the apertural excavations occupy 1/4 of the total stipe width but distally this is reduced to about 1/6. A short and narrow nema is occasionally seen.

Remarks. C? caudatus is readily distinguished from C. tubuliferus Lapworth 1876 by its thecal style and poorly developed nema and is different in rhabdosomal form from any other coeval diplograptids. The change in thecal style from Climacograptus proximally to Orthograptus or Glyptograptus distally is normally taken to be diagnostic of the genus Diplograptus. The change may however be partly due to differential effects on diagenetic flattening dependent on the orientation of the rhabdosome and is not considered sufficient to warrant the removal of this species to Diplograptus. The change must indicate a thecal style different to that typically found in Climacograptus as most members of this genus show little variation in style when compressed in a number of orientations.

The specimens figured by Ruedemann & Decker (1934) and Ross & Berry (1963) are not preserved sufficiently well to allow positive identification. The specimens of 'C. caudatus' figured by Hadding (1913) agree well with the Scottish material from the D. clingani Zone but come from the Lower Dicellograptus Shale which is equivalent to the N. gracilis Zone. Certain specimens of C? caudatus have been described from North America (Ruedemann 1908, 1947) and Australia (Harris & Thomas 1955).

Climacograptus normalis Lapworth 1877
(pls. 34 - 36)

1877 Climacograptus scalaris var. normalis var. nov.; Lapworth, p. 138, pl. 6, fig. 31.

?1897 Climacograptus scalaris var. normalis Lapworth; Perner, p. 7, pl. 10, fig. 1.

1906 Climacograptus scalaris (Hisinger) var. normalis Lapworth; Elles & Wood, p. 186, pl. 26, figs. 2a-g, text-figs. 119a-d.

1922 Climacograptus scalaris His. sp. var. normalis Lapworth; Gortani, p. 104, pl. 17, fig. 23.

1924 Climacograptus scalaris normalis Elles & Wood; Hundt, pp. 55-56, pl. 1, figs. 28-31.

1929 Climacograptus scalaris var. normalis Lapworth; Davies, p. 8, text-fig. 29.

1929 Climacograptus scalaris - C. medius transient; Davies, text-figs. 28, 31.

1934 Climacograptus scalaris var. normalis Lapworth; Hsü, p. 60, pl. 4, figs. 8a-i.

1945 Climacograptus scalaris var. normalis Lapworth; Waterlot, pl. 4, fig. 92.

1948 Climacograptus (Climacograptus) scalaris normalis Lapworth; Pribyl, p. 17.

1948 Climacograptus scalaris v. normalis; Waern, pp. 449-452, pl. 26, fig. 1, text-fig. 5.

1952 Climacograptus scalaris normalis Lapworth; Münch, p. 50, pl. 1, figs. 5a, b, ?c.

1963 Climacograptus scalaris cf. var. normalis? Lapworth; Willefert, p. 14, text-fig. 5.

1965 Climacograptus scalaris normalis Lapworth; Stein, pp. 157-160, pl. 14c, text-figs. 13, 14a-e, tables 3, 4.

1970 Climacograptus normalis Lapworth; Rickards, p. 28, pl. 1, figs. 1, 7, 8, text-fig. 13, figs. 7, 8.

1974 Climacograptus normalis Lapworth; Hutt, pp. 19-20, pl. 1, figs. 8, 9, pl. 2, figs. 1-4.

?1978 Climacograptus cf. normalis Lapworth; Wang et al., p. 638, pl. 206, fig. 12.

Holotype. BU 1136. The specimen figured by Lapworth 1877, pl. 6, fig. 31, Elles & Wood 1906, pl. 26, fig. 2a and here (pl. 34, fig. 1). From the Birkhill Shale, Dob's Linn.

Material. Several specimens from the C. Lapworth and H. Lapworth collections (Birmingham University) and numerous specimens preserved both flattened and in relief, collected by the writer.

Horizons and localities. The Anceps Bands, Upper Hartfell Shale and the basal 2.3m of Birkhill Shale, D. anceps to early O? acuminatus zones, Dob's Linn.

Diagnosis. Rhabdosome over 30mm long with a maximum width of 1.5mm attained within 10mm. Thecae typically Climacograptus in style, numbering 8-13 in 10mm. Virgella and nema long.

Description. The rhabdosome is over 30mm long. It measures about 0.7mm at the aperture of $th1^1$ in tectonically undeformed specimens (range 0.6-1.1mm), widening to 1.1-1.6mm in 5mm and reaching the maximum width (characteristically 1.5mm) within 10mm. Proximally the thecae number 11-13 in 10mm, reducing distally to 8-12 in 10mm (commonly 9 in 10mm when undeformed). The sicula is exposed in obverse view for 1.0-1.3mm which may represent its entire length. It possesses a long virgella which sometimes exceeds 10mm long. $Th1^1$ and 1^2 grow upwards for their entire length; the wall of the sicula on the side of $th1^2$ is normally free for 0.15-0.2mm, resulting in a slight 'notch' at the base of the supragenicular wall of $th1^2$. The thecae are typically Climacograptus in style with angular sigmoidal curvature. The supragenicular walls are normally straight, vertical and with thickened genicular hoods producing sharp genicula. When preserved in slightly oblique orientation the supragenicular walls exhibit a slight convexly curved profile with less pronounced genicula. The apertures are horizontal or very slightly everted and open into excavations which occupy 1/4 of the total rhabdosome width proximally and 1/5 distally, although they appear deeper when the rhabdosome is preserved in oblique orientation. A nema is invariably present in complete specimens and may reach several cm long.

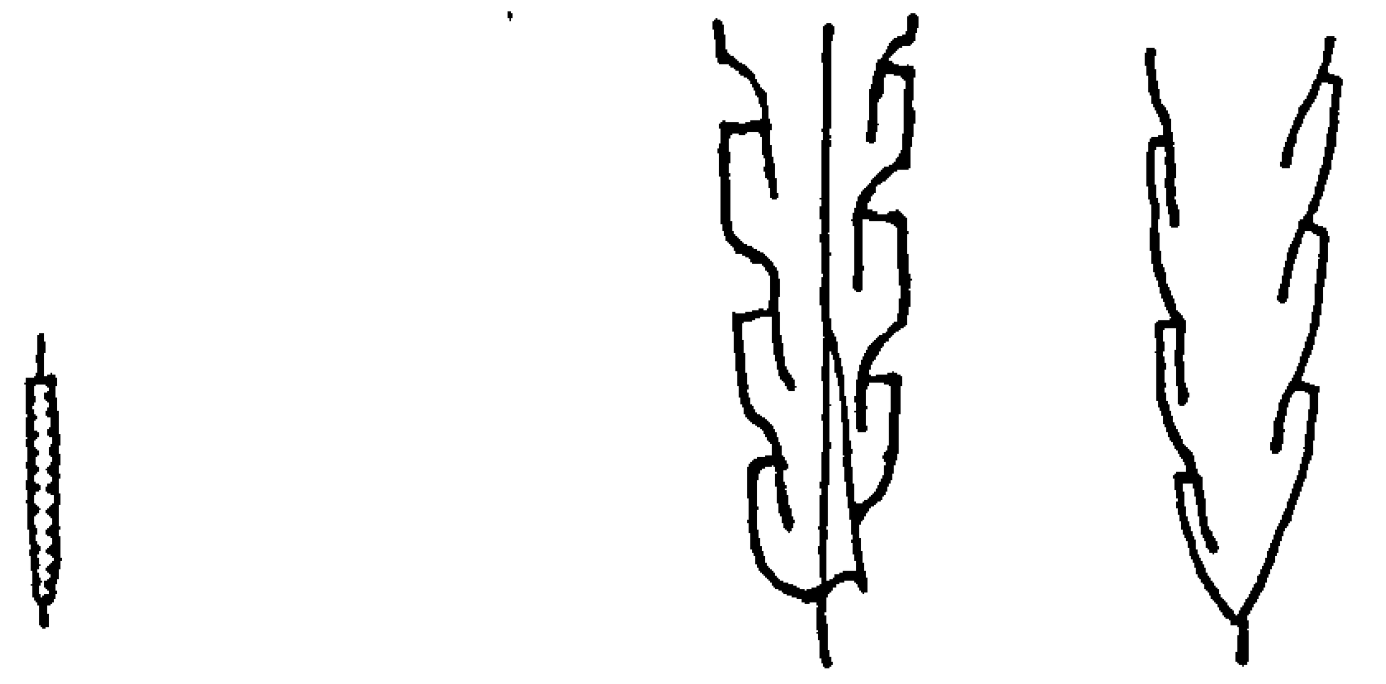
Remarks. The specimens of C. normalis described here clearly show the difference between internal and external moulds of graptolites when preserved in relief. The internal moulds (e.g. pl. 36, figs. 1-3) show prominent interthecal septa while the external moulds (e.g. pl. 34, fig. 7, pl. 35, fig. 1, pl. 36, fig. 7) have smoothly rounded stipes and the junctions of the interthecal septa with the outer walls are only indicated by shallow rounded depressions.

C. normalis may be confused with C. miserablis Elles & Wood 1906, C. medius Törnquist 1897, C. rectangularis (M'Coy 1850), Glyptograptus? avitus Davies 1929 and Glyptograptus? sp. A when the specimens have suffered tectonic distortion. It may normally be separated from C. miserablis by its more gradual widening and maximum width which normally exceeds 1.2mm even when tectonically stretched in comparison with the usual 1.0mm maximum width of C. miserablis. C. medius has a more robust form and rounded proximal end and lacks the 'notch' formed by the exposed wall of the sicula in C. normalis. According to recent descriptions by Rickards (1970, pp. 30-31) and Hutt (1974, p. 19) C. rectangularis has a much wider form than C. normalis with a maximum width of 2.0-2.5mm, although the proximal end seems very similar to several specimens assigned here to C. normalis (e.g. pl. 34, figs. 2, 5, 6). C. rectangularis has not been recorded earlier than the A. atavus or C. vesiculosus zones. C. normalis is separable from both G? avitus and Glyptograptus sp. A by its consistently 'box-like' thecae and it never displays the rather rounded supragenicular walls nor the forked virgella commonly seen in G? avitus.

C. normalis has been widely recorded from the top Ordovician and lower Silurian of north-west Europe (see synonymies), north-east Russia (Koren' et al. 1979, 1980), Greenland (Poulsen 1934), Morocco (Willefert 1963), North America (Churkin et al. 1970), China (Hsü 1934) and Australia (Thomas 1960).

Climacograptus miserablis Elles & Wood 1906

(pls. 37 - 38)



?1895 Diplograptus (Glyptograptus) euglyphus Lapworth var. angustus mihi; Perner, p. 27, pl. 8, figs. 14a, b.

?1895 Diplograptus (Glyptograptus) lobatus n. sp.; Perner, p. 28, pl. 7, fig. 15, pl. 8, fig. 15.

1906 Climacograptus scalaris (Hisinger) var. miserablis var. nov.; Elles & Wood, pp. 186-187, pl. 26, figs. 3a-h, text-figs. 120a-c.

?1924 Climacograptus miserablis Elles & Wood; Hundt, pl. 1, figs. 20, 21, 26.

1929 Climacograptus scalaris var. miserablis Elles & Wood; Davies, pp. 7-8 (pars), text-fig. 27.

1945 Climacograptus scalaris var. miserablis Elles & Wood; Waterlot, pl. 4, fig. 91.

?1949 Climacograptus angustus (Perner); Přibyl, pp. 7-10, pl. 11, figs. 2-9.

?1963 Climacograptus scalaris var. miserablis? Elles & Wood; Willefert, pp. 14-15, text-fig. 4, pl. 3, figs. 12, 16.

?1963 Climacograptus angustus (Perner); Skoglund, pp. 40-42, pl. 3, figs. 1, 2, 4-6, pl. 4, fig. 7, pl. 5, fig. 6.

1965 Climacograptus scalaris miserablis Elles & Wood; Stein, pl. 60, figs. 14f, h.

1970 Climacograptus scalaris miserablis Elles & Wood; Toghill, p. 23, pl. 12, figs. 1-11.

1970 Climacograptus miserablis Elles & Wood; Rickards, p. 28, pl. 1, figs. 3-5, 10.

1974 Climacograptus miserablis Elles & Wood; Hutt, p. 20, pl. 1, figs. 1, 2, text-fig. 8, fig. 1.

?1975 Climacograptus angustus (Perner); Bjerreskov, p. 23, text-fig. 9a.

?1980 Climacograptus angustus (Perner); Koren' et al., pp. 131-132, pl. 37, figs. 2-7, text-figs. 34a-e.

?1980 Climacograptus aff. angustus (Perner); Koren' et al., p. 132, text-fig. 35.

(see 'Remarks' concerning C. angustus)

Type specimen. Not yet designated. Elles & Wood's material is from the Upper Hartfell Shale of Dob's Linn (mainly lower Complanatus Band).

Material. Specimens in the Lapworth Collection (Birmingham University) used by Elles & Wood in their original description and numerous specimens, mostly flattened but some preserved in full relief, collected by the writer.

Horizons and localities. The Complanatus and Anceps Bands, Upper Hartfell Shale, and basal 2.3m of Birkhill Shale, D. complanatus to early O? acuminatus zones, Dob's Linn. Probable specimens from 8.9 to 1.2m below the top of the Lower Hartfell Shale, late D. clingani to P. linearis zones, North Cliff trench, Dob's Linn.

Diagnosis. Small rhabdosome up to 20mm long, with a rapidly attained maximum width of 0.8mm. Thecae may appear typically Climacograptus in style or possess slightly curved supragenicular walls, numbering 10-11 in 10mm. Long virgella and nema commonly present.

Description. The rhabdosome is only up to 20mm long, widening from 0.5-0.7mm at the aperture of $th1^1$ to the maximum 0.7-0.8mm (1.0mm in tectonically widened specimens) within 4mm. Proximally the thecae number about 11 in 10mm, reducing only slightly to about 10 in 10mm distally. The sicula is 1.0-1.3mm long and is exposed for its entire length in obverse aspect. It possesses a conspicuous virgella which sometimes reaches over 10mm long. $Th1^1$ grows initially down until it reaches the aperture of the sicula then bends sharply upwards. $Th1^2$ grows upwards for its entire length. When specimens are preserved in full dorso-ventral view a slight proximal 'notch' is present where the sicula extends beyond $th1^2$ but the proximal end appears pointed when orientated obliquely. The median septum appears to commence on the reverse side opposite the aperture of $th1^2$ (below the apex of the sicula) and possesses an initial thickened node (pl. 37, fig. 13). The remaining thecae may appear either typically Climacograptus in style with straight supragenicular walls and pronounced sharp genicula, or slightly Glyptograptus-like with rounded genicula and slightly convexly curved supragenicular walls, depending on the orientation of the rhabsome. The apertures are normally slightly everted, opening into long excavations which occupy 1/4 the total width of the rhabdosome and are sub-alternate. The interthecal septa are slightly curved and short, extending only 1/2 the length of the supragenicular walls. A long nema is commonly present.

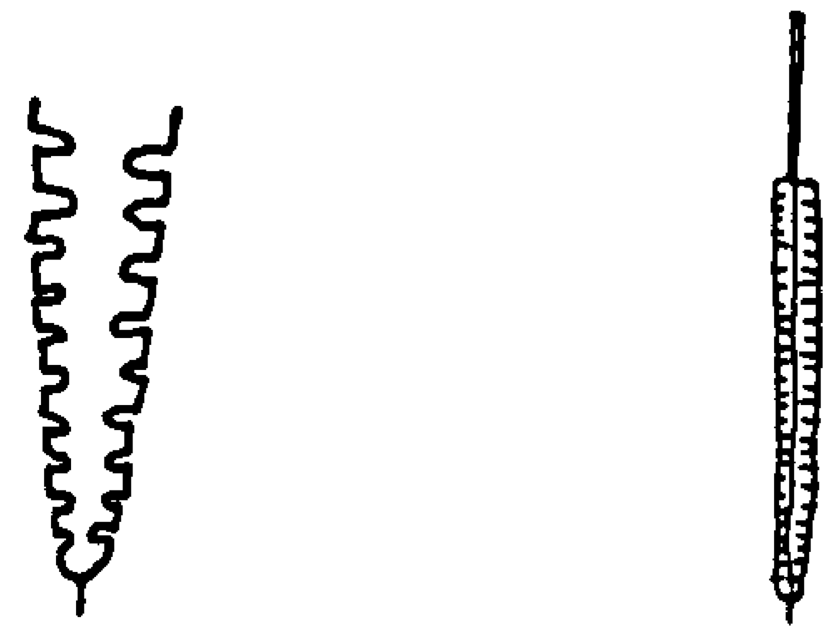
Remarks. The only coeval species with which C. miserablis can be easily confused is C. normalis Lapworth 1877 when tectonically stretched. C. miserablis however reaches its maximum width quickly as opposed to the more gradual widening of C. normalis, and even when stretched specimens rarely exceed 1.0mm wide. The proximal development and thecal style of C. miserablis is also different with shorter interthecal septa and commonly slightly curved supragenicular walls. Toghill (1970) recorded C. miserablis from the P. linearis Zone and the present work indicates that it is found as low as the late D. clingani Zone in the Lower Hartfell Shale at Dob's Linn. Elles & Wood record the earlier small Climacograptus, C. brevis Elles & Wood 1906 to be characteristic of the N. gracilis and C. peltifer zones with only rare specimens in the Lower Hartfell Shale.

The similarity of C. miserablis to C. angustus (Perner 1895) was first noted by Přibyl (1949, p. 7) who listed Elles & Wood's species as a junior synonym. Strachan (1971, p. 34) however pointed out that Perner's original specimen was a distal fragment and insufficient to erect as the type of a new species. Přibyl raised Perner's G. euglyphus angustus to full specific status, assigned it to Climacograptus and synonymised G. lobatus which was first described by Perner on the page following the description of C. angustus. It has since become apparent that the lower Silurian specimens of C. miserablis match Perner's description of C. angustus more closely than the late Ordovician ones which have a more typically Climacograptus thecal style (Rickards, pers. comm.). It is here considered that C. miserablis is best retained as a separate species from C. angustus until further study of Perner's type and any topotype material is possible, although it is recognised that the lower Silurian specimens described here are probably synonymous with Perner's material. It should be noted that C. angustus Sobolevskaya 1969, a small longispinus group Climacograptus from the late Ordovician of Russia is a junior homonym of C. angustus (Perner 1895) and should not be used.

C. miserablis is a widespread upper Ordovician and lower Silurian species, and if synonymised with C. angustus has been recorded from every continent of the world.

Climacograptus medius Törnquist 1897

(pl. 39, figs. 1(?), 3-7)



1870a Climacograptus teretiusculus; Nicholson (pars), p. 373, text-figs. 1a, b, f (non text-figs. 1c-e).

1872 Climacograptus teretiusculus; Nicholson (pars), p. 33, text-figs. 8a, b, f (non text-figs. 8c-e).

1873 Climacograptus scalaris; Malaise, p. 104, pl. 6, figs. 5-6.

(non 1837 Prionotus scalaris; Hisinger, p. 113, pl. 35, fig. 4)

1897 Climacograptus medius n. sp.; Törnquist, pp. 7-8, pl 1, figs. 9-15.

1906 Climacograptus medius Törnquist; Elles & Wood (pars), pp. 189-190, pl. 26, figs. 4a-e, text-figs. 122a, c (non pl. 26, fig. 4f, text-fig. 122b).

1919 Climacograptus medius Törnquist; Kirste (pars), p. 107, pl. 1, figs. 4b, 4a? (non pl. 1, figs. 4c, d).

?1924 Climacograptus medius Törnquist; Hundt, pl. 1, figs. 22, 23, 35, 36.

?1924 Climacograptus medius Törnquist; Manck, p. 7, text-fig. 6.

?1929 Climacograptus medius Törnquist; Davies, text-fig. 32, fig. 4.

1933 Climacograptus medius Törnquist; Sun, p. 23, pl. 4, fig. 2.

?1940 Climacograptus medius Törnquist; Desio, p. 27, pl. 1, figs. 16, 17.

1945 Climacograptus medius Törnquist; Waterlot, pl. 6, fig. 113.

1948 Climacograptus medius Törnquist; Waern, pp. 449-452, pl. 25, fig. 4, text-fig. 5.

?1949 Climacograptus medius Törnquist; Obut, p. 13, pl. 1, figs. 3a, b.

?1957 Climacograptus medius Törnquist; Suner Coma, pp. 49-50, text-fig. 1.

1965 Climacograptus medius Törnquist; Stein, pp. 163-165, text-figs. 16a-g, tables 7, 8.

?1970 Climacograptus cf. C. medius Törnquist; Churkin & Carter, p. 16, pl. 1, figs. 4, 5, text-fig. 6f.

1970 Climacograptus medius Törnquist; Rickards, p. 30, pl. 1, fig. 2.

1974 Climacograptus medius Törnquist; Hutt, p. 19, pl. 1, fig. 3.

Lectotype. The specimen figured by Törnquist 1897, pl. 1, fig. 9, from the Rastrites Beds of Nyhamm, Sweden. Designated by Přibyl 1948, p. 16.

Material. Fifteen flattened specimens and one in full relief, collected by the writer.

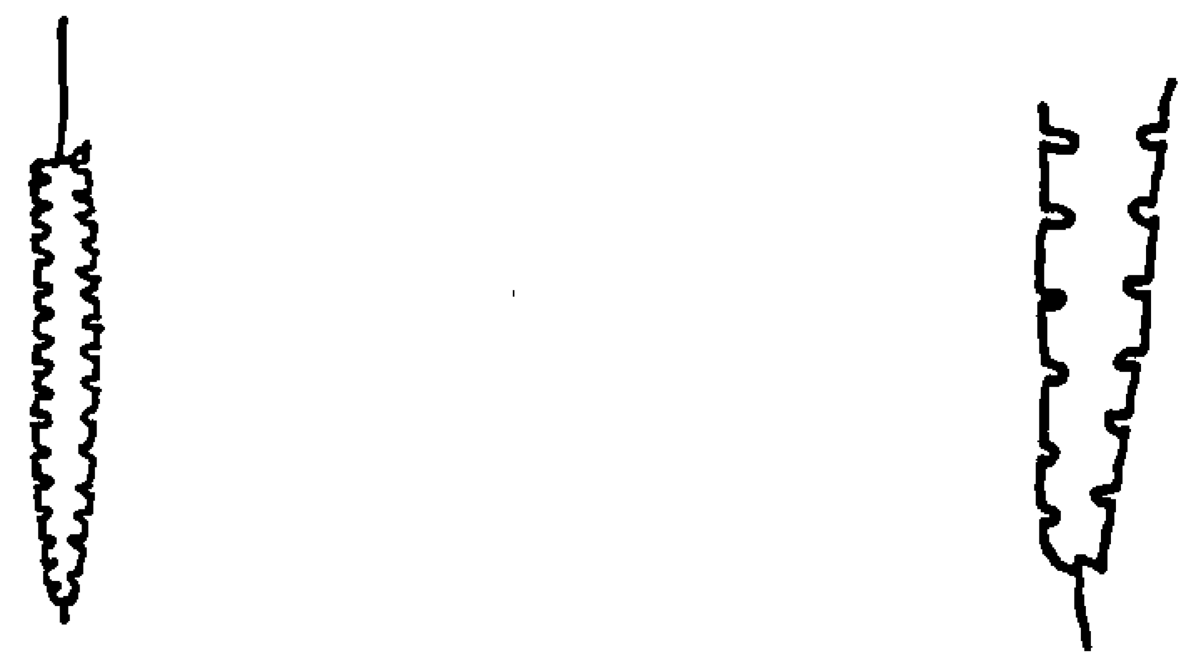
Horizons and localities. 1.1 to 2.3m above the base of the Birkhill Shale, G. persculptus and early O? acuminatus zones, Linn Branch trench, Dob's Linn.

Diagnosis. Robust rhabdosome with a maximum width of 2.5mm, a wide rounded proximal end and sicula with short virgella. Thecae with short straight supragenicular walls, numbering 12-13 in 10mm, excavations long and deep. Nema often broad.

Description. The rhabdosome is over 30mm long, increasing from a width of 1.0mm at the aperture of $th1^1$ to 1.7-1.9mm in 5mm and slowly reaching the maximum 2.2-2.5mm within 15mm. The thecae usually number 13 in 10mm proximally, reducing only slightly to 12 in 10mm distally. The proximal development has not been observed in the described material. The sicula possesses a conspicuous virgella and the proximal region is wide and rounded. The thecae have short, straight supragenicular walls which are normally sub-vertical. They are sometimes slightly inclined but this may be due to greater lateral spread at the apertures on flattening. The apertures are horizontal and open into very deep and long excavations which occupy 1/3 the total width of the rhabdosome and over 1/3 of the ventral walls. The excavations often appear even deeper as the rhabdosome is commonly preserved in oblique orientation; the specimen preserved in full relief shows that this is due to the almost circular cross-section of the rhabdosome. The virgula is normally extended as a long and wide nema which may have been cylindrical owing to the median groove that is commonly present.

Remarks. C. medius is the most robust Climacograptus species found in the O? acuminatus Zone. It could be confused with tectonically widened specimens of C. normalis Lapworth 1877 but this never attains the maximum width of C. medius. C. medius seems closest to C. trifilis Manck 1923 which has a similar sized rhabdosome but the sicula of this species possesses three spines and the rhabdosome widens more rapidly to a rather narrower maximum width. C. medius is distinguishable from C. rectangularis (M'Coy 1850) by its more robust proximal end. C. medius has sometimes been recorded as occurring rarely in the O? acuminatus Zone but with its main development in the A. atavus to M. triangulatus zones (Rickards 1970, Hutt 1974) although both Stein (1965) and Toghill (1968b) record the range as G. persculptus to C. cyphus zones. It has been recorded from several parts of Europe, Morocco (Waterlot 1945), China (Sun 1933), Russia (Obut & Sobolevskaya 1966) and questionably from North America (Churkin & Carter 1970).

Climacograptus mohawkensis (Ruedemann 1912)
(pl. 40, figs. 1-8)



1906 Climacograptus minimus (Carruthers); Elles & Wood, p. 191, pl. 27, figs. 1a-g, text-figs. 124a-d.

non 1868 Diplograptus minimus sp. nov.; Carruthers, p. 74, pl. 5, figs. 12a, b.

1912 Diplograptus (Mesograptus) mohawkensis sp. nov.; Ruedemann, pp. 80-82, pl. 2, figs. 18, 19, text-figs. 19, 20.

1947 Diplograptus (Mesograptus) mohawkensis Ruedemann; Ruedemann, pp. 419-420, pl. 71, figs. 24-26.

1948 Climacograptus cf. minimus (Carruthers); Henningsmoen, pp. 404-405.

1960 Climacograptus minimus (Carruthers); Berry, p. 80, pl. 19, fig. 2.

?1963 Climacograptus minimus (Carruthers); Ross & Berry, pp. 125-126, pl. 8, fig. 7.

1964 Climacograptus minimus (Carruthers); Obut & Sobolevskaya, pp. 57-58, pl. 11, figs. 8-9.

1969 Climacograptus minimus (Carruthers); Riva, p. 521, text-figs. 3h-j.

non 1969 Climacograptus minimus (Carruthers); Strachan, pp. 191-192, pl. 4, fig. 3, text-fig. 4a.

1977 Climacograptus mohawkensis (Ruedemann); Walters, pp. 937-938, pl. 2, figs. f, h, i.

Holotype. The specimen figured by Ruedemann 1947, pl. 71, fig. 24. From the Canajoharie Shale, Carlsbad Spring, Saratoga, New York State.

Material. Numerous flattened specimens collected by the writer.

Horizons and localities. 6.6m below the top to the top of the Lower Hartfell Shale, top D. clingani and P. linearis zones, North Cliff trench, Dob's Linn.

Diagnosis. Small rhabdosome up to 15mm long, rapidly widening to the maximum 1.4mm. Proximal end with conspicuous virgella. Thecae number 12-14 in 10mm.

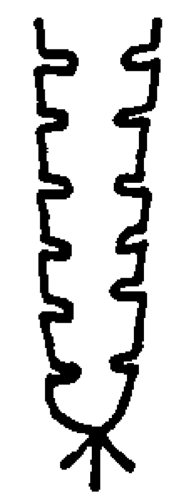
Description. The rhabdosome measures up to 15mm long, rapidly widening from 0.7mm at the aperture of $th1^1$ to the maximum 1.4mm within 6mm. Proximally the thecae number 15 in 10mm, decreasing to about 12 in 10mm distally. The proximal development is obscure but is similar to *C. normalis* Lapworth 1877, the virgella which is up to 0.9mm long being the only proximal spine. The thecae are typically *Climacograptus* in style with straight, vertical supragenicular walls. The apertural excavations are short, narrow and horizontal, occupying about 1/4 the total width of the rhabdosome, and possess well developed genicular hoods. The virgula is commonly pressed through the periderm and in one scalariform specimen (pl. 40 , fig. 8) is visible through the apertures. It is commonly preserved distally as a nema.

Remarks. Strachan (1969) demonstrated that Carruthers' type specimens of '*D.*' *minimus* were an *Orthograptus* species, probably from the Birkhill Shale (*C. vesiculosus* or *C. cyphus* zone), and not the *Climacograptus* species described by Elles & Wood (1906) from the Lower Hartfell Shale (*D. clingani* and *P. linearis* zones). However, Elles & Wood's definition of the species is the one which has since been utilised. It is now clear (Riva 1969, p. 550, Walters 1977, p. 938) that *C. mohawkensis* is synonymous with *C. minimus* sensu Elles & Wood; Walter's proposal to restrict the name '*C. minimus*' to Carruthers' type slab is here accepted.

The specimens described here appear to be rather narrower than those described by most previous authors (with the exception of Henningsmoen 1948). However, when the illustrations are measured most specimens appear to have a maximum width of about 1.5mm rather than the commonly stated 2.0mm; it is considered that the larger measurement probably refers to tectonically widened specimens. All other measurements and characters agree well with previous descriptions. The specimen figured by Ross & Berry (1963) is insufficient for positive identification.

Although the rhabdosome of *C. mohawkensis* has no particularly distinctive characters there are apparently no coeval species with which it can be easily confused. If the synonymy with C. minimus sensu Elles & Wood is accepted it has been recorded from horizons equivalent to the D. clingani and P. linearis zones from North America, Australia (Thomas 1960), Scandinavia and Russia (see list of synonymies) and has been found by the writer to occur abundantly in black shales equivalent to the late D. clingani and/or earliest P. linearis zones at Llanystumdwy near Criccieth, North Wales (see Appendix 1).

Climacograptus trifilis Manck 1923
(pl. 39, fig. 2)



1906 Climacograptus medius Törnquist; Elles & Wood (pars), pp. 189-190, pl. 26, fig. 4f, text-fig. 122b (non pl. 26, 4a-e, text-figs. 122a, c).

1923 Climacograptus trifilis spec. nov.; Manck, p. 288, text-fig. 32.

1965 Climacograptus trifilis Manck; Stein, pp. 165-167, text-figs. 17a-d.

(summary list only - complete list of synonymies given by Stein)

Holotype. The specimen figured by Manck 1923, text-fig. 32 from unknown locality and horizon (Stein 1965, p. 166).

Material. One flattened specimen collected by the writer.

Horizons and localities. The interval 2.2 to 2.3m above the base of the Birkhill Shale, early O? acuminatus Zone, Linn Branch trench, Dob's Linn.

Remarks. This species was recently described in detail by Stein (1965). It has a similarly robust proximal end to C. medius Törnquist 1897 but is distinguished by the presence of three proximal spines, apparently derived from a point near the origin of the virgella. From Stein's description it appears to be preserved commonly in scalariform and oblique orientation and probably had a similar cylindrical cross-section to C. medius. From Toghill (1968b, p. 658) and Stein (1965, p. 167) it appears to be restricted to the middle part of the O? acuminatus Zone and has not been recorded outside Europe.

Climacograptus? extraordinarius (Sobolevskaya 1974)

(pl. 41, figs. 1-7, text-figs. 25a-m)

1974 Fenhsiangograptus extraordinarius sp. nov.; Sobolevskaya, pp. 69-70, pl. 3, figs. 6-7.

* ?1974 Diplograptus orientalis sp. nov.; Wang et al., p. 213, pl. 98, fig. 11.

* ?1978 Diplograptus orientalis Mu et al.; Wang et al., p. 641, pl. 207, fig. 6.

1979 Climacograptus? extraordinarius (Sobolevskaya); Rickards, text-fig. 2.

?1980 Glyptograptus? persculptus (Salter) forma A; Koren' et al., pp. 147-150, pl. 42, figs. 3-6, pl. 43, fig. 1, pl. 44, figs. 1-6, text-figs. 44a-j.

(* - both these illustrations are of the same specimen)

Holotype. The specimen figured by Sobolevskaya 1974, pl. 3, fig. 6, No. 602x/1.

Material. About fifty specimens in the Ingham Collection (Hunterian Museum) and six specimens collected by the writer (all flattened).

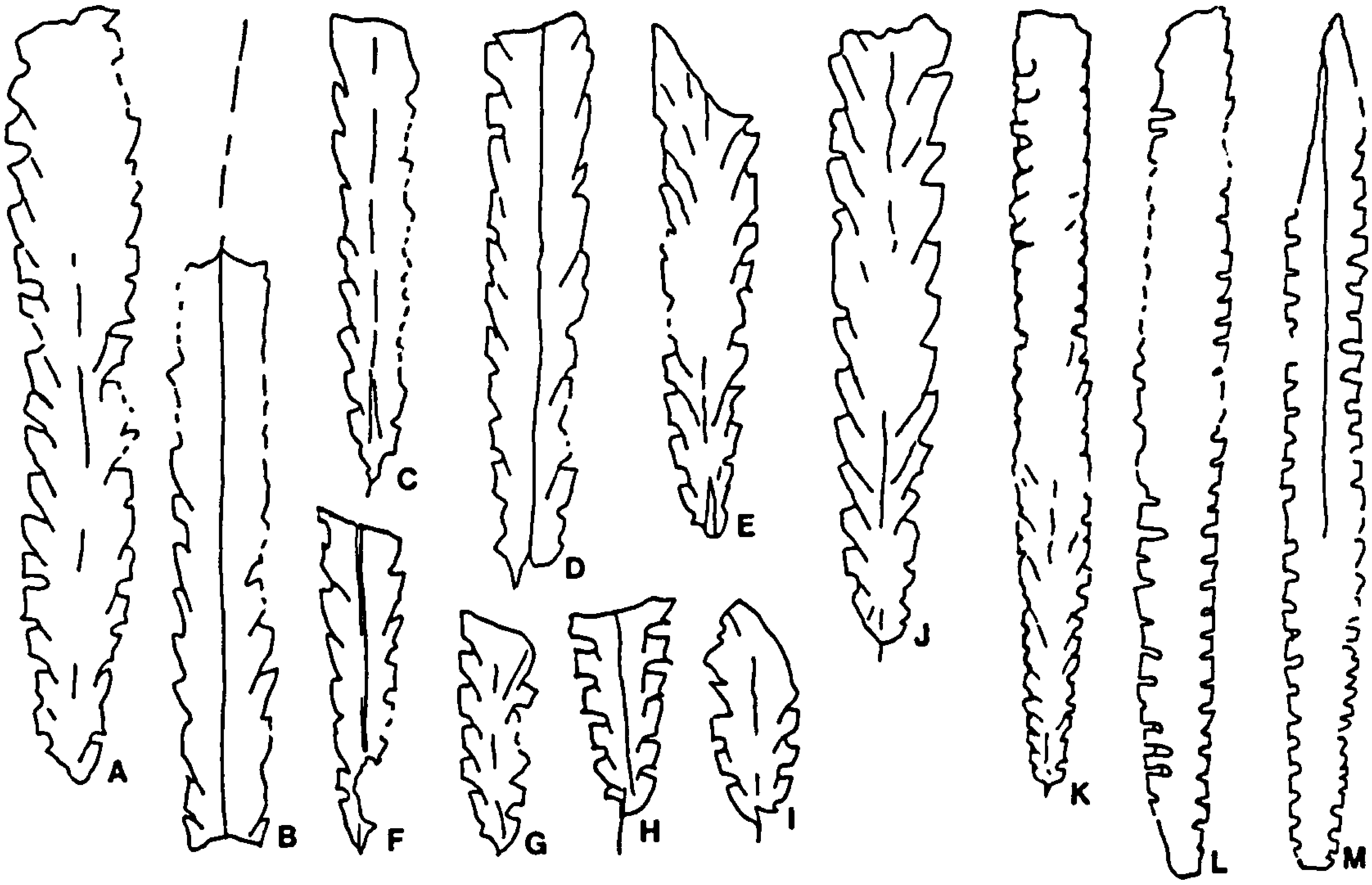
Horizons and localities. Extraordinarius Band, Upper Hartfell Shale, C? extraordinarius Zone, Long Burn trench and Main Cliff, Dob's Linn. Anceps Band E, Upper Hartfell Shale, P. pacificus Subzone, Main Cliff, Dob's Linn. Anceps Bands, Rae Grain, Craigmichan Scaurs.

Diagnosis. Rhabdosome over 35mm long, rapidly widening to the maximum 2.5-3.0mm. Distally somewhat fusiform. Thecae intermediate between Glyptograptus and Climacograptus, numbering 10-12 in 10mm. Sicula with prominent virgella, anti-virgellar side forms 'notch' under th1^2.

Description. The rhabdosome is up to 35mm long with a robust, sub-fusiform outline, rapidly widening from 1.0-1.2mm at the aperture of th1^1 to the maximum 2.3-3.0mm within 8mm and commonly decreasing in width soon after. Proximally the thecae number 12 in 10mm, reducing distally to 10 in 10mm. The sicula is rarely seen but possesses a conspicuous virgella up to 1mm long. Th1^1 grows initially downwards until it reaches a level about 0.3mm below the aperture of the sicula then bends abruptly upwards to give an aperture about 0.9mm above its lowest point. Th1^2 appears to grow upwards throughout its length, cutting diagonally across the sicula some 0.3mm above its aperture and resulting in a 'notch' where the anti-virgellar side of the sicula remains exposed (text-figs. 25g-i). The remaining thecae are highly variable in style due to diagenetic flattening in a variety of orientations and tectonic deformation. When relatively undistorted dorso-ventral orientations occur the thecae have short, straight gently inclined supragenicular walls with conspicuous genicular flanges. The apertural excavations are slightly everted and deep, occupying over 1/3 of the total ventral wall, but are narrow, commonly occupying only 1/5 to 1/6 of the total rhabdosome width. The interthecal septa are almost straight. The virgula is commonly pressed through the periderm and visible throughout the rhabdosome; it occasionally extends distally as a nema up to 5mm long. It is unclear whether a median septum exists.

Remarks. The proximal development of the specimens here assigned to C? extraordinarius is very similar to that found in Glyptograptus persculptus (Salter 1865). The main differences between the two species are the prominent genicular flanges and distal narrowing of C? extraordinarius and they are evidently closely related. It is possible that some of the specimens figured here as C? extraordinarius are actually specimens of G. ex gr. persculptus as the tectonic deformation present at Dob's Linn may alter the thecal style drastically, especially when they are preserved in oblique orientation, and subtle differences may not be reliably recognised.

The dimensions and thecal counts agree well with Sobolevskaya's original description and figures. The remaining specimens from the Ingham Collection figured by Rickards (1979, text-fig. 2) have consistently more vertical supragenicular walls but are otherwise similar to those described here. The three-dimensional specimens of G. persculptus forma A described by Koren' et al. (1980) appear similar



TEXT-FIGURE 25. Climacograptus? extraordinarius (Sobolevskaya 1974).
A - I. Extraordinarius Band, Upper Hartfell Shale, C? extraordinarius Zone, Long Burn trench, Dob's Linn. Ingham Collection. (all x5)
J - K. Anceps Band E, Upper Hartfell Shale, P. pacificus Subzone, Main Cliff, Dob's Linn.
L - M. Anceps Bands, Upper Hartfell Shale, P. pacificus Subzone, Rae Grain, Craigmichan Scaurs. Eales Collection.
A. HM C14479/33. B. HM C14479/23. C. HM C14479/5. D. HM C14479/24.
E. HM C14479/45. F. HM C14479/21. G. HM C14479/22. H. HM C14479/16.
I. HM C14479/1. J. HM C13690 (x5). K. HM C13709 (x2.5)
L. HM 2080/12a (Eales MS Cat. No.) (x2.5). M. HM C12365 (x2.5).

to C? extraordinarius proximally but they do not figure any complete specimens. Dr. R.B. Rickards is currently making a major study on the G. persculptus group (pers. comm.) and further conclusions concerning the Russian material should be left until it is completed. Only the holotype of D. orientalis has been figured; it has prominent supragenicular flanges on the early thecae and a sub-fusiform form very similar to C? extraordinarius and Mu (pers. comm.) considers that the two species may be synonymous. Diplograptus multidens orientalis Wang, Jin & Mu 1977 is from an earlier horizon containing Dicranograptus ramosus longicaulis Elles & Wood 1904 and Dicranograptus clingani Carruthers 1868 and should not be confused with the late Ordovician D. orientalis.

C? extraordinarius is now used as a late Ordovician zone fossil in both Russia and Scotland although this study shows it to range from the late P. pacificus Subzone at Dob's Linn. If D. orientalis from the top Ordovician D. bohemicus Zone of China is synonymous with C? extraordinarius it would appear to be a reasonably widespread species and even more useful for correlation than presently recognised.

10.2 Genus Orthograptus Lapworth 1873

Type species (by original designation). Graptolithus quadrimucronatus Hall 1865, p. 144, pl. 13, fig. 1-10.

Stratigraphical range. Upper Ordovician to Lower Silurian (N. gracilis to ?M. sedgwickii)

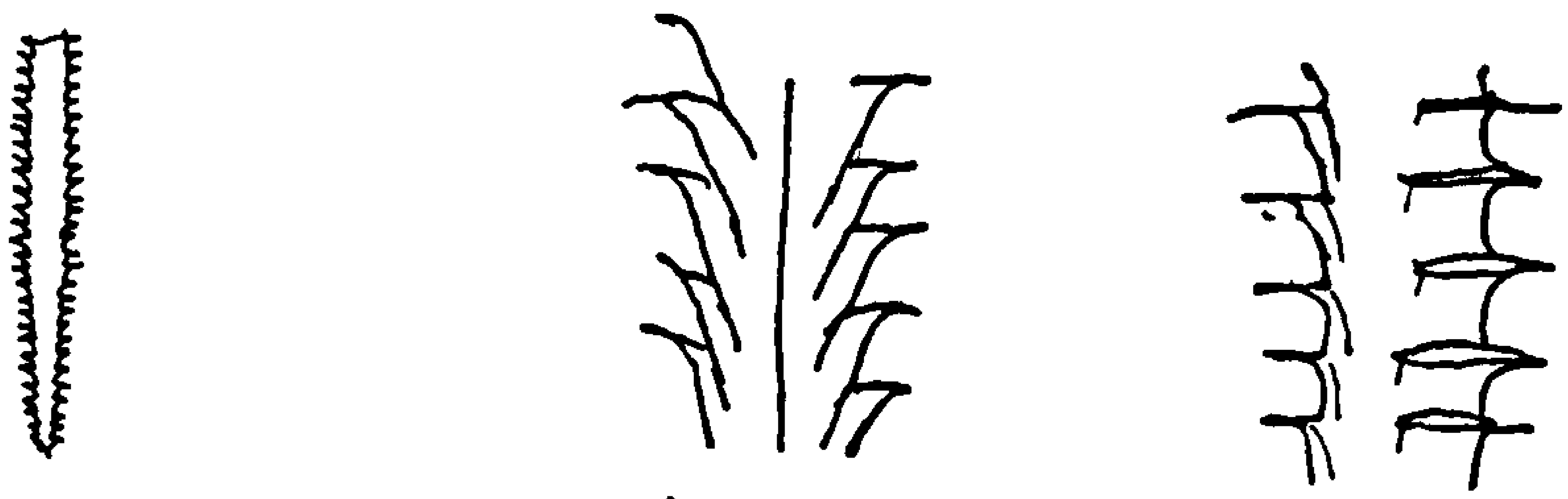
Diagnosis (after Bulman 1970, V126). Thecae straight or with slight sigmoidal curvature; large basal spines not uncommon; rhabdosome rectangular or ovoid in cross section.

Remarks. The amplexicaulis group diplograptids are no longer considered to belong to Orthograptus s.s. (p. 163) and are here questionably assigned to this genus. O? acuminatus acuminatus (Nicholson 1867a) is questionably retained in this genus following Hutt (1974).

Species described.

O. quadrimucronatus quadrimucronatus (Hall 1865) (D. clingani to late P. linearis/early D. complanatus)
O. quadrimucronatus spinigerus (Lapworth 1876) (P. linearis)
O. ex gr. calcaratus (D. clingani to late P. linearis/early D. complanatus)
O. fastigatus Davies 1929 (D. anceps - mainly D. complexus Subzone)
O? amplexicaulis (Hall 1847) (D. clingani to P. linearis)
O? pauperatus Elles & Wood 1907 (P. linearis)
O? socialis (Lapworth 1880) (?late P. linearis to D. complanatus)
O? abbreviatus Elles & Wood 1907 (D. anceps)
O? acuminatus (Nicholson 1867a)s.l. (O? acuminatus)

Orthograptus quadrimucronatus quadrimucronatus (Hall 1865)
(pl. 42, figs. 1-8, text-figs. 26a-g)



1865 Graptolithus (Diplograptus) quadrimucronatus sp. nov.; Hall, J., p. 144, pl. 13, figs. 1-10.

1876 Diplograptus aculeatus sp. nov.; Lapworth, pl. 2, fig. 44.

1877 Diplograptus quadrimucronatus Hall; Lapworth, p. 133, pl. 6, fig. 20.

1906 Diplograptus (Orthograptus) quadrimucronatus (Hall); Hall, T.S., p. 277, pl. 34, figs. 10-11.

1907 Diplograptus (Orthograptus) quadrimucronatus (Hall); Elles & Wood, pp. 223-224, pl. 28, figs. 1a-d, text-figs. 145a-f.

1908 Glossograptus (Orthograptus) quadrimucronatus (Hall); Ruedemann, pp. 385-392, text-fig. 336.

1915 Diplograptus quadrimucronatus Hall; Hadding, pp. 12-13, text-figs. 3a-f.

1947 Glossograptus quadrimucronatus (Hall); Ruedemann, pp. 452-454, pl. 78, figs. 1-5.

1948 Diplograptus (Orthograptus) quadrimucronatus (Hall); Henningsmoen, pp. 403-404.

1955 Diplograptus (Orthograptus) quadrimucronatus (Hall); Harris & Thomas, p. 37, pl. 2, fig. 37.

1970 Orthograptus quadrimucronatus (Hall); Toghill, p. 23, pl. 13, figs. 10-11.

(the synonymies given here are only a summary of the many descriptions of O. quadrimucronatus s.l. and are restricted to those decribed as O. quadrimucronatus quadrimucronatus s.s.)

Syntypes. G.S.C. 1898a, b, d. (from Strachan 1971, p. 41). From the Utica Formation at Lake St. John, Quebec.

Material. Over thirty flattened specimens collected by the writer.

Horizons and localities. 7.5 to 1.0m below the top of the Lower Hartfell Shale, late D. clingani and P. linearis zones, North Cliff trench, Dob's Linn. Dark Shale Member, Mill Formation, Upper Whitehouse Group, late P. linearis/early D. complanatus zone, Myoch Bay, Girvan.

Diagnosis. Large rhabdosome over 50mm long and 3.0mm wide. All thecae with paired apertural spines and prominent apertural lists. Periderm sometimes reduced distally.

Description. The rhabdosome is over 50mm long, rapidly increasing from 1.0-1.2mm wide at $th1^1$ to the maximum width in 8 or 10mm which is maintained or narrows slightly distally. The dorso-ventral width is wider (about 3.0mm) than the scalariform one (about 2.0mm). Proximally the thecae number 14 in 10mm, rapidly reducing to 10 in 10mm distally. Proximal detail in the specimens described here is unclear. The thecae are typically Orthograptus in style with straight inclined supragenicular walls and approximately horizontal apertures surrounded by thickened lists. All the thecae possess paired apertural spines which may reach 2.0mm long proximally. Distally the periderm is commonly reduced, the apertural lists and interthecal septa resulting in an almost retiolitid appearance (text-fig. 26c). Although the virgula is commonly prominent throughout the length of the rhabdosome a distal nema has only been observed in a few specimens.

Remarks. Lapworth designated O. q. quadrimucronatus to be the type species of Orthograptus in the original description of his new genus (1873). It was assigned to Glossograptus by Ruedemann (1908, 1947) because of its thecal lists and spines, although it is now recognised that the proximal development of the two genera are very different. Many subspecies of O. quadrimucronatus have been erected by Ruedemann and others and the species group is now in need of major revision.

O. q. quadrimucronatus may easily be confused with O. ex gr. calcaratus when the apertural spines are hidden, but the two may be separated by the more rapid widening of O. q. quadrimucronatus in dorso-ventral view and by the lack of a wide nema. Confusion between the two is often furthered by the frequent scalariform and oblique views of O. q. quadrimucronatus encountered owing to the original equidimensional section of the rhabdosome and positioning of the apertural spines.

TEXT-FIGURE 26

A - G. Orthograptus quadrimucronatus quadrimucronatus (Hall 1865).

A. HM C13030. Long fragment passing from well sclerotised proximal to poorly sclerotised distal parts. Base of Dark Shale Member, Mill Formation, Upper Whitehouse Group, P. linearis/D. complanatus Zone. Loc. M2, Myoch Bay, Girvan. (x5)

B. HM C13029. Well sclerotised specimen with proximal part. Horizon and locality as 'A'. (x10)

C. HM C13044/1. Poorly sclerotised fragment in oblique view (note prominent 'lists'). Horizon and locality as 'A'. (x10)

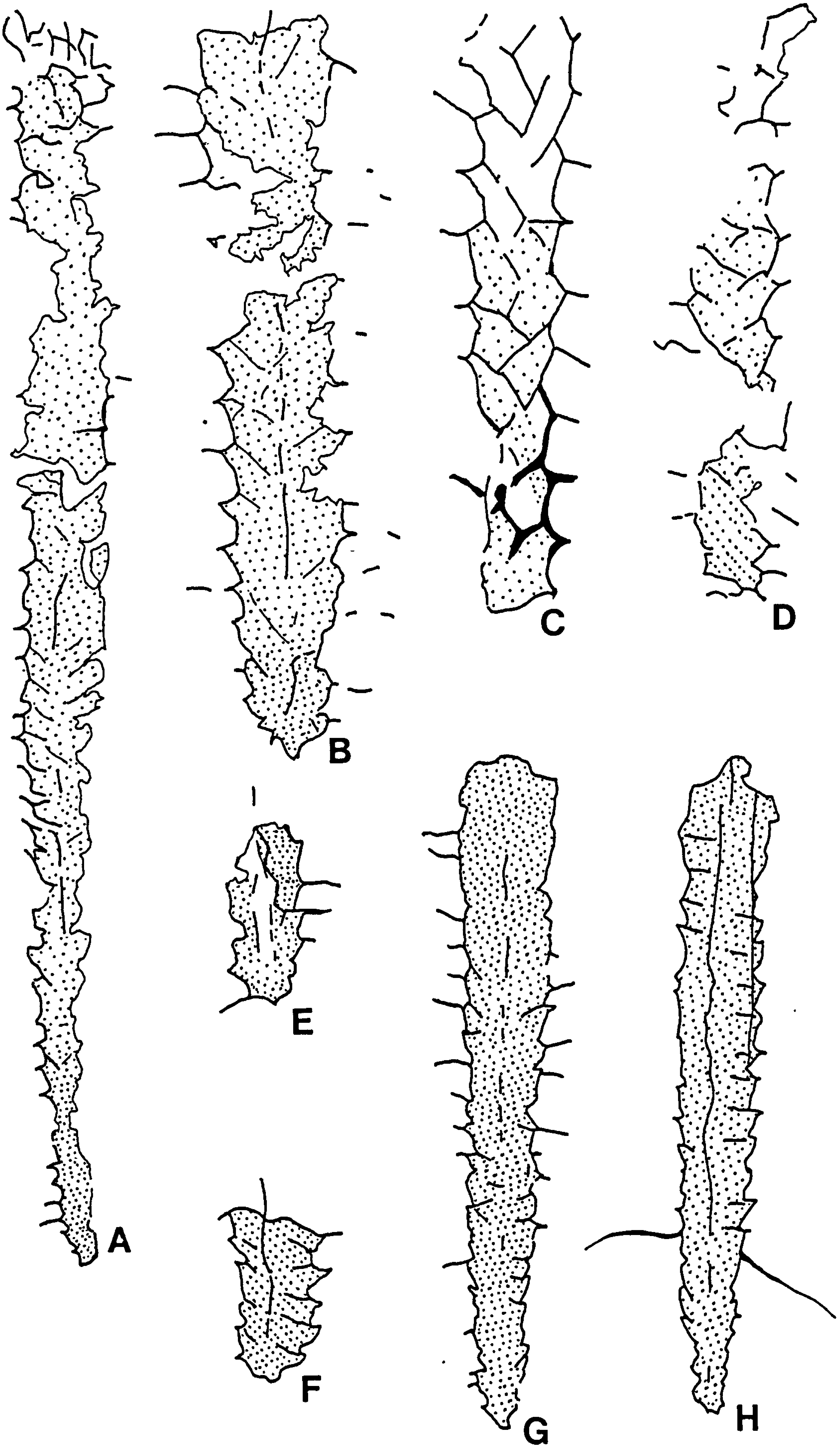
D. HM C13044/2. Poorly sclerotised fragment. Horizon and locality as 'A'. (x10)

E. HM C13071. Juvenile specimen with short nema. Horizon as 'A'. Loc. M1 , Myoch Bay, Girvan. (x10).

F. HM C14400. Juvenile specimen with nema. 1.8 - 2.0m, Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn. (x10)

G. HM C14396/1a. Unweathered fragment with good apertural spines on many thecae. 1.8 - 2.0m, Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn. (x5)

H. HM C14361. Orthograptus quadrimucronatus spinigerus (Lapworth 1876). Note long spines at some distance from the proximal end. 2.15 - 2.25m, Lower Hartfell Shale, North Cliff trench, Dob's Linn.


A
B
C
D
E
F
G
H

O. q. quadrimucronatus has been described from horizons equivalent to the D. clingani and P. linearis zones in North America (Hall 1965, etc.), Scandinavia (Hadding 1915, Henningsmoen 1948), Russia (Koren' et al. 1979) and Australia (Hall 1906, Harris & Thomas 1955).

Orthograptus quadrimucronatus spinigerus (Lapworth 1876)
(text-fig. 26h)

1876 Diplograptus quadrimucronatus var. spinigerus nov.; Lapworth, pl. 2, fig. 43.

1907 Diplograptus (Orthograptus) quadrimucronatus var spinigerus Lapworth; Elles & Wood, p. 225, pl. 28, figs. 2a-d, text-fig. 146.

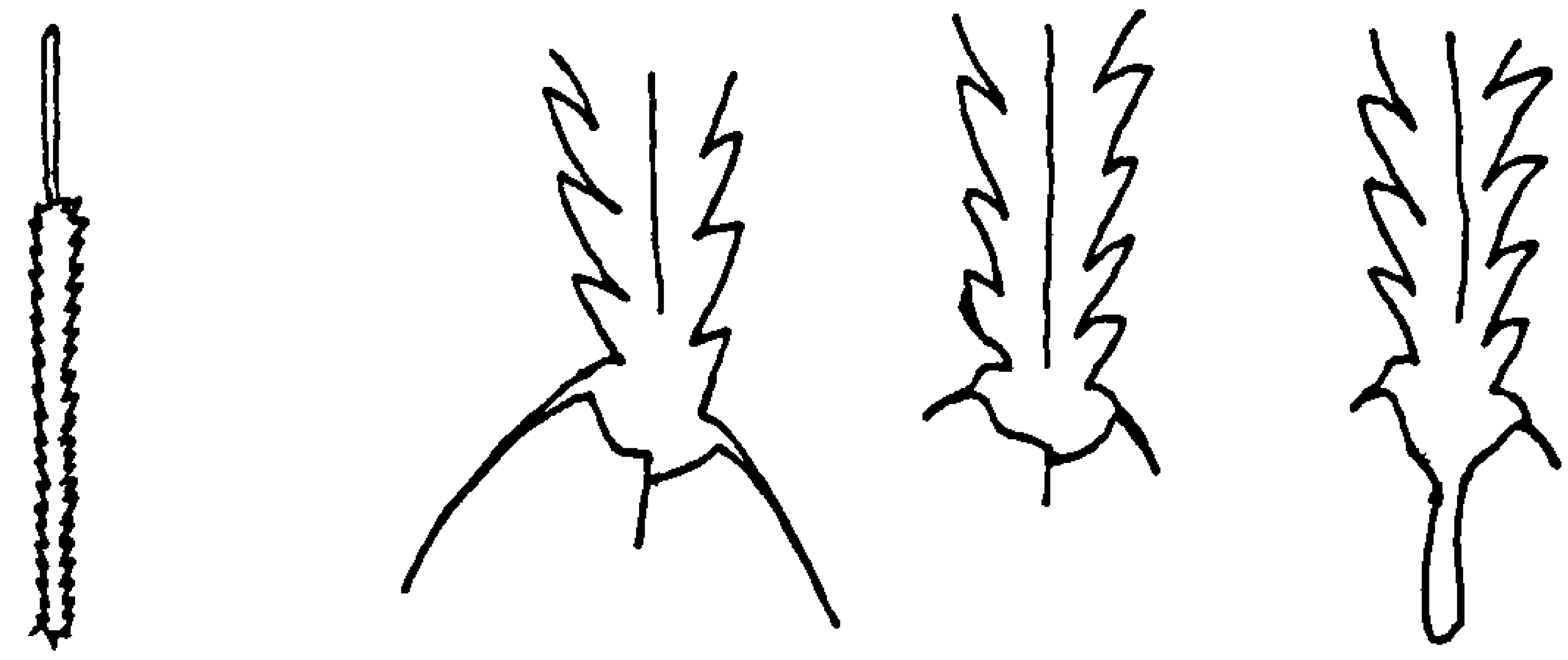
Type specimen. Not yet found (Strachan 1971, p. 41).

Material. Several flattened specimens collected by the writer.

Horizons and localities. Approximately 4.0 to 2.2m below the top of the Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn.

Remarks. This subspecies differs from O. q. quadrimucronatus (Hall 1865) by two pairs of long spines given off at a variable distance from the proximal end. It has been recorded as occurring with O. q. quadrimucronatus at many localities throughout the world and is obviously closely related.

Orthograptus ex gr. calcaratus
(pls. 43 - 45, text-fig. 27)



(1876 Diplograptus foliaceus var. calcaratus nov.; Lapworth, pl. 1, fig. 30.)

Material. Numerous flattened specimens and a few from Girvan preserved in relief collected by the writer.

Horizons and localities. 8.5 to 0.8m below the top of the Lower Hartfell Shale, late D. clingani and P. linearis zones, North Cliff trench, Dob's Linn. Dark Shale Member, Mill Formation, Upper Whitehouse Group, late P. linearis/early D. complanatus zone, Myoch Bay, Girvan.

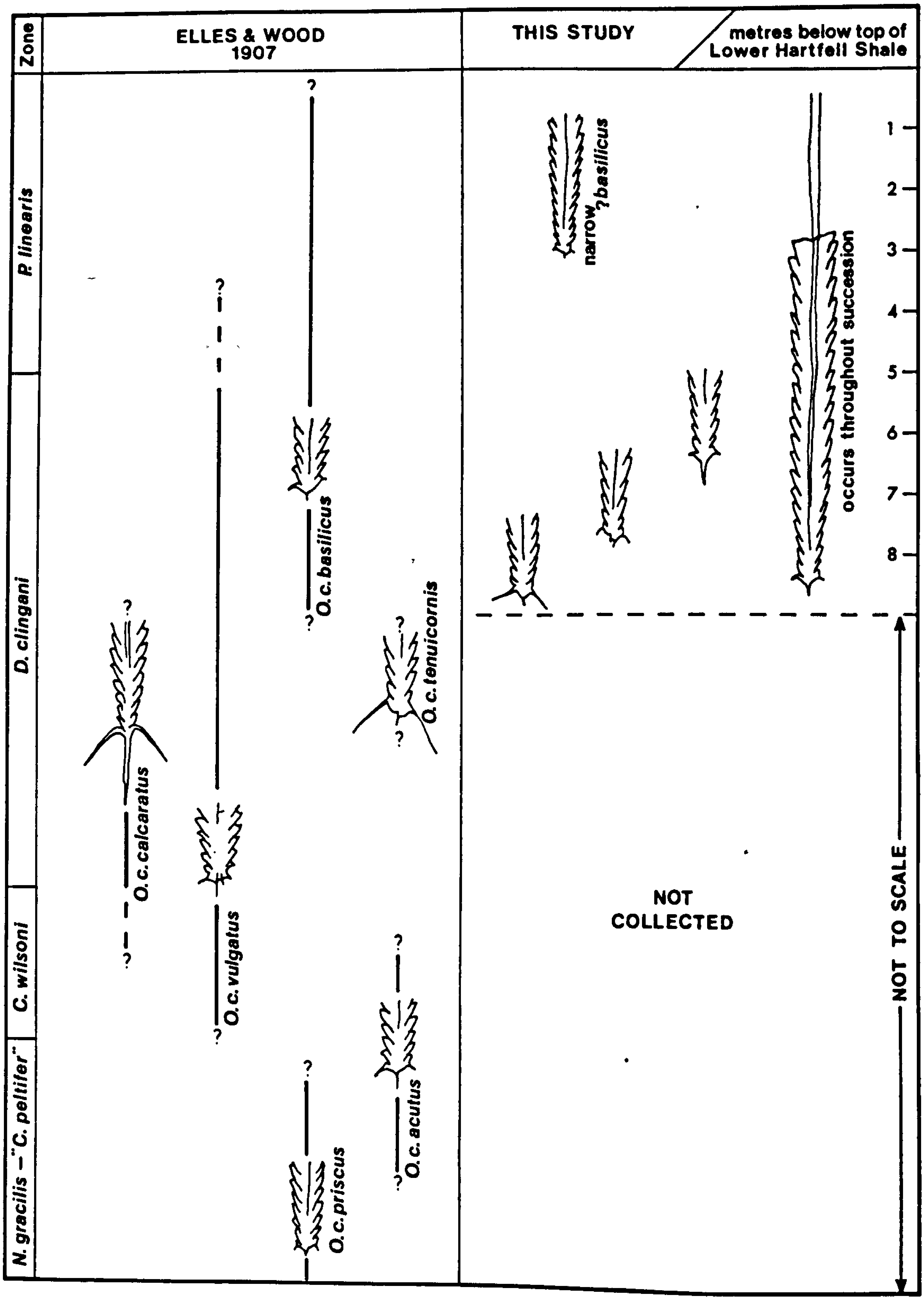
Diagnosis. Large rhabdosome over 50mm long and up to 3.5mm wide. Thecae typically Orthograptus in style, numbering 7-12 in 10mm. Sicula and first two thecae bear normally conspicuous spines.

Description. The rhabdosome is over 50mm long, normally rapidly widening from 1.0-1.3mm at the aperture of $th1^1$ to 2.0mm in 5mm. The maximum width is attained gradually and varies from 2.0 to 3.5mm. The average thecal count proximally is 10-12 in 10mm, reducing to 7-8 in 10mm distally. The proximal development is unclear in the specimens described here but Elles & Wood (1907, text-figs. 159a, 160a-c, 162a) show the sicula to be 2mm long and $th1^1$ and 1^2 to grow relatively straight and upwards throughout their entire length. Both the sicula and first two thecae possess commonly conspicuous spines which are often thickened in specimens from the D. clingani and earlier zones. Some rhabdosomes have long thecal spines up to 1.3mm long with a subordinate virgella, while others have a long virgella up to 2mm long and 0.25mm wide at the base and others possess only small spines (pls. 43-45). Elles & Wood record specimens of O. c. calcaratus with stout spines up to 7mm long and rhabdosomes up to 100mm long.

The thecae are typically Orthograptus in style; they are straight, but sometimes mucronate with pronounced apertural lists and slightly introverted apertures which normally occupy about 1/5 of the total rhabdosome width. A thickened virgula is commonly present which often extends distally for some distance as a thin or robust nema. A.T. Kearsley (pers. comm.) considers the rhabdosome to be aseptate.

Remarks. Elles & Wood (1907) and later authors have recognised the great deal of variation occurring in this species group and have attempted to solve the problem by erecting numerous subspecies. The specimens described here emphasise the variation present but do not appear to demonstrate any clear-cut boundaries between the previously erected subspecies. There does appear to be some stratigraphical variation (text-fig. 27) but until extensive work utilising a statistically viable number of specimens from the entire species group range can be undertaken it is proposed that all the specimens of this group from the late D. clingani to top P. linearis zone described here should be grouped together under the general term O. ex gr. calcaratus. The specimens collected for this work indicate that rhabdosomes with three very long and thick basal spines, corresponding to O. calcaratus calcaratus sensu Elles & Wood, are probably restricted to horizons earlier than those studied here. Rhabdosomes with long but narrow thecal spines and subordinate virgellae, approximating to O. calcaratus tenuicornis Elles & Wood 1907, appear to be restricted to an interval in the D. clingani Zone about 8.5 to 8.0m below the top of the Lower Hartfell Shale at Dob's Linn. These are followed in the top D. clingani Zone by rather more robust forms with fairly long virgellae up to 2mm long and small thecal spines, approximating most closely to O. calcaratus vulgatus Elles & Wood 1907. However, Elles & Wood record this subspecies to range throughout the C. wilsoni and D. clingani zones. Forms with three small basal spines seem to occur throughout the collected interval. Rather narrower forms with a maximum width of 2.0-2.5mm and only small spines, approximating to O. calcaratus basilicus Elles & Wood 1907, appear to be restricted to the top 3m of Lower Hartfell Shale (P. linearis Zone). The variation illustrated by this species group must also be affected by astogenetic development but until far more, better preserved, specimens can be studied it may only be stated that the spines appear to thicken, but not appreciably lengthen, throughout the growth of the rhabdosome. Because of the large number of O. calcaratus group

TEXT-FIGURE 27. Stratigraphical variation in Orthograptus ex gr. calcaratus noted for the top Lower Hartfell Shale in this study and summarised for the whole of the Glenkiln and Lower Hartfell Shale from Elles & Wood (1907).



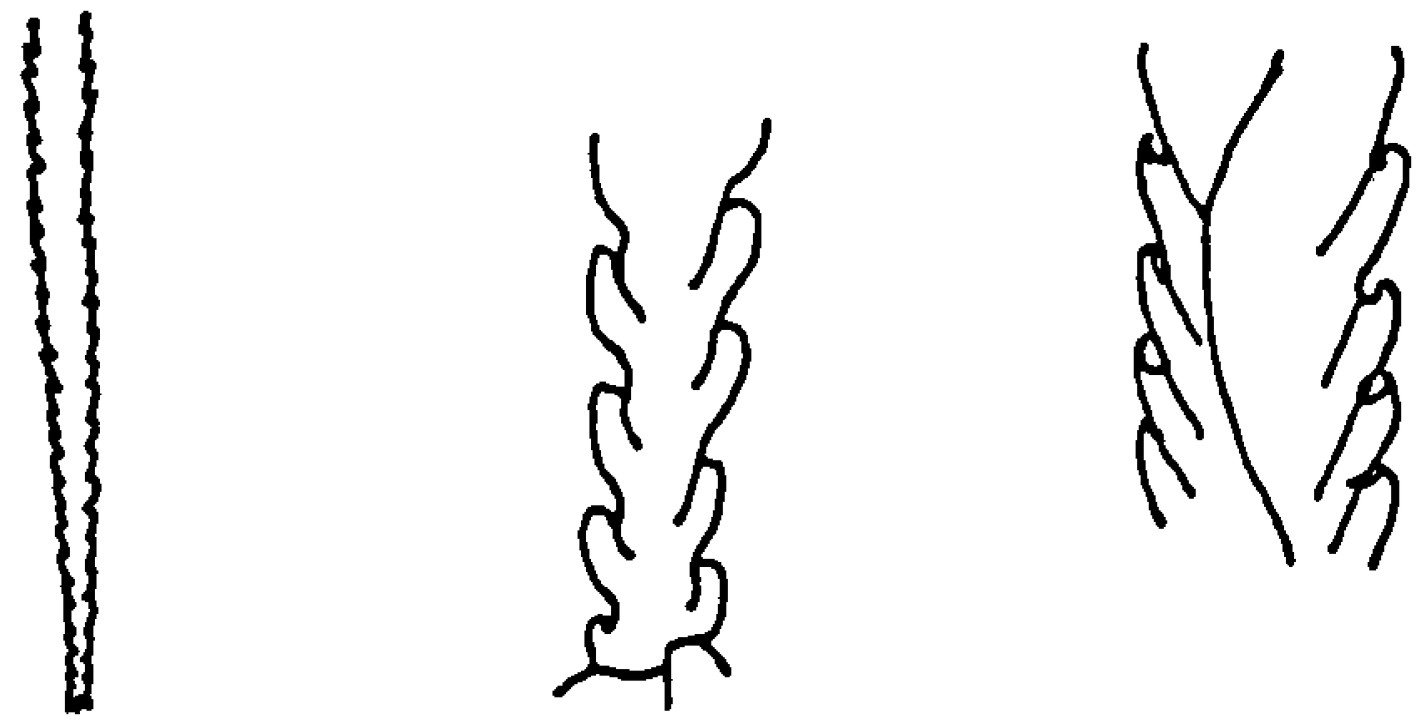
Zone
ELLES & WOOD 1907
THIS STUDY
metres below top of Lower Hartfell Shale
P. linearis
D. clingani
C. wilsoni
N. gracilis – "C. peltifer"
O.c.calcaratus
O.c.vulgatus
O.c.basilicus
O.c.tenuicornis
O.c.acutus
O.c.priscus
narrow ?basilicus
occurs throughout succession
NOT COLLECTED
NOT TO SCALE
1
2
3
4
5
6
7
8

species and subspecies described from outside Britain a thorough revision is outside the scope of this work.

The only other coeval species which may be confused with *O.* ex gr. *calcaratus* is *O. q. quadrimucronatus* (Hall 1865). While the two are readily distinguishable when the spines of the latter species are visible, the thecal styles are very similar when preserved in oblique view. The main difference in this instance is the more rapid increase to the maximum width of *O. q. quadrimucronatus* and its tendency to narrow distally. *O. fastigatus* Davies 1929 is probably a late representative of the *O. calcaratus* group but occurs appreciably later than any other similar species.

As stated by Strachan (1971, pp. 39-40) *O. calcaratus* subspecies have been recorded from North America, Australia and China and doubtfully from South America. Keller (1956) described from Russia *Rectograptus almatyensis* sp. nov., *R. tesikiensis* sp. nov., *R. kostenkoi* sp. nov., *R. pavlinovi* sp. nov. and *R. giganteus* sp. nov., all of which appear to be *calcaratus* group *Orthograpti*. Abdullaev & Khaletskaya (1970) also described *O.* ex gr. *calcaratus* and *O. calcaratus grandis* (Ruedemann 1947) from Russia so the species group is evidently a cosmopolitan one.

Orthograptus fastigatus Davies 1929
(pl. 46, figs. 1-9)



1929 Orthograptus fastigatus sp. nov.; Davies, p. 4, text-figs. 3-5.

1970 Diplograptus fastigatus (Davies); Toghill, p. 21, pl. 14, figs. 1-9.

Holotype. SM A10003. The specimen figured by Davies 1929, text-fig. 4. From the Upper Hartfell Shale, D. anceps Zone, Dob's Linn.

Material. Specimens from the Toghill Collection (British Museum, Nat. Hist.) and numerous flattened specimens collected by the writer.

Horizons and localities. Anceps Bands A to C, Upper Hartfell Shale, D. anceps Zone (predominantly D. complexus Subzone), Dob's Linn.

Diagnosis. Rhabdosome up to 40mm long, widening to the maximum 2.5mm within 15mm. Sicula and first two thecae with small but conspicuous spines. Thecae numbering 12-16 in 10mm, proximally somewhat Glyptograptus in appearance, distally markedly introverted.

Description. The rhabdosome is up to 40mm long, measuring 0.7-1.0mm (normally 0.9mm) wide at the aperture of $th1^1$, increasing to 1.3-1.7mm (normally 1.5mm) in 5mm and reaching the maximum width of 2.0-2.6mm in about 15mm which is then maintained. The thecae number a consistent 12-16 in 10mm throughout the rhabdosome. No well preserved proximal parts have been observed by the writer but Davies recorded the sicula to be 1mm long and both $th1^1$ and 1^2 to grow upwards throughout their length. The sicula and first two thecae bear prominent spines up to 0.5mm long. The proximal thecae are sub-alternate and have a somewhat Glyptograptus-like appearance with curved supragenicular walls. Differential lateral spread resulting from diagenetic flattening often gives the proximal thecae a 'boxed' Climacograptus-like appearance. By the tenth thecal pair they are typically Orthograptus in style with straight, inclined supragenicular walls and interthecal septa. The thecae narrow aperturally and are slightly introverted. Contrary to Davies there does not seem to be a median septum although the virgula may sometimes form a wavy median line. The virgula has never been observed to project beyond the distal thecae as a nema.

Remarks. O. fastigatus is probably a late representative of the Orthograptus calcaratus group and is very similar in both thecal style and rhabdosomal form to those found in the middle to late P. linearis Zone. Contrary to Toghill (1970) there is little doubt that it is a true Orthograptus; he assigned this species to Diplograptus owing to the Climacograptus-like appearance of its proximal thecae which is here recognised as an effect of differential lateral spread on flattening. It is readily separable from O? abbreviatus Elles & Wood 1907, the only other 'Orthograptus' at this horizon, by its thecal style in comparison with the everted thecae of O? abbreviatus. O. fastigatus may be superficially confused with Climacograptus latus Elles & Wood 1906 which commonly exhibits inclined supragenicular walls, and with Orthoretiograptus denticulatus Wang et al. 1977 which has a broadly similar outline but a very different thecal style with an internal polygonal structure of apertural lists and interthecal septa.

The only occurrence of O. fastigatus seen outside Scotland is in the Killy Bridge Beds (Tripp Collection, pers. observ.) where it is associated with a typical D. anceps Zone fauna. At Dob's Linn it is apparently restricted to the three lower Anceps Bands and is considered characteristic of the D. complexus Subzone.

Orthograptus? amplexicaulis (Hall 1847)
(pl. 47, figs. 1-2)

1847 Graptolites amplexicaule sp. nov.; Hall, pp. 79-80, 316, pl. 26, figs. 11a-b.

1877 Diplograptus truncatus sp. nov.; Lapworth, p. 133, pl. 6, fig. 17.

1907 Diplograptus (Orthograptus) truncatus Lapworth; Elles & Wood, pp. 233-234, pl. 29, figs. 3a-e, text-figs. 154a, b.

1974a Orthograptus amplexicaulis (Hall); Riva, pp. 29-34, pl. 2, figs. 7-10, text-figs. 9a-k.

(summary synonymy only - see 'Remarks')

Lectotype. A.M.N.H. 634/1. Designated by Riva (1974a, p. 29). The specimen figured by Hall 1867, pl. 25, figs. 6-7 and Riva 1974a, pl. 2, fig. 7. From the Trenton Limestone at Middlesville, New York State.

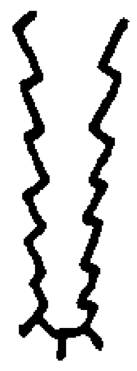
Material. Several specimens collected by the writer.

Horizons and localities. 7.1 to 0.3m below the top of the Lower Hartfell Shale, late D. clingani and P. linearis zones, North Cliff trench, Dob's Linn.

Remarks. This species was described and discussed in detail by Riva (1974a) who suggested that 'O.' truncatus was a junior synonym of 'O.' amplexicaulis. The whole O? amplexicaulis species group is currently being revised by A.T. Kearsley (Cambridge University) and only a summary list of synonymies is given above. O? amplexicaulis differs from related species (e.g. O? pauperatus Elles & Wood 1907, O? intermedius Elles & Wood 1907, O? abbreviatus Elles & Wood 1907) chiefly by its much wider rhabdosome. Kearsley considers that the group does not belong to Orthograptus s.s., whose type species is O. q. quadrimucronatus (Hall 1865), but does not accept Přibyl's (1949) new genus Rectograptus which included both 'O. truncatus' and O. ex gr. calcaratus.

O? amplexicaulis is a well known cosmopolitan species that has been found in the Upper Ordovician of all continents. Toghill (1970) recorded a fragmentary specimen of 'O. truncatus' from the D. anceps Zone of Dob's Linn, but the writer considers this to be a tectonically widened specimen of O? abbreviatus.

Orthograptus? pauperatus Elles & Wood 1907
(pl. 47, figs. 3-6)



1907 *Diplograptus* (*Orthograptus*) *truncatus* var. *pauperatus* var. nov.; Elles & Wood, p. 237, pl. 29, figs. 5a-d.

1915 *Diplograptus truncatus* Lapw. var. *pauperatus* Lapw. mscr.; Hadding, p. 15, pl. 2, figs. 8-11.

1948 *Diplograptus* (*Orthograptus*) *truncatus pauperatus* Elles & Wood; Henningsmoen, p. 403.

1963 *Orthograptus pauperatus* Elles & Wood; Skoglund, pp. 45-46, pl. 1, fig. 11.

1970 *Orthograptus truncatus pauperatus* Elles & Wood; Toghill, p. 24, pl. 16, figs. 1, 2.

Type specimen. Not yet designated. Elles & Wood's specimens from the Lower Hartfell Shale of Hartfell Spa (Lapworth Collection).

Material. Numerous flattened specimens collected by the writer.

Horizons and localities. 5m below the top to the top of the Lower Hartfell Shale, *P. linearis* Zone, North Cliff trench, Dob's Linn.

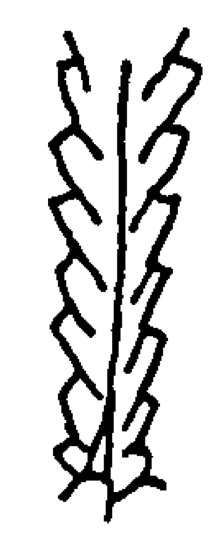
Diagnosis. Small *amplexicaulis* group diplograptid up to 25mm long and 2mm wide. Thecae simple and everted, numbering 10-12 in 10mm. Sicula and first two thecae with small spines.

Description. The rhabdosome is up to 25mm long, measuring 0.9-1.0mm at the aperture of $th1^1$, increasing to 1.5-1.7mm in 5mm and reaching the maximum 2.0mm within 10mm. The rhabdosome narrows slightly distally. Henningsmoen (1948) stated that the sicula is free for 1mm on the obverse side; it bears a small virgella, while $th1^1$ and 1^2 bear short mesial to sub-apertural spines. The proximal development is unclear in the described material. The remaining thecae are straight with everted apertures and typical of *amplexicaulis* group diplograptids. A distally projecting nema has not been observed in the described material.

Remarks. Although O? pauperatus is similar in development and thecal style, and is probably closely related, to O? amplexicaulis (Hall 1847) the rhabdosome is consistently shorter and narrower. Elles & Wood recorded O? pauperatus as being typical of both the D. clingani and P. linearis zones but this study indicates that it is restricted to the P. linearis Zone. It is possible that Elles & Wood included some juvenile rhabdosomes of the longer and slightly wider O? intermedius Elles & Wood 1907 which they considered characteristic of the C. wilsoni and D. clingani zones.

O? pauperatus has been recorded from horizons equivalent to the P. linearis Zone in Scandinavia (Hadding 1915, Henningsmoen 1948, Skoglund 1963), Australia (Thomas 1960), Alaska (Churkin et al. 1971) and doubtfully from Peru (Bulman 1931).

Orthograptus? socialis (Lapworth 1880)
(text-figs. 28a-t)



1880 Diplograptus socialis sp. nov.; Lapworth, p. 166, pl. 4, figs. 13a-e.

1907 Diplograptus (Orthograptus) truncatus var. socialis Lapworth; Elles & Wood, pp. 237-238, pl. 29, figs. 7a-e, text-figs. 157a-d.

1963 Orthograptus truncatus var. socialis (Lapworth); Ross & Berry, pp. 151-152, pl. 11, fig. 21.

1970 Orthograptus truncatus socialis (Lapworth); Toghill, p. 24, pl. 13, figs. 7-9, pl. 16, fig. 7.

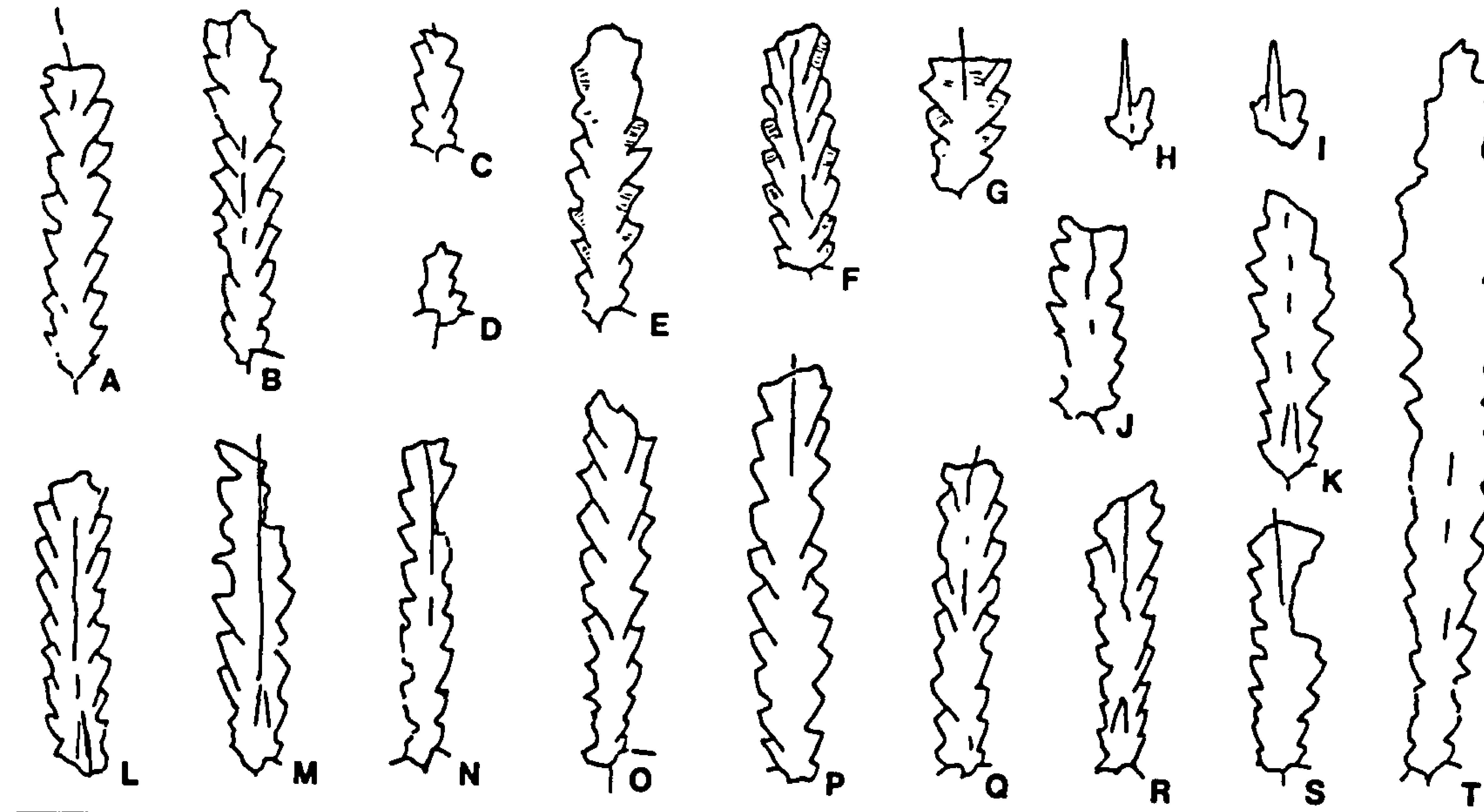
Type specimen. Not yet designated.

Material. Many flattened specimens collected by the writer.

Horizons and localities. Lower Complanatus Band, Upper Hartfell Shale, D. complanatus Zone, Main Cliff, Linn Branch and Main Cliff, Dob's Linn. Dark Shale Member, Mill Formation, Upper Whitehouse Group, late P. linearis/early D. complanatus zone, Myoch Bay, Girvan.

Diagnosis. Small amplexicaulis group diplograptid up to 15mm long and 2.0mm wide. Thecae everted, numbering about 13 in 10mm proximally and reducing only slightly distally. Sicula and first two thecae with small but conspicuous spines.

Description. The rhabdosome is small, the largest specimen seen being 15mm long. It is 0.8-1.0mm wide at the aperture of $th1^1$, increasing to an average of 1.4mm in 5mm. Most specimens are under 8mm long with a maximum width of 1.5mm although the larger specimens slowly increase to about 2.0mm in 10mm and narrow somewhat distally. Proximally the thecae number 12-14 in 10mm, reducing slightly to about 12 in 10mm distally. The sicula is about 2mm long and bears a small but conspicuous virgella. $Th1^1$ grows continuously straight upwards while $th1^2$ grows initially across the sicula before bending upwards; both possess



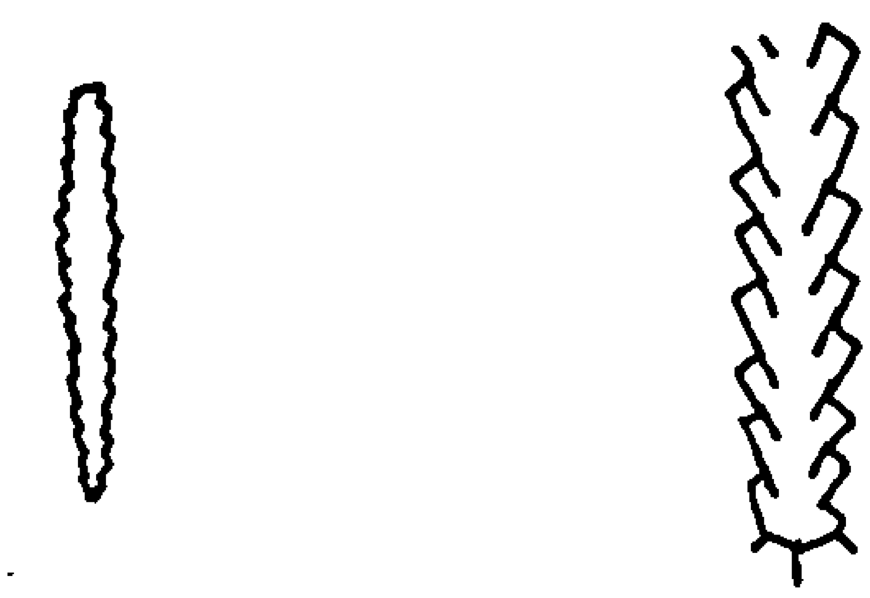
TEXT-FIGURE 28. Orthograptus? socialis (Lapworth 1880) (all x5)
A - D. Dark Shale Member, Mill Formation, Upper Whitehouse Group, P. linearis/D. complanatus zone, Myoch Bay, Girvan.
E - M, P, Q, S. Lower Complanatus Band, Upper Hartfell Shale, D. complanatus Zone, Main Cliff, Dob's Linn.
N, O, R, T. Lower Complanatus Band, Upper Hartfell Shale, D. complanatus Zone, North Cliff (10m west of North Cliff trench), Dob's Linn.
A. HM C13065/11. Loc. M2, Myoch Bay. B. HM C13065/12. Loc. M2, Myoch Bay. C. HM C13065/13. Loc. M2, Myoch Bay. D. HM C13022/1. Juvenile specimen. Loc. M1, Myoch Bay. E. HM C14471/8. Specimen showing growth fusellae. F. HM C14471/9 Specimen preserved in partial relief showing growth fusellae. G. HM C14471/10. Juvenile specimen with growth fusellae. H. HM C14471/3. Juvenile specimen with sicula and first three thecae. I. HM C14471/11. Juvenile specimen with sicula and first four thecae. J. HM C14470/3. K. HM C14471/4. L. HM C14471/12. M. HM C14471/7. N. HM C14465/7. O. HM C14465/5. P. HM C14471/5. Q. HM C14471/13. R. HM C14465/4. S. HM C14471/14. T. 14465/9. Unusually large specimen.

conspicuous mesial spines. The remaining thecae are straight with gently inclined supragenicular walls and everted apertures which occasionally have a slight 'lip'. Growth fusellae are commonly visible. The virgula is apparent throughout the length of the rhabdosome and sometimes projects distally as a short nema.

Remarks. O? socialis is very similar to other amplexicaulis group diplograptids but differs from all of them by its consistently small size. The rate of width increase is similar to O? pauperatus Elles & Wood 1907 but rather less than the later O? abbreviatus Elles & Wood 1907. The thecal count is rather higher than O? pauperatus but similar to O? abbreviatus. It is evidently closely related to both these species and Kearsley's work on the O? amplexicaulis group should help to clarify the situation.

O? socialis occurs crowded on some bedding planes in the lower Complanatus Band but does not appear to occur in the upper one. It is also found in the P. linearis/D. complanatus zonal transition beds at Girvan in association with D. complanatus Lapworth 1880, O. q. quadrimucronatus (Hall 1865), etc. (see p. 30). O? socialis has only been recorded from outside Britain by Ross & Berry (1963) in North America and by Thomas (1960) in Australia.

Orthograptus? abbreviatus Elles & Wood 1907
(pl. 48, figs. 1-9)



1907 Diplograptus (Orthograptus) truncatus var. abbreviatus var. nov.; Elles & Wood, pp. 235-236, pl. 29, figs. 6a-e, text-figs. 155a-d.

1970 Glyptograptus nicholsoni sp. nov.; Toghill, p. 21, pl. 15, fig. 3.

1970 Orthograptus truncatus abbreviatus Elles & Wood; Toghill, p. 24, pl. 15, figs. 4-6, pl. 16, figs. 4, 5.

?1970 Rectograptus artus n. sp.; Mikhaylova, p. 389, pl. 8, figs. 6-8.

1977 Orthograptus abbreviatus Elles & Wood; Wang et al., p. 338, pl. 103, fig. 2.

1978 Orthograptus abbreviatus Elles & Wood; Wang et al., p. 643, pl. 205, figs. 18, 19.

?1980 Orthograptus amplexicaulis artus Mikhaylova; Koren' et al., p. 158, pl. 50, fig. 2.

Type specimen. Not yet designated. Elles & Wood's specimens from the Upper Hartfell Shale, D. anceps Zone, Dob's Linn.

Material. Numerous flattened specimens and one preserved in partial relief, collected by the writer.

Horizons and localities. All five Anceps Bands, Upper Hartfell Shale, D. anceps Zone, Dob's Linn.

Diagnosis. Fusiform rhabdosome normally up to 25mm long and 3mm wide. amplexicaulis group diplograptid with simple thecae and everted apertures, numbering 12-14 in 10mm.

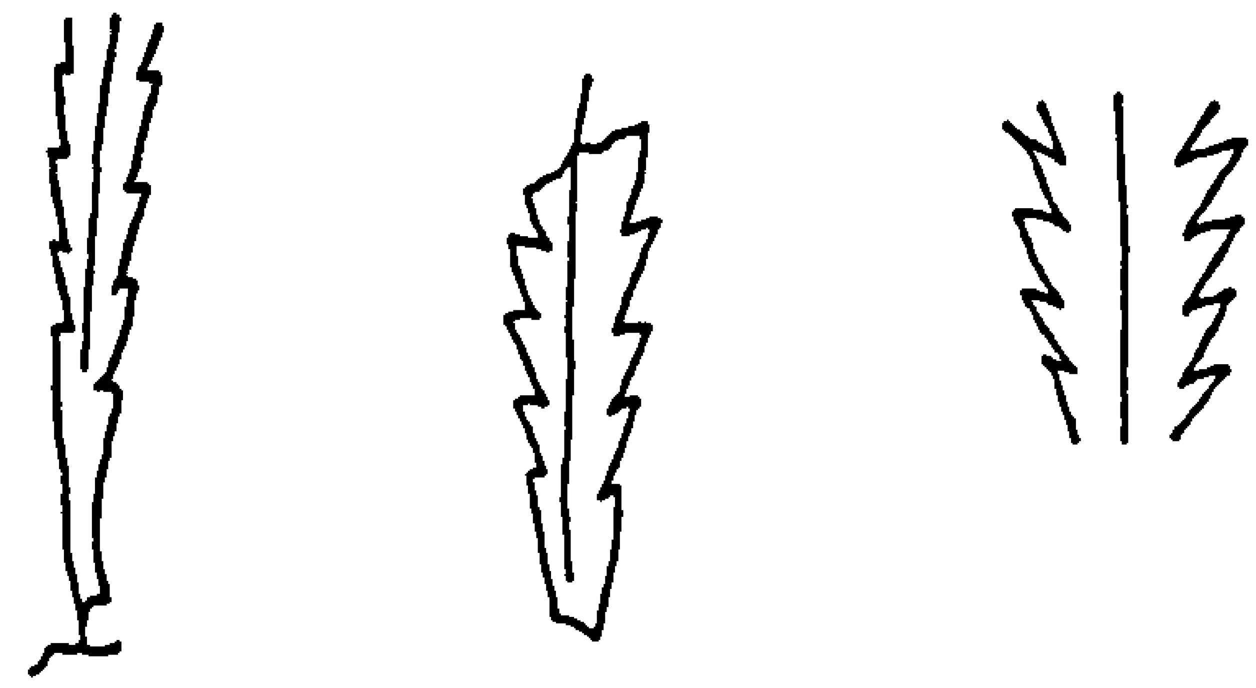
Description. The rhabdosome is normally up to 25mm long, measuring 0.7-1.0mm wide proximally, increasing to 1.4-2.0mm in 5mm and reaching the maximum width of 1.9-2.8mm in 10mm. This width is only maintained for several mm before decreasing. The thecae number a uniform 10-12 in 10mm. The sicula is about 1mm long and possesses a conspicuous virgella. $Th1^1$ initially grows down along the sicula before bending slightly upwards; $th1^2$ grows horizontal before bending up. Both thecae produce conspicuous mesial spines up to 0.4mm long at the point where they change direction. All the remaining thecae are straight with simple everted apertures. Diagenetic deformation occasionally results in convex or concave supragenicular walls. The rhabdosome is aseptate. One fairly mature and two juvenile specimens have been found with distally projecting nema.

Remarks. O? abbreviatus is very closely related to O? amplexicaulis (Hall 1847) but is consistently smaller and has more everted thecae with pronounced apertural lists when preserved in relief. A.T. Kearsley is currently completing an exhaustive study on the amplexicaulis group diplograptids and considers that O? abbreviatus is sufficiently distinct from the other forms to retain as a separate species or subspecies. The generic position of this group is discussed on p. 163.

O? abbreviatus is distinct from all other diplograptids in the D. anceps Zone owing to its simple everted thecae and fusiform rhabdosome. Although it has been described from the lower Silurian (e.g. Hutt 1974, p. 33, pl. 8, figs. 9, 10, text-figs. 8, 9) Kearsley reports (pers. comm.) that these specimens are not O? abbreviatus, possessing a different proximal development and thecal style, and that O? abbreviatus appears to be restricted to the late Ordovician. Glyptograptus nicholsoni Toghill 1970 is a juvenile specimen of O? abbreviatus which has suffered deformation from diagenetic flattening, while O. amplexicaulis artus Mikhaylova 1970 appears identical to O? abbreviatus.

O? abbreviatus is abundant in all five Anceps Bands at Dob's Linn. It is also found in [illegible] the Upper Drummuck Group at Girvan and in the Red Vein of Mid-Wales. It appears to be a very widespread species, but confusion in distinguishing it from O? amplexicaulis has apparently resulted in many misidentifications and a detailed summary must be left until the completion of Kearsley's present work.

Orthograptus? acuminatus (Nicholson 1867) sensu lato
(pl. 49, figs. 1-13)



(1867a Diplograpsus accuminatus n. sp.; Nicholson, pp. 109-110, pl. 7, figs. 16, 16a.)

(1929 Akidograptus acuminatus mut. praematurus nov.; Davies, p. 10, text-fig. 25.)

Material. Several flattened fragmentary specimens collected by the writer.

Horizons and localities. 1.6 to 2.3m above the base of the Birkhill Shale, early O? acuminatus Zone, Linn Branch trench, Dob's Linn.

Remarks. The material grouped here as O? acuminatus s.l. includes several specimens similar in size and overall form to Akidograptus ascensus Davies 1929 but with rather elongate Orthograptus-like thecae and slightly introverted apertures (pl. 49, figs. 9, 10) and a few distal fragments with similar thecae but a maximum width of 1.3-1.7mm (pl. 49, figs. 7, 12). The former specimens agree in distal thecal style with the original description of O? acuminatus praematurus but have more protracted proximal thecae than the type specimens of this subspecies which Davies (1929) described from the G. persculptus Zone of the Lake District. Rickards (1970) recorded both O? a. acuminatus and O? acuminatus praematurus to occur together in the O? acuminatus Zone of the Howgill Fells, northern England but considered that the specimens of O? acuminatus praematurus may have represented a later survival. Toghill (1968b, p. 658) recorded O? a. acuminatus to be most common in the middle and later parts of the O? acuminatus Zone at Dob's Linn.

10.3 Genus Glyptograptus (Glyptograptus) Lapworth 1873

Type species (by original designation). Diplograpsus tamariscus Nicholson 1868, p. 526, pl. 19, figs. 10-13.

Stratigraphical range. ?Lower Ordovician to Lower Silurian (?G. teretiusculus to ?M. sedgwickii)

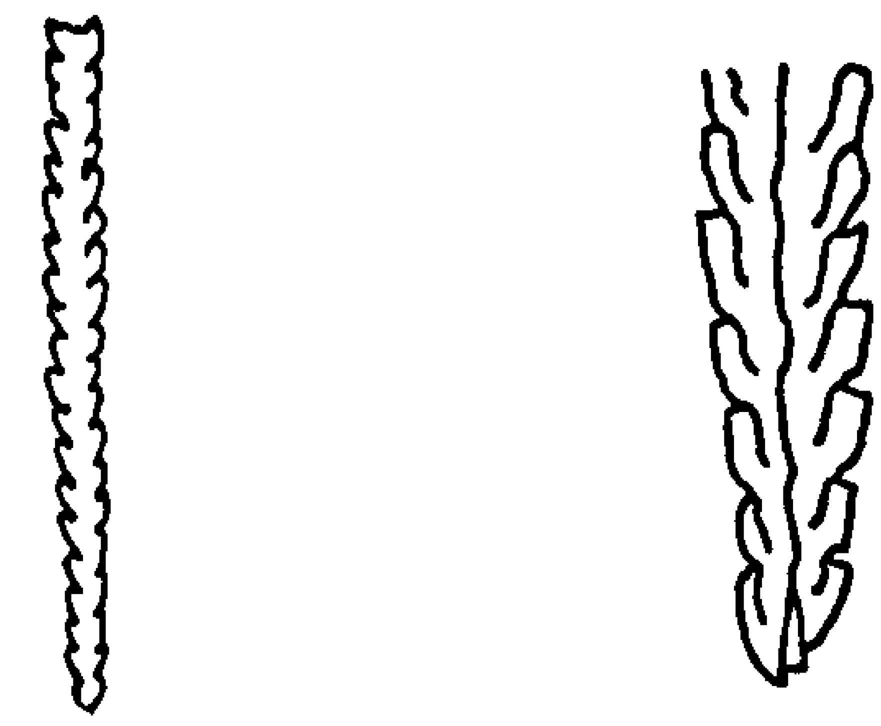
Diagnosis (after Bulman 1970, V126). Thecae alternate with gentle sigmoidal curvature, supragenicular walls normally slightly convex, sometimes with slight genicula.

Remarks. Many species previously assigned to this genus do not correspond to the type species in proximal development or thecal style and a thorough revision is necessary.

Species described.

G. persculptus (Salter 1865) s.s. (G. persculptus to O? acuminatus)
G. cf. persculptus (Salter 1865) (G. persculptus to O? acuminatus)
G. davisi sp. nov. (D. clingani)
G? avitus Davies 1929 (G. persculptus)
G? sp. A (G. persculptus)
G? cf occidentalis Ruedemann 1947 (late P. linearis/early D. complanatus)

Glyptograptus persculptus (Salter 1865)
(pl. 50, figs. 1-3)



1865 Diplograpsus persculptus [Salter?]; Cat. Mus. Pract. Geol., p. 25 (See Strachan 1971).

1868 Diplograpsus persculptus; Carruthers, p. 130.

1878 Diplograpsus persculptus Salter; Cat. Foss. Mus. Pract. Geol., p. 23.

1907 Diplograptus (Glyptograptus) persculptus Salter; Elles & Wood, pp. 257-258, pl. 31, figs. 7a-c, text-figs. 176a, b.

?1929 Glyptograptus aff. persculptus Salter; Davies, pp. 10-14, text-figs. 11-20.

1977 Glyptograptus persculptus (Salter); Rickards et al., p. 99, pl. 2, fig. 4, text-figs. 8, 53.

(summary only - see 'Remarks')

Proposed holotype. GSM 11782. The only well preserved specimen in Salter's collection. From Gogofau, Pumpsaint, mid Wales (figd. pl. 50, fig. 3).

Material. Salter's specimens (I.G.S. collections, South Kensington) and two specimens illustrated by Elles & Wood 1907 (collections of the British Museum, Nat. Hist.).

Horizons and localities. Zones of G. persculptus and O? acuminatus, gold mines at Gogofau, Pumpsaint, Dyfed, mid Wales.

Diagnosis. Large rhabdosome up to 30mm long and 2-3mm wide with sigmoidally curved thecae and wavy median septum. Thecae with curved supragenicular walls and slightly everted apertures, numbering 9-11 in 10mm. Neither virgella nor nema observed.

Description. The rhabdosome is up to 30mm long, widening from about 1.0mm at the aperture of $th1^1$ to 1.5-1.7mm in 5mm and slowly reaching the maximum 2.0-2.7mm in 15mm which is then maintained. Proximally the thecae number 10-11 in 10mm, decreasing distally to 9 in 10mm. The sicula is revealed for 1.2mm in obverse view; Elles & Wood record the sicula to be 2.1mm long when observed in juvenile specimens although Davies' serial sections (1929, text-fig. 11a) indicate that the sicula is only 1.2mm long and obversely exposed for its entire length. $Th1^1$ grows down until it is about 0.15mm below the aperture of the sicula before bending abruptly upwards. Th 1^2 grows upwards for its entire length, giving the proximal region a distinctive asymmetrical appearance. The thecae are sigmoidally curved and possess slightly everted apertures which open into narrow excavations occupying only about 1/6 of the total rhabdosome width. The supragenicular walls are gently convex with slight genicula which become more pronounced when the rhabdosome is obliquely orientated. The thecae remain alternate throughout the rhabdosome, resulting in a gently sinuous median septum which is complete in obverse view, although Davies (op. cit.) considered that the median septum appeared later on the reverse side higher up the succession. Neither virgella nor nema has been observed on any specimens.

Remarks. The classification of G. persculptus is confused owing to its origin as an undescribed nomen nudum. Fortunately the material described by Elles & Wood (1907) appears to be identical to Salter's specimens and it is proposed that their description should be taken as the type one. It does however contain some internal discrepancies both within the text (e.g. the diagnosis lists the thecae as 2mm long while the description records them as 3mm) and with the illustrations, so care must be taken when using it. If Elles & Wood's description is accepted as the type it could be argued either that because the name is a certain nomen nudum it should be dropped, or that Elles & Wood should become the species' authors. As G. persculptus is such a well established species in international literature it would not be wise to remove it. Elles & Wood had access to Salter's material in addition to their own and obviously considered it to be his species; it is therefore considered justified to retain Salter as the author of G. persculptus although he never described or illustrated it.

It appears that many specimens identified as G. persculptus are not strictly referrable to this species and that the name 'G. persculptus' now covers a variety of diplograptids which possibly belong to several different genera. It is suggested here that the name should be used only for specimens strictly comparable with the type material from Pumpsaint. Difficulty arises when comparing flattened specimens with the type material, which is preserved in relief, but an indication of the expected appearances can be seen by comparing specimens of G. cf. persculptus from Dob's Linn (pl. 51, figs. 1 - 9) which are preserved both flattened and in relief. It is not considered possible for G. persculptus s.s. to produce the appearance of Glyptograptus? sp. A from Dob's Linn (pl. 54, figs. 4-10) which R.B. Rickards (pers. comm.) considers to be conspecific.

Hutt's specimens of 'G. persculptus' from the Lake District (1974, pl. 6, figs. 9-12) are similar but rather smaller than the types and are here referred to G. cf. persculptus described from Dob's Linn. This is rather less robust and has a poorly developed periderm, giving far less contrast with the surrounding lithology than the other associated diplograptids, as opposed to the well thickened one of G. persculptus s.s.

Although it is necessary to see the actual specimens before stating anything conclusively, none of the specimens figured by Koren' et al. (1980) as G. persculptus forma A and forma B appear to the writer to belong to G. persculptus s.s. Their forma A has more pronounced genicula, straight supragenicular walls, widens more rapidly and appears to narrow distally; it is possibly synonymous with C? extraordinarius (Sobolevskaya 1974) as, according to their range chart, it is restricted to the base of the G. persculptus Zone. Forma B has a far narrower form and straighter supragenicular walls, interthecal septa and median septum than G. persculptus s.s.; it is here considered to be comparable with Glyptograptus? sp. A from Dob's Linn, although this has a considerably earlier range than forma B.

Davies (1929) only figured two specimens and gave no description of a new subspecies G. persculptus mut. omega. Until the detailed study currently being undertaken by R.B. Rickards of the G. persculptus species group is complete it is here considered best to refer all Davies' specimens recorded as G. aff. persculptus to G. persculptus s.l. Churkin et al. (1971) record G. persculptus from the lowest Silurian of Alaska but do not describe or figure any material.

Glyptograptus cf. persculptus (Salter 1865)
(pl. 51, figs. 1-9, pl. 54, figs. 2, 3)

(1865 Diplograpsus persculptus [Salter?]; Cat. Mus. Pract. Geol., p. 25)
1974 Glyptograptus persculptus (Salter); Hutt, pp. 28-29, pl. 6, figs. 9-12.

Material. Many flattened specimens and two preserved in partial relief, collected by the writer.

Horizons and localities. 0.7 to 2.3m above the base of the Birkhill Shale, G. persculptus and early O? acuminatus zones, Linn Branch trench, Dob's Linn.

Diagnosis. Similar to G. persculptus s.s. but with a smaller rhabdosome up to 20mm long and 1.7mm wide. Thecae number 11-17 in 10mm in tectonically stretched specimens. Sicula normally with short virgella.

Description. The rhabdosome is up to 20mm long, rapidly widening from 1.0mm at the aperture of $th1^1$ to a maximum of 1.5-1.7mm within 5mm. Proximally the thecae number 14-17 in 10mm, reducing distally to 11-13 in 10mm. Only one specimen (pl. 51, fig. 7) preserved in obverse view shows a sicula which is visible for 0.8mm. A short virgella is commonly seen in well preserved material. The proximal development is obscure in the described specimens but appears similar to G. persculptus s.s. The remaining thecae also possess a similar style to G. persculptus s.s., normally possessing curved supragenicular walls, although these may appear straight or have slight geniculation depending on the orientation of the rhabdosome. The thecae are alternate throughout although tectonic deformation may cause them to appear opposite. A nema has only been observed on one specimen.

Remarks. This material is broadly comparable with G. persculptus s.s. but differs from the type specimens in having a smaller and narrower rhabdosome, a higher thecal count and a less well developed periderm.

The specimens from Dob's Linn agree well with those described as *G. persculptus* by Hutt (1974) from the Skelgill Beds (*G. persculptus* and *O? acuminatus* zones) of the Lake District, which Rickards *et al.* (1977) recognised as being smaller than the type specimens. *G.* cf. *persculptus* is distinguished from *Glyptograptus?* sp. A (p. 182) by its less well developed periderm and different thecal style.

Glyptograptus daviesi sp. nov.
(pl. 52, figs. 1-6)

Derivation of name. After K.A. Davies, whose paper in 1929 gave a thorough appraisal of Glyptograptus persculptus (Salter 1865) and descriptions of several stratigraphically important new species from Dob's Linn.

Proposed holotype. HM C14056a, b. From the interval 8.7 to 8.5m below the top of the Lower Hartfell Shale, late D. clingani Zone, North Cliff trench, Dob's Linn (pl. 52, fig. 3).

Material. About twenty flattened specimens collected by the writer.

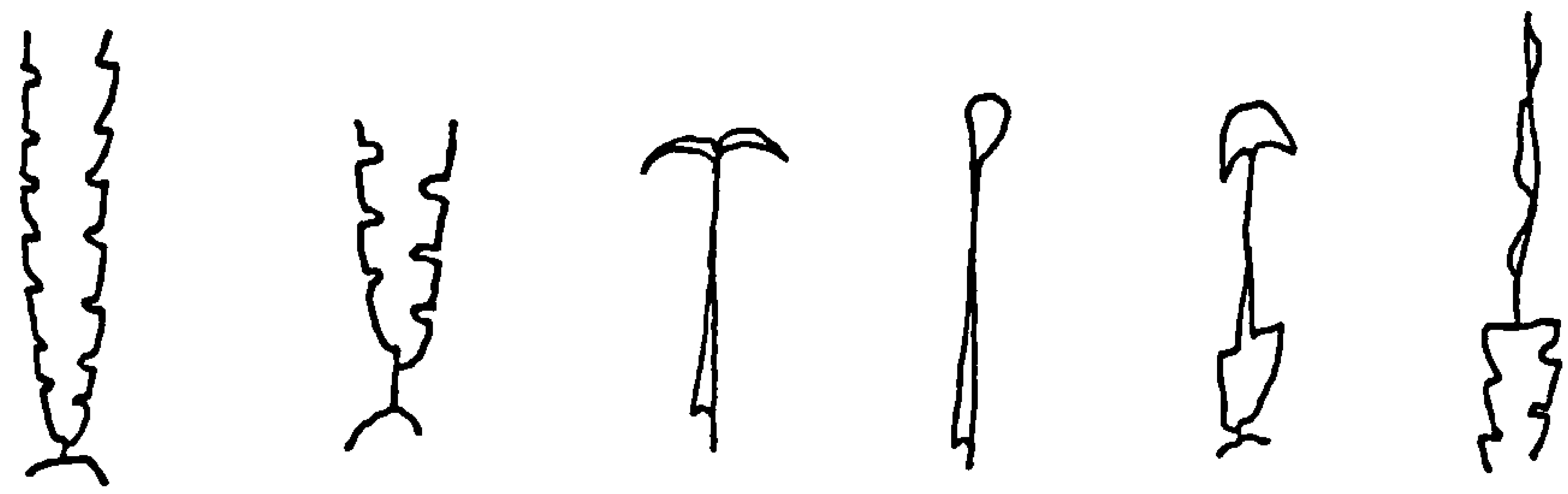
Horizons and localities. 8.9 to 7.25m below the top of the Lower Hartfell Shale, late D. clingani Zone, and one possible fragmentary specimen from 1.2m below the top of the Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn.

Diagnosis. Small rhabdosome up to 17mm long, rapidly widening from 0.9mm to the maximum 1.4mm. Thecae with rounded supragenicular walls, numbering 14 in 10mm.

Description. The rhabdosome is up to 17mm long, rapidly increasing from 0.9-1.0mm wide at the aperture of $th1^1$ to the maximum 1.4-1.5mm within 3mm which is then maintained. The thecae number about 14 in 10mm proximally with only a slight decrease distally, although the thecal count often varies due to tectonic distortion. The sicula has not been observed but bears a prominent virgella up to 0.5mm long. Although no specimens preserved in relief have been found the form of the proximal end indicates an initial development similar to G. persculptus with $th1^1$ growing down initially before bending up and $th1^2$ growing upwards for its entire length. The thecae are alternate with convexly curved supragenicular walls and narrow apertures which occupy 1/5 of the total rhabdosome width. The virgula is normally visible throughout the length of the rhabdosome, pressed through the periderm, and commonly forms a distally projecting nema up to 7mm long.

Remarks. The specimens described agree well with the type species of *Glyptograptus*, *G. t. tamariscus* (Nicholson 1868), and there is little question of their generic affinity. Few *Glyptograptus* species have been described from this horizon and none that are comparable with *G. daviesi*. This species appears to occur abundantly in black shale at Llanystumdwy near Criccieth, North Wales, where it occurs with an assemblage indicating late *D. clingani* or early *P. linearis* zone (see Appendix 1).

Glyptograptus? avitus Davies 1929
(pl. 53, figs. 8-17, pl. 60, figs. 1-4, pl. 61?)



1929 Glyptograptus(?) avitus sp. nov.; Davies, pp. 8-9, text-fig. 21.
1962 Glyptograptus(?) avitus Davies; Packham, text-fig. 7a.
1965 Glyptograptus(?) avitus Davies; Stein, pp. 172-173, text-fig. 22g.

Holotype. SM A10019. The specimen figured by Davies 1929, text-fig. 21. From the Birkhill Shale, G. persculptus Zone, Dob's Linn.

Material. Numerous flattened fragmentary specimens collected by the writer.

Horizons and localities. 0.7 to 1.6m above the base of the Birkhill Shale, G. persculptus Zone, Linn Branch trench, Dob's Linn.

Diagnosis. Small rhabdosome, rapidly increasing from 0.8 to 1.2mm wide in 5mm then slowly to 1.5mm maximum. Thecae with slightly curved or straight, sloping supragenicular walls. Virgella commonly bifurcates, nema often shows irregular, apparently membranous structures.

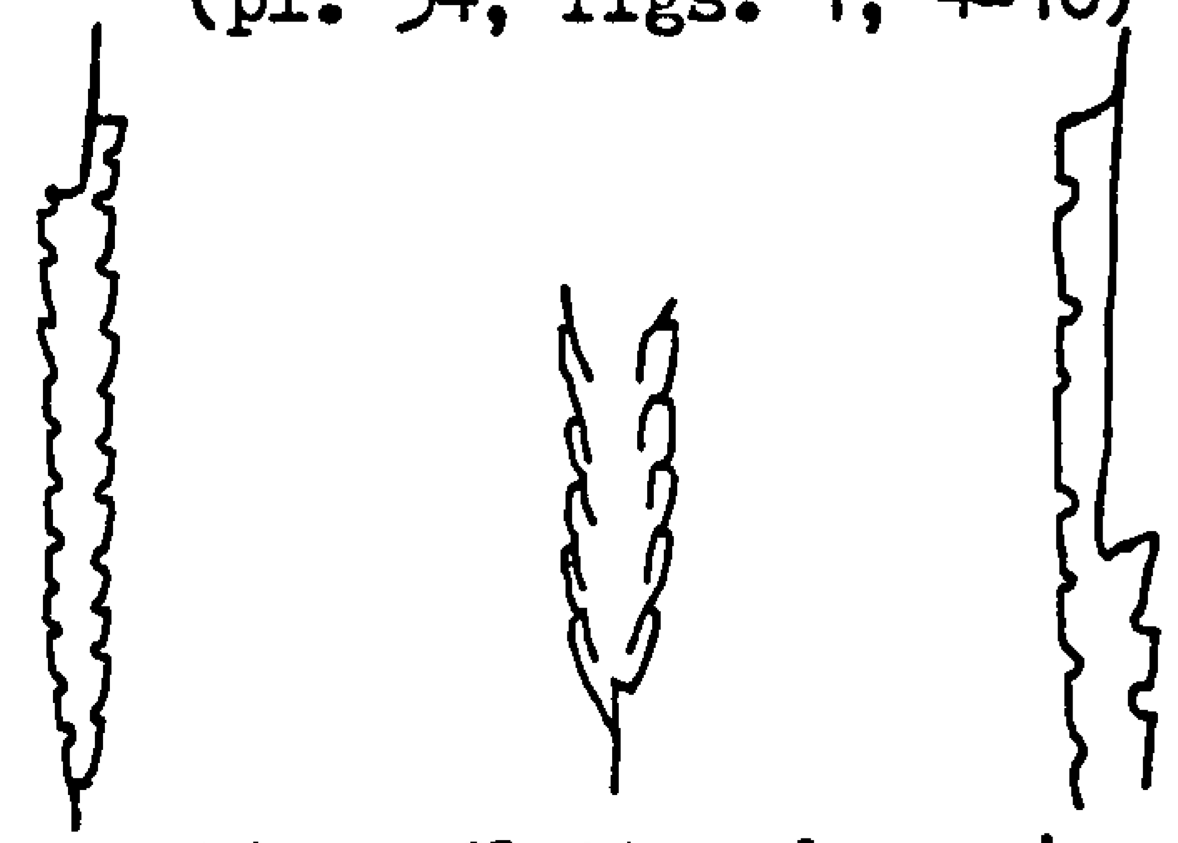
Description. The longest fragment in the material described here is 8mm long. The rhabdosome is 0.8-0.9mm wide at the aperture of $th1^1$ and increases to 1.2mm in 5mm. Davies recorded the rhabdosome to then slowly widen throughout its length to a distal maximum of 1.5mm. The thecae number about 12 in 10mm proximally, reducing to about 10 in 10mm distally. The sicula is approximately 2mm long; it possesses a virgella which bifurcates after 1 to 4mm and occasionally forks a second time (pl. 53, fig. 13). The nema of the sicula characteristically possesses distal poorly preserved structures, taking the form of either a double concavo-convex or a 'balloon' shape (pl. 61, figs. 3, 11). $Th1^1$ appears to grow down below the level of the sicula aperture before bending up while $th1^2$ grows continually upwards, in a similar fashion to G. persculptus (Salter 1865). The later thecae have slightly curved or straight, sloping supragenicular walls although occasionally a slight geniculum is present. The preservation is insufficient to allow determination of the internal structure but the outline with alternate thecae does suggest an affinity with Glyptograptus. A long nema is usually present; in juvenile specimens with only a few thecae it commonly bears a 'sac-like' object at the distal extremity, while more mature specimens often possess apparently membranous structures at various points along its length (pl. 60, figs. 2, 3).

Remarks. G? avitus is distinguished from other coexisting species by its thecal style, which is closest to the earlier Glyptograptus? sp. A (p. 182). Davies suggested that G? avitus was a forerunner of Akidograptus ascensus Davies 1929 although there is insufficient evidence to prove an evolutionary link between the two. The only similar structures associated with nemata of coeval diplograptids were described by Müller (1977, pl. 4, figs. 1-7) who referred his specimens to Climacograptus sp. and Diplograptus cf. modestus Lapworth 1876. None of his specimens are considered to belong to G? avitus. Müller (1975, 1977) considered the O? acuminatus Zone to represent an interval with diplograptids showing 'ramose' type (bifurcating) virgellae.

The structures associated with the siculae and some rather more mature rhabdosomes of G? avitus were probably vane-like structures which may have facilitated dispersion in water currents. The fine membranous structures associated with the nemata of fairly mature rhabdosomes are similar to those that were referred to as 'flotation structures' by Müller (1977) but there is no proof for this and they remain enigmatic in both origin and function.

Glyptograptus? sp. A

(pl. 54, figs. 1, 4-10)



Material. Over thirty flattened specimens collected by the writer.

Horizons and localities. 0.15 to 0.6m above the base of the Birkhill Shale, G. persculptus Zone, Linn Branch trench, Dob's Linn.

Diagnosis. Long rhabdosome up to 40mm, gradually reaching a maximum width of 1.5mm. Thecae intermediate between Climacograptus and Glyptograptus, numbering 8-12 in 10mm. Rhabdosome often becomes uniserial distally. Long virgella and nema commonly present.

Description. The rhabdosome is up to 40mm long. It measures 0.9-1.1mm wide at the aperture of $th1^1$, widening to 1.2-1.5mm in 5mm and reaching the maximum 1.2-1.8mm (1.5mm when not tectonically deformed) in 12mm. Proximally the thecae number 10-12 in 10mm, reducing distally to 8-10 in 10mm. The proximal development is unclear although $th\ 1^1$ extends some 0.2mm below the aperture of the sicula before turning upwards and the proximal end is fairly pointed. Most specimens possess a conspicuous virgella up to 2.5mm long. The thecae appear intermediate between Climacograptus and Glyptograptus; the supragenicular walls are inclined to a certain extent and may be either curved or straight with sharp genicula depending on the orientation of the rhabdosome and the relative direction of tectonic stretching. The apertures are normally horizontal or slightly introverted and open into excavations occupying 1/4 to 1/5 the total rhabdosome width. The stipe often becomes uniserial distally, one specimen having a uniserial portion 13mm long although this interval is normally shorter. This uniserial development appears to be an astogenetic mutation as it does not seem to be preservational and is too random to be a normal growth feature. A nema often reaching several mm long is commonly present.

Remarks. The specimens described here, although tectonically distorted, are clearly separable from G. persculptus (Salter 1865)s.s. by their general form, thecal style and prominent virgella and nema. Their generic position seems intermediate but they are here assigned questionably to Glyptograptus owing to the slight curvature of the supragenicular walls and the lack of well developed genicular hoods. The thecal style, lower thecal count and thicker periderm readily separates them from G. cf. persculptus (p. 176). The overall form is similar to Climacograptus normalis Lapworth 1877 but the thecae of this species have consistently vertical supragenicular walls, conspicuous genicula and horizontal apertures and the proximal development is different. The supragenicular walls, slightly introverted apertures and proximal development of Glyptograptus? sp. A appear close to those of G. persculptus forma B of Koren' et al. (1980) although their material is generally wider, does not show the tendency to develop a distal uniserial portion and ranges from early G. persculptus to early O? acuminatus zone (Koren' et al. 1980, range chart 7, Oradovskaya et al. 1979, range chart). Glyptograptus? sp. A is restricted to the basal 0.6m of Birkhill Shale at Dob's Linn as opposed to the far longer ranges of G. cf. persculptus, C. normalis, etc. (text-fig. 7). Glyptograptus? sp. A also appears similar to Diplograptus bohemicus (Marek 1955) which Koren' et al. (op. cit.) synonymise with their G. persculptus forma B. The top Ordovician zone utilised by Mu et al. (1980) is that of D. bohemicus which is here considered (p. 40 , text-fig. 13) to correlate with the top of the P. pacificus Subzone and the C? extraordinarius Zone of Dob's Linn.

Glyptograptus? cf. occidentalis Ruedemann 1947
(pl. 55, figs. 1-3, text-fig. 29)

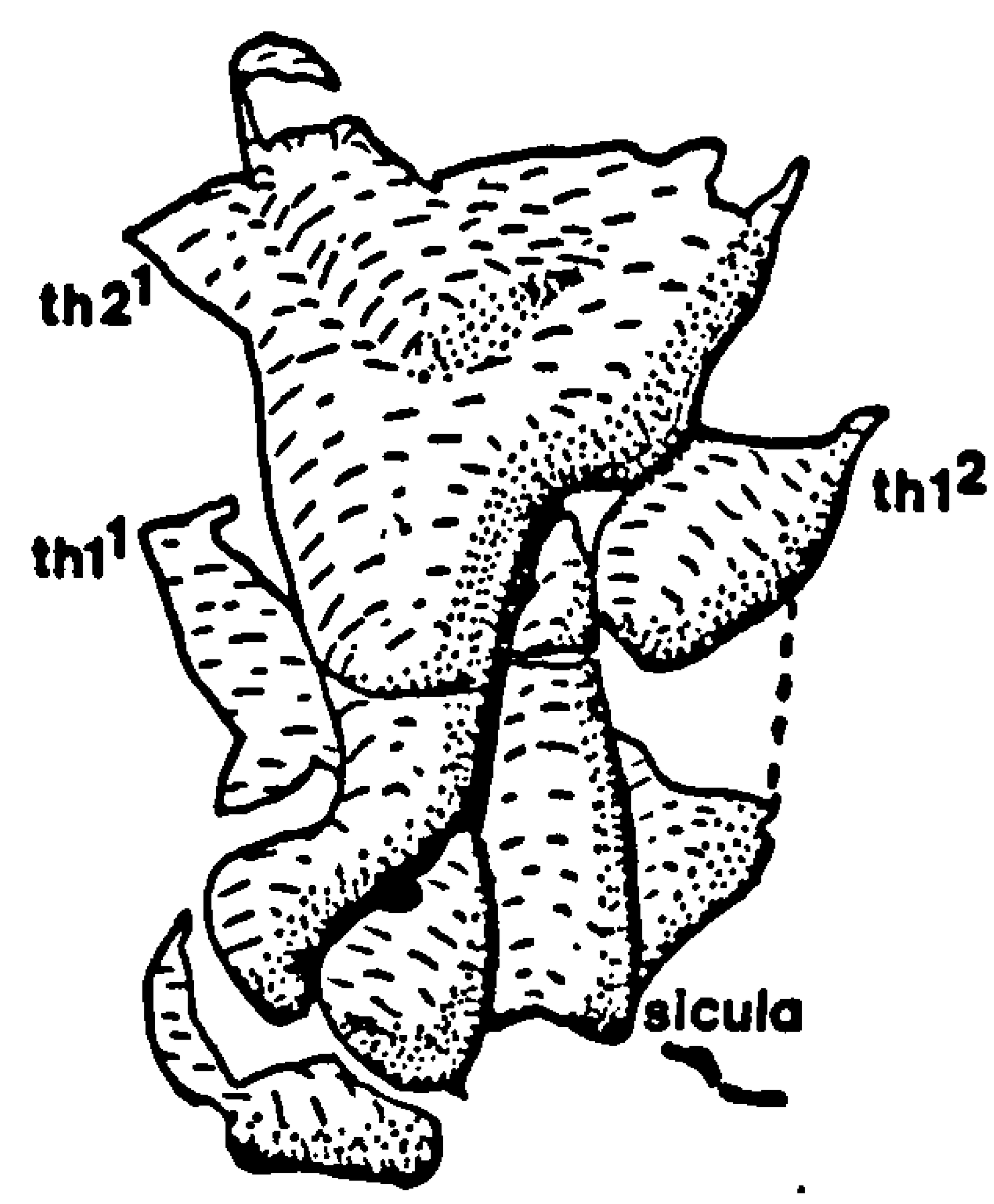
(1947 Diplograptus (Glyptograptus) teretiusculus (Hisinger) mut. occidentalis n. mut.; Ruedemann, p. 409, pl. 69, fig. 61)

Material. Five specimens in varying states of compression from flattened to almost full relief, collected by the writer.

Horizons and localities. Base of the Dark Shale Member, Mill Formation, Upper Whitehouse Group, late P. linearis/early D. complanatus zone, Myoch Bay, Girvan.

Description. The rhabdosome is small, measuring a little over 15mm long. It widens from 0.6mm at the aperture of $th1^1$ to 1.3mm in 5mm and reaches the maximum 1.5mm within 8mm. The thecae number about 12 in 10mm proximally, reducing distally to about 10 in 10mm. The sicula is exposed for 0.5mm of its length in obverse view but its total length is unknown. $Th1^1$ grows downwards initially until it reaches some 0.2mm below the aperture of the sicula before bending upwards. $Th1^2$ appears to grow upwards throughout its length. The first two thecae possess mesial spines and the sicula has a rather thick virgella. The thecae are alternate throughout the length of the rhabdosome with gently curved interthecal septa and strongly curved, convex supragenicular walls which lack genicula. The apertures are slightly introverted, opening into excavations which occupy 1/4 to 1/5 the total width of the rhabdosome. Prominent transverse grooves occur at the level of each aperture which are probably artefacts of preservation.

Remarks. Insufficient specimens have been found to allow precise identification. The overall form agrees well with G? occidentalis but both Ruedemann (1947, p. 409) and Ross & Berry (1963, p. 142) recorded the holotype to have attained a maximum width of 2mm within 7mm. Measurements from their illustrations however indicate a



TEXT-FIGURE 29 . HM C13059. (x50)
Glyptograptus? cf. occidentalis Ruedemann 1947
Juvenile specimen preserved in full relief but with rather fragmentary preservation.
Dark Shale Member, Mill Formation, Upper Whitehouse Group, late P. linearis/early D. complanatus zone.
Loc. 2, Myoch Bay, Girvan.

maximum width of about 1.5mm. Neither the holotype nor the other specimen figured by Ross & Berry (1963, pl. 11, fig. 8) possess complete proximal ends with spines. Ruedemann's 'G. teretiusculus occidentalis' is raised here to full specific status owing to the horizon at which it occurs (D. complanatus Zone sensu Ross & Berry op. cit.) in contrast to the much earlier range of G. teretiusculus teretiusculus (Hisinger 1840). The proximal development of the specimens described here is broadly similar to G. tamariscus tamariscus (Nicholson 1868), the type species of Glyptograptus; it is however much squarer and the first two thecae possess mesial spines in contrast to the pointed proximal end and non-spinose early thecae of G. t. tamariscus. Several early 'Glyptograptus' species such as G. t. teretiusculus have different thecal style and proximal development to the type species and are now considered to belong to a different genus, possibly related to the Orthograptus calcaratus group (Kearsley, pers. comm.). It is therefore concluded that the specimens described here may be only questionably referred to Glyptograptus s.s.

The only other similar species from an approximately equivalent horizon to the Girvan specimens is G. tenuissimus Ross & Berry 1963. This has a similar overall form, gradually widening from 0.6 to 1.6mm, and similar thecae numbering 10-12 in 10mm. It appears to be very like the holotype of G? occidentalis and may be a junior synonym, although Ross & Berry (1963, p. 142) record it to be restricted to the earlier O. quadrimucronatus Zone of North America.

The prominent transverse grooves on the described specimens are similar to those in specimens of G. asiaticus Keller 1956 (Keller op. cit., pl. 3, fig. 9) but this Russian species has a much more robust overall form. They are probably artefacts of compression formed by diagenetic flattening of a rhabdosome with alternate thecae, although their mode of formation is presently unclear.

10.4 Genus Paraorthograptus Mu 1974 (=Pacificograptus Koren' 1979)

Type species (by monotypy). Climacograptus innotatus var. pacificus Ruedemann 1947, p.429, pl. 73, fig. 29.

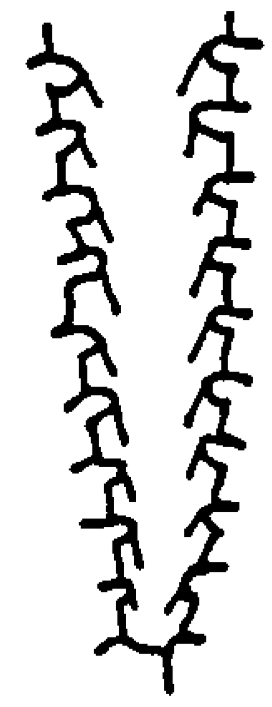
Stratigraphical range. Late Ordovician (P. pacificus Subzone)

Revised diagnosis. Paired genicular spines on all thecae, straight inclined supragenicular walls and interthecal septa, apertures slightly everted, excavations shallow and long; sicula with paired apertural spines and virgella; rhabdosome rectangular in cross section.

Remarks. The proximal structure and thecal style are similar to Amplexograptus Elles & Wood 1907. Paraorthograptus may be separated from this poorly defined genus by its slightly everted apertures and paired genicular spines. Climacograptus innotatus innotatus Nicholson 1869 differs from Paraorthograptus by possessing pronounced genicular flanges rather than spines and a different proximal development.

Paraorthograptus is perhaps the most distinctive diplograptid genus in the late Ordovician. The taxonomic status of both the genus and species is however in confusion; the first new generic name, Paraorthograptus, was published by Mu (in Wang et al.) 1974 with P. typicus defined as the type species. The publication was not however widely known until the end of the 1970's, by which time Koren' (1979) had published her description utilising the name Pacificograptus with P. pacificus as the type species. Most of the subspecies and species of this genus are described in Russian and Chinese; translations of the Chinese descriptions from VandenBerg (pers. comms.) and of the paper by Koren' (Palaeont. Journ. 1979) indicate that most of the divisions have been made using width criteria. This is inherently unreliable in any material which has suffered tectonic or diagenetic deformation. It is suggested here that until an integrated study utilising well preserved material from every continent is carried out all material should be synonymised with the original species described by Ruedemann. P. pacificus therefore becomes the type species of Paraorthograptus by monotypy although not utilised by Mu in his original description.

Paraorthograptus pacificus (Ruedemann 1947)
(pl. 56, figs. 1-13)



1947 Climacograptus innotatus Nicholson pacificus n. var.; Ruedemann, p. 429, pl. 73, fig. 29.

1960 Orthograptus truncatus var. socialis (Lapworth); Berry, p. 93, pl. 20, figs. 4-6.

1963 Climacograptus innotatus var. pacificus Ruedemann; Ross & Berry, p. 125, pl. 8, fig. 21.

1974c Climacograptus pacificus Ruedemann; Riva, pp. 1457-1459, text-figs. 2a-h.

?1974c Climacograptus pacificus pilosus subsp. nov.; Riva, p. 1459, text-fig. 2n.

1974 Paraorthograptus typicus gen. et sp. nov.; Wang et al., p. 161, pl. 70, fig. 15.

1977 Paraorthograptus angustus Mu & Lee (MS); Wang et al., p. 339, pl. 103, fig. 11.

1977 Paraorthograptus jianxiensis Lee (MS); Wang et al., p. 339, pl. 103, fig. 10.

1977 Paraorthograptus latus Wang sp. nov.; Wang et al., p. 339, pl. 103, figs. 6, 7.

1977 Paraorthograptus typicus Mu; Wang et al., pp. 339-340, pl. 103, figs. 8, 9.

1978 Paraorthograptus cf. confertus Lee (MS); Wang et al., p. 644, pl. 205, fig. 16.

1978 Paraorthograptus angustus Mu & Lee (MS); Wang et al., p. 644, pl. 205, fig. 17.

1979 Pacificograptus pacificus pacificus (Ruedemann) gen. nov.; Koren', pp. 71-72, text-figs. 1a-c.

1979 Pacificograptus pacificus kimi Koren' n. subsp.; Koren', pp. 72-74, pl. 8, fig.s 1-8, text-figs. 2a-g.

1980 Pacificograptus pacificus pacificus (Ruedemann); Koren' et al., pp. 126-128, pl. 34, figs. 6-10, text-figs. 32a-i.

1980 Pacificograptus pacificus affinis Koren' & Tzai subsp. nov.; Koren' et al., pp. 128-129, pl. 35, figs. 1-6, text-figs. 32j-m.

Holotype. U.S.N.M. 102838. Ruedemann's only specimen, figured 1947, pl. 73, fig. 20. From the highest Ordovician of Trail Creek, Idaho.

Material. About forty flattened, mostly weathered, specimens collected by the writer.

Horizons and localities. Anceps Bands C to E, Upper Hartfell Shale, *P. pacificus* Subzone, Dob's Linn.

Diagnosis. As for genus.

Description. The rhabdosome is up to 20mm long, widening from 0.7mm at the aperture of $th1^1$ to 1.7mm in 5mm and reaching the maximum 2.0mm in about 7mm. Distally this width may be maintained or decrease slightly. Proximally the thecae number 15-17 in 10mm, reducing distally to about 14 in 10mm. Proximal detail is obscure in the described specimens; Koren' (1979) records the sicula to be 1.6-2.0mm long while Riva (1974) records it to be 0.7-0.9mm. It possesses paired apertural spines 0.3-0.6mm long and a prominent virgella. $Th1^1$ produces a mesial spine at the point where it turns upwards. All other thecae possess paired genicular spines 0.5-0.8mm long. The supragenicular walls are short, straight and gently inclined. The apertures are slightly everted, opening into long but shallow excavations which occupy 1/5 to 1/6 of the width of the rhabdosome. The rhabdosome is aseptate but the virgula commonly forms a median line. A nema is not normally preserved.

Remarks. All described species and subspecies of this genus are here tentatively assigned to *P. pacificus* (see 'Remarks' of generic diagnosis). It is a widely occurring species in the late Ordovician; besides being relatively common in the top three Anceps Bands at Dob's Linn it is found in the *T. typicus* to early *D. bohemicus* zones of China (Mu *et al.* 1980, etc.), the *P. pacificus* Subzone of the *C. l. supernus* Zone of Russia (Koren' *et al.* 1979, etc.), the late *D. complanatus* Zone of North America (Riva 1974, etc.) and the Zone of *D. ornatus* and *C. latus* of Victoria, Australia (VandenBerg, pers. comm.) and would appear to be an extremely useful species for accurate intercontinental correlation.

10.5 Genus *Akidograptus* Davies 1929

Type species (by original designation). *Akidograptus ascensus* Davies 1929, p. 9, text-figs. 22-24.

Stratigraphical range. Lower Silurian (*O? acuminatus*)

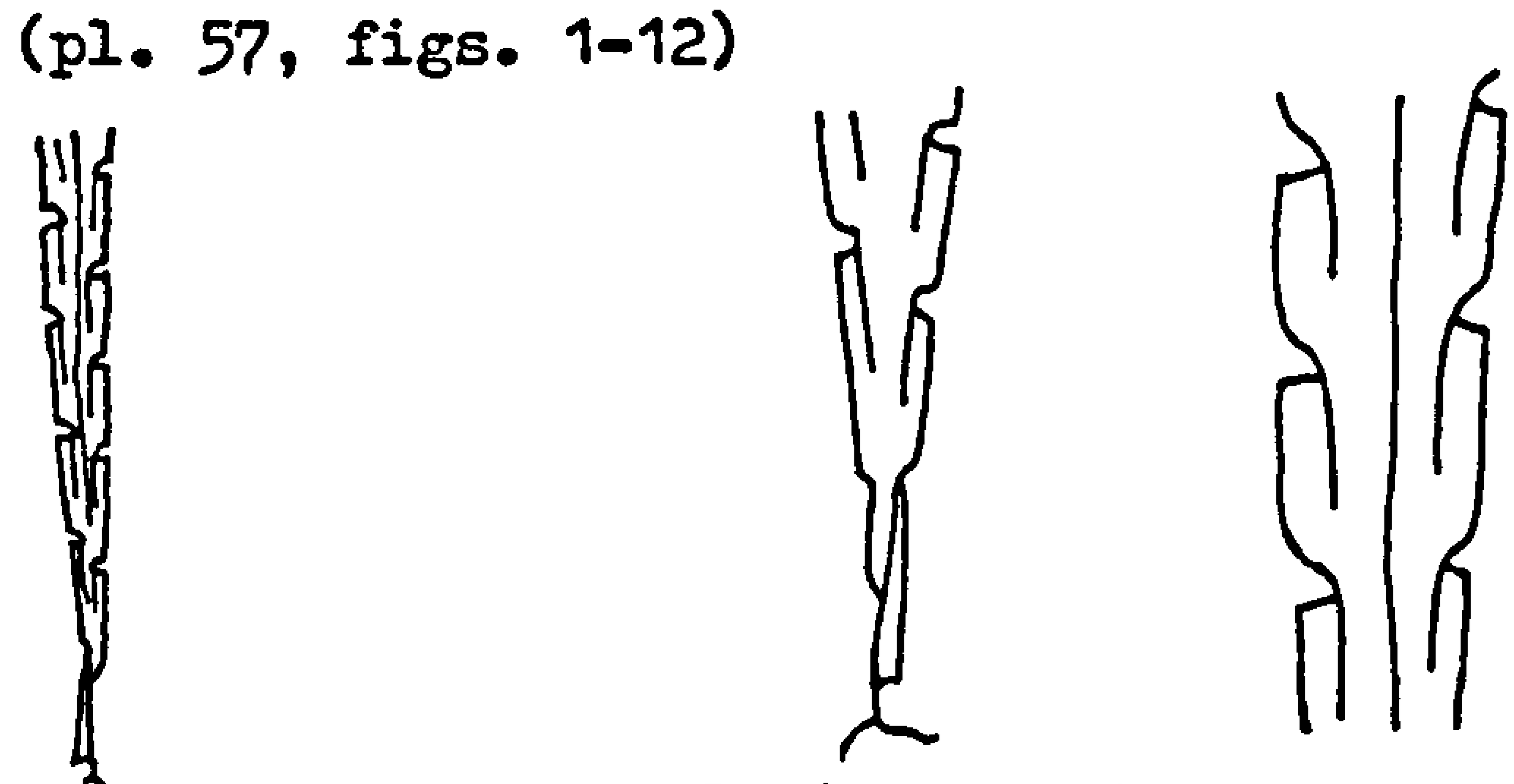
Revised diagnosis. ?*Climacograptus*-like thecae, first two protracted, growing upwards throughout their length.

Remarks. Bulman (1933, 1936) suggested that th1^2 might be lost, but in 1970 (V131) stated that the proximal end was "without definite uniserial portion" while Stein (1965) concluded that development was complete. Rickards (1970) and Hutt (1974) retained *Akidograptus* in the Dimorphograptidae but three-dimensional specimens preserved in black shale from Dob's Linn indicate that the proximal development is complete and the genus is therefore here assigned to the family Diplograptidae.

Species described.

A. ascensus Davies 1929 (*O? acuminatus*)

Akidograptus ascensus Davies 1929
(pl. 57, figs. 1-12)



1929 *Akidograptus ascensus* sp. nov.; Davies, p. 9, text-figs. 22-24.
1933 *Akidograptus ascensus* Davies; Bulman, p. 16, pl. 3b, text-fig. 5.
1934 *Akidograptus ascensus* Davies; Hsü, p. 86, pl. 6, figs. 11a, b.
1936 *Akidograptus ascensus* Davies; Bulman, p. 25, text-fig. 2b.
1962 *Akidograptus ascensus* Davies; Tomczyk, p. 91, pl. 4, fig. 1, pl. 7, fig. 1.
1964 *Akidograptus ascensus* Davies; Yang, p. 634, pl. 1, figs. 6-11.
?1964 *Akidograptus giganteus* sp. nov.; Yang, p. 635, pl. 1, fig. 13.
1965 *Diplograptus (Akidograptus) ascensus* Davies; Stein, p. 176, pl. 14f, pl. 15b, text-figs. 22a, d, 23a-c.
1967 *Akidograptus ascensus* Davies; Obut & Sobolevskaya (& Nikolaev), p. 73, pl. 6, figs. 8, 9.
?1973 *Akidograptus cultus* sp. nov.; Mikhaylova, p. 18, pl. 4, figs. 6, 7.
1974 *Akidograptus ascensus* Davies; Hutt, p. 55, text-fig. 9, figs. 9, 10.
1977 *Akidograptus ascensus* Davies; Rickards *et al.*, p. 98, text-fig. 7.
?1980 *Akidograptus ascensus cultus* Mikhaylova; Koren' *et al.*, p. 169, pl. 53, fig. 4, pl. 54, figs. 2-6, text-figs. 57a-c.

Holotype. SM A10021. The specimen figured by Davies 1929, text-fig. 23. From the Birkhill Shale, *O*? *acuminatus* Zone, of Dob's Linn.

Material. About thirty specimens, mostly flattened but some in relief, collected by the writer.

Horizons and localities. 1.6 to 2.3m above the base of the Birkhill Shale, early *O*? *acuminatus* Zone, Linn Branch trench, Dob's Linn.

Diagnosis. Small rhabdosome with protracted th1^1 and 1^2. Thecae with almost vertical, straight supragenicular walls subparallel to axis, rounded genicula and short, straight, gently inclined interthecal septa. Apertures slightly everted, excavations narrow but long. Virgella commonly forked.

Description. The rhabdosome is up to 20mm long with a protracted proximal region 0.2-0.3mm wide and 2mm long before the first aperture. The width at the aperture of $th1^1$ is 0.3-0.5mm, increasing rapidly to the maximum 0.8-1.0mm in the following 2.5mm by the aperture of $th4^1$. The thecae number about 11 in 10mm. The sicula is exposed for the whole of its 1.3mm length and possesses a bifurcating virgella. $Th1^1$ originates from towards the top of the sicula and grows continually upwards, initially sub-parallel to it but then bending diagonally across the top. $Th1^2$ buds from $th1^1$ just below the apex of the sicula and grows straight upwards and slightly outwards. The remaining thecae are sub-alternate; they are long and thin and grow almost parallel to the rhabdosome but with a slight kink above the infragenicular wall. The supragenicular walls are straight and almost vertical with slight genicula. The apertures are slightly everted, opening into shallow excavations which occupy 1/5 the total width of the rhabdosome. The interthecal septa are straight and terminate above the level of the preceeding apertures. The virgula normally extends distally as a nema which commonly exceeds 5mm long.

Remarks. The only species which may be confused with A. ascensus are Orthograptus? acuminatus acuminatus (Nicholson 1867a) and O? a. praematurus (Davies 1929). It is separable from both of these by its approximately Climacograptus-like thecal style although the thecae of A. ascensus may appear similar to O? acuminatus s.l. in slightly oblique view when greater lateral spread has occurred at the apertures. Davies recorded the proximal portion of O? acuminatus praematurus to be less protracted than either O? a. acuminatus or A. ascensus. O? a. acuminatus s.s. possesses more distinctly Orthograptus-like thecae which are straight with everted apertures. A. giganteus Yang 1964 from the lower Silurian of China has Climacograptus-like thecae proximally which become Orthograptus-like distally; this change may well be due to differential lateral spread and the species is doubtfully referred to A. ascensus. A. cultus Mikhaylova 1973 (A. ascensus cultus of Koren' et al. 1980) from the lower Silurian of Russia is very similar to A. ascensus but has thecae which sometimes have straight, inclined supragenicular walls, giving a somewhat Orthograptus-like appearance. Some specimens figured by Koren' *et al.* (*op. cit.*) appear to be *A. ascensus* s.s. (e.g. text-figs. 57b, c) while others (e.g. text-fig. 57a) look like the forms considered here to represent *A. ascensus* that have suffered greater lateral spread at the apertures. Many similar specimens from the early *O? acuminatus* Zone at Dob's Linn do not conform strictly with the definitions of either *A. ascensus* or *O? a. acuminatus* and considerably more work needs to be done on these forms.

Both at Dob's Linn and the Lake District (Hutt 1974) *A. ascensus* is most typical of the lower part of the *O? acuminatus* Zone where it is associated with *Atavograptus ceryx* (Rickards & Hutt 1970). *A. ascensus* appears to be widespread and is found outside Europe in China (Hsü 1934) and Russia (Obut & Sobolevskaya 1964). It is the most important species in determing the basal *O? acuminatus* Zone, which in the future may be taken as the base of the Silurian.

Chapter 11. Family LASIOGRAPTIDAE Lapworth 1879.

Diagnosis (from Bulman 1970, V126). Rhabdosome usually somewhat flattened, cryptoseptate or with complete or incomplete median septum; thecae geniculate, with short inwardly-inclined supragenicular wall (lasiograptid or gymnograptid); periderm commonly attenuated; more or less well-developed clathria and conspicuous development of genicular (and ?thecal) spines sometimes associated with a lacinia; development streptoblastic or prosoblastic.

Remarks. There seem to be some forms which could be assigned either to the Lasiograptidae or the subfamily Archiretiolitinae (e.g. *P*? *lautus*' Koren & Tzai 1980) as the diagnostic characters of the two seem rather ill-defined.

11.1 Genus *Neurograptus* Elles & Wood 1908

Type species (subsequently designated Bulman 1929, p. 179). *Lasiograptus margaritatus* Lapworth 1876, pl. 2, fig. 60.

Stratigraphical range. Upper Ordovician.

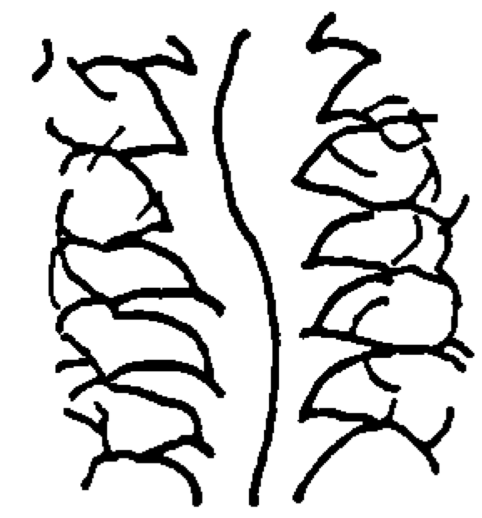
Diagnosis (after Bulman 1970, V127). Thecae with extremely short supragenicular walls and single or paired genicular spines; thecal spines breaking up distally into a highly developed lacinia; scopulate septal processes commonly also developed.

Remarks. The material described here is insufficient to add to Bulman's diagnosis.

Species described.

N. margaritatus (Lapworth 1876) (*D. clingani*)

Neurograptus margaritatus (Lapworth 1876)
(text-figs. 30a-f)



1876 Lasiograptus margaritatus sp. nov.; Lapworth, pl. 2, fig. 60.

1877 Lasiograptus margaritatus Lapworth; Lapworth, p. 135, pl. 4, fig. 25.

1908 Lasiograptus (Neurograptus) margaritatus (Lapworth); pp. 332-333, pl. 34, figs. 6a-e, text-figs. 219a, b.

Type specimen. A specimen to match Lapworth's original figure has not been found (Strachan 1971, p. 46).

Material. About fifteen fragmentary flattened specimens collected by the writer.

Horizons and localities. 8.5 to 5.0m below the top of the Lower Hartfell Shale, D. clingani Zone, North Cliff trench, Dob's Linn.

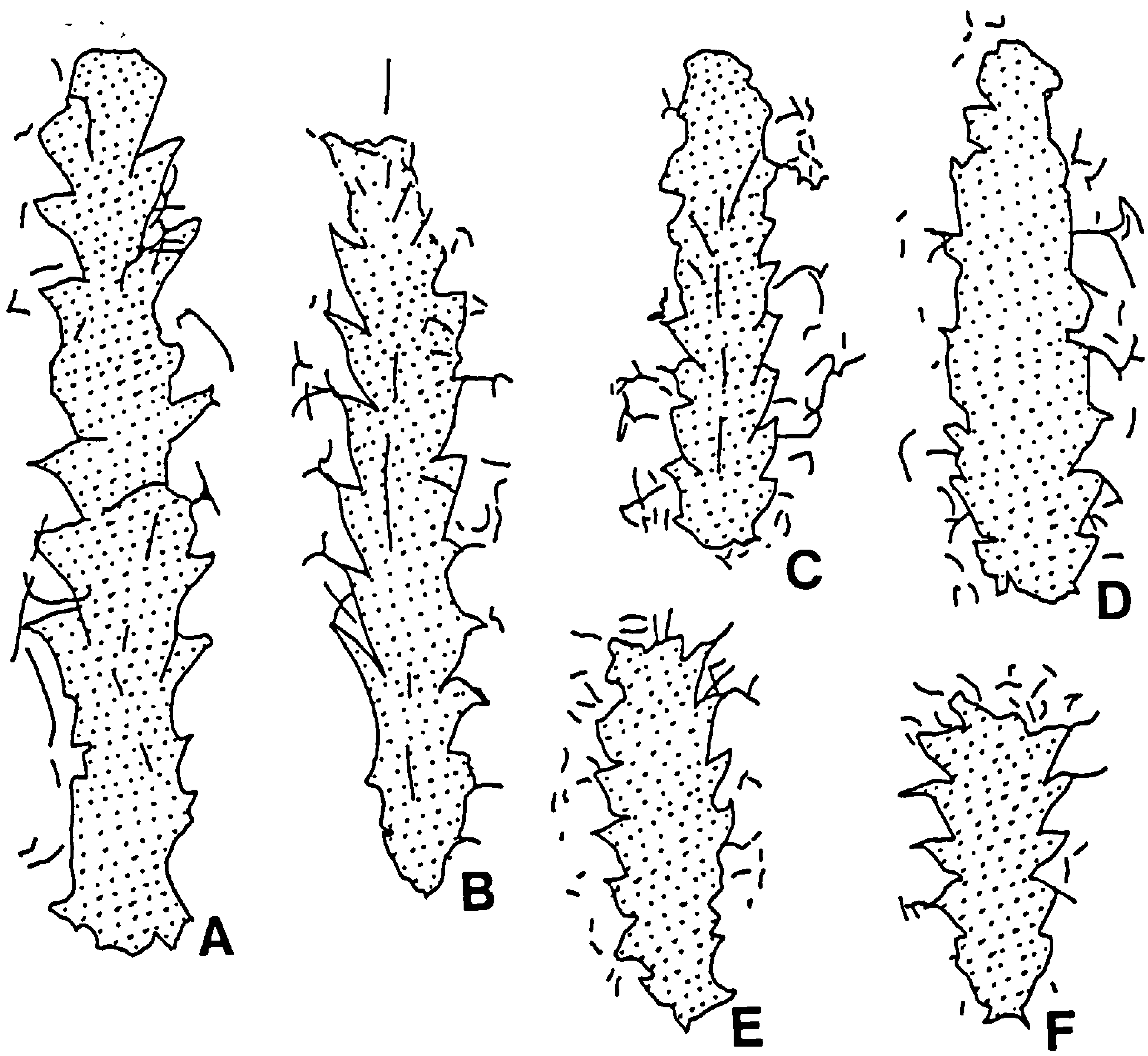
Diagnosis. Small rhabdosome a little over 10mm long. Central sclerotised portion 1.5-2.0mm wide with mucronate Orthograptus-like thecae numbering 12-16 in 10mm. Lacinia delicate and poorly developed.

Description. The rhabdosome is very small with a maximum length of about 10mm. The central sclerotised portion widens rapidly from about 1.0mm proximally to a maximum 1.5-2.0mm. The thecae number 12-16 in 10mm. No complete proximal ends have been observed. The thecae are broadly Orthograptus in style, terminating in spines at the slightly everted apertures. The spines fork to give a poorly developed lacinia up to 0.7mm wide on each side of the rhabdosome. The virgula occasionally extends distally as a short nema.

Remarks. Elles & Wood distinguished N. margaritatus from N. fibratus (Lapworth 1876) by the larger dimensions and 'scopulate processes' of the latter species. N. margaritatus is readily separable from

Plegmatograptus nebula Elles & Wood 1908 when preserved in dorso-ventral orientation due to the well defined Orthograptus-like sclerotised thecae. The two species could be confused when preserved in scalariform orientation but N. margaritatus has a more poorly developed lacinia and is smaller. Plegmatograptus? nebula Koren' & Tzai 1980, from the later P. pacificus Subzone of Russia possesses similarly sclerotised thecae to N. margaritatus but has a larger rhabdosome and a more extensive lacinia.

The only record of N. margaritatus outside Britain is by Thomas (1960) who figures a specimen from the Eastonian of Australia.



TEXT-FIGURE 30. Neurograptus margaritatus (Lapworth 1876) (all x10) 5.1 to 5.0m below the top of the Lower Hartfell Shale, top D. clingani Zone, North Cliff trench, Dob's Linn.

A. HM C14259/1b. B. HM C14265/1a. C. HM C14258/1a.
D. HM C14263/3. E. HM C14263/1 F. HM C14263/2.

11.2 Genus *Nymphograptus* Elles & Wood 1908

Type species (by original designation). *Nymphograptus velatus* Elles & Wood 1908, p. 332, pl. 34, figs. 4a, b, text-figs. 217a-c.

Stratigraphical range. Late Ordovician (*D. anceps*)

Diagnosis (after Bulman 1970, V128). Thecae with extremely short supragenicular walls and single or paired genicula spines; septal strands very strongly developed to form elaborate lacinia enveloping rhabdosome.

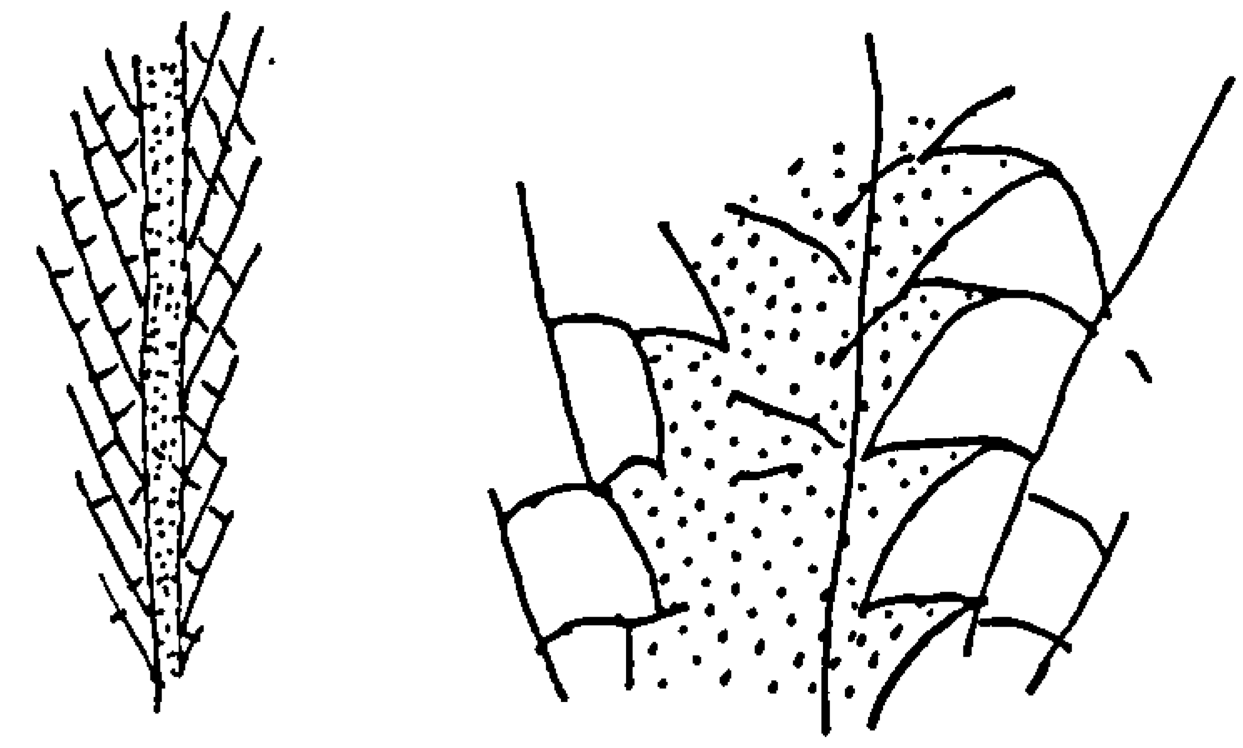
Remarks. The material described here is insufficient to add to Bulman's diagnosis.

Species described.

N. velatus Elles & Wood 1908 (*P. pacificus*)

Nymphograptus velatus Elles & Wood 1908

(text-figs. 31a, b)



1908 Lasiograptus (Nymphograptus) velatus sp. nov.; Elles & Wood, pp. 329-331, pl. 34, figs. 4a, b, text-figs. 217a-c.

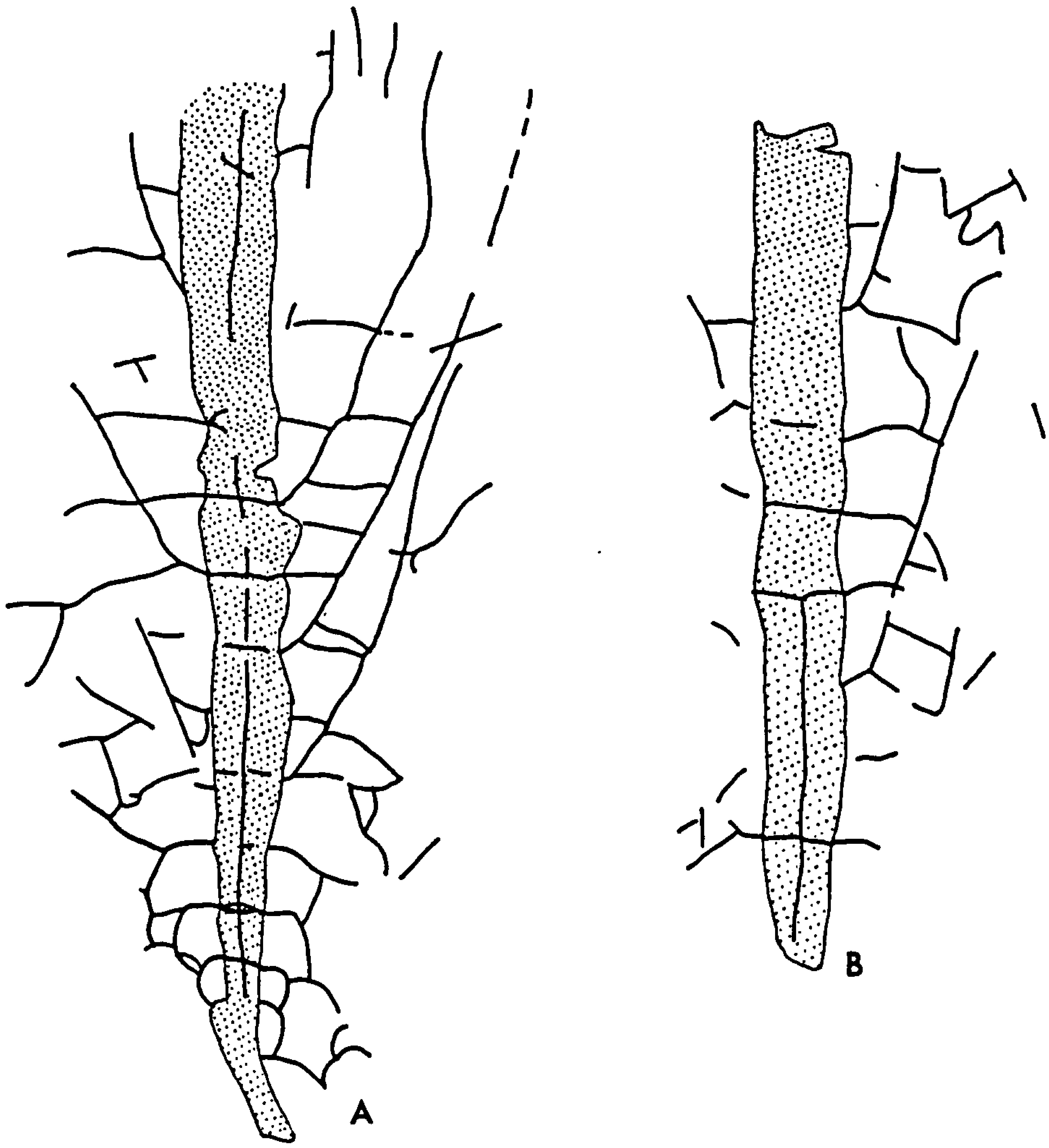
1980 Nymphograptus velatus Elles & Wood; Koren' et al., pp. 164-166, text-figs. 54a-c.

Type specimen. Not yet designated. Elles & Wood's three specimens from the Upper Hartfell Shale, D. anceps Zone, at Ettrickbridge End.

Material. Several fragmentary specimens collected by the writer.

Horizons and localities. Anceps Band C, Upper Hartfell Shale, P. pacificus Subzone, Linn Branch and Long Burn trenches, Dob's Linn.

Remarks. Insufficient material has been found during this study to improve on Elles & Wood's original description. The only other representative of this genus to be described, Nymphograptus halli Harris & Thomas 1955, differs from N. velatus by possessing a more complex disordered lacinia. One specimen figured by Koren' et al. (1980) shows an apparently unsclerotised central reticulum, as is commonly found in distal parts or immature specimens of archiretiolitinids. The description by Koren' et al. (op. cit.) of material from the P. pacificus Subzone of Soviet Central Asia is apparently the only record of N. velatus from outside Scotland. If this species is restricted to the P. pacificus Subzone, as implied by this work and by Koren' et al., it indicates that the black shale band at Ettrickbridge End belongs to late D. anceps Zone.



TEXT-FIGURE 31. Nymphograptus velatus Elles & Wood 1906 (x7.5)
Anceps Band C, Upper Hartfell Shale, P. pacificus Subzone, Long Burn trench, Dob's Linn.

A. HM C13459. B. HM C13460.

Chapter 12. Family RETIOLITIDAE Lapworth 1873.

Diagnosis (from Bulman 1970, V128). Rhabdosome scandent, biserial, dipleural; periderm reduced to meshwork composed of reticulum or clathria or both, lacinia present in some forms. Thecae markedly alternate.

Subfamily ARCHIRETIOLITINAE Bulman 1955

Diagnosis (adapted from Bulman 1970, V130). Complete sicula sclerotised; initial portions of one or more proximal thecae may be sclerotised; development basically diplograptid.

Remarks. *Plegmatograptus? craticulus* sp. nov., which has a completely sclerotised sicula but no sclerotised thecae, would fit into neither of the two subfamilies of Retiolitidae as defined by Bulman (1970). The original diagnosis of Archiretiolitinae ("sicula and initial portion of one or more proximal thecae sclerotised") is therefore changed to accomodate it. The subfamily Archiretiolitinae covers a diverse range of apparently unrelated partially sclerotised biserial forms and is considered by the writer to be an inadequate and misleading grouping. A revision would require study of well preserved isolated material and is beyond the scope of this thesis.

12.1 Genus *Orthoretiograptus* Mu? 1977

Type species (by original designation). *Orthoretiograptus denticulatus* Mu (in Wang *et al.*) 1977, p. 345, pl. 105, fig. 5.

Stratigraphical range. Late Ordovician (*P. pacificus*)

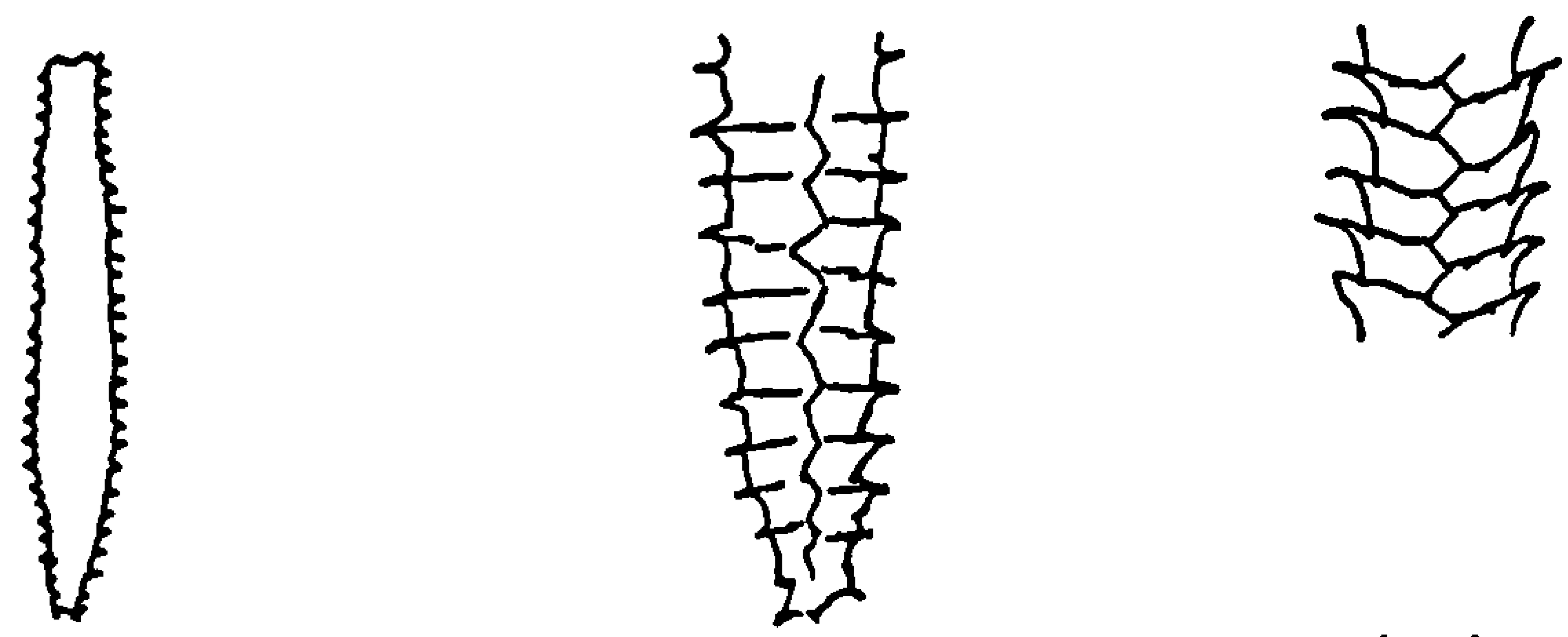
Revised diagnosis. Rhabdosome fusiform with rectangular cross-section; hexagonal clathria supporting a proximally well developed periderm; thecae slightly introverted with straight inclined supragenicular walls.

Remarks. The validity and affinities of this genus remain uncertain; it is possible that it is synonymous with *Reteograptus* Hall 1859, although the specimens of *O. denticulatus* referred to *Reteograptus pulcherrimus* Keble & Harris 1934 by Lenz (1977, p. 1950) do not belong to the latter species. The synonymies listed by him are all of R. pulcherrimus s.s. which is a narrower and rather earlier form. The appearance of flattened specimens of Reteograptus is similar to Orthograptus q. quadrimucronatus (Hall 1865) owing to the thickened apertural lists of the latter species; Koren' (pers. comm.) states that Russian workers are unable to draw the morphological boundary betweem O. q. quadrimucronatus and R. pulcherrimus in their Mirny Creek collections. These two species belong not only to different genera but also to different families. The type species of Pararetiograptus, P. sinensis (?)Wang et al. 1974, is distinct from Orthoretiograptus and only P. regularis (?)Mu 1977 is considered to be synonymous with O. denticulatus.

Species described.

O. denticulatus Wang et al. 1977 (P. pacificus)

Orthoretiograptus denticulatus Wang et al. 1977
(pl. 58, figs. 1-4, text-figs. 32a-d)



1977 Orthoretiograptus denticulatus gen. et sp. nov. Mu (MS); Wang et al., p. 345, pl. 105, fig. 5.

1977 Pararetiograptus regularis sp. nov. Mu (MS); Wang et al., pp. 346-347, pl. 105, fig. 1.

1977 Retiograptus pulcherrimus Keble & Harris; Lenz, pp. 1950-1952, pl. 1, figs. 3-7.

Holotype. The only specimen figured by Wang et al. 1977, pl. 105, fig. 1.

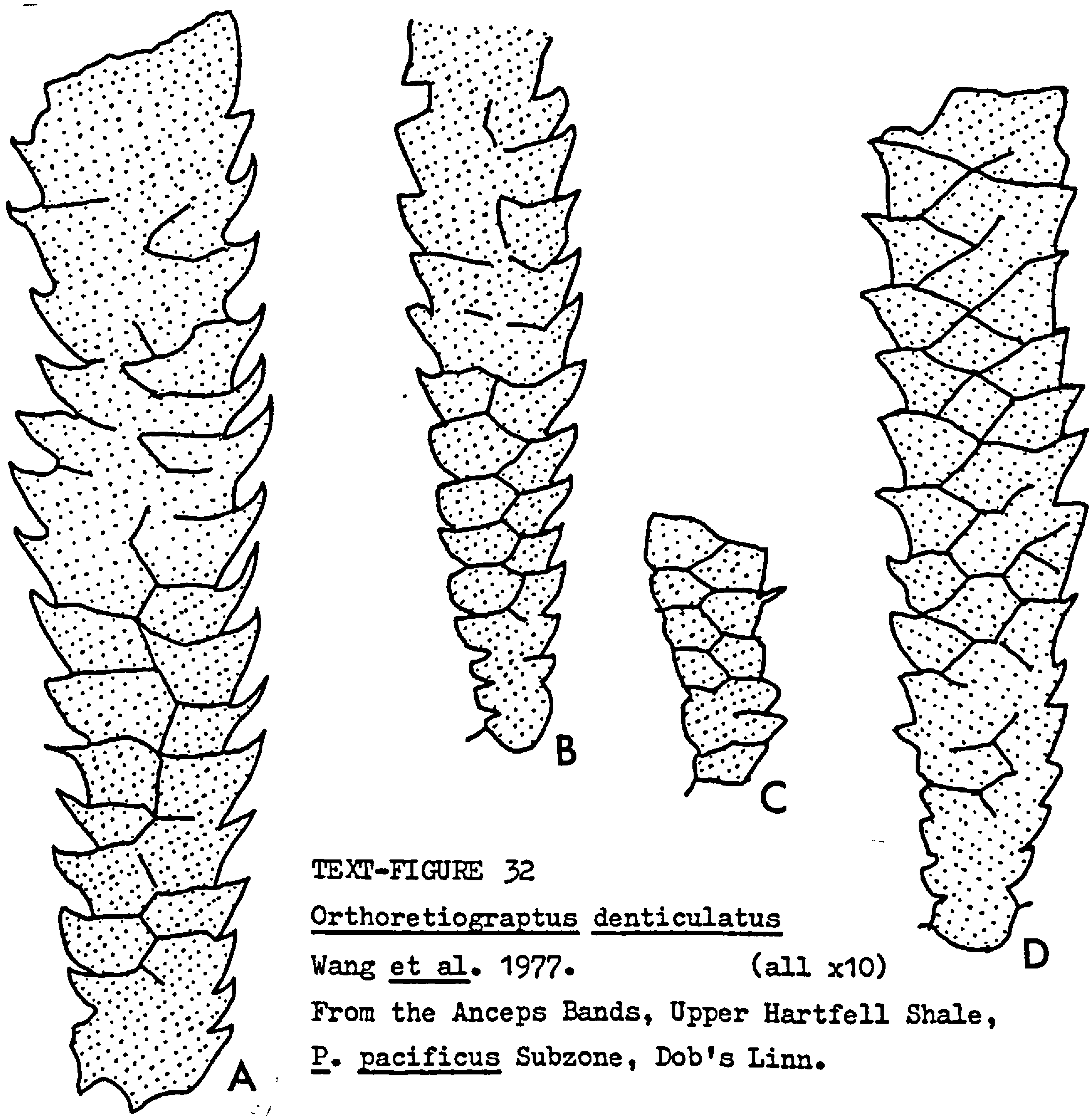
Material. About fifteen flattened fragmentary specimens collected by the writer.

Horizons and localities. Anceps Bands C to E, Upper Hartfell Shale, P. pacificus Subzone, Dob's Linn.

Diagnosis. As for genus.

Description. The largest fragment seen in the described material is 19mm long. The rhabdosome is 1.0mm wide at the aperture of $th1^1$, rapidly widening to about 2.5mm in 5mm and reaching the maximum 3.0mm within 10mm. The rhabdosome narrows distally after only several mm at the maximum width, VandenBerg's specimens from Victoria reducing to less than 2mm wide distally in long specimens (pers. comm.). Proximally the thecae number 17 in 10mm, reducing distally to about 14 in 10mm. The sicula has not been observed. The first two thecae possess rounded supragenicular walls with conspicuous sub-apertural spines. The remaining thecae have straight, inclined supragenicular walls and narrow introverted apertures which are strengthed by 'lists' and occupy 1/4 the width of the rhabdosome proximally and 1/3 distally. The rhabdosome is fairly well sclerotised except for the extreme distal portions. The 'clathria' is composed of a coarse sub-hexagonal structure of interthecal septa and apertural lists, producing a 'zig-zag' median line when preserved in dorso-ventral orientation.

Remarks. The internal structure and general form renders O. denticulatus distinct from all coeval species. The dorso-ventral profile may appear similar to Orthograptus fastigatus Davies 1929 but it has an entirely different internal structure. O. denticulatus has been described from the upper Wufeng Shale of China (Wang et al. 1977), the Zone of D. ornatus and C. latus of Victoria, Australia (VandenBerg, pers. comm.) and the D. ornatus Zone of Canada (Lenz 1977, as Retiograptus pulcherrimus).



TEXT-FIGURE 32
Orthoretiograptus denticulatus
Wang et al. 1977. (all x10)
From the Anceps Bands, Upper Hartfell Shale,
P. pacificus Subzone, Dob's Linn.

A. HM C13469a. Distal fragment, Band C, Main Cliff. B. HM C13488. Proximal fragment, Band C, Linn Branch trench. C. HM C13569. Proximal fragment, Band D, Linn Branch trench. D. HM C13479a. Proximal fragment in oblique view, Band C, Main Cliff.

12.2 Genus Plegmatograptus Elles & Wood 1908

Type species (by original designation). Plegmatograptus nebula Elles & Wood 1908, pl. 34, figs. 14a-d, text-figs. 222a-c.

Stratigraphical range. Upper Ordovician (?D. clingani to ?D. anceps)

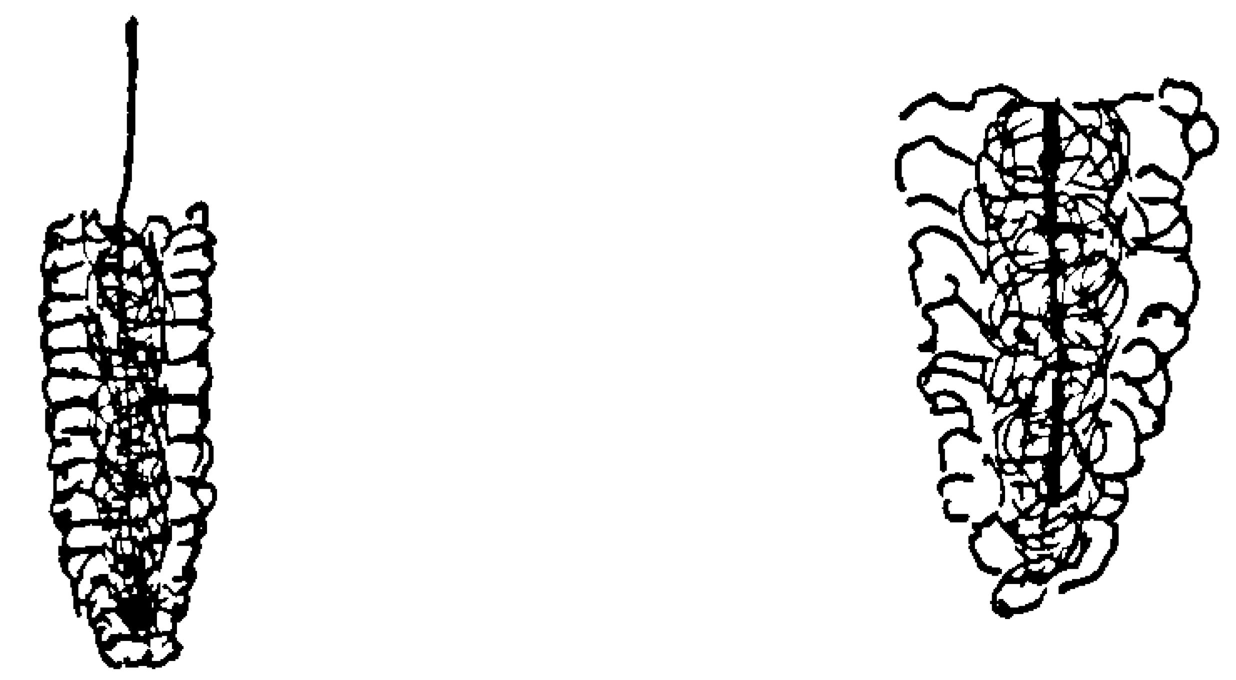
Diagnosis (from Bulman 1970, V130). Reticulum with well-developed lacinia; ?membranous periderm and sclerotised sicula. Development unknown.

Remarks. Neither P? craticulus sp. nov. nor P? lautus Koren' & Tzai 1980 agree in all respects with the type species and a clearer diagnosis would be useful. Juvenile specimens of P. nebula would be useful to compare with the development described here for P? craticulus.

Species described.
P. nebula Elles & Wood 1908 (D. clingani to P. linearis)
P? craticulus sp. nov. (D. anceps)
P? lautus Koren' & Tzai 1980 (P. pacificus)

Plegmatograptus nebula Elles & Wood 1908

(text-figs. 33a-d)



1908 Retiolites (Plegmatograptus) nebula sp. nov.; Elles & Wood, pp. 340-341, pl. 34, figs. 14a-d, text-figs. 222a-c.

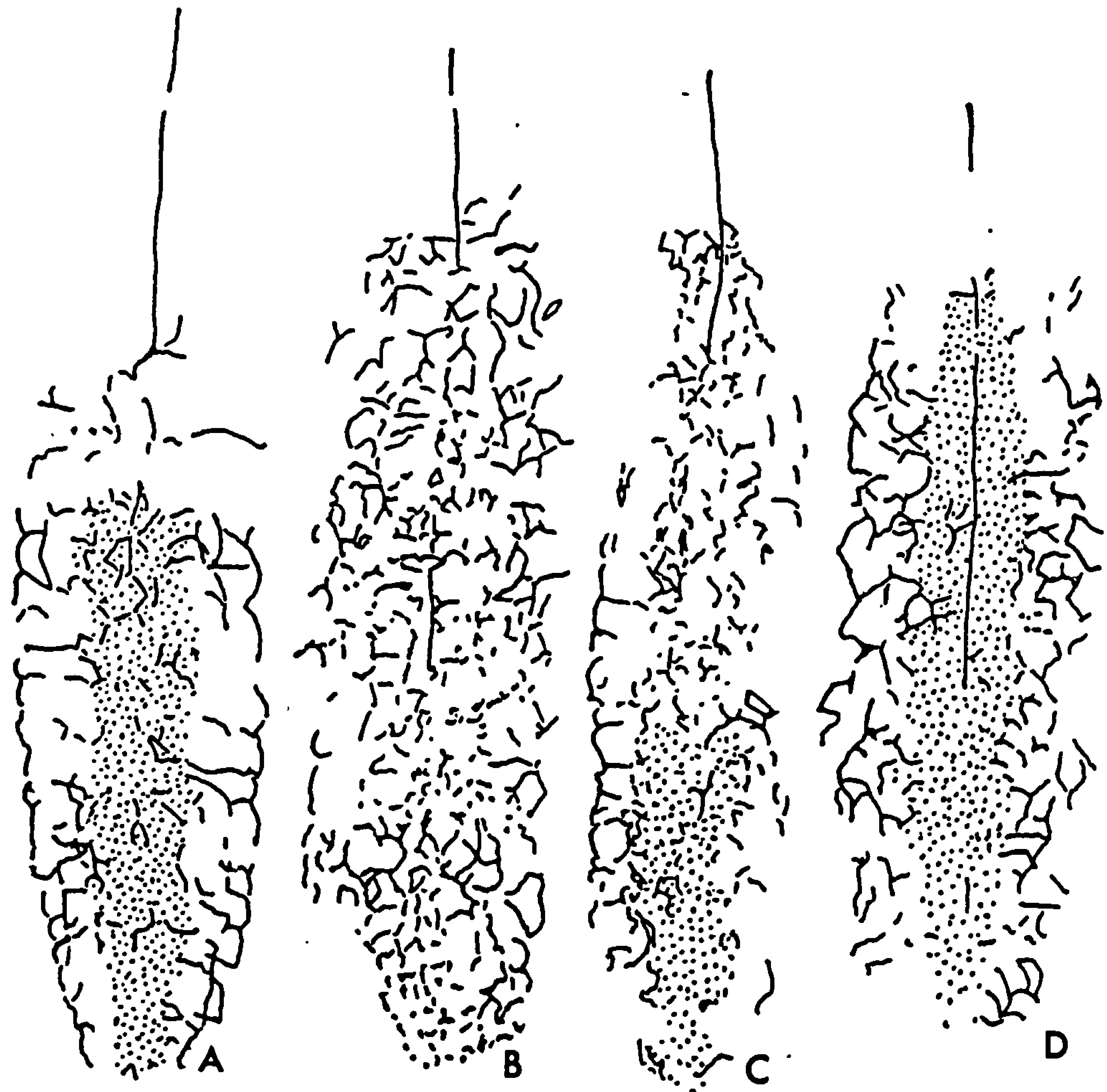
Type specimen. Not yet designated. Elles & Wood's specimens from the Lower Hartfell Shale of Morrach Bay, Portpatrick, Galloway.

Material. Numerous mostly fragmentary specimens collected by the writer.

Horizons and localities. 8.7 to 0.5m below the top of the Lower Hartfell Shale, late D. clingani and P. linearis zones, North Cliff trench, Dob's Linn.

Diagnosis. Small rhabdosome up to 15mm long and 4mm wide. Reticulum poorly defined and fibrous or poorly sclerotised. Lacinia fairly well defined and sub-rectangular. Thecae indistinct, numbering about 12 in 10mm.

Description. The rhabdosome is short but wide, up to 15mm long excluding the nema and rapidly widening from about 1mm proximally to the maximum 3-4mm within 6mm. The thecae are indistinct, numbering about 12 in 10mm. The proximal development has not been observed but the sicula is sclerotised. The reticulum is composed of a fine meshwork, commonly partially sclerotised, with a maximum width in dorso-ventral view of 1.5mm, although this may be greater when the rhabdosome is preserved in oblique or scalariform orientation. The lacinia is well defined with a dorso-ventral width of 1.2mm on each side of the rhabdosome and composed of a sub-rectangular network. When preserved in oblique or scalariform orientation the appearance of the lacinia becomes less well ordered. The virgula is prominent throughout the rhabdosome and commonly extends distally as a narrow nema for up to 10mm.



TEXT-FIGURE 33. Plegmatograptus nebula Elles & Wood 1908 (all x7.5) 1.35 to 1.1m below the top of the Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn.
A. HM C14417/1a. B. HM C14441. C. HM C14417/2a. D. HM C14435.

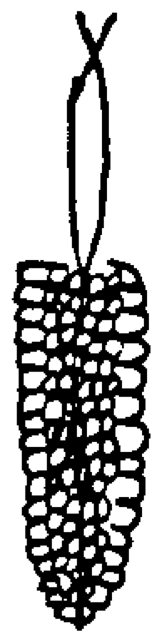
Remarks. Although Elles & Wood record the maximum width of their specimens as 2mm the fragmentary material illustrated by them appears to reach 3mm. The large variation in appearance and width caused by the reaction of a retiolitid rhabdosome to diagenetic flattening means that the specimens described here can safely be accommodated in the species P. nebula s.s.

The only Lower Hartfell species which may be confused with P. nebula is Neurograptus margaritatus (Lapworth 1876). This has a more heavily sclerotised inner portion with distinct Orthograptus-like thecae, an only poorly developed lacinia and a smaller rhabdosome than P. nebula. Koren' & Tzai (1980) describe a new species

Plegmatograptus nebula lautus from the late Ordovician (*P. pacificus* Subzone) of Russia; this appears intermediate between *Plegmatograptus* and *Neurograptus*, having *Orthograptus*-like thecae but with a well developed lacinia. Here (p. 208) it is retained questionably as *Plegmatograptus* but raised to full specific status, leaving *P. nebula* without any subspecies. *Plegmatograptus*? *craticulus* sp. nov. from the Anceps Bands of Dob's Linn (p. 206) is similar to *P. nebula* in general form but has a well ordered, unsclerotised, sub-hexagonal reticulum, a better developed lacinia and a twisting nemal vane.

P. nebula appears to have only been recorded from Britain and from the Eastonian of Australia (Thomas 1960).

Plegmatograptus? craticulus sp. nov.
(text-figs. 34a-h, 35a-f)



Derivation of name. From cratisi (Latin) - a wicker basket.

Proposed holotype. HM C13715 (text-fig. 34a). From the Anceps Bands, Upper Hartfell Shale, P. pacificus Subzone, Rae Grain, Craigmichan Scaurs.

Material. Numerous flattened, mostly weathered, specimens collected by the writer.

Horizons and localities. All five Anceps Bands, Upper Hartfell Shale, D. anceps Zone, Dob's Linn. Anceps Bands, Upper Hartfell Shale, D. anceps Zone, Rae Grain, Craigmichan Scaurs.

Diagnosis. Large rhabdosome with well defined, sub-hexagonal reticulum and box-like lacinia. Prosicula and metasicula sclerotised, long twisting nemal vane distally.

Description. The rhabdosome is over 40mm long excluding the nema, rapidly widening from 1-2mm proximally to 4mm in 5mm and reaching the maximum 5mm within 8mm. The thecae number 8-12 in 10mm. The complete sicula, but no thecae, are sclerotised. The growth stages are shown in text-figs. 35a-f. The sicula produces an apertural spine on the side opposite the virgella which grows down for a short distance before forking, one branch of which grows upwards. A second rod is given off slightly higher up the sicula and the nema grows long and soon becomes robust. It gives rise to branches at regular intervals which fork to produce a rather irregular central clathria. Additional bars are formed between the original clathria which join to form the hexagonal reticulum up to 2mm wide. Each polygonal unit has a diameter of about 0.4mm. The lacinia is well defined and apparently continuous along the ventral margins. Each thecal unit contains two sub-rectangular divisions although the relation of the structure of the lacinia to the clathria is not

TEXT-FIGURE 34

Plegmatograptus? craticulus sp. nov.

A. HM C13715. Proposed holotype showing clear reticulum and lacinia. Note beginning of nemal vane inside rhabdosome. Anceps Bands, P. pacificus Subzone, Rae Grain. (x6)

B. HM C13617. Distal fragment with nemal vane. Anceps Band E, P. pacificus Subzone, Linn Branch trench, Dob's Linn. (x5)

C. HM C13236b. Obliquely orientated, tectonically widened early fragment with clear virgula. Anceps Band A, D. complexus Subzone, Long Burn trench, Dob's Linn. (x5)

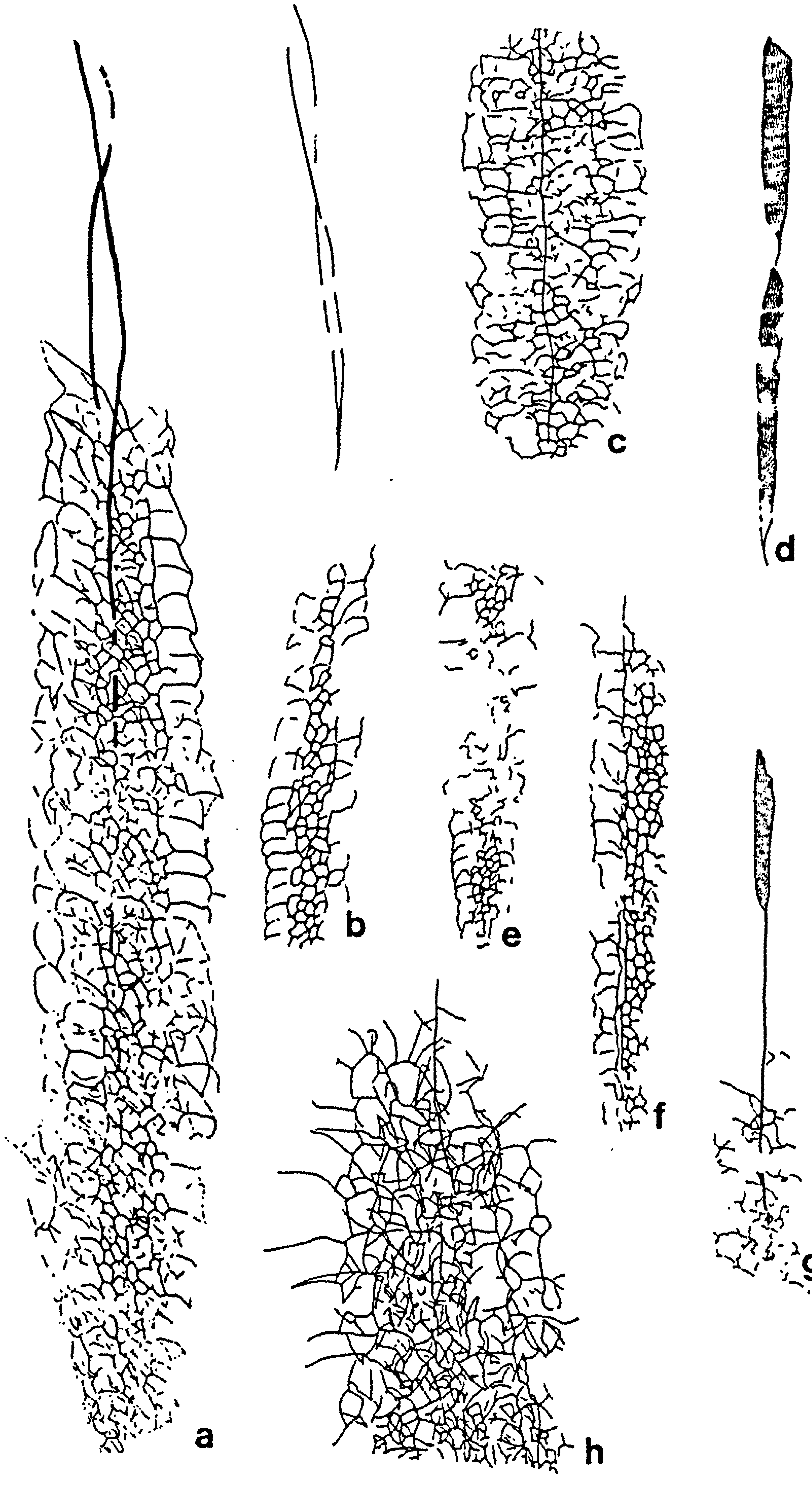
D. HM C13704. Twisting nemal vane with membrane preserved. Anceps Band E, P. pacificus Subzone, Main Cliff, Dob's Linn. (x5).

E. HM C13675. Poor early fragment preserved in metabentonite. Anceps Band E, P. pacificus Subzone, Long Burn trench, Dob's Linn. (x5)

F. HM C13674. Mature fragment. Anceps Band E, P. pacificus Subzone, Long Burn trench, Dob's Linn. (x5)

G. HM C13680. Juvenile? with poorly developed reticulum and distal nemal vane with membrane. Anceps Band E, P. pacificus Subzone, Long Burn trench, Dob's Linn. (x5)

H. HM C13717. Very wide distal fragment. Anceps Bands, P. pacificus Subzone, Rae Grain. (x6)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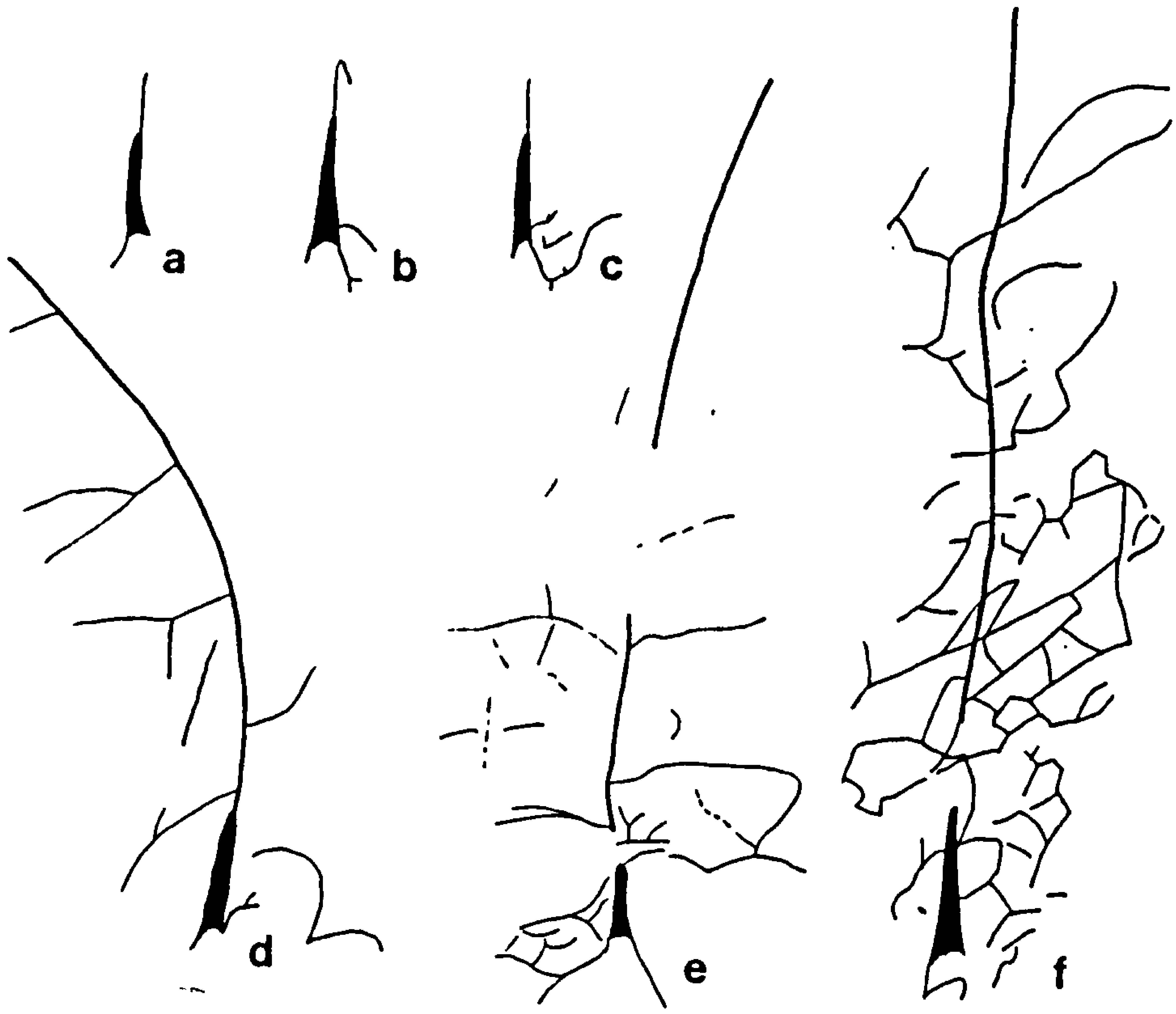


TEXT-FIGURE 35. Plegmatograptus? craticulus sp. nov. (all x15)
Early growth stages.
From the Anceps Bands, Upper Hartfell Shale, Dob's Linn.

A. HM C13114. Band A, D. complexus Subzone, Linn Branch trench.
B. HM C13116. Band A, D. complexus Subzone, Linn Branch trench.
C. HM C13117. Band A, D. complexus Subzone, Linn Branch trench.
D. Specimen lost, but included to demonstrate intermediate stage.
E. HM C13561. Band D, P. pacificus Subzone, Linn Branch trench.
F. HM C13115. Band A, D. complexus Subzone, Linn Branch trench.

clear. The virgula is clearly visible throughout the length of the rhabdosome and splits distally to form a nemal vane with two 'rods' joined by a poorly sclerotised membrane. Only the two rods are normally seen in weathered specimens. The nema may project distally for several cm.

Remarks. P? craticulus is apparently intermediate between the early genus Plegmatograptus s.s., whose reticulum is disordered and commonly partially sclerotised, and the lower Silurian Pseudoplegmatograptus which has a well ordered reticulum and lacinia but lacks a sclerotised metasicula. It is possible that the three forms represent an evolutionary lineage passing from the Archiretiolitinae to the Retiolitinae. A twisting nemal vane is more typical of Silurian biserial graptolites, Plegmatograptus nebula Elles & Wood 1908, the type species of this genus, having only a simple nema.

Several rather indistinct retiolitids have been described from the late Ordovician but none with any growth stages. Přibyl (1949, p. 37) described a new species Plegmatograptus? chuchlensis from the D. anceps Zone of Central Bohemia, which seems fairly similar to P? craticulus but appears to lack a lacinia and has a rather coarser reticulum. Ross & Berry (1963, p. 159) described a new monospecific genus Arachniograptus from the D. complanatus Zone of the Basin Ranges, but recorded it to lack a lacinia and possess a rather disordered reticulum. The holotype of the type species A. laqueus does however possess a nemal vane similar to P? craticulus. Koren' et al. (1980, p. 166, text-fig. 55) describe 'Arachniograptus sp.' from the late Ordovician of Kazakhstan which has a disordered reticulum and lacks a lacinia. VandenBerg (pers. comm.) has found retiolitids similar to P? craticulus in the Upper Bolindian of Victoria but it is not clear whether they belong to this species.

Plegmatograptus? lautus Koren' & Tzai 1980
(text-figs. 36a-c)

1980 Plegmatograptus nebula lautus Koren' et Tzai subsp. nov.; Koren' et al., pp. 167-169, pl. 53, fig. 3, pl. 54, figs. 1a-c, text-figs. 56a, b.

Holotype. The only specimen figured by Koren' et al. 1980. No. 11568/193 and counterpart.

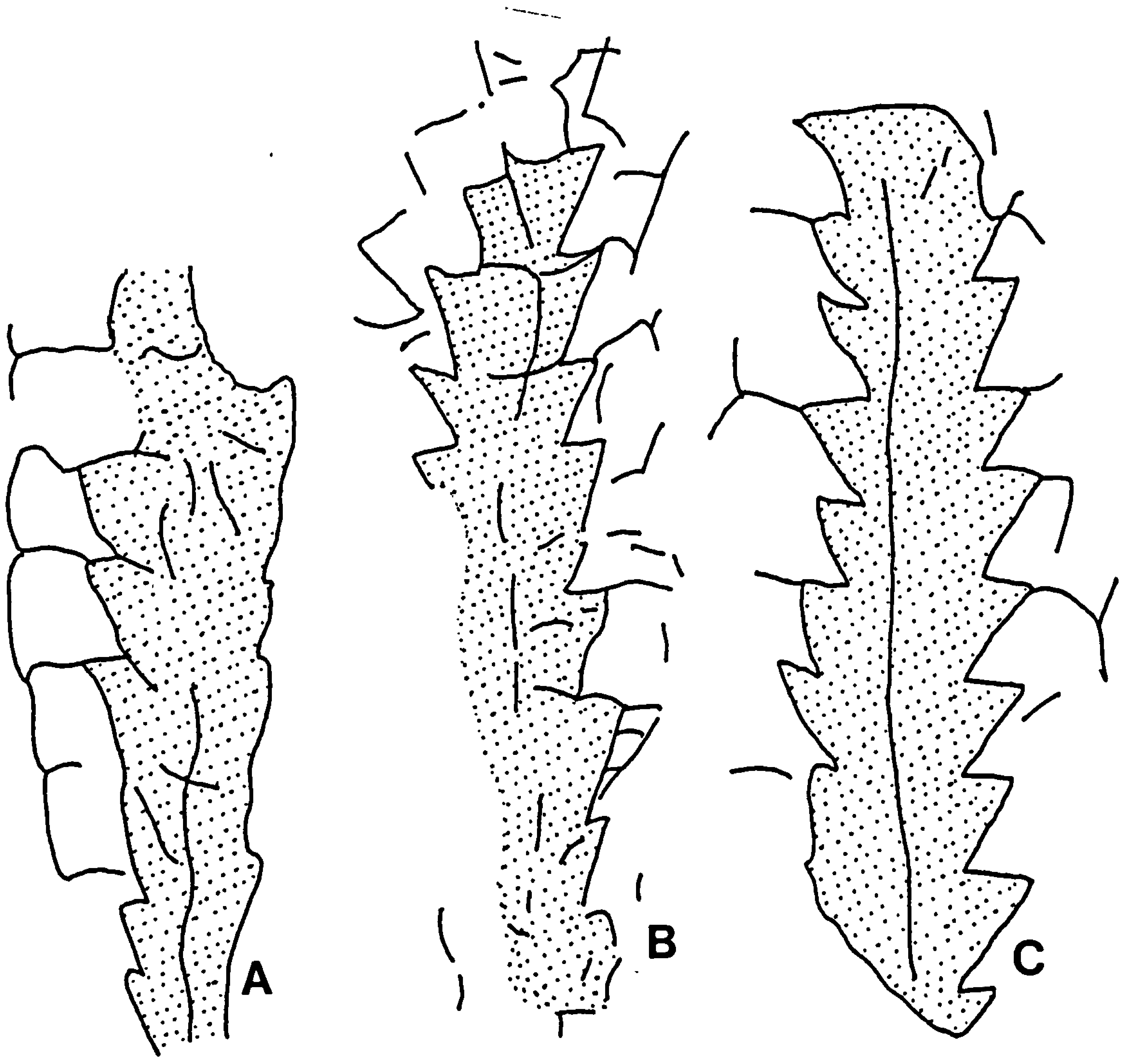
Material. Original photographs of the holotype and eleven poorly preserved flattened fragments collected by the writer.

Horizons and localities. Anceps Bands C and D, Upper Hartfell Shale, P. pacificus Subzone, Dob's Linn.

Diagnosis. Rhabdosome with central poorly sclerotised, Orthograptus-like thecae and disorganised lacinia, measuring over 20mm long and reaching a maximum width of 5mm.

Description. The rhabdosome is greater than 20mm long with a poorly sclerotised central portion and well developed but disorganised lacinia. The sclerotised part has pronounced Orthograptus-like mucronate thecae, numbering 12-14 in 10mm, which pass ventrally into the lacinia. In mature specimens the sclerotised portion is about 1mm wide proximally, gradually widening to a maximum 3mm before narrowing distally to about 2mm. Proximally the lacinia does not extend far beyond the sclerotised portion although distally it makes up most of the maximum 5mm width. Details of proximal development and thecal style are unknown.

Remarks. This is a rare and poorly known species, only one specimen (the holotype) having been found in Russia from the P. pacificus Subzone in Kazakhstan. Koren' (pers. comm.) originally considered the species to belong to Neurograptus because of the Orthograptus-like thecae and similar structure of lacinia. Riva suggested to her an affinity with Plegmatograptus nebula Elles & Wood 1908 because of the poorly sclerotised central periderm with a disorganised reticulum. P? lautus differs from P. nebula in possessing wider spaced, more distinctly Orthograptus thecae and in having a later occurrence, hence the reason for here raising it to full specific status.



TEXT-FIGURE 36. Plegmatograptus? lautus Koren' & Tzai 1980. (all x10) From the Anceps Bands, Upper Hartfell Shale, P. pacificus Subzone, Dob's Linn.

A. HM C13713. Fairly early part of rhabdosome, Band C, Long Burn trench. B. HM C13427. Distal fragment with lacinia, Band C, Long Burn trench. C. HM C13468. Distal fragment. Band C, Main Cliff.

Chapter 13. Family MONOGRAPTIDAE Lapworth 1873.

Diagnosis (from Bulman 1970, V132). Scandent uniserial rhabdosome without cladia.

Genus *Atavograptus* Rickards 1974

Type species (by original designation). *Monograptus atavus* Jones 1909, p. 531, text-figs. 18a-d.

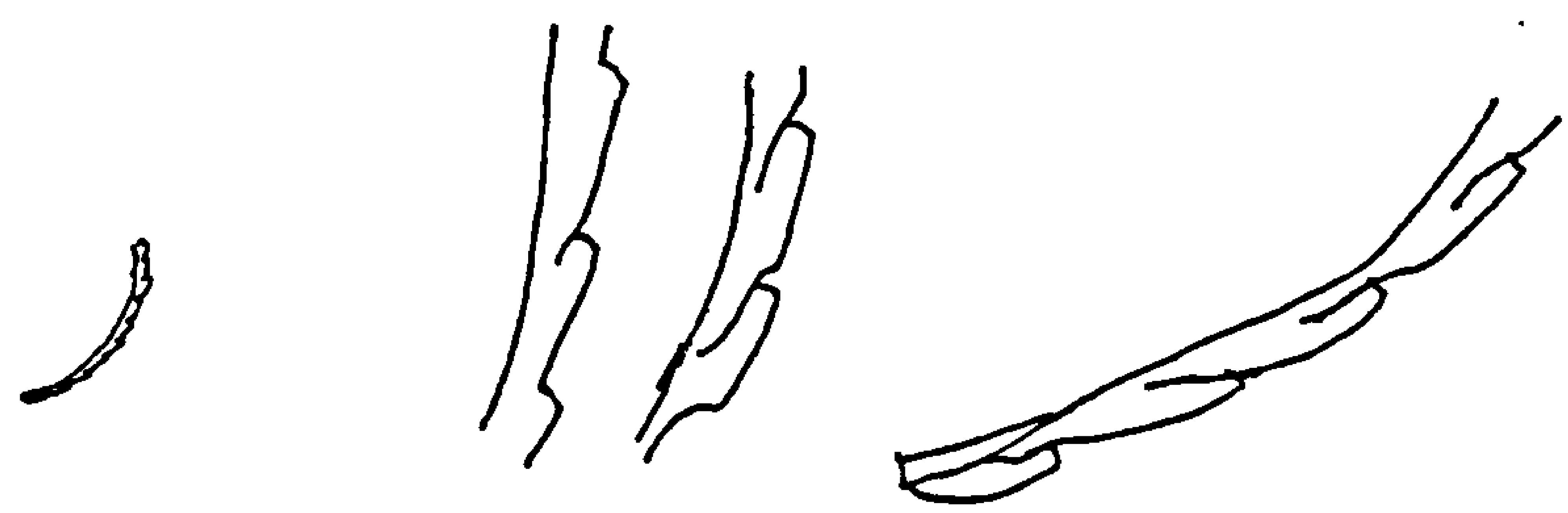
Stratigraphical range. Lower Silurian(?) (*O? acuminatus* to *C. cyphus*)

Diagnosis (from Rickards 1974, p. 141). Long, slender, usually dorsally curved rhabdosome. Long sicula reaching to about the aperture of th1. Thecae generally elongatedly glyptograptid, but in some cases strictly glyptograptid or almost monoclimacid.

Remarks. The specimens described here agree well with this diagnosis.

Species described.
A. ceryx (Rickards & Hutt 1970) (*O? acuminatus*)

Atavograptus ceryx (Rickards & Hutt 1970)
(pl. 59, figs. 1-11)



1970 Monograptus ceryx sp. nov.; Rickards & Hutt, pp. 117-118, text-figs. 1a-d, 2a.
1974 Atavograptus ceryx (Rickards & Hutt); Rickards, pl. 9, fig. 4.
1975 Atavograptus ceryx (Rickards & Hutt); Hutt, p. 63, pl. 11, fig. 7.

Holotype. SM A67087. The specimen illustrated by Rickards & Hutt 1970, text-fig. 2a. From the basal Llandovery Skelgill Beds, G. persculptus Zone, Yewdale Beck, Coniston, Lake District.

Material. Many specimens preserved both flattened and in relief, collected by the writer. Most occur as crowded fragments on two bedding planes.

Horizons and localities. 1.9 to 2.3m above the base of the Birkhill Shale, O? acuminatus Zone, Linn Branch trench, Dob's Linn.

Diagnosis. (from Rickards & Hutt 1970) Rhabdosome short with pronounced dorsal curvature, dorso-ventral width (relief) 0.2mm proximally to 0.3mm distally. Sicula 1.3-1.4mm long, apex reaching just above the level of the aperture of $th1^1$. Thecae with gentle sigmoidal curvature, horizontal to very slightly everted apertures, and numbering 13-15 in 10mm.

Description. Most specimens are less than 5mm long and possess a slight convex curvature (sensu Williams 1981). They increase slightly in width from an average of 0.2mm at the aperture of $th1^1$ to a maximum of 0.3mm when tectonically undeformed. A thecal count is impractical because of the short stipes but the distance between successive apertures varies from 0.06 to 0.1mm, depending on tectonic stretching and position along the stipe. This gives a thecal count of 10-16 in 10mm, while Rickards & Hutt (1970) recorded it to be 13-15 in 10mm.

The sicula is approximately 1.5mm long. Th1[1] appears to develop from near the base of the sicula and grow upwards parallel to it for its entire length. The thecae are variable in style depending on the orientation of the rhabdosome; three-dimensional specimens preserved in full dorso-ventral orientation reveal them to be approximately *Glyptograptus* in style with gently curved supragenicular walls. The apertures are horizontal or slightly everted and open into long triangular excavations which occupy 1/2 the total stipe width. Slight genicula are seen when the stipes are preserved in dorso-ventral view but the supragenicular walls appear straight and uniformly sloping when specimens are obliquely orientated. The interthecal septa are short and straight, extending for only half the length of the supragenicular walls.

Remarks. The specimens from Dob's Linn are extremely similar to the type material of *A. ceryx* from the Lake District and can be safely accommodated in this species (Rickards, pers. comm.). The thecal style appears similar to the distal thecae of *Akidograptus ascensus* Davies 1929 (see pl. 57, fig. 1); Rickards & Hutt (1970) believed that *A. ceryx* could have been derived from a *Glyptograptus* ancestor. *A. ascensus* has a broadly similar thecal style to the specimen figured as '*G. persculptus* mut.' by Davies (1929, text-fig. 14) and by Rickards & Hutt (1970, text-fig. 2c). It therefore seems possible that both *Akidograptus ascensus* and *Atavograptus ceryx* were derived separately from closely related *Glyptograptus* ancestors. *A. ceryx* has a similar proximal development and thecal style to *Atavograptus atavus* (Jones 1909) but has a higher thecal count (Hutt 1975, p. 63).

A. ceryx was first recorded by Rickards & Hutt (1970) from the *G. persculptus* Zone in the Lake District but was later found by Hutt (1975) to also occur in the basal 0.6m of the *O? acuminatus* Zone in the Skelgill Beds associated with *Akidograptus ascensus*; Hutt (1974) defined the base of the *O? acuminatus* Zone in the Lake District on the same criteria used in this work at Dob's Linn (ie. principally on the first occurrence of *A. ascensus*) and it is considered that the occurrence of *A. ceryx* in the early *O? acuminatus* Zone in both parts of Britain is approximately contemporaneous. *A. ceryx* has not yet been recorded from outside Britain but other similar monograptids are known to occur in both the *G. persculptus* and *O? acuminatus* zones elsewhere (Rickards, pers. comm.).

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Abbreviations are in accordance with B.S.4148.

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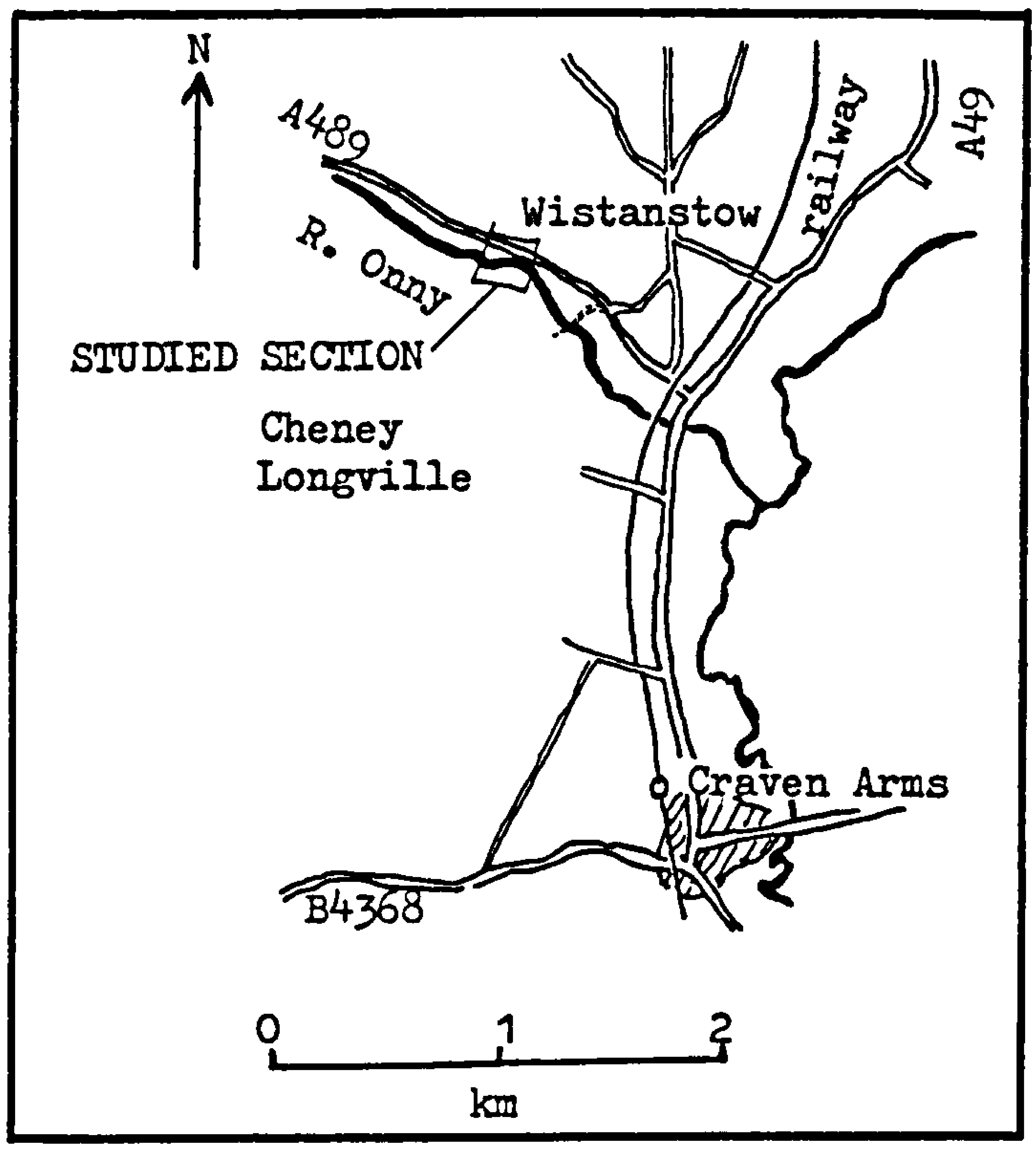
APPENDIX 1

Two localities outside Scotland with mixed late Ordovician shelly and graptolitic faunas.

The Onny River (O.S. SO 425 855). Situated two miles north of Craven Arms in the Welsh Borderlands (see thesis text-fig. 9 and sketch-map below).



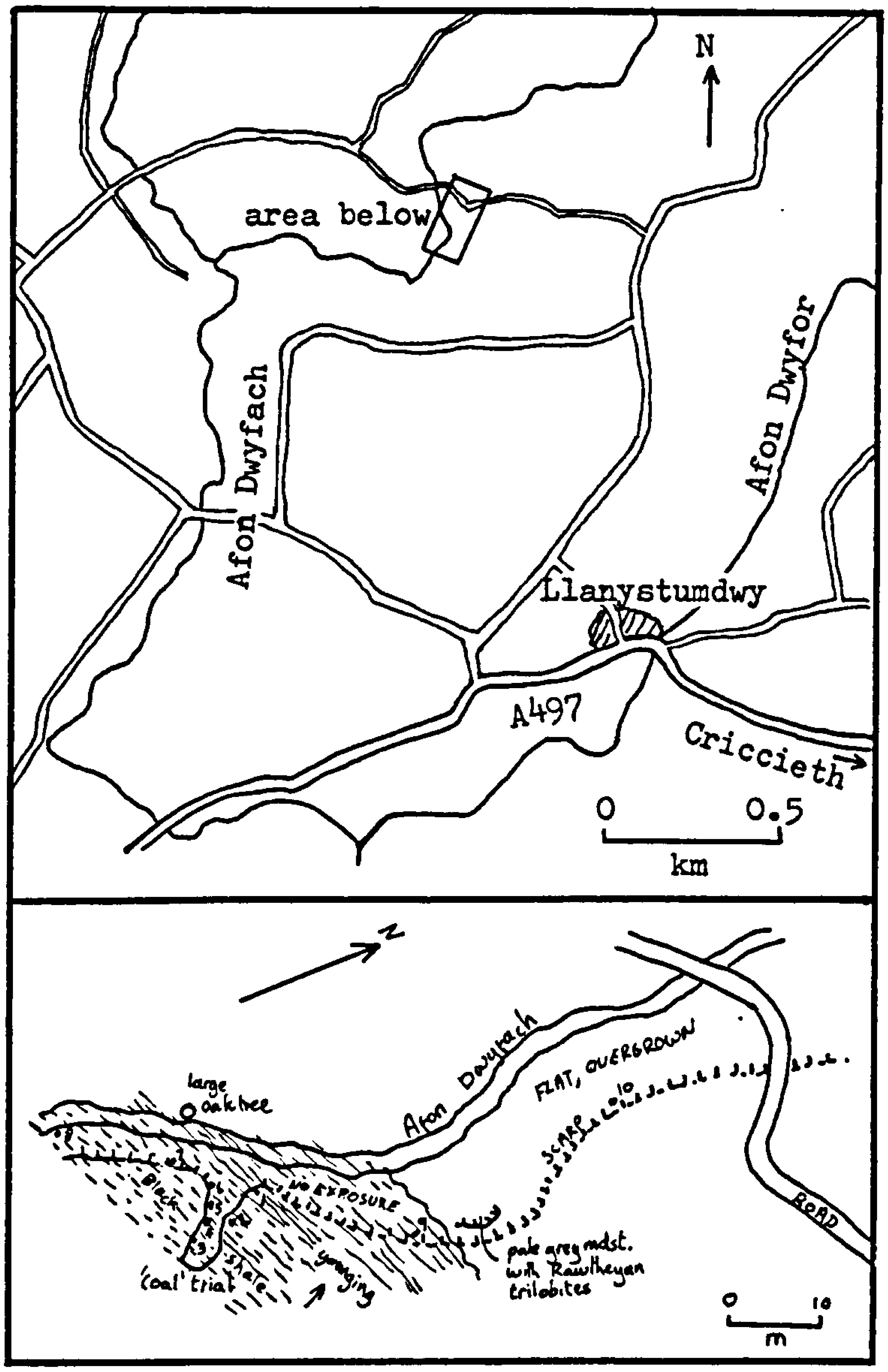
The type section of the Onnian Stage along the Onny River near Wistanstow, Shropshire has long been famous for its rich late Caradoc trilobite fauna which has been studied by, among others, Wade (1911) Bancroft (1933) and Dean (1958). Recently it has been reinvestigated thoroughly by Drs. J.K. Ingham and A.W. Owen (pers. comm.) and their results, including detailed evolutionary studies on the typical late Caradoc trinucleid trilobites *Onnia gracilis* (Bancroft) and *Onnia superba* (Bancroft), are currently being prepared for publication.

Wade (1911) recorded the beds of the Onny River section to contain abundant '*Orthograptus truncatus socialis* (Lapworth 1880)' and assigned them to the Ashgill. Bancroft (1933) equated the Actonian Stage with the *P. linearis* Zone without comment while in 1945 he stated that at Girvan "the Actonian and Onnian are represented in the series of grey flags and fossiliferous limestones underlying the Zone of Dicellograptus complanatus (Pusgillian)". Dean (1958) recorded that contrary to Wade (1911) 'O. truncatus socialis' was not abundant; he obtained a few graptolites from the Actonian Stage of the River Onny which Strachan identified as 'Orthograptus ex gr. truncatus' and 'Diplograptus (s.s.) sp.' and considered to belong to no later than D. clingani Zone. Dean (op. cit.) stated that "there is no acceptable evidence for the existence of the Pleurograptus linearis or Dicellograptus complanatus zones in the Ordovician of south Shropshire". As Ingham & Wright (1970) pointed out the evidence from the Actonian Stage cited by Dean to indicate the D. clingani Zone was tenuous and should not be regarded as reliable. Cave (1965) recorded that graptolites in the Onnian Nod Glas of Mid-Wales indicated an age no higher than D. clingani Zone although lists given earlier by Pugh (1923) and King (1923) indicated a mixed D. clingani/P. linearis zonal assemblage (see Llanystumdwy description).

The importance of obtaining a zonally diagnostic graptolite fauna which can be compared with the Moffat and Girvan successions is therefore obvious; bulk samples have been collected which largely remain unbroken, and have been briefly studied in conjunction with graptolites collected by J.K. Ingham. Provisional results indicate that a rich, moderately well preserved graptolite fauna is present in the Onny Shale of the River Onny including:

Dicellograptus spp.
Climacograptus mohawkensis (Ruedemann 1912)?
Climacograptus spp.
Orthograptus q. quadrimucronatus (Hall 1865)?
Orthograptus ex gr. calcaratus
Diplograptus compactus Elles & Wood 1907?

Scolecodonts (which are currently of little stratigraphical use) are also relatively common in addition to the previously recorded shelly fauna of trilobites and brachiopods. This graptolite assemblage is zonally inconclusive, although if D. compactus s.s. is present it would, according to Elles & Wood, indicate the D. clingani Zone. The writer considers that the remaining collection awaiting study is likely to reveal the true graptolite zonal identity of the Onny Shale when combined with the revised description of the succession at Dob's Linn described in Chapter 2 of this thesis.



Llanystumdwy (O.S. SH 466 395). Situated two miles west of Criccieth in the Lleyn Peninsular, North Wales.

The graptolitic black shales along the Afon Dwyfach north of Llanystumdwy (see sketch maps above) were known to Ramsay (1881) and Fearnsides (1910, 1912) while Elles & Wood (1906) figured specimens of their new subspecies Climacograptus antiquus lineatus from this locality. Harper (1956) gave a detailed account of the succession; he recorded the Snowdon Volcanic Group to be overlain by about 1000ft of intermittently fossiliferous mudstones, shales and tuffs which yielded lower to upper Longvillian shelly faunas. He stated that these were followed by not more than 50ft of graptolitic black shales with a fauna which probably indicated a transition from top D. clingani to P. linearis zones. These were followed by paler grey shelly mustones containing an abundant Ashgill shelly fauna. He recognised that the lowest Ashgill '_Diacalymene marginata_ beds' were absent and recorded the '_P. parabola_ beds' to rest directly on the '_P. linearis_ Zone'. Some 50ft higher in the succession poorly preserved graptolites were found which Bulman tentatively referred to '_Orthograptus truncatus pauperatus_ Elles & Wood 1907' or '_O. truncatus socialis_ (Lapworth 1880); if the latter species was present it would indicate the _D. complanatus_ Zone. Roberts (1967) summarised Harper's findings but gave no additional information on the fossiliferous succession at Llanystumdwy. It is still apparently unclear (Williams _et al_. 1972, p. 21) whether the unnamed black shale at Llanystumdwy should be referred to the Mid-Wales Nod Glas as suggested by Cave (1965) which Pugh (1923) and King (1923) recorded to contain a mixed _D. clingani/ P. linearis_ zone fauna including:

Dicranograptus clingani (Carruthers 1868)
Dicellograptus forchhammeri (Geinitz 1852)
D. morrisi Hopkinson 1871
Climacograptus tubuliferus Lapworth 1876
C. styloideus Elles & Wood 1906
C. miserablis Elles & Wood 1906
C. minimus (= _mohawkensis_ (Ruedemann 1912))
Orthograptus quadrimucronatus (Hall 1865)
'_O. truncatus_' _socialis_ (Lapworth 1880)
'_O. truncatus_' _pauperatus_ Elles & Wood 1907
Plegmatograptus nebula Elles & Wood 1908

Brief recollecting of the black shale at Llanystumdwy by the writer revealed a rich, but not particularly diverse, fauna including:

Dicellograptus morrisi Hopkinson 1871
Climacograptus mohawkensis (Ruedemann 1912)
C. miserablis Elles & Wood 1906
C. antiquus lineatus Elles & Wood 1906
Orthograptus ex gr. _calcaratus_
O. q. quadrimucronatus (Hall 1865)
Glyptograptus daviesi sp. nov.

(see next page for occurrence charts)

Amorphognathiform conodont elements are also relatively common but have not as yet been identified. This faunal assemblage is similar to that recorded by Harper (1956) but lacks _O? pauperatus_, _C. styloideus_ and _D. forchhammeri_ while he did not record _C. antiquus lineatus._

It is possible that C. styloideus, recorded by Elles & Wood to be restricted to the P. linearis Zone, and C. antiquus lineatus, which they stated to range from 'late Glenkiln to Lower Hartfell Shale' could be confused when tectonically distorted but the specimens found by the writer correspond closely to those figured by Elles & Wood (1906) from Llanystumdwy in their original description of C. a. lineatus. The fauna appears, as stated by Harper (1956), to represent a transition from top D. clingani to low P. linearis zone.

Dr. D. Price has recently restudied the trilobite faunas of the overlying Ashgill mudstones (pers. comm.) and records them to belong to the Rawtheyan Stage (Ashgill Shelly Zone 6 or 7). There is therefore a major unconformity in the succession, making it of little use for cross-correlation of shelly and graptolitic zonal schemes. This also makes the record of O? socialis? from above the Ashgill shelly mudstones suspect; the writer found one small diplograptid fragment from an horizon which must be close to Harper's locality (loc. 10 of sketch map) but it is insufficiently well preserved even for generic identification. Comparison with the successions of Girvan and northern England show that this graptolitic horizon must be late D. anceps Zone at the earliest and may belong to the P. pacificus Subzone or C? extraordinarius Zone. Mr. R. Hughes of Cambridge University who is studying the late Ordovician of North Wales is hoping to obtain a more conclusive fauna from this potentially important horizon.

Species occurrence chart (locality numbers refer to those shown on detailed sketch map).

loc.	C. a. lineatus	G. davisi	C. mohawkensis	O. q. quadrimucronatus	O. ex gr. calcaratus	C. miserablis	D. morrisi	diplograptid indet.
10								X
MAJOR UNCONFORMITY								
9			X				X	
NO EXPOSURE			•					
1		X	•			X		
7		X	•		X			
6		X	•		X			
5=2	X	X	•	X				
4	X	•	•					
3	•	•	X					
8	X	X						

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AN EXCURSION GUIDE TO DOB'S* LINN

S. Henry Williams

It is over a century since Lapworth published his classic work on the Moffat Shale in 1878. Since then, although Dob's Linn has been visited by countless geologists, very little thorough research has been done and many problems still require elucidation. The succession consists predominantly of upper Ordovician and lower Silurian black, graptolitic shales overlain by upper Llandovery greywackes.

The black shales were probably deposited in relatively deep water far from land. It is thought that they were formed in the Iapetus Ocean which separated England from Scotland before closing late in the Silurian. The complex structure of the area, composed of many thrust slices, is considered to represent the remnant of an accretionary prism formed over a northerly dipping subduction zone (McKerrow *et al.* 1977).

The following description results from a study of the upper Ordovician graptolite fauna of Dob's Linn by the author over the past two years, supervised by Drs J. K. Ingham of Glasgow and R. B. Rickards of Cambridge. The itinerary largely follows that of a Glasgow Geological Society excursion led by Dr E. N. K. Clarkson and the author (see separate report). The map and range chart include work by Drs J. K. Ingham and J. D. Lawson. Information from all these researchers is gratefully acknowledged. For additional descriptions and a more detailed plan of the Linn Branch see Lawson & Lawson, 1976 (Chapter 7, pp. 127-136).

To get to Dob's Linn travel to Moffat via the A74 then take the A708 Selkirk road from the town centre. Proceed ¼ mile beyond the Grey Mare's Tail car park (10 miles from Moffat) to a double lay-by on the left hand side of the road, from where the gorge in black shale and greywacke is clearly visible. If time allows it is worth making a 'pilgrimage' to Birkhill Cottage, another ¼ mile beyond at the highest point of the road. This is where Lapworth stayed during his fieldwork and a plaque commemorating his work has been erected on the cottage wall.

From the lay-by follow the poorly-defined sheep track into the bottom of the valley then northwards for about 150 yards. The first black shale scree slope traversed is derived from faulted Birkhill Shale. Proceed to a small but prominent bluff which the track crosses after splitting; just to the left of this, under a thin cover of scree, is the only fair-sized exposure of Glenkiln Shale at Dob's Linn (Loc. 1).

*"This is the orthographic version as used on O.S. maps: Lapworth's original spelling is incorrect."

FIG 1

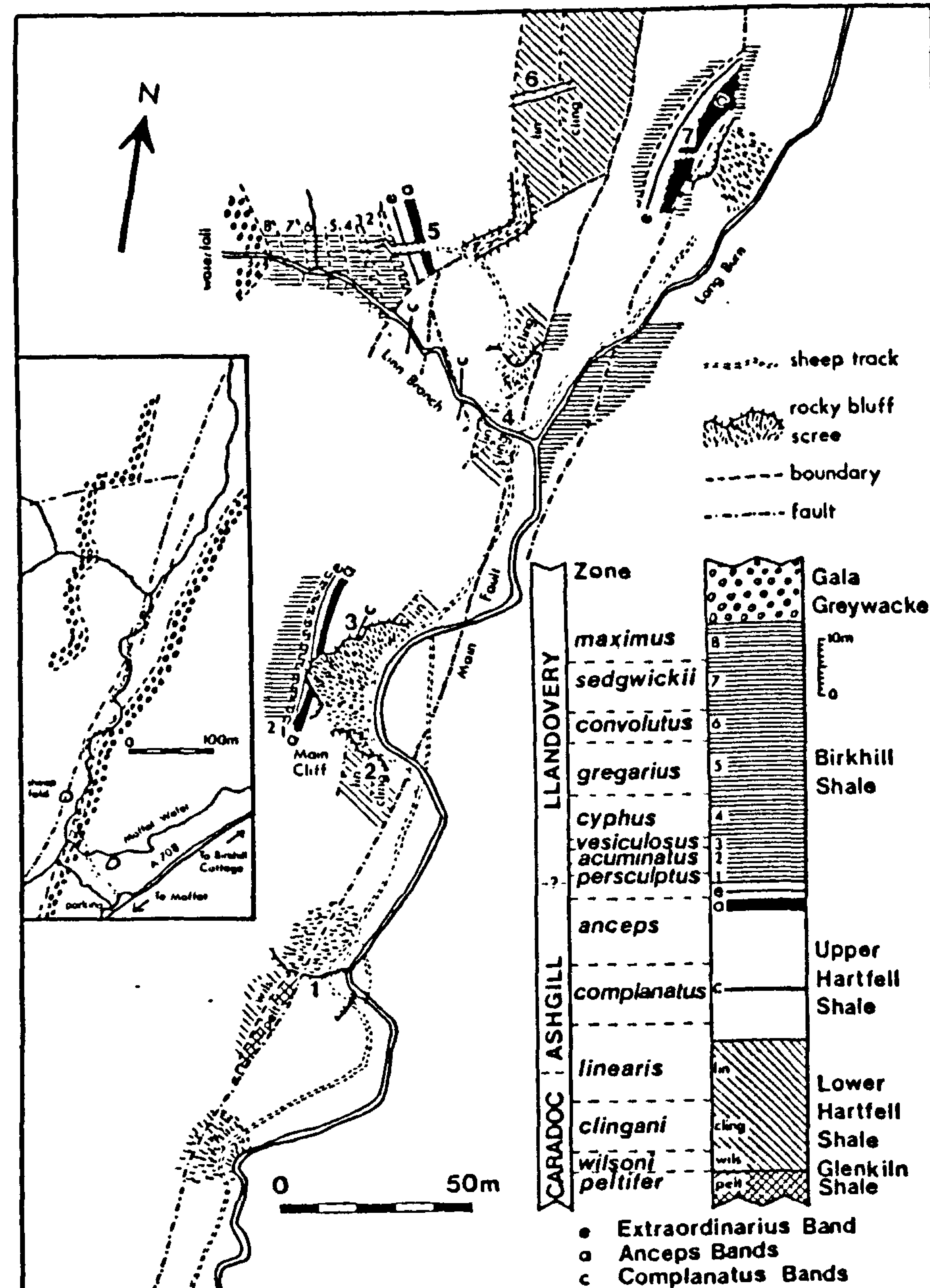

Fig. 1 Locality map and geological succession of Dob's Linn.

It is not however recommended to stop here before seeing the other localities as the graptolites are difficult to find and poorly preserved in the rather cherty shale. It may be worth collecting from this locality after seeing the other outcrops, when specimens of early *Dicellograptus, Dicranograptus, Climacograptus* and *Orthograptus* species may be found.

The first recommended stop is at the Main Cliff (Locs. 2 and.3). Before studying the shales in detail follow the track on to the right hand bank of the stream and look across to the exposure, largely hidden by scree on the lower slopes. Observe how the black Lower Hartfell Shale at the base and the Birkhill Shale at the top are separated by the pale grey Upper Hartfell Shale. At this locality the strata are dipping at about 45° and are the correct way up while at all other parts of Dob's Linn the strata are dipping at a high angle and are overturned (e.g. Linn Branch). The explanation is that the whole of the Main Cliff slumped and rotated during the Pleistocene: it is not a tectonic feature as assumed by early workers. The succession is heavily faulted so detailed sections may only be constructed with extreme care. Now proceed to the lowest bluff just above the stream (Loc. 2). This belongs to the *Dicranograptus clingani* Zone of the Lower Hartfell Shale and contains a fauna including *Dicellograptus (D. moffatensis, D. forchhammeri, D. caduceus), Dicranograptus (D. clingani, D. nicholsoni, D. ramosus), Climacograptus (C. tubuliferous, C. minimus, C. bicornis)* and *Orthograptus (O. intermedius, O. calcaratus).*

Just above this is a second, slightly hollowed out exposure. This is the upper part of the *Pleurograptus linearis* Zone and contains *P. linearis, Leptograptus (L. flaccidus macer, L. capillaris), Dicellograptus (D. morrisi, D. pumilis, D. elegans, D. carruthersi), Climacograptus (C. tubuliferus, C. caudatus, C. styloideus), Orthograptus (O. amplexicaulis, O. quadrimucronatus, O. calcaratus basilicus)* and *Plegmatograptus nebula* but no *Dicranograptus.*

Climb the scree to the exposure of black shale bands and cream bentonites in the top of the Upper Hartfell Shale. These are the five Anceps Bands and contain abundant *Dicellograptus (D. anceps, D. complexus, D. minor), Climacograptus (C. supernus, C. miserablis, C. latus), Orthograptus (O. abbreviatus, O. fastigatus)* and a descendant of *Plegmatograptus.* In the top three bands rare specimens of *Paraorthograptus pacificus* are found while the top band occasionally yields *Dicellograptus ornatus* with extremely long spines, which together with the occurrence of *Dicellograptus complexus* allows accurate correlation of the late Ordovician succession with that of Russia, North America, China and Australia. The presence of bentonites indicates vulcanism possibly related to the northerly dipping subduction zone. The top bands are repeated by strike-faulting before the Birkhill Shale is entered. Only the *Glyptograptus persculptus* and *Orthograptus? acuminatus* Zones are easily accessible on the Main Cliff.

The 1.6m of *G. persculptus* Zone contain *G. persculptus* and *Climacograptus (C. normalis, C. angustus, C. medius)* but no *Dicellograptus* which last occur in the top Anceps Band, and only rare *Orthograptus*

FIG 2

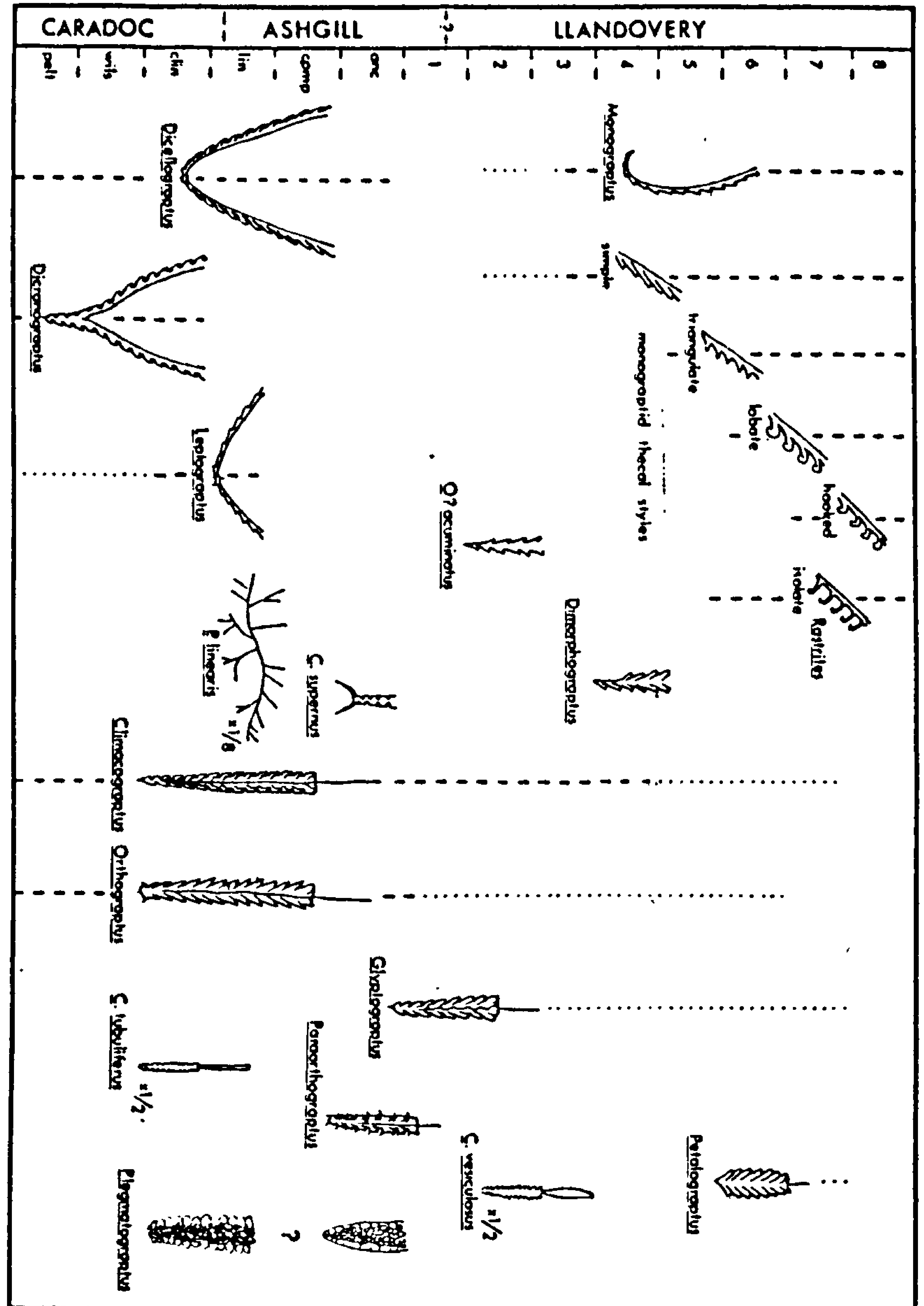

Fig. 2. Ranges of some characteristic graptolite genera and species at Dob's Linn: dotted line indicates rare occurrence (all drawings approx. x2 unless otherwise stated).

abbreviatus. The overlying *O.? acuminatus* Zone contains similar *Glyptograptus* and *Climacograptus* but also contains *O.? acuminatus*, *Akidograptus ascensus* and early, very small monograptids (*Atavograptus ceryx*).

In the past the Ordovician/Silurian boundary was always placed at the bottom of the Birkhill Shales; however it is now considered that a more appropriate and usable horizon would be at the base of the *O.? acuminatus* Zone and this is presently the subject of international debate.

Cross the scree of the Main Cliff without descending to the bottom. If a little time is spent it should be possible to find the black lower Complanatus Band bounded by pale shale (Loc. 3); This contains *Dicellograptus complanatus*, *Orthograptus socialis* and *Climacograptus miserablis* but is more easily seen in the Linn Branch (Loc. 4).

Proceed to Loc. 4 where the main stream divides and turn into the left hand tributary, the Linn Branch. The first exposures of black shale in the hollow on the left bank belong to the *D. clingani* and *P. linearis* Zones and contain the same faunas seen at Loc. 2. Just upstream from this the two Complanatus Bands may be seen at the back of an excavation in the stream bank. These should not be collected from owing to their very limited outcrop. Rare specimens of an inarticulate brachiopod occur in and just above the upper Complanatus Band.

Climb up the track to the trench clearly visible from the junction of the Linn Branch and Long Burn (Loc. 5). This is the least tectonically affected exposure of the Anceps Bands and contains the fauna described for the bands of Loc. 2. Midway between the top Anceps Band and the base of the Birkhill Shale (remember that the beds are inverted and young upstream) is a narrow dark brown band. Rare graptolites have been found on one lamina indicating the presence of the *Climacograptus? extraordinarius* Zone known from Russia. Just below this, in a conchoidally-fracturing calcareous mudstone, rare fragments of a blind dalmanitid trilobite constituting a new genus have been found. The lack of eyes presumably indicates a mode of life in deep water below the photic zone. If the succession is followed along the trench the basal Birkhill Shale containing the *G. persculptus* and *O.? acuminatus* Zones is encountered with faunas as described for Loc. 2.

It is now best to descend to the stream to observe the remaining graptolite zones; full faunal listings for the lower Silurian graptolite zones are given by Toghill (1968) and are summarised here. Common monograptids first appear at the base of the *Cystograptus vesiculosus* Zone and are associated with abundant *Dimorphograptus*, *Climacograptus*, *Glyptograptus* and the zone fossil. In the Zone of *Monograptus cyphus* monograptics become far more abundant while *Climacograptus* all but disappears by the top. The *Monograptus gregarius* Zone contains the first *Petalograptus* and is followed by the *Monograptus convolutus* Zone which contains common *Rastrites* and the late *Orthograptus* (*O. bellulus*). The Zone of *Monograptus sedgwickii* is the last one to contain *Glyptograptus* while the highest zone at Dob's Linn of *Rastrites maximus* has a fauna consisting almost entirely of monograptids. During this zone the shales become interspersed with greywacke partings which become dominant to give the transitional boundary of the Gala Greywackes. Monograptid thecal style changes throughout the Silurian succession as shown in Fig. 2.

If time (and energy) allow it is worth visiting the final two localities. Locality 6 may be reached by climbing up the gully on the down stream side of the Anceps Bands trench or via the scree and grass slopes above the junction of the Linn Branch and Long Burn. The trench is excavated through the only unfaulted succession in the *P. linearis* and top *D. clingani* Zones and contains abundant well-preserved graptolites typical of these zones. The boundary between the two zones is approximately marked by the line of an old trench excavated along strike, possibly by Lapworth himself.

Loc. 7 is another trench cut through the Anceps Bands and is situated above a scree slope in the Long Burn. At this locality the succession is more than twice as thick as that in the Linn Branch. The apparently rapid thickening is more easily explained when realising that the localities are separated by a major thrust and would have been deposited tens or even hundreds of miles apart. The greater thickness of graptolitic shale means that there is a more abundant and better preserved *D. anceps* Zone fauna than at Locs. 2 or 4.

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Form and mode of life of *Dicellograptus* (Graptolithina)

S. HENRY WILLIAMS

(Plates 1–2)

Summary. The majority of *Dicellograptus* species have stipes which spiralled to a greater or lesser extent; this explains continuous variation of axial angle found in several species and many anomalous features of flattened or partially flattened specimens. The effects of variation in thecal style along the stipe are distinguished from those produced by variable orientation of the rhabdosome during flattening and by later tectonic distortion. It is concluded that *Dicellograptus* probably lived with stipes pointing upward and that the rhabdosome rotated in a horizontal plane due to eddies created by the non-directional ciliary activity of radially dispersed zooids in order to improve feeding efficiency.

1. Introduction

Variation in *Dicellograptus* is being studied in order to revise taxonomy and to help produce more accurately defined and reliably correlatable graptolite zones in the Upper Ordovician of southern Scotland. Far greater variation in the rhabdosomal form of flattened specimens of several species, especially *D. complanatus complanatus* Lapworth, 1880, occurs than has been previously recorded, affecting especially the axial angle and curvature of stipes (Fig. 1). Much variation appears to result from deformation during flattening of the original three-dimensional shape of the rhabdosome. 'Axial angle' is used here in preference to 'angle of divergence of stipes from the sicula' to obviate ambiguity, e.g. a larger 'angle of divergence' indicates a narrower angle enclosed by the dorsal walls (Fig. 1). When the stipes are gently curved the axial angle is here arbitrarily measured between the tenth theca on either stipe and the sicula. If the stipes are strongly curved in several places an initial axial angle should be measured and recorded as such. The terms 'convex' and 'concave' curvature for *Dicellograptus* stipes are used as shown in Figure 1 to describe the curvature of the ventral wall. Remaining descriptive terms are those used by Bulman (1970). Museum prefixes quoted are from the Sedgwick Museum, Cambridge University (SM A), Birmingham University (BU), Hunterian Museum, Glasgow University (HM C) and British Museum, Natural History (BM H, P, Q).

2. Evidence for the original form of *Dicellograptus*

The axial angle of *D. complanatus complanatus* varies between specimens from 10° to 130°. Figure 2 shows a unimodal, negatively skewed distribution with modal and mean values of 45° and 60° respectively. Most *Dicellograptus* species show stipe torsion, this being the distally progressive offsetting of the thecae about the stipe axis. The sense of torsion may be observed in specimens both flattened and in relief (e.g. both stipes in part and counterpart of *D complanatus complexus* Davies, 1929, in Plate 1, figs 5 and 6 illustrate a left-handed torsion, as does the hypothetical specimen in Fig. 1). In a single specimen both stipes exhibit the same sense of torsion: approximately 50% of each sense occurs in some species (e.g. *D. morrisi* Hopkinson, 1871) while in some others most specimens are of one sense (e.g. the great majority of *D. complanatus complanatus* possess a right-handed torsion while those of *D. complanatus complexus* exhibit a left-handed one). The reason for this variation is unknown: at present the sense of torsion is considered unreliable for taxonomic differentiation.

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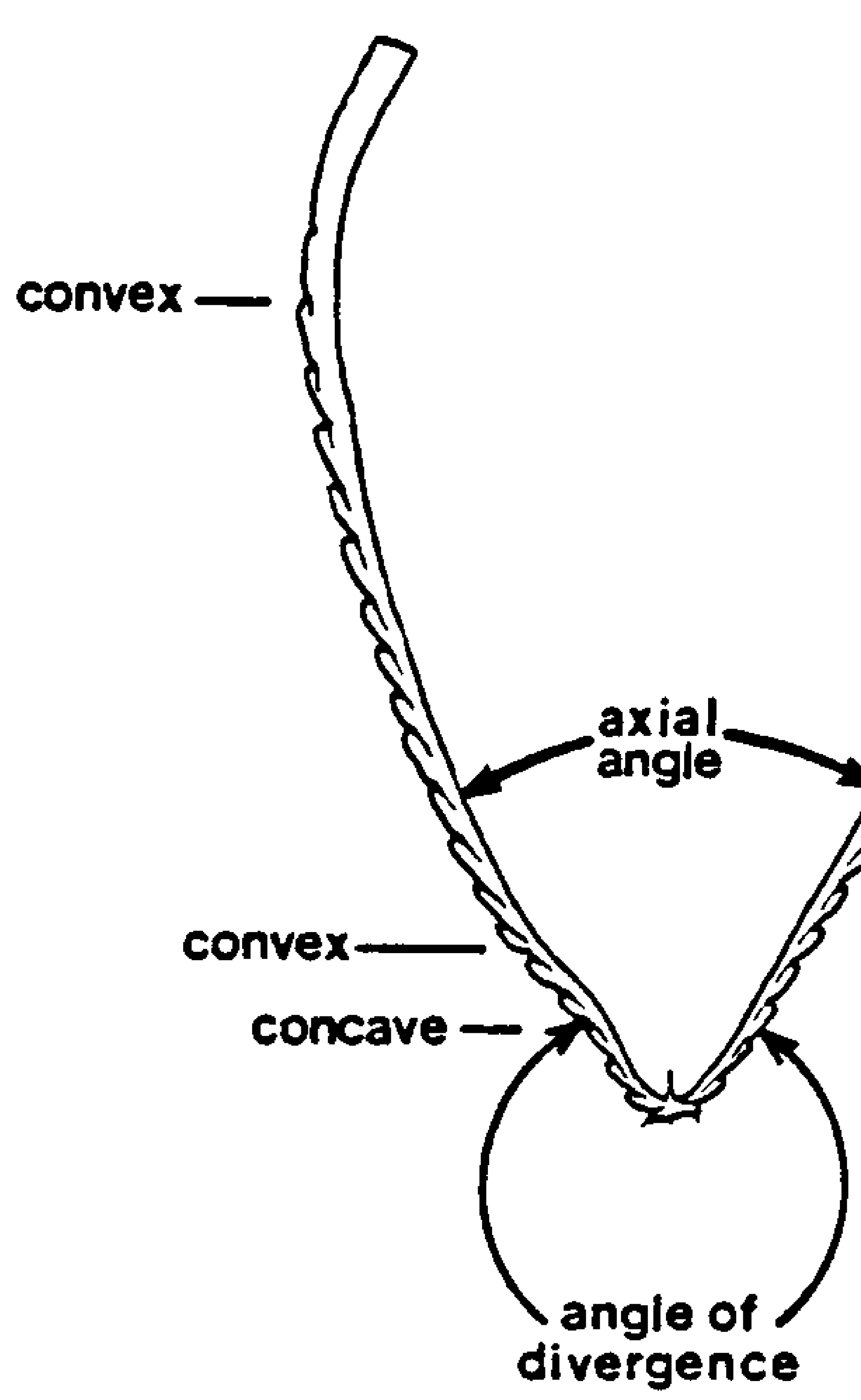

Figure 1. Hypothetical *Dicellograptus* with left handed torsion, to illustrate terms used in text.

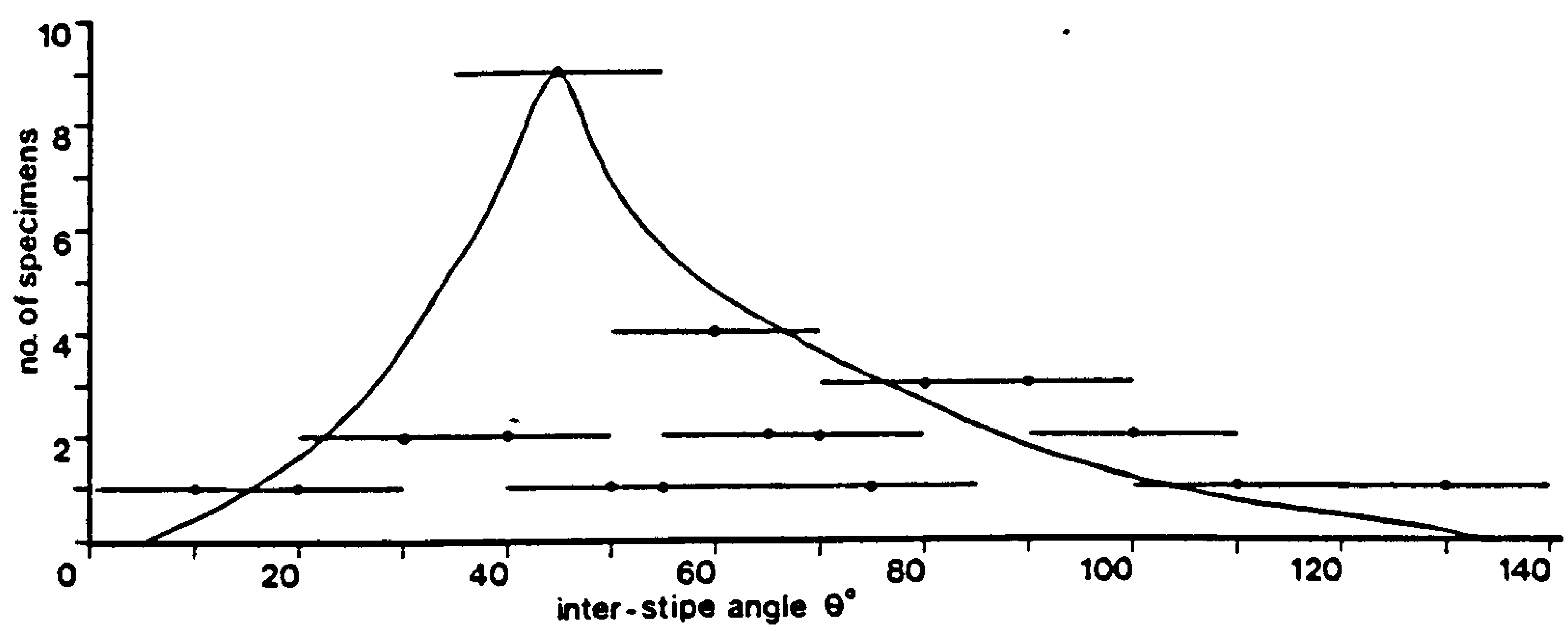

Figure 2. Frequency distribution plots of inter-stipe angles for *D. complanatus complanatus* Lapworth. Error bars of 20° are employed owing to the difficulty of accurate measurement and the change of angle along the stipe (see Fig. 3*c*) (36 specimens, mode 45°, mean 60°).

It has been previously realised (e.g. Bulman, 1970, fig. 72.1) that some *Dicellograptus* species probably had spiral forms (e.g. *D. intortus* Lapworth, 1880, *D. caduceus* Lapworth, 1876). The variable effects of flattening on the spiral had, however, been largely ignored until Finney (1977, unpubl. thesis, Ohio State University) described well-preserved, isolated material of *D. bispiralis bispiralis* (Ruedemann, 1947) and *D. gurleyi* Ruedemann, 1908 from the Athens Shale (Caradoc) of Alabama, and reinterpreted the variation of *Nemagraptus gracilis* (Hall, 1847) and several related species as being the effects of deformation on a spiralled, branching rhabdosome. Many *Dicellograptus* species with simply divergent stipes and torsion commonly show a slight proximal 'double curvature' on one stipe while the other is straight (see Fig. 1): occasionally specimens are found with two straight stipes or with both showing double curvature. It is suggested here that this feature results from the deformation of stipes which were originally openly spiralled about an axis passing through the sicula. It is integrally related to torsion and is the reason for the continuous variation of curvature and axial angle.

To test this hypothesis a plasticine model of a *D. complanatus complanatus* (with a necessarily exaggerated spiral) has been constructed; the effects of flattening can be imitated by photographing the model from different angles. The resulting images compare well with actual flattened or partially flattened specimens (Plate 1, fig. 3) and account for the double curvature of one stipe. It is rare to find specimens with crossing stipes as illustrated in Plate 1, fig. 4 because of the unstable position the rhabdosome would have had to adopt on settling on the sediment. Occasional specimens are however found in this mode of preservation, indicating either partial collapse of the rhabdosome on settling or more probably the low sediment density and high water content of the sediment on the substrate prior to compaction.

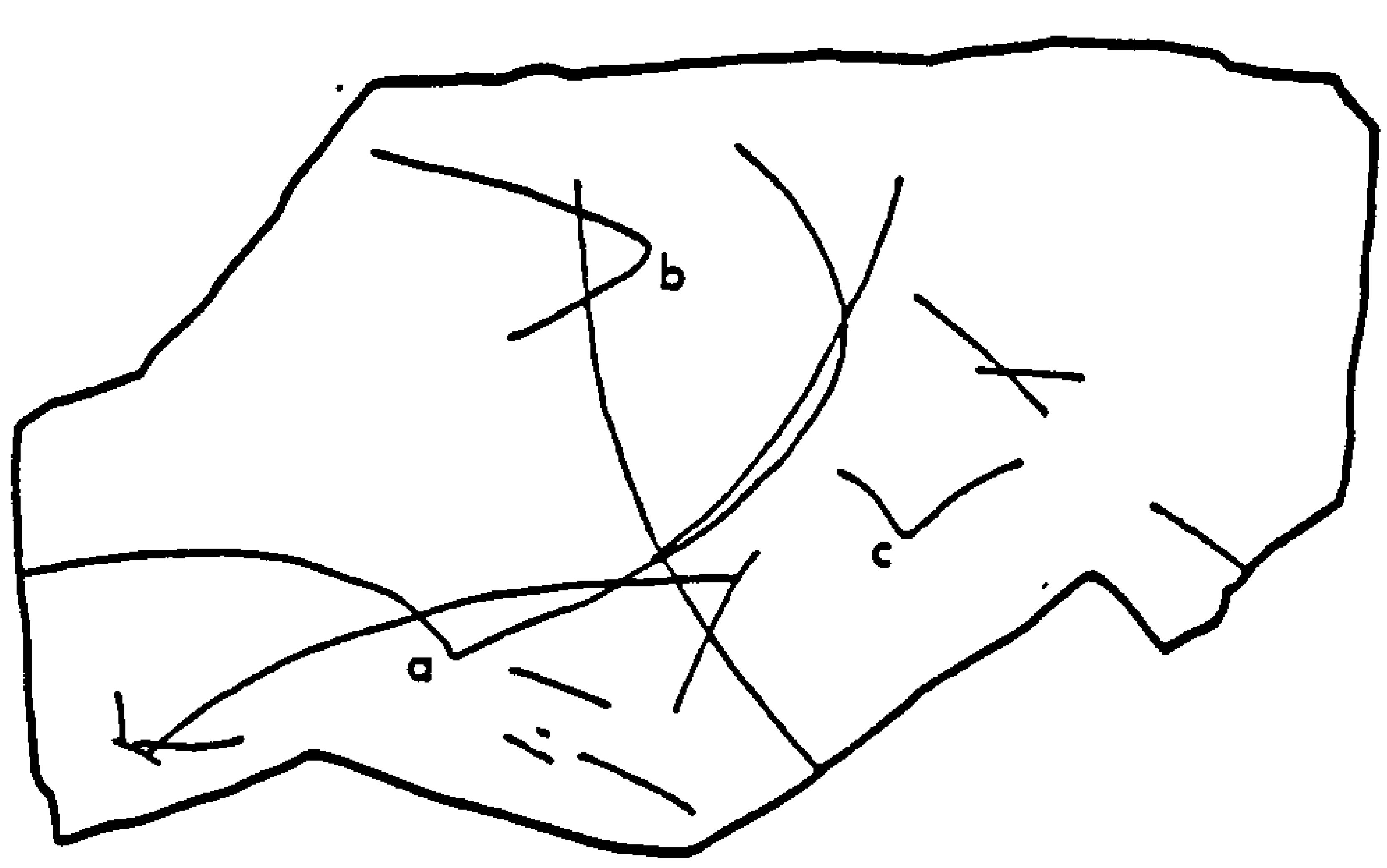

Figure 3. Line drawing from photograph of slab with unusually large specimen of *D. complanatus complanatus* Lapworth HM C 18476a (×½), first (lower) Complanatus Band, Upper Hartfell Shale. *D. complanatus* Zone, Dob's Linn, Moffat. Note distal convex curvature on specimen (*a*) and variation of form among specimens.

Further evidence for the spiral of *Dicellograptus* rhabdosomes is illustrated by other specimens; an unusually large specimen of *D. complanatus complanatus* with stipes over 160 mm long (Fig. 3*a*) shows a distal convex curvature as expected from the plasticine model with gradual stipe torsion. The specimen was originally a flexuous, loosely spiralled rhabdosome. *Dicellograptus* specimens are occasionally found with one stipe sharply bent at one or more points (Plate 1, fig. 2). This is best explained if the sicula and two stipes did not lie in one plane so that one stipe crumpled as the rhabdosome was compressed in the sediment during compaction. A specimen of *D. complanatus complanatus* from Girvan, southwest Scotland, preserved in relief (HM C 772/2) shows the proximal thecae of the left hand stipe compressed on to each other (Plate 1, fig. 1). This occurred because the left hand stipe lay at a larger angle to the bedding before compression. Further evidence for a spiral form is shown by a specimen of *D. complanatus complanatus* (BU 1386) figured by Elles & Wood (1901–18; text-fig. 84*c*) which shows radial cracks around the proximal curvature, presumably formed as the curved rhabdosome was compressed into a single plane.

Because some *Dicellograptus* species had fairly flexible, openly spiralled stipes, among specimens of a species normally with simply divergent forms an occasional one will exhibit crossing stipes (e.g. *D. vagus* Hadding, 1913). This is most clearly seen in *Dicellograptus* sp. of late Caradoc age from Matlock, Victoria, Australia, housed in the British Museum (Nat. Hist). One slab (H 1083) contains four mature specimens (Plate 2, fig. 1): one has widely divergent stipes, one has a distinctive 'lyre' shape and two have crossing stipes. These are interpreted as having been originally loosely spiralled but having since been flattened in different orientations. Rarely species of *Dicellograptus* do not show torsion, a common example being *D. forchhammeri* (Geinitz, 1852). Although the stipes of this species are long and flexuous the thecae consistently present a profile view, presumably because both stipes and the sicula lay in a single plane.

Whereas there are real thecal changes along the length of stipe in many graptolite species some variation is more apparent than real and is due to varying effects of compression on different orientations of thecae. The inconsistency of this apparent variation allows separation from actual change in thecal style which also occurs in *Dicellograptus* and has been well documented for many other graptolite genera, especially the monograptids (e.g. Rickards & Palmer, 1977; Urbanek, 1973). Many graptolites are affected by tectonic distortion, linear stretching producing a most confusing appearance with radically altered widths and thecal style. Plate 2, fig. 4 illustrates the effect of linear stretching on two distal stipes of *D. anceps* (Nicholson, 1867) lying parallel and perpendicular to a lineation.

3. Mode of Life

Spirally disposed stipes must have had important implications for the mode of life of *Dicellograptus*. A rotating, spiralled rhabdosome may have covered a volume of water more effectively than one with straight stipes and consequently have filter-fed more efficiently, although the sphere of influence of the zooid would also have been important, especially if it was as mobile as suggested by Crowther & Rickards (1977). The efficiency of a spiralled rhabdosome appears to be more clearly demonstrated in one species of a related genus, *Dicranograptus ziczac* Lapworth, 1876. Careful study of flattened specimens shows each stipe to be independently spiralled, stipe torsion revealing alternately the ventral and dorsal walls, while occasionally the two stipes become intertwined (Plate 2, figs. 6–7, Figure 4). If this reconstruction is correct all apertures on any one stipe would have been on the outside of a helix, giving the maximum efficiency for non-directional filter-feeding but no auto-rotation would have been possible. Spiralled stipes could alternatively have been an aid to flotation where auto-rotation was possible as proposed by Kirk (1969). In this case all zooidal activity would have been uni-directional and co-ordinated via the common canal, producing an upward spiralling of the rhabdosome during feeding and allowing it to sink during periods of rest. While this may have been feasible for species with simply spiralled rhabdosomes it is unlikely that *Dicranograptus ziczac* could have moved in this fashion owing to the complexity of the necessary currents and the interference eddies induced by such automobility. *Cyrtograptus* has a spiralled rhabdosome which may reach diameters of 2 m and would seem well-suited to a vertical spiralling movement (Bulman, 1 64). Rickards (1975; p. 423) felt, however, that for vertical lift to be achieved the distal parts of a large adult rhabdosome would have to move too quickly to make it feasible. The author believes that the rhabdosome of *Dicellograptus* probably rotated slowly and moved in a horizontal plane due to non-directional bea ing of the radially dispersed zooids.

The question of the life orientation of several graptolite genera, including *Dicellograptus*, was considered by Kirk (1969, 1980). She suggested that the sicula would have been at the

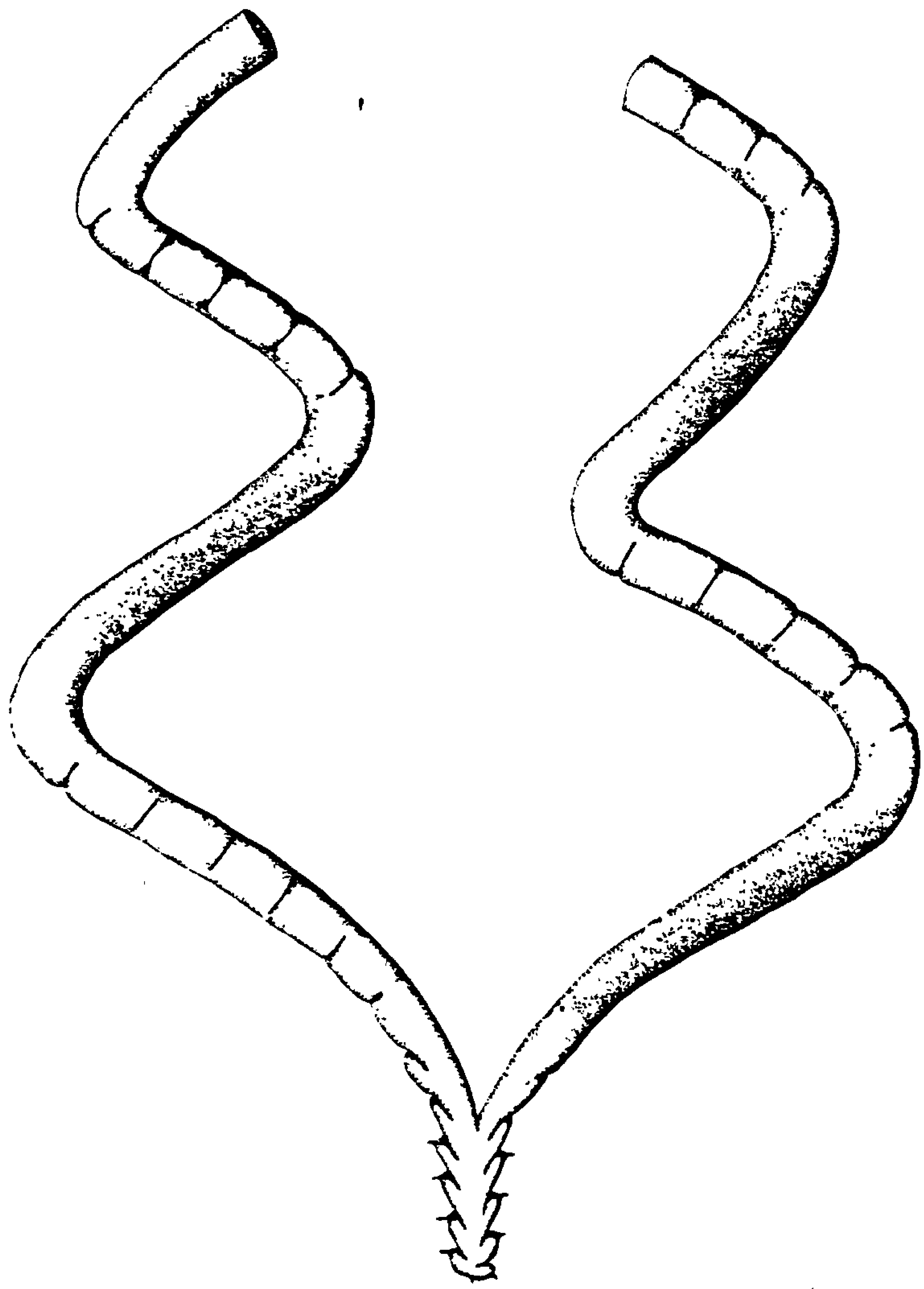

Figure 4. Reconstruction of *Dicranograptus ziczac* Lapworth (approx. × 5) to illustrate independent spiralling of stipes.

top with the stipes hanging down, as opposed to the 'normal' way-up used in most illustrations with the sicula at the bottom. The stability of the rhabdosome during life would have been heavily dependant upon any buoyant soft tissue of the zooid, but unfortunately to date none has been found preserved. There is no unequivocal evidence for flotation structures in mature *Dicellograptus*; the only possible one belonged to an immature, isolated specimen described by Finney (1979) who recorded a small bubble-like object attached to the distal end of the nema which would support the 'normal' orientation. Although many juvenile specimens possess a nema it is apparently lost at an early stage in astogeny, ruling out the possibility of attachment to a buoyant object by soft tissue with a nematophorous structure. Proximal structures in *Dicellograptus* are restricted to spines on the early thecae and connecting webs between the dorsal walls. *D. moffatensis* (Carruthers, 1858) has a proximal membranous web between the initially sub-parallel stipes (Plate 2, fig. 2), although this only occurs in mature specimens and is by no means a consistent character. Small spines are present on the sicula and first two thecae of most *Dicellograptus*. Occasionally these become developed more fully in mature specimens, the most extreme examples being found in *D. ornatus* Elles & Wood, 1904 (Plate 2, fig. 5). Some species may have spines on several thecae, while *D. bispiralis bispiralis* has spines throughout. Perhaps the most bizarre spinose *Dicellograptus* is a new species labelled 'Hudson River Group', Albany, New York State (Normanskill, upper Llandeilo equivalent) in the collection of the British Museum (Nat. Hist.), P 3851, with eleven long proximal spines (Plate 2, fig. 3). These proximal structures, combined with the secondary thickening of proximal thecae, would probably make the rhabdosome 'bottom heavy' if the effect of soft tissue is ignored. The reason for the astogenetic development of larger spines, proximal webs and secondary thickening would be to offset the increase in distal weight caused by the growth of the rhabdosome. If this hypothesis is correct, one would expect the best-developed proximal structures in those species with long or wide distal stipes; while this does seem true in many cases it must be stressed that the soft tissue would have played an important role in buoyancy and until further evidence of this is found it would be dangerous to draw any more positive conclusions.

4. Conclusions

Variation in axial angle, double curvature on one or both stipes and stipe torsion found in many *Dicellograptus* species are preservational features related to the original openly spiralled nature of the rhabdosome. Proximal spines, webs and secondary thickening are interpreted as ballast to keep mature specimens in their normally accepted orientation with stipes pointing upwards, although it is recognised that soft tissue may have provided opposing buoyancy. Spiralled stipes may have proved more efficient than straight ones for filter-feeding but efficiency would also have been dependant on the presently unknown sphere of influence of individual zooids. The rhabdosome is considered to have been rotated in a horizontal plane due to differential drag caused by the beating of radially dispersed zooids. The directional movement of the rhabdosome in a vertical sense by co-ordinated beating of the zooids as postulated by Kirk (1969) does not seem likely in this case but, until less equivocal evidence becomes available, must remain a possibility for *Dicellograptus* and other apparently free-floating graptolite genera.

Acknowledgements to Drs J. K. Ingham, P. R. Crowther, R. B. Rickards and Miss A. J. Chapman for much helpful discussion and reading the manuscript. Receipt of a N.E.R.C. studentship is also acknowledged.

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EXPLANATION OF PLATES

Plate 1

Fig. 1. *D. complanatus complanatus* Lapworth HM C 772/2 (× 10). Upper Whitehouse Group, directly above red mudstones, *D. complanatus* Zone, Port Cardloch, Girvan, Ayrshire. Ingham collection. Preserved in relief, note proximal thecae on left hand stipe are squashed on each other, exaggerating the prothecal folds.

Fig. 2. *D. complanatus complanatus* Lapworth BM H 2039 (× 5). Upper Whitehouse Group, *D. complanatus* Zone, Whitehouse shore, Girvan. Gray collection.

Fig. 3. *D. complanatus complanatus* Lapworth; plasticine model, reconstruction. Viewed perpendicular to general plane of stipes (note proximal 'double curvature' on right hand stipe).

Fig. 4. *D. complanatus complanatus* Lapworth; plasticine model, reconstruction. Viewed in general plane of stipes.

Fig. 5. *D. complanatus complexus* Davies BM Q 2831 part (× 5). Upper Hartfell Shale, *D. anceps* Zone, Dob's Linn, Moffat, Scotland. Note left handed torsion on both stipes of this and counterpart.

Fig. 6. *D. complanatus complexus* Davies BM Q 2830c counterpart (× 5). Figd. Toghill (1970), pl. 3, fig. 8.

Fig. 1. *Dicellograptus* sp. BM H 1083 (× 1). Matlock, Victoria, Australia (Eastonian, late Caradoc equivalent).

Fig. 2. *D. moffatensis* (Carruthers) BM Q 843 lectotype (× 5). Lower Hartfell Shale, Hartefell Spa, Moffat. Figd. Carruthers (1858), p. 469, fig. 3; Elles & Wood (1901–18), p. 157, fig. 99*a*, pl. 23, fig. 1*a*.

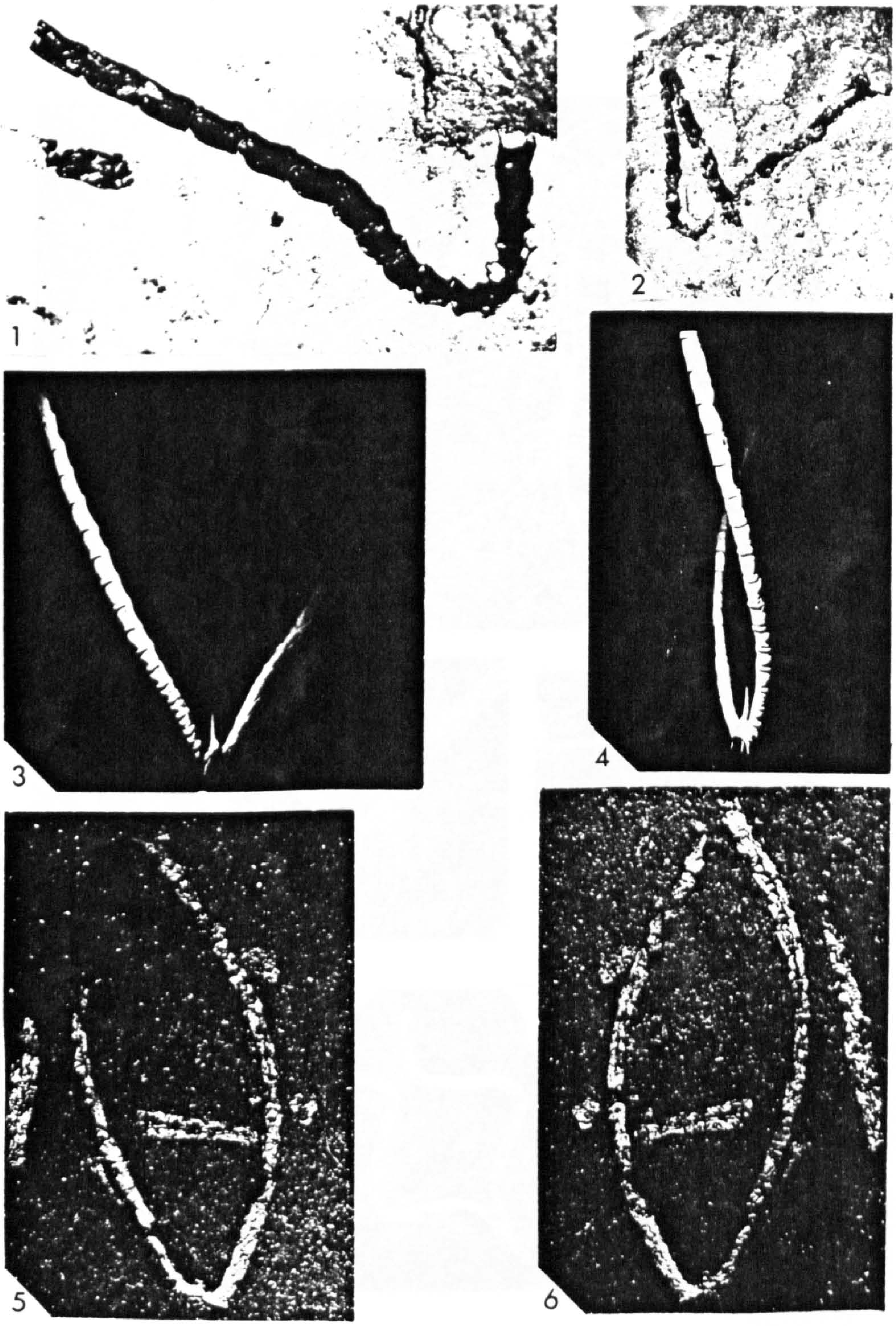
Fig. 3. *Dicellograptus* sp.nov. BM P 3851 (× 5). Labelled 'Hudson River Group' (Normanskill, late Llandeilo equivalent), Albany, New York State, North America.

Fig. 4. *D. anceps* (Nicholson) HM C 13109 (× 2). Second Anceps Band, *D. anceps* Zone, Upper Hartfell Shale, Dob's Linn, Moffat. Bar shows direction of tectonic stretching.

Fig. 5. *D. ornatus* Elles & Wood SM A 19331a paralectotype (× 5). Upper Hartfell Shale, *D. anceps* Zone, Dob's Linn, Moffat. Figd. Elles & Wood (1901–18), p. 140, figs. 85*a*, pl. 20, fig. 2*a*; Toghill (1970), p. 15, fig. 3*b*, pl. 6, fig. 3.

Fig. 6. *Dicranograptus ziczac* Lapworth BU 1133 holotype (× 2). Glenkiln Shale, Dob's Linn, Moffat. Figd. Lapworth (1876), p. 13, fig. 77; Elles & Wood (1901–18), pl. 25, fig. 3*a*.

Fig. 7. *D. ziczac* Lapworth SM A 18654 (× 2). Glenkiln Shale, Beldcraig Burn, Moffat. Figd. Elles & Wood (1901–18), pl. 25, fig. 3*d*. Note interlocking stipes indicate two separate spirals.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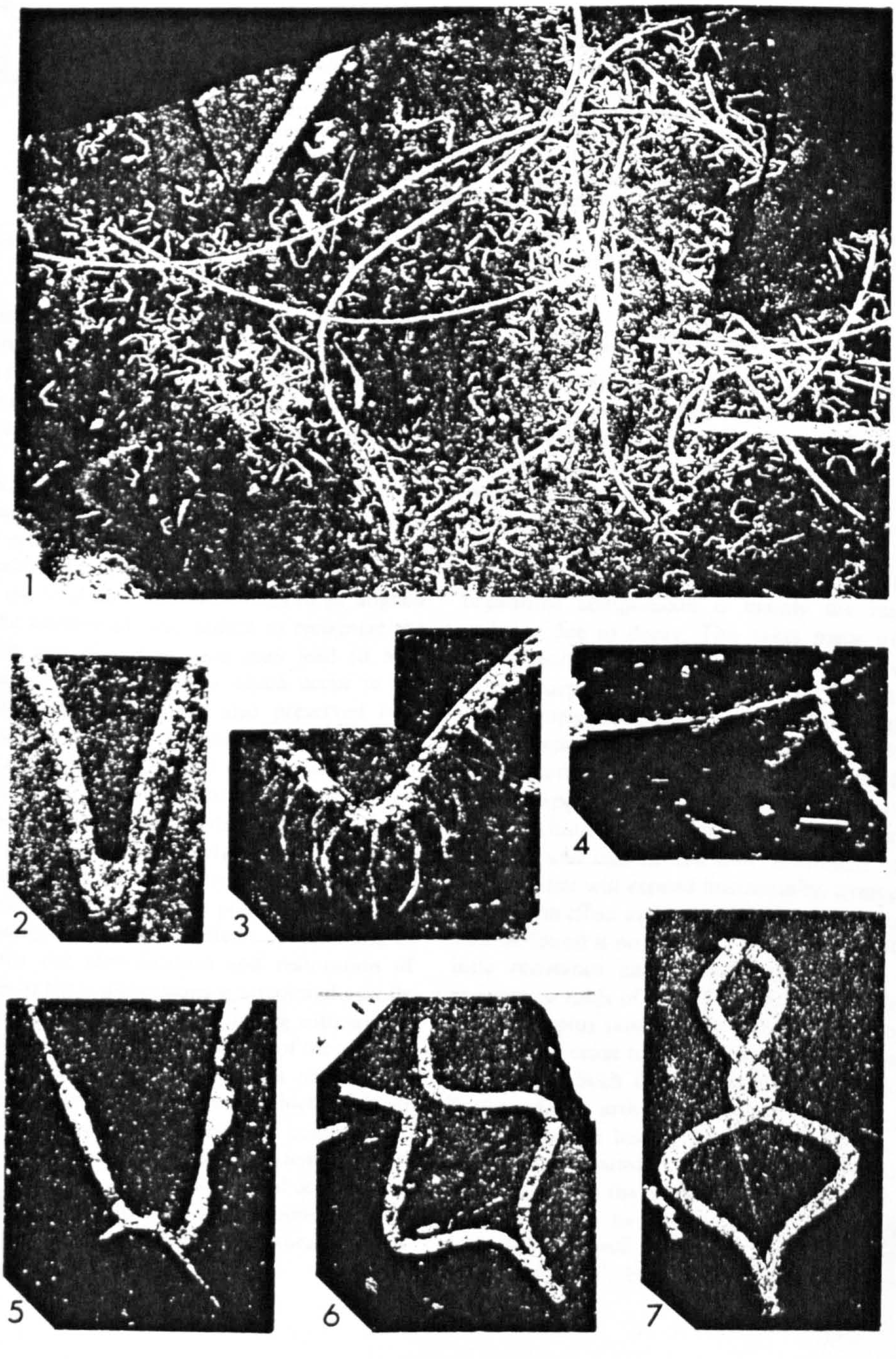

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The restoration of flattened fossils

DEREK E. G. BRIGGS AND S. HENRY WILLIAMS

LETHAIA

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Neither collapse, due to decay in a soft-bodied organism, nor compaction, due to overburden pressure, normally lead to significant lateral expansion in flattened fossils except in the case of some with rigidly mineralized skeletons. The fossils are thus analogous to a variety of two-dimensional views of a three-dimensional object. This realization provides a foundation for drawing and testing a reconstruction using either computer or manual graphic restoration methods. A complementary approach based on the photography of simple models, which is particularly useful where a complex three-dimensional morphology is under study, is described and illustrated by two examples, the Middle Cambrian arthropod *Odaraia* and the Upper Ordovician graptolite *Dicellograptus*.

Restoration, preservation, arthropod, Burgess Shale, Graptolithina, Dicellograptus.

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The flattening of organisms during preservation is the norm in finer grained sediments, particularly when a substantially mineralized skeleton is lacking. It is the usual type of preservation in the graptolites, for example, and characterizes a number of Lagerstätten, notably the celebrated Middle Cambrian Burgess Shale of British Columbia and the Devonian Hunsrück Slate of Germany. Graptolites differ in their precise orientation to the bedding ('lateral' and 'scalariform' preservations, for example), although the long axis naturally tends to be aligned along the horizontal, and failure to recognize the effects of variable orientation may lead to misidentification. The organisms which occur in the Lagerstätten mentioned are also preserved in a variety of attitudes to the bedding as a result of being transported and buried in a rapid influx of sediment (Whittington 1980; Stürmer & Bergström 1973). An understanding of the attitude of specimens to the bedding is critical to their reconstruction, particularly when complex morphological details such as soft tissues are preserved.

The interpretation of the effects of flattening as a basis for the identification and restoration of organisms in three dimensions is attempted usually on simple deductive grounds. Working with several specimens allows a qualitative notion of the appearance to be built up. Central to this process are assumptions regarding the degree to which the fossil has expanded laterally as a result of compaction. This question has received some attention with reference to specific organisms or fossil occurrences but nowhere have its full implications for the methodology of interpretation and restoration been discussed.

Flattening in sediment

Harris (1974), in a study of the compression of spores in a matrix, reviewed the ideas of Walton (1936) regarding the compression of plant organs. Walton showed that compression results in dewatering in the case of tissue of negligible rigidity, and no lateral expansion occurs. Zangerl & Richardson (1963), Zangerl (1969) and Conway Morris (1979) demonstrated that in the case of soft-bodied organisms compression is mainly the result of collapse due to decay. This takes place within a much shorter time scale than compaction due to sedimentary overburden and is consequently of greater importance. In the case of decay collapse no lateral expansion can occur although fluids may seep beyond the outline of the specimen. Harris (1974) experimented with more resilient objects (various hollow balls) in different compressible matrices and commented that 'it is hard to find a model that will expand horizontally, overcoming the Walton effect of the matrix'. To produce expansion he found it necessary to use a matrix offering little resistance and 'a ball with a rigid skin, resistant to folds of any kind. Once a fold forms it accepts surplus skin and the stresses caused by the surplus skin cease to be available to thrust out into the matrix'. Such folds occur in the majority of Burgess Shale arthropod carapaces, which were presumably not heavily mineralized. Harris concluded that expansion in spores would only 'be expected where the wall is strong and rigid and moreover keeps its rigidity for a long time after deposition and well into the period of compression of the sediment'. Even relatively hard skeletons,

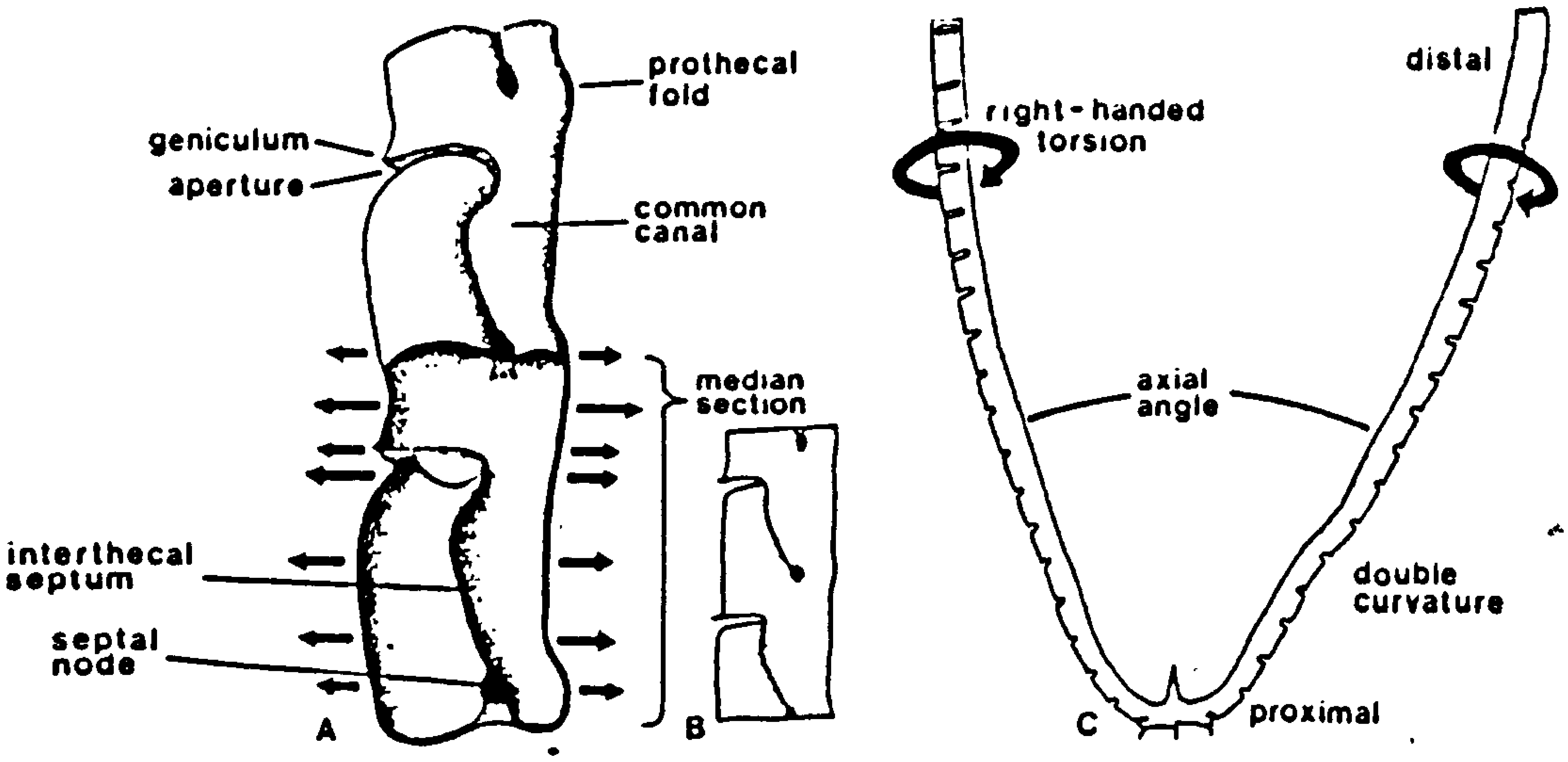

Fig. 1. Dicellograptus complanatus complanatus. □A. Reconstruction of early proximal thecae showing internal and external structures: *ca* ×40. Length of arrow indicates expected amounts of lateral spread on flattening if the graptolite behaved like a hollow tube. □B. Actual appearance of flattened thecae showing apparent morphological simplification owing to differential lateral spread: *ca* ×15. □C. Diagram illustrating terms used in text.

therefore, may compact (under overburden pressure) without significant lateral expansion due to the constraint of the confining sediment. The original convexity will tend to be taken up by crushing or plastic distortion. Expansion is rare and can usually be recognized by fragmentation of the specimen, fracture of the border, or by gross distortion of the shape (as in Harris's demonstration of the distortion of a spherical table-tennis ball into an ellipse because of its tensile strength which resisted fracturing and expansion). Fortey (1974:67, Pl. 22:9, 11), for example, showed how flattening in a shale affected the appearance of cranidia of the olenid trilobite *Bienvillia*. The cranidium fractures, predictably, along the mid-line of maximum convexity and this facture continues across the anterior border which becomes pushed anteriorly into a point. In tubular skeletons distortion of this kind is often most pronounced at the aperture where the confining forces of the skeleton itself are reduced. Thus compacted ammonites usually retain their original dimensions if the bedding plane parallels that of coiling, except at the aperture where some lateral expansion may take place.

The periderm of graptolites usually behaves as a semi-brittle material during compression due to secondary thickening by cortical secretion, particularly in mature specimens, and in some cases due to early diagenetic mineralization. The simplified model of Rickards & Palmer (1977, Fig. 1) envisages compression of a graptolite as if it lay on a hard substrate and ignores the effects of lateral confining pressures. Their contention that lines sub-parallel to the interthecal septa are produced by folding and compaction is probably correct, but the degree of lateral expansion is exaggerated. Many flattened graptolites show little or no increase in width compared to specimens preserved in full or partial relief. Some do show lateral spread, particularly at the thecal aperture, but the rhabdosome cannot be compared to a simple ovoidal tube when considering the effects in detail. The buttressing of interthecal septa and the protection afforded by genicular hoods, for example, make compaction more complex. A study of *Dicellograptus* (Figs. 1, 2), for example, has revealed that the thecal morphology appears simpler in flattened specimens than it does in specimens preserved in relief. Prothecal folds are prominent in three-dimensional specimens but at best obscure and often apparently absent in flattened ones. Likewise thecal apertures and supragenicular areas tend to be squared-off in flattened specimens. These apparently anomalous features may be explained as the result of differential spread on compression. The interthecal septa and genicular hoods provide support in different parts of the thecae, particularly opposite the prothecal fold due to secondary thickening of the interthecal septal node. The portion of the stipe lying between this node and the genicular hood

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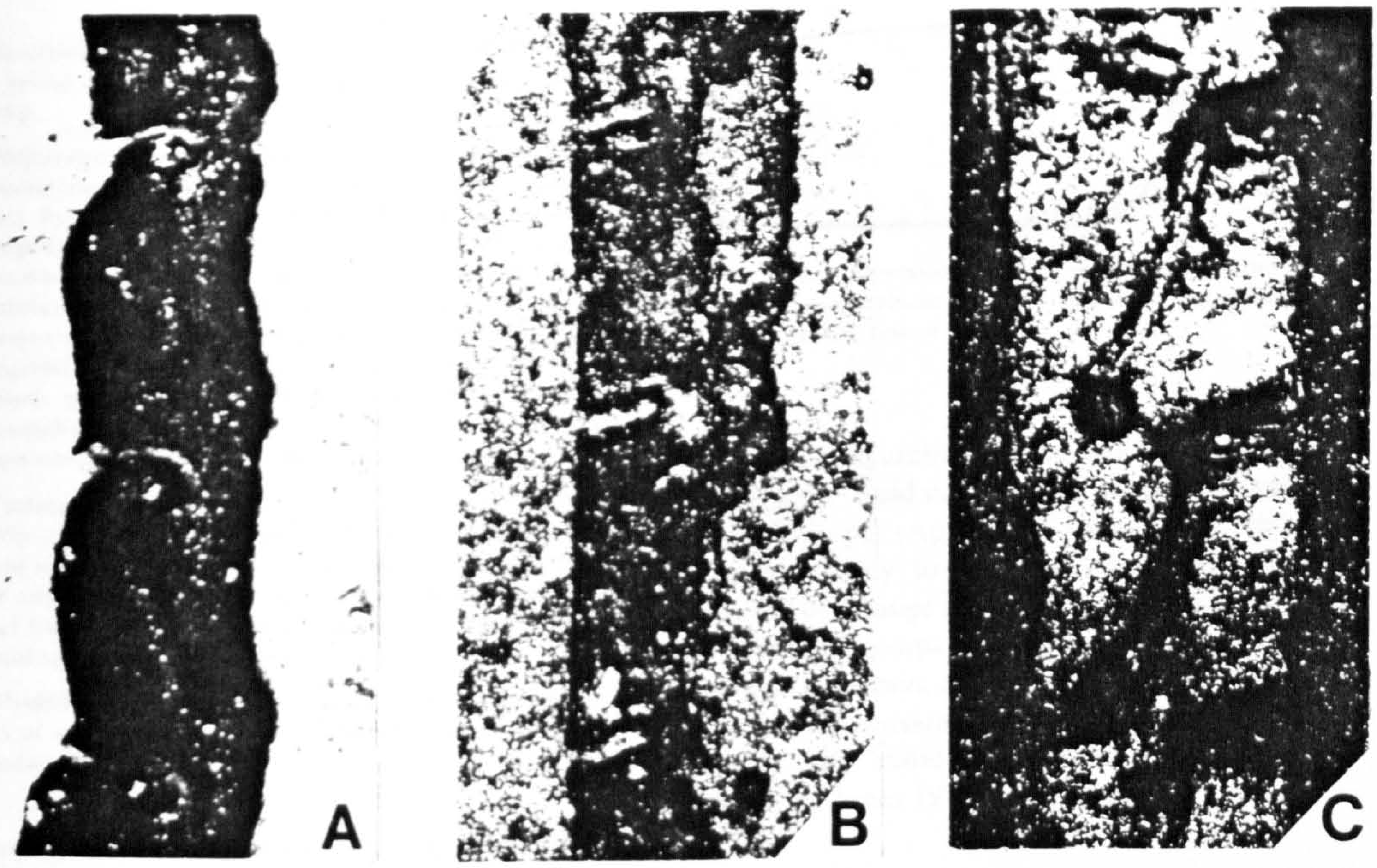

Fig. 2. Dicellograptus complanatus complanatus early thecae: all *ca* × 50. □A. Preserved in relief, external cast, HM C 772 2, Upper Whitehouse Group, directly above red mudstones, *D. complanatus* Zone, Port Cardloch, Girvan, Ingham collection. □B. Flattened, external cast, RU 2967, Upper Whitehouse Group, Myoch Bay, Girvan, Rushton collection. □C. Flattened, internal mould, BU 1074 (paratype), first Complanatus Band, Upper Hartfell Shale, Dob's Linn, Moffat, Lapworth collection.

proximal to it has no central supporting septum. Thus the aperture, which is intrinsically weak structurally, coincides with that portion of the stipe with least support. On compression the lateral spread is therefore concentrated in this area giving rise to an apparently simplified thecal morphology, but little increase in overall stipe width (Figs. 1, 2). Thus the morphology of the rhabdosome as a whole is not significantly distorted. Differential spread has also been observed in other graptolites, such as *Orthograptus amplexicaulis* (= *O. truncatus*) the thecae of which may acquire a glyptograptid-like appearance (A. T. Kearsley, personal communication).

In many cases the relation between the three-dimensional organism and the flattened (either collapsed or compacted) fossil is essentially that of a three-dimensional object projected onto a two-dimensional plane, the bedding. The flattened fossils are only distorted in the plane normal to the bedding; different configurations on the bedding plane are similar to views from different angles. The appearance of individuals within a suite of flattened fossils thus varies depending mainly on the original attitude of the organism to the bedding plane. Other contributory factors may include, for example, real variation (sexual dimorphism, intraspecific or even inter-specific variation), distortion due to decay, and changes in the relative attitudes of parts of the organism such as movement of the appendages in arthropods. Such variation commonly presents the investigator with two related problems, determining whether differences between specimens are simply the result of variation in orientation to bedding or involve other factors, and restoring the original organism in three-dimensions from the two-dimensional fossils. (Flattened fossils may not be strictly two-dimensional; both the Burgess Shale arthropods and many compacted graptolites, for example, are made up of discrete layers, but they may still be considered as confined to a single plane).

Restoration

The reconstruction of the organism involves a number of major steps:

(1) Interpretation of the state of preservation – to what extent do the constituent parts retain their original spatial relationship to one another?

(2) Determination of how differently preserved configurations relate to the organism's original orientation to the bedding

(3) Preparation of a reconstruction, the outline based largely on specimens affording lateral and dorsal views but supplemented by those preserved in intermediate orientations. An important, but sometimes overlooked consideration is that restored lateral and dorsal views, for example, should be compatible. This can easily be achieved by projecting one view onto another using graph paper so that the dimensions correspond. It is surprising how often this degree of precision is not attained in published reconstructions; occasionally the opposing sides of a dorsal view are not even proportioned symmetrically about the axis.

(4) Testing of the reconstruction by comparing the result with the compacted specimens (qualitatively) and seeking to explain satisfactorily any divergence from the restoration as either apparent (due to unusual orientations to the bedding) or real but explicable in terms of decay or distortion of the original specimen, for example.

(5) Modification of the reconstruction to meet the requirements of stage 4. Stages 4 and 5 naturally are repeated until a satisfactory result is achieved.

A mathematical method for drawing a reconstruction from compacted fossils has been published recently by Doveton (1979) based on distances between homologous reference points. The technique was illustrated by the reconstruction of the Burgess Shale arthropod *Waptia fieldensis* based on two specimens, one in lateral and one in dorsal view. While this computer based technique has considerable promise there are disadvantages. A practical (although not theoretical) limitation is introduced by the number of points which can be readily located and plotted for distance measurement. In addition, many morphological features of organisms are curved and the method does not deal satisfactorily with curves which lack intermediate reference points (the margins of the carapace of *Waptia*, for example, Doveton 1979, Fig. 4 and Pl. 1). Although the method can be extended readily to produce perspective views of the reconstruction, the user need never consider the true three-dimensional nature of the organism, only a series of two-dimensional views, essentially like the flattened fossils.

Other more familiar methods for altering the outline of organisms in a controlled fashion generally apply a similar approach to D'Arcy Thompson's (1917) transformation grid and differ fundamentally from Doveton's technique in that they introduce a distortion. Whittington (1975, Fig. 1) used such a technique to illustrate manually stages in the flattening of specimens of *Opabinia*, but this concerned a section normal to the bedding plane and is irrelevant to a consideration of the resultant

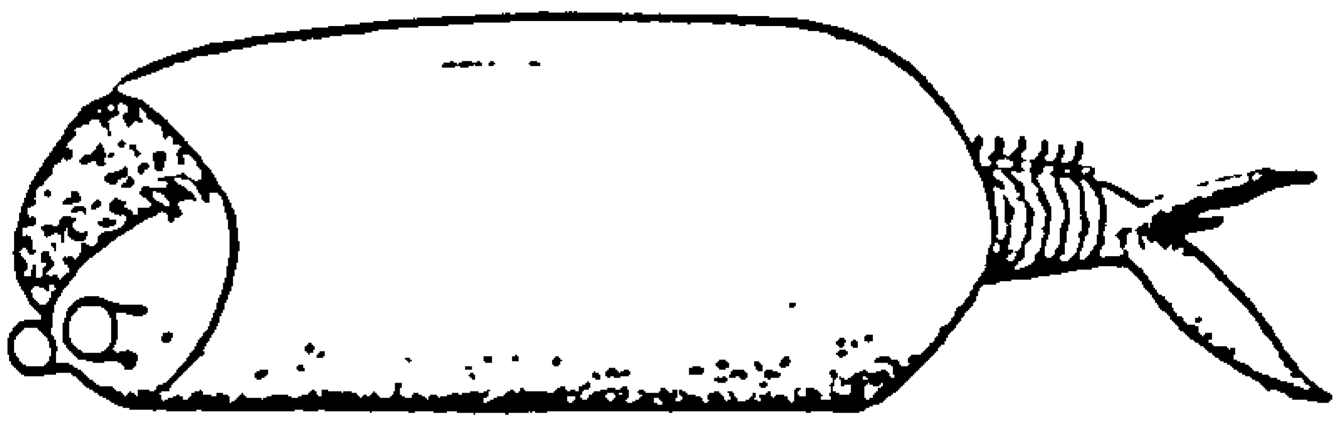

Fig. 3. Artist's impression of *Odaraia alata* swimming on its back (in dorsal-oblique view), to illustrate the relation of the telson to the rest of the body; ca ×0.9

flattened configuration on the bedding plane itself. Whittington could equally have used the Analogue-Video Reshaper (Appleby & Jones 1976), which is designed mainly to simulate real morphological variation or change in two dimensions rather than the effects of compaction. It may also be used for investigating strain, but the fossil is then considered as a two-dimensional object at the outset (for example, the 'removal' of shear from *Angelina*, Appleby & Jones 1976:571, Pl. 85).

The new technique

Where a complex three-dimensional morphology is under investigation, neither the manual graphic approach nor the computer-based technique of Doveton (1979) alone may be adequate or appropriate, as the elucidation of orientation to bedding and subsequent restoration may have to be approached by a process of trial and error. In this case a simple but elegant technique involving the preparation and photography of models may be applied profitably. The usual procedure for preparing a restoration (stages 1 to 3 above) is followed, but in addition to (or initially instead of) a graphic reconstruction, a simple model incorporating the salient features of the morphology is made. (A variety of materials can be used for this purpose [Chase 1979] but for models designed only to fulfil the requirements of the technique, self-hardening plasticine, 'Plastone', has been found ideal. At the outset it can be worked like a slightly sticky modelling clay, after initial drying it can be pared with a sharp scalpel, and finally when dry it can be sanded.) To test this three-dimensional reconstruction it is now necessary to flatten it in various attitudes into two dimensions and compare the result with the specimens upon which it was based. This can be achieved by photographing the model in a variety of orientations. The three-dimensional organism (or part of it) is thus projected onto the two-dimensional focal plane of the camera, providing a direct analogy with

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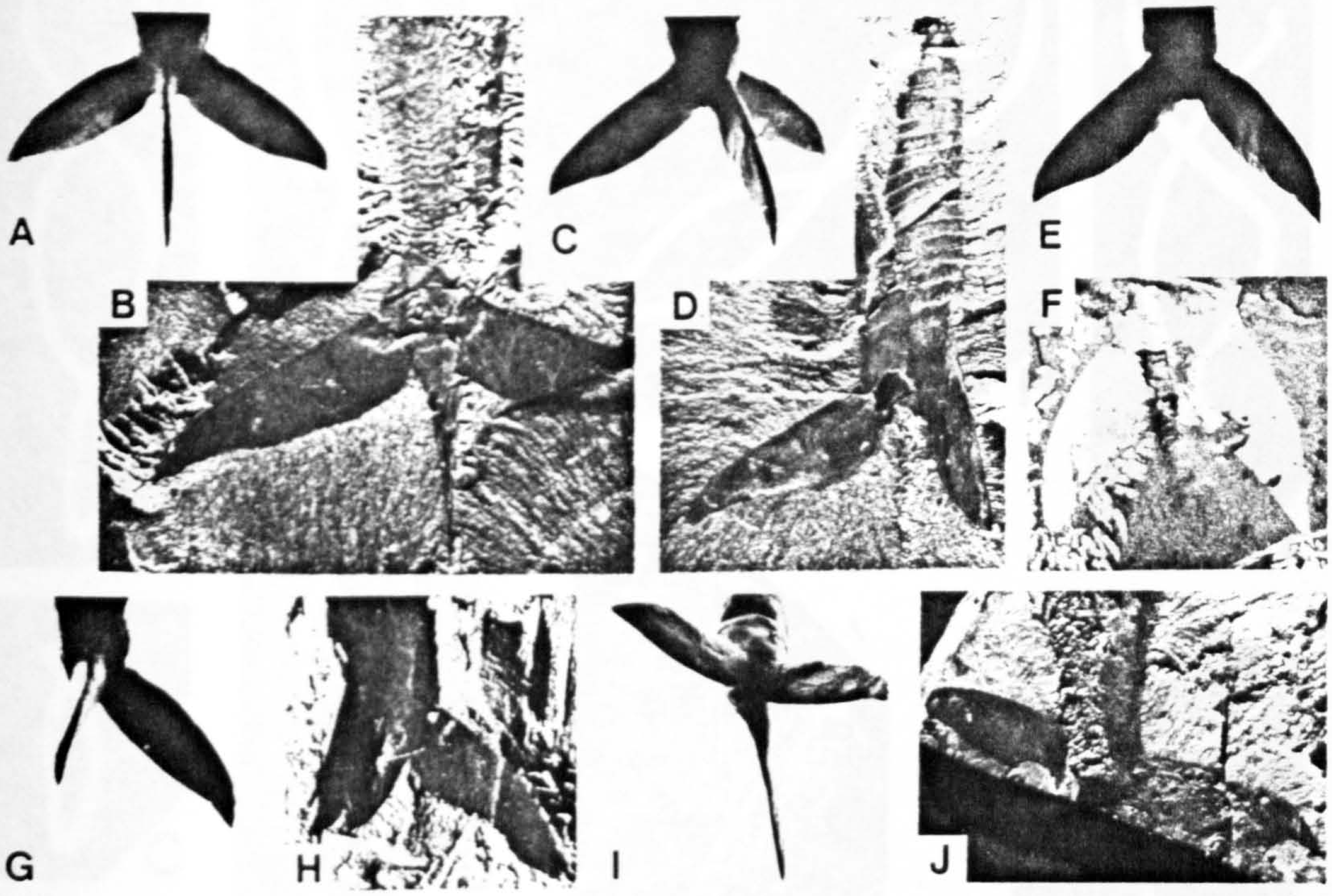

Fig. 4. Odaraia alata Walcott 1912. □A, C, E, G, I. Model of the telson photographed in different attitudes. From A, in dorsal view, the model was rotated through C and E to G, in lateral view. I shows the result of tilting the long axis down anteriorly, combined with a rotation. □B, D, F, H, J. Specimens of the telson preserved in orientations to the bedding comparable to the attitude of the model in the adjacent figure. B. USNM 213812a, right fluke incomplete; ×1. D. USNM 189238, right fluke not evident; ×1. F. USNM 213813, right fluke not evident, reflected; ×1.5. H. USNM 189233; ×1.5. J. USNM 241050, right fluke not evident; ×0.75. Middle Cambrian, Stephen Formation, *Pagetia bootes* faunule, Walcott Quarry, near Field, southern British Columbia.

the flattening of the organism onto a bedding plane. If desired the model may be rotated about a variety of axes and the orientation precisely quantified. The results may then be compared with the range of configurations in the flattened fossils providing an empirical 'test' of the validity of the model as a reconstruction. A similar method can be employed on simple shapes graphically by drawing corresponding plan views and sections (Whittington 1977, Fig. 3; Briggs 1978, Fig. 127), provided displacement from the horizontal is generally confined to rotation about a single major axis (longitudinal or transverse).

Examples of the application of the method

The telson of Odaraia

A new investigation of the Middle Cambrian Burgess Shale arthropod *Odaraia alata* Walcott 1912 (Briggs, in press) has shown that the telson of this large branchiopod-like arthropod (Fig. 3) was unique, bearing three nearly identical flat processes, or flukes, which projected at high angles to one another. The combination of this almost radially symmetrical telson and an essentially tubular carapace, the valves almost meeting ventrally, makes the recognition of the orientation of specimens to the bedding very difficult. Specimens in parallel aspect (dorsal or ventral view; identified by their bilateral symmetry), however, show the median fluke symmetrically flanked by the lateral flukes (Fig. 4B), and, in lateral aspect (identified by the carapace hinge line), it is evident that it projected dorsal rather than ventral of the others (Fig. 4H). Difficulties arise, however, in interpreting specimens preserved in other orientations to the bedding. It is by no means clear whether the variation is simply a function of the orientation of fixed flukes to the bedding, or whether they articulated proximally thus altering their attitude relative to the trunk. The

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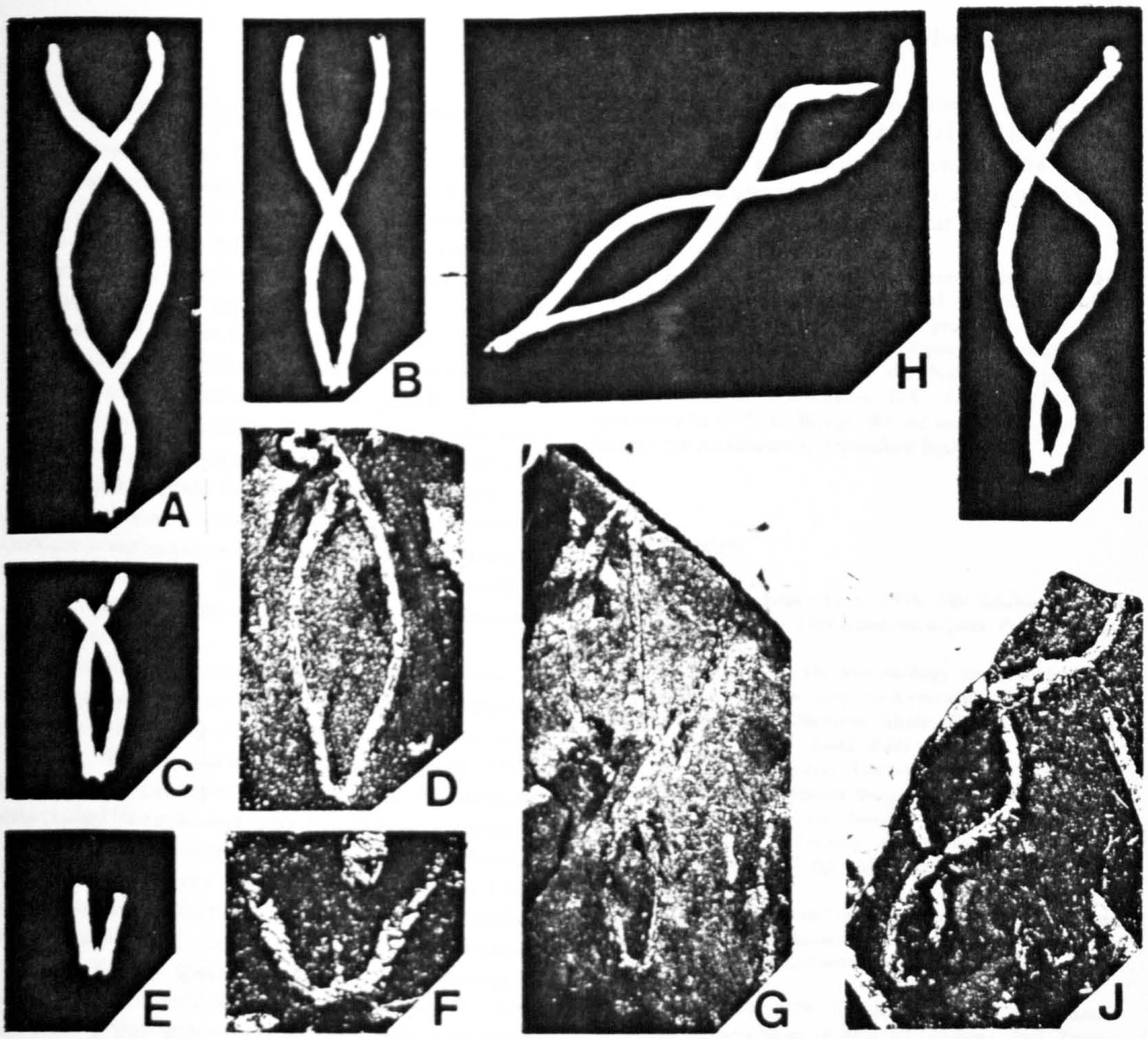

Fig. 5. Dicellograptus complanatus complexus. □A–C. Simple wire and plasticine model to illustrate varying separation of crossing points due to rotation of the model. □D. Specimen showing large distance to first cross. HM C 13385a; ×2.5. □E, F. Model and specimen of juvenile with sicula preserved. HM C 13112; ×5. □G. Mature specimen with apparent open spiral HM C 13110; ×2.5. □H–I. Plasticine model showing angle of rest to horizontal and resultant appearance to imitate specimen in J which has an exaggerated spiral and shortened thecae. □J. HM C 13111; ×2.5. All specimens from Anceps Band B. Upper Hartfell Shale, Dob's Linn, Moffat.

morphological evidence for the presence or absence of articulations at the base of the flukes is inconclusive. Fortunately the specimens preserved in lateral and parallel aspect provide a basis for a reconstruction of the telson. A three-dimensional model was made and photographed in a variety of orientations for comparison with the other specimens (Fig. 4).

This approach shows that the preservation of the majority of specimens can be explained simply by rotation around the sagittal axis to points intermediate between parallel and lateral aspect. Tilting of the axis must be taken into account in explaining some of these configurations, but it is of secondary importance. A small number of additional specimens evidently are preserved at orientations approaching vertical to the bedding (Fig. 4I, J) but in no case is it necessary to postulate movement about a proximal articulation. The telson and flukes clearly formed a relatively rigid structure and this conclusion is naturally critical to an interpretation of the functional morphology of the arthropod (Briggs, in press).

7

The spiralling stipes of Dicellograptus

Specimens of the Upper Ordovician graptolite *Dicellograptus complanatus complanatus* Lapworth, 1880 display a wide range of continuously varying axial angles. Flattened specimens of several *Dicellograptus* species often show a slight proximal double curvature on one stipe while the other is straight (Fig. 1C). Williams (in press) concluded that both these features, which are normally associated with stipe torsion, indicate an original openly spiralled rhabdosome. A model of *D. complanatus complanatus* with a rather exaggerated spiral was constructed and photographed from a variety of angles. An apparent 'kink' is seen on one stipe when viewed in certain orientations while the other remains straight, closely resembling the double curvature found in actual flattened specimens, and thus vindicating the reconstruction.

D. complanatus complexus Davies 1929 is one of several *Dicellograptus* species with stipes illustrating an approximate figure of eight owing to two stipe crosses. Several earlier authors (Bulman 1970, Fig. 72.1, for example) realized that the rhabdosome was coiled like a double helix, but did not investigate further. Recent intensive collecting of the Anceps Bands in the Upper Hartfell Shale of Dob's Linn near Moffat, southern Scotland, revealed a number of specimens of this previously poorly known species. Young specimens have simply divergent stipes and are only separable from other *D. complanatus* group graptolites by their well developed stipe torsion (Fig. 5E, F). As the stipes increase in length, however, an open spiral is indicated by prominent, usually left-handed, stipe torsion (Fig. 5D). In more mature rhabdosomes the stipes may cross once or twice (Fig. 5G, J). In younger specimens the first cross is approximately 1.5 cm from the sicula aperture, but this distance decreases with increasing stipe length. A simple scale model with the hypothetical double helix has been constructed. During rotation of the model about a vertical axis the distance between the sicula and first stipe-crossing point appears to vary. A series of photographs shows how actual flattened specimens may be imitated in this way (Fig. 5A–C). This distance in flattened specimens is therefore not an indication of an increasingly tighter spiral during rhabdosome growth, but simply a function of the stable orientation of the rhabdosome on the bedding plane.

The thecae in some specimens (Fig. 5J) appear shorter and wider than normal and the stipe-crossing points are more closely spaced. The specimen figured must have rested in the sediment at a fairly high angle to bedding prior to compaction, as illustrated by the model (Fig. 5H, I). The sediment must have had a high water content and low density to allow the specimen to sink in and remain in an unstable orientation during burial.

Acknowledgements. – This paper grew out of our independent contributions to the Palaeontological Association annual conference at Cardiff, 1979. We are grateful to Drs. C. P. Hughes, J. K. Ingham and J. C. Tipper for criticizing an earlier draft. F. J. Collier of the National Museum of Natural History, Washington D.C. facilitated study of specimens by D. E. G. Briggs. We are indebted to the Royal Society for permission to reproduce figures.

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Upper Ordovician and lowest Silurian graptolite biostratigraphy in southern Scotland.

(2 volumes)

Volume 2 (plates)

STEPHEN HENRY WILLIAMS

Thesis submitted for the Degree of Ph.D.

University of Glasgow
Department of Geology

July 1981

All figured specimens are from the writer's collection, housed in the Hunterian Museum (Glasgow University) unless otherwise stated.

HM C, L, X, Y Hunterian Museum (Glasgow University)
BU Birmingham University (Geology Department)
SM A Sedgwick Museum (Cambridge University)
Q, H, P British Museum (Natural History)
I.G.S. I.G.S. South Kensington

Most figured graptolites are preserved in dorso-ventral orientation unless otherwise described. Specimens from the Lower Hartfell and Birkhill Shale are given the sample interval from which they were collected.

Dob's Linn localities:

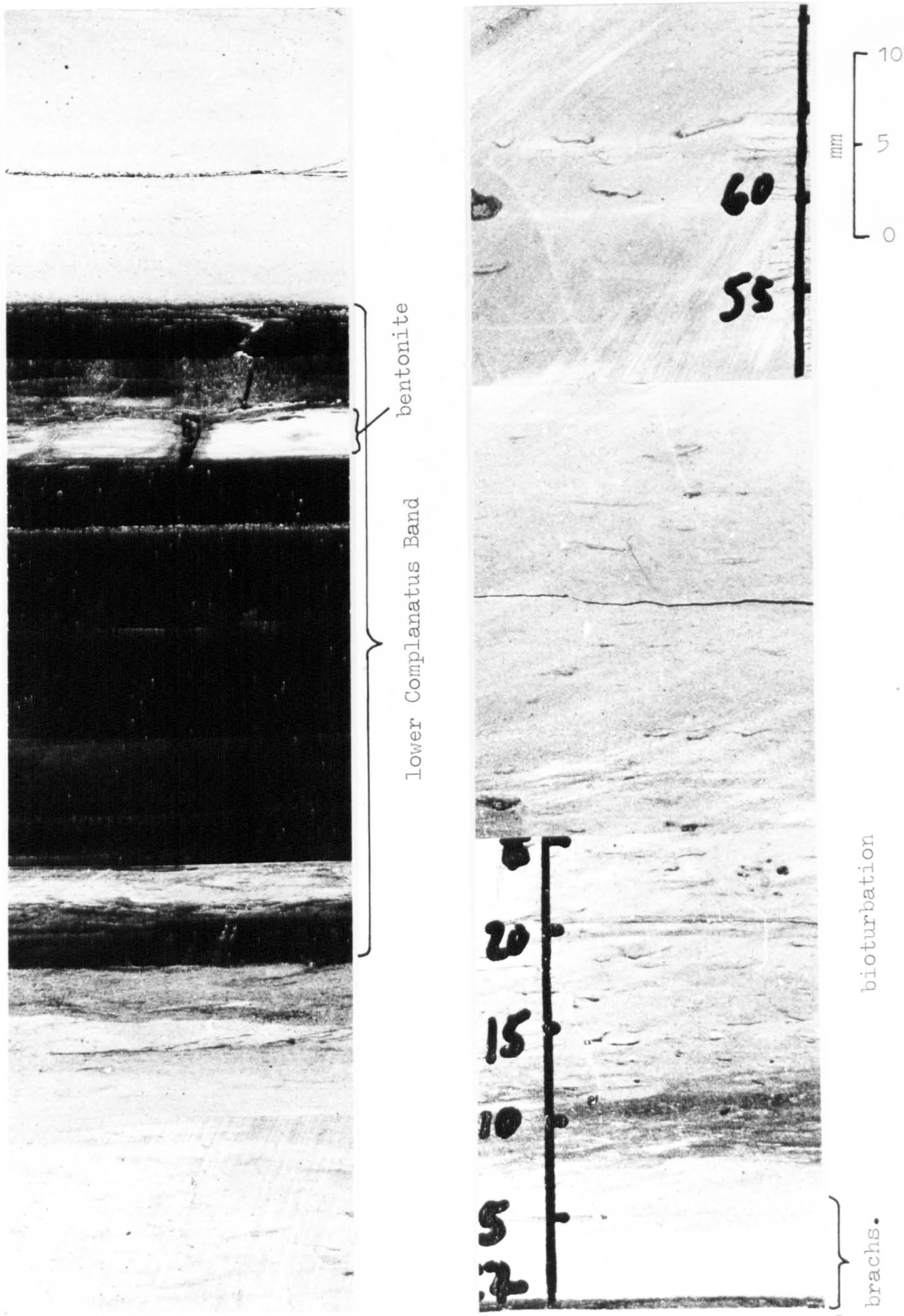
North Cliff trench - text-fig. 1, loc. 6
Linn Branch trench - text-fig. 1, loc. 5
Linn Branch (Complanatus Bands) - text-fig. 1, 12m upstream from loc. 4, on the south bank of the stream
Long Burn trench - text-fig. 1, loc. 7
Main Cliff section (Anceps Bands) - text-fig. 1, 25m WNW of loc. 2
Main Cliff (Complanatus Bands) - text-fig. 1, loc. 3

PLATE 1

Composite lithological sections through the Complanatus Bands, Upper Hartfell Shale, of Dob's Linn.

FIGURE

1. Lower Complanatus Band, Main Cliff (text-fig. 1, loc. 3).
2. Upper Complanatus Band, Linn Branch (text-fig. 1, upstream from loc. 4), showing horizon with inarticulate brachiopods.



1

upper Complanatus Band 2

PLATE 2

Barbatulella lacunosa gen *et* sp. nov.
From just above the upper Complanatus Band, Upper Hartfell Shale, *D. complanatus* Zone, Linn Branch, Dob's Linn.

FIGURE

A - B. HM L14655a. Proposed holotype.

A. General view of brachial valve. (x10)

B. Detail of lateral commissure. (x20)

C - E. HM L14655b. Counterpart. SEM micrographs.

C. General view of lateral and anterior commissure. (x25)

D. Detail of lateral commissure. (x50)

E. Detail of anterior commissure. (x75)

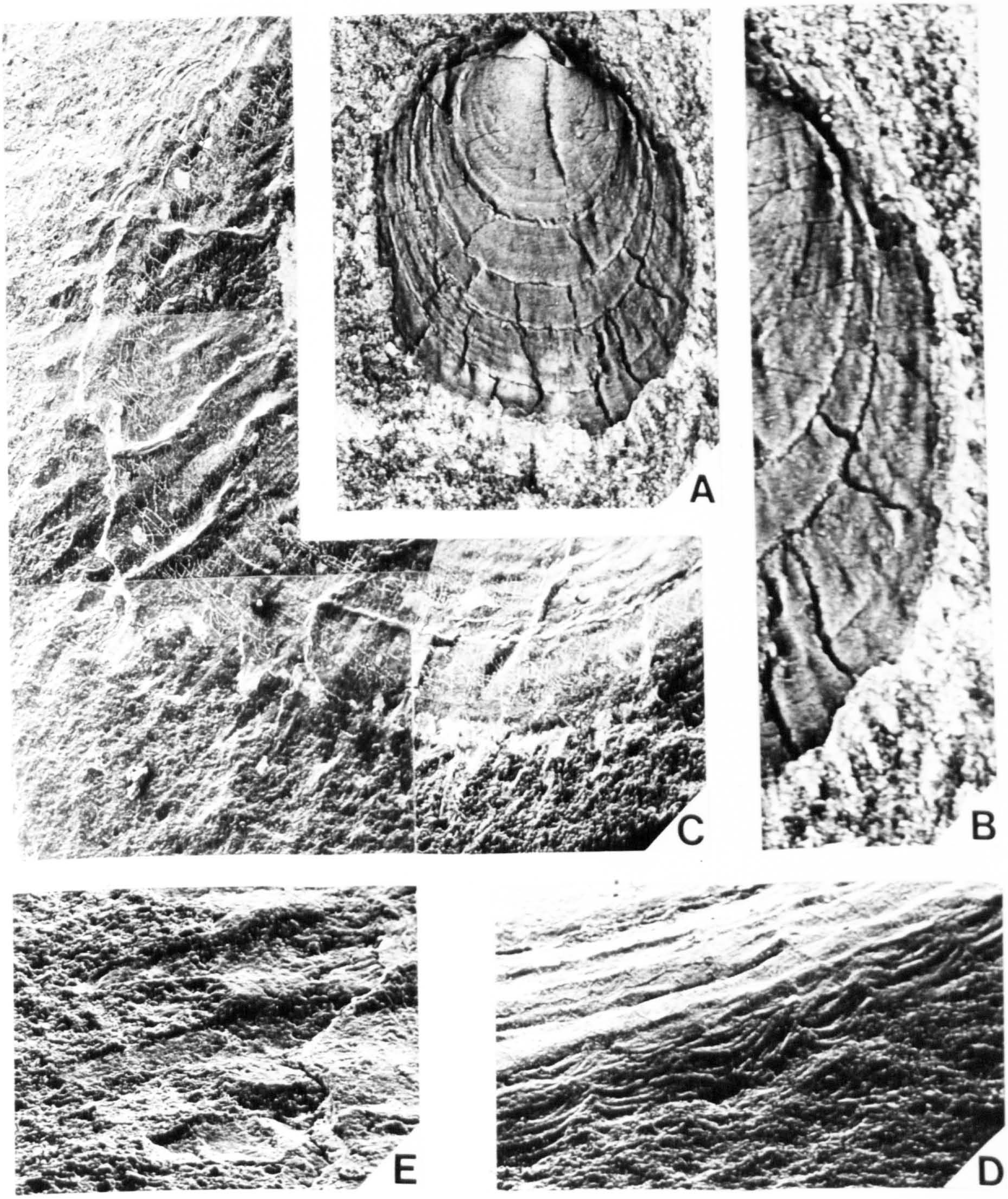

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PLATE 3

Barbatulella lacunosa gen. *et* sp. nov.

SEM micrographs.

All from just above the upper Complanatus Band, Upper Hartfell Shale, *D. complanatus* Zone, Linn Branch, Dob's Linn.

FIGURE

A. HM L14653. Pedicle valve. (x10)

B. HM L11794/1. General view of brachial valve. (x10)

C. HM L11794/1. Detail of umbo showing pitting. (x25)

D. HM L14634a. Detail of pit moulds and a 'pustule' mould. (x250)

E. HM L11794/1. Detail of pit moulds and laminar shell. (x250)

F. HM L14634a. Detail of umbo showing pitting. (x50)

G. HM L14634a. General view of brachial valve. (x10)

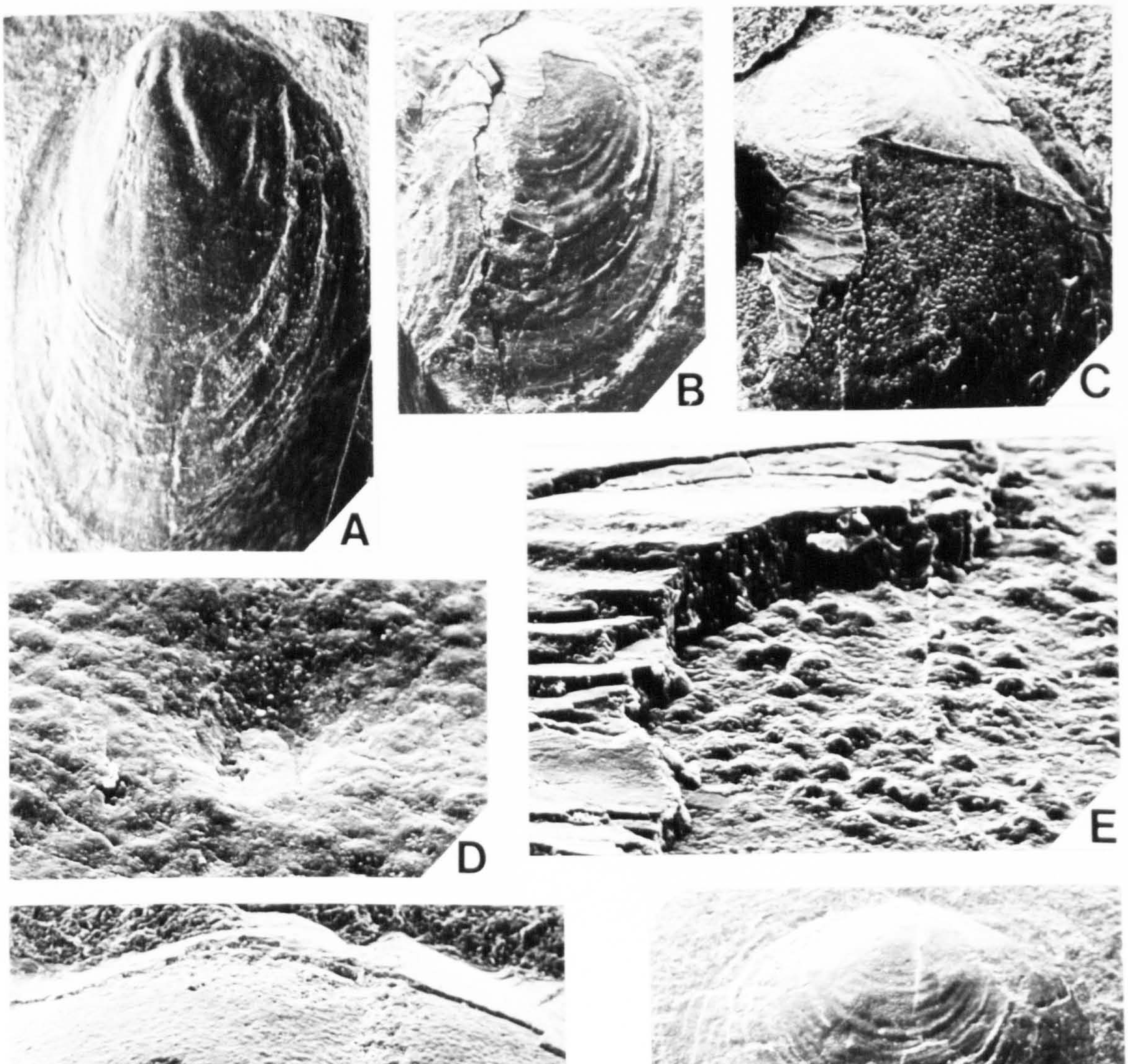
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PLATE 4

Barbatulella _lacunosa_ gen. _et_ sp. nov.

Fig. B, C, F, G. SEM micrographs.

All from just above the upper Complanatus Band, Upper Hartfell Shale, _D._ _complanatus_ Zone, Linn Branch, Dob's Linn.

FIGURE

A. HM L14647b. General view of pedicle valve associated with strand. (x5)

B. HM L14647a. Oblique view of counterpart showing radial struts. (x50)

C. HM L14647a. Detail of struts showing pits between. (x100)

D. HM L14631a. Exterior view of pedicle valve. (x6)

E. U.C.W. 10928. Incomplete specimen of articulated valves (x10)

F. HM L14652. General view of brachial valve. (x8)

G. HM L14652. Detail of pit moulds and shell near umbo. (x250)

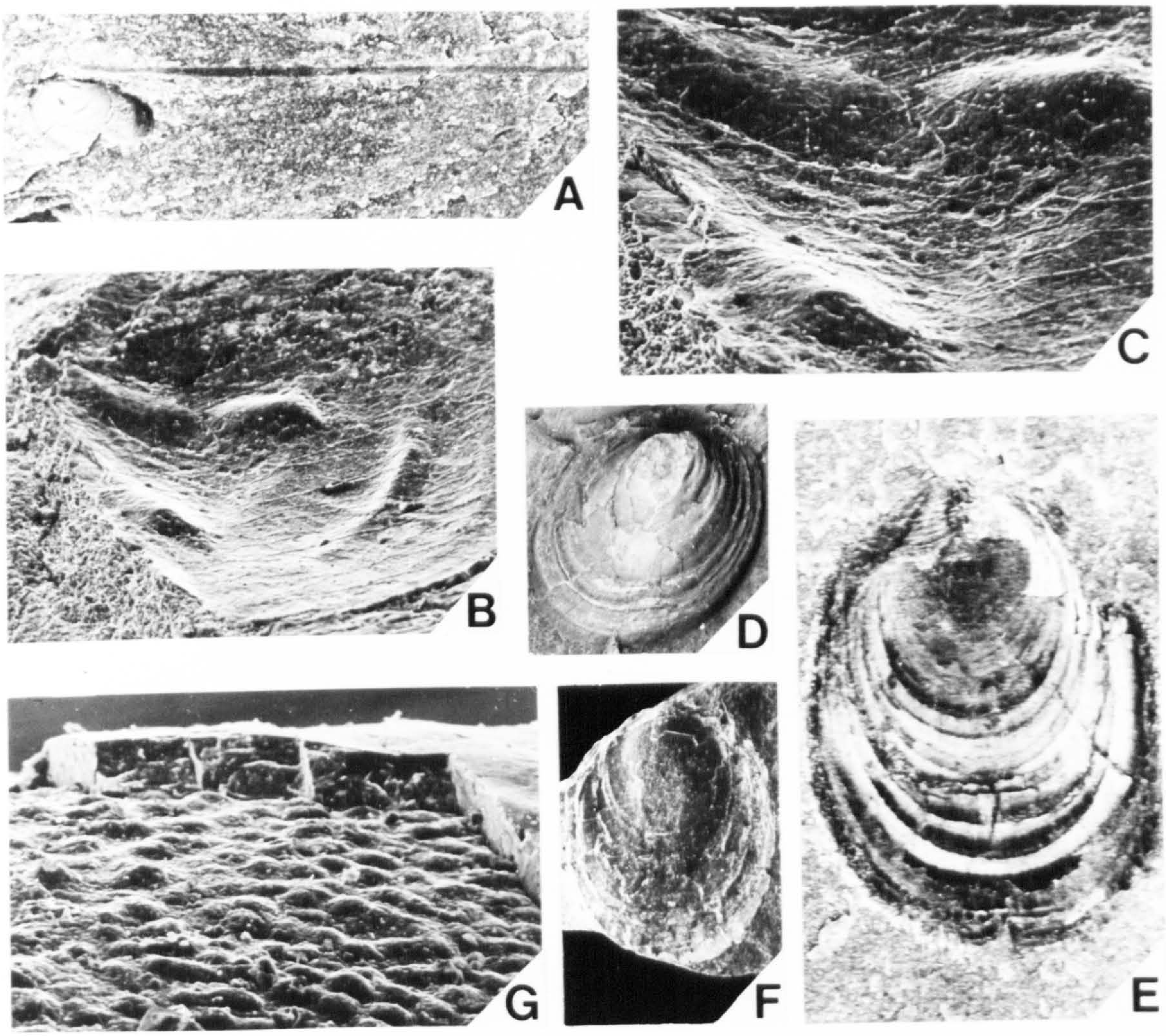
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PLATE 5 (cont.)

Conodonts from Dob's Linn (all x25)

FIGURE

15. HM Y142. N. gen. A (platform element). 0.15 - 0.2m above base of Birkhill Shale, G. persculptus Zone, Linn Branch trench.

16. HM Y143/1. ?Dapsilodus sp. 0.85 - 0.96m above base of Birkhill Shale, G. persculptus Zone, Linn Branch trench.

17. HM Y144. ?spathognathodiform element. 0.85 - 0.96m above base of Birkhill Shale, G. persculptus Zone, Linn Branch trench.

(all identifications by Prof. C.R. Barnes)

PLATE 5

Conodonts from Dob's Linn. (all x25)

FIGURE

1. HM Y141. Protopanderodus liripipus Kennedy et al. Anceps Band E, Upper Hartfell Shale, P. pacificus Subzone, Main Cliff section.
2. HM Y120. ?Panderodus sp. Anceps Band C, Upper Hartfell Shale, P. pacificus Subzone, Main Cliff section.
3. HM Y138a. Simple cone indet. Anceps Band E, Upper Hartfell Shale, P. pacificus Subzone, Long Burn trench.
4. HM Y106. Scabbardella sp. Anceps Band A, Upper Hartfell Shale, D. complexus Subzone, Main Cliff section.
5. HM Y121. Protopanderodus liripipus Kennedy et al. Anceps Band C, Upper Hartfell Shale, P. pacificus Subzone, Main Cliff section.
6. HM Y109a. Protopanderodus liripipus Kennedy et al. Anceps Band A, Upper Hartfell Shale, D. complexus Subzone, Long Burn trench.
7. HM Y119/1a. Simple cone indet. cf. Walliserodus sp. Anceps Band C, Upper Hartfell Shale, P. pacificus Subzone, Main Cliff section.
8. HM Y126. Scabbardella cf. altipes (Henningsmoen). Anceps Band D, Upper Hartfell Shale, P. pacificus Subzone, Long Burn trench.
9. HM Y117. Ramiform element of Amorphognathus ordovicicus Branson & Mehl, Anceps Band C, Upper Hartfell Shale, P. pacificus Subzone, Main Cliff section.
10. Specimen lost. A. ordovicicus. Anceps Band B, Upper Hartfell Shale, D. complexus Subzone, Main Cliff section.
11. HM Y136. Amorphognathus sp. Anceps Band E, Upper Hartfell Shale, P. pacificus Subzone, Linn Branch trench.
12. HM Y111. Amorphognathus sp. Anceps Band B, Upper Hartfell Shale, D. complexus Subzone, Main Cliff section.
13. HM Y129. Amorphognathus ordovicicus Branson & Mehl. Anceps Band D, Upper Hartfell Shale, P. pacificus Subzone, Main Cliff section.
14. HM Y107. A. ordovicicus. Anceps Band A, Upper Hartfell Shale, D. complexus Subzone, Long Burn trench.

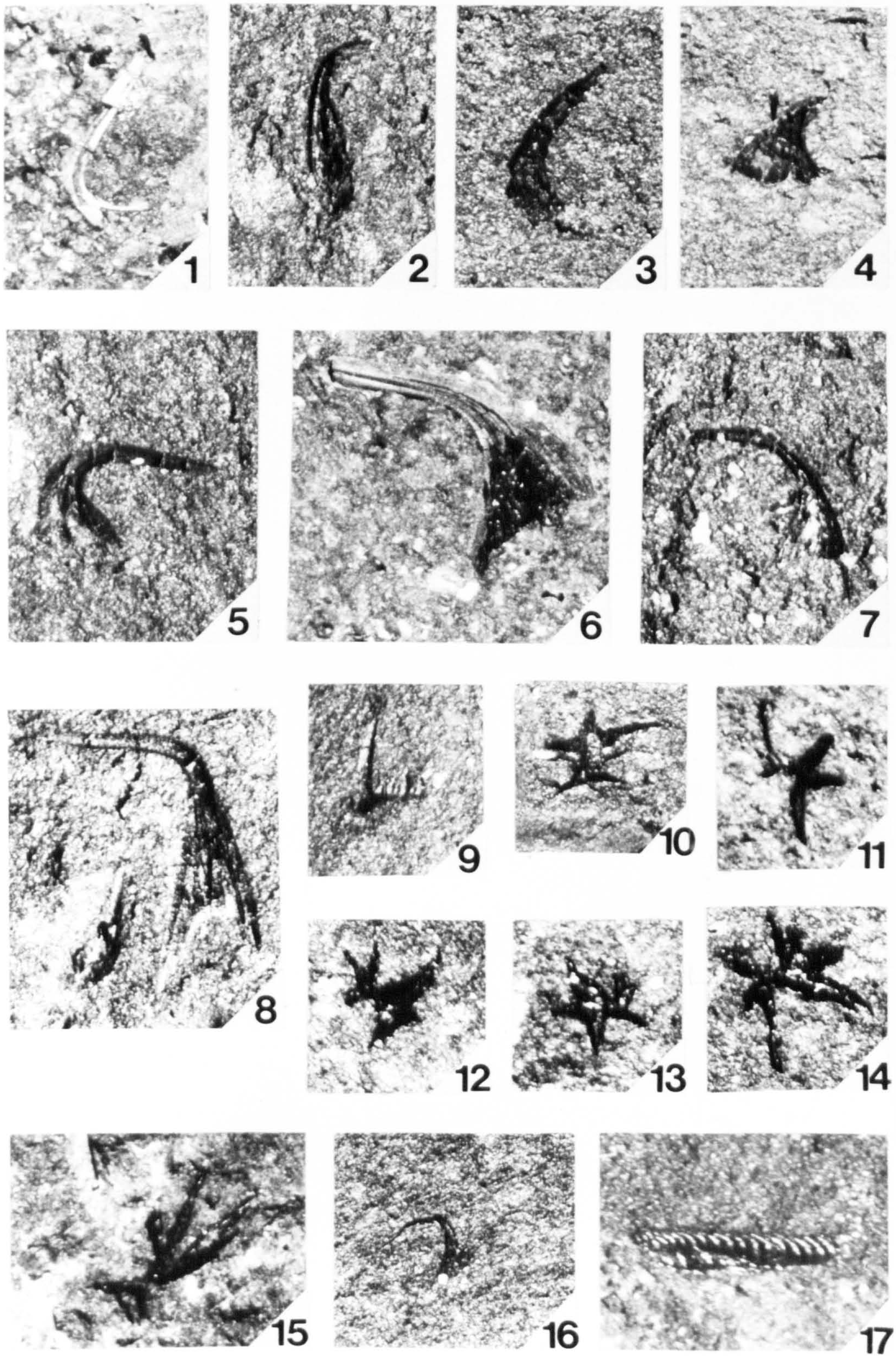
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PLATE 6

Dawsonia campanulata Nicholson 1873. (all x10)

All specimens from the O? acuminatus Zone, Dob's Linn.

All from the Linn Branch trench, except those from the Rickards Collection which come from the Main Cliff.

1. HM X375. Anterior neck preserved in relief, showing original hollow nature of body. 2.01 - 2.14m above base of Birkhill Shale.
2. HM X316/1. Anterior with transverse (preservational?) grooves. Rickards Coll.
3. HM X373. 2.01 - 2.14m above base of Birkhill Shale.
4. HM X372. Large complete specimen with typically well defined anterior and diffuse posterior margins. 2.01 - 2.14m above base of Birkhill Shale.
5. HM X368/7. 1.88 - 2.0m above base of Birkhill Shale.
6. HM X368/5. 1.88 - 2.0m above base of Birkhill Shale.
7. HM X368/6. 1.88 - 2.0m above base of Birkhill Shale.
8. HM X316/3. Rickards Coll.
9. HM X371a. Very large specimen with diffuse margins. 2.01 - 2.14m above base of Birkhill Shale.
10. HM X368/1. 1.88 - 2.0m above base of Birkhill Shale.
11. HM X370. Specimen with distinctive posterior 'notch'. 2.01 - 2.14m above base of Birkhill Shale.
12. HM X368/2. 1.88 - 2.0m above base of Birkhill Shale.
13. HM X316/2. Rickards Coll.
14. HM X374a. 2.01 - 2.14m above base of Birkhill Shale.
15. HM X316/7. Rickards Coll.

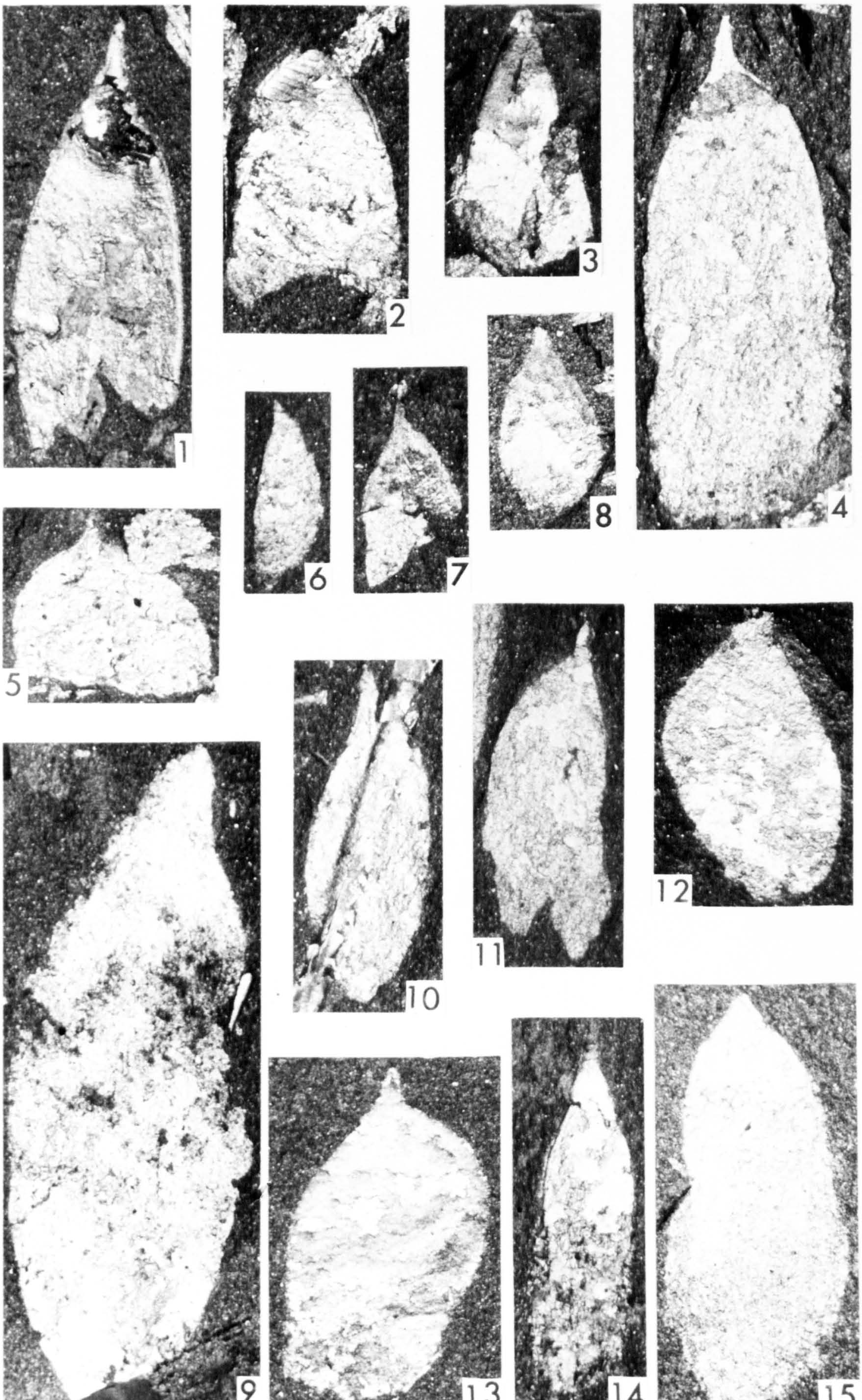


PLATE 7.

Miscellaneous ?algae.

All from the Linn Branch trench, Dob's Linn.

FIGURE

1. HM X365a. Coiled filamentous strand. 1.2 - 1.32m above base of Birkhill Shale, _G. persculptus_ Zone. (x5)
2. HM X364a. 'Horseshoe-shaped' specimen. Anceps Band B, Upper Hartfell Shale, _D. complexus_ Subzone. (x5)
3. HM X362. Structureless, slightly tapering fragment. Anceps Band B, Upper Hartfell Shale, _D. complexus_ Subzone. (x5)
4. HM X367. Sub-circular filamentous mass. 1.56 - 1.66 m above base of Birkhill Shale, _G. persculptus_ Zone. (x5)
5. HM X366a. Filamentous mass. 1.2 - 1.32m above base of Birkhill Shale, _G. persculptus_ Zone. (x10)
6. HM X369/1-nb. _Dawsonia campanulata_ Nicholson 1873. Plane crowded with specimens. 2.01 - 2.14m above base of Birkhill Shale, _O? acuminatus_ Zone. (x3)

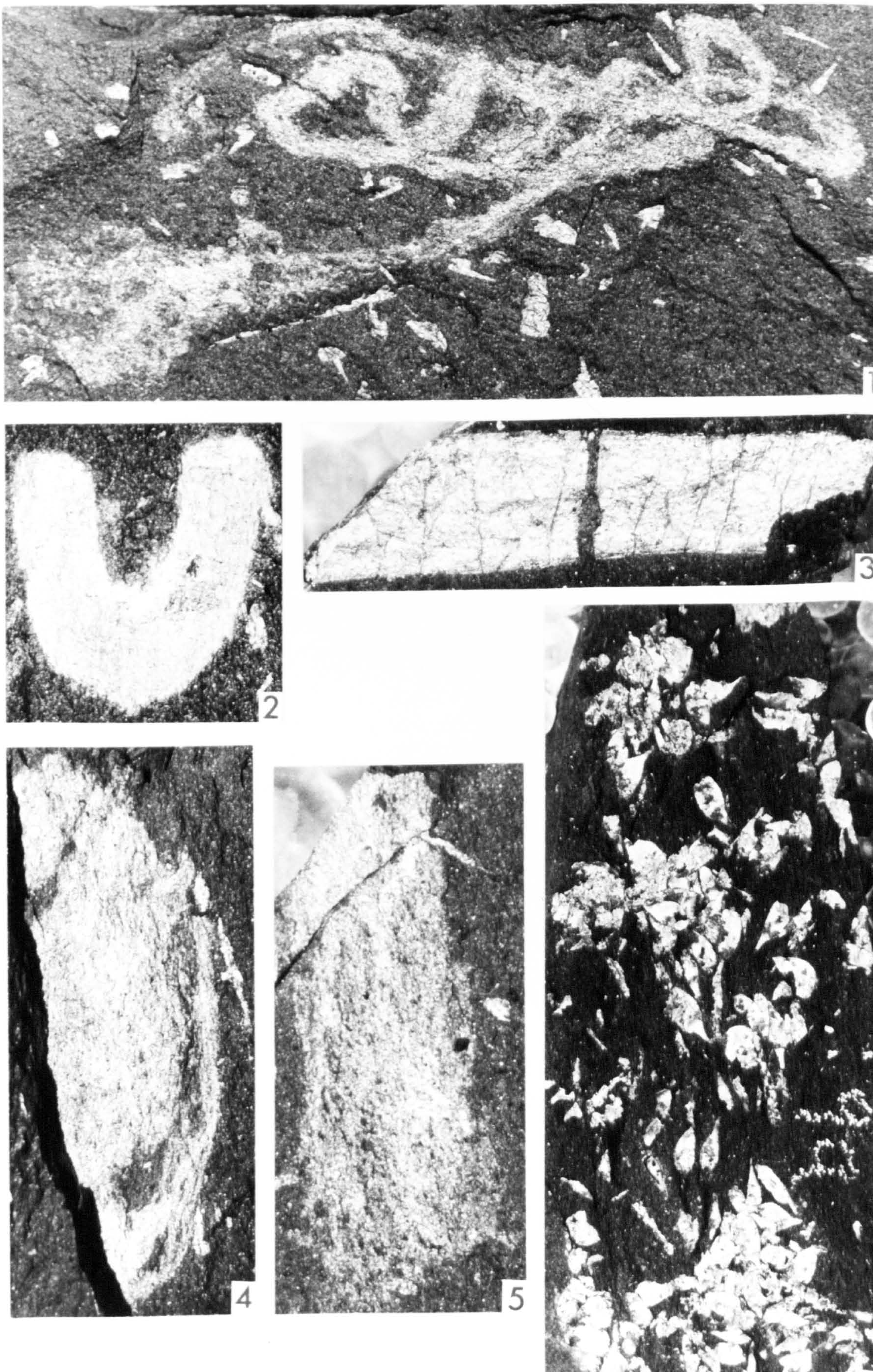


PLATE 8

FIGURE

1. HM X222. Scolecodont. Anceps Band E, Upper Hartfell Shale, *P. pacificus* Subzone, Linn Branch trench, Dob's Linn. (x25)

2. Lapworth's specimen of an 'eurypterid' from the Lower Hartfell Shale, Dob's Linn. Lapworth Collection (Birmingham University). Considered here to be of algal origin (cf. pl. 7). (x2)

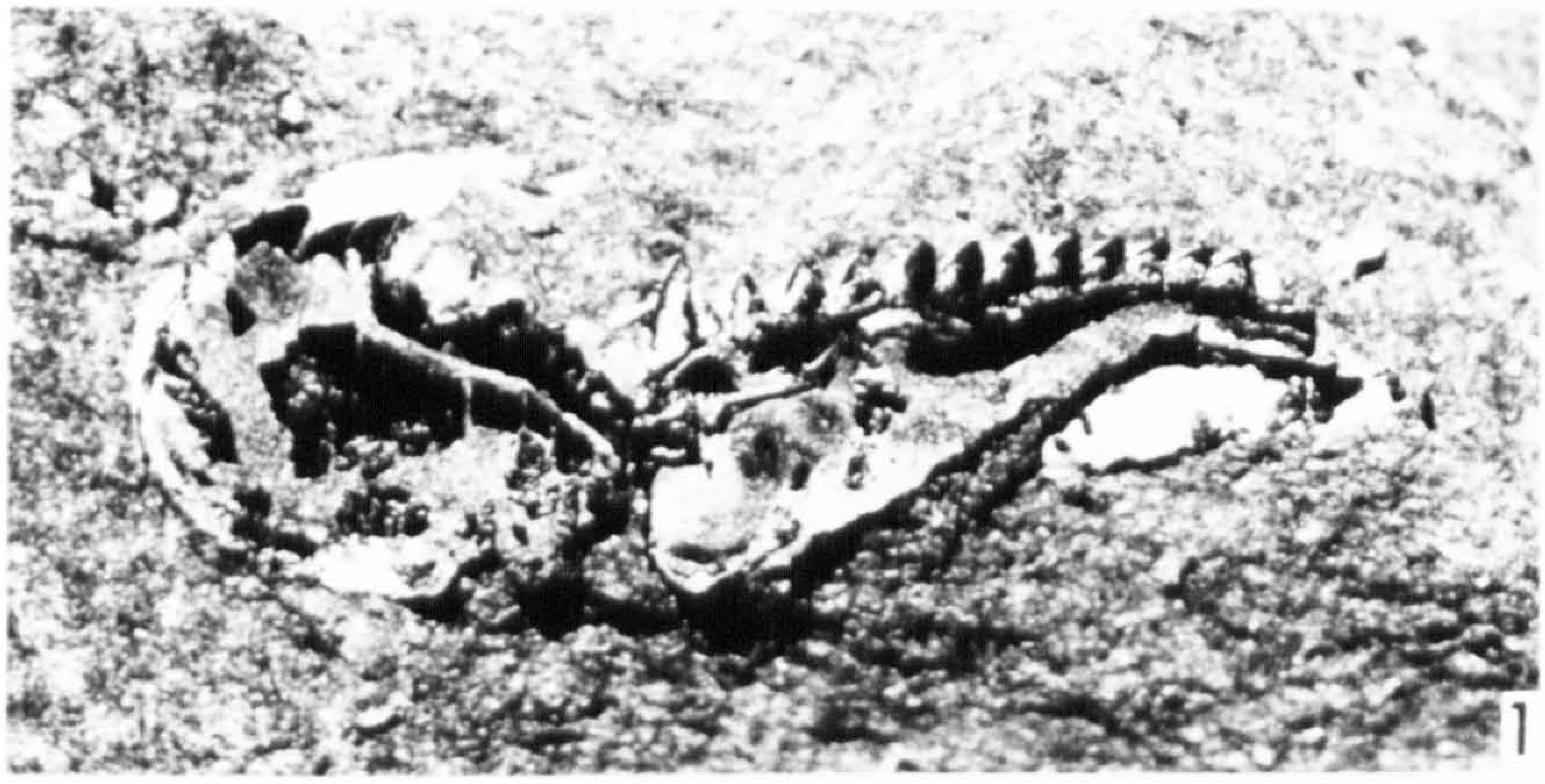


PLATE 9.

Deformation styles of graptolite rhabdosomes resulting from diagenetic flattening.

FIGURE

1 - 8. HM C14483/1-8. Transversely sectioned diplograptid stipes in a slab of silty limestone from Laggan Burn, Girvan (coll. A.T. Kearsley). Rhabdosomes vary from almost full relief (fig. 1) to flattened (fig. 8). Note that deformation in this slab is partly controlled by sedimentary grains.

9 - 20. Sections of cylinders constructed for the first experiment concerning diagenetic flattening (chapter 6.5.3), showing accurate transverse sections before and after compression.

Materials used to construct cylinders:

9. Thin denture repair resin (plaster filled).

10. Resin and cigarette paper (plaster filled).

11. Thick resin (hollow).

12. Resin, filled with polyurethane foam (plaster filled).

13. Plastic drinking straw (plaster filled).

14. Straw, filled with foam (plaster filled).

15. Straw, filled with foam and given thecal apertures (plaster filled).

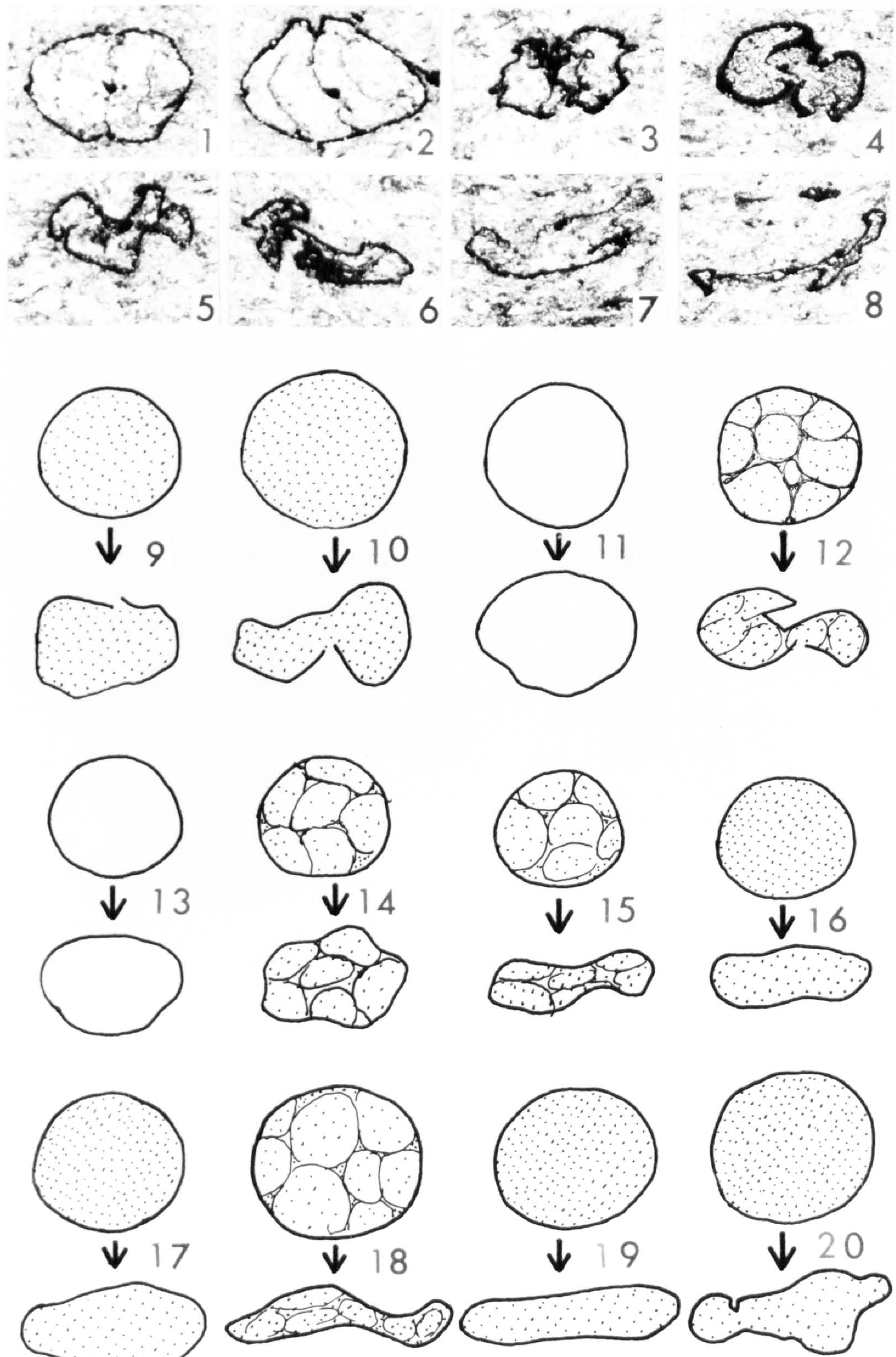
16. Straw and 'Super Glue' (plaster filled).

17. Thin card (plaster filled).

18. Masking tape, filled with foam (plaster filled).

19. Masking tape (plaster filled).

20. Paper and 'Super Glue' (plaster filled).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Changes in thecal style resulting from diagenetic flattening.

FIGURE

17. HM C13947. Climacograptus normalis Lapworth 1877. External mould in partial relief, in oblique view. Note preservational median fold. 1.88 - 2.0m above base of Birkhill Shale, O? acuminatus Zone, Linn Branch trench, Dob's Linn. Complete specimen figured pl. 36, fig. 7. (x10)

18. HM C13972. C. normalis. External mould in partial relief, in oblique view. Note longitudinal collapse groove. 1.88 - 2.0m above base of Birkhill Shale, O? acuminatus Zone, Linn Branch trench, Dob's Linn. Complete specimen figd. pl. 34, fig. 7. (x10)

19. HM C13787a. C. normalis. Flattened, scalariform view. Note apertures do not extend across total width of rhabdosome. 0.7 - 0.85m above base of Birkhill Shale, G. persculptus Zone, Linn Branch trench, Dob's Linn. Complete specimen figd. pl. 36, fig. 11. (x10)

20. HM C13002. Orthograptus ex gr. calcaratus. External mould in partial relief, dorso-ventral view. Note formation of preservational 'medium septum' in an aseptate rhabdosome. Dark Shale Member, Mill Formation, Upper Whitehouse Group, P. linearis/D. complanatus zone, Myoch Bay, Girvan. Complete specimen figd. pl. 45, fig. 8. (x10)

PLATE 10

Changes in thecal style resulting from diagenetic flattening. Models from second experiment (chapter 6.5.4).

FIGURE

1 - 6. Denture repair resin models of Dicellograptus complanatus thecae before and after compression in dorso-ventral view (figs. 1-2), oblique view (figs. 3-4) and scalariform view (figs. 5-6). Note 'squaring-up' of thecae and disappearance of prothecal folds in fig. 1 (cf. figs. 7-8), additional lateral spread at apertures giving 'stepped appearance to ventral margin in fig. 4 (cf. fig. 9) and lack of lateral spread in fig. 6 (cf. pl. 24, figs. 1-5, D. complexus). (all x1/2)

7. HM C772/2. Dicellograptus complanatus Lapworth 1880. Detail of th10-11 in relief (see pl. 23, fig. 4 for complete specimen). Dark Shale Member, Mill Formation, Upper Whitehouse Group, P. linearis/D. complanatus zone, Myoch Bay, Girvan. Ingham Collection. (x25)

8. BU 1074. D. complanatus. Flattened internal mould of early thecae. Note 'squared-up' apertures and prominent inter-thecal septal nodes. Lower Complanatus Band, Upper Hartfell Shale, D. complanatus Zone, Dob's Linn. Lapworth Collection. Figd. Briggs & Williams (1981, fig. 2c), complete specimen figd. Elles & Wood (1904, text-fig. 84a). (x25)

9. HM C14464/10. D. complanatus. Flattened external mould in oblique orientation, showing 'stepped' ventral wall due to greater lateral spread at apertures. Lower Complanatus Band, Upper Hartfell Shale, D. complanatus Zone, west of North Cliff trench, Dob's Linn. (x25)

10 - 15. Denture repair resin models of an aseptate diplograptid distal portion before and after compression in dorso-ventral view (figs. 10-11), oblique view (figs. 12-13) and scalariform view (figs. 14-15). (all x1/2)

16. HM C13955a. Climacograptus normalis Lapworth 1877. External mould in relief, slightly oblique view. 1.88 - 2.0m above base of Birkhill Shale, O? acuminatus Zone, Linn Branch trench, Dob's Linn. Complete specimen figd. pl. 35, fig. 1. (x10)

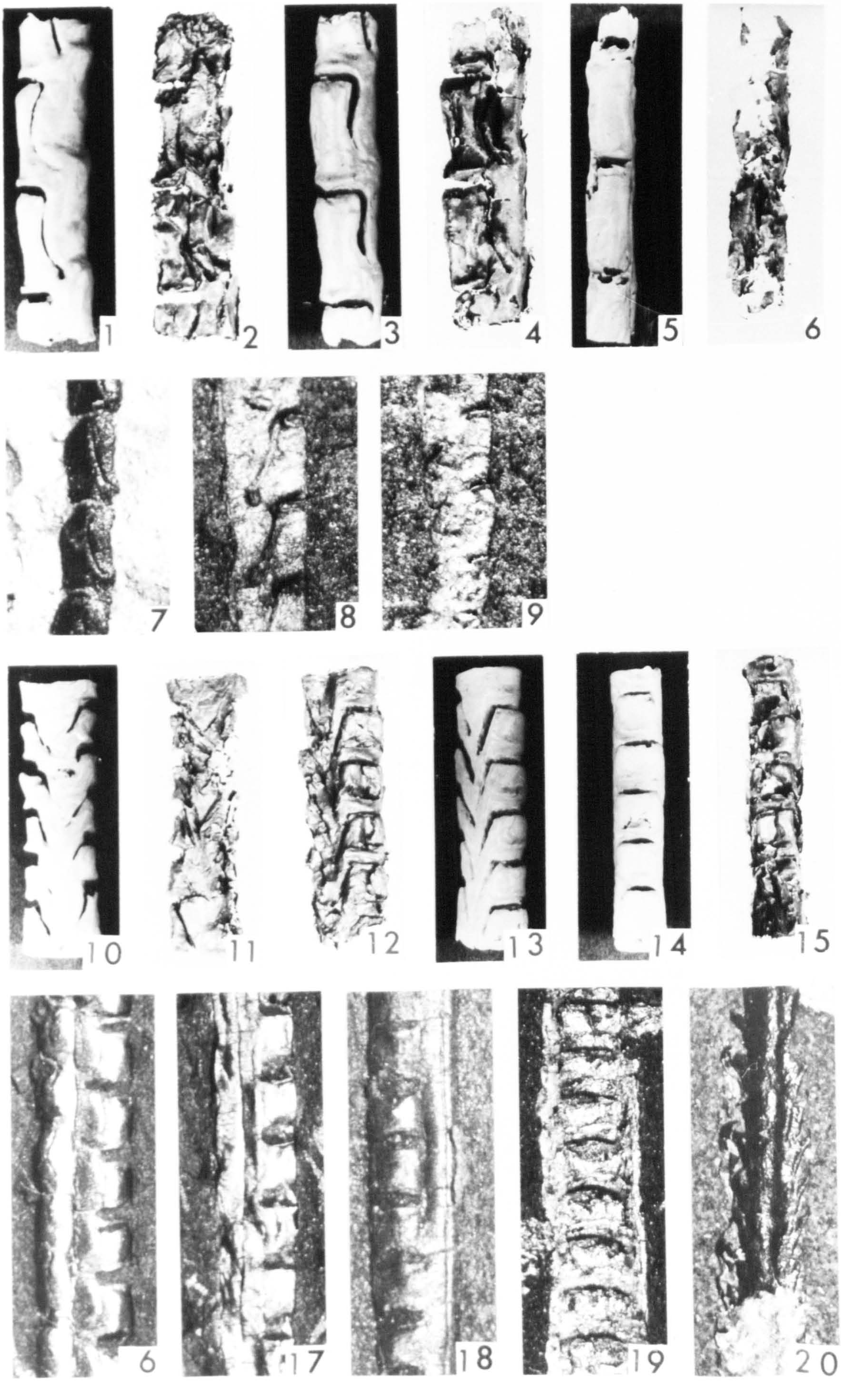
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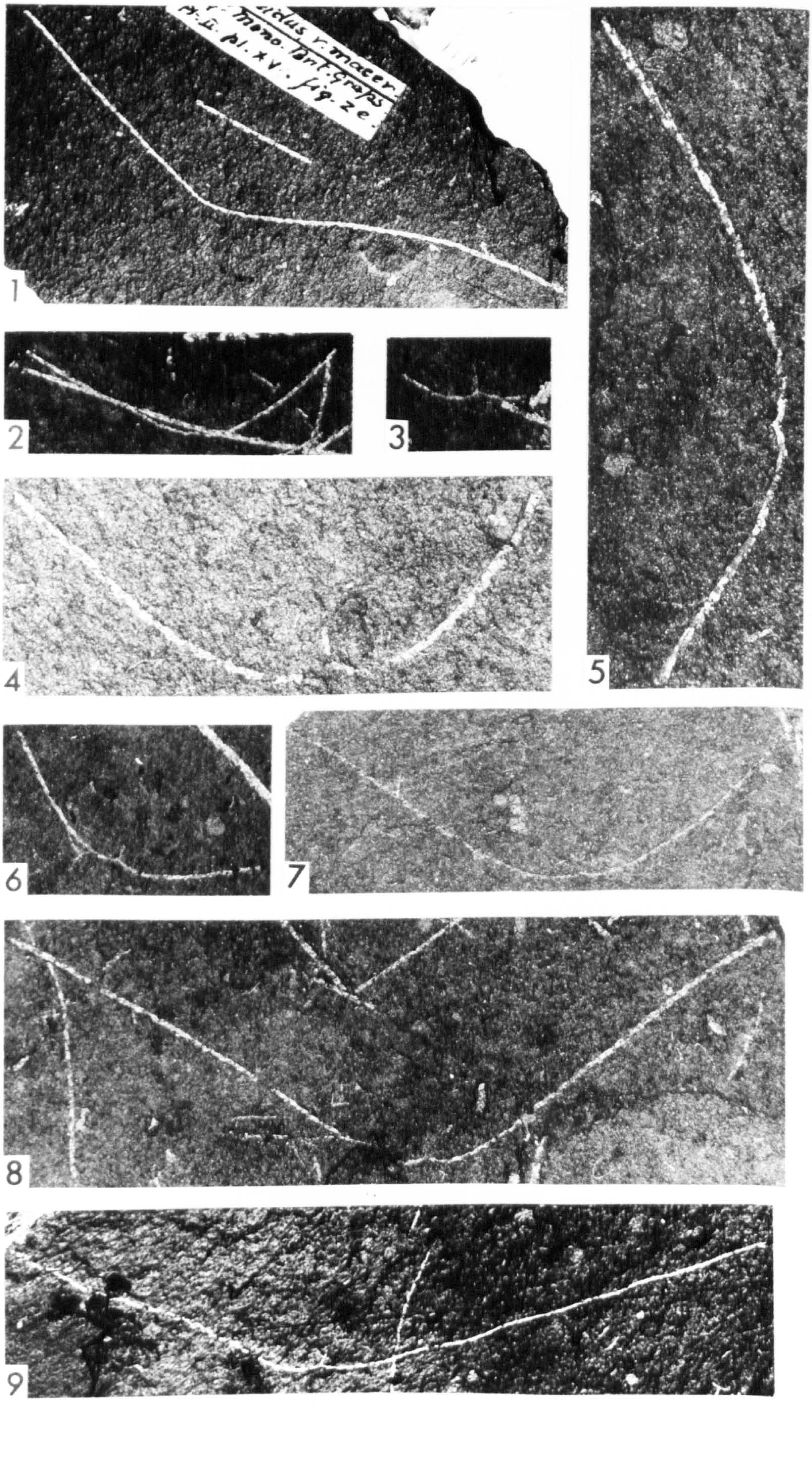
PLATE 11

Leptograptus flaccidus macer Elles & Wood 1903.

FIGURE

1. BU 1377. Proposed lectotype. Lower Hartfell Shale, P. linearis Zone, Hartfell Spa. Wood Collection. Figd. Elles & Wood 1903, pl. 15, fig. 2e. (x2)
2. HM C14341/2b. 2.9 - 2.75m below top of Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn. (x2.5)
3. HM C14341/3b. Juvenile specimen with long complete sicula. 2.9 - 2.75m below top of Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn. (x2.5)
4. HM C14326. 3.0 - 2.75m below top of Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn. (x5)
5. HM C14343/1a. 2.9 - 2.75m below top of Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn. (x5)
6. HM C14341/1b. 2.9 - 2.75m below top of Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn. (x2.5)
7. HM C14339a. 3.0 - 2.9m below top of Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn. (x2.5)
8. HM C14343/2a. 2.9 - 2.75m below top of Lower Hartfell Shale, P. linearis Zone, North Cliff trench, Dob's Linn. (x2.5)
9. BU 1376a. Hartfell Shale, Hartfell Spa. Wood Collection. Figd. Elles & Wood 1903, pl. 15, fig. 2c.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...tidus v. macer.
Mono. Brit. Grapts
pl. xv. fig. 2e.

PLATE 12

Pleurograptus linearis linearis (Carruthers 1858).

All from middle to upper P. linearis Zone.

FIGURE

1. Q 848. Holotype (the left-hand specimen). Lower Hartfell Shale, Hartfell Spa. Carruthers Collection. Figd. Carruthers 1858, text-fig. 1, Strachan 1969, pl. 2, fig. 1. (x1)
2. HM C14444. Narrow main stipe (preserved in relief) with two wider secondary branches (due to lateral spread on diagenetic flattening). 1.0 - 0.9m below top of Lower Hartfell Shale, North Cliff trench, Dob's Linn. (x2.5)
3. HM C14407a. Narrow main stipe in relief with several flattened secondary branches. 1.8 - 1.5m below top of Lower Hartfell Shale, North Cliff trench, Dob's Linn. (x2.5)
4. HM C14449a. Small fragment. 0.9 - 0.7m below top of Lower Hartfell Shale, North Cliff trench, Dob's Linn. (x2.5)
5. HM C14412/1. Right hand primary branch with sicula on left of photograph. Well preserved flattened thecae. 1.8 - 1.5m below top of Lower Hartfell Shale, North Cliff trench, Dob's Linn. (x5)
6. HM C14412/2. Proximal portion with sicula. 1.8 - 1.5m below top of Lower Hartfell Shale, North Cliff trench, Dob's Linn. (x5)
7. HM C14412/3. Proximal portion with sicula. 1.8 - 1.5m below top of Lower Hartfell Shale, North Cliff trench, Dob's Linn. (x5)
8. HM C14404a. Fragment of main branch in partial relief. 2.0 - 1.8m below top of Lower Hartfell Shale, North Cliff trench, Dob's Linn. (x5)

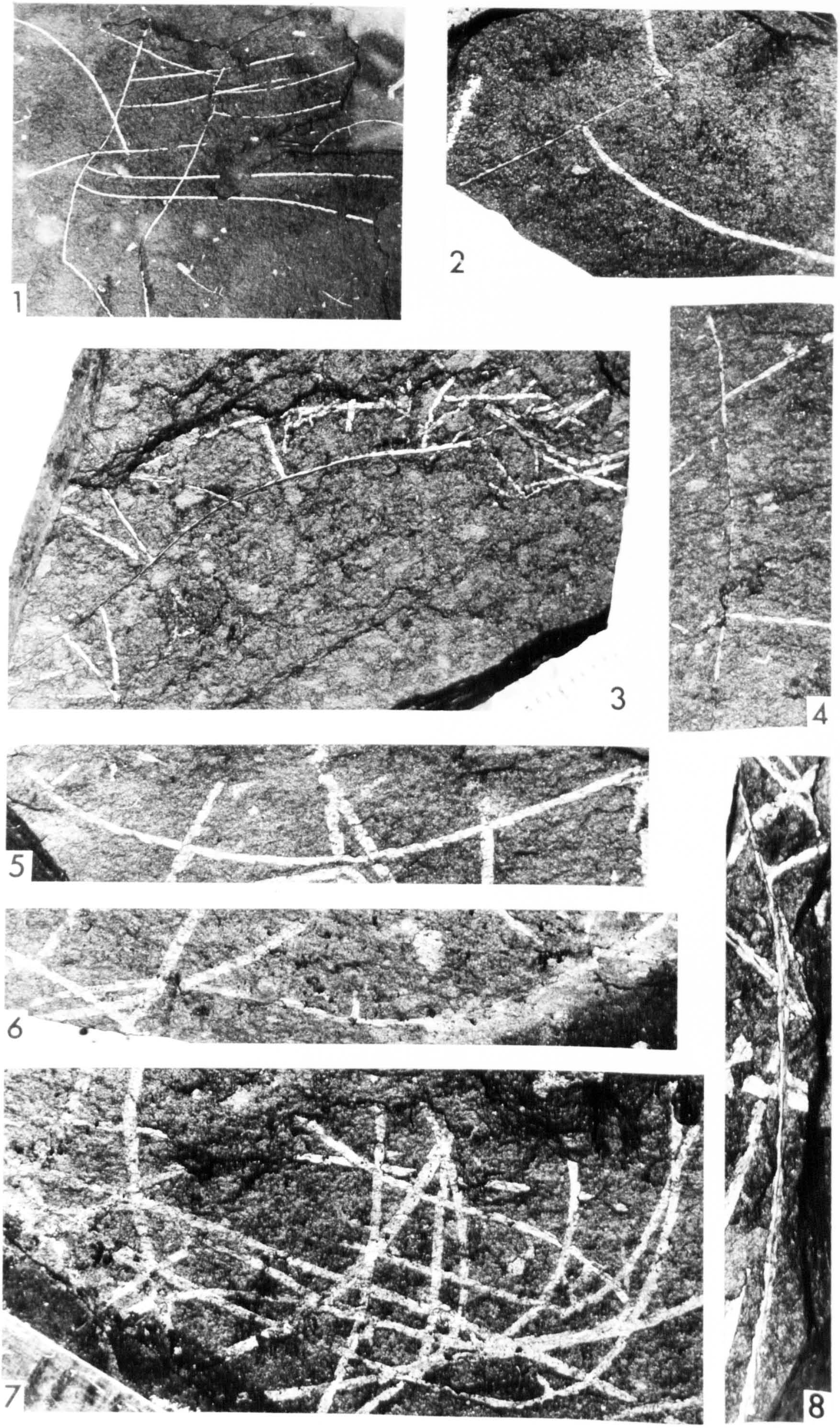
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PLATE 13

<u>Pleurograptus</u> <u>lui</u> Mu 1950. (all x10 except fig. 1)

All specimens from the Anceps Bands, Upper Hartfell Shale, Dob's Linn.

FIGURE

1. HM C13565b. Large rhabdosome with two secondary stipes. Band D, <u>P.</u> <u>pacificus</u> Subzone, Linn Branch trench. (x15)
2. HM C13216. Distal fragment. Band A, <u>D.</u> <u>complexus</u> Subzone, Linn Branch trench.
3. HM C13175/1. Distal fragment. Band A, <u>D.</u> <u>complexus</u> Subzone, Linn Branch trench.
4. HM C13398. Distal fragment. Band B, <u>D.</u> <u>complexus</u> Subzone, Long Burn trench.
5. HM C13233a. Distal fragment. Band A, <u>D.</u> <u>complexus</u> Subzone, Long Burn trench.
6. HM C13328. Juvenile with almost complete sicula. Band B, <u>D.</u> <u>complexus</u> Subzone, Main Cliff section.
7. HM C13404. Sicula with prominent virgella. Band B, <u>D.</u> <u>complexus</u> Subzone, Long Burn trench.
8. HM C13165. Proximal end with sicula. Band A, <u>D.</u> <u>complexus</u> Subzone, Linn Branch trench.

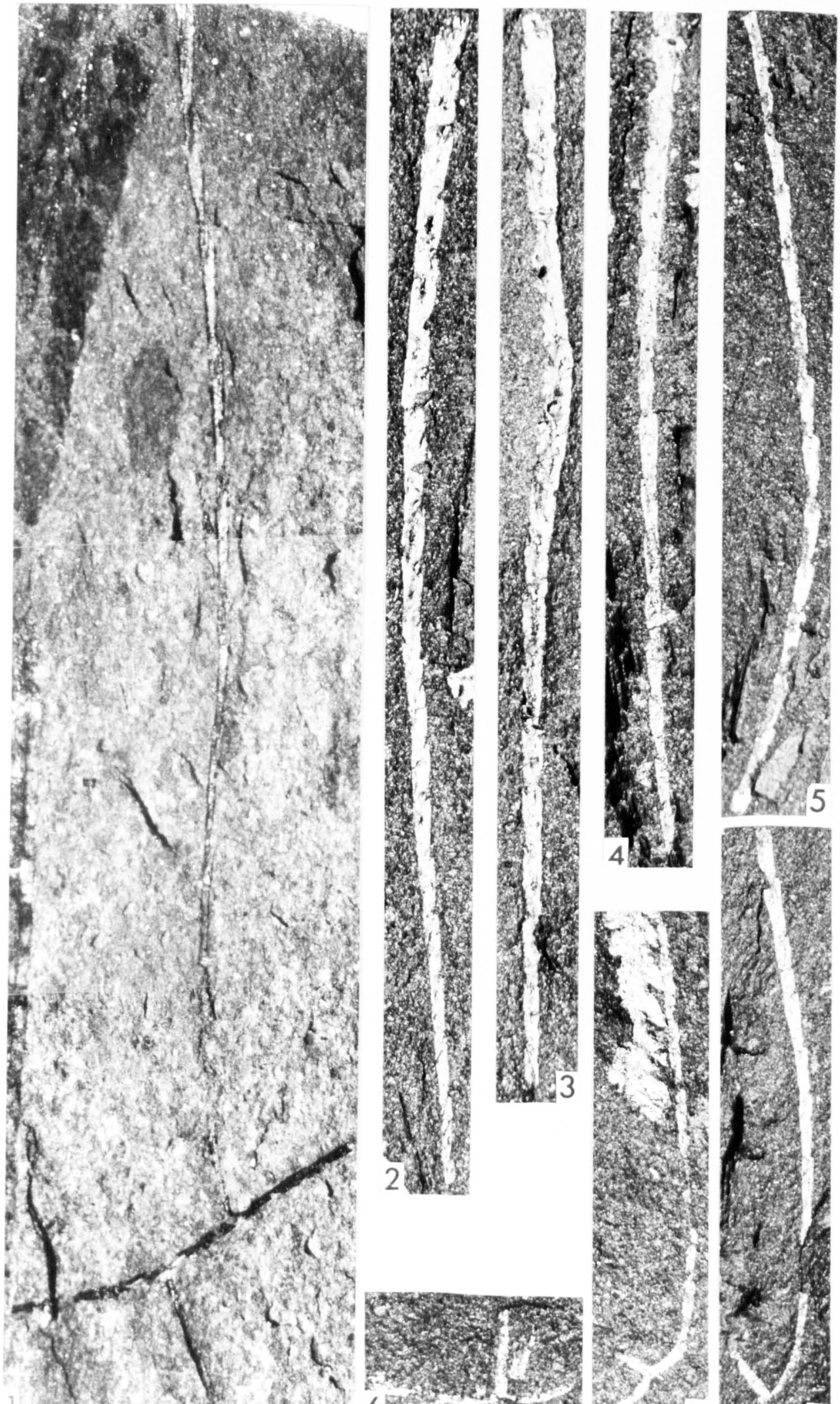
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PLATE 14

<u>Amphigraptus</u> <u>divergens</u> <u>divergens</u> (Hall 1859).

All from middle <u>P.</u> <u>linearis</u> Zone, North Cliff trench, Dob's Linn.

FIGURE

1. HM C14352a. Proximal detail showing resorbed(?) sicula and paired proximal secondary branching. 2.75 - 2.65m below top of Lower Hartfell Shale. (x10)
2. HM C14347a. Good specimen showing overall form and paired nature of secondary branching. 2.9 - 2.75m below top of Lower Hartfell Shale. Proximal detail shown in text-fig. 19a. (x2.5)
3. HM C14328/1b. Proximal fragment. 3.0 - 2.9m below top of Lower Hartfell Shale. (x10)
4. HM C14328/2-na. Several fragmentary specimens. 3.0 - 2.9m below top of Lower Hartfell Shale. (x2.5)

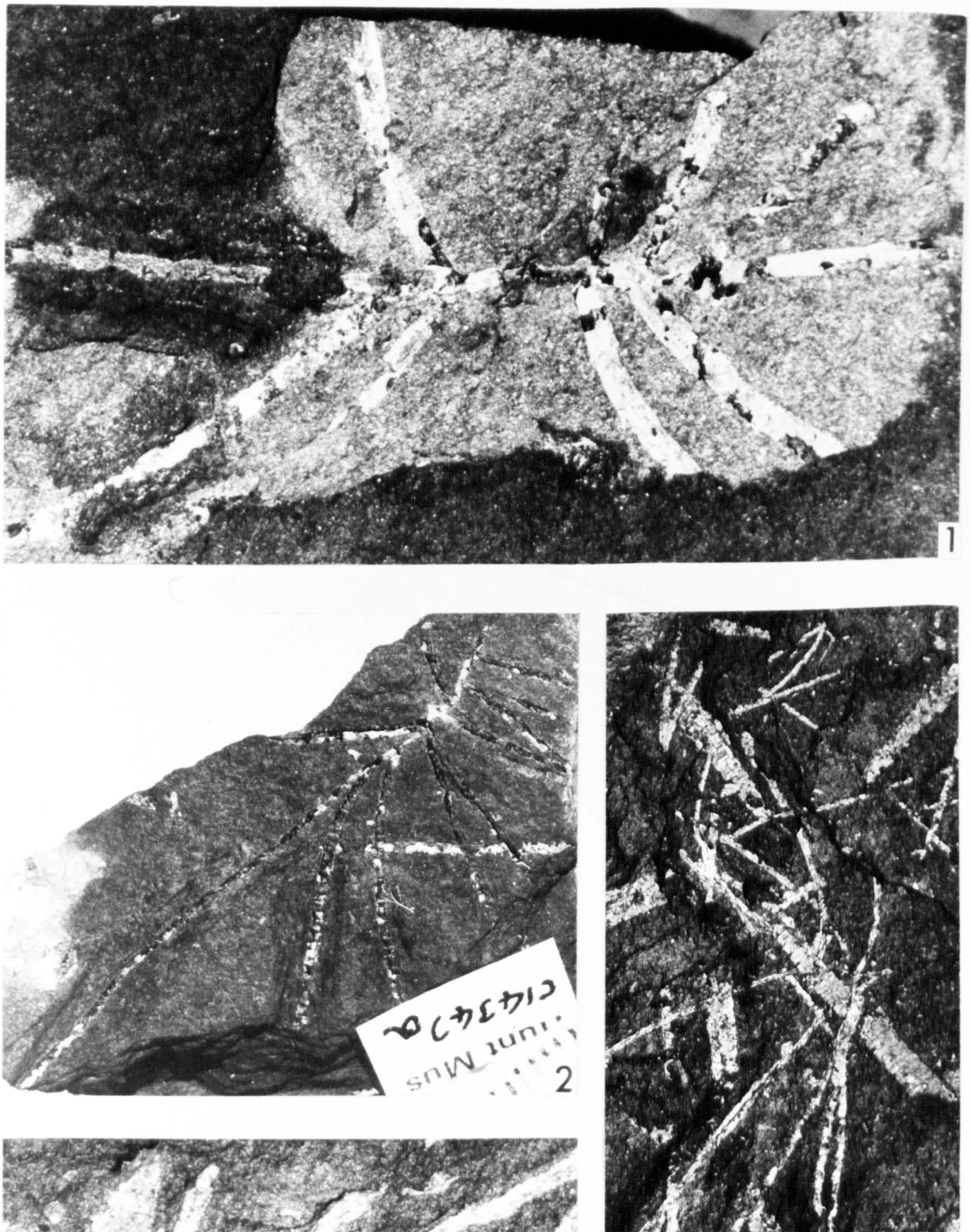


PLATE 15

Dicellograptus elegans elegans (Carruthers 1867a).

All from the Lower Hartfell Shale, (P. linearis Zone?).

FIGURE

1. BU 1110. General view of slab. Hartfell Spa. Lapworth Collection. Figd. Elles & Wood 1904, pl. 23, fig. 2e, text-fig. 100b. Proximal details figd. text-figs. 20a, f. (x2)

2. BU 1108. Proximal portion with complete sicula. Hartfell Spa. Lapworth Collection. Figd. Elles & Wood 1904, text-fig. 100a. Specimen also figd. text-fig. 20b. (x10)

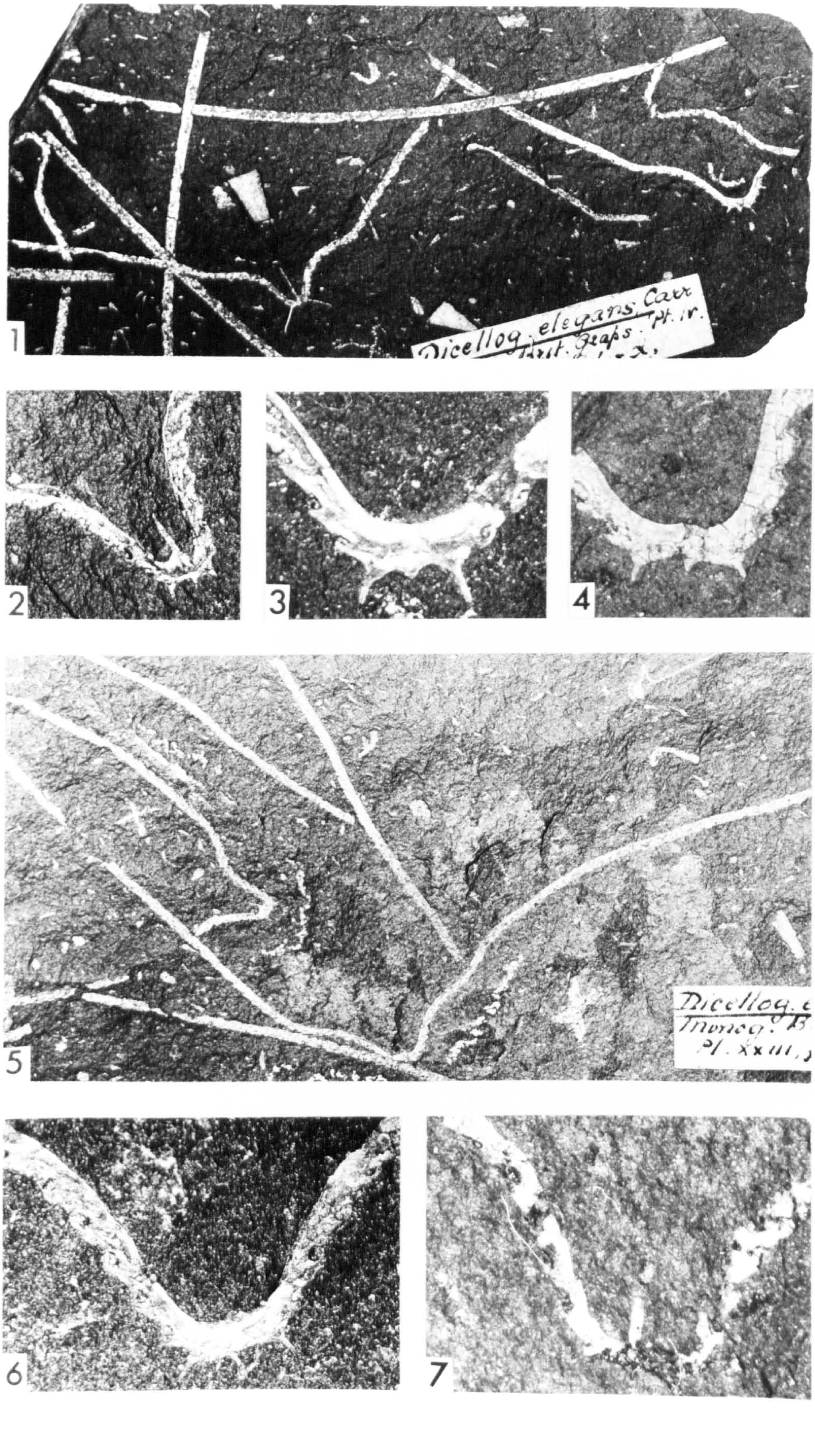
3. SM A19446. Proximal detail of resorbed sicula. Dob's Linn. Hopkinson Collection. (x10)

4. SM A19445. Proximal detail showing slight remnant of sicula. Dob's Linn. Hopkinson Collection. Figd. Hopkinson 1871, pl. 1, figs. 3c, d, Elles & Wood 1904, pl. 23, fig. 2c. (x10)

5. BU 1108. General view of slab. Dob's Linn. Lapworth Collection. Figd. Elles & Wood 1904, pl. 23, fig. 2d, text-fig. 100a. Proximal details figd. pl. 15, fig. 2, text-figs. 20b, d. (x2)

6. Q 850. Holotype, proximal detail showing base of sicula. Dob's Linn. Carruthers Collection. Figd. Carruthers 1867(a), pl. 2, fig. 16a, Elles & Wood 1904, pl. 23, fig. 2a, Strachan 1969, pl. 3, fig. 1. (x10)

7. HM C14359/1b. Proximal detail showing complete sicula. 2.25 - 2.15m below top of Lower Hartfell Shale, North Cliff trench, Dob's Linn. (x10)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Monog. B
Pl. XXIII,
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PLATE 16

Dicellograptus morrisi Hopkinson 1871.
All from the Lower Hartfell Shale.

FIGURE

1. SM A19399. Syntype. Hartfell Spa. Hopkinson Collection. (x5)
2. HM C14305/1-4. 4.75m below top of Lower Hartfell Shale, *P. linearis* Zone, North Cliff trench, Dob's Linn. (x2.5)
3. SM A19400. Syntype, showing crumpled stipes. Hartfell Spa. Hopkinson Collection. Figd. Hopkinson 1871, pl. 1, fig. 2c. (x5)
4. HM C14463a. Large specimen with straight stipes. 5.0m below top of Lower Hartfell Shale, *P. linearis* Zone, North Cliff trench, Dob's Linn. (x2.5)
5. HM C14325a. Large specimen showing slight double curvature on left hand stipe. 3.0 - 2.75m below top of Lower Hartfell Shale, *P. linearis* Zone, North Cliff trench, Dob's Linn. (x2.5)

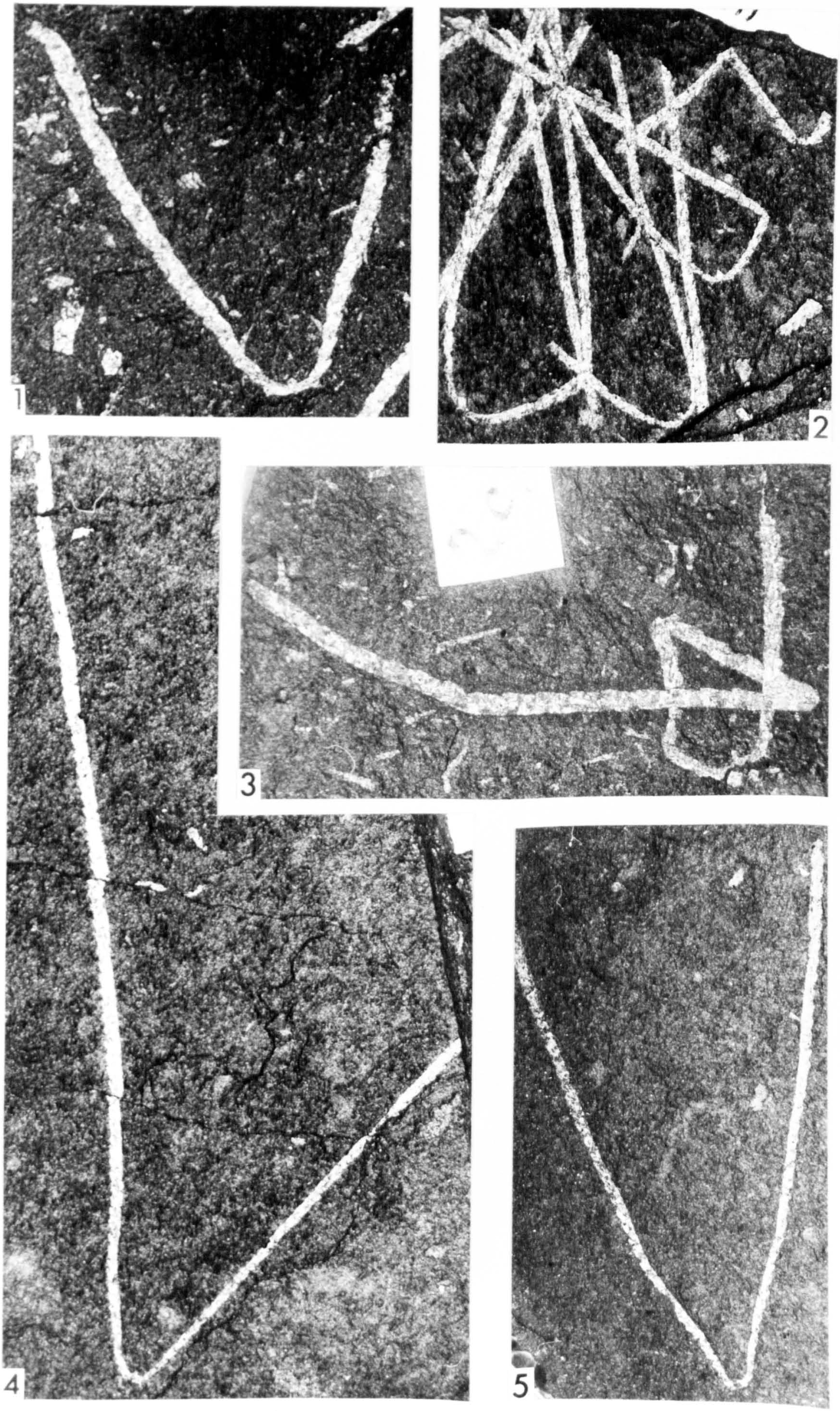
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PLATE 17

Dicellograptus anceps (Nicholson 1867a)

All from the Anceps Bands, Upper Hartfell Shale, Dob's Linn.

FIGURE

1. HM C13389a. Mature specimen with crossing stipes, associated with D. complexus (HM C13390a). Band B, D. complexus Subzone, Long Burn trench. (x5)
2. HM C13298a. Specimen with crossing stipes and almost complete sicula. Band B, D. complexus Subzone, Linn Branch trench. (x10)
3. HM C13324/1. Tectonically widened specimen with short distance to stipe crossing. Band B, D. complexus Subzone, Linn Branch trench. (x10)
4. HM C13616a. Sicula attached to right-hand stipe, axial membrane present. Band E, P. pacificus Subzone, Linn Branch trench. (x5)
5. HM C13495b. Juvenile(?) with complete, centrally placed sicula and conspicuous thecal spines. Band D, P. pacificus Subzone, Long Burn trench. Counterpart figd. text-fig. 21c. (x10)
6. HM C13345. Specimen with one stipe broken off (on part and counterpart) but with complete, bent sicula. Band B, D. complexus Subzone, Main Cliff section. (x10)
7. HM C13340a. Straight openly divergent stipes. Band B, D. complexus Subzone, Main Cliff section. (x5)
8. HM C13375a. Stipes subparallel (crossing distally in cpt.). Band B, D. complexus Subzone, Main Cliff section. (x10)
9. HM C13386. Straight openly divergent stipes, thecal spines prominent, associated with O? abbreviatus. Band B, D. complexus Subzone, Long Burn trench. (x5)

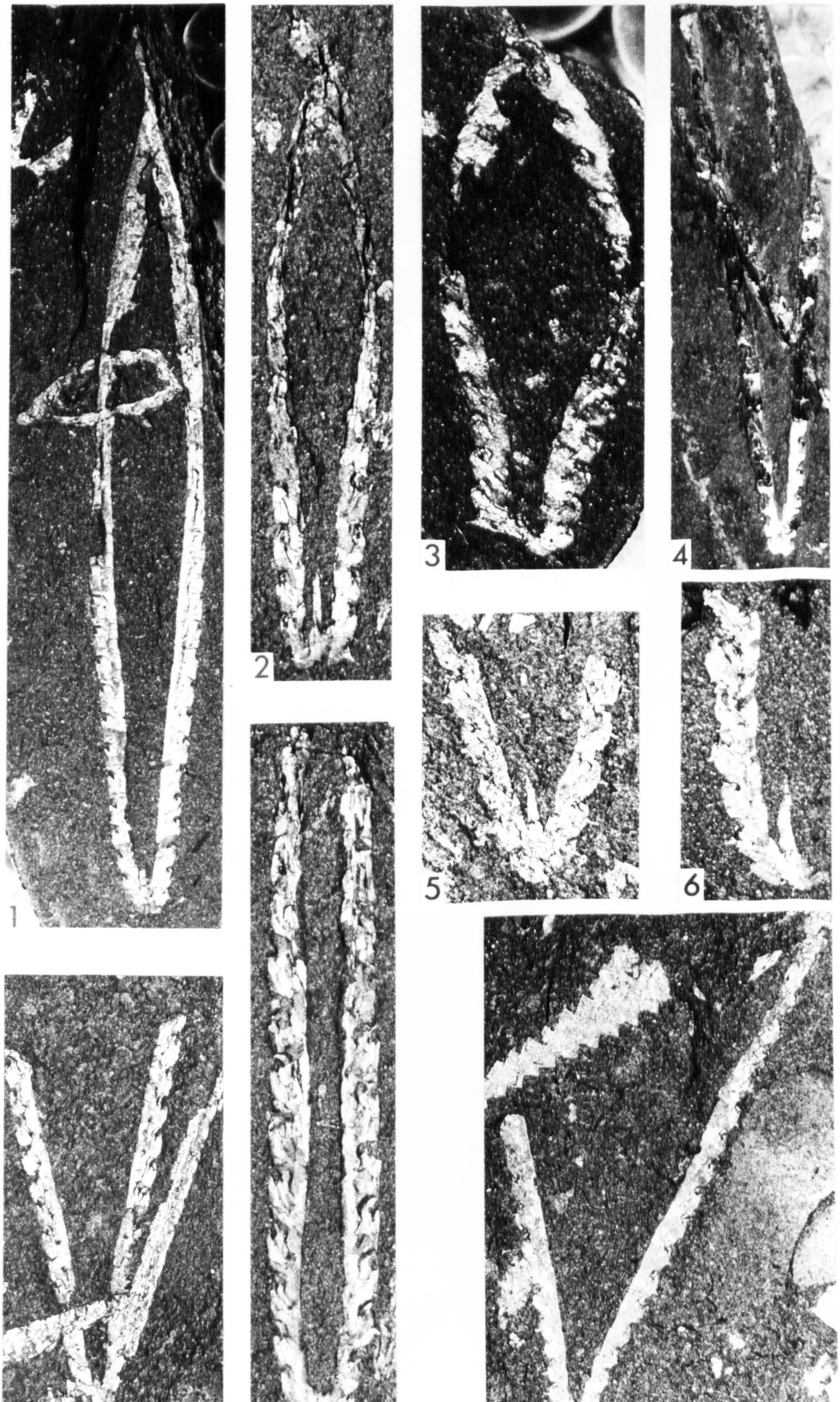
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PLATE 18

Dicellograptus pumilis Lapworth 1876.

All except fig. 2 from the latest D. clingani Zone, North Cliff trench, Dob's Linn.

FIGURE

1. HM C14246/1-na. General view of slab crowded with specimens. 5.25 - 5.15m below top of Lower Hartfell Shale. Proximal detail of specimens shown in figs. 6, 7, 10. (x1)
2. H(B.M.) 137. Slab with crowded specimens. Lower Hartfell Shale, Hartfell Spa. (x2)
3. HM C14261a. 5.1 - 5.0m below top of Lower Hartfell Shale. (x5)
4. HM C14266. 5.1 - 5.0m below top of Lower Hartfell Shale. (x5)
5. HM C14251. 5.25 - 5.15m below top of Lower Hartfell Shale. (x5)
6. HM C14246/6a. 5.25 - 5.15m below top of Lower Hartfell Shale. (x5)
7. HM C14246/5a. 5.25 - 5.15m below top of Lower Hartfell Shale. (x5)
8. HM C14253a. Specimen with thick basal spine. 5.25 - 5.15m below top of Lower Hartfell Shale. (x10)
9. HM C14250/1-2a. 5.25 - 5.15m below top of Lower Hartfell Shale. (x5)
10. HM C14246/3-4a. 5.25 - 5.15m below top of Lower Hartfell Shale. (x5)

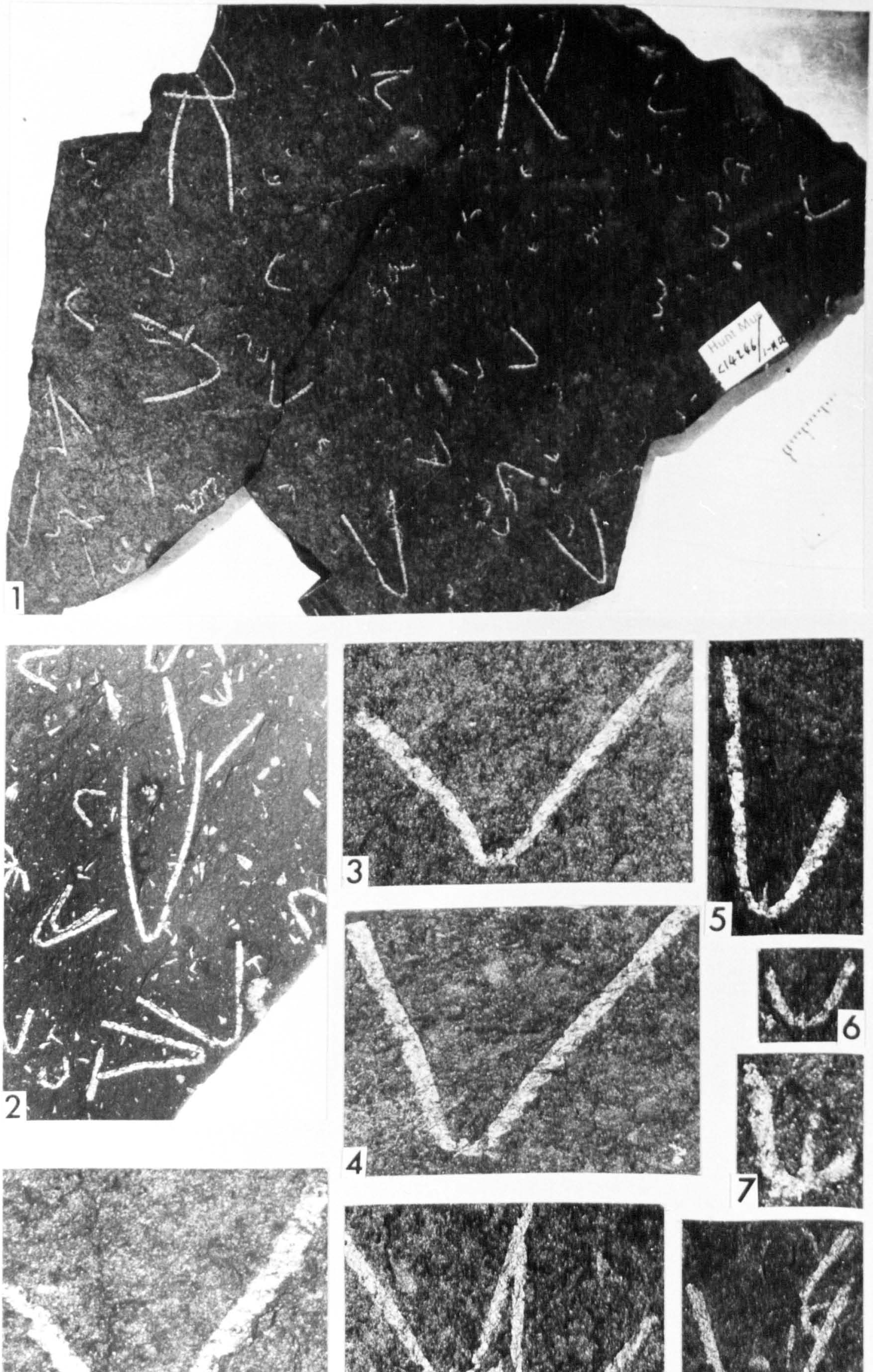
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PLATE 19

Dicellograptus forchhammeri (Geinitz 1852) s.l.

All from the D. clingani Zone, North Cliff trench, Dob's Linn.

FIGURE

1. HM C14095. 8.5 - 8.4m below top of Lower Hartfell Shale. (x5)
2. HM C14078. Specimen with well preserved thecae. 8.5 - 8.4m below top of Lower Hartfell Shale. (x5)
3. HM C14105/1. Proximal detail. Note sicula on this and other specimens is missing above a mid-point of the metasicula (cf. those in most other Dicellograptus species which are almost totally resorbed). 8.5 - 8.4m below top of Lower Hartfell Shale. (x10)
4. HM C14105/2. 8.5 - 8.4m below top of Lower Hartfell Shale. (x5)
5. HM C14241/1b. Large specimen but poorly preserved. 6.25 - 6.1m below top of Lower Hartfell Shale. (x2.5)

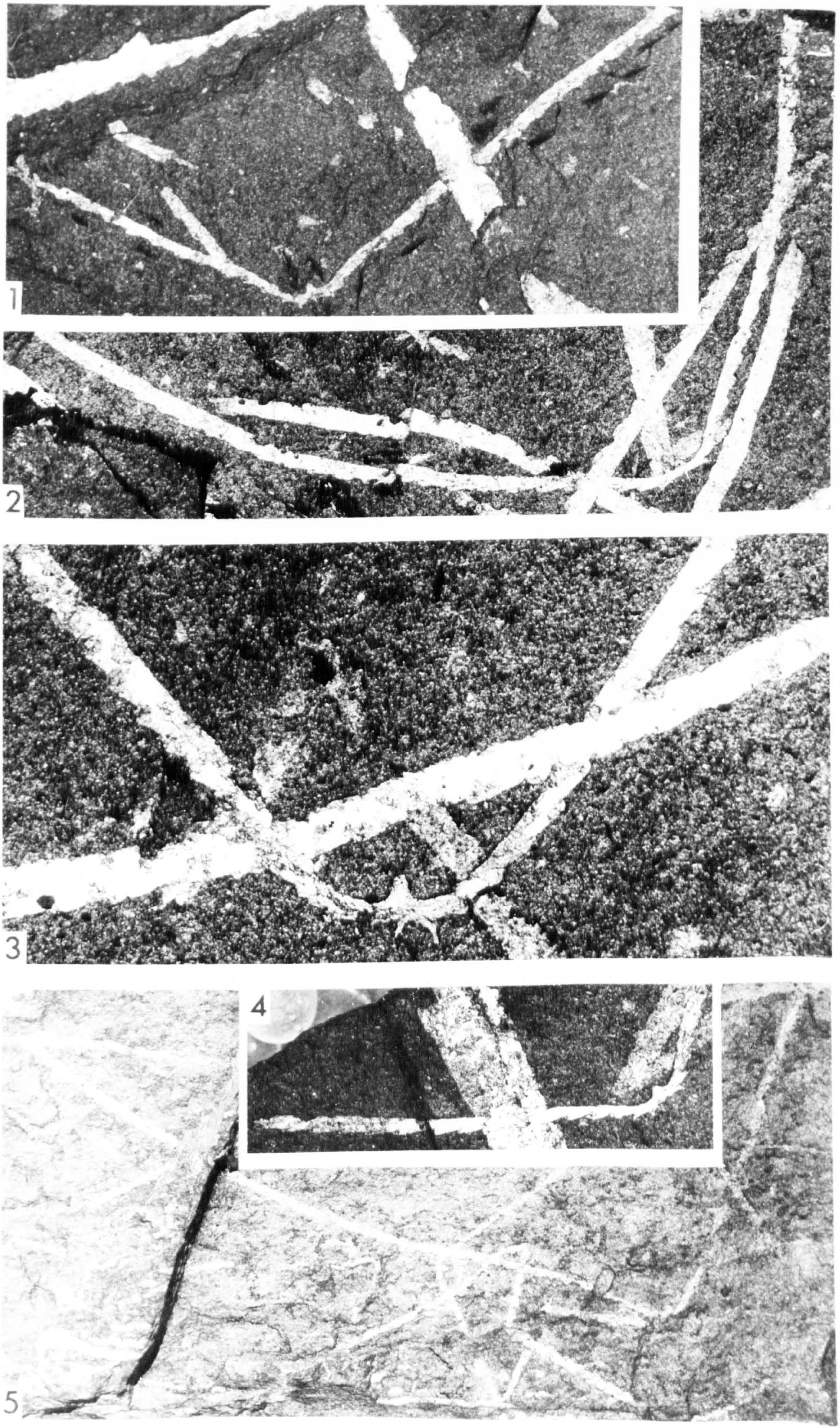
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PLATE 20

Dicellograptus _carruthersi_ Toghill 1970.
All from top Lower Hartfell Shale, middle/late _P._ _linearis_ Zone, Dob's Linn.

1. HM C14457. 0.45 - 0.3m below top of Lower Hartfell Shale, North Cliff trench. (x2.5)
2. Q 2915. Holotype (proximal only). Toghill Collection. Figd. Toghill 1970, pl. 7, fig. 6, text-fig. 4c. (x10)
3. HM C14455a. 0.45 - 0.3m below top of Lower Hartfell Shale, North Cliff trench. (x10)
4. HM C14452a. 0.55 - 0.45m below top of Lower Hartfell Shale, North Cliff trench. (x5)


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PLATE 21

Dicellograptus ornatus Elles & Wood 1904.

All from the Anceps Bands, Upper Hartfell Shale, P. pacificus Subzone, Dob's Linn.

FIGURE

1. HM C13708a. Mature specimen with large axial membrane and robust spine(s). Band E, Main Cliff section. (x25)
2. HM C13606a. Fairly immature specimen with small spines and narrow proximal stipes. Band D, Main Cliff section. (x10)
3. HM C13666. Juvenile specimen with small spines. Note sicula has apparently already been resorbed(?). Band E, Long Burn trench. Also figd. text-fig. 22b. (x10)
4. HM C13684. Specimen with long thin spines. Band E, Long Burn trench. (x10)
5. HM C13694a. Mature specimen with very robust spines and apparently spiralled stipes. Band E, Main Cliff section. (x25)
6. HM C13619a. Weathered specimen showing one stipe and robust spine. Band E, Linn Branch trench. Also figd. text-fig. 22f. (x10)
7. HM C13679. Weathered specimen with short but robust spines. Band E, Long Burn trench. (x10)

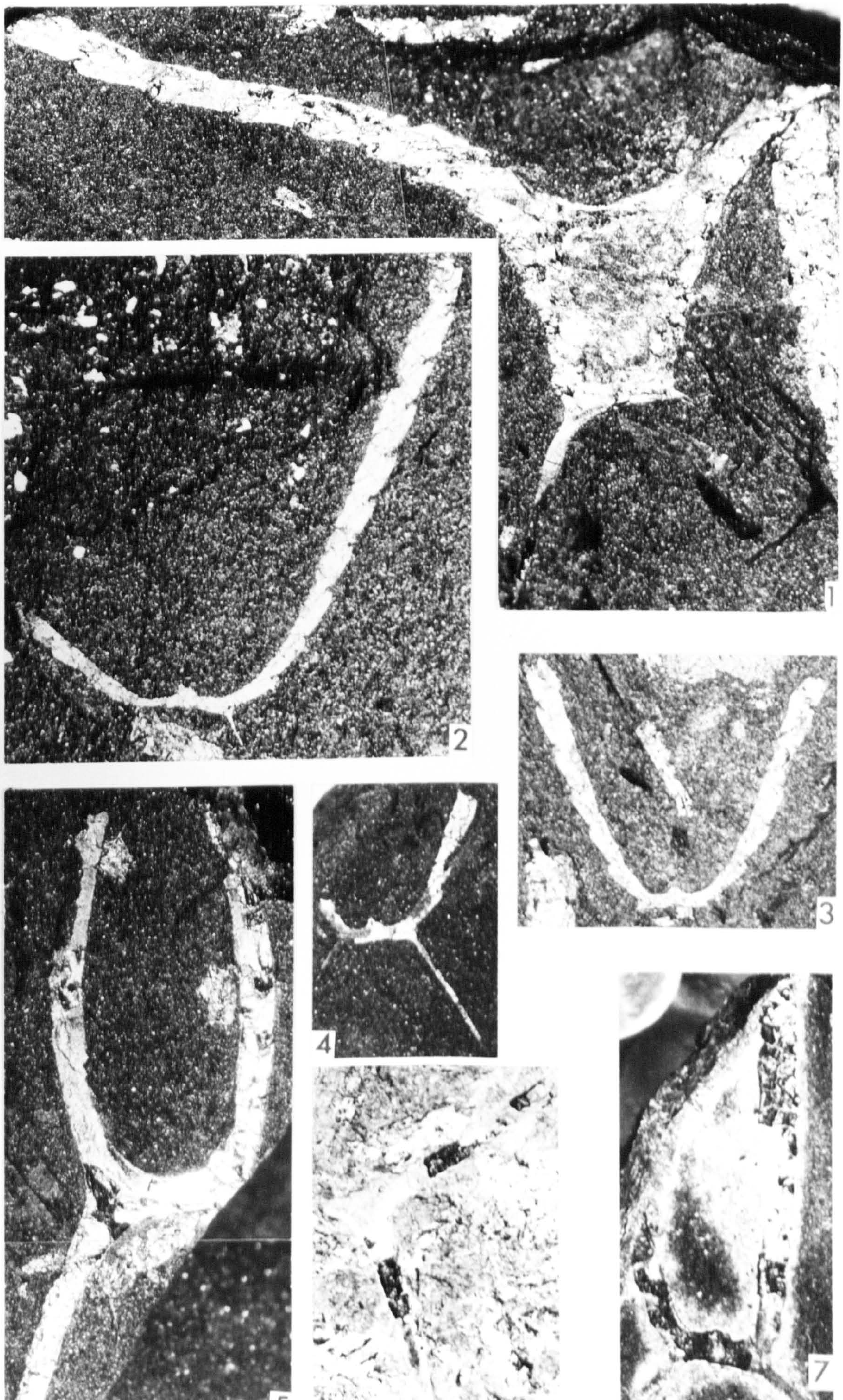

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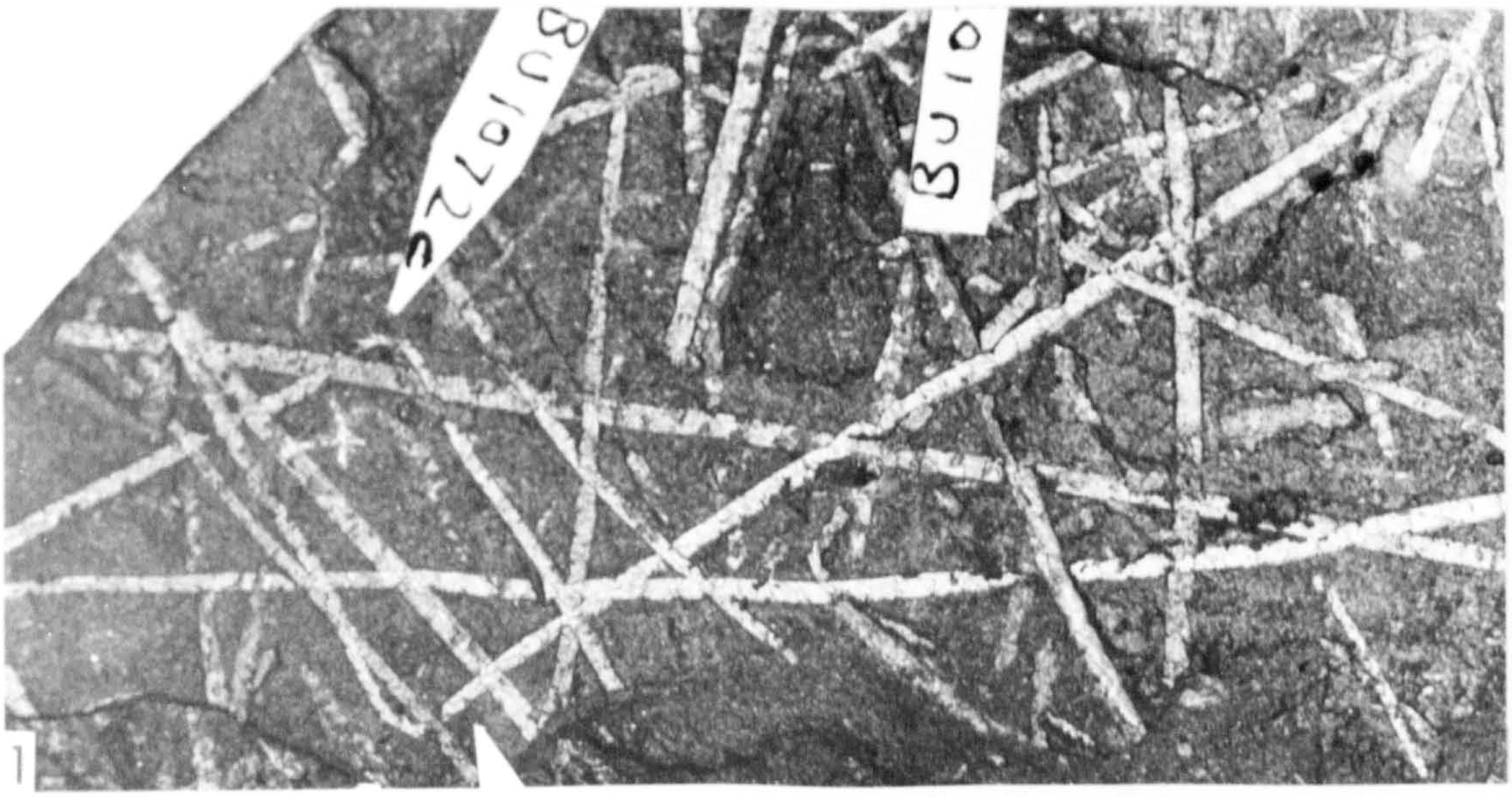
PLATE 22

<u>Dicellograptus</u> <u>complanatus</u> Lapworth 1880.

All from the Lower Complanatus Band, Upper Hartfell Shale, <u>D.</u> <u>complanatus</u> Zone, Dob's Linn.

FIGURE

1. BU 1072b. Lectotype (with BU 1072c). Lapworth Collection. Figd. Elles & Wood 1904, pl. 20, fig. 1b, Toghill 1970,pl. 4, fig. 1, text-fig. 2g. (x2.5)
2. BU 1072b. Lectotype. Proximal detail. (x10)
3. HM C14470/4. Main Cliff (loc. 3 of text-fig. 1). (x5)
4. HM C14470/3. Main Cliff (loc. 3 of text-fig. 1). (x5)
5. HM C14464/6. West of North Cliff trench. (x5)
6. BU 1074. Detail of early thecae, flattened internal mould (see also pl. 10, fig. 8). Lapworth Collection. Figd. Briggs & Williams 1981, fig. 2c, complete specimen figd. Elles & Wood 1904, text-fig. 84a.



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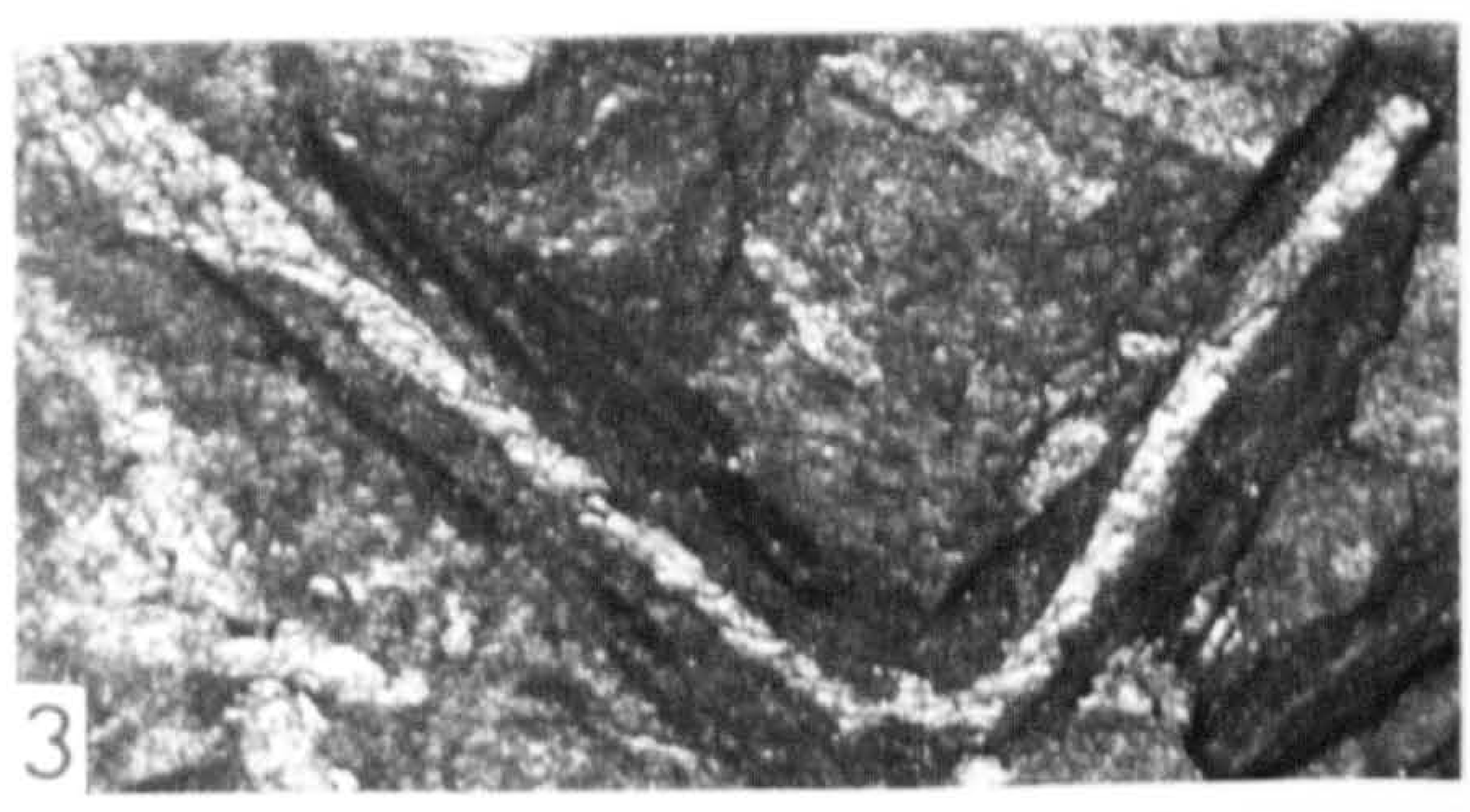
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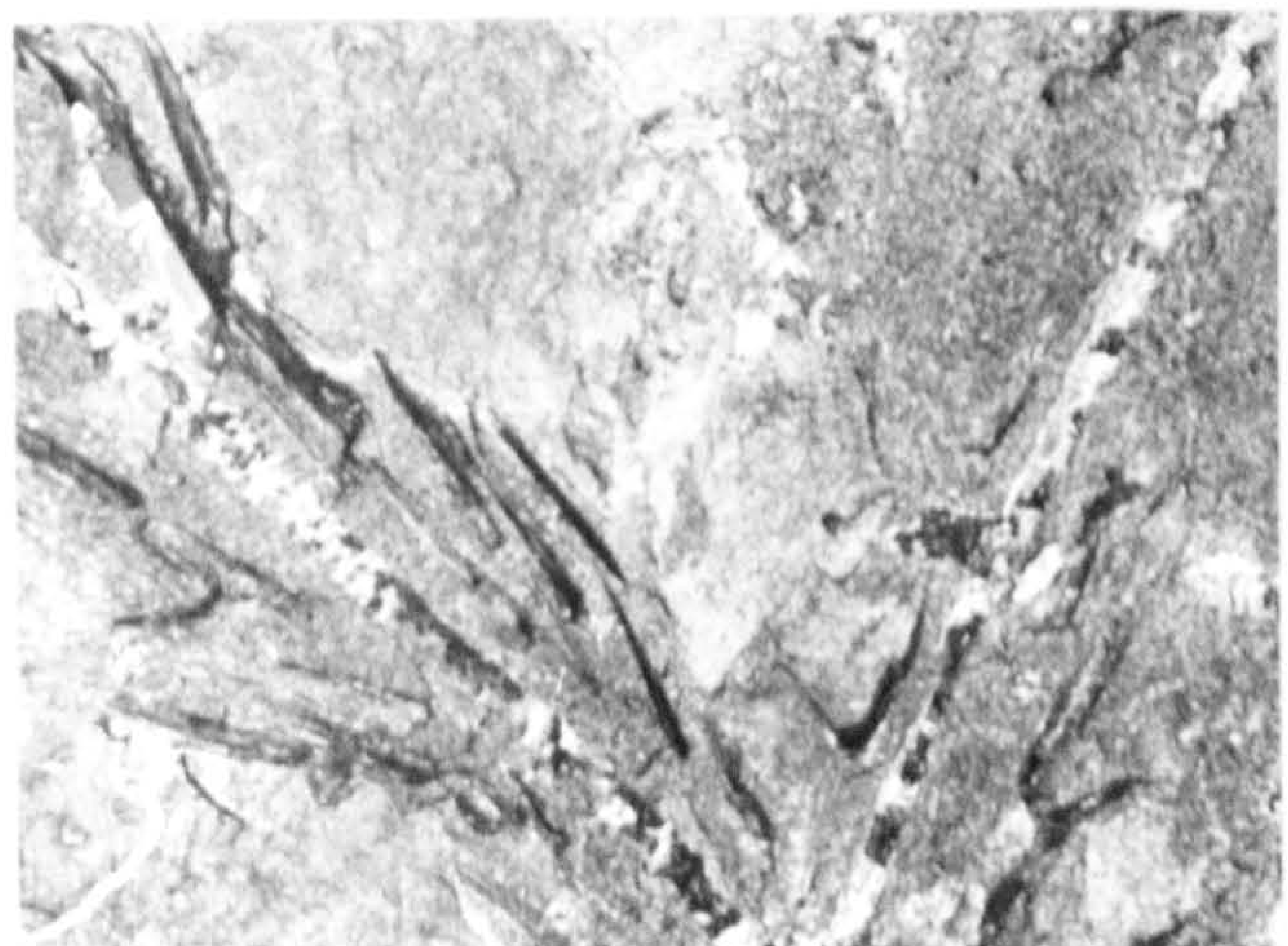
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PLATE 23

Dicellograptus complanatus Lapworth 1880.

All specimens from the *D. complanatus* Zone, from the foreshore south of Girvan.

FIGURE

1. H(B.M.) 2038. Right-hand stipe in oblique view. 'Ardmillan Series, Whitehouse Bay'. Gray Collection. (x5)
2. HM C764/4. Shalloch Formation, Whitehouse Shore. Ingham Collection. (x5)
3. HM C764/4. Proximal detail of specimen in fig. 2 showing mesial spine on $th2^1$. (x25)
4. HM C772/2. Note proximal thecae (in relief) compressed onto each other, presumably due to original high angle of rhabdosome to bedding prior to diagenetic compression. Black Neuk Shale Member, Mill Formation, Upper Whitehouse Group, Myoch Bay. Ingham Collection. Figd. Williams 1981, pl. 1, fig. 1. Detail of thecae figd. Briggs & Williams 1981, fig. 2a. Thecae also figd. pl. 10, fig. 7. (x10)
5. HM C13080a. Part of long distal fragment preserved in full relief. Black Neuk Shale Member, Mill Formation, Upper Whitehouse Group, Myoch Bay. (x2.5)
6. HM C13102/3a. Left-hand stipe bent over distally. Just below detrital limestones, Shalloch Formation, Whitehouse Shore. (x10)

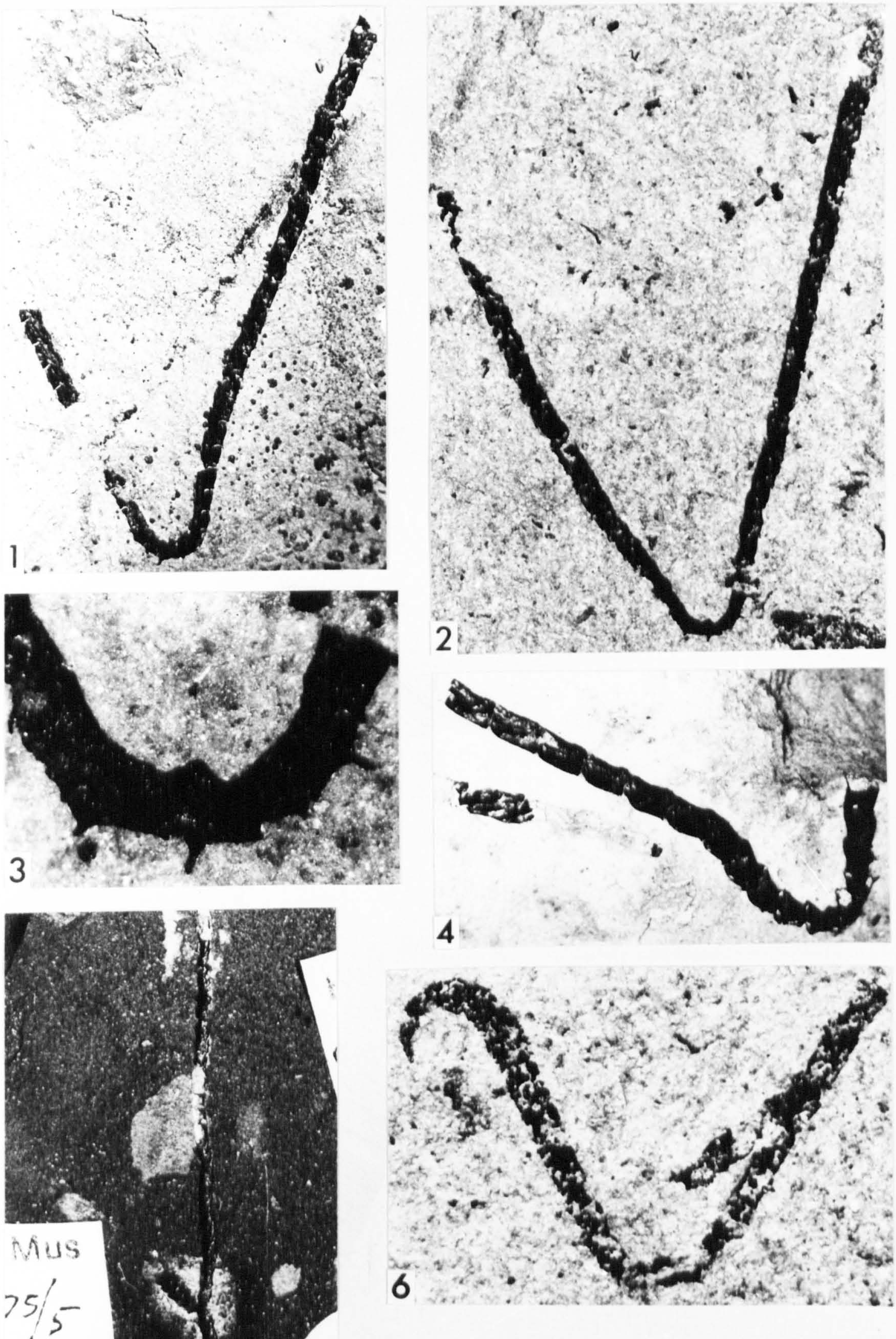
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PLATE 24

Dicellograptus complexus Davies 1929

All except fig. 5 from Anceps Band B, Upper Hartfell Shale, *D. complexus* Subzone.

FIGURE

1. HM C14482. Note introversion of distal thecae after cross. Main Cliff, Dob's Linn. (x5)
2. HM C13111. Specimen with two closely spaced stipe crosses. Long Burn trench, Dob's Linn. Figd. Briggs & Williams 1981, fig. 5j. (x5)
3. HM C13110a. Linn Branch trench, Dob's Linn. Figd. Briggs & Williams 1981, fig. 5g. (x5)
4. HM C13326/1. Proximal fragment. Linn Branch trench, Dob's Linn. (x10)
5. *D. szechuanensis* Mu 1954 (=*D. complexus*). From an original photograph sent by Prof. Mu. Note thecal style when preserved in partial relief. (x15)

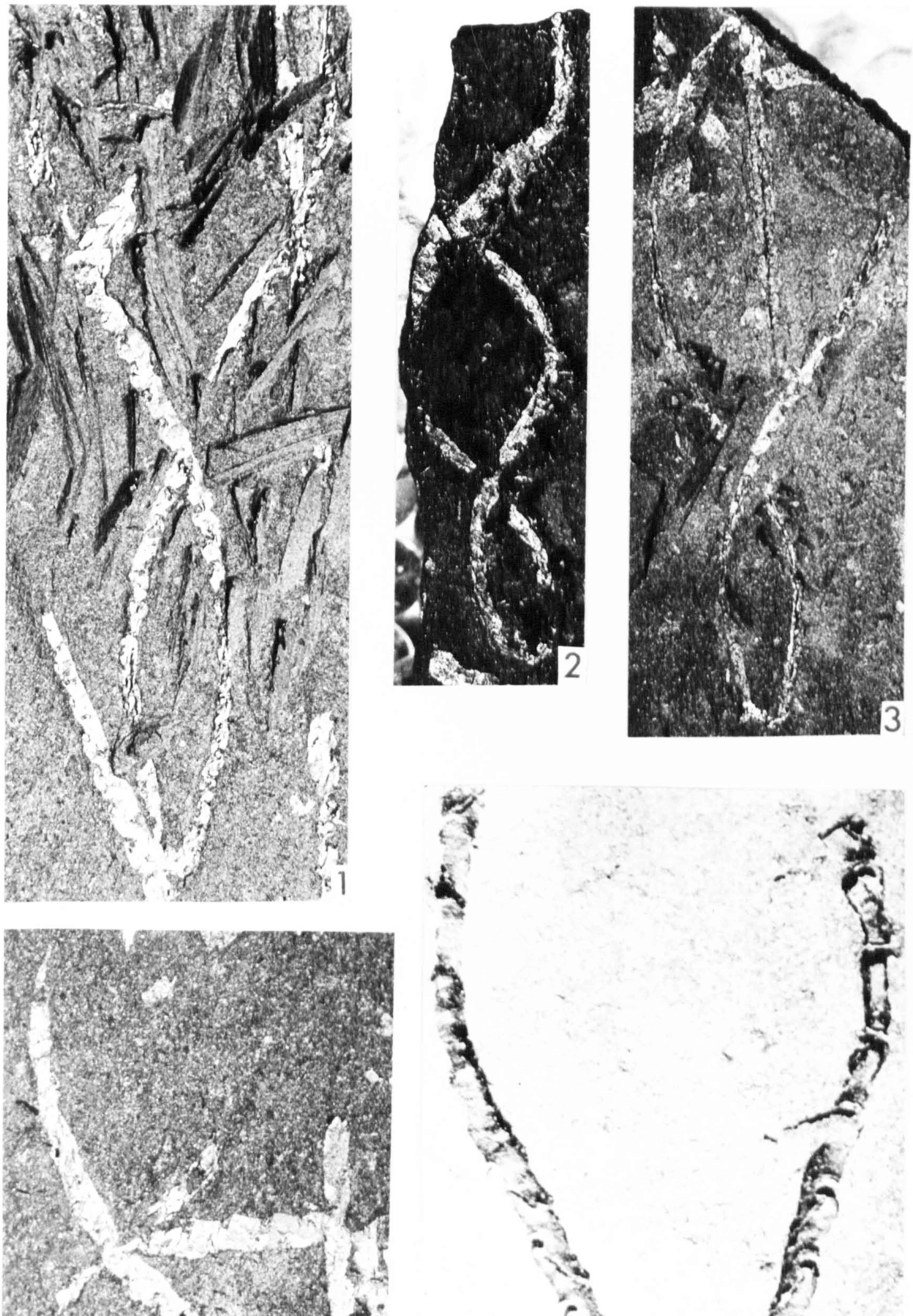
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PLATE 25

(all x10 except figs. 1, 5)

FIGURE

1 - 5. Dicellograptus complexus Davies 1929.

1. HM C13385a. Well preserved specimen with one cross. Anceps Band B, Upper Hartfell Shale, D. complexus Subzone, Long Burn trench, Dob's Linn. Figd. Briggs & Williams 1981, fig. 5d. (x5)

2. HM C13158b. Proximal fragment. Anceps Band A, Upper Hartfell Shale, D. complexus Subzone, Linn Branch trench, Dob's Linn.

3. HM C13361. Juvenile specimen with sicula. Anceps Band B, Upper Hartfell Shale, D. complexus Subzone, Main Cliff section, Dob's Linn. Figd. Briggs & Williams 1981, fig. 5f.

4. HM C13290. Juvenile specimen with sicula. Anceps Band B, Upper Hartfell Shale, D. complexus Subzone, Linn Branch trench, Dob's Linn.

5. Q 2831. Anceps Bands, Dob's Linn (Toghill Collection). Figd. Williams 1981, pl. 1, fig. 5. (x5)

6 - 8, 10. Dicellograptus aff. complexus Davies 1929.

6. HM C13163. Anceps Band A, Upper Hartfell Shale, D. complexus Subzone, Linn Branch trench, Dob's Linn.

7. HM C13181b. Anceps Band A, Upper Hartfell Shale, D. complexus Subzone, Linn Branch trench, Dob's Linn.

8. HM C13142. Straight distal fragment. Anceps Band A, Upper Hartfell Shale, D. complexus Subzone, Linn Branch trench, Dob's Linn.

9. D. complexus? Similar to D. ornatus but far earlier than any others recorded from Dob's Linn. Anceps Band B, Upper Hartfell Shale, D. complexus Subzone, Linn Branch trench, Dob's Linn.

10. Specimen disintegrated since photography, but included to show distinctive open spiral (cf. D. complexus s.s.). Anceps Band A, Upper Hartfell Shale, D. complexus Subzone, Linn Branch trench, Dob's Linn.

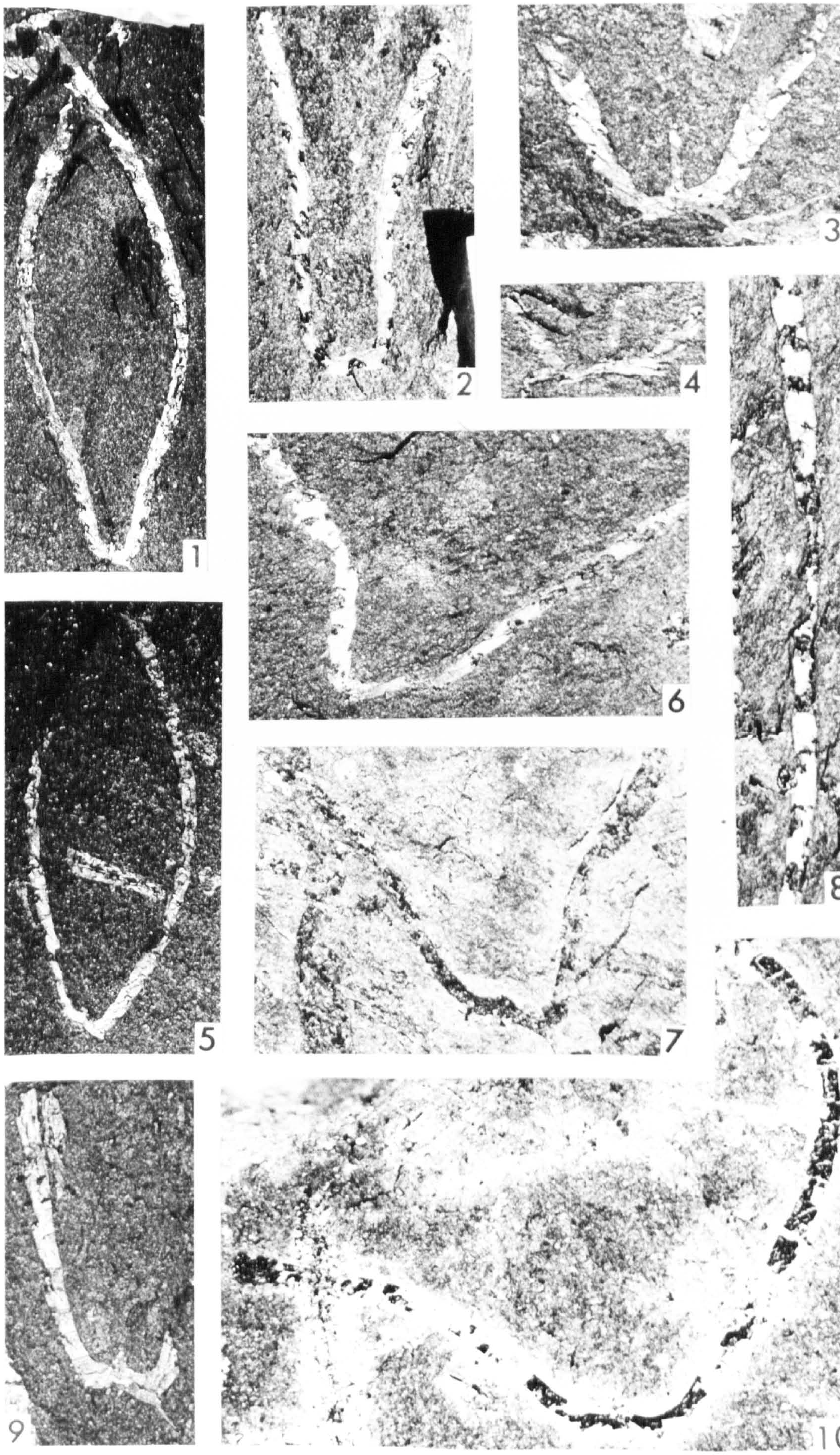

PLATE 26

FIGURE

1. HM C13098. Dicellograptus cf. minor Toghill 1970. Stipes are distally narrower than D. minor s.s. Dark Shale Member, Mill Formation, Upper Whitehouse Group, P. linearis/D. complanatus zone, Loc. M2, Myoch Bay, Girvan. (x10)

2. HM C13660. Dicellograptus minor Toghill 1970. With complete sicula. Anceps Band E, Upper Hartfell Shale, P. pacificus Subzone, Long Burn trench, Dob's Linn. (x10)

3. HM C13667. D. minor. With C. latus? distal fragment. Anceps Band E, Upper Hartfell Shale, P. pacificus Subzone, Long Burn trench, Dob's Linn. (x5)

4. HM C13099. D. cf. minor. Left hand stipe only. Dark Shale Member, Mill Formation, Upper Whitehouse Group, P. linearis/ D. complanatus zone, Loc. M2, Myoch Bay, Girvan. (x10)

5. HM C13013. D. cf. minor. Dark Shale Member, Mill Formation, Upper Whitehouse Group, P. linearis/D. complanatus Zone, Loc. M2, Myoch Bay, Girvan. (x10)

6 - 12. Dicellograptus minor Toghill 1970. Anceps Bands, Upper Hartfell Shale, Dob's Linn.

6. HM C13687. With complete sicula. Band E, P. pacificus Subzone, Main Cliff section. (x10)

7. HM C13671. ?Resorbed sicula. Band E, P. pacificus Subzone, Long Burn trench. (x5)

8. HM C13310. Band B, D. complexus Subzone, Linn Branch trench. (x10)

9. SM A10032. Sicula and first two thecae, preserved in full relief. K.A. Davies Collection, recorded as 'D. complanatus'. (x60)

10. SM A10033. Specimen preserved in full relief, lacking sicula. K.A. Davies Collection, recorded as 'D. complanatus'. (x12)

11. HM C13439/1. Distal thecae. Band C, P. pacificus Subzone, Long Burn trench. (x10)

12. HM C13653a. Distal thecae. Band E, P. pacificus Subzone, Linn Branch trench. (x10)

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PLATE 27

Climacograptus longispinus supernus Elles & Wood 1906 (all x10)
All specimens from the Anceps Bands, Upper Hartfell Shale,
D. anceps Zone, Dob's Linn.

FIGURE

1. HM C13405a. Band B, D. complexus Subzone, Long Burn trench.
2. HM C13292. Band B, D. complexus Subzone, Linn Branch trench.
3. HM C13299/1b. Band B, D. complexus Subzone, Linn Branch trench.
4. Q 2773b. Toghill Collection. Figd. Toghill 1970, pl. 11, fig. 10.
5. HM C13320a. Band B, D. complexus Subzone, Linn Branch trench.
6. SM A19608. Elles Collection. Figd. Riva 1974b, text-fig. 8e.
7. HM C13512. Band D, P. pacificus Subzone, Long Burn trench.
8. HM C13513a. Band D, P. pacificus Subzone, Long Burn trench.
9. HM C13379. With crowded fragments of P? craticulus. Band B, D. complexus Subzone, Main Cliff section.

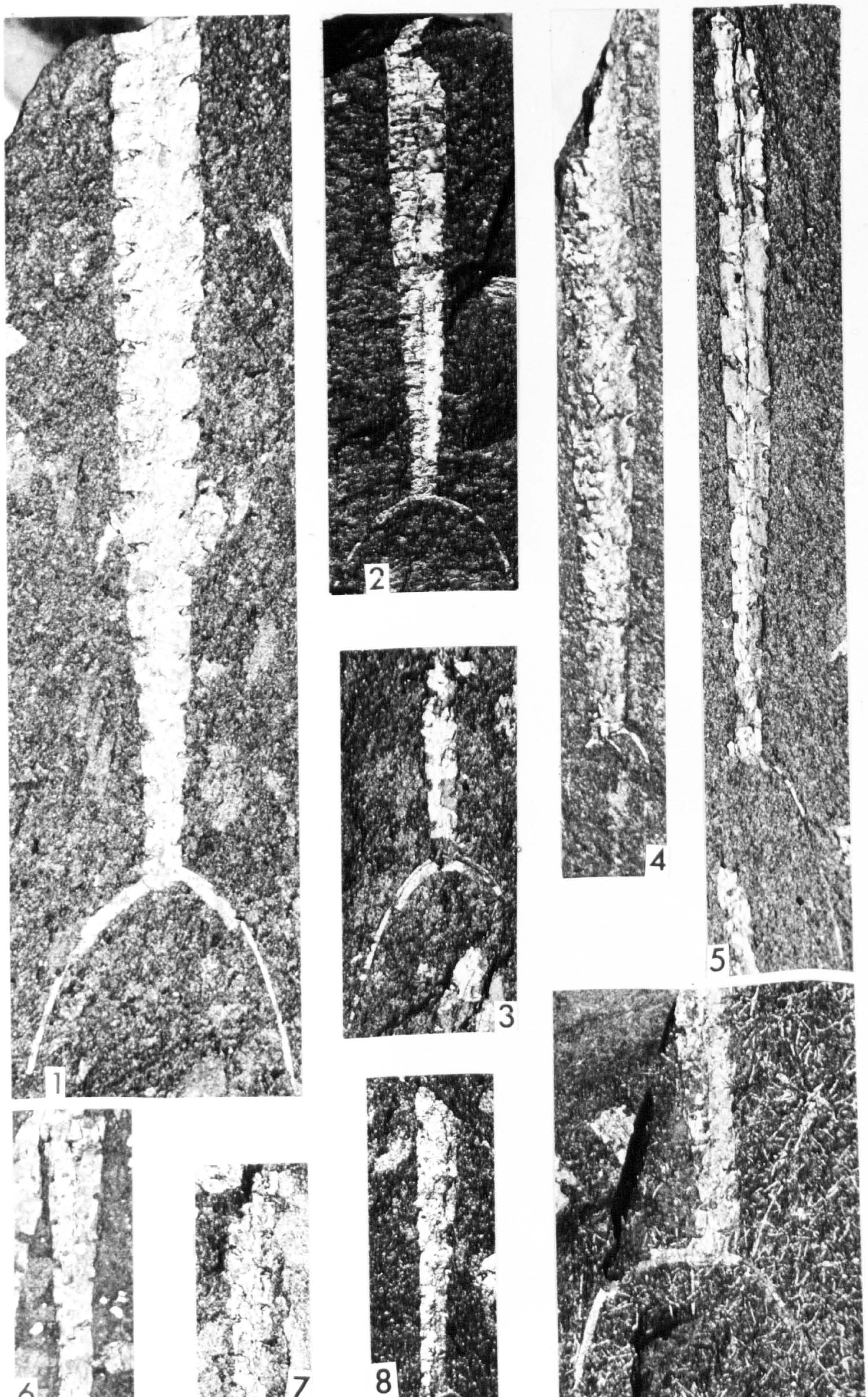
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PLATE 28

Climacograptus longispinus supernus Elles & Wood 1906
(all x10 except fig. 6)
All specimens from the Anceps Bands, Upper Hartfell Shale,
D. anceps Zone, Dob's Linn.

FIGURE

1. Q 2837. Toghill Collection. Figd. Toghill 1970, pl. 11, fig. 4 (as *C. hvalross*).
2. BU 1167. Lectotype. Wood Collection. Figd. Elles & Wood 1906, pl. 26, fig. 11c, Riva 1974b, text-fig. 8n.
3. Q 2770a. Toghill Collection. Figd. Toghill 1970, pl. 11, fig. 6.
4. HM C13399. Band B, *D. complexus* Subzone, Long Burn trench.
5. HM C13320a. Band B, *D. complexus* Subzone, Linn Branch trench.
6. HM C13573. Band D, *P. pacificus* Subzone, Long Burn trench.
7. SM A19611. Elles Collection. Figd. Riva 1974b, text-fig. 8g.
8. BU 1169. Wood Collection. Figd. Elles & Wood 1906, text-fig. 127b, Riva 1974b, text-fig. 8l.
9. Q 2786. Toghill Collection. Figd. Toghill 1970, pl. 11, fig. 5.

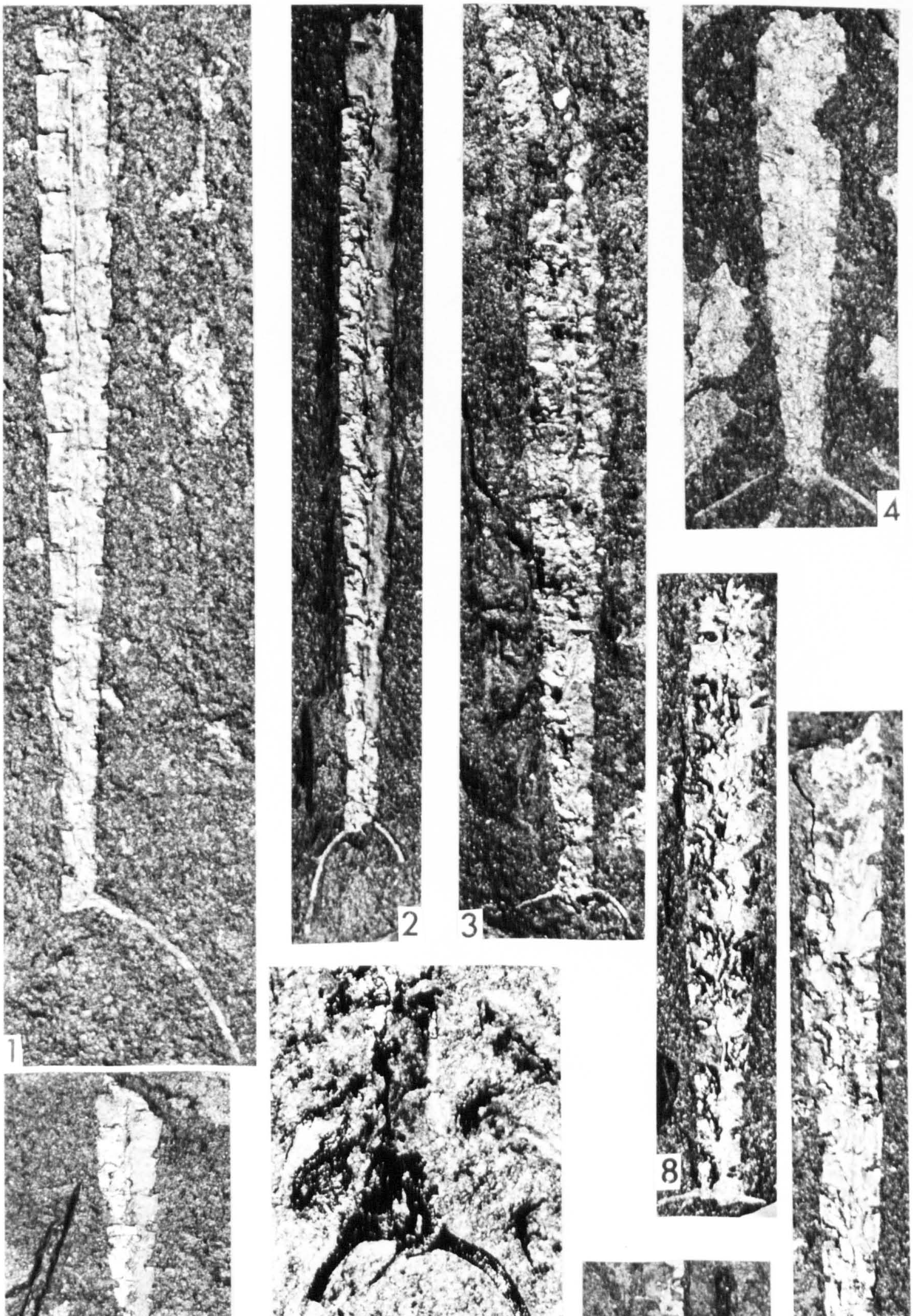
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PLATE 29

Climacograptus longispinus supernus Elles & Wood 1906. (x5)

HM C13384/1-n. Anceps Band B, Upper Hartfell Shale, *D. complexus* Subzone, Long Burn trench, Dob's Linn.

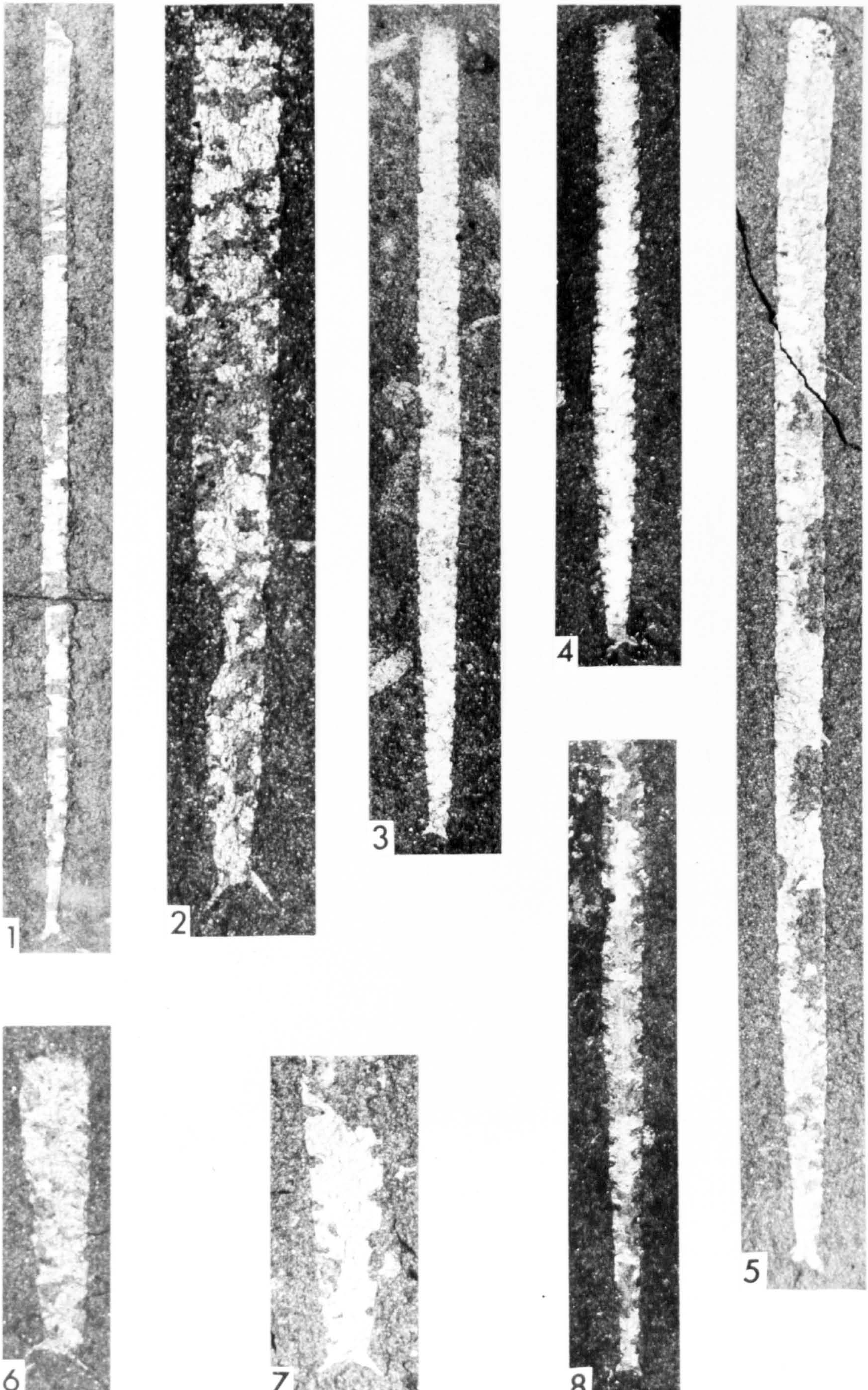
PLATE 30

Climacograptus spiniferus Ruedemann 1912.

All from the D. clingani Zone, North Cliff trench, Dob's Linn.

FIGURE

1. HM C14120. Long rhabdosome. 8.4 - 8.3m below top of Lower Hartfell Shale. (x2.5)
2. HM C14112. Detail of proximal end with long thin spines on sicula and $th1^1$. 8.4 - 8.3m below top of Lower Hartfell Shale. (x10)
3. HM C14141/1a. 8.2 - 8.0m below top of Lower Hartfell Shale. (x5)
4. HM C14128a. Thickened proximal spines. 8.4 - 8.3m below top of Lower Hartfell Shale. (x5)
5. HM C14113. Thickened proximal spines. 8.4 - 8.3m below top of Lower Hartfell Shale. (x5)
6. HM C14132. Juvenile specimen with thin periderm and narrow spines. 8.4 - 8.3m below top of Lower Hartfell Shale. (x10)
7. HM C14102. Proximal detail. 8.5 - 8.4m below top of Lower Hartfell Shale. (x10)
8. HM C14130. Thickened proximal spines. 8.4 - 8.3m below top of Lower Hartfell Shale. (x5)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Climacograptus latus Elles & Wood 1906.

All from the Anceps Bands, Upper Hartfell Shale, Dob's Linn.

FIGURE

1. HM C13352/1. Distal fragment, obliquely orientated, with sloping supragenicular walls due to greater lateral spread at apertures. Band B, D. complexus Subzone, Main Cliff section. (x10)
2. HM C13592/1a. Band D, P. pacificus Subzone, Main Cliff section. (x5)
3. HM C13592/2a. Band E, P. pacificus Subzone, Main Cliff section. (x5)
4. HM C13707. Band E, P. pacificus Subzone, Main Cliff section. (x5)
5. HM C13665. Band E, P. pacificus Subzone, Long Burn trench. (x10)
6. HM C13710a. Band B, D. complexus Subzone, Main Cliff section. (x10)
7. HM C13378. Band B, D. complexus Subzone, Main Cliff section. (x10)
8. HM C13349/1a. Band B, D. complexus Subzone, Main Cliff section. (x10)
9. HM C13362/1-2. Band B, D. complexus Subzone, Main Cliff section. (x10)
10. HM C13363. Band B, D. complexus Subzone, Main Cliff section. (x10)
11. HM C13572. Band D, P. pacificus Subzone, Long Burn trench. (x5)
12. HM C13531. Band D, P. pacificus Subzone, Long Burn trench. (x10)
13. HM C13352/2. Band B, D. complexus Subzone, Main Cliff section. (x10)

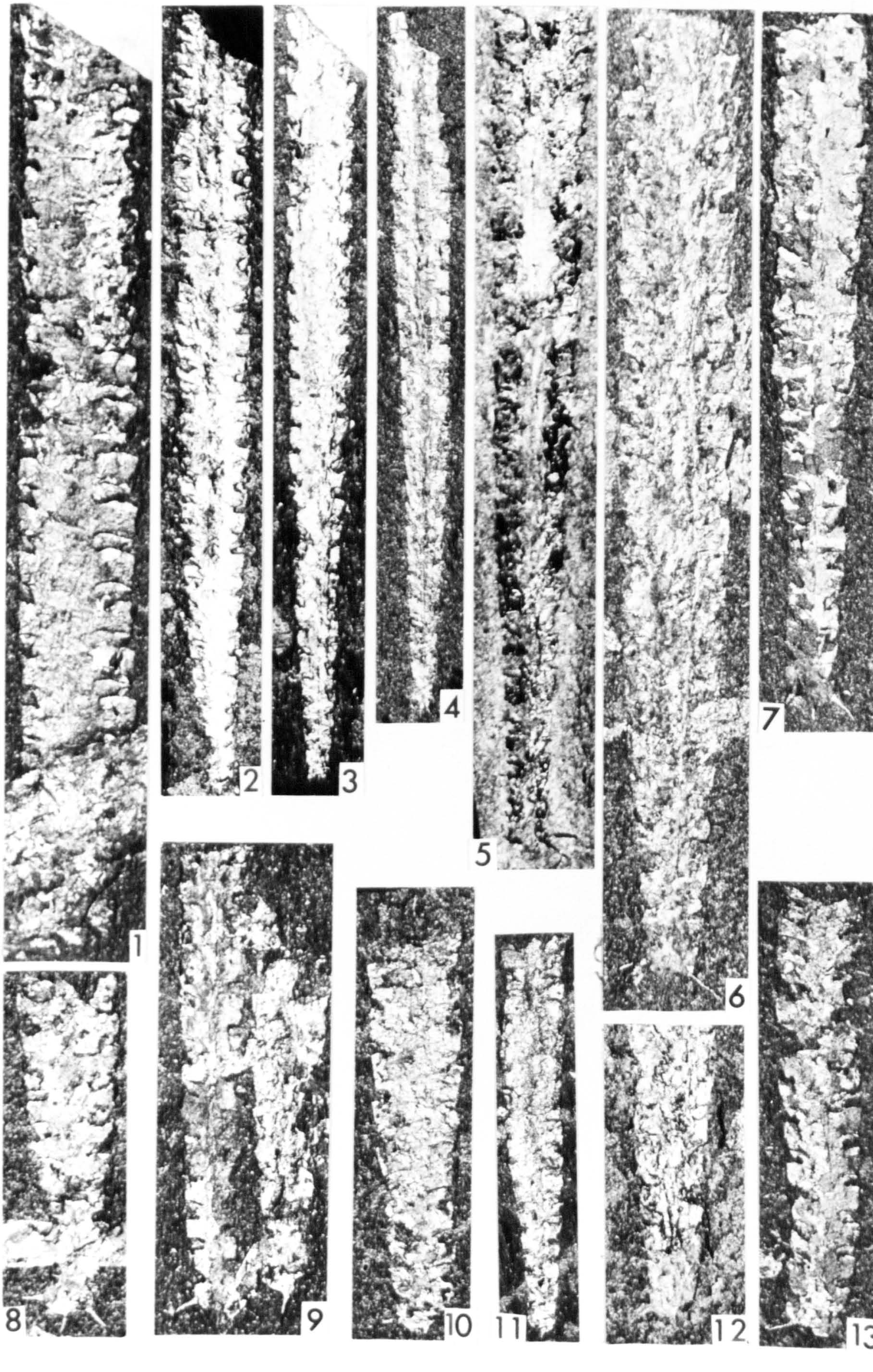

PLATE 32

<u>Climacograptus</u> <u>tubuliferus</u> Lapworth 1876. (all x5)

All from the <u>P.</u> <u>linearis</u> Zone, North Cliff trench, Dob's Linn.

FIGURE

1. HM C14354/1a. Distal fragment with very wide nemal vane. 2.75 - 2.65m below top of Lower Hartfell Shale.
2. HM C14353a. Distal fragment showing rhabdosome to have grown around already thickened vane. 2.75 - 2.65m below top of Lower Hartfell Shale.
3. HM C14334b. Nemal vane distally bent over. 3.0 - 2.9m below top of Lower Hartfell Shale.
4. HM C14336/2. Distal fragment with thickened nema. 3.0 - 2.9m below top of Lower Hartfell Shale.
5. HM C14357/1. Juvenile specimen with already thickened nema. 2.65 - 2.5m below top of Lower Hartfell Shale.
6. HM C14329/1b. Proximal detail showing thickened virgella. 3.0 - 2.9m below top of Lower Hartfell Shale.
7. HM C14356/1a. Proximal fragment with thickened virgella. 2.65 - 2.5m below top of Lower Hartfell Shale.
8. HM C14332/1. Juvenile specimen with thin nema and virgella. 3.0 - 2.9m below top of Lower Hartfell Shale.
9. HM C14332/2. Juvenile specimen with thin nema; preserved in oblique view. 3.0 - 2.9m below top of Lower Hartfell Shale.
10. HM C14357/2. 2.65 - 2.5m below top of Lower Hartfell Shale.
11. HM C14357/3. 2.65 - 2.5m below top of Lower Hartfell Shale.
12. HM C14336/1. Juvenile specimen showing distal thickening of nema. 3.0 - 2.9m below top of Lower Hartfell Shale.
13. HM C14357/4. 2.65 - 2.75m below top of Lower Hartfell Shale.


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PLATE 33

<u>Climacograptus?</u> <u>caudatus</u> Lapworth 1876.

FIGURE

1. HM C14064/1. Note prominently sloping supragenicular walls and slightly everted apertures. 8.7 - 8.5m below top of Lower Hartfell Shale, <u>D.</u> <u>clingani</u> Zone, North Cliff trench, Dob's Linn. (x5)
2. HM C14065. Short virgella, slightly thickened proximally. 8.7 - 8.5m below top of Lower Hartfell Shale, <u>D.</u> <u>clingani</u> Zone, North Cliff trench, Dob's Linn. (x10)
3. BU 1190. Specimen with very long and wide virgella. Lower Hartfell Shale, Hartfell Spa. Lapworth Collection. Figd. Elles & Wood 1906, pl. 27, fig. 2c. (x2)
4. BU 1191. Lower Hartfell Shale, Glenkiln Burn. Lapworth Collection. Figd. Elles & Wood 1906, pl. 27, fig. 7d. (x2)
5. HM C14063. Short virgella. 8.7 - 8.5m below top of Lower Hartfell Shale, <u>D.</u> <u>clingani</u> Zone, North Cliff trench, Dob's Linn. (x5)
6. BU 1192. Specimens with long, proximally thickened virgellae. Upper specimen shows forking virgella. Lower Hartfell Shale, Hartfell Spa. Lapworth Collection. Cpts. figd. Elles & Wood 1906, pl. 27, fig. 7e, text-fig. 133a. (x2)

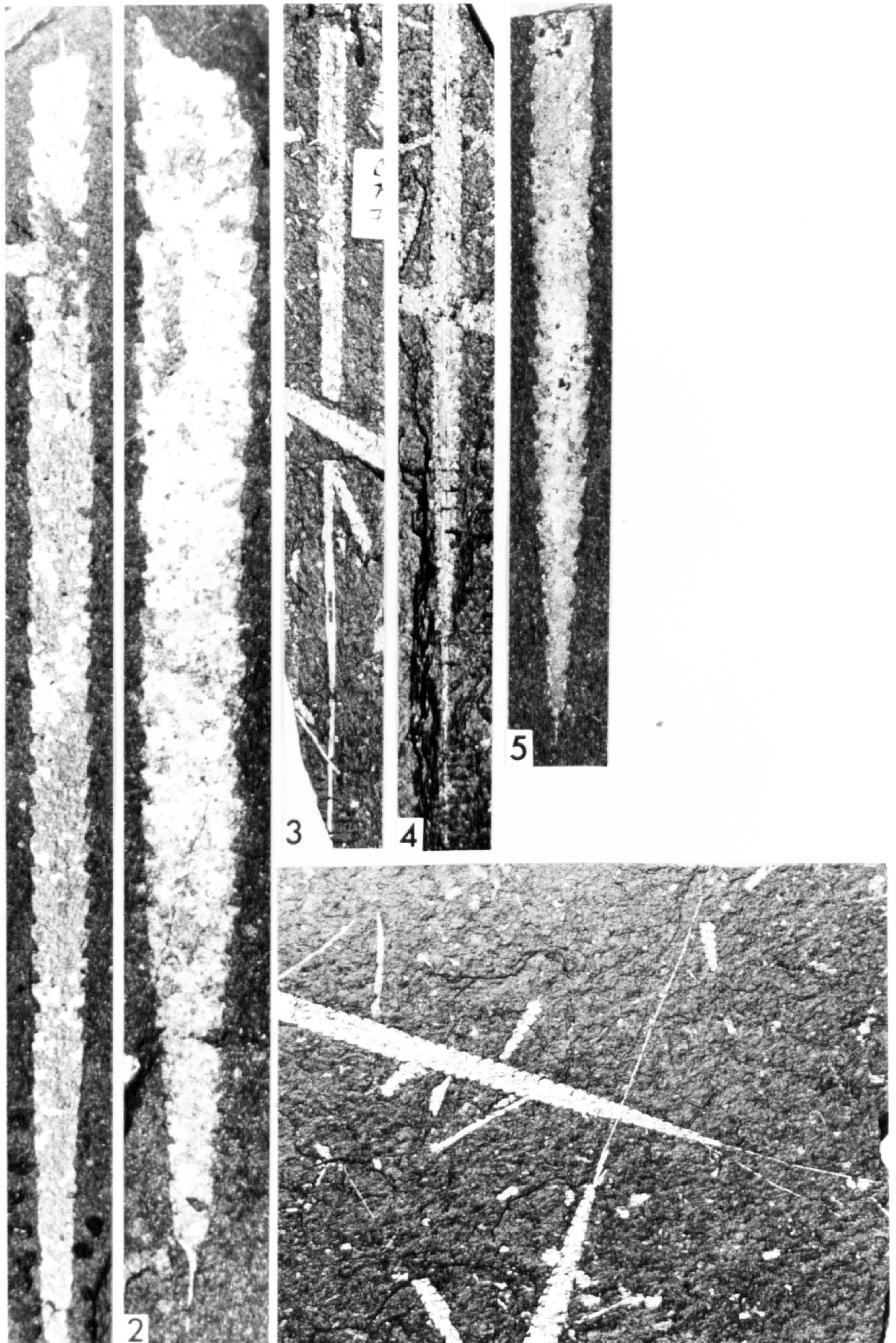
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PLATE 34

Climacograptus normalis Lapworth 1877. (all x5 except fig. 4)

FIGURE

1. BU 1136. Holotype. Birkhill Shale, Dob's Linn. Figd. Lapworth 1877, pl. 6, fig. 31, Elles & Wood 1906, pl. 26, fig. 2a.
2. BU 1140. Drawn out proximal widening, in relief. Birkhill Shale, Dob's Linn. Elles Colln. Figd. Elles & Wood 1906, pl. 26, fig. 2.
3. BU 1144. Distal fragment, in relief. Birkhill Shale, Dob's Linn. Lapworth Colln. Figd. Elles & Wood 1906, text-fig. 119d.
4. BU 1142b. Mutation showing distal forking - note formation of two nemata. Birkhill Shale, Dob's Linn. H. Lapworth Colln. Cpt. figd. Elles & Wood 1906, text-fig. 119b. (x12)
5. HM C13795/1. Gradual widening and long virgella. 0.85 - 0.96m above the base of the Birkhill Shale, G. perculptus Zone, Linn Branch trench, Dob's Linn.
6. HM C13795/2. Specimen orientated at 45° to HM C13795/1, indicates drawn out widening of other specimen to be tectonic. Also with long virgella. Locality as fig. 5.
7. HM C13972. Preserved in relief, in oblique view (see pl. 10, fig. 18) for enlarged detail of thecae). 1.88 - 2.0m above base of Birkhill Shale, O? acuminatus Zone, Linn Branch trench, Dob's Linn.

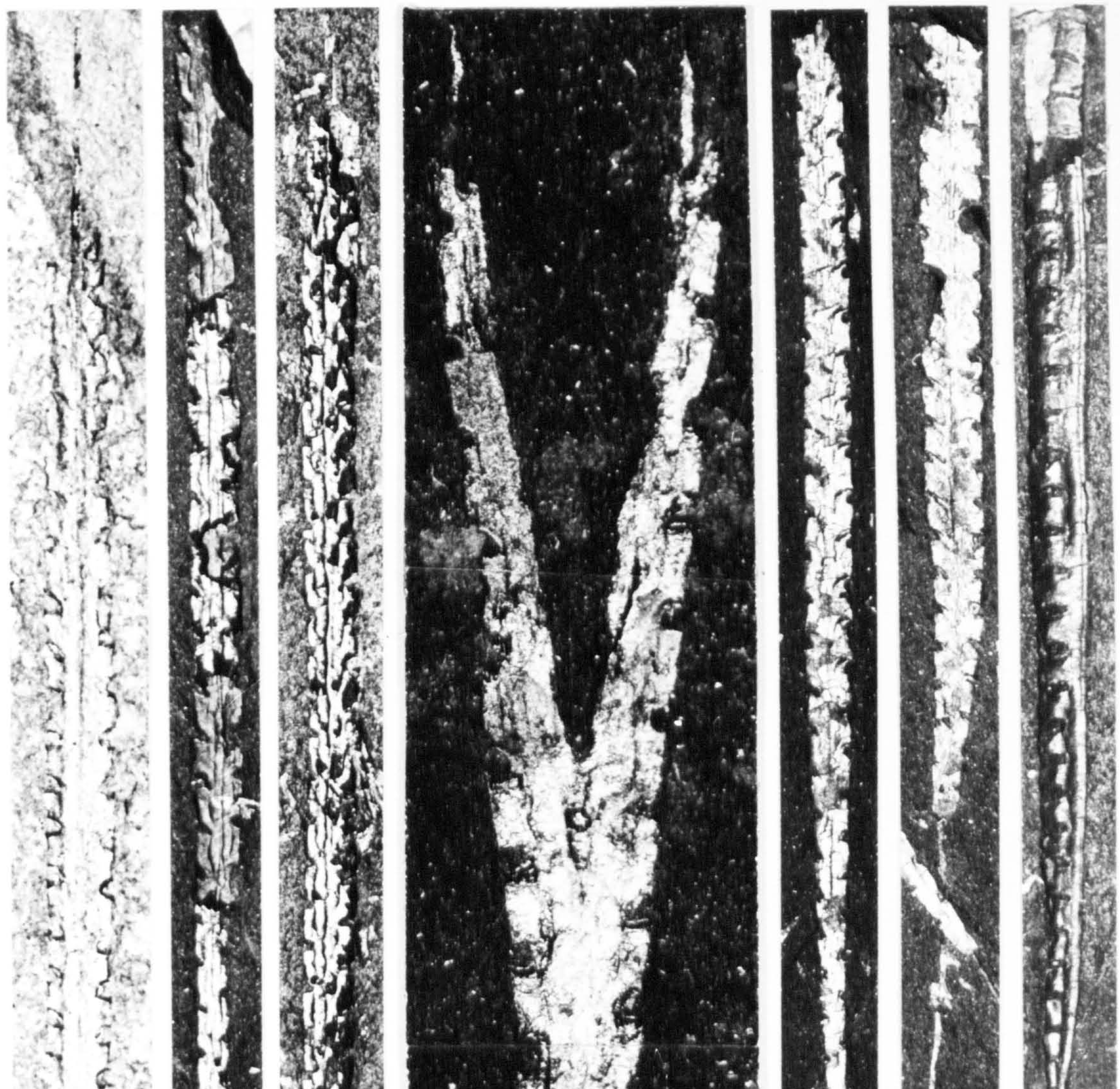
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PLATE 35

Climacograptus normalis Lapworth 1877 (all x10)

All specimens from the Linn Branch trench, Dob's Linn.

FIGURE

1. HM C13955a. External mould, in relief, slightly oblique orientation. 1.88 - 2.0m above the base of the Birkhill Shale, *O? acuminatus* Zone.
2. HM C13732a. 0.2 - 0.35m above the base of the Birkhill Shale, *G. persculptus* Zone.
3. HM C13744a. 0.2 - 0.35m above the base of the Birkhill Shale, *G. persculptus* Zone.
4. HM C13838. 1.2 - 1.32m above the base of the Birkhill Shale, *G. persculptus* Zone.
5. HM C13774a. Internal mould, in partial relief. 0.7 - 0.85m above the base of the Birkhill Shale, *G. persculptus* Zone.
6. HM C13846. 1.2 - 1.32m above the base of the Birkhill Shale, *G. persculptus* Zone.
7. HM C13754. Internal mould, in relief. From silty horizon with three-dimensional graptolites 0.6m above the base of the Birkhill Shale, *G. persculptus* Zone.

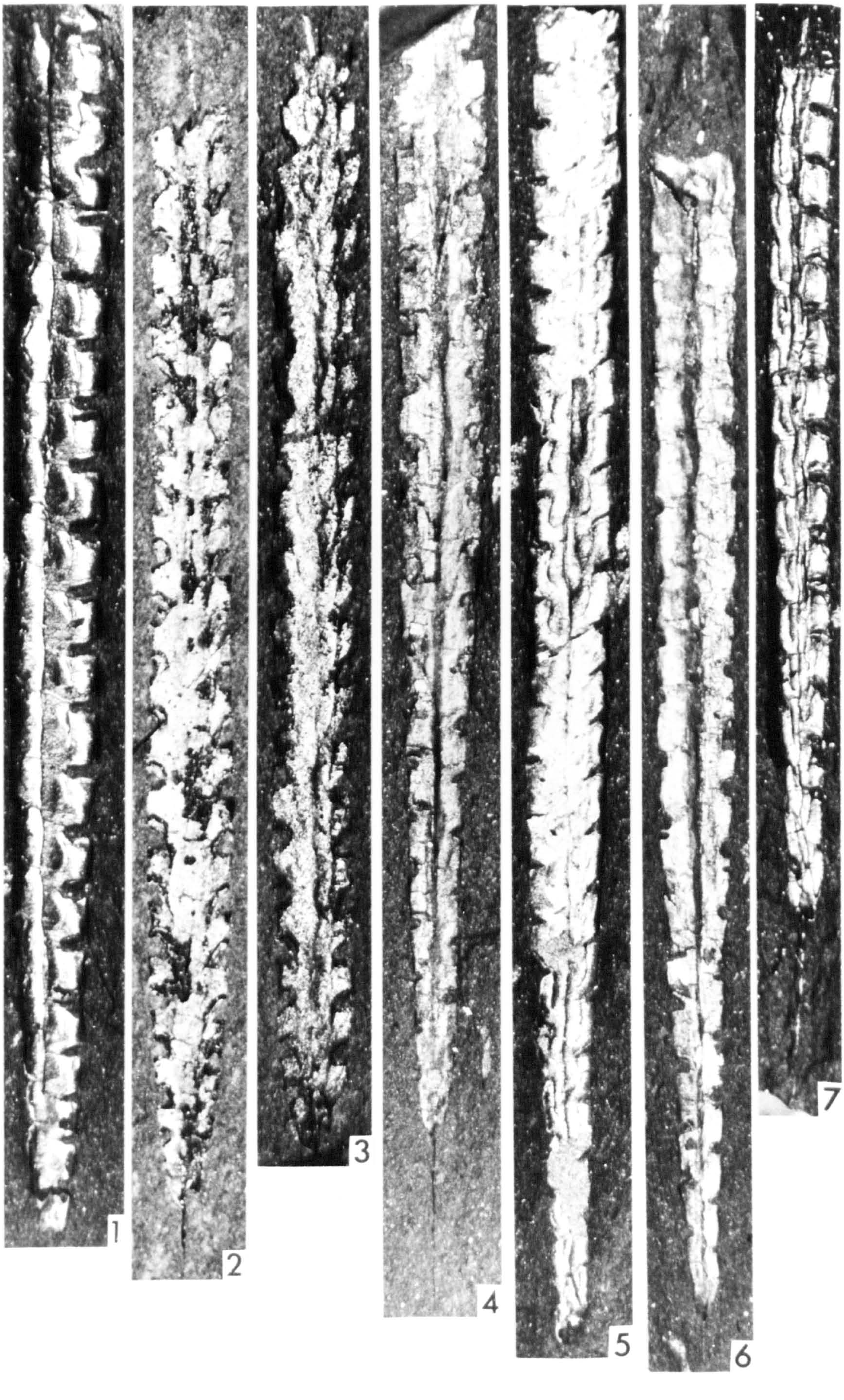
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PLATE 36

Climacograptus normalis Lapworth 1877 (all x10)

All except fig. 8 from the Linn Branch trench, Dob's Linn.

FIGURE

1. HM C13759/1a. Internal mould, in partial relief, with preservational longitudinal grooves in addition to median and interthecal septa. From silty horizon 0.6m above the base of the Birkhill Shale, G. persculptus Zone.
2. HM C13757. C. normalis/C. miserablis. Internal mould, in partial relief. Horizon as fig. 1.
3. HM C13756. Internal mould, in partial relief, in oblique orientation. Horizon as fig. 1.
4. HM C13958. Flattened, in slightly oblique orientation. 1.88 - 2.0m above the base of the Birkhill Shale, O? acuminatus Zone.
5. HM C13862a. 1.38 - 1.46m above the base of the Birkhill Shale, G. persculptus Zone.
6. HM C13821/1. In oblique orientation, tectonically widened. 1.2 - 1.32m above the base of the Birkhill Shale, G. persculptus Zone.
7. HM C13947. External mould, in partial relief, in oblique orientation. Note preservational median fold. 1.88 - 2.0m above the base of the Birkhill Shale, O? acuminatus Zone.
8. HM C13613. C. normalis/C. miserablis. Anceps Band D, Upper Hartfell Shale, P. pacificus Subzone, Main Cliff, Dob's Linn.
9. HM C14001. C. normalis/C. miserablis. Proximal fragment, in partial relief. 2.01 - 2.14m above the base of the Birkhill Shale, O? acuminatus Zone.
10. HM C13872b. Juvenile rhabdosome. 1.38 - 1.46m above the base of the Birkhill Shale, G. persculptus Zone.
11. HM C13787a. Scalariform distal fragment. Note apertures do not extend across total width of rhabdosome, indicating lateral spread along median line (detail shown in pl. 10, fig. 19). 0.7 - 0.85m above the base of the Birkhill Shale, G. persculptus Zone.

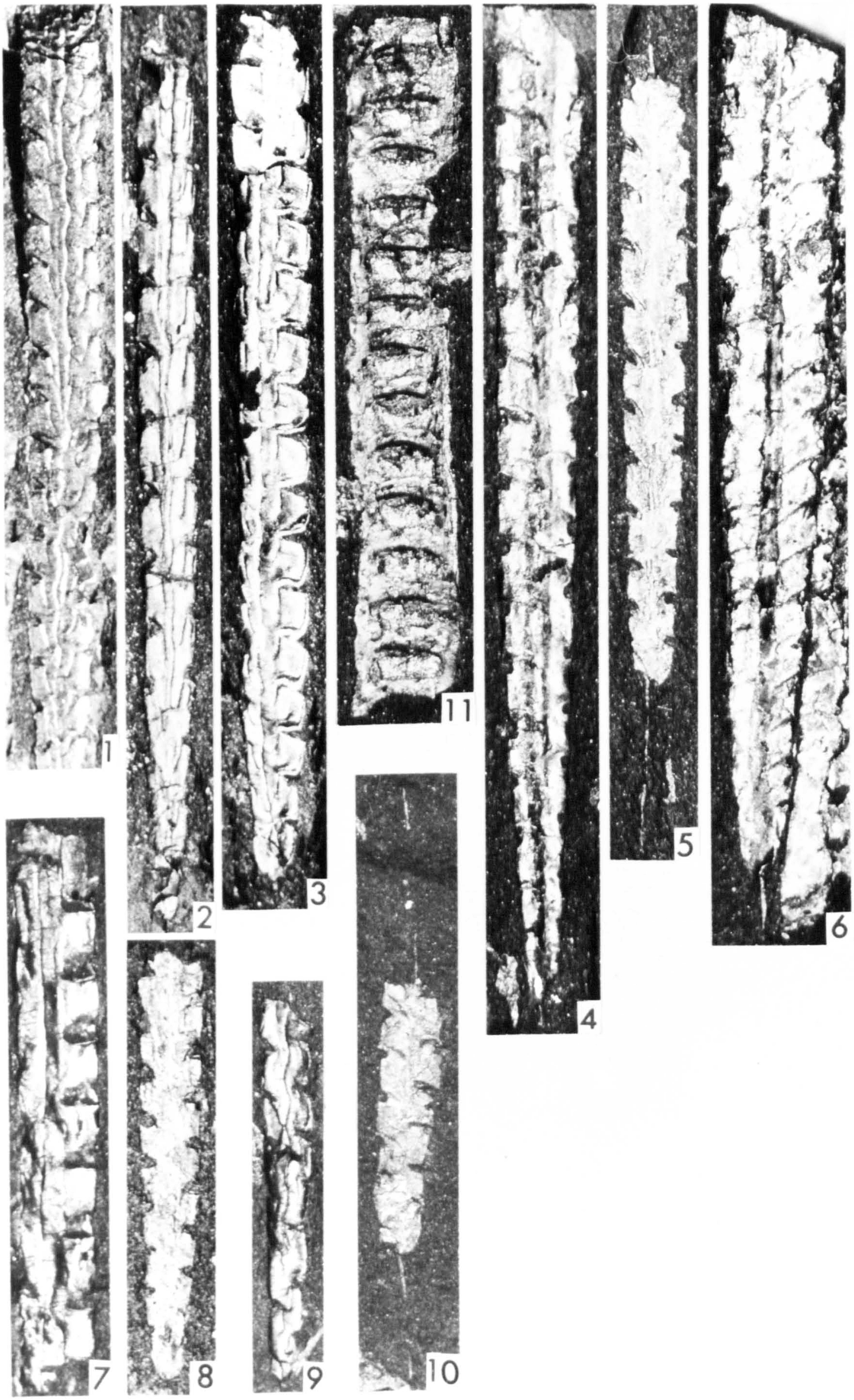

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PLATE 37 (cont.)

Climacograptus miserablis Elles & Wood 1906.

FIGURE

15. HM C13834/1a. 1.2 - 1.32m above base of Birkhill Shale, G. persculptus Zone. (x10)

16. HM C13926a. Fragment in partial relief, internal mould. 1.76 - 1.91m above base of Birkhill Shale, O? acuminatus Zone. (x10)

PLATE 37

<u>Climacograptus miserablis</u> Elles & Wood 1906. (figs. 1-10 x10)
All specimens from the Linn Branch trench, Dob's Linn.

FIGURE

1. HM C13783. 0.7 - 0.85m above base of Birkhill Shale, <u>G. persculptus</u> Zone.
2. HM C13902. 1.56 - 1.66m above base of Birkhill Shale, <u>G. persculptus</u> Zone.
3. HM C13752. Obverse view, preserved in partial relief. 0.35 - 0.56m above base of Birkhill Shale, <u>G. persculptus</u> Zone.
4. HM C13989. Obverse view, external(?) mould, preserved in partial relief. 2.01 - 2.14m above base of Birkhill Shale, <u>O? acuminatus</u> Zone.
5. HM C13788. Reverse view, internal mould, in partial relief. 0.7 - 0.85m above base of Birkhill Shale, <u>G. persculptus</u> Zone.
6. HM C13826. 1.2 - 1.32m above base of Birkhill Shale, <u>G. persculptus</u> Zone.
7. HM C13885b. Membranous growth on nema. 1.46 - 1.56m above base of Birkhill Shale, <u>G. persculptus</u> Zone.
8. HM C13938. Flattened in oblique view, prominent virgula. 1.69 - 1.79m above base of Birkhill Shale, <u>O? acuminatus</u> Zone.
9. HM C13870/1a. Long rhabdosome. 1.38 - 1.46m above base of Birkhill Shale, <u>G. persculptus</u> Zone.
10. HM C13904/1a. Long virgella. 1.56 - 1.66m above base of Birkhill Shale, <u>G. persculptus</u> Zone.
11. HM C13964. Obverse view, internal mould, in full relief. 1.88 - 2.0m above base of Birkhill Shale, <u>O? acuminatus</u> Zone. (x25)
12. HM C14004. Reverse view, in full relief. 2.01 - 2.14m above base of Birkhill Shale, <u>O? acuminatus</u> Zone. (x25)
13. HM C13971. Reverse view, internal mould, in full relief. Note terminal thickened node of median septum. 1.88 - 2.0m above base of Birkhill Shale, <u>O? acuminatus</u> Zone. (x25)
14. HM C13909. Reverse view, in partial relief. Note growth fusellae. 1.56 - 1.66m above base of Birkhill Shale, <u>G. persculptus</u> Zone. (approx. x35)


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PLATE 38

Climacograptus miserablis Elles & Wood 1906. (all x10)

All from the Lower and Upper Hartfell Shale, Dob's Linn.

FIGURE

1. BU 1148. Lower Complanatus Band, Upper Hartfell Shale, *D. complanatus* Zone. Lapworth Collection. Figd. Elles & Wood 1906, pl. 26, fig. 3e.
2. BU 1149. Lower Complanatus Band, Upper Hartfell Shale, *D. complanatus* Zone. Lapworth Collection.
3. BU 1150. Lower Complanatus Band, Upper Hartfell Shale, *D. complanatus* Zone. Wood Collection. Figd. Elles & Wood 1906, text-fig. 120a.
4. HM C14477/1a. Lower Complanatus Band, Upper Hartfell Shale, *D. complanatus* Zone, west of North Cliff trench.
5. HM C14472/1. Lower Complanatus Band, Upper Hartfell Shale, *D. complanatus* Zone, Main Cliff (text-fig. 1, loc. 3).
6. HM C14466. Lower Complanatus Band, Upper Hartfell Shale, *D. complanatus* Zone, west of North Cliff trench.
7. HM C13613. Anceps Band D, Upper Hartfell Shale. *P. pacificus* Subzone, Main Cliff section.
8. HM C14382a. 2.25 - 2.0m below top of Lower Hartfell Shale, *P. linearis* Zone, North Cliff trench.
9. HM C14374. 2.25 - 2.0m below top of Lower Hartfell Shale, *P. linearis* Zone, North Cliff trench.
10. HM C14061. 8.7 - 8.5m below top of Lower Hartfell Shale, *D. clingani* Zone, North Cliff trench.
11. HM C14074. 8.7 - 8.5m below top of Lower Hartfell Shale, *D. clingani* Zone, North Cliff trench.
12. HM C14060a. Periderm reduced distally with long nema. 8.7 - 8.5m below top of Lower Hartfell Shale, *D. clingani* Zone, North Cliff trench.
13. HM C14384. 2.25 - 2.0m below top of Lower Hartfell Shale, *P. linearis* Zone, North Cliff trench.

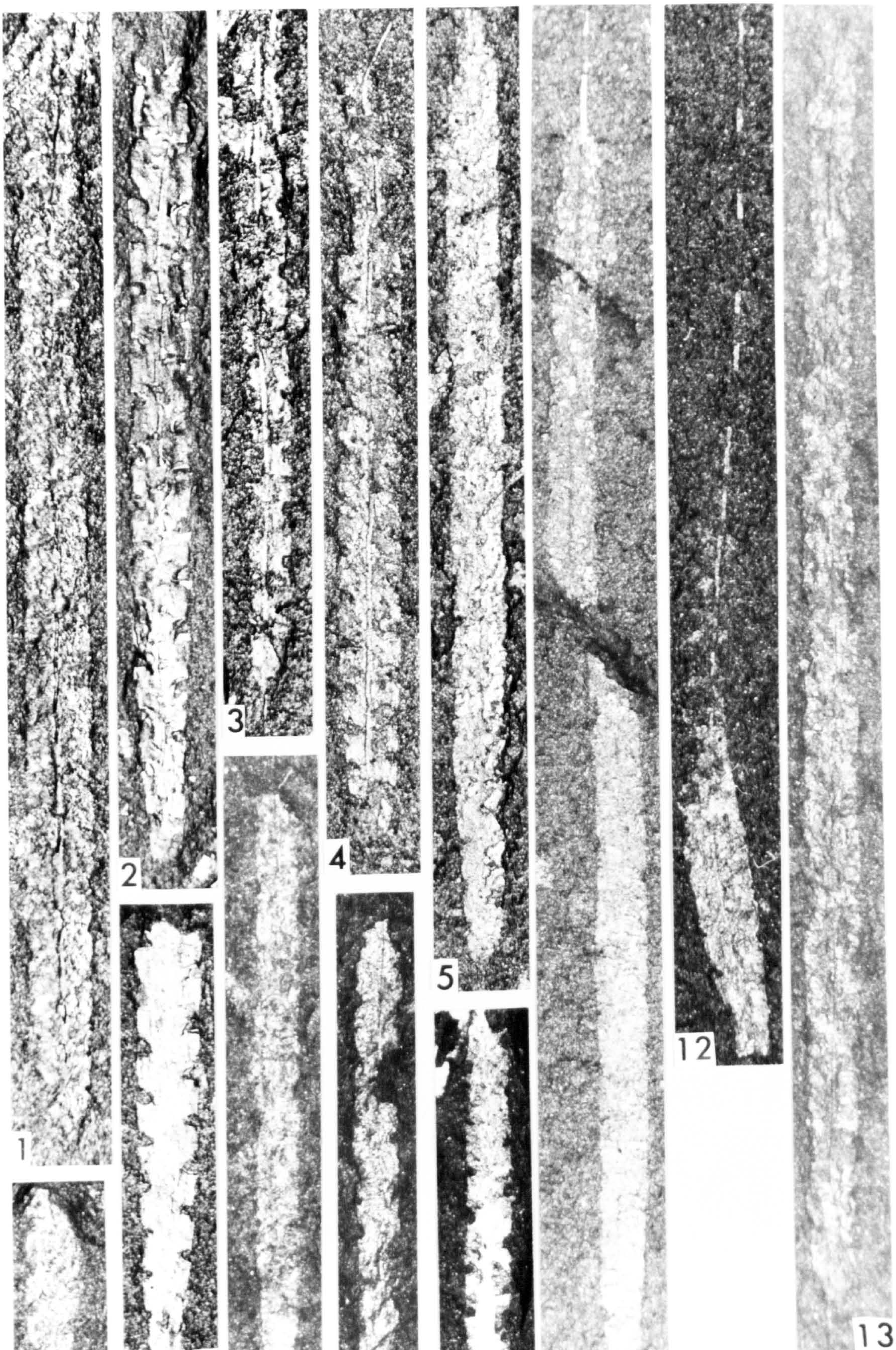
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PLATE 39

All specimens from the Linn Branch trench, Dob's Linn.
(all x10 except fig. 1)

FIGURE

1. HM C13764. _C. normalis_ Lapworth 1877/_C. medius_ Törnquist 1897. 0.7 - 0.85m above the base of the Birkhill Shale, _G. persculptus_ Zone. (x5)
2. HM C14020. _Climacograptus trifilis_ Manck 1923. 2.19 - 2.31m above the base of the Birkhill Shale, _O? acuminatus_ Zone.

Figs. 3 - 7. _Climacograptus medius_ Törnquist 1897.

3. HM C13988a. 1.46 - 1.56m above the base of the Birkhill Shale, _G. persculptus_ Zone.
4. HM C13916/1. 1.76 - 1.91m above the base of the Birkhill Shale, _O? acuminatus_ Zone.
5. HM C13888a. 1.46 - 1.56m above the base of the Birkhill Shale, _G. persculptus_ Zone.
6. HM C13814. 1.1 - 1.2m above the base of the Birkhill Shale, _G. persculptus_ Zone.
7. HM C13951. Note median groove of wide nema. 1.88 - 2.0m above the base of the Birkhill Shale, _O? acuminatus_ Zone.

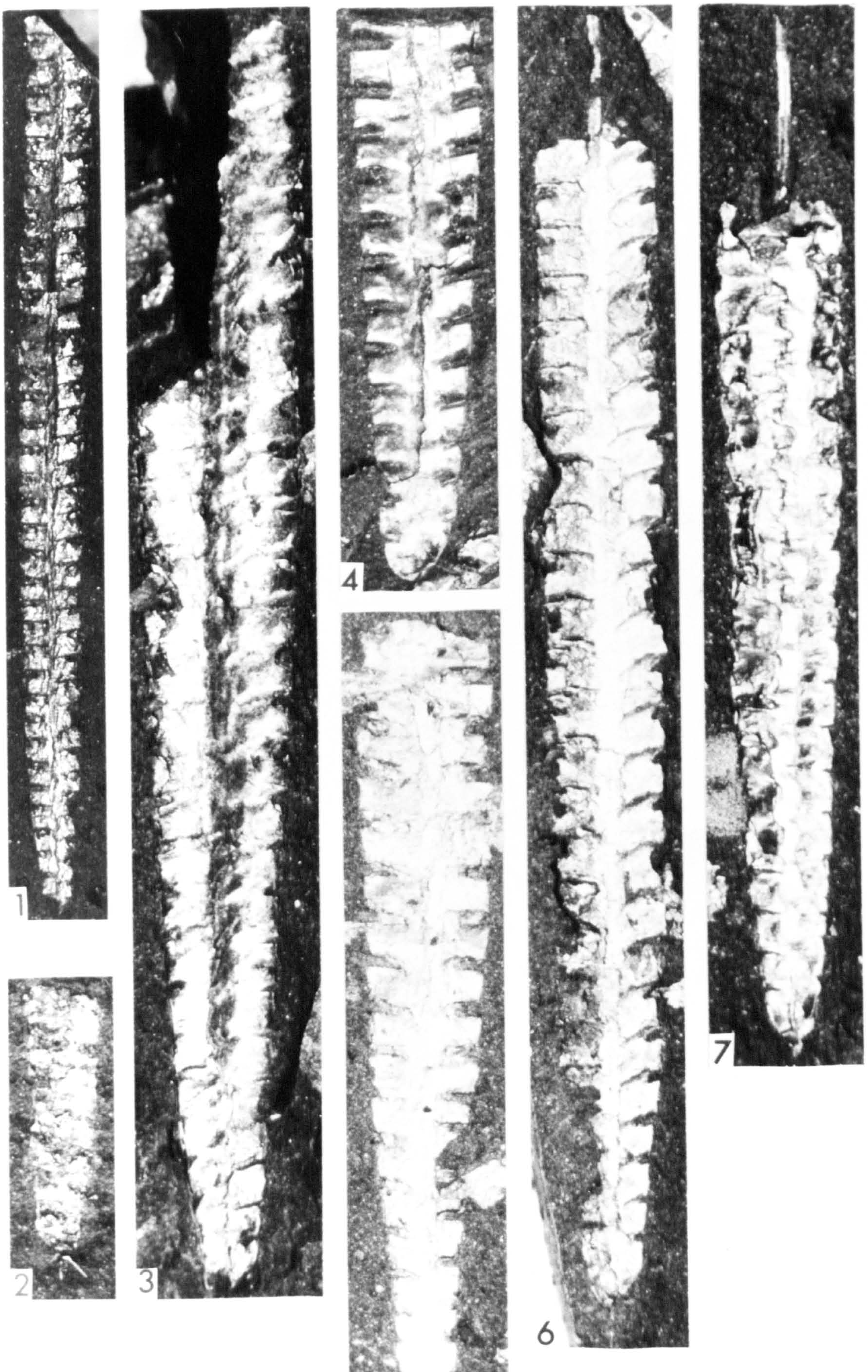
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PLATE 40

Climacograptus *mohawkensis* (Ruedemann 1912). (all x10)
All from the *P. linearis* Zone, North Cliff trench, Dob's Linn.

FIGURE

1. HM C14394/1. Preserved in oblique view. 2.0 - 1.8m below top of Lower Hartfell Shale.
2. HM C14363. 2.25 - 2.15m below top of Lower Hartfell Shale.
3. HM C14378/1. 2.25 - 2.0m below top of Lower Hartfell Shale.
4. HM C14450/1. With prominent virgella. 0.9 - 0.7m below top of Lower Hartfell Shale.
5. HM C14370a. 2.25 - 2.15m below top of Lower Hartfell Shale.
6. HM C14454. 0.45 - 0.3m below top of Lower Hartfell Shale.
7. HM C14381. 2.25 - 2.0m below top of Lower Hartfell Shale.
8. HM C14330. In scalariform view, virgula visible through thecal apertures. 3.0 - 2.9m below top of Lower Hartfell Shale.

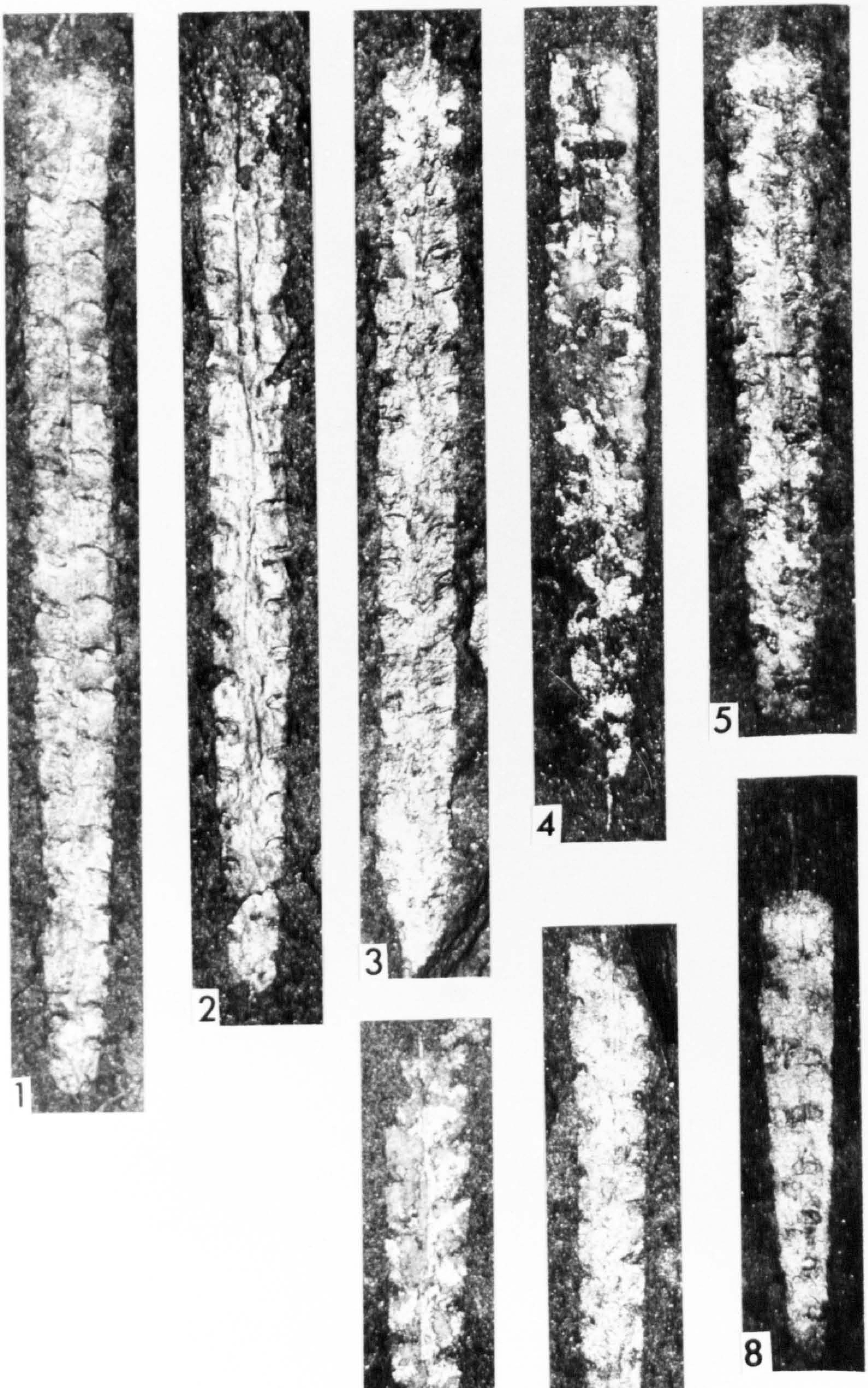
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PLATE 41

Climacograptus? extraordinarius (Sobolevskaya 1974).
All from the Upper Hartfell Shale, Dob's Linn.

FIGURE

1. HM C13689. Almost complete specimen with prominent distal narrowing. Anceps Band E, P. pacificus Subzone, Main Cliff section. (x5)
2. HM C13709. Anceps Band E, P. pacificus Subzone, Main Cliff section. (x5)
3. HM C14479/23-32. Extraordinarius Band, C? extraordinarius Zone, Long Burn trench. Also figd. text-figs. 25b, d. Ingham Collection. (x5)
4. HM C14479/22. Proximal detail. Extraordinarius Band, C? extraordinarius Zone, Long Burn trench. Also figd. text-fig. 25g. Ingham Collection. (x10)
5. HM C14479/1. Proximal detail. Extraordinarius Band, C? extraordinarius Zone, Long Burn trench. Also figd. text-fig. 25i. Ingham Collection. (x10)
6. HM C13705. Anceps Band E, P. pacificus Subzone, Main Cliff section. (x5)
7. HM C14479/1-4. Note different effects of tectonic deformation, depending on orientation of rhabdosome. Extraordinarius Band, C? extraordinarius Zone, Long Burn section. Ingham Collection. (x5)

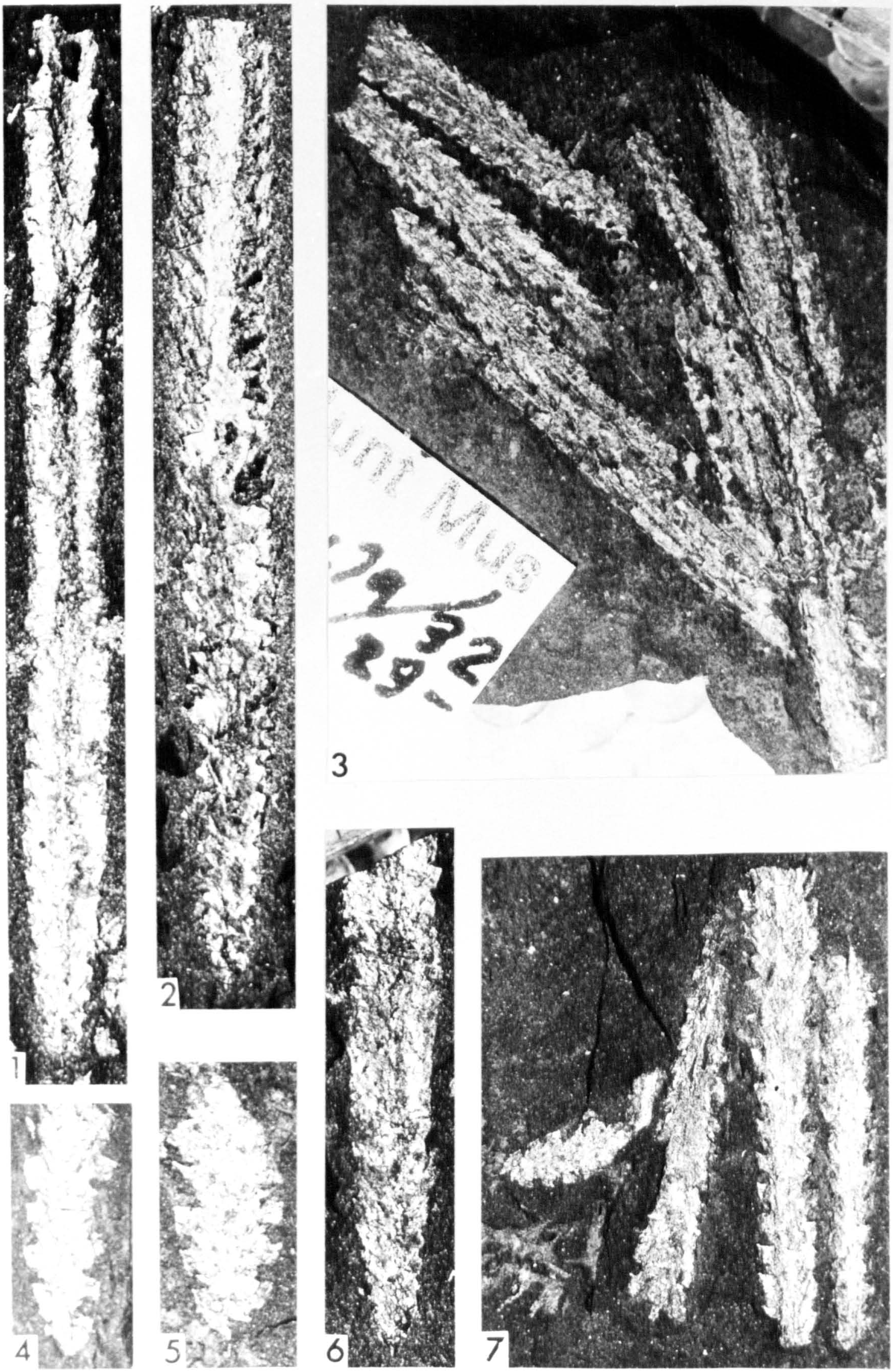
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PLATE 42

Orthograptus quadrimucronatus quadrimucronatus (Hall 1865) (all x5)
All from the P. linearis Zone, North Cliff trench, Dob's Linn.

FIGURE

1. HM C14396/2b. Long distal fragment with nema, in scalariform view. 2.0 - 1.8m below top of Lower Hartfell Shale.
2. HM C14358. Long distal fragment in dorso-ventral view. 2.25 - 2.15m below top of Lower Hartfell Shale.
3. HM C14375. Distal fragment in scalariform view. 2.12 - 2.0m below top of Lower Hartfell Shale.
4. HM C14376. Oblique view. 2.12 - 2.0m below top of Lower Hartfell Shale.
5. HM C14368. Distal fragment in oblique view. 2.12 - 2.0m below top of Lower Hartfell Shale.
6. HM C14369. With proximal end, in oblique view. 2.12 - 2.0m below top of Lower Hartfell Shale.
7. HM C14377a. Distal fragment in scalariform view, with long spines. 2.12 - 2.0m below top of Lower Hartfell Shale.
8. HM C14380. Proximal fragment in oblique view. 2.12 - 2.0m below top of Lower Hartfell Shale.

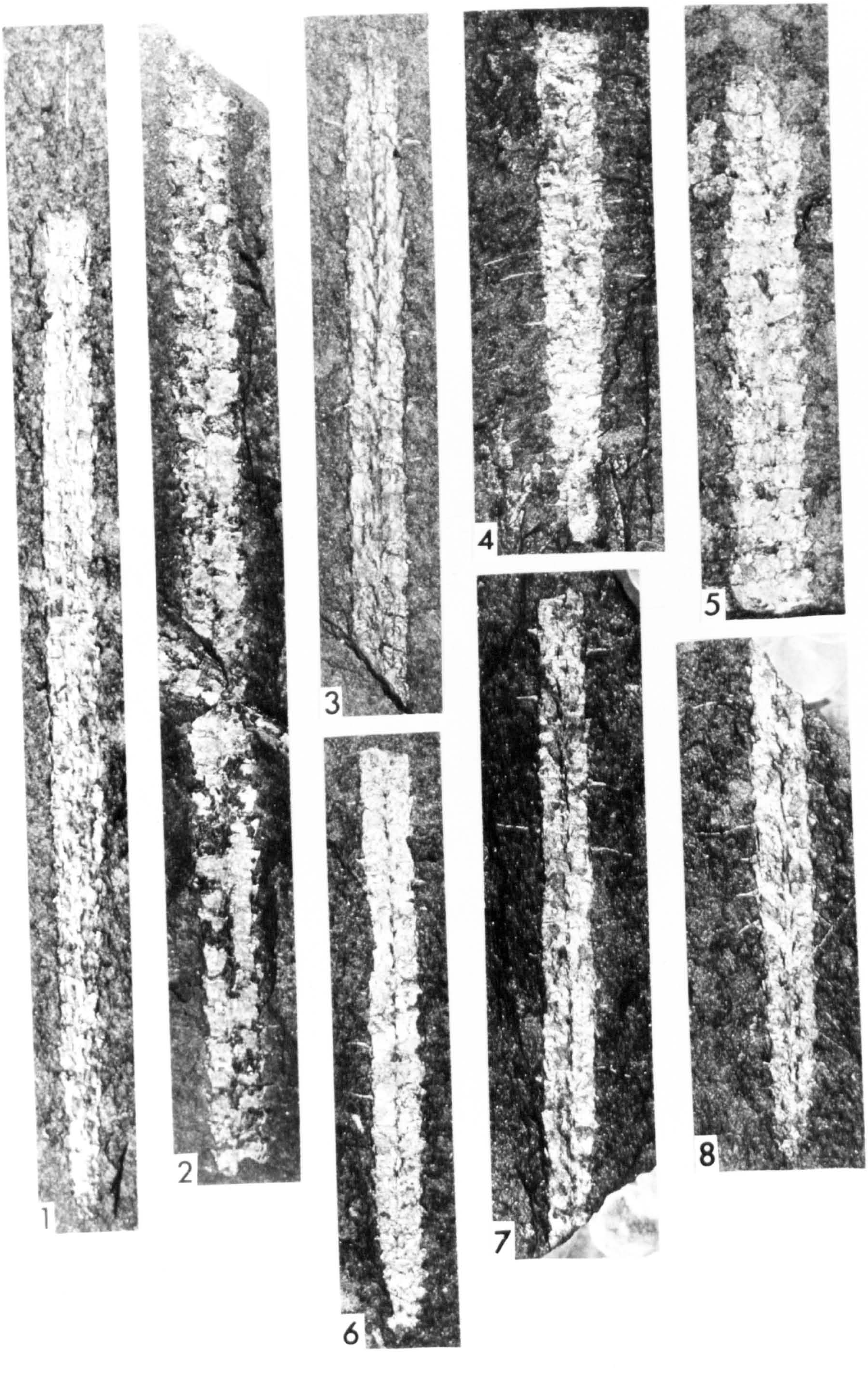
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PLATE 43

Orthograptus ex gr. calcaratus

All from the North Cliff trench, Dob's Linn.

FIGURE

1. HM C14131. cf. O. c. tenuicornis sensu Elles & Wood. With long thin spines on first two thecae and smaller virgella. 8.4 - 8.3m below top of Lower Hartfell Shale, D. clingani Zone. (x5)
2. HM C14117. As fig. 1, but with thicker basal spines and nema. 8.4 - 8.3m below top of Lower Hartfell Shale, D. clingani Zone. (x5)
3. HM C14115. Juvenile specimen as fig. 1. 8.4 - 8.3m below top of Lower Hartfell Shale, D. clingani Zone. (x5)
4. HM C14143. As fig. 1. 8.0 - 7.8m below top of Lower Hartfell Shale, D. clingani Zone. (x5)
5. HM C14183a. As fig. 1 but with uniserial distal portion. 8.0 - 7.8m below top of Lower Hartfell Shale, D. clingani Zone. (x5)
6. HM C14134/1a. As fig. 1. 8.4 - 8.3m below top of Lower Hartfell Shale, D. clingani Zone. (x5)
7. HM C14268. Proximal detail of specimen with long thickened virgella and short thecal spines. 5.1 - 4.9m below top of Lower Hartfell Shale, D. clingani/P. linearis zone. (x5)
8. HM C14276/1a. Complete specimen with proximal end similar to fig. 7. 5.0 - 4.9m below top of Lower Hartfell Shale, P. linearis Zone. (x5)
9. HM C14198. Proximal detail with thecal spines and virgella of similar lengths and robust proximal development (cf. O. c. vulgatus sensu Elles & Wood). 7.35 - 7.25m below top of Lower Hartfell Shale, D. clingani Zone. (x10)
10. HM C14185. As fig. 9. 7.35 - 7.25m below top of Lower Hartfell Shale, D. clingani Zone. (x10)
11. HM C14271/1a. Proximal end with long narrow virgella and short thecal spines. 5.1 - 4.9m below top of Lower Hartfell Shale, D. clingani/P. linearis zone. (x10)
12. HM C14276/1a. Proximal end with long thick virgella and small thecal spines. 5.0 - 4.9m below top of Lower Hartfell Shale, P. linearis Zone. (x10)

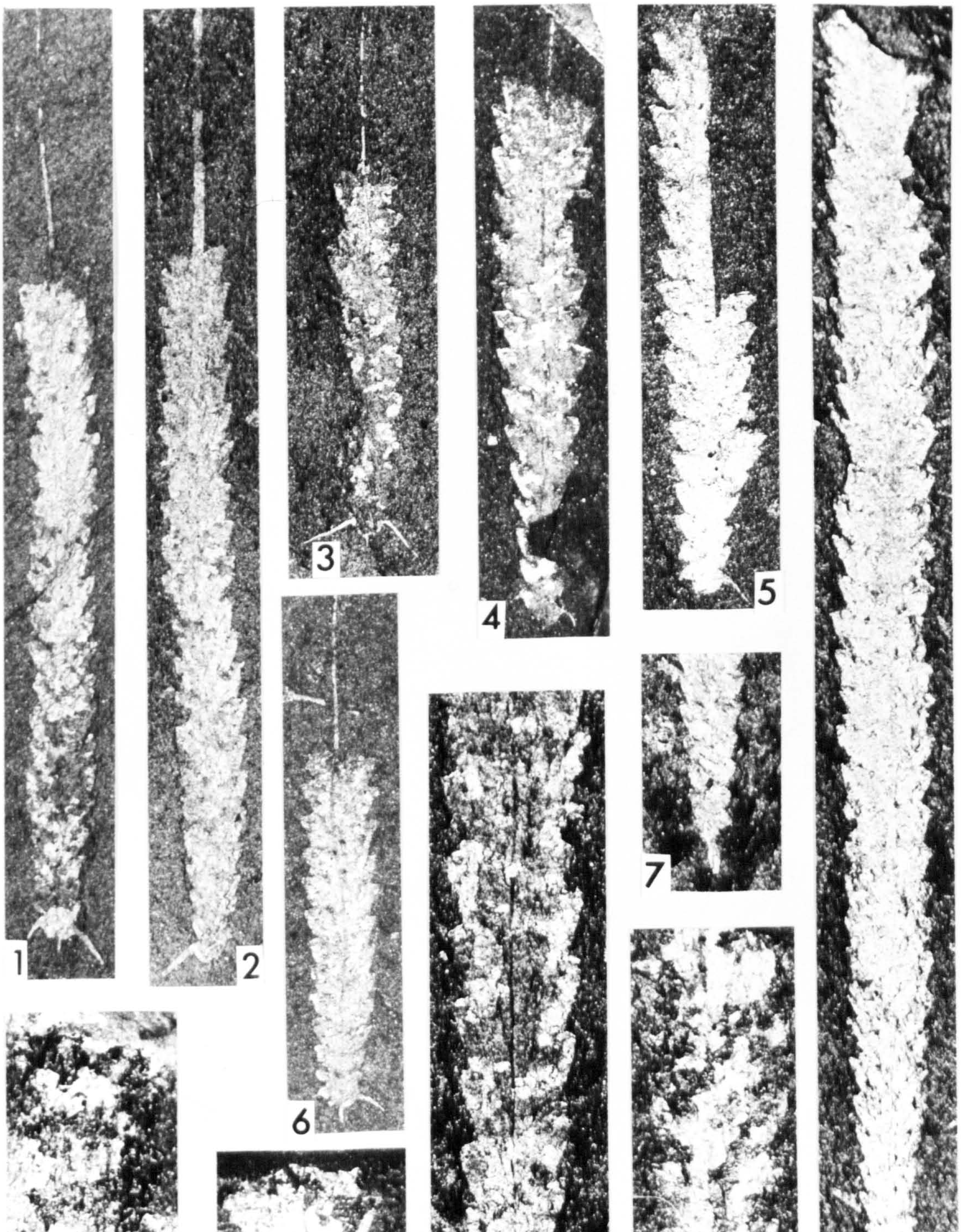
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PLATE 44

Orthograptus ex gr. calcaratus. (all except fig. 4 x5)
All from the North Cliff trench, Dob's Linn.

FIGURE

1. HM C14164a. Robust distal fragment with distal uniserial portion, possibly broken. 7.85 - 7.7m below top of Lower Hartfell Shale, D. clingani Zone.
2. HM C14274. Distal fragment with long wide nemal vane. Note proximal extension of vane into stipe. 5.1 - 4.9m below top of Lower Hartfell Shale, D. clingani/P. linearis zone.
3. HM C14286/1. Well preserved flattened specimen with thickened nema. 5.0 - 4.9m below top of Lower Hartfell Shale, P. linearis Zone.
4. HM C14280a. Distal fragment with long thickened nema. 5.0 - 4.9m below top of Lower Hartfell Shale, P. linearis Zone.(x2.5)
5. HM C14385a. Specimen in oblique view. 2.25 - 2.0m below top of Lower Hartfell Shale, P. linearis Zone.
6. HM C14271/1a. Proximal end with long narrow virgella and short narrow thecal spines. 5.1 - 4.9m below top of Lower Hartfell Shale, D. clingani/P. linearis zone.
7. HM C14364a. Note 'Glyptograptus-like' appearance of proximal thecae (as in O. fastigatus). 2.5 - 2.25m below top of Lower Hartfell Shale, P. linearis Zone.


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PLATE 45

Orthograptus ex gr. calcaratus (all except fig. 7 x5)

FIGURE

1 - 7. cf. O. c. basilicus sensu Elles & Wood. P. linearis Zone, North Cliff trench, Dob's Linn.

1. HM C14426/2a. 1.35 - 1.2m below top of Lower Hartfell Shale.
2. HM C14424a. 1.35 - 1.2m below top of Lower Hartfell Shale.
3. HM C14426/1a. With thin nema. 1.35 - 1.2m below top of Lower Hartfell Shale.
4. HM C14436/1a. In oblique view with short proximal spines. 1.2 - 1.1m below top of Lower Hartfell Shale.
5. HM C14436/2b. Immature specimen with short proximal spines and thin nema. 1.2 - 1.1m below top of Lower Hartfell Shale.
6. HM C14423a. Proximal fragment. 1.35 - 1.2m below top of Lower Hartfell Shale.
7. HM C14276/2-3a. Juvenile specimens. 5.0 - 4.9m below top of Lower Hartfell Shale. (x10)

8 - 11. Fragments in partial relief, showing preservational 'median septum'. Dark Shale Member, Mill Formation, Upper Whitehouse Group, P. linearis/D. complanatus zone, Loc. M1, Myoch Bay, Girvan.

8. HM C13002. Also figd. pl. 10, fig. 20.
9. HM C13003/1a.
10. HM C13046/16.
11. HM C13003/3a.

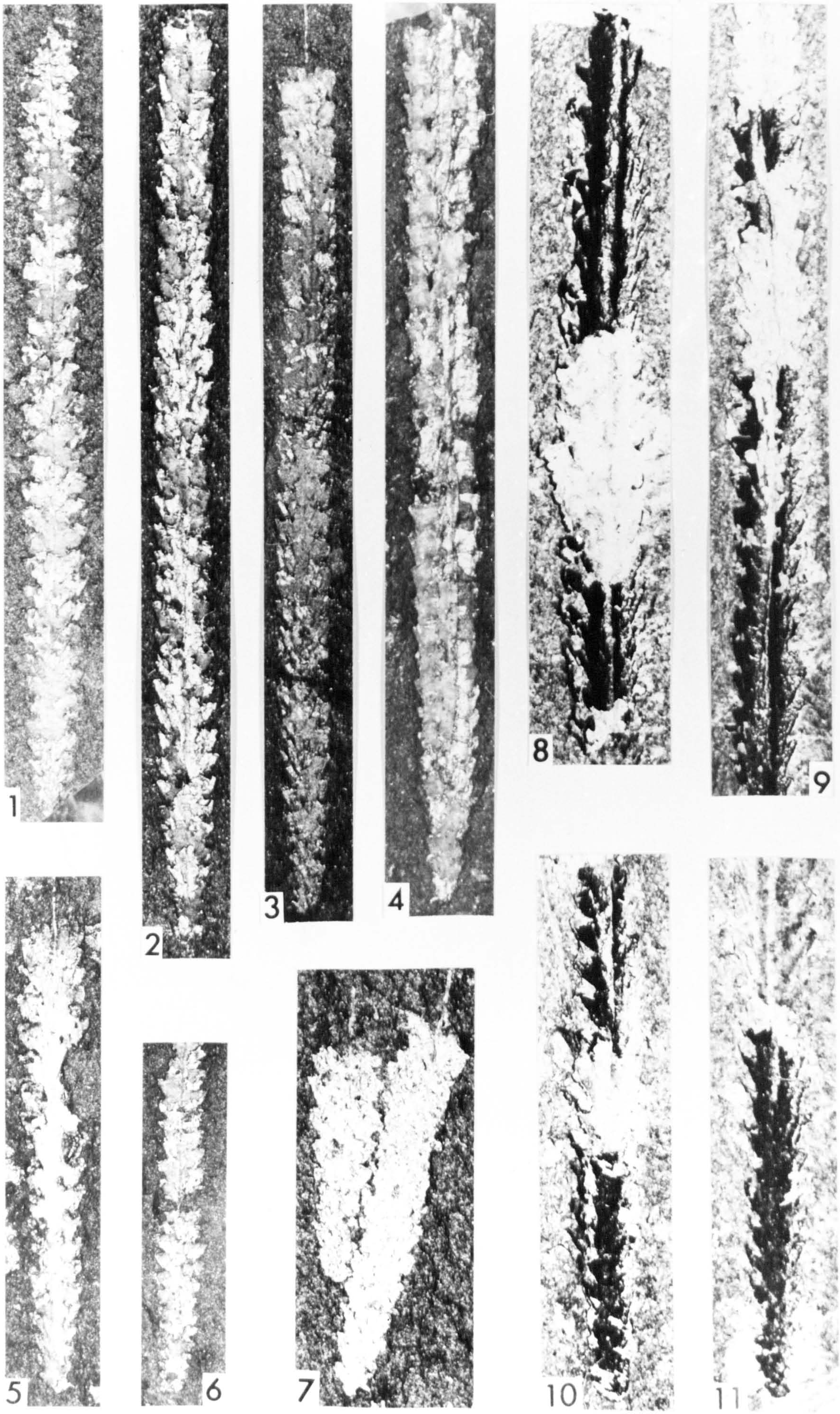
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PLATE 46

Orthograptus fastigatus Davies 1929.

All specimens from Anceps Band B, Upper Hartfell Shale, *D. complexus* Subzone, Dob's Linn.

FIGURE

1. HM C13296a. Linn Branch trench. (x2.5)
2. HM C13280. Linn Branch trench. (x5)
3. HM C13341a. Main Cliff section. (x5)
4. HM C13311a. Linn Branch trench. (x5)
5. HM C13279a. Linn Branch trench. (x5)
6. HM C13317/1. Linn Branch trench. (x10)
7. HM C13344. Main Cliff section. (x10)
8. HM C13314. Linn Branch trench. (x10)
9. HM C13334/1. Main Cliff section. (x10)

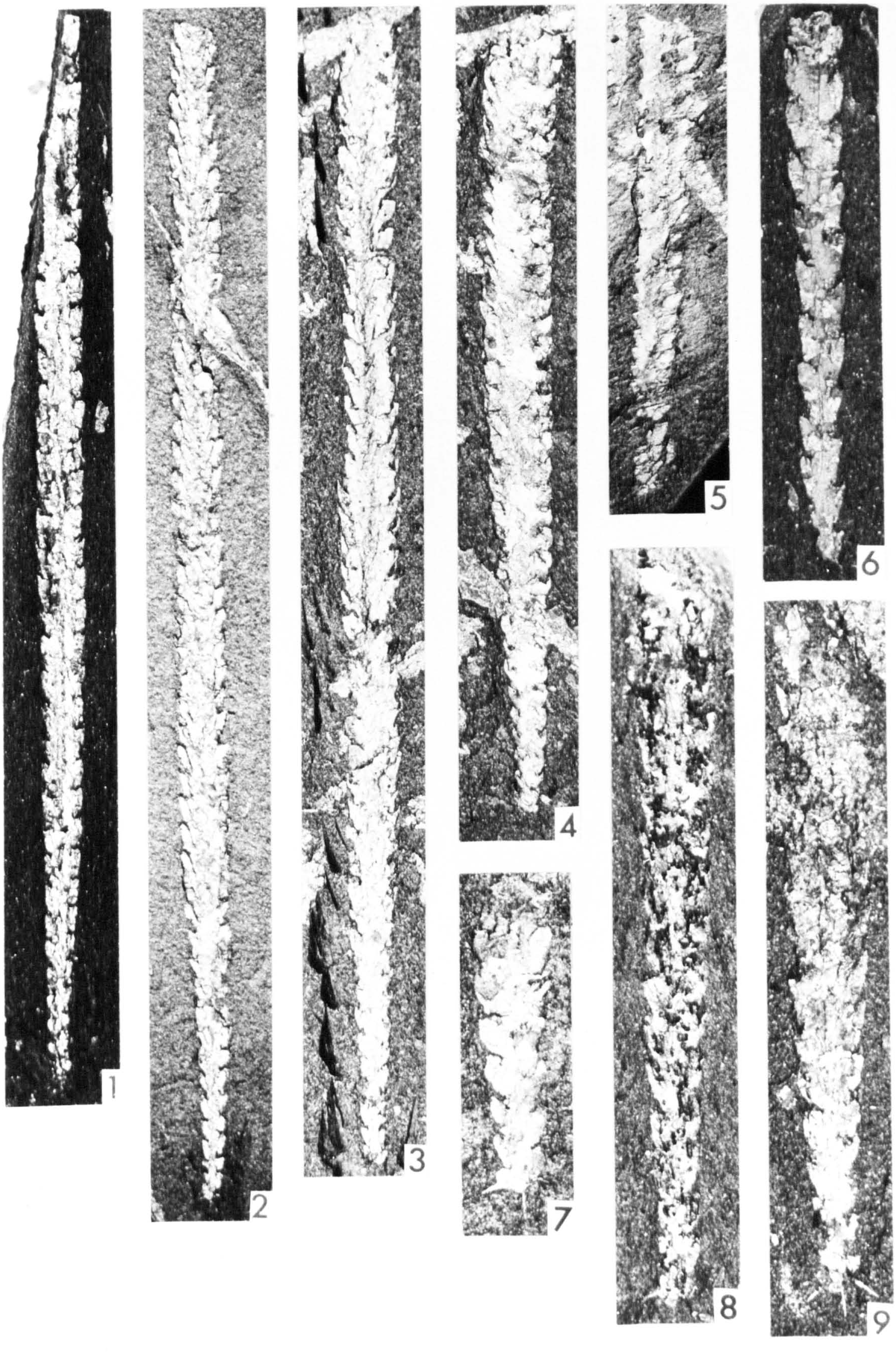
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PLATE 47

All from the _P. linearis_ Zone, North Cliff trench, Dob's Linn (all except fig. 5 x5)

FIGURE

1 - 2. _Orthograptus? amplexicaulis_ (Hall 1847).

1. HM C14447. 1.0 - 0.9m below top of Lower Hartfell Shale.
2. HM C14443/1a. 1.1 - 1.0m below top of Lower Hartfell Shale.

3 - 6. _Orthograptus? pauperatus_ Elles & Wood 1907.

3. HM C14429/1. Tectonically stretched specimen. 1.35 - 1.2m below top of Lower Hartfell Shale.
4. HM C14298/1-2. Note difference in tectonic deformation between specimens parallel and oblique to stretching direction. 5.0 - 4.8m below top of Lower Hartfell Shale.
5. HM C14306. Juvenile specimen with well preserved proximal spines. 4.75m below top of Lower Hartfell Shale. (x10)
6. HM C14303/1. Specimen with proximal spines. 4.75m below top of Lower Hartfell Shale.


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PLATE 48

Orthograptus? abbreviatus Elles & Wood 1907.

All specimens from the Anceps Bands, Upper Hartfell Shale, D. anceps Zone, Dob's Linn.

FIGURE

1. HM C13598b. Complete specimen in partial relief. Band D, P. pacificus Subzone, Main Cliff section. (x10)
2. HM C13598a. Proximal detail of counterpart of fig. 1. Obverse view, in partial relief. (x25)
3. HM C13397/1-2a. Specimens clearly showing basal spines. Band B, D. complexus Subzone, Long Burn trench. (x10)
4. HM C13322. Band B, D. complexus Subzone, Linn Branch trench. (x10)
5. HM C13524. Juvenile specimen with short nema. Band D, P. pacificus Subzone, Long Burn trench. (x10)
6. HM C13548. Band D, P. pacificus Subzone, Long Burn trench. (x10)
7. HM C13339/1. Long rhabdosome. Band B, D. complexus Subzone, Main Cliff section. (x5)
8. HM C13590. Band D, P. pacificus Subzone, Long Burn trench. (x5)
9. HM C13339/2. Band B, D. complexus Subzone, Main Cliff section. (x5)

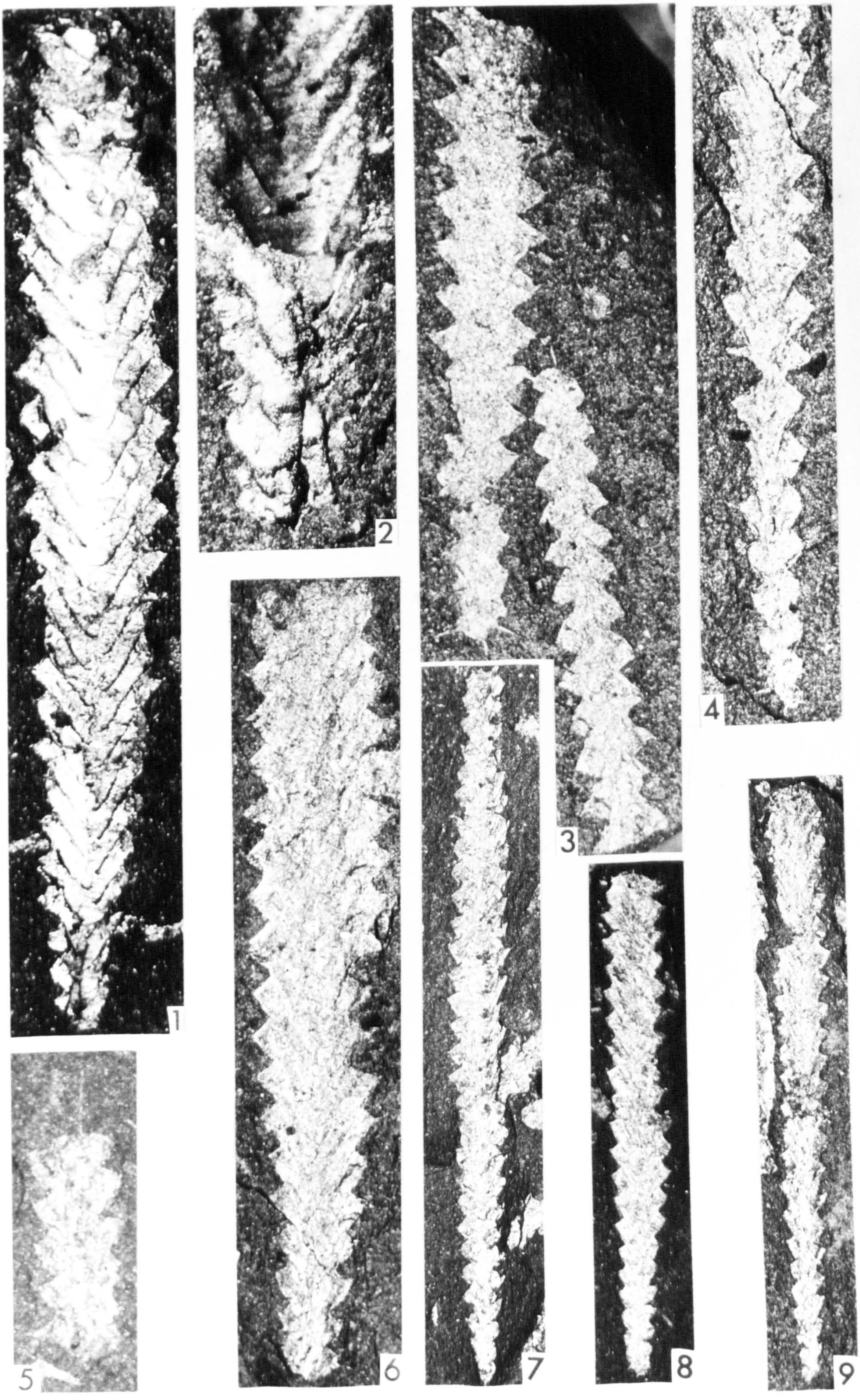
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PLATE 49

Orthograptus? acuminatus (Nicholson 1867) sensu lato. (all x10)
All from the O? acuminatus Zone, Linn Branch trench, Dob's Linn.

FIGURE

1. HM C13950. Possibly A. ascensus with thecal style altered by diagenetic flattening. 1.88 - 2.0m above base of Birkhill Shale.
2. HM C13956a. As fig. 1.
3. HM C13933/1. As fig. 1. 1.66 - 1.76m above base of Birkhill Shale.
4. HM C13936. More similar to O? acuminatus s.s. in thecal style. 1.69 - 1.79m above base of Birkhill Shale.
5. HM C13935/1a. Proximal fragment - if complete, more like O? a. praematurus in development. 1.69 - 1.79m above base of Birkhill Shale.
6. HM C13911. 1.56 - 1.66m above base of Birkhill Shale.
7. HM C13934/1. Distal fragment with nema. 1.66 - 1.76m above base of Birkhill Shale.
8. HM C14006/1. 2.01 - 2.14m above base of Birkhill Shale.
9. HM C13931. 1.66 - 1.76m above base of Birkhill Shale.
10. HM C13992. In partial relief. 2.01 - 2.14m above base of Birkhill Shale.
11. HM C13939. 1.69 - 1.79m above base of Birkhill Shale.
12. HM C13935/1a. 1.69 - 1.79m above base of Birkhill Shale.
13. HM C13934/2. Proximal fragment as fig. 5. 1.66 - 1.76m above base of Birkhill Shale.

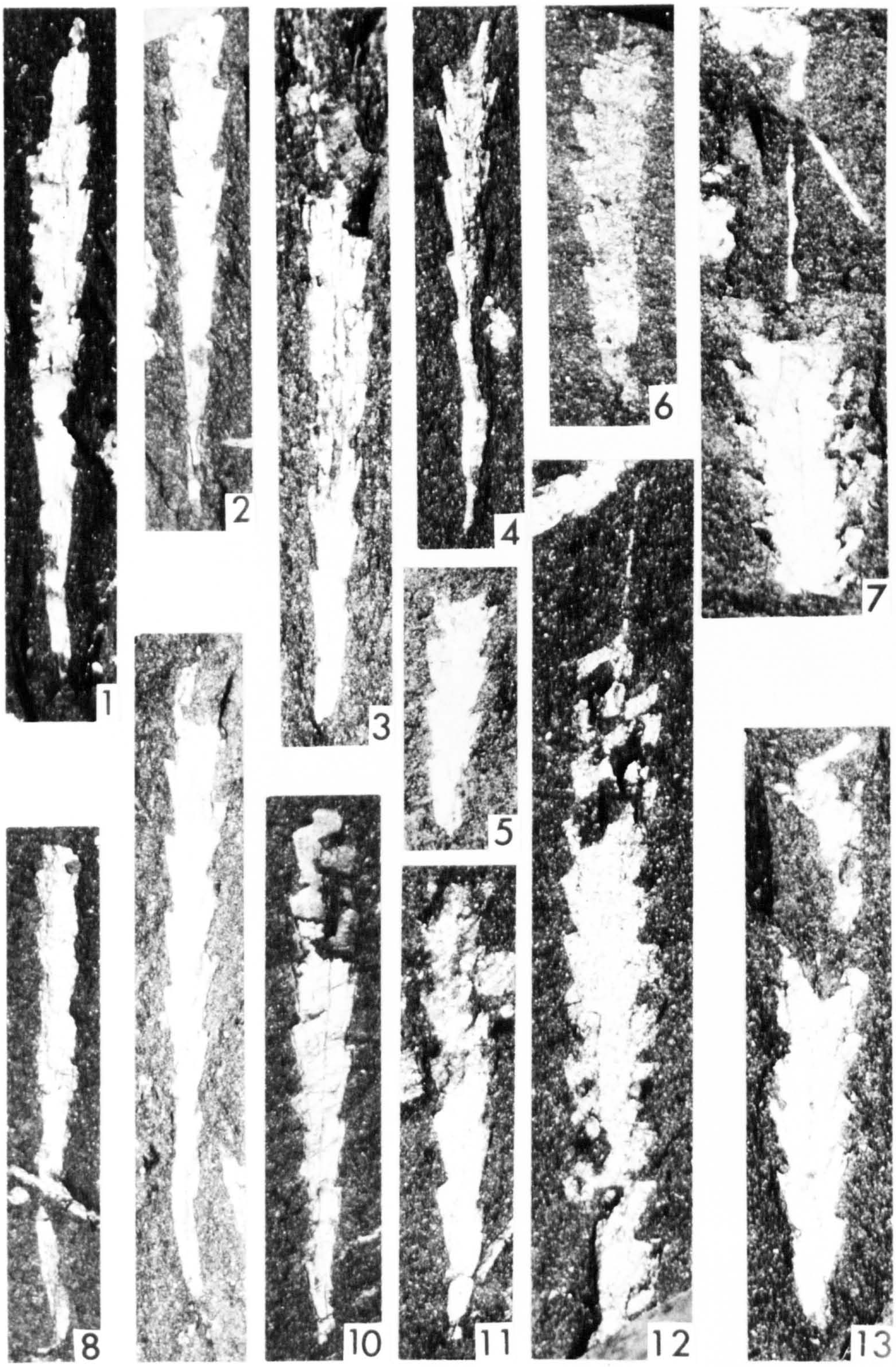
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PLATE 50

Glyptograptus persculptus (Salter 1865)
All from the basal Silurian, *G. persculptus/O? acuminatus* zones, Gogofau, Pumpsaint, Dyfed, Mid-Wales.

FIGURE

1. Q112. Obverse view with apparently complete sicula, in full relief. British Museum (Nat. Hist.) collections. ?Figd. Elles & Wood 1907, text-fig. 176a. (approx. x20)
2. Q113. Broad specimen with broken proximal end, in partial relief. Note effect of compression on thecal style (cf. fig. 1). British Museum (Nat. Hist.) collections. Figd. Elles & Wood 1907, text-fig. 176b (with complete proximal end). (approx. x20)
3. I.G.S.11782. Proposed holotype. Long fragment, preserved in relief. Salter's Collection (I.G.S. South Kensington). (x10)

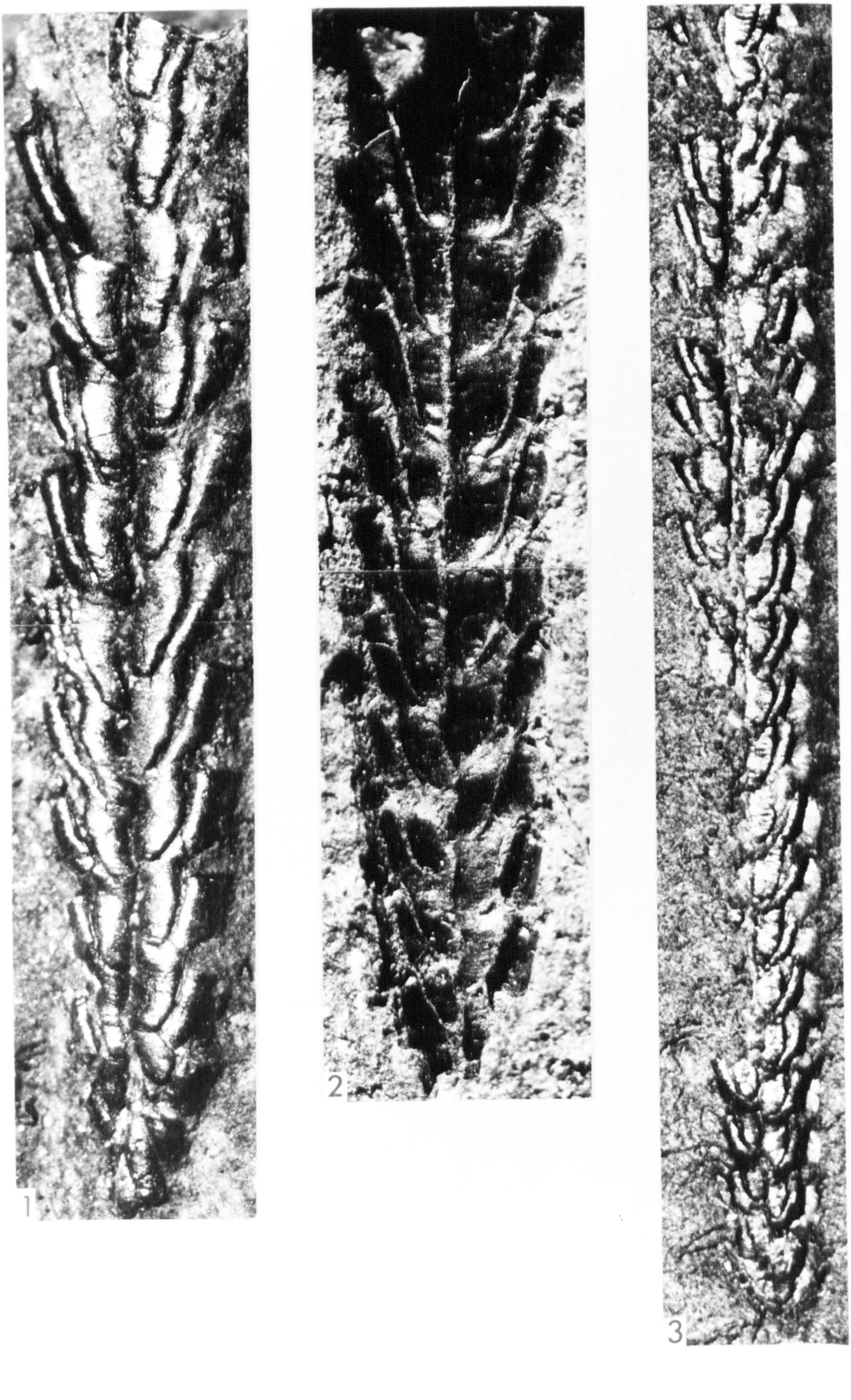
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PLATE 51

Glyptograptus cf. persculptus (Salter 1865) (all x10)

All from the Linn Branch trench, Dob's Linn.

FIGURE

1. HM C13848a. 1.2 - 1.32m above the base of the Birkhill Shale, G. persculptus Zone.
2. HM C13949. 1.88 - 2.0m above the base of the Birkhill Shale, O? acuminatus Zone.
3. HM C14016. 2.01 - 2.14m above the base of the Birkhill Shale, O? acuminatus Zone.
4. HM C13771/2. 0.7 - 0.85m above the base of the Birkhill Shale, G. persculptus Zone.
5. HM C13963. 1.88 - 2.0m above the base of the Birkhill Shale, O? acuminatus Zone.
6. HM C14015. 2.01 - 2.14m above the base of the Birkhill Shale, O? acuminatus Zone.
7. HM C13965a. Well preserved specimen in partial relief, but tectonically widened. 1.88 - 2.0m above the base of the Birkhill Shale, O? acuminatus Zone.
8. HM C14023/1a. 2.19 - 2.31m above the base of the Birkhill Shale, O? acuminatus Zone.
9. HM C13839. 1.2 - 1.32m above the base of the Birkhill Shale, G. persculptus Zone.

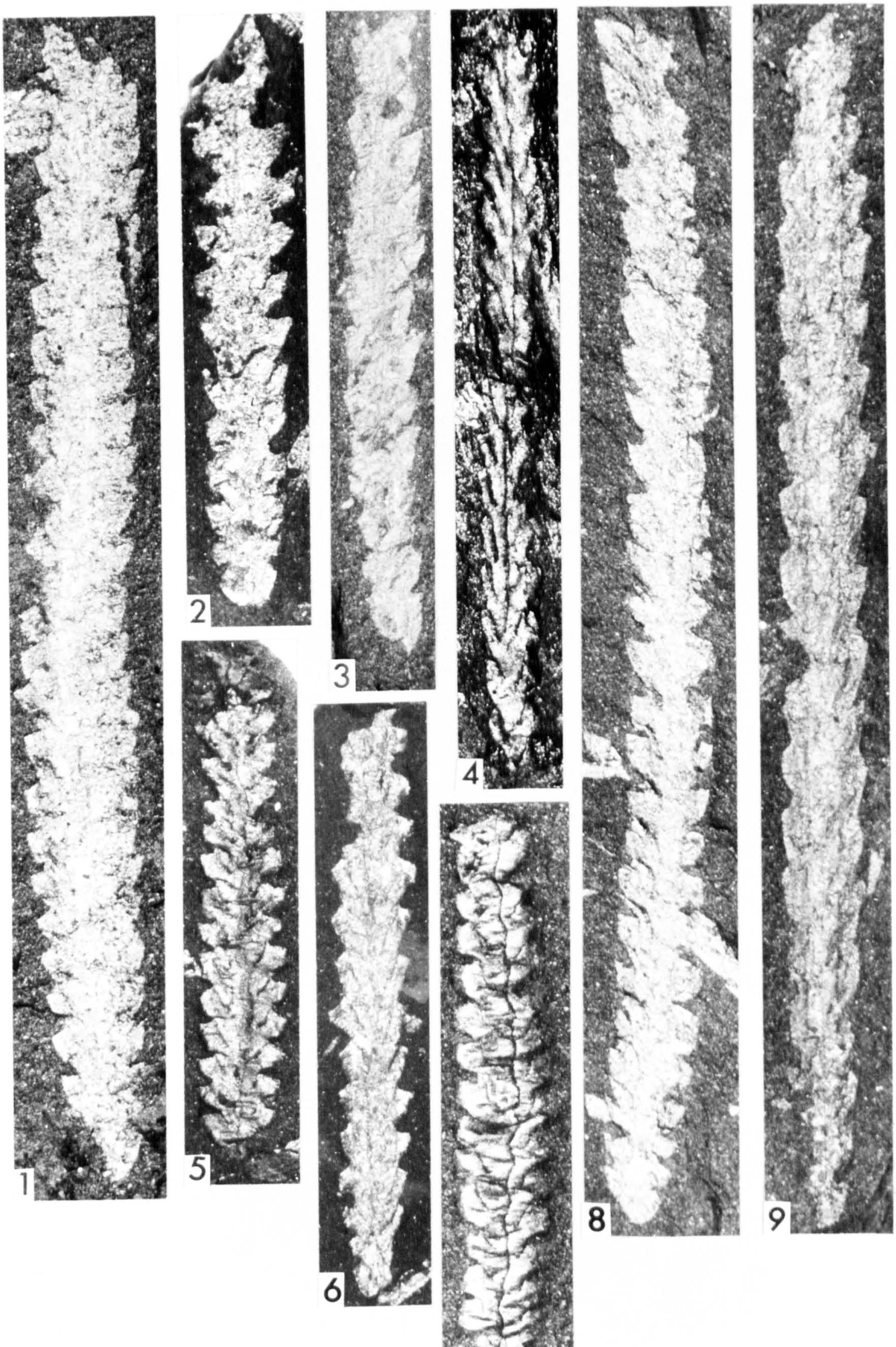

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PLATE 52

<u>Glyptograptus</u> <u>daviesi</u> sp. nov. (all x10)

All from the North Cliff trench, Dob's Linn.

All except fig. 2 from the <u>D.</u> <u>clingani</u> Zone.

FIGURE

1. HM C14070. Large rhabdosome with nema. 8.7 - 8.5m below top of Lower Hartfell Shale.
2. HM C14439. <u>G.</u> <u>davisi?</u> Much later than all other specimens. Could be deformed specimen of a different diplograptid. 1.2 - 1.1m below top of Lower Hartfell Shale, <u>P.</u> <u>linearis</u> Zone.
3. HM C14056a. Proposed holotype, showing proximal detail. 8.7 - 8.5m below top of Lower Hartfell Shale.
4. HM C14196. Proximal fragment showing conspicuous virgella. 7.35 - 7.25m below top of Lower Hartfell Shale.
5. HM C14194. Distal fragment. 7.35 - 7.25m below top of Lower Hartfell Shale.
6. HM C14071. Specimen in scalariform view, showing virgella and nema. 8.7 - 8.5m below top of Lower Hartfell Shale.


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PLATE 53

(all x10 except figs. 12, 13)

FIGURE

1 - 7. Glyptograptus cf. persculptus (Salter 1865)?

1. HM C13937/1a. Long distal fragment. 1.69 - 1.79m above the base of the Birkhill Shale, O? acuminatus Zone.

2. HM C13937/2b. 1.69 - 1.79m above the base of the Birkhill Shale, O? acuminatus Zone.

3. HM C14021. 2.19 - 2.31m above the base of the Birkhill Shale, O? acuminatus Zone.

4. HM C13880/1. 1.46 - 1.56m above the base of the Birkhill Shale, G. persculptus Zone.

5. HM C13876. 1.46 - 1.56m above the base of the Birkhill Shale, G. persculptus Zone.

6. HM C13990. 2.01 - 2.14m above the base of the Birkhill Shale, O? acuminatus Zone.

7. HM C13880/2. 1.46 - 1.56m above the base of the Birkhill Shale, G. persculptus Zone.

8 - 17. Glyptograptus? avitus Davies 1929. (all G. persculptus Zone)

8. HM C13895. 1.56 - 1.66m above the base of the Birkhill Shale.

9. HM C13886. Juvenile with kinked nema. 1.46 - 1.56m above the base of the Birkhill Shale.

10. HM C13824/2. 1.2 - 1.32m above the base of the Birkhill Shale.

11. HM C13887. Nema with membranous growths. 1.46 - 1.56m above the base of the Birkhill Shale.

12. HM C13822. Sicula with forked virgella. 1.2 - 1.32m above the base of the Birkhill Shale. (x25)

13. HM C13820/1. Juvenile with branching virgella. 1.2 - 1.32m above the base of the Birkhill Shale. (x25)

14. HM C13785. 0.7 - 0.85m above the base of the Birkhill Shale.

15. HM C13906/1. 1.56 - 1.66m above the base of the Birkhill Shale.

16. HM C13841. 1.2 - 1.32m above the base of the Birkhill Shale.

17. HM C13824/1. 1.2 - 1.32m above the base of the Birkhill Shale.

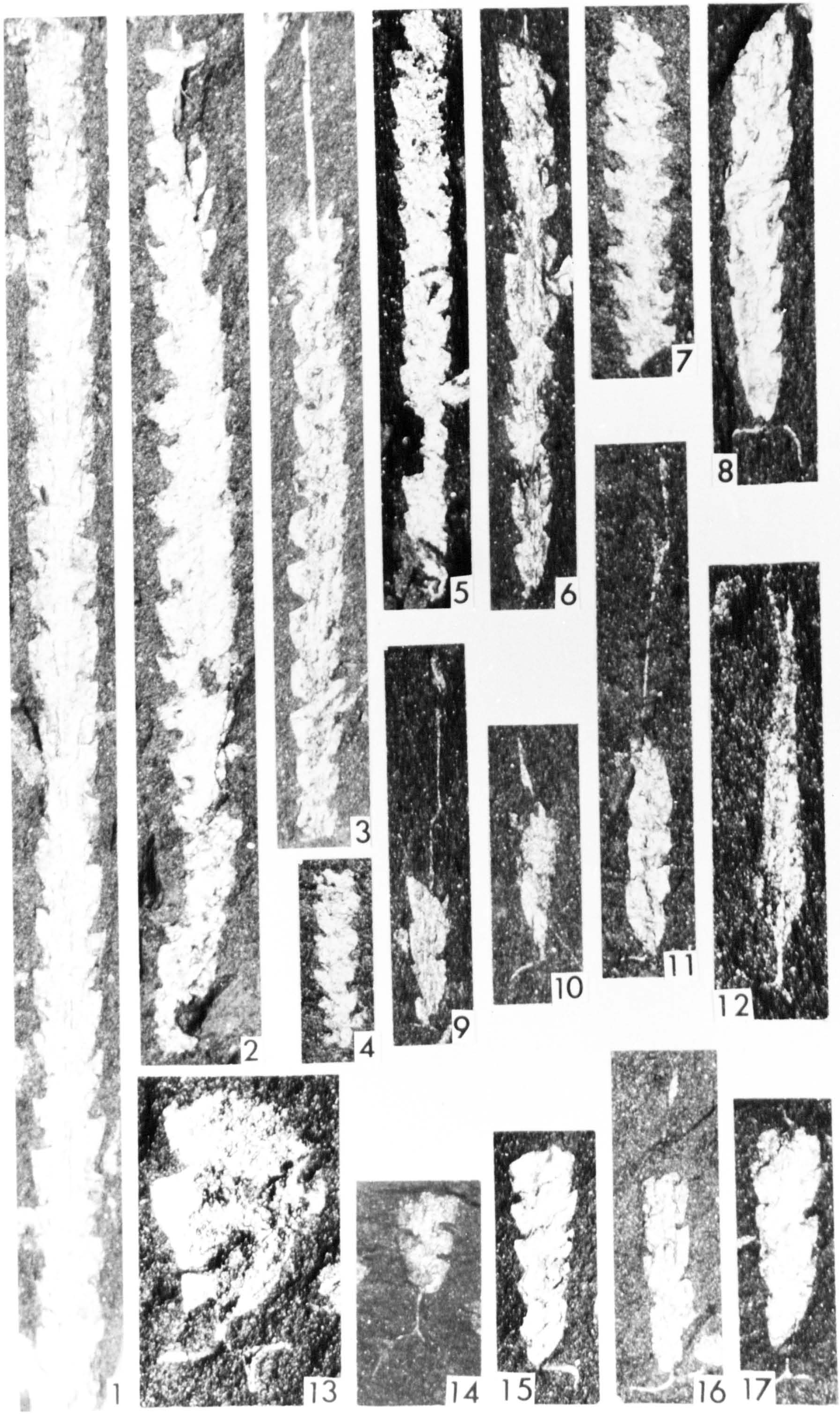

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PLATE 54

Figs. 1, 4 - 10. Glyptograptus? sp. A.

Figs. 2, 3. Glyptograptus cf. persculptus (Salter 1865)

All from the Linn Branch trench, Dob's Linn.

FIGURE

1. HM C13747/1. 0.2 - C.35m above the base of the Birkhill Shale, G. persculptus Zone. (x10)

2. HM C13929/2. Long distal uniserial portion in G. cf. persculptus. 1.66 - 1.76m above the base of the Birkhill Shale, O? acuminatus Zone. (x10)

3. HM C13856. Juvenile specimen of G. cf. persculptus. 1.2 - 1.32m above the base of the Birkhill Shale, G. persculptus Zone. (x10)

4. HM C13729/2. Distal fragment with long nema. 0.2 - 0.35m above the base of the Birkhill Shale, G. persculptus Zone. (x10)

5. HM C13738/1. Immature specimen with proximal end and uniserial distal portion. 0.2 - 0.35m above the base of the Birkhill Shale, G. persculptus Zone. (x10)

6. HM C13747/4. Distal fragment. 0.2 - 0.35m above the base of the Birkhill Shale, G. persculptus Zone. (x10)

7. HM C13729/1. Long, complete rhabdosome. 0.2 - 0.35m above the base of the Birkhill Shale, G. persculptus Zone. (x5)

8. HM C13747/2-3. 0.2 - 0.35m above the base of the Birkhill Shale, G. persculptus Zone. (x5)

9. HM C13722. 0.15 - 0.2m above the base of the Birkhill Shale, G. persculptus Zone. (x5)

10. HM C13738/2. 0.2 - 0.35m above the base of the Birkhill Shale, G. persculptus Zone. (x5)

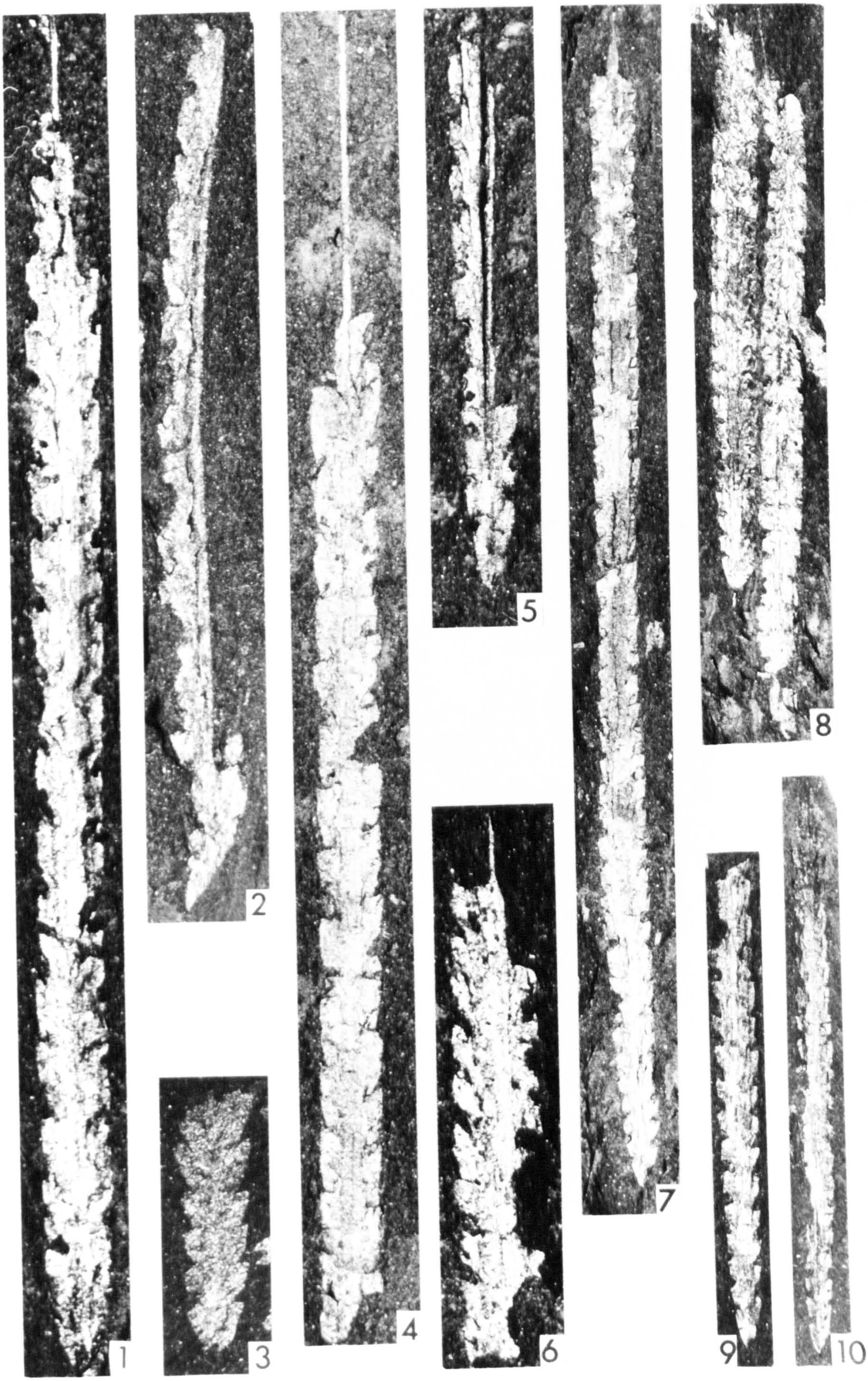
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PLATE 55

Glyptograptus? cf. *occidentalis* Ruedemann 1947.

All from the Dark Shale Member, Mill Formation, Upper Whitehouse Group, *P. linearis*/*D. complanatus* zone, loc. M2, Myoch Bay, Girvan.

FIGURE

1. HM C13060. In full relief, showing (preservational?) transverse grooves. (x20)
2. HM C13058. Partially flattened, with complete proximal end. Note apparent change in thecal style when flattened. (x10)
3. HM C13061. Flattened distal fragment. (x10)

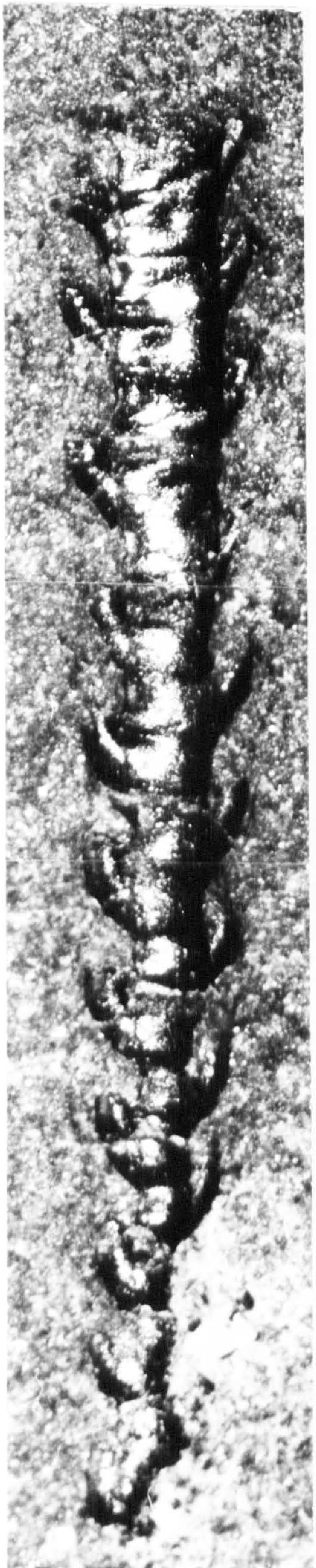

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PLATE 56

Paraorthograptus pacificus (Ruedemann 1947). (all x10)

All from the Anceps Bands, Upper Hartfell Shale, P. pacificus Subzone, Dob's Linn.

FIGURE

1. HM C13457/2. Band C, Long Burn trench.
2. HM C13457/3. Band C, Long Burn trench.
3. HM C13416/1. Band C, Long Burn trench.
4. HM C13456/1a. Band C, Long Burn trench.
5. HM C13440/1a. Band C, Long Burn trench.
6. HM C13461. Band C, Long Burn trench.
7. HM C13544/1a. Band D, Long Burn trench.
8. HM C13577a. Unweathered specimen. Band D, Long Burn trench.
9. HM C13444. Unweathered specimen. Band C, Long Burn trench.
10. HM C13652/1a. Band E, Linn Branch trench.
11. HM C13440/2a. Band C, Long Burn trench.
12. HM C13457/1. Band C, Long Burn trench.
13. HM C13438a. Band C, Long Burn trench.

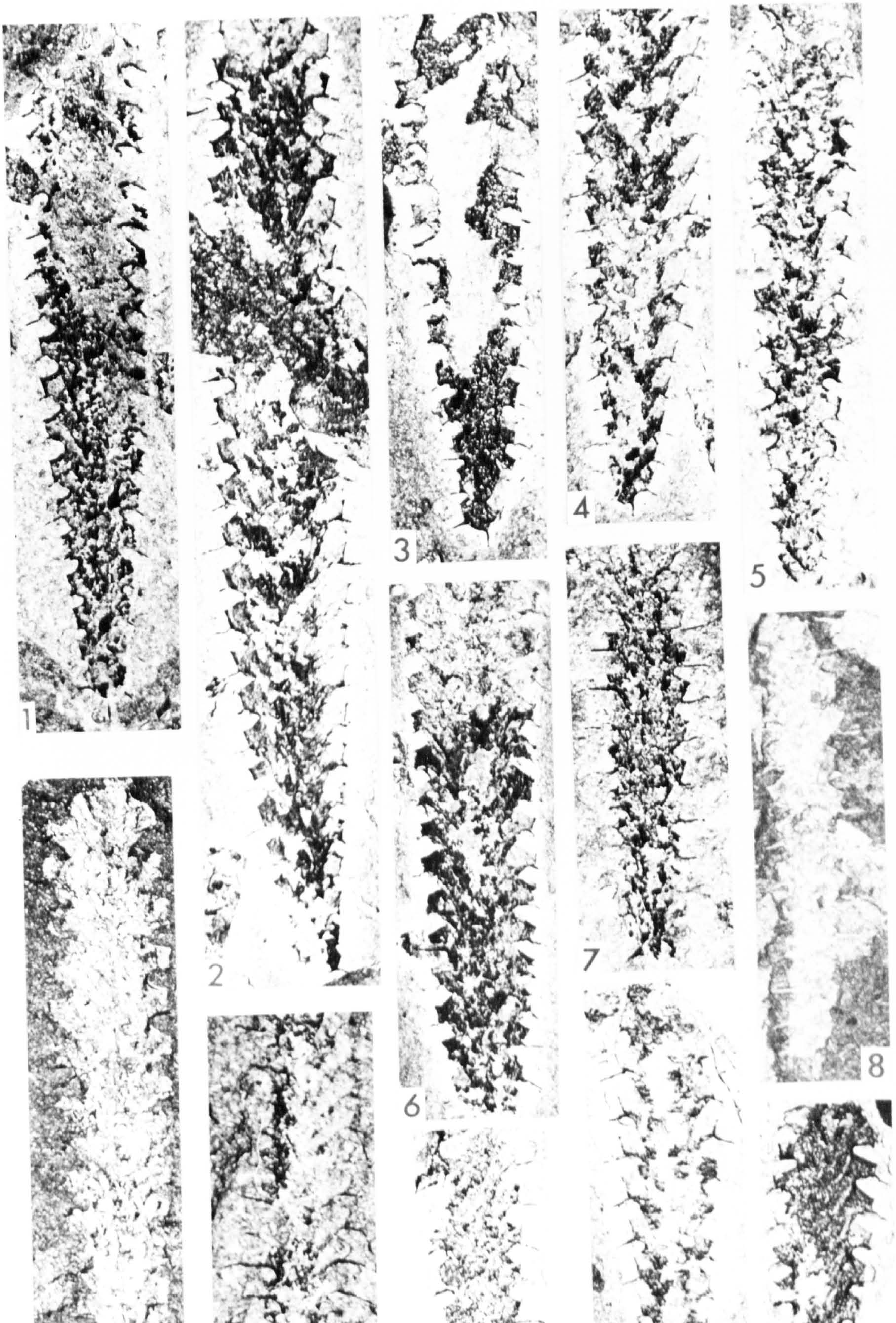
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PLATE 57

Akidograptus _ascensus_ Davies 1929. (all x10 except figs. 1 - 2)
All from the Linn Branch trench, Dob's Linn.

FIGURE

1. HM C14003. Well preserved specimen in partial relief, showing proximal development clearly. 2.01 - 2.14m above the base of the Birkhill Shale, _O?_ _acuminatus_ Zone. (x25)
2. HM C14002. Proximal fragment preserved in relief. 2.01 - 2.14m above the base of the Birkhill Shale, _O?_ _acuminatus_ Zone. (x25)
3. HM C13925. 1.76 - 1.91m above the base of the Birkhill Shale, _O?_ _acuminatus_ Zone.
4. HM C13980a. With forked virgella. 2.01 - 2.14m above the base of the Birkhill Shale, _O?_ _acuminatus_ Zone.
5. HM C13940. 1.69 - 1.79m above the base of the Birkhill Shale, _O?_ _acuminatus_ Zone.
6. HM C14006/2. With long nema. 2.01 - 2.14m above the base of the Birkhill Shale, _O?_ _acuminatus_ Zone.
7. HM C13976. 2.01 - 2.14m above the base of the Birkhill Shale, _O?_ _acuminatus_ Zone.
8. HM C13998a. With kinked nema. 2.01 - 2.14m above the base of the Birkhill Shale, _O?_ _acuminatus_ Zone.
9. HM C13982a. Preserved in partial relief. 2.01 - 2.14m above the base of the Birkhill Shale, _O?_ _acuminatus_ Zone.
10. HM C13913. 1.56 - 1.66m above the base of the Birkhill Shale, _O?_ _acuminatus_ Zone.
11. HM C14026/1a. 2.19 - 2.13m above the base of the Birkhill Shale, _O?_ _acuminatus_ Zone.
12. HM C13919. 1.76 - 1.91m above the base of the Birkhill Shale, _O?_ _acuminatus_ Zone.


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PLATE 58

FIGURE

1 - 4. *Orthoretiograptus denticulatus* Wang *et al.* 1977. (all x10)

All from Anceps Band C, Upper Hartfell Shale, *P. pacificus* Subzone, Dob's Linn.

1. HM C13488. Dorso-ventral view, showing proximal spine. Linn Branch trench. Also figd. text-fig. 32b.
2. HM C13479a. Proximal fragment in oblique view, with apertural lists and clathria forming apparent central polygonal mesh. Main Cliff section. Also figd. text-fig. 32d.
3. HM C13467a. Distal fragment in dorso-ventral view. Main Cliff section.
4. HM C13469a. Distal fragment in dorso-ventral view, showing 'zig-zag' median line and prominently introverted apertures. Main Cliff section. Also figd. text-fig. 32a.

5 - 7. *Plegmatograptus? lautus* Koren & Tzai 1980.

All from Anceps Band C, Upper Hartfell Shale, *P. pacificus* Subzone, Main Cliff section, Dob's Linn.

5. HM C13468a. Distal fragment showing poorly sclerotised central thecae and fine lacinia. Also figd. text-fig. 36c. (x5)
6. HM C13462/3a. Long but poorly preserved distal fragment. (x10)
7. HM C13462/1-2a. Two proximal(?) fragments showing well defined central thecae and simple lacinia. (x10)

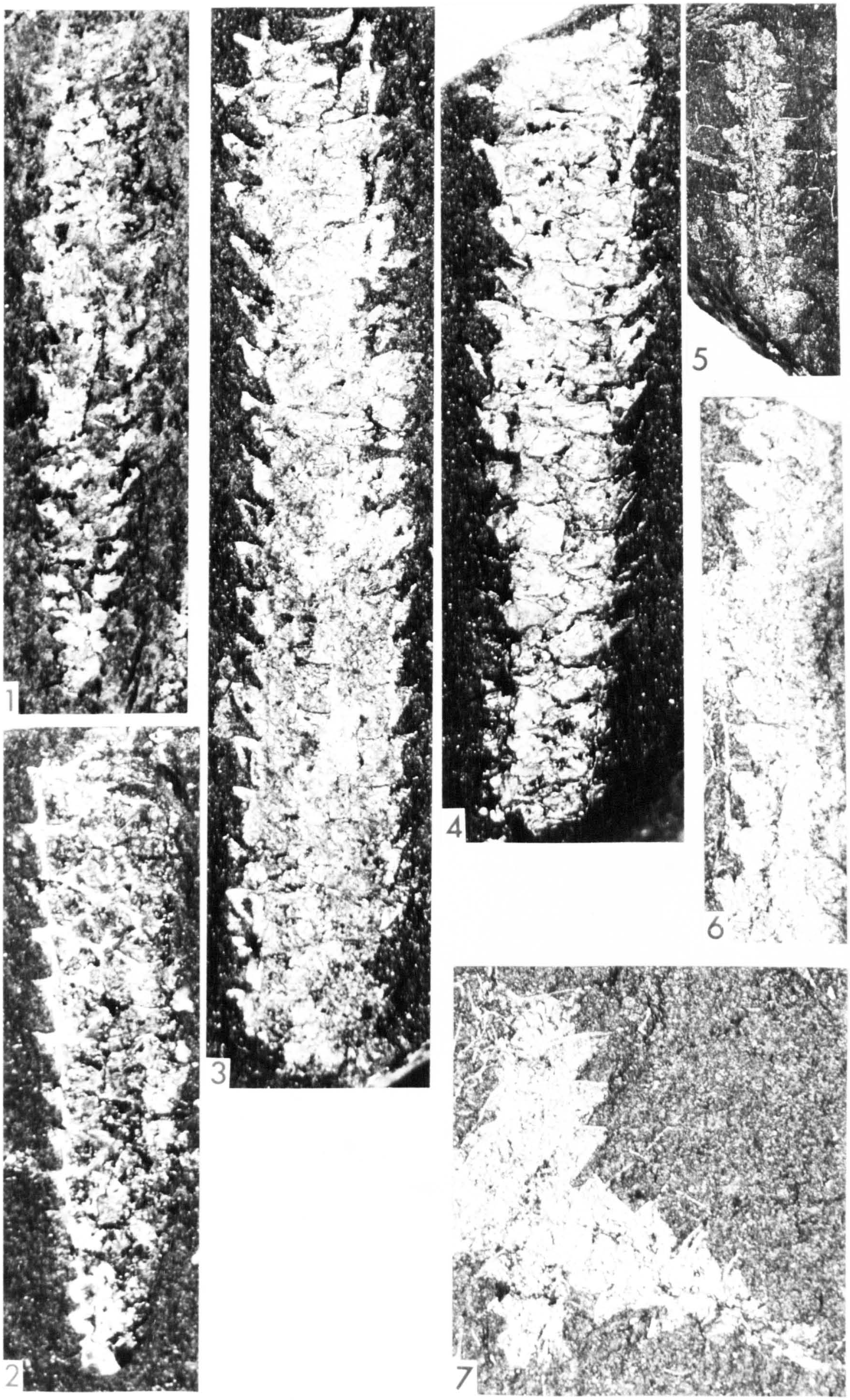
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PLATE 59

Atavograptus ceryx (Rickards & Hutt 1970). (all x20 except fig. 11)
All from 2.01 - 2.14m above the base of the Birkhill Shale,
O? acuminatus Zone, Linn Branch trench, Dob's Linn.

FIGURE

1. HM C13977/1a.
2. HM C13993/1a. Sicula almost complete
3. HM C14009/2a.
4. HM C14000/1a.
5. HM C14010/2a. Oblique orientation.
6. HM C13977/3b.
7. HM C14010/1a. Flattened (cf. fig. 8).
8. HM C13977/2a. Long fragment.
9. HM C14009/3a.
10. HM C14009/1b.
11. HM C14010/1-nb. General view of slab. (x5)

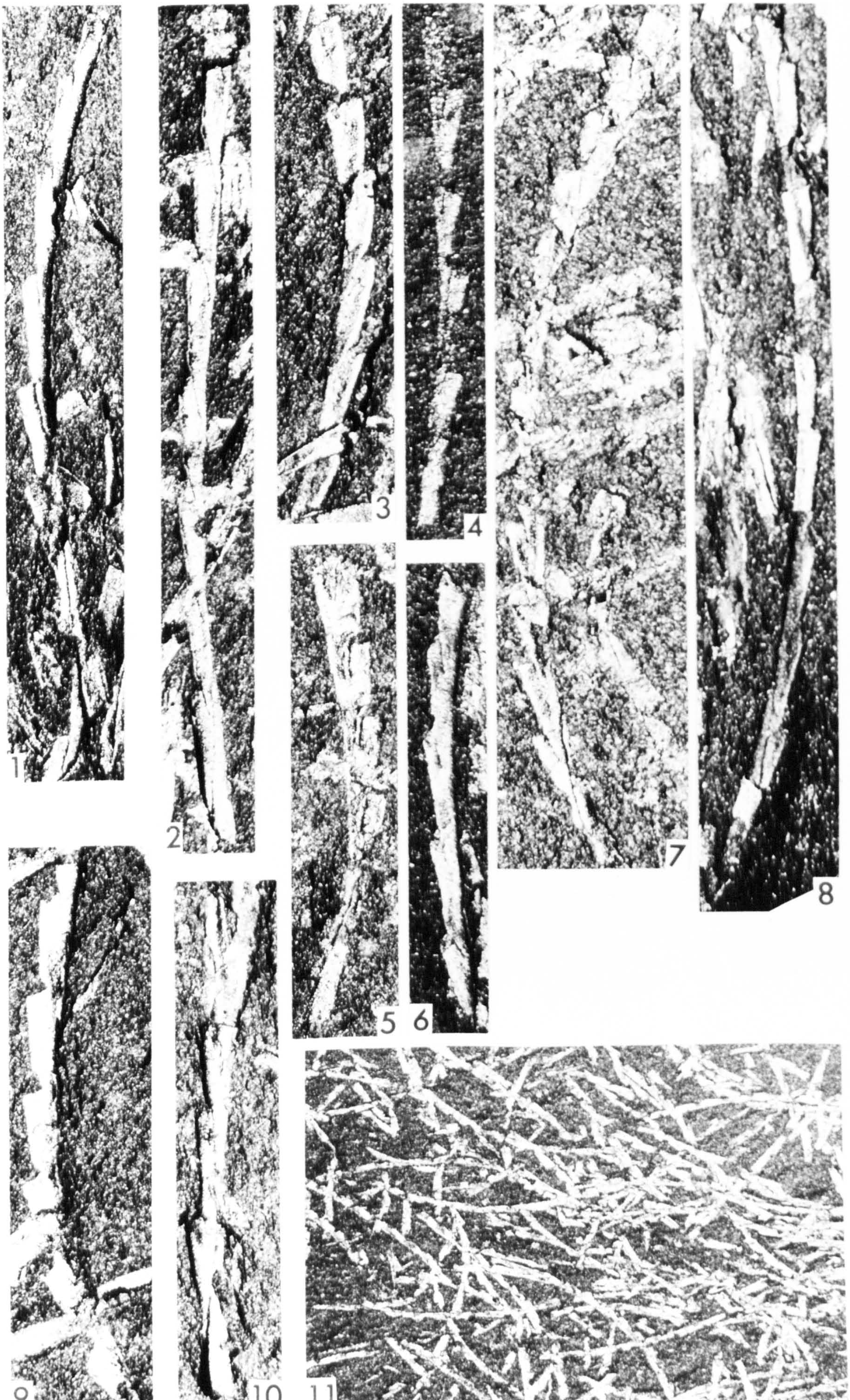
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PLATE 60

(all x10 except figs. 1, 4)

FIGURE

1 - 4. Glyptograptus? avitus Davies 1929.

1. HM C13851/2. Sicula and first theca. 1.2 - 1.32m above base of Birkhill Shale, G. persculptus Zone. (x25)

2. HM C13806. Distal fragment with membranous nema. 1.1 - 1.2m above base of Birkhill Shale, G. persculptus Zone.

3. HM C13898. Distal fragment. 1.56 - 1.66m above base of Birkhill Shale, G. persculptus Zone.

4. HM C13866. Proximal fragment with branching virgella. 1.38 - 1.46m above base of Birkhill Shale, G. persculptus Zone. (x25)

5. HM C13978. Climacograptus sp. with three basal spines similar to C. trifilis, but much narrower. 2.01 - 2.14m above base of Birkhill Shale, O? acuminatus Zone.

6. HM C13901. Kinked nema with membranous structures. 1.56 - 1.66m above base of Birkhill Shale, G. persculptus Zone.

7. HM C14027. Climacograptus sp., as fig. 5. 2.19 - 2.31m above base of Birkhill Shale, O? acuminatus Zone.

8. HM C13808. Juvenile Climacograptus sp. with membranous structures on virgella and nema. 1.1 - 1.2m above base of Birkhill Shale, G. persculptus Zone.

9. HM C13953. Climacograptus? sp. in relief with long narrow thecae. 1.88 - 2.0m above base of Birkhill Shale, G. persculptus Zone.

10. HM C13786. Climacograptus sp., narrow with forked virgella. 0.7 - 0.85m above base of Birkhill Shale, G. persculptus Zone.

11. HM C14022. Atavograptus sp., very narrow with long thecae. 2.19 - 2.31m above base of Birkhill Shale, O? acuminatus Zone.

12. HM C13996b. Atavograptus sp., as fig. 11. 2.01 - 2.14m above base of Birkhill Shale, O? acuminatus Zone.

13. HM C13762/1-na. Sicula cluster? 0.7 - 0.85m above base of Birkhill Shale, G. persculptus Zone.

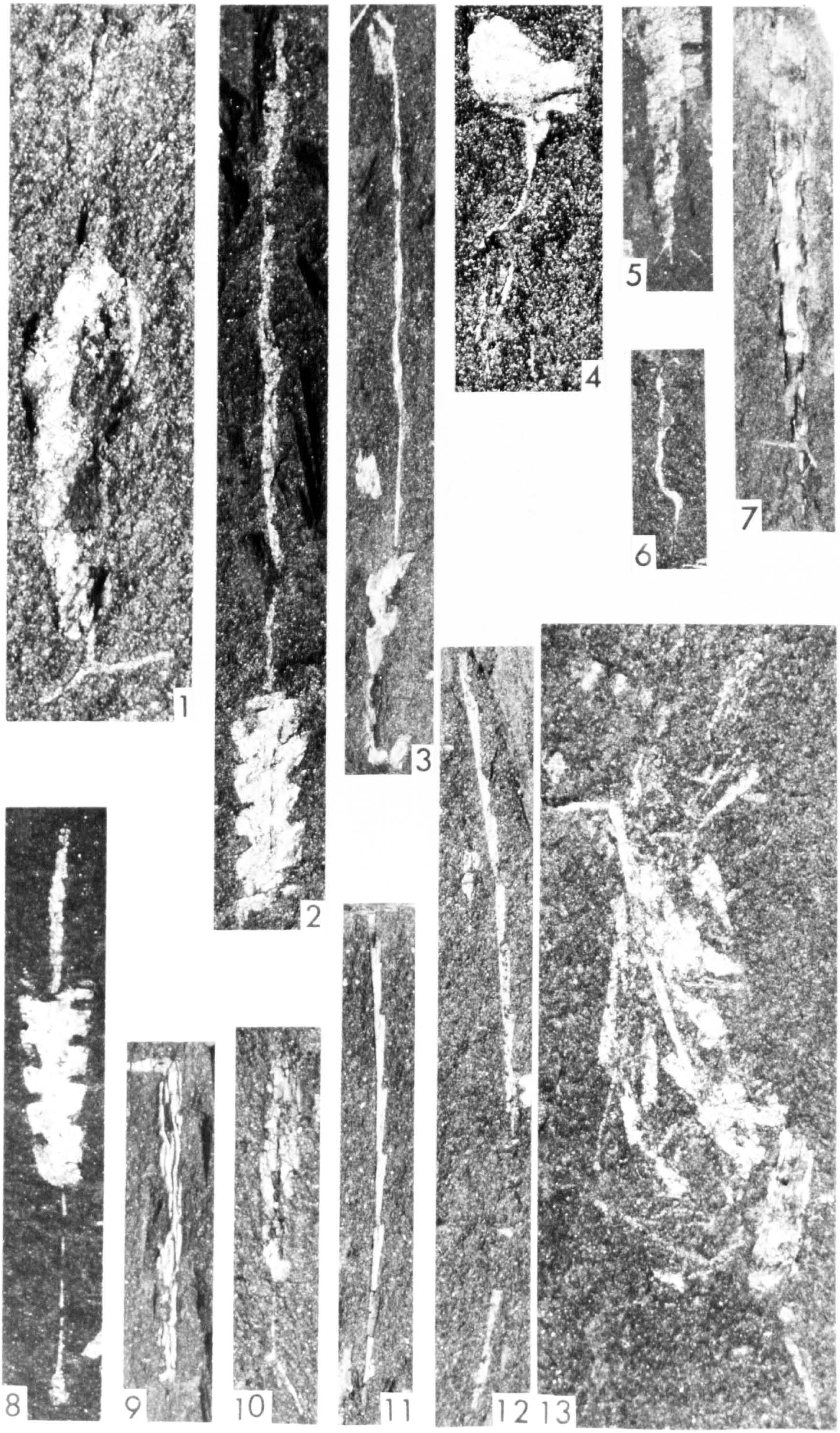
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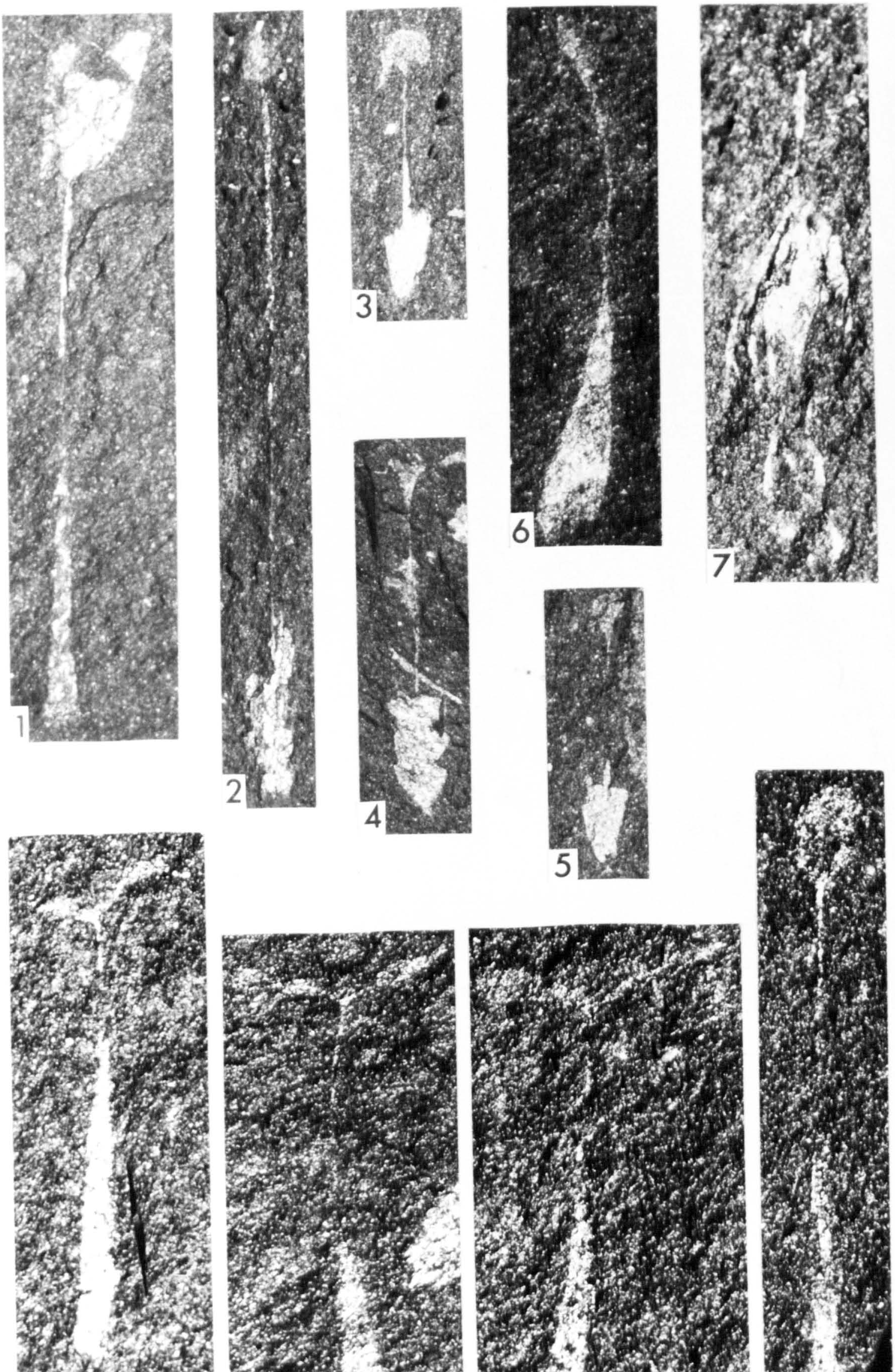
PLATE 61

Structures associated with siculae. (all from the G. persculptus Zone) Most considerered to be Glyptograptus? avitus Davies 1929.

FIGURE

1. HM C13811. 1.1 - 1.2m above base of Birkhill Shale. (x25)
2. HM C13910. Distal stipe fragment. 1.56 - 1.66m above base of Birkhill Shale. (x10)
3. HM C13882. Sicula and first two thecae. 1.46 - 1.56m above base of Birkhill Shale. (x10)
4. HM C13892. Juvenile with membranous growths on nema. 1.56 - 1.66m above base of Birkhill Shale. (x10)
5. HM C13883. Sicula and first two(?) thecae. 1.46 - 1.56m above base of Birkhill Shale. (x10)
6. HM C13810. 1.1 - 1.2m above base of Birkhill Shale. (x25)
7. HM C13791. Sicula cluster? 0.85 - 0.9m above base of Birkhill Shale. (x25)
8. HM C13840. Sicula with 'lime tree seed' type vane(?). 1.2 - 1.32m above base of Birkhill Shale. (x25)
9. HM C13850. 1.2 - 1.32m above base of Birkhill Shale. (x25)
10. HM C13837. 1.2 - 1.32m above base of Birkhill Shale. (x25)
11. HM C13815. 1.1 - 1.2m above base of Birkhill Shale. (x25)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