5. SITE 324

The Shipboard Scientific Party[1]

SITE DATA

Position: 69°03.21′S, 98°47.20′W

Water Depth: 4433 corrected meters, echo sounding; 4449 meters, drill pipe measurement

Number of Holes: 1

Number of Cores: Attempted: 10

Penetration: 218 meters

Total Length of Cored Section: 95.0 meters

Total Core Recovered: 48.1 meters

Percentage Core Recovered: 51%

Oldest Sediment Cored:

Depth Subbottom: 199.0 meters
Nature: Claystone fragments, coarse sand
Age: Pliocene
Velocity: 1.60 km/sec in firm clay at 174.6 meters subbottom depth

Basement: Not reached

Principal Results: A single shallow hole was drilled on the lower continental rise. Fifty meters of Pliocene and Pleistocene gray clay and minor claystone were recovered from the 218 meters penetrated. Ice-rafted debris, common in the upper part of the sequence, decreases with depth but is present throughout. An upper (50 m thick) acoustically laminated unit corresponds to soft watery diatomaceous clay and ooze with abundant ice-rafted debris. This is underlain by an acoustically transparent layer which comprises about 120 meters of gray unfossiliferous clay with silt laminae and thin (<1 cm) beds. A deeper acoustically stratified zone is composed of silty clay and sand beds. It was in this lower unit that sand plugged the bit causing abandonment of the hole.

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BACKGROUND AND OBJECTIVES

Background

Site 324 is located on the lower continental rise of Antarctica, about 75 miles north of the base of the continental slope (Figures 1 and 2). Water depth here is about 4449 meters, but it decreases gradually and then rapidly southward. The closest land is Thurston Island, about 160 miles to the south, and Peter I Island, about 160 miles to the east. Tectonically, the site lies in the oceanic part of the Antarctic plate. A seismic profile through the site, parallel to bathymetric contours, *Eltanin*-42 (198) 2100 hr, 31 March 1970, shows a relatively thick (2.0 km) sedimentary sequence which includes an acoustically transparent and lenticular near-surface layer about 200 meters thick (Figures 3, 4, and 5).

Present knowledge of the geology of Antarctica has been summarized in a series of recent geologic maps (Craddock, 1970, 1972). The rocks of coastal West Antarctica record a complex history of Phanerozoic sedimentation, volcanism, plutonism, metamorphism, and orogenic deformation; no rocks of definitely Precambrian age are presently known. Several orogenic cycles have been identified, and the youngest is the Andean of Cretaceous to early Tertiary age. Cenozoic volcanic rocks are widespread in coastal West Antarctica. Peter I Island is a basaltic volcano, probably Miocene in age, and other seamounts are known near this site. Thurston Island consists of Paleozoic and Mesozoic igneous and metamorphic rocks. Upper Tertiary basaltic extrusives rest upon a glaciated unconformity in the Jones Mountains, just inland from Thurston Island.

Due to lack of magnetic profiles near Site 324, the pattern of magnetic anomalies has not been established. It appeared probable that the crust at this site was formed at the east Pacific-Antarctic Ridge. Because the axis of the east Pacific-Antarctic Ridge lies more than 1000 miles away, the crust at Site 324 could be of Mesozoic age.

Scattered piston cores taken in the area recovered siliceous clayey silt, silty clay, and clayey silt. Goodell et al. (1973) give an average acculumation rate of 2.5 cm/1000 yr for glaciomarine sediments on the continental rise of Antarctica. However, even higher rates were encountered at Sites 322 and 323 on the abyssal plain.

Site 324 lies nearly 600 miles south of the surface axis of the eastward-flowing Antarctic circumpolar current, but beneath the westward-flowing bottom countercurrent (Hollister and Heezen, 1967). Kennett et al. (1972) reported a regional unconformity of Oligocene age in the southwestern Pacific Ocean Basin which they attribute to paleocirculation changes related to the separation of Australia from East Antarctica and to glacial episodes in Antarctica.

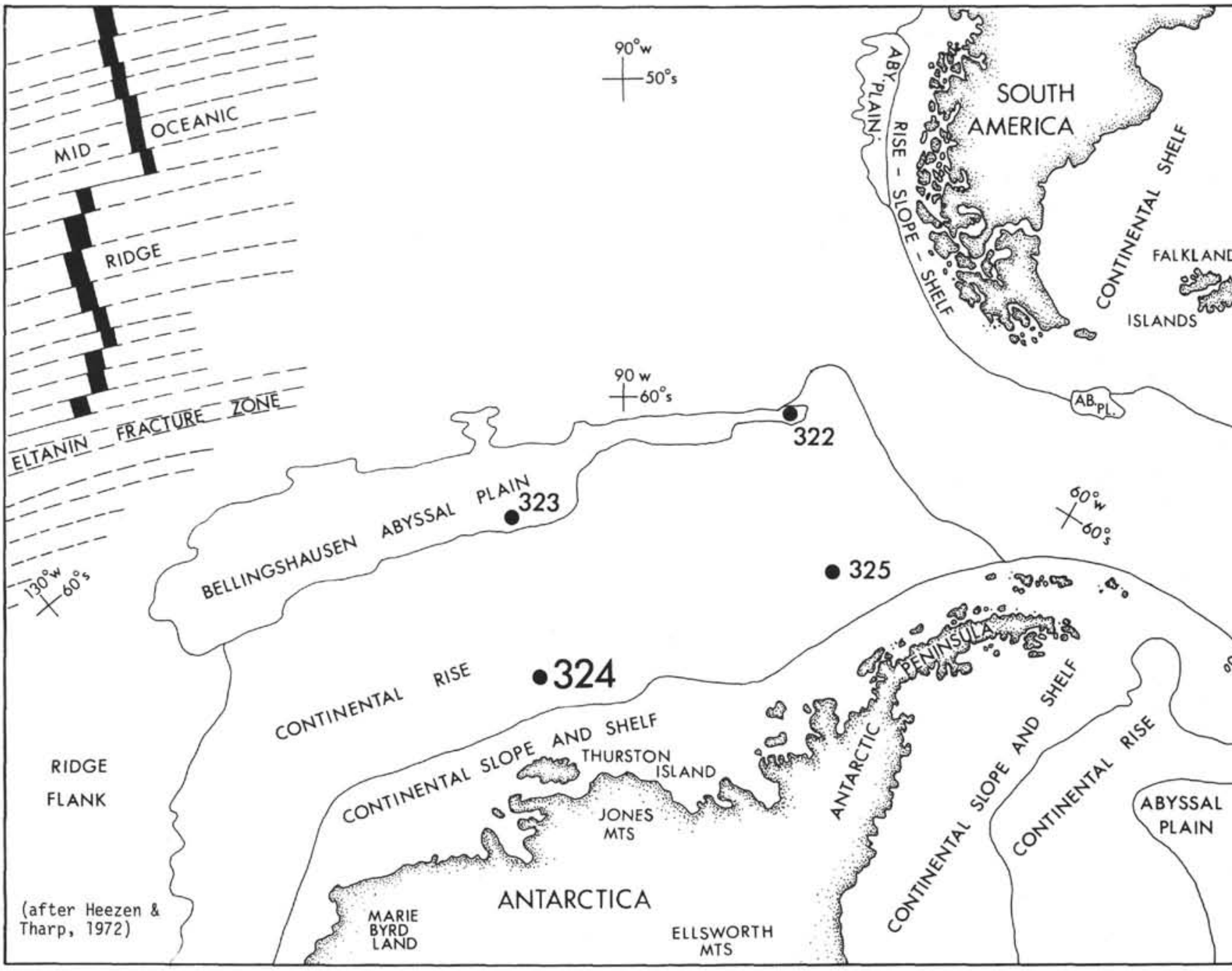

Figure 1. *Location of Site 324.*

Evidence for Tertiary glaciation in the Jones Mountains (74°S, 94°W) was first reported by Craddock et al. (1964) and later summarized by Rutford et al. (1972). LeMasurier (1972) described the volcanic history of Marie Byrd Land and postulated the existence of a West Antarctic ice sheet since the Eocene. Margolis and Kennett (1970) studied the quartz grains and foraminifers in 18 piston cores from the South Pacific and inferred that Antarctica was glaciated during much of the time since the Eocene, but with a warm episode in the Miocene. During DSDP Leg 28 glaciomarine sediments were found in holes in the Ross Sea, including beds as old as Oligocene at Site 270.

The Jones Mountains have yielded important evidence for Miocene glaciation of ice-sheet dimensions in this part of West Antarctica. Radiometric (K-Ar) ages on basaltic rocks overlying a fresh glacial pavement give discordant results, probably due to incomplete degassing of mantle-derived Ar^{40}during subglacial eruptions. The calculated ages cluster in the 7-10 m.y. range. Site 324 was strategically located to test the existence of the postulated Miocene ice sheet in the region of the Jones Mountains. Such an ice sheet should have calved many bergs, which would have drifted both northward and eastward; at least some should have reached the vicinity of Site 324 and dropped their entrained rock debris to the sea floor.

Objectives

The main objectives at this site were: (1) to determine, if feasible, the age or a minimum age of the basement by drilling through or deeply into the thick sedimentary sequence; (2) to determine lithology, provenance, and processes of depositon that were responsible for building this portion of the continental rise; (3) to seek evidence of Tertiary glaciation in Antarctica, especially during the period of 7-10 m.y.B.P. (late Miocene); (4) to understand the biostratigraphy and paleooceanographic environment of this region; (5) to obtain samples of pore waters for studies of geochemical gradients and halmyrolysis.

OPERATIONS

The ship arrived in the vicinity of Site 324 at approximately 2300 hr 12 March 1974 and slowed to 170 rpm. At 2345 hr *Glomar Challenger* changed course to

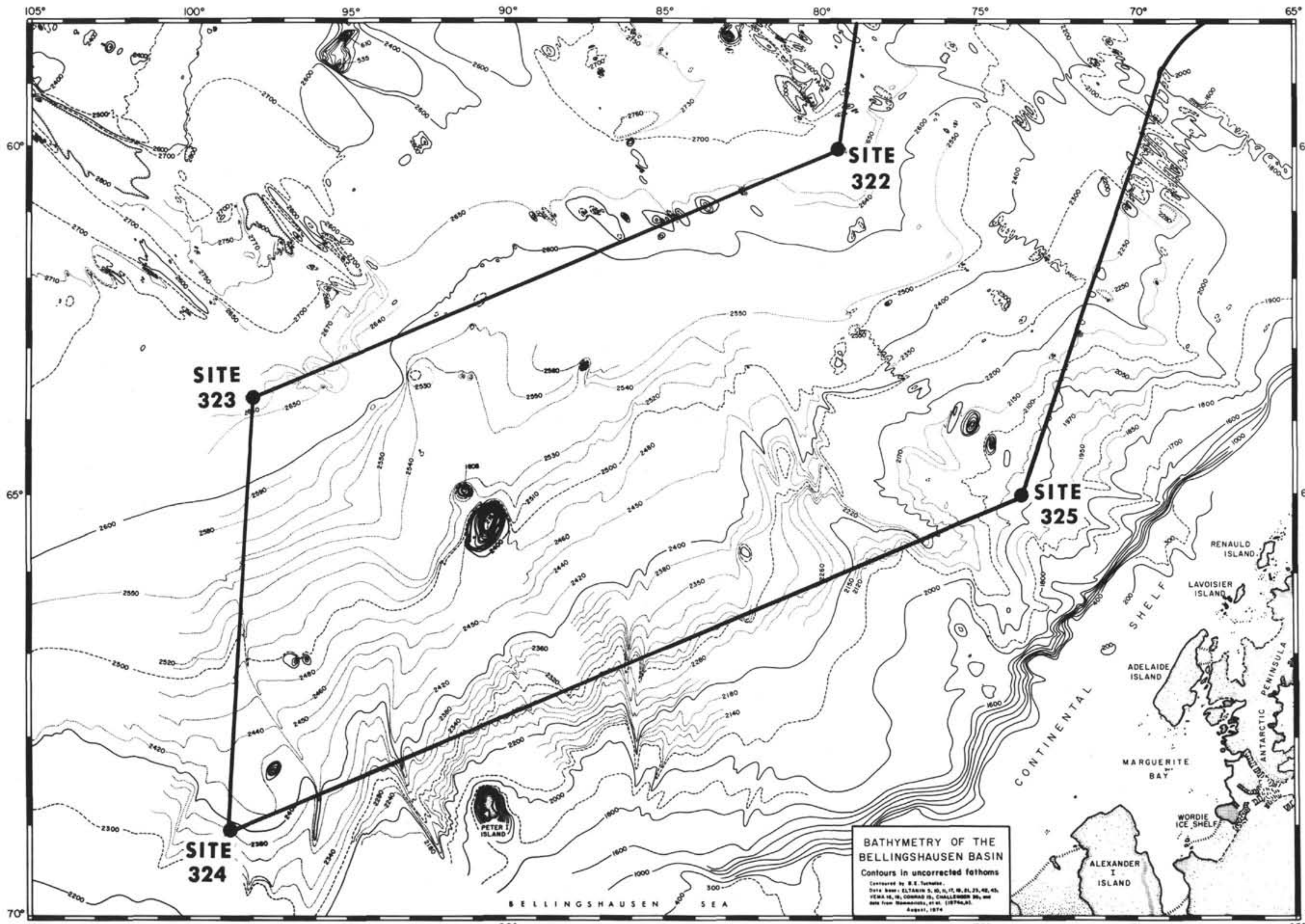

Figure 2. *Bathymetric map of the Bellingshausen region. (See also foldout in back cover.)*

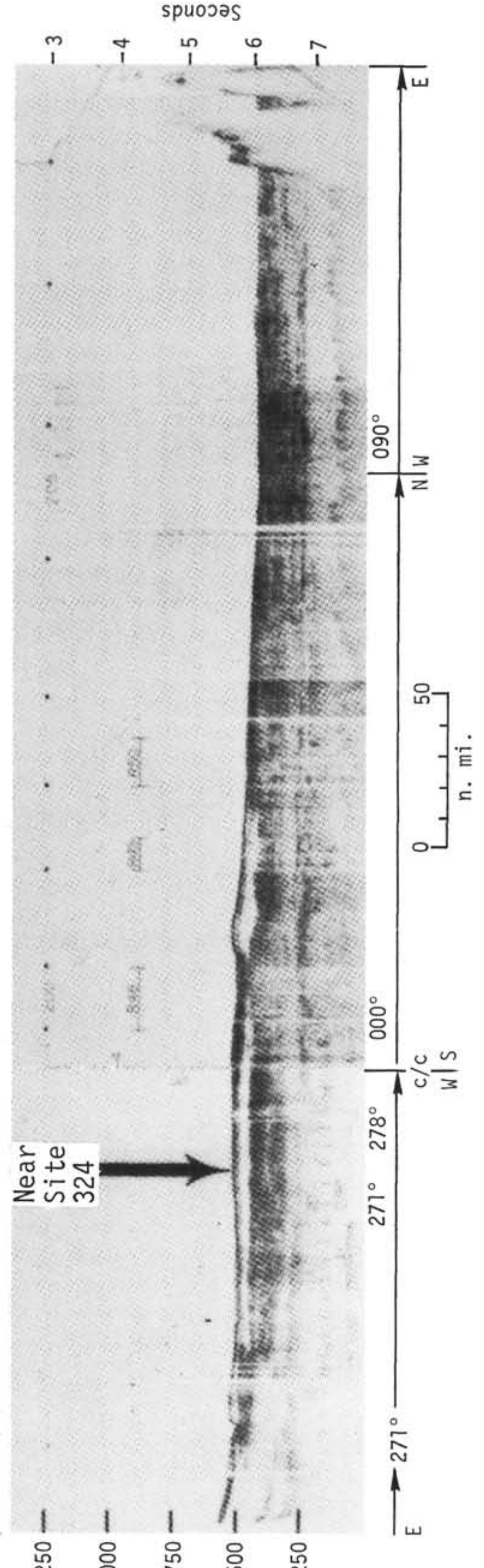

Figure 3. Eltanin-42 *seismic profile in vicinity of Site 324 (approximately 69°03'S, 98° 50'W). See Figure 4 for location.*

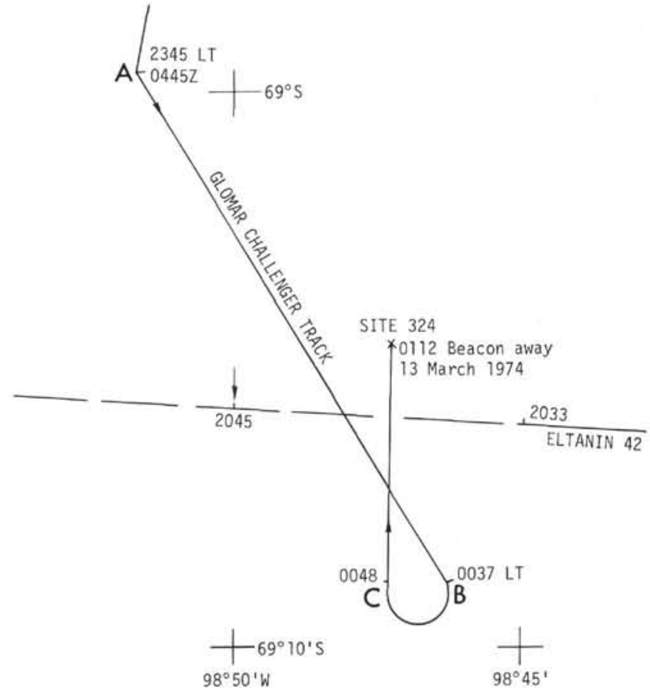

Figure 4. Glomar Challenger *and* Eltanin-42 *track in the vicinity of Site 324. Arrow corresponds to arrow on* Eltanin *profile, Figure 3.*

160° for a final pass across the *Eltanin*-42 profiler track (Figure 3 and 4) prior to dropping the beacon (13.5 kHz O.R.E.) 0112 hr 13 March 1974. Figure 5 shows the *Glomar Challenger* profile approaching Site 324. The beacon reached the sea floor at about 0157 hr and the vessel stabilized over the site at about 0220 hr (4433 m corrected echo sounding depth). Bottom contact was made with the drill pipe (1530 hr) at a depth of 4459 meters below the rig floor. (The rig floor is 10 m above the sea surface.)

The first core was taken at 9 meters subbottom in unconsolidated pebble clay. The rest of the cores, except the last one which contained sand and claystone, consisted of soft silty clay with thin lenses and laminae of well-sorted silt. Coring rates dropped sharply from nearly 5 meters per minute at 9-18 meters subbottom (Core 1) to 1.5 meters per minute at 50 meters (Core 2) and remained at about 1 meter per minute to the bottom of the hole (218 m total depth).

A total of 10 cores (9.5 m each) was attempted in the hole. Recovery averaged 51% for the entire hole and ranged from 0% to 100%. The core bit became plugged with sand shortly after cutting Core 10, and as the hole appeared to be collapsing and filling it was necessary to terminate drilling. The end of the core barrel was found to be highly polished, and a few grains of fine sand were found adhering to the empty core liner (Core 10). Apparently a sand and claystone formation with clean, unconsolidated sand had collapsed into the hole. Coring at Site 324 is summarized in Table 1.

LITHOLOGY

Site 324 was drilled to 218 meters in acoustically nonlaminated sediments on the lower continental rise and

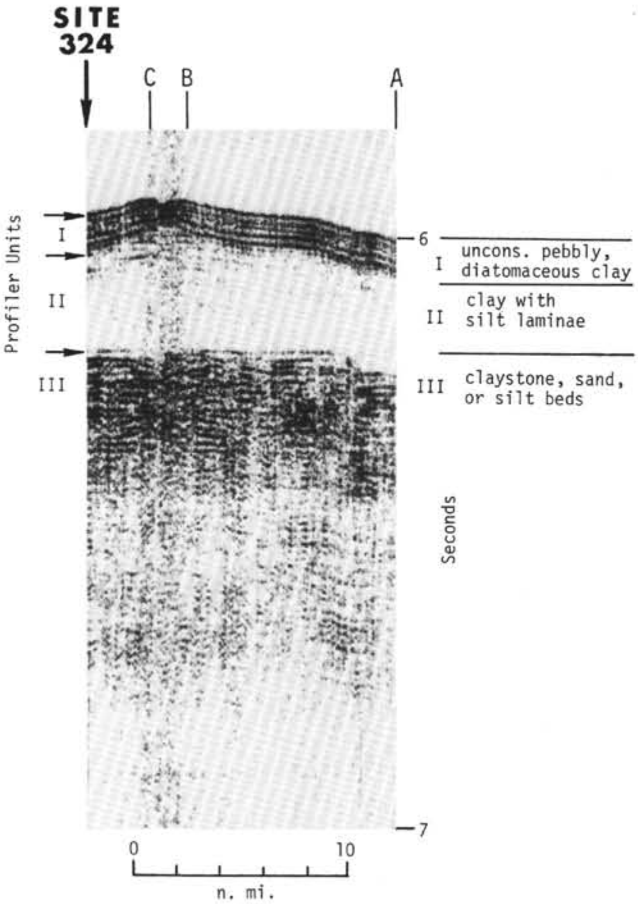

Figure 5. Glomar Challenger *seismic profile approaching Site 324, see Figure 4 for location. Acoustic units (I, II, III) are discussed in text.*

the deepest sediment recovered was at 189.5 to 199 meters. The deepest, unsuccessful core (10) contained only traces of coarse sand, and the hole collapsed when the interval was penetrated; the combined evidence suggests that the drill string had penetrated coarse, unconsolidated sand underlying the nonlaminated sediments (see Tucholke, Edgar, and Boyce, this volume).

The sediment recovered is remarkably uniform in lithology, and the entire sequence is discussed as one unit. Cores 1 through 9 contain gray Pliocene to Pleistocene clays with scattered ice-rafted debris and well-sorted silt and sand in beds, stringers, and pods created by drilling disturbance. Diatom clays and oozes were found only in Core 1; both diatoms and radiolarians are rare in deeper sediments.

Figure 6 graphically presents estimates of the principal components as determined from smear slides.

Silt-sized quartz is ubiquitous in the clays, usually in amounts of 5%-10%. The clays are mostly structureless, although a few trace fossils are present. Color changes in the clays are normally subtle and gradational, but are occasionally sharp. Very well sorted laminae and 0.5 to 1.0 cm thick beds of quartz silt were found in most cores. Their frequency appears to be inversely related to the amount of ice-rafted debris in the cores.

In addition to quartz, the layers contain heavy and opaque minerals, feldspar, and mica. Rock fragments are present in some cores. Even where core disturbance was not severe, primary structures were seldom observed in the silt layers. Occasionally, alternating light/dark, silt/clay laminae form the beds. Upper and lower contacts are invariably sharp.

The clays in Core 8-3 (174 m) show incipient induration to claystone, but are still pliable. A clay gall in Core 8, Section 2 and silt and clay beds in Core 9, Section 1 and 9, CC are weakly silicified.

Sedimentation Processes

The Pliocene and Pleistocene sediments recovered at Site 324 exhibit the strongest evidence for bottom current activity that was encountered during Leg 35. Nearly every core contains quartz-silt and sandy-silt layers (contourites) interbedded in terrigenous clay and ranging from a few millimeters to about 1 cm in thickness. The layers have sharp upper and lower contact, generally show excellent sorting, but rarely exhibit internal structure. A few are faintly laminated because of thin, dark mineral placers or clayey laminae. Size grading was not observed in the beds, and heavy minerals are usually present in amounts of 5%-10%.

Site 324 lies beneath the westward-flowing countercurrent on the continental rise and the cores were all recovered from a section of acoustically nonlaminated sediment (Heezen and Hollister, 1964). Sediment with this acoustic character on the rise appear to be confined to channel levees; the limited profiler data near this site do not show clearcut evidence for an adjacent channel (Tucholke and Houtz, this volume), although a broad trough exhibiting highly reflective sediments east of the site may represent a primary path of turbidite dispersal.

Although the texture and structure of the silt layers appear to present strong evidence for their current-controlled origin, the mechanism of formation can be twofold. They may have been formed as placer deposits by winnowing of fines from silty clay, or they may have been deposited from contour-following currents which pirated sediment placed in suspension by turbidity currents (Hollister and Heezen, 1972); when the current is not competent to carry the material entrained, it deposits it as a laterally graded bed downstream from the channel. Ideally, slight vertical grading also would be present in the bed, with the finest material at the top representing the limit of competence of the bottom current.

If the silt beds were formed as placer deposits by winnowing of silty clay, we would expect the frequency and thickness of the silt beds to increase in siltier sediment. However, as shown in Figure 7, there is no correlation between bed frequency and percent silt-in-clay, and bed thickness shows no correlative trend. In addition, the beds commonly contain a small fraction of sand (>62 μm), whereas the interbedded clays contain no sand. One exception is the clays containing ice-rafted detritus, but silt beds are not observed in these intervals.

The alternative explanation, deposition of turbidity-current-derived sediment by contour currents, is more satisfactory. Variations in the intensity of contour-

TABLE 1
Coring Summary, Site 324

Core	Cored Interval Total Depth (m)	Cored Interval Subbottom Depth (m)	Cored (m)	Recovered (m)	Recovered (%)	Lithology	Age
1	4468.0-4477.5	9.0-18.5	9.5	8.1	85	Clay and diatom ooze	Pleistocene
2	4506.0-4515.5	47.0-56.5	9.5	9.7	100	Clay with silt stringers	Pleistocene
3	4534.5-4544.0	75.5-85.0	9.5	8.3	87	Clay with silt stringers and pods	Pleistocene
4	4563.0-4572.5	104.0-113.5	9.5	5.0	53	Clay with silt layers and pods	Pleistocene
5	4591.5-4601.0	132.5-142.0	9.5	4.5	47	Clay and interbedded silt and clay	?
6	4601.0-4610.5	142.0-151.5	9.5	2.0	21	Clay with silt layers	?
7	4610.5-4620.0	151.5-161.0	9.5	5.6	59	Quartz-silty clay	?
8	4629.5-4639.0	170.5-180.0	9.5	4.2	44	Clay with interbeddes silt	?
9	4648.5-4658.0	189.5-199.0	9.5	0.7	7	Clay and claystone with ice-rafted debris	Pliocene
10	4667.5-4677.0	208.5-218.0	9.5	0.0	0	No recovery except for fine sand on core liner	–
Total	4677.0	218.0	95	48.1	51		

Recovery of total sequence penetrated = 22%.

current flow and in the magnitude of turbidity currents can account for the variability in the silt-layer thickness, development of internal structure, and median grain size (fine to coarse silt). In this instance, each silt layer results from a discrete turbidity current traversing the continental rise upcurrent from the site. At the observed accumulation rates (5.5 cm/1000 yr average), the frequency of silt beds suggests turbidity currents as frequent as one per 500 yr, but at a lower average rate of about one per 2000 yr during the Pliocene (Figure 7). These are minimum frequencies because all turbidity currents may not result in deposition of a recognizable contourite down-current from the turbidite channel.

Structures generally cannot be recognized in the clay-size sediment recovered, although faint color laminations and contacts occur locally. Trace fossils are very rare. It is likely that most of the clay was deposited from a current-maintained nepheloid layer during periods of less intense bottom current activity.

The grain size data for Site 324 clays show dramatic evidence for hydraulic sorting in the form of very symmetrical sigmoid curves typical of well-sorted material (see Tucholke, Hollister, Weaver and Vennum, this volume). This is the only site dominated by sediment exhibiting this characteristic, and we interpret the data to represent clayey contourites. Unfortunately, no detailed grain size analyses were made on the coarser contourite silts; however, one sand-silt-clay determination made on a contourite silt in Sample 7-6, 133 cm showed that the size-class percentage are 0-86-14. This is very well sorted silt (14% less than 4 μm) and is clean compared to matrix values for abyssal turbidites (Hollister and Heezen, 1967); the data thus support our contourite interpretation of the silt.

GEOCHEMISTRY

The mineralogy of this site is dominated by a terrigenous suite of minerals. Minor amounts of clinoptilolite were noted in the sediments above 110 meters (Gorbunova; Zemmels and Cook, this volume). Its presence is possibly a result of alteration of minor amounts of volcanic glass which was also present in these sediments.

Concentration gradients of calcium in the interstitial water suggest reactions of an undefined nature, but possibly related to alteration of volcanic debris. The observed oxygen isotope gradients do not require an explanation related to extensive alteration.

A source for dissolved calcium was present in the Pliocene/Pleistocene sediments, leading to a maximum concentration at about 115 meters. This may be due to the same processes active at Sites 322 and 323 in similar horizons. Small amounts of clinoptilolite (Zemmels and Cook, this volume) and glass shards, however, could indicate alteration of volcanic matter. Changes in δO^{18} are relatively large. Unfortunately, we do not know much about the nature of the underlying sediments, so that interpretations of interstitial water composition are necessarily hampered.

PHYSICAL PROPERTIES

Syringe measurements of water content, saturated bulk density, and porosity, as well as GRAPE measurements of saturated bulk density (continuous mode), were made on Cores 1-8 (Table 2 and Figure 8), but only Cores 6 and 8 contained firm sediment with little deformation. The other cores exhibited moderate to intense deformation, and the measurements made on these sediments are not considered reliable.

Unfortunately, deteriorating hole conditions forced abandonment of this site before many cores were recovered from the deeper, firmer clays of the sedimentary column.

Saturated Bulk Density

Gamma Ray Attenuation Porosity Evaluator (GRAPE) determinations of saturated bulk density ($\pm$11%) are plotted in Figure 9. An estimated grain den-

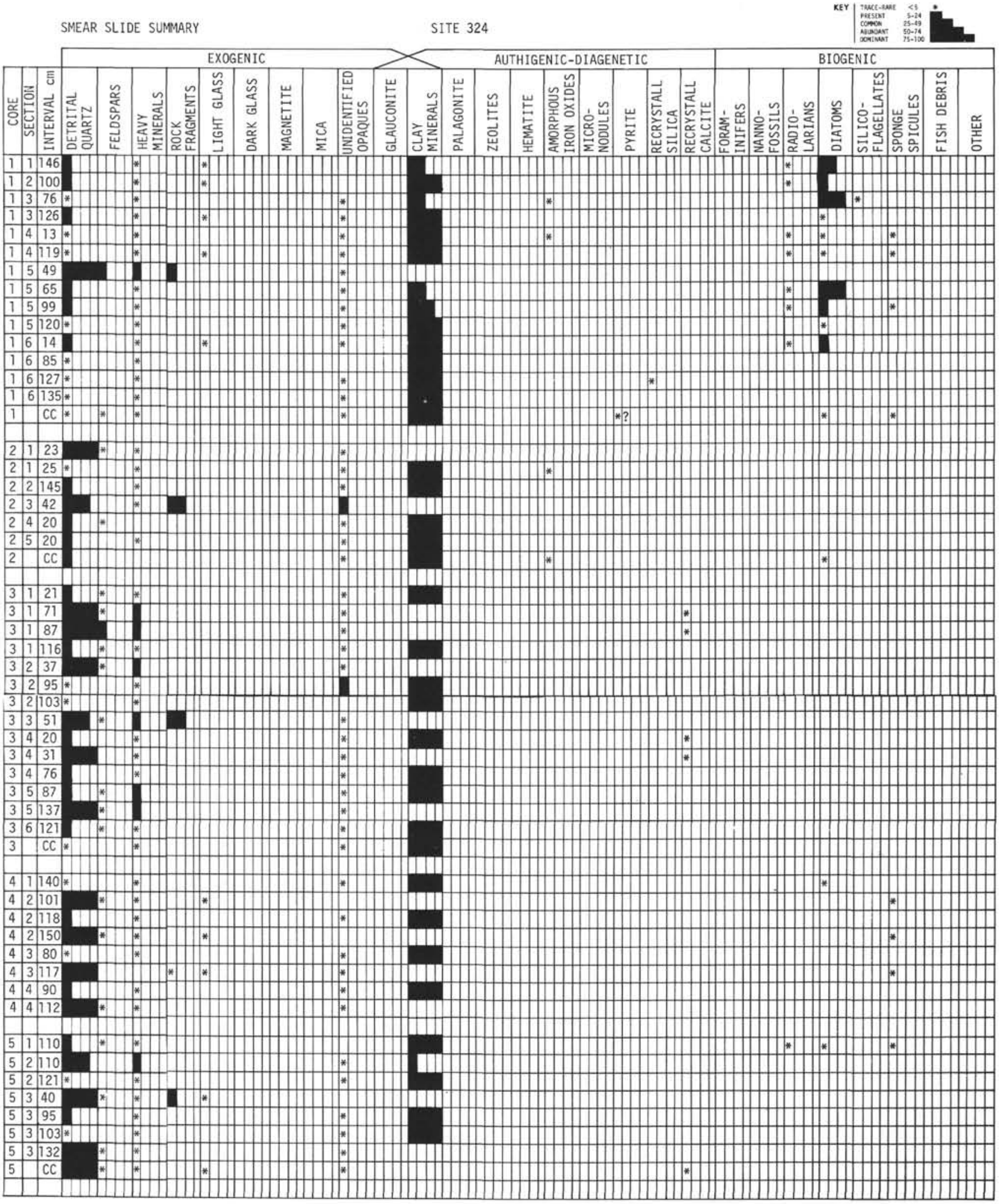

Figure 6. *Estimate of principal components from smear slides, Site 324.*

sity of 2.61 g/cm³ (collapsed montmorillonite) was used in these determinations. The wide scatter of values reflects the variability of deformation in the cores.

Syringe determinations (±5% relative error) of saturated bulk density have a similar scatter, again reflecting core deformation. However, the syringe values tend to be higher than the GRAPE values. Probably the most accurate values of saturated bulk density are 1.73 to 2.16 g/cm³ in the nearly undeformed sediments of Cores 6 and 8. Bulk density increases

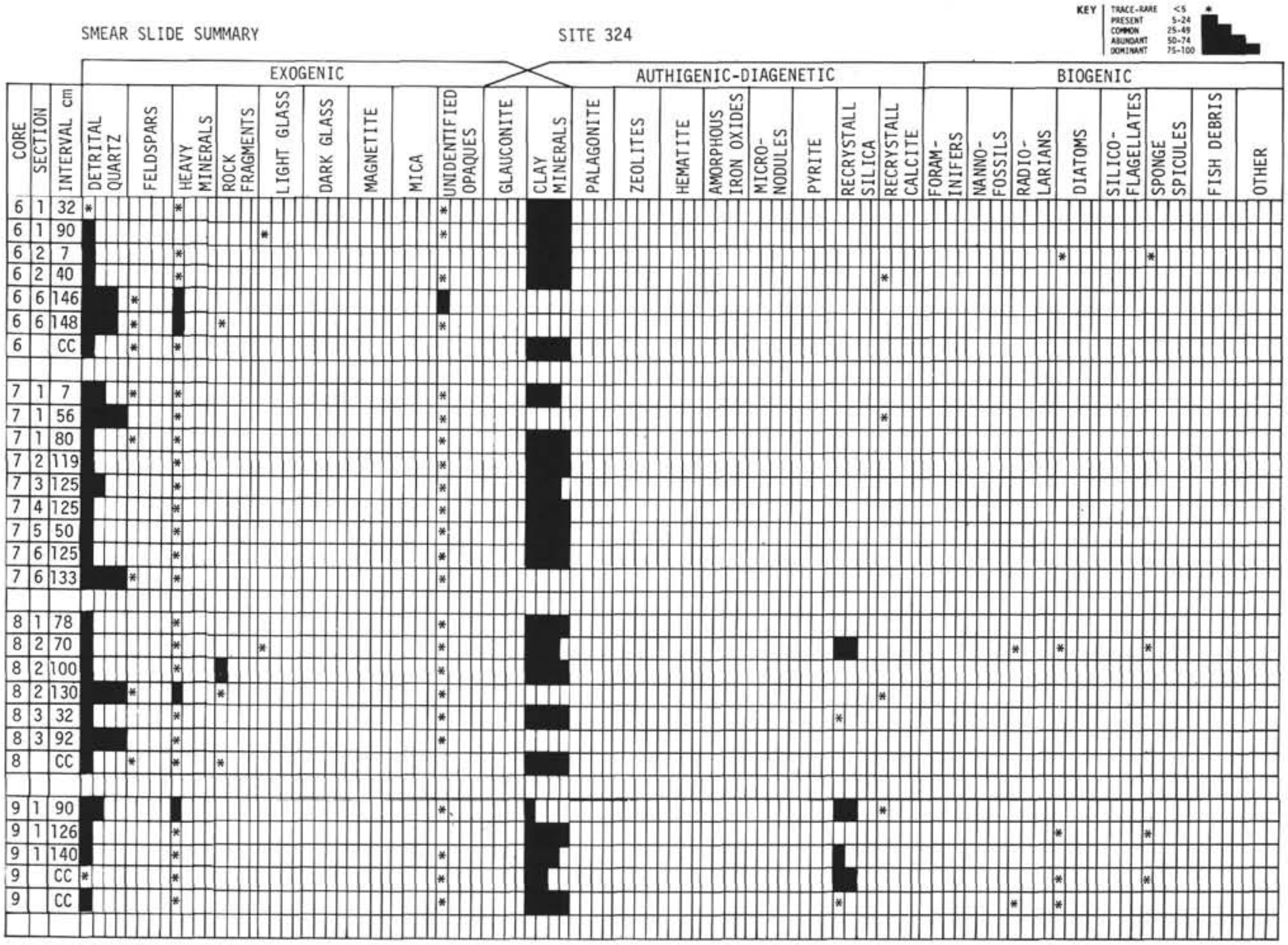

Figure 6. *(Continued).*

downhole, from 1.56 g/cm^3 at 16 meters to about 1.9 g/cm^3 at 150 meters; the latter values also are comparable to those of deeper diatom-free sediment at Sites 322 and 323.

Water Content and Porosity

Syringe determination of water content (% wet weight; 2% absolute error) and porosity (±4% absolute error) are slightly more consistent than determination of saturated bulk density (Figure 8), although the intense deformation in the uppermost cores undoubtedly affects the measured values. Water content and porosity both decrease rapidly in the first 70 meters of hole, but at a lesser rate below. The values in the lower part of the hole (25% water content and 50% porosity) approach those found at depths of several hundred meters at Sites 322 and 323. Diatoms are very rare in all the cores except Core 1, and their absence probably accounts for the low porosity and water content at the shallow depths.

Only one sonic velocity measurement was made on the virtually undeformed sediments of Core 8, Section 3 at 110 cm. The value obtained (1.60 km/sec) perpendicular to the bedding in firm clay at 174.6 meters subbottom is probably somewhat higher than the average *Vp* for the overlying unconsolidated sediments. The sample was a very firm clay, and adjacent clays exhibited incipient induration to claystone.

INTERPRETATION OF SEISMIC PROFILES IN VICINITY OF SITE 324

Site 324 was drilled 218 meters into a wedge of nonlaminated sediment on the continental rise (Figures 3 and 4). The prolonged, reverberant character of the airgun signal is repeated in the sea-floor reflection, but a single reflection event at about 0.05 sec subbottom does not match the pulse character and appears to be a real reflector. Acoustically laminated sediment at about 0.23 sec subbottom underlies the sediment drilled.

Physical properties measurements were made only on the unconsolidated and slightly consolidated clays which comprise the bulk of sediment cored at Site 324. Small samples of partially silicified quartz silt and claystone were recovered just below 190 meters in Core 9. The last core attempted at this site (Core 10) failed to recover any sediment except a trace of sand; this failure, and the high polish on the core barrel, suggest that a thick interval of unconsolidated sand was penetrated. Thus the sediments represented by Cores 9 and 10 are the first deviation from unconsolidated clay sediments in the hole, and they may correspond to the top of the acoustically laminated sediment at 0.23 sec in the profiler record. The acoustic lamination of the interval below 0.23 sec is similar to that caused by interbedding of unconsolidated sand, silt, and clay in the upper 300 meters of Sites 322 and 323. If the boundary between

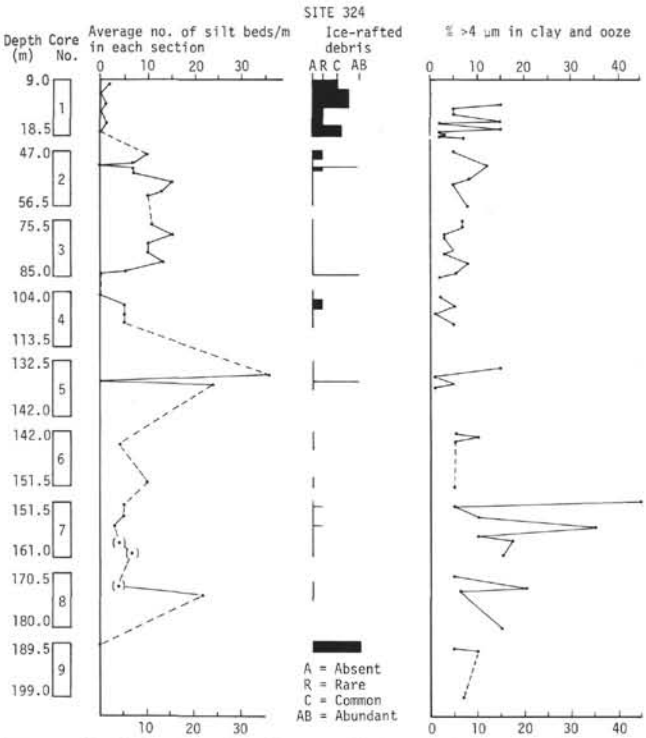

Figure 7. *Relative abundance of clastic debris with respect to average number of silt beds and depth as determined from smear slides.*

the two units is placed at the level where silicified sediment was first recovered, a minimum average velocity of 1.66 km/sec for the nonlaminated layer is indicated; if the boundary were as deep as Core 10 (208.5 m), the interval velocity would be 1.81 km/sec. The only direct velocity measurement was 1.60 km/sec on the consolidated clay at 176.4 meters. This value, if corrected for overburden stress, hydrostatic pressure, and temperature to in situ conditions, probably would be only slightly higher than the first of the above average interval velocities, suggesting that it is the better estimate. Two sonobuoy profiles recorded over nonlaminated sediments adjacent to this site suggest a similar low velocity. The sonobuoy closest to Site 324 (E42-47) was on the eastern edge of the nonlaminated sediment wedge; it indicates an interval velocity of 1.68 km/sec for the upper 473 meters of sediment. The interval velocity for the nonlaminated layer alone is probably slightly lower.

The apparent reflector at 0.05 sec probably lies at about 40 meter depth. We have no velocity or impedance measurements in this interval, but the reflector may relate to the marked changes in density and in drilling/coring rates near this level. The sediments in the upper 40-50 meters are lithologically dissimilar to the deeper clays in that they are enriched in diatoms and ice-rafted debris.

BIOSTRATIGRAPHY

Foraminifers

Only a small number of left-coiling *Neogloboquadrina pachyderma* and of *Globigerina quinqueloba* were found in the Pliocene sediments within Cores 5 to 8.

Calcareous Nannoplankton

No calcareous nannoplankton were found in cores recovered at Site 324.

Radiolarians

Sixty-five samples were examined for radiolarians from the first nine cores (Table 3). Forty-eight of the samples analyzed between 324-1, CC and 324-9-1 are totally barren of any radiolarian remains. Only the core catcher of Core 9 and Core 1 contain any radiolarians.

TABLE 2
Summary of Physical Properties, Site 324

Sample (Interval in cm)	Estimated Depth (m)	Velocity (km/sec)		GRAPE Special 2-Min Count Sat. Bulk Density (g/cc)		Sat. Bulk Density (g/cc)[a]	Wet Water Content (%)	Grain Density (g/cc)[a]	Porosity (%)[a]	Impedance (g/cm^2 sec) × 10^5	Lithology Remarks
		∥ Beds	⊥ Beds	∥ Beds	⊥ Beds						
1-5, 135-150	16.35					1.56	44	2.82	69		Intensely deformed clay
2-1, 113	48.63					1.78	35	3.04	62		Intensely deformed clay
2-3, 105	51.55					1.75	33	2.82	59		Intensely deformed clay
2-6, 0-15	55.00					1.75	34	2.87	60		Intensely deformed clay
3-4, 54	80.54					1.83	31	2.89	56		Intensely deformed clay
3-5, 0-15	81.50						31				Intensely deformed clay
4-3, 36	107.36					1.89	26	2.78	50		Moderately deformed clay
4-4, 0-15	108.50						27				Moderately deformed clay
4-4, 86	109.36					1.86	30	2.94	56		Moderately deformed clay
5-2, 135-150	135.35						31				Slightly deformed clay
5-3, 55	136.05					1.73	31	2.55	53		Slightly deformed clay
6-6, 139	150.89					1.86	28	2.83	53		Slightly deformed clay
7-0, 0-15	151.50						24				Gassy clay
7-1, 73	152.43					1.94	25	2.84	49		Gassy clay
7-4, 124	157.44						27				Gassy clay
8-2, 135-150	173.35						24				Slightly deformed clay
8-3, 101	174.51						26				Slightly deformed clay
8-3, 110	174.60		1.60								Firm clay

[a]Syringe values.

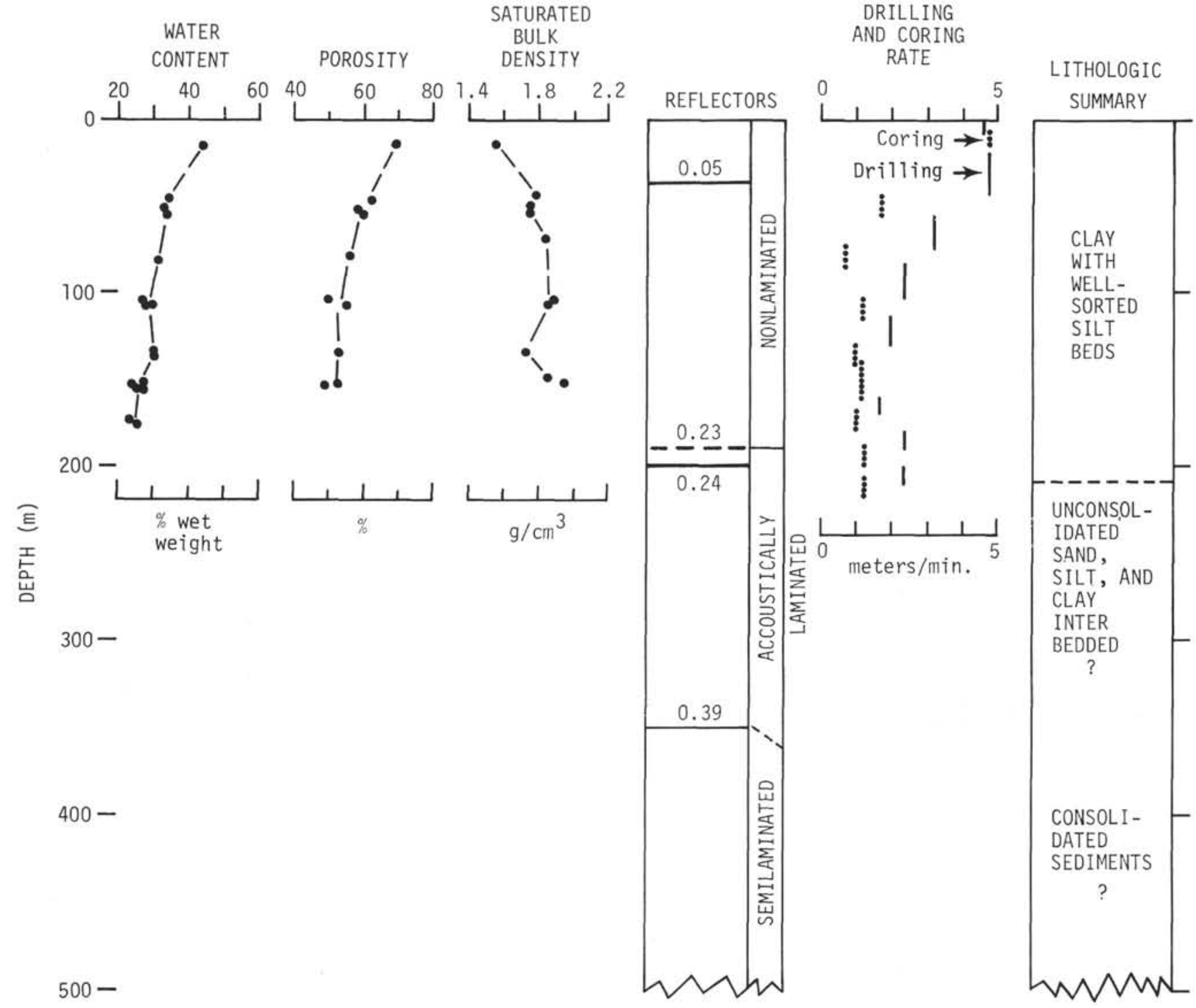

Figure 8. *Summary of physical properties, acoustic character and lithology of sediments at Site 324. Velocities are those measured perpendicular to bedding or on unoriented samples. Relative strength of reflectors is indicated by heavy solid lines (strongest) to dotted lines (weakest), and depth of each reflector (in seconds reflection time) is indicated. All physical properties values were determined by the syringe technique.*

Core 1, Section 1 is of Pleistocene age, and two biostratigraphic zones defined by Chen (1975) are recognized. Samples 324-1-1, 143-145 cm through 324-1-2, 53-55 cm fall within the *Antarctissa denticulata* Zone, while the *Saturnalis circularis* Zone extends from Samples 324-1-2, 138-140 cm through 324-1-6, 128-130 cm.

Most samples from Core 1 contain the typical Quaternary Southern Ocean radiolarian assemblage which consists of *Antarctissa denticulata*, *A. strelkovi*, *Stylatractus neptunus*, *Lithelius nautiloides*, *Spongothrochus glacialis*, *Spongodiscus osculosus*, *Saccospyris antarctica*, *Triceraspyris antarctica*, *Stylodictya validispina*, *Spongoplegma antarcticum*, *Peripyramis circumtexta*, *Prunopyle antarctica*, *Cycladophora davisiana*, and *Spongurus pylomaticus*.

The *Stylatractus universus* Zone of Chen (1975) is not recognized in Core 324-1, although this species was found in the *Saturnalis circularis* Zone.

Sample 324-9, CC contains a few moderately well preserved radiolarians diagnostic of an early Pliocene age, but this age determination is very questionable because the hole was collapsing while Core 9 was being taken. Downhole contamination from radiolarian-rich stringers between the coring intervals cannot be ruled out even though much of the sediment at Site 324 was barren.

Silicoflagellates

Detailed study of Core 1, Section 5, which contains well-preserved siliceous microfossils, revealed the following silicoflagellate species: *Cannopilus binoculus*, *Distephanus speculum* (long-spined variety), *D. polyactis*, and *D. quinquangellus*. This assemblage is tentatively placed in the middle Pliocene *Distephanus boliviensis* Zone. Some unidentifiable silicoflagellate fragments were found in Core 9. All other samples were barren.

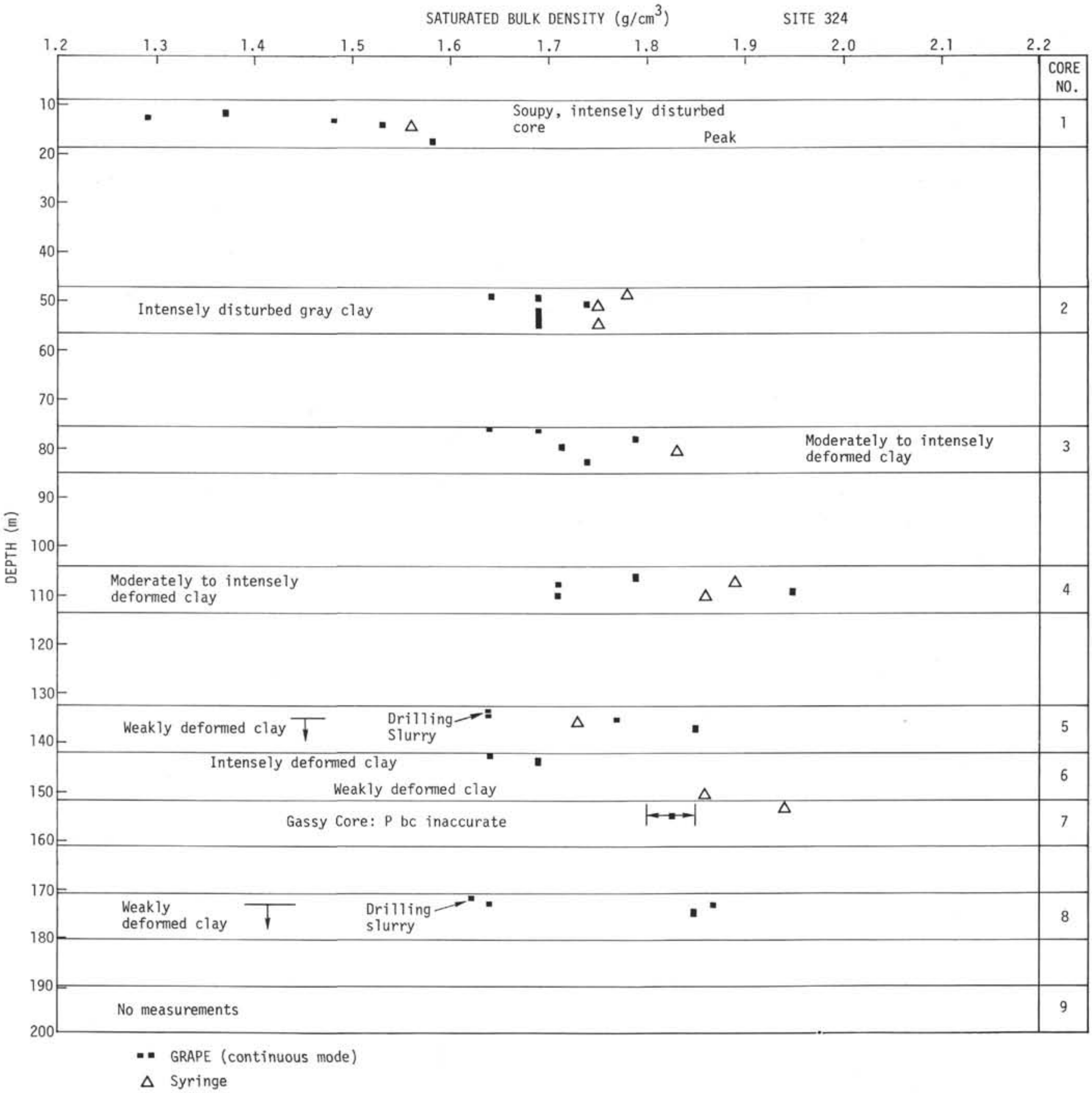

Figure 9. *Saturated bulk density with respect to depth determined from the Gamma Ray Attenuation Porosity Evaluator (GRAPE) and syringe technique.*

Diatoms

The sediments recovered in Cores 1 through 9 consist of terrigenous clays and silty clays with thin layers of well-sorted silt. Thin intervals of Cores 1, 4, and 9 are composed of diatom ooze to diatom-bearing hemipelagic clays. Samples 1-1, 141 cm to 1-4, 37 cm belong to the *Nitzschia kerguelensis* Zone of Abbott (in press) (uppermost part of the Brunhes normal epoch), the *Fragilariopsis kerguelensis* Partial Range Zone of Donahue (1970), (0.35 m.y.B.P.), and the *Coscinodiscus lentigenosus* Partial Range Zone of McCollum (1975). Reworked older fossils, such as *Denticula hustedtii* and *Actinocyclus ingens*, occur in trace amounts throughout this core. The top of Core 1 (at 9 m) to 14 meters subbottom is therefore younger than 0.35 m.y.B.P. based on the upper boundary of Donahue's (1970) *Rouxia californica* Partial Range Zone.

The interval between Sample 1-4, 66 cm to 1-5, 69 cm is correlated to the *Rouxia california* Partial Range Zone of Donahue (1970) and is 0.35-0.66 m.y. in age, on the basis of rare occurrences of *Rouxia californica*.

TABLE 3
Occurrence of Radiolarians at Site 324

Sample (Interval in cm) \ Species	Abundance	Preservation	Age	Zone	*Antarctissa denticulata*	*A. strelkovi*	*Stylatractus neptunus*	*Lithelius nautiloides*	*Cycladophora davisiana*	*Spongotrochus glacialis*	*Cyrtopera languncula*	*Saccospyris antarctica*	*S. conithorax*	*Cornutella profunda*	*Triceraspyris antarctica*	*Spongodiscus osculosus*	*Spongurus pylomaticus*	*Peripyramis circumtexta*	*Spongoplegma antarcticum*	*Theocalyptra bicornis*	*Pterocorys hirundo*	*Dictyophimus gracilipes*	*D. mawsoni*	*Stylodicta validispina*	*Prunopyle antarctica*	*Echinomma leptodermum*	*E. popofskii*	*Acanthosphaera* sp.	*Siphocampe aquilonaris*	*Stylatractus universus*	*Saturnalis circularis*	*Sethoconus* (?) *galea*	*Dendrospyris haysi*	*Eucyrtidium calvertense*	*Actinomma yosii*
324-1-1, 143-145	F	M			F	C	F	R	R	R	R	F	–	R	R	R	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
324-1-2, 53-55	C	G			C	C	R	R	F	F	–	C	–	R	R	C	R	R	F	R	R	F	–	F	R	–	–	–	–	–	+	R	–	–	–
324-1-2, 138-140	C	G		*A. denticulata*	A	A	C	F	F	C	–	C	–	R	C	R	F	C	C	R	R	F	–	F	F	–	–	–	C	–	F	R	–	–	–
324-1-3, 30-32	C	G			A	A	C	R	F	C	–	C	R	–	C	R	R	R	C	–	R	F	–	F	F	–	R	–	F	R	–	R	–	–	R
324-1-3, 82-84	C	G			A	A	C	F	F	C	–	C	–	–	C	F	R	F	A	–	–	R	–	F	R	–	R	R	C	R	F	R	–	–	R
324-1-3, 134-136	F	M			C	C	F	F	R	F	–	F	–	R	F	F	–	R	F	–	–	–	–	R	R	–	–	R	R	–	R	–	–	–	–
324-1-4 34-36	R	P			F	F	R	–	R	–	–	R	–	–	R	–	–	–	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	F
324-1-4, 68-70	C	G			C	C	C	F	F	C	–	C	–	R	C	C	F	F	C	R	–	–	R	F	R	F	–	F	R	R	R	–	–	–	R
324-1-4, 115-117	–	–																		Barren															
324-1-5, 28-30	–	–	Pleistocene																	Barren															
324-1-5, 58-59	C	G			C	C	R	F	F	C	–	C	–	R	C	F	F	F	F	–	–	R	–	F	R	F	–	F	R	F	–	–	–	–	–
324-1-5, 86-88	R	M			R	R	R	R	R	R	–	R	–	–	R	–	R	–	–	–	–	–	–	R	–	R	–	–	–	R	–	–	–	–	–
324-1-5, 127-129	R	M		*S. circularis*	R	R	R	–	–	R	–	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	–
324-1-6, 17-19	F	G			F	C	F	R	–	F	–	C	–	–	F	–	–	R	R	–	–	–	–	R	–	R	–	–	–	–	–	–	–	–	–
324-1-6, 53-55	R	M			R	R	–	R	–	–	–	R	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	–	–	–	–	–
324-1-6, 128-130	R	M			R	R	R	–	–	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
324-1, CC	–	–																		Barren															
324-2-1 18-20	–	–																		Barren															
324-2-1, 78-80	–	–																		Barren															
324-2-2 74-78	–	–																		Barren															
324-2-2, 146-148	–	–																		Barren															
324-2-3, 75-77	–	–	?																	Barren															
324-2-3, 111-113	–	–																		Barren															
324-2-4, 77-79	–	–																		Barren															
324-2-5, 72-74	–	–																		Barren															
324-2-6, 112-114	–	–																		Barren															
324-2, CC	–	–																		Barren															
324-3-1, 19-21	–	–																		Barren															
324-3-2, 23-25	–	–																		Barren															
324-3-2, 111-113	–	–		?																Barren															
324-3-3, 49-51	–	–																		Barren															
324-3-4, 44-46	–	–																		Barren															
324-3-5, 86-88	–	–																		Barren															
324-3-6, 119-121	–	–																		Barren															
324-3, CC	–	–																		Barren															
324-4-1, 141-143	–	–																		Barren															
324-4-2, 22-24	–	–																		Barren															
324-4-2, 68-70	–	–	?																	Barren															
324-4-2, 143-145	–	–																		Barren															
324-4-3, 50-52	–	–																		Barren															
324-4-3, 108-110	–	–																		Barren															
324-4-4, 57-59	–	–																		Barren															
324-4, CC	–	–		?																Barren															
324-5-1, 96-98	–	–																		Barren															
324-5-2, 94-96	–	–																		Barren															
324-5-2, 122-123	–	–																		Barren															
324-5-3, 43-45	–	–																		Barren															
324-5-3, 89-91	–	–																		Barren															
324-5, CC	–	–																		Barren															
324-6-1, 100-102	–	–																		Barren															
324-6-2, 34-36	–	–																		Barren															
324-6-6, 133-135	–	–																		Barren															
324-6, CC	–	–																		Barren															
324-7-1, 83-85	–	–																		Barren															
324-7-2, 114-116	–	–																		Barren															
324-7-3, 129-131	–	–																		Barren															
324-7-4, 140-142	–	–																		Barren															
324-7-6, 141-143	–	–																		Barren															
324-7, CC	–	–																		Barren															
324-8-2, 129-131	–	–																		Barren															
324-8-3, 23-25	–	–																		Barren															
324-8-3, 103-105	–	–		?																Barren															
324-8, CC	–	–																		Barren															
324-9-1, 117-119	–	–																		Barren															
324-9, CC	R	M	E. Pliocene		R	I	–	–	–	–	–	–	–	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–

The interval between Sample 1-5, 103 cm through Sample 4-2, 66 cm is placed into the *Actinocyclus ingens* Partial Range Zone of Donahue (1970) which is characterized by the occurrence of *Actinocyclus ingens* (upper boundary ≅ 0.66 m.y.B.P.) and into the *Coscinodiscus elliptopora/Actinocyclus ingens* Concurrent Range Zone of McCollum, 1975 which has been dated by paleomagnetic stratigraphic correlation to a radiometric time scale as being 0.7 to 1.6 m.y.B.P. All samples below Core 4 are nearly barren of diatoms except 9, CC which contains a moderately well preserved diatom assemblage with low species diversity.

Denticula hustedtii and *Trinacria excavata* are interpreted as being reworked because *Cosmiodiscus insignis* and *Nitzschia kerguelensis* are still present. This sample is placed into the *Cosmiodiscus insignis* Partial Range Zone of McCollum (1975) and is correlative to the upper part of the Gauss normal epoch and is approximately 2.43 to 2.82 m.y. in age.

RATES OF SEDIMENT ACCUMULATION

Sediment accumulation rates cannot be effectively determined for this site. Core 1 provides a date of 0.7-1.6 m.y. (Matuyama) based on radiolarian species. This gives us a minimum sedimentation rate of 11.2 cm/1000 yr and a maximum of 25.6 cm/1000 yr for the first core (Figure 10). (The rates are based on the assumption that no hiatus occurs between the sediment-water interface and the bottom of Core 1.)

The remainder of the cored interval does not provide sufficiently good dates from paleontological data. However, in Sample 9, CC scattered fragments of one Pliocene radiolarian species were found. However, these fragments could easily have been reworked and even if they are autochthonous, the age of 9, CC can be placed anywhere between 1.8 and 5 m.y.B.P. At best, we can only be certain that sediment accumulation rates ranged between 4.3 and 17.3 cm/1000 yr.

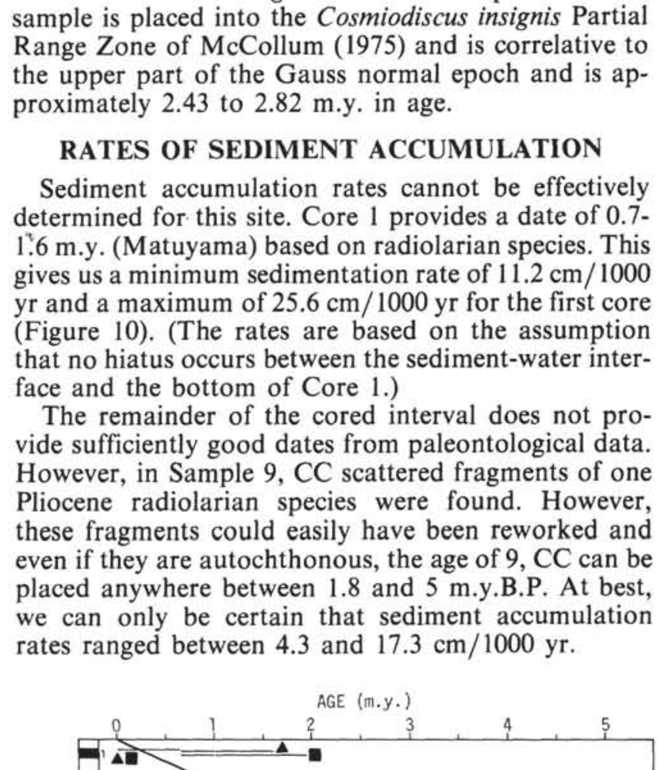

Figure 10. *Rate of sediment accumulation, Site 324.*

SUMMARY AND CONCLUSIONS

Summary

Site 324 is located at 69°03.21'S, 98°47.20'W on the lower continental rise of Antarctica, about 75 miles north of the base of the continental slope. The single hole drilled at this site reached a total depth of 218 meters before hole cavings of loose sand forced its abandonment. The entire sequence penetrated consists of Pliocene and Quaternary sedimentary deposits. A total of 95.0 meters was cored, and 48.0 meters (51%) of core were recovered. The results of drilling are summarized in Figure 11.

The sedimentary materials recovered in Cores 1 through 9 are rather uniform and can be treated as a single lithologic unit. Almost all the sediment recovered consists of terrigenous clays and silty clays with thin layers of well-sorted silt; a small part of Core 1 is composed of diatom ooze. Detrital silt-sized quartz is a minor component in most of the clays. Silt layers, mainly 0.5 to 1.0 cm thick, are common throughout the sequence; they consist largely of quartz with minor amounts of feldspar, mica, heavy minerals, opaque minerals, and rock fragments. Ice-rafted detritus is common in the upper part of the sequence, but it appears to decrease with depth. There was no recovery in Core 10, but grains of sand on the core liner, scratches and polish on the outside of the core barrel, and caving of the hole suggest that an unconsolidated sand layer was penetrated at the bottom of the hole.

Seismic profiles near Site 324 show a near-surface acoustically transparent layer (about 150 m thick) overlain by a thin reverberant layer and underlain by a very thick acoustically reverberant layer (about 500 m thick). These three seismic units have been identified in the sequence penetrated, and they are numbered in descending order. Unit I is the surficial reverberant layer, about 40 meters thick; Core 1 shows that this unit consists of soft, watery clay with minor diatomaceous ooze. Unit II is the acoustically transparent layer about 150 meters thick; Cores 2-7 indicate that this unit is comprised of unconsolidated gray clay with thin silt layers. Unit III is the lower reverberant layer at least 48 meters thick; Cores 8-10 suggest that this unit is composed of claystone and sand beds.

Most fossils were recovered from Cores 1 and 9; the intervening cores are barren except for a few foraminifers (*Neogloboquadrina pachyderma*) and some diatom fragments. Core 1 is dated as Pleistocene on the basis of abundant diatoms of the *Nitzschia kerguelensis* and *Rouxia californica* zones, radiolarians of the *A. denticulata* and *S. circularis* zones, and silicoflagellates of the *Distephanus boliviensis* Zone. The lower part of Core 1 through Core 4 is also Pleistocene and belongs to the diatom *Actinocyclus ingens* Zone. Core 9 is considered to be Pliocene on the basis of diatoms of the *Cosmiodiscus insignis* Zone and a few radiolarians.

A 15-cm sample was taken from each of seven cores for geochemical studies. Measurements were obtained on formation factor, water content, porosity, and certain chemical properties. Water contents in the uppermost 200 meters are lower here than at Sites 322 and 323. Downhole increases in formation factor and in dissolved ammonia were noted, along with decreases in water content, porosity, and dissolved silica and magnesium. The value of *p*H rises slightly at first, but stabilizes near 8 at greater depth. Values of alkalinity and dissolved calcium increase with depth in the upper part of the hole and then decrease below 150 meters.

Conclusions

The sequence penetrated at Site 324 may comprise an uninterrupted section representing most of the Pliocene

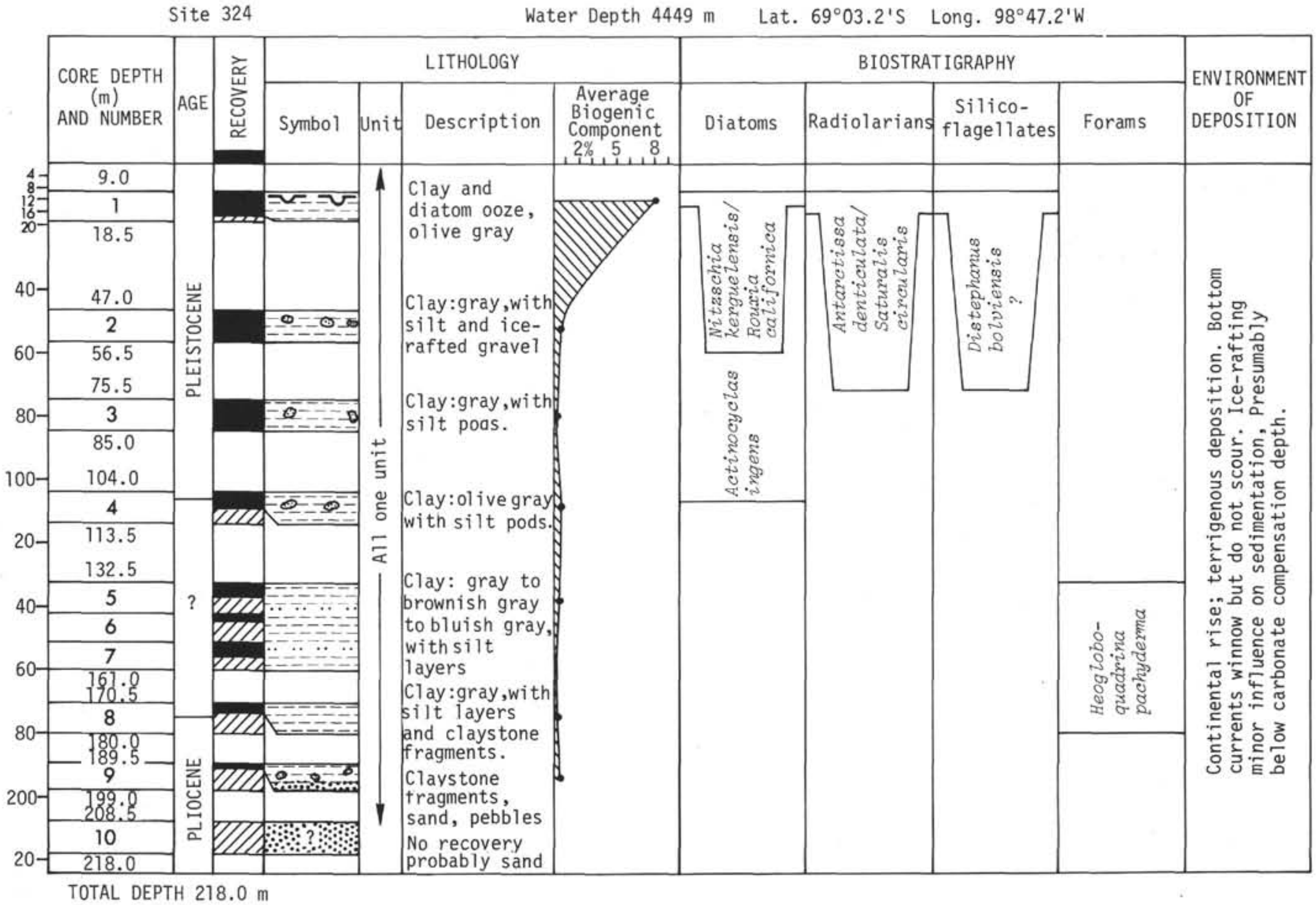

Figure 11. *Lithologic and biostratigraphic summary, Site 324.*

and Quaternary time. Core 9 from near the bottom of the hole yielded Pliocene microfossils. Goodell et al. (1973) gave 2.5 cm/1000 yr as a mean accumulation rate for glaciomarine sediments on the continental rise of Antarctica; accumulation at this rate will produce 125 meters in 5 m.y. A somewhat higher rate, however, occurred at Site 324, inasmuch as the Pliocene-Quaternary sequence appears to be at least 200 meters thick.

The processes by which the clays, silty clays, and silts at this site were deposited are not fully understood. The geologic location and composition of the sediments show that these detrital materials were derived from Antarctica. These beds are similar to those in the continental rise along the Atlantic coast of North America where both turbidity currents and contour currents are important agents of sediment transportation and deposition. Interbedded clays and well-sorted silt beds may be laterally graded beds deposited by contour currents.

Several pronounced changes occurred in the depositional environment at this site during the last 2 m.y. There was a sharp upward decrease in the number of silt layers deposited, perhaps indicating a diminished importance of contour currents. Moreover, there was a complementary increase in the abundance of ice-rafted detritus and diatoms abounded in great numbers. (Diatoms were not found in the underlying beds.)

These changes in sedimentation pattern are probably related to changes in the extent of the Antarctic ice sheet, but their exact significance is not clear. The increase in ice-rafted debris may imply a more vigorous continental glaciation during the Quaternary than during the Pliocene. On the other hand, the appearance of diatoms may indicate the disappearance of pack-ice, which existed during the Pliocene, from this site during the Quaternary, suggesting that the Antarctic ice sheet was diminishing during Pliocene time. The relationship between the abundance of silt layers and the extent of glaciation, if any, is unknown. Because the hole did not penetrate beds older than about 5 m.y., it was not possible to seek marine evidence for the postulated late Miocene glaciation in the Jones Mountains to the south.

Geochemical gradients rather similar to those observed at Sites 322 and 323 were detected at Site 324. The shallow depth of penetration and the inferred great thickness of sediments, however, make the interpretation of these gradients difficult. Thus it is not clear whether or not the gradients at this site are related to basement alteration.

Since drilling penetrated only a small fraction of the sedimentary sequence, the age of basement remains unknown. Major uncertainties about the true thickness of the total sedimentary sequence and about the range of accumulation rates preclude a meaningful estimate of basement age by this method. The great thickness of these sediments (estimated at about 1900 m) and the great depth to basement (about 7 sec below sea level), however, suggest a probable Mesozoic or early Tertiary age for basement.

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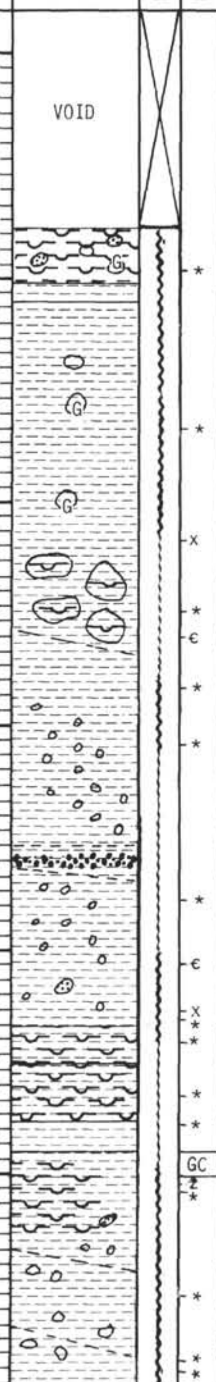
Hole 324, Core 1 — Cored Interval: 9.0-18.5 m

AGE	ZONE	FOSSIL	ABUND.	PRES.	SECTION	METERS
PLEISTOCENE	(R) Antarctissa denticulata; (D) Nitzschia kerguelensis	D	A	G	0	
		R	F	M	1	0.5, 1.0
		R	C	G	2	
		D	A	G		
		D	A	G		
		R	C	G		
		R	C	G	3	
		D	A	M		
		R	C	G		
		D	A	G		
	(D) Rouxia californica	D	R	D		
		R	F	M		
		D	R	M	4	
		R	R	P		
		D	C	M		
		R	C	G		
		D	R	P		
		R	—	—		
	(R) Saturnalis circularis	R	—	—		
		R	C	G	5	
		D	A	G		
		R	R	M		
		D	R	M		
		R	R	M		
		D	F	M		
		D	R	G	6	
		R	F	G		
		D	R	M		
		R	R	M		
		D	F	M		
		R	R	M		
		D	—	—	Core Catcher	
		R	—	—		

LITHOLOGY / DEFORMATION / LITHO.SAMPLE



LITHOLOGIC DESCRIPTION

CLAY AND DIATOM OOZE

QUARTZ-BEARING DIATOM OOZE: light olive gray (5Y 6/1) with pale yellow brown (10YR 6/2) mottles and small sandy silt pods. One quartzite cobble. Composition: 50% diatoms, 40% clay mins., 10% qtz.

CLAY: grayish brown (10YR 5/2).

CLAY: olive gray (5Y 5/3), soft, wet, sticky. Intensely deformed, no internal structures preserved. Ice-rafted gravel and coarse sand scattered throughout (<1%) and 0.5-1.0 cm gravel (G) where noted. Composition: 85% clay mins., 10% qtz., 5% diatom frags.

CLAYEY DIATOM OOZE in mottles: grayish brown (2.5Y 5/2). Composition: 60% diatoms, 35% clay mins., 3% qtz., 2% Fe-oxides. Carbon/carbonate: 3-92 (0.1-0.1-0.0).

BULK X-RAY (3: 27-29)

Amorph. 64.2% — Crystal. 35.8%

Percent of Crystalline Component

Quartz	15.7%	Chlorite	5.1%
K-Fldspr.	9.3%	Mont.	30.3%
Plag.	19.2%	Clinop.	0.3%
Kaol.	18.4%	Amphi.	1.8%

Faint color transition (Sect. 3, 85-100 cm to brownish olive (5Y 5/3).

CLAY: olive (5Y 5/3), firm, sticky, faintly mottled. Traces of ice-rafted sand and gravel. Composition: 90% clay mins., 5% qtz., 3% Fe micronodules, 2% opaques. Few silt pods. Grain size: 4-29 (0.2-21.3-78.5).

CLAY: color transition (Sect. 4, 70 cm) to olive gray (5Y 5/2). Contains Mn micronodules.

CLAY: gray (5Y 5/1) with light gray mottling. Silt pods. Trace ice-rafted sand and gravel. Composition: 95% clay mins., 5% qtz. silt. Silt pod composition: 80% qtz., 7% heavy mins., 5% feldspar, 5% rock frags., 3% opaque mins. Grain size: 5-15 (9.3-20.9-69.9). Ca/CO_3 5-10 (0.1-0.1-0.0).

CLAYEY DIATOM OOZE: light olive gray (5Y 6/2).

QUARTZ-RICH DIATOM CLAY: pale olive (5Y 6/3) mottled, 20% diatoms.

CLAY: pale olive (5Y 6/3).

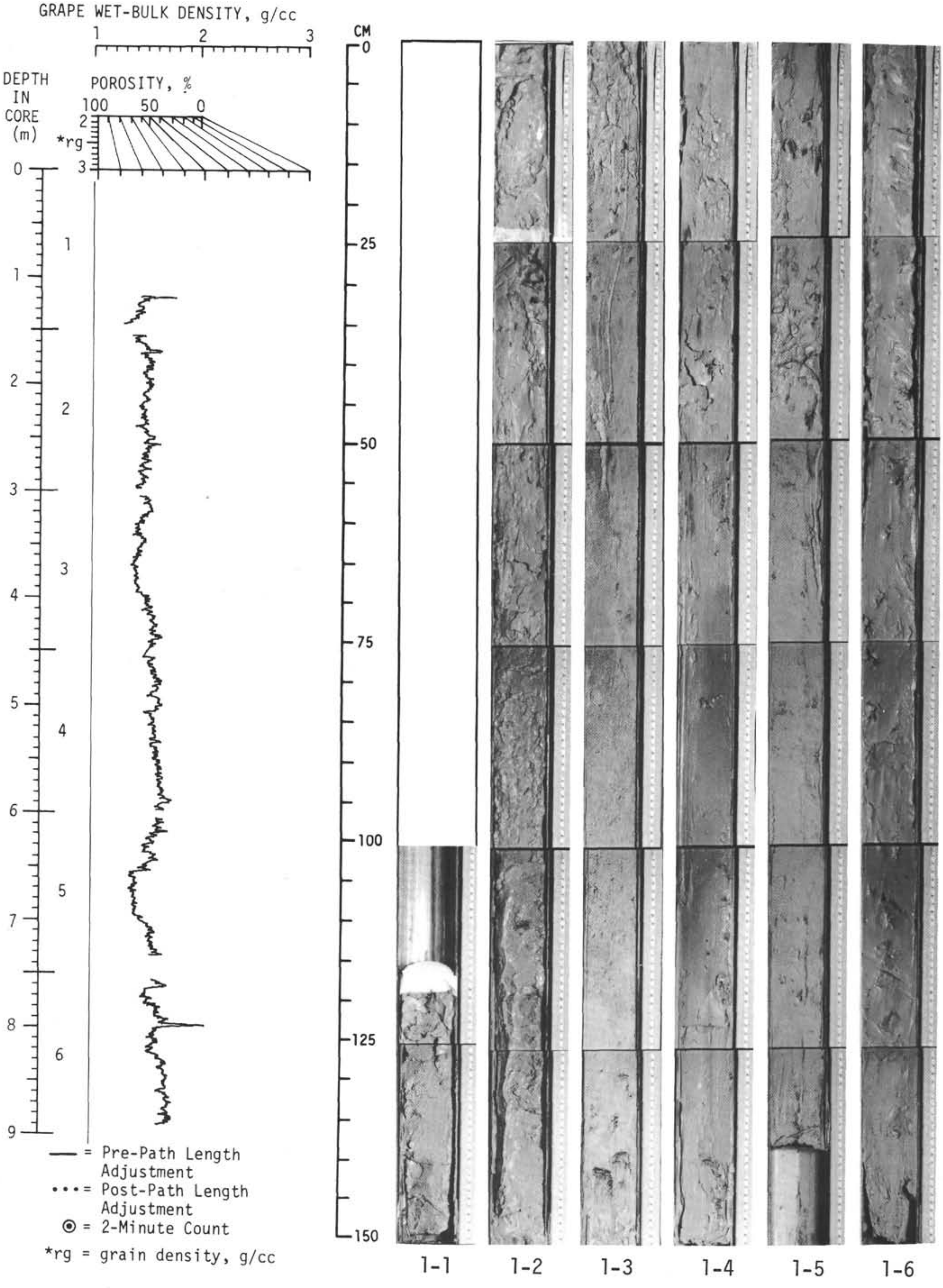
DIATOM-BEARING CLAY: olive gray (5Y 5/2), <1% ice-rafted sand and gravel. Two pebbles, one is basalt. Mottled at base. Grain size: 6-10 (3-25-72).

CLAY: gray (5Y 5/1) with brown mottling.

CLAY: olive (5Y 5/3). Composition: 97% clay mins., 2% qtz., 1% opaque mins.

CLAY: light olive gray (5Y 5/2), greasy, soft. One 0.7 cm pebble, one 3.5 cm cobble (ice-rafted).

Explanatory notes in Chapter 2


GRAPE WET-BULK DENSITY, g/cc
1 2 3
DEPTH IN CORE (m)
POROSITY, %
100 50 0
2
*rg
3
0 1 2 3 4 5 6 7 8 9
1 2 3 4 5 6
— = Pre-Path Length Adjustment
• • • = Post-Path Length Adjustment
⊙ = 2-Minute Count
*rg = grain density, g/cc
CM
0 25 50 75 100 125 150
1-1 1-2 1-3 1-4 1-5 1-6

Hole 324, Core 2 Cored Interval: 47.0-56.5 m

AGE	ZONE	FOSSIL	ABUND.	PRES.	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE
PLEISTOCENE	(Barren)				0		VOID		
		D	–	–					
		D	–	–	1	0.5, 1.0			**
		D	–	–	2				x, x
		D	–	–					x, N, **, x
		D	–	–	3				*
		D	–	–					
		D	–	–	4				*
		D	–	–	5				*
		D	–	–	6				GC
		D	–	–	Core Catcher				*

LITHOLOGIC DESCRIPTION

CLAY WITH SILT LAYERS

CLAY WITH SILT LAYERS: gray (5Y 5/1) stiff, greasy with deformed 0.3-1.0 cm well sorted qtz. silt beds. Sharp upper and lower contacts on beds and no size grading noted. Mainly free of ice-rafted material.

Ice-rafted gravel.

Composition: 95% clay mins., 3% qtz., 2% opaque mins.

QUARTZ-RICH CLAY: medium bluish gray (5B 5/1). Abundant ice-rafted fine gravel and sand in upper part. Pods of coarse sand with composition: 65% qtz., 27% rock fragments, 5% opaque mins., 3% heavy mins. No silt stringers. Grain size: 2-138 (15-21-64).

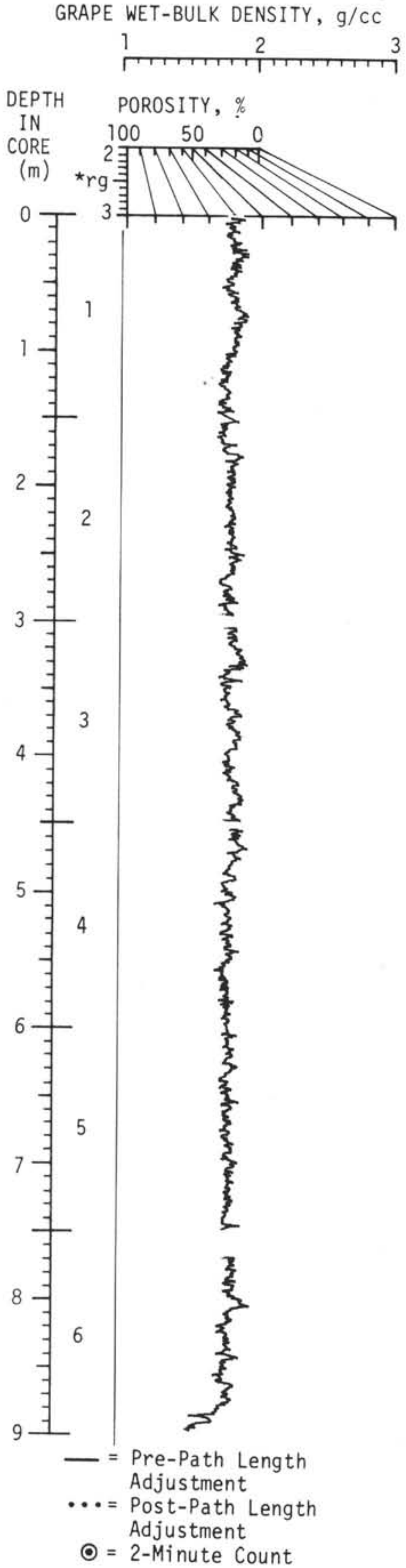
CLAY WITH SILT BEDS: gray (5Y 5/1), stiff with qtz. silt layers (up to 15 per meter). No ice-rafted material noted. Composition: 90% clay mins., 8% qtz., 2% opaque mins.

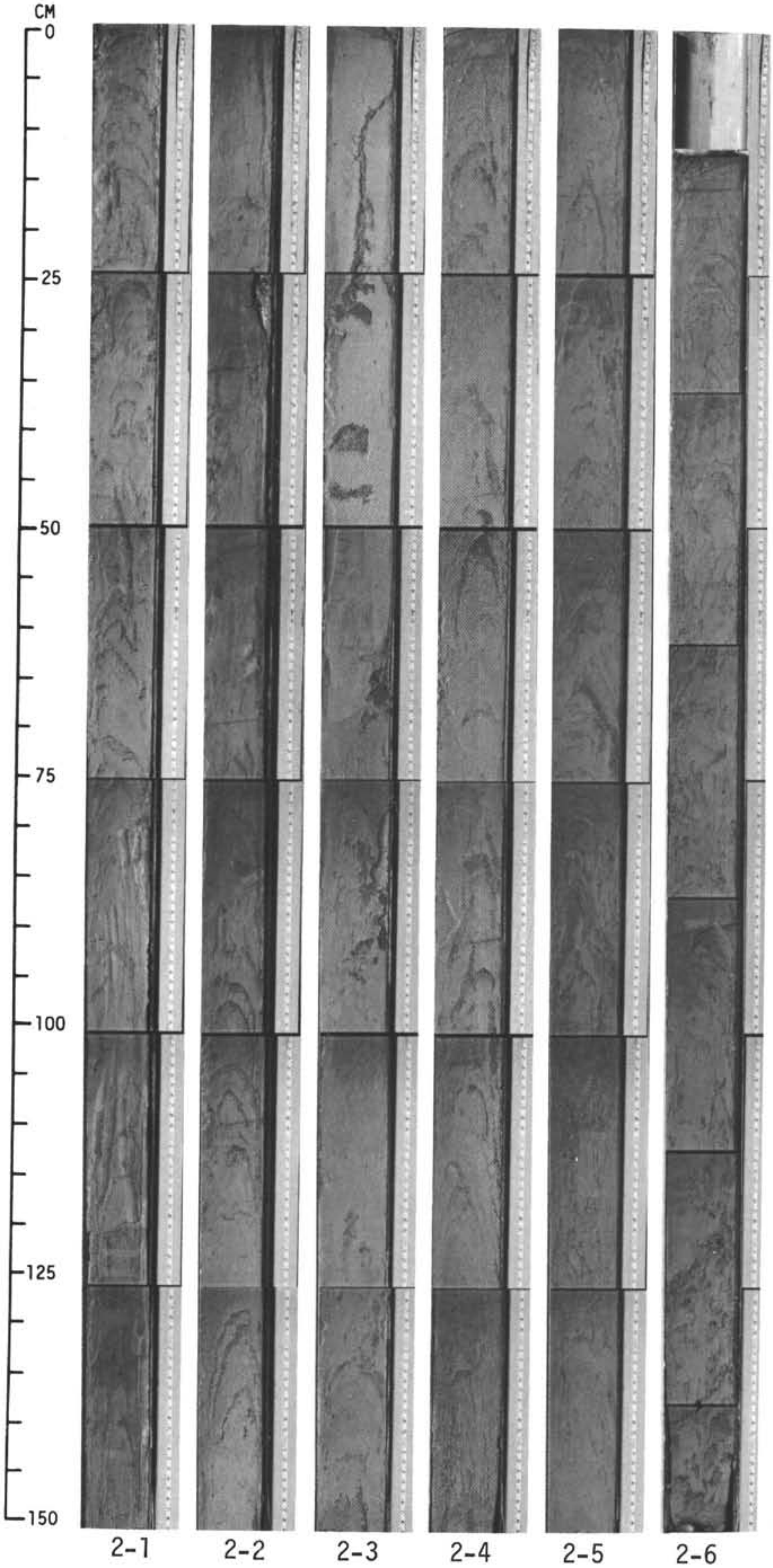
BULK X-RAY

	2: 18-21	2: 120-125	3: 6-11
Amorph.	58.4%	54.4%	48.9%
Crystal.	41.6%	45.6%	51.1%
	Percent of Crystalline Component		
Quartz	36.8%	22.2%	27.5%
K-Feldspr.	25.8%	15.4%	16.2%
Plag.	24.2%	15.3%	21.9%
Kaol.	0.8%	4.3%	0.7%
Mica	6.8%	24.3%	12.2%
Chlorite	1.4%	4.2%	3.5%
Mont.	4.2%	13.3%	16.2%
Clinop.	-	0.4%	0.5%
Amphi.	-	0.6%	1.4%

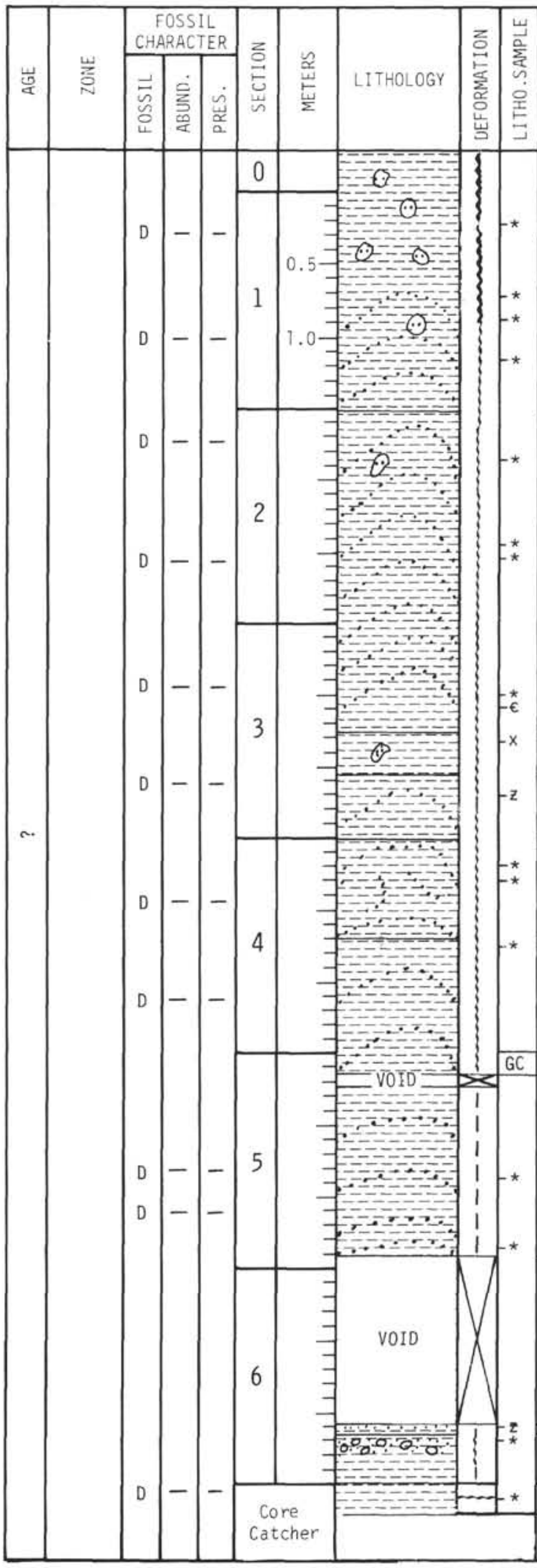
Core catcher composition: 92% clay mins., 8% qtz.

Explanatory notes in Chapter 2


GRAPE WET-BULK DENSITY, g/cc
1
2
3
DEPTH IN CORE (m)
POROSITY, %
100
50
0
*rg
0
1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
— = Pre-Path Length Adjustment
• • • = Post-Path Length Adjustment
◉ = 2-Minute Count
*rg = grain density, g/cc


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

Hole 324, Core 3 Cored Interval: 75.5-85.0 m



LITHOLOGIC DESCRIPTION

CLAY WITH SILT LAYERS AND PODS

QUARTZ-BEARING CLAY: dark gray (5Y 4/1), stiff. Greenish gray (5G 6/1) and medium gray (N5) mottles. Qtz. silt pods and 0.3-1.0 cm layers. Sharp upper and lower contacts on most beds. Not graded. No evidence of ice-rafting.
Composition: 90% clay mins., 8% qtz., 2% opaque mins.

CLAY: dark gray (5Y 4/1 and 10YR 5/1), stiff, faint layering. Silt layers and pods. No evidence of ice-rafting. Silt composition: 75% qtz., 16% rock frags., 7% heavy mins., 2% opaque mins. Carbon/carbonate: 3-59 (0.5-0.4-1.0).

BULK X-RAY (3: 81-86)

Amorph. 49.2% Crystal. 50.8%

Percent of Crystalline Component

Quartz	21.8%	Mica	19.5%
K-Fldspr.	15.0%	Chlorite	5.4%
Plag.	16.9%	Mont.	18.2%
Kaol.	2.6%	Amphi.	0.6%

CLAY: gray (10YR 5/1) with silt pods.

CLAY: dark gray (10Y 4/1), with thin silt layers. Grain size: 3-121 (0-31-69).

QUARTZ-BEARING CLAY: dark gray (5Y 4/1), stiff, with thin silt beds. No indication of ice-rafting. Silt composition: 90% qtz., 5% heavy mins., 5% opaque mins.

CLAY: dark gray (5Y 4/1), with pods and thin beds of qtz. silt. No evidence of ice-rafting.

Clay composition: 87% clay mins., 9% qtz., 4% heavy mins.

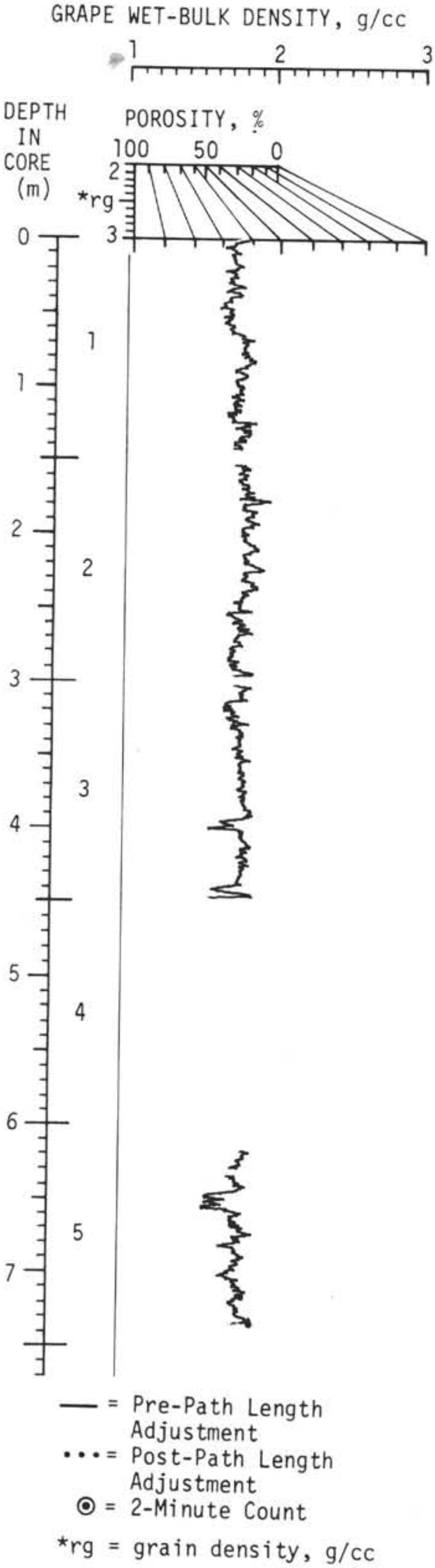
Silt composition: 88% quartz, 8% heavy mins., 2% feldspar, 2% opaque mins.

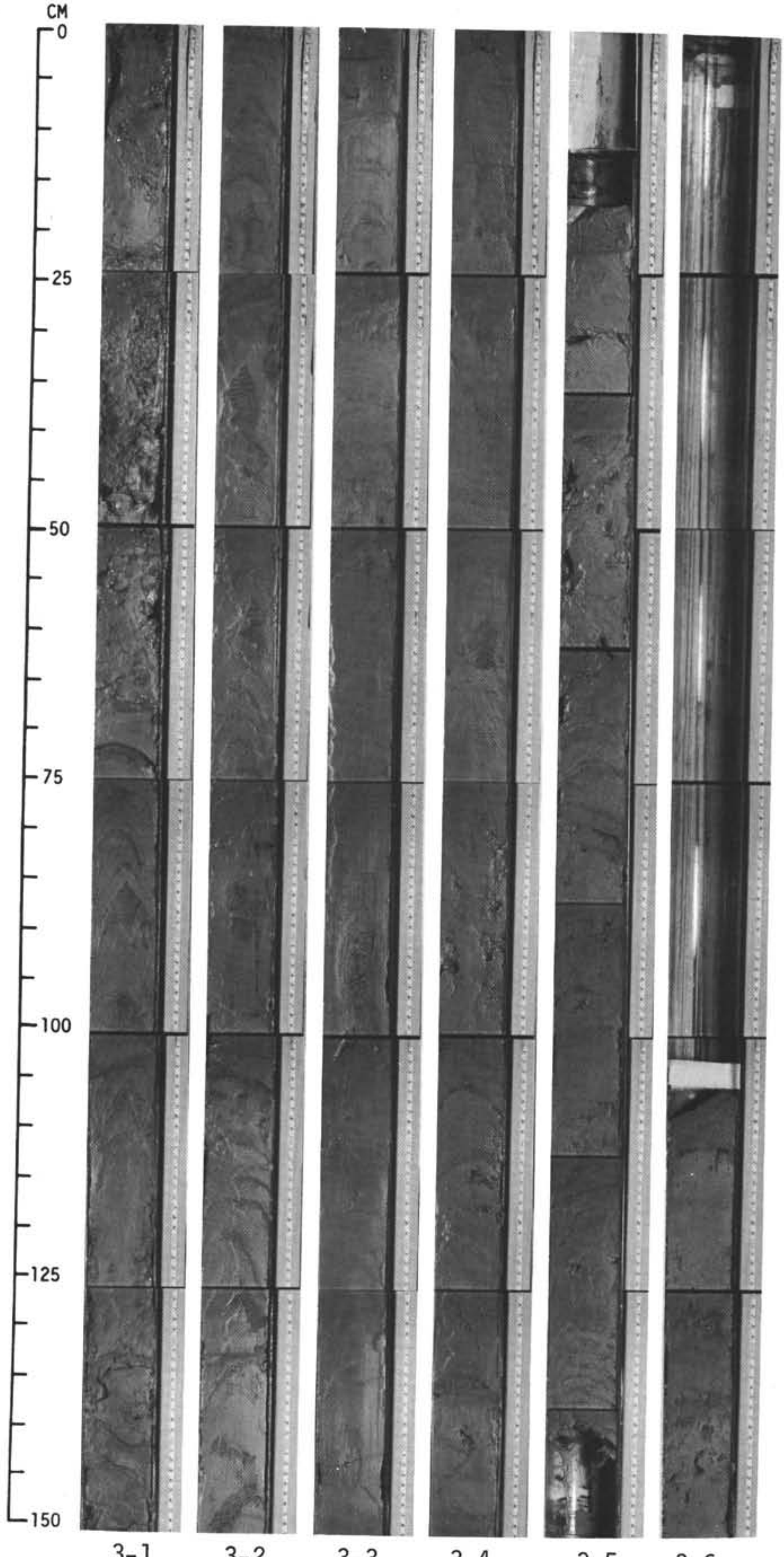
CLAY: dark gray (5G 6/1) with thin silt layers. Grain size: 6-110 (11-25-64).

CLAY: greenish gray (5G 6/1) with ice-rafted sand and gravel.

CLAY: dark greenish gray (5G 4/1), faintly bedded. Composition: 98% clay mins., 2% qtz.

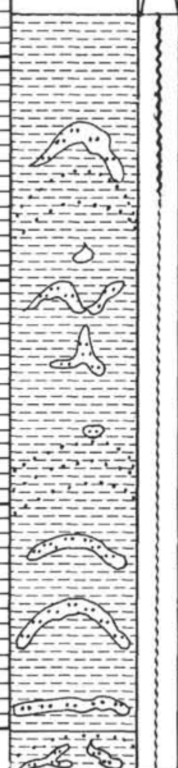
Explanatory notes in Chapter 2


GRAPE WET-BULK DENSITY, g/cc
1
2
3
DEPTH IN CORE (m)
POROSITY, %
100
50
0
*rg
0
1
2
3
4
5
6
7
1
2
3
4
5
— = Pre-Path Length Adjustment
••• = Post-Path Length Adjustment
⊙ = 2-Minute Count
*rg = grain density, g/cc


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

Hole 324, Core 4 — Cored Interval: 104.0-113.5 m

AGE	ZONE	FOSSIL	ABUND.	PRES.	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE
PLEISTOCENE	(D) Actinocyclas ingens				0				
					1	0.5, 1.0	VOID		
		D	R	P					*
		D	—	—	2				
		D	F	M					*, *
		D	—	—					*, ≢
?	Barren	D	—	—	3				*,€
		D	—	—					*
					4				GC, x, €, *, *
		D	—	—					
		D	—	—	Core Catcher				



LITHOLOGIC DESCRIPTION

CLAY WITH SILT LAYERS AND PODS

CLAY: olive gray (5Y 4/1), stiff, with layers of well sorted quartz silt. Mainly lacks evidence of ice-rafting. Clay composition: 95% clay mins., 5% qtz., traces heavy mins., opaque mins., and mica. Silt composition: 97% qtz., 3% heavy mins., traces opaque mins., fldspr., volc. glass, and rock frags. Grain size: 3-16 (0-35-65). Carbon/carbonate: 3-77 (0.4-0.4-1.0), 4-81 (0.5-0.4-1.0).

Ice-rafted gravel.

BULK X-RAY (4: 40-41, silt bed)

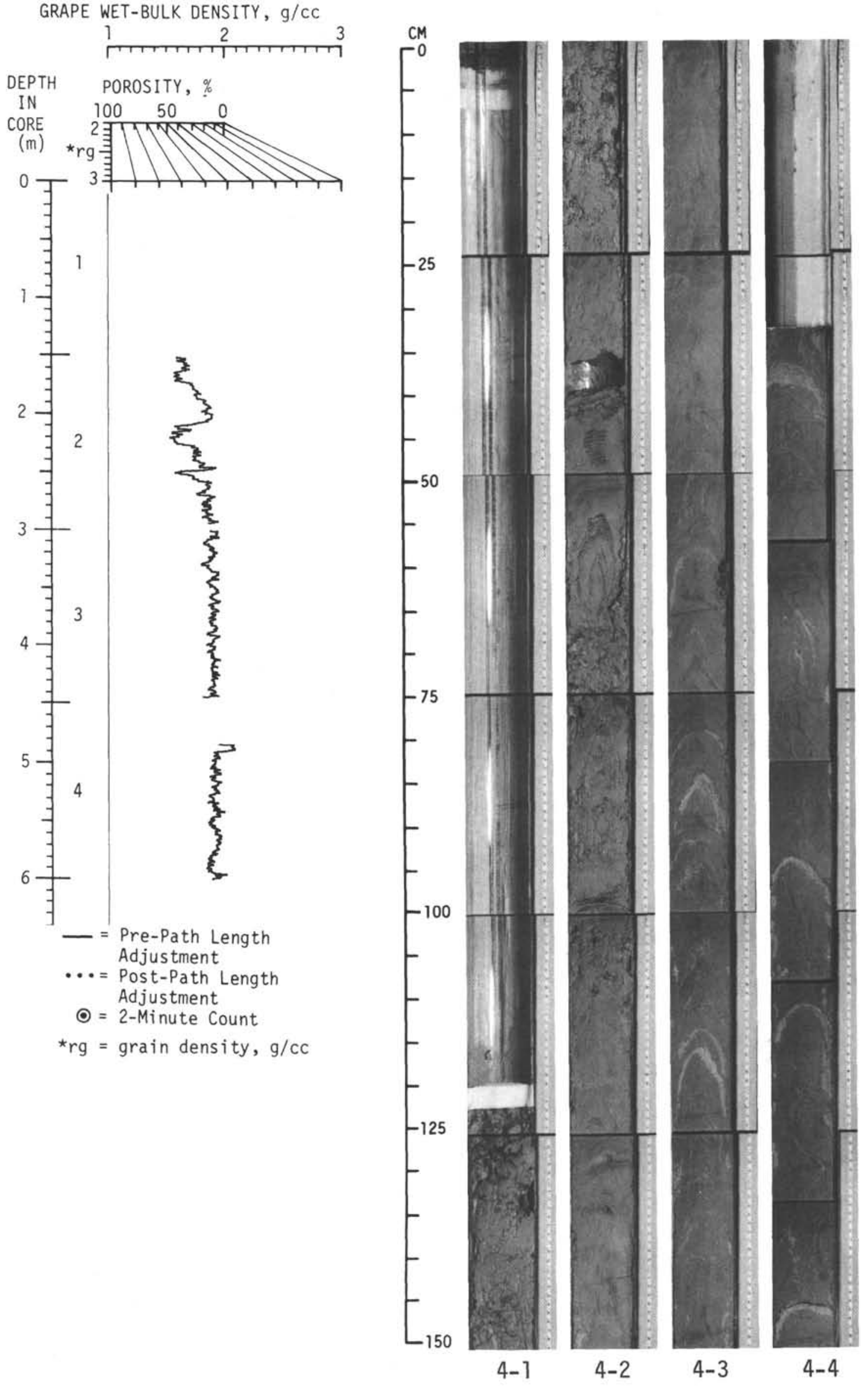
Amorph. 20.5% — Crystal. 79.5%

Percent of Crystalline Component

Quartz	38.9%	Chlorite	1.4%
K-Fldspr.	25.6%	Clinop.	0.6%
Plag.	27.8%	Amphi.	1.0%
Mica	4.8%		

CLAY: dark greenish gray (5GY 4/1) with deformed silt pods and faint gray color banding.

Explanatory notes in Chapter 2


GRAPE WET-BULK DENSITY, g/cc
1 2 3
DEPTH IN CORE (m)
POROSITY, %
100 50 0
*rg
0 1 2 3 4 5 6
1
2
3
4
— = Pre-Path Length Adjustment
• • • = Post-Path Length Adjustment
⊙ = 2-Minute Count
*rg = grain density, g/cc
CM
0
25
50
75
100
125
150
4-1
4-2
4-3
4-4

Hole 324, Core 5 — Cored Interval: 132.5-142.0 m

AGE	ZONE	FOSSIL	ABUND.	PRES.	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO.SAMPLE
? PLIOCENE					0		VOID		
		D	R	P	1	0.5, 1.0			*
		D	—	—	2				*, *, GC
		D	—	—	3				*, X, *, *, X, *
		F / D	R / —	G / —	Core Catcher				

LITHOLOGIC DESCRIPTION

CLAY AND INTERBEDDED CLAY AND SILT

CLAY: gray (5Y 5/1), quartz-rich, totally disturbed.

Composition: 88% clay mins., 12% qtz., traces feldspar, mica, opaque mins., diatoms, radiolarians, sponge spicules.

CLAY AND INTERBEDDED SILT: brownish gray (5YR 4/1), with 0.1-1.0 cm silt beds, moderately to well sorted. Silt composition: 90% qtz., 5% rock frags., 3% heavy minerals, traces feldspar, volc. glass.

CLAY AND INTERBEDDED SILT: medium bluish gray (5B 5/1) with interbedded brownish gray (5YR 4/1) clay and gray (5Y 5/1) silt. Ice-rafted sand and gravel at Sect. 3, 100-110 cm. Silt composition: 95% qtz., 3% heavy mins., 2% opaque mins., trace feldspar. Grain size: 3-100 (0.8-25.1-74.1).

CLAY: gray (5Y 5/1), with silt stringers. Silt composition: 95% qtz., 3% heavy mins., 2% opaque mins., traces feldspar, volc. glass, nonbiogenic carbonate.

BULK X-RAY

	3: 60-65	3: 118-123
Amorph.	41.9%	45.0%
Crystal.	58.1%	55.0%
Percent of Crystalline Component		
Quartz	30.9%	30.7%
K-Fldspr.	15.2%	13.8%
Plag.	17.1%	20.6%
Kaol.	1.4%	0.7%
Mica	17.4%	23.0%
Chlor.	5.2%	5.8%
Mont.	12.6%	5.4%

Hole 324, Core 6 — Core — Cored Interval: 142.0-151.5 m

AGE	ZONE	FOSSIL	ABUND.	PRES.	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO.SAMPLE
PLIOCENE					0		VOID		
		F	—	—	1	0.5			*
		D	—	—		1.0			*
							VOID		
		F	R	G	2		VOID		X, X
					6		VOID		€, **, *
		F / D	R / —	G / —	Core Catcher				

LITHOLOGIC DESCRIPTION

CLAY WITH SILT BEDS

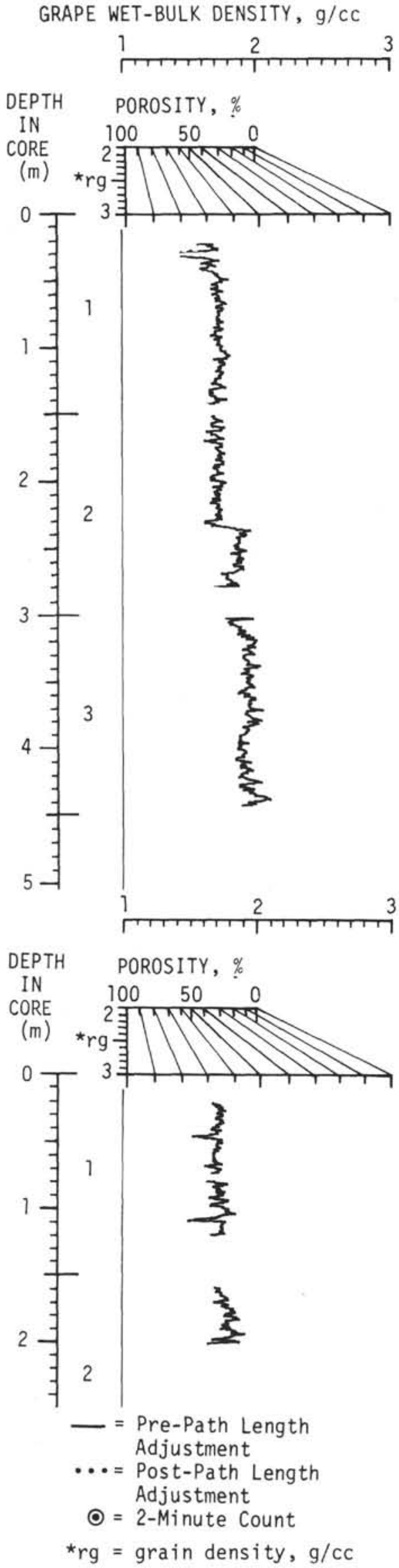
CLAY: gray (5Y 5/1) to dark gray (5Y 4/1), firm, some silt beds. No ice-rafted material observed.

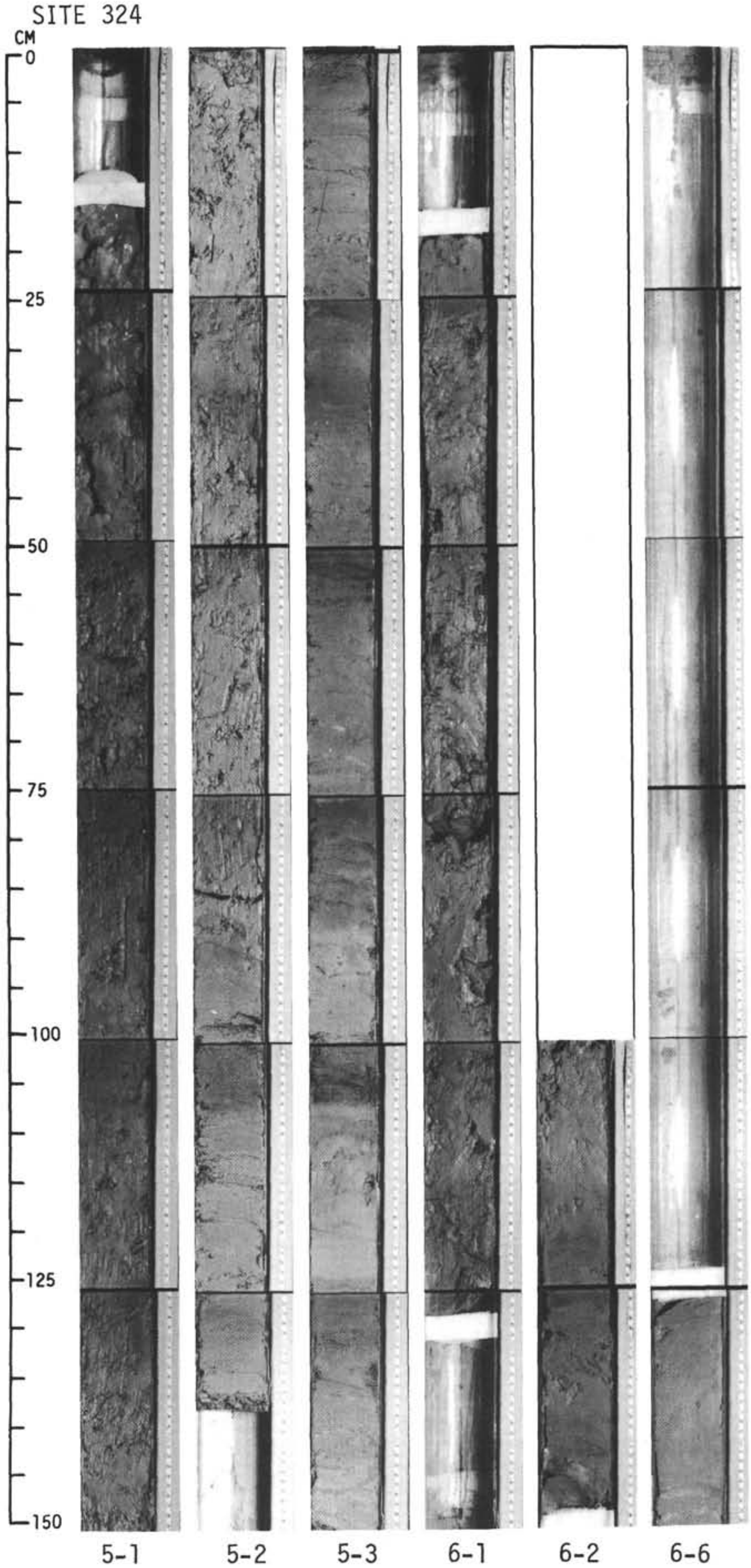
Composition: 90-95% clay mins., 2-10% qtz., 1-2% opaque mins., traces heavy mins., volc. glass, and carbonate.

CLAY: dark gray (5Y 4/1), with quartz-silt beds. No ice-rafted material. Silt composition: 89% qtz., 7% heavy mins., 3% opaque mins., 1% rock frags., traces fldspr. and mica.

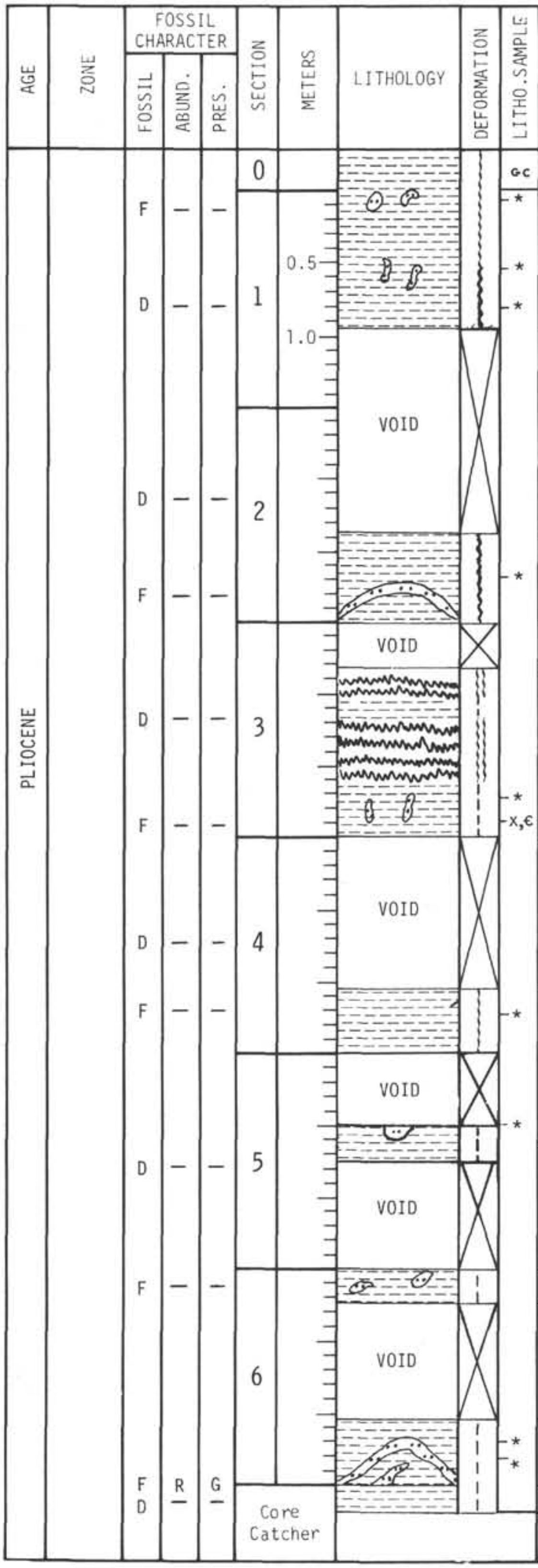
Carbon/carbonate: 6-137 (0.5-0.4-2.0).

Explanatory notes in Chapter 2


GRAPE WET-BULK DENSITY, g/cc
DEPTH IN CORE (m)
POROSITY, %
100 50 0
*rg
1 2 3
— = Pre-Path Length Adjustment
••• = Post-Path Length Adjustment
⊙ = 2-Minute Count
*rg = grain density, g/cc


SITE 324
CM
0
25
50
75
100
125
150
5-1
5-2
5-3
6-1
6-2
6-6

Hole 324, Core 7 Cored Interval: 151.5-161.0 m



LITHOLOGIC DESCRIPTION

CLAY AND SILTY CLAY

QUARTZ-SILTY CLAY: dark gray (5Y 4/1), with silt pods and stringers. Clay composition: 95% clay mins., 5% qtz. Silt composition: 98% qtz., 2% heavy mins., traces opaque mins., carbonate. Minor ice-rafted gravel at Sect. 1, 90 cm.

QUARTZ-BEARING CLAY: dark gray (5Y 4/1), firm with silt layers. Composition: 85-90% clay mins., 5-10% qtz., traces opaque and heavy mins., mica.

QUARTZ-SILTY CLAY: dark gray (5Y 4/1), mainly firm but some beds disturbed by gas expansion. Minor ice-rafted gravel. Composition: 65% clay mins., 30% qtz., 3% heavy mins., traces opaque mins., mica. Carbon/carbonate: 3-142 (0.5-0.4-1.0).

BULK X-RAY (3: 137-141)

Amorph. 47.3% Crystal. 52.7%

Percent of Crystalline Component

Quartz	23.4%	Mica	22.4%
K-Fldspr.	12.9%	Chlorite	6.2%
Plag.	14.6%	Mont.	18.1%
Kaol.	1.7%	Amphi.	0.6%

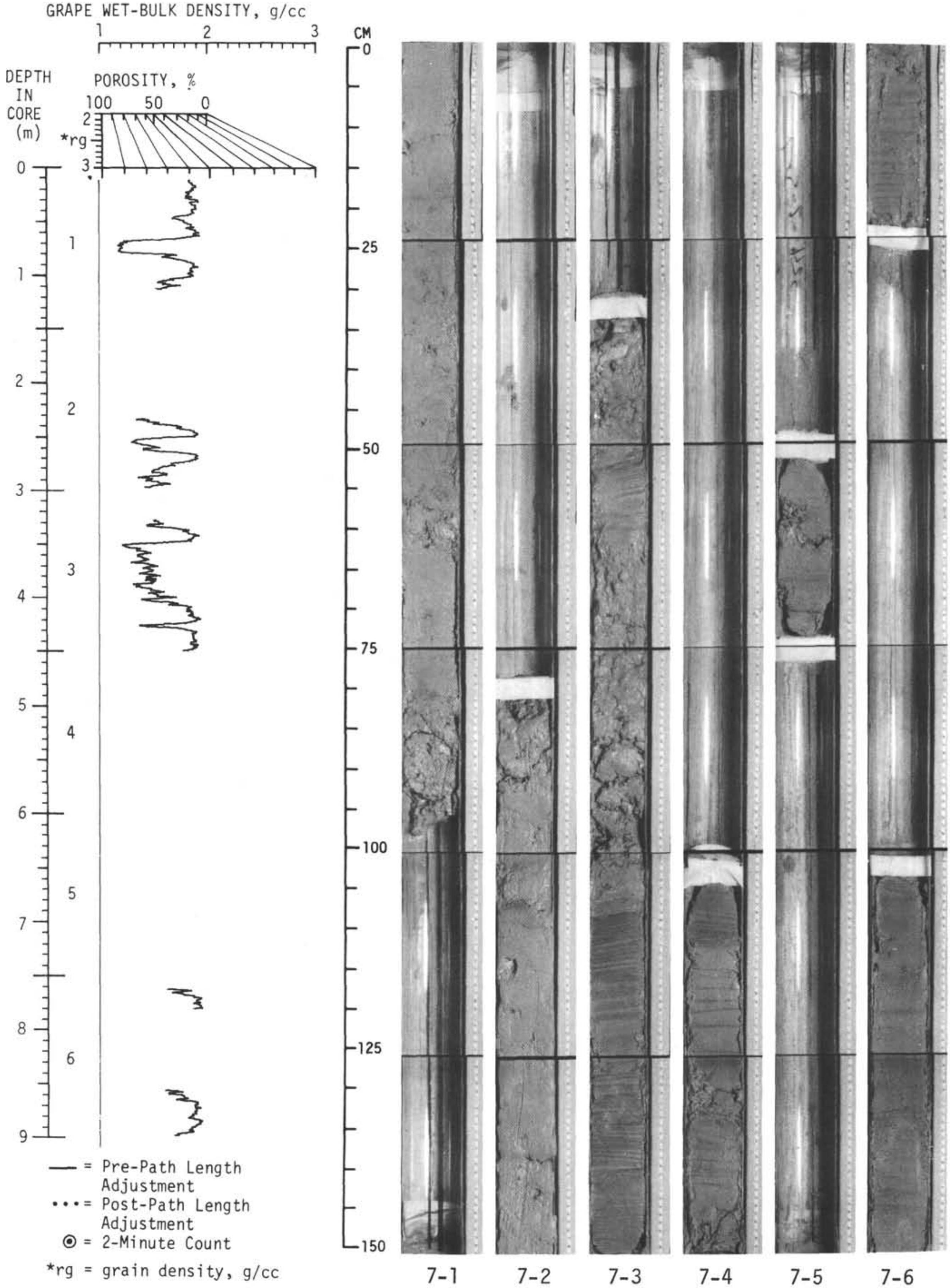
CLAY: dark gray (5Y 4/1), one silt stringer. No ice-rafted material. Composition: 80-90% clay mins., 5-15% qtz., 2-3% opaque mins., 1-2% heavy mins.

CLAY: dark gray, firm, with small silt pods.

QUARTZ-BEARING CLAY: dark gray (5Y 4/1), firm, with layers of well sorted silt. Grain size: 6-133 (0.0-85.6-14.4).

CLAY: gray (5Y 5/1), soft, sticky.

Explanatory notes in Chapter 2


GRAPE WET-BULK DENSITY, g/cc
1
2
3
DEPTH IN CORE (m)
POROSITY, %
100
50
0
*rg
CM
0
25
50
75
100
125
150
0
1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
— = Pre-Path Length Adjustment
• • • = Post-Path Length Adjustment
⊙ = 2-Minute Count
*rg = grain density, g/cc
7-1
7-2
7-3
7-4
7-5
7-6

Hole 324, Core 8 Cored Interval: 170.5-180.0 m

AGE	ZONE	FOSSIL	ABUND.	PRES.	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE
PLIOCENE	?				0		VOID		
		D	—	—	1	0.5, 1.0	DRILLING SLURRY		*
		F	R	G	2				*, *, *
		D	—	—					GC
					3				*, *,X
		D	—	—	Core Catcher				*

LITHOLOGIC DESCRIPTION

CLAY WITH INTERBEDDED SILT

Drilling slurry comprised of firm gray (5Y 5/1) clay galls and minor claystone fragments in matrix of silty clay. Clay composition: 95% clay mins., 5% qtz., traces opaque and heavy mins.

BULK X-RAY (3: 91-92)

Amorph. 24.8% Crystal. 75.2%

Percent of Crystalline Component

Quartz	35.4%	Mica	15.2%
K-Fldspr.	18.6%	Chlorite	3.8%
Plag.	21.2%	Mont.	4.0%
Kaol.	0.8%	Amphi.	0.9%

CLAY AND INTERBEDDED SILT: gray (5Y 5/1). Clay is semi-indurated to claystone in several places. A few silt beds are laminated with fine silt/clay alternations. 34 distinct silt beds in Sect. 3. No ice-rafting observed. Silt composition: 95% quartz, 5% heavy mins., traces opaque mins., mica.

CLAY: gray (5Y 5/1), soft, disturbed. Composition: 85% clay mins., 10% qtz., 3% rock frags., 2% heavy mins., trace feldspar.

Hole 324, Core 9 Cored Interval: 189.5-199.0 m

AGE	ZONE	FOSSIL	ABUND.	PRES.	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE
PLIOCENE	?				0		VOID		
					1	0.5, 1.0	VOID		*, Z, *
	(D) Denticula hustedtii (D) Cosmodiscus insignis	R / D	R / C	M / M	Core Catcher				*,C, *

LITHOLOGIC DESCRIPTION

CLAY AND CLAYSTONE WITH ICE-RAFTED DEBRIS

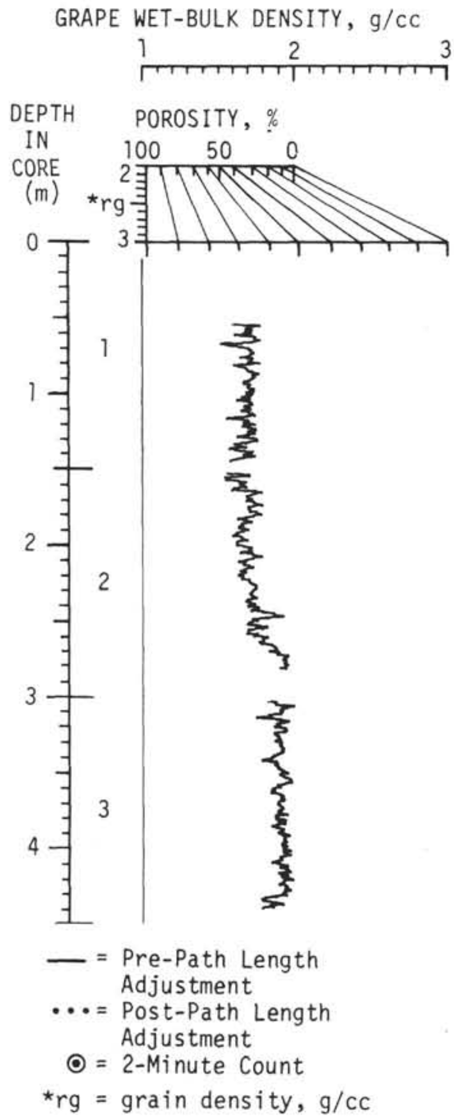
CLAY: gray (5Y 5/1), rich in ice-rafted silt, sand, gravel, and pebbles. Also silicified quartz silt. Silt composition: 45% recrystallized silica, 38% qtz., 10% clay mins., 5% heavy mins., 2% authigenic carbonate, trace opaque mins. Grain size: 1-102 (23-21-56).

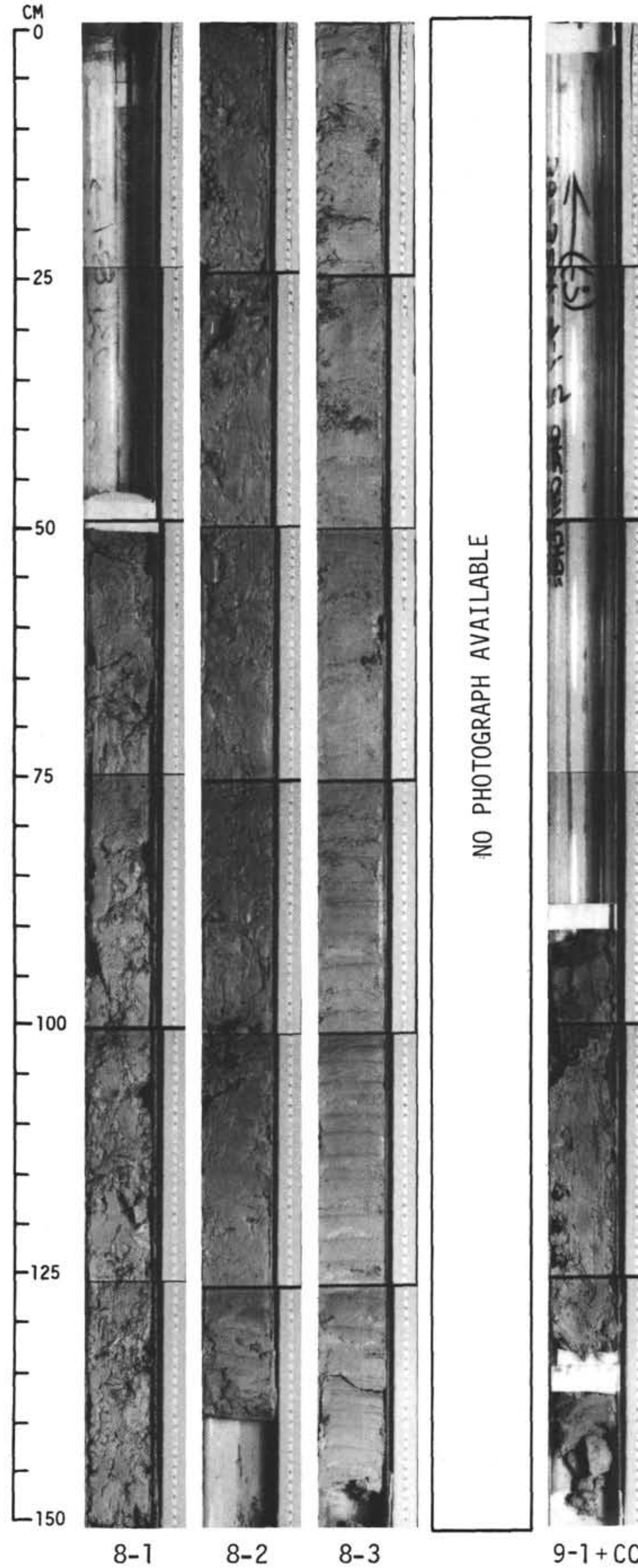
SILICIFIED CLAY: gray (5Y 5/1), with ice-rafted debris. Carbon/carbonate: CC (0.2-0.1-0.0).

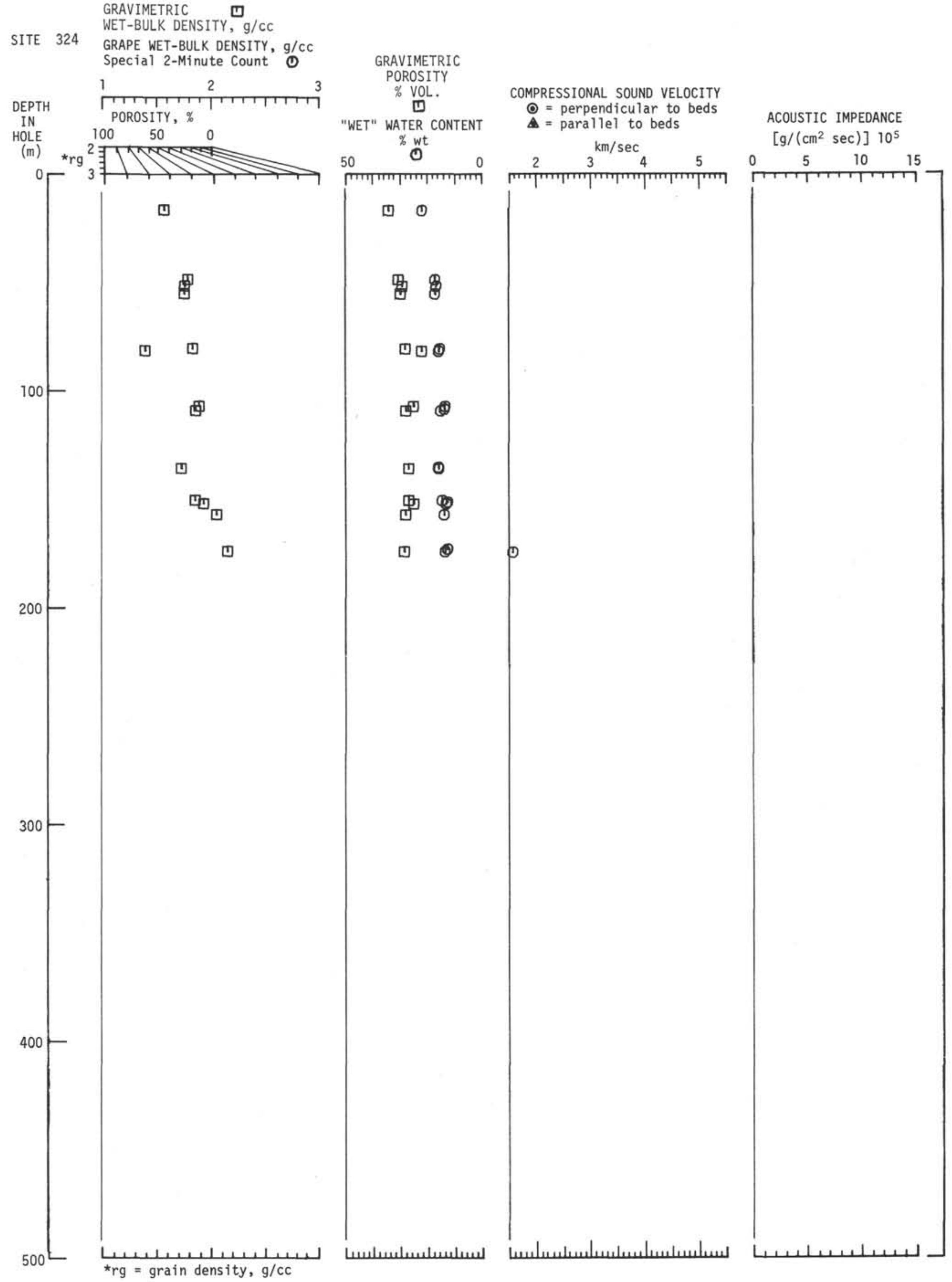
CLAYSTONE: greenish gray (5G 6/1), with ice-rafted debris. Contains 2% diatoms.

There was no recovery in Core 10. The end of the core barrel, however, was polished by abrasion and a small amount of fine, gritty sand was found on core liner.

Explanatory notes in Chapter 2


GRAPE WET-BULK DENSITY, g/cc
1
2
3
DEPTH IN CORE (m)
POROSITY, %
100
50
0
*rg
0
1
2
3
4
1
2
3
— = Pre-Path Length Adjustment
••• = Post-Path Length Adjustment
⊙ = 2-Minute Count
*rg = grain density, g/cc


CM
0
25
50
75
100
125
150
NO PHOTOGRAPH AVAILABLE
8-1
8-2
8-3
9-1 + CC


SITE 324
GRAVIMETRIC WET-BULK DENSITY, g/cc
GRAPE WET-BULK DENSITY, g/cc
Special 2-Minute Count
DEPTH IN HOLE (m)
POROSITY, %
*rg
GRAVIMETRIC POROSITY % VOL.
"WET" WATER CONTENT % wt
COMPRESSIONAL SOUND VELOCITY
= perpendicular to beds
= parallel to beds
km/sec
ACOUSTIC IMPEDANCE
[g/(cm2 sec)] 10^5
*rg = grain density, g/cc