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MICROPALAEONTOLOGY OF A COURCEYAN (CARBONIFEROUS) BOREHOLE SECTION FROM BALLYVERGIN, COUNTY CLARE, IRELAND

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Abstract

Conodonts, plant miospores, and acritarchs are described from the Courceyan (Lower Carboniferous) Ballyvergin borehole in County Clare. Two new miospore taxa, *Retusotriletes crassus* sp. nov. and *Apiculatisporis heteroconus* sp. nov., are erected. Almost all the acritarchs recorded occur in the Ballyvergin Shale, and are mostly recycled Cambro-Ordovician and Silurian forms. The conodont evidence suggests that the *Spelaeotriletes pretiosus – Raistrickia clavata* (PC) Miospore Zone spans the Tn2/Tn3 boundary in terms of Belgian stratigraphical notation.

Introduction

The borehole (BV-14) which forms the subject of this paper was drilled by Irish Base Metals Ltd. in 1961, at a location 474′(165m) from the old mine chimney at Ballyvergin, County Clare (Fig. 1) on a bearing S.41°30′E. The hole was drilled vertically and cored throughout (core diameter 32mm ($1\frac{1}{4}''$)) with core recovery better than 90%. The terminal depth of the hole was 458 feet. The lithological sequence and macropalaeontology of the borehole, which penetrated marine limestones and shales and the underlying Old Red Sandstone, were described by Hudson and Sevastopulo (1966). Since 1966, as a result of the activity of the Irish mineral exploration industry, numerous boreholes have been drilled north of the South Munster Basin (Fig. 1), which prove lithological successions similar to that in the Ballyvergin borehole. The geographical spread of the boreholes is so wide that detailed sedimentological analyses of the sequence should lead to a complete picture of the evolving palaeogeography of the south of Ireland during latest Devonian and early Carboniferous times. Such a synthesis depends, however, on accurate correlation and, as Hudson and Sevastopulo have pointed out (1966, p.292), there are doubts as to whether the tradition coral-brachiopod assemblage zones provide such a correlation. Since 1966, there has been a flood of information on the distribution of microfossils, particularly miospores and conodonts, in latest Devonian and early Carboniferous rocks of Ireland, Bri-

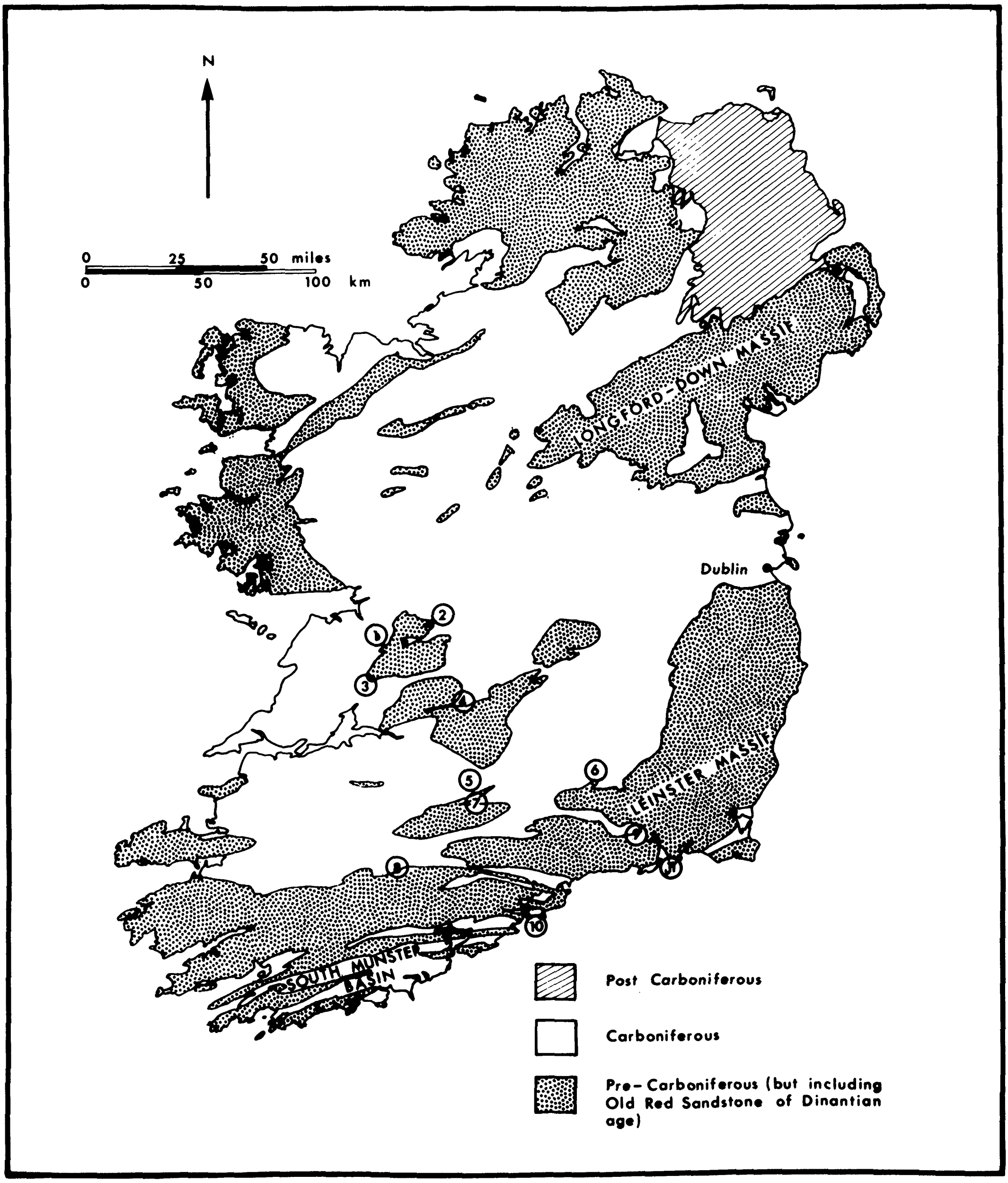

Fig. 1. Generalised geological map of Ireland, showing the location of places mentioned in the text. 1– Gort; 2 – Tynagh; 3 – Ballyvergin; 4 – Silvermines; 5 – Gortdrum; 6 – Callan, Baunta, south County Kilkenny; 7 – Aherlow; 8 – Mallow; 9 – Granny, Carrick-on-Suir syncline; 10 – Whiting Bay; 11 – Hook Head.

tain, and elsewhere. We decided that the micropalaeontology of the Ballyvergin borehole should be investigated with the aim of providing a microfloral and microfaunal biostratigraphy which might allow more precise correlations than those based on the macrofossils. With this in view, palynological samples from the borehole have been studied by G. Clayton and D.G. Smith, and conodonts by I.S. Johnston and G.D. Sevastopulo.

Lithostratigraphy

A general stratigraphical succession is shown in Figure 2; details were published by Hudson and Sevastopulo (1966, p. 294). The following features of the borehole core which were either not noted or not emphasized in that earlier account now seem important from the standpoint of regional lithological correlation and environmental interpretation. All depths quoted in feet are down-the-hole depths, whilst those quoted in metric units are true thicknesses (dips in the core vary from 20°-30°).

The lowest 23.9 m of the core consists of repeated sequences of sandstone grading up into red siltstones with cornstones. These typical 'Old Red Sandstone' sediments were interpreted as being of fluviatile origin. They are followed by 5.5 m of grey and green sandstones of uncertain origin.

At 350′ there is a significant lithological change, with the incoming of dark grey siltstones and mudstones. Between 350′ and 349′3″, units of dark grey, micaceous, muddy siltstones, 5 mm in thickness, are interlayered with four units of pale grey cross-bedded sandstone, each 15-35 mm thick. Between 349′3″ and 303′, sandstones are prominent, and the interbedded siltstones and mudstones are dark grey to black in colour. Occasional flaser bedding occurs within the interval between 350′ and 307′. Burrowing occurs as low as 344′6″, where vertical sections through small circular horizontal burrows (?*Chondrites*) were noted. Although some of the sandstones are calcareous, the carbonate generally occurs interstitially, except at 338′3″, where a horizon described by Hudson and Sevastopulo as a quartz pebble conglomerate, in fact contains micrite clasts. No oolitic or skeletal limestones are present, such as those which occur at this level in the succession farther south, for example in the 'Transition Limestone' of Gortdrum, County Tipperary (Thompson 1967). It seems likely that marine environments are first represented in the core at the entry of dark mudstones and siltstones at 350′.

From 307′3″ to 303′, there is a distinctive unit of wavy-bedded rippled sandstones and mudstones, cut by desiccation cracks. This unit has been widely recognised elsewhere at this level in the succession, for instance at Gortdrum where it has been called the 'Laminated Shale' (Thompson 1967).

Skeletal carbonates first occur abruptly at 303′. For 4.32 m above that level, silty limestones occur as thin bands within dark silty mudstones, which also contain lenses and thin beds of rippled unfossiliferous pale siltstones. The limestones contain some sand-grade quartz and common granules of phosphate. The contact between the wavy-bedded sandstones and mudstones below, and the thin limestones and mudstones above, is distinctive and easily recognised elsewhere, for instance, at the base of the 'Dark Limestones' at Gortdrum (Thompson 1967). The succeeding 19.15 m of dark fossiliferous shales contain few limestone beds.

At 217′8″ there is a change from calcareous shales to interlayered greenish grey mudstones and siltstones. This mudstone and siltstone unit is 5.62 m thick, and has come to be known informally as the Ballyvergin Shale. It is one of the most useful marker horizons in the Dinantian of the south of Ireland, and is generally easily recognised because it is non-calcareous, contains a characteristic brachiopod fauna including chonetaceans, and is almost always devoid of bryozoans and crinoid ossicles. The present investigation has also proved it to contain a distinctive palynomorph assemblage, including reworked Lower Palaeozoic acritarchs. There are

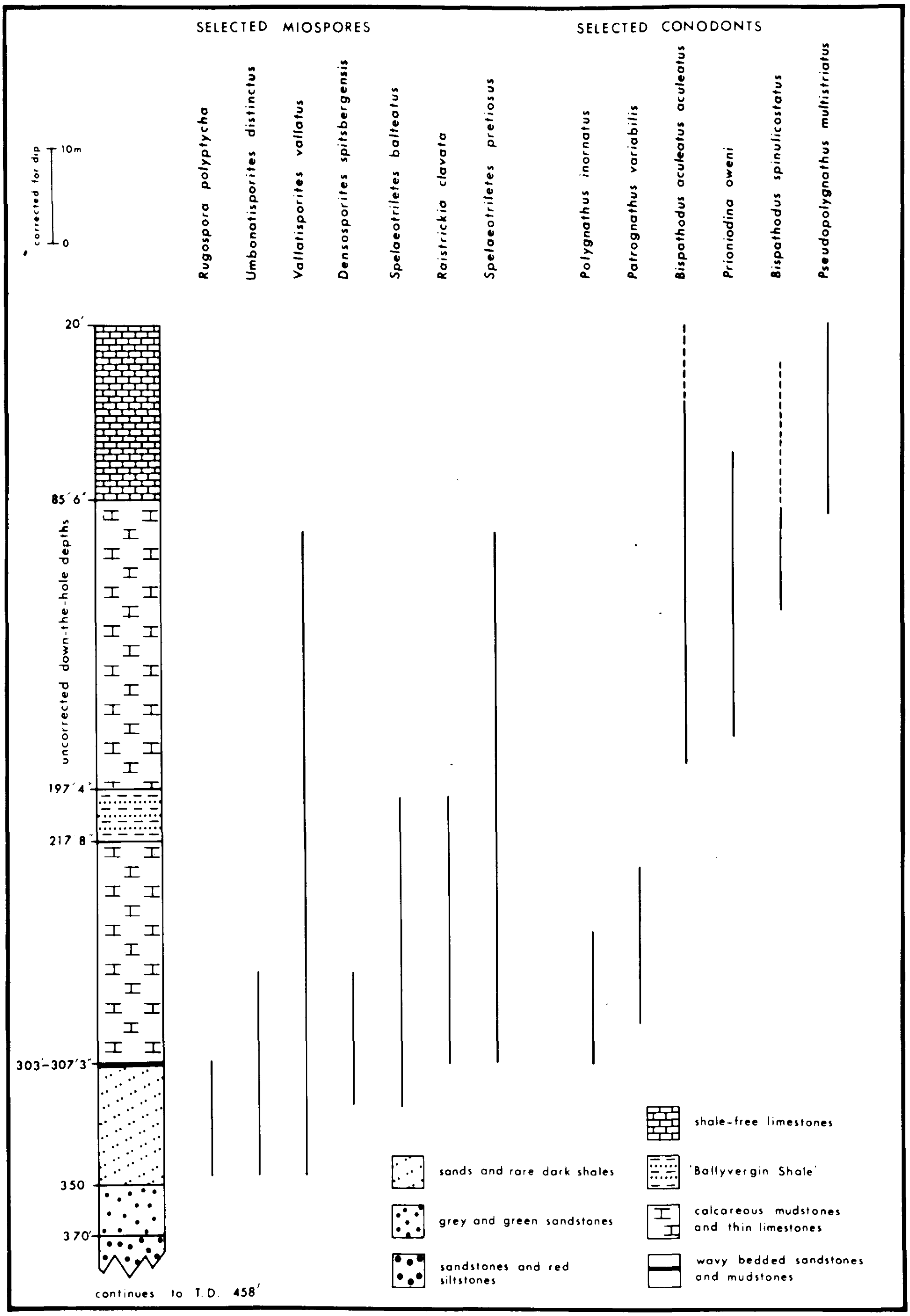

Fig. 2. Generalised lithological succession encountered in the Ballyvergin borehole with the ranges of important miospores and conodonts. The broken line represents records based on juvenile specimens. T.D. = terminal depth.

published records of the Ballyvergin Shale from Aherlow, County Tipperary (as the 5-8′ thick mudstone band of Cameron and Romer, 1970), from Gortdrum (as the 10′ mudstone of Thompson, 1967), from Silvermines (Taylor and Andrew 1978) and from the Mallow area (Wilbur and Royall 1975). Above the 'Ballyvergin Shale' are 30.89 m of calcareous shales and thin limestones.

The incoming of shale-free limestones at 85′6″ in the Ballyvergin borehole is a significant lithological change, which can also be widely recognised elsewhere in south Connaught and Munster. In northwest County Limerick a corresponding change occurs at the base of the Ballysteen Limestone (Shephard - Thorn 1963).

*Micropalaeontological preparation techniques

The core from 303′ upwards was split into 5′ channel samples, which were then crushed and dissolved in 10% acetic acid. Most of the samples consisted of all the limestone available in a 5′ section, and weighed from 0.25 kg low in the succession to approximately 3 kg in the shale-free limestones. The acid-insoluble residues were floated in tetrabromoethane, and the conodonts picked from the heavy fraction.

100 g mudrock samples were prepared for palynology, mainly from 5′ channels from the core. The rock was dissolved in warm, 40% hydrofluoric acid, and the neutralised organic residues were floated in tetrabromoethane, oxidised residues were mounted using 'Clearcol' dispersal agent and 'Elvacite' mounting medium.

The conodont faunas and palynomorph assemblages are reposited in the collections of the Department of Geology, Trinity College, Dublin. A single catalogue number has been allocated to the total conodont fauna from each 5′ channel sample; type and other figured palynomorphs have been individually catalogued.

Biostratigraphy

Conodonts

Our hope that the Ballyvergin borehole would provide a reference section for conodont biostratigraphy in Munster has not been realised, because the number of conodonts recovered was disappointingly low and is not sufficient to give more than an approximate picture of the true distribution of taxa (Table 1).

Of the platform and blade forms (Fig. 2), only *Polygnathus inornatus* E.R. Branson 1934, *Bispathodus spinulicostatus* (E.R. Branson 1934) and *Pseudopolygnathus multistriatus* (Mehl and Thomas 1947) seem likely to be useful in dividing the succession biostratigraphically. *P. inornatus* is restricted to the lower part of the core (303′-260′) but above its upper limit is an interval (260′-130′) from which very few conodonts were obtained (partly a reflection of the small amount of limestone available). This is particularly unfortunate, because a very useful horizon in sections with rich faunas is that at which *Polygnathus inornatus*, and *Siphonodella* spp. which commonly accompany it, last appears. This can be recognised at Whiting Bay, County Waterford, at the level of sample WB2 (Matthews and Naylor 1973, p.338), which is now known to be just below the Ballyvergin Shale. Since it is unlikely that the Ballyvergin Shale is diachronous, the true range of *P. inornatus* in the Ballyvergin area probably also extends up to the same level. The faunas with *P. inornatus* from 260′-303′ are similar to that recorded by Austin *et al.* (1970) from the Ringmoylan Shales of County Limerick, and probably are of approximately the same age as richer faunas recorded from the Lyraun Shale Member of the Houseland Formation at Hook Head by Sleeman *et al.* (1974) and from the lower parts of the Courtmacsherry and Reenydonagan Formations in southwest County Cork by Matthews and Naylor (1973).

Groessens (1977) has shown that the upper limit of the range of *P. inornatus* in Belgium is at the Middle/Upper Tournaisian boundary,

SAMPLE DEPTH \ CONODONTS	*Polygnathus communis communis*	*Polygnathus inornatus*	*Patrognathus variabilis*	*Spathognathodus stabilis*	*Bispathodus aculeatus aculeatus*	*Prioniodina oweni*	*Gnathodus* sp.	*Bispathodus spinulicostatus*	*Spathognathodus* cf. *cristulus*	*Pseudopolygnathus multistriatus*	*Gnathodus* cf. *delicatus*	Others, mainly bar forms	T. C. D. catalogue number
20 - 25'	8			2 Juv.	1 Juv.				2	5		C	198 44
25 - 30'	1									2		R	- 43
30 - 35'	1								1	1		R	- 42
35 - 40'	12				2 Juv.			1 Juv	2	8		C	- 41
40 - 45'	4			6	1 Juv.				4	11		C	- 40
45 - 50'	2			2					4	8		C	- 39
50 - 55'	7			6	2				6	7		C	- 38
55 - 60'	12			2				2 Juv.	2	2		C	- 37
60 - 65'	4			1	1							C	- 36
65 - 70'	5			3	1 Juv.				2			C	- 35
70 - 75'	1			1		2			4	1	1	C	- 34
75 - 80	14			4						9		C	- 33
80 - 85'										3		R	- 32
85 - 90'	7			1	1 Juv.	2			1	3	1	C	- 31
90 - 95'	2			3				3	1			C	- 30
95 - 100'	7			2								C	- 29
100 - 105'	21			5	2	1		6	2			C	- 28
105 - 110'	10			2	3 + 1 Juv.	3		1 Juv.				C	- 27
110 - 115'	6				3 Juv.	1			2			C	- 26
115 - 120'	2					1		1	3			C	- 25
120 - 125'	6			1	cf.			1				C	- 24
125 - 130'	3							3				R	- 23
130 - 135'	7			3		1						C	- 22
135 - 140'					2	1						C	- 21
140 - 145'	2			1								R	- 20
145 - 150'					2							R	- 19
150 - 155'												R	- 18
155 - 160'							1					R	- 17
160 - 165'												R	- 16

SAMPLE DEPTH \ CONODONTS	*Polygnathus communis communis*	*Polygnathus inornatus*	*Patrognathus variabilis*	*Spathognathodus stabilis*	*Bispathodus aculeatus aculeatus*	*Prioniodina oweni*	*Gnathodus sp.*	*Bispathodus spinulicostatus*	*Spathognathodus cf. cristulus*	*Pseudopolygnathus multistriatus*	*Gnathodus cf. delicatus*	Others, mainly bar forms	T. C. D. catalogue number
165 - 170'				1								R	19815
170 - 175'	2			1								R	- 14
175 - 180'	1					1						R	- 13
180 - 185'												R	- 12
185 - 190'	5			2	1							R	- 11
190 - 195'	1											R	- 10
195 - 200'												A	
200 - 205'												A	
205 - 210'												A	
210 - 215'												A	
215 - 220'												A	
220 - 225'												A	
225 - 230'												A	
230 - 235'			1									R	- 09
235 - 240'												R	- 08
240 - 245'												A	
245 - 250'	1											R	- 07
250 - 255'												A	
255 - 260'		1										R	- 06
260 - 265'	2	2										C	- 05
265 - 270'	2			2								C	- 04
270 - 275'	1	1										R	- 03
275 - 280'												A	
280 - 285'												A	
285 - 290'	1	5	1									R	- 02
290 - 295'	1	1 Juv.										R	- 01
295 - 300'	1	7										R	- 00
300 - 305'												A	

Table 1. Distribution of conodonts in the Ballyvergin borehole. A – absent; R – rare, less than 10 specimens; C – common, 10 or more specimens.

PALYNOMORPHS / SAMPLE DEPTH	347′ 6″	321′	306′	300 – 303′	270′	200 – 205′	170 – 175′	140 – 145′	120 – 125′	100 – 105′
SCOLECODONTS			X	X	X	X	X	X	X	X
ACRITARCHS					X	X				
MIOSPORE TAXA										
Umbonatisporites abstrusus (1)	X									
Rugospora cf. *corporata* (2)	X		X							
Pulvinispora scolecophora (3)	X	X	X	X						
Raistrickia variabilis (4)	X			X						
Rugospora polyptycha (5)	X	X	X	X						
Auroraspora macra (6)	X	X	X	X	X					
Grandispora echinata (7)	X	X	X	X	X					
Raistrickia corynoges (8)	X		X	X	X					
Umbonatisporites distinctus (9)	X			X	X					
Auroraspora solisortus (10)	X				X	X				
Baculatisporites fusticulus (11)	X	X	X			X				
Calamospora spp.	X	X	X			X				
Crassispora cf. *maculosa* (12)	X		X	X		X				
Latosporites sp.	X					X				
Perotrilites magnus (13)	X			X		X				
Punctatisporites irrasus (14)	X	X	X	X	X	X				
Vallatisporites verrucosus (15)	X	X	X	X	X	X				
Corbulispora cancellata (16)	X	X	X	X		X	X	X	X	
Knoxisporites literatus (17)	X	X		X	X		X	X	X	
Spinozonotriletes uncatus (18)	X	X	X	X	X	X	X		X	
Retusotriletes incohatus (19)	X	X	X	X	X	X	X	X	X	X
Vallatisporites vallatus (20)	X	X	X	X	X	X	X		X	X
Verrucosisporites nitidus (21)	X	X		X	X	X	X	X	X	X
Discernisporites sp. A (22)		X		X		X				
Retusotriletes planus (23)		X	X		X					
Densosporites spitsbergensis (24)		X	X	X	X					
Retusotriletes crassus sp. nov.		X	X	X		X				
Spelaeotriletes balteatus (25)		X	X		X	X				
Pulvinispora quasilabrata (26)			X			X				
Discernisporites micromanifestus (27)				X	X					
Raistrickia clavata (28)				X	X	X				
Apiculatisporis heteroconus sp. nov.				X	X	X				
Spelaeotriletes pretiosus (29)				X	X	X				X
Dictyotriletes trivialis (30)					X					
Granulatisporites micrograifer (31)					X					
Dictyotriletes submarginatus (32)					X					
Leiotriletes inermis (33)						X				
Leiotriletes tortilis (34)						X				
Lophozonotriletes cristifer (35)						X				
MIOSPORE ZONATION	NV Zone VI Subzone			PC Zone			? PC Zone			

Hatched columns 170–175′ to 100–105′: EXTENSIVELY PYRITISED MIOSPORE ASSEMBLAGES; MOST THIN-WALLED FORMS DESTROYED which indicates the Middle Tournaisian or olderage of levels below 260′ in the Ballyvergin borehole.

If, as we suspect, *Ps. multistriatus* was descended from *B. spinulicostatus* and ultimately from *Bispathodus aculeatus* (Branson and Mehl 1934a), the entry of the former taxon (between 90′ and 85′ in the borehole) may be at a valuable horizon for correlation; unpublished results from elsewhere (southern County Kilkenny – G.Ll. Jones personal communication; the Carrick-on Suir syncline – M.L. Keeley personal communication; Hook Head, County Wexford) confirm its usefulness. Austin *et al.* (1970) recorded faunas from the Ballysteen Limestone of northwest County Limerick, which are similar to those from the upper 75′ of the limestones in the borehole. We are unable to correlate our information regarding the derivation of *P. multistriatus* with that of Rhodes *et al.* (1969, p. 207, fig. 43), which was based on material collected from the Bristol area of England. The presence of *Prioniodina oweni* Rhodes, Austin, and Druce (see notes on identification, below) indicates that the interval from 70′-180′ in the borehole falls within the *Spathognathodus* cf. *bultyncki* Subzone of the *Polygnathus communis carina* Zone of Groessens (1977), which in Belgium occurs in Upper Tournaisian rocks. The faunas from the top of the borehole are clearly older than those recorded by Sleeman *et al.* (1974) from the uppermost part of the Hook Head Limestone Formation at Hook Head, County Wexford.

Plant miospores

Ten samples from the core yielded plant miospores which were quite carbonised, but diverse in composition. The composition of these assemblages is summarised in Table 2 and the ranges of the stratigraphically important taxa are shown in Figure 2.

All the miospore assemblages between depths 347′6″ and 250-205′ are dominated by acamerate, mainly laevigate miospores such as *Punctatisporites irrasus* Hacquebard, *Retusotriletes incohatus* Sullivan, and *Retusotriletes crassus* sp. nov., though *Spelaeotriletes* spp. and *Vallatisporites* spp. are numerically important between depths 200- 205′ and 300-303′. Several taxa such as

Table 2. Qualitative composition of the miospore assemblages from the Ballyvergin borehole. Authors of the taxa recorded are listed below:

1. (Playford) Clayton
2. Neves and Owens
3. Neves and Ioannides
4. Neves and Dolby
5. Neves and Ioannides
6. Sullivan
7. Hacquebard
8. Sullivan
9. Clayton
10. Hoffmeister, Staplin and Malloy
11. Sullivan
12. (Knox) Sullivan
13. Hughes and Playford
14. Hacquebard
15. Hacquebard
16. (Waltz) Bharadwaj and Venkatachala
17. (Waltz) Playford
18. Hacquebard
19. Sullivan
20. Hacquebard
21. (Naumova) Playford
22. Sullivan
23. Dolby and Neves
24. Playford
25. (Playford) Higgs
26. Higgs
27. (Hacquebard) Sabry and Neves
28. Playford
29. (Playford) Neves and Belt
30. (Naumova) Kedo
31. Ibrahim
32. Playford
33. (Waltz) Ishchenko
34. Playford
35. (Luber) Kedo

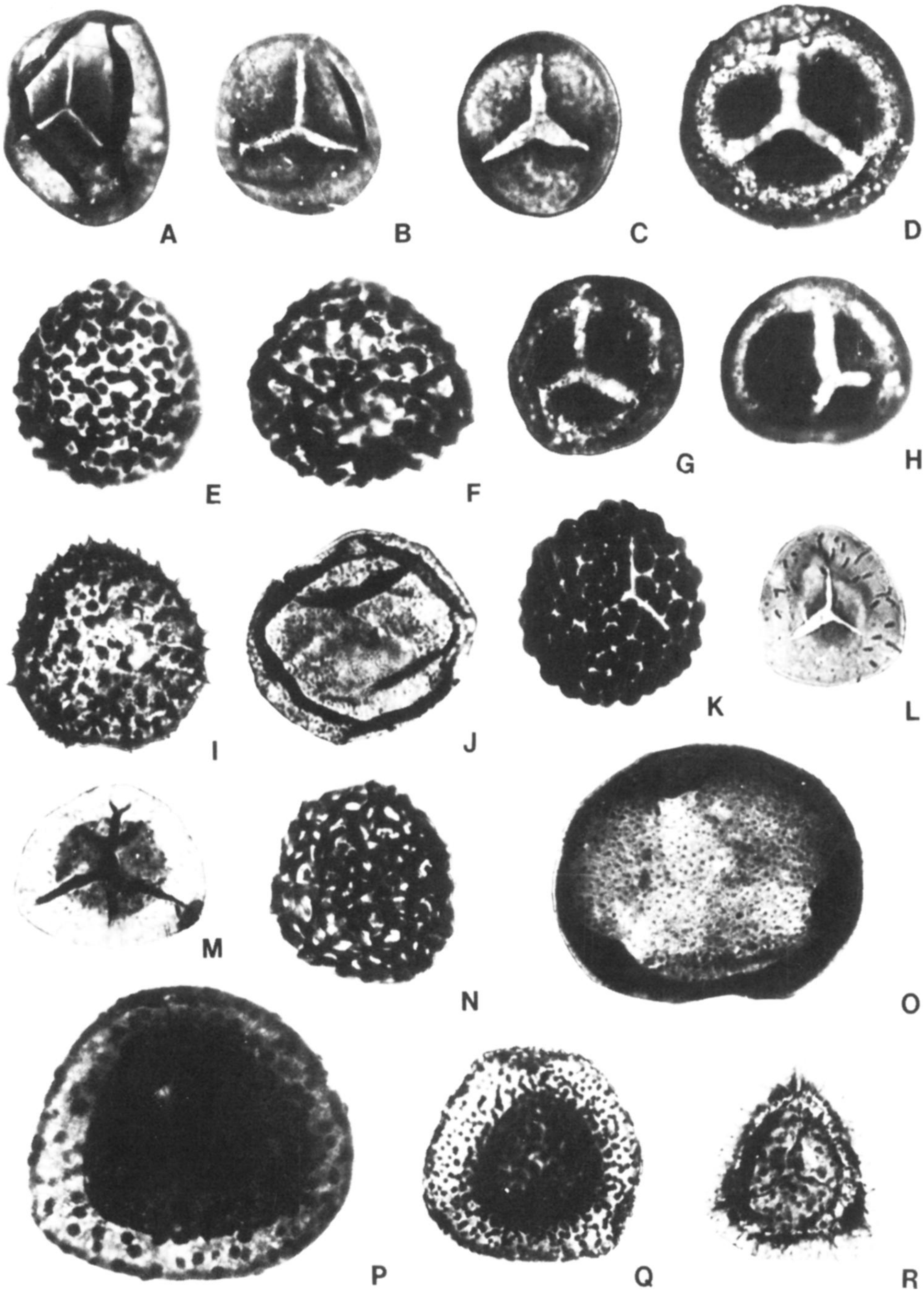

Fig. 3. Miospores from the Ballyvergin borehole. All approximately X 500. A (TCD 20010) and B(TCD 20011). *Punctatisporites irrasus* Hacquebard (A sample 321′, B sample 347′6″). C (TCD 20012) *Retusotriletes incohatus* Sullivan (sample 347′6″). D (TCD 20013), G (TCD 20014) and H (TCD 20015). *Retusotriletes crassus* sp. nov. (all from sample 200-205′, D Holotype). E (TCD 20016), F (TCD 20017) and I (TCD 20018). *Apiculatisporis heteroconus* sp. nov. (all from sample 200-205′, F Holotype). J (TCD 20019). *Baculatisporites fusticulus* Sullivan (sample 347′6″). K (TCD 20020). *Verrucosisporites nitidus* (Naumova) Playford (sample 347′6″). L (TCD 20021) *Umbonatisporites abstrusus* (Playford) Clayton (sample 347′6″). *M (TCD 20022). Discernisporites* sp. A Sullivan (sample 321′). N (TCD 20023). *Dictyotriletes trivialis* Naumova in Kedo (sample 347′6″). O (TCD 20024). *Crassispora maculosa* (Knox) Sullivan (sample 347′6″). P (TCD 20025). *Spelaeotriletes pretiosus* (Playford) Neves and Belt (sample 200-205′). Q (TCD 20026). *Spelaeotriletes balteatus* (Playford) Higgs (sample 200-205′). R (TCD 20027). *Vallatisporites vallatus* Hacquebard (sample 306′).

Lophozonotriletes cristifer (Luber) Kedo and *Pulvinispora scolecophora* Neves and Ioannides, which occur sporadically in the core, have in fact been recorded through greater stratigraphical intervals elsewhere.

The assemblage from 347′6″ contains *Umbonatisporites distinctus* Clayton, *Raistrickia corynoges* Sullivan, *Rugospora polyptycha* Neves and Ioannides, and *Vallatisporites vallatus* Hacquebard, and is assigned to the upper part of the VI Subzone of the NV Miospore Zone, *sensu* Clayton *et al.* (1978, pp. 139-140). *U. distinctus* occurs throughout the upper part of the VI Subzone in Ireland, but does not occur in the basal Tn2 strata of the Yvoir section in Belgium (Paproth and Streel 1970). The oldest Ballyvergin borehole assemblage (347′6″) is therefore unlikely to be older than Tn2 in age. It compares closely with assemblages 2, 4, and 5 from the 'Old Red Sandstone' and lower part of the Houseland Sandstone Member at Hook Head, County Wexford recorded by Higgs (1975).

The miospore assemblages from depths 321′ and 306′ contain *Spelaeotriletes balteatus* (Playford) Higgs, and closely resemble assemblages from the uppermost levels of the VI Subzone at Hook Head (Higgs 1975, sample 6), in the Callan area, County Kilkenny (Clayton *et al.* 1977, samples 2 and 3), and in the South Munster Basin (Clayton *et al.* 1978, p. 142).

Spelaeotriletes pretiosus (Playford) Neves and Belt first appears in the assemblage from depth 300-303′, defining the base of the PC Zone. This assemblage is similar to assemblage 7 from the upper part of the Houseland Sandstone Member at Hook Head (Higgs 1975) and assemblage 4 from the Callan area, County Kilkenny (Clayton *et al.* 1977). On conodont evidence, this level is just below the Tn2/Tn3 boundary in terms of Belgian stratigraphical notation.

Other taxa which typically occur in PC Zone assemblages in the Ballyvergin borehole and elsewhere include *Densosporites spitsbergensis* Playford, *Punctatisporites irrasus, Retusotriletes crassus* sp. nov., *R. incohatus, Spelaeotriletes balteatus, Vallatisporites vallatus,* and *V. verrucosus* Hacquebard. Unlike assemblages from the preceeding NV Zone, PC Zone assemblages do not contain abundant *Lophozonotriletes* spp.

There is no significant qualitative change in the miospore assemblages at the level of the 'Ballyvergin Shale', though the assemblage from 200-205′ is well preserved relative to those from the samples below. The four samples above the 'Ballyvergin Shale' are extensively pyritised, so that only thick-walled or very distinctively ornamented taxa such as *Knoxisporites literatus* (Waltz) Playford and *Verrucosisporites nitidus* (Naumova) Playford can be identified. In the absence of *Schopfites claviger* Sullivan, the first appearance of which defines the base of the CM Zone, the assemblages between (170-175′) and (100-105′) are tentatively assigned to the PC Zone.

Acritarchs

In addition to its persistent lithological uniformity, the Ballyvergin Shale bears a constant and remarkable micropalaeontological character. Palynological preparations of the shale always contain acritarchs, which are otherwise rarely observed in the Irish Lower Carboniferous, and part at least of the acritarch assemblage is reworked. Besides Ballyvergin, this has now been verified at Tynagh Mine (K. McKee, pers. comm.) at Granny, County Waterford and Baunta, County Kilkenny (K. Higgs, personal communication) and at Gort, County Galway (authors' unpublished results).

In a channel sample of the Ballyvergin Shale from 200-205′ acritarchs constitute approximately 1% of total palynomorphs, and are moderately well preserved, being much less extensively pyritised than the miospores in the same material. The reason for this preservational difference is not clear, but may in part be connected with the fact that many of the acritarchs were reworked and had acquired some resistance to bacterial degradation before being incorporated in the Ballyvergin sediment. Thin sections of the shale suggest

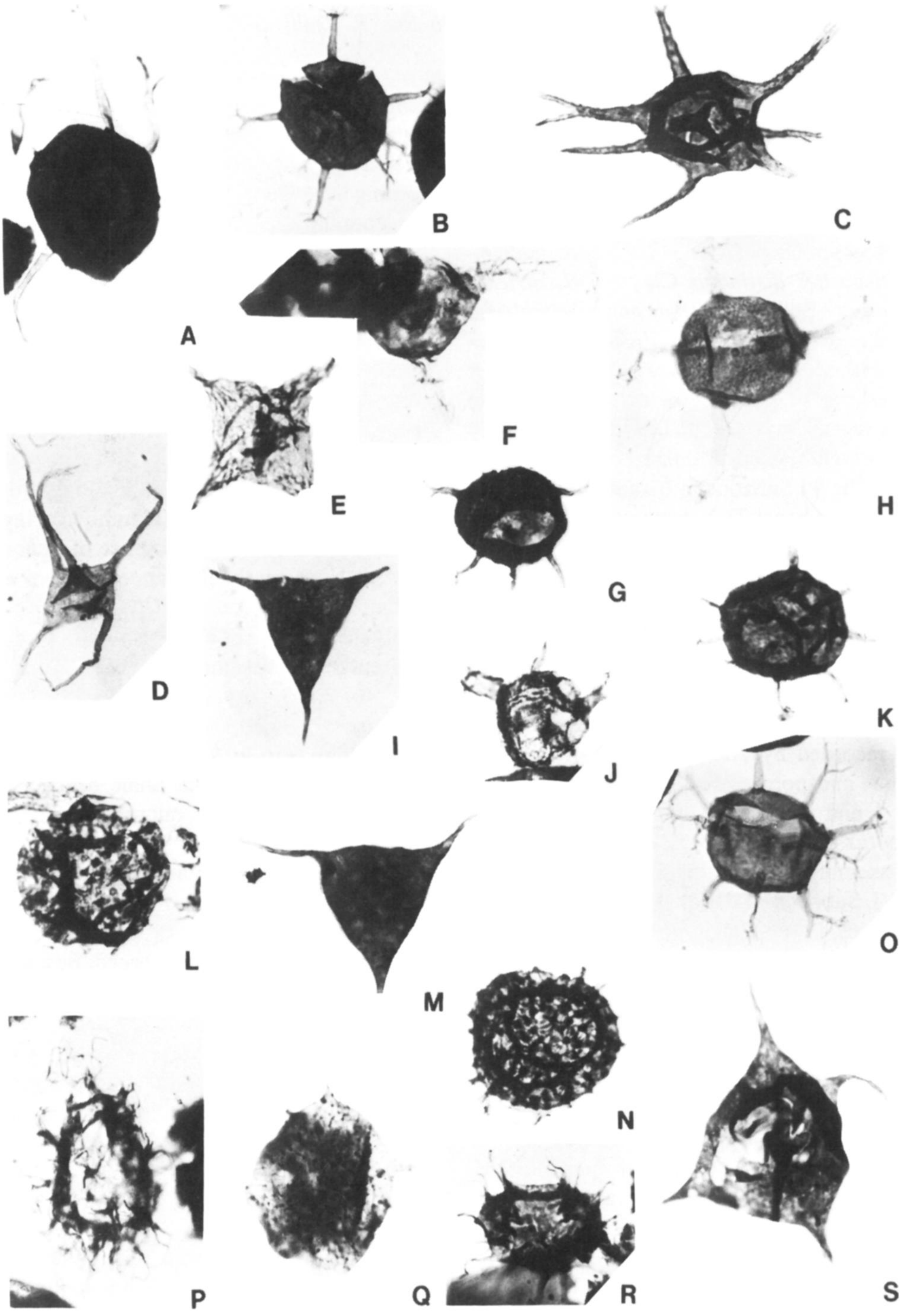

Fig. 4. Reworked acritarchs from the Ballyvergin Shale (200-205′), all approximately X 500. Figures A-K, M and O Silurian; figures L, N and P-S Cambro-Ordovician. A (TCD 20028). *Oppilatala* sp. *B (TCD 20029). Cymbosphaeridium pilar* (Cramer). C (TCD 20030). *Diexallophasis denticulata* (Stockmans and Willière) Loeblich. D (TCD 20031. *Diexallophasis remotum* (Deunff). E (TCD 20032). *Costatilobus traumaticus* (Cramer). F (TCD 20033). *Tyligmasoma alargadum* (Cramer). G (TCD 20034). *?Cymbosphaeridium pilar* (Cramer). H (TCD 20035). cf. *Baltisphaeridium gueltaense* Jardiné *et al.* I (TCD 20036). *Onondagaella* cf. *asymmetrica* (Deunff). J (TCD 20037). *Dilatisphaera willierae* (Martin). K (TCD 20038). cf. *Baltisphaeridium areolatum* Jardiné *et al.* L (TCD 20039). *Priscogalea distincta* Rasul. M (TCD 20040). *Onondagaella* cf. *asymmetrica* (Deunff). N (TCD 20041). *Stelliferidium striatulum* (Vavrdova). O (TCD 20042). *Oppilatala* sp. P. (TCD 20043). *Vulcanisphaera africana* Deunff. Q(TCD 20044). *Veryhachium fakirum* Martin. R (TCD 20045). *Acanthodiacrodium tremadocum* Gorka. S. (TCD 20046). *Tectitheca* sp.

that the acritarchs were deposited as isolated individuals, rather than in derived pellets of pre-existing rock. Only two acritarch specimens were recorded other than from the Ballyvergin Shale; both were from the sample from 270′, and were stratigraphically non-diagnostic.

The acritarch assemblage is diverse; well over 40 taxa are represented. They appear to belong to at least three distinct suites. Silurian forms predominate; Cambro-Ordovician forms are less common but are nevertheless diverse; and Dinantian forms are present, though they will not be discussed here. There are also acritarchs of long-ranging type, and others which could belong to more than one of the suites represented. Only those forms which can be reasonably securely dated will be discussed here (Table 3). Further study is in progress on the remainder of the assemblage, together with those from the same lithological unit at the other localities mentioned above.

Cambro-Ordovician (*i.e.* Tremadoc and Arenig) acritarchs include some particularly distinctive forms of short range. Several of the species encountered in the Ballyvergin Shale are known elsewhere only from rocks of Tremadoc age; others have been found only in Arenig strata. However, although assemblages of both epochs have been abundantly described in the literature there is a lack of information from strata spanning both Series and the precise range of most taxa cannot therefore be determined. The Cambro-Ordovician acritarchs in the Ballyvergin Shale may have been derived from a single horizon,

Table 3. Selected taxa of reworked acritarchs and their known stratigraphical ranges.

Acanthodiacrodium tremadocum Gorka	Tremadoc
Baltisphaeridium aerolatum Jardiné *et al.*	Wenlock-Ludlow
B. gueltaense Jardiné *et al.*	Wenlock-Ludlow
Costatilobus traumaticus (Cramer) Playford	Wenlock-Gedinnian
Cymatiogalea cristata (Downie) Rasul	Tremadoc
Cymbosphaeridium pilar (Cramer) Lister	Wenlock-Gedinnian
Dasydiacrodium filamentosum Vavrodova	Tremadoc-Arenig
Diexallophasis denticulata (Stockmans & Willière) Loeblich	Llandovery-Gedinnian
D. remotum (Deunff) Loeblich	Wenlock-Gedinnian
Dilatisphaera willierae (Martin) Lister	U. Llandovery
Goniosphaeridium uncinatum (Downie) Kjellström	Tremadoc-Caradoc
Multiplicisphaeridium maroquense Cramer *et al.*	Arenig-Llanvirn
M. monterrosea Cramer	U. Llandovery-M. Wenlock
Onodagaella cf. *asymmetrica* (Deunff)	U. Llandovery- M. Devonian
Oppilatala Loeblich & Wicander spp.	M. Silurian-L. Devonian
Polygonium gracile Vavrdova	Tremadoc-Arenig
Priscogalea distincta Rasul	Tremadoc
P. fimbria Rasul	Tremadoc
Pulvinosphaeridium cf. *oligoprojectum* Downie	L.-M. Wenlock
Stelliferidium simplex (Deunff) Deunff *et al.*	Tremadoc
S. striatulum (Vavrdova) Deunff *et al.*	Tremadoc-Llanvirn
Trunculumarium revinium (Vanguestaine) Loeblich & Tappan	U. Cambrian-Tremadoc
Tyligmasoma alargadum (Cramer) Playford	M. Silurian-L. Devonian
Veryhachium fakirum Martin	Arenig
Vulcanisphaera africana Deunff	Tremadoc
V. britannica Rasul.	Tremadoc

or perhaps from a sequence spanning the Tremadoc-Arenig boundary. It is highly significant that Tremadoc-Arenig acritarchs are commonly found reworked into later strata, for instance in the Caradoc of the Welsh Borderland (R. Turner, personal communication) and the Silurian of Belgium (Martin 1969), as well as the later Lower Palaeozoic rocks of parts of Ireland (Colthurst and Smith 1977, Emo and Smith 1978, Brück *et al.* 1980). It is characteristic of such occurrences that the reworked acritarchs are at least as well, and often better, preserved than indigenous palynomorphs. No assemblage of equivalent diversity or preservational quality has yet been recovered from Cambro-Ordovician or Silurian rocks in Ireland.

The Silurian acritarch suite may also represent more than a single horizon, though the same problem of lack of precise information on taxon ranges applies here also. The most likely age appears to be within the interval from late Llandovery to Wenlock. Again, no assemblage of comparable diversity has yet been found in Irish Silurian strata. Palynological preparations of rocks of Llandovery and Wenlock age in Ireland have generally yielded few palynomorphs, and the rare productive preparations tend to be rich in trilete spores, with a few poorly preserved acritarchs of small size only (Smith 1975, 1980). The Silurian suite from the Ballyvergin Shale is much closer in character to the rich assemblages described from the Welsh Borderlands (Downie 1959, 1963; Lister 1970), suggesting that the Ballyvergin acritarchs may have been derived from Silurian sediments of shelf facies, quite different from the thick sequences of turbidite facies which predominate in the outcropping Irish Silurian. The few chitinozoa present are probably of Silurian age although their numbers are too small to allow any confident identifications.

As at least two suites of reworked acritarchs of quite distinct ages are present in the Ballyvergin Shale, the question arises as to whether one or two cycles of reworking occurred. Either the Cambro-Ordovician acritarchs were first reworked into acritarch-bearing mid-Silurian sediments, which were later the principal source for the Ballyvergin Shale, or the Shale was derived from two distinct sources, or perhaps from a sequence of Lower Palaeozoic rocks which included acritarch-bearing horizons of Cambro-Ordovician and mid-Silurian age. The following factors may be taken into account in weighing up the alternatives. First, the derived acritarch assemblage of the Ballyvergin Shale is remarkably similar wherever it has been observed, and, although the sample points are few in number they enclose an area of several thousand square km. This suggests rapid derivation from a limited source area, a suggestion which is further substantiated by the way in which the Ballyvergin Shale cuts across facies changes only to be succeeded by a resumption of the same pattern of sedimentation as that which preceded its deposition. Second, reworking within the Lower Palaeozoic, particularly of Cambro-Ordovician acritarchs, has been frequently reported in Ireland and elsewhere, as mentioned above. Richardson and Rasul (1978) have recently reported on subsurface Lower Devonian palynological assemblages from southern England in which suites of reworked acritarchs were found in association with early Devonian miospores. The reworked acritarchs were judged to be of Tremadoc, Ordovician, and Silurian ages, and it was observed that the Tremadoc acritarchs were rare and carbonised. Third, the acritarchs of both derived suites are diverse and well-preserved, both characteristics being generally true of acritarch assemblages of shelf rather than 'geosynclinal' facies. This is equivocal as concerns one or two cycles of reworking, since it would be consistent both with derivation from a shelf sequence in which both Cambro-Ordovician and mid-Silurian were represented, and equally with derivation from a shelf sequence within which local reworking had already taken place.

The provenance and depositional environment of the Ballyvergin Shale

Certain conclusions concerning the provenance and depositional environment of the Ballyvergin Shale can be drawn from its lithology, palynology, and geographical extent. These are summarised below:

1. The terrain from which the Ballyvergin Shale was derived must have included some unmetamorphosed mudrocks, since the reworked acritarchs in the Ballyvergin Shale are not extensively carbonised.
2. The mixed Silurian and Cambro-Ordovician acritarch assemblage suggests that at least some of these mudrocks were Silurian in age, and were probably in turn derived from Cambro-Ordovician mudrocks.
3. The diverse nature of the Silurian acritarch assemblage suggests a 'shelf' rather than 'geosynclinal' environment. The nature and preservation of the reworked Silurian palynomorphs preclude derivation from the Longford-Down Massif, the Leinster Massif, or the Silurian inliers of the Midlands.
4. The homogeneous and geographically widespread nature of the Ballyvergin Shale suggests rapid deposition relative to the underlying and overlying mudrocks and carbonates. Deposition was not as rapid, however, as in a turbidite or ash fall, since changes in thickness of the unit are evident which reflect differential subsidence within the area of deposition.
5. The close similarity in composition between the miospore assemblage from the Ballyvergin Shale and assemblages from the marine samples below suggests that the deposition of the Ballyvergin Shale was not caused by any major change in palaeogeography or climate.

It seems most likely that the deposition of the Ballyvergin Shale was caused by the unroofing or rapid uplift of a Silurian mudrock unit. The source area almost certainly lay to the north of Tynagh, possibly in Galway or Mayo.

Taxonomic micropalaeontology

Notes on the conodont taxa recorded

Bispathodus aculeatus aculeatus (Branson and Mehl) 1934a.

Our concept of this species accords with that of Ziegler *et al.* (1974, p. 101). The Ballyvergin specimens are mostly typical with 2-4 lateral nodes on the right side. The specimen in TCD 19824 recorded as *B.* cf. *a. acuelatus* has a ridge-like single node anterior of the basal cavity on the left side of the blade.

Bispathodus spinulicostatus (E.R. Branson) 1934.

We apply this name to forms which have a lateral denticle row extending to the posterior end of the right side of the blade and lateral denticles on the left side of the blade over and posterior to the basal cavity. In juvenile specimens the left side denticles are restricted to the posterior end. Ziegler *et al.* (1974, p. 103) were of the opinion that *B. spinulicostatus* evolved from *B. aculeatus aculeatus* in the late Devonian. We believe that the Carboniferous forms assigned to *B. spinulicostatus* were derived from *B. aculeatus* in the Upper Tournaisian, because we have never found them in older Tournaisian rocks of shallow water facies in Ireland.

Pseudopolygnathus multristriatus Mehl and Thomas 1947.

The specimens assigned to this taxon appear to have evolved from *B. spinulicostatus* from which they differ in possessing a true platform, particularly on the left side of the blade. Many of the Ballyvergin examples are similar to those figured by Austin and Husri (1974, pl. 7, figs 6-9) which were obtained from the Ballysteen Limestone of northwest County Limerick. The total range of variation, however, is considerable, and makes us suspect that the characters used to distinguish Carboniferous species of *Pseudopolygnathus* should be reassessed. For instance, many specimens, particularly small individuals, have an aboral cavity which is as wide, or almost as wide, as the platform, a character supposedly diagnostic of *Pseudopolygnathus dentilineatus* Branson 1934 (Klapper 1966, p. 15). The Ballyvergin specimens in oral view show platform outlines varying from lanceolate to crudely triangular, with nearly smooth to sharply serrated peripheries, and a surface ornament of weak to strong ridges or nodes. A number of specimens have a platform with an almost smooth left side.

It is probable that some of the specimens identified as *B. acuelatus acuelatus* juv. and *B. spinulicostatus* juv. are immature examples of *Ps. multistriatus*.

Spathognathodus Branson and Mehl 1941.

The taxonomy of Carboniferous elements formerly assigned to *Spathognathodus* is in a poor state, and a revision based on type material and large faunas is overdue. The Ballyvergin material consists of two distinct forms assigned to *Sp.* cf. *cristulus* Youngquist and Miller 1949 and *Sp. stabilis* (Branson and Mehl) 1934a. Sweet (1970, p. 221) has erected the multi-element genus *Anchignathodus* to contain late Permian and early Triassic elements similar to *Sp. cristulus*, and Ziegler *et al.* (1974, p. 103) have placed *Sp. stabilis* within *Bispathodus*. We retain *Spathognathodus* as the generic category for the Ballyvergin elements, because it remains to be proved that early Carboniferous *Sp.* cf. *cristulus* were components of *Anchignathodus* assemblages, (see, for instance, Druce *et al.* 1972), and because all the known Irish specimens of *Sp. stabilis* lack accessory denticles, a distinguishing feature of *Bispathodus*.

Spathognathodus cf. *cristulus* Youngquist and Miller 1949.

The Ballyvergin specimens are closely comparable to *Sp. cristulus* Youngquist and Miller, whose type is from the Pella Formation of Iowa of late Mississippian (late Dinantian) age. They have between six and ten (normally seven or eight) denticles behind the prominent anterior denticle. Although only few statistics for *Sp. cristulus* are available, it appears from the illustrated types (Youngquist and Miller 1949, pl. 101, figs 1-3) and other examples, that the normal total number of denticles may be greater, perhaps ten or eleven. An increase in the number of denticles with time might be anticipated, in the light of the findings of Merrill (1973) concerning the evolution of *Sp. minutus* and *Sp. ellisoni,* the descendants of *Sp. cristulus*. One of the Ballyvergin specimens (in TCD 19830) has a small denticle anterior to the main denticle, a feature which according to Merrill (p.307) is not known in *Sp. cristulus.*

Similar spathognathodids have been reported from comparable stratigraphical levels in the British Isles (Rhodes *et al.* 1969, p. 227, 293; Austin and Husri 1974, pl. 8, figs 1,2; Butler 1973, pl. 59, fig. 18 as *Sp. crassidentatus* (Branson and Mehl 1934b)).

Spathognathodus stabilis (Branson and Mehl 1934a).

The Ballyvergin specimens accord with Klapper's (1966, p. 23) diagnosis of *Sp. stabilis,* and with the concept of the species as understood by Matthews (*in* Matthews and Naylor 1973, p. 379). Some of the specimens are transitional to *Sp. crassidentatus* in that the two anterior denticles are slightly larger than the remainder.

Prioniodina oweni Rhodes, Austin, and Druce 1969.

Specimens assigned to this species are straight to slightly curved elements, each with a prominent compressed posteriorly directed apical denticle, a short posterior process with 1-3 short denticles, and an anterior process with 3-6 denticles. They each have a distinctive basal cavity which tapers anteriorly, but has an arcuate margin at, or close to, the posterior end. Similar elements were identified as *Spathognathodus* cf. *bultyncki* Groessens by Groessens (1971, p. 15, pl. 1, figs 2,3).

Gnathodus cf. *delicatus* Branson and Mehl 1938.

American and European concepts of *G.*

delicatus differ in important respects (see Rexroad and Scott 1964; Thompson and Fellows 1970; Matthews *et al.* 1972; Matthews and Naylor 1973). The Ballyvergin specimens are small, and comparable to that figured by Matthews *et al.* (1972, pl. 110, fig. 6) in having a single straight row of nodes on both the inner and outer sides, which meet the carina near the posterior end.

Miospore systematics

The terminology and classification used are those of Grebe (1971) and Neves and Owens (1966) respectively.

Anteturma SPORITES H. Potonié 1893.
Turma TRILETES (Reinsch) Dettmann 1963.
Suprasubturma ACAMERATITRILETES Neves and Owens 1966.
Subturma AZONOTRILETES (Luber) Dettmann 1963.
Infraturma LAEVIGATI (Bennie and Kidston) R. Potonié 1956.
Genus RETUSOTRILETES Naumova 1953.

Type species: Retusotriletes simplex Naumova 1953.

Retusotriletes crassus Clayton sp. nov.
Fig. 3, D, G and H.

1969 *Phyllothecotriletes* sp. no. 840 Lanzoni and Magloire, pl. 1, figs 3 and 4.
1975 *Retusotriletes* sp. A. Higgs, p. 395, pl. 1, figs 9 and 13.

Holotype: Fig. 3D (TCD 20013)

Type locality: Channel sample from depth 200-205′, Ballyvergin borehole, County Clare, Ireland.

Dimensions: 43 (56) 73 μm, 25 specimens, 200-205′.

Diagnosis: Spores radial, trilete, acamerate. Amb circular to oval, or rarely rounded triangular. Suturae rarely seen; straight, simple, and approximately three quarters of the spore radius in length. The suturae terminate in curvaturae perfectae which delimit the contact areas. Large thickened sectors are present in the contact areas, separated from each other by radial zones of thin, granulose exine 2-8 μm wide along the suturae, and separated from the curvaturae by a concentric zone of similar width and nature. The equatorial and distal exine is relatively thick and more or less laevigate.

Comparsion: Retusotriletes crassus sp. nov. is distinguished from other species of *Retusotriletes* by the large thickened sectors within the contact areas.

Infraturma APICULATI (Bennie and Kidston) R. Potonié 1956.
Genus APICULATISPORIS Potonié and Kremp 1956.

Type species: Apiculatisporis aculeatus (Ibrahim) Smith and Butterworth 1967.

Apiculatisporis heteroconus Clayton sp. nov.
Fig. 3, E, F, and I.

Holotype: Fig. 3F. (TCD 20017)

Type locality: Channel sample from depth 200-205′, Ballyvergin borehole, County Clare, Ireland.

Dimensions: 57 (66) 79 μm, 25 specimens, 200-205′.

Diagnosis: Spores radial, trilete, acamerate. Amb rounded convexly triangular. Trilete mark normally indistinct. Suturae straight, simple; length at least three quarters of spore radius. Distal and equatorial exine approximately 2 μm thick, somewhat thinner on proximal surface. The distal and equatorial ornament consists mainly of coni with subsidiary spinae 2-4 μm high, which often coalesce at the base. Interspersed between the larger elements are much smaller coni and grana up to 1 μ m in basal diameter. The ornament is strongly reduced on the proximal surface.

Comparison: Apiculatisporis pineatus Hoffmeister, Staplin and Malloy (1955) has relatively coarse ornament consisting of more rounded elements. *?Apiculatisporis porosus* Williams *in* Neves *et al.* (1973) has a more strongly foveolate exine.

Genus CRASSISPORA (Bharadwaj) Sullivan 1964.

Type species: Crassispora kosankei (Potonié and Kremp) Bharadwaj 1957.

Crassispora maculosa (Knox) Sullivan 1964. Fig. 3O.

Dimensions: 80 (94) 111 μm, 20 specimens, 347′6″.

Description: Spores radial, trilete, variably camerate. Amb circular to oval. Trilete mark distinct, often gaping. Suturae straight, simple; length at least four fifths of spore radius, terminate in curvaturae perfectae. The equator and distal surface are thickened relative to the proximal surface, and are ornamented by small coni up to 1 μ m high. On rare specimens a folded, membranous intexine can be seen.

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ERRATUM

CLAYTON, G., JOHNSTON, I.S., SEVASTOPULO, G.D. (1980). Micropalaeontology of a Courceyan (Carboniferous) borehole section from Ballyvergin, County Clare, Ireland. *J. Earth Sci. R. Dubl. Soc. 3*, 81-100.

Due to a printer's error subsequent to the return of the corrected proofs by the authors, a seriously misleading line implying the use of tetrabromoethane in palynological preparation techniques was wrongly inserted in the above paper (p. 85, line 33). The section dealing with preparation techniques should read as follows:

Micropalaeontological preparation techniques

The core from 303' upwards was split into 5' channel samples, which were then crushed and dissolved in 10% acetic acid. Most of the samples consisted of all the limestone available in a 5' section, and weighed from 0.25 kg low in the succession to approximately 3 kg in the shale-free limestones. The acid-insoluble residues were floated in tetrabromoethane, and the conodonts picked from the heavy fraction.

100 g mudrock samples were prepared for palynology, mainly from 5' channels from the core. The rock was dissolved in warm, 40% hydrofluoric acid, and the neutralised organic residue oxidised with fuming nitric acid. The oxidised residues were mounted using 'Clearcol' dispersal agent and 'Elvacite' mounting medium.

The conodont faunas and palynomorph assemblages are reposited in the collections of the Department of Geology, Trinity College, Dublin. A single catalogue number has been allocated to the total conodont fauna from each 5' channel sample; type and other figured palynomorphs have been individually catalogued.