23. JURASSIC CALCAREOUS NANNOFOSSIL ZONATION, AN OVERVIEW WITH NEW EVIDENCE FROM DEEP SEA DRILLING PROJECT SITE 534[1]

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ABSTRACT

A zonation is presented for the oceanic late Middle Jurassic to Late Jurassic of the Atlantic Ocean. The oldest zone, the *Stephenolithion bigotii* Zone (subdivided into a *Stephanolithion hexum* Subzone and a *Cyclagelosphaera margerelii* Subzone), is middle Callovian to early Oxfordian. The *Vagalapilla stradneri* Zone is middle Oxfordian to Kimmeridgian. The *Conusphaera mexicana* Zone, subdivided into a lower *Hexapodorhabdus cuvillieri* Subzone and a *Polycostella beckmannii* Subzone, is the latest Kimmeridgian to Tithonian. Direct correlation of this zonation with the boreal zonation established for Britain and northern France (Barnard and Hay, 1974; Medd, 1982; Hamilton, 1982) is difficult because of poor preservation resulting in low diversity for the cored section at Site 534 and a lack of Tithonian marker species in the boreal realm.

Correlations based on dinoflagellates and on nannofossils with stratotype sections (or regions) give somewhat different results. Dinoflagellates give generally younger ages, especially for the Oxfordian to Kimmeridgian part of the recovered section, than do nannofossils.

INTRODUCTION

Calcareous nannofossils of the Jurassic have received less study than those of any other time period for two main reasons. First, preservation of calcareous nannofossils is poor in strongly lithified pelagic limestones. Second, suitable sections with a considerable pelagic component are not widely exposed on land nor have they been extensively recovered in the ocean basins.

Early taxonomic studies of Jurassic coccoliths by Deflandre (1939), Deflandre and Fert (1954) and Noël (1957, 1959) laid the foundation for later biostratigraphic work. Subsequent taxonomic studies of Middle and Late Jurassic coccoliths, largely using the electron microscope, greatly increased our knowledge of Jurassic nannofossils and made more refined biostratigraphic investigation possible (Grün and Zweili, 1980; Keupp, 1976, 1977; Medd, 1971, 1979; Noël, 1965, 1973; Reinhardt, 1964, 1965, 1966; Rood and Barnard 1972; Rood, Hay, and Barnard, 1971, 1973; Stradner, 1963; Trejo, 1961; Wilcoxon, 1972; and Wise and Wind, 1976).

The earliest calcareous nannofossil biostratigraphy was published by Stradner (1963) before more detailed taxonomic studies were available. More elaborate biostratigraphic schemes for the Middle and Late Jurassic were proposed by Amezieux (1972), Barnard and Hay (1974), Hamilton (1977, 1978, 1979, 1982), Medd (1982), Moshkovitz and Ehrlich (1976), Thierstein (1975, 1976), and Worsley (1971). The fact that so many different zonations have been introduced for the Jurassic is indicative that none has found general acceptance. The zonation proposed in this report will probably follow the others on a path to oblivion as our knowledge of Jurassic nannofossils increases. For the present time, however, it seems to provide a useful biostratigraphic framework, and it can be used in the study of Jurassic samples in the light microscope.

But why not use one of the existing zonations instead of proposing yet another zonation for the Middle and Late Jurassic of the western Atlantic Ocean? Two reasons can be given. First, many of the more delicate marker species present in epicontinental deposits of Britain and northern France have not been found in the hemipelagic and pelagic sediments of the Blake-Bahama Basin. Second, the uppermost Jurassic and lowermost Cretaceous deposits on land either lack well preserved and abundant coccoliths (e.g., in Britain, northern and southeastern France) or are of a brief stratigraphic extent (e.g., Tithonian of southern Germany). Thus a slightly coarser zonation is proposed for the upper Middle Jurassic to middle Upper Jurassic interval and a more detailed zonation is suggested for the uppermost Jurassic based on pelagic sections. However, correlation of the zonation for the uppermost Jurassic with ammonite zonations and classical stages is somewhat uncertain. Such uncertainty about the correlation of Late Jurassic nannofossil biostratigraphic units with land stages also characterizes earlier studies of pelagic sections recovered by DSDP (Bukry and Bramlette, 1969; Worsley, 1971; Wilcoxon, 1972; Wise and Wind, 1976; Thierstein, 1971, 1975, 1976; Wind, 1978; Čepek, 1978; and Čepek et al., 1980). We propose a nannofossil zonation for the latest Middle Jurassic and the Late Jurassic; it has a biostratigraphic resolution of 2 to 6 m.y. Thus calcareous nannofossil zones are somewhat shorter than stages but much longer than ammonite zones. There are two zones per stage at best. We shall compare our nannofossil zonation

[1] Sheridan, R. E., Gradstein, F. M., et al., *Init. Repts. DSDP*, 76: Washington (U.S. Govt. Printing Office).

with other zonations (Barnard and Hay, 1974; Thierstein, 1976; Medd, 1982; and Hamilton, 1982) and attempt to relate it to the classical land stages. Detailed accounts of the species observed at Site 534, nannofossil preservation, and some observations on paleobiogeography evolution are presented in a separate chapter (Roth, this volume).

Nannofossil Zonation for the Middle Callovian to Tithonian

The light microscope is sufficient to recognize all major marker species used in this zonation. All of the marker species have been used in zonal schemes of other authors. The proposed zonation is outlined in Figure 1. We discuss the various zones briefly here. Initial shipboard studies of the nannofossils in these cores were performed by P. H. Roth (Cores 91 through 122) and D. K. Watkins and J. L. Bowdler (Cores 123–128, during the extension of Leg 76). A. W. Medd scrutinized samples from the whole interval (Cores 80 through 127) in a shore-based laboratory study. All studies were done using the light microscope. The zonation used in this report was developed jointly during a postcruise meeting at Lamont by the three co-authors. This zonation is applicable in part to land sections from the Tethyan and Boreal realms, although more refined zonation appears to be possible for particular regions (see Medd, 1982). The following zones from the oldest to the youngest are used.

Stephanolithion bigotii Zone, Stradner, 1963, emend.

Definition. Interval from the first occurrence of *Stephanolithion bigotii* Deflandre to the first occurrence of *Vagalapilla stradneri* (Rood, Hay, and Barnard) (equals *Staurorhabdus magnus* Medd, 1979).

Remarks. In England an interval of similar stratigraphic extent was subdivided into three zones (Medd, 1982). We tentatively subdivide this interval into two subzones but are aware of problems of poor preservation at Site 534 (see Figs. 1 and 2 and Roth, this volume). Barnard and Hay (1974) subdivided this interval into seven zones. Recent studies of the same interval report discrepancies in the ranges of some of the species used by Barnard and Hay (1974) for their very detailed zonation and propose less refined zonations (Medd, 1982; Hamilton, 1982). In the zonation proposed by Hamilton (1982) a *Stephanolithion bigotii* Zone with slightly different boundaries but similar stratigraphic extent is used (Fig. 2).

Stephanolithion hexum Subzone

Definition. Interval from the first occurrence of *Stephanolithion bigotii* Deflandre to the last occurrence of *Stephanolithion hexum* Rood and Barnard.

Remarks. This subzone is based on a rare and fairly delicate species, and it might not always be possible to use it in sections with poorly preserved coccoliths. Even in our section *S. hexum* Rood and Barnard is last encountered just below an interval with very poorly preserved coccoliths, and its range might thus be truncated. As an additional marker, *Ansulosphaera helvetica* Grün and Zweili appears useful; this species does not seem to range above the *S. hexum* Subzone of the *S. bigotii* Zone, although it has only been observed by the original authors and by one of us (see Roth, this volume) in two localities. The base of the range of *Ansulosphaera helvetica* Grün and Zweili seems to lie in the lower Callovian, but it could be older.

Medd (1982) shows the range of *S. hexum* Rood and Barnard to extend as high as the lower Oxfordian *Cardioceras cordatum* Ammonite Zone, but it is only common up to the middle Callovian *Erymnoceras coronatum* Ammonite Zone. Barnard and Hay (1974) and Ham-

Core-section	Zone	Subzones	Occurrence surfaces
91,CC	*Nannoconus colomii*		*Nannoconus colomii* s. str. *Lithraphidites carniolensis*
92-1 96-5	*Conusphaera mexicana*	*Polycostella beckmannii*	*Polycostella beckmannii* Small nannoconids
97-1 101-2		*Hexapodorhabdus cuvillieri*	*Stephanolithion bigotii* *Conusphaera mexicana*
101-3 ▲ 113-1	*Vagalapilla stradneri*		*Vagalapilla stradneri*
114-1 123-2	*Stephanolithion bigotii*	*Cyclagelosphaera margerelii*	
123-3 * 126-4		*Stephanolithion hexum*	*Stephanolithion hexum* *Stephanolithion bigotii*
127-1			

▲ Sporadic occurrence; common occurrence down to Core 105.
* Roth, this volume; Watkins found *S. bigotii* in Core 127.

Figure 1. Middle Callovian to lower Berriasian calcareous nannofossil zonation and occurrence surfaces, Site 534.

Stage	Barnard and Hay (1974)	Medd (1982)	Hamilton (1982)	This chapter	
Berriasian	*N. colomii*	*P. embergeri*	*N. colomii*	*Nannoconus colomii*	
Tithonian	*Parhabdolithus embergeri*		*Conusphaera mexicana*	*Conusphaera mexicana*	*Polycostella beckmannii*
			P. embergeri		*Hexapodor. cuvillieri*
Kimmer-idgian	*Watznaueria communis*	*Polypodorhabdus mandingleyensis*	*Polypodorhabdus madingleyensis*	*Vagalapilla stradneri*	
		S. tortuosus			
Oxfordian	*Vekshinella stradneri*	*E. britannica*			
		Stradnerlithus bifurcatus or *Actinozygus geometricus*			
	A. geometricus	*Stephanolithion bigotii maximus*		*Stephanolithion bigotii*	*Cyclagelosphaera margerelii*
	D. dorsetense				
Callovian	*D. jungii*	*P. rahla*			
	P. rahla	*Stephanolithion bigotii bigotii*	*Stephanolithion bigotii*		*Stephanolithion hexum*
	P. escaigii				
	S. bigotii	*Ellipsagelosphaera lucasii*			
	S. hexum				
Bathonian	*S. speciosum* var. *octum*		*S. speciosum*		

Figure 2. Correlation of calcareous nannofossil zonations by Barnard and Hay (1974), Medd (1982), Hamilton (1982), and the new zonation proposed in this report. (The relationships of these zones with the classical land stages are shown. The correlation is achieved, if possible, by using first and last occurrence surfaces; in some instances the correlation is shown by using the relationship of a particular zone with the classical stages.)

ilton (1982) show ranges for *Stephanolithion hexum* Rood and Barnard that differ from the range shown by Medd (1982). This difference indicates that the ranges of some of the important Jurassic nannofossil species are still not known with certainty. At Site 534 we probably observed the acme of *Stephanolithion hexum* Rood and Barnard.

Cyclagelosphaera margerelii Subzone

Definition. Interval from the last occurrence of *Stephanolithion hexum* Rood and Barnard to the first occurrence of *Vagalapilla stradneri* (Rood, Barnard, and Hay) (equals *Staurorhabdus magnus* Medd, 1979).

Remarks. This is an interval zone, and *Cyclagelosphaera margerelii* Noël is not restricted to this interval nor is it particularly common. In Hole 534A much of this interval contains poorly preserved coccolith assemblages, making it impossible to provide further biostratigraphic refinement. The relationship of this subzone with the zonation of Barnard and Hay (1974), Medd (1982), and Hamilton (1982) is shown in Figure 2.

Vagalapilla stradneri Zone, Barnard and Hay, 1974, emend.

Definition. Interval from the first occurrence of *Vagalapilla stradneri* (Rood, Barnard, and Hay) (equals *Staurorhabdus magnus* Medd, 1979) to the first occurrence of *Conusphaera mexicana* Trejo.

Remarks. Taxonomic problems with the marker species *Vagalapilla stradneri* (Rood, Barnard, and Hay) that has been assigned by various authors to several different genera and species do not diminish the usefulness of this form as a biostratigraphic marker in epicontinental and oceanic sections. As the typical form for this marker we use the specimen illustrated by Barnard and Hay (1974, pl. VI, fig. 8) and assigned to *Vagalapilla stradneri* (Rood, Barnard, and Hay) by Roth (this volume). Medd (1979, 1982) assigns it to *Staurorhabdus magnus* Medd, and Hamilton (1982) to *Staurorhabdus crux* (Deflandre in Deflandre and Fert) Caratini. The last choice of name seems most unfortunate, because the holotype of *S. crux* (Deflandre in Deflandre and Fert) Caratini is probably a Cretaceous specimen reworked into Eocene sediments. It is a name that has been used for too many different coccolith species with a narrow rim and a central cross and is best forgotten, as it has already created enough confusion (see Stafleu et al., 1972, Article 69).

The *Vagalapilla stradneri* Zone correlates with the zone of the same name by Barnard and Hay (1974) but has a slightly younger top. It covers the interval from the upper part of the *Stephanolithion bigotii maximum* Zone and the *Stradnerlithus bifurcatus* or *Actinozygus geometricus* Zone of Medd (1982) and is almost the same age as the *Polypodorhabdus madingleyensis* Zone of Hamilton (1982).

Conusphaera mexicana Zone, Thierstein, 1975

Definition. Interval from the first occurrence of *Conusphaera mexicana* Trejo to the first occurrence of *Nannoconus colomii* (de Lapparent) s. str. and the last occurrence of *Polycostella beckmannii* Thierstein.

Remarks. Small nannoconids, here assigned to *Nannoconus* cf. *dolomiticus* Cita and Pasquare if they are cylindrical in shape and to *Nannoconus* sp. cf. *N. colomii* (de Lapparent) if they are more conical, definitely appear below the base of the *Nannoconus colomii* Zone and the Jurassic/Cretaceous boundary as defined by calpionellids (Remane, this volume) and dinoflagellates (Habib and Drugg, this volume). The first occurrence of *Lithraphidites carniolensis* Deflandre is difficult to determine as *Conusphaera mexicana* Trejo produces numerous elongated laths upon disintegration that closely resemble *Lithraphidites* although they lack the central ridge. The first occurrence of *Rhagodiscus asper* (Stradner) is also close to the upper boundary of the *Conusphaera mexicana* Zone but other similar forms (such as *Ahmuellerella*? *retiformis* Reinhardt) occur in the Upper Jurassic.

Coccolith preservation is not very good in the uppermost part of this zone and in the overlying basal Cretaceous at Site 534, which makes it difficult to determine the exact position of the upper boundary of this zone.

The first occurrence of small specimens of *Parhabdolithus embergeri* (Noël) that have the typical construction described by Wind (1978) is only slightly below the first occurrence of *Conusphaera mexicana* Trejo. This species evolves gradually from a *Zygodiscus* ancestor (from *Z. salillum* [Noël] according to Wind [1978] or *Z. erectus* [Deflandre] according to Thierstein [1976], and it seems a less reliable marker because of different species concepts employed by different authors. *Parhabdolithus embergeri* (Noël) is of small size (7.5–9 μm) throughout most of the *Conusphaera mexicana* Zone and reaches a size of over 12 μm only in the Cretaceous. In the absence of *Conusphaera mexicana* Trejo the first occurrence of typical specimens of *P. embergeri* (Noël) with a thick multicycle rim can be used to locate approximately the base of this interval; it is slightly above the base of typical but small *P. embergeri* (Noël). This zone can be divided into two subzones. However, one of the markers used for the definition of subzones (*Stephanolithion bigotii* Deflandre) is more susceptible to destruction by dissolution and diagenesis; the other one (*Polycostella beckmannii* Thierstein) displays some variation of its first occurrence with respect to the first appearance of *Conusphaera mexicana* Trejo. Thus it might not always be possible to subdivide this zone into the subzones defined as follows.

Hexapodorhabdus cuvillieri Subzone

Definition. Interval from the first occurrence of *Conusphaera mexicana* Trejo to the last occurrence of *Stephanolithion bigotii* Deflandre.

Remarks. The first occurrence of *Polycostella beckmanii* Thierstein and of small primitive nannoconids closely approximates the last occurrence of *Stephanolithion bigotii* Deflandre. These events can be used to define the upper boundary of this subzone. *Hexapodorhabdus cuvillieri* Noël has a much longer range but does not occur much above the top of this subzone.

The first occurrence of *Polycostella beckmannii* Thierstein and of small nannoconids with respect to the first occurrence of *Conusphaera mexicana* Trejo is somewhat variable (see Medd, unpublished data). Further studies seem important to work out the exact sequence of events or possible environmental or preservational controls of the range of these species.

Polycostella beckmannii Subzone

Definition. Interval from the last occurrence of *Stephanolithion bigotii* Deflandre to the first occurrence of *Nannoconus colomii* (de Lapparent) s. str.

Remarks. As just discussed, the subzone is generally characterized by the occurrence of *Polycostella beckmanii* Thierstein, which appears to be restricted to this zone. Primitive nannoconids also occur. *Helenea* sp. cf. *H. chiastia* Worsley occurs throughout most of this zone, and *Cruciellipsis* cf. *cuvillieri* (Manivit) is found in the upper part according to Roth (this volume). Medd proposes a contrasting view on the range of *Cruciellipsis cuvillieri* (Manivit) (unpublished data). The top of this zone is difficult to determine accurately because small nannoconids range throughout the subzone. The first appearance of well developed *Lithraphidites carniolensis* Deflandre and *Rhagodiscus asper* (Stradner) help to define the top of this zone. An increase in size and abundance of nannoconids and the first occurrence of typical *Nannoconus colomii* (de Lapparent) is used to define this boundary. *Nannoconus* sp. cf. *N. colomii* (de Lapparent) is less than 8 μm in length. The typical *Nannoconus colomii* (de Lapparent) s. str. that first appears at the Jurassic/Cretaceous boundary ranges in length from 8 to 20 μm.

RELATIONSHIP OF THE NANNOFOSSIL ZONATION AND CLASSICAL STAGES

The classical European stages for the Jurassic are now well defined in terms of ammonite zones and provide the standard for the stratigraphy and historical geology of the Jurassic. Thus it is useful to relate our zonation to the ammonite zonation and corresponding stages to the extent possible (Fig. 3).

The lowest occurrence of *Stephanolithion bigotii* Deflandre marking the base of the *Stephanolithion bigotii* Zone lies in the *Kosmoceras jasoni* Ammonite Zone (Medd, 1982); the latter marks the lowest ammonite zone of the middle Callovian. The last common occurrence of *Stephanolithion hexum* Rood and Barnard is observed in the middle Callovian *Erymnoceras coronatum* Ammonite Zone, although rare specimens occur throughout the upper Callovian and lower Oxfordian of England. We tentatively correlate the top of the *Stephanolithion hexum* Subzone with the boundary between the

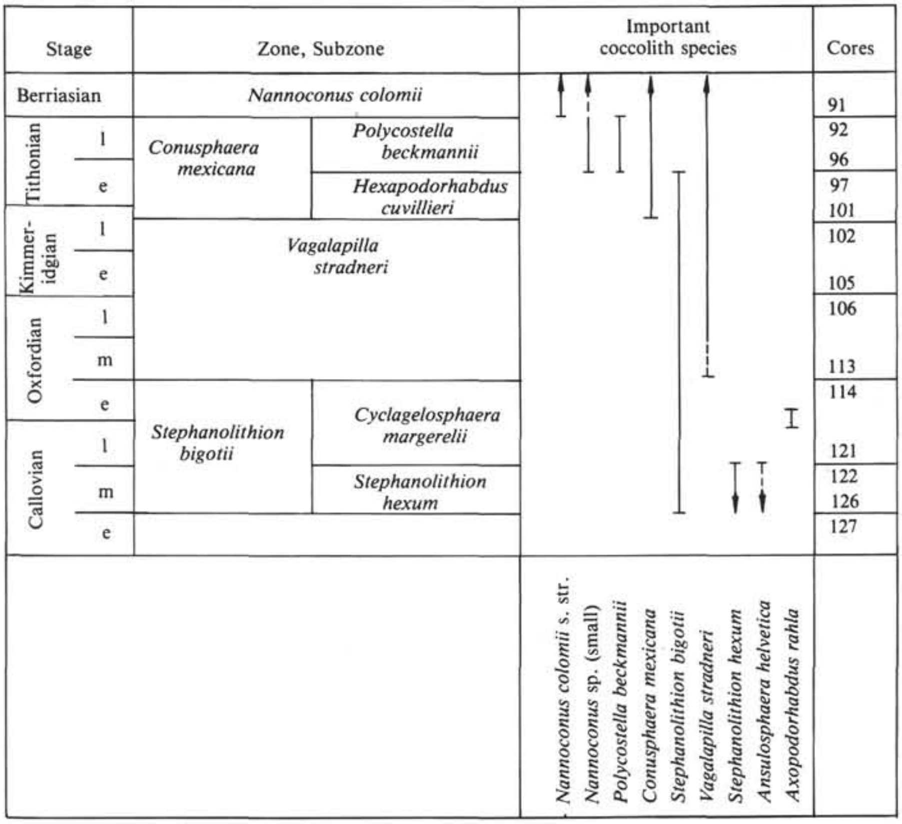

Figure 3. Calcareous nannofossil zonation proposed in this report and ranges of important marker species, Site 534.

middle and the late Callovian. The Callovian/Oxfordian boundary lies within the *Cyclagelosphaera margerelii* Subzone of the *Stephanolithion bigotii* Zone. Evidence from dinoflagellates (Habib and Drugg, this volume) would favor the position of the Callovian/Oxfordian boundary between Cores 121 and 122. The occurrence of a single specimen of *Axopodorhabdus rahla* (Noël) in Core 118 is indicative of upper Callovian to lower Oxfordian. The increase in abundance of *Polypodorhabdus escaigii* Noël is also an indication of the proximity of the Callovian/Oxfordian boundary near Core 119. *Stephanolithion bigotii maximum* Medd, which first appears in the lowermost Oxfordian of England, was not observed at Site 534.

The first occurrence of *Vagalapilla stradneri* (Rood, Barnard, and Hay) is difficult to determine at Site 534 because of poor preservation. In Britain *Vagalapilla stradneri* (Rood, Barnard, and Hay) (equals *Staurorhabdus magnus* Medd, 1979 or *Staurolithites crux* [Deflandre in Deflandre and Fert] Caratini of Hamilton, 1982) first occurs at the base of the *Cardioceras densiplicatum* Ammonite Zone, that is, the base of the middle Oxfordian. In Hole 534A common and well developed typical specimens of *Vagalapilla stradneri* (Rood, Barnard, and Hay) first appear in Core 105, Section 2. Rare and scattered occurrences of *Vagalapilla stradneri* (Rood, Barnard, and Hay) were found in Cores 110 and 113, Section 1 by Roth (see Roth, this volume). A compilation of sedimentation rates based on coccoliths (Fig. 4) and dinoflagellates (Fig. 5) shows that it is unlikely that the base of the continuous range of *Vagalapilla stradneri* (Rood, Barnard, and Hay) in Core 105 marks the boundary between the lower and middle Oxfordian. This would result in a sedimentation rate for the interval between the last occurrence of *Stephanolithion hexum* Rood and Barnard and the first occurrence of *Vagalapilla stradneri* (Rood, Barnard, and Hay) that is almost twice as high as the average sedimentation rate for the middle Callovian to Tithonian interval (using the scale of Van Hinte, 1976). If the base of the *Vagalapilla stradneri* Zone is located in Core 113, sedimentation rates are more consistent, and age assignments based on coccoliths are in better agreement with age determinations based on dinoflagellates. Cores 106 through 109 contain very poorly preserved coccolith assemblages, and it is possible or even likely that *Vagalapilla stradneri* (Rood, Barnard, and Hay) is missing because of species preferential dissolution. Scattered occurrences of this species in Cores 110 to 113 would corroborate this assumption. Unfortunately calcareous nannofossils in the cores below Core 113 (Cores 114–116) are also poorly preserved, and the oldest specimens of *Vagalapilla stradneri* (Rood, Barnard, and Hay) might not have survived dissolution and diagenesis. Thus we are uncertain about the first occurrence of *Vagalapilla stradneri* (Rood, Barnard, and Hay) at Site 534 and its relationship to the classical stages. Sedimentation rates based on dinoflagellate ranges are reasonable throughout the Upper Ju-

	Occurrence surfaces (T = last occurrence, B = first occurrence)	Core-section	Age (m.y.) (Van Hinte, 1976)	Sedimentation rate (1) (m/m.y.)	Sedimentation rate (2) (m/m.y.)
B	*Nannoconus colomii*	91,CC	135	7	7
T	*Stephanolithion bigotii*	97-1	141	22	22
B	*Conusphaera mexicana*	100-1	142	11	
1)[a] B	*Vagalapilla stradneri*	105-2	147		22
2) B	*Vagalapilla stradneri*	113-1	147	36	21
T	*Stephanolithion hexum*	123-3	151	13	13
B	*Stephanolithion bigotii*	126-4	153		

[a] Explanation: 1) First occurrence of *Vagalapilla stradneri* in Core 105, Section 2. 2) First occurrence of *Vagalapilla stradneri* in Core 113, Section 1.

Figure 4. Sedimentation rates at Site 534 calculated by estimating absolute ages for important nannofossil occurrences surfaces, using the time scale of Van Hinte (1976). (Two different first occurrence surfaces for *Vagalapilla stradneri* are used, namely a first occurrence in Core 105 and a first occurrence in Core 113. The second produces more regular sedimentation rates and is preferred. The mean sedimentation rate ≃16 m/m.y.)

Stage boundary	Core-Section	Age (m.y.) (Van Hinte, 1976)	Sedimentation rate (m/m.y.)
Berriasian/Tithonian	91-2/91-3	135	19
Tithonian/Kimmeridgian	104,CC/105-1	141	34
Kimmeridgian/Oxfordian	111-1/112-1	143	14
Oxfordian/Callovian	121-2/122-1	149	11
middle Callovian	127-4	153	

Figure 5. Sedimentation rates at Site 534 using the stage boundaries as determined by dinoflagellate stratigraphy (Habib and Drugg, this volume) and radiometric ages estimated by Van Hinte (1976). (The mean sedimentation rate ≃16 m/m.y.)

rassic, with the exception of the Kimmeridgian (*sensu gallico*), which seems to be too short in Van Hinte's time scale. However, this problem has only been recognized at Site 534, where sedimentation by turbidity currents was important, and changes in sedimentation rates might be responsible for this anomaly.

The next biohorizon that can be correlated with the stratigraphic land record is the first occurrence of *Conusphaera mexicana* Trejo. Thierstein (1975) places it within or below the lower Tithonian (below the *Subplanites contiguus* Ammonite Zone). The lack of *Conusphaera mexicana* Trejo in the lower Tithonian Solnhofen Limestone of Franconia (Keupp, 1977) is probably due to ecological exclusion of this form from the restricted environment. *Conusphaera mexicana* Trejo was found in the upper Tithonian Oberalm beds (Eastern Alps) by Flügel and Keupp (1979) and in the Diaspiri Formation (Kimmeridgian to Tithonian) of the northern Appennines by Canuti and Marcucci (1969), illustrated as *Rhabdosphaera* sp. 1, as well as in southern France by Thierstein (1975). Thus *Conusphaera mexicana* Trejo occurs widely in Tithonian beds, although we are not absolutely certain where in the uppermost Kimmeridgian or lower Tithonian it first appears.

The last occurrence of *Stephanolithion bigotii* Deflandre in England is in the lower Kimmeridgian *Aulacostephanus autissiodorensis* Ammonite Zone. Keupp (1976, 1977) reports *Stephanolithion bigotii* Deflandre from the lower Tithonian (*Hybonoticeras hybonotum* Ammonite Zone) Solnhofen Limestone. Because this is the only reported Tithonian occurrence of *Stephanolithion bigotii* Deflandre, reworking cannot be completely ruled out. Flügel and Keupp (1979) did not observe this species in the Oberalm beds, and it appears to be absent from the Tithonian beds of southern France (Thierstein 1975, 1976). The best estimate for the last occurrence of *Stephanolithion bigotii* Deflandre is lower Tithonian, which agrees with the dinoflagellate data of Site 534.

Primitive nannoconids and *Polycostella beckmannii* Thierstein make their first appearance in the Tithonian (Deres and Achéritéguy, 1980), and typical *Nannoconus colomii* (de Lapparent) and *Lithraphidites carniolensis* (Deflandre) mark the base of the Berriasian (Lower Cretaceous). Thus our nannofossil zonation can be tied into the classical European stages and correlated with dinoflagellate age units (no formal zones proposed by Habib and Drugg, this volume). Coccoliths provide a reasonable biostratigraphic zonal scheme that allows correlation with other DSDP sites.

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