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# Statistical biostratigraphical analysis of graptolites from the Southern Uplands Terrane

Evolution of the Southern Uplands Terrane

Internal Report IR/02/046



BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/02/046

## **Statistical biostratigraphical analysis of graptolites from the Southern Uplands Terrane**

Mark Williams, Ben Wood & James D. Floyd

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## Summary

Stratigraphical evaluation, including cluster-analysis, of more than 150 lower Caradoc graptolite-bearing localities from southern Scotland has failed to identify a discrete assemblage that can be used to recognise the *Climacograptus bicornis peltifer* Biozone. Instead, the lowermost Caradoc *Nemagraptus gracilis* Biozone is redefined as a partial range zone. It is succeeded by the *Climacograptus bicornis* Biozone, divisible into a lower *Orthograptus apiculatus-Dicranograptus ziczac* Sub-biozone, identified by the appearance of the eponyms together with the earliest occurrences of *Amplexograptus leptotheca*, *Dicranograptus tardiusculus* and several other graptolite taxa, and an upper *wilsoni* Sub-biozone, formerly the *wilsoni* Biozone, marked by the first appearance of *Climacograptus wilsoni*. *Nemagraptus gracilis* and *Didymograptus superstes* range through at least the lower part of the *apiculatus-ziczac* Sub-biozone, but may be absent from the upper part of the sub-biozone, an interval that may equate approximately to the *peltifer* Biozone as formerly recognised. As recognised, the *bicornis* Biozone of Scotland is the approximate equivalent of the *bicornis* Biozone of North America and, at least in part, of the *foliaceus* Biozone of southern Britain. It is succeeded in Scotland by the *clingani* Biozone.

## 1 INTRODUCTION

The *gracilis*, *peltifer*, *wilsoni*, *clingani* and *linearis* graptolite biozones of the Caradoc Series were recognised in southern Scotland during the period 1878 to 1925, commencing with the classic work of Lapworth (1878) on the ‘Moffat Series’ (see Rushton 2001a; Fig. 1). More

recently, definitions for the mid- to late Caradoc *wilsoni*, *clingani* and part of the *linearis* biozones have been refined (Williams 1982, 1994; Zalasiewicz *et al.* 1995), but the relationships of the *gracilis* and *peltifer* biozones remain poorly constrained (see Rushton 1990, 2001a; Rushton *et al.* 1996a, p. 141; Floyd 2001, p. 360). Indeed, the classical works of Lapworth (1878) and Peach and Horne (1899) made no distinction of this interval in their graptolite biostratigraphies of the Southern Uplands.

In Scotland, the *gracilis* Biozone (lowermost Caradoc according to Fortey *et al.* 2000) is defined by the total range of the zonal species *Nemagraptus gracilis* (see Finney and Bergström 1986). It is divisible into two intervals: a lower interval that lacks *Climacograptus bicornis* s.l.; and an upper interval in which the ranges of *N. gracilis*, *C. bicornis* s.l. and several other key taxa overlap (Fig. 1). This upper interval is approximately equivalent to the lower part of the *bicornis* Biozone as recognised in North America (e.g. Berry 1960; Williams 1995) and elsewhere (e.g. Finney *et al.* 1999), and Williams (1994) has suggested that a *bicornis* Biozone can be distinguished in Scotland.

Many lower Caradoc graptolites are long-ranging (e.g. Berry *et al.* 1999, fig. 2). Thus, for example, *Climacograptus bicornis* s.l. extends above the range of *N. gracilis* and into the *wilsoni* Biozone as defined by Williams (1994; see Fig. 1). Most of the graptolite species that occur in the lowermost Caradoc of Scotland (see Rushton *et al.* 1996b; Rushton 2001b; Armstrong *et al.* 1998), prior to the first occurrence of *C. bicornis* s.l., have ranges which also overlap with that species (Fig. 1), and are also recorded from the *peltifer* Biozone as defined by Elles (1925). However, the *peltifer* Biozone appears to be, at best, an interregnum without any age-diagnostic species: graptolites that Elles (1925) identified as diagnostic of the *peltifer* Biozone (namely *Dicellograptus patulosus*, *Dicranograptus furcatus minimus*) have subsequently been recorded with *N. gracilis* or *D. superstes* (e.g. see Floyd 1999, appendix 2). The problem is exacerbated by the zonal eponym *Climacograptus bicornis peltifer*, whose subspecies status is in any case questionable (see Riva 1976; Webb *et al.* 1993, p. 8), and which overlaps with the range of *N. gracilis* (Fig. 1). As a result, distinction of the *peltifer* Biozone is highly problematic, particularly at spot localities and from stratigraphically incomplete sections which do not include zone-specific graptolites: this is typical of many graptolite-bearing localities in the Southern Uplands (Finney and Bergström 1986). Nevertheless, the *peltifer* Biozone has been widely, though tentatively, recognised in the Ordovician rock-sequences of southern Scotland (e.g. Williams 1994; Stone 1995; Floyd 1999; Rushton 2001a; McMillan 2002), partly for reasons of historical continuity and partly for pragmatic reasons involving the construction of geological map sheets.

One approach to resolving the status of the *peltifer* Biozone is to use statistical techniques. In cases where the vast majority of species are long-ranging through a particular stratigraphical interval or where data are derived from a number of disparate, incomplete sections, objective statistical techniques such as cluster-analysis can help to refine the biostratigraphy. This study applies cluster-analysis to over 150 lower Caradoc graptolite assemblages from the Southern Uplands, collectively yielding over 90 taxa, and collected during the British Geological Survey's mapping programme since the late nineteenth century.

The statistical analysis provides an indication of the quality of material needed to identify graptolite biozones precisely, and provides a useful guide to collection procedures during reconnaissance mapping. The graptolite analysis indicates that a redefinition of the lower Caradoc graptolite biozones in Scotland is necessary.

## 2 DATASET

The principal graptolite dataset is from the New Cumnock-Leadhills district of the Southern Uplands (Fig. 2). This comprises material from 82 localities in the lower Caradoc rock-sequence collected during surveying since the nineteenth century (e.g. Peach and Horne 1899,

Macconochie, and more recent survey collections of Williams, Floyd, Rushton and others). The district provides the greatest concentration of geographically associated assemblages of lower Caradoc age in the Southern Uplands and is the locus of the proposed type-section for the base of the Glenkiln Shale Formation of the Moffat Shale Group (Floyd 2001, p. 354). Other key datasets used for this study are from: the Carrick-Loch Doon district where 32 localities are identified as *gracilis* or *peltifer* Biozone (Floyd 1999, appendix 2); the Rhins of Galloway, where 21 localities are identified as of *gracilis* or *peltifer* Biozone age (Stone 1995, appendix 2); Glenkiln Burn, in the Lochmaben district, where there is a rock sequence of lower Caradoc age with several closely associated graptolite-bearing horizons (see Williams 1994); the New Galloway-Thornhill district where six localities are identified as lower Caradoc (McMillan 2002, appendix 1); the Kirkudbright-Dalbeattie district, where four localities are identified as lower Caradoc (Lintern and Floyd 2000, appendix 1A); and the Kirkcowan-Wigtown district, where four lower Caradoc localities are identified (BGS internal reports). These areas are represented in BGS collections by many thousands of graptolite specimens stored at BGS Edinburgh (Murchison House) and Keyworth (BGS Headquarters). Historically important and pertinent graptolite localities from the Moffat-Ettrick district are also reviewed (see Lapworth 1878; Webb *et al.* 1993). Lowermost Caradoc *N. gracilis*-bearing (but sub-*C. bicornis*-bearing) graptolite faunas from the Midland Valley Terrane and Currarie Formation are included for comparison (see Rushton *et al.* 1996b; Rushton 2001b; Armstrong *et al.* 1998).

The analysis is based on identifications made since the 1980s when BGS biostratigraphical revision of the Southern Uplands Terrane commenced (particularly the work of Adrian Rushton, Denis White and Steve Tunnicliff). Unless otherwise stated, the 19<sup>th</sup> Century collections of Macconochie for Peach and Horne (1899) have been used only after revision of the identifications. Identifications published by Peach and Horne cannot be accepted without checking the original material (see Rushton 2001a), and even those of Lapworth (1878), which are generally more reliable, have to be reviewed in the light of the revision of the whole British graptolite fauna made by Elles and Wood (1901-1918).

### 3 METHODOLOGY

The graptolite data for cluster-analysis are stored in a relational Microsoft Access database (BGS 'gracilis Zone database'), which records locality, collector, lithostratigraphy, fauna and other data. Raw data for the study were available from BGS Biostratigraphy Technical Reports and memoirs, each describing one or more graptolite-bearing locality, and from Palaeosaurus©, where, at present, the data mostly represents original register entries of the nineteenth century. The dataset in the 'gracilis Zone database' can potentially be expanded to analyse lower Caradoc graptolite-bearing sequences globally.

For this study, the graptolite data from over 150 localities in the Southern Uplands have been entered onto the 'gracilis Zone database' (see Appendix 1) and the results used to test for discrete faunas that might qualify the *peltifer* Biozone.

Cluster-analysis is used to calculate similarity between each locality based on graptolite presence-absence data, objectively grouping together localities with statistically more similar assemblages. Analysis here is restricted to the unsupervised or 'hierarchical' methods, in which clustering is carried out automatically without an enforced number of clusters.

Graptolite presence-absence data were exported from the 'gracilis Zone database' as a comma-separated ASCII text file representing an  $n \times m$  matrix, the rows  $n$  representing the localities, with columns  $m$  representing taxa. This data file was imported directly into the cluster analysis software and hierarchical clustering was carried out in so-called Q-mode, where the resultant dissimilarities between samples are computed locality against locality, and in R-Mode where species occurrences are compared. The data were not reduced; all identified taxa were

used in defining the clusters. Etter (1999) suggests this approach is usually preferable in that rare taxa may be critical in defining biozones. Other possible techniques for improving the results of the cluster-analysis, for example transposing the raw data onto a logarithmic or exponential scale, were not considered relevant to the essentially binary presence-absence data of this study. However, although not dealing with abundance data, lower weightings were applied to taxa identified as 'aff.', 'cf.' or '?', so that more precise species identifications would have a greater bearing on the results.

The hierarchical clustering methods fall into two classes; divisive and agglomerative. Divisive clustering puts all of the localities into one cluster, then iterates through, looking for dissimilarities between each locality in order to break the data down into smaller and smaller clusters. Agglomerative clustering works the opposite way, starting as though each locality belongs to a separate cluster, and then iteratively building up larger groupings according to the similarity of each locality. Both divisive and agglomerative methods were applied during our analysis. The divisive approach gives slightly clearer clusters, although in general there was little difference between the methods.

During analysis of the data we noted that addition or removal of one or several localities sometimes affected the clustering of some of the other localities. These sorts of chaotic responses to slight variations in the dataset have been commented on by Lespérance (1991). In this case they are due to the large number of taxa common to most of the assemblages analysed, and the varying diversity of assemblages across the dataset. Best results were achieved from analysis of stratigraphically well-constrained localities bearing many species. Analysis of localities with poor age constraint, based on a few species or several species described in open nomenclature, generally produce poor results.

Although hierarchical cluster analysis is an unsupervised statistical process, it does allow room for expert input through interpretation of the dendrogram by the biostratigrapher. By analysing the clustering behaviour of localities having less well constrained biozone assignments with respect to those that are well constrained, the less well known localities can be more confidently assigned. In this way the cluster analysis of the graptolite faunas provides a comparative dataset which can be used to re-assess the age assignments at specific localities.

## 4 ANALYSIS OF THE GRAPTOLITE FAUNAS

In the following sections the term 'Survey' is used to denote the British Geological Survey.

More than 150 lower Caradoc graptolite assemblages have been entered onto the 'gracilis Zone database' (see Appendix 1). The total complement of graptolites for these localities is 91 taxa (including those described in open nomenclature; see Appendix 2). Of these localities, 66 were referred by the Survey to the *gracilis* Biozone and 9 to the *peltifer* Biozone. Some 79 localities were referred more circumspectly to lie within the range of the *gracilis* or *peltifer* biozones, sometimes questionably. No assemblage yields the total fauna, so that each is a subset of the total graptolites available, controlled by palaeoecological, temporal, preservational and collection differences at each locality. The assemblages are from very low- to very high-diversity, with between 1 to 25 taxa. Three graptolite-bearing localities, diagnostic of the sub-C. *bicornis*-bearing interval of the lowermost Caradoc in the Currarie Formation of the Northern Belt of the Southern Uplands Terrane (see Armstrong *et al.* 1998) and from the adjoining Midland Valley Terrane (Rushton *et al.* 1996b; Rushton 2001b), are used in the cluster-analysis to help discriminate older faunas in the Southern Uplands (see Figs 3, 4).

In Q-Mode analysis clustergrams have been generated of all localities, but a clearer distinction of stratigraphical intervals is presented by analysis of a smaller dataset comprising the 75 localities where firm age assignments were given by the Survey. In the larger dataset there are many localities where only long-ranging taxa occur (e.g. those localities referred to the *gracilis*

or *peltifer* Biozone), but as these taxa are also components of the more age-diagnostic assemblages, their inclusion in the clustergrams tends to dilute the pattern of age-significant clusters (see discussion of Figures 4 and 5 and following sections).

Analysis of the smaller dataset (75 localities + 3 ‘test’ localities) differentiates graptolite assemblages that can be used to distinguish sub-*C. bicornis*-bearing horizons from younger Caradoc horizons. The analysis also provides an indication of the quality of data needed to provide good age assignments. In R-Mode analysis graptolite taxa from all 157 localities were analysed (Fig. 5). This approach has proved particularly useful for discriminating associations of widespread and stratigraphically useful taxa. The results of the cluster-analysis are summarised as follows.

1. There are 78 graptolite taxa recognised for the 66 localities identified by the Survey as *gracilis* Biozone (Appendix 3). No more than 25 taxa (32%) are present at any one locality. There are 34 graptolite taxa for the 9 localities firmly identified as *peltifer* Biozone (Appendix 4). Including those localities referred to the *peltifer* Biozone questionably, this figure rises to 47 taxa. Nearly all of the named taxa for these localities also occur at localities identified as *gracilis* Biozone, except for single occurrences of *Corynoides calicularis*, *Orthograptus calcaratus basilicus* and a *Dicranograptus* that resembles the species *D. longicollis*. Except for *Corynoides serpens*, *Thamnograptus scoticus* and *Orthograptus amplexicaulis*, all of the taxa from the 79 lower Caradoc graptolite localities with loosely defined age assignments are also recorded from localities identified by the Survey as *gracilis* Biozone or *peltifer* Biozone.
2. Faunas with 10 or more species provide the most secure age determinations. These higher-diversity faunas typically contain rare, short-ranging age-diagnostic taxa, and also those taxa associated with the incoming of *C. bicornis* s.l. Such faunas can differentiate the lower, sub-*C. bicornis*-bearing part of the Caradoc from the succeeding interval, characterised by the overlapping ranges of *N. gracilis* and *C. bicornis* s.l. (Fig. 1).
3. The sub-*C. bicornis*-bearing interval of the lower Caradoc (Fig. 1) is tentatively identified at only one locality in the Southern Uplands (locality 86 of Appendix 1), signalled by a high-diversity assemblage with *Dicellograptus geniculatus*? (one specimen) and by the absence of *Climacograptus bicornis* s.l. and typically younger graptolite species. Nevertheless, most of the species in this assemblage are also known from younger horizons and include *Nemagraptus gracilis*, *Didymograptus superstes*, *Dicranograptus furcatus*, *Dicellograptus salopiensis*, *D. aff. patulosus* and *Orthograptus calcaratus acutus*.
4. Graptolites that are frequently associated with *C. bicornis* s.l. and therefore appear to have their first occurrences at about the same or higher level as that species are: *Climacograptus bicornis peltifer*, *Amplexograptus leptotheca*, *Dicranograptus tardiusculus*, *Dicranograptus brevicaulis*, *Dicranograptus ziczac* and *Orthograptus apiculatus*. Less common graptolites which also appear in this interval are *Amplexograptus perexcavatus*, *A. arctus* and *Dicranograptus celticus* and more than 20 other species, though some are known from older horizons in southern Britain (see Fig. 1). All of these graptolites occur with *C. bicornis* s.l. and either *N. gracilis* or *D. superstes* (Fig. 1). Assemblages characterised by these taxa form a very stable cluster in Figures 3 and 4 (Cluster [1]) that are clearly diagnostic for the part of the Caradoc where *N. gracilis* and *C. bicornis* s.l. have overlapping ranges. They suggest an interval equivalent to the lower part of the *bicornis* Biozone of North America (e.g. Berry 1960; see also Fig. 1). The common occurrence of *O. apiculatus* with *C. bicornis* s.l. may also support the approximate correlation of this interval with the lower part of the *foliaceus* Biozone of southern Britain (see Bettley *et al.* 2001, fig. 7).
5. Distinction of the *peltifer* Biozone (cf. Elles 1925) is untenable. Assemblages referred by the Survey to the *peltifer* Biozone are widely distributed through the clustergrams (Figs 3, 4) and do not cluster to form a discrete assemblage. This is because *C. bicornis* s.l., *C. tricornis*, *D.*

*exilis*, *D. salopiensis*, *D. superstes*, *O. ex gr. calcaratus* and *P. scharenbergi*, all of which are common at horizons identified by the Survey as *peltifer* Biozone, also occur very commonly with *N. gracilis* (Appendix 3). Furthermore, *N. gracilis* co-occurs with *C. bicornis peltifer*, so that the *peltifer* form of *C. bicornis* cannot be used to identify its eponymous zone (Fig. 1). However, as *N. gracilis* and *D. superstes* are present in nearly all of the high-diversity (10 or more taxa) assemblages identified by the Survey as *gracilis* Biozone, it follows that high-diversity assemblages that lack these species might signal an interregnum between *N. gracilis*-bearing and *C. wilsoni*-bearing strata (see Fig. 1), in which no new species appear. Such assemblages, in which *C. bicornis* s.l. is common, are also suggested by the cluster of species in R-Mode analysis associated with *Amplexograptus leptotheca* (Fig. 5), though all of these species are also known to occur with *N. gracilis*. Interestingly though, the uncommon *C. bicornis peltifer* does not cluster with these species (Fig. 5).

6. Many low-diversity assemblages which yield long-ranging graptolites considered typical of assemblages referred to the *gracilis* and *peltifer* biozones by the Survey, but which lack *N. gracilis*, *D. superstes* or other short-ranging graptolites, can only be assigned loosely to the sub-*wilsoni* Biozone part of the Caradoc.
7. Most lower Caradoc graptolite-bearing localities firmly identified as *gracilis* Biozone by the Survey in the Southern Uplands indicate an interval in the upper range of *N. gracilis*, where that species overlaps the range of *C. bicornis* s.l. (see Fig. 1). These include the assemblages of the stable Cluster (1) of Figures 3 and 4 alluded to above (point 2). They are somewhat younger than the lowermost Caradoc graptolite-assemblages of the adjoining Midland Valley Terrane (see Rushton *et al.* 1996b; Rushton 2001b), or of the Currarie Formation in the north-westernmost part of the Southern Uplands (see Armstrong *et al.* 1998; Floyd 2001). These latter occurrences yield graptolite assemblages including *N. gracilis* that are clearly older than the first appearance of *Climacograptus bicornis* s.l. and are equivalent to the *gracilis* Biozone as it is identified in North America and elsewhere (i.e. a partial range zone; see Berry 1960; Finney *et al.* 1999; see Fig. 1).

## 5. EVALUATION OF LOWER CARADOC GRAPTOLITE-BEARING LOCALITIES FROM INDIVIDUAL AREAS

The results of the cluster-analysis provide a number of criteria (points 1-7 above) that can be used to assess the age of graptolite-bearing localities assigned to the lower Caradoc *gracilis* and *peltifer* biozones at individual localities and sections throughout Southern Scotland.

### New Cumnock-Leadhills district

For the New Cumnock-Leadhills district (BGS Scotland 1:50 000 Sheets 15W and 15E) the Survey identified 82 localities with lower Caradoc graptolites including: 37 localities identified as *gracilis* Biozone; 6 localities identified as *peltifer* Biozone; 38 localities identified as *gracilis?*, *peltifer?*, and *gracilis* or *peltifer* Biozone (sometimes questionably) and one locality recorded as uncertain (see Appendix 1).

The 37 localities identified as *gracilis* Biozone are included in the Q-Mode cluster analyses of Figure 3 and 4. They range from high diversity assemblages which are clearly indicative of the part of the lower Caradoc where *C. bicornis* s.l. and *N. gracilis* have overlapping ranges (Figs 3, 4), to those which bear no diagnostic taxa (e.g. localities 43 and 45). One of the *gracilis* Biozone assemblages from the Southern Uplands, at Shield Burn (locality 86) might represent the sub-*C. bicornis*-bearing interval of the lower Caradoc. It yields a graptolite assemblage from a possible interbed in the Kirkcolm Formation which, in the analysis of the 66

localities referred to the *gracilis* Biozone, clusters with the lower Caradoc graptolite assemblages of the Midland Valley and Currarie Formation (Fig. 3). The assemblage includes *Dicellograptus geniculatus*? (one specimen), but lacks *C. bicornis* s.l. or other diagnostically younger taxa. However, the other species in this assemblage are *Nemagraptus gracilis*, *Didymograptus superstes*, *Dicranograptus furcatus*, *Dicellograptus salopiensis*, *D. aff. patulosus* and *Orthograptus calcaratus acutus*, which are longer-ranging. Because of the presence of these taxa, in Figure 4 (analysis of all localities) the assemblage clusters close to several moderate-diversity graptolite assemblages which indicate the upper range of *N. gracilis* (localities 87, 136 and 209). This indicates the instability in some of the clusters where short-ranging species or diagnostic assemblages such as characterise Cluster (1) are lacking. This is because most species in the sub-*C. wilsoni*-bearing part of the Caradoc are long-ranging.

Of the six assemblages from the New Cumnock-Leadhills district referred to the *peltifer* Biozone by the Survey, four moderate-diversity (5-9 taxa) assemblages cluster together with *gracilis* Biozone assemblages in Figure 3 (localities 59, 60, 90, 111). These assemblages bear graptolites which have ranges which overlap the upper range of *N. gracilis*, including *C. bicornis bicornis*, *C. bicornis peltifer*, *O. apiculatus*, *P. scharenbergi*, *A. leptotheca* and *C. tricornis*. They were distinguished as the *peltifer* Biozone by the Survey on the absence of *N. gracilis* and *D. superstes*, and in one case by the occurrence of the eponym. The two other *peltifer* assemblages (localities 54 and 84) yield more impoverished faunas but include *A. leptotheca* and *O. apiculatus*. As the complement of graptolites of all six assemblages (22 taxa) is essentially that of the *gracilis* Biozone, except for the absence of *D. superstes* and *Nemagraptus*, all may actually lie within the range of *N. gracilis*. When analysed with all localities (Fig. 4) they cluster with moderate to low-diversity assemblages variously referred to the *gracilis* or *peltifer* Biozone and do not form a discrete cluster.

Some 38 of the lower Caradoc graptolite-bearing localities from this district were assigned more tentative ages. Of these, five localities were referred to the *gracilis* Biozone tentatively. At four of these localities (localities 91, 109, 123, 164), the occurrence of *Nemagraptus*? spp. together variously with *A. leptotheca*, *C. bicornis* s.l., *D. ziczac*, *D. tardiusculus* and *D. sextans* suggests horizons in the upper range of *N. gracilis*, where it overlaps with *C. bicornis* (Fig. 1). In Figure 4 they plot amongst lower-diversity assemblages of the Survey's questionable *gracilis* or *gracilis-peltifer* Biozone assignments. The fifth locality, at Kiln Burn (locality 85) yields only *Pseudoclimacograptus* sp., *Dicellograptus* sp. and a dicranograptid stipe which are not age-diagnostic.

The graptolite assemblage from Glenkip Cleuch (locality 73) identified by the Survey as *gracilis* or *peltifer* Biozone, includes *N. gracilis*?, *C. bicornis* s.l. and *L. costatus*. It probably represents a horizon in the upper range of *N. gracilis* where it overlaps with *C. bicornis* s.l. (Fig. 1). The Glenkip Cleuch locality is a few hundred metres along strike from the Gripps Cleuch locality which constrains the age of the Glenkiln Shales Formation near the base of its exposure at the type-locality for the formation (see Floyd 2001, fig. 2).

Of the remaining 32 localities (Fig. 4), most yield graptolites such as *A. leptotheca*, *C. bicornis*, *D. ziczac*, *O. apiculatus* and others, which indicate a level below the *wilsoni* Biozone, at or above the level where *C. bicornis* s.l. originates. Only a few assemblages (localities 88, 89, 151, 157) are of indeterminate age within the Caradoc.

#### Glenkiln Burn (Lochmaben district)

At Glenkiln Burn [National Grid Reference NY 006 894; BGS Sheet 10W], one of the classical Moffat Shale localities reported by Lapworth (1878, pp. 305-6), Williams (1994, fig. 3) identified several graptolite-bearing localities as *gracilis*, *peltifer*, *wilsoni* and *clingani* Biozone, in a structurally complex sequence of the Moffat Shale Group (Glenkiln Shale and Lower Hartfell Shale formations). More recent collections from near the mouth of, and along the banks

of the small tributary called Lambfoot Linn, provide no definite signature for the *peltifer* Biozone (Fig. 6), despite Williams' (1994, fig. 3) report of *gracilis* and *peltifer* Biozone graptolite assemblages there. One high-diversity graptolite assemblage from Lambfoot Linn, identified by the Survey as either *gracilis* or *peltifer* Biozone (locality 246), lacks *D. superstes* and *N. gracilis* but contains *Leptograptus grandis*, known to be confined to the range of *N. gracilis* elsewhere. This assemblage also yields *C. bicornis peltifer*, indicating a level younger than the lowermost Caradoc successions of the Midland Valley. Locality 246 is also a few metres also along strike from locality 250, where *C. bicornis* s.l. and *N. gracilis* indicate a similar level above the base of the Caradoc (Fig. 6). The Lambfoot Linn collection at locality 246 indicates that even high-diversity faunas in the lower Caradoc which lack *N. gracilis* or *D. superstes* may not definitively signal a stratigraphical interregnum above *N. gracilis*-bearing and below *C. wilsoni*-bearing strata (cf. point 5 above). Localities 246 and 250 share several taxa in common, but plot at very different points in the clustergram of Figure 4. Locality 250 lies within the stable Cluster (1), but locality 246 clusters with several assemblages identified by the Survey as *gracilis-peltifer* (localities 222, 241), *gracilis?* (184) and *peltifer* (243). Again, this indicates the dilution factor caused by analysing a large number of localities with very similar faunal complement.

#### Carrick-Loch Doon

Survey of the Carrick-Loch Doon district (BGS Scotland 1: 50 000 Sheets 8W and 8E) identified 32 graptolite-bearing localities of lower Caradoc age (see Floyd 1999, appendix 2). None of these were definitely referred to the *peltifer* Biozone by the Survey, though eight were referred to that zone questionably (see Appendix 1). At these localities species such as *A. leptotheca*, *O. apiculatus* and *L. harknessi* were used to indicate the biostratigraphical horizon, though data from other localities in the Southern Uplands indicates that these species also overlap with the upper range of *N. gracilis* and *D. superstes* and therefore are not diagnostic of a discrete *peltifer* Biozone. However, the four possibly *peltifer* Biozone localities at Kirriemore Burn (localities 192-195 [between NGR NX 379 868 and NX 367 855]) are all consistently poor-diversity and might, based on their spatial distribution in the rock sequence and local geological setting, signal an interregnum between *N. gracilis*-bearing and *C. wilsoni*-bearing strata. They yield longer-ranging and commonly occurring species such as *C. bicornis* s.l., *D. ramosus* s.l. and *Normalograptus brevis* (Floyd 1999, appendix 2) and in the cluster-analysis for all 157 localities they plot with poorly defined assemblages referred to the *gracilis* or *peltifer* Biozone (Fig. 4).

Eight graptolite-bearing localities in the Carrick-Loch Doon district were identified by the Survey as *gracilis* or *peltifer* Biozone, sometimes questionably (Floyd 1999; see Appendix 1). The graptolite assemblages at these localities are characterised by low-diversity and species that sometimes indicate a level between the upper range of *N. gracilis* (where it overlaps the range of *C. bicornis* s.l.) and the first occurrence of *Climacograptus wilsoni*. They include the three localities (180-182) at Cross Water which yield species such as *C. bicornis* s.l., *C. tricornis*, *A. leptotheca*, *A. perexcavatus*, *D. exilis*, *D. sextans* and *L. costatus*. The graptolite assemblages at four other localities (179, 186, 189, 208) also suggest this range, and variously yield *D. rectus*, *C. bicornis* s.l., *D. celticus*, *D. exilis* and *D. furcatus minimus*, but that at Knocklach Burn (locality 186) is non-diagnostic.

Sixteen localities of lower Caradoc age in the Carrick-Loch Doon district were referred to the *gracilis* Biozone by the Survey, some tentatively (Floyd 1999). All of these, including Knockingarroch, Water of Deugh (locality 190), which contains some 25 taxa, yield *Nemagraptus* spp. or *D. superstes*, sometimes identified tentatively. Ten of these localities were referred to the *gracilis* Biozone firmly, and at least seven of these (localities 187, 188, 190, 196, 198, 199, 209) bear faunas which indicate the level in the Caradoc where *N. gracilis* and *C. bicornis* s.l. have overlapping ranges: six of them occur in the same stable Cluster (1) in both Figures 3 and 4. Other species associated with this interval include: *G. hincksii fimbriatus*, *D.*

*celticus* and *D. brevicaulis*, for example at Water of Minnoch (locality 196). The three other *gracilis* assemblages are of low- to moderate-diversity (4-6 taxa), but include graptolites that suggest a similar level in the Caradoc, including at Garryhorn Burn (localities 205, 206) *D. superstes* together with *D. exilis* and at the latter locality *N. gracilis*, and at Pulnabrick Burn (locality 200), *D. superstes*, *Nemagraptus* and *Corynoides* cf. *pristinus*.

Of the six assemblages where the *gracilis* Biozone is identified tentatively by the Survey (localities 183, 184, 197, 201, 202, 207), at least two represent the level in the Caradoc where *N. gracilis* and *C. bicornis* s.l. have overlapping ranges. Thus *C. bicornis* s.l. and *N. gracilis* occur with *A. perexcavatus*? and *L. harknessi* at Altercannoch Quarry (locality 184) and *D. superstes*, *D. exilis* and *D. furcatus minimus* at Cairlin's Cairn (locality 201). The others bear less diagnostic assemblages variously with *N. gracilis* and *D. superstes* (both sometimes questionably), and can be assigned only to a general level in the sub-*C. wilsoni*-bearing part of the lower Caradoc.

### Rhins of Galloway

During survey of the Rhins of Galloway (BGS 1: 50 000 Scotland Sheets 1 and 3) 21 localities were identified as bearing lower Caradoc graptolite assemblages (Stone 1995, appendix 2). Of these, one was referred by the Survey to the *peltifer* Biozone, ten to the *gracilis* Biozone and ten to the *gracilis* or *peltifer* Biozone. Many of the localities are situated at Morroch Bay and Water of Luce (see Stone 1995 for further details). These graptolite assemblages provide further data on the ranges of *Lasiograptus costatus* and *Halograptus mucronatus*, the earliest occurrences of which appear to be associated with the lower Caradoc interval where *C. bicornis* s.l. and *N. gracilis* have overlapping ranges (Fig. 1).

The *peltifer* Biozone graptolite assemblage from the Rhins of Galloway was recognised in the Kirkcolm Formation (Leadhills Supergroup) at several sub-localities in Dounan Bay (see Stone 1995, fig. 9 [NGR NW 966 687]), on the basis of the graptolites *A. leptotheca*, *D. exilis*, *D. ramosus spinifer*?, *D. rectus*, *O. aff. whitfieldi* and three species listed in open nomenclature. Cluster-analysis of the graptolite-bearing localities in Q-Mode does not provide any evidence that this fauna is diagnostic of a discrete stratigraphical interval (locality 214), as it plots amongst a group of poorly diverse assemblages referred to the *gracilis* Biozone or *gracilis-peltifer* biozones by the Survey (Figs 3, 4). Thus, the graptolite assemblage of locality 214 could equally represent an impoverished fauna within the upper range of *N. gracilis*, indicated by the presence of *A. leptotheca*, or may represent an interregnum between *N. gracilis*-bearing and *C. wilsoni*-bearing strata. Similarly, cluster analysis of these species in R-Mode places them in different clusters and does not identify a discrete *peltifer* assemblage (Fig. 5).

The ten faunas from the Rhins of Galloway referred by the Survey to the *gracilis* Biozone (Stone 1995, appendix 2) all contain *Nemagraptus* (*N. gracilis* and *N. pertenus*) or *D. superstes*. Most of these localities yield graptolite assemblages indicative of the interval in the upper range of *N. gracilis* where it overlaps with *C. bicornis* s.l., five of the assemblages occurring in clusters (1) and (2) of Figure 3 (localities 212, 219, 223, 224 and 227) and two others in sub-cluster (4a) of Figure 3 (localities 211, 221). Of these assemblages, one at Polymodie Burn (locality 212) has *D. foliaceus* and *D. superstes* occurring with *H. mucronatus*, whilst at Cairnryan Quarry a graptolite assemblage referred to the *gracilis* Biozone by the Survey (Appendix 1, locality 213) has *H. mucronatus* with *D. superstes* and *L. cf. costatus*. Data from the R-Mode cluster analysis place *L. costatus* and *H. mucronatus* in clusters with *C. bicornis* s.l. (Fig. 4), suggesting that these three species originate at about the same level in the Caradoc.

At Morroch Bay [NGR NX 015 525] are several Caradoc graptolite-bearing localities including assemblages identified by the Survey as *gracilis* (localities 227, 229), *gracilis-peltifer* (localities 228, 230), *wilsoni* and *clingani* Biozone age (Fig. 7). One of the *gracilis-peltifer* localities, with eight taxa, is 'sandwiched' by the two *gracilis* Biozone localities bearing *N.*

*gracilis* and *D. superstes* respectively (see Fig. 6). The *gracilis-peltifer* assemblage (locality 230) contains *D. sextans*, *C. bicornis* s.l. and *Thamnograptus scoticus*?, species that suggest a level in the lower range of *C. bicornis* s.l. (Fig. 1). The moderate diversity of this assemblage and the absence of *N. gracilis* and *D. superstes* might suggest a possible interregnum between *N. gracilis*- and *C. wilsoni*-bearing strata, though this cannot be confirmed with the available data, particularly as *D. sextans* and *C. bicornis* s.l. also occur commonly with *N. gracilis* and *D. superstes* (Fig. 5).

Of the remaining 8 localities on the Rhins of Galloway referred by the Survey to the *gracilis* or *peltifer* Biozone, two localities at Water of Luce (locality 225) and Portayew Bay, south of Morroch Bay (locality 231), yield assemblages with *D. superstes* (Stone 1995, appendix 2, localities 20, 42) and may belong to horizons in the upper range of *N. gracilis* (see Fig. 1). None of the remaining 6 assemblages (localities 215, 216, 18, 220, 222, 226) yield graptolites diagnostic of a discrete *peltifer* Biozone: they are generally characterized by low-diversity and widespread taxa such as *C. bicornis* s.l., *D. rectus*, *L. costatus* and *L. harknessi*.

### New Galloway-Thornhill

Survey of the New Galloway-Thornhill district (BGS Scotland 1:50 000 Sheets 9W and 9E; McMillan 2002, appendix 1) identified six graptolite-bearing localities in Moffat Shale underlying the Portpatrick Formation and assigned to the *gracilis* or *peltifer* Biozone. Of these, only one was referred to the *peltifer* Biozone definitely, at Appin Burn (locality 239). This contains a moderate diversity fauna of seven taxa including *D. ziczac*, *C. bicornis bicornis*, *L. harknessi* and *D. nicholsoni*. All of these species have ranges which overlap with the upper range of *N. gracilis* and *D. superstes* and they are therefore not diagnostic of a separate *peltifer* Biozone (see Fig. 1). Locality 239 plots with several moderate diversity *gracilis* Biozone assemblages in Figure 3.

Two graptolite assemblages at Dibbin Lane were referred by the Survey to the *gracilis* Biozone. One of these (locality 236) yields a moderate-diversity assemblage with *Glyptograptus euglyphus*, *C. tricornis*, *D. exilis*, *D. superstes* and *N. gracilis*. The second (locality 237) yields *L. costatus*, *L. harknessi*, *C. antiquus* s.l., *N. gracilis* and *N. pertenuis*? and represents an horizon in the upper range of *N. gracilis* (see Fig. 1). It clusters with several moderate-diversity *gracilis* Biozone assemblages with faunas indicative for the *N. gracilis/C. bicornis*-bearing part of the Caradoc (Fig. 3). Three other faunas are identified as *gracilis – peltifer*. Two of these, from Appin Burn (locality 238) and Glenjaan Burn (locality 240) are low-diversity faunas of 3 to 4 taxa including *C. bicornis bicornis*. Importantly, the Appin Burn locality indicates the overlap of *H. teretiusculus* in its upper range with *C. bicornis* s.l. One further *gracilis-peltifer* locality, at Appin Burn (locality 241), yields a high-diversity fauna of eleven species, including *D. ziczac*, *L. costatus*, *D. nicholsoni*, *C. bicornis bicornis* and two *Corynoides* species, *C. calicularis* and *C. serpens*. This assemblage might indicate an interregnum between *N. gracilis*-bearing and *C. wilsoni*-bearing strata. However, it plots with the Lambfoot Linn assemblage of locality 246 in Figure 4, a locality that bears a high-diversity fauna without *N. gracilis* or *D. superstes*, but which bears *L. grandis* considered indicative of the *gracilis* Biozone. Equally then, the graptolite assemblage of locality 241 might also represent a horizon in the upper range of *N. gracilis*.

### Kirkudbright-Dalbeattie

Survey of the Kirkudbright-Dalbeattie district (BGS Scotland 1:50 000 Sheets 5W, 5E and part of 6W [Kirkbean Sheet], Lintern and Floyd 2000, appendix 1A) identified four localities of *gracilis* Biozone age within the Moffat Shale Group (Appendix 1, localities 232-235). These faunas are all of low-diversity (3 to 5 taxa per locality) and plot with low-diversity assemblages in Figure 3. They variously yield *Dicellograptus divaricatus* (and its subspecies *D. v. rigidus*), *D. intortus*, *N. gracilis*, *D. superstes*, *H. bimucronatus* and *C. antiquus*?. The range of the latter

species in Scotland suggests, at Tottlehams Glen (localities 232 and 233), where the accompanying fauna includes *D. divaricatus*, a stratigraphical level in the upper range of *N. gracilis* and below the first occurrence of *C. wilsoni* (see Fig. 1). One further locality (not included in the cluster analysis), at Kilnotrie [c. NX 751 673], is referred to the *peltifer* or *wilsoni* Biozone. It yields only *C. bicornis bicornis* (Fig. 1), but lies close to a locality from which a *clingani* Biozone fauna is recorded and might represent a level in the *wilsoni* Biozone.

#### Kirkcowan-Wigtown

Modern graptolite data from the Kirkcowan-Wigtown district (BGS 1: 50 000 Sheets 4W and 4E) are not yet published. Biostratigraphy reports by Adrian Rushton and Steve Tunnickliff detail the graptolite biostratigraphy at numerous localities and are available for consultation at the BGS. Four localities in this area were identified by the Survey as bearing lower Caradoc graptolite assemblages. At Tanylaggie Flow (Appendix 1, locality 242) a moderate-diversity assemblage of six taxa comprising *D. superstes*, *N. gracilis*, *C. bicornis peltifer*, *D. exilis*, *D. salopiensis* and *Hallograptus* fragments indicates a stratigraphical level in the upper range of *N. gracilis* (Fig. 1). Thus, some moderate-diversity graptolite assemblages can yield precise age-diagnoses. At Camrie Burn (locality 243) a high-diversity assemblage identified by the Survey as *peltifer* Biozone comprises: *C. bicornis* s.l., *N. brevis*, *C. calicularis*, *C. tricornis*, *D. nicholsoni*, *D. ziczac*, *L. harknessi*, *P. scharenbergi*, *O. cf. whitfieldi*, *O. calcaratus cf. basilicus* and *Pseudoclimacograptus* sp. Except for *O. calcaratus cf. basilicus*, which is normally typical of higher horizons (see Williams 1982), all of these taxa are also known from stratigraphical levels in the upper range of *N. gracilis* (Fig. 1). Indeed, this locality plots amongst moderate-diversity *gracilis* Biozone assemblages in Figure 3, which, like this assemblage are characterised by widespread taxa of the lower Caradoc. The Camrie Burn locality might represent an interregnum between *N. gracilis*- and *C. wilsoni*-bearing strata, as suggested for similar assemblages elsewhere (e.g. localities 143, 239): low-diversity faunas from several adjacent localities at Camrie Burn seem to suggest this. Or, the assemblage may represent a stratigraphical level in the upper range of *N. gracilis*, where, however, *N. gracilis* and *D. superstes* are absent: at least one high-diversity graptolite assemblage at Glenkiln Burn (locality 246) lacks *N. gracilis* and *D. superstes* but is probably referable to this interval on the basis of *L. grandis* (see also discussion above). Two further localities at Camrie Burn (locality 244) and Garwachie roadside (locality 245) were identified by the Survey as *gracilis* or *peltifer* Biozone. These yield poorly diverse faunas, at Garwachie including *Orthograptus* sp. and *C. bicornis* s.l., and at Camrie Burn long-ranging forms such as *D. aff. ramosus*, *C. cf. bicornis* s.l. and *D. cf. exilis* (see Fig. 1). At the latter locality *D. cf. angulatus* is also recorded though this is typically a much younger form (see Zalasiewicz *et al.* 1995). Both of these assemblages suggest a level in the Caradoc at or above the first occurrence of *C. bicornis* s.l., but below the level of *C. wilsoni* (see Fig. 1).

#### Moffat-Ettrick district

Lower Caradoc graptolites from the Moffat-Ettrick district (BGS 1: 50 000 Scotland Sheets 16W and 16E) were reported in detail by Lapworth (1878). These have not been revised by the Survey and have not been included in the cluster analysis. However, several assemblages are worth mentioning as part of the overall review of lower Caradoc graptolite faunas presented here.

At Craigmichan Scaur [approximately, NGR NS 165 063], Lapworth (1878, p. 303) identified two graptolite assemblages which together include *Dicellograptus divaricatus*, *Diplograptus foliaceus*, *Thamnograptus typicus*, *Dicranograptus ziczac*, '*Climacograptus perexcavatus*', '*Diplograptus tricornis*' and '*Climacograptus scharenbergi*'. These graptolites suggest a level in the lower range of *C. bicornis* s.l. (see Fig. 1), but cannot be used to differentiate either the *gracilis* or *peltifer* Biozone *per se*. Later, Peach and Horne (1899, p. 103) reported assemblages at Craigmichan Scaur which include *N. gracilis* and also identify the

*wilsoni* Biozone. Based on old records, all five Caradoc graptolite biozones recognised by Elles (1925), including the *peltifer* Biozone, were recorded on the BGS' Moffatdale Special Sheet at this locality (British Geological Survey 1991).

At the main cliff in Dob's Linn, Lapworth (1878, p. 306) reported a fauna with *D. superstes*, *D. ziczac*, *D. foliaceus*, *C. bicornis* and *C. bicornis peltifer*. Although this locality is now covered with scree (see Webb *et al.* 1993, p. 6), the fauna suggests the level in the lower Caradoc where *D. superstes* and *C. bicornis* s.l. have overlapping ranges (see Fig. 1). At Berrybush Burn, Lapworth (1878, pp. 303-5) reported graptolites which also indicate this level, with *N. gracilis*, *C. bicornis* s.l., *D. ziczac* and many other taxa. This interval is also suggested by the graptolites recorded at this locality by Peach and Horne (1899, p. 119) which include '*Coenograptus gracilis*', *Didymograptus superstes*, *Climacograptus bicornis* s.l., *Dicellograptus patulosus* and '*Diplograptus whitfieldi*'.

## 6. REDEFINING THE LOWER CARADOC GRAPTOLITE BIOZONES IN SCOTLAND

Using the existing diagnoses of graptolite biozones, the Survey typically identified the *peltifer* Biozone by assemblages bearing the species *A. leptotheca*, *D. foliaceus*, *L. costatus*, *L. harknessi*, *C. bicornis* s.l., *C. bicornis peltifer* and *C. antiquus*, and by the absence of *Nemagraptus* spp., *D. superstes*, *L. grandis*, *D. geniculatus* and *D. alabamensis*. Except for the latter two species, which are diagnostic of the lowermost part of the Caradoc (sub-*C. bicornis*), all of the graptolites that are typically used to identify the *peltifer* Biozone have been recorded as having overlapping ranges with *N. gracilis* and *D. superstes*. Furthermore, cluster-analysis shows that low-diversity graptolite assemblages (particularly those with less than 5 named species) often lack one or both of *N. gracilis* or *D. superstes*, bringing into doubt all low-diversity assemblages identified as the *peltifer* Biozone. As there also appear to be no species unquestionably arising for the first time in the *peltifer* Biozone, that biozone remains without adequate definition. It appears to be no more than an interregnum between *N. gracilis*-bearing and *C. wilsoni*-bearing strata. This necessitates the following redefinition of the lower Caradoc graptolite biozones in southern Scotland.

1. Because of the wide occurrence of *C. bicornis* s.l. and its association at the same stratigraphical level with the incoming of the species *A. leptotheca*, *O. apiculatus*, *D. ziczac* and many others (see Fig. 1), in most cases, the problems of distinguishing the *gracilis* from the *peltifer* Biozone can be resolved by redefining the *gracilis* Biozone as a partial range zone and recognising a succeeding *Climacograptus bicornis* Biozone, with a lower *Orthograptus apiculatus-Dicranograptus ziczac* Sub-biozone (see Fig. 1).
2. As redefined for southern Scotland, the *gracilis* Biozone becomes a partial range zone represented by graptolite assemblages such as those from the Superstes Mudstone Formation of the Midland Valley (see Rushton 2001b), Currarie Formation of the Northern Belt of the Southern Uplands (see Armstrong *et al.* 1998), and possibly that from the Kirkcolm Formation of the New Cumnock-Leadhills district (e.g. Shield Burn, locality 86 of Appendix 1). These assemblages are earlier than the first occurrence of *C. bicornis* s.l. and are characterised by *Dicellograptus alabamensis* and possibly by *D. geniculatus*. The presence of *Leptograptus validus* s.l. in one of these faunas, from the Currarie Formation (see Armstrong *et al.* 1998), may indicate a high-level in the sub-*C. bicornis*-bearing part of the Caradoc, equivalent to the *L. validus* Sub-biozone of Bettley *et al.* (2001, fig. 7).
3. The *bicornis* Biozone and its lower division the *apiculatus-ziczac* Sub-biozone is marked by the first appearance of the eponyms. Numerous other taxa also make their first appearance in Scotland at approximately this level (see Fig. 1), though several (e.g. *C. antiquus*, *D. foliaceus*, *D. salopiensis*, *H. mucronatus*) are known from older horizons in southern Britain (see Bettley

*et al.* 2001). At least the lower part of the *apiculatus-ziczac* Sub-biozone is *N. gracilis*-bearing (formerly the upper part of the *gracilis* Biozone as recognised in Scotland; see Fig. 1) in which the ranges of *D. superstes*, *N. gracilis*, *C. bicornis* s.l., *O. apiculatus*, *D. ziczac* and many other species overlap (Fig. 1). Most of the firmly identified *gracilis* Biozone localities in the Southern Uplands are of this age. The occurrence of *O. apiculatus* in these assemblages might also signal a similar level to the lower part of the *foliaceus* graptolite Biozone of southern Britain (see Bettley *et al.* 2001), though in Scotland it is clear that *N. gracilis* and *O. apiculatus* have overlapping ranges.

4. The upper part of the *apiculatus-ziczac* Sub-biozone has a similar complement of species that occur in the lower part of the Sub-biozone, but lacks *N. gracilis* (Fig. 1): this interval is the probable equivalent of the *peltifer* Biozone as formerly recognised, though not all localities previously referred to that biozone necessarily represent this interval (see point 5 below). In Scotland, the *apiculatus-ziczac* Sub-biozone is succeeded by the *wilsoni* Sub-biozone, formerly the *wilsoni* Biozone (see Williams 1994), indicated by the first appearance of the eponym *Climacograptus wilsoni* (Fig. 1) and representing the upper interval of the *bicornis* Biozone in Scotland.
5. In practice, the interval between *N. gracilis*-bearing and *C. wilsoni*-bearing strata in the upper part of the *apiculatus-ziczac* Sub-biozone will always be difficult to identify in the structurally complex Southern Uplands Terrane. There is an indication that individual lower Caradoc graptolite assemblages of 10 or more species that lack *N. gracilis* and *D. superstes* may signal this interval, though this is not always the case. This is demonstrated by the high-diversity locality at Kiln Burn (locality 246) which yields *L. grandis*, regarded as diagnostic of the *gracilis* Biozone, though *N. gracilis* itself is absent. Even in well exposed and intensively studied sections such as Glenkiln Burn or Morroch Bay, it is not clear whether any of the graptolite assemblages can be positively referred to such an interval. At many localities, poorly diverse graptolite assemblages still yield faunal assemblages that indicate only a general level within the Caradoc below the *clingani* Biozone.

## 7. PALAEOECOLOGY

Although no quantitative analysis of the graptolite faunas has been undertaken for this study, the 'gracilis Zone Database' does indicate the frequency of occurrence of taxa in the 157 lower Caradoc graptolite-bearing localities analysed for southern Scotland (see Appendix 2). Thus, species like *Didymograptus superstes*, *Nemagraptus gracilis* and *Cryptograptus tricornis* are widespread, whilst others, such as *Amplexograptus arctus* and *Glossograptus armatus* appear rarely. It is evident that rare species cluster in those localities which yield high-diversity faunas (Fig. 3). Williams *et al.* (2003) noted a similar association of rare graptolite taxa in higher-diversity assemblages in the Caradoc of South Wales. They interpreted high-diversity assemblages as representing graptolite climax communities from the overlying water column. Low-diversity assemblages in South Wales are typified by species which occur across a spectrum of low- to high-diversity faunas and probably represent generalists, able to withstand more adverse environmental conditions in the water column. In south Wales species of *Normalograptus* are particularly widespread in various facies of the Caradoc rock sequence (Williams *et al.* 2003). In the Southern Uplands, *Didymograptus superstes*, *Cryptograptus tricornis* and many other commonly occurring taxa (see Appendix 2) appear to have had similarly wide environmental tolerance.

## 8. CONCLUSIONS

Analysis of graptolite-bearing localities referred over several decades to the *peltifer* Biozone indicates that there is no discrete graptolite assemblage that can be used to distinguish this interval. This necessitates a revision of the lower Caradoc graptolite biozones in Scotland. The lowermost Caradoc *gracilis* Biozone is redefined as a partial range zone characterised by *N. gracilis*, *D. alabamensis* and possibly *D. geniculatus*. It is succeeded by the *bicornis* Biozone which is divisible into a lower *apiculatus-ziczac* Sub-biozone and an upper *wilsoni* Sub-biozone (Fig. 1). The *apiculatus-ziczac* Sub-biozone bears *N. gracilis*, at least in its lower part. The upper part of the Sub-biozone appears to be an interregnum, in which *N. gracilis* and *D. superstes* are absent and only longer-ranging species are present. This interregnum may be the equivalent of the former *peltifer* Biozone. However, there is insufficient data to allow formal subdivision of the *apiculatus-ziczac* Sub-biozone into lower (*gracilis*-bearing) and upper (non *gracilis*-bearing) intervals. For the lower Caradoc, cluster-analysis suggests the number of graptolite species needed to provide a firm age assignment at any one locality: the firmest age assignments are based on assemblages of 10 or more graptolites; lower-diversity assemblages are generally less well-constrained as they lack many age diagnostic species.

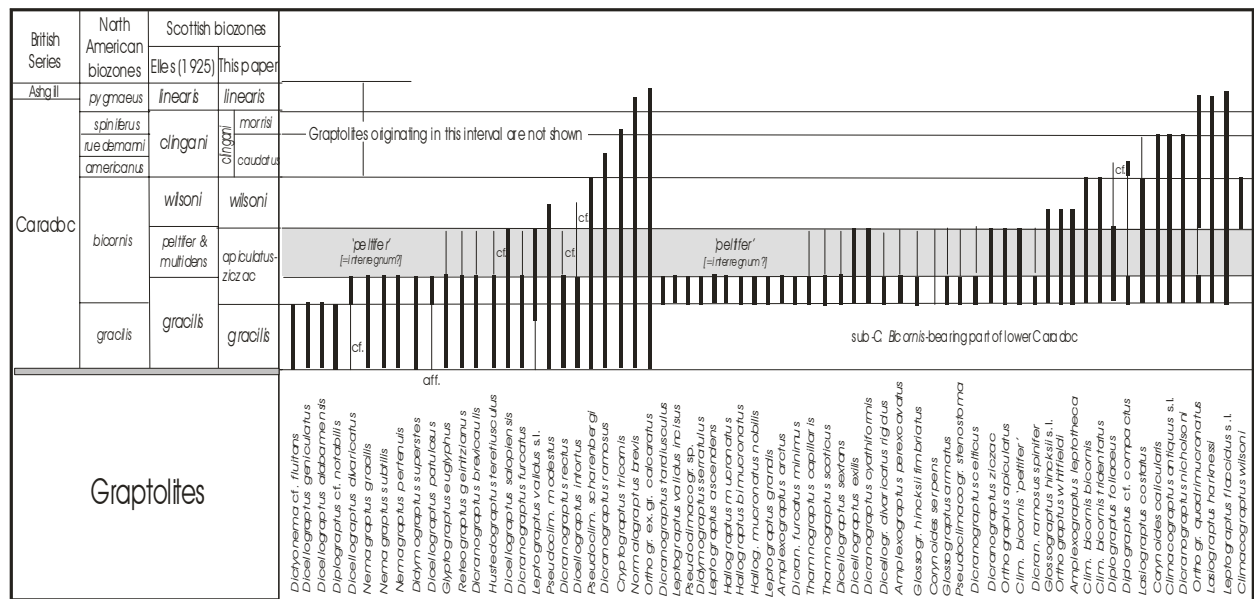
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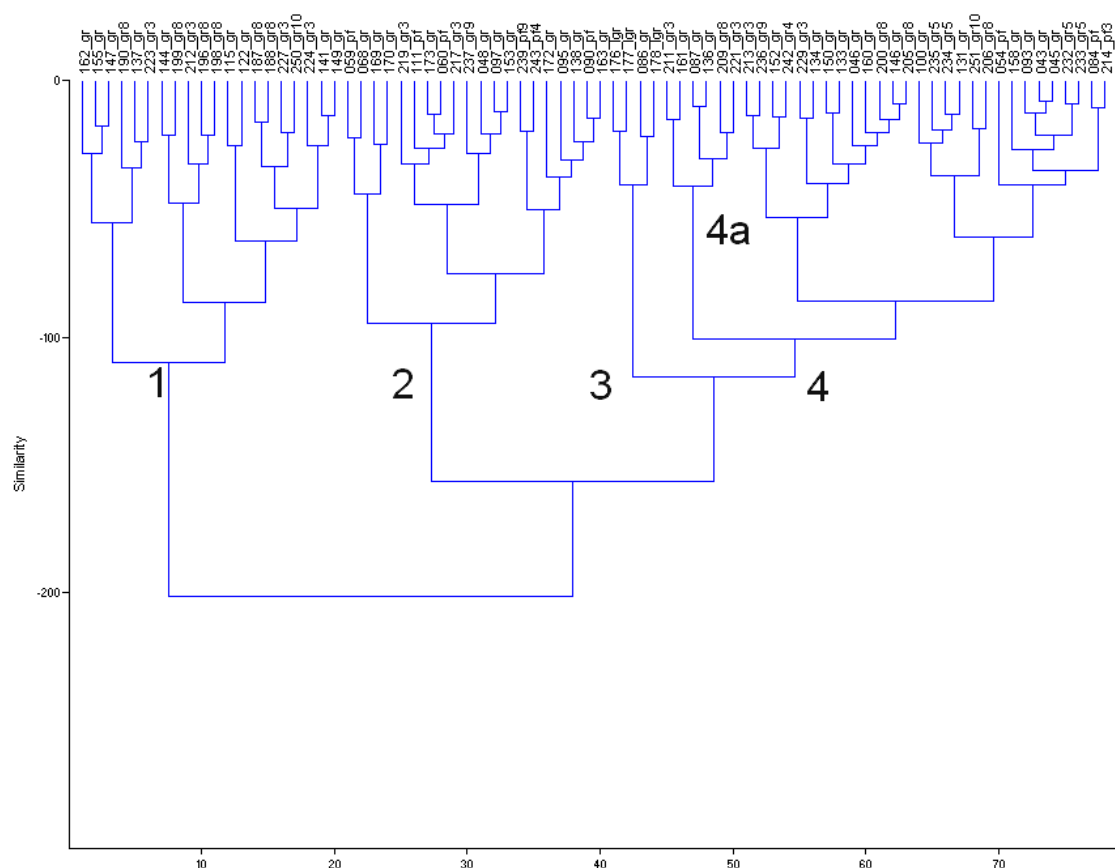
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## Explanation of Figures



**Figure 1.** Graptolite biozones recognised in the Caradoc of southern Scotland by Elles (1925), the approximately equivalent zones in North America and southern Britain, and the revised biozonation for the lower Caradoc interval of Scotland for this paper. The graptolite ranges are reconstructed from data in Lapworth (1878), Peach and Horne (1899), Elles and Wood (1901-1918), Stone (1995), Rushton *et al.* (1996b), Rushton (2001b), Armstrong *et al.* (1998), Floyd (1999, 2001), Lintern and Floyd (2000), McMillan (2002), Zalasiewicz *et al.* (1995), Williams (1982, 1994) and Palaeosaurus©, and from the results of the Q- and R-Mode cluster analysis (Figs 3-5). Some graptolite data for the New Cumnock-Leadhills and Kirkcowan-Wigtown districts are unpublished, but are available for consultation at the BGS. Some species and subspecies occurring in this stratigraphical interval (for example of *O. ex gr. calcaratus* subspecies) are not shown. *L. validus* s.l. is depicted as ranging through the upper part of the *gracilis* Biozone as redefined. This is based on its occurrence in the Currarie Formation (see Armstrong *et al.* 1998), regarded as the sub-*C. bicornis*-bearing part of the Caradoc, and also by reference to its relatively late appearance in southern Britain (see Bettley *et al.* 2001). The range of *D. superstes* is depicted as similar to *N. gracilis*, with which it occurs very commonly in southern Scotland (see Fig. 5). *N. gracilis* also occurs with *D. superstes* in Wales (see Cave and Rushton 1996, p. 57), though Bettley *et al.* (2001, fig. 7) depict a younger first appearance for *D. superstes*. Some species, such as *Climacograptus antiquus*, are known from older horizons in Wales (Bettley *et al.* 2001). Given that the ranges of species are reconstructed from many stratigraphically incomplete sections, coincidence of the first occurrence of species in the range data should only be considered approximate.





**Figure 3.** Cluster-analysis in Q-Mode of 66 graptolite-bearing localities from the Southern Uplands identified by the BGS as *gracilis* Biozone, 9 localities identified as *peltifer* Biozone (see Appendices 1-4 for locality details and species complements) and 3 ‘test’ localities referred to the lower *gracilis* Biozone (for which, see Rushton *et al.* 1996b, Armstrong *et al.* 1998, and Rushton 2001b). The analysis is designed to identify differences in graptolite assemblages from localities that have been firmly assigned to the *gracilis* and *peltifer* biozones. Several species occur across the spectrum of localities referred to the *gracilis* Biozone, particularly *Didymograptus superstes*, present at 44 localities, in both low- and high-diversity assemblages. Other species which occur commonly in assemblages referred to the *gracilis* Biozone are: *Nemagraptus gracilis* (38 localities), *Cryptograptus tricornis* (35 localities), *Dicellograptus exilis* (26 localities), *Climacograptus bicornis* s.l. (over 26 localities), *Dicellograptus salopiensis* (23 localities), *Pseudoclimacograptus scharenbergi* (19 localities), *Dicranograptus rectus* (18 localities), *Hallograptus mucronatus* (18 localities), *Dicellograptus intortus* (17 localities), *Hustedograptus teretiusculus* (16 localities), *Dicellograptus sextans* (16 localities), and *Orthograptus* ex gr. *calcaratus* (more than 15 localities).

Based on the distribution of graptolites through the clustergram, four main clusters are differentiated. The majority of the high-diversity assemblages (10 or more taxa) occur on the left of the clustergram. Some 20 of these localities, all assigned to the *gracilis* Biozone by the Survey, form Cluster (1). These are characterised by between 10 to 25 species and bear *N. gracilis* mostly with *Climacograptus bicornis* s.l. (except at three localities, 196, 198 and 224). Species which are characteristic of, or more commonly occur in Cluster 1 are: *Diplograptus foliaceus*, *Reteograptus geinitzianus*, *Amplexograptus perexcavatus*, *A. leptotheca*, *A. arctus*?, *Leptograptus ascendens*, *Dicranograptus cyathiformis*, *D. brevicaulis*, *D. tardiusculus*, *D. ziczac* and *Climacograptus bicornis tridentatus*. These assemblages appear to be characteristic of the stratigraphical interval of the lower Caradoc where *N. gracilis* and *C. bicornis* s.l. have overlapping ranges (Fig. 1). In some assemblages, either *Dicranograptus ziczac*, *C. bicornis peltifer*, *Orthograptus apiculatus* and *A. leptotheca* co-occur with *N. gracilis* and *D. superstes* (e.g. localities 144, 147, 162), demonstrating the overlapping ranges of these species. No

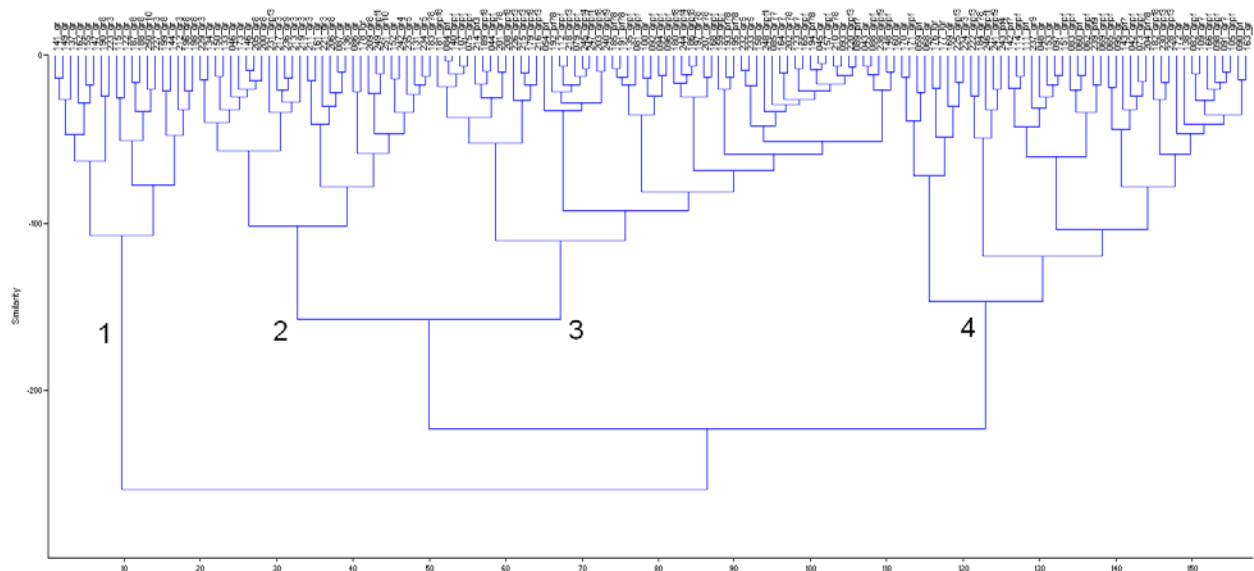
graptolite assemblage assigned by the Survey to the *peltifer* Biozone occurs within this area of the clustergram.

To the right of Cluster (1) are 58 lower Caradoc localities including 9 graptolite assemblages referred to the *peltifer* Biozone, and the three ‘test’ localities referred to the lower *gracilis* Biozone. These localities form 3 clusters (2-4). Cluster (2), which includes six of the localities referred to the *peltifer* Biozone, is the last place in the clustergram where ‘firmly identified’ species typical for the *C. bicornis*-bearing part of the Caradoc commonly occur, particularly *C. bicornis peltifer*, *D. ziczac*, *O. apiculatus* and *A. leptotheca*. Assemblages in this cluster referred to the *gracilis* Biozone generally bear one or both of *N. gracilis* and *D. superstes*, whereas localities referred to the *peltifer* Biozone in this cluster lack these species. Nevertheless, the close association of six *peltifer* Biozone assemblages with 14 *gracilis* Biozone assemblages demonstrates the many taxa that are commonly recorded from assemblages referred to these biozones (see also Fig. 1). As for Cluster (1), higher diversity assemblages (9-17 species) referred by the Survey to the *gracilis* (localities 68, 169) and *peltifer* biozones (localities 59, 170) occur towards the top of Cluster 2.

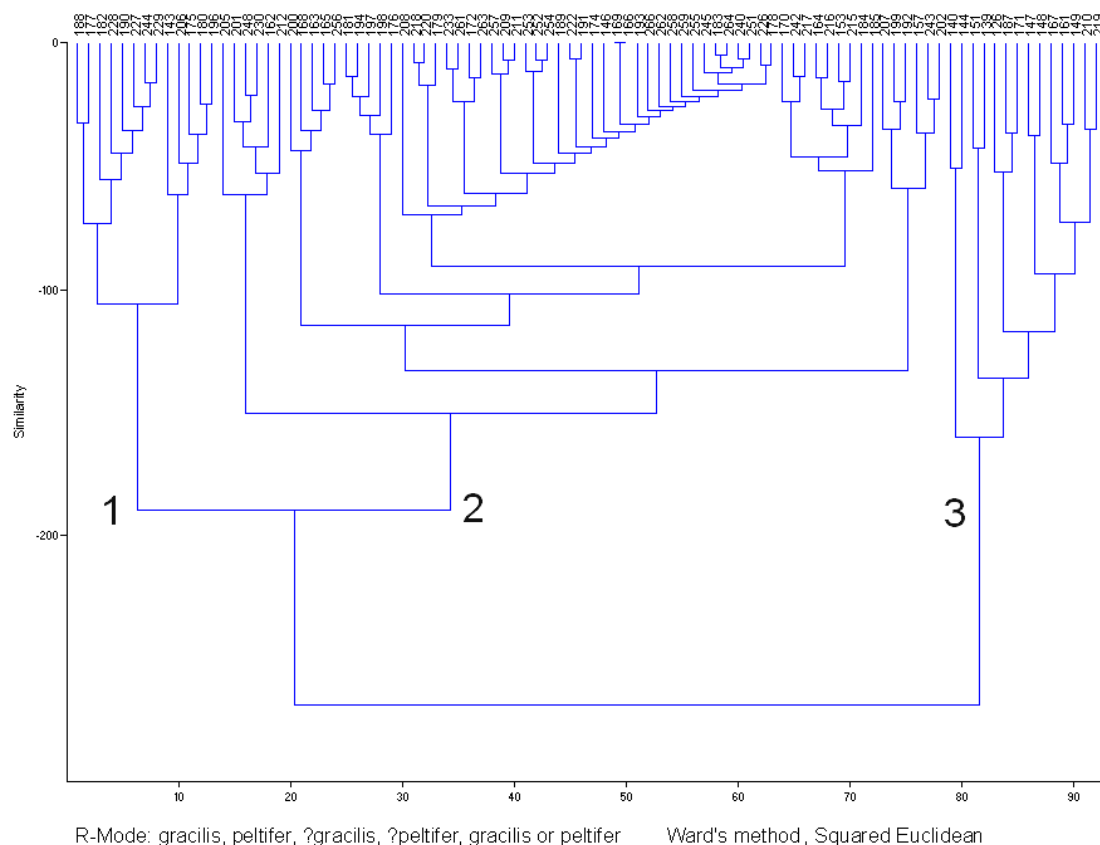
The three ‘test’ localities of the older, sub-*C. bicornis*-bearing part of the lower Caradoc from the Midland Valley (Rushton 2001b; Rushton *et al.* 1996b) and north-westernmost part of the Southern Uplands (Armstrong *et al.* 1998) form the small Cluster 3 of high-diversity assemblages near the middle of the Figure (localities 176-178). This cluster includes one fauna from the New Cumnock-Leadhills district at Shield Burn (locality 86), which yields a possible *Dicellograptus geniculatus*, regarded as diagnostic of the *gracilis* Biozone in its North American usage (i.e. a partial range zone, see Williams 1995, text-fig. 4). Shield Burn might therefore be the oldest graptolite-bearing horizon in this area, though additional graptolite evidence is needed to confirm this. Importantly, the assemblages of Cluster 3 do not include graptolites regarded as diagnostic of the *C. bicornis*-bearing part of the lower Caradoc, particularly *C. bicornis* s.l., *C. bicornis peltifer*, *D. ziczac*, *O. apiculatus* and *A. leptotheca* (see above).

Some 34 localities with low- to moderate-diversity graptolite assemblages (between 1–9 species) or with several taxa described in open nomenclature (see localities 209 and 221, characterised by 10 and 11 taxa respectively) are situated to the right of Cluster 3, and form Cluster 4. The 31 localities in this cluster referred to the *gracilis* Biozone yield *D. superstes*, *C. bicornis* s.l. and *N. gracilis* only intermittently (and sometimes questionably), together with many of the more common lower Caradoc taxa. Some of these assemblages, particularly those that cluster towards the top of the figure (differentiated as sub-cluster 4a), can be referred to that part of the Caradoc where *C. bicornis* s.l. and *N. gracilis* have overlapping ranges (for which, see Fig. 1), but many others, particularly those lower diversity assemblages below locality 221 and the three *peltifer* Biozone assemblages that cluster here, contain graptolites that indicate only an imprecise level in the sub-*C. wilsoni*-bearing part of the Caradoc. That sub-*C. bicornis*-bearing assemblages of Cluster 3 plot between assemblages of clusters 2 and 4 reflects the many long-ranging taxa of these lower Caradoc assemblages.

The clustergram also indicates that the *peltifer* Biozone assemblages are distinguishable from the *gracilis* Biozone assemblages only by the absence of *N. gracilis* and *D. superstes*. Their complement of species is entirely those of the *C. bicornis*-bearing upper range of *N. gracilis*, such as *D. exilis*, *C. tricornis*, *G. hincksi*, *A. leptotheca*, *D. patulosus*, *L. harknessi*, *C. bicornis* s.l., *O. apiculatus* and *D. cyathiformis* (see Appendices 2-4 and Figure 1). Evaluation of the dataset indicates that many age-diagnostic species are lacking from low-diversity faunas, so that *peltifer* Biozone age assignments based on low-diversity assemblages are untenable.



**Figure 4.** Cluster-analysis in Q-Mode of all graptolite-bearing localities from the Southern Uplands (see Appendices 1-4 for locality details and species complements) and 3 ‘test’ localities referred to the lower *gracilis* Biozone (for which, see Rushton *et al.* 1996b, Armstrong *et al.* 1998, and Rushton 2001b). Assemblages of Cluster (1) in Figure 3 also cluster together on the left of the clustergram: no fauna referred to the *peltifer* Biozone is present in this cluster. This appears to be a very stable cluster of high-diversity assemblages indicative of the interval of the Caradoc where *N. gracilis* and *C. bicornis* s.l. have overlapping ranges (Fig. 1). At least 3 other clusters are formed in Figure 4, but these are not representative of clusters 2-4 of Figure 3. Instead, the inclusion of graptolite assemblages from the 79 localities with loosely defined age assignments, many of which are characterised by long-ranging and widespread taxa, results in 3 clusters of low stratigraphical significance.

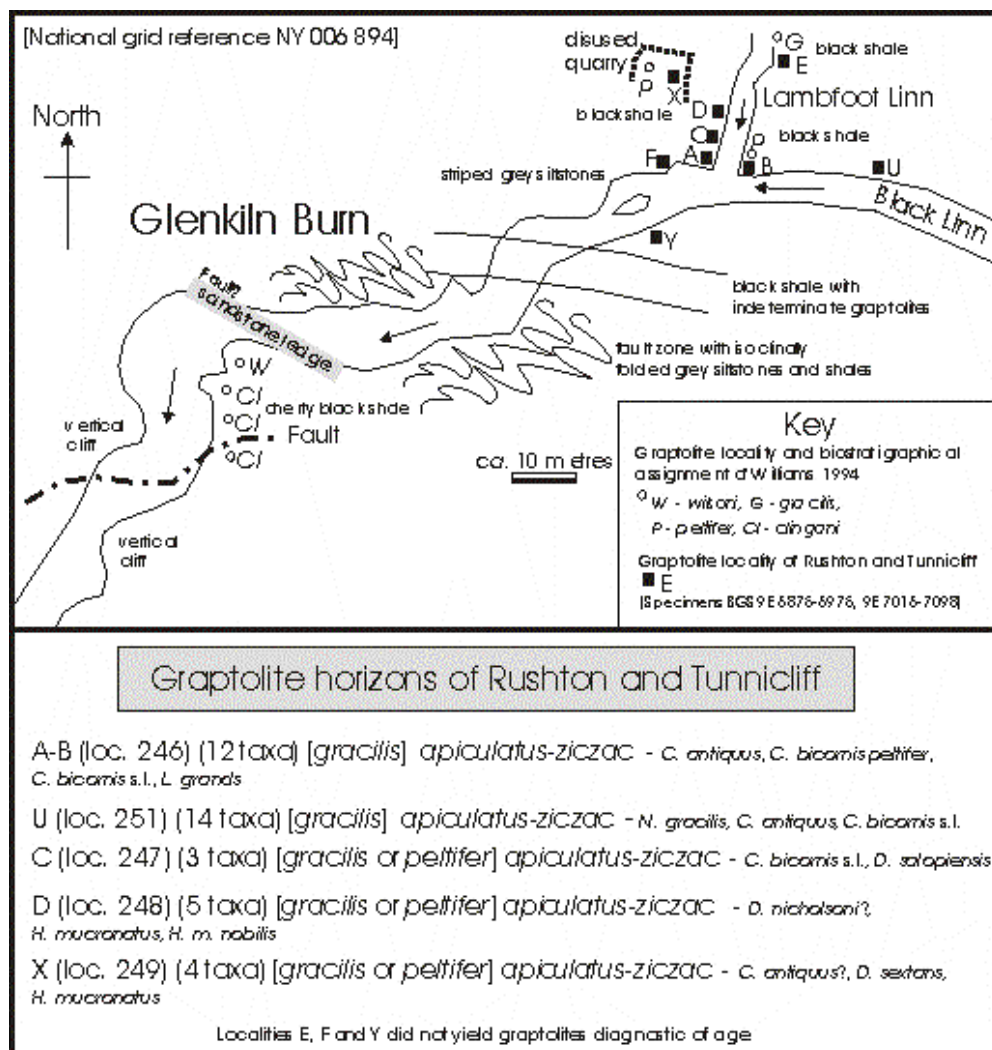


**Figure 5.** Cluster analysis in R-Mode for the 91 graptolite taxa recorded from all of the lower Caradoc graptolite-bearing horizons analysed herein (see Appendices 1, 2). Three clusters are differentiated. Thirteen taxa associated with *Nemagraptus gracilis* including *Climacograptus bicornis* s.l. form Cluster (3). All of these graptolites represent very common elements of the lower Caradoc fauna. Thus, *Cryptograptus tricornis* is present at 64 of the 154 localities from the Southern Uplands. Other species in this cluster which occur commonly in the Southern Uplands are: *Climacograptus bicornis* s.l. (over 56 localities), *Didymograptus superstes* (49 localities), *Nemagraptus gracilis* (44 localities), *Dicellograptus exilis* (40 localities), *Dicellograptus salopiensis* (37 localities), *Pseudoclimacograptus scharenbergi* (29 localities), *Dicranograptus rectus* (27 localities), *Glyptograptus euglyphus* (23 localities), *Hustedograptus teretiusculus* (22 localities), *Dicellograptus sextans* (22 localities), *Hallograptus mucronatus* (21 localities), *Orthograptus* ex gr. *calcaratus* (more than 20 localities) and *Pseudoclimacograptus modestus* (15 localities).

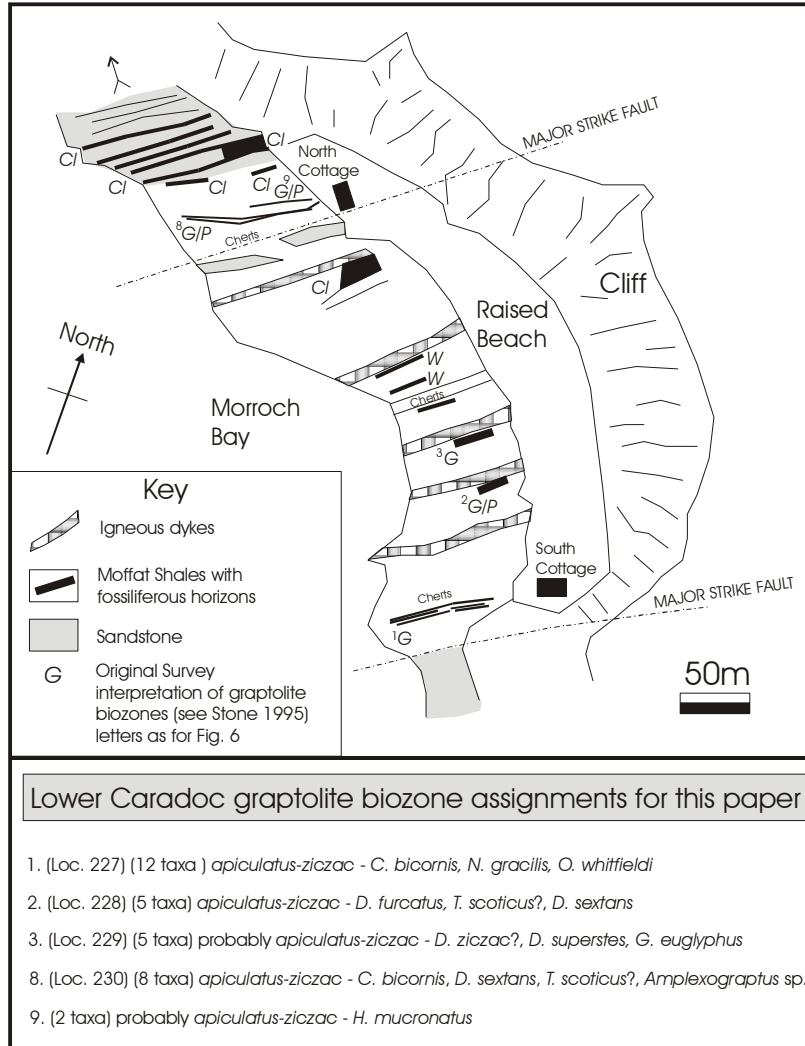
Cluster (1) is also characterised by (thirteen) commonly occurring graptolites comprising: *Dicellograptus intortus* (29 localities), *Amplexograptus leptotheca* (22 localities), *Dicranograptus nicholsoni* (20 localities), *Glossograptus hincksii* s.l. (17 localities), *Normalograptus brevis* (16 localities), *G. fimbriatus* (15 localities), *Lasiograptus costatus* (15 localities), *Dicellograptus rigidus* (12 localities), *C. bicornis bicornis* (12 localities), *Leptograptus validus* (8 localities), *Diplograptus foliaceus* (7 localities) and *Dicranograptus brevicaulis* (7 localities). All of these graptolites have also been recorded with *Nemagraptus* or *D. superstes*.

In the middle of the figure are 65 taxa forming Cluster (2). The overall significance of this cluster is low, as it tends to reflect less commonly occurring graptolites such as *Thamnograptus scoticus* (257) and *Amplexograptus arctus* (199). Some sub-clusters indicate the relatively common occurrence of: *C. bicornis peltifer* (176) with *D. celticus* (198) and *D. divaricatus* (197); *D. ziczac* (192) with *O. apiculatus* (157); and *D. tardiusculus* (217) with *A. perexcavatus* (242). Within this broad cluster *Nemagraptus pertenuis* (263), *N. subtilis* (253) and

*Didymograptus serratulus* (259) also plot, as do the lower *gracilis* Biozone indicators *Dicellograptus alabamensis* (252) and *D. geniculatus* (209).



**Figure 6.** Graptolite-bearing localities for the Glenkiln Burn and Lambfoot Linn section (partly adapted from Williams 1994). None of the faunas collected by the BGS identify a discrete *peltifer* Biozone graptolite assemblage. The locality numbers of Appendix 1, collection numbers of Rushton and Tunnicliff's material, the number of taxa identified, the new age assignment and the previous age-assignments of the BGS (in square brackets; see Fig. 1 and main body of text) and key age-diagnostic species are indicated. One further BGS locality ('X', not shown) lies on the south bank of Black Linn about 50m upstream from locality U. It yields a moderate diversity assemblage (6 taxa) including *N. gracilis*, *C. antiquus*, *H. mucronatus*, *D. sextans*, *O. calcaratus acutus* and *D. aff. divaricatus* which suggest an horizon in the *apiculatus-ziczac* Biozone as defined in this paper (Fig. 1).



**Figure 7.** Graptolite-bearing localities for Morroch Bay, the Rhins of Galloway (see Stone 1995, fig. 9). Key graptolites for the five lower Caradoc horizons are given: numbers 1-3, 8 and 9 were used in a BGS internal report by Adrian Rushton and are employed here in brackets for continuity, with the locality numbers of Appendix 1 given adjacent to them. Graptolite species indicative of the *wilsoni* and *clingani* graptolite biozones are not shown (see Stone 1995).

## Explanation of Appendices

**Appendix 1.** The lower Caradoc graptolite-bearing localities for the BGS Southern Uplands graptolite localities and the three ‘test’ localities of the Currarie Formation and Midland Valley. The localities are listed by map sheet. For each locality the appendix provides a number for cross referencing with Figures 3 and 4 and the text, a brief locality name, the national grid reference, where applicable, the British Geological Survey’s original graptolite age assignment used for the cluster-analysis (where identified), an indication of how accurately the locality is positioned, and the graptolite taxa recorded. For the latter, ‘P’=present, whilst ‘cf.’, ‘aff.’ and ‘?’ indicate more tentative taxonomic assignments.

### Sheet 15

**42:** Docker Burn : NS 6655 1145 (+- 1m) :gracilis or peltifer

*Amplexograptus leptotheca* (P)

*Climacograptus bicornis* (P)

*Corynoides* (P)

*Cryptograptus tricornis* (P)

*dicranograptid stipe* (P)

*Pseudoclimacograptus modestus* (P)

**43:** N of Polhote Burn : NS 6836 1091 (+- 1m) :gracilis

*Hustedograptus teretiusculus* (P)

**44:** Polhote Burn : NS 6830 1085 (+- 0m) :gracilis or peltifer

*Dicellograptus exilis* (P)

*Dicranograptus rectus* (cf)

*Pseudoclimacograptus modestus* (P)

**45:** Polmarlach Burn : NS 6792 1153 (+- 0m) :gracilis

Climacograptus (sp)

**46:** Polmarlach Burn2 : NS 6790 1149 (+- 0m) :gracilis

Corynoides (sp)

Dicranograptus (P)

Didymograptus superstes (P)

Pseudoclimacograptus modestus (P)

**48:** Polmarlach Burn4 : NS 6783 1141 (+- 0m) :gracilis

Corynoides (sp)

Cryptograptus tricornis (P)

Dicellograptus exilis (?)

Dicranograptid (P)

Lasiograptus small species (P)

Pseudoclimacograptus modestus (cf)

**54:** Stoodfold Burn : NS 7677 1381 (+- 1m) :peltifer

Climacograptus bicornis (P)

Dicellograptus (P)

Lasiograptus (P)

Orthograptus apiculatus (?)

Pseudoclimacograptus (P)

**59:** Sowen Burn : NS 8542 1452 (+- 10m) :peltifer

Climacograptus bicornis bicornis (P)

Climacograptus bicornis peltifer (P)

Cryptograptus tricornis (P)

Dicellograptus patulosus (cf)

Dicranograptus ramosus longicaulis (P)

Lasiograptus costatus (P)

Leptograptus validus (P)

Normalograptus (sp)

Orthograptus calcaratus group (P)

**60:** Brandleys cottage : NS 81 11 (+- 100+m) :peltifer

Climacograptus bicornis bicornis (P)

Cryptograptus tricornis (?)

Dicellograptus patulosus (cf)

Glossograptus hincksii (P)

Thamnograptus (P)

**62:** Coal Burn : NS 8155 1142 (+- 10m) :probably gracilis or peltifer

Climacograptus bicornis bicornis (P)

Dicellograptus (sp)

Dicellograptus salopiensis (P)

Glossograptus hincksii (P)

**65:** old quarry hole : NS 8240 1230 (+- 10m) :gracilis or peltifer

Climacograptus (?)

Corynoides (sp)

Cryptograptus tricornis (?)

Dicellograptus intortus (P)

Glossograptus hincksii (P)

Glossograptus hincksii fimbriatus (P)

Lasiograptus costatus (cf)

Pseudoclimacograptus scharenbergi (cf)

Pseudoclimacograptus stenostoma (P)

**68:** Rein Gill : NS 9810 2590 (+- 10m) :gracilis

Climacograptus bicornis bicornis (P)

Climacograptus bicornis peltifer (P)

Cryptograptus tricornis (P)

Dicellograptus divaricatus (P)

Dicellograptus intortus (P)

Dicellograptus salopiensis (?)

Dicranograptus celticus (P)

Dicranograptus nicholsoni (P)

Dicranograptus rectus (cf)

Didymograptus superstes (P)

Glossograptus hincksii fimbriatus (P)

Lasiograptus costatus (P)

Leptograptus validus (P)

Leptograptus validus incisus (P)

Nemagraptus gracilis (P)

Normalograptus (P)

Orthograptus calcaratus group (P)

**69:** Rein Gill - contact with cherts : NS 9810 2590 (+- 0m) :gracilis or peltifer

Amplexograptus (P)

Climacograptus bicornis bicornis (P)

Climacograptus bicornis peltifer (P)

Cryptograptus tricornis (P)

Dicellograptus (sp)

Dicranograptus ziczac (P)

Normalograptus (sp)

**73:** Glenkip Cleuch : NS 8782 1699 (+- 0m) :gracilis or peltifer

Climacograptus bicornis (P)

Corynoides (sp)

Cryptograptus tricornis (P)

Dicellograptus (sp)

Dicellograptus intortus (cf)

Dicranograptus ramosus spinifer (P)

Lasiograptus costatus (P)

Nemagraptus gracilis (?)

Orthograptus calcaratus group (?)

Pseudoclimacograptus modestus (cf)

**75:** forestry track - Black Grain : NS 9812 2494 (+- 10m) :gracilis or peltifer

Amplexograptus leptotheca (P)

Dicranograptus ramosus (?)

Orthograptus apiculatus (cf)

**79:** Rein Gill, forestry track, HB355 : NS 9856 2620 (+- 1m) :gracilis or peltifer

Climacograptus bicornis (P)

Dicellograptus salopiensis (cf)

Dicranograptus ramosus spinifer (P)

**81:** Rein Gill, forestry track, HB357 : NS 9834 2606 (+- 1m) :gracilis or peltifer

Corynoides calicularis (cf)

Dicranograptus nicholsoni (cf)

Orthograptus apiculatus (P)

Pseudoclimacograptus modestus (P)

Thamnograptus (?)

**82:** Wandel Burn HB358 : NS 9775 2578 (+- 1m) :gracilis or peltifer

Climacograptus bicornis (P)

Corynoides (sp)

Cryptograptus tricornis (P)

Dicranograptus nicholsoni (cf)

Nemagraptus (?)

Normalograptus (sp)

Orthograptus apiculatus (P)

**83:** Well Hill : NS 841 150 (+- 0m) :gracilis or peltifer

Dicranograptus ramosus spinifer (P)

Glossograptus hincksii (P)

Lasiograptus harknessi (P)

Orthograptus (sp)

Pseudoclimacograptus modestus (?)

**84:** Kiln Burn, right bank : NS 7584 1462 (+- 1m) :peltifer

Amplexograptus leptotheca (P)

Dicellograptus exilis (P)

**85:** Kiln Burn, in stream : NS 7606 1456 (+- 1m) :gracilis??

Dicellograptus (sp)

dicranograptid stipe (P)

Pseudoclimacograptus (sp)

**86:** Shield Burn : NS 893 230 (+- 100m) :gracilis

Cryptograptus (sp)

Dicellograptus divaricatus (cf)

Dicellograptus geniculatus (?)

Dicellograptus patulosus (aff)

Dicellograptus salopiensis (P)

Dicranograptus furcatus (P)

Dicranograptus ramosus (P)

Didymograptus superstes (P)

Hustedograptus teretiusculus (P)

Nemagraptus gracilis (P)

Orthograptus calcaratus acutus (P)

Pseudoclimacograptus scharenbergi (P)

**87:** Shield Burn, nearby locality : NS 893 230 (+- 100m) :gracilis

Climacograptus bicornis (P)

Cryptograptus (sp)

Dicellograptus (sp)

Dicellograptus intortus (aff)

Dicranograptus rectus (P)

Didymograptus superstes (P)

Hustedograptus teretiusculus (P)

**88:** Glencaple Burn lower : NS 9265 2050 (+- 1m) :gracilis or peltifer

Cryptograptus (sp)

Hustedograptus teretiusculus (cf)

Normalograptus brevis (cf)

**89:** Glencaple Burn upper : NS 9265 2050 (+- 1m) :peltifer?

Corynoides (sp)

Glyptograptus (sp)

Lasiograptus (?)

Orthograptus (sp)

**90:** Gallow Rig Quarry : NS 6112 0352 (+- 1m) :peltifer

climacograptid (P)

Climacograptus bicornis (P)

Cryptograptus tricornis (P)

Dicellograptus patulosus (aff)

Normalograptus (?)

Orthograptus apiculatus (P)

Pseudoclimacograptus scharenbergi (P)

**91:** Glentewing Burn ETS568 : NS 8802 2193 (+- 1m) :gracilis?

Amplexograptus leptotheca (P)

Climacograptus bicornis (P)

Cryptograptus tricornis (P)

Glossograptus (?)

Nemagraptus (?)

**92:** Glentewing Burn ETS569 : NS 8830 2205 (+- 1m) :gracilis or peltifer

Dicranograptus rectus (cf)

Leptograptus validus (P)

Normalograptus brevis (P)

**93:** Nether Whitecleuch Burn ETS570 : NS 8398 1908 (+- 0m) :gracilis

Dicranograptus nicholsoni (cf)

Lasiograptus (sp)

Nemagraptus (cf)

Orthograptus (?)

**94:** Glenrae Burn ETS571 : NS 8380 1819 (+- 1m) :gracilis or peltifer

Amplexograptus leptotheca (P)

Dicellograptus (sp)

Dicranograptus nicholsoni (cf)

Lasiograptus (?)

Leptograptus validus (P)

Orthograptus apiculatus (P)

Pseudoclimacograptus (sp)

**95:** Glenrae Burn of Peach & Horne : NS 838 182 (+- 100m) :gracilis

Amplexograptus leptotheca (cf)

Climacograptus bicornis (P)

Corynoides (sp)

Cryptograptus tricornis (P)

Dicellograptus (sp)

Dicellograptus salopiensis (cf)

Dicranograptus nicholsoni (P)

Glossograptus hincksii (P)

Lasiograptus costatus (P)

Nemagraptus (?)

Pseudoclimacograptus scharenbergi (P)

Thamnograptus (sp)

**96:** Glenrae Burn Peach and Horne2 : NS 838 182 (+- 0m) :gracilis or peltifer

Amplexograptus leptotheca (cf)

Climacograptus bicornis (cf)

Dicellograptus (sp)

Dicellograptus salopiensis (cf)

Dicranograptus nicholsoni (P)

Glossograptus hincksii (P)

Leptograptus validus (P)

Orthograptus apiculatus (cf)

**97:** Wanlock Water ETS572 : NS 8309 1725 (+- 0m) :gracilis

Cryptograptus tricornis (P)

Dicellograptus (sp)

Nemagraptus gracilis (P)

Normalograptus brevis (P)

**98:** Back Burn (lower) ETS573 : NS 8350 1547 (+- 1m) :gracilis or peltifer

Climacograptus bicornis (P)

Cryptograptus tricornis (P)

Dicellograptus (sp)

Lasiograptus harknessi (P)

Nemagraptus (?)

Normalograptus brevis (cf)

**100:** Duntercleuch Burn of Peach and Horne : NS 840 161 (+- 0m) :gracilis

Climacograptus bicornis (?)

Dicranograptus nicholsoni (P)

Leptograptus validus (P)

Nemagraptus gracilis (P)

Orthograptus (?)

**105:** Brown's Cleuch (lower) ETS577 : NS 8102 1623 (+- 1m) :gracilis or peltifer

Amplexograptus leptotheca (?)

Cryptograptus tricornis (P)

Dicellograptus (sp)

**107:** Craignorth Hill : NS 81 16 (+- 100m) :gracilis or peltifer

Amplexograptus leptotheca (P)

Pseudoclimacograptus scharenbergi (?)

**109:** Wanlock Water : NS 848 159 (+- 100m) :gracilis?

Climacograptus bicornis (P)

Cryptograptus tricornis (P)

Dicranograptus nicholsoni (cf)

Dicranograptus ziczac (P)

Nemagraptus (?)

**111:** Crawick Water ETS581 : NS 8155 1721 (+- 1m) :peltifer

Amplexograptus leptotheca (P)

Cryptograptus tricornis (P)

Dicranograptus cyathiformis (cf)

Glossograptus hincksii (P)

Lasiograptus harknessi (P)

**112:** Hay Cleuch ETS582 : NS 8078 1575 (+- 1m) :gracilis or peltifer

Climacograptus bicornis (P)

Dicellograptus exilis (cf)

Dicranograptus (sp)

Lasiograptus (?)

Pseudoclimacograptus modestus (cf)

**114:** Crawfordjohn old survey : NS 893 195 (+- 10m) :gracilis or peltifer

Amplexograptus leptotheca (P)

Cryptograptus tricornis (P)

Dicellograptus intortus (P)

Dicellograptus salopiensis (cf)

Glossograptus hincksii (?)

Lasiograptus (sp)

**115:** course of Wandel Burn : NS 9720 2590 (+- 10m) :gracilis

Climacograptus bicornis (P)

Cryptograptus tricornis (P)

Dicellograptus patulosus (P)

Dicellograptus salopiensis (cf)

Dicranograptus cyathiformis (P)

Dicranograptus rectus (P)

Didymograptus superstes (P)

Glossograptus hincksii fimbriatus (P)

Hallograptus mucronatus (P)

Lasiograptus harknessi (P)

Leptograptus ascendens (P)

Nemagraptus gracilis (P)

Pseudoclimacograptus scharenbergi (cf)

**122:** Wandel Burn Head 3 : NS 9955 2600 (+- 25m) :gracilis

Amphigraptus (P)

Climacograptus bicornis (P)

Climacograptus bicornis tridentatus (P)

Cryptograptus tricornis (P)

Dicellograptus rigidus (P)

Dicellograptus salopiensis (cf)

Dicellograptus sextans (P)

Dicranograptus brevicaulis (cf)

Dicranograptus nicholsoni (P)

Didymograptus superstes (P)

Glossograptus hincksii (P)

Glossograptus hincksii fimbriatus (P)

Hallograptus mucronatus (P)

Nemagraptus gracilis (P)

Retiograptus geinitzianus (P)

**123:** Head of Wandel Burn : NS 9948 2602 (+- 25m) :gracilis?

Dicellograptus sextans (cf)

Dicranograptus (?)

Hallograptus (?)

Nemagraptus gracilis (?)

**131:** Fingland Burn : NS 744 173 (+- 0m) :gracilis

Dicellograptus sextans (cf)

Dicranograptus (sp)

Nemagraptus gracilis (P)

Orthograptus calcaratus acutus (?)

Pseudoclimacograptus modestus (cf)

Thamnograptus (P)

**133:** Guffock Hill 2 : NS 7488 1423 (+- 10m) :gracilis

Dicellograptus exilis (P)

Dicellograptus rigidus (P)

Didymograptus superstes (P)

Hustedograptus teretiusculus (P)

Lasiograptus (sp)

**134:** Guffock Hill 3 : NS 7488 1420 (+- 10m) :gracilis

climacograptid (P)

Dicellograptus exilis (cf)

Dicranograptus (sp)

Didymograptus superstes (P)

Glossograptus (P)

Glyptograptus euglyphus (P)

Hallograptus (sp)

**135:** Cat Cleuch : NS 7578 1324 (+- 1m) :gracilis - peltifer

Normalograptus brevis (P)

Orthograptus apiculatus (P)

**136:** Cat Cleuch 2 : NS 7578 1314 (+- 1m) :gracilis

Climacograptus bicornis (P)

Corynoides (sp)

Dicranograptus rectus (P)

Didymograptus superstes (P)

Hustedograptus teretiusculus (P)

Orthograptus calcaratus group (P)

**137:** Cat Cleuch 3 : NS 7586 1326 (+- 10m) :gracilis

Amplexograptus perexcavatus (P)

Climacograptus antiquus (P)

Climacograptus bicornis (P)

Corynoides (sp)

Cryptograptus tricornis (P)

Dicellograptus exilis (P)

Dicellograptus intortus (aff)

Dicellograptus rigidus (cf)

Dicranograptus rectus (P)

Dicranograptus tardiusculus (aff)

Didymograptus superstes (P)

Glyptograptus euglyphus (P)

Halograptus (sp)

Hustedograptus teretiusculus (P)

Lasiograptus (sp)

Nemagraptus gracilis (P)

Orthograptus calcaratus acutus (P)

Pseudoclimacograptus scharenbergi (P)

**138:** Kiln Burn - Head : NS 7572 1477 (+- 10m) :gracilis

Climacograptus antiquus (?)

Climacograptus bicornis (P)

Cryptograptus tricornis (P)

Dicellograptus intortus (aff)

Dicranograptus celticus (P)

Didymograptus superstes (P)

Halograptus bimucronatus (P)

Nemagraptus (P)

Pseudoclimacograptus scharenbergi (P)

**140:** Kiln Burn - Head 2 : NS 7584 1462 (+- 1m) :gracilis or peltifer

Amplexograptus leptotheca (P)

Dicellograptus exilis (cf)

**141:** Kiln Burn - near bend : NS 7673 1499 (+- 0m) :gracilis

Climacograptus bicornis (P)

Corynoides (sp)

Cryptograptus tricornis (P)

Dicellograptus intortus (?)

Dicranograptus tardiusculus (aff)

Didymograptus superstes (P)

Glyptograptus euglyphus (P)

Nemagraptus gracilis (P)

Orthograptus calcaratus group (P)

Pseudoclimacograptus scharenbergi (P)

**143:** Kiln Burn - again 1 : NS 7689 1386 (+- 0m) :peltifer?

Amplexograptus leptotheca (P)

Climacograptus bicornis (P)

Climacograptus bicornis peltifer (P)

Corynoides (sp)

Cryptograptus tricornis (P)

Dicellograptus intortus (aff)

Dicellograptus salopiensis (P)

Dicranograptus ramosus spinifer (P)

Glyptograptus euglyphus (P)

Hustedograptus teretiusculus (aff)

Orthograptus calcaratus acutus (?)

Pseudoclimacograptus scharenbergi (P)

**142:** Stoodfold Burn : NS 7673 1384 (+- 1m) :peltifer?

Amplexograptus leptotheca (?)

Cryptograptus tricornis (P)

Dicellograptus intortus (aff)

Hustedograptus teretiusculus (aff)

Leptograptus validus incisus (P)

Orthograptus calcaratus group (P)

**144:** Kiln Burn - 2 : NS 7715 1350 (+- 10m) :gracilis

Climacograptus antiquus (cf)

Climacograptus bicornis (P)

Corynoides (sp)

Cryptograptus tricornis (P)

Dicellograptus exilis (P)

Dicellograptus intortus (aff)

Dicellograptus sextans (cf)

Dicranograptus brevicaulis (P)

Dicranograptus rectus (P)

Dicranograptus ziczac (P)

Didymograptus superstes (P)

Diplograptus foliaceus (cf)

Glossograptus hincksii (P)

Halograptus bimucronatus (P)

Lasiograptus (?)

Nemagraptus gracilis (P)

Orthograptus calcaratus group (P)

Pseudoclimacograptus modestus (P)

**146:** Polycraig Burn 2 : NS 7818 1418 (+- 1m) :gracilis

Didymograptus superstes (P)

**147:** Polcraig Burn 3 : NS 7817 1419 (+- 1m) :gracilis

Amplexograptus (?)

Climacograptus bicornis (P)

Climacograptus bicornis peltifer (P)

Cryptograptus tricornis (P)

Dicellograptus exilis (P)

Dicellograptus intortus (aff)

Dicellograptus salopiensis (P)

Dicellograptus sextans (cf)

Dicranograptus ramosus (P)

Dicranograptus rectus (P)

Didymograptus superstes (?)

Halograptus mucronatus (P)

Hustedograptus teretiusculus (P)

Nemagraptus gracilis (P)

Orthograptus calcaratus group (P)

Pseudoclimacograptus modestus (P)

Pseudoclimacograptus scharenbergi (P)

**148:** Spothfore Burn : NS 7793 1521 (+- 1m) :gracilis or peltifer

Dicellograptus intortus (cf)

Hustedograptus teretiusculus (cf)

Orthograptus calcaratus group (?)

Pseudoclimacograptus stenostoma (P)

**149:** Polholm Burn : NS 7800 1539 (+- 1m) :gracilis

Amplexograptus perexcavatus (?)

Climacograptus bicornis (P)

Corynoides (sp)

Cryptograptus tricornis (P)

Dicellograptus exilis (cf)

Dicellograptus salopiensis (P)

Dicranograptus ramosus (P)

Dicranograptus tardiusculus (?)

Didymograptus superstes (P)

Glyptograptus euglyphus (P)

Hallograptus mucronatus (P)

Nemagraptus gracilis (P)

Orthograptus calcaratus group (P)

Pseudoclimacograptus scharenbergi (P)

**150:** NW of Spothfore Burn : NS 7861 1506 (+- 1m) :gracilis

Dicellograptus rigidus (P)

Dicellograptus salopiensis (?)

Didymograptus superstes (P)

Glyptograptus (sp)

Orthograptus (sp)

**151:** Spothfore Burn 1 : NS 7865 1507 (+- 1m) :gracilis or peltifer?

Cryptograptus tricornis (P)

Dicranograptus (sp)

Glyptograptus euglyphus (P)

Normalograptus brevis (cf)

**152:** Spothfore Burn 2 : NS 7867 1506 (+- 1m) :gracilis

Dicellograptus exilis (cf)

Dicellograptus salopiensis (cf)

Dicranograptus tardiusculus (aff)

Didymograptus superstes (P)

Hallograptus mucronatus (P)

Nemagraptus gracilis (P)

Pseudoclimacograptus scharenbergi (P)

**153:** Spothfore Burn 3 : NS 7868 1506 (+- 1m) :gracilis

Amplexograptus perexcavatus (?)

Cryptograptus tricornis (P)

Dicellograptus salopiensis (cf)

Dicranograptus rectus (P)

Nemagraptus gracilis (P)

**154:** Back Burn ETS 281 : NS 7903 1594 (+- 1m) :uncertain

Dicellograptus divaricatus (cf)

Glossograptus (sp)

Hustedograptus teretiusculus (?)

Pseudoclimacograptus extraspiney (P)

**155:** Back Burn ETS 280 : NS 7904 1594 (+- 1m) :gracilis

Amplexograptus arctus (?)

Climacograptus bicornis (P)

Corynoides (sp)

Cryptograptus tricornis (P)

Dicellograptus exilis (P)

Dicellograptus salopiensis (P)

Dicranograptus ramosus (?)

Dicranograptus rectus (P)

Dicranograptus tardiusculus (aff)

Didymograptus superstes (P)

Glossograptus hincksii (P)

Glyptograptus euglyphus (cf)

Hallograptus mucronatus (P)

Hustedograptus teretiusculus (P)

Leptograptus ascendens (P)

Nemagraptus gracilis (P)

Orthograptus calcaratus group (P)

Pseudoclimacograptus scharenbergi (P)

**157:** SW bank of Back Burn ETS 278 : NS 7974 1516 (+- 1m) :gracilis or peltifer?

Dicranograptus celticus (?)

**158:** Back Burn ETS 277 : NS 7974 1514 (+- 1m) :gracilis

climacograptid (P)

Dicellograptus salopiensis (?)

Dicranograptus rectus (?)

Hallograptus bimucronatus (P)

Nemagraptus (P)

Orthograptus (sp)

**159:** Polthistly Burn 1 : NS 7952 1624 (+- 1m) :gracilis or peltifer

Climacograptus bicornis (P)

Climacograptus bicornis peltifer (P)

Dicranograptus ramosus (P)

Diplograptus (?)

Pseudoclimacograptus modestus (cf)

**160:** Polthistly Burn 2 : NS 7956 1626 (+- 1m) :gracilis

Dicranograptus ramosus (?)  
 Didymograptus superstes (?)  
 Hustedograptus teretiusculus (P)  
 Nemagraptus gracilis (?)  
 Orthograptus calcaratus group (P)  
 Pseudoclimacograptus scharenbergi (cf)  
 Pseudoclimacograptus stenostoma (cf)

**161:** Head of Polthistly Burn : NS 7975 1635 (+- 0m) :gracilis

Climacograptus bicornis (P)  
 Cryptograptus (sp)  
 Dicellograptus salopiensis (P)  
 Dicellograptus sextans (P)  
 Dicranograptus ramosus (cf)  
 Didymograptus superstes (P)  
 Hustedograptus teretiusculus (cf)  
 Nemagraptus (P)  
 Pseudoclimacograptus (sp)

**162:** Eller Scaur : NS 8057 1561 (+- 1m) :gracilis

Amplexograptus leptotheca (?)  
 Climacograptus antiquus (P)  
 Climacograptus bicornis (P)  
 Climacograptus bicornis peltifer (P)  
 Dicellograptus exilis (P)  
 Dicellograptus intortus (aff)  
 Dicellograptus salopiensis (P)  
 Dicranograptus rectus (P)  
 Didymograptus superstes (P)  
 Glossograptus hincksii (cf)  
 Glyptograptus euglyphus (P)  
 Hallograptus mucronatus (P)  
 Hustedograptus teretiusculus (P)  
 Lasiograptus (sp)  
 Lasiograptus costatus (P)  
 Leptograptus validus incisus (P)  
 Nemagraptus gracilis (P)  
 Orthograptus calcaratus group (P)  
 Pseudoclimacograptus modestus (P)  
 Pseudoclimacograptus scharenbergi (cf)  
 Pseudoclimacograptus stenostoma (cf)

**163:** Brown's Cleuch again : NS 8105 1622 (+- 1m) :gracilis

Amplexograptus perexcavatus (?)  
 Climacograptus bicornis (P)  
 Cryptograptus tricornis (P)  
 Dicellograptus intortus (aff)

Dicellograptus salopiensis (cf)  
 Dicranograptus tardiusculus (aff)  
 Glossograptus hincksii fimbriatus (cf)  
 Hustedograptus teretiusculus (aff)  
 Nemagraptus gracilis (?)  
 Pseudoclimacograptus scharenbergi (P)

**164:** Glenrae Burn again : NS 8375 1820 (+- 10m) :probably gracilis

Dicellograptus salopiensis (cf)  
 Dicranograptus tardiusculus (cf)  
 Glossograptus (sp)  
 Glyptograptus (sp)  
 Nemagraptus (?)  
 Thamnograptus (sp)

**165:** old quarry hole : NS 810 134 (+- 100m) :gracilis or peltifer

Dicellograptus intortus (aff)  
 Glossograptus (sp)  
 Hallograptus (sp)

**166:** Brandley's cottage: NS 816 114 (+- 100m) :gracilis or peltifer

Climacograptus bicornis (P)  
 Cryptograptus tricornis (P)  
 Dicellograptus intortus (aff)  
 Thamnograptus (P)

**168:** Howcan Burn (Cogshead) : NS 8325 1290 (+- 10m) :gracilis or peltifer?

diplograptid indet (P)  
 leptograptid (P)  
 Orthograptus whitfieldi (P)

**169:** Polhote Burn 1 : NS 6827 1081 (+- 1m) :gracilis

Amplexograptus leptotheca (P)  
 Climacograptus bicornis bicornis (P)  
 Cryptograptus tricornis (P)  
 Dicellograptus intortus (cf)  
 Dicellograptus salopiensis (P)  
 Dicranograptus (sp)  
 Didymograptus superstes (P)  
 Glossograptus hincksii fimbriatus (P)  
 Glyptograptus euglyphus (P)  
 Hallograptus bimucronatus (P)  
 Lasiograptus costatus (P)  
 Nemagraptus gracilis (P)  
 Normalograptus brevis (?)  
 Orthograptus (?)  
 Orthograptus apiculatus (P)

Pseudoclimacograptus scharenbergi (P)

**170:** Polhote Burn 2 : NS 6389 1090 (+- 1m) :gracilis

Amplexograptus leptotheca (P)

Climacograptus bicornis bicornis (P)

Cryptograptus tricornis (P)

Dicellograptus (sp)

Dicellograptus salopiensis (P)

Dicranograptus nicholsoni (P)

Diplograptus (?)

Glossograptus hincksii fimbriatus (P)

Halograptus mucronatus (P)

Lasiograptus (?)

Leptograptus validus (P)

Normalograptus brevis (P)

Pseudoclimacograptus (?)

**171:** Polmarlach Burn 1 : NS 6785 1144 (+- 1m) :gracilis or peltifer

Amplexograptus leptotheca (?)

Climacograptus bicornis bicornis (P)

Cryptograptus tricornis (P)

Dicellograptus salopiensis (P)

Dicranograptus nicholsoni (P)

Leptograptus validus (P)

Normalograptus brevis (P)

Orthograptus (?)

Pseudoclimacograptus (?)

**172:** Polmarlach Burn 2 : NS 6789 1149 (+- 1m) :gracilis

Climacograptus bicornis bicornis (P)

Cryptograptus tricornis (P)

Dicellograptus sextans (P)

Dicranograptus ramosus (P)

Nemagraptus (P)

Normalograptus brevis (?)

Orthograptus apiculatus (P)

Pseudoclimacograptus scharenbergi (P)

**173:** Whing Burn 1 : NS 7648 0749 (+- 1m) :gracilis

Climacograptus bicornis bicornis (P)

Cryptograptus tricornis (P)

Didymograptus superstes (P)

## Sheet 10

**246:** Glenkiln BurnA-B : NY 006 984 (+- 10m) :gracilis or peltifer

Climacograptus antiquus (P)

Climacograptus bicornis (P)

Dicellograptus intortus (P)

Dicranograptus nicholsoni (P)

Glossograptus (sp)

Halograptus (sp)

Leptograptus grandis (P)

Normalograptus brevis (P)

Orthograptus calcaratus acutus (P)

Pseudoclimacograptus scharenbergi (P)

Thamnograptus (sp)

**247:** Glenkiln BurnC : NY 006 894 (+- 10m) :gracilis or peltifer

Climacograptus bicornis (P)

Dicellograptus salopiensis (P)

Orthograptus (sp)

**248:** Glenkiln BurnD : NY 006 894 (+- 10m) :gracilis or peltifer

Climacograptus (sp)

Dicellograptus (sp)

Dicranograptus nicholsoni (?)

Halograptus mucronatus (P)

Halograptus mucronatus nobilis (P)

**249:** Glenkiln BurnX : NY 006 894 (+- 10m) :gracilis or peltifer

Climacograptus antiquus (?)

Dicellograptus sextans (P)

Halograptus mucronatus (P)

**250:** Glenkiln BurnU : NY 006 894 (+- 10m) :gracilis

Climacograptus antiquus (P)

Climacograptus bicornis (P)

Corynoides (?)

Cryptograptus tricornis (P)

Dicellograptus divaricatus (aff)

Dicellograptus exilis (P)

Dicellograptus sextans (P)

Glossograptus (sp)

Halograptus mucronatus (P)

Lasiograptus (?)

Nemagraptus gracilis (P)

Normalograptus brevis (P)

Orthograptus calcaratus group (P)

Pseudoclimacograptus scharenbergi (P)

**251:** Glenkiln BurnZ : NY 006 894 (+- 10m) :gracilis

Climacograptus antiquus (P)

Dicellograptus divaricatus (aff)

Dicellograptus sextans (P)

Halograptus mucronatus (P)

Nemagraptus gracilis (P)

Orthograptus calcaratus acutus (P)

**Sheet 3**

**211:** Finnarts Bay : NX 052 722 (+- 100m) :gracilis

Climacograptus (sp)

Climacograptus bicornis (P)

Cryptograptus (?)

Dicellograptus exilis (P)

Dicellograptus salopiensis (cf)

Dicellograptus sextans (P)

Dicranograptus rectus (P)

Didymograptus superstes (P)

Glyptograptus euglyphus (P)

Lasiograptus (?)

Nemagraptus (?)

Pseudoclimacograptus (?)

**212:** Polymodie Burn : NX 0585 7020 (+- 1m) :gracilis

Climacograptus (sp)

Cryptograptus tricornis (P)

Dicellograptus exilis (P)

Dicellograptus sextans (P)

Dicranograptus ramosus spinifer (P)

Didymograptus superstes (P)

Diplograptus foliaceus (P)

Glyptograptus euglyphus (P)

Hallograptus mucronatus (P)

Nemagraptus pertenus (P)

Orthograptus whitfieldi (?)

Pseudoclimacograptus modestus (P)

**213:** Cairnryan Quarry : NX 0683 6886 (+- 1m) :gracilis

Cryptograptus tricornis (P)

Dicellograptus divaricatus (cf)

Dicellograptus exilis (P)

Didymograptus superstes (P)

Hallograptus mucronatus (P)

Lasiograptus costatus (cf)

Orthograptus (sp)

**214:** Dounan Bay : NW 966 687 (+- 100m) :peltifer

Amplexograptus leptotheca (P)

Climacograptus (sp)

Dicellograptus exilis (P)

Dicranograptus ramosus spinifer (?)

Dicranograptus rectus (P)

Glyptograptus (sp)

Orthograptus whitfieldi (aff)

Pseudoclimacograptus (sp)

**215:** Stocknamorrow Bay : NW 9608 6658 (+- 1m) :gracilis or peltifer

Climacograptus (sp)

Dicranograptus rectus (P)

Hallograptus bimucronatus (P)

**216:** Portobello : uncertain (+- 100+m) :gracilis or peltifer

Amphigraptus (sp)

Climacograptus (sp)

Dicellograptus exilis (P)

Dicranograptus rectus (P)

Pseudoclimacograptus scharenbergi (P)

Retiograptus geinitzianus (P)

**217:** Trap Arch : NW 977 587 (+- 10m) :gracilis

Cryptograptus tricornis (P)

Dicellograptus exilis (cf)

Didymograptus superstes (P)

Glossograptus hincksii (P)

Glyptograptus (sp)

Nemagraptus (sp)

Nemagraptus pertenus (P)

**218:** Cable House : NW 9804 5813 (+- 1m) :gracilis or peltifer

Climacograptus bicornis (P)

Dicellograptus exilis (?)

**219:** Craillloch Burn : NX 0332 5936 (+- 1m) :gracilis

Climacograptus (sp)

Cryptograptus tricornis (P)

Dicellograptus (sp)

Dicranograptus ramosus (P)

Didymograptus superstes (P)

Orthograptus calcaratus acutus (?)

Pseudoclimacograptus (sp)

Thamnograptus capillaris (P)

**220:** Cross Water of Luce : uncertain (+- 100+m) :gracilis or peltifer

Dicellograptus salopiensis (?)

Orthograptus (sp)

**221:** Valley of Luce1 : NX 1442 6709 (+- 1m) :gracilis

Climacograptus bicornis (P)

Corynoides (P)

Cryptograptus (sp)

Dendrograptus (sp)

Dicranograptus rectus (P)

Didymograptus superstes (P)

Glossograptus hincksii (P)

Nemagraptus gracilis (P)

Nemagraptus pertenus (cf)

Orthograptus calcaratus acutus (P)

Pseudoclimacograptus modestus (P)

**222:** Valley of Luce2 : NX 1442 6709 (+- 1m) :gracilis or peltifer

Climacograptus antiquus (P)

Cryptograptus tricornis (P)

Dicellograptus exilis (P)

Dicranograptus rectus (P)

Glossograptus (sp)

Glyptograptus euglyphus (P)

Lasiograptus costatus (P)

Lasiograptus harknessi (P)

Nemagraptus (P)

Normalograptus brevis (P)

Pseudoclimacograptus scharenbergi (P)

**223:** Water of Luce 4 & 6 : NX 1521 6746 (+- 1m) :gracilis

Climacograptus bicornis (P)

Corynoides (sp)

Cryptograptus tricornis (P)

Dicellograptus exilis (P)

Dicellograptus intortus (P)

Dicellograptus rigidus (P)

Dicellograptus salopiensis (P)

Dicranograptus ramosus spinifer (P)

Dicranograptus rectus (P)

Didymograptus superstes (P)

Diplograptus compactus (cf)

Diplograptus foliaceus (?)

Glossograptus hincksii (P)

Glyptograptus euglyphus (P)

Lasiograptus costatus (P)

Nemagraptus gracilis (P)

Orthograptus calcaratus acutus (P)

Orthograptus whitfieldi (P)

Pseudoclimacograptus (sp)

**224:** Water of Luce 9 : NX 1519 6750 (+- 1m) :gracilis

Cryptograptus tricornis (P)

Dicellograptus intortus (P)

Dicellograptus salopiensis (P)

Dicranograptus nicholsoni (P)

Dicranograptus ramosus (cf)

Didymograptus superstes (P)

Halograptus mucronatus (P)

leptograptid (P)

Nemagraptus gracilis (P)

Pseudoclimacograptus scharenbergi (P)

**225:** Water of Luce 10 : NX 1517 6751 (+- 1m) :gracilis or peltifer

Climacograptus (sp)

Cryptograptus tricornis (P)

Dicellograptus intortus (P)

Dicellograptus patulosus (?)

Dicellograptus rigidus (P)

Dicellograptus salopiensis (P)

Didymograptus superstes (P)

Glyptograptus euglyphus (P)

Halograptus mucronatus (P)

leptograptid (P)

Pseudoclimacograptus scharenbergi (cf)

**226:** Water of Luce : NX 1517 6752 (+- 1m) :gracilis or peltifer

Climacograptus (sp)

Dicellograptus salopiensis (cf)

Dicranograptus brevicaulis (P)

Dicranograptus rectus (P)

Glyptograptus euglyphus (P)

Nemagraptus (sp)

Orthograptus calcaratus acutus (P)

Pseudoclimacograptus (sp)

Thamnograptus capillaris (P)

**227:** Morroch Bay1 : NX 015 525 (+- 1m) :gracilis

Climacograptus bicornis (P)

Cryptograptus tricornis (P)

Dicellograptus exilis (P)

Dicellograptus intortus (P)

Dicellograptus rigidus (P)

Dicellograptus sextans (P)

Dicranograptus ramosus (P)

Halograptus mucronatus (P)

Nemagraptus gracilis (P)

Orthograptus calcaratus group (P)

Orthograptus whitfieldi (P)

**228:** Morroch Bay2 : NX 015 525 (+- 1m) :gracilis or peltifer

Cryptograptus tricornis (P)

Dicellograptus sextans (P)

Dicranograptus furcatus (P)

Orthograptus (P)

Thamnograptus scoticus (P)

**229:** Morroch Bay3 : NX 015 525 (+- 1m) :gracilis

Cryptograptus (P)

Dicranograptus rectus (?)  
 Didymograptus superstes (P)  
 Glyptograptus euglyphus (P)  
 Orthograptus calcaratus group (?)

**230:** Morroch Bay4 : NX 015 525 (+- 1m) :gracilis or peltifer

Amphigraptus (sp)  
 Climacograptus bicornis (P)  
 Corynoides (sp)  
 Cryptograptus tricornis (P)  
 Dicellograptus sextans (P)  
 Glossograptus (sp)  
 leptograptid (P)  
 Thamnograptus scoticus (?)

**231:** Portayew Bay : NX 0392 5024 (+- 100m) :gracilis-peltifer

Cryptograptus tricornis (P)  
 Dicranograptus furcatus minimus (P)  
 Didymograptus superstes (P)  
 leptograptid (P)  
 Orthograptus amplexicaulis (P)  
 Orthograptus whitfieldi (P)

#### Sheet 4

**242:** Tanylaggie Flow : NX 287 717 (+- 10m) :gracilis

Climacograptus bicornis peltifer (P)  
 Dicellograptus exilis (P)  
 Dicellograptus salopiensis (P)  
 Didymograptus superstes (P)  
 Hallograptus (sp)  
 Nemagraptus gracilis (P)

**243:** Camrie Burn : NX 2050 6055 (+- 1m) :peltifer

Climacograptus bicornis (P)  
 Corynoides calicularis (P)  
 Cryptograptus tricornis (P)  
 Dicranograptus nicholsoni (P)  
 Dicranograptus ziczac (P)  
 Lasiograptus harknessi (P)  
 Normalograptus brevis (P)  
 Orthograptus calcaratus basilicus (cf)  
 Orthograptus whitfieldi (cf)  
 Pseudoclimacograptus (sp)  
 Pseudoclimacograptus scharenbergi (P)

**244:** Camrie Burn2 : NX 2018 6040 (+- 1m) :gracilis or peltifer

Climacograptus (sp)  
 Climacograptus bicornis (cf)

Dicellograptus angulatus (cf)  
 Dicellograptus exilis (cf)  
 Dicranograptus ramosus (aff)  
 diplograptid indet (P)

**245:** Garwachie Roadside : NX 344 693 (+- 10m) :gracilis or peltifer

Climacograptus bicornis (P)  
 Cryptograptus (?)  
 Orthograptus (sp)

#### Sheet 8

**179:** Laggish Burn : NX 209 780 (+- 10m) :gracilis or peltifer

Climacograptus (sp)  
 Dicellograptus (sp)  
 Dicranograptus rectus (P)  
 Pseudoclimacograptus scharenbergi (P)

**180:** Cross Water1 : NX 2204 8067 (+- 1m) :gracilis or peltifer

Cryptograptus tricornis (?)  
 Dicranograptus rectus (P)  
 diplograptid indet (P)  
 Glyptograptus euglyphus (?)

**181:** Cross Water2 : NX 2289 8119 (+- 1m) :gracilis or peltifer

Amplexograptus leptotheca (P)  
 Dicellograptus exilis (P)  
 Dicellograptus salopiensis (cf)  
 Dicellograptus sextans (P)  
 diplograptid indet (P)

**182:** Cross Water3 : NX 2291 8120 (+- 1m) :gracilis or peltifer

Amplexograptus leptotheca (P)  
 Amplexograptus perexcavatus (P)  
 Climacograptus bicornis (P)  
 Cryptograptus tricornis (P)  
 Dicellograptus rigidus (P)  
 Dicellograptus sextans (P)  
 Dicranograptus (sp)  
 Hallograptus (sp)  
 Lasiograptus costatus (P)  
 Nemagraptus gracilis (sp)

**183:** Cross Water4 : NX 2294 8145 (+- 1m) :probably gracilis

Amplexograptus (sp)  
 Climacograptus (sp)  
 Cryptograptus (sp)  
 Dicellograptus patulosus (cf)  
 Glyptograptus (sp)

Nemagraptus gracilis (P)

Orthograptus calcaratus acutus (P)

**184:** Altercannoch Quarry : NX 2517 8096 (+- 0m) :probably gracilis

Amplexograptus perexcavatus (?)

Climacograptus bicornis (P)

Cryptograptus tricornis (P)

Dicellograptus exilis (P)

Dicellograptus intortus (P)

Glyptograptus (sp)

Glyptograptus euglyphus (cf)

Hustedograptus teretiusculus (cf)

Lasiograptus harknessi (P)

leptograptid (P)

Nemagraptus gracilis (P)

Normalograptus brevis (P)

Orthograptus (sp)

Pseudoclimacograptus (sp)

Thamnograptus capillaris (P)

**185:** Feoch Burn : NX 252 817 (+- 10m) :possibly peltifer

Climacograptus (sp)

Dicellograptus (sp)

Orthograptus apiculatus (P)

**186:** Knocklach Burn : NX 370 895 (+- 0m) :possibly gracilis-peltifer

Dicellograptus (sp)

Dicellograptus salopiensis (?)

diplograptid indet (P)

**187:** River Stinchar : NX 399 944 (+- 10m) :gracilis

Climacograptus (sp)

Climacograptus bicornis (P)

Cryptograptus tricornis (P)

Dicellograptus exilis (P)

Dicellograptus patulosus (P)

Halograptus mucronatus (P)

Nemagraptus gracilis (P)

Orthograptus calcaratus group (P)

**188:** Quarry at Craiglure : NX 420 969 (+- 10m) :gracilis

Climacograptus bicornis (P)

Climacograptus bicornis tridentatus (?)

Cryptograptus tricornis (P)

Dicellograptus patulosus (cf)

Dicellograptus salopiensis (cf)

Dicranograptus celticus (P)

Halograptus mucronatus (P)

Nemagraptus gracilis (P)

Orthograptus calcaratus acutus (P)

**189:** Meadowhead : NX 520 995 (+- 10m) :gracilis or peltifer

Climacograptus (sp)

Dicellograptus exilis (P)

Orthograptus calcaratus acutus (cf)

**190:** Knockingarroch : NX 5574 9666 (+- 0m) :gracilis

Climacograptus bicornis (P)

Corynoides (sp)

Cryptograptus tricornis (P)

Dicellograptus exilis (P)

Dicellograptus intortus (P)

Dicellograptus rigidus (P)

Dicellograptus salopiensis (cf)

Dicranograptus brevicaulis (P)

Dicranograptus rectus (P)

Dicranograptus tardiusculus (P)

Didymograptus superstes (P)

Diplograptus foliaceus (P)

Glossograptus hincksii (P)

Glossograptus hincksii fimbriatus (P)

Glyptograptus euglyphus (P)

Halograptus bimucronatus (P)

Halograptus mucronatus (P)

Hustedograptus teretiusculus (P)

Lasiograptus costatus (P)

Nemagraptus gracilis (P)

Normalograptus (sp)

Orthograptus calcaratus acutus (P)

Pseudoclimacograptus scharenbergi (P)

Retiograptus geinitzianus (P)

Thamnograptus capillaris (?)

**191:** Cross Burn : NX 395 880 (+- 0m) :possibly peltifer

Climacograptus bicornis (?)

Dicellograptus (sp)

Dicranograptus nicholsoni (?)

Glossograptus hincksii fimbriatus (?)

Orthograptus apiculatus (?)

**192:** Kirriemore Burn : NX 379 868 (+- 10m) :possibly peltifer

Climacograptus bicornis (P)

Cryptograptus (sp)

Dicellograptus (sp)

Dicellograptus salopiensis (?)

Leptograptus flaccidus (?)

Normalograptus brevis (P)

Orthograptus (sp)

**193:** Kirriemore Burn2 : NX 385 870 (+- 0m) :possibly peltifer

Amplexograptus leptotheca (?)

Dicranograptus nicholsoni (?)

Dicranograptus ramosus (P)

Glossograptus (sp)

Lasiograptus (sp)

Leptograptus flaccidus (?)

**194:** Kirriemore Burn3 : NX 369 864 (+- 10m) :possibly peltifer

Cryptograptus (sp)

Dicellograptus (sp)

**195:** Kirriemore Burn4 : NX 367 855 (+- 10m) :possibly peltifer

Cryptograptus (sp)

Dicranograptus ramosus (P)

Dicranograptus ziczac (P)

Glossograptus armatus (P)

**196:** Water of Minnoch : NX 369 790 (+- 10m) :gracilis

Cryptograptus tricornis (P)

Dicellograptus sextans (P)

Dicranograptus brevicaulis (P)

Dicranograptus celticus (P)

Didymograptus serratus (P)

Didymograptus superstes (P)

Diplograptus foliaceus (P)

Glossograptus hincksii fimbriatus (P)

Hallograptus (sp)

Nemagraptus gracilis (P)

Orthograptus calcaratus group (P)

Thamnograptus (sp)

**197:** Green Torr : uncertain (+- 100+m) :probably gracilis

Climacograptus (sp)

Dicellograptus (sp)

Didymograptus superstes (?)

diplograptid indet (P)

**198:** Pulnabrick Burn : NX 399 802 (+- 10m) :gracilis

Climacograptus (sp)

Cryptograptus tricornis (P)

Dicellograptus exilis (P)

Dicellograptus rigidus (cf)

Dicellograptus sextans (P)

Dicranograptus brevicaulis (P)

Didymograptus superstes (P)

Diplograptus foliaceus (P)

Glossograptus hincksii (P)

Glyptograptus euglyphus (P)

Hallograptus (sp)

Hustedograptus teretiusculus (cf)

Nemagraptus gracilis (P)

Retiograptus geinitzianus (P)

Thamnograptus (sp)

**199:** Pulnabrick Burn3 : NX 399 807 (+- 10m) :gracilis

Climacograptus bicornis (P)

Corynoides (P)

Cryptograptus tricornis (P)

Dicellograptus exilis (P)

Dicellograptus rigidus (P)

Dicranograptus brevicaulis (P)

Dicranograptus rectus (P)

Didymograptus superstes (P)

Hallograptus (?)

Nemagraptus gracilis (P)

Orthograptus (?)

Pseudoclimacograptus (P)

**200:** Pulnabrick Burn2 : NX 401 806 (+- 10m) :gracilis

Corynoides pristinus (cf)

Dicellograptus sextans (cf)

Didymograptus superstes (P)

Hustedograptus teretiusculus (cf)

Nemagraptus (sp)

Pseudoclimacograptus scharenbergi (P)

**201:** Cairlin's Cairn1 : NX 497 878 (+- 10m) :probably gracilis

Dicellograptus exilis (P)

Dicranograptus furcatus minimus (P)

Didymograptus superstes (?)

Glyptograptus (sp)

Pseudoclimacograptus (sp)

Thamnograptus capillaris (?)

**202:** Carlin's Cairn2 : NX 500 901 (+- 10m) :probably gracilis

Climacograptus (sp)

Cryptograptus (sp)

Dicranograptus furcatus minimus (?)

Didymograptus superstes (?)

Glossograptus (sp)

Nemagraptus (sp)

Orthograptus (sp)

**203:** Halfmark Burn : NX 524 915 (+- 10m) :gracilis or peltifer

Climacograptus bicornis (P)  
Dicranograptus celticus (P)  
Diplograptus foliaceus (?)  
Glyptograptus euglyphus (P)

**204:** Cairnsgralloch Gairry : NX 515 919 (+- 10m) :probably peltifer

Climacograptus bicornis (P)  
Corynoides (P)  
Cryptograptus (sp)  
Dicranograptus ramosus spinifer (P)  
leptograptid (P)  
Orthograptus calcaratus group (P)

**205:** Garyhorn Burn : NX 5370 9335 (+- 1m) :gracilis

Dicellograptus exilis (cf)  
Didymograptus superstes (P)  
Orthograptus calcaratus group (P)  
Pseudoclimacograptus (sp)

**206:** Garryhorn black shale clast : NX 5491 9332 (+- 1m) :gracilis

Climacograptus (sp)  
Dicellograptus exilis (P)  
Dicellograptus intortus (?)  
Dicellograptus sextans (P)  
Dicranograptus rectus (P)  
Didymograptus superstes (P)  
Hustedograptus teretiusculus (P)  
Nemagraptus gracilis (P)  
Orthograptus calcaratus acutus (P)

**207:** Larg Hill, Cardokin : NX 427 759 (+- 10m) :possibly gracilis

Cryptograptus (sp)  
diplograptid indet (P)  
Lasiograptus costatus (P)  
Nemagraptus gracilis (?)

**208:** Lamachan Hill : NX 424 759 (+- 100m) :possibly gracilis-peltifer

Climacograptus (sp)  
Cryptograptus (?)  
Dicellograptus divaricatus (?)  
Dicellograptus exilis (P)  
Dicellograptus intortus (?)  
Dicranograptus furcatus minimus (P)  
Glyptograptus (sp)  
Orthograptus (?)

**209:** Pulharrow Burn1 : NX 545 867 (+- 10m) :gracilis

Climacograptus bicornis (P)  
Corynoides (P)  
Dicellograptus intortus (?)  
Dicellograptus sextans (cf)  
Dicranograptus ramosus (P)  
Didymograptus superstes (P)  
Glyptograptus (sp)  
Hallograptus mucronatus (P)  
Nemagraptus gracilis (?)  
Orthograptus apiculatus (?)

**210:** Pulharrow Burn2 : NX 551 871 (+- 10m) :possibly gracilis

Nemagraptus (sp)

#### Sheet 5

**232:** Tottlehams Glen : NX 7769 6985 (+- 1m) :gracilis

Climacograptus antiquus (?)  
Dicellograptus divaricatus (P)  
Hallograptus bimucronatus (P)  
Nemagraptus (?)

**233:** Tottlehams Glen2 : NX 7723 6949 (+- 1m) :gracilis

Climacograptus antiquus (?)  
Dicellograptus divaricatus (P)  
Dicellograptus exilis (cf)

**234:** Old Bridge of Urr : NX 7622 6848 (+- 1m) :gracilis

Climacograptus (sp)  
Dicellograptus rigidus (P)  
Nemagraptus gracilis (P)

**235:** Old Bridge of Urr2 : NX 7656 6862 (+- 1m) :gracilis

Climacograptus (sp)  
Dicellograptus intortus (P)  
Didymograptus superstes (P)  
Nemagraptus gracilis (P)  
Orthograptus (sp)

#### Sheet 9

**236:** Dibbin Lane : NX 6930 9605 (+- 1m) :gracilis

Cryptograptus tricornis (P)  
Dicellograptus exilis (P)  
Didymograptus superstes (P)  
Glyptograptus euglyphus (P)  
Nemagraptus gracilis (P)

**237:** Dibbin Lane2 : NX 700 967 (+- 10m) :gracilis

Climacograptus antiquus (?)

Cryptograptus tricornis (P)  
Dendrograptus (sp)  
Hallograptus (sp)  
Lasiograptus costatus (P)  
Lasiograptus harknessi (P)  
Nemagraptus gracilis (P)  
Nemagraptus pertenus (P)  
Orthograptus whitfieldi (P)

**238:** Appin Burn : NX 710 978 (+- 10m) :gracilis-peltifer

Climacograptus bicornis (P)  
Hustedograptus teretiusculus (P)  
Orthograptus calcaratus acutus (cf)

**239:** Appin Burn2 : NX 7135 9820 (+- 1m) :peltifer

Climacograptus bicornis bicornis (P)  
Dicranograptus nicholsoni (P)  
Dicranograptus ziczac (P)  
Glossograptus (sp)  
Lasiograptus harknessi (P)  
Orthograptus (sp)  
Thamnograptus (sp)

**240:** Glenjaan Burn : NX 6949 9470 (+- 1m) :gracilis-peltifer

Climacograptus bicornis (P)  
Glyptograptus euglyphus (P)  
Normalograptus (sp)  
Orthograptus (sp)

**241:** Appin Burn3 : NX 727 978 (+- 10m) :gracilis-peltifer

Climacograptus (sp)  
Climacograptus bicornis (P)  
Climacograptus bicornis bicornis (P)  
Corynoides calicularis (P)  
Corynoides serpens (P)  
Cryptograptus tricornis (P)  
Dicranograptus nicholsoni (P)  
Dicranograptus ziczac (P)  
Glossograptus (sp)  
Lasiograptus costatus (P)  
Orthograptus (P)

**Girvan district (Midland Valley) and Currarie Formation**

**176:** Knock gowan Cliff : NX 0590 7860 (+- 0m) :lower gracilis

Cryptograptus (sp)  
Dicellograptus alabamensis (P)  
Dicellograptus intortus (P)  
Dicellograptus notabilis (cf)  
Dicellograptus salopiensis (P)  
Glyptograptus euglyphus (aff)  
Hustedograptus teretiusculus (P)  
Leptograptus validus (P)  
Nemagraptus subtilis (P)  
Normalograptus brevis (cf)  
Pseudoclimacograptus modestus (P)  
Pseudoclimacograptus scharenbergi (P)  
Retiograptus geinitzianus (P)

**177:** Girvan : circa NX 2375 9272 (+- 0m) :lower gracilis

Cryptograptus tricornis (P)  
Dicellograptus alabamensis (P)  
Dicellograptus salopiensis (P)  
dichograptid stipes (P)  
Glyptograptus euglyphus (P)  
Hustedograptus teretiusculus (P)  
Nemagraptus gracilis (P)  
Normalograptus (?)  
Normalograptus brevis (P)  
Pseudoclimacograptus modestus (P)  
Pseudoclimacograptus scharenbergi (P)  
Retiograptus geinitzianus (P)  
Thamnograptus (sp)

**178:** Girvan : NX 2892 9401 (+- 0m) :lower gracilis

Dicellograptus intortus (P)  
Dicellograptus patulosus (aff)  
Dicranograptus brevicaulis (P)  
Dictyonema fluitans (P)  
Didymograptus superstes (P)  
Hustedograptus teretiusculus (P)  
Nemagraptus gracilis (P)  
Pseudoclimacograptus modestus (P)  
Pseudoclimacograptus scharenbergi (P)

**Appendix 2.** All graptolites recorded for localities of Caradoc age in the Southern Uplands analysed herein, and the three ‘test’ localities of lower *gracilis* Biozone age. Each taxon is assigned a number which identifies its position in the R-mode cluster analysis of Figure 5.

| <b>Identity number</b> | <b>graptolite</b>                               |
|------------------------|-------------------------------------------------|
| 126                    | <i>Pseudoclimacograptus scharenbergi</i>        |
| 139                    | <i>Nemagraptus gracilis</i>                     |
| 140                    | <i>Climacograptus bicornis</i>                  |
| 143                    | <i>Amplexograptus leptotheca</i>                |
| 144                    | <i>Cryptograptus tricornis</i>                  |
| 146                    | dicranograptid stipe                            |
| 147                    | <i>Dicellograptus exilis</i>                    |
| 148                    | <i>Dicranograptus rectus</i>                    |
| 149                    | <i>Pseudoclimacograptus modestus</i>            |
| 151                    | <i>Didymograptus superstes</i>                  |
| 153                    | climacograptid                                  |
| 156                    | <i>Orthograptus quadrimucronatus spinigerus</i> |
| 157                    | <i>Orthograptus apiculatus</i>                  |
| 161                    | <i>Hustedograptus teretiusculus</i>             |
| 162                    | <i>Corynoides</i>                               |
| 163                    | <i>Dicellograptus</i>                           |
| 164                    | <i>Dicranograptus</i>                           |
| 165                    | <i>Pseudoclimacograptus</i>                     |
| 166                    | <i>Lasiograptus</i> small species               |
| 167                    | <i>Orthograptus calcaratus</i> group            |
| 168                    | <i>Climacograptus</i>                           |
| 169                    | dicranograptid                                  |
| 170                    | <i>Lasiograptus</i>                             |
| 171                    | <i>Glyptograptus euglyphus</i>                  |
| 172                    | <i>Glyptograptus</i>                            |
| 173                    | <i>Corynoides curtus</i>                        |
| 174                    | <i>Corynoides calicularis</i>                   |
| 175                    | <i>Climacograptus bicornis bicornis</i>         |
| 176                    | <i>Climacograptus bicornis peltifer</i>         |
| 177                    | <i>Lasiograptus costatus</i>                    |
| 178                    | <i>Dicranograptus ramosus longicaulis</i>       |
| 179                    | <i>Dicellograptus patulosus</i>                 |
| 180                    | <i>Leptograptus validus</i>                     |
| 181                    | <i>Normalograptus</i>                           |
| 182                    | <i>Glossograptus hincksii</i>                   |
| 183                    | <i>Dicellograptus angulatus</i>                 |
| 184                    | <i>Thamnograptus</i>                            |
| 185                    | <i>Climacograptus antiquus</i>                  |
| 186                    | <i>Orthograptus truncatus intermedius</i>       |
| 187                    | <i>Dicellograptus salopiensis</i>               |
| 188                    | <i>Dicellograptus intortus</i>                  |

|     |                                            |
|-----|--------------------------------------------|
| 189 | <i>Pseudoclimacograptus stenostoma</i>     |
| 190 | <i>Glossograptus hincksii fimbriatus</i>   |
| 191 | <i>Climacograptus bicornis tridentatus</i> |
| 192 | <i>Dicranograptus ziczac</i>               |
| 193 | <i>Amplexograptus</i>                      |
| 194 | <i>Leptograptus validus incisus</i>        |
| 196 | <i>Dicranograptus nicholsoni</i>           |
| 197 | <i>Dicellograptus divaricatus</i>          |
| 198 | <i>Dicranograptus celticus</i>             |
| 199 | <i>Orthograptus</i>                        |
| 200 | <i>diplograptid indet</i>                  |
| 201 | <i>Dicranograptus ramosus spinifer</i>     |
| 202 | <i>Nemagraptus</i>                         |
| 203 | <i>Ensigraptus caudatus</i>                |
| 204 | <i>Neurograptus margaritatus</i>           |
| 205 | <i>Dicranograptus ramosus</i>              |
| 206 | <i>Normalograptus brevis</i>               |
| 207 | <i>Lasiograptus harknessi</i>              |
| 208 | <i>Cryptograptus</i>                       |
| 209 | <i>Dicellograptus geniculatus</i>          |
| 210 | <i>Dicellograptus sextans</i>              |
| 211 | <i>Dicranograptus furcatus</i>             |
| 212 | <i>Orthograptus calcaratus acutus</i>      |
| 215 | <i>Glossograptus</i>                       |
| 216 | <i>Halograptus</i>                         |
| 217 | <i>Dicranograptus tardiusculus</i>         |
| 218 | <i>Dicranograptus cyathiformis</i>         |
| 219 | <i>Halograptus mucronatus</i>              |
| 220 | <i>Leptograptus ascendens</i>              |
| 221 | <i>Amplexograptus praetypicalis</i>        |
| 222 | <i>Amphigraptus</i>                        |
| 223 | <i>Orthograptus pageanus</i>               |
| 224 | <i>Orthograptus truncatus</i>              |
| 225 | <i>Climacograptus spiniferus</i>           |
| 226 | <i>Leptograptus flaccidus</i>              |
| 227 | <i>Retiograptus geinitzianus</i>           |
| 228 | <i>Dicellograptus rigidus</i>              |
| 229 | <i>Dicranograptus brevicaulis</i>          |
| 230 | <i>Orthograptus whitfieldi</i>             |
| 231 | <i>Climacograptus dorotheus</i>            |
| 232 | <i>Leptograptus flaccidus macilentus</i>   |
| 233 | <i>Orthograptus amplexicaulis</i>          |
| 234 | <i>Plegmatograptus</i>                     |
| 235 | <i>Dicellograptus morrisi</i>              |
| 236 | <i>Dicellograptus pumilus</i>              |
| 237 | <i>Corynoides ultimus</i>                  |
| 238 | <i>Orthograptus quadrimucronatus</i>       |
| 239 | <i>Dicellograptus flexuosus</i>            |

|     |                                            |
|-----|--------------------------------------------|
| 240 | <i>Orthograptus calcaratus basilius</i>    |
| 241 | <i>Orthograptus calcaratus tenuicornis</i> |
| 242 | <i>Amplexograptus perexcavatus</i>         |
| 243 | <i>Halograptus bimucronatus</i>            |
| 244 | <i>Diplograptus foliaceus</i>              |
| 245 | <i>Diplograptus</i>                        |
| 246 | <i>Pseudoclimacograptus extraspiney</i>    |
| 247 | <i>Amplexograptus arctus</i>               |
| 248 | <i>leptograptid</i>                        |
| 250 | <i>Dicellograptus notabilis</i>            |
| 251 | <i>Dendrograptus</i>                       |
| 252 | <i>Dicellograptus alabamensis</i>          |
| 253 | <i>Nemagraptus subtilis</i>                |
| 254 | <i>dichograptid stipes</i>                 |
| 255 | <i>Dictyonema fluitans</i>                 |
| 256 | <i>Thamnograptus capillaris</i>            |
| 257 | <i>Thamnograptus scoticus</i>              |
| 258 | <i>Glossograptus armatus</i>               |
| 259 | <i>Didymograptus serratulus</i>            |
| 260 | <i>Corynoides pristinus</i>                |
| 261 | <i>Dicranograptus furcatus minimus</i>     |
| 262 | <i>Halograptus mucronatus nobilis</i>      |
| 263 | <i>Nemagraptus pertenus</i>                |
| 264 | <i>Diplograptus compactus</i>              |
| 265 | <i>Corynoides serpens</i>                  |
| 266 | <i>Leptograptus grandis</i>                |
| 267 | <i>Leptograptus</i>                        |
| 268 | <i>Pseudoclimacograptus setosus</i>        |
| 269 | <i>Climacograptus antiquus lineatus</i>    |
| 270 | <i>glyptograptid</i>                       |

**Appendix 3.** The complement of 78 graptolite taxa recognised for the 66 localities identified by the BGS as *gracilis* Biozone for the Southern Uplands. The appendix also indicates the total number of occurrences for each taxon.

| Species                                 | Occurrences |
|-----------------------------------------|-------------|
| <i>Amphigraptus</i>                     | 1           |
| <i>Amplexograptus</i>                   | 1           |
| <i>Amplexograptus arctus</i>            | 1           |
| <i>Amplexograptus leptotheca</i>        | 4           |
| <i>Amplexograptus perexcavatus</i>      | 4           |
| <i>climacograptid</i>                   | 2           |
| <i>Climacograptus</i>                   | 9           |
| <i>Climacograptus antiquus</i>          | 9           |
| <i>Climacograptus bicornis</i>          | 26          |
| <i>Climacograptus bicornis bicornis</i> | 5           |

|                                            |    |
|--------------------------------------------|----|
| <i>Climacograptus bicornis peltifer</i>    | 4  |
| <i>Climacograptus bicornis tridentatus</i> | 2  |
| <i>Corynoides</i>                          | 15 |
| <i>Corynoides pristinus</i>                | 1  |
| <i>Cryptograptus</i>                       | 6  |
| <i>Cryptograptus tricornis</i>             | 35 |
| <i>Dendrograptus</i>                       | 2  |
| <i>Dicellograptus</i>                      | 5  |
| <i>Dicellograptus divaricatus</i>          | 7  |
| <i>Dicellograptus exilis</i>               | 26 |
| <i>Dicellograptus geniculatus</i>          | 1  |
| <i>Dicellograptus intortus</i>             | 17 |
| <i>Dicellograptus patulosus</i>            | 4  |
| <i>Dicellograptus rigidus</i>              | 10 |
| <i>Dicellograptus salopiensis</i>          | 23 |
| <i>Dicellograptus sextans</i>              | 16 |
| <i>Dicranograptid</i>                      | 1  |
| <i>Dicranograptus</i>                      | 4  |
| <i>Dicranograptus brevicaulis</i>          | 6  |
| <i>Dicranograptus celticus</i>             | 4  |
| <i>Dicranograptus cyathiformis</i>         | 1  |
| <i>Dicranograptus furcatus</i>             | 1  |
| <i>Dicranograptus nicholsoni</i>           | 7  |
| <i>Dicranograptus ramosus</i>              | 11 |
| <i>Dicranograptus ramosus spinifer</i>     | 2  |
| <i>Dicranograptus rectus</i>               | 18 |
| <i>Dicranograptus tardiusculus</i>         | 7  |
| <i>Dicranograptus ziczac</i>               | 1  |
| <i>Didymograptus serratulus</i>            | 1  |
| <i>Didymograptus superstes</i>             | 44 |
| <i>Diplograptus</i>                        | 1  |
| <i>Diplograptus compactus</i>              | 1  |
| <i>Diplograptus foliaceus</i>              | 6  |
| <i>Glossograptus</i>                       | 2  |
| <i>Glossograptus hincksii</i>              | 10 |
| <i>Glossograptus hincksii fimbriatus</i>   | 8  |
| <i>Glyptograptus</i>                       | 3  |
| <i>Glyptograptus euglyphus</i>             | 14 |
| <i>Hallograptus</i>                        | 7  |
| <i>Hallograptus bimucronatus</i>           | 6  |
| <i>Hallograptus mucronatus</i>             | 18 |
| <i>Hustedograptus teretiusculus</i>        | 16 |
| <i>Lasiograptus</i>                        | 8  |

|                                   |    |
|-----------------------------------|----|
| Lasiograptus costatus             | 8  |
| Lasiograptus harknessi            | 2  |
| Lasiograptus small species        | 1  |
| leptograptid                      | 1  |
| Leptograptus ascendens            | 2  |
| Leptograptus validus              | 3  |
| Leptograptus validus incisus      | 2  |
| Nemagraptus                       | 10 |
| Nemagraptus gracilis              | 38 |
| Nemagraptus pertenus              | 4  |
| Normalograptus                    | 2  |
| Normalograptus brevis             | 5  |
| Orthograptus                      | 8  |
| Orthograptus apiculatus           | 3  |
| Orthograptus calcaratus acutus    | 10 |
| Orthograptus calcaratus group     | 15 |
| Orthograptus whitfieldi           | 4  |
| Pseudoclimacograptus              | 7  |
| Pseudoclimacograptus modestus     | 8  |
| Pseudoclimacograptus scharenbergi | 19 |
| Pseudoclimacograptus stenostoma   | 2  |
| Retiograptus geinitzianus         | 3  |
| Thamnograptus                     | 4  |
| Thamnograptus capillaris          | 2  |

**Appendix 4.** The complement of 34 graptolite taxa recognised for the nine localities identified by the BGS as *peltifer* Biozone for the Southern Uplands. The appendix indicates the total number of occurrences for each taxon.

| Species                          | Occurrences |
|----------------------------------|-------------|
| Amplexograptus leptotheca        | 3           |
| climacograptid                   | 1           |
| Climacograptus                   | 1           |
| Climacograptus bicornis          | 3           |
| Climacograptus bicornis bicornis | 3           |
| Climacograptus bicornis peltifer | 1           |
| Corynoides calicularis           | 1           |
| Cryptograptus tricornis          | 5           |
| Dicellograptus                   | 1           |
| Dicellograptus exilis            | 2           |
| Dicellograptus patulosus         | 3           |
| Dicranograptus cyathiformis      | 1           |
| Dicranograptus nicholsoni        | 2           |

|                                    |   |
|------------------------------------|---|
| Dicranograptus ramosus longicaulis | 1 |
| Dicranograptus ramosus spinifer    | 1 |
| Dicranograptus rectus              | 1 |
| Dicranograptus ziczac              | 2 |
| Glossograptus                      | 1 |
| Glossograptus hincksii             | 2 |
| Glyptograptus                      | 1 |
| Lasiograptus                       | 1 |
| Lasiograptus costatus              | 1 |
| Lasiograptus harknessi             | 3 |
| Leptograptus validus               | 1 |
| Normalograptus                     | 2 |
| Normalograptus brevis              | 1 |
| Orthograptus                       | 1 |
| Orthograptus apiculatus            | 2 |
| Orthograptus calcaratus basilius   | 1 |
| Orthograptus calcaratus group      | 1 |
| Orthograptus whitfieldi            | 2 |
| Pseudoclimacograptus               | 3 |
| Pseudoclimacograptus scharenbergi  | 2 |
| Thamnograptus                      | 2 |