

The *messaoudensis*–*trifidum* acritarch assemblage and correlation of the base of Ordovician Stage 2 (Floian)

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Abstract – The Global Stratotype Section and Point (GSSP) for Stage 2 of the Ordovician System, now the Floian Stage and approximately equivalent to the lower and middle Arenig of England and Wales, is defined by the first appearance datum (FAD) of the graptolite *Tetragraptus approximatus* in the Diabasbrottet Quarry section at Mount Hunneberg, Sweden. One of the issues this raises is how to correlate the base of Stage 2 at the GSSP with areas and successions that do not contain a correlative graptolite fauna. The distinctive *Cymatiogalea messaoudensis*–*Stelliferidium trifidum* acritarch assemblage is present in the upper Tremadocian *Araneograptus murrayi* Graptolite Biozone of NW England and ranges across the Tremadocian–Stage 2 boundary there (the Tremadoc–Arenig boundary of Anglo-Welsh nomenclature). It also occurs widely at other high southern Ordovician palaeolatitudes around the margin of Gondwana, being reported from Ireland, Wales, the Isle of Man, Belgium, Germany, Spain and Turkey, and may also be present in Bohemia and Argentina (Eastern Cordillera). It therefore has the potential to contribute towards the recognition and correlation of the base of Stage 2 in those areas. Of particular interest are the First Appearance Datums of various taxa within the stratigraphical range of the *messaoudensis*–*trifidum* assemblage, notably that of *Aureotesta clathrata simplex*, which is considered to be close to the base of Stage 2 in NW England.

Elements of the *messaoudensis*–*trifidum* assemblage also occur in Baltica, the palaeoplate on which the GSSP for the base of Stage 2 is located. However, many of the taxa used to subdivide the *messaoudensis*–*trifidum* assemblage around Gondwana have not been recorded from Baltica and may be restricted palaeobiogeographically to the Gondwanan margin. Furthermore, acritarch microfloras have not been reported from the Diabasbrottet Quarry section itself, and there are hiatuses across the base of Stage 2 in the two sections from Baltica considered in this paper. Hence, direct correlation of the base of Stage 2 between the GSSP and other sections using acritarchs is not yet possible. Nevertheless, some taxa, for example the genera *Peteinosphaeridium* and *Rhopaliophora*, are shown to have FADs at similar stratigraphical levels in the late Tremadocian Stage of both Baltica and Gondwana, and therefore have the potential to correlate time slices in the late Tremadocian Stage between palaeoplates.

Keywords: acritarchs, stratigraphic correlation, Lower Ordovician, Tremadocian–Floian boundary.

1. Introduction

The *Cymatiogalea messaoudensis*–*Stelliferidium trifidum* acritarch assemblage comprises a distinctive association of species that was first described from the Lower Ordovician Series of NW England (Molyneux & Rushton, 1988). Since then, the assemblage has been reported from localities in Ireland, Wales, the Isle of Man, Belgium, Rügen (Germany), Spain and Turkey, and there are indications that it might also be present in Bohemia and the Eastern Cordillera of Argentina. Furthermore, taxa of the *messaoudensis*–*trifidum* assemblage have been recorded from Lower Ordovician sections of Baltica. The assemblage is

characteristically a cold-water, southern hemisphere assemblage, with most records from high latitudes (>60° S) around the southern margin of Gondwana (Fig. 1). Occurrences of characteristic species in Baltica are also at relatively high southern latitudes according to the palaeogeographical reconstruction shown in Figure 1.

Graptolite evidence shows that the lower part of the *messaoudensis*–*trifidum* assemblage in NW England is in the late Tremadocian *Araneograptus murrayi* Graptolite Biozone, and that its highest occurrences are in the early Arenig *Tetragraptus phyllograptoides* Graptolite Biozone. The stratigraphical range of the assemblage therefore spans the Tremadocian–Stage 2 boundary in the global chronostratigraphical scheme being developed for the Ordovician System (Fig. 2).

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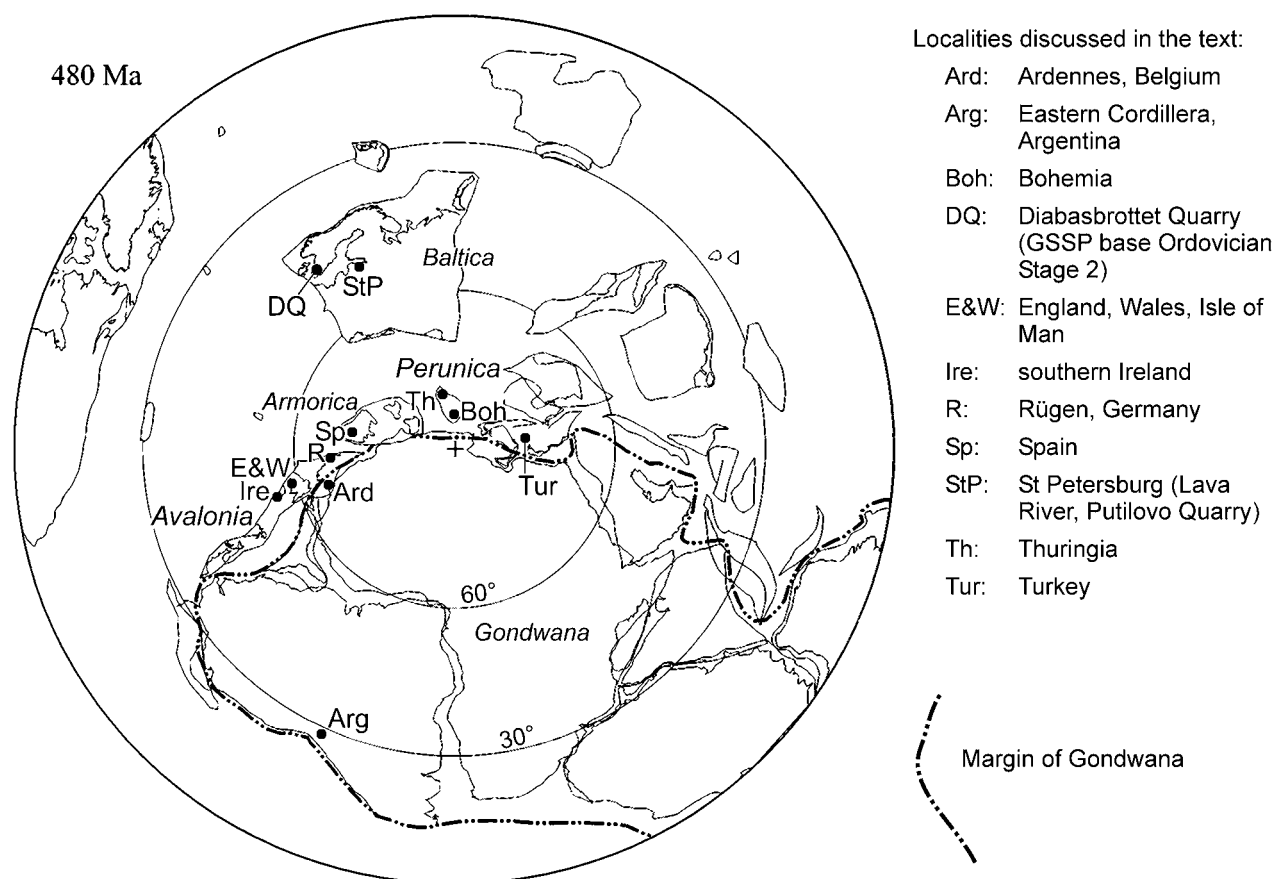


Figure 1. Early Ordovician palaeogeography, after Cocks & Torsvik (2002, fig. 1), showing the distribution of the *messauoudensis-trifidum* assemblages discussed in the text.

Ma	Global Series & Stages	Regional Divisions			Time Slices	Graptolite Biozones		Conodont Biozones	Chitinozoan Biozones
		N. Amer.	British	Baltic		England & Wales	Baltoscandia	N. Atlantic	N. Gondwana
471.8	Lower Ordovician	Tremadocian	Ibexian	Tremadoc	2c	<i>simulans</i> (part)	<i>elongatus</i>	<i>evae</i>	<i>brevis</i>
						<i>varicosus</i>	<i>densus</i>		
					2b	?	<i>balticus</i>	<i>elegans</i>	<i>baculata</i>
					2a	<i>phyllograptoides</i>	<i>phyllograptoides</i>	<i>elongatus-deltatus</i>	<i>symmetrica</i>
478.6					1d	<i>murrayi</i>	<i>copiosus</i>	<i>proteus</i>	<i>conifundus</i>
					1c		<i>murrayi</i>	<i>gracilis</i>	
					1b	?	<i>supremus</i>	<i>Tripodus</i>	
					1a	<i>tenellus</i>	<i>honnebergensis</i>	<i>amoenus</i>	?
								<i>deltifer</i>	
488.3						<i>flabelliformis</i> s.l.	<i>socialis/flabelliformis/desmograptoides/parabola</i>	<i>angulatus</i>	<i>destombesii</i>

Figure 2. Correlation of Lower Ordovician chronostratigraphy, time slices, and graptolite, conodont and chitinozoan zonation. After Webby *et al.* (2004). Time scale is GTS2004 (Gradstein *et al.* 2004).

The Global Stratotype Section and Point (GSSP) for Stage 2 (Floian), recently ratified by the International Union of Geological Sciences, is defined by the First Appearance Datum (FAD) of the graptolite *Tetragraptus approximatus* in the Diabasbrottet Quarry section at Mount Hunneberg, Sweden, which also correlates with the base of the *phyllograptoides* Biozone. One of the issues this raises is how to correlate the base of Ordovician Stage 2 at the GSSP with areas and successions that do not contain a correlative graptolite fauna. Acritarch biostratigraphy has not figured prominently in the development of Ordovician chronostratigraphy at a global scale, unlike graptolite, conodont and latterly chitinozoan biostratigraphical schemes. Nevertheless, the stratigraphical range of the *messaoudensis*–*trifidum* assemblage clearly raises the possibility that it can contribute towards correlation of the base of Stage 2.

The aims of this paper are: (1) to review occurrences of the *messaoudensis*–*trifidum* assemblage around the margin of Gondwana, particularly its correlation with the graptolite zonal scheme and/or zonal schemes of other biostratigraphically useful groups such as chitinozoa and conodonts; (2) to compare and contrast the peri-Gondwanan *messaoudensis*–*trifidum* assemblage with contemporaneous assemblages from Baltica, and therefore with assemblages from the same palaeogeographical region as the GSSP; (3) to identify key taxa with First Appearance Datums (FADs) that might be used to correlate time slices in the Tremadocian Stage and the base of Stage 2 around the margin of Gondwana and between Gondwana and Baltica.

2. Occurrences of the *messaoudensis*–*trifidum* assemblage around the margin of Gondwana

2.a. England, Wales, Isle of Man

Recognition of the distinctive *messaoudensis*–*trifidum* acritarch assemblage dates from Molyneux & Rushton's (1988) description of the acritarch microflora from the Watch Hill Formation in the Skiddaw Group of the Lake District, NW England. Subsequent work has established that the *messaoudensis*–*trifidum* assemblage occurs in the Bitter Beck Formation, Watch Hill Formation and the lower part of the Hope Beck Formation, which comprise a succession of muddy, silty and sandy turbidites with a total thickness of approximately 1700 m in the northern Lake District (Fig. 3). The acritarch assemblage defines the *Cymatiogalea messaoudensis*–*Stelliferidium trifidum* Assemblage Biozone (Cooper *et al.* 2004).

Previously referred to as the *trifidum* microflora by Fortey *et al.* (1991), the *messaoudensis*–*trifidum* assemblage is characterized by a number of acritarch species, including *Acanthodiacrodium? dilatatum*, *Cal-dariola glabra* s.l., *Cymatiogalea deunffii*, *C. mes-*

saoudensis, *Stellechinatum sicaforme*, *Stelliferidium trifidum* and *Vavrdovella areniga* s.l.. However, the incoming of additional taxa upwards through the succession enabled Cooper *et al.* (2004) to divide the *messaoudensis*–*trifidum* assemblage into five sub-assemblages (Fig. 3). The generalized vertical section shown in Figure 3 is based on a traverse northwards from Bitter Beck [British National Grid Reference NY 1650 3096], in the type area of the Bitter Beck Formation, to Jonah's Gill [NY 1904 3420], where the contact between the Hope Beck Formation and the overlying Loweswater Formation is exposed.

The lowest subdivision of the *messaoudensis*–*trifidum* assemblage occurs in the Bitter Beck Formation. Specimens of the genus *Striatotheca* and *Veryhachium lairdii*, taxa that are not known from older Tremadocian assemblages, are present at the base of the sampled section (Fig. 3). The FADs of the genera *Peteinosphaeridium* and *Rhopaliophora* near the base of the Watch Hill Formation mark the base of the second subdivision of the *messaoudensis*–*trifidum* assemblage. Other important FADs (Fig. 3) are those of *Veryhachium trispinosum*, at a level just above the base of sub-assemblage 3 in the lower part of the Watch Hill Formation; the genus *Coryphidium*, just below the base of sub-assemblage 4 in the upper part of the Watch Hill Formation; *Coryphidium* aff. *elegans* at the base of sub-assemblage 4; *Aureotesta clathrata simplex*, represented by rare and poorly preserved specimens at the base of sub-assemblage 5; and *Arbusculidium filamentosum* from outcrops estimated to be about 240 m above the base of the Hope Beck Formation on the River Derwent [NY 1429 3319], in an assemblage assigned to sub-assemblage 5.

As the lower four divisions of the *messaoudensis*–*trifidum* assemblage in the Skiddaw Group are based on microfloras from the Bitter Beck and Watch Hill formations (Fig. 3), they correlate with the *Araneograptus murrayi* Biozone, which extends through the Bitter Beck and Watch Hill formations and into the base of the Hope Beck Formation (Cooper *et al.* 2004, p. 12, fig. 6). The upper part of the *murrayi* Biozone in the Skiddaw Group might include equivalents of the *Hunnegraptus copiosus* Biozone of Scandinavia; *Araneograptus murrayi* ranges through both the *murrayi* and *copiosus* biozones there (Lindholm, 1991).

Correlation of the highest subdivision of the *messaoudensis*–*trifidum* assemblage with the graptolite zonation is more problematical. Based on the occurrence of *Acanthodiacrodium* aff. *angustum* and poorly preserved specimens of probable *Aureotesta clathrata simplex*, Cooper *et al.* (2004) placed the base of sub-assemblage 5 about 90 m above the base of the Hope Beck Formation north of Watch Hill in the traverse from Bitter Beck to Jonah's Gill (Fig. 3, sample MPA 28692). The highest occurrence of *A. murrayi* is estimated to be about 30 m above the base of the Hope Beck Formation at Trusmadoor [NY 2782 3360], and the

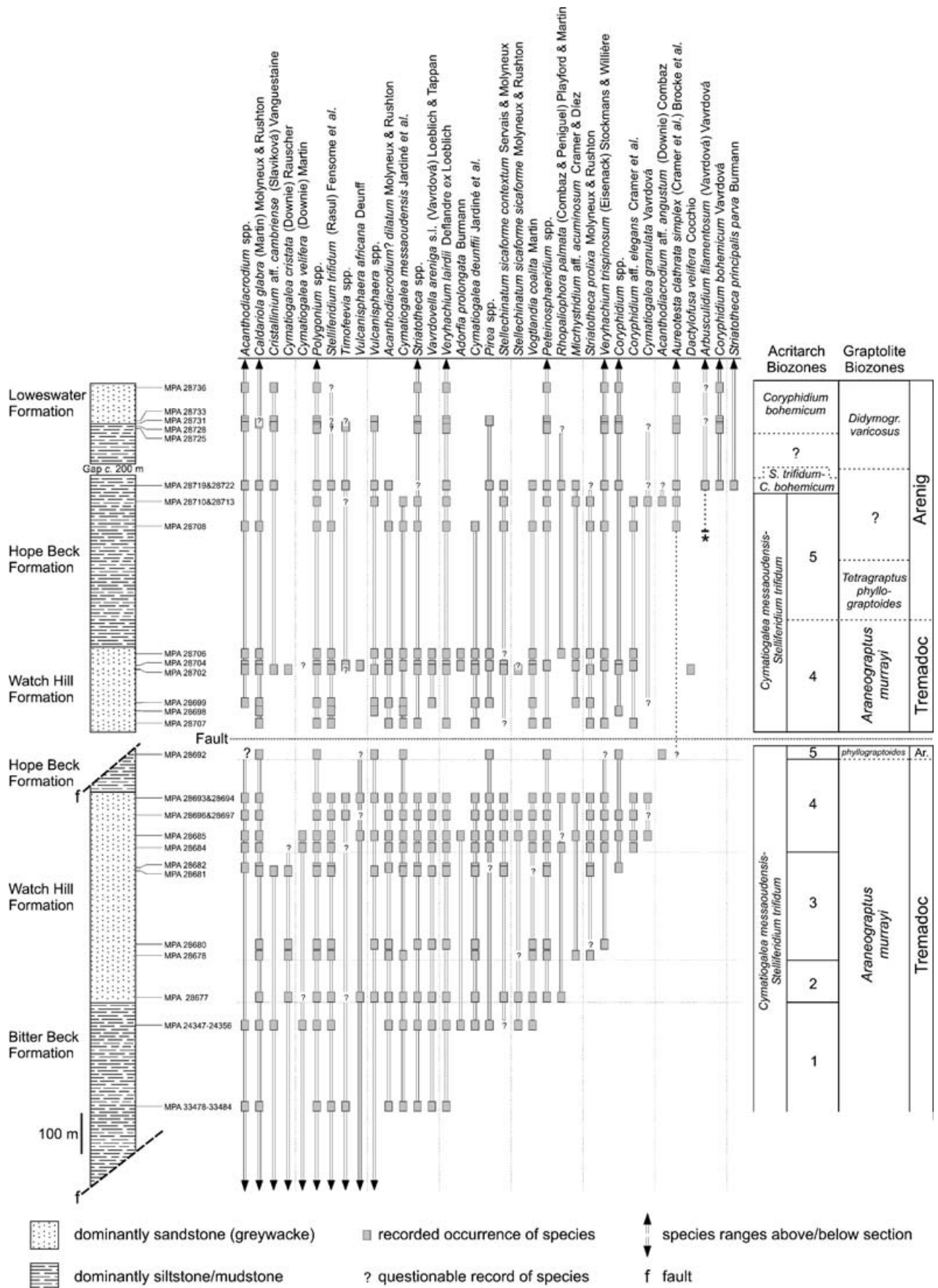


Figure 3. Ranges of acritarch taxa in the *messaoudensis-trifidum* assemblage across the Tremadocian–Stage 2 (Tremadoc–Arenig) boundary in the Skiddaw Group of NW England. Numbers 1–5 in the acritarch biozone column indicate the stratigraphical extent of *messaoudensis-trifidum* sub-assemblages 1–5 respectively. *See text (Section 2.a) for explanation of the FAD of *Arbusculidium filamentosum*.

base of the succeeding *Tetragraptus phyllograptoides* Biozone is suggested to be about 100 m above the base of the Hope Beck Formation in the same section, based on an indicative but non-diagnostic graptolite fauna (Cooper *et al.* 2004, fig. 6). A sampling gap separates these two faunas. The lowest microflora assigned to sub-assemblage 5 is therefore stratigraphically close to the lowest fauna indicative of the *phyllograptoides* Biozone in the lower Hope Beck Formation, although not in the same section. Hence, the base of sub-assemblage 5 is tentatively correlated with the base of the *phyllograptoides* Biozone in Figures 3 and 4.

Correlation between the graptolite zonation and the highest microflora assigned to sub-assemblage 5 (and therefore the highest *messaoudensis–trifidum* microflora) is also imprecise. Graptolite faunas collected about 170 m above the base of the Hope Beck Formation at Trusmadoor and about 210 m above the base of the formation in Burn Tod Gill [NY 2795 3339] definitely indicate the *phyllograptoides* Biozone (Cooper *et al.* 2004, fig. 6), and a microflora assigned to sub-assemblage 5 occurs in close proximity to the *phyllograptoides* Biozone locality in Burn Tod Gill [c. NY 2797 3340]. However, the lowest faunas of the overlying *Didymograptus varicosus* Biozone occur about 200 m below the top of the Hope Beck Formation. Given the estimated thickness of the Hope Beck Formation in the northern Lake District (600–800 m), this means that there is perhaps as much as 400 m in the middle of the formation from which zonally diagnostic graptolite faunas have not been recorded (Cooper *et al.* 2004). The highest microfloras assigned to sub-assemblage 5 (Fig. 3, samples MPA 28710, 28713) are estimated to be about 340 m above the base of the Hope Beck Formation and are therefore likely to fall within this gap in the graptolite succession.

There is little doubt that some part of the *messaoudensis–trifidum* sub-assemblage 5 in the Lake District correlates with the *phyllograptoides* Biozone, given the presence of both in the lower part of the Hope Beck Formation and the close association of the acritarch assemblage and graptolite fauna at Burn Tod Gill. Less certain is correlation of the lower and upper extent of sub-assemblage 5 with the graptolite zonation. The base is tentatively correlated with the base of the *phyllograptoides* Biozone, but could equally lie in the lower part of the *phyllograptoides* Biozone or towards the top of the *murrayi* Biozone. Correlation between the highest assemblages assigned to sub-assemblage 5 and the graptolite zonation is also uncertain, as discussed above.

Apart from the northern Lake District, other occurrences of the *messaoudensis–trifidum* assemblage in Britain are from the Skiddaw Group of the Cross Fell Inlier (Cooper & Molyneux, 1990), from the Manx Group of the Isle of Man, which is equivalent to the Skiddaw Group in terms of age and facies (Molyneux 1999; Molyneux *in* Chadwick *et al.* 2001), and from

S Wales (Molyneux & Dorning, 1989). The successions at Cross Fell and on the Isle of Man are along strike from the Lake District. In the Cross Fell Inlier, the *messaoudensis–trifidum* assemblage occurs in the Catterpallot Formation; some of the samples studied by Cooper & Molyneux (1990) yielded microfloras that suggest sub-assemblage 4. On the Isle of Man, microfloras from the Lonan and Glen Dhoo formations of the Manx Group are similar to those from the upper part of the *messaoudensis–trifidum* assemblage or slightly higher in the Skiddaw Group (Molyneux, 1999; Molyneux *in* Chadwick *et al.* 2001). The record of the *messaoudensis–trifidum* assemblage in S Wales is from fine sandstones and thin interbedded shales ('Login Beds') that underlie the basal Arenig Allt Cystanog Member of the Ogof Hên Formation (Molyneux & Dorning, 1989). All of these occurrences are south of the Iapetus Suture, and are therefore Avalonian, but none is associated with graptolite or other faunas that enable correlation with other zonal schemes.

2.b. Ireland

An acritarch assemblage that is closely comparable with the *messaoudensis–trifidum* assemblage of NW England has been recorded from the Illaunglass Member of the Annascaul Formation, Dingle Peninsula, SW Ireland (Connery & Higgs, 1999; Todd *et al.* 2000). The assemblage is diverse, with 24 taxa recorded, and contains a number of characteristic forms, including *Acanthodiacrodium? dilatatum*, *Caldariola glabra*, *Coryphidium* spp. including *C. aff. elegans*, *Cymatiogalea deunffii*, *C. messaoudensis*, *Stelliferidium trifidum* and *Vavrdovella areniga*.

There is no independent evidence of age, but comparison with the acritarch succession in the Skiddaw Group suggests correlation with sub-assemblage 4 of the *messaoudensis–trifidum* assemblage in NW England. *Coryphidium* aff. *elegans* appears at the base of sub-assemblage 4 there and ranges to the top of sub-assemblage 5, but *Cymatiogalea cristata*, also recorded from the Illaunglass Member, does not range above sub-assemblage 4. This also implies correlation with the latest Tremadocian Stage, and probably with time slice 1d (Fig. 4).

The Bealacoon Member of the Annascaul Formation, immediately overlying the Illaunglass Member, yielded an acritarch assemblage of lower diversity with 13 taxa, only five of which range up from the Illaunglass Member. Of the remaining eight taxa, four are determined to genera only (Connery & Higgs, 1999; Todd *et al.* 2000). The most significant difference between the Illaunglass and Bealacoon assemblages is the incoming of *Coryphidium bohemicum* in the latter. The association of *C. bohemicum* with *Stelliferidium trifidum* in the Bealacoon Member suggests correlation with the *trifidum–bohemicum* Biozone, which overlies the *messaoudensis–trifidum* Biozone in NW England

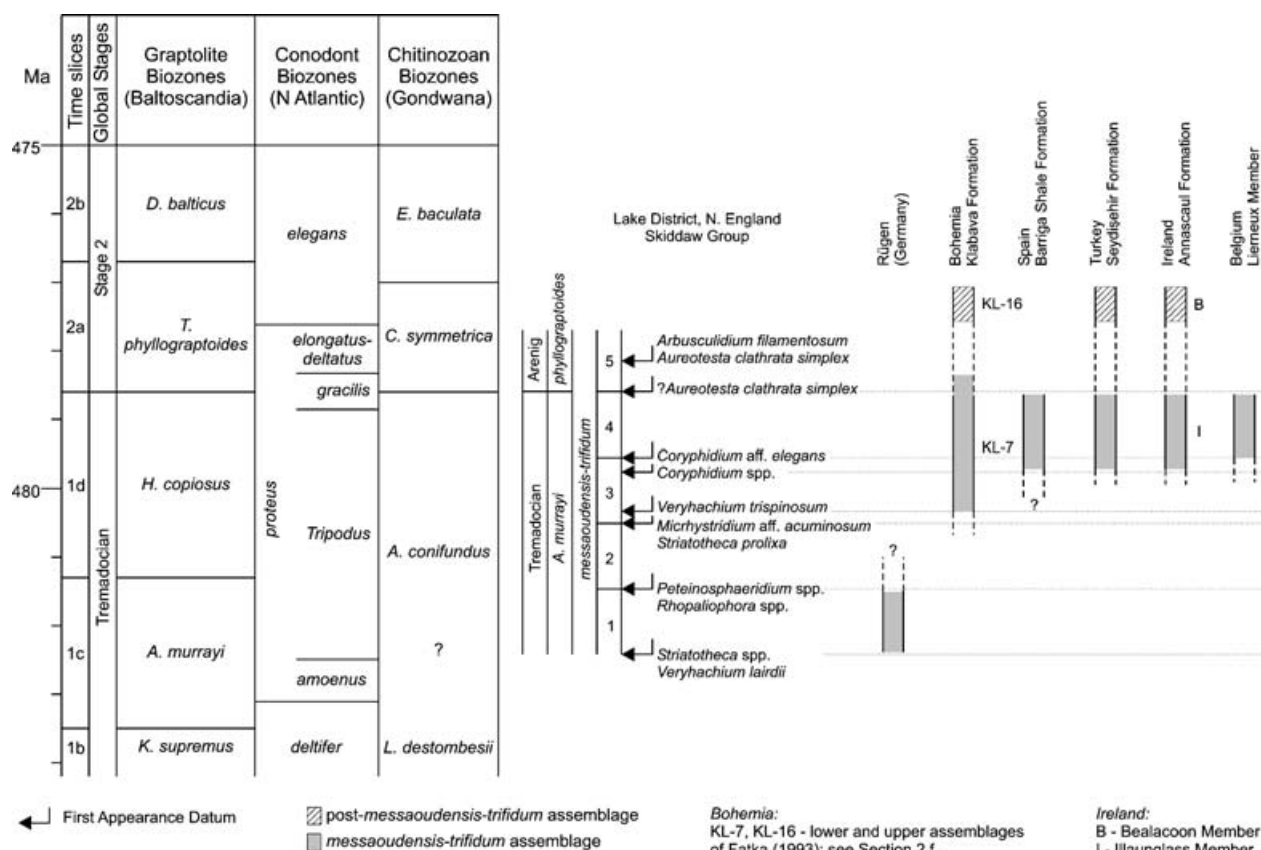


Figure 4. FADs of selected acritarch taxa in the Skiddaw Group of NW England, and correlation of other occurrences of the *messaoudensis-trifidum* assemblage around the margin of Gondwana. Time slices, global stages and biozones are from Webby *et al.* (2004). Time scale is GTS2004 (Gradstein *et al.* 2004).

(Fig. 3). There, the *trifidum-bohemicum* Biozone is placed at a level in the Hope Beck Formation above the highest *phyllograptoides* Biozone graptolite faunas, but below the lowest *varicosus* Biozone faunas, which in turn suggests correlation with the lower part of time slice 2b or possibly the upper part of 2a. *Cymatiogalea messaoudensis* is missing from the Bealacoen assemblage, as it is from the *trifidum-bohemicum* Biozone in NW England.

2.c. Belgium

Acritarch microfloras containing many of the characteristic taxa of the *messaoudensis-trifidum* assemblage have been reported from the upper part of the Lierneux Member, at the top of the Jalhay Formation (Salm Group) in the Stavelot Inlier of the Belgian Ardennes (Vanguetaine & Servais, 2002; Breuer & Vanguetaine, 2004). Species recorded include *Acanthodiacrodium?* *dilatatum*, *Caldariola glabra*, *Stellechinatum sicaforme sicaforme*, *Stelliferidium trifidum*, *Striatotheca prolixa* and *Vavrdovella areniga*. *Cymatiogalea messaoudensis* was not recorded by Breuer & Vanguetaine (2004), although Vanguetaine & Servais (2002) had previously recorded *?Cymatiogalea messaoudensis inconnexa*.

The acritarch assemblage from the Lierneux Member is closest to sub-assemblage 4 of NW England. Breuer & Vanguetaine (2004) recorded *Cymatiogalea cristata*, *C. velifera*, *Dactylofusa velifera* and *Stellechinatum sicaforme sicaforme*, none of which ranges above sub-assemblage 4 in the Skiddaw Group. Furthermore, the specimens of *Coryphidium* figured by Breuer & Vanguetaine (2004, pl. 1, figs 11, figs 12) resemble *C. aff. elegans* from the Skiddaw Group, which has its first appearance at the base of sub-assemblage 4. There is no direct independent evidence for the age of the Lierneux Member, but the underlying part of the Jalhay Formation is dated as early Tremadocian in age by the graptolite *Rhabdinopora flabelliformis* (Breuer & Vanguetaine, 2004), and conodonts from the Ottré Formation, immediately above the Lierneux Member, indicate a late Tremadocian age (Oliver Lehnert, pers. comm.).

Interestingly, Breuer & Vanguetaine (2004) also recorded *Athabascaella playfordii* from the Lierneux Member. Previously, this acritarch species had been regarded as characteristic of low to middle latitudes, being recorded from assemblages across the Tremadocian–Stage 2 boundary in Laurentia, Baltica and China (Servais *et al.* 2003). The record from Belgium also indicates a Gondwanan occurrence

that might aid in correlating Tremadocian–Stage 2 successions between palaeoplates.

2.d. Germany

The *messaoudensis*–*trifidum* assemblage, recorded from core at depths of 3615.80 to 3835.30 m in the Rügen 5 borehole, on the island of Rügen off the northern Baltic coast of Germany, was first documented by Servais & Katzung (1993) and subsequently described in more detail by Servais & Molyneux (1997).

The assemblage from Rügen comprises 30 acritarch species, 13 of which also occur in the Skiddaw Group. None of the latter has a restricted range in NW England, the shortest ranges being from sub-assemblage 1 to 4 (*Stellechinatum sicaforme sicaforme*, *Vavrdovella areniga* s.l., *Vulcanisphaera africana*). However, chitinozoa from the same depths in Rügen 5 are reported to indicate the middle Tremadocian *Lagenochitina destombesii* Biozone (Samuelsson, Verniers & Vecoli, 2000; Servais *et al.* 2001) (Figs 2, 4), suggesting that the Rügen microflora is from a level that correlates with the lower part of the *messaoudensis*–*trifidum* assemblage interval in NW England. In this context, the absence of the genera *Peteinosphaeridium*, *Rhopaliophora* and *Coryphidium* from the Rügen assemblage is notable, and is consistent with the assemblage being from a low level in the *messaoudensis*–*trifidum* interval, possibly equivalent to sub-assemblage 1 (Fig. 4).

Acritarch assemblages recorded by Heuse, Erdtmann & Kraft (1994) from the Phycodenschiefer (Phycodes Group) of the Schwarzburg Anticline, Thuringia, are associated with ?*Araneograptus* cf. *murrayi*, but have very limited similarity to the *messaoudensis*–*trifidum* assemblage. In part, this may be due to the low diversity and low abundance of the acritarch microfloras. Even so, none of the characteristic *messaoudensis*–*trifidum* taxa are present apart from *Caldariola glabra* (including *C. glabra annulifera*), recorded from the upper part of the Phycodenschiefer (Obere Lauschensteinschichten).

Ahrendt *et al.* (2001) also reported possible elements of the *messaoudensis*–*trifidum* assemblage, including *Caldariola glabra*, *Cymatiogalea* sp. cf. *C. messaoudensis*, *Stelliferidium* sp. cf. *S. trifidum* and *Vavrdovella* cf. *areniga*, in clasts from a late Middle Devonian conglomerate in the subsurface of the northwestern Rheinischen Schiefergebirges near Krefeld, NW Germany. The provenance of the clasts is unknown, but Ahrendt *et al.* (2001) thought it unlikely that they had been transported far and postulated an eastward extension of the Brabant Massif into western Germany as a possible source.

2.e. Spain

The *messaoudensis*–*trifidum* assemblage is fully developed in the Barriga Shale Formation of Huelva

Province, SW Spain (Mette, 1989; Servais & Mette, 2000), where it is very similar in composition to the assemblage described from NW England. Graptolites recorded from the same stratigraphical interval in the Barriga Formation comprise two successive faunas, a lower fauna with *Araneograptus murrayi* and an upper fauna with *Hunnegraptus* aff. *copiosus*. The graptolite faunas were reported in Servais & Mette (2000) to indicate the *murrayi* Biozone, or the *murrayi* Biozone plus perhaps the lower part of the *copiosus* Biozone.

Specimens of *Coryphidium* sp., *Peteinosphaeridium* spp., *Rhopaliophora palmata*, *Striatotheca* spp. and *Veryhachium lairdii* have all been recorded from the Barriga Shale, and all are present at the base of the sampled section. Based on the FADs of these taxa in NW England, the presence of *Coryphidium* suggests correlation with the upper part of the *messaoudensis*–*trifidum* assemblage (top sub-assemblage 3 and above) and the other taxa are consistent with this interpretation (Fig. 4). Combining the acritarch evidence with the graptolite data suggests a latest Tremadocian age for the Barriga Shale, probably equivalent to time slice 1d (Fig. 4).

2.f. Bohemia

Fatka (1993) described acritarch assemblages from two levels in the lower part of the Klabava Formation of the Prague Basin. The lower assemblage comprises 20 acritarch taxa, only 10 of which have been recorded from the English Lake District, including *Caldariola glabra*, *Cymatiogalea messaoudensis*, *Peteinosphaeridium* sp., *Rhopaliophora palmata*, *Stelliferidium* cf. *trifidum*, *Vavrdovella areniga*, *Veryhachium lairdii* and *V. trispinosum*. Comparison with the *messaoudensis*–*trifidum* assemblage of NW England is limited. Nevertheless, the association of *Veryhachium trispinosum* with *Cymatiogalea messaoudensis* suggests correlation with the upper part of the *messaoudensis*–*trifidum* interval (sub-assemblages 3–5; Fig. 4), a conclusion that is supported by the association of the chitinozoan *Amphorachitina conifundus* with this lower assemblage. *Amphorachitina conifundus*, which occurs here in a monospecific chitinozoan microfauna, suggests either a latest Tremadocian age (*murrayi* or *copiosus* biozones) or possibly correlation with the lower part of the *phyllograptoides* Biozone (Paris, 1990), probably equivalent to time slice 1d or the lowest part of time slice 2a (Fig. 2).

The higher acritarch assemblage described by Fatka (1993) is associated with the chitinozoan *Conochitina symmetrica*, the index species for the *symmetrica* Biozone. This biozone is correlated with the *phyllograptoides* Biozone and time slice 2a at the base of Stage 2 (Fig. 2). However, the acritarch assemblage lacks *Cymatiogalea messaoudensis* and *Stelliferidium* cf. *trifidum*, and has very little in common with the *messaoudensis*–*trifidum* assemblage of the English

Lake District. Of the 11 taxa recorded by Fatka (1993), only five have been recorded from the Lake District: *Acanthodiacrodium* spp., *Caldariola glabra*, *Peteinosphaeridium* spp., *Veryhachium lairdii* and *V. trispinosum*. Either the Bohemian assemblage is not typical of the *messauoudensis*–*trifidum* microflora or else this is a post-*messauoudensis*–*trifidum* microflora (Fig. 4).

2.g. Turkey

Dean & Martin (1992) recorded two acritarch assemblages that they thought might be latest Tremadocian to earliest Arenig in age, although independent evidence of age was lacking. Martin (1996) provided further information on the two assemblages. Based on data from both papers, the acritarch microflora from the Seydişehir Formation on the E bank of the River Zap near Şort Tepe in SE Turkey contains *Acanthodiacrodium*? *dilatatum*, *Caldariola glabra*, *Coryphidium* spp., *Cymatiogalea deunffii*, *C. messauoudensis*, *Dactylofusa velifera*, *Peteinosphaeridium* spp., *Vavrdovella areniga cumbriensis* and *Vavrdovella*–*Coryphidium* transients. A similar assemblage, from the Bağbaşı section N of Hadim in the central Taurides, and also from the Seydişehir Formation, contains *A.*? *dilatatum*, *C. glabra*, *Coryphidium elegans*, *Cymatiogalea messauoudensis*, *D. velifera*, *Peteinosphaeridium* spp., *Stelliferidium* aff. *trifidum* and *V. areniga cumbriensis*. Servais & Molyneux (1997) considered the specimens of *Stelliferidium* aff. *trifidum* recorded by Martin (1996) from the Hadim area to be synonymous with *S. trifidum*. The microfloras from both localities are characteristic of the *messauoudensis*–*trifidum* assemblage, and the presence of *Coryphidium* and *Vavrdovella areniga cumbriensis* in both suggests correlation with the interval from the upper part of sub-assemblage 3 to sub-assemblage 4 in NW England (Fig. 4); the latter subspecies of *V. areniga* has not been recorded above sub-assemblage 4 there (Cooper *et al.* 2004, figs 14, figs 15), and *Coryphidium* appears just below the top of sub-assemblage 3 (Fig. 3).

Higher in the Seydişehir Formation of the Taurus Mountains, S of Saimbeyli, Dean & Martin (1992) reported *Arbusculidium filamentosum*, *Aureotesta clathrata* and *Striatotheca principalis parva* Burmann 1970 in post *messauoudensis*–*trifidum* microfloras from a level dated as early Arenig on trilobite evidence (Fig. 4).

2.h. Argentina

The definite presence of a fully developed *messauoudensis*–*trifidum* assemblage in Argentina has not yet been demonstrated. The possibility that it might be present is inferred from the record of *Cymatiogalea messauoudensis messauoudensis* in the Acoite Formation of the Rio La Huerta and Quebrada Grande sections

of the Santa Victoria area, in the Eastern Cordillera of NW Argentina (Rubinstein, Toro & Waisfeld, 1999; Rubinstein & Toro, 1999, 2001). There are also indications, although not yet fully documented, that the *messauoudensis*–*trifidum* assemblage might be present in the upper Tremadocian succession near Parcha, some 260 km SSW of Santa Victoria, also in the Eastern Cordillera (Rubinstein, 2003), where it is associated with *Araneograptus murrayi*. Palaeogeographically, these occurrences are situated on the margin of Gondwana (Fig. 1). Two significant differences between the Argentinian records and other records of the *messauoudensis*–*trifidum* assemblage are that Argentina was at low palaeolatitudes (Fig. 1), and that *C. messauoudensis* itself might range higher in Argentina than at higher palaeolatitudes, ranging to the top of the Lower Ordovician Series (time slice 2c; see below).

The Rio La Huerta and nearby Rio Acoite sections of the Santa Victoria area both expose the Santa Rosita Formation overlain conformably by the Acoite Formation. The former is late Tremadocian in age, equivalent to the *Adelograptus*–*Bryograptus* graptolite association, which in turn is reported to correspond to the *Hunnegraptus copiosus* Biozone (Rubinstein, Toro & Waisfeld, 1999; Rubinstein & Toro, 2001). The Santa Rosita Formation has yielded varied and moderately well preserved acritarchs, but there is no evidence for the *messauoudensis*–*trifidum* assemblage. In many respects, the microfloras recorded from the Santa Rosita Formation in Rio La Huerta and Rio Acoite (Rubinstein, Toro & Waisfeld, 1999; Rubinstein & Toro, 2001) are more typical of pre-*messauoudensis*–*trifidum* Tremadocian assemblages, with *Cymatiogalea* spp. (*C. cristata*, *C. multarea*, *C. cuvillieri*, *C. velifera*), diacromorph acritarchs (*Acanthodiacrodium* cf. *A. spinum*, *Actinotodissus* cf. *A. achrasii*), *Stelliferidium simplex* and *Vulcanisphaera* sp.

The overlying Acoite Formation is correlated with the Lower Ordovician *Tetragraptus phyllograptoides*, *T. akzharensis*, *Baltograptus deflexus* and *Didymograptellus bifidus* graptolite biozones. In both the Rio La Huerta and Rio Acoite sections, strata of the *phyllograptoides* Biozone were either palynologically barren or yielded only sparse, low diversity, non-diagnostic assemblages (Rubinstein, Toro & Waisfeld, 1999; Rubinstein & Toro, 2001). Similarly, samples from the overlying *akzharensis* Biozone (equivalent to the lower part of time slice 2b) in both sections yielded low diversity acritarch assemblages with no taxa diagnostic of the *messauoudensis*–*trifidum* assemblage, although *Vavrdovella areniga* occurs in Rio Acoite (Rubinstein, Toro & Waisfeld, 1999, text-fig. 3, sample A3; note that the higher sample A4 from the Rio Acoite section, placed in the *akzharensis* Biozone by Rubinstein, Toro & Waisfeld, was reassigned to the overlying *deflexus* Biozone by Rubinstein & Toro, 2001). Notable first acritarch appearances in the *deflexus* Biozone (equivalent to the upper part of time

slice 2b and lower part of 2c) of the Rio La Huerta and Rio Acoite sections (Rubinstein, Toro & Waisfeld, 1999, text-fig. 3; Rubinstein & Toro, 2001) include those of *Coryphidium* sp., *Cymatiogalea granulata*, *Dactylofusa velifera brevis*, *Rhopaliophora palmata*, *Peteinosphaeridium?* sp., *Stelliferidium* cf. *trifidum* and *Striatotheca* cf. *principalis parva*. The overlying *bifidus* Biozone in the Rio La Huerta section (upper part of 2c) is characterized by increasing numbers and diversity of acritarchs, with the first appearances in that section of *Arbusculidium filamentosum*, *Aureotesta clathrata simplex* and *Cymatiogalea messaoudensis messaoudensis* (Rubinstein & Toro, 2001).

The lower part of the Acoite Formation in the nearby Quebrada Grande section, which is probably entirely within the *deflexus* Biozone (Rubinstein & Toro, 2001), yielded assemblages with *Arbusculidium filamentosum*, *Aureotesta clathrata simplex*, *Coryphidium* spp., including *C.* cf. *bohemicum*, *Cymatiogalea granulata*, *C. messaoudensis messaoudensis*, *Dactylofusa velifera brevis* and *Striatotheca* spp., including *S. principalis parva* (Rubinstein & Toro, 1999, 2001).

The association of *Arbusculidium filamentosum* and *Aureotesta clathrata simplex* with *Cymatiogalea messaoudensis messaoudensis* in the Acoite Formation of the Quebrada Grande and Rio La Huerta sections suggests correlation with the upper part of the *messaoudensis–trifidum* assemblage, possibly equivalent to sub-assemblage 5 of northern England. The graptolite control on these two sections suggests that, in Argentina at least, sub-assemblage 5 extends through most of Stage 2. In contrast, the *messaoudensis–trifidum* assemblage is absent from the *varicosus* Biozone, equivalent to upper 2b and lower 2c, in northern England, being replaced by successor acritarch assemblages (Figs 2, 3).

Rubinstein (2003) and Toro *et al.* (2003) reported that the occurrence of the *messaoudensis–trifidum* assemblage in the Parcha area had been confirmed by the presence of *Coryphidium*, *Cymatiogalea messaoudensis* and *C. deunffii* in strata ‘related to the *A. murrayi* graptolite Biozone’. Although not yet documented in detail, Toro *et al.* (2003) indicated the presence of *Acanthodiacrodium*, *Caldariola glabra glabra*, *Coryphidium*, *Cymatiogalea deunffii*, *C. messaoudensis messaoudensis* and *Stelliferidium* cf. *trifidum*.

3. FADs of selected acritarch taxa and correlation of *messaoudensis–trifidum* occurrences around Gondwana

The conclusions reached regarding the age and correlation of occurrences of the *messaoudensis–trifidum* assemblage are summarized in Figure 4, which also shows the first appearance datums (FADs) of selected acritarch taxa through the succession from the *murrayi* Biozone to the *phyllograptoides* Biozone in

the Lake District of NW England. The taxa selected include those that have been used to subdivide the *messaoudensis–trifidum* assemblage in NW England.

Striatotheca spp. and *Veryhachium lairdii* are present at the base of the sampled section in the Lake District so their FADs have not been demonstrated in NW England. However, they are unlikely to be much below the level indicated in Figure 4 as neither has been reported from older Tremadocian assemblages, either in the UK or elsewhere. Neither *Striatotheca* spp. nor *V. lairdii* was recorded, for example, from the rich and diverse acritarch assemblages reported from the Shineton Shales Formation of the Welsh Borderland by Rasul (1979), the highest samples being from the *Shumardia pusilla* Beds (*Shumardia salopiensis* Trilobite Biozone). Nor were they recorded from the acritarch assemblage associated with trilobites of the *Angelina sedgwickii* Biozone from the River Calder section in the Lake District (Molyneux & Rushton, 1984; Rushton, 1988). International correlation of the *Shumardia salopiensis* and *Angelina sedgwickii* biozones is difficult, but they post-date the *Adelograptus tenellus* Graptolite Biozone (lower part of time slice 1b) and they are regarded as belonging to the upper Tremadocian Stage.

Correlation of the other FADs shown in Figure 4 with the Ordovician time slices and zonal schemes of other fossil groups is approximate. Nevertheless, except for those of *Arbusculidium filamentosum* and *Aureotesta clathrata simplex*, all must be within the *murrayi* Biozone of NW England given their position in the lithostratigraphical succession (Figs 3, 4). The FADs of *Coryphidium* spp. and *Veryhachium trispinosum* are instrumental in interpreting the maximum ages of the *messaoudensis–trifidum* microfloras from Spain, Turkey, Ireland (Illaunglass Member) and Belgium.

The lowest occurrence of *Arbusculidium filamentosum* is in the middle Hope Beck Formation (Fig. 3) between graptolites of the *phyllograptoides* and *varicosus* biozones. The FAD of *Aureotesta clathrata simplex*, however, might be closer to the base of the *phyllograptoides* Biozone (Fig. 3). The lowest specimens, from sample MPA 28692 (Fig. 3), are poorly preserved, the determinations are probable rather than definite, and further investigation is needed to establish the exact relationship between the FAD of this species and the base of the *phyllograptoides* Biozone and Stage 2. Nevertheless, there is sufficient evidence to warrant further investigation, particularly to ascertain whether the FAD of *Aureotesta clathrata simplex* might serve as a proxy for the base of the *phyllograptoides* Biozone and the base of Stage 2 in peri-Gondwanan successions. The FADs of both *Aureotesta clathrata simplex* and *Arbusculidium filamentosum* might be useful for correlating the lower part of Stage 2 around Gondwana. In addition to NW England, both species occur in early Arenig assemblages from Turkey (Section 2.g) and Argentina

(Section 2.h), and although not recorded by Fatka (1992, 1993; see Section 2.f above), both are present in Arenig assemblages from the Klabava Formation of Bohemia (Vavrdová, 1986).

4. Equivalents of the *messaoudensis*–*trifidum* acritarch assemblage in Baltica and South China

In addition to their peri-Gondwanan occurrences, some of the characteristic taxa of the *messaoudensis*–*trifidum* assemblage have been reported from sections on the East European Platform. Raevskaya (1999) discussed the acritarch assemblages from the Leetse Formation around St Petersburg. The Leetse Formation comprises quartzose and clayey, glauconitic sandstone, with glauconitic clay and glauconitic limestone, and has yielded graptolites of the *phyllograptoides* Biozone, including *Tetraraptus phyllograptoides* and *Didymograptus rigoletto* 0.35–0.4 m above the base of the formation in the Lava River section (Tolmacheva *et al.* 2001; Raevskaya, Tongiorgi & Vecoli, 2003), and conodonts of the *Paroistodus proteus* (*Oelandodus elongatus*–*Acodus deltatus* Subzone) and *Prioniodus elegans* biozones (Tolmacheva *et al.* 2001). The formation is thus early Arenig in age (time slices 2a to 2c; Fig. 2). In the Lava River and Putilovo Quarry sections (Figs 5, 6), the Leetse Formation is unconformable on the Nazya Formation of middle Tremadocian age (Varangu Stage, *Kiaerograptus supremus* Graptolite Biozone, *Paltodus deltifer* Conodont Biozone; time slice 1b), so correlatives of the *murrayi* and *copiosus* biozones are missing.

Abundant acritarchs have been obtained from the lowest metre or so of the Leetse Formation in both the Lava River and Putilovo Quarry sections (Figs 5, 6), from strata of the *elongatus*–*deltatus* Subzone and the lower part of the *phyllograptoides* Biozone. *Caldariola glabra* and *Cymatiogalea messaoudensis inconnexa* are the most abundant species, and other taxa present include *Cymatiogalea* aff. *deunffii*, *C. messaoudensis messaoudensis* and *Stelliferidium* aff. *trifidum*. Acritarch assemblages from the Leetse Formation therefore have some elements in common with contemporaneous microfloras from the Gondwanan margin, indicating a potential for correlation between palaeoplates.

The taxa listed above range across the Tremadocian–Stage 2 boundary in the high latitude Gondwanan sections, and many of the taxa used to subdivide the *messaoudensis*–*trifidum* assemblage around the southern margin of Gondwana, notably species of *Coryphidium*, *Striatotheca*, *Aureotesta* and *Arbusculidium*, have not been recorded from Baltica. *Peteinosphaeridium*, *Rhopaliophora* and rectangular specimens of *Veryhachium* similar to *V. lairdii* have been recorded from the East European Platform, however, and in the Lava River and Putilovo Quarry sections, *Peteinosphaeridium* and *Rhopaliophora* are present with *Cymatiogalea messaoudensis* just above the

unconformable base of the Leetse Formation (Figs 5, 6). Paalits & Erdtmann (1993) indicate the FADs of *Cymatiogalea messaoudensis*, *Peteinosphaeridium* and *Rhopaliophora* to be in the lower part of the *Paroistodus proteus* Conodont Biozone on the East European Platform, at a level that correlates with either the *Hunnegraptus copiosus* or *Araneograptus murrayi* Biozone (Fig. 2). Hence, these taxa have FADs at similar stratigraphical levels in the late Tremadocian in both Baltica and Gondwana.

Work on acritarch microfloras across the Tremadocian–Stage 2 boundary in the Oslo region (Ribecai, Bruton & Tongiorgi, 1999; Tongiorgi, Bruton & Di Milia, 2003) has revealed a pattern of acritarch occurrences similar to those in sections from the East European Platform. Samples from the lower part of the Hagastrand Member of the Tøyen Formation at Bjørkåsholmen in the Oslo–Asker district yielded *Caldariola glabra*, *Cymatiogalea* cf. *deunffii*, *C. messaoudensis inconnexa* and *C. messaoudensis messaoudensis*, the last dominating the assemblages. Other taxa recorded are *Athabascaella* spp., including *A. playfordii*, *Peteinosphaeridium* spp., *Rhopaliophora pilata* and *Stelliferidium* spp. (Tongiorgi, Bruton & Di Milia, 2003). These samples are reported to be from beds that correspond to the *Hunnegraptus copiosus* Biozone and the lower part of the *Paroistodus proteus* Conodont Biozone (Tongiorgi, Bruton & Di Milia, 2003). Hence, the local FADs of *Cymatiogalea messaoudensis* and the genera *Peteinosphaeridium* and *Rhopaliophora* are in the upper Tremadocian Stage of the Oslo region, as they are on the East European Platform (Paalits & Erdtmann, 1993) and in peri-Gondwanan sections.

?*Cymatiogalea deunffii* and ?*Cymatiogalea messaoudensis* were also recorded by Ribecai, Bruton & Tongiorgi (1999) from the *Tetraraptus phyllograptoides* Biozone in the Hagastrand Member at Rortunet Nord. Furthermore, *Cymatiogalea messaoudensis messaoudensis* was reported to be common in a sample from the base of the overlying Galgeberg Member of the Tøyen Formation, of earliest Billingen, early *Prioniodus elegans* Conodont Biozone age, but has not been recorded above that level (Tongiorgi, Bruton & Di Milia, 2003). None of the other acritarch taxa that are characteristic of the *messaoudensis*–*trifidum* assemblage around the margin of Gondwana have been recorded from the Oslo region.

Similarity between the *messaoudensis*–*trifidum* assemblage and acritarch assemblages from the Tremadocian–Stage 2 boundary interval of the Yangtze Platform, SW China (Brocke, 1997) is limited. Many species of the *messaoudensis*–*trifidum* assemblage, including *C. messaoudensis* and *S. trifidum*, have not been recorded from the Chinese sections. Nevertheless, these have yielded *Vavrdovella areniga* and related forms, including specimens transitional between *Vavrdovella* and *Coryphidium*, together with

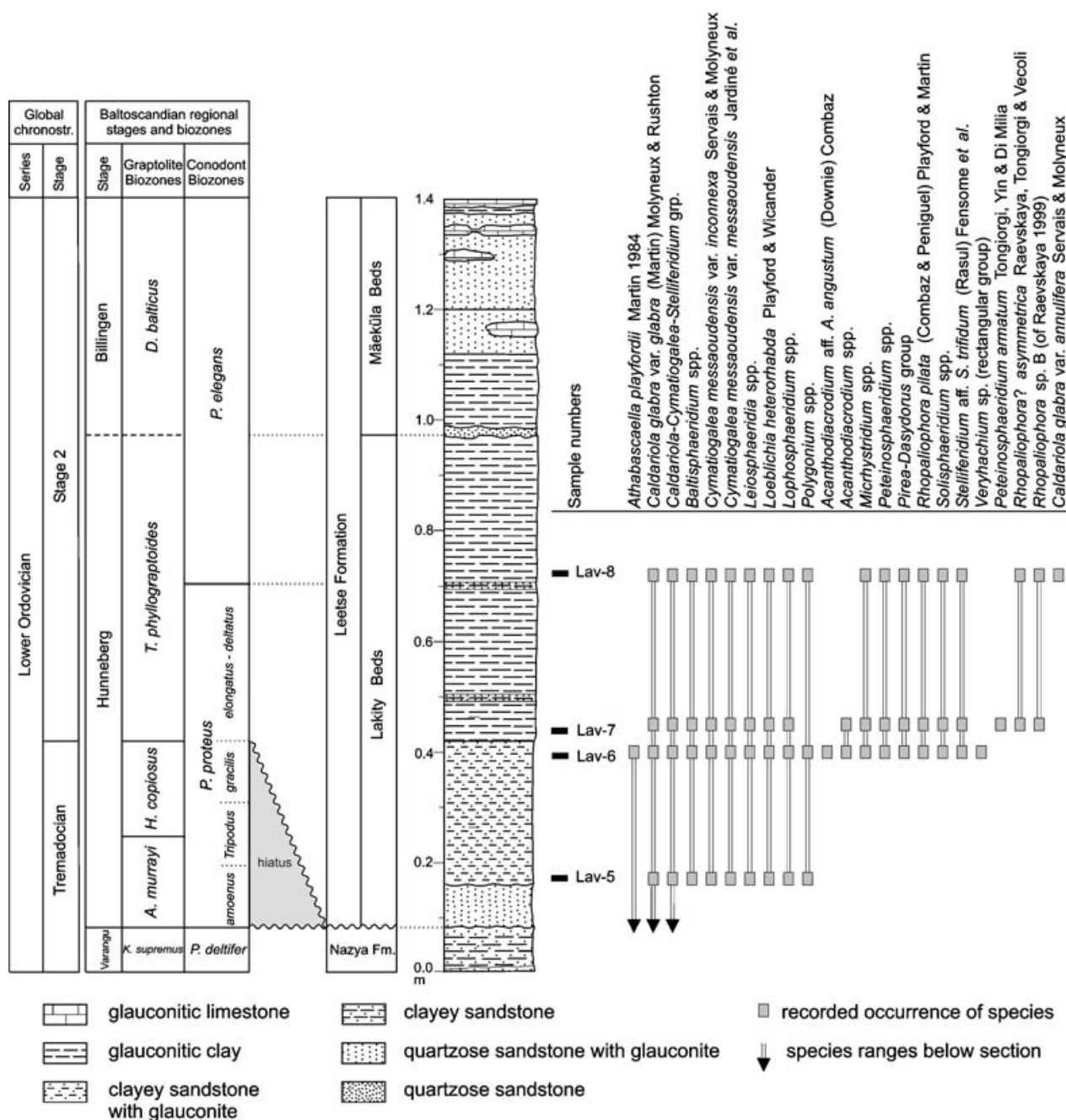


Figure 5. Ranges of acritarchs at the base of Stage 2 (Floian) in the Lava River section, St Petersburg region, Russia.

Dactylofusa velifera, species of *Rhopaliophora* and *Athabascaella playfordii*. *Dactylofusa velifera* and *Rhopaliophora pilata* appear in the upper member of the Fenghsiang Formation (*P. deltifer* Conodont Biozone; approximately time slice 1b), *Vavrdovella areniga*, *Vavrdovella-Coryphidium* transients and *Athabascaella playfordii* at a higher level in the upper member of the Fenghsiang Formation (*P. proteus* Conodont Biozone; approximately time slices 1c–1d), and *Rhopaliophora palmata* at about the base of the Hunghuayuan Formation, at about the Tremadocian–Stage 2 boundary (Brocke, 1997). *Athabascaella playfordii* also occurs in assemblages from the latest Tremadocian–Stage 2 interval in Baltica and has now

also been reported from Gondwanan assemblages in Belgium (Breuer & Vanguetaine, 2004), and so this species might be important for inter-plate correlation.

5. Conclusions

The analysis presented above confirms that the *messaoudensis*–*trifidum* acritarch assemblage occurs widely around the margin of Gondwana at high southern latitudes, and shows that it spans the Tremadocian–Stage 2 boundary in the Lake District of NW England. Furthermore, characteristic taxa of the assemblage also occur in Baltica. Acritarchs of the *messaoudensis*–*trifidum* assemblage therefore have the potential to

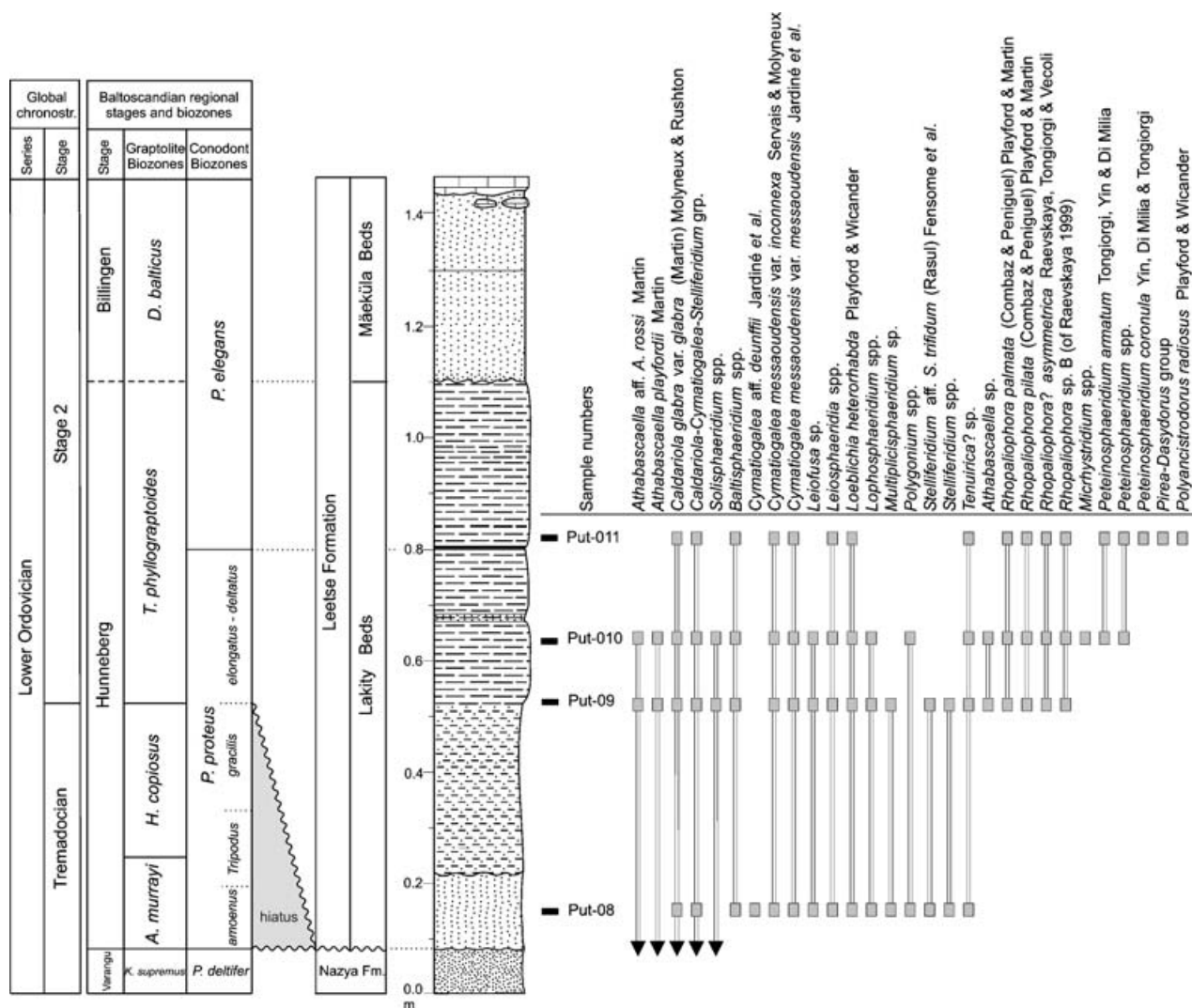


Figure 6. Ranges of acritarchs at the base of Stage 2 (Floian) in the Putilovo Quarry section, St Petersburg region, Russia. For legend see Figure 5.

contribute towards correlation of the base of Stage 2. The FAD of *Aureotesta clathrata simplex* is especially interesting in this context, given that it is interpreted as being close to the base of the *phyllograptoides* Biozone in NW England. This warrants further investigation.

In addition to the potential for acritarchs of the *messaoudensis-trifidum* assemblage to correlate the Tremadocian–Stage 2 boundary, there is also a distinct probability that acritarchs can contribute towards inter-plate correlation of late Tremadocian time slices. In particular, *Peteinosphaeridium*, *Rhopaliophora* and species of *Veryhachium* appear in the *Araneograptus murrayi* and/or *Hunnegraptus copiosus* biozones of both Gondwana and Baltica, and therefore have the potential to correlate time slices in the late Tremadocian between these plates.

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