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On Jurassic Coccoliths: A tentative zonation of the Jurassic of Southern England and North France[1])

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ABSTRACT

This paper presents the first attempt at an overall zonation of the Jurassic by use of coccoliths. The area chosen, Southern England, includes many of the classic localities of the Jurassic, with almost continuous sequences. Twenty-two zones are proposed and these are correlated with the existing ammonite zonation. The range zones, distribution of the assemblages and their relationship to the lithofacies are discussed.

The study has been carried out both optically and with the aid of an electron microscope.

Introduction and Review of previous Zonations of the Jurassic, using calcareous nannofossils

Although several studies have now been published on Jurassic coccoliths, they are mostly concerned with description, and taxomony of the flora, and no attempt has been made to produce a detailed overall zonation of the Jurassic.

BRONNIMANN (1955) utilizing nannoconids exclusively, proposed a three-fold subdivision of the latest Jurassic and earliest Cretaceous rocks, basing his study on samples collected mostly from Cuba. His one Jurassic unit was the *Nannoconus steinmanni* Zone, characterised by the abundant occurrence of that species, and the absence of other nannoconids. The age of the *Nannoconus steinmanni* Zone was considered to be "Tithonian" or Purbeckian.

STRADNER (1963) was the first to realize the stratigraphical importance of coccoliths through the whole of the Jurassic, in a general discussion on Mesozoic nannofossils. He established five divisions of the Jurassic (including BRONNIMANN's *Steinmanni* zone), based on "associations", and limited by the first appearances of these "assemblages":

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Table 1

Purbeckian	"*Nannoconus*" Zone	*Nannoconus* associations related to Lower Cretaceous floras
Callovian–Portlandian	*Bigoti* association	*Stephanolithion bigoti* easily recognized in Callovian–Oxfordian
Bathonian	*Decorus* association	Double rimmed "trumpet" forms *Rhabololithus decorus*
Pliensbachian–Bajocian	*Opacus* association	Appearance of *Discolithus crassus* and *Coccolithus opacus*
Sinemurian	*Liasicus* association	*Rhabdolithus liasicus*

The authors, in the tables, have used the names given to the genera and species by STRADNER, NOËL, PRINS, etc., but have brought them up to date in the discussion.

Of STRADNER's five zonal "associations" the oldest of these was the "*Liasicus*"-association, which he indicated was characterized by the presence of *Schizosphaerella punctulata* DEFLANDRE and *Parhabdolithus liasicus* DEFLANDRE. He listed the age of the "*Liasicus*"-association as Sinemurian. The next oldest assemblage was the "*Opacus*"-association, which was characterized by the presence of the two species of the underlying "*Liasicus*"-association and *Discolithus crassus* DEFLANDRE and *Coccolithus opacus* STRADNER.

Discolithus crassus is now known as *Crepidolithus crassus*, but the identity of *Coccolithus opacus* in terms of the species recognized by recent authors is uncertain. The age of "*Opacus*"-associations was given as Pliensbachian, Aalenian and Bajocian. The next higher assemblage was termed "*Decorus*"-association, and was indicated to be wholly different from those below. Four species were listed: *Coccolithus britannicus* STRADNER, *Hexalithus lecali* GARDET, *Discolithus asper* STRADNER, and *Rhabdolithus decorus* DEFLANDRE. *Coccolithus britannicus* is now known as *Watznaueria britannica; Discolithus asper* may be conspecific with *Ethmorhabdus gallicus* NOËL or *Ethmorhabdus anglicus* ROOD, HAY & BARNARD; "*Rhabdolithus decorus*" of STRADNER was a species of *Discorhabdus; Hexalithus lecali* was a nannofossil not readily identified with species recognized today. The age of the "*Decorus*"-association was given as Bathonian. The next higher assemblage was termed the "*Bigoti*"-association, recognized by an abundance of *Stephanolithion bigoti* DEFLANDRE. Other species indicated to be present included *Coccolithus britannicus*, *Discolithus asper*, *Zygolithus fibulus* (LECAL) and *Coccolithus pelagius* (WALLICH). Specimens referred by STRADNER to *Zygolithus fibulus* would now be assigned to *Zeugrhabdotus erectus* (DEFLANDRE) or *Zeugrhabdotus noeli* ROOD, HAY & BARNARD. The specimens STRADNER identified as *Coccolithus pelagicus* are now termed *Watznaueria communis* REINHARDT. The age of the "*Bigoti*"-associations was given as Callovian, Oxfordian, Kimmeridgian and Portlandian. The highest Jurassic assemblage recognized by STRADNER was termed *Nannoconus steinmanni*-association, and indicated to include *Discolithus asper*, *Coccolithus pelagicus* and *Parhabdolithus embergeri* (NOËL) in addition to *Nannoconus steinmanni*. The age of the *Nannoconus steinmanni*-association was given as Portlandian. Comments on the relation of STRADNER's "associations" with the zones recognized here is presented below in the discussion of each of the biostratigraphic units.

NOËL (1965*b*) in her monograph on Jurassic coccoliths presented the ranges of most species, but did not stress their stratigraphical importance, although (p. 174–177) a short discussion was given summarized as follows in Table 2:

Table 2

Portlandien – Valanginien		Rich, appearance of new Lower Cretaceous assemblages, including *Nannoconus* group	
Kimmeridgien	Malm	Poor, remnants from Oxfordien	
Oxfordien		Richest group; *Stephanolithion bigoti*	
Callovien	Dogger	Poor but heralds Oxfordien acme	
Bathonien		Poor, least characteristic	
Bajocien		Abundant only in the marls	
Aalénien			
Toarcien	Lias	Characterized by "massive" coccoliths	*Crepidolithus crassus*
Charmouthien			*Parhabdolithus liasicus*, *marthae*, *robustus*, *Crepidolithus crassus*
Sinémurien			

Although differences occur there is a strong similarity between the divisions of STRADNER and NOËL. The differences are largely due to the much more extensive study of the Jurassic coccoliths by NOËL, and also to the different emphasis given by both authors, according to whether the study was made by light or electron microscopy.

PRINS (1969) presented a zonation for the Lower and Middle Lias, based on study of samples from England, France and western Germany. Many of the species listed on his range chart had not been formally described, but he presented a series of useful drawings which have allowed subsequent authors, particularly ROOD, HAY & BARNARD (1973), to recognize and validate most of them. He concentrated on two aspects, the evolution of Liassic coccoliths and also the zonal sequence, summarized as follows (see Table 3, p. 566).

PRINS recognized four zones and five subzones. The lowest unit, termed the *Crucirhabdus* Zone was indicated to extend from the base of the range of "*Crucirhabdus primulus*" to the base of the range of *Parhabdolithus liasicus* DEFLANDRE. This unit was succeeded by the *Parhabdolithus* Zone, divided into a lower *Parhabdolithus marthae* Subzone and an upper *Parhabdolithus liasicus* Subzone. The lower subzone has the appearance of *Parhabdolithus liasicus* as its base, and the disappearance of *Parhabdolithus marthae* as its top. The upper subzone apparently has the appearance of "*Paleopontosphaera veterna*" as its top. In our work, we have interpreted these low occurrences of *Paleopontosphaera* as belonging to *Paleopontosphaera dubia* NOËL. The next higher unit is the *Crepidolithus* Zone, divided into a lower *Crepidolithus cavus* Subzone and a *Crepidolithus crassus* Subzone.

PRINS indicated the range of *Crepidolithus cavus* to begin just below the base of the *Crepidolithus cavus* Subzone, and that of *Crepidolithus crassus* to begin in the middle of the *Crepidolithus cavus* Subzone. It is evident that the limits of these units were marked by events other than the appearance of the name species. As noted above, the base of the *Crepidolithus cavus* Subzone coincides with the base of the range

Table 3

Nannoplankton Zone	Subzones	Ammonite Zone		Time Stratigraphic Zonation	
Striatococcus Zone	*Striatococcus opacus*	*tenuicostatum*	L	Toarcian	Upper Lias
		spinatum	U		
	Crepidolithus crassus	*margaritatus*		Pliensbachian	Middle Lias
Crepidolithus Zone	*Crepidolithus cavus*	*davoei*			
		ibex	L		
		jamesoni			
		raricostatum			
Parhabdolithus Zone	*Parhabdolithus liasicus*	*oxynotum*			
		obtusum	U		
		turneri		Sinemurian	
	Parhabdolithus marthae	*semicostatum*	L		
		bucklandi			Lower Lias
Crucirhabdus Zone		*angulata*	U		
		Als. liasicus		Hettangian	
		planorbis	L		
		pre-planorbis			

of "*Paleopontosphaera veterna*". The base of the *Crepidolithus crassus* Subzone coincides with the base of the range of "*Lucidiella intermedia*" or "*Mitrolithus irregularis*", two species which we have been unable to recognize. PRINS' highest unit he termed the *Striatococcus* Zone, with a single subzone, the *Striatococcus opacus* Subzone. The base of this unit was clearly intended to be defined by the base of the range of "*Striatococcus opacus*", which we assume is *Coccolithus opacus* STRADNER. Recent authors have been uncertain as to the identification of this species, and the name has not been used since PRINS' paper appeared.

WORSLEY (1971) proposed a zonation for the latest Jurassic and early Cretaceous encountered in Holes 4 and 5A of the Deep Sea Drilling Project. Brief accounts of the calcareous nannofossils from the two holes, drilled just east of the Bahamas Platform, had been published by BUKRY & BRAMLETTE (1969) and HAY (1969). To each of these investigators, seven samples were available, three from Hole 4 and four from Hole 5A. The relative position of the samples from the two holes has become a matter of controversy, and because each of the samples was regarded as the type level of a zone by WORSLEY, some discussion is necessary. WORSLEY adopted a short form of referring to the samples, assigning them letters of the alphabet. This is a convenient form of terminology for the following discussion, and is utilized here. The terminology and sequence of the samples is as follows:

Sample	Hole	Barrel	Section	Depth in section	Depth below sea floor
G	4	3	1	20 cm	134 m
B	4	4	1	80 cm	191 m
A	4	5	core catcher		207 m
F	5A	3	core catcher		145 m
E	5A	4	1	30 cm	185 m
D	5A	6	core catcher		236 m
C	5A	7	core catcher		274 m

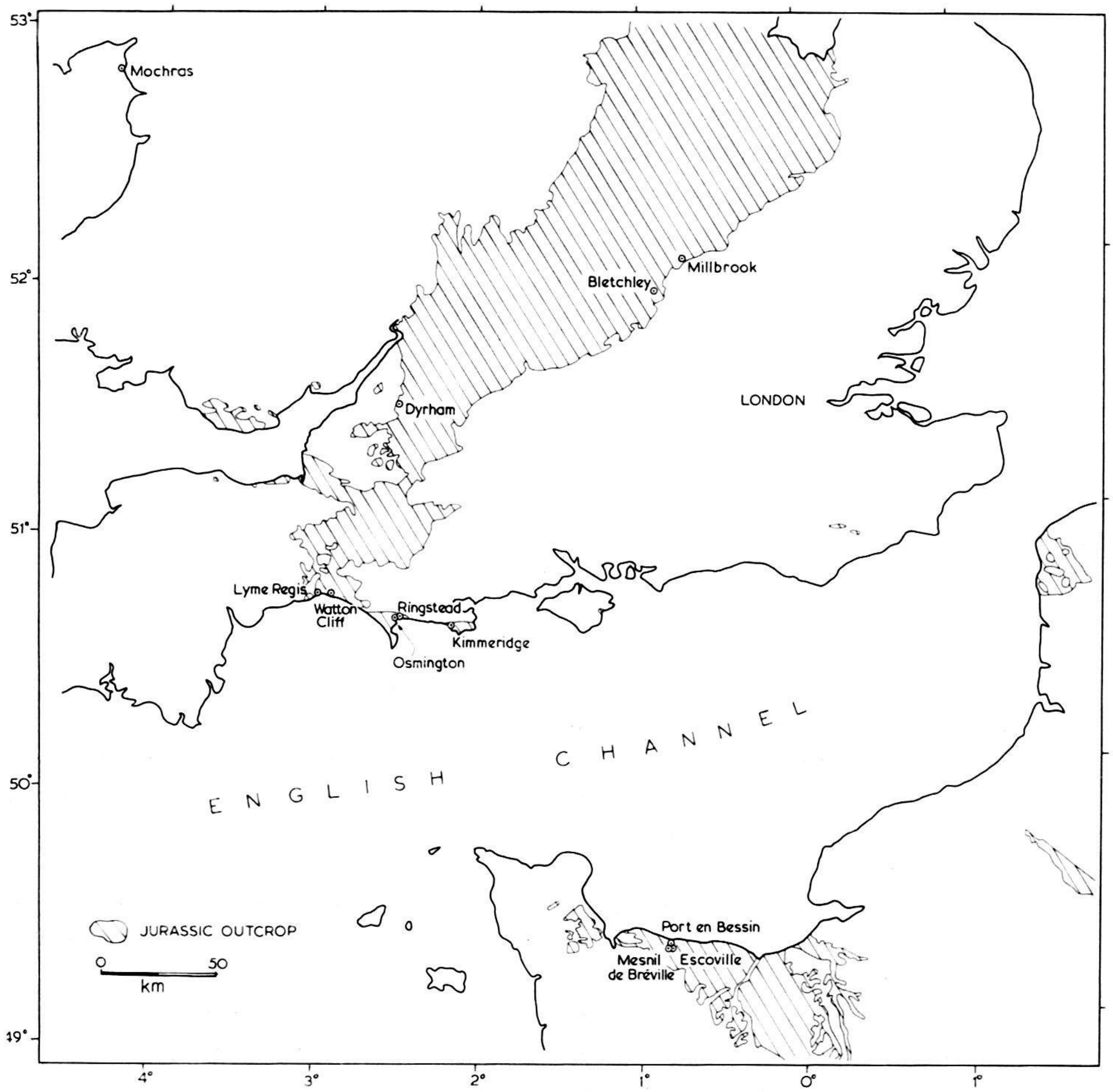

Fig. 1. Outcrop of Jurassic rocks of Southern England and Northern France (Normandy) showing position of major collecting areas.

From superposition, it is evident that in Hole 4, sample G overlies sample B, which in turn overlies sample A. In Hole 5A, the sequence, from top to bottom is F, E, D, C. In attempting to place the samples from these two holes into a single sequence, the authors arrived at somewhat different conclusions. HAY gave no age determinations for four of the samples, and his determination for the remaining three indicates the sequence, from top to bottom: G, D, B. BUKRY & BRAMLETTE provided age determination for all of the samples, suggesting a sequence, from top to bottom: F, G, E, B, D, A, C. WORSLEY rearranged the sequence of the samples, determining it to be, from top to bottom: G, F, E, D, C, B, A. Using this sequence, he recognized seven zones, two of which were considered to be Jurassic. WORSLEY's lowest unit was termed the *Parhabdolithus embergeri* Zone, defined as extending from the lowest occurrence of *Parhabdolithus embergeri* to the lowest occurrence of *Nannoconus steinmanni*. This unit has been adopted here. WORSLEY considered the age of this zone to be Kimmeridgian–Portlandian, and this is consistent with our results. His highest Jurassic unit was termed the *Nannoconus steinmanni* Zone, and was defined as extending from the lowest occurrence of *Nannoconus steinmanni* to the lowest occurrence of *Diadorhombus rectus* WORSLEY. He considered its age to be Portlandian. This unit is also included in our zonation of the Jurassic, although we have not studied samples containing its assemblage.

THIERSTEIN (1971) questioned WORSLEY's zonation, proposing an almost wholly different scheme for zonation of the latest Jurassic and early Cretaceous. His results were based on studies of sections in South Western Europe, and on reinterpretation of the samples from Holes 4 and 5A of the Deep Sea Drilling Project. He rearranged the order of the samples to be, from top to bottom: G, F, E, B, A, D, C. THIERSTEIN's sequence differs from that of WORSLEY in assuming that samples C and D lie below A. An interesting feature of THIERSTEIN's sequence is that by following it, all samples are in order by depth below the sea floor. This is not an unreasonable or extraordinary circumstance, because the two sites are only 20 miles apart.

THIERSTEIN proposed a single zone which extended into the uppermost Jurassic, the *Nannoconus colomi* Zone. *Nannoconus colomi* (DE LAPPARENT) is considered to be the senior synonym of *Nannoconus steinmanni*, so the case of this zone defined by the earliest occurrence of *Nannoconus colomi* corresponds to the base of the *Nannoconus steinmanni* zone of BRONNIMANN (1955), STRADNER (1963), and WORSLEY (1971). THIERSTEIN considered the type sample (A) of WORSLEY's *Parhabdolithus embergeri* Zone to be much younger, and assigned it to his *Calcicalathina oblongata* Zone, which he considered to be of Valanginian–Hauterivian age. Although THIERSTEIN stated that the assemblage of sample A was identical to that of this *Calcicalathina oblongata* Zone except that it lacked *Nannoconus colomi* and *Micrantholithus hoschulzi* (REINHARDT) his range chart indicated more extensive differences. Sample A lacks *Rucinolithus wisei* THIERSTEIN, *Manivitella pemmatoidea* (DEFLANDRE ex MANIVIT), *Bipodorhabdus roeglii* THIERSTEIN, and *Diadorhombus rectus* WORSLEY, all species considered characteristic of the *Calcicalathina oblongata* Zone. THIERSTEIN discounted the absence of these species and considered the absence of *Nannoconus colomi* and *Micrantholithus hoschulzi* to have been "influenced by water depth and temperature", so that "their absence should not be used exclusively for biostratigraphic correlation". This seems an unusual conclusion because of the spatial proximity of the samples from Holes 4 and 5A.

MEDD (1971) dealt with coccoliths from the Middle and Upper Jurassic, from a number of localities in S. England and N. France, giving occurrences of the various species in the different ammonite zones. No zonation however, was given.

WILCOXON (1972) reported the occurrence of calcareous nannofossils in late Jurassic and early Cretaceous strata cored at sites 99, 100, 101 and 105 by the Deep Sea Drilling Project. Although he did not propose a zonation scheme, he recognized a sequence of datum levels considered important for biostratigraphy. The Jurassic datum levels of WILCOXON are all lowest occurrences, and are indicated below:

Highest:	LOS	*Cretarhabus splendens, Lithraphidites carniolensis, Braarudosphaera discula*
	LOS	Nannoconids
	LOS	*Stephanolithion lafittei*
	LOS	*Podorhabdus quadriperforatus*
	LOS	*Cyclagelosphaera margereli*
Lowest:	LOS	*Watznaueria britannica*

The oldest samples studied by WILCOXON, core catcher samples from barrels 8, 9, 10 and 11 at site 100 contain relatively sparse assemblages; the lowest sample contains only four species, and must be regarded as abnormal. The sequence of other lowest and highest occurrences in the late Jurassic found by WILCOXON is particularly interesting in that the highest occurrence of *Stephanolithion bigoti* DEFLANDRE is below the lowest occurrence of *Parhabdolithus embergeri*. WILCOXON found nannoconids to appear at the same level as *Parhabdolithus embergeri*, but on his range chart he indicated this horizon to lie below the lowest occurrence of an interesting species he referred to as *Corollithion* sp.

His illustration of *Corollithion* sp. reveals that it is identical with *Diadorhombus rectus* WORSLEY. Detailed examination of WILCOXON's data reveals nothing that conflicts with WORSLEY's (1971) zonation. However, the ranges for a number of species in the North Atlantic, particularly *Glaukolithus diplogrammus*, *Cyclagelosphaera margereli*, *Diazomatolithus lehmani* and *Cretarhabdus crenulatus* as reported by WILCOXON differ markedly from their ranges in South Western Europe as reported by THIERSTEIN (1971).

THIERSTEIN's zonation is not readily applicable to WILCOXON's data. Comparison of the ranges indicated by WILCOXON with those by WORSLEY and THIERSTEIN suggests that WORSLEY's interpretation of the sequence of samples from Deep Sea Drilling Holes 4 and 5A was correct.

Systematics

INCERTAE SEDIS

Genus *Annulithus* ROOD, HAY & BARNARD

Type: *Annulithus arkelli* n. sp. ROOD, HAY & BARNARD (Genotype: 40.5.1).
Type locality: Lyme Regis, Dorset.
Type level: Lias, Bed, Hl (LANG), Lower Hettangian, *Ostrea liasica* Zone.

Diagnosis: A coccolith-like object consisting of a simple ring of a few large, coarse, irregular elements.

Annulithus arkelli n. sp. ROOD, HAY & BARNARD

Pl. I, Fig. 1 and Pl. IV, Fig. 1

Diagnosis: As for genus.
Description: The type specimen consists of about 10 irregular elements, arranged into a circlet. The elements are apparently mostly organic and the degree of calicification is relatively light in comparison with most coccoliths.

Remarks: This coccolith has been named after the late Dr. W. J. Arkell in honour of his important contributions to Jurassic stratigraphy. The coccolith is abundant and important enough to warrant a zone named after it. It is the oldest coccolith we have encountered and may represent the ancestral primitive form which gave rise to the coccolithophorids. A similar object was reported from Permian strata in Turkey by PIRINI RADRIZZANI (1971) as *Cricolithus* sp.

Calcareous nannofossil zones of the Jurassic

Annulithus arkelli Zone

Definition: Interval from the lowest occurrence of *Annulithus arkelli* ROOD, HAY & BARNARD to the lowest occurrence of *Crucirhabdus primulus* PRINS ex ROOD, HAY & BARNARD.

Species present: *Annulithus arkelli* rare to common, *Crepidolithus cavus* PRINS ex ROOD, HAY & BARNARD is rare to common but its occurrence is not consistent in all samples from the interval; *Tubirhabdus patulus* PRINS ex ROOD, HAY & BARNARD and *Vekshinella quadriarculla* (NOËL) are rare in this interval; *Schizosphaerella punctulata* DEFLANDRE is common to rare. The occurrence of *Annulithus arkelli* is consistent. It has its lowest occurrence below that of any of the other species and is present in all of the samples from this interval examined in the course of the investigation. The other species are present in only a few samples, and may be absent through dissolution from others.

Remarks: PRINS (1969) indicated only a single species, *Crucirhabdus primulus*, to be present in the lowest Lias. Our investigation of the Dorset Lias reveals that several species are present, but that *Crucirhabdus primulus* does not appear at the base of the Lias. The evolutionary scheme of PRINS (1969) does not appear to be an accurate reflection of the occurrences of species in the Dorset Lias. It is possible that specimens referred to by PRINS as "*Crucirhabdus primulus*" var. "*nanus*" may belong to *Vekshinella quadriarculla*.

The *Annulithus arkelli* Zone corresponds to the lower part of the *Crucirhabdus* Zone of PRINS (1969).

Crucirhabdus primulus Zone

Definition: Interval from the lowest occurrence of *Crucirhabdus primulus* to the lowest occurrence of *Parhabdolithus liasicus* DEFLANDRE.

Species present: *Crucirhabdus primulus*, *Vekshinella quadriarculla* and *Zeugrhabdotus erectus* (DEFLANDRE) are common; *Schizosphaerella punctulata* is abundant and may be the dominant species in many samples; *Tubirhabdus patulus*, *Crepidolithus cavus*, *Crepidolithus crucifer* PRINS ex ROOD, HAY & BARNARD, and *Annulithus arkelli* are rare to common; *Chiastozygus primitus* PRINS ex ROOD, HAY & BARNARD is rare and sporadic in occurrence.

Remarks: This corresponds to the upper part of the *Crucirhabdus* Zone of PRINS (1969), in which he indicated *Tubirhabdus patulus* and "*Crucirhabdus expansus*" to be present along with an abundance of *Crucirhabdus primulus*.

Parhabdolithus marthae Zone

Definition: Interval from the lowest occurrence of *Parhabdolithus liasicus* to the highest occurrence of *Parhabdolithus marthae* DEFLANDRE.

Species present: *Parhabdolithus liasicus* and *Parhabdolithus marthae* tend to dominate samples from this interval; *Crucirhabdus primulus*, *Tubirhabdus patulus*, *Zeugrhabdotus erectus*, *Vekshinella quadriarculla* and *Schizosphaerella punctulata* are common to rare; *Crepidolithus crucifer*, *Crepidolithus cavus* and *Annulithus arkelli* are rare.

Remarks: PRINS (1969) indicated on his Table 1 that the lowest occurrence of *Parhabdolithus marthae* was slightly higher than the lowest occurrence of *Parhabdolithus liasicus* and the same sequence of appearance has been noted in our study of the Dorset Lias. PRINS apparently intended the lower limit of his *Parhabdolithus* Zone – *Parhabdolithus marthae* Subzone to be marked by the lowest occurrence of *Parhabdolithus liasicus*, so that the interval as defined here corresponds exactly to the *Parhabdolithus marthae* Subzone of PRINS.

Parhabdolithus liasicus Zone

Definition: Interval from the highest occurrence of *Parhabdolithus marthae* to the lowest occurrence of *Paleopontosphaera dubia* NOËL.

Species present: In the Dorset Lias, *Crucirhabdus primulus*, *Tubirhabdus patulus* and *Parhabdolithus liasicus* are common, the latter species sometimes dominating the assemblages; *Zeugrhabdotus erectus*, *Vekshinella quadriarculla* and *Crepidolithus cavus* are rare to common; *Annulithus arkelli* is present, but always rare.

Remarks: PRINS (1969) evidently intended the *Parhabdolithus liasicus* Subzone of his *Parhabdolithus* Zone to be determined by the highest occurrence of *Parhabdolithus marthae* and the upper limit by the lowest occurrence of "*Paleopontosphaera veterna*". He did not recognize *Paleopontosphaera dubia* in the Lias, but apparently included it in his concept of "*P. veterna*". *Paleopontosphaera veterna* PRINS ex ROOD, HAY & BARNARD, is restricted to specimens which show vestiges of a central cross, and does not appear until the late Lias.

STRADNER (1963) proposed a "nannoplanktonic zone, which might be called '*Liasicus*'-association", characterized by an abundance of *Parhabdolithus liasicus* and *Schizosphaerella punctulata*. It was undoubtedly intended to include the *Parhabdolithus liasicus* Zone as defined here, and probably portions or all of the overlying and underlying zones.

Paleopontosphaera dubia Zone

Definition: Interval from the lowest occurrence of *Paleopontosphaera dubia* to the lowest occurrence of *Crepidolithus crassus* (DEFLANDRE).

Species present: In the Dorset Lias *Crucirhabdus primulus*, *Parhabdolithus liasicus*, *Tubirhabdus patulus* and *Paleonpontosphaera dubia* are common; *Zeugrhabdotus erectus*, *Vekshinella quadriarculla*, *Crepidolithus cavus* and *Schizosphaerella punctulata* are rare to common. The rare species *Chiastozygus primitus* PRINS ex ROOD, HAY & BARNARD has its highest occurrence in this zone.

Remarks: Prins (1969) indicated that the lower limit of his *Crepidolithus* Zone – *Crepidolithus cavus* Subzone was defined by the lowest occurrence of *Paleopontosphaera veterna*. As noted above, he probably included *Paleopontosphaera dubia* in his concept of "*Paleopontosphaera veterna*".

The upper limit of his *Crepidolithus cavus* Subzone seems to have been defined by the lowest occurrence of "*Mitrolithus irregularis*" or "*Lucidiella perforata*", species which we have been unable to recognize. Prins indicated that *Crepidolithus crassus* was rare in the early part of its range, becoming more abundant in superjacent strata. Because of the differences in species interpretation which may exist, it must be assumed that the *Paleopontosphaera dubia* Zone here defined is only an approximate equivalent of the *Crepidolithus cavus* Subzone of Prins. Stradner (1963) stated that the "*Liasicus*"-association was overlain by an "*Opacus*"-association, "characterized by the appearance of *Discolithus crassus* Deflandre and *Coccolithus opacus* Stradner... the first coccolith with double rim." Stradner's illustration of *Coccolithus opacus* indicates a placolith with a cribrate centre. We have not observed such a form in the Dorset Lias. Prins referred to "*Striatococcus opacus*" and indicated this species to be abundant in Upper Piensbachian and Lower Toarcian strata. Prins' illustration of the species shows no indication of a cribrate centre. The first coccolith having typical placolith form is *Paleopontosphaera dubia* and subsequent re-examination of type material may reveal that *Coccolithus opacus* and *Paleopontosphaera dubia* are identical. For the present, however, the identity of *Coccolithus opacus* is uncertain, and it is not clear whether any of the *Paleopontosphaera dubia* Zone corresponds to the "*Opacus*"-association of Stradner (1963).

Crepidolithus crassus Zone

Definition: Interval from the lowest occurrence of *Crepidolithus crassus* to the lowest occurrence of *Podorhabdus cylindratus* Noël.

Species present: *Crepidolithus crassus*, *Crepidolithus cavus*, *Paleopontosphaera dubia*, *Tubirhabdus patulus* and *Schizosphaerella punctulata* are common; *Crucirhabdus primulus* may be common in the base of this zone, but becomes rare and has its highest occurrence within this interval; *Parhabdolithus liasicus* is abundant in the lower part of this zone but becomes less abundant near the top; *Zeugrhabdotus erectus* and *Vekshinella quadriarculla* are rare to common.

Remarks: This zone cannot be regarded as a strict equivalent of the *Crepidolithus crassus* Subzone of Prins' (1969) *Crepidolithus* Zone, but may approximate the lower part of Prins' unit.

This interval is probably the closest approximation to the "*Opacus*"-association of Stradner (1963). On his range chart he indicated that *Parhabdolithus liasicus* was a constituent of the assemblage, and this interval occupies the upper part of the range of that species.

Podorhabdus cylindratus Zone

Definition: Interval from the lowest occurence of *Podorhabdus cylindratus* to the lowest occurrence of *Discorhabdus tubus* Noël.

Species present: *Podorhabdus cylindratus* is rare, and must be carefully sought to determine its lowest occurrence. *Tubirhabdus patulus*, *Zeugrhabdotus erectus*, *Vekshinella quadriarculla*, *Crepidolithus crassus*, *Crepidolithus cavus*, *Paleopontosphaera dubia* and *Schizosphaerella punctulata* are all present in samples from this interval in the Dorset Lias, but all tend to be rare. *Parhabdolithus liasicus* has its highest occurrence in this interval.

Remarks: This unit corresponds to part or all of PRINS' (1969) *Crepidolithus crassus* Subzone of his *Crepidolithus* Zone and the *Striatococcus opacus* Subzone of his *Striatococcus* Zone. As noted above, the identity of *Striatococcus opacus* is uncertain, so that detailed correlation with PRINS' zonation is not possible. The lower part of the *Podorhabdus cylindratus* Zone might belong to the "*Opacus*"-association of STRADNER (1963), because *Parhabdolithus liasicus* indicated on his range chart to be typical of that unit, has its highest occurrence in this zone.

Discorhabdus tubus Zone

Definition: Interval from the lowest occurrence of *Discorhabdus tubus* to the lowest occurrence of *Stephanolithion speciosum* DEFLANDRE.

Species present: *Discorhabdus tubus*, *Zeugrhabdotus erectus*, *Vekshinella quadriarculla*, *Crepidolithus crassus*, *Podorhabdus cylindratus* and *Paleopontosphaera dubia*, all having their lowest occurrence below this interval, are common in it at Dorset but tend to be rare in samples from Mochras (Wales). In contrast, *Tubirhabdus patulus* is rare in Dorset samples but common in one from Mochras. In addition to *Discorhabdus tubus*, *Podorhabdus macrogranulatus* PRINS ex ROOD, HAY & BARNARD, *Striatomarginis primitivus* ROOD, HAY & BARNARD, *Alvearium dorsetense* BLACK and *Paleopontosphaera veterna* PRINS ex ROOD, HAY & BARNARD all appear at the base of this unit and are common in it so that assemblages of this zone have a strikingly different aspect from the subjacent units.

Remarks: This zone does not correspond directly to any of the units of PRINS (1969) or STRADNER (1963).

Stephanolithion speciosum Zone

Definition: Interval from the lowest occurrence of *Stephanolithion speciosum* s. str. to the lowest occurrence of *Diazomatolithus lehmani* NOËL.

Species present: In samples from Port-en-Bessin (France), *Zeugrhabdotus erectus*, *Podorhabdus cylindratus*, *Striatomarginis primitivus* and *Paleopontosphaera dubia* are common in this zone; *Tubirhabdus patulus*, *Vekshinella quadriarculla*, *Crepidolithus cavus*, *Paleopontosphaera veterna* and *Discorhabdus tubus* are rare. All of these species are rare in samples from Dyrham (England). In addition to *Stephanolithion speciosum* s. str., *Hexapodorhabdus cuvillieri* NOËL, *Octopodorhabdus decussatus* (MANIVIT), *Watznaueria communis* REINHARDT, and *Discorhabdus biperforatus* ROOD, HAY & BARNARD appear at the base of this zone and are common in samples from both England and France. *Alvearium dorsetense* has its highest occurrence within this zone, being present in the sample from Dyrham.

Diazomatolithus lehmani Zone

Definition: Interval from the lowest occurrence of *Diazomatolithus lehmani* to the lowest occurrence of *Stephanolithion speciosum* var. *octum* Rood & Barnard.

Species present: *Zeugrhabdotus erectus*, *Stephanolithion speciosum* s. str. and *Watznaueria communis* are consistently common in this interval; *Vekshinella quadriarculla*, *Crepidolithus crassus*, *Paleopontosphaera dubia*, *Discorhabdus tubus*, *Ethmorhabdus gallicus*, *Hexapodorhabdus cuvillieri*, *Schizosphaerella punctulata* and *Discorhabdus biperforatus* are common to rare; *Tubirhabdus patulus*, *Crepidolithus cavus*, *Octopodorhabdus decussatus* and *Paleopontosphaera veterna* are rare. *Striatomarginis primitivus* and *Discorhabdus biperforatus* both have their highest occurrence within this interval; *Diadozygus asymmetricus* and *Cyclagelosphaera margereli* have their lowest occurrence in this unit, all of these species being generally rare.

Stephanolithion speciosum var. *octum* Zone

Definition: Interval from the lowest occurrence of *Stephanolithion speciosum* var. *octum* to the lowest occurrence of *Stephanolithion hexum* Rood & Barnard.

Species present: At Watton Cliff, *Zeugrhabdotus erectus*, *Vekshinella quadriarculla*, *Stephanolithion speciosum* s. str. and *Watznaueria communis* are common; *Paleopontosphaera dubia*, *Discorhabdus tubus*, *Ethmorhabdus gallicus* and *Cyclagelosphaera margereli* are common to rare; *Tubirhabdus patulus*, *Crepidolithus cavus*, *Podorhabdus cylindratus*, *Diazomatolithus lehmani*, *Hexapodorhabdus cuvillieri*, *Octopodorhabdus decussatus*, *Diadozygus asymmetricus* and *Schizosphaerella punctulata* are rare. The sample of this zone from Dyrham resembles those from Watton Cliff, but contains fewer species. *Watznaueria britannica* has its lowest occurrence in this interval and is rare.

Stephanolithion hexum Zone

Definition: Interval from the lowest occurrence of *Stephanolithion hexum* to the lowest occurrence of *Stephanolithion bigoti* Deflandre.

Species present: *Watznaueria communis* generally dominates the assemblages. *Crepidolithus crassus*, *Stephanolithion hexum*, and *Stephanolithion speciosum* var. *octum* are common; *Zeugrhabdotus erectus*, *Paleopontosphaera dubia*, *Discorhabdus tubus*, *Ethmorhabdus gallicus* and *Diazomatolithus lehmani* are common to rare; *Vekshinella quadriarculla*, *Hexapodorhabdus cuvillieri*, *Octopodorhabdus decussatus*, *Diadozygus assymmetricus*, *Watznaueria britannica* and *Cyclagelosphaera margereli* are rare. *Stephanolithion speciosum* s.str. has its highest occurrence in the lower part of this unit; *Tubirhabdus patulus* disappears near the top. *Schizosphaerella punctulata* becomes rare and its occurrence sporadic in this interval.

Remarks: Stradner (1963) described what he termed "*Decorus*"-associations from Bathonian samples. The species he listed as characteristic were *Coccolithus britannicus*, *Hexalithus lecali*, *Discolithus asper* and *Rhabdolithus decoratus*. *Coccolithus britannicus* Stradner is now *Watznaueria britannica* (Stradner) and has its lowest occurrence in the *Stephanolithion speciosum* var. *octum* Zone.

We have been unable to correlate any of the coccoliths in our samples with that identified by STRADNER as *Hexalithus lecali* GARDET. *Discolithus asper* STRADNER seems to be a species of *Ethmorhabdus*, but from the illustration it is not possible to determine with certainty whether it is the senior synonym of *Ethmorhabdus gallicus* NOËL, *Ethmorhabdus anglicus* ROOD, HAY & BARNARD, or is a distinct species. Examination of STRADNER's type material would be necessary to settle this question. Specimens illustrated by STRADNER as *Rhabdolithus decorus* DEFLANDRE represent *Discorhabdus patulus* or some other flaring species of that genus. From a consideration of the range of the species, it seems likely that STRADNER's "*Decorus*"-associations probably represent the upper part of the *Stephanolithion hexum* Zone.

Stephanolithion bigoti Zone

Definition: Interval from the lowest occurrence of *Stephanolithion bigoti* to the lowest occurrence of *Podorhabdus escaigi* NOËL.

Species present: *Watznaueria communis* tends to dominate the assemblages. *Zeugrhabdotus erectus*, *Paleopontosphaera dubia* and *Stephanolithion bigoti* are common; *Crepidolithus cavus*, *Crepidolithus crassus*, *Podorhabdus cylindratus*, *Stephanolithion hexum* and *Cyclagelosphaera margereli* are common to rare; *Vekshinella quadriarculla*, *Discorhabdus tubus*, *Ethmorhabdus gallicus*, *Diazomatolithus lehmani*, *Hexapodorhabdus cuvillieri*, *Octopodorhabdus decussatus*, *Paleopontosphaera veterna*, *Diadozygus asymmetricus*, *Watznaueria britannica* and *Stephanolithion speciosum* var. *octum* are rare. *Discorhabdus patulus* NOËL has its lowest occurrence at the base of this unit, and is common to rare. *Schizosphaerella punctulata* occurs sporadically. *Zeugrhabdotus noeli* ROOD, HAY & BARNARD has its lowest occurrence near the top of this zone.

Remarks: STRADNER (1963) named a unit the "*Bigoti*"-Zone ("*Bigoti*-associations" on his chart I) for assemblages "dominated by double rimmed coccoliths" with abundant *Stephanolithion bigoti*. STRADNER's unit may correspond to the *Stephanolithion bigoti* Zone as defined here or to any of the superjacent units up to the *Vekshinella stradneri* Zone.

Podorhabdus escaigi Zone

Definition: Interval from the lowest occurrence of *Podorhabdus escaigi* to the lowest occurrence of *Podorhabdus rahla* NOËL.

Species present: *Watznaueria communis* dominates assemblages of this zone. *Stephanolithion bigoti* is common; *Zeugrhabdotus erectus*, *Podorhabdus cylindratus*, *Paleopontosphaera dubia*, *Ethmorhabdus gallicus*, *Diadozygus asymmetricus* and *Cyclagelosphaera margereli* are common or rare. *Zeugrhabdotus noeli*, *Octopodorhabdus decussatus*, *Schizosphaerella punctulata*, *Watznaueria britannica* and *Vekshinella quadriarculla* occur sporadically.

Podorhabdus rahla Zone

Definition: Interval from the lowest occurrence of *Podorhabdus rahla* to the lowest occurrence of *Discorhabdus jungi* NOËL.

Species present: *Watznaueria communis* dominates the assemblages. *Stephanolithion hexum* and *Stephanolithion bigoti* are common; *Zeugrhabdotus erectus, Crepidolithus crassus, Podorhabdus cylindratus, Hexapodorhabdus cuvillieri* and *Cyclageosphaera margereli* are common to rare; *Discorhabdus tubus, Ethmorhabdus gallicus, Diazomatolithus lehmani, Diadozygus asymmetricus, Stephanolithion speciosum* var. *octum, Watznaueria britannica* and *Zeugrhabdotus noeli* are rare.

Remarks: This unit is represented by the upper part of the section at Bletchley and extends into the interval between the sections at Bletchley and Millbrook. It is not known whether the highest occurrence of *Stephanolithion hexum* is above or below the lowest occurrence of *Discorhabdus jungi*.

Discorhabdus jungi Zone

Definition: Interval from the lowest occurrence of *Discorhabdus jungi* to the lowest occurrence of *Diadozygus dorsetense* Rood, Hay & Barnard.

Species present: *Watznaueria communis* dominates; *Zeugrhabdotus erectus, Podorhabdus cylindratus, Discorhabdus tubus, Discorhabdus jungi, Podorhabdus escaigi,* and *Stephanolithion bigoti* are common; *Vekshinella quadriarculla, Paleopontosphaera dubia, Ethmorhabdus gallicus, Hexapodorhabdus cuvillieri, Octopodorhabdus decussatus, Diadozygus asymmetricus, Cyclagelosphaera margereli, Zeugrhabdotus noeli* and *Watznaueria britannica* are common to rare. *Diadozygus minutus* and *Truncatoscaphus delftensis* appear near the top of this unit and are rare.

Remarks: *Stephanolithion hexum* has its highest occurrence in the interval between the Bletchley and Millbrook sections, so it is uncertain whether it ranges into this zone.

Diadozygus dorsetense Zone

Definition: Interval from the lowest occurrence of *Diadozygus dorsetense* to the lowest occurrence of *Actinozygus geometricus* (Gorka).

Species present: *Watznaueria communis* dominates; *Zeugrhabdotus erectus* and *Stephanolithion bigoti* are common. *Vekshinella quadriarculla, Podorhabdus cylindratus, Paleopontosphaera dubia, Discorhabdus tubus, Ethmorhabdus gallicus, Hexapodorhabdus cuvillieri, Discorhabdus jungi, Zeugrhabdotus noeli, Discorhabdus patulus* and *Podorhabdus escaigi* are common to rare; *Octopodorhabdus decussatus, Watznaueria britannica, Diadozygus asymmetricus, Diadozygus minutus* and *Truncatoscaphus delftensis* are rare.

Actinozygus geometricus Zone

Definition: Interval from the lowest occurrence of *Actinozygus geometricus* to the lowest occurrence of *Vekshinella stradneri* Rood, Hay & Barnard.

Species present: *Watznaueria communis* dominates the assemblages; *Zeugrhabdotus erectus, Paleopontosphaera dubia, Discorhabdus tubus, Cyclagelosphaera margereli* and *Stephanolithion bigoti* are common; *Podorhabdus cylindratus, Ethmorhabdus gallicus, Hexapodorhabdus cuvillieri, Octopodorhabdus decussatus, Diadozygus* *asymmetricus, Diadozygus minutus, Diadozygus dorsetense, Podorhabdus escaigi* and *Watznaueria britannica* are rare.

Vekshinella stradneri Zone

Definition: Interval from the lowest occurrence of *Vekshinella stradneri* to the highest occurrence of *Stephanolithion bigoti*.

Species present: *Watznaueria communis* dominates the assemblages; *Zeugrhabdotus erectus, Paleopontosphaera dubia, Cyclagelosphaera margereli, Podorhabdus escaigi* and *Stephanolithion bigoti* are generally common; *Vekshinella quadriarculla, Podorhabdus cylindratus, Discorhabdus tubus, Ethmorhabdus gallicus, Hexapodorhabdus cuvillieri, Zeugrhabdotus noeli, Vekshinella stradneri* and *Diadozygus dorsetense* are common to rare; *Diadozygus asymmetricus, Watznaueria britannica* and *Truncatoscaphus delftensis* are rare. *Octopodorhabdus decussatus, Podorhabdus rahla* and *Diadozygus minutus* are rare and have their highest occurrence in this unit.

Remarks: This unit is represented by samples from Millbrook and by the Nothe Clay. A sample from Ringstead (R-1) belongs to this zone, but contains an impoverished assemblage.

Watznaueria communis Zone

Definition: Interval from the highest occurrence of *Stephanolithion bigoti* to the lowest occurrence of *Parhabdolithus embergeri* (NOËL).

Species present: *Watznaueria communis* dominates; *Paleopontosphaera dubia* and *Cyclagelosphaera margereli* are common; *Zeugrhabdotus erectus* is rare.

Remarks: This unit is represented in the lowest part of the sampled section at Kimmeridge. The assemblage is generally poor.

The existence of this unit might be questioned, because WORSLEY (1971) shows that *Stephanolithion bigoti* and *Parhabdolithus* occur together in Deep Sea Drilling Holes 4 and 5A off the Bahamas. However, the data of WILCOXON (1972) show a gap between the highest occurrence of *Stephanolithion bigoti* and the lowest occurrence of *Parhabdolithus embergeri* in Deep Sea Drilling Hole 105 in the western North Atlantic off North Carolina. The data of NOËL (1965) are also consistent with the presence of this unit.

Parhabdolithus embergeri Zone

Definition: Interval from the lowest occurrence of *Parhabdolithus embergeri* to the lowest occurrence of *Nannoconus colomi* (DE LAPPARENT).

Species present: *Watznaueria communis* dominates the assemblages; *Zeugrhabdotus erectus, Vekshinella quadriarculla, Paleopontosphaera dubia, Cyclagelosphaera margereli, Podorhabdus escaigi, Vekshinella stradneri, Diadozygus dorsetense* and *Parhabdolithus embergeri* are common to rare; *Ethmorhabdus gallicus, Diadozygus asymmetricus* and *Truncatoscaphus delftensis* are rare. *Crepidolithus crassus* and *Podorhabdus cylindratus* have their highest occurrence in this interval.

Remarks: Most of the Kimmeridgian section at Kimmeridge, and at Ringstead belongs to this zone. In definition, this corresponds exactly to the *Parhabdolithus embergeri* Zone of WORSLEY (1971).

Nannoconus colomi Zone

Definition: Interval from the lowest occurrence of *Nannoconus colomi* to the lowest occurrence of *Diadorhombus rectus* WORSLEY.

Species present: See WORSLEY (1971) and THIERSTEIN (1971).

Remarks: This unit corresponds exactly to the *Nannoconus steinmanni* Zone of WORSLEY (1971). THIERSTEIN noted that *Nannoconus colomi* is a senior synonym of *Nannoconus steinmanni* DEFLANDRE, according to FARINACCI (1964).

Coccolith distribution related to the Jurassic stages and existing Ammonite Zonation

The coccolith zones described earlier in the paper do not relate directly to the existing ammonite zonation and subsequent definition of the stages, it was, therefore, necessary to record this and briefly discuss the lithologies prevalent in these stages.

From the coccolith distribution chart (Fig. 2) it is clear that with minor differences there are three major floras: 1) a Liassic flora dominant in Lower and Middle Lias, with reduced number of species and individuals in the lower part of the Upper Lias; 2) this is replaced in the Upper Lias by a flora remaining dominant through the Middle Jurassic, and being reinforced by a second burst of species at the beginning of the Middle Jurassic. This flora continues, with significant reduction in the overall number of species, except for the addition of several new forms in the Cornbrash. 3) a new flora characteristic of the Upper Jurassic is introduced in the Callovian and early Oxfordian. This continues until a marked reduction of species occurs in the Corallian and throughout the Kimmeridgian.

Some of these changes are clearly related to major changes in facies. The largely clay facies of the Lias is replaced by a wide range of shallow water deposits including sands, clays, skeletal limestones of the Middle Jurassic, some of which are barren, but many still contain a considerable number of individual coccoliths as well as new species, so that a connection with open seas was maintained.

The Cornbrash deposits in England are for the most part thin hard limestones with no recovery of coccoliths, so the clay-facies of the North French equivalent of this "stage" was used.

These shallow water deposits were gradually replaced by the clay facies of the Callovian to Oxfordian and the third flora is common. However, a marked diminution of both individuals and species occurs with the shallow water, sands, skeletal limestones and oolites of the "Corallian" of Southern England. On the whole this period marks the decline of the Upper Jurassic floras, which continues sporadically throughout the Kimmeridgian.

The absences and reoccurrences of certain of the species throughout the Kimmeridgian may possibly be explained by the turbid environment, followed by the elimination

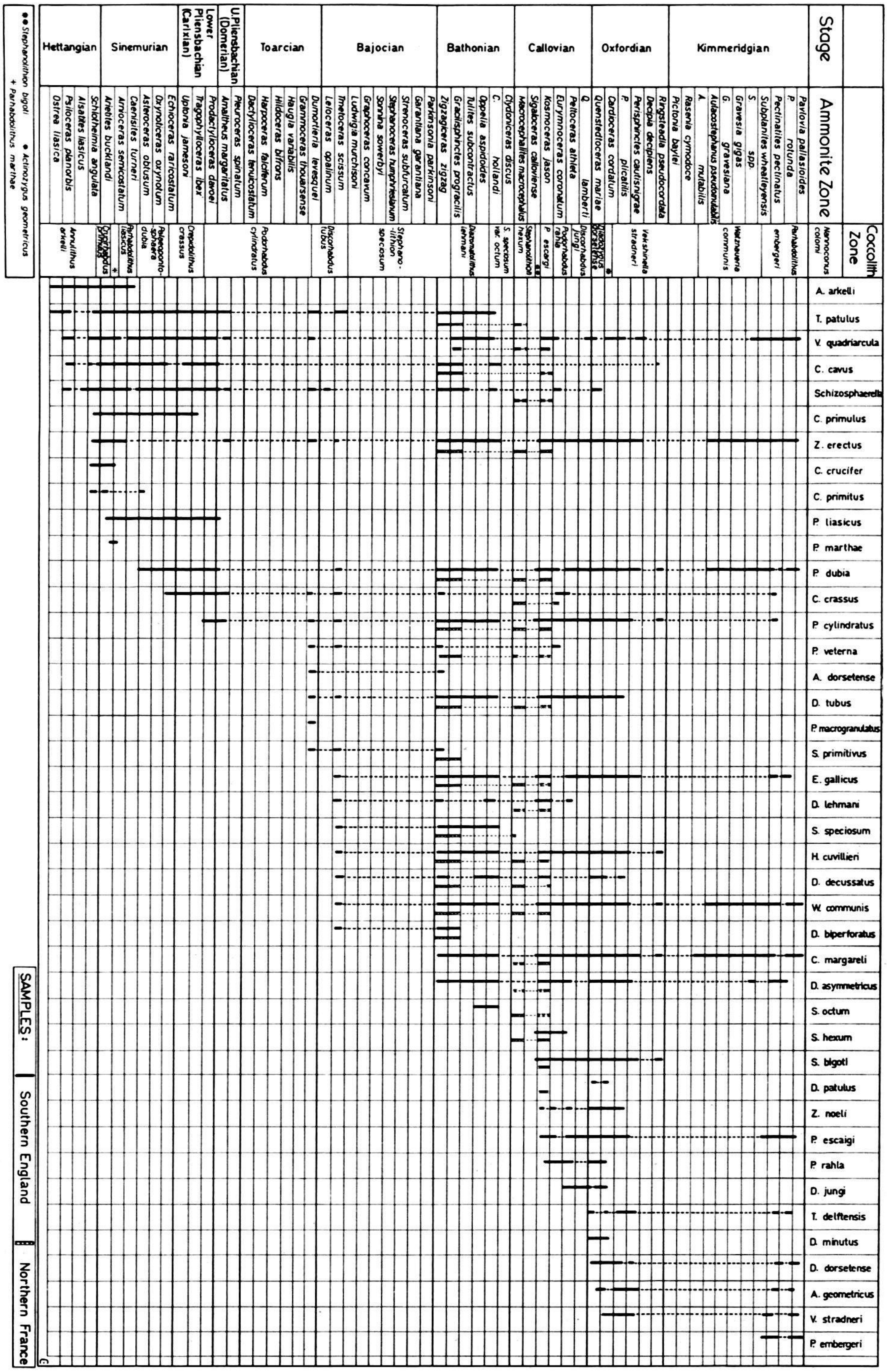

Fig. 2. Chart showing the distribution of Jurassic coccoliths, and a new coccolith zonation related to that of the ammonites.

of most of the calcareous flora and fauna by the action of organic acids at certain levels where bituminous remains are abundant. The obvious non-recovery of coccoliths from many of the shallow water skeletal limestones, oolites, sands of both the Middle Jurassic and "Corallian" emphasise these lithofacies changes.

LOWER JURASSIC

Stage HETTANGIAN

Zones *liasica–angulata*

The lithologies of the early part of this stage in Southern England consist of rapid alternation of dark shales and tabular limestones. The shales are often paper shales and a considerable amount of redistribution of the calcium carbonate has taken place subsequent to consolidation of the sediment. This factor contributes to what appears to be a slow introduction of the Liassic coccolith flora.

Ostrea liasica Zone

Is characterized by only two coccolith species: *Annulithus arkelli*, which is rare at the start of the zone, becoming established and abundant later, and *Tubirhabdus patulus*, which occurs in the upper part of the zone only.

Planorbis Zone

Annulithus arkelli is the most persistent and abundant coccolith, accompanied by sporadic occurrences of *Tubirhabdus patulus*, *Crepidolithus cavus*, *Vekshinella quadriarculla*.

Liasicus Zone

Apart from *Annulithus arkelli* which occurred throughout the zone, but sporadically at times, no other coccoliths were recorded.

Angulata Zone

Although *Annulithus arkelli* occurs throughout this zone, only sporadic horizons are abundant, and it is no longer the dominant species. This zone marks the introduction of most of the main elements of the Liassic flora. Some initially are rare and sporadic, but most become abundant and rapidly established. *Crucirhabdus primulus*, *Zeugrhabdotus erectus*, *Crepidolithus crucifer* occur for the first time, and *Crepidolithus cavus* and *Vekshinella quadriarculla* which occured in the *planorbis* Zone, but were absent from the *liasicus* Zone, recur and are much more abundant becoming main elements of the flora. Although rarer than the other species *Chiastozygus primitus* occurs sporadically.

Stage SINEMURIAN

Zones *bucklandi–raricostatum*

The lithologies for the most part are dark clays except for a few isolated thin tabular and nodular limestones. This more uniform lithology and conditions are reflected to a large extent in the abundance and persistence of the coccoliths. *Crucirhabdus primulus*, *Tubirhabdus patulus*, *Zeugrhabdotus erectus*, *Vekshinella quadriarculla* and *Crepidolithus cavus* occur throughout all the zones of the stage.

Bucklandi–semicostatum Zones

Two important species occur near the top of the *bucklandi* Zone, *Parhabdolithus liasicus* which remains abundant thoughout the rest of the Sinemurian, and *Parhabdolithus marthae* a short ranged but abundant coccolith which also occurs at the beginning of the *semicostatum* Zone only.

Obtusum Zone

Apart from *Parhabdolithus marthae* all other Sinemurian species occur with the addition of *Paleopontosphaera dubia*.

The non-sequence in Southern England between the *obtusum* Zone, *stellare* Subzone and *raricostatum* Zone, *densinodulum* Subzone, which eliminates the *denotatus*, *simpsoni* and *oxynotum* Subzones, does not seem to affect the distribution of the coccoliths, all Sinemurian species range through the gap, except the short range forms.

Stage PLIENSBACHIAN

Zones *jamesoni–spinatum*

In the early part of the stage, *ibex–davoei* Zones, the flora is abundant and a continuation of the Sinemurian. However later zones, *margaritatus–spinatum*, show a decline in the number of species and individuals. This is largely due to the sandy and silty clay facies that exists in Dorset at this age, the peculiar conditions are not conducive to coccoliths.

Stage TOARCIAN

Zones *tenuicostatum–levesquei*

This part of the succession in Dorset is characterised by condensed sequences and in general shallow water deposits, heralding the Middle Jurassic sedimentation. However at certain clay horizons an abundance of coccoliths occur, together with several important new species. *Tubirhabdus patulus*, *Zeugrhabdotus erectus*, *Vekshinella quadriarculla*, *Crepidolithus crassus* and *Paleopontosphaera dubia* still occur. *Podorhabdus macrogranulatus*, *Striatomarginis primitivus*, *Discorhabdus tubus* and *Alvearium dorsetense* are new.

MIDDLE JURASSIC

Stages BAJOCIAN–BATHONIAN

Zones *opalinum–discus*

The Middle Jurassic in S. England and N. France presents considerable problems for detailed zoning by coccoliths, as unfavourable lithologies, sand and oolitic limestones, and condensed sequences do not allow a continuous succession to be studied. So for the most part only isolated samples were taken, those from the Bajocian were barren. However in the Bathonian good clay horizons occur in the Fullers Earth sequence.

Tubirhabdus patulus, *Zeugrhabdotus erectus*, *Vekshinella quadriarculla*, *Crepidolithus cavus*, *Podorhabdus cylindratus*, *Striatomarginis primitivus*, *Paleopontosphaera* *dubia*, *Discorhabdus tubus* continue into and through the Bathonian from the Toarcian. New Bathonian species are *Ethmorhabdus gallicus*, *Dizomatolithus lehmani*, *Stephanolithion speciosum*, *Hexapodorhabdus cuvillieri*, *Octopodorhabdus decussatus*, *Watznaueria communis*, *Discorhabdus biperforatus*, *Diadozygus asymmetricus*, *Cyclagelosphaera margereli*.

Watznaueria communis dominates most Middle Jurassic samples. *Stephanolithion speciosum* var. *octum* occurs in the upper Bathonian.

Stage CALLOVIAN

Zones *macrocephalus–lamberti*

The early part of the Callovian is represented in Southern England by skeletal and oolitic limestones of the Cornbrash from which coccoliths are impossible to extract, however in Normandy these horizons are represented by clays. The Kellaways Clay also has a reduced flora, the residues contain much silt size quartz grains and a considerable amount of secondary iron. It is only high up in this stage and the subsequent Oxfordian that coccolith floras become extremely abundant. The Callovian stage has therefore not been separated out into zones.

Tubirhabdus patulus rare, *Zeugrhabdotus erectus* common, *Crepidolithus cavus* sporadic, *Crepidolithus crassus*, *Podorhabdus cylindratus* common, *Paleopontosphaera dubia* common, *Discorhabdus tubus* rare, *Ethmorhabdus gallicus* rare, *Diazomatolithus lehmani* rare, *Hexapodorhabdus cuvillieri* rare, *Octopodorhabdus decussatus* rare and sporadic. *Watznaueria communis* dominant, *Stephanolithion hexum* common to rare, *Diadozygus asymmetricus* sporadic to rare, *Stephanolithion speciosum* var. *octum* sporadic to rare, *Cyclogelosphaera margereli* persistent but rare, *Discorhabdus patulus* occurs near the end of the Callovian, *Stephanolithion bigoti*, common near the end of the Callovian, *Podorhabdus rahla* common in the late part of the stage, *Polypodorhabdus escaigi* is common.

UPPER JURASSIC

Stage OXFORDIAN

Zones *mariae–pseudocordata*

The clay facies of the later part of the Callovian is continued into the Oxfordian until late in the stage when in the *pseudocordata* Zone shallow water sediments dominate in the Corallian.

Zeugrhabdotus erectus common, *Vekshinella quadriarculla* sporadic, *Podorhabdus cylindratus* common, *Paleopontosphaera dubia* common, *Discorhabdus tubus* common at most horizons, *Ethmorhabdus gallicus* common to rare, *Hexapodorhabdus cuvillieri* common in earlier part of the stage becoming extinct later, *Watznaueria communis* dominant, *Diadozygus asymmetricus* rare to common but persistent, *Cyclagelosphaera margereli* common, *Podorhabdus rahla* extends into the lower part of the stage, *Discorhabdus jungi* confined to the earlier part of the stage, *Zeugrhabdotus noeli* common to rare, *Polypodorhabdus escaigi* common, *Stephanolithion bigoti* common, *Actinozygus geometricus* common in late stage, *Vekshinella stradneri* common in late stage, *Diadozygus dorsetense* common in late stage, *Truncatoscaphus delftensis* rare but persistent, *Diadozygus minutus* rare but persistent in the lower part of the stage.

Stage KIMMERIDGIAN

Zones *baylei–pallasioides*

The changes of lithology towards the end of the Oxfordian eliminate most of the Oxfordian flora, only a few species persisting in any numbers into the Kimmeridgian. *Zeugrhabdotus erectus* common, *Vekshinella quadriarculla* common but sporadic, *Podorhabdus cylindratus* dies out in lower part of the stage, *Paleopontosphaera dubia* sporadic, *Ethmorhabdus gallicus* rare but persistent, *Watznaueria communis* common, *Diadozygus asymmetricus* sporadic, *Cyclagelosphaera margereli* common, *Polypodorhabdus escaigi* common, *Parhabdolithus embergeri* common but confined to Kimmeridgian; *Vekshinella stradneri*, *Diadozygus dorsetense*, *Truncatoscaphus delftensis* are all rare but sporadic.

Acknowledgments

The authors wish to acknowledge the help given by Mr. Horrel, Geologist, London Brick Co. for arranging access to various quarries and helping with the collecting of the material and to Miss V. Russell for help in collecting Bathonian material from Calvados, reading the manuscript and for photographic help in preparing the plates; also to Dr. M.K. Curtis, Bristol Museum for supplying material from Dyrham. The collecting of material from northern France was partly financially supported by the Esso Petroleum Company. The authors greatly appreciate the help given by Dr. A.P. Rood in the preparation of the electron micro-graphs and general discussion in the early part of the preparation of this paper.

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Plate I

All transmission electron micrographs

Fig. 1 *Annulithus arkelli* n. gen. n. sp.; Genotype 40.5.1.
Lyme Regis (Dorset); Lias, Bed Number H1 (LANG), Zone *Ostrea liasica*. × 16,000

Fig. 2 *Crepidolithus cavus* PRINS ex ROOD, HAY & BARNARD; Hypotype 42.3.2.
Lyme Regis (Dorset); Lias, Bed Number 90a (LANG), zone *raricostatum*, subzone *densinodulum*. × 10,000

Fig. 3 *Vekshinella quadriarculla* (NOËL); Hypotype 34.8.1.
Millbrook (Bedfordshire); Ampthill Clay, zone *transversarium*. × 14,000

Fig. 4 *Tubirhabdus patulus* PRINS ex ROOD, HAY & BARNARD; Hypotype 56.10.2.
Escoville (Northern France); Cornbrash, zone *macrocephalus*. × 8,000

Fig. 5 *Crepidolithus crucifer* PRINS ex ROOD, HAY & BARNARD; Hypotype 43.1.1.
Eype (Dorset); Upper Lias, Downcliff Clay, zone *levesquei*. × 4,500

Fig. 6 *Chiastozygus primitus* PRINS; Hypotype 42.7.1.
Lyme Regis (Dorset); Lias, Bed Number 90a (LANG), zone *raricostatum*, subzone *densinodulum*. × 14,000

Fig. 7 *Crucirhabdus primulus* PRINS ex ROOD, HAY & BARNARD; Hypotype 44.1.2.
Golden Cap (Dorset); Lias, Bed Number 122a (LANG), zone *davoei*, subzone *maculatum*. × 9,000

Fig. 8 *Crucirhabdus primulus* PRINS ex ROOD, HAY & BARNARD; Hypotype 42.8.1.
Lyme Regis (Dorset); Lias, Bed Number 90a (LANG), zone *raricostatum*, subzone *densinodulum*. × 14,000

Fig. 9 *Parhabdolithus liasicus* (DEFLANDRE); Hypotype 41.7.2.
Lyme Regis (Dorset); Lower Lias; Bed Number 48 (LANG), zone *semicostatum*, subzone *reynesi*. × 7,000

Fig. 10 *Zeugrhabdotus erectus* (DEFLANDRE); Hypotype 32.6.2.
Millbrook (Bedfordshire); Upper Oxford Clay, zone *mariae*, subzone *praecordatum*. × 18,000

Fig. 11 *Crepidolithus crassus* (DEFLANDRE); Hypotype 29.8.1.
Millbrook (Bedfordshire); Ampthill Clay, zone *transversarium*. × 12,000

Fig. 12 *Parhabdolithus marthae* DEFLANDRE; Hypotype 41.8.1.
Lyme Regis (Dorset); Lower Lias, Bed Number 48 (LANG), zone *semicostatum*, subzone *reynesi*. × 4,500

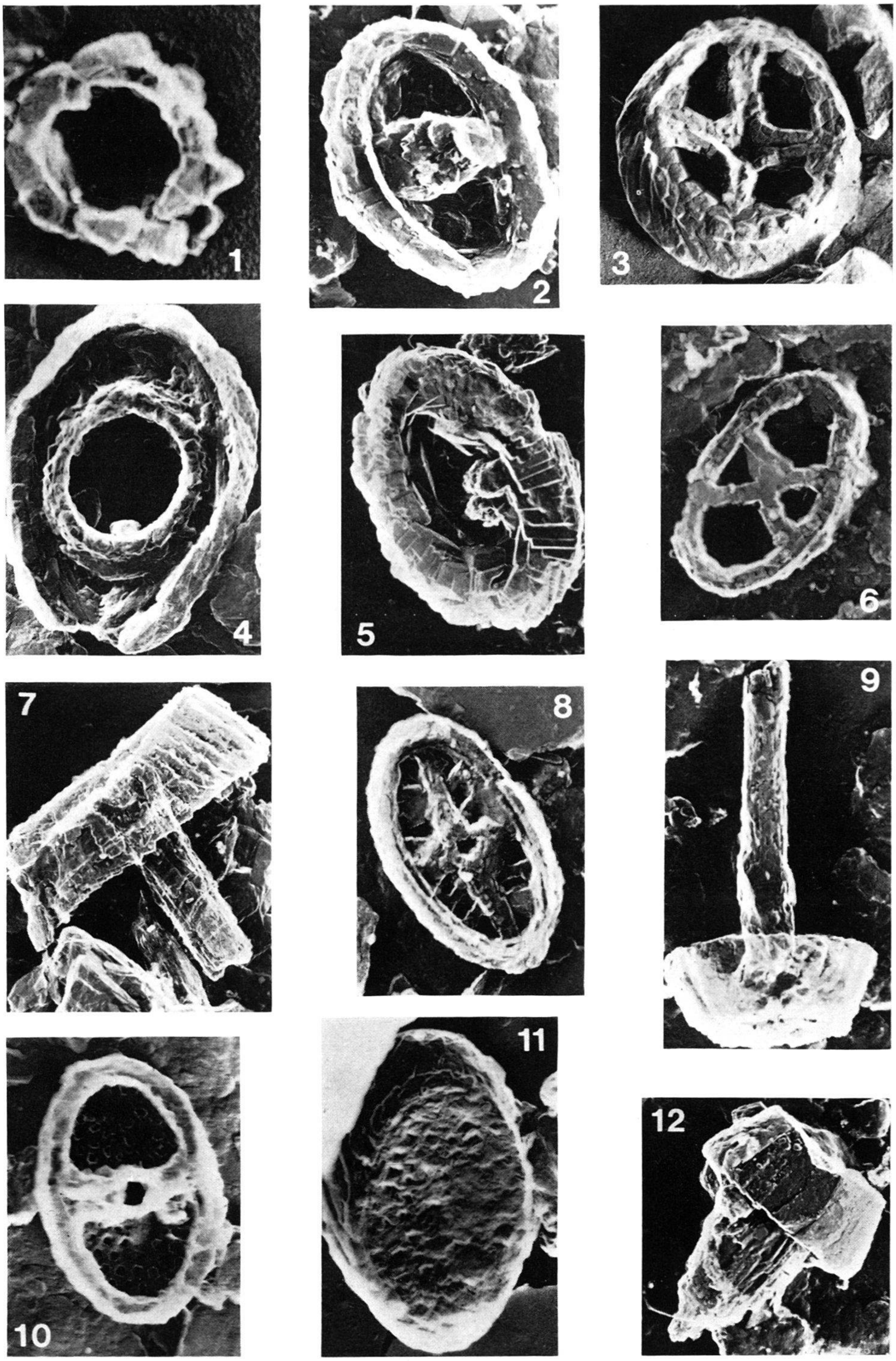
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Plate II

All transmission electron micrographs

Fig. 1 *Podorhabdus cylindratus* NOËL; Hypotype 56.10.1.
Escoville (Northern France); Cornbrash, zone *macrocephalus*. × 5,000

Fig. 2 *Paleopontosphaera dubia* NOËL; Hypotype 42.10.2.
Golden Cap (Dorset); Lias, Bed Number 120d (LANG), zone *davoei*, subzone *valdani*. × 9,000

Fig. 3 *Striatomarginis primitivus* ROOD, HAY & BARNARD; Hypotype 44.10.1.
Eype (Dorset); Upper Lias, Downcliff Clay, zone *levesquei*. × 12,000

Fig. 4 *Paleopontosphaera veterna* PRINS ex ROOD, HAY & BARNARD; Hypotype 55.11.1.
Port en Bessin (Normandy); Fullers Earth, zone *progracilis*. × 12,000

Fig. 5 *Podorhabdus macrogranulatus* PRINS ex ROOD, HAY & BARNARD; Hypotype 43.10.2.
Eype (Dorset); Upper Lias, Downcliff Clay, zone *levesquei*. × 10,500

Fig. 6 *Ethmorhabdus gallicus* NOËL; Hypotype 55.7.1.
Escoville (Northern France); Cornbrash, zone *macrocephalus*. × 5,000

Fig. 7 *Watznaueria britannica* (STRADNER); Hypotype 52.2.1.
Redcliff Point (Dorset); Oxford Clay, zone *mariae*, subzone *praecordatum*. × 8,500

Fig. 8 *Stephanolithion speciosum* DEFLANDRE; Hypotype 56.1.1.
Port en Bassin (Normandy); Fullers Earth, zone *progracilis*. × 8,000

Fig. 9 *Hexapodorhabdus cuvillieri* NOËL; Hypotype 38.8.1.
Millbrook (Bedfordshire); Ampthill Clay, zone *transversarium*. × 10,000

Fig. 10 *Cyclagelosphaera margereli* NOËL; Hypotype 30.7.1.
Tidmoor Point (Dorset); Oxford Clay, zone *mariae*. × 9,500

Fig. 11 *Diazomatolithus lehmani* NOËL; Hypotype 6.1.2.
Redcliff Point (Dorset); Oxford Clay, zone *mariae*, subzone *praecordatum*. × 5,000

Fig. 12 *Diadozygus asymmetricus* ROOD, HAY & BARNARD; Hypotype 33.7.1.
Millbrook (Bedfordshire); Oxford Clay, zone *cordatum*, subzone *bukowskii*. × 13,000

PLATE II

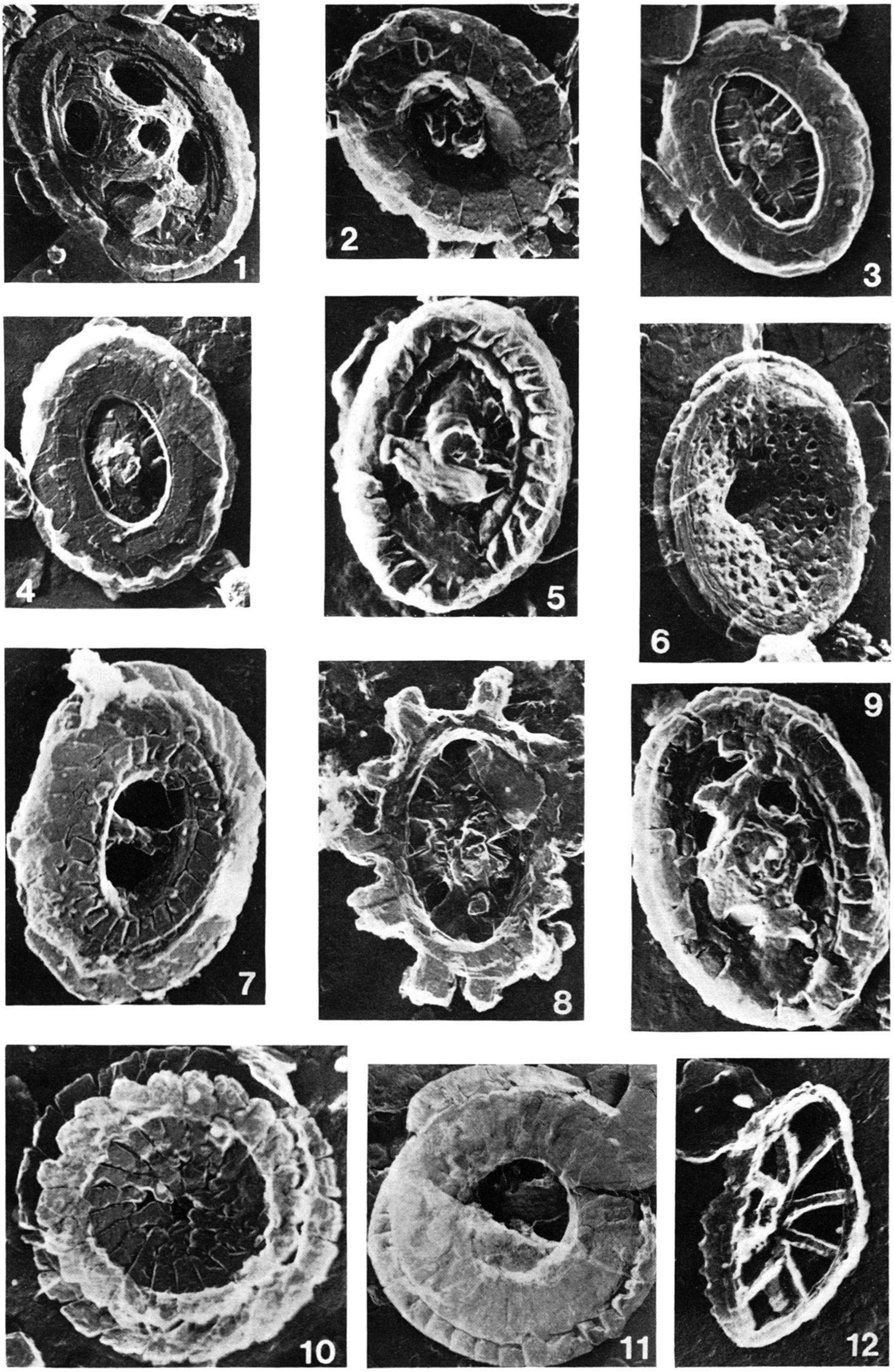

Plate III

All transmission electron micrographs

Fig. 1 *Stephanolithion hexum* Rood & Barnard; Hypotype 55.8.1.
Escoville (Northern France); Cornbrash, zone *macrocephalus*. × 5,500

Fig. 2 *Stephanolithion speciosum* var. *octum* Rood & Barnard; Hypotype 57.4.2.
Escoville (Northern France): Cornbrash, zone *macrocephalus*. × 4,500

Fig. 3 *Podorhabdus rahla* Noël; Hypotype 32.1.1.
Millbrook (Bedfordshire); Oxford Clay, zone *athleta*. × 8,000

Fig. 4 *Watznaueria communis* Reinhardt; Hypotype 55.3.1.
Port en Bessin (Normandy); Fullers Earth, zone *progracilis*. × 10,000

Fig. 5 *Discorhabdus jungi* Noël; Hypotype 27.7.2.
Millbrook (Bedfordshire); Oxford Clay, zone *mariae*, subzone *praecordatum*. × 5,000

Fig. 6 *Stephanolithion bigoti* Deflandre; Hypotype 28.12.1.
Millbrook (Bedfordshire); Oxford Clay, zone *mariae*, subzone *praecordatum*. × 2,000

Fig. 7 *Actinozygus geometricus* (Gorka); Hypotype 26.9.1.
Millbrook (Bedfordshire); Upper Oxford Clay, zone *mariae*, subzone *scarburgense*. × 13,000

Fig. 8 *Zeugrhabdotus noeli* Rood, Hay & Barnard; Hypotype 32.11.1.
Millbrook (Bedfordshire); Upper Oxford Clay, zone *mariae*, subzone *praecordatum*. × 24,000

Fig. 9 *Vekshinella stradneri* Rood, Hay & Barnard; Hypotype 34.5.1.
Millbrook (Bedfordshire); Ampthill Clay, zone *transversarium*. × 14,000

Fig. 10 *Polypodorhabdus escaigi* Noël; Hypotype 53.12.1.
Hounstout Cliff (Dorset); Kimmeridge Clay, zone *pallasioides*. × 8,000

Fig. 11 *Diadozygus dorsetense* Rood, Hay & Barnard; Hypotype 29.11.1.
Millbrook (Bedfordshire); Upper Oxford Clay, zone *cordatum*, subzone *costicardia*. × 13,000

Fig. 12 *Discorhabdus patulus* (Deflandre); Hypotype 24.6.1.
Millbrook (Bedfordshire); Middle Oxford Clay, zone *athleta*. × 5,000

Fig. 13 *Parhabdolithus embergeri* (Noël); Hypotype 33.11.1.
Millbrook (Bedfordshire); Oakley Beds, zone *transversarium*. × 6,000

Plate III

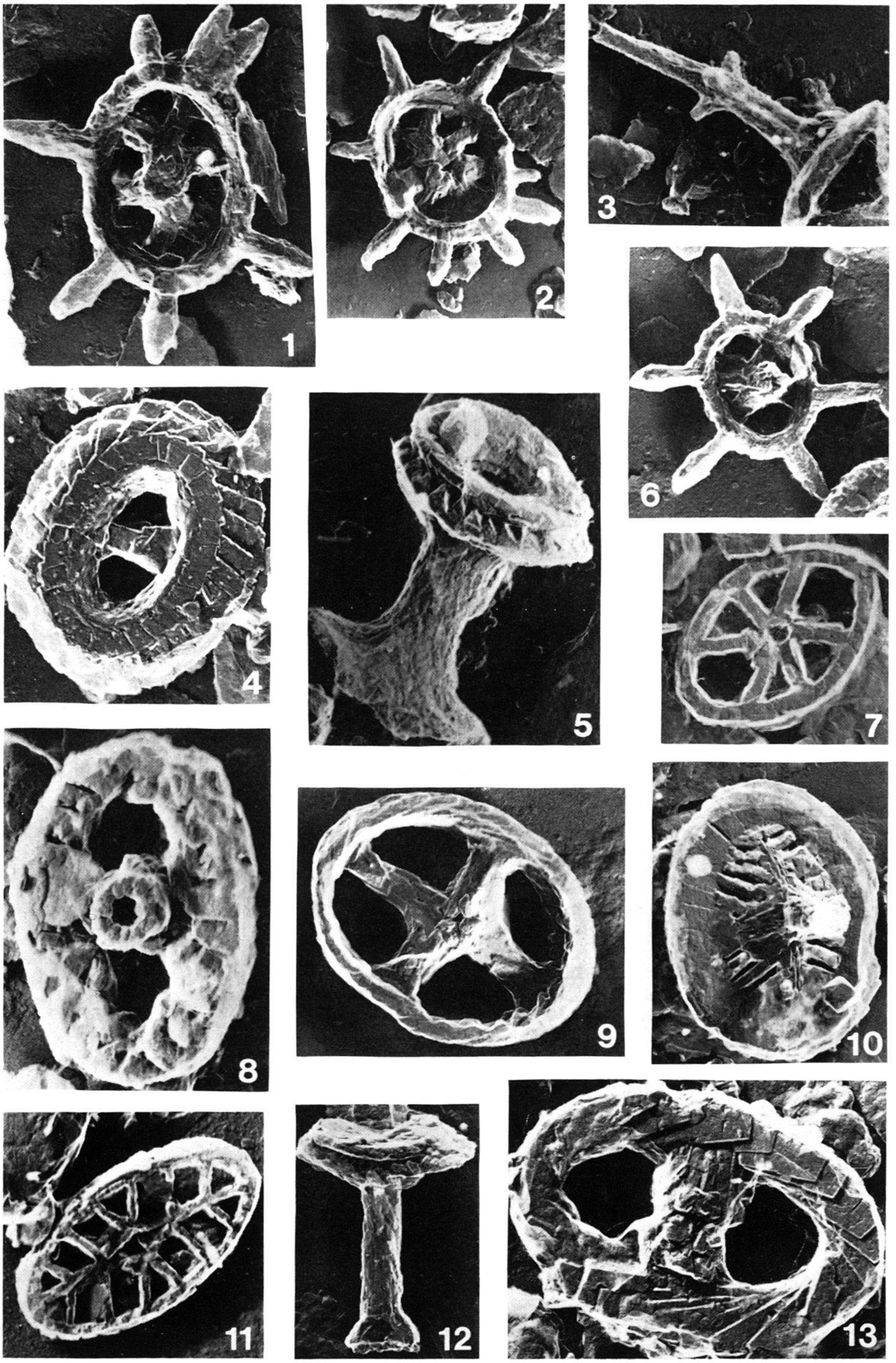

Plate IV

All phase contrast light micrographs × 4,000

Fig. 1 — *Annulithus arkelli* n. gen. n. sp.
Lyme Regis (Dorset); Lias, Bed Number H. 75 (LANG), zone *angulata*, subzone *extranodosa*.

Fig. 2 — *Crepidolithus cavus* PRINS ex ROOD, HAY & BARNARD
Lyme Regis (Dorset); Lias, Bed Number 74s (LANG), zone *turneri*, subzone *birchi*.

Fig. 3 — *Vekshinella quadriarculla* (NOËL)
Lyme Regis (Dorset); Lias, Bed Number H41 (LANG), zone *planorbis*, subzone *planorbis*.

Fig. 4 — *Tubirhabdus patulus* PRINS ex ROOD, HAY & BARNARD
Burton Bradstock (Dorset); Fullers Earth, zone *progracilis*.

Fig. 5 — *Crepidolithus crucifer* PRINS ex ROOD, HAY & BARNARD
Lyme Regis (Dorset); Lias, Bed Number 97 (LANG), zone *raricostatum*, subzone *densinodulum*.

Fig. 6 — *Chiastozygus primitus* PRINS
Lyme Regis (Dorset); Lias, Bed Number 83g (LANG), zone *obtusum*, subzone *obtusum*.

Fig. 7 — *Crucirhabdus primulus* PRINS ex ROOD, HAY & BARNARD
Lyme Regis (Dorset); Lias, Bed Number 30e–f (LANG), zone *bucklandi*, subzone *rotiforme*.

Fig. 8 — *Crucirhabdus primulus* PRINS ex ROOD, HAY & BARNARD
Lyme Regis (Dorset); Lias, Bed Number 26 (LANG), zone *bucklandi*, subzone *conybeari*.

Fig. 9 — *Parhabdolithus liasicus* DEFLANDRE
Lyme Regis (Dorset); Lias, Bed Number 30 e–f (LANG), zone *bucklandi*, subzone *rotiforme*.

Fig. 10 — *Zeugrhabdotus erectus* (DEFLANDRE)
Port en Bessin (Normandy); Fullers Earth, zone *progracilis*.

Fig. 11 — *Crepidolithus crassus* (DEFLANDRE)
Lyme Regis (Dorset); Lias, Bed Number 97 (LANG), zone *raricostatum*, subzone *densinodulum*.

Fig. 12 — *Parhabdolithus marthae* DEFLANDRE
Lyme Regis (Dorset); Lias, Bed Number 36b (LANG), zone *bucklandi*, subzone *rotiforme*.

Fig. 13 — *Podorhabdus cylindratus* NOËL
Eype (Dorset); Upper Lias, Downcliff Clay, zone *levesquei*.

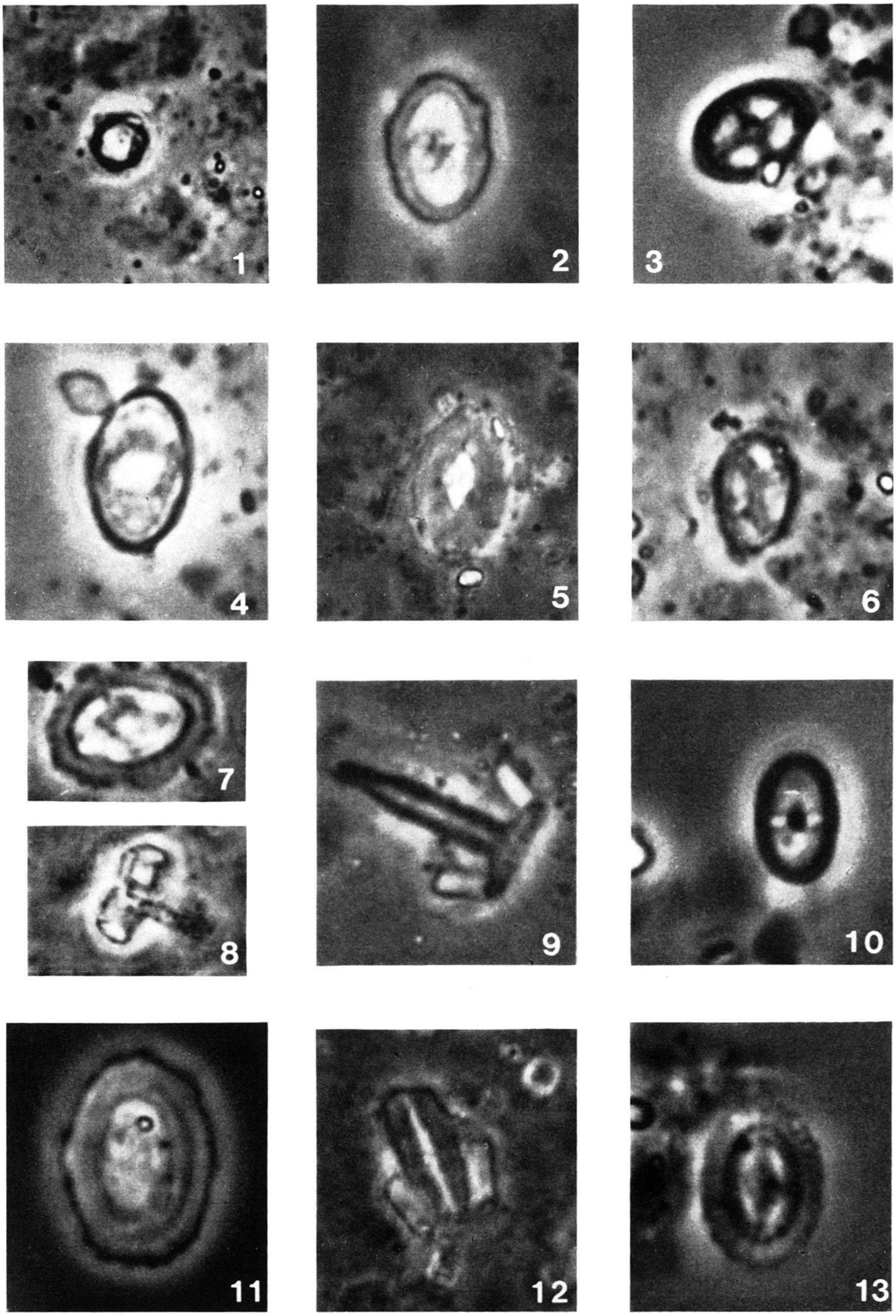
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Plate V

All phase contrast light micrographs × 4,000

Fig. 1 *Paleopontosphaera dubia* NOËL
Lyme Regis (Dorset); Lias, Bed Number 121 (LANG), zone *davoei*, subzone *luridum*.

Fig. 2 *Striatomarginis primitivus* ROOD, HAY & BARNARD
Millbrook (Bedfordshire); Oxford Clay, zone *athleta*.

Fig. 3 *Paleopontosphaera veterna* PRINS ex ROOD, HAY & BARNARD
Eype (Dorset); Downcliff Clay, Upper Lias, zone *levesquei*.

Fig. 4 *Podorhabdus macrogranulatus* PRINS ex ROOD, HAY & BARNARD
Eype (Dorset); Downcliff Clay, Upper Lias, zone *levesquei*.

Fig. 5 *Ethmorhabdus gallicus* NOËL
Millbrook (Bedfordshire); Oxford Clay, zone *cordatum*, subzone *bukowskii*.

Fig. 6 *Watznaueria britannica* (STRADNER)
Bletchley (Buckinghamshire); Oxford Clay, zone *athleta*.

Fig. 7 *Stephanolithion speciosum* DEFLANDRE
Burton Bradstock (Dorset); Fullers Earth, zone *zigzag*.

Fig. 8 *Hexapodorhabdus cuvillieri* NOËL
Millbrook (Bedfordshire); Oxford Clay, zone *cordatum*, subzone *bukowskii*.

Fig. 9 *Cyclagelosphaera margereli* NOËL
Eype (Dorset); Downcliff Clay, Upper Lias, zone *levesquei*.

Fig. 10 *Diazomatolithus lehmani* NOËL
Millbrook (Bedfordshire); Oxford Clay, zone *mariae*, subzone *scarburgense*.

Fig. 11 *Diadozygus asymmetricus* ROOD, HAY & BARNARD
Millbrook (Bedfordshire); Oxford Clay, zone *mariae*, subzone *scarburgense*.

Fig. 12 *Stephanolithion hexum* ROOD & BARNARD
Escoville (Northern France), Cornbrash, zone *macrocephalus*.

PLATE V

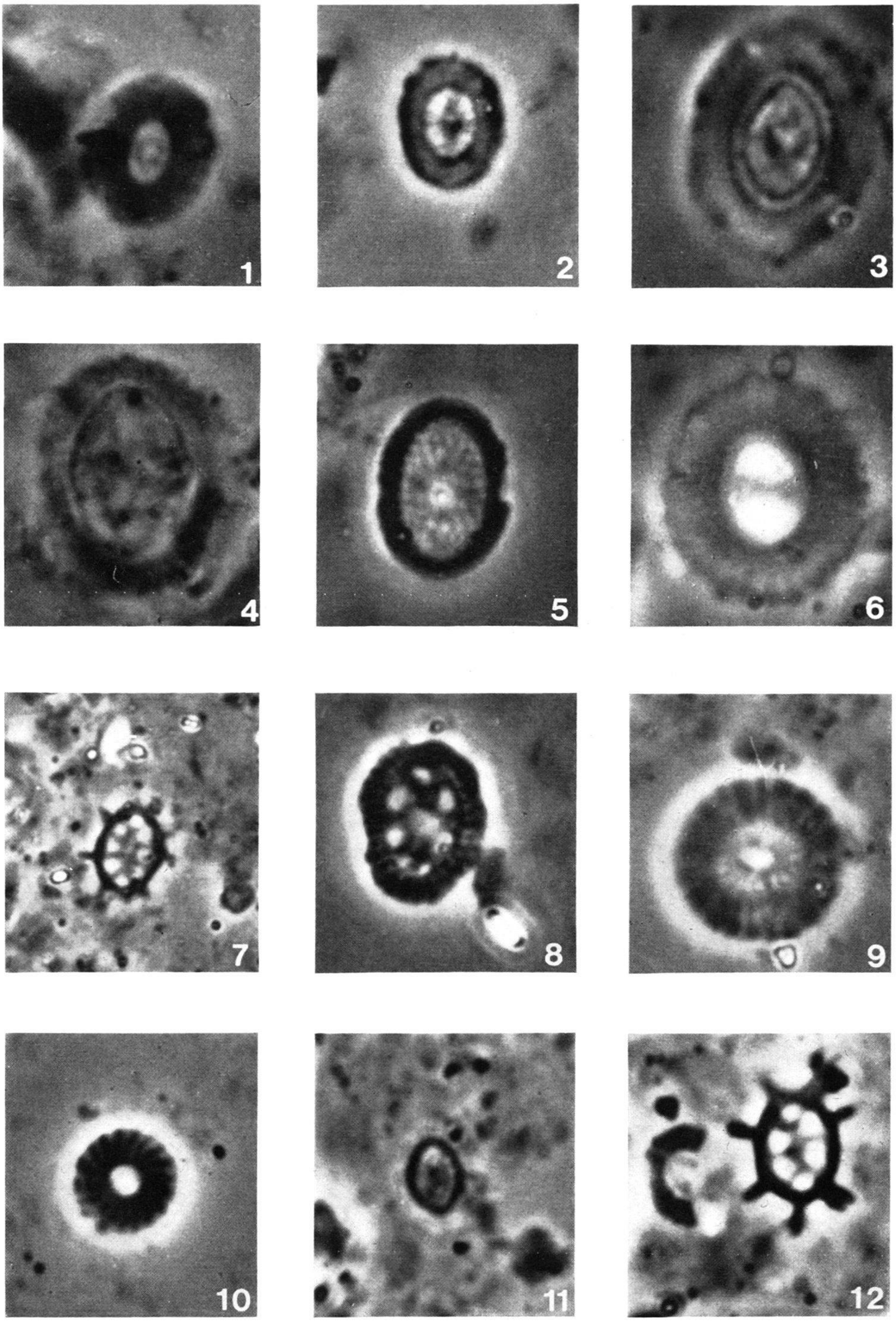


Plate VI

All phase contrast light micrographs × 4,000

Fig. 1 *Stephanolithion speciosum* var. *octum* ROOD & BARNARD
Escoville (Northern France); Cornbrash, zone *macrocephalus.*

Fig. 2 *Podorhabdus rahla* NOËL
Millbrook (Bedfordshire); Oxford Clay, zone *mariae*, subzone *praecordatum.*

Fig. 3 *Watznaueria cummunis* REINHARDT
Millbrook (Bedfordshire); Oxford Clay, zone *cordatum*, subzone *bukowskii.*

Fig. 4 *Discorhabdus jungi* NOËL
Millbrook (Bedfordshire); Oxford Clay, zone *mariae*, subzone *scarburgense.*

Fig. 5 *Stephanolithion bigoti* DEFLANDRE
Millbrook (Bedfordshire); Oxford Clay, zone *athleta.*

Fig. 6 *Actinozygus geometricus* (GORKA)
Millbrook (Bedfordshire); Oxford Clay, zone *mariae*, subzone *praecordatum.*

Fig. 7 *Zeugrhabdotus noeli* ROOD, HAY & BARNARD
Dyrham (Gloucestershire); Lower Fullers Earth Clay, zone *zigzag.*

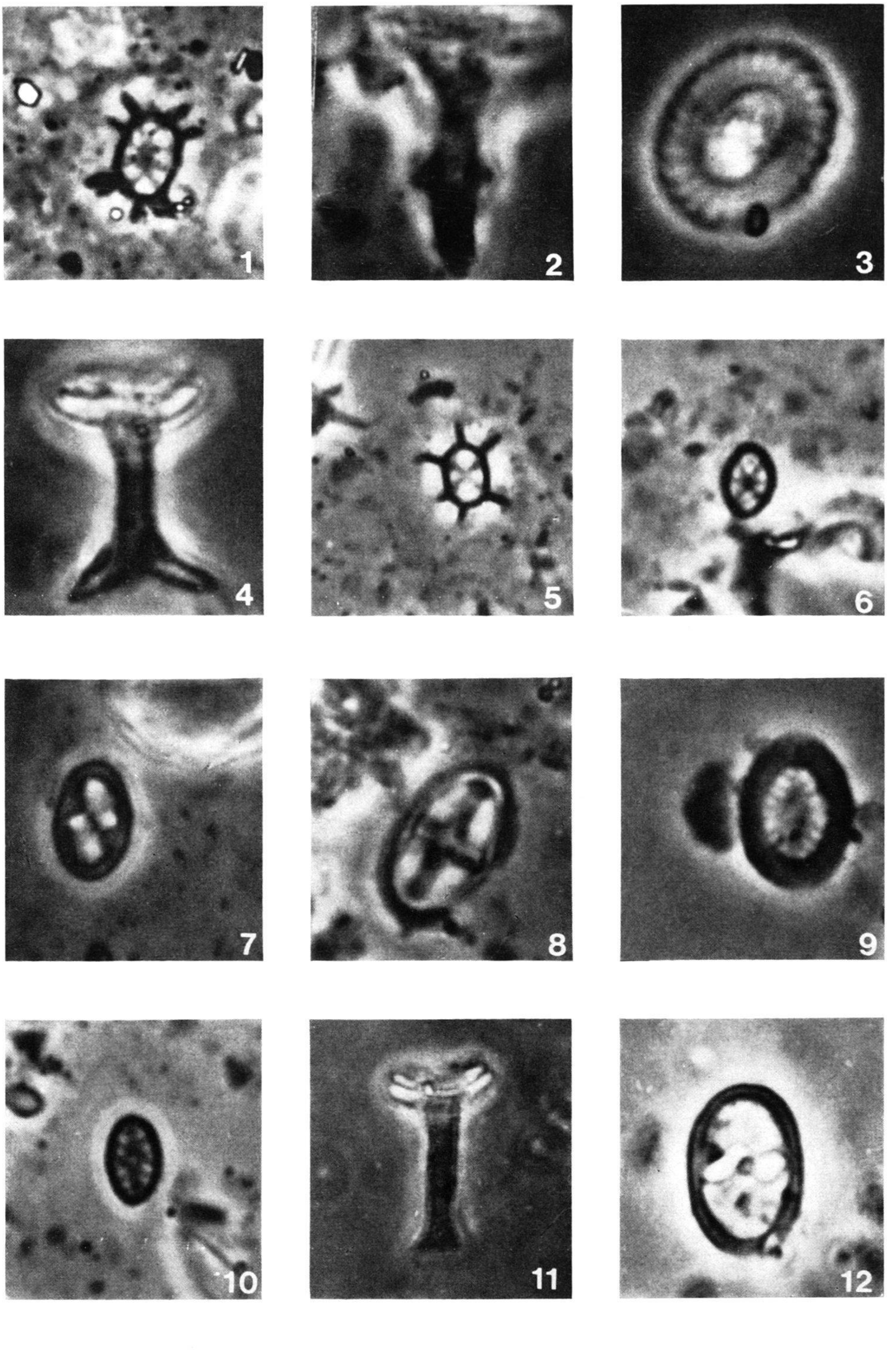
Fig. 8 *Vekshinella stradneri* ROOD, HAY & BARNARD
Lyme Regis (Dorset); Bed Number 30e–f (LANG), zone *bucklandi*, subzone *rotiforme.*

Fig. 9 *Polypodorhabdus escaigi* NOËL
Millbrook (Bedfordshire); Oxford Clay, zone *cordatum*, subzone *bukowskii.*

Fig. 10 *Diadozygus dorsetense* ROOD, HAY & BARNARD
Millbrook (Bedfordshire); Oxford Clay, zone *mariae*, subzone *scarburgense.*

Fig. 11 *Discorhabdus patulus* (DEFLANDRE)
Mesnil de Bréville (Northern France); Callovian, zone *jason.*

Fig. 12 *Parhabdolithus embergeri* (NOËL)
Hounstout Cliff (Dorset); Kimmeridgian, zone *pectinatites.*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