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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, Carghidown 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 lithlogical 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-Llandovery 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 griestoniensis 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. exiguus, 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 Ammonidium 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 Ammonidium telychense and Ammonidium 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. griestoniensis 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 Cymatiogalea 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 Edgarton 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 Edgarton 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. 6e-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 monograptids 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 triangulate 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 Carghidown Formation.

The Barr Burn collections are dominated by fragments of broad monoclimacids (up to 2.2mm wide). The majority are identified as examples of Monoclimacis vomerina s.l., but a few slim fragments are close to Mcl. linnarssoni; 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. griestoniensis 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 Monoclimacis crenulata Biozone, the topmost biozone of the Llandovery Series. Monograptus priodon (common), M. cf. simulatus and M. cf. tullbergi also occur, together with retiolitids 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. linnarssoni, 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 ?Barrandeograptus pulchellus. The latter species has not previously been recorded in Britain from strata older than lowest Wenlock, but Bjerreskov (1975, p.88) has described examples associated with Mcl. linnarssoni 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 Tylotopalla 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 Fauldbog Bay (Locs. 61–63), on the Isle of Whithorn, (Loc.69) (White in Barnes 1989) and at Burrow Head (Loc. ?64, 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. Monoclimacids are characteristically well represented by Mcl. vomerina basilica and Mcl. vomerina vomerina. Other species recorded include Monograptus cf. danbyi (Loc. 66) and M. minimus cautleyensis (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 Monoclimacis 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, Cymatiosphaera cf. mirabilis, Domasia bispinosa, D. elongata, D. trispinosa, G. encantador, T. wenlockia, Tunisphaeridium caudatum, and Visbysphaera dilatispinosa. A. wychense was previously recorded only in the Telychian (Dorning & 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 Ambitisporites 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, 13e, 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. linnarssoni 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 flumendosae flumendosae, 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. ellesae 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 flumendosae 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. linnarssoni Biozone where Estiastra 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. linnarssoni) 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 Grennan slate quarries (Locs.2,3) and the Mcl. griestoniensis Biozone occurs at Kirkmaiden (Locs.12,13). However, evidence for the Mcl. 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 Mcl. griestoniensis 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 Mcl. 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 Retiolites 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 monoclimacids 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. linnarssoni and C. ellesae biozones were not proved but the presence of the succeeding C. lundgreni 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. linnarssoni 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. linnarssoni 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 Kirkmaiden 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. Molyneux (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., Micrhystridium nannacanthum, Micrhystridium spp., Tylotopalla caelamenicutis and T. wenlockia recorded by Molyneux 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, particulary 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/Baltican 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/Baltican origin.

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 Lophosphaeridium 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.

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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. GRAPTOLITE LOCALITIES (faunal lists are given in Appendix 2)

Gala Group (undifferentiated)

1. 0883 4146. Shore, Cairnie Finnart. M. turriculatus Bz.
2. 1267 3943. Grennan slate quarry (1). M. crispus Bz.
3. 1268 3932. Grennan slate quarry (2) M. crispus Bz.
4. 0955 3850. Seastack, Dunbuck. ?M. crispus Bz.
5. 2846 5024. Crag, Alticry. M. turriculatus or M. crispus Bz.
6. 2860 5032. Crag, Alticry. M. turriculatus or M. crispus Bz.

Hawick Group

Cairnharrow Formation

7. 405 502. Old railway cutting, Whaup Hill. M. turriculatus Bz.
8. 6718 6309. Crag, Edgarton Farm. M. turriculatus Bz.
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

12. 3716 3931. Base of cliff, Kirkmaiden. Mcl. griestoniensis Bz.
13. 3722 3926. Base of cliff, Kirkmaiden. Mcl. griestoniensis Bz.
14. 3725 3913. Base of cliff, Kirkmaiden. uncertain
15. 6654 5868. Quarry, Waterside. uncertain

Carghidown 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.

23. 6729 4554. M. riccartonensis Bz.
24. 6729 4549. M. riccartonensis Bz. (upper part).
25. 6731 4542. M. riccartonensis Bz. (middle part)
26. 6731 4539. M. riccartonensis Bz. (middle part)
27. 6729 4537. M. riccartonensis Bz. (middle part)
28. 6731 4531. M. riccartonensis Bz. (middle part)
29. 6731 4526. M. riccartonensis Bz. (middle part)
30. 6729 4521. not determinable.
31. 6729 4521. M. riccartonensis Bz. (?upper part).

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

32. 6730 4486. M. riccartonensis Bz. (?upper part).
33. 6740 4474. M. riccartonensis Bz. (?upper part).
34. 6672 4442. M. riccartonensis Bz. (?middle part).
35. 6773 4441. M. riccartonensis Bz. (lower part).
36. 6774 4439. M. riccartonensis Bz. (lower part).
37. 6774 4439. M. riccartonensis Bz. (lower part).
38. 6774 4436. M. riccartonensis Bz. (lower part).
39. 6780 4428. M. riccartonensis Bz. (upper part).
40. 6787 4425. M. riccartonensis Bz. (upper part).
41. 6785 4422. M. riccartonensis Bz. (upper part).
42. 6785 4419. M. riccartonensis Bz. (uncertain).
43. 6785 4416. uncertain.
44. 6785 4414. M. riccartonensis Bz. (middle part).
45. 6792 4406. M. riccartonensis Bz. (middle part).
46. 6799 4405. M. riccartonensis Bz. (middle part).

b) W side of Kirkcudbright Bay.

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

47. 656 454. C. centrifugus Bz.
48. 652 449. ?C. centrifugus Bz.
49. 649 449 ?C. centrifugus Bz.
50. 6543 4444. M. riccartonensis Bz. (middle part).
51. 6545 4437. M. riccartonensis Bz. (middle part).

(ii) Meikle Ross

52. 6562 4394. ?M. riccartonensis Bz.
53. 6552 4376. ?M. riccartonensis Bz.
54. 6537 4331. ?M. riccartonensis Bz. (upper part).
55. 6532 4326. M. riccartonensis Bz. (?upper part).
56. 6455 4355. M. riccartonensis Bz. (middle part).
57. 6442 4366. M. riccartonensis Bz. (middle part).
58. 6440 4370. M. riccartonensis Bz. (middle part).
59. 6448 4392. M. riccartonensis Bz. (middle part).
60. 6445 4393. M. riccartonensis Bz. (middle part).

(iii) Fauldbog Bay

61. 6442 4429. C. centrifugus Bz.
62. 6428 4455. C. centrifugus Bz.
63. 6420 4455. C. centrifugus Bz.

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. antennularius Bz.
74. 6808 4398. post M. riccartonensis Bz.
75. 6825 4398. M. antennularius Bz.
76. 6826 4397. M. antennularius Bz. or C. rigidus Bz.
77. 6834 4388. uncertain
78. 6835 4378. C. linnarssoni Bz.
79. 6852 4358. uncertain

(ii) Port Muddle, E side

80. 6883 4360. M. antennularius Bz.
81. 6885 4358. uncertain
82. 6889 4355. M. riccartonensis Bz. (upper part) and M. antennularius 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.
99. 0934 4042. Manxman's Rock, Port Logan. MPA 31191.
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

109. 1142 3166. Clifftop, Cave of the Broad Stone. MPA 31196.
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 4446. 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.
119. 6743 4615. Bathinghouse Bay. MPA 29795.

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. exiguus exiguus (Nicholson) 2, 3, 3(aff.)
M. exiguus (Nicholson) s.l. 3, 4
M. marri Perner 2, 3(cf.), 4
M. cf. plumosus (Baily) 4
M. cf. planus (Barrande) 4
M. priodon (Bronn) 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 (Bronn) 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
Barrandeograptus? bornholmensis (Laursen) 47, 61
B? 63
Cyrtograptus centrifugus Bouček 22(cf.), 61(cf.), 62(cf.), 63(cf.), 66, 69
cf. C. grayi 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 basilica (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 (Bronn) 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.)
Pristiograptus 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
Cyrtograptus linnarssoni Lapworth 78
C. cf. rigidus rigidus Tullberg 85
C. cf. rigidus cautleyensis Rickards 78
C. spp. 85(?), 92(?), 94
Monoclimacis flumendosae flumendosae (Gortani) 71, 74, 76, 77(aff.), 78, 79(cf.), 82, 84(cf.), 85
Mcl. flumendosae kingi Rickards 79(?), 85, 86(cf.), 88(cf.), 92, 93(cf.)
Mcl. vomerina basilica (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 (Bronn) 72
M. radotinensis inclinatus Rickards 72(cf.), 82

M. riccartonensis Lapworth 72, 82, 83
Pristiograptus 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 Dorning & Hill 1991
A. wychense Dorning & Hill 1991
A. spp.
?Baltisphaeridium (R)
Cymatiogalea cristata? (Downie 1958) Rauscher 1973 (R)
Cymatiosphaera llandoveryensis Dorning & Hill 1991
C. cf. mirabilis Deunff 1959
C. octoplana Downie 1959
Dictyotidium dictyotum (Eisenack 1938) Eisenack 1955
D. telychense Dorning & Hill 1991
Diexallophasis denticulata (Stockmans & Willière 1963) Loeblich 1970
D. granulatispinosa (Downie 1963) Hill 1974
D. sp. A
D. sp.
Domasia antiquita Dorning & Hill 1991
D. bispinosa Downie 1960
D. elongata Downie 1960
D. limaciforme (Stockmans & Willière 1963) Cramer 1971
D. quadrispinosa Hill 1974
D. quinquispinosa Dorning & Hill 1991
D. symmetrica Cramer 1971
D. trispinosa Downie 1960
Duvernaysphaera aranaides (Cramer 1964) emend Cramer & Díez 1972
Elektoriskos cf. aurora Loeblich 1970
Estiastra barbata Downie 1963
Eupoikilofusa striatifera (Cramer 1964) Cramer 1971
E. sp.
Geron sp.
?Goniosphaeridium
Gracilisphaeridium encantador (Cramer 1971) Eisenack et al. 1973
Helosphaeridium sp.
Leiosphaeridia spp.
Lophosphaeridium sp.
Micrhystridium inflatum (Downie 1959) Lister 1970
M. nannacanthum Deflandre 1945
M. parinconspicuum Deflandre 1945
M. spp.

Moyeria cabottii (Cramer 1971) Miller & Eames 1982
M. telychensis Dorning & Hill 1991
Multiplicisphaeridium cladum (Downie 1963) Eisenack 1969
M. fisherii (Cramer 1968) Lister 1970
M. imitatum? (Deflandre 1945) Lister 1970
M. cf. martiniae Priewalder 1987
M. cf. raspum (Cramer 1964) Eisenack et al. 1973
M. spp.
Oppilatala eoplanktonica (Eisenack 1955) Dorning 1981
O. frondis (Cramer & Díez 1972) Dorning 1981
O. ramusculosa (Deflandre 1945) Dorning 1981
O. sp.
Parvifusa parvitatis (Loeblich 1970) Dorning & Hill 1991
Peteinosphaeridium trifurcatum breviradiatum (Eisenack 1959) Eisenack 1965 (R)
Salopidium granuliferum (Downie 1959) Dorning 1981
Stellechinatum 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. caelamenicutis Loeblich 1970
T. cf. cellonensis Priewalder 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 downiei 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.
Visbysphaera dilatispinosa (Downie 1963) Lister 1970
?V. ranaemanum (Le Herissé 1989) Dorning & Hill 1991
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
Tetrahedraletes medinensis Strother & Traverse 1979
spore tetrad

CHITINOZOA

Ancyrochitina ancyrea (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. llandoveryensis Dorning & Hill 1991
Diexallophasis denticulata (Stockmans & Willière 1963) Loeblich 1970
Deunffia monospinosa Downie 1960
Domasia trispinosa Downie 1960
Helosphaeridium citrinipeltatum (Cramer & Díez 1972) Dorning 1981
Helosphaeridium cf. citrinipeltatum (Cramer & Díez 1972) Dorning 1981
Leiosphaeridia spp.
Lophosphaeridium hauskae Priewalder 1987
Lophosphaeridium malvernense Dorning & Hill 1991
Lophosphaeridium spp.
Micrhystridium 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. griestoniensis 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 assignation. 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. antennularius Bz., RS = C. rigidus Bz., LS = C. linnarssoni 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.

(b) Monograptus cf. plumosus (Baily), GSE 14866 Loc. 7, Whaup Hill, M. turriculatus 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. griestoniensis (Nicol), Loc. 13, Kirkmaiden, (e) GSE 14886, (f–g) proximal and distal parts of GSE 14885, (h) GSE 14887, Mcl. griestoniensis 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. griestoniensis (Nicol), (a) GSE 14904, (b) GSE 14886, Loc. 13, Kirkmaiden, Mcl. griestoniensis 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) Retiolites geinitzianus geinitzianus Barrande, GSE 14883, Loc. 63, Fauldbog Bay, C. centrifugus Biozone.

(i) Cyrtograptus linnarssoni Lapworth, GSE 14061, Loc. 78, S of Balmae Haven, C. linnarssoni 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) Diexallophasis 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) Eupoikilofusa 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. martiniae, MPK 6867, slide MPA 31193/1, V434, Loc. 101.

(k) Stellechinatum sp. A, MPK 6868, slide MPA 31193/1, L430, Loc. 101.

(l) ?Visbysphaera ranaemanum, MPK 6869, slide MPA 31193/3, F292, Loc. 101.

(m) Tunisphaeridium cf. parvum, MPK 6870, slide MPA 31192/1, K360, Loc. 100.

(n) Tylotopalla 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) Cymatiosphaera llandoveryensis, MPK 6873, slide MPA 27824/2, M344, Loc. 15, Waterside.

(c) Dictyotidium telychense, 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 quadrispinosa, 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 telychensis, 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) Oppilatala eoplanktonica?, MPK 6881, slide MPA 31197/1, L420, Loc. 110, Portavaddie.

(k,l) Moyeria telychensis, 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. linnarssoni (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 ((Bronn), GSE 14872, locality as for (d).

Figure 11. Acritarchs from the Eskdalemuir area. Barr Burn (a–c, e–o), Glendearg (d). Mcl. crenulata Zone. All specimens x 1000.

(a) Ammonidium telychense, MPK 6887, slide MPA 28470/3, K392.

(b) Cymatiosphaera 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 hauskae, 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) Tylotopalla 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. riccartonenesis 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 antennularius (Meneghini), (= M. capillaceus Tullberg of Kemp & White 1985), GSE 14064, Loc. 75, S side of Balmae Haven, M. antennularius 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. belophrorus (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 antennularius (Meneghini) (=M. capillaceus Tullberg of Kemp & White 1985), (a) GSE 14064, (b)GSE 14063, Loc. 75, S of Balmae Haven; M. antennularius Biozone.

(c) Pristiograptus dubius dubius (Suess), GSE 14882, loc. 76, S of Balmae Haven; M. antennularius 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 flumendosae flumendosae (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 caelamenicutis, MPK 6902, slide MPA 28939/2, N320, Loc. 16, Long Robin, E side of Kirkcudbright Bay.

(e) Visbysphaera 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.

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

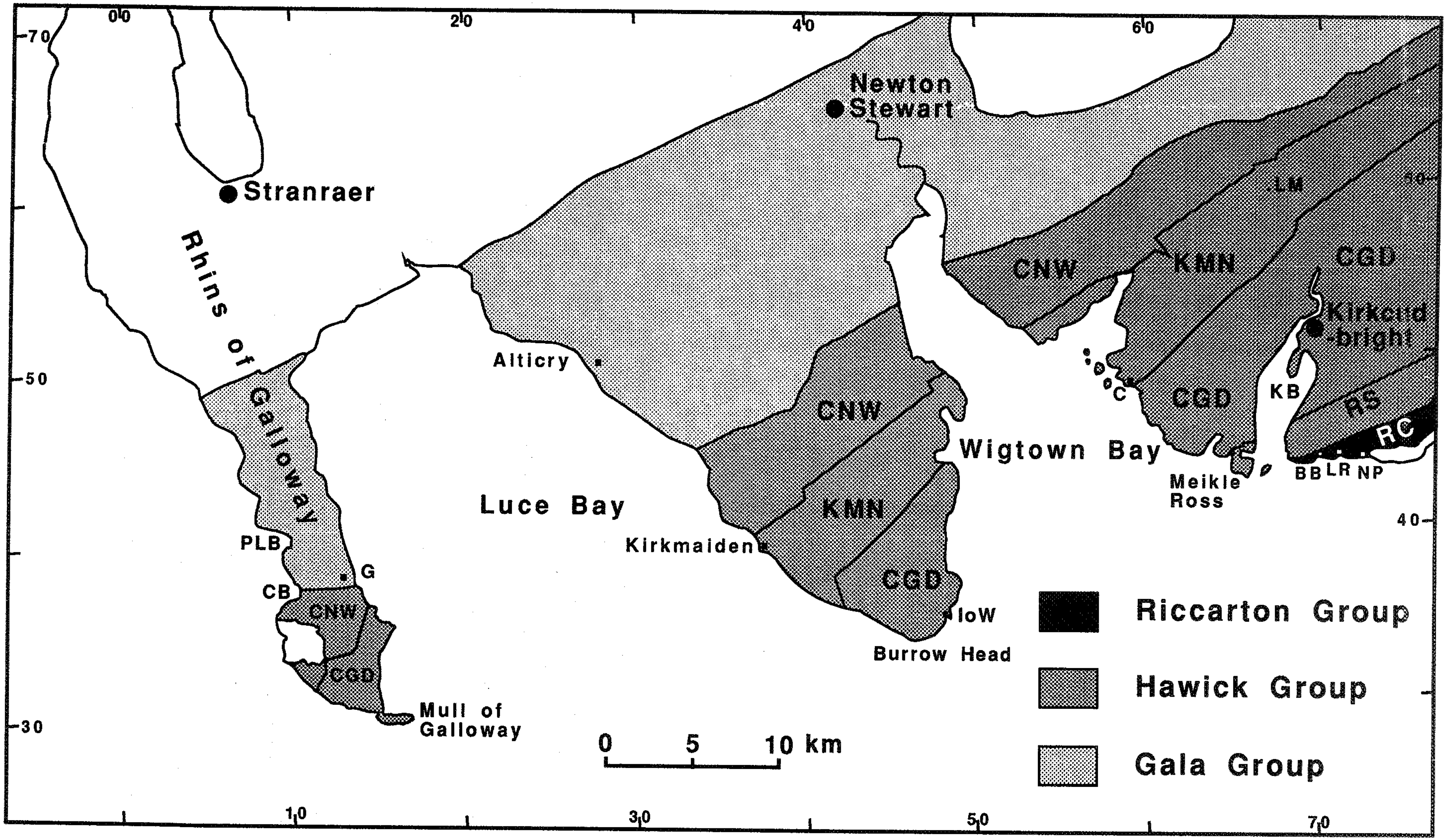
(g,i) Strophomorpha ovata, MPK 6906,slide MPA 29804/1, F430, Loc. 135, Raeberry Castle, Howwell Bay.

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

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

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

(m–o) Tylotopalla aff. digitifera sensu Barron 1989, MPK 6910, MPA 28960/3, P351, Loc. 92, Mullock Bay. m. 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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KMN
CGD
IoW
Burrow Head
Wigtown Bay
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Kirkcud-bright
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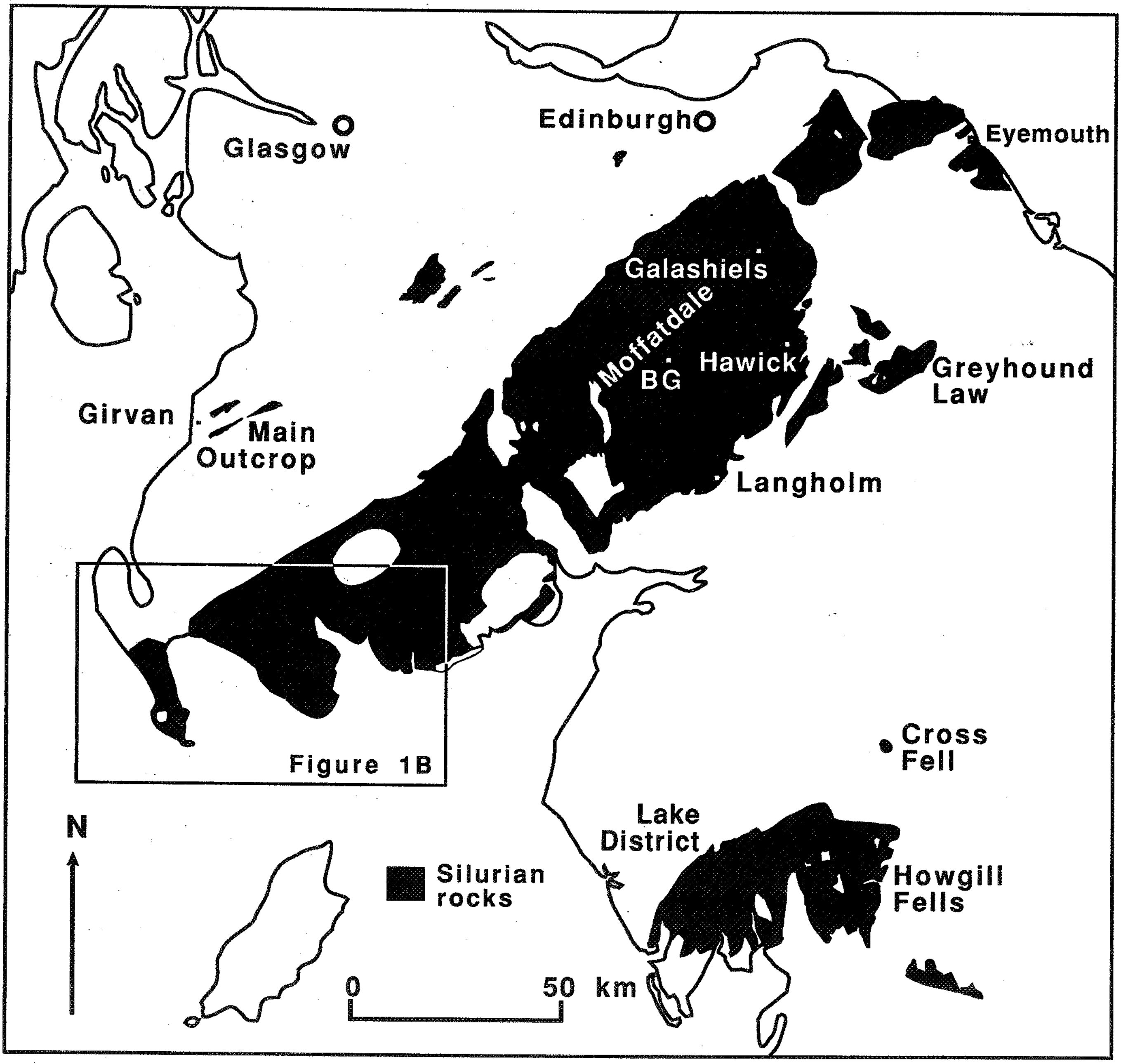
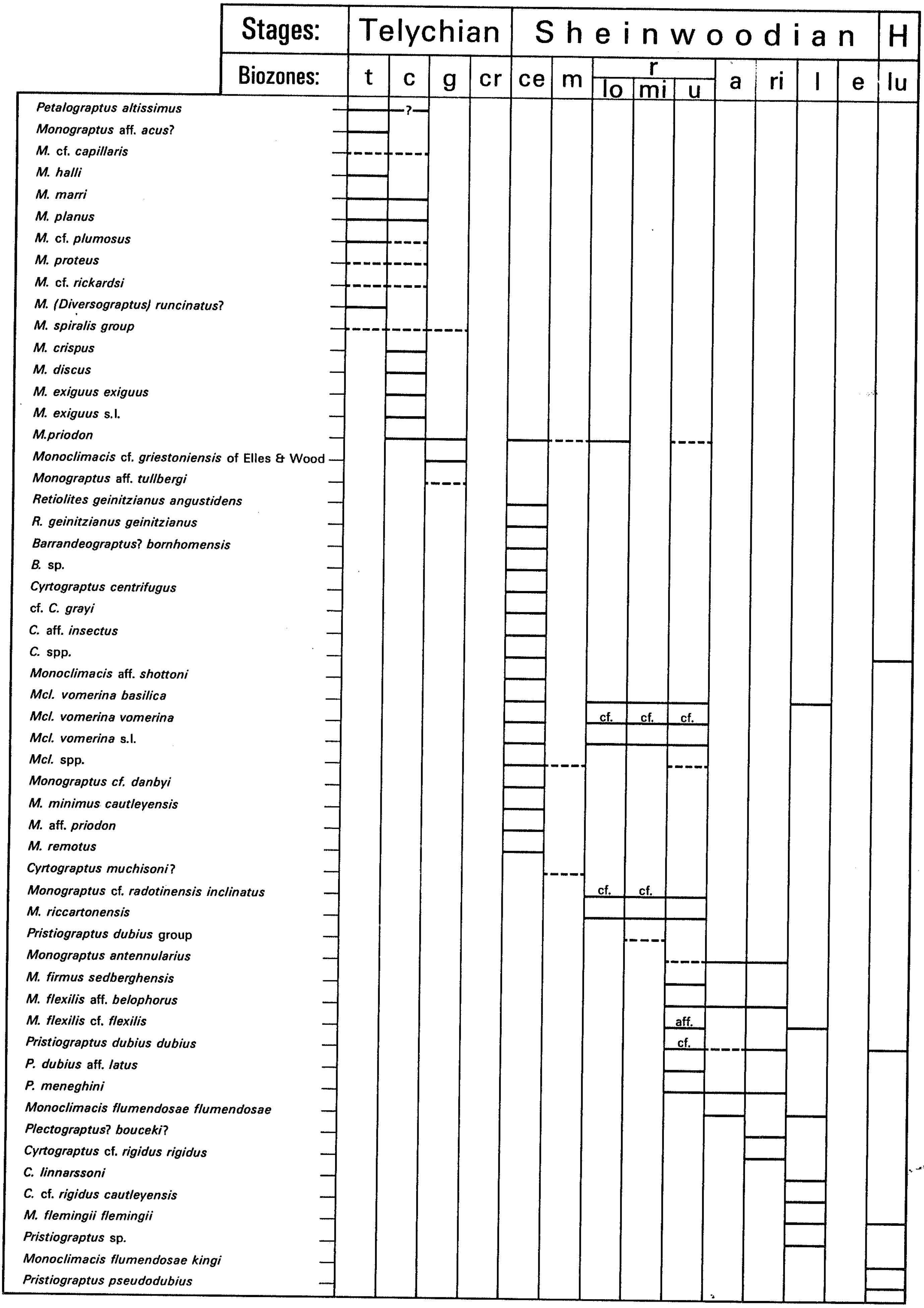

Glasgow
Edinburgh
Eyemouth
Galashiels
Moffatdale
BG
Hawick
Greyhound Law
Girvan
Main Outcrop
Langholm
Figure 1B
Cross Fell
N
Lake District
Silurian rocks
Howgill Fells
0
50 km

SERIES	Stage	Graptolite biozone		Formation	Group
WENLOCK (part.)	Hom.	*C. lundgreni*		Raeberry Castle	Riccarton
	Sheinwoodian	*C. ellesae*			
		C. linnarssoni			
		C. rigidus			
		M. antennularius			
		M. riccartonensis	upper	?	
			middle	Ross	Hawick
			lower		
		C. murchisoni			
		C. centrifugus		?	
LLANDOVERY (part.)	Telychian	*Mcl. crenulata*		Carghidown	
		Mcl. griestoniensis		? Kirkmaiden	
		M. crispus		? Cairnharrow	
		M. turriculatus		?	Gala (part.)


Stages:
Telychian
Sheinwoodian
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Biozones:
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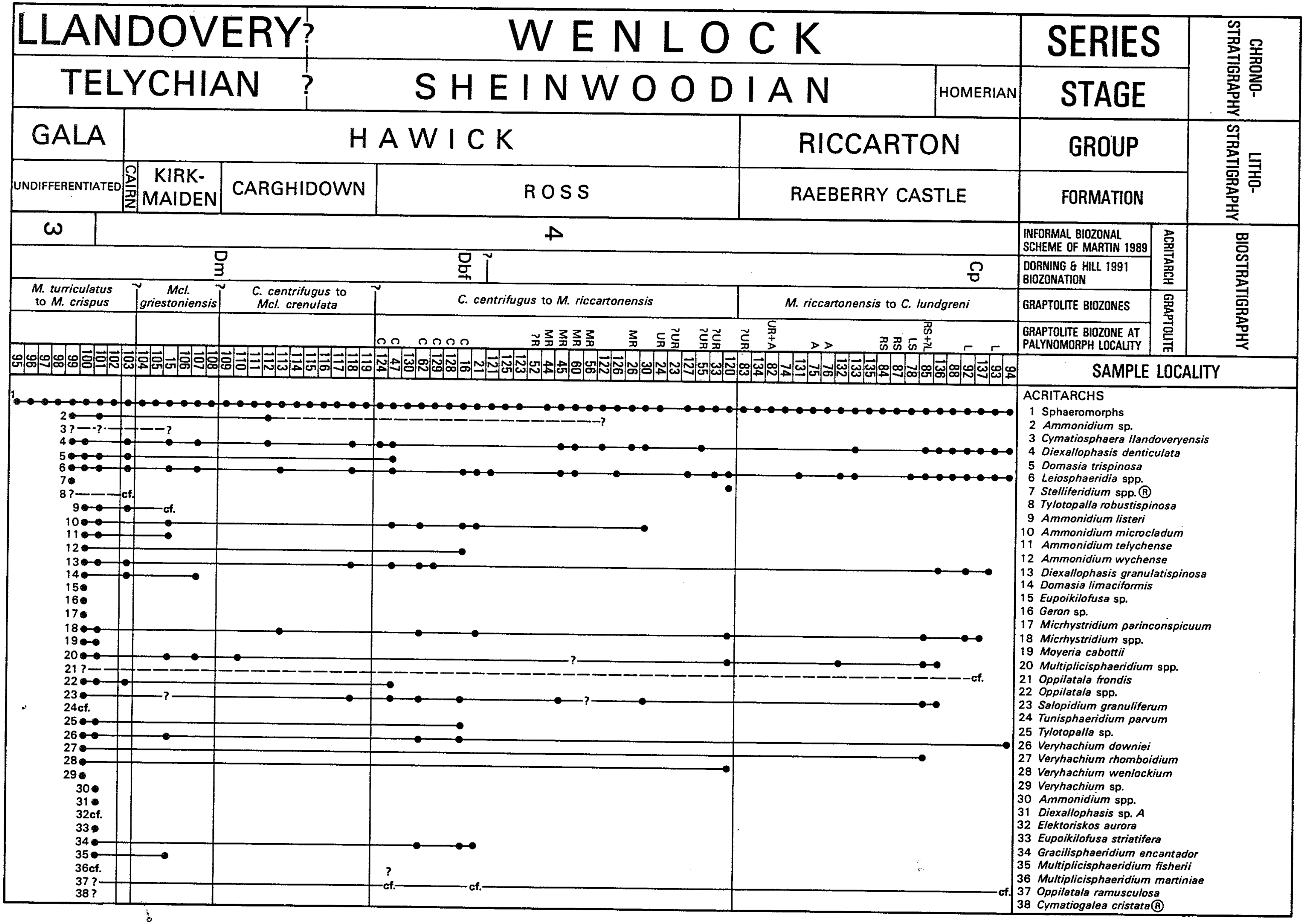
lu
Petalograptus altissimus
?
Monograptus aff. acus?
M. cf. capillaris
M. halli
M. marri
M. planus
M. cf. plumosus
M. proteus
M. cf. rickardsi
M. (Diversograptus) runcinatus?
M. spiralis group
M. crispus
M. discus
M. exiguus exiguus
M. exiguus s.l.
M.priodon
Monoclimacis cf. griestoniensis of Elles & Wood
Monograptus aff. tullbergi
Retiolites geinitzianus angustidens
R. geinitzianus geinitzianus
Barrandeograptus? bornhomensis
B. sp.
Cyrtograptus centrifugus
cf. C. grayi
C. aff. insectus
C. spp.
Monoclimacis aff. shottoni
Mcl. vomerina basilica
Mcl. vomerina vomerina
cf.
cf.
cf.
Mcl. vomerina s.l.
Mcl. spp.
Monograptus cf. danbyi
M. minimus cautleyensis
M. aff. priodon
M. remotus
Cyrtograptus muchisoni?
Monograptus cf. radotinensis inclinatus
cf.
cf.
M. riccartonensis
Pristiograptus dubius group
Monograptus antennularius
M. firmus sedberghensis
M. flexilis aff. belophorus
M. flexilis cf. flexilis
aff.
Pristiograptus dubius dubius
cf.
P. dubius aff. latus
P. meneghini
Monoclimacis flumendosae flumendosae
Plectograptus? bouceki?
Cyrtograptus cf. rigidus rigidus
C. linnarssoni
C. cf. rigidus cautleyensis
M. flemingii flemingii
Pristiograptus sp.
Monoclimacis flumendosae kingi
Pristiograptus pseudodubius


CHRONO-STRATIGRAPHY
SERIES
STAGE
LITHO-STRATIGRAPHY
GROUP
FORMATION
BIOSTRATIGRAPHY
ACRITARCH
INFORMAL BIOZONAL SCHEME OF MARTIN 1989
DORNING & HILL 1991 BIOZONATION
GRAPTOLITE
GRAPTOLITE BIOZONES
GRAPTOLITE BIOZONE AT PALYNOMORPH LOCALITY
SAMPLE LOCALITY
LLANDOVERY?
WENLOCK
TELYCHIAN ?
SHEINWOODIAN
HOMERIAN
GALA
HAWICK
RICCARTON
UNDIFFERENTIATED
CAIRN
KIRK-MAIDEN
CARGHIDOWN
ROSS
RAEBERRY CASTLE
3
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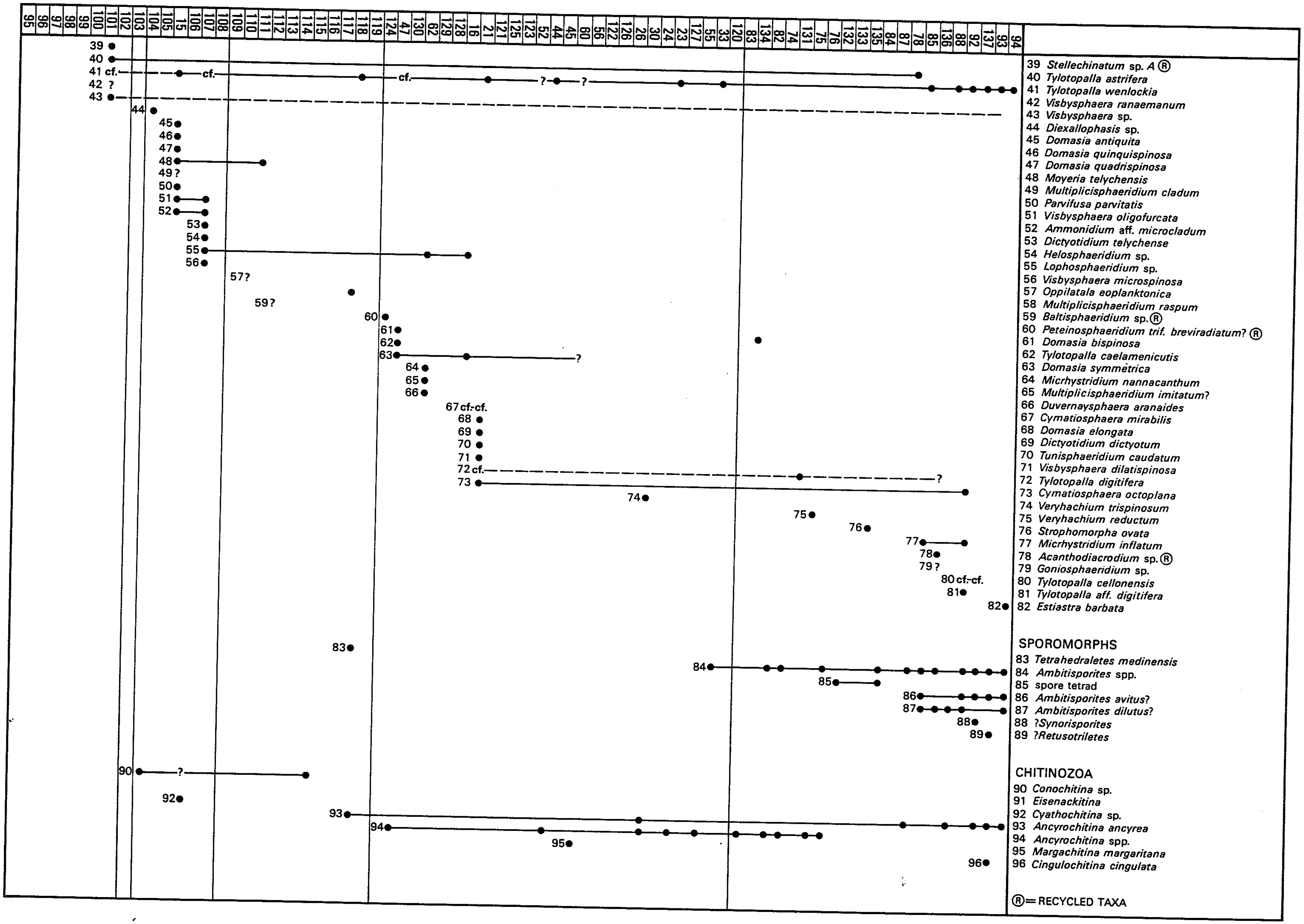
Dm
Dbf
Cp
M. turriculatus to M. crispus
Mcl. griestoniensis
C. centrifugus to Mcl. crenulata
C. centrifugus to M. riccartonensis
M. riccartonensis to C. lundgreni
95 96 97 98 99 100 101 102 103 104 105 15 106 107 108 109 110 111 112 113 114 115 116 117 118 119 124 47 130 62 129 128 16 21 121 125 123 52 44 45 60 56 122 126 26 30 24 23 127 55 33 120 83 134 82 74 131 75 76 132 133 135 84 87 78 85 136 88 92 137 93 94
C C C C C C C ?R MR MR MR MR MR UR ?UR ?UR ?UR ?UR UR+A A A RS RS LS RS+?L L L
ACRITARCHS
1 Sphaeromorphs
2 Ammonidium sp.
3 Cymatiosphaera llandoveryensis
4 Diexallophasis denticulata
5 Domasia trispinosa
6 Leiosphaeridia spp.
7 Stelliferidium spp.®
8 Tylotopalla robustispinosa
9 Ammonidium listeri
10 Ammonidium microcladum
11 Ammonidium telychense
12 Ammonidium wychense
13 Diexallophasis granulatispinosa
14 Domasia limaciformis
15 Eupoikilofusa sp.
16 Geron sp.
17 Micrhystridium parinconspicuum
18 Micrhystridium spp.
19 Moyeria cabottii
20 Multiplicisphaeridium spp.
21 Oppilatala frondis
22 Oppilatala spp.
23 Salopidium granuliferum
24 Tunisphaeridium parvum
25 Tylotopalla sp.
26 Veryhachium downiei
27 Veryhachium rhomboidium
28 Veryhachium wenlockium
29 Veryhachium sp.
30 Ammonidium spp.
31 Diexallophasis sp. A
32 Elektoriskos aurora
33 Eupoikilofusa striatifera
34 Gracilisphaeridium encantador
35 Multiplicisphaeridium fisherii
36 Multiplicisphaeridium martiniae
37 Oppilatala ramusculosa
38 Cymatiogalea cristata®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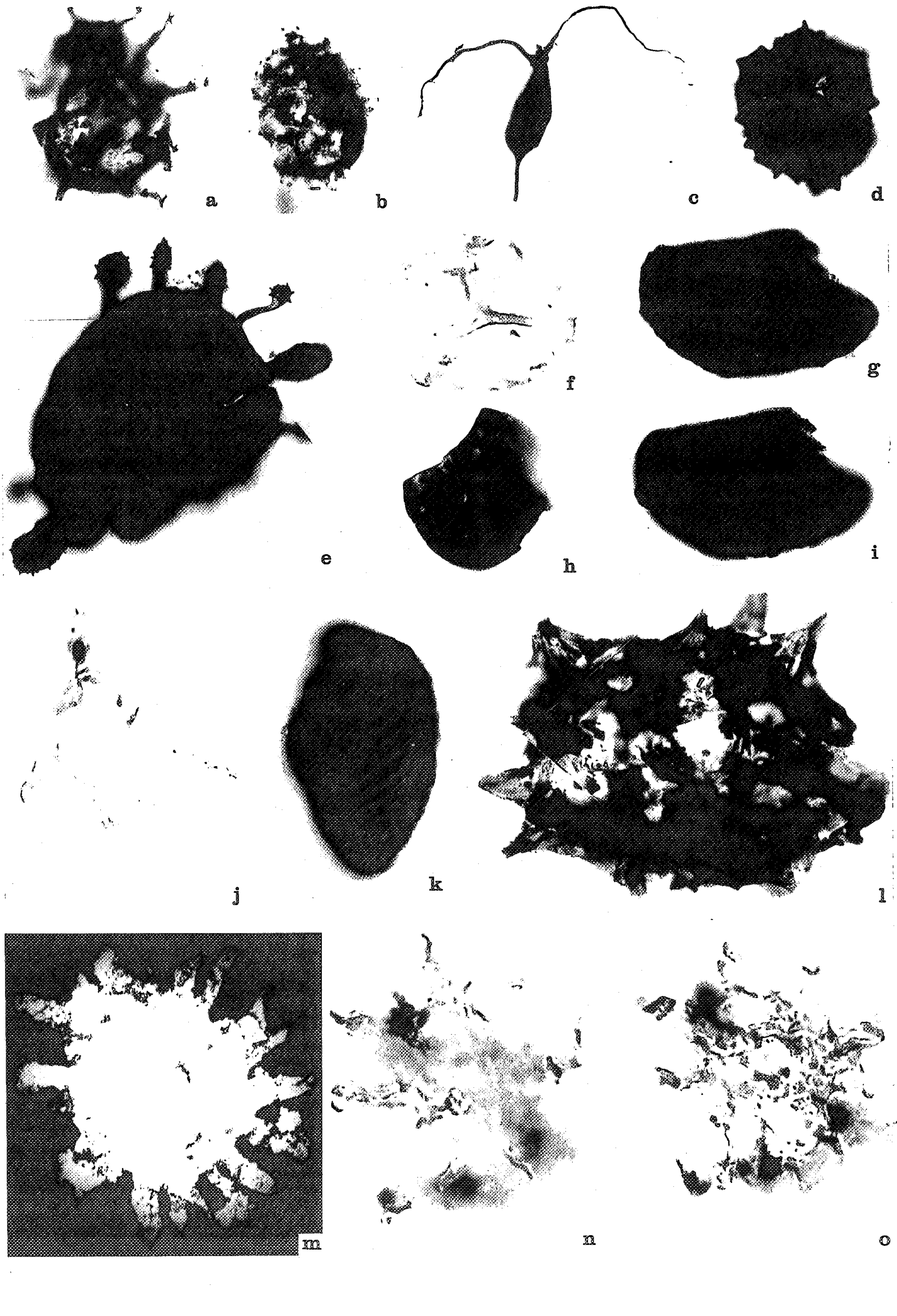
39 Stellechinatum sp. A ®
40 Tylotopalla astrifera
41 Tylotopalla wenlockia
42 Visbysphaera ranaemanum
43 Visbysphaera sp.
44 Diexallophasis sp.
45 Domasia antiquita
46 Domasia quinquispinosa
47 Domasia quadrispinosa
48 Moyeria telychensis
49 Multiplicisphaeridium cladum
50 Parvifusa parvitatis
51 Visbysphaera oligofurcata
52 Ammonidium aff. microcladum
53 Dictyotidium telychense
54 Helosphaeridium sp.
55 Lophosphaeridium sp.
56 Visbysphaera microspinosa
57 Oppilatala eoplanktonica
58 Multiplicisphaeridium raspum
59 Baltisphaeridium sp. ®
60 Peteinosphaeridium trif. breviradiatum? ®
61 Domasia bispinosa
62 Tylotopalla caelamenicutis
63 Domasia symmetrica
64 Micrhystridium nannacanthum
65 Multiplicisphaeridium imitatum?
66 Duvernaysphaera aranaides
67 Cymatiosphaera mirabilis
68 Domasia elongata
69 Dictyotidium dictyotum
70 Tunisphaeridium caudatum
71 Visbysphaera dilatispinosa
72 Tylotopalla digitifera
73 Cymatiosphaera octoplana
74 Veryhachium trispinosum
75 Veryhachium reductum
76 Strophomorpha ovata
77 Micrhystridium inflatum
78 Acanthodiacrodium sp. ®
79 Goniosphaeridium sp.
80 Tylotopalla cellonensis
81 Tylotopalla aff. digitifera
82 Estiastra barbata
SPOROMORPHS
83 Tetrahedraletes medinensis
84 Ambitisporites spp.
85 spore tetrad
86 Ambitisporites avitus?
87 Ambitisporites dilutus?
88 ?Synorisporites
89 ?Retusotriletes
CHITINOZOA
90 Conochitina sp.
91 Eisenackitina
92 Cyathochitina sp.
93 Ancyrochitina ancyrea
94 Ancyrochitina spp.
95 Margachitina margaritana
96 Cingulochitina cingulata
® = RECYCLED TAXA

Series	Stage	Dorning and Hill 1991	Martin 1989	Graptolite biozone bases
WENLOCK	Homerian	*Dictyotidium amydrum*	? 4	
		Eisenackidium wenlockensis		
	Shein-woodian	*Cymatiosphaera pavimenta*		
		Deunffia brevifurcata		
		Deunffia brevispinosa		*C. centrifugus*
LLANDOV. (part.)	Telychian	*Deunffia monospinosa*	? 3	
	Aeronian (part.)	*Dactylofusa estillis*	? 2	
		Ammonidium microcladum		*M. sedgwickii*



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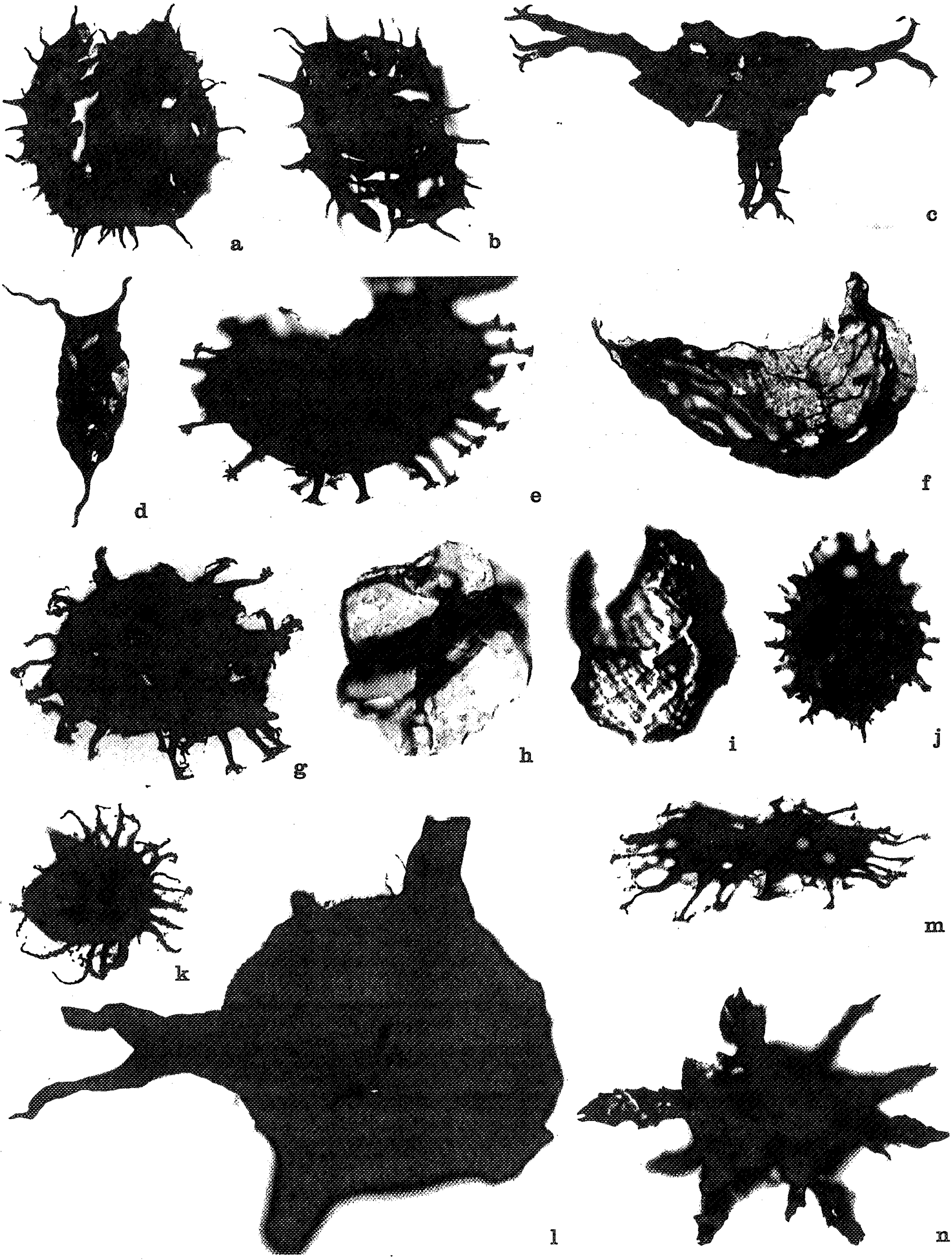
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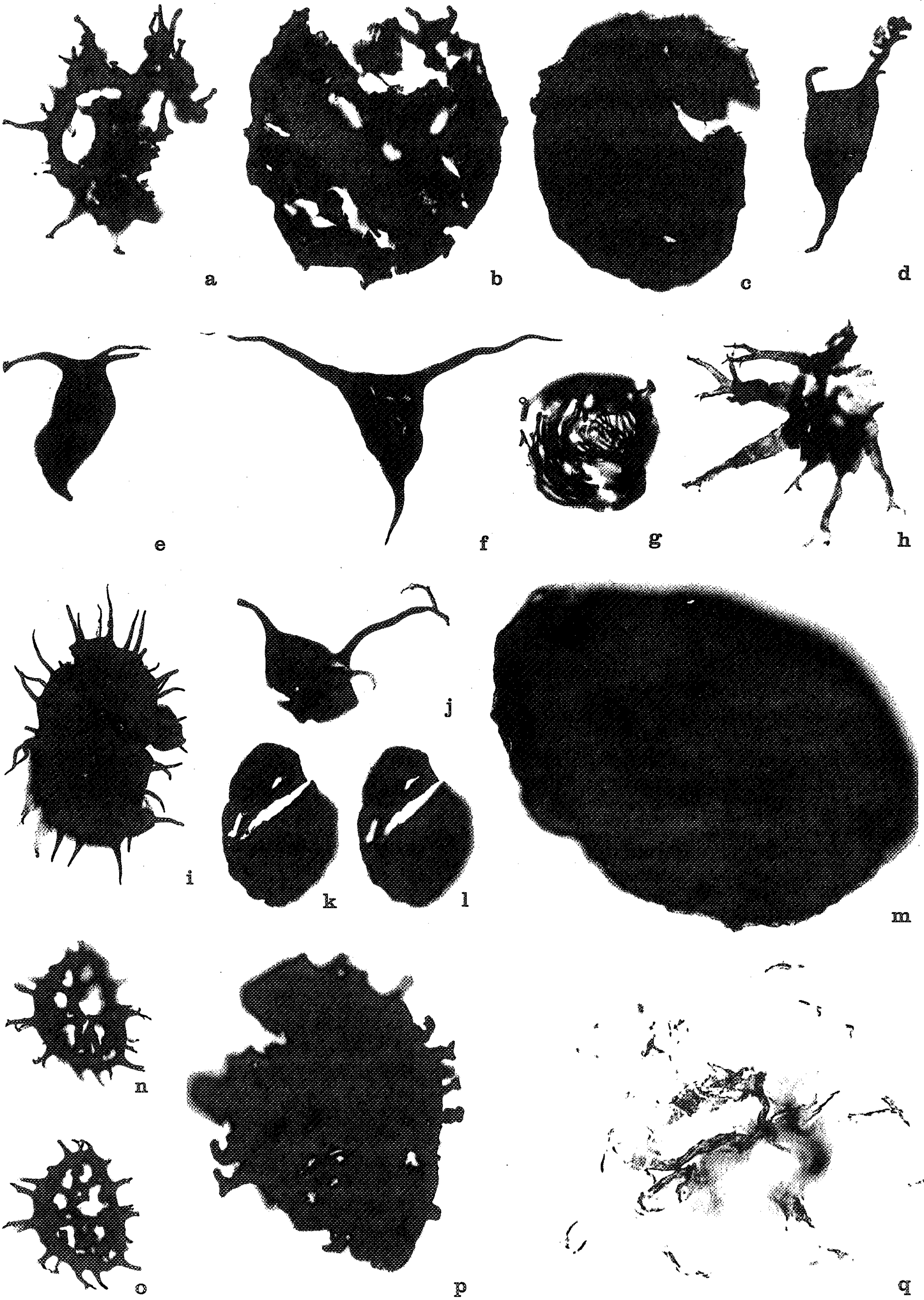
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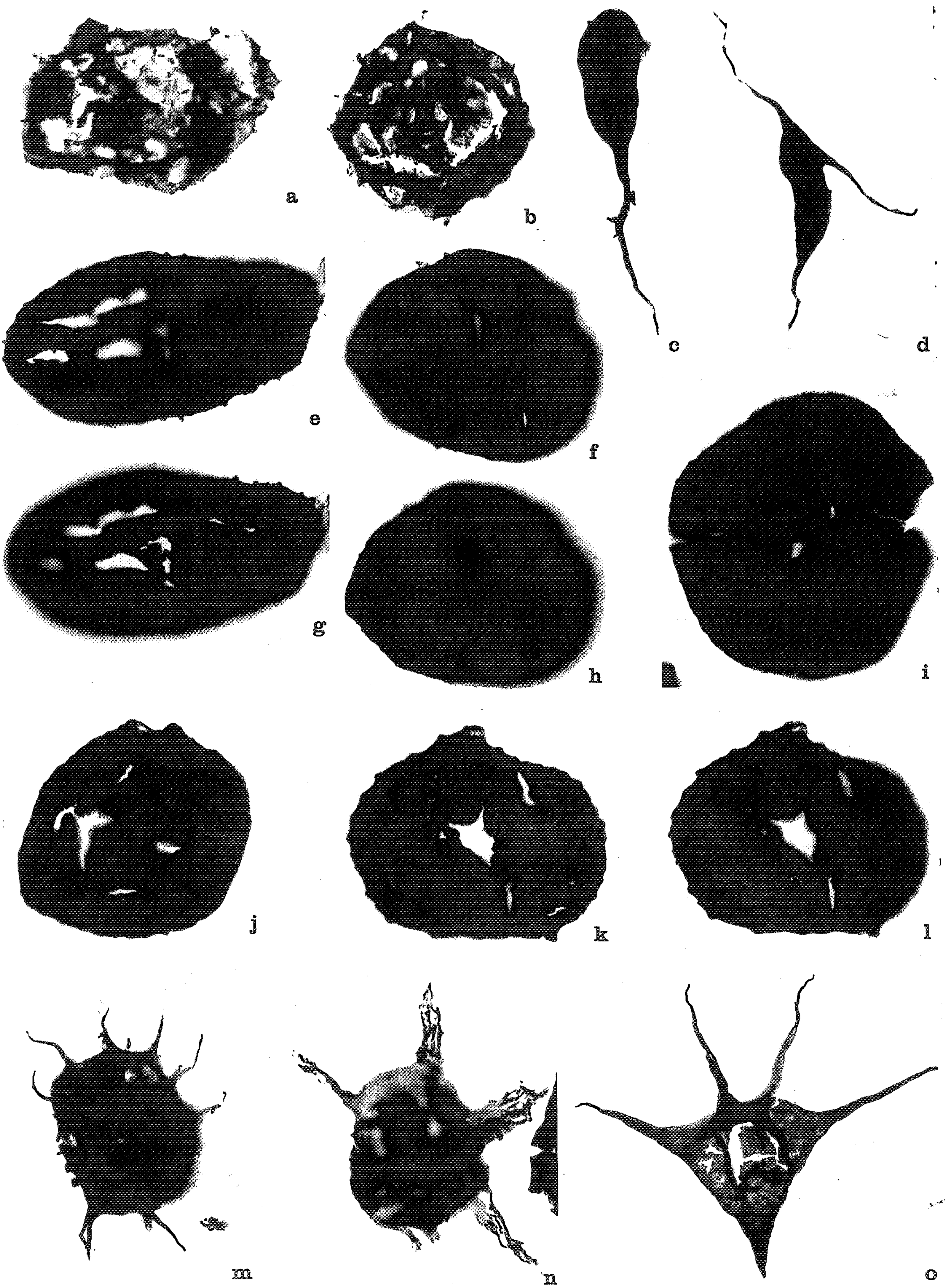
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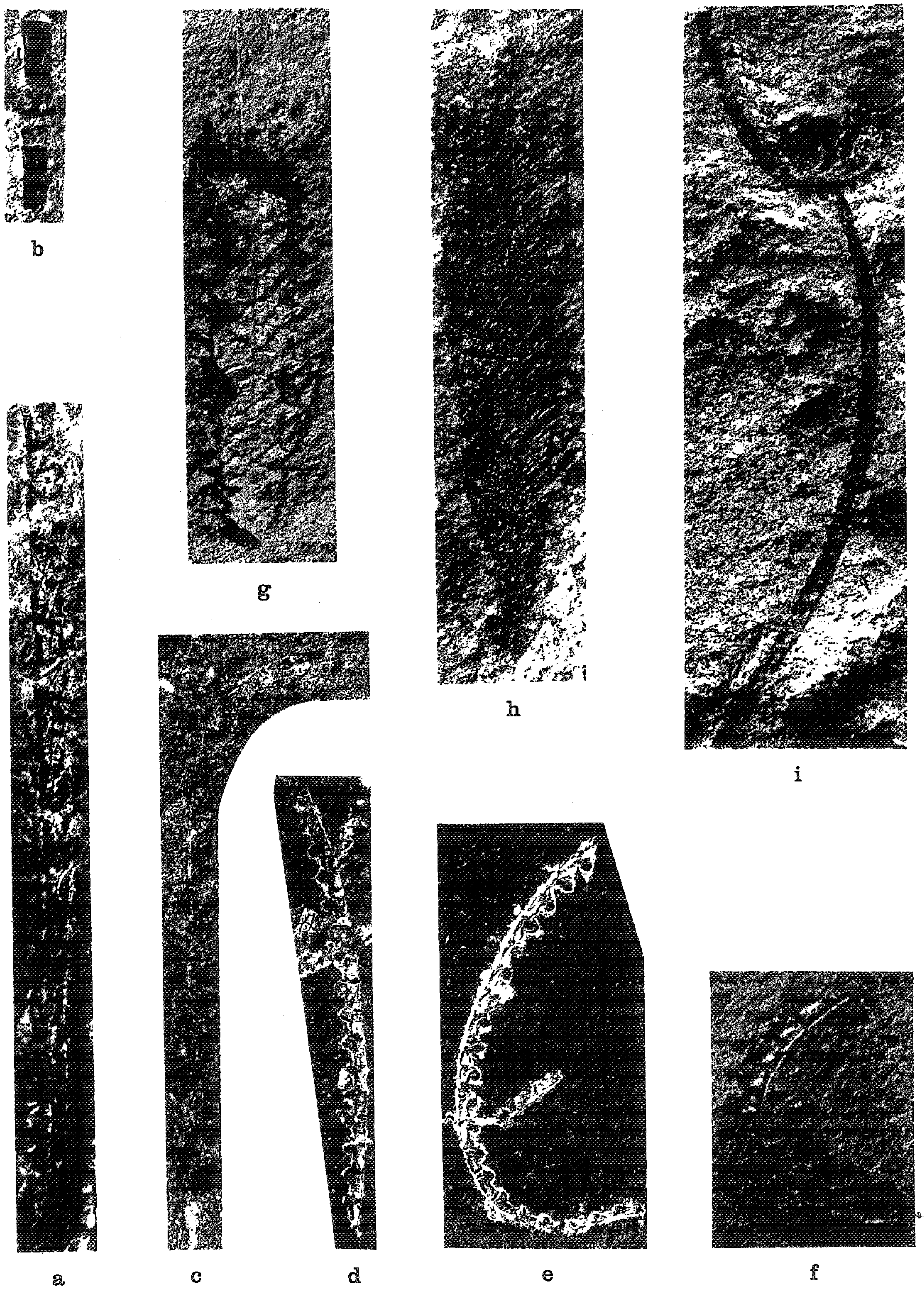
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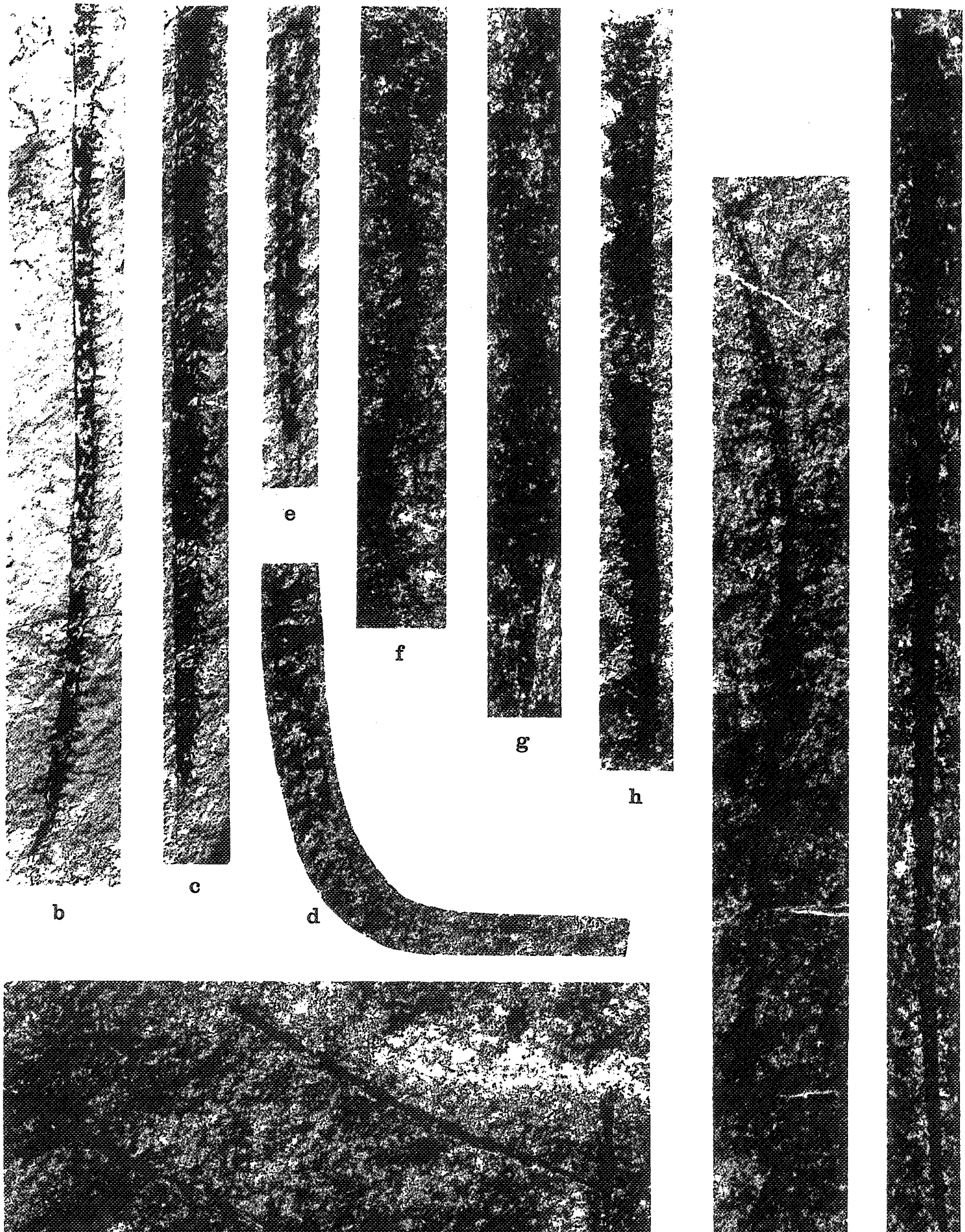
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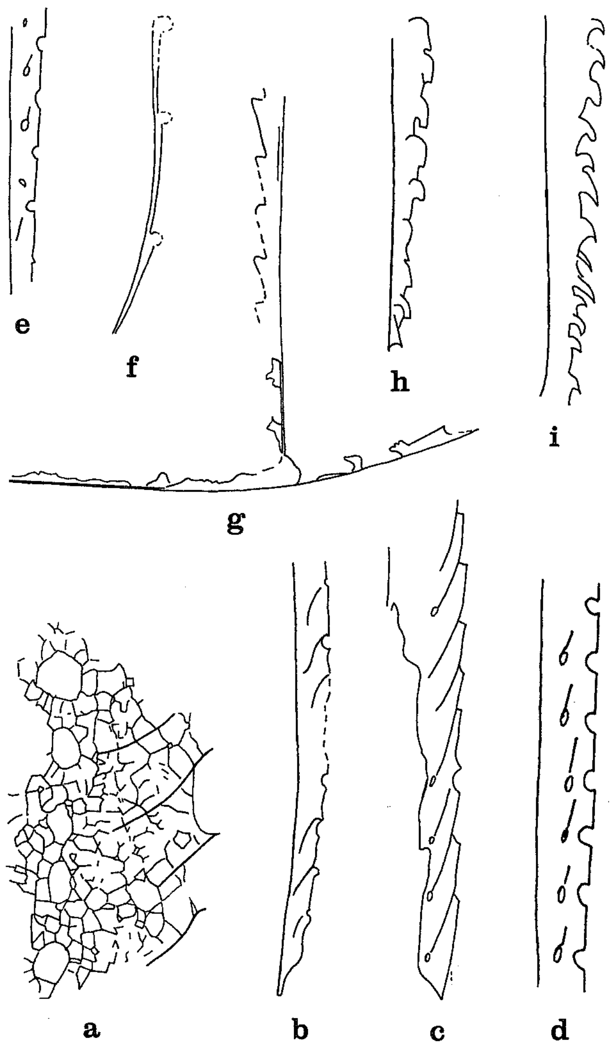
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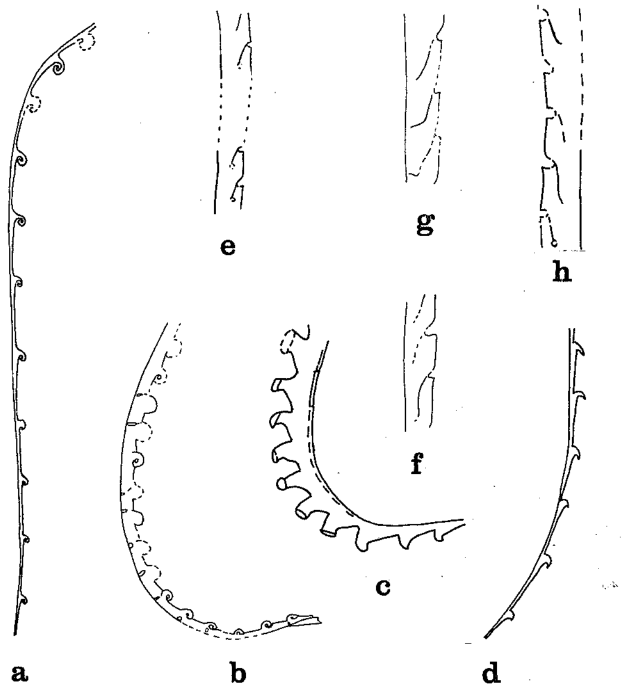

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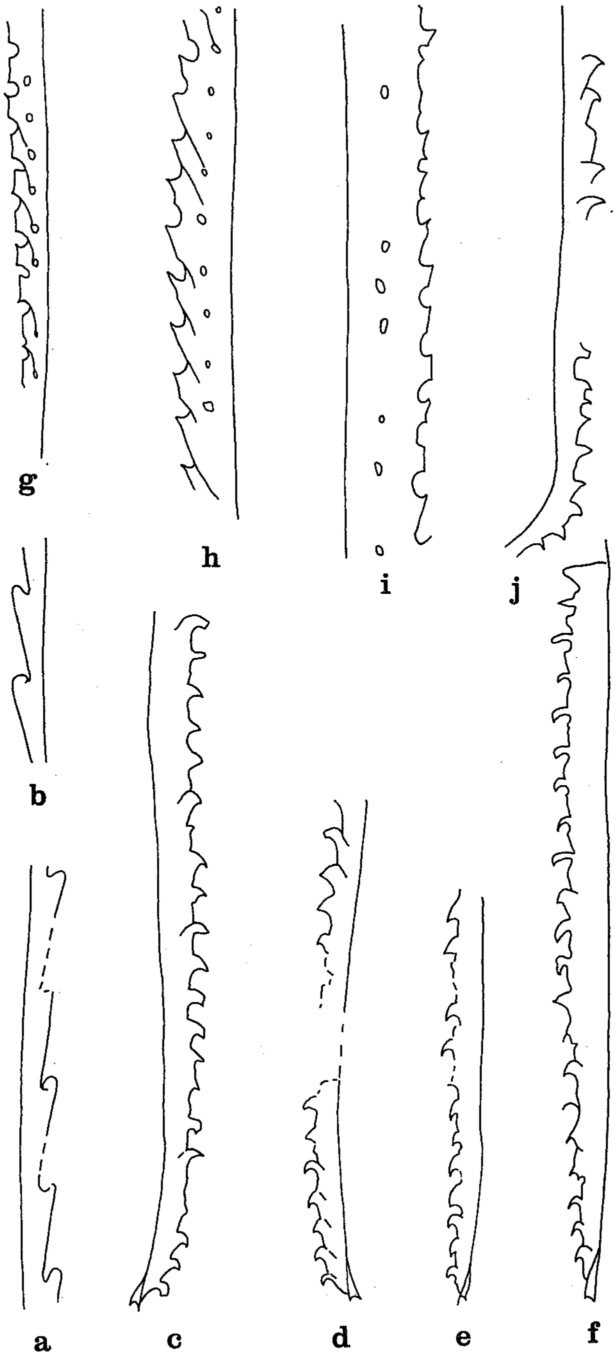

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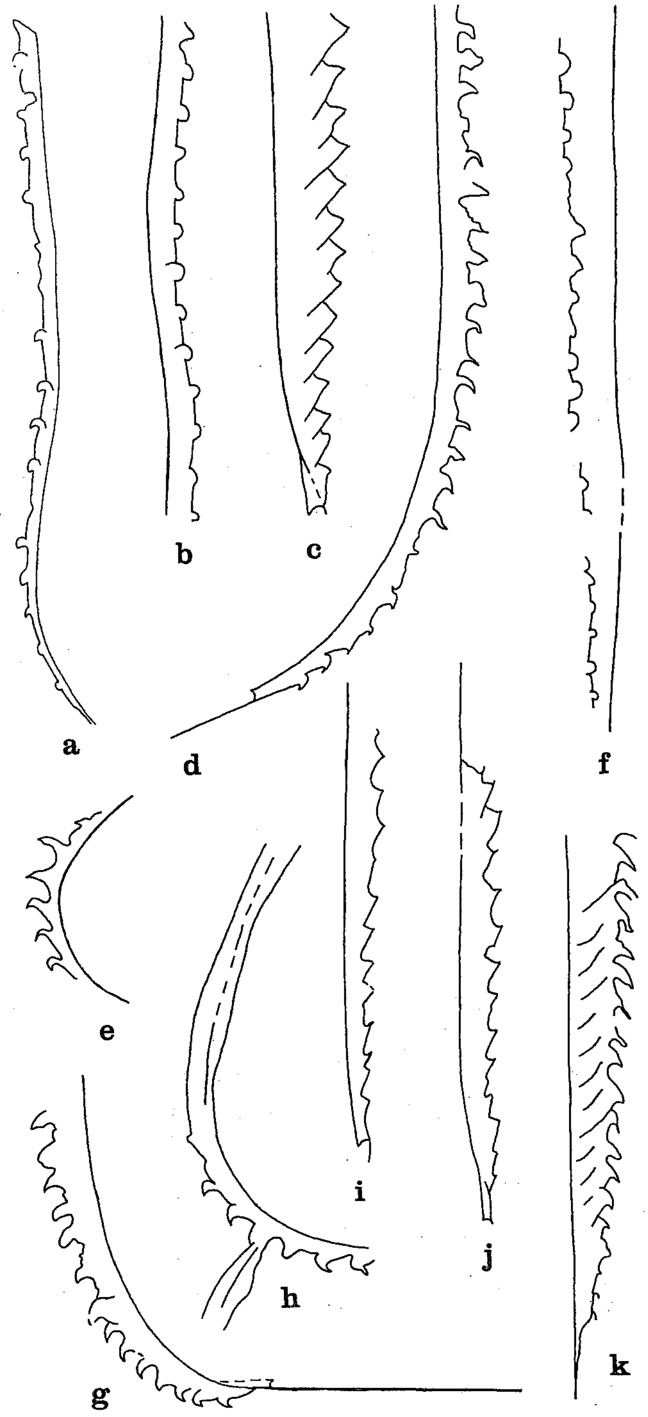
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