

Jurassic

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4.1 INTRODUCTION

For the stratigrapher the Jurassic is the very well and fountain of his subject. It was on the Jurassic rocks that William Smith, Father of Historical Geology, founded the science of stratigraphy, enunciated the law of superposition, identified fossils with particular strata, and named the classic formations. It was on Jurassic rocks that Oppel founded modern zonal stratigraphy and named the classic zones. It was for Jurassic rocks that d'Orbigny introduced the first scheme of stages. All these concepts became part of the fabric of stratigraphical geology the world over.

Arkell, 1956

The study of calcareous nannofossils has come relatively late to the Jurassic system (the first Jurassic nannofossil was described by Deflandre and Dangeard in 1938) and, as the quotation above reveals, we are following a prestigious and lengthy history of stratigraphic research. Jurassic strata (Calcaires de Jura) were first recognized by von Humboldt in 1795 in the Jura Mountains of France and Switzerland, although the term 'Jurassique' was not introduced until 1829 by Brongniart. In Britain, William Smith, working as a canal company surveyor, published lists of Jurassic stratal successions, fossil contents, and a geological map, between 1797 and 1817. The grouping of Jurassic strata into stages, and the correlation of these units using assemblages of fossils, was demonstrated by d'Orbigny in 1842, and in 1858 Oppel divided the Jurassic into 33 'biostratigraphic' zones. Since these basic principles of stratigraphy were established, there has been an immense amount of data published on

Jurassic strata. This has included the development of a standard biochronologic scale based upon ammonites, which provide a finer biostratigraphic resolution than any other fossil group. It is against this background that the study of Jurassic calcareous nannofossils is proceeding. While we have not yet achieved (and may never do so) the biostratigraphic resolution that ammonites can provide (albeit after 150 years of work!) the last two decades have seen the introduction of successively improved nannofossil biozonations.

This chapter aims to summarize work carried out in the NW European area and the biozonation scheme that has resulted from it, together with comments on the wider application of this zonation scheme and the nature of Jurassic nannofossil provincialism.

4.2 IMPORTANT REFERENCES

The first taxonomic descriptions of Jurassic nannofossils were published by Deflandre (1938, 1939, 1952, 1954) and Noël (1956, 1958, 1965, 1973). More recent contributions include Prins (1969), Rood *et al.* (1971, 1973), Grün *et al.* (1974), Medd (1979), Grün and Zweili (1980), Goy (1981), Bown (1987), Bralower *et al.* (1989), de Kaenel and Bergen (1993) and Bergen (in press).

The utility of Jurassic nannofossils in biostratigraphy was first demonstrated by Stradner (1963), followed by a succession of new or revised biozonation schemes including Prins (1969), Amezieux (1972), Barnard and Hay (1974), van Hinte (1976a), Thierstein (1976), Hamilton (1977, 1979, 1982), Medd (1982), Roth *et al.* (1983), Haq (1983a), Crux (1984, 1987a), Bown (1987), Lord

et al. (1987), Bown *et al.* (1988) and Bralower *et al.* (1989). Comprehensive reviews of the current biostratigraphic literature are presented in Bown (1996) and de Kaenel *et al.* (1996).

Most early biostratigraphic work was based on sections from northern Europe, and first Barnard and Hay (1974) and then Bown *et al.* (1988) presented zonation schemes which were established as 'standards' for the Jurassic. In the last two decades, the focus has shifted from northern Europe to Jurassic studies elsewhere, with particular impetus being provided by a number of DSDP sites in the Atlantic Ocean and new onshore studies in Italy (e.g. Baldanza and Mattioli, 1992; Cobianchi, 1992; Reale *et al.*, 1992), Portugal (Bergen, in press), North Africa (de Kaenel, in press), Timor (Bown, 1987, 1992a; Kristan-Tollmann, 1988a, b) and western Canada (Bown, 1992a). The Atlantic Ocean DSDP sites have provided valuable material for the Bathonian to Tithonian time-interval and have prompted new zonation schemes (Roth *et al.*, 1983; Bralower *et al.*, 1989) reflecting the recognition of increased provincialism through this interval.

4.3 JURASSIC NANNOFOSSIL SUCCESSION

The Jurassic period was extremely significant in the early evolutionary history of calcareous nannofossils. Nannofossils first appeared in the Late Triassic and were initially restricted to low latitudes (Bown, 1992a). Triassic nannofloras consisted of nannolith (*incertae sedis*) forms, together with rarer and very small (~2µm) coccoliths. A significant extinction event at the Triassic/Jurassic boundary was followed by the expansion of nannoplankton into all open-marine environments and the establishment of coccolithophores as the dominant nannofossil group. Coccolithophores diversified rapidly in the Early Jurassic (Hettangian–Early Toarcian) and latest Jurassic (Tithonian) by which time nannoplankton were producing biogenic carbonate in rock-forming proportions (Bown *et al.*, 1992).

Earliest Jurassic (Hettangian) nannofloras were dominated by the nannolith, *Schizosphaerella punctulata*, along with rare coccoliths of *Crucirhabdus primulus*, the only coccolith species known to have survived the earlier extinction event. In the late Hettangian and Sinemurian, simple, murolith

coccoliths (e.g. *Parhabdololithus* and *Crepidolithus*) diversified but were soon joined by coccoliths with radically new morphologies (placoliths) which evolved rapidly and began to dominate numerically. In the Early Pliensbachian, the placolith genus, *Similiscutum* (early forms, formerly included within *Biscutum*), appeared and diversified rapidly through the remaining Early Jurassic, giving rise to *Biscutum*, *Sollasites*, *Calyculus*, *Carinolithus* and *Discorhabdus*. The Sinemurian appearance of another placolith group, represented by the genus *Mazaganella*, is not recorded in NW Europe. Representatives of the Mazaganellaceae did not occur here until the appearance of *Triscutum* in the latest Toarcian. In the Late Pliensbachian, a third placolith family, the Watznaueriaceae (represented by the genus *Lotharingius*), appeared and almost immediately began to numerically dominate assemblages.

A nannofloral turnover event occurred through the Pliensbachian/Toarcian boundary-interval, as placolith coccoliths diversified, seemingly at the expense of the earlier murolith species. Thus, *Biscutum* and *Lotharingius* became important assemblage components, whilst *Parhabdololithus*, *Crucirhabdus* and *Mitrolithus* became extinct.

The Late Toarcian was a period of relative stasis, although the family Cretarhabdaceae and genus *Triscutum* first appeared at the Toarcian/Aalenian boundary. By the end of the Toarcian, nine coccolith families were established, forming lineages which gave rise to the majority of remaining Middle and Late Jurassic taxa (Fig. 1.5).

The Aalenian to Early Bajocian saw the evolutionary transition from *Lotharingius* to *Watznaueria*. These two genera dominated nannofloras through the Bajocian and Bathonian. By Callovian times, *Watznaueria* had become the dominant genus. This trend continued through the Late Jurassic and into the Cretaceous. The Middle Jurassic was also characterized by diversification of the families Stephanolithiaceae and Axopodorhabdaceae. The former family includes the distinctive genus, *Stephanolithion*, which is utilized extensively for biostratigraphy through the Middle and Late Jurassic.

The Callovian and Early Oxfordian were intervals of high diversity, including many delicate species of Stephanolithiaceae. The remaining Jurassic saw a progressive reduction of diversity in the boreal area, with extinctions outnumbering

inceptions through the Oxfordian, Kimmeridgian and Volgian. Throughout this time, however, nannofossil abundance remained high, with *Watznaueria* (particularly *W. britannica*) constituting the principal component of all assemblages.

This evolutionary succession is essentially observed worldwide for the Hettangian to Kimmeridgian interval, however, in the Volgian (= Tithonian), a diversification event occurred which was initially restricted to western Tethys and the proto-Atlantic Ocean. Diversity increased significantly in the tethyan area and introduced new nannolith groups, such as *Conusphaera* and *Nannoconus*. A number of boreal endemic species, e.g. *Stephanolithion atmetos*, also appeared at this time. This interval saw the maximum degree of Jurassic biogeographic differentiation, and also coincided with the first occurrence of significant thicknesses of nannofossil-generated, pelagic carbonates, as represented by, e.g., the Maiolica Formation in Italy.

This pattern of distributions continued into the Early Cretaceous, although many of the new tethyan forms became more widely distributed. Provincialism, however, remained significant through much of the Neocomian.

4.4 BIOSTRATIGRAPHY

The Bown *et al.* (1988) biozonation scheme was an attempt to stabilize biostratigraphic nomenclature for the Jurassic, utilizing many of the well-established nannofossil bioevents which had been successfully introduced in previous zonations, e.g. Prins (1969), Barnard and Hay (1974), Thierstein (1976), Medd (1982) and Crux (1984). The Bown *et al.* (1988) scheme has been used as the basis for comparison and correlation in this chapter. The biostratigraphic framework and regional biostratigraphic zonations and events are presented in Figs 4.1–4.2 with zonal markers directly correlated with the standard boreal ammonite zonation, where possible. The stratigraphic distribution of selected Jurassic nannofossil taxa is shown in Fig. 4.3. Marker-species and principle assemblage components are illustrated in Plates 4.1–4.16.

A number of the Upper Jurassic boreal zones have been modified here following a detailed study of the Kimmeridgian–Upper Volgian section at

Gorodische (Russia): the Gorodische data is provided in the Appendix (section 4.9).

NJ1 *Schizosphaerella punctulata* Zone

Author. Bown (1987).

Definition. FO of *Schizosphaerella punctulata* to the FO of *Parhabdololithus liasicus distinctus*.

Range. Triassic/Jurassic boundary to upper Hettangian (angulata AZ).

Remarks. Assemblages are generally low in abundance although 'floods' of *S. punctulata* have been recorded. Generally, only two species are recorded, *S. punctulata* and *Crucirhabdus primulus*. The record of Triassic nannofossils in NW Europe is at present limited to reports of *S. punctulata* from the Rhaetian of southern England (Hamilton, 1982; Crux, 1987a) which has not been confirmed by our research (PRB, pers obs.). In sections from the Austrian Alps, where Triassic nannofossils are well-represented, *S. punctulata* is not present in the Rhaetian and does not occur until the Hettangian. *Prinsiosphaera triassica* and *Eoconusphaera zlambackensis*, which characterize the Upper Triassic, both became extinct at the Triassic/Jurassic boundary, also approximating the base of this zone (Bown and Lord, 1990; Bralower *et al.*, 1991).

NJ2 *Parhabdololithus liasicus* Zone

Author. Bown (1987).

Definition. FO of *Parhabdololithus liasicus distinctus* to the FO of *Crepidolithus crassus*.

Range. Upper Hettangian (angulata AZ) to Upper Sinemurian (oxynotum AZ).

Remarks. Characterized by increased abundance and diversity in murolith coccoliths, and continued abundance of *S. punctulata*.

NJ2a *Parhabdololithus marthae* Subzone

Author. Prins (1969).

Definition. FO of *Parhabdololithus liasicus distinctus* to the LO of *Parhabdololithus marthae*.

Range. Upper Hettangian (angulata AZ) to Lower Sinemurian (semicostatum AZ).

Remarks. *Parhabdololithus* coccoliths are abundant and display a plexus of variable morphologies. The genera *Mitrolithus* and *Crepidolithus* have FOs within the subzone. *S. punctulata* and *C. primulus* are both common.

Italy/S France Mattioli et al., in prep.	Portugal Bergen, in prep.	BOREAL NF ZONES Bown et al., 1988		NANNOFOSSIL EVENTS		BOREAL AMM. ZONES	AGE
		NJ12	NJ12a	Secondary events	Zonal events		
	▲ S. hexum			▲ S. hexum ▲ T. shawensis	▲ A. helvetica	discus aspidoides hodsoni morrissi subcontractus progracilis tenuiplicatus zigzag parkinsoni garantiana subfurcatum humphriesianum sauzei laeviuscula discites murchisonae opalinum levesquei thouarsense variabilis bifrons falciatum tenuicostatum spinatum margaritatus davoei ibex jamesoni raricostatum oxynoyum obtusum turneri semicostatum bucklandi angulata liasicus planorbis	BATHONIAN
W. barnesae C. magharensis L. contractus C. superbus	▲ H. cuvillieri	NJ11					
	▲ T. shawensis ▲ S. spec. octum			▲ H. cuvillieri, ▲ T. shawensis, ▲ C. margerelii ▲ S. spec. octum	▲ P. enigma		
D. striatus acme C. superbus S. speciosum D. constans T. sullivanii	▲ ▲ ▲ ▲ ▲	NJ10		▲ C. superbus ▲ D. constans	▲ S. speciosum		BAJOCIAN
W. manivillae	▲ T. tiziense ▲ W. britannica acme	NJ9			▲ W. britannica		
W. britannica	▲ D. constans ▲ T. sullivanii ▲ T. tiziense ▲ B. prinslii ▲ R. incompta ▲ D. crotus	NJ8	NJ8b	▲ P. grassei ▲ B. prinslii ▲ C. importus	▲ L. contractus		AALENIAN
C. margerelii C. magharensis L. contractus R. incompta D. crotus	▲ ▲ ▲ ▲ ▲	NJ8a		▲ Trisc. sp. ▲ B. intermedium	▲ R. incompta		
	▲ L. hauffii acme	NJ7		▲ L. hauffii acme ▲ D. crotus			TOARCIAN
D. striatus	▲ D. striatus			▲ O. hamiltoniae	▲ D. striatus		
C. superbus	▲ C. superbus	NJ6		▲ B. finchii			
L. sigillatus	▲ C. primulus	NJ5	NJ5b	▲ C. primulus ▲ L. sigillatus	▲ C. superbus		
L. hauffii	▲ L. hauffii		NJ5a	▲ B. finchii	▲ C. importus		PLIENSABACH.
B. novum	▲ B. novum	NJ4	NJ4b		▲ L. hauffii		
B. aff. B. dubium	▲ C. pliensbach. ▲ B. prinslii ▲ S. cruciulus ▲ C. granulatus		NJ4a	▲ C. pliensbachensis	▲ P. robustus		
?	▲ C. pliensbachensis	NJ3			▲ S. cruciulus		
	▲ C. crassus			▲ O. hamiltoniae	▲ C. crassus		SINEMURIAN
		NJ2		▲ P. robustus	▲ P. marthae		
	no data		NJ2a	▲ C. pliensbachensis ▲ M. elegans	▲ P. liasicus		
C. pliensbach. M. fairsae M. elegans P. liasicus	▲ ▲ ▲ ▲	NJ1		▲ P. triassica	▲ S. punctulata		HETTANGIAN

Fig. 4.1 Hettangian to Bathonian biostratigraphic zones and events.

NJ2b *Mitrolithus elegans* Subzone

Author. Bown (1987).

Definition. LO of *Parhabdolithus marthae* to the FO of *Crepidolithus crassus*.

Range. Lower Sinemurian (semicostatum AZ) to Upper Sinemurian (oxynotum AZ).

NJ3 *Crepidolithus crassus* Zone

Author. Bown (1987).

Definition. FO of *Crepidolithus crassus* to the FO of *Similiscutum cruciulus*.

Range. Upper Sinemurian (oxynotum AZ) to Lower Pliensbachian (jamesoni AZ).

Remarks. The FO of *C. crassus* has been variably recorded in the literature (e.g. Crux, 1987a), reflecting the presence of intermediate forms between *C. crassus* and its ancestor, which is probably *Crepidolithus pliensbachensis* or *Crepidolithus timorensis*. The assemblages are composed of murolith coccoliths, together with the nannoliths *S. punctulata* and *Orthogonoides hamiltoniae*.

NJ4 *Similiscutum cruciulus* Zone

Author. Bown (1987), emended herein.

Definition. FO of *Similiscutum cruciulus* to the FO of *Lotharingius hauffii*.

Range. Lower Pliensbachian (jamesoni AZ) to Upper Pliensbachian (margaritatus AZ).

Remarks. The FO of the Biscutaceae is a notable and distinctive bioevent. These placolith-coccoliths are very different in appearance to the murolith coccoliths which characterize the lower Lower Jurassic assemblages. The naming of the first radiating placolith-coccolith has varied from author to author, e.g. *Palaeopontosphaera vetera* in Prins (1969), *Biscutum dubium* in Crux (1987a), *Biscutum novum* in Bown (1987) and, most recently, *Similiscutum cruciulus* (de Kaenel and Bergen, 1993), but the stratigraphic level has been consistently recorded as Lower Pliensbachian. The distinctive nature of these first Biscutaceae warrants taxonomic separation and therefore the zone name has been modified according to the new taxonomy of de Kaenel and Bergen (1993). The species *S. cruciulus* is applied here in a slightly broader sense than that of de Kaenel and Bergen (1993), to include all sub-circular to elliptical forms with variable central-area widths which may or may not reveal a central-area axial cross; this probably includes the species *S. praecarium*, *S. avitum* and *S. orbiculus*, as defined by de Kaenel

and Bergen (1993).

Sollasites and *Calculus* also have their FOs in the NJ4 Zone (Crux, 1987a; Bown *et al.*, 1988) but they are rare and sporadic.

NJ4a *Crepidolithus pliensbachensis* Subzone

Author. Bown (1987).

Definition. FO of *Similiscutum cruciulus* to the LO of *Parhabdolithus robustus*.

Range. Lower Pliensbachian (jamesoni to ibex AZs).

NJ4b *Crepidolithus granulatus* Subzone

Author. Bown (1987).

Definition. LO of *Parhabdolithus robustus* to the FO of *Lotharingius hauffii*.

Range. Lower Pliensbachian (ibex AZ) to Upper Pliensbachian (margaritatus AZ).

Remarks. The LO of *C. pliensbachensis* also approximates the base of NJ4b.

NJ5 *Lotharingius hauffii* Zone

Author. Bown (1987).

Definition. FO of *Lotharingius hauffii* to the FO of *Carinolithus superbus*.

Range. Upper Pliensbachian (margaritatus AZ) to Lower Toarcian (falciferum AZ).

Remarks. The NJ5 Zone sees an important nannofloral turnover, with many murolith-coccoliths becoming extinct and new placolith groups diversifying and becoming more abundant. The *Lotharingius* group, particularly, begins to dominate the assemblages numerically. The zone is also characterized by the near-total range of *Biscutum finchii*.

NJ5a *Biscutum finchii* Subzone

Author. Bown (1987).

Definition. FO of *Lotharingius hauffii* to the FO of *Crepidolithus impontus*.

Range. Upper Pliensbachian (margaritatus to spinatum AZs).

Remarks. The FO of *B. finchii* also approximates the base of this zone.

NJ5b *Crepidolithus impontus* Subzone

Author. Bown (1987), emended herein.

Definition. FO of *Crepidolithus impontus* to the FO of *Carinolithus superbus*.

Range. Upper Pliensbachian (spinatum AZ) to

Lower Toarcian (falciferum AZ).

Remarks. The nominate taxon (previously called *Crepidolithus cavus*) is given an alternative name, *C. impontus*, to avoid the confusion which has arisen over the identification of earlier *Crepidolithus* coccoliths which have a central-area bar. *C. impontus* has a wide central-area spanned by a delicate, narrow bar, and is quite distinct from *C. cavus* which was described by Rood *et al.* (1973) from the Lower Pliensbachian.

Many new species have FOs, or first occur consistently, in this subzone, e.g. *Axopodorhabdus atavus*, *Biscutum grande*, *Bussonius prinsii*, *Calyculus* spp., *Sollasites arcus* and *Zeugrhabdodus erectus*.

The LOs of murolith taxa, such as *P. liasicus*, *C. primulus* and *M. elegans*, have been variably reported in the literature. This may be due to increasing rarity in the highest parts of their ranges.

The evolutionary transition from *Calyculus* to *Carinolithus* is observed through this subzone.

NJ6 *Carinolithus superbus* Zone

Author. Bown (1987).

Definition. FO of *Carinolithus superbus* to the FO of *Discorhabdus striatus*.

Range. Lower Toarcian (falciferum AZ).

Remarks. The LOs of *B. finchii*, *B. grande* and *O. hamiltoniae* are recorded in this zone.

NJ7 *Discorhabdus striatus* Zone

Author. Bown (1987).

Definition. FO of *Discorhabdus striatus* to the FO of *Retecapsa incompta*.

Range. Lower Toarcian (falciferum AZ) to Upper Toarcian (levesquei AZ).

Remarks. Few FOs and LOs are observed through this interval. The FO of *Discorhabdus criotus* may prove to be useful in dividing the zone. Assemblages are dominated by *Lotharingius*.

NJ8 *Biscutum intermedium* Zone

Author. (Bown, 1987) Bown *et al.* (1988).

Definition. FO of *Retecapsa incompta* to the FO of *Watznaueria britannica*.

Range. Upper Toarcian (levesquei AZ) to Lower Bajocian (laeviuscula AZ).

Remarks. The FOs of *Biscutum intermedium* and *Triscutum* sp. also approximate the base of the zone. NJ8 includes the evolutionary transition from *Lotharingius* to *Watznaueria* and many

intermediate morphologies occur. All younger Jurassic zones are characterized by assemblages dominated by species of *Watznaueria*, particularly *W. britannica*.

NJ8a *Retecapsa incompta* Subzone

Author. Bown *et al.* (1988).

Definition. FO of *Retecapsa incompta* to the FO of *Lotharingius contractus*.

Range. Upper Toarcian (levesquei AZ) to Aalenian (murchisonae AZ).

NJ8b *Lotharingius contractus* Subzone

Author. Bown *et al.* (1988).

Definition. FO of *Lotharingius contractus* to the FO of *Watznaueria britannica*.

Range. Aalenian (murchisonae AZ) to Lower Bajocian (laeviuscula AZ).

Remarks. The evolutionary plexus which occurs at the *Lotharingius*–*Watznaueria* transition, may hinder the correct identification of the nominate species but the base of this subzone is also approximated by the LOs of *B. prinsii* and *C. impontus*.

NJ9 *Watznaueria britannica* Zone

Author. Bown *et al.* (1988).

Definition. FO of *Watznaueria britannica* to the FO of *Stephanolithion speciosum*.

Range. Lower Bajocian (laeviuscula to humphriesianum AZs).

Remarks. The abundant co-occurrence of *L. contractus* and *W. britannica* is characteristic of this zone. The application of the FO of *W. britannica* has proven somewhat problematical as it has been recorded earlier by other authors, and in southern Europe. However, at present, we believe this is a taxonomic problem related to the *Lotharingius*–*Watznaueria* plexus, which may be alleviated by the application of more restricted taxonomic concepts.

NJ10 *Stephanolithion speciosum* Zone

Author. Bown *et al.* (1988).

Definition. FO of *Stephanolithion speciosum* to the FO of *Pseudoconus enigma*.

Range. Lower Bajocian (humphriesianum AZ) to Upper Bajocian (parkinsoni AZ).

NJ11 *Pseudoconus enigma* Zone

Author. Bown *et al.* (1988).

Definition. FO of *Pseudoconus enigma* to the

MAGNETO-STRATIGRAPHY	TETHYAN NF ZONES Bralower <i>et al.</i> , 1989	BOREAL NF ZONES Bown <i>et al.</i> , 1988	NANNOFOSSIL EVENTS		BOREAL AMM. ZONES	AGE	
			Secondary events	Zonal events		PORTLANDIAN	VOLGIAN
M18	NJK	NJKd FO N. stert. min.	▲ N. steinmanni minor*		lamplughii		BERR
		NJKc FO R. laffitei	▲ C. cuvillieri		prepicomphalus		
M19		NJKb FO L. granulosa	▲ C. mexicana minor, P. beckmannii*		primitivus		
	NJK	NJKa			oppressus		VOLGIAN
			▲ W. britannica decline		anguliformis		
			▲ E. gallicus		kerberus		
M20	NJK	NJKa	▲ H. chiasia, H. noellae, P. senaria*	S. atmetos ▼	okusensis		VOLGIAN
			▲ A. cylindricus	S. bigotii ▼	glaucolithus		
			▲ Nannoconus*		albanii		
M21	NJK	NJKa	▲ C. mex. mex.*		fittoni		VOLGIAN
			▲ C. mex. minor*		rotunda		
			▲ Z. embergeri*		pallasioides		
M22	NJK	NJKa		S. atmetos ▲	pecinatus		VOLGIAN
				A. harrisonii ▼	hudlestoni		
					wheatleyensis		
	NJK	NJKa			scitulus		VOLGIAN
					elegans		
					aufissiodorensis		
	NJK	NJKa	▲ C. conicus	S. brevispinus	eudoxus		KIMMERIDGIAN
					mutabilis		
					cymodoce		
	NJK	NJKa	▲ C. perforata		baylei		KIMMERIDGIAN
			▲ F. multicolumnatus*		rosenkrantzi		
				L. crucicentralis ▼	regulare		
	NJK	NJKa			serratum		OXFORDIAN
					glosense		
					tenuiserratum		
	NJK	NJKa			densiplicatum		OXFORDIAN
					cordatum		
					mariae		
	NJK	NJKa		S. bigotii maximum ▲	lamberti		CALLOVIAN
			▲ A. helvetica		athleta		
			▲ S. hexum		coronatum		
	NJK	NJKa			jason		CALLOVIAN
			▲ C. perforata	S. bigotii ▲	calloviense		
			▲ S. speciosum	P. enigma ▼	macrocephalus		

Fig. 4.2 Callovian to Volgian/Tithonian biostratigraphic zones and events (those with an asterisk have only been reported from the tethyan area).

FO of *Ansulasphaera helvetica*.

Range. Upper Bajocian (*parkinsoni* AZ) to Upper Bathonian (*aspidoides* AZ).

Remarks. The base is also marked by the FOs of *Cyclagelosphaera tubulata*, *Hexapodorhabdus cuvillieri*, *Tetrapodorhabdus shawensis* and *Stauroolithites stradneri* (small variety). *T. shawensis* has a total range within NJ11. The small, distinctive holococcolith, *Anfractus harrisonii*, has its first consistent occurrence towards the base of the zone; it is virtually never found below this level, except where preservation is exceptional (Bown, 1993).

NJ12 *Ansulasphaera helvetica* Zone

Author. Bown *et al.* (1988).

Definition. FO of *Ansulasphaera helvetica* to the FO of *Stephanolithion bigotii bigotii*.

Range. Upper Bathonian (*aspidoides* AZ) to Callovian (*calloviense* AZ).

Remarks. The base of this zone is also approximated by the FO of *Stephanolithion hexum*.

NJ12a *Stephanolithion hexum* Subzone

Author. Bown *et al.* (1988).

Definition. FO of *Ansulasphaera helvetica* to the LO of *Pseudoconus enigma*.

Range. Upper Bathonian (*aspidoides* AZ) to the Callovian (*macrocephalus* AZ).

NJ12b *Watznaueria manivitiae* Subzone

Author. Bown *et al.* (1988).

Definition. LO of *Pseudoconus enigma* to the FO of *Stephanolithion bigotii bigotii*.

Range. Callovian (*macrocephalus* to *calloviense* AZs).

NJ13 *Stephanolithion bigotii bigotii* Zone

Author. Stradner (1963).

Definition. FO of *Stephanolithion bigotii bigotii* to the FO of *Stephanolithion bigotii maximum*.

Range. Callovian (*calloviense* to *lamberti* AZ).

Remarks. The base of this zone is also approximated by the FO of *Crepidolithus perforata*.

NJ14 *Stephanolithion bigotii maximum* Zone

Author. Medd (1982).

Definition. Total range of *Stephanolithion bigotii maximum*.

Range. Callovian (*lamberti* AZ) to Lower Oxfordian (*cordatum* AZ).

Remarks. Reworked Lower and Middle Jurassic nannofossils are common in sections from England and France. The highest diversities of Jurassic nannofossils from northern Europe are recorded from this interval.

NJ15 *Cyclagelosphaera margerelii* Zone

Author. Bown *et al.* (1988).

Definition. LO of *Stephanolithion bigotii maximum* to the FO of *Stephanolithion brevispinus* (= *helotatus* of Cooper, 1987).

Range. Lower Oxfordian (*cordatum* AZ) to Upper Kimmeridgian (*autissiodorensis* AZ).

Remarks. NJ15 is a long zone, reflecting a period of evolutionary stasis. This, and all younger, boreal Jurassic zones record steadily declining nannofloral diversity as extinctions outweigh inceptions. Assemblages are typically dominated by *W. britannica* and also include *Axopodorhabdus cylindratus*, *B. dubium*, *C. margerelii*, *Ethmorhabdus gallicus*, *Polypodorhabdus escaigii*, *S. bigotii bigotii*, *S. stradneri* and *Z. erectus*.

NJ15a *Lotharingius crucicentralis* Subzone

Author. Bown *et al.* (1988).

Definition. LO of *Stephanolithion bigotii maximum* to the LO of *Lotharingius crucicentralis*.

Range. Lower Oxfordian (*cordatum* AZ) to Upper Oxfordian (*regulare* AZ).

Remarks. The LO of *L. crucicentralis* has been recorded at this level in a number of sections but it is rare towards the top of its range. This datum has been reported from the Middle Oxfordian in SE France and Portugal (de Kaenel *et al.*, 1996). Other, potentially-useful LOs include *C. perforata* (*baylei* AZ - NJ15b) and *D. striatus* (*glosense* AZ).

NJ15b *Hexapodorhabdus cuvillieri* Subzone

Author. Bown *et al.* (1988).

Definition. LO of *Lotharingius crucicentralis* to the FO of *Stephanolithion brevispinus*.

Range. Upper Oxfordian (*regulare* AZ) to Upper Kimmeridgian (*autissiodorensis* AZ).

Range. The FO of *Faviconus multicolumnatus* has been reported from the Upper Oxfordian in de Kaenel *et al.* (1996).

NJ16 *Stephanolithion brevispinus* Zone

Author. Bown *et al.* (1988), emended herein.

Definition. FO of *Stephanolithion brevispinus* to the FO of *Stephanolithion atmetos*.

Range. Upper Kimmeridgian (autissiodorensis AZ) to Lower Volgian (klimovi AZ, equivalent to ?elegans/scitulus AZs in England).

Reference section. Gorodische, Russia; Beds 3 through 6.

Remarks. The name of this zone has been changed in order to satisfy taxonomic criteria, which are discussed in the Appendix (section 4.9). The concept of the zone as defined in Bown *et al.* (1988) remains the same. The range of the zone is somewhat reduced due to the extended lower range of *S. atmetos*, reported herein, which defines the base of the overlying zone. The zone is divided into two subzones based on the LO of *Anfractus harrisonii*.

NJ16a *Anfractus harrisonii* Subzone

Author. Defined herein.

Definition. FO of *Stephanolithion brevispinus* to the LO of *Anfractus harrisonii*.

Range. Upper Kimmeridgian (autissiodorensis AZ).

Reference section. Gorodische, Russia; Beds 3 and 4.

Remarks. See Appendix (section 4.9).

NJ16b *Zeugrhabdotus erectus* Subzone

Author. Defined herein.

Definition. LO of *Anfractus harrisonii* to the FO of *Stephanolithion atmetos*.

Range. Lower Volgian (klimovi AZ).

Reference section. Gorodische, Russia; Beds 5 and 6.

NJ17 *Stephanolithion atmetos* Zone

Author. Bown *et al.* (1988), emended herein.

Definition. Total range of *Stephanolithion atmetos*.

Range. Lower Volgian (upper klimovi AZ) to Middle Volgian (upper panderi AZ).

Reference section. Gorodische, Russia; Beds 6 through 11.

Remarks. The modified range of this zone reflects new observations of the range of the nominate taxon, and the zonal definition is emended to include the total range of *S. atmetos*. The zone is divided into two subzones using the

LO of *Stephanolithion bigotii*. The upper limit of the zone is constrained by the LO of *S. atmetos* but the exact level of this datum is uncertain due to the scarcity of nannofossil-bearing boreal sediments at this level. However, the species has not been recorded above the panderi AZ (zarasjkensis AsZ), and the base of the overlying zone is thus tentatively placed at this level. The base of NJ17 is also approximated by the LO of *Staurolithites lumina*. The zone is characterized by the successive LOs of *S. lumina*, *S. brevispinus*, *A. cylindratus* and *S. bigotii*. The top of the zone may also be marked by the LO of *E. gallicus*.

NJ17a *Axopodorhabdus cylindratus*

Subzone

Author. Defined herein.

Definition. FO of *Stephanolithion atmetos* to the LO of *Stephanolithion bigotii bigotii*.

Range. Lower Volgian (upper klimovi AZ) to Middle Volgian (lowermost zarasjkensis AsZ).

Reference section. Gorodische, Russia; Beds 6 through 10.

Remarks. The reliability of this subzonal boundary is uncertain due to the rarity of *S. bigotii bigotii* towards the top of its range.

NJ17b *Ethmorhabdus gallicus* Subzone

Author. Defined herein.

Definition. LO of *Stephanolithion bigotii bigotii* to the LO of *Stephanolithion atmetos*.

Range. Middle Volgian (zarasjkensis AsZ).

Reference section. Gorodische, Russia; Beds 10 and 11.

NJ18 *Watznaueria fossacincta* Zone

Author. Defined herein.

Definition. LO of *Stephanolithion atmetos* to ?

Range. Middle Volgian (?virgatus AZ) to ~Jurassic/Cretaceous boundary.

Remarks. The present scarcity of boreal Upper Volgian material has so far precluded the definition of well-defined nannofossil biozones for this interval, and the Gorodische observations do not provide sufficient data to apply nannofossil datums with any confidence. However, it is almost certain that *S. atmetos* and *E. gallicus* disappear before the virgatus/nikitini AZs, and that relatively depauperate, *Watznaueria*-dominated assemblages are characteristic of the Upper Volgian. It is presumed that new 'typically Cretaceous' taxa must

have reached the boreal area during this interval, as many new species are recorded in the lowest boreal (Upper) Ryazanian samples from Speeton and the North Sea. However, the data from Gorodische does not provide a suitable index-species candidate, although the questionable FO of *Rhagodiscus asper* is recorded in the nodiger AZ of the Kashpir section and may prove to be useful if found at this level elsewhere. Other bioevents which are recognised worldwide and occur close to the Jurassic/Cretaceous boundary include FO *C. cuvillieri*, FO *Rotelapillus laffitei*, FO *Micrantholithus* and FO *Lithraphidites carniolensis*.

Upper Jurassic Tethyan Nannofossil Zones (after Bralower *et al.*, 1989)

The following zones are stratigraphically equivalent to the preceding NJ16 to NJ18 zones, but are required and desirable due to the restricted geographic distributions of many Upper Jurassic taxa and the enhanced biostratigraphic resolution provided by exclusively tethyan taxa. The letter 'T' is placed in brackets after the zonal number in order to distinguish the zones from their boreal counterparts.

NJ19(T) *Staurolithites stradneri* Zone

Author. (Barnard and Hay, 1974) Bralower *et al.* (1989).

Definition. FO of *Staurolithites stradneri* to the FO of *Conusphaera mexicana minor*.

Range. Upper Oxfordian to Lower Tithonian (CM22n).

Remarks. Rigorous species concepts are difficult to apply within the *Staurolithites* group, and this factor may compromise the biostratigraphic integrity of this zone; in any case Bralower *et al.* (1989) believe the zone cannot be recognized in southern Europe.

NJ19a(T) Unnamed Subzone

Author. Bralower *et al.* (1989).

Definition. FO of *Staurolithites stradneri* to the FO of *Zeugrhabdotus embergeri*.

Range. Upper Oxfordian to Upper Kimmeridgian.

NJ19b(T) *Zeugrhabdotus embergeri* Subzone

Author. (Worsley, 1971) Bralower *et al.* (1989).

Definition. FO of *Zeugrhabdotus embergeri* to

the FO of *Conusphaera mexicana minor*.

Range. Kimmeridgian/Tithonian boundary interval (within CM22n).

Remarks. The problems associated with the taxonomic definition and identification of *Z. embergeri* are well known (e.g. Roth, 1983; Bralower *et al.*, 1989), and rigorous taxonomic concepts must be strictly applied. The time of entry of this species into the boreal area is also uncertain, and is discussed further in the Appendix (section 4.9).

NJ20(T) *Conusphaera mexicana* Zone

Author. (Thierstein, 1975) Bralower *et al.* (1989).

Definition. FO of *Conusphaera mexicana minor* to the FO of *Helenea chiastia*.

Range. Lower to middle Tithonian (CM22n–CM20).

Remarks. The appearance of *C. mexicana minor*, followed by *C. mexicana mexicana* and the earliest nannoconids (*Nannoconus compressus*), provide a distinctive series of bioevents through this zone. The decline in *W. britannica* abundance occurs in this zone at DSDP Site 534 (North Atlantic Ocean) (pers. obs.). Although this event is well known, it is poorly constrained stratigraphically. *W. britannica* remains abundant in boreal sections into the uppermost Bolonian at least (i.e. Upper Tithonian).

NJ20a(T) *Hexapodorhabdus cuvillieri* Subzone

Author. (Roth *et al.*, 1983) Bralower *et al.* (1989).

Definition. FO of *Conusphaera mexicana minor* to the FO of *Polycostella beckmannii*.

Range. Lower Tithonian (CM22n–CM21n).

NJ20b(T) *Polycostella beckmannii* Subzone

Author. (Roth *et al.*, 1983) Bralower *et al.* (1989).

Definition. FO of *Polycostella beckmannii* to the FO of *Helenea chiastia*.

Range. Middle Tithonian (CM21n–CM20).

NJK *Helenea chiastia* Zone

Author. Bralower *et al.* (1989).

Definition. FO of *Helenea chiastia* to the FO *Nannoconus steinmannii steinmannii*.

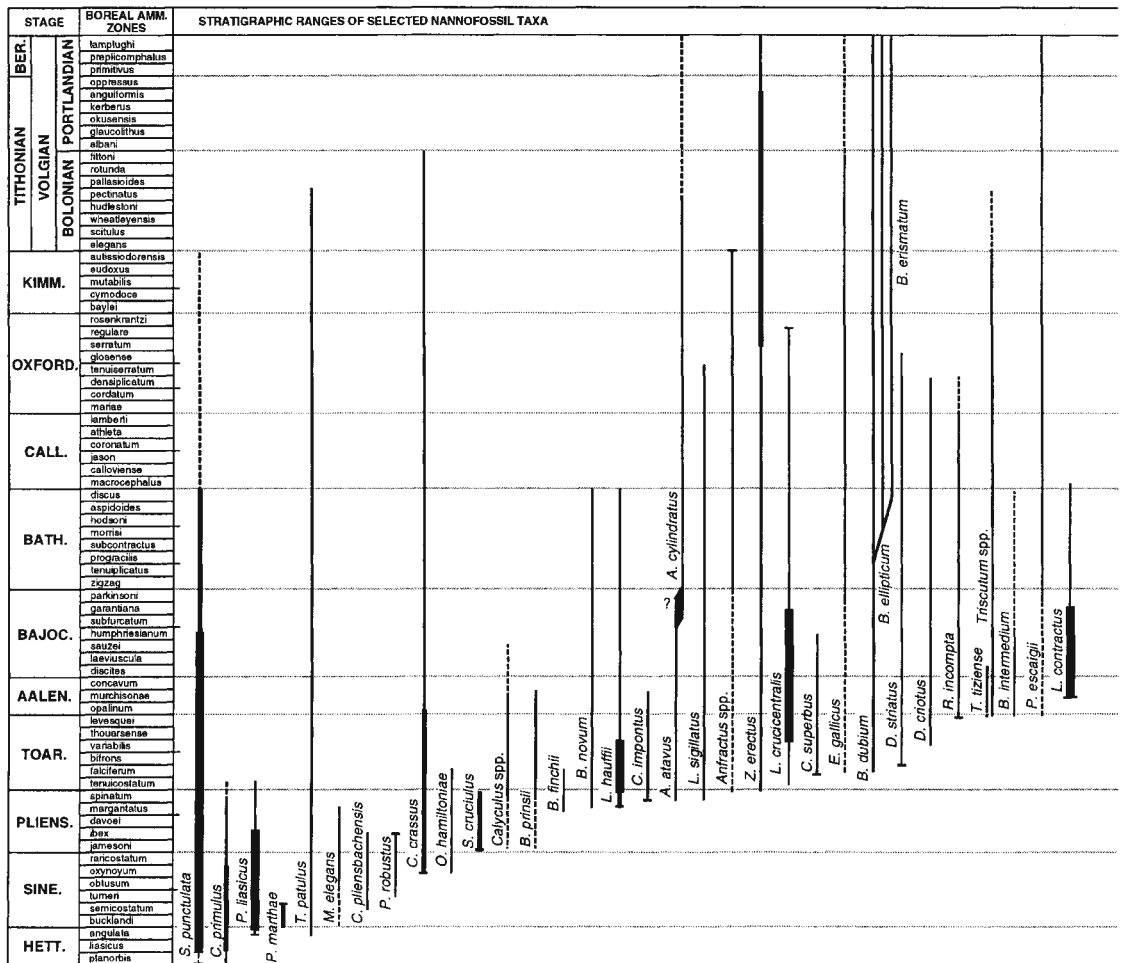
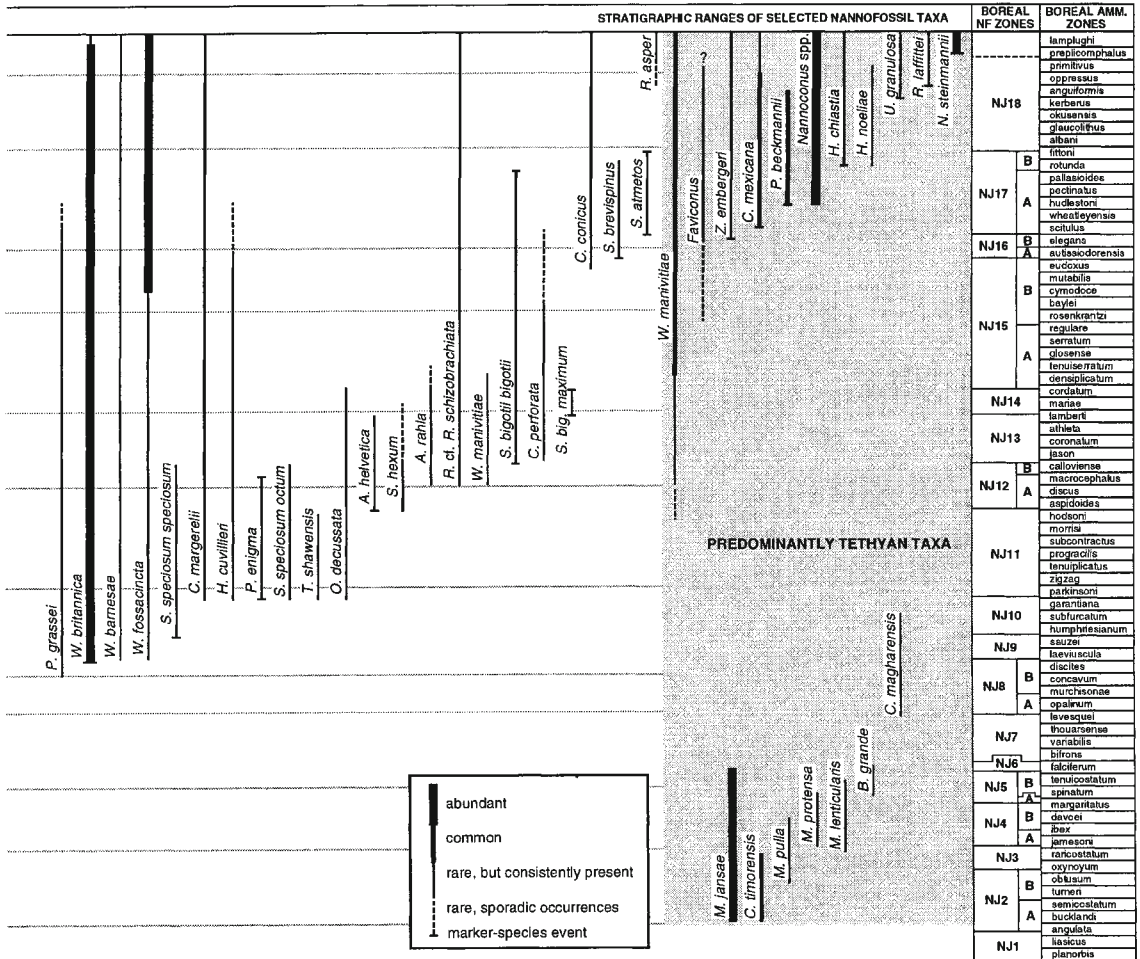


Fig. 4.3 Stratigraphic ranges of selected Jurassic taxa.



Range. Upper Tithonian to Lower Berriasian (CM20–CM17).

Remarks. This zone encapsulates much of the late Tithonian evolutionary radiation, which occurred in the western Tethys/proto-Atlantic Ocean region, and saw the introduction of many new coccolith (*Helenea*, *Umbria*, *Speetonia*, *Cruciellipsis*, *Manivitella* and *Rhagodiscus*) and nannolith (*Lithraphidites*, *Nannoconus globulus*, *N. winteri*, *N. kamptneri* and *N. steinmannii*) taxa. The FO of *H. chiastia* is coincident with the FOs of *Hexalithus noeliae* and *Polycostella senaria*.

NJKa *Hexalithus noeliae* Subzone

Author. Bralower *et al.* (1989).

Definition. FO of *Helenea chiastia* to the FO of *Umbria granulosa granulosa*.

Range. Upper Tithonian (CM20–CM19n).

NJKb *Umbria granulosa granulosa* Subzone

Author. Bralower *et al.* (1989).

Definition. FO of *Umbria granulosa granulosa* to the FO of *Rotelapillus laffittei*.

Range. Uppermost Tithonian (CM19n).

NJKc *Rotelapillus laffittei* Subzone

Author. Bralower *et al.* (1989).

Definition. FO of *Rotelapillus laffittei* to the FO of *Nannoconus steinmannii minor*.

Range. Tithonian/Berriasian boundary interval (CM19n–CM18n).

NJKd *Nannoconus steinmannii minor* Subzone

Author. Bralower *et al.* (1989).

Definition. FO of *Nannoconus steinmannii minor* to *Nannoconus steinmannii steinmannii*

Range. Lowermost Berriasian (CM18n–CM17).

4.5 GLOBAL CORRELATION

Two Jurassic nannofloral realms are presently well-known: the northern-high-latitude Boreal Realm and the low-latitude Tethyan Realm. A third, southern-high-latitude Austral Realm has been postulated but very little information is available at present.

The realms are defined by endemic species distributions and contrasting assemblage composi-

tions. It has also been suggested that species ranges may vary between the realms but this has yet to be conclusively proven and may simply reflect taxonomic and preservational problems.

Currently, only the Upper Jurassic interval has required the development of separate biozonation schemes for the northern-high-latitude and low-latitude regions.

4.5.1 Lower Jurassic

The Bown *et al.* (1988) zonation has been successfully applied worldwide, including northern Europe (Bown, 1987), British Columbia, Timor, Argentina (Bown, 1992a), India, eastern Africa, northwestern Australian shelf (Bown, pers. obs.), Mazagan Plateau (offshore Morocco) (Wiegand, 1984; Bown, 1987) and Portugal (Bown, 1987; Bergen, in press). Despite relatively high percentages of endemic taxa, all of those species which are utilized as zonal fossils have virtually cosmopolitan distributions.

4.5.2 Middle Jurassic

Compared to the Lower Jurassic, much less work has been carried out on Middle Jurassic sections outside the European area. For the most part, the zonation of Bown *et al.* (1988) can be applied, although further subdivision has been achieved in the excellent sections of Portugal (Bergen, in press) (Figs 4.1–4.2). Correlation of the Aalenian and Bajocian zones has been problematical, due to the apparent diachroneity of a number of *Lotharingius* and *Watznaueria* species, although this most probably reflects differing species concepts applied to a difficult lineage. However, these zones (NJ8b, NJ9) may require subsequent modification.

4.5.3 Upper Jurassic

The restricted biogeographic distributions of a high proportion of Upper Jurassic taxa, particularly in the Tithonian, has necessitated the development of separate biozonations for the tethyan and boreal areas (Fig. 4.2), with far greater refinement currently achieved in the former region. This

currently achieved in the former region. This interval presents the most problems for correlation of the boreal and tethyan regions for the following reasons:

- declining nannofossil diversity in the boreal area (Middle Volgian = Bolonian);
- unfavourable facies and incomplete sections in the boreal area (Upper Volgian = Portlandian);
- absence of new and biostratigraphically-valuable tethyan taxa in the boreal area;
- poor nannofossil preservation in carbonate-rich, tethyan facies; and
- tethyan nannofossil events poorly-constrained and mainly defined in DSDP cores.

The development of tethyan biostratigraphy has relied almost completely on one DSDP site in the western Atlantic Ocean (Site 534) which has yielded an excellent succession of nannofossil events, which are correlated with magnetostratigraphic chronozones (Roth *et al.*, 1983; Bralower *et al.*, 1989). Further refinement of the scheme has been hampered by poor preservation in onshore tethyan sections and a lack of direct correlation with ammonite data.

The few potentially correlatable marker-species found in both realms are beset with problems: *S. bigotii bigotii* appears to have a diachronous LO, *Z. embergeri* is poorly-constrained taxonomically, and *S. brevispinus* (= *helotatus*) is a small and rare species which is easily overlooked.

A number of workers are presently addressing the problems listed above but good sections of this age, particularly those which yield co-occurring boreal and tethyan markers, are few and far between. Recent work from Bulgaria and the Czech Republic (pers. obs.) has confirmed the co-occurrence of boreal and tethyan species, e.g. *S. brevispinus* with *C. mexicana minor* and *S. atmetos* with *C. mexicana mexicana* underlining the great potential nannofossils have for providing correlation through this problematical interval.

4.6 MAGNETOBIOCHRONOLOGY

The lack of magnetostratigraphic data for the Jurassic has meant that few studies have correlated nannofossil datums and the geomagnetic time-scale. Ogg and Steiner (1988) and Bralower *et al.* (1989) present data for the Upper Jurassic of the tethyan area. No data are available at present for boreal areas.

4.7 BIOGEOGRAPHY

The biogeographic differentiation of Jurassic marine invertebrate faunas has long been recognised (Neumayr, 1883), and similar patterns are also seen in many other fossil groups. Arkell (1956) distinguished three faunal realms on the basis of ammonite distributions, the Boreal, Tethyan and Pacific. In contrast, Hallam (1975) distinguished only the former two. The Boreal Realm corresponded to the northern part of the Northern Hemisphere, the Tethyan Realm to the rest of the globe. The limit between the two realms, while variable through time, corresponded approximately with a gradational zone through southern Europe and, in the North Pacific region, with a zone through northern California and between Japan and eastern Siberia (Hallam, 1975). The Jurassic Boreal Realm is well-defined by ammonites and belemnites but for other groups it is defined by an absence of tethyan forms rather than by a distinct fauna/flora of its own. Ammonite distributions reveal a temporal variability in the degree of provincialism, with differentiation in the Pliensbachian and Bathonian, and extreme endemism in the Tithonian and Volgian. In general, the faunas of the Tethyan Realm have a greater diversity than those of the Boreal Realm (Hallam, 1975).

The cause of Jurassic provincialism has been the subject of much debate, and explanations have included temperature gradients, land barriers, water depth and salinity. Arguments for and against these explanations are set out in Hallam (1975). More recently, the concept of environmental stability has been proposed as a possible explanation, with the Tethyan Realm reflecting a region of high stability with oceanic influence, and the Boreal Realm the product of variable and stressful environments in widespread epeiric seas (Hallam, 1975).

The global distribution of Jurassic nannofloras is still poorly known and information remains heavily weighted towards Europe. Several DSDP and ODP sites have provided information from the Atlantic and Indian Ocean regions but these generally penetrate only Middle and Upper Jurassic strata. Despite a somewhat limited data set, nannofossil distribution is seen to exhibit variable degrees of provincialism through the Jurassic, with nannofloras from the tethyan region distinguish-

able from those of northern Europe.

In the Lower Jurassic, nannofloras from western Tethys and the proto-Atlantic area are characterized by the abundant occurrence of *Mitrolithus jansae*. *M. jansae* ranges from Sinemurian to Lower Toarcian and is often the principal component of assemblages. This species has been reported from certain stratigraphic intervals in NW European sections but is always rare (Bown, 1987). There are a number of other essentially endemic tethyan forms which also occur in Timor (further to the east in the Tethys Ocean), e.g. *Mitrolithus lenticularis*, *Biscutum grande*, *Timorella cypella*, and the Family Mazaganellaceae (*Mazaganella pulla* and *M. protensa*).

The Late Jurassic (Middle Oxfordian and younger) saw the renewal of biogeographic distinctness in nannofloral distribution, which increased in Tithonian (= Volgian) times. This corresponds with similar observations of ammonite distributions. Many new nannofossil groups which had their first occurrences in the Tithonian, e.g. the genera *Nannoconus* and *Conusphaera*, were initially restricted in distribution to the western Tethys and North Atlantic region. The tethyan nannofloras are thus distinguished by the presence of endemic taxa and by considerably higher diversities. The existence of endemic boreal taxa in the Late Jurassic is uncertain but a number of species have been suggested, e.g. *Stephanolithion atmetos* (Cooper, 1989), and distinct boreal species are clearly present by Early Cretaceous times (Cooper, 1989). Preliminary research in central Europe and the Balkans has provided evidence of a transitional zone between the Boreal and Tethyan realms (pers. obs.).

The occurrence of nannofossils in Upper Jurassic DSDP/ODP sections from the Argo Abyssal Plain (NW Australian shelf; palaeolatitude of ~35°S) (Bown, 1992b) and Falkland Plateau (palaeolatitude of ~60°S) (Wise and Wind, 1977) allows a limited assessment of Southern Hemisphere nannofossil distributions, and the results suggest the existence of an Austral Realm, a counterpart to the Boreal Realm, which was dominated by taxa with boreal (i.e. high-latitude) affinities, e.g. *Stephanolithion brevispinus*, and devoid of tethyan taxa such as *Conusphaera* and *Nannoconus*. The presence of common *Watznaueria manivitiae* on the Argo Abyssal Plain,

however, also infers a degree of tethyan-austral mixing, inferring a transitional biogeographic zone in this region. Bipolar distributions, together with endemism in northern and southern high-latitudes, has been well documented in the Cretaceous (Wise, 1988; Watkins *et al.*, 1996). These observations are presently at odds with interpretations of cephalopod distributions, which do not indicate a distinct Austral Realm.

4.8 ATLAS OF SPECIES

Most Jurassic calcareous nannofossils are listed and illustrated in Plates 4.1 to 4.16. Taxa are listed according to the classification of Bown and Young (1997), firstly by order and secondly by family. Electron micrographs are not uniformly enlarged but magnifications are given in the plate captions. Light micrographs are uniformly enlarged at x2300. Stratigraphic information is given as stages (L=Lower, M=Middle, U=Upper) and ammonite zones (in brackets), where possible; question marks indicate a degree of uncertainty. Photographs are identified by a UCL number (film and frame) and are stored in the Postgraduate Unit of Micropalaeontology, University College London. The majority of photographs come from the research of Drs Paul Bown, Kevin Cooper and Hilary Dockerill.

4.9 APPENDIX 1. CALCAREOUS NANNOFOSSILS FROM THE UPPER KIMMERIDGIAN-VOLGIAN OF GORODISCHE, RUSSIA (P.R. BOWN)

4.9.1 Introduction

A total of 44 samples from the Gorodische section in Russia (Kimmeridgian to Volgian; proposed Volgian lectostratotype) were examined for calcareous nannofossils. A previous study by Cooper (1987) reported well-preserved and diverse nannofossil assemblages from a stratigraphically shorter suite of fewer samples (10).

All but two of the samples yielded nannofossil assemblages which, in general, are well-preserved, abundant and diverse. These results show that the Gorodische section provides the finest nannofossil succession for this time interval in the boreal area,

confirming Cooper's (1987a) preliminary findings. Other coeval boreal sections, notably the Kimmeridge Clay of southern England, are in part comparable but generally nannofossil assemblages are lower in diversity or through certain intervals, absent (Cooper, 1987b). Tethyan sections generally yield poorly-preserved nannofossils due to the predominance of micritic limestone lithologies, however, a number of DSDP sections from the Atlantic Ocean (e.g. Sites 391 and 534) have provided excellent results for this interval, revealing markedly different assemblage compositions from those seen in the boreal area (e.g. Roth, 1983; Bralower *et al.*, 1989).

The Gorodische nannofossil results are particularly valuable in confirming a sequence of extinction events which characterizes this interval, but more importantly it has allowed the testing of the Upper Jurassic zonal scheme of Cooper (1987a) and Bown *et al.* (1988) and revealed a number of problems which are discussed below.

4.9.2 Stratigraphic terminology

Kimmeridgian is used throughout in the restricted, *sensu gallico*, sense. The term Bolonian is adopted, as discussed by Cope (1993), for the Upper Kimmeridgian (*sensu anglico*). Ammonite correlations between England and Russia are based upon Cope (1993).

4.9.3 Nannofossil results

a. Kimmeridgian–Middle Volgian

Samples 1A–25, from the Upper Kimmeridgian to lower Middle Volgian (eudoxus AZ through panderi AZ, zarasjkensis AsZ), yielded well-preserved, abundant, and diverse nannofossil assemblages. Samples 26A–28, from the Middle and Upper Volgian (virgatus, fulgens, subditus and nodiger AZs), were either barren or depauperate (Fig. 4.4). The Upper Volgian results are discussed separately below.

The Upper Kimmeridgian to Volgian part of this section has yielded the best succession of nannofossil events yet seen in the boreal area. Diversity is highest in the Kimmeridgian (27–29 species) but falls to lower levels in the Lower and Middle Volgian (15–20 species). The assemblages

are characterized by the numerical dominance of *Watznaueria*, and in particular *W. britannica*.

The stratigraphic distribution of nannofossils is presented in Fig. 4.4, along with ammonite and nannofossil zone designations. The Gorodische nannofossil succession is particularly notable for:

(i) **common *Zeugrhabdotus erectus*** – this distinctive species occurs commonly in most of the samples studied. Its increase in size through this interval is well documented (e.g. Roth, 1983; Bralower *et al.*, 1989) but its differentiation from *Zeugrhabdotus embergeri* has remained a source of much discussion, particularly as the latter species has been commonly used as a zonal marker around the Kimmeridgian–Volgian (= Tithonian) boundary (e.g. Barnard and Hay, 1974; Medd, 1982; Hamilton, 1982). First Stradner (1963) and later Bralower *et al.* (1989) attempted to differentiate these species by imposing morphometric limits, but the latter observed 'complete gradation between true *Z. erectus* and *Z. embergeri* and it is impossible to divide the two taxa morphometrically', underlining the difficulty encountered in this lineage. The present study did not recognize *Z. embergeri* in any of the Gorodische samples, although Roth (pers. comm.) recorded its first occurrence in the klimovi AZ (lowermost Volgian), and considers it a potentially valuable interregional marker-species. Its first occurrence in the tethyan area is better known, occurring in polarity chron CM22n (Site 534, Bralower *et al.*, 1989, but CM22r, pers. obs.), which is correlated to the middle hybonotum AZ (lowermost Tithonian). The opinion of the author is that *Z. embergeri* is not present, or only rarely present, in the Volgian of the boreal area, and did not move into this area until the earliest Cretaceous.

(ii) **the abundant occurrence of small, delicate coccoliths of the Family Stephanolithiaceae (*Stradnerlithus* and *Truncatoscapus*)** – these coccoliths are rarely preserved but have often been described in vast numbers from sediments which are laminated and organic-rich, e.g. the Posidonienschiefer, Schistes Carton, Kimmeridge Clay and Munk Marl. It is uncertain whether their occurrence is a result of exceptional preservation in these unusual sediments, or a reflection of a particular, primary surface-water environment, e.g. high productivity.

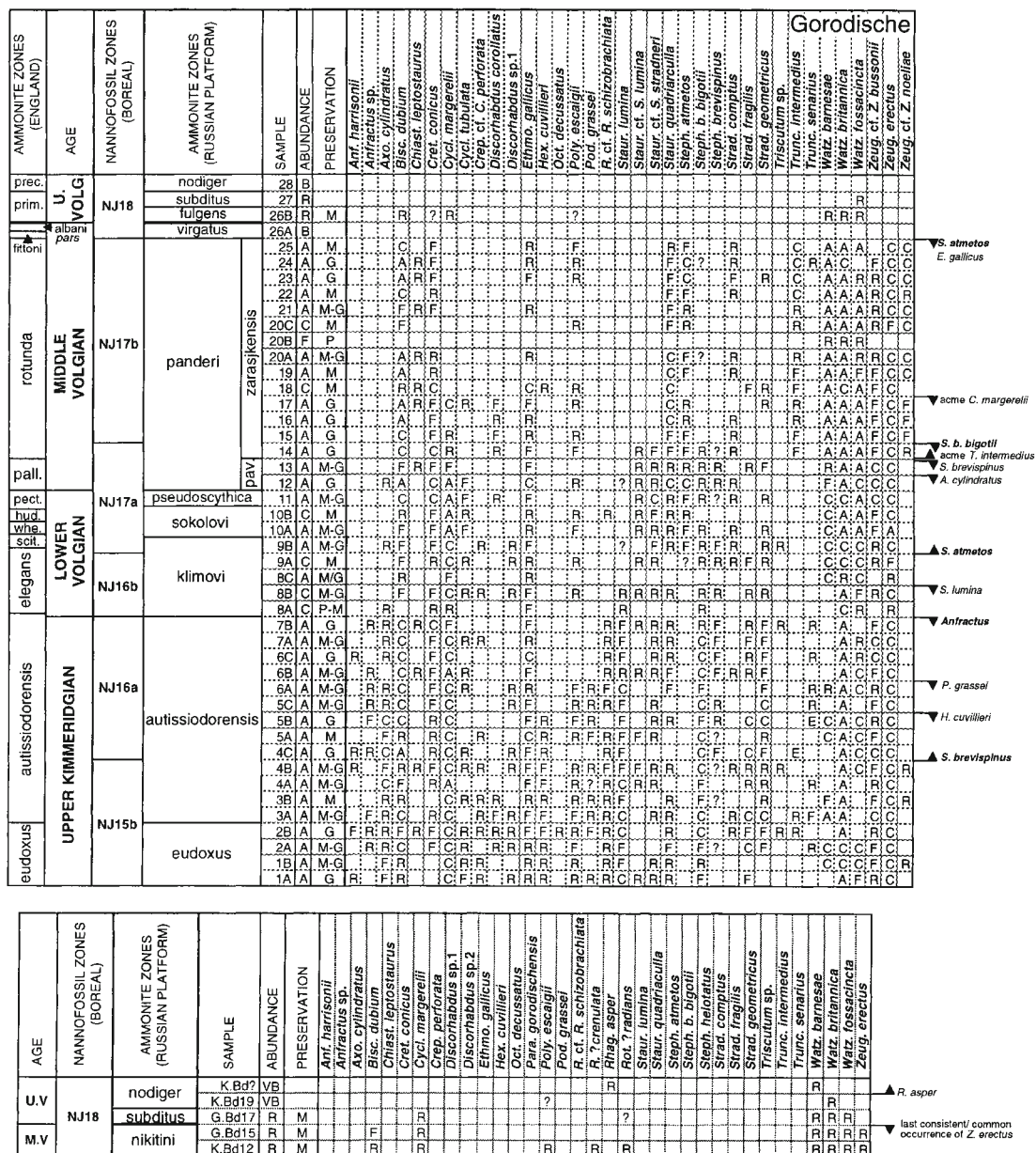


Fig. 4.4 Stratigraphic distribution of nannofossils for the Gorodische section, Russia. The lower chart includes additional spot samples from Gorodische and Kashpir. Species abundance: A >10/FOV, C 1-10/FOV, F 1/2-10 FOV, R 1/11-100 FOV. Nannofossil abundance: A >10%, C 1-10%, F 0.1-1%, R <0.1%, VB virtually barren, B barren.

The species *S. fragilis* and *S. geometricus* are particularly common.

(iii) **the occurrence of holococcoliths** – due to the fragile nature of holococcolith construction, most Jurassic forms have only been found in assemblages which are exceptionally well-preserved (Bown, 1993). The exception is *Anfractus harrisonii*, which is relatively consistently recorded in Lower Bathonian through Upper Kimmeridgian sediments. *A. harrisonii* is recorded in the Gorodische section but its upper range is slightly extended here, into the autissiodorensis AZ. In addition, a number of other *Anfractus*-type holococcoliths have been seen in both LM and SEM observation.

(iv) **evolution and extinction of three *Stephanolithion* species** – three species of *Stephanolithion* are recorded in the Gorodische section, *S. atmetos*, *S. bigotii bigotii* and *S. brevispinus* (= *S. helotatum* of Cooper, 1987a), and all have previously been utilized as biostratigraphic marker-species. Cooper (*in* Lord *et al.*, 1987) proposed two new nannofossil zones based upon the successive first occurrences of *S. helotatum* and *S. atmetos*, and formally defined these zones in Bown *et al.* (1988), using Gorodische as a reference section. The present study has revealed a number of problems with these zones which have thus been emended herein.

b. Upper Volgian

These samples yielded low-abundance and -diversity nannofossil assemblages, were virtually barren (i.e. <10 specimens), or were barren. Preservation, however, is not particularly poor, which suggests that the rare occurrences reflect dilution by clastic material and/or unfavourable primary environmental conditions, rather than post-sedimentation destruction by etching. A number of supplementary spot samples from Gorodische and the nearby Kashpir section were provided by Prof. John Calloman.

Boreal nannofossil data from this time interval are virtually unknown. The Russian Upper Volgian correlates with the Purbeck Group of southern England which is in predominantly marginal and non-marine facies. The highest record of nannofossiliferous sediments for this interval in England are of fittoni and albani AZ age (Middle

Volgian) (Cooper, 1987b; Bown *in* Lord and Bown, 1987). The oldest Ryazanian sediments with recorded nannofloras are from the albidum AZ (Upper Ryazanian) of the Speeton section (NE England). Rahman and Roth (1992) studied Ryazanian samples from central Russia but give no assemblage or stratigraphic information.

The significance of the Gorodische/Kashpir results is uncertain as the assemblages appear to be depauperate, for the reasons given above. However, they do show the continued range of all three *Watznaueria* species, and also include discontinuous ranges of *B. dubium*, *C. margerelii*, *P. escaigii*, and *Z. erectus* (all of which have Lower Cretaceous records). The absence of *S. atmetos* and *E. gallicus* is thought to be the result of extinctions in the Middle Volgian (?prior to the virgatus/nikitini AZs).

The decline in *W. britannica* abundance, which was shown by Cooper (1984) to approximate the Jurassic/Cretaceous boundary could not be assessed in these samples because of the low number of specimens involved.

4.9.4 Taxonomy

Family CHIASTOZYGACEAE Rood, Hay and Barnard, 1973 emend. Varol and Girgis, 1994

Genus *Staurolithites* Caratini, 1963

Staurolithites lumina Bown sp. nov.

Plate 4.1, fig. 20; Plate 4.9, figs 21–25

Derivation of name. From *lumino*, Latin for 'light up', and referring to the appearance of the coccolith's cross-bars in XPL.

Diagnosis. An elliptical, bicyclic (in distal view) murolith with broad, axial cross-bars which are highly birefringent in XPL (maximum birefringence is achieved in both cross-bars in the same orientation, although the c-axes are perpendicular as shown by the gypsium-plate).

Description (SEM). Outer, distal rim is composed of numerous, highly-inclined, i.e. imbricating, elements. In distal view, a second inner rim-cycle is seen but structural details are unclear (it is assumed that, like other murolith-coccoliths, this inner cycle is a distal extension of the proximal rim-cycle). The central-area is spanned by an axial cross which is attached to the inner rim-cycle. The bars are formed from elongate laths, and are bisected by a median suture. The

cross supports a central spine-base/?spine.

Description (LM). The rim is bicyclic; both cycles are narrow. The outer cycle is slightly birefringent (dark, and high relief in PC) and the inner cycle is birefringent (bright in PC). The cross-bars show coincident maximum birefringence colours (white) when orientated approximately 25° anticlockwise from the N–S position. The junction of the four cross-bars is marked by distinct, dark suture-lines.

Remarks. The genus *Staurolithites* (= *Vagalapilla*, *Vekshinella*) is a taxonomic grouping which has become virtually unusable because of poor species-definition, somewhat reflecting almost infinite variety on a basic, and stratigraphically long-ranging, morphological theme. A variety of species names have been applied to Jurassic murolith coccoliths with axial cross-bars, including *stradneri*, *dibrachiata*, *quadriarcula*, *crux* and *magnus*, but the ill-defined species concepts have resulted in poorly-defined ranges. Barnard and Hay (1974) and later Roth *et al.* (1983) used the first occurrence of '*V. stradneri*' to define the base zone in the Lower Oxfordian, but this has rarely been recognized due to the presence of *stradneri*-type coccoliths throughout the Jurassic. The new species, *S. lumina*, is found in the Kimmeridgian and Lower Volgian samples from Gorodische, and is very distinctive in the LM. Its LO in the klimovi AZ is also recognized in English material, but this species has not yet been recognized in tethyan samples.

Holotype. Plate 4.9, fig. 21 (LM).

Paratype. Plate 4.1, fig. 20 (EM).

Type locality. Gorodische, Russia.

Type level. Upper Kimmeridgian (autissiodorensis AZ).

Range. Gorodische: eudoxus AZ (Upper Kimmeridgian) to klimovi AZ (Lower Volgian).

Family STEPHANOLITHIACEAE Black, 1969
Genus *Stephanolithion* Deflandre, 1939

Stephanolithion atmetos Cooper, 1987
Plate 4.3, fig. 8 and Plate 4.11, figs 8–10

Remarks. The stratigraphic range of this species is poorly defined, being reported as lower Middle Volgian (panderi AZ) from Gorodische by Cooper (1987) and Upper Kimmeridgian (autissiodorensis AZ) from Russia by Roth (pers. comm.). In the

present study, the FO was observed in the klimovi AZ, considerably lower than Cooper's (1987a) record, which calls into question the position and validity of the *S. atmetos* Zone. This problem is a reflection of the gradualistic evolutionary development of *S. atmetos*, which is clearly an end-member descendant of the *S. bigotii bigotii*–*S. brevispinus* lineage/plexus.

Stephanolithion bigotii bigotii Deflandre, 1939
Plate 4.3, fig. 9–11; Plate 4.11, figs 11–13

Remarks. This distinctive taxon has been used extensively as a marker-species, particularly its FO which occurs in the Callovian. Its LO is less well-constrained, firstly because of the evolution of the two new species discussed above, and secondly because of its apparent rarity or total absence towards the top of its range in the classical Kimmeridgian sequences of England. This study found the LO in the lower Middle Volgian (panderi AZ, zarasjkensis AsZ). Considering the importance of this species, as one of the only cosmopolitan marker-species for this interval, it is suggested that this datum be upgraded to zonal status, although the synchronicity of this horizon requires testing in tethyan sections. It has been recorded within polarity chron CM20r in Site 534 (pers. obs.), near the Lower/Middle Tithonian boundary, which is probably equivalent to one ammonite zone lower than in the Gorodische section, although this is difficult to substantiate.

Stephanolithion brevispinus (Wind and Wise in Wise, 1988) Bown stat. nov.

Plate 4.3, figs 13–14; Plate 4.11, figs 16–20

- 1983 *Stephanolithion bigotii* Deflandre; Wise, pl. 34, figs 3 and 4.
- 1987 *Stephanolithion helotatum* (Wise and Wind); Cooper, p. 610, fig. 1 (13–15).
- 1988 *Stephanolithion bigotii brevispinus* Wind and Wise in Wise, p. 175.

Emended diagnosis. An elliptical species of *Stephanolithion* with short, ?irregular, lateral rim-spines and a central-area diagonal cross which supports a spine.

Remarks. The generic affinity and taxonomy of *S. helotatum* has been questioned by both Wise (1988) and Rahman and Roth (1992). Both rejected

the inclusion of this species in *Stephanolithion* on the grounds that the holotype, and other recorded specimens, have no lateral rim spines. Wise (1988) recognized the existence of similar, and probably closely-related forms which possess the short spines that Cooper (1987a) illustrated, and proposed a new subspecies of *S. bigotii* (*S. bigotii brevispinus* Wind and Wise in Wise, 1988) to include them. It is thought best to conform to these suggestions, although the subspecies of Wise (1988) is here elevated to species level.

The stratigraphic range of *S. brevispinus* is still poorly defined, reflecting the gradualistic evolution of *S. brevispinus* from the ancestral species *S. bigotii*. In the present study, the first occurrence of *S. brevispinus* was observed in the autissiodorensis AZ, confirming the observation of Cooper (1987a) and the lower level of the NJ16 *S. brevispinus* Zone.

Differentiation. *S. bigotii* has long, lateral rim-spines, normally six in number, which are regularly arranged, and its outline is often angular

rather than elliptical. *Stradnerlithus helotatus* is similar in shape, size and central-area configuration but lacks rim spines. *S. atmetos* has merged cross-bars and is narrowly elliptical in outline, with almost parallel sides.

Range. *Gorodische*: autissiodorensis AZ (Upper Kimmeridgian) to sokolovi AZ (Lower Volgian) (this study); *Gorodische*: autissiodorensis AZ (Upper Kimmeridgian) to zarasjkensis AsZ (Middle Volgian) (Lord *et al.*, 1987); *Falkland Plateau* (Site 511): ?Kimmeridgian-Lower Volgian (Wise, 1983) (the stratigraphy of these cores, Sites 330 and 511, is questionable and evidence from the range-charts of Wise and Wind (1977) and Wise (1983) suggests the range could be limited to the Upper Kimmeridgian-Volgian); *Dorset coast*: huddlestoni AZ to rotunda AZ (Bolonian = Lower Volgian) (Cooper, 1987b); *S. England*: wheatleyensis AZ (Bolonian = Lower Volgian) (pers. obs.); *Central Russia*: Oxfordian (Rahman and Roth, 1992 – non-spinose forms, i.e. true *Stradnerlithus helotatus*).

Plate 4.1

Order EIFFELLITHALES Rood *et al.*, 1971

Family CHIASTOZYGACEAE Rood *et al.*, 1973 emend. Varol and Girgis, 1994

Fig. 1. *Crepidolithus crassus* (Deflandre in Deflandre and Fert, 1954) Noël, 1965. Distal (lower three specimens), side and proximal (upper specimen) views, Ilminster (UK), L. Toarcian, UCL-2615-8, x2400. Range: U. Sinemurian (oxynotum) – U. Tithonian (fittoni).

Figs 2–3. *Crepidolithus granulatus* Bown, 1987. Distal (2) and side (3) views of same specimen, Brenha (Portugal), L. Pliensbachian (ibex), UCL-2170-3/4, x5450. Range: L. Pliensbachian (ibex) – U. Pliensbachian (margaritatus).

Figs 4–5. *Crepidolithus impontus* (Grün *et al.*, 1974) Goy, 1979. Distal (4) and side (5) views of same specimen, Unterstürmig (Germany), L. Toarcian, UCL-2036-2/3, x6560. Range: U. Pliensbachian (spinatum) – Aalenian (murchisonae).

Figs 6–8. *Crepidolithus perforata* (Medd, 1979) Grün and Zweili, 1980. Distal (6), side (7) and proximal (8) views, Villers-sur-mer (France), L. Oxfordian (mariae), UCL-2032-17/7; UCL-2207-4, x6905/8095/6788. Range: L. Callovian (jason) – L. Volgian (klimovi).

Figs 9–10. *Crepidolithus plienschachensis* Crux, 1985. Distal (9) and side (10) views of same specimen, Timor, L. Pliensbachian, UCL-2072-25/26, x4950. Range: L. Sinemurian (semicostatum) – L. Pliensbachian (ibex).

Figs 11–12. *Crepidolithus timorensis* (Kristan-Tollmann, 1988a) Bown comb. nov.. Distal (11) and proximal oblique (12) views, Timor, Sinemurian, UCL-2736-25/26, x7777. Range: ?Sinemurian.

Basionym: *Timorhabdus timorensis* Kristan-Tollmann, 1988a (*Geol. Paläont. Mitt. Innsbruck*, **15**, 71–83, p. 74–75, pl. 2, figs 1, 3, 5).

Figs 13–15. *Tubirhabdus patulus* Rood *et al.*, 1973. Distal (13), side (14) and distal oblique (15) views. 13, Mochras Borehole (UK), L. Toarcian (falciferum), UCL-1993-5, x8095. 14, Timor (L. Pliensbachian), UCL-2072-7, x7866; 15, modified Middle Jurassic morphotype, Dorset (UK), Bathonian (zigzag), UCL-1902-9, x4686. Range: L. Sinemurian (bucklandi) – L. Tithonian (pectinatus).

Fig. 16. *Vacherauvillius implicatus* Goy, 1979. Distal (upper specimen) and proximal (lower right specimen) views, Hambühren (Germany), L. Toarcian, UCL-3848-28, x11500. Range: ?L. Toarcian (tenuicostatum – falciferum).

Fig. 17. *Stauroolithites stradneri* (Rood *et al.*, 1971) Bown comb. nov.. Distal view, Gorodische (Russia), U. Kimmeridgian (eudoxus), UCL-1502-3, x6975. Range: L. Pliensbachian? – ?Cretaceous.

Basionym: *Vekshinella stradneri* Rood *et al.*, 1971 (*Eclogae Geologicae Helvetiae*, **64**, 245–272, p. 249, pl. 1, fig. 2).

Figs 18–19. *Stauroolithites quadriarculla* (Noël, 1965) Wilcoxon, 1972. 18, Distal and proximal views, Hambühren (Germany), L. Toarcian, UCL-3776-3, x4500; 19, Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-1506-11, x10555. Range: U. Sinemurian – ?Cretaceous.

Fig. 20. *Stauroolithites lumina* Bown sp. nov.. Distal view, Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-1539-11, x7000. Range: U. Kimmeridgian (eudoxus) – L. Volgian (klimovi).

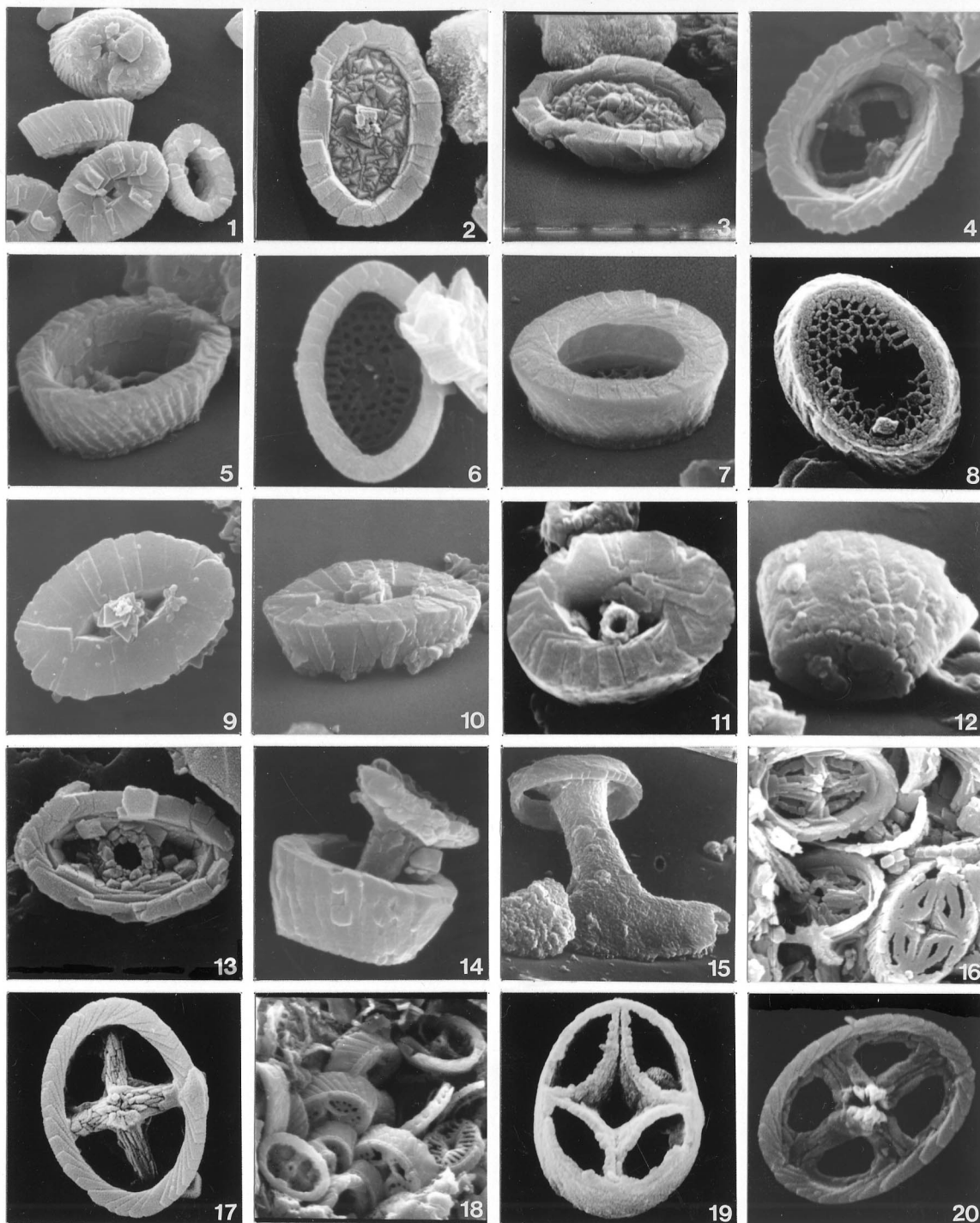


Plate 4.2

Family CHIASTOZYGACEAE Rood *et al.*, 1973 emend. Varol and Girgis, 1994

Fig. 1. *Zeugrhabdotus burolleti* Goy, 1979. Distal, side and proximal views, Hambühren (Germany), L. Toarcian, UCL-3771-30, x2946. Range: L. Toarcian (?tenuicostatum) – Aalenian (opalinum).

Figs. 2–3. *Zeugrhabdotus cooperi* Bown, 1992b. Distal (2) and side (3) views of same specimen, DSDP Site 261 (Indian Ocean), Berriasian, UCL-2999-13/14, x3655/3933. Range: L. Tithonian – Valanginian.

Figs 4–8. *Zeugrhabdotus erectus* (Deflandre in Deflandre and Fert, 1954) Reinhardt, 1965. Distal (4, 5, 8), proximal (6) and side (7) views. 4, Mochras Borehole (UK), U. Toarcian (levesquei), UCL-1888-21, x7450; 5, Villers-sur-mer (France), L. Oxfordian (mariae), UCL-2197-25, x10250; 6, Aylesbury, U. Kimmeridgian (wheatleyensis), UCL-2634-16, x5458; 7, Dorset (UK), Bathonian (zigzag), UCL-2191-10, x5525; 8, Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-1502-24, x11666. Range: L. Pliensbachian? – U. Maastrichtian.

Order STEPHANOLITHIALES Bown and Young, 1997

Family PARHABDOLITHACEAE Bown, 1987

Figs 9–11. *Crucirhabdus primulus* Rood *et al.*, 1973. Distal (9), side (10) and proximal (11) views, Trunch Borehole (UK), L. Pliensbachian (jamesoni), UCL-2095-8/9/12, x5150. Range: Norian – L. Toarcian (tenuicostatum).

Fig. 12. *Diductius constans* Goy, 1979. Distal view, Brenha (Portugal), Aalenian/Bajocian, UCL-2173-6, x5120. Range: L. Toarcian (?tenuicostatum) – L. Bajocian (sauzei).

Figs 13–14. *Mitrolithus elegans* Deflandre in Deflandre and Fert, 1954. Side (13) and distal view (spine detached) (14), Trunch Borehole (UK), Lower Pliensbachian (jamesoni), UCL-2097-25/2095-25, x5650/5100. Range: L. Sinemurian (bucklandi) – U. Pliensbachian (margaritatus).

Figs 15–16. *Mitrolithus jansae* (Wiegand, 1984b) Bown in Young *et al.*, 1986. Distal (15) and side (16) views, DSDP Site 547 (Atlantic Ocean), U. Sinemurian, UCL-2190-3/2046-36, x7500. Range: L. Sinemurian (semicostatum) – L. Toarcian (falciferum).

Figs 17–18. *Mitrolithus lenticularis* Bown, 1987. Distal oblique (17) and distal (18) views of same specimen, Timor, L. Pliensbachian, UCL-2148-26/25, x7200. Range: U. Sinemurian (raricostatum) – ?L. Toarcian (tenuicostatum).

Figs. 19–20. *Parhabdolithus liasicus* Deflandre in Grassé, 1952 ssp. *distinctus* Bown, 1987. Side (19) and distal (20) views. 19, Mochras Borehole (UK), U. Sinemurian (raricostatum), UCL-1917-17, x6500; 20, DSDP Site 547 (Atlantic Ocean), U. Sinemurian, UCL-2190-14, x6150. Range: Hettangian (angulata) – L. Toarcian (?falciferum).

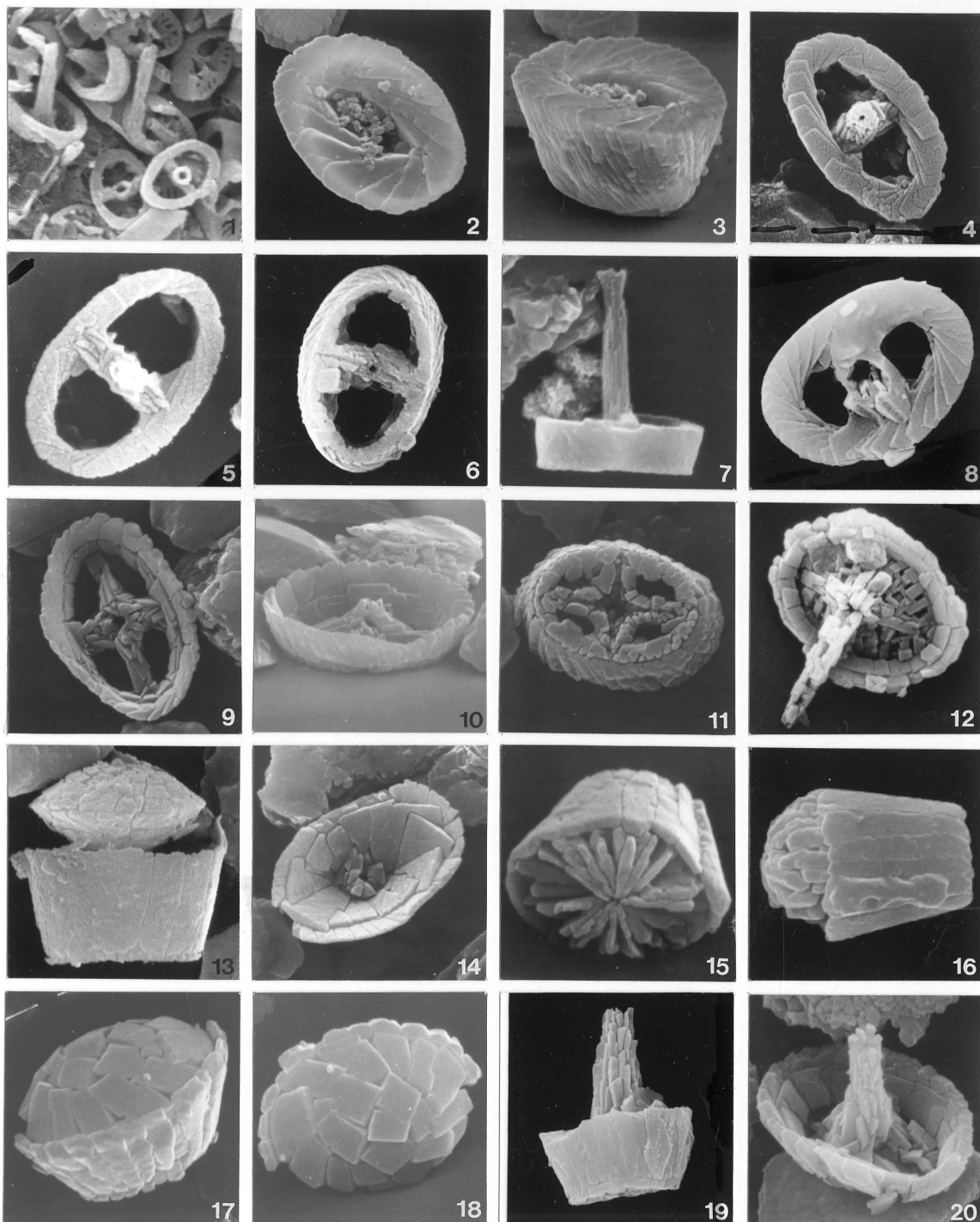


Plate 4.3

Family PARHABDOLITHACEAE Bown, 1987

Fig. 1. *Parhabdolithus liasicus* Deflandre in Grassé, 1952 ssp. *liasicus*. Side view, DSDP Site 547 (Atlantic Ocean), L. Pliensbachian, UCL-2028-36, x4365. Range: Hettangian (angulata) – L. Toarcian (?falciferum).

Fig. 2. *Parhabdolithus marthae* Deflandre in Deflandre and Fert, 1954. Side view, Hock Cliff (UK), L. Sinemurian (bucklandi), UCL-2268-33, x4390. Range: L. Sinemurian (bucklandi – semicostatum).

Figs 3–4. *Parhabdolithus robustus* Noël, 1965. Side (3) and distal (4) views of the same specimen, Timor, L. Pliensbachian, UCL-2117-27/25, x6200/6400. Range: L. Sinemurian (turneri) – L. Pliensbachian (ibex).

Figs 5–6. *Timorella cypella* Bown, 1987. Distal (5) and side (6) views of the same specimen, Timor, Lower Pliensbachian, UCL-2149-6/4, x4900/6490. Range: L. Pliensbachian.

Family STEPHANOLITHACEAE Black, 1968

Fig. 7. *?Thurmannolithion clatratum* Grün and Zweili, 1980. Distal view, Roslyn Pit (UK), U. Kimmeridgian (?eudoxus), UCL-1411-11, x4791. Range: Callovian? – ?Kimmeridgian

Fig. 8. *Stephanolithion atmetos* Cooper, 1987. Distal view, Gorodische (Russia), M. Volgian (panderi), UCL-1506-21, x8685. Range: L. Volgian (klimovi) – M. Volgian (panderi).

Figs 9–11. *Stephanolithion bigotii* Deflandre, 1939 ssp. *bigotii*. Distal (9, 10) and proximal (11) views. 9, Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-1513-7, x5485; 10, Villers-sur-mer (France), Oxfordian (cordatum), UCL-2039-14, x5129; 11, Villers-sur-mer (France), Oxfordian (mariae), UCL-2197-5, x6295. Range: L. Callovian (calloviense) – U. Tithonian (panderi).

Fig. 12. *Stephanolithion bigotii* Deflandre, 1939 ssp. *maximum* Medd, 1979. Distal view, Villers-sur-mer (France), Oxfordian (mariae), UCL-2027-1, x4835. Range: U. Callovian (lamberti) – L. Oxfordian (cordatum).

Figs 13–14. *Stephanolithion brevispinus* (Wind and Wise in Wise, 1988) Bown stat. nov.. 13, distal view, Aylesbury (UK), Bolonian (wheatleyensis), UCL-2635-27, x8222; 14, distal view, Gorodische (Russia), M. Volgian (panderi), UCL-1495-15, ?x4317. Range: U. Kimmeridgian (autissiodorensis) – M. Volgian (panderi).

Fig. 15–16. *Stephanolithion hexum* Rood and Barnard, 1972. 15, distal view, Escoville (N France), U. Bathonian (discus), UCL-2075-16, x6910; 16, distal view, Dorset (UK), Bathonian, UCL-2214-6, x6128. Range: U. Bathonian (aspidoides) – U. Callovian (lamberti).

Figs 17–18. *Stephanolithion speciosum* Deflandre in Deflandre and Fert, 1954 ssp. *speciosum*. Distal (17) and proximal (18) views, Dorset (UK), Bathonian (aspidoides/zigzag), UCL-2180-13/18, x4796/7339. Range: L. Bajocian (humphresianum) – L. Callovian (calloviense).

Fig. 19. *Stephanolithion speciosum* Deflandre in Deflandre and Fert, 1954 ssp. *octum* Rood and Barnard, 1972. Distal view, Escoville (France), Callovian (macrocephalus), UCL-2075-17, x5036. Range: U. Bajocian (parkinsoni) – L. Callovian (calloviense).

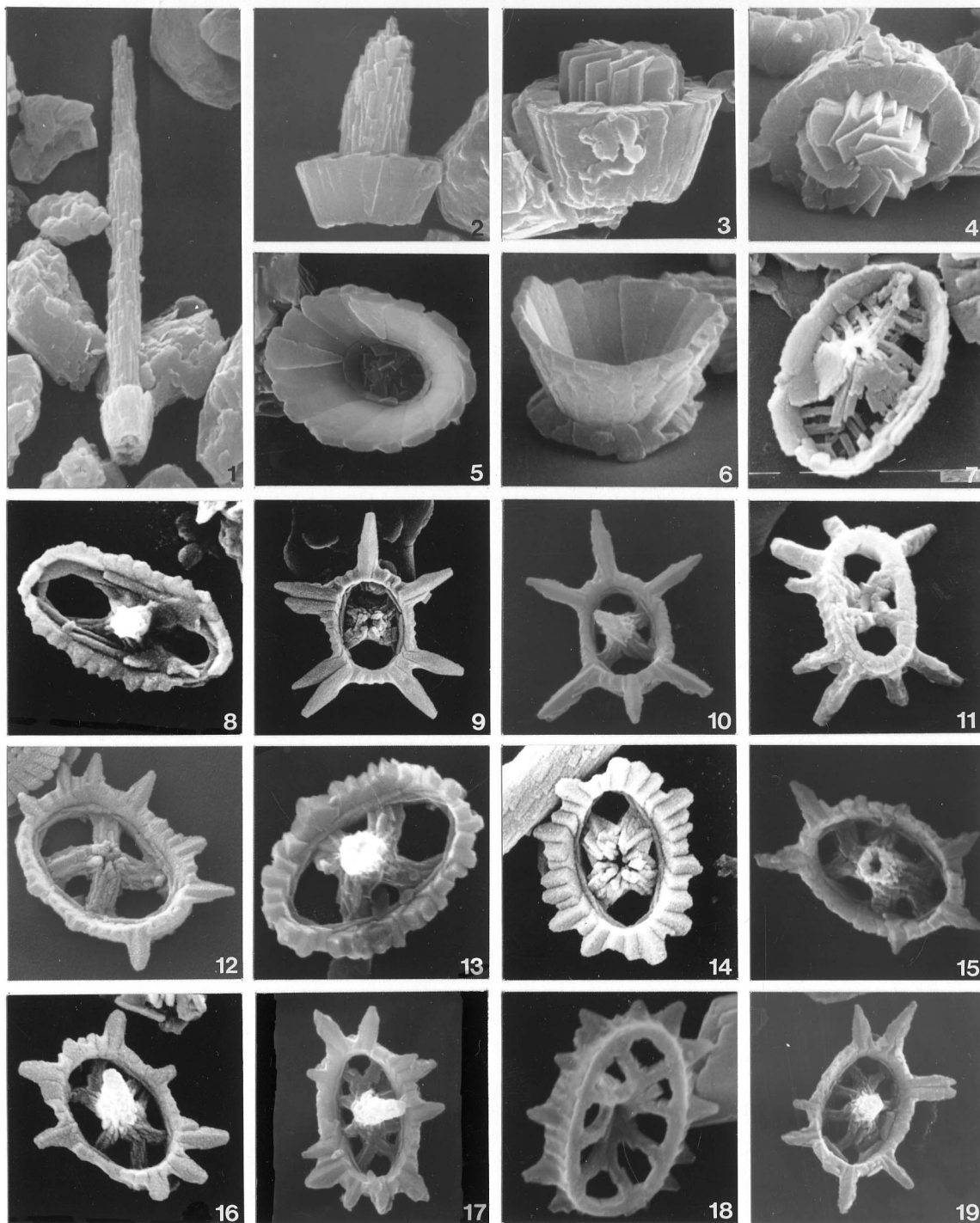


Plate 4.4

Family STEPHANOLITHACEAE Black, 1968

Figs 1–2. *Stradnerlithus clatriatus* (Rood *et al.*, 1973) Goy, 1979. Distal (1) and side (2) views, Hambühren (Germany), Lower Toarcian, UCL-3622-33/3857-6, x6861/7125. Range: L. Pliensbachian (davoei) – Aalenian (opalinum).

Fig. 3. *Stradnerlithus comptus* Black, 1971a. Distal view, Gorodische (Russia), M. Volgian (panderi), UCL-1525-18, x9588. Range: L. Toarcian (?tenuicostatum) – M. Volgian (panderi).

Fig. 4. *Stradnerlithus fragilis* (Rood and Barnard, 1972) Perch-Nielsen, 1984. Distal view, Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-1499-4, x9363. Range: U. Callovian (lamberti) – M. Volgian (panderi).

Fig. 5. *Stradnerlithus geometricus* (Górka, 1957) Bown and Cooper, 1989a. Distal view, Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-1502-21, x11333. Range: L. Oxfordian (mariae) – M. Volgian (panderi).

Fig. 6. *Stradnerlithus* spp. Hambühren (Germany), Upper Toarcian/Lower Aalenian, UCL-3856-29, x4531.

Fig. 7. *Stradnerlithus asymmetricus* (Rood *et al.*, 1971) Medd, 1979. Distal view.

Fig. 8. *Truncatoscapus intermedius* Perch-Nielsen, 1986b. Distal view, Gorodische (Russia), M. Volgian/U. Kimmeridgian (panderi/eudoxus), UCL-1504-28, x11995. Range: U. Kimmeridgian (autissiodorensis) – M. Volgian (panderi).

Order PODORHABDALES Rood *et al.*, 1971 emend. Bown, 1987

Family BISCUTACEAE Black, 1971a

Fig. 9. *Biscutum depravatum* (Grün and Zweili, 1980) Bown 1987. Distal view, Brenha (Portugal), Aalenian/Bajocian, UCL-2173-13, x5769. Range: Aalenian? – M. Oxfordian.

Figs 10–11. *Biscutum dorsetensis* Varol and Girgis, 1994 Bown comb. nov.. Distal (10) and proximal (11) views, Aylesbury (UK), Bolonian (wheatleyensis), UCL-2635-12/10, x10344/10294. Range: U. Bathonian (discus) – Bolonian (pectinatus).

Basionym: *Palaeopontosphaera dorsetensis* Varol and Girgis, 1994 (*N. Jb. Geol. Paläont. Abh.*, **192**, 221–253, p.243–244, Fig. 8 (A)).

Fig. 12. *Biscutum dubium* (Noël, 1965) Grün in Grün *et al.*, 1974. Distal view, Warboys (UK), Oxfordian (mariae), UCL-2212-5, x8963. Range: L. Toarcian (falciferum) – ?Berriasian.

Fig. 13. *Biscutum finchii* Crux, 1984. Distal view, Brenha (Portugal), L. Pliensbachian (ibex), UCL-2178-37, x4715. Range: L. Pliensbachian (davoei) – L. Toarcian (falciferum).

Fig. 14. *Biscutum grande* Bown, 1987. Distal view, Brenha (Portugal), L. Pliensbachian (ibex), UCL-2170-15, x4850. Range: U. Pliensbachian (spinatum) – L. Toarcian (falciferum).

Fig. 15. *Biscutum intermedium* Bown, 1987. Distal view, Brenha (Portugal), Aalenian/Bajocian, UCL-2173-20, x5800. Range: U. Toarcian (levesquei) – U. Bathonian (discus).

Figs 16–17. *Biscutum novum* (Goy, 1979) Bown, 1987. 16, Distal view, Trimeusel (Germany), L. Toarcian (bifrons), UCL-2049-34, x6847; 17, proximal view, Ballrechten (Germany), U. Toarcian (thoursense), UCL-2074-17, x6250. Range: U. Pliensbachian (margaritatus) – U. Bathonian (discus).

Fig. 18. *Discorhabdus corollatus* Noël, 1965. Distal oblique view, Villers-sur-mer (France), Oxfordian (mariae), UCL-2027-10, x6287. Range: L. Callovian – U. Tithonian (panderi).

Figs 19–20. *Discorhabdus criotus* Bown, 1987. Distal (19) and proximal (20) views, Brenha (Portugal), U. Toarcian, UCL-2178-3/2170-6, x8377/5353. Range: U. Toarcian (variabilis) – M. Oxfordian (densiplicatum).

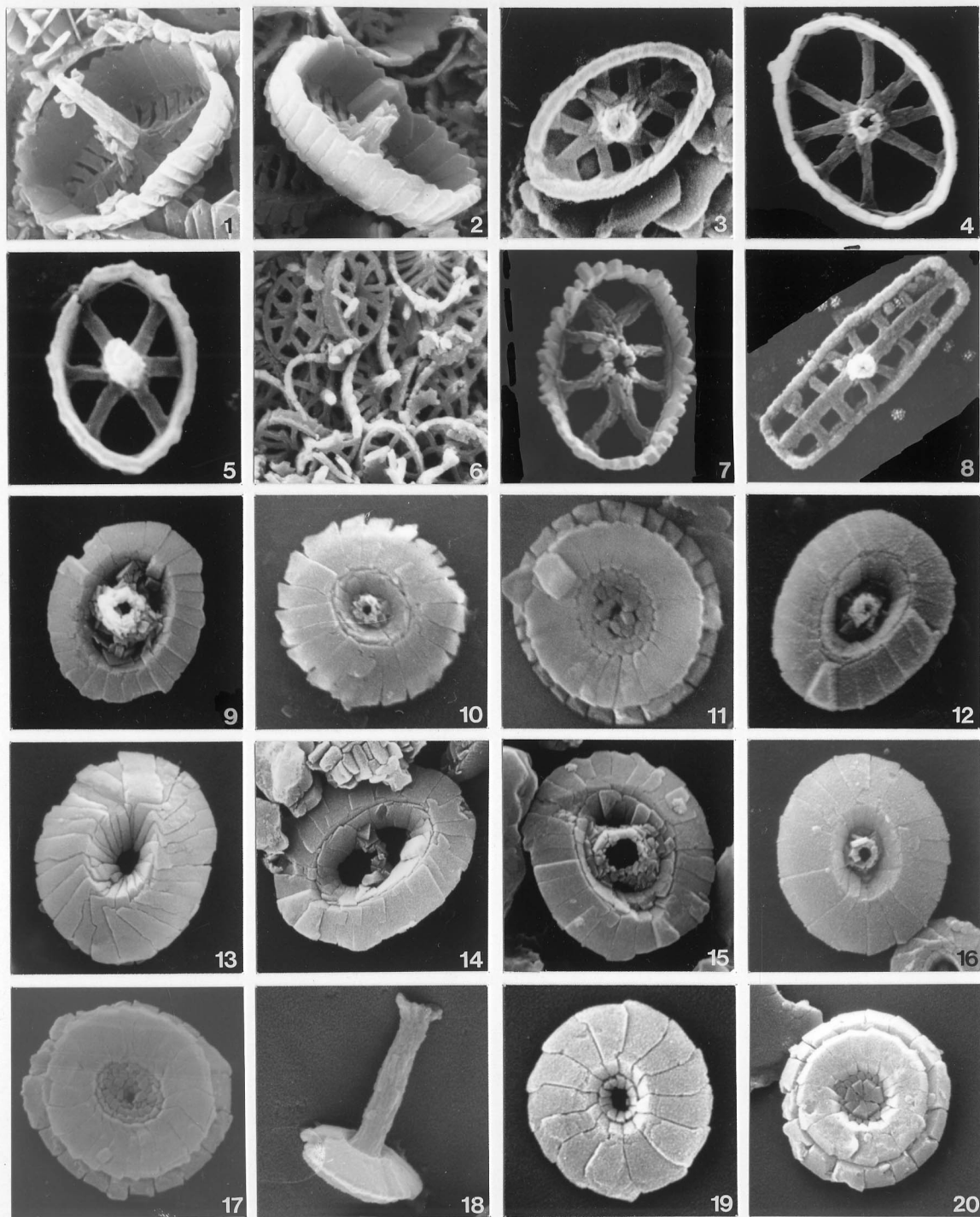


Plate 4.5

Family BISCUTACEAE Black, 1971a

Fig. 1. *Discorhabdus ignotus* (Górka, 1957) Perch-Nielsen, 1968. Distal view, Warboys (UK), Oxfordian (mariae), UCL-2114-22, x8105. Range: Oxfordian? – Maastrichtian.

Fig. 2. *Discorhabdus striatus* Moshkovitz and Ehrlich, 1976. Distal view, Brenha (Portugal), L. Pliensbachian (davoei), UCL-2173-36, x4700. Range: L. Toarcian (falciferum) – U. Oxfordian (glosense).

Figs 3–4. *Similiscutum cruciulus* de Kaenel and Bergen, 1993. Distal (3) and proximal (4) views, DSDP Site 547 (Atlantic Ocean), L. Pliensbachian, UCL-2199-24/2014-2, x8741/9729. Range: L. Pliensbachian (ibex) – L. Toarcian (tenuicostatum).

Fig. 5. *Similiscutum ?avitum* de Kaenel and Bergen, 1993. Distal view, Mochras Borehole (UK), L. Pliensbachian (ibex), UCL-1952-19, x7625. Range: L. Pliensbachian (ibex) – L. Toarcian (tenuicostatum).

Fig. 6–7. *Sollasites arctus* (Noël, 1973) Bown, 1987. Distal views, Unterstürmig (Germany), L. Toarcian, UCL-2268-22/2036-7, x6375/8250. Range: ?L. Toarcian.

Fig. 8. *Sollasites lowei* (Bukry, 1969) Rood *et al.*, 1971. Distal view, Hambühren (Germany), Lower Toarcian, UCL-3848-17, x8000. Range: L. Pliensbachian (jamesoni)? – ?Campanian.

Family CALYCVLACEAE Noël, 1973

Fig. 9. *Calyculus* sp. indet.. Distal view, displaying typical rim structure but lacking central area grill, Unterstürmig, (Germany), L. Toarcian, UCL-2034-23, x6150.

Fig. 10. *Calyculus serrai* (Goy, 1981) Crux, 1987. Side, proximal and cross-section views, Hambühren (Germany), Upper Toarcian/Lower Aalenian, UCL-3889-37, x4800. Range: L. Toarcian – Aalenian.

Fig. 11. *Calyculus cribrum* Noël, 1973. Distal and proximal views, Hambühren (Germany), L. Toarcian, UCL-3781-26, x6000. Range: U. Pliensbachian (spinatum)? – L. Bajocian (sauzei).

Fig. 12. *Calyculus noeliae* (Goy, 1979) Crux, 1987. Distal, side and cross-section views, Hambühren (Germany), L. Toarcian, UCL-3848-12, x6513. Range: ?L. Toarcian.

Figs 13–14. *Carinolithus magharensis* (Moshkovitz and Ehrlich, 1976) Bown, 1987. Side (13) and distal (14) views of the same specimen, Brenha (Portugal), Aalenian/Bajocian, UCL-2173-16/15, x3685/5200. Range: Aalenian? – U. Bajocian (subfurcatum).

Figs 15–16. *Carinolithus superbus* (Deflandre *in* Deflandre and Fert, 1954) Prins *in* Grün *et al.*, 1974. Side (15) and proximal oblique (16) views of the same specimen, Ilminster (UK), Toarcian, UCL-2616-33/31, x3816/5416. Range: L. Toarcian (falciferum) – L. Bajocian (humphresianum).

Family CRETARHABDACEAE Thierstein, 1973

Fig. 17. *Cretarhabdus conicus* Bramlette and Martini, 1964. Distal view, Aylesbury (UK), Bolonian (wheatleyensis), UCL-2635-5, x7789. Range: U. Kimmeridgian (eudoxus) – Maastrichtian.

Fig. 18. *Polypodorhabdus escaigii* Noël, 1965. Distal view, Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-1520-22, x5715. Range: Aalenian (opalinum) – ?Albian.

Fig. 19. *Retecapsa incompta* Bown, 1987. Brenha (Portugal), Aalenian/Bajocian, UCL-2622-33, x5666. Range: U. Toarcian (levesquei) – ?M. Oxfordian.

Fig. 20. *Retecapsa* cf. *R. schizobrachiata* (Gartner, 1968) Grün *in* Grün and Allemann, 1975 Distal view, Gorodische (Russia), U. Kimmeridgian (eudoxus), UCL-1502-5, x6900. Range: L. Callovian (macrocephalus) – Maastrichtian. Originally described from the Upper Cretaceous (Campanian – Maastrichtian); these Jurassic forms are smaller, more delicate, and may not represent the same species.

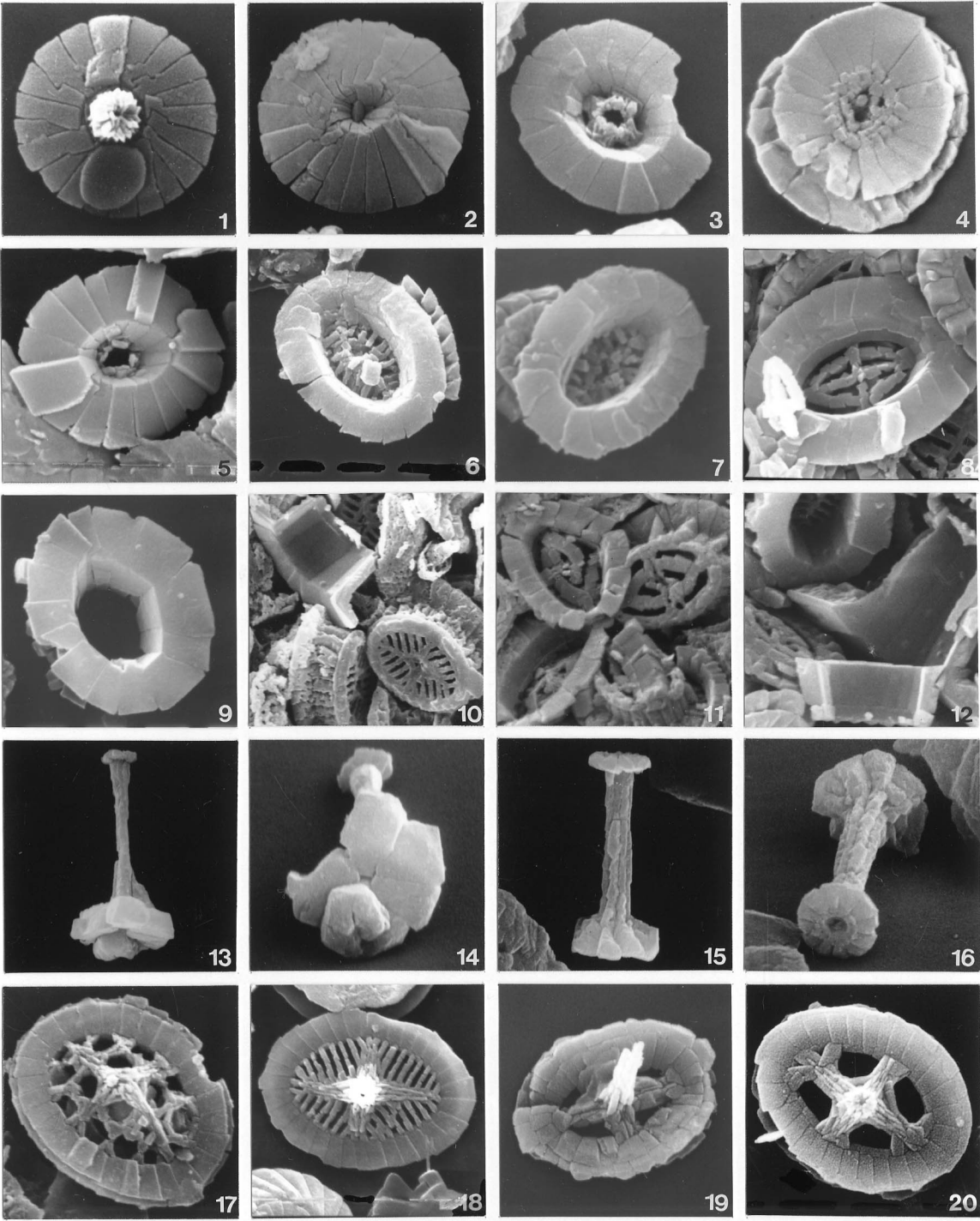


Plate 4.6

Family MAZAGANELLACEAE Bown, 1987

Figs 1–3. *Mazaganella protensa* Bown, 1987. Distal (1), side (2) and proximal views (3), DSDP Site 547 (Atlantic Ocean), L. Pliensbachian, UCL-2007-33/31/22, x4900. Range: L. Pliensbachian (?jamesoni – ?spinatum).

Figs 4–5. *Mazaganella pulla* Bown, 1987. Distal (4) and proximal (5) views, DSDP Site 547 (Atlantic Ocean), Sinemurian, UCL-2049-36/2046-7, x7950/6200. Range: U. Sinemurian (?obtusius) – ?L. Pliensbachian (?davoei).

Figs 6–8. *Triscutum beaminsterensis* Dockerill, 1987. Distal (6), proximal (7) and side (8) views, Dorset (UK), Bathonian (zigzag), UCL-1894-29/1891-23/2048-5, x3350/3650/4100. Range: L. Bathonian (zigzag) – M. Oxfordian (tenuiserratum).

Figs 9–10. *Triscutum expansus* (Medd, 1979) Dockerill, 1987. Distal (9) and distal oblique (10) views, Warboys (UK), Oxfordian (mariae), UCL-1921-13/20, x4625/4160. Range: Aalenian? – ?Kimmeridgian.

Figs 11–12. *Triscutum sullivanii* de Kaenel and Bergen, 1993. Distal (11) and side (12) views of same specimen, Picun Leufu (Argentina), U. Toarcian/L. Aalenian, UCL-2065-13/12, x3750. Range: Aalenian (murchisonae) – L. Bajocian (sauzei).

Family AXOPODORHABDACEAE Bown and Young, 1997

Fig. 13. *Axopodorhabdus atavus* (Grün *et al.*, 1974) Bown, 1987. Distal view, Hambühren (Germany), Lower Toarcian, UCL-3889-1, x6450. Range: U. Pliensbachian (spinatum) – ?L. Tithonian (?pallasioides).

Figs 14–15. *Axopodorhabdus cylindratus* (Noël, 1965) Wind and Wise *in* Wise and Wind, 1977. 14, Distal view, Roslyn Pit (UK), U. Kimmeridgian (?eudoxus), UCL-1411-20, x4047; 15, Distal view, Villers-sur-mer (France), Oxfordian (densiplicatum), 2039-16, x4341. Range: U. Pliensbachian (spinatum) – ?L. Tithonian (?pallasioides).

Fig. 16. *Axopodorhabdus rahla* (Noël, 1965) Grün and Zweili, 1980. Side view, Warboys (UK), Oxfordian (mariae), UCL-1921-18, x4530. Range: L. Callovian (macrocephalus) – M. Oxfordian (tenuiserratum).

Fig. 17. *Ethmorhabdus anglicus* Rood *et al.*, 1971. Distal view, Dorset (UK), Bathonian (zigzag), UCL-2207-24, x6860. Range: L. Oxfordian (mariae) – ?U. Tithonian (?fittoni).

Fig. 18. *Ethmorhabdus crucifer* Noël, 1965. Distal view, Hambühren (Germany), Lower Toarcian, UCL-3620-24, x5166. Range: L. Toarcian (?tenuicostatum – falciferum).

Figs 19–20. *Ethmorhabdus gallicus* Noël, 1965. Distal (19) and proximal (20) views. 19, Roslyn Pit (UK), U. Kimmeridgian (?eudoxus), UCL-1411-18, x4268. 20, Aylesbury (UK), Bolonian (wheatleyensis), UCL-2634-11, x4789. Range: L. Toarcian (falciferum) – U. Tithonian (?fittoni).

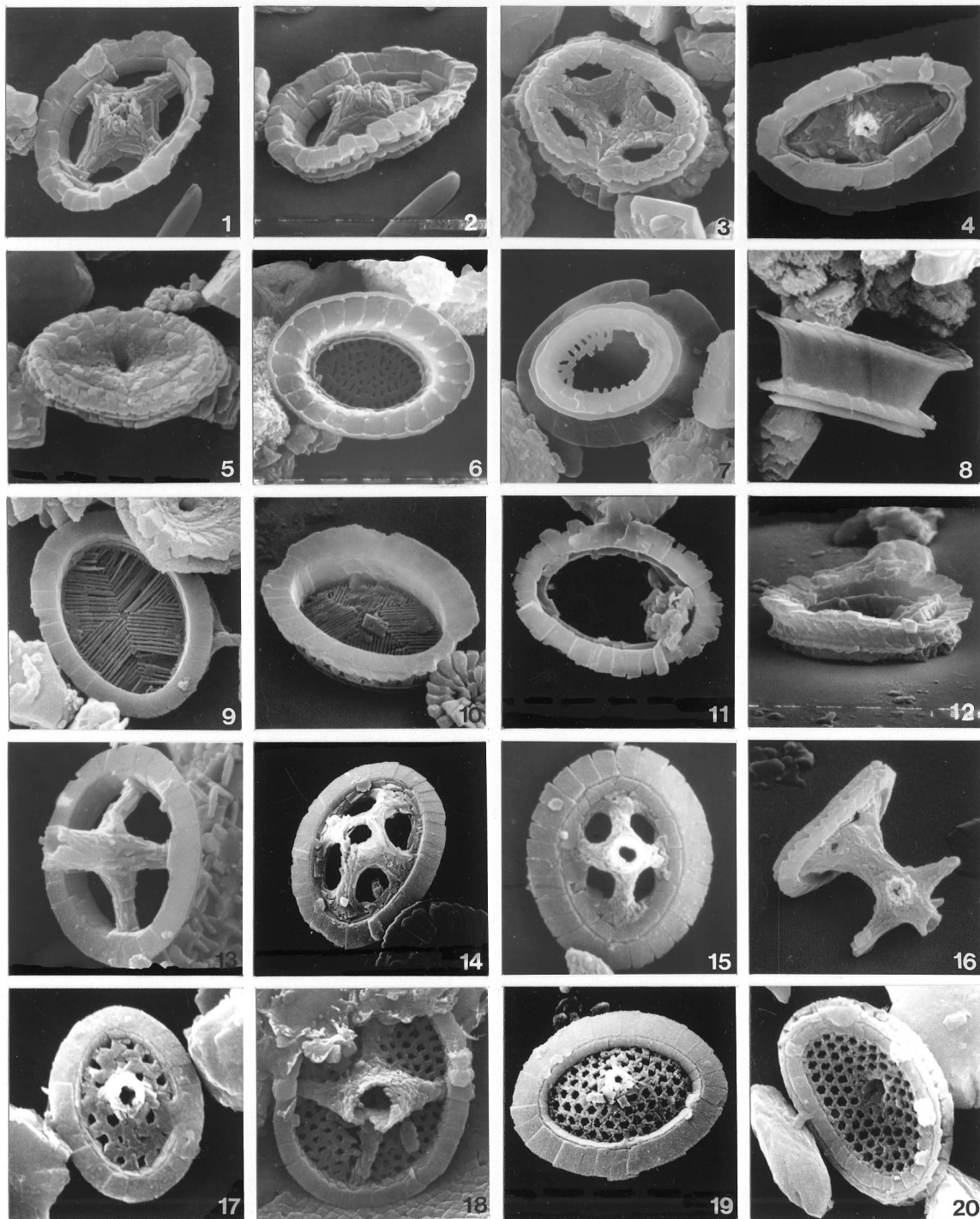


Plate 4.7

Family AXOPODORHABDACEAE Bown and Young, 1997

Figs 1–2. *Hexapodorhabdus cuvillieri* Noël, 1965. Distal (1) and proximal (2) views, Villers-sur-mer (France), L. Oxfordian (cordatum/mariae), UCL-1903-2/2207-7, x7750/6450. Range: U. Bajocian (parkinsoni) – U. Kimmeridgian (autissiodorensis).

Figs 3–4. *Octopodorhabdus decussatus* (Manivit, 1961) Rood *et al.*, 1971. Distal (2) and proximal (3) views. 1, Warboys (UK), Oxfordian (mariae), UCL-1921-7, x5240; 2, Dorset (UK), Bathonian (zigzag), UCL-1891-13, x7120. Range: L. Bathonian (zigzag) – L. Oxfordian (cordatum).

Figs 5–7. *Podorhabdus grassei* Noël, 1965. Distal (5), side (6) and proximal oblique (7) views. 5, Dorset (UK), Bathonian (zigzag), UCL-1891-2, x5250; 6–7, Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-1502-13/14, x4320. Range: L. Bajocian (discus) – L. Tithonian (scitulus).

Fig. 8. *Tetrapodorhabdus shawensis* Medd, 1979. Distal view, Dorset (UK), Bathonian (zigzag), UCL-1891-12, x7350. Range: U. Bajocian (parkinsoni) – U. Bathonian (hodsoni).

Order WATZNAUERIALES Bown, 1987

Family WATZNAUERiaceae Rood *et al.*, 1971

Figs 9–10. *Ansulasphaera helvetica* Grün and Zweili, 1980. Distal (9) and proximal oblique (10) views. 9, Denver Borehole (UK), Callovian (athleta), UCL-2166-9, x9250; 10, Clapgate Farm (UK), Callovian (athleta), UCL-1912-2, x7885. Range: U. Bathonian (aspidoides) – U. Callovian (lamberti).

Figs 11–12. *Bussonius prinsii* (Noël, 1973) Goy, 1979. Distal (11) and distal oblique (12) views of the same specimen, Ilminster (UK), Toarcian, UCL-2615-9/10, x6483. Range: L. Pliensbachian (jamesoni) – Aalenian (murchisonae).

Fig. 13. *Cyclagelosphaera margerelii* Noël, 1965. Coccosphere, DSDP Site 105 (N Atlantic Ocean), Oxfordian, UCL-509-22, x2689. Range: U. Bajocian (parkinsoni) – L. Paleocene.

Fig. 14. *Cyclagelosphaera tubulata* (Grün and Zweili, 1980) Cooper, 1987. Distal view, Roslyn Pit (UK), U. Kimmeridgian (?eudoxus), UCL-1465-14, x6010. Range: U. Bajocian (parkinsoni) – M. Volgian (fittoni).

Fig. 15. *Lotharingius barozii* Noël, 1973. Distal views on coccosphere, Hambühren (Germany), Lower Toarcian, UCL-3848-34, x5750. Range: L. Toarcian (tenuicostatum) – ?Aalenian.

Fig. 16–17. *Lotharingius contractus* Bown and Cooper, 1989a. Brenha (Portugal), Aalenian/Bajocian, UCL-2645-34/2622-2, x4513/4642. Range: Aalenian (murchisonae) – L. Callovian (macrocephalus).

Fig. 18. *Lotharingius crucicentralis* (Medd, 1971) Grün and Zweili, 1980. Distal view, Ilminster, Dorset (UK), Toarcian, UCL-2616-11, x6956. Range: L. Toarcian (tenuicostatum) – U. Oxfordian (regulare).

Fig. 19. *Lotharingius hauffii* Grün and Zweili in Grün *et al.*, 1974. Collapsed coccosphere, Unterstürmig (Germany), L. Toarcian, UCL-2034-10, x2425. Range: U. Pliensbachian (margaritatus) – U. Bathonian (discus).

Fig. 20. *Lotharingius sigillatus* (Stradner, 1961) Prins in Grün *et al.*, 1974. Distal view, Trimeusel (Germany), Lower Toarcian (bifrons), UCL-2049-13, x5940. Range: U. Pliensbachian (spinatum) – M. Oxfordian (tenuiserratum).

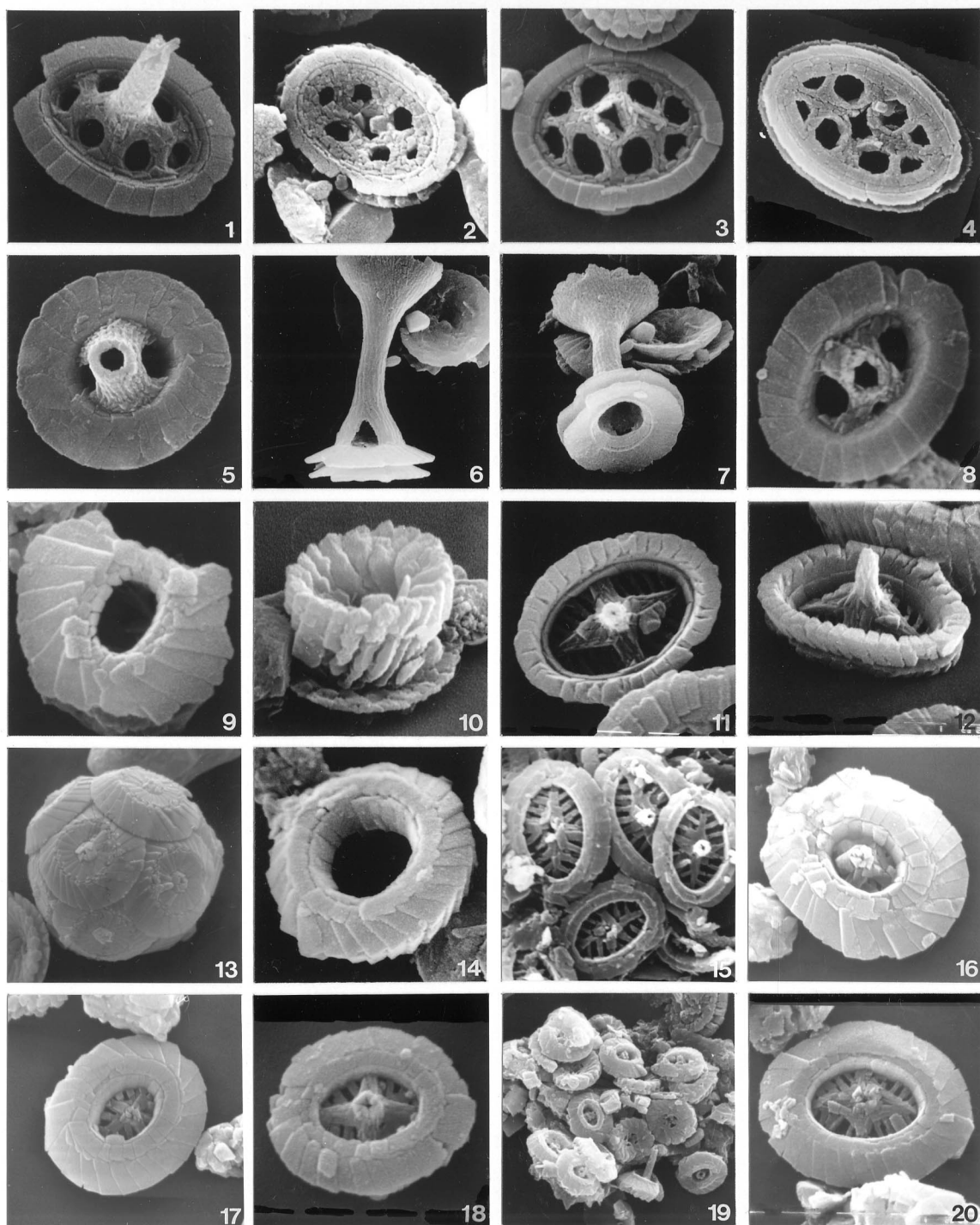


Plate 4.8

Family WATZNAUERiaceae Rood *et al.*, 1971

Fig. 1. *Lotharingius velatus* Bown and Cooper, 1989a. Distal view, St. Honorine (France), Bajocian, UCL-2689-25, x5500. Range: Aalenian (concaum) – L. Callovian (macrocephalus).

Fig. 2. *Watznaueria barnesae* (Black, 1959) Perch-Nielsen, 1968. Distal view, St. Honorine (France), Bajocian (humphresianum-parkinsoni), UCL-2689-7, x4080. Range: L. Bajocian (laeviuscula) – Maastrichtian.

Figs 3–6. *Watznaueria britannica* (Stradner, 1963) Reinhardt, 1964. 3, coccosphere, Clapgate Farm (UK), Callovian (athleta), UCL-1912-5, x3150; 4–6, distal (4), distal oblique (5) and proximal (6) views, Aylesbury (UK), Bolonian (wheatleyensis), UCL-2635-21/23/2634-5, x~5000. Range: L. Bajocian (laeviuscula) – L. Cenomanian.

Fig. 7. *Watznaueria fossacincta* (Black, 1971a) Bown *in* Bown and Cooper, 1989a. Coccosphere, Gorodische (Russia), M. Volgian (panderi), UCL-1513-4, x3350. Range: L. Bajocian (laeviuscula) – Maastrichtian.

Fig. 8. *Watznaueria manivitiae* Bukry, 1973d. Distal view, DSDP Site 261 (Indian Ocean), L. Tithonian, UCL-3000-33, x2200. Range: L. Callovian (macrocephalus) – U. Maastrichtian.

Family CALYPTROSPHAERACEAE Boudreaux and Hay, 1969

Figs 9–10. *Anfractus harrisonii* Medd, 1979. 9, distal view, Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-1506-20, x8905; 10, proximal view, Villers-sur-mer (France), L. Oxfordian (mariae), UCL-2207-15, x8750. Range: Aalenian (?opalinum) – Kimmeridgian (autissiodorensis).

Fig. 11. *Anfractus youngii* Bown, 1993. Side view, Hambühren (Germany), Lower Toarcian, UCL-3889-9, x10000. Range: L. Toarcian (falciferum) – Aalenian (?opalinum).

Fig. 12. *Pseudoconus enigma* Bown and Cooper, 1989b. Side view, Dorset (UK), U. Bathonian (aspidoides), UCL-2512-11, x5675. Range: U. Bajocian (parkinsoni) – L. Callovian (macrocephalus).

NANNOLITHS

Family EOCONUSPHAERACEAE Krystan-Tollmann, 1988a

Figs 13–15. *Conusphaera mexicana* Trejo, 1969 ssp. *mexicana*. Side (13), distal (14) and proximal (15) views, DSDP Site 534 (N Atlantic Ocean), Tithonian, UCL-1652-2/1976-20/19, x3677/4530/4850. Range: L. Tithonian (?u. hybonotum) – L. Aptian.

Family NANNOCONACEAE Deflandre, 1959

Fig. 16. *Nannoconus compressus* Bralower and Thierstein *in* Bralower *et al.*, 1989. Side view, DSDP Site 534 (N Atlantic Ocean), Tithonian, UCL-1671-1, x6000. Range: L. Tithonian – L. Berriasian.

?Family POLYCYCLOLITHACEAE Forchheimer, 1972 emend. Varol, 1992

Fig. 17. *Hexalithus noeliae* Loeblich and Tappan, 1966. DSDP Site 534 (N Atlantic Ocean), Tithonian, UCL-1744-17, x7000. Range: U. Tithonian – L. Berriasian.

Family SCHIZOSPHAERELLACEAE Deflandre, 1959

Figs 18–19. *Schizosphaerella punctulata* Deflandre and Dangeard, 1938. Side view (18) and ultrastructure detail (19). 18, Trimeusel (Germany), U. Toarcian (levesquei), UCL-2052-12, x3064; 19, Hambühren (Germany), Lower Toarcian, UCL-3857-8, x9680. Range: L. Hettangian (?planorbis) – ?U. Bathonian (discus).

INCERTAE SEDIS NANNOLITHS

Fig. 20. *Orthogonoides hamiltoniae* Wiegand, 1984. DSDP Site 547 (Atlantic Ocean), L. Pliensbachian, UCL-2028-22, x4920. Range: U. Sinemurian (oxynotum) – L. Toarcian (falciferum).

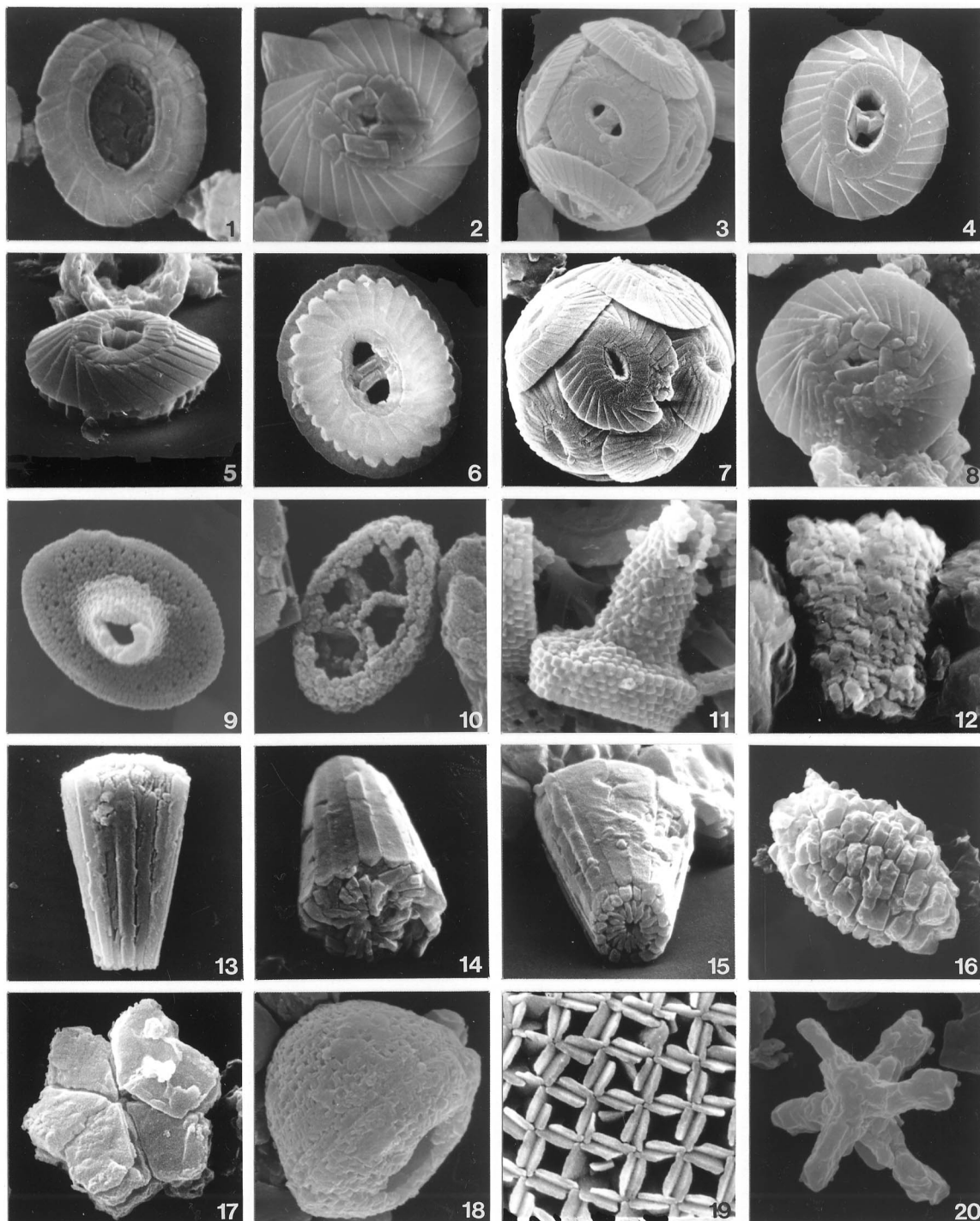


Plate 4.9

Order EIFFELLITHALES Rood *et al.*, 1971

Family CHIASTOZYGACEAE Rood *et al.*, 1973 emend. Varol and Girgis, 1994

Figs 1–2. *Crepidolithus crassus* (Deflandre *in* Deflandre and Fert, 1954) Noël, 1965. XPL (1) and PC (2), Trimeusel, (Germany), L. Toarcian (bifrons), UCL-5625-9/10.

Figs 3–5. *Crepidolithus granulatus* Bown, 1987. XPL (2, 3) and PC (4), Brenha (Portugal), L. Plienbachian (davoei), UCL-5627-13/19/20.

Figs 6–7. *Crepidolithus impontus* (Grün *et al.*, 1974) Goy, 1979. XPL (6) and PC (7), Hambühren (Germany), Aalenian, UCL-5626-20/19.

Figs 8–10. *Crepidolithus perforata* (Medd, 1979) Grün and Zweili, 1980. XPL (8, 10) and PC (9). 8-9, BGS Denver Borehole (UK), Callovian (athleta), UCL-5563-14/13; 10, Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-19.

Figs 11–12. *Crepidolithus plienschachensis* Crux, 1985. XPL (11) and PC (12), Timor, L. Plienschachian, UCL-5625-32/31.

Figs 13–15. *Crepidolithus timorensis* (Krystan-Tollmann, 1988a) Bown comb. nov.. XPL (13, 15) and PC (14), 14 is side view, Timor, Sinemurian, UCL-5630-18/19/16. Basionym given in Pl. 4.1.

Figs 16–17. *Tubirhabdus patulus* Rood *et al.*, 1973. Small morphotype, XPL (16) and PC (17), Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-13/14.

Figs 18–19. *Tubirhabdus patulus* Rood *et al.*, 1973. Large morphotype, XPL (18) and PC (19), Port en Bessin (N France), L. Bathonian (tenuiplicatus), UCL5628-5/6.

Fig. 20. *Staurolithites leptostaurus* (Cooper, 1987a) Bown comb. nov.. PC, Gorodische (Russia), Volgian (panderi), UCL-5628-32. Range: Kimmeridgian (eudoxus) – M. Volgian (panderi).

Basionym: *Chiastozygus leptostaurus* Cooper, 1987 (*N. Jb. Geol. Paläont. Mh.*, **1987**, H10, 606–612, p. 611, Fig. 1.1).

Figs 21–25. *Staurolithites lumina* Bown sp. nov.. XPL (21, 23) and PC (22, 24, 25), Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-5628-28/29/25/26, UCL-5638-33.

Fig. 26. *Staurolithites* cf. *S. lumina* Bown sp. nov.. XPL (unicyclic rim), Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-5631-18.

Figs 27–28. *Staurolithites quadriarculla* (Noël, 1965) Wilcoxon, 1972. XPL (27) and PC (28), Hambühren (Germany), Aalenian, UCL-5626-21/22.

Figs 29-30. *Staurolithites quadriarculla* (Noël, 1965) Wilcoxon, 1972. XPL (29) and PC (30), Gorodische (Russia), M. Volgian (panderi), UCL-5629-1/2.

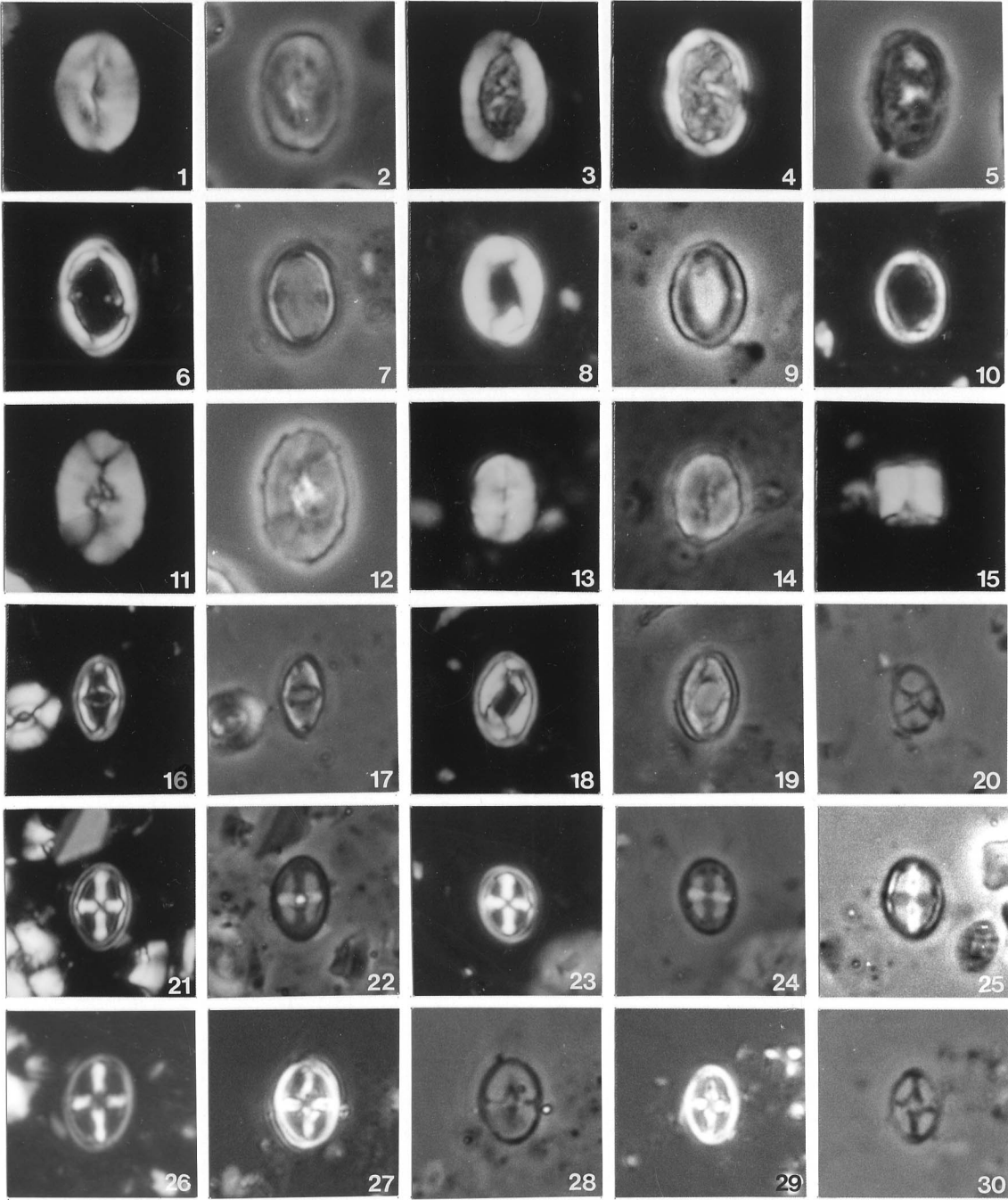


Plate 4.10

Family CHIASTOZYGACEAE Rood *et al.*, 1973 emend. Varol and Girgis, 1994

Figs 1–3. *Zeugrhabdotus cooperi* Bown, 1992b. Distal (1, 2, XPL and PC different specimens) and side (3, XPL) views, DSDP Site 261 (Indian Ocean), Berriasian, UCL-5631-8/10/5630-11.

Figs 4–5. *Zeugrhabdotus embergeri* (Noël, 1959) Perch-Nielsen, 1984. XPL (4) and PC (5), DSDP Site 261 (Indian Ocean), Berriasian, UCL-5631-12/13.

Figs 6–10. *Zeugrhabdotus erectus* (Deflandre in Deflandre and Fert, 1954) Reinhardt, 1965. XPL (6, 9) and PC (7, 8, 10). 6–8, Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-33/34, UCL-5331-19; 9–10, Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-5628-33/34.

Figs 11–12. *Zeugrhabdotus fissus* Grün and Zweili, 1980. XPL (11) and PC (12), Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-5560-4, UCL-5628-22. Range: M. Oxfordian – ?U. Valanginian.

Order STEPHANOLITHIALES Bown and Young, 1997

Family PARHABDOLITHACEAE Bown, 1987

Fig. 13. *Bucanthus decussatus* Bown, 1987. XPL, Timor, L. Pliensbachian, UCL-5652-23. Range: ?L. Pliensbachian.

Figs 14–15. *Crucirhabdus primulus* Rood *et al.*, 1973. XPL (14) and PC (15), Timor, L. Pliensbachian, UCL-5626-6/5.

Figs 16–17. *Diductius constans* Goy, 1979. XPL (16) and PC (17), Brenha (Portugal), Aalenian/Bajocian, UCL-5626-25/26.

Figs 18–20. *Mitrolithus elegans* Deflandre in Deflandre and Fert, 1954. XPL side view with spine (18); XPL plan view without spine (19) and isolated spine in XPL plan view (20), Timor, L. Pliensbachian, UCL-5626-1/5625-35/5652-18.

Figs 21–23. *Mitrolithus jansae* (Wiegand, 1984b) Bown in Young *et al.*, 1986. XPL (21) and PC (22) of tall morphotype; XPL (23) of short morphotype, DSDP Site 547 (Atlantic Ocean), U. Sinemurian, UCL-5627-23/24/25.

Figs 24–25. *Mitrolithus lenticularis* Bown, 1987. XPL (24) and PC (25), Timor, L. Pliensbachian, UCL-5626-3/4.

Figs 26–29. *Parhabdolithus liasicus* Deflandre in Grassé, 1952 ssp. *distinctus* Bown, 1987. Plan view XPL (26) and PC (27); side view XPL (28) and PC (29), Timor, L. Pliensbachian, UCL-5652-16/17/5625-21/22.

Figs 30–31. *Parhabdolithus liasicus* Deflandre in Grassé, 1952 ssp. *liasicus*. Side view XPL (30) and PC (31), Timor, L. Pliensbachian, UCL-5625-27/28.

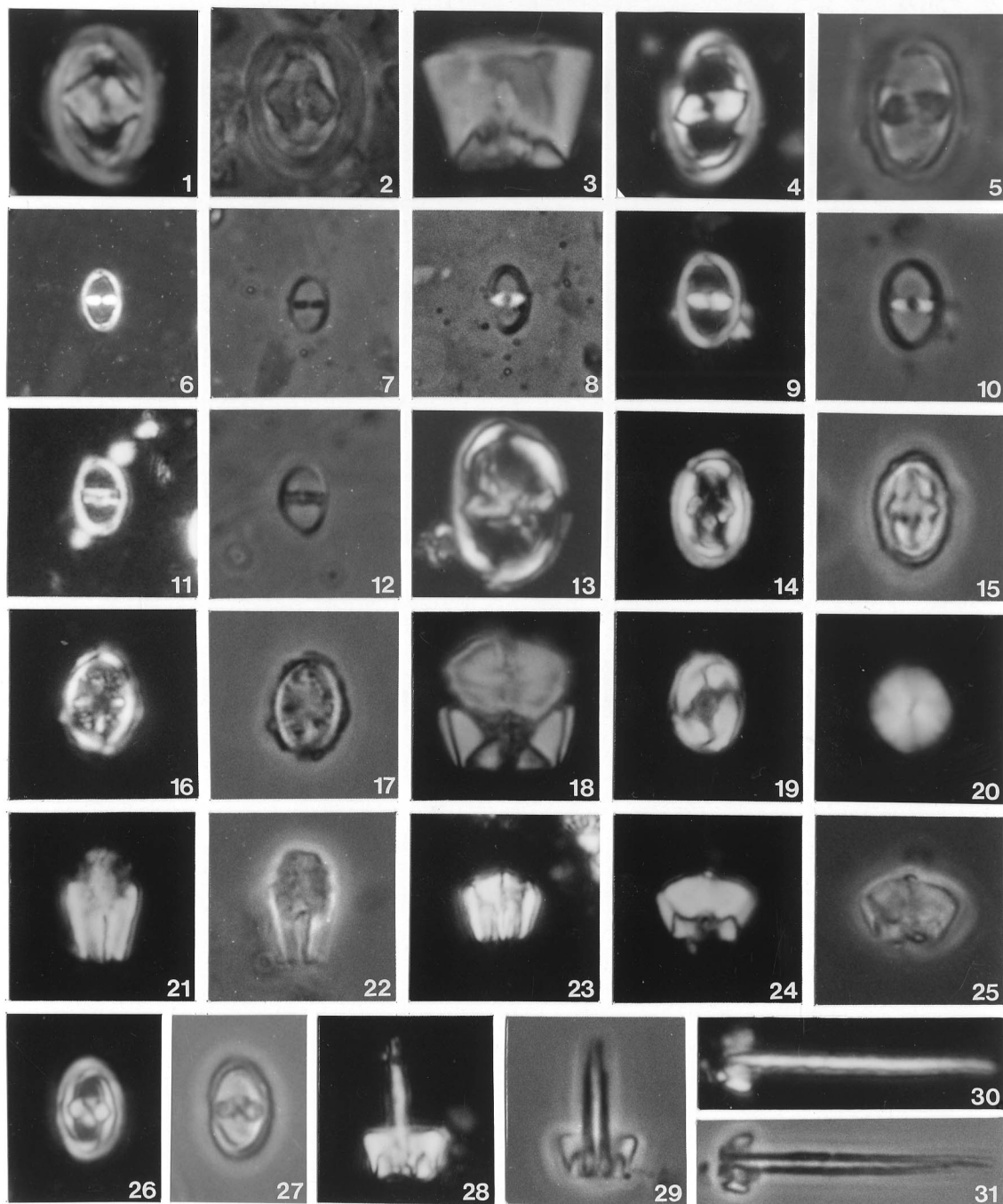


Plate 4.11

Family PARHABDOLITHACEAE Bown, 1987

Figs 1–2. *Parhabdolithus marthae* Deflandre *in* Deflandre and Fert, 1954. Side view XPL (1) and PC (2, different specimen), Hock Cliff (UK), L. Sinemurian (bucklandi), UCL-5627-30/5545-7.

Fig. 3. *Parhabdolithus robustus* Noël, 1965. Side view XPL, Timor, L. Pliensbachian, UCL-5626-33.

Figs 4–5. *Timorella cypella* Bown, 1987. Side view XPL (4) and PC (5), Timor, L. Pliensbachian, UCL-5626-7/8.

Figs 6–7. *Umbria granulosa* Bralower and Thierstein *in* Bralower *et al.*, 1989. XPL (6) and PC (7, different specimen), DSDP Site 534 (N Atlantic Ocean), U. Tithonian, UCL-5630-6/5564-28. Range: U. Tithonian – U. Berriasian.

Family STEPHANOLITHACEAE Black, 1968

Figs 8–10. *Stephanolithion atmetos* Cooper, 1987a. XPL (8) and PC (9, 10, latter different specimen), Gorodische (Russia), M. Volgian (panderi), UCL-5628-35/36/5560-25.

Figs 11–13. *Stephanolithion bigotii* Deflandre, 1939 ssp. *bigotii*. XPL (11) and PC (12, 13, latter different specimen), Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-27/28/5331-29.

Figs 14–15. *Stephanolithion bigotii* Deflandre, 1939 ssp. *maximum* Medd, 1979. XPL (14) and PC (15, different specimen), Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-24/5331-28.

Figs 16–17. *Stephanolithion brevispinus* (Wind and Wise *in* Wise, 1988) Bown stat. nov.. Large morphotype, XPL (16) and PC (17), Gorodische (Russia), L. Volgian (klimovi), UCL-5629-13/12.

Figs 18–19. *Stephanolithion brevispinus* (Wind and Wise *in* Wise, 1988) Bown stat. nov.. Large, narrow morphotype (approaching *S. atmetos* outline), XPL (18) and PC (19), Gorodische (Russia), L. Volgian (klimovi), UCL-5629-10/11.

Fig. 20. *Stephanolithion brevispinus* (Wind and Wise *in* Wise, 1988) Bown stat. nov. Small morphotype, PC, Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-5560-6.

Figs 21–22. *Stephanolithion hexum* Rood and Barnard, 1972. XPL (21) and PC (22), Escoville (N France), Callovian (macrocephalus), UCL-5628-15/14.

Figs 23–24. *Stephanolithion speciosum* Deflandre *in* Deflandre and Fert, 1954 ssp. *octum* Rood and Barnard, 1972. XPL (23) and PC (24), Port en Bessin (N France), L. Bathonian (tenuiplicatus), UCL-5628-7/8.

Fig. 25. *Stephanolithion speciosum* Deflandre *in* Deflandre and Fert, 1954 ssp. *speciosum*. PC, Watton Cliff (S England), U. Bathonian (aspidoideis), UCL-5628-4.

Figs 26–27. *Stradnerlithus clatriatus* (Rood *et al.*, 1973) Goy, 1979. XPL (26, the bright image is an artefact of the photograph; this species is inconspicuous in XPL but does exhibit a distinctive flaring rim image and occasionally the major cross-bars are visible), Hambühren (Germany), Aalenian, UCL-5545-27/5626-17.

Fig. 28. *Stradnerlithus comptus* Black, 1971a. PC, Gorodische (Russia), M. Volgian (panderi), UCL-5631-16.

Figs 29–30. *Stradnerlithus fragilis* (Rood and Barnard, 1972) Perch-Nielsen, 1984. PC, Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-5628-27/5560-16.

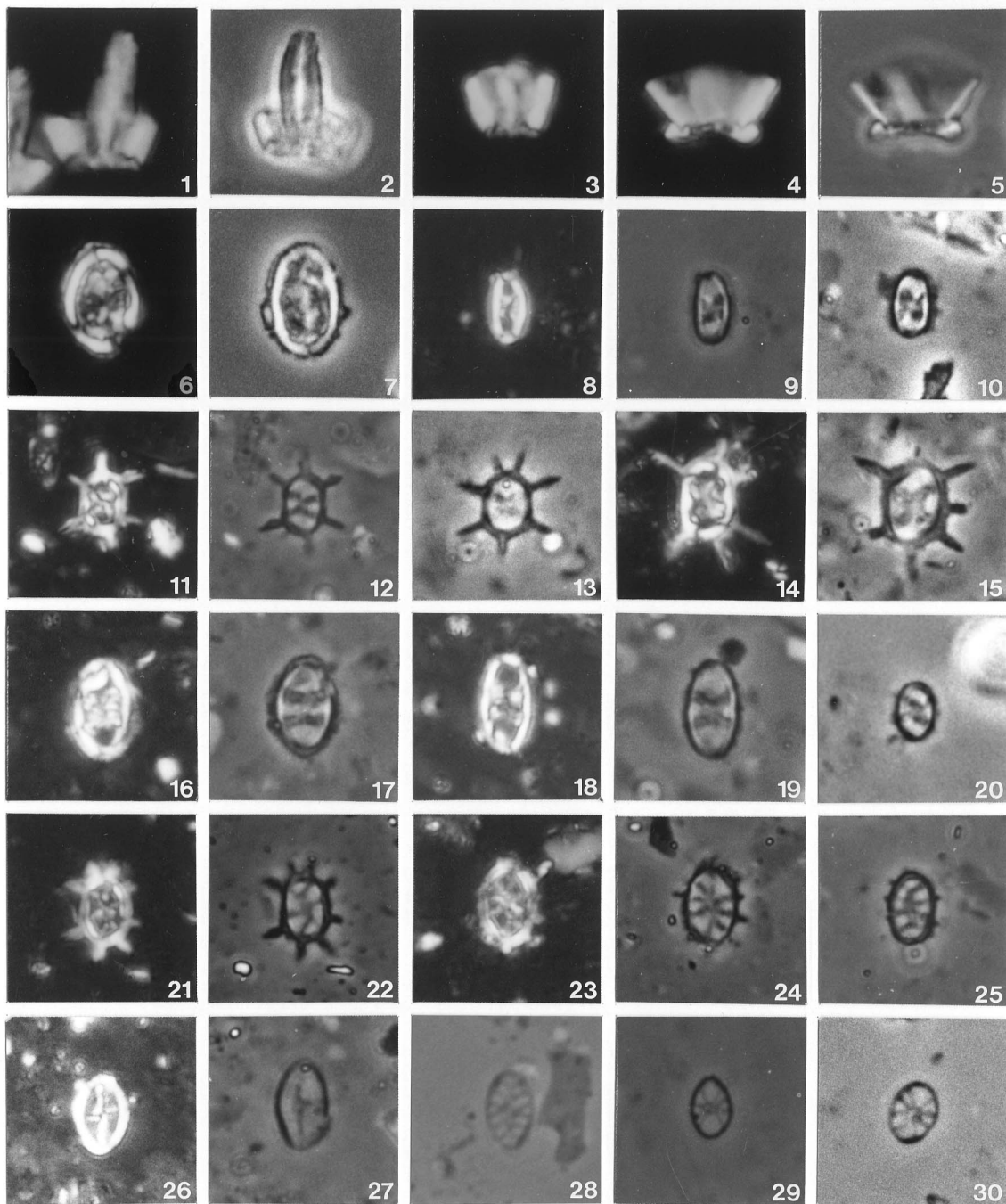


Plate 4.12

Family STEPHANOLITHIACEAE Black, 1968

Fig. 1. *Stradnerlithus geometricus* (Górka, 1957) Bown and Cooper, 1989a. PC, Gorodische (Russia), M. Volgian (panderi), UCL-5629-5. Range: L. Oxfordian (mariae) – M. Volgian (panderi).

Fig. 2. *Stradnerlithus primitus* (Rood *et al.*, 1973) Bown comb. nov.. XPL, Hambühren (Germany), Aalenian, UCL-5631-36. Range: U. Sinemurian (raricostatum)? – ?Aalenian (opalinum).

Basionym: *Chiastozygus primitus* Rood *et al.*, 1973 (*Eclogae Geologicae Helvetiae*, **66**, 365–382, p. 370, Pl. 1, fig. 8).

Figs 3–4. *Truncatoscaphus intermedius* Perch-Nielsen, 1986b. XPL (3, the high colours are an artefact of the photograph; this species is small and inconspicuous in XPL but exhibits high relief in PC), and PC (4), Gorodische (Russia), M. Volgian/U. Kimmeridgian (panderi/eudoxus), UCL-1504-28/22.

Fig. 5. *Truncatoscaphus pauciramus* (Black, 1973) Perch-Nielsen, 1984 (?= *Stradnerlithus tortuosus* Noël, 1973). PC, Watton Cliff (UK), U. Bathonian (aspidoidea), UCL-5628-3.

Order PODORHABDALES Rood *et al.*, 1971 emend. Bown, 1987

Family BISCUTACEAE Black, 1971a

Fig. 6. *Biscutum depravatum* (Grün and Zweili, 1980) Bown 1987. PC, Brenha (Portugal), Aalenian, UCL-5632-8.

Figs 7–8. *Biscutum dorsetensis* Varol and Girgis, 1994 Bown comb. nov. XPL (7) and PC (8), Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5331-17/16. Basionym given in Pl. 4.4.

Figs 9–10. *Biscutum dubium* (Noël, 1965) Grün in Grün *et al.*, 1974. XPL (9) and PC (10), Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-6/5.

Figs 11–12. *Biscutum finchii* Crux, 1984. Small morphotype with transverse bar (*Similiscutum gephyrion* of de Kaenel and Bergen, 1993), XPL (11) and PC (12), Brenha (Portugal), L. Pliensbachian (davoei), UCL-5627-9/10.

Figs 13–14. *Biscutum finchii* Crux, 1984. Large morphotype, XPL (13) and PC (14), Picun Leufu (Argentina), U. Pliensbachian/L. Toarcian, UCL-5630-12/13.

Figs 15–16. *Biscutum grande* Bown, 1987. XPL (15) and PC (16), Brenha (Portugal), L. Pliensbachian (davoei), UCL-5627-17/18.

Figs 17–18. *Biscutum intermedium* Bown, 1987. XPL (17) and PC (18), Brenha (Portugal), Aalenian/Bajocian, UCL-5626-31/32.

Figs 19–21. *Biscutum novum* (Goy, 1979) Bown, 1987. XPL (19, 21) and PC (20). 19-20, Unterstürmig (Germany), L. Toarcian, UCL-5652-9-10; 21, Brenha (Portugal), Aalenian/Bajocian.

Fig. 22. *Discorhabdus corollatus* Noël, 1965. PC, Warboys (UK), Oxfordian (mariae), UCL-5631-27.

Figs 23–25. *Discorhabdus criotus* Bown, 1987. 23-24, XPL (23) and PC (24), Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-29/30. 25, PC, Brenha (Portugal), Aalenian/Bajocian, UCL-5562-20.

Figs 26–27. *Discorhabdus striatus* Moshkovitz and Ehrlich, 1976. XPL (26) and PC (27), Brenha (Portugal), Aalenian/Bajocian, UCL-5626-27/28.

Figs 28–30. *Similiscutum cruciulus* de Kaenel and Bergen, 1993. XPL (28) and PC (29, 30, latter is a different specimen), Brenha (Portugal), L. Pliensbachian (davoei), UCL-5627-11/12/16.

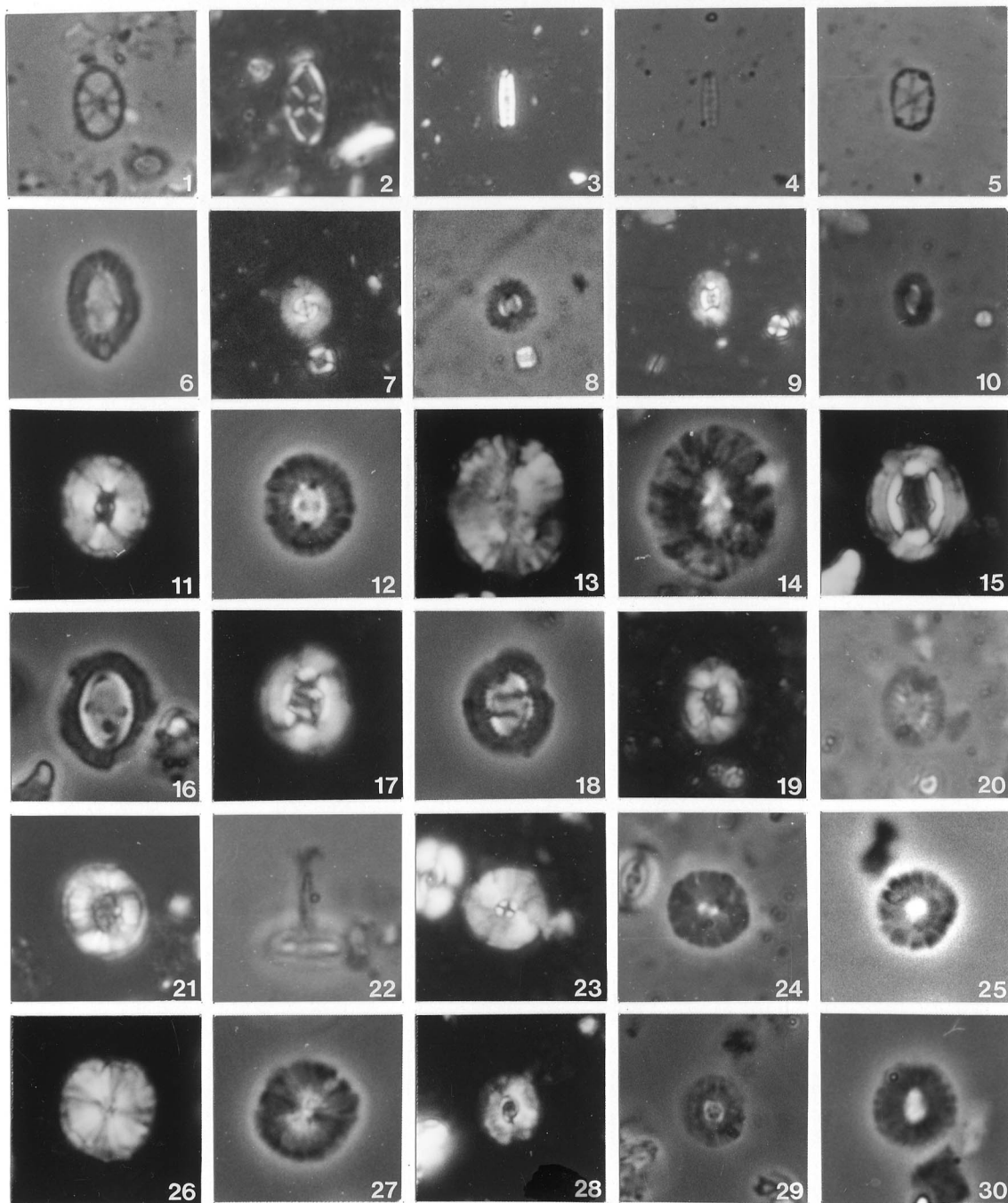


Plate 4.13

Family BISCUTACEAE Black, 1971a

Fig. 1. *Sollasites arctus* (Noël, 1973) Bown, 1987. PC, Unterstürmig (Germany), L. Toarcian, UCL-5545-14.

Family CALYCULACEAE Noël, 1973

Figs 2–5. *Calyculus* spp. *indet.*. 2–3, plan XPL (2) and PC (3), Ballrechten (Germany), L. Toarcian (bifrons), UCL-5562-14/15; 4–5, plan XPL (4) and side XPL (5), Hambühren (Germany), Aalenian, UCL-5631-34/32.

Figs 6–9. *Carinolithus magharensis* (Moshkovitz and Ehrlich, 1976) Bown, 1987. Side view, XPL (6, 8) and plan view of distal 'shield' termination, XPL (7) and PC (9), Brenha (Portugal), Aalenian/Bajocian, UCL-5562-33/5627-1/3/5562-30.

Figs 10–11. *Carinolithus superbus* (Deflandre in Deflandre and Fert, 1954) Prins in Grün *et al.*, 1974. Side views, XPL, Ilminster (UK), Toarcian, UCL-2616-33/31.

Family CRETARHABDACEAE Thierstein, 1973

Figs 12–13. *Cretarhabdus conicus* Bramlette and Martini, 1964. XPL (12) and PC (13), Gorodische (Russia), L. Volgian (klimovi), UCL-5629-8/9.

Figs 14–15. *Helenea chiasia* Worsley, 1971. XPL (14) and PC (15, different specimen), DSDP Site 534 (N Atlantic Ocean), U. Tithonian, UCL-5630-3/5564-21. Range: U. Tithonian – L. Turonian (devonense).

Fig. 16. *Helenea stauroolithina* Worsley, 1971 (= *Microstaurus quadrata* Black, 1971a). XPL, specimen is close to the morphometric *chiasia/stauroolithina* boundary, DSDP Site 534 (N Atlantic Ocean), U. Tithonian, UCL-5630-1. Range: Tithonian – Hauterivian.

Fig. 17. *Miravetesina favula* Grün in Grün and Allemann, 1975. XPL, DSDP Site 534 (N Atlantic Ocean), U. Tithonian, UCL-5629-36. Range: Kimmeridgian? – ?Valanginian.

Figs 18–20. *Polypodorhabdus escaigii* Noël, 1965. XPL (18) and PC (19), Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-1/2/5331-13.

Figs 21–22. *Retecapsa incompta* Bown, 1987. XPL (21) and PC (22), Brenha (Portugal), Aalenian/Bajocian, UCL-5626-30/29.

Fig. 23. *Retecapsa octofenestrata* (Bralower in Bralower *et al.*, 1989) Bown comb. nov.. XPL, DSDP Site 534 (N Atlantic Ocean), U. Tithonian, UCL-5564-2/3. Range: L. Callovian (macrocephalus) – ?Maastrichtian.

Basionym: *Cretarhabdus octofenestratus* Bralower in Bralower *et al.*, 1989 (*Marine Micropaleontology*, **14**, 153–234, p.212–213, pl. 3, figs 1–3).

Fig. 24. *Retecapsa* cf. *R. schizobrachiata* (Gartner, 1968) Grün in Grün and Allemann, 1975. XPL, Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-5631-17.

Family MAZAGANELLACEAE Bown, 1987

Figs 25–26. *Mazaganella protensa* Bown, 1987. XPL (25) and PC (26), DSDP Site 547 (Atlantic Ocean), L. Pliensbachian, UCL-5652-5/6.

Figs 27–28. *Mazaganella pulla* Bown, 1987. XPL (27) and PC (28), Timor, L. Pliensbachian, UCL-5625-24/23.

Fig. 29. *Triscutum ?beaminsterensis* Dockerill, 1987. XPL, Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-25.

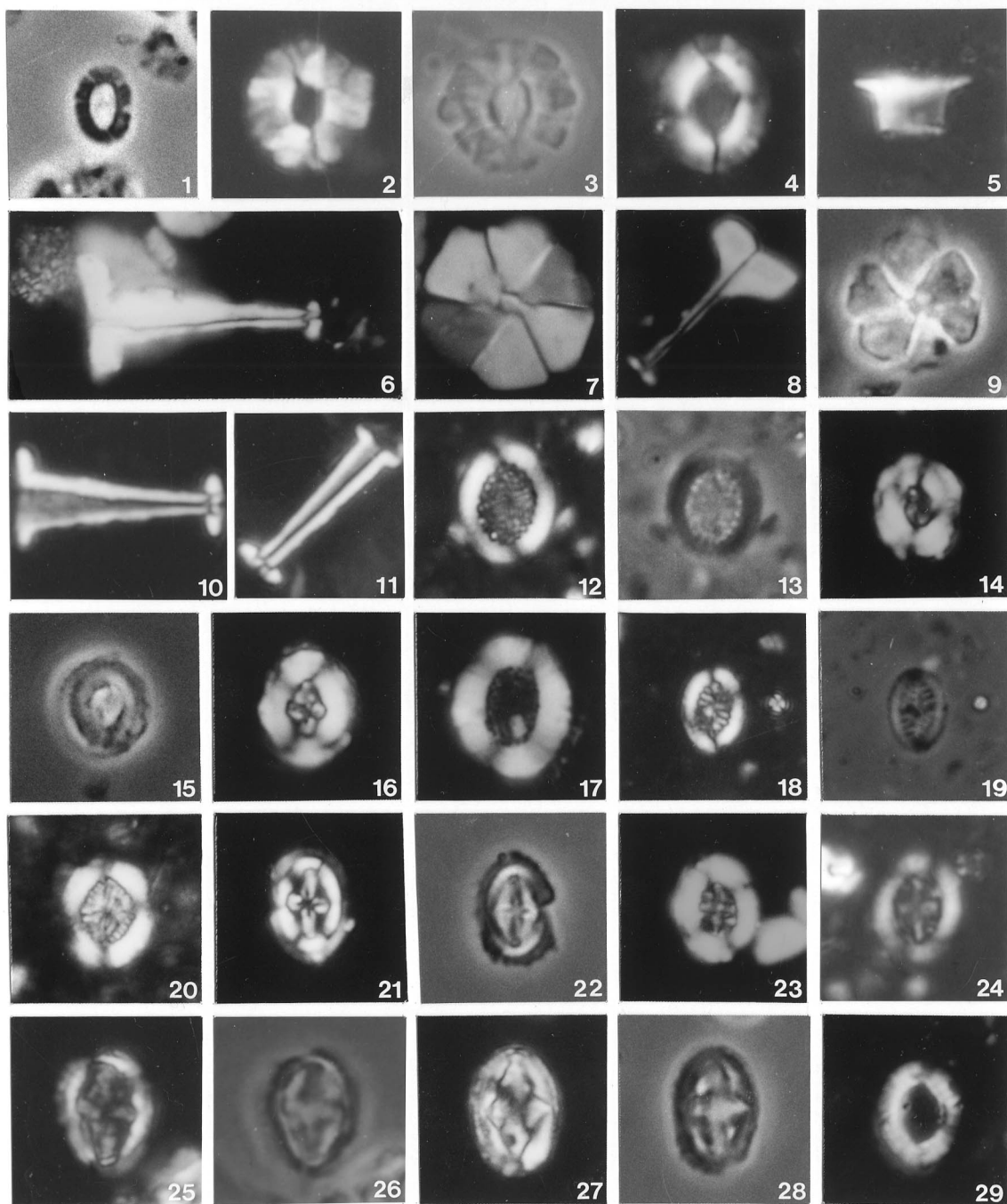


Plate 4.14

Family MAZAGANELLACEAE Bown, 1987

Figs 1–2. *Triscutum ?expansus* (Medd, 1979) Dockerill, 1987. XPL (1) and PC (2), Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5331-33/34.

Figs 3–4. *Triscutum ?expansus* (Medd, 1979) Dockerill, 1987. XPL (3) and PC (4), Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5625-1/2.

Figs 5–6. *Triscutum sullivanii* de Kaenel and Bergen, 1993. XPL (5) and PC (6), Hambühren (Germany), Aalenian, UCL-5626-13/14.

Figs 7–8. *Triscutum sullivanii* de Kaenel and Bergen, 1993. XPL (7) and PC (8), Brenha (Portugal), Aalenian/Bajocian, UCL-5626-35/36.

Figs 9–10. *Triscutum tiziense* de Kaenel and Bergen, 1993. XPL (different specimens), Brenha (Portugal), Aalenian/Bajocian, UCL-5562-34/5627-7. Range: Aalenian (opalinum) – L. Bajocian (discites).

Family AXOPODORHABDACEAE Bown and Young, 1997

Figs 11–12. *Axopodorhabdus atavus* (Grün *et al.*, 1974) Bown, 1987. XPL (11) and PC (12), Hambühren (Germany), Aalenian, UCL-5626-9/10.

Figs 13–14. *Axopodorhabdus cylindratus* (Noël, 1965) Wind and Wise *in* Wise and Wind, 1977. XPL (13) and PC (14), Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-31/32.

Fig. 15. *Axopodorhabdus rahla* (Noël, 1965) Grün and Zweili, 1980. Side view PC, Warboys (UK), Oxfordian (mariae), UCL-5631-26.

Figs 16–17. *Ethmorhabdus gallicus* Noël, 1965. XPL (16) and PC (17), Gorodische (Russia), U. Kimmeridgian (autissiodorensis), UCL-5628-31/30.

Fig. 18. *Hexapodorhabdus cuvillieri* Noël, 1965. PC, Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-15.

Figs 19. *Octopodorhabdus decussatus* (Manivit, 1961) Rood *et al.*, 1971. PC, Warboys (UK), Oxfordian (mariae), UCL-5631-24.

Figs 20–23. *Podorhabdus grassei* Noël, 1965. Side XPL (20) and plan XPL (21) and PC (22, 23) views, Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-11/17/18.

Figs 24–25. *Tetrapodorhabdus shawensis* Medd, 1979. XPL (24) and PC (25), Port en Bessin (N France), L. Bathonian (tenuiplicatus), UCL5628-12/13.

Order WATZNAUERIALES Bown, 1987

Family WATZNAUERiaceae Rood *et al.*, 1971

Figs 26–28. *Ansulasphaera helvetica* Grün and Zweili, 1980. Side XPL (26) and PC (27) and plan XPL (28) views, Denver Borehole (UK), Callovian (athleta), UCL-5627/35/5563-16/5627-31.

Figs 29–30. *Bibreviconus atlanticus* Rahman and Roth, 1991. Side XPL (29) and plan XPL (30) views, DSDP Site 534 (N Atlantic Ocean), L. Tithonian, UCL-5629-32/30. Range: L. Tithonian (?hybonotum).

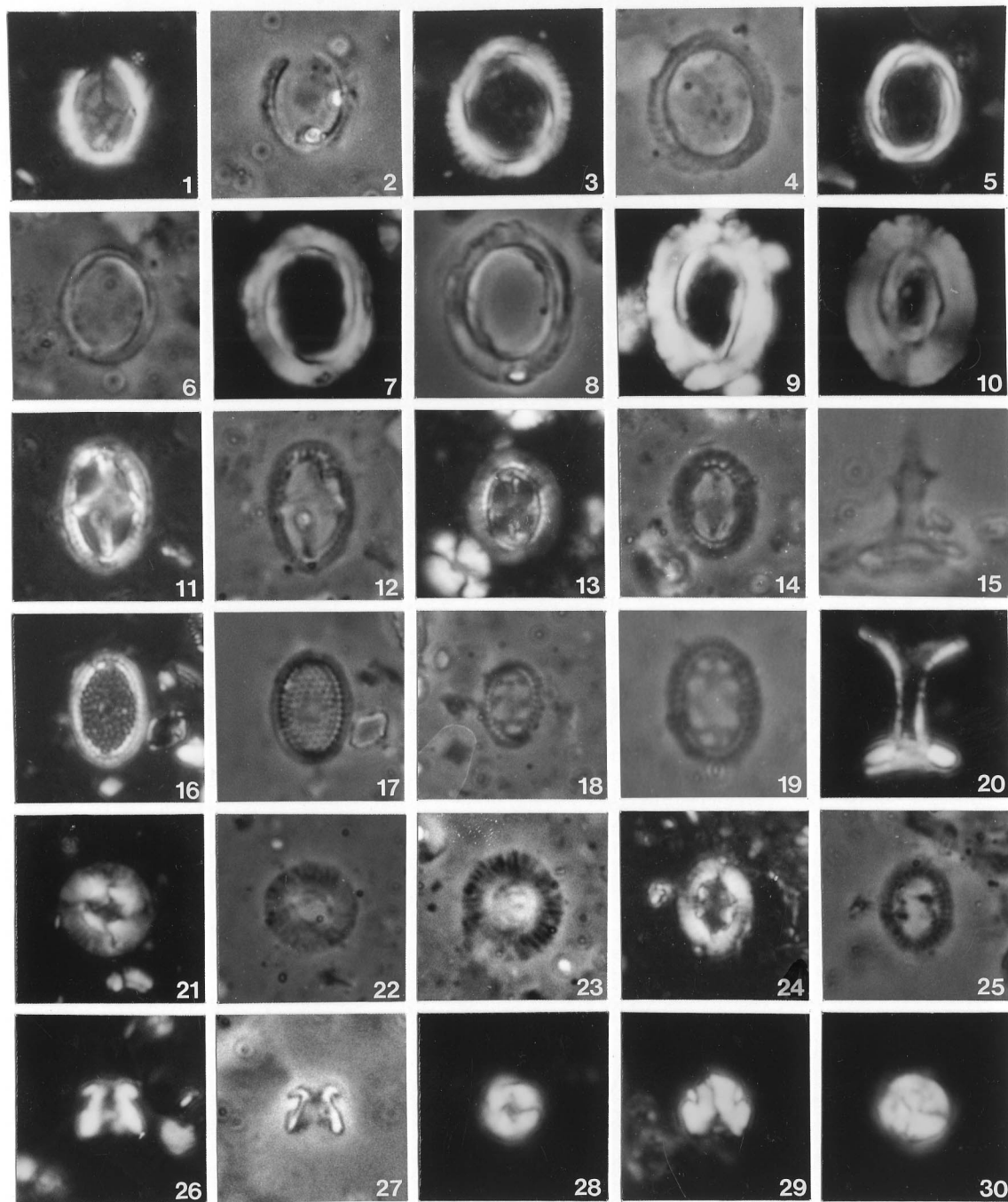


Plate 4.15

Family WATZNAUERiaceae Rood *et al.*, 1971

Figs 1–2. *Bussonius prinsii* (Noël, 1973) Goy, 1979. XPL (1) and PC (2, different specimen), Trimeusel, (Germany), L. Toarcian (bifrons); Hambühren (Germany), Aalenian, UCL-5625-5/5545-36.

Fig. 3. *Cyclagelosphaera argoensis* Bown, 1992b. XPL, DSDP Site 261 (Indian Ocean), Tithonian, UCL-5631-6. Range: Tithonian – Maastrichtian.

Figs 4–5. *Cyclagelosphaera deflandrei* (Manivit, 1966) Roth, 1973. XPL (4) and PC (5), DSDP Site 534 (N Atlantic Ocean), L. Tithonian, UCL-5564-10/11.

Fig. 6. *Cyclagelosphaera margerelii* Noël, 1965. XPL, Denver Borehole (UK), Callovian (athleta), UCL-5627/33.

Figs 7–8. *Cyclagelosphaera tubulata* (Grün and Zweili, 1980) Cooper, 1987. XPL (7) and PC (8), Gorodische (Russia), M. Volgian (panderi), UCL-5631-14/15.

Figs 9–10. *Diazomatolithus lehmanii* Noël, 1965. XPL (9) and PC (10), DSDP Site 534 (Atlantic Ocean), U. Tithonian, UCL-5564-18/19. Range: Tithonian? – ?M./U. Albian.

Fig. 11. *Lotharingius barozii* Noël, 1973. Collapsed coccosphere XPL, Hambühren (Germany), Aalenian, UCL-5626-23.

Figs 12–15. *Lotharingius contractus* Bown and Cooper, 1989a. XPL (12–14) and PC (15), Brenha (Portugal), Aalenian/Bajocian, UCL-5562-23/5627-5/5626-33/34.

Figs 16–18. *Lotharingius crucicentralis* (Medd, 1971) Grün and Zweili, 1980. XPL (16, 17) and PC (18), Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5625-3/5368-23/24.

Figs 19–20. *Lotharingius hauffii* Grün and Zweili in Grün *et al.*, 1974. XPL (19) and PC (20), Unterstürmig (Germany), L. Toarcian, UCL-5625-20/19.

Figs 21–22. *Lotharingius sigillatus* (Stradner, 1961) Prins in Grün *et al.*, 1974. XPL (21) and PC (22), Trimeusel, (Germany), L. Toarcian (bifrons), UCL-5625-8/7.

Figs 23–24. *Watznaueria barnesae* (Black in Black and Barnes, 1959) Perch-Nielsen, 1968. XPL (23) and PC (24), Gorodische (Russia), M. Volgian (panderi), UCL-5629-3/4.

Figs 25–26. *Watznaueria britannica* (Stradner, 1963) Reinhardt, 1964. XPL, Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-21/5331-24.

Fig. 27. *Watznaueria fossacincta* (Black, 1971a) Bown in Bown and Cooper, 1989a. XPL, Gorodische (Russia), L. Volgian (klimovi), UCL-5629-6.

Fig. 28. *Watznaueria manivitiae* Bukry, 1973d. XPL, Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5331-7.

Family CALYPTROSPHAERACEAE Boudreaux and Hay, 1969

Figs 29–30. *Anfractus harrisonii* Medd, 1979. XPL (29) and PC (30, different specimen), Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-3/5331-32.

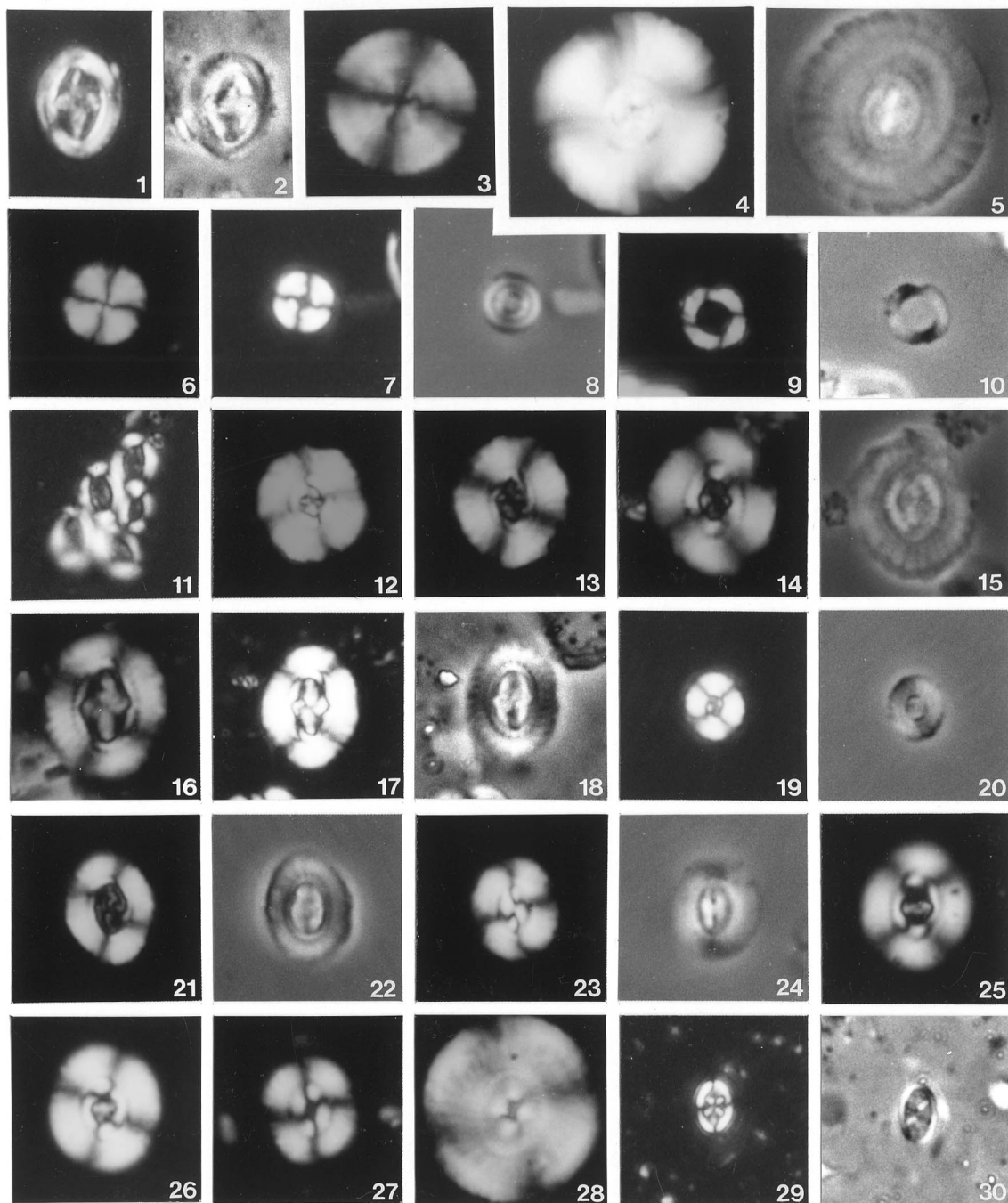


Plate 4.16

Family CALYPTROSPHAERACEAE Boudreaux and Hay, 1969

Figs 1–2. *Pseudoconus enigma* Bown and Cooper, 1989b. XPL (1) and PC (2), Port en Bessin (N France), L. Bathonian (tenuiplicatus), UCL5628-11/10.

NANNOLITHS

Family EOCONUSPHAERACEAE Krystan-Tollmann, 1988a

Figs 3–4. *Conusphaera mexicana* Trejo, 1969 ssp. *mexicana*. XPL (3) and PC (4), DSDP Site 534 (N Atlantic Ocean), U. Tithonian, UCL-5563-23/24.

Figs 5–6. *Conusphaera mexicana* Trejo, 1969 ssp. *minor* Bown and Cooper, 1989b. XPL (5) and PC (6), DSDP Site 534 (N Atlantic Ocean), U. Tithonian, UCL-5629-20/21. Range: L. Tithonian (?m. hybonotum) – U. Tithonian.

Family NANNOCONACEAE Deflandre, 1959

Figs 7–10. *Faviconus multicolumnatus* Bralower in Bralower *et al.*, 1989. XPL (7, 9) and PC (8, 10), DSDP Site 534 (N Atlantic Ocean), L. Tithonian, UCL-5564-4/5/5629-34/35. Range: Oxfordian? – L. Berriasian.

Figs 11–12. *Nannoconus compressus* Bralower and Thierstein in Bralower *et al.*, 1989. XPL (11) and PC (12), DSDP Site 534 (N Atlantic Ocean), U. Tithonian, UCL-5629-16/17.

Fig. 13. *Nannoconus kamptneri* Brönnimann, 1955 ssp. *minor* Bralower in Bralower *et al.*, 1989. XPL, DSDP Site 534 (N Atlantic Ocean), L. Berriasian, UCL-5564-31. Range: ?Berriasian.

Fig. 14. *Nannoconus steinmannii* Kamptner, 1931 ssp. *minor* Deres and Achéritéguy, 1980. XPL (14) and PC (15, different specimen), Middle East, L. Berriasian, UCL-5652-29/36. Range: Berriasian – ?Valanginian.

Family POLYCYCLOLITHACEAE Forchheimer, 1972 emend. Varol, 1992

Figs 16–17. *Hexalithus noeliae* Loeblich and Tappan, 1966. XPL (16) and PC (17), DSDP Site 534 (N Atlantic Ocean), U. Tithonian, UCL-5629-22/23. Range: U. Tithonian – L. Berriasian.

Figs 18–19. *Polycostella beckmanii* Thierstein, 1971. XPL (18) and PC (19, different specimen), DSDP Site 534 (N Atlantic Ocean), U. Tithonian, UCL-5629-25/5564-26. Range: Tithonian.

Fig. 20. *Polycostella senaria* Thierstein, 1971. XPL, Middle East, L. Berriasian. Range: U. Tithonian – L. Berriasian.

Family SCHIZOSPHAERELLACEAE Deflandre, 1959

Figs 21–22. *Schizosphaerella punctulata* Deflandre and Dangeard, 1938. XPL (21) and PC (22) of single disarticulated valve, Cleveland Farm Pit, Wiltshire (UK), L. Oxfordian (mariae), UCL-5624-35/36.

INCERTAE SEDIS NANNOLITHS

Figs 23–24. *Orthogonoides hamiltoniae* Wiegand, 1984b. XPL (23) and PC (24, different specimen), Unterstürmig (Germany), L. Toarcian, UCL-5625-15/5545-18.

