4. SITE 316

The Shipboard Scientific Party[1]

SITE DATA

Date Occupied: 22 November 1973 (0725Z)

Date Departed: 27 November 1973 (0259Z)

Time on Site: 115 hours, 34 minutes

Position:
Latitude: 00°05.44'N
Longitude: 157°07.71'W

Water Depth (sea level): 4451.0 corrected meters, echo sounding

Water Depth (rig floor): 4456.8 corrected meters, echo sounding

Bottom Felt at: 4464.5 meters, drill pipe

Penetration: 837.0 meters

Number of Holes: 1

Number of Cores: 30

Total Length of Cored Section: 285.0 meters

Total Core Recovered: 102.8 meters

Percentage Core Recovery: 36.1%

Oldest Sediment Cored:
Depth subbottom: 837.0 meters
Nature: Tan claystone
Age: Early Campanian
Measured velocity: c/c only-not measured

Basement:
Depth below sea floor: Not reached at 837.0 meters

Principal Results: As at Site 315, the uppermost sediments at Site 316 are Quaternary and Pleistocene nannofossil-foram oozes. The Tertiary section above the Eocene chert is principally foram-nannofossil chalk; it is thinner than the coeval section at Site 315—about 460 meters versus 720 meters. The middle to lower Eocene contains abundant white and brown sugary dolomite not encountered at Site 315. The Paleocene section is very thick (66 m), as is the entire Cretaceous, the Maestrichtian being on the order of 57 meters and the Campanian 150+ meters. A few very thin volcaniclastic sands are present in middle Maestrichtian strata, but constitute almost all of the middle and lower Campanian section. It seems likely that the thin volcanogenic sands of Maestrichtian age represent very late erosional products of earlier volcanism, but the thick middle and lower Campanian volcanogenic debris appears to represent the nearly simultaneous growth and rapid erosion of nearby Line Islands edifices. It is apparent that the thick section of volcanogenic sands and breccias is coeval at Sites 165, 315, and 316. It also seems apparent that the youngest volcanic rocks in what is commonly accepted as the Line Islands seamount chain do not young to the south, at least in the approximately 1270-km distance along the chain between Sites 165 and 316. On leaving the site, a seamount or ridge was crossed approximately 10 n.mi. southeast of the site, which may have been a principal source of the redeposited volcanogenic sediments.

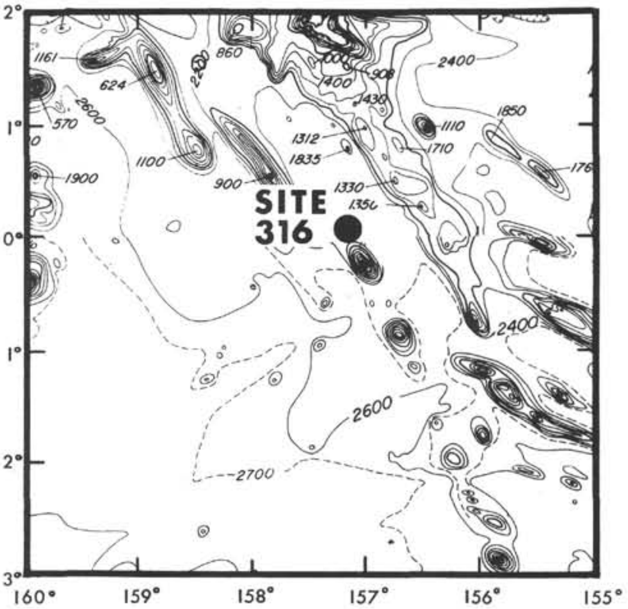

Figure 1. *Location of Site 316; bathymetry by Chase, et al., 1970 and Mammerickx, et al., 1973.*

BACKGROUND AND OBJECTIVES

The objectives of Site 316 (Figure 1) were (1) to determine the date of cessation of volcanism at the southern end of the Line Islands chain; (2) to study the petrology of the volcanic rocks that form the south end of the Line Islands chain; and (3) to decipher the postvolcanic geological history of the chain at this site by study of the sedimentary rocks that occur here. In the precruise planning stage, we felt these objectives could only be met by a program of continuous coring. Airgun profiles (Figure 2) provided by R/V *Thomas Washington*, SOTW-11, 2230 hr, 8 December 1972, suggested a stratigraphic thickness to acoustic basement just south of Site 316 of approximately 0.7 sec. Accordingly, 6.5 days were allocated for the site. In the revised schedule, a spot coring program was substituted, in which most of the upper

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[1] S.O. Schlanger, University of California, Riverside, California (Co-chief scientist); E.D. Jackson, U.S. Geological Survey, Menlo Park, California (Co-chief scientist); R.E. Boyce, Scripps Institution of Oceanography, La Jolla, California; H.E. Cook, University of California, Riverside, California; H.C. Jenkyns, University of Durham, Durham, England; D.A. Johnson, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts; A.G. Kaneps, Scripps Institution of Oceanography, La Jolla, California; K.R. Kelts, Eidg. Technische Hochschule, Zürich, Switzerland; E. Martini, Johann-Wolfgang-Goethe Universität, Frankfurt-am-Main, Germany; C.L. McNulty, University of Texas at Arlington, Arlington, Texas; E.L. Winterer, Scripps Institution of Oceanography, La Jolla, California.

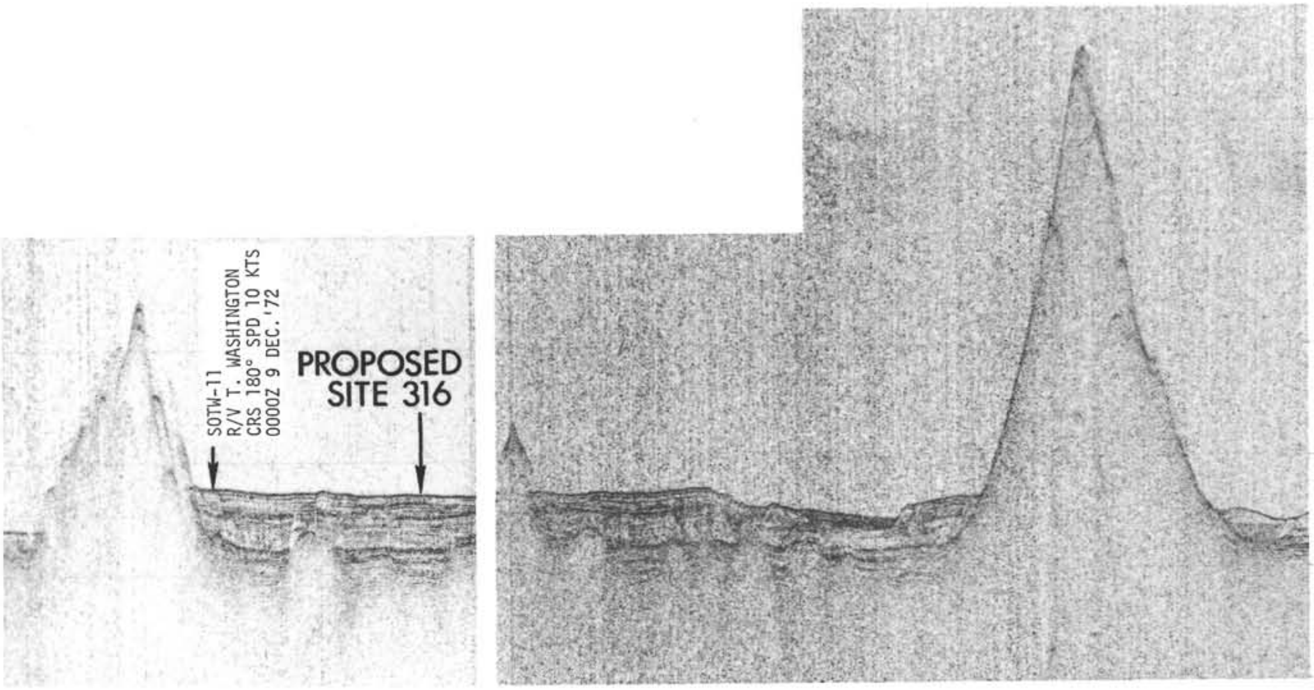


Figure 2a. *SOTW-11 seismic reflection profile showing the location of the originally proposed Site 33-4 (Site 316).*

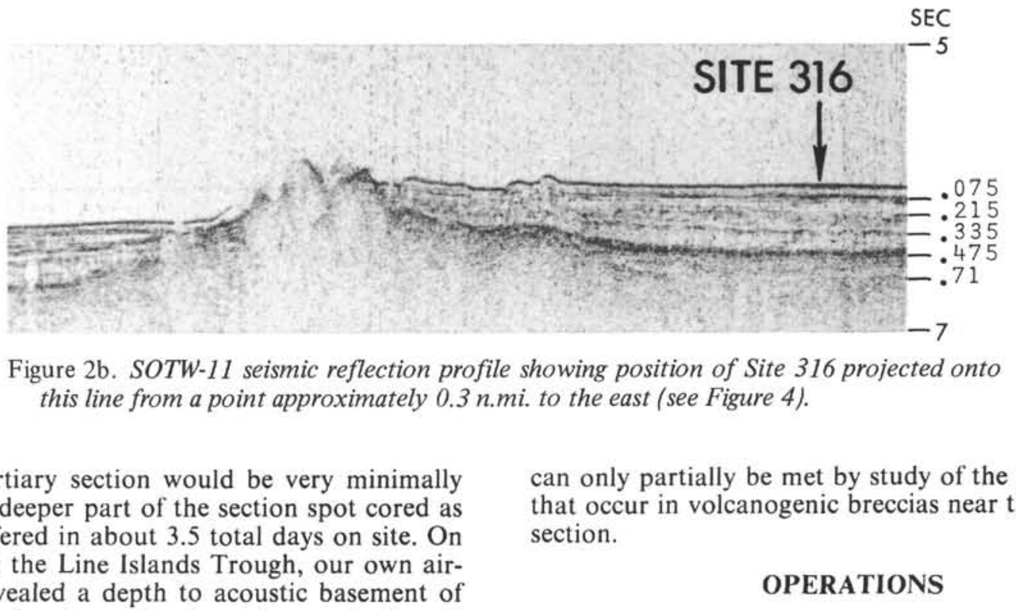


Figure 2b. *SOTW-11 seismic reflection profile showing position of Site 316 projected onto this line from a point approximately 0.3 n.mi. to the east (see Figure 4).*

part of the Tertiary section would be very minimally cored, and the deeper part of the section spot cored as opportunity offered in about 3.5 total days on site. On approach down the Line Islands Trough, our own air-gun profiles revealed a depth to acoustic basement of 0.68-0.70 sec at the site, and a short site survey showed increasingly complex behavior of the lower reflector to the south (Figure 3). Accordingly, we chose Site 316 about 1°30'N of that originally proposed (Figure 4).

On drilling Site 316, we found, much as we did at Site 315, that the acoustic basement in this area is dense, high velocity limestone rather than chert as had been assumed. The section, particularly from the Paleocene downwards, is considerably thicker than we had anticipated. The major objectives of the site were accomplished about 0615 hr (local) on 25 November, and we departed about 1659 hr (local) the same day, having spent approximately 4.8 days on site. We did not reach basement at Site 316, however, and objective 2 above can only partially be met by study of the basaltic clasts that occur in volcanogenic breccias near the base of the section.

OPERATIONS

Predrilling Site Survey

On leaving Fanning Island *Glomar Challenger* steamed on a course of 200° True for 80 n.mi., turned to 116° True for 78 n.mi., and steamed to a point west of Christmas Island at 2°00'S latitude; 158°40'W longitude. These maneuvers put us in a position to run a seismic profile exactly down the axis of the Line Islands Trough, at the southern terminus of which lay proposed Site 316 (Figure 4). At the proposed site a SOTW-11 survey had been used in precruise planning (Figure 2); we assumed that the section to be drilled in the trough would contain turbidite debris from the bordering ridges that would define their former volcanic history. The

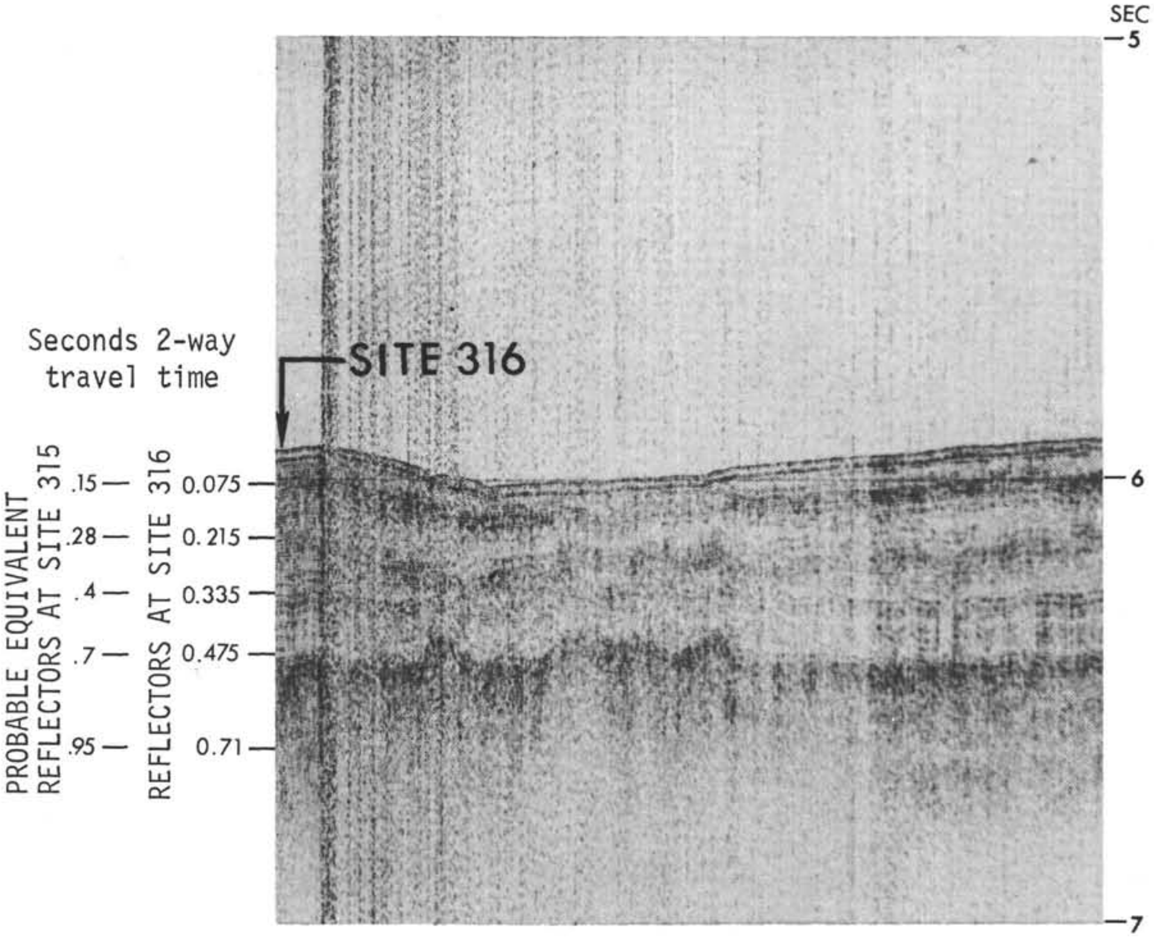


Figure 3. Glomar Challenger *seismic reflection profile on approach to Site 316 (see Figure 4 for line of profile).*

stratigraphy as envisioned at Site 316 was thought to consist of 0.7 sec of highly stratified oozes and chalks over chert, underlain by perhaps 0.3 sec of pre-Eocene sediments over basalt. One problem with the proposed site was the prevalence of a bumpy bottom and, apparently, a locally channeled and partially stripped sedimentary cover. In steaming down the axis of the trough it became apparent that the stratigraphy of the post-Eocene reflectors drilled at Site 315 could be followed southeastward, although the total thickness of the section gradually decreased.

It seemed desirable to drill at a site (1) where the acoustic-stratigraphy could be easily correlated with that of Site 315 and (2) such that the distance between the site and Sites 165 and 315 would be sufficient to test the "hot spot," linear distance versus cessation of volcanism argument. A site near the northwest limit of the SOTW-11 survey seemed to fit these requirements. Accordingly, on crossing the SOTW-11 line a brief site survey was carried out (Figure 4) to put us near the SOTW-11 line between 1650Z and 1730Z 9 December 1972. The beacon was dropped at 2125 (local) on 21 November 1973. The correlations of reflectors between the SOTW-11 line and Site 316 is shown on Figure 2 and a similar comparison between Sites 316 and 315 is shown on Figure 3. On departure, a seamount or ridge was crossed approximately 10 n.mi. southeast of Site 316 (Figure 5).

Sonobuoy Survey

A sonobuoy was released at 2220 (local) on 21 November about 30 min before the site was occupied, but failed to return usable records. A second sonobuoy was then deployed which, during the period of its useful life, was carried about 10 km west by the strong equatorial current that prevails at the site. This unit provided records that permitted depths to reflectors in the area to be calculated (see below).

Heave Compensator

The heave compensation apparatus was considered ready for testing by the Cruise Operations Manager, and was accordingly rigged at 0630 (local) 22 November, after the drill string had been lowered to a position about 15 meters above PDR depth for the sea floor. During testing prior to spudding in, the Olmstead valve of the heave compensator malfunctioned and the test of the compensator was aborted at about 0915 (local). Considerable difficulty was experienced in raising the compensating pistons in order to stow the apparatus. Accordingly, spud-in was delayed until 1200 (local), and we lost altogether about 6 hr of drilling time at the site.

Drilling Program

Some difficulty was experienced in feeling bottom with the bit, and the pipe depth of 4464.5 meters to bot-

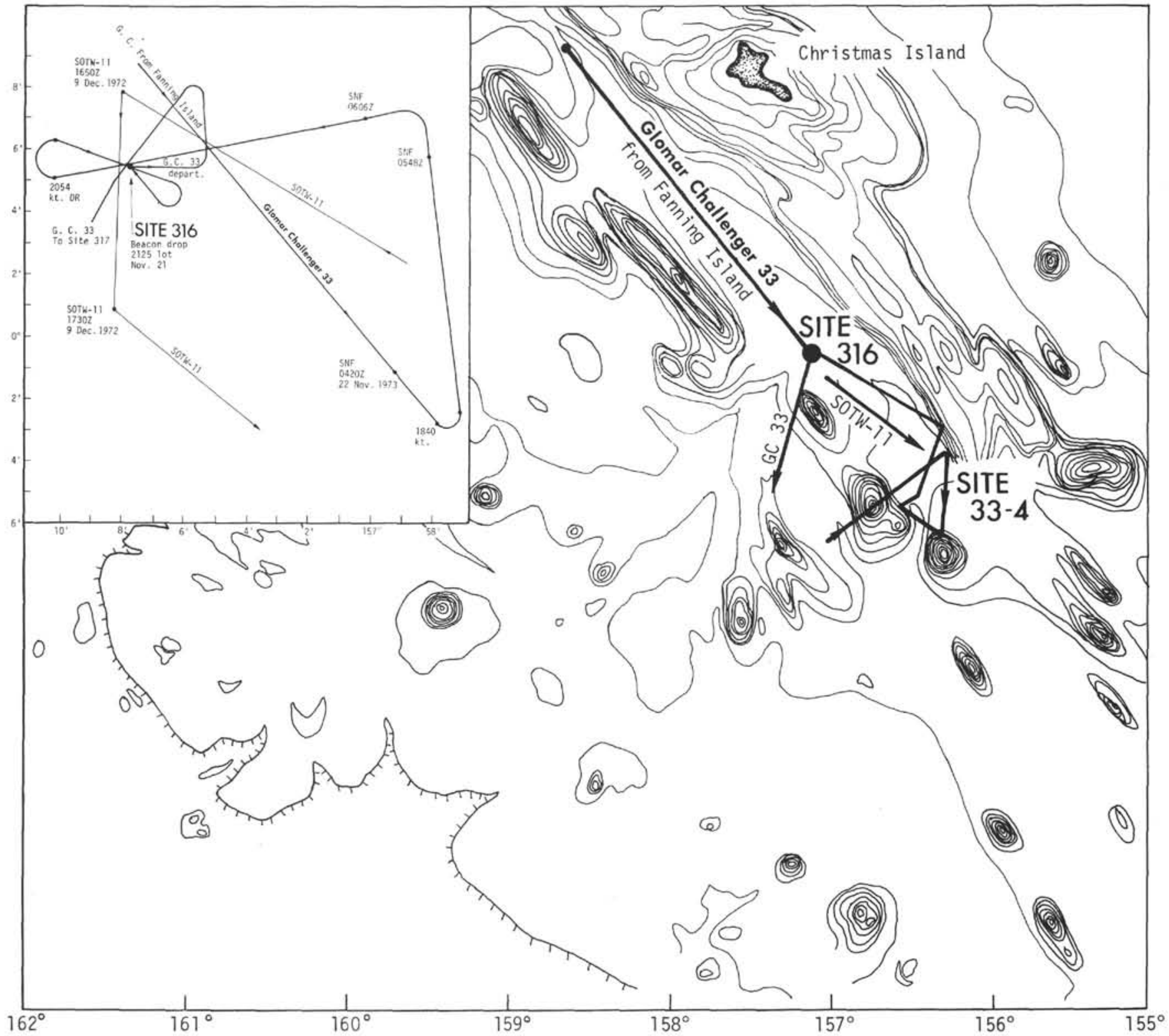


Figure 4. *Bathymetry of the southern Line Islands showing* Glomar Challenger *Leg 33 and SOTW-11 tracks; bathymetry by Winterer and Mammerickx (from Winterer, this volume).*

tom was 7.7 meters deeper than that calculated from PDR readings. The first core attempted was a 9.5-meter punch core at the bottom, which recovered soft, white, nannofossil ooze. The second core was taken between 153 and 162.5 meters, and contained upper Miocene ooze. The third core was cut between 267.0-276.5 meters to attempt to core a seismic reflector; indeed, an unconformity within the Miocene was found in the core. The fourth core was cut at 390.5-400.0 meters to core a second reflector, and again, an upper and middle Oligocene section was missing within the cored interval. The fifth core was taken for stratigraphic control at 447.5-457.0 meters. An upper Eocene unconformity was detected in the core, and we estimated that we were nearing the Eocene chert and would encounter difficult drilling conditions. Continuous coring was therefore begun, and for the most part continued from 447.5-590.0 meters. Spot coring was then resumed, and continued to the bottom of the hole.

Below about 630 meters, drilling time became increasingly longer, and, in our estimation, units of equal hardness required nearly three times the drilling time below the chert than above it (Figure 6). At the completion of drilling, we were advised that the bit retained between 2 and 12 hr of usefulness. On withdrawing the string, the center points of the bit cones were found to be severely buttoned, and one cone bearing had failed.

In summary, we drilled a total of 837.0 meters of rock, and recovered 30 cores, the last at 0630 (local) 25 November. The hole was terminated because of slow drilling rates, leg scheduling, and because we had fulfilled the primary objective of the hole, although we did not reach basement. A summary of drilling results is given in Table 1.

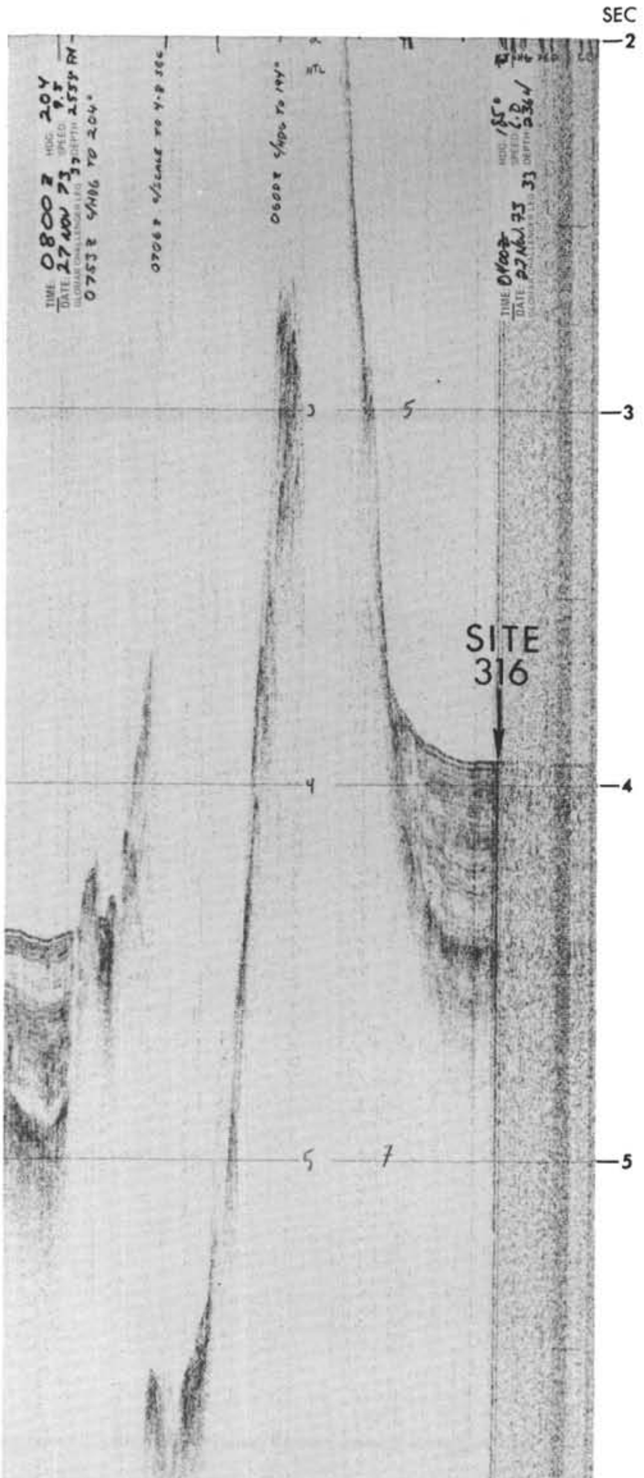


Figure 5. Glomar Challenger *seismic reflection profile on departure from Site 316 (see Figure 4 for line of profile).*

LITHOLOGIC SUMMARY

Sediments at this site are divided into four lithologic units (Figure 6). These same units are lithologically correlative with the upper four units at Site 315. Unit 5, which is a brown ferruginous claystone that lies directly above basalt at Site 315 was not penetrated at Site 316. Whether it is present at Site 316 is not known, inasmuch as coring was terminated before reaching basalt. The four units recognized at Site 316 are:

Unit 1 (0-2.0 m)—A cyclic unit, consisting of white and pale orange calcareous ooze interbedded with yellowish-gray siliceous ooze.

Unit 2 (2.0-380 m)—Unit 2 is divided into two parts; an upper part, Unit 2A, which consists of purple, green, and gray calcareous and siliceous ooze; and a lower part, Unit 2B, which consists of purple, green, and gray calcareous and siliceous chalk.

Unit 3 (380-580 m)—This unit contains abundant brown chert, and calcareous and siliceous chalk, limestone, and dolomite of various shades of brown.

Unit 4 (580-837 m)—Unit 4 consists of grayish-green to greenish-black volcaniclastic breccia. and graded sandstone and grayish-green and white calcareous chalk and limestone.

Unit 1—Cyclic Ooze (0-2.0 m)

Unit 1 is lithologically correlative with Unit 1 at Site 315 and is provisionally correlative with the cyclic unit of the Clipperton Oceanic Formation which occurs over a widespread area of the equatorial Pacific (Tracey, Sutton, et al, 1971; Cook, 1972; 1975). Although at Site 316 Unit 1 is only about 2 meters thick, at least 5 cycles of interbedded brown and white oozes are present. The brown beds are yellowish gray (5Y7/2) to pale yellowish brown (10YR6/2) radiolarian-nannofossil ooze whereas the lighter colored beds are white (N9) to very pale orange (10YR8/2) foraminifer-nannofossil ooze. These beds range in thickness from about 2 to 25 cm. Interbedded with these cyclic units are white 5 to 20-cm-thick beds of foraminifer-rich ooze which contains variable amounts of palagonite and pyroxene or amphibole grains. Many of the palagonite grains are altered to clay minerals and zeolites. These alteration products are probably montmorillonite and clinoptilolite (Cook and Zemmels, this volume).

The cyclic unit appears to be concordantly underlain by the varicolored beds of Unit 2. This contact is gradational over at 25-cm interval through which brown oozes are interbedded with greenish oozes. The contact is placed at the base of the lowest brown bed.

Unit 2—Varicolored Ooze and Chalk (2.0-380 m)

Unit 2 is about 380 meters thick at this site, whereas at Site 315 it attains a thickness of 665 meters. Characteristic of Unit 2A is the presence of brilliant purple, green, blue, and gray oozes that are repeatedly interlaminated in thin (1-10 mm) beds. This unit is correlated with Unit 2 at Site 315 and is provisionally correlated with the varicolored unit of the Clipperton Oceanic Formation which is widespread in the central equatorial Pacific (Tracey, Sutton, et al., 1971; Cook, 1972; 1975).

Typical sediments consist of pale purple (5P6/2) to very dusky purple (5P2/2) foraminifer-nannofossil oozes and radiolarian-nannofossil oozes. Acid-treated insoluble residues show that the purple coloration is present as a coating on the radiolarians and sponge spicules. In some samples, this coating has a pale brassy

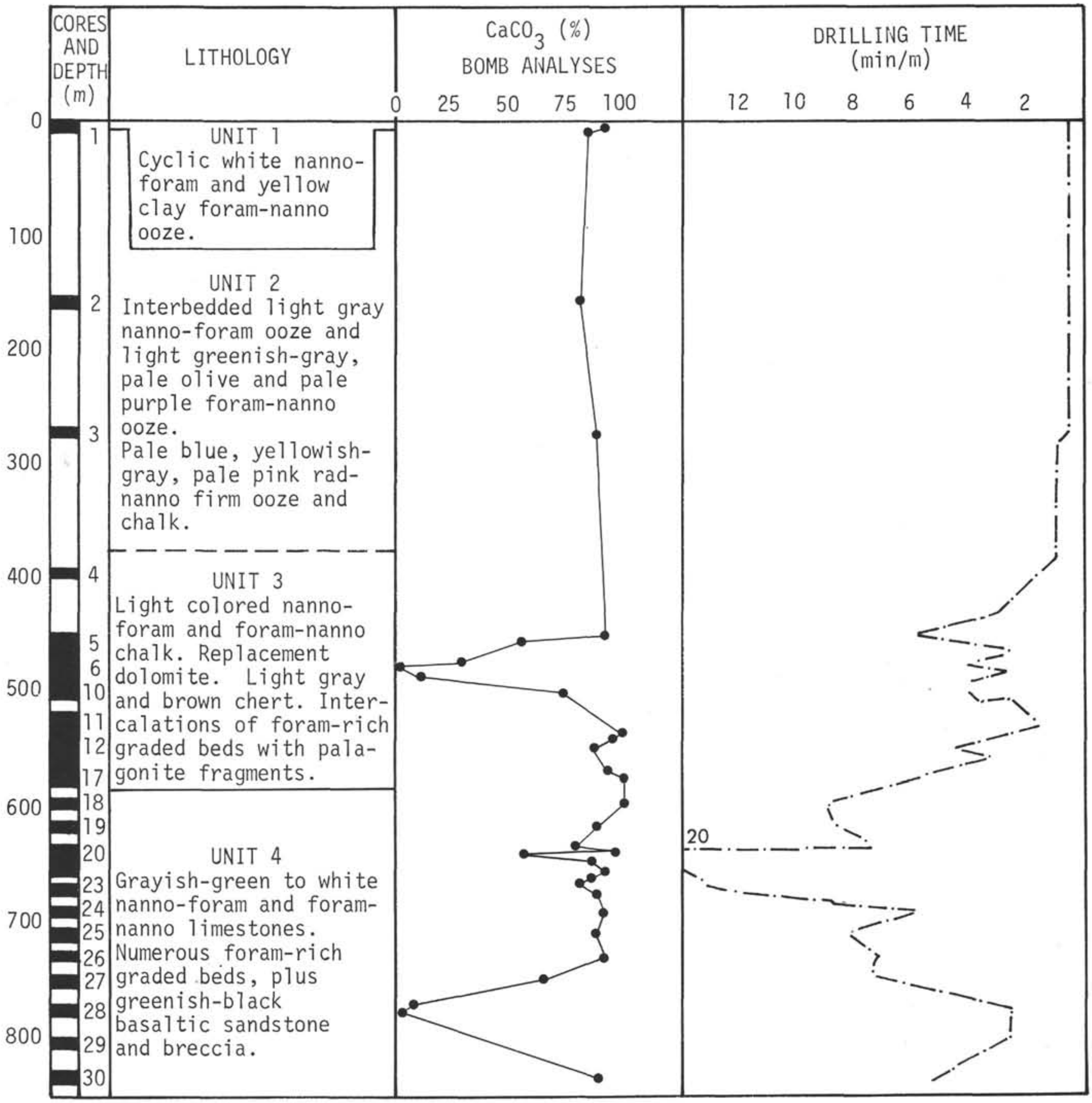


Figure 6. *Graphic log of lithologic units, carbonate content, and drilling rates at Site 316.*

yellow luster in reflected light and probably consists of pyrite. Cook and Zemmels (this volume) report trace amounts of pyrite from Core 3 of this unit. The various blue and green sediments consist of foraminifer-nannofossil oozes and nannofossil-foraminifer oozes that contain lesser amounts of radiolarians. Interbedded with these sediments are coarse-grained light gray (N7) more foraminifer-rich oozes which occur in beds 10-50 cm thick. Insoluble residues of these beds contain palagonite, pyroxene, feldspar, glass, and zeolite grains. X-ray analyses (Cook and Zemmels, this volume) confirm the presence of the zeolites, clinoptilolite, and phillipsite, and also plagioclase and K-feldspar. The sediments are badly disturbed and all primary textures and sedimentary structures are obscure.

Between Cores 1 and 2 the sediments change from oozes to firm oozes. In smear slides of Core 2, Sections 1 and 2 (153-158 m) discoasters already show slight overcalcification.

Core 3 (267.0-276.5 m) has abundant soupy zones which were probably disturbed during coring; however, there are sufficiently undisturbed portions of the core to show that the sediments in at least part of Core 3 are indurated to chalk. On the basis of this lithologic change

TABLE 1
Coring Summary

Core	Date (1973)	Time (local)	Depth From Drill Floor (m)	Depth Below Sea Floor (m)	Length Cored (m)	Length Recovered (m)	Recovery (%)
1	22 Nov	1240	4464.5-4474.0	0-9.5	9.5	9.0	95
2	22 Nov	1520	4617.5-4627.0	153.0-162.5	9.5	2.7	29
3	22 Nov	1740	4731.5-4741.0	267.0-276.5	9.5	2.2	23
4	22 Nov	2024	4855.0-4864.5	390.5-400.0	9.5	2.2	23
5	22 Nov	2255	4912.0-4921.5	447.5-457.0	9.5	1.8	19
6	23 Nov	0040	4921.5-4931.0	457.0-466.5	9.5	CC	<1
7	23 Nov	0232	4931.0-4940.5	466.5-476.0	9.5	2.0	21
8	23 Nov	0415	4940.5-4950.0	476.0-485.5	9.5	0.6	6
9	23 Nov	0750	4950.0-4959.5	485.5-495.0	9.5	1.5	16
10	23 Nov	1010	4959.5-4969.0	495.0-504.5	9.5	1.2	13
11	23 Nov	1225	4978.5-4988.0	514.0-523.5	9.5	1.0	11
12	23 Nov	1415	4988.0-4997.5	523.5-533.0	9.5	1.7	18
13	23 Nov	1610	4997.5-5007.0	533.0-542.5	9.5	1.5	16
14	23 Nov	1820	5007.0-5016.5	542.5-552.0	9.5	1.3	14
15	23 Nov	2015	5016.5-5026.0	552.0-561.5	9.5	0.6	6
16	23 Nov	2220	5026.0-5035.5	561.5-571.0	9.5	3.0	32
17	24 Nov	0027	5035.5-5045.0	571.0-580.5	9.5	2.2	23
18	24 Nov	0445	5054.5-5064.0	590.0-599.5	9.5	6.7	71
19	24 Nov	0910	5073.5-5083.0	609.0-618.5	9.5	5.4	57
20	24 Nov	1325	5092.5-5102.0	638.0-637.5	9.5	5.0	53
21	24 Nov	1810	5102.0-5111.5	637.5-647.0	9.5	5.3	59
22	24 Nov	2245	5111.5-5121.0	647.0-656.5	9.5	4.5	47
23	25 Nov	0350	5130.5-5140.0	666.0-675.5	9.5	6.6	70
24	25 Nov	0722	5149.5-5159.0	685.0-694.5	9.5	7.0	74
25	25 Nov	1145	5168.5-5178.0	704.0-713.5	9.5	7.5	76
26	25 Nov	1640	5187.5-5197.0	723.0-732.5	9.5	7.0	73
27	25 Nov	2020	5206.5-5216.5	742.0-751.5	9.5	6.4	65
28	25 Nov	2255	5235.0-5244.5	770.5-780.0	9.5	2.3	24
29	26 Nov	0235	5263.5-5273.0	799.0-808.5	9.5	1.9	20
30	26 Nov	0630	5292.0-5301.5	827.5-837.0	9.5	2.7	28
Total					837.0	285.0	36.1
Total depth 837.0 meters							

these rocks are separated out as Unit 2B. At this stratigraphic interval calcareous chalks have heavily overcalcified nannofossils, whereas the foraminifers are still well preserved. Much of the micrite in these chalks apparently represents broken fragments of overcalcified nannofossils. Subordinate amounts of the micrite, however, may be broken foraminiferal debris. Smear slides of Core 3, Section 2 (123 cm) illustrate the nannofossil origin of much of the micrite. With downhole increase in induration, burrow structures become better defined.

The contact with the underlying brown rocks of Unit 3 was not cored, but is provisionally placed at about 380 meters (10 m above the top of the brown chalk in Core 4). This is the approximate location of a seismic reflector which is assumed to mark the top of the brown chalks.

Unit 3—Limestone, Chert, and Dolomite (380-580 m)

Unit 3 is about 300 meters thick at Site 316 whereas at Site 315 the same unit has a thickness of only 100 meters (Figure 6).

Although sediments of Unit 3 are quite complex in detail their distinguishing characteristics include brown color, chalk to limestone transitions, abundant brown chert, as well as a brown dolomite sequence. The carbonates are composed of various shades of brown, pink, and gray radiolarian-nannofossil chalk and nannofossil-foraminifer chalk. These chalks exhibit parallel laminations, cross-laminations, burrows, and a variety of postdepositional structures. Interbedded with these above rocks at a few levels are white (N9) chalk beds that grade upward from coarse-grained palagonite- and pyroxene-bearing, foraminifer-nannofossil chalks to nannofossil chalks. These beds have massively bedded bases which change upward to low angle cross-laminations and parallel laminations.

X-ray data show that Unit 3 is further characterized by the relatively high abundance of barite, pyrite, and chlorite in the <20 μm fractions in contrast to its virtual absence in Unit 4 (Cook and Zemmels, this volume).

Brown and gray dolomite beds of lower Eocene age occupy a stratigraphic interval between 467 and 486 meters (Cook, this volume). Through this cored interval about 5 meters of dolomite and interbedded chert were recovered. Although some of the dolomitized rocks exhibit perfectly preserved laminations and burrowed zones, most of the dolomite exhibits no obvious remnants of primary sedimentary structures. These rocks are composed of 25 to 500 μm rhombohedra, many of which have cloudy interiors. Crystals are tightly packed and exhibit interpenetration features that have significantly reduced the potential intercrystalline porosity. Porosity is further reduced because ferruginous specks, clay laths, and poorly preserved fossils occupy most of the intercrystalline space. The calcium carbonate content of three dolomites analyzed by the shipboard "bomb method" (7-1, 144-150 cm; 7-2, 133-135 cm; 8-1, 120-121 cm) shows their content to vary through 1%, 10%, and 30 %. These dolomites were tested for hydrocarbons using a "black light" apparatus with negative results.

Abundant brown, red, white, and gray chert was recovered. These cherts occur in a number of forms which includes wholesale silicification of limestones over several tens of centimeters, small chert nodules, thin chert bands distributed parallel to bedding planes, and cherts which fill fractures in other chert. Thin sections of chert reveal that several factors are probably responsible for controlling silicification patterns in these rocks. These controls include differences in both constituents and permeabilities in the sediments. Thinly laminated rocks with interbedded mud-supported nannofossil layers, and grain-supported foraminiferal layers have the grain-supported fabrics silicified first. This produces thin laminations of chert. Within rocks of uniform texture small nodules of chert form by first replacing the nannofossils in random patches and then filling foraminiferal chambers. This progresses until the foraminifer test walls have been silicified. X-ray analyses of chert from 495.9 meters show the silica phase is dominantly cristobalite with lesser amounts of tridymite and quartz.

Through a long interval from about Core 10 to Core 17 (495-571 m) the sediments are hard chalk with minor limestone interbeds, but starting with Core 17 (571 m), the sediments are mainly limestone with minor chalk interbeds.

Unit 4—Limestone and Volcaniclastic Sediment (580-837 m)

About 250 meters of this unit were penetrated before coring was terminated. The unit is lithologically and stratigraphically correlative with Unit 4 of Site 315, but at Site 316 the unit is more than 250 meters thick, whereas at Site 315 it is about 110 meters thick (Figure 6).

This unit is characterized by its overall dark green color, commonly graded and massively bedded volcaniclastic breccia and sandstone, and abundant graded foraminifer-rich limestone. All of these rock types commonly display moderate to intense burrowing. The mineral content of this unit further serves to differentiate these sediments from the overlying sediments; montmorillonite, clinoptiloliite, analcite, goethite, and hematite are more abundant in Unit 4 than in superjacent units (Cook and Zemmels, this volume).

The dominant lithology, especially in the upper part of Unit 4 is graded layers of light gray nannofossil-foraminiferal limestone with packstone textures that grade rapidly upward into greenish-gray nannofossil-foraminifer and foraminifer-nannofossil limestone with wackestone textures. These beds range from about 5 to 100 cm in thickness and average about 25 cm over a 250-meter interval. It is estimated that there are about 1000 such beds in Unit 4. The base of each unit is generally laminated (1-2 mm) or cross-laminated. Laminations are manifested by selective sorting of green palagonite grains. These coarse basal parts of the beds are foraminiferal limestones with a packstone fabric. Interparticle void space is filled with sparry calcite and poorly preserved fossils. No shallow water benthonic fossils are present. The upper finer textured part of each bed commonly had faint, widely spaced laminations with varying degrees of burrowing in the uppermost few centimeters. As at Site 315, there appears to be an "exponential" decrease of burrowing downward in each graded bed.

In Cores 19, 27, 28, and 29 there are thick (0.35-2.5 m) beds of greenish basaltic-scoria-rich breccia. These breccia beds exhibit a variety of textures and primary sedimentary structures. Some are massively bedded and poorly sorted, with clasts as much as several centimeters across set in a mud-supported fabric. Other beds of volcaniclastic breccia are normally graded and have well-defined laminations and cross-laminations. A wide range of clast types is present in the breccias, including green basaltic scoria, brown basaltic scoria, green montmorillonite-rich volcanic sandstone clasts, white foraminiferal grainstones, nannofossil limestones, and large disc-shaped foraminifera. The shallow water benthonic foraminifer Pseudorbitoidides is present in these breccias (Beckmann, personal communication). At Site 165 and 315 foraminifers of this type were also found at the comparable Maestrichtian-Campanian stage level.

Drilling was terminated at this site before basalt was reached. Whether or not the ferruginous claystones of Unit 5 at Site 315 are present at Site 316 is unknown. However, judging from a comparison of lithology at the two sites, and from a comparison of drilling rate curves and seismic records at Sites 315 and 316, it seems reasonable to assume that basalt was on the order of 10-75 meters below our last core.

A 1 cm × 1 cm × 5 cm clast of basalt was noted in volcanogenic breccia in impacted material in the core-catcher sample of Core 28. Under binocular microscope observation, the clast appeared to be a vesicular basalt with a medium dark gray matrix (N3) and abundant vesicles filled with light olive-gray material (5Y6/1). In thin section the rock proved to be an aphyric scoriaceous basalt. Vesicles are spherical, ranging from 0.2 to 1.3 mm in diameter, and averaging 0.5 mm. More than 90% of the vesicles are filled with calcite; some are concentrically zoned, as though calcite were partially space filling and partially replacing a former inner wall-filling material (clay?). The remainder of the vesicles are filled with what are apparently sheaf-like zeolites. The interstitial, dark, glassy material contains about 20% microlites of plagioclase and pyroxene; the plagioclases are lath-like, and average about 0.01 × 0.05 mm in size; the pyroxenes are blocky and average about 0.02 mm in size. The glassy matrix is altered to dense black palagonitic material.

GEOCHEMICAL MEASUREMENTS

The results of *p*H, alkalinity, and salinity analyses of interstitial waters are summarized in Table 2 and graphically in Figure 7. The calcium carbonate ($CaCO_3$) content of the sediments is shown in Figure 6. Procedures for analysis were those routinely performed aboard ship on *Glomar Challenger.*

Five samples down to a depth of 468 meters were measured before increased lithification reduced recovery of the interstitial waters.

pH Values

From 0 to 468 meters the *p*H values remained below that of surface seawater, which averaged 8.16 at this site.

TABLE 2
Summary of Shipboard Geochemical Data

Sample (Interval in cm)	Depth Below Sea Floor (m)	pH		Alkalinity^a (meq/kg)	Salinity (°/oo)	pH^b	Alkalinity^c (meq/kg)
		Punch-in	Flow through				
Surface Seawater		8.16	8.12	2.35	35.5	8.24	2.33
1-4, 144-150	6	7.33	7.47	2.83	35.5	7.51	3.07
2-1, 144-150	154.5	7.20	7.22	3.42	35.2	7.70	3.44
3-1, 144-150	268.5	–	7.47	2.64	35.2	7.51	2.45
4-1, 144-150	392	–	7.24	2.64	35.2	7.38	2.76
7-1, 144-150	468	–	7.30	1.66	35.5	–	–

[a] Colorimetric titration.

[b] Combination electrode.

[c] Potentiometric titration.

The pH value of samples range from 7.20 to 7.70. Values decreased from 7.5 at 6 meters to 7.22 at 154 meters, then rose to 7.5 at 268 meters, and again decreased to values near 7.35 from 400 to 468 meters depth. A pH value of 7.70 at 154 meters given by the combination electrode technique method was greatly divergent from that given by the punch-in and flow-through methods.

Alkalinity

Values for alkalinity range from 1.66 to 3.44 meq/kg. From 0 to 154 meters values are greater than that of surface seawater, which averages 2.34 meq/kg at this site. In the interval from 260 to 390 meters. they closely approach the alkalinity of surface seawater, and then decrease to 1.66 meq/kg in the dolomitic zone at 468 meters depth.

Salinity

Salinity values range from 35.5 °/oo to 35.2 °/oo, which is equal to or slightly below the average value of 35.5 °/oo for surface seawater at this site.

The above values of pH, alkalinity, and salinity are similar to values for calcareous oozes and chalks from other DSDP sites in the central Pacific area. A change in these three parameters at 468 meters reflects the presence of replacement dolomite found at this depth.

$CaCO_3$

The bulk of the sediments measured fall in the range 75%-100% calcite; the darker colored sediments are generally less calcareous than the lighter ones. Few can justly be described as claystones. This provides a contrast in total $CaCO_3$ with rocks sampled at Site 315A, where basal rocks are claystones, and have very low amounts or are lacking in carbonate. The low carbonate lithologies at Site 316 are cherts and volcaniclastic sandstones.

Considerable amounts of dolomite (54% to 71%) were measured in samples: Core 7, Section 1; Core 7, Section 2; and Core 8, Section 1. These samples were low in calcium carbonate (1% to 24%).

PHYSICAL PROPERTIES

The physical properties methods, presentation in hole and core plots, presentation in tables, and definitions are discussed briefly in the Physical Properties section of the Site 315 report and in detail in Appendix I of this volume, and therefore will not be discussed in detail here.

The GRAPE analog data are displayed in the core scale graphs only. Where the sediment was soft and the core liner completely filled, the analog GRAPE shore-based computer program requires no diameter corrections, and the data are plotted as a single solid line. Where the analog GRAPE scans cores of hard rocks with varying diameter, the data are presented as two lines. The solid line is the routine analog data without correction for core diameter and assuming a 6.61-cm diameter. This line is presented in case it is felt necessary to consult photographs, measure diameters, and apply other diameter corrections for a discrete interval, or simply for the manipulation of data. The dotted line represents data to which diameter corrections have been applied as described in Appendix I of this volume. Where rock segments were very short, the data appear as a series of peaks; only the maximum density of the peak in these cases represents good density values, and the density values of the shoulders of the analog peaks should be ignored.

The GRAPE Special wet-bulk density, gravimetric wet-water content, porosity, sound velocity (perpendicular and parallel to bedding), absolute velocity anisotropy, percentage velocity anisotropy, acoustic impedance, and reflection coefficients are presented in Table 3, with most of these parameters graphically displayed in the site plots and core plots.

The physical properties data are primarily presented in tables and graphs, and only briefly discussed. Detailed discussion and interpretation about the interrelationships of the laboratory physical properties data are treated more thoroughly in Chapter 26, this volume.

Results

Sound velocities, wet-bulk densities, wet-water contents, and porosity were measured or calculated from ooze, chalk, limestone, chert, and volcaniclastic rocks from depths of 0 to 837 meters below the sea floor. Five intervals of typical or characteristic physical properties were noted. All of these intervals do not coincide precisely with the lithologic units described in the Lithology section or with the paleontological zonal boundaries. However, there are some correlations with

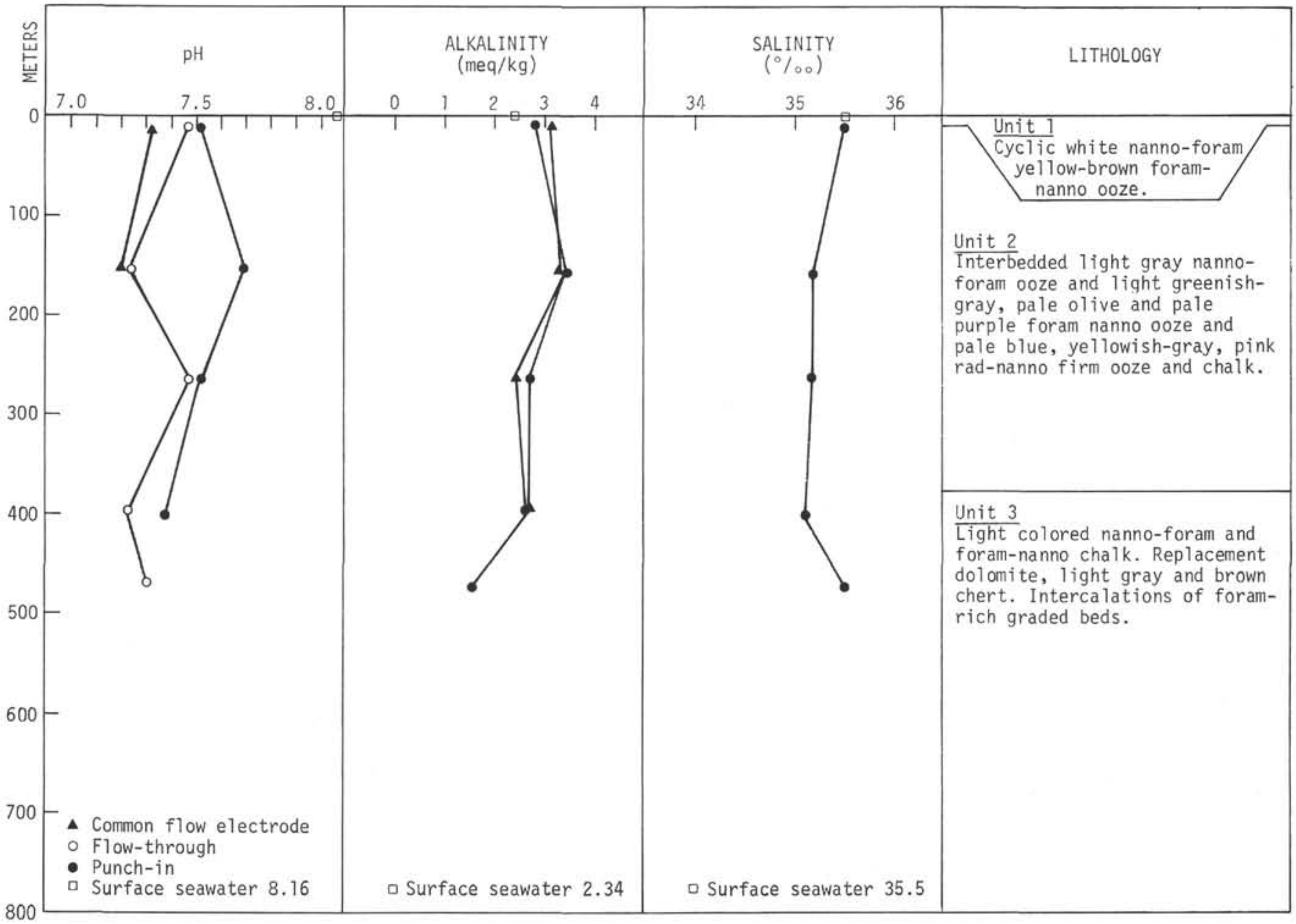


Figure 7. *Graphic log of shipboard* pH, *alkalinity, and salinity measurements at Site 316.*

lithology, sedimentation rate, and drill rate (Figure 6). Of course the accuracy and resolution of these physical property intervals are directly proportional to core spacing and the ability to retrieve unbiased and undisturbed lithologic samples.

The characteristic intervals of physical properties are given in Figure 8, with the interval boundaries indicated by horizontal dashed lines: the first interval is Quaternary to Miocene ooze and chalk from 0 to 268 meters. At 268 meters, in Core 3, an unconformity was noted and a prominent reflector at 0.335 sec is correlated with this depth. The second is the Miocene to Eocene chalk from ~269 to ~457 meters. The third, is Eocene to Paleocene chalk, with layers of chert and dolomite, from ~457 to ~580 meters. At ~580 meters is the contact between the Paleocene and Maestrichtian and a reflector at 0.65 sec is correlated with that contact . The fourth, Maestrichtian to Campanian limestone from ~580 to ~752 meters; and fifth, Campanian volcanogenic clastics from ~752 to 837 meters, where the hole was terminated. These intervals of lithology and corresponding typical physical properties are summarized in Table 4.

The Quaternary to Eocene oozes and chalks are divided into two groups from (1) 0 to ~269 meters and (2) ~269 to ~457 meters, based mainly on the drilling rate at Site 316, which decreased where Core 3 was retrieved and below. The characteristic physical properties of this interval are that the wet-water content of this upper interval is significantly higher than that of the interval below; however, these are disturbed samples and they probably do not represent in situ conditions. The first interval from 0 to ~269 meters is essentially arbitrary, from a laboratory physical property point of view, as the core spacing is extremely great and the cores are disturbed.

Physical property interval 2, ~269 to ~457 meters, is distinguished from interval 3, ~457 to ~580 meters, by an abrupt increase (in interval 3) of sound velocity, wet-bulk density, and acoustic impedance, and a decrease in wet-water content and porosity.

In interval 3, ~457 to ~580 meters, the velocity, wet-bulk density, acoustic impedance (other than chert and dolomite) tend to increase with increasing depth. The bottom on interval 3 is subtly marked where the velocity remains relatively constant with increasing depth, which occurs at approximately 580 meters (arbitrary within a few tens of meters).

Physical properties interval 4, from ~580 to ~752 meters, is characterized by uniform and high wet-bulk density, velocity, and acoustic impedance in limestone. The lower contact is arbitrary due to interlayering of

TABLE 3
Velocity-Density Parameters, Site 316

		Compressional Sound Velocity					"Special" Wet-Bulk Density[a] 2-minute count (g/cc)					
				Anisotropy								
Sample (Interval in cm)	Depth in Hole (m)	∥ Beds (km/sec)	⊥ Beds (km/sec)	∥−⊥ (km/sec)	(∥−⊥) ÷ ⊥ (%)	Temp. (°C)	∥ Beds	∥ Beds	Wet-Water Content Salt Cor. (%)	Porosity[b] (%)	Acoustic Impedance $\frac{g\ 10^5}{cm^2\ sec}$	Lithology
1-3, 141-145	4.42	1.534				20.0			43.67			Foram nanno ooze, disturbed
1-4, 116-118	5.61	1.541				20.0			43.96?			Foram nanno ooze, disturbed
2-2, 135-137	155.86	1.541				20.0			45.94			Rad nanno ooze
3-1, 145-147	268.45	1.556	1.551	+0.005	+ 0.32	21.0		1.541	45.79	70.56	2.39	Rad nanno chalk
3-2, 97-99	269.47	1.598	1.610	−0.012	− 0.75	21.0		1.631	39.20	63.94	2.63	Rad nanno chalk
4-1, 80-87	391.30	1.625	1.611	+0.014	+ 0.87	23.0		1.748	34.29	59.94	2.82	Rad nanno chalk
4-2, 56-59	392.56	1.632	1.605	+0.027	+ 1.68	23.0		1.582	40.16	63.53	2.54	Rad nanno chalk
5-1, 145-147	448.95	1.691	1.647	+0.044	+ 2.67	23.0		1.748	33.69	58.89	2.88	Rad nanno chalk
5-2, 44-46	449.44	1.649	1.625	+0.024	+ 1.48	23.0		1.772	32.59	57.75	2.88	Rad nanno chalk
5-2, 120-122	450.20	4.181				23.0	2.338		4.16	9.73	9.78^c	Chert (ragged edge)
7-1, 138-140	467.88	4.856				22.0	2.396		1.47	3.52	11.63^c	Chert
7-1, 140-144	467.90	2.683				22.0	2.432		10.74	26.12	6.53^c	Dolomitic nanno chalk
7-2, 0-2	468.00	4.287				22.0	2.538		1.73	4.39	10.88^c	Chert
7-2, 21-23	468.21	2.607	2.694	−0.087	− 3.23	22.0		2.314	13.46	31.15	6.23	Dolomitic nanno chalk
7-2, 39-41	468.39	5.141				22.0	2.509		0.88	2.20	12.90^c	Chert
7-2, 125-127	469.25	4.694	4.524	+0.170	+ 3.76	22.0		2.645	4.88	12.91	11.97	Dolomitic nanno limestone
8-1, 116-118	477.16	4.788				22.0	2.694				12.90^c	Dolomitic nanno limestone
9-1, 8-10	485.58	3.943	3.949	−0.006	− 0.15	22.0		2.358	7.86	18.53	9.31	Dolomitic foram nanno limestone
9-1, 102-105	486.52	2.060	2.105	−0.045	− 2.18	22.0		2.130	17.28	36.81	4.48	Dolomitic foram nanno chalk
9-1, 140-145	486.90	4.931				22.0	2.473		2.29	5.66	12.19^c	Chert
9-1, 145-148	486.95	5.277				22.0	2.491		0.33	0.82	13.15	Chert
10-1, 67-69	495.67	2.528	2.416	+0.112	+ 4.64	22.0		2.136	17.06	36.44	5.16	Foram nanno chalk
10-1, 89-94	495.89	5.120				22.0	2.510		4.05	10.17	12.85	Chert
11-1, 98-100	514.98	4.908				20.0	2.471		2.27	5.61	12.13	Chert
11-1, 113-115	515.13	2.168	2.051	+0.117	+ 5.70	20.0		2.106	16.80	35.38	4.32	Nanno chalk
12-1, 144-146	524.94	2.663	2.489	+0.174	+ 6.99	20.0			14.48			Foram nanno chalk
12-2, 118-120	526.18	2.620	2.444	+0.176	+ 7.20	20.0		2.200	17.75	39.05	5.38	Foram nanno chalk
13-1, 37-39	533.37	4.957				20.0	2.465		0.28	0.69	12.22^c	Chert
13-1, 115-117	534.15	2.149	2.000	+0.149	+ 7.45	20.0		2.224	15.97	35.52	4.45	Foram nanno chalk
14-1, 118-120	543.68	2.698	2.384	+0.314	+13.17	23.0		2.321	8.58	19.91	5.53	Foram nanno chalk
14-1, 145-150	543.94	4.772				23.0	2.324		3.02	7.02	11.09^c	Chert
15-1, 90-92	552.90	5.080				22.0			2.00			Chert
16-1, 79-83	562.29		2.913			22.0		2.387	5.68	13.56	6.95	Calcareous sandstone, laminated
16-1, 90-92	562.40	3.026	2.774	+0.252	+ 9.08	22.0		2.375	7.48	17.77	6.59	Foram nanno chalk
16-2, 78-81	563.78	2.879	2.588	+0.291	+11.24	21.0		2.370	6.94	16.45	6.13	Foram nanno chalk
17-1, 81-83	571.81	3.130	2.288	+0.842	+36.80	20.0	2.299		7.03	16.27	5.29	Nanno chalk, laminated and burrowed
17-2, 37-39	572.87	2.617	2.452	+0.165	+ 6.73	21.0	2.400		8.90	21.23	5.85	Foram nanno limestone
17-2, 138-140	573.88		3.498			21.0	2.447	2.479	6.90	17.11	8.67	Foram nanno limestone
18-1, 81-83	581.31	5.153				21.0			0.10			Chert
18-1, 129-131	581.79	3.022	2.697	+0.325	+12.05	21.0		2.323	7.06	16.40	6.27	Foram nanno limestone
18-2, 61.5-63.5	582.61	4.953	4.440	+0.513	+11.55	21.0	2.543	2.513	3.41	8.57	11.16	Foram nanno limestone
18-3, 27.5-29.5	583.77	3.321	3.228	+0.093	+ 2.88	21.0		2.331	6.96	16.22	7.52	Foram nanno limestone
18-4, 49-52	585.49	3.366	3.092	+0.274	+ 8.86	21.0		2.416	1.45	3.50	7.47	Foram nanno limestone
18-5, 129-131	587.79	3.462	3.264	+0.198	+ 6.07	21.0		2.450	6.05	14.82	8.00	Foram nanno limestone
19-1, 80-82	609.80	2.879	2.723	+0.156	+ 5.73	20.0		2.289	12.53	28.68	6.23	Foram nanno limestone
19-1, 140-142	610.40	2.254				20.0	1.931				4.35^c	Graded volcanic sandstone
19-4, 109-111	614.60	2.910	2.703	+0.207	+ 7.66	20.0		2.460	7.94	19.53	6.65	Foram nanno limestone
20-1, 125-127	629.25	2.925	2.759	+0.166	+ 6.02	21.0		2.443	7.67	18.74	6.74	Nanno foram limestone
20-2, 73-75	630.23	3.044	2.838	+0.206	+ 7.26	21.0		2.397	6.70	16.06	6.80	Foram nanno limestone
20-3, 65-67	631.75	3.320	3.108	+0.212	+ 6.82	21.0		2.350	8.86	20.82	7.30	Foram nanno limestone
20-4, 82-84	633.32	2.824	2.624	+0.200	+ 7.62	21.0		2.312	13.90	32.14	6.07	Foram nanno limestone
21-1, 29-30	637.79	3.077	2.909	+0.168	+ 5.78	23.0		2.350	9.70	22.80	6.84	Foram nanno limestone
21-2, 58-60	639.58	3.131	3.027	+0.104	+ 3.44	23.0		2.283	15.15	34.59	6.91	Foram nanno limestone
21-3, 31-33	640.81	3.286	3.045	+0.241	+ 7.91	23.0		2.371	10.64	25.23	7.22	Nanno foram limestone
21-4, 127-129	643.27	3.230	2.952	+0.278	+ 9.42	23.0		2.259	11.13	25.14	6.67	Foram nanno limestone
22-1, 41-43	647.41	3.266	3.033	+0.233	+ 7.68	23.0		2.454	7.35	18.04	7.44	Nanno foram limestone
22-2, 86-88	649.36	3.559	3.196	+0.363	+11.37	23.0		2.411	10.12	24.40	7.71	Nanno foram limestone
22-3, 144-146	651.44	3.108	3.042	+0.066	+ 2.17	23.0		2.451	5.81	14.31	7.46	Nanno foram limestone
23-1, 120.5-122.5	667.20	3.037	2.851	+0.186	+ 6.52	23.0		2.461	5.29	13.02	7.02	Nanno foram limestone
23-2, 109-111	668.59	3.319	3.783	−0.464	−12.27	23.0		2.321	7.90	18.34	8.78	Foram nanno chalk
23-3, 93-95	669.93	3.330	2.888	+0.442	+15.30	23.0		2.440	4.37	10.66	7.05	Nanno foram limestone
23-4, 5-7	670.55	3.112	2.837	+0.275	+ 9.69	23.0		2.437	6.39	15.57	6.91	Foram nanno limestone
23-5, 94-96	672.94	3.891	3.386	+0.505	+14.91	23.0		2.569	5.59	14.36	8.70	Foram nanno limestone
24-1, 85-87	685.85	3.331	3.074	+0.257	+ 8.36	22.0		2.446	8.23	20.13	7.52	Nanno foram limestone
24-2, 59-61	687.09	3.206	3.091	+0.115	+ 3.72	22.0		2.347	9.92	23.28	7.25	Nanno foram limestone
24-3, 104-106	689.04	3.154	2.946	+0.208	+ 7.06	22.0		2.369	11.26	26.67	6.98	Nanno foram limestone
24-4, 54-56	690.04	3.283	2.832	+0.451	+15.93	22.0		2.424	8.22	19.93	6.86	Foram nanno limestone
24-5, 99.5-101.5	691.99	3.168	2.903	+0.265	+ 9.13	22.0		2.338	9.27	21.67	6.79	Nanno foram limestone
25-1, 48-50	704.48	3.263	2.937	+0.326	+11.10	22.0		2.441	9.49	23.17	7.17	Foram nanno limestone
25-2, 67-70	706.17	3.142	2.791	+0.351	+12.58	22.0		2.409	9.29	22.38	6.72	Foram nanno limestone
25-3, 91-93	707.91		3.207			22.0		2.319	10.39	24.09	7.44	Foram nanno limestone
25-5, 48-50	710.48	3.103	2.920	+0.183	+ 6.27	21.0		2.330	10.14	23.63	6.80	Nanno limestone
26-1, 84-86	723.84	3.333	2.985	+0.348	+11.66	21.0		2.406	6.40	15.40	7.18	Clayey foram nanno limestone
26-2, 96-98	725.46	3.536	3.093	+0.443	+14.32	21.0	2.420	2.416	8.48	20.49	7.47	Clayey foram nanno limestone
26-3, 72-74	726.72	3.465	3.067	+0.398	+12.98	21.0	2.412	2.406	7.53	18.12	7.38	Clayey foram nanno limestone
26-4, 48-50	727.98	2.579	2.256	+0.323	+14.32	21.0	2.345	2.328	10.37	24.14	5.25	Clayey nanno limestone
26-5, 122-124	730.22	3.341	3.017	+0.324	+10.74	22.0	2.350	2.337	8.43	19.70	7.05	Foram nanno limestone
27-1, 76-78	742.76	3.815	3.490	+0.325	+ 9.31	22.0	2.451	2.472	7.41	18.32	8.63	Foram nanno limestone
27-1, 127-129	743.28	2.331				21.0	2.088				4.87^c	Volcanic sandstone
27-2, 71-73	744.21	3.316	3.009	+0.307	+10.20	22.0	2.447	2.445	10.56	25.82	7.36	Foram nanno limestone
27-3, 14-16	745.14	2.419				22.0	2.045		21.47	43.91	4.95^c	Volcanic sandstone
27-4, 86-88	747.36	3.381	3.142	+0.239	+ 7.61	22.0	2.406	2.392	9.27	22.17	7.52	Foram nanno limestone
27-5, 52-54	748.52	2.629	2.437	+0.192	+ 7.88	22.0	1.943	1.927	24.70	47.60	4.70	Volcanic sandstone
28-1, 72-74	771.22	2.596	2.556	+0.040	+ 1.56	23.0	1.930	1.916	17.35	33.24	4.90	Volcanic breccia
28-2, 106-108	773.06	2.642	2.529	+0.113	+ 4.47	23.0	1.924	1.995	23.96	47.80	5.05	Volcanic breccia
29-2, 79-101	801.49	2.661	2.512	+0.149	+ 5.93	23.0	1.893	1.922	25.29	48.61	4.83	Volcanic sandstone
30-1, 52-54	828.02	2.701	2.413	+0.288	+11.94	22.0	1.903	1.898	27.14	51.51	4.58	Volcanic sandstone
30-2, 134-136	830.32	3.490	3.225	+0.265	+ 8.22	22.0	2.302	2.304	12.32	28.39	7.43	Foram nanno limestone

[a] ρ_g & ρ_{gc} = 2.70 for sed. rocks, 2.65 for cherts, and 2.86 for basalt.

[b] Porosity = (salt corrected wet-water content) X (wet-bulk density).

[c] Horizontal.

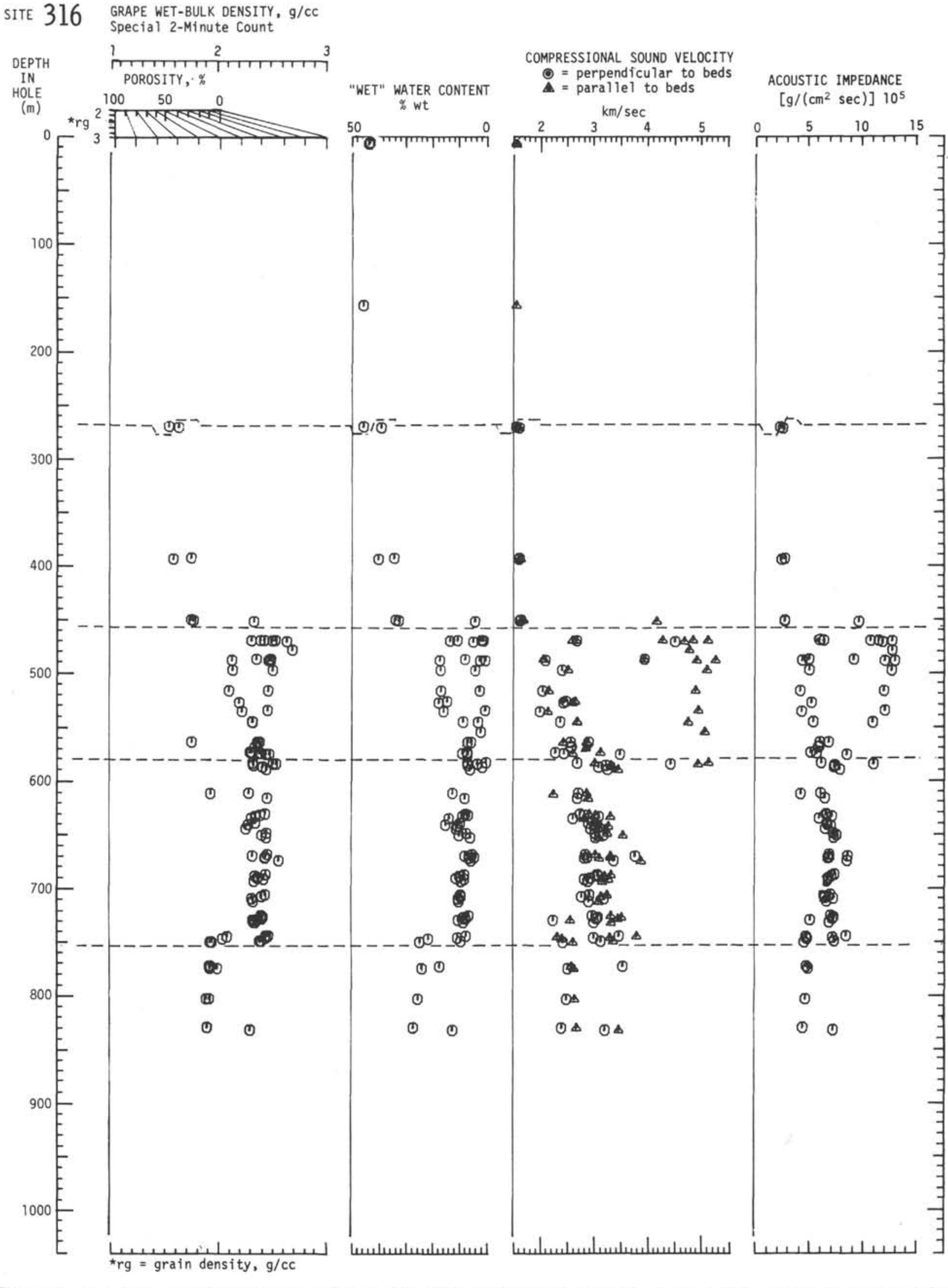


Figure 8. *Summary of physical properties at Site 316. GRAPE analog data, both corrected and uncorrected for actual core diameter, are presented separately at the end of this chapter.*

TABLE 4
Site 316 Summary of Stratigraphic Grouping on the Basis of Rock Physical Properties (Lab Temperature Pressure)

Lithology	Depth (m)	Cores	Typical Wet-Bulk Density (g/cc)	Typical Wet-Water Content (wt %)	Typical Porosity (vol %)	Typical Sound Velocity (km/sec)	Typical Acoustic Impedance $\frac{g\ 10^5}{cm^2\ sec}$	Typical Reflection Coefficient at Boundary (no chert)
Foram nanno, rad nanno ooze and chalk: Quaternary to late Miocene	0 to ~269	1-3	1.54-1.67 disturbed	43-46 disturbed	70? disturbed	1.53-1.55 disturbed	2.39 disturbed	0.05
Rad nanno, nanno foram, and nanno chalk: Mid Miocene to Eocene	~269 to ~457	3-5	1.63-1.78 (chert 2.34)	32-40 (chert 4.0)	59-64 (chert 9)	1.60-1.65 (chert 4.18)	2.54-2.88 (chert 9.8)	0.39
Foram nanno, nanno foram, and nanno chalk: Chert and dolomite layers: Eocene to Paleocene	~457 to ~580	5-17	2.1-2.7 generally increasing with depth (chert, dolomite 2.3-2.5)	6-17 generally decreasing with depth (chert, dolomite 0.3-4)	12-39 generally decreasing with depth (chert 0.7-10)	2.0-2.5V 2.1-2.7H generally increasing with depth (chert, dolomite 4.2-5.3)	4.0-9.0 generally increasing with depth (chert, dolomite 9-13)	-0.02
Foram nanno, nanno foram, nanno limestone: Maestrichtian to Campanian	~580 to ~752	18-27	2.30-2.45	5-11	11-30	2.7-3.2V 2.9-3.4H	6.0-7.5	-0.02
Volcanogenic claystone, siltstone, sandstone, breccia, and conglomerate; thin limestone layers: Campanian	~752 to ~837	28-30	1.95 1.9-2.3	25 12-27	49 29-51	2.50V 2.65H	4.5-5.1	

Note: V = vertical, H = horizontal.

volcaniclastics and core spacing, but was arbitrarily selected at about 752 meters because the drill rate has a significant decrease here.

The fifth physical property interval from ~752 meters to ~837 meters is marked by significantly lower velocity, wet-bulk density, and acoustic impedance, and higher porosity and wet-water content in the volcanic clastics compared the overlying limestone. The hole was terminated in this interval.

Discussion

The reflection coefficient for a density-velocity change in Core 3 at 268 meters is very small (0.05), yet seems to be sufficient to provide a good reflection at 0.335 sec. If this is correct, then the reflection may be the result of an abrupt change or contact between two basic lithologic units with subtle differences.

Another item of interest is velocity anisotropy. Sound velocity is generally faster in a direction parallel to bedding. the Miocene to early Oligocene chalk, 0 to ~457 meters, has an anisotropy of about 0 to 2.5%, while Eocene-Paleocene chalk from ~457 to ~580 meters has increasing anisotropy with increasing depth, with 4% to 18% with 6% to 12% being typical. The greatest anisotropy appears to occur in cemented claystone, clayey limestone, and some limestone. There are a few significant negative anisotropies, but error in these cases cannot be precluded, or perhaps caused by burrows, cracks, veins, nodules, etc. The anisotropy data are discussed further in Chapter 26, this volume.

Sound velocity anisotropy in the sedimentary rocks and the low velocity volcaniclastics underlying high velocity limestones are significant to the proper interpretation of refraction data. In addition, the anisotropy is significant when using refraction data to interpret reflection profile records.

Other items of interest are several very long uniform core sections, which were rare in the analog GRAPE, which continuously scanned the density of these 1.5-meter sections. An example of a continuous record of limestone is Core 23, Section 4. In a few cases density variations were exponential, with interbedded or graded lithologic contacts.

CORRELATION OF REFLECTION PROFILE WITH DRILLING RESULTS

The acoustic stratigraphy in the vicinity of Site 316 is well displayed on the seismic profiler record obtained by *Glomar Challenger* during the traverse from Site 315 to 316, and the final 24 hr of record (Figure 9) shows in a striking manner the gradual thinning of the spacings between easily traced prominent reflectors. The close resemblance between the right-hand (northern) end of the profile in Figure 9, and the seismic profile obtained at Site 315 (see Figure 4 in the report for Site 315, Chapter 3) suggests that the same reflectors are present at both sites. At Site 316, the profiler record shows the following succession of acoustic units:

1) An upper unit with weak internal reflectors, about 0.075 sec thick. This unit tends to be more transparent in its lower part.

2) A persistent reflector at 0.075 sec below the sea floor.

3) A stronger, very persistent reflector at about 0.215 sec. The upper limit of this reflector is difficult to discern on the record in the immediate vicinity of Site 316, but it is well developed regionally.

4) A weak reflector is visible at 0.265 sec, but this reflector cannot be consistently followed on the records away from the site. Below this level, and down to the next reflector, the sediments are acoustically nearly transparent.

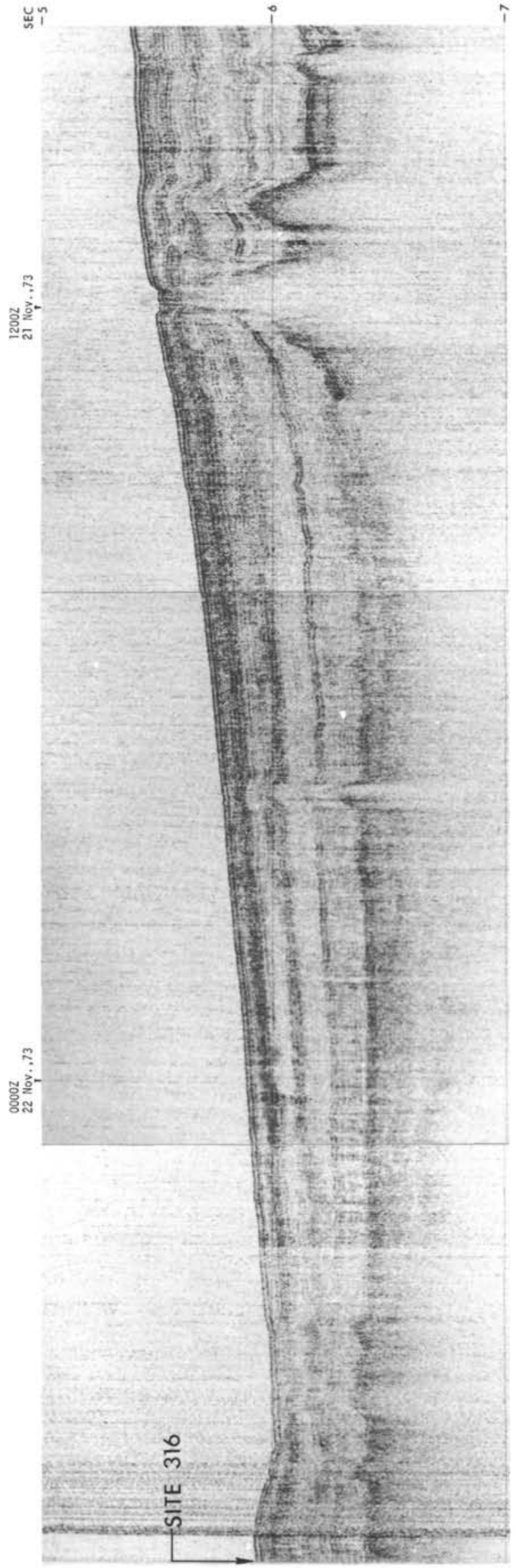


Figure 9. *Seismic reflection profile obtained from* Glomar Challenger *during 24 hr preceding arrival at Site 316. The spacing between prominent reflectors steadily diminishes along the line of the profile.*

5) A very persistent and strong reflector at 0.335 sec.

6) A less persistent reflector at 0.39 sec can be recognized on the records at Site 316.

7) A strong reflector, the clearest and most persistent one in the region, occurs at 0.475 sec. The much weaker and less persistent reflector visible in some places about 0.03 sec above the strong reflector is not certainly identifiable at Site 16.

8) A very fuzzy reflector can be discerned at about 0.65 and 0.71 sec, overlain by a somewhat transparent interval about 0.05 to 0.10 sec thick. This deepest reflector observable of the *Glomar Challenger* profiler record can be followed back along the track for about 100 km (Figure 9).

A sonobuoy released from *Glomar Challenger* at Site 316 was carried during the 2-hr period of its useful life about 10 km to the west of the site by a strong equatorial current of about 3 knots. The record (Figure 10) gave results as shown in Table 5.

The most plausible sequence of acoustistratigraphic units at Site 316, as inferred from the seismic profiles, sonobuoy, drilling rate, and cored stratigraphic sequence is shown in Table 6 and displayed graphically in Figure 11. The 0.335-sec reflector is correlated with a hiatus in the middle Miocene section; the 0.475-sec reflector is correlated with a hiatus between the lower Oligocene and lower Miocene sections and the 0.65-sec reflector correlates with the contact between Maestrichtian and Paleocene strata.

This acoustistratigraphic succession resembles that at Site 315, as shown in Table 7. The values in this table suggest slightly higher velocities at Site 316 for the Neogene section, and slightly lower velocities for the pre-Neogene strata, but the uncertainties in estimating the interval velocities are so great that considerably more data would be needed to establish real differences in velocity structure between the two drilling sites.

PALEONTOLOGY

Biostratigraphic Summary

The biostratigraphy of Site 316 is summarized in the site log at the end of this chapter. In the interval overlying the Eocene chert horizons (0-457 m), five cores containing a total of only 18 meters of sediment were recovered. The post-Eocene depositional record at this site, therefore, is poorly represented, and only limited interpretations can be made. The interval between the chert horizons and the Cretaceous/Tertiary boundary (457 to 585 m) was cored continuously, but core recovery was low (15%). The Cretaceous section (585 to 837 m) was alternately cored and drilled, with good recovery (~60%) in the cored intervals.

Each of the microfossil groups (foraminifers, calcareous nannoplankton, radiolarians, silicoflagellates) is well represented in the Neogene cores (1 through 3). Cores from below the Neogene are barren of silicoflagellates. Cores from below the lower Oligocene (Core 5, Section 2) are barren of radiolarians. Foraminifers are present in all but five of the Cenozoic cores, but preservation is poor in the lower part of the section because of diagenetic effects. Nannofossils are present in all cores,

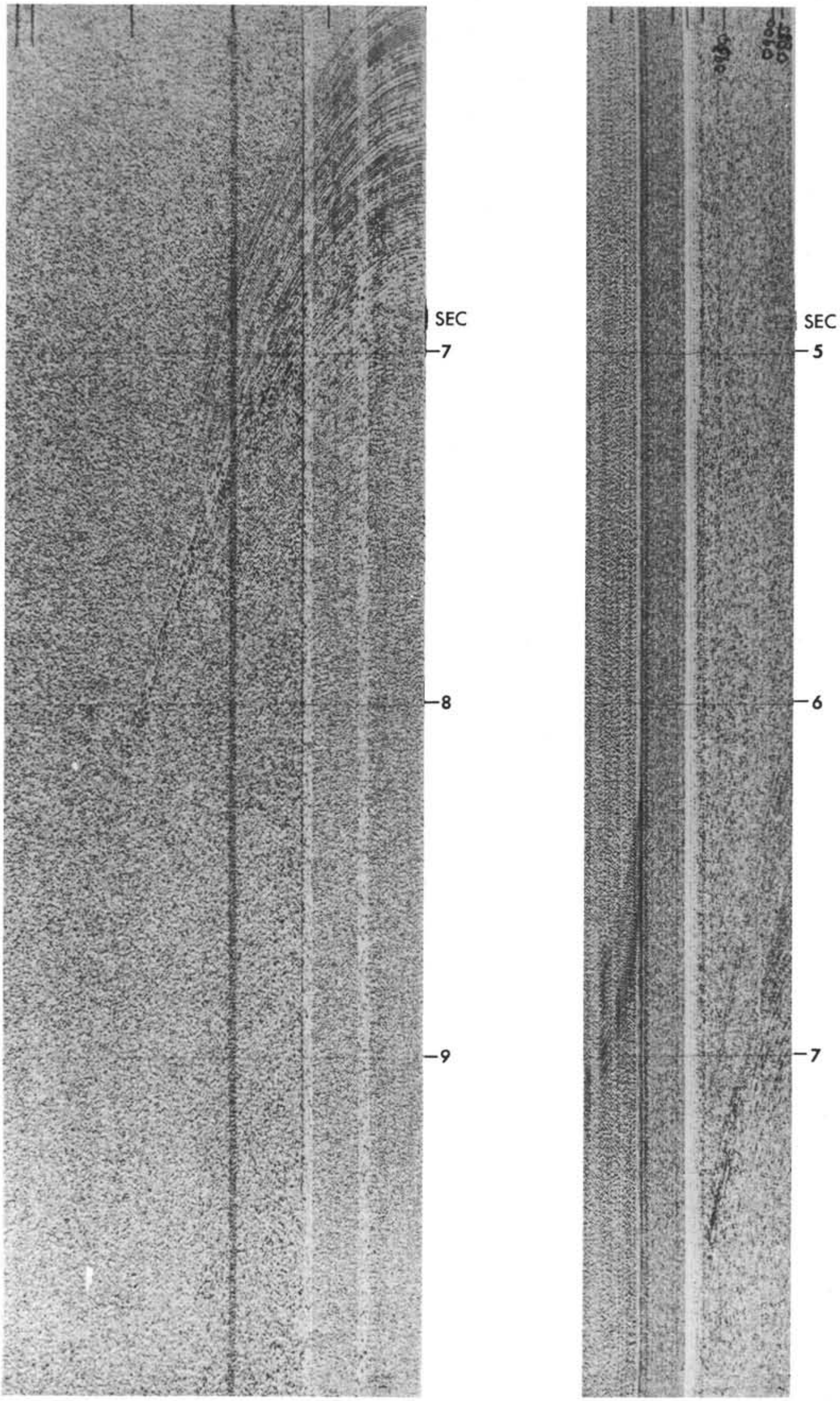


Figure 10. Glomar Challenger *sonobuoy record obtained at Site 316.*

TABLE 5
Shipboard Sonobuoy Results, Site 316

Two-Way Reflection Time Below Sea Floor (sec)	Average Velocity From Sea Floor to Reflector (km/sec)[a]	Deduced Depth To Reflector (m)	Interval Velocity of Unit Above Reflector (km/sec)
0.075	1.52	57	1.52
0.215	1.55	167	1.57
0.335	1.60	268	1.68
0.475	1.61	382	1.63
0.71	1.84	653	2.31

[a] Velocity of sound in water column = 1.502 km/sec (from Matthews tables).

but assemblages in parts of the section, especially in the lower Eocene and Maestrichtian material, are severely altered by the dissolution and/or recrystallization of calcite.

Five principal unconformities were observed in the material recovered. Some of these depositional hiatuses may correlate approximately with observed acoustic reflectors at this site. The locations of these unconformities, and the approximate interval of material missing, are listed below:

Core-Section	Depth Below Sea Floor (m)	Missing Interval (m.y. approx.)
316-3-2	275	~3
316-4-1	400	>10
316-5-2	456	>7
316-14/15	557	~2
316-17/18	580-590	~5

Cenozoic Foraminifers

Foraminifers were recovered from all but five of the cores from the Cenozoic sequence cored at Site 316. Core 5 is in a radiolarian facies and barren of planktonic foraminifers, and Cores 6, 7, and 8 contain dolomitic sediments that were not sampled for foraminifers. The upper part of the sequence (Cores 1-4) comprises lower Oligocene to Quaternary calcareous oozes in which the foraminiferal fauna has generally undergone considerable solution. Foraminifers are abundant in the lower part of the sequence (Paleocene-lower Eocene) but preservation is poor owing to diagenetic effects.

Core 1 contains a typical equatorial Pacific Quaternary assemblage dominated by *Globorotalia tumida, Pulleniatina obliquiloculata, Globoquadrina pseudofoliata,* and *G. dutertrei.* Also present are frequent *Globorotalia truncatulinoides.* Based on the occurrence of *P. obliquiloculata finalis*, the core is of upper Pleistocene age.

Core 2 is of upper Miocene age, belonging either in the *Globorotalia menardii* or *G. acostaensis* zones. The latter is more likely based on the overall aspect of the fauna. The marker for the zone is absent, but results at Site 315 indicate that it is extremely scarce in its zonal interval and may, in addition, be missing as a result of dissolution, which is rather pronounced in Core 2. Reworked specimens of lower and middle Miocene species were also noted in the assemblage from Core 2 (*Globorotalia siakensis, G. fohsi robusta,* and *G. Kugleri*).

The assemblage of Core 3 (upper lower to lowermost middle Miocene) shows a high degree of dissolution and is from a largely radiolarian facies. It consists dominantly of *Globorotalia mayeri* and *Globoquadrina venezuelana*

TABLE 6
Acoustistratigraphic Units, Site 316

Two-way Reflection Time Below Sea Floor (sec)	Depth Below Sea Floor (m)	Lithology	Average Velocity From Sea Floor to Base of Unit (km/sec)	Interval Velocity (km/sec)
0-0.075	0-57	Soft ooze	1.52	1.52
0.075-0.215	57-167	Firm ooze to soft chalk	1.55	1.57
0.215-0.335	167-268	Soft chalk	1.60	1.68
0.335-0.475	268-391	Chalk	1.61	1.76
0.475-0.65	391-580	Chalk, cherty chalk, cherty limestone, dolomite	1.78	2.2
0.65-0.71	580-666	Limestone	1.88	2.9
0.71-[0.92]	666-[912][a]	Limestone, sandstone	2.0	2.4[b]

[a] Assuming 75 meters of sediments between TD and basement.

[b] From sonic velocity measurements on cores.

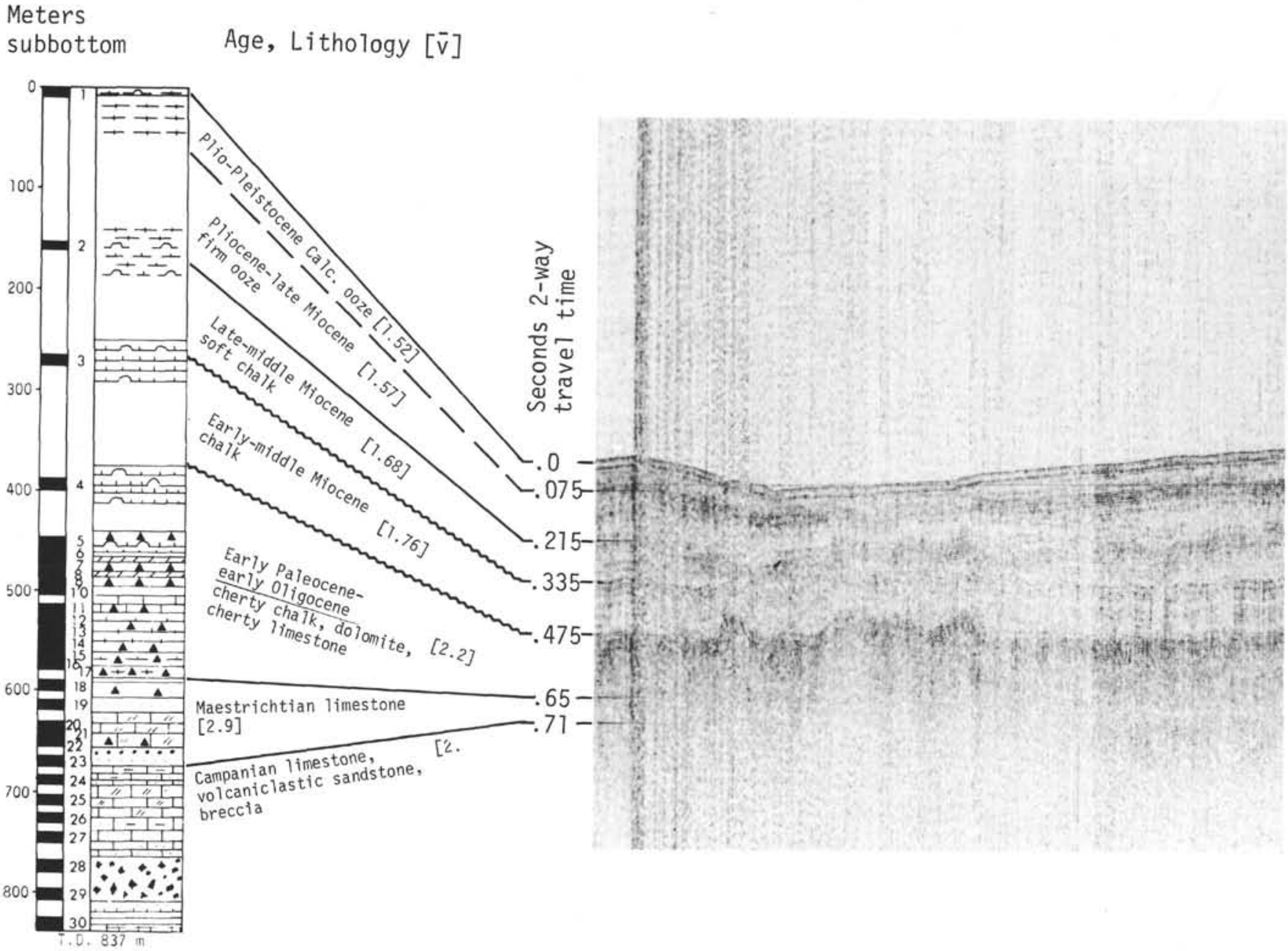


Figure 11. *Correlation of* Glomar Challenger *seismic reflection profile with the section drilled at Site 316.*

with rare specimens of *Globorotalia siakensis* and *Globoquadrina dehiscens* and trace specimens of *Sphaeroidinella seminulina* and *Globorotalia peripheroronda.* A firm zonal assignment cannot be made, but the sample probably belongs in the *Globigerinatella insueta* interval of the upper lower Miocene or possibly in the lowermost middle Miocene.

The core catcher of Core 4 contains a seemingly fairly well preserved, but unusually limited fauna of lower Oligocene age. The fauna is of pre-*opima* and pre-*ciperoensis* age but if this is true, the absence of *Globigerina ampliapertura* and members of the *G. tripartita-sellii* and *gortannii* groups is puzzling. The fauna consists of abundant to common *Globorotalia* cf. *G. opima, G. galavisi,* and *G. angustiumbilicata,* frequent *G. prasaepic* and *Catapsydrax dissimilis,* and rare *G. ouchitaensis, G. anguliofficinalis,* and *Cassigerinella chipolensis.* Nannofossils indicate a lower Oligocene age (NP22), suggesting a placement in the *G. ampliapertura* Zone. As seen elsewhere in Leg 33, *G. ampliapertura* seems to be a solution-susceptible form.

Core 5 is in a radiolarian facies and is barren of planktonic foraminifers.

Cores 6, 7, and 8 contain dolomitic sediments that were not sampled for foraminifers.

TABLE 7
Comparison of Acoustic Stratigraphy at Sites 315 and 316

Site 315		Site 316	
Depth Interval (m)	Interval Velocity (km/sec)	Depth Interval (m)	Interval Velocity (km/sec)
0-115	1.54	0-57	1.52
115-312	1.56	57-167	1.57
115-312	1.56	167-268	1.68
312-510	1.64	268-391	1.76
510-560	1.68	268-391	1.76
560-725	1.71	391-580	2.2
725-790	2.25	391-580	2 2
790-850	3.3	580-666	2.9
850-996	2.3	666-[912]	(2.4)

The limestones or hard chalks of the lower part of the Cenozoic section, including Cores 9 through 17 generally contain abundant foraminifers of Paleocene to lower Eocene age, but preservation is extremely poor owing to recrystallization and overgrowth. Also, most foraminiferal tests in these cores show extreme deformation as a result of compaction and/or diagenetic effects. Most assemblages are "dwarfed," but this is more likely a result of the disaggregation technique used to obtain specimens from the indurated sediments rather than ecological factors. Nonetheless, identification of some of the more distinctive marker species allowed the placement of these cores in the planktonic zonal sequence.

Core 9 contains an abundance of spiny globorotalliids of lower Eocene aspect. Core 10 contains specimens tentatively identified as *Globorotalia subbotinae* (= *G. rex*) of the lowermost Eocene. Cores 11 and 12 yielded a number of specimens of *G. velascoensis* of the upper Paleocene *G. velascoensis* Zone. The assemblage of Core 13 was not identifiable; the assemblages of Cores 14 and 15 are similar, though Core 14 contains rare specimens of ?*G. pseudomenardii* Zone. Core 16 contains abundant foraminiferal specimens, but without keeled globorotalliids, indicating placement in the lower Paleocene. The assemblage of Core 17 of early Paleocene age (as indicated by nannofossils) includes a considerable admixture of Cretaceous species.

Mesozoic Foraminifera

The Cretaceous succession at Site 316 is less volcanogenic and more calcareous than that at Site 315. Contamination and/or contemporaneous mixing appears common and is confusing in the upper part of the sequence, obscuring zonal relations.

The lower part of Core 17 and upper part of 18 contain a mixture of Cretaceous and Tertiary foraminifers, in which the latter are dominant. This fauna suggests Tertiary, containing reworked Cretaceous forms. However nannofossils indicate Cretaceous contaminated by Tertiary.

Cores 19 through 22 yield unquestionable Maestrichtian foraminifers. However zonal markers, such as *G. gansseri*, *G. contusa*, occur sporadically, and uncommon to rare forms of other species occur out of order. Considered in a general way, the middle of the interval, Core 21, is most typical of the *G. gansseri* Zone, but even so the upper and lower limits of the zone could not be determined.

Samples 23-1, 138-140 cm through 27-4, 133-135 cm can be safely assigned to the upper Campanian *Globotruncana calcarata* Zone.

Cores 28, 29, and 30 lie below the *G. calcarata* appearance horizon and are assigned to the *G. elevata* Zone, although only 30, CC yielded foraminifers, and they are long-ranging Campanian benthonics.

Calcareous Nannoplankton

At Site 316 five survey cores were taken between 0 and 450 meters, followed by more or less continuous coring down to the terminal depth of 837 meters, with some spacing between cores in the lower part of the section. Nannoplankton in the 30 cores recovered indicated a succession from Recent to the uppermost lower Campanian, with some major unconformities in the Tertiary.

Core 1 (0 to 9.5 m) contains calcareous nannoplankton of the Quaternary Zones NN19 to NN21. In Core 2 (154 to 163.5 m) *Discoaster quinqueramus* was found, indicating the presence of the upper Miocene Zone NN11. The upper part of Core 3 (267 to 276.5 m) belongs to Zone NN10, whereas the lower part contains nannoplankton of the middle Miocene Zones NN5 and NN6. In Core 4 (390.5 to 400 m) another unconformity is present as indicated by the calcareous nannoplankton of the lower Miocene Zone NN1 in the upper part and of lower Oligocene age (Zone NP22) in the lower part. A third unconformity was found in Core 5 (447.5 to 457 m) between lower Oligocene Zone NP21 and middle Eocene Zone NP16. Except in Cores 1, 2, and the lower part of Core 3, preservation of the calcareous nannoplankton is poor, with dissolution-affected assemblages and heavy excess calcite on discoasters. The lower Eocene and Paleocene section was continuously cored, although assemblages encountered are poorly preserved and placement into the standard nannoplankton zonation is somewhat questionable. Preservation in the Paleocene is slightly better, perhaps a result of a shallower depth of deposition during this interval. Another unconformity may be present between Cores 14 and 15, at approximately 505 meters, as nannoplankton Zones NP6 and NP7 are missing, even though this interval was continuously cored. The lowest core in the Paleocene is Core 17 (572.5 to 572 m), in which a nannoplankton assemblage of Zone NP3/4 (highest Danian equivalent) was encountered. Cores 18 to 30 penetrated middle Maestrichtian to lower Campanian, the latter encountered only in the lowest core. The cretaceous nannoplankton are poorly preserved and heavily reduced in diversity by dissolution throughout most of the section with, however, some improvement within the volcanic sandstones of the Campanian interval. The Upper Cretaceous nannoplankton zones of Roth (1973) as well as Bukry (1973) were found to be only of partial use, with some zones nonexistent by their definition. Consequently the same marker species as for Hole 315A (*Marthasterites furcatus, Tetralithus aculeus, T. gothicus, T. trifidus*) were used to subdivide the Maestrichtian and Campanian. The ranges of some species in the Campanian and Maestrichtian, the subdivision used at Holes 315A and Site 316, and correlation with the zones of Roth and Bukry are shown in the chapter on Nannoplankton (Martini, Chapter 9, this volume).

Radiolarians

Radiolarians are abundant and well preserved in all samples down to the top of the chert at a depth of 457 meters beneath the sea floor. No radiolarians were found in any of the samples below this level. Extensive and varied sample preparation techniques for extracting radiolarians were performed on numerous sediment types from the chert and underlying sediments. All of these procedures proved to be unproductive. A possible explanation is that virtually all the silica originally deposited as radiolarian tests at this site during the Late Cretaceous and Early Tertiary was subsequently remobilized and accumulated in the form of chert.

Within the radiolarian-rich sediments cored, the following zones can be recognized: Core 1 (0-9.5 m) lies entirely within the Quaternary. Core 2 (153-162.5 m) lies entirely within the *Ommatartus antepenultimus* Zone. The base of the *O. antepenultimus* Zone lies within Core 3, Section 1 (268 m). There is an unconformity between Section 1 and Section 2 of Core 3 (269 m); Section 2 lies within the *Dorcadospyris alata* and *Calocycletta costata* zones, and the remainder of Core 3 lies within the *C. costata* Zone. The base of the *Calocycletta virginis* Zone lies within Core 4, Section 2 (393 m). The *Lychnocanoma elongata* Zone was observed in a single sample within Core 4, Section 2, 83-85 cm. The underlying material in Core 4 is within the lower *Dorcadospyris ateuchus* Zone. Core 5 lies with the *Theocyrtis tuberosa* Zone. Radiolarians are absent in all samples examined from below Core 5 (457 m).

Silicoflagellates

Silicoflagellates occur only in Cores 1 to 3 in varying numbers, and as usual are associated with diatoms. They show a low species diversity due to the equatorial position of Site 316. The *Dictyocha epiodon* Zone and *Mesocena quadrangula* Zone are present in Core 1 (0 to 9.5 m) and the *Dictyocha rhombica* zone was identified in Core 2 (104 to 113.5 m) and the upper part of Core 3 (267 to 276.5 m). In Core 3 an unconformity with several nannoplankton zones missing marks the last common occurrence of silicoflagellates. Below, in Core 3, Section 2, 30-31 cm, only a single specimen of *Dictyocha* cf. *rhombica*, probably belonging in the *Dictyocha triacantha* Zone, was found.

ACCUMULATION RATES

In spite of the fact that operational constraints necessitated a spot rather than a continuous coring program at Site 316, including a minimum program in the Miocene and younger portion of the section, usable data on accumulation rates were acquired; these are summarized in Figure 12, where coring depth in meters is plotted against time. It is apparent from the figure that accumulation rates at Site 316 from Pleistocene to late Eocene time are somewhat less than those at Site 315. Inasmuch as we were able to follow a number of reflectors (see Figure 9) along the traverse between the two sites, it is apparent that the Tertiary accumulation rate change is gradual, and not abrupt. Comparison of accumulation rates between the two sites shows a reversal in Eocene time, and Site 316 shows a considerably greater accumulation rate than Site 315 from Paleocene time through all of the Cretaceous section drilled. If the Lower Maestrichtian-Campanian accumulation rate were extrapolated to basement in the same manner as was done for Site 315, basalt could lie as much as 70-150 meters beneath the bottom of Site 316, although other lines of evidence (see Lithology section) place the most probably depth of basalt at about 10-75 meters below deepest penetration. The exceedingly rapid accumulation rates in the Cretaceous at this site influenced our decision to terminate the hole at 837.0 meters subbottom.

SUMMARY AND CONCLUSIONS

Site 316 was drilled in a water depth of 4464.5 meters, at a location about 100 n.mi. south of Christmas Island. The site was chosen in a trough that lies between Line Islands seamounts between 1650 and 2450 meters below sea level. In spite of less time at the site than had been anticipated, due largely to installation and subsequent abortive testing of the heave compensation apparatus, most of the objectives of the site were met.

The principal objective of Leg 33 was to test the "Hot Spot" theory that postulates a progressive younging of cessation of volcanic activity from northwest to southeast along the Line Islands chain. The results from Site 165 of Leg 17 (Winterer, Ewing, et al., 1973) and Sites 315 and 316 of Leg 33 indicate that the date of cessation of volcanism as defined by the age of the youngest basalt flows is essentially coeval along the 1270-km length of the chain embraced by Sites 165, 315, and 316. Table 8 summarizes the arguments for this conclusion.

At Site 165 the oldest datable zone above basalt is the *Eiffelithus eximus* Zone (Roth, 1973; Bukry, 1973). The base of this zone, at a depth of 396 meters, was approximately 40 meters above the stratigraphically highest basalt encountered, which lay between 424 and 451 meters. The sedimentation rate during Late Cretaceous at Site 165 was probably close to 15 m/m.y. considering the nature of the rapidly deposited volcaniclastic debris; the date of cessation of volcanism at Site 165 can thus be placed at between 79 and 83 m.y.B.P. At Site 315 the oldest datable zone above basalt is at a depth of 915 meters, and is the top of the *M. furcatus* Zone at 80 m.y.; the interval from these fossils to basalt, which lay at a depth of 997 meters, is 82 meters. The sedimentation rate at Site 315 for this part of the section was probably similar to that at Site 165, giving a probable age for the youngest basalt of approximately 85 m.y.B.P. At Site 316 basalt was not reached. The oldest datable fossil zone was found at the bottom of the hole at a depth of 837 meters, and is considered to be lower Campanian in age, in the *T. aculeus* Zone. If basalt at this site lay immediately below the bottom of the hole, it would have a minimum age of between 77 and 80 m.y.B.P. The sedimentation rate at Site 316 during Late Cretaceous was approximately 25 m/m.y., and it is unlikely that the basalt lay more than 75 meters below the bottom of the hole, an estimate based on a correlation of drilling rate curves and lithologic units (Figure 6) and on the extrapolation of the sedimentation rate (Figure 12). The maximum age for the cessation of volcanism at Site 316 would be 81 to 83 m.y.B.P., if this depth were used.

If basalt flows and thin sills that underlie the sedimentary sections at the three sites have probable ages of 79-83 m.y., 85 m.y., and 81-83 m.y. from north to south, respectively, it can be said from present data that the cessation of flow-type volcanism at the three sites is coeval, insofar as uncertainties in the data permit correlation. If one turns to the Hawaiian chain as the best dated example for comparison, 1270 km, on a great circle, would extend roughly from Kilauea to northwest of French Frigate Shoals. La Perouse Pinnacle (French Frigate Shoals) and Pearl and Hermes Reef are roughly 12 and 20 m.y. old, respectively (Dalrymple et al., 1974; Clague et al., 1975). If one instead chooses the rate of cessation of volcanism along the Emperor chain for comparison a chain whose ages are only very roughly known (Scholl et al., 1973; Clague and Dalrymple, 1973; Larson et al., 1973; and Clague et al., 1975), then the edifices near Site 316 should be about 16 m.y. younger than those near Site 165.

Turning to the volcanogenic sediments that occur at all three sites, one finds bits of volcanic debris in sediments as young as Pleistocene, but the first recognizable beds occur, at all three sites, in the

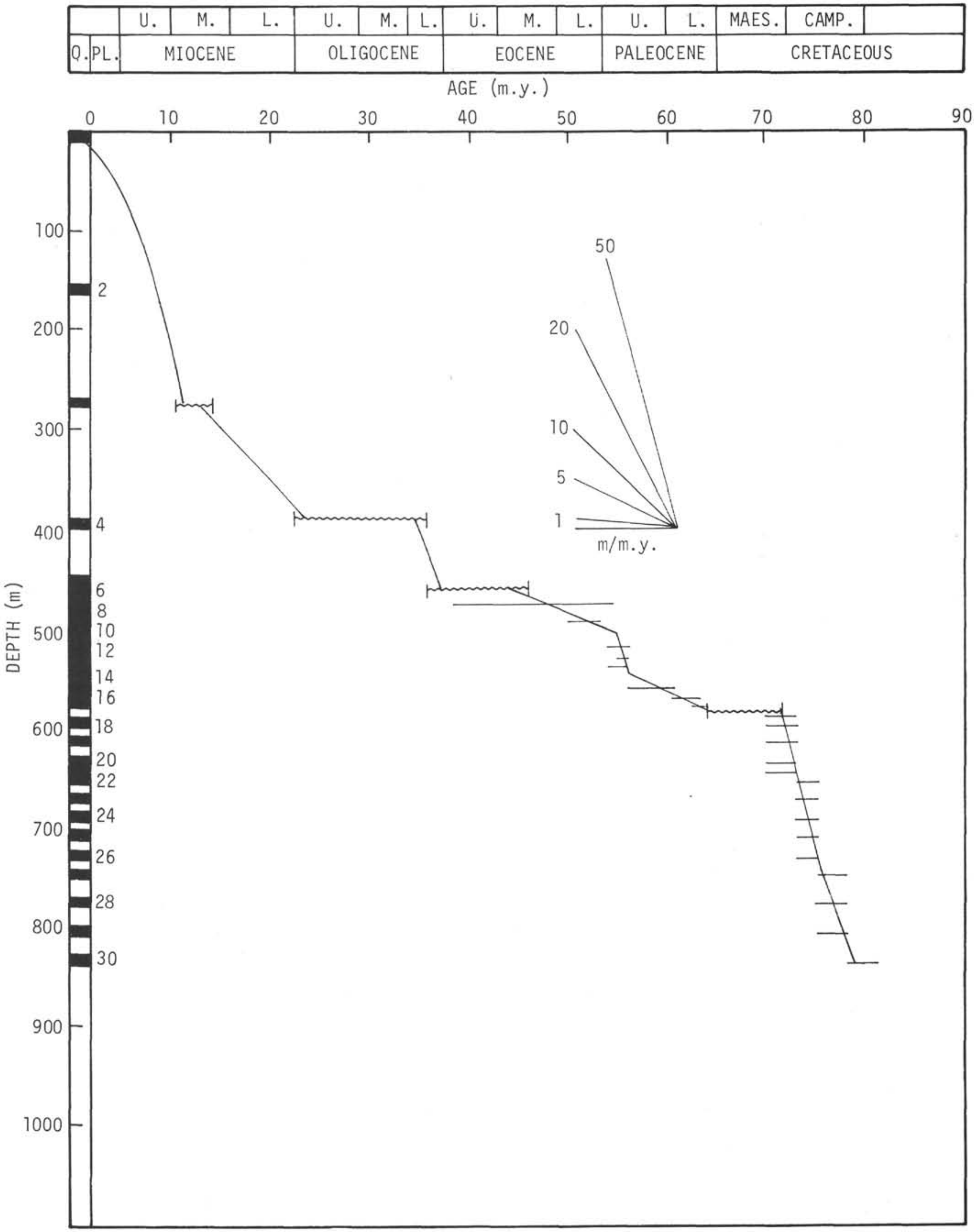
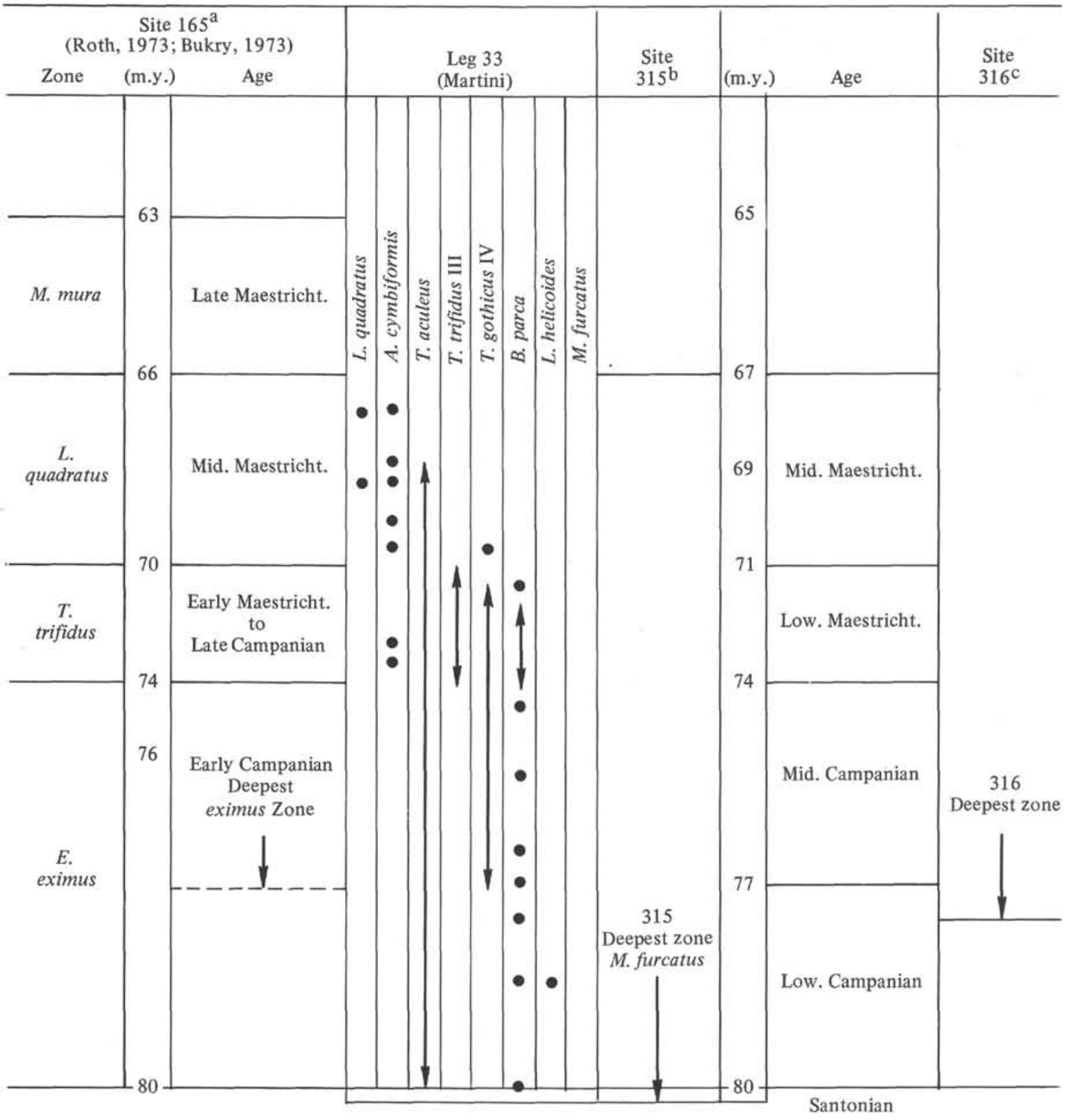


Figure 12. *Graphic log showing rate of sediment accumulation at Site 316.*

TABLE 8
Comparative Ages of "Basement" at Sites 165, 315, and 316



[a] 40 meters of sediment (@ 15 m/m.y.*) lay between base of *E. eximus* and uppermost basalt flow. Probable age of youngest basalt = >76 <80 +3 m.y. or 79-83 m.y.

*See text for discussion of sedimentation rates.

[b] Approximately 80 meters of sediment (@ 15 m/m.y.) lay between *M. furcatus* and the basalt. Probable age of the youngest basalt ≅ 85 m.y.

[c] x meters of sediment are beneath the oldest zone (*T. aculeus*) at approximately 77-80 m.y. The sed rate at 316 ≅ 25 m/m.y.; the drilling rate curve and the lack of Unit 5 (seen at 315) suggest approximately 75 meters of sediment. Probable basalt age = 81-83 m.y.

Maestrichtian, become more abundant and coarser in the Campanian, and are present in the Santonian at sites where rocks of this age have been drilled. These volcanogenic rocks, where fine-grained, are composed largely of altered (commonly described as palagonitized) glass with shard-like shapes, mixed with broken plagioclase, pyroxene, and calcite grains (Winterer, Ewing, et al., 1973; see also Lithology sections of this report and that for Site 315). Where coarser, they are poorly sorted, but contain altered glass and basalt fragments as large as several centimeters (Winterer, Ewing, et al., 1973; Lithology section, this report). Although the basalt fragments at Site 165 have not been described in detail, those at Site 316 are scoriaceous vitrophyres that contain tiny microlites of pyroxene and plagioclase, and that bear little resemblance to the flows at Site 165 or Site 315 (Bass et al., 1973; Site 315, Lithology, and, this report). One must question, therefore, whether the volcanogenic beds at the three sites are locally derived, or were carried into deeper water by growing and eroding edifices some distance away, which may or may not be contemporaneous with the basement flows. Again, turning to the Hawaiian analogy, a period of intense erosion of volcanic debris occurs from about 1 to 6 m.y. after Hawaiian edifices form (Stearns, 1966; Macdonald and Abbott, 1970); but, of course, these edifices continue to shed small amounts of debris throughout their lifetimes. The span of maximum erosion time compares very favorably with the heavy concentration of Campanian debris associated with basalt flows of general Santonian-Campanian boundary ages, but a detailed comparison of the composition, mineralogy, and the texture of the volcanic debris with the composition, minerology, and texture of the basalts which they overlie is badly needed. It is clear that along the flanks of edifices and in the basins between the main portion of the Line Islands seamount chain, neither the basement basalts nor the thick volcanogenic debris that lies above them, young appreciably to the south (Figure 13).

If the Morgan (1972a, b) hypothesis were correct, then a hot spot would be required to move within the limits of our error in dating, which, conservatively estimated, would lead to a hot spot movement rate of some 12 to 21 cm/yr over this major segment of the chain, assuming all our errors were in a direction favorable to the hypothesis. We think this unreasonable. If the Shaw and Jackson (1973) model for Hawaii is entertained, then we have sampled three areas of episodic volcanism that occurred at average rates far in excess of those observed in the Hawaiian-Emperor chain. We think this unlikely and fortuitous. Other possibilities include (1) younger coeval volcanism over an entire, very old, linear island chain of the Wilson-Morgan type some 80 m.y. ago; (2) that the Line Islands seamount chain represents coeval central plate eruptions along a set of en echelon fractures, or (3) that the Line Islands seamount chain represents a trapped mid-oceanic ridge, active until about 80 m.y. ago.

The second major objective at Site 316, that of studying the petrology of volcanic rocks that underly the site, was not met in that operational constraints caused the hole to be terminated before basaltic flows or sills were encountered.

The third major objective of Site 316 on the other hand, that of deciphering the postvolcanic geologic history of the Line Islands seamount chain through a study of the stratigraphy and chronology of the sedimentary rocks above basement, met with considerable success. The sedimentary section of Site 316 may be subdivided into four major units and one subunit as follows:

1) Cyclic ooze, white to yellowish-gray foraminifer, nannofossil, radiolarian ooze that occupies the interval 0-2 meters, and which is Quaternary in age.

2A) Variegated ooze; greenish, olive, and purple foraminifer, nannofossil, radiolarian ooze that occupies the interval between 2 and 267 meters depth. This unit is Quaternary to middle Miocene is age. A minor hiatus separates this subunit from 2B below.

2B) Variegated chalk; greenish, bluish, and bluish-white radiolarian nannofossil chalk, and bluish-white foraminifer nannofossil chalk that occupies the interval between 267 and 380 meters. This unit is middle Miocene to lower Miocene in age.

3) Variegated chalk and chert; white, yellowish-brown, and gray radiolarian nannofossil chalk and foraminifer nannofossil chalk; tan to reddish-orange to brown chert, and a few beds of dolomitic chalk and dolomite. This unit occupies the interval from 380 to 580 meters and is lower Oligocene through Paleocene is age. Hiatuses of more than 10 m.y. occur in Core 4 at a depth of 400 meters; of more than 7 m.y. in Core 5 at a depth of 456 meters; of about 2 m.y. between Cores 14 and 15 at a depth of about 557 meters; and of about 5 m.y. at the base of the section, between Cores 17 and 18, at a depth of about 580-590 meters.

4) Chalk, limestone, chert, and volcaniclastic claystone, sandstone, and breccia; in general the chalk, limestone, and chert dominate the upper part of this unit, and volcanogenic fragmental rocks dominate the lower part, in a total interval of 580-837 meters. The unit ranges in age from middle Maestrichtian through lower Campanian, as dated by both foraminifers and nannoplankton.

Unit 5 of Site 315 is missing in this section and appears to lie at still greater depths than those drilled. The presence of dolomite here further distinguishes the section from that at Site 315. In general, the accumulation rate of rocks above the Eocene chert is less at Site 315, but the rocks below the Eocene have considerably greater accumulation rates at Site 316 than at Site 315.

A remarkable coherence continues to be maintained among the lithostratigraphic and chronostratigraphic units above basement at Sites 165, 315, and 316, despite the minor differences noted above. Lithologic and chronologic correlations between the three sites are discussed in detail in Chapter 31, this volume.

Larger forams (pseudorbitoids) were found only in the lowest part of the section, in a sandy volcanogenic turbidite. They therefore occur lower in the section than larger forams at Site 315, which are lower still than those at Site 165. In Core 23 abraded tests of the large foraminifer *Sulcoperculina* and bryozoan? and mollusc fragments were seen in thin sections. The presence of these large benthonic foraminifers here, as at the other two sites, indicates that Late Cretaceous shallow water debris from a reefal environment was being at least locally provided to the volcanogenic sediments. The source of this shallow water debris is unknown, and may have been from a local ridge or seamount that has subsided since Late Cretaceous time. It seems unlikely, but not impossible, that these larger foraminifer tests could have been derived from a site as distant as Christmas Island.

At Site 316, in order to save time and yet drill as far as possible toward basement, it was decided to sparsely spot core the interval above chert. In an approach down the trough axis from Fanning Island the thinning of the stratigraphic section seemed regular, and the shallow reflectors seen at Site 315 could be tentatively correlated

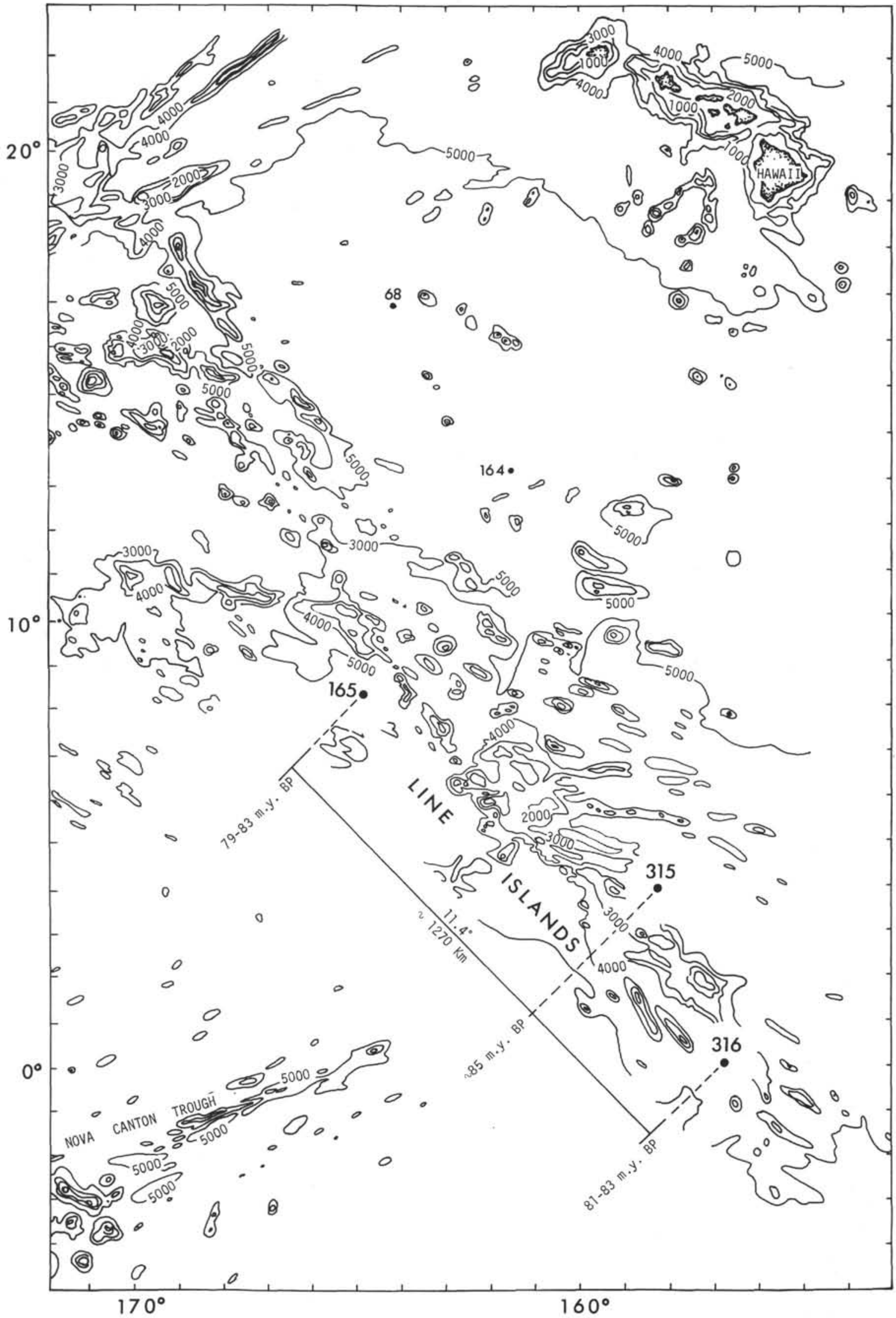


Figure 13. *Map showing probable age of uppermost basalt flows along the Line Islands chain as determined by drilling at DSDP Sites 165, 315, and 316.*

TABLE 9
Results of Attempts to Core Specific Reflectors in the "a" to "d" Series at Site 316 Using a Velocity Structure Derived From Site 315

Predicted Reflector/Age (m.y.)[a]	Site 315 Two-way time	Site 316 Two-way time[b]	V km/sec To Reflector (316)	Predicted Depth to Reflector (m)	Interval Cored	Age at Cored Depth
"a"/3	0.15	0.08 (0.075)	1.54	61.6	Not cored	By interpolation on sed. rate graph ~3 m.y.
"b"/5-6	0.28	0.20 (0.215)	1.55	155	153-162.5 (316-2)	0.5-10 m.y.
"c"/13-14	0.40	0.34 (0.335)	1.56 1.60	265 272	267-276.5 (316-3)	NN 10 base @ 10.5 NN 6 top @ 13
"d"/22-26	0.64	0.48 (0.475)	1.59 1.63 1.65	382 391 396	390.5-400 (316-4)	NN upper 21–22 NP 22 33 ~23 m.y.

[a] Schlanger and Douglas (1974).

[b] Numbers not in parentheses from profiler record; numbers in parentheses from sonobuoy record.

with the shallow reflector at Site 316 (Figure 9). An experiment was devised to test the correlation and the regional applicability of the "a" to "d" series of reflectors proposed by Schlanger and Douglas (1974). Three intervals were chosen to core the reflectors at ~0.20, 0.34, and ~0.48 sec using the velocity structure determined at Site 315. The results are summarized in Table 9. The Site 316 two-way travel times to the "a" to "d" reflector series given in this table differ slightly from the two-way travel times given in Table 5, since the former were picked prior to arrival at the site and the latter were picked from on site sonobuoy data. The values in parentheses for Site 316 in Table 9 are the sonobuoy results. Also, analyses of the sonobuoy data allowed identification of a reflector at 0.65 sec that marks the Cretaceous-Tertiary boundary, and another at 0.71 sec within the Cretaceous. At Site 316 the "c" and "d" reflectors lie at hiatuses as shown by missing biostratigraphic zones in Cores 3 and 4.

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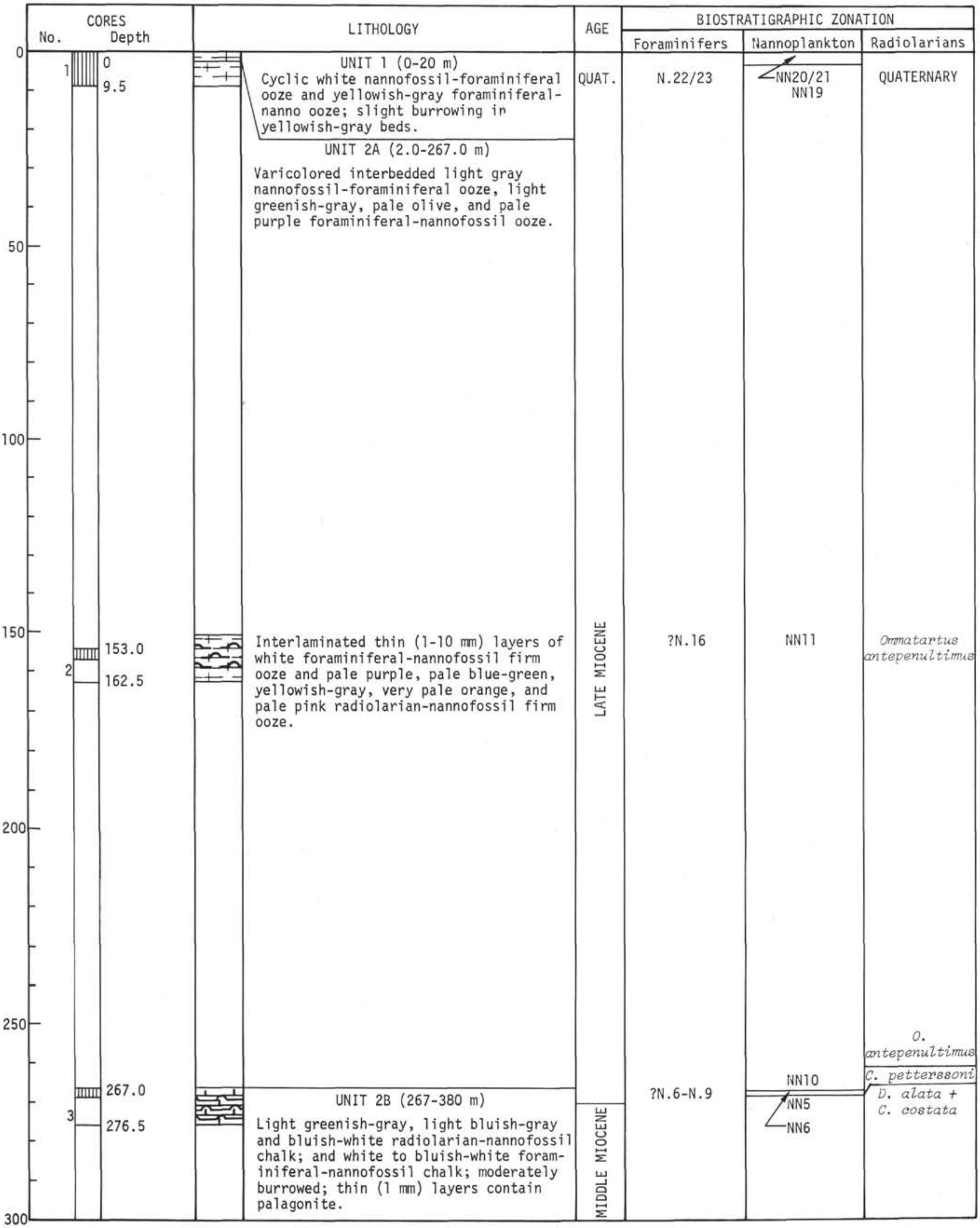


UNIT 1 (0-20 m)

Cyclic white nannofossil-foraminiferal ooze and yellowish-gray foraminiferal-nanno ooze; slight burrowing in yellowish-gray beds.

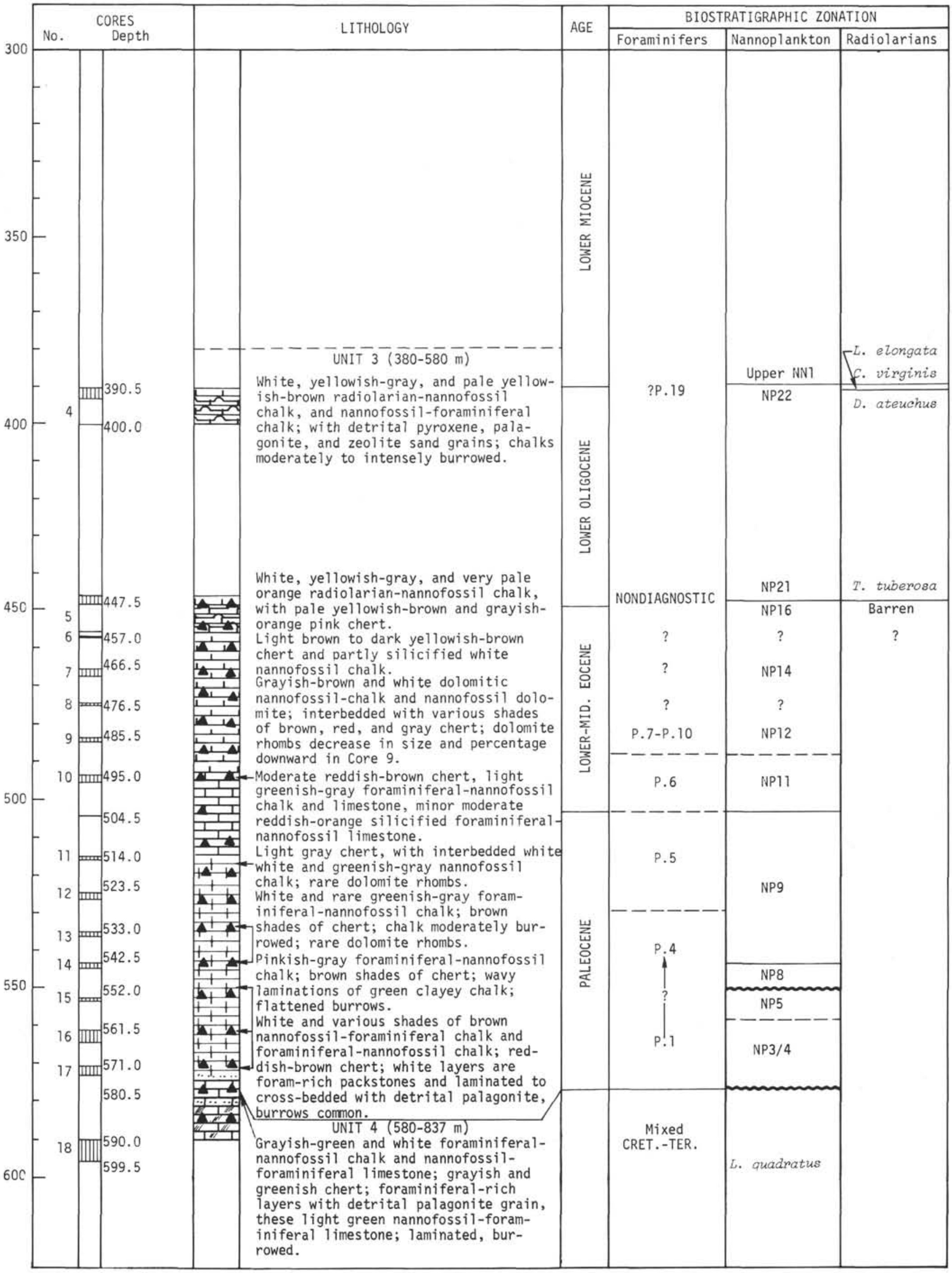
UNIT 2A (2.0-267.0 m)

Varicolored interbedded light gray nannofossil-foraminiferal ooze, light greenish-gray, pale olive, and pale purple foraminiferal-nannofossil ooze.

Interlaminated thin (1-10 mm) layers of white foraminiferal-nannofossil firm ooze and pale purple, pale blue-green, yellowish-gray, very pale orange, and pale pink radiolarian-nannofossil firm ooze.

UNIT 2B (267-380 m)

Light greenish-gray, light bluish-gray and bluish-white radiolarian-nannofossil chalk; and white to bluish-white foraminiferal-nannofossil chalk; moderately burrowed; thin (1 mm) layers contain palagonite.



UNIT 3 (380-580 m)

White, yellowish-gray, and pale yellowish-brown radiolarian-nannofossil chalk, and nannofossil-foraminiferal chalk; with detrital pyroxene, palagonite, and zeolite sand grains; chalks moderately to intensely burrowed.

White, yellowish-gray, and very pale orange radiolarian-nannofossil chalk, with pale yellowish-brown and grayish-orange pink chert.

Light brown to dark yellowish-brown chert and partly silicified white nannofossil chalk.

Grayish-brown and white dolomitic nannofossil-chalk and nannofossil dolomite; interbedded with various shades of brown, red, and gray chert; dolomite rhombs decrease in size and percentage downward in Core 9.

Moderate reddish-brown chert, light greenish-gray foraminiferal-nannofossil chalk and limestone, minor moderate reddish-orange silicified foraminiferal-nannofossil limestone.

Light gray chert, with interbedded white white and greenish-gray nannofossil chalk; rare dolomite rhombs.

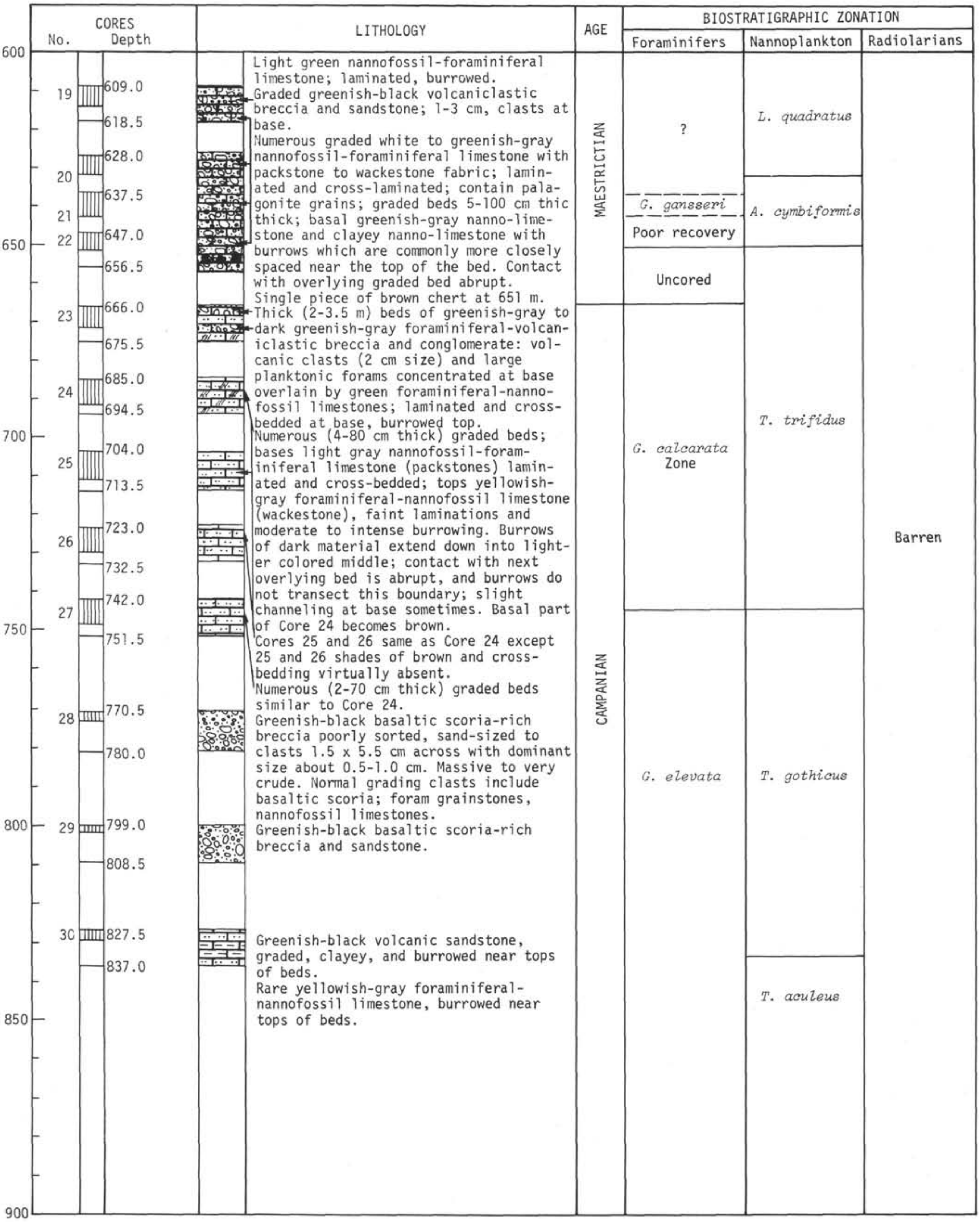
White and rare greenish-gray foraminiferal-nannofossil chalk; brown shades of chert; chalk moderately burrowed; rare dolomite rhombs.

Pinkish-gray foraminiferal-nannofossil chalk; brown shades of chert; wavy laminations of green clayey chalk; flattened burrows.

White and various shades of brown nannofossil-foraminiferal chalk and foraminiferal-nannofossil chalk; reddish-brown chert; white layers are foram-rich packstones and laminated to cross-bedded with detrital palagonite, burrows common.

UNIT 4 (580-837 m)

Grayish-green and white foraminiferal-nannofossil chalk and nannofossil-foraminiferal limestone; grayish and greenish chert; foraminiferal-rich layers with detrital palagonite grain, these light green nannofossil-foraminiferal limestone; laminated, burrowed.



Light green nannofossil-foraminiferal limestone; laminated, burrowed.

Graded greenish-black volcaniclastic breccia and sandstone; 1-3 cm, clasts at base.

Numerous graded white to greenish-gray nannofossil-foraminiferal limestone with packstone to wackestone fabric; laminated and cross-laminated; contain palagonite grains; graded beds 5-100 cm thic thick; basal greenish-gray nanno-limestone and clayey nanno-limestone with burrows which are commonly more closely spaced near the top of the bed. Contact with overlying graded bed abrupt.

Single piece of brown chert at 651 m.

Thick (2-3.5 m) beds of greenish-gray to dark greenish-gray foraminiferal-volcaniclastic breccia and conglomerate: volcanic clasts (2 cm size) and large planktonic forams concentrated at base overlain by green foraminiferal-nannofossil limestones; laminated and cross-bedded at base, burrowed top.

Numerous (4-80 cm thick) graded beds; bases light gray nannofossil-foraminiferal limestone (packstones) laminated and cross-bedded; tops yellowish-gray foraminiferal-nannofossil limestone (wackestone), faint laminations and moderate to intense burrowing. Burrows of dark material extend down into lighter colored middle; contact with next overlying bed is abrupt, and burrows do not transect this boundary; slight channeling at base sometimes. Basal part of Core 24 becomes brown.

Cores 25 and 26 same as Core 24 except 25 and 26 shades of brown and cross-bedding virtually absent.

Numerous (2-70 cm thick) graded beds similar to Core 24.

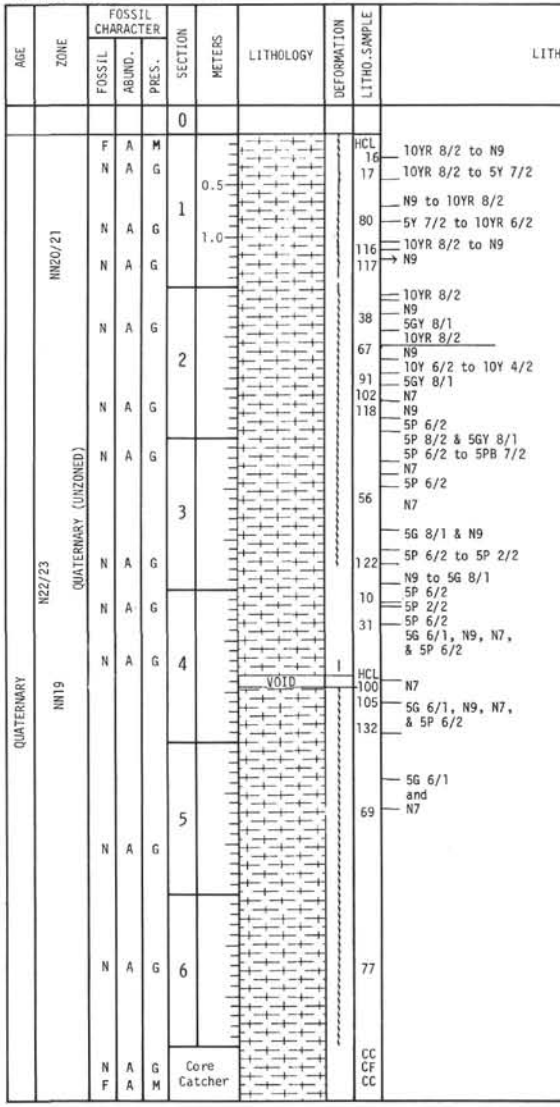
Greenish-black basaltic scoria-rich breccia poorly sorted, sand-sized to clasts 1.5 x 5.5 cm across with dominant size about 0.5-1.0 cm. Massive to very crude. Normal grading clasts include basaltic scoria; foram grainstones, nannofossil limestones.

Greenish-black basaltic scoria-rich breccia and sandstone.

Greenish-black volcanic sandstone, graded, clayey, and burrowed near tops of beds.

Rare yellowish-gray foraminiferal-nannofossil limestone, burrowed near tops of beds.

Site 316 Hole Core 1 Cored Interval: 0.0-9.5 m



LITHOLOGIC DESCRIPTION

0-2.0 m:
Repeated cycles consisting of white (N9) NANNO FORAM OOZE, with rare volcanic sand grains grading up into yellowish gray (5Y 7/2) and very pale orange (10YR 8/2) FORAM NANNO OOZE with slight burrowing.

Smear Slides:

Forams	D to C
Nannos	D to A
Rads	C to R
Diatoms	R
Silicofl.	R
Sp. Spic.	R
Vol. Sd.	R

2.0-9.5 m:
Varicolored interbedded light gray (N7) NANNO FORAM OOZE, with detrital palagonite and zeolites; light greenish gray (5G 8/1), pale olive (10Y 6/2), and pale purple (5P 6/2) FORAM NANNO OOZE.

Smear Slides:

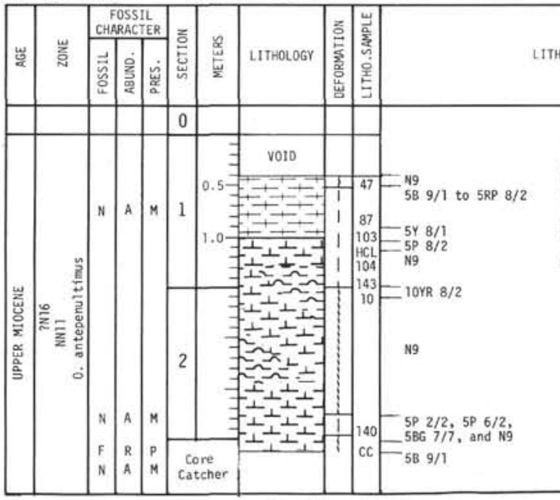
Light gray foram ooze:	
Forams	D
Nannos	A
Diatoms	R
Rads	R
Sp. Spic.	R
Palagonite	R
Zeolite (sand-sized grains	R
Nannofossil ooze:	
Forams	A
Nannos	D
Rads	R to C
Diatoms	R
Sp. Spic.	R

Purple coloration from pyrite on rads and forams.

Bulk X-ray (0.80 m):

Amorph.	15.8%
Ident.	84.2%
Calc.	97.6%
Quar.	0.4%
Mica	1.4%
Bari.	0.6%

Site 316 Hole Core 2 Cored Interval: 153.0-162.5 m



LITHOLOGIC DESCRIPTION

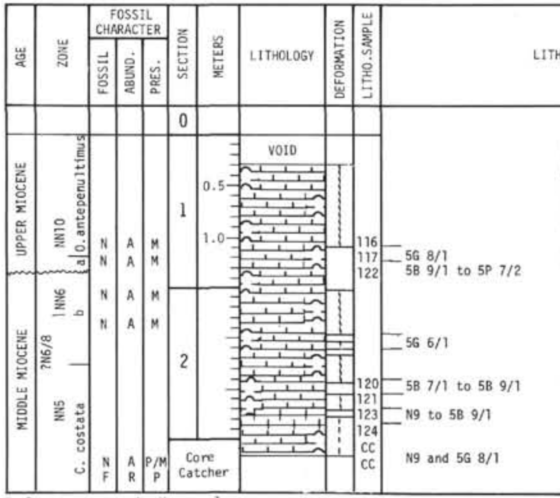
Interlaminated thin (1-10 mm) layers of white (N9) FORAM NANNO firm OOZE and pale purple (5P 6/2), pale blue green (5BG 7/7), yellowish gray (5Y 8/1), very pale orange (10YR 8/2), and pale pink (5RP 8/2) RADIOLARIAN NANNOFOSSIL firm OOZE.

Smear Slide:

Forams	R to C
Nannos	D
Rads	C
Diatoms	R to C
Sp. Spic.	R to C
Pyrite	R

(coatings on Rads and spicules)

Site 316 Hole Core 3 Cored Interval: 267.0-276.5 m



LITHOLOGIC DESCRIPTION

Light greenish gray (5G 8/1), light bluish gray (5B 7/1), and bluish white (5B 9/1) RADIOLARIAN NANNOFOSSIL CHALK; and white (N9) to bluish white (5B 9/1) FORAM NANNOFOSSIL CHALK. Moderately burrowed. Thin (1 mm) laminations 123-126 cm. Coarse-grained layer 118-123 cm contains rare grains of palagonite.

Smear Slides:

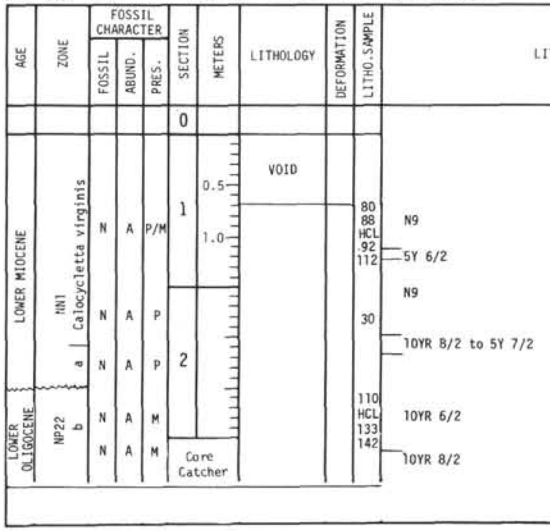
Forams	R to C
Nannos	A to D
Micrite	C to D
Rads	R to C
Diatoms	R
Sp. Spic.	R to C

[a] Cannartus petterssoni

[b] Dorcadospyris alata

Explanatory notes in Chapter 1

Site 316 Hole Core 4 Cored Interval: 390.5-400.0 m



White (N9), yellowish gray (5Y 6/2), and pale yellowish brown (10YR 6/2) RADIOLARIAN NANNOFOSSIL CHALK, white (N9) NANNOFOSSIL CHALK, and (at 2.90 m) NANNOFOSSIL FORAMINIFERAL CHALK, with detrital pyroxene, palagonite, and zeolite sand grains. Chalks moderately to intensely burrowed.

Smear Slides, Rad-Nanno Chalks:

Nannos	D
Micrite	C
Rads	C to A
Sp. Spic.	R

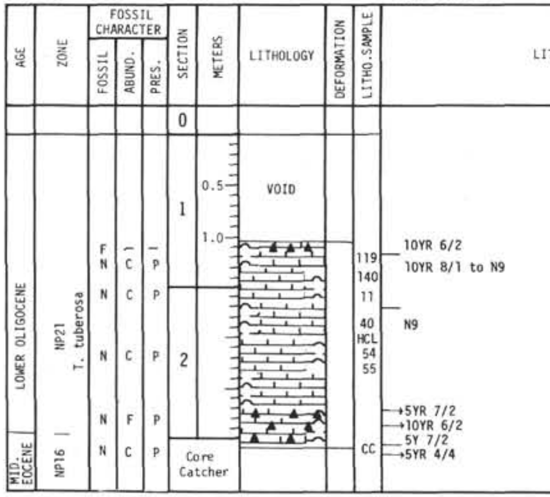
Smear Slides, Nanno-Foram Chalks:

Forams	A
Nannos	A
Micrite	C
Rads	R
Sp. Spic.	R
Palagonite, zeolite sand	R

[a] Lychnocanoma elongata

[b] Dorcadospyris ateuchus

Site 316 Hole Core 5 Cored Interval: 447.5-457.0 m



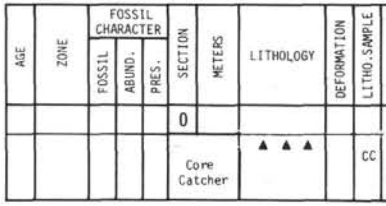
White (N9), yellowish gray (5Y 7/2), and very pale orange (10YR 8/1) RADIOLARIAN NANNOFOSSIL CHALK, with moderate brown (5YR 4/4), pale yellowish brown (10YR 6/2), and grayish orange pink (5YR 7/2) CHERT. Coarser laminae at 11, 55, 75, and 85 cm in section 2 contain rare palagonite grains.

Remnant limestone fragments in chert indicate replacement origin for chert.

Smear Slides:

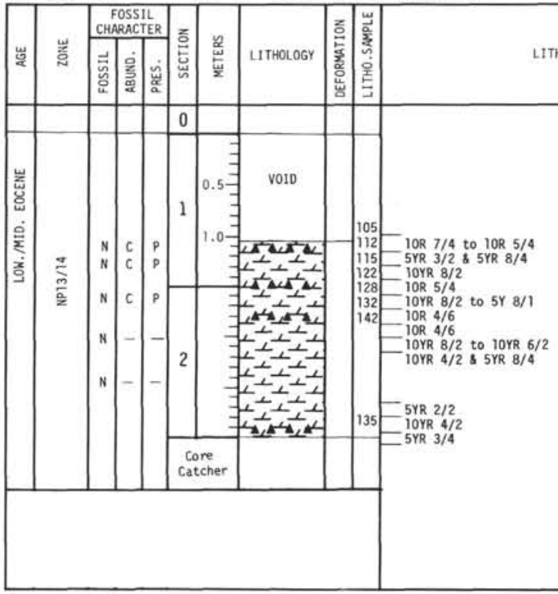
Forams	R (in coarse laminae)
Nannos	A to D
Micrite	C to D
Rads	C to A
Sp. Spic.	R
Palagonite, glass	R (in coarse laminae)

Site 316 Hole Core 6 Cored Interval: 457.0-466.5 m



Light brown (5YR 5/6) to dark yellowish brown (10YR 4/2) CHERT, with an irregular lump of partly silicified white (N9) NANNOFOSSIL CHALK.

Site 316 Hole Core 7 Cored Interval: 466.5-476.0 m



Brownish (5YR 8/1 to 8/4, 5YR 3/2, 10YR 8/2 to 4/6) and white (N9) DOLOMITIC NANNOFOSSIL CHALK, and reddish brown (10YR 5/4 to 4/6) CHERT. Dolomite occurs as 50 to 100μm rhombs, scattered or in close contact, in chalk. Chert has chalk inclusions.

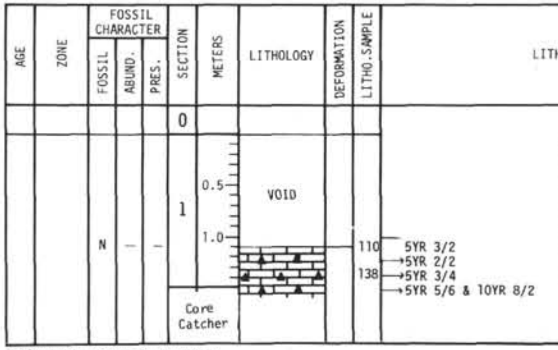
Smear Slides:

Nannos	A
Micrite	C to A
Dolomite Rhombs	A
Rads	R (at 122 cm only)
Fe_2O_3	C (in darker brown samples, as tiny grains.

Bulk X-ray (469.30μm):

Amorph.	55.7%
Ident.	44.3%
Dolo.	83.4%
Quar.	0.8%
K-Fs	1.3%
Plag.	0.9%
Mica	3.3%
Mont.	3.0%
Clin.	5.6%
Bari.	1.7%

Site 316 Hole Core 8 Cored Interval: 476.0-485.5 m



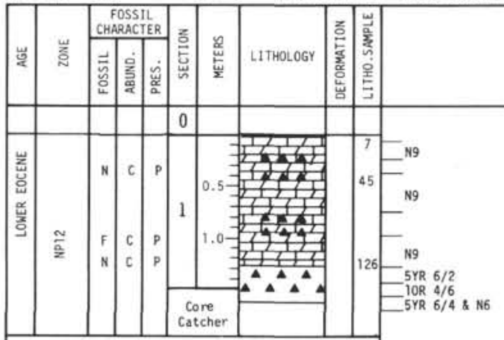
Grayish brown (5YR 3/2) DOLOMITIC NANNOFOSSIL LIMESTONE, and dusky brown (5YR 2/2), light brown (5YR 3/4), and very pale orange (10YR 8/2) CHERT. Rhomble dolomite crystals average about 100μm in diameter. Fragments of partly silicified laminated dolomitic limestone in chert.

Smear Slides:

Dolomite Rhombs	A
Nannos	C
Micrite	A

Explanatory notes in Chapter 1

Site 316 Hole Core 9 Cored Interval: 485.5-495.0 m



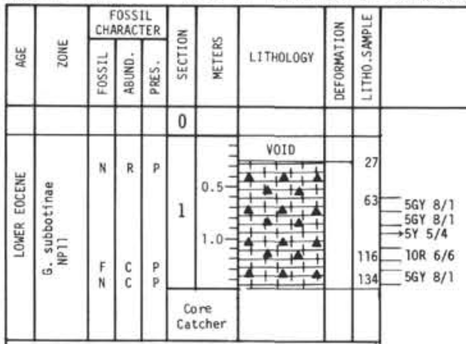
LITHOLOGIC DESCRIPTION

White (N9) DOLOMITE, DOLOMITIC NANNOFOSSIL CHALK, and DOLOMITIC FORAMINIFERAL NANNOFOSSIL CHALK; and gray (N6), light brown (5YR 6/4), moderate reddish brown (10R 4/6), and pale red (5R 6/2) CHERT, enclosing white blebs of partly silicified chalk. Dolomite rhombs decrease in abundance and size from 50 to 100µm to 20µm from top of core downward.

Smear Slides:

7 cm:	
Dolomite	D (100µm)
Nannos	R
45 cm:	
Dolomite	A (10 to 100, avg. 50µm)
Nannos	C
Micrite	D
126 cm:	
Dolomite	R (20µm)
Forams	C
Nannos	A
Micrite	A

Site 316 Hole Core 10 Cored Interval: 495.0-504.5 m



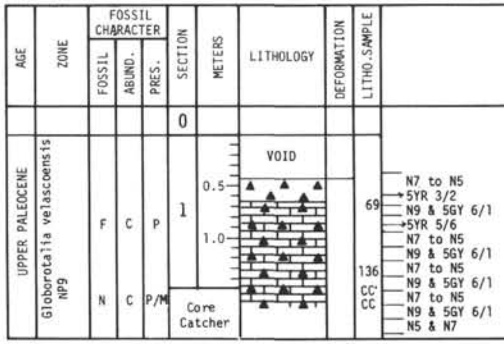
LITHOLOGIC DESCRIPTION

Fragments of moderate reddish brown (10R 4/6), moderate brown (5YR 3/4), and moderate olive brown (5Y 4/4) CHERT, and light greenish gray (5GY 8/1) FORAMINIFERAL NANNOFOSSIL CHALK and LIMESTONE, with minor moderate reddish orange (10R 6/6) silicified FORAMINIFERAL NANNOFOSSIL LIMESTONE.

Smear Slides (limestone):

Forams	R to C
Nannos	D
Rads	R
Sp. Spic.	R

Site 316 Hole Core 11 Cored Interval: 514.0-523.5 m



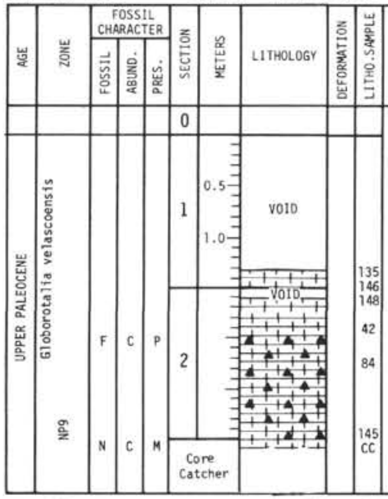
LITHOLOGIC DESCRIPTION

Light gray (N7), medium gray (N5) and minor light brown (5YR 5/6) CHERT, and interbedded white (N9) and greenish gray (5GY 6/1) NANNOFOSSIL CHALK. Rare dolomite rhombs (5-10µm) at 136 cm and in core catcher.

Smear Slides (chalk):

Nannos	D
Micrite	A

Site 316 Hole Core 12 Cored Interval: 523.5-533.0 m



LITHOLOGIC DESCRIPTION

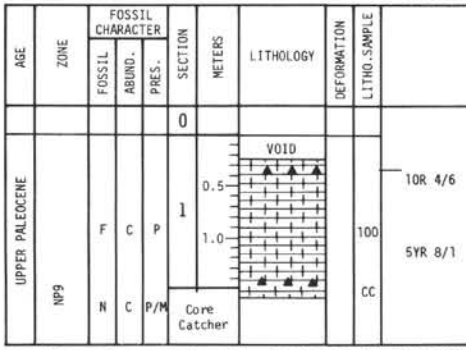
White (N9) with minor thin laminations of greenish gray (5G 6/1) to dark greenish gray (5G 4/1) FORAMINIFERAL NANNOFOSSIL CHALK, and pieces of moderate brown (5YR 4/4) and related color shades of CHERT. Chalk is moderately burrowed. From 140-150 cm, chalk is very pale purple (5P 6/2), and contains very rare dolomite rhombs.

Smear Slides (chalk):

Forams	Absent to C
Nannos	D
Micrite	C to A

Palagonite, 1 grain (148 cm) glass, RI >1.57, 1 grain (cc).

Site 316 Hole Core 13 Cored Interval: 533.0-542.5 m



LITHOLOGIC DESCRIPTION

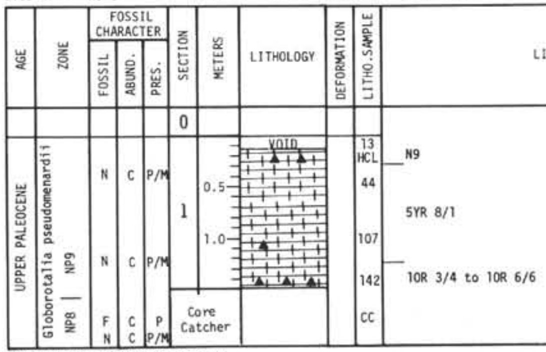
Pinkish gray (5YR 8/1) FORAMINIFERAL NANNOFOSSIL CHALK, and fragments of moderate reddish brown (10R 4/6) CHERT.

Delicate irregular wavy laminations of darker green more clayey streaks, and scattered flattened burrows.

Smear Slides:

Forams	C to D
Nannos	A to D
Micrite	C

Site 316 Hole Core 14 Cored Interval: 542.5-552.0 m



LITHOLOGIC DESCRIPTION

Pinkish gray (5YR 8/1) and white (N9) FORAMINIFERAL NANNOFOSSIL CHALK, and dark reddish brown (10R 3/4) CHERT.

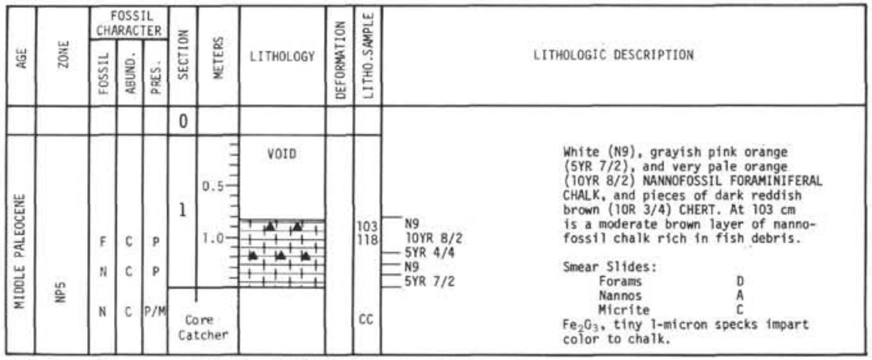
Smear Slides:

Forams	C to A
Nannos	C to D

Palagonite, in HCL resid. at 21 cm, and at 13 cm.

Explanatory notes in Chapter 1

Site 316 Hole Core 15 Cored Interval: 552.0-561.5 m



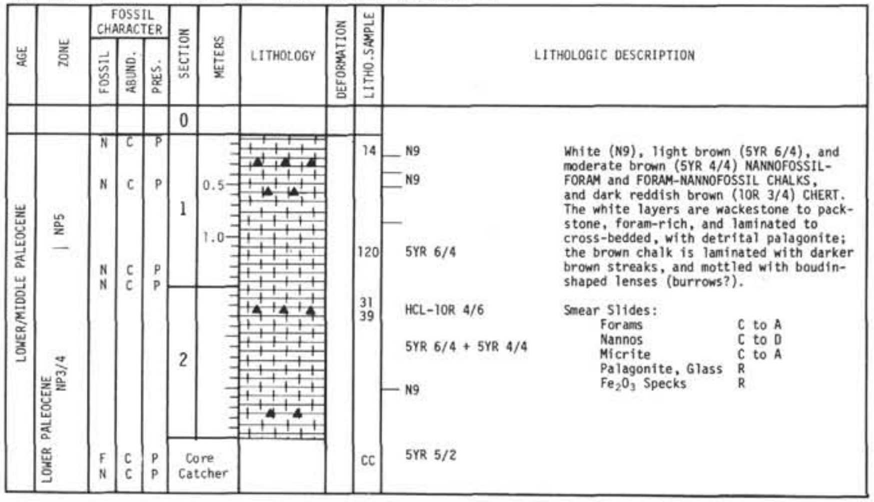
White (N9), grayish pink orange (5YR 7/2), and very pale orange (10YR 8/2) NANNOFOSSIL FORAMINIFERAL CHALK, and pieces of dark reddish brown (10R 3/4) CHERT. At 103 cm is a moderate brown layer of nannofossil chalk rich in fish debris.

Smear Slides:

Forams	D
Nannos	A
Micrite	C

Fe_2O_3, tiny 1-micron specks impart color to chalk.

Site 316 Hole Core 16 Cored Interval: 561.5-571.0 m

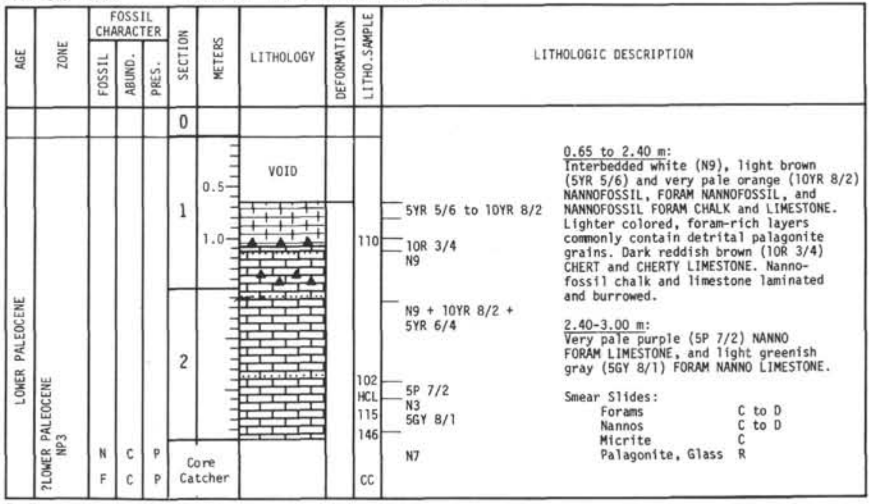


White (N9), light brown (5YR 6/4), and moderate brown (5YR 4/4) NANNOFOSSIL-FORAM and FORAM-NANNOFOSSIL CHALKS, and dark reddish brown (10R 3/4) CHERT. The white layers are wackestone to packstone, foram-rich, and laminated to cross-bedded, with detrital palagonite; the brown chalk is laminated with darker brown streaks, and mottled with boudin-shaped lenses (burrows?).

Smear Slides:

Forams	C to A
Nannos	C to D
Micrite	C to A
Palagonite, Glass	R
Fe_2O_3 Specks	R

Site 316 Hole Core 17 Cored Interval: 571.0-580.5 m



0.65 to 2.40 m:
Interbedded white (N9), light brown (5YR 5/6) and very pale orange (10YR 8/2) NANNOFOSSIL, FORAM NANNOFOSSIL, and NANNOFOSSIL FORAM CHALK and LIMESTONE. Lighter colored, foram-rich layers commonly contain detrital palagonite grains. Dark reddish brown (10R 3/4) CHERT and CHERTY LIMESTONE. Nannofossil chalk and limestone laminated and burrowed.

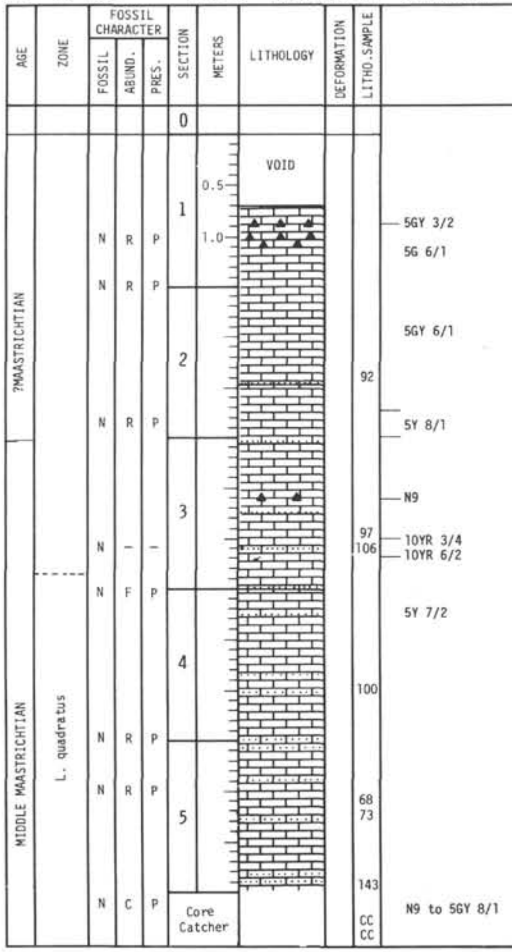
2.40-3.00 m:
Very pale purple (5P 7/2) NANNO FORAM LIMESTONE, and light greenish gray (5GY 8/1) FORAM NANNO LIMESTONE.

Smear Slides:

Forams	C to D
Nannos	C to D
Micrite	C
Palagonite, Glass	R

Explanatory notes in Chapter 1

Site 316 Hole Core 18 Cored Interval: 590.0-599.5 m



LITHOLOGIC DESCRIPTION

Grayish green (5G 6/1), greenish gray (5GY 6/1), yellowish gray (5Y 8/1, 5Y 7/2), and white (N9) FORAM NANNO and NANNO FORAM LIMESTONE. Grayish olive green (5GY 3/2) CHERT at 0.85 and 1.05 m, and dark reddish brown (10R 3/4) CHERT at 3.55 m.

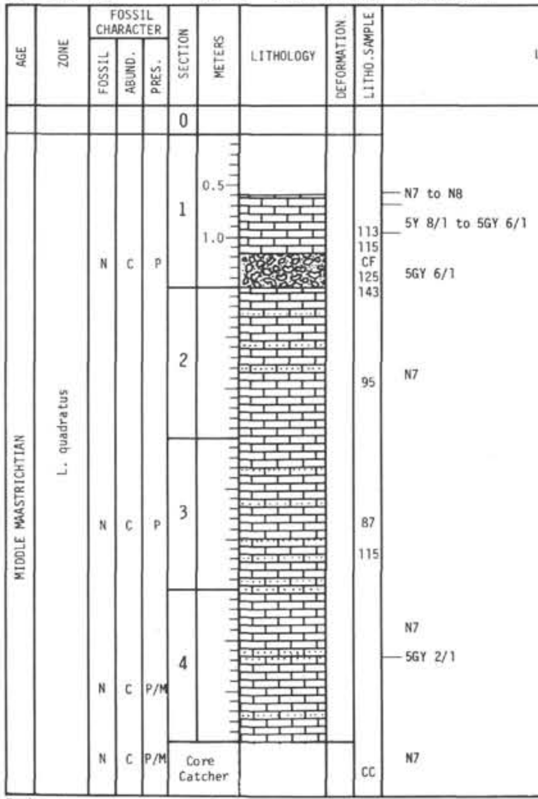
Foram-rich light-colored layers at 2.42, 3.05, 3.75, 4.08, 4.18, 4.50, 4.80, 5.40, 5.60, 5.75, 6.00, 6.05, 6.40, 6.85, 7.00, and 7.50 m commonly contain dark-colored detrital palagonite grains and show parallel and cross-stratified lamination. These generally grade upward into darker, more nannofossil-rich limestone showing wavy laminations of more clayey layers, and moderate burrowing.

Smear Slides:

Foram-rich layers:

Forams	A to D
Nannos	C
Micrite	C to A

Site 316 Hole Core 19 Cored Interval: 609.0-618.5 m



LITHOLOGIC DESCRIPTION

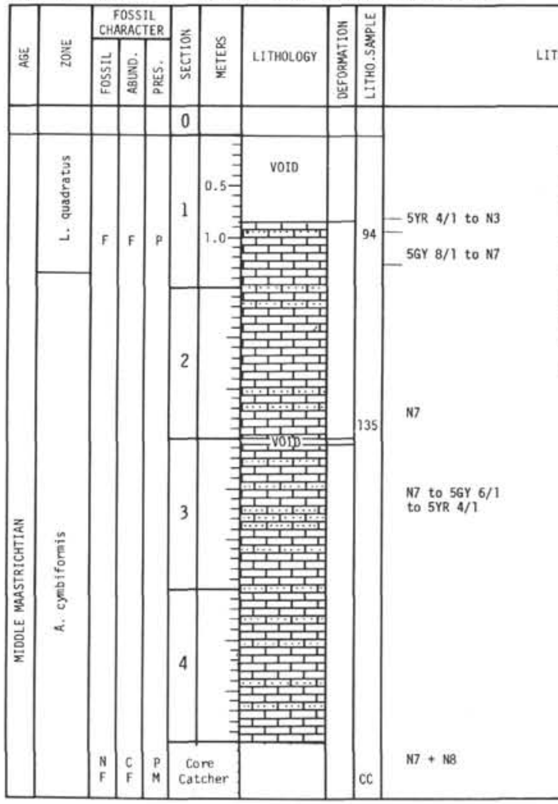
0.6-1.15 m:
Light gray (N7), yellowish gray (5Y 8/1) and greenish gray (5GY 6/1) NANNO FORAM LIMESTONE. Laminated, burrowed.

1.15-1.50 m:
Graded bed at greenish black (5GY 2/1) VOLCANICLASTIC BRECCIA and SANDSTONE 1-cm clasts at base, and slabs of greenish gray (5GY 6/1) CLAYEY NANNO LIMESTONE at 1.35 m.

1.50-6.00 m:
Sequence of 15 beds, from 5 cm to 100 cm thick, consisting at the base of white (N9) to light gray (N7) NANNO FORAM LIMESTONE, with packstone fabric, and generally with laminations or cross-laminations, and containing volcanogenic (palagonite, glass) sand grains. Beds grade upward to light gray (N7) to greenish gray (5GY 6/1) NANNO FORAM and FORAM NANNO LIMESTONE, with wackestone fabric and with faint laminations, and, near the top, burrows.

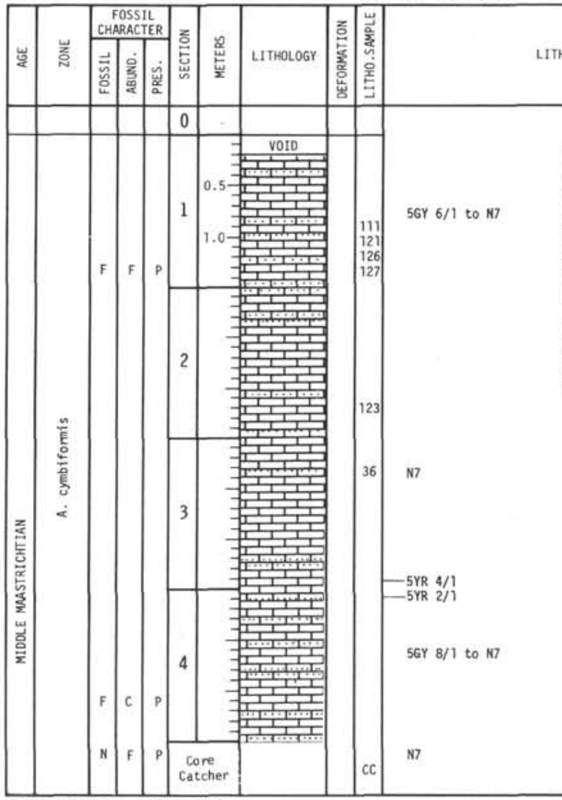
Explanatory notes in Chapter 1

Site 316 Hole Core 20 Cored Interval: 628.0-637.5 m



Twenty-one beds, from 5 to 90 cm thick, each consisting of a basal part of light gray (N7) NANNO FORAM LIMESTONE, or dark gray (N3) PALAGONITE FORAM SANDSTONE, commonly laminated or cross-laminated, with a packstone fabric; grading upward into light gray (N7), to greenish gray (5GY 6/1) to brownish gray (5YR 4/1) FORAM NANNO LIMESTONE, massive to faintly laminated in the middle, and burrowed toward the top. Clay content increases upward, with darker colors. The volcanic sand layers are chiefly palagonite, with rare glass (R. I. >1.57) and feldspar.

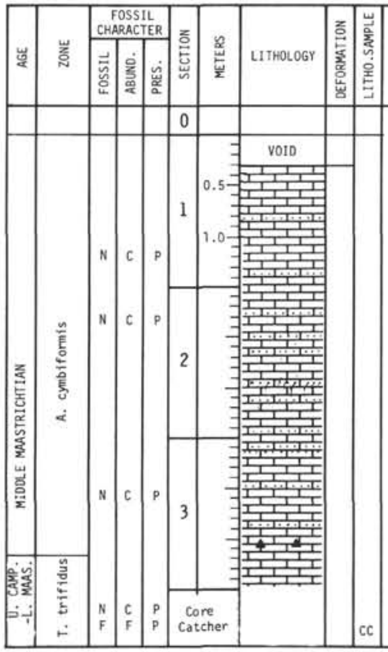
Site 316 Hole Core 21 Cored Interval: 637.5-647.0 m



Twenty-two beds, from 5 to 100 cm thick, each consisting of a basal portion a few cm thick of light gray (N7) NANNO FORAM LIMESTONE, with variable amounts of dark green palagonite sand, generally well laminated and commonly cross-stratified, and resting with an abrupt contact on the unit beneath. The basal layers grade upward by loss of lamination into faintly laminated to massive light gray (N7) FORAM NANNO LIMESTONE, which gives way upward to greenish gray (5GY 6/1) NANNO LIMESTONE and CLAYEY NANNO LIMESTONE, with burrows which are commonly more closely spaced near the top of the bed.

Explanatory notes in Chapter 1

Site 316 Hole Core 22 Cored Interval: 647.0-656.5 m



LITHOLOGIC DESCRIPTION

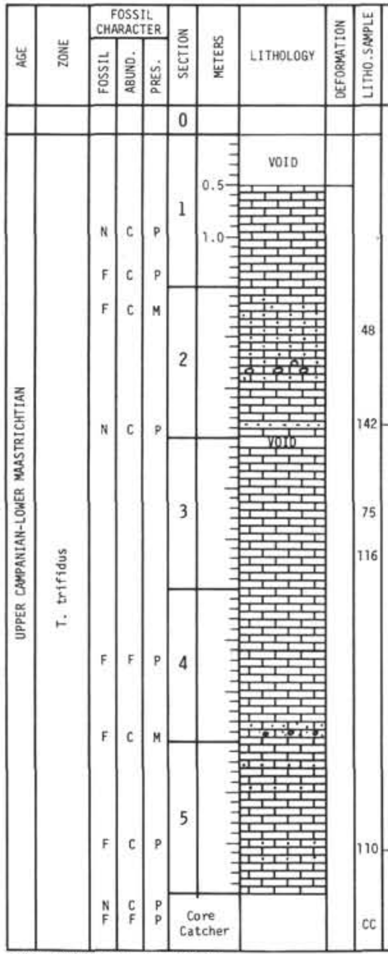
5GY 6/1 to N7

N7

Thirteen beds, from 4 to 60 cm thick, each consisting of a basal portion of light gray (N7) NANNO FORAM LIMESTONE, with packstone texture, laminated and/or cross-stratified; grading upward through less well laminated light gray (N7) FORAM NANNO LIMESTONE, with wackestone texture, to greenish gray (5GY 6/1) FORAM NANNO LIMESTONE, with moderate to intense burrowing toward the top. The contact with the next overlying bed is abrupt.

At 4.05 m, a piece of brown CHERT.

Site 316 Hole Core 23 Cored Interval: 666.0-675.5 m



LITHOLOGIC DESCRIPTION

N7

5GY 6/1 to N7

N9

5B 5/1

N6

N6 to 5GY 4/1

N7 to 5Y 4/1

N9 to 5Y 8/1

0.5-2.35 m:
Single bed, consisting of a lower portion of light gray (N7) to greenish gray (5GY 6/1) NANNO FORAM LIMESTONE, with common green volcanic sand grains and pebbles, grading upward to light gray (N7) NANNO FORAM and FORAM NANNO LIMESTONE, massive, with a wackestone texture.

2.40-2.80 m:
White (N9) NANNO LIMESTONE with rare forams; cut by steep fractures.

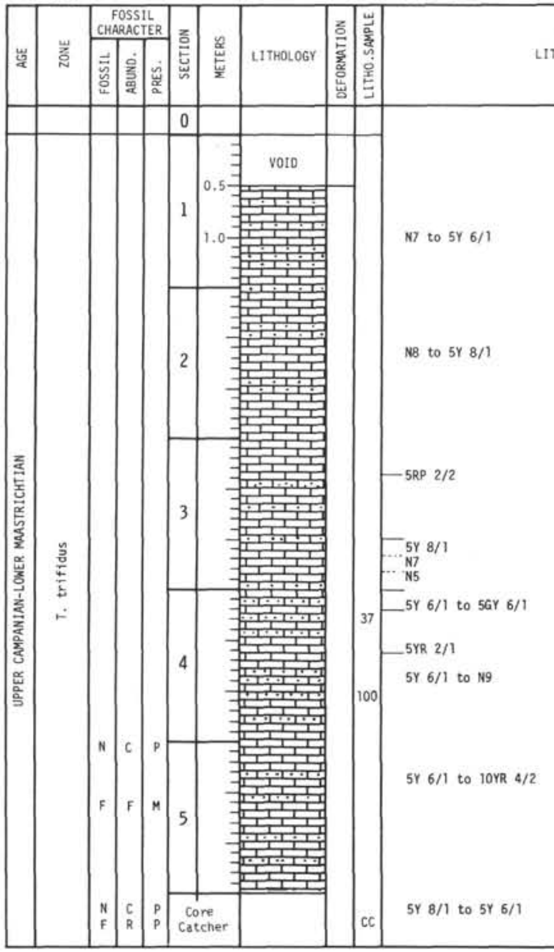
2.80-2.95 m:
Medium bluish gray (5B 5/1) NANNO-BEARING VITRIC SANDSTONE, cemented with sparry calcite, and overlain by burrowed NANNO LIMESTONE.

2.95-6.00 m:
Probably a single bed, consisting of a 2-cm layer of granules of palagonite and large planktonic forams, overlain by medium light gray (N6) to dark greenish gray (5GY 4/1) FORAM NANNO and NANNO FORAM LIMESTONE, distinctly laminated and faintly cross-stratified in the lower 50 cm, with faint laminations and slight burrowing up to the top 20 cm, where burrowing is moderate to intense. A wackestone texture prevails.

6.00-9.50 m:
Five beds (base of lowest not recovered) consisting of a basal portion of light gray (N7) FORAM LIMESTONE, laminated, with a packstone texture, and commonly with rare grains of palagonite, glass, and feldspar; grading upward to olive gray (5Y 4/1) NANNO FORAM and FORAM NANNO LIMESTONE, burrowed near the top.

Explanatory notes in Chapter 1

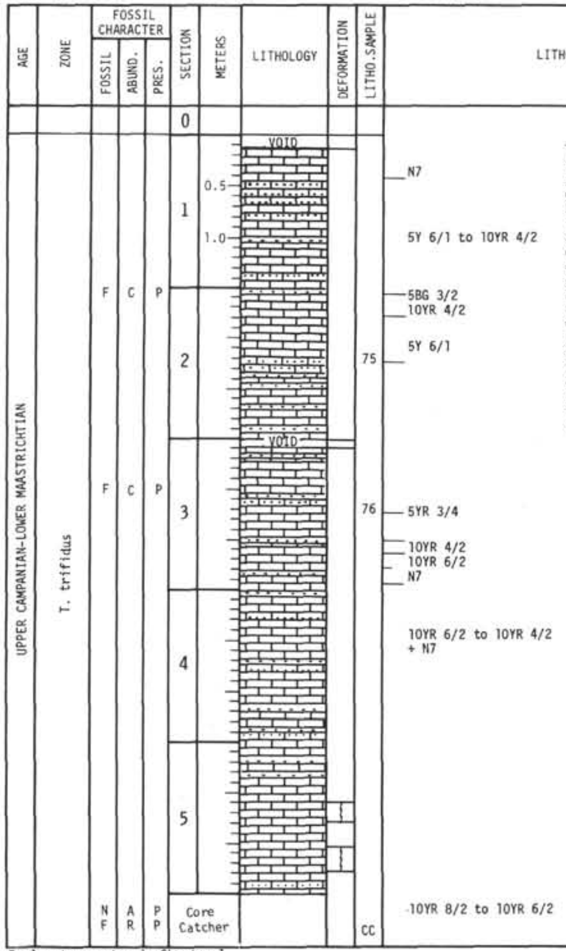
Site 316 Hole Core 24 Cored Interval: 685.0-694.5 m



Twenty-nine beds, from 4 to 80 cm thick, each consisting of a basal portion of very light gray (N8) to medium gray (N5) NANNO FORAM LIMESTONE, with variable amounts of volcanic grains, in a packstone texture, well laminated to cross-stratified, grading upward to yellowish gray (5Y 8/1), and light olive gray (5Y 6/1) NANNO FORAM and FORAM NANNO LIMESTONE, with faint laminations in the central part and moderate to intense burrowing near the top, and a wackestone texture. The contact with the base of the next overlying bed is abrupt, and shows minor channeling at some places.

From 6.0 to 6.5 m, the color become dark yellowish brown (10YR 4/2) in the upper burrowed parts of the beds, and the general color is light olive gray (5Y 6/1).

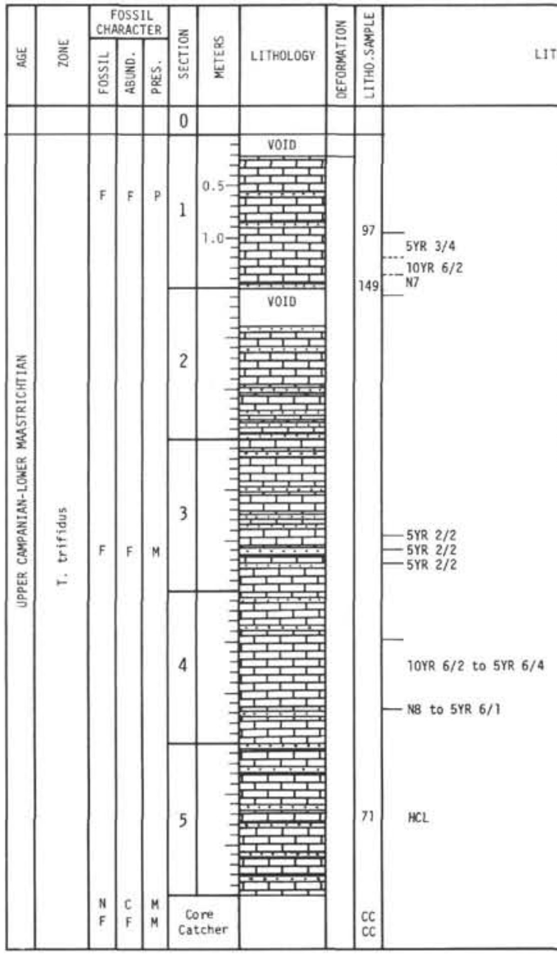
Site 316 Hole Core 25 Cored Interval: 704.0-713.5 m



Thirty-two beds, from 5 to 100 cm thick, each consisting of a basal portion of light gray (N7), light olive gray (5Y 6/1) NANNO FORAM LIMESTONE, with packstone texture; laminated, with minor channeling at some places and redeposited dark clayey clasts (at 2.25 m); grading upward to light olive gray (5Y 6/1) to pale yellowish brown (10YR 8/2) NANNO FORAM and FORAM NANNO LIMESTONE, which gives way to dark yellowish brown (10YR 4/2) NANNO LIMESTONE and CLAYEY NANNO LIMESTONE, with moderate to intense burrowing. Burrows of dark material extend down into lighter-colored middle parts of beds. Contact with next overlying bed is abrupt, and burrows do not transect this boundary.

Explanatory notes in Chapter 1

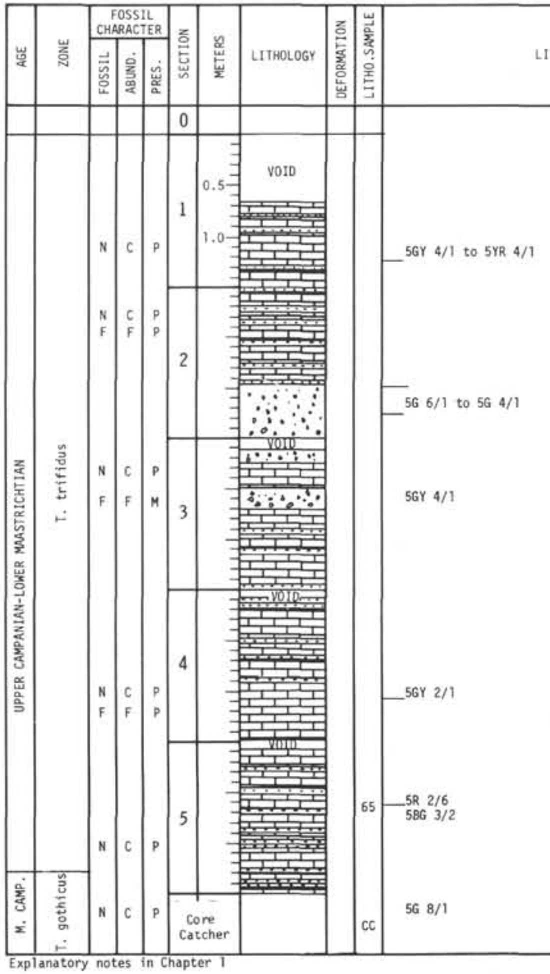
Site 316 Hole Core 26 Cored Interval: 723.0-732.5 m



Thirty-three beds, from 5 to 80 cm thick, each consisting of a basal portion of very light gray (N8), brownish gray (5YR 6/1), and pale yellowish brown (10YT 6/2) NANNO FORAM LIMESTONE or dusky brown (5YR 2/2) PALAGONITE FORAM SANDSTONE, finely laminated grading upward into pale yellowish brown (10YR 6/2) to light brown (5YR 6/4) CLAYEY FORAM NANNO LIMESTONE, with widely spaced (1-2 cm) fine laminations, giving way at the top of the bed to moderate brown (5YR 3/4) CLAYEY NANNOFOSSIL LIMESTONE, moderately to intensely burrowed.

Contact with next overlying bed is abrupt, and at one place (4.60 m), dark brown burrows in light brown limestone are transected by the contact, with no source remaining for the burrow fills.

Site 316 Hole Core 27 Cored Interval: 742.0-751.5 m



Thirty-eight beds, from 2 to 70 cm thick, all but two of these consists of a basal portion of light gray (N8) or pale yellowish gray (10YR 6/2) NANNO FORAM LIMESTONE, or of dark greenish gray (5GY 4/1) brownish gray (5YR 4/1), and greenish black (5GY 2/1) PALAGONITE-RICH FORAM VOLCANIC SANDSTONE, thinly laminated; grading upward to pale yellowish brown (10YR 6/2) to light brown (5YR 6/4) CLAYEY NANNO LIMESTONE with widely spaced fine laminations, which gives way upward to moderate brown (5YR 3/4) and dark greenish gray (5GY 4/1) CLAYEY NANNO LIMESTONE and CALCAREOUS CLAYSTONE. The colors are brownish in the upper part of the core, becoming more green in the lower part, reflecting the increasing proportions of volcanic sandstone and clay.

At 6.65 m, 3 cm of interbedded very dark red (5R 2/6) and dusky blue green (5BG 3/2) CLAYEY PALAGONITIC fine-grained SILTY SANDSTONE.

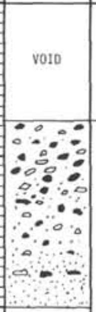
At 2.45 to 3.23, and at 3.45 to 3.70 m, graded beds of greenish gray (5G 6/1) to dark greenish gray (5G 4/1) pebbly FORAMINIFERAL VOLCANIC SANDSTONE.

Explanatory notes in Chapter 1

Site 316 Hole Core 28 Cored Interval: 770.5-780.0 m

AGE	ZONE	FOSSIL CHARACTER			SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO.SAMPLE	LITHOLOGIC DESCRIPTION
		FOSSIL	ABUND.	PRES.						
					0					
MIDDLE CAMPANIAN	T. gothicus	N N	R F	P P	1	0.5 1.0	VOID			5GY 2/1 Greenish black (5GY 2/1) BASALTIC SCORIA-RICH BRECCIA and SANDSTONE. Broken pieces in core may represent parts of several beds. Faintly laminated in some places. Altered palagonitic fragments (D), clay, sand, and rare nannofossils in matrix. Mainly poorly sorted.
					2					
		N	F	P/M	Core Catcher				CC	5GY 2/1

Site 316 Hole Core 29 Cored Interval: 799.0-808.5 m

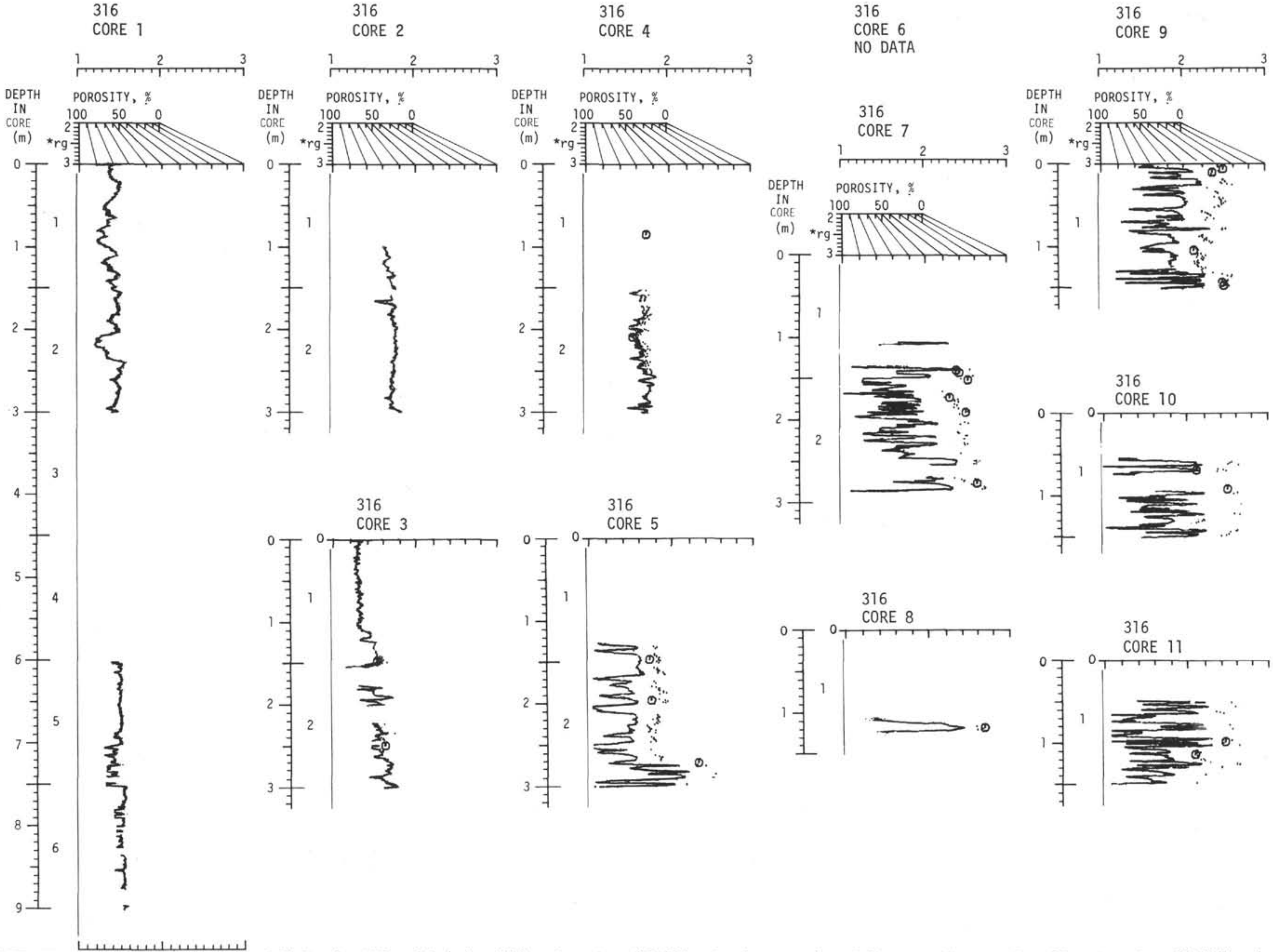


AGE	ZONE	FOSSIL CHARACTER			SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO.SAMPLE	LITHOLOGIC DESCRIPTION
		FOSSIL	ABUND.	PRES.						
					0					
MIDDLE CAMPANIAN	T. gothicus				1	0.5 1.0	VOID			5Y 2/1 Greenish black (5Y 2/1) BASALTIC SCORIA-RICH BRECCIA. Part of one bed, massive, with no internal lamination or bedding. Many tabular clasts oriented in subhorizontal attitudes. Poorly sorted, sand size to clasts 1.5 x 5.5 cm, with dominant size 0.5 to 1.0 cm. Very crudely graded, with largest clasts and greatest proportion of large clasts near base. Clasts include greenish black altered basaltic scoria (D), white foram limestone (C), dark green second-cycle volcanic sandstone (C), and brownish gray fresh basaltic scoria (R). Rock is grain supported, with intercalst space filled with poorly sorted clay, sand, and nannofossils.
		N	C	P/M	2					5Y 2/1
		N	F	M	Core Catcher				CC	5Y 2/1

Site 316 Hole Core 30 Cored Interval: 827.5-837.0 m

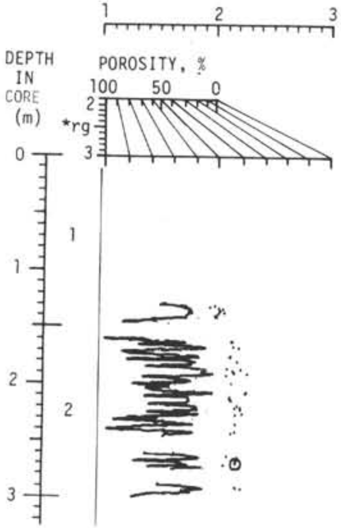
AGE	ZONE	FOSSIL CHARACTER			SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO.SAMPLE	LITHOLOGIC DESCRIPTION
		FOSSIL	ABUND.	PRES.						
					0					
MIDDLE CAMPANIAN	T. gothicus	N	C	P	1	0.5 1.0	VOID			5GY 2/1 0-1.51 m: Five beds of greenish black (5GY 2/1) VOLCANIC SANDSTONE, graded, clayey and burrowed near the tops of the beds. 1.51-3.00 m: Fifteen beds, 1 to 20 cm thick, each consisting of a basal portion of greenish black (5GY 2/1) VOLCANIC SANDSTONE, grading upward to light greenish gray (5G 8/1), greenish gray (5G 6/1), and rare yellowish gray (5Y 8/1) FORAM NANNOFOSSIL and CLAYEY NANNOFOSSIL LIMESTONE, burrowed near the tops of the beds.
		N N	C C	P P	2					5GY 2/1 5G 8/1 to 5G 6/1
L. CAMP.	T. aculeus	N F N	C F C	P P P	Core Catcher				CC	10YR 8/2 + 5YR 6/4

Explanatory notes in Chapter 1

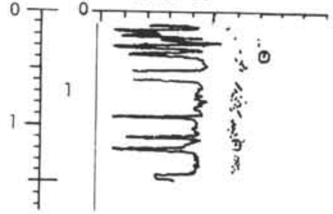


NOTE: The upper scale is GRAPE Wet-Bulk Density (1.0 to 3.0 g/cc): solid lines (——) are GRAPE analog data assuming a 6.61 cm core diameter; dotted lines (. . . . .) are GRAPE analog data adjusted for actual core diameter; circled (ʘ) dots are the wet-bulk density calculated from two-minute counts on a stationary sample; the porosity nomogram allows a porosity scale to be determined by selecting the proper grain density (r_g) and extrapolating horizontally.

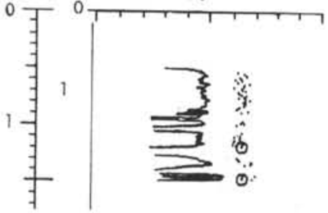
316
CORE 12



316
CORE 13

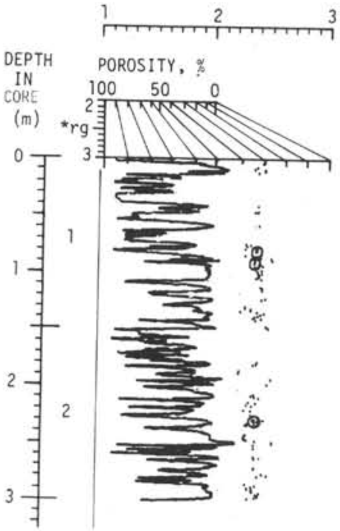


316
CORE 14

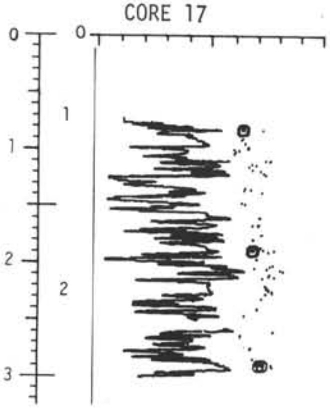


316
CORE 15
NO DATA

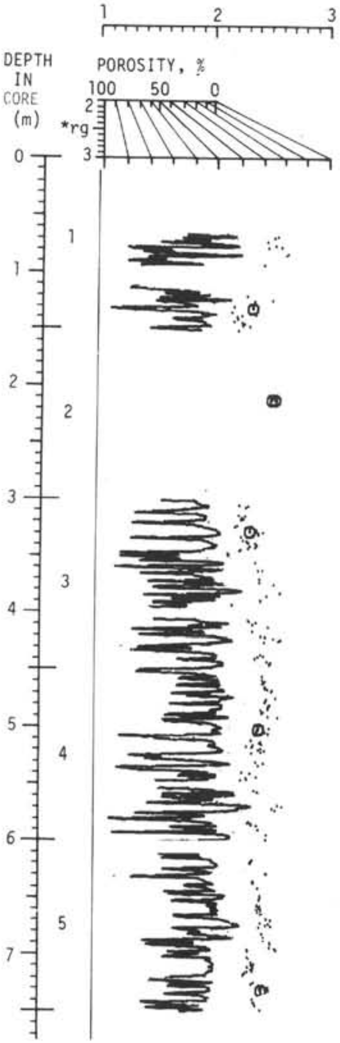
316
CORE 16



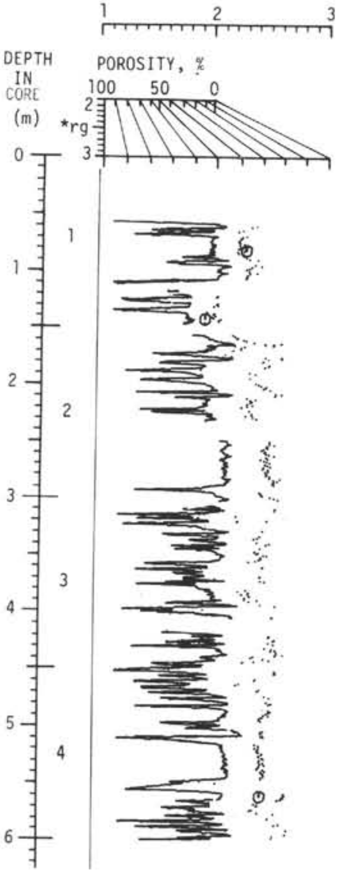
316
CORE 17



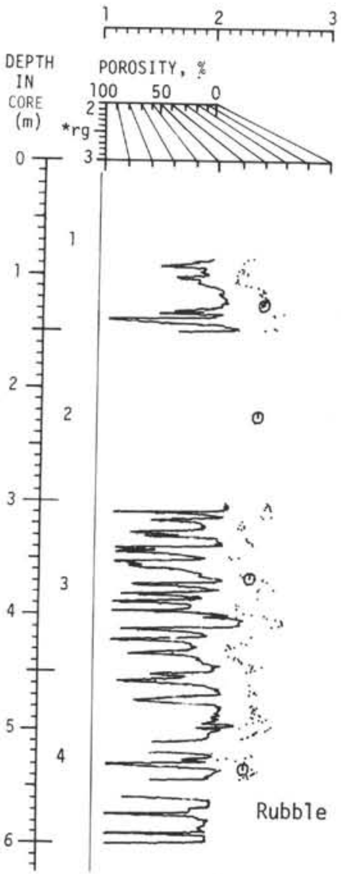
316
CORE 18



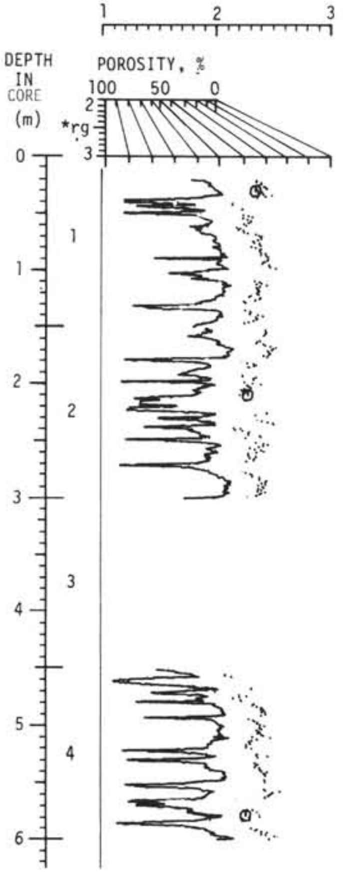
316
CORE 19



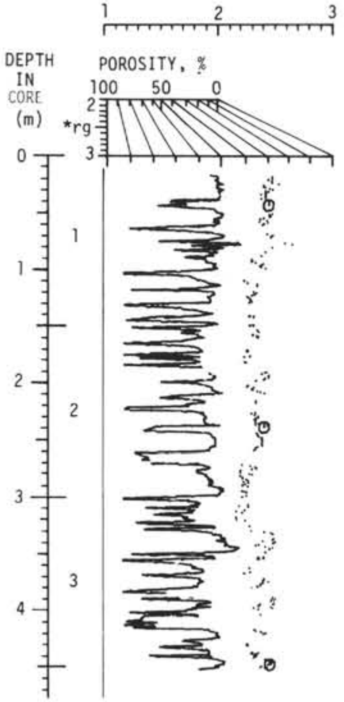
316
CORE 20



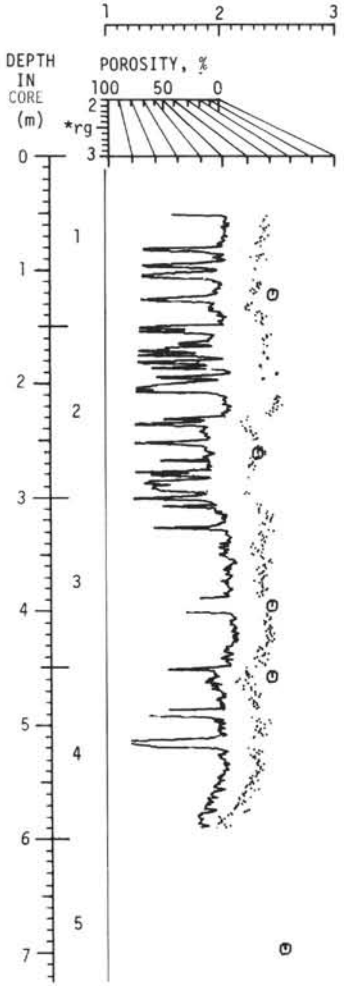
316
CORE 21



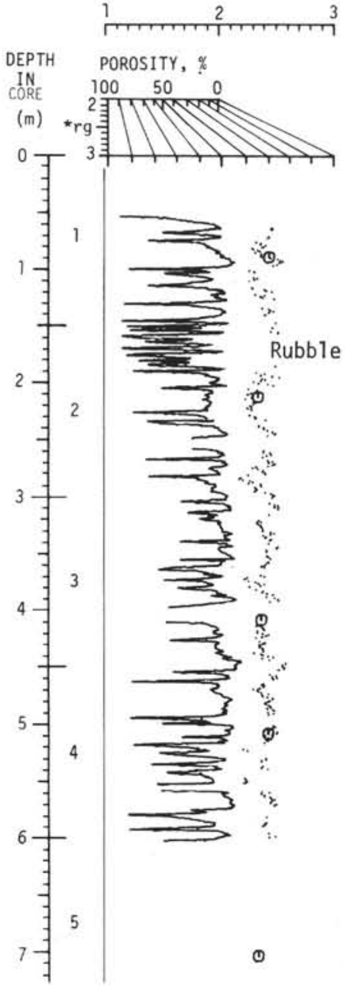
316
CORE 22



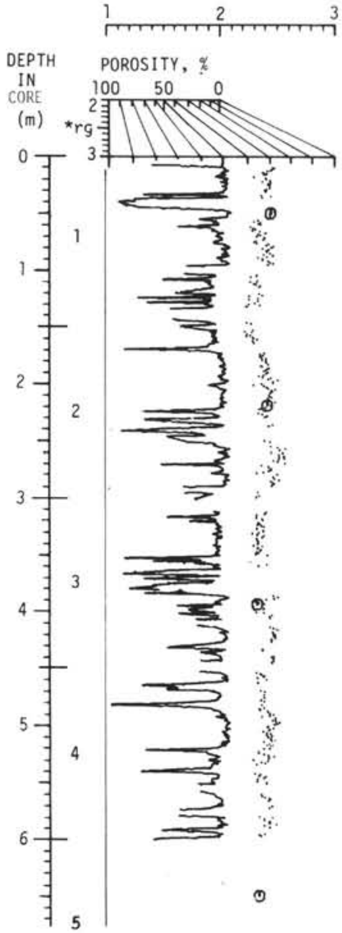
316
CORE 23



316
CORE 24



316
CORE 25



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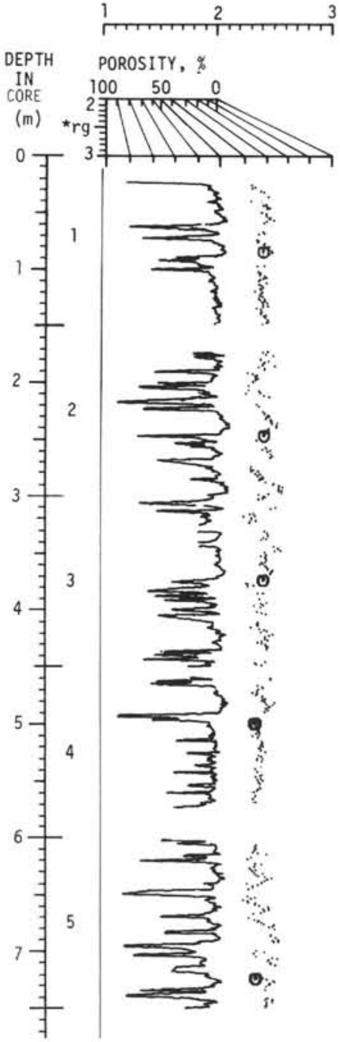

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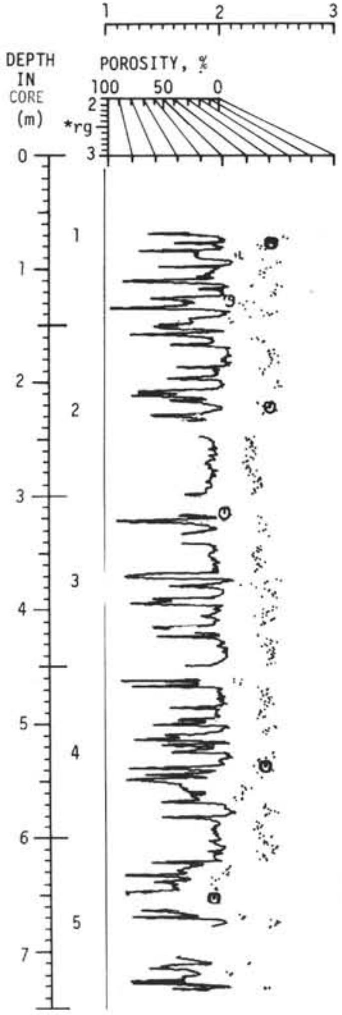

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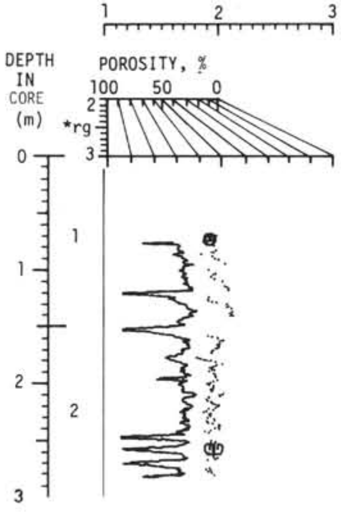

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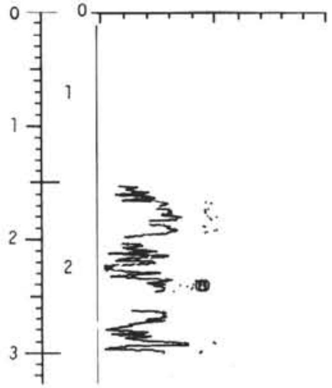

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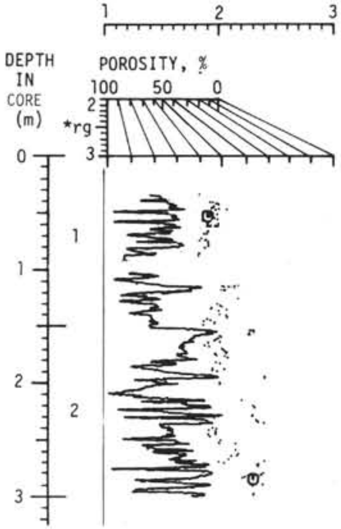

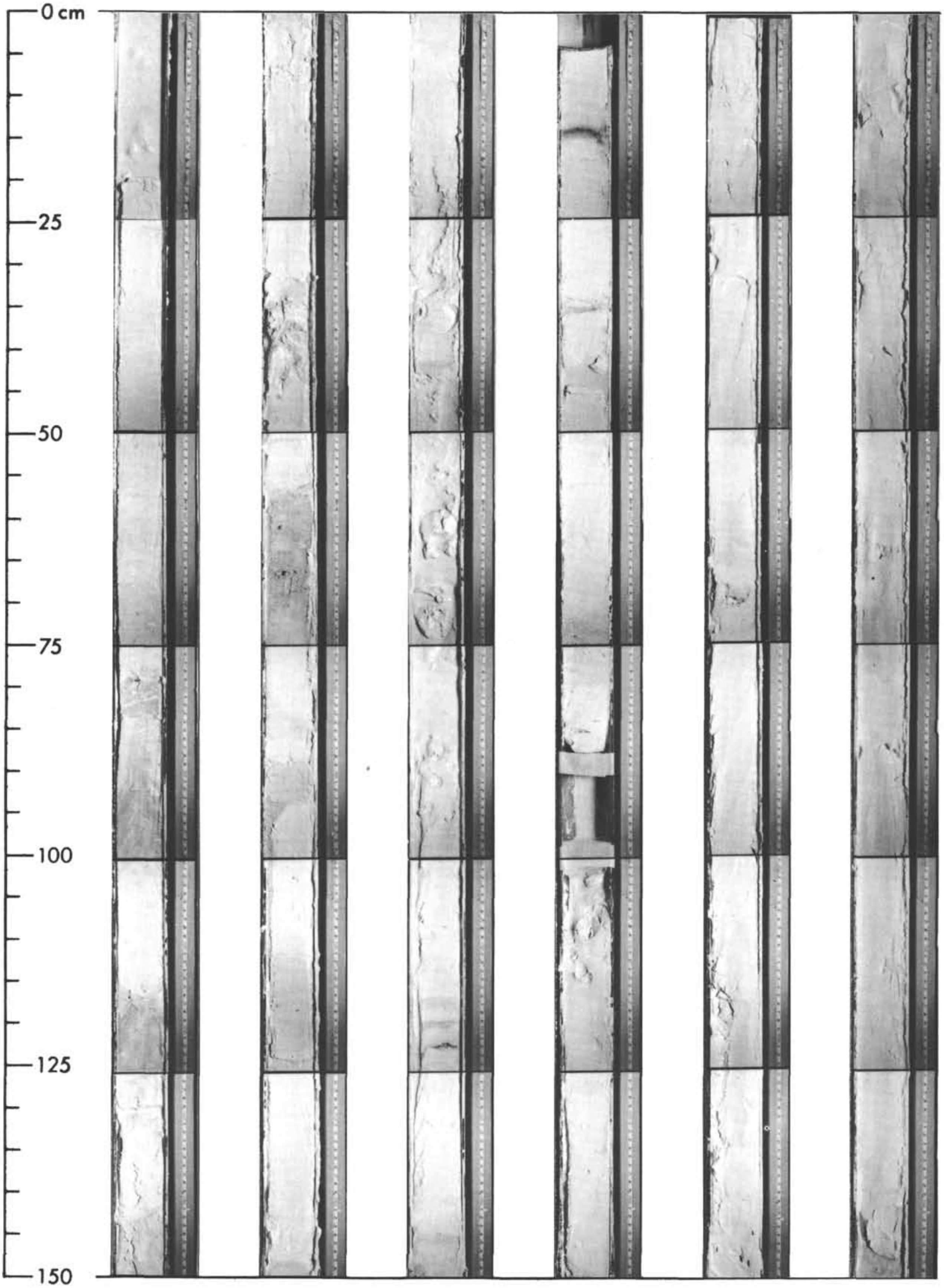

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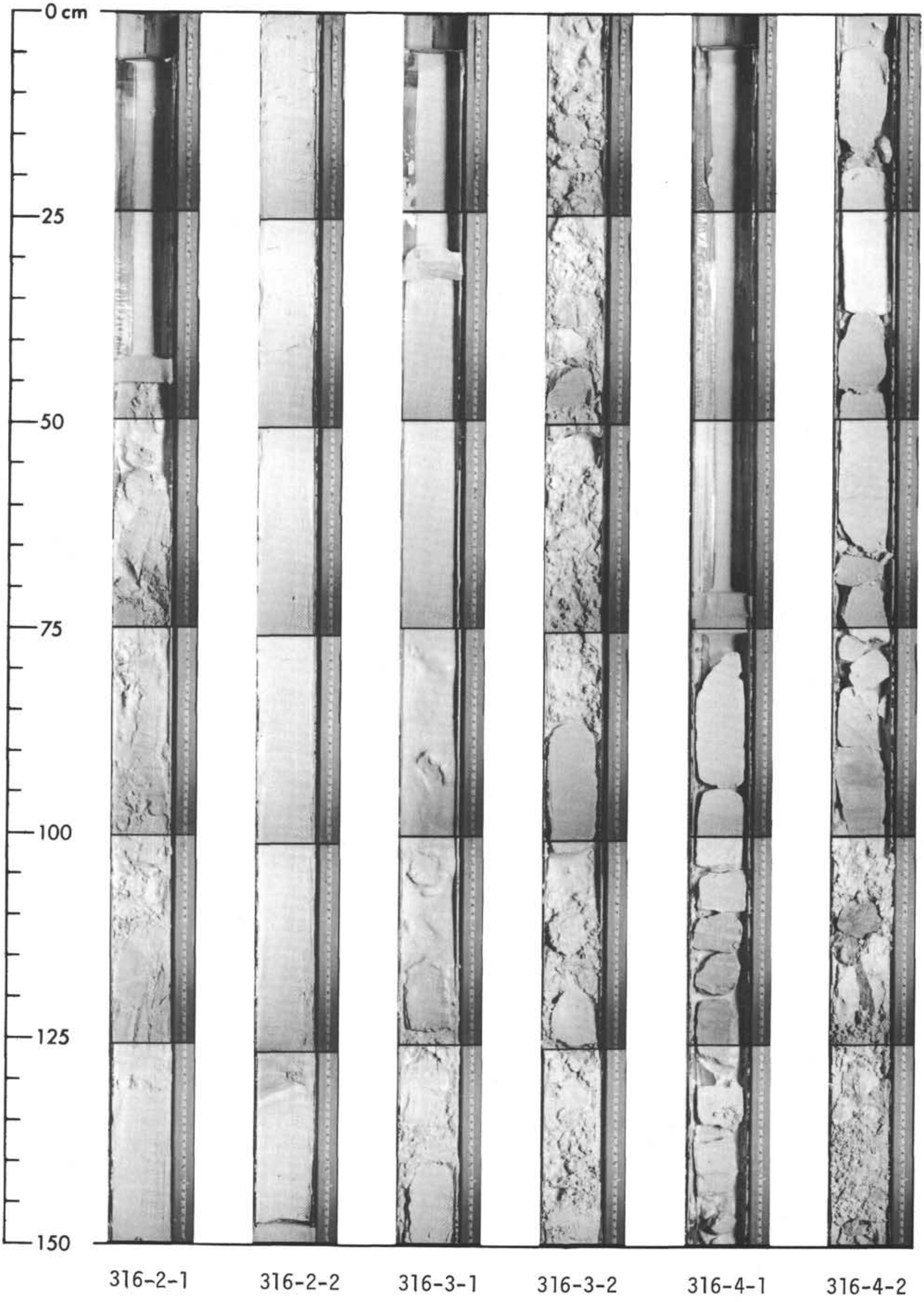
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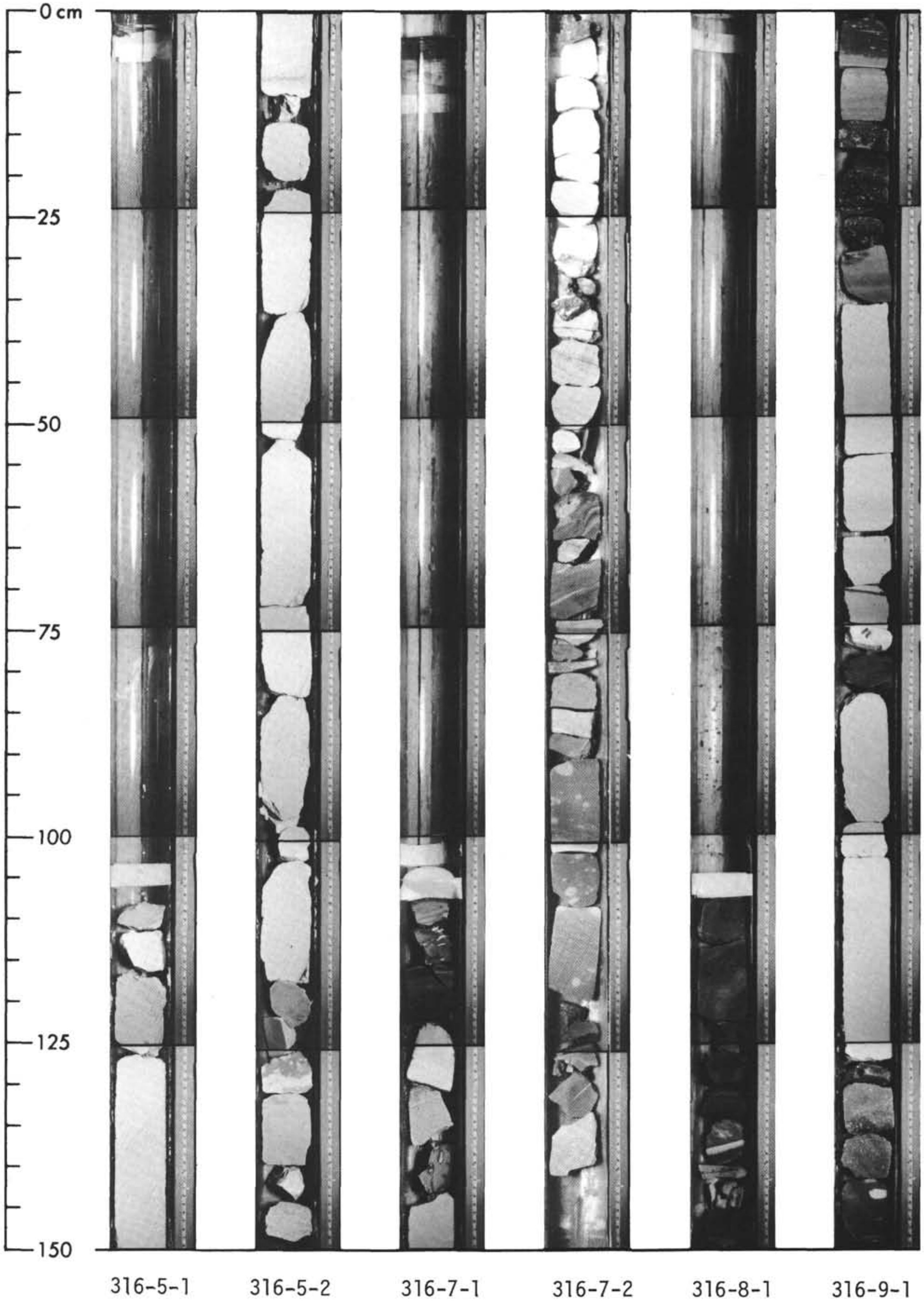
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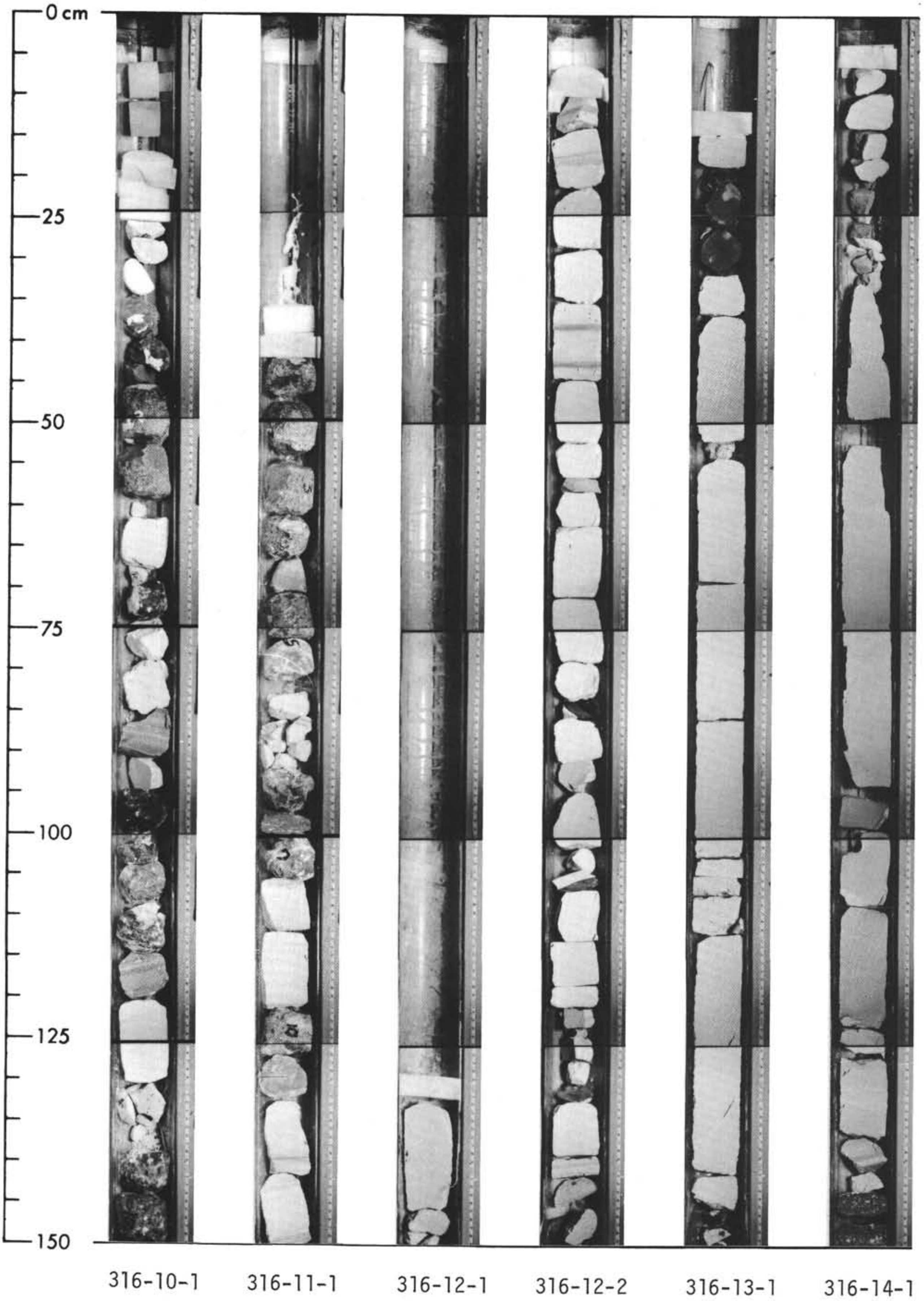
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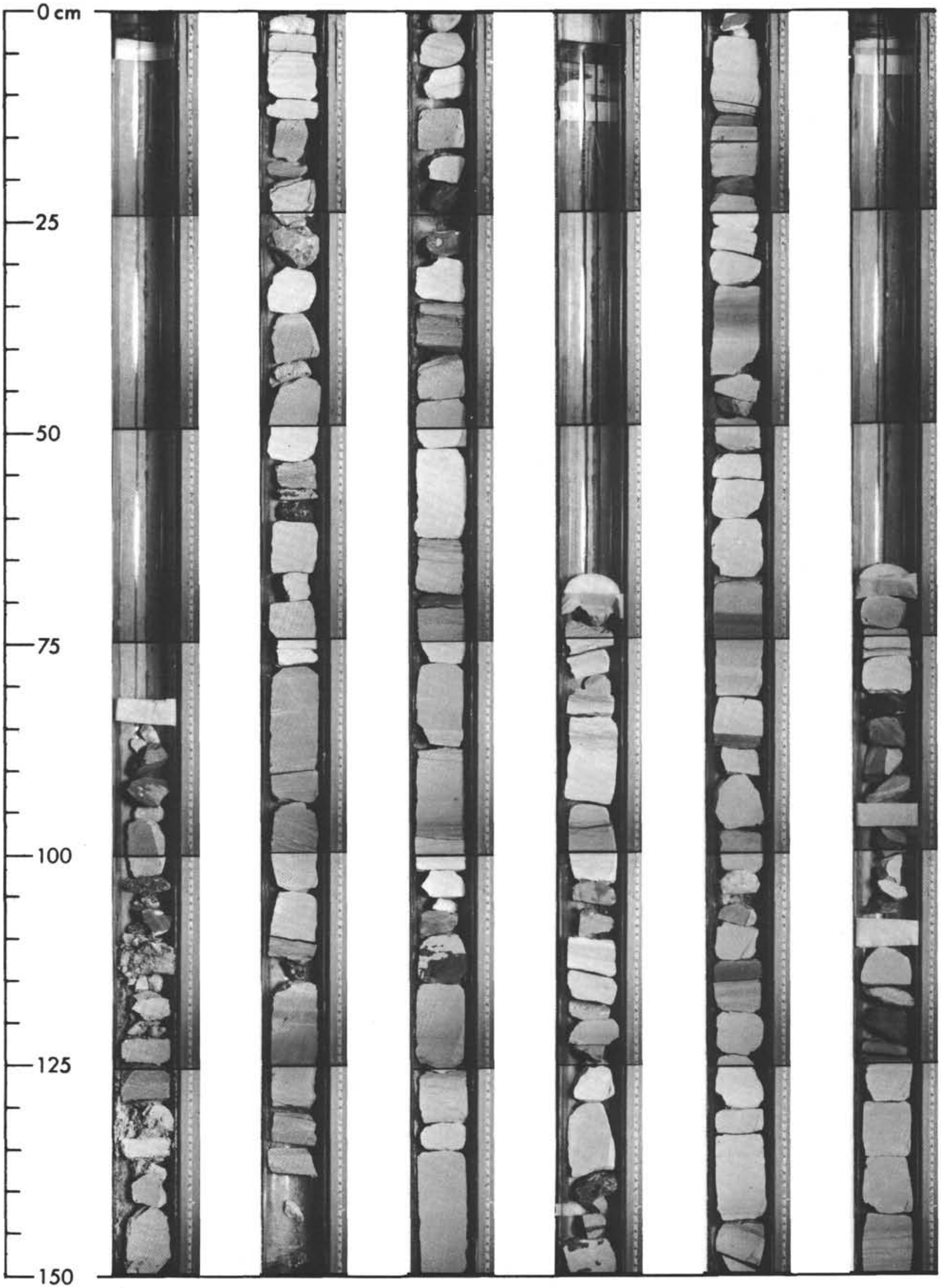

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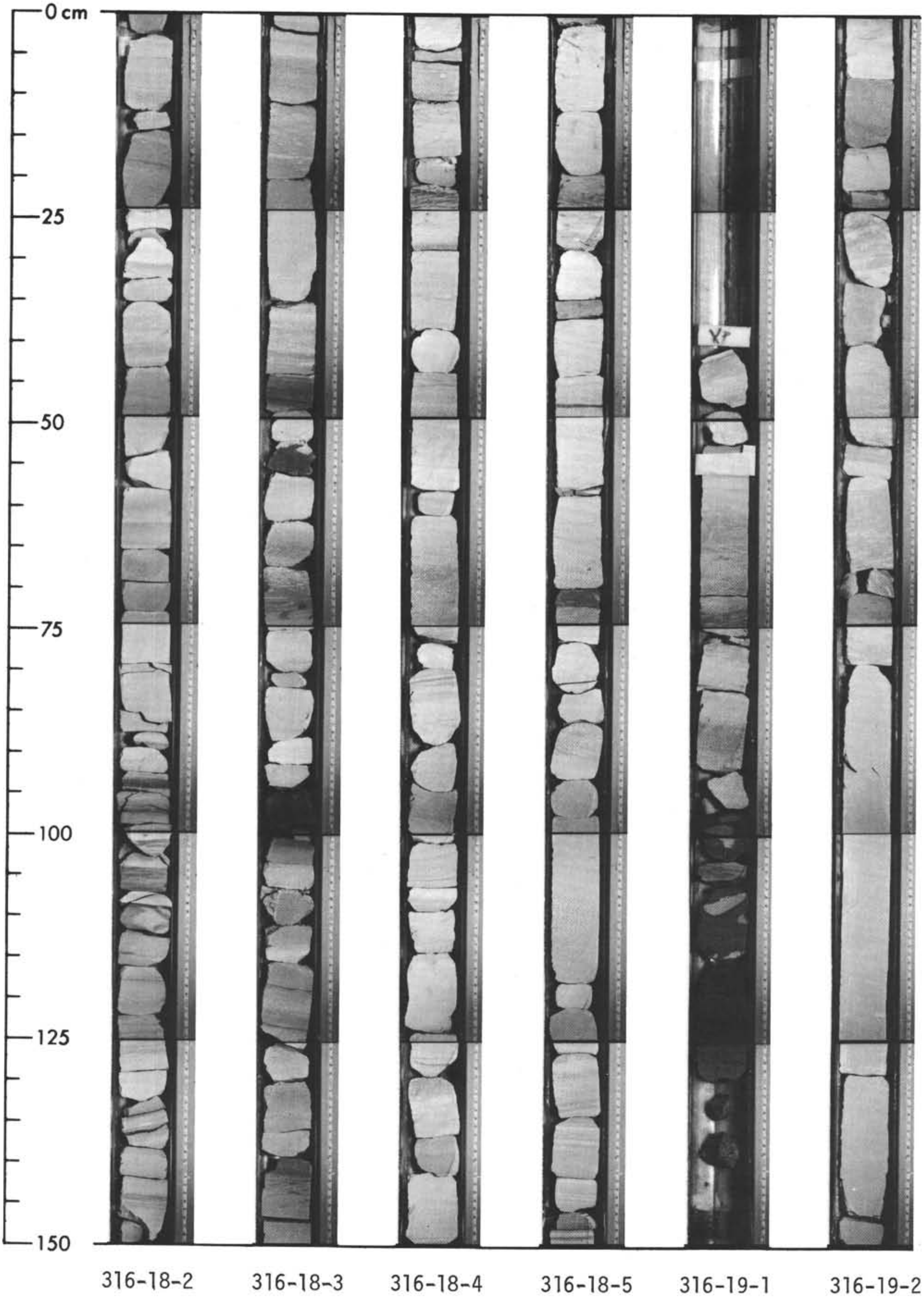
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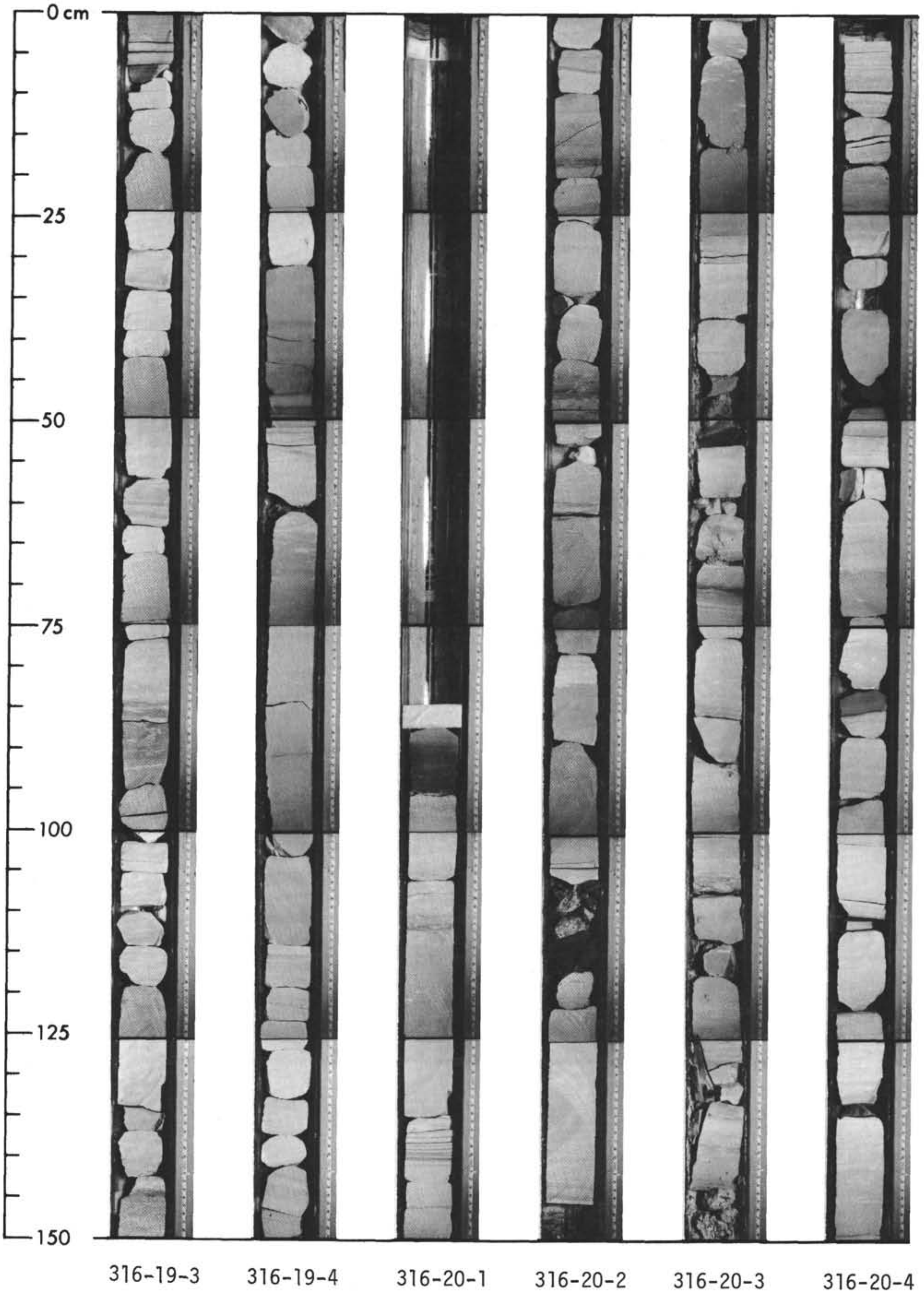
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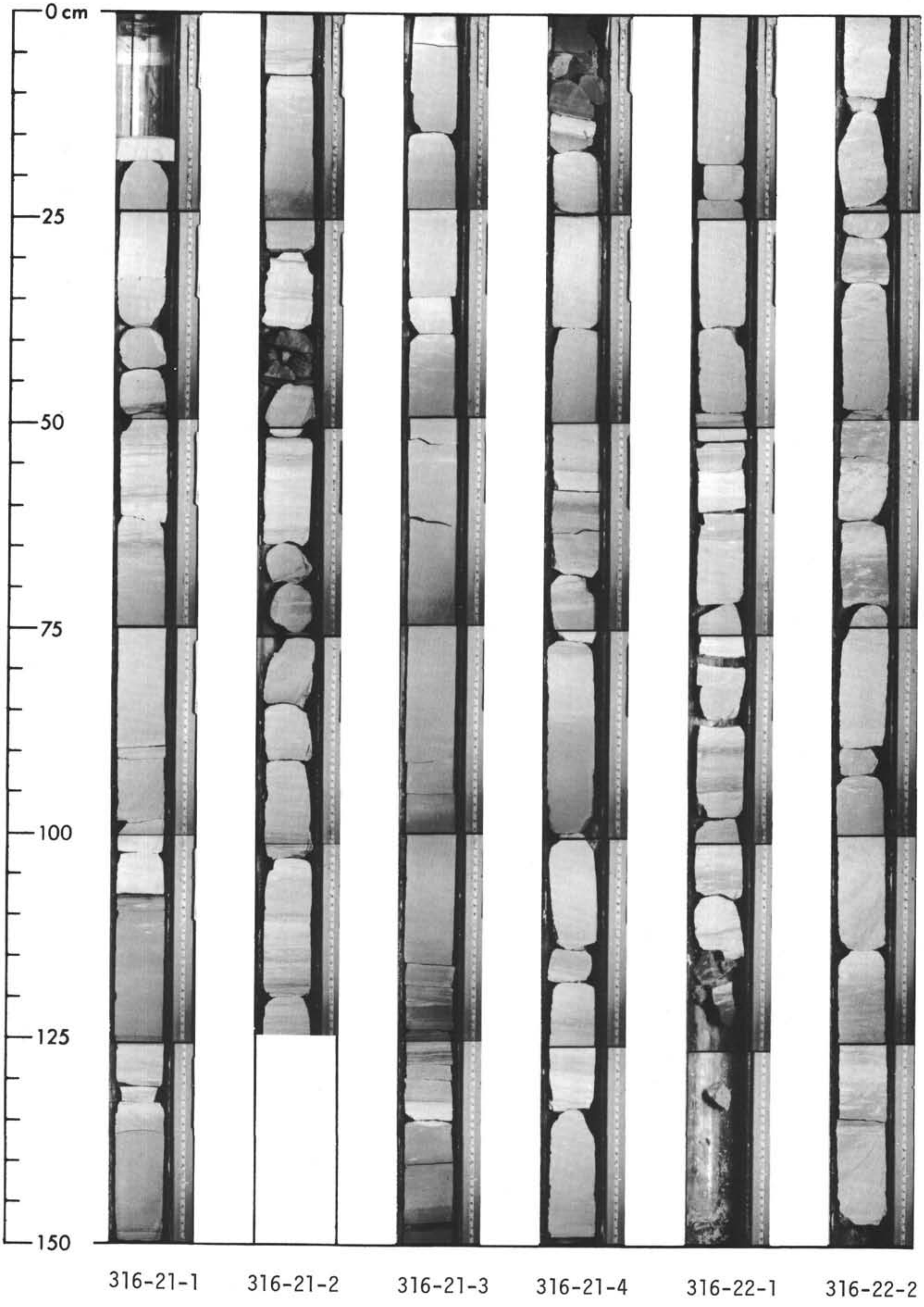
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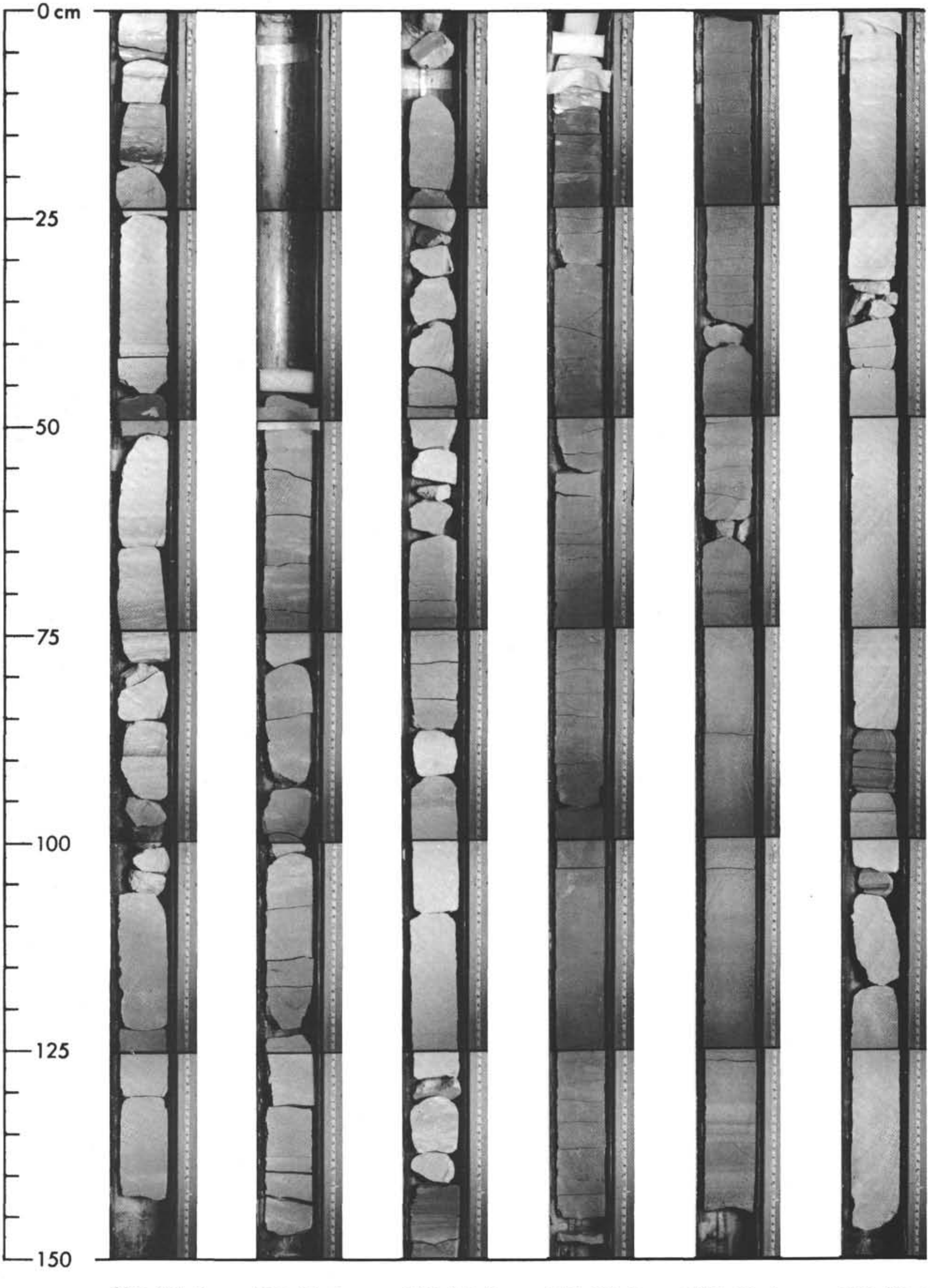
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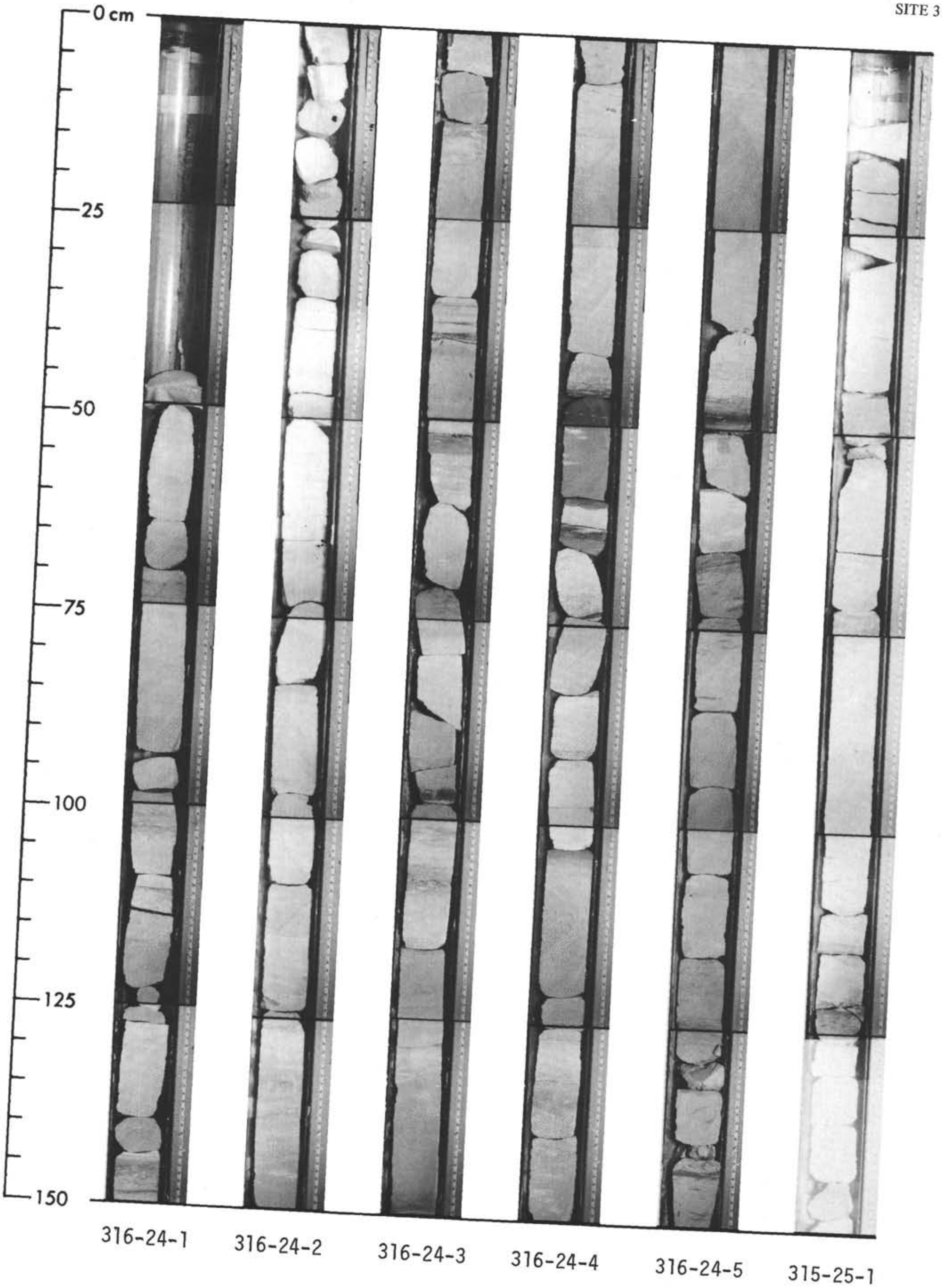
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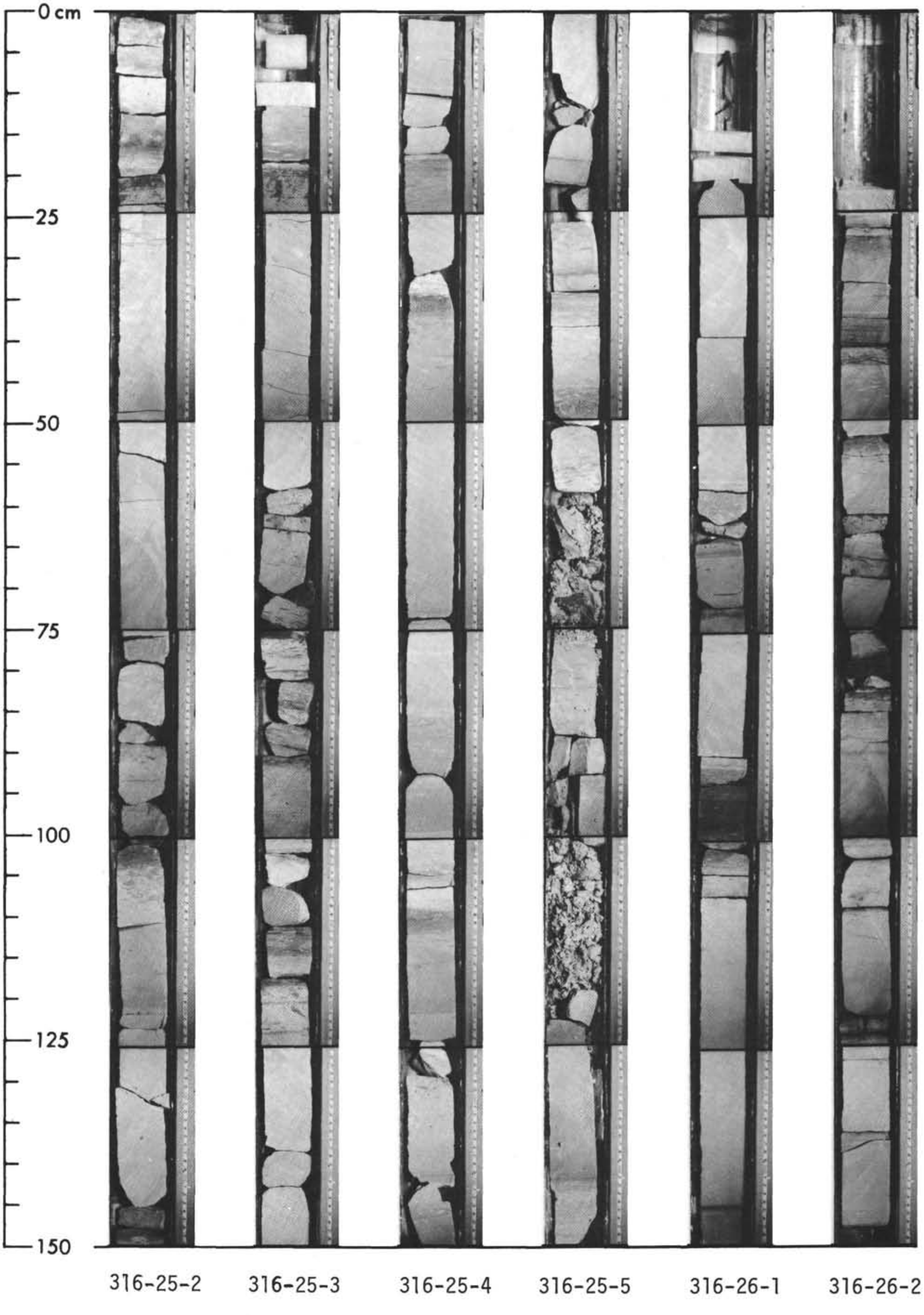
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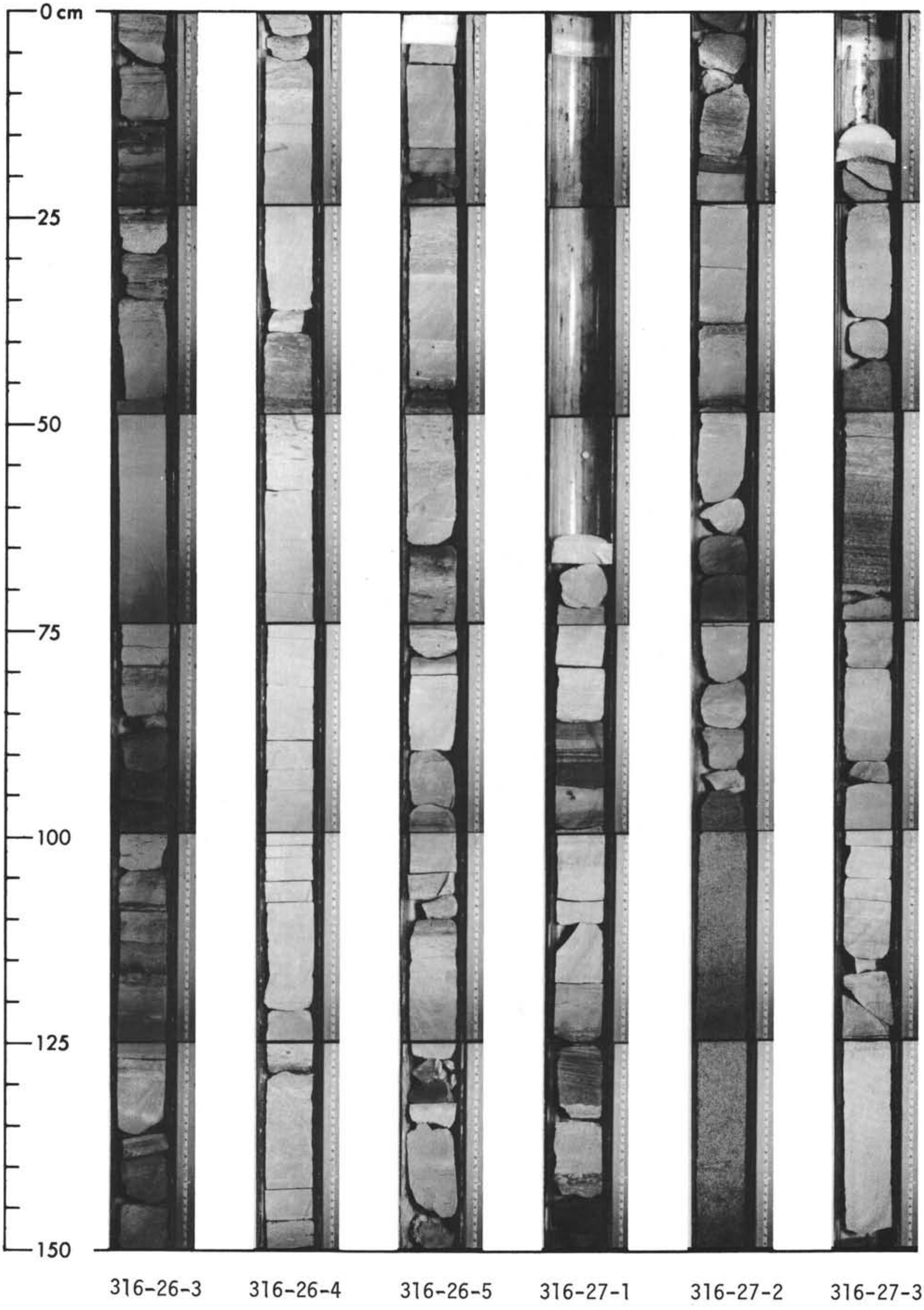

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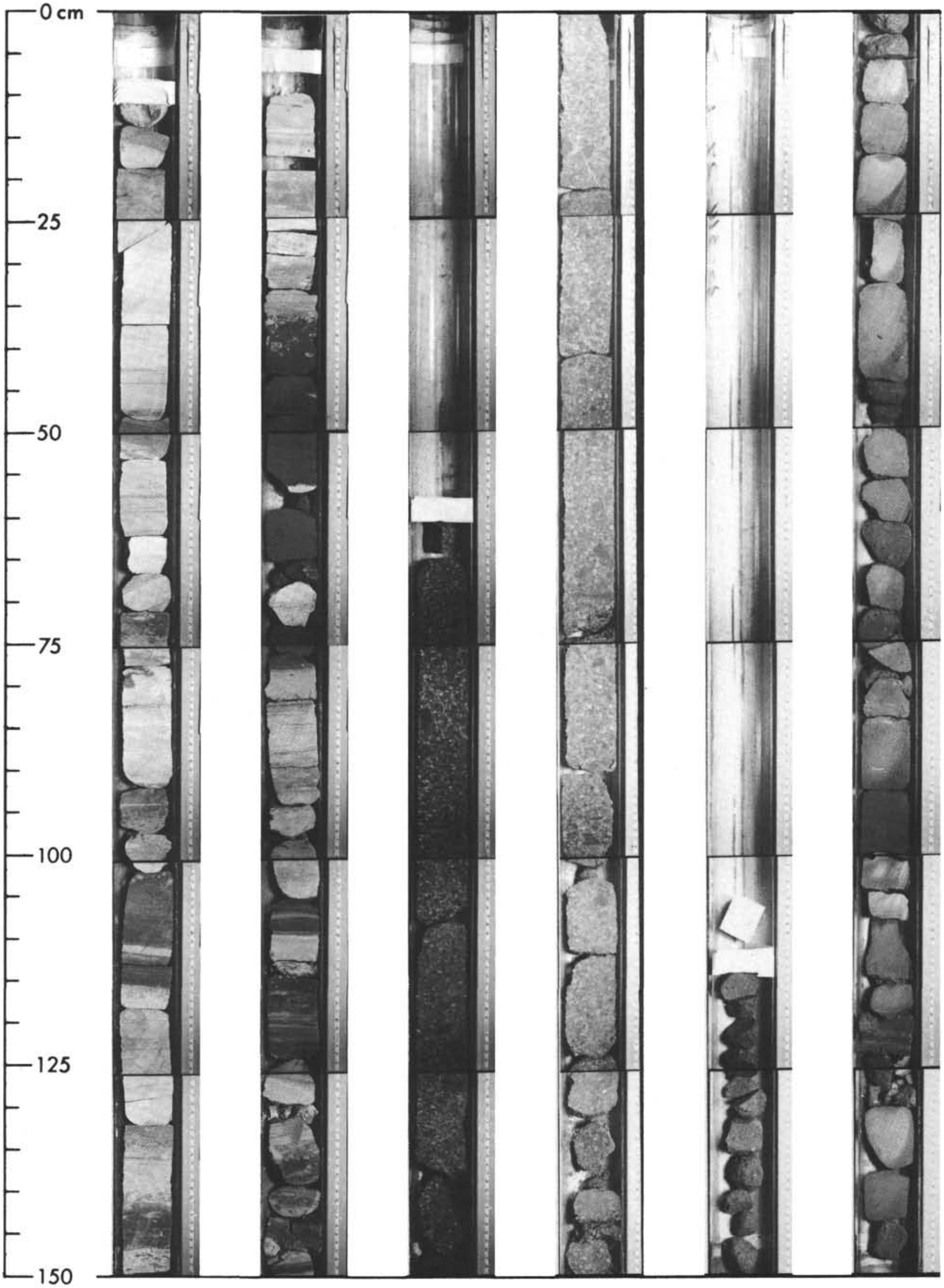
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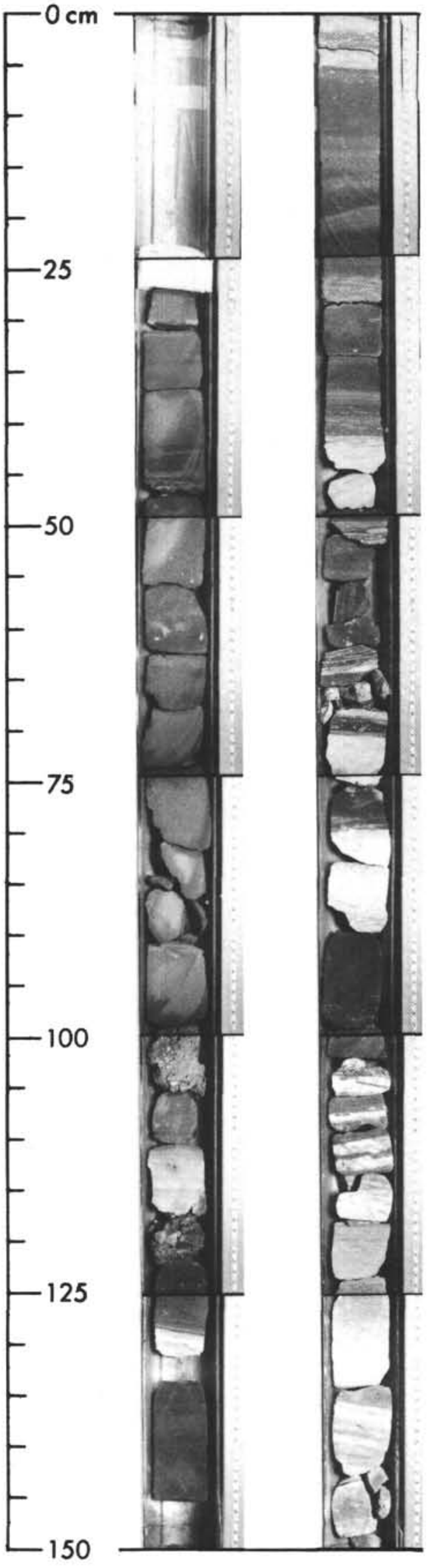
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