1. SITE 98 – NORTHEAST PROVIDENCE CHANNEL

The Shipboard Scientific Party[1]

INTRODUCTION

The Atlantic Advisory Panel selected one of the deep troughs of the Bahama Platform for Site 98 in the hope that comparisons of the deep-water section with sections on Andros Island, Cay Sal Bank and the Florida Keys would provide information on the history and development of this large carbonate province. A major question has been whether the deep areas, such as Tongue of the Ocean, the Providence Channels and Exuma Sound, have been deeper than the banks and southern Florida for most or all of their history, or whether the entire area was one of shallow-water carbonate deposition until perhaps the end of the early Cretaceous, following which the banks continued to accumulate sediments at a rate equal to that of regional subsidence while deposition in the presently deep channels occurred at a much slower rate (Hess, 1933, 1960; Newell, 1955). Suggestions have also been made that the deep troughs have resulted from downfaulting at some stage of the development of the province (Talwani *et al.*, 1960). Therefore, a major objective of drilling in the Northeast Providence Channel was to ascertain if shallow-water sediments would be found and, if so, to determine their age.

Seismic profiler data available before *Glomar Challenger* arrived at the site indicate a variable thickness of acoustically transparent sediment (up to 500 meters). Sediment as old as Eocene has been recovered with a piston corer near this site by Lynts (1971). These sediments lie above a prominent reflector that is exposed at the sea floor in places – notably in the central, deep part of the channel. After a short survey of the area by *Glomar Challenger*, the site was chosen at a place where the water depth is 2769 meters and the thickness of sediment above the prominent reflector is about 250 meters (0.25 seconds of reflection time). The sea floor and the subbottom reflectors slope toward the axis of the channel in the vicinity of the site; this made significant slope corrections necessary when making comparisons of the borehole data and the seismic profiler reflectors.

OPERATIONS

The ship arrived at the vicinity of the site at 0500 hours on 9 April, 1970. A brief seismic reflection survey was run (Figures 1 and 2a), and the beacon was dropped at 0930 hours. The PDR depth was 1450 fathoms or 2750 meters (corrected, including a 6° slope correction). Bottom contact was made at 2779 meters according to drill pipe measurements from the derrick floor. Some rotation of the drill string was required to begin penetration; this suggests the presence of a hard crust on the sea floor. After the initial penetration was made, the first few cores were taken with little or no rotation. As the bit went deeper, rotation and occasional application of circulating water were required. During coring of Core 7 there were many indications of the presence of hard layers. Rotation was needed continuously, and it was necessary to pump on three occasions. Core 7 contained several large fragments of chert.

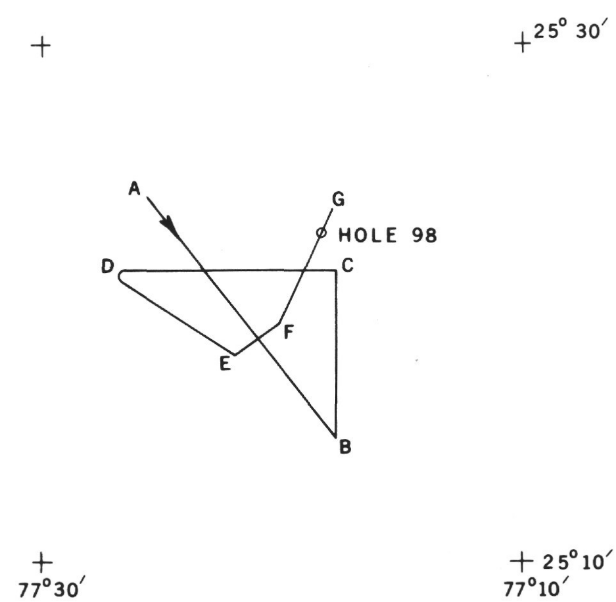


Figure 1. Glomar Challenger *track approaching Site 98.*

From approximately the level of Core 7 to almost total depth the core recovery was poor, apparently because without water circulation the firm chalk formation would clog the bit, while with circulation it would wash out. Attempts to improve recovery by varying the amount of water, speed of rotation, and weight on the bit were unsuccessful. Although this formation could be penetrated rather easily if a substantial amount of circulation was applied, it was firm enough to give strong indications on the weight gauge when the bit

[1]Charles D. Hollister, John I. Ewing, Daniel Habib, John C. Hathaway, Yves Lancelot, Hanspeter Luterbacher, Fred J. Paulus, C. Wylie Poag, James A. Wilcoxon, Paula Worstell.

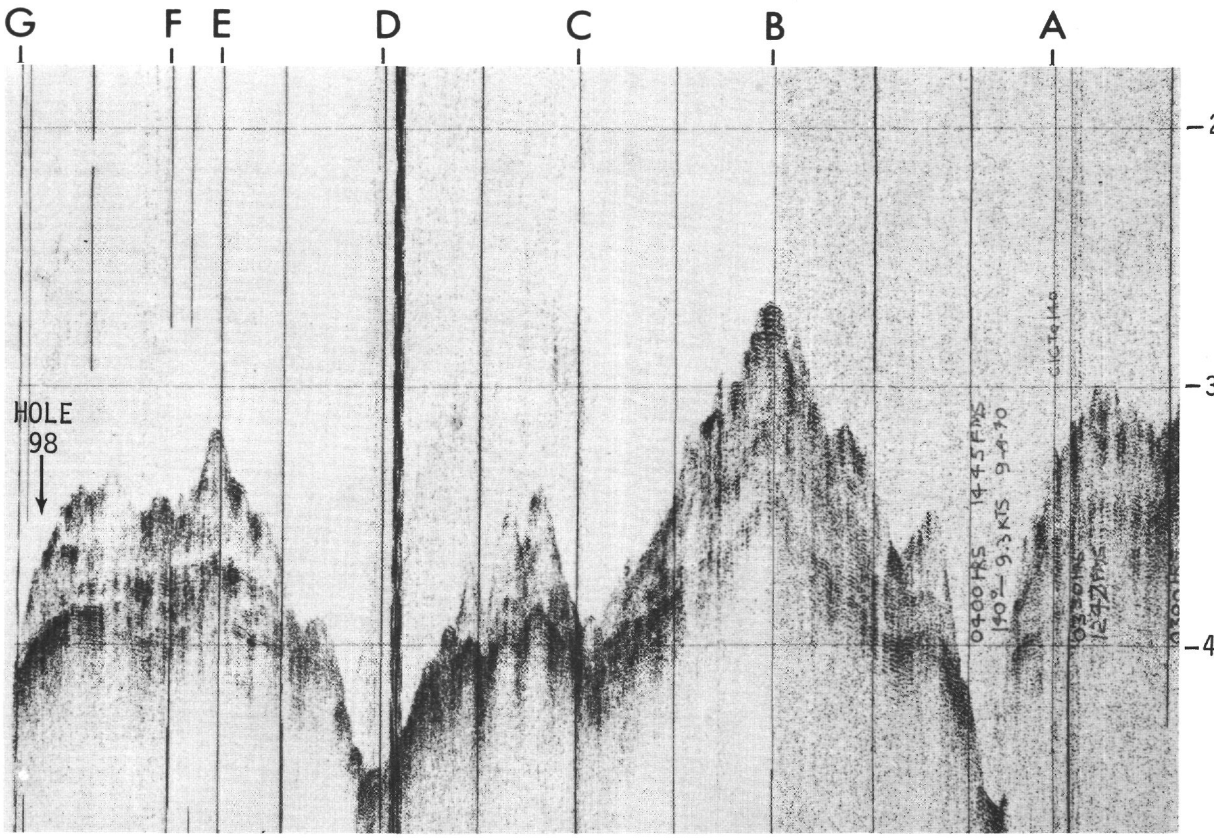


Figure 2a. Glomar Challenger *seismic record near Site 98. See Figure 1 for track location.*

touched down at the bottom of the hole. Therefore, except for occasional pieces which had not been slurried by the circulating water, the samples recovered probably do not reflect the compactness of the *in-situ* material.

The 3097 to 3127 meter interval (between Cores 14 and 15) was drilled using a center bit. Two hard layers were encountered between 3097 and 3106 meters, another between 3106 and 3115 meters, and a particularly hard zone at about 3125 to 3127 meters. When the center bit was pulled, the barrel had several liters of hard limestone cuttings in it, apparently forced in through the water port after circulation was stopped.

Most of these cuttings are believed to have come from near the bottom of the drilled interval.

Mud was pumped down hole to remove drill cuttings prior to cutting Core 15. Coring times for this core indicated hard zones in the upper two meters and at the bottom of the interval. The core consisted of a few centimeters of hard vuggy limestone underlain by nannoplankton chalk. Hard drilling in the interval above this core suggests that additional amounts of hard limestone are present in this part of the hole. (The top of Core 13 also contained a few centimeters of the same type of hard limestone). After recovery of Core 15, the hole was plugged and abandoned. Cement plugs were set at 3049 to 2926 meters and at 2906 to 2783 meters. Figure 2b shows our interpretation of the correlation between the seismic record and lithology.

STRATIGRAPHY

Biostratigraphy

Cores 1 and 2 were taken immediately below the sea floor. The uppermost meter of Core 1 contains common pink *Globigerina rubescens* and *Globigerina calida* and is, therefore, placed in the Holocene. Most of Core 1 has a planktonic-foraminiferal fauna of late Pleistocene Age. An unconformity is present near the base of Core 1, since late Pleistocene deposits directly overlie beds with planktonic-foraminiferal faunas and nannoplankton floras indicating an early Pliocene age.

According to the calcareous nannoplankton, all of Core 2 is of late Miocene age (*Ceratolithus tricorniculatus* Zone). However, the planktonic foraminifera of Core 2 are characteristic of the early Pliocene (*Sphaeroidinella dehiscens*/*Globoquadrina altispira* Zone). The fauna of

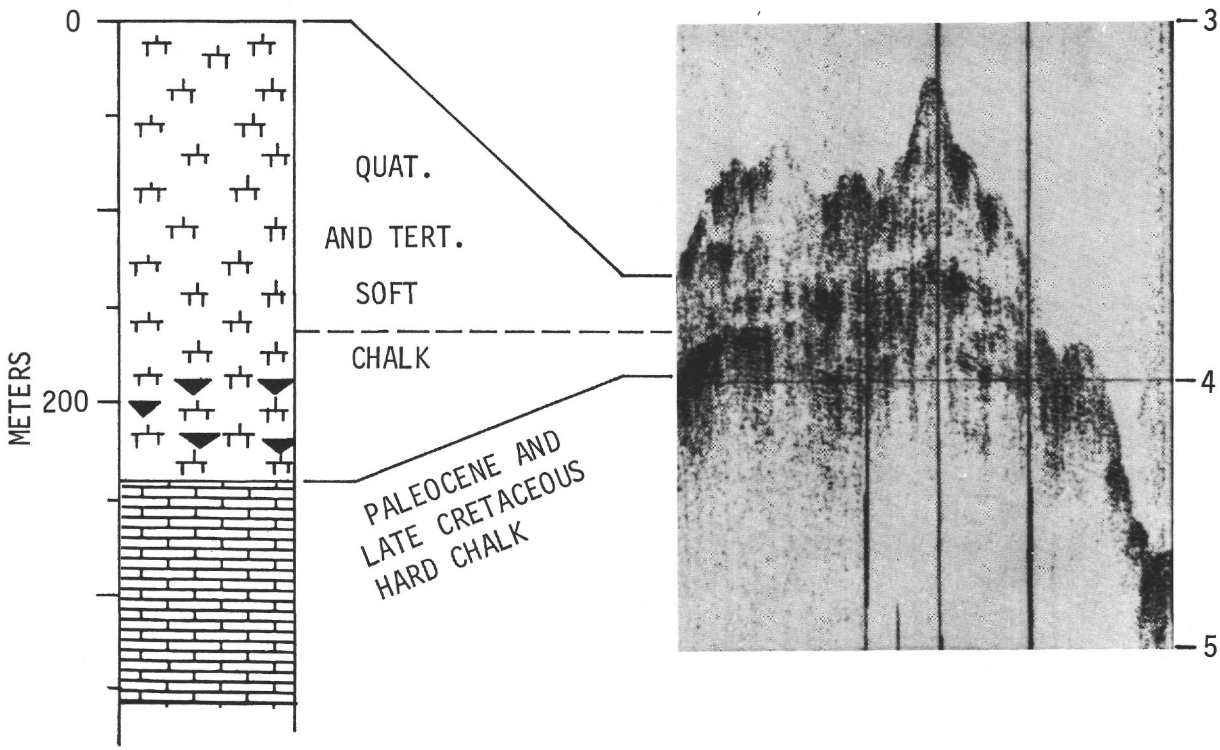


Figure 2b. *Seismic stratigraphy and lithology at Site 98.*

the core catcher belongs to the early Pliocene *Globorotalia tumida/Sphaeroidinellopsis paenedehiscens* Zone.

The two samples from Core 3 examined for calcareous nannoplankton contain floras of late Miocene age (*Discoaster quinqueramus* Zone). This age is corroborated by the planktonic foraminifera, which belong to the *Globorotalia tumida/Sphaeroidinellopsis paenedehiscens* Zone (Section 2) and to the *Globorotalia plesiotumida* Zone (Sections 3 to 6, and core catcher).

Core 4 is of late Miocene age (*Globorotalia plesiotumida* Zone and *Discoaster variabilis* Zone).

The Miocene/Oligocene boundary was cored in Section 1 of Core 5. The upper 82 centimeters contain *Globigerinoides primordius* and belong therefore to the early Miocene (*Globigerinoides primordius/Turborotalia kugleri* Zone). The rest of the core has planktonic foraminifera of the *Globigerina angulisuturalis* Zone and calcareous nannoplankton of the *Sphenolithus ciperoensis* Zone. These two zones denote a late Oligocene age.

The washed residues of Core 6 are dominated by generally well-preserved planktonic foraminifera. Radiolarians are frequent at the base and top of the core. Excellently preserved sponge spicules are found in great numbers in most of the residues. The planktonic foraminifera from the middle and upper part of the core belong to the early part of the late Eocene (*Globigerapsis semiinvoluta* Zone), whereas those from its lower part are late middle Eocene in age (*Truncorotaloides rohri* Zone). The calcareous nannoplankton of Core 6 are typical of the *Helicopontosphaera compacta* Zone of the late middle Eocene.

The planktonic foraminifera of Core 7 are typical of the late early Eocene *Globorotalia pentacamerata* Zone, whereas the calcareous nannoplankton indicate a somewhat younger age (*Chiphragmalithus alatus* Zone in Sections 1 to 4; *Sphenolithus radians* Zone in Section 4, 5, and core catcher). Radiolarians are found only in small numbers. Sponge spicules become more frequent toward the base of the core.

The interval between 207 and 241 meters below bottom was cored continuously (Cores 8 to 12). Most of Core 8 is attributed to the early Eocene *Globorotalia formosa formosa* Zone, and Cores 9, 10 and 11 are in the *Globorotalia subbotinae* Zone. The assemblages of Core 12 are intermediate between the early Eocene *Globorotalia subbotinae* Zone and the late Paleocene *Globorotalia velascoensis* Zone. Cores 8 and

9 are very rich in radiolarians and sponge spicules. Redeposited rotalids of nearshore origin are found in the lowermost two samples of Core 11.

According to the calcareous nannoplankton, Cores 8 and 9 are early Eocene in age (*Marthasterites contortus* Zone). Cores 10 and 11 are late Paleocene *Discoaster multiradiatus* Zone. Core 12 is in either the *Discoaster multiradiatus* Zone or the underlying *Heliolithus riedeli* Zone.

Core 13 contains *Globotruncana calcarata* and calcareous nannoplankton that indicate a late Campanian age.

Core 14 contains calcareous nannoplankton and foraminifera (globotruncanids) which broadly indicate a Campanian age. Intercalations of coarse calcarenite containing numerous orbitoids of Campanian age indicate pene-contemporaneous redeposition.

A sample recovered from the center bit between Cores 14 and 15 consists of coarse calcarenite with Campanian orbitoids.

Only one section was recovered from Core 15. The globotruncanids contained in the chalky part belong either to the early Campanian or late Santonian. The calcareous nannoplankton suggest a slightly older age. In addition, a few reworked specimens of early Cretaceous age were observed. A few centimeters of detrital (peri-reef) limestone at the top of Core 15 contain fragments of algae (mainly *Solenopora*), corals and echinoids.

Preliminary examination of core catcher samples from Site 98 shows a general absence of pollen grains and spores. A few pollen grains were observed in the core catcher sample of Core 1. (Refer to individual chapters by Poag, Luterbacher and Wilcoxon for more detailed analyses of the microfossil assemblages at Site 98.)

Lithology

The 122 meters of sediments recovered from the 357-meter hole at Site 98 consist primarily of white to cream colored foraminiferal-nannoplankton carbonate oozes and chalks of Tertiary and late Cretaceous ages. Noteworthy variations on this theme include: (1) clayey and micaceous Holocene carbonate ooze, (2) early Eocene cherts, and (3) late Cretaceous detrital limestone. In the following discussion all formation depths are as measured from the derrick floor.

Holocene (Core 1)

After penetrating a thin hard crust on the sea floor (driller's report), coring encountered about 1 meter of pale yellowish-brown ooze consisting principally of foraminifera and calcareous nannoplankton. Pteropods are common. Sand size terrigenous detritus, including mica flakes, is abundant, as are clay minerals. Also abundant are aragonite needles and calcite spicules. The Holocene, together with the late Pleistocene, constitute the only section at Site 98 which contains significant amounts of clay minerals.

Pleistocene (Core 1)

The upper 5 meters consist of late Pleistocene pale yellowish-brown foraminiferal-nannoplankton ooze with inclusions of greenish-gray ooze. Clay minerals and micas are common, as are aragonite needles and calcite spicules. Occasional dolomite rhombs were also noted. High magnesium-calcite is present in Section 3. The clay mineral suite in the Pleistocene is a chlorite-illite-rich assemblage with some kaolinite and very little montmorillonite.

Pliocene (Cores 1 and 2)

About 21 meters of early Pliocene soft cream-white foraminiferal-nannoplankton ooze, with a few specks of limonite and pyrite, immediately underlie the darker late Pleistocene ooze. Occasional aragonite needles and dolomite rhombs occur throughout this interval. Zeolites occur in Core 2, Section 5 but were not observed above this depth. Mica and light glass are scattered throughout the rather homogeneous sections. The late Pleistocene-early Pliocene contact (about 2785 meters in Core 1) is the only significant unconformity recognized at this site.

Miocene (Cores 3 and 5)

The Miocene is about 75 meters thick at Site 98. About 18 meters of this interval were recovered in cores. The sediments consist of soft, gray to greenish-gray, foraminiferal-nannoplankton ooze. Clay minerals vary from rare to sometimes common. Occasional aragonite needles and dolomite rhombs were found scattered throughout this interval. In addition, there were rare occurrences of grains of volcanic glass, mica, pyrite and zeolites. Glauconite grains were common in one instance (Section 98-4-3, 111 centimeters). The top of the Miocene is at about 2798 meters.

Oligocene (Core 5)

About 4.5 meters of Oligocene sediments were recovered at Site 98. They consist of soft to moderately indurated, light greenish-gray to light olive gray foraminiferal-nannoplankton ooze. Siliceous fossils are a conspicuous component of these sediments. Sponge spicules are abundant throughout most of the core. Radiolaria are rare in the upper portion and absent in the lower. Occasional rare occurrences of clay minerals and aragonite needles were noted. The top of the Oligocene is at 2873 meters (Core 5). The base was not cored.

Late Eocene (Core 6)

About 8 meters of late Eocene sediments were recovered at Site 98. They consist of a soft to firm light greenish-white foraminiferal-nannoplankton ooze containing the first traces of recrystallized nanno-calcite.[2] The older beds sampled at Site 98 contain an abundance of such calcite. Pentalith forms are common in the upper parts of Sections 4 to 6. Clay minerals were noted as sometimes common, but mainly rare to absent. Siliceous fossils are present; sponge spicules are generally common; Radiolaria are rare (see chapter by Luterbacher in this volume).

Middle Eocene (Core 6)

About 100 centimeters of middle Eocene ooze were recovered at Site 98. The sediment appears identical to the overlying late Eocene ooze except for a marked increase in the percentage of Radiolaria (see chapter by Luterbacher in this volume). The top of the middle Eocene is at 2916 meters in this core. The base of the middle Eocene was not cored.

Early Eocene (Cores 7 to 12)

About 73 meters of early Eocene sediments were penetrated at Site 98. The base of the Eocene was arbitrarily placed at 3019 meters—at the top of Core 12. The fauna in Core 12 is of the early Eocene-late Paleocene transition zone.

Core 7 recovered 8.5 meters of mainly soft, white foraminiferal-nannoplankton ooze, which contains an abundance of recrystallized nanno-calcite and fragments of pentaliths. Calcite spicules are common throughout the core while siliceous fossils are virtually absent. Their absence might well be directly related to the development of chert in this part of the section.

A 75-centimeter zone containing large fragments of light tan chert was encountered immediately below the top of Core 7 – at about 2946 meters (see section page for detailed illustration). The thickness of the zone is based on the distribution of three large pieces of chert plus several smaller ones. The large chert fragments at the top and bottom of this 75-centimeter zone show sharp contacts with the adjacent white carbonate ooze. The lower piece shows a flat, bedding-plane type of contact, whereas, the upper piece shows a strongly undulating contact. The ooze adjacent to the chert is very hard and appears to be partially silicified. A thin section made from a chert fragment shows foraminiferal tests replaced by quartz, and contained in a matrix of nannoplankton replaced by disordered cristobalite.

[2]By recrystallized nanno-calcite we refer to calcitic material of the size of nannoplankton or nannoplankton debris which shows no evidence of organic structure, but probably represents recrystallization of calcareous nannoplankton.

One insoluble residue from the core catcher contains grains of zeolites cemented in a silica matrix.

In the coarse fraction of Core 7, foraminifera are predominant and siliceous sponge spicules showing outgrowths of silica are abundant. A few chert fragments were also observed.

Core 8 recovered 4.5 meters of soft to firm, white to yellowish-white foraminiferal-nannoplankton ooze. There is no sign of chert. Siliceous fossils are abundant. Recrystallized nanno-calcite and fragments of pentaliths are common. Clay minerals are rare.

Core 9 recovered 2.3 meters of yellowish-white foraminiferal-nannoplankton ooze. Siliceous fossils are abundant. Recrystallized nanno-calcite and fragments of pentaliths are common. Again, there was no evidence of having penetrated chert in this core interval.

Core 10 recovered about 10 centimeters of large, light-tan chert fragments containing many sizable, very hard, inclusions of white chalk. Underlying the chert are 35 centimeters of firm to hard, white nannoplankton chalk in contact with 35 centimeters of hard, white, laminated, micritic chalk, the base of which is at 3010 meters. Siliceous fossils are absent. Clay minerals were noted as common, with montmorillonite dominant and chlorite absent. Clinoptilolite is common in the laminated chalk, more so in the darker than in the lighter laminations. An occurrence of volcanic glass was also noted.

Post-depositional movement is suggested in Core 10, by a slickensided surface which dips at about 45 degrees at 131 centimeters to 135 centimeters. The slickensided surface is covered with exceptionally large (several millimeters) fibers of sepiolite associated with numerous black manganese-oxide dendrites. This is believed to be the first occurrence of such large fibers of sepiolite in deep sea sediments. (See section page for a detailed illustration of this recovery.)

Core 11 recovered 2.2 meters of soft to firm, yellowish-white foraminiferal-nannoplankton ooze. Recrystallized nanno-calcite and fragments of pentaliths are abundant, as are zeolites. A few yellow limonite nodules and a thin, brown layer of limonite are present.

Core 12 penetrated 1 meter of sediments and recovered 45 centimeters of faintly laminated, yellowish-white, micritic nannoplankton chalk. Recrystallized nanno-calcite and fragments of pentaliths are abundant. Zeolites are common. This is the oldest occurrence of zeolites at Site 98. Underlying the indurated chalk are 85 centimeters of interbedded, soft to firm, yellowish-white, foraminiferal-nannoplankton ooze. This core contains the early Eocene-late Paleocene boundary.

The base of the Eocene was arbitrarily placed at 3019 meters—the bottom of the cored interval. (See section page for a detailed illustration of this core recovery.)

Late Campanian (Core 13)

Core 13 recovered about 5 centimeters of very hard, vuggy, yellowish-gray calcirudite. An identical-appearing limestone was also recovered in Core 15. B. F. Perkins (Louisiana State University) examined the limestone in Core 13. He recognized several large fragments of rudists which appear to be hippuritid and radiolitid forms. He states that the largest and best preserved fragment appears to be a hippuritid rudist which would indicate a Turonian-Maestrichtian age. Perkins considers this rock to be representative of a near-reef (peri-reef) environment.

E. G. Purdy (Esso Exploration, Inc.) examined a sample of the peri-reef limestone from the top of Core 15. He described the rock as a calcite-cemented, skeletal grainstone that has been subjected to subaerial diagenesis. His report is quoted in full as follows:

1. The limestone is a calcite cemented skeletal grainstone in which mollusc fragments predominate among the *identifiable* constituents. Judging from the hand specimen, many of these are probably gastropod remains. Fragments of corals, calcareous algae, and echinoderms are also in evidence. There appears to be *one* good example of *Solenopora* in the thin section and another more problematic example of a Codiacean fragment. I also noted a possible rudist fragment.
2. Micrite envelopes serve to identify the periphery of many of the constituents that are so severely recrystallized (*sensu lateralis*) to calcite that their depositional identity is in doubt. Similar "dust lines" mark the walls of completely recrystallized coral fragments. Many of the smaller constituents are completely "micritized" and once again identification is doubtful. There is some difference of opinion in the literature on the origin of micrite envelopes and micritization, but there does seem to be ample justification for regarding both as a submarine diagenetic phenomenon.
3. Skeletal architecture is preserved best in the mollusc fragments and least in the coral and algal fragments. I hasten to add here that I have not x-rayed the sample, but I have little doubt that *all* the constituent grains have recrystallized to calcite, and that all the observed differences in preservation of skeletal architecture are best attributed to original differences in crystal fabric and mineralogy.
4. In addition to recrystallization attributes, pore space precipitation and leaching effects are also in evidence. The last is made obvious by the molds of corals and gastropods, among other things, that are apparent in the hand specimen. Dissolution effects are also manifested in thin section, and not infrequently one can observe calcite crystals growing into the voids left by solution. The intimate textural relationship between intergranular calcite cement on the one hand and calcite replaced constituents on the other suggests that both events occurred at essentially the same time. In contrast, leaching, at least in some instances, seems to have been a post-replacement phenomenon. This, of course, does not rule out the possibility that leaching, replacement, and pore space precipitation all occurred in the same diagenetic environment: the subaerial one. Indeed, regarding this last point, it is my distinct impression that the diagenetic fabric of this particular rock is no different than that of many of the Pleistocene limestones that I have seen in the Caribbean area. This being the case, I would favor a tentative conclusion that we are dealing here with a shallow water limestone that has been subjected to subaerial diagenesis.

It is proposed that the peri-reef limestones encountered at Site 98 represent bioclastic turbidites. The limestone fragments in the core recovery are believed to be parts of large pieces of detrital peri-reef limestone which slumped off the rim of a nearby carbonate platform to be deposited by turbidity currents in a mid-channel, deep-water environment.

Immediately underlying the peri-reef limestone at 3057 meters in Core 13 are about 15 centimeters of soft, yellowish-white, foraminiferal-nannoplankton ooze. Recrystallized nanno-calcite and fragments of pentaliths are abundant. A few dolomite rhombs were noted. Below the ooze is a 10-centimeter interval containing several fragments of chalky calcarenite.

Section 2 of Core 13 recovered 75 centimeters of alternating beds of chalky calcarenite, micritic chalk, and soft, yellowish white, foraminiferal-nannoplankton ooze. Recrystallized nanno-calcite is common. (See section pages for detailed illustrations.)

Campanian (Core 14)

Core 14 recovered 1 meter of firm, yellowish-white, micritic chalk, with at least three well-defined zones of graded bedding. The laminated layers of these graded calcarenites show distinct flow structures, and consist of foraminifera and sand-sized calcite grains.

Burrow-like structures occur at the base of two of the graded beds. These and other graded beds are interpreted as bioclastic turbidites, most of which are about 4 centimeters thick; intervening pelagic chalk beds average 12 centimeters in thickness. See section page for an illustration of the graded beds. Near the middle of this core, at 91 centimeters, is a coarse, graded layer of sand-sized calcite fragments in a matrix of recrystallized nanno-calcite. Another slightly clayey nannoplankton matrix occurs in the lower part of the core, at 138 centimeters. A smear slide from the micritic chalk, at 115 centimeters, contains foraminifera and recrystallized nanno-calcite. The core catcher sample had a similar composition; it also includes some fragments of large, calcareous fossils.

Early Campanian - Late Santonian (Core 15)

Core 15 recovered about 15 centimeters of the same type of shallow-water, peri-reef limestone as found in Core 13. Refer to Core 13 discussion for descriptions by B. F. Perkins and E. G. Purdy.

Immediately underlying the peri-reef limestone, at about 3515 meters, are about 15 centimeters of firm, yellowish-white, nannoplankton chalk. Recrystallized nanno-calcite and fragments of pentaliths are abundant. Clay minerals, calcite clasts, and dolomite rhombs were noted as very rare.

The remaining 75 centimeters of Core 15 is calcarenitic nannoplankton chalk. It is moderately hard and yellowish white. The calcarenitic character is attributed to the abundance of calcite shell debris, which are dispersed through the chalk in highly variable concentrations. The clasts have a mean size of 2 millimeters and range up to 6 millimeters in size. Despite the absence of grading, this zone is considered to be a bioclastic turbidite.

Mineralogy

Aragonite needles are common in the Holocene and Pleistocene sediments and rare in those of Pliocene and Miocene age. None were seen in the Oligocene or older sediments. Calcite spicules occur abundantly in the Holocene. They are common in the Pleistocene as well as in the early Eocene, 75 centimeter chert zone. High-magnesium calcite occurs in sediments no older than Pleistocene. Recrystallized nanno-calcite does not appear in sediments younger than late Eocene. Dolomite rhombs are present, but always rare, in Pleistocene, Pliocene and Miocene sediments. A few rhombs were noted in the late and early Campanian ooze and chalk.

Clay minerals and mica are abundant in Holocene sediments and common in Pleistocene deposits. Clay minerals are generally absent in the remainder of the cored intervals at Site 98 except for minor occurrences in the Miocene and early Eocene. Occasional black specks of pyrite were found in the Pliocene, Miocene and Oligocene. One black module of pyrite was found in the Miocene. Occasional specks of limonite were noted in almost all cored intervals. Two yellow nodules containing limonite and some hematite were found in the early Eocene (Core 11). In addition, a few glass shards were seen in the early Eocene (Core 8).

Chert was found only in the early Eocene sediments: a 75-centimeter zone at the top of Core 7, and a 10-centimeter interval at the top of Core 10. Each occurrence of chert was accompanied by the virtual absence of siliceous fossils in the adjacent calcareous ooze and nannoplankton chalks. The chert consists of foraminiferal tests which have been replaced by quartz, and nannoplankton which have been replaced by disordered cristobalite.

SUMMARY AND CONCLUSIONS

The distribution of cores was such that portions of all tertiary epochs and at least one late Cretaceous stage were sampled. Five epochal boundaries were cored, including the unconformity between pale-brown late Pleistocene ooze and cream-white early Pliocene ooze at 2785 meters (6 meters below the sea floor). Other boundaries cored include the Pliocene-Miocene at 2798 meters, the Miocene-Oligocene at 2873 meters, the late Eocene-middle Eocene at 2916 meters, and the Eocene-Paleocene at 3019 meters. The bottom of the hole (3136 meters) is believed to be at or very near the base of the Campanian stage. The Maestrichtian is believed to be present in the 31-meter drilled interval above Core 13. The above depths were corrected for a derrick floor elevation of 10 meters and plotted on a cross section which runs from the Andros Island deep well (91.8 kilometers southwest of Site 98) to the shallow borehole on New Providence Island (40.2 kilometers south of Site 98 (Figure 6). The cross-section shows the relationships of three major depositional environments in the Bahama carbonate province.

Deposition at Site 98 has taken place in a deep-water environment more or less continuously – except for the Pleistocene-Pliocene hiatus – since at least early Campanian time. Rates of sedimentation have been plotted for this location (Figure 3). An average rate was calculated for the interval from the top of the middle Eocene to the base of the Campanian. This rate, 0.7 cm/1000 yr., was used to calculate a depth of 3304 meters for the top of the lower Cretaceous. The comparison of the depth of this horizon with its stratigraphic equivalent in the Andros Island well (Figure 6) suggests that pelagic rates of deposition do not apply to sediments laid down at Site 98 prior to late Cretaceous time. If they were applied to the lower

Cretaceous deposits, an apparently abnormal structural condition would result, wherein deep-water beds beneath the Bahama Channels would be structurally higher than the correlative shallow-water bank deposits in the Andros Island well.

A review of the geological history of Site 98 and of the Bahama Platform in general is presented in Chapter 31.

Conclusions

(1) The predominance of comparatively well-preserved calcareous foraminifera and nannoplankton suggests that deposition in the Northeast Providence Channel during Tertiary and late Cretaceous times occurred in a deep-water environment and above the calcium carbonate compensation depth.

(2) The absence of inorganic debris, spores and pollen suggests a lack of terrigenous sediment contribution. Volcanic glass and zeolites found in the Miocene, early Eocene and Paleocene sediments may be related to volcanism in Cuba.

(3) The presence of shallow-water benthonic foraminifera and peri-reef limestone indicate displacement of coarse material into the deep channel during late Cretaceous time. The peri-reef limestone from Site 98 is strikingly similar to the Cretaceous turbidites of the Monte Gargano area of Southern Italy (see chapter by D. Bernoulli, especially Plates 12, 13 and 14).

(4) Most lower Tertiary and upper Cretaceous foraminiferal-nannoplankton ooze has been recrystallized.

(5) Sediments from Site 98 and data from wells drilled on Andros and New Providence Islands suggest that the Northeast Providence Channel has been built by the upward growth of reef walls on a subsiding Bahama platform and that it has been the site of deep-water deposition of pelagic carbonate oozes since at least late Cretaceous time.

(6) Seismically, the most important sediments at Site 98 are the hard zeolitic chalks of the late Paleocene (Core 12) and the limestones and chalks of the late Cretaceous. The depths of major seismic reflectors in Northeast Providence Channel correspond quite well with these horizons. The sequence of strong reflectors beginning at about 0.25 seconds probably corresponds to the top of a sequence of hard chalk beds which extends from the late Paleocene (Core 12) down into the late Cretaceous, where the chalk beds are interbedded with very hard limestones of Campanian age (Cores 13 and 15). The Site Summary Chart (Figure 3) tends to corroborate this interpretation by showing marked decreases in both the drilling rate curve and the penetrometer plot for Cores 12 through 15 as compared to the generally softer and more easily drilled sediments of Eocene and younger ages.

A lesser reflection observed on the record made while on site appears at 0.17 to 0.18 seconds. This may correspond to the reflector, slightly above the prominent one, which is visible in the underway record south of the site but which faded and was barely visible when the ship crossed the site. If this is, indeed, a legitimate stratigraphic reflector, and not a side echo, it might correspond to the Eocene chert zone found in Core 7 at 170 meters. However, this type of record (hove to) can be misleading, particularly over sloping terrain where topographic side echoes cannot be distinguished from those of subbottom interfaces. In general, we did not try to use the "hove to" records for correlation. The correlation of the reflector at 0.25 second with the top of the hard Paleocene chalks gives an interval velocity of 1.92 km/sec for the upper 250 meters of sediment, a value consistent with others similarly determined from carbonate-ooze sections at Sites 5, 99 and 100.

REFERENCES

Hess, H. H., 1933. Interpretation of geological and geophysical observations in Navy-Princeton Gravity Expedition to the West Indies in 1932. *Bull. U.S. Hydrographic Office*. 26.

———, 1960. The origin of the Tongue of the Ocean and other great valleys of the Bahama Banks. *Trans. Second Caribbean Geol. Conf., Puerto Rico Univ.*, 1960.

Lynts, G. W., 1970. Conceptual model of the Bahamian Platform for the last 135 million years. *Nature*. **225**, 1226.

Newell, N. D., 1955. Bahamian platforms. *Geol. Soc. Am. Spec. Paper 62*. 303.

Talwani, M., Worzel, J. L. and Ewing, M., 1960. Gravity anomalies and structure of the Bahamas. *Trans. Second CaribbeanGeol. Conf.* 156.

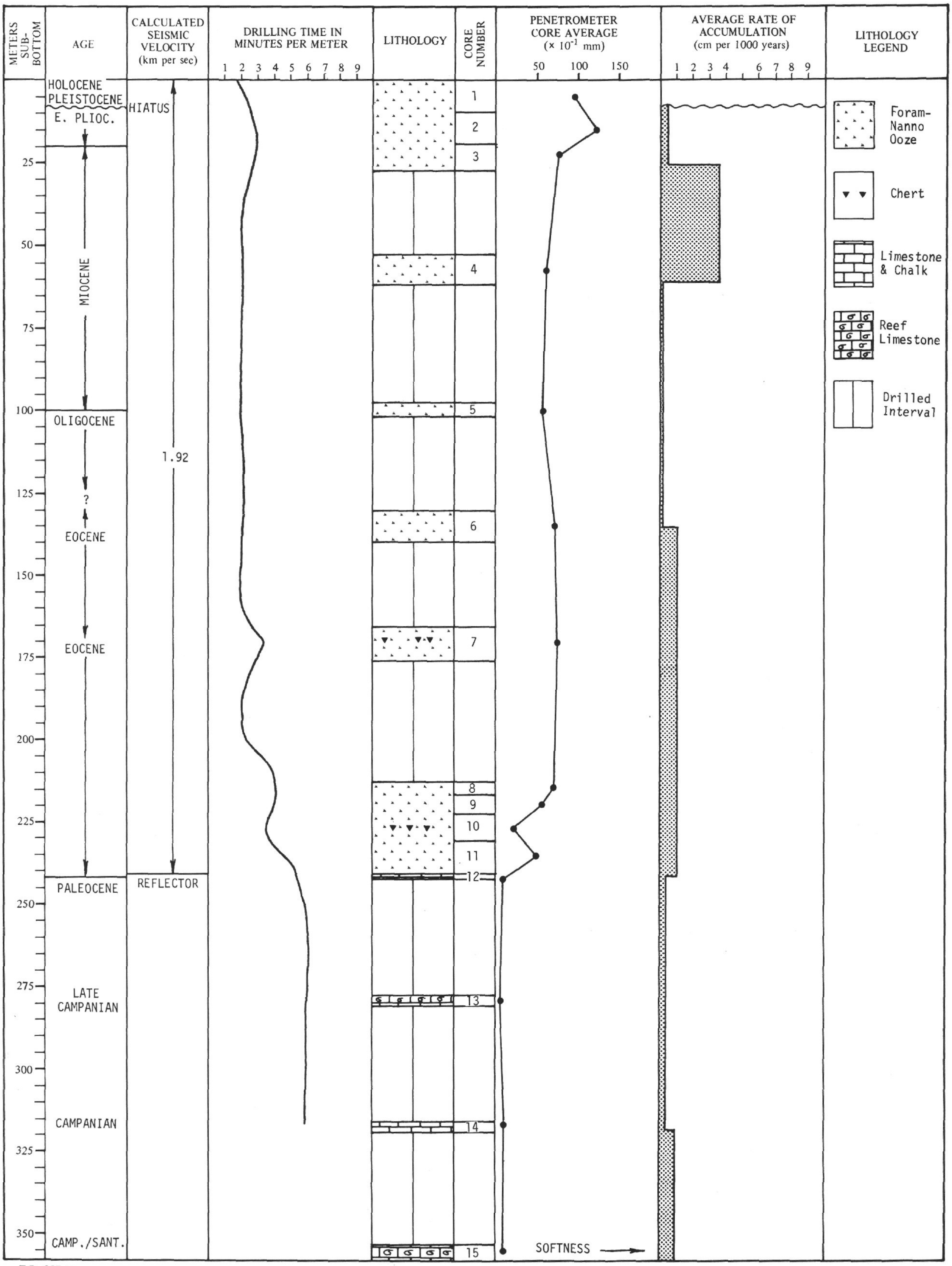


Figure 3. *Site 98 summary chart*

Hole 98

Latitude: 25°22.95′N
Longitude: 77°18.68′W
Water depth: 2769 meters (drill pipe); 2750 meters (PDR)

<table>
<tr><th rowspan="2">Core No.</th><th colspan="4">Interval Cored (meters)[a]</th><th rowspan="2">Lithology</th><th colspan="3">Age</th></tr>
<tr><th>Depth</th><th>Amount</th><th>Recovery</th><th>Subbottom Depth</th><th>Foraminifera</th><th>Nannoplankton</th><th>Dinoflagellates</th></tr>
<tr><td>1</td><td>2779-2788</td><td>9</td><td>9</td><td>9</td><td>Foraminiferal-nannoplankton ooze</td><td colspan="2">← Holocene-Late Pleistocene →
← Early Pliocene →</td><td></td></tr>
<tr><td>2</td><td>2788-2797</td><td>9</td><td>9</td><td>18</td><td>Foraminiferal-nannoplankton ooze</td><td>Early Pliocene</td><td>Late Miocene</td><td></td></tr>
<tr><td>3</td><td>2797-2806</td><td>9</td><td>9</td><td>27</td><td>Foraminiferal-nannoplankton ooze</td><td>Early Pliocene
Late Miocene</td><td>Late Miocene</td><td></td></tr>
<tr><td>(Drilled)</td><td>(2806-2834)</td><td>(28)</td><td></td><td>(55)</td><td></td><td colspan="3"></td></tr>
<tr><td>4</td><td>2834-2843</td><td>9</td><td>9</td><td>64</td><td>Foraminiferal-nannoplankton ooze</td><td colspan="2">← Late Miocene →</td><td></td></tr>
<tr><td>(Drilled)</td><td>(2843-2872)</td><td>(29)</td><td></td><td>(93)</td><td></td><td colspan="3"></td></tr>
<tr><td>5</td><td>2872-2881</td><td>9</td><td>4.7</td><td>102</td><td>Foraminiferal-nannoplankton ooze</td><td colspan="2">Early Miocene
Late Oligocene</td><td></td></tr>
<tr><td>(Drilled)</td><td>(2881-2909)</td><td>(28)</td><td></td><td>(130)</td><td></td><td colspan="3"></td></tr>
<tr><td>6</td><td>2909-2918</td><td>9</td><td>9</td><td>139</td><td>Foraminiferal-nannoplankton ooze</td><td>Late Eocene
Middle Eocene</td><td>Late Middle Eocene</td><td></td></tr>
<tr><td>(Drilled)</td><td>(2918-2946)</td><td>(28)</td><td></td><td>(167)</td><td></td><td colspan="3"></td></tr>
<tr><td>7</td><td>2946-2955</td><td>9</td><td>9</td><td>(176)</td><td>Foraminiferal-nannoplankton ooze</td><td>Late Early Eocene</td><td>Middle Eocene</td><td></td></tr>
</table>

Figure 4. *Core Summary table, Site 98.*

Core No.	Interval Cored (meters)[a]				Lithology	Age		
	Depth	Amount	Recovery	Subbottom (Depth)		Foraminifera	Nannoplankton	Dinoflagellates
(Drilled)	(2955-2986)	(31)		(207)				
8	2986-2995	9	4.5	216	Foraminiferal-nannoplankton ooze	← Early Eocene →		
9	2995-3001	6	2.3	222	Foraminiferal-nannoplankton ooze	← Early Eocene →		
10	3001-3010	9	.85	231	Foraminiferal-nanno-planton ooze and chalk	Early Eocene	Late Paleocene	
11	3010-3019	9	2.2	240	Foraminiferal-nannoplankton ooze	Early Eocene	Late Paleocene	
12	3019-3020	1	1.35	241	Foraminiferal-nanno-plankton ooze and chalk	Early Eocene Late Paleocene	Late Paleocene	
(Drilled)	(3020-3051)	(31)		(272)				
13	3051-3060	9	3	281	Chalk and limestone	← Late Campanian →		
(Drilled)	(3060-3090)	(30)		(311)				
14	3090-3097	7	1	318	Chalk	← Campanian →		
(Drilled)	(3097-3127)	(30)		(348)				
15	3127-3136	9	1.1	357	Chalk and limestone	Early Campanian-Late Santonian	Slightly older	

[a]All intervals are measured by drill pipe from the derrick floor which is 10 meters above water surface.

Figure 4. *Core Summary table, Site 98.* (Cont)

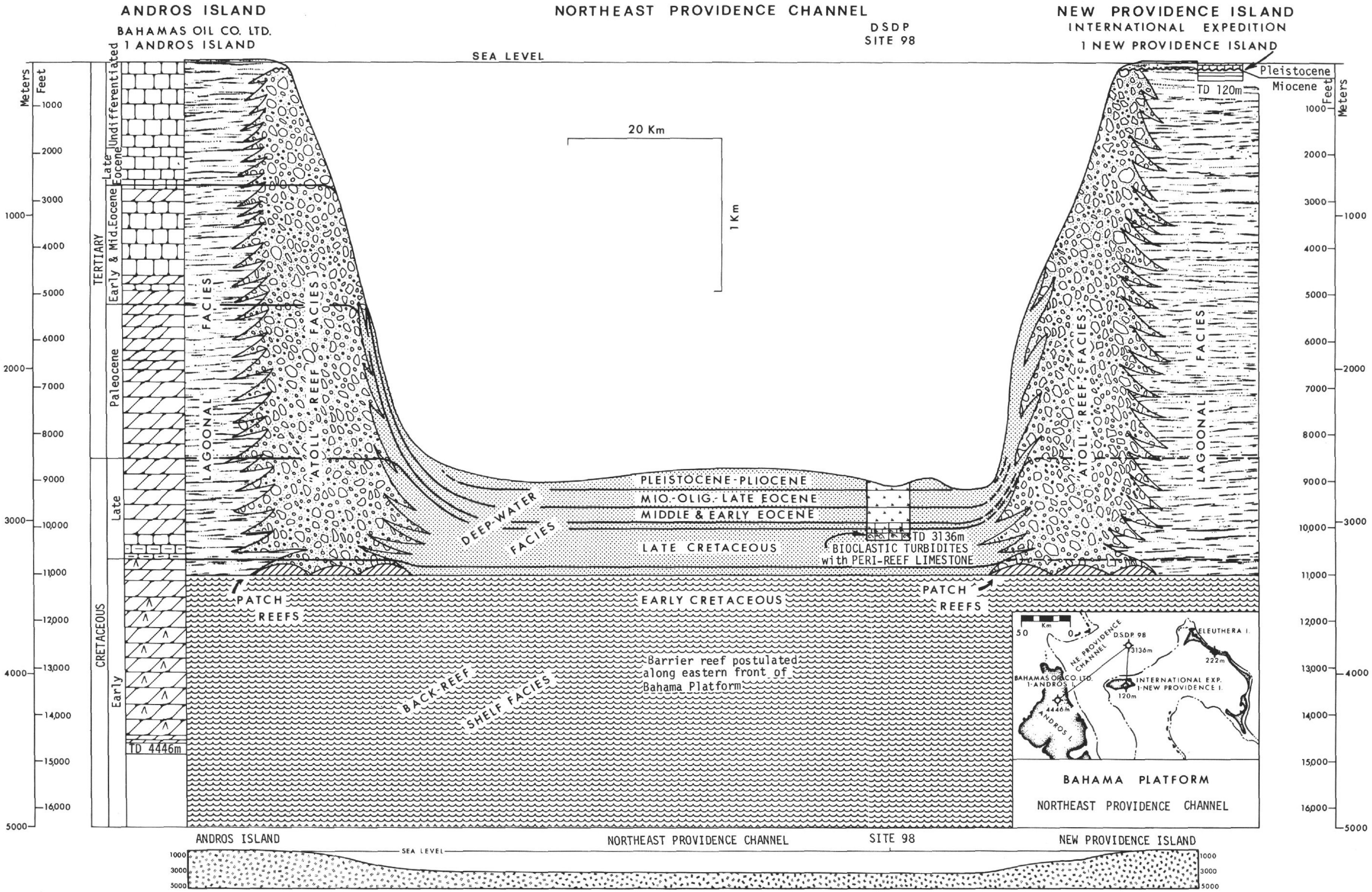
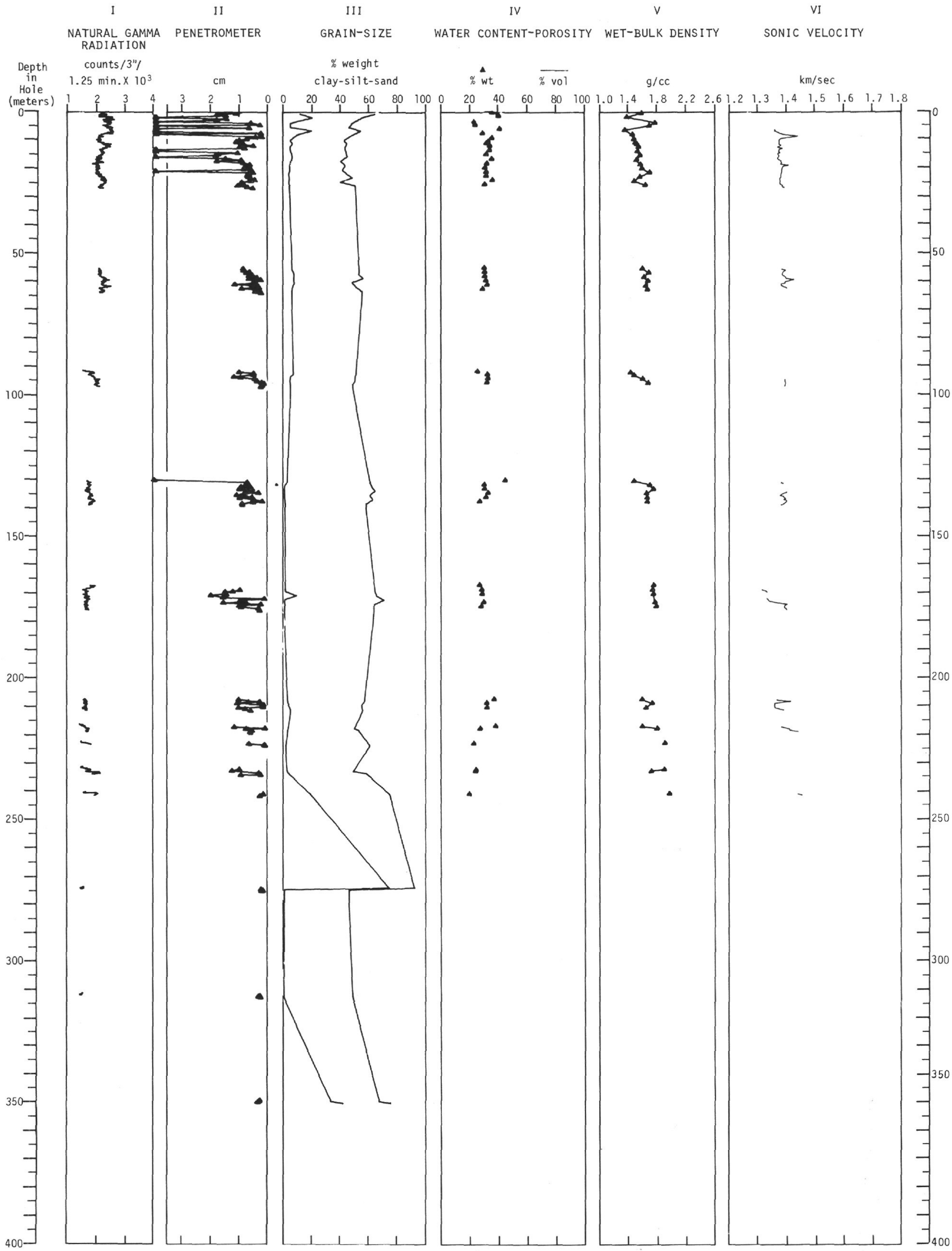


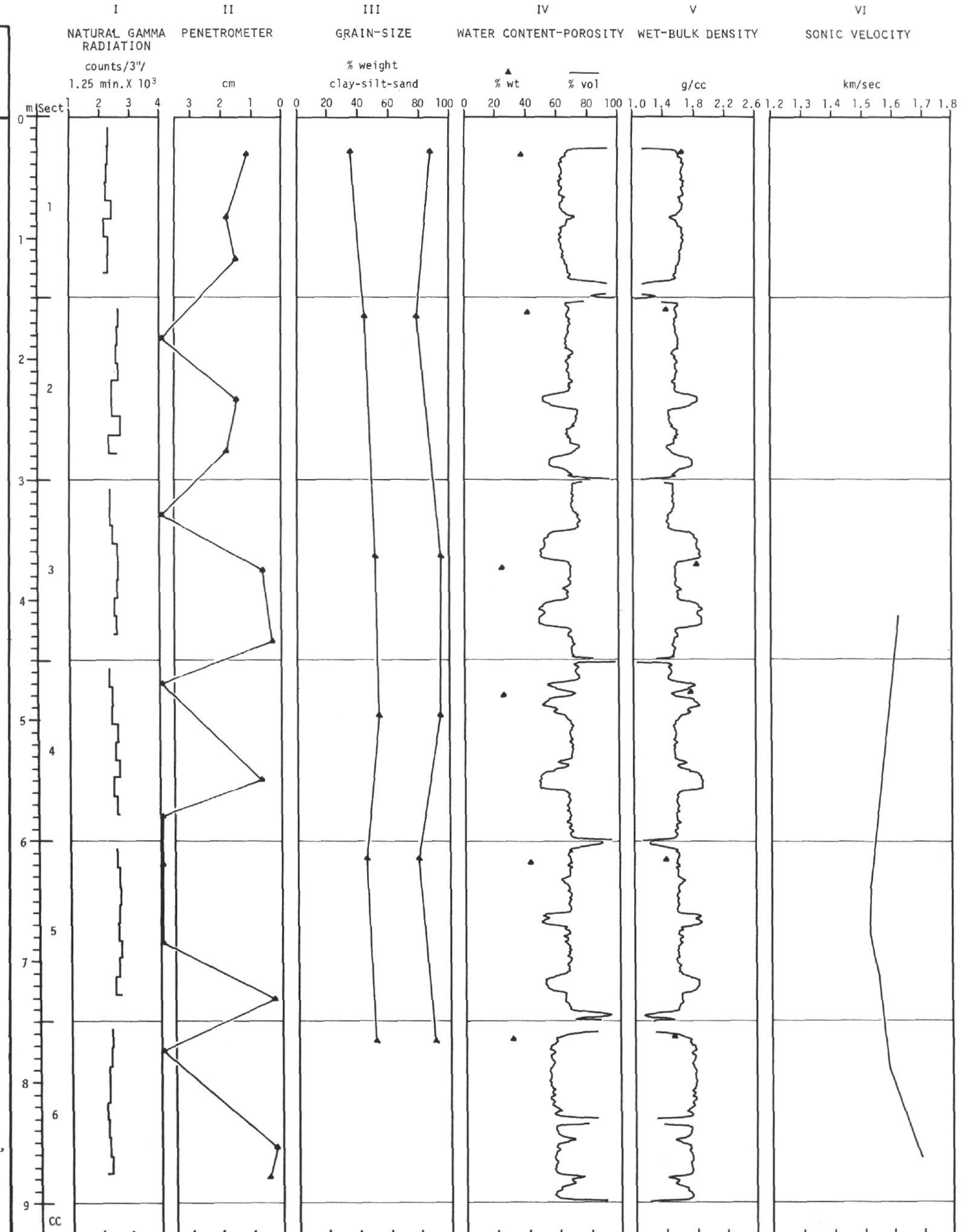
Figure 6. *Cross-section of a portion of the Bahama Platform through Site 98 from Andros Island to New Providence Island showing the relationships of shallow-water bank and shelf facies to the deep-water channel facies. Time lines are based on ages from the Andros Island well and the Site 98 core hole.*



Summary of Physical Properties, Hole 98

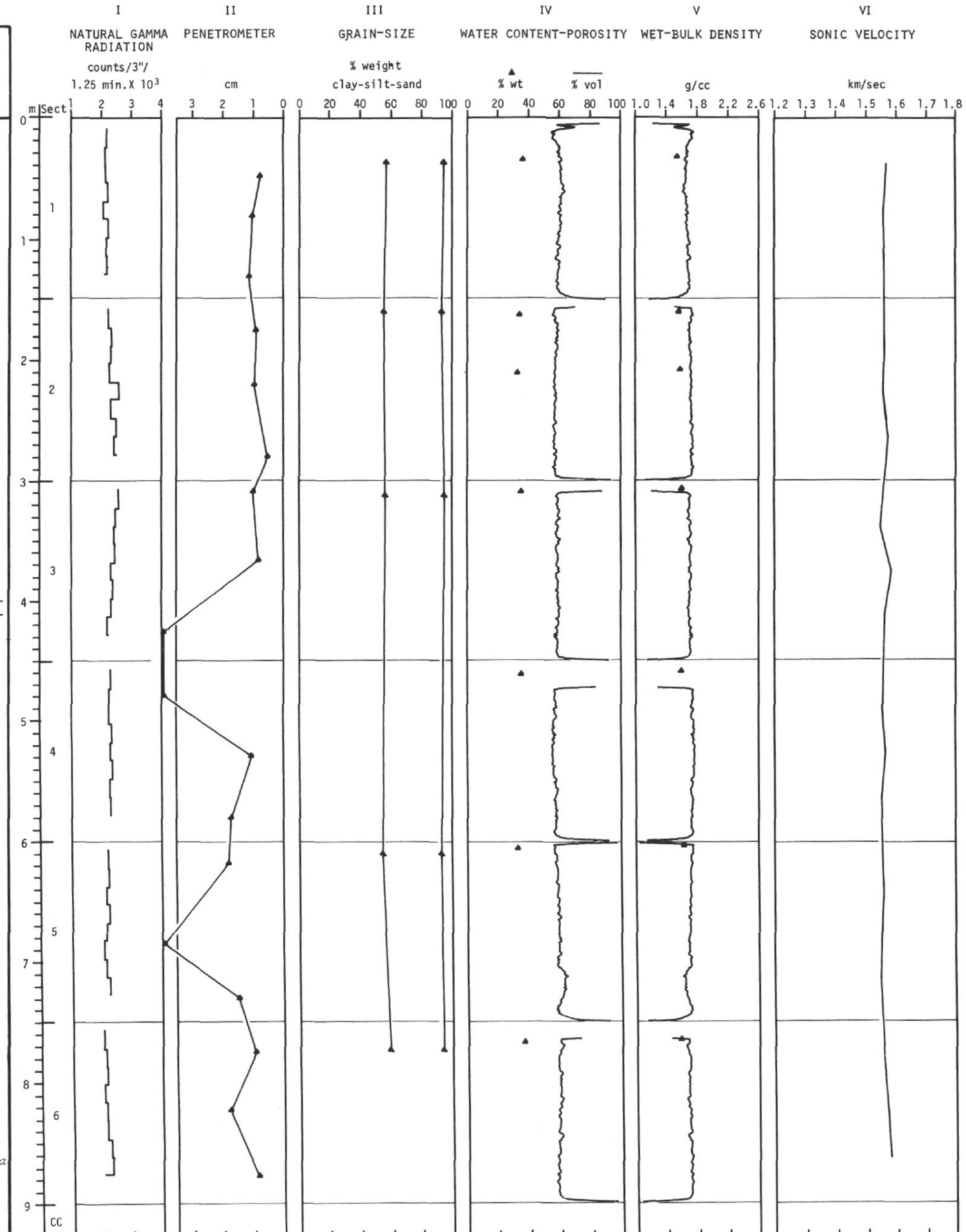
Hole 98, Core 1 (0 m to 9 m)

AGE	ZONE	DEPTH (m)	SECTION NO.	LITHOLOGY	SAMPLE INTERVAL	LITHOLOGY	DIAGNOSTIC FOSSILS
HOLOCENE	*Globigerina calida/Sphaeroidinella excavata* N.23	0–1	1		PF, SS, PF, SS, PF, SS	Foram-nannoplankton ooze, very soft, various shades of pale yellowish brown (10YR7/2, 10Y7/2, 10YR5/4), abundant sand size terrigenous detritus and calcareous debris, faint layering, aragonite needles common, clay minerals common to abundant, dolomite rhombs rare, pteropods common.	PLANKTONIC FORAMINIFERS: *Globigerina calida*, *Globigerina rubescens* (pink), *Globigerinoides ruber* f. *rosea*, *Globorotalia cultrata*, *Globorotalia truncatulinoides*
LATE PLEISTOCENE		2–4	2, 3		PF, SS, SS, PF, SS, SS, SS, SS	Bands and spots of indurated greenish gray (5G8/1) in Sections 3 and 4.	PLANKTONIC FORAMINIFERS: *Turborotalia inflata*, *Globorotalia truncatulinoides*, *Globigerinoides ruber* f. *rosea*
		5–8	4, 5, 6		SS, PF, SS, SS, PF, SS, SS, SS, PF, PF	Soft and plastic, cream white (5Y8/1), few indurated zones in Section 6.	*CORE CATCHER* CALCAREOUS NANNOPLANKTON: *Reticulofenestra pseudoumbilica*, *Sphenolithus abies*, *Discoaster asymmetricus*, *D. surculus*, *D. pentaradiatus* *Ceratolithus tricorniculatus*, *C. rugosus*, *Cyclococcolithina macintyrei* PLANKTONIC FORAMINIFERS: *Globorotalia margaritae*, *Globigerina nepenthes*, *Globoquadrina altispira*, *Globorotalia cibaoensis*, *Globigerinoides extremus*
EARLY PLIOCENE		9	CC		CN, SS		



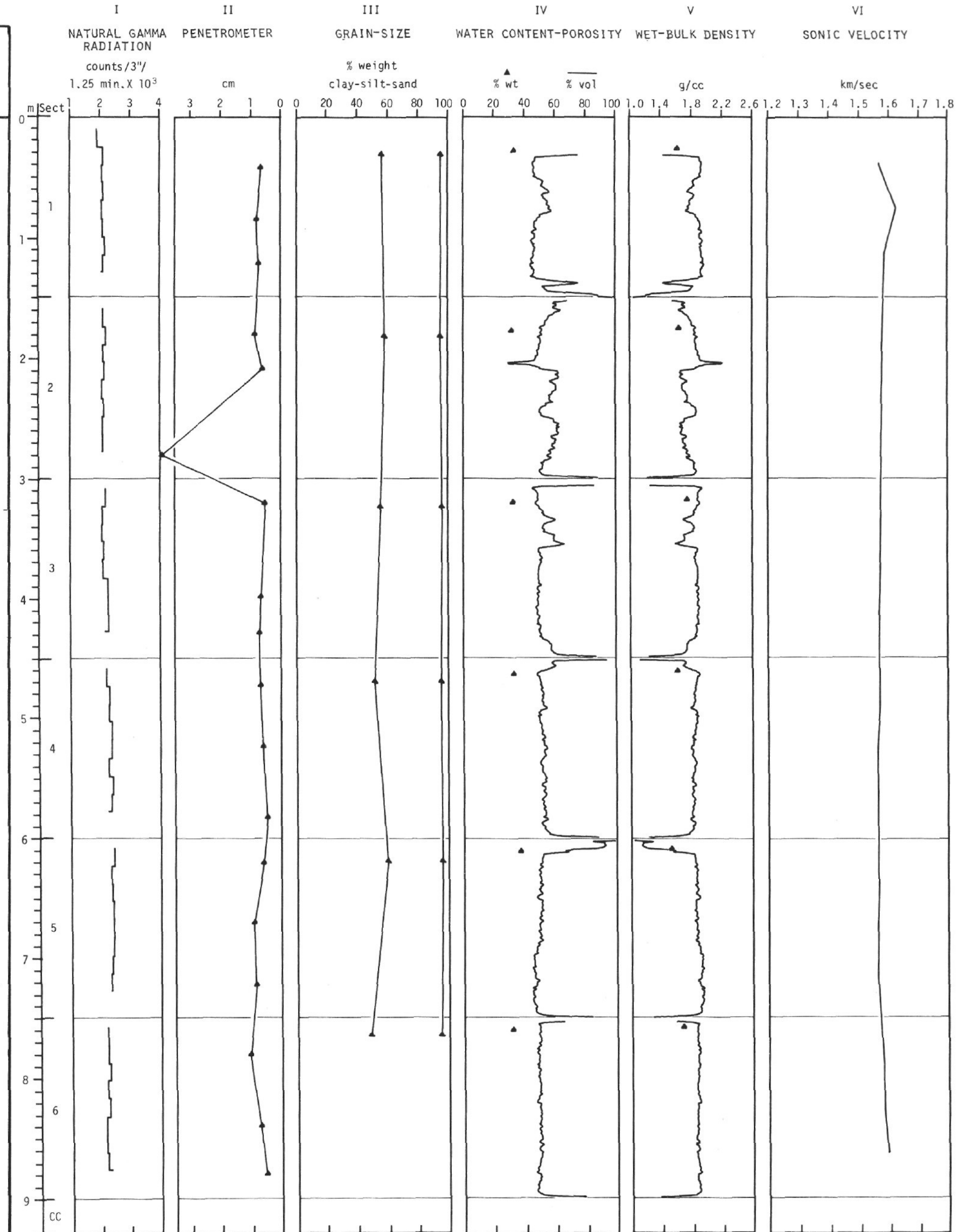
Hole 98, Core 2 (9 m to 18 m)

AGE	ZONE	DEPTH (m)	SECTION NO.	LITHOLOGY	SAMPLE INTERVAL	LITHOLOGY	DIAGNOSTIC FOSSILS
LATE MIOCENE (calcareous nannoplankton) or EARLY PLIOCENE (planktonic foraminifera)	*Sphaeroidinella dehiscens/Globoquadrina altispira* N.19; *Ceratolithus tricorniculatus*	1–3	1, 2		PF, PF, SS; PF, CN, SS	Foram-nannoplankton ooze, soft, cream white (5Y8/1), specks of orange (5YR5/6) iron oxide (?) and black (N3) iron sulfide, aragonite needles rare to absent, disturbed core. Light yellow (10YR8/2) with orange specks. Light gray (N7) with mottle of greenish gray (5G6/1) and olive gray (5Y6/1) thru section 6.	
		3–6	3, 4		PF, SS, CN, SS, PF; SS, SS		CALCAREOUS NANNOPLANKTON: *Ceratolithus tricorniculatus, Reticulofenestra pseudoumbilica, Discoaster challengeri, D. variabilis, D. pentaradiatus, Scyphosphaera campanula* PLANKTONIC FORAMINIFERS: *Globoquadrina altispira, Globigerina nepenthes, Globorotalia cibaoensis, G. margaritae, Globigerinoides extremus, Sphaeroidinellopsis seminulina*
		6–9	5		SS, PF, SS		CORE CATCHER
	Globorotalia tumida/Sphaeroidinellopsis	8–9	6, CC		SS, SS, PF, CN, SS		CALCAREOUS NANNOPLANKTON: *Ceratolithus tricorniculatus, Reticulofenestra pseudoumbilicata, Discoaster brouweri, D. surculus, D. quinqueramus, Scyphosphaera amphora, S. campanula* PLANKTONIC FORAMINIFERS: *Globigerinoides mitra, Globorotalia plesiotumia, Globoquadrina altispira, Globigerina nepenthes*



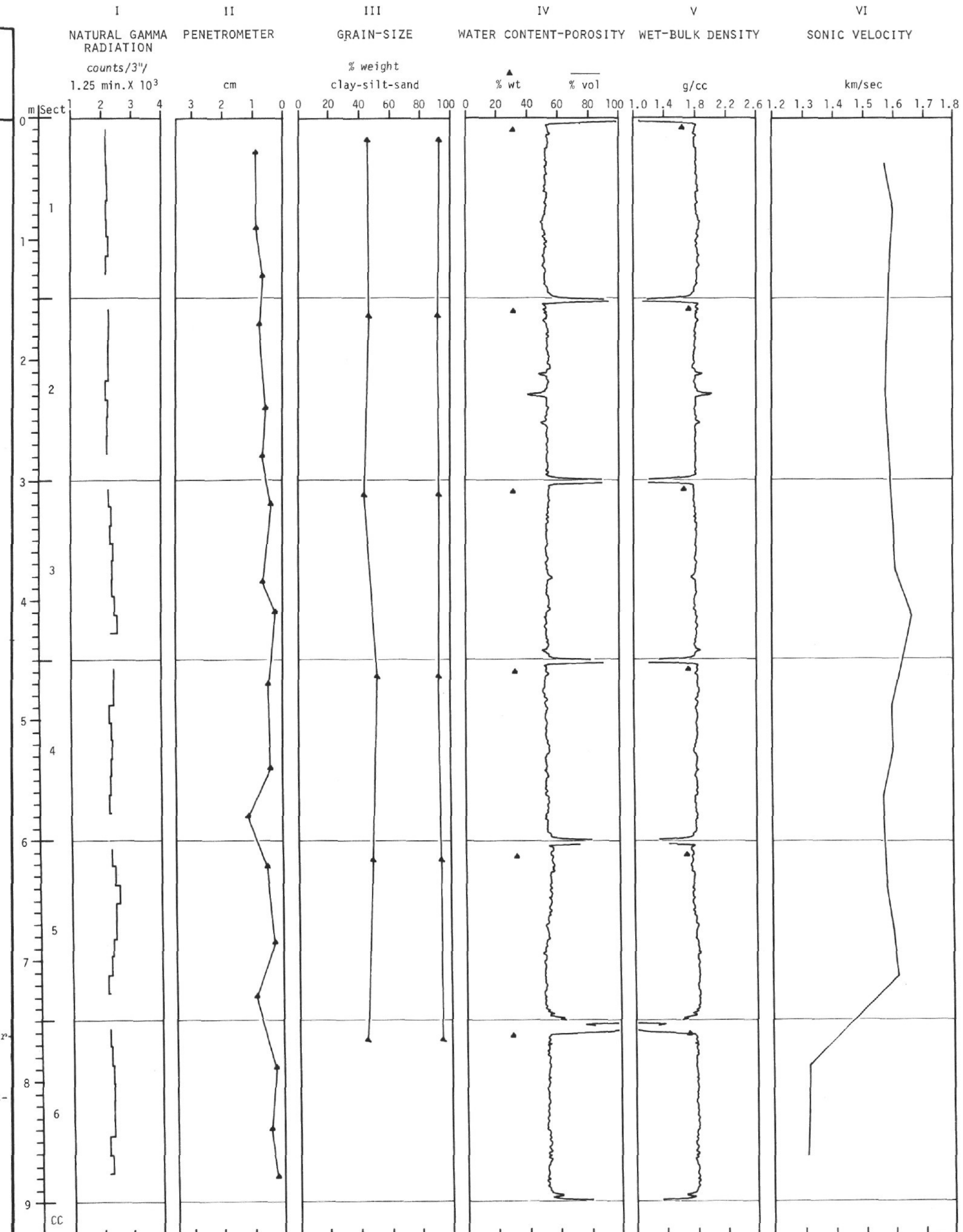
Hole 98, Core 3 (18 m to 27 m)

AGE	ZONE	DEPTH (m)	SECTION NO.	LITHOLOGY	SAMPLE INTERVAL	LITHOLOGY	DIAGNOSTIC FOSSILS
LATE MIOCENE	*Globorotalia tumida/Sphaeroidinellopsis paenedehiscens* N.18	1	1		SS SS	<u>Foram-nannoplankton ooze</u>, soft, gray (N7), inclusions of cream white (5Y8/1) ooze, specks of black (N1, N3) iron sulfide, aragonite needles rare, very soft zones are highly disturbed.	CALCAREOUS NANNOPLANKTON: *Discoaster quinqueramus, D. challengeri, D. variabilis, D. surculus, Ceratolithus tricorniculatus, Reticulofenestra pseudoumbilica* PLANKTONIC FORAMINIFERS: *Globigerinoides mitra, Globorotalia plesiotumia, Globoquadrina altispira, Globigerina nepenthes*
		2	2		SS CN PF SS		
	Globorotalia plesiotumida N.17 / *Discoaster quinqueramus*	3 4	3		PF SS SS	Greenish gray (5G6/1) mottle.	
		5	4		SS SS	Greenish gray (5G6/1) with olive gray (5Y6/1) mottle in Sections 4 thru 6.	
		6 7	5		SS SS	Trace of glass shards.	*CORE CATCHER* CALCAREOUS NANNOPLANKTON: *Discoaster variabilis, D. quinqueramus, D. nephados, Scyphosphaera campanula, S. pulcherrima, Sphenolithus abies* PLANKTONIC FORAMINIFERS: *Globorotalia plesiotumida, G. merotumida, Turborotalia acostaensis, Globigerinoides mitra*
		8	6		SS SS PF		
			CC		CN SS		



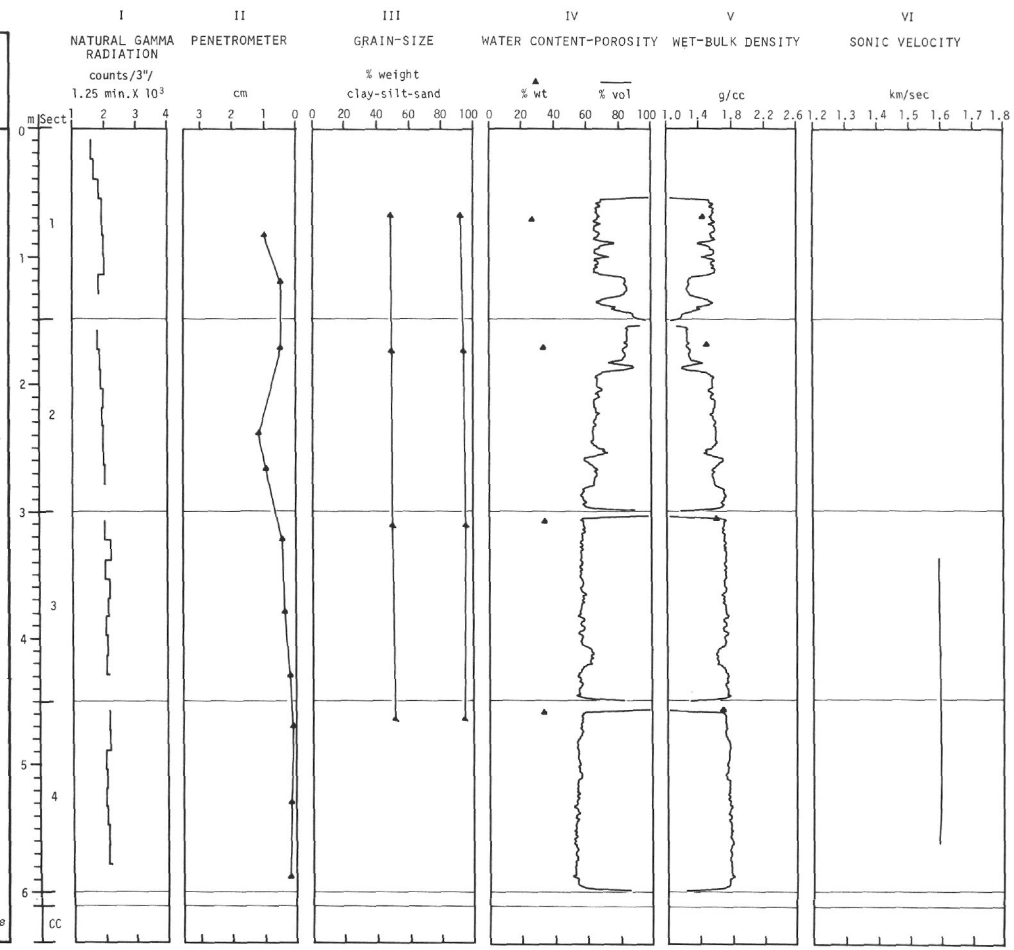
Hole 98, Core 4 (55 m to 64 m)

AGE	ZONE	DEPTH (m)	SECTION NO.	LITHOLOGY	SAMPLE INTERVAL	LITHOLOGY	DIAGNOSTIC FOSSILS
LATE MIOCENE	N.17 *Globorotalia plesiotumida* *Discoaster variabilis*	0–1	1		SS	Foram-nannoplankton ooze, soft, light greenish gray (5G8/1), black (N1) specks of iron sulfide, aragonite needles rare, slightly disturbed core.	
		2	2		SS, SS, CN, SS	Black (N2) pyrite nodule, 1.8 cm x 0.7 cm.	CALCAREOUS NANNOPLANKTON: *Discoaster variabilis, D. quinqueramus, Sphenolithus abies, Reticulofenestra pseudoumbilica, Crassapontosphaera jonesi, Scyphosphaera campanula, S. pulcherrima, Cyclococcolithina macintyrei*
		3–4	3		SS, SS		
		5	4		SS, SS	Band of firm, greenish gray (5G6/1), glauconitic ooze.	
		6–7	5		PF, SS, PF, SS	Intense olive gray (5Y6/1) mottle.	
		8	6		PF, PF, PF, SS	Olive gray (5Y6/1) and pale green (5G7/2) mottle.	CORE CATCHER CALCAREOUS NANNOPLANKTON: *Discoaster variabilis, D. quinqueramus, D. nephados, Scyphosphaera campanula, S. pulcherrima, Sphenolithus abies* PLANKTONIC FORAMINIFERS: *Globorotalia merotumida, Turborotalia acostaensis, Globigerinoides extremus, Globigerina nepenthes, Globoquadrina altispira*
		9	CC		CN, SS		

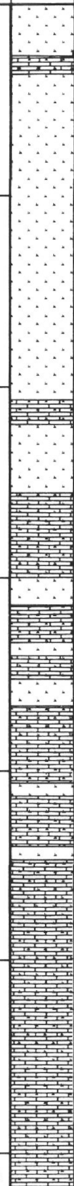


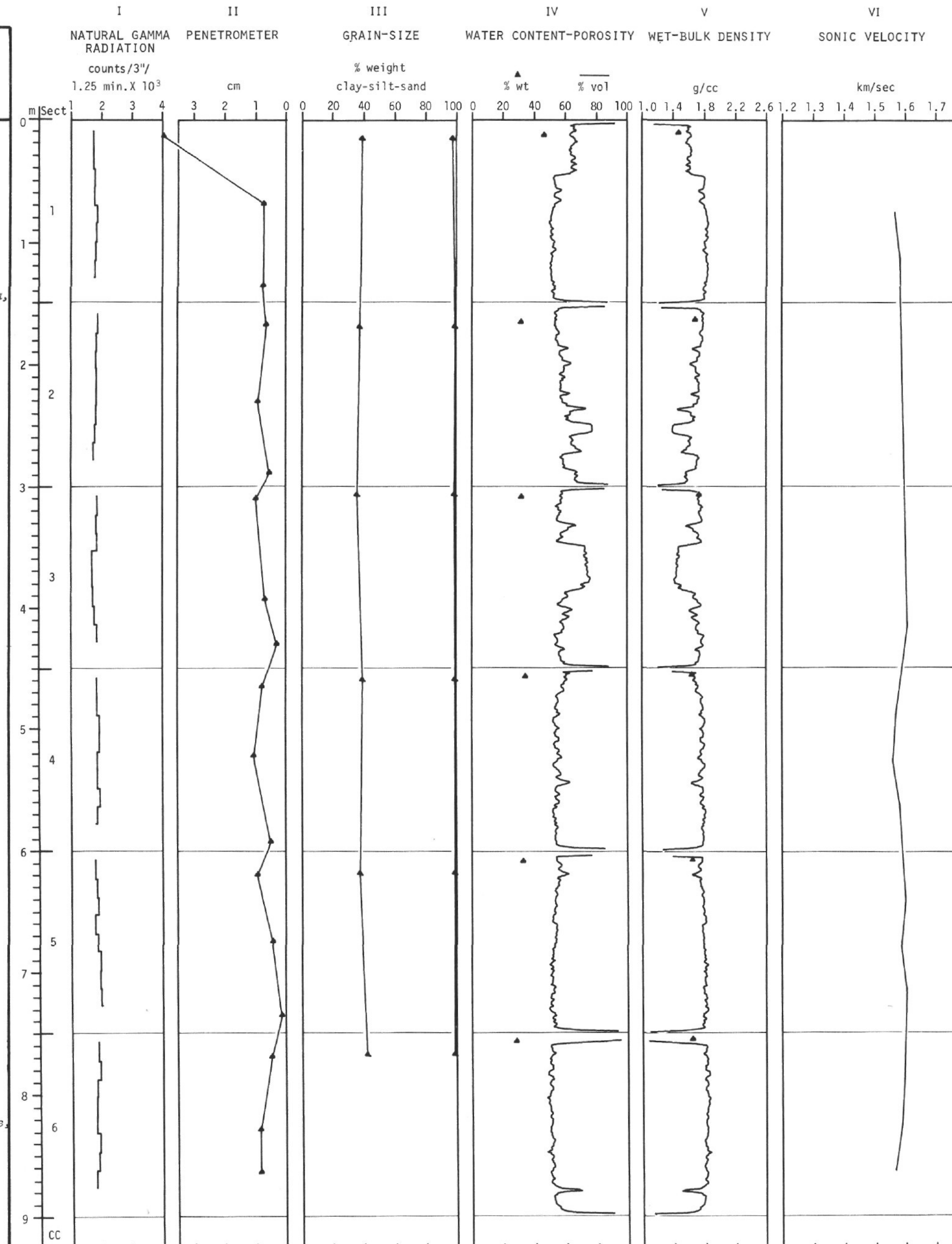
Hole 98, Core 5 (93 m to 102 m)

AGE	ZONE	DEPTH (m)	SECTION NO.	LITHOLOGY	SAMPLE INTERVAL	LITHOLOGY	DIAGNOSTIC FOSSILS
EARLY MIOCENE	*Globigerinoides primordius/ Turborotalia kugleri* N.4	0–1	1		SS, PF, SS, PF, PF	Foram-nannoplankton ooze, soft to very soft, light greenish gray (5G8/1) with slight mottle of light olive gray (5Y6/1), black (N2) specks of iron sulfide, aragonite needles rare, sponge spicules abundant, radiolarians rare.	PLANKTONIC FORAMINIFERS: *Turborotalia siakensis, Globigerinoides primordius, Turborotalia kugleri, T. pseudokugleri*
LATE OLIGOCENE	*Globigerina angulisuturalis* N.3 *Sphenolithus ciperoensis*	2–3	2		PF, SS, CN, PF, SS		CALCAREOUS NANNOPLANKTON: *Cyclococcolithina neogammation, Sphenolithus ciperoensis, S. moriformis, Helicopontosphaera truncata, H. parallela, H. intermedia, Coronocyclus nitescens, Discoaster trinidadensis* PLANKTONIC FORAMINIFERS: *Globigerina angulisuturalis, G. sellii, G. gortanii, G. ciperoensis, G. angustiumbilicata, Turborotalia opima, Globigerina tripartita*
		4	3		PF, SS, SS	Clay minerals common in Section 3.	
		5–6	4		SS, PF, SS, PF	Thin layers of moderately indurated, light gray (N7), foram-nanno ooze in Section 4.	
			CC		CN, PF, SS		*CORE CATCHER* CALCAREOUS NANNOPLANKTON: *Sphenolithus ciperoensis, S. moriformis, Cyclococcolithina neogammation, Helicopontosphaera truncata, H. intermedia, H. parallela, Discoaster trinidadensis*



Hole 98, Core 6 (130 m to 139 m)

AGE	ZONE	DEPTH (m)	SECTION NO.	LITHOLOGY	SAMPLE INTERVAL	LITHOLOGY	DIAGNOSTIC FOSSILS
MIDDLE to LATE EOCENE	*Helicopontosphaera compacta*; *Globigerapsis semiinvoluta*; *Truncorotaloides rohri ?*	1, 2, 3, 4, 5, 6, 7, 8	1, 2, 3, 4, 5, 6, CC		CN, SS, PF, PF, PF, SS, SS, PF, PF, PF, PF, SS, PF, SS, PF, PF, SS, PF, SS, SS, PF, SS, PF, PF, PF, SS, CN, PF, SS	Nannoplankton ooze, soft and plastic, grading into firm nanno-chalk, light greenish white (5G9/1), recrystallized nanno-calcite abundant in indurated zones, clay minerals common (Section 1), sponge spicules common forams rare. This core contains youngest occurrence of recrystallized nanno-calcite in Hole 98.	CALCAREOUS NANNOPLANKTON: *Helicopontosphaera compacta, Discoaster barbadiensis, D. saipensis, Coccolithus bisectus, Cyclococcolithina lusitanica, Reticulofenestra umbilicata, Pemma papillatum* PLANKTONIC FORAMINIFERS: *Hantkenina primitiva, H. longispina, Globigerapsis semiinvoluta, Globigerinatheka barri* PLANKTONIC FORAMINIFERS: *Hantkenina alabamensis, H. longispina, Globorotalia cocoaensis, Globigerapsis semiinvoluta* PLANKTONIC FORAMINIFERS: *Globorotalia cocoaensis, G. centralis, Globigerapsis semiinvoluta, Globigerina corpulenta* PLANKTONIC FORAMINIFERS: *Globorotalia cocoaensis, G. centralis Globigerapsis semiinvoluta* PLANKTONIC FORAMINIFERS: *Globorotalia cocoaensis, Globigerapsis semiinvoluta, Globigerina corpulenta, G. eocaena* PLANKTONIC FORAMINIFERS: *Globorotalia cocoaensis, G. centralis, Globigerapsis semiinvoluta* *CORE CATCHER* CALCAREOUS NANNOPLANKTON: *Discoaster barbadiensis, D. saipanensis, Cyclococcolithina lusitanica, Coccolithus eopelagicus, Sphenolithus radians.* PLANKTONIC FORAMINIFERS: *Truncorotaloides rohri, Hantkenina alabamensis, Globorotalia cocoaensis.*



Hole 98, Core 7 (167 m to 176 m)

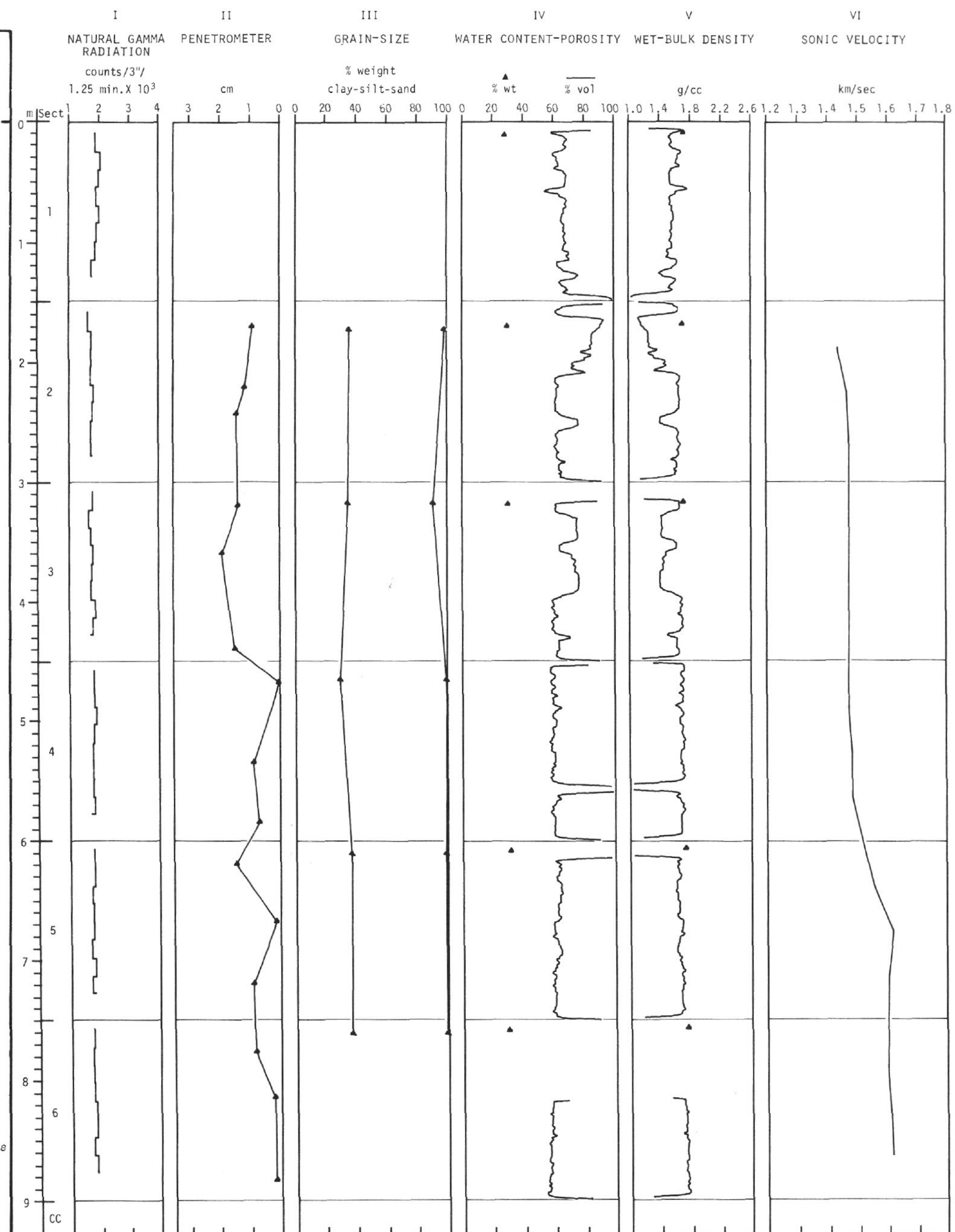
AGE: EARLY to MIDDLE EOCENE

ZONE: *Chiphragmalithus alatus* / *Globorotalia pentacamerata*; *Sphenolithus radians*

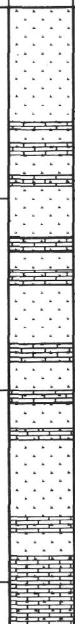
DEPTH (m) | SECTION NO. | LITHOLOGY | SAMPLE INTERVAL

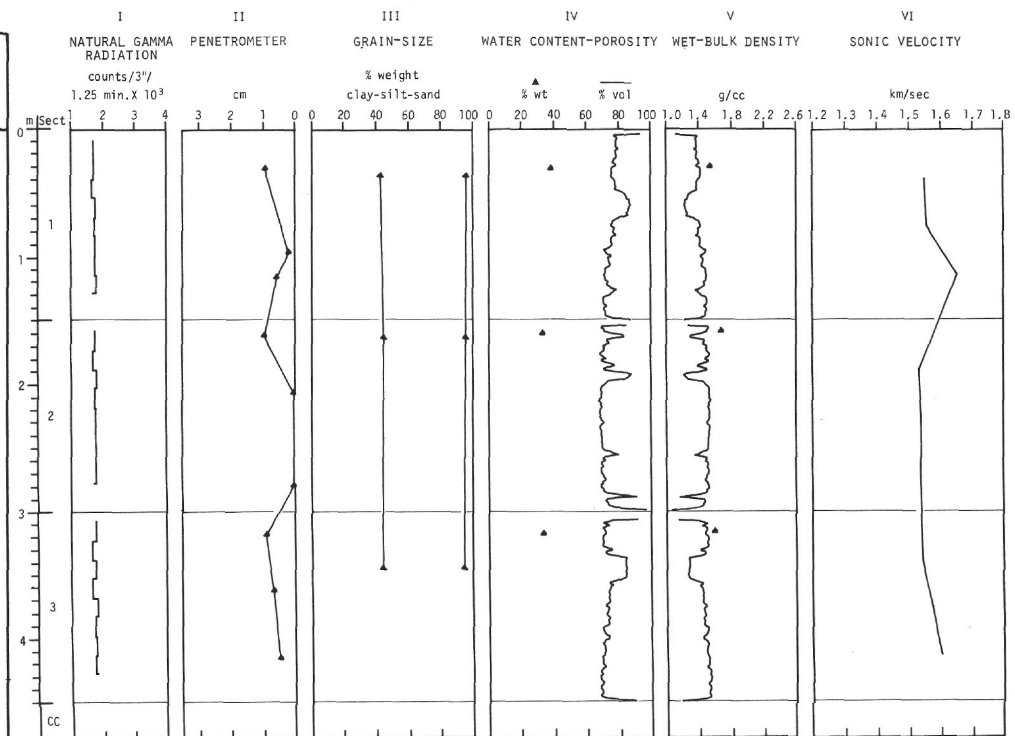
Sections 1–6, CC. Sample intervals: CN, SS, SS, PF, SS, SS, PF, PF, SS, SS, SS, PF, PF, CN, SS, PF, SS, SS, PF, PF, SS, PF, SS, PF, PF, SS, CN, PF, SS

LITHOLOGY	DIAGNOSTIC FOSSILS
Foram-nannoplankton ooze, very soft, plastic, white (N9), light tan chert in contact with very hard white chalk at 30 cm. and 105 cm in section 1. Recrystallized nanno-calcite abundant throughout core.	CALCAREOUS NANNOPLANKTON: *Chiphragmolithus alatus, Reticulofenestra umbilica, Chiasmolithus gradis, Discoaster barbadiensis, D. lodoensis, Sphenolithus radians*
See section summary.	PLANKTONIC FORAMINIFERS: *Globorotalia aragonensis, G. pentacamerata, G. bullbrooki, Truncorotaloides topilensis, Globigerina frontosa*
Firm with several highly fluid zones in Sections 2 and 3.	PLANKTONIC FORAMINIFERS: *Globorotalia aragonensis, G. pentacamerata, Globigerina frontosa*
	PLANKTONIC FORAMINIFERS: *Globorotalia aragonensis, G. pentacamerata, G. bullbrooki, Globigerina frontosa*
	CALCAREOUS NANNOPLANKTON: *Reticulofenestra umbilica, Chiasmolithus grandis, C. gigas, Triquetrorhabdulus inversus, Discoaster barbadiensis, D. lodoensis, Cyclococcolithina lusitanica*
Soft and plastic with a few indurated zones in Sections 4 and 5.	PLANKTONIC FORAMINIFERS: *Globorotalia aragonensis, G. pentacamerata, Globigerina frontosa, G. soldadoensis angulosa*
Soft, pinkish white (5YR9/1), clay minerals common.	PLANKTONIC FORAMINIFERS: *Globorotalia caucasica, G. aragonensis, G. quetra, Globigerina frontosa, G. senni*
Black (N2) specks of iron sulfide.	CORE CATCHER CALCAREOUS NANNOPLANKTON: *Sphenolithus radians, Chiasmolithus grandis, C. gigas, C. consuetus, Discoaster barbadiensis, Braarudosphaera bigelowi, B. discula*



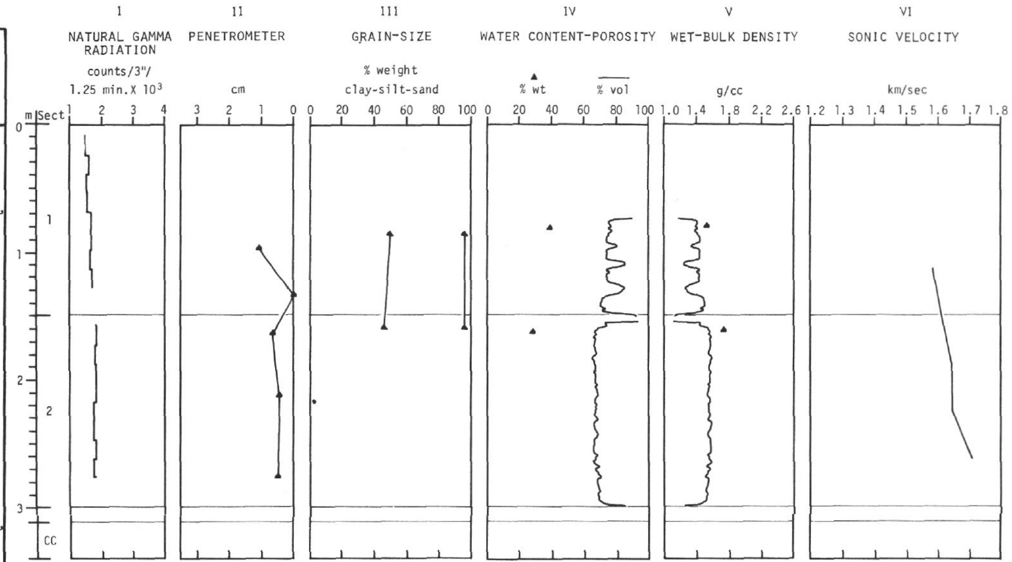
Hole 98, Core 8 (207 m to 216 m)

AGE	ZONE		DEPTH (m)	SECTION NO.	LITHOLOGY	SAMPLE INTERVAL	LITHOLOGY	DIAGNOSTIC FOSSILS
EARLY EOCENE	*Marthasterites contortus*	*Globorotalia formosa formosa*	0–1.5	1		SS, PF, PF, SS, PF	<u>Nannoplankton ooze</u>, soft yellowish white (5Y9/1) zones interbedded with firm indurated yellowish gray (5Y8/1) zones, sponge spicules and radiolarians common.	PLANKTONIC FORAMINIFERS: *Globorotalia formosa formosa, G. aragonensis, G. lensiformis, G. subbotinae*
			1.5–3	2		PF, SS, CN, SS, PF		CALCAREOUS NANNOPLANKTON: *Markalius astroporus, Ellipsolithus macellus, Sphenolithus radians, Coccolithus cavus, Discoaster diastypus, D. gemmeus* PLANKTONIC FORAMINIFERS: *Globorotalia formosa formosa, G. aragonensis, G. lensiformis, G. subbotinae*
			3–4.5	3		SS, SS, PF, PF	Clay minerals common. Indurated zones are brittle in Section 3.	PLANKTONIC FORAMINIFERS: *Globorotalia formosa formosa, G. aragonensis, G. lensiformis, G. subbotinae*
		Globorotalia subbotinae		CC		SS, SS, CN, PF		*CORE CATCHER* CALCAREOUS NANNOPLANKTON: *Sphenolithus radians, Campylosphaera dela, Ellipsolithus macellus, Chiasmolithus bidens, Lophodolithus nascens, Fasciculithus tympaniformis* PLANKTONIC FORAMINIFERS: *Globorotalia subbotinae, G. marginodentata, G. formosa gracilis*



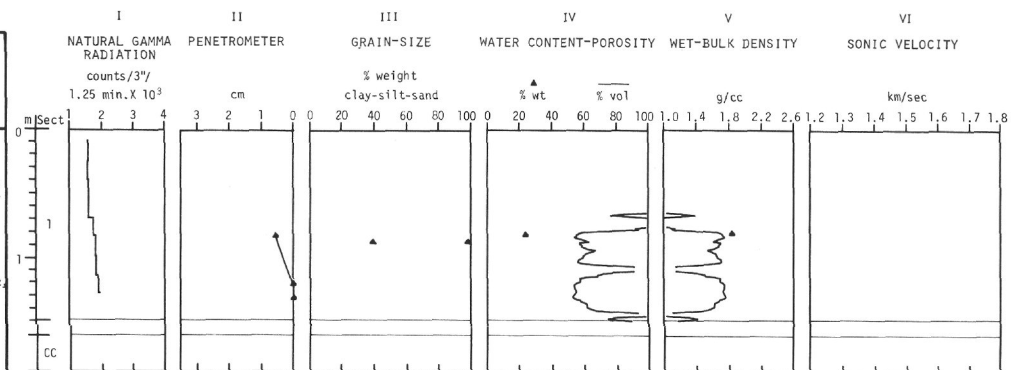
Hole 98, Core 9 (216 m to 222 m)

AGE	ZONE		DEPTH (m)	SECTION NO.	LITHOLOGY	SAMPLE INTERVAL	LITHOLOGY	DIAGNOSTIC FOSSILS
EARLY EOCENE	*Marthasterites contortus*	*Globorotalia subbotinae*	1 2 3	1 2 CC		SS PF SS PF SS SS CN PF PF SS SS CN, PF	Foram-nannoplankton ooze, soft yellowish white (5Y9/1) interbedded with firm indurated brittle zones, clay minerals common to rare, recrystallized nanno-calcite present throughout but more common in indurated zones than in soft zones.	PLANKTONIC FORAMINIFERS: *Globorotalia subbotinae, G. formosa gracilis, G. marginodentata, Globigerina nitida* CALCAREOUS NANNOPLANKTON: *Markalius astroporus, Sphenolithus radians, Heliorthus concinnus, Marthasterites contortus, Campylosphaera dela, Ellipsolithus macellus* PLANKTONIC FORAMINIFERS: *Globorotalia subbotinae, G. formosa gracilis, G. marginodentata, Globigerina nitida* *CORE CATCHER* CALCAREOUS NANNOPLANKTON: *Campylosphaera dela, Sphenolithus radians, Marthasterites contortus, Discoaster binodosus, D. delicatus, D. diastypus* PLANKTONIC FORAMINIFERS: *Globorotalia subbotinae, G. formosa gracilis, G. marginodentata, Globigerina nitida*



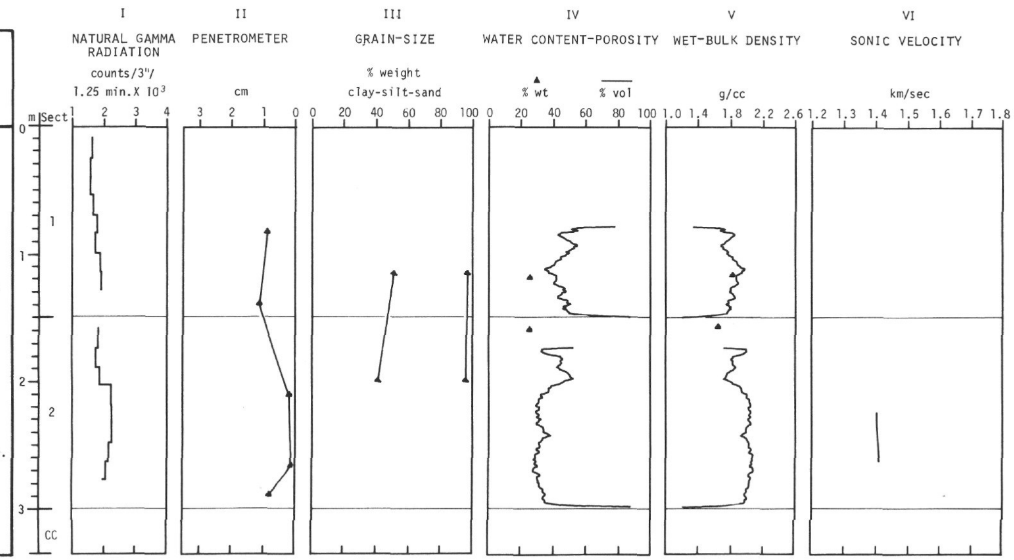
Hole 98, Core 10 (222 m to 231 m)

AGE	ZONE		DEPTH (m)	SECTION NO.	LITHOLOGY	SAMPLE INTERVAL	LITHOLOGY	DIAGNOSTIC FOSSILS
LATE PALEOCENE to EARLY EOCENE	*Discoaster multiradiatus*	*Globorotalia subbotinae*	1	1 CC		PF SS SS SS PF SS SS SS CN, PF	Nanno-chalk, firm to hard, yellowish white (5Y9/1), large chert fragments, laminated at 115 cm to 150 cm. Slump fault at 125 cm, clay minerals common, recrystallized nanno-calcite abundant. See section summary.	PLANKTONIC FORAMINIFERS: *Globorotalia subbotinae, G. formosa gracilis, G. marginodentata, Globigerina nitida* PLANKTONIC FORAMINIFERS: *Globorotalia subbotinae, G. formosa gracilis, G. marginodentata, Globigerina nitida* *CORE CATCHER* CALCAREOUS NANNOPLANKTON: *Discoaster multiradiatus, D. nobilis, D. diastypus, Campylosphaera dela, Heliorthus concinnus, Markalius astroporus, Chiasmolithus consuetus* PLANKTONIC FORAMINIFERS: *Globorotalia subbotinae, G. formosa gracilis, Globigerina nitida*



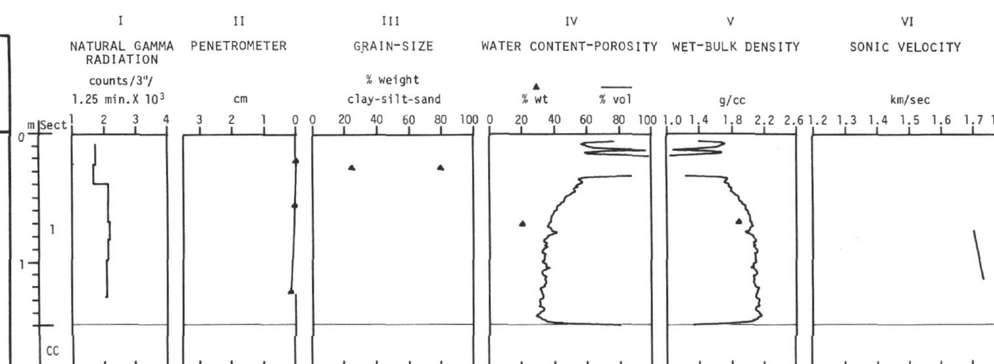
Hole 98, Core 11 (231 m to 240 m)

AGE	ZONE	DEPTH (m)	SECTION NO.	LITHOLOGY	SAMPLE INTERVAL	LITHOLOGY	DIAGNOSTIC FOSSILS
LATE PALEOCENE to EARLY EOCENE	*Discoaster multiradiatus* *Globorotalia subbotinae*	1, 2, 3	1, 2, CC		SS, PF, SS, SS, PF, PF, CN, PF, SS, CN, PF	Foram-nannoplankton ooze, soft to firm, yellowish white (5Y9/1), recrystallized nanno-calcite and zeolites abundant, clay minerals common, yellow (5Y7/6) limonite/ hematite nodules. Induration common in Section 2. Thin light brown (5YR5/6) layer at 57 cm, zeolites very abundant.	CALCAREOUS NANNOPLANKTON: *Discoaster multiradiatus, D. nobilis, Toweius craticulus, Fasciculithus tympaniformis, Chiasmolithus consuetus, Lophodolithus nascens* PLANKTONIC FORAMINIFERS: *Globorotalia aequa, G. marginodentata, G. subbotinae, G. formosa gracilis* *CORE CATCHER* CALCAREOUS NANNOPLANKTON: *Discoaster multiradiatus, D. nobilis, Coccolithus cavus, Cruciplacolithus tenuis, Fasciculithus tympaniformis, Chiasmolithus consuetus, C. bidens.* PLANKTONIC FORAMINIFERS: *Globorotalia aequa, G. marginodentata, G. subbotinae, G. formosa gracilis.*

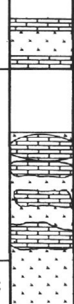


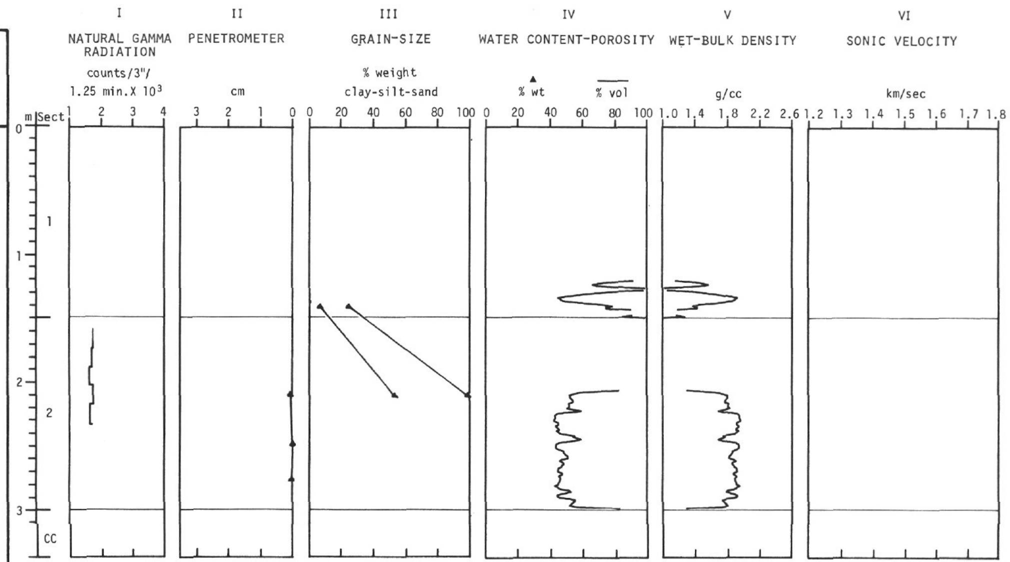
Hole 98, Core 12 (240 m to 241 m)

AGE	ZONE	DEPTH (m)	SECTION NO.	LITHOLOGY	SAMPLE INTERVAL	LITHOLOGY	DIAGNOSTIC FOSSILS
LATE PALEOCENE	*Discoaster multiradiatus* *Globorotalia velascoensis* or *Globorotalia subbotinae*	1	1, CC		O, SS, PF, SS, PP, CN, PF, SS, PF, SS, CN, PF	Micritic chalk, yellowish white (5Y9/1), faint laminations, nannoplankton dominant, forams and recrystallized nanno-calcite abundant, zeolites common. Core Laboratories, Inc. core analysis at 20-22 cm. Foram-nannoplankton ooze, interbedded soft and indurated zones, yellowish white (5Y9/1), zeolites common. See Section 1 summary.	CALCAREOUS NANNOPLANKTON: *Discoaster multiradiatus, D. gemmeus, Toweius craticulus, T. eminens, Fasciculithus tympaniformis, Chiasmolithus bidens, C. consuetus* PLANKTONIC FORAMINIFERS: *Globorotalia velascoensis, G. acuta, G. aequa, G. subbotinae* *CORE CATCHER* CALCAREOUS NANNOPLANKTON: *Discoaster multiradiatus, D. gemmeus, D. nobili, Fasciculithus tympaniformis, Campylosphaera dela, Chiasmolithus consuetus* PLANKTONIC FORAMINIFERS: *Globorotalia velascoensis, G. acuta, G. aequa, G. subbotinae*



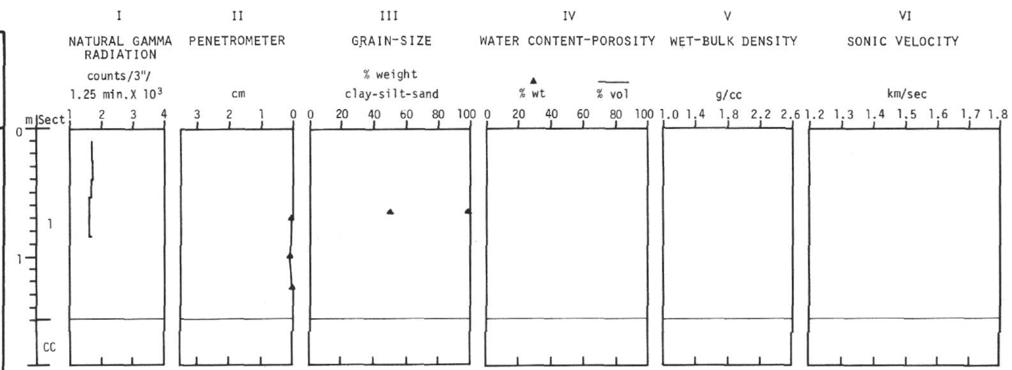
Hole 98, Core 13 (272 m to 281 m)

AGE	ZONE	DEPTH (m)	SECTION NO.	LITHOLOGY	SAMPLE INTERVAL	LITHOLOGY	DIAGNOSTIC FOSSILS
LATE CAMPANIAN	*Globotruncana calcarata*	1, 2, 3	1, 2, CC		PF, SS, PF, O, PF, CN, SS, PF, PF, SS, CN, PF	See section summary. Limestone, hard, yellowish gray (5Y8/2), abundant fossil molds. Foram-nannoplankton ooze, very soft, yellowish white (5Y9/1), zeolites common. Micritic chalk, friable. Core Laboratories, Inc. core analysis at 139-140 cm. Nannoplankton chalk, very firm, yellowish white (5Y9/1), interbedded with very soft, highly disturbed, foram-nannoplankton ooze; brown (5YR5/6) specks of iron oxide in chalk. See section summary.	PLANKTONIC FORAMINIFERS: *Globotruncana suartiformis, G. arca, G. fornicata, G. linneiana, G. aegyptiaca, G. tricarinata* CALCAREOUS NANNOPLANKTON: *Arkhangelskiella parca, A. cymbiformis, Mikrorhabdulus decoratus, Deflandrius intercisus, Micula decussata, Prediscosphaera cretacea, Tetralithus nitidus nitidus* PLANKTONIC FORAMINIFERS: *Globotruncana calcarata, G. stuartiformis, G. fornicata, G. linneiana, Pseudotextularia elegans* *CORE CATCHER* CALCAREOUS NANNOPLANKTON: *Arkhangelskiella cymbiformis, C. parca, Cretarhabdus conicus, Eiffellithus turriseiffeli, Micula decussata, Tetralithus pyramidus, Microrhabdulus decoratus, Deflandrius intercisus* PLANKTONIC FORAMINIFERS: *Globotruncana calcarata, G. stuartiformis, G. arca, G. fornicata, G. tricarinata, G. linneiana, G. subspinosa*



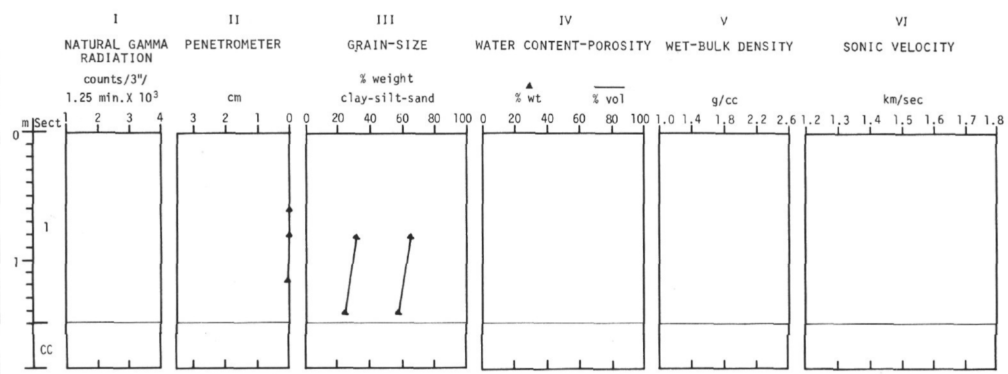
Hole 98, Core 14 (311 m to 318 m)

AGE	ZONE	DEPTH (m)	SECTION NO.	LITHOLOGY	SAMPLE INTERVAL	LITHOLOGY	DIAGNOSTIC FOSSILS
CAMPANIAN	*Globotruncana elevata*	1	1 CC		PF PF SS CN SS SS F SS CN,PF	Chalk, firm, yellowish white (5Y9/1) chalk, firm, yellowish white (5Y9/1) with orange brown (10YR6/6) specks and stains. Interlayered with graded beds of foram sand, some beds with burrow structures at base. See section summary.	CALCAREOUS NANNOPLANKTON: *Eiffelithus turriseiffeli, Cretarhabdus conicus, Tetralithus pyramidus, T. nitidus nitidus, Micula decussata, Microrhabdulus decoratus, Arkhangelskiella parca* PLANKTONIC FORAMINIFERS: *Globotruncana falsostuarti, G. stuartiformis, G. stuarti, G. tricarinata, G. linneiana, G. elevata* LARGER FORAMINIFERS: *Pseudorbitoides israelskii, Vaughanina cubensis, V. barkeri* *CORE CATCHER:* CALCAREOUS NANNOPLANKTON: *Kamptnerius magnificus, Eiffelithus turriseiffeli, Tetralithus pyramidus, Arkhangelskiella parca, Micula decussata* PLANKTONIC FORAMINIFERS: *Globotruncana fornicata, G. stuartiformis, G. stuarti parva* LARGER FORAMINIFERS: *Vaughanina cubensis, V. barkeri, Pseudorbitoides israelskii*

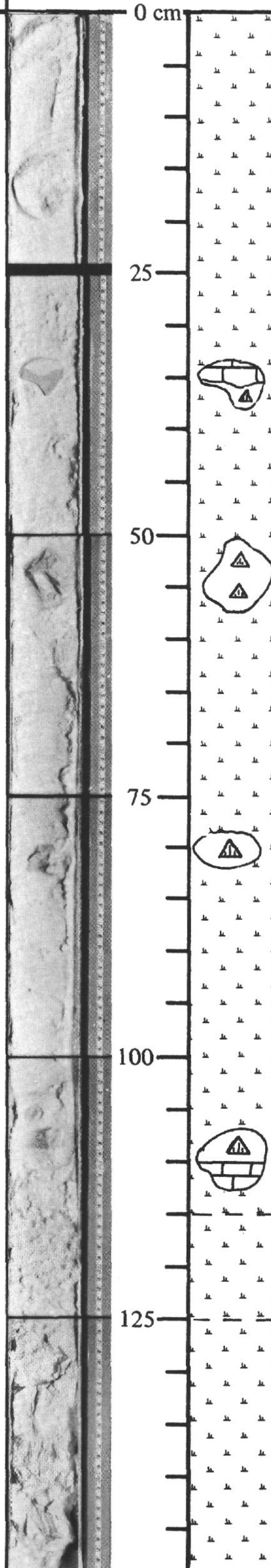


Hole 98, Core 15 (348 m to 357 m)

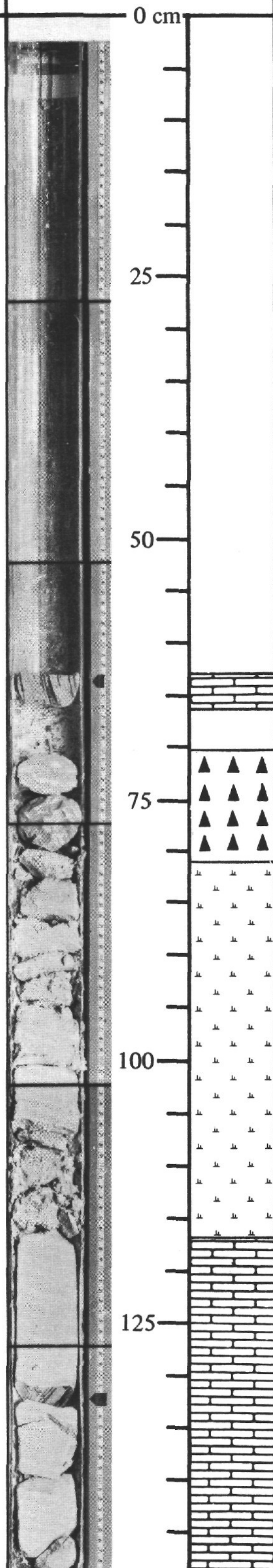
AGE	ZONE	DEPTH (m)	SECTION NO.	LITHOLOGY	SAMPLE INTERVAL	LITHOLOGY	DIAGNOSTIC FOSSILS
CAMPANIAN	*Globotruncana elevata*	1	1 CC		CN SS SS PF SS PF PF CN, PF	Limestone, hard, yellowish gray (5Y8/2), abundant fossil molds. Nannoplankton chalk, firm, yellowish white (5YR9/1). Nannoplankton chalk with abundant calcite clasts throughout, firm to hard, yellowish white (5YR9/1). See section summary.	CALCAREOUS NANNOPLANKTON: *Deflandrius intercisus, Tetralithus pyramidus, Micula decussata, Microrhabdulus decoratus, Arkhangelskiella cymbiformis, Cylindralithus crassus* PLANKTONIC FORAMINIFERS: *Globotruncana stuartiformis, G. fornicata, G. lapparenti lapparenti, G. linneiana* *CORE CATCHER* CALCAREOUS NANNOPLANKTON: *Arkhangelskiella cymbiformis, Tetralithus pyramidus, Micula decussata, Glaukolithus diplogrammus, Cylindralithus crassus, Eiffemithus turriseiffeli* PLANKTONIC FORAMINIFERS: *Globotruncana fornicata, G. stuartiformis, G. stephensoni, G. linneiana*



Hole 98, Core 7, Section 1

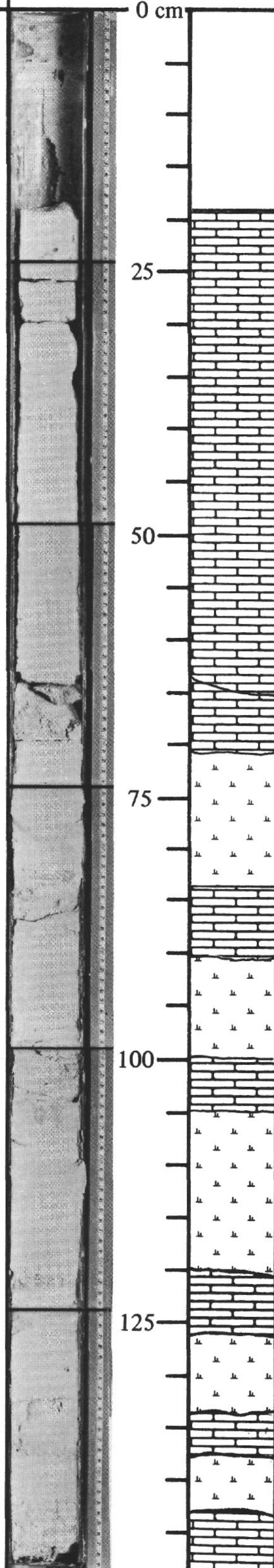
AGE	ZONE	LITHOLOGY	SAMP. INT	LITHOLOGY	DIAGNOSTIC FOSSILS
EARLY TO MIDDLE EOCENE	*Chiphragmalithus alatus* / *Globorotalia pentacamerata*		CN TS SS PF SS	<u>Foram-nanno ooze</u>, soft & plastic, white (N9), recrystallized nanno calcite dominant, forams common, calcite spicules common; no siliceous spicules or radiolaria; firm ooze at 15-20 cm. Very hard white <u>chalk</u> in sharp contact with underlying tan <u>chert</u>. Thin section shows chert to be silicified ooze with foram tests which are replaced by quartz and filled with and surrounded by disordered cristobalite. Very soft disturbed ooze with numerous small chips and a few large fragments of chert at 20-115 cm. Chert-chalk contacts at 34 and 109 cm believed to represent top and bottom of 75 cm zone of chert fragments. Tan chert in contact with underlying white chalk. "Soupy" at 115-125 cm. Disturbed core.	CALCAREOUS NANNOPLANKTON: *Chiphragmalithus alatus*, *Reticulofenestra umbilica*, *Chiasmolithus grandis*, *Discoaster barbadiensis*, *D. lodoensis*, *Sphenolithus radians*. PLANKTONIC FORAMINIFERS: *Globorotalia aragoensis*, *G. pentacamerata*, *Truncorotaloides topilensis*, *Globigerina frontosa*.

Hole 98, Core 10, Section 1

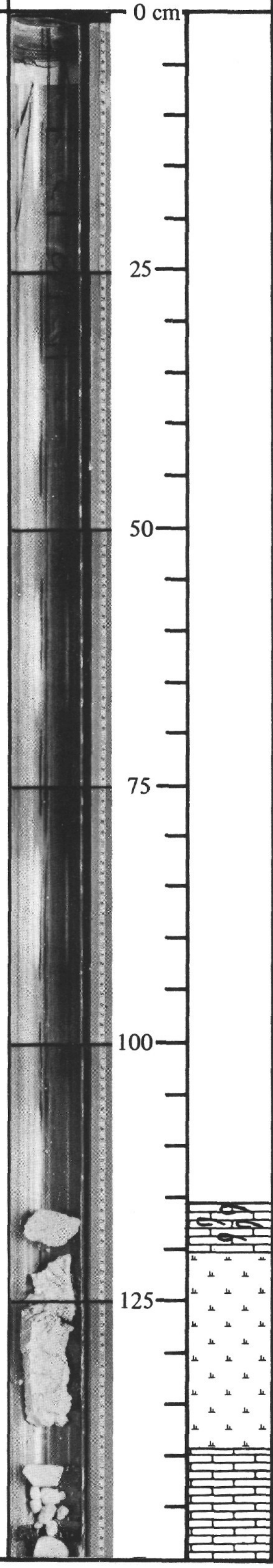
AGE	ZONE	LITHOLOGY	SAMP. INT	LITHOLOGY	DIAGNOSTIC FOSSILS
EARLY EOCENE	*Globorotalia subbatinae*		PF SS SS SS PF	*Core catcher sample: Smear slide in core catcher sample (immediately below Sect. 1) showed calcareous nannoplankton as dominant with forams common, radiolarians rare. Forams dominant in coarse fraction. Slickensided piece from fault plane at 131-135 cm. Chert, olive gray (5Y6/1) with white (N8) inclusions. Foram-nanno ooze, slightly indurated, yellowish white (5Y9/1); calcareous nannoplankton dominant; forams rare; clay minerals and zeolites common; siliceous spicules and radiolarians absent. Micritic chalk, firm to hard, yellowish white (5Y9/1), faintly laminated; zeolites more common in dark laminae than in light; forams rare; siliceous spicules and radiolarians absent. Black MnO_2 dendrites & large fibers of sepiolite on slickensided fault plane at 131-135cm	PLANKTONIC FORAMINIFERS: *Globorotalia subbotinae, G. formosa gracilis, G. marginodentata, Globigerina nitida*

*Core catcher sample (immediately below Section 1).

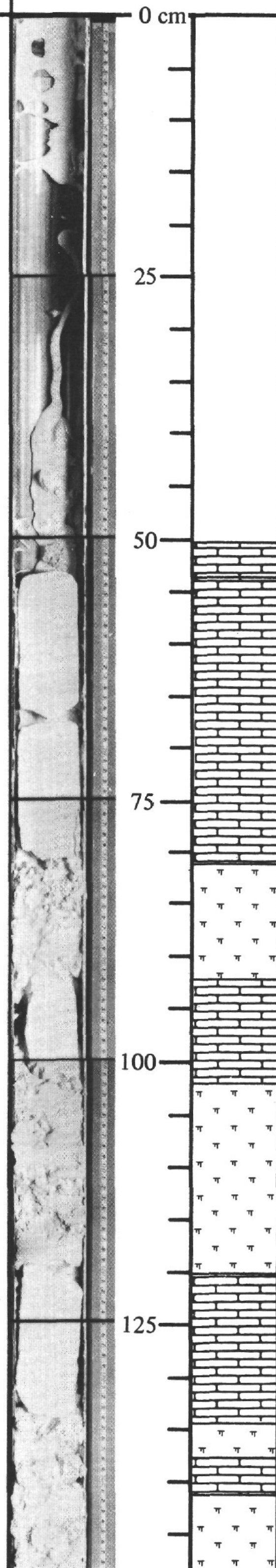
Hole 98, Core 12, Section 1

AGE	ZONE	LITHOLOGY	SAMP. INT	LITHOLOGY	DIAGNOSTIC FOSSILS
LATE PALEOCENE	*Discoaster multiradiatus*/*Globorotalia velascoensis* or *G. subbotinae*		0 SS PF SS PF CN PF SS PF	Sample analysis at 20-22 cm by Core Laboratories, Inc. porosity: 47.3% permeability: 6.2 mud grain density: 2.72gr/cc <u>Micritic chalk</u>, firm to hard yellowish white (5Y9/1), faintly laminated; calcareous nannoplankton dominant; recrystallized nanno calcite abundant; forams abundant to common; clay minerals & zeolites common to rare. Brown (5YR5/6) iron oxide (?) fragment at 24 cm. Clasts up to 300 microns at 20-46 cm. <u>Foram-nanno ooze</u>, soft with several very firm indurated zones. Calcareous nannoplankton dominant; recrystallized nanno-calcite abundant; forams and zeolites common; clay minerals rare.	CALCAREOUS NANNOPLANKTON: *Discoaster multiradiatus, D. gemmeus, Toweius craticulus, T. eminens, Fasciculithus tympaniformis, Chiasmolithus bidens, C. consuetus* PLANKTONIC FORAMINIFERS: *Globorotalia velascoensis, G. acuta, G. aequa, G. subbotinae*

Hole 98, Core 13, Section 1

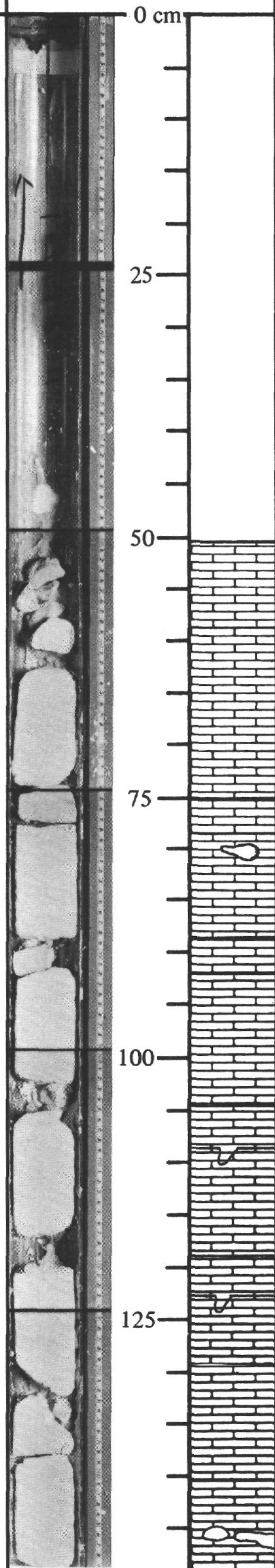
AGE	ZONE	LITHOLOGY	SAMP. INT	LITHOLOGY	DIAGNOSTIC FOSSILS
LATE CAMPANIAN	*Globotruncana calcarata*		SS PF O	Sample analysis at 139-140 cm by Core Laboratories, Inc. porosity: 35.4% permeability: 250 md. grain density: 2.72gr/cc <u>Limestone</u>, hard, yellowish gray (5Y8/2), abundant fossil molds, sparry calcite cement. <u>Foram-nanno ooze</u>, very soft, yellowish white (5Y9/1); calcareous nannoplankton dominant; recrystallized nanno calcite common; clay minerals and zeolites common. Dolomite rhombs rare <u>Micritic chalk</u>, firm to hard yellowish white (5Y9/1).	PLANKTONIC FORAMINIFERS: *Globotruncana stuartiformis*, *G. arca*, *G. fornicata*, *G. linneiana*, *G. aegyptiaca*, *G. tricarinata*

Hole 98, Core 13, Section 2

AGE	ZONE	LITHOLOGY	SAMP. INT	LITHOLOGY	DIAGNOSTIC FOSSILS
LATE CAMPANIAN	*Globotruncana calcarata*			Core catcher sample: <u>Limestone</u>, very coarse, hard yellowish white (5Y9/1), very porous. Consists of firmly cemented but loosely packed, well-rounded calcite fragments (shell debris). Very slightly chalky, mainly as sparse coating on shell fragments.	
				<u>Chalky limestone</u>, hard, yellowish white (5Y 9/1); consists primarily of calcite clasts.	
			PF	<u>Micritic chalk</u>, firm to hard, yellowish white (5Y9/1); specks of brown (5YR5/6) iron oxide (?) at 55-65 cm. Calcareous nannoplankton dominant; forams and recrystallized nanno calcite common.	CALCAREOUS NANNOPLANKTON: *Arkhangelskiella parca, A. cymbiformis, Microrhabdulus decoratus, Deflandrius intercisus, Micula decussata, Prediscosphaera cretacea, Tetralithus nitidus nitidus*
				<u>Foram-nanno ooze</u>, very soft, yellowish white (5Y9/1); recrystallized nanno calcite rare.	PLANKTONIC FORAMINIFERS: *Globotruncana calcarata, G. stuartiformis, G. fornicata, G. linneiana, Pseudotextularia elegans*
			SS	<u>Micritic chalk</u>, as above.	
			PF CN	<u>Foram-nanno ooze</u>, as above.	
				<u>Micritic chalk</u>, as above.	
			PF	<u>Foram-nanno ooze</u>, as above.	
				<u>Micritic chalk</u>, as above.	
			SS	<u>Foram-nanno ooze</u>, as above.	

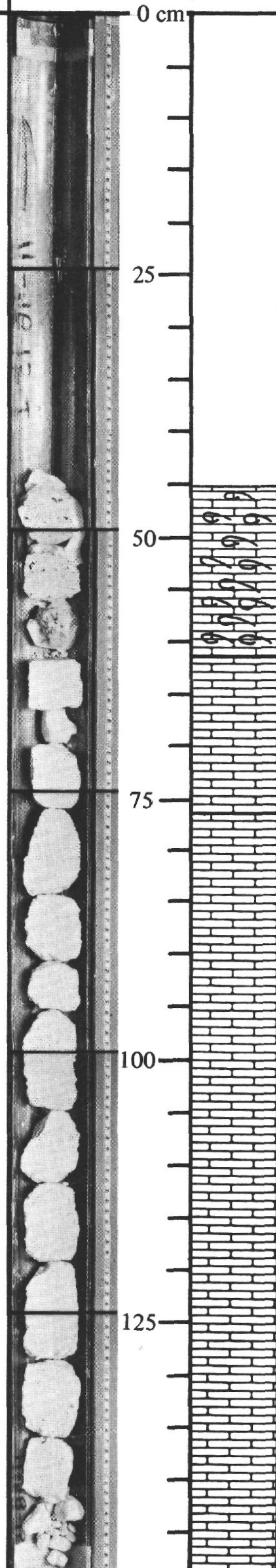
*Core catcher sample (immediately below Sect.2)

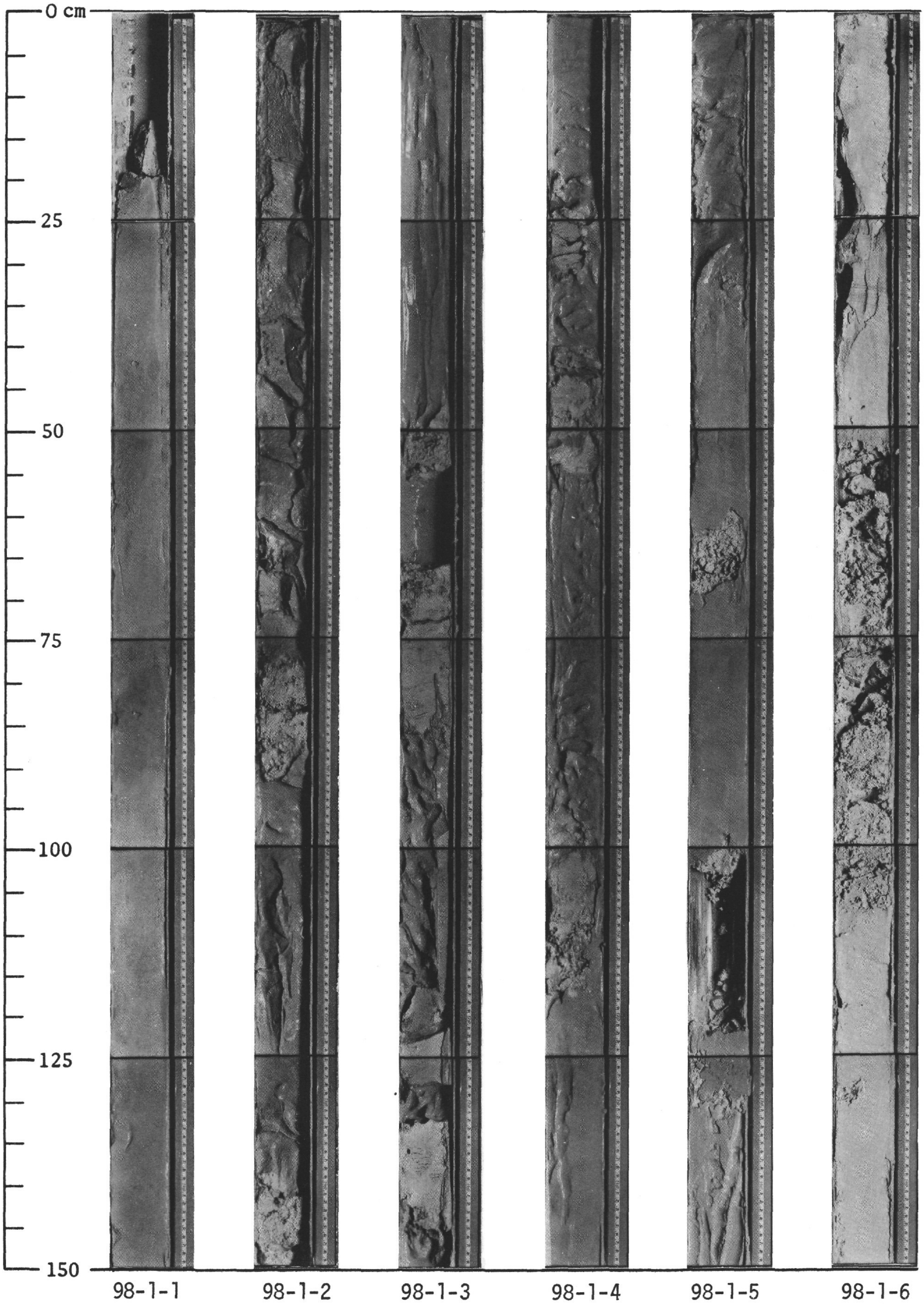
Hole 98, Core 14, Section 1

AGE	ZONE	LITHOLOGY	SAMP. INT	LITHOLOGY	DIAGNOSTIC FOSSILS
CAMPANIAN	*Globotruncana elevata*			<u>Micritic chalk</u> beds between 58 and 150 cm are firm and yellowish white (5Y9/1); calcareous nannoplankton dominant; forams abundant; recrystallized nanno calcite common; interbedded with yellowish white calcarenites made dominantly of well-rounded calcite grains. Distinct graded bedding in lower three calcarenites.	CALCAREOUS NANNOPLANKTON: *Eiffelithus turriseiffeli, Cretarhabdus conicus, Tetralithus pyramidus, T. nitidus nitidus, Micula decussata, Microrhabdulus decoratus, Arkhangelskiella parca.* PLANKTONIC FORAMINIFERS: *Globotruncana falsostuarti, G. elevata, G. stuarti, G. tricarinata, G. stuartiformis, G. linneiana.* LARGER FORAMINIFERS: *Pseudorbitoides israelskii, Vaughanina cubensis, V. barkeri.*
			PF	<u>Limestone</u>; well-rounded shell debris; firm, indurated, porous, chalky.	
			PF	<u>Micritic chalk</u> with bands and lenses of orange brown (10YR6/6) limonite (?) specks.	
				<u>Calcarenite</u>; forams, calcite grains; uneven laminations.	
				<u>Micritic chalk</u> with calcarenite lens.	
			SS	<u>Calcarenite</u>; calcite grains.	
			CN	<u>Micritic chalk</u> with lenses of orange brown (10 YR6/6) limonite (?) specks.	
				<u>Calcarenite</u>; forams, calcite grains; graded bedding.	
			SS	<u>Micritic chalk</u> with few limonite (?) specks.	
				Graded <u>calcarenite</u> as above.	
				<u>Micritic chalk</u>.	
			PF SS	Graded <u>calcarenite</u> as above; bedding more discrete.	
				<u>Micritic chalk</u> with calcarenite lenses.	

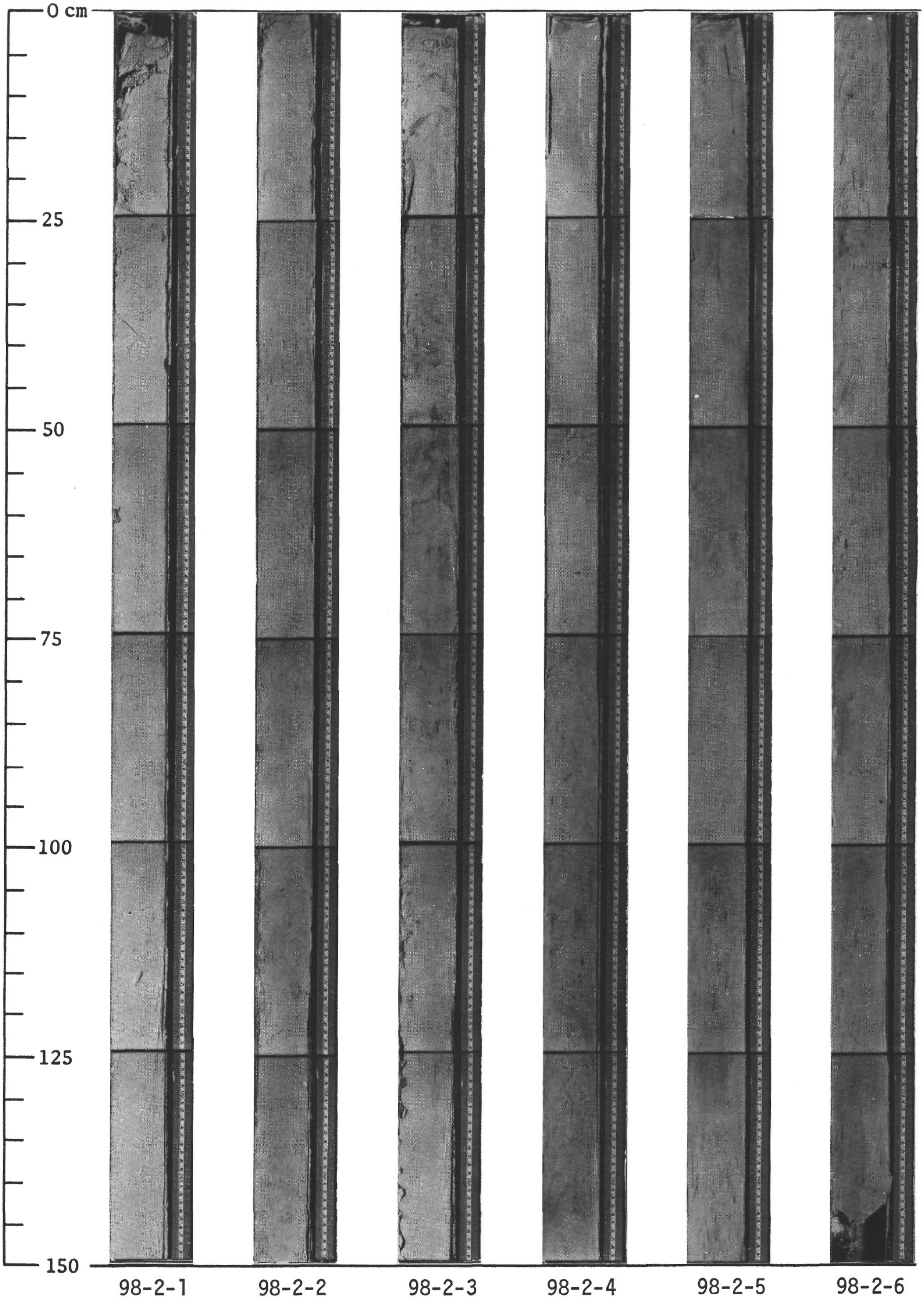
Core catcher sample similar to that from Core 13 but fine-grained in this core

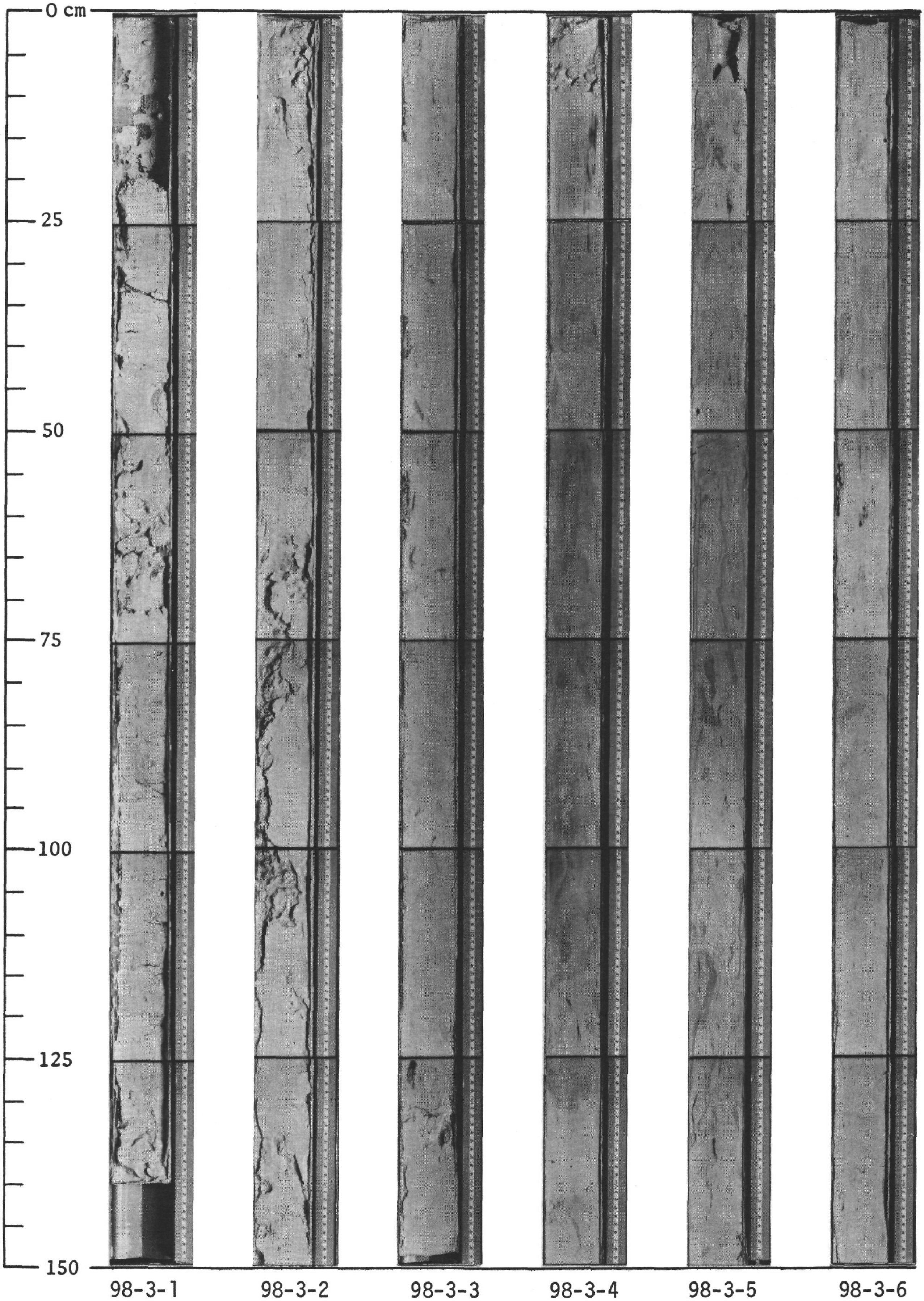
Hole 98, Core 15, Section 1

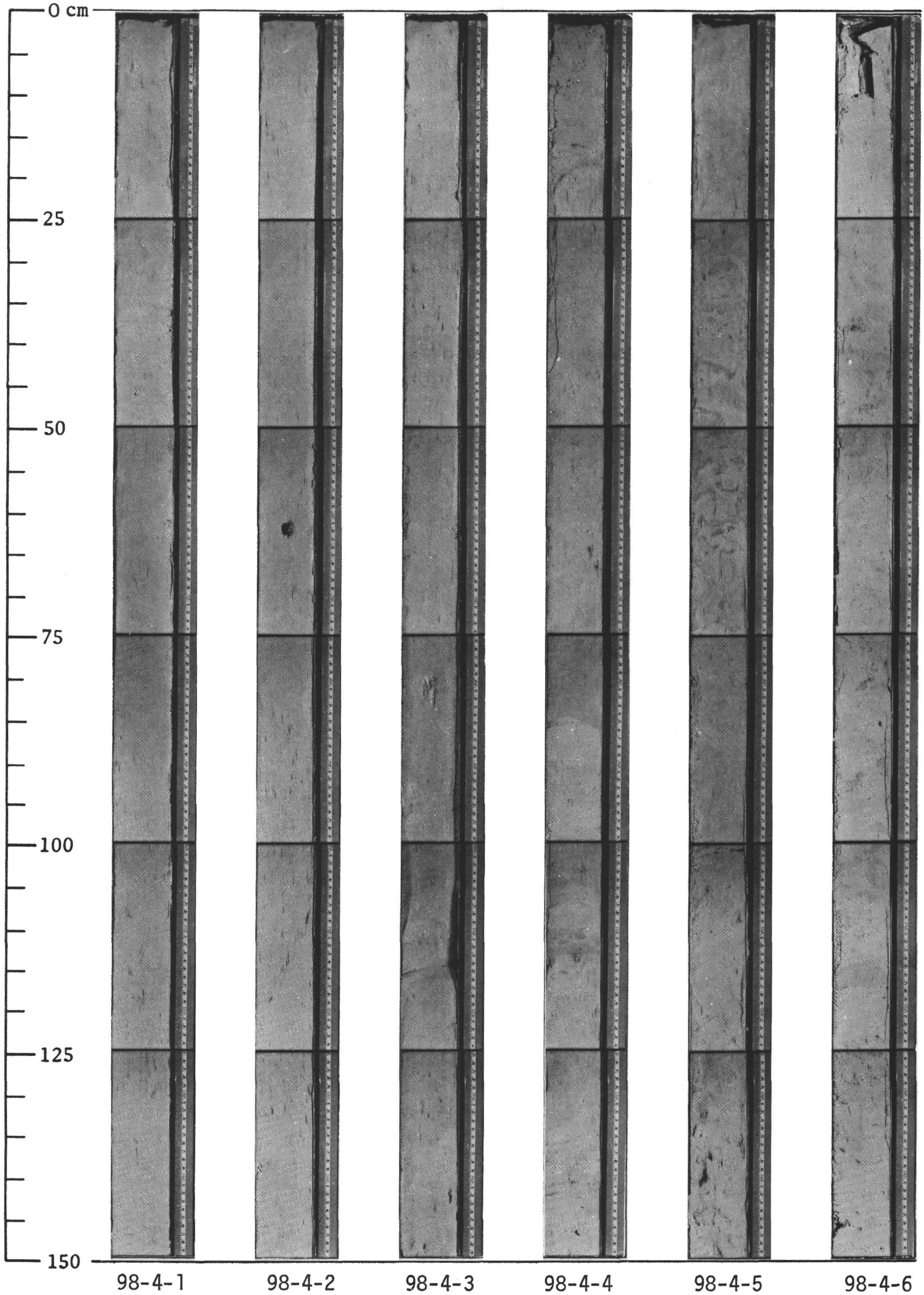
AGE	ZONE	LITHOLOGY	SAMP. INT	LITHOLOGY	DIAGNOSTIC FOSSILS
EARLY CAMPANIAN TO LATE SANTONIAN	*Globotruncana elevata*		TS, SS, PF, CN, SS, PF, PF	Limestone, hard, yellowish gray (5Y8/2); abundant fossil molds (some with drussy calcite); thin section shows calcite clasts cemented with sparry calcite. Chalk, firm, yellowish white (5YR9/1); calcite clasts rare; thin zones of pale yellowish orange (10YR8/4). Calcareous nannoplankton dominant. Chalk, hard, yellowish white (5YR9/1); abundant calcite clasts of shell debris dispersed in nanno chalk. Clasts have mean size of 2mm and range up to 6mm. No apparent graded bedding. Large fragment of nanno-chalk at 78-83cm. Chalk is dominantly calcareous nannoplankton; forams are rare.	CALCAREOUS NANNOPLANKTON: *Deflandrius intercisus, Tetralithus pyramidus, Micula decussata, Microrhabdulus decoratus, Arkhangelskiella cymbiformis, Cylindralithus crassus* PLANKTONIC FORAMINIFERS: *Globotruncana stuartiformis, G. fornicata, G. lapparenti lapparenti, G. linneiana*

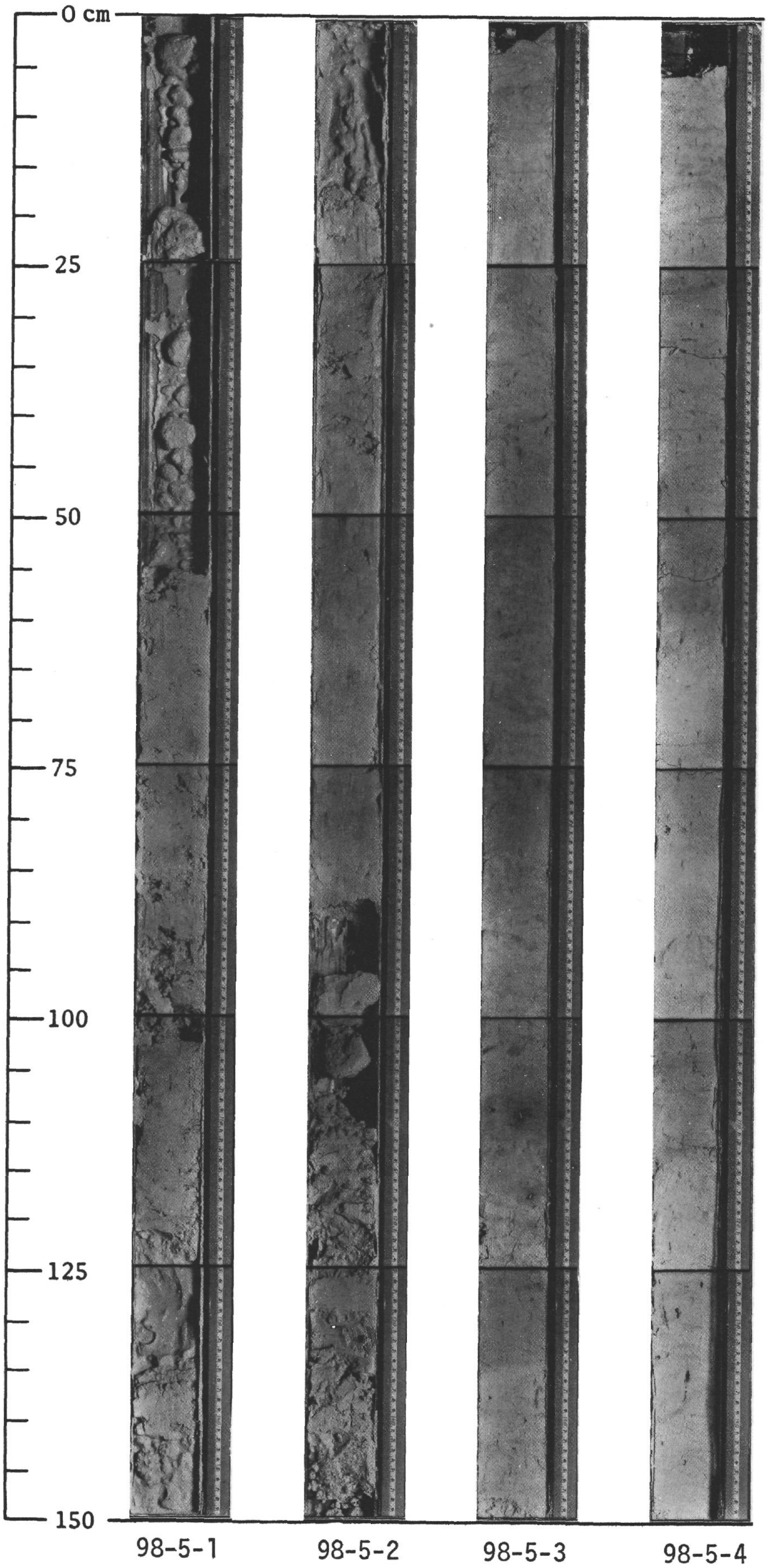


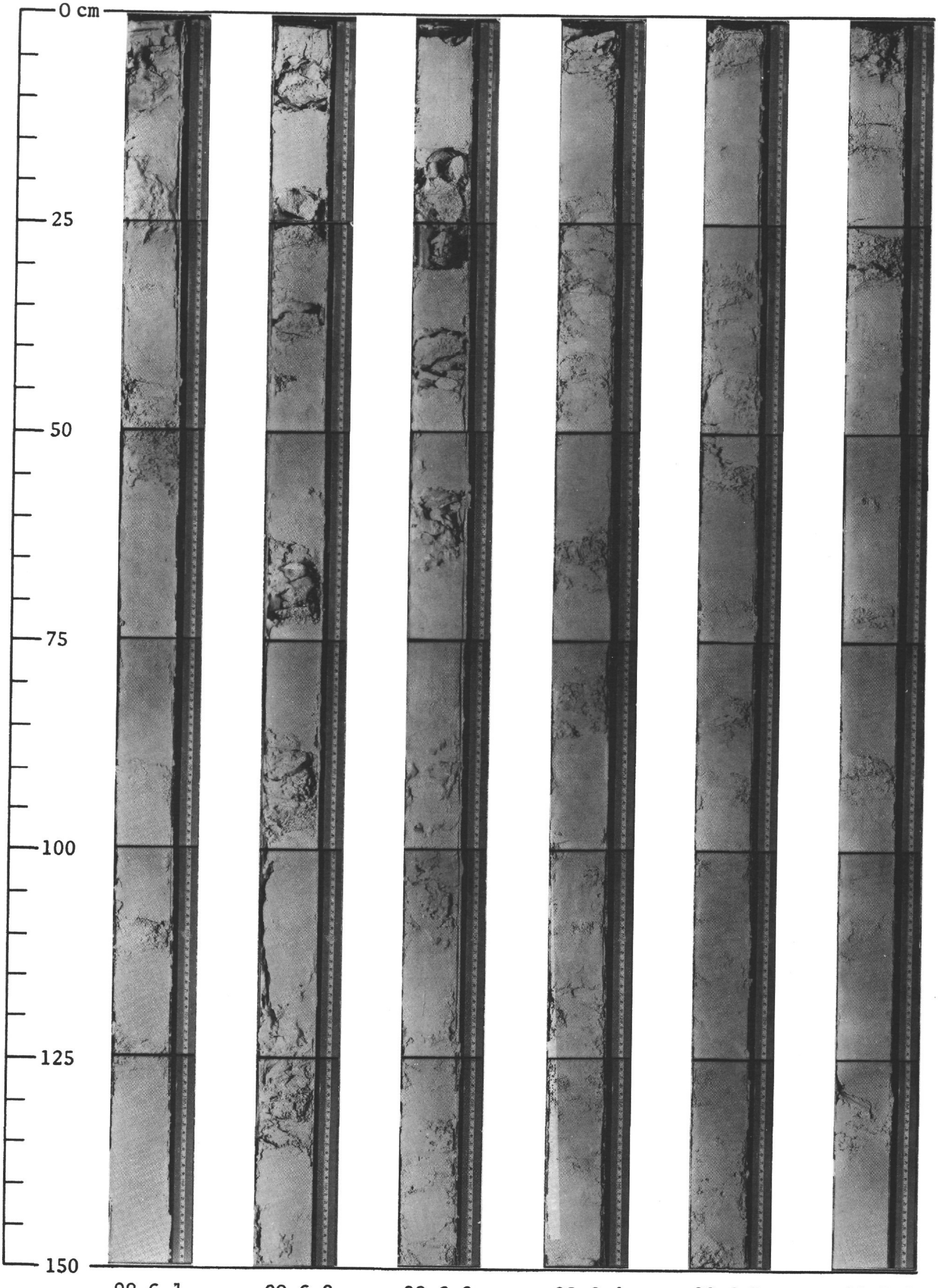
0 cm
25
50
75
100
125
150
98-1-1
98-1-2
98-1-3
98-1-4
98-1-5
98-1-6

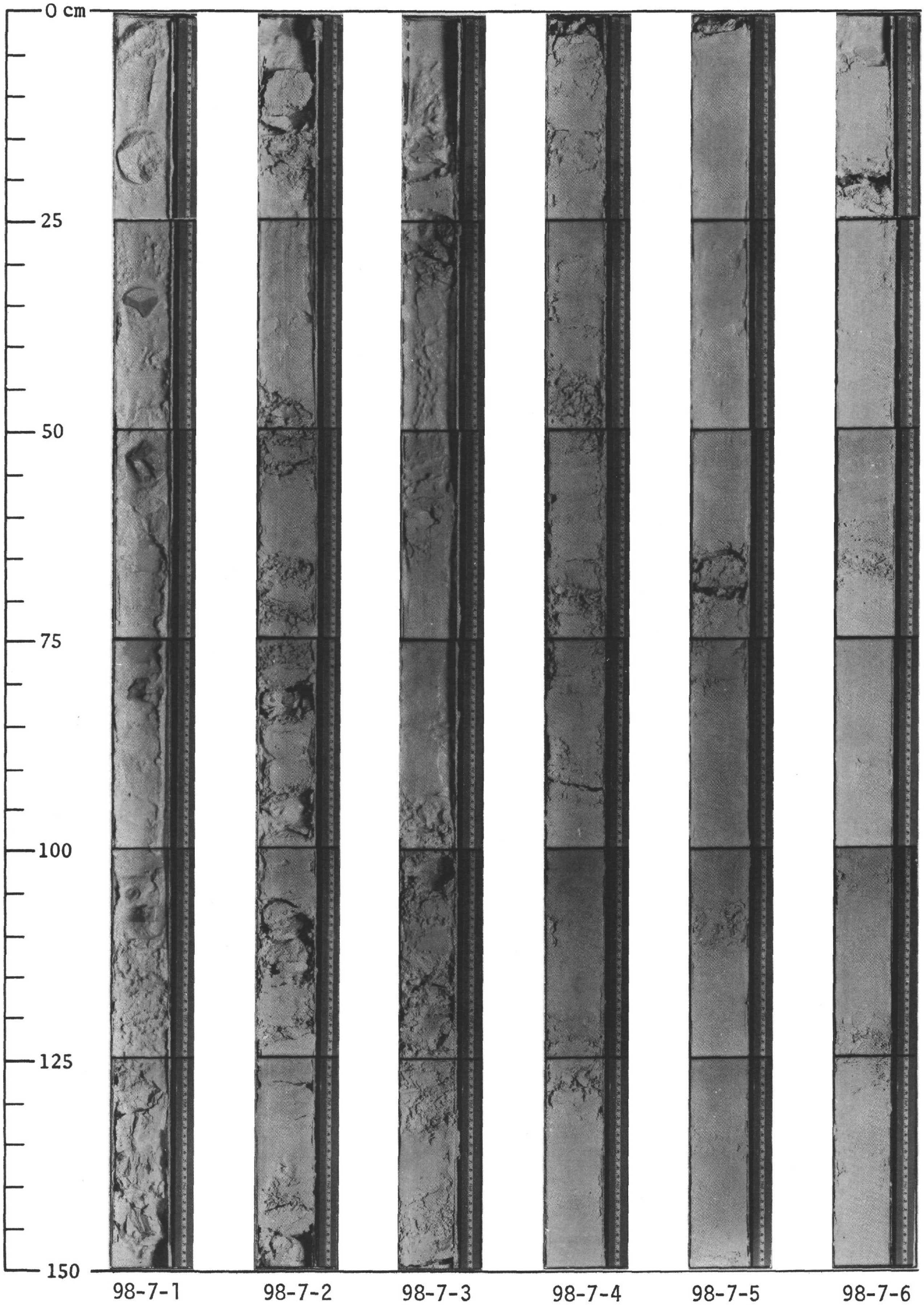

0 cm
25
50
75
100
125
150
98-2-1
98-2-2
98-2-3
98-2-4
98-2-5
98-2-6

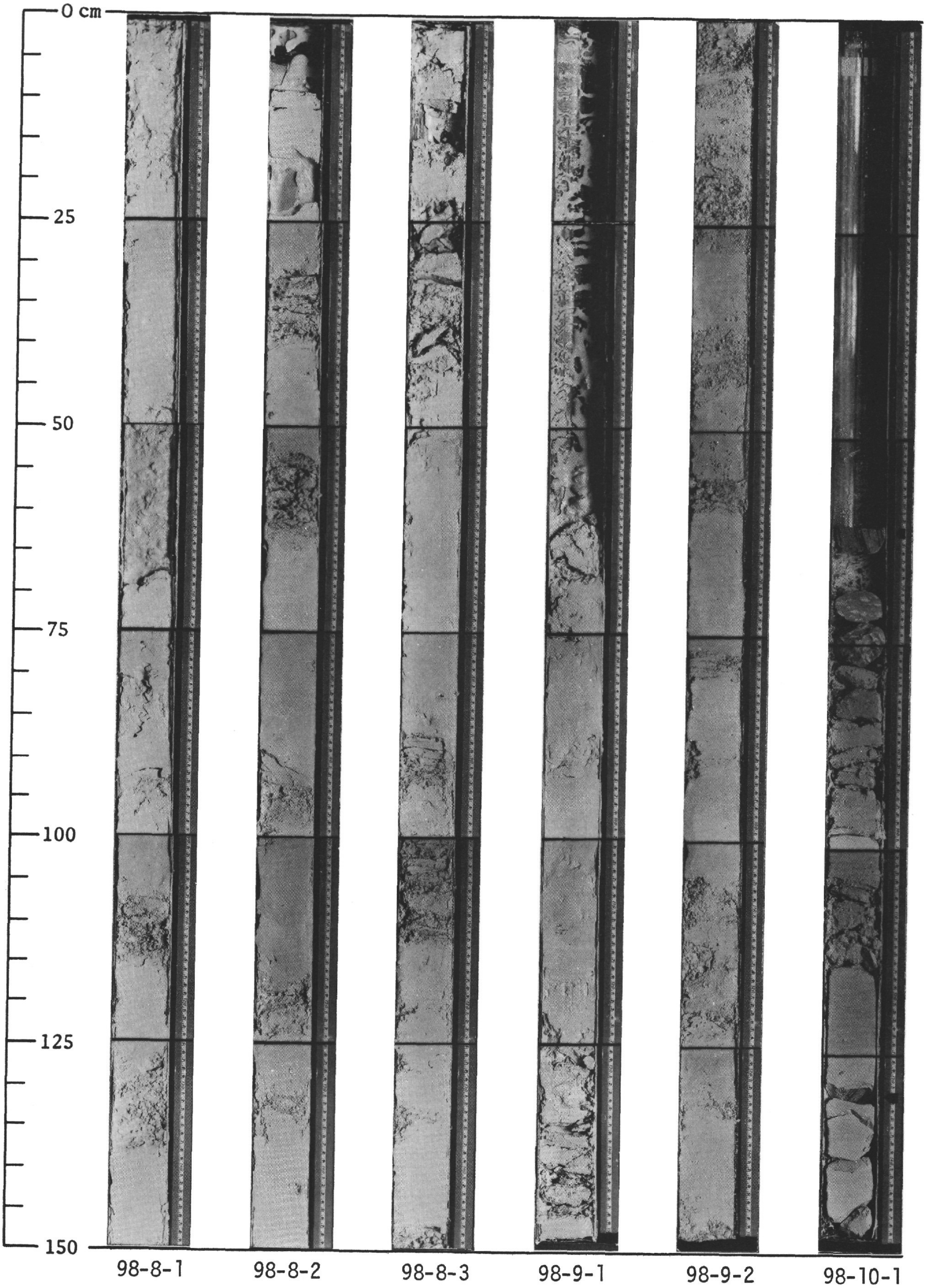

0 cm
25
50
75
100
125
150
98-3-1
98-3-2
98-3-3
98-3-4
98-3-5
98-3-6

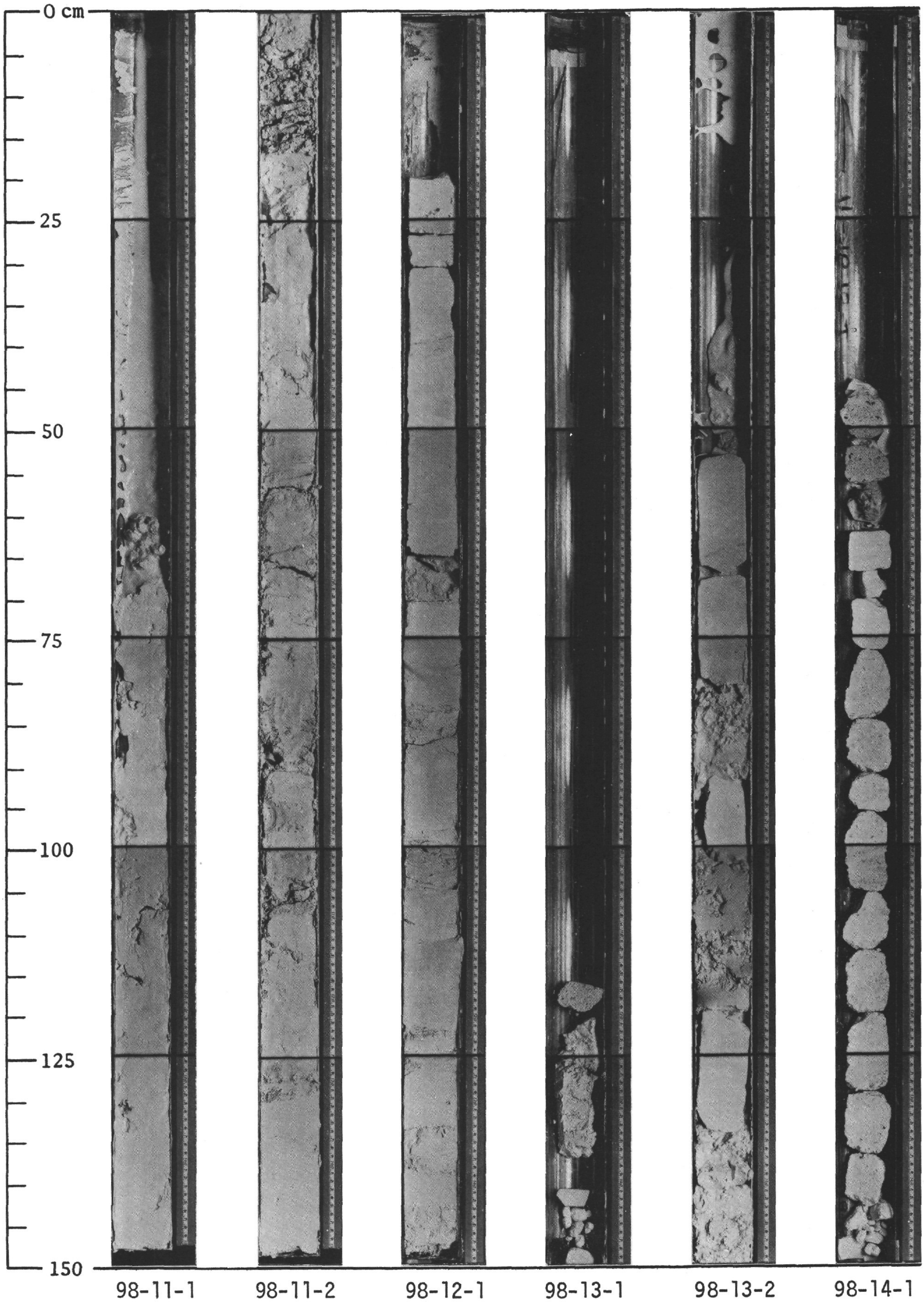

0 cm
25
50
75
100
125
150
98-4-1
98-4-2
98-4-3
98-4-4
98-4-5
98-4-6

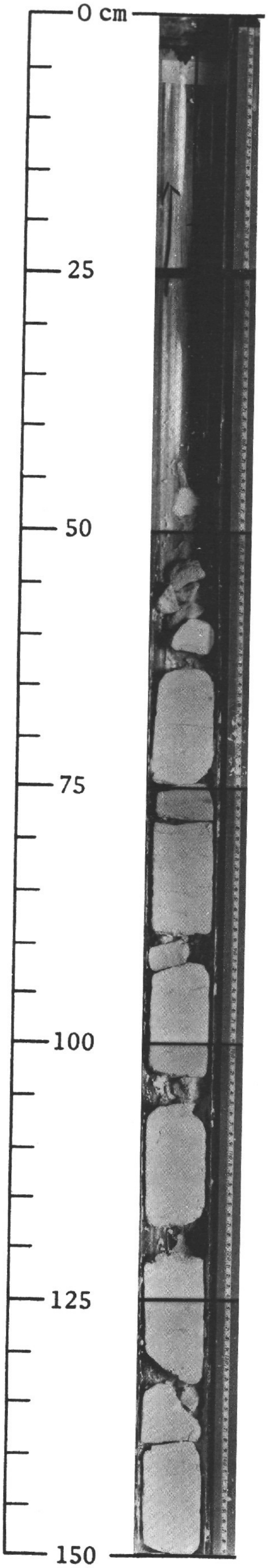

0 cm
25
50
75
100
125
150
98-5-1
98-5-2
98-5-3
98-5-4


0 cm
25
50
75
100
125
150
98-6-1
98-6-2
98-6-3
98-6-4
98-6-5
98-6-6


0 cm
25
50
75
100
125
150
98-7-1
98-7-2
98-7-3
98-7-4
98-7-5
98-7-6


0 cm
25
50
75
100
125
150
98-8-1
98-8-2
98-8-3
98-9-1
98-9-2
98-10-1


0 cm
25
50
75
100
125
150
98-11-1
98-11-2
98-12-1
98-13-1
98-13-2
98-14-1



98-15-1