# THE ORDOVICIAN–SILURIAN BOUNDARY GRAPTOLITE FAUNA OF DOB'S LINN, SOUTHERN SCOTLAND

*by* S. HENRY WILLIAMS

ABSTRACT. The strata at Dob's Linn from the Extraordinarius Band of the Upper Hartfell Shale Formation to 2·3 m above the base of the Birkhill Shale Formation and their contained taxa are described and accurate faunal ranges provided. The boundary separating the *Climacograptus*? *extraordinarius* and *Glyptograptus persculptus* zones occurs within a 1·17 m thick unfossiliferous part of the succession. The boundary between the *G. persculptus* and *Parakidograptus acuminatus* zones is defined at 1·6 m above the base of the Birkhill Shale in the Linn Branch section, where *Akidograptus ascensus* and *P. acuminatus s.l.* first occur. A member of the *Glyptograptus*? '*venustus*' group is recorded from Britain for the first time. Accurate correlation is attempted with zonal sequences in Soviet central Asia, central China, and eastern Canada.

STUDIES by Toghill (1968*a*, *b*, 1970) and more recently by Ingham (1979) have shown that much research remains to be done at the classic locality of Dob's Linn near Moffat, southern Scotland, although the pioneering work by Lapworth (1878) and taxonomic descriptions by Elles and Wood (1901–18) still form a good foundation. Present debate surrounding the Ordovician–Silurian boundary renders the need for detailed study of all possible stratotype sections. Thus the succession at Dob's Linn from the top of the Upper Hartfell Shale Formation up to unequivocal *P. acuminatus* Zone strata in the Birkhill Shale Formation was examined in order to cover all possible horizons being considered for a future-defined Ordovician–Silurian boundary.

The least tectonically affected section through these strata at Dob's Linn is on the north bank of the Linn Branch, where a continuous section has now been excavated (Williams 1980, loc. 5); all measurements and most of the material referred to here originate from this 'Linn Branch trench'. During collecting bulk samples were made, either of a single black shale band in the Upper Hartfell Shale, or of a convenient interval, normally about 15 cm thick, in the continuously black Birkhill Shale. These were split in the laboratory and all slabs examined with a binocular microscope. This method ensured maximum recovery of specimens and obviated damage during transport from the field. Although such a technique commonly limited the accuracy with which horizons could be located to the thickness of the sampling interval, this disadvantage was easily outweighed by the more efficient recovery of rare specimens. Critical intervals could also be recollected in greater detail.

## STRATIGRAPHY

### *Upper Hartfell Shale Formation*

The Upper Hartfell Shale consists of some 28 m of mostly pale grey, barren mudstone or shale. There are, however, three intervals containing black shale bands, named the Complanatus, Anceps, and Extraordinarius bands after their respective zonally diagnostic faunas. The two Complanatus Bands occur just over 9 m above the base of the Upper Hartfell Shale (as defined in Williams 1982*a*) and yield the typical *Dicellograptus complanatus* Zone fauna. They are followed by approximately 13 m of apparently unfossiliferous pale grey mudstone before the first of the Anceps Bands. The five bands A to E have now been subdivided into two subzones of the high *D. anceps* Zone (Williams 1982*b*); bands A and B are contained within the *D. complexus* Subzone, whilst bands C to E are accommodated within the *Paraorthograptus pacificus* Subzone (text-fig. 2). The top Anceps Band (E) yields the lowest known specimens of *C*? *extraordinarius* (Sobolevskaya, 1974). It is followed by

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0·96 m of unfossiliferous pale grey mudstone before the thin dark-brown Extraordinarius Band, first discovered by Ingham (1974). This contains rare diplograptids, especially in the Long Burn section (Williams 1980, loc. 7), which Rickards (1979) identified as *C? extraordinarius* (Sobolevskaya, 1974), *Climacograptus* cf. *normalis* Lapworth, 1877, and *Glyptograptus* cf. *persculptus* (Salter, 1865). It is here concluded that tectonic deformation of this band is too great to allow even generic determination of many specimens, although the characteristic fusiform outline of *C? extraordinarius* permits identification of this species. The faunal assemblage indicates the late Ordovician *C? extraordinarius* Zone, described from the north-eastern U.S.S.R. by Koren′ *et al.* (1979) 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 lies within the pale, unfossiliferous mudstone a short distance above Anceps Band E. Intensive study between this band and the base of the Birkhill Shale has failed to reveal any additional graptolite bands.

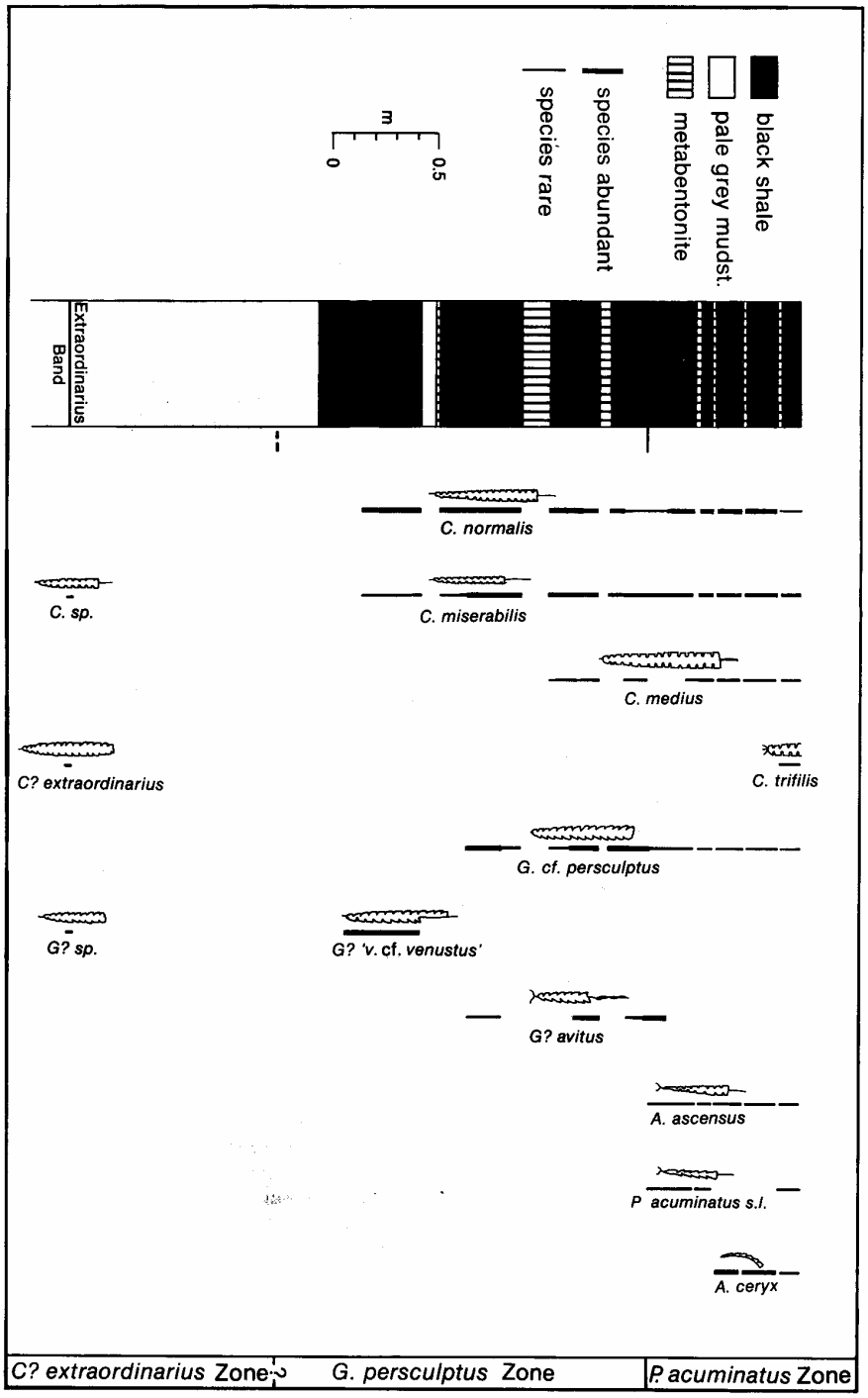
*Birkhill Shale Formation*

The 43 m of Birkhill Shale (Toghill 1968*b*) are composed predominantly of black graptolitic shale or mudstone. They also contain thin metabentonite seams, which have commonly acted as planes of bedding slip, and occasional pale grey-green mudstones which become common in the *Monograptus convolutus* and *M. sedgwickii* zones and dominant in the *Rastrites maximus* Zone. The mudstones then give way transitionally into the Gala Greywacke Group, which at Dob's Linn begins within the *R. maximus* Zone.

The junction between the pale grey mudstones of the Upper Hartfell Shale and the black shales and mudstones of the Birkhill Shale is sharp and occurs 1·17 m above the Extraordinarius Band in the Linn Branch section (text-fig. 1). The basal 15 cm of black shale are unfossiliferous and coarse with a fine mottled appearance. They are followed by more typical graptolitic black shale, although this again is mottled and contains common bands of silty material. This basal interval is probably the one referred to by Elles and Wood (1906, p. 186) as the 'gingerbread' bed at the base of the Birkhill Shale, which they recorded as containing abundant *C. normalis* Lapworth, 1877. At 0·2 m above the base typical black graptolitic shale is present, yielding a fairly abundant fauna of *C. normalis* and *G?* '*venustus* cf. *venustus*' (Legrand, 1976), with rarer specimens of *C. miserabilis* Elles and Wood, 1906. At 0·46 m there is a sharp reversion to pale grey-green mudstone, followed by 10 cm of variously coloured and laminated mudstones. At 0·56 m these are overlain by a thin metabentonite, which is followed by typical black graptolitic shale. *G?* '*v.* cf. *venustus*' last occurs just below the pale mudstone unit, whilst *C. normalis* and *C. miserabilis* continue into the overlying black shale. At about 0·6 m is a silty horizon containing beautifully preserved, three-dimensional specimens of *C. normalis*. *C. miserabilis* becomes abundant by about 0·7 m and remains so throughout the remainder of the collected interval, while *Glyptograptus* cf. *persculptus* (Salter, 1865) and *G? avitus* Davies, 1929 first appear at this horizon.

A thick metabentonite occurs from 0·96 to 1·1 m; it contains irregular slivers of black shale and has evidently acted as a plane of bedding slip. However, it appears to be concordant with the bedding and it is unlikely that it has had any significant effect on the succession. Possible specimens of *C. medius* Törnquist, 1897 first appear just above the metabentonite, but they are rather narrow and may represent tectonically widened specimens of *C. normalis*. Definite specimens of *C. medius* appear soon after and occur sporadically throughout the remainder of the collected interval. *G? avitus* first becomes abundant at 1·2 m.

Another metabentonite is present from 1·32 to 1·38 m but no significant faunal changes occur until 1·6 m when *Akidograptus ascensus* Davies, 1929 and *Parakidograptus acuminatus* (Nicholson, 1867) *s.l.* first appear and where *G? avitus* was last seen in the present study. Davies, however, recorded his holotype as coming from the '*A. acuminatus* Zone' (see systematic description) while Stein (1965) and Rickards (1976*a*) also recorded *G? avitus* from the *P. acuminatus* Zone elsewhere. The appearance of *A. ascensus* is considered by most workers on lower Silurian graptolites to mark the base of the *P. acuminatus* Zone; whilst this effectively means that the *G. persculptus–P. acuminatus* zonal boundary is defined on the appearance of a single species, it appears to be a synchronous,




TEXT-FIG. 1. Lithological succession and species ranges of the top Lower Hartfell Shale and basal Birkhill Shale in the Linn Branch trench.

cosmopolitan event when compared with other recorded graptolite ranges. It is here suggested that the base of the *P. acuminatus* Zone should be defined at 1·6 m above the base of the Birkhill Shale in the Linn Branch section at Dob's Linn. Toghill (1968*a*, *b*) previously defined the base of the *P. acuminatus* Zone, employing the same criteria, at only 1·06 m above the base of the Birkhill Shale, using sections on the Main Cliff and on the 'North Cliff' (some 20 m north along strike from the Linn Branch section). The most recent description given by Toghill on the basal Birkhill Shale succession was in Cocks *et al.* (1970, p. 83); here it was stated that 'the basal bed is a conspicuous 10 cm (4 in) hard grey silty mudstone which yields abundant specimens of *Climacograptus scalaris normalis* in half-relief . . . and has recently yielded *Glyptograptus persculptus* itself'. No mention was made of the basal mottled, unfossiliferous unit, the lowest strata with poorly preserved *C. normalis* and *C. miserabilis*, or the temporary reversion to an Upper Hartfell-type of lithology. As stated above, the silty horizon containing three-dimensional specimens of *C. normalis* was found during the present study at about 0·6 m, just above a metabentonite which directly follows the lithological reversion to pale grey mudstone (text-fig. 1). I conclude that the 'basal bed' of the Birkhill Shale recorded by Toghill (1968*a*, *b*) and Cocks *et al.* (1970) was in fact the black shale overlying the lithological reversion and that the lowest part of the Birkhill Shale underlying this unit was either missed during collecting or was faulted out of their sections. If these strata (0·58 m) are added to Toghill's 1·06 m a true thickness of 1·64 m is obtained, corresponding closely to that found during the present study. Confirmation of this hypothesis is apparently found in Toghill (1968*b*, text-fig. 2) which shows only two metabentonites ('claystones' of Toghill) in the *G. persculptus* Zone in positions corresponding to those found by the present author above the lithological reversion.

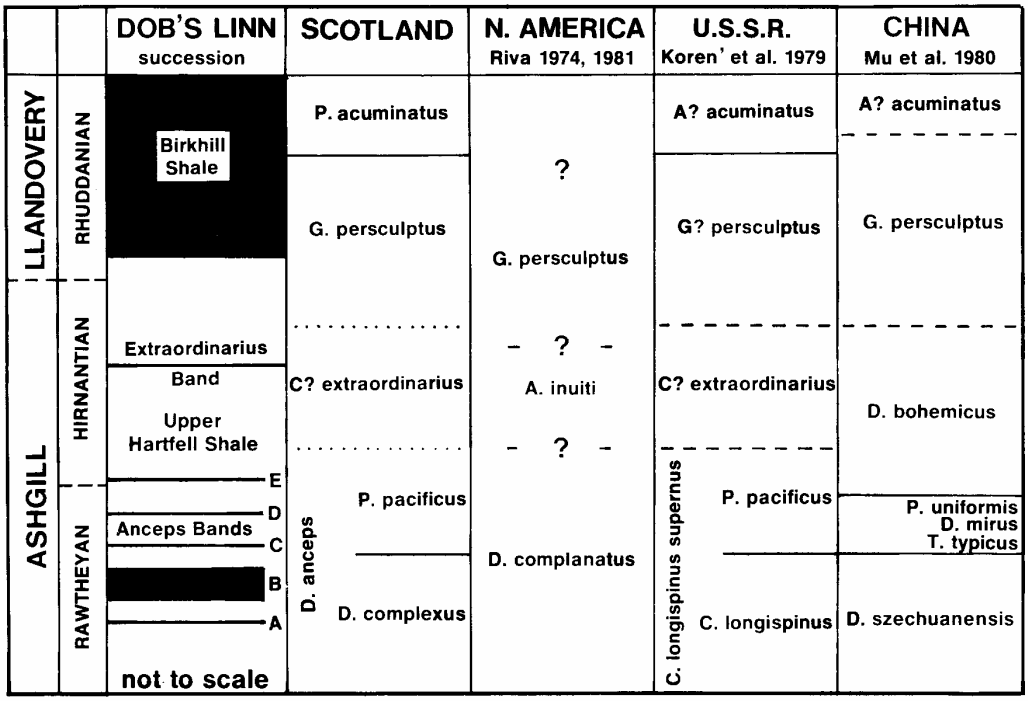
*A. ascensus* seems to occur consistently earlier and more commonly than *P. a. acuminatus* in the low *P. acuminatus* Zone (Davies 1929, p. 10; Toghill 1968*b*, p. 658; Hutt 1974, p. 6; Oradovskaya *et al.* 1979, field guide range chart). It is probable that the *P. acuminatus* Zone could be formally divided into two subzones after detailed collecting of the remainder of this zone at Dob's Linn.

The early monograptid *Atavograptus ceryx* (Rickards and Hutt, 1970) is crowded on a few bedding planes from about 1·9 to 2·1 m, whilst occasional specimens occur above this level. Several fragments of an indeterminate *Atavograptus* have also been found (text-figs. 9*i*, *j*). Monograptids have not been recorded previously lower than the *Cystograptus vesiculosus* Zone at Dob's Linn (Toghill 1968*a*, p. 48), although Rickards and Hutt (1970) and Hutt (1974) recorded *A. ceryx* from both the *G. persculptus* and *P. acuminatus* zones of the English Lake District. Only one specimen of *Climacograptus trifilis* Manck, 1923 was found, in the interval 2·19 to 2·31 m; this species is considered to be restricted to the *P. acuminatus* Zone (Stein 1965, p. 168; Toghill 1968*b*, p. 658). Toghill (1968*b*) also recorded *Diplograptus m. modestus* Lapworth, 1876 and *D. modestus parvulus* H. Lapworth, 1900 to occur throughout the *G. persculptus* and *P. acuminatus* zones at Dob's Linn, as did Jones (1909) from equivalent strata in mid Wales. No specimens resembling this large diplograptid or its subspecies have, however, been found, neither have forms corresponding to *C. indivisus* Davies, 1929, recorded to occur in the *G. persculptus* Zone of Dob's Linn by Rickards (1976*a*, p. 157). The enigmatic fossil *Dawsonia campanulata* Nicholson, 1873 occurs fairly commonly from 1·9 to 2·1 m, but the affinity and stratigraphical range of this form are still unknown.

*Discussion of correlation chart* (text-fig. 2)

The original top Ordovician and basal Silurian British graptolite zones identified by Lapworth (1878) and Elles and Wood (1901–18) have since been somewhat modified. Jones (1909) recognized the *G. persculptus* Zone as a clearly distinguishable part of the *P. acuminatus* Zone *sensu* Elles and Wood in the Welsh succession and this division has since been recognized in Ordovician–Silurian successions around the world. Rickards (1979) established the presence of the *C? extraordinarius* Zone at Dob's Linn, represented by the impoverished fauna of the Extraordinarius Band. Williams (1982*b*) subdivided the Anceps Bands at Dob's Linn into the *Dicellograptus complexus* (Bands A and B) and *Paraorthograptus pacificus* (Bands C to E) subzones.

The discrepancies resulting from equating lithostratigraphical units, shelly fossil stages, and graptolite zones have caused confusion concerning the position of the Ordovician–Silurian




TEXT-FIG. 2. Correlation of the Dob's Linn succession with shelly stages and graptolite zonal sequences elsewhere. Dotted boundaries for Scottish zones indicate that zonal boundaries lie within unfossiliferous parts of the succession and may not be determined accurately. Dashed lines in other columns indicate uncertain correlation with the Scottish zonal sequence (correlation with North America is tentative).

boundary. Correlation of the shelly fossil stages with the graptolite zonation is discussed by Williams (in press; 1982*b*). In Kazakhstan (Koren' *et al.* 1979) and eastern North America (Lésperance and Sheehan 1981) the *C*? *extraordinarius* Zone and equivalent strata lie entirely within the Hirnantian Stage, which has also been recorded to encompass portions of the *P. pacificus* Subzone and *G. persculptus* Zone. Rickards (1982) states, however, that specimens from Kazakhstan which were previously named as *G. persculptus* do not belong to this taxon and may be referable to *C*? *extraordinarius*. This implies that the whole of the *G. persculptus* Zone may fall within the Llandovery, although Lésperance and Sheehan (1981, p. 231) record '*C. v. venustus*' in association with a *Mucronaspis* [*Dalmanitina*] trilobite fauna referable to the Hirnantian Stage. Clearly additional work needs to be published before any reliable correlation between the shelly and graptolitic biostratigraphy at this level can be demonstrated. The Hirnantian–Rhuddanian boundary is unlikely to coincide with either the *C*? *extraordinarius–G. persculptus* zonal boundary or the Upper Hartfell Shale–Birkhill Shale lithological boundary. The junctions between the *P. pacificus* Subzone, *C*? *extraordinarius* Zone, and *G. persculptus* Zone are at unknown horizons in the pale grey, non-graptolitic lithology of the Upper Hartfell Shale and cannot be defined accurately in southern Scotland.

Riva (1981) added the zone of *G. persculptus* to the zonal scheme that he erected for eastern North America in 1974, owing to the presence of '*C. v. venustus*' in the Gaspé Peninsula. Riva and Petryk (1981) renamed the *C. prominens–C. elongatus* Zone the *Amplexograptus inuiti* Zone, as the last species proved to be a senior synonym of the other two. The *A. inuiti* Zone of Anticosti Island and

other north-eastern American localities yields *Orthograptus? abbreviatus* Elles and Wood, 1907, a species known from much of the *D. anceps* Zone in Britain; specimens recorded from the *P. acuminatus* Zone by Toghill (1968*b*) and Hutt (1974) are now considered to belong to a separate diplograptid lineage. The *A. inuiti* Zone also contains the apparently endemic taxa *Peiragraptus fallax* Strachan, 1954, *G.* ex gr. *lorrainensis* (Ruedemann, 1925), and *A. inuiti prominens* (Barrass, 1954) in addition to *A. i. inuiti* (Cox, 1933) itself. Koren′ *et al.* (1980, p. 125 footnote) acknowledged Koren"s joint work with Riva, which established that *A. i. inuiti* was a senior synonym of *A. stukalinae* Mikhaylova, 1973 from the *C. longispinus supernus* Zone of Kazakhstan.

Riva (1974) stated that the '*C. prominens–elongatus* Zone' (= *A. inuiti* Zone) might correlate with the 'barren interval between the *D. anceps* and *G. persculptus* Zone of the Moffat Region'. Although *O? abbreviatius* and *A. i. inuiti* suggest a horizon equivalent to part of the *D. anceps–C. longispinus supernus* Zone, the lack of any other late Ordovician taxa characteristic of these intervals suggests a correlation with the *C? extraordinarius* Zone. Except for its base, the underlying *D. complanatus* Zone (*sensu* Riva) contains only rare graptolites and the position of the boundary with the *A. inuiti* Zone appears uncertain. In the Gaspé Peninsula the boundary between the *A. inuiti* and *G. persculptus* zones is apparently defined on the first appearance of *G?* '*v. venustus*' and *C. normalis s.s.* (Riva 1981), although the only evidence given by Riva and Petryk (1981) for the 'Silurian' on Anticosti Island is the presence of *C. normalis s.s.* (known to occur in the Ordovician Anceps Bands at Dob's Linn) and the absence of the *A. inuiti* zonal fauna. Although the presence of *G?* '*v. venustus*' is likely to prove useful in the future, the first occurrence has not yet been determined in a continuously graptolitic sequence elsewhere, and is therefore of little help at present. It is evident that the Ordovician–Silurian boundary graptolite succession at Anticosti Island is poor, and that correlation with graptolite zonal sequences elsewhere is rather tentative.

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 of the *C. longispinus supernus* to '*Akidograptus*?' *acuminatus* zones. The *C. longispinus supernus* Zone is divided into a lower *C. longispinus* and an upper '*Pacificograptus*' *pacificus* Subzone. The *C. longispinus* Subzone contains *D. complanatus* Lapworth, 1880, *D.* aff. *complanatus*, *C. longispinus longispinus* Hall, 1902, *C. longispinus supernus* Elles and Wood, 1906, *C.* ex gr. *longispinus*, *C. hastatus* Hall, 1902, and *Orthograptus*? ex gr. *amplexicaulis* (Hall, 1847). By comparison with the Australian succession (Vandenberg 1981), this fauna indicates an interval approximating to the *D. complanatus* and lower *D. anceps* zones of Britain, although the exact correlation is uncertain. It is succeeded by the *P. pacificus* Subzone which contains a diverse fauna including *D. ornatus* Elles and Wood, 1904, *C. longispinus supernus*, *C. hastatus*, *C. normalis*, *P. pacificus* subspp., and *Plegmatograptus*? *lautus* Koren′ and Tzai, 1980, indicating an interval equivalent to the *P. pacificus* Subzone of Dob's Linn.

The *C. longispinus supernus* Zone is followed by that of *C? extraordinarius* which yields only the zonal species, *C. normalis* Lapworth, 1877, *C. angustus* (Perner, 1895) [? = *C. miserabilis* Elles and Wood, 1906], 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. 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 diplograptids not yet recognized in Britain.

Several papers giving the zonal scheme for the top Ordovician and basal Silurian of central 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 (1980), although this only gives faunal lists for the *Diplograptus bohemicus* and *G. persculptus* zones. Wang and Zhao (1978) and other regional handbooks record the *Dicellograptus szechuanensis* Zone to contain *D. szechuanensis* Mu, 1954 [= *D. complexus* Davies, 1929], *C. longispinus*, 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*, *Diceratograptus 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. and probably equate with most of the *P. pacificus* Subzone of Dob's Linn. Li and Ge (1981) record a new species, *Akidograptus antiquus*, from the *T. typicus* 'Zone'. All previous records of *Akidograptus* have been restricted to the Silurian; if this species is a true member of the genus the stratigraphical significance of *A. ascensus* becomes solely at the specific level.

Mu (1980) records the *D. bohemicus* Zone to contain *Dicellograptus* spp., *C. longispinus supernus*, *Glyptograptus* spp., *Diplograptus bohemicus* (Marek, 1955), *D. orientalis* Mu *et al.*, 1974 [? = *C? extraordinarius*], *Paraorthograptus* sp., and '*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 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 top *P. pacificus* Subzone and much of the *C? extraordinarius* Zone of Scotland. The following *G. persculptus* Zone contains *C.* cf. *normalis*, *C. miserabilis*, *G. persculptus*, and *A. ascensus*. The firm assertion of Mu (1980) to include the first occurrence of *A. ascensus* within his *G. persculptus* Zone differs from the ideas of Koren' and most fellow Soviet workers and the present author, and means that the base of the '*A?*' *acuminatus* Zone is higher in China than elsewhere. Mu combines the first occurrence of *A. ascensus* with the fact that monograptids first appear in the *G. persculptus* Zone (Rickards and Hutt 1970) 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.

## SYSTEMATIC PALAEONTOLOGY

Specific diagnoses are revised unless otherwise stated. Terminology follows that of Bulman (1970). Most material is from the author's collection, housed in the Hunterian Museum, Glasgow University (HM). Other specimens are from Birmingham University (BU), Sedgwick Museum, Cambridge (SM), British Museum (Natural History) (BM), and Institute of Geological Science, South Kensington (GSM). Stratigraphical intervals recorded refer to the height above the base of the Birkhill Shale.

### Family DIPLOGRAPTIDAE Lapworth, 1873
### Genus CLIMACOGRAPTUS Hall, 1865

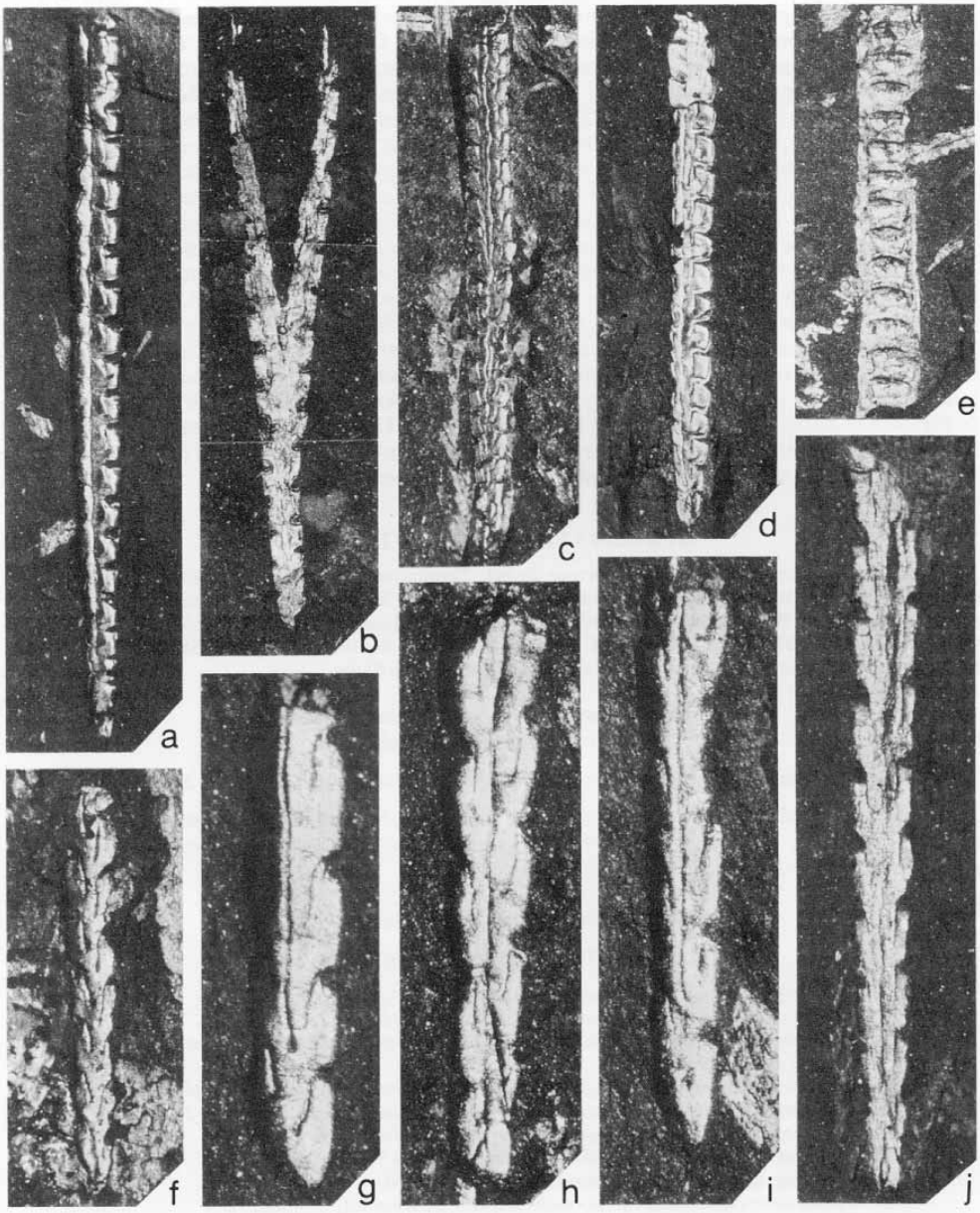
*Type species* (by original designation). *Graptolithus bicornis* Hall 1847, p. 268, pl. 73, fig. 2 (*pars*-Riva 1974).

*Diagnosis* (from Bulman 1970, p. 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.

#### *Climacograptus normalis* Lapworth, 1877

Text-figs. 3*a–e*, 4*a–e*, 7*g*

1877 *Climacograptus scalaris* var. *normalis* 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 and Wood, p. 186, pl. 26, fig. 2*a–g*; text-fig. 119*a–d*.
1922 *Climacograptus scalaris* His. sp. var. *normalis* Lapworth; Gortani, p. 104, pl. 17, fig. 23.
1924 *Climacograptus scalaris normalis* Elles and Wood; Hundt, p. 55, 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, fig. 8*a–i*.
1945 *Climacograptus scalaris* var. *normalis* Lapworth; Waterlot, pl. 4, fig. 92.
1948 *Climacograptus* (*Climacograptus*) *scalaris normalis* Lapworth; Přibyl, p. 17.
1948 *Climacograptus scalaris* v. *normalis*; Waern, p. 449, pl. 26, fig. 1; text-fig. 5.
1952 *Climacograptus scalaris normalis* Lapworth; Münch, p. 50, pl. 1, fig. 5*a*, *b*, ?*c*.
1963 *Climacograptus scalaris* cf. var. *normalis*? Lapworth; Willefert, p. 14, text-fig. 5.


a
b
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1965 *Climacograptus scalaris normalis* Lapworth; Stein, p. 157, pl. 14*c*, text-figs. 13, 14*a–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, p. 19, pl. 1, figs. 8, 9; pl. 2, figs. 1–4.
?1978 *Climacograptus* cf. *normalis* Lapworth; Wang and Zhao, p. 638, pl. 206, fig. 12.

*Holotype.* BU 1136, the specimen possibly figured by Lapworth (1877, pl. 6, fig. 31). The original illustration is insufficient to determine whether this or the other specimen on the slabs (part and counterpart) is his figured specimen, but I consider this to be the most likely one. Also figured by Elles and Wood (1906, pl. 26, fig. 2*a*) and this paper (text-fig. 4*a*). From the Birkhill Shale, Dob's Linn.

*Material.* Several specimens from the C. Lapworth and H. Lapworth collections (BU) and numerous specimens preserved both flattened and in relief from my own collections.

*Horizons and localities.* The basal 2·3 m of Birkhill Shale, *G. persculptus* and low *P. acuminatus* zones, Dob's Linn.

*Diagnosis.* Rhabdosome over 30 mm long with a normal maximum undeformed width of 1·5 mm attained within 15 mm. Thecae of *Climacograptus* style, numbering nine to eleven in 10 mm (undeformed). Virgella and nema long.

*Description.* The rhabdosome is over 30 mm long. It measures about 0·7 mm at the aperture of th1[1] in tectonically undeformed specimens (range 0·6–1·1 mm), widening to 1·1–1·6 mm in 5 mm and reaching the maximum width (characteristically 1·5 mm when undeformed) within 10 mm. Proximally the thecae number ten to thirteen in 10 mm, reducing distally to eight to twelve in 10 mm (commonly nine in 10 mm when undeformed). The holotype is tectonically widened with a maximum width of 2 mm. The sicula is exposed in obverse view for 1·0–1·3 mm, which may represent its entire length. It possesses a long virgella which sometimes exceeds 10 mm long. Th1[1] and th1[2] grow upwards for most of their length; the wall of the sicula on the side of th1[2] is normally free for 0·15–0·2 mm, resulting in a slight 'notch' at the base of the supragenicular wall of th1[2]. The thecae are sub-alternate and typically *Climacograptus* in style with angular sigmoidal curvature. The supragenicular walls are normally straight, vertical, and with thickened genicular hoods producing sharp genicula. The apertures are horizontal or very slightly everted and open into excavations which occupy one-quarter of the total rhabdosome width proximally and one-fifth distally, although they appear deeper when the rhabdosome is preserved obliquely. A distally free nema is invariably present and may reach several centimetres long.

*Remarks.* The specimens of *C. normalis* described here show clearly the difference between the internal and external moulds of graptolites when preserved in relief. The internal moulds (e.g. text-fig. 3*c*, *d*) show prominent interthecal septa, while the external moulds (e.g. text-figs. 3*a*, 7*g*) 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. miserabilis*, *C. medius* Törnquist, 1897, *C. rectangularis* (M'Coy, 1850), *Glyptograptus*? *avitus*, and *G*? '*v.* cf. *venustus*' when the specimens have suffered tectonic distortion. It may normally be separated from *C. miserabilis* by its more gradual widening and maximum width, which normally exceeds 1·2 mm even when tectonically stretched, in comparison with the usual 1 mm maximum width of *C. miserabilis*. *C. medius* has a more robust form

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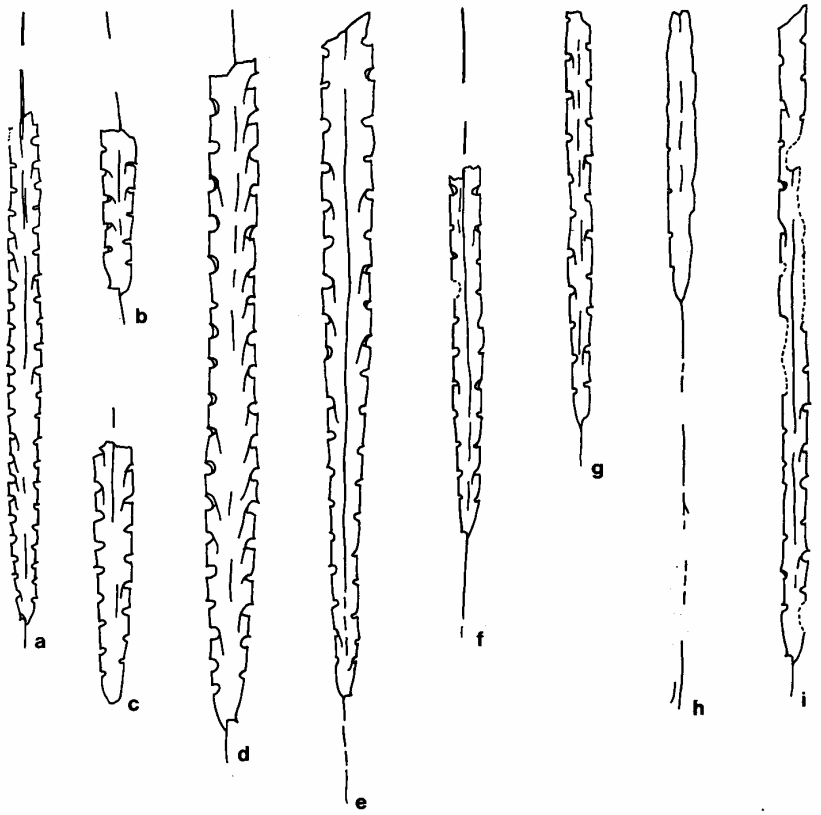
TEXT-FIG. 3. All except *b* from the Linn Branch trench, Dob's Linn. *a–e*, *Climacograptus normalis* Lapworth, 1877, ×5. *a*, HM C13955a, external mould in relief, slightly oblique orientation, 1·88–2·0 m, *P. acuminatus* Zone. *b*, BU 1142b, mutation showing distal forking; note formation of two nemata, Birkhill Shale, Dob's Linn, H. Lapworth Collection; counterpart figured (proximal only) Elles and Wood (1906, text-fig. 119*b*). *c*, HM C13759/1a, internal mould in partial relief, silty horizon at 0·6 m, *G. persculptus* Zone. *d*, HM C13756, internal mould in partial relief, oblique orientation, silty horizon at 0·6 m, *G. persculptus* Zone. *e*, HM C13787a, flattened distal fragment in scalariform orientation, 0·7–0·85 m, *G. persculptus* Zone. *f–i*, *Climacograptus miserabilis* Elles and Wood, 1906. *f*, HM C13788, reverse view, in partial relief, 0·7–0·85 m, *G. persculptus* Zone, ×10. *g*, HM C13971, reverse view, in full relief; note terminal thickened node of median septum, 1·88–2·0 m, *P. acuminatus* Zone, ×20. *h*, HM C13964, obverse view, in full relief, 1·88–2·0 m, *P. acuminatus* Zone, ×20. *i*, HM C14004, reverse view, in full relief, 2·01–2·14 m, *P. acuminatus* Zone, ×20. *j*, *Climacograptus miserabilis* Elles and Wood?, HM C13752, obverse view, in partial relief, 0·35–0·56 m, *G. persculptus* Zone, ×10.




TEXT-FIG. 4. All ×5 except fig. *a*. *a–e*, *Climacograptus normalis* Lapworth, 1877. Dob's Linn (*b–e* from the Linn Branch trench). *a*, BU 1136, Holotype?, note basal notch on wall of th1²; Lapworth's original illustration is insufficient to determine whether this or the other specimen on the slab is his figured specimen; figured Lapworth (1877, pl. 6, fig. 31)?, counterpart figured Elles and Wood (1906, pl. 26, fig. 2*a*), ×2·5. *b*, HM C13872b, juvenile rhabdosome, 1·38–1·46 m, *G. persculptus* Zone. *c*, HM C13613, Anceps Band D, Upper Hartfell Shale, *P. pacificus* Subzone. *d*, HM C13732a, specimen with rapid widening, 0·2–0·35 m, *G. persculptus* Zone. *e*, HM C13838, specimen with only gradual widening, 1·2–1·32 m, *G. persculptus* Zone. *f–i*, *Climacograptus miserabilis* Elles and Wood, 1906, Linn Branch trench, Dob's Linn. *f*, HM C13938, specimen with long virgella and nema, 1·69–1·79 m, *P. acuminatus* Zone. *g*, HM C13783, 0·7–0·85 m, *G. persculptus* Zone. *h*, HM C13904/1a, very long, apparently branching virgella, 1·56–1·66 m, *G. persculptus*/*P. acuminatus* Zone. *i*, HM C13870/1a, long rhabdosome, 1·38–1·46 m, *G. persculptus* Zone.

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) and Hutt (1974) *C. rectangularis* is a much wider form than *C. normalis* with a maximum width of 2·0–2·5 mm, although the proximal end seems very similar to several specimens here assigned to *C. normalis* (e.g. text-fig. 4*e*). *C. rectangularis* has not been recorded earlier than the *A. atavus* or *C. vesiculosus* zones. *C. normalis* is separable from both *G*? *avitus* and *G.* '*v.* cf. *venustus*' 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* is also found in the *D. anceps* Zone at Dob's Linn (text-fig. 4*c*). It 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 and Eberlein 1971; Riva and Petryk 1981), China (Hsü 1934), and Australia (Thomas 1960).

### *Climacograptus miserabilis* Elles and Wood, 1906

Text-figs. 3*f–i*, ?*j*, 4*f–i*, 5*a*, *b*

?1895 *Diplograptus* (*Glyptograptus*) *euglyphus* Lapworth var. *angustus* mihi; Perner, p. 27, pl. 8, fig. 14*a*, *b*.
?1895 *Diplograptus* (*Glyptograptus*) *lobatus* n. sp.; Perner, p. 28, pl. 7, fig. 15; pl. 8, fig. 15.
1906 *Climacograptus scalaris* (Hisinger) var. *miserabilis* var. nov.; Elles and Wood, p. 186, pl. 26, fig. 3*a–h*; text-fig. 120*a–c*.
?1924 *Climacograptus miserabilis* Elles and Wood; Hundt, pl. 1, figs. 20, 21, 26.
1929 *Climacograptus scalaris* var. *miserabilis* Elles and Wood; Davies, p. 7 (*pars*), text-fig. 27.
1945 *Climacograptus scalaris* var. *miserabilis* Elles and Wood; Waterlot, pl. 4, fig. 91.
1949 *Climacograptus angustus* (Perner); Přibyl, p. 7, pl. 11, figs. 2–9.
?1963 *Climacograptus scalaris* var. *miserabilis*? Elles and Wood; Willefert, p. 14, pl. 3, figs. 12, 16; text-fig. 4.
1963 *Climacograptus angustus* (Perner); Skoglund, p. 40, pl. 3, figs. 1, 2, 4–6; pl. 4, fig. 7; pl. 5, fig. 6.
1965 *Climacograptus scalaris miserabilis* Elles and Wood; Stein, pl. 60, fig. 14*f*, *h*.
1970 *Climacograptus scalaris miserabilis* Elles and Wood; Toghill, p. 23, pl. 12, figs. 1–11.
1970 *Climacograptus miserabilis* Elles and Wood; Rickards, p. 28, pl. 1, figs. 3–5, 10.
1974 *Climacograptus miserabilis* Elles and Wood; Hutt, p. 20, pl. 1, figs. 1, 2; text-fig. 8, fig. 1.
1975 *Climacograptus angustus* (Perner); Bjerreskov, p. 23, text-fig. 9*a*.
1976 *Gl.* (*sic*) (*Climacograptus*) *miserabilis* Elles and Wood; Legrand, text-fig. 7.
1980 *Climacograptus angustus* (Perner); Koren′ *et al.*, p. 131, pl. 37, figs. 2–7; text-fig. 34*a–e*.
?1980 *Climacograptus* aff. *angustus* (Perner); Koren′ *et al.*, p. 132, text-fig. 35.

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

*Material.* Specimens in the Lapworth Collection (BU) used by Elles and Wood in their original description and numerous specimens, mostly flattened but some preserved in full relief, in my collections.

*Horizons and localities.* The basal 2·3 m of Birkhill Shale, *G. persculptus* and low *P. acuminatus* zones, Dob's Linn.

*Diagnosis.* Small rhabdosome up to 20 mm long, with a rapidly attained maximum width of 0·8 mm. Thecae may appear typically *Climacograptus* in style or possess slightly curved supragenicular walls, numbering nine to eleven in 10 mm. Long virgella and nema commonly present.

*Description.* The rhabdosome is only up to 20 mm long, widening from 0·5–0·7 mm at the aperture of th1$^1$ to the maximum 0·7–0·8 mm (1·0 mm in tectonically widened specimens) within 4 mm. Proximally the thecae number about eleven in 10 mm, reducing only slightly to nine to ten in 10 mm distally. The sicula is 1·0–1·3 mm long and is exposed for its entire length in obverse aspect. It possesses a conspicuous virgella which sometimes reaches over 10 mm long. Th1$^1$ grows initially down until it reaches the aperture of the sicula, then bends sharply upwards. Th1$^2$ appears to grow upwards for its entire length. When specimens are preserved in full biprofile orientation a slight proximal 'notch' is present where the sicula extends beyond th1$^2$, but the proximal end appears pointed when oriented 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 (text-fig. 3*g*). 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 rhabdosome. The apertures are normally slightly everted, opening into long excavations which occupy one-quarter the total width of the rhabdosome and are sub-alternate. The interthecal septa are slightly curved and short, extending only half the length of the supragenicular walls. A long nema is commonly present.

*Remarks*. The only coeval species with which *C. miserabilis* can be easily confused is *C. normalis* when tectonically widened. *C. miserabilis*, however, reaches its maximum width quickly as opposed to the more gradual widening of *C. normalis*, and even when tectonically stretched *C. miserabilis* rarely exceeds 1 mm wide. The proximal development and thecal style of *C. miserabilis* are also somewhat different with shorter interthecal septa and commonly slightly curved supragenicular walls. Toghill (1970) recorded *C. miserabilis* from the *P. linearis* Zone, whilst Williams (1982*a*) shows that it is found as low as high *D. clingani* Zone in the Lower Hartfell Shale at Dob's Linn. Elles and Wood recorded the earlier small *Climacograptus*, *C. brevis* Elles and 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. miserabilis* to *C. angustus* (Perner, 1895) was first noted by Přibyl (1949, p. 7) who listed Elles and Wood's species as a junior synonym. Strachan (1971), 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 synonymized *G. lobatus* which was described by Perner on the page following the description of *C. angustus*. It has since become apparent that the lower Silurian specimens of *C. miserabilis* match Perner's description of *C. angustus* more closely than the late Ordovician ones, which have a more typically *Climacograptus* thecal style (R. B. Rickards, pers. comm.). It is here considered that *C. miserabilis* 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 recognized that the lower Silurian specimens described here may be synonymous with Perner's material. It should be noted that *C. angustus* Sobolevskaya, 1969, a small *longispinus* group *Climacograptus* from the late Ordovician of the U.S.S.R., is a junior homonym of *C. angustus* (Perner, 1895) and should not be used.

*C. miserabilis* is a widespread upper Ordovician and lower Silurian species, and if synonymized with *C. angustus* has been recorded from all equivalent graptolitic successions.

### *Climacograptus medius* Törnquist, 1897

Text-fig. 5*f–i*

1870 *Climacograptus teretiusculus*; Nicholson (*pars*), p. 373, text-fig. 1*a*, *b*, *f* (*non* text-fig. 1*c–e*).
1872 *Climacograptus teretiusculus*; Nicholson (*pars*), p. 33, text-fig. 8*a*, *b*, *f* (*non* text-fig. 8*c–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, p. 7, pl. 1, figs. 9–15.
1906 *Climacograptus medius* Törnquist; Elles and Wood (*pars*), p. 189, pl. 26, fig. 4*a–e*; text-fig. 122*a*, *c* (*non* pl. 26, fig. 4*f*; text-fig. 122*b* = *C. trifilis* Manck, 1923).
1919 *Climacograptus medius* Törnquist; Kirste (*pars*), p. 107, pl. 1, fig. 4*b*, 4*a*? (*non* pl. 1, fig. 4*c*, *d*).
?1924 *Climacograptus medius* Törnquist, Hundt, pl. 1, figs. 22, 23, 35, 36.
?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.

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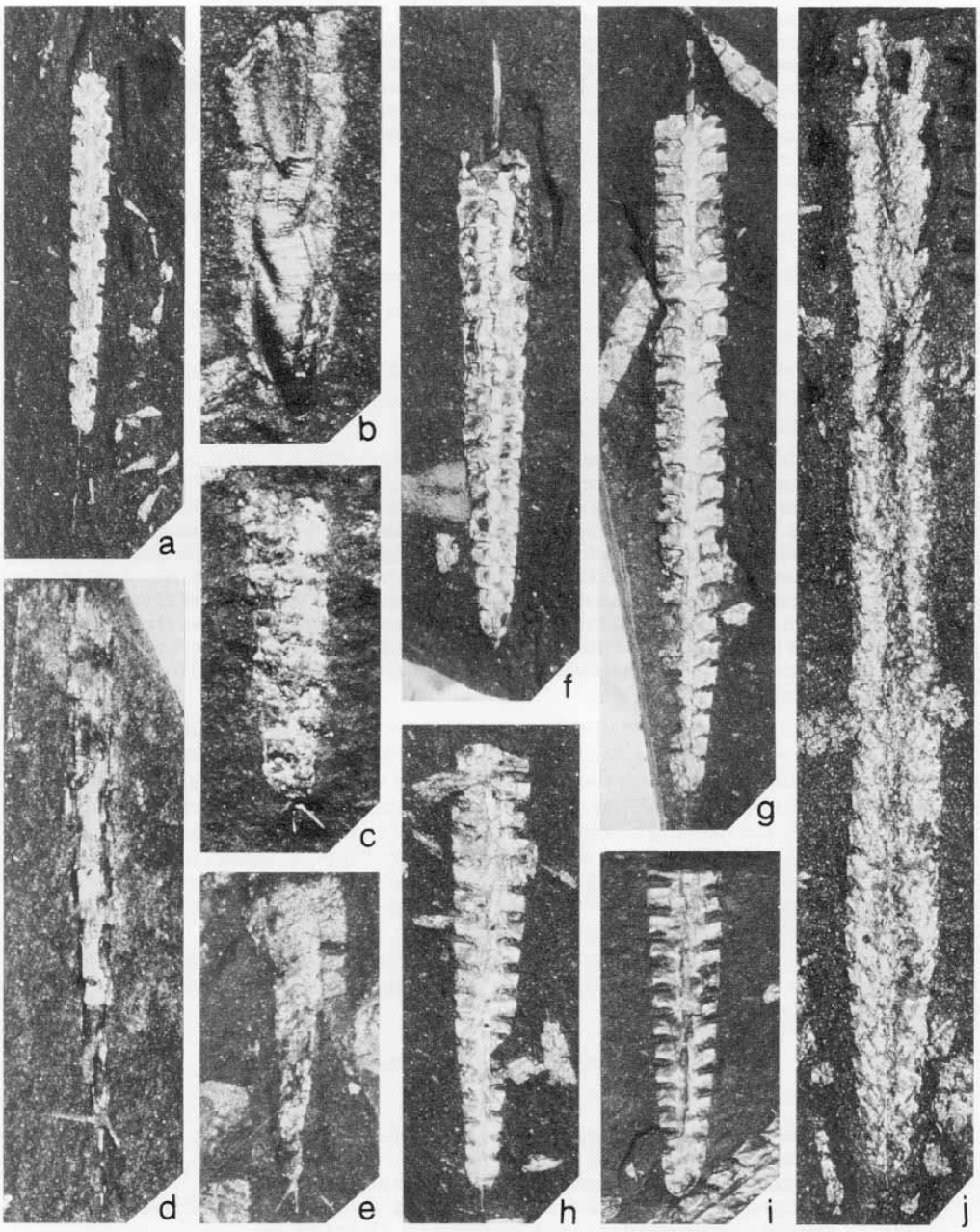
TEXT-FIG. 5. All except *j* from the Linn Branch trench, Dob's Linn. *a*, *b*, *Climacograptus miserabilis* Elles and Wood, 1906. *a*, HM C13862a, complete specimen with long virgella, 1·38–1·46 m, *G. persculptus* Zone, × 5. *b*, HM C13909, reverse view, in partial relief; note growth fusellae and flattened exterior portions of thecae, 1·56–1·66 m, *G. persculptus*/*P. acuminatus* Zone, × 20. *c*, *Climacograptus trifilis* Manck, 1923, HM C14020, 2·19–2·31 m, *P. acuminatus* Zone, × 10. *d*, *e*, *Climacograptus* sp. (cf. *C. miserabilis*), with three basal spines as *C. trifilis*, but narrower, × 10. *d*, HM C14027, 2·19–2·31 m, *P. acuminatus* Zone. *e*, HM C13978, 2·01–2·14 m, *P. acuminatus* Zone. *f–i*, *Climacograptus medius* Törnquist, 1897, × 5. *f*, HM C13951, note median groove of wide nema, 1·88–2·0 m, *P. acuminatus* Zone. *g*, HM C13814, 1·1–1·2 m, *G. persculptus* Zone. *h*, HM C13888a, 1·46–1·56 m, *G. persculptus* Zone. *i*, HM C13916/1, 1·76–1·91 m, *P. acuminatus* Zone. *j*, *Climacograptus*? *extraordinarius* (Sobolevskaya, 1974), HM C13689, Anceps Band E, Upper Hartfell Shale, *P. pacificus* Subzone, Main Cliff section, Dob's Linn, × 5.


a
b
c
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j

1948 *Climacograptus medius* Törnquist; Waern, p. 449, pl. 25, fig. 4; text-fig. 5.
?1949 *Climacograptus medius* Törnquist; Obut, p. 13, pl. 1, fig. 3*a*, *b*.
?1957 *Climacograptus medius* Törnquist; Suner Coma, p. 49, text-fig. 1.
1965 *Climacograptus medius* Törnquist; Stein, p. 163, text-fig. 16*a–g*, tables 7, 8.
?1970 *Climacograptus* cf. *C. medius* Törnquist; Churkin and Carter, p. 16, pl. 1, figs. 4, 5; text-fig. 6*f*.
1970 *Climacograptus medius* Törnquist; Rickards, p. 30, pl. 1, fig. 2.
1971 *Climacograptus medius* Törnquist subsp. indet.; Schauer, p. 31, pl. 2, figs. 1, 2; pl. 4, figs. 1–3.
1974 *Climacograptus medius* Törnquist; Hutt, p. 19, pl. 1, fig. 3.
1975 *Climacograptus medius* Törnquist; Bjerreskov, p. 24, text-fig. 9*c*.

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

*Material.* Fifteen flattened specimens and one in full relief, my collection.

*Horizons and localities.* From 1·1 to 2·3 m above the base of the Birkhill Shale, *G. persculptus* and low *P. acuminatus* zones, Linn Branch trench, Dob's Linn.

*Diagnosis.* Robust rhabdosome with a maximum width of 2·5 mm and wide rounded proximal end. Thecae with short straight supragenicular walls, numbering twelve or thirteen in 10 mm, excavations long and deep. Nema often broad.

*Description.* The rhabdosome is over 30 mm long, increasing from a width of 1 mm at the aperture of th1[1] to 1·7–1·9 mm in 5 mm and slowly reaching the maximum 2·2–2·5 mm within 15 mm. The thecae usually number thirteen in 10 mm proximally, reducing only slightly to twelve in 10 mm distally. The proximal development has not been observed in the described material. The sicula possesses a conspicuous but short virgella and the proximal region is wide and rounded. The thecae have short, straight supragenicular walls which are normally vertical but sometimes slightly inclined. The apertures are horizontal and open into very deep and long excavations which occupy one-third the total width of the rhabdosome and over one-third of the ventral walls. The excavations often appear deeper as the rhabdosome is commonly preserved in oblique orientation; the one 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 *P. acuminatus* Zone of Britain. It could be confused with tectonically widened specimens of *C. normalis* 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 more robust proximally than *C. rectangularis* which is only 0·7 mm wide at the aperture of th1[1]. *C. medius* has sometimes been recorded as occurring rarely in the *P. acuminatus* Zone but with its main development in the *A. atavus* to *M. triangulatus* zones (Rickards 1970; Hutt 1974), although Stein (1965), Toghill (1968*b*), and Rickards (1976*a*, *b*) record the range as *G. persculptus* to *C. cyphus* zones.

*C. medius* has been recorded from the lower Silurian of Europe, Morocco (Waterlot 1945), China (Sun 1933), U.S.S.R. (Obut and Sobolevskaya 1966), and questionably from North America (Churkin and Carter 1970).

## *Climacograptus trifilis* Manck, 1923

Text-fig. 5*c*

1906 *Climacograptus medius* Törnquist; Elles and Wood (*pars*), p. 189, pl. 26, fig. 4*f*; text-fig. 122*b* (*non* pl. 26, fig. 4*a–e*; text-fig. 122*a*, *c* = *C. medius s.s.*).
1923 *Climacograptus trifilis* spec. nov. Manck, p. 288, text-fig. 32.
1965 *Climacograptus trifilis* Manck; Stein, p. 165, text-fig. 17*a–d* [see also for full synonymy list].
1975 *Climacograptus trifilis trifilis* Manck; Bjerreskov, p. 23, text-fig. 9*b*.

*Holotype.* The specimen figured by Manck (1923, text-fig. 32) from an unknown locality and horizon.

*Material.* One flattened specimen in my collection.

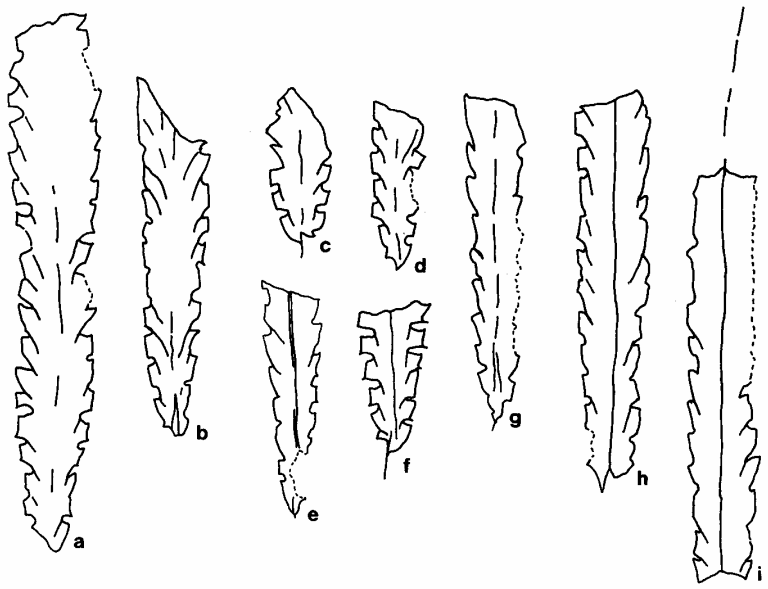
*Horizons and localities.* The interval 2·2 to 2·3 m above the base of the Birkhill Shale, low *P. acuminatus* Zone, Linn Branch trench, Dob's Linn.

*Remarks.* This species was described in detail by Stein (1965). It has a similarly robust proximal end to *C. medius* 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 *C. trifilis* appears to be commonly preserved in scalariform and oblique orientation and therefore probably had a similar cylindrical cross-section to *C. medius*. From the records by Stein (1965, p. 167), Toghill (1968*b*, p. 658), and Bjerreskov (1975, p. 23) *C. trifilis* appears to be restricted to the *P. acuminatus* Zone and it has not been recorded outside Europe.

*Climacograptus? extraordinarius* (Sobolevskaya, 1974)

Text-figs. 5*j*, 6*a–i*, 7*a–c*

1974 *Fenhsiangograptus extraordinarius* sp. nov.; Sobolevskaya, p. 69, pl. 3, figs. 6, 7.
?1974 *Diplograptus orientalis* sp. nov.; Mu *et al.*, p. 213, pl. 98, fig. 11.
?1978 *Diplograptus orientalis* Mu *et al.*; Wang and Zhao, p. 641, pl. 207, fig. 6 [same specimen as illustrated by Mu *et al.* 1974].
1979 *Climacograptus? extraordinarius* (Sobolevskaya); Rickards, text-fig. 2.
?1980 *Glyptograptus? persculptus* (Salter) forma A; Koren' *et al.*, p. 147, pl. 42, figs. 3–6; pl. 43, fig. 1; pl. 44, figs. 1–6; text-fig. 44*a–j*.




TEXT-FIG. 6. *Climacograptus? extraordinarius* (Sobolevskaya, 1974). Extraordinarius Band, Upper Hartfell Shale, *C? extraordinarius* Zone, Long Burn trench, Dob's Linn, Ingham collection, all × 5. *a*, HM C14479/33, distal fragment. *b*, HM C14479/45, proximal fragment in obverse view showing sicula and proximal development. *c*, HM C14479/1, proximal fragment with prominent virgella and 'notch' below th1[2]. *d*, HM C14479/22. *e*, HM C14479/21. *f*, HM C14479/16, proximal fragment with clear proximal structure. *g*, HM C14479/5, proximal fragment with sicula faintly visible. *h*, HM C14479/25, distal fragment. *i*, HM C14479/23, distal fragment with free nema.

*Holotype.* Specimen No. 602x/1 figured by Sobolevskaya (1974, pl. 3, fig. 6).

*Material.* About fifty specimens in the Ingham Collection (HM) and six specimens in my collection (all flattened).

*Horizons and localities.* Extraordinarius Band, Upper Hartfell Shale, *C? extraordinarius* Zone, Long Burn and Main Cliff sections, Dob's Linn. Anceps Band E, Upper Hartfell Shale, *P. pacificus* Subzone, Main Cliff section, Dob's Linn.

*Diagnosis.* Rhabdosome over 35 mm long, rapidly widening to the maximum 2·5–3·0 mm. Distally somewhat fusiform. Thecae intermediate between *Glyptograptus* and *Climacograptus*, numbering ten to twelve in 10 mm. Sicula with prominent virgella, anti-virgellar side forms conspicuous 'notch' under th1[2].

*Description.* The rhabdosome is up to 35 mm long with a robust, sub-fusiform outline, widening rapidly from 1·0–1·2 mm at the aperture of th1[1] to the maximum 2·3–3·0 mm within 8 mm and commonly decreasing in width soon after. Proximally the thecae number twelve in 10 mm, reducing distally to ten in 10 mm. The sicula is rarely seen but possesses a conspicuous virgella up to 1 mm long. Th1[1] grows downwards initially until it reaches a level about 0·3 mm below the aperture of the sicula, then bends abruptly upwards to give an aperture about 0·9 mm above its lowest point. Th1[2] appears to grow upwards throughout its length, cutting diagonally across the sicula some 0·3 mm above its aperture and resulting in a 'notch' where the anti-virgellar side of the sicula remains exposed. The remaining thecae are highly variable in style due to diagenetic flattening in a variety of orientations and to tectonic deformation. When relatively undeformed biprofile orientations are seen, the thecae have short, straight, gently inclined suprageniculars walls with conspicuous genicular flanges. The apertural excavations are long, occupying over one-third of the total ventral wall, but are shallow, commonly occupying only one-fifth to one-sixth 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 free nema up to 5 mm long. It is unclear whether a median septum exists, although by comparison with other similar diplograptids this is likely to be present.

*Remarks.* The proximal development of the specimens here assigned to *C? extraordinarius* is very similar to that found in *Glyptograptus persculptus* and they are evidently closely related. The main differences between the two species are the prominent genicular flanges and distal narrowing of *C? extraordinarius*. It is possible that some of the specimens figured here as *C? extraordinarius* are actually deformed specimens of *G. persculptus s.l.*, as the tectonic deformation present at Dob's Linn, particularly in the Extraordinarius Band where it is more extreme, may alter the thecal style drastically, and subtle differences may not be recognized reliably.

The dimensions and thecal counts (when deformation is accounted for) agree well with Sobolevskaya's original (1974) description and figures. The remaining specimens from the Ingham Collection figured by Rickards (1979, text-fig. 2) have consistently more vertical suprageniculars walls but are otherwise similar to those described here. The three-dimensional specimens of *G. persculptus*

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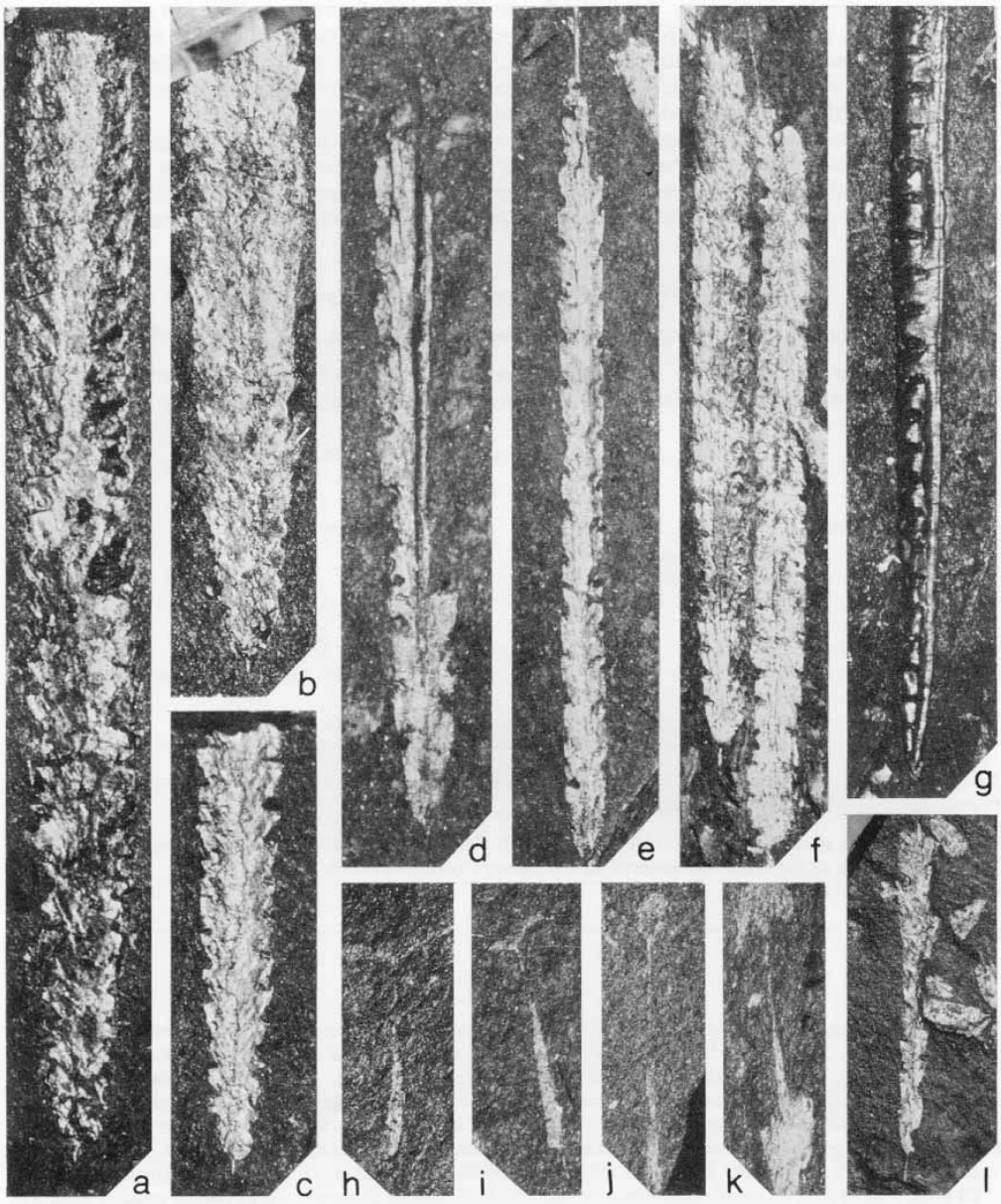
TEXT-FIG. 7. *a–c*, *Climacograptus? extraordinarius* (Sobolevskaya, 1974). Anceps Band E, Upper Hartfell Shale, *P. pacificus* Subzone, Main Cliff section, Dob's Linn, × 5. *a*, HM C13709. *b*, HM C13705. *c*, HM C13690. *d–f*, *Glyptograptus? 'venustus* cf. *venustus'* (Legrand, 1976). Basal 0·46 m, *G. persculptus* Zone, Linn Branch trench, Dob's Linn. *d*, HM C13738/1, with uniserial distal portion, possibly due to post-mortem breakage in this specimen (also figured text-fig. 8*h*), × 10. *e*, HM C13747/1, almost complete rhabdosome (also figured text-fig. 8*d*), × 5. *f*, HM C13747/2–3, tectonically widened rhabdosomes (also figured text-fig. 8*a*), × 5. *g*, *Climacograptus normalis* Lapworth, 1877, HM C13972, external mould, in relief, oblique orientation, 1·88–2·0 m, *P. acuminatus* Zone, Linn Branch trench, Dob's Linn, × 5. *h–l*, *Glyptograptus? avitus* Davies, 1929. *h–k*, *G. persculptus* Zone, Linn Branch trench, Dob's Linn, × 10. *h*, HM C13837, sicula with 'lime seed vane'-like structure, 1·2–1·32 m. *i*, HM C13840, as *h*, 1·2–1·32. *j*, HM C13815, sicula with 'disc'-like structure, 1·1–1·2 m. *k*, HM C13882, juvenile with first two thecae and biconcavo-convex structure, 1·46–1·56 m. *l*, SM A10019, Holotype, note specimen is tectonically stretched, giving a more slender appearance than is normal for this species; from the low Birkhill Shale (labelled '*acuminatus*' Zone but may actually be from the *persculptus* Zone—see comments in text), Dob's Linn; figured Davies (1929, text-fig. 21), Packham (1962, text-fig. 7*a*), × 5.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forma A described by Koren′ *et al.* (1980) appear similar to *C? extraordinarius* proximally but they do not figure any complete specimens. Only the holotype of *D. orientalis* has been figured; it has prominent genicular flanges on the early thecae and a sub-fusiform outline very similar to *C? extraordinarius*, and Enzhi Mu (pers. comm.) considers that the two species may be synonymous. *Diplograptus multidens orientalis* Wang *et al.*, 1977 is from an earlier horizon containing *Dicranograptus ramosus longicaulis* Elles and 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 high *P. pacificus* Subzone at Dob's Linn. If *D. orientalis* from the top Ordovician *D. bohemicus* Zone of central China is synonymous with *C? extraordinarius* it would appear to be a fairly widespread species and even more useful for correlation than presently recognized.

## Genus GLYPTOGRAPTUS (GLYPTOGRAPTUS) Lapworth, 1873

*Type species* (by original designation). *Diplograpsus tamariscus* Nicholson, 1868, p. 526, pl. 19, figs. 10–13.

*Diagnosis* (after Bulman 1970, p. V126). Thecae alternate with gentle sigmoidal curvature, supragenicular walls normally slightly convex, sometimes with slight genicula.

### *Glyptograptus persculptus* (Salter, 1865)

Plate 66, figs. 1–3

1865 *Diplograpsus persculptus* [Salter?]; Salter, p. 25 (see Strachan 1971).
1868 *Diplograpsus persculptus*; Carruthers, p. 130.
1878 *Diplograpsus persculptus* Salter; Salter, p. 23.
1907 *Diplograptus* (*Glyptograptus*) *persculptus* Salter; Elles and Wood, p. 257, pl. 31, fig. 7*a–c*; text-fig. 176*a*, *b*.
1929 *Glyptograptus* aff. *persculptus* Salter; Davies, p. 10, text-fig. 11*a*.
1929 *Glyptograptus persculptus* mut.; Davies (*pars*), p. 11, text-figs. 11, 13, 15–18 (*non* text-figs. 12, 14, 19 = *G.* cf. *persculptus sensu* this paper).
1929 *Glyptograptus persculptus* mut. *omega* nov.; Davies, text-figs. 15, 20.
1977 *Glyptograptus persculptus* (Salter); Rickards *et al.*, p. 99, pl. 2, fig. 4; text-figs. 8, 53.

*Lectotype* (here designated). GSM 11782, the only well-preserved specimen in Salter's collection; from Ogofau, Pumpsaint, mid Wales; figured Pl. 66, fig. 3.

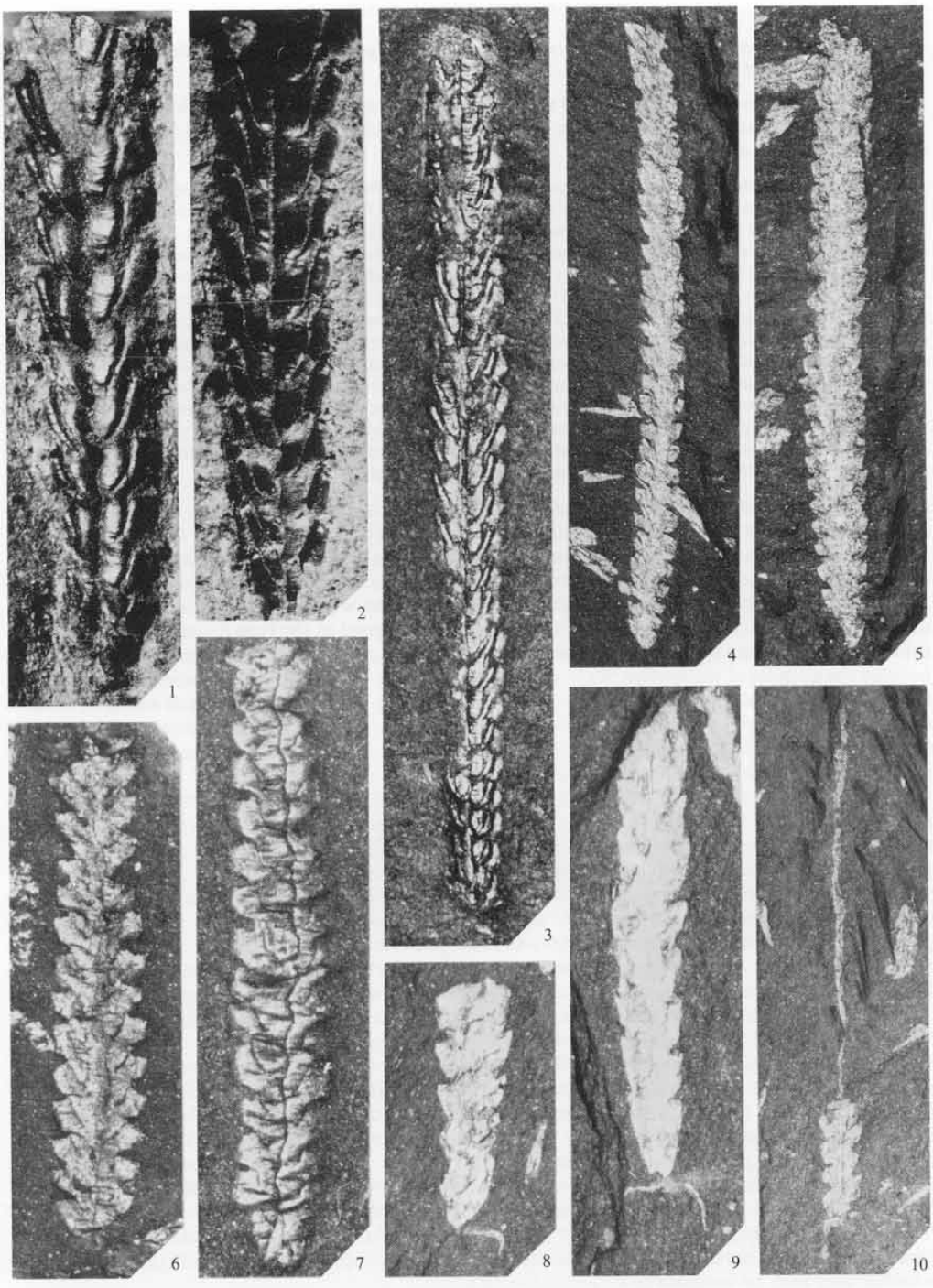
*Material.* Salter's specimens (I.G.S. collections, South Kensington), two specimens illustrated by Elles and Wood (collections of the BM) and material in the Davies Collection (SM).

EXPLANATION OF PLATE 66

Figs. 1–3. *Glyptograptus persculptus* (Salter, 1865) *sensu stricto*. Basal Silurian(?), *G. persculptus*/*P. acuminatus* Zones, Ogofau, Pumpsaint, Dyfed, mid Wales. 1, BM Q112, obverse view in full relief, with apparently complete sicula, (?)figured Elles and Wood (1907, text-fig. 176*a*), × 10. 2, BM Q113, broad specimen with broken proximal end, in partial relief, figured Elles and Wood (1907, text-fig. 176*b*, with complete proximal end), × 10. 3, GSM 11782, proposed lectotype, the only well-preserved specimen collected by Salter, × 5.

Figs. 4–7. *Glyptograptus* cf. *persculptus* (Salter, 1865). Linn Branch trench, Dob's Linn. 4, HM C14023/1a, 2·19–2·31 m, *P. acuminatus* Zone, × 5. 5, HM C13848a, 1·2–1·32 m, *G. persculptus* Zone, × 5. 6, HM C13963, 1·88–2·0 m, *P. acuminatus* Zone, × 10. 7, HM C13965a, obverse view in partial relief, 1·88–2·0 m, *P. acuminatus* Zone, × 10.

Figs. 8–10. *Glyptograptus*? *avitus* Davies, 1929. *G. persculptus* Zone, Linn Branch trench, Dob's Linn. 8, HM C13906/1, 1·56–1·66 m, × 10. 9, HM C13895, 1·56–1·66 m, × 10. 10, HM C13806, distal fragment with membranous nema, 1·1–1·2 m, × 5.




WILLIAMS, *Glyptograptus*

*Horizons and localities.* Zones of *G. persculptus* and *P. acuminatus*, gold mines at Ogofau, Pumpsaint, Dyfed, and other localities in mid Wales.

*Diagnosis.* Large rhabdosome up to 30 mm long and 2–3 mm wide with sigmoidally curved thecae and wavy median septum. Thecae with curved supragenicular walls and slightly everted apertures, numbering nine to eleven in 10 mm.

*Description.* The rhabdosome is up to 30 mm long, widening from about 1 mm at the aperture of th1[1] to 1·5–1·7 mm in 5 mm and slowly reaching the maximum 2·0–2·7 mm in 15 mm which is then maintained. Proximally the thecae number ten to eleven in 10 mm, decreasing distally to nine in 10 mm. The sicula is revealed for 1·2 mm in obverse view; Elles and Wood recorded the sicula to be 2·1 mm long when observed in juvenile specimens, although Davies's serial sections (1929, text-fig. 11*a*) indicated that the sicula is only 1·2 mm long and obversely exposed for its entire length. Th1[1] grows down until it is about 0·15 mm below the aperture of the sicula before bending abruptly upwards. Th1[2] apparently grows upwards for its entire length, giving the proximal region a distinctive, asymmetrical appearance. The remaining thecae are sigmoidally curved and possess slightly everted apertures which open into narrow excavations occupying only about one-sixth of the total rhabdosome width. The supragenicular walls are gently convex, with slight genicula which become more pronounced when the rhabdosome is oriented obliquely. The thecae remain alternate throughout the rhabdosome, resulting in a gently sinuous median septum which is complete in obverse view, although Davies (1929) considered that the median septum appeared later on the reverse side higher up the succession. Neither virgella nor distally free nema have 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 and Wood (1907) appears to be identical with 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 2 mm long, while the description records them as 3 mm) and with the illustrations, so care must be taken when using it. If Elles and 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 and Wood should become the authors of the species. As *G. persculptus* is such a well-established species in international literature it would not be wise to change the name. Elles and Wood apparently had access to Salter's material in addition to their own and obviously considered it to be his species; it is therefore considered justifiable to retain Salter as the author of *G. persculptus* in the cause of nomenclatorial stability, although he never described or illustrated it.

It appears that many specimens identified as *G. persculptus* are not strictly referable to this species and that the name is now applied to 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. 66, figs. 4–7) which are preserved both flattened and in relief. Davies (1929, p. 14) and Rickards (1976*a*, p. 158) pointed out that *G. persculptus* and *Diplograptus m. modestus* Lapworth, 1876 may be easily confused when flattened and that caution should be exercised when using faunal lists containing both names.

Davies's specimens (1929, text-figs. 14, 19 and unfigured material in the Sedgwick Museum) of '*G. persculptus* mut.' and Hutt's specimens of '*G. persculptus*' (1974, pl. 6, figs. 9–12), all from the English Lake District, are similar but rather smaller than the type material and are here referred to *G.* cf. *persculptus*, as is Davies's figured specimen of '*G. persculptus* mut.' from Dob's Linn (1929, text-fig. 12). This latter form is rather less robust and has a poorly developed periderm, giving far less contrast with the surrounding lithology than other associated diplograptids, as opposed to the well thickened one of *G. persculptus s.s.* Davies (1929, p. 14) seems to have been aware of this variation; he stated that specimens of *G. persculptus* from the Moffat area were, on the whole, smaller than those in Wales whilst those in the Lake District were intermediate between the two. The specimens of '*G. persculptus*' described by Bjerreskov (1975) from Bornholm have a fairly narrow rhabdosome (maximum 1·6 mm in relief, 2·0 mm flattened) but a low thecal count (ten in 10 mm) and it is unclear whether they may be assigned to *G. persculptus s.s.*

Although it would be necessary to see the specimens before stating anything conclusively, none of the specimens figured by Koren′ *et al.* (1980) as *G. persculptus* forma A and forma B appears to me to belong to *G. persculptus s.s.* Their forma A has more pronounced genicula, straighter supragenicular walls, widens more rapidly, and appears to narrow distally; it is possibly synonymous with *Climacograptus? extraordinarius* 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.* Churkin *et al.* (1971) recorded *G. persculptus* from the lowest Silurian of Alaska but did not describe or figure any material.

### *Glyptograptus* cf. *persculptus* (Salter, 1865)

Plate 66, figs. 4–7

1929 *Glyptograptus persculptus* mut.; Davies (*pars*), p. 11, text-figs. 12, 14, 19 (*non* text-figs. 11, 13, 16–18 = *G. persculptus s.s.*).
1974 *Glyptograptus persculptus* (Salter); Hutt, p. 28, pl. 6, figs. 9–12.

*Material.* Specimens in the Davies and Hutt collections (SM) and many specimens in my collections, including several preserved in partial relief.

*Horizons and localities.* From 0·7 to 2·3 m above the base of the Birkhill Shale, *G. persculptus* and low *P. acuminatus* zones, Linn Branch trench, Dob's Linn. Davies's and Hutt's material mostly from the Skelgill Beds, *G. persculptus* and *P. acuminatus* zones, Torver Beck and Yewdale Beck, Coniston, northern England. One of Davies's specimens (1929, text-fig. 12) from the Birkhill Shale, Dob's Linn.

*Diagnosis.* Similar to *G. persculptus s.s.* but with a smaller rhabdosome up to 20 mm long and 1·7 mm wide. Thecae number eleven to seventeen in 10 mm in tectonically distorted specimens.

*Description.* The rhabdosome is up to 20 mm long, widening rapidly from 1 mm at the aperture of th1[1] to a maximum of 1·5–1·7 mm within 5 mm (undistorted). Proximally the thecae number fourteen to seventeen in 10 mm, reducing distally to eleven to thirteen in 10 mm. Only one specimen (Pl. 66, fig. 7) preserved in oblique view shows a sicula, which is visible for 0·8 mm. A short virgella is commonly visible in well-preserved material. The proximal development is obscure in the described specimens but appears similar to *G. persculptus s.s.* The remaining thecae have 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 oblique tectonic deformation sometimes causes them to appear opposite. A distally free 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 of the Lake District, which Rickards (1976*a*, p. 157) and Rickards *et al.* (1977) recognized as being smaller than the type material. Rickards (1976*a*), however, stated that much variation occurred in specimens from the Lake District and Dob's Linn, concluding that there were probably several subspecies involved. *G.* cf. *persculptus* may only be confused with *G*? '*v.* cf. *venustus*' in the collections from Dob's Linn, but differs from this by its less well-developed periderm, thecal style, and lack of a long virgella or nema. The present work indicates clearly that *G.* cf. *persculptus* occurs, albeit rarely, in the low *P. acuminatus* Zone, supporting the range given by Toghill (1968*b*) for '*G. persculptus*'.

### *Glyptograptus*? *avitus* Davies, 1929

Plate 66, figs. 8–10; text-figs. 7*h–l*, 9*a–c*, ?*d*, 10*a–c*

1929 *Glyptograptus*(?) *avitus* sp. nov.; Davies, p. 8, text-fig. 21.
1962 *Glyptograptus*(?) *avitus* Davies; Packham, text-fig. 7*a*.
1965 *Glyptograptus*(?) *avitus* Davies; Stein, p. 172, text-fig. 22*g*.

*Holotype.* SM A10019, the specimen figured by Davies (1929), Packham (1962), and in this paper as text-fig. 7*l*; from the Birkhill Shale (*P. acuminatus* Zone?—see *Remarks*), Dob's Linn.

*Material.* The holotype and numerous flattened fragmentary specimens in my collections.

*Horizons and localities.* From 0·7 to 1·6 m above the base of the Birkhill Shale, *G. persculptus* Zone, Linn Branch trench, Dob's Linn.

*Diagnosis.* Small rhabdosome, increasing rapidly from 0·8 to 1·2 mm wide in 5 mm then slowly to 1·5 mm maximum. Thecae with slightly curved or straight, sloping supragenicular walls. Virgella commonly bifurcating, nema often with irregular, apparently membranous, structures.

*Description.* The longest fragment in the material described here is 8 mm long. The rhabdosome is 0·8–0·9 mm wide at the aperture of th1$^1$ and increases to 1·2 mm in 5 mm. Davies (1929) recorded the rhabdosome to then widen slowly throughout its length to a distal maximum of 1·5 mm. The thecae number about twelve in 10 mm proximally, reducing to about ten in 10 mm distally. The sicula is approximately 2 mm long; it possesses a virgella which bifurcates after 1 to 4 mm and occasionally forks a second time (text-fig. 9*b*). The nemata of siculae in association with, and apparently belonging to, *G? avitus* characteristically possess distal structures, taking the form of a double concavo-convex or 'disc'-shaped vane-like structure (text-fig. 7*h–k*). Th1$^1$ appears to grow down below the level of the sicula before bending up whilst th1$^2$ grows continuously upwards, in a similar fashion to *G. persculptus*. 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, distally free nema is usually present; in juvenile specimens it commonly bears a vane-like structure at the distal extremity (see above) whilst more mature specimens often possess apparently membranous structures at various points along its length. (Pl. 66, fig. 10, text-figs. 9*c*, 10*b*).

*Remarks.* The holotype has been tectonically stretched longitudinally. The specimens described here agree well with Davies's description except that he did not record any specimens with forked virgellae. *G? avitus* is distinguished from other coexisting species by its thecal style, which is closest to the earlier *G.* '*v.* cf. *venustus*'. Davies recorded *G? avitus* to be characteristic of the *G. persculptus* Zone (1929, p. 22, text-fig. 32), but in his description of the holotype (1929, text-fig. 21) recorded it to originate from the '*A. acuminatus* Zone'. Unfortunately, he gave no reference to the range of the species in the description other than 'L. Birkhill Shale'. The type slab contains no other zonally diagnostic faunal elements. The present study suggests that *G? avitus* is restricted to the *G. persculptus* Zone at Dob's Linn and that the label on the holotype must therefore be incorrect. Stein (1965), however, recorded *G? avitus* (with a forked virgella) from the *P. acuminatus* Zone of the Frankenvald, and Rickards (1976*a*) stated that he had identified the species from the *P. acuminatus* Zone at Conwy, north Wales.

In his original description Davies suggested that *G? avitus* was a 'forerunner' of *Akidograptus ascensus* Davies, 1929; I consider that there is insufficient evidence to demonstrate an evolutionary link between the two as implied by Davies. The membranous features attached distally to the nemata of siculae and juvenile rhabdosomes of *G? avitus* may have been vane-like structures to facilitate dispersal. The only structures in coeval diplograptids similar to those associated with the nemata of mature rhabdosomes of *G? avitus* were described by Müller (1977, pl. 4, figs. 1–7), who referred his specimens to *Climacograptus* sp. and *Diplograptus* cf. *modestus*. None of his specimens is considered here to belong to *G? avitus*. Müller (1975, 1977) considered the *P. acuminatus* Zone to represent an interval with diplograptids showing 'ramose' type (bifurcating) virgellae, although *G? avitus* is restricted to the *G. persculptus* Zone at Dob's Linn. The specimen referred to '*G.* aff. *avitus*' by Koren' *et al.* (1980, p. 140, text-fig. 41) is much narrower than *G? avitus* and has more steeply inclined supragenicular walls.

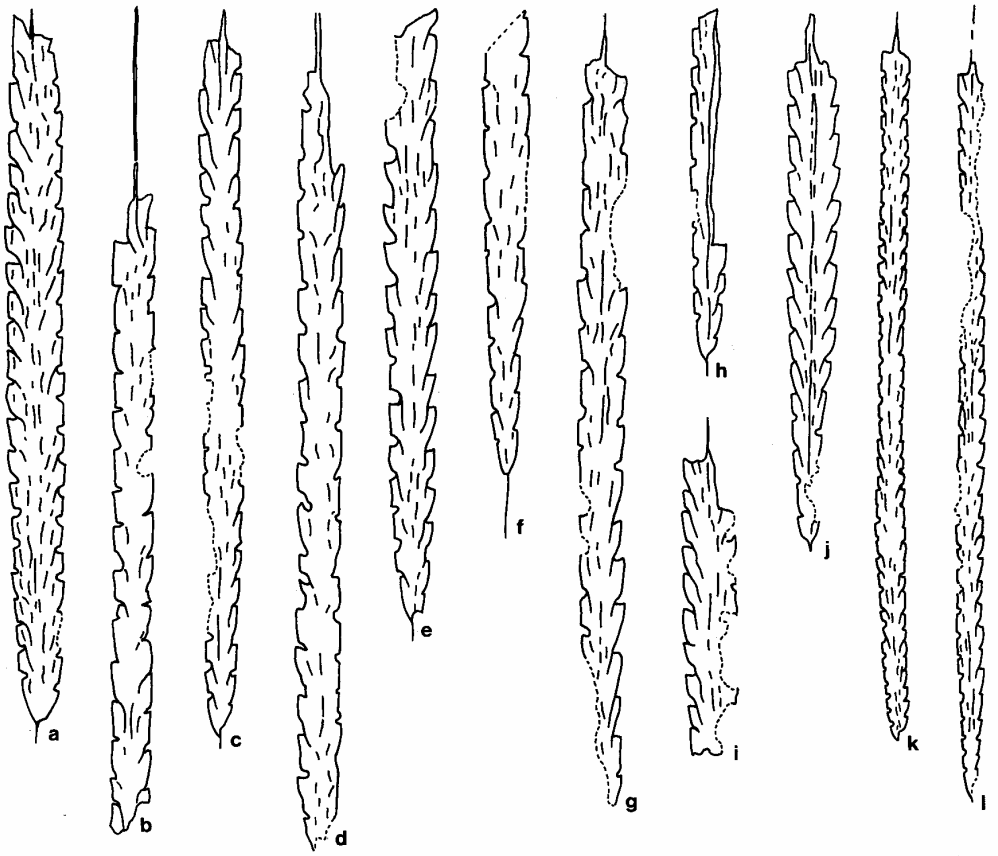
### *Glyptograptus*? '*venustus* cf. *venustus*' (Legrand, 1976)

Text-figs. 7*d–f*, 8*a–l*

*non* 1959 *Climacograptus venustus* sp. nov.; Hsü, p. 349, pl. 1, figs. 1–6, 13.

cf. 1976 *Cl.* (*Climacograptus*) *venustus venustus* nov. subsp.; Legrand, p. 158, text-fig. 3*a–e*, table 3.
1976 ?*Cl.* (*Climacograptus*) *venustus venustus* nov. subsp.; Legrand, text-fig. 4*a*.
1976 *Cl.* (*Climacograptus*) cf. *normalis* Lapworth; Legrand (*pars*), text-fig. 4*b* (*non* text-fig. 4*c* = *C. normalis*?).
*non* 1976 ?*Climacograptus* (*Climacograptus*) *venustus venustus* nov. subsp.; Legrand, p. 164, text-fig. 5*a*, *b*.
?1976 *Climacograptus* (*Climacograptus*) *venustus venustus* (*sic* = *venustus venustulus*) nov. subsp.; Legrand, p. 166, text-fig. 6.

*Note.* This species group is about to be renamed by Legrand (in press) to avoid confusion with Hsü's (1959) previously described species.




TEXT-FIG. 8. *Glyptograptus*? '*venustus* cf. *venustus*' (Legrand, 1976). Basal 0·46 m, *G. persculptus* Zone, Linn Branch trench, Dob's Linn, all × 5 except figs. *k*, *l*. *a*, HM C13747/2, complete, tectonically widened specimen (also figured text-fig. 7*f*). *b*, HM C13729/2, distal fragment with long nema. *c*, HM C13738/2, complete specimen with characteristic proximal thickening at base of nema. *d*, HM C13747/1, almost complete specimen with short uniserial distal portion (also figured text-fig. 7*e*). *e*, HM C13722, specimen showing proximal 'notch' below th1$^2$ and typical thecal style. *f*, HM C13747/5, proximal fragment with long virgella. *g*, HM C13747/6, distal fragment. *h*, HM C13738/1, small rhabdosome with long uniserial portion, possibly broken (also figured text-fig. 7*d*). *i*, HM C13747/4, distal fragment with short uniserial portion. *j*, HM C13747/7, complete specimen with thickened nema. *k*, HM C13729/1, long complete rhabdosome, × 2·5. *l*, HM C13747/8, long complete rhabdosome, × 2·5.

*Material.* Over thirty flattened specimens in my collections.

*Horizons and localities.* From 0·2 to 0·46 m above the base of the Birkhill Shale, *G. persculptus* Zone, Linn Branch trench, Dob's Linn.

*Description.* The rhabdosome is up to 40 mm long. It measures 0·8–1·1 mm (0·9 mm undeformed) wide at the aperture of th1[1], widening to 1·2–1·5 mm in 5 mm (1·3 mm undistorted) and reaching the maximum 1·2–1·8 mm (1·5 mm undistorted) in 12 mm. The thecae proximally number ten to twelve in 10 mm (undistorted), reducing distally to eight to ten in 10 mm. The proximal development is unclear, although th1[1] extends some 0·2 mm below the aperture of the sicula before turning up and the proximal end is fairly pointed. Most specimens possess a conspicuous virgella up to 2·5 mm long. The thecae appear intermediate between *Climacograptus* and *Glyptograptus*; the supragenicular walls are inclined to an extent and may be either curved or straight with a sharp geniculum, depending on the orientation of the rhabdosome and relative direction of tectonic stretching. The apertures are normally horizontal or slightly introverted and open into excavations occupying one-quarter to one-fifth the total rhabdosome width. The stipe often becomes uniserial distally, one specimen having a uniserial portion 13 mm long, although this interval is normally shorter. This uniserial development commonly appears to be an astogenetic mutation rather than a post-mortem preservational feature (although this does occur, e.g. text-fig. 7*d*) and is too random to be a normal growth development. A nema often reaching several millimetres long is commonly present.

*Remarks.* This material from the lowest Birkhill Shale has been strongly affected by tectonic distortion, making quantitative measurements unreliable. The specimens described here are slightly longer with shorter virgellae than the type material of *G*? '*v. venustus*', but otherwise agree well both in thecal style and overall form. In his original description Legrand (1976) stated that the main difference between '*C. v. venustus*' and '*C. venustus venustulus*' (misspelt in the original title as '*C. venustus venustus*') was the smaller overall form of the latter subspecies. This criterion would seem unreliable; however, he recorded '*C. venustus venustulus*' to be restricted to the lowest part of the 'Silurian' succession in the Algerian Sahara whilst '*C. v. venustus*' had a far longer range. It is therefore possible that they are true stratigraphical subspecies.

One of the specimens figured by Legrand (1976, text-fig. 4*b*) as '*C.* cf. *normalis*' from the *G. persculptus* Zone of Dob's Linn is evidently identical to those specimens described here, as is the specimen of '?*C. v. venustus*' from the Sahara figured by him (1976, text-fig. 4*a*). His specimen in text-fig. 4*c* is, however, closer to *C. normalis s.s.* The material described by Legrand (1976, p. 164, text-fig. 5*a*, *b*) as '?*C. v. venustus*' is closer to *C. normalis* in thecal style and overall form but has much larger, *Amplexograptus*-like thecal excavations. '*C. venustus* nov. subsp. A' described by Legrand (1976, p. 169, text-fig. 8) has a much narrower, shorter rhabdosome than *G*? '*v. venustus*' and is restricted to a higher part of the succession.

The members of the *G*? '*venustus*' group are clearly distinct from *G. persculptus s.s.* in their general form, thecal style, and prominent virgella and nema. Their generic position is uncertain but they are here assigned questionably to *Glyptograptus* because of 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*. The overall form is similar to *C. normalis* but the thecae of that species have consistently vertical supragenicular walls, conspicuous genicula, and horizontal apertures. I therefore consider that Riva (1981, p. 297) is incorrect in stating that 'there is no clearcut morphological criterion separating these two taxa [*C. normalis* and '*C. v. venustus*'] besides relative width and a longer virgella in the Sahara specimens. A lumping paleontologist might be tempted to expand the diagnosis of *C. normalis* to include *C. venustus venustus*.'

*G*? '*v.* cf. *venustus*' is similar to *G. persculptus* forma B of Koren′ *et al.* (1980) in both form and stratigraphical range, but the latter taxon has more steeply inclined supragenicular walls, is generally wider, and does not show the tendency to develop a distal uniserial portion. *G*? '*v.* cf. *venustus*' also appears similar to *Diplograptus bohemicus* (Marek, 1955) which Koren′ *et al.* (1980) synonymize with their *G. persculptus* forma B. *D. bohemicus* is, however, used by Mu *et al.* (1974) as the top Ordovician zone fossil and I consider that this zone, which also contains *D. orientalis*, correlates with the top of the *P. pacificus* Subzone and the *C*? *extraordinarius* Zone at Dob's Linn (text-fig. 2).

*G*? '*v.* cf. *venustus*' appears to be restricted to the basal 0·46 m of Birkill Shale at Dob's Linn;

although Legrand (1976) recorded '*C. venustus venustulus*' to have a similarly restricted occurrence in the Sahara, he showed that '*C. v. venustus*' ranged longer. '*C. v. venustus*' has been reported recently from the 'basal Silurian' of Percé, Quebec (Lésperance and Sheehan 1981), and of the Gaspé Peninsula (Riva 1981). It therefore seems likely that the *G*? '*venustus*' species group may prove useful in correlating any future-defined Ordovician–Silurian boundary.

## Genus AKIDOGRAPTUS Davies, 1929

*Type species* (by original designation). *Akidograptus ascensus* Davies, 1929, p. 9, text-figs. 22–24.

*Revised diagnosis.* ?*Climacograptus*-like thecae, first two protracted, growing upwards throughout most of their length.

*Remarks.* Bulman (1933, 1936) suggested that th1$^2$ might be lost, but in 1970 (p. V131) stated that the proximal end was 'without definite uniserial portion'. Stein (1965) concluded that development was complete. Rickards (1970) and Hutt (1974) retained *Akidograptus* in the Dimorphograptidae, but three-dimensional specimens from Dob's Linn indicate that proximal development is complete and the genus is therefore here assigned to the Diplograptidae as suggested by Stein (1965). Although *Akidograptus* had not been previously recorded earlier than the Silurian, Li and Ge (1981) recorded a new species *A. antiquus* from the late Ordovician *Tangyagraptus typicus* Zone of China.

### *Akidograptus ascensus* Davies, 1929

Text-figs. 9*f–h*, 10*j–n*

1929 *Akidograptus ascensus* sp. nov. Davies, p. 9, text-figs. 22–24.
1933 *Akidograptus ascensus* Davies; Bulman, p. 16, pl. 3*b*, text-fig. 5.
1934 *Akidograptus ascensus* Davies; Hsü, p. 86, pl. 6, fig. 11*a*, *b*.
1936 *Akidograptus ascensus* Davies; Bulman, p. 25, text-fig. 2*b*.
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, pls. 14*f*, 15*b*, text-figs. 22*a*, *d*, 23*a–c*.
1967 *Akidograptus ascensus* Davies; Obut *et al.*, p. 73, pl. 6, figs. 8, 9.
1971 *Akidograptus ascensus* Davies; Schauer, p. 53, pl. 11, figs. 4–6; pl. 12, figs. 6–10.
?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.
1975 *Akidograptus ascensus* Davies; Bjerreskov, p. 42, text-fig. 13*d*, *e*.
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-fig. 57*a–c*.
1981 *Akidograptus ascensus* Davies; Li and Ge, p. 227, pl. 1, figs. 1–2.

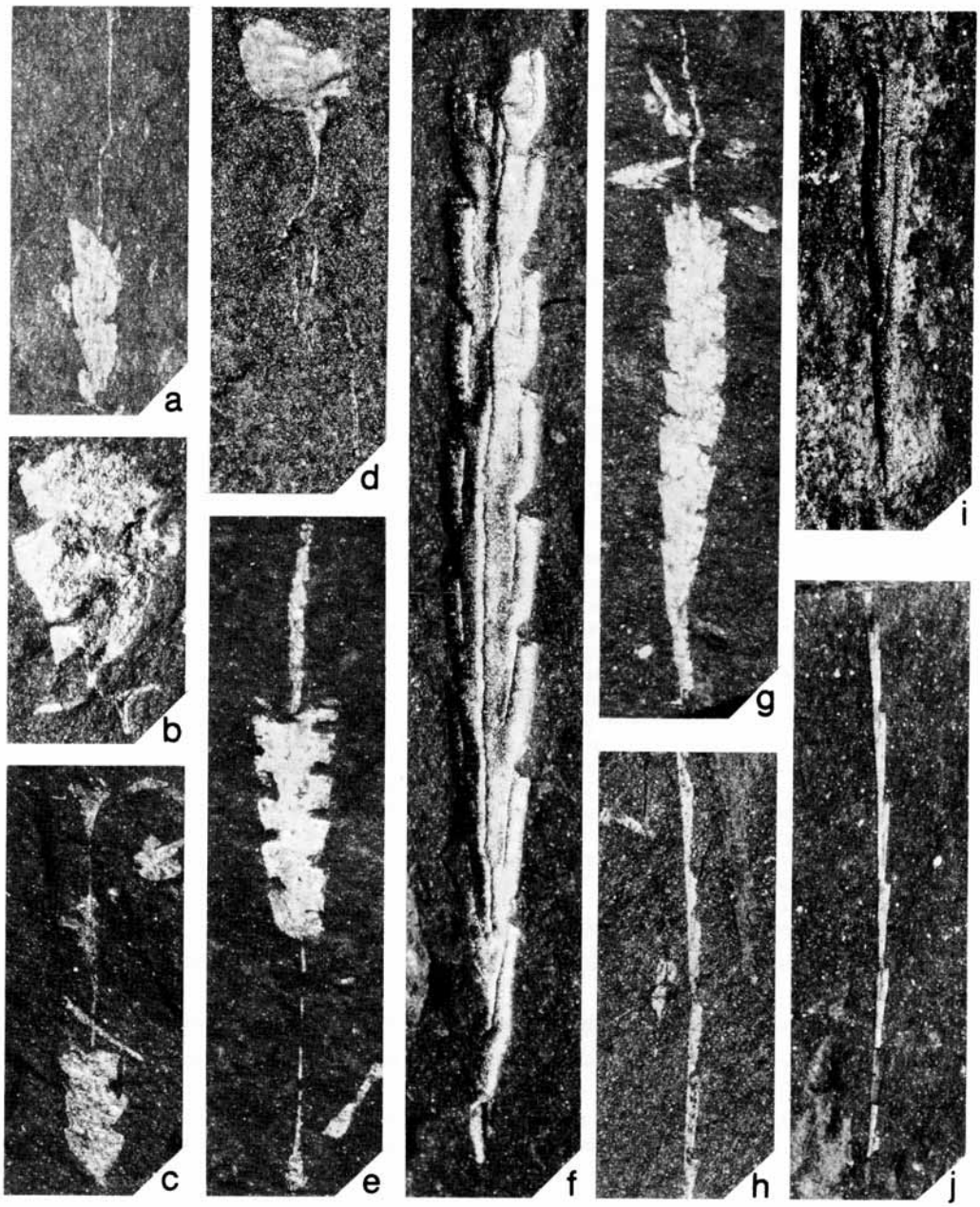
*Holotype.* SM A10021, the specimen figured by Davies (1929, text-fig. 23), from the Birkhill Shale, *P. acuminatus* Zone, Dob's Linn.

*Material.* The type material and about thirty specimens in my collections, mostly flattened but some in relief.

*Horizons and localities.* From 1·6 to 2·3 m above the base of the Birkhill Shale, low *P. acuminatus* Zone, Linn Branch trench, Dob's Linn.

*Diagnosis.* Small rhabdosome up to 1 mm wide with protracted th1$^1$ and 1$^2$. Thecae, numbering about eleven in 10 mm, with almost vertical, straight supragenicular walls, 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 20 mm long with a protracted proximal region 0·2–0·3 mm wide and 2 mm long before the first thecal aperture. The width at the aperture of th1$^1$ is 0·3–0·5 mm, increasing rapidly to the maximum 0·8–1·0 mm in the following 2·5 mm, by the aperture of th4$^1$. The thecae number about eleven in


a
b
c
d
e
f
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j

10 mm. The sicula is exposed for the whole of its 1·3 mm length and commonly possesses a bifurcating virgella. Th1[1] originates from towards the top of the metasicula and grows upwards for the majority of its length. After its presumed initial downward growth it runs sub-parallel to the sicula, then bends 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 axis 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 one-fifth the total width of the rhabdosome. The interthecal septa are straight and terminate above the level of the preceding aperture. A nema is normally present and commonly exceeds 5 mm long.

*Remarks.* The only British species which may be confused with *A. ascensus* are *Parakidograptus a. acuminatus* (Nicholson, 1867) and *P. acuminatus 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 those of *P. acuminatus s.l.* when preserved in slightly oblique orientation. Davies recorded the proximal portion of *P. acuminatus praematurus* to be less protracted than either *P. a. acuminatus* or *A. ascensus*. *P. 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 on diagenetic flattening (Briggs and Williams 1981) and the species is doubtfully referred here to *A. ascensus*. *A. cultus* Mikhaylova, 1973 (*A. ascensus cultus* of Koren′ *et al.* 1980) from the lower Silurian of the U.S.S.R. 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.* (1980) appear to be *A. ascensus s.s.* (e.g. text-fig. 57*b*, *c*) whilst others (e.g. text-fig. 57*a*) look like the forms considered here to represent *A. ascensus* that have suffered greater lateral spread at the apertures. Many similar specimens from the low *P. acuminatus* Zone at Dob's Linn do not conform strictly with the definitions of either *A. ascensus* or *P. a. acuminatus* and considerably more work needs to be done on these forms. Three new species, *A. antiquus*, *A. anhuiensis*, and *A. parallelus* were described by Li and Ge (1981), but translations of the descriptions are needed before any comment may be made concerning their distinctiveness.

Both at Dob's Linn and the Lake District (Hutt 1974) *A. ascensus* is most typical of the lower part of the *P. acuminatus* Zone, where it is associated with *Atavograptus ceryx* (Rickards and Hutt 1970). *A. ascensus* appears to be widespread and is found outside Europe in China (Hsü 1934; Li and Ge 1981) and the U.S.S.R. (Obut and Sobolevskaya 1964). It is the most important species in determining the base of the *P. acuminatus* Zone.

## Genus PARAKIDOGRAPTUS Li and Ge, 1981

*Type species* (by original designation). *Diplograpsus acuminatus* Nicholson, 1867, p. 109, pl. 7, figs. 16, 16*a*.

*Diagnosis* (after Li and Ge). Rhabdosome with protracted proximal development. The sicula is almost completely free on the side of th1[2] and the lower half is free below th1[1], as in *Akidograptus*.

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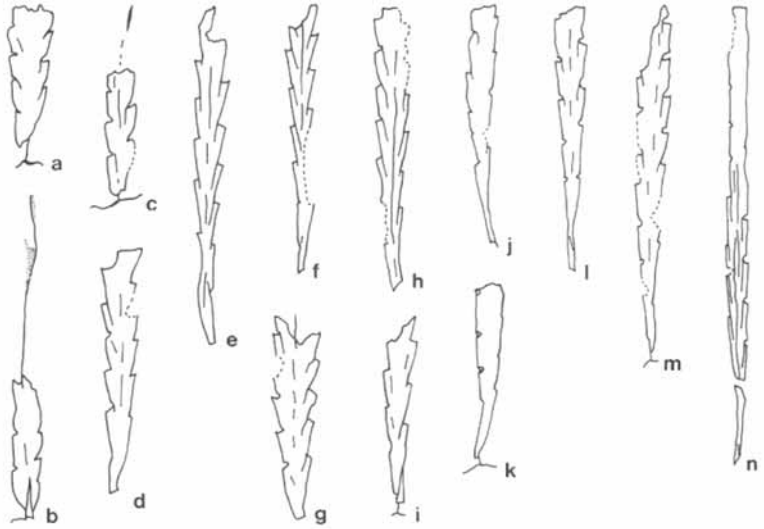
TEXT-FIG. 9. All from the Linn Branch trench, Dob's Linn. *a–c*, *Glyptograptus*? *avitus* Davies, 1929. *G. persculptus* Zone. *a*, HM C13886, juvenile with kinked nema, 1·46–1·56 m, × 10. *b*, HM C13820/1, proximal end with branching virgella, 1·2–1·32 m, × 20. *c*, HM C13892, nema with membranous growths, 1·56–1·66 m, × 10. *d*, *Glyptograptus*?, *avitus* Davies, 1929?, HM C13866, proximal fragment with branching virgella, 1·38–1·46 m, *G. persculptus* Zone, × 20. *e*, juvenile *Climacograptus* sp. (cf. *C. normalis*) with membranous structures on virgella and nema, HM C13808, 1·1–1·2 m, *G. persculptus* Zone, × 10. *f–h*, *Akidograptus ascensus* Davies, 1929, 2·01–2·14 m, *P. acuminatus* Zone. *f*, HM C14003, well-preserved specimen in partial relief, showing development of proximal end in reverse view, × 20. *g*. HM C13998a, with kinked nema and showing proximal development although flattened, × 10. *h*, HM C14002, proximal fragment preserved in relief, in reverse view, × 20. *i*, *j*, *Atavograptus* sp., very narrow distal fragments, *P. acuminatus* Zone, × 20. *i*, HM C13996b, 2·01–2·14 m. *j*, JM C14022, 2·19–2·31 m.




TEXT-FIG. 10. All from the Linn Branch trench, Dob's Linn, ×5. *a–c*. *Glyptograptus*? *avitus* Davies, 1929. *G. persculptus* Zone. *a*, HM C13824/1, with somewhat thickened, forked virgella, 1·2–1·32 m. *b*, HM C13887, nema with membranous growths, 1·46–1·56 m, *c*, HM C13841, juvenile with slightly thickened nema and forked virgella, 1·2–1·32 m. *d–i*, *Parakidograptus acuminatus* (Nicholson, 1867) *sensu lato*, 1·66–1·79 m, *P. acuminatus* Zone. *d*, HM C13939. *e*, HM C13931. *f*, HM C13936. *g*, HM C13934/2, proximal fragment(?) with short first two thecae, similar to *P. acuminatus praematurus*. *h*, HM C13933/1. *i*, HM C13940, fragment showing proximal development and forked virgella. *j–n*, *Akidograptus ascensus* Davies, 1929, *P. acuminatus* Zone. *j*, HM C13925, 1·76–1·91 m. *k*, HM C13980a, showing forked virgella, 2·01–2·14 m. *l*, HM C13956a, in obverse view, showing proximal portion of sicula, 1·88–2·0 m. *m*, HM C13950, 1·88–2·0 m. *n*, HM C13982a, proximally in partial relief, 2·01–2·14 m.

Th1[2] is dicalycal, the median septum is complete. Thecae straight and inclined with simple, everted apertures.

*Remarks*. The erection of a new diplograptid genus with *P. a. acuminatus* as its type species is a reasonable solution to the problem of generic assignment of this species. Neither its position in *Akidograptus*, whose type species *A. ascensus* has a similar proximal development but different thecal style, nor questionably in *Orthograptus*, whose type species *O. q. quadrimucronatus* (Hall, 1865) has a more normal diplograptid proximal development and spinose thecae reinforced by apertural lists, was satisfactory. The many forms intermediate between *A. ascensus* and *P. a. acuminatus s.s.* found during this study (see *P. acuminatus s.l.* description) present a problem owing to distortion caused by both diagenetic and tectonic deformation. However, the erection *Parakidograptus* appears to solve more problems than it creates and it is therefore adopted here.

*Parakidograptus acuminatus* (Nicholson, 1867) *sensu lato*

Text-fig. 10*d–i*

?1867 *Diplograpsus accuminatus* [*sic*] n. sp. Nicholson, p. 109, pl. 7, figs. 16, 16*a*.
?1908 *Cephalograptus*? *acuminatus* (Nicholson); Elles and Wood, pp. 289, 295, pl. 32, fig. 11*a–d*; text-fig. 199.

?1929 *Akidograptus acuminatus* mut. *praematurus* nov.; Davies, p. 10, text-fig. 25.
?1974 *Orthograptus? acuminatus acuminatus* (Nicholson); Hutt, p. 37, pl. 7, fig. 9; text-fig. 9, fig. 11; text-fig. 10, fig. 4.
?1974 *Orthograptus? acuminatus praematurus* (Davies); Hutt, p. 38, pl. 4, fig. 11.
?1981 *Parakidograptus acuminatus* (Nicholson); Li and Ge, p. 229, pl. 1, figs. 8–10.

*Material.* Many flattened fragmentary specimens in my collections.

*Horizons and localities.* From 1·6 to 2·3 m above the base of the Birkhill Shale, low *P. acuminatus* Zone, Linn Branch trench, Dob's Linn.

*Remarks.* The material assigned to *P. acuminatus s.l.* includes several specimens similar in size and overall form to *A. ascensus* but with rather elongate, *Orthograptus*-like thecae (text-fig. 10*d–f*). A few fragments, however, have an apparently less protracted proximal region and a greater maximum width up to 1·4 mm (text-fig. 10*g*). The former specimens have a similar distal thecal style to *P. acuminatus praematurus* but their proximal thecae are more protracted than those of the type specimens which Davies (1929) described from the *G. persculptus* Zone of the Lake District. The latter specimens have a more similar proximal development to this subspecies but have a more robust overall form and different thecal style. Rickards (1970) recorded both '*A.*' *a. acuminatus* and '*A.*' *acuminatus praematurus* to occur together in the '*A.*' *acuminatus* Zone of the Howgill Fells, northern England, but considered that the specimens of '*A.*' *acuminatus praematurus* may have represented a later survival. Toghill (1968*b*, p. 658) recorded '*A.*' *a. acuminatus* to be most common in the middle and upper parts of the '*A.*' *acuminatus* Zone at Dob's Linn.

Previous revisers of *P. a. acuminatus* have ignored the presumably mistaken spelling of the species name in the title of Nicholson's original description. As the spelling with one 'c' has been adopted by later workers and was apparently the version which Nicholson intended it is here adopted.

Li and Ge (1981) erected four new *Parakidograptus* taxa, viz. *P. acuminatus minimus*, *P. angustitubus*, *P. helixiensis*, and *P. huloensis*. Only one specimen of each is illustrated and until translations of the Chinese descriptions are available, comments on their affinities are not possible. *P. a. acuminatus* is a widespread species and has been recorded from the lower Silurian throughout the world.

## Family MONOGRAPTIDAE Lapworth, 1873
## Genus ATAVOGRAPTUS Rickards, 1974

*Type species* (by original designation). *Monograptus atavus* Jones, 1909, p. 531, text-fig. 18*a–d*.

*Diagnosis* (from Rickards 1974, p. 141). Long, slender, usually curved rhabdosome. Long sicula reaching to about the aperture of th1. Thecae generally elongatedly glyptograptid, but in some case strictly glyptograptid or almost monoclimacid.

### *Atavograptus ceryx* (Rickards and Hutt, 1970)

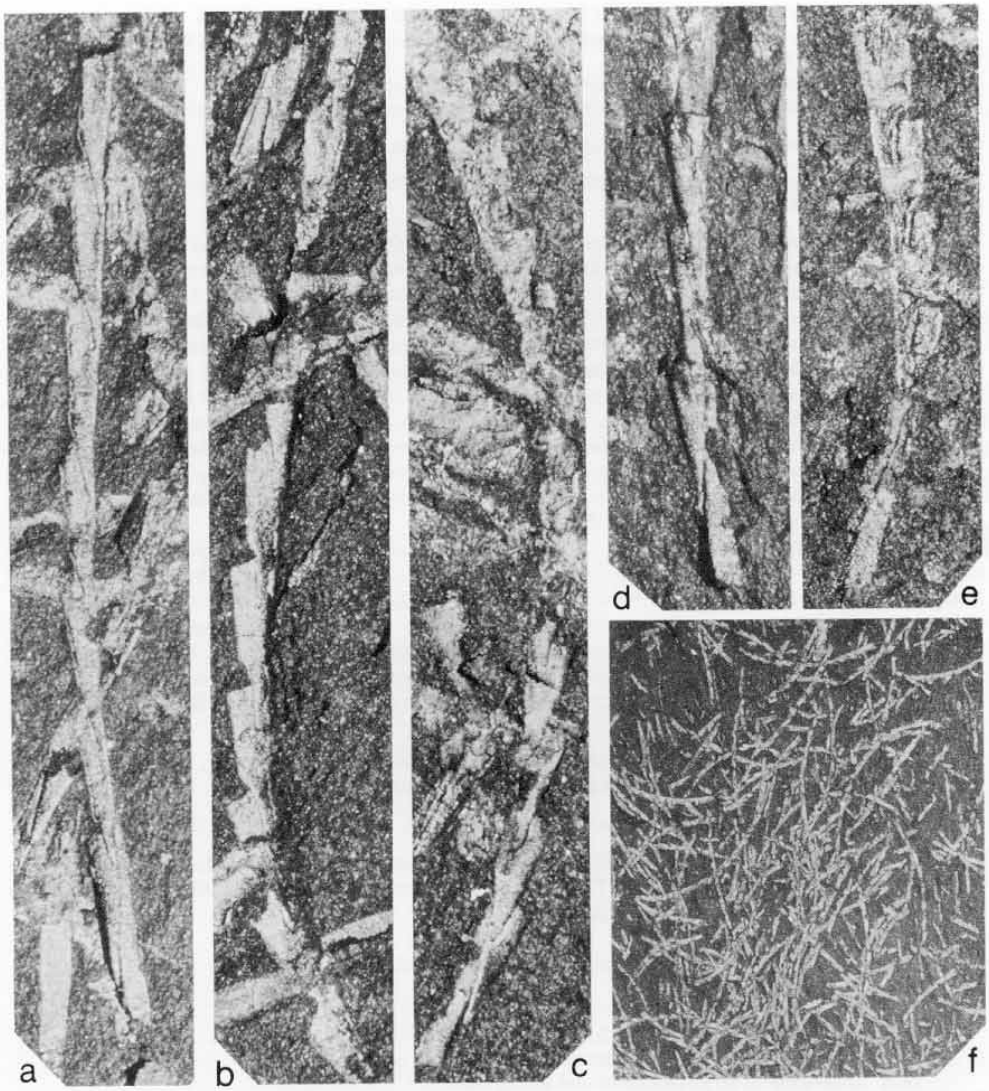
Text-fig. 11*a–f*

1970 *Monograptus ceryx* sp. nov. Rickards and Hutt, p. 117, text-figs. 1*a–d*, 2*a*.
1974 *Atavograptus ceryx* (Rickards and Hutt) Rickards, pl. 9, fig. 4.
1975 *Atavograptus ceryx* (Rickards and Hutt); Hutt, p. 63, pl. 11, fig. 7.

*Holotype.* SM A67087, the specimen figured by Rickards and Hutt (1970, text-fig. 2*a*), from the Skelgill Beds, *G. persculptus* Zone, Yewdale Beck, Coniston, Lake District.

*Material.* Many specimens, preserved both flattened and in relief, in my collections. Most occur as crowded fragments on two bedding planes.

*Diagnosis* (after Rickards and Hutt 1970). Rhabdosome short with pronounced dorsal curvature, dorsoventral width 0·2 mm proximally to 0·3 mm distally. Sicula 1·5 mm long, apex reaching just above the level of the aperture of th1. Thecae with gentle sigmoidal curvature, horizontal to very slightly everted apertures, numbering thirteen to fifteen in 10 mm.




TEXT-FIG. 11. *Atavograptus ceryx* (Rickards and Hutt, 1970). 2·0–2·14 m, *P. acuminatus* Zone, Linn Branch trench, Dob's Linn. All × 20 except *f*. *a*, HM C13993/1a. *b*, HM C14009/3a. *c*, HM C14010/1b. *d*, HM C14009/1a. *e*, HM C14010/2a. *f*, HM C14010/1–nb, general view of slab, × 2·5.

*Description*. Most specimens are less than 5 mm long and possess a slight dorsal curvature. They increase slightly in width from an average 0·2 mm at the aperture of th1 to a maximum of 0·3 mm when not tectonically deformed. A thecal count is impractical because of the short stipes, but the distance between successive thecal apertures varies from 0·06 to 0·1 mm, depending on tectonic stretching and position along the stipe. This gives a thecal count of ten to sixteen in 10 mm. When undistorted the figure is nearer the thirteen to fifteen in 10 mm recorded by Rickards and Hutt (1970). The sicula is approximately 1·5 mm long (cf. 1·3–1·4 mm recorded by Rickards and

Hutt). Th1 appears to bud 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 dorsoventral 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 half the total stipe width. Slight genicula are seen when the stipes are preserved in dorsoventral orientation but the supragenicular walls appear straight and uniformly sloping when specimens are obliquely oriented. 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 similar to the type material of *A. ceryx* from the English Lake District and can definitely be assigned to this species. The thecal style appears similar to the distal thecae of *Akidograptus ascensus*, whilst Rickards and Hutt (1970) believed that *A. ceryx* could have been derived from a *Glyptograptus* ancestor. It is therefore possible that both *Akidograptus ascensus* and *Atavograptus ceryx* were derived from *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). Rare, unidentifiable fragments of a much narrower *Atavograptus* also occur in the *P. acuminatus* Zone at Dob's Linn (text-fig. 9*i*, *j*).

*A. ceryx* was first recorded by Rickards and Hutt (1970) from the *G. persculptus* Zone of the Lake District, but was later found by Hutt (1975) to occur also in the basal 0·6 m of the *P. acuminatus* Zone in the Skelgill Beds associated with *A. ascensus*; Hutt (1974) defined the base of the *P. acuminatus* Zone in the Lake District on the same criteria used in this work at Dob's Linn (i.e. principally on the first occurrence of *A. ascensus*) and I consider that the occurrence of *A. ceryx* in the low *P. acuminatus* Zone in both parts of Britain is contemporaneous. *A. ceryx* has not yet been recorded from outside Britain, although Rickards (1976*a*, p. 158) recorded that Sennikov (pers. comm.) had obtained a similar monograptid from the *P. acuminatus* Zone of the Altai Mountains, U.S.S.R.

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S. HENRY WILLIAMS
Paleontologisk Museum
Universitetet i Oslo
Sarsgate 1
Oslo 5
Norway

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