8. SITE 224

The Shipboard Scientific Party[1]
With Additional Reports From
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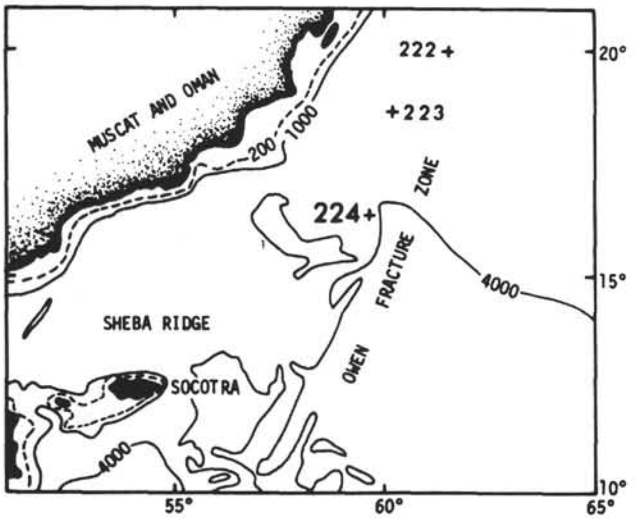


Figure 1. *Position of Site 224 and adjacent Leg 23 sites (shown by +). Contours at 200, 1000, and 4000 meters from Laughton et al. (1971).*

SITE DATA

Dates: 0800 5 Apr-1415 7 Apr 72

Time: 54 hours

Position (Figure 1): 16°32.51′N, 59°42.10′E

Holes Drilled: 1 **Total Penetration:** 792 meters

Water Depth by Echo-Sounder: 2500 corr. meters

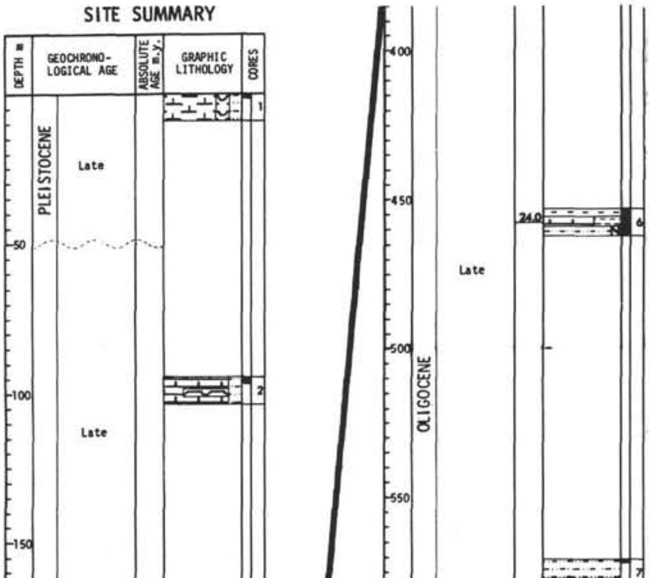
Total Core Recovered: 30 meters from 11 cores

Age of Oldest Sediment: mid-Early Eocene

Basement: Lamprophyre

ABSTRACT

Lower Eocene nanno-rich clay was laid down on a lamprophyre flow. The clay grades upwards into a nanno chalk which by the Late Eocene was mixed with silty claystone and sandstone. In the Late Oligocene, the sedimentation rate changed from 10 to at least 61 m/m.y. A 400-meter-thick Oligocene to Miocene dominantly clastic section, with rare graded beds, followed. The site rose in the earliest Miocene and the detrital component decreased. Subsequently, nanno ooze or chalk accumulated at about 30 m/m.y. up to the present. Sometime between the early Middle and the Late Miocene, biogenic silica appeared, suggesting the onset of upwelling.



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BACKGROUND AND OBJECTIVES

The operations at Site 224 were controlled by the logistics of a rendezvous to take place afterwards off Djibouti for the exchange of personnel before *Glomar Challenger* entered the Red Sea. When Site 223 was completed, only two days remained for drilling and site surveys. A sixth site in the Arabian Sea had been proposed before the cruise, and this site lay over the thick continental margin sediments off Muscat (at 16°N, 53°35′E) with no basement visible on the single seismic reflection profile across the site. In view of our time consuming experience with thick sediments at Site 222 and the short time remaining to us, the Co-Chief Scientists decided that there was little to be gained by drilling this site with almost no hope of reaching basement. Although several alternatives were considered, it was agreed that the most profitable course of action would be to drill at another site which would fit into the context of the sites already drilled on Leg 23.

The oldest sediments at Site 223 are surprisingly young (Late Paleocene). It had been expected that they would have been contemporary with the initial splitting apart of this portion of Gondwanaland, i.e., at least as old as Cretaceous. Thus, it was of considerable interest to discover whether or not the relatively youthful sediments found at Site 223 are an exception, and whether the trachybasalt of this site, an unusual type of deep-sea basement, exists elsewhere along the Owen Fracture Zone. A further problem was associated with the ridges of the Owen Fracture Zone south of Site 223. Although they are drawn as three separate features on Laughton's bathymetric chart, the gaps between them really reflect a lack of soundings. It is quite possible, by analogy with Chain Ridge at the south end of the fracture zone, that the ridges are continuous. It is important for an understanding of the distribution of Indus Cone turbidites and for determining the spreading history of the Arabian Sea to know whether the Owen Fracture Zone has a single continuous ridge, acting as a barrier to turbidites, and if so, what its trend is across the sea floor.

For the above reasons, a zig-zag survey was conducted southwards from Site 223 across the ridges of the Owen Fracture Zone and a site sought for south of 16°30′N. In fact, the survey strongly suggested that a continuous ridge exists, at least as far south as 15°20′N (Figure 2), and this ridge was named the Owen Ridge by the shipboard scientists.

Thus, the main objectives of drilling this site were to determine the nature of the igneous basement and the age of the oldest sediments, but it was also hoped to compare the stratigraphy with that at Site 223 insofar as time allowed coring of the sedimentary column.

No constraints were laid down by the JOIDES Advisory Panel on Pollution Prevention and Safety since this was a new unscheduled site.

OPERATIONS

After leaving Site 223, *Glomar Challenger* carried out a zig-zag survey southwards across the gaps between the ridges indicated on Laughton's bathymetric chart. As well as confirming that the Owen Ridge is at least 550 km long, the survey also showed that the westward dipping structure of the ridge, seen between Sites 222 and 223, is maintained to the south (Figure 2). This strengthened the hope that a site comparable to Site 223 could be found. Because the sediment thickness over the ridge increased southwards and because of the short time available for drilling, several hours were spent searching for a reduced sediment thickness. This was found eventually, by chance, in a region a short distance west of the ridge crest (Figure 3) where a large slump appeared to have removed some of the upper part of the section and where a faint deep reflector, possibly igneous basement, came closer to the sea bed. The beacon was dropped at 1158 hours on 5 April in a water depth of 2500 meters.

Rigid time constraints guided the drilling and coring program at this site. Because of the rendezvous off Djibouti, only 40 hours could be allocated for a drilling and coring program to reach what was believed to be igneous basement at about 720 meters. The penetration rate achieved at Site 223 suggested that there was time for taking only nine cores. Of these, one was planned at the sediment surface so as to satisfy the general policy laid down by the Pollution Prevention and Safety Panel, three were to be located at the inferred depths of seismic reflectors, two were to be at intermediate depths and three were allowed for basal sediments and igneous basement. As igneous basement was not found at the anticipated depth, the rendezvous time was changed and a maximum of 12 more hours was allowed; this permitted the taking of two more cores, of which the second did reach igneous basement.

The isolated coring and the drilling of large sediment intervals went smoothly, and as expected, the penetration rate decreased with depth (Table 1). Within several cored and drilled intervals, alternating hard and soft layers were encountered. This served to reduce the core recovery rate as the hard layers tended to clog the core catcher or fill the inner core barrel, and the water circulation system often washed away the softer sediments.

It is believed that here, as at other sites, sediments entered the core barrel during the time the hole was being drilled. Consequently, the sediments in the core barrel were not necessarily recovered from only the cored interval.

In several instances where dips were found in the sediments, it was noted that they reversed direction within a section. This strongly suggests that the inner core barrel and its contents were rotating within the outer barrel.

Mud was first spotted in the hole at 350 meters and thereafter at roughly 120-meter intervals in order to remove dense cuttings from the hole.

After igneous rock had been recovered in Core 11 (783 to 792 m), an attempt was made to sidewall core at a depth of 175 meters. After the attempt, the drillers were unable to pull the inner barrel. Upon pulling the pipe string, it was found that the lower two-thirds of the sidewall corer had broken off resulting in no sediment recovery.

Glomar Challenger left Site 224 at 1815 hours 7 April. Because of the tight schedule, necessary if we were to arrive at the rendezvous point off Djibouti on time, no pass over the beacon was made at this site. Instead, the ship departed

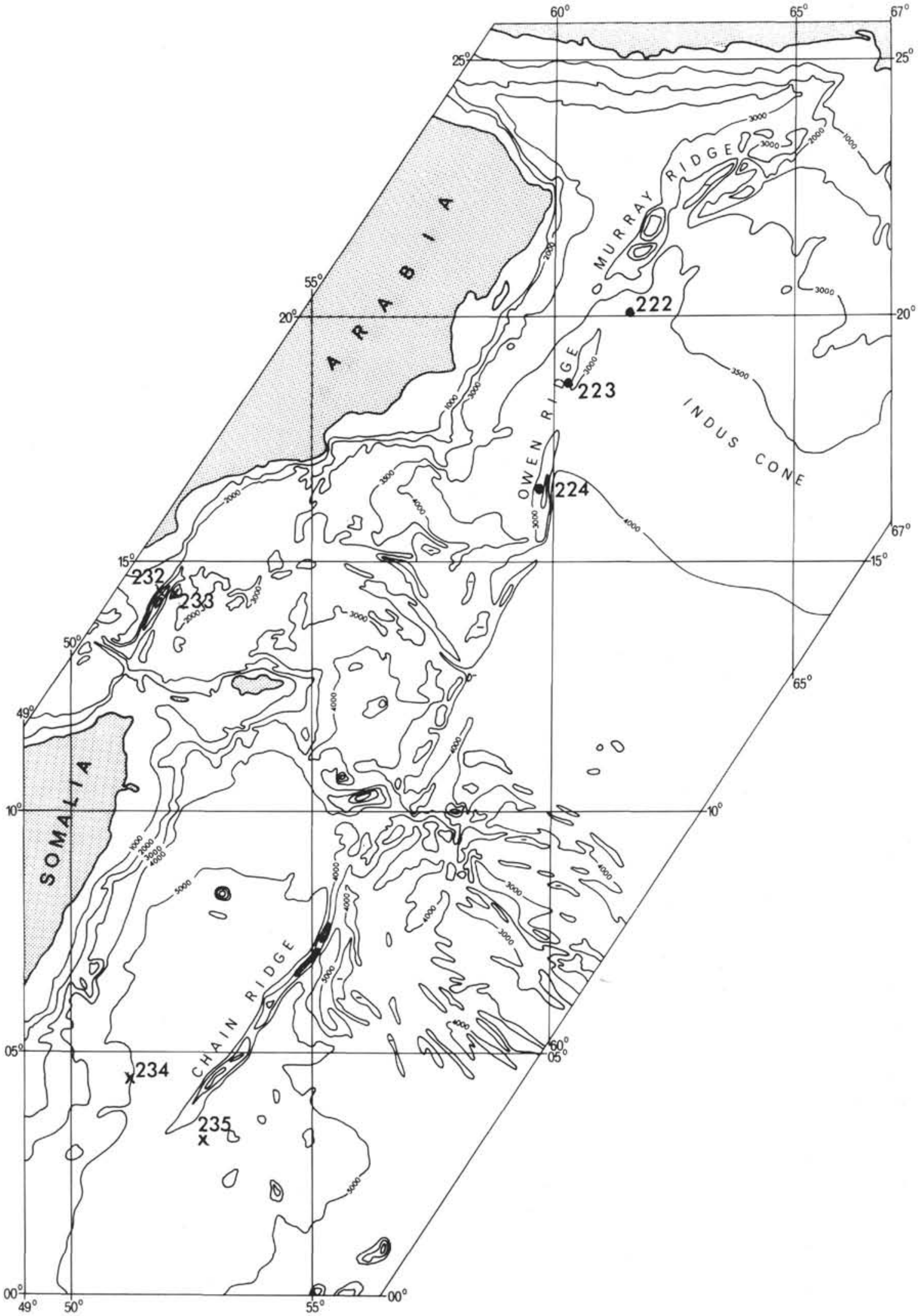

Figure 2. *Bathymetric chart of the Owen Fracture Zone from Laughton's unpublished charts with Leg 23 soundings added. Contours at 1000-meter intervals, 3500-meter contour added north of 15°N. Closed contours around depressions contain a minus sign, all other closed contours represent positive features. Leg 23 sites shown by dots, Leg 24 sites, by crosses. The Owen Ridge is almost certainly continuous between Sites 223 and 224 and only appears discontinuous here because of the chosen contour spacing.*

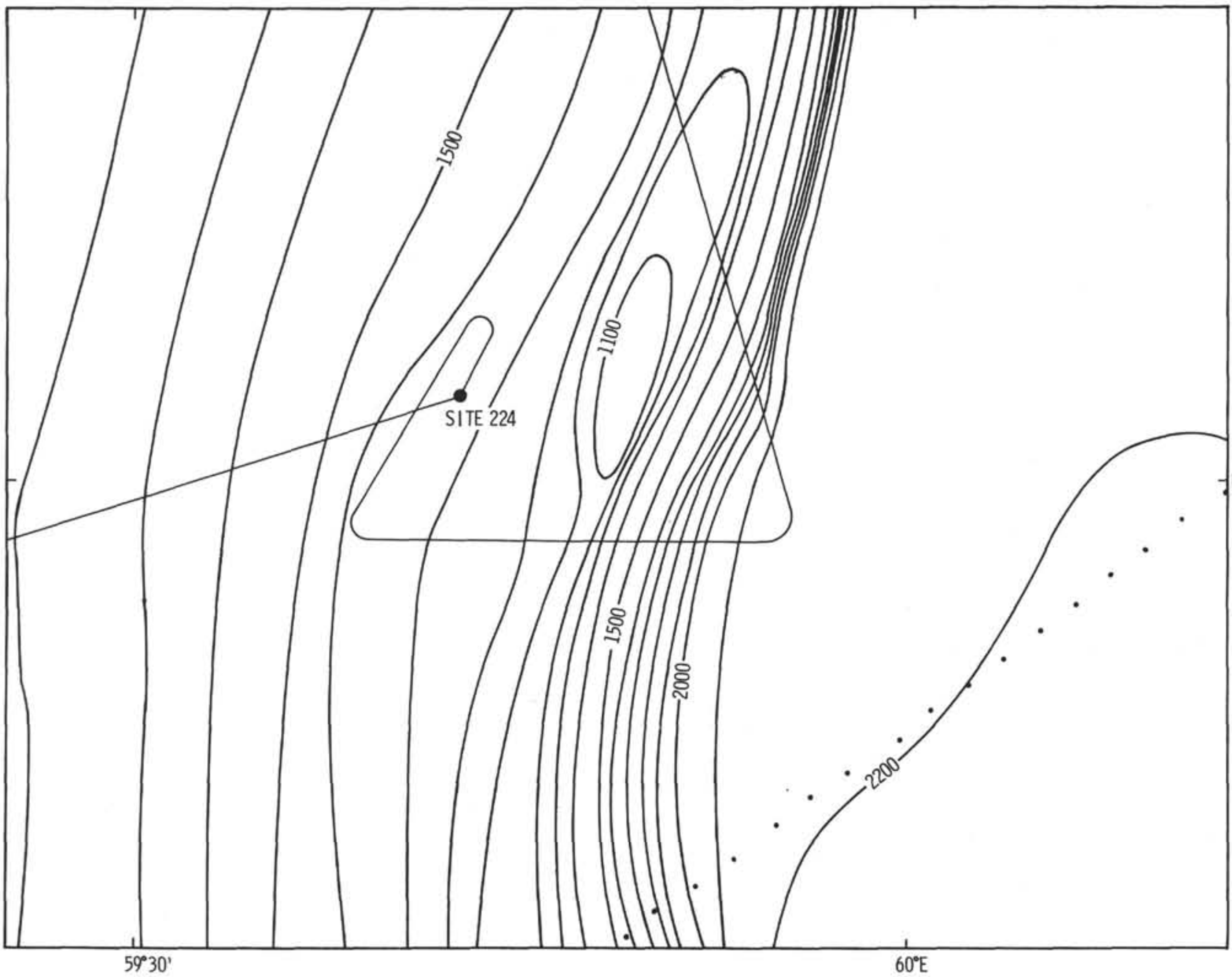

Figure 3. *Bathymetric chart of the area around Site 224 with the tracks of* Glomar Challenger. *Contour interval 100 fathoms; depths in corrected fathoms; dots represent soundings by other vessels (after Laughton, unpublished).*

on a westerly course at 4 knots while gear was being streamed and then came up to full speed afterwards.

LITHOLOGY

A 792-meter-thick stratigraphic section was drilled. The main objective of this site was to reach basement and establish the stratigraphic sequence, taking as many cores as time constraints allowed. Unfortunately, only 11 cores could be taken, and the positions of the unit boundaries are necessarily indefinite (see Table 2).

Unit I

This unit consists of soft-to-semilithified pale olive to greenish-gray detrital clayey silt-rich nanno ooze and chalk. Diatoms occur in the top two cores only, the sediments being diatom-rich in Core 1 and ranging from diatom-bearing nanno chalk to an impure diatomite in Core 2. The latter core also contains 5 percent each of Radiolaria and sponge spicules. A downward increase of the detrital clay and silt content can be observed as well as a regular alternation of detrital silty clay-rich nanno chalk (64% carbonate) and nanno-bearing detrital silty claystone (2% carbonate). These lithologic differences are reflected by color changes from greenish gray to grayish olive. Small amounts of palygorskite and dolomite occur in this unit.

Unit I encompasses an unconformity in the drilled interval between Cores 1 and 2. The seismic profile indicates that at the site 150 meters of the uppermost sediment, which are present at the top of the Owen Ridge, are absent because of slumping from the ridge flank. Core 1 probably represents a surface veneer of sediments deposited after slumping took place.

Unit II

This unit consists of semilithified to lithified detrital clayey silt and claystone. The carbonate content of this unit ranges from 2 to 15 percent. X-ray mineralogy reveals that mica and quartz are very abundant (Appendix III). Two subunits are recognized according to color and according to the amount of nannofossils and sand layers present in the sediments.

Subunit IIa is a finely laminated grayish detrital silty claystone with a 3-meter interbedded interval of light bluish detrital clay-rich nanno chalk. The sediments are moderately to intensely bioturbated. In places, the burrows dip 22° to 30°. The lower part of this unit shows slump

TABLE 1
Coring Summary, Site 224

Core	Date/Time Core on Deck (Time Zone -4)	Depth Below Sea Floor (m)	Cored (m)	Recovered (m)
	5 April:			
1	1820	0-9	9.0	CC
2[a]	2045	94-103	9.0	1.6
	6 April:			
3	0055	250-259	9.0	CC
4	0220	259-268	9.0	1.1
5[b]	0550	350-359	9.0	2.4
6[c]	0900	453-462	9.0	9.5
7[c]	1420	571-580	9.0	1.2
8	1820	632-641	9.0	9.5
9[b]	2350	698-707	9.0	1.1
	7 April:			
10	0605	754-763	9.0	1.8
11[b]	1100	783-792	9.0	2.7
Sidewall	1250	175		
Total			99.0	30.9

[a] Pumps used continuously from here.

[b] Spotted 50 barrels of mud before coring.

[c] Spotted 50 barrels of mud.

structures and micro-faulting with a dip of about 40° on the fault plane. A few thin sand beds are found in the zero section of Core 6.

Subunit IIb is a semilithified to lithified brownish-gray detrital sandy to clayey siltstone characterized by graded sand and silt beds. Nannofossils occur only in small amounts and then only in some beds.

Unit III

This unit consists of semilithifed massive greenish-gray micarb-rich clay nanno chalk and pale red nanno-rich claystone. Gray massive sandstones, one with cross-laminations and clay pebbles, are intercalated in the homogeneous greenish-gray to grayish-red claystones. The chalk interval is mottled with fine white specks. The pale red nanno-rich to nanno-bearing claystones is heavily mottled with pale green nanno-rich material.

The X-ray mineralogical analyses of the $<2\mu$ fraction in Cores 9 to 11 indicate that the clay minerals are mostly of montmorillonite (63%-72%). An exception occurs at Sample 11-2, 45 cm where only 29 percent montmorillonite is present. However, there, 45 percent of the clay fraction consists of the authigenic minerals cristobalite, tridymite, and clinoptilolite. Palygorskite is also a minor constituent in most analyses although, surprisingly, it comprises 50 percent of the bulk analysis of Sample 11-1, 80 cm.

Volcanic glass is quite common in this unit becoming abundant near the contact with the underlying lamprophyre.

Unit IV[2]

The black fine-grained igneous rock recovered from the core catcher is massive but cut by veins (3–4 mm) of secondary material. The texture is intersertal with square, prismatic, titan-augite forming rosettes set in a groundmass of brown glass. A dark brown hornblende (probably barkevikite) rims many of these titan-augite prisms and also forms small discrete needles in the glassy matrix. Olivine, now pseudomorphed by serpentine and calcite, made up less than one percent of the original rock. Skeletal iron oxides are abundant in the glassy matrix. No feldspar was recognized, however, tabular-shaped pseudomorphs, now containing calcite and chlorite, may have originally been plagioclase. The mineralogy and texture of this rock is very similar to the group of rocks called lamprophyres. Specifically, where plagioclase is lacking and titan-augite-barkevikite predominate, the rock is called a monchiquite. Chlorite and carbonate are common alteration products within the glassy matrix. Cross-cutting veins consist of calcite, brown clay (montmorillonite?), and unidentified zeolite.

Basement igneous rock from this site is quite distinct from previously described rock suites that are considered to have formed at mid-ocean ridges. Also, they do not resemble volcanic suites from island arc environments. Chemical and spectrographic analyses of this rock confirm its unusual nature (see Table 3). Lamprophyres are ordinarily found as dikes or sills of limited extent.

Due to limited space, the tables of grain size, carbon-carbonate, X-ray, and *p*H and salinity are presented with the data of other sites in Appendices I, II, III, and IV, respectively, at the end of the volume.

BIOSTRATIGRAPHY

Foraminifera

Common planktonic foraminifera of Pleistocene (N.22) age were found in the sediments of Sample 1, CC and rare Miocene-Pliocene species in Sample 2, CC. They are absent, however, in all samples from Cores 3 through 8. Sample 9-1, 43-45 cm contains rare Oligocene species, but no zonal determination was possible. Abundant and well-preserved planktonics in Sample 10, CC include *Globigerinatheka tropicalis* and *Truncorotaloides pseudodubia*, indicative of late Middle Eocene Zone P.14. Planktonic species are also abundant in Sample 11-2, 111-113 cm, but preservation of these forms is so poor (due to crushing) that only two species—*Acarinina soldadoensis* and *Morozovella aragonensis*—could be identified that indicate an Early Eocene age.

Deep-water (lower bathyal to abyssal) benthic species are present but rare in all samples except those from Cores 4 through 7, where foraminifera were completely absent. The indication, thus, is that heavy solution of foraminiferal tests has virtually eliminated fossils from all horizons except Pleistocene and Lower to Middle Eocene.

Nannofossils

Hole 224 was drilled in sediments ranging in age from Pleistocene to middle Early Eocene which are underlain

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[2] R. G. Coleman.

TABLE 2
Lithological Summary, Site 224

Lithology		Thickness (m)	Subbottom Depth (m)	Core
Units	Subunits			
I Gray DETRITAL CLAYEY SILT-RICH NANNO OOZE/ CHALK		ca. 300	0-300	1-4
II DETRITAL CLAYEY SILT and CLAYSTONE	a.Gray DETRITAL SILTY CLAYSTONE b.Brownish Gray DETRITAL SAND and CLAYEY SILTSTONE	ca. 170 Ca. 380 ca. 210	300-680	5-8
III Gray MICARB RICH CLAY NANNO CHALK to Red NANNO-RICH CLAYSTONE		Ca. 107	680-787	9-11
IV Grayish Black LAMPROPHYRE		5	787-792	11

by igneous basement. Gaps of 100 meters or more between cored intervals greatly hinder the accurate stratigraphic reconstruction of sediments at this site. An unconformity may be present between Cores 3 and 4; however, paleontological control is limited due to lack of closely spaced samples.

A total of 11 cores were recovered from Hole 224. Core 1 contains abundant *Gephyrocapsa oceanica* and associated Upper Pleistocene flora. The *Discoaster calcaris* Zone of lower Upper Miocene is present in Core 2. Sample 3, CC, presumably representative of sediments between 250 and 259 meters, also contains nannofossils of the *D. kugleri* Zone. Sample 4-1, 90 cm contains a rich nannofossil assemblage representing the *Triquetrorhabdulus carinatus* Zone of Early Miocene. As Cores 3 and 4 were contiguous, either an unconformity is present within the cored interval or Sample 3, CC is out of place and was acquired somewhere in the 147-meter drilled interval which preceded Core 3.

TABLE 3
Monchiquite Analyses, Site 224

Chemical [a]		Spectrographic [b]	
Oxide	Weight (%)	Element	ppm
SiO_2	43.2	Mn	1200
Al_2O_3	14.6	Ba	400
Fe_2O_3	3.6	Co	44
FeO	6.1	Cr	300
MgO	7.4	Cu	80
CaO	11.5	Ni	120
Na_2O	2.4	Sc	40
K_2O	1.2	Sr	420
H_2O+	2.3	V	230
H_2O-	3.6	Y	50
TiO_2	2.4	Zr	190
P_2O_5	0.46	Yb	3
MnO	0.09		
CO_2	1.6		
	100.5		
Spec. Gravity of Powder	2.76		

Note: Sample used was 224-11, CC.

[a] Analysis performed in Rapid Rock Analysis Laboratory by Sam Botts, U.S. Geological Survey, Washington, D.C.

[b] Quantitative spectrographic analysis by R.E. Mays, Spectrographic Services and Research, U.S. Geological Survey, Menlo Park, California.

Few nannofossils are present in Core 5. Sample 6-2, 105-106 cm contains *Sphenolithus belemnos, Discoaster druggi,* and *Sphenolithus* cf. *ciperoensis* belonging to the Early Miocene/Late Oligocene. *Sphenolithus ciperoensis* is rarely seen in Samples 6-4, 121-122 cm and 7-1, 52-53 cm, suggesting a Late Oligocene age. The presence of *Reticulofenestra laevis, Coccolithus margaritae,* and *Discoaster tani* in Core 8 suggest an early Middle Oligocene age for this interval (Roth et al., 1971).

The early Late Eocene is present in Sample 10-2, 105-106 cm with the abundant occurrence of *Discoaster saipanensis, Discoaster barbadiensis, Reticulofenestra umbilica,* and *Coccolithus eopelagicus.* The Middle Eocene *Chiasmolithus grandis* Zone appears in Sample 10, CC. *Marthasterites tribrachiatus* and *Discoaster lodoensis* are abundantly present in Sample 11-2, 131-132 cm, suggesting a middle Early Eocene age for sediments immediately overlying igneous basement.

Radiolaria

Radiolaria are common and well preserved in Cores 1 and 2. Core 1 is Pleistocene; Core 2 is Upper Miocene (*Ommatartus antepenultimus* Zone). Radiolaria are absent from the remaining cored intervals.

Biostratigraphic Summary

Pleistocene to middle Lower Eocene sediments are present in Hole 224. The objectives of drilling this hole were to reach basement, to obtain the age of overlying sediments, and to examine the stratigraphy. All this had to be accomplished in the 40 hours available for drilling. Large gaps are present between cored intervals which hinder proper stratigraphic reconstruction. An age of 51.5 m.y. is assigned to the oldest sediments penetrated in Hole 224.

The Late Pleistocene is well represented in Core 1 (0 to 9 m) by abundant planktonic foraminifera (Zone N.22), nannofossils (*Gephyrocapsa oceanica* Zone), and Radiolaria. Abundant well-preserved Radiolaria belonging to the *Ommatartus antepenultimus* Zone are present in Core 2 (103 m). Abundant nannofossils of the *Discoaster calcaris* Zone and rare lower bathyal to (abyssal?) benthonic foraminifera are also present. An early Late Miocene age is assigned to sediments recovered in Core 2.

Core 3 (250 to 259 m) contains abundant nannofossils of the *D. kugleri* Zone, as well as *Discoaster exilis* which represents older strata approaching the *Discoaster exilis* Zone of the lower Middle Miocene. Planktonic foraminifera are absent from Core 3, and Radiolaria are absent from Core 3 and the remaining cored intervals.

Abundant nannofossils of the *Triquetrorhabdulus carinatus* Zone are present in Sample 4-1, 90 cm (268 meters), and an Early Miocene age is assigned to these sediments. An unconformity seems to be present between Cores 3 and 4 as evidenced by the absence of at least four nannofossil zones ranging in age of from early Middle Miocene (*Discoaster exilis* Zone) to early Early Miocene (*Discoaster druggi* Zone). However, the lack of adequate paleontological control below Core 4 does not provide concrete evidence for its existence, but there is seismic evidence for an unconformity of about this age (see Discussion, Conclusions, this chapter). As the sediments of Sample 3, CC may have entered the core barrel higher in the hole, due to the long drilled interval of 147 meters between Cores 2 and 3, this may be still another explanation for the missing interval. Foraminifera were not noted in Core 4. Core 5 contains a few nondiagnostic nannofossils, probably of Early Miocene age. Foraminifera are also absent in Cores 5, 6, and 7. Sample 6-2, 105-106 cm contains sparse *Discoaster druggi, Sphenolithus belemnos,* and *Sphenolithus* cf. *ciperoensis*, which are of either earliest Miocene or latest Oligocene age.

Samples 6-4, 121-122 cm and 7-1, 52-53 cm (580 meters) contains a few nannofossils with very rare *Sphenolithus ciperoensis* belonging to the Late Oligocene. The presence of claystone in Cores 5, 6, and 7 may indicate sedimentary deposition very near or below the nannofossil compensation depth as verified by the general lack of diagnostic nannofossils and the complete absence of foraminifera. Core 8 contains a lower Middle Oligocene assemblage of nannofossils. Core 9 contains very rare Oligocene foraminifera. The presence of *Cyclococcolithus formosus*, rare *Helicopontosphaera reticulata*, and rare fragments of *Sphenolithus predistentus* suggest a late Early Oligocene age for sediments in Core 9.

The lower Upper Eocene is well represented in Sample 10-2, 105-106 cm with an abundant nannofossil assemblage containing *Discoaster saipanensis, Discoaster barbadiensis,* and *Reticulofenestra umbilica.* The Middle Eocene *Chiasmolithus grandis* Zone appears in Sample 10, CC. Abundant foraminifera belonging to Zone P.14 are also present in Sample 10, CC. Sample 11-2, 131-132 cm and a sample taken at the sediment-lamprophyre contact contain very abundant nannofossils of the *Marthasterites tribrachiatus* Zone of middle Early Eocene. Abundant planktonic foraminifera in Sample 11-2, 111-113 cm also belong to the Early Eocene.

Sedimentation Rate

The lowest samples recovered at this site, in Core 11, contain faunas of Early Eocene age. Middle Eocene fossils are present, however, in Core 11, Section 1; if this sediment is in place, a minor unconformity is present between Sections 1 and 2 of this core.

Middle Eocene to Lower Oligocene sediments (630 to 780 m) accumulated at the relatively slow rate of 10 m/m.y. (see Figure 4). This rate increased markedly during the Late Oligocene, to over 61 m/m.y. (255 to 570 m). The discrepancy in age between sediments in Cores 3 and 4 suggests an unconformity representing most of the Early Miocene at about 255 meters, but this may be artificial if floras in Sample 3, CC were emplaced by contamination during the long drilling period between recovery of Cores 2 and 3.

Little sediment was recovered from the upper 250 meters penetrated at this site, and it is not possible to precisely determine a sedimentation rate for the interval. An unconformity near the top of the hole is indicated by seismic evidence of a missing 150-meter-thick layer removed by slumping, but there is no way of determining its age from the available samples. If there has been little sediment accumulation since the slumping, then the sedimentation rate line can be projected to pass through a point 150 meters above the sea bed. In this manner a mean Middle to Late Miocene rate of about 30 m/m.y. is obtained.

PHYSICAL PROPERTIES

Since only eleven cores were recovered from this site over a penetrated interval of 792 meters the Site Summary displays little data for general interpretation. However, a number of features from the core logs are worthy of consideration.

Sediment Density, Porosity, and Water Content

GRAPE density values show a general increase in density with depth over the top four cores, which may be related to the progressive lithologic increase in detrital silt content over this unit I interval.

The remainder of the sedimentary sequence shows a fairly constant GRAPE density level with a number of prominent fluctuations away from the general level.

In more detail, the core logs show that the gradient noted in unit I may be made up of a number of short step increases in density; for example, one step in Core 4, Section 1 results in a rise from 1.68 g/cc to 1.88 g/cc. Also, there is a fairly strong density contrast between Core 2, with values between 1.5 and 1.6 g/cc (excluding voids), and Core 4, at around 1.7 g/cc. The variability evident in the density plot of Core 2 is not wholly due to voids. The individual low GRAPE values may be caused by the presence of beds containing opaline silica.

Over the interval of Cores 5 to 10, sand and silt beds cause peaks in the density plot to over 2.1 g/cc; for example, at the boundary between the upper two sections of Core 6; at 120 cm in Core 8, Section 2; at 110 cm in

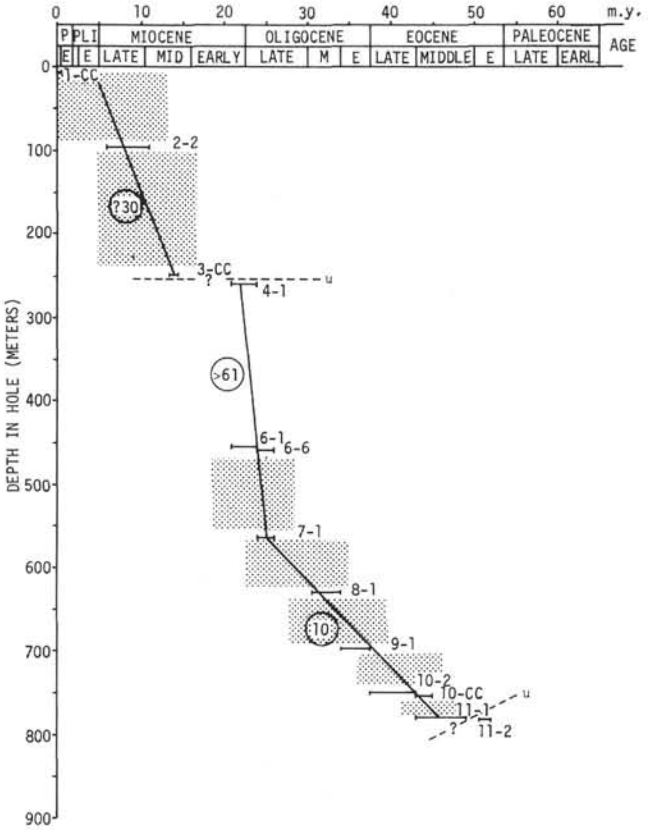

Figure 4. *Sedimentation Rate Curve, Site 224. Plotted bars are those sufficient to control slopes of lines. Stippled pattern represents some uncored intervals. See Chapter 2, Explanatory Notes, for explanation of age ranges and other symbols.*

Core 8, Section 4; at 20 cm in Core 8, Section 5; and in Core 10, Section 2. Where these sand and silt beds have become lithified, they formed layers resistant to the drilling and have distinctly high density values. The three most prominent such layers from the cored intervals, were at 453 meters in Core 6, Section 0; 573 meters in Sample 7, CC, and 641 meters in Sample 8, CC. That in Core 6, Section 0 has a GRAPE measured density of 2.42 g/cc, while the Sample 7, CC horizon was measured ashore and displayed a value of 2.52 g/cc.

The two sections of Core 11 between 783 and 792 meters have too many voids to allow a valid GRAPE density estimate to be made, but two peaks reach 2.28 and 2.08 g/cc.

Compressional Wave Velocity

A general increase in velocity values is evident from 1.64 km/sec in Core 4 to around 2.5 km/sec in Core 10, but too few measurements are recorded to outline any specific trends against depth in the hole.

The calcareous sandstones show the most strikingly high velocities, reaching 4.34 km/sec, 4.94 km/sec, and 3.49 km/sec in Core 6, Section 0, and Samples 7, CC and 8, CC, respectively.

Specific Acoustic Impedance

Due to the low number of velocity values, the impedance plot is based on few points.

It is worth emphasizing, though, that the calcareous sandstones have notably high impedance values as can be seen at the levels of Core 6, Section 0 and Sample 8, CC at 453 and 641 meters, respectively. The Sample 7, CC horizon would have an extreme value outside the scale of the plots, if one multiplies its velocity of 4.95 km/sec by the shore laboratory density measurement of 2.52 g/cc (I = 12.474).

CORRELATION OF REFLECTION PROFILES AND LITHOLOGIES

Reflections on the seismic profile obtained on the approach to Site 224 are particularly distinct except for the basement reflection (Figure 5). Unfortunately, due to the time available at this site, very few cores were taken and so it is impossible to correlate the observed reflections with particular lithologies.

Site 224 was initially approached from the southwest. Two strong reflections, each marking the top of a layered sequence, were seen. Beneath these reflections there are two weaker ones. The upper one of these is conformable with the overlying beds but is seen to onlap against the deeper reflection, which is apparently rough, judging by its diffuse nature and the occurrence of faint hyperbolae. The site was chosen at a point where this rough reflector appears to come closest to the sea bed. This choice was also influenced by the occurrence of an area from which the top 150 meters of sediment were missing, presumably by slumping, since the subbottom reflectors were continuous and unbroken.

At Site 224, the top three reflectors were picked at 0.13, 0.32, and 0.75 seconds (Figure 6). The deeper rough reflector could not be discerned with certainty because of a lack of coherent reflections, however, it would appear to lie above about 1.0 seconds since below here no more returning energy can be detected on the record. Because of the scattered cores, lithology changes cannot be correlated with the reflections. However, the driller did notice hard streaks while cutting Core 2 (94 to 103 m) in which some semilithified nanno chalk was recovered, and beds of this chalk may correspond to the top reflector. The drillers Totco sheet shows two marked decreases in penetration rate, one around 205 meters and the other during the cutting of Core 4 (259 to 268 m). This latter change may correspond to the second reflector. Hard semilithified sandstones, siltstones, and claystones were met in Cores 8 to 11, and the alternation of these lithologies, undoubtedly, gave rise to the zone of diffuse reflected energy. The only definitely identified reflector in this region, however, is the igneous basement, which probably causes a reflection at less than 1.0 second beneath the site. Thus, the minimum velocity to basement is 1.58 km/sec. The reflection data are summarized on Figure 7.

PALEOMAGNETIC MEASUREMENTS

Sampling for paleomagnetic study at this site yielded 19 sediment samples, principally detrital silty claystones, and a single sample of lamprophyre. The sediment samples range

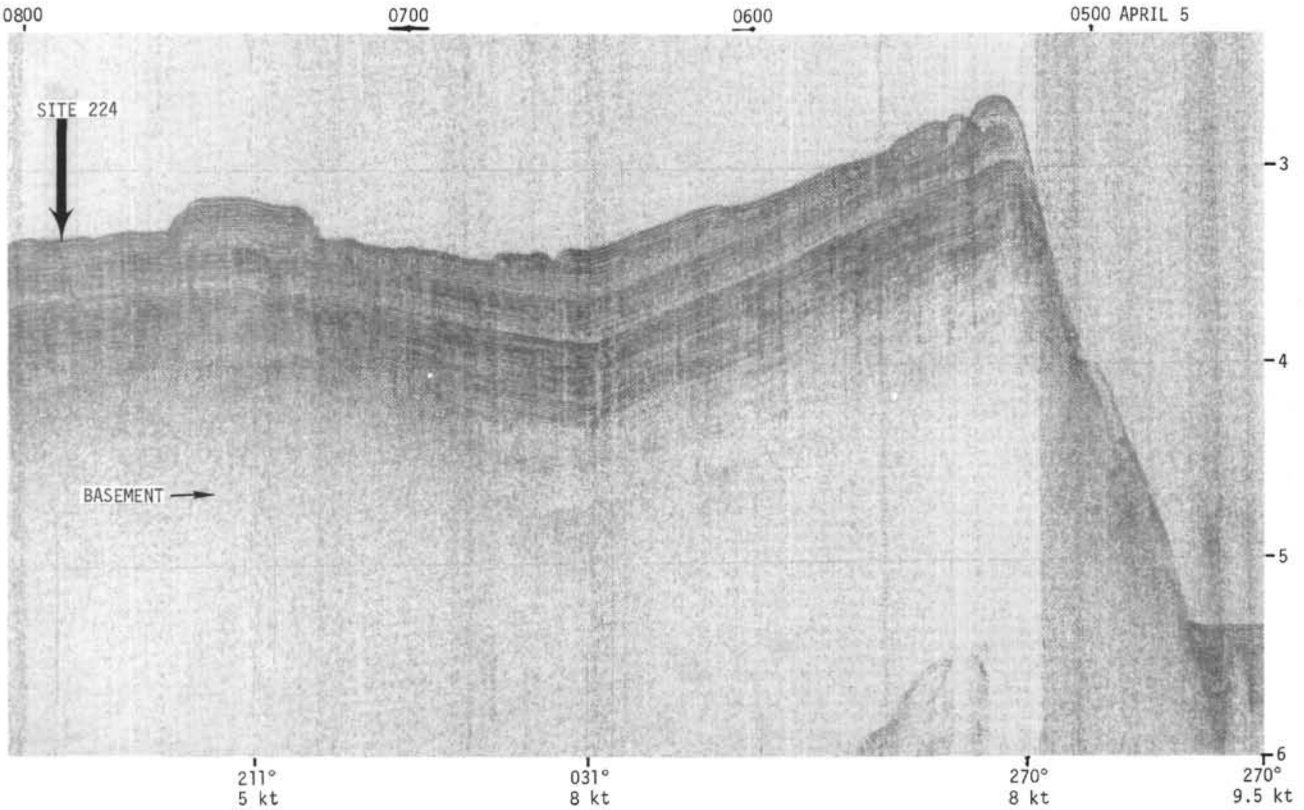

Figure 5. *Seismic reflection profile obtained on the approaches to Site 224. The Indus Cone sediments and east scarp of the Owen Ridge can be seen at the right and the position of the site (arrowed) at the left. Note the terrace on the scarp coincident with the outcrop of the acoustic basement.*

in age from late Late Eocene through Early Miocene. However, the majority of samples come from the Oligocene and Lower Miocene sequences. They provide a useful coverage of stratigraphic intervals not sampled for paleomagnetic purposes at the neighboring Site 223.

A striking feature of the remanence measurements on these sediment samples (Table 4) is a tendency for the majority to show good stability after partial alternating field (Af) demagnetization. Such a result is confirmed by the pilot progressive demagnetizations carried out on Samples 6-0, 29 cm and 7, CC reported in Table 5. Intensity decay curves for these samples are shown in Figure 9. The mean natural remanent magnetization (NRM) intensity value of the sediments is $1.8 \pm 0.4 \times 10^{-5}$ G/cm^3. As described from other sites within this Leg, there is again some variability in inclination values within individual cores.

The Lower Miocene sample has a mean absolute inclination of 7 ± 0.5°after partial Af demagnetization whilst the underlying Oligocene strata are associated with a higher mean absolute inclination of 10.5 ± 1.5. The relevance of these results to the projected motion of the Arabian plate is discussed in the review chapter (Whitmarsh et al., this volume). Evidence of polarity reversal within the Late Oligocene is provided by the negative inclinations exhibited both before and after partial demagnetization by the two samples from Core 7. Sample 9-1, 22 cm is also associated with a consistent negative inclination, but its magnitude is anomalously high when compared with the other observations from the series and this value was not used to obtain the above average.

Evidence of a very high degree of magnetic stability is provided by the progressive demagnetization of the single lamprophyre sample, 11, CC (Table 4 and Figure 8). This sample also has the highest NRM intensity recorded for igneous rocks examined from this leg.

DISCUSSION AND CONCLUSIONS

The necessarily discontinuous coring at this site, with substantial gaps between cores, only allows an incomplete description of the geological history of the site. However, the rather complete sampling at Site 223, 230 km to the north at least provides a yardstick against which the cores from Site 224 can be compared.

Upwelling

One of the striking features of Site 223 is the continuous history of upwelling since the Middle Miocene. Site 224, on the other hand, is slightly farther from the continental shelf edge and lies more on the fringe of present day upwelling (Wyrtki, 1971). Nevertheless, some influence of the upwelling is suggested by the high proportion (15% to 30%) of biogenic silica (Radiolaria, sponge spicules, and diatoms) in the top two cores. No sign of this silica is seen in deeper cores. On the evidence of the siliceous microfossils alone, one may deduce the upwelling commenced between earliest Middle and Late Miocene times. This is consistent with the history of upwelling at Site 223.

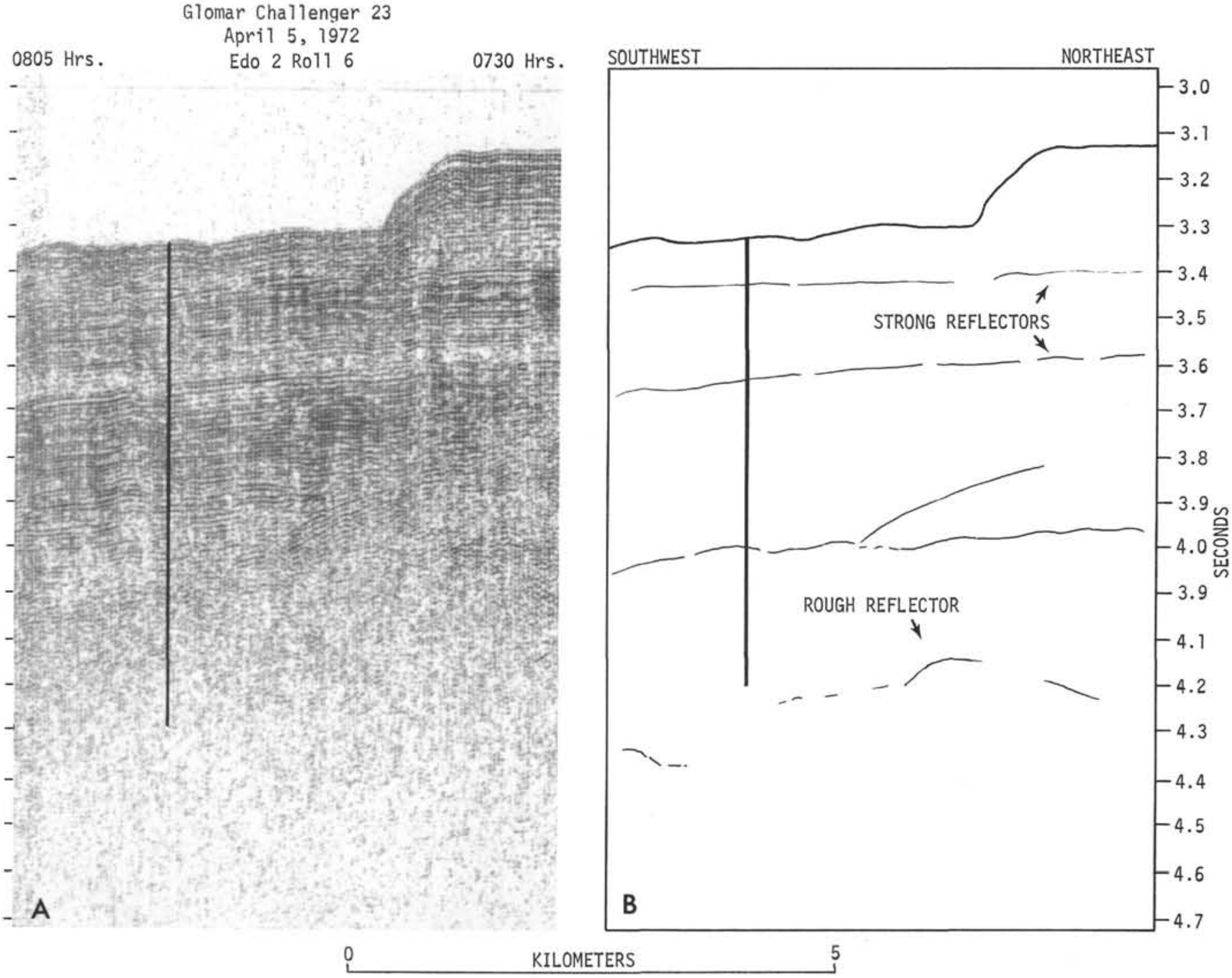

Figure 6. (a). *Seismic reflection profile obtained on the final approach to Site 224. The vertical line marks the position of the drilled hole.* (b). *The interpretation of Figure 6*a *was used to construct Figure 7. The vertical line has 0.1 second divisions.*

Terrigenous Sediments

Perhaps the most marked feature of Site 224 is the roughly 400-meter-thick Middle Oligocene Lower Miocene interval of detrital clayey silt and claystone. Not only are the cores from this section estimated to contain close to 100 percent detrital material but also in the deeper Upper to Middle Oligocene part of the stratigraphic section, there are graded silt and sand beds. The sedimentation rate for most of this interval is high (at least 61 m/m.y.), and the carbonate content is very low (2% to 14%). Foraminifera are absent and even nannofossils are rare in the section. The rarity of nannofossils, and the relative amounts of planktonic and benthic foraminifera in cores just above and below this interval, suggest that the sea bed was close to, or just below, the calcium carbonate compensation depth at this time. However, nannofossils are sometimes found in the section, but with a restricted occurrence. In the top part of the section, bluish chalk layers rich in nannofossils are found, and in the lower part, a few nannofossils occur in isolated beds.

Studies of the heavy mineralogy of the graded beds (Mallik; Jipa and Kidd; this volume) suggest a metamorphic and acid igneous provenance. Many grains are well rounded, which is indicative of a long transportation history. It is interesting to consider what was the likely source region for the detrital sediment and in particular for the graded beds. Since detrital sediments are absent from the Oligocene sediments of Site 223, it appears that a northern source for the heavy minerals can be ruled out. In Oligocene time, sea floor spreading between Arabia and Somalia had not yet begun, and the proto-Gulf of Aden was probably a narrow shallow sea. On the other hand, there would probably have been an almost complete semicircle of shallow seas or land to the west of Site 224 (Figure 9). It is to these areas that we should look for signs of unconformities or nondeposition in the Oligocene which would indicate a likely source area of detrital sediments. In Dhufar, the Oligocene and

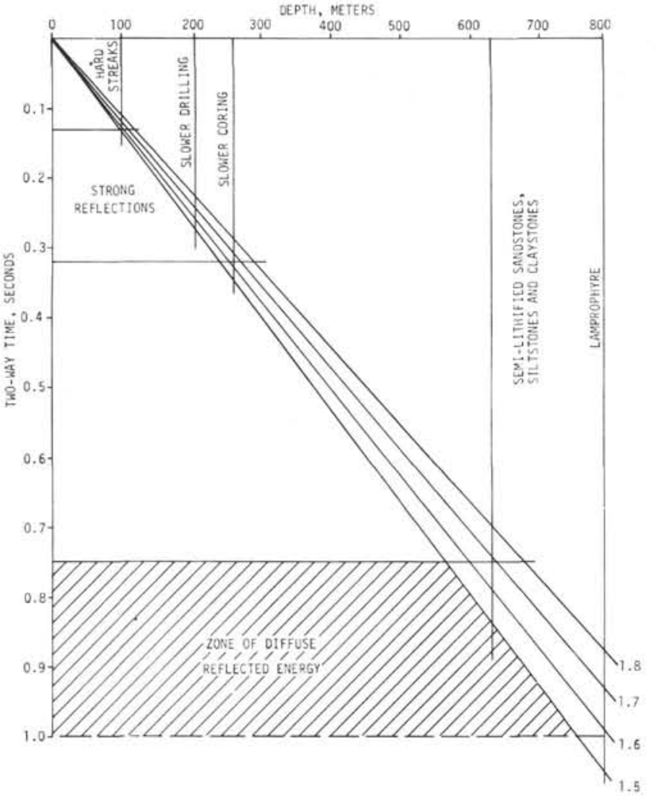

Figure 7. *Plot of reflection times beneath Site 224 against the depths where significant changes in bit penetration occurred. Lines have been drawn with slopes corresponding to mean velocities of 1.5, 1.6, 1.7 and 1.8 km/sec.*

Miocene are represented by a thick chalky limestone (Beydoun, 1966) and, similarly, 50 meters of Oligocene chalk with signs of contemporaneous vertical movements are found in Socotra (Beydoun and Bichan, 1970). Farther east, the Oligocene history is less clear. Powers et al. (1966), without specifying the boreholes, state that drilling throughout Saudi Arabia has failed to detect Upper Eocene or Oligocene sediments, except near Jordan. At Duqm, in the Gulf of Masirah, there are 170 meters of chalky Oligocene limestones exposed, and the Upper Oligocene is said to extend far to the west (Morton, 1959). Shallow-water limestones are also known in the Oligocene of Oman (Henson, 1951). Thus, at the present state of knowledge, it seems unlikely that either Socotra or the Dhufar-Oman coast of Arabia could have been the source areas of the Oligocene detrital sediments found at Site 224. It may be significant that Oligocene clastics (quartz sandstones) are found along the Gulf of Aden and Indian Ocean coasts of the Horn of Africa. The source area is believed to have been to the west (Azzaroli and Fois, 1964). An equally close source of detrital material may, however, have been the mouth of a large river in the north-west part of peninsular India. Accepting the Early/Middle Miocene uplift of the Owen Ridge (see below and Chapter 7), this feature may not have existed in Oligocene time to prevent turbidites from the east crossing the Owen Fracture Zone. Nevertheless, the trough or trench of the then active Owen Fracture Zone would itself have been a formidable barrier to turbidites, and it appears more likely that the detrital source lay to the west in the now submerged shallow areas of unknown geology around Socotra or along the Arabian coast, or else it lay along the proto-Gulf of Aden.

TABLE 4
Summary of Magnetic Data

	NRM			Af demagnetization			
Sample (Interval in cm)	Intensity (G/cm^3)	Relative Declination (degrees)	Inclination (degrees)	Peak Field (oersted)	Intensity (G/cm^3)	Relative Declination (degrees)	Inclination (degrees)
Sediments							
4-1, 148	2.3×10^{-5}	135.9	1.0	50	2.4×10^{-5}	135.3	- 7.5
6-0, 29	1.4×10^{-5}	193.5	6.4	50	1.4×10^{-5}	196.6	5.4
6-1, 63	2.1×10^{-5}	282.7	-6.9	50	2.0×10^{-5}	281.9	- 4.4
6-3, 90	4.1×10^{-7}	104.8	31.6	50	2.8×10^{-7}	107.4	13.6
6-4, 142	2.5×10^{-6}	88.3	12.9	50	1.4×10^{-6}	90.9	7.3
6-5, 84	2.0×10^{-6}	349.4	28.7	50	1.7×10^{-6}	294.9	10.8
6-6, 101	1.2×10^{-5}	73.3	-1.2	50	9.1×10^{-6}	98.7	2.0
7-1, 47	1.9×10^{-5}	37.9	-4.3	50	1.6×10^{-6}	39.4	- 8.1
7, CC	1.2×10^{-5}	43.2	-11.8	50	1.0×10^{-5}	41.7	-12.4
8-1, 62	8.2×10^{-5}	271.1	17.2	50	8.1×10^{-5}	272.2	16.3
8-1, 74	1.9×10^{-5}	47.6	21.0	50	1.7×10^{-5}	48.6	20.7
8-3, 62	2.5×10^{-5}	138.9	12.2	50	2.5×10^{-5}	141.0	9.9
8-4, 72	9.1×10^{-6}	14.4	8.7	50	8.0×10^{-6}	17.2	10.2
8-5, 18	3.8×10^{-5}	39.8	19.1	50	2.7×10^{-5}	78.1	18.1
8-5, 72	2.4×10^{-6}	191.4	17.1	50	3.9×10^{-6}	198.2	16.8
8-6, 72	1.2×10^{-5}	9.3	1.7	50	1.1×10^{-5}	11.8	- 1.2
9-1, 22	2.4×10^{-5}	293.6	-58.2	50	2.2×10^{-5}	278.7	-78.2
10-2, 9	1.2×10^{-5}	356.8	9.9	50	3.4×10^{-6}	71.3	39.7
10-2, 144	9.3×10^{-6}	145.0	13.0	50	9.3×10^{-6}	148.9	4.9
Basalts							
11, CC	1.0×10^{-2}	4.0	-28.7	100	8.7×10^{-3}	4.3	-30.4

TABLE 5
Af Demagnetization, Site 224

Sample	Peak Field (oersted)	Intensity (G/cm^3)	Relative Declination (degrees)	Inclination (degrees)
6-0, 29 cm	NRM	1.4×10^{-5}	193.5	6.4
	25	1.5×10^{-5}	196.0	6.4
	50	1.3×10^{-5}	196.6	5.4
	75	1.2×10^{-5}	197.4	5.0
	100	1.1×10^{-5}	198.5	6.5
	150	7.3×10^{-6}	200.5	7.3
	200	5.4×10^{-6}	202.0	5.7
7, CC	NRM	1.2×10^{-5}	43.2	-11.8
	25	1.1×10^{-5}	44.5	-15.2
	50	1.0×10^{-5}	41.7	-12.4
	75	8.3×10^{-6}	43.3	-12.0
	100	6.8×10^{-6}	44.6	-13.5
	150	4.0×10^{-6}	46.7	-14.9
	200	3.6×10^{-6}	54.3	-19.9
11, CC	NRM	1.0×10^{-2}	4.0	-28.7
	50	9.9×10^{-3}	5.3	-29.1
	100	8.7×10^{-3}	4.3	-30.4
	150	6.3×10^{-3}	5.6	-30.8
	225	4.5×10^{-3}	4.4	-32.9
	300	3.4×10^{-3}	4.8	-31.2
	375	2.7×10^{-3}	4.5	-32.3
	450	2.0×10^{-3}	3.5	-27.6
	525	1.7×10^{-3}	6.8	-30.2
	600	1.6×10^{-3}	20.1	-42.0

Beds of cross-laminated sandstone with clay pebbles occur in the early Late Eocene. It is comparatively simple to postulate source areas for these beds since Upper Eocene sediments are missing from Socotra (Beydoun and Bichan, 1970) and from Dhufar and southwest Arabia, generally (Beydoun, 1966). A large part of eastern Socotra now contains outcrops of igneous rocks (granites, gabbros, and volcanics). Such a provenance is indicated by the heavy mineralogy of the sandstone (see Mallik, this volume).

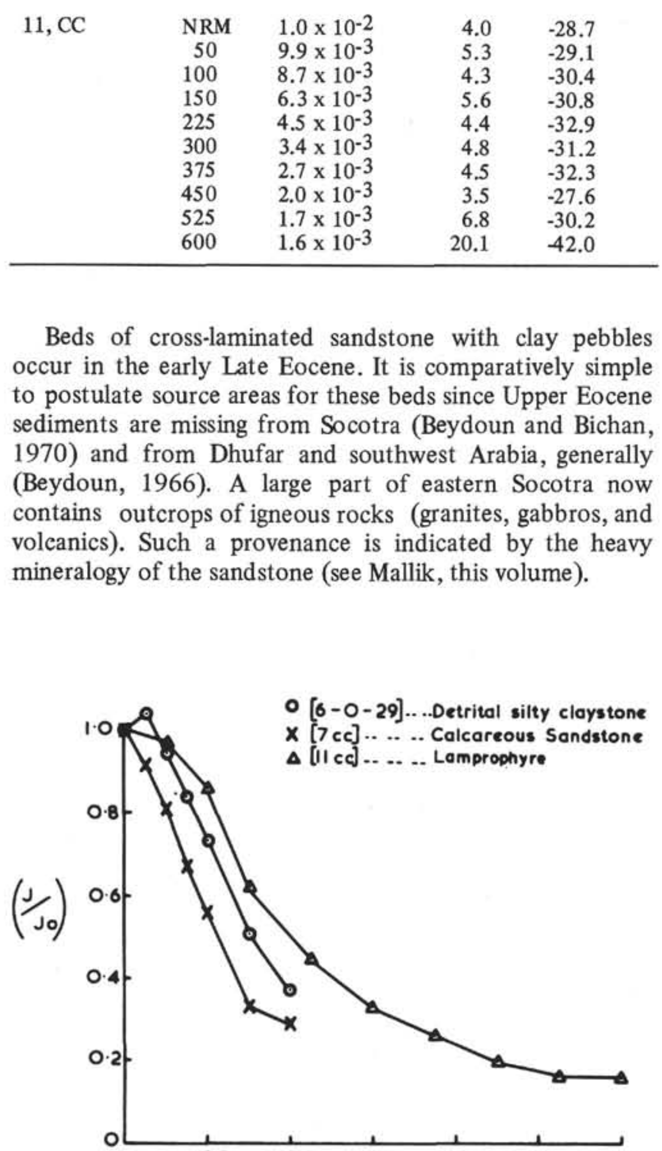

Figure 8. *Normalized intensity decay curves.*

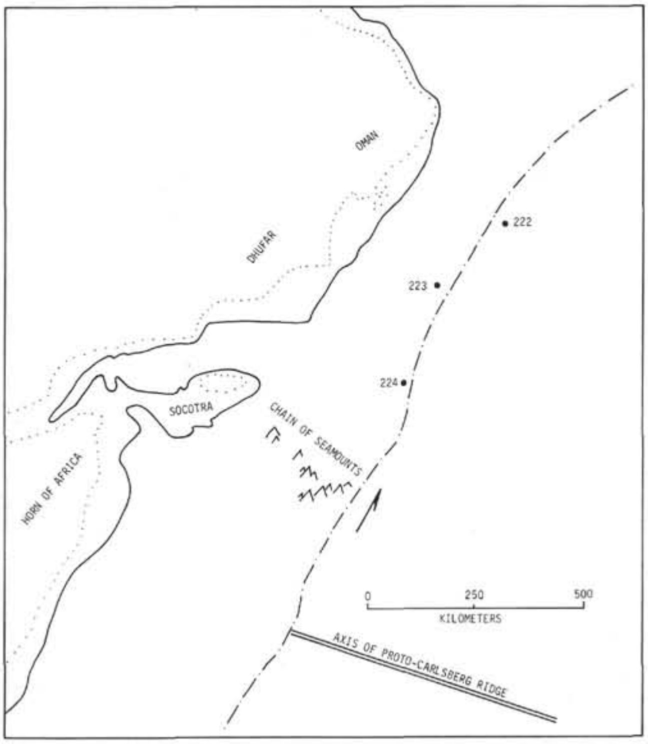

Figure 9. *Reconstruction of the region around Site 224 for Oligocene time based on the pole of McKenzie et al., 1970, which gives the best fit of the 500 fathoms contours on either side of the Gulf of Aden. Present coast lines–dotted; 1000 meters contour–solid line; and Owen Fracture Zone–dash-dot. The axis of the proto-Carlsberg Ridge is deduced from the older sea floor spreading magnetic anomalies in this part of the Arabian Sea, assuming symmetrical spreading.*

Uplift of the Owen Ridge

Uplift of Site 224, and hence of the Owen Ridge, has been alluded to above. There seems little doubt that considerable post-Late Oligocene uplift has occurred simply because turbidites were sampled between 2950 and 3140 meters below sea level and, therefore, lie several hundred meters above the present general level of the sea bed on either side of the Owen Ridge. The seismic profiles also indicate that these beds have a westward dip of about 2.5 degrees, indicating that they have been tilted since the deposition of the turbidites. A slight angular unconformity between the two strong reflectors (Figure 6) is visible at the foot of the west slope of the ridge and suggests that tilting did not begin before early Middle Miocene. Additional pertinent evidence comes from various structural features in the cores which may be attributable to the period of uplift. Thus, normal microfaults are found in the Early Oligocene and Late Oligocene sediments slump structures (disturbed bedding, deformed or drawn out clasts) are found in the semilithified Upper Oligocene to Lower Miocene sediments. Older sediments are without such features. The uppermost Lower Miocene core (Core 4) also shows several layers with dipping burrows which are bounded by horizontal discontinuities. Of the overlying cores, only Core 2 yielded greater recovery than just the core catcher, and this core too has slump features. Inconclusive evidence can be adduced from the seismic reflection profiles across the site and at three crossings of the Owen Ridge farther north (Figure 10). All of these profiles show that between 100 and 200 meters of the uppermost sediments have been stripped off, presumably by sliding of the beds over more competent semilithified beds. Underlying reflectors appear undeformed. Slumps can be initiated in several ways, and this late slump does not necessarily indicate renewed tilting of the sea floor. Finally, lower bathyal to abyssal benthic foraminifera were found in the Late Miocene (Core 2), but middle bathyal forms occur in the Upper Pleistocene core taken at the sea bed (Core 1). At first sight, this evidence suggests an uplift of at least 500 meters in the last 5 m.y. or so; however, another explanation might simply be that the Pleistocene benthic foraminifera were reworked from upslope on the Owen Ridge, the crest of which is at least 500 meters higher up, during the sliding disturbances already noted on the seismic profiles. Thus, this evidence of uplift is rejected. However, the changing foraminiferal faunas in this hole are consistent with decreasing solution of tests since the Middle Miocene. This suggests the sea bed may have been getting shallower, perhaps in part due to tectonic uplift.

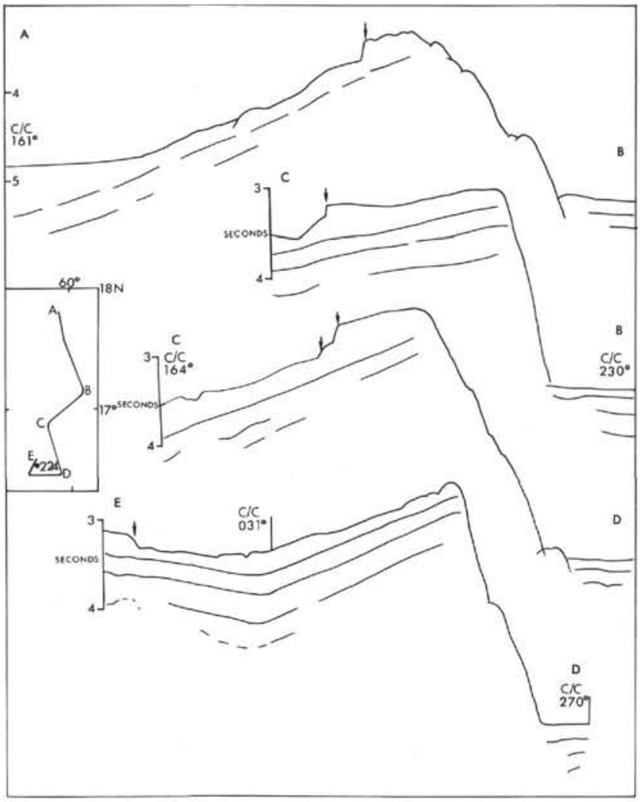

Figure 10. *Line drawings based on the seismic reflection profiles obtained on the approach to Site 224 (see inset which also shows the position of Site 224). The drawings indicate how sliding of the uppermost sediments has occurred quite recently on the west slope of the Owen Ridge without disturbing underlying reflectors (décollement). Scarps produced at the point of detachment of the upper layers are arrowed.*

In summarizing the tectonic history of the site, therefore, it would appear that uplift and tilting began after the last graded bed was laid down, probably at about the same time as the first signs of soft sediment slump structures appear in the cores and contemporary with the angular unconformity at the foot of the west slope, that is in Late Oligocene to early Middle Miocene times. Thus, uplift began at about the same time as, or slightly later, than it did at Site 223.

Igneous Basement

One aspect of Site 224 is that, like Site 223, it lies in a region of very low magnetic relief. For instance, an anomaly of less than 50 gammas was observed on crossing the Owen Fracture Zone and Ridge on the approach to Site 224. This is remarkable in view of the fact that the lamprophyre cored at this site has an intensity of remanent magnetization (10×10^{-3} G/cm^3) and a susceptibility (0.4×10^{-3} G/cm^3) in the normal range for oceanic extrusives. If the mean magnetic properties of the Owen Ridge were the same as those of the lamprophyre, an anomaly of well over 100 gammas should be observed due to the shape of the ridge alone.

The finding of lamprophyre at this site together with the relatively young age of the oldest sediments confirms the unusual chemistry of the igneous rocks of the Owen Ridge and suggests an Early Tertiary age for this part of the Owen Fracture Zone. This age conflicts with generally held notions about the history of the Arabian Sea and requires further explanation.

Depositional History

The geological history of the site may thus be summarized as follows. Beginning in the Early Eocene, a lamprophyre flow was extruded. The overlying nanno-rich detrital clay is rich in volcanic glass for some 10 cm. The clay mineralogy of the claystone suggests that this rock may represent devitrified pyroclastic material. The clay grades upwards into detrital clay-bearing nanno chalk. In the Late Eocene, a mixed lithology of nanno chalk, silty claystone, and sandstone was deposited. The sand came from the land areas to the west and northwest which were emergent in the Late Eocene. In the Early Oligocene, clayey siltstones and claystones were laid down at a depth close to the lysocline, suggesting the possibility of sinking at this time. In the remaining Oligocene time, and continuing through Early Miocene time, there was a strong clastic influence (quartz and mica are dominant) with beds of silt and sand, some graded, from an unknown source area to the west. Although the sedimentation rate increased 6-fold (to at least 61 m/m.y.) in Late Oligocene times, but forminifera and nannofossils were still rare in the sediments, suggesting deposition close to the calcium carbonate compensation depth; however, occasional nannofossil-rich beds were laid down. There was an intermittent benthic population, as indicated by horizontal burrows, but at other times well-developed laminae, 0.5 to 2 mm thick, were formed.

Sometime between Late Oligocene and earliest Middle Miocene the site began to rise, probably contemporaneously with post-Early Miocene uplift in Socotra (Beydoun and Bichan, 1970) and Arabia (Beydoun, 1966). Subsequently, the detrital component in the sediments decreased, the sedimentation rate dropped to about 30 m/m.y., and mainly nanno chalk or ooze was laid down. Sometime between the early Middle and Late Miocene, biogenic silica began to form an appreciable proportion of the sediment, and this probably reflects the onset of monsoonal upwelling along the South Arabian coast.

As a result of the uplift, the younger sediments were deformed by slight slumping the older rocks by normal faulting. In quite recent times 100 to 200-meter-thick beds of sediment had slid off the west slope of the Owen Ridge without disturbing the underlying beds.

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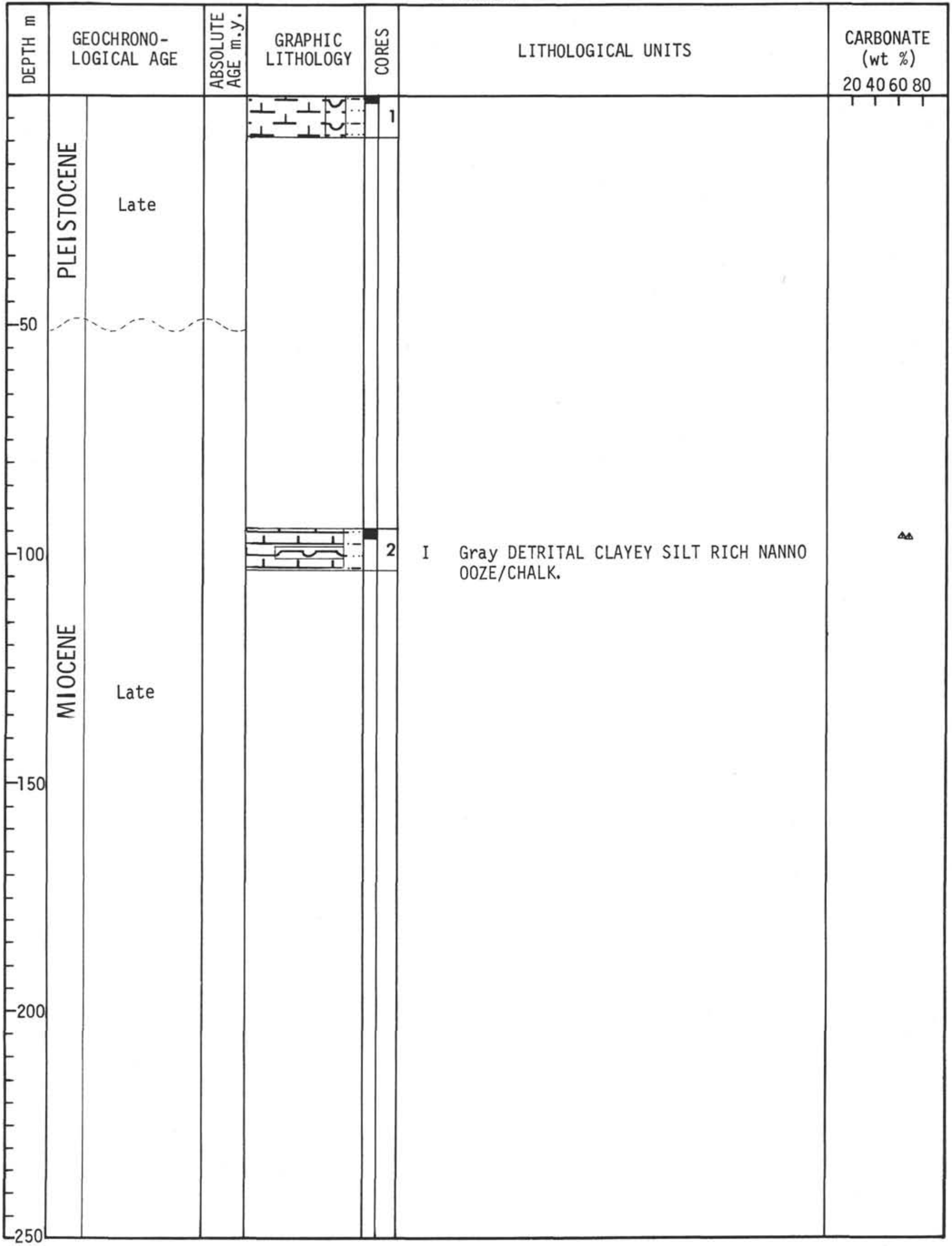
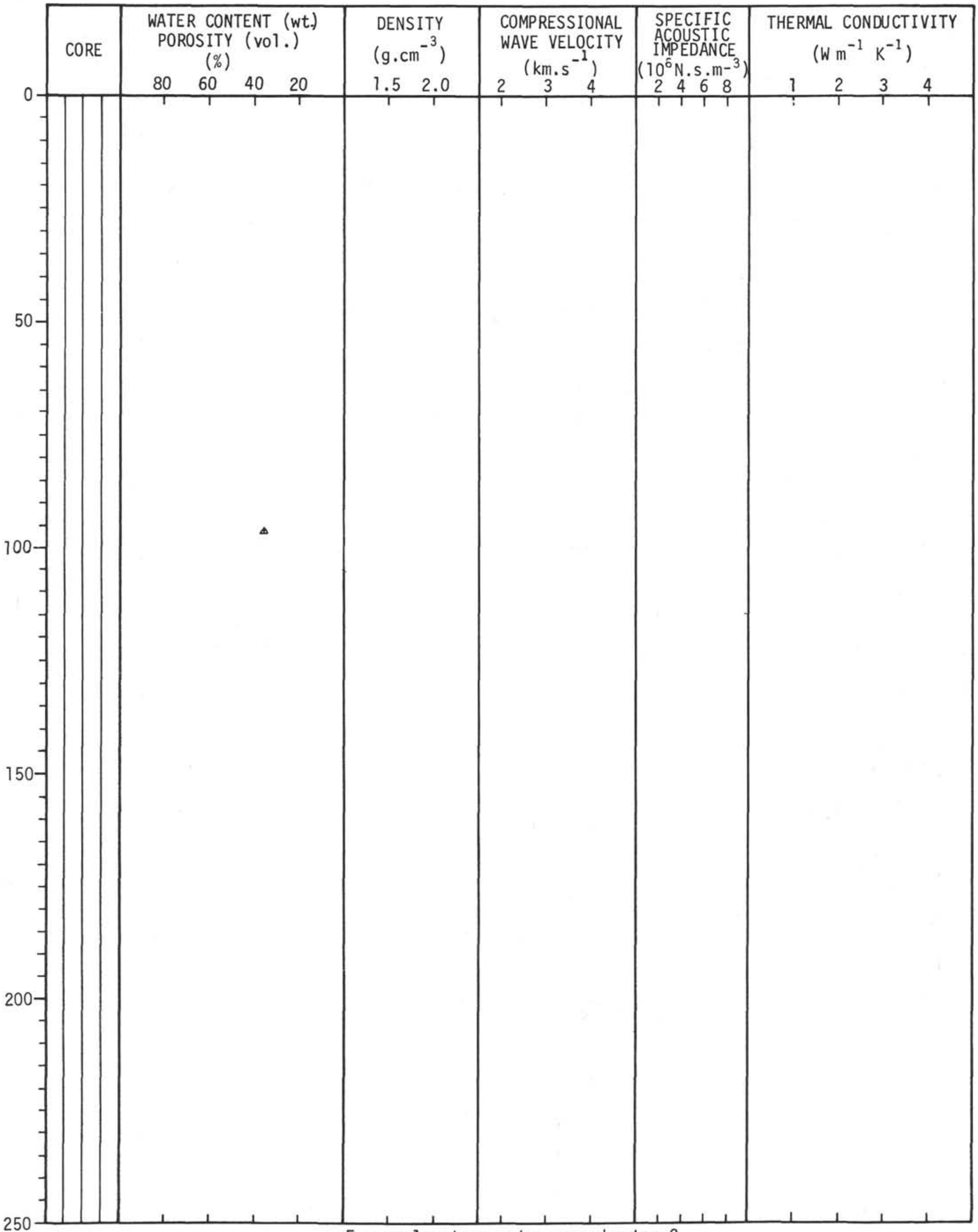
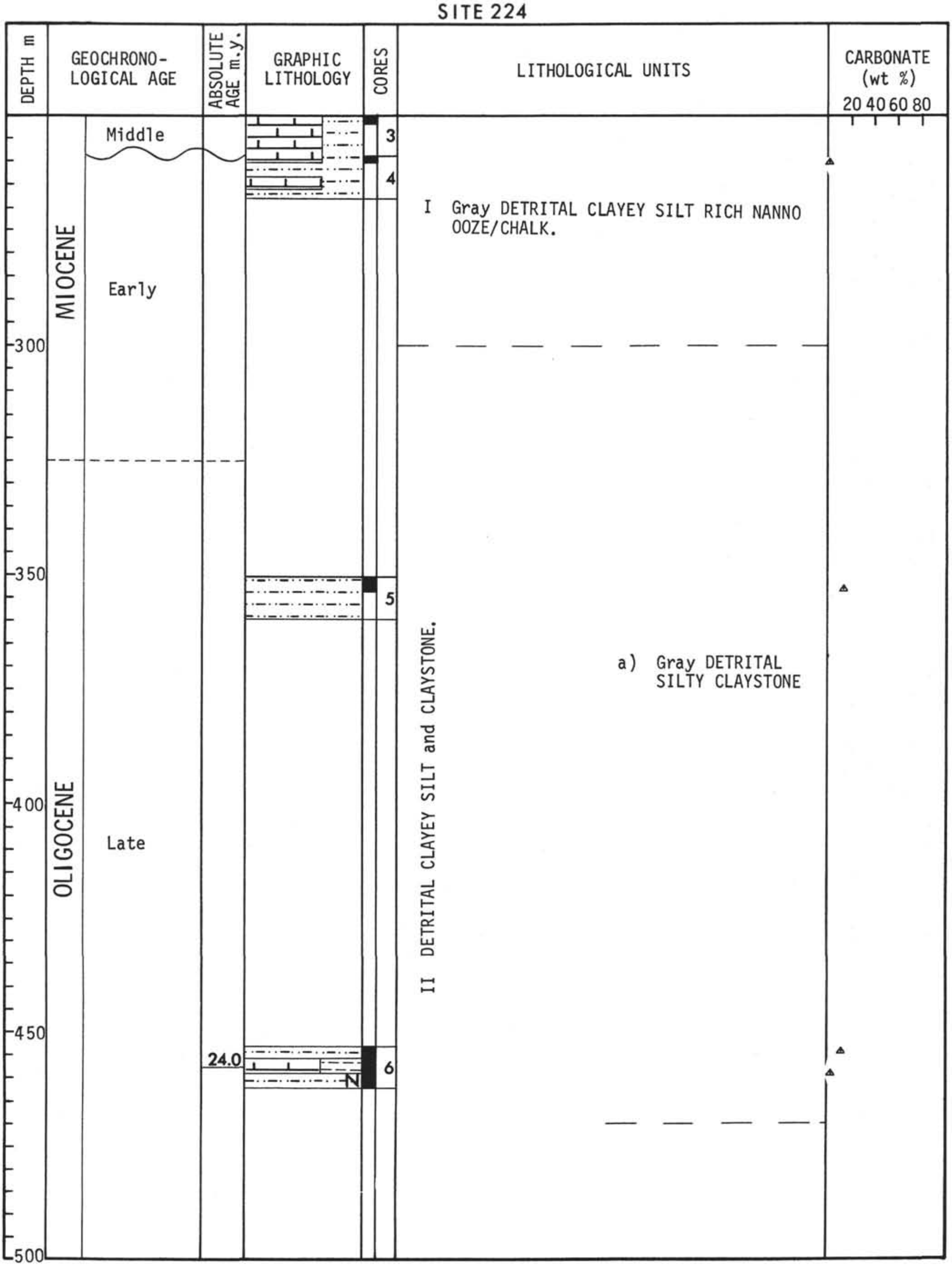
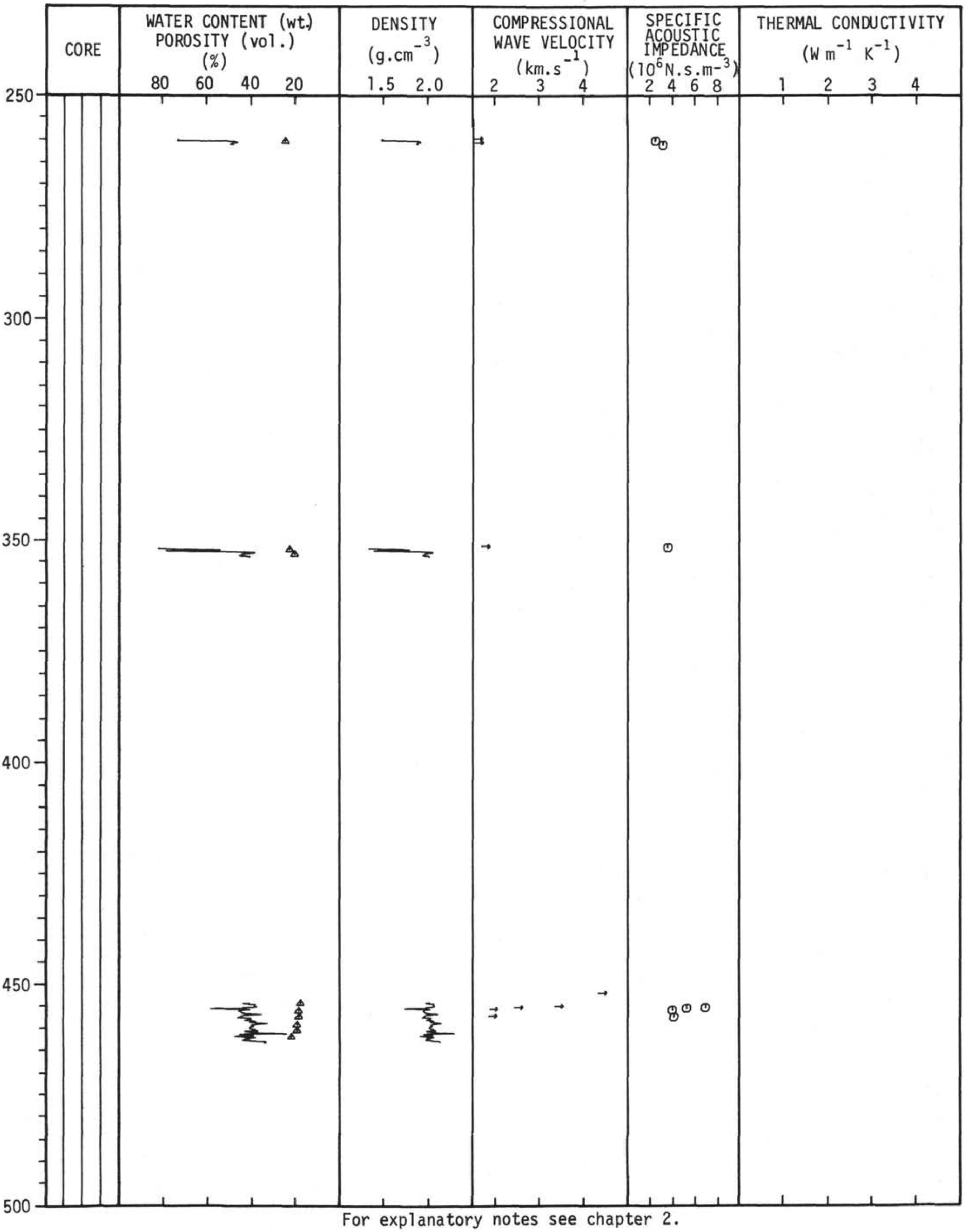
SITE 224


DEPTH m
GEOCHRONO-LOGICAL AGE
ABSOLUTE AGE m.y.
GRAPHIC LITHOLOGY
CORES
LITHOLOGICAL UNITS
CARBONATE (wt %)
20 40 60 80
PLEISTOCENE
Late
MIOCENE
Late
50
100
150
200
250
1
2
I Gray DETRITAL CLAYEY SILT RICH NANNO OOZE/CHALK.



For explanatory notes see chapter 2.


SITE 224
DEPTH m
GEOCHRONO-LOGICAL AGE
ABSOLUTE AGE m.y.
GRAPHIC LITHOLOGY
CORES
LITHOLOGICAL UNITS
CARBONATE (wt %)
20 40 60 80
Middle
MIOCENE
Early
OLIGOCENE
Late
300
350
400
450
500
24.0
3
4
5
6
N
I Gray DETRITAL CLAYEY SILT RICH NANNO OOZE/CHALK.
II DETRITAL CLAYEY SILT and CLAYSTONE.
a) Gray DETRITAL SILTY CLAYSTONE



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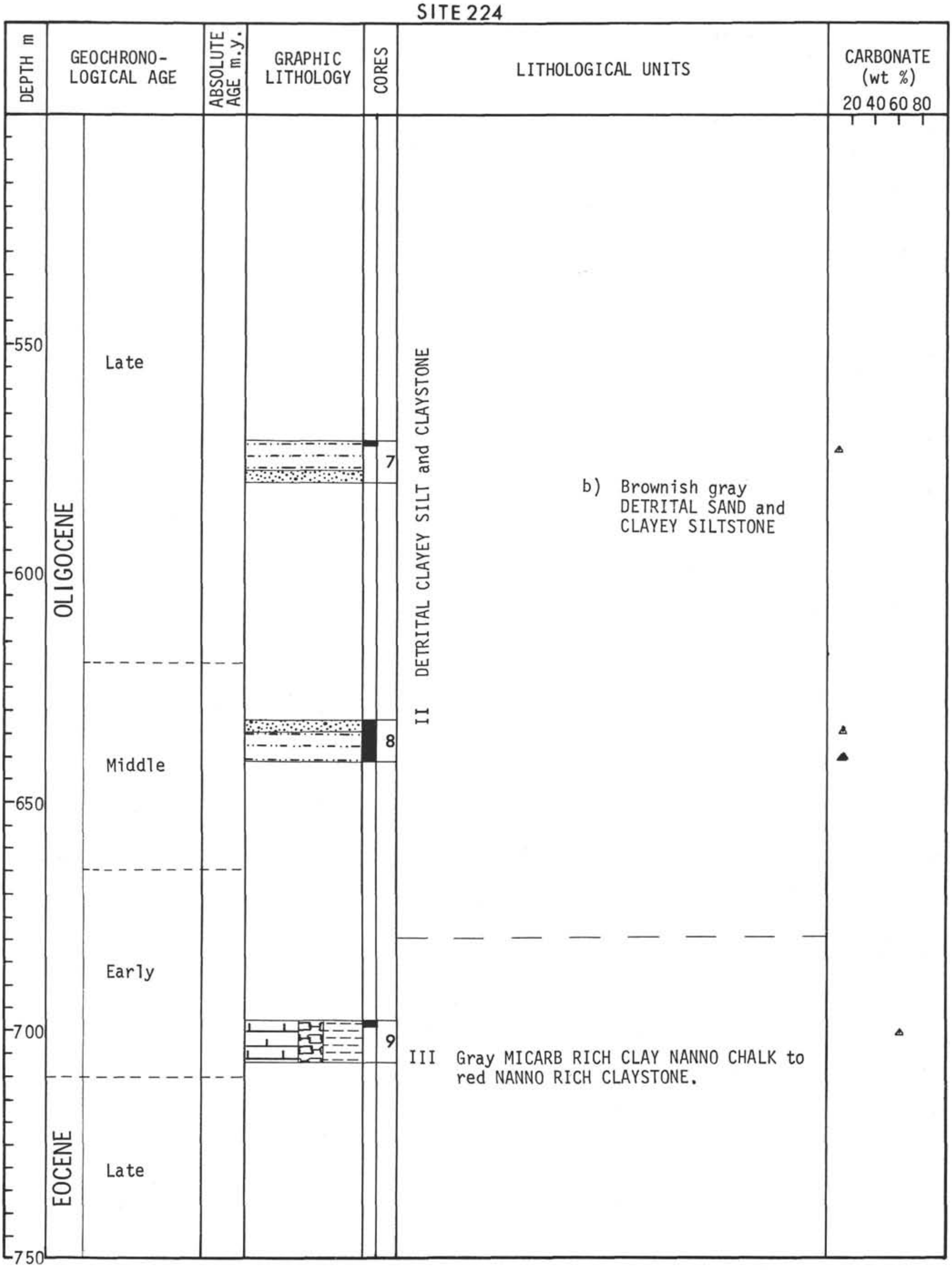
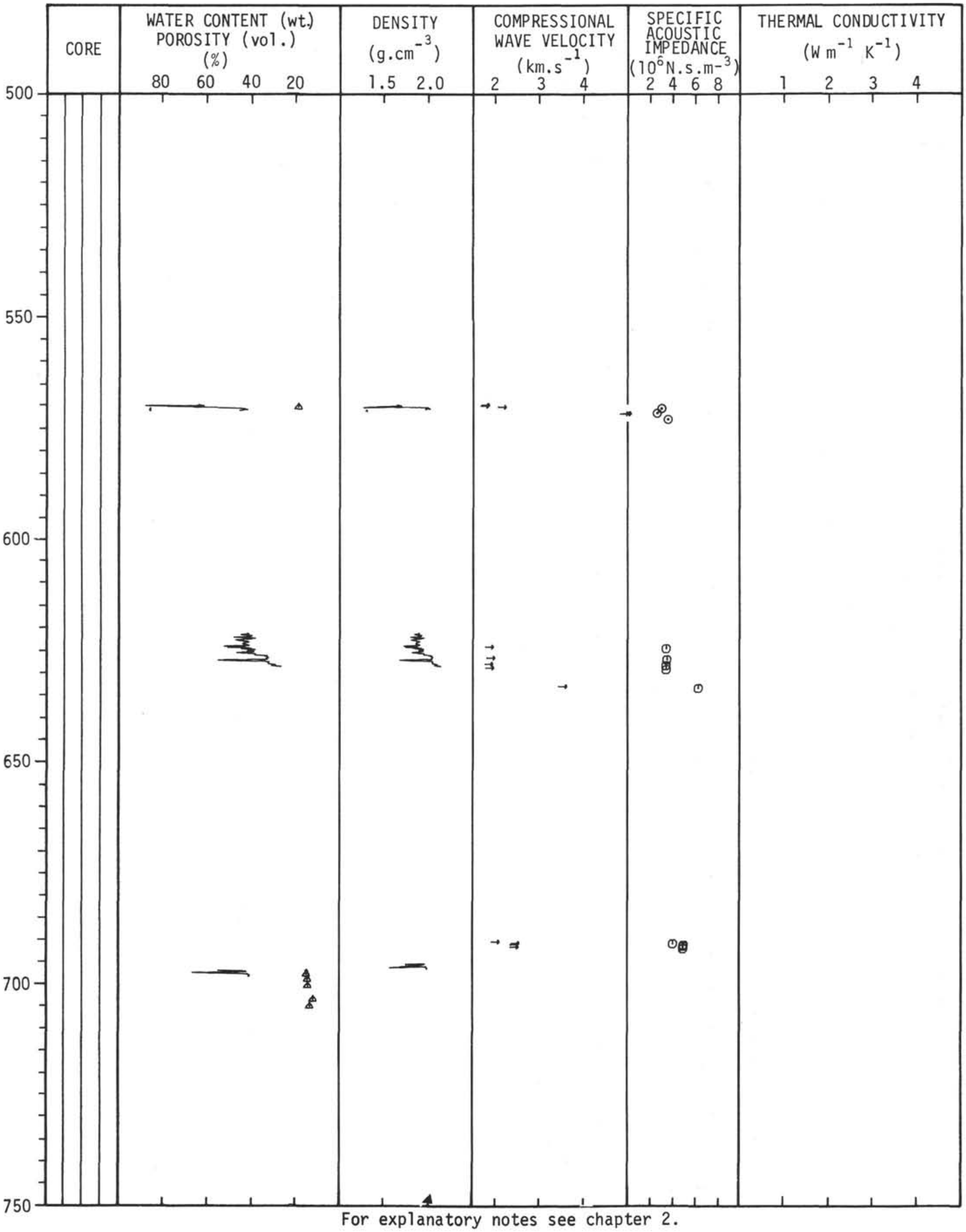

SITE 224
DEPTH m
GEOCHRONO-LOGICAL AGE
ABSOLUTE AGE m.y.
GRAPHIC LITHOLOGY
CORES
LITHOLOGICAL UNITS
CARBONATE (wt %)
20 40 60 80
550
600
650
700
750
OLIGOCENE
Late
Middle
Early
EOCENE
Late
7
8
9
II DETRITAL CLAYEY SILT and CLAYSTONE
b) Brownish gray DETRITAL SAND and CLAYEY SILTSTONE
III Gray MICARB RICH CLAY NANNO CHALK to red NANNO RICH CLAYSTONE.



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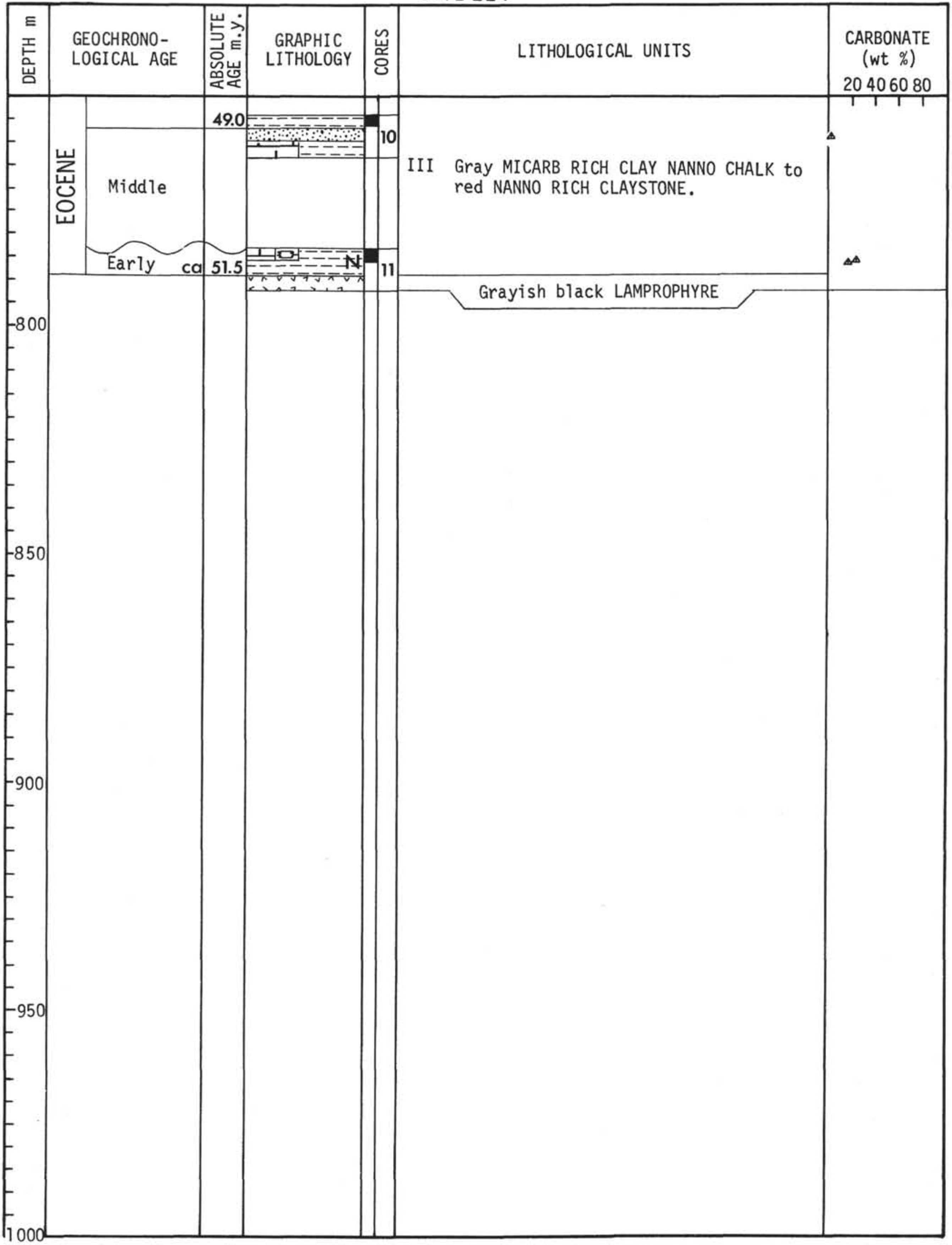
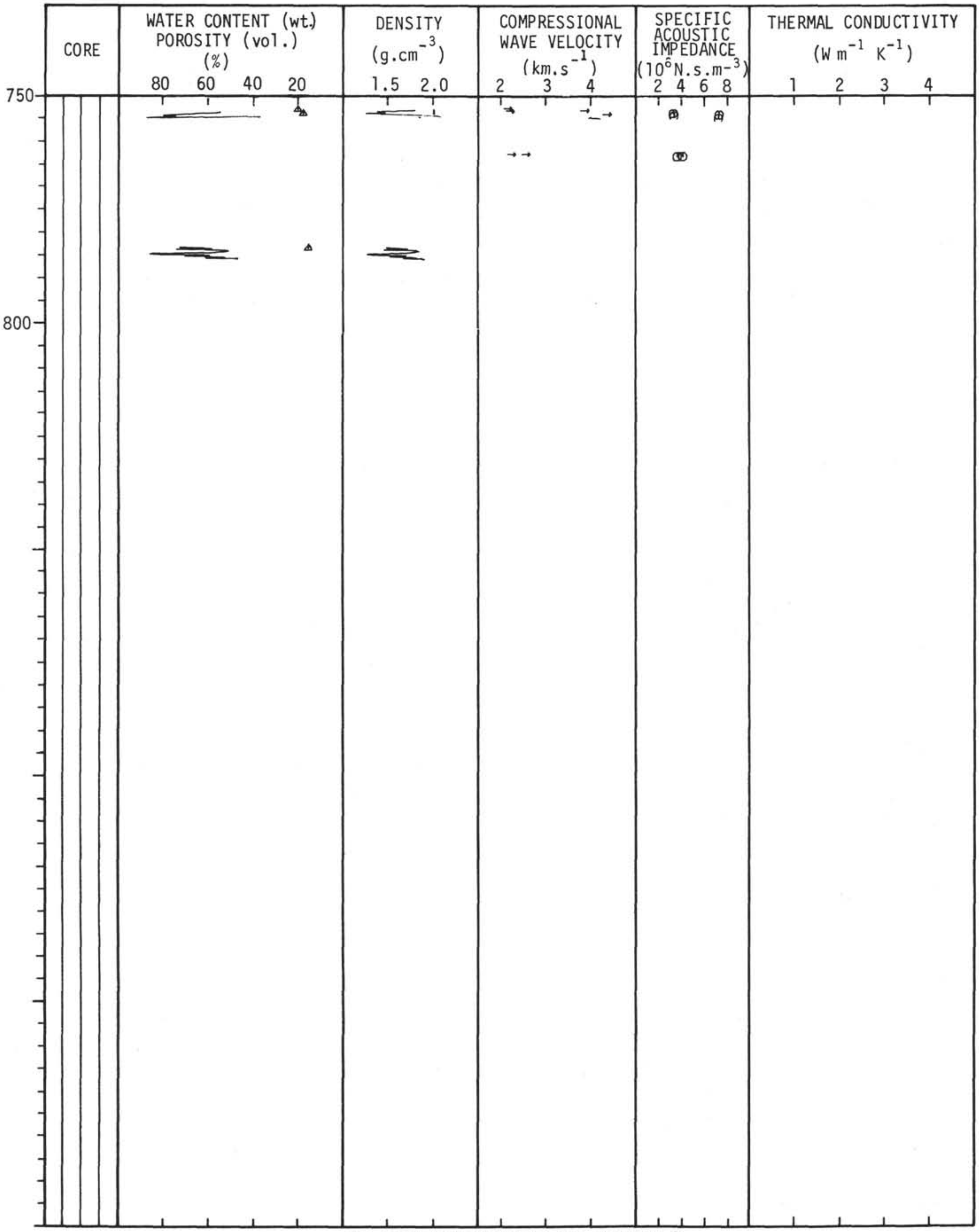
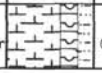

DEPTH m
GEOCHRONO-LOGICAL AGE
ABSOLUTE AGE m.y.
GRAPHIC LITHOLOGY
CORES
LITHOLOGICAL UNITS
CARBONATE (wt %)
20 40 60 80
EOCENE
Middle
Early
49.0
ca 51.5
10
11
III Gray MICARB RICH CLAY NANNO CHALK to red NANNO RICH CLAYSTONE.
Grayish black LAMPROPHYRE
800
850
900
950
1000



For explanatory notes see chapter 2.

Site 224 Hole Core 1 Cored Interval: 0-9

AGE	ZONE F	ZONE N	ZONE R	FOSSIL CHARACTER FORAMS	FOSSIL CHARACTER NANNOS	FOSSIL CHARACTER RADS	FOSSIL CHARACTER OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO.SAMPLE	LITHOLOGIC DESCRIPTION
LATE PLEISTOCENE	N.22	Gephyrocapsa oceanica ?	Unzoned	Common, well preserved	Abundant and well preserved	Common and well preserved		Core Catcher				CC	1



Olive DIATOM DETRITAL SILTY CLAY RICH NANNO OOZE.

Dominant lithology SS: core catcher DIATOM DETRITAL SILTY CLAY RICH NANNO OOZE

Composition:

Nannos	50%
Detrital minerals	25%
Diatoms	20%
Spicules	2%
Radiolarians	Trace
Forams	Trace

Two-thirds of the detrital material is carbonate. Some pyrite replacement of diatoms was noted.

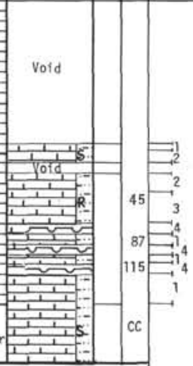
Color legend:

1 =	pale olive	10Y 6/2

Explanatory notes in chapter 2

Site 224 Hole Core 2 Cored Interval: 94-103

AGE	ZONE F	ZONE N	ZONE R	FOSSIL CHARACTER FORAMS	FOSSIL CHARACTER NANNOS	FOSSIL CHARACTER RADS	FOSSIL CHARACTER OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO.SAMPLE
LATE MIOCENE		Discoaster calcaris	Ommatartus antepenultimus	Rare to absent	Abundant and well preserved	Common and well preserved		1	0.5 1.0	Void		
								2		Void		45 87 115
								Core Catcher				CC



Olive to gray DETRITAL CLAYEY SILT RICH NANNO CHALK and DETRITAL CLAYEY SILT NANNO RICH DIATOMITE.

Latter as alternating bands 10-40 cm thick. Sediments are semilithified, slight to moderate mottling, no significant deformation.

Dominant lithology SS: Sec. 2-45 cm DETRITAL CLAYEY SILT RICH NANNO CHALK

Composition:

Nannos	70%
Detrital minerals	15%
Rads	5%
Spicules	5%
Diatoms	5%

Color legend:

1 =	light green gray	5G 8/1
2 =	pale olive	10Y 6/2
3 =	gray yellow green	5GY 7/2
4 =	gray olive	10Y 4/2

Shore-based laboratory results

Carbonate:

Sec. 2-37 cm = 64%

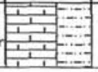
Sec. 2-61 cm = 70%

X-ray mineralogy (R): Sec. 2-57 cm

Calcite	54%
Dolomite	30%
Quartz	6%
Plagioclase	3%
Mica	3%
Palygorskite	3%
Chlorite	1%

Site 224 Hole Core 3 Cored Interval: 250-259

AGE	ZONE F	ZONE N	ZONE R	FOSSIL CHARACTER FORAMS	FOSSIL CHARACTER NANNOS	FOSSIL CHARACTER RADS	FOSSIL CHARACTER OTHERS	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO.SAMPLE	LITHOLOGIC DESCRIPTION
MIDDLE MIOCENE		Discoaster kugleri		Absent	Common and well preserved	Absent		Core Catcher			CC		1



Brown DETRITAL SILTY CLAY NANNO CHALK

Dominant lithology SS: core catcher DETRITAL SILTY CLAY NANNO CHALK

Composition:

Nannos	60%
Detrital minerals	40%
Forams	Trace

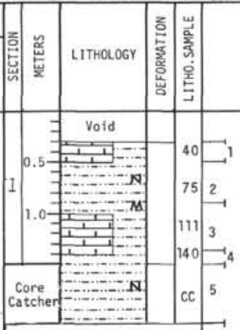
Color legend:

1 =	pale yellow brown	10YR 6/2

Explanatory notes in chapter 2

Site 224 Hole Core 4 Cored Interval: 259-268

AGE	ZONE F N R	FOSSIL CHARACTER FORAMS	NANNOS	RADS	OTHERS
EARLY MIOCENE	Triquetrorhabdulus carinatus	Absent	Abundant and well preserved Absent in c.c.	Absent	



LITHOLOGIC DESCRIPTION

Brown to gray DETRITAL SILTY CLAY NANNO CHALK and DETRITAL CLAYSTONE.

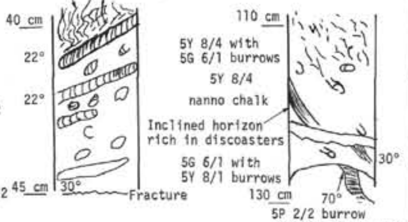
The latter occur in 40 cm thick alternating beds. The sediments are semilithified, moderately mottled and moderately disturbed. Some portions show burrowing 40-45 cm, 110-130 cm (see below). Burrows dip at about 25°. Lowest part of the section shows slight lamination and streaks of pyrite.

Dominant lithology SS: Sec. 1-40 cm
DETRITAL CLAYEY SILT NANNO CHALK
Composition:

Nannos	60%
Detrital minerals	40%

Color legend:

1 =	pale yellow brown	10YR 6/2
2 =	dark yellow brown	10YR 4/2
3 =	medium light gray	N6
4 =	brown gray	5YR 4/1
5 =	olive gray	5Y 4/1



Melange of burrowed and slumped material in browns - 10YR 7/4, 10YR 5/4 and 5YR 4/4

Brown silt/chalk 5YR 4/4 with light 10YR 7/4 inclined burrows and 5BY 7/2 speckles

Pale blue-green 5BY 7/2 inclined horizon with 5BG 2/2 burrows above

Fracture

5Y 8/4 with 5G 6/1 burrows

5Y 8/4 nanno chalk

Inclined horizon rich in discoasters

5G 6/1 with 5Y 8/1 burrows

5P 2/2 burrow rich in discoasters

Shore-based laboratory results

Carbonate:
Sec. 1-62 cm = 2%

X-ray mineralogy: Sec. 1-64 cm (WHOI)

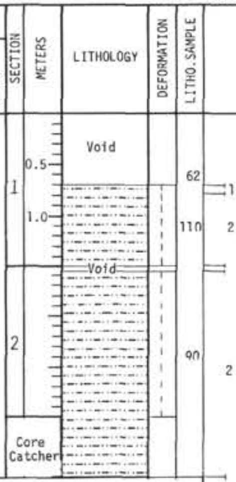
Quartz	14%
Layer silicate	80%
Plagioclase	6%

Grain size: Sec. 1-64 cm

Sand	0%
Silt	18%
Clay	82%

Site 224 Hole Core 5 Cored Interval: 350-359

AGE	ZONE F N R	FOSSIL CHARACTER FORAMS	NANNOS	RADS	OTHERS
		Absent	Absent	Absent	



LITHOLOGIC DESCRIPTION

Gray DETRITAL CLAYEY SILTSTONE.

Homogenous, semilithified, finely laminated (0.1 cm). In section 2 between 113-115 cm cross-laminated. Slight deformation.

Dominant lithology SS: Sec. 1-74 cm
DETRITAL CLAYEY SILTSTONE
Composition:
Detrital minerals 100%

Color legend:

1 =	green gray	5G 6/1
2 =	brown gray	5YR 4/1

Shore-based laboratory results

Carbonate:
Sec. 2-75 cm = 14%

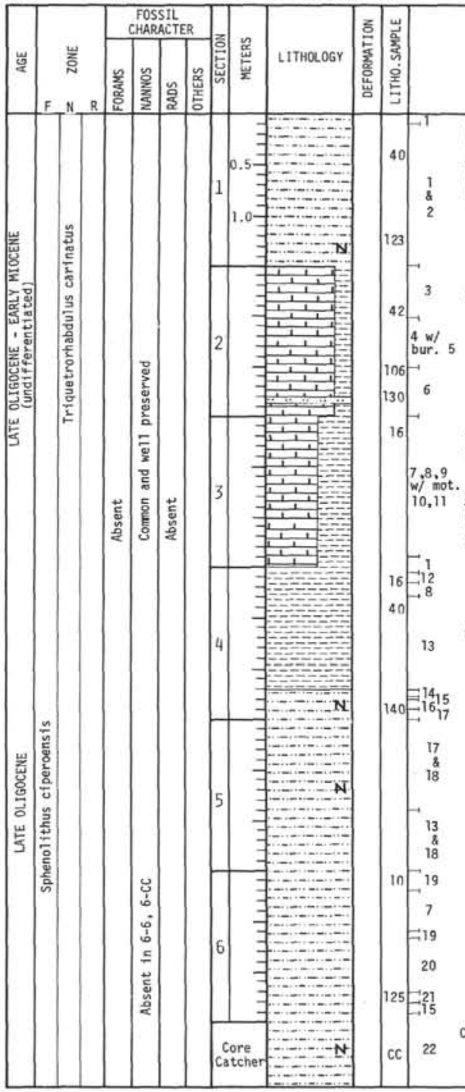
X-ray mineralogy: Sec. 2-75 cm

Calcite	12%
Quartz	39%
K feldspar	2%
Plagioclase	12%
Dolomite	2%
Mica	27%
Chlorite	6%

Grain size: Sec. 2-75 cm

Sand	0%
Silt	72%
Clay	28%

Site 224 Hole Core 6 Cored Interval: 453-462



LITHOLOGIC DESCRIPTION

Gray DETRITAL CLAYSTONE to DETRITAL SILTY CLAYSTONE interbedded with DETRITAL CLAY RICH NANNO CHALK.

Semilithified, moderately mottled and burrowed. Laminated in silt rich portions. In section 5 (121-125 cm) faulting and slump structures occur (see below). Burrowing is parallel to bedding.

Dominant lithology SS: Sec. 4-40 cm
DETRITAL CLAYSTONE
Composition:
Total detrital minerals 100%

Color legend:

1 = ol. gy.	5Y4/1	12 = pale red brn.	10R5/4
2 = ol. bl.	5Y2/1	13 = dk. red brn.	10R3/4
3 = gy. ol.	10Y4/2	14 = pale bl.	5PB7/2
4 = pale gn.	10G6/2	15 = med. gy.	N5
5 = lt. ol. gn.	5Y5/2	16 = pale brn.	5YR5/2
6 = mod. brn.	5YR3/4	17 = gy. red	5R4/2
7 = dk. yl. brn.	10YR4/2	18 = gy. yl. gn.	5GY7/2
8 = pale yl. brn.	10YR6/2	19 = lt. brn. gy.	5YR6/1
9 = mod. brn.	5YR4/4	20 = gy. blk.	5GY2/1
10 = lt. gn. gy.	5G8/1	21 = gn. gy.	5G6/1
11 = pale bl. gn.	5BG7/2	22 = med. bl. gy.	5B5/1

Shore-based laboratory results

Carbonate: Sec. 1-9 cm = 11% Sec. 4-42 cm 2%

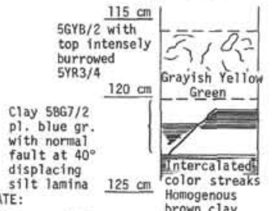
X-ray mineralogy:	Sec. 1-9 cm (WHOI)	Sec. 4-42 cm(WHOI)
Quartz	16%	13%
Plagioclase	12%	4%
Layer silicate	62%	81%
Calcite	10%	0%
Microcline	0%	2%

Grain size:	Sec. 1-9 cm	Sec. 4-42 cm
Sand	0%	0%
Silt	25%	18%
Clay	75%	82%

*Zero section 0 to 60 cm. Gray DETRITAL CLAYSTONE semilithified to lithified, laminated locally graded. Interbedded with silty sand layers.

*Represents extra interval at top of core

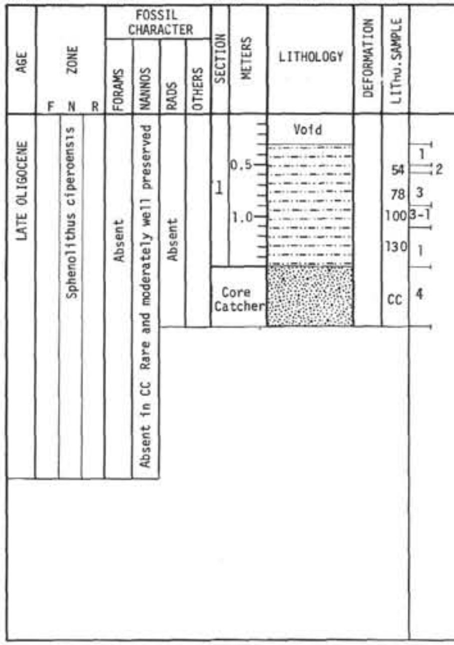
Section 5



CARBONATE:
6-1-9 cm = 11%
6-4-42 cm = 2%

Explanatory notes in chapter 2

Site 224 Hole Core 7 Cored Interval: 571-580



LITHOLOGIC DESCRIPTION

Gray DETRITAL SILTY CLAYSTONE

Semilithified, thinly bedded with burrow mottling between 90-110 cm. Burrows are of elliptical shape mostly parallel to bedding, little deformation except between 55-75 cm.

Dominant lithology SS: Sec. 1-130 cm
DETRITAL SILTY CLAYSTONE
Composition:
Detrital minerals 100%

Color legend:
1 = brown gray 5YR 4/1
2 = green gray 5Y 6/1
3 = dark green gray 5GY 4/1
4 = brown gray 5YR 2/1

Shore-based laboratory results

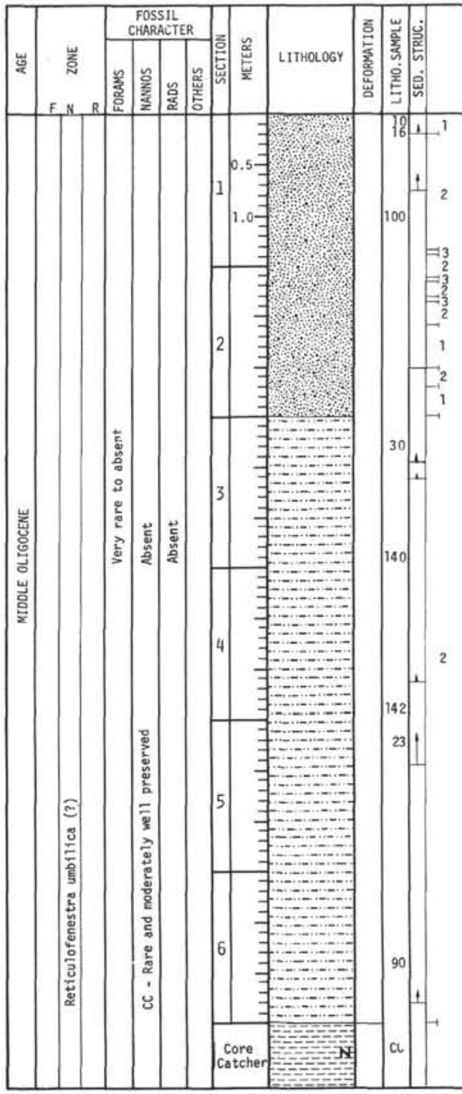
Carbonate: Sec. 1-48 cm = 9%

X-ray mineralogy:	Sec. 1-48 cm (WHOI)
Quartz	18%
Plagioclase	10%
Layer silicate	66%
Calcite	6%

Grain size:	Sec. 1-48 cm
Sand	0%
Silt	37%
Clay	63%

Explanatory notes in chapter 2

Site 224 Hole Core 8 Cored Interval: 632-641



LITHOLOGIC DESCRIPTION

Gray DETRITAL SANDY to CLAYEY SILTSTONE with graded SILT and SAND beds.

These have sharp lower and diffuse upper contact. Semilithified, homogenous, undisturbed finely laminated, some portions show cross-lamination. Dips 2-10°.

Dominant lithology SS: Section 1-10 cm
CARBONATE RICH DETRITAL SILTY CLAY
Composition:

Detrital minerals	88%
Carbonate	12%

Color legend:
1 = olive gray 5Y 4/1
2 = brown gray 5YR 4/1
3 = medium dark gray N4

Shore-based laboratory results

Carbonate: Sections 1-70 cm = 12%, 5-18 cm = 12%, 5-32 cm = 13%, 5-45 cm = 12%, 5-52 cm = 10%.

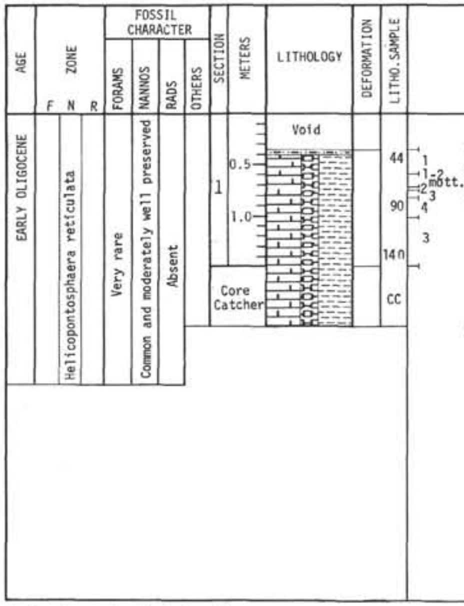
X-ray mineralogy:	Sections 1-70 cm(WHOI),	5-6 cm,	5-32 cm
Calcite	0%	10%	10%
Quartz	36%	27%	27%
Plagiocalse	14%	6%	6%
Layer silicate	38%	0%	0%
Calcite	12%	0%	0%
Dolomite	0%	2%	2%
K-feldspar	0%	2%	3%
Mica	0%	42%	40%
Chlorite	0%	9%	6%
Montmorillonite	0%	2%	2%
Kaolin	0%	0%	3%

Grain size:	Sections 1-70 cm,	5-13 cm,	5-18 cm,	5-26 cm
Sand	0%	0%	6%	9%
Silt	77%	59%	68%	69%
Clay	34%	42%	26%	22%

Core catcher:
Portion of sediments show abundance of nannos (discoasters) NANNO RICH DETRITAL CLAY, others as in core.

Explanatory notes in chapter 2

Site 224 Hole Core 9 Cored Interval: 698-702



LITHOLOGIC DESCRIPTION

Gray MICARB RICH CLAY NANNO CHALK.

Semilithified to lithified, high to moderate mottling and burrowing. Lower section shows some lamination.

Dominant lithology SS: Section 1-90 cm
MICARB RICH CLAY NANNO CHALK
Composition:

Nannos	50%
Detrital clay	35%
Micarb	15%

Color legend:
1 = brown gray 5YR 4/1
2 = green gray 5G 6/1
3 = light olive gray 5Y 6/1
4 = light gray N7
trace of micarb particles is needle-like.

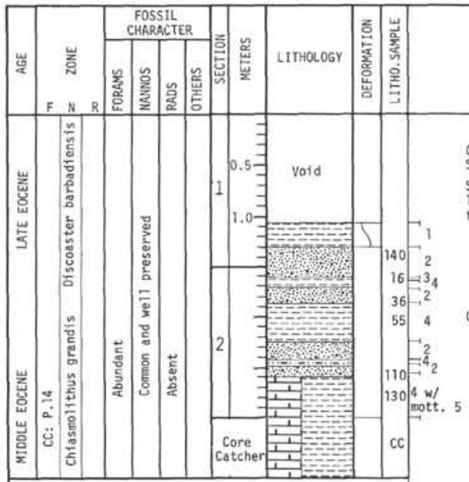
Shore-based laboratory results

Carbonate: Section 1-45 cm = 59%

X-ray mineralogy:	Section 1-45 cm
Calcite	83%
Quartz	2%
Kaolinite	1%
Montmorillonite	8%
Palygorskite	6%

Explanatory notes in chapter 2

Site 224 Hole Core 10 Cored Interval: 754-763



LITHOLOGIC DESCRIPTION

Gray or red CLAYSTONE intercalated with gray SANDSTONE, lower part of core is NANNO CLAYSTONE.

Semilithified to lithified; sandstone shows cross-lamination and clay pebbles. Very little deformation by drilling.

Dominant lithology SS: Section 2-16 cm
CLAYSTONE
Composition:

Detrital minerals	100%

Color legend:
1 = green gray 5G 6/1
2 = medium gray N5
3 = gray blue green 5BG 5/2
4 = gray red 5R 4/2
5 = pale blue 5PB 7/2

Shore-based laboratory results

Carbonate: Section 2-75 cm = 1%

X-ray mineralogy: Section 2-49 cm

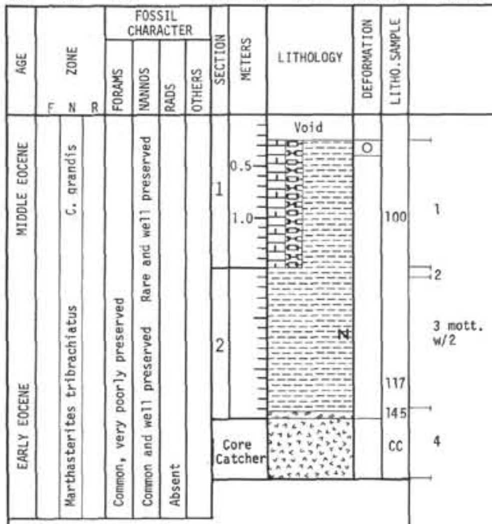
Quartz	11%
K-feldspar	9%
Plagioclase	9%
Kaolinite	10%
Mica	5%
Chlorite	2%
Montmorillonite	43%
Palygorskite	11%

Grain size: Section 2-71 cm

Sand	0%
Silt	6%
Clay	94%

Explanatory notes in chapter 2

Site 224 Hole Core 11 Cored Interval: 783-792



LITHOLOGIC DESCRIPTION

Gray NANNO MICARB RICH CLAYSTONE changing to red CLAYSTONE. BASALT in core catcher.

Semilithified to lithified, almost massive. Section 1 is spotted with fine white dots. Complex fissure pattern in sediments. In section 2 color changes from red at the bottom to green at the top, yet fissure walls are green throughout. Calcite filled veins in the basalt. VOLCANIC ASH at bottom of section 2.

Dominant lithology SS: Section 1-100 cm
NANNO MICARB RICH CLAYSTONE
Composition:

Clay	70%
Nannos	12%
Micarb	12%
Feldspar	5%
Glass	1%

Dominant lithology SS: Section 2-117 cm
CLAYSTONE
Composition:

Clay	90%
Nannos	10%

Minor lithology SS: Section 2-145 cm
CLAY RICH ASH
Composition:

Volcanic glass	87%
Clay	10%
Nannos	3%

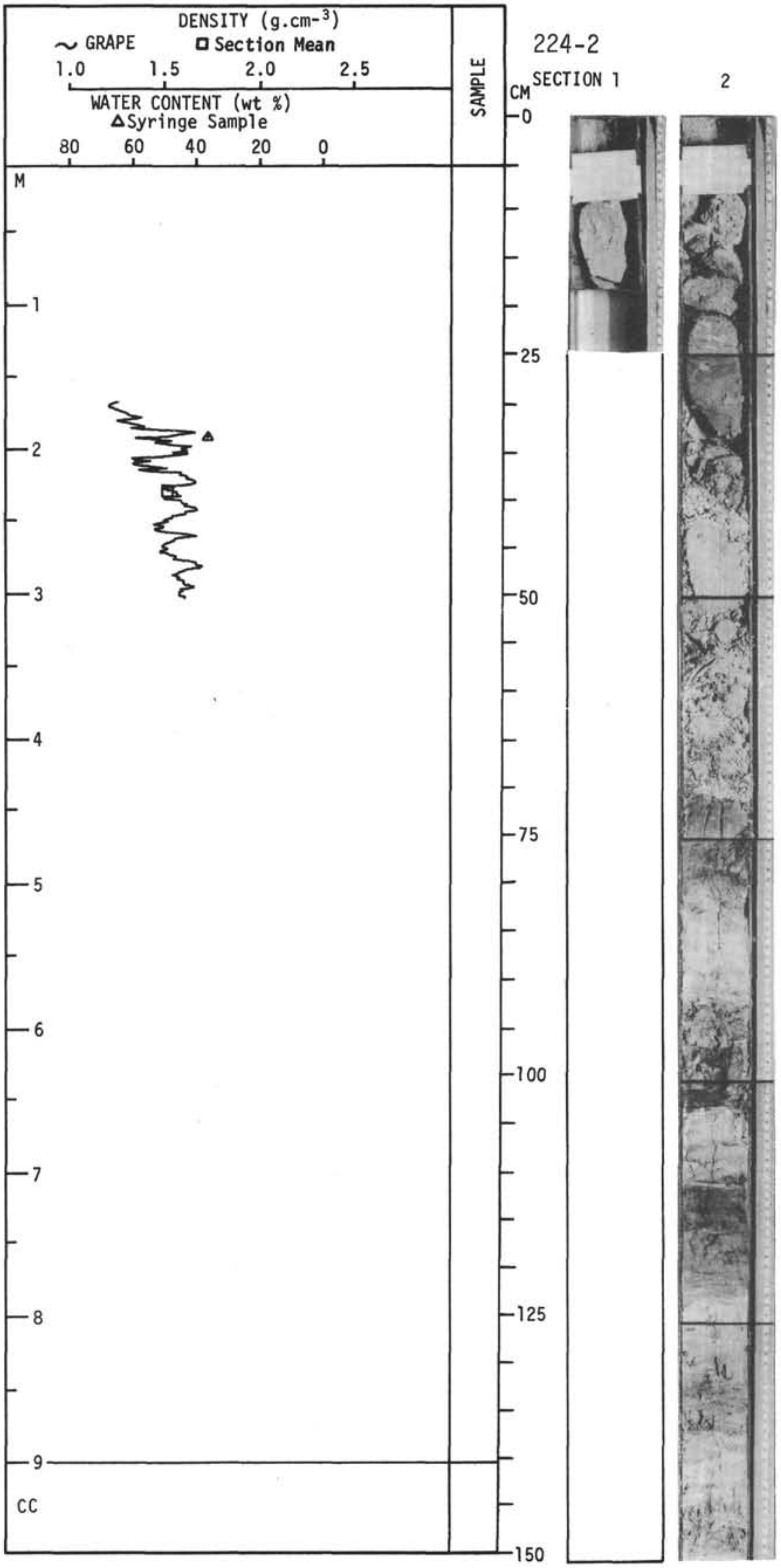
Color legend:
1 = green gray 5G 6/1
2 = pale green 10G 6/2
3 = pale red 5R 6/2
4 = gray blue N2

Shore-based laboratory results

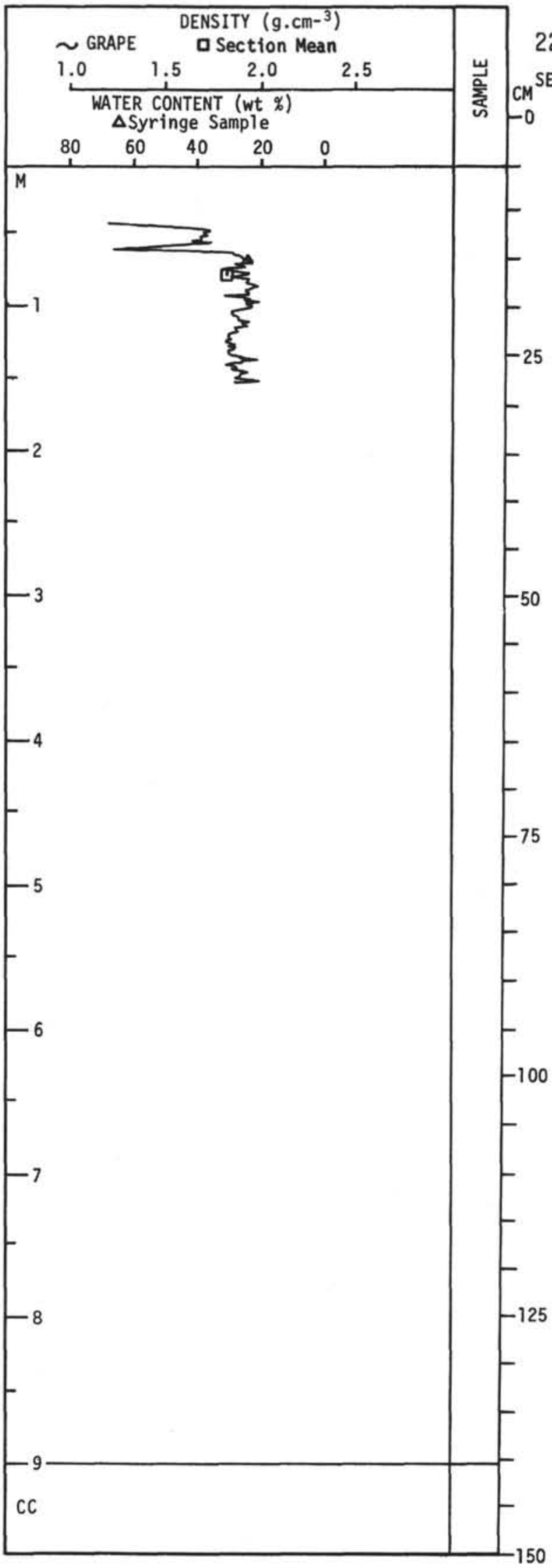
Carbonate: Sections 1-30 cm = 23%, 1-80 cm = 16%.

X-ray mineralogy:	Sections 1-30 cm,	2-44 cm,	2-145 cm
Calcite	55%	54%	25%
Quartz	6%	6%	10%
Kaolinite	8%	0%	0%
Mica	2%	1%	7%
Montmorillonite	29%	0%	41%
Palygorskite	0%	4%	17%
Cristobalite	0%	29%	0%
Tridymite	0%	5%	0%
Clinoptilolite	0%	1%	0%
	Section 1-80 cm (WHOI)		
Calcite	10%		
Palygorskite	50%		
Plagioclase	8%		
Layer silicate	32%		

Explanatory notes in chapter 2

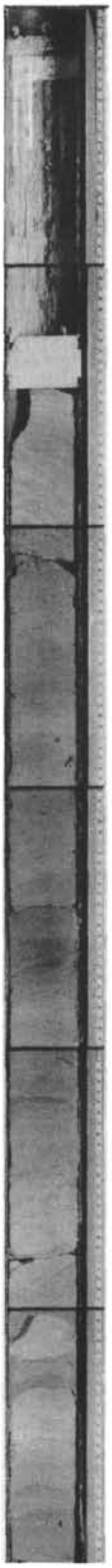


For Explanatory Notes, see Chapter 2

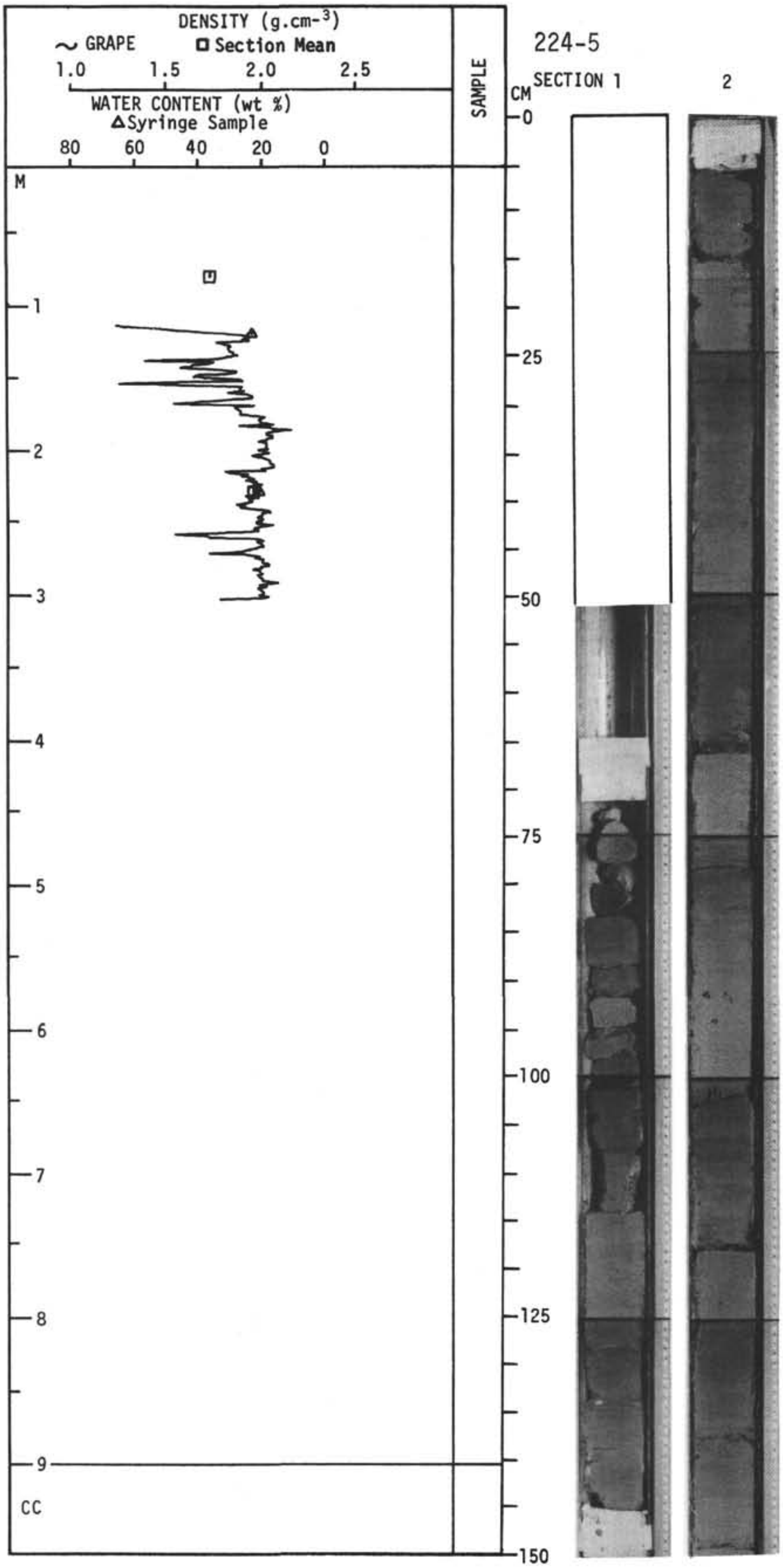


224-4

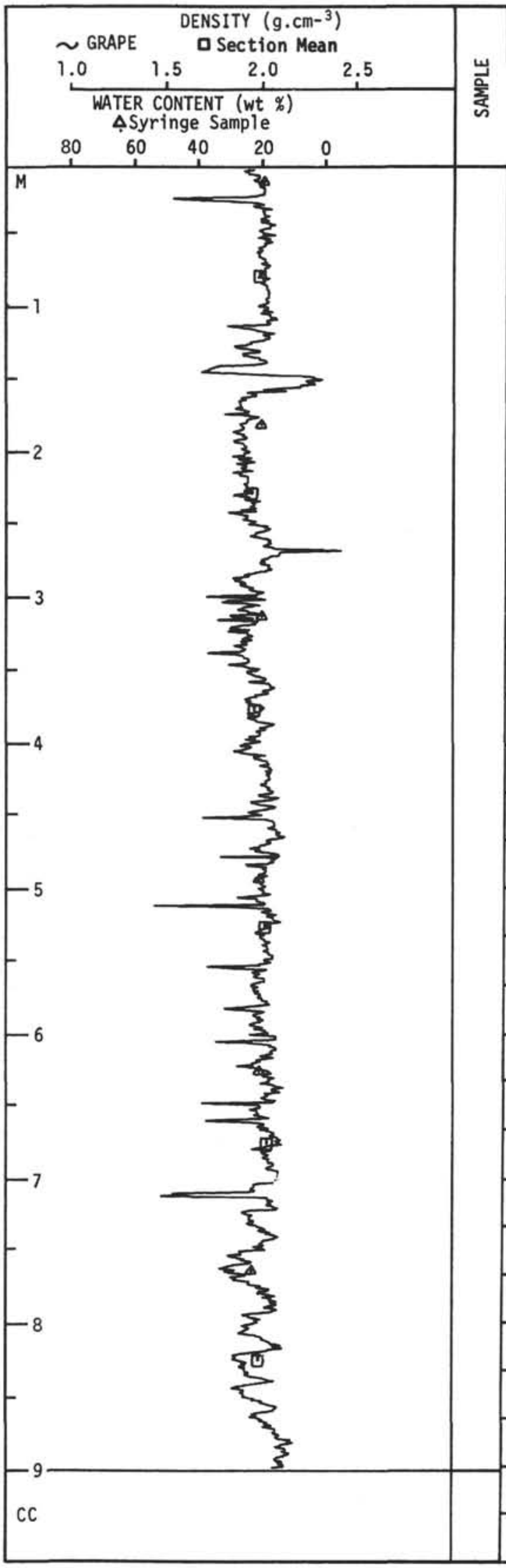
SECTION 1

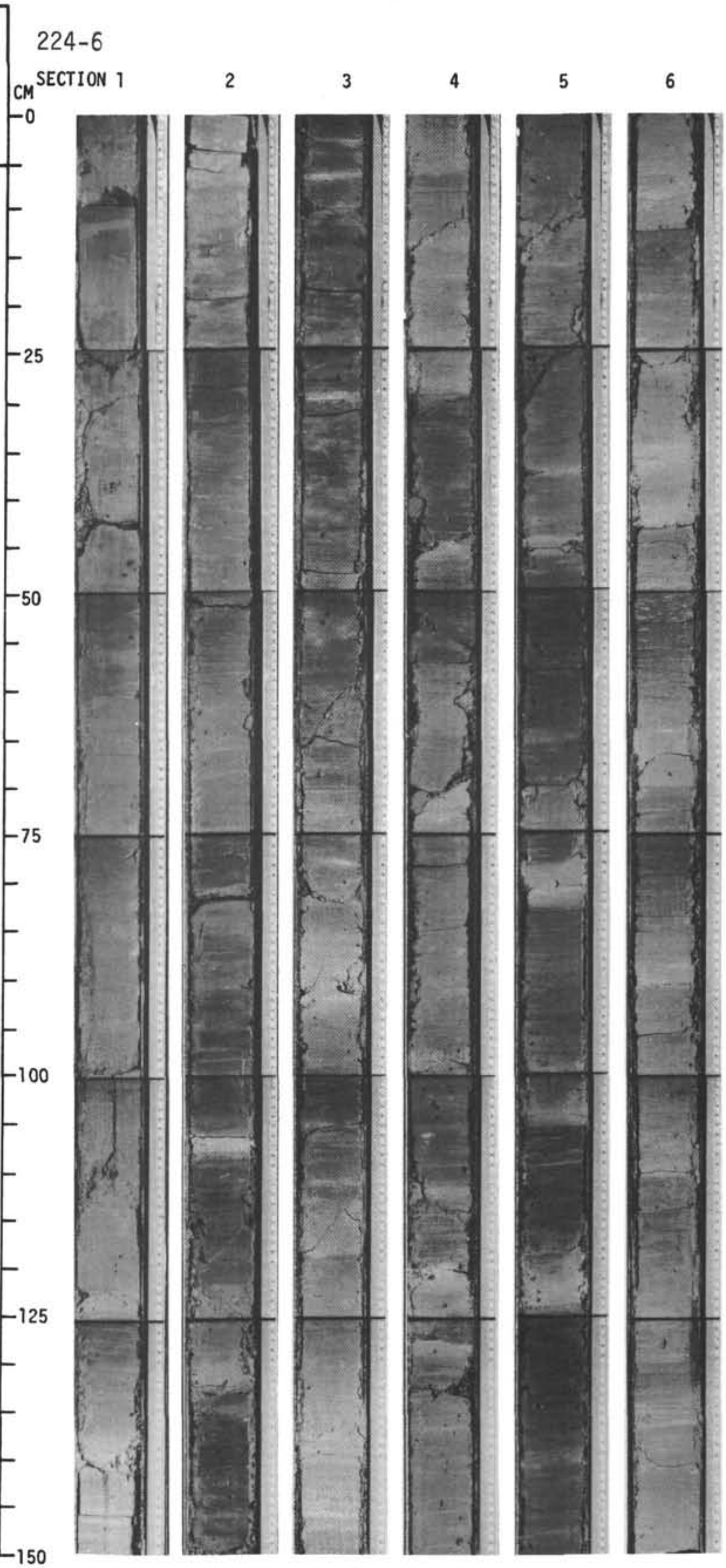


For Explanatory Notes, see Chapter 2

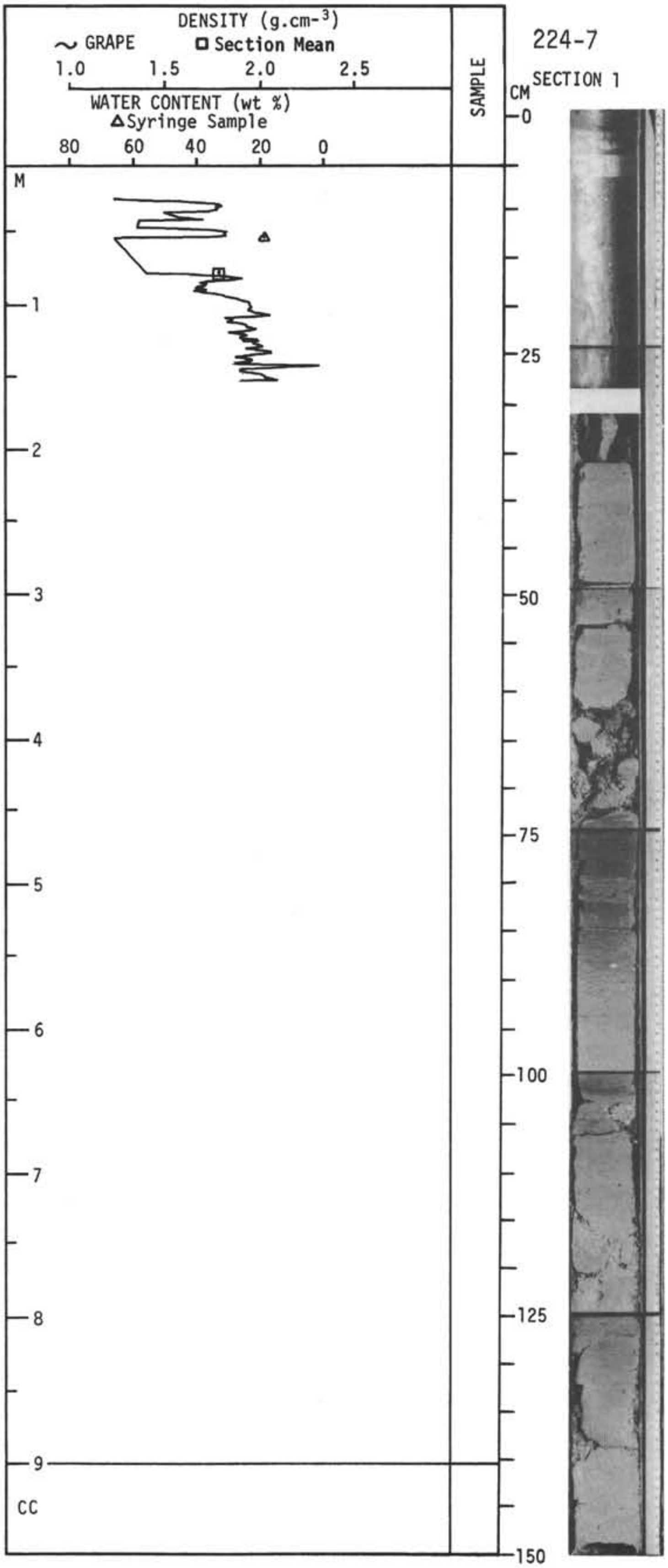


For Explanatory Notes, see Chapter 2



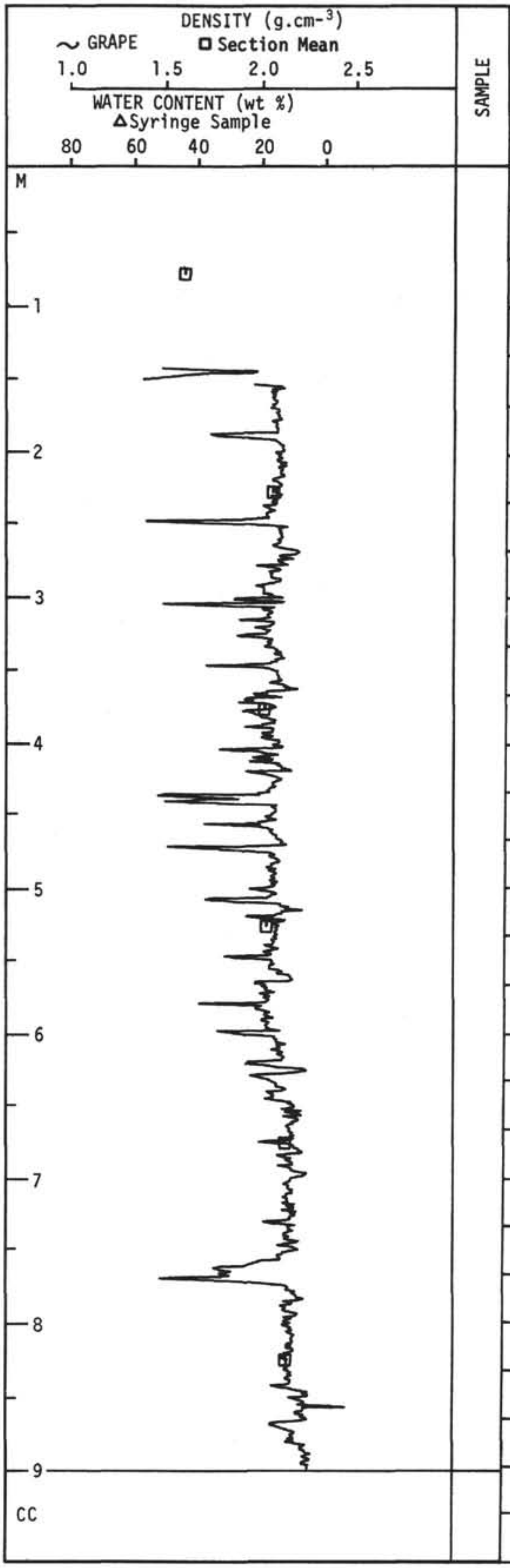


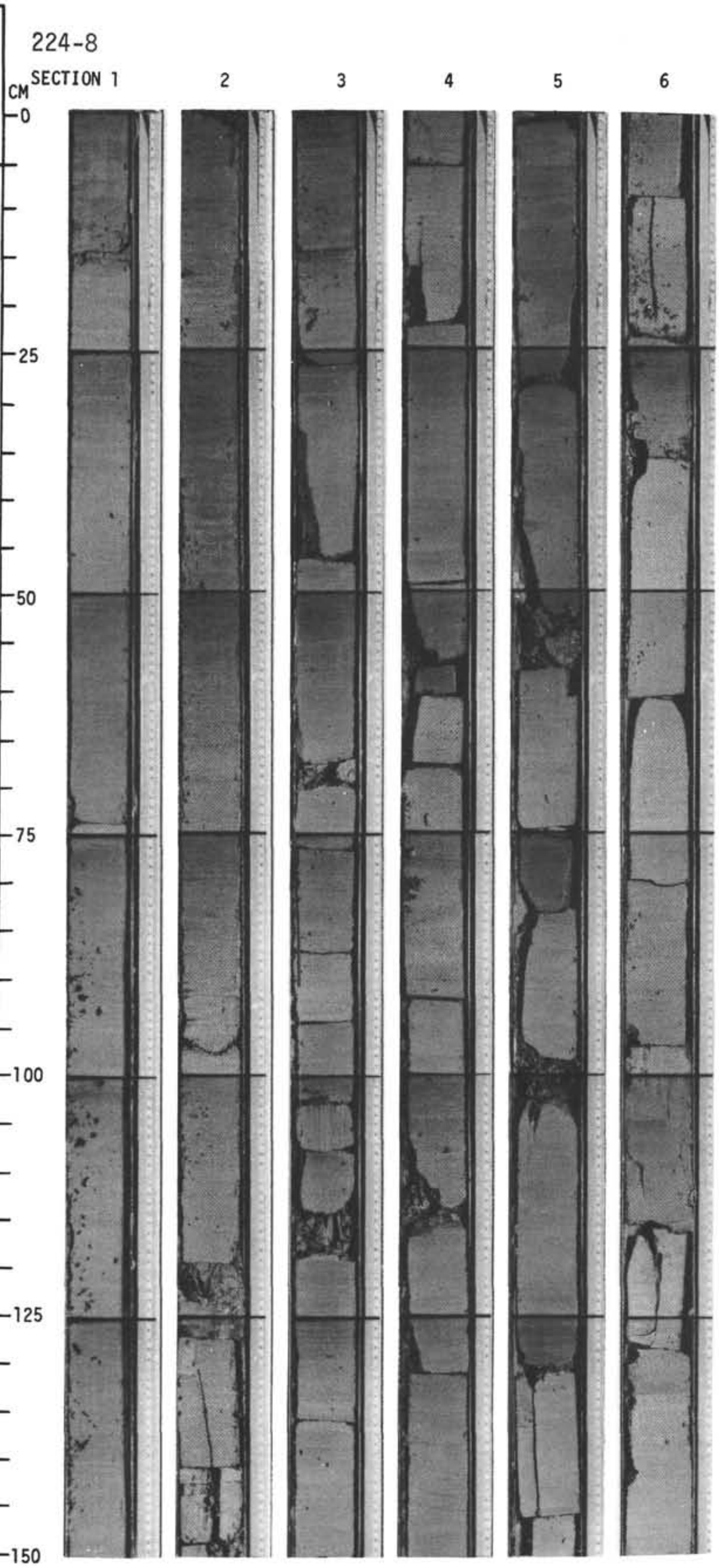
For Explanatory Notes, see Chapter 2



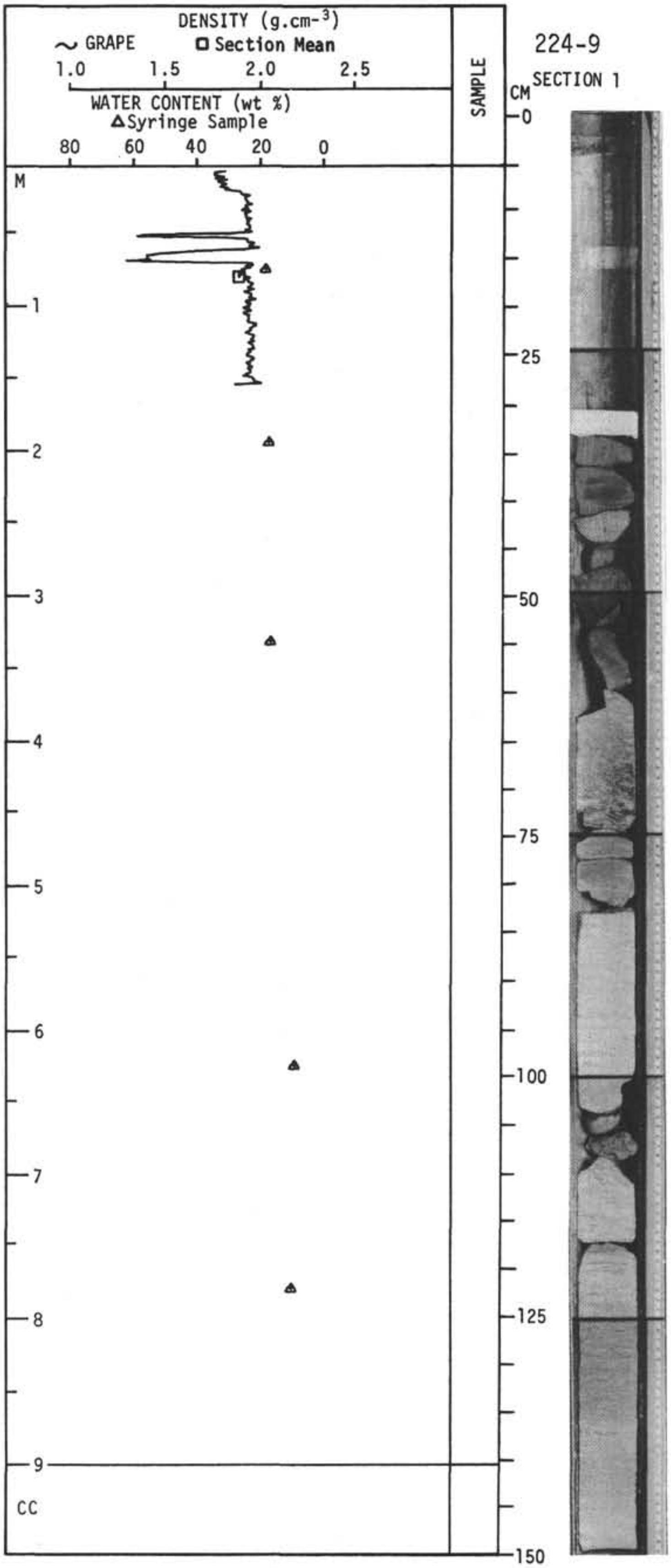
224-7

SECTION 1

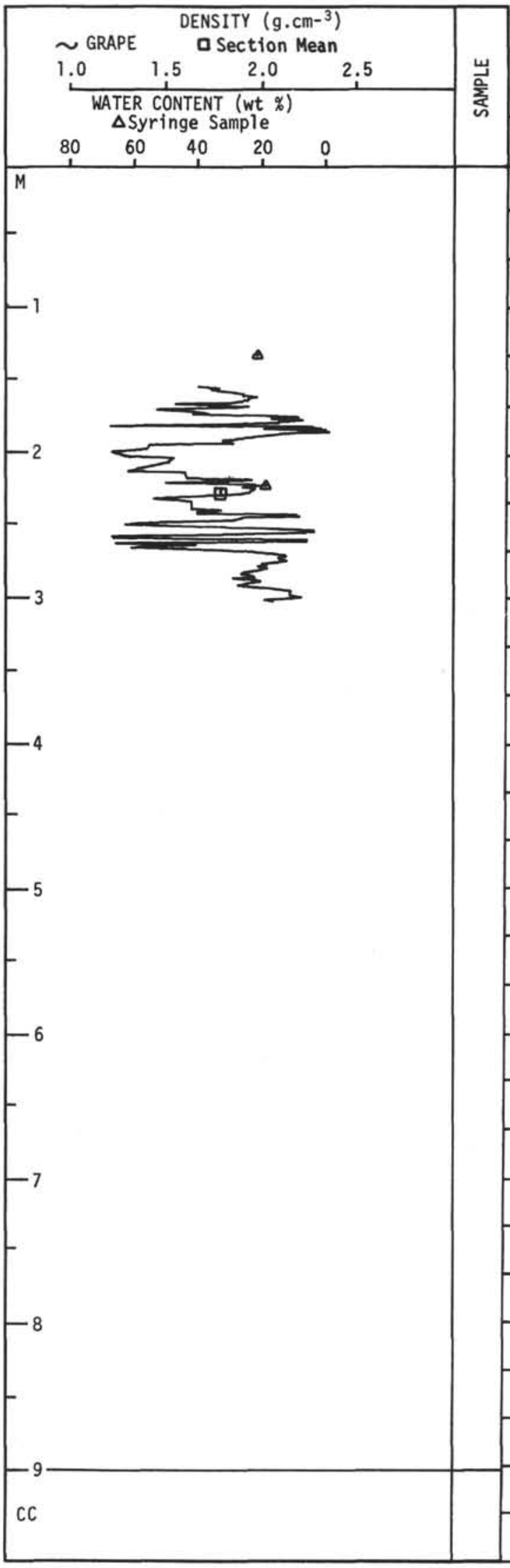


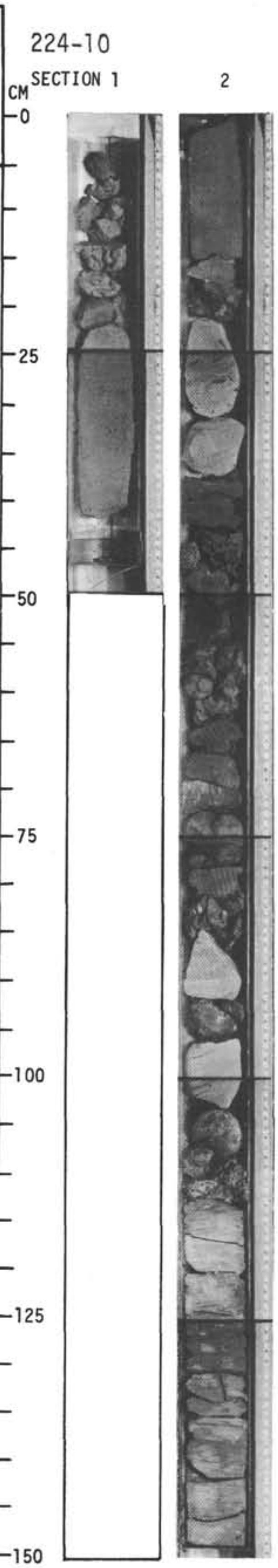


For Explanatory Notes, see Chapter 2

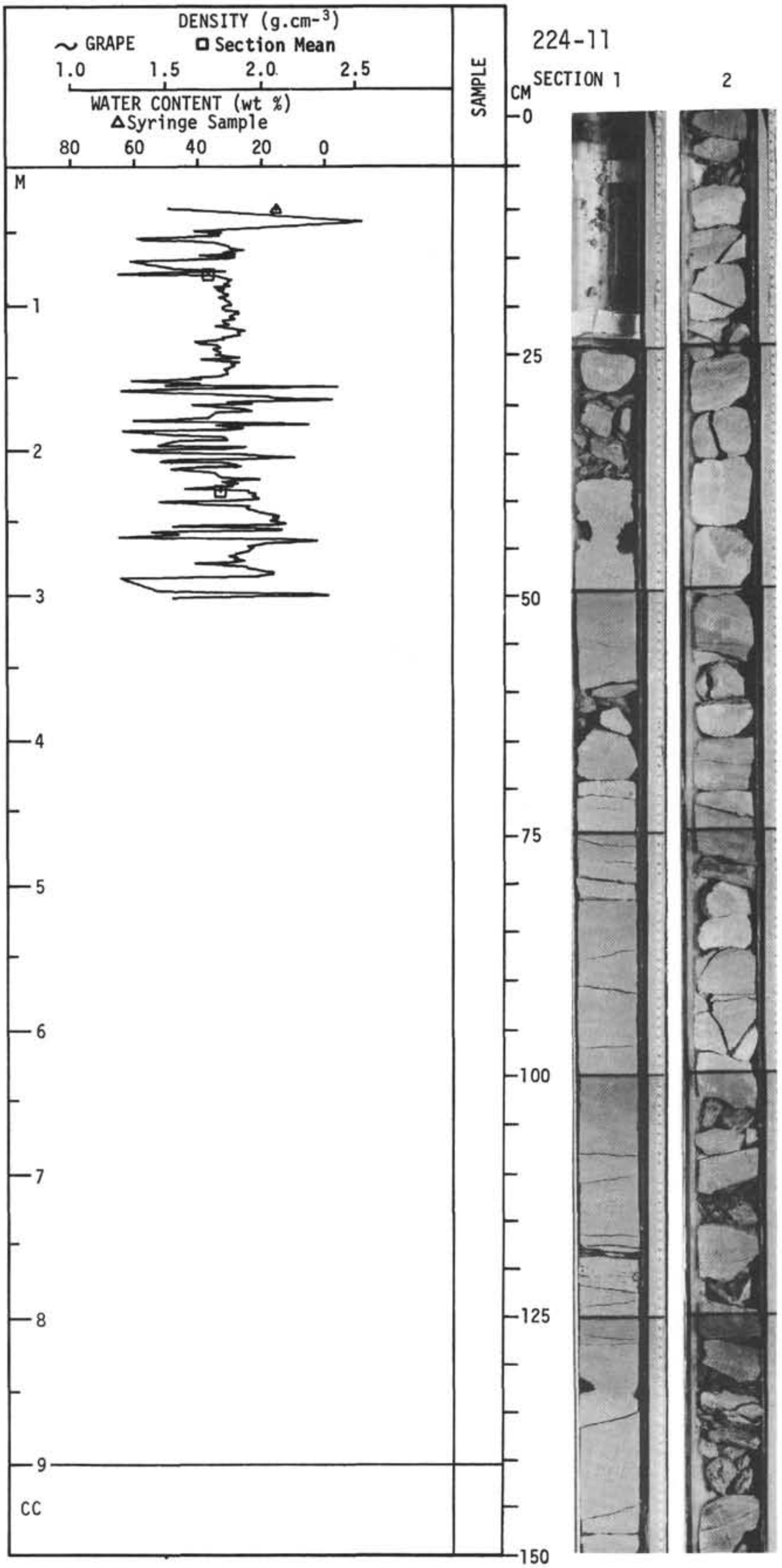


For Explanatory Notes, see Chapter 2





For Explanatory Notes, see Chapter 2



For Explanatory Notes, see Chapter 2