8. SITE 177

The Shipboard Scientific Party[1]

ABSTRACT

Site 177 was drilled through a probable fault zone on a structural bench at the northwestern end of Paul Revere Ridge. Seven Pleistocene to lower Pliocene lithologic units occur in Holes 177 and 177A. In general, the upper 190 meters consist of lower Pleistocene sand and silt turbidites which grade into silty clay near the top. An upper Pliocene clayey silt nannofossil ooze is present from 190 to 222 meters. A tholeiitic basalt sill (378 to 383 m) separates an overlying thick section of lower Pliocene graded sand and silt turbidites (222 to 378 m) from an underlying nannofossil ooze and silty clay (383 to 451 m). A lower Pliocene massive sandstone, with an average porosity of 31 percent, was recovered from the top of the interval from 451 to 507 meters. These sediments probably represent deposition on a submarine fan, which was constructed on oceanic crust. As Paul Revere Ridge was uplifted during the late Pliocene to early Pleistocene, turbidity current deposition produced an onlapping sedimentary wedge in an elongate trough between the continent and the ridge.

SITE SUMMARY

Date Occupied: 23-27 June 1971.

Position (Satellite):
Latitude: 50°28.18′ N;
Longitude: 130°12.30′ W.

Number of Holes: Two (Holes 177 & 177A).

Water Depth: 2006 meters below sea level.

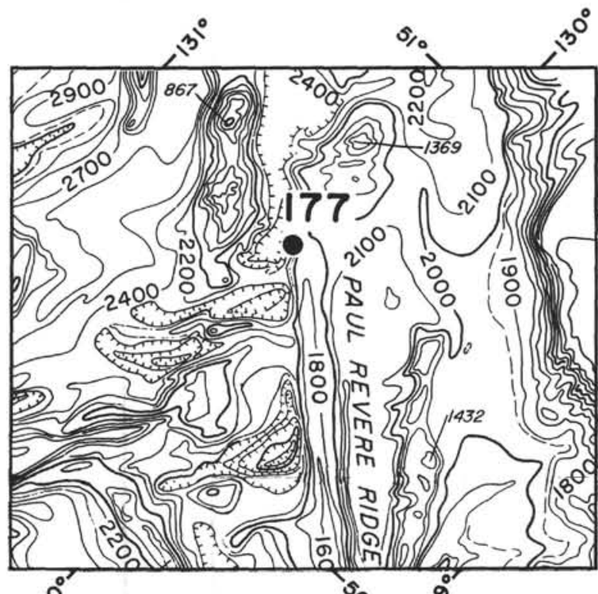
Penetration: 507 meters below sea floor..

Number of Cores:
Hole 177: One.
Hole 177A: 26.

Total Core Recovered:
Hole 177: (9 meters - 100%).
Hole 177A: (136.5 meters - 58.5%).

Age of Oldest Sediment: Early Pliocene.

Acoustic Basement: Depth calculated at 520 meters.



BACKGROUND AND OBJECTIVES

Site Description

Paul Revere Ridge is a long linear topographic ridge that parallels the continental slope near the northwest tip of Vancouver Island (Figure 1 and 2). It is about 130 km long and extends from lat 49°50′ N.; long 129°00′ W. to lat 50°30′N; long 130°15′ W. Water depths are as shallow as 1600 meters near the ridge crest. Paul Revere Ridge truncates the ridge and valley topography of Explorer Ridge to the southwest, forming a complex juncture with, probably, a spreading ridge. The triple junction of the Pacific, American, and Juan de Fuca plates apparently is located near the ridge, which adds to the tectonic complexity of the region.

Seismic reflection profiles made perpendicular to Paul Revere Ridge show that it forms the seaward boundary of a sedimentary basin that extends from the base of the continental slope to the ridge (for detailed discussion, see Couch and Chase, this volume). The section is thickest near

[1]L. D. Kulm, Oregon State University, Corvallis, Oregon; R. von Huene, U. S. Geological Survey, Menlo Park, California; J. R. Duncan, ESSO Production and Reserarch Company, Houston, Texas; J. C. Ingle, Stanford University, Palo Alto, California; S. A. Kling, City Service Oil Company, Tulsa, Oklahoma; L. F. Musich, Scripps Institution of Oceanography, La Jolla, California; D. J. W. Piper, Dalhousie University, Halifax, Nova Scotia; R. M. Pratt, NOAA, Rockville, Maryland; Hans-Joachim Schrader, Geologisch Institut und Museum der Universitat Kiel, Kiel, Germany; O. Weser, Scripps Institution of Oceanography, La Jolla, California; and S. W. Wise, Jr., Geologisches Institut-Zurich, Zurich, Switzerland.

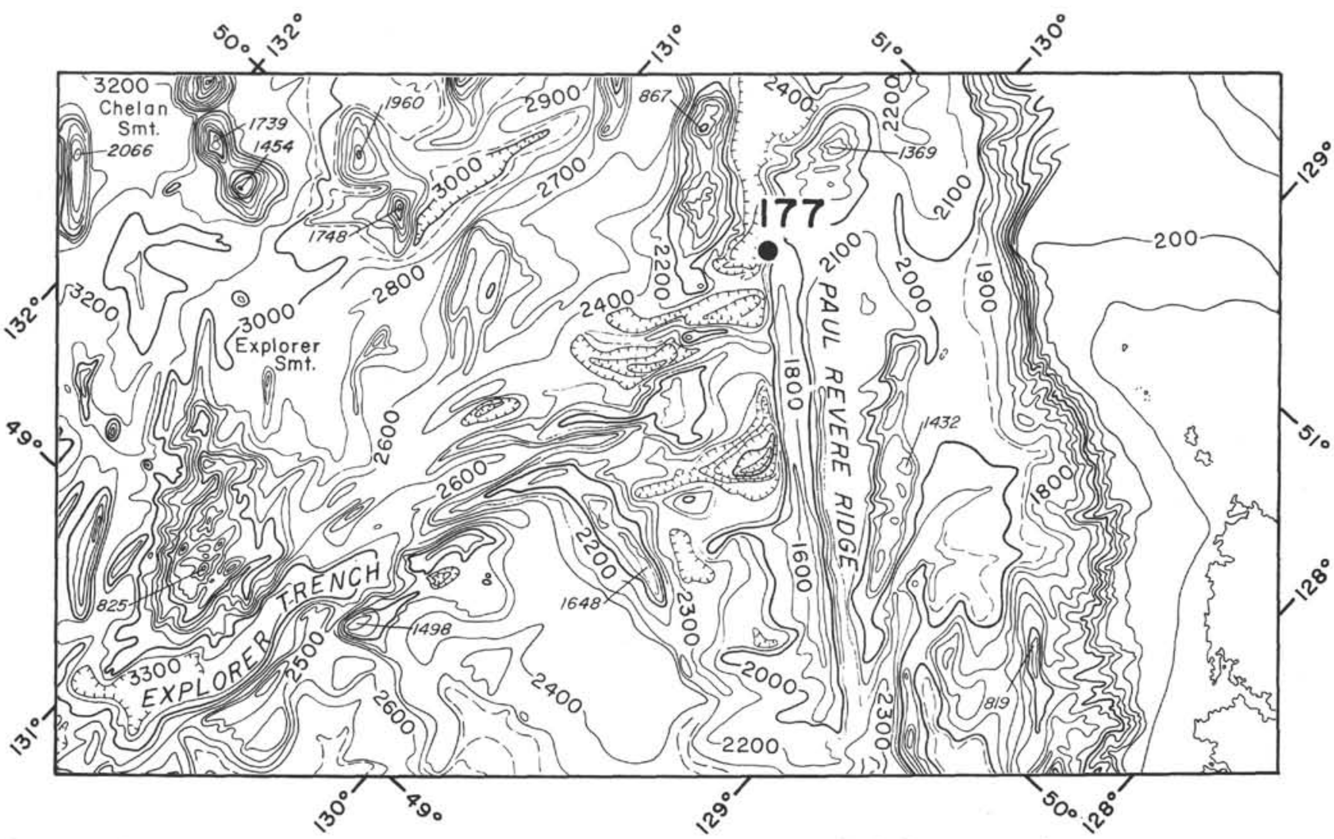


Figure 1. *Bathymetry in the vicinity of Site 177 (Mammerickx and Taylor, 1971). Contours are in meters.*

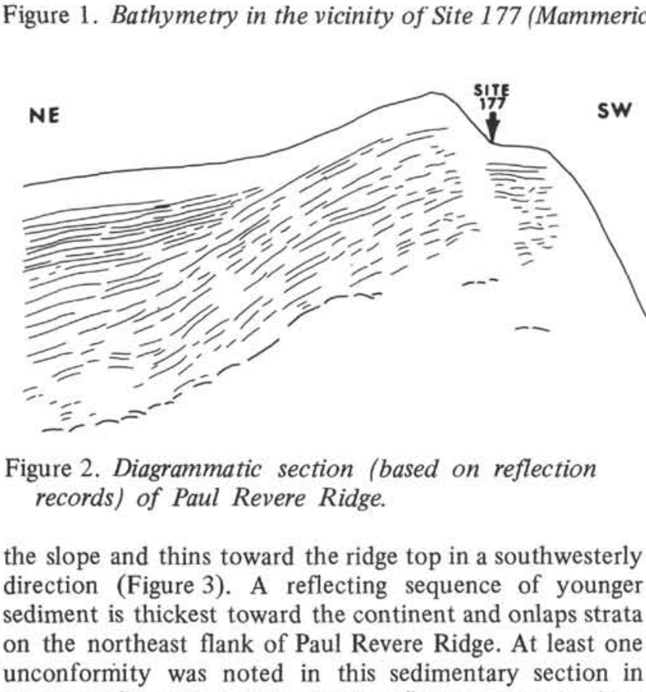


Figure 2. *Diagrammatic section (based on reflection records) of Paul Revere Ridge.*

the slope and thins toward the ridge top in a southwesterly direction (Figure 3). A reflecting sequence of younger sediment is thickest toward the continent and onlaps strata on the northeast flank of Paul Revere Ridge. At least one unconformity was noted in this sedimentary section in seismic reflection records. Most reflection records show that these basin deposits are deformed.

An acoustic basement reflector occurs at least 3 sec (2-way time) below the center of the basin and shallows near the crest of the ridge to within 0.5 sec of the elevated sea floor. On the southwest side of the ridge, the basement reflector dips steeply seaward along the scarp. Dredge samples collected from Paul Revere Ridge consist of graywacke, sheared and slickensided siltstones and mudstones. They occasionally contain carbonized plant fragments, stringers of coal, and rock fragments tentatively identified as serpentinite. It is not known whether these unusual lithologies are indicative of the ridge sediments or whether they are ice-rafted debris.

Site Objectives

The overall objective of the drilling at Site 177 was to elucidate the history of the triple junction of the Pacific, American, and Juan de Fuca plates. The junction is believed to be located at Paul Revere Ridge, or just to the north of it. To determine the tectonic framework of this complex junction, it is necessary to date and determine the paleoenvironment of the sedimentary section above the basement reflector on Paul Revere Ridge. In addition, the age and lithology of the acoustic basement should determine if it is oceanic or continental in origin. Uplift of the basement and overlying sediments is implied from seismic profiles made over the ridge crest, but the timing of this event is unknown.

LITHOLOGIC SUMMARY

General Statement

Site 177 was spudded in 2006 meters of water and drilled to a depth of 507 meters below the sea floor. However, sediments were recovered only in the upper 460 meters. One core was taken from Hole 177 before it was abandoned because of a storm. Hole 177A was spudded-in over the same beacon two days later, and the lithology of the two holes at Site 177 is considered as one continuous section.

The sedimentary column is described in terms of seven lithologic units. The division of the upper part of the

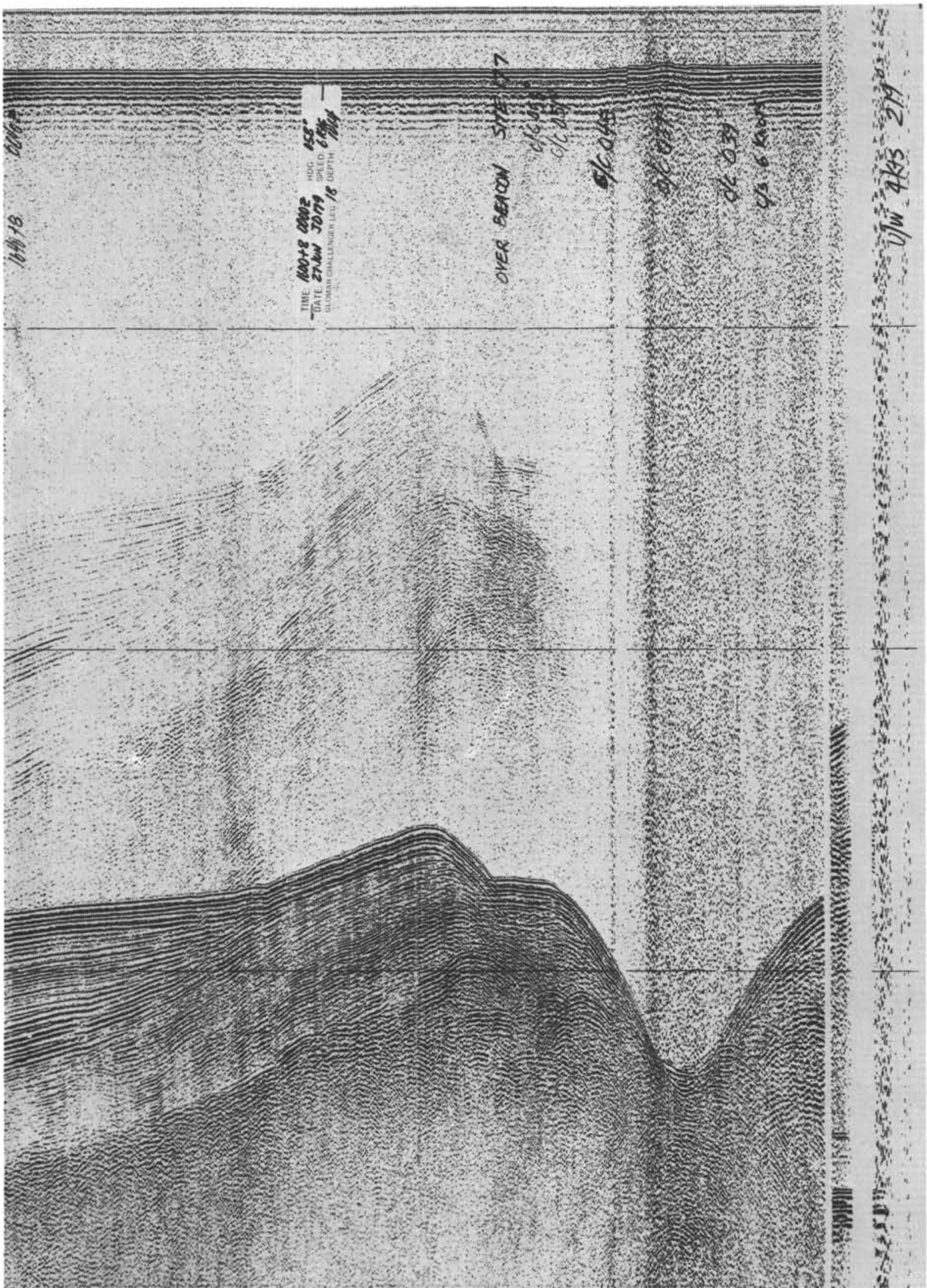


Figure 3. *Seismic reflection profile of Paul Revere Ridge (from* Glomar Challenger*). Note location of Site 177 near probable fault.*

column (Units 1 to 4) is based on the relative amount of graded sand and is composed mostly of terrigenous turbidites, silty clay, and clayey silt. A basalt layer and a hard basal sandstone give a more definitive division to the lower three units, although poor recovery in the lower part of the hole makes it difficult to fully describe the section.

Lithologic Units

Unit 1 (0-62 m, Cores 1-6)

The top of the sedimentary section is composed of silty clay, coarse silt, and foram-rich and diatom-bearing silty clay. The silty clay is soft to firm and olive gray to dark greenish gray in color. Fifteen fine to very fine sand laminae were noted near the top of the unit, but basically the silty clay is massive without any sorted sand or silt beds. A few scattered sandy clasts were noted on the scraped surface of cut cores, and two round 2 cm pebbles were found at 36 meters. The pebbles and sand could be ice-rafted, but their general scarcity suggests that ice-rafting was not a major factor in the deposition of Unit 1.

Unit 2 (62-190 m, Cores 7-13)

The top of Unit 2 was picked at the first bed of sand in the hole, and the unit is generally marked by thin sand and silt beds, some of which are graded. The highest sand layer is 12 cm thick and consists of fine-grained, well-sorted subrounded quartz sand with 5 to 10 percent green hornblende. Most sand beds in the unit are 3 to 5 cm thick and alternate with layers of hard fissile clay and firm silty clay. The fissile clay is olive gray and fine-grained and stands out in well-defined 3- to 5-cm beds in contrast to the firm, uniform dark green gray silty clay that represents most of the unit. Toward the lower part of the unit, very fine-grained sand and silt beds become better sorted, more rythmic, grade up into silt and silty clay, and have well-defined basal contacts. Sand layers range up to 30 cm in thickness.

Unit 3 (190-222 m, Cores 14-15)

The basis for defining Unit 3 is the absence of graded sand and silt beds and the presence of nannofossil and carbonate-rich silty clay. In the top of Core 14, the sediments consist of nannofossil ooze; lower in the unit the sediments are foram-rich. In three thin layers, the sediments are hard and cemented with calcium carbonate and are best described as muddy limestone. Typically, the nannofossil-rich silt and clay is olive gray rather than greenish gray and is compact, uniform, and massive. In Core 15, several smear slides contain abundant dolomite rhombohedrals. A couple of pyrite nodules and a few limonite-filled cracks occur in the sediments at 208 meters. Silt and silty sand laminae increase in abundance toward the bottom of Core 15, but there is no distinct lithologic break between Unit 3 in Core 15 and Unit 4 in Core 16.

Unit 4 (222-378 m, Cores 16-23)

The dominant characteristic of Unit 4 is the repetition of well-defined graded beds. On top of the sequence in Core 16 is a 130-cm bed of dark greenish gray, medium to fine-grained, moderately sorted sand that is rich in hornblende and feldspar. Some of the sand is semi-indurated, but some of it may be downhole filling of cuttings. Two other sand beds with thicknesses of 45 cm and 35 cm occur near the top of Unit 4, but most of the unit, especially toward the bottom, contains fine-grained sand layers which are only 5 to 10 cm thick. The fine sand grades upward into silt and mud and usually has a sharply defined basal contact with the underlying silty clay. Individual sedimentation units average 20 to 30 cm with a maximum thickness of 70 cm for an undisturbed unit. Most of the thicker units, and much of the sand, are disturbed and shortened by the coring operation. The thickest part of the graded turbidite units is silty clay to clayey silt which is dark greenish gray, compact, and slightly mottled. Biogenous constituents are generally absent throughout Unit 4.

Unit 5 (378-383 m, Cores 24-25)

Hard drilling was encountered in the section at 378 meters where Core 24 recovered basalt. The next core (25) broke through the basalt and into sediment again. This is an altered basalt with a subophitic texture. The lower contact is fine-grained and contains small clay-filled amygdules, but the top contact was not defined in the cores. Chemical and petrographic analyses show the basalt is a tholeiitic with below average alkali content (MacLeod and Pratt, this volume). It is similar to the basalts from the Juan de Fuca and Gorda ridges.

Unit 6 (383-451 m, Cores 25-26)

Sediments of Unit 6 lie directly beneath the basalt, but the contact is disturbed by drilling. The sediments in Core 25 are nannofossil-bearing clayey silt and silty clay to nannofossil ooze with no sand or silt either in beds or dispersed in the sediment. The silty clay and ooze are dark olive gray, very compact and massive with rare carbonate cement. Slight mottling and occasional bedding can be seen. Bedding features have apparent dips that range up to 31 or 32 degrees. The deposits that lie directly beneath the basalt (Unit 5) have three areas that are laced with slickensided fractures that appear to be structural deformations rather than drilling artifacts. There is a 61 meter gap between Core 25 and 26 of Unit 6. Core 26 is a clayey silt and silty clay similar to that found higher in Unit 6. Based upon drilling rates, it is assumed that the lithology between the cores is similar to Core 25.

Unit 7 (451-507 m, Core 26)

The lower half of Core 26, directly beneath and in contact with Unit 6, consists of dark greenish gray sandstone. The sand is hard, fine-grained and poorly sorted. The unit is uniform and massive with no apparent bedding and is slightly mottled. One broken consolidated fragment on top of the sandstone is ash-bearing coarse silt and another is a cross-bedded fine sand with carbonate cement. These lithologies, along with the nannofossil ooze of Unit 6, are evidence that Core 26 represents a major lithologic break. The hard, massive nature of the sandstone is distinctly different from the find-grained, graded, discontinuous sands in the turbidite sequence (Units 2 and 4). Sands in Unit 7 contain 5 to 7 percent mica in contrast to the sand in the higher units which are rich in hornblende. Drilling rates below Core 26 were less than one-half of those encountered higher in the hole, and they were consistent from 450 to 507 meters. On the basis of this data, it is inferred that the sandstone extends to the bottom of the hole. Shore-based studies show that this unit has sufficient porosity to be a good reservoir rock (see "Petrology of Indurated Sandstones," (Hayes, this volume).

PALEONTOLOGIC SUMMARY

Introduction

Unfortunately, much of the sedimentary column at Site 177 proved to be barren of all microfossils, especially the sediments below Core 12 (155.5 meters). However, the fossiliferous horizons encountered yielded sufficient numbers of stratigraphically diagnostic foraminifera, calcareous nannofossils, radiolarians, and diatoms to determine that this sequence encompasses a late Pleistocene through early Pliocene interval. Low species diversity again characterizes floras and faunas as at other adjacent high latitude locations creating problems in the biostratigraphic zonation of calcareous microfossils. Dilution, masking, and destruction of microfossil remains is apparently a product of essentially continuous deposition of coarse terrigenous sediments at this site during the interval represented. The displaced nature of most of the sediments is emphasized by the presence of neritic, upper bathyal, and upper middle bathyal benthonic foraminifera along with in situ lower bathyal faunas throughout the entire sequence penetrated with the exception of a basalt sill at 378.5 to 384 meters (Cores 24 and 25).

The Pliocene-Pleistocene boundary is arbitrarily placed between Cores 5 and 6 (54 meters) based upon the oldest occurrence of the radiolarian *Eucyrtidium matuyamai* and the upper limit of *Lamprocyclas heteroporos* near the bottom of Core 5 (52.1 to 53.8 meters), thought to be equivalent to an estimated radiometric age of 2.0 m.y. (Hays, 1970). However, the base of an interval representing combined North Pacific Diatom (NPD) Zones III and IV occurs in Core 6 (60.5 meters), and the base of NPD Zone V occurs in the top of Core 7 (61.5 meters). In addition, the youngest occurrence of dextral populations of the foraminifer *Globigerina pachyderma*, thought to be equivalent to Pliocene Zone N.21, takes place at the base of Core 6 (60.7 meters). Thus, the Pliocene-Pleistocene boundary could be placed at any one of several horizons between 54 and 61.5 meters. Pleistocene calcareous nannofossils were recovered from 0 to 45 meters (Cores 1 to 4), but, unfortunately, the interval from 45.6 to 184 meters encompassing the Plio-Pleistocene boundary was essentially barren of these fossils.

Pliocene radiolarians and diatoms were identified in Cores 6 through 12 (54 to 147.5 meters) with sediments below this interval being barren of these two groups. Sparse calcareous nannofossils in Cores 18 to 26 (250.5 to 459.5 meters) are assigned to the Pliocene. A well-developed planktonic foraminiferal fauna of Pliocene age and dominated by *Globorotalia puncticulata* occurs in Core 14 (203 to 212.6 meters). This fauna is correlated with Blow's (1969) Zone N.20. A similar fauna representing a relatively warm biofacies occurs in Core 25 (381.5 to 389 meters) and is correlated with lower Pliocene Zone N.19. The sediments recovered from 389 meters to the base of Hole 177A (507 meters) are barren of all microfossils.

Calcareous Nannofossils

Calcareous nannofossils are generally sparse or absent in Holes 177 and 177A, and species diversity is extremely low. Assemblages are highly diluted by terrigenous turbidites and muds throughout much of the section. Ceratoliths, discoasters, and the lower Pleistocene index species *Emiliania annula* (=*Pseudoemiliania lacunosa* Gartner) were not observed. Therefore, the "Standard Neogene Calcareous Nannoplankton Zonation" developed in lower latitude regions (and summarized by Martini and Worsley, 1970) is essentially unworkable at this more northerly site (lat 50°28'N) where cold water floras prevail. *Gephyrocapsa* spp. is used as a secondary marker species in order to distinguish Pleistocene and Pliocene strata at this site as well as other sites drilled on Leg 18. Its presence is here considered indicative of Pleistocene floras.

The single core recovered in Hole 177 (0-9 meters) and Cores 1 through 4 in Hole 177A (9 to 45 meters) contain small numbers of *Coccolithus pelagicus* and *Gephyrocapsa* spp. and are considered Pleistocene in age. Cores 5 to 13 (45.6 to 184 meters) are essentially barren except for occasional *Coccolithus pelagicus*. Core 14 (203 to 212.5 meters) contains an unusually high abundance of *Coccolithus doronicoides* in a mud undiluted by turbidite sands. Cores 15 to 18 (212.5 to 250.5 meters) are barren. However, the occasional presence of *Coccolithus doronicoides* and *Coccolithus pelagicus*, and the absence of *Gephyrocapsa* spp. in the 250.5-459.5-meter interval (Cores 18 to 26) suggests this lower portion of the section is Pliocene in age. Below the basalt sill encountered in Cores 24 and 25 (378.5 to 384 meters), an olive gray mud contains abundant small placoliths attributable to the nondiagnostic *Coccolithus doronicoides* and perhaps to small species of *Reticulofenestra*.

The nearshore indicator *Braarudosphaera bigelowii* was encountered in only two samples (Cores 1 and 13) at Site 177.

Diatoms ·

Moderately to well-preserved diatoms are abundant in fine-grained sediments within the 0-150-meter interval at Site 177 (Core 1, Hole 177 and Cores 1 through 12 of Hole 177A). Sediments recovered from 150 to 459.5 meters (Cores 12 through 26) are barren of diatoms. A few recrystallized frustules were encountered at the base of Core 14 (212.5 meters). The abundance of reworked older fossils was high in the middle portion of this sequence (Cores 6 through 8; 60.5 to 81.5 meters), but the amount of displaced littoral freshwater benthic, and freshwater planktonic diatoms was negligible throughout the diatom-bearing sediments.

The base of Pleistocene NPD Zone I is at 27 meters (177A-2-6, 107-108 cm) and the base of Pleistocene NPD

Zone II is at 47.6 meters (177A-5-2, 64-66 cm). The base of an interval encompassing both NPD Zones III and IV is at 60.5 meters (177A-6-5, 64-66 cm), thus, the Pliocene-Pleistocene boundary as defined by NPD zones falls within Core 6 (54 to 61 meters). The base of NPD Zone V is at 61.5 meters (177A-7-1, 63-66 cm). The oldest diatom-bearing sediment recovered in Hole 177A is in Core 12 (147.5 meters; 177A-12-1, 188-120 cm) and falls within Pliocene NPD Zone V1.

Planktonic Foraminifera

The abundance and preservation of planktonic foraminifera at Site 177 is generally marginal. Well-preserved faunas are common in the single core recovered from Hole 177 (0 to 9 meters), whereas moderately to well-preserved faunas are present from 9 to 31 meters (Cores 1 to 3) and 42 to 46.6 meters (Cores 4 and 5) in Hole 177A. Extensive intervals in Hole 177A from 61 to 174.5 meters (Cores 7 to 13) and 212 to 378.5 meters (Cores 15 to 24) are essentially barren of foraminifera with only rare poorly preserved specimens appearing at scattered horizons in Cores 7, 13, 19, 20, 21, 22, and 23. A relatively undisturbed fine-grained interval in Core 14 (203.-212.5 meters) contains moderately well-preserved common assemblages, and Core 25 (381.5 to 389 meters) contains rare to common poorly to well-preserved assemblages. Core 26 (250. to 459.5 meters) is barren of foraminifera.

Faunas recovered from 0 to 54 meters (Core 1 in Hole 177 and Cores 1 to 5 in Hole 177A) are assigned to Pleistocene planktonic Zones N. 23 and N. 22 and contain assemblages dominated by sinistral coiling specimens of *Globigerina pachyderma* along with lesser percentages of *G. bulloides, G. quinqueloba, Globigerinita glutinata,* and *G. uvula.* This particular planktonic biofacies is characteristic of both the modern and Plio-Pleistocene water masses associated with the Alaskan Current gyre.

Exclusively dextral coiling populations of *Globigerina pachyderma*, signifying mean summer surface temperatures in excess of 15°C, occur at the base of Core 6 (177A-6-5, 60-62 cm; 60.7 meters) and are considered upper Pliocene in age, equivalent to Zone N. 21. Core 14 (203 to 212.6 meters) contains faunas dominated by *Globorotalia puncticulata* and dextral populations of *Globigerina pachyderma* s.l. This indicates a significant northward migration of the transitional water mass biofacies during the Pliocene which is similarly expressed at Site 173, in the Mohole cores (Bandy and Ingle, 1970), and in surface sections of California (Ingle, 1967; 1968) and Washington (Fowler, 1965). Other significant species occurring within this interval include *Globorotalia crassaformis* s.s. and *G. crassaformis ronda.* Similar faunas, containing abundances of *Globorotalia puncticulata* but greater percentages of *Globigerina bulloides* s.s. and *G. bulloides umbilicata*, occur in Core 25 (381.5 to 389 meters) and are also assigned a Pliocene age. Correlation of these faunas with sequences in nearby surface sections and at Site 173, along with their stratigraphic position, indicate a probable equivalency with Blow's (1969) Zone N. 19.

Benthonic Foraminifera

Typical lower middle bathyal[2] benthonic foraminiferal assemblages characterized by *Melonis barleeanus* and *Uvigerina senticosa* occur at various horizons throughout the entire sequence penetrated at Site 177. Abundance and preservation of benthonic specimens is generally similar to that noted for planktonic foraminifera. However, rare benthonic specimens do appear at some horizons barren of planktonic species and small broken pieces of arenaceous forms occasionally occur in samples otherwise devoid of all microfossils. Individuals displaced from neritic, upper bathyal, and upper middle bathyal depths, including species of *Elphidium, Epistominella, Cibicides,* and *Bulimina*, occur together with in situ deeper water faunas. Indeed, displaced species constitute the predominant elements within numerous faunas attesting to the continuous downslope transport of sediments during the interval represented.

Interestingly, *Melonis pompilioides*, a species indicative of depths in excess of 2000 meters, is common within the Pleistocene interval (0 to 54 meters; Cores 1 to 5) at Site 177 but is rare, or absent, within the great thickness of Pliocene sediments, suggesting the possibility that subsidence, or alternately, a slower rate of deposition, may have characterized the Pleistocene interval.

Finally, it should be noted that the sediment and benthonic faunal associations present at Hole 177A are not indicative of a submarine ridge environment despite the fact that this particular Plio-Pleistocene sediment-package currently forms a portion of a major submarine ridge. The sandy nature of the sedimentary column together with the continuous presence of displaced benthonic species and an in situ lower middle bathyal biofacies suggest these sediments represent deposition on a distal portion of the continental rise or fan and were later uplifted to their present position.

Radiolaria

Sediments at Site 177 contain relatively rich radiolarian assemblages at certain levels within Cores 1 through 11 of Hole 177A (9 to 127 meters). Preservation in these cores is moderate to good. Cores 12 through 26 (146 to 459.5 meters) are barren of radiolarians.

The single core recovered in Hole 177 (0 to 9 meters) and Cores 1 through 3 of Hole 177A (9 to 36 meters) contain an assemblage indicating the upper Pleistocene *Artostrobium miralestense* Zone of Hays (1970). The upper limit of *Druppatractus acquilonius* occurs in Core 4 of Hole 177A indicating a paleomagnetic-radiometric age of 0.3 m.y. within the *A. miralestense* Zone (177A-3-CC to 177A-4-2, 69-71 cm; 36 to 38.2 meters). The next lower radiolarian horizon occurs in the top of Core 5 (47 to 47.7 meters) where both *Stylatractus universus* and *Eucyrtidium matuyamai* reach an upper limit. This suggests that the *S. universus* Zone cannot be differentiated from the lower *D. acquilonius* Zone, and that this level represents the top of

[2]See Chapter 14 for depth classification of marine environments.

the *E. matuyamai* Zone which in turn is correlated with an estimated radiometric age of 0.9 m.y. (177A-5-1, 91-93 cm to 177A-5-2, 67-69 cm).

The bottom of Core 5 (52.1 to 53.8 meters) contains the upper limit of *Lamprocyclas heteroporos* and the oldest occurrence of *Eucyrtidium matuyamai* correlated with an estimated radiometric age of 2.0 m.y. (177A-5-5, 90-92 cm to 177-5-6, 72-74 cm).

Cores 6 through 11 (54 to 127 meters) contain *Lamprocyclas heteroporos* indicating a Pliocene age for this lowest interval of radiolarian-bearing sediment.

Spores and Pollen

Cores examined for pollen at Site 177 are predominately barren of spores and pollen. Reasonably well-preserved pollen grains (*Pinus, Tsuga, Picea*) and spores (*Lycopodium*) occur in very small quantity at the base of Core 5 (54 meters), whereas Cores 1 through 10 have very fine-grained residue with no plant material.

Abundant, poorly preserved pollen grains occur at the base of Core 13 (184 meters) along with coaly material (Yves Lancelot, personal communication). The assemblage has a very low diversity and is almost entirely gymnospermous in nature. Members of the family polypodiaceae (*Polypodium* sp. aff. *P. vulgare* type) occur frequently. The occurrence of a badly preserved grain of the genus *Ephedra* is the only palynological indicator of Pliocene material in this area; it is possible that this specimen was reworked from older sediments.

PHYSICAL PROPERTIES

Cores from Site 177 were run through the GRAPE, natural gamma, and sonic velocimeter instruments as on previous sites except that higher carriage speeds were used on the GRAPE and resulted in a greater number of measurements. Also, three parts of a section were subjected to sonic velocity measurements because of the variability of material in many cores. After Core 17, syringe volumes were impossible to take because the fissile muds and sands were too well indurated for insertion of the syringe. The poor correspondence of GRAPE and syringe measurements is not readily explained, especially in Core 11.

Porosity has a wide range of values which is a good indicator of the variability of sedimentary materials. In Core 8, for instance, the materials vary from a diatom-rich mud with porosities greater than 70 percent to a muddy sand with a 37 percent porosity (interestingly, sonic velocities measured in this interval are relatively constant). Most sands are less porous (commonly 10 percent) than adjacent hard fissile muds, probably because the sands are not well sorted and contain some mud or silt. However, the sandstone from Core 26 has a porosity of 47 to 55 percent whereas the adjacent mudstone has a porosity of 30 to 35 percent indicating that the GRAPE records are best interpreted with reference to the lithologic log. The porosity of the sandstones at Site 177 averages about 31 percent as measured by standard porosimeter techniques at the Marathon Oil Company Research Center (see "Petrology of Indurated Sandstones," Hayes, this volume). However, when viewed in thin section, porosity is variable and may reach 45 percent in the more porous patches of the sandstones.

A comparison of GRAPE records and lithology was made in the lower part of the hole. There is an excellent qualitative correlation between GRAPE records and grain size in undisturbed lithologies and less correlation where the core has been disturbed or broken.

In consolidated lithologies requiring slow band saw splitting, the individual segments of broken core do not appear to cause undesired spikes in the traces of porosity and density.

When the GRAPE records are correlated with the lithologies in the split cores, they can add desirable detail to descriptions of the variable lithologies in continental margin areas, but the time required is at least twice that available for logging when cores are continuously coming aboard.

Sonic velocity values remain relatively constant at about 1.60 ± .05 km/sec from Core 1 through Core 10 and then increase to roughly 1.70 ± .05 km/sec. At Core 15, the velocity values rise sharply and increase at a rapid rate along with a corresponding decrease of porosity. This change probably reflects a change toward greater consolidation with patchy cementation noted in the detailed study of the indurated sandstones. The increased range of velocity values measured in an interval may be caused by the increasing variability of sediment grain-size.

CORRELATION BETWEEN REFLECTION RECORDS AND THE STRATIGRAPHIC COLUMN

During the pre- and post-drilling site surveys, three seismic records were made along ship's tracks perpendicular to the trend of Paul Revere Ridge. Ship speeds during the surveys were 4, 6, and 8 knots, and records were made with a 4 sec sweep and fire rate.

Paul Revere Ridge is a tilted block of basement and overlying reflecting strata with a landward ramp and a seaward escarpment (Figure 3). The ridge has ponded most sediments moving down the continental slope on its landward side. Its seaward side, an escarpment standing 1500 meters high, is complicated by an upper secondary escarpment at Site 177. The site is on a narrow terrace or bench dropped down from the crest of the ridge along the upper escarpment. In Figure 3 the drill hole appears to be at the base of the upper escarpment. Actually, it is about in the middle of the narrow terrace. Steep slopes cause defraction patterns that extend beyond the physical slope in the records. Therefore, the foot of the upper escarpment is in the steeply dipping reflectors landward of the site, and the edge of the terrace is also landward from its recorded position.

Similar sequences of reflections in the seismic records near the site can be grouped into four main acoustic units (Figure 4). Lowest is the acoustic basement (F in Figure 4) which has a characteristic rough irregular pattern of short hyperbolic reflections where it is covered by a thick layered sequence; but, where it is shallower at the crest of the ridge, its reflections are stronger and the basement shows layering. Basement is overlain by a lower unit (C, D, and E, Figure 4)

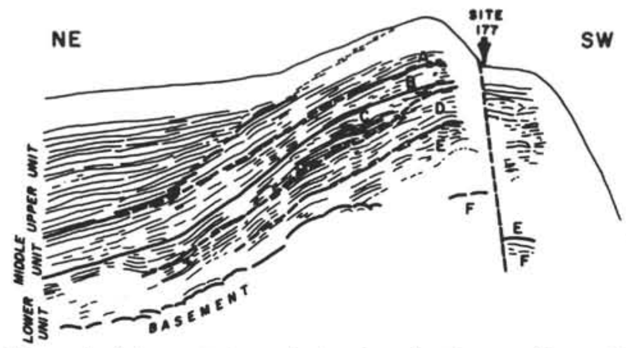


Figure 4. *Interpretation of seismic reflection profile made by* Glomar Challenger *over Paul Revere Ridge.*

of closely spaced reflections, intermediate in length, somewhat irregular, and relatively reflective. The unit appears more massive at its base (E, Figure 4) and more finely laminated near its top (C, Figure 4). The middle unit (A and B, Figure 4) has weaker and more continuous reflections, and the top reflectors (A, Figure 4) appear to merge into the upper unit. The upper unit is characterized by strong continuous reflectors that are not tilted as steeply as those in the units below. A thick onlapping wedge of sediment lies landward of Unit A and represents ponded turbidites from the continent.

From the geometry and strength of reflectors, the following geologic inferences can be made in regard to each acoustic unit. Acoustic basement may be hard stratified rock (at least in part) that is disconformable with the overlying sedimentary section. Immediately overlying it is a basal, more massively bedded, part of the lower unit that grades into more closely spaced regular interbeds and then to a very regular thinly bedded sequence. The middle unit (A and B, Figure 4) may indicate even thinner and more continuous bedding by virtue of its more regular stratification. Its upper part (A, Figure 4) shows a fine uniformity, and grades laterally into the upper unit (Figure 4). The upper unit indicates continued tilting of the ridge.

The acoustic units described are not seen at Site 177 because a fault zone, with probably more than one fault plane (shown as a single fault in Figure 4), causes hyperbolic reflections that mask most other features and because of scattered and weak reflections from the narrow surface on which the site is located. Thus, it is assumed here that faulting has displaced the section just described and that it can be correlated with the lithology drilled.

Figure 5 is also a correlation diagram showing the acoustic and lithologic units. The acoustic units are keyed to Figure 4 by letters, and the lithologic units are keyed by numbers to the lithology summary.

If velocities assumed from the physical properties measurements are correct, basement would have been encountered within a few meters. The massive sandstone and mudstone of lithologic Units 6 and 7 could produce the seismic characteristics of acoustic Unit E. Surprisingly, the tholeiitic basalt is not an outstanding reflector, which indicates limited thickness and possibly limited extent.

The short, strong, irregular reflections of Unit D correlate well with interbedded sands and muds. Seismic Unit C and lithologic Unit 3 appear to correlate well suggesting that the nannofossil ooze and carbonate muds

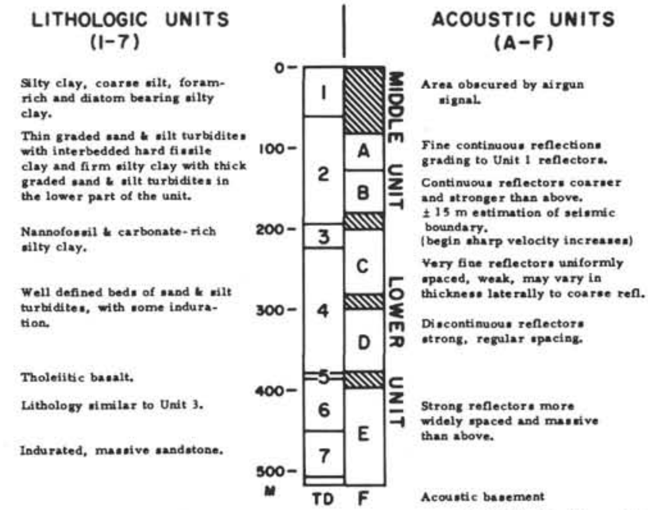


Figure 5. *Correlation of acoustic units with lithologic units.*

are thickest landward. The fine, continuous reflections of Units A and B suggest uniform conditions of sedimentation, possibly hemipelagic with occasional turbidites, during the time when the ponded sediments just landward of the ridge were deposited.

Figure 4 indicates the fault zone was penetrated at Site 177. Slickened sides were noted on the compacted nannofossil oozes of Unit 6 and the tholeiitic basalt sill is fractured.

SUMMARY AND CONCLUSIONS

Sedimentary deposits cored at Site 177 lie on a structural bench that is located near the northwestern end of Paul Revere Ridge. The 130 km long ridge is situated at, or near, the triple junction of the Pacific, American, and Juan de Fuca plates. Paul Revere Ridge forms the western limb of a ponded sedimentary trough that lies between the ridge and the North American continent.

Seven Pleistocene to lower Pliocene lithologic units were recognized in Holes 177 and 177A. Unit 1 (0 to 62 meters) is an upper Pleistocene silty clay with foraminiferal-bearing and diatom-rich horizons. The silty clay is massive with few very thin sand-silt beds or laminae. A sedimentation rate of 40 m/m.y. is calculated on the basis of diatom stratigraphy. Unit 2 (62 to 190 meters) is characterized by thin, occasionally graded lower Pleistocene sand and silt turbidites. Most sand beds are 3 to 5 cm thick and are interbedded with layers of hard fissile and firm silty clay. Unit 3 (190 to 222 meters) is an upper Pliocene clayey silt nannofossil ooze and carbonate-rich clayey silt which is locally cemented forming a muddy limestone. In contrast, Unit 4 (222 to 378 meters) consists of well-defined graded beds of lower Pliocene sand and silt turbidites which have sharp basal contacts. Unit 5 (378 to 383 meters) is a tholeiitic basalt 5 to 7 meters thick. Unit 6 (393 to 451 meters) underlies the basalt and is quite similar lithologically to Unit 3. It consists of lower Pliocene nannofossil-bearing silty clay to nannofossil ooze with no sand or silt. Unit 7 (451 to 507 meters) is probably a lower Pliocene indurated fine-grained, poorly sorted, massive sandstone. Although barren of microfossils, it is distinct from the turbidite sequences in Units 2 and 4.

This unit was discontinuously cored, but the drilling records suggest it extends throughout the interval drilled. In general, the thick sequences of turbidites cored at Hole 177A are lithologically similar to the Unit 2 deposits of Astoria Fan (Hole 174A).

The depositional history of Site 177 begins on an acoustic basement which is Early Pliocene or older. Poorly sorted, massive sands of Unit 7 were deposited as turbidites on the basement in a deep-sea fan environment some distance from the continent. The exact origin of this unit and its age are unknown but are inferred from the stratigraphic sequence at Site 177 and the regional tectonic framework of the area (Couch & Chase, this volume). As the fan developed, block faulting occurred over a broad regional front ponding the turbidites and leaving other areas above the general level of turbidite deposition. Lower Pliocene nannofossil-bearing silty clay and nannofossil ooze of Unit 6 represent hemipelagic and pelagic sedimentation on one of these slightly higher topographic areas.

It is also possible that shifting submarine fan channels deposited the coarse-grained sediments in other areas of the fan allowing the fine-grained sediments of Unit 6 to accumulate at this site. Benthonic foraminiferal displaced from the outer shelf, upper bathyal, and upper middle bathyal environments are present in all samples containing foraminifera. These displaced faunas indicate that Site 177 was never completely isolated from turbidity current deposition; the hemipelagic and pelagic-like units (3 and 6) may be levee deposits or slightly higher bathymetric highs that received spillover from passing sediment-laden turbidity currents.

The tholeiitic basalt was probably intruded as a sill at a later date but prior to the late Pleistocene faulting since it is fractured. In either case, its chemical composition strongly suggests an origin from oceanic crust, with Juan de Fuca Ridge affinities. The acoustic basement or the crust below this reflecting surface probably is oceanic in character. After a period of hemipelagic and pelagic deposition, turbidite deposition filled the basins between the continent, and Site 177 began to receive sand and silt turbidites once again (Unit 4). Another period (Unit 3) of pelagic sedimentation followed as further subsidence and basinal deepening occurred to the east. The upper Pliocene sand and silt turbidites of Unit 2 represent the final episode of turbidite deposition at this site. Uplift of Paul Revere Ridge commenced in the late Pliocene-early Pleistocene time (approximately two million years ago). Turbidite deposition declined and the fine-grained hemipelagic silty clays of Unit 1 were deposited. Thin, poorly sorted sand layers probably represent ice-rafting during the glacial periods of the Pleistocene; the adjacent continent had extensive glaciation at this time. Bottom currents may have winnowed the poorly sorted glacial debris on the ridge, producing the thin, coarse laminae.

As Paul Revere Ridge was uplifted, Pleistocene turbidites produced the onlapping sedimentary wedge on the landward flank of the ridge which filled an elongate trough that developed between the continent and the ridge. With continued uplift in the late Pleistocene, a major fault developed on the seaward flank of the ridge creating the structural bench upon which Site 177 was drilled. Pelagic oozes of Unit 6 are compacted and characterized by slickened sides which suggest a fault zone. The tholeiitic basalt is also fractured. If Site 177 was drilled through the fault, it is possible that a portion of the sedimentary section is repeated (i.e. turbidite and/or pelagic units). Although it is not possible to resolve this matter with data obtained on the *Challenger*, the tectonic and environmental setting is essentially the same.

The diagenetic production of porosity (average 31 percent) noted in the sand and silt turbidites (see "Petrology of Indurated Sandstones, Leg 18, DSDP", Hayes, this volume) is probably associated with the deformation described at this site. Fracturing through faulting would allow fluids to be conducted through the sedimentary section.

REFERENCES

Bandy, O. L. and Ingle, J. C., Jr., 1970. Neogene planktonic events and radiometric scale, California. *In* Radiometric dating and paleontologic zonation. Bandy, O. L. (Ed.). Geol. Soc. Am. Spec. Paper 124, 131.

Blow, W. H., 1969. Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. Proc. First Intern. Conf. Planktonic Microfossils. **1**, 199.

Fowler, G. A., 1965. The stratigraphy, foraminifera, and paleoecology of the Montesano Formation, Grays Harbor County, Washington. Univ. Southern California. Unpub. Ph.D. Diss. 355 p.

Hays, J. D., 1970. Stratigraphy and evolutionary trends of Radiolaria in North Pacific deep sea sediments. *In* Geological investigations of the North Pacific. Hays, J. D. (Ed.). Geol. Soc. Am. Mem. 126, 185.

Ingle, J. C., Jr., 1967. Foraminiferal biofacies and the Miocene-Pliocene boundary in southern California. Bull. Am. Paleontol. **52** (236), 217.

———, 1968. Pliocene planktonic foraminifera from northern California and paleo-oceanographic implications. Geol. Soc. Am. Spec. Paper 121, 147 (abstract).

Mammerickx, J. and Taylor, I. L., 1971. Bathymetry of the Pioneer Survey area north of 45°N lat. Scripps Institution of Oceanography, Geological Data Center. (Map)

Martini, E. and Worsley, T., 1970. Standard Neogene calcareous nannoplankton zonation. Nature. **225**, 289.

APPENDIX A. OPERATIONS

Pre-drilling Survey

The *Challenger* approached Paul Revere Ridge (Site 177) from the northeast flank starting in the flat portion of the sedimentary basin that lies between the ridge and the continental slope (Figure 6).

The approach course to this point was 350° T at 1500, 23 June 1971. At 1520, the course was changed to 225° T to make a seismic reflection profile perpendicular to the strike of the ridge, and speed was reduced to 8 knots. A 4 sec seismic record was made during the survey. At 1619, the course was changed to 135° for a distance of 1.5 km at which point (1628) the course was changed to 045°. The first pass over the ridge failed to produce a crestal high noted on the presite survey records. The second pass, 1628 to 1700 hours, produced the desired feature and a broad

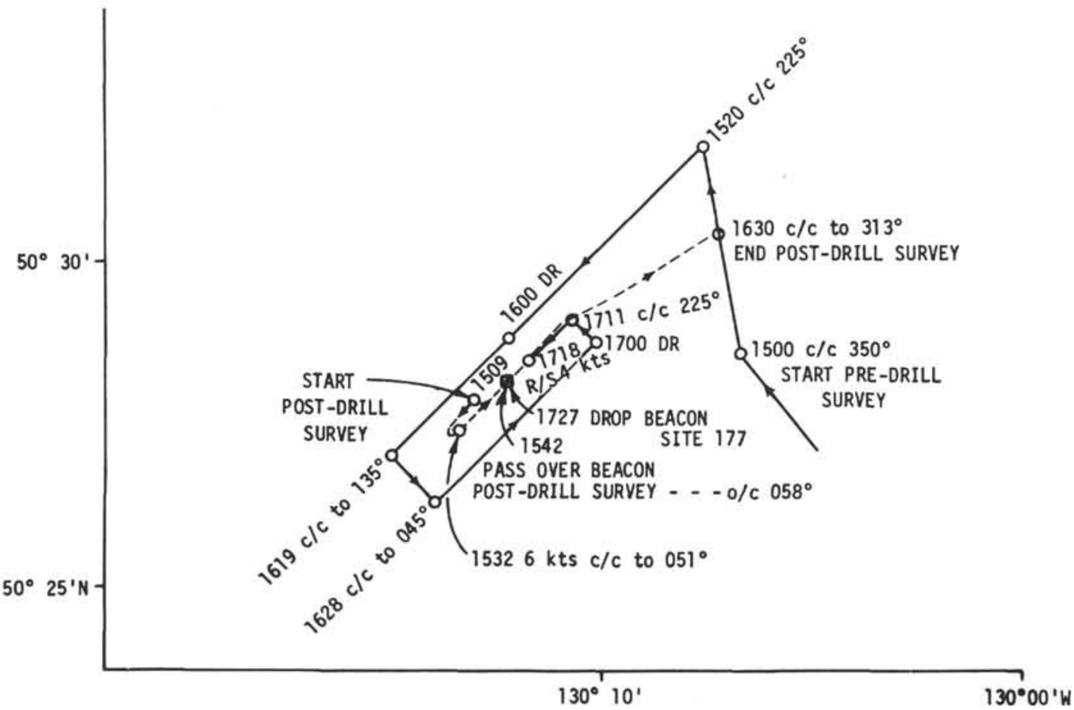


Figure 6. Glomar Challenger *presite survey of Site 177.*

turn to course 225° was executed. At 1718, the *Challenger* slowed to 4 knots and at 1727 the beacon was dropped while the vessel was underway. The beacon was positioned on a small flat structural bench on the northwestern end of Paul Revere Ridge.

The initial signal from the beacon proved to be somewhat erratic when the vessel was positioned directly over it. The *Challenger* was offset 61 meters south and 61 meters west (225° T) improving the character of the incoming signal. The beacon was dropped on the bench fairly close to a steep wall, which may have caused side echoes.

Drilling Program

The water depth at Site 177 is 2006 meters below sea level. The corrected depth at the transducer was determined from the Matthews tables (1986 meters) and the addition of the Hawaii factor of +14 meters brought the total depth to 2000 meters at the transducer. Drill pipe touched bottom at 2013, as measured from the derrick floor, or 3 meters shallower than calculated (i.e., 2000 + 16 = 2016 meters). The bottom-hole assembly consisted of a 10/8" Smith 3 cone seal-bearing bit, bit sub, one core barrel, three 8¼" drill collars, one bumper sub, three 8¼" drill collars, two bumper subs, two 8¼" and one 7¼" drill collars.

Hole 177 was continuously cored to a depth of 9 meters before high winds (30 to 60 knots) and rough seas (15 to 18 feet high) terminated operations. The pipe was pulled from the hole about 0200 hours on 24 June. The bottom-hole assembly was left hanging in the elevators and all equipment secured during the storm. After six hours of waiting for the high seas to subside, the hole assembly was brought aboard the vessel. The satellite antenna was blown off its mount during the storm. In the meantime, the *Challenger* drifted off the beacon to the southeast.

About 0100 on 25 June, the *Challenger* headed back to the general vicinity of the beacon, navigating largely by bathymetry. The ridge crest was located south of the beacon's position and a northwesterly course was set to follow the bottom contour of the beacon site. The beacon was located rather easily at 0430 and its signal detected 2 km away. The drill was lowered and the first 9 meters were drilled. The first core was taken from 9 to 18 meters and brought aboard at 1110. Hole 177A was continuously cored from 9 to 108 meters, below which selected intervals were cored. A 5- to 6-meter basalt layer was first encountered at 378.5 meters, which slowed the drilling. The entire layer was cored with penetration into the underlying muds; the contact was preserved in the core.

A hard fine-grained sandstone was the last lithology recovered in Hole 177A (450 to 459.5 meters). Drilling continued to a total depth of 507 meters below the sea floor. At this point, the bottom-hole assembly twisted off due to tool failure. A loss of 12,000 pounds on the drill string indicated that the bottom-hole assembly had parted at the bumper subs. The hole was filled with 10.2 ppg drilling mud. A bit, bit sub, core barrel, three drill collars, and part of a Shaffer bumper sub were left in the hole.

Recovery for the one core in Hole 177 was 100 percent and for the 26 cores in Hole 177A it was 58.5 percent (Table 1).

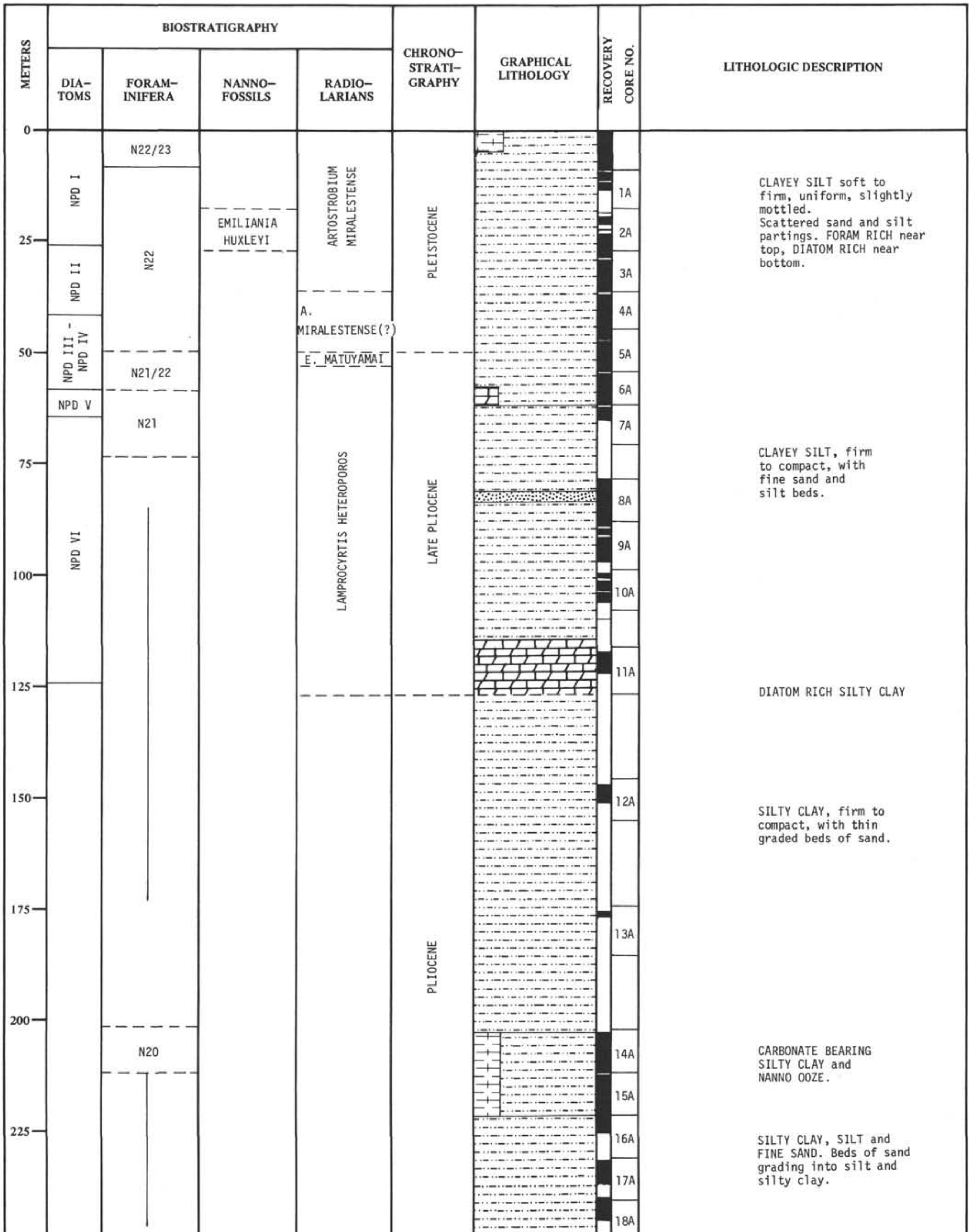
TABLE 1
DSDP Site 177 Coring Summary

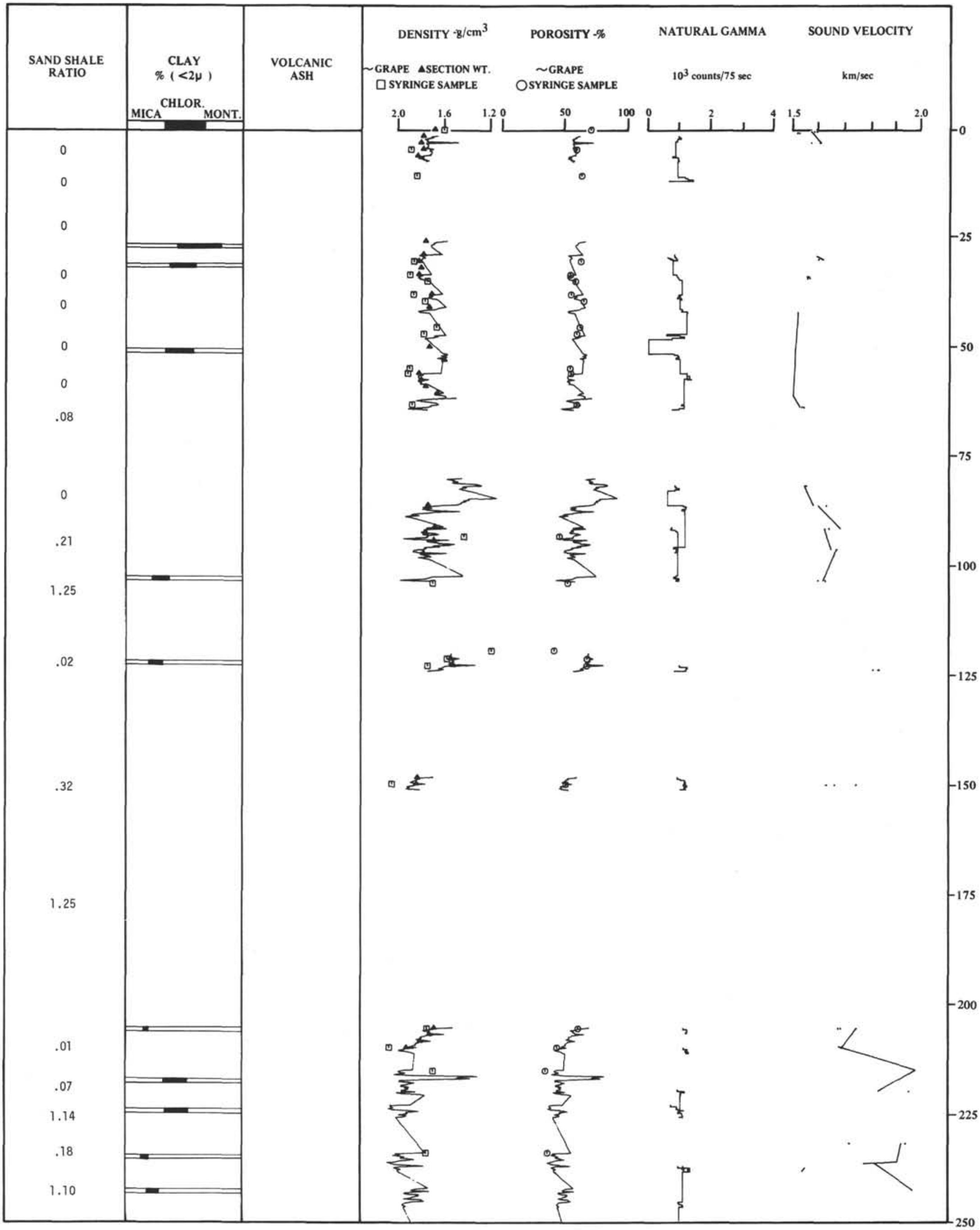
Core	Cored Interval Below Derrick Floor (m)	Sea Floor[a] (m)	Cored (m)	Recovered (m)	Recovered (%)
Hole 177					
1	2013.0-2022.0	0-9.0	9.0	9.0	100.0
Hole 177A					
1	2022.0-2031.0	9.0-18.0	9.0	3.0	33.3
2	2031.0-2040.0	18.0-27.0	9.0	8.0	88.9
3	2040.0-2049.0	27.0-36.0	9.0	9.0	100.0
4	2049.0-2058.0	36.0-45.0	9.0	7.5	83.3
5	2058.0-2067.0	45.0-54.0	9.0	9.0	100.0
6	2067.0-2074.0	54.0-61.0	7.0	7.0	100.0
7	2074.0-2084.0	61.0-70.0	9.0	3.0	33.3
8	2092.5-2102.0	79.5-89.0	9.5	9.5	100.0
9	2102.0-2111.5	89.0-98.5	9.5	9.5	100.0
10	2111.5-2121.0	98.5-108.0	9.5	5.5	57.9
11	2130.5-2140.0	117.5-127.0	9.5	4.5	47.4
12	2159.0-2168.5	146.0-155.5	9.5	3.5	36.8
13	2187.5-2197.0	174.5-184.0	9.5	0.5	53.
14	2216.0-2225.5	203.0-212.5	9.5	8.0	84.2
15	2225.5-2235.0	212.5-222.0	9.5	6.0	63.2
16	2235.0-2244.5	222.0-231.5	9.5	3.0	31.6
17	2244.5-2254.0	231.5-241.0	9.5	4.5	47.4
18	2254.0-2263.5	241.0-250.5	9.5	4.5	47.4
19	2263.5-2273.0	250.5-260.0	9.5	3.5	36.8
20	2273.0-2282.5	260.0-269.5	9.5	3.5	36.8
21	2282.5-2292.0	269.5-279.0	9.5	3.5	36.8
22	2292.0-2301.5	279.0-288.5	9.5	5.0	52.6
23	2358.5-2368.0	345.5-355.0	9.5	7.0	73.7
24	2391.5-2394.5	378.5-381.5	3.0	2.0	66.7
25	2394.5-2402.0	381.5-389.0	7.5	5.0	66.7
26	2463.0-2472.5	450.0-459.9	9.5	1.5	15.8
		Total/Average	233.0	136.5	58.5

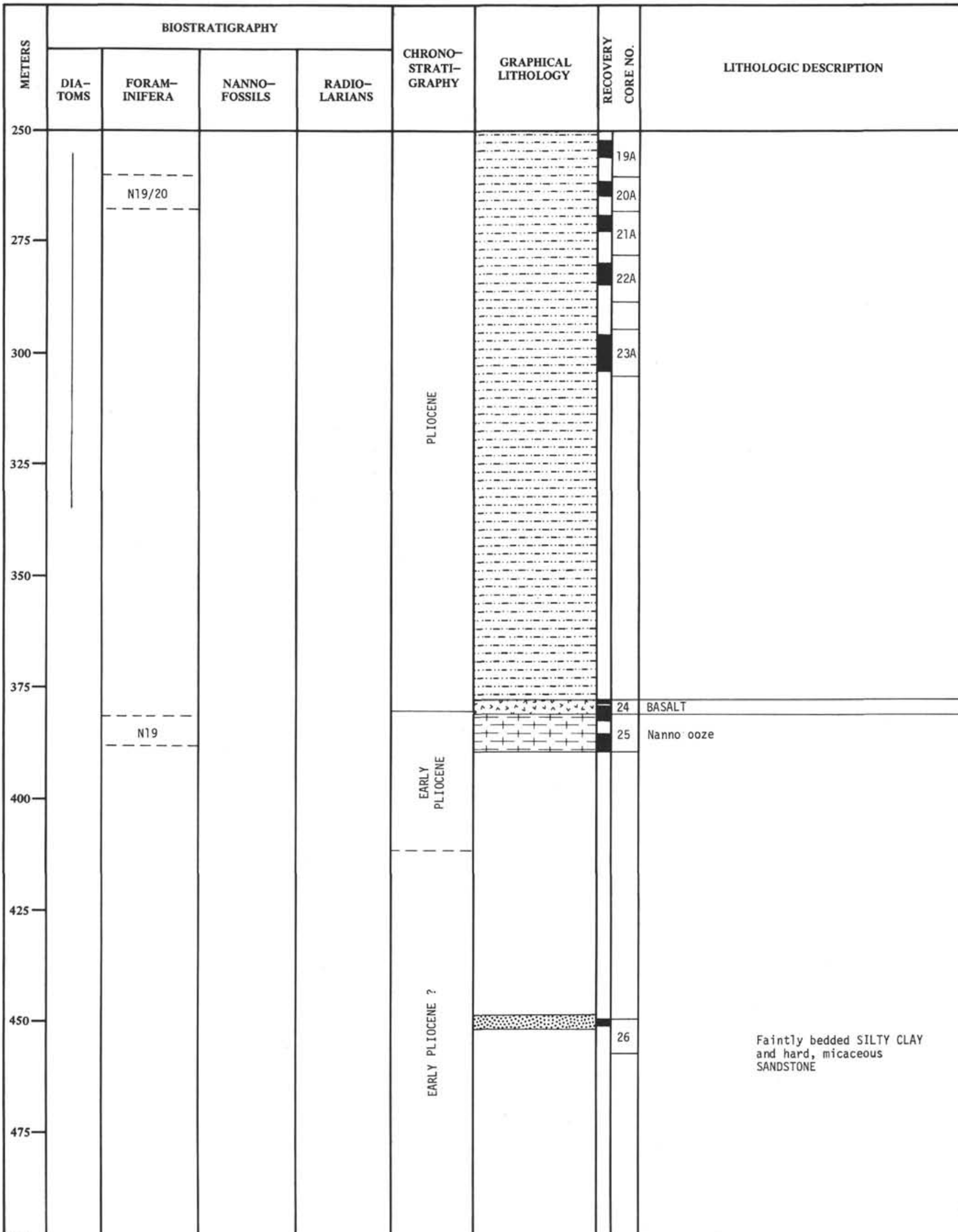
[a]Twisted off bottom-hole assembly at 507.0 meters below sea floor–the last depth (T.D.) drilled.

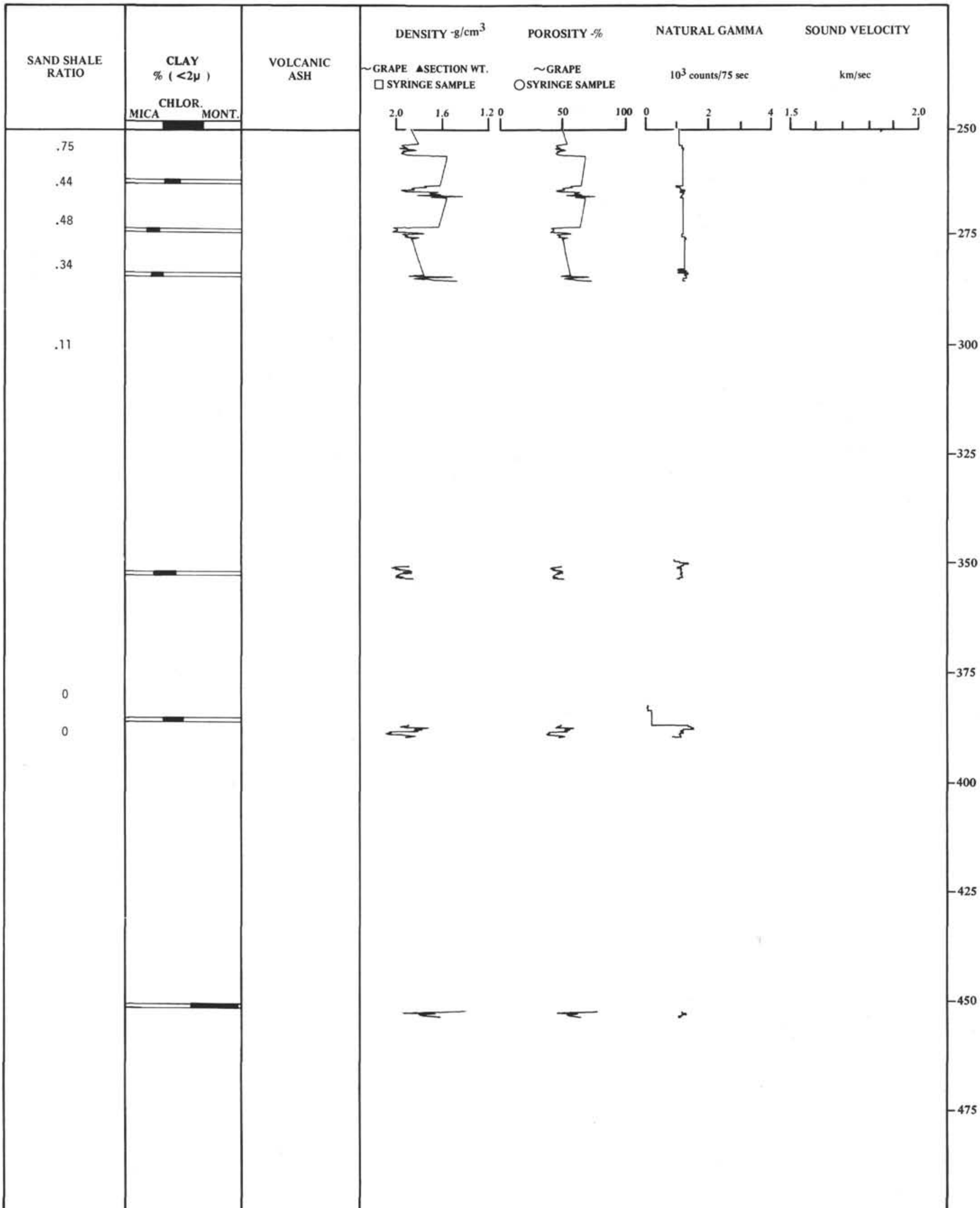
Post-drilling Survey

The *Challenger* got underway at 1509 on 27 June 1971 and steamed southwest (219° T) of the beacon at 6 knots. This course was set to come to a point midway down the southwestern scarp of Paul Revere Ridge. A turn was made between 1531 and 1535 coming to course 051° and then to 058° at 1539. The vessel passed over the beacon offset at 1542 and continued on course 058° at 6 knots. At 1630, the course was changed to 313° and speed increased to 10 knots.


METERS
BIOSTRATIGRAPHY
DIA-TOMS
FORAM-INIFERA
NANNO-FOSSILS
RADIO-LARIANS
CHRONO-STRATI-GRAPHY
GRAPHICAL LITHOLOGY
RECOVERY
CORE NO.
LITHOLOGIC DESCRIPTION
0
25
50
75
100
125
150
175
200
225
250
NPD I
NPD II
NPD III - NPD IV
NPD V
NPD VI
N22/23
N22
N21/22
N21
N20
EMILIANIA HUXLEYI
ARTOSTROBIUM MIRALESTENSE
A. MIRALESTENSE(?)
E. MATUYAMAI
LAMPROCYRTIS HETEROPOROS
PLEISTOCENE
LATE PLIOCENE
PLIOCENE
1A
2A
3A
4A
5A
6A
7A
8A
9A
10A
11A
12A
13A
14A
15A
16A
17A
18A
CLAYEY SILT soft to firm, uniform, slightly mottled.
Scattered sand and silt partings. FORAM RICH near top, DIATOM RICH near bottom.
CLAYEY SILT, firm to compact, with fine sand and silt beds.
DIATOM RICH SILTY CLAY
SILTY CLAY, firm to compact, with thin graded beds of sand.
CARBONATE BEARING SILTY CLAY and NANNO OOZE.
SILTY CLAY, SILT and FINE SAND. Beds of sand grading into silt and silty clay.


SAND SHALE RATIO
CLAY % (<2μ)
MICA CHLOR. MONT.
VOLCANIC ASH
DENSITY -g/cm³
~GRAPE ▲SECTION WT.
□ SYRINGE SAMPLE
2.0 1.6 1.2
POROSITY -%
~GRAPE
○ SYRINGE SAMPLE
0 50 100
NATURAL GAMMA
10³ counts/75 sec
0 2 4
SOUND VELOCITY
km/sec
1.5 2.0
0
0
0
0
0
0
0
.08
0
.21
1.25
.02
.32
1.25
.01
.07
1.14
.18
1.10
0
25
50
75
100
125
150
175
200
225
250


METERS
BIOSTRATIGRAPHY
DIA-TOMS
FORAM-INIFERA
NANNO-FOSSILS
RADIO-LARIANS
CHRONO-STRATI-GRAPHY
GRAPHICAL LITHOLOGY
RECOVERY
CORE NO.
LITHOLOGIC DESCRIPTION
250
275
300
325
350
375
400
425
450
475
500
N19/20
N19
PLIOCENE
EARLY PLIOCENE
EARLY PLIOCENE ?
19A
20A
21A
22A
23A
24
25
26
BASALT
Nanno ooze
Faintly bedded SILTY CLAY and hard, micaceous SANDSTONE


SAND SHALE RATIO
CLAY % (<2μ)
MICA CHLOR. MONT.
VOLCANIC ASH
DENSITY -g/cm3
~GRAPE ▲SECTION WT.
□ SYRINGE SAMPLE
POROSITY -%
~GRAPE
○SYRINGE SAMPLE
NATURAL GAMMA
10³ counts/75 sec
SOUND VELOCITY
km/sec
2.0 1.6 1.2
0 50 100
0 2 4
1.5 2.0
.75
.44
.48
.34
.11
0
0
250
275
300
325
350
375
400
425
450
475
500

Site 177 Hole Core 1 Cored Interval: 0-9.0 m

AGE	ZONE	FORAM*	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
PLEISTOCENE	N22/23 ? Artostrobium miralestense North Pacific Diatom Zone I	C/G			R/P	1	0.5, 1.0				0-19 cm, moderate yellowish brown FORAM RICH SILTY CLAY
		C/G			R/P	2					Medium blue-gray to olive gray, slightly mottled, massive SILTY CLAY
		C/G			R/M	3					
		C/G			R/M	4					thin silty and fine sand partings.
		C/G			R/M	5					
		A/G			R/M	6					Sand filled worm burrows 95-115 cm, sec. 6
		A/G	R/M	F/G	R/G	Core Catcher					

Explanatory notes in chapter 1
*PLANKTONIC FORAMINIFERA

Site 177 Hole A Core 1 Cored Interval: 9.0-18.0 m

AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
PLEISTOCENE	N22 Artostrobium miralestense North Pacific Diatom Zone I	A/G			R/G	1	0.5, 1.0	VOID			Olive gray and dark greenish gray CARBONATE BEARING SILTY CLAY, some mottling. soft to firm and massive.
		A/G			R/M	2		VOID			PYRITE nodule sec. 2, 50 cm.
		A/G	F/M	F/G	R/G	Core Catcher					

Explanatory notes in chapter 1

Site 177 Hole A Core 2 Cored Interval: 18.0-27.0 m

AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	LITHOLOGY	LITHOLOGIC DESCRIPTION
PLEISTOCENE	N22 / Artostrobium miralestense / North Pacific Diatom Zone I					1	VOID	Dark greenish-gray, massive SILTY CLAY
						2	VOID	soft to firm.
						3	VOID	
						4	VOID	
						5	VOID	
		R/P			F/M	6		
	NPDZ II	C/P	F/G	R/M	R/M	Core Catcher		

Explanatory notes in chapter 1

Site 177 Hole A Core 3 Cored Interval: 27.0-36.0 m

AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	LITHOLOGY	LITHOLOGIC DESCRIPTION
PLEISTOCENE	N22 / Artostrobium miralestense / North Pacific Diatom Zone II	R/P		R/M	R/M	1	VOID	Olive gray and dark greenish gray soft to firm SILTY CLAY with several sand filled burrows.
		R/P			R/P	2		
		R/M			R/P	3		
		B			R/M	4		
		B		R/M	R/P	5		1 cm SAND layer Quartz (105-106 cm)
		R/P		R/M	R/P	6		Silt layer with pyrite nodules.
		B	B	R/M	R/M	Core Catcher		

Explanatory notes in chapter 1

Site 177 Hole A Core 4 Cored Interval: 36.0-45.0 m

AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
PLEISTOCENE	N22; Artostrobium miralestense (?); North Pacific Diatom Zone II	R/M			R/P	1	0.5, 1.0				Olive gray to dark greenish gray SILTY CLAY.
		R/P		C/M	R/M	2					
		B			C/G	3					fine sand layer
		R/P		R/M	R/M	4					1 cm pyrite nodule
		A/G			C/G	5					FORAM-BEARING SILTY CLAY, dark gray-green.
	NPDZ IV/III										Well-sorted medium coarse SAND layer, sec. 6, 130-135 cm.
		A/M	C/M	C/G	R/G	Core Catcher					

Explanatory notes in chapter 1

Site 177 Hole A Core 5 Cored Interval: 45.0-54.0 m

AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
PLEISTOCENE	N22; A.M.	F/M		F/M	R/M	1	0.5, 1.0				Dark green-gray SILTY CLAY, firm, massive, slightly mottled.
	Eucyrtidium matuyamai; North Pacific Diatom Zone IV-III	B		F/M	C/G	2					
								VOID			
		B		R/M	R/P	3					
		R/P		R/M	R/M	4					
		R/P		R/M	R/M	5					
				A/G	R/M	6		D D D D; G-G-G-G-G-G			SHALE chips; DIATOM-BEARING SILTY CLAY; GLAUCONITE-BEARING SILTY CLAY (sec. 6, 110-115 cm)
?	N21/22; L. Heteroporos.	R/P	R/P	C/G	C/M	Core Catcher					

Explanatory notes in chapter 1

Site 177 Hole A Core 6 Cored Interval: 54.0-61.0 m

AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
LATE PLIOCENE	N21/22; Lamprocyrtis heteroporos; North Pacific Diatom Zone IV-III	R/P			R/M	1	0.5, 1.0	VOID		–	Dark green-gray, SILTY CLAY, stiff, uniform, massive, slightly mottled.
					R/M	2				–	
					R/M	3				–	
				A/G	C/M	4				–	
	N21; NPDZ V	R/P			C/G	5				–	1 cm quartz Schist pebble. DIATOM-RICH SILTY CLAY, olive gray.
		R/P	B	F/M	C/G	Core Catcher					

Explanatory notes in chapter 1

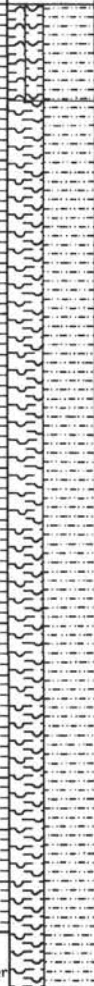
Site 177 Hole A Core 7 Cored Interval: 61.0-70.0 m

AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
LATE PLIOCENE	NPDZ V; N21; Lamprocyrtis heteroporos; NPDZ VI	R/P		F/M	C/G	1	0.5, 1.0	VOID		–	Dark greenish gray, CLAYEY SILT, friable, slightly mottled. Burrows filled with fine sand.
		B		F/M	C/M	2				–	FINE SAND layer (100-115 cm, sec. 2), moderate sorting, grains subangular to subround.
		B	F/M	R/M	R/M	Core Catcher					

Explanatory notes in chapter 1

Site 177 Hole A Core 8 Cored Interval: 79.5-89.0 m

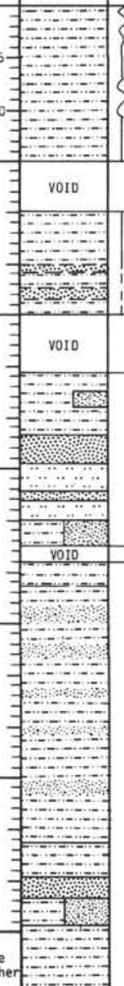
AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
LATE PLIOCENE	Lamprocyrtis heteroporos / North Pacific Diatom Zone VI	B		C/G	A/G	1	0.5, 1.0			—	DIATOM AND RADIOLARIA BEARING SILTY CLAY, olive gray, compact and massive. DIATOM BEARING SILTY CLAY also local DIATOM OOZE, hard fissile SILTY CLAY and layers FINE SAND.
		B		F/G	A/G	2				—	
						3				—	
					C/G, A/M	4				—	
		B		R/M	R/M, R/M	5				—	
		B		R/M		6				—	
		B	B	R/M	R/M	Core Catcher					



Explanatory notes in chapter 1

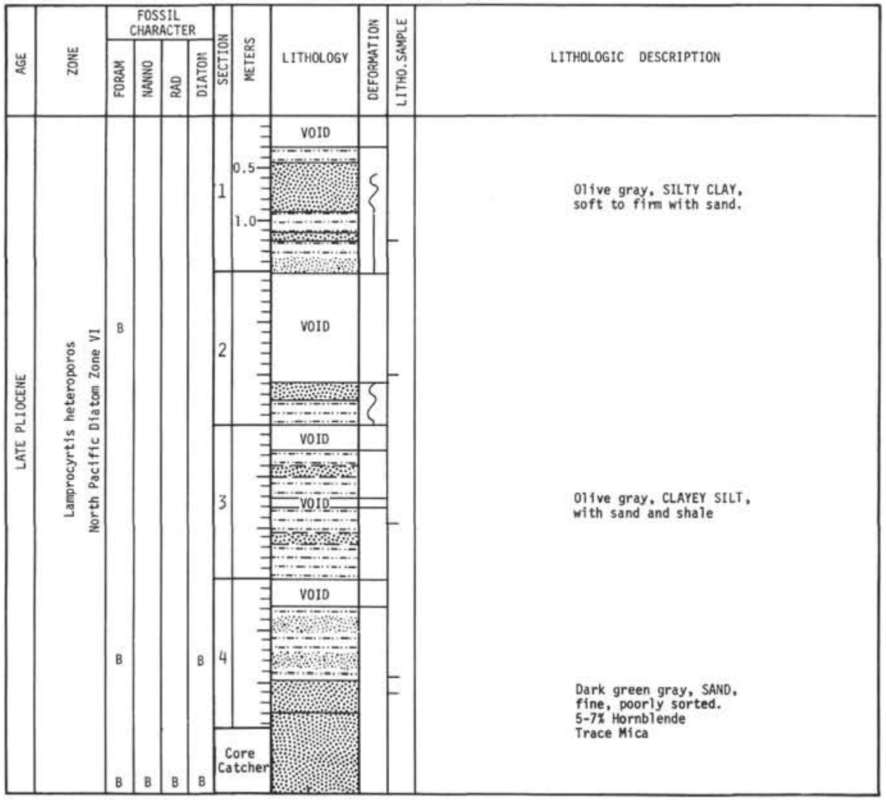
Site 177 Hole A Core 9 Cored Interval: 89.0-98.5 m

AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
LATE PLIOCENE	Lamprocyrtis heteroporos / North Pacific Diatom Zone VI					1	0.5, 1.0			—	Dark green gray, CLAYEY SILT, compact, slightly mottled with sandy and shaly layers.
		B				2		VOID		—	
						3		VOID		—	
		B			R/G	4		VOID		—	
		B			R/M	5				—	
		B			R/P	6				—	
		B	B	R/M	B	Core Catcher					



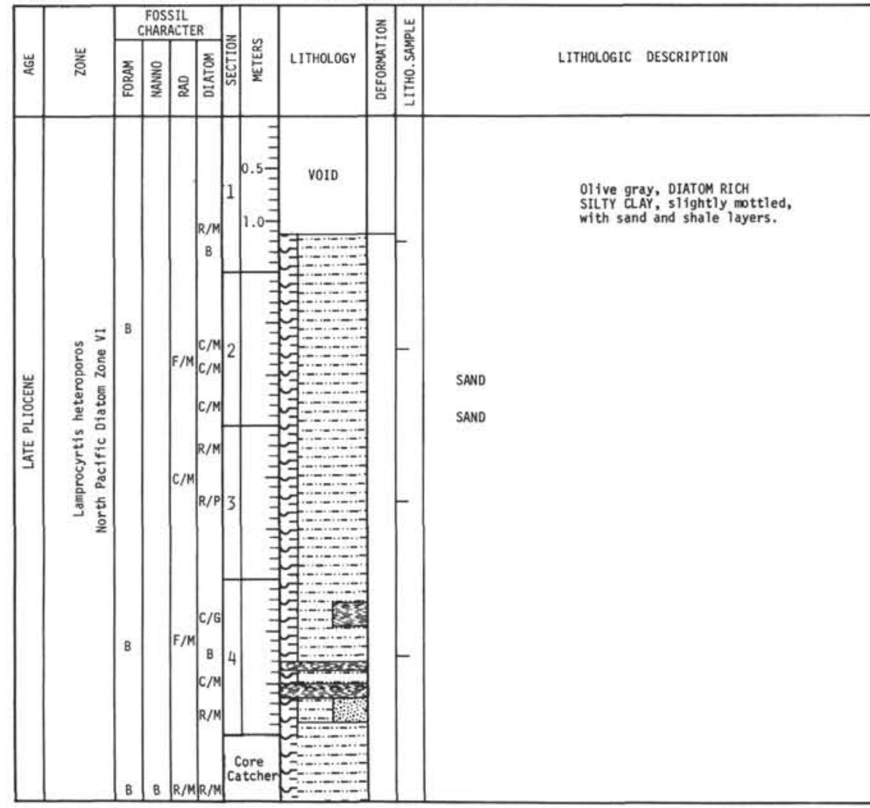
Explanatory notes in chapter 1

Site 177 Hole A Core 10 Cored Interval: 98.5-108.0 m



Explanatory notes in chapter 1

Site 177 Hole A Core 11 Cored Interval: 117.5-127.0 m



Explanatory notes in chapter 1

Site 177 Hole A Core 12 Cored Interval: 146.0-155.5 m

AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
PLIOCENE		B			R/M	1	0.5, 1.0	VOID			Olive gray, CLAYEY SILT, compact and uniform
		B			B	2					ASH-BEARING CLAYEY SILT
		B			B	3					SAND and SILT layers show graded bedding.
		B	B	B	B	Core Catcher					

Site 177 Hole A Core 13 Cored Interval: 174.5-184.0 m

AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
PLIOCENE		B				1	0.5, 1.0	VOID			SILTY CLAY, olive gray (GY4/1). SAND layer at bottom of core.
		B	F/M	B	B	Core Catcher					

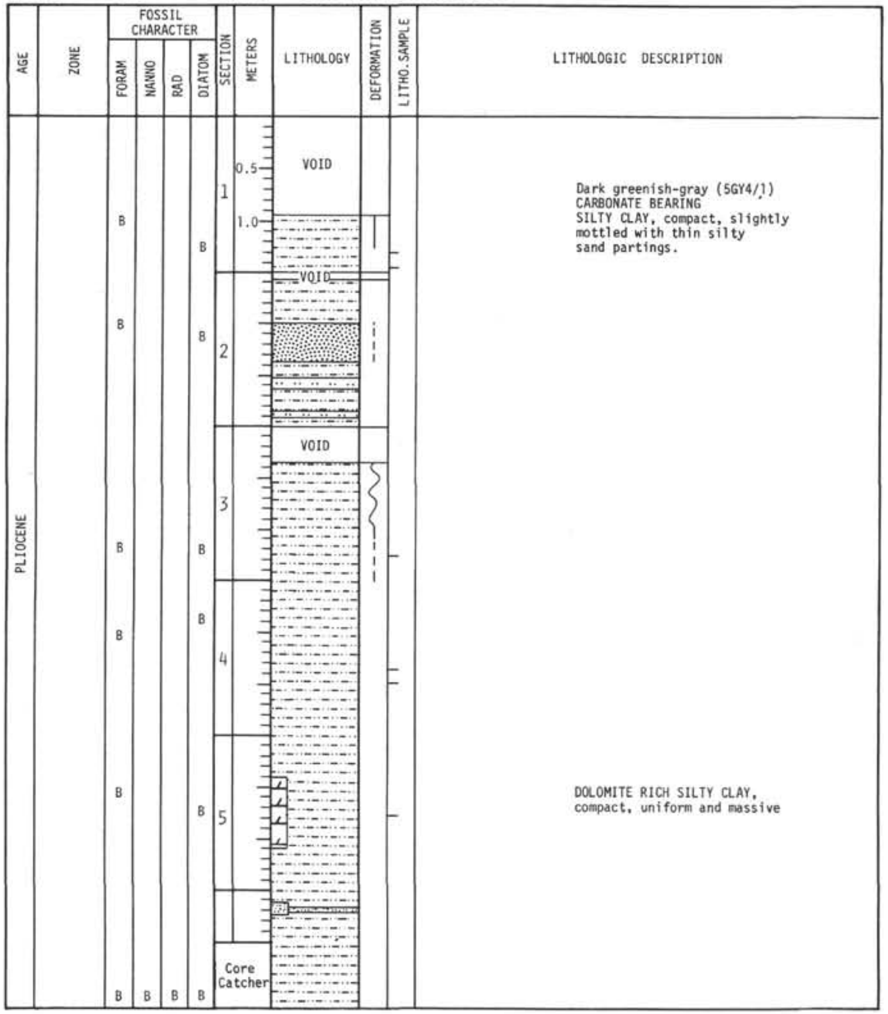
Explanatory notes in chapter 1

Site 177 Hole A Core 14 Cored Interval: 203.0-212.5 m

AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
PLIOCENE	N20					1	0.5, 1.0	VOID			
		F/P			B	2					SAND layer; Olive gray, SILTY CLAY, compact and uniform.
		R/P			B	3					
		C/M			B	4					NANNO OOZE
		F/M									
		R/P			B	5					
		R/P			B	6					COARSE SAND; CARBONATE BEARING CLAYEY SILT
		B	R/M	B	B	Core Catcher					

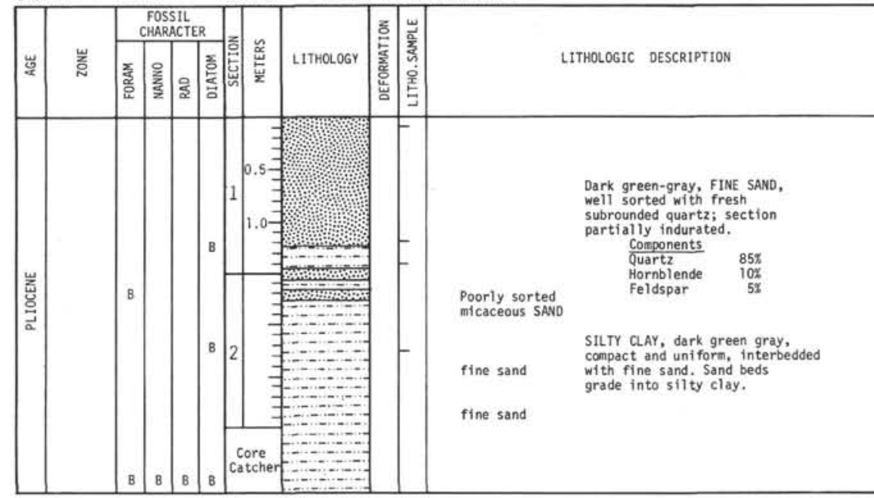
Explanatory notes in chapter 1

Site 177 Hole A Core 15 Cored Interval: 212.5-222.0 m

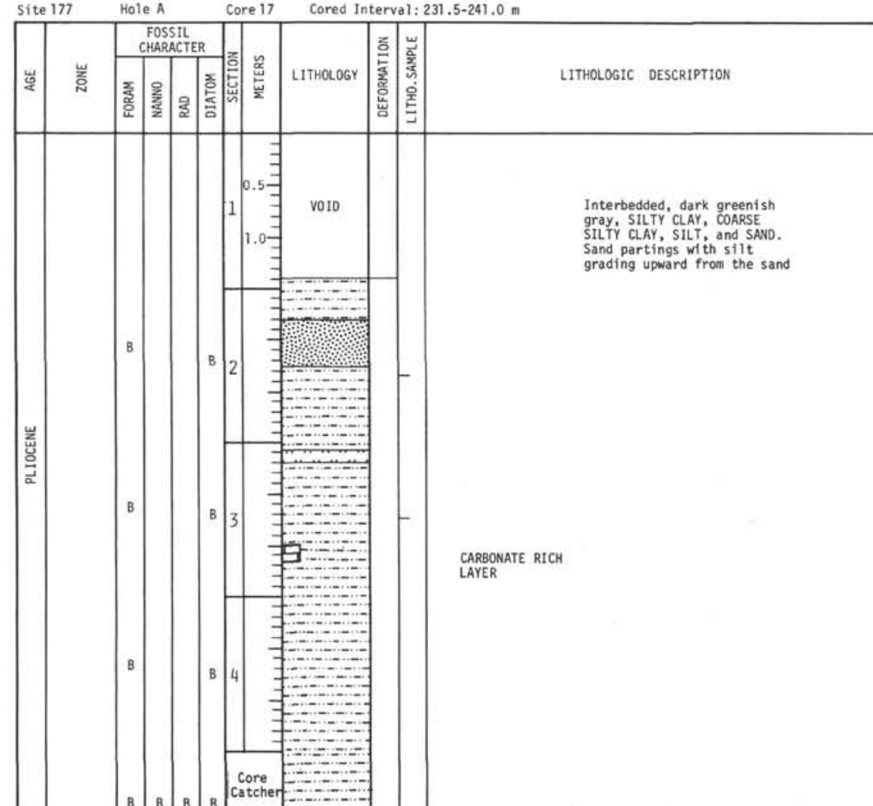


Explanatory notes in chapter 1

Site 177 Hole A Core 16 Cored Interval: 222.0-231.5 m



Site 177 Hole A Core 17 Cored Interval: 231.5-241.0 m



Explanatory notes in chapter 1

Site 177 Hole A Core 18 Cored Interval: 241.0-250.5 m

AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
PLIOCENE		B			B	1	0.5, 1.0			—	Dark greenish gray SILTY CLAY, compact, and massive, interbedded with fine grained sands. Graded bedding.
		B			B	2				— —	
		B			B	3				—	
		B	B	B	B	Core Catcher					

Site 177 Hole A Core 19 Cored Interval: 250.5-260.0 m

AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
PLIOCENE		B			B	1	0.5, 1.0	VOID 		—	Interbedded, olive gray and dark greenish gray SILTY CLAY, SILT, and SAND. The SILTY CLAY is compact with the FINE SAND and SILT beds grading up into the mud. Coarse beds have sharp basal contact.
		B			B	2					
		B			B	3				—	worm burrow
		B	R/P	B	B	Core Catcher					

Explanatory notes in chapter 1

Site 177 Hole A Core 20 Cored Interval: 260.0-269.5 m

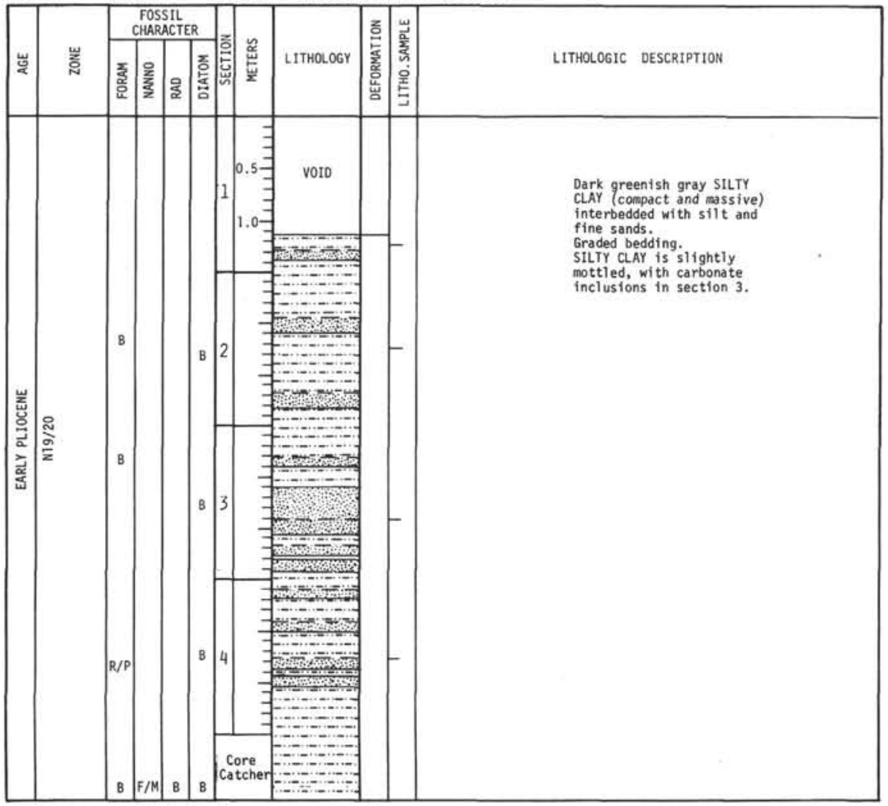
AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
PLIOCENE	N19/20	R/P			B	1	0.5, 1.0	VOID 		—	Dark green gray SILTY CLAY compact and massive with graded interbeds of SAND and SILT.
		B			B	2					
		B			B	3				— —	CARBONATE RICH CLAYEY SILT (sec. 3, 55-65 cm)
		B	R/M	B	B	Core Catcher					

Site 177 Hole A Core 21 Cored Interval: 269.5-279.0 m

AGE	ZONE	FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
PLIOCENE					B	1	0.5, 1.0	VOID 			Dark green gray interbeds of hard SILTY CLAY, SILT, and VERY FINE SAND. Graded bedding.
		B			B	2				—	
		B				3				— —	
		B	R/M	B	B	Core Catcher					

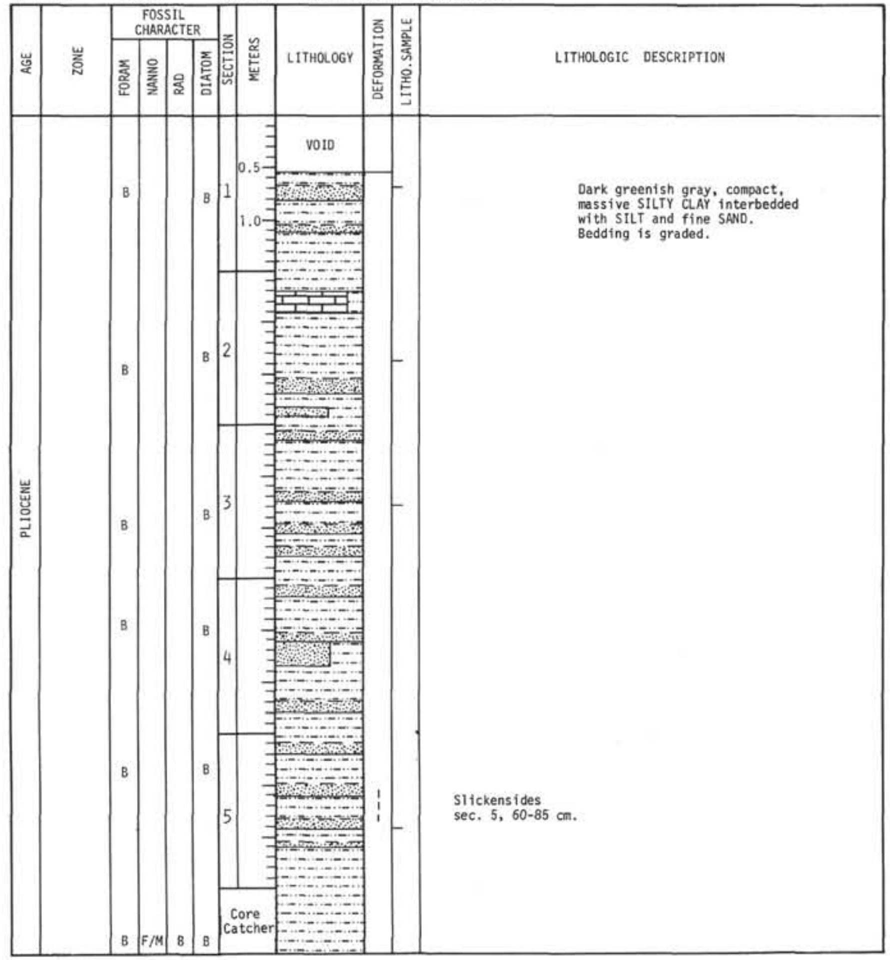
Explanatory notes in chapter 1

Site 177 Hole A Core 22 Cored Interval: 279.0-288.5 m



Explanatory notes in chapter 1

Site 177 Hole A Core 23 Cored Interval: 345.5-355.0 m



Explanatory notes in chapter 1

Site 177 Hole A Core 24 Cored Interval: 378.5-381.5 m

AGE	ZONE	FOSSIL CHARACTER: FORAM	DIATOM	RAD	NANNO	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
PLIOCENE						1	0.5, 1.0	VOID			BASALT, hard fractured, diabasic. Fractures are filled with carbonate veinlets.
						2					
						Core Catcher					

Site 177 Hole A Core 25 Cored Interval: 381.5-389.0 m

AGE	ZONE	FOSSIL CHARACTER: FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
EARLY PLIOCENE	N19					1	0.5, 1.0	VOID			Dark green DIABASE, greenstone alteration.
						2					Nanno bearing silty clay.
		C/G			B	3					
		C/M									NANNO OOZE, compact, solid, uniform, very slightly mottled. Dipping beds (not a result of drilling disturbance).
		C/P			B	4					
		F/P									
		C/M	A/G	B	B	Core Catcher					

Explanatory notes in chapter 1

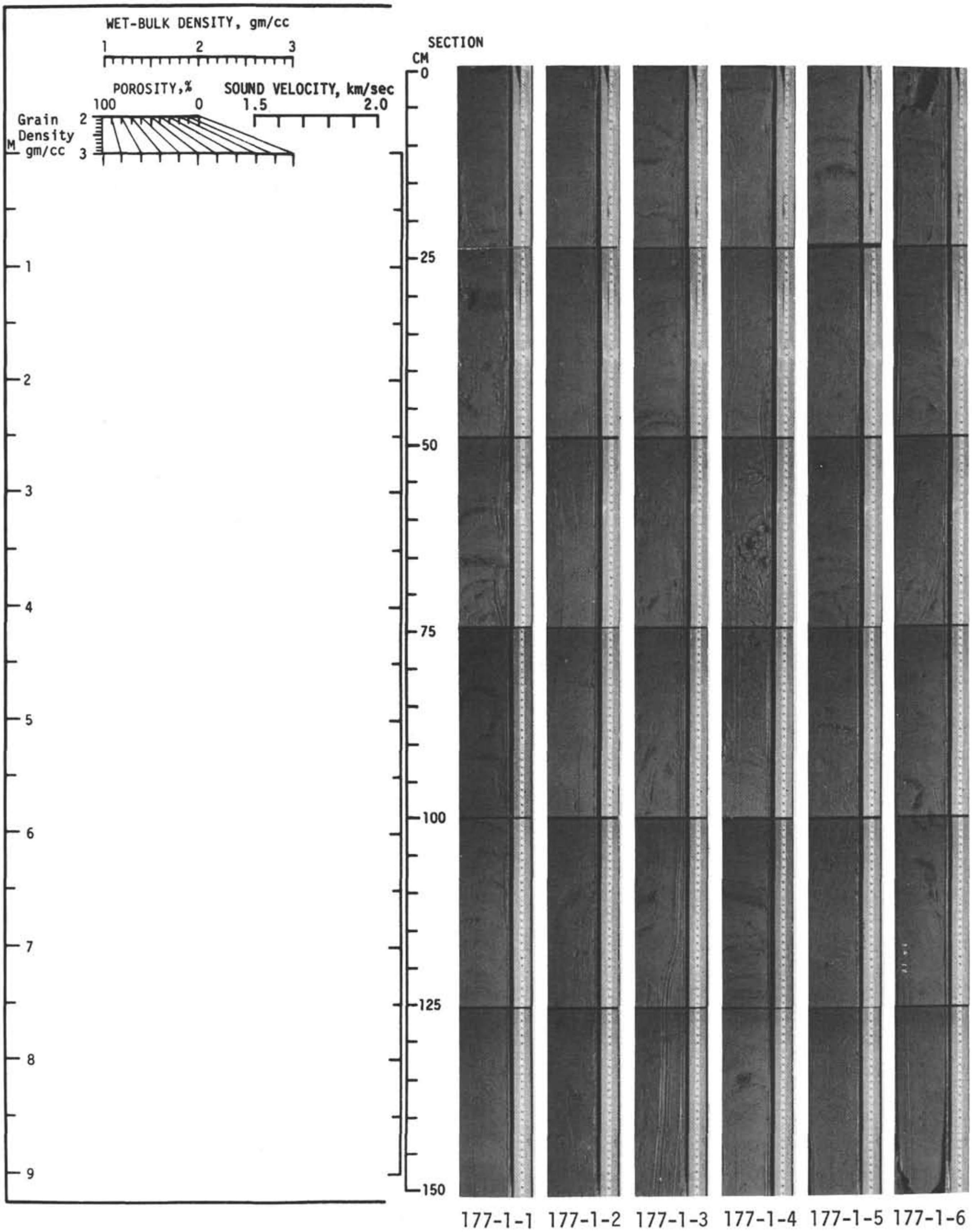
Site 177 Hole A Core 26 Cored Interval: 450.0-459.5 m

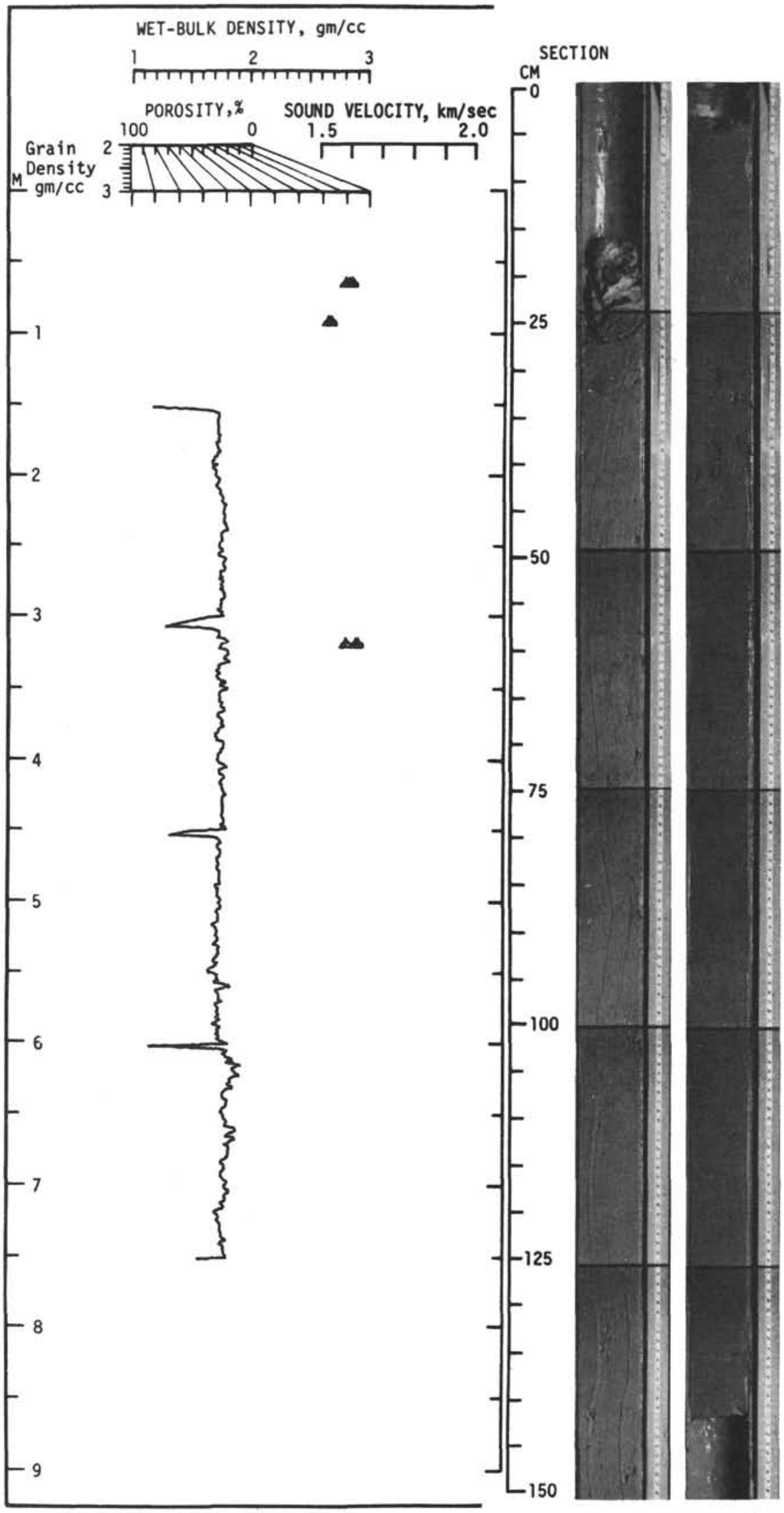
AGE	ZONE	FOSSIL CHARACTER: FORAM	NANNO	RAD	DIATOM	SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
EARLY PLIOCENE ?		B			B	1	0.5				True dip 31° — Olive gray compact, uniform SILTY CLAY with some carbonate.
		B			B		1.0				ASH-BEARING COARSE SILT, dark greenish gray, slightly burrow mottled.
		B				Core Catcher					Hard carbonate cement SAND - poorly sorted, quartzose.

Components

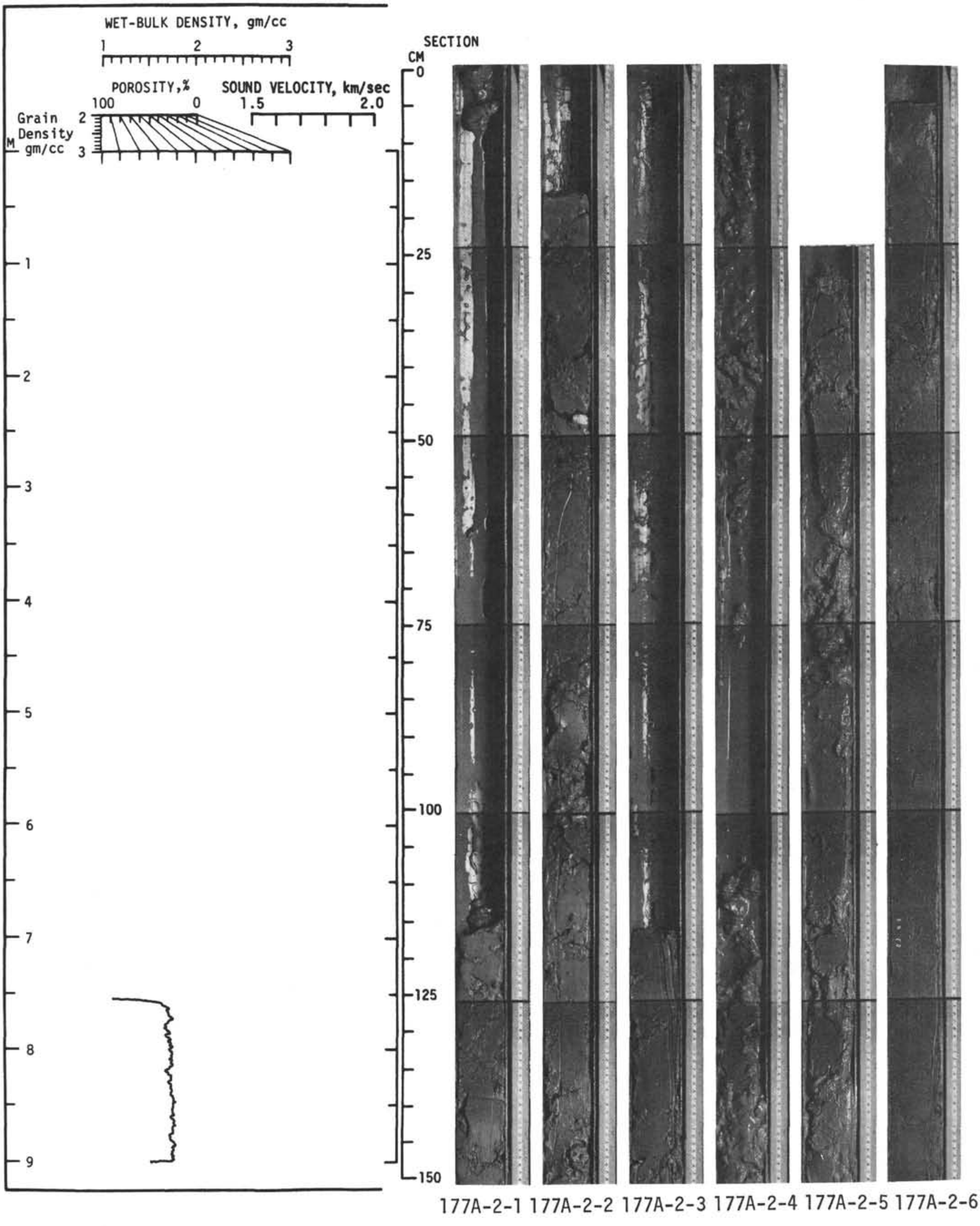
Components	
Dark and Light Mica	5-7%
Hornblende	rare
Garnet	rare

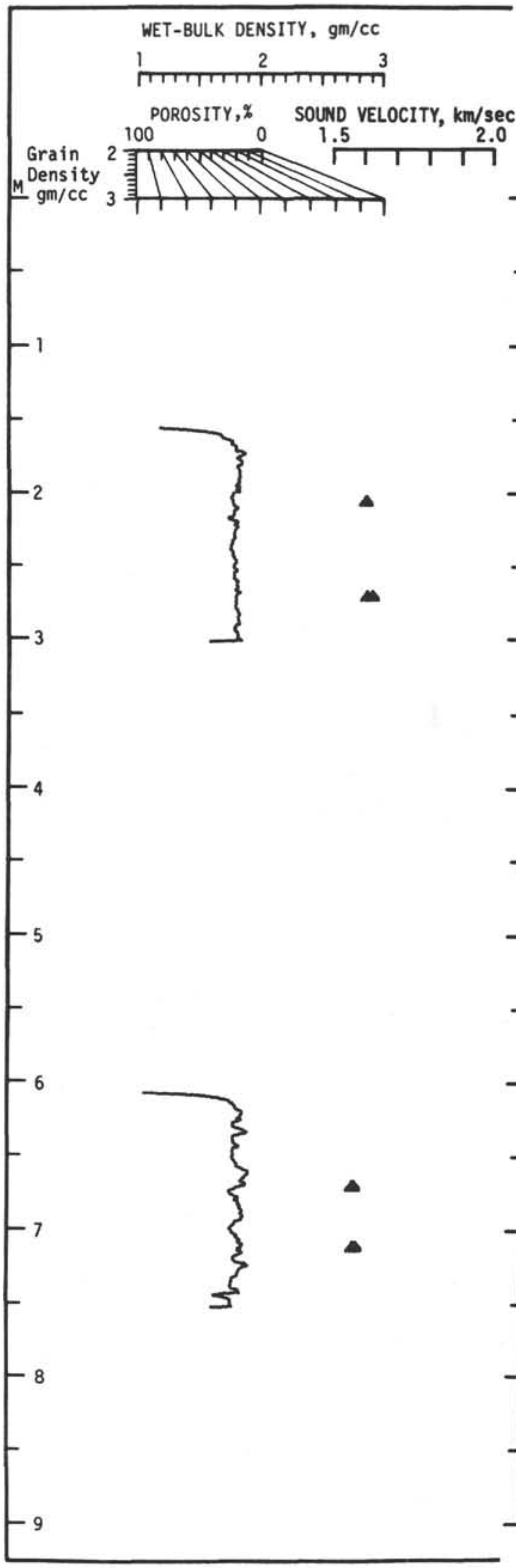
Explanatory notes in chapter 1

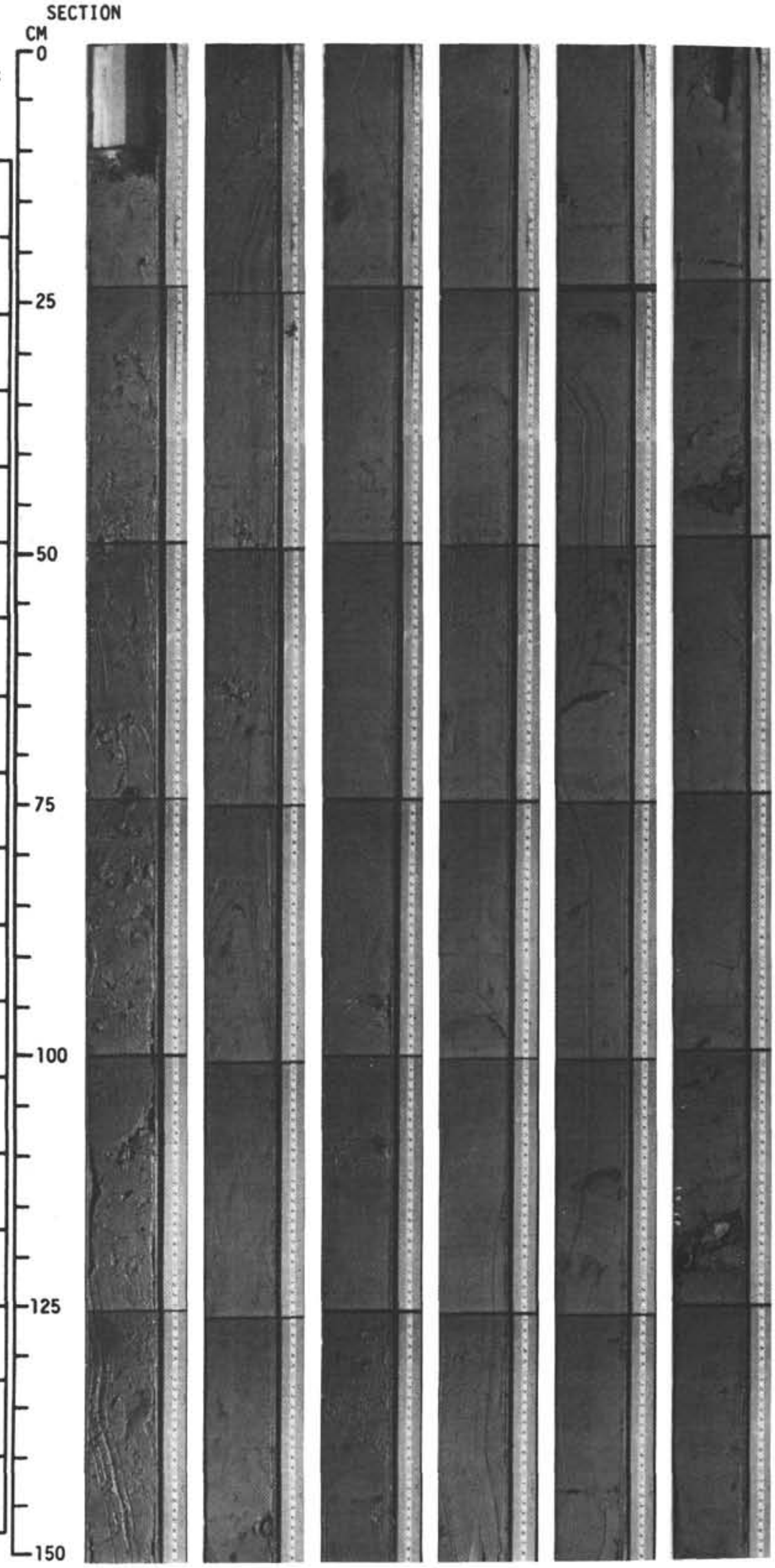

WET-BULK DENSITY, gm/cc
1
2
3
POROSITY,%
100
0
SOUND VELOCITY, km/sec
1.5
2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150
177-1-1
177-1-2
177-1-3
177-1-4
177-1-5
177-1-6



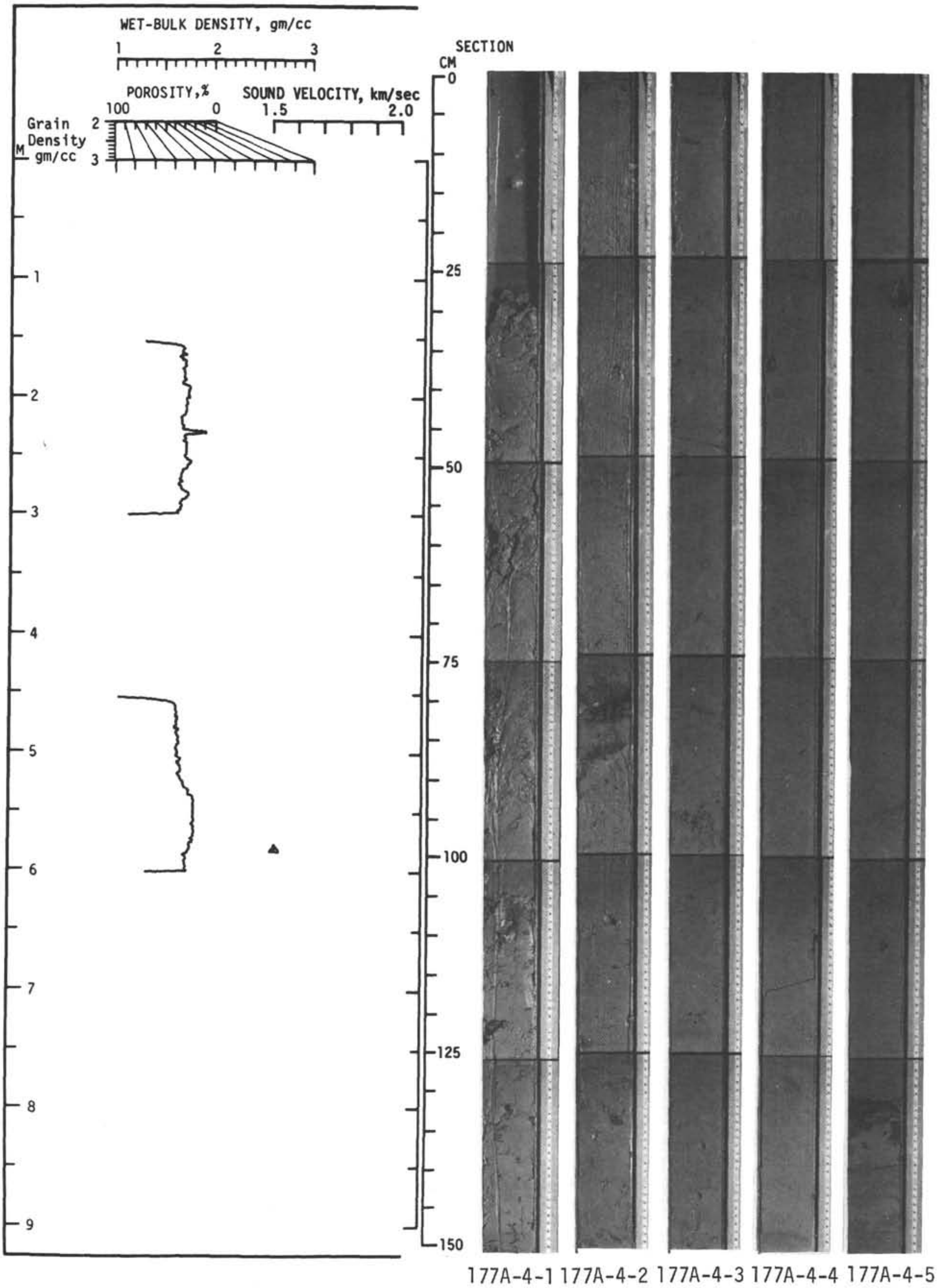
177A-1-1 177A-1-2

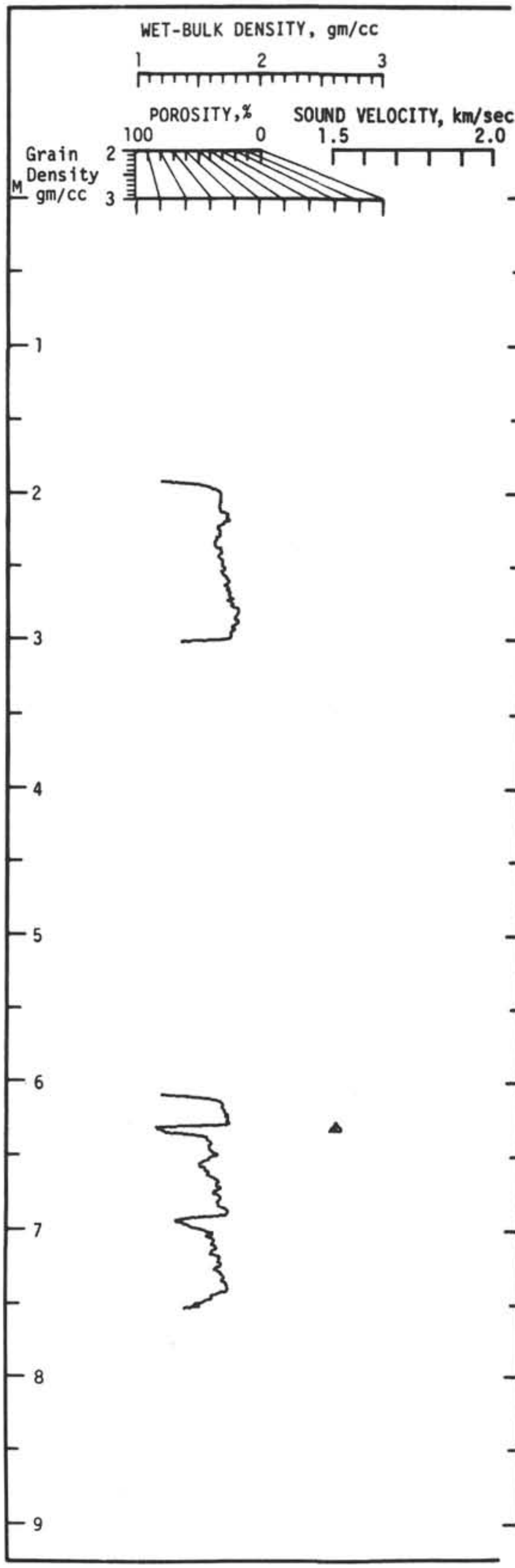

WET-BULK DENSITY, gm/cc
1
2
3
POROSITY,%
100
0
SOUND VELOCITY, km/sec
1.5
2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150
177A-2-1
177A-2-2
177A-2-3
177A-2-4
177A-2-5
177A-2-6

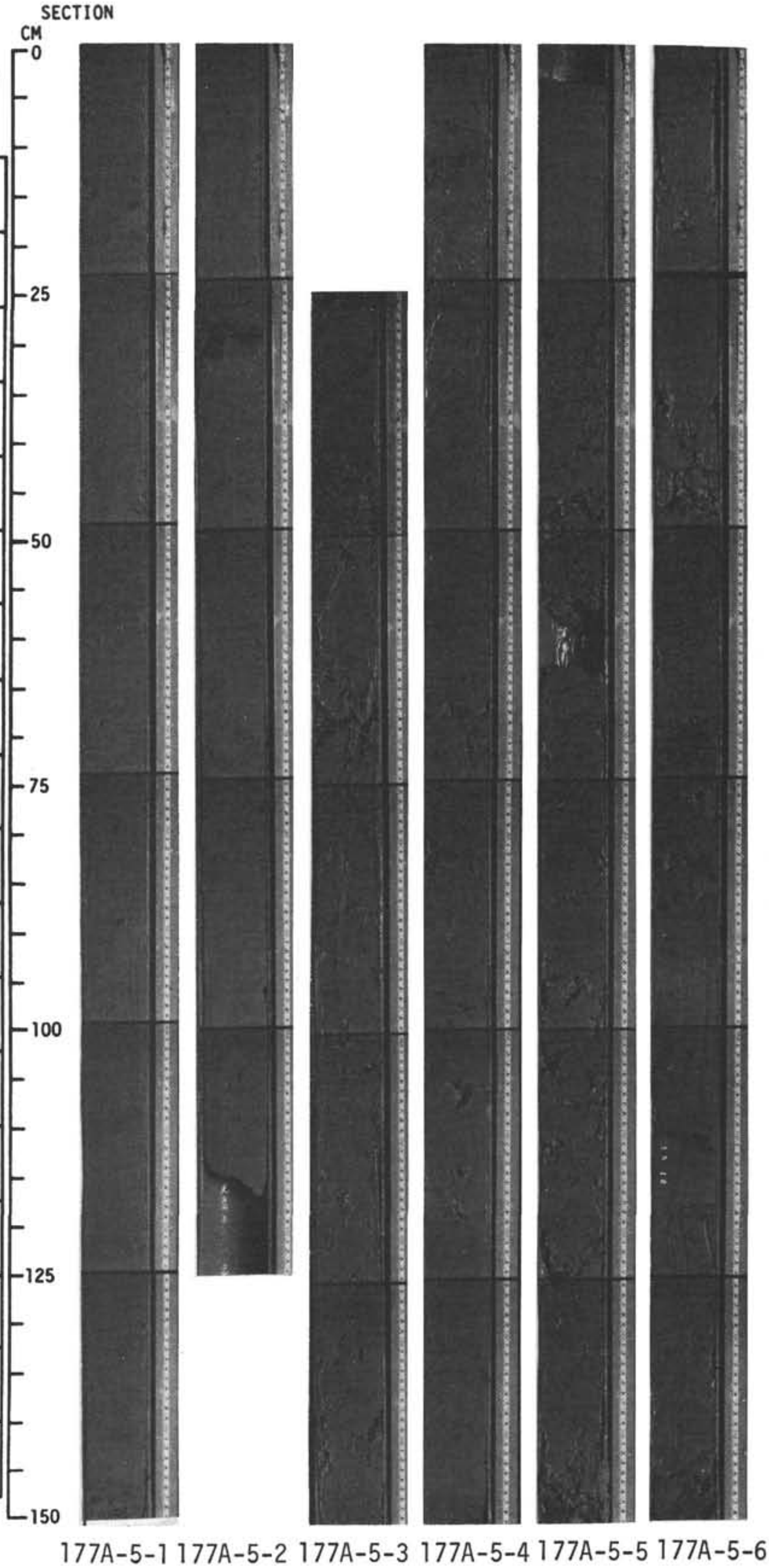


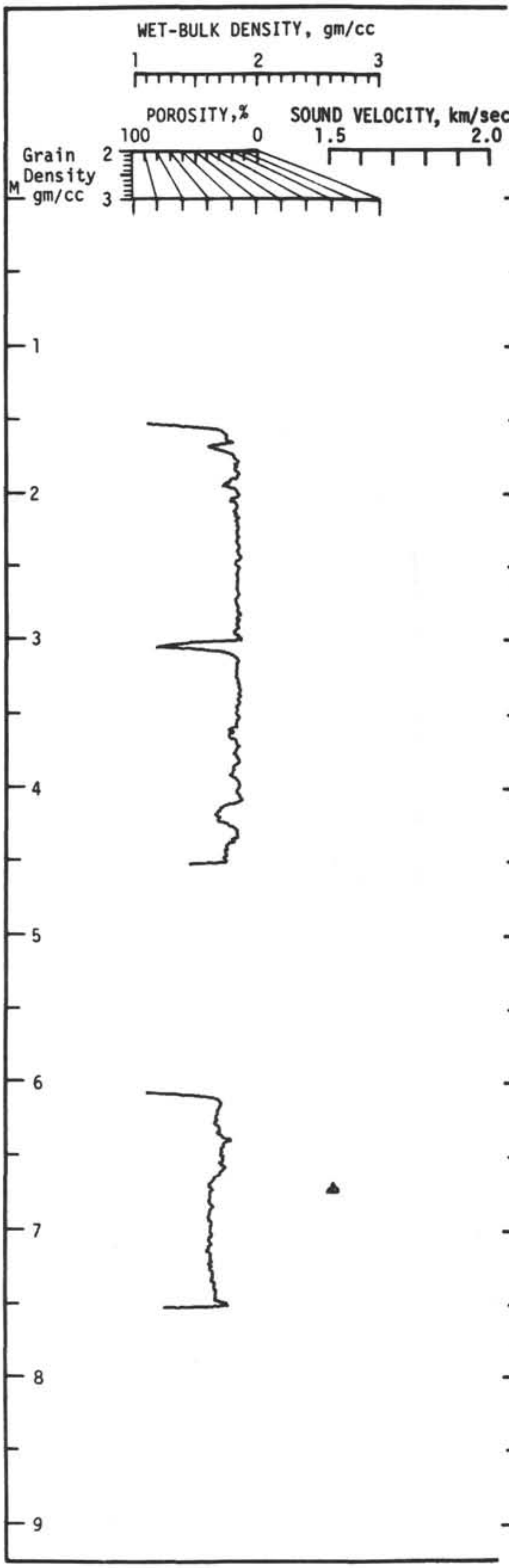


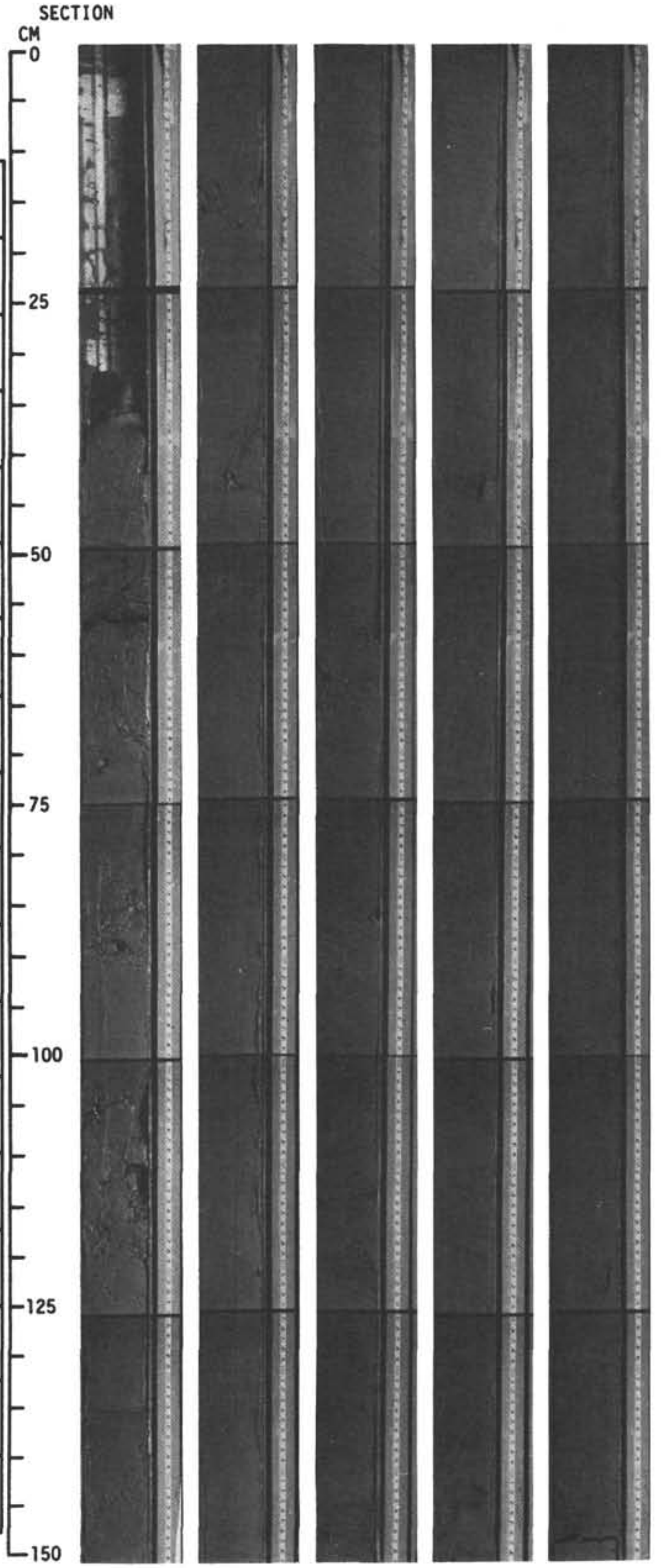
177A-3-1 177A-3-2 177A-3-3 177A-3-4 177A-3-5 177A-3-6


WET-BULK DENSITY, gm/cc
1
2
3
POROSITY,%
100
0
SOUND VELOCITY, km/sec
1.5
2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150
177A-4-1
177A-4-2
177A-4-3
177A-4-4
177A-4-5

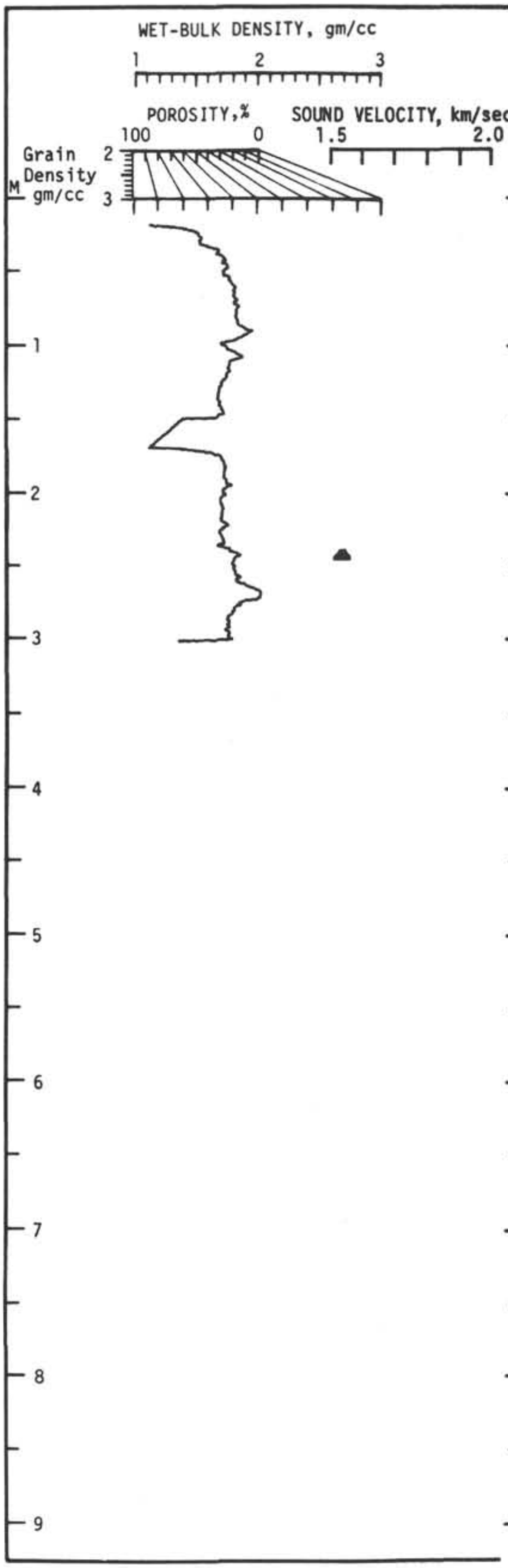

WET-BULK DENSITY, gm/cc
1
2
3
POROSITY,%
100
0
SOUND VELOCITY, km/sec
1.5
2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9

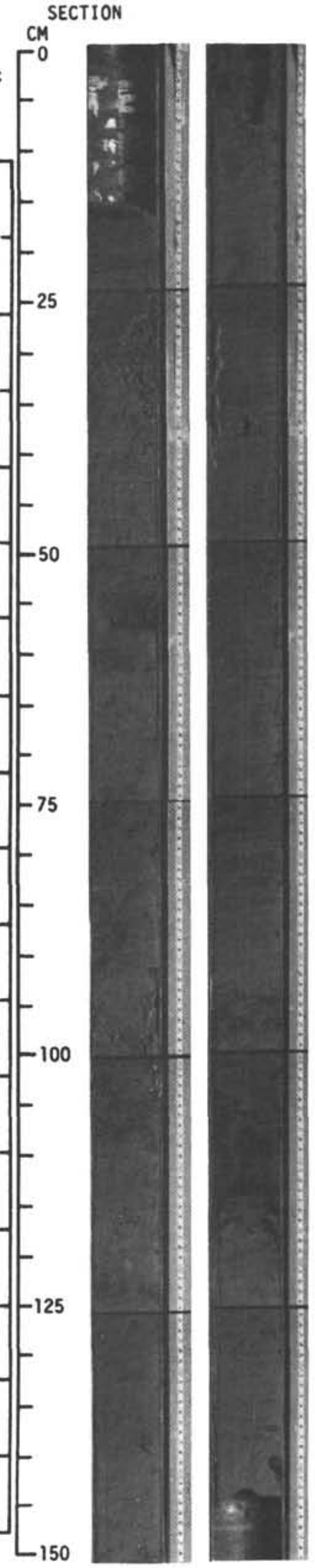

SECTION
CM
0
25
50
75
100
125
150
177A-5-1
177A-5-2
177A-5-3
177A-5-4
177A-5-5
177A-5-6



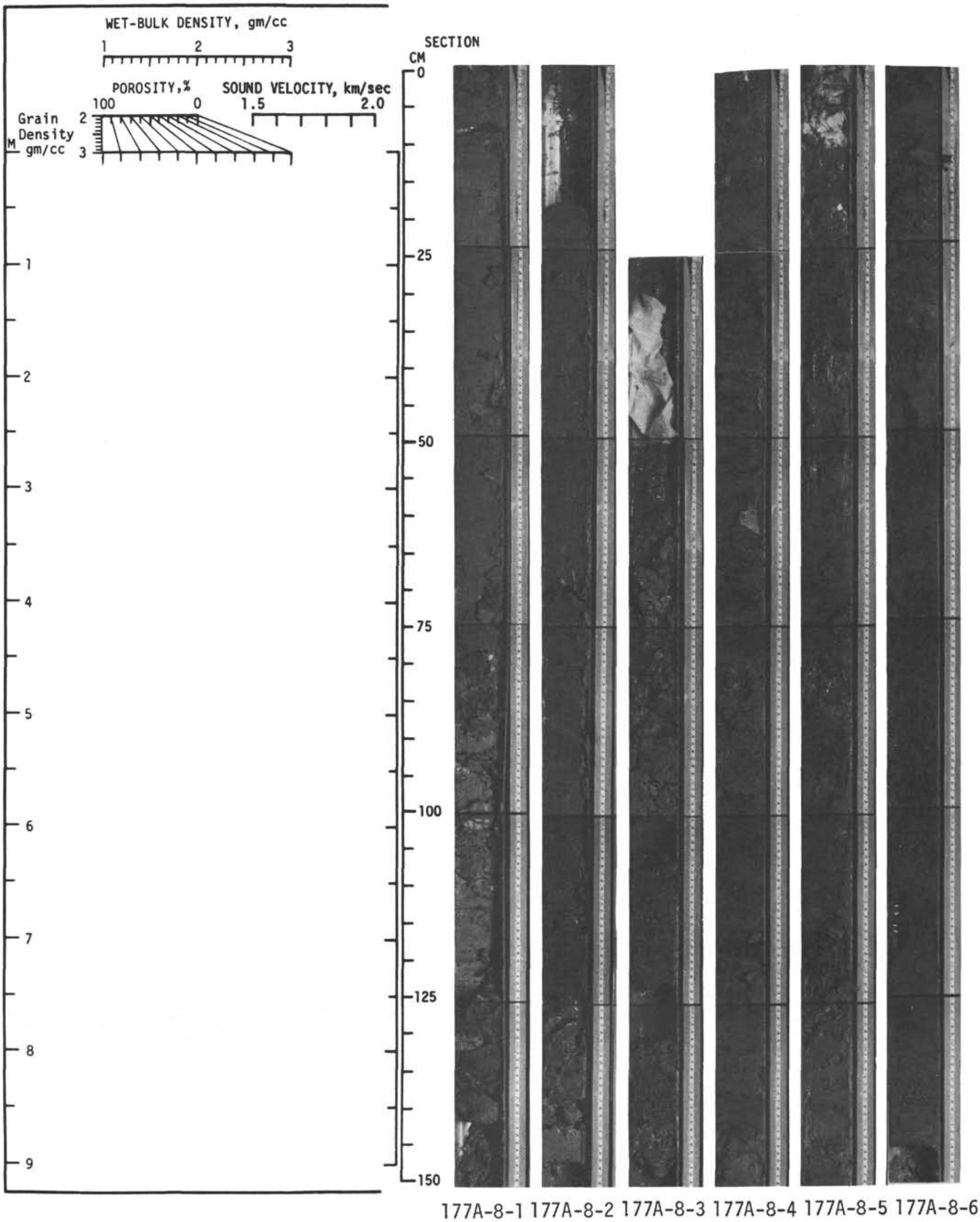


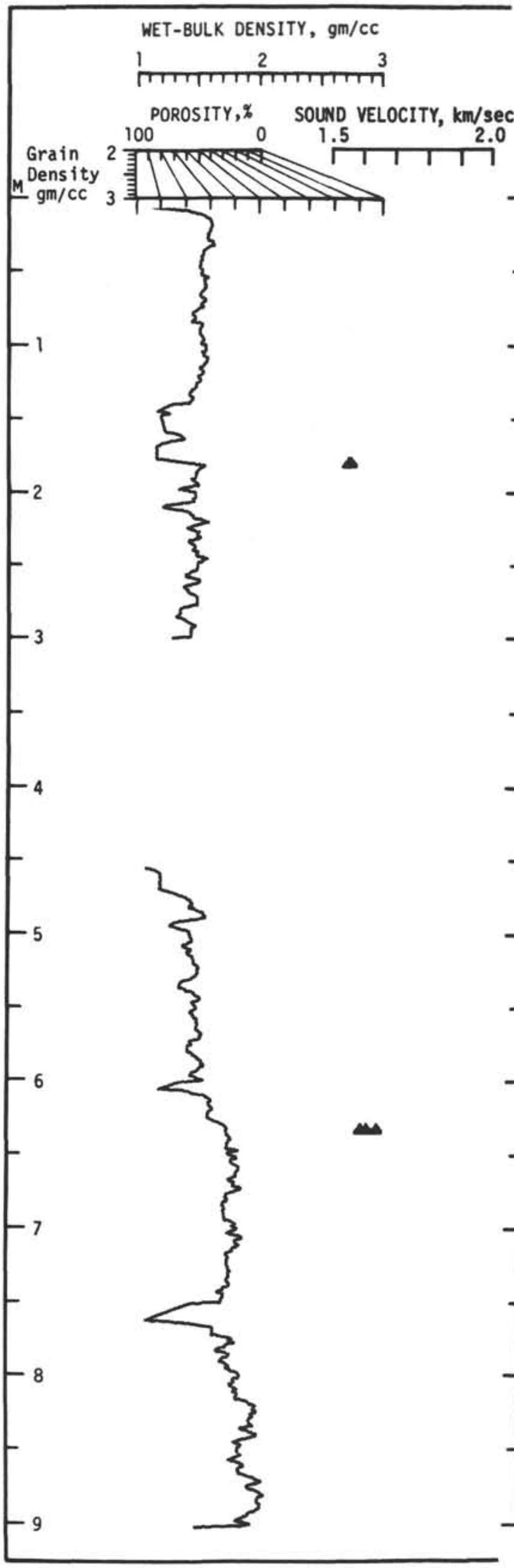
177A-6-1 177A-6-2 177A-6-3 177A-6-4 177A-6-5

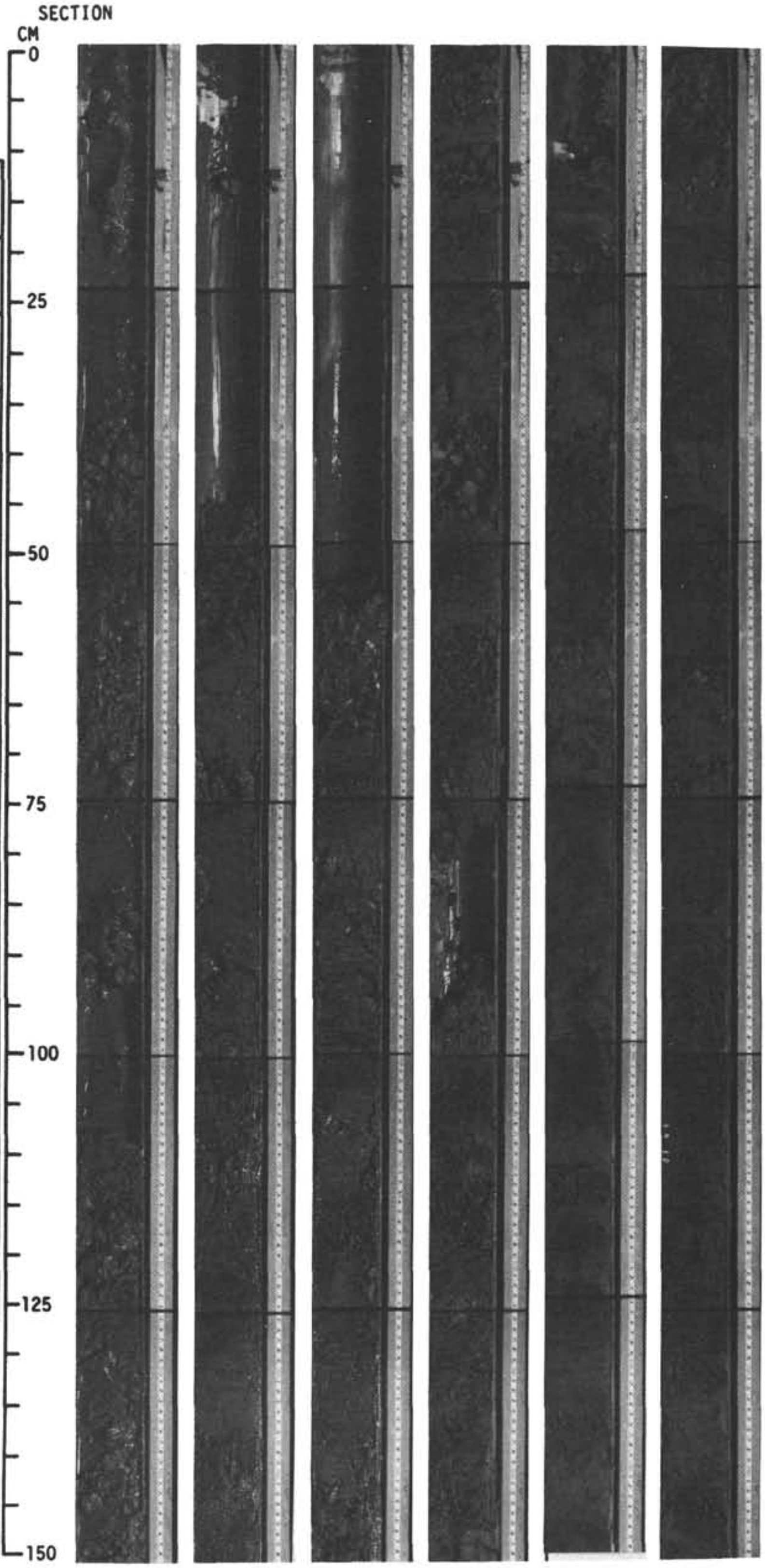




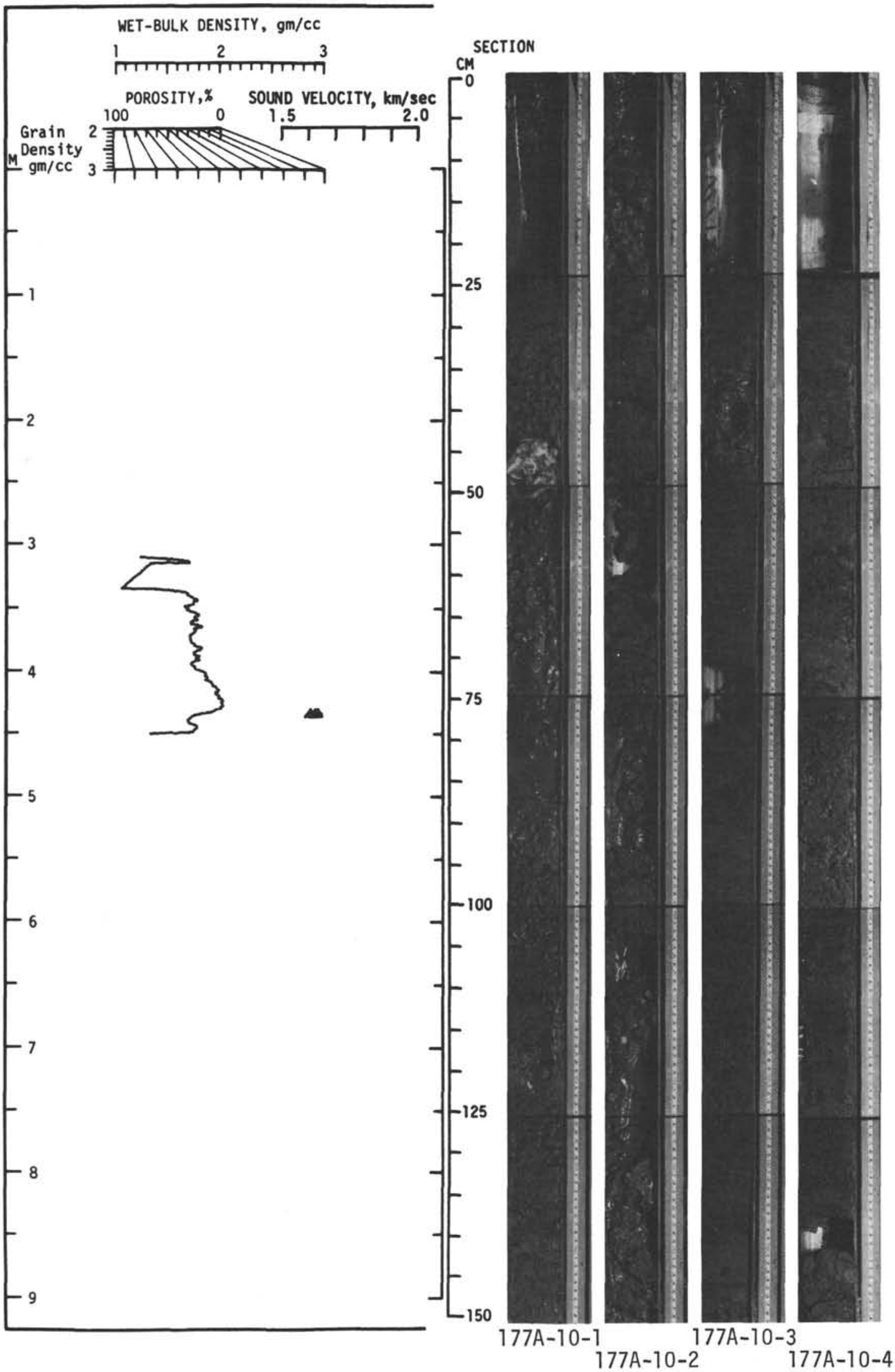
177A-7-1 177A-7-2

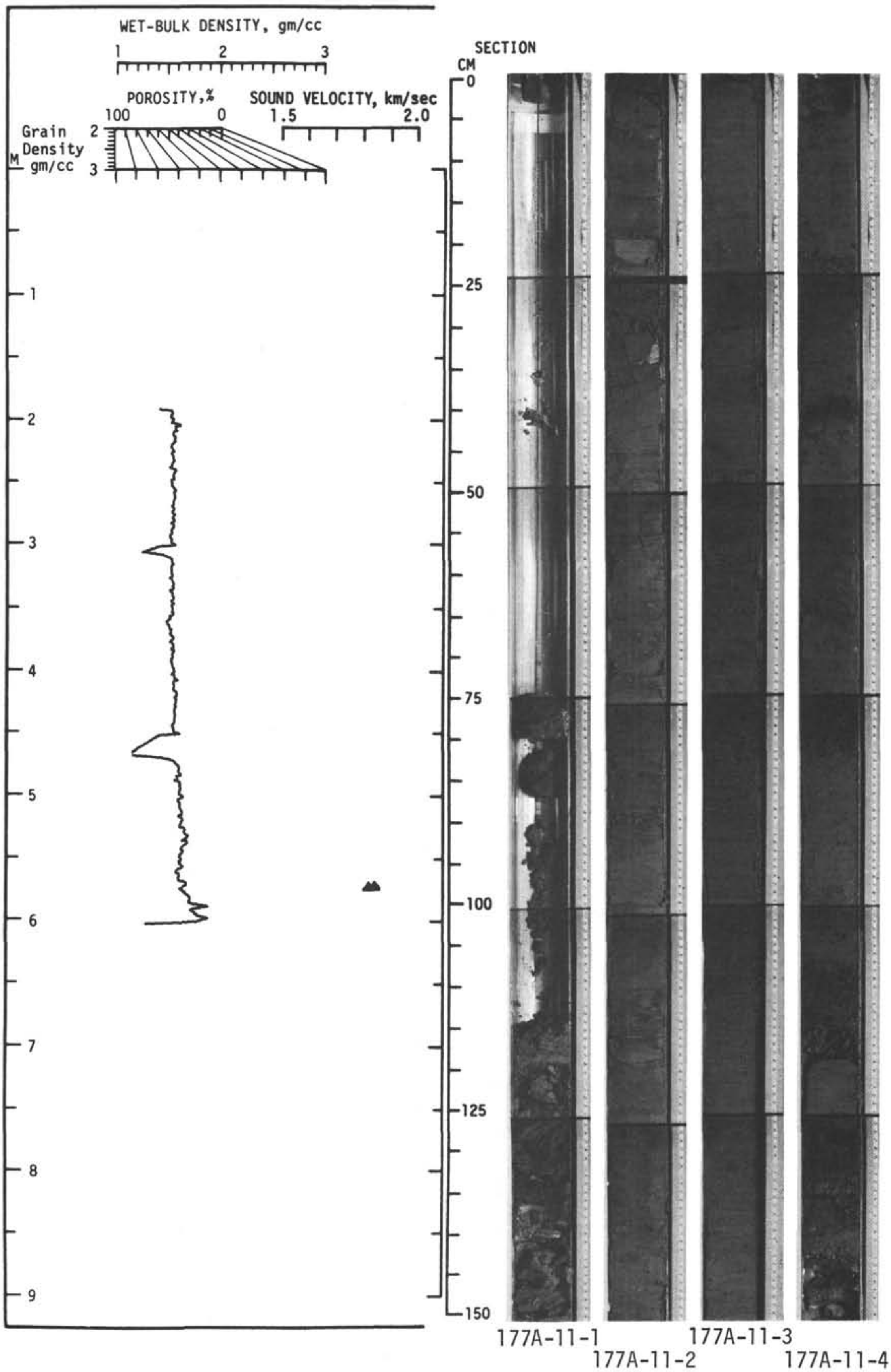

WET-BULK DENSITY, gm/cc
1 2 3
POROSITY,% 100 0
SOUND VELOCITY, km/sec 1.5 2.0
Grain Density gm/cc 2 3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150
177A-8-1 177A-8-2 177A-8-3 177A-8-4 177A-8-5 177A-8-6

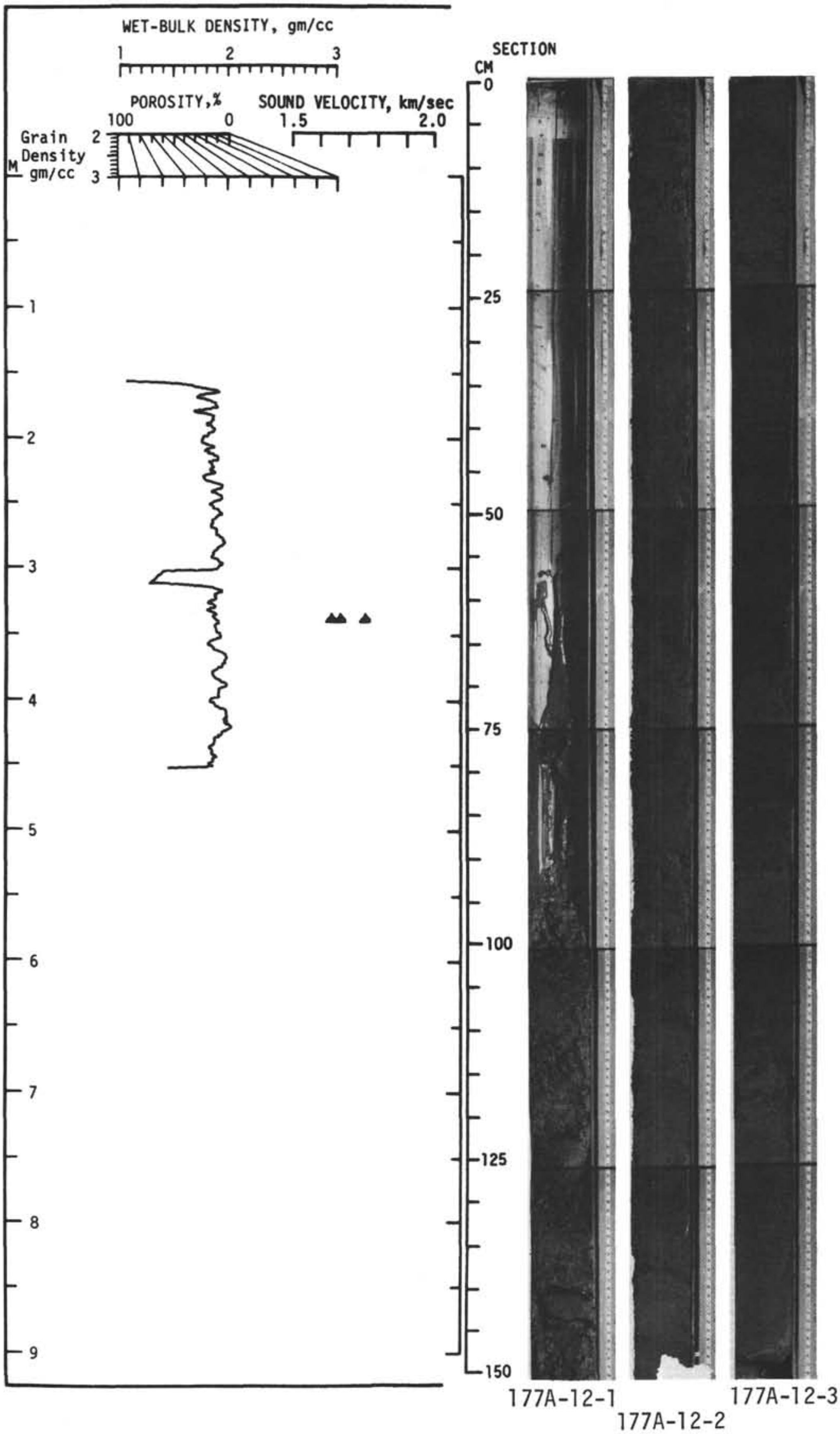


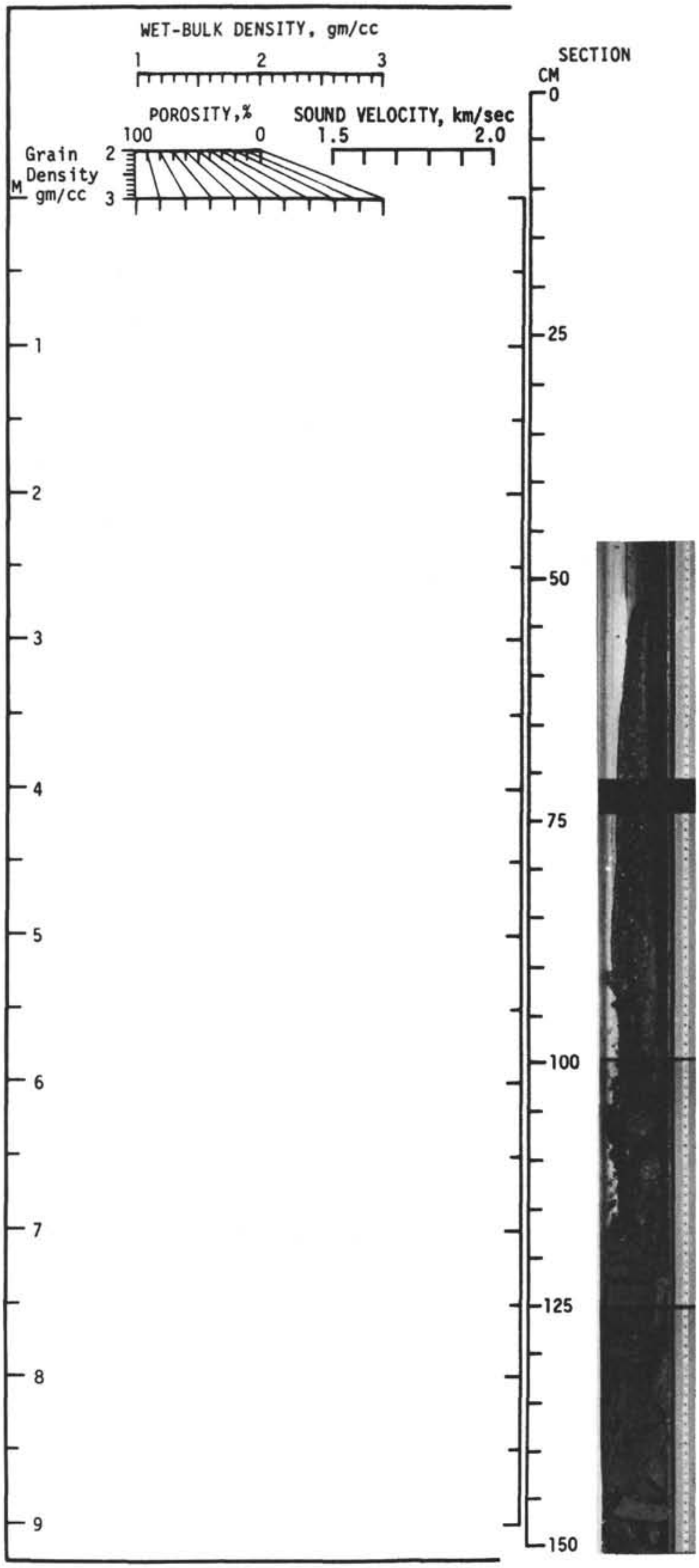


177A-9-1 177A-9-2 177A-9-3 177A-9-4 177A-9-5 177A-9-6

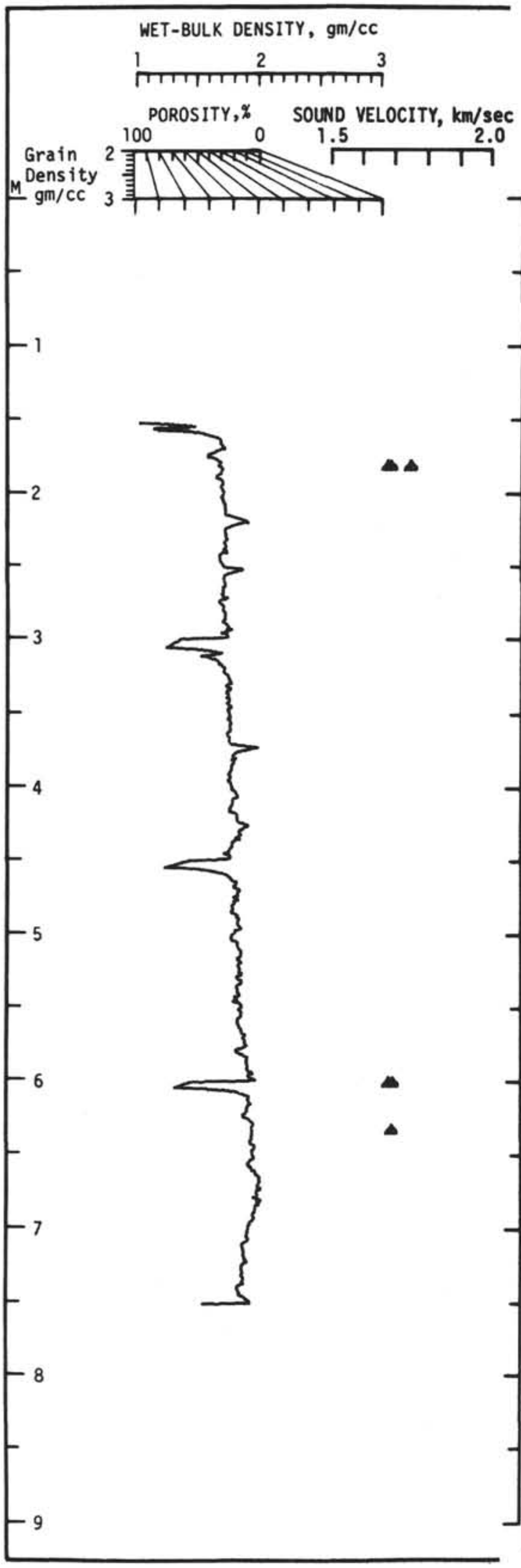

WET-BULK DENSITY, gm/cc
1
2
3
POROSITY,%
100
0
SOUND VELOCITY, km/sec
1.5
2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150
177A-10-1
177A-10-2
177A-10-3
177A-10-4

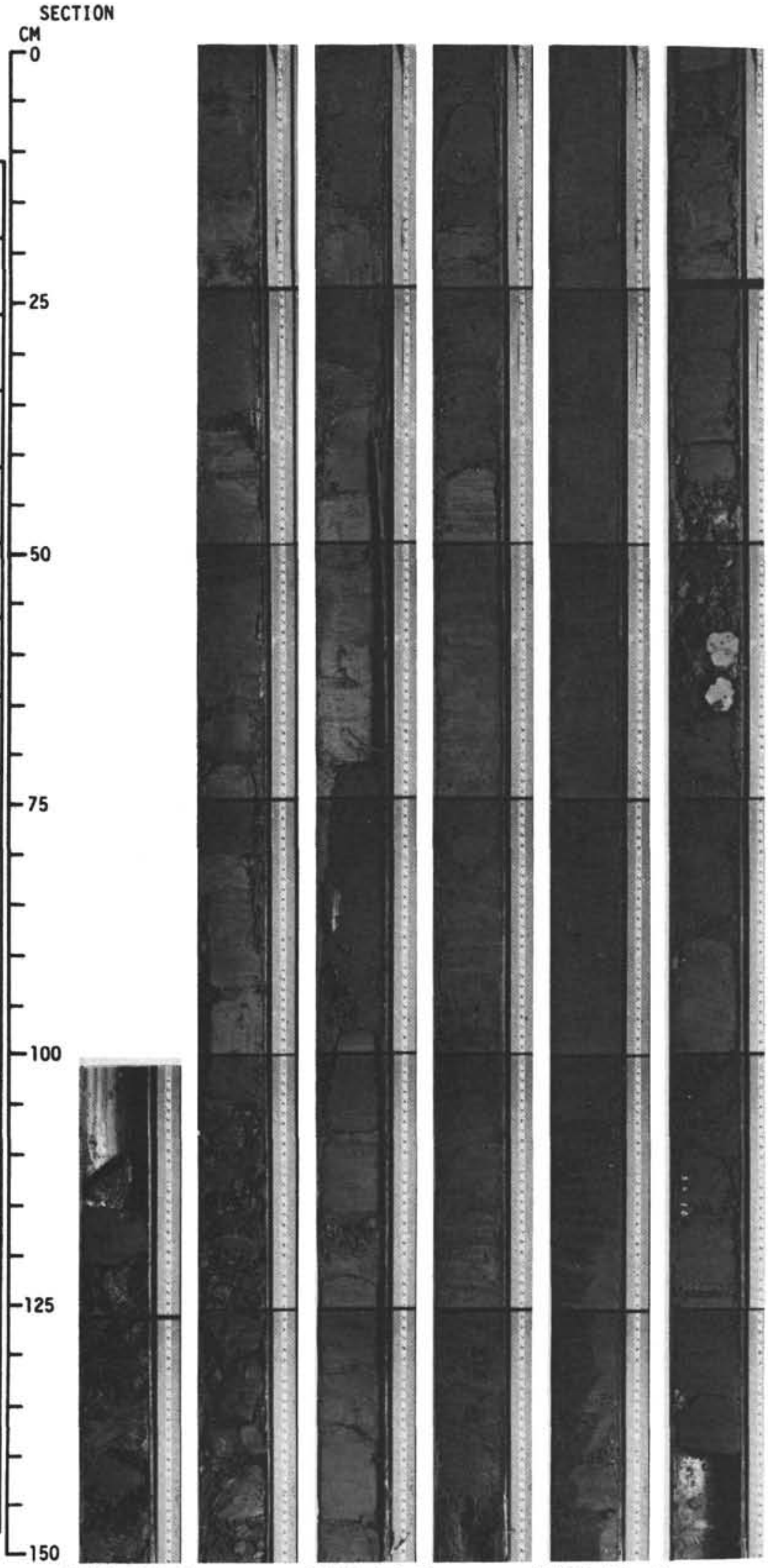

WET-BULK DENSITY, gm/cc
1 2 3
POROSITY,%
100 0
SOUND VELOCITY, km/sec
1.5 2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150
177A-11-1
177A-11-2
177A-11-3
177A-11-4


WET-BULK DENSITY, gm/cc
1
2
3
POROSITY,%
100
0
SOUND VELOCITY, km/sec
1.5
2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150
177A-12-1
177A-12-2
177A-12-3

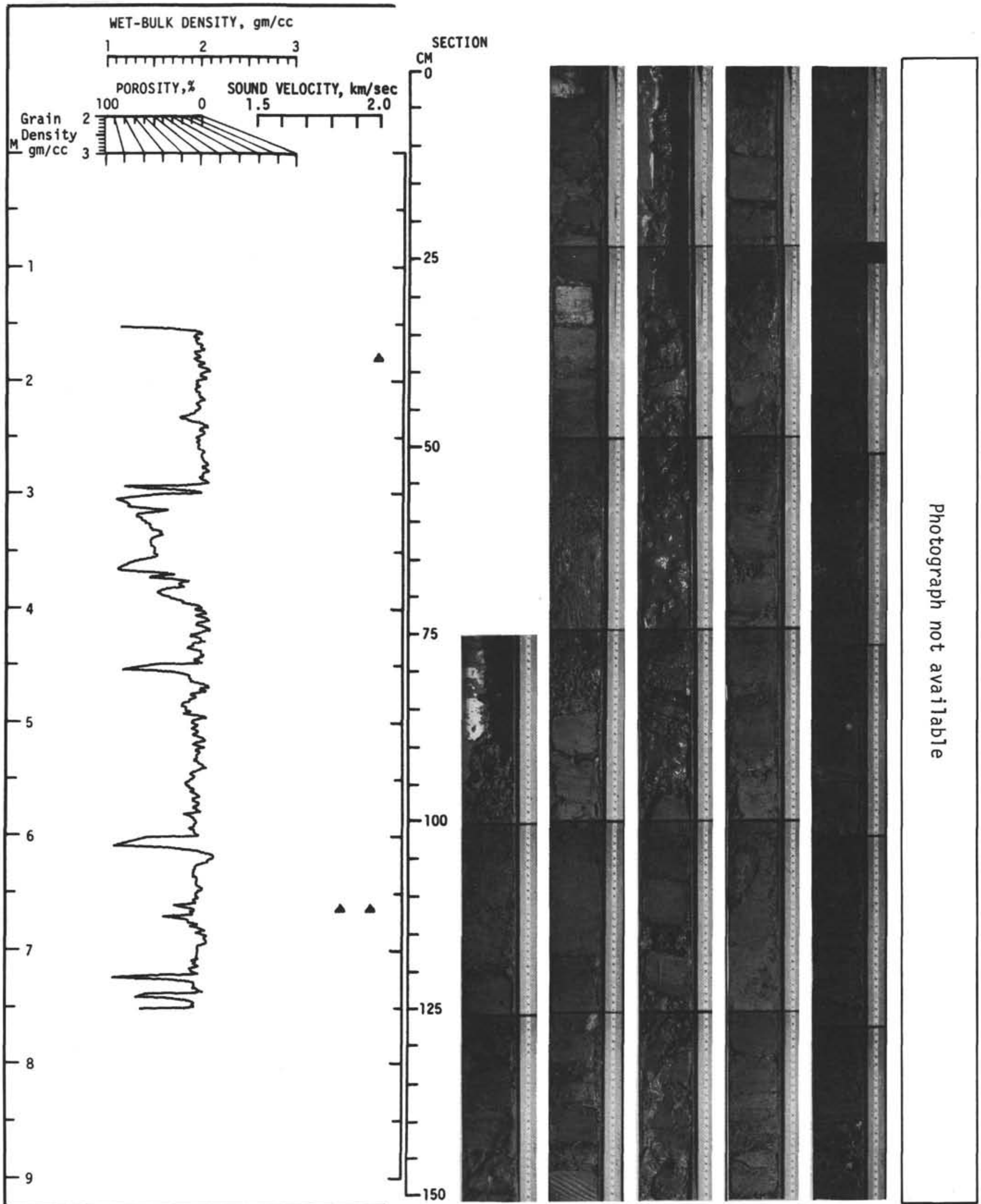

WET-BULK DENSITY, gm/cc
1 2 3
POROSITY,%
100 0
SOUND VELOCITY, km/sec
1.5 2.0
Grain Density gm/cc
2 3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150

177A-13-1

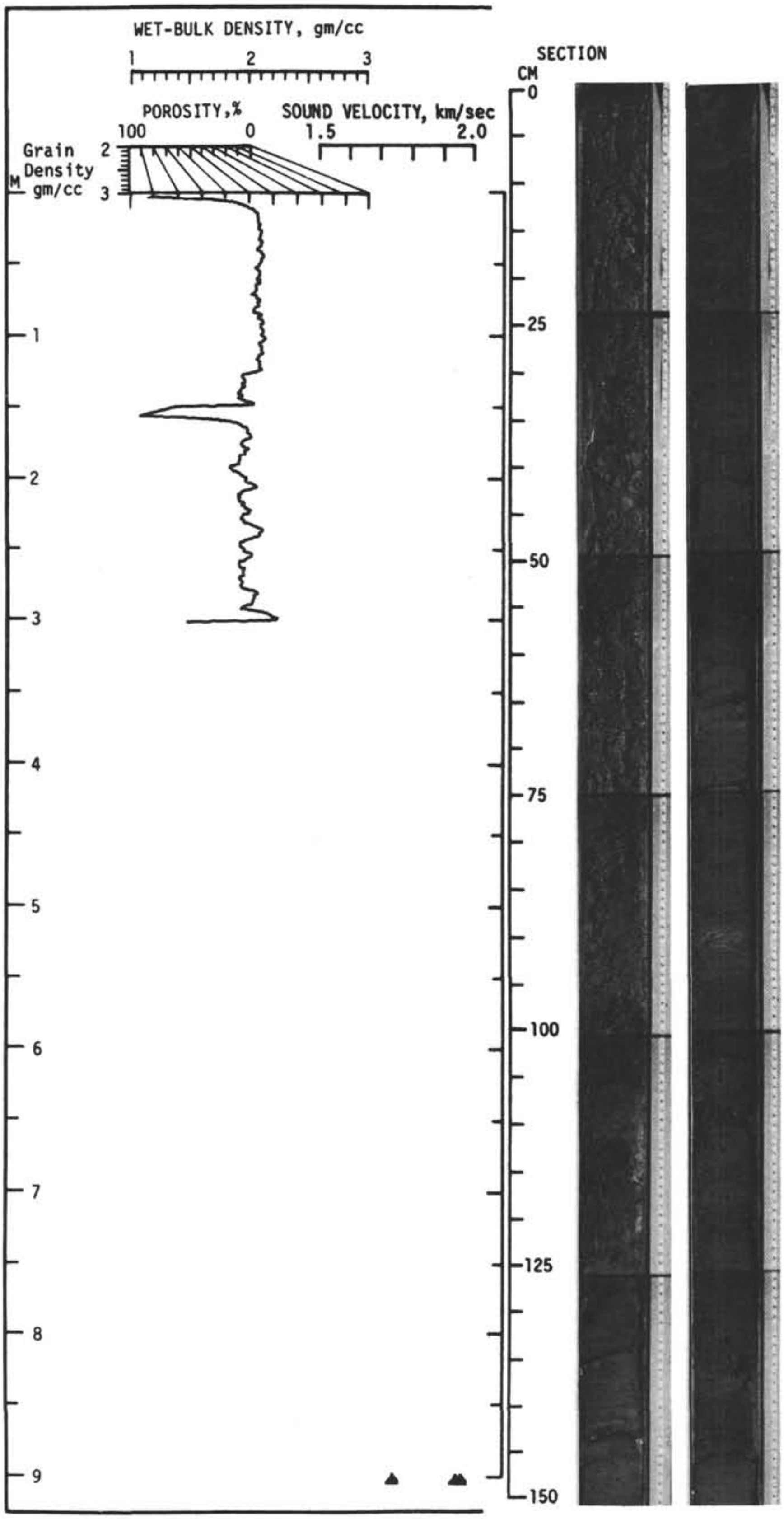




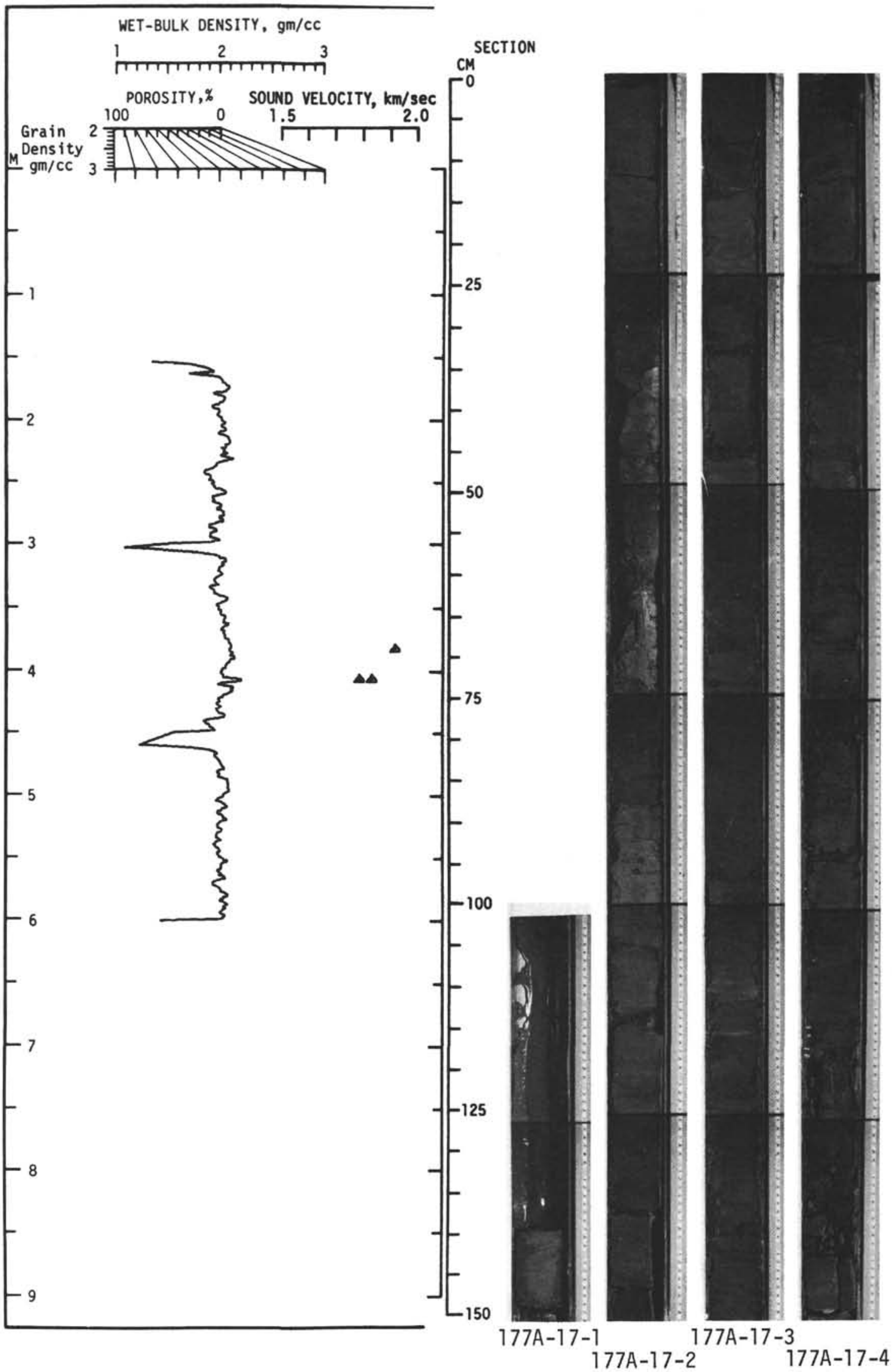
177A-14-1
177A-14-2
177A-14-3
177A-14-4
177A-14-5
177A-14-6

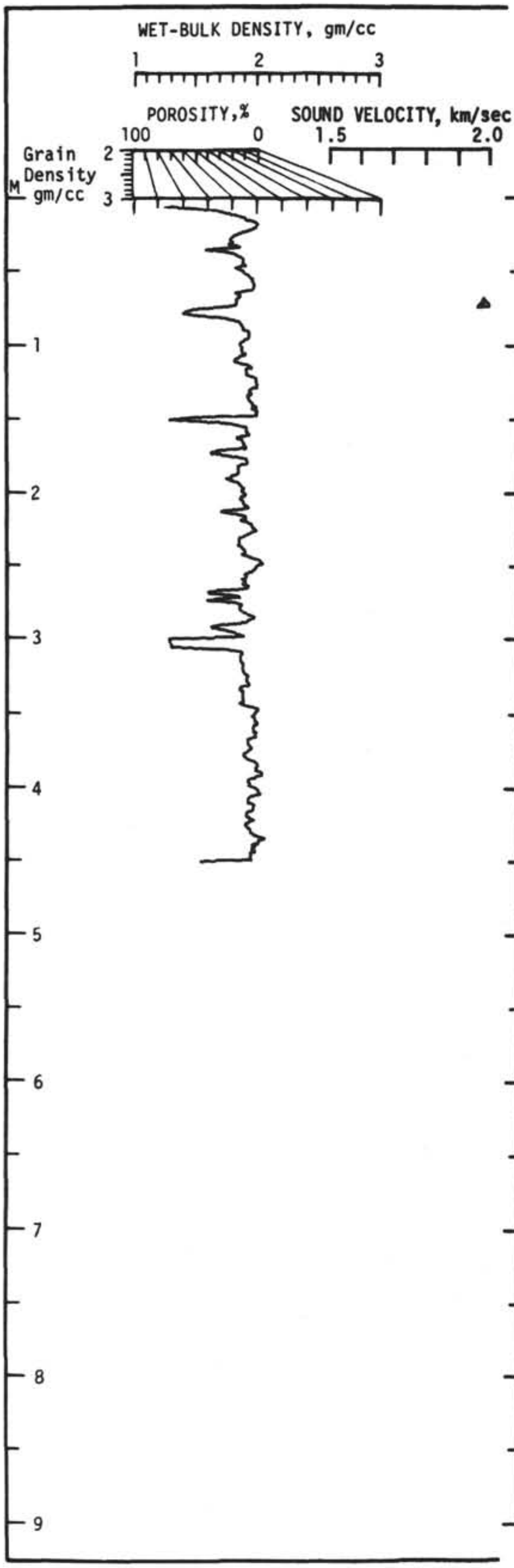


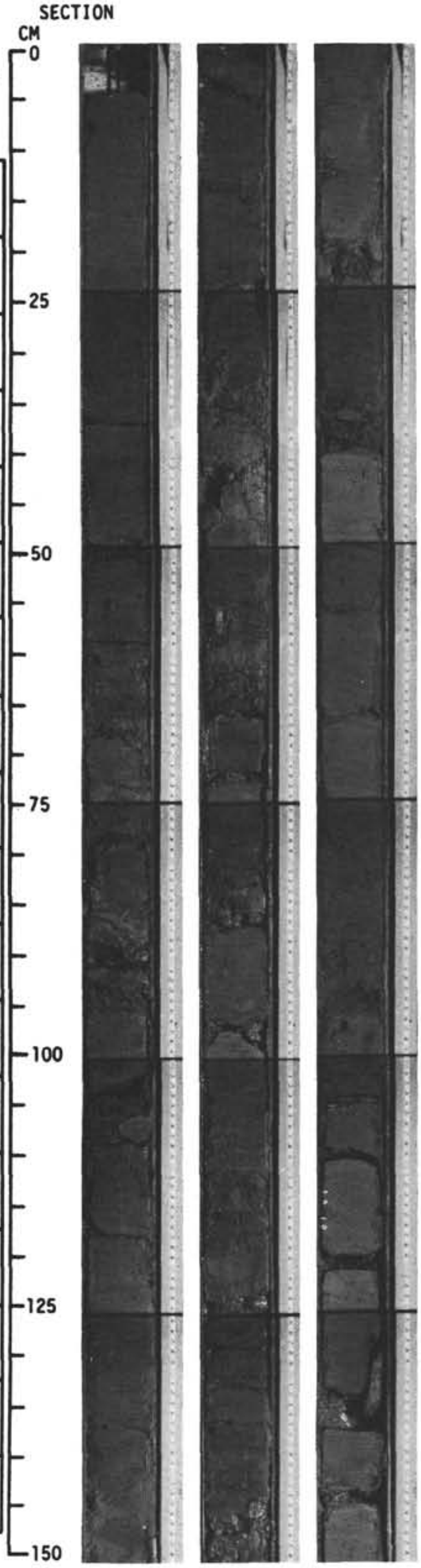
177A-15-1 177A-15-2 177A-15-3 177A-15-4 177A-15-5 177A-15-6



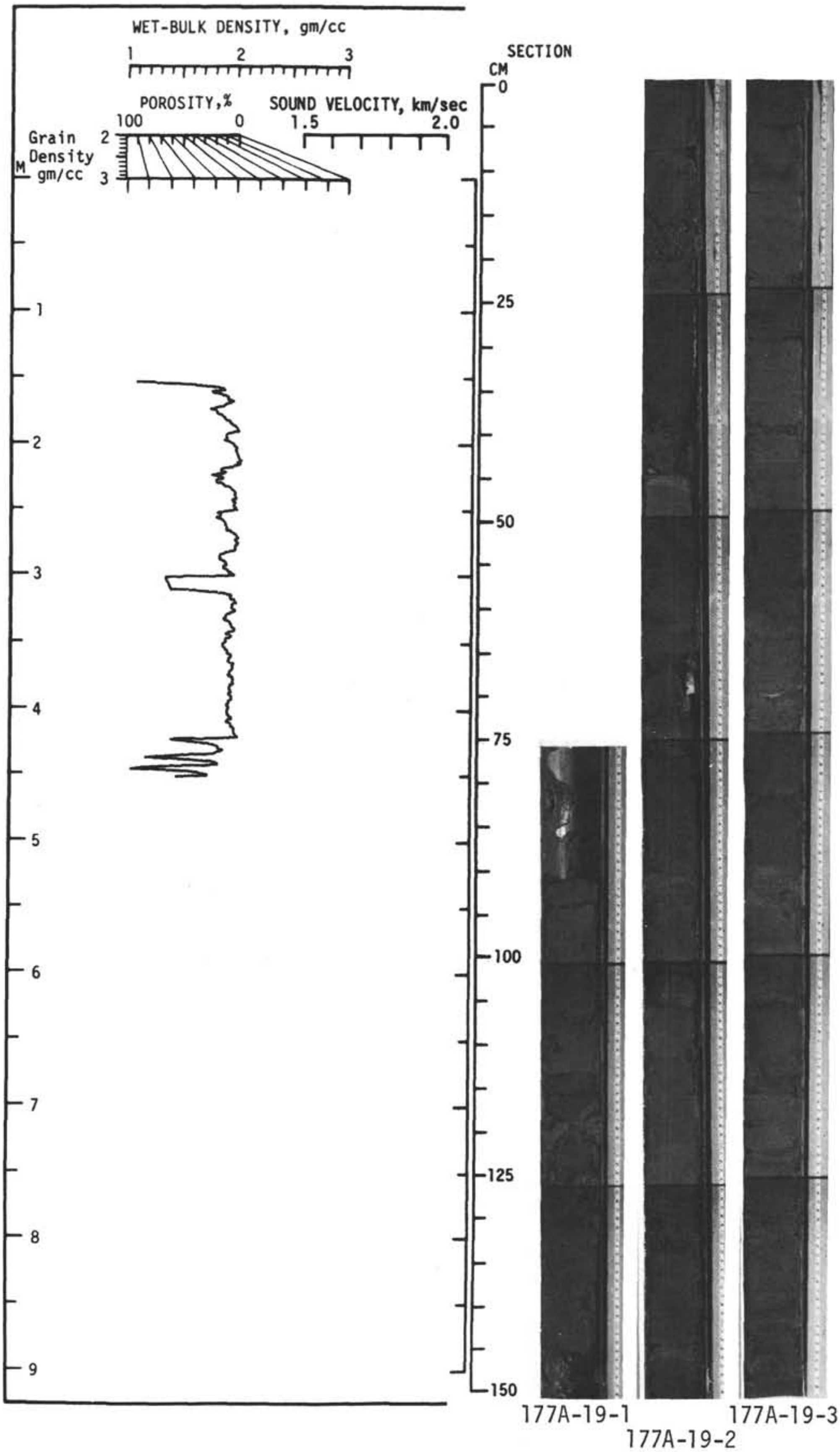
177A-16-1 177A-16-2

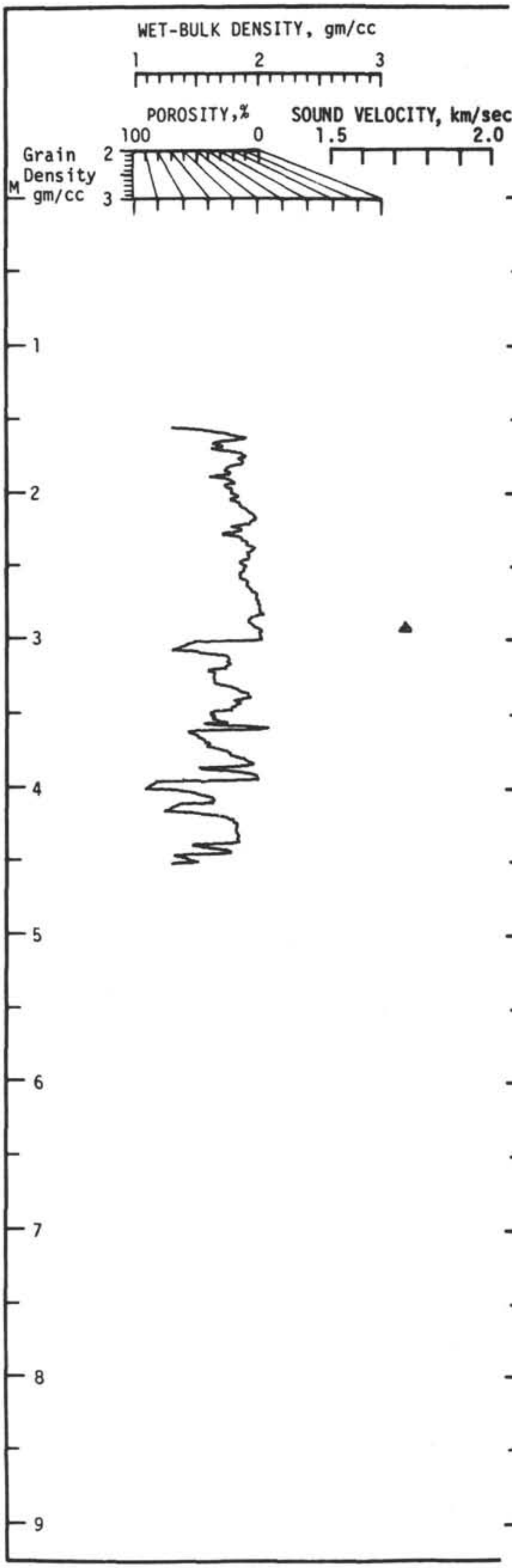

WET-BULK DENSITY, gm/cc
1
2
3
POROSITY,%
100
0
SOUND VELOCITY, km/sec
1.5
2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150
177A-17-1
177A-17-2
177A-17-3
177A-17-4

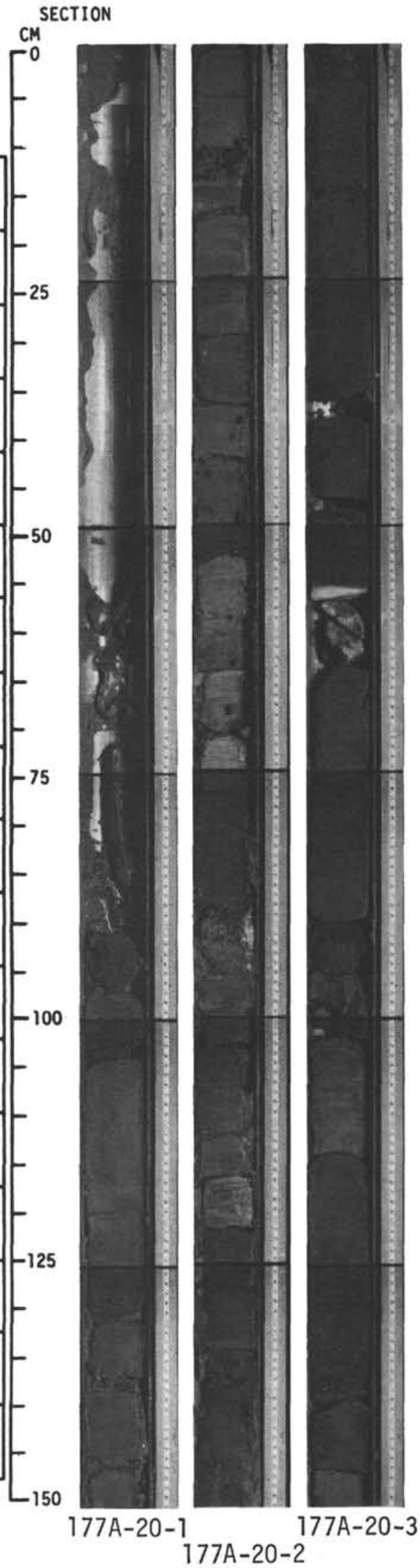


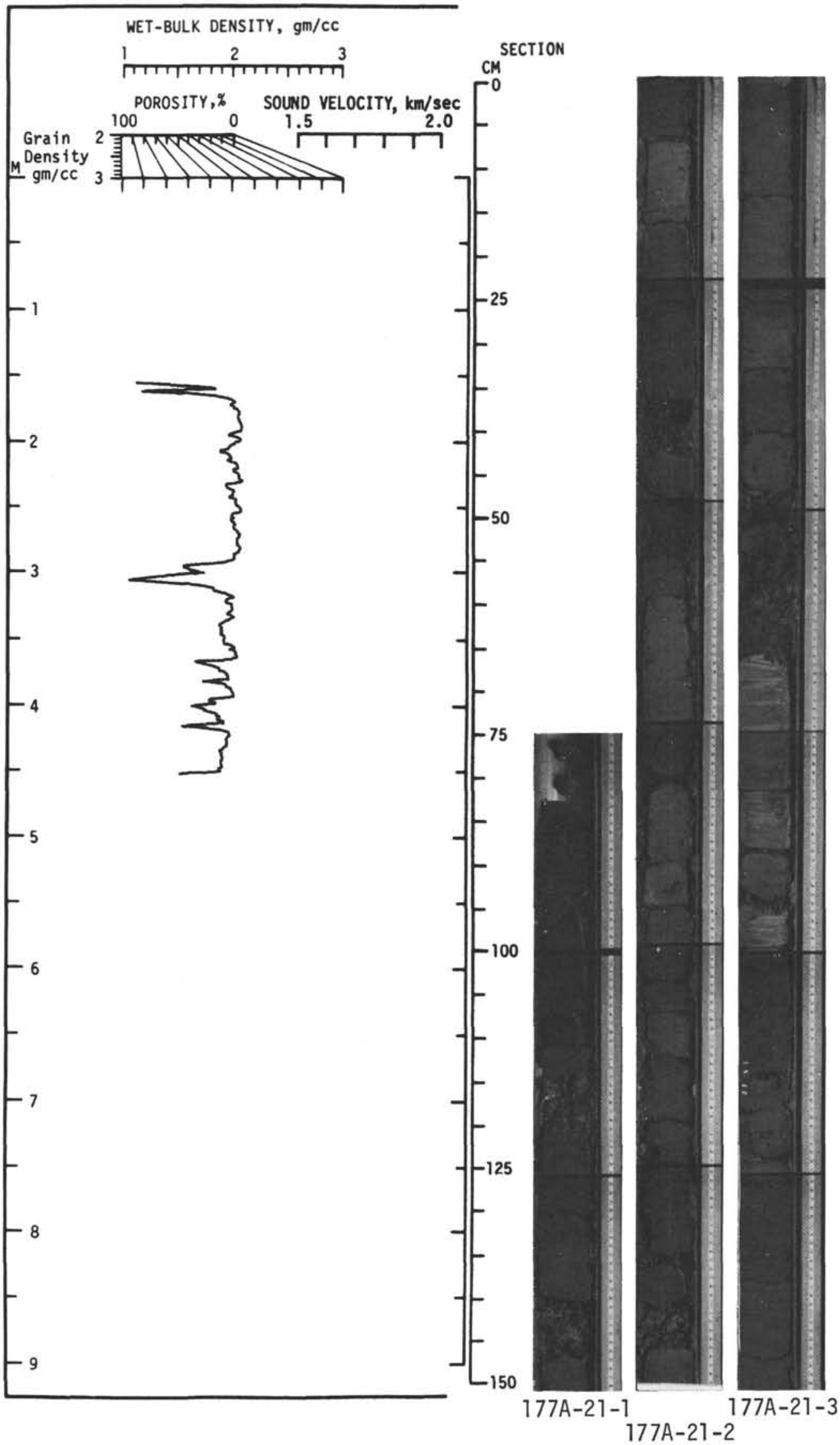


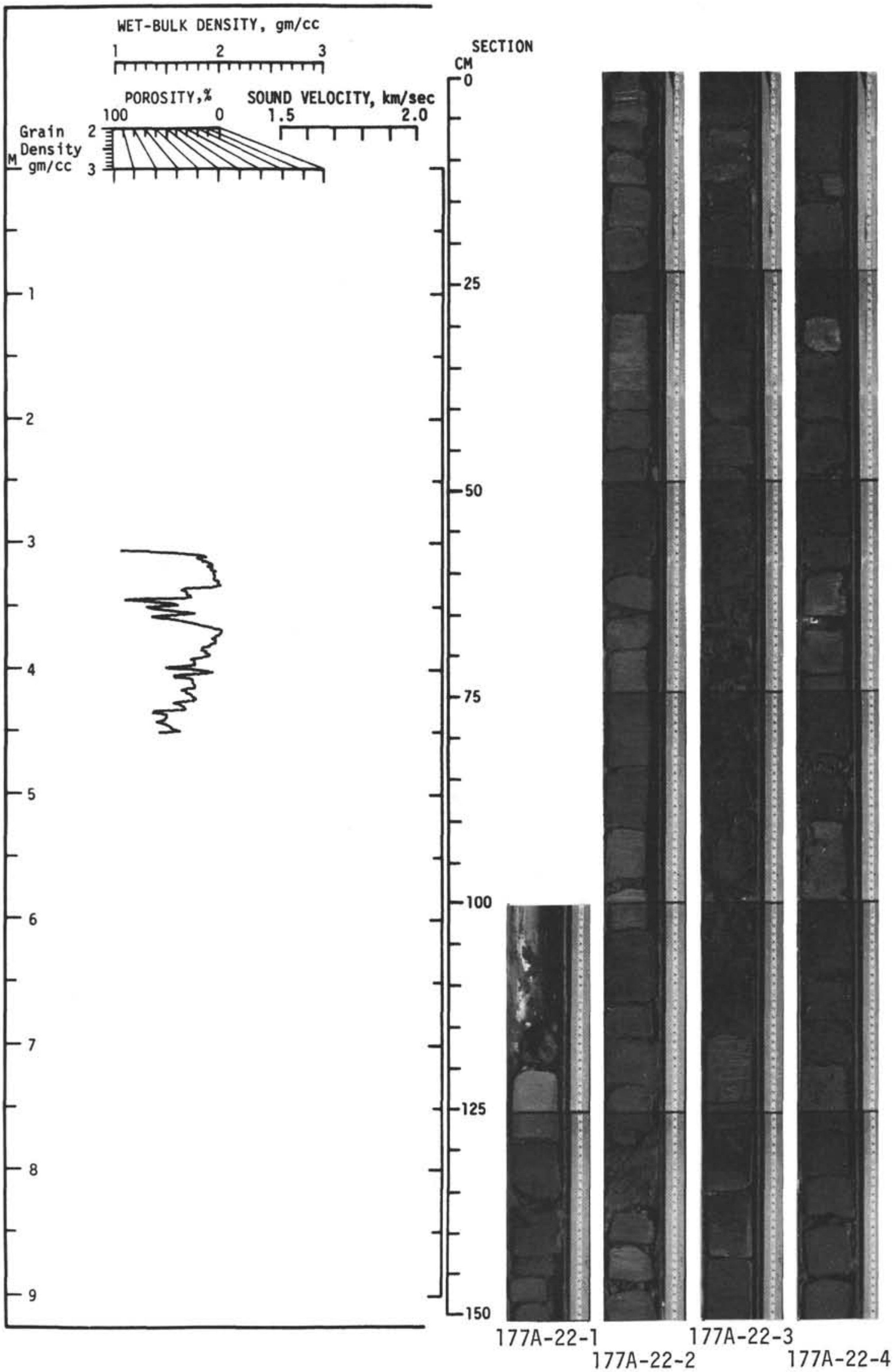
177A-18-1 177A-18-2 177A-18-3

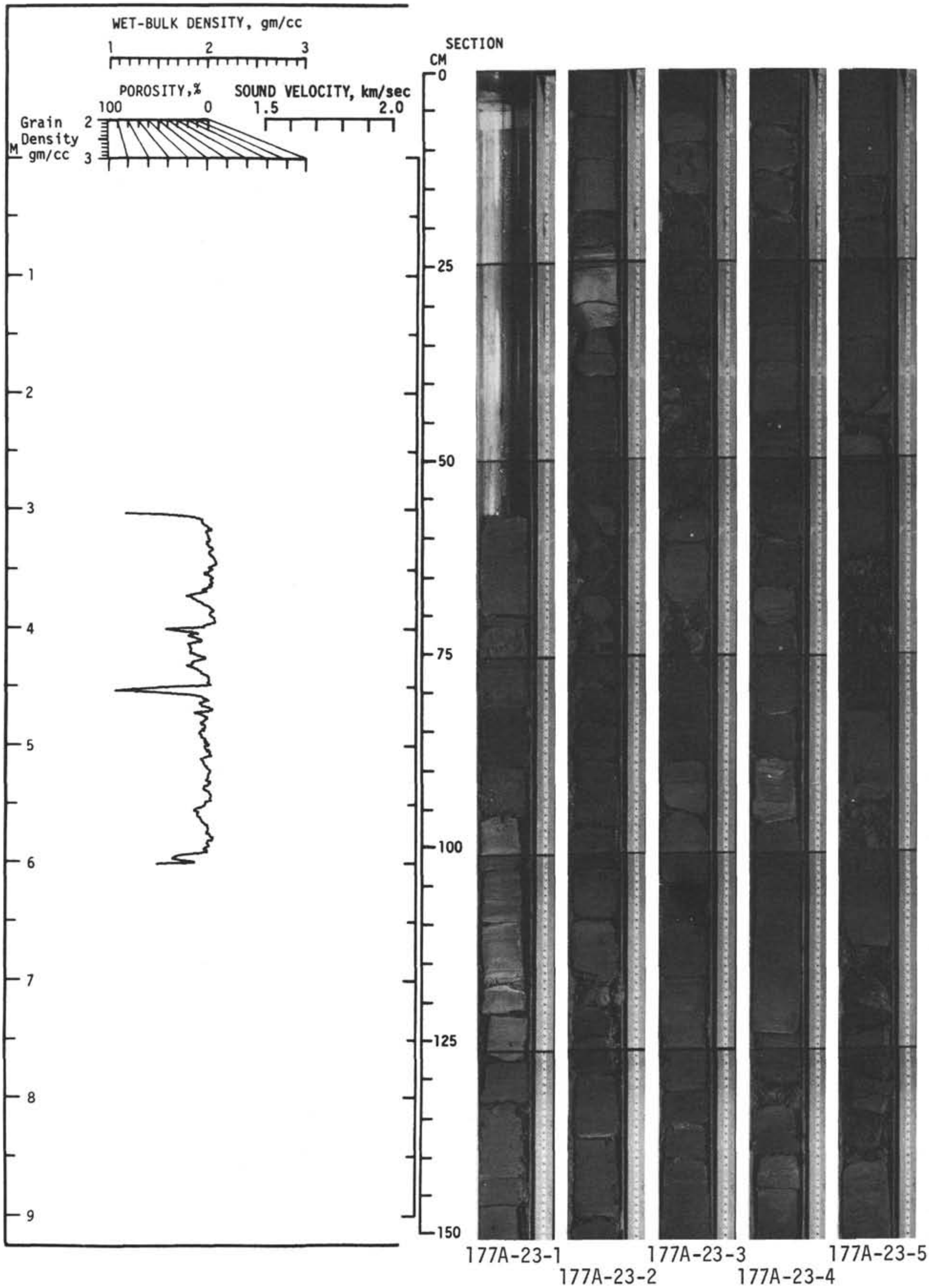

WET-BULK DENSITY, gm/cc
1
2
3
POROSITY,%
100
0
SOUND VELOCITY, km/sec
1.5
2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150
177A-19-1
177A-19-2
177A-19-3

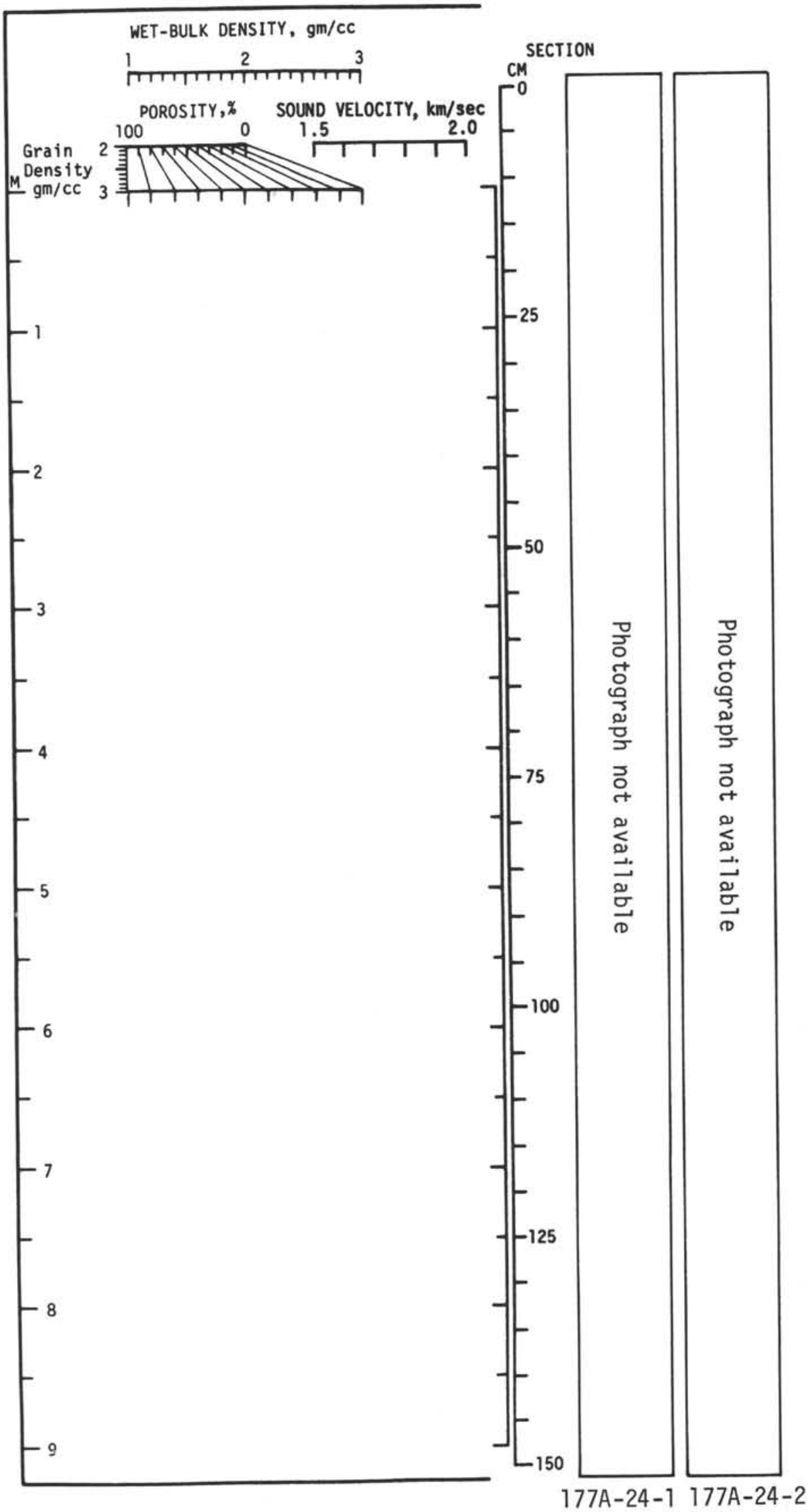

WET-BULK DENSITY, gm/cc
1
2
3
POROSITY,%
100
0
SOUND VELOCITY, km/sec
1.5
2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9

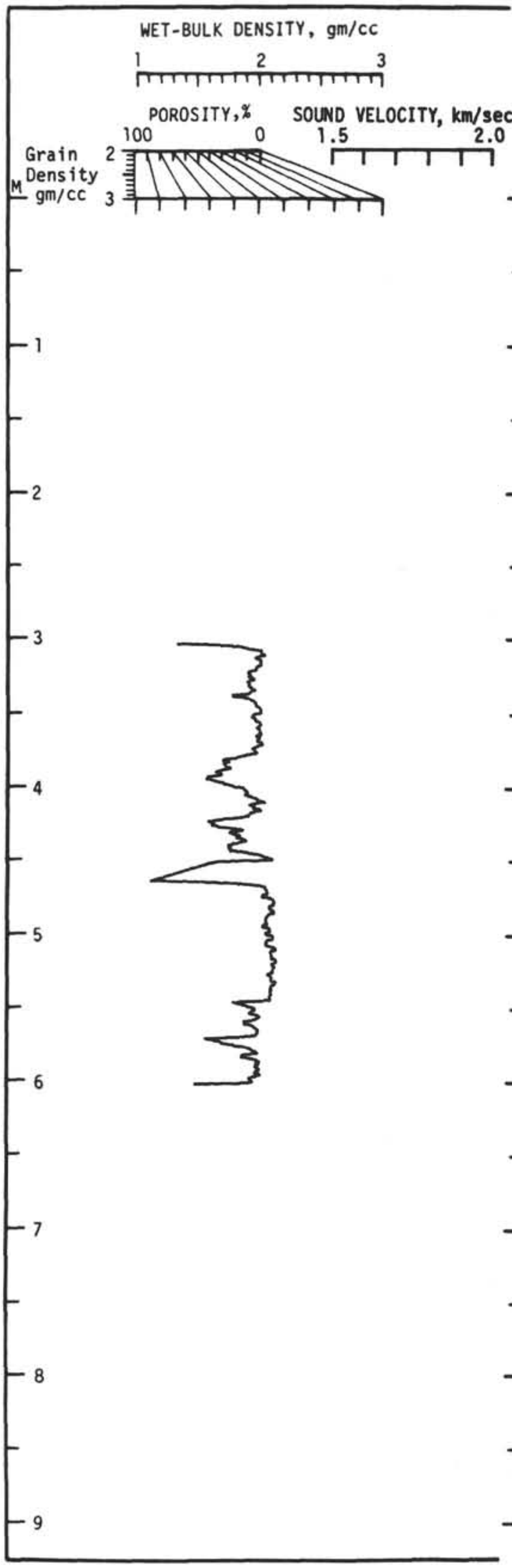

SECTION
CM
0
25
50
75
100
125
150
177A-20-1
177A-20-2
177A-20-3

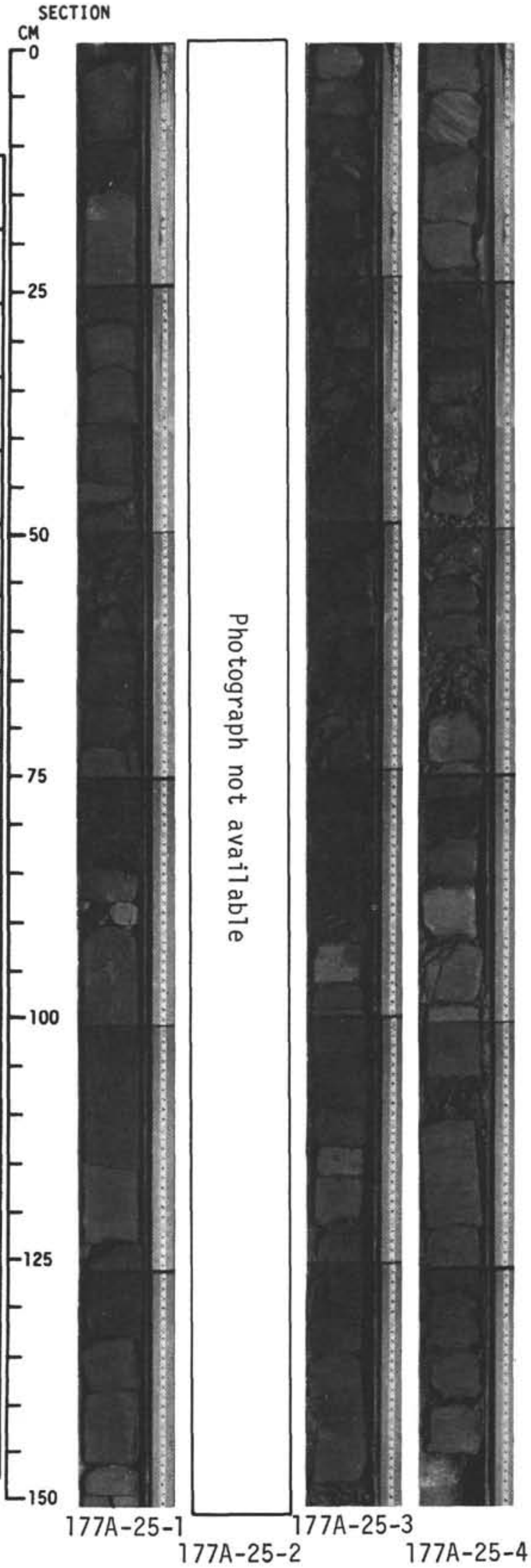

WET-BULK DENSITY, gm/cc
1
2
3
POROSITY,%
100
0
SOUND VELOCITY, km/sec
1.5
2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150
177A-21-1
177A-21-2
177A-21-3

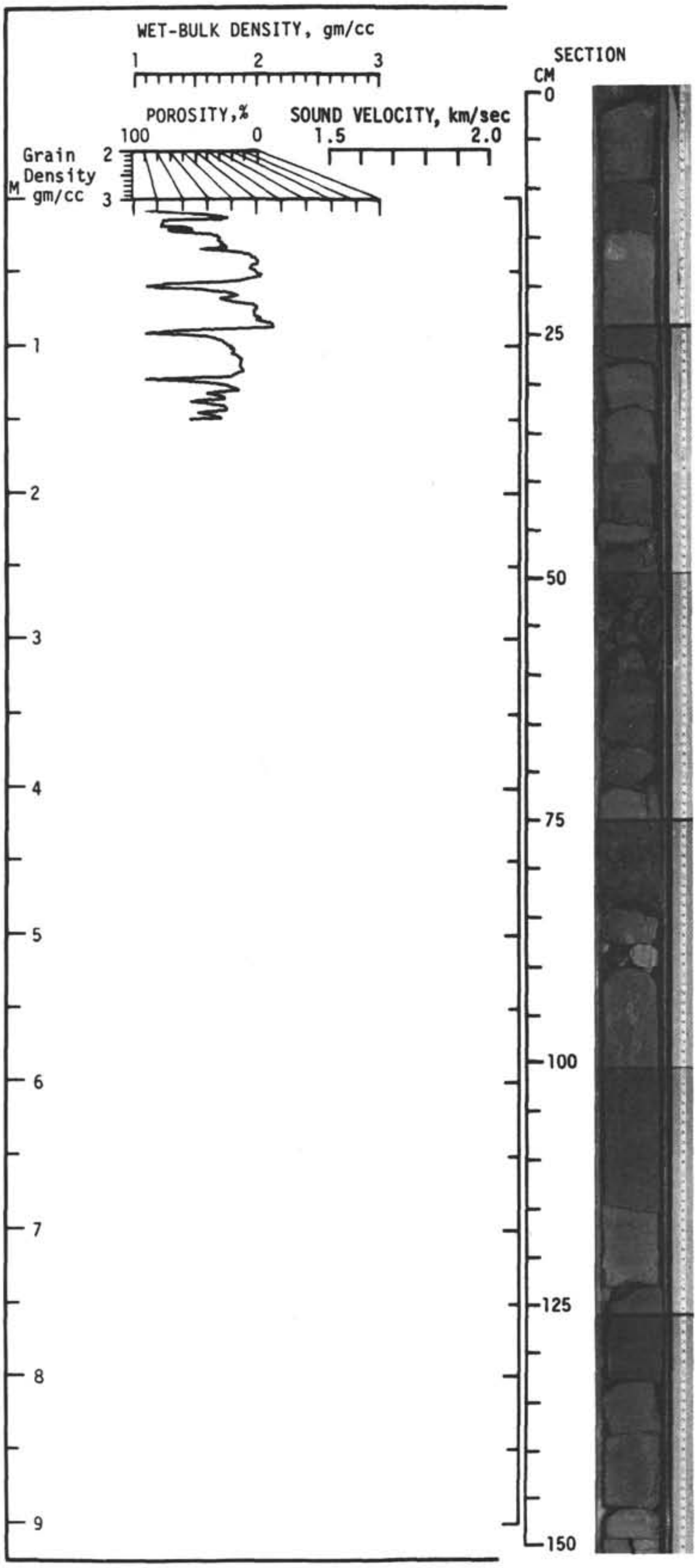

WET-BULK DENSITY, gm/cc
1 2 3
POROSITY,%
100 0
SOUND VELOCITY, km/sec
1.5 2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150
177A-22-1
177A-22-2
177A-22-3
177A-22-4


WET-BULK DENSITY, gm/cc
1
2
3
POROSITY,%
100
0
SOUND VELOCITY, km/sec
1.5
2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150
177A-23-1
177A-23-2
177A-23-3
177A-23-4
177A-23-5


WET-BULK DENSITY, gm/cc
1 2 3
POROSITY,%
100 0
SOUND VELOCITY, km/sec
1.5 2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150
Photograph not available
Photograph not available
177A-24-1
177A-24-2


WET-BULK DENSITY, gm/cc
1
2
3
POROSITY,%
100
0
SOUND VELOCITY, km/sec
1.5
2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9


SECTION
CM
0
25
50
75
100
125
150
Photograph not available
177A-25-1
177A-25-2
177A-25-3
177A-25-4


WET-BULK DENSITY, gm/cc
1
2
3
POROSITY,%
100
0
SOUND VELOCITY, km/sec
1.5
2.0
Grain Density gm/cc
2
3
M
1
2
3
4
5
6
7
8
9
SECTION
CM
0
25
50
75
100
125
150

177A-26-1