OCEAN DRILLING PROGRAM

LEG 113 PRELIMINARY REPORT

WEDDELL SEA, ANTARCTICA

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INTRODUCTION

Cenozoic oceanographic and climatic evolution is largely a record of progressive cooling and glaciation of the polar regions and perhaps slight warming in the tropics, resulting in an increase in the planet's latitudinal thermal gradient (Savin et al., 1975; Shackleton and Kennett, 1975; Kennett, 1977; Loutit et al., 1983). The climatic and glacial evolution of Antarctica is crucial to our understanding of long-term climatic change (Hayes, Frakes et al. 1975; Kennett, Houtz et al. 1975; Kennett, 1977). In this region, powerful climatic feedback mechanisms occur such as those related to ice albedo and bottom water formation. Also, the high latitudes are among the most sensitive to externally imposed change.

Global cooling during the Cenozoic did not proceed uniformly but was marked by discrete and sudden periods of cooling that may have originated in the polar regions, particularly Antarctica. A better understanding of the history of Antarctica and the surrounding Southern Ocean over the past 100 m.y. is central to the study of global climate and circulation.

Antarctica was originally part of Gondwanaland and subsequently became increasingly isolated within the oceanic realm as the other fragments of Gondwanaland dispersed northwards. For the past 90 m.y., Antarctica has remained over the south geographic pole. The development of the circum-Antarctic circulation system occurred as the southern land masses moved away, permitting unrestricted latitudinal flow. Changing boundary conditions in this region included the opening of the Tasman Seaway (Kennett, Houtz et al., 1975; Kennett, 1977), the opening of Drake Passage (Barker and Burrell, 1977; 1982) and perhaps the subsidence of the Kerguelen Plateau. The development of the Antarctic Circumpolar Current effectively isolated Antarctica thermally by decoupling the warmer subtropical gyres (Kennett, 1977). This led, in turn, to Antarctic glaciation and the formation of ice sheets, a climatic change with a profound effect on the environment, and thus the biogeography, of high southern latitudes. The climatic change included the cooling of waters surrounding the continent, extensive seasonal sea-ice production, and wind-driven upwelling of nutrient-rich intermediate waters which had a profound effect on biogenic productivity in the Southern Ocean.

Yet the history of development of Antarctic continental glaciation and of water masses in the Southern Ocean is still poorly known. Virtually no stable isotopic measurements have yet been made on Cenozoic sequences in the area of the present-day Antarctic water mass. No high-resolution stratigraphic sequences had been obtained using the hydraulic piston corer (HPC), advanced hydraulic piston corer (APC), or extended core barrel (XCB). Previous work by many investigators led to the development of general scenarios of climatic and oceanographic evolution of the Antarctic region; these hypotheses will be tested by studies of material recovered during Leg 113 and subsequent legs in the Antarctic and Subantarctic areas.

Leg 113 was designed to address a number of major questions that include the following:

1. When did the Antarctic ice sheets first form, and have they been permanent since their formation?

2. When did marine glacial conditions develop sufficiently for initiating formation of cold Antarctic Bottom Water in the Antarctic region, particularly in the Weddell Sea? How have bottom and intermediate water temperatures changed in response to Antarctic glacial development?
3. What has been the history of oceanic planktonic productivity in the Weddell Sea sector of the Southern Ocean? How is this development linked to the evolution of Antarctic climates and the oceanic environment, particularly the Polar Front?
4. What has been the evolution of the Antarctic planktonic and benthic biota and their biogeographic patterns? How is this linked with the environmental changes?

To assist in answering these questions, nine sites were drilled using D/V JOIDES Resolution in the Weddell Sea (Figures 1 and 2; Table 1). These sites form a depth transect for studies of vertical water mass stratification, climatic evolution, and oceanographic history of Antarctica and the surrounding ocean during the late Mesozoic and Cenozoic. Approximately 1945 m of sediments and 2 m of igneous rocks were recovered in a total of 22 holes. The cruise comprised 44 operational days and 21 days of transit, between 5 January and 11 March, 1987, beginning in Punta Arenas, Chile, and ending in East Cove, Falkland Islands.

SITE 689 (MAUD RISE)

Site 689 (W1A) consists of four holes and is located near the crest of Maud Rise (Figures 1, 2, and 3; Table 1) at a water depth of 2080 m. It is isolated from influences of terrigenous sediment transportation from the East Antarctic continent except for wind-blown and ice-rafted components. This site was selected to obtain a high-quality continuously cored (APC/XCB) biogenic sequence through the Upper Mesozoic and Cenozoic in the present-day Antarctic water mass. The quality of the cores is generally excellent, with marked disturbance observed only in the uppermost one or two cores. The hole was abandoned at 297.3 mbsf, an estimated 25-45 m above basement, when progress in drilling cherty layers became extremely slow.

The sedimentary sequence (Figures 4 and 5) is exclusively pelagic, biogenic in origin, and ranges in age from middle Campanian to earliest Maestrichtian (~75 Ma) at the base to Pleistocene at the top. The preliminary biostratigraphy and magnetostratigraphy indicate the presence of brief sedimentary hiatuses or highly condensed sequences throughout the section. These breaks represent time intervals in the lower Paleocene (upper Danian--calcareous nannofossil Zones CP2 and CP3); upper Paleocene to lower Eocene; uppermost Oligocene to lowermost Miocene; upper Miocene (about 9 to 6 Ma); and upper Pliocene to Pleistocene.

Site 689 provides a biostratigraphic sequence that, in conjunction with Site 690, will form the southernmost anchor for Atlantic biostratigraphic, biogeographic and isotopic stratigraphic studies. This is the first sequence cored in the Antarctic that provides a late Mesozoic through Cenozoic calcareous nannofossil and planktonic foraminiferal biostratigraphy. Mixed assemblages of calcareous and siliceous microfossils from the late Eocene through the Neogene have allowed the first biostratigraphic intercalibration to be carried out between these groups in the Antarctic region. Deposition was continuous across the Cretaceous/Tertiary boundary at Site 689. This boundary is associated with a 40-cm interval of vitric ash and clay of apparently volcanic origin and is extensively bioturbated.

The recovered section consists of 297.3 m of almost pure siliceous and calcareous oozes to chalk, with thin chert layers at the top and bottom of the sequence. The sequence has been divided into three lithostratigraphic units based upon compositional differences and diagenetic maturity (Figures 4 and 5):

Unit I (0-31 mbsf; late Miocene to Pleistocene) consists predominantly of diatom ooze with varying amounts of other biosiliceous components. Thin chert layers (<10 cm) were recovered at the top of the unit (cores 1H-2H).

Unit II (31-149.1 mbsf; late Eocene to late Miocene) consists of a mixture of biosiliceous and calcareous oozes. The calcareous component is dominated by calcareous nannofossils; foraminifers are relatively rare. Unit II is divided into two subunits based on the abundance of diatoms, on the appearance of foraminifers and the disappearance of radiolarians. Subunit IIA (31-72 mbsf; late Oligocene to late Miocene) consists of alternating biosiliceous and calcareous ooze. Subunit IIB (72-149.1 mbsf; late Eocene to late Oligocene) is dominated by calcareous nannofossil ooze with thin diatomaceous zones. Rare glacial marine dropstones were found in sediments as old as upper Oligocene.

Unit III (149.1-297.3 mbsf; Campanian? to late Eocene) consists of nannofossil ooze and chalk with varying amounts of foraminifers. Two subunits are defined. Subunit IIIA (149.1-236 mbsf; late Maestrichtian to late Eocene) is a semi-lithified calcareous ooze to chalk sequence. Subunit IIIB (236-297.3 mbsf; Campanian to late Maestrichtian) consists of chalk with some thin chert layers.

The dominant microfossil components change through the sequence as follows: Upper Cretaceous to upper Eocene: calcareous nannofossils and planktonic foraminifers; Oligocene: calcareous nannofossils and diatoms; Miocene: diatoms and calcareous nannofossils; upper Miocene and Pliocene: diatoms and silicoflagellates.

Discussion

Cooling of the Antarctic water mass is reflected by changes in the sediment composition, the microfossil diversity and changes in the microfossil assemblages. The cooling is inferred to be related to Antarctic glacial development. The siliceous biogenic facies progressively replaced the carbonate facies during the Cenozoic, with initial siliceous sedimentation in the latest Eocene-earliest Oligocene, a major increase in siliceous sedimentation starting near the beginning of the Neogene, and exclusively siliceous sedimentation from the late Miocene through the Pliocene. The sediment accumulation rate of the biogenic sediments was low compared with that in many other oceanic areas. During the Eocene, sedimentation rates were about 4 m/m.y.; during the Oligocene and Neogene, sedimentation rates between hiatuses double to about 7-9 m/m.y. This indicates that Site 689 has always lain well to the south of the high productivity biogenic belt of the Polar Front.

SITE 690 (MAUD RISE)

Site 690 (W2A) consists of three holes drilled on the southwestern flank of Maud Rise (Figures 1, 2, and 6; Table 1), in 2914 m of water, and is the deeper of the two sites drilled on Maud Rise. Scientific objectives at this site were similar to those at Site 689, located 116 km to the northeast.

The 321.2-m sedimentary sequence recovered at Site 690 ranges in age from the Late Cretaceous to the Pleistocene (Figures 7 and 8). It consists of almost pure siliceous and calcareous oozes in the upper half of the sequence, mixed calcareous ooze/chalk and terrigenous sediments in the lower half, and penetrated 4.6 m into basement. Minor cherts occur in the basal sediments. The quality of the cores is generally excellent with marked disturbance only in the uppermost one or two cores. A major hiatus spans the middle-upper Eocene and part of the lower Oligocene. Another hiatus spans the Oligocene/Miocene boundary. The upper Pliocene-lower-middle Pleistocene section is marked by very low rates of deposition and may possibly be a hiatus.

Site 690 provides a biostratigraphic section that reinforces and supplements the biostratigraphy of Site 689. Site 690 provides a superb Paleocene calcareous biostratigraphic sequence. The early Eocene to lower Oligocene interval (hiatus at Site 690) is preserved at Site 689, whereas the Oligocene/Miocene boundary hiatus is present at both sites. Therefore, together the two sites provide a complete Paleogene sequence except for an undefined interval in the uppermost Oligocene-lowermost Miocene. Deposition across the Paleocene/Eocene boundary was continuous at Site 690, as it was across the Cretaceous/Tertiary boundary. The latter is associated with an 85 cm thick, brown clay that appears to be of volcanogenic origin.

The sequence at Site 690 is divided into six lithostratigraphic units (Figures 7 and 8) based upon compositional differences.

Unit I (0-24.4 mbsf; late Miocene to Pleistocene) is composed of two subunits based upon microfossil composition. Subunit IA; (0-2.1 mbsf; Pleistocene) consists of foraminiferal ooze Subunit IB (2.1-24.4 mbsf; Pliocene to upper Miocene) consists of diatom ooze with varying amounts of other biosiliceous components.

Unit II (24.4-92.9 mbsf; early Oligocene to late Miocene) consists of pure and mixed biogenic siliceous and biogenic calcareous oozes. Two subunits are defined based upon microfossil composition. Subunit IIA (24.4-53.4 mbsf; late Miocene to latest Oligocene) consists of interbedded diatom-bearing calcareous ooze and calcareous nannofossil ooze. Subunit IIB (53.4-92.9 mbsf; Oligocene) is dominated by calcareous nannofossil ooze, with diatom-bearing layers. Rare glacial marine dropstones are not observed in sediments older than Miocene age.

Unit III (92.9-137.8 mbsf; late Paleocene to early Oligocene) consists of foraminiferal nannofossil ooze.

Unit IV (137.8-281.1 mbsf; late Maestrichtian to late Paleocene) has been subdivided into three subunits based on composition and degree of lithification. Subunit IVA (137.8-177.3 mbsf; late Paleocene) is dominated by nannofossil ooze, with more than 15% terrigenous material. Subunit IVB (177.3-252.5 mbsf; late Paleocene to latest Maestrichtian) contains less than 10% terrigenous material, and chalk is dominant over ooze. Subunit IVC (252.5-281.1 mbsf; late Maestrichtian) contains more than 15% terrigenous sediments and chalk is dominant over ooze.

Unit V (281.1-317.0 mbsf; late Campanian(?) to late Maestrichtian) is dominated by terrigenous components (including volcanic glass), calcareous ooze and chalk; planktonic foraminifers are common. Dominant sediments are muddy chalk, calcareous mudstone, and nannofossil-bearing mudstone. Unit V is directly underlain by basaltic basement.

Unit VI (317.0-321.2 mbsf) consists of 1.71 m of amygdaloidal pyroxene-olivine basalt.

The dominant microfossil components change through the sequence: Upper Cretaceous to lower Oligocene: calcareous nannofossils and planktonic foraminifers; upper Oligocene: calcareous nannofossils and diatoms; Miocene: diatoms and calcareous nannofossils; upper Miocene to Pliocene: diatoms and silicoflagellates; Pleistocene: diatoms and planktonic foraminifers.

Discussion

As at Site 689, the sediment sequence and biotic changes reflect a sequential cooling of the Antarctic water mass with biosiliceous facies progressively replacing carbonate facies during the late Cenozoic. The sedimentary sequence recovered at Site 690 differs from that at Site 689 by having an important terrigenous component (fine-grained quartz, clay, and mica) in the lower Paleogene and Upper Cretaceous, most abundant in the lower Eocene to upper Paleocene (an interval missing at Site 689) and the Maestrichtian. This clay is either (1) eolian material derived from East Antarctica, (2) winnowed by bottom currents from the crest of Maud Rise and deposited in the flank area of Site 690, or, less likely, (3) deposited from a nepheloid layer that originated in East Antarctica, and was at depths greater than 2000 m (depth of Site 689). In any case, East Antarctica was a rich source of fine-grained terrigenous sediments for Maud Rise during the Paleocene and Late Cretaceous. The clay is rich in chlorite and kaolinite, and the rich reddish colors perhaps suggest laterite formation, indicating that conditions were warm, humid, and probably unglaciated during the Paleocene. Eocene clays are dominantly smectite (suggesting warm climatic conditions). In the early Oligocene, illite first appeared as a major clay component. This change suggests that hydrolysis strongly decreased on Antarctica, possibly due to a major cooling and/or increase in aridity.

SITES 691/692 (DRONNING MAUD LAND MARGIN)

Sites 691 and 692 (W4) lie on a mid-slope bench on the Weddell Sea margin of East Antarctica (Figures 1, 2, and 9; Table 1). Drilling on this margin aimed to examine the Cenozoic record of cooling and ice-sheet formation on the continent, and to complement the description of circum-Antarctic water mass development obtained from the other sites drilled on

Leg 113. Three holes were attempted at Site 691 in the axis of Wegener Canyon; two holes were attempted at Site 692, higher on the canyon shoulder. Considerable difficulty was experienced in spudding these holes, because of the presence of coarse, unconsolidated material. The move from Site 691 to Site 692 was an effort to overcome this difficulty. Only Hole 692B in 2875 m of water provided useful information.

Three lithologic units were recognized in Hole 692B (Figures 10 and 11). Recovery was generally poor, 26% in Unit I, 3.5% in Unit II and 48% in Unit III.

Unit I (0-30.4 mbsf; Miocene to Pleistocene) consists of silty and clayey mud that becomes sandier toward the base of the unit (possibly with an unsampled coarser component). Sediments within this unit have been homogenized by drilling disturbance. The fine sand fraction contains abundant quartz, opaques and glauconite.

Unit II (30.4-53.2 mbsf; age unknown) contains pebbles and cobbles of igneous, metamorphic and indurated sedimentary rocks, probably with an unsampled finer matrix. Unit II may have been responsible for the failure to spud in at the previous four holes.

Unit III (53.2-97.9 mbsf; Early Cretaceous--probably Aptian to Albian) consists of nannofossil claystone and nannofossil-bearing claystone, with laminae and lenses of clay, probably altered volcanic ash and beds of organic-rich claystone. The organic carbon content averaged 8.6% of Type II kerogens (Tissot et al., 1974). The age is Aptian to Barremian on the basis of nannofossils, Albian based on planktonic foraminifers, "Neocomian" based on benthic foraminifers, but apparently normally magnetized and thus probably post-Barremian and tentatively assumed to be Aptian to Albian in age. Abundant water-escape structures suggest high sedimentation rates. The unit contains macrofossils (ribbed bivalves, Inoceramus, belemnites, and ammonites).

Discussion

Diatoms date the canyon-cutting at Site 692 as early late Miocene or older. Physical properties suggest that 250 to 300 m of overburden was eroded, implying an original continuity of the parallel-bedded reflectors at the canyon walls. Wegener Canyon has cut through the outer high of the "Explora Wedge," a seaward dipping reflector province, creating a narrow inner canyon (Site 691) and permitting slow deposition (evidenced by glauconite) on the flanks (Site 692). The relation of the canyon-cutting to Antarctic ice sheet growth may emerge from later studies.

The Lower Cretaceous claystones of lithostratigraphic Unit III resemble sediments of the same age from the Falkland Plateau, then nearby (Ludwig, Krasheninnikov et al., 1983). These claystones were deposited in 500 to 1000 m of water at a middle latitude site under weakly aerobic conditions. By analogy with the Falkland Plateau section, a similar facies probably extends all or most of the estimated 1200 m depth to the seaward-dipping reflectors, which are considered to be Middle Jurassic in age.

SITE 693 (DRONNING MAUD LAND MARGIN)

Site 693 lies on a mid-slope bench on the Weddell Sea margin of East Antarctica (Figures 1, 2, and 12; Table 1), 10 km southwest of the rim of Wegener Canyon and 30 km southwest of Sites 691 and 692, in 2359 m of water. Like those sites it was drilled to examine the Cenozoic record of Antarctic continental cooling and ice-sheet formation.

The sedimentary section recovered at Site 693 consists of 397.8 m of Pleistocene to lower Oligocene hemipelagic muds and 86.1 m of Lower Cretaceous claystone, mudstone, diatomite and silicified sandstone (Figures 13 and 14). Seven lithostratigraphic units are recognized:

Unit I (0.0-12.2 mbsf; Pleistocene) consists of foraminifer-bearing clayey mud.

Unit II (12.2-31.4 mbsf; late Pliocene to Pleistocene) consists of clayey mud.

Unit III (31.4-325.0 mbsf; late Oligocene to late Pliocene) consists of diatom mud and diatom-bearing silty to clayey mud. The unit is divided into three subunits. Subunit IIIA (31.4-243.9 mbsf; late Miocene to late Pliocene) consists predominantly of diatom mud and clay with minor occurrences of diatom ooze. Subunit IIIB (243.9-255.1 mbsf; late Miocene) consists of clayey diatom nannofossil ooze. Subunit IIIC (255.1-325.0 mbsf; late Oligocene to late Miocene) is similar to Subunit IIIA and consists of diatom mud, clay and ooze.

Unit IV (325.0-345.1 mbsf; late Oligocene) contains alternating diatomaceous mud and ooze and minor muddy nannofossil ooze and nannofossil-bearing clayey mud.

Unit V (345.1-397.8 mbsf; Oligocene) consists of diatomaceous mud and silt, with minor occurrences of muddy diatomaceous ooze. These sediments have been deformed by slumping that also increases the thickness of this unit.

Unit VI (397.8-409.0 mbsf; Cretaceous-?Albian to Santonian) consists of radiolarian diatomite.

Unit VII (409.0-483.9 mbsf; Early Cretaceous-Albian), dark terrigenous claystones and mudstones with organic-rich beds. The organic carbon content averaged 2.6%. These sediments appear to be the oxidized equivalent of the Aptian mudstones recovered at Site 692 (Unit III).

Sedimentation rates were moderate (10 m/m.y.) in the Pleistocene and latest Pliocene, high (20-70 m/m.y.) through the Pliocene and late Miocene, and low (5 m/m.y.) in the early Miocene and Oligocene. Cretaceous rates could not be determined. The hiatus documented at 265 mbsf lasted over 6 m.y. during the early late and middle Miocene. The hiatus at 398 mbsf extended from the middle of the Cretaceous into the early Oligocene, a period of about 55 m.y.

Glacial dropstones are abundant down to the middle Miocene hiatus, and are present but less common to the Oligocene-Cretaceous hiatus at 398 mbsf. Illite is the dominant clay through the Cenozoic section sampled, reflecting the physical nature of weathering. Smectite is the most abundant clay in the Cretaceous sediments, possibly originating from a volcanic source. The biogenic component is almost entirely siliceous: diatoms are common to abundant and well-preserved in the lower Pliocene and upper Miocene but are rare with poor preservation elsewhere. Silicoflagellates and radiolarians are less abundant but show similar preservation. Foraminifers occur in the upper Pleistocene and in part of the Albian sediments, are well preserved, and occur with calcareous nannofossils in thin upper Oligocene interbeds in Unit V. In contrast to Maud Rise, they are absent elsewhere. Magnetostratigraphy is good for the top 140 m (Gilbert Chron, Pleistocene through early Pliocene) and in the Cretaceous, but needs more onshore work elsewhere in the section.

Discussion

Cretaceous sediments are more oxidized and less organic-rich than the Aptian sediments of Site 692. Seismic profiles confirm speculation that 90% of sediments around Site 693 are pre-Late Cretaceous in age. Benthic diatoms in the lower Miocene and Oligocene indicate a shallow, partly ice-free shelf, but rare ice-rafted detritus suggests some glaciation. We conclude that the East Antarctic ice sheet probably formed in the middle Miocene. Ice-sheet formation was accompanied by an increasing sediment supply to the margin and initiation of canyon-cutting. The high siliceous productivity in the Pliocene also occurred on the Maud Rise (Sites 689 and 690) but there sedimentation rates were lower. This time period parallels coeval high calcareous productivity in lower latitudes. There is no evidence of a major East Antarctic deglaciation since the middle Miocene, including sediments recovered in the high-resolution lower Pliocene sequence. Lower sedimentation rates and lower diatom abundance and poor preservation over the last 2.4 m.y. may reflect glacial intensification.

SITE 694 (WEDDELL ABYSSAL PLAIN)

Site 694 (W5), on the northern part of the Weddell Abyssal Plain, is remote from continental areas (Figures 1, 2, and 15; Table 1). This is the deepest (4653 m) of the seven Leg 113 sites that form a depth transect in the Weddell Sea region for studies of vertical water-mass evolution and related sediment history around Antarctica during the Cenozoic and late Mesozoic. The site consists of three holes and was selected to obtain a continuously cored, largely terrigenous sequence of hemipelagic clays and turbidites to provide a record of continental erosion during the glacial and preglacial climatic regimes of Antarctica, and obtain data on the history of bottom-water production in the Weddell Sea.

The sedimentary sequence (0-391.3 mbsf), of middle Miocene to Pleistocene age (Figures 16 and 17), is mostly terrigenous with a minor biosiliceous component and fluctuating abundances of ice-rafted material throughout. Almost all sediments are hemipelagic silts and clays, and turbidites. The paleomagnetic polarity stratigraphy in the topmost 20 m of Hole 694B extends from the Brunhes to early Gilbert Chrons. Biostratigraphic ages are based on diatoms and radiolarians and are broadly defined. The quality of the cores is good only in the uppermost 20 m of the sequence; otherwise the cores are moderately to highly disturbed and core recovery is poor (37% overall). The site (Hole 694C) was abandoned at 391.3 mbsf, well above target depth, when the XCB stuck at the bottom of the drill string, requiring a drill-pipe trip.

The sequence at Site 694 has been divided into four lithostratigraphic units (Figures 16 and 17) based upon differences in grain size, diatom content, lithification and inferred sedimentation processes.

Unit I (0-21.1 mbsf; early Pliocene to Pleistocene) is a condensed sequence of clay and clayey mud with minor silt, and diatom-bearing clayey mud. The sediments are interpreted as cyclic distal turbidites and hemipelagic sediment.

Unit II (21.1-111.7 mbsf; early Pliocene?) is dominated by well- to moderately-well-sorted lithic and quartz sands, and is interpreted as a sandy turbidite sequence. Core recovery was very low (16%) in this unit because of the sediment's unconsolidated nature.

Unit III (111.7-304.3 mbsf; middle Miocene? to earliest Pliocene?) consists of hemipelagic sediments and turbidites; graded silt sequences, some with diatoms; and diatom-bearing silty and clayey muds with interbedded silts and sandy muds. Unit III has been subdivided into five subunits based on compositional differences and inferred processes of sedimentation. Subunit IIIA (111.7-150.4 mbsf;? lower Pliocene to upper Miocene) consists of fine grained sands, silts and clays. Grading is common. Subunit IIIB (150.4-179.2 mbsf; upper Miocene) contains sands, silts and clays similar to Subunit IIIA, but the interbedded clayey muds contain diatoms. Subunit IIIC (179.2 to 208.3 mbsf; late Miocene) consists of severly disturbed silts and clays. Subunit IIID (208.3-298.2 mbsf; middle to late Miocene) includes a variety of diatom-bearing silty and clayey muds with interbedded silts and sandy muds. Subunit IIIE (298.2-304.3 mbsf; middle Miocene) consists of gravel bearing sandy and silty mud.

Unit IV (304.3-391.2 mbsf; middle Miocene) consists of diatom-bearing and diatomaceous claystones, with silts near the base. This unit becomes increasingly lithified downwards. Sand, excluding ice-rafted detritus, is rare. Sponge spicules are present (8-10%) in a few intervals near the base of this unit. The graded silts represent distal turbidites; the mudstones are either hemipelagic or turbiditic. The base of Unit IV is marked by a hard layer of silicified claystone displaying subconchoidal fractures and resembling chert. The sequence at Site 694 is similar to the middle and upper parts of Site 323 in the Bellingshausen Basin, west of the Antarctic Peninsula.

Discussion

Ice-rafted debris exhibiting a wide size range was found discontinuously throughout the sequence in varying abundances, suggesting changes in the intensity of Antarctic glaciation from the middle Miocene to the Pleistocene. A dominance of sedimentary rocks in the lithic material of the turbidites and the glacial material at Site 694 suggests that the principal source area is the Antarctic Peninsula and the present day region of the Filchner-Ronne Ice Shelf, rather than East Antarctica. Hence the site provides insights about the development of glaciation on West Antarctica.

Several criteria based on sediment composition, neritic diatoms and clay mineralogy suggest the development of the West Antarctic ice sheet during the late Miocene and early Pliocene. The sedimentary sequence suggests instability of this ice sheet during its growth. Based on magnetostratigraphy the most rapid deposition of turbidites (about 180 m/m.y. or greater) occurred within an interval of only 0.5 m.y. or less during the early Gilbert Chron (C3R4), before 4.8 Ma in the latest Miocene to earliest Pliocene. This rapid turbiditic deposition occurred during an interval marked elsewhere by major cooling, increased and highly variable O^{18} values and low sea level. High rates of turbidite sedimentation in this interval probably resulted from an expanding, yet unstable, West Antarctic ice sheet. After 4.8 Ma, turbidite deposition virtually ceased at Site 694, indicating that the West Antarctic ice sheet has been a permanent and stable feature since early Pliocene time.

SITE 695 (SOUTH ORKNEY MICROCONTINENT)

Site 695 (W7) is the intermediate site of three (Sites 695, 696, and 697) which form a paleodepth transect through the circum-Antarctic water masses on the edge of the Weddell gyre. One hole was drilled at this site which lies on the southeastern edge of the South Orkney Microcontinent (SOM) on the northern margin of the Weddell Sea (Figures 1, 2, and 18; Table 1) in 1305 m of water.

The South Orkney Microcontinent separated from the Antarctic Peninsula in the west at between 30-35 Ma (Barker et al., 1984; King and Barker, in press; Lawver et al., in press). The microcontinent was pervasively block-faulted by these events, which thus provide an effective older limit to the period for which the South Orkney Microcontinent can be used as a passive "dip-stick" into the paleo-ocean. In addition to the largely pelagic Neogene and uppermost Oligocene section which was predicted for this site, the reflection profiles also showed a bottom-simulating seismic reflector (BSR) at about 600 mbsf, which was thought to be a methane gas hydrate. Drilling was required to stop 50 m above the BSR for safety reasons.

The section recovered at Site 695 consists of 345.1 m of Pleistocene to uppermost Miocene or lowermost Pliocene sediment with minor core disturbance. Three lithostratigraphic units are recognized (Figures 19 and 20).

Unit I (0-190.7 mbsf; Pleistocene to early Pliocene) was subdivided into four subunits and consists of diatom-rich (up to 80%) sediments. Subunit IA (0-19.9 mbsf; Pleistocene to middle Pliocene) contains mainly diatom-bearing silty and clayey muds with minor foraminifers above 4 mbsf. Subunit IB (19.9-51.3 mbsf; middle to early Pliocene) consists of muddy diatom ooze. Subunit IC (51.3-93.7 mbsf; early Pliocene) consists of mainly silty and muddy diatom oozes with some volcanic ash. Subunit ID (93.7-190.7 mbsf, early Pliocene) consists of diatom ooze to diatom silty mud.

Unit II (190.7-306.9 mbsf; early Pliocene) has a much smaller biosiliceous component (10-25%) than Unit I, and consists of diatom-bearing silty and clayey muds with some volcanic ash.

Unit III (306.9-345.1 mbsf; early Pliocene to latest Miocene) consists of silty mud with 0-10% diatoms.

Ice-rafted detritus occurs throughout the sequence, but is most common above 20 mbsf and in lithostratigraphic Unit II. Volcanic ash beds and glass also occur throughout, but are most common between 50 and 250 mbsf (Units I and II). Illite and chlorite dominate the clay mineral assemblages. Graded beds are rare and the terrigenous component is primarily hemipelagic or ice-rafted.

The biogenic component is mainly siliceous; foraminifers are confined to the upper 4 mbsf (Pleistocene). Diatoms dominate, with minor radiolarians and silicoflagellates, and are common to abundant, moderately to well preserved between 5 and 293 mbsf, but less so elsewhere. Good core recovery and low disturbance promise well for a high resolution magnetostratigraphy, but low remanent intensities defer conclusive determinations to post-cruise analysis. Sedimentation rates were moderate (<30 m/m.y.) in the latest Miocene and earliest Pliocene (early Gilbert), very high (about 200 m/m.y.) in the late Gilbert, and decreased through the Gauss to low rates (2.5 to 8 m/m.y.) in the Matuyama and the Brunhes.

Discussion

The indication of high biosiliceous productivity observed in the early Pliocene at this site was also seen at other Leg 113 sites (Sites 689, 690, 693, and 694), and in the Subantarctic (DSDP Site 514; Ludwig, Krasheninnikov, et al., 1983). A parallel increase in calcareous productivity is observed in the subtropical southwest Pacific (DSDP Sites 586-593; Kennett, von der Borch, et al., 1986). The expanded section should yield a high resolution magneto- and siliceous biostratigraphic correlation, and contribute to paleoceanographic and evolutionary studies of siliceous organisms. Volcanic glass will aid correlation between the three South Orkney transect sites.

The well-constrained measured heat flow of 1.5 HFU is too high for the BSR at 600 m to be the base of a methane hydrate. No BSR is visible within the 310 to 360 m depth range predicted by the heat flow data to be the depth range of a methane hydrate base. A sharp methane increase at 250 m is related to depletion of pore water sulfate, and indicates an in situ biogenic origin, presumably related to the high biosiliceous accumulation rates. The origin of the 600 m inverse-polarity BSR remains uncertain.

SITE 696 (SOUTH ORKNEY MICROCONTINENT)

Site 696 (W8), on the southeast margin of the South Orkney Microcontinent (SOM), South Scotia Ridge (Figures 1, 2, and 21; Table 1), is the shallowest (650 m) of seven sites in the Weddell Sea depth transect for studies of Late Mesozoic and Cenozoic water mass stratification and Antarctic climatic history. Two holes were drilled at this site. The site was selected to provide a continuously cored, shallow-water sedimentary record of late Paleogene to Neogene oceanographic and climatic history for the SOM, a region adjacent to and down-current from the West Antarctic margin.

The sedimentary sequence (Figures 22 and 23), poorly recovered and commonly disturbed, is terrigenous, hemipelagic and pelagic with minor ice-rafted detritus and volcanogenic components. The sequence ranges from the middle or upper Eocene to the Pleistocene. Ice-rafted detritus of all sizes is common from the middle upper Miocene (330 mbsf) to the Pleistocene. Otherwise, only rare coarse-grained ice-rafted detritus was observed at two levels between 530 and 570 mbsf in likely Oligocene or lower Miocene sediments. Calcareous material is present only as a planktonic foraminifer component in the uppermost 4 m (Pleistocene), as minor nannofossils and planktonic and benthic foraminifers in a low core recovery interval (upper Miocene) at about 300 mbsf, and as benthic foraminifers and nannofossils in the basal 40 m (Eocene). The pelagic component is almost totally biosiliceous, dominantly diatoms.

The Site 696 sequence consists of three parts: an upper hemipelagic part to 214 mbsf, a middle diatomaceous part to 530 mbsf and a lower terrigenous and authigenic part to the base of the hole (645.6 mbsf). The sequence consists of condensed Pleistocene to upper Pliocene, expanded lower Pliocene and upper to middle Miocene, and condensed lower Oligocene(?) to Eocene sections. Preliminary stratigraphy indicates a brief hiatus or condensed sequence during the latest Pliocene to earliest Pleistocene, and a possible brief hiatus during the middle Pliocene. A condensed, barren interval separates Neogene and Paleogene sequences and hinders understanding of the transition.

A magnetic polarity stratigraphy has been identified for the lower Pliocene to the present. Prospects are poor for the Miocene interval due to low core recovery, but good for Paleogene interval. Biostratigraphic ages for the Neogene are based almost entirely on diatoms and radiolarians. Siliceous microfossils were not observed in Paleogene sediments; age assignments in this interval are therefore based upon calcareous nannofossils and palynomorphs. This is the first recovery of pollen and spores in sediments of the Weddell Sea. Benthic foraminifers are persistent but rare through the sediment sequences, and are almost exclusively low-diversity assemblages of agglutinated forms (except in the carbonate-containing intervals mentioned above).

The sequence at Site 696 has been divided into seven lithostratigraphic units (Figures 22 and 23) based upon compositional differences and diagenetic maturity. In the Neogene, the units are largely differentiated on the relative abundance of biosiliceous and terrigenous components. In the Paleogene, units are subdivided on the basis of changes in terrigenous and authigenic components and the degree of diagenetic maturity.

Unit I (0-64.5 mbsf; Pleistocene to early late Pliocene) is composed primarily of diatomaceous muds and oozes and has been subdivided into two subunits. Subunit IA (0-8.5 mbsf; Pleistocene) consists of diatom-bearing silty mud. Subunit IB (8.5-64.5 mbsf; late Pliocene) contains diatom clayey mud and muddy diatom ooze.

Unit II (64.5-124.8 mbsf; early late Pliocene to early Pliocene) contains less biosiliceous material than Unit I (30% versus 70%) and is composed mainly of diatom-bearing silty and clayey mud.

Unit III (124.8-211.8 mbsf; early Pliocene to late Miocene) is dominated by silty and clayey mud, with less important diatom-bearing clayey mud. The biosiliceous component comprises less than 15% of the sediment.

Unit IV (211.8-260.1 mbsf; late Miocene) is marked by a significant increase in biosiliceous material (up to 90%) and consists of diatom ooze and muddy diatom ooze.

Unit V (260.1-269.7 mbsf; late Miocene) consists of coarse-grained sand, probably representing a turbidite sequence.

Unit VI (269.7-529.8 mbsf; late Miocene to middle Miocene) consists of diatomaceous sediments and has been subdivided into two subunits. Subunit VIA (269.7-472.5 mbsf, late to middle Miocene) is composed of diatom ooze and mud-bearing diatom ooze. Subunit VIB (472.5-529.8 mbsf, middle Miocene) consists of lithified diatomite and mud-bearing diatomite.

Unit VII (529.8-645.6 mbsf; middle? Miocene to late Eocene) is dominantly terrigenous in origin and has been subdivided into four subunits as follows: Subunit VIIA (529.8-548.9 mbsf, middle Miocene?) is sandy mudstone; Subunit VIIB (548.9-569.4 mbsf; undifferentiated middle Miocene to late Paleogene) is claystone, clayey mudstone and silty mudstone; Subunit VIIC (569.4-606.9 mbsf; undifferentiated late Paleogene to early Miocene) is barren glauconitic silty mudstone and claystone; and Subunit VIID (606.9-645.6 mbsf; Eocene) is sandy mudstone. The harder layers of Unit VII are thought to cause the strong seismic reflection horizons associated with the break-up unconformity.

Discussion

The Eocene mudstones reflect the depositional environment of the South Orkney Microcontinent while still contiguous with the West Antarctic continental margin and before the opening of Drake Passage. Benthic foraminiferal assemblages indicate deposition in an inner neritic environment under slightly hyposaline and hypoxic conditions. The sediments contain abundant assemblages of Mollusca and Cnidaria. Diverse calcareous nannofossil assemblages attest to the warmth of the Southern Ocean in the Eocene. The palynoflora indicates the presence of temperate beech forests with an undergrowth of ferns on West Antarctica. The inference of warm climate is supported by a clay association dominated by smectite (as in the Eocene sediments of Maud Rise) and resulting from the predominance of chemical over physical weathering processes.

A sequence of about 77 m (Subunits VIIA-VIIC) of mainly barren terrigenous glauconitic sandstones and silts separates sediments of Eocene (Subunit VIID) and middle(?) Miocene (Subunit VI) age. Rare, reworked freshwater diatoms indicate the presence of freshwater lakes in West Antarctica. The section from Subunit VIIB up contains only agglutinated benthic foraminifers (except for an interval in the upper Miocene) and virtually no calcareous planktonic microfossils, indicating a change to highly undersaturated bottom waters, even at these shallow depths. The paucity of fossils makes it difficult to interpret climatic conditions in the interval of Subunits VIIA-VIIC, but rare agglutinated benthic foraminifers in Subunit VIIB suggest cool bottom waters. Ice-rafted detritus is almost totally absent. Clay mineral associations consist of abundant to exclusive smectite and common to abundant illite.

This condensed sequence passes up (perhaps disconformably) into a 300 m sequence of very poorly recovered but dominantly biosiliceous (90% diatoms) sediment of middle to latest Miocene age. Lack of terrigenous sediment deposition in the middle Miocene reflects the isolation of the South Orkney Microcontinent from West Antarctica due to the formation of Powell Basin. Sedimentation rates may have been fairly constant and moderately high from about 5 to 14 Ma, with an average of 35-41 m/m.y., but we have little data due to the extremely low-core recovery (~16%). High productivity, excellent preservation and the species composition of diatoms in the few intervals recovered suggest that the Antarctic Convergence may have been located to the north of the South Orkney Microcontinent during much of the Miocene and that there was little sea-ice in the area. The continued absence of calcareous microfossils through most of the Miocene interval suggests that the carbonate compensation depth was exceedingly shallow (except for a short, poorly recovered interval in the upper Miocene), and less than 650 m (present-day depth). The lack of ice-rafted detritus in the poorly recovered middle and lower upper Miocene sediments may suggest that major glaciation had not yet commenced on West Antarctica, in concordance with trends observed in other Leg 113 sites (Sites 694, 695, and 696.

A major change in the climate of West Antarctica possibly during the middle Miocene is indicated by changes in clay mineral assemblages. Smectite, the dominant clay mineral, is replaced by illite and chlorite. This indicates a marked decrease in chemical relative to physical weathering, and may have resulted from major cooling of West Antarctica. A similar change in clay associations occurred in the early Oligocene at sites adjacent to East Antarctica (Site 693) and Maud Rise (Sites 689 and 690) suggesting that major cooling may have started earlier in East Antarctica than West Antarctica. In the early late Miocene, diatomaceous sediments continued to dominate. An increase in the terrigenous component, the appearance of an important ice-rafted component and the further increase in illite and chlorite all might have resulted from development of a West Antarctic ice sheet during the latest Miocene to Pliocene.

Site 696 exhibits the characteristic regional decrease in sedimentation rates from the early Pliocene to the late Pliocene and Pleistocene. The Pleistocene is marked by intervals of abundant Neogloboquadrina pachyderma and a low-diversity benthic foraminiferal assemblage, as found at other Weddell Sea sites.

SITE 697 (SOUTH ORKNEY MICROCONTINENT - JANE BASIN)

Site 697 (W6), in 3484 m water depth in Jane Basin, consists of two holes. It is the deepest site of a three-site transect (Sites 695, 696, and 697) on the northern margin of the Weddell gyre (Figures 1, 2, and 24; Table 1). Jane Basin formed 25 to 30 Ma as a back-arc basin separating the then-active island arc of Jane Bank from the South Orkney Microcontinent. Sediments in Jane Basin extend from the Pleistocene to the upper Oligocene but a prominent seismic reflection horizon probably of middle Miocene age, at 550 ms (two-way travel-time), separates what is interpreted to be a lower terrigenous and volcaniclastic turbidite sequence from an upper hemipelagic sequence. This reflecting horizon was the target for drilling here. Antarctic Bottom Water flows northward through Jane Basin, and the hemipelagics promised a high-resolution record of fluctuations in bottom water production and sediment transport in the past.

The sedimentary sequence at Site 697 consists of hemipelagic sediments, with a minor siliceous biogenic component and numerous thin, altered volcanic ash layers (Figures 25 and 26). Ice-rafted detritus is abundant only near the base of the sequence. Two lithologic units are recognized; the first is divided into three subunits.

Unit I (0-293.0 mbsf; Pliocene to Pleistocene) includes silty and clayey mud, diatom-bearing silty and clayey mud, clay and diatom clayey mud. Subunit IA (0-15.5 mbsf; late Pleistocene) consists of silty mud and diatom-bearing silty mud with a fluctuating diatom content. Subunit IB (15.5-85.7 mbsf; late Pliocene to Pleistocene) consists of clayey mud and clay with diatoms rare to absent. Subunit IC (85.7-293.0 mbsf; early to late Pliocene) is mainly diatom-bearing clayey mud with clayey mud. Diatoms are disseminated and occur in thin laminae. Three thin turbidites (less than 10 cm thick) occur near 161 mbsf. At about 293 mbsf, an ungraded burrowed silt with dropstones may reflect an episode of stronger bottom currents.

Unit II (293.0-322.9 mbsf; early Pliocene) consists of silty and clayey mud, and is more coarse-grained than Unit I, with abundant ice-rafted detritus and very rare diatoms. At most one thin silt turbidite is present.

Volcanic material occurs in both units as dark gray and green fine-grained ash laminae altered to clay, as disseminated glass, and in a few thin beds of coarse vitric ash. Dropstones are mostly sedimentary, rounded or subrounded, and less than 2 cm in diameter. Bioturbation is minor. Authigenic minerals comprise fine-grained carbonates near 200 mbsf, common pyrite below 90 mbsf and possibly zeolite (irregularly between 20 and 90 mbsf). Illite and chlorite dominate the clay minerals.

The biogenic component is siliceous: diatoms dominate, fluctuating in abundance and preservation but including a few thin pristine ooze interbeds in the topmost 5 m. As at other sites, biosiliceous abundance and preservation vary with time but at lower general levels. Magnetostratigraphic zonation indicates high and smoothly-varying sedimentation rates of up to 135 m/m.y. for the Gilbert, to 78 m/m.y. until the middle Gauss and 43 m/m.y. to the late Brunhes. The biostratigraphy is in general agreement with the magnetostratigraphy.

Discussion

The expanded Pliocene section at Site 697 provides a high-resolution magnetostratigraphic record with opportunities for calibration of high-latitude biosiliceous zonations and paleoceanographic studies. The Blake

Event occurs as a doublet at 4 mbsf, confirming its global range and reversed nature. Whole-core susceptibilities may reflect orbitally-induced changes in sediment composition. Volcanic ash beds can provide additional correlation between South Orkney transect sections, which will be particularly useful for high-resolution studies of bottom-water variability.

Pleistocene sedimentation rates are more than 5 times higher than at all other Leg 113 sites, and indicate continued sediment supply and bottom-water nepheloid transport in the Weddell gyre. The absence of a calcareous layer in the Pleistocene at Site 697 (present on Maud Rise, the Dronning Maud Land margin and the other South Orkney Microcontinent sites) indicates that the carbonate compensation depth (CCD) did not descend to 3500 m in Jane Basin.

CONCLUSIONS

During Leg 113 we investigated the climatic, glacial and oceanographic history and biotic evolution of the Weddell Sea region, Antarctica, at nine sites (Figures 1 and 2; Table 1) representing a wide range of sedimentary environments. These included open-ocean pelagic biogenic sediments on Maud Rise (Sites 689 and 690), hemipelagic and terrigenous sediments on or close to the continental margins of both East and West Antarctica (Sites 691 through 693 and 695 through 697) and a deep sea turbiditic to hemipelagic sequence in the Weddell Abyssal Plain (Site 694).

These sites have provided a rich data base for evaluation of the environmental history of Antarctica and the adjacent ocean from the Early Cretaceous through the Pleistocene. The sequences have been dated aboard ship using integrated bio- and magnetostratigraphy. Calcareous microfossil biostratigraphy was primarily employed for dating sediments of Cretaceous and Paleogene age; siliceous microfossils were used for the Neogene. We studied general sediment facies (including pelagic calcareous and siliceous biogenic sediments, ice-rafted detritus, and clay mineralogy), sedimentation rates, the abundance, preservation and diversity of several planktonic microfossil groups and benthic foraminifers, palynomorphs, neritic and fresh-water diatoms, physical properties, and paleomagnetics. Additional parameters will be studied after the cruise, including oxygen, carbon, and strontium isotopes. The organic and inorganic chemistry have also provided information about environments of deposition.

During Leg 113 we concluded that there was a sequential cooling of Antarctica and surrounding oceans during the Cenozoic, that profoundly affected the sediments and the biota. Glacial development probably began during the late Paleogene in East Antarctica and during the Neogene in West Antarctica.

Organic-rich Lower and middle Cretaceous sediments indicate deposition under anoxic or weakly oxic conditions. These sediments may have been deposited at times of fluctuating surface-water salinities in environments that were similar to those on the Falkland Plateau at that time. By the late Campanian, open-ocean pelagic biogenic sediments were being deposited on Maud Rise.

On Maud Rise, a siliceous biogenic facies progressively replaced a carbonate facies during the Cenozoic, with initial siliceous sedimentation in the latest Eocene-earliest Oligocene leading to an almost completely siliceous biofacies by the late Miocene.

Diverse calcareous planktonic and benthic microfossil assemblages reflect the relative warmth of the surface and bottom water masses adjacent to Antarctica during the Late Cretaceous to the Eocene. During the Late Cretaceous to Paleocene, East Antarctica was a rich source of fine-grained terrigenous sediment. The clay is dominated by smectite. Kaolinite (associated with chlorite) appeared during the Paleocene, suggesting that climates were warm and that humidity increased during the Paleocene on East Antarctica to the south, which was probably totally unglaciated. Rich reddish colors of some Paleocene clays may indicate laterite formation.

Eocene clays are dominated by smectite both on Maud Rise and the South Orkney Microcontinent, indicating the continuation of warm climatic conditions and a predominance of chemical over physical weathering processes. An Eocene palynoflora at Site 696 indicates the presence of temperate beech forests with an undergrowth of ferns on the northern Antarctic Peninsula. A coeval moderately diverse, abundant assemblage of neritic calcareous benthic foraminifers reflects the presence of waters that were not undersaturated in $CaCO_3$ and were probably warm.

During the early Oligocene, diversity began to decrease in planktonic microfossil assemblages as the Antarctic ocean cooled. Nearly all sediments of Oligocene and younger age from both East and West Antarctic margin sites contain only agglutinated benthic foraminiferal assemblages and virtually no calcareous planktonic microfossils. All younger assemblages are dominated by, or are exclusively made up of, agglutinated forms. The change in the benthic foraminiferal assemblages probably reflects the production of highly undersaturated and probably cool water even at the very shallow water depths of Site 696 (present depth 650 m). It is likely that the change in bottom water characteristics over the margin occurs at the Eocene/Oligocene boundary, but our stratigraphic resolution is not adequate to determine this.

On Maud Rise, illite first appeared as a major clay in the early Oligocene, while smectite decreased, suggesting that hydrolysis strongly decreased on East Antarctica due to major cooling and/or increased aridity. This supports previous isotopic and biogeographic data for global cooling at the beginning of the Oligocene, widely considered to be related to glacial development of the Antarctic. Smectite continued its dominance until the middle Miocene, however, at Site 696, which is more influenced by West Antarctic climate, suggesting that warm conditions prevailed longer there than in East Antarctica.

Oligocene sequences drilled during Leg 113 on the Antarctic continental margin (Sites 693 and 696) are not of high enough quality to provide details about glacial development during the Oligocene, particularly to determine if any minor ice sheets accumulated on the continent at this time. We found no evidence for major ice build-up during the Oligocene. Upper Oligocene sediments on Maud Rise, rather remote from the continent, contain rare ice-rafted detritus (Site 689 only). The presence of IRD at

Site 693, also, indicates the existence of some ice on East Antarctica during the late early Oligocene, the earliest detected during Leg 113. Reworked benthic diatoms of Oligocene to early Miocene age at Site 693 reveal that part of the continental shelf was shallow and at least partly ice free. Rare, reworked freshwater diatoms of possible Oligocene or early Miocene age, at Site 696, indicate the presence of freshwater lakes on the northern Antarctic Peninsula.

Near the beginning of the Neogene, a pronounced increase occurred in the siliceous relative to the calcareous biofacies on Maud Rise. This coincides with the development of the biosiliceous biofacies observed in other sectors of Antarctica and is perhaps related to the northward expansion of cool surface waters.

A further step in Antarctic evolution occurred during the middle Miocene as suggested by data from Sites 693 and 696. The middle Miocene is missing in a hiatus at 693, and a noticeable increase occurs in the abundance of IRD in the lower upper Miocene sediments immediately above. A significant cooling probably also occurred during the middle Miocene in West Antarctica; smectite is replaced by illite and chlorite at Site 696. This indicates that strong physical weathering, inferred to have resulted from climatic cooling, developed much later than in East Antarctica. The continued absence of IRD at Site 696, however, through the middle and early late Miocene, suggests that major glaciation might not yet have begun on West Antarctica.

Leg 113 data do not suggest that the East Antarctic ice sheet, once formed, underwent significant deglaciation, even during the early Pliocene for which we have expanded sequences. The data also indicate that the West Antarctic ice sheet probably did not begin to form until the late Miocene. This tentative conclusion is based on sedimentary evidence from Site 694, the distribution of reworked neritic diatoms, and changes in clay minerals. Site 696 exhibits an increase in hemipelagic sedimentation, the appearance of an abundant ice-rafted component and further increases in concentration of illite and chlorite during the late Miocene. The West Antarctic ice sheet may have been unstable during the early stages of its development, as indicated by the variability of sediments at Site 694. The highest rates of turbidite deposition at this site (180 m/m.y. or greater) may have occurred within an interval of only 0.5 m.y. or less during the early Gilbert Chron (C3R4) before 4.8 Ma, in the latest Miocene to earliest Pliocene. These high sedimentation rates possibly resulted from an expanding, yet unstable, West Antarctic ice sheet and occurred during an interval marked elsewhere by major cooling, increased and highly variable $\delta^{18}O$ values and low sea level.

In the earliest Pliocene at about 4.8 Ma, turbidite deposition virtually ceased at Site 694, suggesting that the West Antarctic ice sheet may have become a permanent and stable feature. At Site 696, diatomaceous sediments were largely replaced by diatom-bearing silty and clayey muds as a result of development of this ice sheet on the South Orkney Microcontinent and northern Antarctic Peninsula. Sedimentation rates increased markedly in the early Pliocene at most Leg 113 sites (Figure 27) due to increased terrigenous sedimentation and biosiliceous productivity.

This was followed throughout the region by markedly lower sedimentation rates (Figure 27) and diatom abundances and poor microfossil preservation during the last 2.4 m.y. This seems to represent another step in glacial intensification and an expansion of sea-ice, and perhaps is related to known global climatic cooling known at this time.

The Pleistocene is marked by low sedimentation rates and intervals of abundant Neogloboquadrina pachyderma and a calcareous benthic foraminiferal assemblage at nearly all Weddell Sea sites shallower than about 3400 m. The continued high rates of hemipelagic deposition at Site 697 in Jane Basin during the Pleistocene reflect the continued transport of sediment down the West Antarctic margin and perhaps a stronger northward flow of Antarctic Bottom Water.

Table 1
Leg 113 Coring Summary

Hole	Dates, 1987	Latitude	Longitude	Water depth*	Pen.	No. co.	m cored	m rec.	% rec.
689A	Jan. 15-16	64°31.01'S	03°05.99'E	2080	11.8	1	9.5	9.35	98.4
689B	Jan. 16-18	64°31.01'S	03°05.99'E	2080	297.3	33	297.3	229.44	77.2
689C	Jan. 18	64°31.01'S	03°06.03'E	2080	27.6	3	27.1	20.54	75.8
689D	Jan. 18-19	64°31.01'S	03°06.03'E	2080	133.8	12	114.3	115.97	101.4
690A	Jan. 19-20	65°09.63'S	01°12.30'E	2914	7.7	1	7.7	9.86	128.0
690B	Jan. 20-21	65°09.63'S	01°12.30'E	2914	213.4	25	213.4	214.59	100.5
690C	Jan. 21-23	65°09.62'S	01°12.29'E	2914	321.2	24	200.6	177.19	88.3
691A	Jan. 25-26	70°44.54'S	13°48.66'W	3035	0.1	1	0.1	0.1	100.0
691B	Jan. 26	70°44.64'S	13°48.56'W	3038	1.7	1	0	0	0
691C	Jan. 26	70°44.58'S	13°48.68'W	3025	12.7	1	0	0	0
692A	Jan. 26	70°43.44'S	13°49.21'W	2880	6.7	1	6.7	0.65	10.0
692B	Jan. 26-30	70°43.43'S	13°49.20'W	2875	97.9	13	97.9	28.60	29.0
693A	Jan. 30-Feb. 5	70°49.89'S	14°34.41'W	2359	483.9	51	483.9	213.58	44.1
693B	Feb. 5-6	70°49.89'S	14°34.46'W	2359	401.2	19	167.4	92.16	55.1
694A	Feb. 9-10	66°50.83'S	33°26.80'W	4653	9.8	1	9.8	9.85	100.0
694B	Feb. 10-14	66°50.84'S	33°26.83'W	4653	188.9	25	188.9	65.03	34
694C	Feb. 14-18	66°50.82'S	33°26.76'W	4653	391.3	23	211.5	71.73	33.7
695A	Feb. 20-23	62°23.48'S	43°27.10'W	1305	345.1	42	341.1	254.39	73.7
696A	Feb. 23-24	61°50.95'S	42°55.98'W	650	103.0	12	106.0	58.30	55.0
696B	Feb. 24-Mar. 2	61°50.96'S	42°56.00'W	650	645.6	62	569.0	156.69	27.5
697A	Mar. 3-4	61°48.63'S	40°17.73'W	3481	20.9	3	28.1	26.60	94.7
697B	Mar. 4-7	61°48.63'S	40°17.73'W	3483	322.9	32	304.9	188.30	61.7

Pen. : Penetration
No. co. : Number of cores
m cored : Meters cored
m rec. : Meters recovered
% rec. : Percentage recovered
*Water depth = bottom felt (m drill pipe from the dual elevator stool) - 11.1 m

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FIGURE CAPTIONS

Figure 1. Location of Leg 113 Sites (689 to 697) in the Weddell Sea. All sites lie in the present-day Antarctic water mass, south of the Polar Front. SOM = South Orkney Microcontinent.

Figure 2. The relative position and depth distribution of Leg 113 sites in the Weddell Sea. Maud Rise has been offset onto the line of section, along a northwest-southeast strike of the Weddell Sea (see Figure 1). Vertical exaggeration = 10X; mbsl = meters below sea level.

Figure 3. A. Norwegian (NARE 85) multichannel seismic line (U.B. MAUD-3), across Site 689. Location of seismic line is shown in Figure 3B.

B. Bathymetric map of Maud Rise showing location of seismic lines given in Figures 3A and 6.

Figure 4. A. Lithostratigraphy, age, and core recovery (black equals recovered interval) of Site 689 holes. The lithologic legend is given in Figure 4B, dashed lines between chronostratigraphic boundaries indicate continuous sedimentation, wavy lines between chronostratigraphic boundaries indicate a hiatus, and mbsf = meters below sea-floor.

B. Lithologic legend used for Leg 113 sites.

Figure 5. Compilation of Site 689 shipboard data, including seismic reflection profile, lithologic units, smear slide components, NRM inclination and intensity, calcium carbonate, and physical properties. Legend for the smear slide components is given in the middle right-hand side. In this smear slide component column the blank fill area on the far right indicates zeolites, not clay.

Figure 6. Norwegian (NARE 85) multichannel seismic reflections profile (U.B. MAUD-2), across Site 690. Location of profile is shown in Figure 3B.

Figure 7. Lithostratigraphy, age, and core recovery (black equals recovered interval) of holes drilled at Site 690. The lithologic legend is given in Figure 4B, dashed lines between chronostratigraphic boundaries indicate continuous sedimentation, wavy lines between chronostratigraphic boundaries indicate a hiatus, and mbsf = meters below sea-floor.

Figure 8. Compilation of Site 690 shipboard data, including seismic reflection profile, lithologic units, smear slide components, NRM inclination and intensity, calcium carbonate, and physical properties. In physical properties data, dots = measurements from Hole 690B, plus signs (+) = measurements from Hole 690C. Legend for the smear slide components is given in the middle

right-hand side of Figure 5. In this smear slide component column the horizontal fill at the right with Z's indicates zeolites and the blank fill with F's indicates foraminifers.

Figure 9. A. Multichannel seismic reflection profile (BGR 78-019) across Dronning Maud Land Margin and Wegener Canyon, showing locations of Sites 691 and 692 and reflection horizon U6. Location map is shown in Figure 9B.

B. SeaBeam bathymetry of Dronning Maud Land Margin showing location of Sites 691, 692, and 693 and Figures 9A and 12. From unpublished data collected by Polarstern during austral seasons 1985-1986 and 1986-1987.

Figure 10. Lithostratigraphy, age and core recovery (black equals recovered interval) of Site 692 holes. The lithologic legend is given in Figure 4B, dashed lines between chronostratigraphic boundaries indicate continuous sedimentation, wavy lines between chronostratigraphic boundaries indicate a hiatus, and mbsf = meters below sea-floor.

Figure 11. Compilation of Site 692 shipboard data, including seismic reflection profile, lithologic units, NRM inclination and intensity, and physical properties. In the bulk density plot, dots = bulk density measurements and plus signs (+) = GRAPE measurements.

Figure 12. Multichannel seismic profile (BGR 86-07), across Dronning Maud Land margin and Wegener Canyon, showing location of Site 693 and seismic reflector U6. Location of profile is given in Figure 9B.

Figure 13. Lithostratigraphy, age, and core recovery (black equals recovered interval) of Site 693 holes. The lithologic legend is given in Figure 4B, dashed lines between chronostratigraphic boundaries indicate continuous sedimentation, wavy lines between chronostratigraphic boundaries indicate a hiatus, and mbsf = meters below sea-floor.

Figure 14. Compilation of Site 693 shipboard data, including seismic reflection profile, lithologic units, smear slide components, NRM inclination and intensity, and physical properties. In physical properties data, dots = measurements from Hole 693A and plus signs (+) = measurements from Hole 693B. Legend for the smear slide components is given in Figure 5. In addition, the N near 250 m = nannofossils and the G near 400 m = glauconite.

Figure 15. A. Multichannel seismic reflection profile (AMG 845) in Weddell Sea Basin, showing approximate location of Site 694. Location of profile is shown in Figure 15B.

B. Shiptracks showing location of seismic reflection profile shown in Figure 15A.

Figure 16. Lithostratigraphy, age, and core recovery (black equals recovered interval) of Site 694 holes. The lithologic legend is given in Figure 4B, dashed lines between chronostratigraphic boundaries indicate continuous sedimentation, wavy lines between chronostratigraphic boundaries indicate a hiatus, and mbsf = meters below sea-floor.

Figure 17. Compilation of Site 694 shipboard data, including seismic reflection profile, lithologic units, smear slide components, and physical properties. In physical properties data, dots = measurements from Hole 694B and plus signs (+) = measurements from Hole 694C. Legend for smear slide components is given in Figure 5.

Figure 18. A. Section of seismic reflection profile (AMG 845-18) showing location of Site 695 and prominent bottom-simulating reflector (BSR).

B. Bathymetric map of South Orkney Region with location of seismic reflection profiles shown in Figures 18A, 21, and 24.

Figure 19. Lithostratigraphy, age, and core recovery (black equals recovered interval) of Site 695 holes. The lithologic legend is given in Figure 4B, dashed lines between chronostratigraphic boundaries indicate continuous sedimentation, wavy lines between chronostratigraphic boundaries indicate a hiatus, and mbsf = meters below sea-floor.

Figure 20. Compilation of Site 695 shipboard data, including seismic reflection profile, lithologic units, smear slide components, clay mineralogy, NRM inclination and intensity, and physical properties. Legend for smear slide components is given in Figure 5, and the C in the blank fill along the far right-hand border = carbonate.

Figure 21. Section of seismic reflection profile (AMG 845-18) showing location of Site 696. Location of seismic reflection profile is given in Figure 18B.

Figure 22. Lithostratigraphy, age, and core recovery (black equals recovered interval) of Site 696 holes. The lithologic legend is given in Figure 4B, dashed lines between chronostratigraphic boundaries indicate continuous sedimentation, wavy lines between chronostratigraphic boundaries indicate a hiatus, and mbsf = meters below sea-floor.

Figure 23. Compilation of Site 696 shipboard data, including seismic reflection profile, lithologic units, smear slide components, NRM inclination and intensity, and physical properties. In physical properties data, dots = measurements from Hole 696A and plus signs (+) and circles = measurements from Hole 696B. Legend for the smear slide components is given in Figure 5, and the blank fill on the far right hand side with the R = rock fragments.

Figure 24. Section of seismic reflection profile (BRAN 790-E), showing location of Site 697. Location of seismic reflection profile is given in Figure 18B.

Figure 25. Lithostratigraphy, age, and core recovery (black equals recovered interval) of Site 697 holes. The lithologic legend is given in Figure 4B, dashed lines between chronostratigraphic boundaries indicate continuous sedimentation, wavy lines between chronostratigraphic boundaries indicate a hiatus, and mbsf = meters below sea-floor.

Figure 26. Compilation of Site 697 shipboard data, including seismic reflection profile, lithologic units, smear slide components, NRM inclination and intensity, and physical properties. Legend for the smear slide components is given in Figure 5, and the blank fill patterns on the far right indicate as follows: Z = zeolite, C = carbonate, and R = rock fragments.

Figure 27. Comparison of sedimentation rates at all Leg 113 sites. Solid lines indicate good chronostratigraphic control, dotted and dashed lines indicate poor chronostratigraphic control, question marks indicate questionable interval (possibly slumped interval or barren interval), and thin wavy lines mark hiatuses. The lower right-hand insert is an expanded graph for the upper 100 m of all sites. Mbsf = meters below sea-floor.

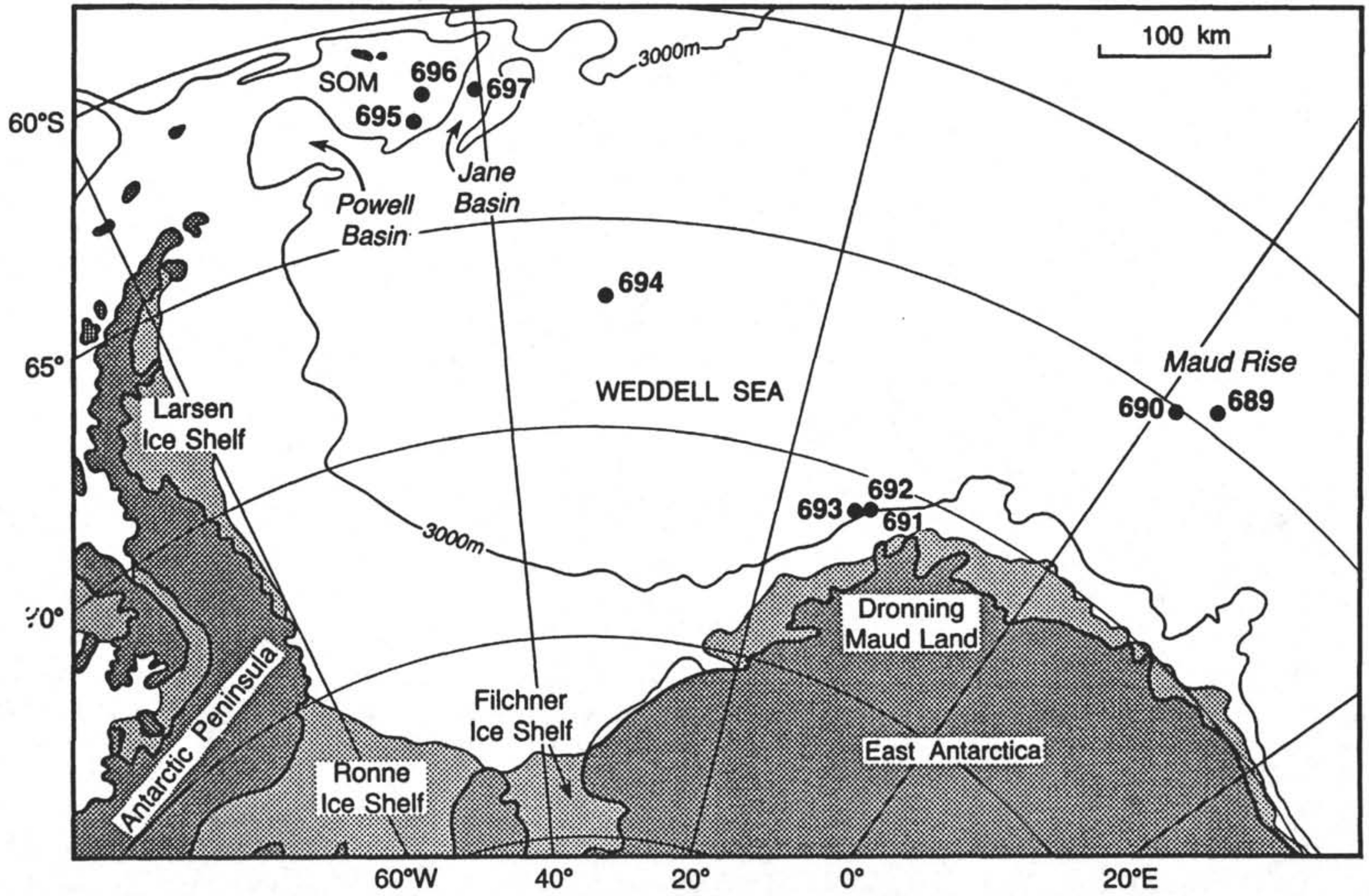

100 km
SOM
696
697
695
3000m
60°S
Jane Basin
Powell Basin
694
65°
WEDDELL SEA
Maud Rise
690
689
Larsen Ice Shelf
692
693
691
3000m
70°
Dronning Maud Land
Antarctic Peninsula
Filchner Ice Shelf
East Antarctica
Ronne Ice Shelf
60°W
40°
20°
0°
20°E

FIGURE 1.

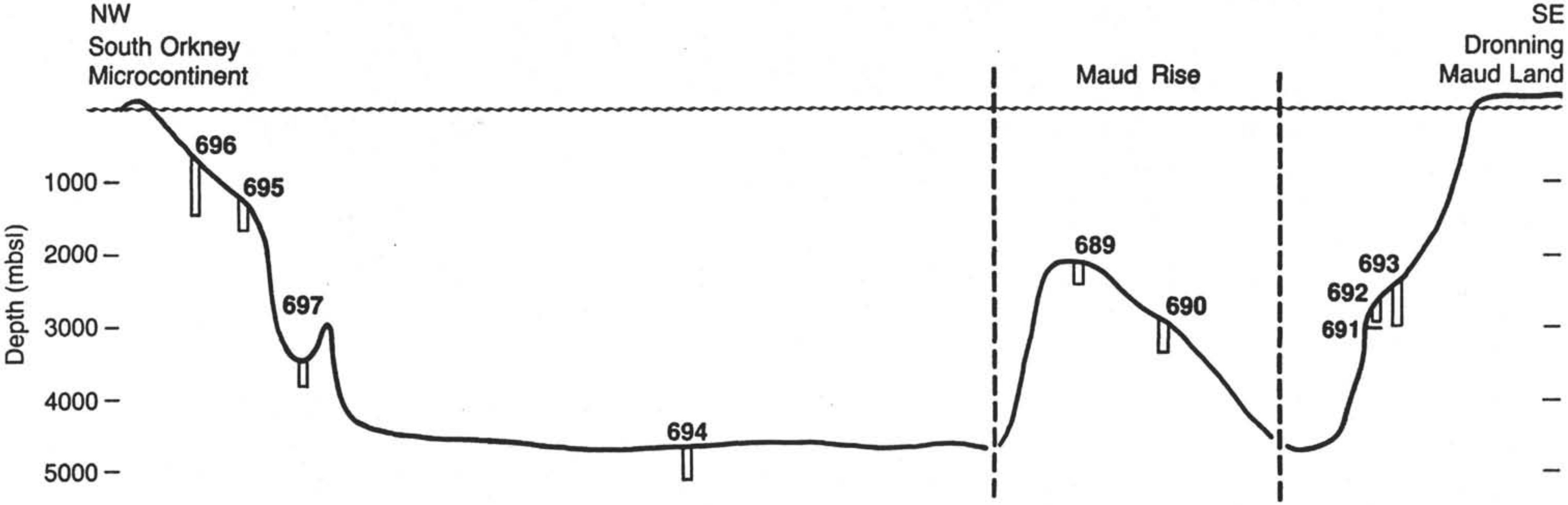

NW
South Orkney Microcontinent
Maud Rise
SE
Dronning Maud Land
Depth (mbsl)
1000
2000
3000
4000
5000
696
695
697
694
689
690
693
692
691

FIGURE 2.

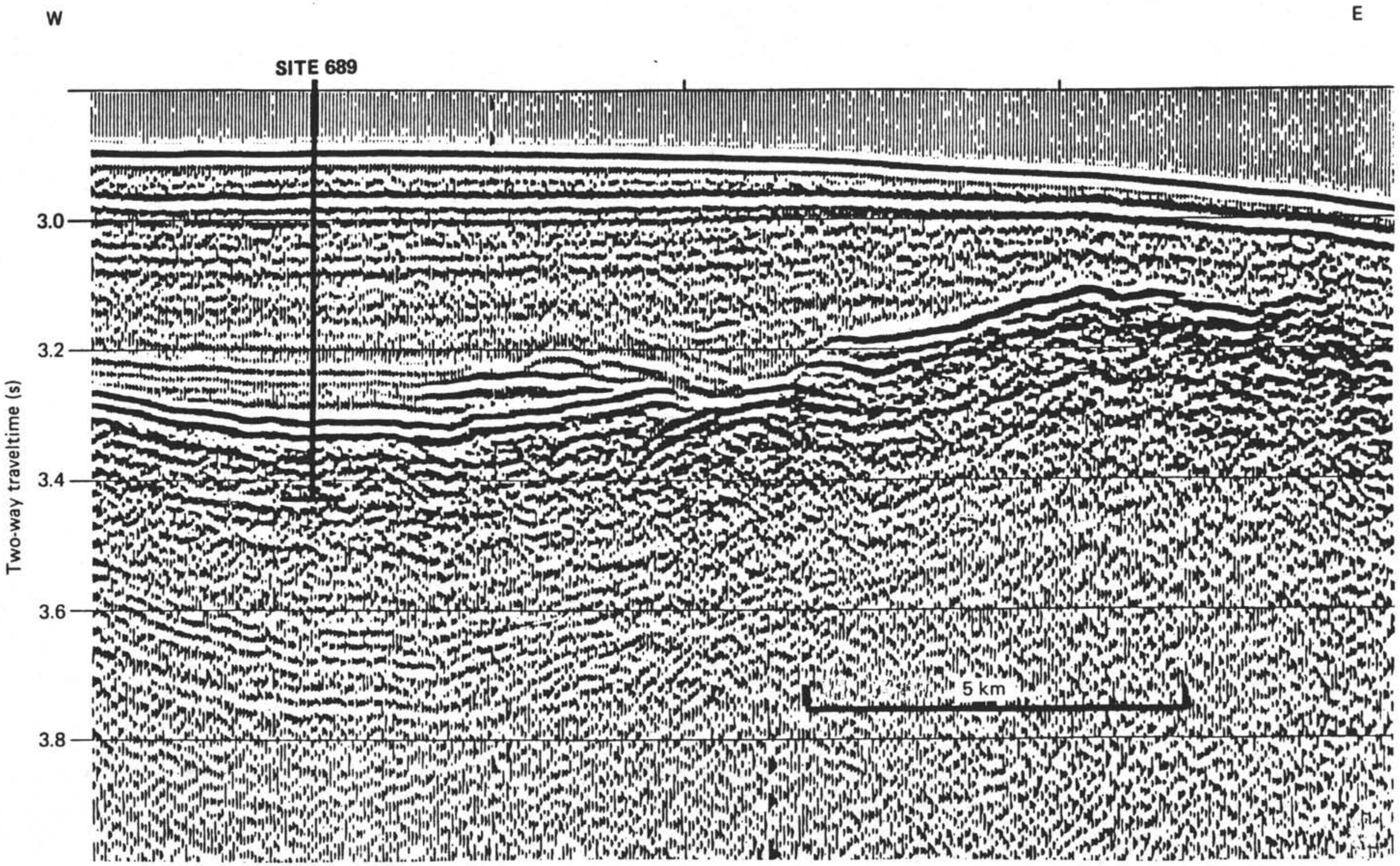


FIGURE 3A.

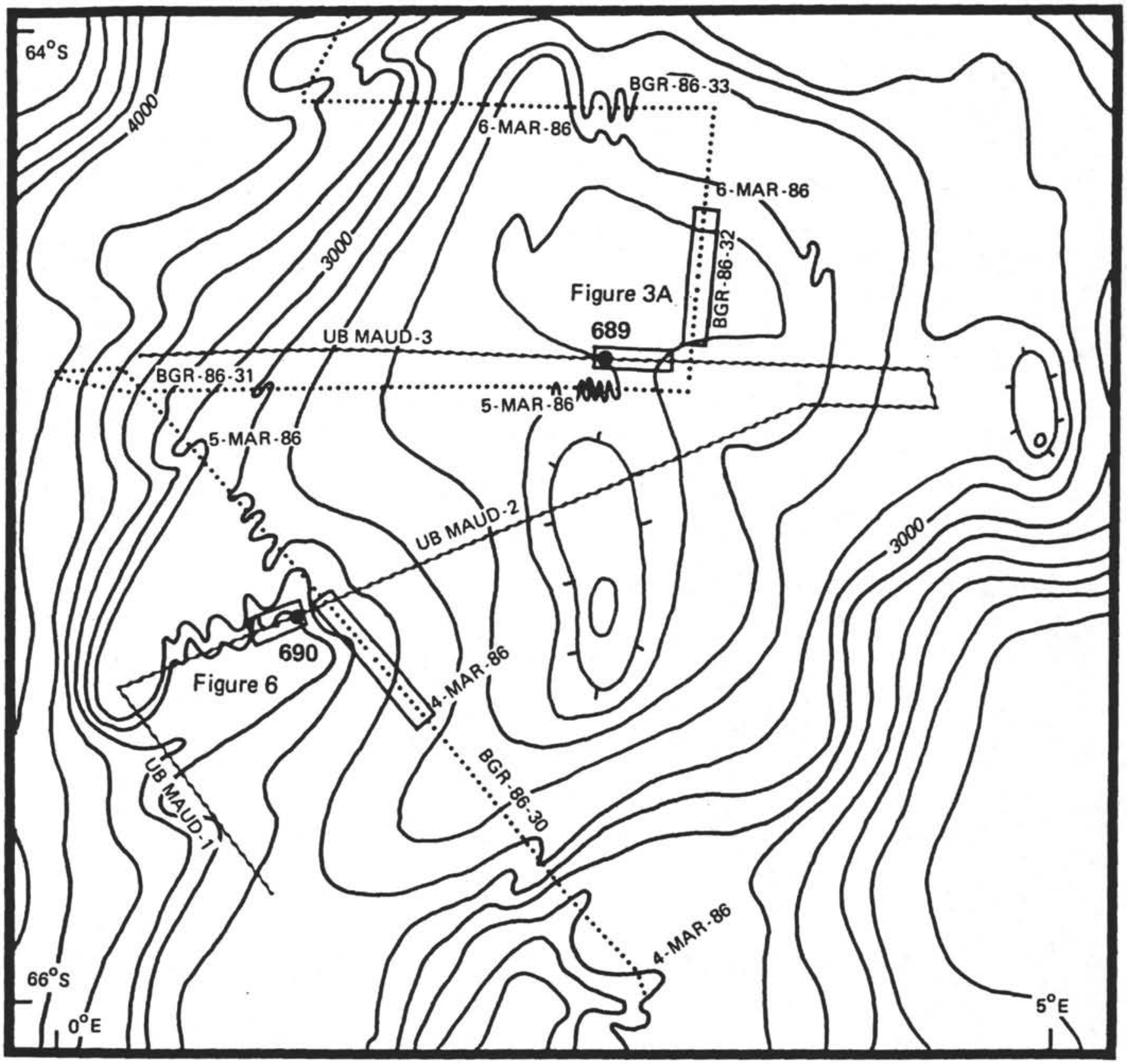

64°S
66°S
0°E
5°E
4000
3000
3000
3000
BGR-86-33
6-MAR-86
6-MAR-86
BGR-86-32
Figure 3A
689
UB MAUD-3
BGR-86-31
5-MAR-86
5-MAR-86
UB MAUD-2
690
Figure 6
4-MAR-86
BGR-86-30
UB MAUD-1
4-MAR-86

FIGURE 3B.

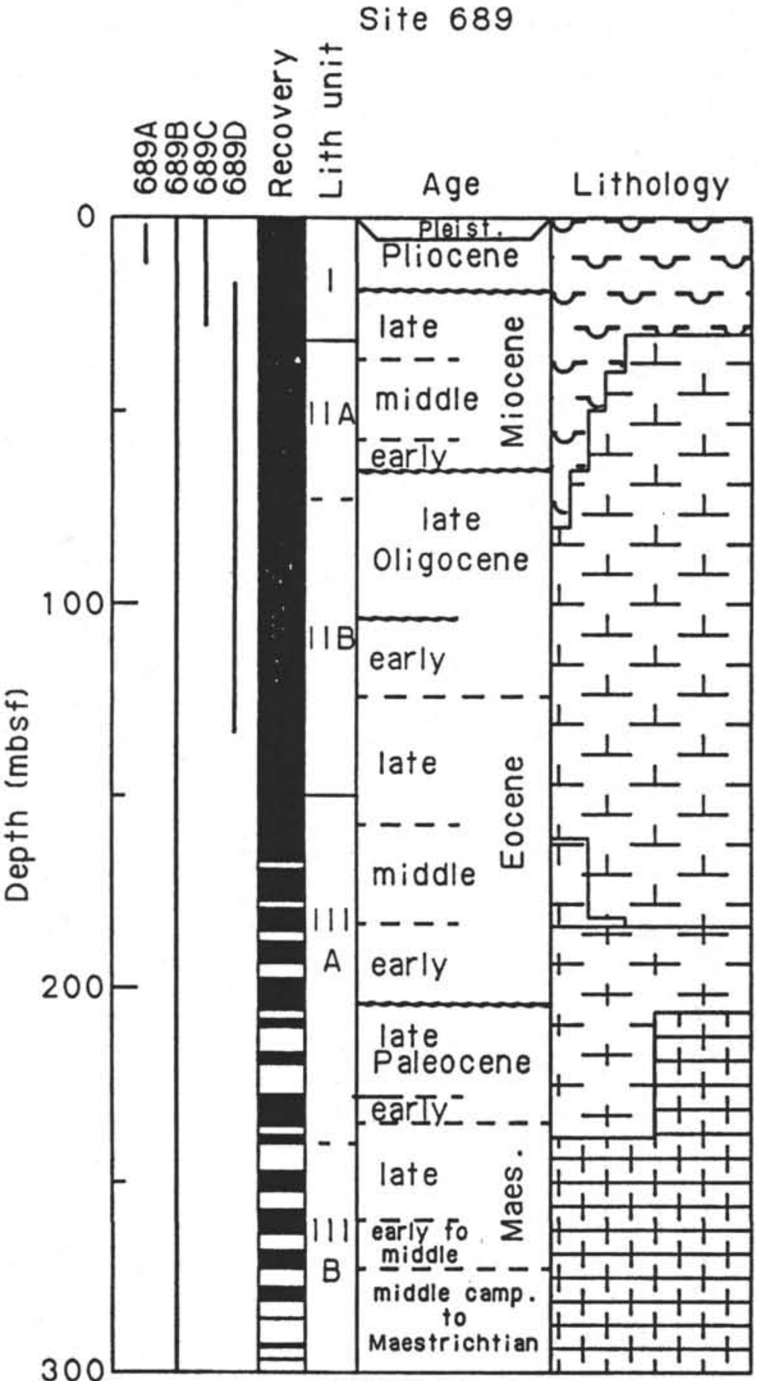

Site 689
689A
689B
689C
689D
Recovery
Lith unit
Age
Lithology
Depth (mbsf)
0
100
200
300
I
IIA
IIB
III A
III B
Pleist.
Pliocene
late
middle
early
Miocene
late Oligocene
early
late
middle
Eocene
early
late Paleocene
early
late
early to middle
Maes.
middle camp. to Maestrichtian

FIGURE 4A.

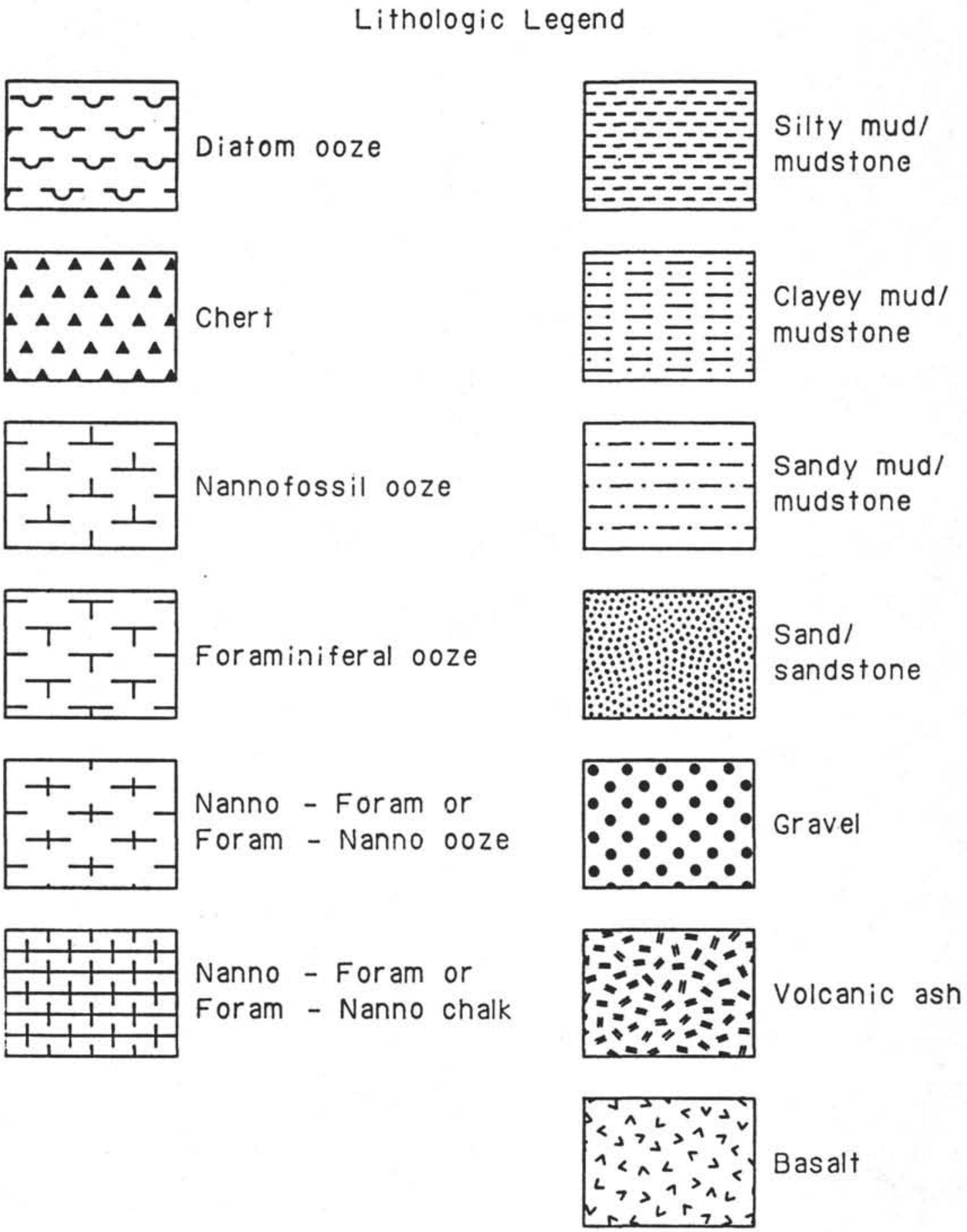

Lithologic Legend
Diatom ooze
Chert
Nannofossil ooze
Foraminiferal ooze
Nanno - Foram or Foram - Nanno ooze
Nanno - Foram or Foram - Nanno chalk
Silty mud/ mudstone
Clayey mud/ mudstone
Sandy mud/ mudstone
Sand/ sandstone
Gravel
Volcanic ash
Basalt

FIGURE 4B.

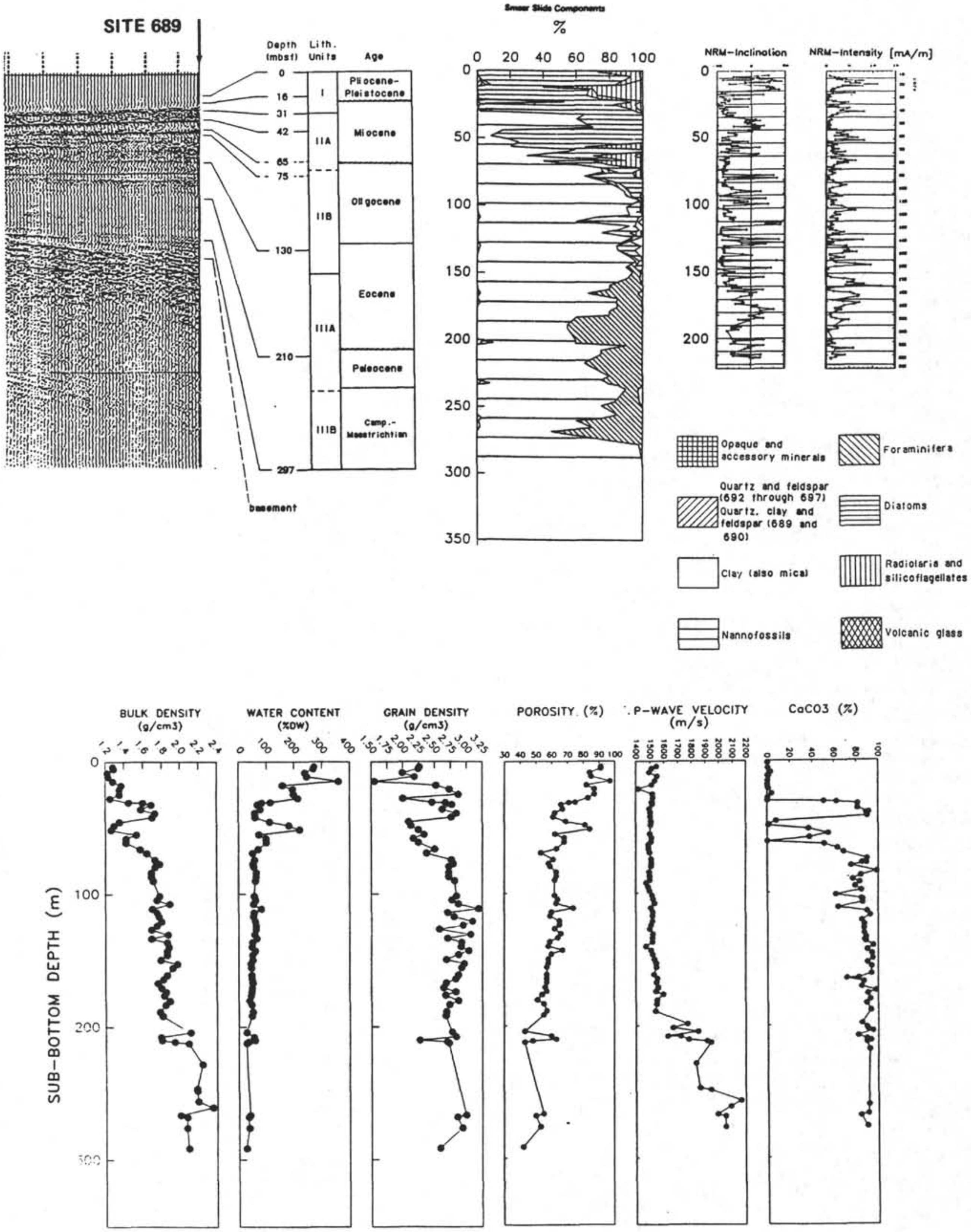

SITE 689
Depth (mbsf)
Lith. Units
Age
0
16
31
42
65
75
130
210
297
basement
I
IIA
IIB
IIIA
IIIB
Pliocene-Pleistocene
Miocene
Oligocene
Eocene
Paleocene
Camp.-Maastrichtian
Smear Slide Components
%
0 20 40 60 80 100
0 50 100 150 200 250 300 350
NRM-Inclination
NRM-Intensity [mA/m]
Opaque and accessory minerals
Foraminifera
Quartz and feldspar (692 through 697) Quartz, clay and feldspar (689 and 690)
Diatoms
Clay (also mica)
Radiolaria and silicoflagellates
Nannofossils
Volcanic glass
BULK DENSITY (g/cm3)
WATER CONTENT (%DW)
GRAIN DENSITY (g/cm3)
POROSITY (%)
P-WAVE VELOCITY (m/s)
CaCO3 (%)
SUB-BOTTOM DEPTH (m)
0 100 200 300
1.2 1.4 1.6 1.8 2.0 2.2 2.4
0 100 200 300 400
1.50 1.75 2.00 2.25 2.50 2.75 3.00 3.25
30 40 50 60 70 80 90 100
1400 1500 1600 1700 1800 1900 2000 2100 2200
0 20 40 60 80 100

FIGURE 5.

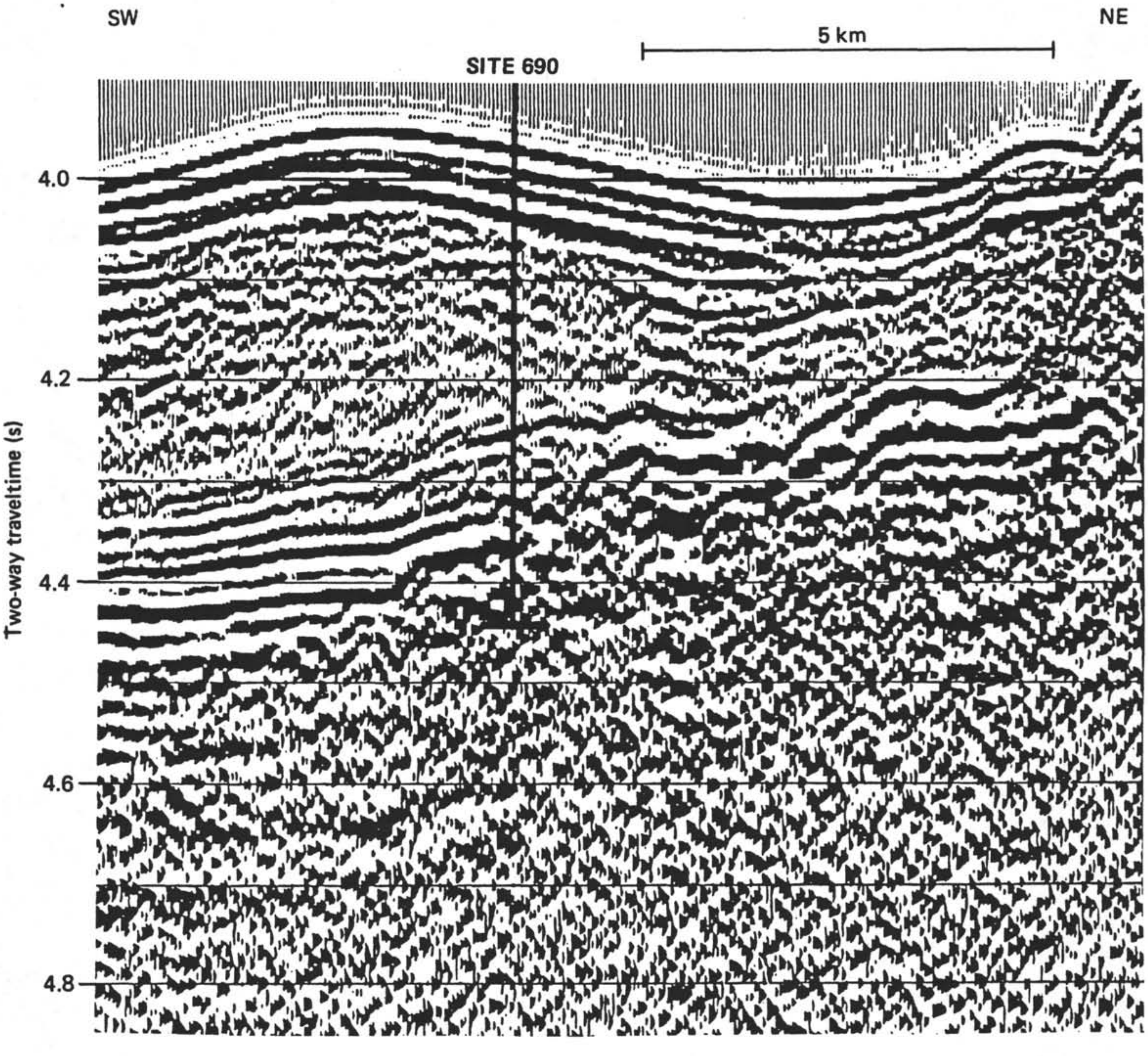


FIGURE 6.

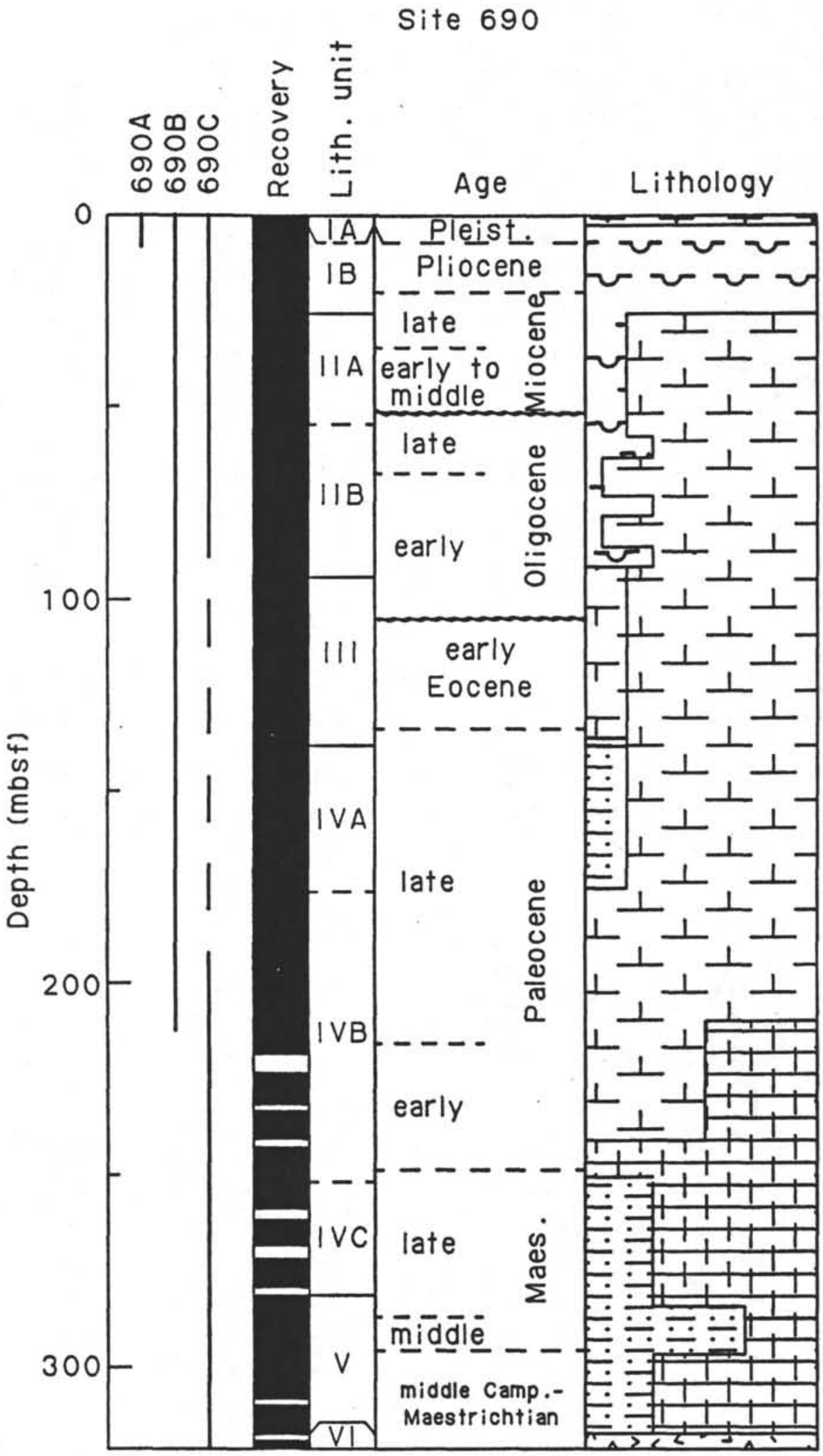

Site 690
690A
690B
690C
Recovery
Lith. unit
Age
Lithology
Depth (mbsf)
0
100
200
300
IA
IB
IIA
IIB
III
IVA
IVB
IVC
V
VI
Pleist.
Pliocene
late
early to middle
Miocene
late
early
Oligocene
early Eocene
late
early
Paleocene
late
middle
Maes.
middle Camp.-Maestrichtian

FIGURE 7.

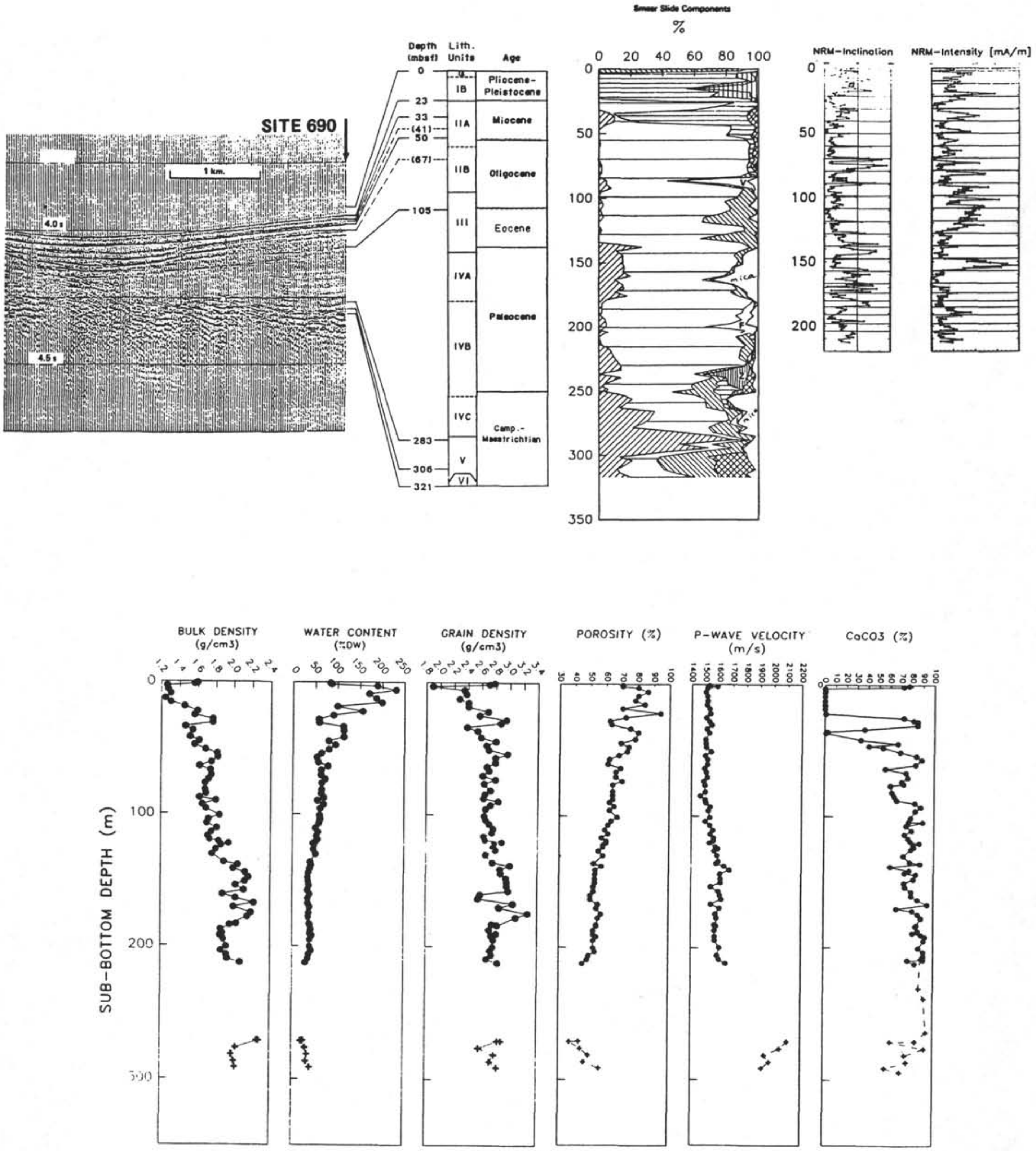

SITE 690
1 km.
4.0 s
4.5 s
Depth (mbsf)
Lith. Units
Age
0
23
33
(41)
50
(67)
105
283
306
321
IB
IIA
IIB
III
IVA
IVB
IVC
V
VI
Pliocene-Pleistocene
Miocene
Oligocene
Eocene
Paleocene
Camp.-Maastrichtian
Smear Slide Components
%
0 20 40 60 80 100
0
50
100
150
200
250
300
350
mica
NRM-Inclination
NRM-Intensity [mA/m]
BULK DENSITY (g/cm3)
1.2 1.4 1.6 1.8 2.0 2.2 2.4
WATER CONTENT (%DW)
0 50 100 150 200 250
GRAIN DENSITY (g/cm3)
1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4
POROSITY (%)
30 40 50 60 70 80 90 100
P-WAVE VELOCITY (m/s)
1400 1500 1600 1700 1800 1900 2000 2100 2200
CaCO3 (%)
0 10 20 30 40 50 60 70 80 90 100
SUB-BOTTOM DEPTH (m)
0
100
200
300

FIGURE 8.

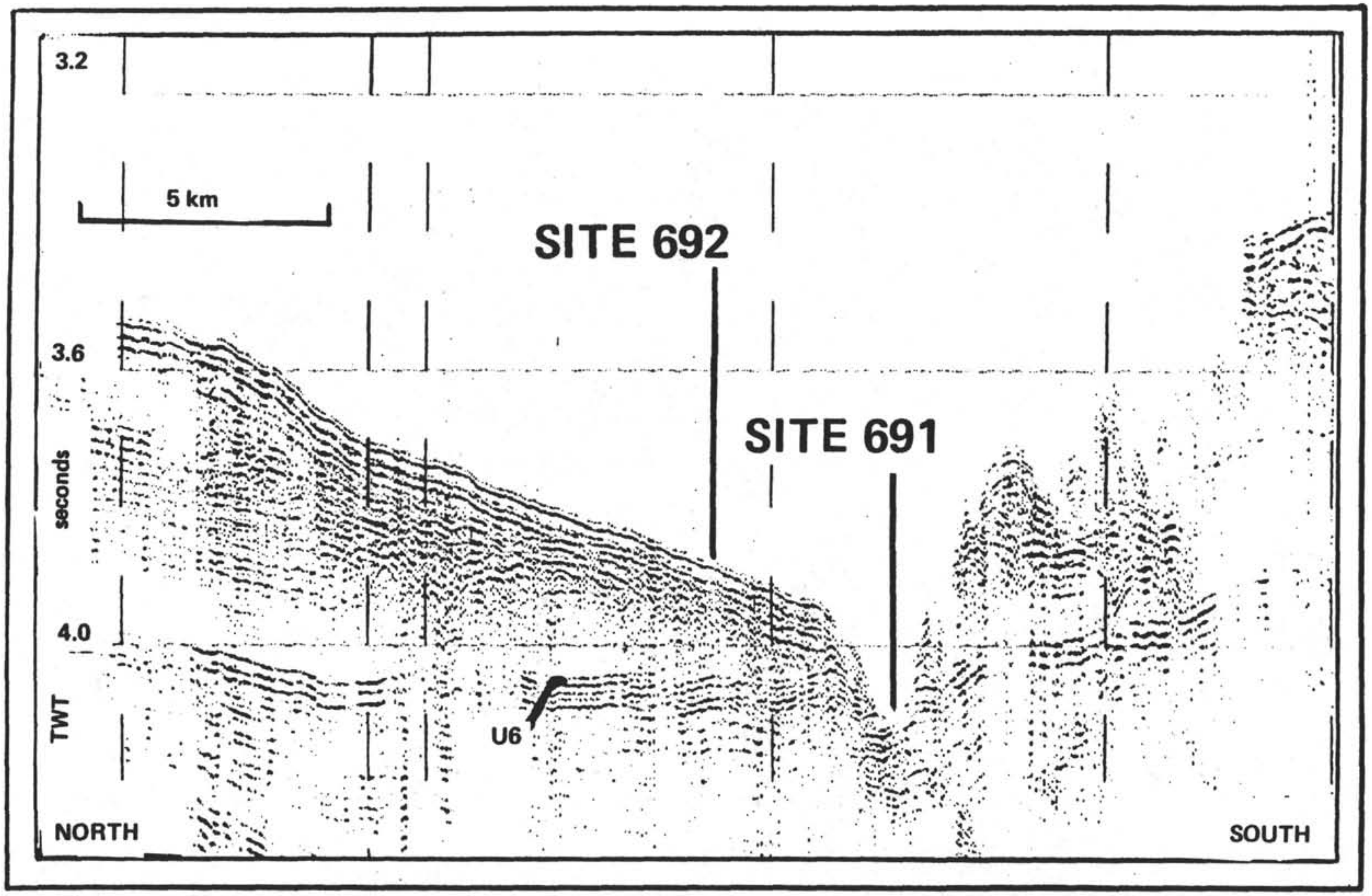


FIGURE 9A.

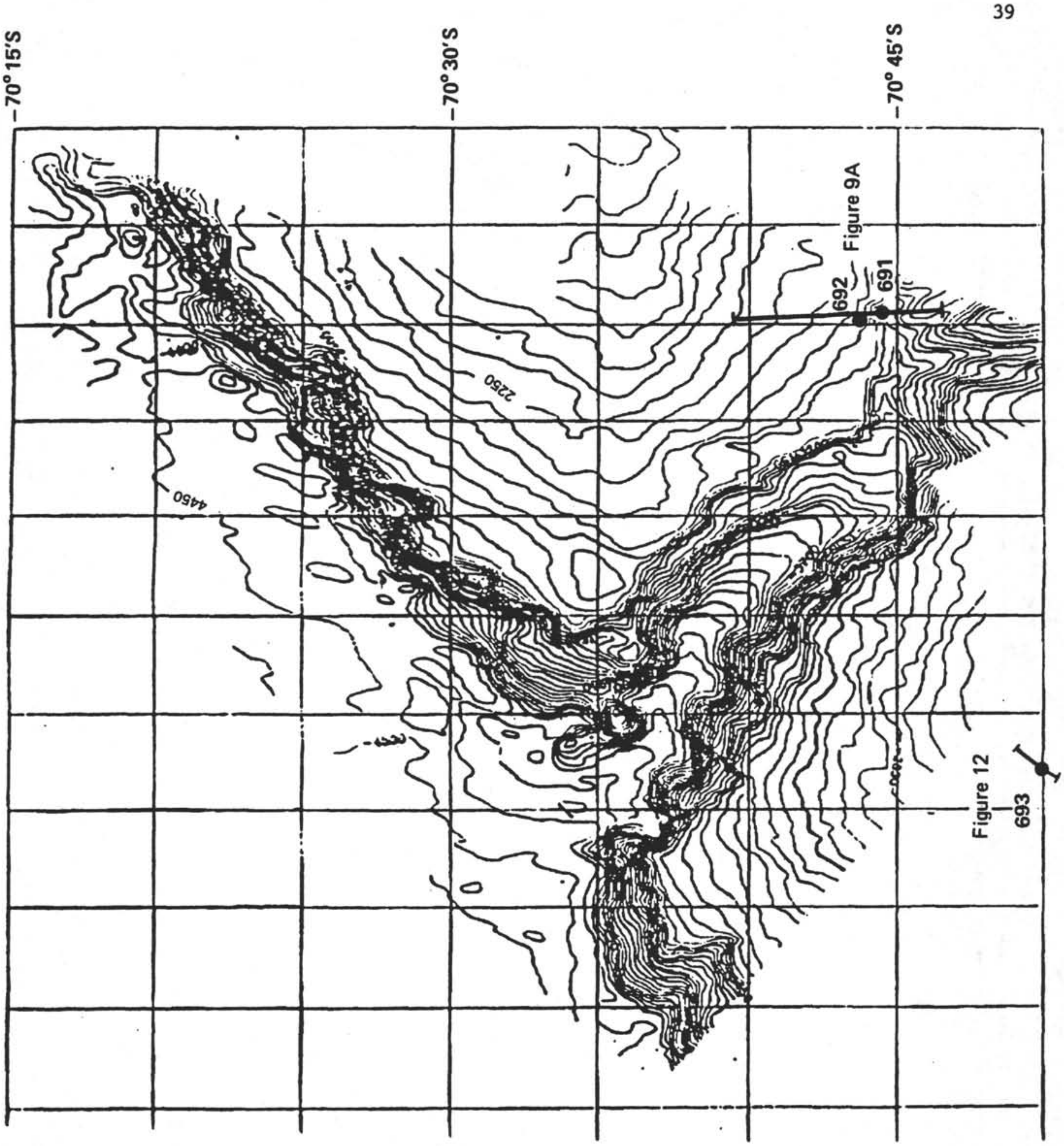

-70°15'S
-70°30'S
-70°45'S
Figure 9A
692
691
2250
4450
-14°W
Figure 12
693
-15°W

FIGURE 9B.

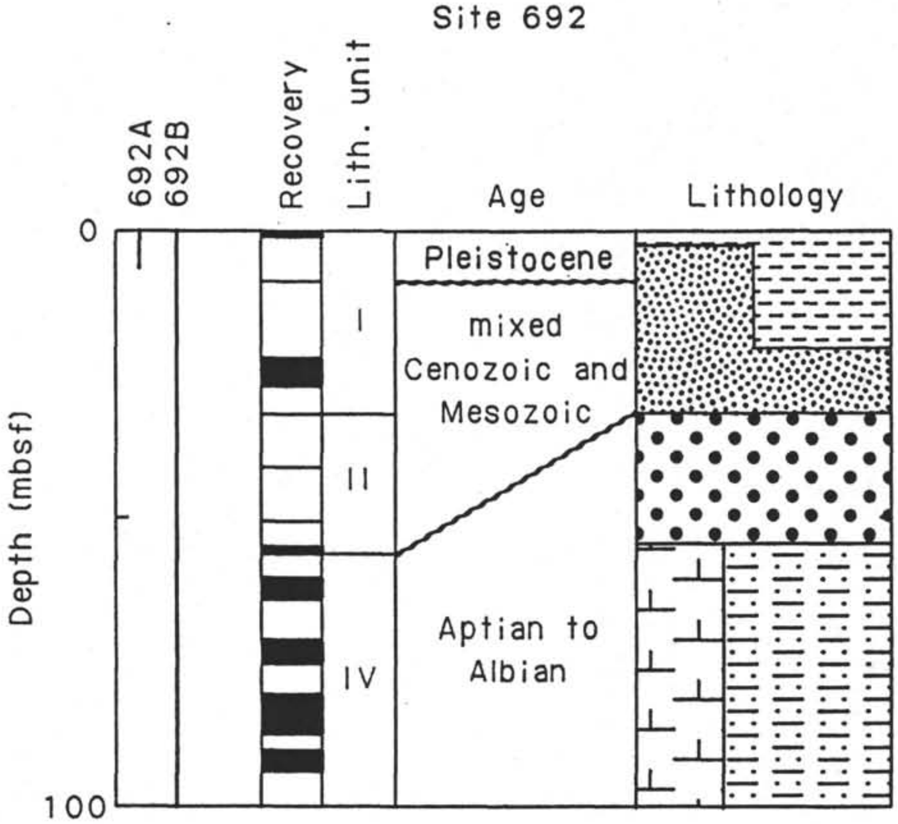

Site 692
692A
692B
Recovery
Lith. unit
Age
Lithology
0
100
Depth (mbsf)
Pleistocene
I
mixed Cenozoic and Mesozoic
II
IV
Aptian to Albian

FIGURE 10.

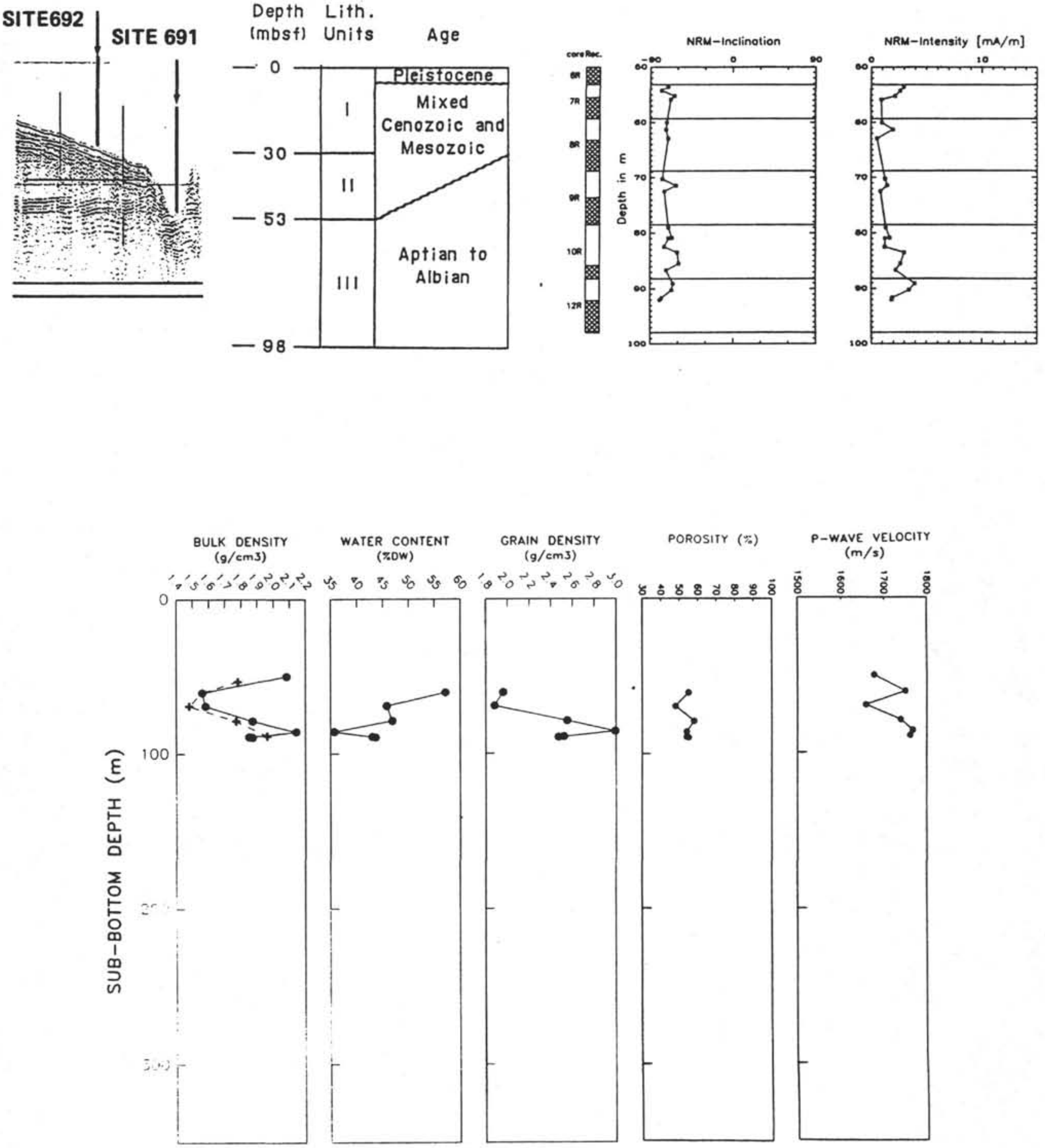

SITE692
SITE 691
Depth (mbsf)
Lith. Units
Age
0
30
53
98
I
II
III
Pleistocene
Mixed Cenozoic and Mesozoic
Aptian to Albian
core Rec.
6R
7R
8R
9R
10R
12R
NRM-Inclination
-90
0
90
Depth in m
60
70
80
90
100
NRM-Intensity [mA/m]
0
10
BULK DENSITY (g/cm3)
1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2
WATER CONTENT (%DW)
35 40 45 50 55 60
GRAIN DENSITY (g/cm3)
1.8 2.0 2.2 2.4 2.6 2.8 3.0
POROSITY (%)
30 40 50 60 70 80 90 100
P-WAVE VELOCITY (m/s)
1500 1600 1700 1800
SUB-BOTTOM DEPTH (m)
0
100
200
300

FIGURE 11.

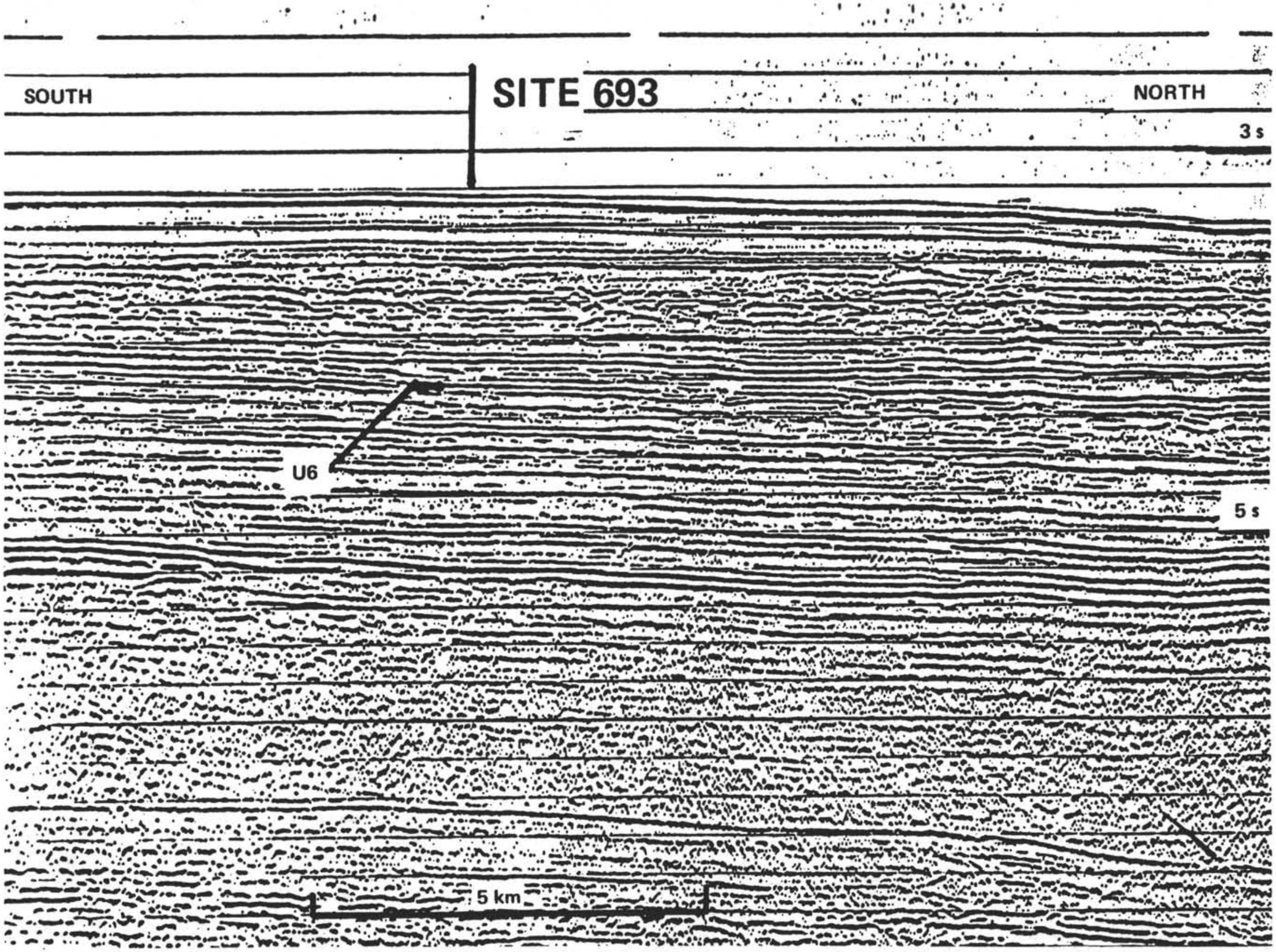


FIGURE 12.

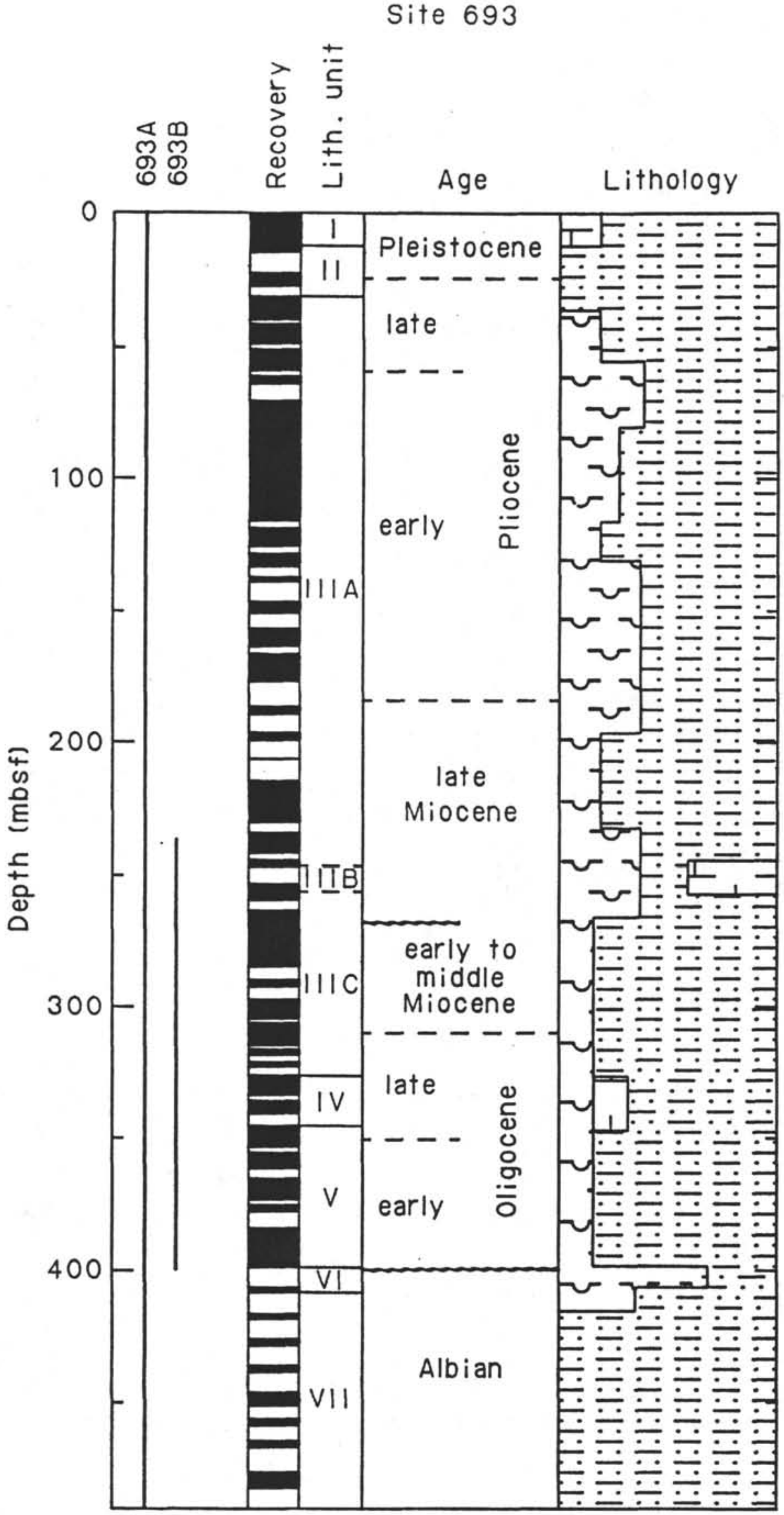

Site 693
693A
693B
Recovery
Lith. unit
Age
Lithology
Depth (mbsf)
0
100
200
300
400
I
II
IIIA
IIIB
IIIC
IV
V
VI
VII
Pleistocene
late
early
Pliocene
late
Miocene
early to
middle
Miocene
late
early
Oligocene
Albian

FIGURE 13.

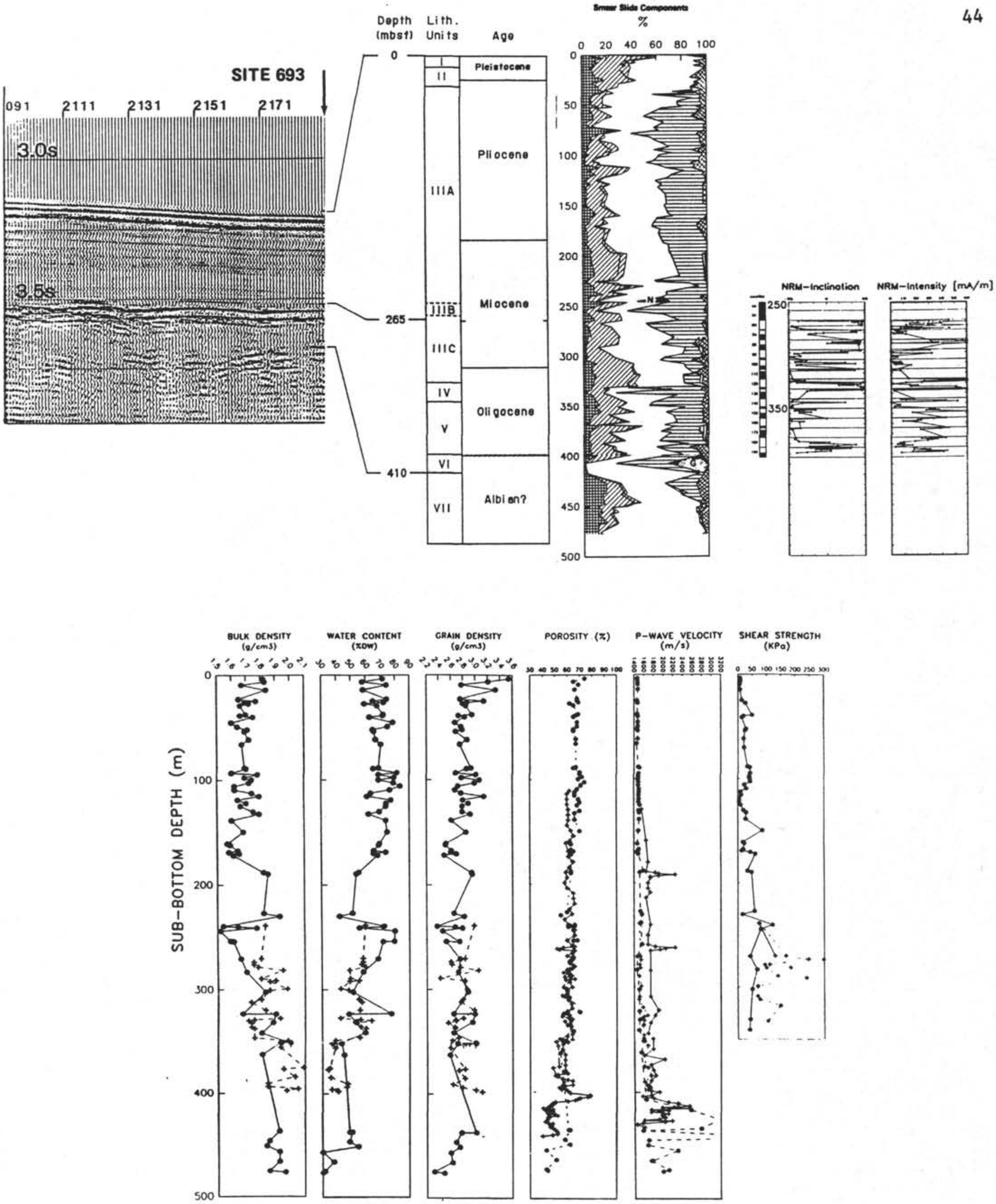

SITE 693
091
2111
2131
2151
2171
3.0s
3.5s
Depth (mbsf)
Lith. Units
Age
0
265
410
I
II
IIIA
IIIB
IIIC
IV
V
VI
VII
Pleistocene
Pliocene
Miocene
Oligocene
Albian?
Smear Slide Components
%
0 20 40 60 80 100
0
50
100
150
200
250
300
350
400
450
500
N
G
NRM-Inclination
NRM-Intensity [mA/m]
250
350
BULK DENSITY (g/cm3)
WATER CONTENT (%DW)
GRAIN DENSITY (g/cm3)
POROSITY (%)
P-WAVE VELOCITY (m/s)
SHEAR STRENGTH (KPa)
30 40 50 60 70 80 90 100
0 50 100 150 200 250 300
SUB-BOTTOM DEPTH (m)
0
100
200
300
400
500

FIGURE 14.

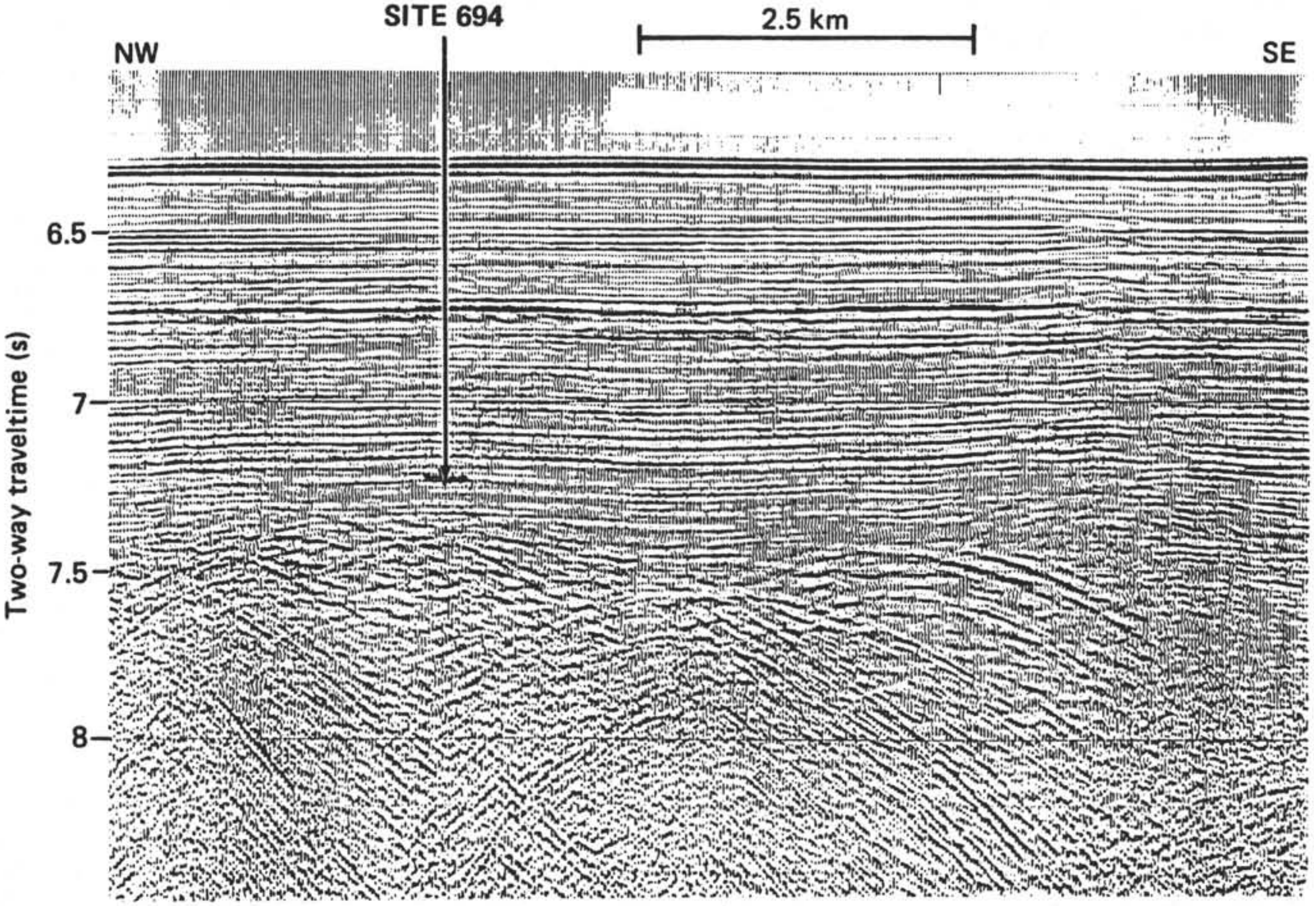


FIGURE 15A.

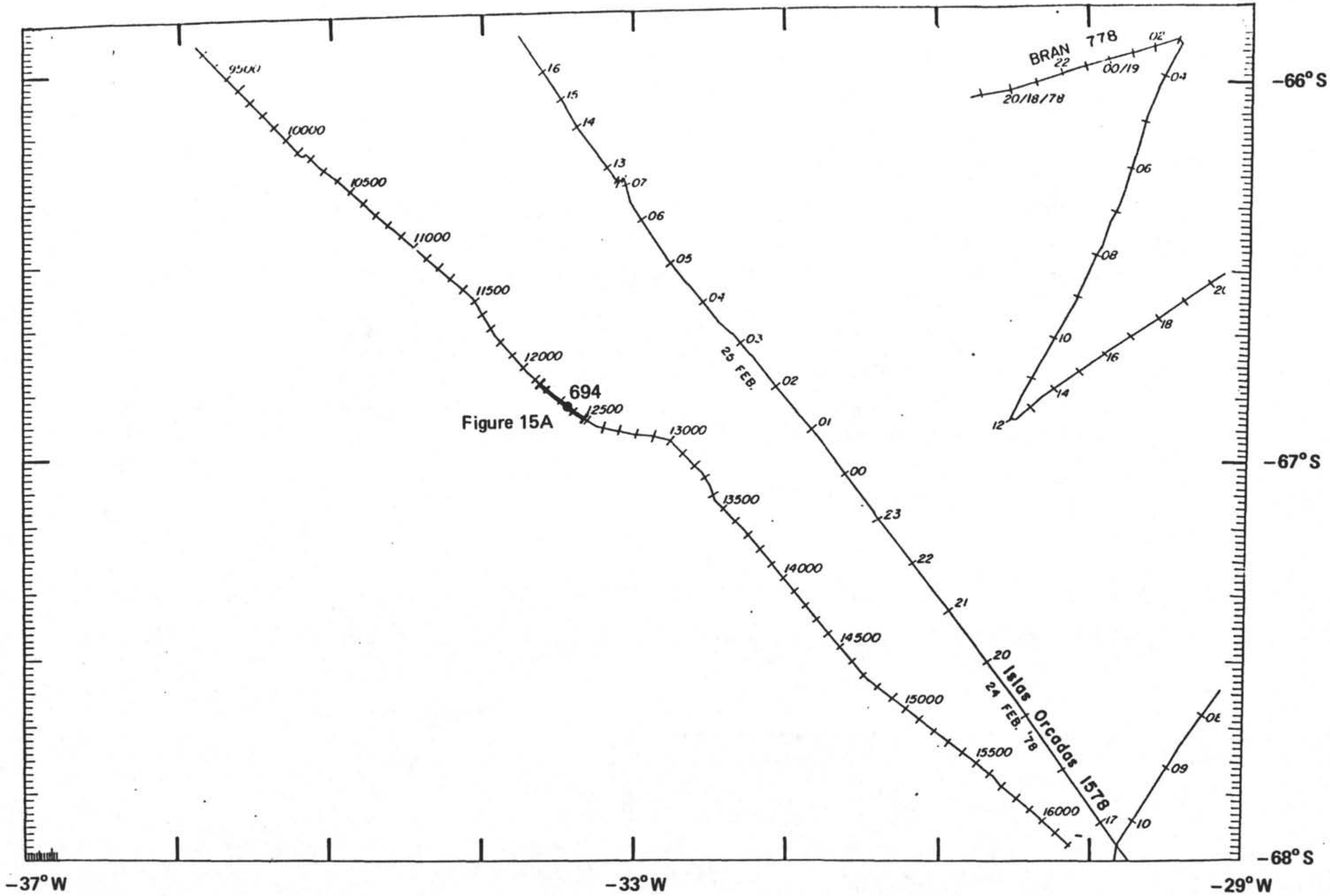

BRAN 778
20/18/78
22
00/19
02
04
06
08
10
12
14
16
18
20
9500
10000
10500
11000
11500
12000
694
Figure 15A
12500
13000
13500
14000
14500
15000
15500
16000
16
15
14
13
07
06
05
04
03
25 FEB.
02
01
00
23
22
21
20
Islas Orcadas 1578
24 FEB. '78
17
10
09
08
-66° S
-67° S
-68° S
-37° W
-33° W
-29° W

FIGURE 15B.

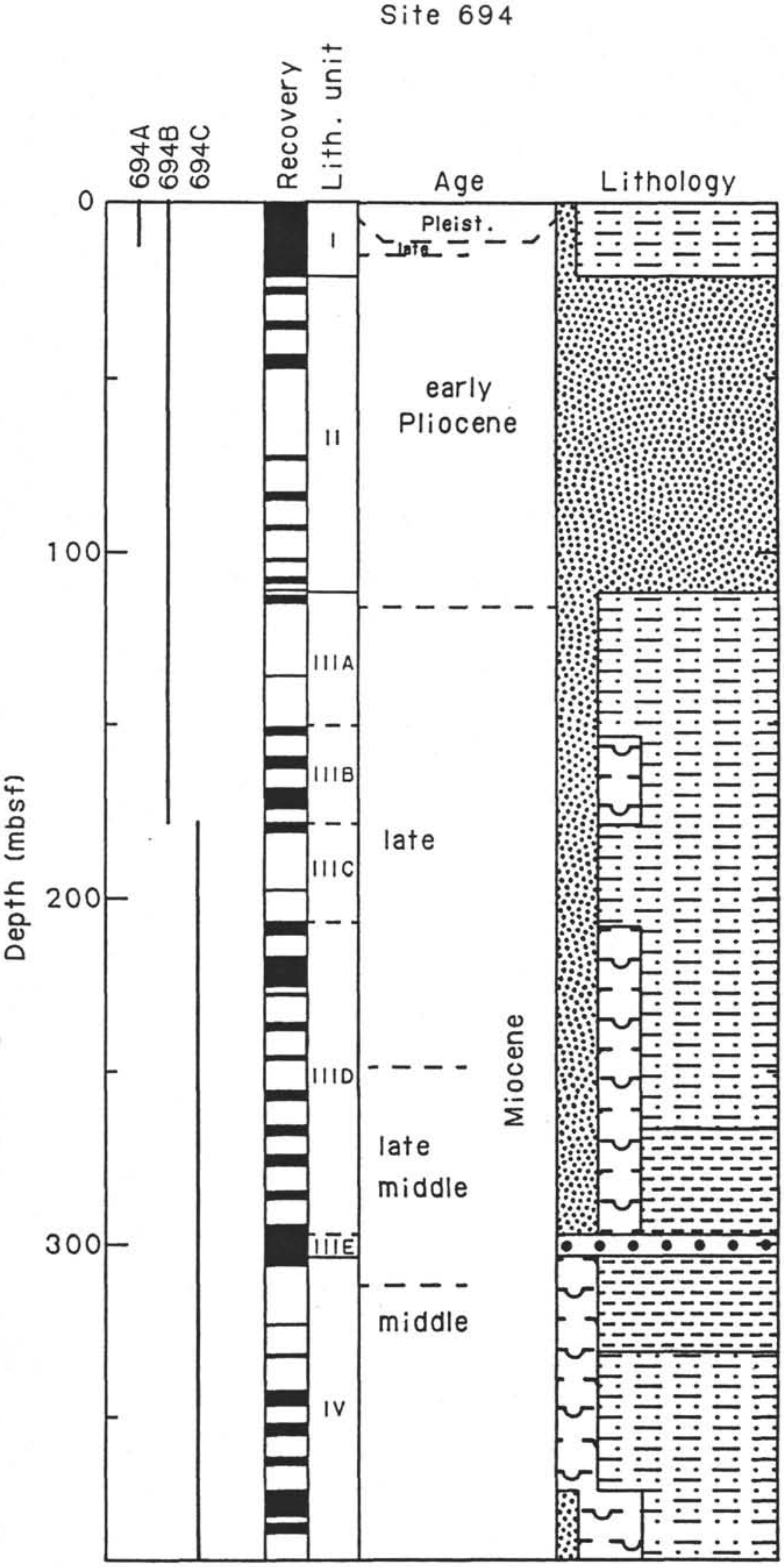

Site 694
694A
694B
694C
Recovery
Lith. unit
Age
Lithology
Depth (mbsf)
0
100
200
300
I
II
IIIA
IIIB
IIIC
IIID
IIIE
IV
Pleist.
late
early
Pliocene
late
late
middle
middle
Miocene

FIGURE 16.

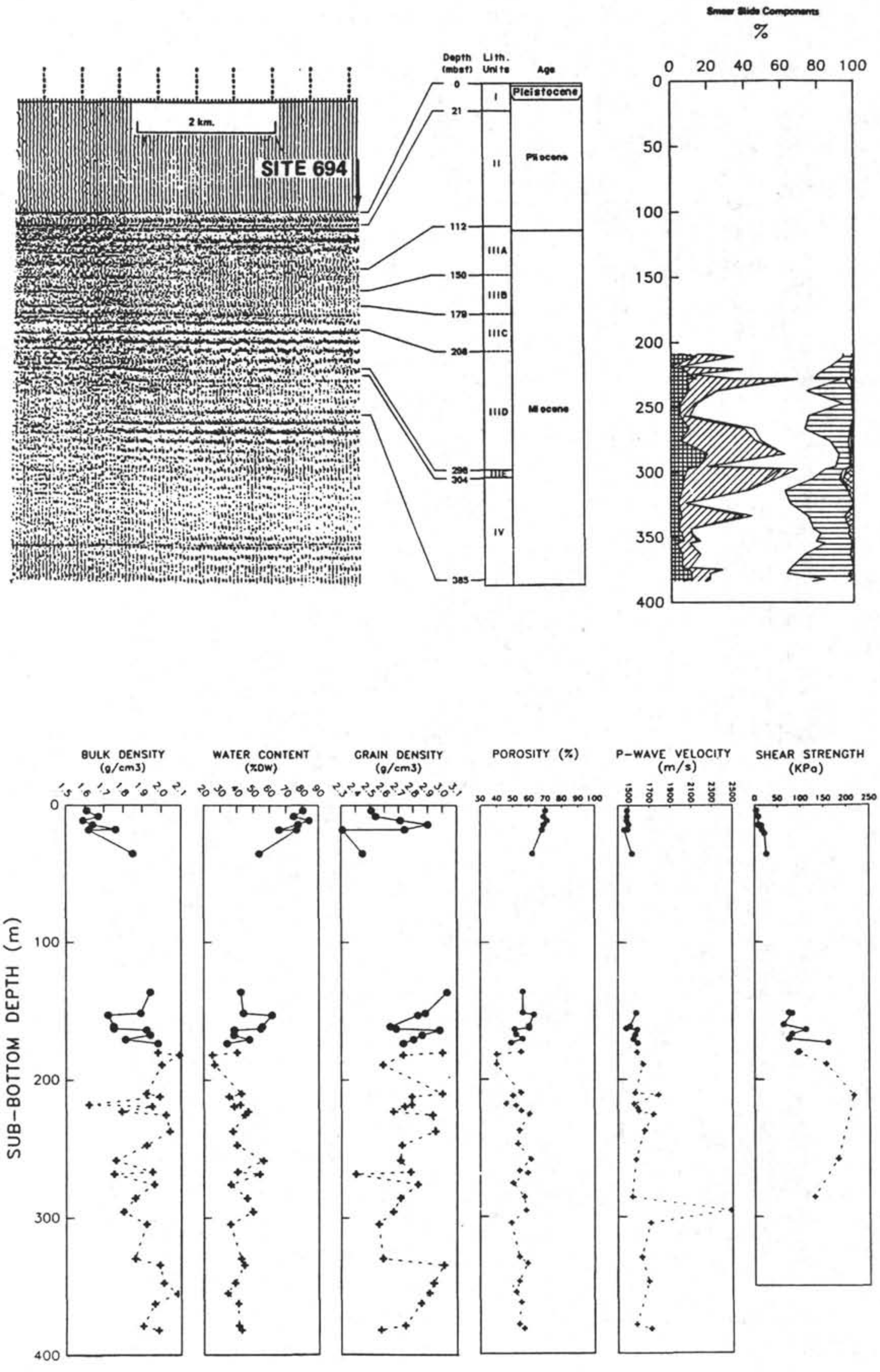

2 km.
SITE 694
Depth (mbsf)
Lith. Units
Age
0
21
112
150
179
208
298
304
385
I
II
IIIA
IIIB
IIIC
IIID
IIIE
IV
Pleistocene
Pliocene
Miocene
Smear Slide Components
%
0
20
40
60
80
100
50
100
150
200
250
300
350
400
BULK DENSITY (g/cm3)
WATER CONTENT (%DW)
GRAIN DENSITY (g/cm3)
POROSITY (%)
P-WAVE VELOCITY (m/s)
SHEAR STRENGTH (KPa)
SUB-BOTTOM DEPTH (m)

FIGURE 17.

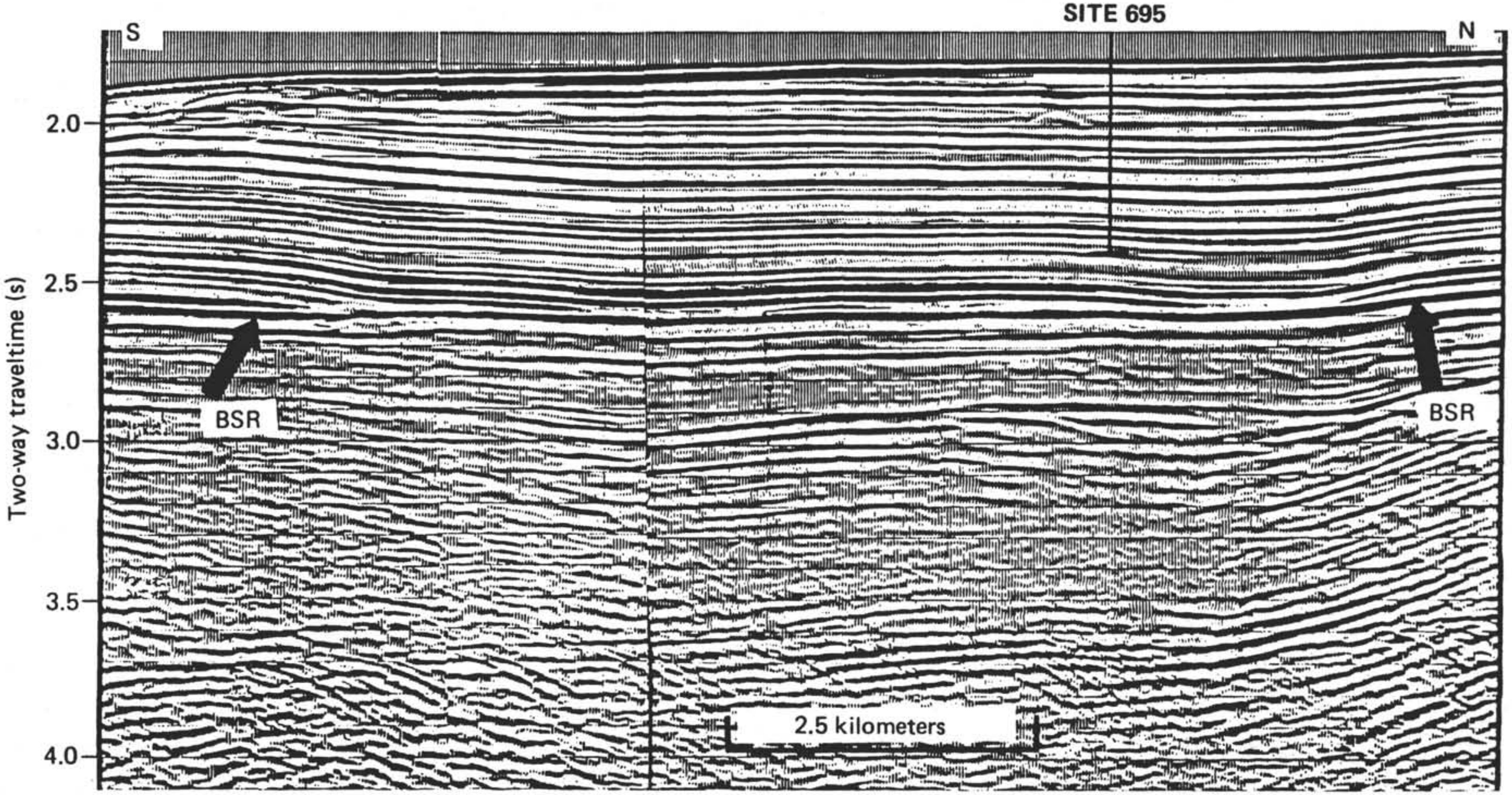

SITE 695
S
N
Two-way traveltime (s)
2.0
2.5
3.0
3.5
4.0
BSR
BSR
2.5 kilometers

FIGURE 18A.

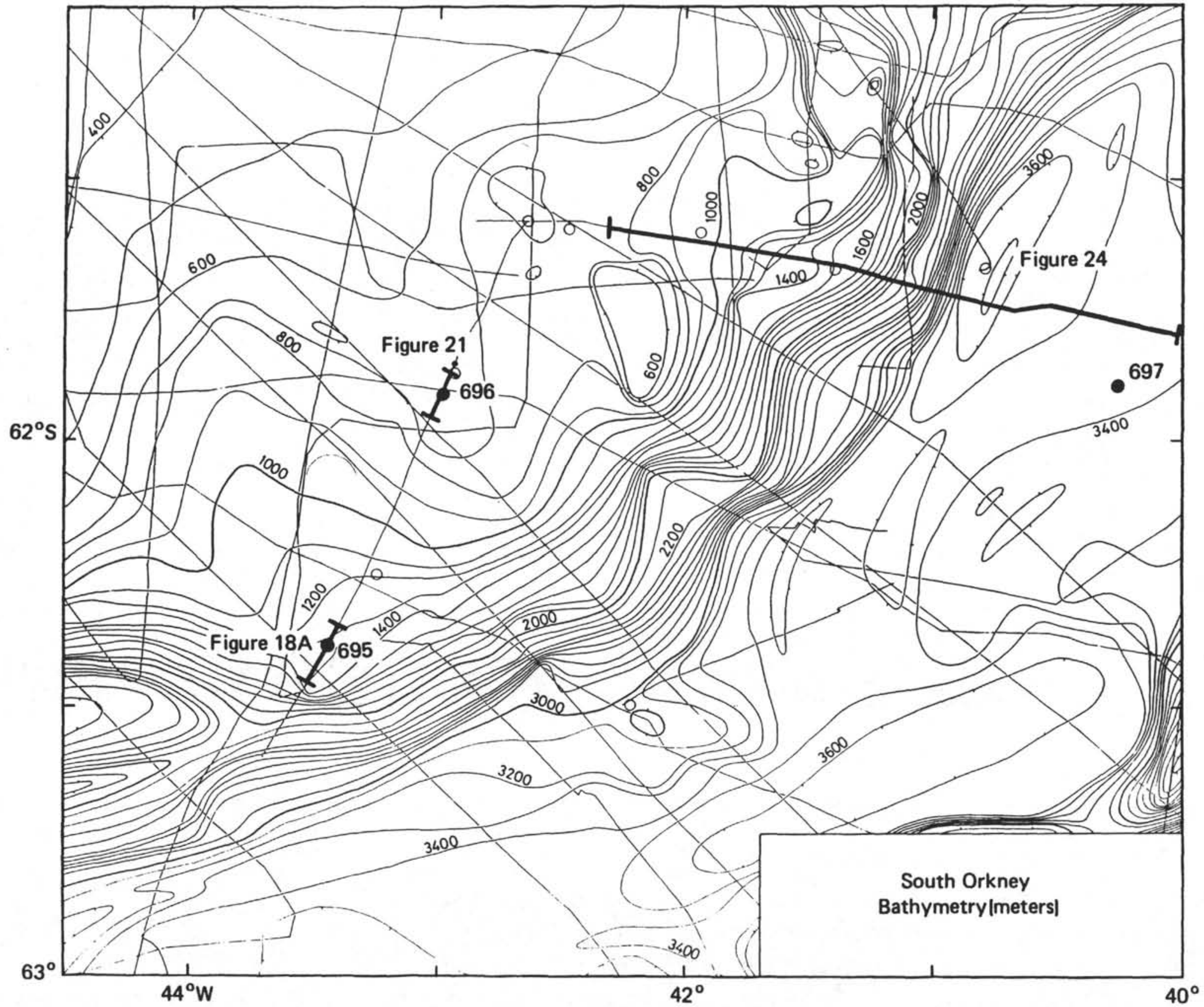

400
600
800
1000
1200
1400
1600
2000
2200
3000
3200
3400
3600
Figure 21
696
Figure 18A
695
Figure 24
697
62°S
63°
44°W
42°
40°
South Orkney
Bathymetry(meters)

FIGURE 18B.

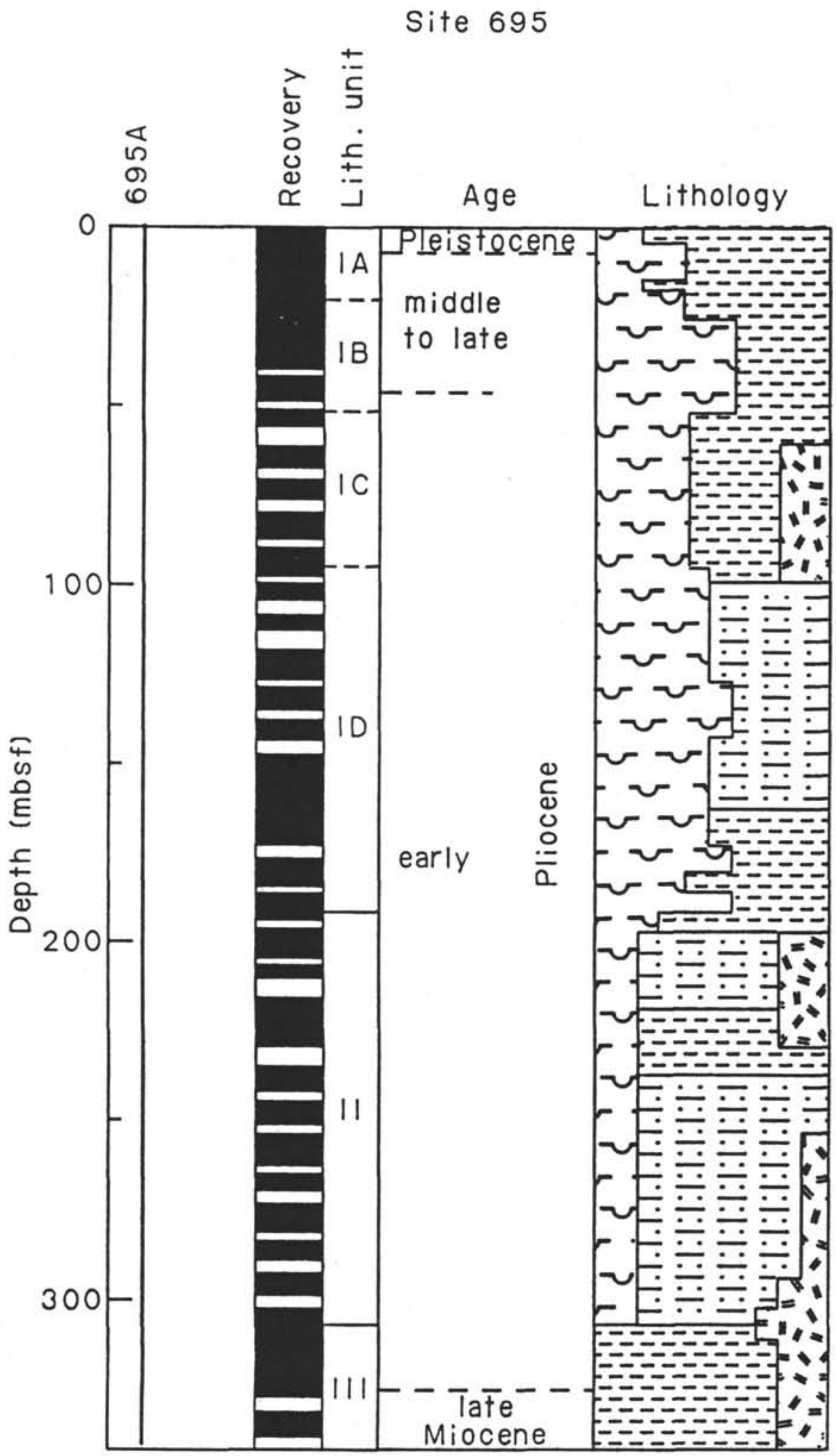

Site 695
695A
Recovery
Lith. unit
Age
Lithology
Depth (mbsf)
0
100
200
300
IA
IB
IC
ID
II
III
Pleistocene
middle
to late
early
Pliocene
late
Miocene

FIGURE 19.

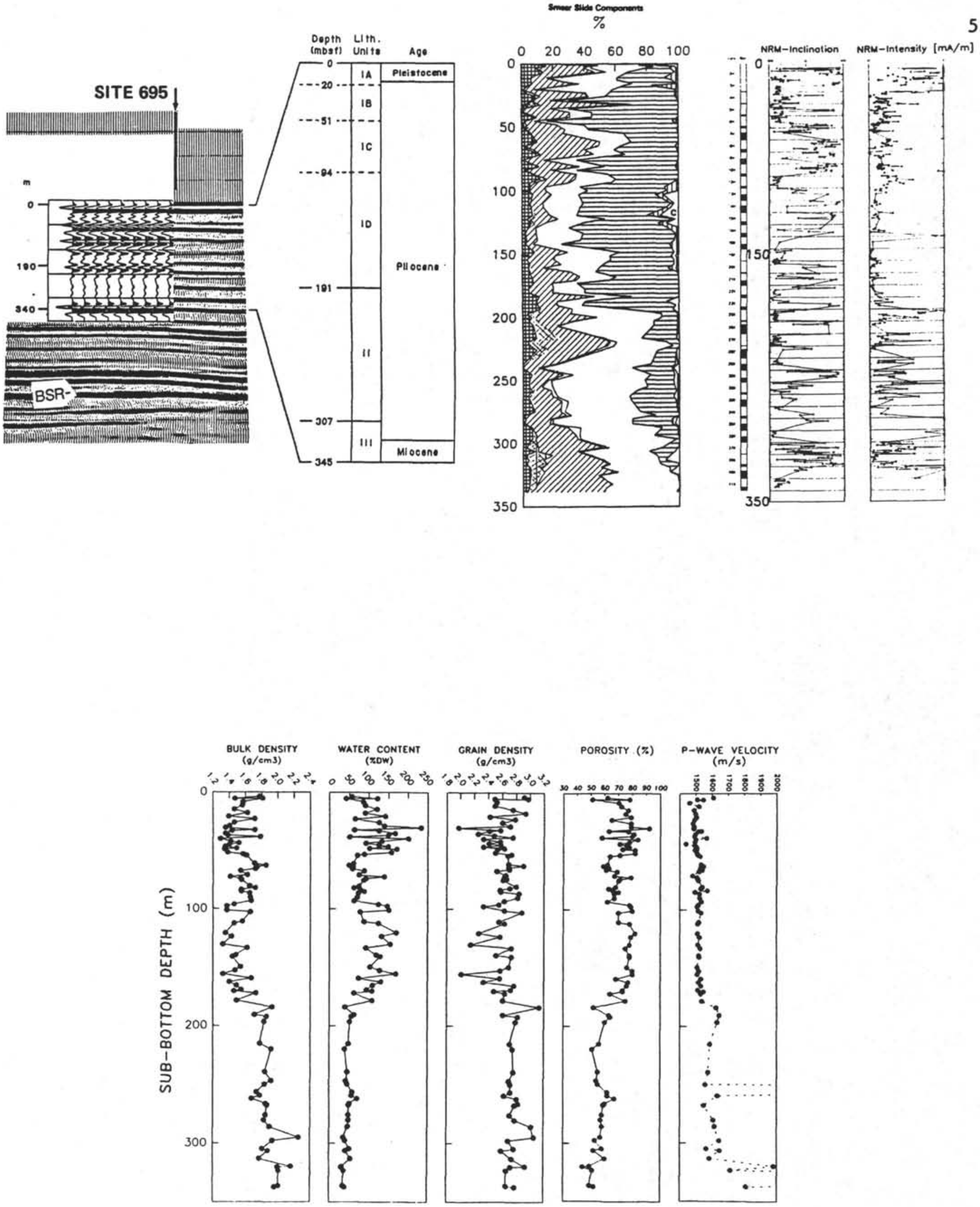

SITE 695
m
0
190
340
BSR-
Depth (mbsf)
Lith. Units
Age
0
20
51
94
191
307
345
IA
IB
IC
ID
II
III
Pleistocene
Pliocene
Miocene
Smear Slide Components
%
0 20 40 60 80 100
0
50
100
150
200
250
300
350
c
NRM-Inclination
NRM-Intensity [mA/m]
0
150
350
BULK DENSITY (g/cm3)
1.2 1.4 1.6 1.8 2.0 2.2 2.4
WATER CONTENT (%DW)
0 50 100 150 200 250
GRAIN DENSITY (g/cm3)
1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2
POROSITY (%)
30 40 50 60 70 80 90 100
P-WAVE VELOCITY (m/s)
1500 1600 1700 1800 1900 2000
SUB-BOTTOM DEPTH (m)
0
100
200
300

FIGURE 20.

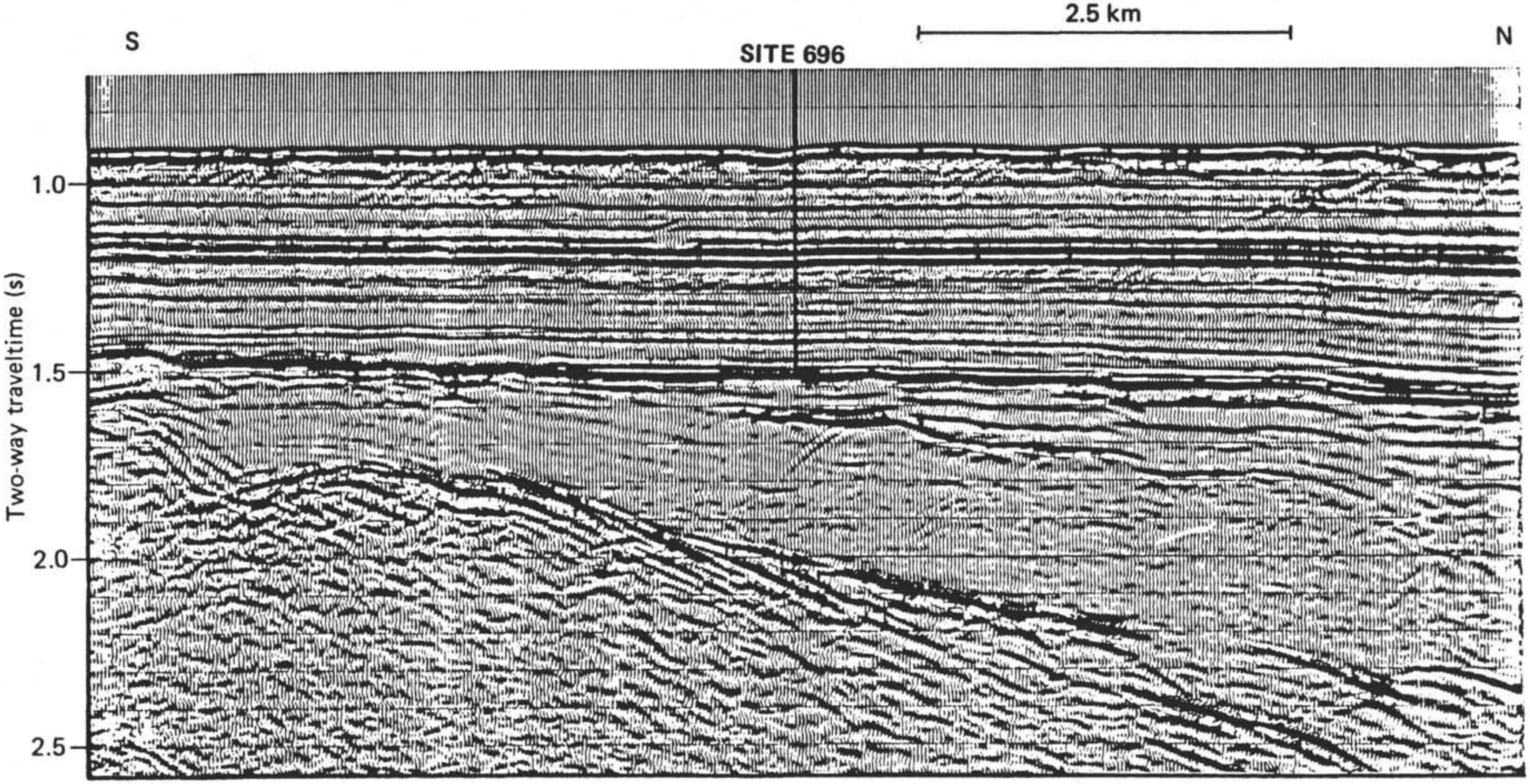


FIGURE 21.

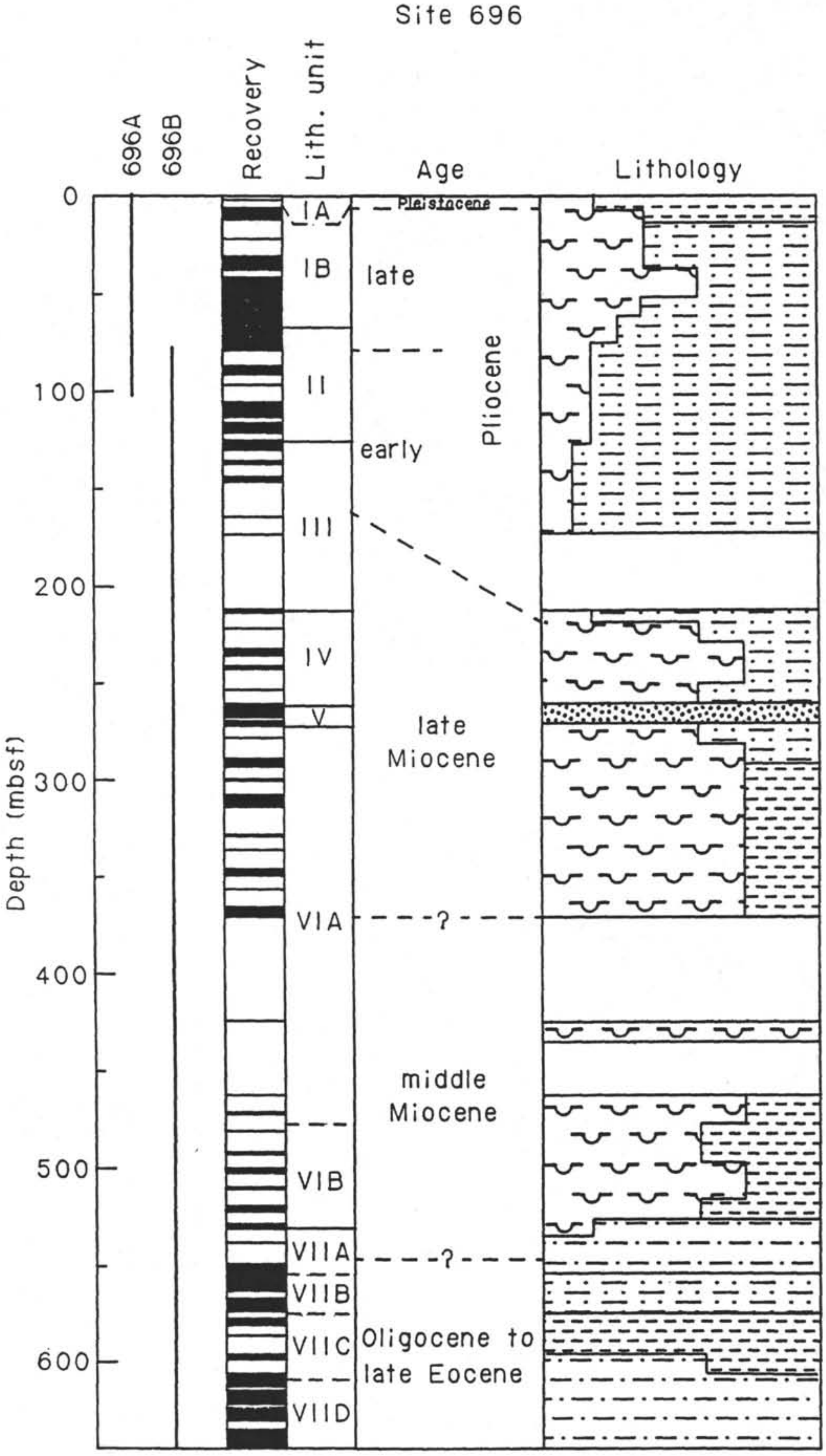

Site 696
696A
696B
Recovery
Lith. unit
Age
Lithology
Depth (mbsf)
0
100
200
300
400
500
600
IA
IB
II
III
IV
V
VIA
VIB
VIIA
VIIB
VIIC
VIID
Pleistocene
late
early
Pliocene
late Miocene
middle Miocene
Oligocene to late Eocene
?
?

FIGURE 22.

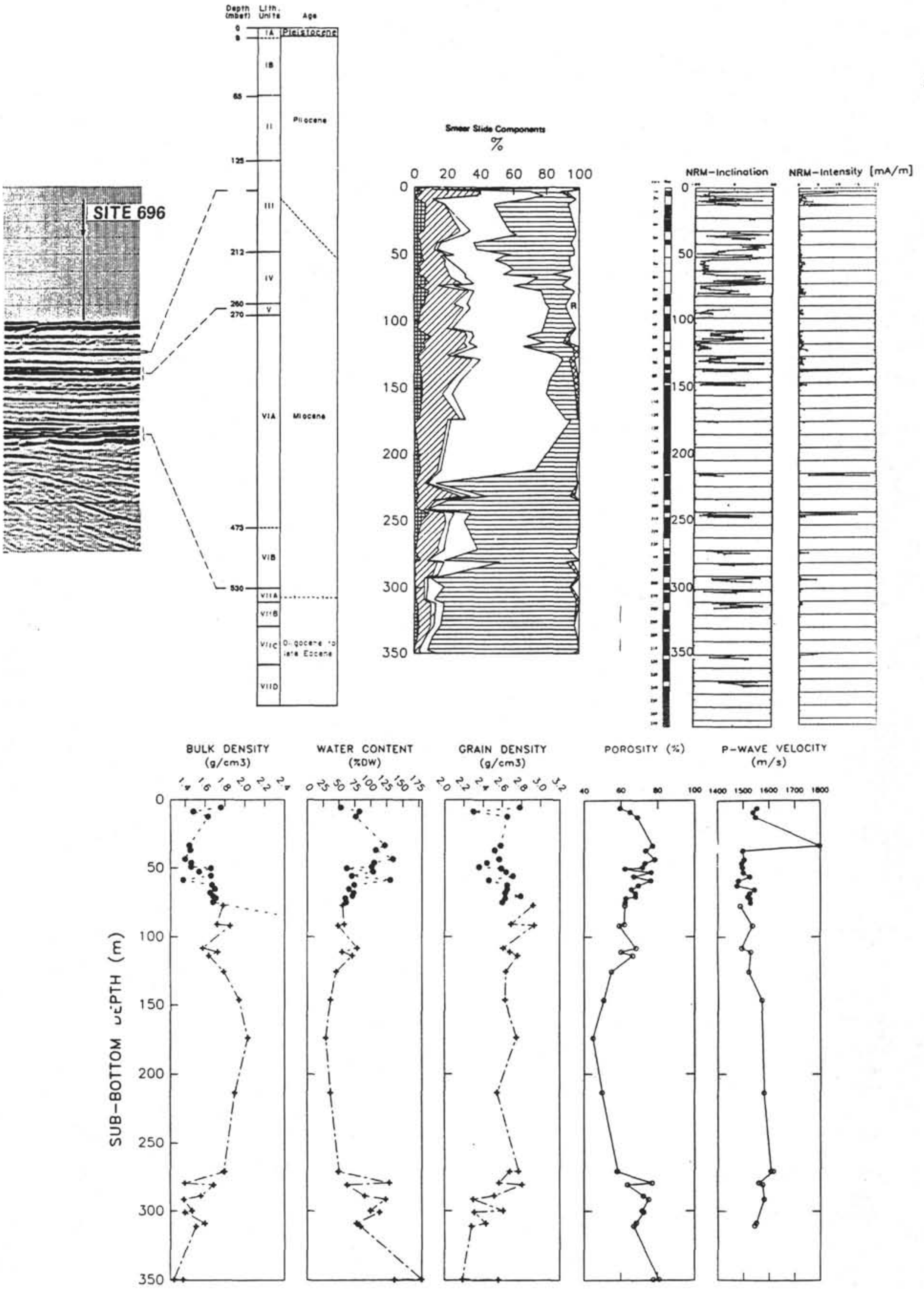
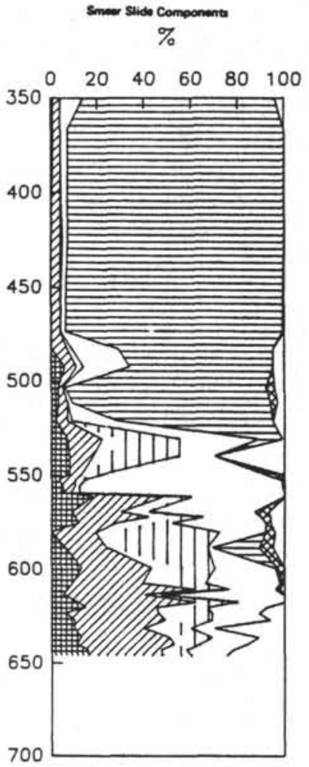
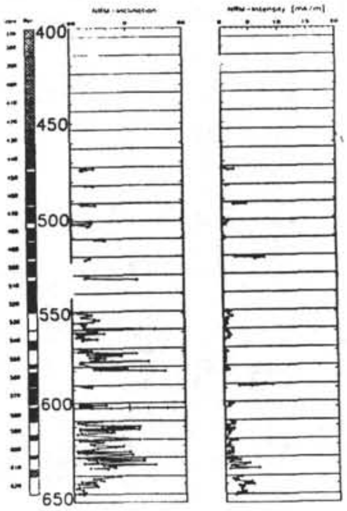

SITE 696
Depth (mbsf)
Lith. Units
Age
IA
Pleistocene
IB
II
Pliocene
III
IV
V
VIA
Miocene
VIB
VIIA
VIIB
VIIC
Oligocene to late Eocene
VIID
0
8
65
125
212
260
270
473
530
Smear Slide Components
%
0 20 40 60 80 100
R
NRM-Inclination
NRM-Intensity [mA/m]
0
50
100
150
200
250
300
350
BULK DENSITY (g/cm3)
1.4 1.6 1.8 2.0 2.2 2.4
WATER CONTENT (%DW)
0 25 50 75 100 125 150 175
GRAIN DENSITY (g/cm3)
2.0 2.2 2.4 2.6 2.8 3.0 3.2
POROSITY (%)
40 60 80 100
P-WAVE VELOCITY (m/s)
1400 1500 1600 1700 1800
SUB-BOTTOM DEPTH (m)

FIGURE 23.

SITE 696 continued





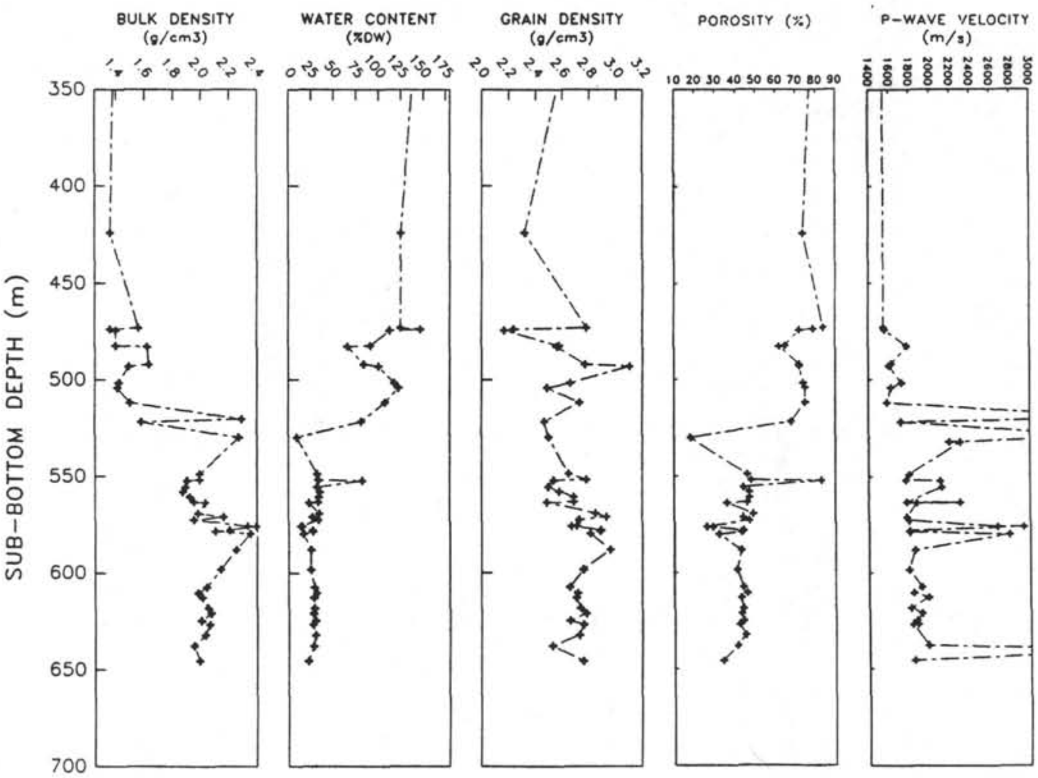


FIGURE 23 CONT'D.

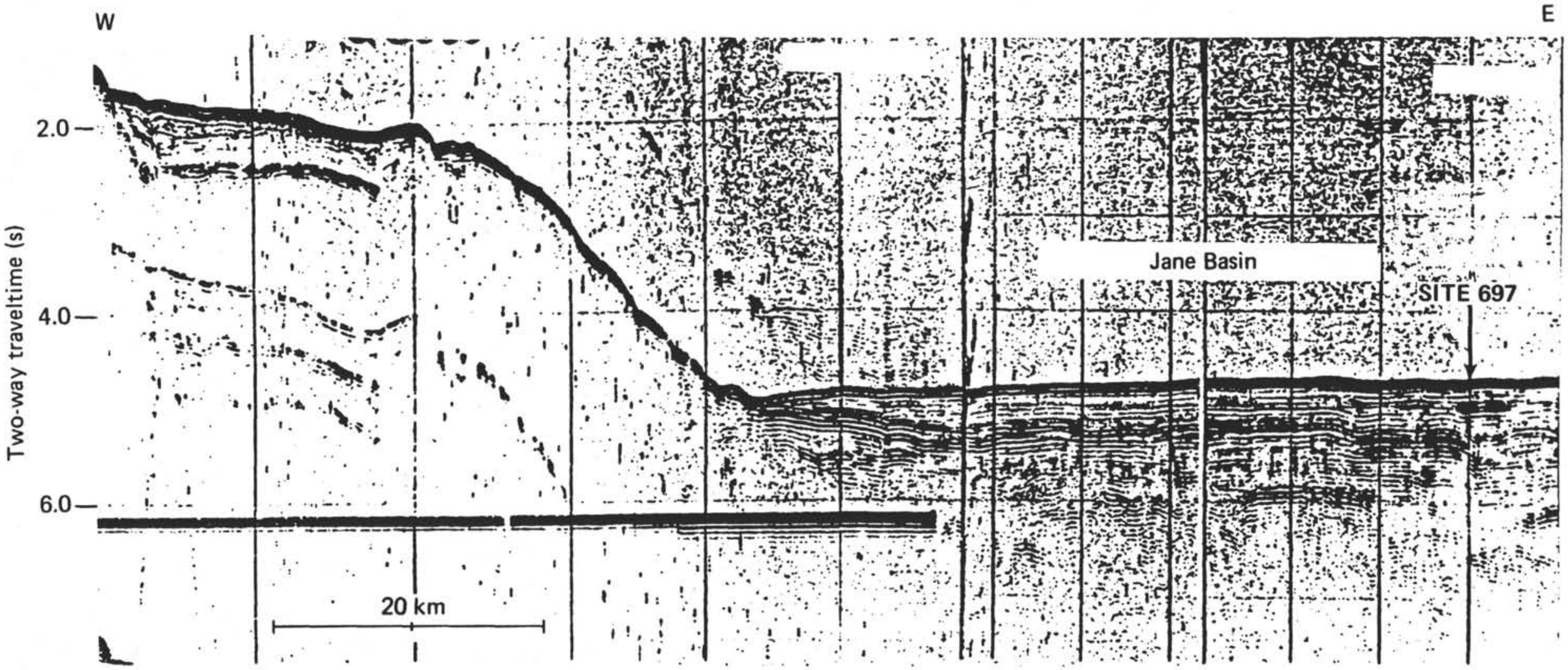
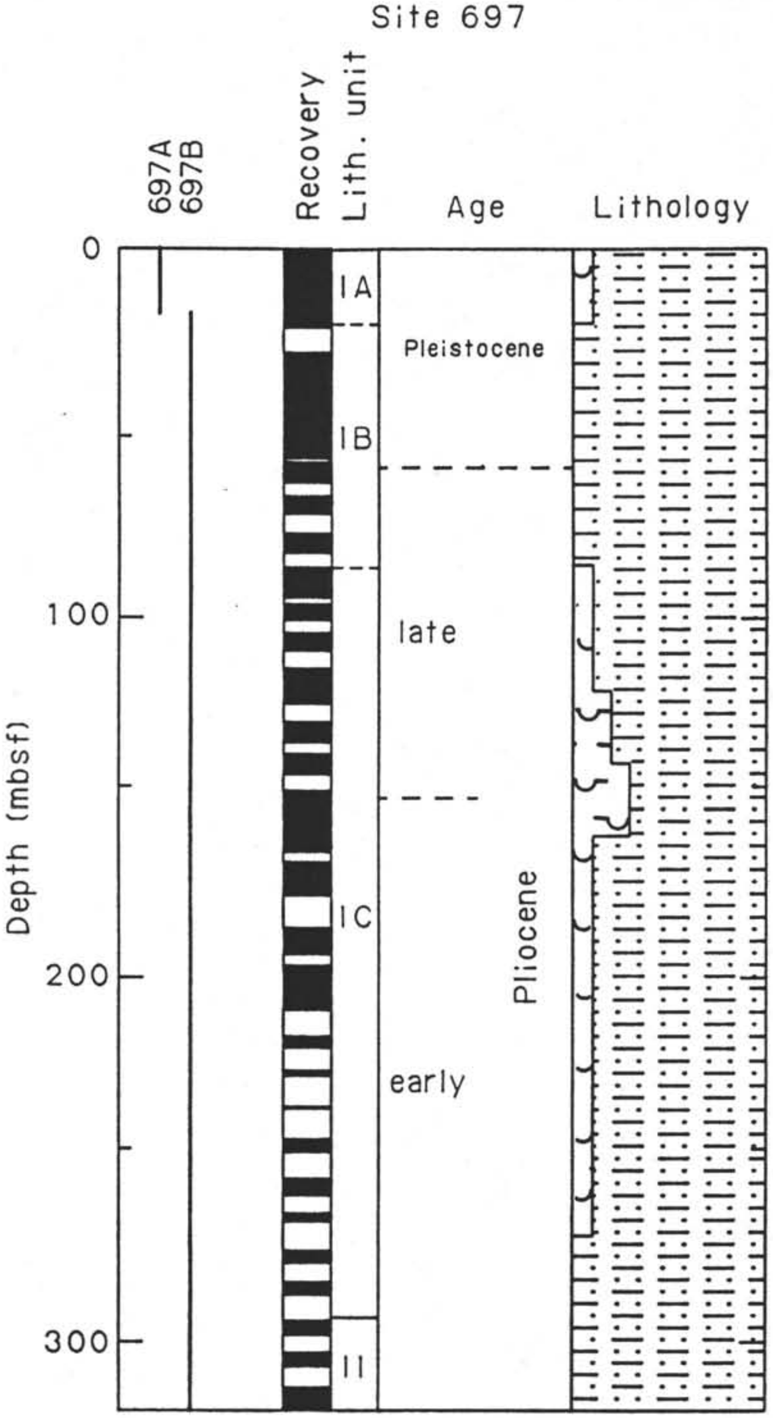


FIGURE 24.



Site 697
697A
697B
Recovery
Lith. unit
Age
Lithology
Depth (mbsf)
0
100
200
300
IA
IB
IC
II
Pleistocene
late
early
Pliocene

FIGURE 25.

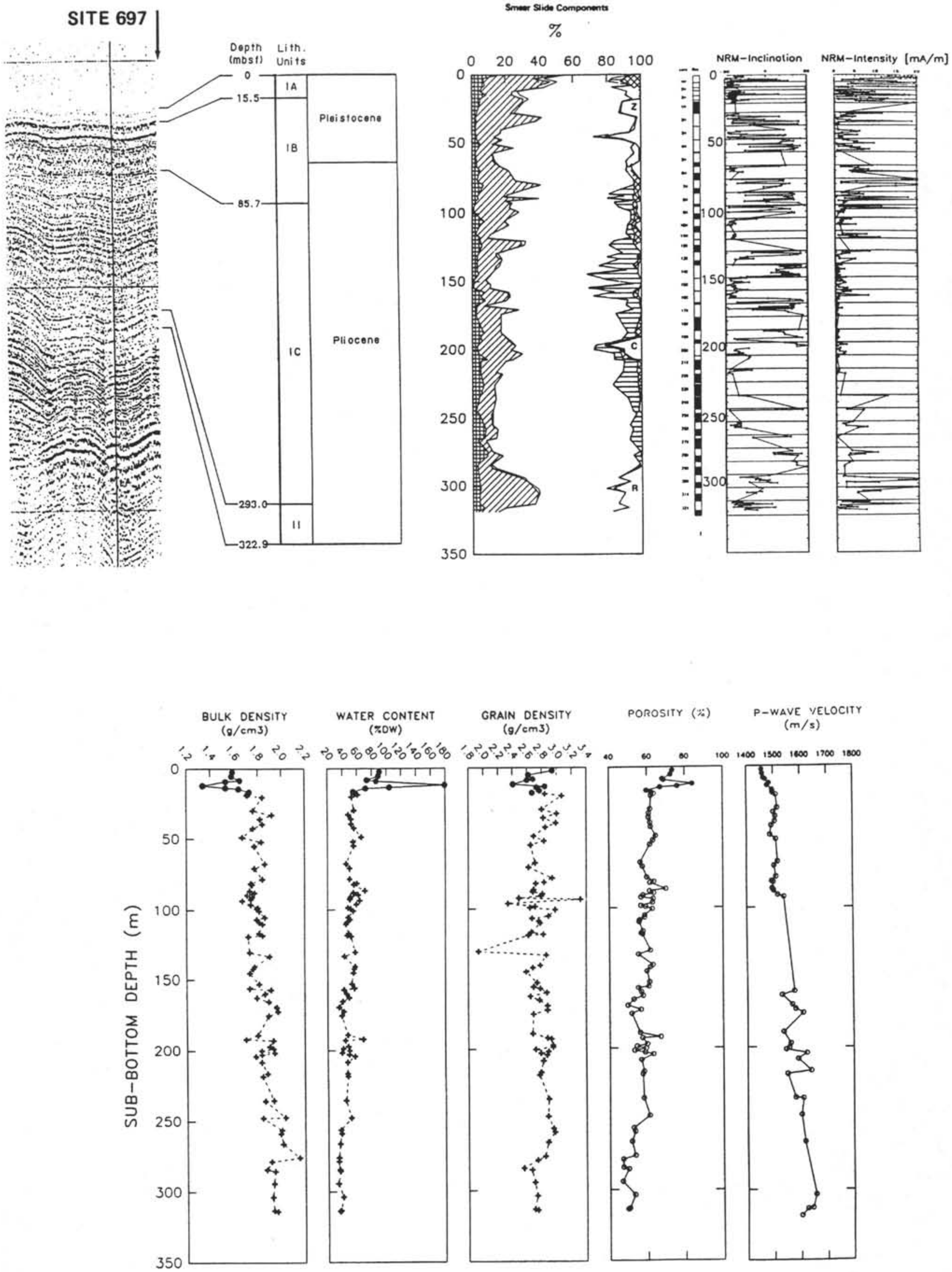

SITE 697
Depth (mbsf)
Lith. Units
0
15.5
85.7
293.0
322.9
IA
IB
IC
II
Pleistocene
Pliocene
Smear Slide Components
%
0 20 40 60 80 100
0
50
100
150
200
250
300
350
Z
C
R
NRM-Inclination
NRM-Intensity [mA/m]
BULK DENSITY (g/cm3)
1.2 1.4 1.6 1.8 2.0 2.2
WATER CONTENT (%DW)
20 40 60 80 100 120 140 160 180
GRAIN DENSITY (g/cm3)
1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4
POROSITY (%)
40 60 80 100
P-WAVE VELOCITY (m/s)
1400 1500 1600 1700 1800
SUB-BOTTOM DEPTH (m)

FIGURE 26.

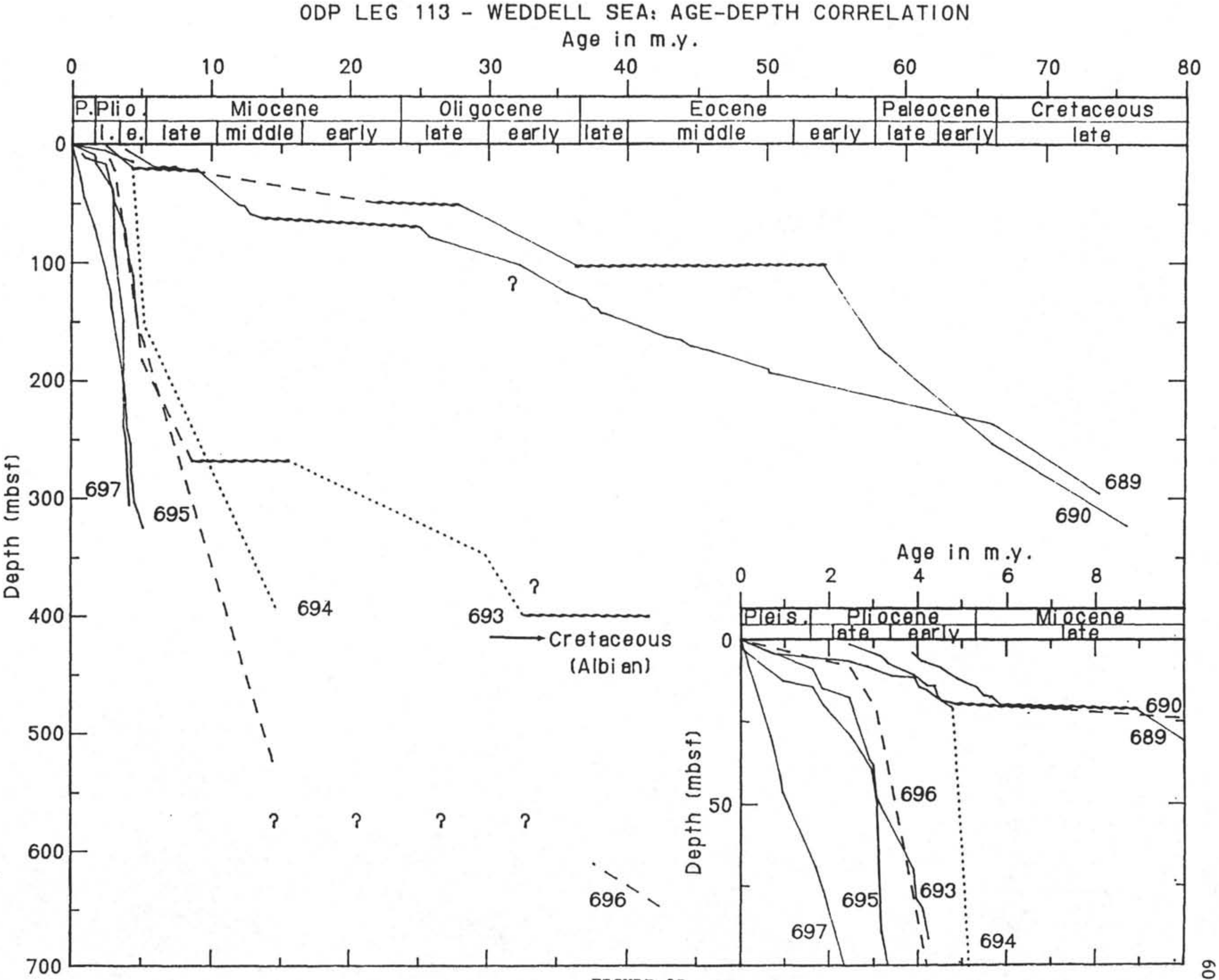

ODP LEG 113 - WEDDELL SEA: AGE-DEPTH CORRELATION
Age in m.y.
0
10
20
30
40
50
60
70
80
P.
Plio.
Miocene
Oligocene
Eocene
Paleocene
Cretaceous
l.
e.
late
middle
early
late
early
late
middle
early
late
early
late
Depth (mbsf)
0
100
200
300
400
500
600
700
?
?
?
?
?
?
689
690
697
695
694
693
696
Cretaceous
(Albian)
Age in m.y.
0
2
4
6
8
Pleis.
Pliocene
Miocene
late
early
late
Depth (mbsf)
0
50
690
689
696
693
695
697
694

FIGURE 27.

OPERATIONS REPORT

The ODP Operations Superintendent aboard JOIDES Resolution for Leg 113 of the Ocean Drilling Program was Charles Hanson. Other operations and engineering personnel aboard JOIDES Resolution for Leg 113 were:

Schlumberger Logger:	Mr. Steve Diana Schlumberger Houston 8460 Gulf Freeway Houston, TX 77023

OCEAN DRILLING PROGRAM
OPERATIONS SYNOPSIS
LEG 113

Leg 113 officially commenced at 0900 hours on Christmas Day 1987 in the port of Valparaiso, Chile. The primary operational purpose of the port call was to inspect the drill pipe in anticipation of the harsh weather conditions which were expected on Legs 113-114. During the 26th, cores from Leg 112 and other ocean freight were unloaded and repair representatives from Zeiss and Xerox called. Sedco began the installation of a Thyrig transformer which was a replacement for one that had been damaged in a fire during Leg 110. The entire day of the 28th was devoted to pipe inspection. On the 29th, outbound air freight was offloaded and the drill pipe inspection was completed.

Two Chilean transit pilots came aboard during the afternoon. The last line was cast off at 2010 hours on 29 December and the ship set sail for Punta Arenas, Chile.

By 1800 hours on 4 January the ship was secured to the South Pier in Punta Arenas. A distance of 1459 nautical miles had been sailed in 140.5 hours at an average of 10.4 knots.

The escort vessel, Maersk Master, was waiting for Resolution. Classified as a total support vessel, her primary purpose on Leg 113 was to act as an ice management vessel and in the unlikely event of a disaster to be our rescue ship. A secondary function was to do magnetometer surveys and set sediment traps.

Maersk Master came alongside and 1000 sacks of bulk gel were pumped on board Resolution, topping off the tanks. Four large food containers were transferred. During the night fuel trucks refueled Resolution, bringing the fuel on board to a near capacity 994,200 gallons.

Members of the scientific staff moved on board during the night. At 1110 on 5 January the last line was in and JOIDES Resolution was on the way to Antarctica. Maersk Master stayed behind to wait for spare parts that were due in by air at midnight.

SITE 689 (W1)

Early on the morning of the 10th Master overtook Resolution. The location was reached at 1552 hours on the 15 January after having steamed 2467 nautical miles from Punta Arenas in 241.5 hours at an average rate of 10.2 knots. There was only one piece of ice in the area and Master broke it up with propwash.

Hole 689A

The PDR water depth was 2095 m (depths will be given in meters from the rig floor dual elevator stool (DES) and in meters below sea floor (mbsf)). The mudline core was shot with the bit at 2093.6 m. The barrel was full, indicating the bit had been below the mudline.

Hole 689B

The second shot was taken with the bit at 2087.1 m and the mudline was established to be at 2091.3 m. Twenty-one APC cores were taken to 197.5 mbsf (2288.8 m). A total of 183.29 m was recovered, for a recovery rate of 92%.

Following APC refusal the XCB coring system was deployed for cores 689B-22X to 689B-33X (197.5-297.3 mbsf; 2288.8-2388.6 m), with a recovery rate of 68%. Core 689B-31X encountered a significant quantity of chert which could not be penetrated with the XCB sawtooth cutting shoe. After two more attempts that resulted in poor recovery, it became evident that further penetration with the XCB would probably result in damage to the coring system. The hole was abandoned filled with sea water.

Hole 689C

The ship was moved 50 ft for the overlap APC hole. The first shot was with the bit at 2090.4 m, or about 1 m above the sea floor. The core barrel was completely filled. Operational problems forced abandonment of this hole after three cores.

Hole 689D

The bit was washed to 18.1 mbsf, the depth at which Hole 689C had been abandoned. Cores were taken to a total depth of 133.8 mbsf (2225.1 m), and recovery was 101%. The hole was abandoned filled with sea water.

As the ship left the site at 0930 on 19 January, the geophysical gear was streamed and a final pass was made over the location. Full ahead for Site 690 was ordered at 1110.

SITE 690 (W2)

Site W2 is about 60 miles southwest of Hole 689. The PDR indicated a water depth of 2931.3 m and the first APC was shot with the bit at 2924 m. A full 9.5-m core, the only core from Hole 690A, was obtained.

Hole 690B

For the second hole the bit was positioned 6 m higher at 2918 m and a 2.12-m core was recovered. This established the mudline at 2925.4 m. Eighteen APC cores were taken to a depth of 166.6 mbsf with 100% recovery. Cores 690B-19H to 690B-24H were taken to a depth of 213.4 mbsf with only partial piston stroke out. The bit was advanced only the amount the piston stroked each core. Core 690B-25H was recovered full, but Core 690B-26H (213.4 mbsf; 3138.7 m) could not be freed. While attempting to rotate the bit over the barrel, the APC assembly was lost, and the hole was abandoned.

Hole 690C

The drill pipe was pulled clear of the mudline and the ship was moved 50 ft. Nine APC cores were taken from the mudline at 2925.4 m to a depth of 83.6 mbsf (3009.0 m). Recovery was 100%. Heat flow measurements were taken on cores 690C-3, 690C-6 and 690C-9. Core 690C-10W was an XCB wash core from 83.6-204.2 mbsf (3009.0-3129.6 m).

The bottom of Core 690C-22X at 320.1 mbsf (3245.5 m) contained a small amount of ground black material that appeared to be basalt. The same soft formation XCB cutter was run on Core 690C-23X and only 0.5 m was made in 30 minutes. The core was pulled and contained 0.58 m of basalt; the cutter was worn about 1/2 inch. An Acker Amalgated diamond XCB shoe was run. One meter of hole was made in one hour. A beautifully cut basalt core 1.1 m long was recovered. The hole was abandoned at a depth of 321.2 mbsf (3247.0 m) with an average recovery rate of 88%. Full speed ahead for Site W4A was ordered at 2310 on 23 January.

SITE 691 (W4A)

Site W4A was the most southern location for Leg 113. During the previous week, the icebreaker Polarstern from the Federal Republic of Germany had passed over the location and reported it ice-free. The site was 484 miles southwest of Site 690 and the voyage was made in 41.4 hours at 11.5 knots. The area of the location was reached near noon on 25 January. The sea bed was very rough with many deep canyons, and four hours of surveying were required to locate the site. The beacon was dropped at 1600 hours about 200 yards north of the biggest iceberg within 10 miles.

The thrusters were lowered and JOIDES Resolution stood by while Maersk Master began the first ice management of the leg. The berg was 80m x 80m x 25m high and was estimated to displace 640,000 tons. Master deployed the 4,000-ft long towing rope. The drift rate of the berg was increased by 0.6 knots and it was dragged off to the south where it was released to continue its .2-.3 knot natural drift to the southwest.

Hole 691A

The PDR indicated a drilling depth to the mudline of 3048.3 m. The bit encountered bottom at 3045.95 m. Essentially no penetration was possible because of the hard sea floor. The hole was deemed undrillable and was abandoned.

Hole 691B

The ship was moved 500 ft south in an attempt to find a soft bottom. The bottom was "felt" at 3047.2 m and about 1.7 m of penetration was made with difficulty. Torque was high and no additional advancement was made in the hard bottom. Core recovery was zero. The hole was deemed undrillable and was abandoned.

Hole 691C

The ship was moved 1000 ft east-northeast. The mudline was "felt" at 3036 m. The hole was drilled with high torque to 13 mbsf (3049 m) in 3.5 hours and it caved in during the connection. The surface drilling parameters indicated the bottom was gravel and loose rock but no core was recovered. The hole was deemed undrillable and was abandoned.

Hole 692A

It was concluded that the canyon sites had a bottom with a thin veneer of soft sediments on top of gravel and rock and so were undrillable. It was decided to move two miles to a site up out of the canyon. The PDR indicated a total drilling depth to the mudline of 2889.3 m. Bottom was "felt" about 2891 m and about 6 m of soft material was punched. The formation then became very hard and high torque was required to rotate the pipe. The hole was declared undrillable after 45 minutes. Of 6.7 m cored, only 0.65 m was recovered.

Hole 692B

The ship was moved 500 ft north in an attempt to escape the hard sea floor. PDR water depth was 2885.3 m. Bottom was "felt" at 2886 m. The bit punched easily through 5.5 m of soft mud and then encountered a layer of hard material. The drill pipe torque was high and the rate of penetration was slow but the first core advanced the bit 9.1 m with 1.07 m recovery. The second core resulted in advancing the bit 11.8 m in 165 minutes. The hole was cored to 50 mbsf (2936 m) and what was interpreted to be a zone of boulders was encountered. Torque was high and erratic and penetration was slow. At a depth of 88 mbsf (2974 m) the entire hole below the bit fell in during a connection and redrilling was as difficult as the original drilling. After cleaning out the hole a core was cut from 88-98 mbsf (2974-2984 m). While the core was being recovered the bottom 10 m of hole were again lost. The 10 m were redrilled in four hours with difficulty. It was decided to abandon the hole. In all, 28.59 m of core were recovered from the 97.9 m drilled, for a recovery rate of 29%.

Based on surface drilling indications it was concluded that an unstable zone of gravel and boulders at approximately 49-62 mbsf (2935-2948 m) caved in the hole.

On 26 January the ice breaker Polarstern from the Federal Republic of Germany stopped for a visit. Maersk Master transferred over 100 people between Polarstern and Resolution. Tours were conducted of both ships.

Resolution was under way to the next site at 0115 hours on 30 January 1987.

SITE 693

It was concluded that the only effective way to escape the impossible drilling conditions of the canyon was to drill at a site on the continental slope away from the canyons. Special approval was obtained for a location 16.3 miles west-southwest of Site 692. Steaming time was a little less than seven hours and the site was reached on the morning of 30 January.

Hole 693A

The PDR indicated a water depth of 2374.3 m and the mudline was established at 2370.5 m. A total of 483.9 m was rotary cored and 213.58 m were recovered for a recovery rate of 44%.

The weather at this site was excellent, but ice was present in the area. On 30 January Master towed a 6.24 million ton iceberg. A 335,000 ton tow on 2 February was also a success.

On 4 February the bit was released hydraulically to run electric logs. The drill pipe was withdrawn to 108 mbsf and the side door entry sub (SES) was installed. Using the DIT/GR/CAL tool, the hole was logged up from a depth of 441.5 mbsf (2812 m).

The drill pipe was pulled and Hole 693A was concluded on 5 February 1987.

Hole 693B

Because of the low core recovery with the rotary system in Hole 693A and the scientific interest in the site, the site was recored with the APC/XCB system.

When the bit was 122 m above the sea floor it became obvious that the tailing portion of a patch of pack-ice would pass over the site. When the ice came to within one mile of the ship, the ship moved northwest, 2.2 miles from the site. Three hours after leaving the site, Master began towing operations on Berg 142 and Resolution began to move back to the site.

The first core was a wash core to 233.8 mbsf. The combined recovery on the next four cores was a disappointing 5.2 m. A piston core was then taken at 277 mbsf, recovering 9.17 m of sticky gray clay. The next APC core contained only 4.51 m of sediment. The remaining twelve cores were obtained with the XCB to the total penetration of 401.2 mbsf (2771.7 m), averaging 6.023 m per core. The overall recovery rate was 55%.

For Core 693B-19X, it took 60 minutes to make 5.5 m and when the barrel reached the surface it was found that about six inches of the XCB cutter had been left in the hole, forcing abandonment. The bit was positioned at 398.5 mbsf (2769 m) and 200 sacks of cement were mixed and placed. The ship was underway to Site W5 at 2115 on 7 February 1987.

SITE 694 (W5)

Site W5 is located 472 miles northwest of Hole 693. The beacon was dropped at 1650 on 9 February. Thrusters were lowered and station-keeping established. The pipe was lowered with the modified APC/XCB bit.

The ship could not move immediately to the location because Berg 155 (350,000 tons) was a half mile from the site. It was towed off by Master. Berg 161 (2 million tons) was also a potential threat and was removed. There were 15 bergs in the 12-mile radar range and 3 or 4 were in a position to be a problem. The air temperature on the morning of the 10th was -2.5°C, the coldest of the leg to date. The sea conditions were a Beaufort 5 and there was a strong hint that the good weather in the Weddell Sea was finished for the summer.

Hole 694A

The PDR water depth was 4671.3 m and the first APC was shot 5 m above the sea floor. A full core with no mudline was obtained.

Hole 694B

The bit was raised 7 m and Core 694B-1H established the mudline at 4664.39 m. APC coring continued with poor recovery. The material being cored was mostly sand and penetration by the barrel was small. The bit was being advanced by the amount cored and the overall progress was slow.

February 10-13 were days in which the ice management system was sorely tested. Berg 168 was routinely towed the morning of 11 February. There were 16 bergs in 20 nautical miles and a lot of growlers near the ship had to be propwashed. The tow of Berg 168 was followed by a 9-hour tow of Berg 165 (2 million tons). While it was under tow, Berg 162 (6.02 million tons) turned suddenly towards the ship from a distance of 3.2 miles. Emergency ice avoidance procedures were begun immediately: wire line operations were suspended and the drill pipe was pulled to 21 mbsf. Master took Berg 162 under tow when it had approached to within 2.3 miles of the ship. She pulled 95 tons at 90 degrees to the drift path and 1.2 miles from the ship the berg began to divert. When it was clear the berg would pass a safe distance from the ship, the drill pipe was started back into the hole.

At 0900, with the drill pipe only 18 m above the bottom of the hole, a failure in the Automatic Station Keeping (ASK) system occurred. The problem was traced to a portion of the ASK system which was not actively in use and repairs were made in two hours.

In the meantime, Master was attempting to tow Berg 173, a small (25,000 ton) berg, which was low, round and smooth. Four times the rope slipped up and off the berg. Finally as a last resort it was propwashed. It was not really expected to be possible to move a berg this big by propwashing but it was a complete success.

Berg 162, which was thought to be safely behind the ship, then made a 180-degree turn and had to be towed a second time. Berg 173 returned and had to be washed a second time. Meanwhile, the bit was reamed back to bottom. The bit was almost on bottom when Berg 163 entered the danger zone. It was considered untowable because of its size (12.6 million tons), but when it became obvious that it would drive Resolution from the site, the captains of Master and Resolution decided to try. Forty barrels of mud were spotted in the hole and the bit again pulled to just below the mudline.

Master rigged a combination of rope and steel towing cable to get sufficient length for a safe tow. Icebergs can become unstable when under tow and it was prudent to be a couple of thousand feet away from the multi-million ton object in case it rolled over. By this time the berg was only 0.6 miles from Resolution's bow and all hands had a good view of the operation. Master took a 90 ton bind on the berg just as it reached 0.4 miles, the termination distance at which the ship would have to move out of the way. After 20.5 hours the berg was released 2 miles from the ship.

By 13 February, Berg 163 was a safe distance from the site and the drill pipe was started back into the hole. Core 694B-20W was a wash core from 14.6-140.6 mbsf (4679-4805 m). Coring resumed at 0000 hours on 14 February after having lost 24.25 hours to Berg 163. Cores 694B-21X to 694B-25X were cut to 188.6 mbsf (4853 m) where the spring stop of the latch assembly in the XCB parted. The lower portion of the XCB stayed in the hole, forcing abandonment. Total recovery for the hole was 65.03 m, or 36%.

Hole 694C

The ship was moved 100 ft north and Hole 694C was spudded at 1422 hours on 14 February. Core 694C-1W was a wash core from the mudline to 179.2 mbsf (4843.7 m), the total depth of Hole 694B. XCB coring continued from 188.9-391.3 mbsf (4843.7-5055.8 m). The formation apparently contained a large amount of sand and core recovery was not high, averaging 34%. At 391.3 mbsf (5055.8 m) the inner core barrel became stuck in the outer barrel. Two wire-line runs were made in an attempt to free it. On the second wire-line run the motor on the wire-line winch required repair. While the electrician was working on the winch motor at 0830 on 17 February, Berg 163 reentered the danger zone. The hole was displaced with 100 barrels of mud and for the third time in recent days the drill pipe was pulled to just below the mudline. Master took Berg 163 under tow at a distance of 0.9 miles and dragged it 2 miles away to release it.

When the berg was 2 miles from the ship, three unsuccessful wire-line runs were made in an attempt to pull the stuck inner barrel. The hole was abandoned and the drill pipe was pulled. The thrusters and hydrophones were raised and the sea voyage to Site W7 was begun on 18 February at 0800.

SITE 695 (W7)

Site W7 is located 371 miles northwest of Site 694. The site was reached and the beacon was dropped at 0930 hours on 20 February.

Hole 695A

The PDR water depth was 1316.3 m and the first APC found established the mudline at 1311.1 m. Sixteen APC cores were taken to a depth of 137.6 mbsf (1448.7 m). Recovery with the APC was 80%.

Site W7 was predicted to contain a possible gas hydrate zone. Four heat flow measurements were taken during the APC interval and they produced a thermal gradient of 57°C/km, yielding a calculated base of hydrate stability to 319 mbsf. Geophysical interpretation does not support a hydrate zone this shallow.

XCB coring continued from 137.6-345.1 mbsf (1448.7-1656.2 m). At 345.1 mbsf (1656.2 m) there was a dramatic decrease in the pump pressure. The core barrel was pulled and it was found that the spring stop in the XCB had parted, leaving the lower portion of the barrel in the hole. The hole was abandoned at 1000 hours 23 February 1987.

SITE 696 (W8)

Site W8 is located 35.6 nautical miles north-northeast of Site 695. The sea voyage was 3 hours and the site was reached near noon on 23 February.

Hole 696A

The PDR water depth was 659.3 m and the mudline was established at 661 m. Core recovery was poor for the first 41 m, probably because of the presence of sand. Cores 696A-10H and 696A-11H had only partial stroke out and no recovery, so XCB coring was begun. Core 696A-12X hit a hard streak after making 6.6 m. As a precaution it was retrieved. The cutter was not damaged and a regular saw tooth cutter was again run. The next core cut 3 m in a normal time. After two wire-line attempts to free the barrel from the BHA, the drill pipe was pulled to the surface. With the drill collars in the rotary table, an attempt was made to jar free the barrel with the wire line. The coring assembly parted inside the spring shaft housing and the lower portion of the XCB was lost. The hole was abandoned. Recovery averaged 55% over the 106 m cored.

Site W6 had a high XCB priority and it was decided to conserve the remaining stock of XCB parts for W6. A rotary coring system was used to continue Site 696.

Hole 696B

The first core was a wash core to the depth of Hole 696A (76.6 mbsf). Cores 696B-2R to 696B-48R (76.6-510.7 mbsf; 737.6-1171.7 m) had nearly zero core recovery. Many combinations of surface variables were tried in an effort to increase recovery but it seemed impossible to core soft, high-sand-content formations with a rotary system.

Cores 696B-9C and 696B-18C were interstitial pore water (ISPW) tool runs. A downhole temperature of 7.4°C from Core 696B-9C established the thermal gradient as 52°C/km. This gradient required any gas hydrate zone to be at 264 m and there was no geophysical evidence to support one at that depth. During the second ISPW run, the probe broke off in what may have been hard sand or rocks, ending temperature measurements in the hole.

Core recovery below 510.7 mbsf (1171.7 m) increased steadily and the last core, recovered from 645.6 mbsf (1306.6 m), contained 9.79 m. However, the depth limitation imposed by the safety panel because of possible gas hydrates had been reached, and the bit was released for logging on 2 February.

The pipe was pulled to 99 mbsf with no abnormal pipe drag. Because of the six-hour rig time required for the SES, it was decided to try logging without it. The logging tools contacted a bridge at only 62 meters below the drill pipe (161 mbsf). A wiper trip was made with the bitless drill pipe. Many ledges and bridges were encountered and there were about 30 m of fill on bottom which was washed out with some difficulty.

The SES and logging tools were then rigged up. The tools were lowered out the end of the pipe and the hole was logged from 631.0 mbsf (1292 m) to the end of the drill pipe at 555.5 mbsf (1216.5 m).

While pumping in preparation for further logging, something failed downhole with a bang and 1,000 pounds of tool weight were lost from the line tension. The drill pipe was pulled to the SES. It was found that the weak point in the logging line had failed, leaving the entire string of logging tools in the hole. Apparently sand or other materials had packed off around the tools, forming a hydraulic seal, and the tools were blown off the end of the line during pumping. An attempt to fish for the tools was not successful and Hole 696B was abandoned on 2 March 1987. Average recovery over the 569-m cored interval was 27.5%.

SITE 697 (W6)

Site W6 is 74.9 nautical miles east of Site 696. The area of the site was reached on the late morning of 2 March.

Hole 697A

Dropping the beacon was delayed three hours while waiting on Safety Panel approval to move the site location about six miles. Weather conditions were deteriorating as the drill pipe was started down. Winds were gusting to 40-50 knots and the seas were building past 20 feet in height. The weather did not stop the pipe running operation but the resulting ship motion did slow the trip. This was the first time on the leg, excluding ship transit, that weather had hampered the operation.

The water depth indicated by the PDR was 3495.3 m. The bit was positioned at 3491 m for the first core. Ship heave was in the range of 3 m and coring the mudline under these conditions is at best unpredictable. The first core contained 8.93 m and established the mudline at 3491.6 m.

Three piston cores were taken to a depth of 20.9 mbsf. The cores were overlapped so that 28.1 m were cored with 95% recovery. After shooting the third core the inner core barrels became stuck and could not be pulled out of the BHA with the wire line. The drill pipe was pulled to recover the barrel and the hole was abandoned. What caused the stuck barrel has not been determined.

Hole 697B

Hole 697B was spudded at 0400 on 4 March. The first core was washed to 18 m. Piston coring continued to 119.8 mbsf (3611.4 m), averaging 74% recovery. XCB cores 697B-12X to 697B-32X were from 119.8-322.9 mbsf (3611.4-3814.5 m), with a recovery rate of 55.8%. The last core reached the surface at 0315 on 7 March. The proposed total depth had not been reached but there was no remaining time in the leg to continue the operation.

The drill pipe was secured on the ship in the early afternoon of 7 March, thrusters were pulled, and JOIDES Resolution departed for East Cove, Falkland Islands, at 1400 on 7 March 1987.

TRANSIT

The ship arrived at East Cove on 11 March 1987 and had the first line ashore at 0800. Since leaving Valparaiso, Chile, she had steamed 6342 nautical miles in a total leg time of 74.92 days.

OCEAN DRILLING PROGRAM
OPERATIONS RESUME
LEG 113

Total Days 25 December 1986 -- 11 March 1987)	74.92	
Total Days in Port		5.13
Total Days Under Way (including survey)		25.92
Total Days on Site		43.87
Trip Time	8.48	
Coring Time	28.33	
Drilling Time	0.33	
Logging/Downhole Science Time	1.11	
Reentry Time	0	
Mechanical Repair Time (contractor)	0.27	
Ice Delay	2.57	
Other	5.34	
Total Distance Traveled (nautical miles)		6432
Average Speed (knots)		10.2
Number of Sites		9
Number of Holes		22
Total Interval Cored (m)		3385.2
Total Core Recovery (m)		1943.0
Percent Core Recovered		57.4
Total Interval Drilled (Washed) (m)		628.3
Total Penetration (m)		4044.5
Maximum Penetration (m)		645.6
Maximum Water Depth (m from drilling datum)		4664.5
Minimum Water Depth (m from drilling datum)		661.0

TECHNICAL REPORT

The ODP Technical and Logistics personnel aboard JOIDES Resolution for Leg 113 of the Ocean Drilling Program were:

Laboratory Officer:	Bill Mills
Computer System Manager:	Jack Foster
Computer System Manager:	Bill Meyer
Curatorial Representative:	Gerald Bode
Ass't Curatorial Representative:	Bob Wilcox
Yeoperson:	Dawn Wright
Photographer:	John Beck
Electronics Technician:	Dwight Mossman
Electronics Technician:	Jim Briggs
Chemistry Technician:	Tamara Frank
Chemistry Technicnan:	Larry Bernstein
X-ray Technician:	Bettina Domeyer
Marine Technician:	Wendy Autio
Marine Technician:	Stacey Cervantes
Marine Technician:	Henrike Groschel-Becker
Marine Technician:	Jessy Jones
Marine Technician:	Frank Rack
Marine Technician:	Caryn Smith
Ice Observer:	Tor Fosnaes
Weather Observer:	Vernon Rockwell

INTRODUCTION

Leg 113 is the first southern high-latitude leg of the Ocean Drilling Program. In addition to coring operations aboard JOIDES Resolution, ice picket vessel TS/V Maersk Master (when not engaged in ice management) conducted magnetic surveys and sediment flux studies.

Cruise operations commenced in Punta Arenas, Chile on 5 January 1987 and terminated on 11 March in East Cove, Falkland Islands. JOIDES Resolution spent a total of 65 days in the Weddell and Scotia Seas.

PORT CALL, PUNTA ARENAS

Shipments for Leg 113 were handled by the Leg 112-Transit crew in Valparaiso, Chile. Activities in Punta Arenas were minimized so that the ship could depart in less than 24 hours. Major activities included the transfer of drilling water from Maersk Master to JOIDES Resolution and transfer of Dr. Stephen Berkowitz's equipment to Maersk Master. Cross-over between the two technical staff was brief, but nine days of transit to the first site allowed the technical staff to get shipments stowed and labs running.

UNDERWAY ACTIVITIES

Adverse environmental conditions of polar waters, from ice in the guns to growlers on the seas, provided a challenge to both technicians and equipment. Approximately 6000 nautical miles of geophysical records were collected. Navigational and bathymetric data were collected continuously when conditions allowed. The seismic system was used frequently for site selection. Despite some operational problems we were able to return quality single-channel records surveyed at 6 knots. Geophysical surveys were often interrupted when darkness or fog forced the ship to slow below 5 knots. The captain requested that no gear be towed during these times so that emergency maneuvers could be made to avoid ice without fear of tangling or backing over geophysical gear.

One day away from the first site we deployed the seismic gear. For the first half hour both guns (SSI 80's) worked without problems, then both guns began to misfire and plume. The starboard gun was retrieved and air was noticed escaping from the exhaust vents. Upon inspection ice was found on top of the air distributor. Past experience in polar waters had indicated that icing would not be a problem when using water guns. Therefore, no de-icing gear was provided. A variety of methods were improvised for injecting methanol or ethylene glycol into the high-pressure air system. An in-line injection system for the port gun was installed, but the lack of a large pressure vessel for the antifreeze made this impractical to use. As the cruise progressed, icing problems with the starboard gun cleared up while the port gun continued to have problems.

On approach to Site 693 the starboard tow line caught a growler that pulled the airline out of the towing bracket and damaged the firing lead. Since the hose connector was not damaged the airline was connected directly into the jumper air line, by-passing the towing bracket. Despite these problems, the site approach was completed with little loss of data.

The 3.5-kHz towfish was tested during this leg. This time it was rigged to tow from the taut-wire boom on the starboard side amidships. Results of the test again showed that the hull-mounted 3.5-kHz PDR is superior at all speeds. Unfortunately, the tow fish was lost before it could be retrieved, when a welded joint failed on the aft end of the tow bracket.

A second live section was added to the starboard streamer to see if it would improve record quality at high speeds. Our test did not show a significant improvement. The streamer has been left on for evaluation by the Leg 114 crew.

ON SITE ACTIVITIES

Twenty-two holes cored at nine sites on Leg 113 kept scientists and technicians busy. A total of 1943 m of core was recovered, from which 18,211 samples were taken.

Core Processing

Occasional shattered liners were repaired with sleeving that worked well when liners were only slightly shattered. More serious damage required reconstruction into pre-split liners.

Physical Properties

One technician was required to attend to the GRAPE/P-wave logger full time during this cruise. The new GRAPE unit was installed during this trip for use on upcoming legs, but there was insufficient time between sites to transfer the source and detector to the new GRAPE. The vane shear was modified with new limit switches that prevent wires from being twisted off and a fast rewind that shortens measurement times.

Paleomagnetics

Although the cryogenic magnetometer was onshore for repairs, the paleomagnetics lab analyzed 4,983 samples using the spinner magnetometer. Whole core susceptibility measurements were done on sediment cores from only a few sites.

Downhole Measurements

The two Von Herzen temperature recorders saw regular use on all APC holes. The old Barnes water sampler was put back in service in lieu of the new In-Situ Pore Water (ISPW) tool lost on Leg 112. It was not needed until the latter half of the leg, giving us time to build and test the tool. The Uyeda temperature recorder was used with success. The Multishot was not used this leg.

Thin Section Lab

Dropstones accounted for most of the 125 thin sections made. All equipment performed well.

X-Ray Lab

The X-ray diffractometer was used extensively for clay mineral analysis. Three hundred samples were analyzed for a total of 1000 scans.

After swapping x-ray tubes, the X-ray fluorescence unit was recalibrated to the same precision as on Leg 111. The XRF was used to analyze 30 samples. The two XRF problems this trip were attributed to normal wear and tear. First, the de-ionized water pump failed and was replaced. Second, the P-10 gas density regulator malfunctioned. A new regulator is on order. The existing regulator was cleaned and rebuilt. It has been operating without trouble since then.

Chemistry Lab

The Chemists conducted routine organic and inorganic analyses. The headspace analysis system is being returned to shore for repair of the oil bath temperature controller. Poor reproducibility on the inorganic carbon Coulometer has been traced to the anode solutions. New solutions have been ordered.

SEM

The SEM started Leg 113 in good working order. However, while in transit to the first site, the regulated power failed briefly and, after burning up several filaments, it was discovered that the diffusion pump heater wire had separated. As a result the diffusion pump could not pull down a sufficient vacuum for operation. A new heater was requisitioned for Leg 114.

Paleontology Lab

Overcrowding in the paleontology lab's microscope room was alleviated somewhat by annexing space in the petrography and XRF prep areas. Bench space in the paleontology prep lab could not be extended and overcrowding was constant. To help the situation, a marine tech was assigned to keep the lab stocked with supplies throughout the cruise.

Computer Facilities

Two system managers sailed on Leg 113. This allowed for a significant amount of development work to be done along with normal operations.

The RA81 disk drives and controllers were responsible for a series of crashes that kept both system managers busy rebuilding the system. Spares and repairs at the Falklands port call should bring system back to normal operation. The possibility of losing the VAX computer system revealed how critical it is to normal lab operations, and how important the backup systems are!

Software Development

Numerous software tools were created and old program versions were updated. Electronic notebooks were created for most lab areas and have been a success with the technicians. Navlog and Smooth (programs for developing ship's tracks) were improved this leg and a new instruction manual was written. A spin-off from Smooth and Navlog is an application called Fixer, which can determine the final hole position using just the ODP satellite navigation system. Although the new GRAPE installation has not been completed, we are using the new GRAPE software to collect data while operating the old GRAPE hardware. A data transfer routine from the P-wave logger to the Vax has been set up along with a PicSure plotting routine for P-wave data.

Weather Equipment and Current Meter

The old Koden fax receiver was resurrected when special paper casettes for the Alden Marinefax ran out. Crystals for Russian weather satellites have been ordered to increase available satellite coverage.

The current meter, installed on Leg 112, was deployed at all sites except the last two. Current data were helpful to ice management. On the next to the last site, heavy sea conditions and the fear of tangling with SEDCO's taut wire prevented deployment of the current meter. On the last site the cable jumped the sheave and was damaged, requiring reheading.

Recreation and Entertainment Facilities

In the gymnasium, Unistrut framing was completed, and enclosed hand rails, overhead lights, heaters and fans were added. Audio-visual equipment, a weight rack, and a new base plate for the weight machine were also installed.

The science lounge speakers were remounted in proper geometry as recommended by the manufacturer. The resulting modifications have improved sound quality.

Storekeeping

Operations were routine and a physical count was conducted midway through the cruise. To organize supplies in the casing hold, the gap between the gym and starboard bulkhead was filled in with drop-in platforms. Most of the D-tubes are now stacked there. A materials rack was built in the wood shop to hold our supply of plywood and plastic stock.

SAFETY

Working in Antarctica required that everyone pay special attention to safety. All hands were required to attend training, conducted by ship's officers, in the use of survival suits and life boats. Technicians were required to wear flotation work suits and be hooked into safety lines when working near railings or on the stern catwalk deploying seismic gear.

Special training for the M.E.T.S. was limited because of the heavy work load in the core lab. Checks on all safety equipment, first aid kits and hazardous storage areas were conducted as usual and safe lab practices were enforced.

SPECIAL EVENTS

For such a remote spot on the planet, the Weddell Sea seemed at times to be positively crowded. Midway thru the cruise on a calm, sunny, Antarctic summer day, F/S Polarstern came along side. All day long mutual tours of each vessel were given for crew and scientists. Maersk Master handled personnel transfers along with sightseeing trips to a nearby iceberg. A small Russian whaler came by to take a look at all of the commotion, but declined our invitation to stay. The hospitality shown by the crew of Polarstern was greatly appreciated by all.

Toward the end of the cruise, R/V John Biscoe came along side needing assistance with their dredging system. With a variety of parts and engineering imagination, John Biscoe was sent on her way with a functioning dredge.

PERSONNEL

Staff morale remained high during the 65 days at sea and adverse weather conditions, a credit to their maturity and professionalism.