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5. Calcareous Nannofossil Biostratigraphy of Cretaceous Sediments Recovered at ODP Site 1149 (Leg 185, Nadezhda Basin, Western Pacific)[1]

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ABSTRACT

Basal carbonate sediments recovered at Ocean Drilling Program (ODP) Site 1149 lie directly on magnetic Anomaly M12. They contain abundant and moderately well preserved calcareous nannofossils. Two nannofossil zones are recognized: the lower *Calcicalathina oblongata* Zone and the upper *Lithraphidites bollii* Zone, indicating a late Valanginian–late Hauterivian age. The close occurrence of two significant bioevents, the first occurrence (FO) of *L. bollii* and the FO of *Rucinolithus terebrodentarius* in Core 185-1149B-20R, together with dip data recorded during in situ geophysical logging, suggest the presence of an unconformity that corresponds to the lower Hauterivian sedimentary section. The continuous occurrence of *L. bollii* is reported for the first time in sediments from the Pacific Ocean. Other marker species regarded as cosmopolitan (e.g., *C. oblongata*) have a sporadic occurrence. Nannoconids, very useful zonal markers for Tethyan areas, are virtually absent. The presence of an unusually high abundance of *Diazomatolithus lehmanii* is also recorded and correlates with the Valanginian $\delta^{13}C$ positive excursion.

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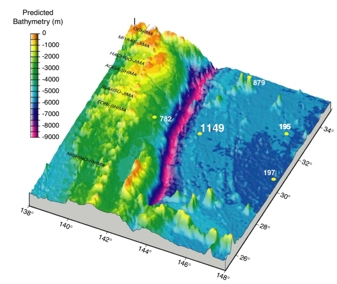
INTRODUCTION

Site 1149 was drilled in the northwestern Pacific during Ocean Drilling Program (ODP) Leg 185 and from it was recovered a reference section for the oceanic crust of the Early Cretaceous Pacific Ocean.

The main objectives of Leg 185 were to provide estimates of the sediment and altered basalt inputs (geochemical fluxes) into the Izu-Bonin subduction zone and to contrast crustal inputs to the Izu-Bonin Trench with those for the Mariana Trench (Hole 801C, drilled during Leg 129 and reentered during Leg 185); the sedimentary section recovered also helped to refine the Early Cretaceous paleomagnetic timescale (Plank, Ludden, Escutia, et al., 2000) and better understand fluctuations in the Early Cretaceous carbonate compensation depth (CCD) and equatorial circulation (E. Erba and R.L. Larson, pers. comm., 2001.

Site 1149 is located at 31.3°N, 143.3°E, southeast of Japan on the Pacific plate in the Nadezhda Basin, in a water depth of ~5800 m. The site lies on a slight high ~100 km east of the Izu-Bonin Trench, where the Pacific plate is flexed upward prior to its entry into the subduction zone (Fig. F1). According to Nakanishi et al. (1992) and confirmed by Plank, Ludden, Escutia, et al. (2000), the site lies on the reversed magnetic Anomaly M12.

F1. Location of Site 1149, p. 12.



Four holes were drilled at Site 1149, and a sedimentary section of 408 m total thickness was recovered; carbonate sediments yielding calcareous nannofossil assemblages were recovered only in Holes 1149B, 1149C, and 1149D, providing direct contact with underlying basalts of the Cretaceous oceanic crust. From Hole 1149A, ~200 m of pelagic brown clay, subdivided into two lithologic units (Plank, Ludden, Escutia, 2000), was recovered. Lithologic Unit I consists of noncalcareous clay with common dispersed ash particles, numerous discrete ash layers, and siliceous microfossils (radiolarians, diatoms, silicoflagellates, and ebridians); it reaches 118 m in thickness and has been dated by means of diatoms (**Laws,** this volume) and silicoflagellates (**Lozar and Mussa,** this volume) as late Miocene to late Pleistocene in age. Lithologic Unit II consists of 62 m of dark brown pelagic clays with several discrete ash layers in the upper 30 m; Unit II clays are barren of any siliceous or calcareous microfossils but contain ichthyoliths (Plank, Ludden, Escutia, 2000). The sedimentary sections recovered in Holes 1149B and 1149C are very similar and are subdivided into Units III and IV. Lithologic Unit III consists of a 104-m-thick alternation of radiolarian chert with porcellanite and siliceous clay (Plank, Ludden, Escutia, 2000); it has been dated by means of radiolarians and suggests a mid-Cretaceous age (A. Bartolini, pers. comm., 2001). Lithologic Unit IV comprises 125 m of intercalated radiolarian chert, porcellanite, and siliceous chalks or marls. Lithologic Unit V was recovered only as interpillow sediment in fractures in the upper 2 m of basement in Hole 1149B and consists of recrystallized calcareous marlstone, barren of calcareous microfossils.

Units III, IV, and V were only continuously cored in Hole 1149B. Despite the very low recovery rate (between 3% and 11%), the contact between the sedimentary cover and the oceanic basement was recovered in Core 185-1149B-29R at 408.2 meters below seafloor (mbsf). Hole 1149C was only spot-cored at the top of Unit IV (283.6–322 mbsf) and the bottom of this unit, just above the contact with the oceanic crust (388.2–401 mbsf). In this hole the basement lies 7 m shallower than in Hole 1149B. In Hole 1149D, some 5 km to the southeast of Hole 1149C, only the interval just above the contact with basalt was cored (272.2–307 mbsf). The basement in Hole 1149D lies 101 m shallower than in Hole 1149B.

Samples analyzed in this work are from carbonate sediments of Units IV and V (Hole 1149B only) in Holes 1149B, 1149C, and 1149D.

MATERIALS AND METHODS

Biostratigraphic and semiquantitative analyses were performed on samples collected from Holes 1149B, 1149C, and 1149D. A total of 101 samples were prepared using standard techniques (Monechi and Thierstein, 1985); no ultrasonic cleaning or centrifuge concentration was applied in order to retain the original biogenic composition of samples. Smear slides were examined using standard light microscope techniques under crossed polarizers and transmitted light at 1000× and 1250× magnification.

Preservation and abundance of calcareous nannofossil species may vary significantly as a result of dissolution or overgrowth. A simple code system has been adopted to characterize the preservation:

VG = very good (no evidence of dissolution and/or overgrowth is present; there is no alteration of primary morphological characteristics, and specimens appear diaphanous; specimens are identifiable to the species level).
G = good (little or no evidence of dissolution and/or overgrowth is present; primary morphological characteristics are only slightly altered; specimens are identifiable to the species level).
M = moderate (specimens exhibit some etching and/or overgrowth; primary morphological characteristics are sometimes altered; most specimens are identifiable to the species level).
P = poor (most specimens exhibit overgrowth or dissolution; primary morphological characteristics are sometimes destroyed; fragmentation has occurred; species identification is often impaired).

Estimates of the total calcareous nannofossils abundance, compared to that of other biogenic particles and inorganic components were recorded as follows:

C = common (>51% of all particles).
F = few (11%–50% of all particles).
R = rare (1%–10% of all particles).
T = trace (<1% of all particles).
B = barren (no nannofossils are present).

Estimates of the relative abundance of calcareous nannofossil species in the studied assemblages were determined as follows:

D = dominant (>51% of the total assemblage).
A = abundant (11%–50% of the total assemblage).
C = common (1%–10% of the total assemblage).
F = few (0.1%–1% of the total assemblage).
R = rare (<0.1% of the total assemblage).

The nannofossil biozonations adopted for the Lower Cretaceous are mainly those of Thierstein (1971, 1973) and Sissingh (1977) and are regarded as standards as summarized in Perch-Nielsen (1985). We also considered Roth (1978), Bralower et al. (1995), Erba et al. (1995), and Bown et al. (1998). The reference timescale adopted in this work follows Channell et al. (1995).

BIOSTRATIGRAPHY

In the last three decades, calcareous nannofossils have become a very important fossil group for age dating and correlation of Mesozoic pelagic carbonates.

Lower Cretaceous biostratigraphy has achieved considerable stability, and cosmopolitan zonations have been proposed (Thierstein, 1971, 1973, 1976; Sissingh, 1977; Roth, 1978; Perch-Nielsen, 1985). More detailed biozonations were recently proposed for several paleoprovinces, but their reliability is geographically restricted. In this study we applied the zonations of Thierstein (1971, 1973) and Bralower et al. (1995) for the Lower Cretaceous sediments recovered at Site 1149.

In the Lower Cretaceous sedimentary succession studied in Holes 1149B, 1149C, and 1149D, calcareous nannofossils are quite common in the carbonate intervals and their preservation ranges from poor to moderate. Despite the absence or sporadic occurrence of the useful zonal markers, it was possible to identify two nannofossil zones.

The sediments recovered in these holes contain nannofossil assemblages spanning from late Valanginian to late Hauterivian age. In general, the nannofossil assemblage in the three Holes 1149B, 1149C, and 1149D is dominated by *Watznaueria barnesae,* a species resistant to diagenesis.

Hole 1149B

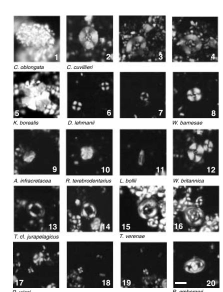
$CaCO_3$-rich sediments were recovered from Cores 16R through 29R in Units IV and V.

The nannofossil assemblages in the interval from Cores 23R through 29R indicate a late Valanginian age, belonging to the *Calcicalathina oblongata* Zone (Thierstein, 1971, 1973) (Zone NK3 in Bralower et al., 1989, 1995). *C. oblongata* is very rare in the samples investigated, but other useful markers whose combined ranges suggest a late Valanginian age such as *Tubodiscus verenae, Tubodiscus jurapelagicus,* and *Rucinolithus wisei* were recognized (Table **T1**, Pl. **P1**). In particular, the stratigraphic ranges of *T. verenae* and *T. jurapelagicus* are restricted to the middle to upper part of the *C. oblongata* nannofossil Zone. *T. verenae* and *R. wisei* display a very continuous occurrence and were detected from the bottom of the sedimentary section, suggesting a late Valanginian age for the basement. The last occurrences (LO) of *T. verenae* and *R. wisei* correspond to Samples 185-1149B-23R-1, 22–26 cm, and 24R-1, 24–28 cm, respectively. Other species commonly recorded in this interval are *Cyclagelosphaera margerelii, Parhabdolithus embergeri, Cruciellipsis cuvillieri, Discorhabdus rotatorius, Assipetra infracretacea, Cretarhabdus angustiforatus, Diazomatolithus lehmanii,* and *Watznaueria* spp.

The nannofossil assemblage in Cores 21R through 23R is dominated by *W. barnesae* but displays an abundant (up to 30%) *D. lehmanii,* including normal-sized and slightly oversized specimens. This sharp increase corresponds to the base of the $\delta^{13}C$ positive excursion (A.

T1. Calcareous nannofossils, Hole 1149B, p. 16.

P1. Microfossils under crossed nichols, p. 21.

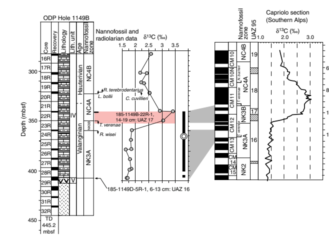


lini, pers. comm., 2001) (Fig. F2) and correlates to peaks in this taxon in the North Sea (Williams and Bralower, 1995) and Southern Alps (Erba and Quadrio, 1987; Tremolada and Erba, 2000).

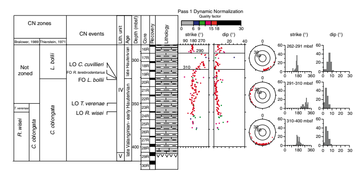
The interval from Cores 20R through 16R is assigned to the *Lithraphidites bollii* Zone (Thierstein, 1971, 1973). We identified the lower boundary of this nannofossil zone by the first occurrence of the zonal marker *L. bollii,* observed in Sample 185-1149B-20R-1, 139–140 cm. *L. bollii* is rare in the Pacific Ocean (Bralower, 1987) and in the Tethys as well (e.g., Erba and Quadrio, 1987; Channell and Erba, 1992), but it shows a quite continuous occurrence in the analyzed samples. The first occurrence of *Rucinolithus terebrodentarius* occurs in Sample 185-1149B-20R-1, 46–47 cm, where geophysical logging records a major change in dip and strike in the sedimentary section (R. Pockalny, pers. comm., 2001) (Fig. F3). The stratigraphic range of *R. terebrodentarius* spans from late Hauterivian to Turonian; its first occurrence just above the change in dip suggests that the lower–middle Hauterivian corresponds to an unconformity. In addition, the last occurrence of *C. cuvillieri* is recorded in Sample 185-1149B-20-1, 8–10 cm, indicating a late Hauterivian age (Thierstein, 1971, 1973). In general, the first occurrence of *R. terebrodentarius* postdates the last occurrence of *C. cuvillieri,* but our data show the range of *C. cuvillieri* overlapping with that of *R. terebrodentarius.* This is in agreement with the results of Erba et al. (1999) and Channell et al. (2000) from the Cismon drill core (Southern Alps, Northeastern Italy). Other species frequently observed in this interval are *C. margerelii, Lithraphidites carniolensis, A. infracretacea, Cretarhabdus conicus, C. surirellus, C. angustiforatus,* and *Watznaueria* spp. The abundance of *D. lehmanii* decreases abruptly in Core 20R. In the upper portion of this interval, overgrown specimens of *C. cuvillieri, T. jurapelagicus,* and *T. verenae* were observed in several samples, suggesting a reworking of older strata.

The overlying noncalcareous interval, in Core 16R, is barren of nannofossils, probably reflecting the passage of the site into the high-fertility equatorial zone, where calcareous plankton is overcome by siliceous plankton (Erba, 1992). This transition is also suggested by the change to more cherty lithologies in Unit III (Plank, Ludden, Escutia, et al., 2000).

The sequence of bioevents recognized in Hole 1149B correlates with that of the Tethys section at Capriolo, Northern Italy (Fig. F2). The Capriolo section is a continuous and expanded section spanning from late Berriasian to Barremian with a good bio- (radiolarians and calcareous nannofossils), magneto-, and chemostratigraphic control.



F2. Hole 1149B Cretaceous section correlated with the Capriolo section, p. 13.



F3. Hole 1149B calcareous nannofossil zones, p. 14.

Hole 1149C

This hole was only spot-cored in two selected intervals, the top and bottom of lithostratigraphic Unit IV, recovering the sediment/basement contact. Recovery rate in Hole 1149C was low (~4%).

The calcareous nannofossil assemblage recorded in this hole is very similar to that recorded in Hole 1149B. Below Core 8R the nannofossil assemblage is assignable to the *C. oblongata* Zone (Thierstein, 1971, 1973) based on the occurrences of *T. verenae, C. cuvillieri, T. jurapelagicus, C. oblongata,* and the large abundance of the genus *Diazomatolithus* (Table T2). The last occurrence of *R. wisei* was observed in Sample 185-1149C-8R-1, 13–14 cm, whereas the last occurrence of *T. verenae* was detected in Sample 8R-1, 0–3 cm. The first occurrence of *L. bollii,* which defines the lower boundary of the *L. bollii* nannofossil Zone (Thierstein, 1971, 1973), was identified in Sample 185-1149C-6R-1, 35–41 cm, to-

T2. Calcareous nannofossils, Hole 1149C, p. 19.

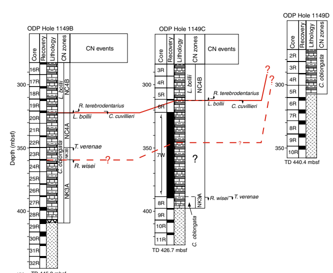
gether with the last occurrence of *C. cuvillieri*. The identification of these two events indicates that Core 6R can be attributable to the middle part of the *L. bollii* Zone. Core 7W is a wash core spanning a ~60-m-thick interval (from 322 to 388.2 mbsf) that corresponds to the upper part of the *C. oblongata* Zone and the lower part of the *L. bollii* Zone. The last occurrence of *C. cuvillieri* precedes the first occurrence of *R. terebrodentarius,* which lies in Sample 185-1149C-6R-1, 30–34 cm. The first occurrence of *R. terebrodentarius* is unreliable because of the scarcity of this species near the beginning of its stratigraphic range. Reworked specimens of *T. verenae* and *T. jurapelagicus* were observed frequently in the upper portion of the cored section.

Hole 1149D

Recovery in this hole was very low (~4%). A few samples were studied to assess the age of the oldest sediments overlying the basement and to compare the results with those from Hole 1149B (Table T3). Preservation is generally poor, and Sample 185-1149D-3R-1, 34–35 cm, is barren of calcareous nannofossils. The two lowermost Samples (185-1149D-5R-1, 13–15 cm, and 4R-1, 66–70 cm) contain a sparse, poorly preserved assemblage, characterized by the rare occurrence of highly resistant species (*W. barnesae, Watznaueria ovata,* and *C. margerelii*). The occurrences of marker species *T. verenae, R. wisei,* and *C. oblongata* are likely affected by poor preservation and cannot be excluded. Based on the occurrence of *T. verenae* and *R. wisei* in Sample 185-1149D-4R-1, 1–5 cm, the base of the hole corresponds to the *C. oblongata* Zone of Thierstein (1971), but no further biostratigraphic detail is possible. This basal age is similar to that in Hole 1149B. Overlying sediments do not contain *L. bollii.* Thus, the lower boundary of the *L. bollii* Zone of Thierstein (1973) has not been cored in this hole, and direct correlation with Holes 1149B and 1149C is only hypothetical (Fig. F4).

T3. Calcareous nannofossils, Hole 1149D, p. 20.

F4. Site 1149 biostratigraphic correlation, p. 15.



CONCLUSIONS

The calcareous nannofossil biostratigraphy of Lower Cretaceous sediments cored at ODP Site 1149 allows identification of the *C. oblongata* and the *L. bollii* Zones of Thierstein (1971, 1973). The continuous occurrence of *L. bollii* is reported for the first time in sediments from the Pacific Ocean. On the contrary, other marker species regarded as cosmopolitan (e.g., *C. oblongata*) have a sporadic occurrence at this site. Nannoconids, very useful zonal markers in Tethyan sections, are virtually absent at this site, preventing enhanced biostratigraphic resolution. Occurrence of unusually high abundances of *D. lehmanii* is also recorded and correlates with the prominent Early Cretaceous $\delta^{13}C$ positive excursion (A. Bartolini, pers. comm., 2001). Continuous and spot-coring in Holes 1149B and 1149C, respectively, allow identification of the first occurrence of *R. terebrodentarius* just above the first occurrence of *L. bollii.* As these two bioevents correlate to the upper and lower Hauterivian, respectively, a condensed section or an unconformity occurs at this depth (310 mbsf).

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TAXONOMIC APPENDIX

Assipetra infracretacea (Thierstein, 1973) Roth, 1973
Biscutum constans (Gorka, 1957) Black in Black & Barnes, 1959
Calcicalathina oblongata (Worsley, 1971) Thierstein, 1971
Cretarhabdus angustiforatus Black, 1971
Cretarhabdus conicus Bramlette & Martini, 1964
Cretarhabdus surirellus (Deflandre & Fert, 1954) Grün in Grün & Alleman, 1975
Cruciellipsis cuvillieri (Manivit, 1966) Thierstein, 1971
Cyclagelosphaera deflandrei (Manivit, 1966) Roth, 1973
Cyclagelosphaera margerelii Noël, 1965
Diazomatolithus lehmanii Noël, 1965
Discorhabdus rotatorius (Bukry, 1969) Thierstein, 1973
Haqius circumradiatus (Stover, 1966) Roth, 1978
Haqius ellipticus (Grün in Grün & Alleman, 1975) Bown, 1992
Kokia borealis Perch-Nielsen, 1988
Lithraphidites bollii (Thierstein, 1971) Thierstein, 1973
Lithraphidites carniolensis Deflandre, 1963
Manivitella pemmatoidea (Deflandre in Manivit, 1965) Thierstein, 1971
Helenea chiastia Worsley, 1971
Micrantholithus hoschulzii (Reinhardt, 1966) Thierstein, 1971
Parhabdolithus embergeri (Noël, 1959) Perch-Nielsen, 1984
Rhagodiscus asper (Stradner, 1963) Reinhardt, 1967
Rhagodiscus dekanelii Bergen, 1994
Rucinolithus terebrodentarius Applegate et al. in Covington & Wise, 1987
Rucinolithus wisei Thierstein, 1971
Speetonia colligata Black, 1971
Tubodiscus burnettae Bown in Kennedy et al., 2000
Tubodiscus jurapelagicus (Worsley, 1971) Roth, 1973
Tubodiscus verenae (Thierstein, 1973) Grün in Grün & Alleman, 1975
Watznaueria barnesae (Black in Black & Barnes, 1959) Perch-Nielsen, 1968
Watznaueria biporta Bukry, 1969
Watznaueria britannica (Stradner, 1963) Reinhardt, 1964
Watznaueria manivitae Bukry, 1973
Watznaueria ovata Bukry, 1969
Zeugrhabdotus cooperi Bown, 1992
Zeugrhabdotus erectus (Deflandre in Deflandre & Fert, 1954) Reinhardt, 1964
Zeugrhabdotus diplogrammus Deflandre in Deflandre & Fert, 1954

Figure F1. Location of Site 1149, drilled during Leg 185; the bathymetric map shows the relative position with respect to the Izu-Bonin arc system (from Plank, Ludden, Escutia, et al., 2000).

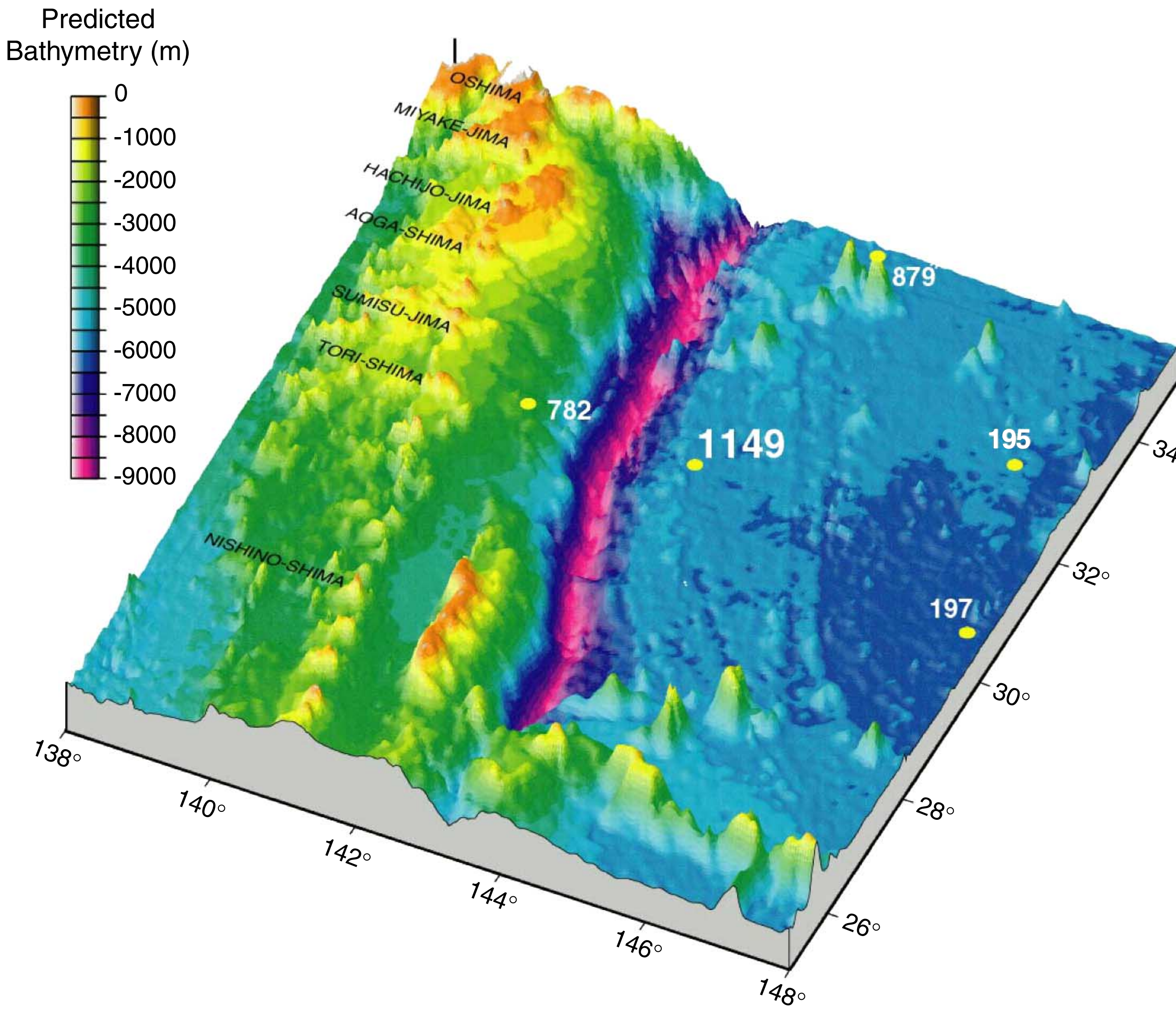

Figure F2. Stratigraphy of the Cretaceous section cored in Hole 1149B and correlation with the Capriolo section in the Southern Alps (Bralower, 1987; Channell and Erba, 1992). Calcareous nannofossil (CN Zones according to Bralower et al., 1995) and radiolarian bioevents (UAZ = Unitarian Association Zones; Baumgartner et al., 1995) are indicated and correlated with the chemostratigraphic data of $\delta^{13}C$ (A. Bartolini, pers. comm., 2001). The pink pattern underlines the interval of relatively high abundance of the calcareous nannofossil species *Diazomatolithus lehmanii*. TD = total depth.

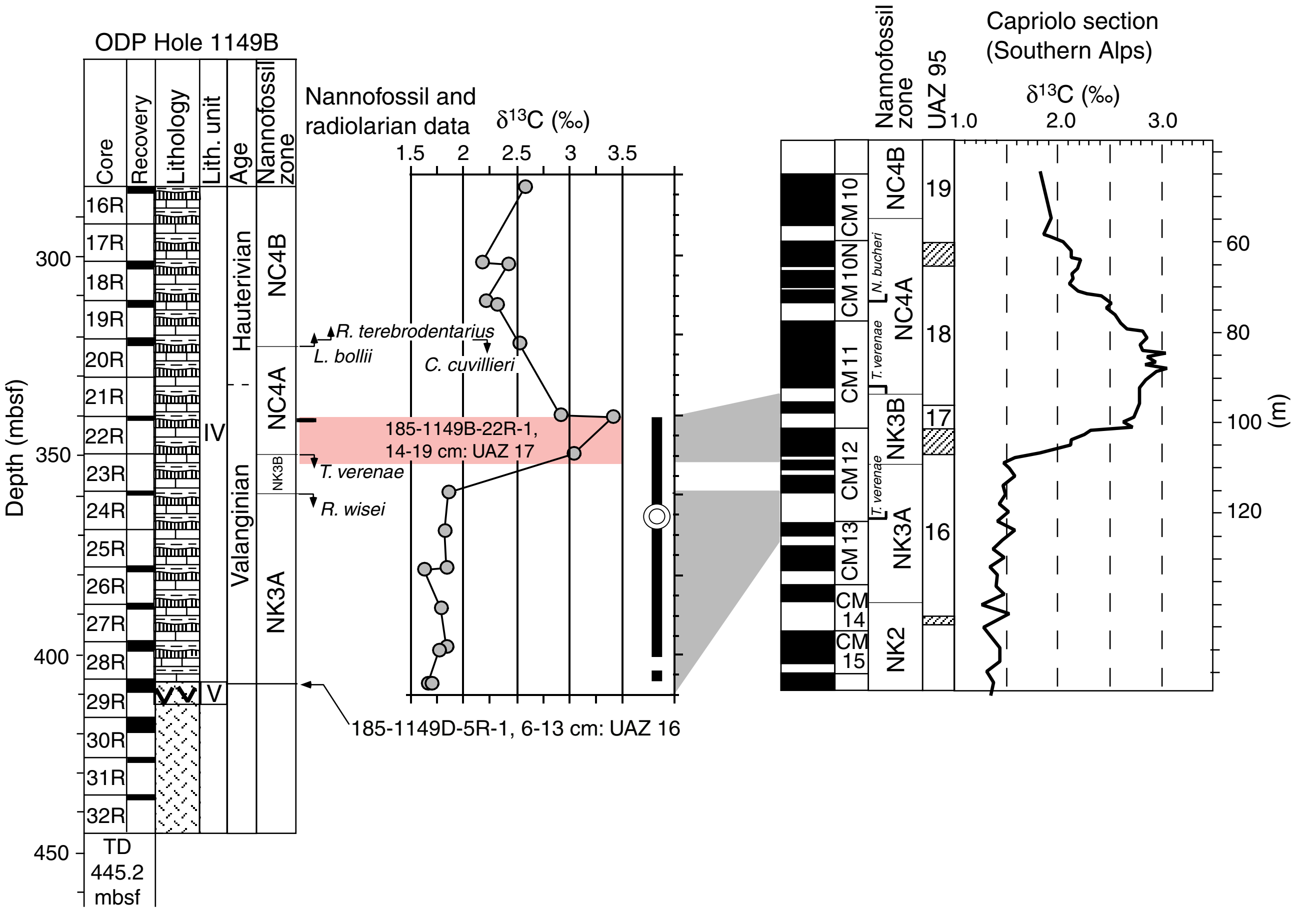

Figure F3. Calcareous nannofossil zones (according to Thierstein, 1971, and Bralower et al., 1995) recognized in Hole 1149B. The correlation with logging data (dip, dynamically normalized; unpubl. data courtesy of R. Pokalny, 2001) shown on the right underlines the presence of an unconformity biostratigraphically detected at ~310 mbsf (see text for detail). LO = last occurrence, FO = first occurrence.

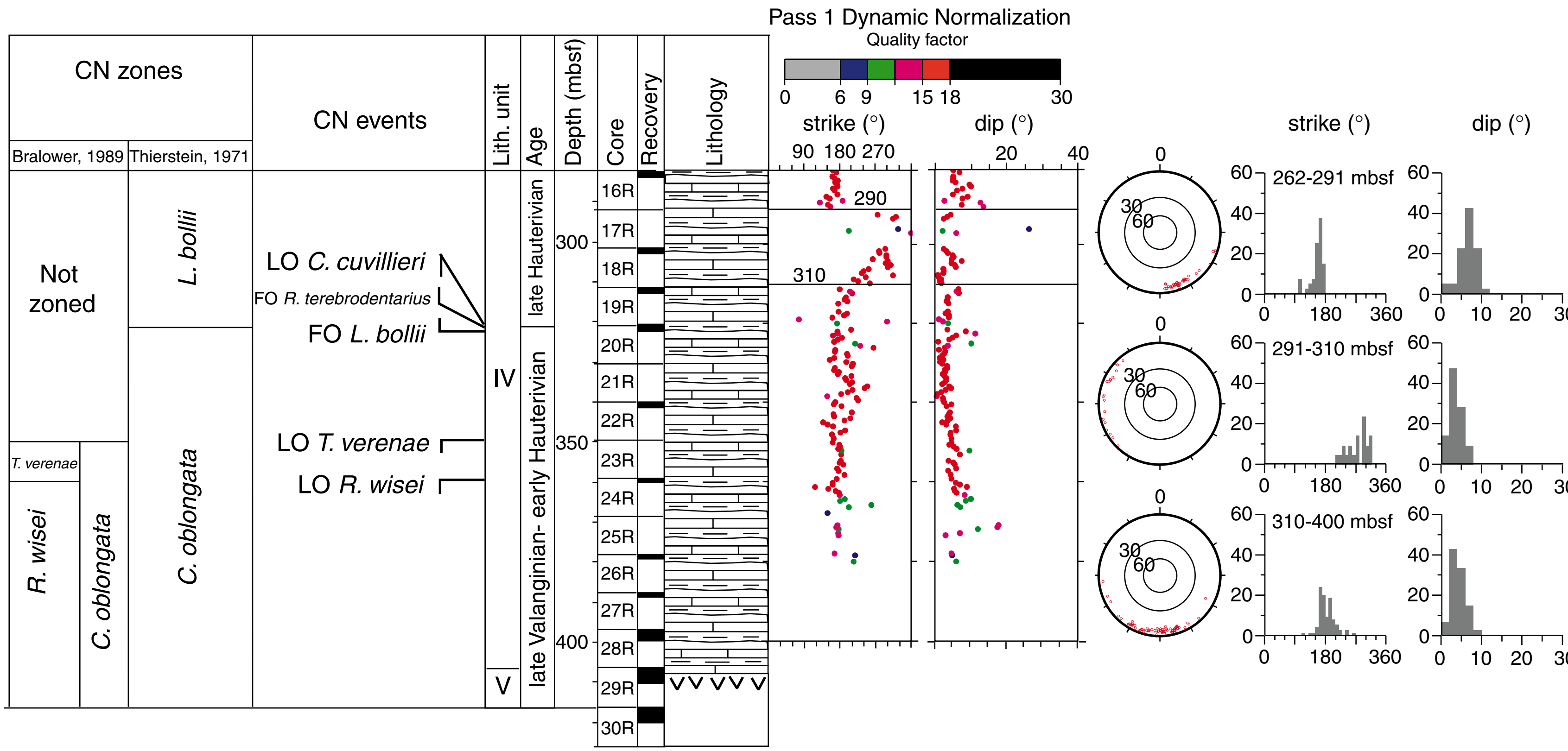

Figure F4. Biostratigraphic correlation of the three holes drilled at Site 1149. Calcareous nannofossil zones are according to Thierstein (1971) and Bralower et al. (1995). The top of NK3A subzone, recognized in Hole 1149B, is not clearly detected in Hole 1149C, where it might fall in the "wash" Core 185-1149C-7W, or in Hole 1149D, where it has not been cored. TD = total depth.

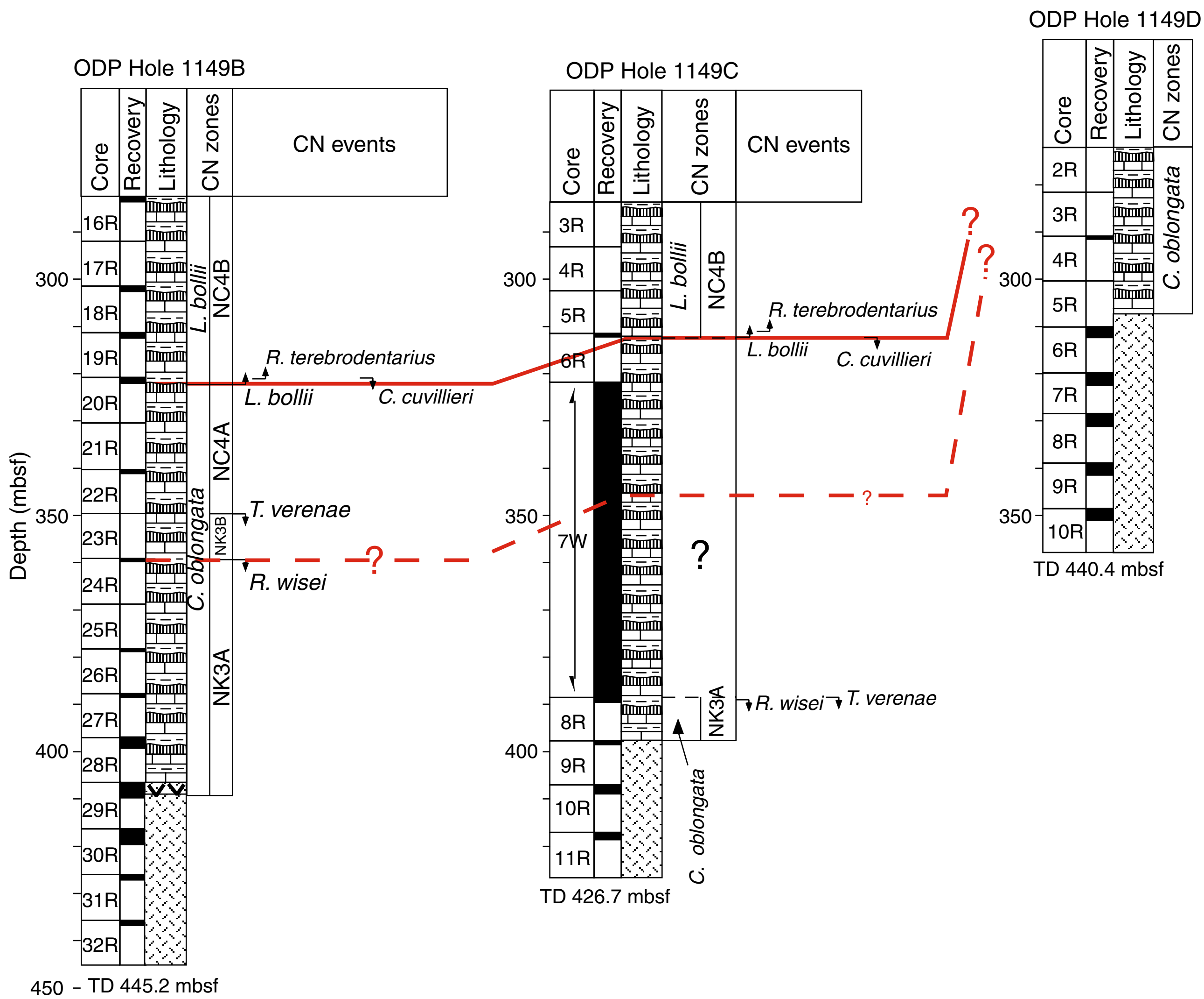

Table T1. Calcareous nannofossil distribution, Hole 1149B. (See table notes. Continued on next two pages.)

Core, section, interval (cm)	Depth (mbsf)	Preservation	Group Abundance	*Assipetra infracretacea*	*Biscutum constans*	*Calcicalathina oblongata*	*Cretarhabdus angustiforatus*	*Cretarhabdus conicus*	*Cretarhabdus surirellus*	*Cruciellipsis cuvillieri*	*Cyclagelosphaera deflandrei*	*Cyclagelosphaera margerelii*	*Diazomatolithus lehmanii*	*Discorhabdus rotatorius*	*Haqius circumradiatus*	*Haqius ellipticus*	*Helenea chiastia*	*Kokia borealis*	*Lithraphidites bollii*	*Lithraphidites carniolensis*	*Manivitella pemmatoidea*	*Micrantholithus hoschulzii*	*Parhabdolithus embergeri*	*Pickelhaube furtiva*	*Rhagodiscus asper*	*Rhagodiscus dekaenelii*	*Rucinolithus terebrodentarius*	*Rucinolithus wisei*	*Tubodiscus burnettae*	*Tubodiscus jurapelagicus*	*Tubodiscus verenae*	*Watznaueria barnesae*	*Watznaueria biporta*	*Watznaueria britannica*	*Watznaueria manivitae*	*Watznaueria ovata*	*Watznaueria supracretacea*	*Zeugrhabdotus cooperi*	*Zeugrhabdotus diplogrammus*	*Zeugrhabdotus erectus*
185-1149B-																																								
16R-1, 51–51	282.81	P	B																																					
16R-1, 55–57	282.85	P	B																																					
16R-1, 74–75	283.04	P	C	R			F			R		C	F		F	F	R	R	R	R	F		F	R			F			F		A	R	F	R		F	R		F
16R-1, 74–76	283.04	P	C	F			R		R	R		R		R	R			R	R	R			C		R		F					A		R						
16R-1, 79–81	283.09	P	F	R								R		R			R		R				R		R		R		R			A		R						
16R-1, 83–87	283.13	M	C	R			R					C	R		R		C	R		C	A		A	R			R			R		A	R	R	R		F			R
16R-1, 88–91	283.18	P	F	F								R		R	R		R			R			C		R		R					A		R						
16R-1, 92–96	283.22	M	C	R			R					C	R		F		R			R	F		F				C					C	F	F			C	R		
17R-1, 5–8	292.05	P	B																																					
17R-1, 14–18	292.14	P	R	R																			R				R										R			
17R-1, 26–26	292.26	P	R																				R				F					R		R						
18R-1, 15–17	301.75	P	F	R	R				R			R					R		R	R			F		R		R		R			A								
18R-1, 35–36	301.95	P	B																																					
18R-1, 59–61	302.19	P	F	R										R	R				R				R				F					C		R	R				R	
18R-1, 84–86	302.44	P	F	R										R									R									C		R	R					
18R-1, 94–97	302.54	P	F	R			R			R	R	C	R		R	R		R					C				R					C		R	R	R	R	R		
19R-1, 8–10	311.38	P	B																																					
19R-1, 20–20	311.5	M	C	C						R		C	R		R	R	R	R	R	F	R		C				F			R		A	C	F	C		R	R	R	F
19R-1, 79–82	312.09	M	C	R		R			R				R	R	R		R		R				R		R		R		R	R	R	A								
19R-1, 123–125	312.53	M	C	R	R		R		R			F	R	R			R	R					R		R		R		R			A								
19R-1, 125–127	312.55	P	F	R			R				R	R	R			R							R				R			R		R		R	R		R			
19R-1, 127–129	312.57	M	C	R				R	R				R	R						R			F				R					A								
20R-1, 8–10	320.98	M	C	R			R	R	R	R		R	F	R	R				R				C		R		R		R			A								
20R-1, 46–47	321.36	P	C	R			C			F		C	F		F	R	R		F	R			C				R			R		A		F	R		C	R		R
20R-1, 55–57	321.45	M	F	F		R	R	R	R	R		R	C				R		R			R	C		R							A		F	R					
20R-1, 139–140	322.29	P	F	F			R			R	R	F			R				R	R			F									F			R					
21R-CC, 15–16	330.65	P	B																																					
22R-1, 0–2	340.1	M	C	R		R				R		C	C		F		R			R	R		C			R						A		A	C			R		
22R-1, 14–19	340.24	M	F	F			R	R	R	R		C	A				R			R			R		R							A		R	R					
22R-1, 17–20	340.27	P	F	C			F			F		R	F		R	F	R	R			R		F									A	F	R						R
22R-1, 28–31	340.38	P	B																																					
22R-1, 42–43	340.52	M	C	F			R			R		C	A		R		R						R		R				R			A		R	R					
22R-1, 60–62	340.7	M	C	C					R	F		C	A				R			R			F		R				R			A		R	R					
22R-1, 82–86	340.92	P	F	R			R			R	R	F	R			R							R									D	F	F		R	R			
23R-1, 0–3	349.7	M	C	R			R			R		A	A	F	R								F		R				R			A		F	R					
23R-1, 8–11	349.78	P	F	R				R				R	C	R				R		R												A								
23R-1, 22–26	349.92	P	F	F						F		C	A	F	R		R			R			F						R		R	A		R	R					
23R-CC, 22–26	349.92	M	C	F	R	R	R			F		A	C		R						R		C		R	R	R					A	C	C	R		R	F		R
24R-1, 21–24	359.41	M	C	R				R		C	R	C	C			R				R			R							R	R	A	R	F		R				

Table T1 (continued).

Core, section, interval (cm)	Depth (mbsf)	Preservation	Group Abundance	*Assipetra infracretacea*	*Biscutum constans*	*Calcicalathina oblongata*	*Cretarhabdus angustiforatus*	*Cretarhabdus conicus*	*Cretarhabdus surirellus*	*Cruciellipsis cuvillieri*	*Cyclagelosphaera deflandrei*	*Cyclagelosphaera margerelii*	*Diazomatolithus lehmanii*	*Discorhabdus rotatorius*	*Haqius circumradiatus*	*Haqius ellipticus*	*Helenea chiastia*	*Kokia borealis*	*Lithraphidites bollii*	*Lithraphidites carniolensis*	*Manivitella pemmatoidea*	*Micrantholithus hoschulzii*	*Parhabdolithus embergeri*	*Pickelhaube furtiva*	*Rhagodiscus asper*	*Rhagodiscus dekaenelii*	*Rucinolithus terebrodentarius*	*Rucinolithus wisei*	*Tubodiscus burnettae*	*Tubodiscus jurapelagicus*	*Tubodiscus verenae*	*Watznaueria barnesae*	*Watznaueria biporta*	*Watznaueria britannica*	*Watznaueria manivitae*	*Watznaueria ovata*	*Watznaueria supracretacea*	*Zeugrhabdotus cooperi*	*Zeugrhabdotus diplogrammus*	*Zeugrhabdotus erectus*
24R-1, 22–25	359.42	M	C	VR						F	F	F	F																	C	F	A	C	C						
24R-1, 24–28	359.44	M	C	F			R		R	R		R	C	F						R			R		R			R	R	R	R	A		R	R					
24R-1, 30–32	359.5	P	F							R	R	F	F							R			R							R	R	C	R	F	R			R		R
24R-1, 42–44	359.62	P	F	F	R			R		R			C	R						R			R					R	R			A		R	R				R	
24R-1, 51–52	359.71	P	F	F			R		R	R		F	C	R									R		R							A	R	R	R					
24R-1, 80–86	360	M	C	F		R				C		F	C			R	R			R	R		R							F	R	A		F	R					
25R-1, 22–28	368.92	M	C	C			F			F		F	C		R	R	R			R	R		F					R		F		A	R	F				R	R	
25R-1, 24–28	368.94	P	B																																					
26R-1, 0–2	378.1	M	C	F			R			F		F			R	R				R			F					R		F	F	C	C	A				F		R
26R-1, 7–7	378.17	M	C	R			R			R	R	C	F										F					R				A	F	A				R		
26R-1, 14–19	378.24	P	F	F																			F					R				A								
26R-1, 20–23	378.3	M	C	R		R			R	F		F	C		R		R						C		R			R	R	R		A	R	F	F					
26R-1, 28–28	378.38	P	C	F			F			F		C	F			R	R			R			F					R		R		A	R	C				R		R
26R-1, 50–52	378.6	P	F	F					R	R		R	C				R			R			R					R		R		A		R	R				R	R
26R-1, 50–53	378.6	P	C	F				R		C	R	C	F							R			R							F		A		C						
26R-1, 80–83	378.9	P	F	F			F			R		C	C			R	R			F	R		R	R				F			R	C		C						
27R-1, 10–10	387.7	M	C	C			R			R		C	F		R					R			R									A		F						
27R-1, 22–26	387.82	P	F				R	R	R	F		C	C				R			R			F					R		R	R	A		F	F					R
27R-1, 26–29	387.86	M	C	F		R		R		R		C	R										F		R			R	R	R	R	A		F	C					F
27R-1, 59–63	388.19	P	F	R			R	R			R	C	C		R								F		R				R	R	R	A		F	F					
27R-1, 71–75	388.31	M	C	R			R	R		C	R	C	F		R		R			R			F					R		R	F	C		C	C					
28R-1, 38–40	397.48	P	F	F						R		C	C				R						C		R							A	F	F	F					R
28R-1, 57–58	397.67	P	F	R						R		C	C										C					R	R	R	R	A	F	F	F					
28R-1, 70–70	397.8	M	C	R			R			R	F	C	C		R	R							C								R	C	F	C	F			F		
28R-1, 88–88	397.98	M	C	C							R	C	F		R								C			R					R	C		C	C	C		R		
28R-1, 99–103	398.09	P	F	R						R		F	C										C		R							A	R	R	C					
28R-1, 118–118	398.28	P	T	R						R	F	C	C										F									C		F	F					R
28R-2, 8–10	398.5	M	C	F						F	F	C	F		R								R					R		R		A			A					
28R-2, 32–36	398.74	P	F	R	R					F		R	C				R						F		R							A			F					
28R-2, 36–38	398.78	M	C	C		R	R			R			C										C		R						R	A		R	C					
28R-2, 42–46	398.84	M	C				R			R	F	C	F		R	F	R						R		R					R	R	A		F	R					
28R-2, 85–87	399.27	P	F	R						R		R	C				R						C								R	A	R	R	F					
28R-2, 126–127	399.68	M	F	F							R	C	F										F									C		F	F					
28R-2, 138–139	399.8	M	C	F			F			R	C	R	F			R							R			R					R	A	F	F	F	R		R		
29R-1, 23–24	407.03	P	F	A			F				C	F	F										R									D		F	R					
29R-1, 25–27	407.05	P	F	R						R		R	C				R						A		R						R	A	R	R	F					
29R-1, 61–64	407.41	P	F	C			R			F		C	C				R						A									A	R	C	A					
29R-1, 67–68	407.47	P	F	F						R	C	C	F										F					R				A			R					
29R-1, 92–93	407.72	M	C	R			F			F	R	A	C			R	R			R			R			R		R			R	A	R	C	F	F				
29R-1, 112–115	407.92	P	T								R	R																				R		R						

Table T1 (continued).

Core, section, interval (cm)	Depth (mbsf)	Preservation	Group Abundance	*Assipetra infracretacea*	*Biscutum constans*	*Calcicalathina oblongata*	*Cretarhabdus angustiforatus*	*Cretarhabdus conicus*	*Cretarhabdus surirellus*	*Cruciellipsis cuvillieri*	*Cyclagelosphaera deflandrei*	*Cyclagelosphaera margerelii*	*Diazomatolithus lehmanii*	*Discorhabdus rotatorius*	*Haqius circumradiatus*	*Haqius ellipticus*	*Helenea chiastia*	*Kokia borealis*	*Lithraphidites bollii*	*Lithraphidites carniolensis*	*Manivitella pemmatoidea*	*Micrantholithus hoschulzii*	*Parhabdolithus embergeri*	*Pickelhaube furtiva*	*Rhagodiscus asper*	*Rhagodiscus dekaenelii*	*Rucinolithus terebrodentarius*	*Rucinolithus wisei*	*Tubodiscus burnettae*	*Tubodiscus jurapelagicus*	*Tubodiscus verenae*	*Watznaueria barnesae*	*Watznaueria biporta*	*Watznaueria britannica*	*Watznaueria manivitae*	*Watznaueria ovata*	*Watznaueria supracretacea*	*Zeugrhabdotus cooperi*	*Zeugrhabdotus diplogrammus*	*Zeugrhabdotus erectus*
29R-1, 131–132	408.11	P	T									R																				R								
29R-1, 139–141	408.19	P	B																																					
29R-2, 18–20	408.48	P	T									R																				R								

Notes: Preservation: VG = very good, G = good, M = moderate, P = poor. Abundance: A = abundant, C = common, F = few, R = rare, B = barren.

Table T2. Calcareous nannofossil distribution, Hole 1149C.

Core, section, interval (cm)	Depth (mbsf)	Preservation	Group Abundance	*Assipetra infracretacea*	*Calcicalathina oblongata*	*Cretarhabdus angustiforatus*	*Cruciellipsis cuvillieri*	*Cyclagelosphaera deflandrei*	*Cyclagelosphaera margerelii*	*Diazomatolithus lehmanii*	*Haqius circumradiatus*	*Haqius ellipticus*	*Helenea chiastia*	*Kokia borealis*	*Lithraphidites bollii*	*Lithraphidites carniolensis*	*Manivitella pemmatoidea*	*Parhabdolithus embergeri*	*Rhagodiscus asper*	*Rhagodiscus dekaenelii*	*Rucinolithus terebrodentarius*	*Rucinolithus wisei*	*Tubodiscus burnettae*	*Tubodiscus jurapelagicus*	*Tubodiscus verenae*	*Watznaueria barnesae*	*Watznaueria biporta*	*Watznaueria britannica*	*Watznaueria manivitae*	*Watznaueria ovata*	*Watznaueria supracretacea*	*Zeugrhabdotus cooperi*	*Zeugrhabdotus erectus*
185-1149C-																																	
4R-1, 6–9	293.26	P	F	C		R									R	R					R					A							
5R-1, 23–27	303.03	M	C	F		F		R	C	F	F	R	R	R	R			F		R	C			F		A		F	R		F		
6R-1, 18–20	312.58	P	F			R			R						R	R					R					A							
6R-1, 30–34	312.70	P	F	C	R						R		R	R		R		C	R		R		R	F	R	A							
6R-1, 35–41	312.75	P	C	R		R	R		C	C	F				R	F	R	C	R							A		F	F	F			
8R-1, 0–3	388.2	P	C	R			C		F	C							F	C							R	A		A	C				R
8R-1, 13–14	388.33	M	C	R	R	R	F		C	C								C				R	R	R	R	A	R	R	R				
8R-1, 51–53	388.71	M	C	R	R	R	C		R	C	R		R					C	R				R	R	R	A	C	C	F				
8R-1, 76–77	388.96	M	C	R		R	C	F	F	C			R			R		F	R			R		F	R	A		C	R			R	R
9R-1, 10–11	398	P	C	R		R	F	C	F	C		F	R			R		F	R	R						A		F	R			R	
9R-1, 22–24	398.12	M	C	F		R	C		C	C			R					C	R				R			A		R	F				
9R-1, 30–32	398.20	M	C	F			C		C	C			R					C	R			R	R		R	A		R	C				

Notes: Preservation: M = moderate, P = poor. Abundance: A = abundant, C = common, F = few, R = rare.

Table T3. Calcareous nannofossil distribution, Hole 1149D.

Core, section, interval (cm)	Depth (mbsf)	Preservation	Group Abundance	*Assipetra infracretacea*	*Cretarhabdus angustiforatus*	*Cruciellipsis cuvillieri*	*Cyclagelosphaera deflandrei*	*Cyclagelosphaera margerelii*	*Diazomatolithus lehmanii*	*Haqius circumradiatus*	*Helenea chiastia*	*Lithraphidites carniolensis*	*Parhabdolithus embergeri*	*Pickelhaube furtiva*	*Rucinolithus wisei*	*Speetonia colligata*	*Tubodiscus jurapelagicus*	*Tubodiscus verenae*	*Watznaueria barnesae*	*Watznaueria biporta*	*Watznaueria britannica*	*Watznaueria manivitae*	*Watznaueria ovata*	*Watznaueria supracretacea*
185-1149D-																								
2R-1, 0–5	272.2	P	T						VR										VR					
2R-1, 1–2	272.21	P	R				R	R	R				R						R				R	
3R-1, 34–35	281.94		B																					
4R-1, 1–5	290.91	M	C	F	R	R	R	F	F	R	R	R	C	R	F	R	F	F	A	R	R			R
4R-1, 1–5	290.91	P	R					F	A				R		R			R	A		C		C	
4R-1, 66–70	291.56	P	F				F	C	C										A		C	R		
5R-1, 13–15	300.43	P	T					VR	VR										VR				VR	

Notes: Preservation: M = moderate, P = poor. Abundance: A = abundant, C = common, F = few, R = rare, VR = very rare, T = trace, B = barren.

Plate P1. Microfossils shown under crossed nichols. **1.** *Calcicalathina oblongata* (Sample 185-1149B-19-1, 79–82 cm). **2–4.** *Cruciellipsis cuvillieri;* (2) Sample 185-1149B-24-1, 42–44 cm; (3, 4) Sample 185-1149B-25-1, 24–28 cm. **5.** *Kokia borealis* (Sample 185-1149B-16-1, 74–76 cm). **6, 7.** *Diazomatolithus lehmanii;* (6) Sample 185-1149B-24-1, 42–44 cm; (7) Sample 185-1149B-24-1, 42–44 cm. **8.** *Watznaueria barnesae* (Sample 185-1149B-24-1, 42–44 cm). **9.** *Assipetra infracretacea* (Sample 185-1149B-16-1, 74–76 cm). **10.** *Rucinolithus terebrodentarius* (Sample 185-1149B-16-1, 74–76 cm). **11.** *Lithraphidites bollii* (Sample 185-1149B-16-1, 79–81 cm). **12.** *Watznaueria britannica* (Sample 185-1149B-16-1, 79–81 cm). **13, 14.** *Tubodiscus* cf. *jurapelagicus;* (13) Sample 185-1149B-24-1, 24–28 cm; (14) Sample 185-1149B-24-1, 21–24 cm. **15, 16.** *Tubodiscus verenae;* (15) Sample 185-1149B-24-1, 30–32 cm; (16) Sample 185-1149B-28-1, 57–58 cm. **17–19.** *Rucinolithus wisei;* (17) Sample 185-1149B-28-1, 57–58 cm; (18, 19) Sample 185-1149B-26-1, 14–19 cm. **20.** *Parhabdolithus embergeri* (Sample 185-1149B-28-1, 57–58 cm).