Biostratigraphy of late Llandovery (Telychian) and Wenlock turbiditic sequences in the SW Southern Uplands, Scotland

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Running header: Biostratigraphy of the SW Southern Uplands
Abstract

In the SW part of the Southern Uplands of Scotland the relatively thin Moffat Shale Group (late Ordovician–early Silurian) is succeeded by a thick development of Silurian greywackes, of variable turbiditic facies. This includes late Llandovery (Telychian) quartzose greywackes with interbedded thin graptolitic shales of the *turriculatus* and *crispus* biozones, in the upper part of the Gala Group, a sequence which is laterally equivalent to the basal part of the Hawick Group. The age of the finer-grained calcareous Hawick Group, which here includes the Ross Formation, ranges from late Llandovery (*turriculatus* Biozone) to early Wenlock (*riccartonensis* Biozone). The Riccarton Group, which contains thick units of thinly bedded siltstones and mudstones, is of Wenlock age (*riccartonensis* to *lundgreni* biozones). Within this sequence, all the biozones of the standard graptolite zonal scheme have been recognized in the area, with the exception of the *crenulata* Biozone of the late Llandovery (Telychian Stage) and the *murchisoni* and *ellesae* biozones of the Wenlock (Sheinwoodian Stage). Details of the graptolite biostratigraphy are closely comparable with those of the markedly thinner sequences of northern England. Acritarchs occur throughout the sequence but are most numerous and best preserved in the Gala Group. Poorly preserved chitinozoa and spores are also present, the former occurring sporadically throughout the succession but the latter become common only in the Riccarton Group.

Key words: Silurian, graptolites, acritarchs, spores, chitinozoa
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In his introductory remarks to observations on the Silurian rocks of the south of Scotland (Fig. 1A), Murchison (1851, p.139) commented that "no one can be more impressed than myself with the difficulty which must for some time prevail in producing a detailed monograph of the Silurian Rocks of Scotland. Their numberless dislocations and contortions would be difficult to unravel, even in a clearly exposed mountain-chain; but when we add to this, that, for the most part, the strata are obscured by vegetation, bogs or drift and also broken through by a variety of igneous rocks, every one will perceive that the task of placing them in their original order of succession is one which can only be accomplished by long-continued and close labour such as has characterised the Geological Survey of England and Wales".

Following the pioneering work of Lapworth (1878), which demonstrated the stratigraphical value of the graptolite faunas, the Geological Survey were obliged to revise their maps of the Southern Uplands. The results were summarised in the classic memoir on the Silurian rocks of Scotland (Peach & Horne 1899). However, Greig (1971, p.35) over a century after Murchison made his remarks, justly observed that "the subdivision and order of succession of the Silurian rocks of the Southern Uplands are controversial subjects." This is nowhere better illustrated than in SW Scotland, where BGS resurveying of the geology of the Southern Uplands has recently been concentrated, and has resulted in new interpretations of the lithostratigraphy and tectono-stratigraphical relationships of the formations across the Llandovery – Wenlock Series boundary (Barnes et al., 1989 and in preparation), together with their biostratigraphical classification.

The purpose of this paper is to record some of the biostratigraphical results of the recent British Geological Survey investigations in the SW part of the Southern Uplands (Fig. 1B). For the first time, a complete modern biostratigraphical account of the late Llandovery (Telychian) and Wenlock sequences in the area is presented. It is based on new information integrated with the revision of previously published data and focuses upon longstanding controversies concerned with the ages of the 'Hawick Rocks' and Raeberry Castle Formation, and includes the upper part of the Gala Group, where there is lateral transition
into the lower part of the Hawick Group. In addition, the zonal sequence of graptolites is compared with those occurring elsewhere in Scotland and in northern England (Fig. 1A). New microfossil assemblages are recorded and their age implications and relationship to the graptolite zonal scheme are discussed.

1. Stratigraphical framework

The lithostratigraphical classification of the late Llandovery and Wenlock rocks in the SW Southern Uplands currently in use by the BGS (Barnes et al. 1989, and in preparation) is summarised in Fig. 2, together with chronostratigraphical and biostratigraphical relationships. It should be noted that in the tectonostratigraphic scheme of Kemp (1986) the Ross Formation was regarded as part of the Riccarton Group but on lithological, sedimentological and structural grounds it is now considered to show greater affinities with rocks of the Hawick Group (Barnes et al. 1989, and in preparation).

1.1 Gala Group

Although the Gala Group is undivided in this account, a number of fault-bounded blocks have been named in SW Scotland (Barnes et al. 1987). It abruptly succeeds the Moffat Shales Group and consists of massive to thick-bedded, medium to coarse grained, generally quartzo-feldspathic greywacke. There is a gradational change towards predominantly finer-grained, more thinly bedded greywacke in younger blocks of the Gala Group which suggests there may originally have been a gradational sedimentary contact with the Hawick Group. Indeed, a lateral transition from one to the other is recognized locally and is confirmed by the graptolite data, although for most of the outcrop the boundary is now regarded as a major strike-parallel fault. Graptolites diagnostic of the Llandovery Series have long been known from the Gala Group (e.g. Peach & Horne 1899) and an early to late Llandovery age is well established. However, an account of the whole of the Gala Group is beyond the scope of the present paper and the biostratigraphy of only the upper part of the Group (Telychian) is considered here.
1.2 Hawick Group

The Hawick Group is composed of very uniform sequences of dominantly medium to thin-bedded, fine to medium-grained, greenish grey calcareous greywacke with interbedded silty mudstone. As now defined (Barnes et al., 1989 and in preparation) the Group comprises the Cairnharrow, Kirkmaiden, Carnish down and Ross formations (Fig.2), which are distinguished by facies variations within the turbidite regime. An early Wenlock age for the beds now comprising the Ross Formation is well established (e.g. Peach & Horne 1899, p.80, as "Riccarton Beds"). However, the three remaining formations of the Group, approximate to the so-called 'Hawick Rocks', the age of which has long been a subject of controversy, due largely to structural complications and the sparseness of stratigraphically useful fossils. The name 'Hawick Rocks' was first introduced by Lapworth and Wilson (1871), who considered them to be the oldest in the Southern Uplands, bearing "a strong resemblance both in lithological characters and fossil contents [trace fossils] to the Cambrians of the Longmynd, but they are very probably of later age" (p.458).

Subsequently Lapworth (1889) and Peach and Horne (1899) considered their age to be post-Llandoverly as then understood and pre-Wenlock, being equivalent to the Tarannon Shales of Wales. However, O.T. Jones (1921, p.171) showed that the Tarannon Shales of Wales are the equivalents of beds previously classified with the upper part of the Llandovery Series. Later, Craig and Walton (1959) concluded that the 'Hawick Rocks' were of Ludlow age, and Warren (1964) considered them to be part of the Wenlock Series; however, Rust (1965) reported that graptolites from the Hawick Rocks of the W coast of the Whithorn area at Kirkmaiden (Fig.1B) were considered by Strachan to be indicative of a late Llandovery age (Monoclimacis giestoniensis or Monoclimacis crenulata biozones). Nevertheless, Clarkson, Craig and Walton (1975) concluded that the Hawick Rocks are younger than the early Wenlockian Ross Formation, belonging principally to the Ludlow Series, although with the possibility of a late Wenlock age for the lower beds of the formation. This was based partially upon the erroneous conclusion that the Raeberry Castle Formation is of Llandovery age. Subsequently Kemp and White (1985) and Kemp (1986) assigned a probable latest Llandovery age to the Hawick Rocks on the basis of structural and biostratigraphic studies of their southernmost outcrops in the Kirkcudbright and Langholm districts. The new biostratigraphic details supporting this conclusion are included in this paper.
1.3 Riccarton Group

At the junction between the Hawick and Riccarton groups, there is a marked sedimentological change to more diverse sequences of the Raeberry Castle Formation which include thick units of thinly bedded siltstones and mudstones, pebbly sandstones and very thick hemipelagites. The formation name was established by Peach and Horne (1899, p.80) who recorded shells from conglomerates which they considered to be of probable Ludlow age. However, Pringle (1948) assigned the formation to the Wenlock Series on the grounds that graptolite assemblages from the Riccarton Beds (i.e. Ross Formation of this account) were limited to early Wenlock forms and that the shells from the Raeberry Castle Beds provided no evidence of a Ludlow age.

Subsequent detailed mapping and assessment of new palaeontological data led Clarkson, Craig and Walton (1975) to confirm the Wenlock age of the Riccarton Beds, which they renamed the Ross Formation; but they erroneously deduced a mid- and late Llandovery age for the Raeberry Castle Formation. Most recently, however, Kemp and White (1985) having assessed the biostratigraphical implications of new graptolite collections reviewed in the present paper, concluded that the age of the Raeberry Castle Formation is mid- to late Wenlock.

2. Biostratigraphy

2.1 Macro- and micro-fossil occurrences

Macrofossils, other than graptolites, are rare. An isolated, derived tabulate coral from the Gala Group on the W coast of the Rhins of Galloway and another isolated example from the Hawick Group (Carghidown Formation) of Burrow Head (Fig. 1B), have been described by Scrutton and McCurry (1987). Bioclastic material, including corals, bryozoans, brachiopods and molluscs, has also been recorded from conglomeratic grits and limestone nodules of the Riccarton Group (Raeberry Castle Formation) at Gipsy Point and Little Balmae on the E side of Kirkcudbright Bay (Peach & Horne 1899, pp.554–556; Pringle 1948, p.45).
Graptolites are the most useful macrofossils for biostratigraphical studies. However, they are present in black and dark grey shales which are generally very thin and are only rarely interbedded with the greywackes of the Gala Group, and also the Cairnharrow and Kirkmaiden formations of the Hawick Group; no graptolite horizons have been found in the Carghidown Formation of this area. This suggests that pauses in turbidite deposition were few and of short duration until the earliest Wenlock. Thereafter graptolitic grey silty mudstones (hemipelagites) are relatively common in the Ross Formation and also in the Raeberry Castle Formation, the latter unit containing some hemipelagites several metres thick. Stratigraphical ranges of Telychian and younger graptolites found in this area are shown in Fig. 3.

Palynomorphs, dominantly acritarchs, but also sporomorphs and chitinozoa have been recovered from graptolite shales and turbidite mudstones, siltstones, and fine grained sandstones. Many samples were not collected specifically for palynology; some were taken from graptolite collections and others are from petrological samples. Nevertheless, out of a total of 74 samples, 66 yield at least some palynomorphs and Fig. 4 illustrates the distribution of all taxa recorded. Palynomorphs are most numerous and best preserved in the turbidite mudstones and siltstones; assemblages from graptolitic shales and turbidite sandstones are often sparse and poorly preserved.

A full listing of the graptolite and palynomorph localities in the Gala, Hawick and Riccarton groups are included in Appendix 1. Graptolite faunal lists of the Gala Group and formations of the Hawick and Riccarton groups are given in Appendix 2, while Appendix 3 lists all the palynomorph taxa identified within these sequences. The graptolite specimens are held in the macrofossil collections at the British Geological Survey, Murchison House, Edinburgh and figured microfossil specimens are stored in the MPK collection at the British Geological Survey, Keyworth.

2.2 Silurian biozonal schemes

Biostratigraphical classification based on graptolites is well established in Lower Palaeozoic stratigraphy. A comprehensive, up-dated account of the Silurian graptolite biozones was published by Rickards (1976) and has been found to be readily applicable to the Scottish succession described in this paper.
A Silurian acritarch zonation has recently been defined by Dorning and Hill (1991) with seven biozones for the Llandovery and five for the Wenlock (Fig. 5). This zonation is based on earlier work by Hill (1974), Hill and Dorning (1984) in the type Llandovery, and Dorning (1981a) in the type Wenlock and Ludlow areas. According to Dorning and Hill (1991) the scheme is not only applicable to the Welsh Basin, but also to northern Europe and eastern N America.

Martin (1989) erected an informal worldwide acritarch biozonation for the Silurian based on a synthesis of published data, and correlated it approximately with the graptolite zonation. However, this classification is less useful since her Group 4 spans the stratigraphical range of all except the early Telychian localities of this paper (Fig. 5). Where possible the Scottish acritarch assemblages described in this account are assigned to the biozones of both schemes (Fig. 4).

2.3 Gala Group – undifferentiated (Monograptus turriculatus and M. crispus biozones)

Graptolites (Figs. 6a, 7c; Appendices 1,2, Locs. 1–6). In the SW Southern Uplands the younger units of the Gala Group are referable to the lower biozones of the Telychian (late Llandovery). For example, in the Rhins of Galloway, near Cairnie Finnart (Locality 1 of Appendix 1) on the north side of Port Logan Bay, fragments of possible Monograptus proteus and M. runcinatus, suggesting a M. turriculatus Biozone age, were collected from a single dark lamina in a bed of shale. About 4.5 km to the SE, in the Grennan slate quarries (Locs. 2,3) (Peach & Horne 1899, p.216), recent collections have been made of a comparatively well preserved M. crispus Biozone fauna which includes Monograptus crispus, M. discus, M. exiguis, and M. marri. Some 3 km to the WSW of the quarries a black shale in a sea stack at Dunbuck, to the N of Clanyard Bay (Loc. 4) yielded a fauna of less certain age, However, a M. crispus Biozone age is suggested by an overall assessment of the assemblage, which includes M. marri, M. cf. planus, M. cf. plumosus, M. cf. priodon, M. proteus and a possible example of Petalograptus altissimus. Black, sparsely graptolitic shale laminae, only a few mm thick, found in two small field exposures near Alticry, 9 km NW of Port William (Locs. 5,6), yielded only M. proteus, indicating either the M. turriculatus or M. crispus Biozone.

Microfossils (Fig. 8; Fig. 4; Appendices 1,3, Locs. 95–102). The most diverse and abundant acritarch floras yet recorded from the Southern Uplands were recovered from coastal exposures near Muldaddie, on
the S side of Port Logan Bay (Fig. 4, Locs. 99–101). Species of Ammoniidium are common, especially A. listeri and A. microcladum. The assemblages from Locs. 99 and 100 suggest only an A. microcladum to D. monospinosa Biozone (mid- to late Llandovery) age, although according to Dorning and Hill (1991) the total ranges of Ammoniidium telychense and Ammoniidium wychense lie within their D. monospinosa Biozone (Fig. 5), and the presence of these taxa at Loc. 100 should restrict the assemblage to this Biozone. However, both these species are recorded from the mid-Llandovery of the Welsh Borderland (HFB, unpublished BGS data). At Loc. 101 the presence of Gracilisphaeridium encantador indicates that the assemblage lies within Group 4 of Martin (1989), the base of which she places within the Mcl. griesonensis or Mcl. crenulata Biozone (Martin 1989, p.209). However, graptolite evidence (see above) indicates a M. turriculatus to M. crispus Biozone age for the younger part of the Gala Group in the Rhins of Galloway, suggesting an earlier range base for G. encantador in the Southern Uplands (see also 3.2.1). Taxa such as A. listeri, A. telychense and Cymatiosphaera llandoveryensis? also suggest that Loc. 101 is not younger than D. monospinosa Biozone age. The remaining four samples from the Gala Group (Locs. 95–98) yielded only sphaeromorph acritarchs of no biostratigraphical value. The Gala Group assemblages also yielded recycled Ordovician acritarchs including Cymatiogaelea cristata?, Stelliferidium sp., and Stellechinatum sp. A. and Stellechinatum sp. A. The latter has only been recorded from around the Tremadoc–Arenig boundary in the Lake District, the Isle of Man, and from Bell Island, Newfoundland (S G Molyneux, unpublished data). C. cristata is restricted to the Tremadoc.

2.4 Hawick Group

2.4.1 Cairnharrow Formation (M. turriculatus and ?M. crispus biozones). Graptolites (Fig. 6b–d; 7d–g; Appendices 1,2, Locs 7–11). Thin graptolitic shales interbedded with the turbidites are extremely rare in the Cairnharrow Formation but have furnished some evidence for the M. turriculatus and possibly also the M. crispus Biozone of the Telychian. Three occurrences (Locs. 7, 9, 10) were reported by Peach and Horne (1899, pp. 167, 215–216) but a recent search for these was unsuccessful. However, small numbers of specimens from each locality are present in the collections of the BGS, Edinburgh and these have been re–examined, together with an old collection from Tarff Glen (Loc. 11) and specimens from another locality
(Loc. 8) which was discovered near Edgerton Farm during the present survey.

The graptolites (full faunal list in Appendix 2) are usually fragmented and crushed flat, making identification difficult. Although *M. turriculatus* itself is not present in any of the collections, the record of *M. halli* in the abandoned railway cutting N of the site of the former Whaup Hill station (Loc. 7) suggests the presence of the *M. turriculatus* Biozone, as does the doubtful identification of *M. (D.?)* runcinatus from the crag near Edgerton Farm (Loc. 8). The ages of the remaining collections, from the abandoned railway cutting near Baldoon Mains (Loc. 9), from the vicinity of Trowdale Glen (Loc. 10) and from Tarff Glen (Loc. 11) are less certain. Localities 9 and 10 yielded *M. cf. plumosus* of possible *M. turriculatus* Biozone age. However other taxa recorded are long-ranging forms and the absence of monoclimacids is a strong indication that each collection is from a level within either the *M. turriculatus* or the *M. crispus* Biozone.

Microfossils (Fig. 4; Appendices 1,3, Loc. 103). A sample from a 10cm thick dark grey to black shale interbedded with greywackes in Tarff Water, close to the outflow from Loch Mannoch, has yielded an acritarch assemblage in which the presence of *A. listeri* and *D. limaciformis* indicate an *A. microcladum* to *D. monospinosa* Biozone age (Fig. 5), equivalent to mid-Aeronian to Telychian (mid- to late Llandovery).

2.4.2 Kirkmaiden Formation (*Monoclimacis griestoniensis* Biozone). Graptolites (Figs. 6c–h, 7a, b; Appendices 1, 2, Locs. 12–15). New collections from thin black mudstone laminae between greywacke beds at Kirkmaiden and Back Bay (Locs. 12–14) confirm the late Llandovery age (*Monoclimacis griestoniensis* Biozone) tentatively suggested by Strachan (in Rust 1965, p.105). The graptolites are sparse, fragmented and generally poorly preserved, and completely unidentifiable at some outcrops. The BGS collections previously reported by White (in Barnes 1989) include numerous slim monoclimacid fragments together with *M. priodon* and monographtids of the *M. spiralis* group. Of the monoclimacids, a single crushed example has a maximum width of 1.20mm, and a second example is 1.11mm wide, but in the case of all the remaining fragments the width is less than 1.00mm. They differ from typical examples of *Monoclimacis griestoniensis*, which have a maximum width of 0.80mm (Toghill & Strachan 1970, p.516), in the slight angle of inclination of the interthecal wall from the axis of the rhabdosome (parallel in *Mcl. griestoniensis s.s.*) and in the higher proximal thecal counts. They are closely comparable with the form described by Elles and
Wood (1911, p.414) as *Mcl. cf. griestoniensis* from the Tarannon district of Central Wales "typically near the top of the Talerddig Grits, not far below the zone of var. *crenulata"*. In the Kirkmaiden collections, the typical form of *Mcl. griestoniensis* may also be present, but because of the poorly preserved nature of the material, this cannot be confirmed. Nevertheless, the Kirkmaiden graptolite horizons are considered to be within the *Mcl. griestoniensis* Biozone, possibly the upper part.

At one other locality within the area, a small quarry 1.6km SW of Waterside to the E of Loch Mannoch (Loc. 15), similar black laminae have yielded only a single fragmented example of a spirograptid, which resembles *M. tullbergi* in the shape of the rhabdosome and in possessing twisted thecae, but has distal thecae more triangle than in typical examples from the *Mcl. griestoniensis* and *Mcl. crenulata* biozones. Consequently the age of the specimen is uncertain.

Microfossils (Fig. 9a–h; Fig. 4; Appendices 1, 3, Locs. 15, 104–108). The Waterside graptolite locality (Loc. 15) yielded a diverse and abundant but generally poorly preserved acritarch flora dominated by *Domasia* spp., with *Domasia quinquispinosa* and *Moyeria telychensis* indicating a *D. monospinosa* Biozone (late Llandovery) age. On the foreshore near Corseyard (Loc. 107), thin (10–15cm) dark grey mudstones interbedded with greywackes have also yielded acritarchs. *Dictyotidium telychense* and *Domasia* spp. are common, also suggesting a *D. monospinosa* Biozone age. Very poorly preserved chitinozoa were recorded from the Coalheugh Burn (Loc. 104) and Barstobrick Hill (Loc. 106) near Loch Mannoch, but are of little stratigraphical significance.

2.4.3 Carghidown Formation (latest Llandovery, probably *Monoclimacis crenulata* Biozone – possibly earliest Wenlock, *C. centrifugus* Biozone). Graptolites (Fig. 10a–i). No graptolites have been found in the Carghidown Formation in the SW part of the Southern Uplands. However, from a study of structural relationships, lithological comparisons and the palaeontological data from adjacent formations to the N and S, it can reasonably be inferred that the Carghidown Formation is probably of latest Llandovery age, with the possibility that the highest beds are of earliest Wenlock age. This is supported by acritarch evidence which also suggests a latest Llandovery to earliest Wenlock age.

Further support for a latest Llandovery age comes from the equivalent of the Hawick Group along strike in the Eskdalemuir area (Fig. 1A), where graptolites have been found in two thin developments of
dark shale exposed in Barr Burn [NT 227 050; 226 053] and another in Glendearg Burn [NT 231 061]. Red
mudstones occur in both sequences indicating that the beds are probably part of the Carphidown Formation.

The Barr Burn collections are dominated by fragments of broad monoclimacids (up to 2.2mm wide).
The majority are identified as examples of Monoclimacus vomerina s.l., but a few slim fragments are close
to Mcl. linnarssonii; several proximal fragments have traces of hooked thecae reminiscent of Mcl. crenulata
sensu Elles and Wood (1911, p.412), but their thecal counts are much lower. Nevertheless, the presence of
broad monoclimacids indicates a post- Mcl. griesenieri Biozone age while the absence of cyrtograptids
suggests a pre- Cyrtograptus centrifugus Biozone age. The Barr Burn assemblages are therefore interpreted
as belonging to the Monoclimacus crenulata Biozone, the topmost biozone of the Llandovery Series.
Monograptus priodon (common), M. cf. simulatus and M. cf. tullbergi also occur, together with retioliths
represented by Stomatograptus grandis girvanensis and a fragment of loose meshwork.

In the collections from Glendearg, M. priodon is again well represented and the dominant forms
are monoclimacids with a low thecal count. Most of the latter have a dorsoventral width approaching 1.0mm
and may be examples of Mcl. linnarssonii, but, because of the fragmentary nature of the material, it is not
possible to ascertain whether a mature width has been reached, so that identification is uncertain. A few
other fragments have a width of up to 1.66mm and are best assigned to Mcl. vomerina s.l. and one poorly
preserved proximal fragment possibly has hooked thecae, suggesting Mcl. crenulata sensu Elles and Wood.
The Glendearg collection also includes single examples of M. cf. simulatus and ?Barrandegraptus
pulchellus. The latter species has not previously been recorded in Britain from strata older than lowest
Wenlock, but Bjerringkov (1975, p.88) has described examples associated with Mcl. linnarssonii from the
Cyrtograptus lapworthi Biozone of Bornholm, Denmark, underlying the C. centrifugus Biozone.

The Glendearg assemblage is consequently considered to have the same age as the Barr Burn
collections, indicating the Mcl. crenulata Biozone, an interpretation supported by the absence of
cyrtograptids.

To the SE of the Barr Burn and Glendearg localities is a strip of country with a cross-strike width
of 14km, forming the southern part of the Central Belt. No graptolites have ever been recorded. A
reconnaissance of stream and roadside sections together with many new forestry trackside sections failed to
detect any graptolite-bearing horizons. Consequently the biostratigraphical age of these beds lying between
the latest Llandovery (Mcl. crenulata Biozone) Barr Burn localities and the earliest Wenlock (C. centrifugus Biozone) of the Ross Formation of the Southern Belt is uncertain but is presumably latest Llandovery Series and/or earliest Wenlock Series.

Microfossils (Figs. 9i–q, 11a–o; Fig. 4; Appendix 1, Locs. 109–119). Although acritarchs have been found in the Carghidown Formation, yields are low and preservation is generally poor. At the Mull of Galloway the presence of *M. telychensis* at Loc. 111 suggests a *D. monospinosa* Biozone (late Llandovery) age, and *Oppilatala eoplanktonica*? at Loc. 110 indicates a probable Llandovery age. Five samples collected from the W side of Kirkcudbright Bay (Locs. 113–117) yield poor assemblages dominated by sphaeromorphs and contain no age–diagnostic taxa. A sample taken from near the top of the Carghidown Formation at Bathinghouse Bay (Loc. 118) on the E side of Kirkcudbright Bay yields a sparse acritarch assemblage which includes *Salopidium granuliferum* and *Tyloptalla wenlockia*. If the occurrence of the latter species does not represent a downwards extension of the range recorded by Dorning (1981a) in the type Wenlock area, then this sample is probably not older than earliest Wenlock. Also present are abundant thick–walled *Leiosphaeridia* spp. and the spore tetrad *Tetrahedraletes medinensis*, the former suggesting affinity with the deep water assemblage of Dorning (1981b). One recycled specimen of the long–ranging Ordovician acritarch *Peteinosphaeridium trifurcatum breviradiatum*? was recorded from Bathinghouse Bay on the E side of Kirkcudbright Bay (Loc. 119).

Acritarchs have been recovered from samples at Barr Burn and Glendearg. At Barr Burn [NT 2272 0500] one sample (MPA 28470) yields an abundant flora including *Ammonidium* sp. C. llandoveryensis, *Deunffia monospinosa*, *Domasia trispinosa*, *Lophosphaeridium hauskae*, *Lophosphaeridium malvernense*, *Lophosphaeridium* spp., and *S. granuliferum*. The incoming of *D. monospinosa* is used to define the base of the *D. monospinosa* Biozone, while *C. llandoveryensis* and *L. malvernense* are not seen above the Telychian (Dorning & Hill 1991). Priewalder (1987) recorded *L. hauskae* commonly in the lower half of the amorphognathoides Biozone (upper Telychian), and sporadically from there to the lower part of the sagitta Biozone (top Sheinwoodian). Thus an overall assessment of this assemblage suggests a latest Telychian age, which does not conflict with the graptolite evidence. The sample (MPA 28472) from Glendearg [NT 2307 0612] yields a much less diverse assemblage, but the abundance of *Lophosphaeridium* spp. suggests an age similar to the Barr Burn sample. The predominance of *Lophosphaeridium* spp. as seen in these two samples
may provide a useful local acritarch marker for the uppermost part of the D. monospinosa Biozone (approximately Mcl. crenulata Biozone).

2.4.4 Ross Formation (Cyrtograptus centrifugus to Monograptus riccartonensis biozones). Graptolites (Figs. 7h; 12a–j; 13a, b, g, j; Appendices 1, 2, Locs, 16–69). The age of the Ross Formation ranges from the C. centrifugus Biozone at the base of the Wenlock Series to the highest subdivision of the M. riccartonensis Biozone (Kemp & White 1985). The C. centrifugus Biozone has been recognized in the most northerly part of the outcrop on the E side of Kirkcudbright Bay (Locs. 16–20, 22), on the E side of Meikle Ross at Shaw Hole (Locs. 47, 48), on the W side of Meikle Ross in Fauldlog Bay (Locs. 61–63), on the Isle of Whithorn, (Loc.69) (White in Barnes 1989) and at Burrow Head (Loc. 764, 65–66) (White in Barnes 1989). At all these localities, with the exception of the E side of Kirkcudbright Bay, the graptolites are associated with red mudstones. Cyrtograptids are mostly fragmented and poorly preserved. C. centrifugus is recorded together with C. aff. insectus and a form closely comparable with C. grayi. At two localities (Locs. 47, 61) Barrandeograptus? bornholmensis occurs, previous records of which are limited to the Baltic island of Bornholm where it is confined to the C. centrifugus Biozone (Bjerreskov 1975, p.89). Also present are Retiolites geinitzianus angustidens and R. geinitzianus geinitzianus; both species range from the late Llandovery Series but there are no records of either ever having been found in the overlying C. murchisoni Biozone. Monoclumacids are characteristically well represented by Mcl. vomerina basilica and Mcl. vomerina vomerina. Other species recorded include Monograptus cf. danbyi (Loc. 66) and M. minimus causteyensis (Locs. 17,19) originally described by Rickards (1965) from the C. centrifugus Biozone of the Howgill Fells and later recorded by him (1969) from the same biozone in the Lake District. Also present (Locs. 22,61) is M. remotus which was found by Warren (1964) in the basal Wenlock Series SE of Hawick. The C. murchisoni Biozone may be present in the cliff section at Burrow Head (Loc. 67) which has yielded Monograptus priodon and Monoclumacis spp. associated with a cyrtograptid with a high proximal thecal count and which may be an example of C. murchisoni. However, no firm evidence for the presence of the C. murchisoni Biozone was found in the excellent shore sections on the E side of Kirkcudbright Bay and on the W and E side of Meikle Ross. This may not preclude its presence since in both the Howgill Fells and Lake District successions the biozone is only about 3m in thickness (Rickards 1969, pp. 61–62).
Graptolitic mudstones of the *M. riccartonensis* Biozone occupy a broad outcrop along the shore on the E side of Kirkcudbright Bay and around the Meikle Ross peninsula. Detailed study of the assemblages has demonstrated for the first time that the three-fold subdivision of the *M. riccartonensis* Biozone, originally described by Rickards in the Howgill Fells (1967, p.221) and later recognized by him in the Lake District succession (1969, p.63, fig.2) is present in the Southern Uplands, all three subdivisions occurring in the Ross Formation. *M. riccartonensis* is characteristically abundant throughout the biozone, but in the lowest subdivision it is associated with *M. priodon* (for example Locs. 35–38). In the middle subdivision *M. priodon* is absent (for example Locs. 25–29) and in the upper subdivision *M. firmus sedberghensis* and Pristiograptus cf. *dubius* make their earliest appearance (for example Locs. 39–42), and rarely possible examples of *M. priodon* are recorded (Loc. 31 and also Loc. 72 of the Raeberry Castle Formation). *Mcl. cf. vomerina vomerina* and *Mcl. vomerina basilica* are probably present throughout the biozone.

Microfossils (Fig. 15a–e; Fig. 4; Appendices 1, 3, Locs. 16, 21, 23, 24, 26, 30, 33, 44, 45, 47, 52, 55, 56, 60, 62, 120–130). Palynomorphs are present in 25 samples out of a total of 27 collected from within the Ross Formation from the E and W sides of Kirkcudbright Bay. Acritarchs of the *C. centrifugus* Biozone include *A. microcladum, A. wychense, Cymatosphaera cf. mirabilis, Domasia bispinosa, D. elongata, D. trispinosa, G. encantador, T. wenlockia, Tunisphaeridium caudatum, and Visbyphaera dilatispinosa*. *A. wychense* was previously recorded only in the Telychian (Dornig & Hill 1991). This assemblage suggests a *Deunffia brevispinosa* to *Deunffia brevifurcata* Biozone age, and lies within Group 4 of Martin (1989). The last appearance of *Domasia* at Loc. 21 may indicate the top of the *Deunffia brevifurcata* Biozone (Fig. 4). In the *M. riccartonensis* Biozone, preservation is poorer and acritarch diversity and abundance decreases; rare specimens of *A. microcladum, S. granuliferum*, and *T. wenlockia* suggest only a Wenlock age. Recycling of early to mid-Ordovician sediments is suggested by the presence of *Stelliferidium* sp. in a sample from Torrs Point (Loc. 120). Chitinozoa, especially *Ancyrochitina* spp. become more common in the *M. riccartonensis* Biozone and younger strata, but the only spore recovered from the Ross Formation is a single specimen of *Ambitiisporites* from Torrs Point on the E side of Kirkcudbright Bay (Loc. 33).
2.5 Riccarton Group

2.5.1 Raeberry Castle Formation (highest subdivision of the M. riccartonensis to the Cyrtograptus lundgreni biozones). Graptolites (Figs. 7i, 13c, f, h, i; 14a–k; Appendices 1, 2, Locs. 70–94). Exposures of the Raeberry Castle Formation are confined to the shore section E of the Ross Formation outcrop on the E side of Kirkcudbright Bay. Clarkson, Craig and Walton (1975) concluded that the Raeberry Castle Formation was older than the Ross Formation, claiming that it contained graptolite assemblages ranging from the Coronograptus gregarius Biozone to the Monograptus crispus Biozone, indicating a mid- to late Llandovery age. However, Kemp and White (1985) proved the Wenlock age of the formation, ranging from the Monograptus riccartonensis to the Cyrtograptus lundgreni Biozone.

The oldest beds belong to the highest subdivision of the M. riccartonensis Biozone, containing a graptolite assemblage comparable with that recorded from the top of the underlying Ross Formation (for example Loc. 82). In higher beds the Monograptus antennularius Biozone has been recognized for the first time in Scotland, this being the first published record of its occurrence outside the Howgill Fells and the Lake District where it was first established by Rickards (1967 and 1969 respectively). The low diversity assemblage consists mainly of M. antennularius sensu Rickards (equals M. capillaceus Tullberg of Kemp & White 1985), accompanied by Pristiograptus meneghini (for example Loc. 75).

The C. rigidus Biozone occurs at Little Raeberry (Loc. 85) where C. cf. rigidus rigidus has been found associated with M. flexilis aff. belophorus. On this evidence other collections with numerous examples of M. flexilis aff. belophorus but lacking C. rigidus rigidus are here assigned to the C. rigidus Biozone. In the Howgill Fells succession, Rickards (1967) established the M. flexilis belophorus Biozone between the M. antennularius and C. linnarssonii biozones, concluding that it was equivalent, at least in part, to the C. rigidus Biozone of Wales. This was later confirmed in the Lake District where Rickards (1969) found C. rigidus rigidus in stratigraphically equivalent beds associated with M. flexilis belophorus. Consequently he proposed that in the Howgill Fells zonal scheme the C. rigidus Biozone should replace the M. flexilis belophorus Biozone. The Little Raeberry record of C. cf. rigidus rigidus associated with M. flexilis belophorus supports this proposal, and is another example of close comparison of the northern England graptolite zonal sequences with that of the Southern Uplands. However, the Scottish specimens identified
as *M. flexilis* aff. *belophorus* differ from the equivalent form from the Howgill Fells in having a narrower dorso-ventral width proximally and thecae more closely spaced throughout the rhabdosome.

The *C. linnarssoni* Biozone has been proved in the hemipelagite at Balmae Burn (Loc. 78). The fauna includes *C. linnarssoni*, *C. rigidus cautleyensis* and *M. flexilis* aff. *flexilis* which are three of the species most characteristic of the biozone according to Rickards (1969, p.63). The Scottish examples of *M. flexilis* aff. *flexilis* differ from typical examples of the subspecies in having a narrower rhabdosome. Also included in the assemblage are *Monoclimacis inflendosae inflendosae*, *Mcl. vomerina basilica* and *Monograptus flemingii flemingii*; the type specimen of the *Mcl. vomerina basilica* is from the *C. linnarssoni* Biozone of the Builth area in Central Wales. Lamont (1947, p. 319) recorded a graptolite fauna, including *C. lundgreni* Tullberg, from Gipsy Point, 250m SSW of Loc. 78, observing that this was the youngest graptolite fauna so far recorded from the Southern Uplands. However, the specimen supposedly of *C. lundgreni* has since been re-identified as *C. linnarssoni* by Dr Isles Strachan (Clarkson et al. 1975, p.317), and it indicates the *C. linnarssoni* Biozone.

The succeeding *C. ellisae* Biozone has not been recorded in the Raeberry Castle Formation, although it may be represented by unfossiliferous strata; non-deposition or penecontemporaneous erosion are considered unlikely. This biozone was not found by Warren (1964) in the Hawick area and it was not recorded in the Langholm area (Lumsden et al. 1967). Indeed, in the Howgill Fells the biozone is estimated to be only 5.5m thick (Rickards 1967) and is only sporadically developed in the Lake District (Rickards 1969, p.63).

In the most easterly outcrop of the Raeberry Castle Formation in the vicinity of Netherlaw Point (Locs.88–94), the graptolite fauna is sparse and of low diversity. However, examples of *Pristiograptus pseudodubius* are present together with *M. flemingii* and *Monoclimacis inflendosae kingi*. This assemblage is regarded as indicating the *C. lundgreni* Biozone, although *C. lundgreni* itself has not been found. These are the youngest Silurian rocks recorded in the Southern Uplands. Higher strata, if present, are unconformably covered by rocks of Carboniferous age.

Microfossils (Fig. 15f–o; Fig.4; Appendices 1,3, Locs. 74–76, 78, 82–85, 87–88, 92–94, 131–137). Palynomorphs are present in all samples collected from within the Raeberry Castle Formation. However, other than sphaeromorph acritarchs, both acritarchs and sporomorphs are rare in the lower part of the
formation (upper M. riccartonensis to C. rigidus biozones). Acritarchs become more abundant and diverse from approximately the C. linnavsonni Biozone where Estiandra barbata, Oppilatala cf. frondis, O. cf. ramusculosa, Tylotopalla cf. cellonensis, T. aff. digitifera, and numerous specimens of T. wenlockia are present, along with long-ranging species of Micrhystridium, Multiplicisphaeridium and Veryhachium. The relatively high abundance of T. wenlockia and the absence of Domasia spp. suggests these assemblages lie within the Cymatiosphaera pavimenta Biozone as Dorning (1981a, p.202) records the acme of the former within his W2 Zone (= the C. pavimenta Biozone; see Dorning & Bell 1987, fig. 15.2). A single specimen of Acanthodiacrodium sp., recycled from the early Ordovician, was recovered from Little Raeberry (Loc. 136).

Rare spore tetrads were recovered from the Raeberry Castle Formation, but the dominant sporomorph type is the trilete spore Ambitisporites, which is present in small numbers from the M. riccartonensis to the C. rigidus biozones and is common in the C. lundgreni Biozone. The increase in number and taxonomic diversity of spores through this formation probably reflects increased terrestrial input following the restriction of the basin during the closing stages of the Iapetus Ocean. Rapid evolution and diversification of land–plants in the late Wenlock may have contributed to the increase in spore abundance, but Gray et al. (1974, p.262) state that local environmental controls play a more significant role on spore occurrence, abundance, and diversity than evolutionary factors. A single specimen of the chitinozoan Cingulochitina cingulata was found at Netherlaw Point (Loc. 93); Paris (1989) recorded a range for this species from the top M. flexilis (= C. linnavsonni) Biozone to low M. ludensis Biozone which is in agreement with the C. lundgreni Biozone age indicated by graptolites.

3. Biostratigraphical summary and comparison with other areas

The faunal composition of the late Llandovery and Wenlock graptolite biozones in the SW Southern Uplands is shown in Fig.3. The successions are significantly thicker than those of the Howgill Fells and Lake District (Fig.1A) and their outcrop is much affected by strike faulting. Consequently the stratigraphical relationships of the Scottish graptolite horizons would be extremely uncertain without knowledge of the biostratigraphical details of the successions in the Howgill Fells (Rickards 1967; 1970) and Lake District.
(Rickards 1969; Hutt 1974). Comparison with these northern England areas is facilitated by the close similarities of both the Llandovery and Wenlock faunas.

Very few Silurian microfossil data are available for the rest of the Southern Uplands and only sparse, poorly preserved assemblages have been recorded from the Wenlock and Ludlow of northern England (McCaffrey et al., in press).

3.1 Graptolites

3.1.1 Llandovery Series (Telychian Stage). In the SW Southern Uplands Rastrites maximus Carruthers has not been found in the Gala Group so that the presence of the R. maximus Subzone cannot be confirmed. However, although M. turriculatus (Barrande) itself has not been recorded either, the M. turriculatus Biozone is present near Whaup Hill Station (Loc.7) and, less certainly, at other graptolitic shale localities in the Cairnharrow Formation, as well as laterally equivalent beds of the Gala Group. The M. crispus Biozone has been proved in the Gennan slate quarries (Locs.2,3) and the Mel. griesioniensis Biozone occurs at Kirkmaiden (Locs.12,13). However, evidence for the Mel. crenulata Biozone has not been found.

To the NE, in the Moffatdale and Upper Ettrick Valley areas of the Southern Uplands, the R. maximus Subzone has been recorded at several localities in the top part of the Birkhill Shales Formation of the Moffat Shales Group (Toghill 1970; Webb et al. in press). Its fauna also occurs in thin shales interbedded with the turbidites of the overlying Gala Group, as well as an assemblage characteristic of higher horizons in the M. turriculatus Biozone (Webb et al. in press). South of the Ettrick Valley in March Sike [NT 3266 1700] the succeeding M. crispus Biozone has been proved (Toghill, 1970, p.239) and also the Mel. griesioniensis Biozone in a forestry track section [NT 2214 0971] near the watershed between the northerly and southerly flowing streams, both named Glendearg Burn (Webb et al. in press). To the S of these localities the Mel. crenulata Biozone has been proved in the Barr and Glendearg burns (see 2.4.3).

Farther to the NE in the Galashiels–Innerleithen–Lauder area late Llandovery graptolite shale horizons were reported by Lapworth (1870) and by Peach and Horne (1899). Unpublished revised identifications (by DEW) of specimens in the collections of the BGS, Edinburgh from these localities and
newly discovered graptolite localities in the area indicate that the upper part of the *M. turriculatus* Biozone, the *M. crispus* Biozone, the *Mcl. griestoniensis* Biozone are all represented. The *Mcl. crenulata* Biozone may also be present.

In the NE part of the Southern Uplands Strachan (1982) reported the occurrence of the *R. maximus* Subzone and higher *M. turriculatus* Biozone faunas in the Gala Group and also *M. crispus* Biozone faunas. No monoclimacids were found, however, so the presence of the *Mcl. griestoniensis* and *Mcl. crenulata* biozones was not established.

Near Girvan, in the area called the Main Outcrop (Fig.1A), north of the Southern Uplands and S of Girvan Water, both the *R. maximus* Subzone and higher *M. turriculatus* Biozone horizons have been recognized in a predominantly turbidite sequence, together with the *M. crispus* and *Mcl. crenulata* biozones (Cocks & Toghill 1973). Judging from the faunal lists, their recognition of the *Mcl. griestoniensis* Biozone at horizons within the Lauchlan and Drumyork formations seems less certain.

Compared with its development in Scotland, the Telychian in the Lake District, Howgill Fells and Cross Fell Inlier of northern England is greatly attenuated, though the graptolite assemblages are generally more diverse. In the Lake District where the biostratigraphy of the Llandovery Series has been described by Hutt (1974), the *M. turriculatus* Biozone is poorly developed; for example, in Stockdale Beck it consists of 3 black layers totalling 5cm in thickness within 0.6m of pale grey beds, whilst the *R. maximus* Subzone has been recorded at Pull Beck only (Hutt loc.55). The *M. crispus* Biozone is present in several closely spaced black bands, for example, in Stockdale Beck where there are 23 thin black graptolite layers in 4.8m of pale grey mudstone. The *Mcl. griestoniensis* and *Mcl. crenulata* biozones have not been proved, although one of these biozones may be represented by a 2.5cm black layer about 5m below the base of the Wenlock Series on the right bank of Torver Beck (Hutt loc.91).

Rickards (1970) published a measured section of the Howgill Fells upper Llandovery sequence in Spengill, where it is exceptionally well exposed. The *R. maximus* Subzone is represented in 7 black bands and the upper *M. turriculatus* Biozone by 16 black bands within a total thickness of 30m of strata, both units being significantly better developed than in the Lake District. The *M. crispus* and *Mcl. griestoniensis* biozones (undifferentiated) include about 120 black bands within 15m of strata so that the *Mcl. griestoniensis* Biozone is better represented than in the Lake District. Subsequently, Rickards (1973) reported the
collection of a graptolite assemblage associated with red beds in Hebblethwaite Hall Gill [SD 6910 9313] strongly indicative of the *Mcl. crenulata* Biozone, the first record of this zone in the Howgill Fells.

In the Cross Fell Inlier, an almost continuous section through the upper part of the Telychian along Swindale Beck, Knock, demonstrates the attenuated nature of the sequence (Burgess, Rickards & Strachan 1970). The oldest exposed beds of the *R. maximus* Subzone of the *M. turriculatus* Biozone are faulted against older strata but 4 thin dark grey to black mudstone bands contain a diverse graptolite fauna characteristic of the subzone. The upper part of the *M. turriculatus* Biozone is represented by 15 thin bands, the *M. crispus* Biozone by 8 bands and the *Mcl. griestoniensis* Biozone by 4 bands. All 31 of these bands are contained within 16m of predominantly pale grey mudstones. The highest *Mcl. griestoniensis* band is overlain by 6m of pale green mudstone, succeeded by approximately 45m of reddish grey mudstone. This latter lithology contains a single black band, with graptolites indicative of the *Mcl. crenulata* Biozone.

3.1.2 Wenlock Series. Although the *C. murchisoni* and *C. ellesae* biozones have not been recognized with certainty in SW Scotland the remaining graptolite zones from the basal *C. centrifugus* Biozone to the *C. lundgreni* Biozone have been found. Later Wenlock strata may be concealed beneath unconformable Carboniferous sediments.

Along strike to the NE, recognition of the *C. murchisoni, M. riccartonensis* and *C. linnarssoni* biozones has been reported in the Langholm district (Lumsden et al. 1967). However, the published faunal list (p.18) indicates that almost all the *C. murchisoni* Biozone localities belong to the *C. centrifugus* Biozone of the modern classification, on the basis of the occurrence of *Reticolites geinitzianus*, the upper limit of whose range is the *C. centrifugus* Biozone. Nevertheless, the fauna from Loc.2 of that memoir does appear to belong to the overlying *C. murchisoni* Biozone. It was considered by Lumsden et al. that the *C. linnarssoni* Biozone as recognized in the district probably included the underlying and overlying biozones of *C. symmetricus (= C. rigidus), C. linnarssoni* and *C. rigidus (= C. ellesae)* respectively. It should be noted that the list of Silurian fossils collected (Lumsden et al. 1967, p.18) is incomplete – there are several omissions, including all records of monoclimacidic of the vomerinid group.

Farther along strike to the NE in the Hawick area, Warren (1964) recognized a *C. murchisoni* Biozone fauna, including *C. cf. centrifugus*, followed by the *M. riccartonensis* and *C. rigidus* biozones. The
overlying *C. linnarsonni* and *C. ellesae* biozones were not proved but the presence of the succeeding *C. hundgreni* Biozone was established. As in the Kirkcudbright coastal section, this is the highest Wenlock graptolite biozone exposed.

In the Cross Fell Inlier, the Wenlock Series is poorly exposed though graptolite faunas indicative of the *C. centrifugus*, probably the *M. riccartonensis* and the *C. linnarsonni* biozones have been recorded (Burgess, Rickards & Strachan 1970). However, the graptolite zonal sequence in SW Scotland and those of the Howgill Fells and Lake District are closely comparable, including the three-fold division of the *M. riccartonensis* Biozone and the presence of a *M. antennularius* Biozone. Furthermore, Rickards (1965) described several new Wenlock graptolite species from the Howgill Fells, including *Mcl. shottoni*, *M. danbyi* and *M. minimus cautleyensis* from the *Mcl. centrifugus* Biozone, *M. firmus sedberghensis* and *M. radotinensis inclinatus* from the *M. riccartonensis* Biozone and *C. rigidus cautleyensis* from the *C. linnarsonni* Biozone. Representatives of all these species have been found at the same horizons in the Kirkcudbright Bay outcrops.

3.2 Microfossils

3.2.1 Llandovery Series (Telychian Stage). Most samples have yielded acritarch assemblages, but only a small number can be assigned to a single acritarch biozone. Floras are most abundant and diverse in the Gala Group and indicate an age between the base of Group 4 of Martin (1989) and the top of the *D. monospinosa* Biozone (Loc.101) of Dorning and Hill (1991). Other samples which can be assigned to the *D. monospinosa* Biozone include Locs. 15 (Waterside) and 107 (Corseyard) from the Kirkmaden Formation and Loc. 111 (Mull of Galloway) from the Carghidown Formation. The acritarch assemblages from Locs.99 and 100 of the Gala Group and Loc.103 of the Cairnharrow Formation can be placed within the *A. microcladum* to *D. monospinosa* biozones (mid–late Llandovery). The marked abundance of *Lophosphaeridium* spp. at Barr Burn and Glendearg, where *Mcl. crenulata* Zone graptolites were recorded (see 2.4.3) may prove a useful local microfossil marker for the top of the Telychian. Acritarch assemblages from the remaining localities are generally impoverished and poorly preserved.
No published acritarch data exist for the Llandovery of other areas in the Southern Uplands and N England. However, acritarch assemblages from the Telychian of Central Wales and the Welsh Borderland (Hill 1974; Dorning 1981a; Dorning & Hill 1991) are generally similar to those recorded from the Southern Uplands. For example, in Central Wales G. encantador is recorded from the top of the M. turriculatus Biozone (HFB in Davies et al. in prep.), a similar horizon to occurrences in the upper part of the Gala Group.

3.2.2 Wenlock Series. Wenlock acritarch assemblages are most abundant and diverse in the C. centrifugus Biozone where the acritarch assemblages indicate a D. brevispinosa to D. brevifurcata Biozone age, the top of the latter biozone recognized by the demise of many species of Domasia above Loc.21. From the M. riccartonensis to the C. linnarssoni Biozone, acritarchs are sparse, but in the C. lundgreni Biozone acritarchs and spores become more numerous and diverse and the acritarch assemblages can be assigned to the C. pavimenta Biozone.

Dorning (1982) reported a similar acritarch flora from the C. centrifugus Biozone of the Knockgardner Formation in the Girvan area of the Midland Valley. Molynex (1987) described a sparse acritarch assemblage of probable early Wenlock age from the Linkim Beds of the Eyemouth area (Fig.1A). The acritarchs Leiosphaeridia spp., Micryhystridiun nannacanthum, Micryhystridiun spp., Tylotopallia caelamericutis and T. wenlockia recorded by Molynex are also present in the early Wenlock of the SW Southern Uplands. The acritarch and sporomorph floras recorded from the C. lundgreni Biozone are very similar to those recorded from the C. ellesae and C. lundgreni biozones of the Greyhound Law Inlier in the Cheviot area, in the NE Southern Uplands (Barron 1989).

3.3 Recycled Ordovician acritarchs and acritarch provincialism

Rare Ordovician acritarchs are present in the Gala Group and Carghidown, Ross and Raeberry Castle formations (Fig.4); most of the taxa indicate that sediments of early Ordovician (probably Tremadoc/Arenig) age were being recycled during the deposition of these Silurian sequences. The existence of several acritarch provinces, particularly during the early Ordovician (McCaffrey et al., in press and references therein) can
provide clues about the source of the recycled sediments, although conclusions must remain tentative as the study of acritarch provincialism is still in its infancy.

In the Gala Group, Stellechinatum sp. A has only been recovered from Avalonia, while Stelliferidium sp. is known from Avalonia, Gondwana and Baltica (sensu Scotese & McKerrow 1990, pp.1–4), and C. cristata is probably of cosmopolitan occurrence. P. trifurcatum breviradiatum from the Carghidown Formation is of Avalonian/Gondwanan/Baltic affinity, and Acanthodiacrodium sp. from the Raeberry Castle Formation is of cosmopolitan origin. Despite the sparse data, it would appear most likely that the recycled Ordovician sediments are of Avalonian/Gondwanan/Baltic affinity.

4. Conclusions

In spite of the thick development of unfossiliferous greywackes of variable turbiditic facies in the SW Southern Uplands, graptolites preserved in interbedded shales and mudstones provide a vital biostratigraphical control and enable correlation to be established regionally. Further refinement of the graptolite biostratigraphy may result from the analysis of graptolite assemblages from Wales, particularly those of the late Llandovery, Telychian Stage (Zalasiewicz 1990).

Biostratigraphy based on microfossils is at present much less useful in the SW Southern Uplands. Chitinozoa and spores are rarely recorded and cannot form the basis of a biostratigraphical classification, though they may prove useful locally. However, acritarchs are relatively common and were extracted from 66 out of 74 samples. They are best preserved in turbiditic mudstones, but are often sparse and poorly preserved in turbiditic sandstones and graptolitic shales. Unfortunately, diversity and abundance are low in parts of the succession (for example, the M. riccartonensis to C. ellesae biozones of the Sheinwoodian). Even in formations where rich and diverse floras have been found (for example, Gala Group, Locs 99–101) occurrences are patchy and unpredictable. Furthermore such floras can be difficult to assign to one of Dorning and Hill’s (1991) acritarch biozones, in spite of the long ranges of these biozones in terms of the graptolite biostratigraphy. For example, the D. monospinosa Biozone spans 4 graptolite biozones (Fig.5).

The graptolite biozonal age is known for most of the microfossil samples that have been studied, but at present no refinement of Dorning and Hill’s (1991) classification can be made. However, it seems
likely that the *D. monospinosa* Biozone could be subdivided by using the incoming of *G. encantador*, but additional data are required to establish this. Also, a local predominance of *Lophospheiridium* spp. might indicate highest *D. monospinosa* Biozone.

Most acritarch taxa have long stratigraphical ranges. In turbiditic sequences this may in some cases be due to repeated reworking of unconsolidated deposits by the erosive action of turbidity currents, which could lead to the upward extension of the ranges of taxa beyond the actual horizon of their extinction. Such recycled material would be difficult to recognise as such – unlike derived Ordovician taxa recorded from a few of the Southern Uplands samples.

Research into acritarch zonation is still in its infancy, however, and the careful documentation of graptolite controlled occurrences should lead to a more refined scheme. Such a classification would prove extremely useful in successions where there are no graptolites and also in the examination of borehole cores. In addition, provincialism of acritarch floras, especially those of Ordovician age, holds out prospects of identifying source areas of sediments.

5. Acknowledgements

This paper is based on work carried out as part of the BGS Southern Uplands Regional Geological Survey. We are grateful to S P Tunnicliff for help in macrofossil collecting, to H J Evans for photographic work, and to Pat Gunter of Carl Zeiss (Oberkochen) Ltd., Welwyn Garden City, for the use of the LSM (Laser Scanning Microscope). We would also like to thank colleagues for comments on the original manuscript. The paper is published by permission of the Director, British Geological Survey (N.E.R.C.).
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British Geological Survey
Keyworth
Nottingham
NG12 5GG
APPENDIX 1

Upper Llandovery (Telychian) and Wenlock fossil collecting and sample localities, SW Southern Uplands.

Locality information and age of the collections is summarised below; all National Grid references lie within the 100km square NX. Detailed locality data and registered numbers of the BGS specimens are available from the Biostratigraphy and Sedimentology Group, BGS, Keyworth.

A. GRAPTOLOITE LOCALITIES (faunal lists are given in Appendix 2)

Gala Group (undifferentiated)

3. 1268 3932. Grennan slate quarry (2) M. crispus Bz.
5. 2846 5024. Crag, Alticry. M. turriculatus or M. crispus Bz.

Hawick Group

Cairnharrow Formation

9. 424 535. Old railway cutting, Baldoon Mains. M. turriculatus or M. crispus Bz
10. 761 682. Quarry, Trowdale Glen. M. turriculatus or M. crispus Bz.
11. 6735 6130. Tarff Glen. M. turriculatus or M. crispus Bz.

Kirkmaiden Formation

14. 3725 3913. Base of cliff, Kirkmaiden. uncertain
15. 6654 5868. Quarry, Waterside. uncertain

Carginhdown Formation

No localities recorded.

Ross Formation

a) E side of Kirkcudbright Bay.

(i) Long Robin (16) to Witchwife’s Haven (31)

16. 6735 4586. C. centrifugus Bz.
17. 6733 4586. C. centrifugus Bz.
18. 6735 4582. C. centrifugus Bz.
19. 6732 4570. C. centrifugus Bz.
20. 6731 4569. C. centrifugus Bz.
21. 6732 4566. uncertain
22. 6732 4565. C. centrifugus Bz.
<table>
<thead>
<tr>
<th>No.</th>
<th>Sample Code</th>
<th>Location and Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.</td>
<td>6729 4554.</td>
<td>M. riccartonensis Bz.</td>
</tr>
<tr>
<td>25.</td>
<td>6731 4542.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
<tr>
<td>27.</td>
<td>6729 4537.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
<tr>
<td>28.</td>
<td>6731 4531.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
<tr>
<td>29.</td>
<td>6731 4526.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
<tr>
<td>30.</td>
<td>6729 4521.</td>
<td>Not determinable.</td>
</tr>
<tr>
<td>31.</td>
<td>6729 4521.</td>
<td>M. riccartonensis Bz. (upper part).</td>
</tr>
</tbody>
</table>

(ii) Torrs Point (32) to Balmac Haven, S side (46).

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample Code</th>
<th>Location and Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>32.</td>
<td>6730 4486.</td>
<td>M. riccartonensis Bz. (upper part).</td>
</tr>
<tr>
<td>33.</td>
<td>6740 4474.</td>
<td>M. riccartonensis Bz. (upper part).</td>
</tr>
<tr>
<td>34.</td>
<td>6672 4442.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
<tr>
<td>35.</td>
<td>6773 4441.</td>
<td>M. riccartonensis Bz. (lower part).</td>
</tr>
<tr>
<td>36.</td>
<td>6774 4439.</td>
<td>M. riccartonensis Bz. (lower part).</td>
</tr>
<tr>
<td>37.</td>
<td>6774 4439.</td>
<td>M. riccartonensis Bz. (lower part).</td>
</tr>
<tr>
<td>38.</td>
<td>6774 4436.</td>
<td>M. riccartonensis Bz. (lower part).</td>
</tr>
<tr>
<td>40.</td>
<td>6787 4425.</td>
<td>M. riccartonensis Bz. (upper part).</td>
</tr>
<tr>
<td>41.</td>
<td>6785 4422.</td>
<td>M. riccartonensis Bz. (upper part).</td>
</tr>
<tr>
<td>42.</td>
<td>6785 4419.</td>
<td>M. riccartonensis Bz. (uncertain).</td>
</tr>
<tr>
<td>43.</td>
<td>6785 4416.</td>
<td>Uncertain.</td>
</tr>
<tr>
<td>44.</td>
<td>6785 4414.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
<tr>
<td>45.</td>
<td>6792 4406.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
<tr>
<td>46.</td>
<td>6799 4405.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
</tbody>
</table>

b) W side of Kirkcudbright Bay.

(i) Shaw Hole (47) and Ross (Balmangan) Bay (48–51)

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample Code</th>
<th>Location and Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>47.</td>
<td>656 454.</td>
<td>C. centrifugus Bz.</td>
</tr>
<tr>
<td>48.</td>
<td>652 449.</td>
<td>C. centrifugus Bz.</td>
</tr>
<tr>
<td>49.</td>
<td>649 449.</td>
<td>C. centrifugus Bz.</td>
</tr>
<tr>
<td>50.</td>
<td>6543 4444.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
<tr>
<td>51.</td>
<td>6545 4437.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
</tbody>
</table>

(ii) Meikle Ross

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample Code</th>
<th>Location and Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>52.</td>
<td>6562 4394.</td>
<td>M. riccartonensis Bz.</td>
</tr>
<tr>
<td>53.</td>
<td>6552 4376.</td>
<td>M. riccartonensis Bz.</td>
</tr>
<tr>
<td>54.</td>
<td>6537 4331.</td>
<td>M. riccartonensis Bz. (upper part).</td>
</tr>
<tr>
<td>55.</td>
<td>6532 4326.</td>
<td>M. riccartonensis Bz. (upper part).</td>
</tr>
<tr>
<td>56.</td>
<td>6455 4355.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
<tr>
<td>57.</td>
<td>6442 4366.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
<tr>
<td>58.</td>
<td>6440 4370.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
<tr>
<td>59.</td>
<td>6448 4392.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
<tr>
<td>60.</td>
<td>6445 4393.</td>
<td>M. riccartonensis Bz. (middle part).</td>
</tr>
</tbody>
</table>

(iii) Fauldboy Bay

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample Code</th>
<th>Location and Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>61.</td>
<td>6442 4429.</td>
<td>C. centrifugus Bz.</td>
</tr>
<tr>
<td>62.</td>
<td>6428 4455.</td>
<td>C. centrifugus Bz.</td>
</tr>
<tr>
<td>63.</td>
<td>6420 4455.</td>
<td>C. centrifugus Bz.</td>
</tr>
</tbody>
</table>
c) Cliff sections, Burrow Head (64–68) and Isle of Whithorn (69)

64. 4546 3412. ?C. centrifugus Bz.
65. 4543 3409. C. centrifugus Bz.
66. 4538 3411. C. centrifugus Bz.
67. 4638 3434. ?C. murchisoni Bz.
68. 4633 3437. ?M. riccartonensis Bz.
69. 480 360. C. centrifugus Bz.

Riccarton Group

Raeberry Castle Formation

E of Kirkcudbright Bay.

(i) South of Balmae Haven (70) to Gypsy Point (79)

70. 6799 4402. ?post M. riccartonensis Bz.
71. 6799 4400. ?post M. riccartonensis Bz.
72. 6803 4400. ?M. riccartonensis Bz. (upper part)
73. 6803 4400. ?M. antennarius Bz.
74. 6808 4398. post M. riccartonensis Bz.
75. 6825 4398. M. antennarius Bz.
76. 6826 4397. M. antennarius Bz. or C. rigidus Bz.
77. 6834 4388. uncertain
78. 6835 4378. C. linnarssonii Bz.
79. 6852 4358. uncertain

(ii) Port Muddle, E side

80. 6883 4360. M. antennarius Bz.
81. 6885 4358. uncertain
82. 6889 4355. M. riccartonensis Bz. (upper part) and M. antennarius Bz.

(iii) Howwell Bay to Little Raeberry

83. 6945 4385. M. riccartonensis Bz. (?upper part)
84. 702 437. C. rigidus Bz.
85. 7063 4356. C. rigidus Bz. and ?C. lundgreni Bz.

(iv) Mullock Bay to White Port

86. 7091 4360. C. lundgreni Bz.
87. 7100 4390. C. rigidus Bz.
88. 7114 4393. C. lundgreni Bz.
89. 7142 4379. uncertain.
90. 7142 4377. uncertain.
91. 7148 4373. C. lundgreni Bz.
92. 7166 4364. C. lundgreni Bz.
93. 7185 4340. C. lundgreni Bz.
94. 7218 4340. uncertain (no younger than C. lundgreni Bz.).
B MICROFOSSIL LOCALITIES (faunal and floral lists are given in Fig.4 and Appendix 3)

Gala Group (undifferentiated)

95. 0650 4719. Float Bay. MPA 31187.
96. 0615 4728. Float Bay. MPA 31188.
97. 0669 4501. Mary Wilson's Slunk MPA 31189.
98. 0679 4465. Clifftop, Slunk Cottage. MPA 31190.
100. 0924 4032. Quarry Bay, Port Logan. MPA 31192.
101. 0910 4017. Scrangie, Port Logan. MPA 31193.
102. 0928 3966. Stream bed, Slate Heugh Bay. MPA 31194.

Hawick Group

Cairnharrow Formation

103. 6666 6094. Tarff Water. MPA 27821.

Kirkmaiden Formation

104. 6797 5927. Old adit, Coalheugh Burn. MPA 27822.
105. 6970 5916. Coalheugh Burn. MPA 27823.
15. 6654 5868. MPA 27824.
106. 6861 6011. Trackside exposure, Barstobrick Hill. MPA 27825.
107. 5858 4869. Corseyard. MPA 27826.
108. 5855 4870. Corseyard. MPA 27827.

Carghidown Formation

110. 1445 3126. Coastal exposure, Portavaddie, MPA 31197.
111. 1443 3140. Coastal exposure, Portavaddie, MPA 31198.
112. 1560 3035. Clifftop, Foxes Rattle. MPA 31199
113. 5938 4812. Corseyard. MPA 29790.
114. 6153 4494. Harrison' Bay. MPA 29791.
115. 6524 4444. Point of Green. MPA 29292.
116. 6524 4446. Mull Point. MPA 29793.
117. 6590 4795. Goat Well Bay. MPA 29796.
118. 6735 4606. Bathinghouse Bay. MPA 29794.

Ross Formation

a) E side of Kirkcudbright Bay.

(i) Long Robin to Witchwife's Haven

16. 6735 4586. MPA 28939.
21. 6732 4566. MPA 28940.
23. 6729 4554. MPA 28941.
24. 6729 4549. MPA 28942.
26. 6731 4539. MPA 28943.
30. 6729 4521. MPA 28944.

(ii) Torrs Point to Balmae Haven, S side

120. 6727 4490. MPA 29799
33. 6740 4474. MPA 28945.
121. 6773 4441. MPA 28946.
122. 6787 4419. MPA 29798.
44. 6785 4414. MPA 28954
45. 6792 4406. MPA 28947

B. W side of Kirkcudbright Bay.

(i) Shaw Hole and Meikle Ross

47. 656 454 MPA 28473, MPA 29073
123. 6518 4486. MPA 29072.
124. 6490 4488. MPA 29071.
52. 6490 4488. MPA 27819.
125. 6563 4375. MPA 29801.
126. 6528 4375. MPA 29800.
55. 6532 4326. MPA 27818.
56. 6455 4355. MPA 27817.
60. 6445 4393. MPA 27816.
127. 6441 4402. MPA 29802.

(ii) Fauldbog Bay

128. 6430 4450. MPA 29070.
62. 6428 4455. MPA 27815.
129. 6420 4449. MPA 29069
130. 6405 4442. MPA 27814.

Raeberry Castle Formation

E side of Kirkcudbright Bay.

(i) South of Balmae Haven to Gipsy Point

131. 6809 4401. MPA 29797.
74. 6808 4398. MPA 28948.
75. 6825 4398. MPA 28949.
76. 6826 4397. MPA 28950.
78. 6835 4378. MPA 28951.

(ii) Port Muddle, E side

82. 6889 4355. MPA 28952.
132. 6915 4366. MPA 29807.
133. 6920 4365. MPA 29806.
(iii) Howwell Bay to Little Raeberry

83. 6945 4385. MPA 28953.
134. 6944 4385. MPA 29805.
135. 6988 4373. MPA 29804
84. 702 437. MPA 28955.
136. 7046 4356. MPA 29803.
85. 7063 4356 MPA 28956, MPA 28957

(iv) Mullock Bay to White Port

87. 7100 4390. MPA 28958.
88. 7114 4393. MPA 28959.
92. 7166 4364. MPA 28960.
137. 7164 4364. MPA 28596.
93. 7185 4340. MPA 28962.
94. 7218 4340. MPA 28961.

APPENDIX 2

Upper Llandovery (Telychian) and Wenlock graptolite distribution, SW Southern Uplands.

Graptolite faunal lists are given for each formation. Numbers refer to the collecting localities listed in Appendix 1, which also gives the zonal assignation of each collection. Zonal lists are summarised in Fig.3

Gala Group (undifferentiated)

Petalograptus altissimus? Elles & Wood 4
Monograptus crispus Lapworth 2, 3
M. discus Törnquist 2
M. exigus exigus (Nicholson) 2, 3, 3(aff.)
M. exigus (Nicholson) s.l. 3, 4
M. marri Perner 2, 3(cf), 4
M. cf. plumosus (Baily) 4
M. cf. planus (Barrande) 4
M. pridon (Bromn) 3, 4(cf.)
M. proteus (Barrande) 1(?), 4, 5(cf.), 6
M. (Diversograptus) runcinatus? Lapworth 1

Hawick Group

Cairnharrow Formation

Petalograptus altissimus Elles & Wood 7, 10
Monograptus aff. acus? Lapworth 7
M. cf. capillaris (Carruthers) 10
M. halli (Barrande) 7, 10(cf.)
M. marri Perner 7
M. planus (Barrande) 9(cf.), 10
M. cf. plumosus (Baily) 7, 9, 10
M. proteus (Barrande) 7(?), 11
M. cf. rickardsi Hutt 9, 10(?)
M. (Diversograptus) runcinatus? Lapworth 8
M. spiralis group 11
Kirkmaiden Formation

**Monoclimacis** cf. *griestoniensis* of Elles & Wood 12, 13
**Monograptus** *priodon* (Bonn) 13
* M. *spiralis* group 14
* M. sp. aff. *tullbergi*? Bouček 15

Ross Formation

**Retiolites geinitzianus angustidens** Elles & Wood 17, 47(cf), 62, 63, 65, 69
**R. geinitzianus geinitzianus** Barrande 20, 47, 49, 62, 63, 69
**Barrandegraptus? bornholmensis** (Laursen) 47, 61
* B? 63

**Cytograptus centrifugus** Bouček 22(cf), 61(cf), 62(cf), 63(cf), 66, 69
cf. * C. gravi* Lapworth 47, 61
C. aff. *insectus* Bouček 16(?), 17, 69
C. *murchisoni?* Carruthers 67
C. *spp.* 18, 19, 20, 21
Mcl. aff. *shottoni* Rickards 47
* Mcl. *vomerina basilia* (Lapworth) 17(cf), 18, 20(cf), 21(cf), 22, 25(cf), 29, 31, 36, 38, 44, 46, 47, 49, 54, 61, 63, 66(cf), 69(cf).
* Mcl. *vomerina vomerina* (Nicholson) 17, 36(cf), 41(cf), 44(cf), 47, 49, 62, 64, 65, 66(cf), 69
* Mcl. *vomerina s.l.* 16, 18, 20, 21, 22, 25, 30, 35, 37, 43, 46, 48, 61, 62, 63
Mcl. *spp.* 55, 67, 68

**Monograptus** cf. *danbyi* Rickards 66
* M. *firmus sedberghensis* Rickards 23(?), 24, 31(cf), 32(cf), 33(cf), 39(cf), 40, 41, 55(?)
* M. *minimus cautleyensis* Rickards 17, 19
* M. *priodon* (Bonn) 16, 17, 18, 19, 20, 21, 22, 31(?), 35, 36, 37, 38, 47, 48, 49, 61, 62, 67, 69
* M. aff. *priodon* 17, 18, 19, 47, 48, 62(?), 63
* M. *cf. radotinensis inclinatus* Rickards 27, 37, 41(?), 42
* M. *remotus* Elles & Wood 22, 61
* M. *riccartonensis* Lapworth 23(cf), 24, 25, 26, 27, 28, 29, 34(cf), 35, 36, 37, 39(cf), 40, 41, 42, 44, 45, 46, 50, 51, 52(?), 53(?), 55(?), 56, 57, 58, 59, 60, 68(cf)

**Pristograptus** cf. *dubius* (Suess) 39
* P. *dubius* group 30, 34, 43
* P. *meneghini* (Gortani) 24(cf), 40

Riccarton Group

Raeberry Castle Formation

?**Plectograptus? bouceki** Rickards 87
**Cytograptus linnarssonii** Lapworth 78
C. cf. *rigidus rigidus* Tullberg 85
C. cf. *rigidus cautleyensis* Rickards 78
C. *spp.* 83(?), 92(?), 94
**Monoclimacis flumendosaes flumendosaes** (Gortani) 71, 74, 76, 77(aff), 78, 79(cf), 82, 84(cf), 85
* Mcl. *flumendosaes kingi* Rickards 79(?), 85, 86(cf), 88(cf), 92, 93(cf)
* Mcl. *vomerina basilia* (Lapworth) 78
**Monograptus antennularius** (Meneghini) 72, 73(cf), 75, 80, 82, 85
* M. cf. *firmus sedberghensis* Rickards 82
* M. *flemingii flemingii* (Salter) 78, 86, 89, 90, 91, 92, 94
* M. *flexilis* aff. *belophorus* (Meneghini) 82, 84, 85, 87
* M. *flexilis* cf. *flexilis* Elles 76(aff), 78, 82(aff), 84(aff), 85(aff)
* M. cf. *priodon* (Bonn) 72
* M. *radotinensis inclinatus* Rickards 72(cf), 82
M. riccartonensis Lapworth 72, 82, 83
Pristiograpthus dubius dubius (Suess) 70, 76, 79, 82(cf.), 87, 88, 94(?)
P. dubius aff. latus (Bouček) 82
P. meneghini (Gortani) 74, 75, 79, 80, 81(cf.), 82, 87
P. pseudodubius (Bouček) 91, 92, 93
P. sp. 78

APPENDIX 3

Palynomorph species and author list for Gala, Hawick and Riccarton groups in the SW Southern Uplands. For taxonomic references see Fensome et al. 1990. (R) = Recycled from the Ordovician.

Acritarchs

Acanthodiacrodium sp. (R)
Ammonidium listeri Smelror 1987
A. microcladum (Downie 1963) Lister 1970
A. aff. microcladum (Downie 1963) Lister 1970
A. telychense Dornig & Hill 1991
A. wychnese Dornig & Hill 1991
A. spp.
?Baltisphaeridium (R)
Cymatiogalea cristata? (Downie 1958) Rauscher 1973 (R)
Cymatosphaera llanoverensis Dornig & Hill 1991
C. cf. mirabilis Deunff 1959
C. octopiana Downie 1959
Dicyotidium dictyotum (Eisenack 1938) Eisenack 1955
D. telychense Dornig & Hill 1991
Diecalkophiasis denticulata (Stockmans & Willière 1963) Loeblich 1970
D. granulatispinosa (Downie 1963) Hill 1974
D. sp. A
D. sp.
Domasia antiqua Dornig & Hill 1991
D. bispinosa Downie 1960
D. elongata Downie 1960
D. limaciforme (Stockmans & Willière 1963) Cramer 1971
D. quadrispinosa Hill 1974
D. quinquispinosa Dornig & Hill 1991
D. symetrica Cramer 1971
D. trispinosa Downie 1960
Duvernavysphaera aranides (Cramer 1964) emend Cramer & Diez 1972
Elektoriskos cf. aurora Loeblich 1970
Estiastra barabata Downie 1963
Eupoikilofusa striatifera (Cramer 1964) Cramer 1971
E. sp.
Geron sp.
?Goniopsphaeridium
Gracilisphaeridium encantador (Cramer 1971) Eisenack et al. 1973
Helosphaeridium sp.
Leiosphaeridia spp.
Lophosphaeridium sp.
Micrhystridium inflatum (Downie 1959) Lister 1970
M. nannancanthum Deflandre 1945
M. parinconspicuum Deflandre 1945
M. spp.
Moyeria cabottii (Cramer 1971) Miller & Eames 1982
M. telchensis Dorning & Hill 1991
Multiplicisphaeridium cladum (Downie 1963) Eisenack 1969
M. fisherii (Cramer 1968) Lister 1970
M. imitatum? (Deflandre 1945) Lister 1970
M. cf. martiniac Priewaldet al. 1987
M. cf. raspus (Cramer 1964) Eisenack et al. 1973
M. spp.
Oppilatola eoplanktonica (Eisenack 1955) Dorning 1981
O. frondis (Cramer & Diez 1972) Dorning 1981
O. ramusculosa (Deflandre 1945) Dorning 1981
O. sp.
Peteinosphaeridium trifurcatus breviradiatum (Eisenack 1959) Eisenack 1965 (R)
Salopodium granuliferum (Downie 1959) Dorning 1981
Stellechinatun sp. A (R)
Stelliferidium sp. (R)
Strophomorpha ovata Miller & Eames 1982
Tunisphaeridium caudatum Deunff & Evitt 1968
T. cf. parvum Deunff & Evitt 1968
Tylotopalla astrifera Kiryanov 1978
T. caelamenticus Loeblich 1970
T. cf. cellonensis Priewaldet al. 1987
T. digitifera Loeblich 1970
T. aff. digitifera Loeblich 1970
T. robustispinosa (Downie 1959) Eisenack et al. 1973
T. wenlockia Dorning 1981
T. sp.
Veryhachium downie Stockmans & Willière 1962
V. reductum (Deunff 1959) Downie & Sarjeant 1965 (R)
V. rhomboidium Downie 1959 emend. Turner 1984
V. trispinosum (Eisenack 1938) Stockmans & Willière 1962
V. wenlockium (Downie 1959 ex Wall & Downie 1963) Downie & Sarjeant 1965
V. sp.
Visbyphaera dilatispinosa (Downie 1963) Lister 1970
V. microspinosa (Eisenack 1954) Lister 1970
V. oligofurcata (Eisenack 1954) Lister 1970
V. sp.

SPORES

Ambitisporites avitus Hoffmeister 1959
A. dilutus (Hoffmeister 1959) Richardson & Lister 1969
A. spp.
?Retusotriletes
?Synorisporites
Tetraheradraletes medinensis Strother & Traverse 1979
spore tetrad

CHITINOZOA

Ancyrochitina angyrae (Eisenack 1931) Eisenack 1955
A. spp.
Cingulochitina cingulata (Eisenack 1937) Paris 1981
Conochitina sp.
Cyathochitina sp.
?Eisenackitina
Margachitina margaritana (Eisenack 1937) Eisenack 1968

Acritarch species list for Barr Burn and Glendearg.

Ammonidium listeri? Smelror 1987
Ammonidium telychense Dorning & Hill 1991
Cymatiosphaera cf. llanovervensis Dorning & Hill 1991
Diezallophasia denticulata (Stockmans & Willière 1963) Loeblich 1970
Deunffia monospinosa Downie 1960
Domasia trispinosa Downie 1960
Helosphaeridium citrinipeltatum (Cramer & Diez 1972) Dorning 1981
Leiosphaeridia spp.
Lophosphaeridium hauskae Priewald 1987
Lophosphaeridium malvernense Dorning & Hill 1991
Lophosphaeridium spp.
Micropyramidium spp.
Multiplicisphaeridium sp.
Salopidium granuliferum (Downie 1959) Dorning 1981
Veryhachium downiei Stockmans & Willière 1962
Veryhachium sp.
Figure 1A. Distribution of Silurian rocks in southern Scotland and northern England. BG = Barr Burn and Glendearg, Eskdalemuir.

Figure 1B. Silurian outcrops in the SW Southern Uplands. PLB = Port Logan Bay, CB = Clanyard Bay, G = Grennan slate quarries, IoW = Isle of Whithorn, C = Corseyard, LM = Loch Mannoch, KB = Kirkcudbright Bay, BB = Balmae Burn, LR = Little Raeberry, NP = Netherlaw Point, CNW = Cairnharrow Formation, KMN = Kirkmaiden Formation, CGD = Carghidown Formation, RS = Ross Formation, RC = Raeberry Castle Formation.
Figure 2. Late Llandovery and Wenlock lithostratigraphy in the SW Southern Uplands and its relationship to biostratigraphical and chronostratigraphical classifications. Hom. = Homerian (part.).
Figure 3. Zonal distribution of graptolites of the late Llandovery (Telychian) and Wenlock (Sheinwoodian and Homerian) Series in the SW Southern Uplands. Abbreviations: t = M. turricualtus Bz., g = Mcl. griedoniensis Bz., cr = Mcl. crenulata Bz., ce = C. centrifugus Bz., m = C. murchisoni Bz., r = M. riccartonensis Bz. (lo = lower, mi = middle and u = upper parts), a = M. antennularius Bz., ri = C. rigidus Bz., l = C. linnarssoni Bz., e = C. ellesae Bz., lu = C. lundgreni Bz., H = Homerian.

Symbols on the table: A query (?) indicates uncertain specimen identification; a solid line indicates the presence of the taxon within the biozone; a broken line indicates an uncertain zonal assignment. Only the M. riccartonensis Biozone has been subdivided.
Figure 4. Distribution of acritarchs, spores, and chitinozoa in the late Llandovery and Wenlock of the SW Southern Uplands. Cairn. = Cairnharrow, C = C. centrifugus Bz., R = M. riccartonensis Bz., MR = middle M. riccartonensis Bz., UR = upper M. riccartonensis Bz., A = M. antennarius Bz., RS = C. rigidus Bz., LS = C. linnarssonii Bz., L = C. lundgreni Bz., Dm = D. monospinosa Bz., Dbf = D. brevifurcata Bz., Cp = C. pavimenta Bz.
Figure 5. Comparison of part of the acritarch biozonal schemes of Dorning and Hill (1991) and informal acritarch groups of Martin (1989). The graptolite biozone bases are included only where there is good correlation with the acritarch biozones.
Figure 6. Graptolites of the Gala Group (a), Cairnharrow Formation (b–d) and Kirkmaiden Formation (e–h); camera lucida drawings, all x5.

(a) *Monograptus crispus* Lapworth, GSE 14902, Loc. 2, Grennan slate quarry (1), *M. crispus* Biozone.
(c) *Monograptus planus* (Barrande), GSE 14868 Loc. 10, Trowdale Glen, *M. turriculatus* or *M. crispus* biozones.
(d) *Monograptus cf. capillaris* (Carruthers), GSE 14869, Loc. 10, Trowdale Glen, *M. turriculatus* or *M. crispus* biozones.
(e–h) *Monoclimacis cf. giestoniensis* (Nicol), Loc. 13, Kirkmaiden, (e) GSE 14886, (f–g) proximal and distal parts of GSE 14885, (h) GSE 14887, *Mcl. giestoniensis* Biozone.
Figure 7. Graptolites of the Gala Group (c), Cairnharrow (d–g), and Kirkmaiden (a, b), Ross (h) and Raeberry Castle (i) formations. All photographs x6, except (i) x3.

(a,b) **Monoclimacis cf. griesonienis** (Nicol), (a) GSE 14904, (b) GSE 14886, Loc. 13, Kirkmaiden, Mcl. griesonienis Biozone.

(c) **Monograptus crispus** Lapworth, GSE 14902, Loc. 2, Grennan slate quarry (2), M. crispus Biozone.

(d,e) **Monograptus cf. plumosus** (Baily), GSE 14866, Loc. 7, Whaup Hill, M. turriculatus Biozone.

(f) **Monograptus planus** (Barrande), GSE 14868, Loc. 10, Trowdale Glen, M. turriculatus or M. crispus biozones.

(g) **Petalograptus altissimus** Elles & Wood, GSE 14867, Loc. 10, Trowdale Glen, M. turriculatus or M. crispus biozones.

(h) **Reticolites geinitzianus geinitzianus** Barrande, GSE 14883, Loc. 63, Fauldbog Bay, C. centrifugus Biozone.

(i) **Cyrtograptus linnarsoni** Lapworth, GSE 14061, Loc. 78, S of Balmae Haven, C. linnarsoni Biozone.
Figure 8. Acritarchs from the Gala Group, Port Logan. All specimens x1000.

(a) **Ammonidium listeri**, MPK 6858, slide MPA 31193/2, X442, Loc. 101.
(b) **Ammonidium microcladum**, MPK 6859, slide MPA 31193/3, H310, Loc. 101.
(c) **Dielallophasia** sp. A, MPK 6860, slide MPA 31193/3, R351, Loc. 101.
(d) **Domasia trispinosa**, MPK 6861, slide MPA 31191/1, S371, Loc. 99.
(e) **Gracilisphaeridium encantador**, MPK 6862, slide MPA 31193/2, Q373, Loc. 101.
(f) **Eupohlufusa striatifera**, MPK 6863, slide MPA 31193/3, J350, Loc, 101.
(g) **Gracilisphaeridium encantador**, MPK 6864, slide MPA 31193/3, K380, Loc. 101.
(h) **Leiosphaeridia** sp., MPK 6865, slide MPA 31192/1, J501, Loc. 100.
(i) **Moyeria cabottii**, MPK 6866, slide MPA 31192/1, K460, Loc. 100.
(j) **Multiplicisphaeridium** cf. **martiniac**, MPK 6867, slide MPA 31193/1, V434, Loc. 101.
(k) **Stellechinatum** sp. A, MPK 6868, slide MPA 31193/1, L430, Loc. 101.
(m) **Tunisphaeridium** cf. **parvum**, MPK 6870, slide MPA 31192/1, K360, Loc. 100.
(n) **Tytotopalla wenlockia**, MPK 6871, slide MPA 31193/3, U313, Loc. 101.
Figure 9. Acritarchs from the Kirkmaiden Formation (a–h) and Carghidown Formation (i–q). All specimens x1000.

(a) Ammonidium sp., MPK 6872, slide MPA 27826/2, N501, Loc. 107, Corseyard.
(b) Cymatosphaera llandoveryensis, MPK 6873, slide MPA 27824/2, M344, Loc. 15, Waterside.
(c) Dictyotidium telchense, MPK 6874, slide MPA 27826/1, Y350, Loc. 107, Corseyard.
(d) Domasia quinquispinosa, MPK 6875, slide MPA 27824/4, P493, Loc. 15, Waterside.
(e) Domasia quadrirspinosa, MPK 6876, slide MPA 27824/1, G370, Loc. 15, Waterside.
(f) Domasia limaciforme, MPK 6877, slide MPA 27826/1, O370, Loc. 107, Corseyard.
(g) Moyeria telchensis, MPK 6878, slide MPA 27824/1, E452, Loc. 15, Waterside.
(h) Multiplicisphaeridium sp., MPK 6879, slide MPA 27824/3, K561, Loc. 15, Waterside.
(i) Salopidium granuliferum, MPK 6880, slide MPA 29794/2, L490, Loc. 118, Bathinghouse Bay.
(j) Opliata eoplanktonica?, MPK 6881, slide MPA 31197/1, L420, Loc. 110, Portavaddie.
(k,l) Moyeria telchensis, MPK 6882, slide MPA 31198/1, Y521, Loc. 111, Portavaddie.
(m) Leiosphaeridia sp., MPK 6883, slide MPA 29794/2, P441, Loc. 118, Bathinghouse Bay.
(n,o) Multiplicisphaeridium cf. raspum, MPK 6884, slide MPA 31199/1, S374, Loc. 112, Foxes Rattle.
(p) Peteinosphaeridium trifurcatum breviradiatum?, MPK 6885, slide MPA 29795/1, Q590, Loc. 119, Bathinghouse Bay.
(q) Tylotopalla wenlockia, MPK 6886, slide MPA 29794/1, S520, Loc. 118, Bathinghouse Bay.
Figure 10. Graptolites from the Mcl. crenulata Biozone; Carghidown Formation, Eskdalemuir area; camera lucida drawings, all x5 except (a) and (f), x10;

(a) *Stomatograptus grandis girvanensis* Bjerreskov, GSE 14876, Barr Burn, [NT 226 053].

(b,c) *Monograptus vomerina* (Nicholson) s.l., (b) GSE 14874, (c) 14875, Barr Burn [NT 227 050].

(d) *Monoclimacis vomerina* (Nicholson) s.l., GSE 14870, Glendearg Burn. [NT 231 061].

(e) *Monoclimacis* aff. *linnarsoni* (Tullberg), GSE 14893, locality as for (d).

(f) *Monograptus* cf. *simulatus* Rickards, GSE 14880, locality as for (d).

(g) *?Barrandeograptus pulchellus* Tullberg, GSE 14873, locality as for (d).

(h) *Monograptus* cf. *parapriodon* Bouček, GSE 14871, locality as for (d).

(i) *Monograptus* cf. *priodon* ([Brnn]), GSE 14872, locality as for (d).
Figure 11. Acritarchs from the Eskdalemuir area. Barr Burn (a-c, e-o), Glendearg (d). Mcc. crenulata Zone. All specimens x 1000.

(a) Ammonidium telychense, MPK 6887, slide MPA 28470/3, K392.
(b) Cymatosphaera cf. llandoveryensis, MPK 6888, slide MPA 28470/3, P351.
(c) Deunffia monospinosa, MPK 6889, slide MPA 28470/1, L482.
(d) Domasia trispinosa, MPK 6890, slide MPA 28472/1, O472.
(e,g) Helosphaeridium citrinipeltatum, MPK 6891, slide MPA 28470/2, G543.
(f,h) Lophosphaeridium hauskei, MPK 6892, slide MPA 28470/2, F350.
(i) Lophosphaeridium sp., MPK 6893, slide MPA 28470/2, J350.
(j) Lophosphaeridium malvernense, MPK 6894, MPA 28470/3, K404.
(k,l) Lophosphaeridium malvernense, MPK 6895, MPA 28470/2, K541.
(m) Salopidium granuliferum, MPK 6896, slide MPA 28470/3, Q563.
(n) Tyloptella cf. wenlockia, MPK 6897, slide MPA 28470/3, R330.
(o) Veryhachium sp., MPK 6898, slide MPA 28470/2 V480.
Figure 12. Graptolites from the Ross Formation; camera lucida drawings, all x5 except for (a) and (b), x10.

(a,b) *Barrandeograptus* bornholmensis (Laursen), GSE 14903, Loc. 61, Fauldbog Bay; *C. centrifugus* Biozone.

(c,d) *Monograptus riccartonensis* Lapworth, (c) GSE 14891, (d) GSE 14890, Loc. 25, E side of Kirkcudbright Bay, *M. riccartonensis* Biozone (middle part).

(e,f) *Monograptus firmus sedberghensis* Rickards, (e) GSE 14894, Loc. 24, E side of Kirkcudbright Bay; (f) GSE 14896, Loc. 40, E side of Kirkcudbright Bay; *M. riccartonensis* Biozone (upper part).

(g) *Monoclimacis vomerina* (Nicholson) s.l., GSE 14901, Loc. 46, E side of Kirkcudbright Bay; *M. riccartonensis* Biozone (middle part).

(h) *Monoclimacis cf. vomerina vomerina* (Nicholson), GSE 14898, Loc. 44, E side of Kirkcudbright Bay; *M. riccartonensis* Biozone (middle part).

(i) *Monoclimacis vomerina basilica* (Lapworth), GSE 148995, Loc.31, E side of Kirkcudbright Bay; *M. riccartonensis* Biozone (?upper part).

(j) *Monograptus cf. radotinensis inclinatus* Rickards, GSE 14897, Loc. 42, E side of Kirkcudbright Bay; *M. riccartonensis* Biozone.
Figure 13. Graptolites from the Ross (a, b, g, j) and Raeberry Castle (e, f, h, i) formations. All photographs x6 except (i,j) x3.

(a) Barrandeograptus? bornholmensis (Laursen), GSE 14903, Loc. 61, Fauldbog Bay, C. centrifugus Biozone.

(b) Monograptus riccartonensis Lapworth, GSE 14900, Loc. 46, S side of Balmae Haven, M. riccartonensis Biozone (middle part).

(c) Monograptus flemingii flemingii (Salter), GSE 14878, Loc. 92, Mullock Bay, C. lundgreni Biozone.

(d) Monograptus flexilis aff. flexilis Elles, GSE 14879, Loc. 85, Little Raeberry, C. rigidus Biozone.

(e) Pristiograptus pseudodubius (Bouček), GSE 14877, Loc. 92, Mullock Bay, C. lundgreni Biozone.

(f) Monograptus antennarius (Meneghini), (= M. capillaceus Tullberg of Kemp & White 1985), GSE 14064, Loc. 75, S side of Balmae Haven, M. antennarius Biozone.

(g) Monograptus firmus sedberghensis Rickards, GSE 14896, Loc. 40, S side of Balmae Haven, M. riccartonensis Biozone (upper part).

(h) Monograptus flumendosae flumendosae (Gortani), GSE 14881, Loc. 78, S side of Balmae Haven, C. linnarssoni Biozone.

(i) Monograptus flexilis aff. belophorus (Meneghini), GSE 14069, Loc. 87, Mullock Bay, C. rigidus Biozone.

(j) Monoclimacis cf. vomerina vomerina (Nicholson), GSE 14899, Loc. 44, S side of Balmae Haven, M. riccartonensis Biozone (middle part).
Figure 14. Graptolites from the Raeberry Castle Formation, camera lucida drawings, all x5.

(a,b) Monograptus antennarius (Meneghini) (=M. capillaceus Tullberg of Kemp & White 1985), (a) GSE 14064, (b) GSE 14063, Loc. 75, S of Balmae Haven; M. antennarius Biozone.

(c) Pristiograptus dubius dubius (Suess), GSE 14882, loc. 76, S of Balmae Haven; M. antennarius or C. rigidus biozones.

(d) Monograptus flexilis aff. belophorus (Meneghini), GSE 14888 and counterpart GSE 14889 (composite), Loc. 87, Mullock Bay; C. rigidus Biozone

(e) Cyrtograptus cf. rigidus rigidus Tullberg, GSE 14892, Loc. 85, Little Raeberry; C. rigidus Biozone.

(f) Monoclimacis flumendosa flumendosa (Gortani), GSE 14881, Loc. 78, S of Balmae Haven; C. linnarssoni Biozone.

(g) Monograptus flexilis aff. flexilis Elles, GSE 14879, Loc. 85, Little Raeberry; C. rigidus Biozone.

(h) Cyrtograptus linnarssoni Lapworth, GSE 14061, Loc. 78, S of Balmae Haven; C. linnarssoni Biozone.

(i,j) Pristiograptus pseudodubius Bouček, (i) GSE 14877, Loc. 92, Mullock Bay, (j) GSE 14884, loc.93, Mullock Bay; C. lundgreni Biozone.

(k) Monograptus flemingii flemingii (Salter), GSE 14878, Loc. 92, Mullock Bay; C. lundgreni Biozone.
Figure 15. Acritarchs from the Ross Formation (a–e) and Raeberry Castle Formation (f–o). All specimens x1000.

(a) *Ammonidium microcladum*, MPK 6899, slide MPA 28940/1, X523, Loc. 21, Long Robin, E side of Kirkcudbright Bay.

(b) *Ammonidium wychense*, MPK 6900, slide MPA 28939/1, M553, Loc. 16, Long Robin, E side of Kirkcudbright Bay.

(c) *Domasia trispinosa*, MPK 6901, slide MPA 28473/2, M511, Loc. 47, Shaw Hole, W side of Kirkcudbright Bay.

(d) *Tylotopalla caelamicutis*, MPK 6902, slide MPA 28939/2, N320, Loc. 16, Long Robin, E side of Kirkcudbright Bay.

(e) *Visbyphaera dilatispinosa*, MPK 6903, slide MPA 28940/2, U430, Loc. 21, Long Robin, E side of Kirkcudbright Bay.

(f) *Ambitisporites* sp., MPK 6904, slide MPA 28960/1, H542, Loc. 92, Mullock Bay.

(g) *Ambitisporites* sp., MPK 6905, slide MPA 28955/1, D514, Loc. 84, Haystack, Big Raeberry.

(h) *Strophomorpha ovata*, MPK 6806, slide MPA 29804/1, F430, Loc. 135, Raeberry Castle, Howwell Bay.

(i) *Tylotopalla cf. cellonensis*, MPK 6907, slide MPA 28960/2, L380, Loc. 92, Mullock Bay.

(j) *Strophomorpha ovata*, MPK 6908, slide MPA 29804/3, P282, Loc. 135, Raeberry Castle, Howwell Bay.

(k) *Tylotopalla astrifera*, MPK 6909, slide MPA 28951/3, Q530, Loc. 78, S of Balmae Haven.

(l) *Tylotopalla aff. digitifera* sensu Barron 1989, MPK 6910, MPA 28960/3, P351, Loc. 92, Mullock Bay.

(m–o) Computer generated image constructed from 19 separate focus levels using 488nm blue laser light in confocal fluorescent mode. n,o. same specimen in transmitted light.
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### LLANOVERY? WENLOCK TELYCHIAN? SHEINWOODIAN

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#### SERIES

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#### GRAPTOLITE BIOZONES

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#### SAMPLE LOCALITY

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<td>31. Dixiophora sp.</td>
</tr>
<tr>
<td>32. Eupokilotha sp.</td>
</tr>
<tr>
<td>33. Eupokilotha sp.</td>
</tr>
<tr>
<td>34. Graciliscopora sp.</td>
</tr>
<tr>
<td>35. Multiplicophoridium sp.</td>
</tr>
<tr>
<td>36. Multiplicophoridium sp.</td>
</tr>
<tr>
<td>37. Oppilastula sp.</td>
</tr>
<tr>
<td>38. Cymatiscopora cristata</td>
</tr>
</tbody>
</table>

### Notes

- M. tunicatus to M. crispus
- Mcl. giacstoniensis
- C. centricus to M. micriplanus
- C. centricus to M. riccartonensis
- M. riccartonensis to C. lundgreni

#### Stratigraphic Scheme

- Informal Biozonal Scheme of Martin 1989
- Doring & Hill 1991 Biozonation
- Acritarchs
- Grapholite Biozones
- Grapholite Biozones at Polynomorph Localities

#### Stratigraphic Table

<table>
<thead>
<tr>
<th>Sample</th>
<th>Locality</th>
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<tbody>
<tr>
<td>1</td>
<td>Sphenocrinus</td>
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<tr>
<td>2</td>
<td>Ammonia sp.</td>
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<tr>
<td>3</td>
<td>Cymatiscopora llanoverensis</td>
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<tr>
<td>4</td>
<td>Dixiophora denticulata</td>
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<tr>
<td>5</td>
<td>Domasia trispinae</td>
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<tr>
<td>6</td>
<td>Leiotheca sp.</td>
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<tr>
<td>7</td>
<td>Stenolophus spp.</td>
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<tr>
<td>8</td>
<td>Tylotopale robustispinae</td>
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<tr>
<td>9</td>
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<tr>
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<td>11</td>
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<tr>
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<tr>
<td>13</td>
<td>Dixiophora granuliferum</td>
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<tr>
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<td>Genus sp.</td>
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<td>Homerian</td>
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<td>Telychian</td>
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<td>Deunffia monospinosa</td>
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<td>AERONIAN (part.)</td>
<td>Dactylofusa estillis</td>
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<tr>
<td></td>
<td>Ammonidium microcladum</td>
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</tbody>
</table>

Graptolite biozone bases

C. centrifugus

M. sedgwickii