THE GRAPTOLITE ASSEMBLAGES AND ZONES OF THE BIRKHILL SHALES (LOWER SILURIAN) AT DOBB'S LINN

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ABSTRACT. The graptolite assemblages and lithologies of the Birkhill Shales (Lower Silurian) at Dobb's Linn are described. The condensed 141 ft. (43 m.) euxinic sequence is divided into eight graptolite zones in descending order: *Rastrites maximus*, *Monograptus sedgwickii*, *M. convolutus*, *M. gregarius*, *M. cyphus*, *Cystograptus vesiculosus*, *Akidograptus acuminatus*, and *Glyptograptus persculptus*. These zones are compared with the original work of Lapworth (1878), and with equivalent zones elsewhere in Great Britain. The base of the Middle Llandovery at the type locality for the graptolitic Llandovery (Valentian) is taken at the base of the *gregarius* Zone (*triangulatus* Zone in Wales), and not at the base of the *magnus* Zone, as is the current practice in Wales.

THE classic locality of Dobb's Linn, and the surrounding Moffat area, have been left relatively untouched by research workers since the admirable account of Lapworth (1878).

Because of the lack of new information from the Moffat area, recent reviews of Southern Uplands geology (Walton 1963, 1965) have had to discuss the Llandovery geology of the area using information obtained in, and unaltered since, the late 1800s, and thus their discussions are rather speculative. The present work does not, however, suggest any major errors by Lapworth. It is only the application of knowledge obtained since 1878 which has allowed alterations and additions to his classic results. The foundation for a Llandovery graptolite zonal scheme was laid down by Lapworth (1878, 1880), and his original research was quickly followed up in the Lake District by Marr and Nicholson (1888). Table 2 is a correlation of the large number of zonal schemes which have been used in Great Britain for the Llandovery (Valentian) up to the base of *turriculatus* Zone. The most recent scheme given by Curtis (1961) is in fact a compilation of most zones recognized in Wales, and based on the original research of O. T. Jones (1909), and Jones and Pugh (1916, 1935). The present work reappraises the graptolite fauna of the condensed 141 ft. (43 m.) euxinic Birkhill Shale sequence at the type locality, redefines the Llandovery graptolite zones exposed at Dobb's Linn, and compares them with equivalent zones elsewhere. The condensed sequence at Dobb's Linn is almost completely fossiliferous and thus is the most suitable place to define Llandovery graptolite zones, not only because it is the type locality for the graptolitic Llandovery (Valentian) but also because the equivalent sequence in Wales is a thick series (1,000 ft.) of coarse sediments in which the graptolite horizons are separated by considerable thicknesses of unfossiliferous strata (Jones 1909, p. 504).

POSITION OF SECTIONS

Dobb's Linn lies 10 miles north-east of Moffat, and at the head of the Moffat Water. A complicated isoclinal fold structure, with Caledonoid trend, brings the graptolitic condensed sequence of Moffat Shales (Caradoc–Llandovery) to the surface from below

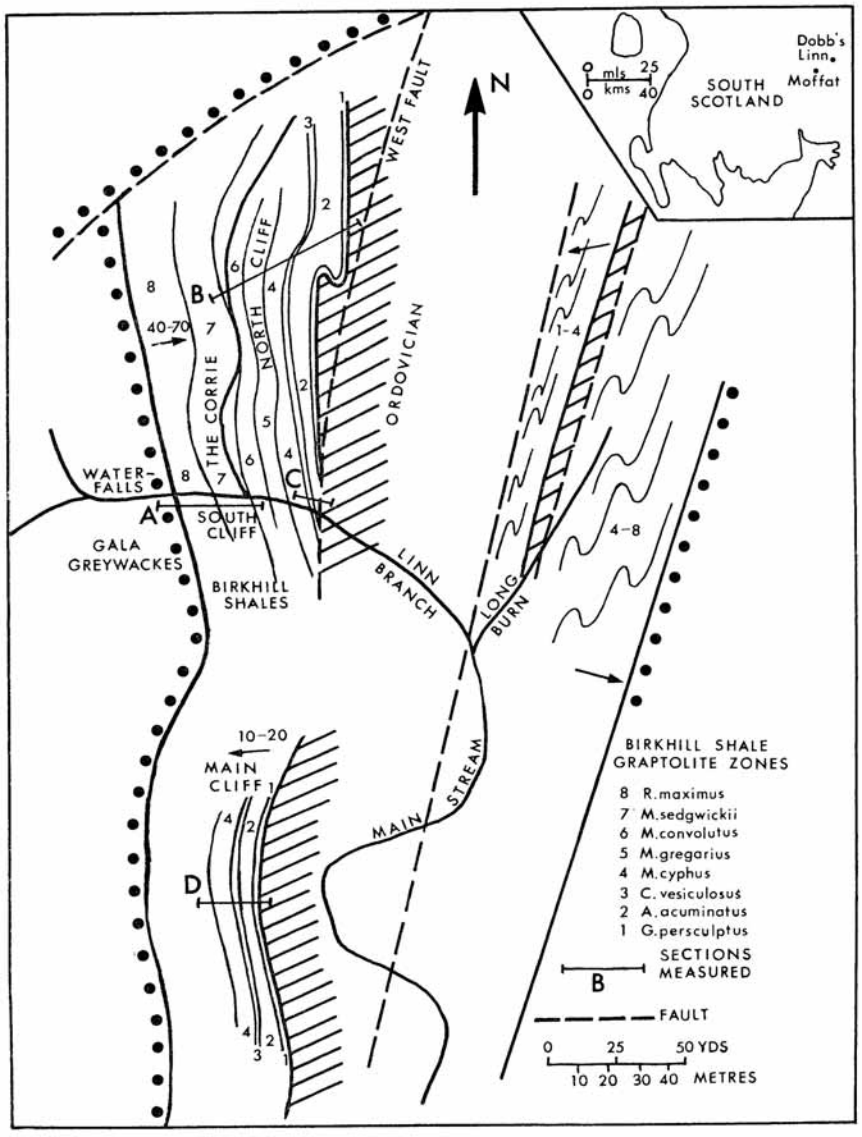
[Palaeontology, Vol. 11, Part 5, 1968, pp. 654–68.]

the overlying Gala Greywackes (Upper Llandovery). This work is only concerned with the highest (Birkhill) division of the Moffat Shales, from the base of the Silurian (*persculptus* Zone) up into the *maximus* Zone of the Upper Llandovery.

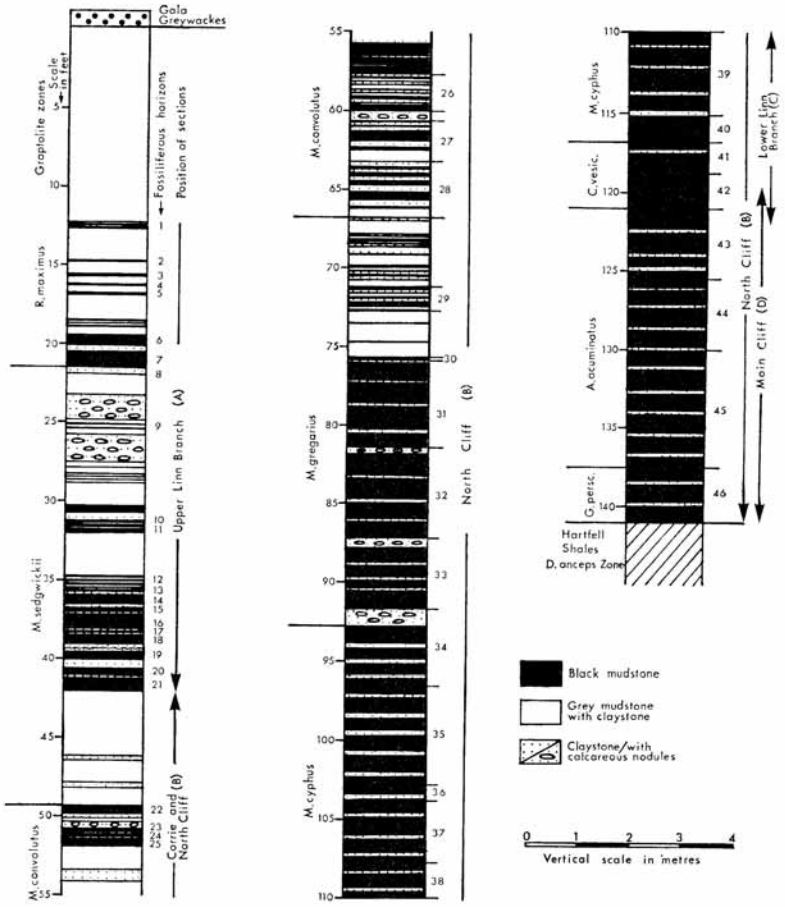
The south-east limb of the fold is highly contorted and no detailed measurements are possible. The north-west (inverted) limb however shows an excellent section of the Birkhill Shales, particularly in the Linn Branch, and on the North and Main Cliffs (text-fig. 1). A large waterfall has developed in the Linn Branch at the junction of Gala Greywackes and Birkhill Shales, and below this all but the lowest beds of the Birkhill Shales are exposed, the beds being inverted and dipping downstream at between 40° and 70°. The basal beds are cut out by a strike fault, and there is also a considerable amount of strike faulting in the *convolutus*, *gregarius*, and upper *cyphus* Zones. The Corrie and North Cliff show a continuous section from the lower *sedgwickii* Zone down to the base of the Silurian with little or no strike faulting. The Main Cliff (text-fig. 1) provides an excellent section across the Ordovician–Silurian boundary, and is by far the best place for measuring up the basal beds of the Birkhill Shales. Using these sections a detailed lithological sequence (text-fig. 2) has been worked out for the Birkhill Shales. Descending from the Gala Greywackes, the *maximus* and *sedgwickii* Zones have been measured up in the Upper Linn Branch (section A, text-fig. 1). Conspicuous lithological horizons in the lower *sedgwickii* Zone then allowed the section to be transferred to the Corrie and North Cliff (section B, text-fig. 1) where the remainder of the sequence was measured down to the base of the *persculptus* Zone. The lower part of the North Cliff section (*persculptus* to *cyphus* Zones) was correlated with, and supplemented by, collections from the Lower Linn Branch section (C) in the *cyphus*, *vesiculosus* and upper *acuminatus* Zones, adjacent to the West Fault, and the Main Cliff section (D) in the *persculptus*, *acuminatus* and *vesiculosus* Zones.

THE LITHOLOGIES OF THE BIRKHILL SHALES

Three main lithological types are present: massive black pyritic graptolitic mudstone, massive barren grey mudstone, and beds of soft, pale grey to orange, clay-like deposits. Lapworth (1878) referred to this latter conspicuous lithology under a variety of names including, 'white clay bands', 'soft shaly clay', and 'white lines', but the term claystone has recently been applied to these deposits by Walton (1965, p. 185). These beds, which often contain lines of calcareous nodules, weather out very easily and may be of volcanic origin (Walton 1963, pp. 85, 89; 1965, p. 185). This lithology makes up a large proportion of the Birkhill Shales and also occurs in the underlying Hartfell Shales, and persists into the Gala Greywackes. If volcanic in origin it indicates a period of vulcanicity from the Caradoc into the Upper Llandovery. The lower 65 ft. of the succession is made up of alternations of black mudstone and pale soft claystone, with occasional nodule bands, but without any grey mudstone at all. These lower Birkhill Shales follow directly on top of grey mudstones of the Hartfell Shales. The black mudstones are generally between 3 in. and 1 ft. thick and the intervening claystones are usually between 1 in. and 3 in. thick, but occasionally up to 1 ft. Within the upper *acuminatus*, *vesiculosus*, and lower *cyphus* Zones is a conspicuous 10-ft. thickness of massive black mudstone with very few claystones. These massive beds, Lapworth's *vesiculosus* Flags, are a conspicuous unit of the lower Birkhill Shales well exposed in the Lower Linn Branch. The upper 76 ft. of



TEXT-FIG. 1. Locality map of Dobb's Linn, showing position of sections.



TEXT-FIG. 2. Vertical section through the Birkhill Shales, showing the position of fossiliferous horizons, etc. Although an attempt has been made to indicate the frequency of claystones, the section is diagrammatic, particularly below 55 ft. The positions of all nodular claystones, and of individual fossiliferous beds above 55 ft. are precise.

the Birkhill Shales is made up of alternations of grey and black mudstones, varying in thickness from mere bedding plane bands to beds of 1 ft., and many soft claystones with occasional nodule bands. The inter-relationships of grey and black mudstones are shown in text-fig. 2. The highest graptolitic horizons in the Birkhill Shales (*maximus* Zone) occur as thin bands $\frac{1}{8}$ in. to 1 in. thick in a dominantly grey mudstone sequence. About 12 ft. above the highest black band the first greywacke appears in the Upper Linn Branch,

below the waterfall. It is 6 in. thick and is taken as the base of the Gala Greywackes, as indicated by Lapworth (1878, p. 322). This bed is followed by 14 ft. of massive grey mudstones, thin greywackes, and claystones, before the massive greywackes at the base of the waterfall are reached.

From the above description, and from text-fig. 2, it can be seen that within the Birkhill Shales there is a gradual change from the exclusively euxinic facies of the lower Birkhill Shales, through the grey and black mudstones of the *convolutus* and *sedgwickii* Zones, into the dominantly grey mudstones of the *maximus* Zone, and finally into greywacke facies. Throughout the Moffat area the base of the Gala Greywackes has been found to be highly diachronous, and this will be further explained when describing the fauna of the *R. maximus* Zone.

THE CHARACTERISTIC GRAPTOLITE FAUNA OF THE BIRKHILL SHALES

The various graptolite zones have been divided up into fossiliferous horizons (1–46) which are indicated on text-fig. 2. The detailed fauna of any horizon can be ascertained from Table 1.

Zone of Glyptograptus persculptus

This zone is well exposed on the Main Cliff (section D, text-fig. 1), but is less accessible at the top of the North Cliff (base of section B). On the Main Cliff the black mudstones of the Birkhill Shales follow barren grey mudstones of the *anceps* Zone of the Hartfell Shales. The highest fossiliferous band with *D. anceps* is approximately 10 ft. below the base of the Birkhill Shales. The *persculptus* Zone (horizon 46, text-fig. 2) comprises $3\frac{1}{2}$ ft. (1·06 m.) of black mudstone with thin claystones. The mudstones are often weathered to a drab grey colour and the fauna is then extensively destroyed. At the base of the zone is a 4-in. bed crowded exclusively with *Climacograptus scalaris normalis*. The remainder of the zone is characterized by this species with the zone fossil, and *Climacograptus medius*, *C. scalaris miserabilis* and *Diplograptus modestus s.l.*

Zone of Akidograptus acuminatus

$16\frac{1}{2}$ ft. (5·0 m.) of black mudstones with many thin claystones are assigned to this zone (horizons 43–5). It is best exposed on the Main Cliff (section D), but the highest beds are well exposed in the Lower Linn Branch (section C). The whole zone is exposed on the North Cliff (section B) but is rather inaccessible. The lower part of the zone weathers in a similar fashion to the *persculptus* Zone, but the highest beds are hard and massively bedded, and form the lowest part of Lapworth's *vesiculosus* Flags.

The base of the zone is marked by the appearance of *Akidograptus* and the zone is characterized by *A. acuminatus s.l.* and *A. ascensus*, neither of which occur outside the zone. The latter occurs commonly before the main burst of *A. acuminatus*, which commences in the middle of the zone. *Glyptograptus persculptus* is common in the lower part and *Climacograptus trifilis* in the middle of the zone. *Cystograptus vesiculosus* appears in the middle and is common at the top of the zone, and *Diplograptus modestus* occurs throughout. *Climacograptus scalaris normalis* and *C. medius* are common throughout, and *C. rectangularis* appears in the upper part.

Zone of Cystograptus vesiculosus

This zone is represented by 4 ft. 3 in. (1·3 m.) of massive black mudstone with a few claystones (horizons 41–2), and is best exposed in the Lower Linn Branch (section C). The base is marked by the most conspicuous horizon in the whole of the Silurian, the appearance of the Monograptidae, together with *Dimorphograptus* and *Rhaphidograptus*. The zone is characterized by the earliest monograptids, with the zone fossil, and dimorphograptids with long uniserial portions: *D. elongatus* and *R. extenuatus*. One particular bedding plane at the base of the zone is crowded with *Monograptus cyphus praematurus* Toghill (1968), which with *M. atavus* Jones is the earliest monograptid. The latter is common throughout the zone and occurs in the upper part with *M. acinaces* and *M. incommodus*. *Climacograptus innotatus* appears at the base of the zone and occurs throughout as does *Diplograptus modestus s.l. Glyptograptus tamariscus s.l.* appears and climacograptids are abundant including *C. medius*, *C. rectangularis*, and *C. scalaris normalis*.

Zone of Monograptus cyphus

This zone is represented by 24 ft. (7·3 m.) of massively bedded black mudstones with yellow and orange claystones, which are rare towards the base. The zone (horizons 34–40) has been measured up in the Lower Linn Branch (section C) and on the North Cliff (section B). The higher parts of the zone in the Lower Linn Branch are extensively strike-faulted. The overlying *gregarius* Zone has at its base a most conspicuous 1 ft. claystone with large calcareous nodules, and this, the lowest nodular claystone, is well exposed on the North Cliff.

At the base of the zone dimorphograptids with short uniserial portions appear, including: *D. confertus*, *D. confertus swanstoni*, *D. erectus*, *D. decussatus s.l.*, and *D. longissimus*. Of these the first three are the commonest, and the first two persist into the upper parts of the zone. *D. physophora* is rare but probably occurs throughout as does *Rhaphidograptus toernquisti*. *Monograptus cyphus* is rare at the base of the zone but soon becomes abundant and ranges throughout the zone as do *M. sandersoni*, *M. incommodus*, *M. atavus*, and *M. acinaces*. *M. gregarius* and *M. revolutus* appear in the middle of the zone and are common at the top. *Cystograptus vesiculosus* and *Climacograptus innotatus* are limited to the basal beds where the latter is common. *Climacograptus medius* and *C. rectangularis* are abundant in the lower part of the zone, but do not reach the top, and neither does *C. scalaris normalis*. *Glyptograptus tamariscus s.l.* occurs throughout the zone.

Zone of Monograptus gregarius

26 ft. (7·9 m.) of strata are assigned to this zone (horizons 29–33) as measured on the North Cliff (section B). Black mudstones with thick nodular claystones occupy the lower 18 ft. but these grade upwards into banded grey and black mudstones with many claystones.

The base of the zone is marked by the appearance of *Monograptus triangulatus s.l.* which occurs throughout the zone and is particularly common in the lower part. *M. gregarius* and *M. revolutus* occur throughout the zone, but *M. sandersoni*, *M. incommodus*, and *M. atavus* are limited to the lower part. *M. communis* is characteristic of the upper part of the zone, and *Rastrites longispinus* and *R. peregrinus* appear in the middle.

A conspicuous horizon (30) 8 ft. from the top of the zone yields abundant specimens of *Monograptus fimbriatus* with many petalograptids, including *Petalograptus minor*, *P. palmeus latus*, *P. palmeus ovato-elongatus*, as well as a few specimens of *Diplograptus magnus*. This is the only horizon with *D. magnus* and *M. fimbriatus*, and the main burst of the latter occurs above that of *M. triangulatus s.l.*, as suggested by Sudbury (1958). This horizon is presumably equivalent to the *magnus* Band in Wales, although here it is only 3 in. thick. The unfossiliferous beds (text-fig. 2) which overlie horizon 30 but underlie the highest fossiliferous horizon (29) of the *gregarius* Zone might be considered part of the *magnus* Zone. This 3-ft. thickness of beds compares with 27 ft. assigned to the *magnus* Zone in Wales, although there the actual *magnus* Band at the base is only 6 in. thick (Jones and Pugh, 1935, p. 275), the remainder of the zone being relatively unfossiliferous.

In horizon 29 *Monograptus leptotheca* is common, *M. denticulatus* appears, and this is the only horizon with *M. argenteus*. It can be equated with the *argenteus* Zone of the Lake District (Marr and Nicholson 1888), and the *leptotheca* Zone of Wales, which are here considered to be equivalent. *M. argenteus* in abundance seems to be restricted to the Lake District, its place in Wales and Scotland being taken by *M. leptotheca*.

Zone of Monograptus convolutus

The foot of the North Cliff (section B) provides an excellent section of this zone (horizons 22–8) which is 17½ ft. (5·35 m.) thick and made up of two groups of highly fossiliferous black mudstones with claystones separated by barren grey mudstones and claystones (text-fig. 2). The upper group of fossiliferous beds (horizons 22–5) is, in fact, Lapworth's original *clingani* Band, and the lower group his *cometa* Zone. The detailed fauna of any horizon can be ascertained from Table 1.

Faunally the base of the zone is marked by the appearance of *Monograptus lobiferus* in abundance, with *M. convolutus*. The former is limited to the basal beds of the zone but the latter persists, with *M. clingani*, throughout the zone and is found as high as the lower *maximus* Zone. *M. triangulatus*, *M. communis*, and *M. leptotheca* are all present in the basal beds, but *M. gregarius* has disappeared. Cephalograptids, and petalograptids with protracted proximal ends are characteristic including in the lower part, *Petalograptus folium* and *Cephalograptus tubulariformis*, and *C. cometa* in the upper part of the zone. Rastritids are common and include *R. hybridus*, *R. peregrinus*, *R. longispinus*, and *R. approximatus geinitzi*. In the higher group of black mudstones the following monograptids are common: *M. clingani*, *M. limatulus*, *M. crenularis*, *M. convolutus*, and *M. decipiens*, together with *Cephalograptus cometa*, *Glyptograptus tamariscus incertus*, and *Orthograptus bellulus*. Of these species *M. crenularis* is very typical of the upper *convolutus* Zone.

Zone of Monograptus sedgwickii

27½ ft. (8·4 m.) of strata are assigned to this zone (horizons 8–25) which is best exposed in the Upper Linn Branch (section A), and the Corrie under the North Cliff (section B). Lithologically the zone can be divided into three units. A lower 7 ft. of barren grey mudstones with claystones, best seen in the Corrie; a middle 6 ft. of fossiliferous black mudstones with claystones (horizons 14–21) exposed in the Corrie and Upper Linn Branch; and an upper 14½ ft. of grey mudstones with claystones and a few fossiliferous

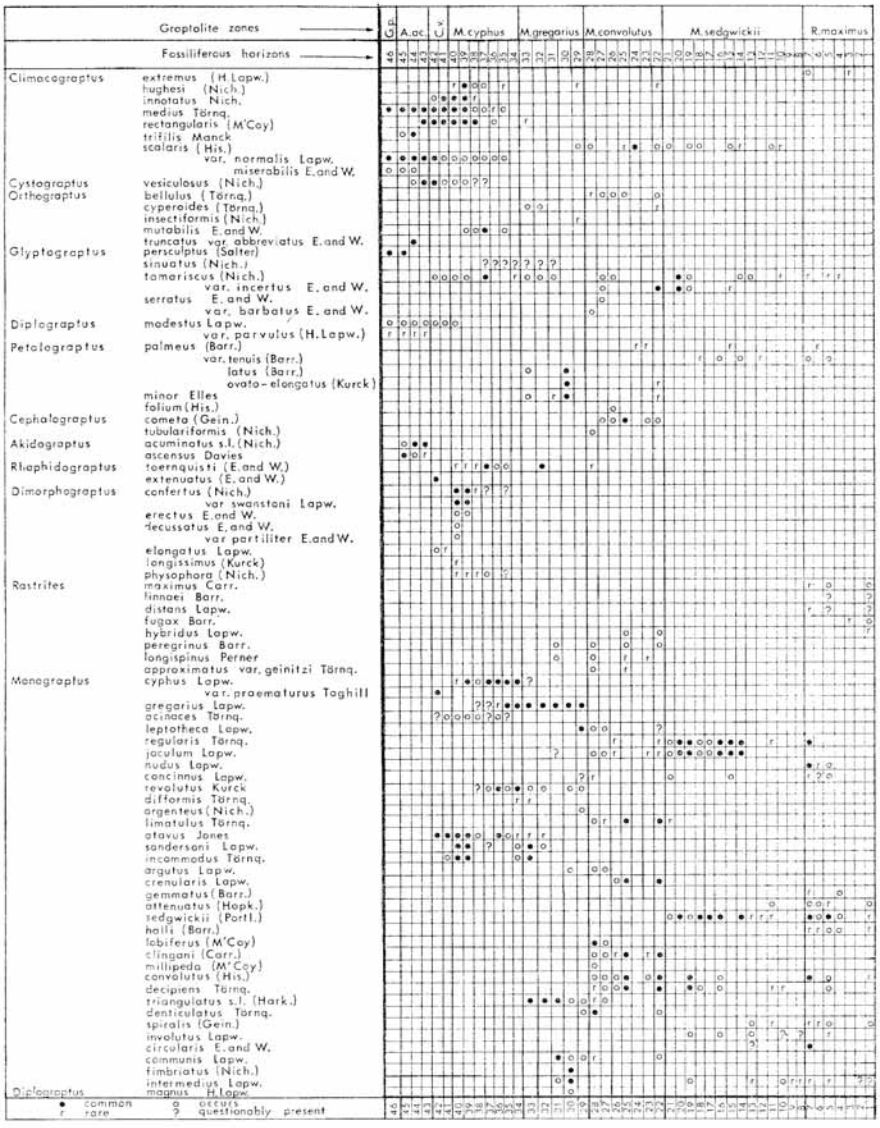


TABLE 1. The vertical distribution of the Graptoloidea in the Birkhill Shales at Dobb's Linn.

black seams (horizons 8–13) exposed in the Upper Linn Branch. The middle unit is characterized by an abundance of *Monograptus sedgwickii*, *M. regularis*, and *M. jaculum*., with triangulate monograptids in the lower part, including *M. convolutus*, *M. involutus*, and *M. decipiens*. Glyptograptids are common and *Petalograptus palmeus tenuis* occurs with *Climacograptus scalaris*. The upper 14½ ft. contain a similar but poorer fauna in which *M. spiralis* and *M. attenuatus* appear.

Zone of Rastrites maximus

The highest 21½ ft. (6·55 m.) of the Birkhill Shales is assigned to this zone. Grey mudstones and claystones predominate, and grade up into the Gala Greywackes, the base of which is taken at the first greywacke seen in the Upper Linn Branch (section A), as indicated by Lapworth (1878, p. 322). Black mudstones are restricted to the lowest 9 ft. Seven separate fossiliferous horizons occur, and of these the two lowest yield a large fauna (Table 1). In these basal beds *Monograptus sedgwickii*, *M. regularis*, *M. nudus*, *M. convolutus*, and *M. circularis* are common, but the latter two species only occur commonly on one particular bedding plane. These common species occur with *M. spiralis*, *M. attenuatus*, *M. gemmatus*, *M. decipiens*, *M. intermedius*, *Climacograptus extremus*, and *Petalograptus palmeus tenuis*. At this lower level *Rastrites maximus* and *M. halli* are rare.

The highest fossiliferous horizon of the Birkhill Shales at Dobb's Linn is a 4-in. composite band of four black mudstones up to 1 in. thick separated by thin claystones. It yields *Rastrites maximus*, *R. fugax*, *R. linnaei*?, *R. distans*?, *R. hybridus*, *Monograptus halli*, *M. sedgwickii*, *M. convolutus*, *M. spiralis*, and *M. intermedius*.

Owing to the diachronism of the overlying Gala Greywackes (see below), higher horizons not represented by fossiliferous strata at Dobb's Linn, but occurring south east of the Caledonoid strike line through Dobb's Linn, are characterized by the following common species: *Rastrites maximus*, *Monograptus halli*, and *M. spiralis*, with *M. runcinatus*, *M. nudus*, and *M. turriculatus minor*.

THE LLANDOVERY GRAPTOLITE ZONES AT DOBB'S LINN

The graptolite zonal scheme used here has been arrived at by considering the original scheme of Lapworth (1878, 1880), as modified by Elles and Wood (1913), and the large number of schemes erected in Wales by Jones (1909), Jones and Pugh (1916), Davies (1926), and others, as summarized by Curtis (1961). Table 2 shows an attempted correlation between the zones used here, and other schemes used elsewhere.

The *Glyptograptus persculptus* Zone was defined at Dobb's Linn for the first time by Toghill (1968), although the species was first recorded from there by Davies (1929). The validity of the zone is emphasized by the absence of *Akidograptus*, which does not appear until the overlying *acuminatus* Zone.

The *Akidograptus acuminatus* Zone as defined here is approximately the same as defined by Lapworth (1878, pp. 250, 252, 318–20), although the basal beds have been separated off as the *persculptus* Zone.

The base of the *Cystograptus* [*Orthograptus*] *vesiculosus* Zone has been taken at the incoming of the monograptids, as suggested by Elles (1925, p. 344). The restricted thickness (4 ft. 3 in.) used here is only the lower part of the zone as originally

defined by Lapworth (1878, pp. 250, 252, 319–20), but the zone has been strictly defined on the ranges of the earliest monograptids, as given by Elles (1925), and dimorphograptids. The fact that the zone is so thin compared with the 16 ft. assigned to it by Lapworth is due to the more precise fixing of monograptid ranges, particularly those of *M. cyphus*, *M. sandersoni*, *M. incommodus*, and *M. atavus*. Lapworth (1878, p. 319) did not give a very detailed monograptid fauna from his *vesiculosus* Zone and lower *gregarius* Zone, recording only *M. 'tenuis'* and *M. attenuatus* from the *vesiculosus* Zone, and of course *M. incommodus* and *M. atavus* were not described until later. Elles (1925) did not give any thicknesses for the *vesiculosus* Zone, and thus this is the first time that the zone has been defined at Dobb's Linn (the type locality) using a comprehensive monograptid fauna. The monograptid ranges agree with Elles's definition of the zone (1925), but she recorded *Dimorphograptus confertus* and *D. confertus swanstoni* as being characteristic of the *vesiculosus* Zone. These are here taken as indicating the base of the overlying *cyphus* Zone together with the appearance of *M. cyphus* and *M. sandersoni*.

Thus, the *vesiculosus* Zone as used here is only the lower part of the zone as defined by Lapworth (1878), Elles and Wood (1913), and Elles (1925). It is probably equivalent to the *atavus* Zone in Wales (Jones 1909, Curtis 1961). The *cyphus* Zone includes the remainder of Lapworth's *vesiculosus* Zone and part of his *gregarius Zone*. It is equivalent to the *cyphus* and *acinaces* Zones in Wales (Jones, 1909). From Table 1 it can be seen that the ranges of *M. atavus* and *M. acinaces* are almost identical, the former having the larger range, and the latter occurs, in the later part of its range, with *M. cyphus*. Although the *vesiculosus* Zone as defined here is equivalent to the *atavus* Zone in Wales, the former title is preferred on historical grounds, Dobb's Linn being the type locality.

The *M. gregarius* Zone as defined here is equivalent to the *triangulatus*, *magnus*, and *leptotheca* Zones in Wales (Curtis, 1961). The base is taken at a conspicuous faunal horizon, the appearance of triangulate monograptids, and is probably the base of Lapworth's Upper Division of his *gregarius* Zone (1878, pp. 319, 321), where he records *M. triangulatus* 'in profusion'. The main horizon (29) with *M. leptotheca* is only 1 ft. thick, and that (30) with *Diplograptus magnus* only 3 in. thick. The former horizon contains *M. argenteus* and is presumably equivalent to the *argenteus* Zone in the Lake District. *M. triangulatus s.l.* ranges right through the *gregarius* Zone as defined here as does the zone fossil, and the title *gregarius* Zone is preferred on historical grounds, although it must be noted that it is equivalent to the *triangulatus s.l.* Zone of W. D. V. Jones (1945). Jones and Pugh (1935, pp. 275, 276) stated that the *magnus* Zone was made up of 27 ft. of mainly unfossiliferous strata with a 6-in. *magnus* Band at the base. Similarly the *leptotheca* Zone was given as 20 ft. of relatively unfossiliferous beds with a 2½-ft. *leptotheca* Band at the base. The practice of erecting zones based on thin graptolite bands separated by barren strata is not considered correct, particularly as one has no idea of the fauna of the intervening beds. Although the horizons with *M. leptotheca* and *Diplograptus magnus* at Dobb's Linn provide direct correlation with the sequence in Central Wales, they should only be regarded as bands and not zones.

Dr. R. B. Rickards records (*in litt.*) that the lithologies and faunas at the level of the *gregarius* Zone in the Howgill Fells (eastern Lake District) are very similar to Dobb's Linn. He recognizes the three zones *triangulatus*, *magnus*, and *argenteus* (*leptotheca*), and reports that there is a marked lithological change from black to grey mudstones at the level of the *magnus* Zone, a state of affairs comparable with the sequence at Dobb's Linn

Birkhill (Lower Valentian)	C. Lapworth 1878	Marr and Nicholson 1888	H. Lapworth 1900	Elles 1909	Jones 1909	Elles and Wood 1913	Jones and Pugh 1916	Jones 1921	Davies 1926	Jones 1929	Jones and Pugh 1933	W.D.V. Jones 1945	Jones 1947	Curtis 1961	This paper	Llandovery
Upper ?	R. maximus	R. maximus	Rhayader Pale Shales	R. maximus	Ystwyth Stage	M. turriculatus / R. max. band	M. halli	R. maximus / M. halli	Mudstones with M. turriculatus	R. maximus / M. halli	M. halli	M. halli	R. maximus	R. maximus / M. halli	R. maximus	Upper
Upper	M. spinigerus	M. spinigerus	sedgwickii Grits	← M. sedgwickii → (to This paper)												Upper
Upper	M. clingani Band	M. clingani Band			C. cometa	C. cometa Band	M. regularis			C. cometa	M. regularis		C. cometa	C. cometa		Middle
Upper	D. cometa	M. convolutus	M. convolutus		M. convolutus			← M. convolutus → (to Jones 1929)				← M. convolutus → (to This paper)				Middle
Middle	M. gregarius	M. argenteus	M. fimbriatus	M. gregarius	M. communis	M. gregarius	← M. leptotheca → (to Jones and Pugh 1933)					M. triangulatus s.l.	M. leptotheca		M. gregarius	Middle
Middle		M. fimbriatus					← D. (M.) magnus → (to Jones and Pugh 1933)						D. magnus			Middle
Middle							Monograptus spp Beds	← M. triangulatus → (to Jones and Pugh 1933)					M. triangulatus			Middle
Middle			M. cyphus		M. cyphus	M. cyphus		← M. cyphus → (to This paper)								Lower
Lower	D. vesiculosus	D. confertus	M. tenuis	M. modestus	M. rheidolensis	M. modestus–D. vesiculosus		M. acinaces	M. acinaces–M. atavus	← M. acinaces → (to Curtis 1961)						Lower
Lower			modestus flags		M. atavus			? M. modestus; M. atavus		M. atavus (to Jones and Pugh 1933)		M. atavus ?	M. atavus		C. vesiculosus	Lower
Lower	D. acuminatus	D. acuminatus	Beds with D. acuminatus		← A. (C.) acuminatus → (to This paper)					M. modestus						Lower
Lower					G. persculptus		← G. persculptus → (to This paper)									Lower

TABLE 2. A correlation of Llandovery (Valentian) graptolite zonal schemes, up to the base of the *M. turriculatus* Zone.

where the first grey mudstones appear immediately above the 3-in. band with *Diplograptus magnus*.

The *M. convolutus* Zone as used here is equivalent to the same zone as defined by Elles and Wood (1913), and Elles (1925), the *cometa* Band being included in the zone. In some cases, in Wales, the *cometa* Band has been treated as a separate zone (Jones, 1909, 1929; Curtis, 1961). The zone is equivalent to the *cometa* Zone of Lapworth (1878, pp. 322–3) together with the *clingani* Band of his *sedgwickii* Zone.

The base of the *M. sedgwickii* Zone as defined here is equivalent to the same horizon in Wales, being taken at the appearance of *M. sedgwickii*. The *clingani* Band of Lapworth's *sedgwickii* Zone has been relegated to the *convolutus* Zone.

The base of the *Rastrites maximus* Zone has been taken at a similar level to Lapworth (1878, pp. 322, 325–7), but the two species which according to Lapworth characterize the zone at Dobb's Linn, *R. maximus* and *M. halli*, have not been found to be at all common in the zone, but occur abundantly in localities south-east of Dobb's Linn (see below). The zone is considered to be equivalent to the *halli* Zone in Wales (Jones and Pugh 1916, W. D. V. Jones 1945). Some authors have suggested in the correlation charts of review papers (Jones 1921, 1929; Curtis 1961) that a *maximus* Zone has been defined in Wales above the *halli* Zone. In fact this has never been done, although within the *halli* Zone around Machynlleth (Jones and Pugh 1916) there is a separate *Rastrites* Band above a *halli* Band. The only use of a *R. maximus* Zone in Wales was by Elles (1909) in the Conway area where it lay between the *sedgwickii* and *crispus* Zones.

Localities south-east of the Caledonoid strike-line through Dobb's Linn (Craigmichan Scars, Thirlstane Scar, and Beldcraig Burn) expose fossiliferous horizons which are higher in the *maximus* Zone than any fossiliferous strata at Dobb's Linn. Lapworth compared these sections directly with the *maximus* Zone at Dobb's Linn (1878, pp. 326–7) as if they were exactly the same horizon. He was unaware of the diachronous nature of the Gala Greywackes south-east of Dobb's Linn which meant that their base had 'stepped up' in relation to Dobb's Linn. He was, however, quite aware that the Gala Greywackes 'stepped down' north-west of Dobb's Linn. These localities south-east of Dobb's Linn yield *Rastrites maximus* and *Monograptus halli* in abundance with *M. runcinatus*, *M. spiralis* and rarely *M. turriculatus minor*, and further substantiate the suggestion that the *halli* and *maximus* Zones are equivalent. The latter name should take priority on historical grounds. Higher horizons in the Gala Greywackes south-east of Dobb's Linn yield a fauna which is typical of the *Monograptus turriculatus* Zone, including, *M. exiguus*, *M. barrandei*, *M. nodifer*, and the zone fossil.

THE TERMS LOWER, MIDDLE, AND UPPER LLANDOVERY APPLIED TO THE BIRKHILL SHALES

The terms Llandovery (Murchison 1859) and Valentian (Lapworth 1876) are now considered to be synonymous, and the former term has priority. However, the Valentian is usually considered to be the graptolitic Llandovery, and as the divisions of the Llandovery are based on a shelly fauna and unconformities in the type area (Jones 1925), it is unlikely that the divisions can be readily applied to the graptolitic sequence.

When the Valentian was further defined by Jones (1921) the base was taken at the base of the *G. persculptus* Zone (1921, pp. 173–4), this zone having been originally

defined in the graptolitic sequence of Central Wales (Jones 1909, p. 482). This level is now accepted as the base of the Llandovery (Curtis 1961, p. 129). The base of the Middle Llandovery is usually equated to the base of the *magnus* Zone in the graptolitic sequence of Central Wales (Curtis 1961, p. 130), but this is entirely based on lithological considerations (Jones, 1925, p. 366; 1947, p. 3; 1954, p. 252; Jones and Pugh 1935, pp. 274–5). The only variation from this opinion was by Jones in 1929 when he included the *magnus* Zone in the Lower Llandovery (1929, p. 97). The highest graptolites recorded from the Lower Llandovery at Llandovery are *Monograptus incommodus* and *Climacograptus hughesi* from the top of A4 (Jones 1925, p. 360; 1929, p. 94), and these were considered to indicate the top of the *acinaces* Zone (Jones 1925, p. 360). The Middle Llandovery at Llandovery has yielded *Monograptus decipiens*, *M.* cf. *lobiferus*, and *M.* cf. *regularis*. These were collected from near to the top of the division and considered by Jones (1925, p. 366) to indicate the *convolutus* Zone. The abundance of *M. sedgwickii* at 150 ft. above the base of the Upper Llandovery at Llandovery (Jones 1925, p. 370) suggests that the present accepted level for the base of the Upper Llandovery in the graptolitic sequence, i.e. the base of the *sedgwickii* Zone, is quite acceptable. However, there is no such fixed level for the base of the Middle Llandovery in the graptolitic sequence which could, on the evidence stated above, lie as low as the base of the *cyphus* Zone, or even as high as the base of the *convolutus* Zone (Jones 1925, p. 366). This is an unsatisfactory situation, and the problem cannot really be solved until more graptolite evidence is obtained from the Llandovery area, or shelly evidence from the graptolitic sequence. Therefore as the type area cannot offer any faunal evidence which will fix the Lower-Middle Llandovery boundary with any certainty in the graptolitic sequence, there can be no harm in considering the graptolite fauna of the Llandovery (Valentian) as a whole, in order to suggest an equivalent horizon in the graptolitic sequence as a working base for the Middle Llandovery.

Within the graptolite fauna of the Birkhill Shales are four distinct divisions corresponding to those erected by Elles (1922) and further elaborated by Bulman (1958). The lowest part of the Birkhill Shales below the incoming of monograptids (*persculptus–acuminatus* Zones) is equivalent to the Ortho-Climacograptid sub-fauna of Bulman (1958, pp. 170–1), the highest division of Elles's Diplograptid Fauna. The next division of the Birkhill Shales, above the incoming of monograptids, but below the appearance of triangulate monograptids, *vesiculosus–cyphus* Zones, (*atavus–cyphus* Zones in Wales) represents the lowest division, A, of Bulman's Monograptid Fauna. The next division, *gregarius-convolutus* Zones, (*triangulatus-convolutus* Zones in Wales), represents the second division, B, of Bulman's Monograptid Fauna, and the final division, *sedgwickii-maximus* Zones represents part of the third division, C, of the Monograptid Fauna (Bulman 1958, pp. 170–1).

The base of the Llandovery is well fixed in the graptolitic sequence at the base of the *persculptus* Zone, which was defined for the first time in Scotland by Toghill (1968). It is worth noting that Elles (1922, p. 195) suggested that the lowest two zones of the Llandovery (*persculptus-acuminatus* Zones) being devoid of monograptids could well be relegated to the Ordovician on faunistic grounds, but this has never been accepted. The base of the Middle Llandovery if taken at the base of the *magnus* Zone is some way above the appearance of triangulate monograptids, and some way above the base of the *gregarius* Zone as defined here. The appearance of triangulate monograptids at the base

of the *gregarius* Zone (*triangulatus* Zone in Wales) corresponds to the base of the second division, B, of the Monograptid Fauna. It would be more convenient if the base of the Middle Llandovery in the graptolitic sequence were to be taken at the base of the *triangulatus* Zone in Wales, and thus equate with the base of the *gregarius* Zone at Dobb's Linn. If acceptable the base of the Middle Llandovery would then correspond to the base of the second division of Bulman's Monograptid Fauna (Bulman 1958, pp. 170–1). The base of the Upper Llandovery taken at the base of the *sedgwickii* Zone is a convenient horizon as it is the base of the third division of the Monograptid Fauna. Thus the stage boundaries of the Llandovery in the graptolitic sequence would now correspond to significant faunal horizons, though within the Lower Llandovery is the most conspicuous horizon of all, the appearance of the monograptids.

In conclusion, the Lower Llandovery at Dobb's Linn is represented by the zones of *Glyptograptus persculptus*, *Akidograptus acuminatus*, *Cystograptus vesiculosus*, and *Monograptus cyphus*, and is 48 ft. (14·6 m.) thick. The Middle Llandovery includes the zones of *M. gregarius* and *M. convolutus* and is 44 ft. (13·4 m.) thick. Only part of the Upper Llandovery is present, represented by the zones of *M. sedgwickii* and *Rastrites maximus*. These two zones are 49 ft. (15 m.) thick and pass up into the great thickness of the Gala Greywackes which (together with the Hawick Rocks?) represent the remainder of the Upper Llandovery.

Acknowledgements. I am extremely grateful to Dr. I. Strachan for his constant advice throughout the research, a grant for which was obtained from the Department of Scientific and Industrial Research (now N.E.R.C.). I would also like to thank Professor O. M. B. Bulman for the loan of supplementary specimens from the Sedgwick Museum.

REFERENCES

BULMAN, O. M. B. 1958. The sequence of graptolite faunas. *Palaeontology*, **1**, 159–73.

CURTIS, M. L. K. 1961. In *Lexique Stratigraphique International*, **1**, Europe, (3aV), Silurian.

DAVIES, K. A. 1926. The geology of the country between Drygarn and Abergwesyn (Breconshire). *Q. Jl geol. Soc. Lond.* **82**, 436–64.

—— 1929. Notes on the graptolite faunas of the Upper Ordovician and Lower Silurian. *Geol. Mag.* **66**, 1–27.

ELLES, G. L. 1909. The relations of the Ordovician and Silurian rocks of Conway (North Wales). *Q. Jl geol. Soc. Lond.* **65**, 169–94.

—— 1922. The graptolite faunas of the British Isles. A study in evolution. *Proc. Geol. Ass. Lond.* **33**, 168–200.

—— 1925. The characteristic assemblages of the graptolite zones of the British Isles. *Geol. Mag.* **62**, 337–47.

—— and WOOD, E. M. R. 1901–18. A monograph of British graptolites. *Palaeontogr. Soc.* [*Monogr.*].

JONES, O. T. 1909. The Hartfell-Valentian succession in the district around Plynlimon and Pont Erwyd (North Cardiganshire). *Q. Jl geol. Soc. Lond.* **65**, 463–537.

—— 1921. The Valentian series. Ibid. **77**, 144–74.

—— 1925. The geology of the Llandovery district: Part I—The southern area. Ibid. **81**, 344–88.

—— 1929. Silurian. In *Handbook of the geology of Great Britain*, J. W. EVANS and C. J. STUBBLEFIELD (eds.), London, 88–127.

—— 1933. The lower Palaeozoic rocks of Britain. *Int. geol. Congr.* 16th session, Washington, **1**, 463–84.

—— 1947. The Llandoverian graptolite succession in Britain. *Bull. Mus. r. Hist. nat. Belg.* **23**, (22), 1–4.

—— 1954. The use of graptolites in geological mapping. *Lpool. Manchr. geol. J.* **1**, 246–60.

—— and PUGH, W. J. 1916. The geology of the district around Machynlleth and the Llyfnant Valley. *Q. Jl geol. Soc. Lond.* **71**, 343–85.

JONES, O. T. and PUGH, W. J. 1935. The geology of the districts around Machynlleth and Aberystwyth. *Proc. Geol. Ass. Lond.* **46,** 247–300.

JONES, W. D. V. 1945. The Valentian succession around Llanidloes, Montgomeryshire. *Q. Jl geol. Soc. Lond.* **100,** 309–32.

—— and RICKARDS, R. B. 1967. *Diplograptus penna* Hopkinson 1869, and its bearing on vesicular structures. *Paläont. Z.* **41,** 173–85.

LAPWORTH, C. 1876. The Silurian system in the south of Scotland. In *Catalogue of the Western Scottish fossils*, J. ARMSTRONG *et al.* (ed.), Glasgow, 1–28.

—— 1878. The Moffat Series. *Q. Jl geol. Soc. Lond.* **34,** 240–346.

—— 1880. On the Geological Distribution of the Rhabdophora. *Ann. Mag. nat. Hist.* (5), **5,** 45–62, 358–69; **6,** 16–29, 185–207.

LAPWORTH, H. 1900. The Silurian sequence of Rhayader. *Q. Jl geol. Soc. Lond.* **56,** 67–137.

MARR, J. E. and NICHOLSON, H. A. 1888. The Stockdale Shales. Ibid. **44,** 654–732.

MURCHISON, R. I. 1859. *Siluria*. 2nd ed. London.

SUDBURY, M. 1958. Triangulate Monograptids from the *Monograptus gregarius* Zone (Lower Llandovery) of the Rheidol Gorge (Cardiganshire). *Phil. Trans. R. Soc.* **B. 241,** No. 685, 485–555.

TOGHILL, P. 1968. The stratigraphical relationships of the earliest Monograptidae, and the Dimorphograptidae. *Geol. Mag.* **105,** 46–51.

WALTON, E. K. 1963. Sedimentation and structure in the Southern Uplands. In *The British Caledonides*. M. R. W. JOHNSON and F. H. STEWART (eds.), Edinburgh, 71–97.

—— 1965. Lower Palaeozoic rocks—stratigraphy, palaeogeography and structure. In *The geology of Scotland*, G. Y. CRAIG (ed.), Edinburgh, 161–227.

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Typescript received 5 February 1968