41. BIOSTRATIGRAPHY AND DEPOSITIONAL HISTORY OF THE MOROCCAN BASIN, EASTERN NORTH ATLANTIC, DEEP SEA DRILLING PROJECT LEG 50

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ABSTRACT

Two sites drilled during DSDP Leg 50 in the Moroccan Basin, near the foot of the North African continental margin, yielded sediments ranging from Pleistocene to Upper Jurassic. Drilling was terminated at Site 415 in Albian sediments at a sub-bottom depth of 1079.5 meters, and at Site 416 in Tithonian sediments at 1624 meters. The stratigraphic sequences at Site 416 and at Site 370, 2 km to the east, were combined.

Comparison of sediment-accumulation rates permits reconstruction of the depositional history of the Moroccan Basin. During Tithonian–Neocomian time, Site 416 occupied a very distal position on a deep-sea fan system. The sea floor was below the CCD, as indicated by indigenous benthic-foraminifer assemblages. Calcareous material from shallower water and terrigenous detritus were redeposited at the site by turbidity currents. Redeposition apparently was mostly penecontemporaneous, as indicated by the normal, sequential order of first occurrences of species from various fossil groups, making biostratigraphic zonation possible. Continued redeposition, however, is evidenced by extended upper limits of species. Berriasian sediments accumulated at an average rate of 10 m/m.y. In the upper lower Valanginian, transported elements increase in abundance, corresponding to an increase in the rate of accumulation. Carbonate turbidite layers decrease in importance, whereas terrigenous material increases and dominates the sediments in the uppermost Valanginian and Hauterivian. The distal flysch sequence of the Valanginian–Hauterivian interval accumulated at the high average rate of 65 m/m.y. A marked change in sedimentation took place near the Barremian/Hauterivian boundary, when the rapid accumulation of flysch ended rather abruptly, to be replaced during the Barremian to Albian interval by distal turbidites and hemipelagic muds accumulating at Sites 416 and 370 at much slower rates (6–12 m/m.y.). A remarkably thick middle Cenomanian sequence (over 300 m) accumulated at Site 415 as a result of gravitational sliding, whereas the entire Cenomanian appears to be missing at Sites 416 and 370. Autochtonous benthic foraminifers in the Cenomanian interval at Site 415 suggest a water depth of 3000 to 4000 meters. A major hiatus, possibly equivalent to a time span as great as 40 m.y., represents the entire Upper Cretaceous at both sites. However, inclusion of allochtonous Maestrichtian nannofossil chalk within Paleocene strata indicates that calcareous pelagic sedimentation has prevailed in nearby areas since the latest Cretaceous.

The substantial hiatus deleted all record across the Cretaceous/ Tertiary boundary at both sites and was followed by several phases of erosion or non-deposition during the early Cenozoic. Paleocene and Eocene pelagic sediments at both sites indicate that the sea floor was above the CCD. Preservation of calcareous fossils, however, remains poor throughout the Paleogene. Paleocene and Eocene sequences are mostly very condensed and include short hiatuses. These sediments accumulated at an average rate of no more than 1 m/m.y., except for intervals where higher accumulation rates are related to influx of detrital material (upper Paleocene and lower Eocene at Site 415, 15 m/m.y.; and middle Eocene at Sites 416 and 370, 27 m/m.y.). A new phase of erosion or non-deposition took place during the late Eocene and Oligocene and lasted through the early early Miocene at Site 415. Turbiditic sedimentation prevailed from the late Oligocene through the end of the middle Miocene at Sites 416 and 370 and started sometime in the early Miocene at Site 415, resulting in a relatively high average rate of accumulation (20 m/m.y.). At the end of the middle Miocene, the turbidites gave way to calcareous oozes, which prevailed until Recent times.

A detailed investigation of Neogene sedimentation is precluded, owing both to the spotty record and to uncertainty of the exact depths from which sediment samples were recovered, so that average accumulation rates given for this interval represent only a rough estimate. Upper Miocene sediments accumulated at both sites at a reduced rate of 9 to 10 m/m.y. At Sites 416 and 370, an unconformity equivalent to a time interval of approximately 1 m.y. spans the Pliocene/Pleistocene boundary, whereas at Site 415 an apparently continuous Pliocene–Pleistocene sequence accumulated at an average rate of 18 m/m.y.

INTRODUCTION

Leg 50 of the international phase of the Deep Sea Drilling Project recovered sediments ranging from Pleistocene to Jurassic from two drill sites (415 and 416) in the eastern North Atlantic, off the North African continental margin (Table 1; Figure 1). The primary objective of Leg 50 was to sample as deeply as possible into the Jurassic to document the history of early rifting and sedimentation in the central Atlantic. The Moroccan continental margin displays all the features of a rifted margin and is one of the oldest "starved" margins of the eastern Atlantic (Lancelot and Winterer, this volume). The evolution of this margin since Early Jurassic time could be studied by drilling into sediments from the deep basin at the foot of the slope. Because of technical difficulties, however, Sites 415 and 416 fell short of our objectives and did not penetrate sediments older than latest Jurassic.

Site 415 is on the northern flank of the Agadir Canyon, at a water depth of approximately 2800 meters. Three holes were drilled at this site. Because of unstable hole conditions, we abandoned the site after reaching

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TABLE 1
Locations and Water Depths of DSDP Sites
Cited in this Report

Leg	Site	Latitude	Longitude	Water Depth (m)
50	415	31°01'N	11°39'W	2804
50	416	32°50'N	10°48'W	4201
41	370	32°50'N	10°46'W	4214
41	369	26°35'N	14°59'W	1752
41	367	12°29'N	20°02'W	4748
47	397	26°50'N	15°10'W	2900

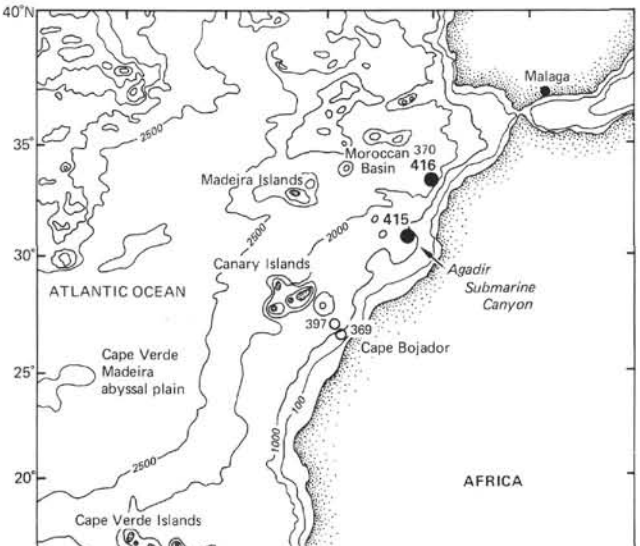


Figure 1. *Location of DSDP sites cited in this report.*

Albian sediments at a sub-bottom depth of 1079.5 meters. Site 416 is in the deep Moroccan Basin, at a water depth of approximately 4200 meters. Two holes were drilled. The first (416), drilled as a pilot hole prior to setting the re-entry cone for the second hole (416A), penetrated less than 20 meters of sediment, and only one core was recovered. Hole 416A was terminated at a sub-bottom depth of 1624 meters in uppermost Jurassic (Tithonian) sediments.

Because of the time required by deep penetration necessary to reach Middle to Early Jurassic sediments, anticipated to lie at depths of 2000 meters or more below the sea floor, the Tertiary section was sampled only sparsely. Neogene sedimentation in the area previously had been well documented by continuous coring at Site 369 (DSDP Leg 41; see Lancelot, Seibold, et al., 1978) and Site 397 (Leg 47; see von Rad, Ryan, et al., 1979) to the south, off Cape Bojador (Figure 1). At Site 397, a remarkable, expanded Neogene section was sampled, especially valuable for late-Miocene biostratigraphy. At Site 370, drilled during Leg 41, about 2 km east of Site 416, the Neogene and upper-Oligocene section was discontinuously cored to a sub-bottom depth of 426 meters. Below that level, coring was nearly continuous to a total depth of 1176.5 meters. Site 416 thus was cored intermittently to that depth and cored continuously below. The two nearby Sites 416 and 370 were combined in order to reconstruct the stratigraphic sequence in the area.

A summary of the drilling results is presented in Figure 2.

INVESTIGATED FOSSIL GROUPS, ZONATIONS, AND AGE ASSIGNMENTS

In addition to the work done by the shipboard paleontologists other specialists have investigated specific groups of microfossils: S. Gartner and T. Cool, calcareous nannofossils, in collaboration with P. Čepek; A. Sanfilippo and W. R. Riedel, radiolarians, in collaboration with M. J. Westberg; R. Lehmann, calpionellids, in collaboration with E. Vincent, W. V. Sliter, and M. J. Westberg; M. B. Cita and A. Vismara Schilling, Miocene-Pliocene planktonic foraminifers; D. Bukry, silicoflagellates and other phytoplankton groups of the middle and lower Miocene; G. L. Williams and J. P. Bujak, Jurassic and Neocomian palynomorphs; H. Bolli, Jurassic and Neocomian calcisphaerulids, which had not been described previously from this part of the stratigraphic column; and E. G. Kauffman, small bivalves from two levels in the Cenomanian and Pleistocene.

The biostratigraphy of the sediments recovered at Sites 415 and 416 was established using zonations based on calcareous nannofossils (Cenozoic and Mesozoic sections of Sites 415 and 416), planktonic foraminifers (Cenozoic and Mesozoic sections of Site 415 and Cenozoic section of Site 416), benthic foraminifers (Mesozoic section of Site 416), radiolarians (Cenozoic and Mesozoic sections of Site 415 and Neogene section of Site 416), palynomorphs (lower Cretaceous and Jurassic section of Site 416), and calpionellids (Lower Cretaceous and Jurassic section of Site 416). The abundance and preservation of these fossils is schematically shown in Figure 3.

The planktonic zonal schemes used are those from (1) Martini (1971) and Gartner (1977) for Cenozoic calcareous nannofossils; (2) Barnard and Hay (1974) (modified) for Mesozoic calcareous nannofossils; (3) Blow (1969) and Cita (1975) for Cenozoic planktonic foraminifers; (4) Sliter (this volume) for Mesozoic planktonic foraminifers (a composite zonation from upper Albian to middle Cenomanian, developed from recent schemes of van Hinte, 1976a, Premoli Silva and Boersma, 1977, and Sigal, 1979); (5) Riedel and Sanfilippo (1978) for radiolarians; and (6) from Remane (1978) for calpionellids.

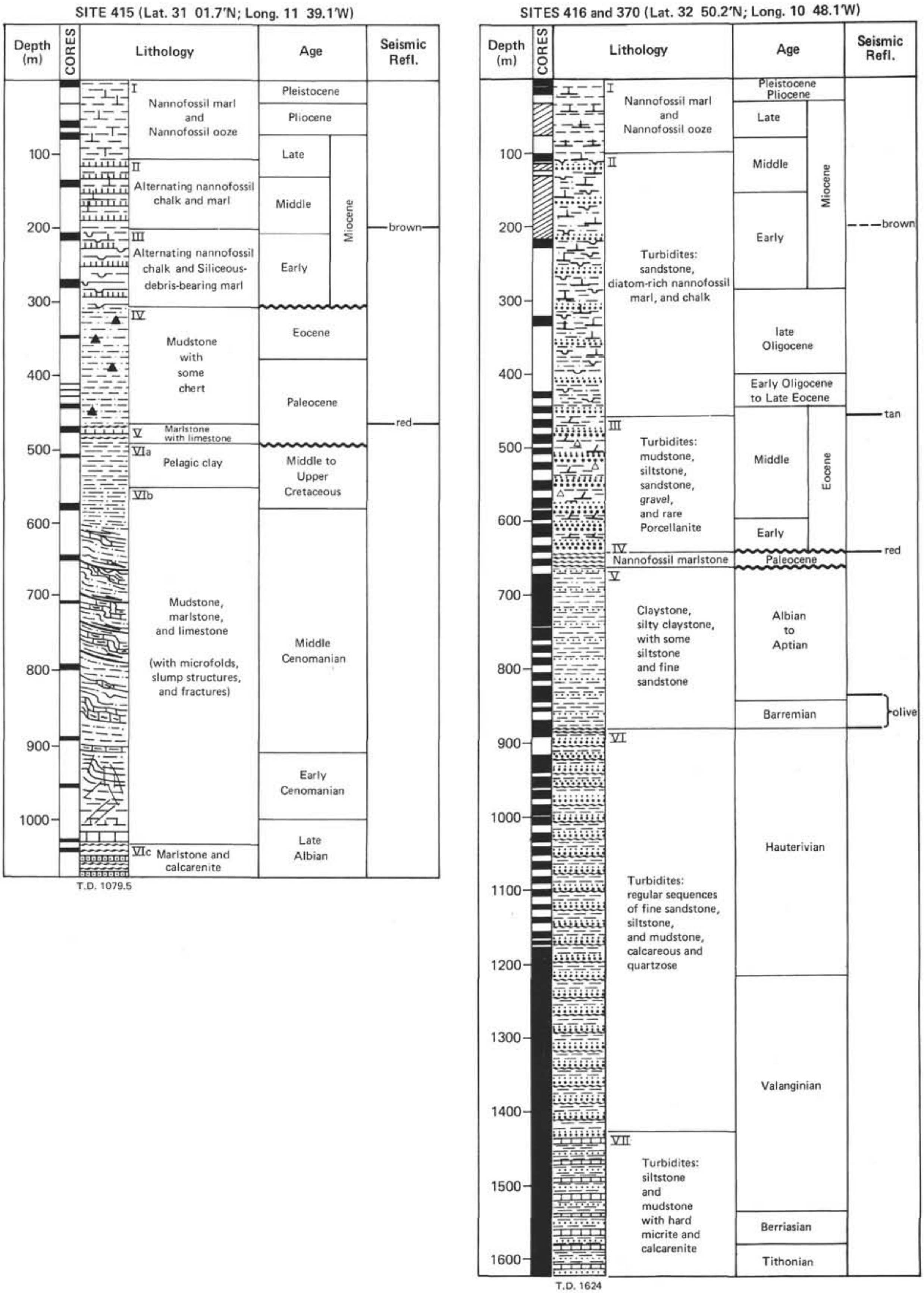


Figure 2. *Stratigraphic summary, Sites 415 and 416/370.*

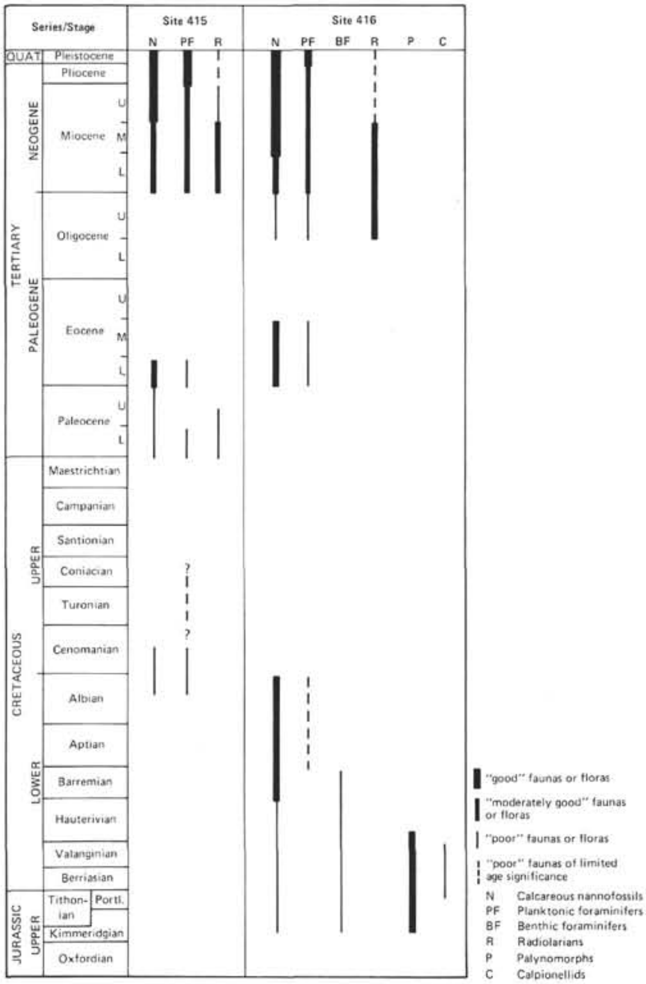


Figure 3. *Stratigraphic distribution of microfossils used for zonation at Sites 415 and 416.*

Correlations among these various planktonic zonal schemes and that of Bukry (1975) applied to the Cenozoic of Site 370, as well as their calibration to the absolute time-scale is shown on Figures 4, 5 and 6, which were used to estimate sediment accumulation rates.

Age assignments for Mesozoic foraminifers from Site 416 (Sliter, this volume) are based on typically poorly preserved and sporadic benthic species. Jurassic assemblages are correlated with those of Kuznetsova and Seibold (1978) from DSDP Leg 41 and Luterbacher (1972) from DSDP Leg 11 in the North Atlantic. In addition, correlation is made with European assemblages described by Haeusler (1890), Seibold and Seibold (1960), Bielecka (1960), and Gross (1967), and with foraminifers from the type Kimmeridgian reported by Lloyd (1959). Neocomian assemblages are dated by the ranges and first appearances of benthic species established in Europe by authors such as Bartenstein and Brand (1951), Bartenstein and Bettenstaedt (1962) and Moullade (1966), and the subsequent recognition of similar distributions in other geographic regions in studies such as those by Bartenstein (1976, 1977) and Bartenstein and Bolli (1977). Correlation is also provided by comparison with previous Neocomian assemblages described from North Atlantic DSDP sites by Kuznetsova and Seibold (1978), Maync (1973), and Luterbacher (1972).

Age assignments for the Mesozoic palynological sequence at Site 416 (Williams and Bujak, this volume) are based on studies by Bujak and Williams (1977, in press) and Williams (1975, 1978a). Bujak and Williams (1977) recognized ten palynological zones in the Jurassic of the Scotian Shelf and Grand Banks off southeastern Canada. Four Callovian–Portlandian zones were formally erected by Williams (1975), who also erected 11 palynological zones in the Cretaceous. All the zones were tentatively correlated with standard European Mesozoic stages, although there is considerable uncertainty as to the precise age of the base and top of each zone. Bujak and Williams (in press) have applied the Cretaceous zonation proposed by Williams (1975), to 26 wells and found that it is a viable zonation, although there is some uncertainty in correlating with the European surface sections.

Williams (1978a), after a comprehensive survey of available literature, formally erected 30 dinocyst concurrent-range zones, which delineate the Late Triassic, Jurassic, Cretaceous, and Tertiary. These are generally equated with the type European stages. Palynological analysis of the Upper Jurassic–Lower Cretaceous interval at Site 416 shows that many of the dinocyst species are ubiquitous. This has permitted correlation with the zonations of Bujak and Williams (1977, in press) and Williams (1975, 1978a), and hence allowed age determinations keyed to the standard European stages.

In general, good agreement among fossil groups for age assignments of recovered sediments was obtained, except for the discrepancy between age assignments based on palynological data and calcareous-fossil data for the Jurassic–Neocomian interval at Site 416. Stratigraphic boundaries based on palynological data are consistently higher in the section than those based on calcareous fossils.

BIOSTRATIGRAPHIC SUMMARY

Site 415

The 1079-meter-thick sedimentary section penetrated at Site 415 represents a sequence from Quaternary to upper Albian with a remarkably thick middle-Cenomanian interval (over 300 meters thick). Included are two substantial gaps equivalent to a time of about 25 to 30 m.y., encompassing the lowermost Miocene through the middle Eocene and most of the Upper Cretaceous, respectively, and two minor ones of approximately 2 to 3 m.y. near the Miocene/Pliocene and the upper/lower Paleocene boundaries.

A summary of the various fossil-group zonations plotted against sub-bottom depths is presented in Figure 7. Spot coring with broad uncored intervals and poor recovery often precludes precise positioning of epoch boundaries. Several of these were placed within uncored intervals on the basis of sedimentation rates or lithologic changes reflected on the gamma-ray log. The various criteria used for placement of stratigraphic boundaries in the sequence are discussed in detail in the sedi-

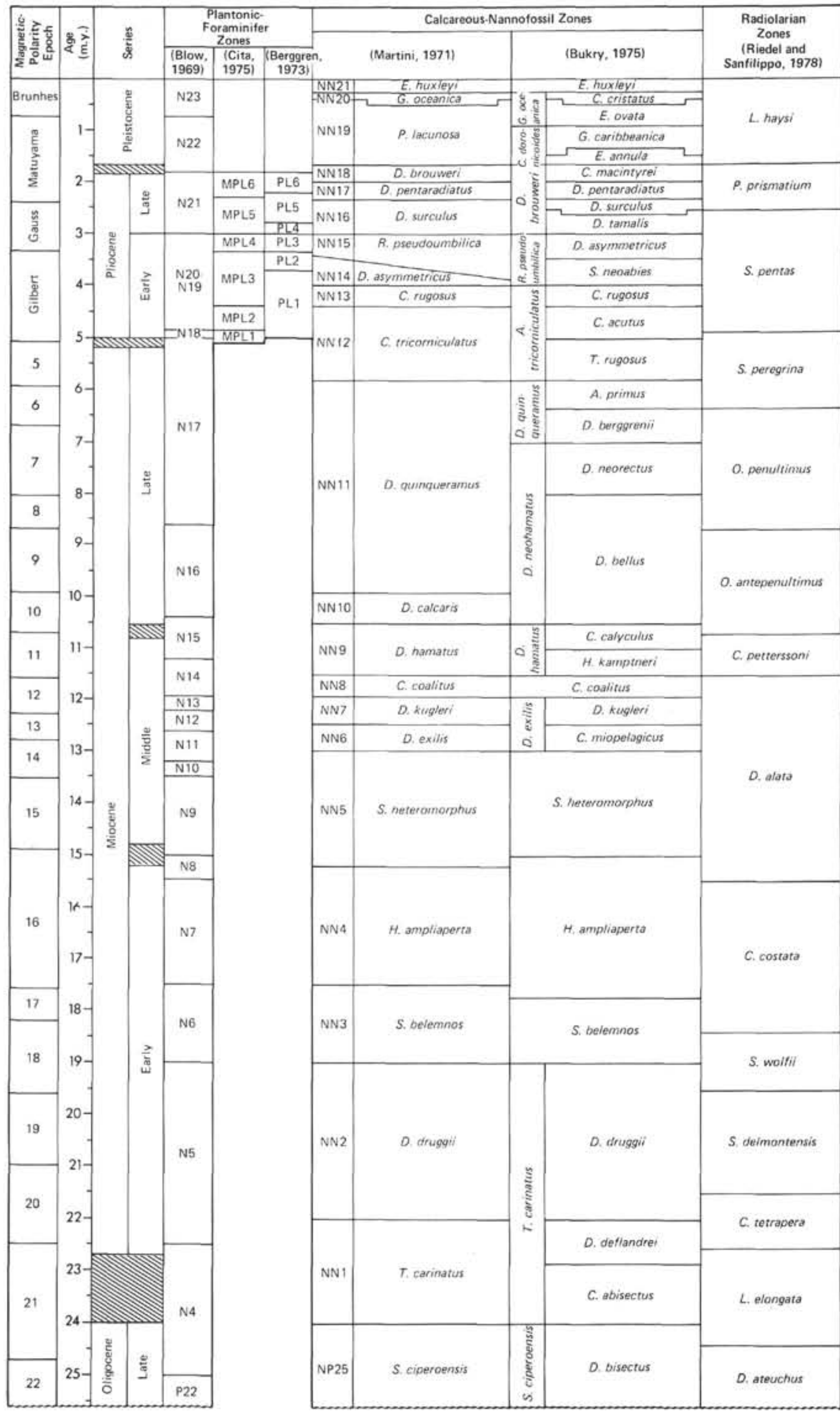


Figure 4. *Neogene time scale used for age assignments of Leg 50 sediments (modified from Vincent, 1977). The correlation of Blow's (1969) planktonic-foraminifer zones for tropical regions with those of Martini (1971) for calcareous nannoplankton and the assignment of absolute ages to the zone boundaries are from Berggren (1973), Berggren and Van Couvering (1974) and Van Couvering and Berggren (1977). The calcareous nannoplankton zonal scheme of Bukry (1975) is correlated with Martini's zonation. The Pliocene planktonic-foraminifer scheme of Berggren (1973) is for the tropical Atlantic and that of Cita (1975) is for the Mediterranean. The ages recognized for the radiolarian zone boundaries of Riedel and Sanfilippo (1978) are those proposed by Theyer and Hammond (1974a,b), and Theyer et al. (1978). The paleomagnetic time scale is from Van Couvering and Berggren (1977) and Theyer and Hammond (1974a,b).*

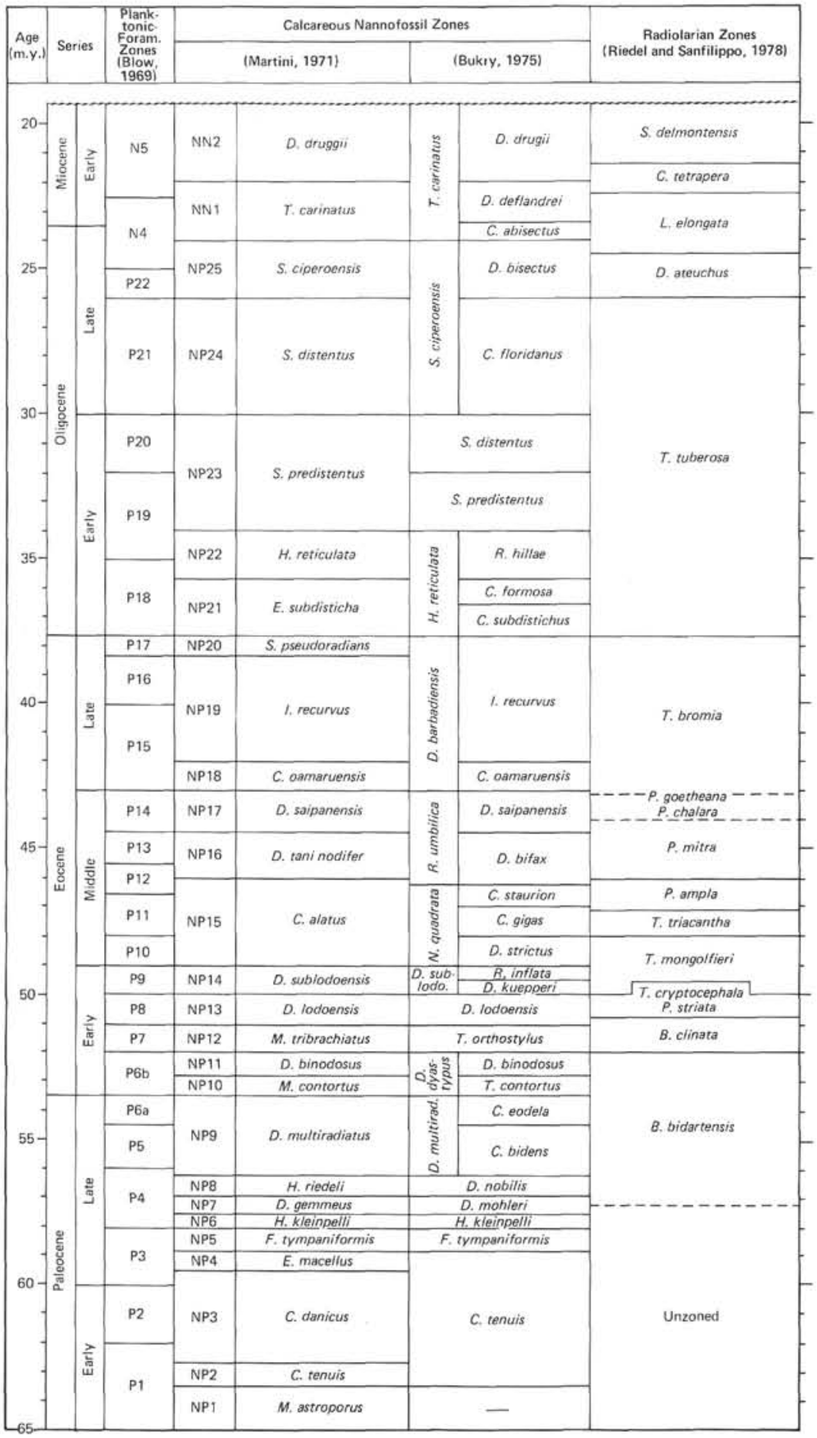
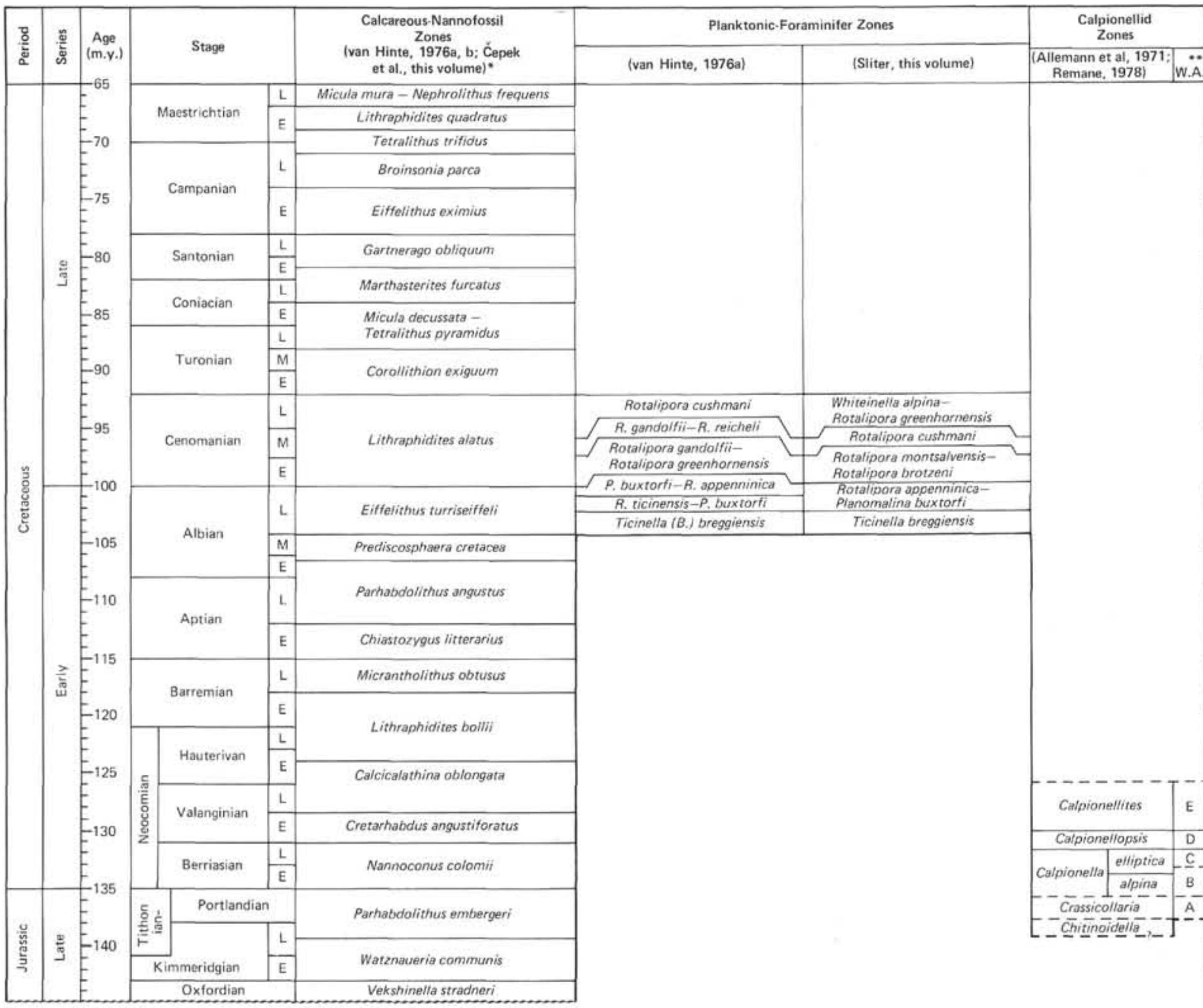


Figure 5. *Paleogene time scale used for age assignments of Leg 50 sediments (modified from Vincent, 1974). (Since the completion of the manuscript for this paper, an improved Paleogene time scale with paleomagnetostratigraphy and the position of stage stratotypes has been published by Hardenbol and Berggren, 1978.)*

mentation-rate section of Site 415 report (this volume) and are summarized in Figure 8. Average accumulation rates are shown in Figure 9, and a mean accumulation curve is given in Figure 10.

Site 416

Because of the drilling technique used at Site 416 while taking the widely-spaced cores of the upper 1100



*The zonal scheme of Cepek *et al.* (this volume) differs from that of van Hinte (1976a) in that the base of the *Lithraphidites alatus* zone (as placed here) is defined by the first appearance of *L. alatus*, and thus extends stratigraphically lower than van Hinte's *L. alatus* zone.

**Calpionellid zones for the Western Alps, after Remane.

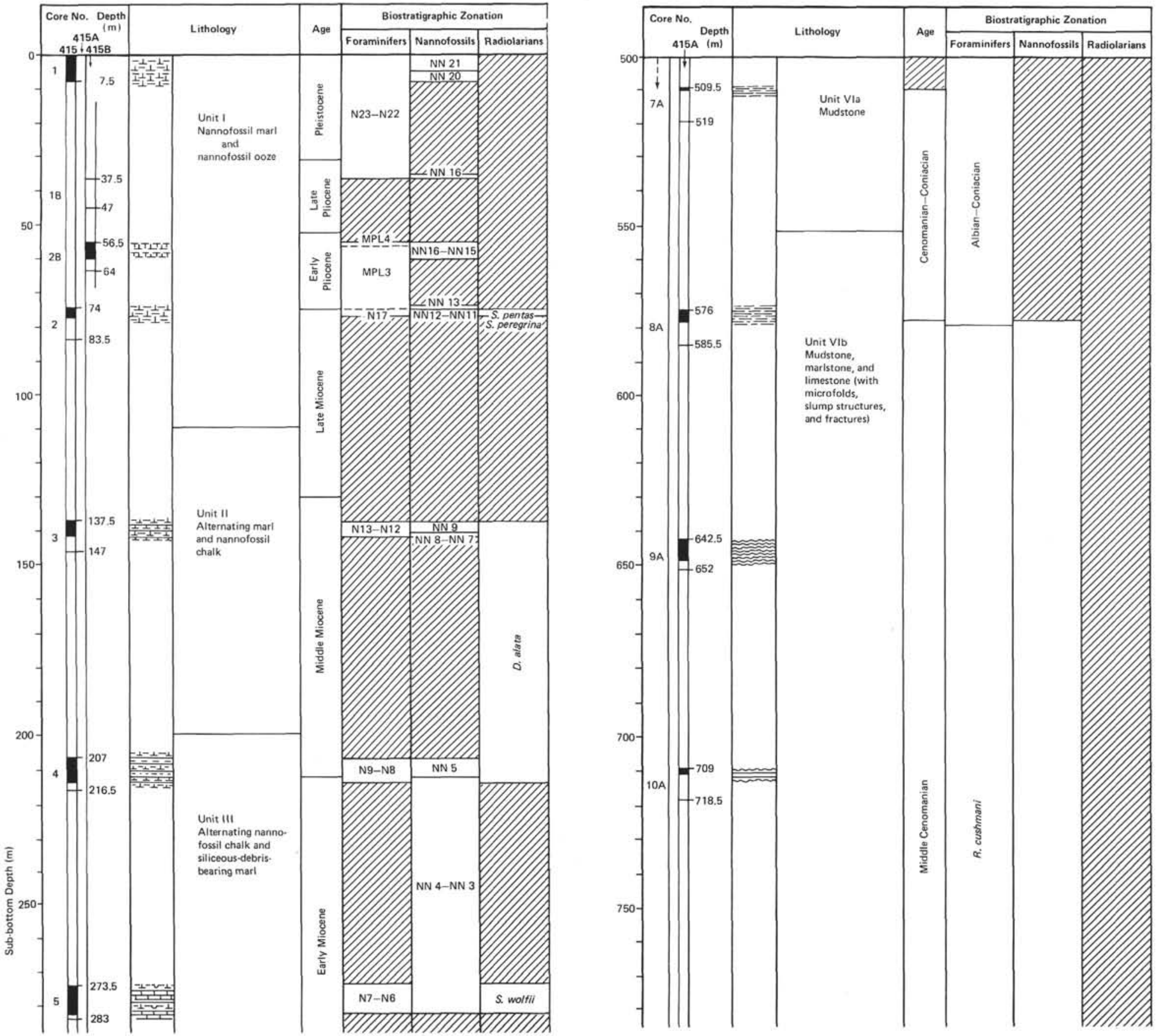
Figure 6. *Cretaceous and latest-Jurassic time scale used for age assignment of Leg 50 sediments. The correlations of the calcareous-nannofossil zones with those of van Hinte (1976a) for planktonic foraminifers (only that part of the latter zonation spanning Site 415 faunas is represented here) and with the calpionellid zones are from van Hinte (1976a). The assignment of absolute ages to the zone boundaries are from van Hinte (1976a,b). The planktonic-foraminifer zonal scheme of Sliter (this volume) is correlated to that of van Hinte according to Sliter (this volume).*

meters, the locations of these are uncertain and are commonly higher than the nominal levels indicated in the coring summary and on the core-description sheets in the Site 416 report (this volume). Results from Site 370, about 2 km to the east, however, have helped us to estimate the actual location of the samples and define the most plausible stratigraphic boundaries. A detailed discussion of the comparison between the two sites is given in the sedimentation-rate section of the Site 416 report. The composite sequence derived from results of both Sites 416 and 370 is shown in Figures 11 and 12. Average accumulation rates are given in Figures 13 and 10.

The 1624-meter-thick sedimentary section represents a sequence from Pleistocene to Tithonian. A substantial hiatus of about 40 m.y. extends from the Late Cretaceous through the earliest Paleocene; a hiatus of lesser importance encompasses part of the late Eocene and probably all of the early Oligocene; and two minor hiatuses of about 1 to 2 m.y., span the Pliocene/Pleistocene and the Paleocene/Eocene boundaries, respectively.

DEPOSITIONAL HISTORY OF THE MOROCCAN BASIN

Our ultimate goal was to reconstruct the early evolution of the passive North African continental margin by sampling pre-Oxfordian sediments and comparing their biofacies in the Atlantic basin with those of western



Core No.
Depth (m)
415A
415
415B
Lithology
Age
Biostratigraphic Zonation
Foraminifers
Nannofossils
Radiolarians
Sub-bottom Depth (m)
0
50
100
150
200
250
7.5
37.5
47
56.5
64
74
83.5
137.5
147
207
216.5
273.5
283
1
1B
2B
2
3
4
5
Unit I
Nannofossil marl and nannofossil ooze
Unit II
Alternating marl and nannofossil chalk
Unit III
Alternating nannofossil chalk and siliceous-debris-bearing marl
Pleistocene
Late Pliocene
Early Pliocene
Late Miocene
Middle Miocene
Early Miocene
N23–N22
MPL4
MPL3
N17
N13–N12
N9–N8
N7–N6
NN 21
NN 20
NN 16
NN16–NN15
NN 13
NN12–NN11
NN 9
NN 8–NN 7
NN 5
NN 4–NN 3
S. pentas
S. peregrina
D. alata
S. wolfii
500
550
600
650
700
750
509.5
519
576
585.5
642.5
652
709
718.5
7A
8A
9A
10A
Unit VIa
Mudstone
Unit VIb
Mudstone, marlstone, and limestone (with microfolds, slump structures, and fractures)
Cenomanian–Coniacian
Middle Cenomanian
Albian–Coniacian
R. cushmani

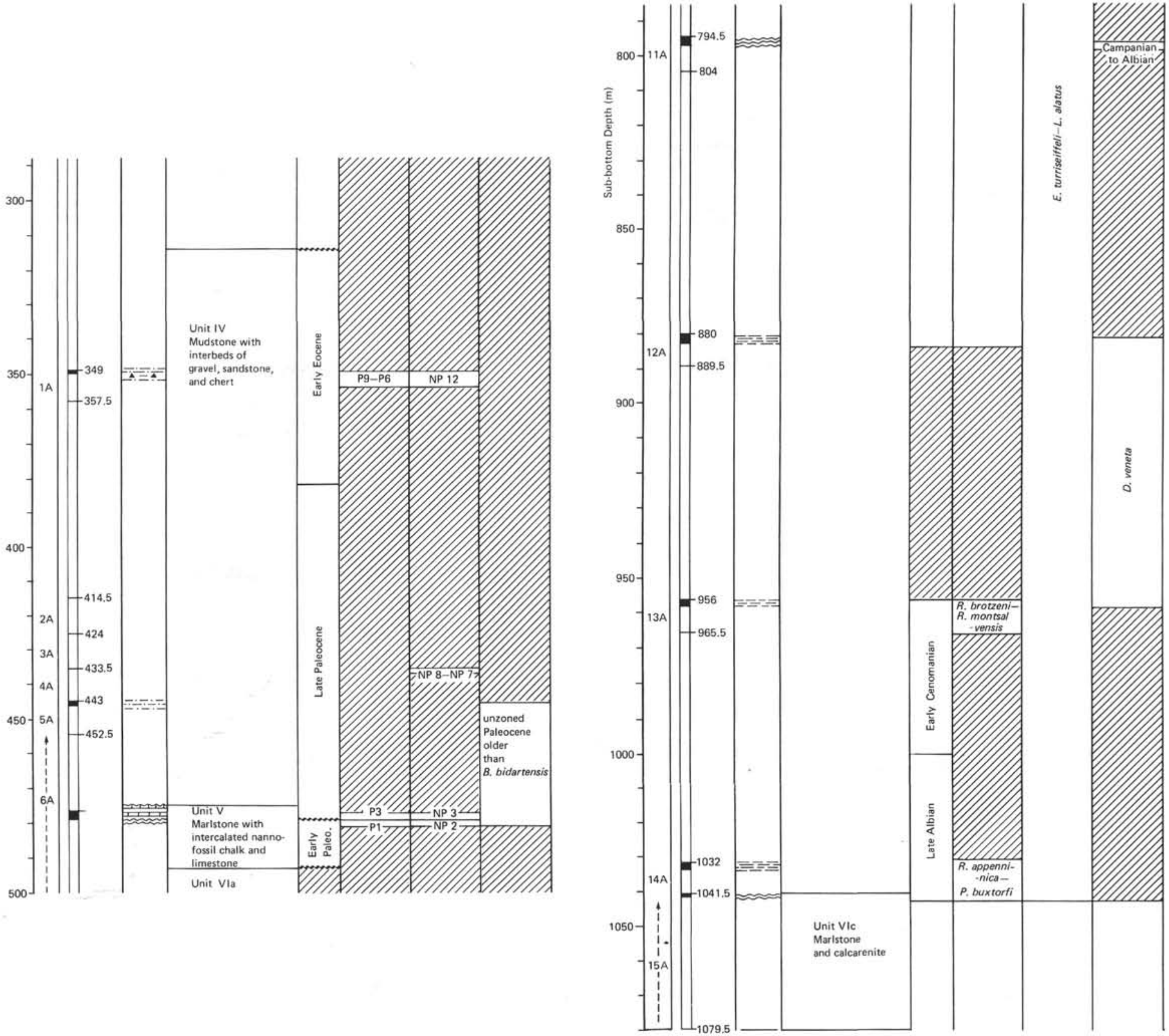


Figure 7. *Biostratigraphy of Site 415. See Figure 8 for placement of series boundaries.*

Series	Cores	Approximate Sub-bottom Depth of Boundary (m)	Basis for Boundary Position
Pleistocene	415-1		
		32	Inferred from sedimentation rate
Upper Pliocene	415B-1		
		54	Inferred from sedimentation rate
Lower Pliocene	415B-2-1, 22 cm		
		75	Highest N17 sample
Upper Miocene	415-2-1, 102 cm 415-2,CC		
		130	Inferred from sedimentation rate
Middle Miocene	415-3 415-4-3		
		211.5	NN 5/NN 4 boundary
Lower Miocene	415-4-4 415-5		
		313	Inferred from gamma-ray log
Lower Eocene	415A-1		
		381	Inferred from sedimentation rate
Upper Paleocene	415A-4 415A-6-1, 69 cm		
		477.2	Overlap of NP 3 and P3
Lower Paleocene	415A-6-1, 74 cm 415A-6,CC		
		491	Inferred from gamma-ray log
Middle to Upper Cretaceous	415A-7 415A-8-1		
		577.5	Highest *R. cushmani* Zone sample
Middle Cenomanian	415A-8-2 415A-12		
		between 883 and 956	Undetermined
Lower Cenomanian	415A-13		
		1000	Arbitrarily placed at mid-point between cores
Upper Albian	415A-14 415A-15		
		TD 1079.5	

Figure 8. *Stratigraphic series at Site 415.*

Moroccan basins, especially the nearby Essaouira Basin, where marine sediments as old as Early Jurassic are exposed. Detailed microfacies and micropaleontological studies of these basins are available in geological syntheses of western Morocco in which one of the authors (Vincent) has been involved (Choubert and Faure-Muret, 1962; Société Chérifienne des Pétroles, 1966). Despite our disappointment in falling short of our objective (we did not reach sediments older than latest Jurassic), we were able to document the evolution of the North African margin, especially for Cretaceous time. A comparison of sediment-accumulation rates at the two drilling sites (Fig. 10), and of biofacies of sediments recovered during Leg 50 with those of onshore basins, permits a reconstruction of the depositional history of the Moroccan Basin.

During the widespread latest Jurassic–Neocomian regression, which resulted in neritic and littoral facies in western Morocco and in the formation of carbonate banks seaward, detrital sediments were deposited by turbidity currents at Site 416, at the foot of the continental slope. This is where the core record at Site 416 begins at a sub-bottom depth of 1624 meters. There is no direct paleontological evidence of the exact age of the lowermost sediments. However, assuming that Jurassic deposits accumulated at the same average rate as those of the overlying Berriasian (10 m/m.y.), the sediments at the base of the hole would be of early Tithonian–late Kimmeridgian age, approximately 140 m.y. old. Thus, the record at Site 416 begins with sediments not much younger than the widespread Oxfordian transgression recorded in all basins surrounding the Atlantic Ocean, whose maximum transgressive episode in western Morocco took place during the Sequanian–early Kimmeridgian (*Pseudocyclammina jaccardi* Zone; Société Chérifienne des Pétroles, 1966). We have no evidence of what the nature of these transgressive deposits is at Site 416 below the bottom of the hole. Lancelot and Winterer (this volume), however, argue that during the widespread transgression accumulation of massive terrigenous clastics may have been interrupted at the site and that Callovian–Oxfordian through lower-Kimmeridgian sediments there may include pelagic deposits. This pelagic interval possibly, intercalated between two clastic intervals, may correlate with the strong ("blue") seismic reflector, estimated to lie a few tens of meters below the lowest level reached at Site 416.

During Tithonian–Neocomian time, Site 416 occupied a very distal position on a deep-sea fan system. Detritus was supplied from carbonate banks and continental sources, both materials coming in separately and becoming mixed during deposition by turbidity currents (Price, this volume). Hemipelagic aragonitic lime

	Paleontological Events	Cores, Site 415	Sub-bottom Depth (m)	Age (m.y.)	Average Sediment Accumulation Rate (m/m.y.)	
					27.8	17.8
1	NN 21/NN 20 boundary	415-1-5/415-1-6	7.5	0.27		
					16.3	
2	Top *G. margaritae*	415B-2 (upper)	Ca. 57	3.3		
					19.6	
3	Bottom *G. puncticulata* Bottom *C. rugosus*	415-2-1, 63 cm	74.63	4.2		
Hiatus spanning approximately 2 m.y. at 75 m						
4	NN 9/NN 8 boundary	415-3-3 (base)	141.5	11.5		
					17.5	19.7
5	NN 5/NN 4 boundary	415-4-3/415-4-4	211.5	15.5		
					22.3	
6	Within the overlap between *S. wolffii* Zone and N.6 and NN 3	415-5 (base)	283	18.5-19		
Probable hiatus spanning approximately 29 m.y. at 313 m						
7	Within NP 12	415A-1 (base)	349.25	51-52		
					16.1	15.5
8	Within NP 8–NP 7	415A-4 (base)	433.75	56-57.5		
					14.5	
9	Within the overlap between P 3 and NP 3	415A-6-1, 69 cm	477.20	59.5-60		
Probable hiatus spanning approximately 3 m.y. at 477.2 m						
10	Within NP 2	415A-6,CC	?	63		
Probable hiatus spanning approximately 20 m.y. at 491 m						
11	Within *R. cushmani* Zone	415A-8-2, 105 cm	578.55	96-97.5		
					203 minimum	
12	Within *R. cushmani* Zone	415A-12,CC	883	96-97.5		
					?	
13	Within *R. brotzeni–R. montsalvensis* Zone	415A-13	956–965.5	97.5–100		
					34.7	
14	Within *R. appenninica–P. buxtorfi* Zone	415A-14 415A-15	1032–1043	100–102		

Figure 9. *Average sediment-accumulation rates at Site 415. Ages are taken from the time scales represented in Figures 4 to 6. The age of paleontological event 2 is from Hays et al. (1969), Berggren (1973), Saito et al. (1975), and Ryan et al. (1974), and that for paleontological event 3 is from Gartner (1973), Cita and Gartner (1973), Kennett and Watkins (1974), and Ryan et al. (1974). When a certain thickness or a time span is indicated for a paleontological event, the mid-point of the interval has been taken arbitrarily for calculating the accumulation rate.*

muds rich in calpionellids were probably deposited between the carbonate banks and Site 416, on the shelf and on the slope, and then were partly eroded by turbidity currents which transported mud pellets and calpionellids to Site 416 (Schlager, this volume; Vincent et al., this volume). The sea floor at the site was below the CCD at a water depth probably well in excess of 2000 meters, as indicated by arenaceous deep-water benthic foraminifers (Sliter, this volume). This indigenous foraminifer assemblage occurs only in the uppermost parts of the turbidite cycles. Other benthic foraminifers are transported and size sorted, bathyal and neritic species which occur with echinoid spines, ostracodes, bivalve fragments, *Inoceramus* prisms, aptychi, calcisphaerulids, calpionellids, ooids, and lime-mud pellets. Thus, all calcareous material was sedimented from shallower water. Redeposition, however, was apparently penecontemporaneous, as indicated by the normal sequential order of first occurrences of species, making biostratigraphic zonation possible. Last occurrences of species, however, do not appear to be reliable, as evidenced by common upward reworking.

Above Core 416A-40 (near the top of lithologic unit VII, in the upper lower Valanginian), indigenous deep-water benthic foraminifers become less dominant, and transported elements increase in abundance, corresponding to an increase in the rate of sediment accumulation. Carbonate turbidite layers also decrease in importance, whereas terrigenous material increases and dominates the sediments in the uppermost Valanginian and Hauterivian. The entire distal "flysch" sequence of the Valanginian–Hauterivian interval appears to have accumulated at the very high average rate of 65 m/m.y.

A marked change in sedimentation took place near the Barremian/Hauterivian boundary, when the rapidly accumulating flysch ended rather abruptly, to be replaced during the Barremian to Albian interval by distal turbidites and hemipelagic muds accumulating at Site 416 at the much slower rate of 6 to 12 m/m.y. This abrupt change in sedimentary regime is recorded by transgressive facies in the Essaouira Basin (Choubert and Faure-Muret, 1962).

A major hiatus spanning most of the Upper Cretaceous and lower Tertiary is a widespread event in the North Atlantic. It is recorded in the western part of this basin (Hollister, Ewing, et al., 1972; Tucholke, Vogt, et al., 1979), as well as in its eastern part (Lancelot, Seibold, et al., 1978; von Rad, Ryan, et al., 1979), but its magnitude varies from area to area.

Leg 50 data are not well suited to date this hiatus in the Moroccan Basin. It appears, however, that in the area of Site 415 and 416 the stratigraphic gap may be equivalent to a time span as great as 40 m.y., and that the entire Upper Cretaceous is missing. The only record of Upper Cretaceous sediments in the Moroccan Basin comes from Site 415, where Maestrichtian chalk, probably reworked from nearby slopes, occurs within lower Paleocene strata.

At both Sites 415 and 416, the unconformity occurs in an unrecovered interval and was placed according to a very abrupt change in sediment properties, marked by a sharp peak in the gamma-ray log. At Site 415, there is very poor biostratigraphic control below the unconformity, where 87 meters of pelagic clay with common zeolites, barren of nannofossils, contains only rare specimens of *Hedbergella,* ranging in age from Albian to Coniacian. Thus, the sedimentation rate for this interval cannot be estimated. In any case sediments must have accumulated slowly. The combination of low sedimentation rate, strong carbonate dissolution, and development of zeolites correlates these deposits with the dissolution facies or barren interval that characteristically extends from the late Cenomanian to the middle Santonian in oceanic sediments (Sliter, 1976, 1977).

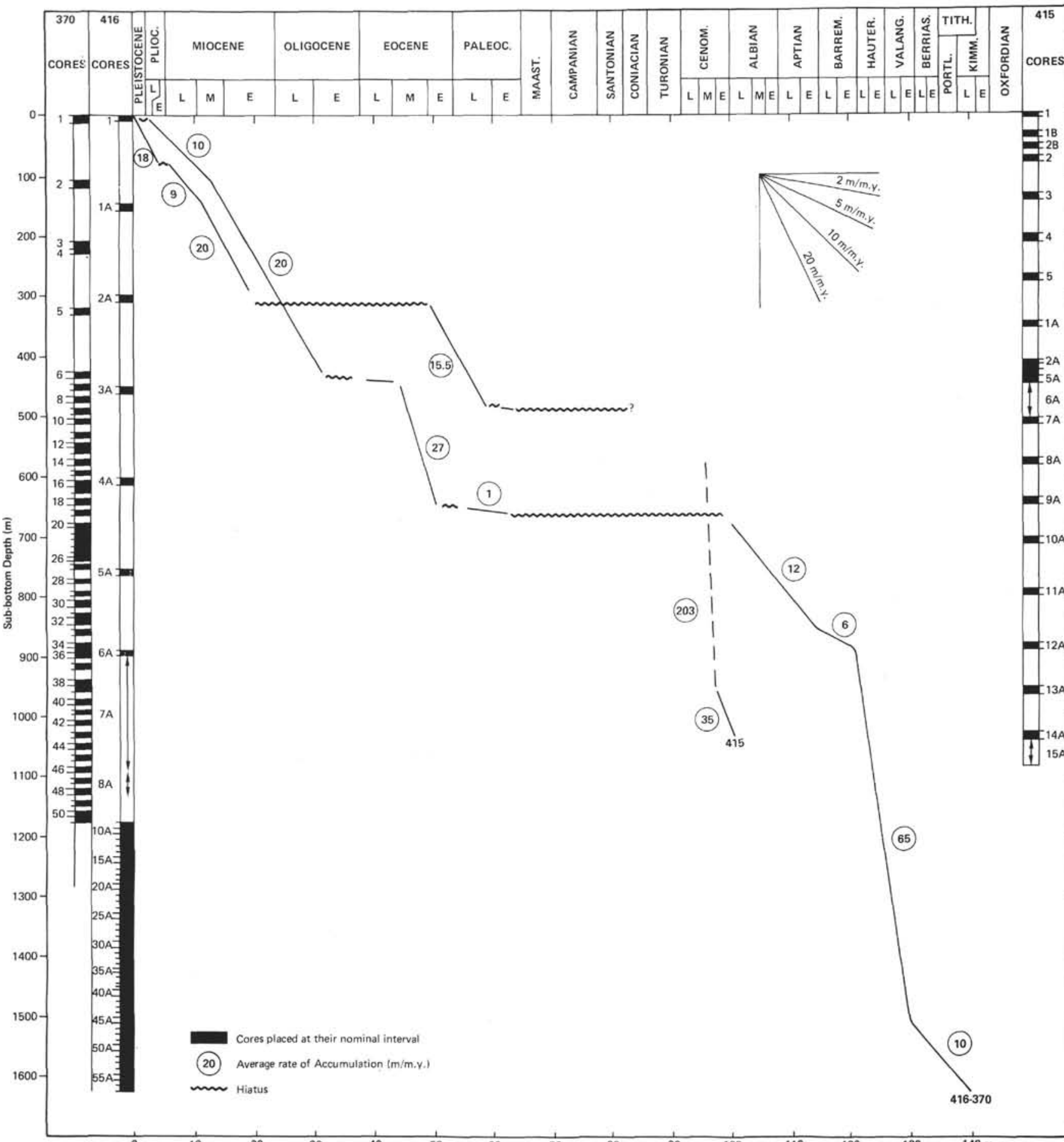


Figure 10. *Sedimentation rate curves for Sites 415 and 416/370.*

Below this poorly dated 87 meters is a remarkably thick (over 300 meters) Cenomanian sequence which is assigned entirely to the *Rotalipora cushmani* foraminifer zone, spanning an interval of time from 96 to 97.5 m.y. (Figure 6). This age assignment indicates a minimum accumulation rate of 203 m/m.y. This extremely high rate obviously does not reflect pelagic deposition at Site 415 during this time and appears to result from gravitational sliding, as suggested by (1) the repetitious nature of the foraminifer fauna within this section and its cyclic preservation patterns probably resulting from increased dissolution in the more-exposed or fractured intervals subsequent to the gravitational sliding (Sliter, this volume); (2) disturbance in the palynological sequence (G.L. Williams, pers. comm.); and (3) disturbed bedding.

Gravitational sliding at that time probably resulted from tectonic activity associated with the uplift of the western High Atlas (Lancelot and Winterer, this volume). Biofacies of this Cenomanian interval show significant dissolution and autochthonous foraminifers suggest water depths of 3000 to 4000 meters. Preservation of a Cenomanian record at Site 415 may result from tectonic stacking, which possibly prevented erosional removal (Lancelot and Winterer, this volume), whereas at Sites 416/370 the entire Cenomanian appears to be missing. The uppermost sediments recovered below the unconformity (12 meters below it) at the latter site belong to the late-Albian *Eiffelithus turriseiffeli* nannofossil zone (Core 370-20; Figure 14).

The substantial hiatus that deleted all record across the Cretaceous/Tertiary boundary at both sites was followed by several phases of erosion or nondeposition during the early Cenozoic. Pelagic sedimentation began very slowly in the early Paleocene. A sedimentary record of that time is present at both sites in the form of marl and calcareous clay with a relatively high proportion of calcium carbonate, indicating that the sea floor was above the CCD. However, preservation of calcareous fossils remains poor throughout the Paleogene.

The lower-Paleocene sequence is very condensed at both sites, where it accumulated at a rate of 1 m/m.y. or less. A hiatus equivalent to a time of approximately 3 m.y. truncates the uppermost lower Paleocene at Site 415. Reworking in this interval at the latter site is evidenced by the inclusion of allochthonous Maestrichtian sediments (within Core 415A-6-2). The Maestrichtian nannofossil chalk redeposited within the Paleocene sediments indicates that pelagic sedimentation prevailed in the area since at least the latest Cretaceous.

During the late Paleocene and early Eocene, pelagic sediments still accumulated very slowly at Sites 416/370, at an average rate of 1 m/m.y., with a short hiatus spanning the Paleocene/Eocene boundary (recorded at Site 370). At Site 415 on the other hand, sediments accumulated during that interval at a relatively high average rate of 15 m/m.y. Although calcareous fossils here too are poorly preserved, showing significant dissolution, this rate of accumulation at Site 415 appears to be related to an influx of coarse detritus, including gravels and conglomerates. Core recovery in this interval of coarse clastic sediments was very poor.

Sedimentation during the Middle Eocene is recorded only at Sites 416/370 where the average accumulation rate is 27 m/m.y. This high value probably results from renewed deposition of detrital turbidites. Calcareous fossils remain poorly preserved, with signs of pronounced dissolution. Common radiolarians, generally transformed into chert, suggest an increase in the productivity of surface waters associated with upwelling.

A new phase of erosion or nondeposition took place during the late Eocene and Oligocene. The record from the upper part of the closely spaced cored interval at Site 370 provides a reasonably good biostratigraphic control of the sequence. At this site, an extremely condensed section (approximately 17 m thick) encompasses the entire upper Eocene to lower Oligocene. At Site 415, the extent of the condensed and (or) missing sequence is poorly understood, because of widely spaced cores. It appears, however, that the sedimentary gap is larger than at Sites 416/370 and encompasses the entire interval from the middle Eocene through the lower lower Miocene. An Oligocene hiatus has been documented in other areas of the eastern North Atlantic (Berger and von Rad, 1972; Lancelot and Seibold, 1978).

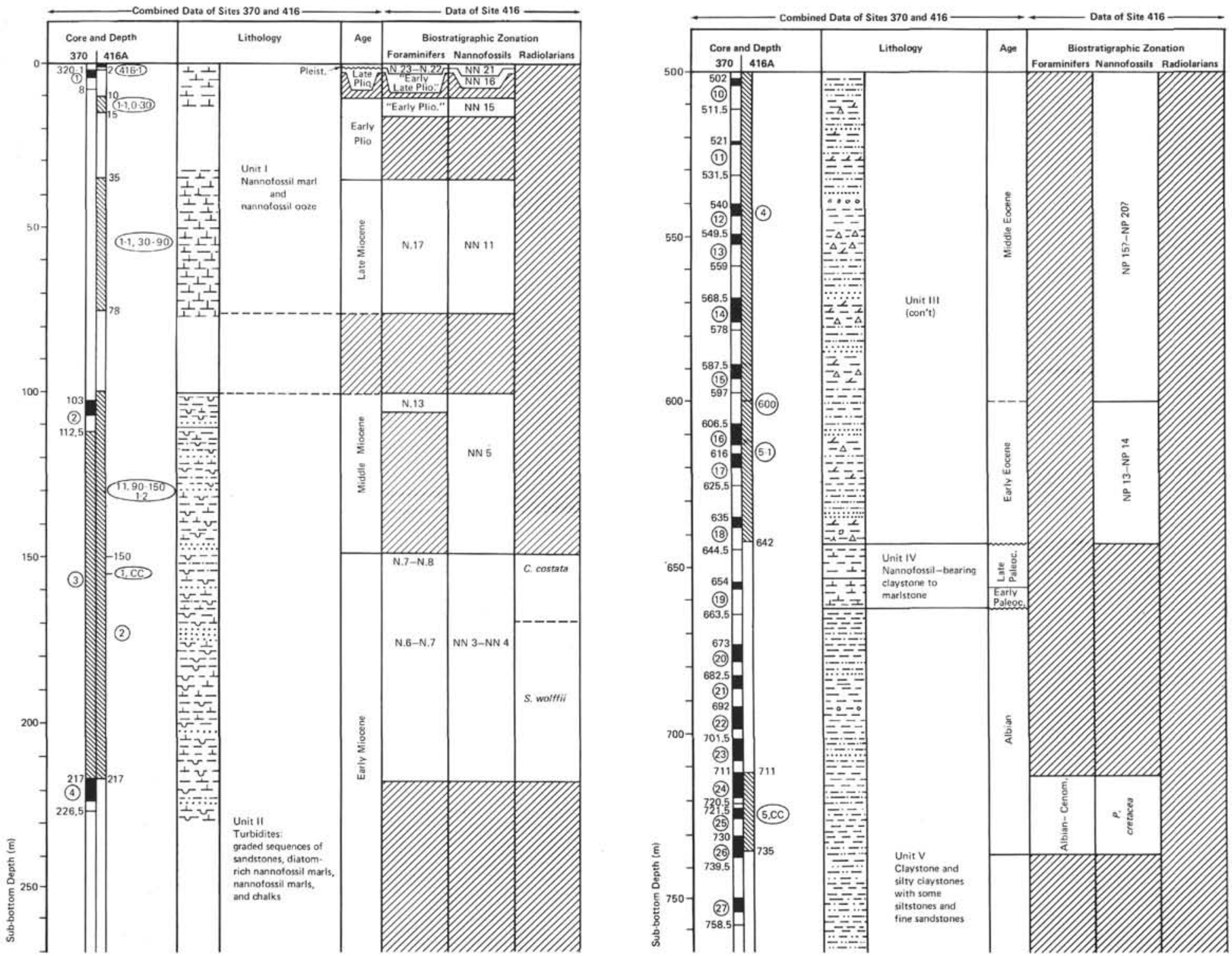
Starting in the upper Oligocene, coring was very discontinuous, and cores are widely spaced at all sites, including 370. A detailed investigation of Neogene sedimentation and evolution of oceanographic conditions in the Moroccan Basin during this time is precluded, owing both to the spotty record and to the uncertainty of the exact depths from which sediment-samples were recovered, so that average accumulation rates for this interval represent only a rough estimate. Turbiditic sedimentation prevailed from the late Oligocene through the end of the middle Miocene at Sites 416/370 and started sometimes in the early Miocene at Site 415. This sedimentation resulted in a high average accumulation rate (20 m/m.y.).

At the end of the middle Miocene, the turbidites gave way to calcareous oozes, which prevailed until Holocene times.

The erosional episode recorded in the upper middle Miocene (Serravalian) of other sites of the eastern North Atlantic (see Cita and Vismara Schilling, this volume) may be also recorded in the Moroccan Basin. However, failure to recover sediments of this age during Leg 50 prevents the identification of such a hiatus. If it were present, it would occur in an unsampled interval at Site 415 and in a section artificially telescoped by coring technique at Site 416. A possible hiatus truncating part of the upper Miocene and shoaling of the CCD (suggested by the relatively poor preservation of upper-Miocene calcareous faunas) result in a reduced average rate of accumulation at both sites for this interval (9 and 10 m/m.y., respectively). A hiatus of approximately 2 m.y. spans the Miocene/Pliocene boundary at Site 415 (Cita and Vismara-Schilling, this volume). Sedimentation then resumed at this site, where an apparently continuous Pliocene–Pleistocene sequence accumulated at an average rate of 18 m/m.y., including a well-developed Pleistocene section which records an alternation of warmer and colder climates. At Sites 416/370, on the other hand, an unconformity equivalent to approximately 1 m.y. spans the Pliocene/Pleistocene boundary and only a 45-cm thick veneer of Pleistocene sediment is present.

JURASSIC AND NEOCOMIAN AGE ASSIGNMENTS

Epoch boundaries based on palynological data in the Jurassic–Neocomian sequence at Site 416 are consistently higher in the section than those based on calcareous-nannofossil data (see Figure 11). A similar discrepancy between palynological and nannofossil biostratigraphies occurs at Site 367 to the south, in the Cape Verde Basin (Čepek, 1978; Williams, 1978b; see Figures 1 and 14), and also in wells of the Atlantic continental margin of North America (S. Gartner, unpublished data). This constant discrepancy does not hold throughout the Cre-


Combined Data of Sites 370 and 416
Data of Site 416
Core and Depth
370 | 416A
Lithology
Age
Biostratigraphic Zonation
Foraminifers Nannofossils Radiolarians
Pleist.
Late Plio.
N 23–N 22
"Early Late Plio."
NN 21
NN 16
"Early Plio."
NN 15
Early Plio
Unit I
Nannofossil marl and nannofossil ooze
Late Miocene
N.17
NN 11
N.13
Middle Miocene
NN 5
N.7–N.8
C. costata
N.6–N.7
NN 3–NN 4
S. wolffii
Early Miocene
Unit II
Turbidites:
graded sequences of sandstones, diatom-rich nannofossil marls, nannofossil marls, and chalks
Sub-bottom Depth (m)
Unit III
(con't)
Middle Eocene
NP 15?–NP 20?
Early Eocene
NP 13–NP 14
Unit IV
Nannofossil–bearing claystone to marlstone
Late Paleoc.
Early Paleoc.
Albian
Albian–Cenom.
P. cretacea
Unit V
Claystone and silty claystones with some siltstones and fine sandstones

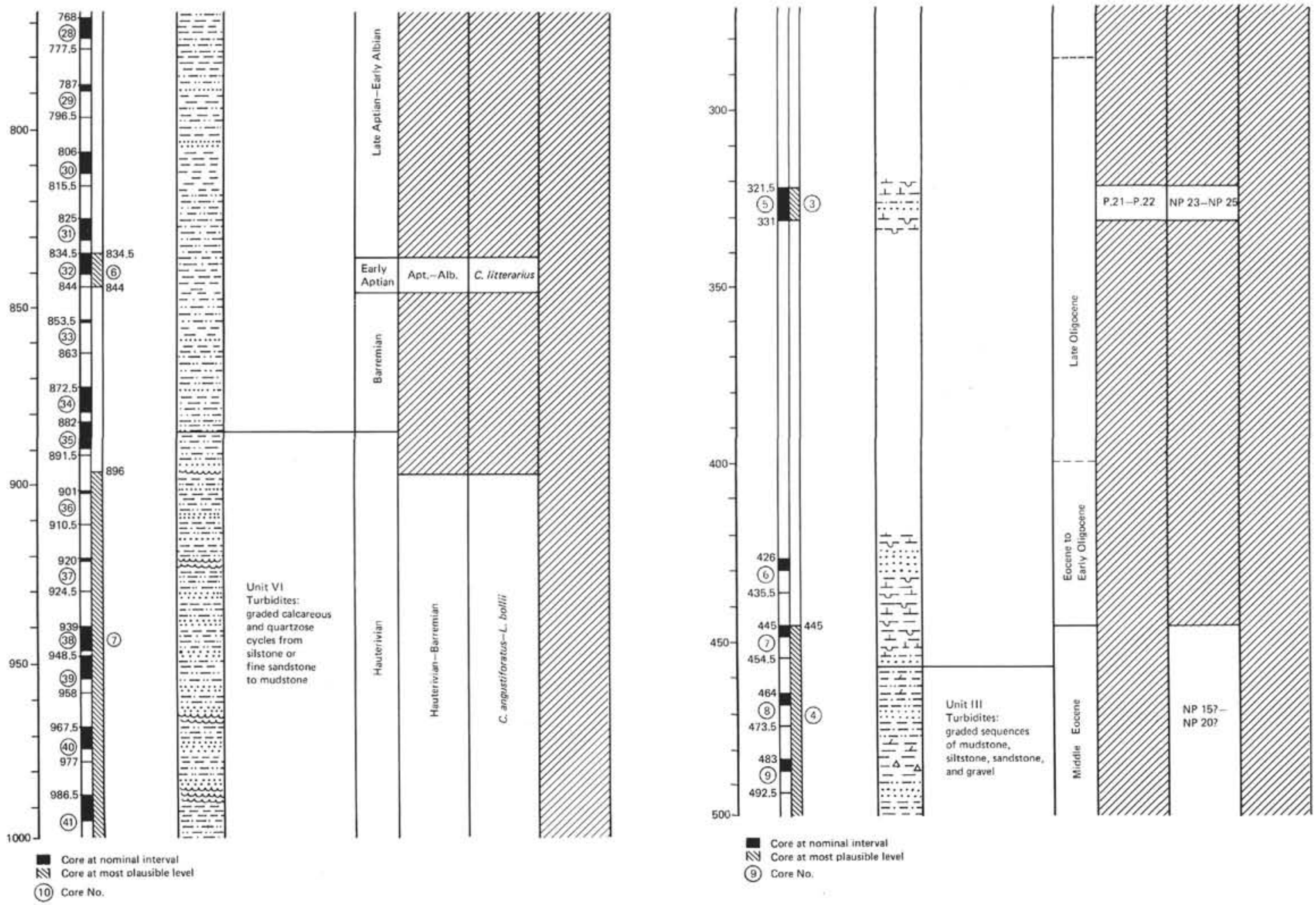
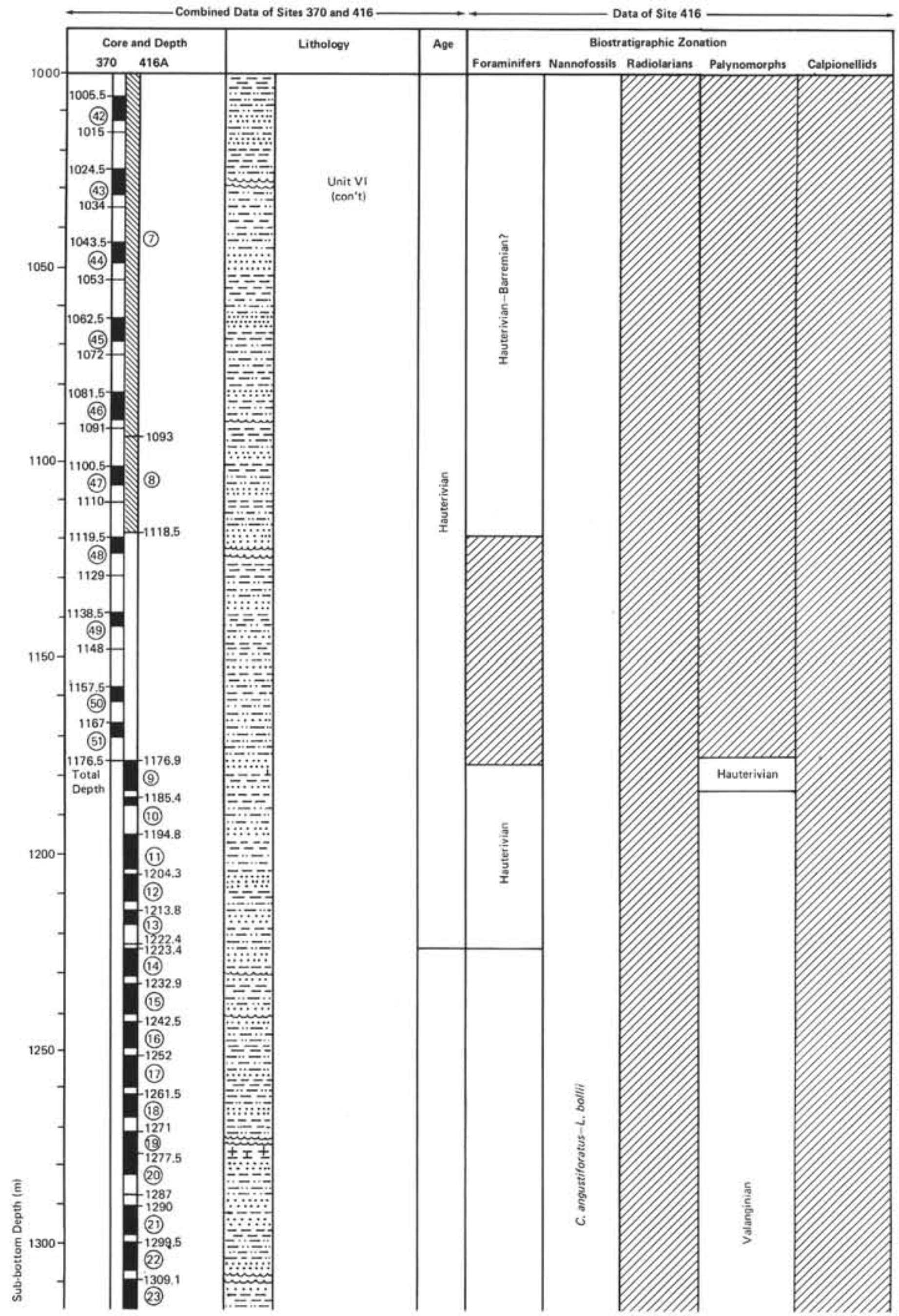


Figure 11. *Biostratigraphy of Site 416. See Figure 12 for placement of epoch boundaries.*


Combined Data of Sites 370 and 416
Data of Site 416
Core and Depth
370
416A
Lithology
Age
Biostratigraphic Zonation
Foraminifers
Nannofossils
Radiolarians
Palynomorphs
Calpionellids
Unit VI
(con't)
Hauterivian–Barremian?
Hauterivian
Hauterivian
Hauterivian
C. angustiforatus–L. bollii
Valanginian
Total
Depth
Sub-bottom Depth (m)
1000
1050
1100
1150
1200
1250
1300

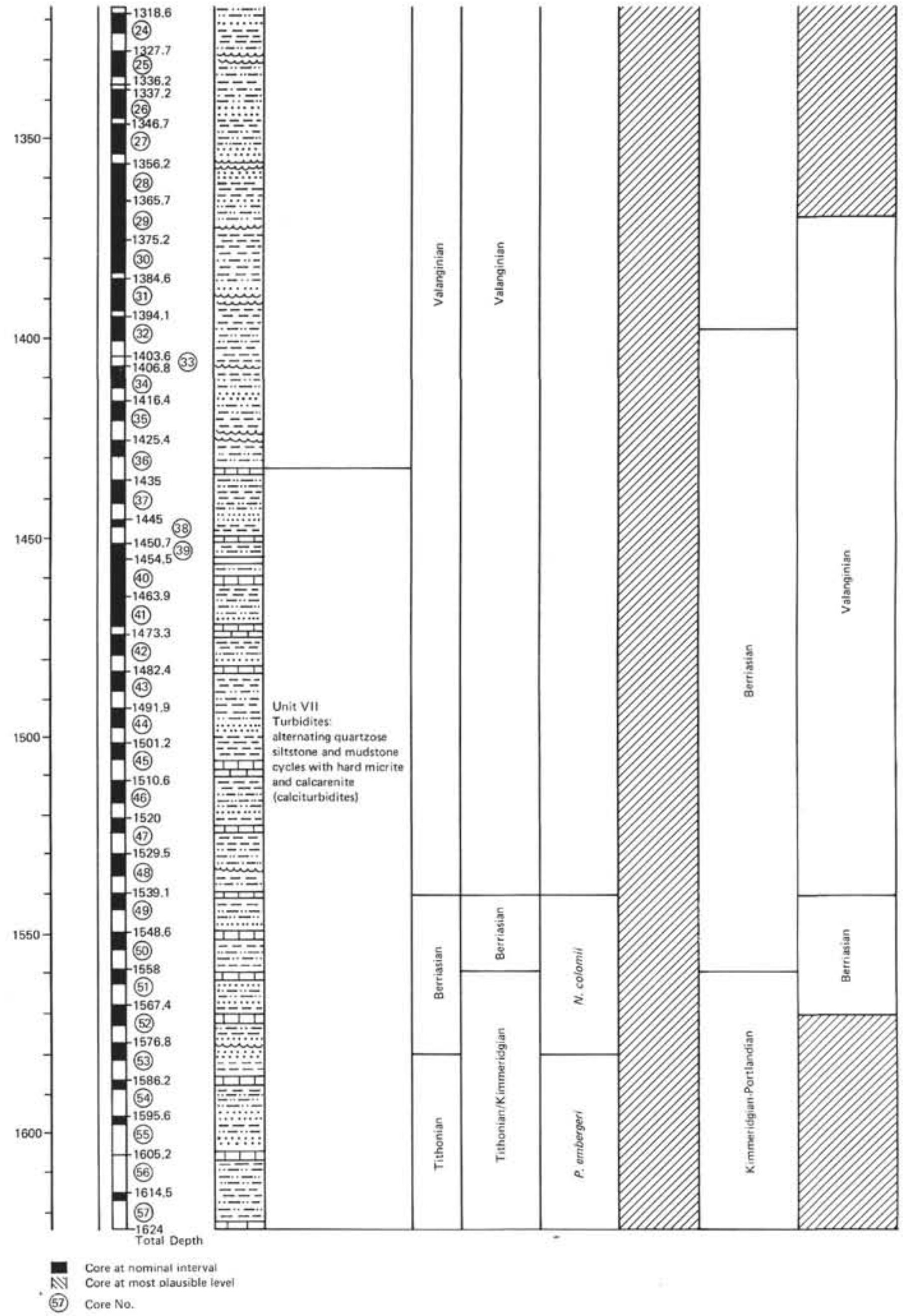


Figure 11. *Continued.*

Series	Cores, Site 370	Cores, Site 416	Approximate Sub-bottom Depth of Boundary (m)	Basis for Boundary Position
Pleistocene	370-1	416-1-1 (top) 416-1-1, 42 cm		
			0.45	Boundary between NN 21 and NN 16
Pliocene	370-1	416-1-1, 45 cm 416A-1-1, 30 cm		
			35	Inferred from average sedimentation rates at Site 370
Upper Miocene	370-2	416A-1-1, 31 cm 416A-1-1, 90 cm		
			78	Inferred from average sedimentation rates at Site 370
Middle Miocene	370-3	416A-1-1 91 cm 416A-1-2		
			150	Inferred from average sedimentation rates at Site 370
Lower Miocene	370-4	416A-1, CC 416A-2		
			285	Inferred from average sedimentation rates at Site 370.
Upper Oligocene	370-5	416A-3		
			400	Inferred from average sedimentation rate at Site 370
Lower Oligocene to Upper Eocene	370-6	None		
			445	Highest NP 16–NP 17 sample
Middle Eocene	370-7 370-15	416A-4		
			600	Inferred from average sedimentation rate at Site 370
Lower Eocene	370-16 370-18-2, 77 cm	416A-5-1		
			642	Inferred from gamma-ray log
Upper Paleocene	37-18,CC	None		
			655.5	Lowest P3 sample
Lower Paleocene	370-19,CC	None		
			661	Inferred from gamma-ray log
Albian	370-20	416A-5,CC 416A-6		
Aptian	370-32	416A-5,CC 416A-6		
			844	Lowest *C. litterarius* Zone sample
Barremian	370-33 370-34	None		
			885	Top *C. cuvillieri*
Hauterivian	370-35 370-51	416A-7 416A-13		
			1222	Bottom *D. hauteriviana* Bottom *L. ouachensis multicella* Bottom *L. hauteriviana cylindrica*
Valanginian	None	416A-14 416A-48		
			1539	Boundary between *C. angustiforatus* (?) and *N. colomii* Zones
Berriasian	None	416A-49 416A-53-2, 26 cm		
			1579	Bottom *P. asper* Bottom common *P. senaria*
Tithonian	None	416A-53-2, 45 cm 416A-57	T.D. = 1624	

Figure 12. *Stratigraphic series at Sites 416 and 370. For the construction of this figure, as well as of Figures 10, 11 and 13, paleontological data for Site 370 from Bukry (1978), Čepek (1978), Johnson (1978), and Krasheninnikov and Pflaumann (1978) were re-evaluated.*

taceous. It is reversed for example at the "Albian/Cenomanian" boundary, which is stratigraphically lower according to palynological data than according to nannofossil data (Figure 14). Considering the uncertainty in correlating the palynological zonation used by Bujak and Williams (this volume) to the standard European stages, palynological data were not taken into account for age assignments of the lower part of the sedimentary sequence at Site 416.

There remains a certain degree of uncertainty in the placement of biostratigraphic boundaries throughout the Jurassic–Neocomian sequence at Site 416. Because of the great water depth at the site during this time, all the calcareous microfossils are poorly preserved, and index species consequently may be eliminated. In addition, reworking was common because of distal resedimentation processes, and highest occurrences of species can be misleading. Thus, only first occurrences of species are reliable for placement of biostratigraphic boundaries, and the possibility that these boundaries, as placed here, are stratigraphically too high should be kept in mind.

The identification of the Jurassic/Cretaceous boundary, in particular, is not unequivocal, as evidenced by the slight discrepancy between various fossil groups for the levels of first occurrence of Berriasian markers (Figure 11). Upper Jurassic faunas and floras present at the bottom of the hole are reworked upward in the section,

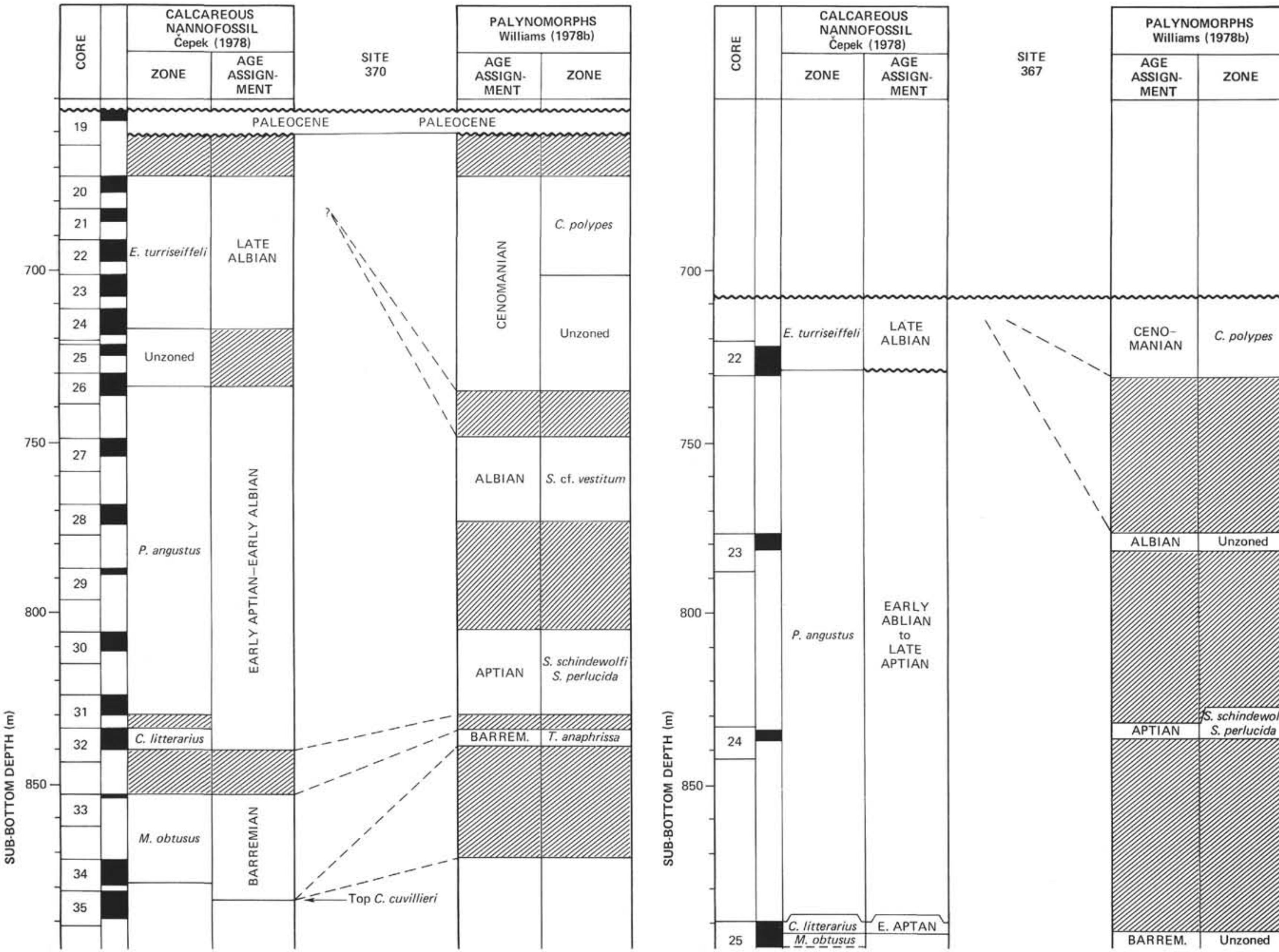
PALEONTOLOGICAL EVENTS	POSITION IN CORES	SUB-BOTTOM DEPTH (m)	AGE (m.y.)	AVERAGE ACCUMULATION RATE (m/m.y.)	
within NN 21	Upper 416-1	0–0.45	0–0.30	Pleistocene veneer	
hiatus of approximately 1 m.y.					
within NN 16	416-1-1, 45 cm	0.45	2.5–3.0		
				10	15
within NN 5	370-2, bottom	112.5	13–15		
				20	
within NP 24–NP 25, P 21 and *D. ateuchus* Zone	370-5, bottom	331	Ca. 26		
				19.3	
within upper NP 23	370-6-1/6-2	427.5	30–32		
				1 (with a hiatus spanning mainly the Late Eocene and Early Oligocene)	
within NP 16–NP 17	370-6/7	445	43–46		
				27	
within NP 13	370-18-2, 27 cm	642	Ca. 50		
				1.5 (including a short hiatus spanning the Paleocene/Eocene bdry)	
within NP 2	370-19,cc	661	63		
hiatus of approximately 40 m.y.					
within *E. turriseiffeli* Zone	370-20, top	673	100 minimum		
				11.7	
C. litterarius/M. obtusus Zonal boundary	370-32/33	844–853.5	115		
				6	
Top *C. cuvillieri*	370-35-3, 70 cm	885	121		
				67.4	65
Bottom *D. hauteriviana* Bottom *L. hauteriviana cylindrica* Bottom *L. ouachensis multicella*	416A-13/14	1222	126		
				71.2	
Bottom *D. prehauteriviana* Top *T. valdensis*	416A-32/33	1400	128.5		
				55.6	
C. angustiforatus(?)/ *N. colomii* Zonal boundary	416A-48/49	1539.1	131		
				10	
Bottom *P. asper* Bottom common occurrence *P. senaria*	416A-53-2, 30 cm	1578.6	135		

Figure 13. *Average sediment-accumulation rates at Sites 416/370 (see Figure 12 for sources of paleontological data for Site 370). Ages are taken from the time scales represented in Figures 4 to 6. When a certain thickness or a time span is indicated for a paleontological event, the mid-point of the interval has been taken arbitrarily for calculating the accumulation rate.*

where they range up into the Lower Cretaceous. The possibility of Jurassic reworking into younger sediments at the bottom of Hole 416A thus cannot be disregarded.

Nevertheless, in view of the absence of Cretaceous faunas and floras below 1539 meters and of the apparent penecontemporaneity of redeposition evidenced by the normal, sequential order of first occurrence of species, the lower 85 meters of the sedimentary sequence is assigned a Late Jurassic age. Nannofossils, which shows the lowest stratigraphic occurrence of Cretaceous species, are utilized here for the placement of the Jurassic/Cretaceous boundary. The similarity in occurrence pattern of nannofossil index species in the lower part of Site 416 and in other subsurface sections of the Atlantic margin, as well as in Mediterranean sections (see discussion on the Jurassic/Cretaceous boundary below), supports a Late Jurassic age assignment for the lowermost sediments at Site 416. The many similarities of the foraminifer faunas of these sediments with those of Upper Jurassic deposits at other North Atlantic DSDP sites (Sites 100 and 105 in the west, Site 367 in the east; see Sliter, this volume) also support this assignment.

The rarity of reliable biostratigraphic datum levels throughout the Neocomian section prohibits detailed reconstruction of sediment accumulation of this 740-meter sequence. Values given in Figure 13 thus represent only average rates of accumulation for entire intervals, without taking into account either short-term variations within each of these intervals or possible hiatuses. Short-term variations in accumulation rates probably occurred, in view of the highly episodic nature of turbidite sedimentation. The presence of one or more hiatuses is not excluded. It is not clear from nannofossil da-


CORE
CALCAREOUS NANNOFOSSIL Čepek (1978)
ZONE
AGE ASSIGN-MENT
SITE 370
PALYNOMORPHS Williams (1978b)
AGE ASSIGN-MENT
ZONE
PALEOCENE
PALEOCENE
E. turriseiffeli
LATE ALBIAN
C. polypes
CENOMANIAN
Unzoned
Unzoned
P. angustus
EARLY APTIAN–EARLY ALBIAN
ALBIAN
S. cf. vestitum
APTIAN
S. schindewolfi
S. perlucida
C. litterarius
BARREM.
T. anaphrissa
M. obtusus
BARREMIAN
Top C. cuvillieri
SUB-BOTTOM DEPTH (m)
700
750
800
850
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
CORE
CALCAREOUS NANNOFOSSIL Čepek (1978)
ZONE
AGE ASSIGN-MENT
SITE 367
PALYNOMORPHS Williams (1978b)
AGE ASSIGN-MENT
ZONE
E. turriseiffeli
LATE ALBIAN
CENO-MANIAN
C. polypes
P. angustus
EARLY ABLIAN to LATE APTIAN
ALBIAN
Unzoned
APTIAN
S. schindewolfi
S. perlucida
C. litterarius
E. APTAN
M. obtusus
BARREM.
Unzoned
SUB-BOTTOM DEPTH (m)
700
750
800
850
22
23
24
25

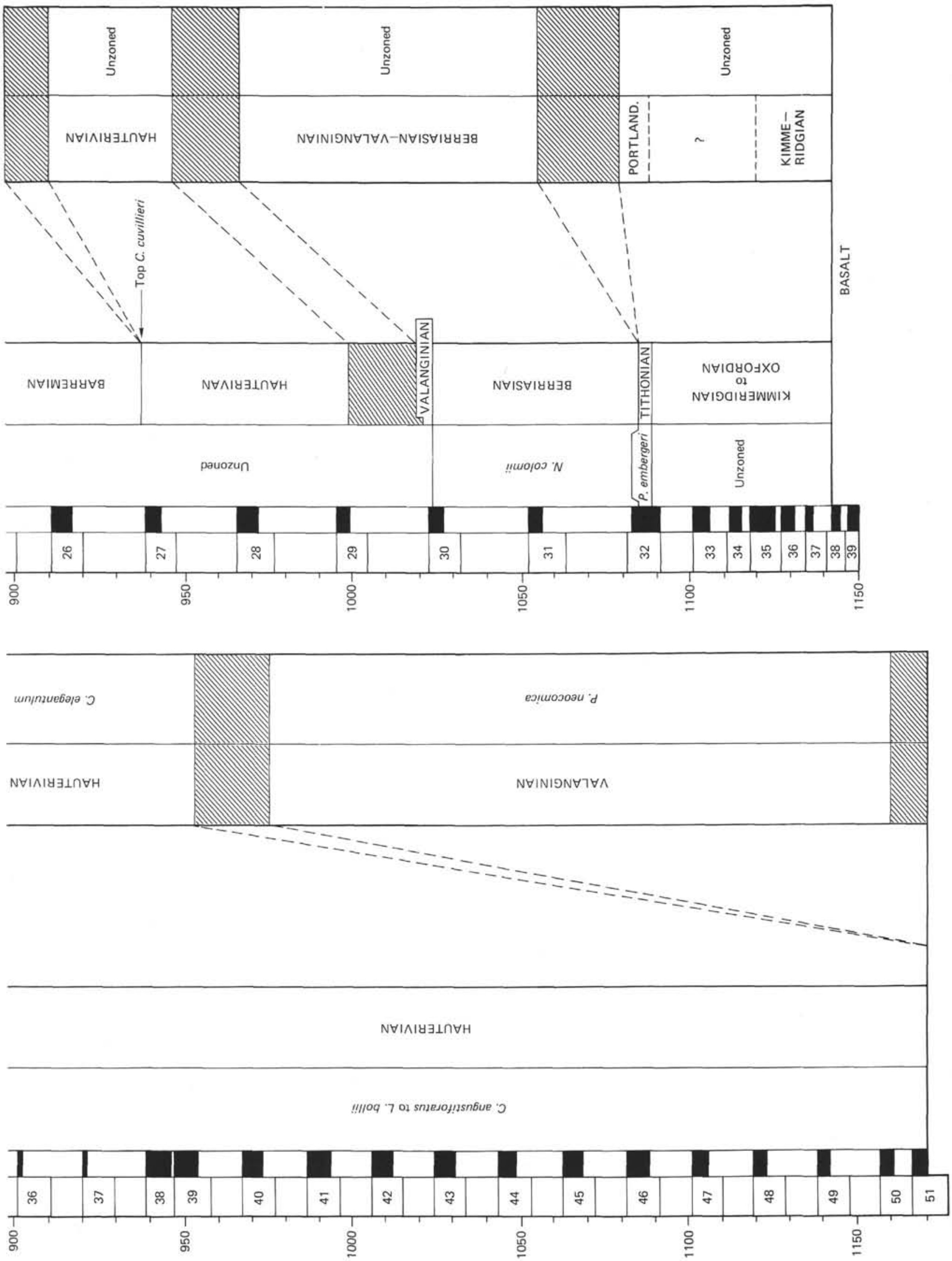


Figure 14. Biostratigraphy of calcareous nannofossils and palynology at Sites 370 and 367.

ta whether a hiatus exists between the Berriasian and the Valanginian (Čepek et al., this volume).

No nannofossil zonal boundaries could be identified in the Valanginian–Hauterivian sequence which encompasses the interval from the *Cretarhabdus angustiforatus* to the *Lithraphidites bollii* Zones. Foraminifer datum levels, however, were identified, marking the Valanginian/Hauterivian boundary and possibly the lower/upper Valanginian boundary. Although the latter is not clearly identified, there is some evidence *(Dorothia prehauteriviana,* an upper-Valanginian index fossil occurring in and above Core 416A-32; and *Trocholina valdensis,* a lower-Valanginian index, below Core 416A-32) that this boundary lies near Core 416A-32.

The highest occurrence of the nannofossil *Rucinolithus wisei* (middle Valanginian) in Core 416A-31 supports this assumption. It thus appears that the upper Valanginian accumulated at a higher average rate (about 71 m/m.y.) than the underlying lower Valanginian (56 m/m.y.) and the overlying Hauterivian (67 m/m.y.; see Figure 13). This inference is in agreement with an increased influx of redeposited shallow-water material during that time (Sliter, this volume; see his fig. 9). It is also to that interval to which the maximum occurrence of calcisphaerulids, which are part of the redeposited calcareous material, corresponds (Bolli, this volume; Sliter, this volume).

The top of the Neocomian, which corresponds to the termination of the flysch sequence, was placed at 885 meters (370-35-3, 70 cm), at the highest occurrence of the nannofossil *Crucilliepsis cuvillieri.*

Jurassic/Cretaceous Boundary

The recognition of the Jurassic/Cretaceous boundary remains somewhat difficult, because of the problem of calpionellid, ammonite, and calcareous-nannofossil zonations in the type area (southeastern France). Calcareous nannofossils across the Jurassic/Cretaceous boundary in the Berriasian stratotype cannot be studied in detail because of poor preservation (H. R. Thierstein, pers. comm.). Several attempts, however, have been made to characterize the Tithonian/Berriasian boundary with calcareous nannofossils in other sections (e.g., Thierstein, 1973, 1975; Grün and Allemann, 1975).

The first appearance of the genus *Nannoconus* is sometimes taken to mark the Jurassic/Cretaceous boundary, although most students of nannoconids, starting with Brönnimann (1955), indicate uncertainty regarding the age of this level. Among other nannofossils recognized in the vicinity of the Jurassic/Cretaceous boundary by Thierstein (1973, 1975) are the two species *Polycostella beckmannii* and *P. senaria.* In two sections studied by this author that extend across the Tithonian/Berriasian boundary, *P. senaria* occurs only within the lower Berriasian; *P. beckmannii,* on the other hand, is most abundant in Tithonian sediments, although it ranges into the Berriasian. A similar pattern of occurrence of the two species has been observed in the subsurface of the U.S. Gulf Coast by Cooper and Shaffer (1976), and in the subsurface of the Atlantic continental margin of North America (S. Gartner, unpublished data).

At site 416, this same pattern of occurrence was observed, albeit modified by redeposition through the agency of turbidity currents. A strict interpretation of the data from Site 416 in accordance with the succession found by Thierstein (1973, 1975) and by Cooper and Shaffer (1976) would require placement of the Jurassic/Cretaceous boundary below the lowest occurrence of *P. senaria,* (i.e., not higher than between samples 416A-55-1, 3-4 cm and 416A-55,CC), although small specimens of *Nannoconus* extend below this level. Actually, the Tithonian/Berriasian boundary was placed below the lowest common occurrence of *P. senaria* in sample 416A-53-2, 22 cm, and immediately below the lowest occurrence of *Parhabdolithus asper* in sample 416A-53-2, 26 cm. For the time being at least, neither set of criteria can be proven to be absolutely correct.

CORING ARTIFACT RESULTING IN CONDENSED SECTION

One of the problems raised by discontinuous coring is to determine the exact level from which the sediments recovered by the core barrels have been obtained. Two techniques are commonly used on *Glomar Challenger.* One consists in reducing pump pressure to core the top of the washed interval, in the hope that the core barrel would be filled before the washing operation, so as to prevent inadvertent sampling of sediment from lower intervals. This technique was employed in the upper, sparsely cored section of Site 370, except for Cores 370-2 and 3. The second technique consists in washing the interval at full pump pressure with the empty core barrel in place down to the last 9.5-meter section, where pump pressures are reduced for coring, which thus opens the possibility that firm sediments from above the nominally cored interval might enter the barrel. The latter technique was used at Site 416, as well as for Cores 370-2 and 3.

At Site 370, coring was closely spaced below 426 meters, so that cores from Site 416 could be traced back to their approximate location by comparing their biostratigraphic data with those of Site 370. A comparison of the results obtained at both sites demonstrates that cores obtained with the second technique include material from strata higher in the section than the nominal interval of the core. Core 416A-5, for example, with a nominal interval of 754 to 763.5 meters, may have recovered sediments from any level in the 152-meter interval over which the core barrel was open (between 611.5 and 763.5 m). According to biostratigraphic data, only the core-catcher sample (Albian) appears to have been recovered in place, that is, close to the actual level reached by the drill bit at the end of the coring. The upper part of the core on the other hand (Section 1, lower Eocene) was sampled considerably higher in the section.

A number of other cores from Site 416 were also younger than strata from corresponding sub-bottom depths at Site 370. A comparison of both sites is discussed in detail in the Site 416 report (sedimentation-rate section) and was used to infer the most-plausible core locations at that site by projecting their biostratigraphic level on the sedimentation rate curve obtained at Site 370.

Above 426 meters, however, coring was widely spaced at both sites, and between 8 and 426 meters only the position of Cores 370-4 and 5 are firmly established. Biostratigraphic data from all other cores indicate only a minimum age. The calculated sediment-accumulation rates for the Neogene section thus represent only a rough estimate (Figure 15). These are 10 m/m.y. for the Pliocene to middle Miocene (between Cores 370-1 and 370-2, using the age of the latter as a minimum age) and 20 m/m.y. for the lower Miocene and uppermost Oligocene.

It is clear that the telescoped Miocene–Pliocene sequence sampled in Core 416A-1 (Figure 16) results from artificial condensing, and that only the core catcher appears to have recovered sediments from the strata corresponding to their nominal interval (Figure 15). This core consists of heterogeneous nannofossil ooze, nannofossil marl, and calcareous mud, with sharp contacts between sediment types. Although some faunal and floral mixing occurs, the order of biostratigraphic zones is normal. An "apparent" unconformity, equivalent to a time gap of some 6 m.y., occurs at 90 cm in the section, at a level corresponding to a sharp contact between different lithologic types. The missing interval corresponds to the middle-Miocene (Serravalian) erosional episode recorded at other drill sites of the eastern North Atlantic (see Cita and Vismara Schilling, this volume). It is not possible, however, to determine if this hiatus is indeed recorded at Site 416, nor is it possible for Site 415, where, if present, it would occur in an unsampled interval.

ACKNOWLEDGMENTS

We thank other paleontologists who studied Leg 50 material, whose data are used in this report, as well as Hans R. Thierstein for valuable discussions. This study was supported under NSF Grant OCE76-83359 (CENOP) to Vincent.

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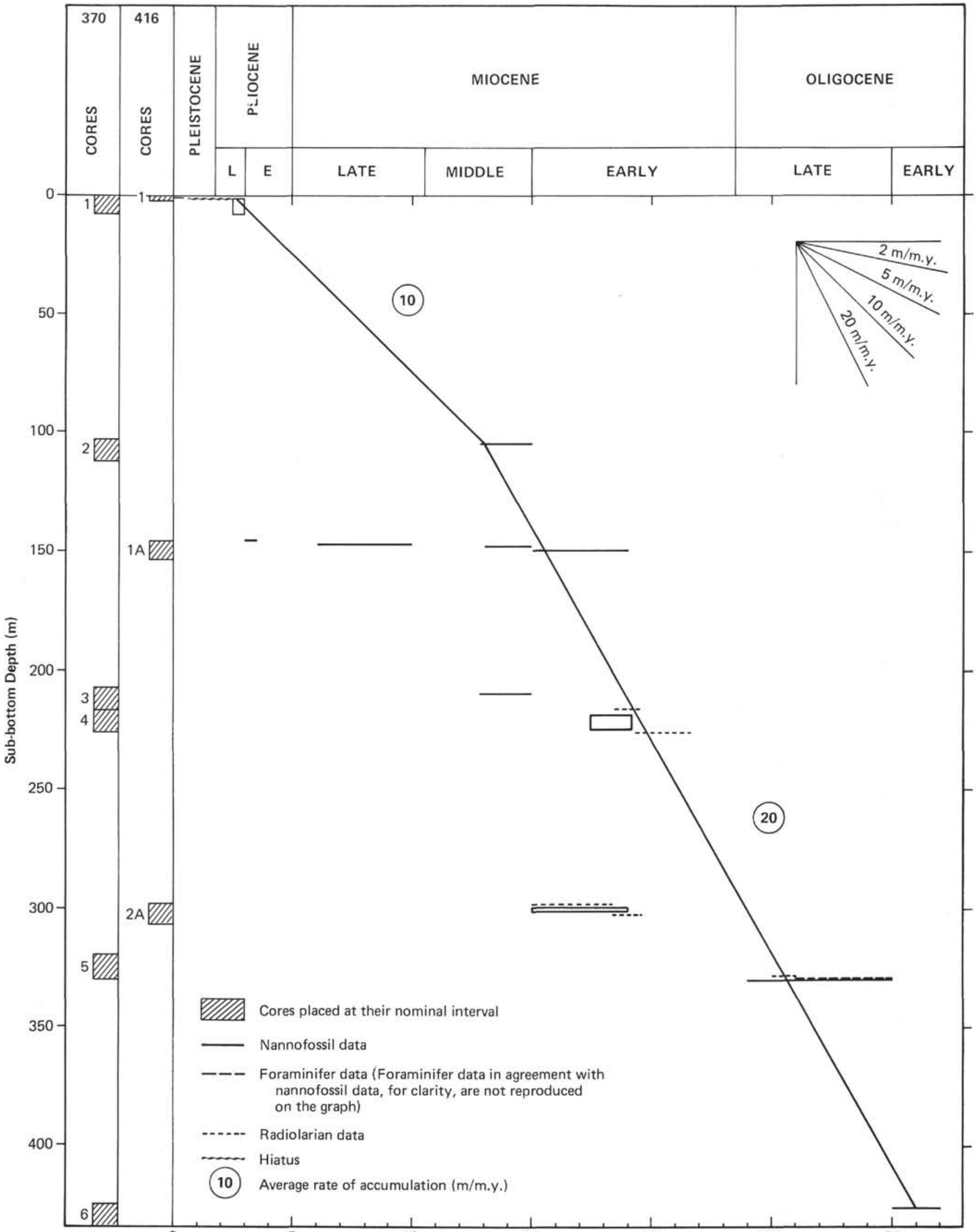

Figure 15. *Neogene sediment accumulation rate curve at Sites 416/370.*

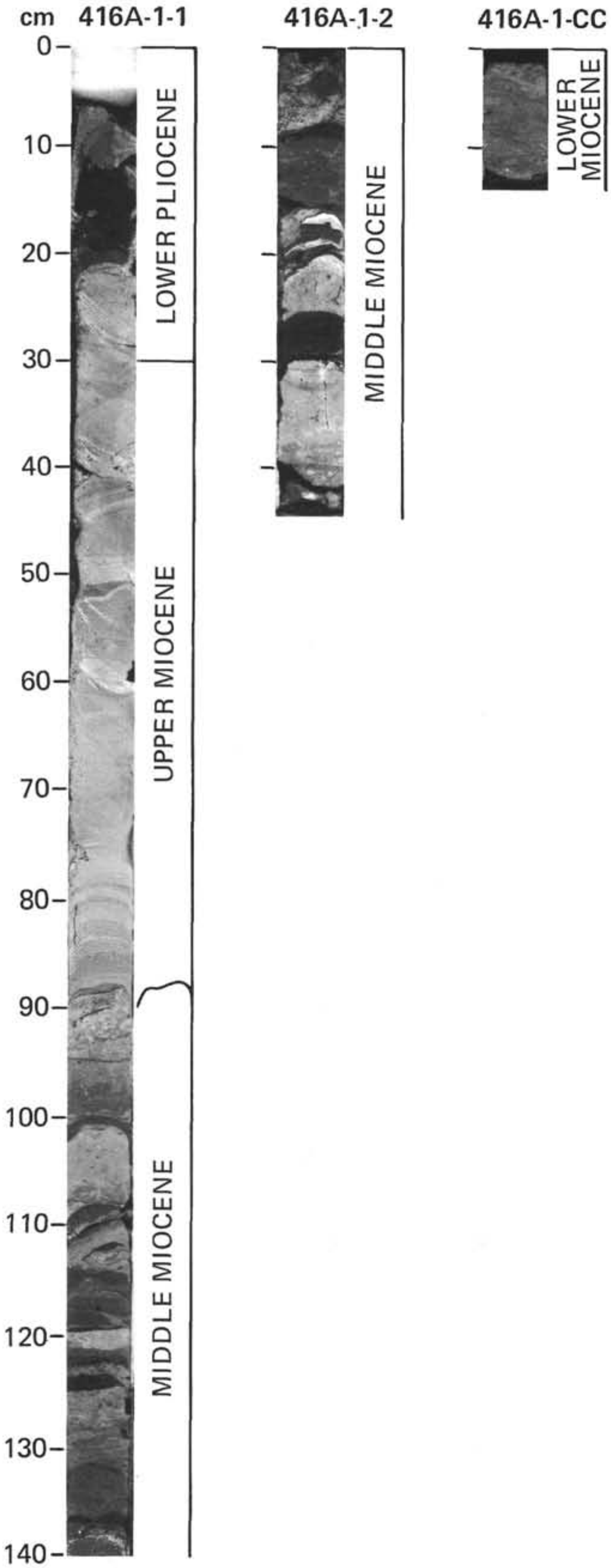

Figure 16. *Telescoped Miocene-Pliocene sequence of Core 416A-1.*

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