25. JURASSIC NANNOFOSSILS FROM THE NORTHWEST AFRICAN MARGIN, DEEP SEA DRILLING PROJECT LEG 79[1]

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ABSTRACT

Sites 544, 545, and 547, drilled on DSDP Leg 79, recovered Jurassic calcareous nannofossils. Lower Jurassic (Sinemurian–lower Pliensbachian) nannofossils are found in Hole 547B; these are the oldest yet recovered by deep sea drilling. Three other Jurassic intervals are delineated by nannofossil biostratigraphy: the Lower-Middle Jurassic in Hole 547B; the Lower-Middle Jurassic in Hole 545; and the Upper Jurassic in Hole 547B. Low species diversity makes age determinations difficult for these portions of the Jurassic. Two new genera, *Calcivascularis* and *Orthogonoides*, have been described from these Lower Jurassic sediments.

INTRODUCTION

In April and May of 1981, Leg 79 drilled four sites on the Northwest African margin, west of Morocco (Fig. 1). Holes 544A, 545, and 547B penetrated Jurassic sediments that are predominantly composed of limestones, limestone breccias, and interbedded claystones and mudstones. These sediments once formed the seaward portion of a carbonate platform before its subsidence and subsequent drowning during the early opening of the Atlantic Ocean (see Site 547 site chapter, this volume).

The coccoliths from the Jurassic sediments range in age from Early to Late Jurassic. The Lower Jurassic sediments are Sinemurian to early Pliensbachian in age as determined by nannofossil biostratigraphy. These Lower Jurassic calcareous nannofossils are the oldest yet recovered by deep sea drilling. The oldest assemblages previously recovered are of Middle Jurassic age (DSDP Legs 71 and 76; Wise, 1983; Roth et al., 1983).

The nannofossil species considered in this report are listed in Table 1. Most of the bibliographic references for these taxa are given in Loeblich and Tappan (1966, 1968, 1969, 1970a, 1970b, 1971, 1973) and in Heck (1979a, 1979b, 1980a, 1980b, 1981a, 1981b, 1982a, 1982b, 1983). References not found therein are listed in the references of this paper. In addition, two new genera have been described from these Lower Jurassic sediments (Wiegand, in press).

METHODS AND PROCEDURES

For this study, smear slides were prepared from raw samples and examined in the light microscope. The smear slides were prepared as uniformly as possible, to allow accurate abundance estimates. If clays flocculated on the slide, a small amount of 3-5% Calgon [$(Na\ PO_3)_6$] solution was added to aid in dispersion.

If this procedure did not adequately disperse the clays, coccoliths were concentrated from the material using the gravitational settling methods described by Hay (1977). The aqueous medium for suspension was distilled water adjusted to a pH of ~8 by the addition of ammonium hydroxide. Calgon solution was added to aid dispersion. When this settling technique was necessary, the original smear slide was used to estimate abundances, since settling concentrates the coccolith assemblage and may introduce bias.

Each smear slide was studied by light microscopy, with approximately 15 traverses made across the slide at 1562× magnification. For each of the samples analyzed two abundances are given: the total abundance of nannofossils on the slide and the abundance of individual species. The estimation method for total abundance of coccoliths (specimens per field of view) on the slide was as follows:

C = common; 30–49
F = few; 10–29
R = rare; 1–9
E = essentially barren; 1 specimen every 2 or more fields
B = barren; no nannofossils observed on the slide

The method of estimating the abundances of the individual species (specimens per field of view) was:

A = abundant; 6–9
V = very common; 3–5
C = common; 1–2
M = moderately common; 1 specimen every 2–40 fields
F = few; 1 specimen every 41–60 fields
R = rare; 1 specimen every 61–120 fields
P = present; 1 specimen every 121 or more fields

Abundances of reworked nannofossils are listed in the tables in lowercase letters in order to separate them from *in situ* taxa, which are in capital letters.

Preservation of the nannofossils in each sample was recorded using the following scheme:

G = good; specimens show little or no dissolution and/or overgrowth
M = moderate; specimens show some dissolution and/or overgrowth; identification of species not impaired
P = poor; specimens show extreme dissolution and/or overgrowth; identification of species usually possible but sometimes impaired

Two types of samples were prepared for scanning electron microscopy: (1) concentrated coccolith assemblages from claystones and mudstones and (2) limestone fracture surfaces. The coccoliths were concentrated from the sediment following the settling technique just described and centrifuged to remove remaining clay; the resulting pellet was then oven-dried to decrease coccolith dissolution during storage. The concentrated material was resuspended in water, placed upon a glass cover slip previously glued to an aluminum SEM stub, and allowed to air dry. The sample was then sputter-coated with a gold-palladium alloy.

[1] Hinz, K., Winterer, E. L., et al., *Init. Repts. DSDP*, 79: Washington (U.S. Govt. Printing Office).
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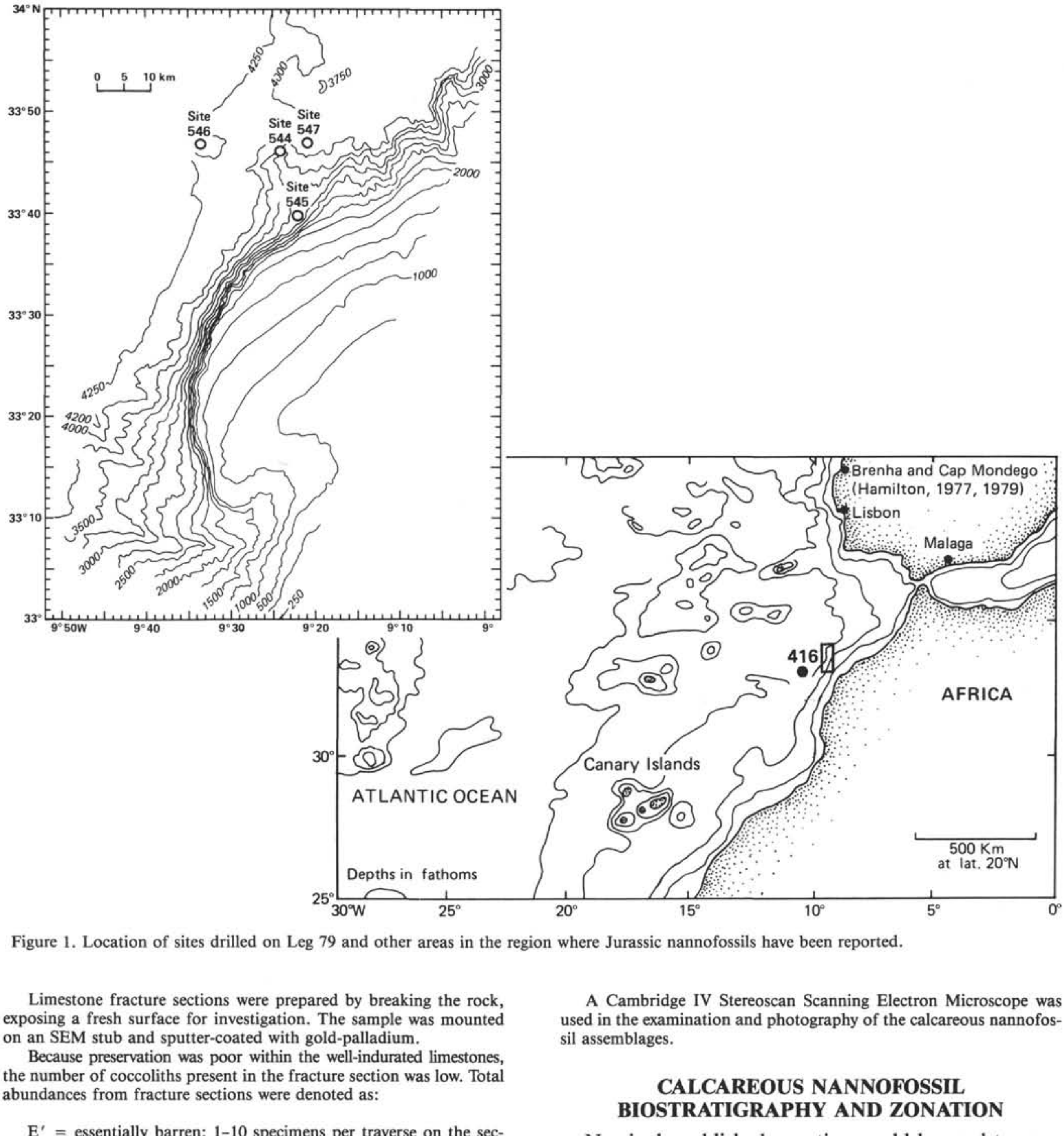

Figure 1. Location of sites drilled on Leg 79 and other areas in the region where Jurassic nannofossils have been reported.

Limestone fracture sections were prepared by breaking the rock, exposing a fresh surface for investigation. The sample was mounted on an SEM stub and sputter-coated with gold-palladium.

Because preservation was poor within the well-indurated limestones, the number of coccoliths present in the fracture section was low. Total abundances from fracture sections were denoted as:

E′ = essentially barren; 1-10 specimens per traverse on the section (by SEM)

B′ = barren; no recognizable nannofossils observed on the section

Limestone fracture sections are denoted by asterisks beside the sample numbers in Tables 2, 3 and 4.

With so few nannofossils observed on the fracture surfaces, a single abundance category was considered appropriate for estimating individual species abundances: P′ = present; < 10 specimens per fracture section.

Other coccoliths found within the fractured samples could be identified only to the generic level because of the poor preservation and are denoted by question marks on the range charts (e.g., *Ellipsagelosphaera* sp.?).

A Cambridge IV Stereoscan Scanning Electron Microscope was used in the examination and photography of the calcareous nannofossil assemblages.

CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY AND ZONATION

No single published zonation could be used to zone the Jurassic nannofossils recovered during Leg 79. For some intervals, no established zonal markers were present, and other coccoliths in the assemblage were used to provide age ranges. These unzoned intervals include the Lower–Upper Jurassic in Hole 544A; the lower Middle Jurassic of Site 545; and the lower Middle and Upper Jurassic in Hole 547B. One section did allow application of a biostratigraphic scheme: the Lower Jurassic of Hole 547B, where datum levels of Hamilton (1977, 1979, 1982) and the zonation of Hamilton (1982) were applied. Hamilton's Portuguese study area is near the Leg

Table 1. Nannofossil species considered in this study, listed alphabetically by specific name.

Watznaueria barnesae (Black) Perch-Nielsen, 1968
Stephanolithion bigotii Deflandre, 1939
Ellipsagelosphaera britannica (Stradner 1963)
Crepidolithus crassus Deflandre, 1954
Ellipsagelosphaera crucicentralis Medd, 1971
Crepidolithus crucifer Prins ex Rood, Hay, and Barnard, 1973
Axopodorhabdus cylindratus (Noël) Wind and Wise, 1976
Cyclagelosphaera deflandrei (Manivit) Roth, 1973
Paleopontosphaera dubia Noël, 1965
Zeugrhabdotus erectus (Deflandre) Stradner, 1965
Orthogonoides hamiltoniae Wiegand, in press
Bidiscus ignotus (Gorka) Lauer *in* Grün et al., 1972
Calcivascularis jansae Wiegand, in press
Ellipsagelosphaera keftalrempti Grün, 1975
Parhabdolithus liasicus Deflandre, 1952
Hexalithus sp. cf. *H. magharensis* Moshkovitz and Ehrlich, 1976
Cyclagelosphaera margereli Noël, 1965
Parhabdolithus marthae Deflandre, 1954
Tubirhabdus patulus Prins ex Rood, Hay, and Barnard, 1973
Crucirhabdus primulus Prins ex Rood, Hay, and Barnard, 1973
Schizosphaerella punctulata Deflandre and Dangeard, 1938
Staurorhabdus quadriacullus (Noël) Noël, 1973
Paleopontosphaera sp. cf. *P. veterna* Prins ex Rood, Hay, and Barnard, 1973
Carinolithus sp.
Crepidolithus sp.
Discorhabdus sp.
Ellipsagelosphaera sp.
Tubirhabdus sp.

Table 2. Distribution of Jurassic nannofossils in Hole 544A.

Sub-bottom depth (m)	Core-Section (interval in cm)	Abundance	Preservation	*Ellipsagelosphaera britannica*	*Discorhabdus* sp.?	*E.* sp.?	Age
108	13-1, 9–10*	B′					
109	13-2, 47–49*	E′	P	P′	P′		
112	14-1, 21–23*	E′	P	P′			
113	14-2, 20–22*	B′					
115	14-3, 16–18*	B′					
116	14-4, 15–17*	E′	P			P′	Jurassic
123	15-2, 73–75*	B′					
126	15-4, 40–41*	B′					
131	16-1, 67–69*	B′					
139	17-1, 13–14*	B′					
148	18-1, 8–9*	B					

Note: * indicates a limestone fracture section; P′ = <10 specimens per fracture section; E′ = essentially barren; B′ = barren (for fracture sections only). P = poor preservation.

79 drilling location, and her datums are applicable to the Hole 547B material.

Site 544 (Hole 544A; 33°46.0′N, 09°24.3′W; water depth 3581 m)

Site 544 was drilled high on the northwestern flank of a horst of sialic basement rock. All samples examined are limestone fracture sections. Nannofossil diversity is low and preservation is poor within the well-indurated limestones. Table 2 shows species abundance and distribution, constructed entirely from SEM observations of fracture surfaces.

The limestones from Core 13 to Sample 544A-17-1, 22 cm (107.5– ~ 139.2 m) lie beneath nannofossil-foraminiferal ooze of early middle Miocene age. The presence of only *Ellipsagelosphaera britannica* in fracture sections from Samples 544A-13-2, 47–49 cm (109.5 m) and 544A-14-1, 21–23 cm (~ 111.7 m) and the absence of any apparently Cretaceous taxa suggest an Aalenian-early Bajocian to Tithonian age (Barnard and Hay, 1974; Thierstein, 1976; Hamilton, 1979) for the upper portion of the limestones. There are no recognizable nannofossils between Samples 544A-15-2, 73–75 cm (~ 123.2 m) and 544A-17-1, 13–14 cm (~ 139.2 m) as the induration of the limestones increases with depth.

Smear slides from continental mudstones and sandstones of Cores 18 and 19 (148–157 m) are barren of nannofossils. No samples were taken below Core 19.

Site 545 (33°39.86′N, 09°21.88′W; water depth 3142 m)

Site 545 was drilled northwest of the Mazagan Plateau, at the base of the Mazagan Escarpment. No samples were taken from the dolomitized limestones from Cores 56 to 67 (~ 530.7–635.5 m sub-bottom depth).

Beneath the dolomitized limestone, from Cores 68 to 75 (635.5-701 m sub-bottom depth), wackestones and packstones with scattered calcareous shales, calcitic sandstones, and claystones are found. The samples examined were taken from the shales and claystones. This interval ranges in age from the late Pliensbachian–early Bathonian to the Oxfordian-middle Kimmeridgian, based on the overlap of ranges of *Axopodorhabdus cylindratus* and *E. crucicentralis* (see later discussion). Table 3 shows species abundance and distribution.

Site 547 (Hole 547B; 33°46.84′N, 09°20.98; W; water depth 3939 m)

Site 547 was drilled on the northeastern flank of the same fault-controlled block as Site 544. As discussed in the following section, three separate intervals are recognized within the Jurassic carbonates of Hole 547B: the Upper Jurassic, the lower Middle Jurassic, and the Lower Jurassic. Table 4 shows species abundance and distribution.

The Upper Jurassic lies beneath Lower Cretaceous bioclastic wackestones, limestone conglomerates, and interbedded claystones. A disconformity lies between Sample 547B-6-2, 6–7 cm (~ 773.6 m) and Sample 547B-6-4, 47–48 cm (~ 777 m), separating the lower Valanginian–lower Hauterivian from the Kimmeridgian–Tithonian. No lithologic change occurs between the Jurassic and Cretaceous. The Upper Jurassic is represented in Samples 547B-6-4, 47–48 cm (~ 777 m) to 547B-7,CC (791 m). A representative coccolith assemblage for this interval consists of *Cyclagelosphaera deflandrei, C. margereli, Ellipsagelosphaera britannica, E. keftalrempti*, and *Watznaueria barnesae*. Nannofossil abundance is rare to few, preservation generally moderate.

Table 3. Distribution of Jurassic nannofossils in Hole 545.

Sub-bottom depth (m)	Core-Section (interval in cm)	Abundance	Preservation	*Axopodorhabdus cylindratus*	*Bidiscus ignotus*	*Ellipsagelosphaera crucicentralis*	*Paleopontosphaera* sp. cf. *P. veterna*	*Staurorhabdus quadriaculllus*	*Tubirhabdus patulus*	*Zeugrhabdotus erectus*	?*Carinolithus* sp.	*Discorhabdus* sp.?	*D.* sp.?	*E.* sp.	*E.* sp.?	?*T.* sp.	Age
636	68-1, 87–88*	B′															
638	68-2, 66–67*	B′															
639	68-3, 14–15*	B′															
645	69-1, 31–32	B															
647	69-2, 30–31*	B′															middle
648	69-3, 12–13*	E′	P										P′		P′		Kimmeridgian–
655	70-1, 66–67*	B															Oxfordian
665	71-1, 105–106	E	M			F						R					
666	71-2, 85–86	E	M		R							M				F	
668	71-3, 88–89	E	M		R							R				R	
669	71-4, 23–24	E	M			P						F		R			to
674	72-1, 6–7	E	M	F	M	M					F	M		M			
676	72-2, 62–63	B															late
677	72-3, 11–12	E	M	P		R						F		R			Pliensbachian–
683	73-1, 67–68	E	M	M		P						R				R	early
683	73-1, 84–85	R	G			M	F	M	F	M	F	M		M			Bathonian
685	73-2, 81–82	R	M	F		M					F	M		M			
692	74-1, 26–27*	E	P			P							P′		P′		
701	75-1, 15–16*	B															

Note: * indicates a limestone fracture section; P′ = <10 specimens per fracture section; E′ = essentially barren; B′ = barren (for fracture sections only). For other sections, M = moderately common; F = few; R = rare. For preservation, M = moderate; P = poor.

An unconformity exists between Core 7 (Upper Jurassic) and Core 8 (lower Middle Jurassic). Nodular limestones are encountered from the top of Core 8 to Section 547B-8-3 (~795.5 m). A typical coccolith assemblage of this interval contains *Bidiscus ignotus, Crepidolithus crassus, E. crucicentralis, Hexalithus* sp. cf. *H. magharensis*, and *Discorhabdus* sp. Nannofossil preservation is generally moderate, with abundance being rare to few in these sections. *W. barnesae* and *E. britannica*, observed in Sample 547B-8-1, 88–89 cm, are considered contaminants from Core 7, since they are not observed below this sample.

Limestone breccias are found from Section 547B-8-4 (~795.5 m) to Section 547B-10-3 (~806.7 m). No claystones or mudstones are present. Limestone fracture sections examined were barren of nannofossils. Section 547B-10-4 (~806.7–810 m) is composed of nodular limestones with poorly preserved nannofossil assemblages.

Core 11 (810–819 m) has alternating boundstones and limestone breccias with laminated claystones. Samples from Sections 547B-11-1 to 547B-11-3, taken from claystones within the breccias, are barren of coccoliths. Section 547B-11-4 yields poorly preserved assemblages of low diversity.

The presence of limestone breccias between Sections 547B-8-4 and 547B-11-4 suggests that the interval may be allochthonous and that the associated nannofossil assemblages may be mixed. If these limestones are out of place, it appears that they originated from strata younger than the Sinemurian–lower Pliensbachian limestones because no reworked coccoliths of that age are observed, unlike in the interval from 547B-11,CC to Section 547B-14-1. The nannofossil assemblages of Sections 547B-8-4 to 547B-11-4 are similar to those at the top of Core 8, except for the absence of *E. crucicentralis*.

Beginning in Sample 547B-11,CC and continuing through Section 547B-14-1 (819–~838.6 m), allochthonous limestone breccias are found. Nannofossils found in the Sinemurian to lower Pliensbachian interval below, such as *Calcivascularis jansae* and *Parhabdolithus liasicus*, are present in Samples 547B-11,CC (819 m) and 547B-14-1, 95–96 cm (~838 m). These taxa are considered reworked from below. Samples 547B-14-2, 56 cm (~839 m) and 547B-14,CC (846 m) are barren of fossil nannoflora.

The age range determined for Cores 8 through 14 (791–846 m) is from the early Pliensbachian to the Aalenian (see later discussion). This interval is characterized by low abundance, low diversity, and poor preservation of coccoliths.

An unconformity separates the limestone breccia sequence (lower Middle Jurassic) from the Lower Jurassic interval below. This interval, from Cores 15 to 24 (846–932.5 m), consists mostly of nodular limestones within a matrix of calcareous mudstones and claystones. Coccoliths are found exclusively in the claystones and mudstones. The nannofossil diversity is greater in this interval than in the other Jurassic portions of Hole 547B. Nannofossils are generally rare to few in abundance with preservation poor to good.

The Sinemurian, represented by the last consistent occurrence of *P. marthae* (see later discussion), is recognized in Samples 547B-20-1, 37–38 cm to 547B-23-2, 34–35 cm (891–923.5 m). A common coccolith assemblage for this interval consists of the following, all of which are figured in Plates 1-3: *C. jansae, Crepidolithus crucifer, Crucirhabdus primulus, Orthogonoides hamiltoniae, P. liasicus, P. marthae, Schizosphaerella punctulata, Staurorhabdus quadriacullus, Tubirhabdus patulus, and Zeugrhabdotus erectus.* Core 24 is barren of nannofossils (923.5–932 m).

The lower Pliensbachian, defined by the last occurrence of *P. liasicus* (see later discussion), is present in Samples 547B-15-1, 2–4 cm to 547B-19-2, 33–34 cm (846–891 m). The coccolith assemblages found in the lower Pliensbachian of this site are similar to those of the Sinemurian except for the absence of *P. marthae*. Cores 25 to 36 (932.5–1030 m) are barren of coccoliths. This interval is composed primarily of sandy mudstones deposited in a continental environment (see Site 547 site chapter, this volume).

BIOSTRATIGRAPHIC DISCUSSION

The Jurassic intervals included in this discussion (Fig. 2) are the Lower and Lower–Middle Jurassic of Hole 547B; the lower Middle Jurassic of Hole 545, and the Upper Jurassic of Hole 547B. These intervals are listed in chronological order, beginning with the oldest.

Lower Jurassic (Hole 547B)

The oldest datum used by Hamilton (1977, 1979, 1982) is the last occurrence datum (LOD) of *Parhabdolithus marthae*, used to define the Sinemurian/Pliensbachian boundary. Several authors (e.g., Deflandre and Fert, 1954; Noël, 1957; Medd, 1982) have reported *P. marthae* to be present as high as the Upper Jurassic, which calls into question the value of this taxon as a biostratigraphic marker. These younger occurrences may be the result of reworking. However, Hamilton's datum has been used to define the Sinemurian/Pliensbachian boundary in the present study (Sample 547B-20-1, 37–38 cm). No further nannofossil datum levels can be resolved below this boundary in Hole 547B. *P. marthae* was observed to Sample 547B-23-2, 34–35 cm; therefore, the interval from there to the boundary in Sample 547B-20-1, 37–38 cm is considered to be Sinemurian, based on the first occurrence of *P. marthae* suggested by Prins (1969), Barnard and Hay (1974), and Medd (1982) (lower Sinemurian).

The location of the Sinemurian/Pliensbachian boundary in Core 547B-20 is also supported by the first occurrence of *Crepidolithus crassus* in Sample 547B-20-1, 126–127 cm. According to Watkins (pers. comm., 1983), the first occurrence of *C. crassus* approximates the Sinemurian/Pliensbachian boundary (see reports by Prins, 1969; Amezieux, 1972; Barnard and Hay, 1974; Thierstein, 1976; and Medd, 1982). Poorly preserved specimens of *Crepidolithus* sp. occur down to Sample 547B-20-2, 59–60 cm, and further SEM investigation

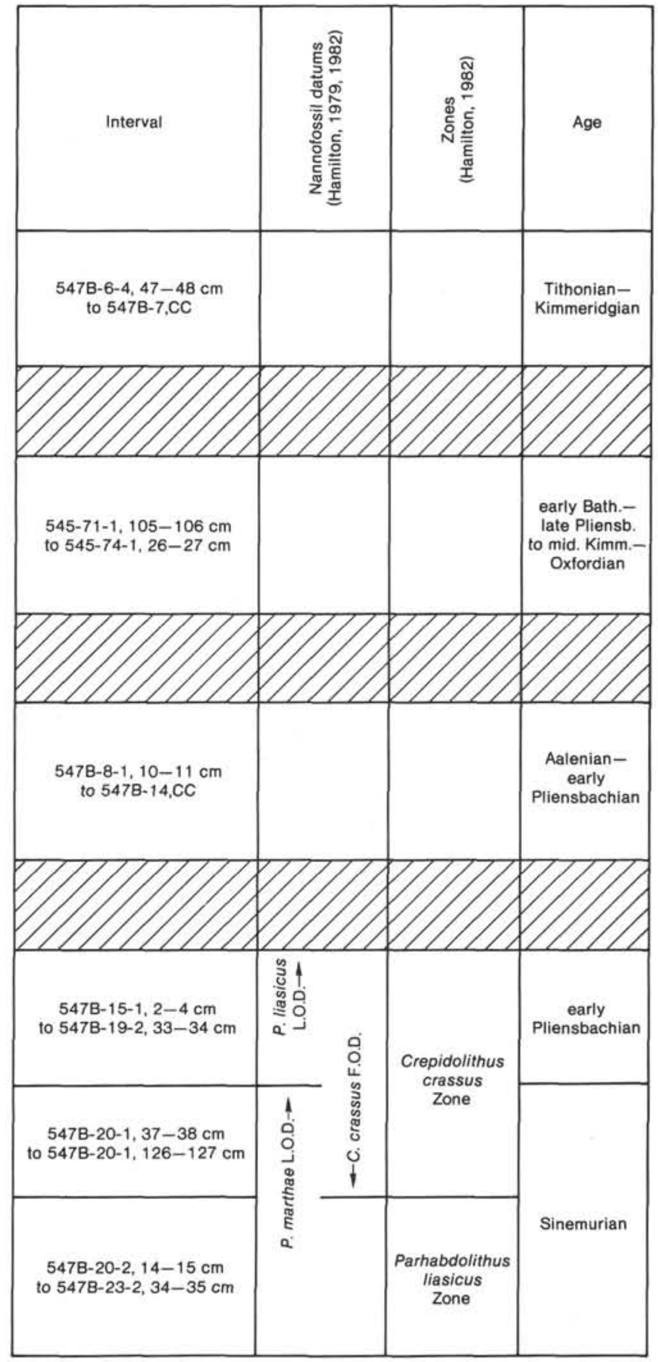

Figure 2. Composite section showing relative order and ages of Jurassic intervals from Leg 79.

may reveal them to be *C. crassus*. This would lower the first appearance of the taxon in this interval but would keep it within Core 20.

The last appearance of *P. liasicus* occurs in Sample 547B-15-1, 2–4 cm. This datum is used by Hamilton (1977, 1979) to separate the lower from the upper Pliensbachian. The interval from Samples 547B-19-2, 33–34 cm to 547B-15-1, 2–4 cm is therefore considered early Pliensbachian in age.

Hamilton (1982) defined the Sinemurian *P. liasicus* Zone as ranging from the first occurrence datum (FOD) of *P. liasicus* to the FOD of *C. crassus* and the latest

Table 4. Distribution of Jurassic nannofossils in Hole 547B.

Sub-bottom depth (m)	Core-Section (interval in cm)	Abundance	Preservation	*Bidiscus ignotus*	*Calcivascularis jansae*	*Crepidolithus crassus*	*C. crucifer*	*Crucirhabdus primulus*	*Cyclagelosphaera deflandrei*	*C. margereli*	*Ellipsagelosphaera britannica*	*E. crucicentralis*	*E. keftalrempti*	*Hexalithus* sp. cf. *H. magharensis*	*Orthogonoides hamiltoniae*	*Paleopontosphaera dubia*	*P.* sp. cf. *P. veterna*	*Parhabdolithus liasicus*	*P. marthae*	*Schizosphaerella punctulata*	*Staurorhabdus quadriacullus*	*Stephanolithion bigoti*	*Tubirhabdus patulus*	*Watznaueria barnesae*	*Zeugrhabdotus erectus*	*Crepidolithus* sp.	*Discorhabdus* sp.	*E.* sp.	?*T.* sp.	Nannofossil datums (Hamilton, 1979, 1982)	Nannofossil zones (Hamilton, 1982)	Age
777	6-4, 47–48 cm	R	G						P	M	R		P											M								
777	6-4, 76–77 cm	F	P							R	P		R											F								
782	7-1, 62 cm	F	M						M	M	M		M											C								
783	7-2, 35–36 cm	R	M							M	M		F									p		M								
784	7-2, 89–90 cm	F	M						R	M	M													C								Tithonian to Kimmer-idgian
784	7-2, 135–136 cm	R	M							M	M													M								
785	7-3, 66–68 cm	R	M							M	M		R											M								
787	7-4, 52–53 cm	R	M						P	M	M·													M								
787	7-4, 135–137 cm	R	M						P	M	M		P											M								
791	7-4,CC	F	G						F	M	M													M								
791	8-1, 10–11 cm	B																														
792	8-1, 88–89 cm	R	M	M		R					M	R		M										M				M	F			
794	8-2, 90–91 cm	F	M	M		M						M		M														M	M			
794	8-2, 118–119 cm	F	M	M		M						M		M													F	M	M			
794	8-3, 22–23 cm	R	M	M		M						R		M														M	F			
795	8-3, 46 cm	R	P	M		M						R		M													M	M	M			
796	8-4, 9–10 cm*	B′																														
801	9-1, 10–11 cm*	B′																														
802	9-2, 13–15 cm	B																														
805	10-1, 112–113 cm*	B′																														
806	10-2, 46–47 cm*	B′																														
807	10-3, 11–12 cm	R	P	M		R								F													M	M	R			
808	10-3, 125–128 cm	R	M	M		M								M		P											M	P	F			Aalenian to early Pliensbachian
809	10-4, 50–54 cm	E	P	M		F								F													M		F			
811	11-1, 140–142 cm	B																														
812	11-1, 147–148 cm	B																														
813	11-3, 3–4 cm	B																														
815	11-4, 68–70 cm	E	P	R		R								R																		
816	11-4, 95–96 cm	R	P	M		M								R			M										M					
819	11,CC	R	P	M	m	M										m	F	r					m				M					
820	12-1, 47–48 cm	B																														
821	12-2, 59–60 cm	E	P	M		R								P			M										F		F			
829	13-1, 77–78 cm*	B′																														
831	13-2, 103–104 cm*	B′																														
838	14-1, 95–96 cm	E	P		r	F												p											P			
839	14-2, 56 cm	B																														
846	14,CC	B																														

846	15-1, 2–4 cm	F	P	V	M	R	F	M	M	F		M		M			M				
848	15-2, 4–5 cm	F	G	C	M	R	M	R	M	M		M	M	M							
848	15-2, 8 cm	E	M	M	R	R	M	F	M	F		M	M	M	P						
848	15-2, 24–25 cm	F	G	V	F	M	C	M		M		V	F	M	M						
856	16-1, 109–110 cm*	B′																			
857	16-2, 51 cm	R	P	M	R	M	M	M		F		M	M	M			M	*Parhabdo-lithus liasicus* L.O.D.			
864	17-1, 14–15 cm	R	G	C			C	M		M		C	M								
864	17-1, 36–39 cm	B																			
865	17-1, 57–58 cm	R	P	C	M	R	M	M		M		C	R								
873	17,CC, 11–12 cm	E	P	M	F		M			F		M					M				
874	18-1, 51–52 cm	R	M	C		F	M			M		M	F	R			R			*Crepido-lithus crassus* Zone	early Pliensbachian
874	18-1, 103–104 cm	R	G	C		R	C	M		F		M	M	M	F						
874	18-1, 110 cm	F	G	V	R	R	C	M		M		C	M	M							
875	18-2, 13–14 cm	F	G	C	F	F	C	M		M		V	F	F			R				
875	18-2, 28–29 cm	C	M	A	M	M	V	M		M		V	F	F	R						
875	18-2, 62–63 cm	F	M	V	M	M	C	M		M		C	F	F			R				
882	19-1, 5–6 cm	R	P	M		M	M	M		F		M	R	R	P	M					
883	19-1, 58–60 cm	R	M	M	F	M	M	M		F		C	F	M	P						
883	19-1, 71–72 cm	F	M	M	F	M	C	M		F		C	F	M	P				*Crepido-lithus crassus* F.O.D.		
883	19-1, 112–113 cm	E	P	F		M	F	M		R		M		R		F					
884	19-2, 10–11 cm	R	P	M		R	M	M		R		M	R	F		F					
884	19-2, 33–34 cm	E	P	M		M	M	F		R		M	R	F	P	R					
891	20-1, 37–38 cm	F	M	C	R	R	M	M		M	R	C	M	C	F						
892	20-1, 63–64 cm	F	G	C			M	M		M	R	C	M	V	M						
892	20-1, 126–127 cm	R	G	C	R	M	M	M		M	R	M	M	M	R						
893	20-2, 14–15 cm	R	M	C		F	M	M		M	R	M	F	M	F						
893	20-2, 59–60 cm	E	P			P	R	P		R			R	P		R		*Parhabdo-lithus marthae* L.O.D.			
894	20-2, 91–92 cm	R	P			M	M	M		M		R	R	M							
896	20,CC	B																			
896	21-1, 77–78 cm	B																			
897	21-2, 8 cm	B																			
905	21,CC, 25–27 cm	B																			
905	22-1, 21–22 cm	C	G	C		M	V	M		M	R	M	M	M	R						
905	22-1, 35–36 cm	R	G	F		M	M	M		M	R	M	F	M	R					*Parhabdo-lithus liasicus* Zone	Sinemurian
906	22-1, 62–63 cm	R	M	C		M	M	M		M	R	C	F	M	M						
906	22-1, 95–98 cm	R	P	M		M	M	R		F	R	M	R	M			R				
907	22-2, 31–32 cm	F	M	A		M	C	M		M		C	F	M							
907	22-2, 54–55 cm	R	P	A		M	M	M		M		C	R	M	M						
908	22-2, 145–146 cm	R	P	F		F	M	F		F		M	R	M	R						
908	22-3, 4–5 cm	R	P	M		F	C			F		M	F	F	R						
915	23-1, 45–47 cm	F	M	M		M	C	M		M	R	M		M	R						
915	23-1, 87–88 cm	R	P	C		M	M	F		M	R	M	R	F	P						
916	23-2, 13–14 cm	F	M	V		M	C	M		M	P	C	R	M	F						
916	23-2, 34–35 cm	F	P	C		M	C	M		F	P	C	R	F							
[a]925	24-1, 141–142 cm	B																			Indeterminate

Note: * indicates a limestone fracture section; E′ = essentially barren; B′ = barren (for fracture sections only). For other sections, A = abundant; V = very common; C = common; M = moderately common; F = few; R = rare; P = present. For preservation, G = good, M = moderate; P = poor.

[a] The following samples were also found to be barren in Hole 547B (core-section, interval in cm): 24,CC; 25-1, 15–16; 25,CC; 26-1, 14–15; 26-4, 23–24; 27-1, 114–115; 27-4, 59–60; 28,CC; 29-1, 113–114; 29-2, 18–19.

Sinemurian–early Pliensbachian *C. crassus* Zone from the FOD of *C. crassus* to the FOD of *Axopodorhabdus cylindratus*. Table 4 shows these zones for the Lower Jurassic of Hole 547B (Cores 15 to 23) along with the datum levels of Hamilton (1977, 1979, 1982). *A. cylindratus* is not present, and thus the upper boundary of the *C. crassus* Zone is not recognized.

The FOD of *C. crassus* and the consistent appearance of *P. marthae* in Hole 547B agree with Hamilton's (1982) zonal scheme, which placed the lower boundary of the *C. crassus* Zone in the uppermost Sinemurian, just below the Sinemurian/Pliensbachian boundary.

Lower Middle Jurassic (Hole 547B)

The age of the overlying lower Middle Jurassic section of Cores 547B-8 to 547B-14 can be determined by one of several different age schemes. Three possibilities are (1) an early Pliensbachian–Aalenian to late Bajocian age, (2) a late Bajocian–early Bathonian age (both based upon the ranges of *Ellipsagelosphaera crucicentralis* and *Hexalithus* sp. cf. *H. magharensis*); and (3) an early Pliensbachian–Aalenian age based upon the lowest occurrence of *Axopodorhabdus cylindratus* (see Fig. 3).

1. Thierstein (1976) and Medd (1982) place the lowest appearance of *E. crucicentralis* in the lower Pliensbachian and Aalenian, respectively. In the Hole 547B samples studied, the species does not occur with *Parhabdolithus liasicus* and *Crucirhabdus primulus*, which Hamilton (1977, 1979, and 1982) considered to be lower Pliensbachian. If *E. crucicentralis* does range into the lower Pliensbachian sediments at this site, it lies stratigraphically above the interval containing *P. liasicus* and *C. primulus*.

The highest occurrence of *H.* sp. cf. *H. magharensis* may be useful in delineating the upper age limit of the interval. Moshkovitz and Ehrlich (1976) report the occurrence of *H. magharensis* from only two localities: Israel (in outcrop) and the Sinai (in well cuttings). They assign it a range of middle to upper Bajocian (Fig. 3). However, Maync (1966 in Moshkovitz and Ehrlich, 1976) reports the taxon in upper Lias well cuttings from the Sinai.

Thus a Pliensbachian–Aalenian lowest occurrence is possible for *H. magharensis;* this would also coincide with the first appearance of *E. crucicentralis* as reported by Thierstein (1976) and Medd (1982).

2. Hamilton (1979) and Grün and Zweili (1980) place the lowest occurrence of *E. crucicentralis* in the lower Bathonian, not the lower Pliensbachian–Aalenian. If this first appearance is accepted, a possible overlap of the ranges of *E. crucicentralis* and *H.* sp. cf. *H. magharensis* could narrow the age range of the interval from Cores 547B-8 to 547B-14 to the late Bajocian–early Bathonian.

Thus, two age ranges may be determined for this interval using the same taxa as biostratigraphic indicators. Such discrepancies occur when different first and/or last appearances are used.

3. The absence of *A. cylindratus* from Hole 547B, although it is observed at Site 545 about 13 km away, suggests another possible age interpretation for this interval. The species may be absent because it was not preserved, because of paleoecologic restrictions, or because of age considerations. The first two possibilities seem unlikely. Even with poor preservation, as in Hole 547B, the distinctive podorhabdid rim should be present, but these rims are not found. Paleoecologic restrictions at Site 547 should also operate at nearby Site 545. Thus it appears that an age difference could explain the absence of *A. cylindratus* in Hole 547B and its presence in Hole 545; if so, the Jurassic interval at Hole 545 is younger than that at Hole 547B—that is, it was deposited after the appearance of *A. cylindratus*. (The possibility that the interval in Hole 547B was deposited after the extinction of *A. cylindratus* is quite remote, because most au-

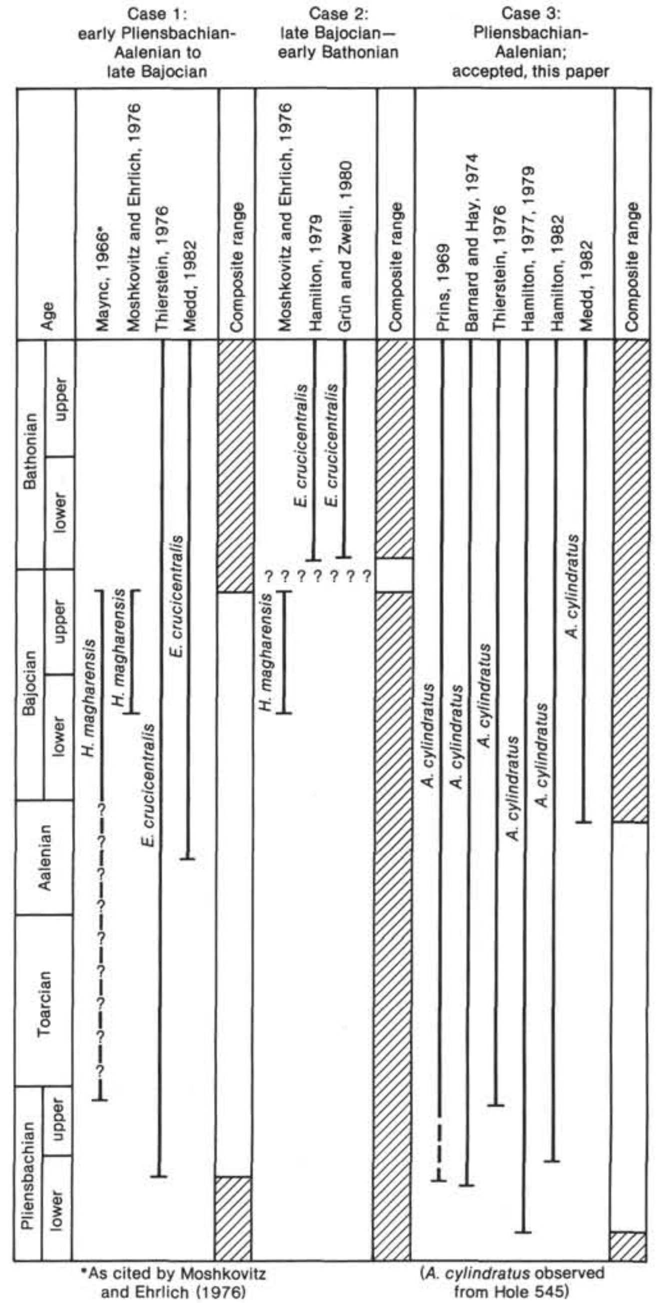

Figure 3. Possible Jurassic age ranges for Hole 547B (Cores 8–14).

thors [e.g., Barnard and Hay, 1974; Thierstein, 1976; Medd, 1982] place the last appearance of this taxon in the uppermost Oxfordian–Kimmeridgian. An upper Jurassic assemblage is not recognized in the interval.)

The lowest occurrence of *A. cylindratus* has been placed between the lower Pliensbachian and Aalenian (Prins, 1969; Barnard and Hay, 1974; Thierstein, 1976; Hamilton, 1977, 1979; Medd, 1982) (see Fig. 3). Among these authors, Barnard and Hay (1974) and Hamilton (1977, 1979) suggest a first occurrence datum for *A. cylindratus* in the lower Pliensbachian. *A. cylindratus* does not, as has been noted, appear at all in the Jurassic of Hole 547B. A problem is created by the fact that *Crucirhabdus primulus*, which occurs from Core 15 down, does not appear in Cores 8–14. If Cores 8–14 are above the last appearance of *C. primulus*, they would, according to the scheme of Hamilton (1977, 1979), be upper Pliensbachian. I believe this last appearance datum for *C. primulus* can be disregarded here because the taxon was not observed in the interval and does not aid in its biostratigraphic zonation, and that even though the lower boundary of Cores 8-14 lies stratigraphically above the lower Pliensbachian to which Cores 15-20 have been assigned, it may still be within the lower Pliensbachian, specifically below the first appearance of *A. cylindratus* and above the last occurrence datum of *P. liasicus* (Hamilton, 1979, 1982; Table 4). This assignment would place the age from early Pliensbachian to Aalenian.

Which of these 3 ranges appears most likely? The first two age ranges, those based upon *H.* sp. cf. *H. magharensis* are questionable for two reasons: (1) the species of *Hexalithus* observed is only conferred to *H. magharensis* and not definitely identified; and (2) there is little information available on the stratigraphic distribution of *H. magharensis*, which has been reported from only two locations. In light of our present information, it appears that the third age range, early Pliensbachian to Aalenian, based upon the absence of *A. cylindratus* from Hole 547B, is the most likely for Cores 8–14.

Lower Middle Jurassic (Hole 545)

The overlapping ranges of *A. cylindratus* and *E. crucicentralis* are used to establish an age range for the Jurassic at Site 545 (Cores 68 to 75). Both of these taxa are present in the late Pliensbachian–early Bathonian to Oxfordian–middle Kimmeridgian. The large variations in age within the lower and upper boundaries of the interval are the result of different first and last occurrences reported by various authors. The authors from whose studies this range of ages was compiled are Prins (1969), Barnard and Hay (1974), Thierstein (1976), Hamilton (1977, 1979), Grün and Zweili (1980), and Medd (1982).

Upper Jurassic (Hole 547B)

The Upper Jurassic interval of Hole 547B (Section 547B-6-4 to Core 547B-7) ranges in age from the Kimmeridgian to the Tithonian. This age is based upon the absence of Lower Cretaceous nannofossils, the presence of *Cyclagelosphaera deflandrei* (Callovian–Lower Cretaceous; Thierstein, 1976; Medd, 1982), the exclusion of *Crepidolithus crassus* (highest occurrence Kimmeridgian; Amezieux, 1972; Barnard and Hay, 1974; Medd, 1982), and the absence of other taxa characteristic of a Bathonian–lower Kimmeridgian assemblage.

A single specimen of *Stephanolithion bigotii* was recognized in Sample 547B-7-2, 35–36 cm, but is considered to be reworked from older sediments and probably has a foreign source, because no *S. bigotii* were found in sediments between Cores 7 and 8, nor are strata containing characteristic Bathonian to lower Kimmeridgian nannofossil assemblages (*Stephanolithion* plexus) present. *Stephanolithion bigotii*, the youngest Jurassic member of the genus, is generally thought to range into the lower Kimmeridgian (Rood and Barnard, 1972; Barnard and Hay, 1974; Medd, 1982). Its absence, other than this one specimen, is considered evidence that Cores 6 and 7 are younger than lower Kimmeridgian.

TAXONOMIC NOTES

The following is a discussion of some taxa examined during the Jurassic nannofossil investigation. Included here are two new genera which have been described from the Lower Jurassic of Hole 547B (Wiegand, in press).

Genus *CALCIVASCULARIS* Wiegand, in press

Diagnosis. A basket-shaped nannolith filled with a core consisting of many radially arranged elements.

Description. The basket is shaped like a laterally compressed, truncated cone. Slightly elliptical in cross section, it flares somewhat distally from the flat, truncated proximal end. The basket appears to be constructed of approximately 12 lath-shaped elements (the exact number is difficult to determine from existing electron micrographs). The laths are essentially rectangular in shape, although a few widen toward the distal end to accommodate the geometry of the basket. The core, housed within the basket, is constructed of several superimposed cycles, each composed of 15–20 elongate radial elements which extend to the periphery of the basket. Each cycle is slightly offset from the others. The overall appearance of the core is that of a stack of wagon wheels with spokes but no rims, the spokes of each wheel being slightly offset from the others in the stack.

Remarks. At present, this is a monotypic genus. *Calcivascularis* appears similar to *Conusphaera* (Trejo, 1969), especially when viewed in the light microscope. Both genera are shaped like a truncated cone and have elongate, rectangular outer cover laths (or plates) that appear as lamellae when viewed in cross-polarized light. When these laths are absent, the central structure of the two genera may most easily be observed on the scanning electron microscope, which reveals the primary difference between them. *Calcivascularis* has a stack of offset radial spokes composing the core, whereas *Conusphaera* has two concentric sets of elongate, flat laths radially arranged and twisted in a spiral about the center of the nannofossil. The lath-covered basket common to *Calcivascularis* and *Conusphaera* appears to have originated at least by the Late Triassic, as evidenced by *Conusphaera zlambachensis* Moshkovitz, 1982 (= *Eoconusphaera tollmanniae* Jafar, 1983). *Calcivascularis* and *Conusphaera* appear related; only the central structure varies between them.

Calcivascularis is similar to *Calcicalathina* (Thierstein, 1971) in that both have an elliptical basket filled with calcite crystals and a flat or nearly flat proximal side. The differences between the two genera are: (1) *Calcivascularis* has radial elements stacked upon one another within the basket whereas *Calcicalathina* is filled with what appear to be randomly oriented crystals; (2) *Calcicalathina*'s core elements extend beyond the distal margin whereas the core of *Calcivascularis* can be either protruding or housed entirely within the basket. The known ranges of the nannofossils are very different; *Calcivascularis* is found in the Lower Jurassic and *Calcicalathina* occurs only in the Lower Cretaceous.

Calcivascularis jansae Wiegand, in press
(Plate 3, Fig. 4)

Description. A species of *Calcivascularis* having the characteristics of the genus (see above).

Remarks. *C. jansae* is recognized from Samples 547B-23-2, 34–35 cm to 547B-15-1, 2–4 cm. This interval includes the Sinemurian and the lower Pliensbachian. This taxon is generally the most abundant in the assemblage (see Table 4).

Genus *CARINOLITHUS* Prins, 1974

***?Carinolithus* sp.**

These specimens were observed only by light microscopy. Some form of base is present, with a straight central process protruding from it. The central process has a straight, narrow, central canal. The process does not diverge distally as it does in many species in this genus.

Genus *CREPIDOLITHUS* Noël, 1965

***Crepidolithus* sp.**

This group includes poorly preserved specimens of the genus *Crepidolithus*. Investigation by scanning electron microscopy may establish these specimens as *C. crassus*.

Genus *DISCORHABDUS* Noël, 1965

***Discorhabdus* sp.**

The coccoliths are circular in shape with from 25–30 wedge-shaped elements radially arranged. The diameter ranges from ~5.5 to 7 μm. The central area appears larger than that of *Bidiscus ignotus*, with no stem observed. The specimens were observed only in the light microscope.

Genus *ELLIPSAGELOSPHAERA* Noël, 1965

***Ellipsagelosphaera* sp.**

This group includes specimens that have a large, open, central area. The specimens may be *E. crucicentralis* with the cruciform structure dissolved or broken out.

Genus *HEXALITHUS* Gardet, 1955

***Hexalithus* sp. cf. *H. magharensis* Moshkovitz and Ehrlich, 1976**
(Plate 1, Figs. 1–4)

Remarks. This species of *Hexalithus* differs from the holotype of *H. magharensis* by having a stem protruding from the center of the hexalith. Many specimens examined had processes extending from the hexalith to the stem (Plate 1, Fig. 2). It is not apparent whether these are effects of overgrowth or if they are natural morphologic parts of the coccolith. Until these questions are resolved, the specimens observed in this study are only conferred to *H. magharensis*.

Hexalithus sp. cf. *H. magharensis* is observed in Hole 547B throughout Cores 8 to 12. *Hexalithus magharensis* has been reported from only two localities: the Upper Lias from the Coastal Plain of Israel (Maync, 1966, *in* Moshkovitz and Ehrlich, 1976) and the middle–upper Bajocian from the Sinai (Moshkovitz and Ehrlich, 1976).

Genus *ORTHOGONOIDES* Wiegand, in press

Diagnosis. Nannolith with six orthogonal rays.

Description. A simple construction of six straight rays joined orthogonally much like a child's jack.

Remarks. The Tertiary genus *Imperiaster* (Martini, 1970) is similar to *Orthogonoides* in that both have six rays. The differences between the genera are: (1) *Imperiaster* has a cylindrical body with six rays arranged as two superposed triplets, where the angle between successive rays is 60°, whereas *Orthogonoides* has six rays, each 90° to the other; (2) the central area of *Imperiaster* is perforated with holes relating to grooves on the inner portion of the rays, while *Orthogonoides* has no apparent ornamentation; (3) *Imperiaster* is dark in cross-polarized light when observed resting in certain orientations, whereas *Orthogonoides* is birefringent in all orientations observed. The known ranges of the two nannofossils are very different since *Orthogonoides* occurs in the Lower Jurassic and *Imperiaster* is found in the lower Eocene.

***Orthogonoides hamiltoniae* Wiegand, in press**
(Plate 3, Fig. 5)

Description. A species of *Orthogonoides* with six straight orthogonally joined rays. Bifurcations appear at the ends of the rays.

Remarks. With overgrowth or dissolution the bifurcated ends may be obscured or not present. *Orthogonoides hamiltoniae* is observed in Samples 547B-23-2, 34–35 cm to 547B-15-1, 2–4 cm, ranging in age from Sinemurian to early Pliensbachian.

Genus *PALEOPONTOSPHAERA* Noël, 1965

***Paleopontosphaera* sp. cf. *P. veterna* Prins ex Rood, Hay, and Barnard, 1973**

Remarks. The specimens found in this study are larger than those described by Rood, Hay, and Barnard; lengths range from 7 to 8 μm and widths from 4 to 5 μm. No central cross is present, as is observed in the holotype of *P. veterna*. Specimens were viewed only by light microscopy in this study.

Genus *TUBIRHABDUS* Prins ex Rood, Hay, and Barnard, 1973

***?Tubirhabdus* sp.**

This group is recognized only in the light microscope. The rim appears similar to that of the genus *Tubirhabdus*, but no stem or central process is observed. No well-defined central area is found. The average length is ~4 μm and the average width is ~1.5 μm.

SUMMARY AND CONCLUSIONS

The Jurassic sediments recovered during Leg 79 are of Early to Late Jurassic age. Only the Lower Jurassic material (Hole 547B) can be placed within an established biostratigraphic scheme. Most of the Jurassic coccolith assemblages examined were of low diversity and poor to moderate preservation. This low diversity makes age determination difficult for much of the Jurassic. The other intervals are placed within broad age ranges, because no zonal markers were observed. All but one of the Jurassic intervals, that of Hole 544A, can be placed in relative order according to age (Fig. 2): the Lower Jurassic of Hole 547B; the lower Middle Jurassic of Hole 547B; the lower Middle Jurassic Hole 545; and the Upper Jurassic of Hole 547B. The interval found within Hole 544A could range from the Lower to Upper Jurassic, since few coccoliths are found that would place age restraints on the limestones.

Few studies near the Leg 79 drilling location have reported *in situ* Jurassic nannofossils. Site 416 (Hole 416A) (Fig. 1) penetrated approximately 45 m of the uppermost Jurassic (Čepek et al., 1980), but no other DSDP cruises in the area have recovered Jurassic coccoliths. A biostratigraphic study of Lower and Middle Jurassic nannofossils in Portugal (Fig. 1) has been conducted by Hamilton (1977, 1979). The Lower Jurassic schemes of Hamilton (1977, 1979, 1982) are used herein.

The Sinemurian and early Pliensbachian sediments of Hole 547B are of the greatest interest. They contain the oldest nannofossils recovered by deep sea drilling. Two new taxa described from this interval are *Calcivascularis jansae* and *Orthogonoides hamiltoniae*. Lower Jurassic calcareous nannofossil biostratigraphy is not well documented, since few studies have been made on coccoliths of that age.

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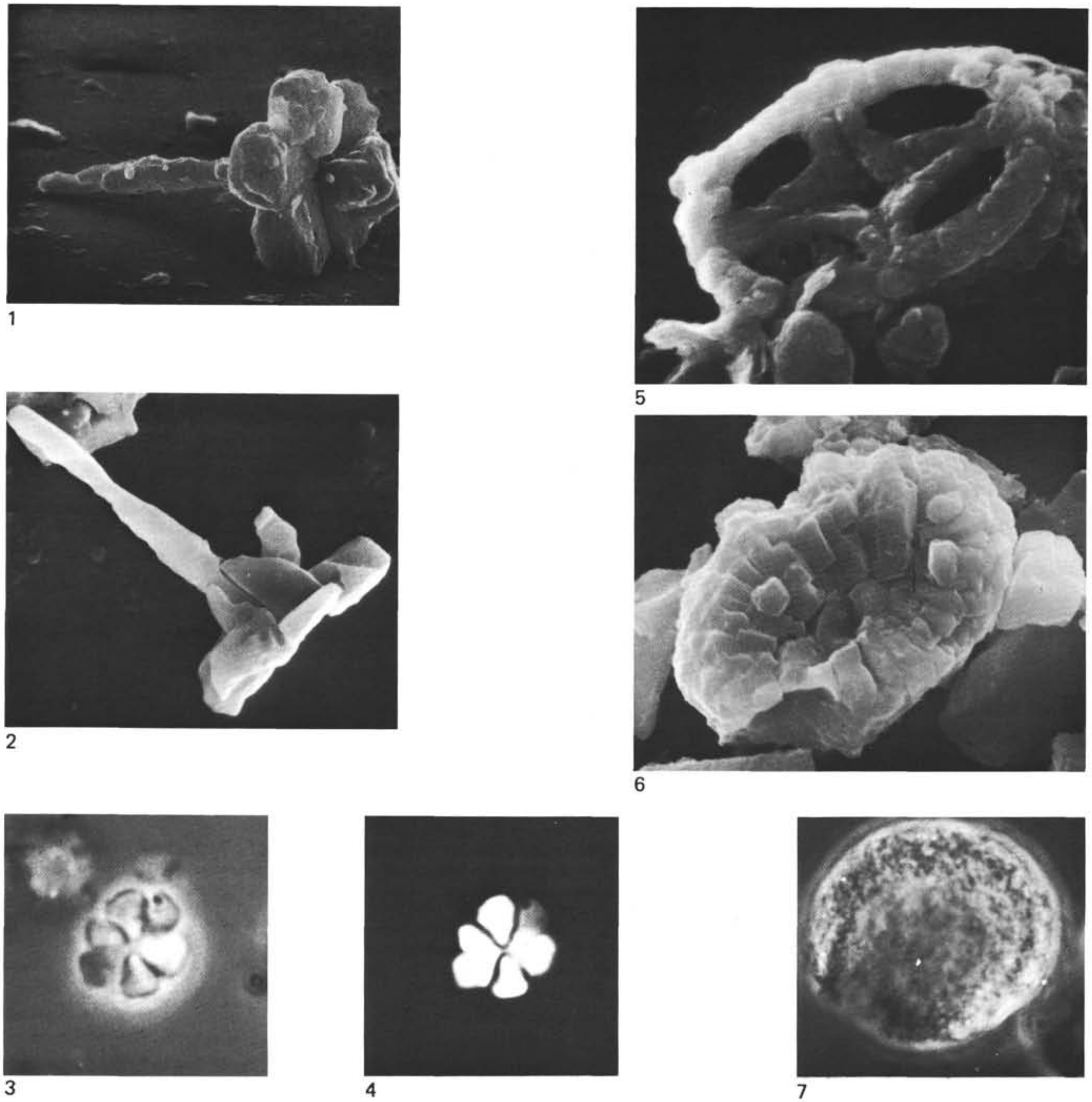


Plate 1. Lower–Middle Jurassic, SEM unless noted otherwise. **1–4.** *Hexalithus* sp. cf. *H. magharensis*, Sample 547B-8-2, 118–119 cm, (1) ×7350, (2) ×5650, (3–4) ×3100 (3, phase contrast; 4, cross-polarized). **5.** *Staurorhabdus quadriacullus*, ×19,100, Sinemurian Sample 547B-22-2, 54–55 cm. **6.** *Crepidolithus crassus*, ×6300, Sample 547B-8-2, 118–119 cm. **7.** *Schizosphaerella punctulata*, ×2550 phase contrast, Sinemurian Sample 547B-22-1, 35–36 cm.

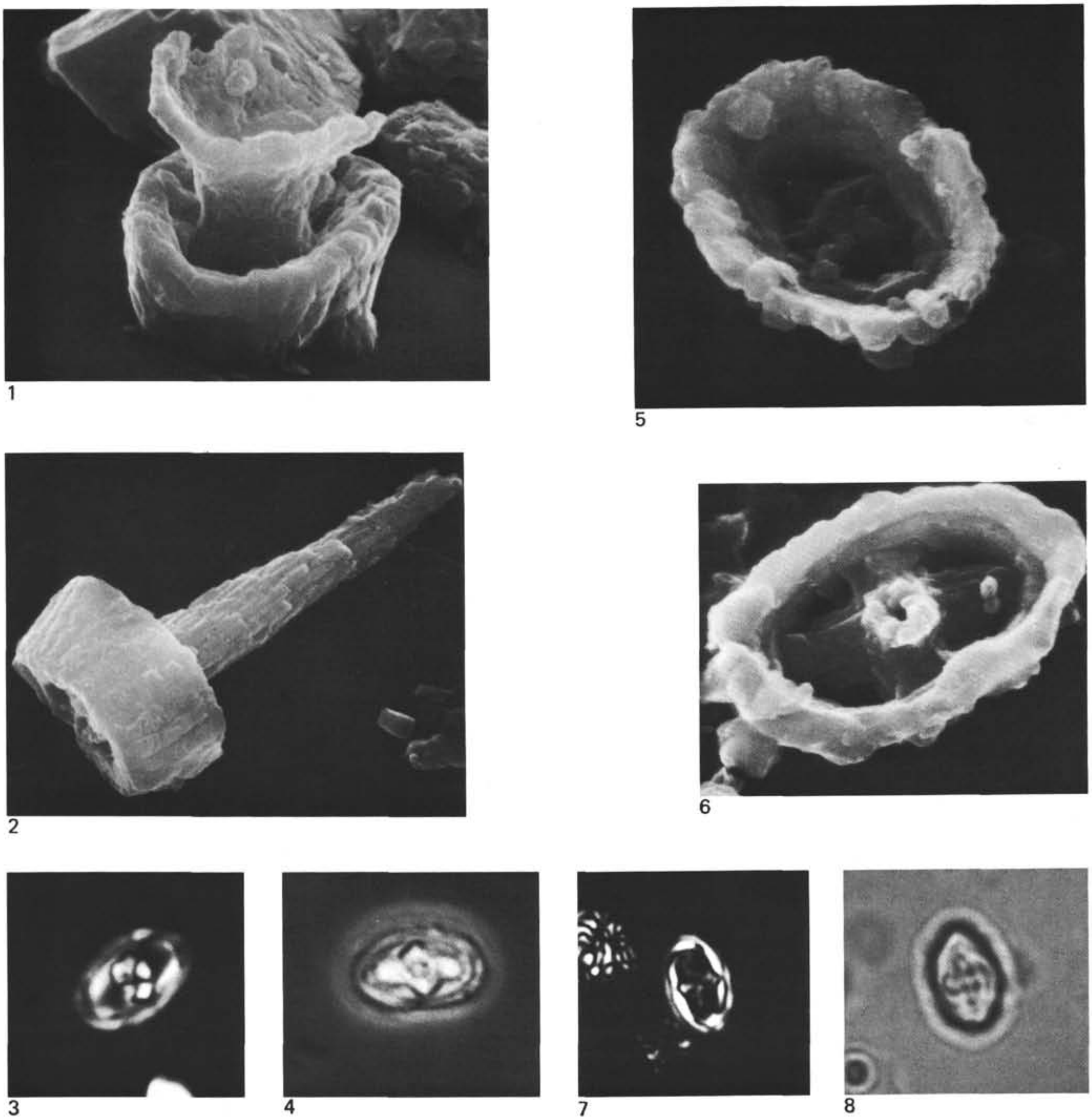
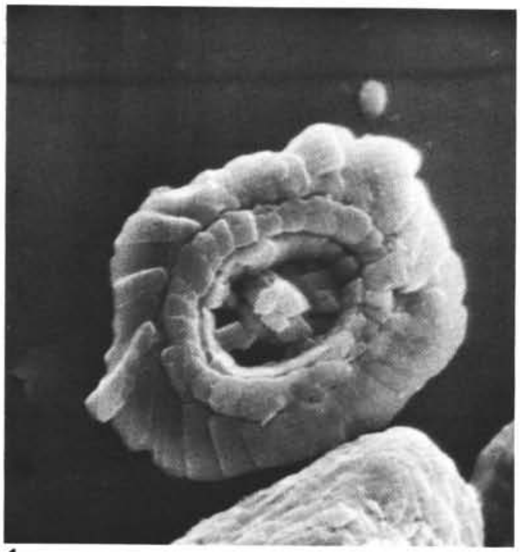


Plate 2. Lower Pliensbachian to Sinemurian, SEM unless noted otherwise. **1.** *Tubirhabdus patulus*, ×14,700, lower Pliensbachian Sample 547B-15-2, 24–25 cm. **2–4.** *Parhabdolithus liasicus*, (2) ×10,150, lower Pliensbachian Sample 547B-15-2, 24–25 cm, (3) ×3200 cross-polarized, Sinemurian Sample 547B-22-1, 35–36 cm, (4) ×2850 phase contrast, lower Pliensbachian Sample 547B-18-1, 103–104 cm. **5.** *Crepidolithus crucifer*, ×14,200, Sinemurian Sample 547B-22-2, 54–55 cm. **6–8.** *Crucirhabdus primulus*, (6) ×17,300, Sinemurian Sample 547B-22-2, 54–55 cm, (7–8) Sinemurian Sample 547B-22-1, 35–36 cm, (7, ×3200 cross-polarized; 8, ×3500 transmitted).



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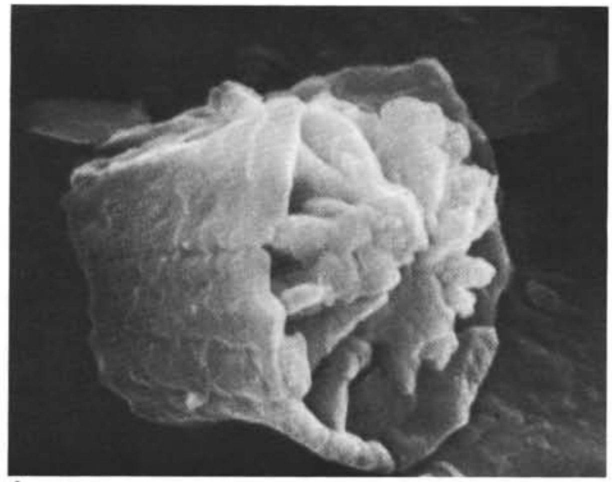

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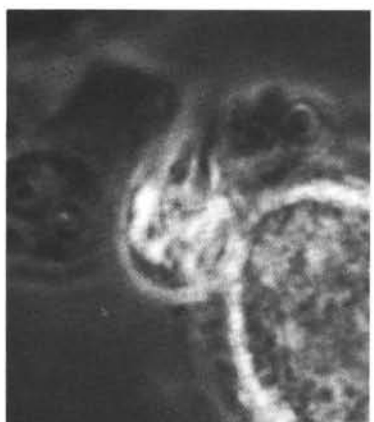

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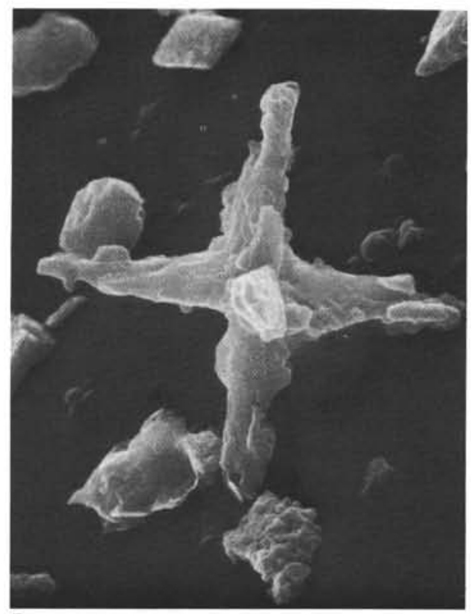

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Plate 3. Lower Middle Jurassic, SEM unless noted otherwise. **1.** *Ellipsagelosphaera crucicentralis*, ×7150, Sample 547B-8-2, 118–119 cm. **2.** *Zeugrhabdotus erectus*, ×22,550, Sinemurian Sample 547B-22-2, 54–55 cm. **3.** *Parhabdolithus marthae*, ×3000 phase contrast, Sinemurian Sample 547B-22-1, 35–36 cm. **4–5.** Lower Pliensbachian Sample 547B-15-2, 24–25 cm, (4) *Calcivascularis jansae*, ×19,150, (5) *Orthogonoides hamiltoniae*, ×5150.