

## 5. CHRONOSTRATIGRAPHY AND ECOSTRATIGRAPHY OF CRETACEOUS FORMATIONS RECOVERED ON DSDP LEG 47B, SITE 398

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### INTRODUCTION

Hole 398D is located 200 km off the coast of Portugal (west of Oporto), in a small bathyal platform on the lower continental rise on the southern margin of Vigo Seamount. The hole was drilled on the western flank of a deep northeast-southwest trough in a region considered part of the continental passive margin of the eastern North Atlantic. Drilled in a water depth of 3910 meters, the hole bottomed at 1740 meters and was cored almost continuously downwards from Core 19 (585 m), with especially good recovery, in the Mesozoic series between Core 41 (800 m) and the basal Core 138.

This report attempts to date the formations encountered between 800 meters and the bottom of the hole at 1740 meters (Figure 1), and to reconstruct their sedimentary history. Sampling and methods have been organized accordingly.

We sampled extensively because of the unique opportunity afforded by the sequential nature of the deposits, in order to provide a statistical basis for these studies. Multiple samples were obtained from the same or a similar lithologic interval in a sequence; certain sequences were closely sampled several times. A total of 1073 samples was collected.

The various components, organic and inorganic, found in the washed residues (on a 63-micron sieve) were estimated semiquantitatively as to their concentration (absent, trace, rare, common, abundant, and very abundant) and their frequency (sporadic, frequent, and permanent). This applies to calcareous benthos ( $\beta$ ), agglutinated benthos (AP), planktonics ( $\pi$ ), radiolarians (Rad), quartz, and mica. A more elementary scale (absent, present, abundant) was used for some other components (organic debris, aptychus, inoceramus, fish remains, plant debris, pyrite, and glauconite). Only the "presence" of ammonites, ostracodes, or spicules was noted. Lastly, the hydrochloric acid reaction of small fragments of sediments discerned under the microscope was tested (calcareous, argillo-calcareous, and non-calcareous).

All these data have been entered on the left (Column B) and the right (Columns H, J) sides of a large stratigraphic range chart (Chart 1A, microfiche in back pocket, this volume). On its left border (Column A), this chart provides a complete listing of the samples examined. In the middle of this chart, the identified species and/or genera were recorded in the stratigraphic order of their first occurrence (with a larger black dot if particularly abundant). From left to right: the first column (Column C) corresponds to the so-called "primitive arenaceous foraminifers" (AP), which are generally considered

residual forms after dissolution processes beneath the CCD; the second large column (Column D) corresponds to the main or most interesting species which serve to establish the biozonation and the age; the third column (Column E) corresponds to a certain number of genera which were not noted in the true biostratigraphic Columns D or C, but whose presence serves to reconstitute the biocoenoses; some of them, on the left side of Column E, also belong to the residual agglutinated group. Two other columns give the results of the analysis of the foraminiferal assemblages (F) and the sedimentary lithofacies (G).

Foraminiferal assemblages were classified according to the presence, absence, or predominance of their three main components:  $\beta$ ,  $\pi$ , and AP (as noted above). To visualize the nature of these assemblages and to shorten our text, we propose the following abbreviations:

		Assemblages	Kinds of Assemblages
$\beta \geq AP$	$\pi \neq 0$	A/ $\beta$	T/ $\beta$
	$\pi = 0$	A/ $\beta'$	
$AP > \beta$	$\beta = 0$	$\left\{ \begin{array}{l} \pi \neq 0 \\ \pi = 0 \end{array} \right.$	R/AP
	$\beta \neq 0$	$\left\{ \begin{array}{l} \pi \neq 0 \\ \pi = 0 \end{array} \right.$	
	$\beta \neq 0$	$\left\{ \begin{array}{l} \pi \neq 0 \\ \pi = 0 \end{array} \right.$	
$AP = \beta = 0$	$\pi \neq 0$	Rad $\neq 0$	A/P
		Rad = 0	
	$\pi = 0$	Rad $\neq 0$	A/Az
		Rad = 0	

where, A = assemblage, T = turbidite, R = residual, P = plankton, and Az = azoic.

Some sedimentary units (I to V) or sub-units will be discussed in the ecostratigraphy section of this report. The designation of sedimentary units and sub-units described in this report are unique to this study and do not apply to the designations provided by the shipboard sedimentologists. These sedimentary units comprise lithologic entities (here called lithoterms) which were partially described onboard ship and upon which we further elaborated at Lanont-Doherty Geological Observatory. The different lithoterms in a given unit roughly correspond to the successive intervals, which are usually distinguished in a sedimentary graded sequence. They have been designated differently, depending on the different units (1, 2, 3 . . . , I, II, III . . . , A, B, C . . .). In the caption of Column G of Chart 1A (back pocket, this volume), these letters and Arabic or Roman numbers have been inserted from one unit to

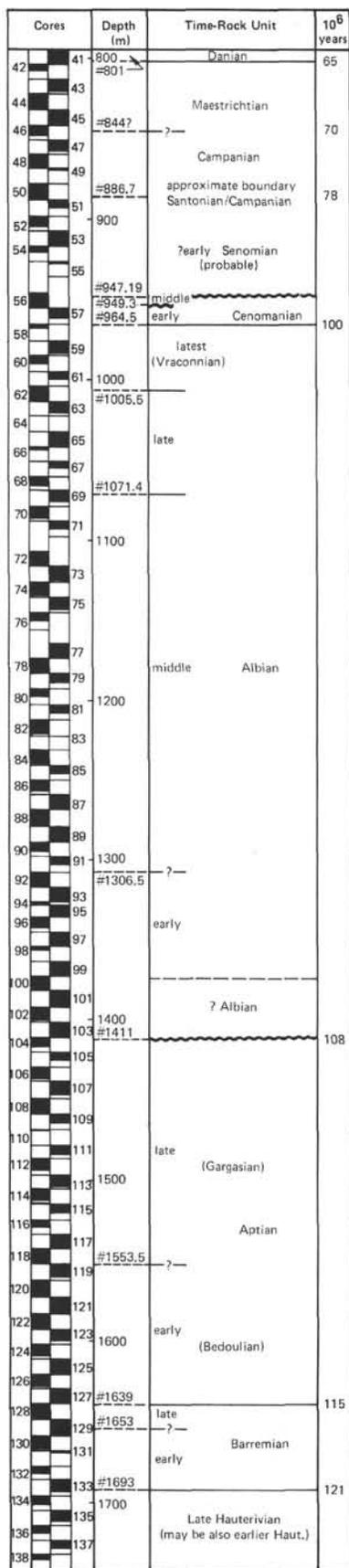


Figure 1. Chronostratigraphic column from Hauterivian to Danian, DSDP Hole 398D.

another, keeping in mind that they designate successive homologous deposits. Of course, the final lithoterm, which is equivalent to the upper interval of a sequence, is not exactly identical lithologically if we compare two different units, e.g., Unit I from Cores 138 to 131 (Figure 2) and Sub-units IIa and IIb from Cores 130 to 117 (Figure 3), particularly according to the respective position of the ocean floor and the CCD. However, in this example, whether rich or poor in carbonate, its geological meaning remains the same, i.e., the deposit corresponding to the upper interval of a sequence. In Chart 1A, such homologous lithoterms have been put in vertical superposition from unit to unit.

The analytical results of foraminiferal content and lithologic nature (Columns F and G, respectively, in Chart 1 at the end of this volume) have been synthesized in two smaller, more convenient tables. The first one (Table 1, in back pocket, this volume) is a conventional stratigraphic range chart for guide fossils. In the second one (Table 2, in back pocket, this volume) symmetric curves depict the variations, core by core, of the average amount of the different faunal components, i.e., calcareous benthos, residual benthos, and planktonics, according to their position in the lower (transported sediments) or upper parts (hemipelagites) of the sedimentary sequences. Table 2 also indicates amount



Figure 2. Lithologic sequence of reference for Cores 138 to 131 of Hole 398D.

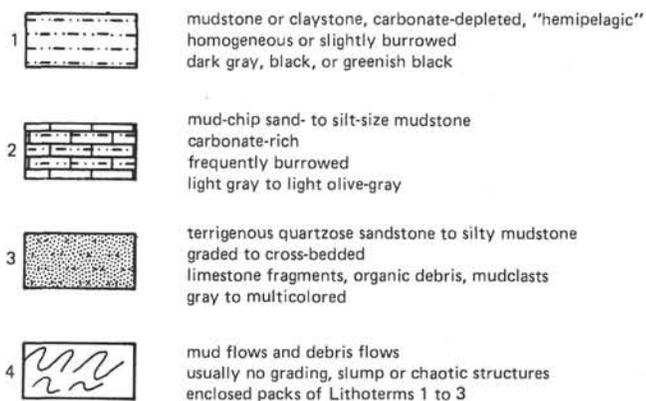


Figure 3. Lithologic sequence of reference for Cores 130 to 117 of Hole 398D.

of radiolarians, plant debris, and pyrite. The presence of aragonitic epistominas, perceptible traces of dissolution on *Epistomina* shells and on other foraminifers, and reworked material are also reported.

The values indicated by the "curves" or zig-zag lines on Tables 1 and 2 can be considered neither singly nor as a calculated exact datum for a given sample or core. Similarly, the "curves" themselves cannot be interpreted as continuous expressions of the various values which a given organic or inorganic component would assume successively. As indicated above, the amount of a given component has been estimated only in a semi-quantitative manner and has not been measured or calculated. Moreover, because of the repetitive character of the strata, these successive estimated values for a given component do not refer to sediments which might have been deposited under similar geological conditions. As has been explained, the samples have been taken repeatedly in either similar or different litho-terms. As a consequence, the "curves" do not link together successive homologous values, rather they link successive values which follow each other in no particular order. Thus, these "curves" must be interpreted in a statistical manner, as an expression of overall evolutive tendencies.

The remainder of this report is divided into two subject areas: chronostratigraphy and ecostratigraphy of Lower Cretaceous formations. The first section comprises biostratigraphical findings (Figure 1, Table 1); the second section discusses the relationship between faunal assemblage and lithology (Figures 2 through 6, Table 2). This report concludes with a synthesis for the geological and sedimentary evolution at the drill site.

Laboratory techniques involved washing the sediment samples with H<sub>2</sub>O<sub>2</sub> + ammonium, cleaning with Calgon, and screening with a 63-micron sieve. Microphotographs were made with a scanning microscope (CAME BAX) by Mr. M. Bisiaux under the supervision of Mme. M.-Th. Chenebaux (French Petroleum Institute).

### CHRONOSTRATIGRAPHY

Foraminiferal assemblages were collected from the upper Hauterivian to the top of the Upper Cretaceous. Because of the nature and structure of the deposits, the stratigraphic succession observed does not contain the complete set of biozones which is usually distinguished during this time span (see Introduction, this volume).

First, the nature of sediments (pelagic deposits, mainly produced below the CCD) does not favor the preservation of microfossils; accordingly, many guide fossils are reported as absent, especially among planktonic species.

Secondly, the structure of the sediments (heterogeneous, owing to their turbiditic origin, with flow deposits and graded sequences, or with a permanent diffuse and sorted supply) is responsible for the incongruous composition of the assemblage or for its rapid change from bed to bed.

Thus attention must always be focused on these qualitative alterations in the sediments to determine which species of these allochthonous populations have actually been reworked from older deposits.

In summary, however, the disturbance to an orderly biozonal progression has been less dramatic than might have been expected. Some foraminifers, as well as other microfossils (e.g., Calpionellids), undoubtedly have been reworked, however they are rare compared with the bulk of the collected microfossils. The latter certainly have been displaced; nevertheless, their natural vertical arrangement does not seem to have been disturbed to the extent that their chronostratigraphic succession has become unrecognizable.

In this section, stages or substages and their boundaries will be analyzed and the text will be restricted to the chronostratigraphic zoning. Consequently, we have dealt with only a small part of the collected foraminifers. The more important species are shown on five photographic plates.

### Lower Cretaceous Series

#### The Oldest Level: Upper Hauterivian

The age of the basal beds was not established utilizing foraminifers; the age determination is based on Hauterivian macrofossils, as determined by Professor O. Renz (this volume). Nevertheless, late Hauterivian is suggested by the planktonic foraminifers, which appear as early as Core 133. In all probability, the sediment facies would have been suitable for their existence from Core 138 upward. It is generally accepted that planktonics did not appear before late Hauterivian. The rate of sedimentation at the bottom of the hole suggests that somewhat older levels in the Hauterivian may have been reached, but this is not substantiated paleontologically.

Some of the most important species here in the hole appear earlier in the Valanginian (†) and frequently continue at least into the Barremian (\*). The following species can be mentioned:

\**Trocholina infragranulata* Noth, 1951 (Plate 1, Figure 19)

†\**Trocholina molesta* Gorbatchik, 1959 (Plate 1, Figures 8 and 9)

*Bigenerina gracilis* Antonova, 1964 (Plate 1, Figures 8 and 9)

\**Ammobaculites* cf. *reophacoides* Bartenstein, 1952 (Plate 1, Figure 16)

\**Marssonella ouachensis* Sigal, 1952 (Plate 1, Figure 21)

\**Lingulina loryi* (Berthelin, 1880) (Plate 1, Figure 17)

*Lingulina loryi* var. *gorringei* Maync, 1972 (Plate 1, Figure 18)

†\**Lenticulina ouachensis* Sigal, 1952 (Plate 1, Figure 22)

†\**Lenticulina ouachensis* var. *multicella* Bart., Bettenst., and Bolli, 1957 (Plate 1, Figure 23)

- †\**Lenticulina eichenbergi* Bartenstein and Brand, 1951 (Plate 1, Figure 20)  
 †*Marginulina schreiteri* (Eichenberg, 1935)  
 †*Conoroides hofkeri* (Bartenstein and Brand, 1951).

Other noteworthy species or specific groups are as follows: *Spiroplectinata* n. sp. 138, *Gubkinella graysonensis* (Tappan, 1940); the first exemplars of "Discorbis" and *Gavelinella*, *Haplophragmoides* cf. *grandis* (Romanova, 1955); *Vidalina bulloides* Antonova 1964; various Lagenids which were listed by H. Bartenstein and T. Neagu; and lastly, some representatives of Polymorphinidae.

From the bottom of the hole upward, agglutinated foraminifers are well represented and particularly recall the assemblage described by H. Bartenstein for DSDP Leg 27: *Hyperammia* sp. p. (*H. gaultina* ten Dam, 1950 [Plate 1, Figure 3]; *H.* sp. 1 Bartenstein, 1974 [Plate 1, Figure 4]; etc.); *Hippocrepina depressa* Vasicek, 1947 (Plate 1, Figure 5); *Ammodiscus* sp. p. (*A. infracretaceus* Akimetz, 1966, etc.); *Glomospira* sp. p. (*G. gordialis* [Jones and Parker, 1860] [Plate 1, Figure 10]; *G. charoides* [Jones and Parker, 1860] [Plate 1, Figure 12]); *Glomospirella* sp. p. (*G. multivoluta* [Romanova, 1955] [Plate 1, Figure 14]); *Reophax* cf. *minutissima* Bartenstein and Brand, 1951 (Plate 1, Figure 2); *Bigennerina gracilis* Antonova, 1964; *Spirillina neocomiana* Moullade, 1961 (Plate 1, Figure 13); and *Haplophragmoides* sp. p. However, in the Hauterivian interval, they do not correspond to the "primitive arenaceous," residual (undissolved) abyssal inhabitants, since they participate in the overall benthic association belonging to sediments deposited above the CCD.

#### Hauterivian/Barremian Boundary

This boundary cannot be properly traced with the help of foraminifers, and is located (based on ammonites) between Cores 136 and 130. The boundary has been placed in Core 133 (i.e., Sample 133-5, 64-66 cm), where planktonic foraminifers first appear; actually, *Hedbergella sigali* Moullade, 1966, appears somewhat earlier, in the uppermost Hauterivian, whereas *H. tuschepsensis* Antonova, 1964, has been described within Barremian and lower Aptian sediments.

#### Barremian (Cores 133 pars to 128)

This stage has been effectively characterized with the help of Ammonites and a group of foraminifers. Nevertheless, few of them are confined to this stage (i.e., *Discorbis agalarovae* Antonova, 1964, and *Clavibergella eocretacea* Neagu, 1975). Many species come from the Hauterivian, some of which continue later into the Aptian (†), as indicated below.

- †*Ammobaculites reophacoides* Bartenstein, 1962  
 †*Spirillina neocomiana* Moullade, 1961  
 †*Trocholina infragranulata* Noth, 1951  
*Trocholina molesta* Gorbachik, 1959  
 †*Marssonella ouachensis* Sigal, 1952  
 †*Lingulina loryi* (Berthelin, 1880)  
*Lingulina loryi* var. *goringei* Maync, 1972

- †*Lenticulina ouachensis* Sigal, 1952  
 †*Lenticulina ouachensis* var. *multicella* Bart., Bett., and Bolli, 1957  
*Gubkinella graysonensis* (Tappan, 1940) (Plate 1, Figure 29)  
*Neobulimina inversa* Antonova and Gnedina, 1964 (Plate 2, Figure 17)  
 †*Hedbergella sigali* Moullade, 1966 (Plate 1, Figures 27 and 28)  
*Hedbergella tuschepsensis* Antonova, 1964 (Plate 1, Figures 25 and 26).

Lastly, the following species begin in this stage and continue into the Aptian:

- Lamarckina* (?) *asteriaformis* Kuznetsova and Antonova, 1964 (Plate 2, Figures 7 and 8)  
*Gavelinella barremiana* Bettenstaedt, 1952 (Plate 2, Figures 5 and 6)  
*Hedbergella aptica* (Agalarova, 1951) (Plate 2, Figures 13 and 14)  
*Hedbergella* aff. *planispira* auct. (Plate 2, Figures 1 and 2)  
*Hedbergella tardita* Antonova, 1969 (Plate 2, Figures 11 and 12).

The planktonic foraminiferal association is far richer than indicated on these lists. They include many small new species belonging to *Hedbergella* and *Globigerinelloides*, and some species more-or-less similar to the open forms listed in the Barremian stratotype (Guillaume and Sigal, 1965).

A singularity must be emphasized, which consists of abundant and short-lived (mainly Core 128) Ophthalmidiidae (mainly *Ophthalmidium tricarinarum* var. *marginatum* [Wisniowsky, 1890], which was mentioned by Neagu in the Rumanian lower Neocomian).

A relatively precocious appearance of *Gavelinella barremiana* must be underlined. This species generally begins approximately in the middle part of the Barremian. However, the distinction from some *Discorbis* in Hole 398D is not clear-cut. We would be tempted to put the lower/upper Barremian boundary in Core 129, i.e., at the MCi 13/MCi 14 boundary (first *Hedbergella aptica*). This boundary is always difficult to determine, particularly when the guide fossil *Conorotalites bartensteini* var. *aptiensis* is missing, as is true at Site 398 (where it appears high in the section), and when the other varieties of the same species are also missing.

The "residual" agglutinated group is still homogeneous, and the same species as before are found here.

#### Barremian/Aptian Boundary

This boundary was not satisfactorily located between Cores 128 and 127, since the Bedoulian group of planktonic species begins its main development somewhat higher (Core 122), probably because of sedimentological conditions or poor preservation.

In other respects, *Hedbergella similis* Longoria, 1974, whose appearance is generally set at the lower limit of the Aptian, co-exists in the hole with Barremian ammonites (see Introduction, this volume). In this case, the scale must be slightly amended, relative to the boundary between Zones MCi 15 and MCi 16.

As usual, the boundary is slightly transgressed by some species like *Lenticulina ouachensis* var. *multicella*, *Epistomina caracolla* (Plate 2, Figures 9 and 10), *Discorbis agalarovae*. The case of *Spirillina neocomiana* is more questionable, even apart from its synonymy with *Vidalina bulloides* (Agalarova, 1951) or with the *Globospirillina* group of Antonova, 1964. The upper limit of the range of this species generally coincides more-or-less with the boundary under discussion, but at Site 398 it is found far higher in the Bedoulian, if we consider its sporadic continuation in the Gargasian and its isolated presence in the middle Albian to be irregular (also evidenced by other accompanying reworked species and turbiditic conditions).

#### Aptian (Cores 127 to 103 or 100)

The following group of species suggests an early Aptian (Bedoulian) age, because of either their continuation (as discussed above) or their first appearance:

- Hedbergella aptica* (Agalarova, 1951)
- Hedbergella quadricamerata* Antonova, 1964 (Plate 2, Figure 19)
- Hedbergella tardita* Agalarova, 1964 (Plate 2, Figures 11 and 12)
- Hedbergella semi-elongata* Longoria, 1974
- Hedbergella similis* Longoria, 1974 (Plate 2, Figures 15 and 16)
- Globigerinelloides (Blowiella) blowi* (Bolli, 1959) (Plate 2, Figure 20)
- Globigerinelloides duboisi* (Chevalier, 1961) (Plate 2, Figure 23)
- Globigerinelloides gottisi* (Chevalier, 1961) (Plate 2, Figure 21)
- Neobulimina egojani* Antonova, 1964 (Plate 2, Figure 22)
- "*Bolivina*" *kuznetsovae* Antonova, 1964 (Plate 3, Figure 2)

The discrepancy we find with the MCi 17-MCi 18 zonal succession is probably due to sampling or sediment sorting, or to depositional conditions. Alternately, a short stratigraphic break could be present at the base of the Aptian. Other noteworthy species are as follows:

- Vidalina bulloides* (Agalarova, 1951)
- Marssonella subtrochus* Bartenstein, 1962
- Lenticulina* gr. *collignoni* Espitalié and Sigal, 1963
- Lenticulina* gr. *ambanjabensis* id.
- Astacolus deilmanni* Kemper, 1963
- Epistomina alveata* Espitalié and Sigal, 1963 (Plate 2, Figure 18)
- "*Bolivina aptica*" Tajrov, 1961 (Plate 3, Figure 1)
- Neobulimina media* Antonova, 1964
- Hedbergella kugleri* (Bolli, 1959)
- Hebergella* cf. *planispira* sp. auct.
- Conorotalites bartensteini* var. *aptiensis* Bettenstaedt, 1952

and various Lagenidae, Anomaliniidae, and Gavelinellidae

The following species come from older intervals and may be considered as not having been reworked, as previously noted:

- Lenticulina ouachensis* var. *multicella* Bart., Bettenst. and Bolli, 1957
- Epistomina caracolla* (Roemer, 1841) (Plate 2, Figures 9 and 10)
- Discorbis agalarovae* Antonova, 1964
- Neobulimina boliviniformis* Antonova and Kalugina, 1964
- Spirillina neocomiana* Moullade, 1961
- The following other Neocomian species are normally found in this substage:
  - Ammobaculites reophacoides* Bartenstein, 1952
  - Marssonella ouachensis* Sigal, 1952
  - Trocholina aptiensis* Iovtcheva, 1962 (Plate 2, Figure 27)
  - Trocholina friburgensis* Guillaume and Reichel, 1957 (Plate 2, Figure 26)
  - Trocholina infragranulata* Noth, 1951
  - Lenticulina ouachensis* Sigal, 1952
  - Gavelinella barremiana* Bettenstaedt, 1952
  - Epistomina laticostata* Antonova, 1964
  - Lamarckina asteriaformis* Antonova, 1964
  - Hedbergella sigali* Moullade, 1966
  - Hebergella tuschepsensis* Antonova, 1964

The belated appearance (Core 113) of *Globigerinelloides maridalensis* (Bolli, 1959) is noteworthy (Plate 3, Figure 8).

The Bedoulian/Gargasian boundary seems to occur between Cores 119 and 118, judging from the upper limit of such species as *Hebergella tuschepsensis* and *H. sigali*, and the possible existence of two poorly preserved exemplars of *Hastigerinella bizonae* Chevalier, 1961 (Sample 117-6, 76-78 cm).

The late Aptian substage (Gargasian and theoretically Clansayesian) is greatly enlarged, for it corresponds to the beginning of the high sequential levels which characterize Sub-unit IIC (with "macrosequences") and precedes the "dark shales" series. Thus, we can expect to trace more easily the succession of biozones, given that the required microfossils exist.

The lowest zone, the *Cabri* zone (MCi 19), was not firmly established for lack of its guide species *Schackoia cabri* Sigal, 1952. Nevertheless, the following observations enabled recognition of this zone which is localized in Cores 118 to 113:

- last occurrence of *Hebergella aptica* (Agalarova, 1951)
- last occurrence of *Hedbergella similis* Longoria, 1974
- last occurrence of *Hedbergella semi-elongata* Longoria, 1974
- continuation of *Hedbergella triangulata* Antonova, 1964 (Plate 3, Figure 7)
- occurrence of *Globigerinelloides escheri* (Kaufman, 1865) (Plate 3, Figure 9)
- occurrence of *Hedbergella* cf. *kuhryi* Longoria, 1974
- occurrence of *Hedbergella gargasiana* Moullade, 1961 (Plate 3, Figures 3 and 4)

The *Ferreolensis* zone (MCi 20) and *Algerianus* zone (MCi 21) are no longer characterized by their guide species. They must exist in Cores 112 to 109 pars:

*Globigerinelloides ferreolensis* (Moullade, 1961) was belatedly first observed in Core 109 (Plate 3, Figure 12). Moreover, only some less evolute or young forms, perhaps referable to *G. algerianus* Cushman and ten Dam, 1948, were found. Additionally, some exemplars seem to belong to *G. macrocamerata* Longoria, 1974, which is restricted to the last zone mentioned.

The *Trochoidea* zone (MCi 22) is well characterized; *Hedbergella trochoidea* (Gandolfi, 1942) was found from the middle of Core 109 upward (Plate 3, Figures 10 and 11). Forerunners, with a large shell, coarsely perforated and pustulose, are present below Core 109. They can be related either to *H. hispaniae* Longoria, 1974, or to "pre-trochoidea" forms, in accordance with observations made in northern Africa and recorded by M. Moullade in southeastern France.

*Ticinella bejaouaensis* Sigal, 1966, was not found. Consequently, the *Bejaouaensis* zone (MCi 23) cannot be defined. Nevertheless, some forms belonging to the group of *H. trochoidea* occur as early as Core 107, with more numerous chambers, a depressed spire, and large umbilical cavity (Plate 3, Figures 14 and 15). Only the indispensable supplementary apertures are missing, in accordance with observations made in northern Africa and southeastern France by the same authors. Such variants probably belong to *Globigerinids*, described as *Praeglobotruncana rohri* by Bolli, 1959. The coexistence of such forms with *Nedbergella trochoidea*, *Planomalina cheniourensis* Sigal, 1952 (Plate 3, Figure 13), and *Globigerinelloides barri* (Bolli, Loeblich, and Tappan, 1957) (Plate 3, Figure 20) suggests that we have not yet reached the Clansayesian substage. Since the samples come from the large slump in Cores 105 and 104, we assume either that their occurrence was contemporaneous with the slumping or that the bulk of the material was displaced soon after its original deposition. We should point out that true reworked material occurs in the cores.

Besides the preceding guide fossils, the upper Aptian deposits yield a characteristic assemblage, composed of benthic forms, such as:

numerous species of *Lagenidae*, *Gavelinella*, *Gyroldina*, well known since Reuss (Hils and Gault)

*Spiroplectinata* group of *dauidi* Moullade, 1961

*Saracenaria spinosa* Eichenberg, 1935

*Eponides morani* Tappan, 1957

*Eurycheilostoma* sp. p. (close to *robinsonae* and *grandstandensis* described by Tappan, 1957, from Alaska) (Plate 3, Figures 18 and 19)

"*Bolivina*" *kuznetsovae* Antonova, 1964 (Plate 3, Figure 2)

"*Bolivina*" *textilarioides* (Reuss, 1863)

*Conorotalites brotzeni* var. *rumanus* Neagu, 1965

and some representatives of the family Pleurostomellidae (*Pleurostomella obtusa* Berthelin, 1880 as early as *Trochoidea* zone, *Ellipsodimorphina* sp.). Affinities with the Canadian realm also are noticeable.

Residual agglutinated forms are especially prominent from Core 119 upward, since they may henceforth compose the entire foraminiferal content of the samples. The assemblage is not fundamentally different: the

same *Hyperammina*, *Hippocrepina*, *Glomospira*, and *Ammodiscus* as below, as well as *Ammodiscus cretaceus* (Reuss, 1845), *Mjatljukella gaultina* (Berthelin, 1880), and *Rothina silesica* Hanzlikova, 1966; for a relatively short time-rock interval, *Verneuilinoides* group of *sub-filiformis* Bartenstein, 1952 (Plate 3, Figure 6) and *Bigenerina variabilis* (Vasicek, 1947) (Plate 3, Figure 5) were found.

Reworked species are undeniable, either because they are now found too far from their usual time range, or because redeposition is indicated by the nature of the sediment itself (turbiditic lower sequential intervals, debris flows, *Calpionellids*-bearing pebbles). These forms include *Pseudonodosaria* group of *mutabilis* (Reuss, 1863), *P.* group of *humilis* (Roemer, 1841), some small *Hedbergellas* (cf. *sigali*, cf. *semi-elongata*), *Dorothia ouachensis*, *Lenticulina ouachensis* var. *multicella*, and the more frequently observed and previously discussed *Spirillina neocomiana*. The last species is encountered mainly in Cores 118, 117, 112, 108, 105, 104, and 103, as indicated in Table 1.

#### Aptian/Albian Boundary, With a Possible Stratigraphic Break

From the foregoing, it follows that the uppermost part of the Aptian has not been paleontologically characterized. Between the *Trochoidea* zone and the next ammonites of the *Mamillatum* zone (which is not the lowest one in the Albian), the sediment sequence appears to be thin, especially if we consider the sedimentation rate at that time. If we assume that the age of the large flow in Cores 105 and 104 is approximately determined by the youngest microfossils found, this boundary occurs somewhere in Cores 103 to 100. We could not attain any greater precision with foraminiferal determinations, since planktonics are missing and benthics are sporadic, uncommon, and generally belong to wide-ranging species without well-defined limits. One of the guide-species frequently utilized for the Aptian/Albian boundary (*Pleurostomella subnodosa* Reuss, 1860) cannot be used for this site because its first occurrence is very late, while *P. obtusa* (sometimes considered as its macrospheric counterpart) appears in the hole as early as the *Trochoidea* zone.

The thinness of the sediments, which should encompass the Clansayesian substage and basal Albian (i.e., MCi 23) and perhaps also part of the *Trochoidea* zone (part of MCi 22), suggests a stratigraphic break. The break might be related to general diastrophic events which resulted in the large allochthonous slump in Cores 105 and 104, and in the definitive development of the "dark shales." For greater convenience and convention, the boundary is placed between Cores 104 and 103.

#### Albian (Cores 103 or 100 to 58)

The thick series dated as Albian (including Vraconian) yielded a characteristic assemblage of foraminifers. Planktonics belong to the common forms which are usually found in the Mesogean realm, although their specific composition and abundance vary greatly. Benthics show a great similarity to the Mesogean microfauna, either Mediterranean (especially

from northern Africa and southeastern France or Spain, from where they have been well described) or from other areas (we find some species described or listed in California or India). Nevertheless, some affinity exists with more northern realms, e.g., with the classic Gault formations as concerns Lagenidae, or with Alaskan areas as concerns some other species or genera. During the Albian, many benthic foraminifers were distributed in a wide geographic belt, including various Lagenidae, many species of Gavelinellidae, Pleurostomellidae, Verneuilinidae, especially *Pseudoclavulina gaultina* var. *carinata* Neagu, 1962 (Plate 4, Figure 7), and *Ossangularia utaturensis* (Sastry and Sastri, 1966) (syn. *O. californica* Dailey, 1970) (Plate 3, Figures 21 and 22) or *O. insigna* Dailey, 1970 (Sample 59-6, 11-13 cm). These are well represented in Hole 398D.

These benthic assemblages were transferred from the outer shelf or the upper-middle slope toward deeper areas below the CCD. A detailed study of successive samples reveals multiple alternations of very different assemblages which represent either "autochthonous" associations of residual microfossils or mixed assemblages, depending on the amount and degree of preservation of the redeposited calcareous material.

Thus, at least during a large part of the stage, some difficulties were encountered in establishing the zonal stratigraphy, because of the impoverishment or the sporadic occurrence of the microfauna. Only from Core 70 or 69 upward (i.e., approximately at the base of the upper Albian) did favorable sedimentological conditions prevail. Rich or sometimes exuberant benthic and planktonic associations allowed a detailed stratigraphic zonation to be established in this interval.

Chronologically, we cannot assert that the first occurrence of *Hedbergella planispira* (Tappan, 1940) in Sample 94-4, 30-32 cm (Plate 3, Figures 23 and 24) determines the MCi 23/MCi 24 boundary (i.e., the middle part of the lower Albian); the microfauna are poor and sporadic at this level. The same unreliability prevails for the MCi 24/MCi 25 boundary (i.e., near the base of the middle Albian), according to the presence of species like *Hedbergella rischi* Moullade, 1973, in Sample 82-1, 51-53 cm or *Ticinella primula* Luterbacher, 1963, in Sample 86-2, 38-40 cm (Plate 4, Figures 5 and 6). For the lower/middle Albian boundary, we accept that it occurs in Cores 92 to 91, according to the ammonites.

The position of the middle/upper Albian boundary (or MCi 25/MCi 26) is placed at the first occurrence of *Biticinella breggiensis* (Gandolfi, 1942) in Sample 69-2, 89-91 cm (Plate 4, Figure 11), and just before the first occurrence of *Ticinella praeticinensis* Sigal, 1966, (Plate 1, Figures 14 and 15). The first occurrence of *Rotalipora ticinensis* (Gandolfi, 1942) in Sample 65-1, 135-137 cm (Plate 4, Figures 19 and 20) approximately defines the middle part of the upper Albian (*Dipoloceras cristatum* Zone), just before the last *Rotalipora praeticinensis* in Sample 65-1, 58-60 cm.

The MCi 26/MCi 27 boundary corresponds to the last occurrence of *Biticinella breggiensis* in Sample 60-3, 13-15 cm; it is preceded as usual by the first occurrences of *Rotalipora balernaensis* Gandolfi, 1957 in Sample 62-2, 148-150 cm (Plate 4, Figures 22 and 23) and *Planomalina buxtorfi* (Gandolfi, 1942) in Sample 61-1, 120-122 cm (Plate 4, Figures 27 and 28), whereas *Rotalipora apenninica* (Renz, 1936) occurs somewhat belated in Sample 60-1, 6-8 cm (Plate 4, Figures 29 and 30).

The upper Albian/Vraconian boundary corresponds to the first occurrence of the above-mentioned species *R. balernaensis* and *P. buxtorfi*, or more precisely at the end of the evolution lineage *Globigerinelloides caseyi* (Bolli, Loeblich, and Tappan, 1957) (Plate 4, Figure 21), *Globigerinelloides praebuxtorfi* (Wonders, 1975) (Plate 4, Figure 26) leading to *P. buxtorfi*, which is well documented at Site 398.

The upper limit of *Rotalipora ticinensis* in Sample 59-3, 103-105 cm approximately defines the middle part of the Vraconian (or the boundary between the *Mortonicerias perinflatum* and *Turrilites hugardianus* zones).

Lastly, the upper limit of the Albian can be located at the base of Core 57, with the first occurrence of *Rotalipora globotruncanoides* Sigal, 1948 (Plate 4, Figures 8 and 9) and *Thalmaninella brotzeni* Sigal, 1948 (Plate 4, Figures 10 and 11), and with the diversification of the *Schackoina cenomana* group (Plate 4, Figures 2 through 7) (*S. cenomana* [Schacko, 1897]; *S. cenomana* var. *bicornis* Reichel, 1948; *S. gandolfii* id.; *S. moliniensis* id.; *S. pentagonalis* id.; and *S. cf. primitiva* Tappan, 1940). Incidentally, we observed a short-living manifestation of *S. cf. cenomana* s. str. (Plate 4, Figure 18) in Sample 65-5, 135-137 cm, approximately in the middle part of the late Albian s. str. (which is earlier than usual). It was found in a few samples, where it occurs together with a very enigmatic form which seems to correspond to an uncoiled *Hedbergella* (see Plate 5, Figures 19 to 25), and probably belongs to the *planispira* group.

Late Albian and Vraconian planktonics are diversified and we found almost all the guide fossils of stratigraphic significance. We noticed that *Ticinella roberti* is nearly absent; *Ticinella raynaudi* Sigal, 1966, and *T. primula* are uncommon; only one exemplar of *Favusella washitensis* (Carsey, 1926) was found. The small-sized planktonics are very numerous and diversified: *Hedbergella planispira* (Tappan, 1940), *H. globigerinelloides* (Subbotina, 1949) (Plate 4, Figures 3 and 4), *Globigerinelloides ultramicra* and *G. modesta* (Bolli, 1959) (Plate 3, Figures 26 and 27) constitute only a small part of the total amount. There are probably many new species (few chambered, or with digitate chambers) or variants (e.g., a subsymmetrical form of *G. modesta*).

The bulk of the residual agglutinated forms remains the same, with some exceptions such as the extinction of

*Verneuilinoides* gr. *subfiliformis* and *Bigenerina variabilis* very early in the stage (Core 99) and the extinction of *Rothina silesica* (Core 71).

#### Cenomanian (Cores 57-56 pars)

The layers which can be assigned to the Cenomanian are thin (Core 57 and Samples 56, CC to 56-2, 23-24 cm), although the uppermost beds (Samples 56-3, 3-5 cm to 56-2, 23-24 cm) cannot be dated with the help of foraminifers which are missing there. The upper limit has been placed at a lithologic change (texture, color).

The Cenomanian is probably incomplete. The first Cenomanian levels, up to the base of Core 56, seem to pursue the Vraconian without change, with the same lithology and microfauna (the persistence of *Planomalina buxtoni* is noteworthy). A subdivision in the lower Cenomanian can be made with the first occurrence of *Rotalipora montsalvensis* Mornod, 1950 in Sample 56-6, 105-107 cm (Plate 5, Figures 13 and 14). This delimitation involves a thin lower part of the lower Cenomanian.

Similarly, a short interval separates this form from the first exemplars of *Rotalipora cushmani* (Morrow, 1934) in Sample 56-3, 45-47 cm (Plate 5, Figures 15 and 16) and *R. reicheli* Mornod, 1950, in Sample 56-3, 76-77 cm (Plate 5, Figures 17 and 18) which probably correspond to a young level in the middle Cenomanian.

It seems that Core 56 belongs to a renewed sequential regime and, consequently, that the microfauna may have been displaced if not reworked. Corrosion and probable solution traces are perceptible, especially from Section 56-5 upward; microfaunal assemblages do not look like those in the underlying beds (less homogeneous, impoverished?); clasticity has increased since Core 59. The middle Cenomanian assemblages come from thin calcareous intercalations, with debris and small rounded pebbles, which are very different from the surrounding, more argillaceous sediment which has few or no microfossils upward from Sample 56-2, 119 cm.

The shortness of the Cenomanian series could result, of course, from condensed sedimentation. However it seems that major perturbations with reworked material and perhaps stratigraphic breaks were important during this long time interval, which is dated only twice by renewed microfaunal assemblages.

Middle Cenomanian deposits are overlain by strata which seemingly belong to the early Senonian. This large hiatus at the top of Core 56 is probably genetically related to well-known worldwide events which particularly have been investigated in the North Atlantic (Bartlett and Smith, 1971; Hart and Tarling, 1974; Hart, 1976).

#### Upper Cretaceous Series

Several units can be distinguished in the sedimentary column above the stratigraphic break in Core 56.

##### Unit 1: From Samples 56-2, 19 cm to 50-6, 15-17 cm

Its upper limit corresponds to the first occurrence of calcareous benthic and planktonic foraminifers (which

are lacking below, with the exception of some reworked exemplars). This first unit is paleontologically characterized by an agglutinated assemblage.

This assemblage seems to be homogeneous from bottom to top; the more important species or genera are as follows:

- Praecystamina* cf. *globigeriniformis* Krasheninnikov, 1973
- Ammodiscus* cf. *rotalarius* Loeblich and Tappan, 1949 or *cretaceus* (Reuss, 1845) in Krashen, 1974.
- Hyperammia* ? sp.
- cf. *Bathysiphon nodosariaeformis* Subbotina, 1950
- Glomospira corona* Cushman and Jarvis, 1928
- Glomospira tortuosa* Eicher, 1960
- Glomospirella* (*Mjatjukella*) *gaultina* (Berthelin, 1880)
- Hormosina ovulum* (Grzybowski, 1901)
- Reophax* sp. cf. *R. bohemicum* (Perner, 1897)
- Trochammina* cf. *böhmi* Franke, 1928
- Trochammina* cf. *gyroidinaeformis* var. *altiformis* Cushman and Renz, 1946
- Paratrochamminoides corpulentus* Krasheninnikov, 1973
- Paratrochamminoides intricatus* Krasheninnikov, 1973
- Haplophragmoides molestus* Krasheninnikov, 1973
- Haplophragmoides* aff. *herbichi* Neagu, 1968 or *linki* Nauss, 1947
- Haplophragmoides decussatus* Krasheninnikov, 1973
- Ammobaculites* sp.
- Verneuilinoides* cf. *perplexa* (Loeblich, 1946)
- Uvigerinammina* sp. p.
- Spiroplectammina* cf. *steinekei* Finlay, 1939
- Recurvoides* cf. *pseudosymmetricus* Krasheninnikov, 1974

Such an assemblage strongly suggests that it is "residual" and represents the benthic part which escaped dissolution beneath the CCD. Many of its components have no stratigraphic value and are encountered in the Upper Cretaceous and the lower Eocene. Nevertheless, some species are important, i.e., *Praecystamina* cf. *globigeriniformis*, *Recurvoides* cf. *pseudosymmetricus*, *Haplophragmoides molestus*, *H. decussatus*, *Trochammina* cf. *böhmi*?, *Paratrochamminoides intricatus*, and *P. corpulentus*. If we compare this assemblage with recent studies by V. A. Krasheninnikov on material from Legs 20 and 27, we can propose a Senonian age, probably Santonian or Campanian.

This determination is significant because it means that a large stratigraphic break extends between the middle Cenomanian and "middle" Senonian. This must be considered as a working hypothesis, because we must not forget that agglutinated foraminifers are facies-linked forms.

In this interval, a few samples yield some calcareous forms which are poorly preserved and sometimes have solution marks. They have probably been displaced and come from older sediments, mainly from the Cenomanian. The following species were found:

- Gavelinella* sp. p. (Samples 54-2, 104-106 cm, and 54-1, 99-101 cm)

- Gyroidina mauretana* Carbonnier, 1952 (Samples 51-2, 66-68 cm)  
*Hedbergella* cf. *modesta* (Bolli, 1959) (Sample 51-2, 66-68 cm)  
*Globigerinelloides* sp. (Sample 52, CC)  
*Rotalipora apenninica* (Renz, 1936) (Samples 53-2, 141-143 cm, and 51-3, 99-101 cm)  
*Globotruncana imbricata* Mornod, 1950 (Sample 53-2, 141-143 cm)

Some agglutinated forms are perhaps reworked from late Cenomanian or Turonian deposits, e.g., *Haplophragmoides* cf. *herbichi* Neagu, 1968 (in Samples 52, CC; 52-4, 143-145 cm; and 52-4, 39-41 cm).

The micropaleontological monotony in the specific composition of the agglutinated residual assemblage is compensated for by some varying features within this interval. Finally, the agglutinated assemblage itself is quantitatively variable, i.e., absent or very rare at the base (Cores 56 and 55), becoming common later (Core 54) and progressively abundant (Cores 53 and 52), then suddenly disappearing or again becoming very rare (Cores 51 and 50 pars).

Similarly, the reaction of sediment fragments to HCl as seen under the microscope changes in the course of Core 52, from dominantly negative below to positive above; then it remains positive upward, until the calcareous or chalky sediments of the upper Senonian. The structure of the sediment also seems to be modified (frequency and length of the rhythmic sequences, color, texture). Within this stratigraphic interval, another break concerns the radiolarians which disappear from Core 55 or 54 upward.

All these features at Site 398 probably reflect, on our microscopic scale, the existence of more widespread geologic phenomena.

**Unit 2: From Samples 50-6, 15-17 cm to 41-5, 140-142 cm**

Henceforth, calcareous species of foraminifers (benthic as well as planktonic) are present and numerous. The first pertinent samples (especially Samples 50-6, 15-17 cm to 50-2, 16-18 cm) are chronostratigraphically important. Diagnostic species are as follows (besides numerous forms belonging to *Pleurostomella*, *Discorbis*, *Epistominella*, *Bulimina*, and *Gümbelina*):

- Spiroplectammina* gr. *dentata* (Alth, 1850)  
*Buliminella pusilla* (Brotzen, 1936)  
*Aragonia* gr. *paynei* (Morrow, 1934) — *ouezzanensis* (Rey, 1955)  
*Globotruncana linnei* (d'Orbigny, 1839)  
*Globotruncana* cf. *cachensis* Douglas, 1966  
*Globotruncana fornicata* Plummer, 1931  
*Globotruncana stuartiformis* Dalbiez, 1955

This sample therefore can be placed in the middle Senonian; it belongs at least to the uppermost Santonian. This oldest age is corroborated by Sample 50-2, 16-18 cm, whose maximum age is lowermost Campanian, based on the presence of *Globotruncana concavata* (Brotzen, 1936).

From Sample 50-6, 15-17 cm to the top of Core 45, the foraminiferal assemblage vary slightly; benthics are

generally numerous, more so than planktonic forms. Solution marks are perceptible, particularly on the latter. Among the more important species are the following:

- Spiroplectammina* gr. *dentata* (Alth, 1850)  
*Spiroplectammina regularis* Hofker, 1957  
*Eouvigerina aculeata* (Ehrenberg, 1854)  
*Pseudouvigerina plummerae* Cushman, 1927  
*Bolivinita eleyi* Cushman, 1927  
*Bolivinita* cf. *selmensis* Cushman, 1933  
*Bulimina kickapooensis* Cole, 1938  
*Buliminella pusilla* (Brotzen, 1936)  
*Reussella szajnochae* var. *praecursor* de Klasz and Knipscheer, 1955  
*Reussella szajnochae* (Grzybowski, 1896)  
*Bolivina kalinini* Vasilenko and Mjatljuk, 1947  
*Aragonia ouezzanensis* (Rey, 1955)  
*Bolivinooides decorata* (Jones, 1886)  
*Bolivinooides miliaris* Hiltermann and Koch, 1950, var.  
*Bolivinooides pustulata* Reiss, 1954  
*Neoconorbina supracretacea* (Schijfsma, 1946)  
*Gavelinella whitei* (Martin, 1954)  
*Stensiöina pommerana* Brotzen, 1936  
*Nuttallinella florealis* (White, 1928)  
*Nuttallinella texana* (Cushman, 1938)  
*Nuttallinella spinea* (Cushman, 1938)  
*Osangularia cordieriana* (d'Orbigny, 1840)  
*Osangularia velascoensis* (Cushman, 1925)  
*Conorotalites subconica* (Morrow, 1934)  
*Pullenia jarvisi* Cushman, 1936  
*Gümbelina costulata* Cushman, 1938  
*Globotruncana arca* (Cushman, 1926)  
*Globotruncana* cf. *arcaformis* Maslakova, 1974  
*Globotruncana cachensis* Douglas, 1966  
*Globotruncana caliciformis* (J. de Lappar, 1918)  
*Globotruncana convexa* Sandidge, 1932  
*Globotruncana elevata* (Brotzen, 1936)  
*Globotruncana fornicata* Plummer, 1931  
*Globotruncana linnei* (d'Orbigny, 1839)  
*Globotruncana rugosa* (Marie, 1941)  
*Globotruncana stuartiformis* Dalbiez, 1955  
*Globotruncana tricarinata* (Quereau, 1893)  
*Hedbergella* cf. *loetterlei* (Nauss, 1947)  
*Globigerinelloides ehrenbergi* (Barr, 1962)  
*Planomalina rowei* Barr, 1962  
*Planomalina yaucoensis* Pessagno, 1960

The age of this assemblage is Campanian. The boundary with the Santonian is characterized by the co-existence, in two close samples, of *Globotruncana concavata* and *G. stuartiformis*. The top of the stage is not well documented because of the absence of *G. calcarata* (Cushman, 1927). Nevertheless, the presence of some exemplars similar to *Bolivinooides draco* and the first occurrence of *Nuttallinella spinea* suggest that Core 47 is still very upper Campanian.

Some previously listed agglutinated species persist in the Campanian (i.e., *Glomospira corona*, *G. tortuosa*, *Glomospirella* sp., *Recurvoides* cf. *subglobosus*, and *Ammodiscus* cf. *cretaceus*).

At the top of Core 45, we observed some *Globotruncana* very close to *G. caliciformis*, as well as probably *G. stuarti* (J. de Lappar., 1918). Core 44 provides the first occurrence of *G. citae* Bolli, 1951; *Bolivina incrassata* Reuss, 1851; *Osangularia lens* Brotzen, 1940; and advanced forms of *Reussella szajnochae*. These sediments were deposited during the Maestrichtian.

From Core 44 to Sample 41-6, 38-40 cm, the following species belong to a Maestrichtian assemblage:

*Ammodiscus* sp.p

*Glomospira corona* Cushman and Jarvis, 1928

*Glomospira tortuosa* Eicher, 1960

*Haplophragmoides* spp

*Trochammina* sp.

*Pseudoclavulina clarata* (Cushman, 1926)

*Arenobulimina obliqua* (d'Orbigny, 1840)

*Arenobulimina cytherea* Marie, 1941

*Aragonia ouezzanensis* (Rey, 1955)

*Bulimina kickapooensis* Cole, 1938

*Reussella szajnochae* (Grzybowski, 1896)

*Bolivina incrassata* Reuss, 1851

*Gavelinella whitei* (Martin, 1954)

*Osangularia lens* Brotzen, 1940

*Nuttallinella spinea* Cushman, 1938

*Globotruncana arca* (Cushman, 1927)

*Globotruncana caliciformis* (J. de Lappar., 1918)

*Globotruncana citae* Bolli, 1951

*Globotruncana contusa* (Cushman, 1926)

*Globotruncana falsostuarti* Sigal, 1952

*Globotruncana fornicata* Plummer, 1931

*Globotruncana fundiconulosa* Subbotina, 1953

*Globotruncana stuarti* (J. de Lappar., 1918)

*Globotruncana stuartiformis* Dalbiez, 1955

*Globotruncana tricarinata* (Quereau, 1893)

*Planomalina yaucoensis* Pessagno, 1960

In Samples 43-3, 17-19 cm; 43-2, 133-136 cm; and 43-1, 31-33 cm, the uppermost Maestrichtian is characterized by the following newly introduced species:

*Gümbelina costulata* Cushman, 1938

*Ventilabrella glabrata* (Cushman, 1938)

*Pseudotextularia elegans* (Rzehak, 1891)

*Racemigümbelina fructicosa* (Egger, 1899)

*Reussella szajnochae* (Grzybowski, 1896) var.

*Globotruncana mayaroensis* Bolli, 1951

*Globigerinella messinae* Brönnimann, 1952

*Globigerinella messinae* var. *subcarinata* Brönnimann, 1952

Noteworthy is the abundance here of Heterohelidae, which in previous cores were sporadic or absent.

From Sample 43-1, 31-33 cm upward, the stratigraphic interpretation is difficult. Between Samples 43-2, 74-76 cm and 41-6, 38-40 cm, the main Maestrichtian species are still present (some persist into the lowermost Eocene), but they are accompanied by small Globigerinids, some of which are similar if not identical to the so-called *Eoglobigerina*. The last *Globotruncana*, *Osangularia lens*, and *Nuttallinella spinea* were observed in Sample 41-6, 38-40 cm.

Up to Sample 41-2, 33-35 cm, the same Globigerinid association continues, whereas some Cretaceous species are still encountered as impoverished and sporadic as-

semblages, with the exception of some samples from Section 41-2 which yield abundant forms (particularly the late Maestrichtian Heterohelidae). The first occurrence of *Chilogümbelina* occurs in Sample 41-5, 52-54 cm.

In summary, the Maestrichtian stage ends with Sample 41-6, 38-40 cm, giving way to the first Danian level with reworked Maestrichtian fauna. The latter are particularly present in Section 41-2, especially between Samples 41-2, 49-51 cm and 41-2, 33-35 cm. It should be emphasized that these layers are intensely disturbed and separate two series of different textures and colors. They were interpreted onboard ship (when drilling, i.e., downward) as representing the Tertiary/Cretaceous boundary because of the sudden appearance (downward) of Maestrichtian assemblages.

These layers with very small Globigerinids correspond to our genuine "small-*Globigerina* zone." They are followed (from Sample 41-2, 34-36 cm upward) by a second Danian level with a multitude of somewhat larger "small Globigerinids," typical forms of the *Eugubina* zone. The last sample examined (Sample 41-1, 132-134 cm) still belongs to this zone.

#### ECOSTRATIGRAPHY OF LOWER CRETACEOUS FORMATIONS

This section introduces the relationships between faunal assemblages and the sediments containing them, for the purposes of determining the general trends in their evolution and perhaps reconstructing the sedimentary milieu.

The following ecostratigraphic interpretation has been based mainly on a distinction between transported-redeposited and autochthonous-residual foraminiferal assemblages. Other criteria were likewise involved, such as specific composition, lithologic nature, and sedimentary components, as well as plant content and other associated organisms and organites.

The transported-redeposited assemblages comprise benthic species with calcareous (and agglutinated) shells and are interpreted as originally having been deposited on shelf or slope areas. Sometimes evidence of predation is present. They were then buried in such a condition (milieu, terrigenous supply, speed of accumulation) that the shells have been at least partly preserved, even when deposition took place beneath the CCD (Arhenius, 1963).

Transported assemblages are generally a composite group of species which lived in different areas (e.g., see Pujos-Lamy, 1973). This will be more thoroughly examined later, along with the paleontological study of the benthic species. The planktonic forms must be considered separately since they are essentially oceanic and, consequently, do not have the same history when found together with benthic ones.

The autochthonous-residual assemblages concern species with non-calcareous (i.e., agglutinated) shells ("deep-water *Rhabdammina*-fauna" of Brouwer, 1965; "Astrorhizidae-Ammodiscidae taxocoenosis of oceanic type" of Saidova, 1965). Schematically, these assemblages have long been considered (Rzehak, 1887) as

thriving in deep and relatively cold water (Pokorny, 1960; Saidova, 1965a, b; Brouwer, 1965; Hiltermann, 1968). Nevertheless, this interpretation has not been unanimously accepted (Stainforth, 1952; Pflaumann, 1967). Such assemblages are now generally considered to be the result of two main processes. First is a relative enrichment, such as an adaptative response of specialized "microaerophile" living associations, coupled with the lack of competition due to a severe environment for calcareous species (Le Calvez, 1956). Secondly is a residual assemblage (niche diversification, selective preservation) through diagenetic dissolution ensuing from a reducing environment, which especially occurs below the CCD.

Appropriate studies of outcropping flysch series have enabled us to understand how such specific observations made in an isolated hole can be applied to regional fossil-life conditions and paleogeographic settings (Ksiazkiewicz, 1961; Brouwer, 1965; Hiltermann, 1968, 1975; Hesse, 1975, 1975; Hesse and Butt, 1976; Sliter, 1975; Van Stuijvenberg, Morel, and du Chene, 1976; among the recent literature).

The estimation of the depth of the CCD has resulted in a prolific literature on two subjects. First is the plotting of crestal depth versus age (or its log) curve, which facilitates constructing the approximately depth of deposition (e.g., see Berger, 1972; Berger and Winterer, 1974; Veevers, 1977). Second is the search for specific factors which could have either disturbed this global environmental evolution or developed local conditions. Thus, in the case of Hole 398D, the required depth for carbonate solution could have occurred shallower because of the vast influx of organic matter-rich sediments delivered from either terrigenous sources, or high phytoplankton or zooplankton surface productivity.

In addition to foraminifers, other organisms are present. Radiolarians are particularly frequent, abundant, and diversified. Ostracodes are poorly and sporadically represented (around 60 exemplars were found). Lastly, ammonites (see Renz, this volume) were encountered at different levels, sometimes abundantly. They are noteworthy as to their preservation (nacreous colored shells); this fact, considering the nature of the enclosing sediment (carbonate-depleted clay or dark shales), remains unexplained. A protective effect of the conchioline layers in the textural pattern of the shell might be an avenue of future research work, as was suggested by Mme. G. Termier and as it is presently in progress by Prof. Ch. Grégoire.

Other organic debris are fairly abundant (aptychus, inoceramus) or rare (belemnites, rhyncholites), to which varying amounts of shell fragments must be added (gastropods, pelecypods, echinoids). The washed residues are frequently rich in debris or fish teeth, together with various spicules (mainly sponges, also gorgonids, ascidids); their study by a specialist is desirable.

Analysis of these data enabled successive diagrams of ecostratigraphic units (November 1976, December 1976, March 1977) to be drawn. They satisfactorily coincide

with other lithological and sedimentological subdivisions which have been proposed.

The data which are available for such ecostratigraphic analysis are shown on the detailed log of Chart 1A (at the back of this volume), sample by sample, as they were observed in the 63-micron sieved residues. These data enabled us to develop a sedimentary history.

In this way, several cored interval (Units I to V, with sub-units) were progressively delineated to trace the evolutionary stages of the sedimentary basin at the drill site. In the following pages, these intervals will be described, first with the help of a comparative analysis of the data, to determine some basic categories, either micropaleontologically (assemblages) or lithologically (lithoterm). They will then be described by trying to discern the correlations which could exist between the assemblages and the elementary sequential intervals. Figures 2 through 6 provide an illustration and a definition of the lithoterm for each unit. Additionally, Tables 3 through 11 correlate assemblage frequencies with each lithoterm in the different cores.

The detailed log (Chart 1A) visually depicts some important features, including the following:

- 1) The location of the large slump in Cores 105 and 104 in the empty space which occurs in the AP (Column C and left side of Column E, Chart 1A) and, conversely, the "populating" with calcareous species (in Column D and right side of Column E).

- 2) The relationship of Core 103 to the slump in Cores 104 and 105, and not to the overlying "dark shales" (as can be seen in Column B, Chart 1A), although this core already belongs to the later facies lithologically (Column J for pyrite) and partially biologically (Column H for radiolarians and plant debris, and Column B for AP).

- 3) Conversely, the forewarning of the giant slump (Cores 104 and 105) as early as Core 110, is exemplified by frequent "peaks" on curves related to  $\beta$  or  $\pi$  (Column B), without any synchronism with similar features concerning AP (same column), as can be expected because these parameters define a calcareous supply in an "autochthonous" residual community.

- 4) Such a synchronism is, on the contrary (Column B) between Cores 138 and 131, when the distinction between  $\beta$  and AP is no longer or not yet valid in the midst of a unique association which was deposited above the CCD.

- 5) An "intermediary" stage (Cores 130 to 121) between these extreme sedimentary regimes. It is individualized by the obliteration of the residual AP in favor of  $\beta$  and  $\pi$ .

- 6) Lastly, the growing clasticity (Column J) in the upper cores.

This study is an example of the difficulty experienced when abundant data is available and when we want to coordinate them into conventional, but perhaps too simplistic schemes. The data themselves are not without some limitations. For instance, there is the already mentioned distinction between  $\beta$  and residual AP, depending on the position of the CCD in relation to the ocean

floor. Like a feed-back effect, the  $\beta/AP$  distinction serves to determine the depth of the CCD which, in turn, limits the validity of this distinction. Another limiting factor is the validity of extrapolating of dissolution criteria back into the Early Cretaceous, as these criteria are based on Recent or late Tertiary populations (Sliter, 1975; Sliter et al., 1975; Thunell, 1976; Sliter, 1974).

Such limitations are of less concern when they involve the statistical utilization of data in helping to define the sedimentary evolution. Thus, we took numerous samples. However, the large number of samples also causes a problem, for we rapidly reach the level where the data are so numerous that we cannot succeed in incorporating them in simple schemes. The clearest example is in deciphering whether the drill site was above or below the CCD when the seemingly pelagic sediments of Unit V were deposited.

### Unit I: From Cores 138 to 131

The first unit of lithologic formations corresponds to "marly-calcareous" alternating series, resulting from a repetitive or rhythmic succession of compact massive calcareous and soft laminated marly layers with a low sedimentation rate (7 to 8 m/m.y.). Each pair simulates a graded sequence whose final interval should be formed by a lime facies with calcareous nannofossils and radiolarians. The other beds are composed of fine laminae which, if they are sufficiently closely samples, yield predominantly varying organic or mineral components, depending on the kind of selective enrichment they underwent during re-depositional processes.

Note that  $A/\beta$  (and  $A/\beta'$  after planktonics have appeared in Core 133) are the only assemblages to be represented and that, conversely,  $R/AP$  s. str. cannot exist as a consequence of deposition shallower than the CCD.

The lithological sequence we refer to involves four lithoterms (Figure 2). The uppermost one (No. 5) forms the skeleton of Cores 138 to 131; the lowermost one (No. 3) is relatively poorly represented; Nos. 1 and 2 are the most common. We attempted to determine the originating lithologic term for laminated sediment; this is specified by an arrow above the Arabic number in Chart 1A.

### Data Analysis

#### Organogenic Components

**$\alpha$  Microfauna:** As mentioned above, only  $A/\beta$  from the beginning (and later  $A/\beta'$ ) can be present; in the same way,  $A/Az$  (and later  $A/P$ ) represent impoverished assemblages.

**Benthos:** Fairly abundant, often poor, and rarely very abundant;  $\beta$  is statistically more abundant in laminae having originated from Lithoterms 2 or 3. Lagenidae and agglutinated species essentially, from the slope or external shelf; some of the agglutinated foraminifers are the ones which will later form the residual assemblages  $R/AP$  underneath the CCD.

**Plankton:** Generally poor; numerous samples are devoid of  $\pi$  (whence a large amount of  $A/\beta'$  and  $A/Az$ ).

**Radiolarians:** Variable quantitatively, more frequently abundant in the lower cores; simple, globular, ellipsoidal, or conical forms only. They are mainly recrystallized.

**$\beta$  Macrofauna:** Shell fragments are frequent and varied (gastropods, pelecypods, echinids, ammonites), particularly in the lower cores, but never very abundant in the other cores. *Aptychus* and *inoceramus* are especially noteworthy. Debris was encountered only in Lithoterms 2 and 3. Fish debris are frequent, sometimes abundant. Spicules are sporadic and rare.

**$\gamma$  Plant debris:** Frequent, but moderately represented, increasing upwards.

#### Inorganic Components

**Clasticity:** Weak, except some samples at the top where abundant quartz and mica are related to Lithoterm 3. Noteworthy is the abundance of both mica and plant debris in the same sample, a feature frequently observed later.

**Pyrite:** Frequent, sometimes abundant, decreasing upwards.

**Glauconite:** Frequent in the upper part and related to  $A/\beta$  in Lithoterms 2 and 3.

**Hydrochloric test:** Dominantly calcareous or semi-calcareous.

#### Assemblage-Lithofacies Relationships (Table 3)

The feasibility of  $A/\beta$  by itself (and later  $(A/\beta')$  is again emphasized.  $A/AP\beta$  or  $A/AP\beta'$  correspond here to internal variations within the former assemblages, seeing that  $AP$  does not exhibit the meaning ("residual") it will possess higher up in the series, when sedimentation takes place beneath the CCD. Cores 138 and 137 exhibit only  $A/\beta$ ; assemblages without benthos ( $A/P$ ,  $A/Az$ ) occur subsequently.

Assemblages  $A/\beta$  and  $A/\beta'$  are coupled with Lithoterms 2 and 3; they show some variety depending on the component, i.e., clastic material, bioclastic remains or micropebbles made up by Lithoterm 5, which prevails singly or in pairs. In this last case, more detailed sampling would probably enable us to separate differently enriched beds; the thickness of the sampled section becomes a significant discriminating factor.

Lithoterm 1 seems to be characterized by the presence of layers where radiolarians have been concentrated; moreover, it frequently yields  $A/Az1$  or  $A/Az2$ .

Assemblage  $A/P$  or  $A/Az$  is encountered in every lithoterm. Such a feature seems to be normal in the upper interval of the sequences (the most decanted Lithoterm 5) or in the basal interval (Lithoterm 3) with dominating clasticity.

Laminations generally can easily be derived from a given lithoterm; nevertheless, the co-existence of two main components suggests a composite origin (for instance samples 3, 4, 9 on Chart 1A) unless the sampling is too inclusive.

TABLE 3  
Various Dominant Organic and/or Inorganic Assemblages  
and Their Frequency in Cores 138 to 131 of Hole 398D

Lithoterm/Components	DSDP Core Numbers							
	138	137	136	135	134	133	132	131
5 $\beta$ , Rad								1
1 { Rad A/Az1 (Rad) A/Az2	2	1	4	2	4	1		
					1	1		
								1
1+2 { Rad $\beta$ , Rad $\theta$ Rad $\theta$	1		?2	2	1	1		
		3	2					
		1						
2 { $\beta, \theta$ , Rad $\beta$ $\beta \theta$ $\theta$ $\beta, \theta$ Q, M A/Az2 A/P1			1		1			
	1			2	1			
	1	2						
		1	1	1				1
				1				
		2			1			1
3 { $\theta$ Rad $\beta$ , Rad $\theta$ Q, Rad Q, M, $\theta$ Q, M A/Az1 (Q) A/Az2 (Q, M) (calc.)								
							1	
							1	
							1	
		1			1	1		
						2		
Unsettled								1
		1	5		1			
					3	2	3	

Statistically, a given outstanding component frequently precludes other ones, e.g., radiolarians, or quartz plus mica (plus organic debris incidentally), or mica plus plant debris, or organic debris. These observations support the theory that such an enrichment can be interpreted as the result of the reworking, redeposition, and sorting of pre-existing material.

Table 3 gives an idea of the diversity of the components observed. The abbreviations Rad.,  $\beta$ ,  $\theta$ , Q, M, and calc. represent, respectively: radiolarians, benthos, debris, quartz, mica, and micropebbles of sediment pertaining to Lithoterm 5. Table 3 also gives an idea of the frequency of the various samples within the cores, according to the dominating component (or components).

**Unit II: From Cores 130 to 103**

Partly disturbed sequential deposits characterize this unit. On one hand, sequential lithoterms may have been secondarily laminated and graded. On the other hand, sequential successions are interrupted by intrusive turbiditic or slumped bodies. The sedimentation rate here is relatively high (25 m/m.y.). Four sub-units are distinguished. The first or lower one and the fourth or uppermost one are based on the mutual behavior of these two disturbing factors. In the first sub-unit, both types occur. The fourth sub-unit consists entirely of a large slump. The second and third sub-units exhibit a different average thickness of the sequences, which are shorter and longer, respectively. More precisely, in the third sub-unit it is mainly the terminal interval of the sequences which becomes thicker and in this way presages the overlying Unit III. The drill site intersected the paleo-CCD during sedimentation of this unit, probably early (near Core 120?).

At the Unit I/II boundary, diagnostic variations affect some biological and sedimentological features: (1) disappearance of nannofossil-rich and radiolarian-rich white colored limestone; (2) spread of plankton; (3) little or no reaction to HC1; and (4) increase in clasticity (and kaolinite), in parallel with either Portuguese or Canadian coeval deposits.

The upper limit of Unit II is defined where sorted sequences disappear in favor of the "dark shales," and where R/AP assemblages become predominant or even exclusive, to the detriment of T/ $\beta$  assemblages.

**Sub-Unit IIa: From Cores 130 to 121**

In the first sub-unit, the sequential deposits have been disturbed either by secondary laminations or by large turbiditic or slumped intrusions. Four main lithoterms (Figure 3) constitute this sub-unit. Lithoterm 1, when present, is never thick. Lithoterms 2 and 3 are the most developed, as sometimes is Lithoterm 4 (Cores 128, 125, and 124). Lithoterm 3 can generally be subdivided into two parts, a sorted lower part and a cross-bedded upper part.

Laminae are the most important features. They are frequently expressed by concentrations of organic or inorganic components, as a probably consequence of local reworking and sorting on the sea floor. As in Unit I, we tried to determine the original lithoterm (designated by an arrow) from which the laminations come, with the help of biological and lithological criteria.

**Data Analysis**

**Organogenic Components**

**$\alpha$  Microfauna:** There are some indications (solution marks, carbonate-depleted samples) that deposition took place below or at least near the CCD. It therefore becomes possible to take into account the R/AP assemblages as such i.e., residual assemblages after dissolution effects.

**Transported benthos:** Usually poor; when relatively rich, it coincides with the presence of debris, either in Lithoterm 2, or more rarely in Lithoterm 3. It seems to be more abundant in the upper cores. Otherwise, the lack of  $\beta$  (resulting in A/AP or A/AP') is rarely observed. Transported benthos generally occur in Lithoterm 1, sometimes in the clastic and plankton-poor Lithoterm 3. Lagenidae and Gavelinellidae are largely represented. Sometimes *Dorothia ouachensis* is very abundant, as well as various species of Epistominidae when they have escaped dissolution. Sample 125-2, 8-10 cm is noteworthy because of its richness in Ophthalmidiidae, a group of fossils rarely present in adjacent samples.

**Residual benthos:** Always poorly represented.

**Plankton:** Highly variable, either very poor, or very luxuriant. Frequently abundant in the lower cores where it is coupled with laminations. Never abundant in Lithoterm 1. The lack of any plankton is frequently observed (A/ $\beta'$ , A/AP', A/Az1); most of the samples belong either to Lithoterm 1 (with or without laminations) or to highly clastic and biodetrital Lithoterm 3, and rarely Lithoterm 2.

**Radiolarians:** From rare to very abundant, but very irregularly distributed. They seem more frequently abundant in the upper cores where they are also more frequently diversified, in this way presaging the next overlying sub-unit. They are well represented in Lithoterm 1. Other lithoterms also are often well supplied, particularly in the laminites or in allochthonous parcels in Lithoterm 4. Recrystallized skeletons predominate widely and occur in all kinds of assemblages; siliceous shells are infrequent, often encountered in the samples where they are abundant, and in every lithoterm, not only when R/AP prevails. Radiolarians are rarely lacking; this is the case in the upper cores especially and mainly occur in every lithoterm, but does not arise with assemblage R/AP.

**Dissolution:** Solution marks on calcareous shells often are obvious, especially among *Epistomina*; however, more resistant forms such as some agglutinated shells (*Dorothia ouachensis*) are also affected.

**Reworking:** Probable reworked species of foraminifers are frequent, in addition to those obviously reworked as Calpionellids (which are found either in pebbles or in the matrix of the breccia).

**$\beta$  Macrofauna:** Generally, the biodetrital character is marked; nevertheless (and paradoxically), organic debris do not predominate in samples from coarse turbiditic material. They are particularly abundant in samples with T/ $\beta$ , where they probably reflect a finer supply. The organic debris consist mainly of pelecypods, rare echinoids, frequent inoceramus, sporadic aptychus, and one belemnite (in Sample 128-4, 39-41 cm). Fish remains are frequent, but not numerous; spicules are rare. Some fractured samples yielded ammonites identified as Barremian.

**$\gamma$  Plant debris:** Very frequent, at times plentiful (in this case, sometimes associated with abundant mica) in every lithoterm, but preferably and more richly when a turbiditic supply exists. The preservation of vascular and tissular fibers is sometimes perfect.

**Inorganic Components**

**Clasticity:** Quartz is rarely lacking; it becomes sporadic and less abundant in the upper cores (126 to 121). Coarse rounded grains are observed occasionally. The abundance of Q is associated with Lithoterms 2 and 3; nevertheless, some samples of Lithoterm 1 (with or without laminae) are also prolific (Cores 125 and 127). Lithoterms 3 and 2 sometimes yield abundant quartz and organic debris together.

**Glaucanite:** Frequently present (e.g., Cores 127, 122, and 121), mostly associated with Lithoterm 3 and rarely with 2 or 4. Generally associated with organic debris. In rare samples, glaucanite is observed in Lithoterm 1 (with A/AP, A/AP $\beta$ ’, A/Az2, or in polluted laminations with A/ $\beta$  or A/ $\beta$ ’).

**Pyrite:** Frequent, sometimes plentiful, it is uncommon in the upper cores; indiscriminantly observed in all lithoterms and with a distribution similar to glaucanite. Found in samples generally containing quartz and organic debris. In most cases, pyrite is associated with radiolarians (pyritized shells), sometimes with spicules,

rarely with planktonic and sometimes benthic foraminifers, and rarely with micro-gastropods or pelecypods.

**Hydrochloric Test:** Dominantly calcareous in all cores; nevertheless, the highest sequential interval (Lithoterm 1, with R/AP or A/Az) often shows a weak or negative test.

**Assemblage-Lithofacies Relationships (Table 4)**

Assemblage diversity and the multiplicity of depositional conditions (laminations, turbiditic supply) make it difficult for a correlation to be established. If we compare “normal” assemblages (T/ $\beta$  and R/AP), a satisfying correlation is found between R/AP and Lithoterm 1, and between T/ $\beta$  and Lithoterms 2, 3, and 4. Two unusual samples with T/ $\beta$  in Lithoterm 1 are explained either through bioturbation in contact with Lithoterm 2 (Core 126), or through the presence of exogenic fragments of Lithoterm 1 in Lithoterm 4 (Core 125).

Laminae have been tentatively associated with a given lithoterm, assuming that a correlation similar to that above can be extended to the laminated samples. Two exceptions in Core 129 (A/AP’ in Lithoterm 3) probably resulted from errors in estimating A/ $\beta$ ’ assemblages, due to low quantities of AP and  $\beta$ .

For impoverished assemblages (A/P and A/Az), we observed wide scatter in the various lithoterms, with or without laminations. Limited sampling does not allow

**TABLE 4**  
Quantitative Distribution of Assemblages According to the Different Lithoterms in Cores 130 to 121 of Hole 398D

Lithoterm/Assemblages	DSDP Core Numbers									
	130	129	128	127	126	125	124	123	122	121
1 {	A/AP				2					
	A/AP’					1		1		
	A/AP $\beta$					1		1		
	A/AP $\beta$ ’						2	2		1
	A/P1						1			
2 {	A/Az1	1		2			1			
	A/Az2				2					
	A/ $\beta$					1	1			
	A/ $\beta$ ’	3	1		5	6	2	2	4	6
	A/ $\beta$ ’	1		1	2		1	1	1	2
3 {	A/P1									1
	A/Az1							2		
	A/ $\beta$	1	2			1	3		3	1
	A/ $\beta$ ’	1	1	1		1		1		3
	A/P1		1							3
4 {	A/Az1									1
	A/Az2									
	A/ $\beta$									
	A/ $\beta$ ’									
	A/P1									
1 + 2 {	A/AP $\beta$ ’									1
	A/Az1		1	1						
	A/Az2	1								
2 {	A/ $\beta$ ’					2				
	A/ $\beta$ ’					2				
	A/AP $\beta$									
	A/Az2									
	A/ $\beta$	2	3							3
3 {	A/ $\beta$ ’	1				1				1
	A/P1									
	A/P2		2							1
	A/Az1	1	1							
	A/Az2									
3 {	A/ $\beta$	1								4
	A/ $\beta$ ’									1
	A/P1		2							
	A/Az1									
?A/AP’	A/Az1		3							
	A/Az2									1

for suitable explanations. Some assemblages were easily situated and their lithology was directly attainable (for instance, Samples 90, 143 in upper; 154, 197, and 234 in middle; 105, 115, 119, and 202 in lower sequential intervals). But the bulk has been indirectly assigned to a given lithoterm, according to organic or inorganic data. Such a procedure can evidently be criticized, inasmuch as no logical link seems to emerge. However, the great number of impoverished foraminiferal assemblages coinciding with radiolarian abundance, or with strong clasticity, is striking. Sometimes this can be determined as the result of the rearrangement inside of laminites; but at least as great a number of cases remains which cannot be explained in this way. Thus, we have a rather negative ascertainment at the present stage.

Lastly, we must inquire into the plankton/radiolarian ratio, when those parameters are either absent or abundant: (a)  $\pi$  and Rad abundant: always in T/ $\beta$  and in Lithoterms 2 or 3 (4 incidentally), never in R/AP and Lithoterm 1, but once in A/P1 and Lithoterm 1. (b)  $\pi$  and Rad absent: always in A/ $\beta$  or A/Az2 and in Lithoterms 2 or 3, never in A/AP' or A/AP $\beta$ '; sometimes in Lithoterm 1 in the shape of A/Az2. (c)  $\pi$  abundant, Rad absent: solely in T/ $\beta$  (and A/P2 once), always in Lithoterm 2 (generally laminated). (d)  $\pi$  absent, Rad abundant: mainly in Lithoterm 1 or in the finest level of 2, with A/AP', A/AP $\beta$ ' or A/Az1, but the situation is less distinct than previously. Sometimes this kind of ratio was observed in laminated and very clastic Lithoterm 3, with A/Az1; sometimes in Lithoterm 4 (artificial mixing?). Lastly, some coupled T/ $\beta$ ' — Lithoterm 2 or A/Az1 — laminated Lithoterm 2 occur, which we cannot explain at present.

### Sub-Unit IIb: From Cores 120 to 117

Microsequences are the characteristics of this second sub-unit, and three main criteria differentiate it from the preceding one: (1) R/AP assemblages prevail, as a consequence of the previously intersected CCD level; (2) siliceous and recrystallized radiolarians are equally numerous; and (3) the part played by turbiditic or slumped events is not preponderant. When upper sequential intervals become lengthened, we arrived at the next overlying sub-unit. The lithologic sequence of reference of the underlying Sub-unit IIa is also valid (Figure 3).

#### Data Analysis

#### Organogenic Components

##### $\alpha$ Microfauna

**Transported benthos:** Rarely abundant, solely in Lithoterms 2 and 3, occurring with abundant organic debris and radiolarians. Lagenidae and Gavelinellidae are the most important components, sometimes also *Gyroidina*; scarce Miliolids were probably transported from the neritic or shelf realm, as well as *Trocholinas*. Assemblages A/AP or A/AP' (i.e., without transported benthos) are found in Lithoterms 1 as usual. Sometimes A/AP or A/AP' are observed also in

Lithoterms 2 and 3 (Cores 119 and 117); because the amount of  $\beta$  and AP is very low in a calcareous sediment, we can suppose that they have been mis-estimated and are actually A/ $\beta$  or A/ $\beta$ ' assemblages.

**Residual benthos:** Uncommon or absent, with the exception of some R/AP in the two upper cores, where an evolution takes place toward the characteristically thick upper sequential intervals of the next sub-unit.

**Plankton:** Uncommon or absent (A/ $\beta$ ', A/AP', A/AP $\beta$ ', and A/Az are accordingly numerous); abundant only in Sample 118-1, 132-134 cm, in a slumped structure where a selective ( $\pi$ , M) enrichment may have occurred. The lack of plankton is noticeable, occurring with an abundance of radiolarians.

**Radiolarians:** Very rarely uncommon and never absent; very abundant as a rule (sometimes constituting nearly the entire of the washed residue), together with a wide morphological fan, in R/AP especially. Recrystallized and siliceous skeletons are equally represented.

**Dissolution:** Solution marks are often still obvious on calcareous shells, particularly on Epistominidae.

**Reworking:** Frequent.

**$\beta$  Macrofauna:** A biotrital character is rarely observed; sometimes organic debris are absent (Core 118). The presence of debris correlates with T/ $\beta$  and Lithoterm 3 in nearly all the samples concerned, generally together with glauconite and radiolarians. Inoceramus are very uncommon (Core 120). Fish remains are sporadic. Spicules are almost absent.

**$\gamma$  Plant debris:** Infrequent and not abundant in Lithoterms 1, 2, or 3 with their corresponding assemblages; exceptionally abundant plant debris together with abundant mica in Lithoterms 2 and 3 of several samples from Core 120.

#### Inorganic Components

**Clasticity:** Quartz generally absent or very rare. Few samples are very clastic, and when it occurs (mainly in the lower core), the clastic material coincides with A/ $\beta$  or A/ $\beta$ ' in Lithoterms 2 or 3, often with abundant mica and radiolarians.

**Glauconite:** Rather infrequent, with the exception of the base of the sub-unit; it is generally connected with Lithoterm 3, rarely 2 or 4, exceptionally 1; it generally occurs with organic debris.

**Pyrite:** Very sporadic and uncommon; distribution similar to glauconite; it occurs mainly as pyritized radiolarians.

**Hydrochloric test:** Partially positive and negative tests are almost equivalent, the first ones predominate in samples with T/ $\beta$ , the second ones in samples with R/AP; totally positive tests become infrequent, and negative ones spread increasingly.

#### Assemblage-Lithofacies Relationships (Table 5)

R/AP-Lithoterm 1 and T/ $\beta$ -Lithoterms 2 to 4 correlations (with or without laminations) lead to normalization. Exceptions are rare, although they are somewhat worrying when R/AP is found in Lithoterms 2 or 3, par-

TABLE 5  
Quantitative Distribution of Assemblages  
According to the Different Lithoterms in  
Cores 120 to 117 of Hole 398D

Lithoterm/Assemblages	DSDP Core Numbers			
	120	119	118	117
1 { A/AP' A/Az1	1	2	8	5
2 { A/β A/β' A/AP A/APβ'	2	1		4
	3		2	
				1
		3		
3 { A/β A/β' A/P1 A/Az1	5		1	1
	2	2		3
		1		
		1		1
4 { A/β				1
1 { A/AP'		2		
1 + 2 { A/APβ'	1			
2 { A/β A/Az1			2	
		1		

ticularly when this kind of lithology has been established without doubt (Samples 256, 260, and 265). Because of the amount of β and AP is very low in a calcareous sediment, we probably are faced with misestimated T/β assemblages. In another case (Sample 117-2, 113-115 cm), the assemblage may have been disturbed at the time of deposition, because the sample belongs to a very clastic and partially calcareous lower sequential interval.

Impoverished assemblages are uncommon. Radiolarians, as noted above, are never absent (consequently, neither A/P2 nor A/Az2 are observed); and the few A/Az1 and the sole A/P1 we have observed are distributed in the different lithoterms without disclosing any rule at the present stage of study.

Lastly, the study of the plankton/radiolarians ratio has been meaningful. Neither π and Rad abundant, nor π and Rad absent, nor π abundant and Rad absent have been encountered. π absent and Rad abundant is, inversely, a very frequently observed ratio, and two kinds of correspondence are evidenced: either with non-calcareous Lithoterm 1 and with A/AP', A/APβ', eventually A/Az1, or with calcareous or partially calcareous, glauconite-rich and benthos-rich samples in Lithoterm 2 and less frequently 3, and with A/β' (and some probably wrongly established A/AP' and A/APβ', because of small quantities of β and AP), eventually A/Az1.

#### Sub-Unit IIc: From Cores 116 to 106 Pars

This third sub-unit corresponds to the continuation of a sequential-type sedimentation, but less intensely laminated and with the constant presence and widening of the decarbonated upper sequential intervals. The other two intervals are also often thicker, resulting in an overall characterization as a "macro-sequential" sub-unit.

The typical features of the upper intervals relate them more to the forthcoming "dark shales" than to underlying Lithoterm 1; we could schematically say that this Lithoterm 1 should lie between Lithoterms II and I of the sub-unit presently being examined.

Lithologic differentiations (Figure 4) have increased here to extremes, and the sub-unit appears as a transitional grouping which retains diminished turbiditic supplies or influences, and foreshadows (but still polluted) the deposition of "dark shales."

#### Data Analysis

##### Organogenic Components

##### α Microfauna

**Transported benthos:** Highly variable quantitatively. As concerns T/β assemblages, we can definitely separate a lower group of cores (116 to 110) where β is very rarely abundant, and an upper one (Cores 109 to 106) where, inversely, its abundance prevails. In Cores 109 to 106, this richness even affects some samples with A/APβ or A/APβ'. Concerning R/AP assemblages, apart from these last exceptions, the part played by β is very moderate; nevertheless, it must be emphasized that while not existing previously, β now increases progressively from Core 112 upward (in other words, an increased quantity of A/APβ or A/APβ' is found). The lack of β in A/AP or A/AP', or in decarbonated Lithoterm 1 (even 0), is frequently observed from Core 116 until Core 113, whereupon β becomes sporadic as said above. Lagenidae are generally the most abundant foraminifers; *Gyroidina* and *Gavelinella* play a less important part than previously, nevertheless they again become more abundant upwards and more diversified, and they presage the usual Albian-rich microfaunas; Textularidae and Valvulinidae spread out in the same trend.

**Residual benthos:** Rare or absent in all T/β assemblages until Core 113, and sometimes abundant in R/AP. From Core 112 upward, it changes and even becomes fre-

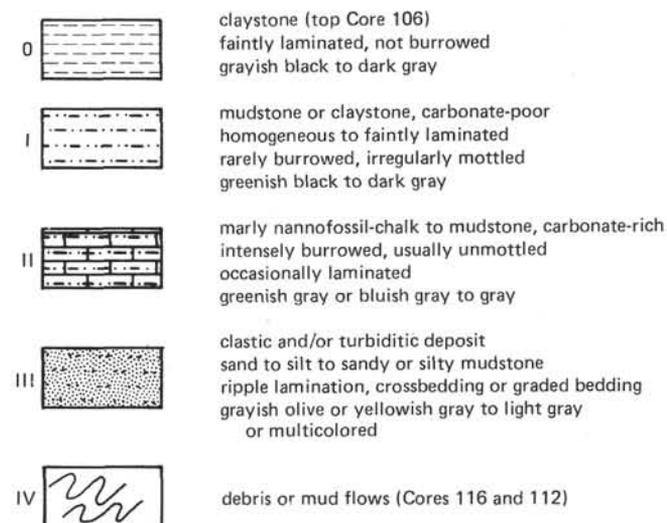


Figure 4. Lithologic sequence of reference for Cores 116 to 106 pars, Hole 398D.

quently abundant in both kinds of assemblages. We must emphasize that true A/AP are missing in this sub-unit.

**Plankton:** Generally uncommon and often absent (hence numerous A/AP', A/ $\beta$ ', A/AP $\beta$ ', even A/Az2, and never A/AP). However, among the A/ $\beta$ , some plankton-rich samples are always observed, which correlate with Lithoterms II and III, even IV; they generally contain abundant radiolarians. This is especially the case with Core 106, where the quantity of samples with A/AP $\beta$  has increased at the same time. However, within this sub-unit a very significant feature appears which is not expressible as a quantitative evaluation. It consists of the development (from Core 108 upward) of the "large planktonic forms, coarsely perforated and pustulose" which develop beside the "small" ones. These new planktonic forerunners will increase immediately and produce the most diagnostic group during the last part of the Lower Cretaceous (*Ticinella*, *Rotalipora*, etc.).

**Radiolarians:** Generally abundant and very diversified morphologically, the fact that only one sample devoid of Rad was observed is noteworthy. A gentle and transient decrease occurs in Cores 109 and 108, in samples with mainly T/ $\beta$  assemblages. Siliceous radiolarians are less numerous than the recrystallized ones.

**Dissolution:** Only the "large" newly appeared planktonics give evidence of solution marks (Core 106).

**Reworking:** Some samples (117-5, 21-23 cm; 112-5, 144-146 cm; and 112-12-4, 18-20 cm) yielded reworked species which are Barremian or older.

**$\beta$  Macrofauna:** The biotrital character is not very pronounced; debris are very rarely encountered, with the exception of irregularly distributed inoceramus. Concerning these last fossils, their presence in almost all samples with T/B in Cores 112, 109, and 107 is noteworthy. Fish remains are sporadic; nevertheless, they are more regularly present from Core 109 upward, in both T/ $\beta$  and R/AP assemblages, and especially in T/ $\beta$  connected with Lithoterms II to IV where they were curiously missing previously.

**$\gamma$  Plant debris:** Frequent throughout all of the cores, perhaps more so in the upper ones; generally uncommon, sporadically abundant, and indiscriminately distributed in all lithoterms.

**Inorganic Components**

**Clasticity:** Quartz generally not very abundant or absent, with some exceptions (Core 111). When abundant, it occurs indiscriminately in all three lithoterms (I, II, and III) where it is almost always coupled with plant debris and frequently with mica. Abundance of mica is always connected with the presence of plant debris, which is also sometimes abundant.

**Glauconite:** Practically absent, with the exception of Cores 112 and 106; it occurs in T/ $\beta$  or T/ $\beta$ ', or Lithoterms II to IV.

**Pyrite:** Relatively frequent and sometimes abundant, with the exception of Cores 115, 114, and 109, pyrite is lacking in Cores 116 and 111; it is indiscriminately distributed in all lithoterms.

**Hydrochloric test:** Quite variable throughout the cores, a feature which probably reveals great variability in the exogenous supply, and perhaps some irregularity in the solution processes. At the base of the series, positive and negative tests are more or less balanced; the negative test prevails in Cores 114 and 113, where even samples with T/ $\beta$  or Lithoterm II are concerned. The ratio is reversed with the turbiditic supply in Core 112 and the base of Core 111. Again, the negative test prevails in Cores 111 to 109 and the extreme base of Core 108. The proportion is reversed again in Cores 108 and 107, and a balanced proportion is observed in Core 106.

**Assemblage-Lithofacies Relationships (Table 6)**

Here again, R/AP-Lithoterm I (and 0) and T/ $\beta$ -Lithoterms II to IV correlations are confirmed and prevail. Exceptions are uncommon, and the same explanation as before can be proposed when A/AP' occurs in Lithoterm II (316, 324) or A/AP $\beta$ ' in Lithoterm III (354) they could be misestimated T/ $\beta$ ' assemblages, owing to the small quantities of  $\beta$  and AP in a calcareous sediment. Conversely, it could be the same for assemblages which are actually A/AP $\beta$ ', but erroneously as T/ $\beta$ ', in Lithoterm I(331). Nevertheless, some other exceptions cannot be explained at present.

Impoverished assemblages are uncommon in this sub-unit. First, neither A/AP2 nor A/Az2 can exist because radiolarians are never lacking. Only one A/P1 was observed, in Lithoterm II, with a very rich radiolarian and planktonic assemblage; some A/Az1 were encountered in Lithoterms I and II without any possible explanation.

An examination of the plankton/radiolarian ratio substantiates the fact that samples devoid of radiolarians are never encountered, whether plankton is abundant or absent. The other two possibilities are well represented. First, abundance of both plankton and radiolarians (a ratio which was not encountered in Sub-

TABLE 6  
Quantitative Distribution of Assemblages According to the Different Lithoterms in Cores 116 to 106 pars of Hole 398D

Lithoterm/Assemblages	DSDP Core Numbers										
	116	115	114	113	112	111	110	109	108	107	106 pars
0 { A/AP' A/AP $\beta$											1
I { A/AP' A/AP $\beta$ A/AP $\beta$ ' A/Az1 A/ $\beta$ '	2	1	3	5	1	1			1		1
				1	2	8	1	1	5	1	2
	2				1	1					4
				1							
II { A/ $\beta$ A/ $\beta$ ' A/P1 A/Az1 A/AP' A/AP $\beta$ ? A/AP $\beta$ '	1	2	3	4	1	1		5	4	7	7
	1	1		4	1			2	7	1	1
				1							
				3	1						
				1	1						1
						1					
III { A/ $\beta$ A/ $\beta$ ' A/AP'?	1				1						1
	1				1						
IV { A/ $\beta$ A/ $\beta$ '	1				2					1	
					1						

unit IIb) occurs sporadically in all cores (except 109), in T/ $\beta$  or Lithoterms II to IV (with two exceptions, Samples 396, 404). The last case, Rad abundant-plankton absent, occurs very frequently in all cores, mainly in A/AP' and A/AP $\beta$ ' (generally with abundant AP) or in Lithoterms I and 0, and secondarily sometimes in T/ $\beta$ ', but without any rule at the present stage of knowledge.

If we consider the evolution of assemblages in Sub-unit IIc from a broad point of view, we must emphasize the far-reaching change which occurs around Cores 112 to 109 and affects various criteria. For instance,  $\beta$  becomes more frequent and A/AP is less represented than A/AP $\beta$  from Core 112 upward; AP is more abundant from Core 111 upward; A/Az1 is present in Lithoterm I until Core 111;  $\beta$  is often abundant and AP more frequently abundant in T/ $\beta$ ; fish remains and spicules are much more frequent from Core 109 upward. It is not easy to find an explanation (if one exists) which could be valid for all these shifting evidences. However we can affirm that two increasing parameters (AP and  $\beta$ ) seem to develop concordantly (hence, the small quantity of A/P or A/Az), and that we are tempted to interpret this phenomenon, respectively, as the expression of the progressive setting in of the "dark shale" sedimentary regime, and simultaneously as the expression of permanent interference by a turbiditic supply. These influences, while conflicting to a certain extent, would be responsible for the variability we insisted on in the section on "Data Analysis." Thus, we think that we are justified in defining Sub-unit IIc as transitional between two extreme sedimentary regimes.

#### Sub-Unit IIc: From Cores 106 Pars to 104

This fourth and last sub-unit corresponds to a massive allochthonous complex. As noted above, premonitory events have been found in the underlying cores of Sub-unit IIc. It is not necessary for the present study to work out a lithologic sequence of reference; it is sufficient to refer to the core description made on board.

#### Data Analysis

##### Organogenic Components

###### $\alpha$ Microfauna

**Transported benthos:** It forms, of course, the main characteristic in such sediments; it is not always abundant, but very diversified. It corresponds to the benthic assemblage which is usually found at this stratigraphic level, with the exception of some species. Lagenidae and Gavelinellidae in the first rank, then *Osangularia*, *Gyroldina*, and *Valvulineria* predominate; Pleurostomellidae and Buliminidae are often present, but are generally few in number.

**Residual benthos:** AP are remarkably missing (with a minor exception), and this feature is the second characteristic. Note that they will reappear in Core 103, where they are generally abundant in R/AP assemblages.

**Plankton:** Its abundance, sometimes very great, forms the third characteristic; it is rarely lacking (top

of Core 106), and it will abruptly lessen or disappear from the base of Core 103 upward.

**"In-situ" or reworked microfauna:** Benthic or planktonic unquestionably reworked specimens do exist in several samples (e.g., *Spirillina neocomiana*, *Dorothia ouachensis*, some small-sized *Hedbergellas* that are Neocomian or Barremian). But we may wonder if all the microfauna observed have not been reworked, too. The question is a weighty one because the age of the formation is based on the benthic and planktonic species we found in the samples. This question was answered in the Biostratigraphy section.

**Radiolarians:** Their scarcity and even their absence are the fourth characteristic of this sub-unit. Their morphologic diversity is small. Recrystallized tests are uncommon.

**Dissolution:** Several times (particularly in Core 105) solution traces are observed, even in benthic forms, but mainly in the "large" planktonic shells.

**$\beta$  Macrofauna:** Debris are paradoxically very sparsely represented (with only one exception). Aptychus are rare, Inoceramus few, other debris are as usual. Fish remains are very frequent, sometimes in abundance. Spicules are infrequent. One piece of Rhyncholites (cf. *Akidocheilus ambiguus* Till, 1907) was found (Sample 105-3, 57-59 cm).

**$\gamma$  Plant debris:** Almost absent in the allochthonous materials; they become frequent as soon as the base of Core 103 is reached.

##### Inorganic Components

**Clasticity:** Quartz sporadically abundant; mica is absent or rare.

**Glaucinite:** Very frequent, especially in Core 104; it disappears from the base of Core 103 upward.

**Pyrite:** Absent in Cores 104 and 105.

**Hydrochloric test:** Very few samples in Cores 105 and 104 are negative.

##### Assemblage-Lithofacies Relationships (Table 7)

The turbiditic and slumped event, which was foreshadowed at least as early as Core 107 is fully developed in the top of Core 106 and in Cores 105 and 104. A/ $\beta$  assemblages predominate almost exclusively in Lithoterm IV which conventionally gives its name to this type of sediment (only one A/ $\beta$ ' was observed in probably packed Lithoterm II).

Three samples stand apart, because they are almost devoid (437, 439) or entirely devoid (419) of planktonics. They probably belong to a pelagic argillaceous sediment derived from a Lithoterm I or 0 which was packed in the slumping flow.

In the full length of the section on "Data Analysis," Core 103 is quite distinct and needs a special judgment. In this core, two parts can be distinguished (from the base to Sample 103-5, 48-50 cm and from Sample 103-3, 122-124 cm to the top), especially with the help of the amount of radiolarians and the amount of AP in R/AP, the frequency of clastic samples and the nature of hydrochloric tests. As a whole, Core 103 is very differ-

TABLE 7  
Quantitative Distribution of Assemblages  
According to the Different Lithoterms in  
Core 103 of Hole 398D

Sample Number (Author's Chart 1)	
According to the lithologic reference for Sub-Unit IIc	
I	A/AP 463
	A/AP' 446, 448, 458
	A/AP $\beta$ 456
	A/AP $\beta'$ 461
II	A/ $\beta$ 447, 452 to 454, 459, 460
	A/ $\beta'$ 449
	A/AP $\beta$ 450, 451, 457
	A/AP $\beta'$ 462
According to the lithologic reference for Sub-Unit IIIa	
D	A/AP' 448
C	A/AP' 446, 458
	A/AP $\beta$ 456
	A/AP $\beta'$ 461
B	A/ $\beta$ 447, 452 to 454, 459
	A/ $\beta'$ 449
	A/AP $\beta$ 450, 451, 457
	A/AP $\beta'$ 462
C'	A/AP 463
S	A/ $\beta$ 460

ent from the other cores in Sub-unit IId and seems to be closer to the cores of the overlying Unit III. As a matter of fact, Core 103 might have been placed in Sub-unit IId because of the large number of samples with T/ $\beta$  assemblages, or at least with polluted R/AP (A/AP $\beta$ , A/AP $\beta'$ ), whereas these assemblages are not found above. Thus, this core looks like a very intermediary core whose sediments already belong to the sedimentary regime which is going to prevail, but in which the large slumped episode of Cores 105 and 104 is still felt temporarily.

### Unit III: From Cores 103 to 79

This unit belongs to a new sedimentary regime. "Dark shales" are accumulated with a high rate of sedimentation (75 to 100 m/m.y.); they were deposited underneath the CCD, with a permanent but diffuse allochthonous supply (probably partially dissolved). At the end of this unit, the sediments progressively become more calcareous, because of the changing depth of the CCD or an increasing supply as discussed further.

In the lithologic sequence of reference (Figure 5), Lithoterm C predominates; it is black and not calcareous when typical, with prevailing R/AP assemblages (A/AP' being the most typical). Lithoterm D, mainly present in the lower cores, more or less corresponds to Lithoterm B, which develops in the cores with a greater calcareous supply. Lastly, Lithoterm C' corresponds to the samples with a laminitic structure and whose assemblages often display a selective enrichment of a given organic or inorganic component. On the whole, lami-

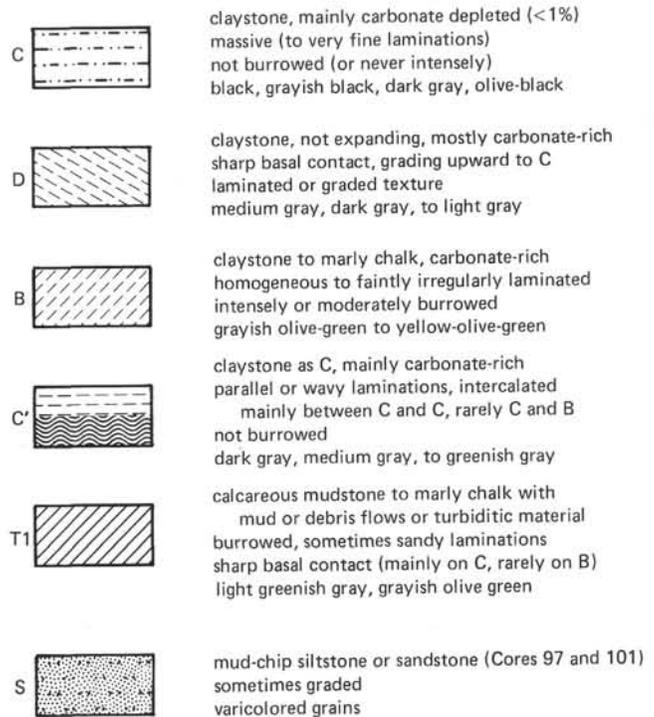


Figure 5. Lithologic sequence of reference for Cores 103 to 88 of Hole 398D.

nated structures (sometimes very fine) are frequent and are very characteristic of Unit III. The last two lithoterms play a minor part and are sometimes missing.

The lower boundary here includes Core 103 which, as noted above, has not been included in the Sub-unit IId. The upper boundary remains more subjective and corresponds to a moment in the sedimentary evolution when lithologic and biocoenotic differentiations started to change, and diminish, and to prefigure the more homogeneous behavior which will characterize the overlying beds.

### Sub-Unit IIIa: From Cores 103 to 88

The first sub-unit corresponds to the most representative development of the dark shales (or so-called "black shales"), although the typical deposit does not actually compose the major thickness. The lithological sequence mainly involves Lithoterms C, C', and D; the last two are best developed in the lower cores. A diffuse calcareous supply is almost continuously perceptible over the full length of this sub-unit; the supply is more significant from time to time, e.g., Cores 100, 98, 96 and 92, and, of course, the base of Core 103.

### Data Analysis

#### Organogenic Components

##### $\alpha$ Microfauna

**Transported benthos:** Generally missing and sporadically present in A/AP $\beta$  or A/AP $\beta'$  where it is rare, with the relative exception of Core 103, with the exception of Cores 96 and 93 (where these assemblages are rather numerous), and Core 92 (where  $\beta$  becomes so

abundant that even some T/ $\beta$  can be distinguished). As a whole, the same families or genera are observed as in the underlying sub-unit, with some specific species which characterize Albian or "Gault" association. However, the dissolution had a considerable impoverishing effect, and the "survivors" are often flooded to some extent in the bulk of the agglutinated residual association.

**Residual benthos:** Rarely absent (very few A/P or A/Az are observed, generally in calcareous Lithoterms C, C', or D), and very often common to abundant, as might be expected.

**Plankton:** Generally lacking (hence the great quantity of A/AP' or A/AP $\beta$ ', and even A/Az). A few rare examples are found in about 10 samples with A/AP or mainly A/AP $\beta$ '; these samples belong to Lithoterms C, C', or D and rarely to S or Tl. The Heterohelicidae family seems to start here (Core 97), in the shape of some rare exemplars of *Gümbelina*. In the stratigraphic section, we emphasized that the population of Globigerinidae was different, on the whole, from the Aptian one. Thus, the entire pelagic population has been renewed.

**Radiolarians:** Almost permanent, abundant, and morphologically diversified, they are the very characteristic of the microfaunal assemblage. Only one sample is devoid of radiolarians, as well as of other microfossils, in Lithoterm C. They are dominantly siliceous.

**Dissolution:** Solution marks were observed in only one sample (88-6, 27-29 cm) on planktonic exemplars, in a laminated Lithoterm C'.

**$\beta$  Macrofauna:** The biodetrital character is weakly expressed and found only in a few samples from Lithoterms C, C', or D, with selectively enriched laminations. Debris are lacking above Core 92. Ammonites were abundantly recovered and enabled an early and a middle Albian age to be recognized. Fish remains are almost permanently present. Spicules (mainly of Spongiae, but also of other organisms such as Gorgonae and Ascidiidae) are present at the base of the sub-unit.

**Plant debris:** Almost permanently present, and sometimes abundant, with the exception of the three upper cores.

### *Inorganic Components*

**Clasticity:** Quartz is very rare or absent, with the exception of the base of Core 103 and of a few samples belonging to laminites or Lithoterm Tl (560) or S (523). Mica is abundant in some samples of Lithoterms C, C', or D; in these cases, plant debris are always present and sometimes abundant (510, 531, 548, 562, 621).

**Glauconite:** Missing.

**Pyrite:** Almost permanent, with the exception of some samples with T/ $\beta$  in Cores 92 and 96, i.e., two cores where the exogenous supply is especially perceptible.

**Gypsum:** Frequent; generally occurring in laminations within the sediment.

**Hydrochloric test:** The non-calcareous test dominates here, with the exception of Cores 98 to 92, an interval

where the calcareous/non-calcareous ratio is sometimes balanced or even reversed, because of the exogenous supply.

### **Assemblage-Lithofacies Relationships (Table 8)**

This sub-unit is the most effective part of the series drilled. Thus, it seems advisable to investigate in some detail the relationships between faunal assemblages and sedimentary facies.

It has already been established that some characteristics predominate almost permanently: A/AP' and A/AP $\beta$ ', negative hydrochloric test, high frequency of plant debris and pyrite, abundance of radiolarians, lack of planktonic foraminifers. Other dominating features are less permanent: abundance of AP, the presence of fish remains, and an absence or uncommonness of  $\beta$ . As a whole, we can assert that the leading characteristic is made up by the doublet: A/AP' and hydrochloric negative test, i.e., the assemblage and the behavior of typical Lithoterm C. In many cores (102, 101, 97, 95, 91, 89, and 88) the samples belong to Lithoterm C one out of two times; conversely, T/ $\beta$  is very limited (in Core 92 alone).

If we pursue the analyses of the R/AP assemblages, we note that, if the A/AP'-negative hydrochloric test correlation is considered normal, other kinds of correlations have to be considered as exceptions (the first three cases hereunder) or anomalies (last two cases):

1) A/AP with non-calcareous hydrochloric test; these samples (544, 546, 598) are particularized by the presence of plankton, which appears rather unusual in such a sediment.

2) A/AP $\beta$  with non-calcareous hydrochloric test; these samples (507, 531, 539, 553) are particularized by the presence of plankton and benthos, which also seems rather unusual. Quartz, mica, and debris are frequent.

3) A/AP $\beta$ ' with non-calcareous hydrochloric test; these samples (468, 483, 491, 494, 496, 509, 518, 527, 561, 569, 571, 576, 596, 599, 602) are particularized by the presence of benthos, still rather unusual. Quartz and debris are frequent.

4) A/AP' with calcareous hydrochloric test; these samples are by far the most numerous and occur in Lithoterms C, C', and D. Sometimes quartz and debris are present; however, they probably owe their positive hydrochloric test to fine calcareous grains which are either disseminated in the sediment or concentrated in some laminae. This kind of sediment, with a sharp basal contact, is assigned a turbiditic origin.

5) A/AP with calcareous hydrochloric test; these samples are particularized by the presence of plankton.

If we now examine the last possible arrangement (563, 621) we are faced with assemblages which we consider as normal in calcareous sediments, i.e., A/ $\beta$  (580, 581), A/AP $\beta$  (486, 560), and A/AP $\beta$ ' (523). These samples are particularized by the presence of benthos, plankton, and debris, often with glauconite and quartz; they occur in Lithoterms Tl or S. The ultimate arrangement (i.e., T/ $\beta$  in non-calcareous sediments) theoretically has little probability and was not actually encountered.

TABLE 8  
Distribution of Assemblages According to the Different Lithoterms in Cores 102 to 88 of Hole 398D

Lithoterm/Assemblages	DSDP Core Numbers															
	102	101	100	99	98	97	96	95	94	93	92	91	90	89	88	
C {	A/AP							1		1			1			
	A/AP'	7	5	4	4		3	3	5	1		3	3	1	4	5
	A/APβ				1					1						
	A/APβ'	1	1		1							1		3	1	
C' {	A/AP															1
	A/AP'	3		1	6	1	3	1	3							
	A/APβ								2							1
	A/APβ'	1	2			3	1	3		1	5					
	A/Az1						1	4								
	A/Az2										1					
D {	A/AP							1								
	A/AP'		2	3	1				1	1						
	A/APβ															
	A/APβ'			3												1
	A/AP1															1
	A/Az1					2										1
T1 {	A/β															1
	A/APβ															2
S {	A/APβ			1												
	A/APβ'							1								

In summary, we can schematize our data as follows:

**Negative test:** Either with A/AP' or A/AP: Lithoterms C or D, sometimes C'; or, with A/APβ or A/APβ': Lithoterms C, C' or D.

**Positive test:** Either Lithoterm C or C', with "calcareous grains": A/AP'; or, Lithoterm C or C', with β, π, debris: various R/AP; or, Lithoterm D, with β, π, debris; "calcareous grains": A/AP', A/APβ', A/β.

Lastly, the assemblages without benthos (A/P and A/Az) are infrequent in this sub-unit. A/Az1 is the most frequent and was observed in Lithoterm C' and D; A/P1 was observed once (579) in Lithoterm D. As can be expected, samples devoid of radiolarians cannot be numerous in such a sediment: A/Az2 was observed once (559) in Lithoterm C', and A/P2 was not encountered.

Among sedimentary processes which led to the deposits observed, the exogenous supply is most important, following the dark shales themselves. The exogenous supply is responsible for the diversification of biocenotic assemblages as well as lithologic facies. If we leave aside the samples which clearly belong to the residual deposit (non-calcareous and with A/AP'), we can see that the exogenous supply occurs permanently. It is revealed by sedimentological structures and figures and, from our point of view, is manifested by various components such as calcareous benthos, plankton, organic debris, and sometimes quartz and glauconite. If we cannot detect such perceptible components in the sieved residue, we nonetheless must admit the presence of fine calcareous particles.

Upward from cores where A/AP' predominate, we find this calcareous supply increased, while the black color tones down and the lamination becomes more pronounced. In this way, Cores 100 to 98, 96, 93, and 92

successively correspond to a renewed supply, going so far as to contain actual small-sized turbidites. This evolutive curve is the reverse of the curve expressing the variation in the frequency of typical Lithoterm C, as has already been said.

In the hierarchy of sedimentary processes, third place goes to the lamination and to the sorting and selective enrichment which follow. Hence, the occurrence of numerous Lithoterms C' and the varying behavior of the different R/AP assemblages, as has been related in detail. Frequently, the distinction of C' from C or D is rather a matter of thinness and visibility of the laminae; sometimes Lithoterm T1 also displays some laminations. On a large scale, the intensity of this sedimentary phenomenon seems to decrease considerably in the upper cores, from Core 92 upward.

**Sub-Unit IIIb: From Cores 87 to 79**

This second sub-unit represents the first stage in the progressive "pollution" of the "dark shales" by turbiditic material: T/β assemblages and calcareous with HCl-treated samples become more frequent; however, neither one nor the other of these criteria predominates. Another aspect, which is not actually characteristic, evolves independently at the same time and gives evidence of a progressive change; namely, solution marks become more perceptible.

The lithological sequence of reference (Figure 5) becomes more diversified and laminations are more developed. Nevertheless, Lithoterm C still predominates. It is possible that dissolution processes may be less significant from now on, and might be responsible, to some extent, for the apparent increase in the transported material. This is the crucial point of discussion, as developed below.

## Data Analysis

## Organogenic Components

 $\alpha$  Microfauna

**Transported benthos:** Rare, with the exception of the two lower cores and Lithoterm T1; it occurs with abundant planktonics in Core 86. The same genera and species as before are present here, but they are more numerous and diverse. Transported benthos in R/AP assemblages is quantitatively low, while giving rise to a relatively great number of A/AP $\beta$  or A/AP $\beta'$  in the different cores.

**Residual benthos:** Relatively frequent occurrences in the lower core and sporadic occurrences in the others, but the difference is great compared with underlying Sub-unit IIIa.

**Plankton:** Generally absent (hence, the small number of A/ $\beta$  and A/AP); Core 86 is again an exception, with its abundant exemplars in all the A/ $\beta$  assemblages observed, and with abundant transported benthos; the same occurs in Core 81 (703). Lastly, abundant plankton was encountered in one sample (675) found in selectively enriched laminations. Solution marks are frequent.

**Radiolarians:** Generally common to abundant; nevertheless, they are never conspicuously abundant and diversified, or absent.

**$\beta$  Macrofauna:** Biodetrital samples are extremely rare, with the exception of Core 82. Organic debris are mainly localized either in laminae or at the base of the mud turbidites. Fish remains are quite permanent in R/AP. Spicules are irregularly present; they are especially abundant in Core 82; they sometimes come from various organisms, such as Spongiae, Gorgonids, Alcyonids, and Holothurids. Some ammonites enable the middle Albian to be recognized.

**$\gamma$  Plant debris:** Rather frequent and sometimes abundant; they are coupled with R/AP in Lithoterm C or in the laminations. Megaspores are encountered in Core 86 (642).

## Inorganic Components

**Clasticity:** Quartz is rather permanently present, but scarcely abundant (in this case, it is generally correlated with Lithoterm C or with laminations and, once, with the lower layers of mud turbidites).

**Glauconite:** Almost absent.

**Pyrite:** Nearly permanent and often abundant (especially in the upper part of this sub-unit), particularly in samples with R/AP.

**Gypsum:** Frequent, especially from Core 82 upwards.

**Hydrochloric test:** The non-calcareous test predominates, although with numerous exceptions, particularly in the lower cores. Samples with T/ $\beta$  are calcareous as a rule, but we also find calcareous tests in samples with A/AP $\beta$  or A/AP $\beta'$ , or even A/AP' (Core 80).

## Assemblage-Lithofacies Relationships (Table 9)

The R/AP-Lithoterm C and T/ $\beta$ -Lithoterm B or T1 usual correlations may have some exceptions. We can see that most of the samples with R/AP in Lithoterm C

TABLE 9  
Distribution of Assemblages According to the Different Lithoterms in Cores 87 to 79 of Hole 398D

Lithoterm/Assemblages	DSDP Core Numbers								
	87	86	85	84	83	82	81	80	79
C {	A/AP'	6	3	1	1		5	2	2
	A/AP $\beta$				1				
	A/AP $\beta'$	1		3		1	2	3	2
	A/AP1			1					
	A/Az1		1				1	1	1
	A/ $\beta$		1						
C' {	A/AP'								
	A/AP $\beta$				4				
	A/P1				1				
	A/Az1		1				1		
B {	A/ $\beta$				1	1	1		
	A/AP'	1							
	A/AP $\beta'$						1		
T1 {	A/ $\beta$	1	4				1		
	A/ $\beta'$		2	1			1	1	
	A/AP $\beta$								1
S {	A/Az1						1		

have a negative hydrochloric test; exceptional cases generally belong to polluted or laminated sediments. Samples with T/ $\beta$  or T/ $\beta'$  are even encountered in this Lithoterm C.

Some typical samples seem to persist, which were deposited underneath the CCD; they yield A/AP' (or A/P1) assemblages, have a negative hydrochloric test, and are black in color (664, 693, 715, 720, 723).

The laminated samples (or C') display various kinds of selective enrichment (debris, benthos, plankton, mica, calcareous grains).

Lithoterms B and T1 generally display T/ $\beta$  assemblages in a more-or-less calcareous sediment, but there are some exceptions which can be explained (small quantities of  $\beta$  and AP for Sample 640, where A/AP' could actually be T/ $\beta'$ ) or not (Samples 687 with A/AP $\beta$  or 672 with A/AP'), at the present stage of knowledge.

All these considerations and indecisions are clear evidence of some hindrance when we try to maintain the criteria we used previously; the lithological terms seem to be adulterated, as will be suspected increasingly later on.

## Unit IV: From Cores 78 to 71

This unit looks like a hinge in the course of the progressive installation of calcareous series and the decrease of the sedimentation rate. T/ $\beta$  now predominate; however, some samples are still found in sediments which agree with the characteristics of a typical decarbonated residual deposit.

As a result, we encounter a great deal of indecision when we try to classify the assemblages into one or another category, as well as when we try to put the samples into this or that lithoterm.

The dominance of T/ $\beta$  and the rarity of R/AP place this unit beside the overlying one, which appears frankly pelagic. However, owing to the still distinct lithoterms

and the importance of laminated Lithoterm C', this unit is still connected with the previous sequential deposits of Unit III.

The last lithological sequence of reference (Figure 5) will also be utilized here. But the lithoterms will be modified by a strong adulteration resulting from the preponderant influence of calcareous material (either more abundant or less dissolved, or both).

**Sub-Unit IVa: From Cores 78 to 74**

The evolution which began in the underlying sub-unit continues here. The material brought in becomes more perceptible, enabling a new evolutionary stage to be discerned. T/β assemblages are always present; the T/β-A/AP ratio will even be reversed in Core 74 (which could in fact belong to the next sub-unit), and this dominance of T/β over R/AP will henceforth subsist.

**Data Analysis**

**Organogenic Components**

**α Microfauna**

**Transported benthos:** Rarely abundant; however, T/β assemblages are always present, and the presence of β in R/AP assemblages is frequent (hence, numerous A/APβ or A/APβ'). Genera and species are the same as before.

**Residual benthos:** Generally rare in R/AP and frequently absent in T/β assemblages.

**Plankton:** Very poor and often absent (hence, numerous T/β', A/AP', A/APβ'), with the exception of two samples (759, 776) with T/B in debris flows (Tl) or in laminated Lithoterm B.

**Radiolarians:** Always present and generally common to abundant.

**Dissolution:** Solution marks are frequently observed, especially in the lower core.

**β Macrofauna:** The biotrital nature is very weak, samples with debris occur sporadically and correspond to debris flows (Lithoterm Tl) or to a diffuse supply (Lithoterms B and C). Fish remains almost permanent. Spicules are more sporadic. Ammonites are uncommon.

**γ Plant debris:** Very sporadic and uncommon; in two laminated samples, abundant plant debris and mica are encountered together.

**Inorganic Components**

**Clasticity:** Quartz is almost permanent, never abundant. We note several samples with T/β or A/Az containing rather coarse and rounded grains in Lithoterm C in the lower core.

**Glauconite:** Not observed.

**Pyrite:** Almost permanent, frequently abundant, in the different assemblages and lithoterms.

**Gypsum:** Frequent.

**Hydrochloric test:** Positive and negative tests are more or less balanced, with the exception of Core 75, where the former predominates (in this core, A/β, A/β', and A/APβ' are predominant). Assemblage T/β belongs mainly to calcareous sediments.

**Assemblage-Lithofacies Relationships (Table 10)**

Lithoterms B and C correlate, as usual, to T/β and R/AP, respectively; however, there are many exceptions especially numerous T/β in Lithoterm C. To be exact, T/β assemblages (which are "regularly" observable in Lithoterm B) are uncommon. With only one exception (780), T/β assemblages (743, 765, 773, 774, 775) belong to argillo-calcareous sediments, and they are not singularized by any peculiar abundance of β, π, or debris. We are probably faced with poor resedimented material or with impoverished material; it must be emphasized that dissolution is sometimes perceptible.

Similar T/β assemblages are sometimes found in Lithoterm C. They indicate that the residual deposit has been polluted by a calcareous supply, either diffuse (Samples 738, 737, 731, 728, 762) and resulting in the presence of β or π or fragments (which have sometimes been subject to dissolution), or else concentrated by a selective enrichment of laminations (e.g., 776 enriched in β, π, mica, and plant debris). We find that assemblages AP are frequently absent (they may have been diluted by the material supplied). In some other cases, the T/β assemblages concerned reveal very low quantities of AP and β, consequently it could actually correspond to an A/APβ assemblage if studied under better conditions (picking, sampling).

Some of the R/AP assemblages which are "regularly" observed in Lithoterm C, probably correspond to typical decarbonated residual deposits underneath the CCD (Samples 745, 747, 760, 783, yielding, of course, an A/AP' assemblage). For the rest (736, 741, 755, 761, 767, 768, 787, 790), some pollution can be detected in various ways, depending on the case (β, π, debris, calcareous grains, solution marks). Lastly, one

TABLE 10  
Distribution of Assemblages According to the  
Different Lithoterms in Cores 78 to 74  
of Hole 398D

Lithoterm Assemblages	DSDP Core Numbers					
	78	77	76	75	74	
C	A/AP'		2	1	1	1
	A/APβ			1		
	A/APβ'	1	2	1	1	2
	A/Az1	3			1	2
	A/β	3				1
	A/β'	1	1	1		1
C'	A/β				1	1
	A/β'					1
	A/P1	1				
	A/Az1		1		1	
B	A/β			1	1	
	A/β'				3	1
	A/AP'		1			
	A/APβ'		1			
T1	A/β		1	1		1
	A/β'			1		2
	A/APβ'				1	
	A/Az1		1	1		

sample (760) corresponds to mixed (Lithoterm C and B) laminations, probably in a slump structure.

Similarly R/AP assemblages are sometimes found in Lithoterm B; they correspond either (753) to a mixed (C and B) sediment or (746) to a swept-away piece of Lithoterm C.

We now have to take into account the more-or-less azoic assemblage and Lithoterm C' and Tl. Note that only A/Azl has been frequently observed in three categories of sediment: (1) mainly in Lithoterm C and probably in a typical residual deposit (733, 735, 764, 784, 791, 829); (2) then in Lithoterm Tl at the base of a sequence or in a debris flow (752, 757); and lastly in Lithoterm C' or sandy laminations with calcareous grains (749, 770). On other hand, A/Pl is observed only once in Lithoterm C', probably a slump (734).

If we compare Lithoterm C' and T, it appears that they may chiefly contain the same varied assemblages (i.e., A/ $\beta$ , A/ $\beta'$ , and A/Azl) and consequently they cannot be differentiated according to this criterion, although they are fundamentally different as to their origin (laminations or turbidity, respectively). The similarity of their assemblages conveys the identity of the origin of their material.

#### Sub-Unit IVb: From Cores 73 to 71

This short sub-unit corresponds to a more advanced stage in the progressive installation of a pelagic calcareous regime. T/ $\beta$  predominates, as well as the positive hydrochloric test. Thus, for the majority of the samples, we are progressively going back to the conditions which prevailed in the lowest Unit I at Site 398. The discriminations between AP and  $\beta$  is losing its meaning; so-called A/AP $\beta$  or A/AP $\beta'$  assemblages mean that AP predominates quantitatively in the overall assemblage, which we will conversely call A/ $\beta$  or A/ $\beta'$  if  $\beta$  predominates. Nevertheless, rare typical decarbonated residual deposits still subsist.

The lithologic sequence of reference is the same as below.

#### Data Analysis

##### Organogenic Components

###### $\alpha$ Microfauna

**Transported benthos:** Rarely abundant (in the lower sequential interval of turbiditic supply or mud flows); but it is also rarely absent (A/APl or A/Azl in various lithoterms, mainly in the residual deposits still present in Lithoterm C'). The amount of  $\beta$  in the now uncommon assemblages A/AP $\beta$  or A/AP $\beta'$  is always very small, insofar as we are authorized (as noted above) to distinguish them as still polluted residual assemblages. Qualitatively, the samples here contain the typical association of the usual argillaceous or marly sediments of the "Gault" or Albian.

**Residual benthos:** If still distinguishable, it is rare and poor.

**Plankton:** Present in 50 per cent of the samples, always in A/ $\beta$ , generally uncommon, with the exception of three samples in Lithoterm Tl (mud flow, samples

805, 806) or C' (829). The group of "large" planktonics develops again here, more intensely than in the upper Aptian, and it will soon give rise to the prolific and characteristic Albian population.

**Radiolarians:** Always present and generally abundant; recrystallized skeletons are observed in some planktonic-rich samples in Lithoterm Tl.

**Dissolution:** Perceptible in several samples.

**$\beta$  Macrofauna:** Organic debris very rare, in only three samples with A/ $\beta'$  assemblages and belonging either to a coarse Lithoterm 5 (794) or to laminated C' (809, 818). Fish remains and spicules are frequent. There are some unidentifiable ammonites.

**$\gamma$  Plant debris:** Very sporadic and vanishing upwards.

##### Inorganic Components

**Elasticity:** Quartz generally uncommon and lessening upward, with the exception of four highly clastic samples belonging to Lithoterm C' (810, 807) or S (794), and probably to a typical residual Lithoterm C (838). Abundant mica occurs in only one sample (826), belonging to a very polluted lithoterm with a great quantity of plant debris.

**Glauconite:** Absent.

**Pyrite:** Relatively frequent, particularly in the samples with A/ $\beta$  or A/ $\beta'$ ; rarely abundant.

**Gypsum:** Abundant, but sporadically observed.

**Hydrochloric test:** The sediment is calcareous, with the exception of some samples belonging to typical residual Lithoterm C. Samples with T/ $\beta$  are always calcareous.

#### Assemblage-Lithofacies Relationships (Table 11)

R/AP or T/ $\beta$  assemblages correlate well with Lithoterm C or Lithoterms C', B, Tl, and S (respectively). Thus, R/AP-Lithoterm C and T/ $\beta$ -Lithoterm B correlations are still found as usual, and we again note the similarity of C' and Tl, as was pointed out for the preceding sub-unit.

As said before, samples which may still represent a decarbonated residual deposit are now very few (i.e., 6 to 7; 3 of which have already been slightly polluted). They typically contain A/AP' or A/Azl assemblages, or A/AP $\beta'$  when polluted. As in the foregoing unit, A/Azl is observed in all kinds of sediments; A/Pl is found in Lithoterm C'.

Generally speaking, we must again emphasize the extensive homogenization which affects the majority of the samples taken and which is caused by the generalization of a calcareous type of sediments.

#### Unit V: From Cores 70 to 57

This last unit, with a large succession of cores, corresponds to the final stage which ends the evolution of the sedimentary regime we have been following approximately since Core 87 (Sub-unit IIIb). The result consists in a relatively thin, calcareous or chalky pelagic series, at least for a large share of the samples, generally with a prolific planktonic association. Another aspect consists in less lithologic diversity (less important terrigenous

TABLE 11  
Distribution of Assemblages According  
to the Different Lithoterms in Cores 73  
to 71 of Hole 398D

Lithoterm/Assemblages	DSDP Core Numbers			
	73	72	71	
C {	A/AP'	1		
	A/AP $\beta$		1	2
	A/AP $\beta$ '		2	
	A/ $\beta$ '		1	
	A/Az1	1	1	
C' {	A/AP $\beta$ '		1	
	A/ $\beta$	3	2	1
	A/ $\beta$ '	2	2	
	A/Az1	2	1	1
	A/Pl		1	1
B {	A/ $\beta$	1	3	
	A/ $\beta$ '	3	2	
	A/Az1		1	
T1 {	A/ $\beta$	2		2
	A/ $\beta$ '	2	3	1
	A/Az1		1	
S {	A/ $\beta$ '	1		

supply), with only two main distinguishable lithofacies, and third lithoterm which corresponds to a laminated texture and probably a mixing of the other two main facies (Figure 6).

#### Data Analysis

##### Organogenic Components

##### $\alpha$ Microfauna

**Benthos:** Quantitatively very variable, but very frequently abundant, the association is qualitatively as usual in these upper Albian-Vraconian levels. However,  $\beta$  is sometimes absent, as will be seen later.

**Residual benthos:** In five samples in Cores 70 to 62, only "residual" arenaceous foraminifers are observed. Since this feature coincides with others (such as lithoterm, color, hydrochloric test) which would previously have determined hemipelagic facies (Lithoterm C), we must examine their meaning in greater detail (see below).

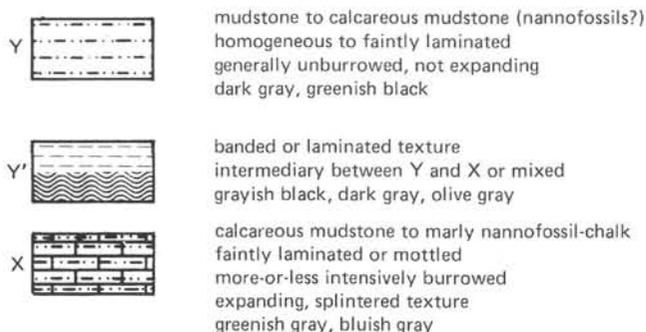


Figure 6. Lithologic sequence of reference for Cores 70 to 57 of Hole 398D.

**Plankton:** One of the main characteristics for this unit consists of pelagic-rich T/ $\beta$  or A/P assemblages. However, plankton is frequently missing, which is a surprising feature; it generally occurs in laminated samples where benthos may remain abundant. Otherwise, this lack of plankton coincides with samples which seem to belong to hemipelagic facies as noted above. Lastly, some plankton samples are devoid of benthos (A/Pl, A/P2); they always correspond to laminites, generally with abundant radiolarians.

**Radiolarians:** Often abundant and diverse, with the exception of Cores 59 and 58 which, on the contrary, contain conspicuously numerous samples devoid of radiolarians. Concerning these last cores, we note that the samples come from laminations where plankton and sometimes benthos or quartz are concentrated. Samples with calcitized radiolarians are very few and scattered, but they suddenly become numerous and predominate in the upper two cores.

**Dissolution:** Perceptible in several samples, mainly when observation is made with high magnifications.

**$\beta$  Macrofauna:** Organic debris are very rare, and they have been observed in a few samples which probably correspond to otherwise enriched laminations (plankton, radiolarians, quartz). Fish remains are almost permanent and often abundant. Spicules are rare with the exception of Cores 63 to 60.

**$\gamma$  Plant debris:** Rarely present, only in laminated samples.

##### Inorganic Components

**Clasticity:** Weak to nonexistent until Core 61; from Core 60 upwards, numerous quartz-rich samples occur in connection with T/ $\beta$  assemblages.

**Glauconite:** Very rare (with T/ $\beta$  in Core 63).

**Pyrite:** Frequent, often abundant, lessening upwards and almost disappearing in the upper core. This feature seems to correspond to the reverse evolution of recrystallized radiolarians.

**Gypsum:** Rare, and only in the lower cores.

**Hydrochloric test:** Positive test predominates. Nevertheless, fairly numerous samples with A/AP', A/Az1, or A/Pl assemblages correspond to a negative test.

##### Assemblage-Lithofacies Relationships

Examination of individual samples has not been made; this would necessitate again working directly on the original core material.

The data on hand do not enable the problem of the sedimentary context to be solved. The general trend of evolution of the sediments above Core 87 clearly leads to an increasingly calcareous deposit, with increasingly calcareous foraminifers. Nevertheless, scattered samples still occur which, according to certain characteristics, we should have assigned to the carbonate-depleted hemipelagic facies in the underlying units. Thus, we are faced with an antinomy, depending on whether we take into account the preservation of a large quantity of calcareous material, or the persistence of residual deposits. In this way, we are faced with the question of the mutual position of the basin floor and the CCD.

If we assume that the sedimentary evolution reached its final stage with the installation of a true pelagic regime, this would account for the presence of luxuriant associations of planktonic foraminifers; on the contrary, it cannot be explained how carbonate-depleted sediments with a residual fauna persist, even sporadically.

Conversely, if we accept that the same bathyal or abyssal regime persists during Unit V, it must be assumed that at least a portion, and sometimes a voluminous quantity, of the calcareous material supplied has been preserved; on the contrary, this would account for the presence of these hemipelagic deposits with residual microfauna.

In this way, we note that a portion of the samples taken from Lithoterm Y (i.e., the equivalent of C previously) yields some but very few typical residual assemblages (i.e., five samples contain A/AP' assemblages, to which we can add six more samples yielding A/AzI assemblages all from a non-calcareous sediment). Another five to six non-calcareous samples with A/AzI could probably be added, but their corresponding lithoterm was not appropriately determined on shipboard.

The other samples taken from Lithoterm Y are calcareous or argillo-calcareous and generally contain A/ $\beta$  or A/ $\beta'$  assemblages (plus one A/AP $\beta$  and three A/PI). Of course, owing to the nature of the sediments, they can be interpreted in this case as being polluted; however, we would have to explain why AP are very rare (Core 65) and generally missing (Cores 61 to 57) possibly "diluted"?

Thus, this crucial problem needs more investigation or sampling to improve our understanding of the sediment itself, and to ascertain that the so-called R/AP assemblages here are really the equivalent of the R/AP which were typically observed in undeniable residual deposits. Moreover, data provided by other micropaleontological or mineralogical techniques must also be taken into consideration.

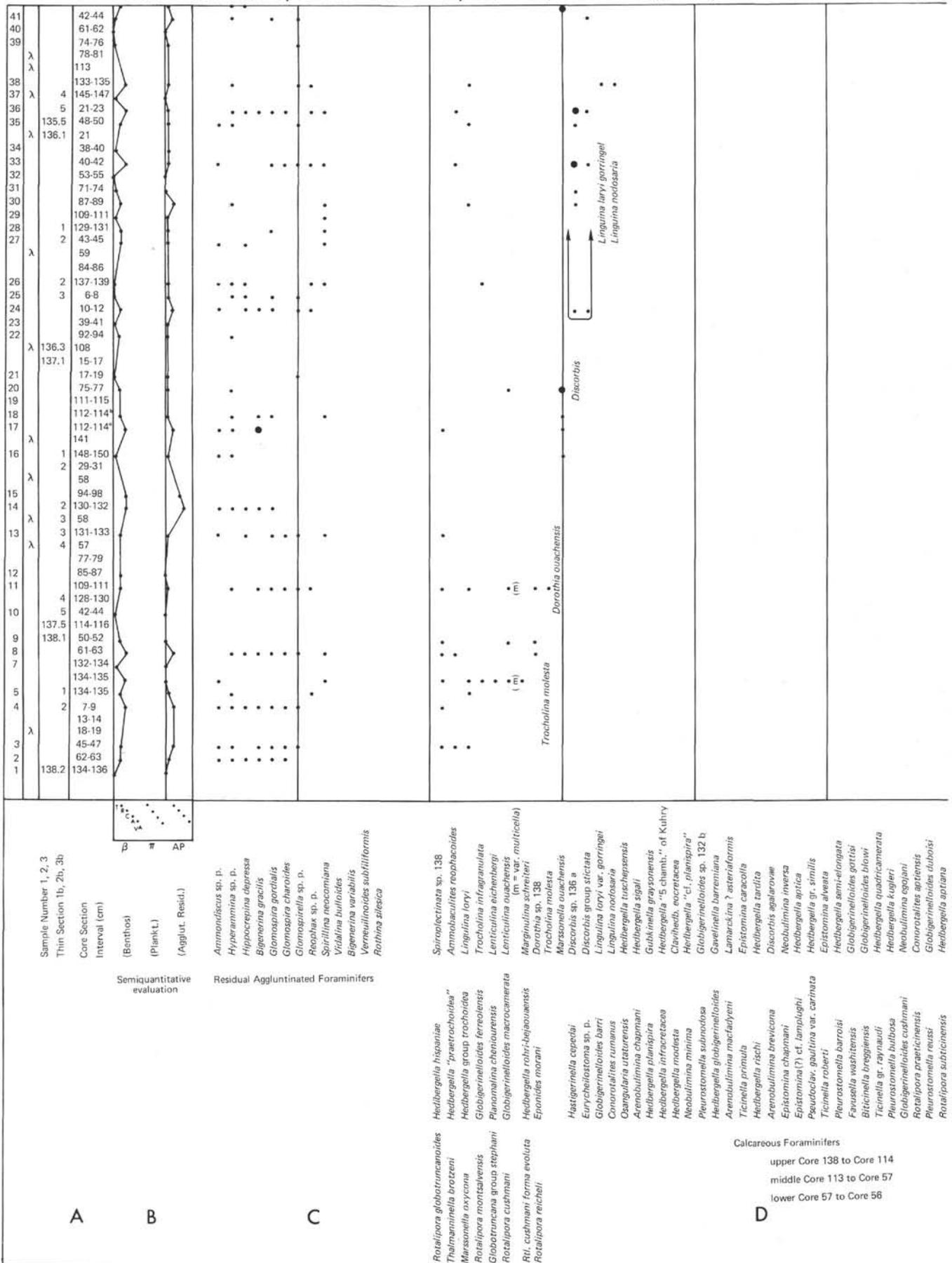
Lastly, we can note that some general stratigraphic features perhaps advance a decisive although indirect argument in favor of the second interpretation, at least for the uppermost part of the series. Reworked species, the short duration of the lower and middle Cenomanian, and the lack of a continuous series of Cenomanian planktonic associations are geologic features which would not fit very well with the opposite hypothesis of a quiet calcareous pelagic sedimentation. But it is correct to say, conversely, that such a regular stratigraphic succession (as we observed for the upper Albian and Vraconian) is not easy to imagine in a continuously turbiditic or slumping context. In summary, at least some implications of the alternative under consideration still remain open. At present, either observations or the general geological setting favor the concept of a still carbonate-depleted sedimentation, but one that is richly supplied with calcareous turbiditic material.

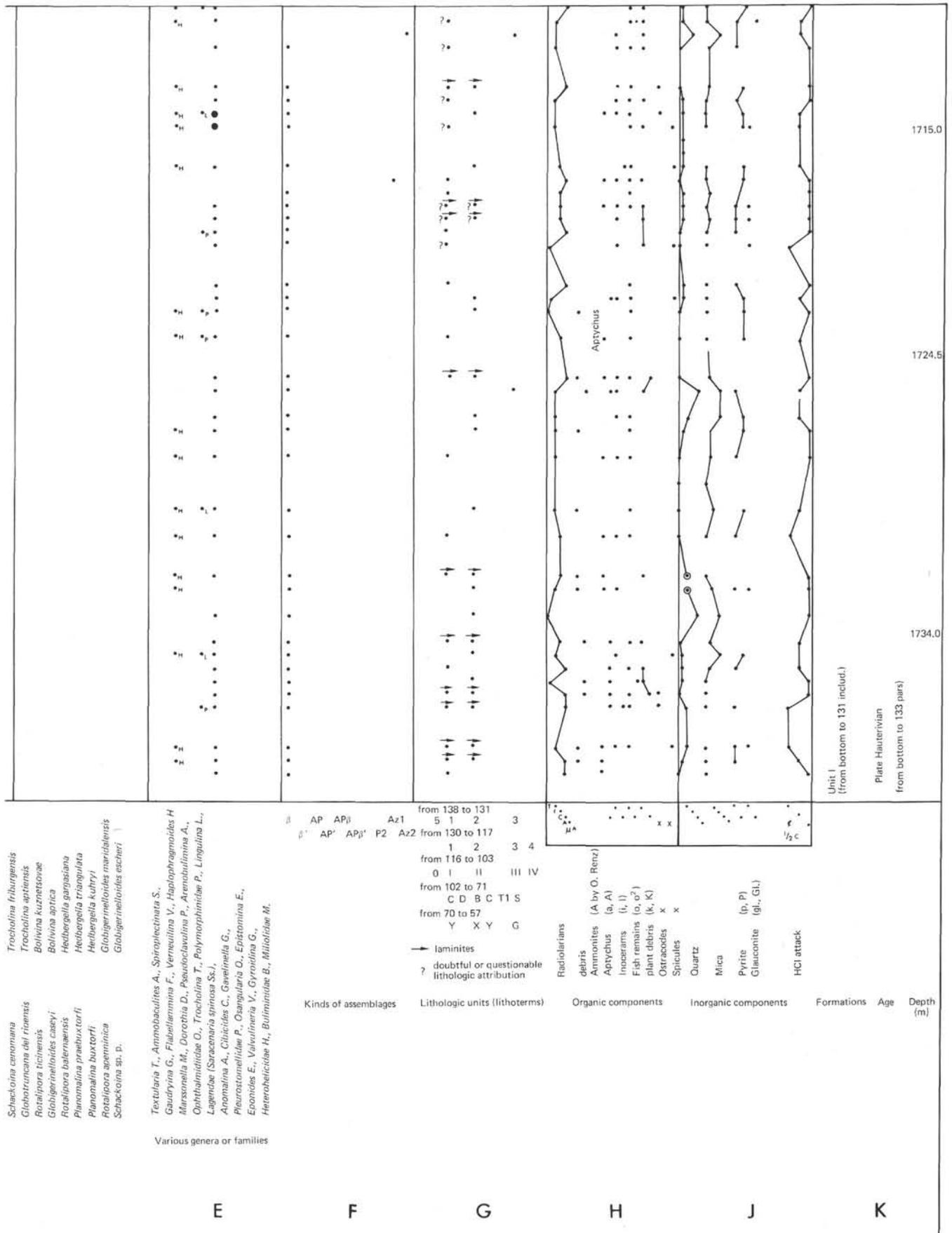
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APPENDIX II: Key to Sediment Summary Chart 1A (on microfiche), back pocket.

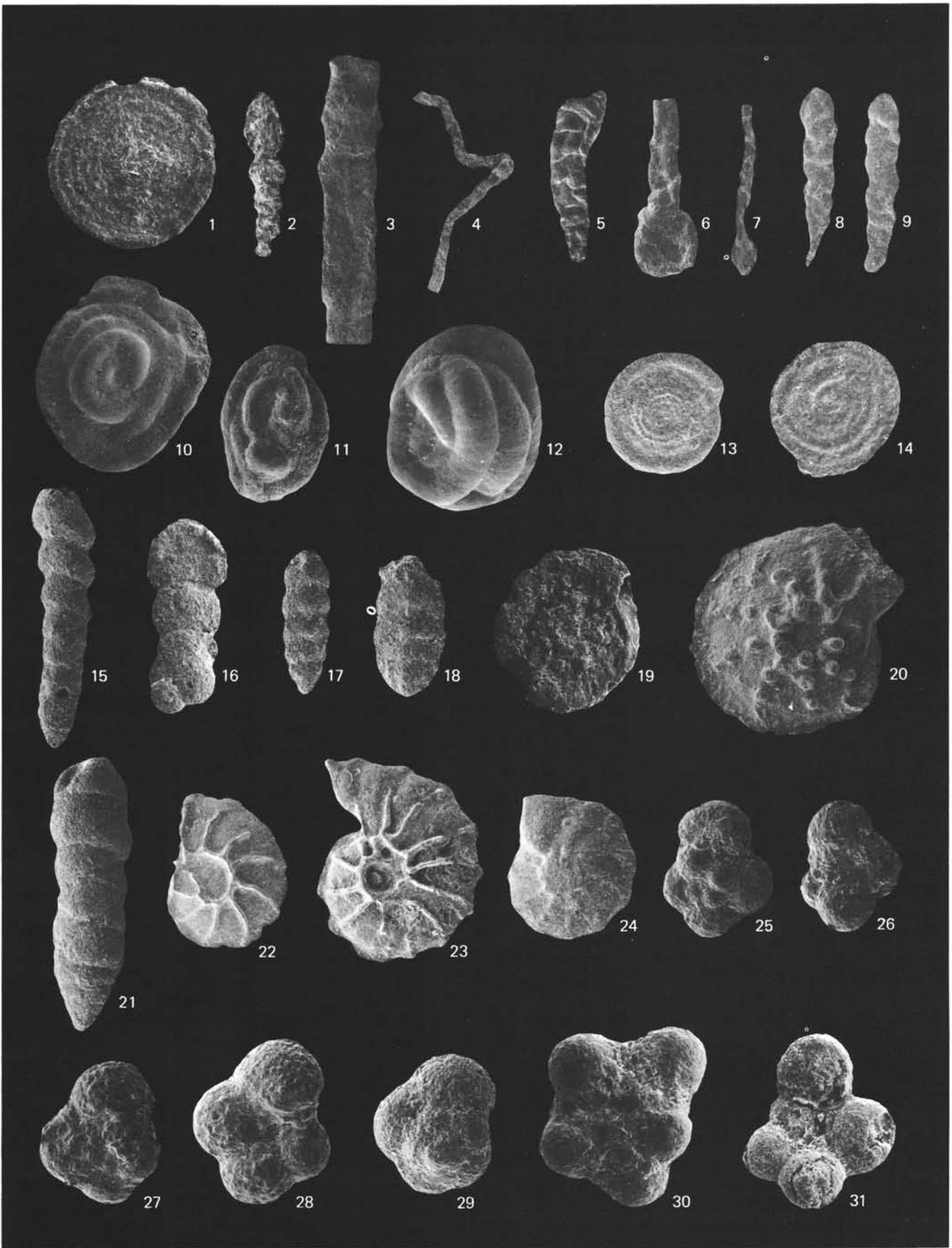




## PLATE 1

- Figure 1 *Ammodiscus* sp., 110 ×. Barremian (Sample 130-5, 91-93 cm).
- Figure 2 *Reophax* cf. *minutissima* Bartenstein and Brand, 1951. 75 ×. Hauterivian (Sample 137-4, 109-111 cm).
- Figure 3 *Hyperammia gaultina* ten Dam, 1950. 50 ×. Hauterivian (Sample 134-2, 120-122 cm).
- Figure 4 *Hyperammia* sp. 1 Bartenstein, 1974. 25 ×. Early Albian (Sample 94-2, 23-25 cm).
- Figure 5 *Hippocrepina depressa* Vasicek, 1947. 75 ×. Hauterivian (Sample 135-5, 21-23 cm).
- Figure 6 *Hippocrepina* sp.a. 50 ×. Early Albian (Sample 100-3, 45-47 cm).
- Figure 7 *Hippocrepina* sp.b. 25 ×. Early Albian (Sample 96-5, 99-101 cm).
- Figures 8, 9 *Bigennerina gracilis* Antonova, 1964. 75 ×. Hauterivian (Samples 137-2, 130-132 cm and 137-1, 112-114 cm). Microspheric and macrospheric specimens.
- Figure 10 *Glomospira gordialis* (Jones and Parker, 1860). 80 ×. Early Aptian (Sample 111-4, 57-59 cm).
- Figure 11 *Glomospira irregularis* (Grzybowski, 1897). 80 ×. Late Aptian (Sample 105-3, 125-127 cm).
- Figure 12 *Glomospira charoides* (Jones and Parker, 1860). 140 ×. Early Aptian (Sample 111-5, 80-82 cm).
- Figure 13 *Spirillina neocomiana*. Moullade, 1961. 100 ×. Hauterivian (Sample 138-1, 133-135 cm).
- Figure 14 *Glomospirella multivoluta* (Romanova, 1955). 125 ×. Hauterivian (Sample 135-1, 70-72 cm).
- Figure 15 *Spiroplectinata* sp. 75 ×. Hauterivian (Sample 138-2, 45-47 cm).
- Figure 16 *Ammobaculites* cf. *reophacoides* Bartenstein, 1952. 70 ×. Barremian (Sample 130-4, 20-22 cm).
- Figure 17 *Lingulina loryi* (Berthelin, 1880). 75 ×. Hauterivian (Sample 135-4, 133-135 cm).
- Figure 18 *Lingulina loryi* var. *gorringei* Maync, 1972. 75 ×. Hauterivian (*Saminelloides escheri* [Kaufmann, 1865]). 300 ×. Late Aptian (Sample 113-3, 32-34 cm).
- Figure 19 *Trocholina infragranulata* Noth, 1951. 200 ×. Early Aptian (Sample 127-4, 16-18 cm).
- Figure 20 *Lenticulina eichenbergi* Bartenstein and Brand, 1951, 50 ×. Hauterivian (Sample 138-1, 133-135 cm).
- Figure 21 *Marssonella ouachensis* Sigal, 1952. 65 ×. Early Aptian (Sample 120-4, 112-114 cm).
- Figure 22 *Lenticulina ouachensis* Sigal, 1952. 50 ×. Hauterivian (Sample 138-1, 133-135 cm).
- Figure 23 *Lenticulina ouachensis* var. *multicella* Bart., Bettenst., and Bolli, 1957. 50 ×. Hauterivian (Sample 138-1, 133-135 cm).
- Figure 24 *Lenticulina nodosa* (Reuss, 1863). 50 ×. Hauterivian (Sample 138-1, 133-135 cm).
- Figures 25, 26 *Hedbergella tuschepsensis* Antonova, 1964. 300 ×. Barremian (Sample 133-2, 139-141 cm). Spiral and umbilical views.
- Figures 27, 28 *Hedbergella sigali* Moullade, 1966. 300 ×. Barremian (Sample 133-2, 139-141 cm). Spiral and umbilical views.
- Figure 29 *Gubkinella graysonensis* (Tappan, 1940). 300 ×. Barremian (Sample 133-2, 139-141 cm).
- Figures 30, 31 *Clavihedbergella eocretacea* Neagu, 1975. 300 ×. Barremian (Samples 129-6, 17-19 cm and 129-7, 33-41 cm). Spiral and umbilical views.

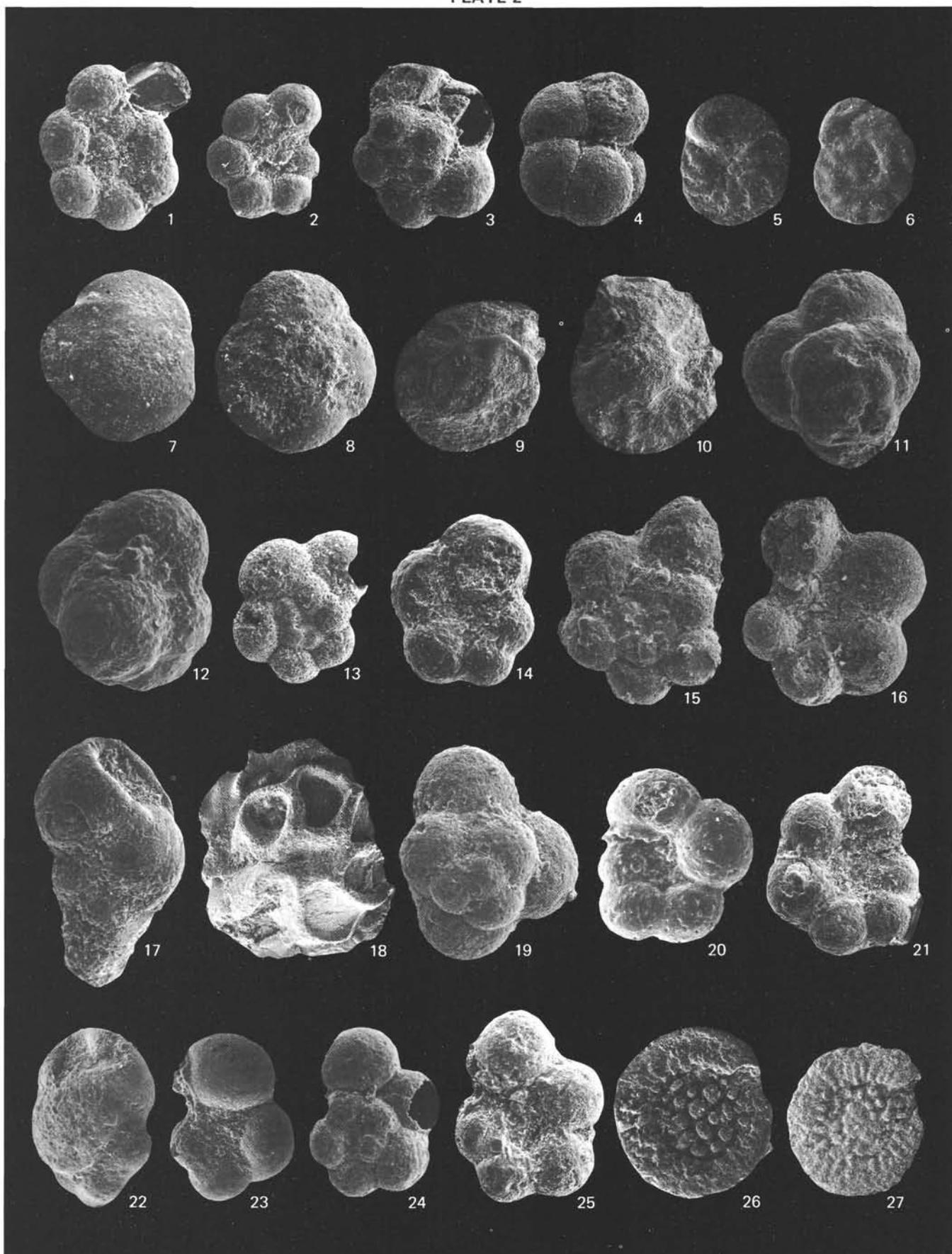
PLATE 1



## PLATE 2

- Figures 1, 2 *Hedbergella* aff. *planispira* auct. 200 ×. Early Aptian (Sample 127-1, 47-49 cm). Spiral and umbilical views.
- Figures 3, 4 *Hedbergella ventriosa* Antonova, 1964. 200 ×. Early Aptian (Sample 127-4, 16-18 cm). Spiral and umbilical views.
- Figures 5, 6 *Gavelinella barremiana* Bettenstaedt, 1952. 100 ×. Barremian (Sample 130-3, 46-48 cm). Umbilical and spiral views.
- Figures 7, 8 *Lamarckina* (?) *asteriaformis* Kuznetsova and Antonova, 1964. 80 × and 100 ×. Barremian (Sample 129-5, 88-90 cm). Spiral and umbilical views.
- Figures 9, 10 *Epistomina caracolla* (Roemer, 1841). 80 × and 70 ×. Barremian (Samples 129-6, 22-23 cm and 129-5, 88-90 cm). Spiral and umbilical views.
- Figures 11, 12 *Hedbergella tardita* Agalarova, 1964. 400 ×. Late Aptian (Sample 108-4, 110-112 cm). Spiral and umbilical views.
- Figures 13, 14 *Hedbergella aptica* (Agalarova, 1951). 250 ×. Early Aptian (Samples 123-5, 8-10 cm and 122-6, 46-48 cm). Spiral and umbilical views.
- Figures 15, 16 *Hedbergella similis* Longoria, 1974. 200 × and 180 ×. Early Aptian (Samples 123-4, 128-130 cm and 121-1, 128-130 cm). Spiral and umbilical views.
- Figure 17 *Neobulimina inversa* Antonova and Gnedina, 1964. 300 ×. Barremian (Sample 129-7, 18-20 cm).
- Figure 18 *Epistomina alveata* Espitalie and Sigal, 1963. 60 ×. Early Aptian (Sample 122-4, 131-133 cm). Umbilical view.
- Figure 19 *Hedbergella quadricamerata* Antonova, 1964. 400 ×. Early Aptian (Sample 127-4, 16-18 cm). Spiral view.
- Figure 20 *Blowiella blowi* (Bolli, 1959) or "*prae-gottisi*." 400 ×. Early Aptian (Sample 121-6, 5-7b cm).
- Figure 21 *Globigerinelloides gottisi* (Chevalier, 1961). 200 ×. Early Aptian (Sample 122-6, 46-48 cm).
- Figure 22 *Neobulimina egojani* Antonova, 1964. 150 ×. Early Aptian (Sample 122-2, 27-29a cm).
- Figure 23 *Globigerinelloides duboisi* (Chevalier, 1961). 200 ×. Late Aptian (Sample 117-7, 38-40 cm).
- Figures 24, 25 *Hedbergella aptiana* Bartenstein, 1965. 220 × and 200 ×. Early Aptian (Samples 123-5, 8-10 cm and 123-4, 18-20 cm). Spiral and umbilical views.
- Figure 26 *Trocholina friburgensis* Guillaume and Reichel, 1957. 180 ×. Early Aptian (Sample 124-4, 6-8 cm).
- Figure 27 *Trocholina aptiensis* Iovtcheva, 1962. 65 ×. Early Aptian (Sample 121-5, 133-135b cm).

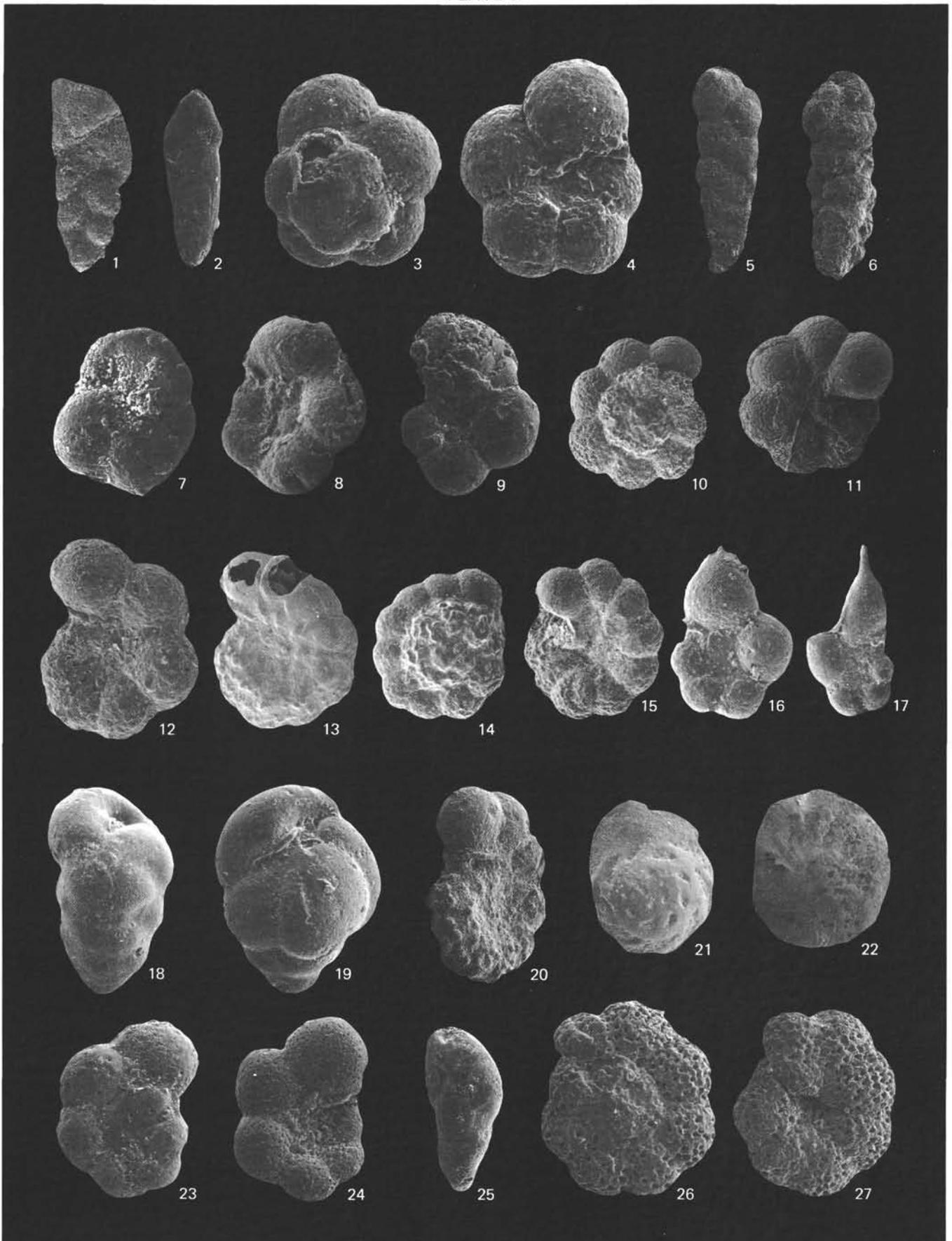
PLATE 2



## PLATE 3

- Figure 1      “*Bolivina*” *aptica* Tajrov, 1961. 150 ×. Early Aptian (Sample 121-5, 133–135 cm).
- Figure 2      “*Bolivina*” *kusnetsovae* Antonova, 1964. 200 ×. Late Aptian (Sample 114-2, 35–37 cm).
- Figures 3, 4    *Hedbergella gargasiana* Moullade, 1961. 400 ×. Late Aptian (Sample 112-5, 10–12 cm). Spiral and umbilical views.
- Figure 5      *Bigenerina variabilis* (Vasicek, 1947). 70 ×. Early Albian (Sample 101-6, 63–65 cm).
- Figure 6      *Verneulinoides* group of *subfiliformis* Bartenstein, 1952. 90 ×. Late Aptian (Sample 112-3, 105–107 cm).
- Figure 7      *Hedbergella triangulata* Antonova, 1964. 400 ×. Late Aptian (Sample 114-5, 12–14 cm). Umbilical view.
- Figure 8      *Globigerinelloides maridalensis* (Bolli, 1959). 300 ×. Late Aptian (Sample 112-3, 32–34 cm).
- Figure 9      *Globigerinelloides escheri* (Kaufmann, 1865). 300 ×. Late Aptian (Sample 113-3, 32–34 cm).
- Figures 10, 11    *Hedbergella trochoidea* (Gandolfi, 1942). 80 ×. Late Aptian (Samples 104-4, 12–14 cm and 104-4, 111–113 cm). Spiral and umbilical views.
- Figure 12      *Globigerinelloides ferreolensis* (Moullade, 1961). 100 ×. Late Aptian (Sample 109-1, 48–50 cm).
- Figure 13      *Planomalina cheniourensis* Sigal, 1952. 80 ×. Late Aptian (Sample 108-5, 44–46 cm).
- Figures 14, 15    “*Hedbergella*” aff. *Ticinella bejaouaensis* Sigal, 1966. 80 ×. Late Aptian (Sample 104-2, 9–11 cm). Spiral and umbilical views.
- Figures 16, 17    *Hastigerinelloides cepedai* Obregon, 1959. 200 × and 150 ×. Late Aptian (Samples 104-2, 67–69 cm and 106-3, 18–20 cm).
- Figure 18      *Eurycheilostoma* cf. *grandstandensis* Tappan, 1957. 200 ×. Late Aptian (Sample 106-2, 83–85 cm).
- Figure 19      *Eurycheilostoma* cf. *robinsonae* Tappan, 1957. 200 ×. Late Aptian (Sample 104-4, 12–14 cm).
- Figure 20      *Globigerinelloides barri* (Bolli, Loeblich, and Tappan, 1957). 100 ×. Late Aptian (Sample 104-2, 9–11 cm). Oblique views.
- Figures 21, 22    *Osangularia utaturensis* Sastry and Sastri, 1966. 100 × and 80 ×. Late Albian (Sample 62-3, 9–11 cm) and Vraconian (Sample 61-2, 56–58 cm). Spiral and umbilical views.
- Figures 23, 24    *Hedbergella planispira* (Tappan, 1940). 300 × and 200 ×. Middle Albian (Sample 69-3, 25–27 cm) and Late Albian (Sample 68-1, 38–40 cm). Spiral and umbilical views.
- Figure 25      *Neobulimina* cf. *minima* Antonova, 1964. 250 ×. Early Albian (Sample 95-4, 36–38 cm).
- Figures 26, 27    *Hedbergella* (? *Praeglobotruncana*) *modesta* (Bolli, 1959). 200 ×. Middle Albian (Sample 71-4, 12–14 cm). Spiral and umbilical views.

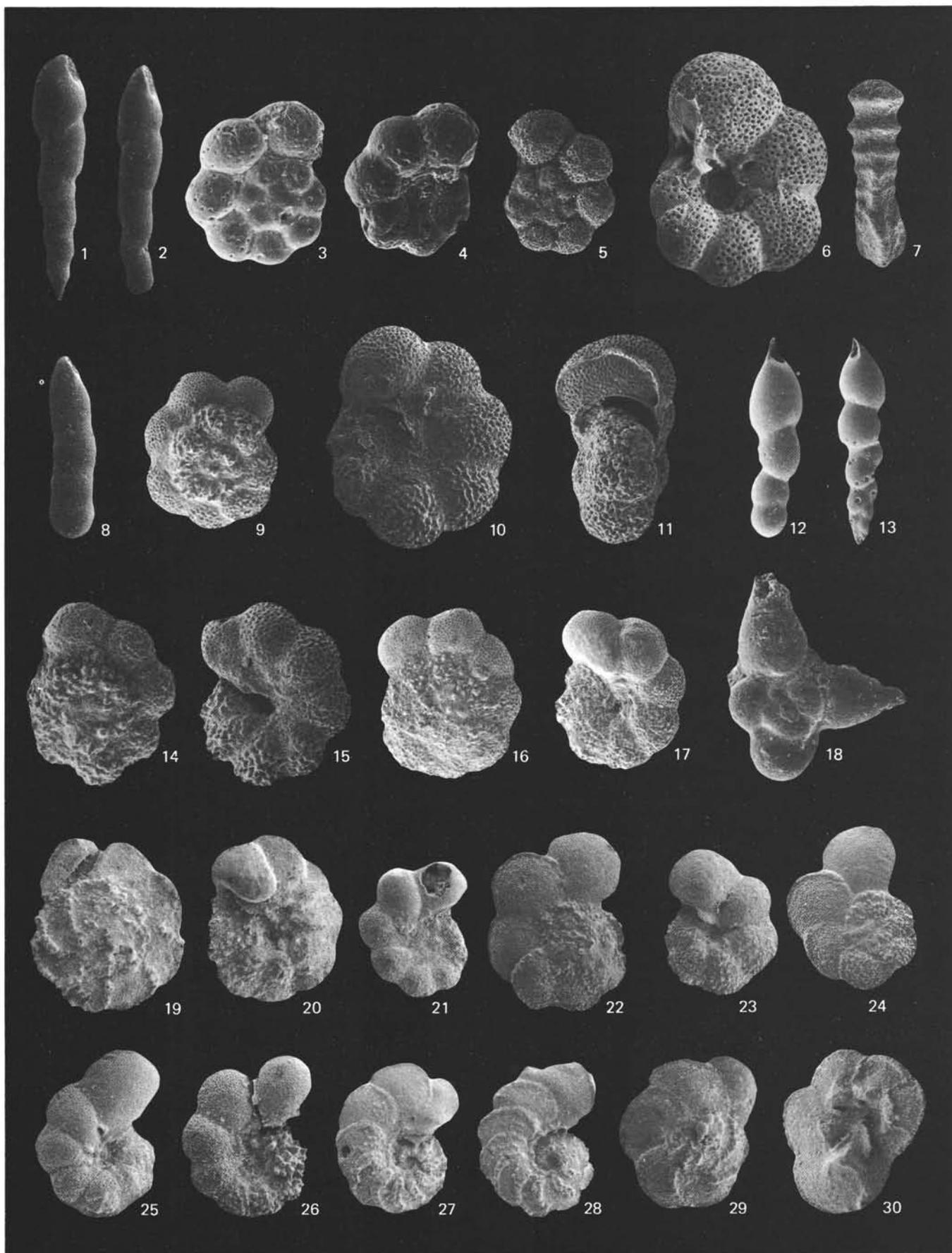
PLATE 3



## PLATE 4

- Figures 1, 2 *Pleurostomella subnodosa* Reuss, 1860. 60 ×. Early Albian (Sample 92-2, 55-57 cm). Microspheric and macrospheric specimens.
- Figures 3, 4 *Hedbergella globigerinelloides* (Subbotina, 1949). 250 × and 300 ×. Middle Albian (Sample 81-3, 131-133 cm). Spiral and umbilical views.
- figures 5, 6 *Ticinella primula* Luterbacher, 1963. 150 × and 200 ×. Late Albian (Sample 69-5, 80-85 cm). Spiral and umbilical views.
- Figure 7 *Pseudoclavulina gaultina* var. *carinata* Neagu, 1962. 40 ×. Late Albian (Sample 65-5, 13-15 cm).
- Figure 8 *Pleurostomella barroisi* Berthelin, 1880. 120 ×. Late Albian (Sample 63, CC)..
- Figures 9, 10 *Ticinella roberti* (Gandolfi, 1942). 70 × and 100 ×. Late Albian (Sample 65-4, 18-20 cm). Spiral and umbilical views.
- Figure 11 *Ticinella (Biticinella) breggiensis* (Gandolfi, 1942). 100 ×. Late Albian (Sample 67-3, 78-80 cm). Front view.
- Figures 12, 13 *Pleurostomella (Clarella) bulbosa* (ten Dam, 1950). 60 × and 70 ×. Late Albian (Sample 66, CC). Macrospheric and microspheric specimens.
- Figures 14, 15 *Rotalipora praeticinensis* Sigal, 1966. 100 ×. Late Albian (samples 66-1, 122-125 cm and 67-3, 78-80 cm). Spiral and umbilical views.
- Figures 16, 17 *Rotalipora (thalmanninella) subticinensis* Gandolfi, 1957. 80 ×. Late Albian (Sample 65-5, 135-137 cm). Spiral and umbilical views.
- Figure 18 *Schackoina* cf. *cenomana* (Schacko, 1897). 300 ×. Late Albian (Sample 65-5, 135-137 cm). Spiral view.
- Figures 19, 20 *Rotalipora (Thalmanninella) ticinensis* (Gandolfi, 1942). 70 × and 100 ×. Late Albian (Sample 62-3, 61-63 cm). Spiral and umbilical views.
- Figure 21 *Globigerinelloides caseyi* (Bolli, Loeblich and Tappan, 1957). 100 ×. Late Albian (Sample 63-3, 143-145 cm).
- Figures 22, 23 *Rotalipora balernaensis* Gandolfi, 1957. 80 ×. Vraconian (Sample 60-2, 6-8 cm). Spiral and umbilical views.
- Figures 24, 25 *Rotalipora balernaensis* forma *evoluta*. 80 × and 100 ×. Vraconian (Sample 60-2, 6-8 cm). Spiral and umbilical views.
- Figure 26 *Planomalina praebuxtorfi* Wonders, 1975. 80 ×. Late Albian (Sample 63-2, 18-20 cm).
- Figures 27, 28 *Planomalina buxtorfi* (Gandolfi, 1942). 50 × and 60 ×. Vraconian (Sample 59-3, 7-9 cm). Normal and uncoiling specimens.
- Figures 29, 30 *Rotalipora apenninica* (Renz, 1936). 50 × and 60 ×. Early Cenomanian (Samples 57-1, 105-107 cm and 57-3, 17-19 cm). Spiral and umbilical views.

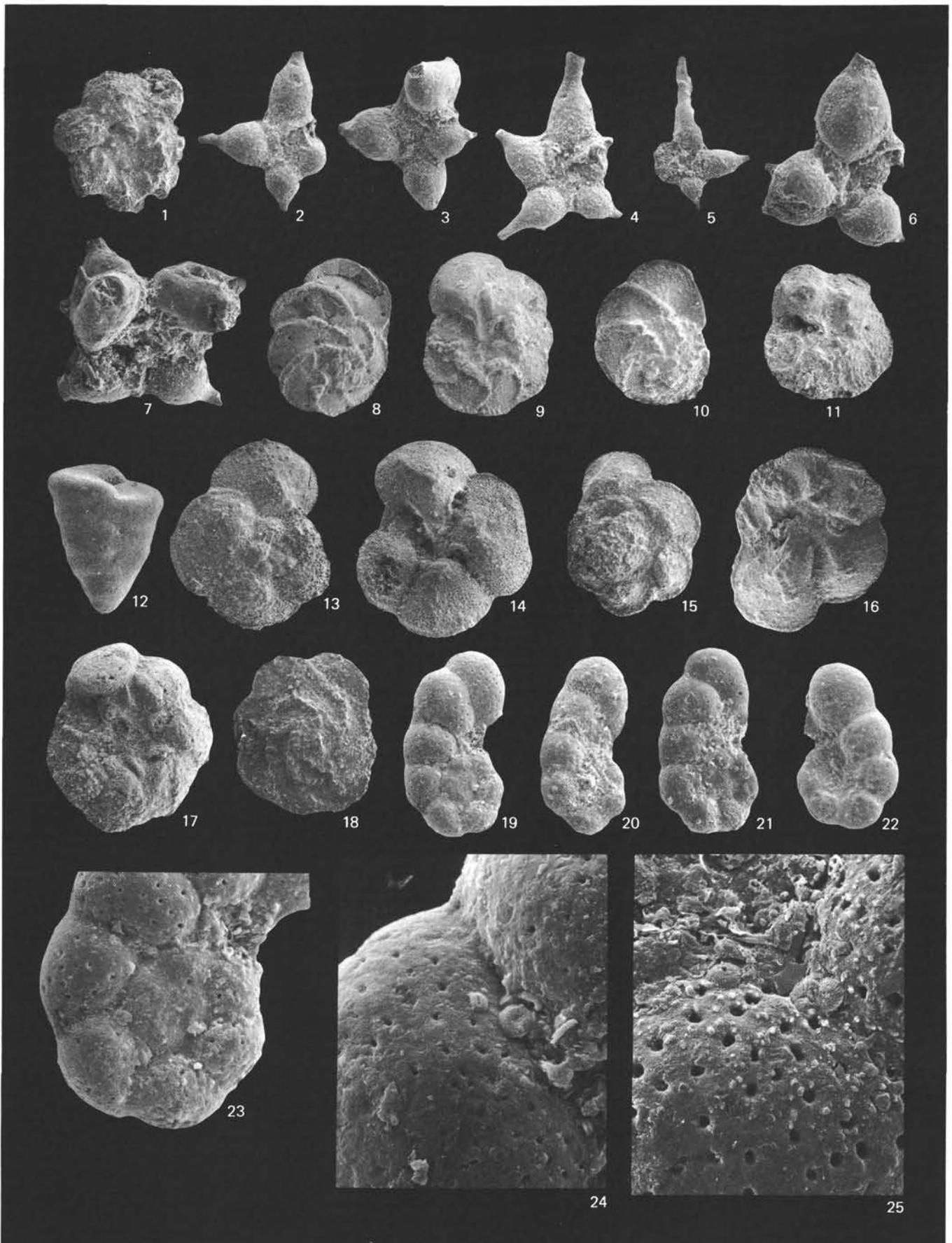
PLATE 4



## PLATE 5

- Figure 1 *Hedbergella costellata* Saint-Marc, 1973. 100 ×. Vraconian (Sample 59-4, 132-134 cm).
- Figure 2 *Schackoia cenomana* (Schacko, 1897). 150 ×. Early Cenomanian (Sample 57-5, 5-7 cm).
- Figure 3 *Schackoia cenomana* var. *bicornis* Reichel, 1948. 150 ×. Early Cenomanian (Sample 57-5, 5-7 cm).
- Figure 4 *Schackoia pentagonalis* Reichel, 1948. 150 ×. Early Cenomanian (Sample 57-5, 5-7 cm).
- Figure 5 *Schackoia gandolfii* Reichel, 1948. 100 ×. Early Cenomanian (Sample 57-4, 69-70 cm).
- Figure 6 *Schackoia gandolfii* Reichel, 1948. 100 ×. Early Cenomanian (Sample 57-4, 69-70 cm).
- Figure 7 *Schackoia moliniensis* Reichel, 1948. 200 ×. Early Cenomanian (Sample 57-4, 69-70 cm).
- Figures 8, 9 *Rotalipora globotruncanoides* Sigal, 1948. 60 ×. Early Cenomanian (Samples 57-5, 8-10 cm and 56-5, 146-148 cm). Spiral and umbilical views.
- Figures 10, 11 *Rotalipora (Thalmaninella) brotzeni* Sigal, 1948. 100 × and 80 ×. Early Cenomanian (Sample 56-5, 146-148 cm). Spiral and umbilical views.
- Figure 12 *Marssonella oxycona* (Reuss, 1860). 100 ×. Early Cenomanian (Sample 57-4, 86-88 cm).
- Figures 13, 14 *Rotalipora montsalvensis* Mornod, 1950. 80 × and 90 ×. Early Cenomanian (Sample 56-6, 105-107 cm). Spiral and umbilical views.
- Figures 15, 16 *Rotalipora cushmani* (Morrow, 1934). 50 ×. Middle Cenomanian (Sample 56-3, 45-47 cm). Spiral and umbilical views.
- Figures 17, 18 *Rotalipora reicheli* Mornod, 1950. 70 × and 60 ×. Middle Cenomanian (Sample 56-3, 45-47 cm). Spiral and umbilical views.
- Figures 19-25 n.gen., n.sp. (aff. *Hedbergella planispira*).  
 19, 20. 200 ×. Late Albian (Sample 65-5, 135-137 cm).  
 21, 22. 200 ×. Late Albian (Sample 65-5, 133-135 cm).  
 23. 500 ×. Detail of specimen Figure 19.  
 24, 25. 1000 ×. Detail of specimen from late Albian (Sample 65-5, 135-137 cm).

PLATE 5



## APPENDIX

## Lower Cretaceous Ostracodes

N. Grekoff<sup>1</sup> and J. F. Babinot<sup>2</sup>

Ostracodes are poorly represented in both Lower and Upper Cretaceous sediments. Hauterivian to Vraconian series, which were especially investigated, yielded only about 50 specimens from 800 samples (generally no more than one specimen to a sample). They can be attributed to 10 to 12 genera or higher taxa. Additionally, they are generally small and their preservation is poor, with the exception of one or two of the largest ones. Carapaces are closed and, consequently, anatomic criteria are irrelevant to a modern taxonomic determination.

From a systematic point of view, we note that *Cytherurinae* and small *Cytheridae* are relatively predominant, and that *Monoceratina*, *Paracypris*, *Cytherella*, and *Bairdia* are frequent. Only one form which was determined belongs to the specific group *Schuleridea jonesiana* (Bosquet, 1846).

No precise stratigraphic conclusion can be formulated because the vertical extension of the different genera is too large. *Schuleridea jonesiana* has been encountered in Europe from the Aptian to the Cenomanian, and agrees with the age given by planktonic foraminifers from Hole 398D.

Paleoecologically two different populations that originated in two paleoenvironments can be distinguished:

1) Small species, which are most numerous in the selected population, with a thin and smooth shell, probably correspond to a deep marine, *in-situ* association. The genera *Cytheropteron* and *Monoceratina* agree with such a hypothesis; it is known that some species of

*Paracypris*, *Cytherella*, *Cytherelloidea*, and *Brachycythere* can live at great depths. Their small size and scarcity support this interpretation.

2) By contrast, a few specimens (i.e., some highly calcified *Cytherella*, some punctate *Bairdia*, large and well-preserved *Schuleridea jonesiana*) belong to populations which inhabit shallower or littoral waters on the continental shelf. Thus, they at least have been displaced if not reworked; Table 2 clearly shows that in three instances they come from cores where reworked microfossils (Calpionellids and foraminifers) were found in slumped sediments.

In summary, the following taxa were recognized:

- Hauterivian:** ?*Cytherurinae* (Samples 138-1, 133-135 cm)  
*Bairdia* (Sample 135-4, 133-135 cm)  
*Monoceratina* (Samples 135-4, 133-135 cm and 135-3, 86-88 cm)  
*Cyprididae* (Sample 134-1, 60-62 cm)  
*Paracypris* (Sample 133-3, 105-107 cm)
- Barremian:** *Monoceratina* (Sample 130-4, 20-22 cm)  
 ?*Paracypris* (Samples 126-4, 27-29 cm and 126-1, 113-115 cm)
- Lower Aptian:** *Paracypris* (Sample 125-4, 49-51 cm)  
*Cytherella* (Samples 125-4, 27-29 cm and 124-4, 6-8 cm)  
*Cytheropteron* (Sample 125-2, 8-10 cm)  
 ?*Brachycythere* (Sample 123-1, 77-79 cm)  
*Bairdia* (punctate) (Sample 122-2, 27-29 cm)  
*Cytherelloidea* (Sample 121-6, 94-96 cm)
- Upper Aptian:** *Paracypris* (Samples 120-4, 112-114 cm and 105-3, 57-59 cm)  
*Cytherella* (Sample 106-2, 83-85 cm)  
 ?*Monoceratina* (Sample 105-2, 143-145 cm)
- Upper Aptian:** *Schuleridea jonesiana* (Sample 65-4, 101-103 cm)  
*Cytherurinae* (Sample 63-6, 85-90 cm)

(along with marine *Cytheridae* and *Cyprididae* in the different stages and substages).

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