7. SITES 691 AND 692[1]

Shipboard Scientific Party[2]

HOLE 691A

Date occupied: 25 January 1987; 1600 local time

Date departed: 26 January 1987; 0245 local time

Time on hole: 10 hr, 45 min

Position: 70°44.54′S, 13°48.66′W

Bottom felt (rig floor: m, drill pipe): 3046

Distance between rig floor and sea level (m): 11

Water depth (drill-pipe measurement from sea level, m): 3035

Penetration (m): 0.05

Number of cores: 1

Total length of cored section (m): 0.05

Total core recovered (m): 0.05

Core recovery (%): 100

Oldest sediment cored:
Depth sub-bottom (m): 0.05
Nature: terrigenous silty mud
Age: Pliocene-Pleistocene

HOLE 691B

Date occupied: 26 January 1987; 0245 local time

Date departed: 26 January 1987; 0600 local time

Time on hole: 3 hr, 15 min

Position: 70°44.64′S, 13°48.56′W

Bottom felt (rig floor: m, drill pipe): 3049

Distance between rig floor and sea level (m): 11

Water depth (drill-pipe measurement from sea level, m): 3038

Penetration (m): 1.7

Number of cores: 1

Total length of cored section (m): 0

Total core recovered (m): 0

Core recovery (%): 0

HOLE 691C

Date occupied: 26 January 1987; 0600 local time

Date departed: 26 January 1987; 1415 local time

Time on hole: 8 hr, 15 min

Position: 70°44.58′S, 13°48.68′W

Bottom felt (rig floor: m, drill pipe): 3036

Distance between rig floor and sea level (m): 11

Water depth (drill-pipe measurement from sea level, m): 3025

Penetration (m): 12.7

Number of cores: 1

Total length of cored section (m): 12.7

Total core recovered (m): 0

Core recovery (%): 0

HOLE 692A

Date occupied: 26 January 1987; 1415 local time

Date departed: 26 January 1987; 2130 local time

Time on hole: 7 hr, 15 min

Position: 70°43.447′S, 13°49.208′W

Bottom felt (rig floor: m, drill pipe): 2891

Distance between rig floor and sea level (m): 11

Water depth (drill-pipe measurement from sea level, m): 2880

Penetration (m): 6.7

Number of cores: 1

Total length of cored section (m): 6.7

Total core recovered (m): 0.65

Core recovery (%): 10

Oldest sediment cored:
Depth sub-bottom (m): 0.65
Nature: terrigenous silty mud
Age: Pliocene-Pleistocene

HOLE 692B

Date occupied: 26 January 1987; 2130 local time

Date departed: 30 January 1987; 0115 local time

Time on hole: 75 hr, 45 min

Position: 70°43.432′S, 13°49.195′W

Bottom felt (rig floor: m, drill pipe): 2886

Distance between rig floor and sea level (m): 11

Water depth (drill-pipe measurement from sea level, m): 2875

Penetration (m): 97.9

Number of cores: 13 (two wash cores)

Total length of cored section (m): 97.9

Total core recovered (m): 29.3 (excluding wash cores)

Core recovery (%): 30

Oldest sediment cored:
Depth sub-bottom (m): 97.9
Nature: clayey mudstone
Age: Valanginian/Hauterivian
Measured velocity (km/s): 1.76

[1] Barker, P. F., Kennett, J. P., et al., 1988. *Proc. ODP, Init. Repts.*, 113: College Station, TX (Ocean Drilling Program).

[2] Shipboard Scientific Party is as given in the list of Participants preceding the contents.

Principal results: Sites 691 (W4/1) and 692 lie on a midslope bench on the Weddell Sea margin of East Antarctica. Drilling on this margin proposed 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. Site 691 (W4/1) at 3035 m water depth at 70°44.54′S, 13°48.66′W, in the axis of Wegener Canyon, was occupied from 25 to 26 January 1987. In each of the three rotary holes attempted one core was taken, with total recovery of 0.05 m. At Site 692, on the canyon shoulder, we rotary-drilled two holes from 26 through 30 January 1987, recovering 0.65 m of 6.7 m penetrated in one core of Hole 692A. At Hole 692B in water 2875 m deep at 70°43.432′S, 13°49.195′W, we penetrated 97.9 m and recovered 29.3 m (30%) in 11 cores (plus 2 wash cores). Three units were recognized:

Unit I. 0–30.4 mbsf, silty and clayey mud, with a nonrecovered coarse fraction, Miocene to upper Pleistocene.

Unit II. 30.4–53.2 mbsf, a "gravel bed" of pebbles, cobbles of several hard-rock lithologies, and probably a fine fraction which was not recovered, of unknown age.

Unit III. 53.2–97.9 mbsf, nannofossil claystone with macrofossils, volcanic ash lenses, and laminae, and organic-rich claystone interbeds, Lower Cretaceous (Lower Aptian through Berriasian?).

Hole 692B was abandoned because the main aim of drilling was inaccessible and because the unstable material of Unit 2 (the "gravel bed") was caving down the hole (this unit was also the likely cause of the failure to spud-in the other four holes).

The Cenozoic record of Antarctic continental climatic change is not present at these sites, but we obtained some interesting and relevant information.

1. Diatom assemblages indicate that the canyon-cutting at Site 692 occurred during or before the early late Miocene. Physical properties suggest that 250–300 m of overburden was eroded, implying a simple original continuity of the parallel-bedded reflectors at the canyon walls. Wegener Canyon has now cut through the outer high of "Explora Wedge," a seaward-dipping reflector province, creating a narrow inner canyon inshore (Site 691) and permitting slow deposition (indicated by the presence of glauconite) on the flanks (Site 692). The relation between canyon-cutting events and Antarctic ice-sheet growth should emerge from later sites.

2. The Lower Cretaceous claystones of Unit III resemble Aptian to Barremian sediments from the Falkland Plateau, which was then nearby. They were deposited in water with a maximum depth of 500–1000 m at middle latitudes under anoxic or weakly aerobic conditions, possibly with fluctuating surface-water salinity. 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 reflector basement, considered to be of Middle Jurassic age.

BACKGROUND AND OBJECTIVES

Site 691 (W4/1 alt) is located at 70°44.54′S, 13°48.66′W, on the eastern margin of the Weddell Sea, in water 3035 m deep. It lies on a bench on the Antarctic continental slope created by the "Explora Wedge" (Hinz, 1981; Hinz and Krause, 1982), a sequence of seaward-dipping seismic reflectors considered similar in origin to the Voring Plateau (Talwani, Udintsev, et al., 1976; Eldholm et al., 1986) and Hatton-Rockall Bank (Roberts et al., 1985). The main objectives at Site 691 were twofold:

1. To examine the Cenozoic record of Antarctic glaciation and pre-glacial climate and terrestrial vegetation in the overlying sediments, adding a continental dimension to Leg 113's thematic concern with the development of the present-day Antarctic water masses and climate; and
2. To find the nature and age of the dipping reflectors.

Site 691 was located in the axis of the upper reaches of a large submarine canyon which cuts through the bench (Figs. 1 and 2). This location appeared to provide a shortcut to the older part of the sedimentary succession, highly desirable in this region where passing icebergs could interrupt drilling, at a margin site where the sedimentary sequence is thick. According to K. Hinz (pers. comm., 1986; Hinz and Krause, 1982; Hinz and Block, 1984), the sediments at Site 691 range in age from Miocene (seismic stratigraphic sequence WS-2, between unconformities U5 and U6) to Middle Jurassic. Thus, apart from the last 15–20 m.y., the sequence could represent all major stages of Antarctic continental history from its beginning as an independent continent following the breakup of Gondwanaland. We might expect to see:

1. Late Jurassic to Early Cretaceous anoxia, as on the Falkland Plateau (Barker, Dalziel, et al., 1977; Ludwig, Krasheninnikov, et al., 1983) and Antarctic Peninsula (Farquharson, 1983), perhaps resulting from restricted circulation in small ocean basins during the early stages of Gondwanaland breakup.
2. Volcanic ash from a range of sources: possibly from the Mozambique Ridge during the Early Cretaceous, from Maud Rise in the middle Cretaceous, and an initially strong, later decreasing calc-alkaline component as the Antarctic Peninsula moved away.
3. A test of our interpretation of Site 690 sediments, in which Eocene to Upper Cretaceous clays and mica are considered probably wind-blown, and their mineralogy thought to indicate a warm, humid climate.
4. A progressive cooling from the early Eocene on, with a sharp change at the Eocene/Oligocene boundary involving seasonal sea-ice formation, a possible ice-cap in the middle Oligocene, and more certainly a thick ice-sheet on East Antarctica from the middle Miocene. Some Miocene glaciogenic sediments could be encountered at the top of the succession at Site 691, but not a great thickness, it is hoped.

Perhaps the crucial contribution at this site was expected to come from study of the pollen and spores. Palynomorphs eroded from sediments beneath the ice, transported in the base of ice-sheets from a large part of the Antarctic continent, and deposited offshore, have provided tantalizingly random glimpses of the pre-glacial Antarctic flora (e.g., Kemp, 1972; Truswell, 1983; Truswell and Anderson, 1984). Exposed rocks are equally interesting (e.g., the middle Cretaceous high-latitude temperate forest described from Alexander Island by Jefferson, 1980) but fragmentary in the climatic record they can provide. The prospect of a much more continuous and high-resolution record at Site 691 was exciting.

The many multichannel seismic profiles collected from this region, mainly by West German and Norwegian expeditions, have defined a well-developed seaward-dipping reflector province at the base of the sedimentary sequence. By comparison with other similar features already drilled, these are interbedded lavas and shallow marine or fluvial sediments, and the environment is one of "subaerial sea-floor spreading" (Mutter et al., 1982) during the very earliest stage of formation of the Weddell Sea. By comparison with other indications of extension in the region, related to Gondwanaland breakup (such as the Ferrar dolerites, Kirkpatrick Basalts, Dufek Massif, etc.), this is considered most probably a Middle Jurassic event, perhaps dating from 165 to 175 Ma. While the age and nature of these reflectors remain uncertain, our understanding of the regional tectonic evolution of this part of Gondwanaland will be incomplete.

The seaward-dipping reflectors lay at about 950–1000 mbsf beneath sites W4/1 and W4/1 alt, our options for Site 691. The presumed Neogene section eroded from the canyon bottoms where these sites are located, would be sampled at the planned advanced piston corer/extended core barrel (APC/XCB) Site W4/2, intended as Site 692. Our intentions at Site 691 were to rotary-core continuously to basement in a single-bit hole, possi-

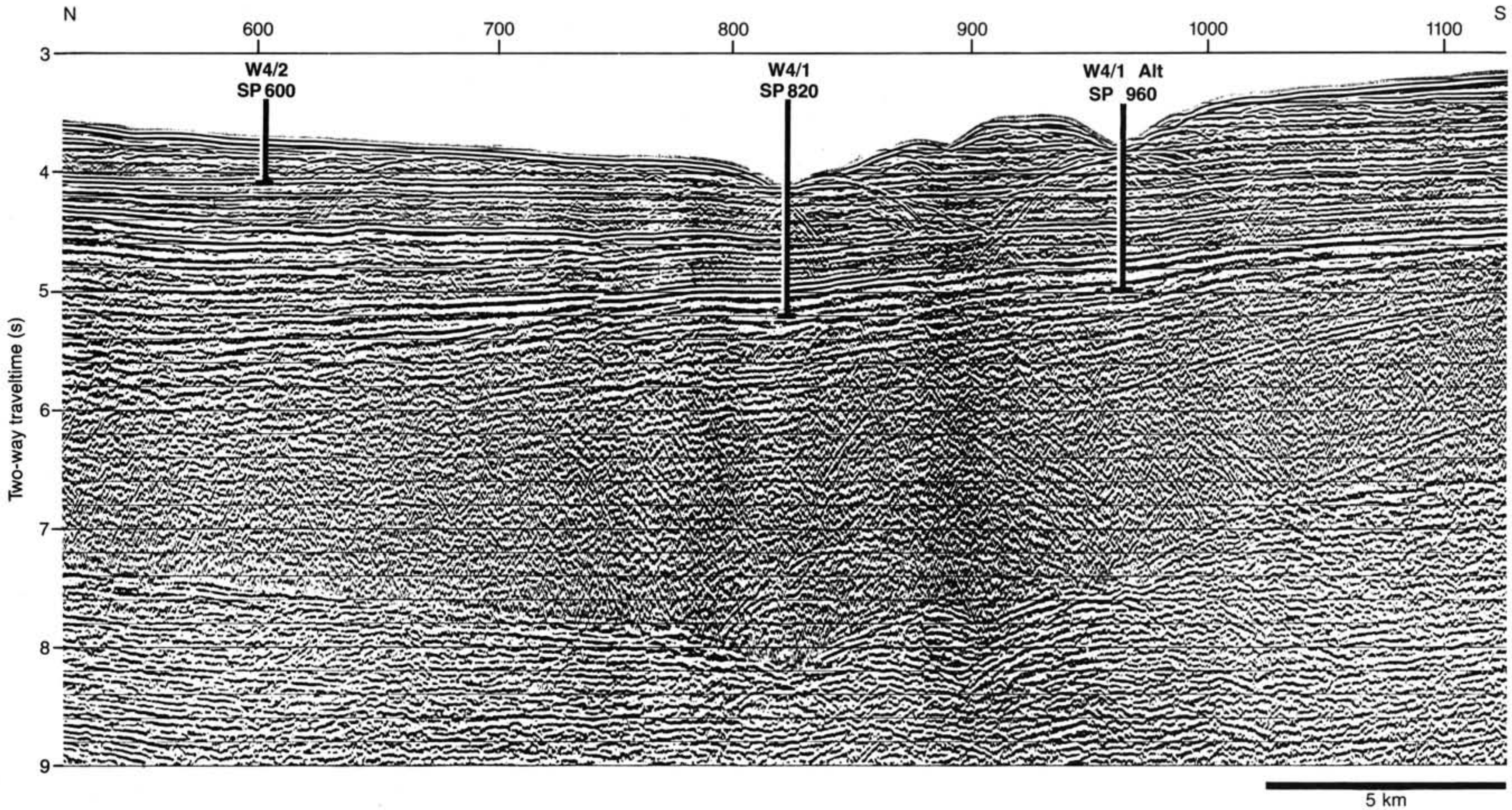


Figure 1. Multichannel seismic profile BGR78-019 showing locations of W4/1 (Site 692), W4/1 alt (intended Site 691), and W4/2. For location see Figure 2. SOM = South Orkney microcontinent.

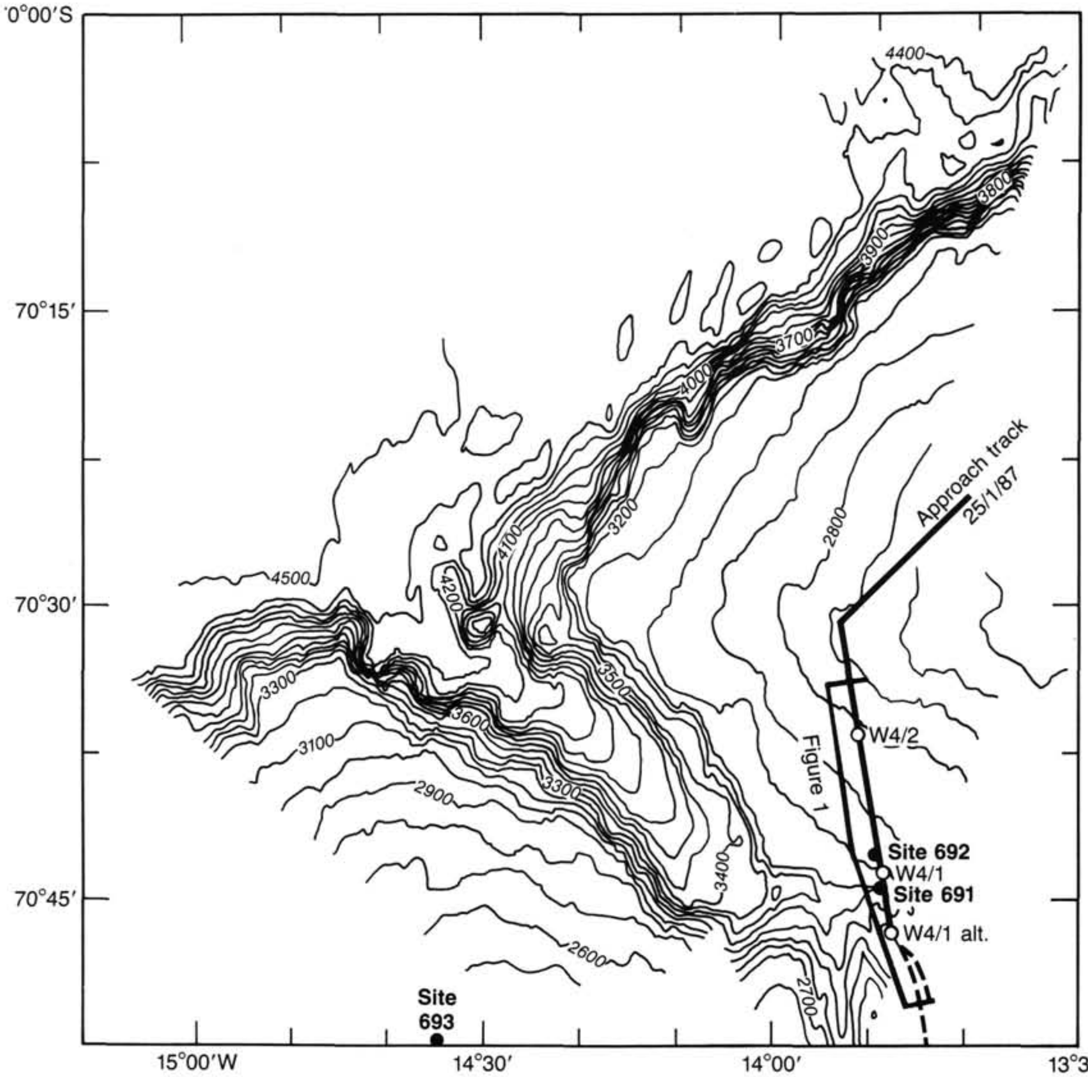


Figure 2. Intended approach to Site 691 (W4/1 alt) in axis of Wegener Canyon on Dronning Maud Land margin of Weddell Sea, off Kapp Norvegia and location of Sites 691, 692, and 693 (Sea Beam map provided by *Polarstern*; depth in meters).

bly setting a minicore against the possibility of being driven off the site by icebergs. The hole was to be logged.

The account of Leg 113 intentions, above, does not reflect what actually happened at the site, but is retained to illustrate aspects of site selection in poorly known regions, and to illuminate the rationale behind the decisions taken during drilling.

OPERATIONS

Site 691

Site W4/1 alt was to be the most southerly location for Leg 113. The probability of the site being ice-free was only about 50%, but 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 mi (780 km) southwest of the Site 690 location, and the voyage was made in 41.4 hr at 11.5 kt. The weather was fine with sea and air temperatures near 0°C. Winds were light and the seas seldom more than a meter. Typically, about five icebergs were within a 20-mi (32-km) radar range. During the first day the icebergs sighted were old and weathered and most had water-erosion lines with position that indicated they had turned over. During the evening of the 24 January we encountered larger, tabular icebergs. On the morning of the 25th the first pack ice was sighted. It was old and rotten; stringers of it extended for several miles. The area of the site was reached near noon on the 25th. The seabed was very rough with many deep canyons, and 4 hr of surveying was required to locate the site. The beacon was dropped at 1600 hr about 180 m north of the biggest iceberg within 10 mi (16 km). The position was 70°44.6′S, 13°48.7′W.

The thrusters were lowered and the *JOIDES Resolution* stood by while the *Maersk Master* began its first serious ice management of the leg. The iceberg was 80 × 80 × 25 m above water and was estimated to displace 640,000 tons. The *Master*'s first attempt to move it was with the water monitors, which can discharge 9000 tons an hour. The display was spectacular but not very effective. The *Master* then deployed the 4000-ft-long (1220-m-long) towing rope which ODP had purchased. The floating rope was towed around the berg and the floating end secured to the towing bollard. The *Master* let out rope and cable and slowly increased towing force to 30 tons. The 15,000 horsepower of the *Master* is more than sufficient to break the rope, which has a breaking strain of 170 tons. The drift rate of the iceberg was increased to 0.6 kt to the south, where it was released to continue its 0.2–0.3 kt natural drift to the southwest.

There is debate about the proper method of calculating the weight of an iceberg. The method used in this report is based on the assumption that the density of the iceberg is 800 kg/m^3 and that of sea water 1025 kg/m^3. Therefore, 800/1025 = 0.78, approximately 4/5, so that the total volume of the iceberg is five times the volume above water. So:

Weight (metric tons) = length (m) × width (m) × height (m) × 5 × 800 (kilos/m^3)/1000 (kilos/ton) = length × width × height × 4. (Kyle Stadium at Texas A&M is 207 × 140 × 67 m. An iceberg of the same size would weigh about 7.7 million tons.)

Hole 691A

The bit selected was a 9 7/8-in. Rock Bit International (RBI) type C3 rotary, which is suitable for drilling the predicted soft sediments with some harder materials near basement. A total of fourteen 8 1/4-in. drill collars were used, and the drilling jars were in the bottom-hole assembly (BHA).

The precision depth recorder (PDR) indicated a depth to the seabed of 3046 m. The bit encountered bottom at 3045.95 m from the rig floor. Essentially no penetration was possible because of the hard seafloor. The hole was deemed undrillable and was abandoned.

Hole 691B

The ship was moved 150 m south in an attempt to find a soft bottom. The bottom was felt at 3049.0 m from the rig floor, 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 (300 m) east-northeast. Sea bottom was felt at 3036 m from the rig floor. The hole was drilled to 3049 m with high torque in 3.5 hr, and it fell 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.

Site 692

Hole 692A

It was concluded that the canyon sites had a bottom which was a thin veneer of soft sediments on top of gravel and rock, and thus were undrillable. It was decided to move 2 mi (3.2 km) on a course of 350° which would produce a site away from the inner canyon. A 3-hr global positioning satellite (GPS) window was open. Initial interpretation of the water depth out of the canyon indicated that if five stands of pipe were pulled the bit would clear the seabed. Seven were pulled and the ship started toward the new site under beacon and GPS control. A recheck of the new site water depth produced the conclusion that the bit would be only 52 m above the seabed at the end of the move. This was considered to be too small a safety margin, and the ship was stopped while another 50 m of pipe were withdrawn. Unfortunately, the wireline was being run inside the drill pipe to recover the core barrel and the line had to be withdrawn before the pipe could be pulled. The end result was that the 3-hr GPS window closed, and the ship was only about halfway to the site. Ship speed through the water was limited to about 0.4 kt on the bridge current meter, and after moving a total of 1.1 mi (1.8 km) the Co-Chiefs concluded that a suitable canyon shoulder location had been reached.

The PDR indicated a total drilling depth to the seabed of 2889.3 m. Bottom was felt at about 2891 m from the rig floor, and 6.7 m of soft material was punched (Table 1). The formation then became very hard, and high torque was required to rotate the pipe. The hole was declared undrillable after 45 min.

Table 1. Coring summary, Sites 691 and 692.

Core no.	Date (Jan. 1987)	Time	Depths (mbsf)	Cored (m)	Recovered (m)	Recovery (%)
Hole 691A-						
1R	26	—	0–0.05	0.05	0.05	100.0
Hole 691B-						
1H	26	—	0–1.7	1.7	0	0
Hole 691C-						
1H	26	—	0–12.7	12.7	0	0
Hole 692A-						
1R	27	2100	0–6.7	6.7	0.65	9.7
				6.7	0.65	
Hole 692B-						
1R	27	0030	0–9.1	9.1	1.07	11.7
2R	27	0515	9.1–20.9	11.8	0.21	1.8
3R	27	1000	20.9–30.4	9.5	5.05	53.1
4R	27	1230	30.4–40.0	9.6	0	0
5R	27	1645	40.0–49.7	9.7	0.40	4.1
6R	27	2215	49.7–53.2	3.5	0.39	11.1
7R	28	0430	53.2–59.3	6.1	2.32	38.0
8R	28	1145	59.3–68.8	9.5	3.90	41.0
9R	28	1430	68.8–78.5	9.7	4.77	49.2
10R	28	1715	78.5–88.2	9.7	7.29	75.1
11W	29	0215	54.8–88.2	N.A.	12.8	N.A.
12R	29	0700	88.2–97.9	9.7	3.90	40.2
13W	29	1245	88.2–97.9	N.A.	1.52	N.A.
				97.9	[a]29.3	

[a] minus wasted intervals.

Hole 692B

The ship was moved 500 ft (150 m) north in an attempt to escape the hard seafloor. PDR water depth was 2885.3 m. Bottom was felt at 2886 m from the rig floor. The bit punched easily through 5.5 m of soft seafloor, 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 (Table 1). The second core advanced the bit 11.8 m in 165 min. Drilling was not good, but progress was better than in the previous holes. The hole was cored to 2936 m or 50 mbsf in a zone of boulders. Torque was high and erratic, and penetration was slow. When the pipe was picked up off bottom, the hole would usually fall in and have to be redrilled. At 2939 m it was necessary to begin drilling with the knobby pipe because of the low rate of penetration. At about 2950 m hole conditions improved and it appeared the hole would be drillable. At 2974 m the rate of penetration was good with the kelly being drilled down in 40 min, and 7.39 m of core was recovered from 9.7 m of advancement. It was necessary to "short-trip" the drill pipe to recover the three knobby joints of pipe from the string. The entire hole below the bit fell in and redrilling was as difficult as the original drilling, with 8 hr required to redrill the hole. After cleaning out the hole, a core was cut from 2974 to 2984 m (rig floor depth). While the core was being recovered, the bottom 10 m of hole were again lost. The 10 m were redrilled in 4 hr with difficulty. It was decided to abandon the hole before the unsupported BHA parted. Also, it was considered unlikely that hole conditions would improve.

Based on drilling indications at the surface, it seems that an unstable zone of gravel and boulders exists between approximately 30 and 53 mbsf. This material, when disturbed, collapses and falls to the bottom of the hole. The lithologic section beneath the rubble is stable and is drillable. The only way a site such as 692 can be drilled is to isolate the boulder zone with casing. Running the casing in the hole through the unstable zone would be a difficult operational problem and may not be possible.

The hole was cemented before abandonment. Because of the unstable hole conditions, the drill pipe was pulled to above the caving zone (2923 m from the rig floor) and a 200-sack cement plug laid. The drill pipe was pulled to the BHA and the connections magnafluxed because of the severe operating conditions to which the BHA had been subjected. No cracked components were found. The bit was in fair condition.

The weather was fine at Sites 691 and 692 with sun and calm seas. Icebergs were in the area but, except for the one which was on location when the ship arrived, they did not present a problem. *JOIDES Resolution* was under way to the next site at 0115 hr on 30 January 1987.

LITHOSTRATIGRAPHY

Site 691, Hole 691A

The sedimentary sequence recovered at Hole 691A is 9 cm long. The hole was abandoned because of coring difficulties created by a surficial overburden of large boulders and pebbles. Due to the length and nature of the recovered core, the core description is included as part of Site 692.

Site 692

Hole 692A was cored to a depth of 6.7 mbsf and recovered 65 cm of Pliocene to Pleistocene sediment. The hole was abandoned because of coring difficulties attributed to an overburden of gravel. The sediment is a terrigenous, olive gray (5Y 4/2), silty mud that was completely homogenized by drilling disturbance. Microfossils (e.g., planktonic foraminifers, radiolarians, and ostracodes) were identified in trace amounts.

Hole 692B was cored to a depth of 97.9 mbsf with a total recovery of 29.3 m (exclusive of washed cores). Three lithostratigraphic units are recognized at this site (Fig. 3), based upon visual core descriptions, smear-slide analyses (Fig. 4), and correlation with biostratigraphic units (see "Biostratigraphy" section, this chapter). Sediment in Unit I, which is 30.4 m thick, is a silty and clayey mud of terrigenous origin that was completely homogenized by drilling disturbance. Both benthic and planktonic foraminifers are present in minor amounts. The unit ranges in age from Pliocene to late Pleistocene. Unit II, of unknown age, is a 22.8-m gravel interval consisting of igneous and sedimentary rocks. However, core recovery from this unit was less than 1 m, so the lithofacies is not really known. Unit III is a 44.7-m-thick carbonate and organic-rich hemipelagic claystone, rich in nannofossils and interlayered with relatively thin layers of volcanic debris, clay, and lapilli.

Cored sediments of Sites 691 and 692 are moderately to extensively disturbed by drilling. Soupy structures occur in Cores 113-692B-1R to 113-692B-3R. Core recovery varied considerably throughout the three lithologic units, and the least recovery occurred in the gravel unit.

Unit I (0–30.4 mbsf; late middle to early late Miocene–Quaternary)

Section 113-691A-1R, CC; depth 0–0.05 mbsf; thickness 0.05 m; Pleistocene. Section 113-692A-1R-1; depth 0–0.58 mbsf; thickness 0.58 m; Pleistocene. Cores 113-692B-1R to 113-692B-3R; depth 0–30.4 mbsf; thickness 30.4 m; late middle to early late Miocene–early Pliocene/Pleistocene.

Unit I, 30.4 m thick, is a silty/clayey mud which becomes sandier toward the base of the unit. The sediment at the top of the unit is olive gray (5Y 4/2), becoming black (5Y 2.5/1) toward the base. Sediments have been completely homogenized by drilling disturbance. The coarse sand fraction (Core 113-692B-3R) is poorly sorted, angular to very angular in shape, and consists of sedimentary lithic grains (gray calcareous siltstone and fine quartzite). The coarse sand fraction is most probably an artifact of the drill cuttings rather than an *in-situ* sedimentary deposit. The coarse sand has a fine sand component mixed with it. The fine sand is a well-sorted, subrounded quartz and botryoidal glauconite assemblage in which the glauconite component increases in abundance downcore. Sediments of Unit I are essentially terrigenous in origin (Fig. 4).

Biogenic material comprises a very small proportion of the sediment. Mainly planktonic and a few benthic foraminifers are dispersed in the middle and top section of the unit, and decrease downcore. Diatoms, sponge spicules, and nannofossils are present in trace amounts. The unit is inferred to be no older than upper middle to lower upper Miocene (see "Biostratigraphy" section, this chapter).

Unit II (30.4–53.2 mbsf; age unknown)

Cores 113-692B-4R to 113-692B-6R; depth 30.4–53.2 mbsf; thickness 22.8 m; age unknown.

Unit II is a 22.8-m-thick gravel unit of unknown age. Core recovery was very poor and consisted of variably sized pebbles and boulders. Sediment was not retained in any of the cores. Details of the pebble petrology are given below (see "Ice-rafted Dropstones" discussion, below). Core 113-692B-4R failed to recover any sediment/rock fragments; Core 113-692B-5R contained six igneous rock fragments (diabase and granite porphyry and diorite), total recovery of 44 cm, and Core 113-692B-6R contained fragments of fine-grained limestone, total recovery of 38 cm.

Unit III (53.2–97.9 mbsf; Early Cretaceous (Valanginian to Barremian-?Hauterivian))

Cores 113-692B-7R through 113-692B-12R; depth 53.2–97.9 mbsf; thickness 44.7 m; Early Cretaceous (Valanginian to Barremian-?Hauterivian).

Three major lithologies dominate Unit III: claystone, nannofossil-bearing claystone and mudstone, and clayey muddy nannofossil chalk. Claystones are common at the top of the unit (Core 113-692B-7R), and are underlain by a mixed assemblage of ash and nannofossil-bearing claystone, organic and nannofossil-bearing mudstone, organic-bearing muddy nannofossil chalk, and carbonate-bearing nannofossil claystone and mudstone in the middle of the unit (Cores 113-692B-8R to 113-692B-10R). The lower part of the unit is predominantly carbonate-bearing and nannofossil-bearing clayey mudstone (Core 113-692B-12R).

Sediment color changes from black (5Y 2.5/1) and very dark gray (10YR 3/1) at the top of the unit to dark olive gray (5Y 3/2) and olive gray (5Y 4/2) toward the middle of the unit and then back to a dark olive gray (5Y 3/2) and black (5Y 2.5/1) at the bottom of the unit. No single color is exclusively associated with specific lithologies. Colors associated with the different lithologies are as follows: claystones, very dark gray (10YR 3/1) and black (5Y 2.5/1); nannofossil claystone, dark olive gray (5Y 3/2), black (5Y 2.5/2), and olive gray (5Y 4/2); nannofossil-bearing claystone, dark olive gray (5Y 3/2); ashy claystone, black (5Y 2.5/1 or 2); organic-rich nannofossil claystone, black (5Y 2.5/1); clayey nannofossil chalk, dark olive gray (5Y 3/2) and olive gray (5Y 4/2); clayey mudstone, dark olive gray (5Y 3/2); and nannofossil-bearing clayey mudstone, dark olive gray (5Y 3/2).

Well-rounded to subrounded ice-rafted pebbles and cobbles were recovered from the top of Cores 113-692B-7R, 113-692B-

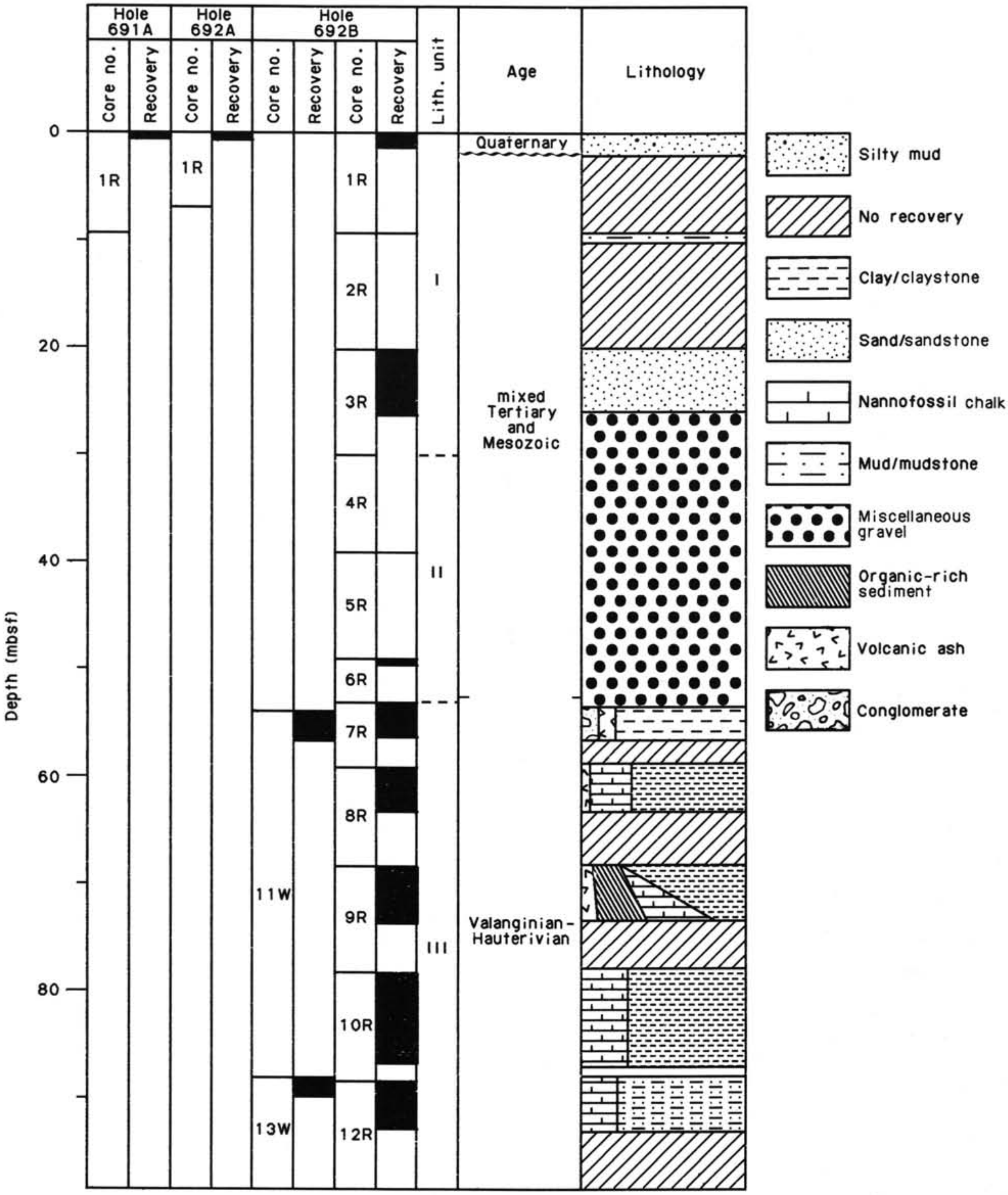


Figure 3. Lithostratigraphic summary of Sites 691 and 692.

8R, and 113-692B-10R. The pebbles are thought to have fallen into the hole during drilling, and are not considered to be an *in-situ* part of Unit III.

Clay is the most abundant component of the terrigenous fraction. Quartz, feldspars, opaque minerals, volcanic ash, and accessory minerals are also present (Fig. 4). Although nannofossils are the dominant microfossil in this unit, they are only recovered in trace amounts in Core 113-692B-7R. There is a sharp increase in nannofossil abundance (>25%) in Cores 113-692B-8R to 113-692B-10R; in Core 113-692B-12R, the abundance decreases to about 12%. In Core 113-692B-8R, fragments of *Inoceramus* were recovered along with a well-preserved pyritized ammonite shell. Shell fragments (particularly ribbed bivalves) are abundant throughout the unit and increase in concentration downcore. Calcispheres were observed throughout the unit and form rare, distinct light gray laminations in the sediment. Within

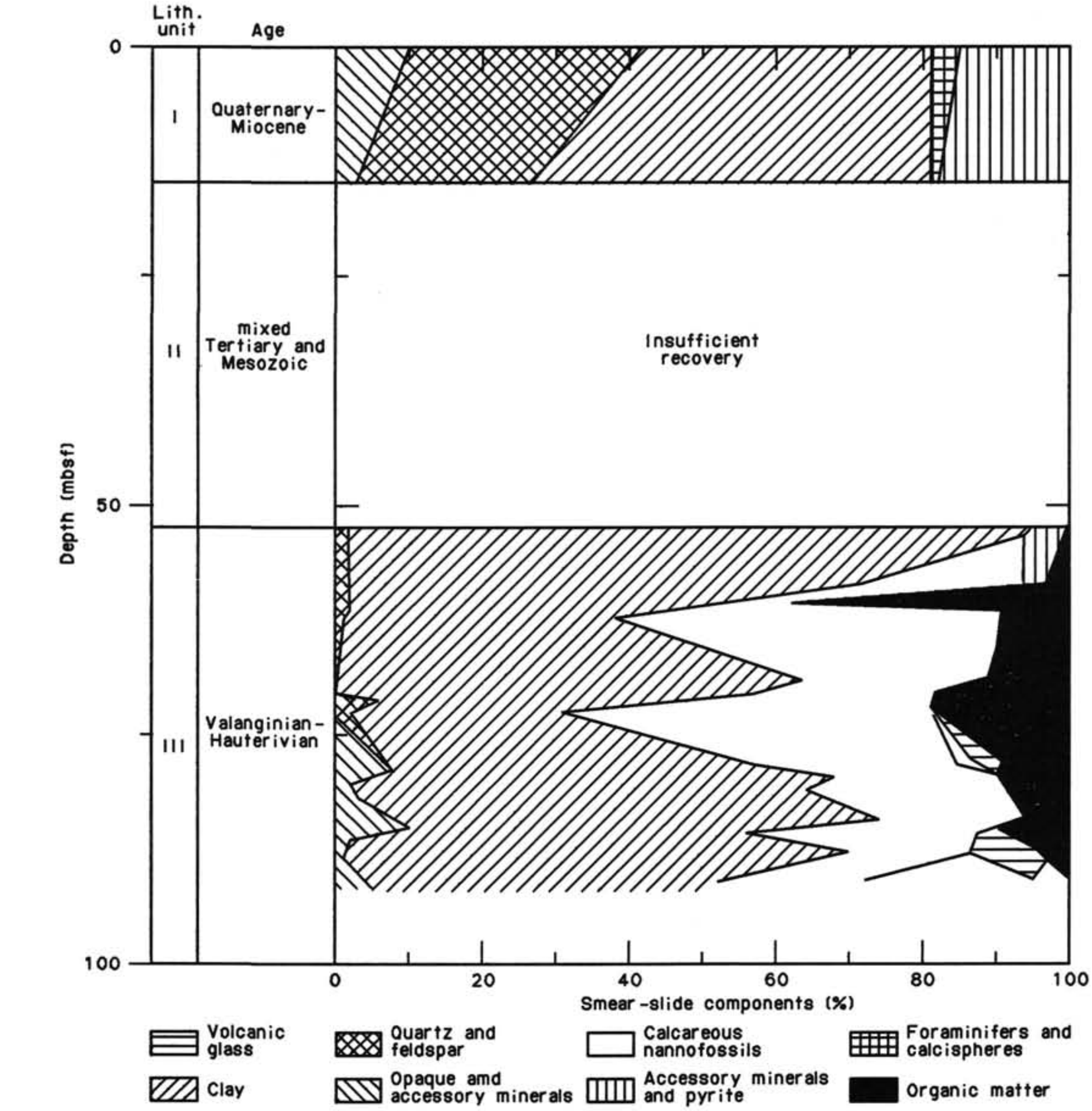


Figure 4. Sediment composition of Hole 692B, from shipboard smear-slide data.

the varieties of claystones identified in Unit III, minor to moderate bioturbation is observed at several levels, especially in Samples 113-692B-7R-1, 100–110 cm, 113-692B-8R-2, 10–40 cm, 113-692B-8R-3, 70–80 cm and 100–110 cm, and 113-692B-9R-1, 80–90 cm.

Volcanic Ash Layers and Lenses

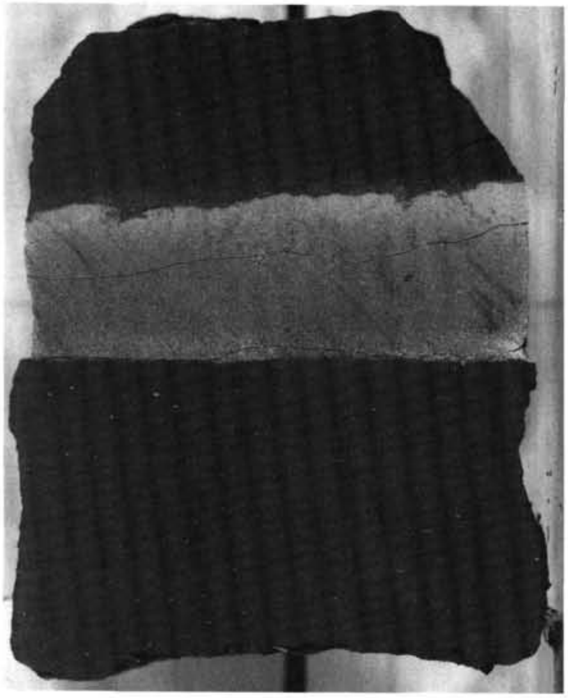
Unit III contains extensive volcanic layers commonly with a high percentage of carbonate (beds, Fig. 5; laminae, Fig. 6; and lenses, Fig. 7). The volcanic ash lenses are rare at the top of the unit (Cores 113-692B-7R and 113-692B-8R), common to abundant in Core 113-692B-10R, and decrease in abundance toward the base of the unit, Section 113-692B-12R-2.

The volcanic ash beds within the upper unit are gray (N 5/0) and may have sharp basal contacts and scoured(?) or differentially compacted(?) tops. There is a particularly thick sequence of volcanic ash (about 8 cm) at the top of Sample 113-692B-9R-1, 12–20 cm. The volcanic ash lenses in the middle and lower unit are predominantly pale yellow olive (5Y 6/6), and a few of the thicker lenses exhibit possible concentric structures (Fig. 7). The lenses may be broken fragments of pumice. Most of the lenses show signs of early diagenetic induration (Fig. 7). In addition, compaction in the surrounding sediment is also observed (Fig. 8, Sample 113-692B-7R-1, 114–120 cm). Some of the ash layers and lenses are pyritized.

Nannofossils (< 1%) occur in traces in nearly all the volcanic ash layers and lenses. However, two of the layers which have diffuse contacts with the surrounding claystones record occurrences as high as 5%. One of the laminae contains 22% calcium carbonate (see "Physical Properties" section, this chapter). This suggests that mixing occurred between the nannofossils within the water column and the descending volcanic ash. However, lenses derived from pumice lapilli were sufficiently cohesive and impervious that mixing was limited to only the outer rim.

Sedimentary Structures

Very fine, thinly laminated beds of silt and clay are found throughout Unit III. Most of the laminae are < 1 mm thick, exhibit no size grading, and vary in color from pale olive (5Y 6/3) to black (5Y 2.5/1). In general, within the claystones (excluding



1 cm

Figure 5. A 2-cm-thick devitrified volcanic ash bed illustrating a sharp basal contact and scoured top (Sample 113-692B-7R-2, 25–32 cm).

the gray volcanic ash lenses), the lighter the color of laminae the greater the nannofossil content. Silt and clay laminae show minor grading in Cores 113-692B-8R and 113-692B-9R (Fig. 9) and to a lesser extent in Core 113-692B-10R. One well-preserved silty clay turbiditic sequence is observed in Section 113-692B-9R-1, and another in Section 113-692B-10R-4.

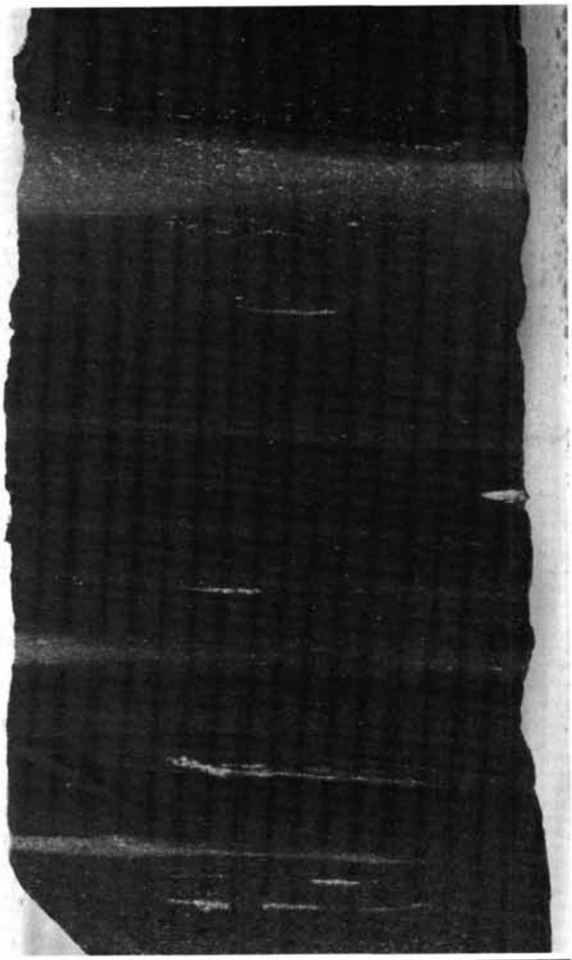
Cores 113-692B-10R and 113-692-12R contain numerous examples of pore-water escape pipes (Fig. 10). Bedding is commonly displaced and in places completely disrupted by these fluid escape structures. The pipes are not observed at the top of the unit. A number of the ash lenses have been displaced by small normal faults, for example, in Samples 113-692B-12R-2, 10–18 cm, and 113-692B-10R-1, 0–30 cm. The widespread occurrence of pore-water escape structures in Cores 113-692B-10R and -12R suggests rapid deposition of the lower part of Unit III.

Clay Mineralogy

X-ray diffraction analyses were completed on four samples from Hole 692B (Fig. 11). The objectives of the clay mineral analyses at Site 692 are as follows: (1) to identify the clay associations in the Lower Cretaceous black claystones, nannofossil chalks, and the pale olive to gray lenses of devitrified volcanic ash; and (2) to compare the clay associations observed at Site 692 with those which occurred during the same geological interval on the Falkland Plateau.

Results and Paleoenvironmental Implications

The clay minerals identified include chlorite, kaolinite, illite, and smectite. Samples were taken from Cores 113-692B-7R to 113-692B-10R. The clay assemblages observed belong to a single clay unit of Valanginian to Hauterivian age. In this unit (C1), black claystones and nannofossil chalks contain very abundant smectite, associated with common illite and rare chlorite and kaolinite. Lenses of devitrified volcanic ash are almost exclusively smectite in content, and illite forms a minor, rare component.



1 cm

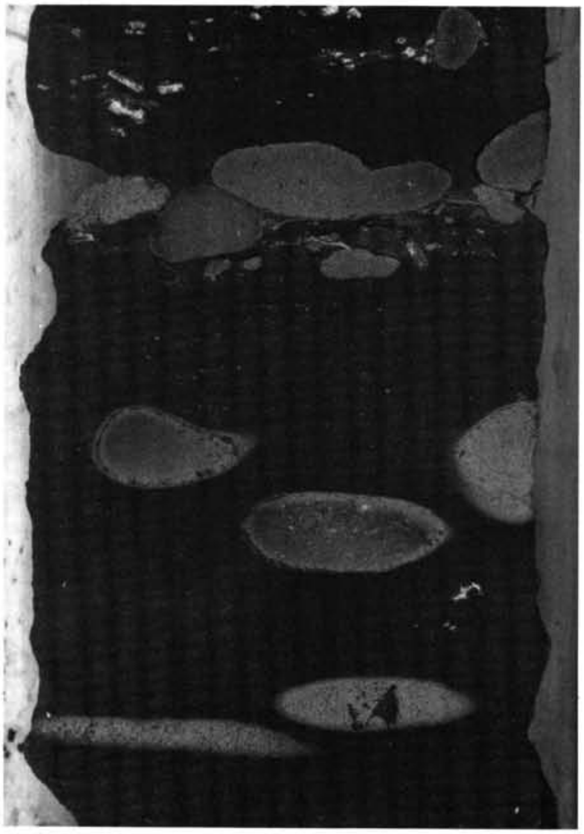
Figure 6. Volcanic ash laminae (Sample 113-692B-8R-2, 78–88 cm).

During the Early Cretaceous, the area of Site 692 was located near the eastern tip of the Falkland Plateau (Smith et al., 1981). The clay associations at Site 692, in black claystones and nannofossil chalks, are very similar to those recognized at DSDP Sites 330 and 511 on the Falkland Plateau for the Early Cretaceous (Robert and Maillot, 1983). Occurrences of very abundant, moderately crystallized smectite in the Early Cretaceous suggest the persistence of globally warm climates with seasonally alternating wet and arid conditions. Very abundant smectite suggests also that the adjacent continent was low-lying and that erosional processes were very weak on the Southern Ocean margins during the same interval (Robert, 1987).

Exclusive and well-crystallized smectite within the lenses of devitrified ash can be formed by two processes: (1) weathering of volcanic ash into smectite in a subaerial environment, devitrified ash and smectite then being transported to the ocean; and (2) volcanic ash deposited directly in the ocean and then partly weathered into smectite by diagenetic processes. More precise studies will permit a determination of the accurate origin of smectite within the lenses of devitrified ash.

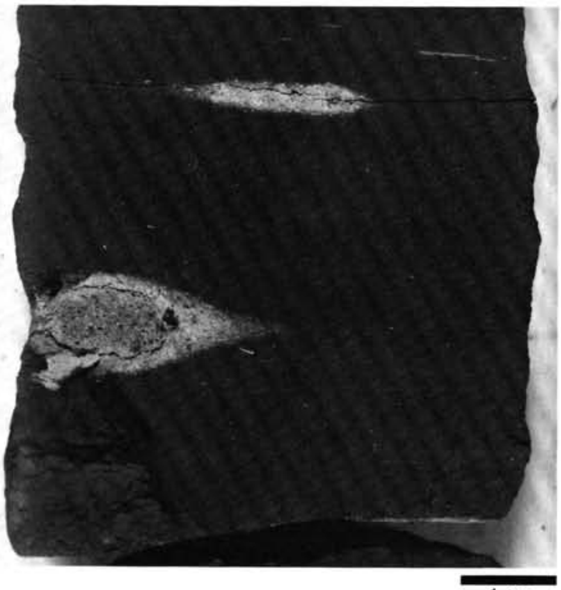
Ice-Rafted Dropstones

Five dropstones were selected for petrographic analysis from Hole 692B. All are from lithologic Unit II and are representative of the recovered lithologies. They are all subangular, unweathered, and 3 × 4 cm in size, and are classified as (1) basic vol-



1 cm

Figure 7. Thin and thick lenses of volcanic ash (Sample 113-692B-10R-5, 135-144 cm).



1 cm

Figure 8. Sediment compaction (Sample 113-692B-7R-1, 114-120 cm).

canic rocks, (2) diabase, and (3) limestone. Detailed descriptions of each specimen are presented in Table 2.

Basalts were found in the top 23 cm of Section 113-692B-5R-1, corresponding to the depth of 39.5 mbsf. The topmost rock (Sample 113-692B-5R-1, 1-4 cm) is a porphyritic pyroxene-olivine tholeiite (glomeroporphyritic texture) with plagioclase dominant in a groundmass also containing clinopyroxene, minor olivine, and magnetite-ilmenite. Phenocrysts are mostly plagioclase with minor spinel. Alteration includes extensive saussuritization of plagioclase (both phenocrysts and groundmass), chloritization of shards, and filling of vesicles. Adjacent to this dropstone is another, somewhat less porphyritic basalt with similar texture, mineralogy, and types of alteration.

1 cm

Figure 9. A well-preserved silty-clay turbiditic sequence in Unit III, (Sample 113-692B-9R-3, 33-45 cm). Also illustrated at the top of the photograph is the scoured base of a silty layer, which cuts down at an angle to bedding. A ribbed bivalve shell occurs in the middle of the photograph.

The second type of basalt is from Sample 113-692B-5R-1, 21-23 cm. This is a porphyritic basalt; white-green euhedral plagioclase phenocrysts are abundant in a flesh-colored groundmass containing oxidized magnetite-ilmenite and fine-grained plagioclase. The plagioclases are extensively epidotized and the rare twins indicate an originally An_{70} composition. Phenocrysts are much larger than in the previously described basalts, up to 12 mm long. Some vesicles are filled with zeolite, and minor chlorite replaces zeolite.

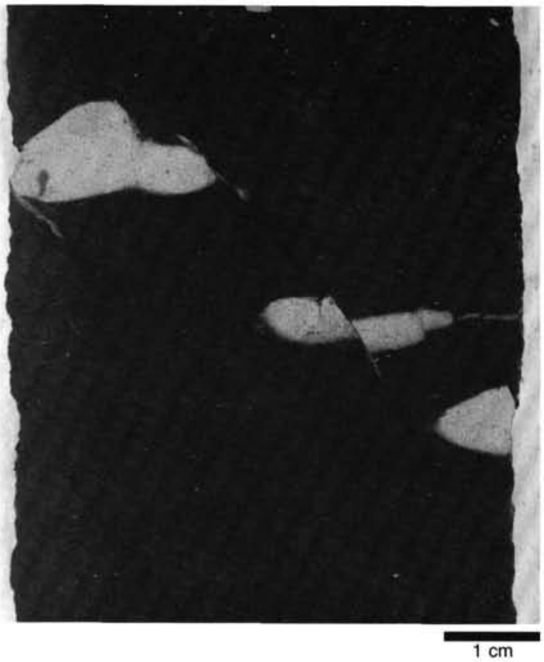


Figure 10. Microfaults displacing volcanic ash lenses, pore-water escape pipes, and gradational contact with claystone (Sample 113-692B-12R-2, 11–17.5 cm).

Diabase occurs at approximately the same depth (Sample 113-692B-5R-1, 25–27 cm). It is a medium-grained rock with porphyritic texture. Phenocrysts include augite, pigeonite (as well as inverted pigeonite), orthopyroxene, and plagioclase. The groundmass consists of fragmented graphic quartz, plagioclase, and pyroxenes. Alteration includes extensive sericitization of plagioclase and amphibolitization of some pyroxene.

One dropstone was recovered from Sample 113-692B-6R-1, 2–3 cm, at a depth of 49 mbsf. It is a fossiliferous limestone with ooids. Calcite comprises 98% of the rock, the rest being a mixture of glauconite, muscovite, biotite, and opaque minerals.

The suite of dropstones recovered from Hole 692B differs from dropstones found at Site 689. The latter were made up of igneous intrusive and metamorphic rocks, whereas the former consist of basic volcanics, diabase, and limestone. Volcanic rocks from Site 692 are a puzzle. Although volcanic rocks of late Mesozoic and Cenozoic age crop out on the Antarctic Peninsula (Dalziel and Elliot, 1973), it is unlikely that they would be transported eastward to the Dronning Maud Land margin. A more precise comparison with Jurassic volcanics of the adjacent land area of East Antarctica (e.g., Juches, 1972; Furnes and Mitchell, 1978) must await further study.

PHYSICAL PROPERTIES

Introduction

Due to the unusual nature of the sediments at Site 692 and the high degree of coring disturbance, few physical property measurements were made. The properties were determined only for Core 113-692B-6R and Cores 113-692B-8R through 113-692B-12R.

Index Properties

The bulk density, porosity, water content, and grain density are listed in Table 3. Profiles of bulk density, water content, and grain density are illustrated in Figure 12. A profile of porosity is illustrated in Figure 13.

Bulk densities range from 1.56 to 2.14 g/cm^3 at 60.6 and 85.8 mbsf, respectively. The average bulk density is 1.83 g/cm^3. Porosities range from 58.3% to 48.4% at 78.8 and 69.2 mbsf, respectively. The average porosity is 53.9%. Water content ranges from 57.1% to 35.7% at 60.6 and 85.8 mbsf, respectively. The average water content is 53.8%. Grain densities range from 1.88 to 2.99 g/cm^3 at 69.2 and 85.8 mbsf, respectively. The low value is very low and may reflect the large amount of organic material present. The high value may reflect the presence of pyrite. The average grain density is 2.34 g/cm^3.

Little can be said about the nature of the index properties at Site 692 because of the lack of measurements on undisturbed sediments. One can, however, use the data available to calculate the most probable thickness of sediment removed or the maximum depth of burial of the mudstones recovered in Cores 113-692B-7R to 113-692B-12R.

The examination of Dickinson's (1953) relationship between porosity and depth of burial of shales produces a depth of burial of 80 m for a 53.9% porosity, the average porosity of sediment measured at Site 692.

The use of Hamilton's (1976) relationship between porosity and overburden pressure for terrigenous sediment results in an estimated overburden pressure of 20–30 kg/cm^2 for a porosity of 53.9%. Bryant et al.'s (1981) analysis of cumulative pressure, porosity, and bulk density as a function of depth of burial produces a depth of burial of 300–400 m for an overburden pressure of 20–30 kg/cm^2 and a depth of burial of 250 m for a porosity of 53.8%. A bulk density of 1.82 g/cm^3, the average bulk density of measured sediments at Site 692, suggests a depth of burial of 250 m.

The index properties of Site 692 sediments thus indicate that the amount of sediment removed from the site was approximately 200 m. The range of the depth of burial to account for the porosities at this site are somewhere between 200 and 400 m. The best estimate is 250–300 m. The organic material in the sediment at this site may increase the porosity, thus decreasing the calculated depth of burial. The mudstone may have also ex-

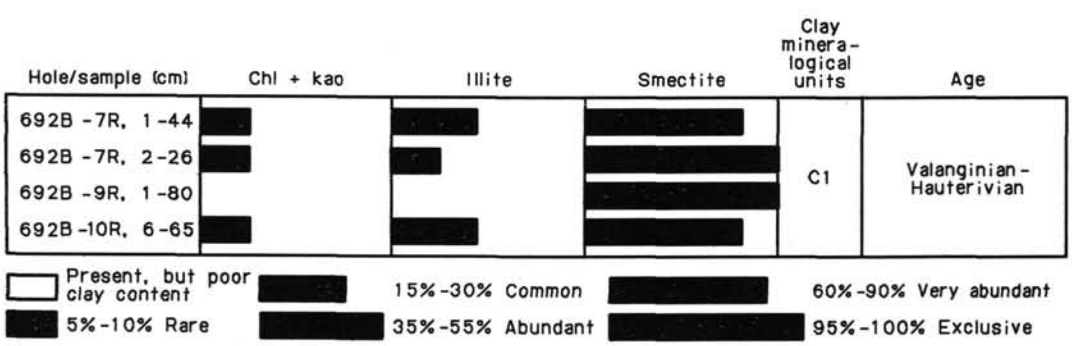


Figure 11. Clay mineralogy, Site 692, Hole 692B. chl = chlorite; kao = kaolinite.

Table 2. Petrographic descriptions of ice-rafted dropstones from Site 692.

Major minerals	%	Accessory minerals	Comments

Rock number: 113-692B-5R-1, 1-4 cm
Name: basalt
Size: 3 × 4 cm
Depth: 40.1 mbsf
Shape: subangular
Weathering: none

Major minerals	%	Accessory minerals	Comments
Plagioclase	55	Olivine	Porphyritic rock with plagioclase-spinel phenocrysts. Saussuritization of plagioclase is extensive, and chlorite fills vesicles and alters shards.
Clinopyroxene	5	Chlorite	
Spinel	10	Talc	
		Epidote	
		Quartz	
		Sphene	

Rock number: 113-692B-5R-1, 8-10 cm
Name: basalt
Size: 3 × 4 cm
Depth: 40.8 mbsf
Shape: subangular
Weathering: none

Major minerals	%	Accessory minerals	Comments
Plagioclase	55	Magnetite-ilmenite	Similar to above sample, but less porphyritic. Same type of alteration.
Clinopyroxene	10	Sphene	
Olivine	1	Quartz	
		Chlorite	

Rock number: 113-692B-5R-1, 21-23 cm
Name: basalt
Size: 3 × 4 cm
Depth: 40.21 mbsf
Shape: subangular
Weathering: none

Major minerals	%	Accessory minerals	Comments
Plagioclase	65	Zeolites	Porphyritic rock. Plagioclase is extensively saussuritized, and spinel is oxidized.
Spinel	35	Chlorite	
		Epidote	
		Sphene	

Rock number: 113-692B-5R-1, 25-27 cm
Name: diabase
Size: 3 × 4 cm
Depth: 40.25 mbsf
Shape: subangular
Weathering: none

Major minerals	%	Accessory minerals	Comments
Plagioclase	55	Hornblende	Porphyritic diabase, phenocrysts are orthopyroxenes and clinopyroxenes. Inverted pigeonite rims some orthopyroxene. Extensive sericitization of plagioclase.
Clinopyroxene	20	Sericite	
Orthopyroxene	20	Quartz	
		Spinel	
		Sphene	

Rock number: 113-692B-6R-1, 2-3 cm
Name: fossiliferous limestone
Size: 3 × 3 cm
Depth: 49.9 mbsf
Shape: subangular
Weathering: none

Major minerals	%	Accessory minerals	Comments
Calcite	98	Glauconite	Small ooids in almost pure limestone.
		Muscovite	
		Biotite	
		Diatoms(?)	
		Opaques	

Table 3. Table of index properties and compressional wave velocities (Hamilton Frame) for Hole 692B.

Index properties

Core, section top (cm)	Depth (mbsf)	Water content (% dry weight)	Porosity (%)	Bulk density (g/cm³)	Grain density (g/cm³)	2-min GRAPE (g/cm³)
113-692B-						
6R-1, 73	50.1			2.08		
7R-2, 15	53.4					1.78
8R-1, 126	60.6	57.11	55.41	1.56	1.96	1.56
9R-1, 110	69.2	45.80	48.42	1.58	1.88	1.48
10R-1, 29	78.8	46.88	58.31	1.87	2.55	1.77
10R-5, 128	85.8	35.66	54.79	2.14	2.99	
12R-1, 20	88.4					1.96
12R-1, 94	89.1	43.01	54.30	1.85	2.52	
12R-1, 123	89.4	43.65	55.51	1.87	2.47	

***P*-wave velocities**

Core, section top (cm)	Depth (mbsf)	Velocity (m/s)
113-692B-		
6R-1, 34	50.1	1677
8R-1, 126	60.6	1750
9R-1, 110	69.2	1658
10R-1, 29	78.8	1739
10R-5, 128	85.8	1768
12R-1, 94	89.1	1762

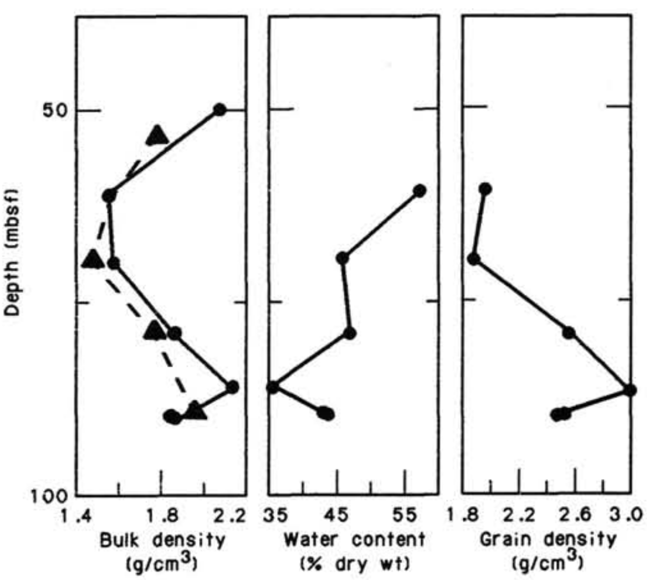


Figure 12. Profile of bulk density (dots = discrete measurements; triangles = GRAPE measurements), water content, and grain density for Hole 692B.

panded due to the release of hydrostatic pressure, increasing the porosity. The organic material may also contribute to an increase in the strength of the clay fabric that would resist the compaction (consolidation) process, resulting in a higher than normal porosity.

An estimated shear strength of about 300 kPa translates to a depth of burial equal to 420 m for hemipelagic and terrigenous clays (Bryant et al., 1981). Even this crude correlation results in a fairly close agreement between the index properties and depth of burial.

Compressional Wave Velocity

The compressional wave velocity (Hamilton Frame) measured on discrete samples ranged from 1658 m/s at 69.2 mbsf to 1768 m/s at 85.8 mbsf (Table 3, Fig. 14). The average measured velocity for the section is 1716 m/s.

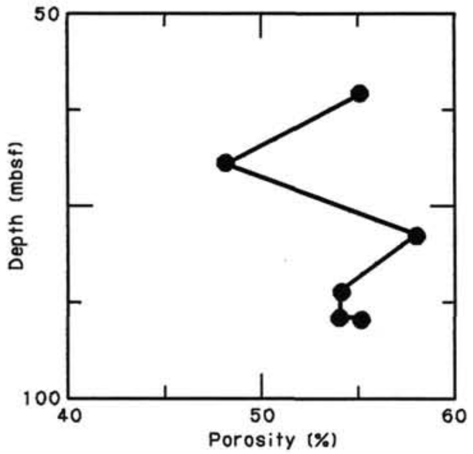


Figure 13. Profile of porosity for Hole 692B.

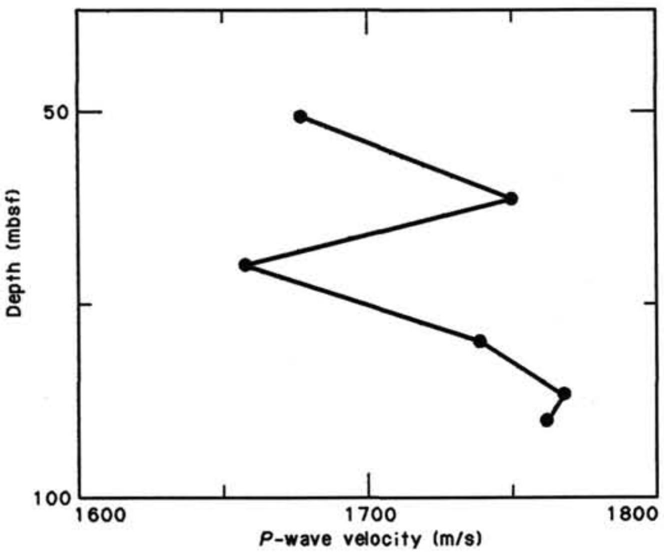


Figure 14. Profile of compressional wave velocity as measured by the Hamilton Frame for Hole 692B.

Summary

The nature of the physical properties at Site 692 is poorly defined because of the absence of measurements in the upper part of the section. Measurements were made on Cores 113-692B-6R through 113-692B-12R. The index properties measured are similar to other mudstones drilled on DSDP legs. Published relationships between the index properties and the depth of burial indicate that the organic-rich mudstones at Site 692 have been subjected to overburden stresses equal to a depth of burial between 250 and 300 m.

SEISMIC STRATIGRAPHY

Seismic stratigraphic aspects of drilling at Sites 691 and 692 are straightforward. The sites were located on one of many West German multichannel seismic reflection profiles (Bundesanstalt für Geowissenschaft und Rohstoffe, Hannover) crossing the Dronning Maud Land margin of East Antarctica, in the eastern Weddell Sea. Site 691 is located at shot point (SP) 820 on profile BGR78-019, and Site 692 approximately at SP 770 on the same profile (Fig. 1). When three attempts to spud-in at Site 691 had failed, we moved onto the shoulder of the canyon to Site 692. The 3.5-kHz profile showing the location of the two sites is Figure 15, and *JOIDES Resolution*'s water-gun profile along the same track is Figure 16. These profiles were acquired during our approach to the drilling area, along a track essentially coincident with that of BGR78-019 (Figs. 2 and 17).

Coring was restricted to only one attempt in each of three holes at Site 691, with only 5 cm recovered. Only 65 cm was recovered in Hole 692A. At Hole 692B a total of 29.3 m of sediment was recovered (exclusive of washed cores) out of 97.9 m drilled. The first six cores of Hole 692B, down to 53.2 mbsf, recovered only 7.1 m, largely gravel and cored sections through cobbles of varying hard-rock lithologies. This lithologic unit was essentially a boulder field located on the upper shoulder of the canyon. At Site 691, located on the canyon floor, we had failed to spud-in to a similar lithology. No measurements were made of the physical properties of samples of this unit. Only five rotary cores, between 53.2 and 97.9 mbsf, sampled the pre-canyon, autochthonous succession in Hole 692B. The recovered sediment was a Lower Cretaceous organic-rich claystone and nannofossil-bearing mudstone. Six measurements of *P*-wave velocity, averaging 1716 m/s, were made on this unit, using the Hamilton Frame method (see "Physical Properties" section, this chapter). No *P*-wave logger measurements were made.

The boulders, rubble, and other unconsolidated material encountered in all of the five holes attempted are poorly imaged in the available seismic profiles. The 3.5-kHz system shows no penetration, so no discrimination can be made between this lithology and any other coarse-grained unconsolidated lithology or consolidated sediment. On the water-gun profile (Fig. 16), the superficial deposits (gravel beds, canyon fill?) and the presumed erosion surface at their base could not be distinguished within the wavetrain of the seabed reflection. (This is puzzling: the water-gun record resembles an air-gun record with a 50-Hz bubble pulse, which it should not do.) Similarly, the separate resolution of the superficial deposits on line BGR78-019 (Fig. 1) is possible only with hindsight and some imagination.

The great interest of the lower, *in-situ* section drilled in Hole 692B lies in the opportunity to calibrate, and test the interpretation of, the extensive multichannel seismic coverage of this margin, of which line BGR78-019 is only a small part. The drilled section does not include a major reflector. It penetrated only an estimated 100 ms two-way traveltime sub-bottom, whereas the shallowest major reflector lies at 160 ms on both water-gun and multichannel records. That reflector has been designated U6 by K. Hinz (pers. comm., 1986) and separates the seismic sequences WS-3B and WS-2 of Hinz and Krause (1982). U6 was considered by Hinz and Krause to represent a late Oligocene hiatus caused by the action of currents related to the opening of Drake Passage. The next prominent reflector higher in the section, U5, thought to be of Miocene age, lies above the level of canyon-cutting at Site 692.

Clearly, the first attempt to interpret the sedimentary history of this margin is incorrect: the presumed Miocene sediments directly above U6 are of Early Cretaceous age. This is not the place to make a second attempt at a comprehensive interpretation, however, beyond the immediate implications for the main aims and tactics of Leg 113 drilling. Site 692 was abandoned partly because of deteriorating hole conditions, but also because it was not addressing the prime aim of drilling (Cenozoic cooling), nor was it any longer an efficient way of reaching the secondary, basement objective. The basal 1200 m of sediment above basement at Site 692 is of Early Cretaceous and Late Jurassic age, assuming a Middle Jurassic age for the basal Weddell Sea unconformity (see Fig. 1 and "Background and Objectives" section, this chapter). The Cenozoic section lies elsewhere. Moreover, assuming that the correlation of reflectors between different reflection profiles is accurate, none of the other drilling options already approved by the Pollution Prevention and Safety Panel before Leg 113 began is located above a particularly thick post-U6 section.

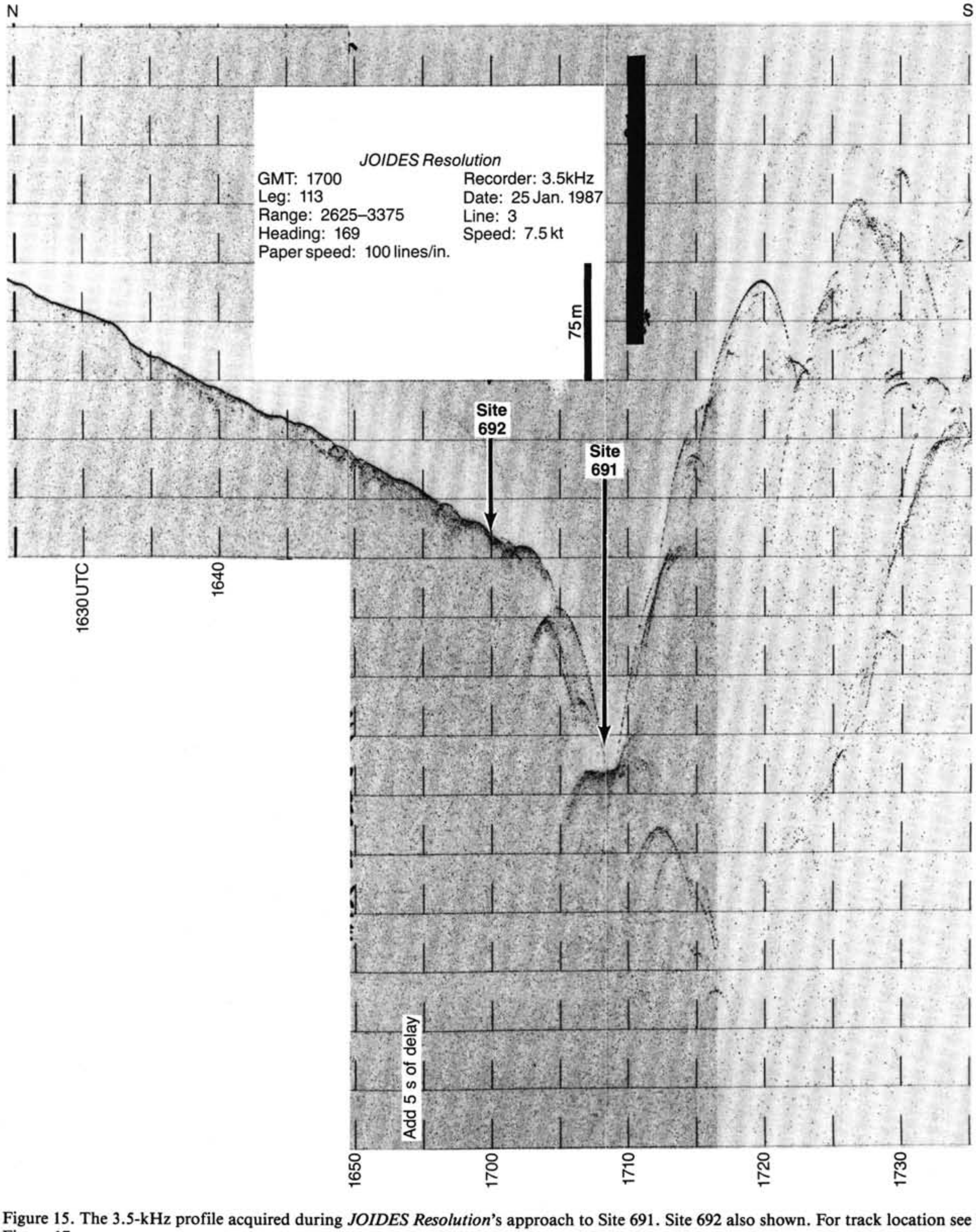


Figure 15. The 3.5-kHz profile acquired during *JOIDES Resolution*'s approach to Site 691. Site 692 also shown. For track location see Figure 17.

BIOSTRATIGRAPHY

Introduction

Site 692 consists of two holes on the flank of a submarine canyon. Hole 692A penetrated 6.7 m into a gravel zone, recovering only 65 cm of Quaternary silty mud. Hole 692B recovered 13 cores and penetrated to a total depth of 97.9 mbsf, with a recovery of 33.11 m. The upper 50 m of Hole 692B consists of Neogene (Fig. 18) diatomaceous clays (Cores 113-692B-1R through 113-692B-3R) and a gravel zone (Cores 113-692B-4R through 113-692B-6R). Very little datable sediment was recovered from the clay interval and none in the gravel zone. Cores 113-692B-7R through 113-692B-12R (53 mbsf to base of hole) consist of Lower Cretaceous organic-rich claystones, mudstones,

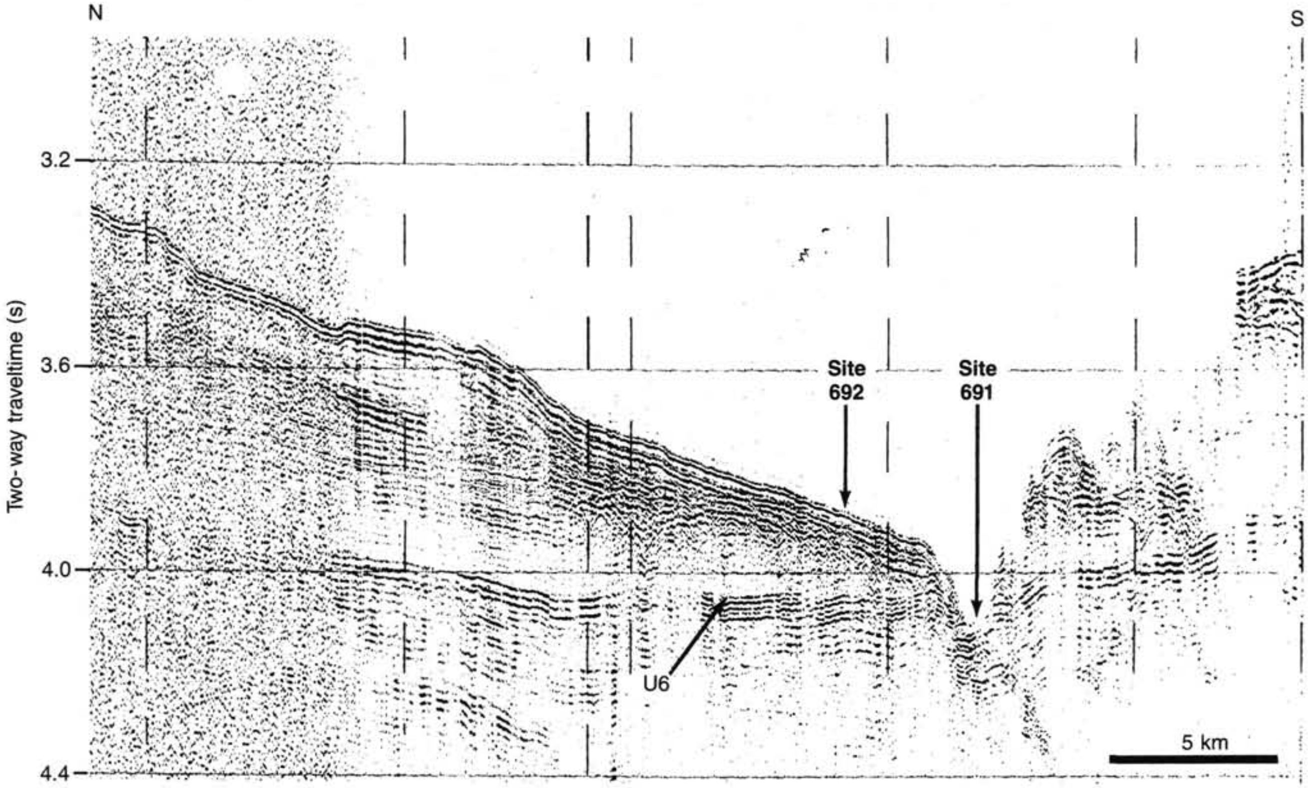


Figure 16. Water-gun profile acquired during *JOIDES Resolution*'s approach to Site 691 (for track location, see Fig. 17). Site 692 also shown.

and chalks. Two wash cores (113-692B-11W and 113-692B-13W) were also taken from this interval. Slightly different age assignments by different microfossil groups and macrofossils make a precise date problematic, but ages obtained from all groups appear to converge on the Berriasian-Valanginian. All depths referred to in the following sections are depths below seafloor, and samples are from the core-catcher (CC) sections unless specified otherwise. Biostratigraphic boundaries are placed midway between overlying and underlying samples. The section is described from the top down.

Planktonic Foraminifers

Planktonic foraminifers are abundant and well-preserved in Quaternary sediments in Holes 692A and 692B. Antarctic forms of *Neogloboquadrina pachyderma* contribute over 99% to the assemblages, with only rare occurrences of *Globigerinita glutinata* and *Globigerina bulloides*. Forms referred to as *Globigerinoides bulloides* are smaller and more tightly coiled than typical temperate forms. Rare occurrences of *N. pachyderma* were noted in Cores 113-692B-2R and 113-692B-3R. In Sample 113-692B-3R, CC, these occur with Pliocene and Miocene diatoms and Cretaceous nannofossils believed to be mixed during coring (see "Diatoms" and "Calcareous Nannofossils" discussions, this section). Therefore, it is unclear whether the planktonic foraminifers observed in these cores are in place or are Quaternary contaminants.

No planktonic foraminifers were observed in core catchers from Cores 113-692B-4R through 113-692B-8R. In Lower Cretaceous Cores 113-692B-7R and 113-692B-8R this may be due to carbonate dissolution after burial. Section 113-692B-9R, CC, within the Lower Cretaceous organic-bearing muddy nannofossil chalk contains rare, well-preserved specimens of *Ticinella* cf. *madecassiana, Heterohelix reussi*, and *Globigerinelloides maridalensis*. These species have been recorded from the lower to middle Albian (*Ticinella primula* Zone to *Biticinella breggiensis–Rotalipora ticinensis* Zones) of southeastern Atlantic DSDP Sites 363 and 364 on the Walvis Ridge (Caron, 1978). They are not, however, recorded from the Albian of Falkland Plateau Sites 327, 330 (Sliter, 1977), or 511 (Krasheninnikov and Basov, 1983), nor from the Albian of southwestern Indian Ocean Sites 256, 257, and 258 (Herb, 1974). Paleogeographic reconstructions of the Atlantic would have all of these sites in relatively close proximity during the Albian (Rabinowitz and LaBrecque, 1979; Lawver et al., 1985), yet *H. reussi* does not occur until the Turonian on the Falkland Plateau and not until the Coniacian in the Southwestern Indian Ocean. The recovery of only one planktonic foraminifer-bearing sample is insufficient to draw any conclusion about paleobiogeographic patterns. Nonetheless, it does provide interesting questions for further investigation. Specifically, why does *H. reussi* occur in the Lower Cretaceous of the Weddell Sea and Southeastern Atlantic but not until much later in the southwestern Indian Ocean and on the Falkland Plateau? Careful examination of the core should reveal other intervals in which planktonic foraminifers are preserved.

Benthic Foraminifers

Benthic foraminifers were studied in Sections 113-692A-1R, CC, 113-692B-1R, CC, through 113-692B-3R, CC, 113-692B-7R, CC, through 113-692B-12R, CC, and some other samples (113-692B-8R-3, 60–62 cm, 113-692B-9R-3, 106–108 cm, and 113-692B-9R-3, 126–128 cm). Sections 113-692A-1R, CC, and 113-692B-1R, CC, contain well-preserved benthic foraminifers (more than 200 specimens). Sections 113-692B-2R, CC, and 113-692B-3R, CC, contain very few (5–10), well-preserved specimens of benthic foraminifers. Sections 113-692B-7R, CC, and 113-692B-8R, CC, are barren; the remaining samples all contain rare benthic foraminifers (see Table 4 for numbers of specimens). Levels with well-preserved calcareous nannofossils con-

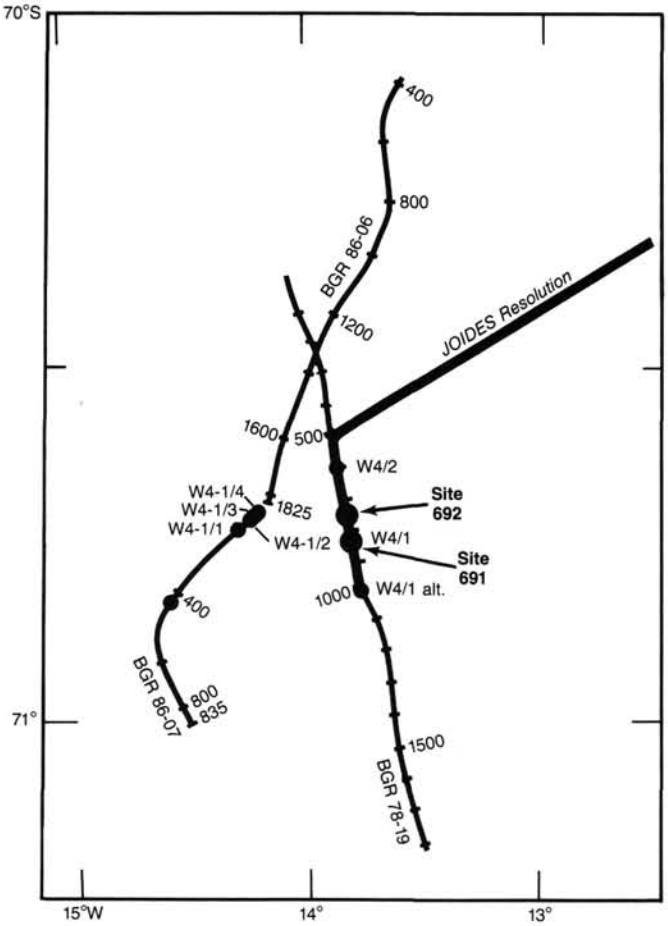


Figure 17. Track chart in area of Sites 691 and 692, showing locations of profile BGR78-019 (Fig. 1) and *JOIDES Resolution*'s approach (arrowed) to Site 691 (Figs. 15 and 16). W4-1/1, etc., are locations of original site transects, all aimed at using the relief of Wegener Canyon (Fig. 1) to reach the deeper parts of the sedimentary succession.

tain the most diverse benthic foraminiferal faunas. All specimens in samples from Core 113-692B-8R and lower are filled with sparry calcite but are not encrusted. Septa could be observed in almost all specimens. The benthic foraminiferal faunas in Sections 113-692A-1R, CC, and 113-692B-1R, CC (Pliocene-Pleistocene), indicate a depth of deposition not significantly different from the present water depth; faunas in samples from Cores 113-692B-8R and deeper (Lower Cretaceous) indicate upper bathyal water depths (maximum depth 500–1000 m).

Sections 113-692A-1R, CC, and 113-692B-1R, CC, contain a fauna similar to the faunas at Sites 689 (mud-line sample) and 690 (mud-line sample and Section 113-690B-1R, CC). The fauna is predominantly calcareous with few agglutinated species and specimens. *Epistominella exigua* is the dominant species (36% in 113-692A-1R, CC; 25% in 113-692B-1R, CC); other common species are *Globocassidulina subglobosa* (8% and 13%), *Nonionella iridea* (4% and 8%), *Angulogerina earlandi* (7% and 22%), and *Stainforthia complanata* (10% and 4%); *Pyrgo murrhyna* is rare (1.5% and 2%). *Nonionella iridea* and *A. earlandi* are absent or very rare at Sites 689 and 690. The differences in the composition of the benthic foraminiferal faunas in the *Neogloboquadrina pachyderma* oozes at Sites 689, 690, and

Table 4. Abundance and diversity of benthic foraminifers, Hole 629B.

Section or sample studied	Number of species	Number of specimens	Dominant forms
113-692B-			
8R-3, 60–62 cm	20	65	Spiral forms
8R, CC	barren	barren	
9R-3, 106–108 cm	9	31	Uniserial forms
9R-3, 126–128 cm	25	152	Spiral forms
9R, CC	1	2	Uniserial forms
10R, CC	12	45	Spiral forms
11R, CC	12	52	Spiral forms
12R, CC	7	14	No spiral forms

692 cannot be evaluated presently, because the precise ages of the different samples are not known; all are probably Pliocene to Quaternary.

Sections 113-692B-2R, CC, and 113-692B-3R, CC, contain very few specimens; most are well-preserved *P. murrhyna*, with a few *Gyroidinoides soldanii* and fragments of agglutinated forms. *Pyrgo murrhyna* has been shown to have a range from the middle Miocene to Recent (Boltovskoy, 1978; Thomas, 1985). The specimens might represent downhole contamination, but this is not probable because *P. murrhyna* is rare in the surface samples and its test is easily damaged.

All samples from Cores 113-692B-8R through 113-692B-12R are either barren or contain rare benthic foraminifers; the faunas have low to moderate diversity (see Table 4 for numbers of species and specimens). Among the most common species are *Citharina harpa, Vaginulinopsis enodis, Lenticulina turgidula, Lenticulina involvens, Saracenaria tsamandroensis, Marginulina bullata, Dentalina communis, Dentalina debilis, Dentalina guttilifera*, and *Nodosaria sceptrum*, all nodosariid species. Other species are *Lagena ovata* (common in Sample 113-692B-9R-3, 126–128 cm), *Globulina prisca* (common in Section 113-692B-11R, CC) and *Eoguttulina biserialis* (rare in Section 113-692B-12R, CC). Similar but more diverse faunas have been described by Luterbacher (1970) from the northeast American continental margin, by Sliter (1980) from the Cape Verde Basin, and by Basov and Krasheninnikov (1983) from the Falkland Plateau. Low-diversity faunas with great resemblance to the Site 692 faunas were described in the Site 249 chapter (Simpson, Schlich, et al., 1974). The faunas at Site 692 are most similar to faunas dated as "Neocomian" (i.e., Berriasian through Hauterivian): typically Aptian and Upper Jurassic forms are absent.

The faunal composition varies considerably between samples: in some samples the uniserial nodosariids dominate, whereas in others the wholly or partially planispiral forms dominate. More samples need to be studied to determine the full range of between-sample variability and evaluate whether changes in the faunas suggest overall changes in environment over the length of the section.

The environment in which the Lower Cretaceous sediments were deposited is debatable, but probably upper bathyal (500–1000 m, with the shallower value more probable). The variability in faunal composition between samples and the occurrence of barren samples in the Lower Cretaceous at Site 692 is probably caused by low (but varying) levels of oxygen in the bottom waters during deposition of the sediments, as documented by the high concentrations of organic carbon (see "Organic Geochemistry" section, this chapter). The environment during deposition of Core 113-692B-7R and the upper parts of Core 113-692B-8R was probably less favorable for benthic foraminifers (lower oxygen levels or lower salinity) than during deposition of the lower cores.

Calcareous Nannofossils

Calcareous nannofossils are common to abundant in some intervals of the Lower Cretaceous sediments of lithostratigraphic Unit III. In general, coccoliths are present in the lighter brown claystones but are absent or rare in the darker intervals. Preservation is good where coccoliths are abundant, but is often poor (etched or overgrown) in the nannofossil-lean intervals.

Cretaceous nannofossils were first encountered in Sample 113-692B-3R-1, 50 cm (Unit I), where few but well-preserved *Watznaueria* were noted in a green clay matrix. As drilling at this point was proceeding with difficulty into a Neogene "gravel zone" of glacial erratics, these *Watznaueria* are presumed to be reworked. No nannofossils were recovered in the next three cores.

Core 113-692B-7R contained a dark claystone which yielded abundant *Watznaueria* in Sample 113-692B-7R-2, 75 cm, but no other identifiable taxa. Most of the specimens are heavily overgrown with calcite, and no zonal age assignment can be given this core. The lithology, however, is quite similar in most respects to the pre-Albian Lower Cretaceous sediments drilled on the Falkland Plateau at Sites 327, 330, and 511.

Better preserved and more diverse assemblages were present in the next core taken. Sample 113-692B-8R-1, 30 cm, contained a sparse assemblage consisting of abundant *Watznaueria barnesae*, few *W. britannica*, common *Vekshinella stradneri*, and *Zeugrhabdotus embergeri*. Not present in the sample, however, are nannoconids or the middle Aptian zonal marker *Lithastrinus floralis*. The sample, therefore, is older than late Aptian.

Preservation is good and nannofossils common to abundant in Sample 113-682B-8R-3, 60 cm. Fragments of the pentalith, *Micrantholithus hoschulzi*, are abundant, as are forms identified as *Crucibiscutum salebrosum*, a diagnosis which has been confirmed via electron microscopy (J. Muttenlose, written comm., 1987). *Cretarhabdus conicus* and *Watznaueria ovata* are common. The assemblage is little changed from this sample down through Core 113-692B-10R, and resembles those of the *Crucibiscutum salebrosum* Subzone of Wise (1983) (lower Aptian to Barremian) from the Falkland Plateau, but could well be older. Jakubowski (1987) shows that *C. salebrosum* ranges as high as the lower Barremian, but that its abundance peak in the North Sea is in the Valanginian to Hauterivian.

Core 113-692B-11W is a wash core taken after the pipe was raised about 30 m to remove knobby joints. The interval was redrilled through cavings and should have bottomed at the same depth as Core 113-692A-10R (88.2 mbsf). About 2.8 m of a coherent Cretaceous claystone sequence was recovered, however, in which the nannofossil assemblage differed somewhat from those of the previously examined material. *Cyclagelosphaera margereli*, not previously noted, is abundant and micrantholith fragments are essentially absent.

The next core, 113-692B-12R, lacked micrantholith fragments and contained a single specimen of *Ethmorhabdus gallicus* (or *Cribrosphaerella hauteriviana*) and another of *Cruciellipsis cuvillieri*. Subsequent shore-based work has revealed other specimens of these taxa (J. Mutterlose, written comm., 1987). The Upper Jurassic index species, *Stephanolithion bigotii*, was not observed. There are no comparable well-dated assemblages of this nature from the Falkland Plateau, but *C. cuvillieri* ranges from the lower Berriasian into the upper Hauterivian (Perch-Nielsen, 1985).

The last core from the hole, 113-692B-13W, was a wash core taken to clean the hole to the depth reached by Core 113-692B-12R (97.2 mbsf). It recovered 1.57 m of drill cuttings and "pebbles" of Lower Cretaceous claystone rounded by drilling. Several of the latter were examined, and all contained uphole nannofossil assemblages similar to those from Core 113-693B-10R.

In summary, the nannofossil assemblages coupled with their host lithology represent a succession somewhat reminiscent of that drilled in the pre-upper Aptian Cretaceous of the Falkland Plateau. This restricted environment has been summarized by Thompson (1977), Wise et al. (1982), and other authors in the DSDP Legs 36 and 71 *Initial Reports*. The ages of these units are not well controlled, however, and further work needs to be done to establish a better Neocomian nannofossil stratigraphy for the Southern Ocean region. The presence of *Cruciellipsis cuvillieri*, however, constrains the base of the hole to the Berriasian–upper Hauterivian.

Diatoms

Hole 692A

Section 113-692A-1R, CC, contains few, poorly preserved diatoms including *Nitzschia kerguelensis, N. curta, Eucampia balaustium, Thalassiosira lentiginosa*, and *Thalassiothrix longissima*, suggesting a Quaternary (undifferentiated) age. An additional sample, taken from 113-692A-1R-1, 50 cm, contained, in addition to the above taxa, *Schimperiella antarctica*. The absence of *Actinocyclus ingens* from this section suggests a late Quaternary age (younger than 600,000 years) for this core.

Hole 692B

Section 113-692B-1R, CC, contains rare, poorly preserved diatoms. Those species that were identifiable included *Nitzschia kerguelensis, Actinocyclus actinochilus*, and *Thalassiothrix longissima* and indicate a Quaternary (undifferentiated) age. Sections 113-692B-3R, CC, to 113-692B-13W, CC, were barren of any diatoms. We examined a number of samples between core catchers in Cores 113-692B-2R and 113-692B-3R and found rare to common diatoms. Sediment chips picked from Sample 113-692B-3R-1, 38–42 cm, contain common, moderately well to well-preserved diatom assemblages including *Nitzschia kerguelensis, N. ritscheri, Eucampia balaustium, Thalassiosira torokina, Rhizosolenia barboi, Coscinodiscus deformans, Nitzschia praeinterfrigidaria, Nitzschia angulata*, and *Rouxia* sp. A. Although some downhole contamination is apparent, the bulk of the diatoms indicates an early Pliocene age. Another sediment chip within this sample interval yielded a few lowermost Pliocene to Miocene diatoms including *Denticulopsis hustedtii* and *D. lauta*.

Sample 113-692B-3R-2, 50 cm, also contains specimens of *Denticulopsis hustedtii* and *Eucampia antarctica*. In Sample 113-692B-3R-3, 140 cm, we found few to common diatoms, including *N. kerguelensis, N. angulata, D. hustedtii, A. actinochilus*, and *E. antarctica*. Note that diatoms were found only in the unconsolidated sediment and sediment chips. No diatoms were observed in the underlying Cretaceous sediment which occurs at approximately 50 mbsf.

Discussion

Despite the fact that diatoms were observed only in the unconsolidated sediment and sediment chips overlying the Cretaceous, we can derive a rough stratigraphy and, within very broad limits, date the sediment and the underlying unconformity. Although we find undifferentiated Quaternary near the sediment/water interface, the underlying sediment, above the unconformity, is at least Neogene in age. Specifically, the diatom-bearing sediment chips present in Core 113-692B-3R can be assigned to the lower Pliocene *Nitzschia angulata* Zone, the *Denticulopsis hustedtii* Zone (middle late Miocene–earliest Pliocene), and to the *D. hustedtii–D. lauta* Zone (late middle Miocene to early late Miocene). Thus, the initiation of the unconformity and subsequent canyon cutting must have predated, at least, the early late Miocene (about 9 Ma).

Radiolarians

Radiolarians from Section 113-692A-1R, CC, are rare but well preserved. Only a few species were seen, including the Pliocene/Pleistocene indicators *Antarctissa strelkovi* and *Antarctissa denticulata*.

Section 113-692B-1R, CC, contained *A. denticulata* and *Cycladophora davisiana*, indicating a late Pliocene or Pleistocene age. Section 113-692B-2R, CC, contains only a few unidentifiable radiolarian fragments. Cores 113-692B-3R through 113-692B-6R were not examined for radiolarians. Radiolarians from Sections 113-692B-7R, CC, and 113-692B-8R, CC, are rare and poorly preserved. Broken specimens of *Prunopyle hayesi, Cornutella* sp., *Dendrospyris stabilis*, and *Peripyramis* sp. were seen, suggesting a Neogene, and probably Miocene, age. These samples, however, have been dated by other means as Early Cretaceous, suggesting that the radiolarians are downhole contaminants. Sections 113-692B-9R, CC, through 113-692B-13W, CC, contain rare, poorly preserved radiolarians which could not confidently be identified even to genus level. However, they are clearly Mesozoic morphotypes, and may possibly belong to the genera *Amphipyndax, Dictyomitra*, and *Cryptamphorella*. The silica in these specimens appears to have been replaced by carbonate. No age can be assigned to these samples based on the radiolarians.

Palynology

The upper part of Hole 692B consists of Neogene glacial boulders, sand, and clay, and yields a reworked palynomorph assemblage in the clay-rich parts. The underlying sequence of organic-rich sediment (up to 18%) is dated as Lower Cretaceous and also contains palynomorphs.

In Section 113-692B-3R, CC (upper Miocene or younger), a well-preserved reworked Mesozoic and Tertiary palynomorph assemblage was observed. This flora is composed of dinoflagellate cysts and sporomorphs. The cyst species *Kallosphaeridium capulatum* (range: lower-upper Oligocene) was reported from the lower Oligocene of the Falkland Plateau by Goodman and Ford (1983). The spore genera *Cycadopites, Gleicheniidites*, and *Dictyophyllidites* occur worldwide from the Mesozoic to the Cenozoic, and also suggest reworking from the Jurassic and/or Cretaceous. The conifer *Podocarpus* (*Podocarpidites*) is the most common pollen type in this sample and has the same range. Two angiosperm pollen grains belonging to *Nothofagus* (*Nothofagidites*, Upper Cretaceous–Recent) and to *Ilex* (*Ilexpollenites*, Paleocene-Recent) were also recognized.

Cores 113-692B-7R through 113-692B-12R contain a mixed flora of sporomorphs, dinocysts, acritarchs, and tasmanitids of Early Cretaceous age. In Core 113-692B-7R sporomorphs predominate (*Callialasporites, Cycadopites, Cyathidites, Osmundacidites wellmanii, Lycopodiumsporites, Cicatricosisporites*, and *Podocarpidites*), but they are probably partly reworked from Upper Jurassic strata. From Core 113-692B-8R down marine organic matter predominates. The species *Canningia* sp. A (Morgan, 1980) and *Dingodinium cerviculum* are indicative of Neocomian to Aptian age. In Section 113-692B-9R, CC, *Tasmanitids, Leiosphaeridia, Pterospermella, Lesanella*, and other acritarch genera are common. The same taxa were observed by Harris (1976) in the Lower Cretaceous of the Falkland Plateau. In Section 113-692B-10R, CC, *Aptea polymorpha* (Lower Cretaceous) is present. In Sections 113-692B-11W, CC, and 113-692B-12R, CC, the preservation is very poor and no genera could be determined.

The organic matter is immature, with a thermal alteration index of approximately 1.5, indicated by the yellow color of the palynomorphs. The reworked vitrinite particles and sporomorphs of Late Jurassic(?) age are darker and indicate an alteration index of more than 2.

Molluscs

The Lower Cretaceous black claystones contain a number of molluscs that are being investigated in a shore-based study. These include buchiid bivalves from Sample 113-692B-10R-2, 99–102 cm, plus an inoceramid from Sample 113-692B-10R-1, 118–126 cm, which bears some resemblance to Berriasian-Valanginian forms from the Antarctic Peninsula. Serpulid worm tubes, a poorly preserved belemnite, and winnowed shell fragments are also present. A single ammonite centered directly at Sample 113-692B-10R-2, 42 cm, has affinities with the Spiticeratinae. Such ammonites show their maximum development in the upper Tithonian and Berriasian, although they may range as high as the Valanginian. In Antarctica, spiticeratids occur in both the South Shetland Islands and Alexander Island, where they are Berriasian in age.

Summary

Site 692 consists of two holes on the flank of a submarine canyon. Hole 692A penetrated 6.7 m into a gravel zone, recovering only 65 cm of Quaternary silty mud. Hole 692B recovered 13 cores and penetrated to a total sub-bottom depth of 97.9 m.

The upper 50 m of Hole 692B consists of Neogene (Fig. 18) diatomaceous clays (Cores 113-692B-1R through 113-692B-3R) and a gravel zone (Cores 113-692B-4R through 113-692B-6R). Very little datable sediment was recovered from the clay interval and none in the gravel zone. Core 113-692B-1R is of Quaternary age based on diatoms. Cores 113-692B-2R and 113-692B-3R contain microfossils from several different age intervals, including reworked Mesozoic and Tertiary nannofossils and palynomorphs, and late Neogene radiolarians, planktonic, and benthonic foraminifers. Presumed *in-situ* sediment chips from this interval contain Pliocene and upper middle to lower upper Miocene diatom assemblages and middle Miocene or younger benthic foraminifers. The onset of canyon formation is thus no younger than early late Miocene.

Cores 113-692B-7R through 113-692B-12R (53 mbsf to base of hole) consist of Lower Cretaceous organic-rich claystones, mudstones, and chalks. Two wash cores (113-692B-11W and 113-692B-13W) were also taken from this interval. The samples examined from these cores are barren of diatoms. Radiolarians occur as carbonate molds and can only be identified as belonging to genera of Cretaceous age. Benthic foraminifers suggest a Neocomian (Berriasian through Hauterivian) age. Calcareous nannofossils and palynomorphs, while not abundant, suggest a Berriasian through Barremian age for the recovered sediments. Slightly different age assignments by different microfossil groups make a more precise date for this interval somewhat problematic at the present time. Nannofossils date Core 113-692B-8R as prelate Aptian, and Cores 113-692B-9R through 113-692B-12R as Neocomian. The core-catcher material of the latter core is early Berriasian to late Hauterivian in age. A similar, though somewhat broader, age assignment is provided for these cores by benthic foraminifers and palynomorphs. Planktonic foraminifers, however, would suggest an early to middle Albian date for Section 113-692B-9R, CC, based on similarities to faunas described from the Walvis Ridge, but the possibility is strong that this core catcher contained downhole cavings from higher strata not recovered during the difficult process of drilling this hole. Further constraints on the age of the sequence will be placed by shore-based work on the molluscan faunas. The age assigned to an ammonite in Sample 113-692B-10R-2, 42 cm, is upper Tithonian to Valanginian.

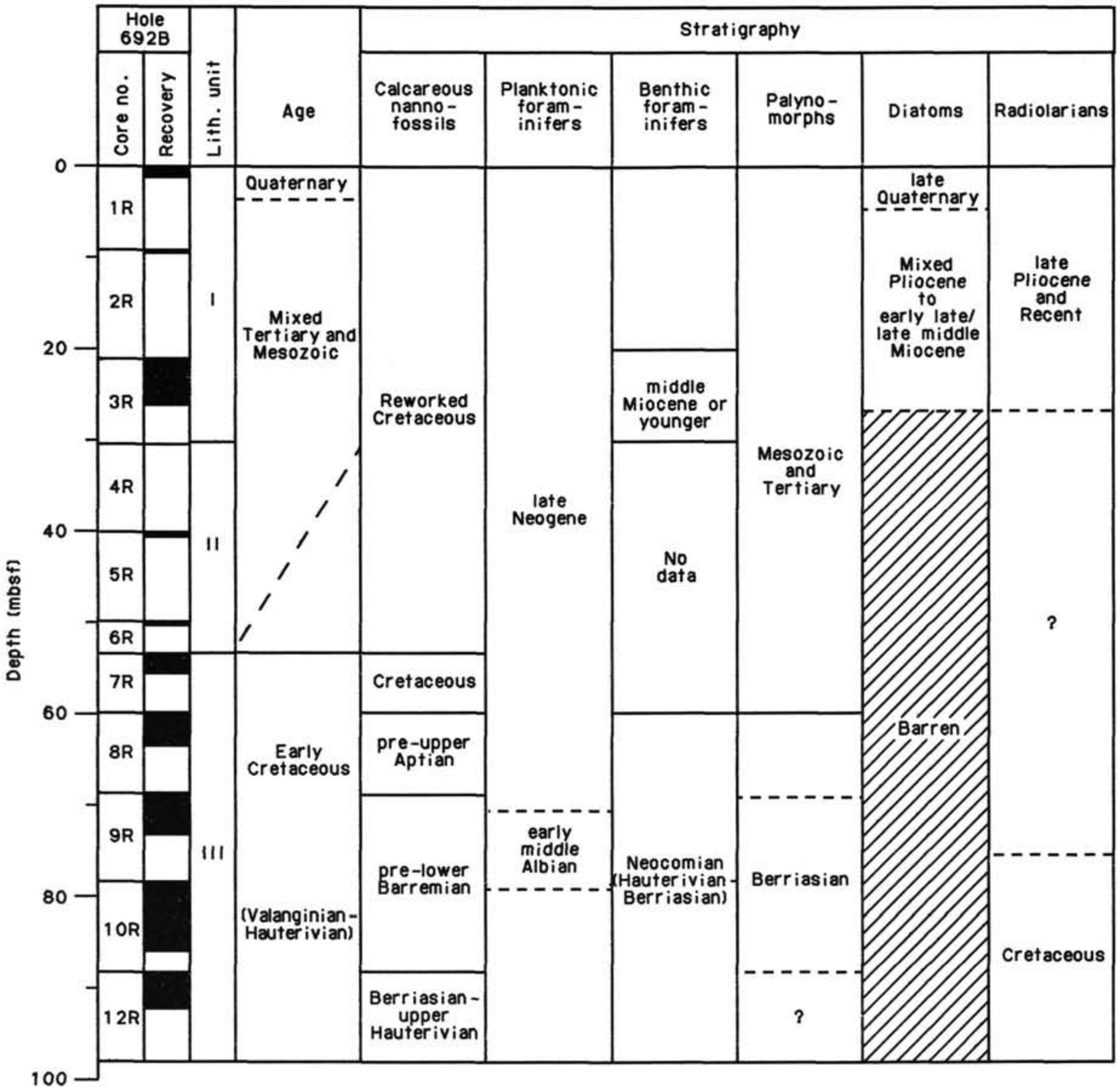


Figure 18. Biostratigraphic summary of Site 692. Lithologic units shown are described in "Lithostratigraphy" section, this chapter. Age column shows ages and boundaries based on combined data from all relevant microfossil groups. The location of the boundary between the Tertiary and Cretaceous is uncertain as there was no recovery in lithologic Unit II (30.4–53.2 mbsf), and is shown as a sloping dashed line.

The high organic carbon content and low abundance and diversity of benthic foraminifers in the Cretaceous sediments indicate that oxygen concentrations and/or salinity at the sediment surface were low and variable.

Site 692 drilled too short a section to permit computation of sedimentation rates.

Discussion

In the absence of prior drilling in the region, geophysical data were used to predict that Site 692 would recover Tertiary, and particularly Paleogene, sediments. The unexpected Early Cretaceous age for the youngest sediments underlying the upper Neogene sediment veneer will thus require reassessment of the geologic interpretation of the history of this region. A precise determination of the age of the oldest sediments will require considerable additional shore-based research. At present, the ages given to Section 113-692B-12R, CC (base of the hole) by palynomorphs, calcareous nannofossils, and molluscs seem to converge on the Berriasian-Valanginian.

PALEOMAGNETISM

Introduction

Site 692 is the first ODP site to be successfully drilled on the continental margin off Antarctica. It is situated on the outer shoulder of a deeply dissected canyon ("Wegener Canyon") located some 87 km northwest of Kapp Norvegia, Dronning Maud Land. Paleomagnetic investigations would have had a key role if the planned objective to penetrate to the seaward-dipping reflector sequence ("Explora Wedge") been achieved. The discovery of organic-rich sediments of Cretaceous age at a sub-bottom depth of 53 m, below a major unconformity, presented an unexpected sequence for paleomagnetic study.

Sampling and Measurement

We limited our sampling of the Cretaceous mudstone sequence to a reconnaissance basis of normally one minicore sample per core section in the absence of any estimate of sedimentation rate. Hence we obtained 21 samples for measurement. All samples are magnetized sufficiently strongly to be reliably measured on the Molspin magnetometer, having natural remanent magnetization (NRM) intensities in the range 0.6–4.0 mA/m.

A partial pilot alternating field (AF) demagnetization of Sample 113-692B-10R-4, 46–48 cm, shown in Figure 19, indicates that the mudstones have good magnetic stability. The remanent magnetization vector of this sample retains its normal polarity throughout demagnetization. It has a median destructive field (MDF) of 8.0 mT and an inclination of −63° at the final demagnetizing field value of 20 mT. NRM measurement of all the remaining samples (Cores 113-692B-7R through 113-692B-12R) presented in Figure 20 reveals that the sequence is apparently normally magnetized with a mean vector inclination of −69°.

Conclusion

Assignment of the polarity results for the organic-rich sediment sequence at Site 692 must necessarily remain speculative until further demagnetization studies are completed and even then could prove inconclusive because of the limited recovery and sampling. If the interval proves to be entirely part of a normal magnetozone, and accepting the validity of the biostratigraphic control, then placement in the older part of Chron 34N is indicated.

The Mesozoic M anomaly sequence represents a time interval of mixed polarity that ended in late Barremian times (Anomaly M-0, DNAG timescale; Palmer, 1983). Our initial interpretation of normal polarity for the sediments of the oldest core recovered at this site implies that these sediments are unlikely to be older than pre-Aptian in age. It is important to emphasize, however, that if sedimentation rates are high then the sequence might equally be correlated with one of the normal polarity intervals within the younger part of the mixed polarity zone.

The single demagnetization result implies that a stable endpoint has been reached. Therefore, assuming that this records a primary characteristic magnetization, acquired at or soon after deposition, then the inclination value can be used to deduce a paleolatitude of approximately 43°S for the site during the interval of mudstone deposition. This paleolatitude is consistent with the position of Antarctica in the Early Cretaceous (Anomaly M-1 times) given by the reconstructions of Norton (1982). Confirmation of this result must await further shore-based magnetic cleaning of the entire sample suite.

ORGANIC GEOCHEMISTRY

Hole 692B was drilled on a shoulder of Wegener Canyon off Kapp Norvegia in the eastern Weddell Sea. No samples were obtained for geochemical analysis above 53.2 mbsf, at which depth a sequence of brownish-black Lower Cretaceous sediments was encountered. The sequence is extremely rich in organic carbon which occurs as amorphous, hydrogen-rich Type II kerogen (Tissot et al., 1974; Espitalié et al., 1977). The sequence comprises a potential petroleum source rock of remarkably high quality. Analytical data are provided in Tables 5–8.

Headspace Analyses

Both methane and ethane concentrations are low (Table 5), as at previous sites. However, a major difference is evident. The light hydrocarbons at Hole 692B are clearly of thermogenic origin.

Analytical

Ungraded rock fragments of 1–5-mm intercept were sealed in Hewlett-Packard headspace vials and maintained at 70°C for minimally 1.5 hr. The volume of fragments was determined by weight and density. One-milliliter volumes of headspace gas were analyzed on the HP Natural Gas Analyser system. Methane in laboratory air was monitored to provide background correc-

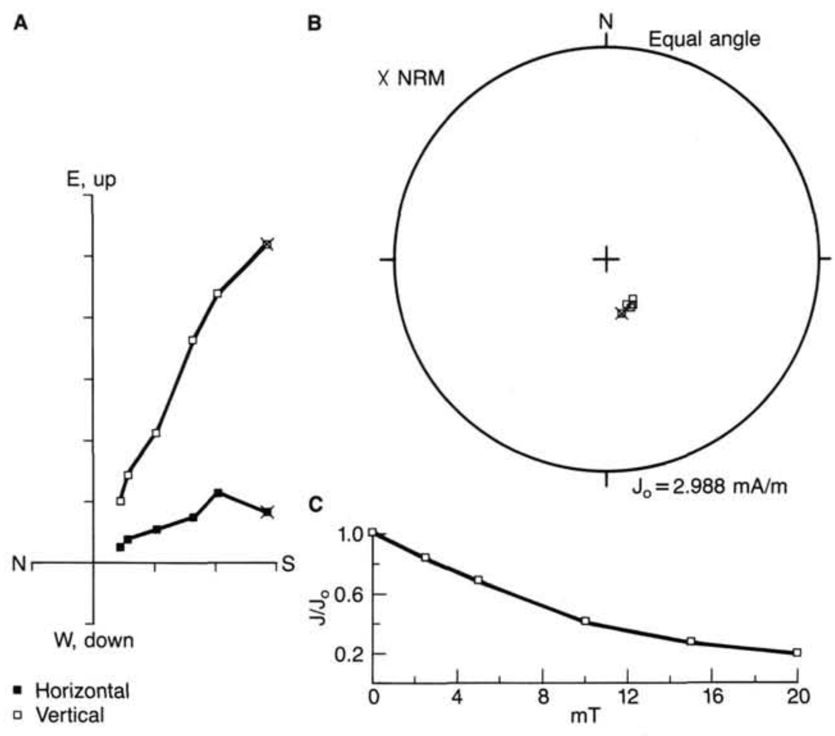


Figure 19. Alternating field demagnetization of Sample 113-692B-10R-4, 46–48 cm. A. Zijderveld orthogonal vector plot. B. Equal area stereographic projection of resultant vector. C. Normalized intensity decay curve.

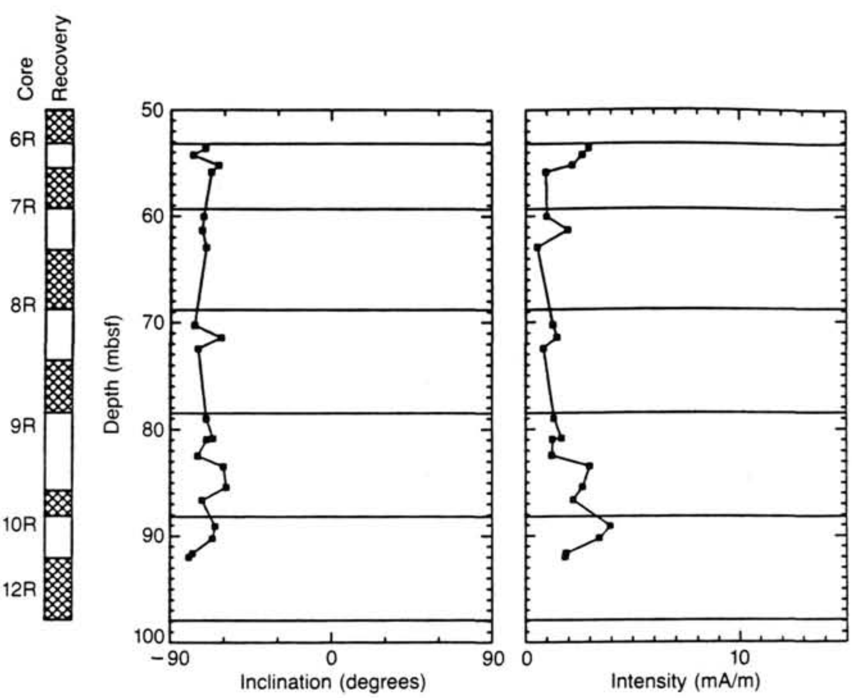


Figure 20. NRM inclination and intensity variation in the organic-rich mudstone sequence recovered in Cores 113-692B-7R through 113-692B-12R.

tions. The mean level was 3.0 ppm, based on Standard 1. Observed hydrocarbon concentrations (parts per million by volume) were converted to a rock volume basis by multiplication by the ratio of headspace volume to that of sediment.

Discussion

The catagenetic origin of the light hydrocarbons is evident from the wide molecular weight spectrum. Compounds through *n*-butane occur at moderate levels, and such can only be generated by the thermal alteration of kerogen. Heavier compounds are no doubt present, but are not detectable because of the very limited sensitivity of the analytical system. A cryogenic method of concentrating light hydrocarbons is required for improvement of sensitivity.

The ratio of *n*-butane/isobutane decreases in a regular curvilinear fashion with depth, possibly a diffusion-controlled process, with loss of the most mobile species, isobutane, at the unconformity above the Cretaceous section. Diffusion processes of similar scale have been observed previously (Thompson, 1979). Adopting this interpretation, the quoted ratio in the deeper samples can be employed as an approximate maturity indicator. Values less than unity, as occurs at 89.51 mbsf, are indicative of immature sediments.

Hydrocarbon levels were sufficiently low to ensure safe drilling conditions. However, it is not rare for immature petroleum source sequences to produce petroleum, evidently by intraformational migration from deep in the basin. Instances are found in the Santa Barbara Channel (California) and the Williston Basin (Saskatchewan); an analogous process is suggested by the occurrence of vein asphalt in the immature Cretaceous "black shales" (nannofossil marls) of Site 535, Leg 77. However, at Site 692 the occurrence of an excess of isobutane over *n*-butane strongly indicates the indigenous nature of the light hydrocarbons. Petroleum liquids almost invariably exhibit the converse condition, characteristic of mature sources.

Rock-Eval Analyses

Rock-Eval data were obtained from a suite of 29 samples from the Lower Cretaceous section between 53.2 and 97.9 mbsf (Table 6), a thickness of 44.7 m. Of this, 22.1 m (exclusive of washed cores) were recovered, or 50%. A statistical summary is provided in Table 7.

The lowest carbon value in the table represents one of the carbonate-rich volcanic ash lenses in the section, in this instance from Sample 113-692B-9R-2, 55–56 cm. These lenses are oblate spheroids, as large as 5 cm across and 1 cm thick, which load-

Table 5. Low-molecular-weight hydrocarbon determinations by headspace analysis, Hole 692B.

Core, section, interval (cm)	Depth (mbsf)	Methane	Ethane	Propane	iso-butane	*n*-butane	C_{6+}	Methane/ ethane	*n*-butane/ isobutane
		μL (HC)/L (sediments)							
113-692B-									
7R-1, 93–94	54.13	44.7	5.6	—	—	—	—	7.9	—
8R-2, 19–23	60.99	51.5	7.4	9.8	17.2	19.6	120	7.0	1.14
9R-1, 143–146	70.23	27.2	24.2	24.3	21.3	16.9	498	1.1	0.79
11W-1, 149–150	[a]87	31.6	[b]25	21.4	19.7	12.1	494	—	0.61
12R-1, 131–132	89.51	32.5	5.7	4.8	10.0	5.4	302	5.7	0.54

[a] Estimated.
[b] Ethane calculated from peak height.

Table 6. Rock-Eval data, Hole 692B.

Core, section, interval (cm)	Depth (mbsf)	TOC (%)	Carbonate (%)	S_1 mg(HC)/g(rk)	S_2 mg(HC)/g(rk)	S_3 mg(CO_2)/g(rk)	HI mg(HC)/g(C)	OI mg(HC)/g(C)	T_{max} (°C)
113-629B-									
7R-1, 47–48	53.67	10.72	3.75	1.77	58.75	2.04	548.0	19.0	409
7R-1, 93–94	54.13	11.24	8.42	0.93	57.21	3.30	509.0	29.4	416
7R-1, 115–116	54.35	6.30	0.83	1.04	29.18	1.28	463.2	20.3	416
7R-2, 42–43	55.12	9.76	3.75	1.20	50.12	2.30	513.5	23.6	413
7R-2, 112–113	55.82	16.82	22.60	1.97	58.66	4.63	348.8	27.5	402
8R-1, 46–47	59.76	10.32	3.42	1.18	57.01	2.89	552.4	28.0	408
8R-1, 71–72	60.01	8.99	8.92	1.16	48.65	2.67	541.2	29.7	412
8R-1, 131–132	60.61	18.41	25.10	3.21	99.34	5.22	539.6	28.4	406
8R-2, 30–31	61.10	1.95	32.11	0.44	8.74	2.07	448.2	106.2	419
8R-2, 116–117	61.96	7.42	41.12	1.06	43.76	3.20	589.8	43.1	412
8R-3, 126–127	63.56	9.51	12.43	1.19	55.27	3.38	581.2	35.5	411
9R-1, 32–33	69.12	11.76	41.87	1.06	58.71	3.45	499.2	29.3	407
9R-1, 118–119	69.98	17.38	3.09	2.13	90.28	3.40	519.5	19.6	404
9R-1, 143–146	70.23	6.73	5.67	0.60	38.64	1.91	574.2	28.4	413
9R-2, 52–53	70.82	8.67	15.68	1.04	46.89	2.76	540.8	31.8	410
9R-2, 55–56	70.85	0.96	22.19	0.19	3.06	1.75	318.8	182.3	425
9R-2, 143–144	71.73	6.00	3.42	0.54	28.56	2.21	476.0	36.8	422
9R-3, 35–36	72.15	5.96	22.69	0.48	30.05	2.56	503.9	43.0	418
9R-3, 122–123	73.02	11.25	4.42	1.14	59.48	2.80	528.7	24.9	413
10R-1, 42–43	78.92	8.30	35.11	0.69	46.29	2.86	557.7	34.5	417
10R-1, 116–117	79.66	8.20	23.35	0.73	44.78	2.58	546.1	31.5	415
10R-2, 51–52	80.51	11.68	32.78	1.14	52.03	3.35	445.5	28.7	412
10R-2, 113–114	81.13	8.43	13.93	0.87	39.96	3.02	474.0	35.8	409
10R-5, 128–129	85.78	5.89	32.03	0.61	27.79	2.19	471.8	37.2	411
12R-1, 28–29	88.48	6.35	2.67	0.94	34.66	2.14	545.8	33.7	416
12R-2, 36–37	90.06	5.09	3.00	0.86	23.32	2.46	458.2	48.3	419
12R-2, 110–111	90.80	5.44	18.85	0.53	25.74	3.50	473.2	64.3	411
12R-3, 44–45	91.64	5.54	23.27	0.82	27.42	3.38	495.0	61.0	414
12R-3, 99–100	92.19	4.35	31.44	0.49	22.17	3.37	509.7	77.5	418

cast the sediment. Their pale olive yellow color suggests the presence of hydrated ferric oxide, and they contain oxidized kerogen. Both features suggest that they are allochthonous to the highly reducing environment of the site. They are possibly pumiceous ejectamenta (see "Lithostratigraphy" section, this chapter).

Organic Carbon

Total organic carbon (TOC) averages 8.6%, exceptionally high for marine shales, and in excess of that of most North American petroleum source rocks such as the Woodford, Phosphoria, and Monterey Formations, which average less than 5%. Analyses were carried out by determining the difference between total and carbonate carbon levels, measured by coulometric means. Data obtained from the Rock-Eval system yielded erratic values of hydrogen index (HI), therefore the coulometric data were adopted. Comparative values are shown in Table 8.

Kerogen

The kerogen in the section is of Type II, according to the designations of Tissot et al. (1974), and Espitalié et al. (1977), and is therefore interpreted as derived from marine planktonic lipids. This preservation required the presence of anoxic bottom waters, further indicated by the abundance of framboidal pyrite (see "Lithostratigraphy" section, this chapter). Hydrogen and oxygen index (OI) values are plotted in Figure 21, which also shows the standard catagenetic pathways for kerogens of Types I, II, and III. Those data points which extend toward HI values less than 500 and OI values greater than 50 are indicative of partial, and progressive, oxidation of the kerogen and therefore of the depositional site. The value at 318.8, HI, and 182.3, OI, represents one of the lenses. Evidently, therefore, these contain substantially oxidized planktonic kerogen.

Table 7. Summary data representing 29 analyses of Lower Cretaceous shales, Hole 692B.

Parameter	Minimum	Maximum	Mean	Standard deviation
Organic carbon (%)	1.95	18.41	8.60	4.11
Hydrogen index (mg HC/gC)	318.8	589.8	502.5	61.6
Oxygen index (mg CO_2/gC)	19.0	182.3	42.7	32.7
S_1 (mg HC/g(rock))	0.44	3.21	1.03	0.61
S_2 (mg HC/g(rock))	3.06	99.34	43.67	20.85
T_{max}	402	425	413	5.0
Calcium carbonate (%)	2.67	41.87	17.17	12.97

Maturity

The T_{max}, HI, and OI values indicate that the section is at an early stage of catagenesis. Equivalent levels of vitrinite reflectance (R_o) are not calibrated at the observed low values of T_{max}, which average 413°C. An equivalent of R_o = 0.2% or less may be inferred.

Petroleum Potential

The penetrated Cretaceous section comprises potential petroleum source rocks of excellent quality. Should there exist laterally equivalent sediments of equal organic quality, buried to an equivalent vitrinite reflectance of approximately 0.85%, they will have released large volumes of petroleum. The developers of the Rock-Eval system, and others at the Institut Francais de Petrole, denote source potential in kilograms of hydrocarbons (HC) per ton of rock. At Site 692 the total which can be generated (S_1 + S_2) equals 44.7 mg HC per gram of rock, or 44.7 kg/ton.

Tissot et al. (1974) compiled analytical data on Cretaceous "black shales" at nine DSDP sites in the Atlantic Ocean. Herbin et al. (1984) and Deroo et al. (1983) added data for two further sites. By visual examination of their diagrams and tables the following approximate comparisons can be made with the section at Site 692 (Table 9).

Table 8. Comparisons of organic carbon determinations by Rock-Eval and coulometric means.

Core, section, interval (cm)	Organic carbon (%)	
	Rock-Eval	Coulometric
113-692B-		
10R-5, 128–129	6.32	5.89
10R-2, 113–114	6.38	8.43
10R-2, 51–52	8.39	11.68
10R-1, 116–117	8.17	8.20
10R-1, 42–43	8.54	8.30
9R-3, 122–123	6.41	11.25
9R-3, 35–36	3.56	5.96
9R-2, 143–144	4.56	6.00
9R-2, 55–56	0.93	0.96
9R-2, 52–53	8.57	8.67
9R-1, 143–146	6.88	6.73
9R-1, 118–119	15.64	17.83
9R-1, 32–33	11.75	11.76
8R-1, 46–47	9.87	10.32
7R-1, 93–94	8.78	11.24

Clearly, Site 692 is matched only by one known section in the Atlantic and adjacent seas, that of the Angola Basin. Further comparisons can be made with published Rock-Eval data for well-known petroleum source formations (Peters, 1986). The sequence at Site 692 almost exactly matches the Jurassic of Saudi Arabia, the Toarcian of France, and the Kimmeridgian of the North Sea in HI and OI values and therefore possibly in petroleum potential.

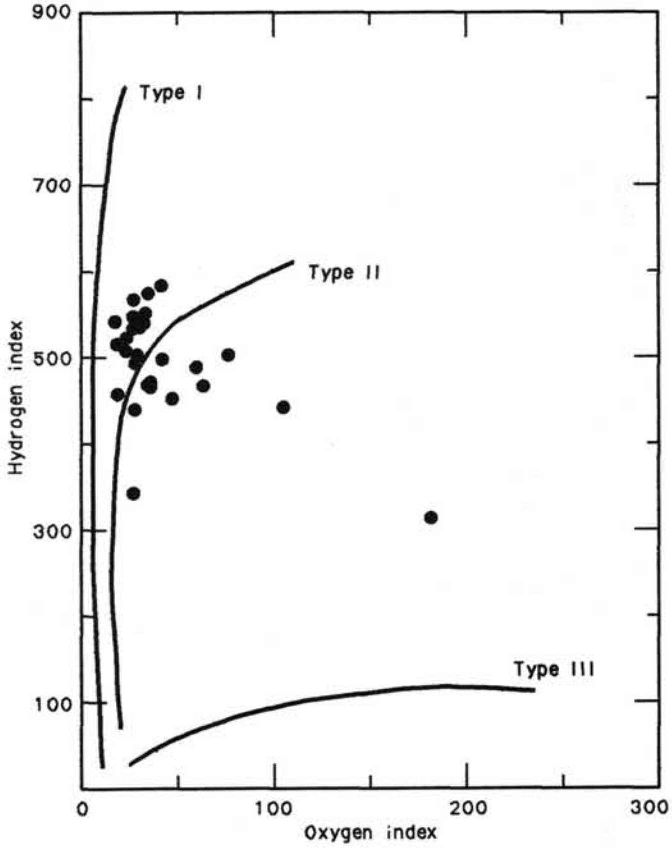


Figure 21. Rock-Eval data, Lower Cretaceous, Hole 692B.

SUMMARY AND CONCLUSIONS

Sites 691 and 692 are located on a midslope bench on the eastern Dronning Maud Land margin of the Weddell Sea. Three holes were attempted at Site 691, in the axis of Wegener Canyon which crosses the bench, and two holes at Site 692 higher on the canyon shoulder. We had considerable difficulty in spudding-in at these sites, because of the presence of coarse, unconsolidated material at the seabed. The move from Site 691 to 692 was an attempt to overcome this difficulty. Of the five holes ventured, only Hole 692B, in 2875 m of water at 70°43.432′S, 13°49.195′W, provided useful information.

Drilling at Site 691 was intended to sample the record of Paleogene and Late Cretaceous cooling of the East Antarctic continent, culminating in the formation of a major ice sheet, and to complement the depth-transect through the circum-Antarctic water masses formed by the other sites of Leg 113. We planned to avoid the presumed thick, fully glacial, Neogene sediments at this site by drilling in the canyon axis. These sediments would be sampled later at a second site located high on the canyon outer slope. It was also our intention to continue drilling down to the basal seaward-dipping reflector sequence of the "Explora Wedge" (Hinz and Krause, 1982), assumed to be a thick sequence of Middle Jurassic plateau basalts formed in the earliest stage of Weddell Sea opening.

Hole 692B was continuously cored by rotary drilling from 0 to 97.9 mbsf, with 30% recovery. It penetrated the following sequence:

1. Unit I, 0–30.4 mbsf (21% recovery); silty and clayey mud, homogenized by drilling disturbance (with probably an unrecovered coarser component), of Miocene to upper Pleistocene. The fine sand fraction contains abundant quartz, opaque minerals, and glauconite.
2. Unit II, 30.4–53.2 mbsf (13.5% recovery); pebbles and cobbles of igneous, metamorphic, and indurated sedimentary rocks, probably with a nonrecovered finer matrix, and of unknown age. Unit II was probably responsible for the failure to spud-in at the four previous holes (Holes 691A, 691B, 691C, and 692A).
3. Unit III, 53.2–97.9 mbsf (50% recovery); nannofossil claystone and nannofossil-bearing claystone, with laminae and lenses of altered volcanic ash and beds of organic-rich claystone (samples averaged 8% organic carbon), Lower Cretaceous (probably Berriasian to Valanginian) age (lower Aptian through upper Berriasian on the basis of nannofossils; Berriasian through Hauterivian from benthic foraminifers; Tithonian to Valanginian from an ammonite; and Berriasian through lower Aptian from palynomorphs). Aptian planktonic foraminifers probably resulted from downcore contamination. The sediments are normally magnetized. Abundant water-escape structures suggest high sedimentation rates. The unit contains macrofossils throughout (ribbed bivalves, *Inoceramus*, belemnites, and ammonites).

Hole 692B was abandoned partly because of repeated caving of Units I and II, but also because the primary objective of drilling in the Dronning Maud Land margin, documenting the Late Cretaceous and (particularly) Paleogene climatic history of the continent, could not be pursued. Nevertheless, some significant results were obtained.

Wegener Canyon Evolution

Among the poorly-recovered, drilling-winnowed, -disturbed, and -contaminated sediment toward the base of Unit I were several small, diatom-rich fragments each yielding a distinct flora, of ages ranging down to the late middle Miocene to early late Miocene and presumed to have been *in situ*. Their presence above the cobbles and boulders of Unit II places an upper limit (lower upper Miocene or older) on the age of the erosional un-

Table 9. Comparative modal levels of organic carbon and source potential in Cretaceous "black shales" of the Atlantic Ocean.

Basin/area	Leg	Site	Organic carbon (%)	Source potential $S_1 + S_2$, kg(HC)/ton
Hatteras Plain	11	105	2	1
Cape Basin	40	361	3	8
Angola Basin	40	364	10	80
Cape Verde	41	367	3	10
Off Morocco	41	370	1	0.8
Bermuda Rise	43	386	1	0.3
Blake-Bahama	44	391	1	1
Off Portugal	47	398	0.8	0.3
Bay of Biscay	48	402	1.5	0.3
Falkland Plateau	71	511	4	20
Caribbean	77	535	1	10
Weddell Sea	113	692	8	50

conformity, assumed to be an earlier phase of canyon-cutting, beneath Unit II. This conclusion is independent of whether Unit II is essentially a canyon lag deposit, or was ice-rafted to its present location. The abundant glauconite in Unit I suggests slow sedimentation after the initial erosional phase had passed.

Relations between various physical properties of sediments and maximum depth of burial, applied to the underlying claystones of Unit III, suggest that 250–300 m of overburden has been eroded. This is compatible with the view that the entire topographic expression of the canyon, including its gentle outer slopes, was erosional in origin rather than being partly an original depression on the margin. All the evidence of the reflection profiles, which show parallel bedding truncated abruptly at the canyon walls, supports this interpretation.

Wegener Canyon has cut through the outer high of the Explora Wedge (Figs. 2 and 22). An outer high is a common feature of seaward-dipping reflector provinces (see, e.g., Roberts et al., 1985) and is located where oceanic basalt has erupted at shallow depth. This outer high has acted as a retaining sill for the sediments overlying the basal seaward-dipping reflectors of the Explora Wedge all along the Dronning Maud Land margin. The canyon is located where the oceanward scarp of the outer high is displaced, suggesting offset by a fracture zone. It is possible, therefore, that the outer high was not fully developed in the canyon area or was even absent. The uniform dip and strike of the reflectors at the present canyon edges, however, give no indication that the retaining sill of the outer high was lower than elsewhere, before canyon-cutting started.

Most probably the canyon would cut rapidly headward through the sediments on its landward side once the basaltic sill had been breached. This rejuvenation of the canyon, similar to the effect of a sea-level drop on the profile of a riverbed, may have been responsible for cutting the deep, narrow inner canyon where Site 691 was located, leaving behind the more gently-sloping relict canyon floor sampled as Unit II at Site 692.

If Wegener Canyon had cut down 250–300 m by the early late Miocene or before, then a fundamental change is implied in the patterns of erosion and transport of sediment to the shelf edge along this margin; this change occurred in the middle Miocene or earlier. The obvious candidate is the progressive glaciation of East Antarctica, but the question of the age remains, and of what stage in glacial development was responsible. We can pursue this question further in the light of drilling at Site 693, which provides a more complete overview of changes in the pattern of terrigenous sedimentation on this margin.

Early Cretaceous and Late Jurassic Sedimentation

The Lower Cretaceous sediments of Unit III were deposited under anoxic or weakly aerobic conditions. Benthic foraminiferal assemblages suggest maximum depths of 500–1000 m, and paleomagnetic inclinations indicate a middle latitude location (43 ± 5°S), in accordance with most tectonic reconstructions (e.g., Norton and Sclater, 1979). Benthic foraminiferal diversity was low probably because of low oxygen levels. The sediments vary considerably in nannofossil abundance and diversity, benthic foraminiferal faunal composition, and organic content. This variability is probably related to changing levels of oxygen, probably resulting from changing salinity of surface waters caused by changing rates of fresh-water runoff from the surrounding continents. Such changes in surface-water salinity are inferred for Neogene basins with restricted circulation, including the Mediterranean (Thunell, 1979; Muerdter et al., 1984), Black Sea (Ross, Neprochnov, et al., 1978), Gulf of Mexico (Kennett et al., 1985), and Persian Gulf (Martini, 1967).

Sediments of similar age and lithology are found on the Falkland Plateau (Barker, Dalziel, et al., 1976; Ludwig, Krasheninnikov, et al., 1983), which in the Early Cretaceous was close to Site 692 (Norton and Sclater, 1979; Lawver et al., 1985). In both areas the kerogen in the organic-rich claystones is Type II, derived from marine planktonic lipids. In both areas Cretaceous sporomorphs are present, and at Site 692 reworked Jurassic forms of terrestrial origin are found. Concentrations of organic carbon at Site 692 are higher than on the Falkland Plateau, but we cannot say if the underlying sediments on this margin are also richer.

The Lower Cretaceous sediments at the base of Hole 692B lie an estimated 60 m above reflector U6, which separates seismic stratigraphic sequences WS-3B and WS-2 (Hinz and Krause, 1982; Fig. 22). The greater part of the sediment on this margin (some 90% of the time section on seismic line BGR78-019 in Fig. 22, for example) was laid down before the Aptian (about 120 Ma). The age of the seaward-dipping reflector basement sequence of the Explora Wedge (WS-4, Hinz and Krause, 1982) is unknown. The sequence is generally considered, however, to be associated with the earliest stages of Weddell Sea formation, by comparison with the regional tectonic environments of similar sequences, as on the Vøring Plateau (Talwani, Udintsev, et al., 1976; Eldholm et al., 1986) and Hatton-Rockall Bank (Roberts et al., 1984). Antarctic regional geological considerations would link the creation of this margin with the early stages of Gondwanaland breakup, in the Middle or Late Jurassic. For example, the wedge extends southward (Hinz and Krause, 1982) towards the Dufek Massif and beyond to the Transantarctic Mountains, areas of basic extensional magmatism of Middle Jurassic age (about 170 Ma). Northward, the earliest signs of Africa-Antarctica motion are the Late Jurassic magnetic anomalies of the western Indian Ocean (for a review, see Lawver et al., 1985), and there are no regional indications of an earlier start for Weddell Sea opening.

If we assume an age of 125 Ma for reflector U2 and an age of 165–175 Ma for seismic stratigraphic sequence WS-4, then we can calculate that the overlying sediments of the lowest part of WS-2, and all of WS-3A and B were deposited at an average rate of about 20 m/m.y. (neglecting compaction). This rate is high for a purely pelagic sequence, but compatible with the mainly terrigenous derivation of Unit III. On the Falkland Plateau (Legs 36 and 71: Barker, Dalziel, et al., 1976; Ludwig, Krasheninnikov, et al., 1983) sediments similar to Unit III and of Kimmeridgian through Aptian age were thinner, possibly because of uplift associated with the initial opening of the South Atlantic. At Site 692, more remote from such influence and perhaps remaining close to a terrigenous source for a longer time, the same lithologic unit could be much thicker. At Site 330 on the Falkland Plateau, Oxfordian sediments were of a different, well-oxygenated shelf facies, and the nature of the sediments in the adjacent basin is unknown. At Site 692 therefore, the intermittent anoxia indicated by Unit III could have influenced sedi-

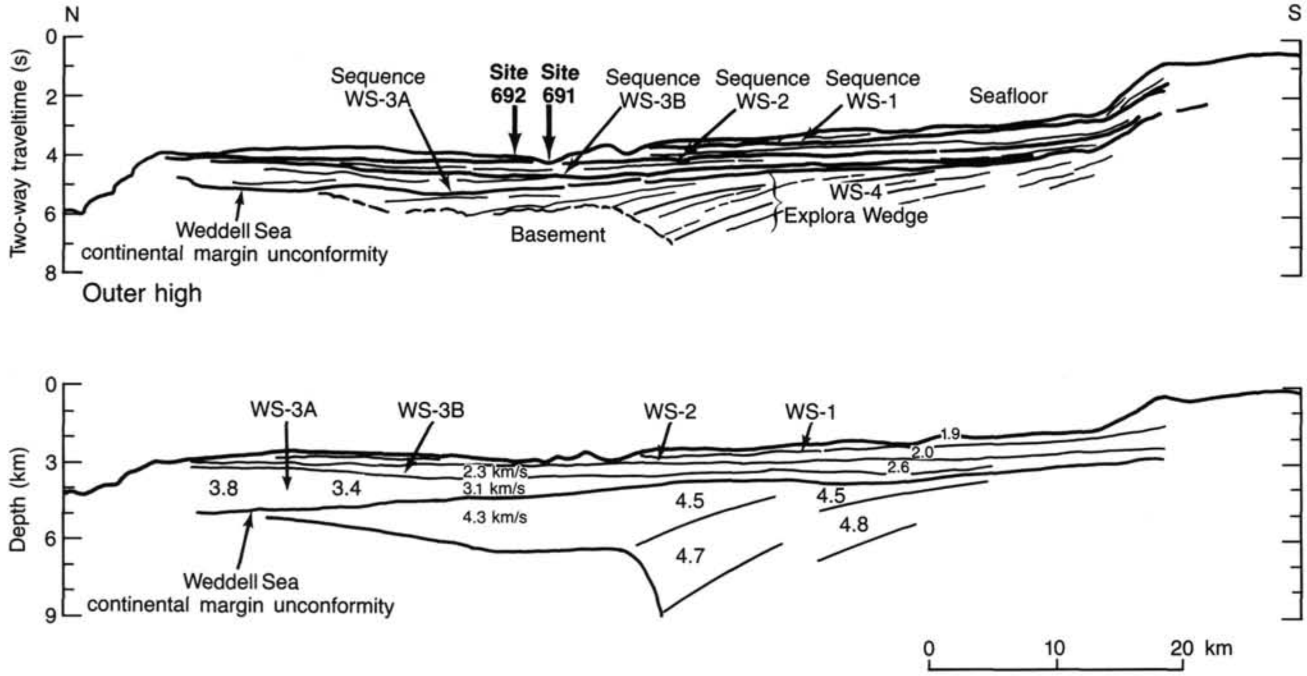


Figure 22. Interpretation of seismic line BGR78-019 by Hinz and Krause (1982) showing seismic stratigraphic sequences WS-1 to WS-4, with the locations of Sites 691 and 692 added.

mentation only to the Kimmeridgian (perhaps only as far down as the unconformity at 600 ms twt beneath Site 692); or it could have persisted all the way up from basement.

The volcanic component of Unit III is absent from sediments of a similar age on the Falkland Plateau. The laminae are ash and the lenses may be pumice. Since the two areas lay close together at the time, with the closest active plate boundary lying between them (Lawver et al., 1985), there are no obvious tectonic differences to explain the discrepancy. The prevailing winds and/or currents may have been significant, but we have no independent evidence. However, there is a similar volcanic component in probably coeval sediments (but a much thinner section) at Site 249 (Mozambique Ridge).

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SITE 691 HOLE A CORE 1R CORED INTERVAL 3034.9 - 3035.0 mbsl; 0.0-0.1 mbsf

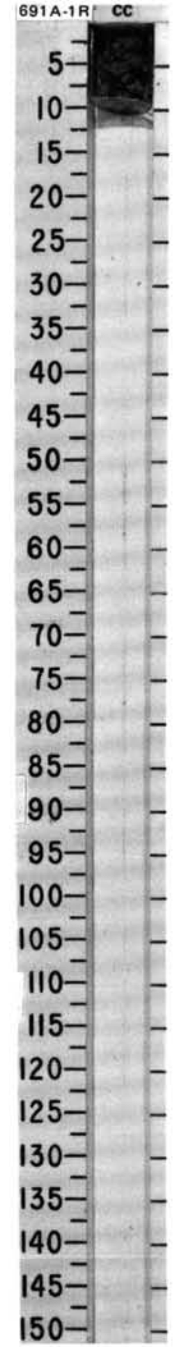
TIME-ROCK UNIT	BIOSTRAT. ZONE/ FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	PALYNOMORPHS	PALEOMAGNETICS	PHYS. PROPERTIES	CHEMISTRY	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURB.	SED. STRUCTURES	SAMPLES	LITHOLOGIC DESCRIPTION
QUATERNARY		B		F.P QUATERNARY	B				CC					*	SANDY MUD or DRILLING MIXTURE

SANDY MUD or DRILLING MIXTURE

CC only: clay, silt, and sand drilling flour, light gray (5Y 7/1), with dropstone at base.

SMEAR SLIDE SUMMARY (%):

	CC, 1
	D
COMPOSITION:	
Quartz	10
Feldspar	5
Clay	75
Accessory minerals:	
Opaques	10



SITE 692 HOLE A CORE 1R CORED INTERVAL 2879.7 - 2886.4 mbsl; 0-6.7 mbsf

TIME-ROCK UNIT	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	PALYNOMORPHS	PALEOMAGNETICS	PHYS. PROPERTIES	CHEMISTRY	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURB.	SED. STRUCTURES	SAMPLES
QUATERNARY		B	UPPER PLIOCENE - QUATERNARY F, G	QUATERNARY R, P	B				1	0.5		OOOO	◇	*

BIOSTRAT. ZONE/ FOSSIL CHARACTER

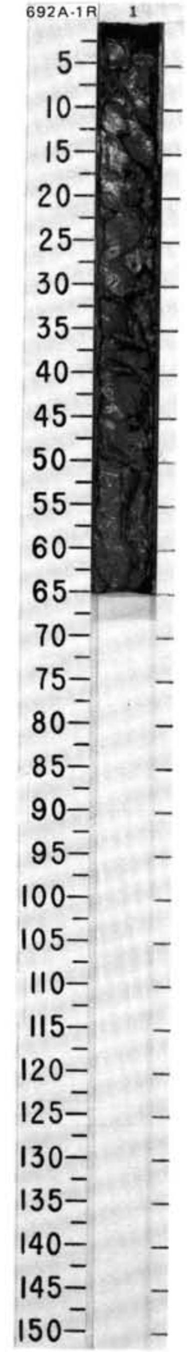
LITHOLOGIC DESCRIPTION

SILTY MUD

Major lithology: Silty mud, olive gray (5Y 4/2), completely homogenized by drilling. Sand fraction consists mainly of planktonic foraminifers, with some quartz; radiolarians and ostracods are present. Sediment is poorly sorted, with angular grains.

SMEAR SLIDE SUMMARY (%):

	1, 50 D
TEXTURE:	
Sand	10
Silt	50
Clay	40
COMPOSITION:	
Quartz	30
Feldspar	4
Mica	4
Clay	40
Accessory minerals	8
Opaques	7
Foraminifers	6
Diatoms	1
Sponge spicules	Tr



SITE 692 HOLE B CORE 1R CORED INTERVAL 2875.1-2884.2 mbsl; 0-9.1 mbsf

TIME-ROCK UNIT	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	PALYNOMORPHS	PALEOMAGNETICS	PHYS. PROPERTIES	CHEMISTRY	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURB.	SED. STRUCTURES	SAMPLES	LITHOLOGIC DESCRIPTION
QUATERNARY		B — LATE PLIOCENE - QUATERNARY	F, G	R, P — QUATERNARY	B				1	0.5 / 1.0	VOID	O O O O		*	SILTY MUD

SILTY MUD

Major lithology: Silty mud, olive gray (5Y 4/2), completely homogenized by drilling. Dispersed planktonic foraminifers. Poorly sorted, grains angular.

SMEAR SLIDE SUMMARY (%):

	1, 35
	D
TEXTURE:	
Sand	8
Silt	52
Clay	40
COMPOSITION:	
Quartz	30
Feldspar	2
Clay	40
Accessory minerals	14
Opaques	10
Foraminifers	3
Diatoms	1
Sponge spicules	Tr

SITE 692 HOLE B CORE 2R CORED INTERVAL 2884.2-2896.0 mbsl; 9.1-20.9 mbsf

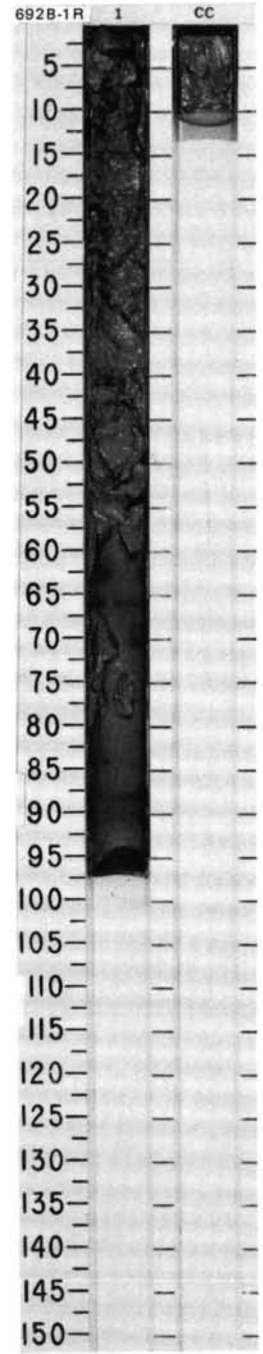
TIME-ROCK UNIT	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	PALYNOMORPHS	PALEOMAGNETICS	PHYS. PROPERTIES	CHEMISTRY	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURB.	SED. STRUCTURES	SAMPLES	LITHOLOGIC DESCRIPTION
?		B	R, P	B	B				CC			O		*	CLAYEY MUD

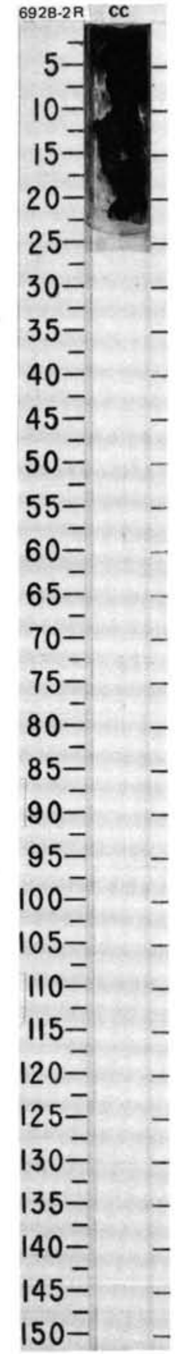
CLAYEY MUD

Major lithology: Clayey mud, dark gray (5Y 3/1), homogenized by drilling; some coarse sand and gravel mixed in by drilling.

SMEAR SLIDE SUMMARY (%):

	CC
	D
TEXTURE:	
Sand	10
Silt	30
Clay	60
COMPOSITION:	
Quartz	15
Feldspar	6
Clay	60
Accessory minerals	11
Glauconite	8
Diatoms	Tr
Sponge spicules	Tr





SITE 692 HOLE B CORE 3R CORED INTERVAL 2896.0-2905.5 mbsl; 20.9-30.4 mbsf

TIME-ROCK UNIT	BIOSTRAT. ZONE/ FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	PALYNOMORPHS	PALEOMAGNETICS	PHYS. PROPERTIES	CHEMISTRY	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURB.	SED. STRUCTURES	SAMPLES
UPPER MIDDLE / LOWER UPPER MIOCENE to LOWER PLIOCENE		F,G		From sediment chips: *Nitzschia angulata* Zone, *D. hustedtii* Zone, *D. hustedtii - lauta* Zone	Reworked PALEOGENE and MESOZOIC *flora (Sporomorphs and Dinocysts)*				1, 2, 3, 4	0.5, 1.0				

LITHOLOGIC DESCRIPTION

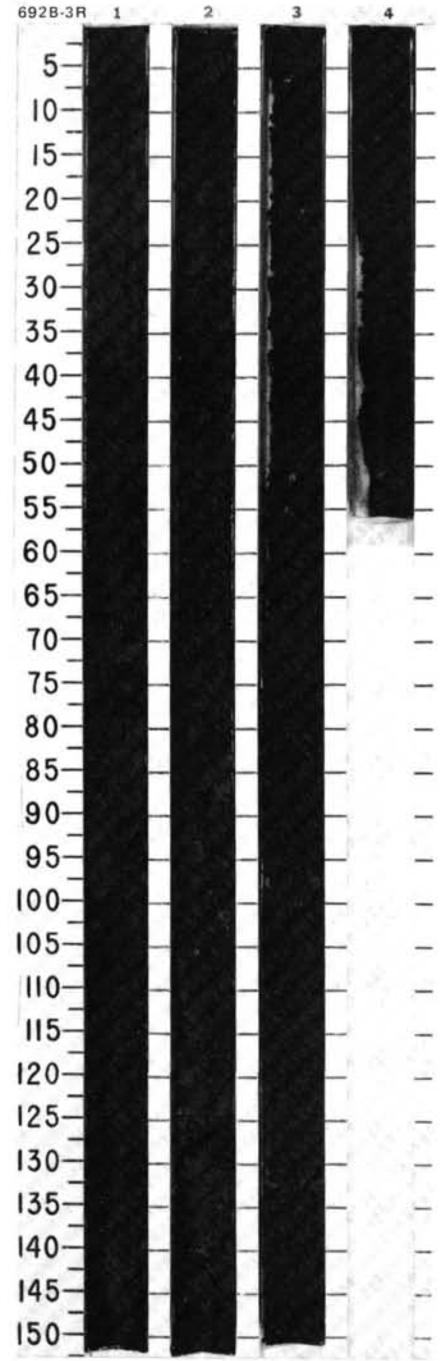
SAND

Major lithology: Sand, coarse, moderately sorted, black (5Y 2/1); angular grains. Homogenized by drilling. Mud clasts, olive gray (5Y 4/2), commonly 1 cm across, are present. Coarse fraction (>63 microns) contains 1) a fine sand mode, mainly of subangular quartz and rounded to botryoidal glauconite; glauconite becomes more abundant downcore; 2) extremely angular, very fine siltstone and quartzite, mainly as flakes up to 4 mm long. Few grains of biotite, garnet, feldspar; biogenic carbonate (i.e., foraminifers extremely rare). (This material may be cuttings from a very hard layer not far below the surface.)

SMEAR SLIDE SUMMARY (%):

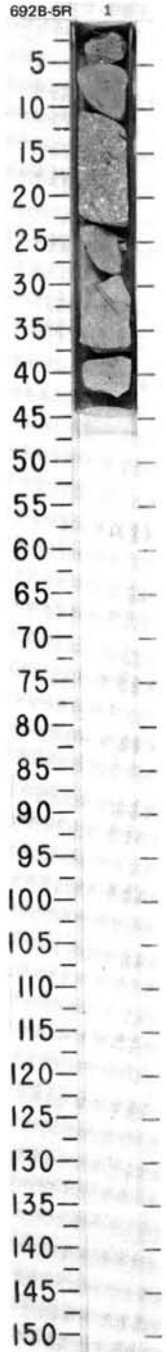
	1, 50 D	2, 50 D	3, 50 D	3, 140 M
TEXTURE:				
Sand	70	85	75	10
Silt	20	10	15	30
Clay	10	5	10	60
COMPOSITION:				
Quartz	50	30	40	25
Rock fragments, palagonite(?)	30	45	25	—
Clay	—	—	—	61
Accessory minerals:				
Heavy minerals	10	5	10	—
Opaques	10	20	25	3
Nannofossils	—	Tr	Tr	—
Diatoms	—	—	—	6
Radiolarians	—	—	—	3
Sponge spicules	—	—	—	2
Silicoflagellates	—	—	—	Tr

CORE 113-692B-4R NO RECOVERY



SITE 692 HOLE B CORE 5R CORED INTERVAL 2915.1-2924.8 mbsl; 40.0-49.7 mbsf

TIME-ROCK UNIT	BIOSTRAT. ZONE/ FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	PALYNOMORPHS	PALEOMAGNETICS	PHYS. PROPERTIES	CHEMISTRY	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURB.	SED. STRUCTURES	SAMPLES	LITHOLOGIC DESCRIPTION
?				B	B				1						DROPSTONES Major lithology: Dropstones consisting of diabase porphyry, buff-green, strongly chloritized, fine-grained with phenocrysts of feldspar and vesicles filled with a radiating botryoidal mineral. Diabase, buff-green, chloritized, fine-grained with some plagioclase phenocrysts. Granite porphyry, pink-purple matrix with light green, chloritized, plagioclase phenocrysts. Matrix consists of fine-grained plagioclase (60%), quartz (35%), and mafic minerals (<5%). Plagioclase phenocrysts, up to 8 mm in size, form 30% of the rock. Diorite, medium gray, chloritized, medium-grained, with some plagioclase phenocrysts.



SITE 692 HOLE B CORE 6R CORED INTERVAL 2924.8-2928.3 mbsl; 49.7-53.2 mbsf

TIME-ROCK UNIT: ?

BIOSTRAT. ZONE/FOSSIL CHARACTER: DIATOMS B; PALYNOMORPHS B

PHYS. PROPERTIES: V=1677 ●

SECTION: 1

LITHOLOGIC DESCRIPTION

DROPSTONES

Major lithology: Dropstones consisting of very fine-grained limestone.

SITE 692 HOLE B CORE 7R CORED INTERVAL 2928.3-2934.4 mbsl; 53.2-59.3 mbsf

TIME-ROCK UNIT: VALANGINIAN - HAUTERIVIAN

BIOSTRAT. ZONE/FOSSIL CHARACTER: NANNOFOSSILS PRE - ALBIAN; BB R,P; B B; B; B B F,P; R,P; B; PALYNOMORPHS *Sporomorphs and Dinocysts*; C,M

SECTION: 1, 2

METERS: 0.5, 1.0

LITHOLOGIC DESCRIPTION

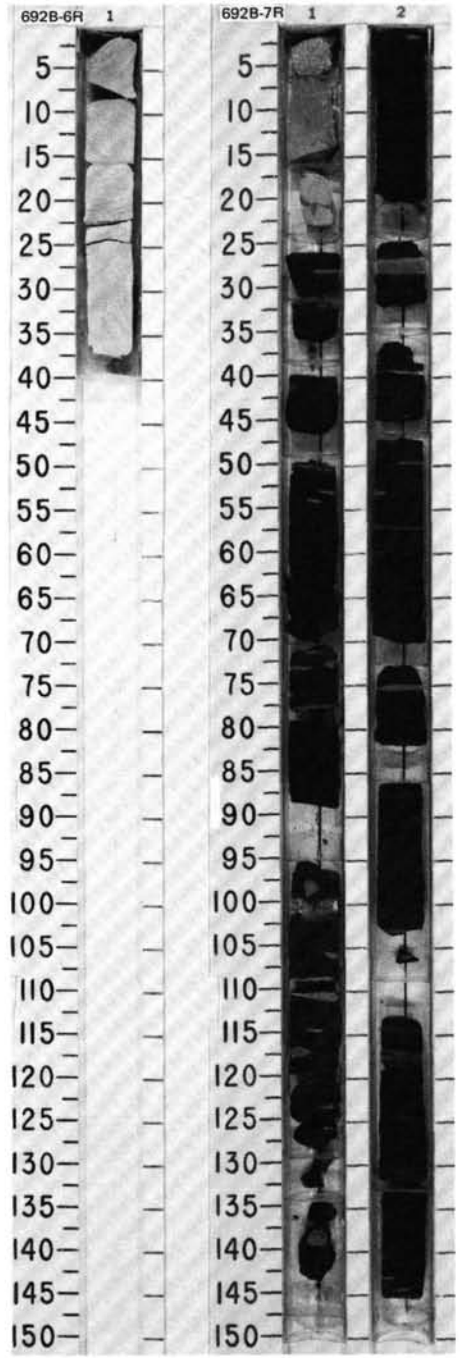
CLAYSTONE

Major lithology: Claystone in Sections 1 and 2, dark gray (10YR 3/1), consolidated, finely laminated, contains 3-8-mm-high and 20-55-mm-long pale olive (5Y 6/3) lenses. Lenses are also laminated. Gray (2.5Y 5/0) layers are observed in Section 1, 50-55, 78-83, and 100.5-103 cm, and Section 2, 27-29 cm. The layer in Section 1, 100.5-103 cm, is bioturbated.

Minor lithology: Dropstones in Section 1, 0-25 cm, consisting of granite porphyry, pink-purple matrix, with green euhedral-subhedral chloritized plagioclase phenocrysts. Diabase, light gray to medium gray, medium-grained with plagioclase, pyroxene, and olivine porphyries. Diorite, light gray, equigranular, and non-porphyritic.

SMEAR SLIDE SUMMARY (%):

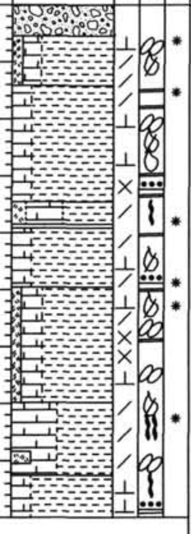
	1, 33 D	1, 49 M	1, 120 D	1, 110 M
TEXTURE:				
Sand	—	—	—	5
Silt	10	10	8	90
Clay	90	90	92	5
COMPOSITION:				
Quartz	5	4	2	—
Feldspar	—	—	—	5
Mica	—	1	—	—
Clay	90	90	92	5
Volcanic glass	—	—	—	88
Accessory minerals:				
Pyrite	5	5	6	—
Opaques	—	—	—	2



SITE 692 HOLE B CORE 8R CORED INTERVAL 2934.4-2943.9 mbsl; 59.3-68.8 mbsf

TIME-ROCK UNIT	BIOSTRAT. ZONE/ FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	PALYNOMORPHS	PALEOMAGNETICS	PHYS. PROPERTIES	CHEMISTRY	SECTION	METERS
VALANGINIAN - HAUTERIVIAN		C,G PRE - UPPER APTIAN C,G	R,P	B	F,M Dinocysts and Sporomorphs	BERRIASIAN - BARREMIAN	ϕ=55 γ=1.56 V=1750 ●	●4.3%	1, 2, 3	0.5, 1.0

GRAPHIC LITHOLOGY | DRILLING DISTURB. | SED. STRUCTURES | SAMPLES



LITHOLOGIC DESCRIPTION

NANNOFOSSIL-BEARING CLAYSTONE and CLAYEY NANNOFOSSIL CHALK

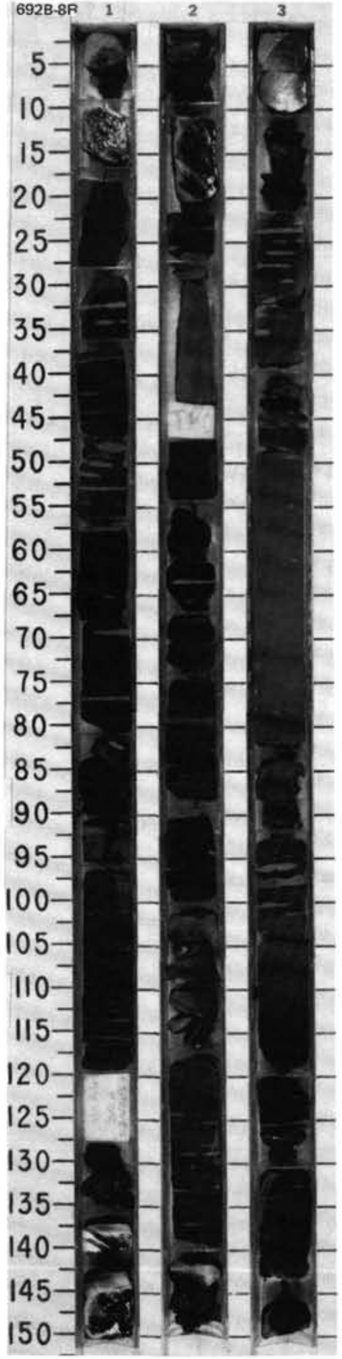
Major lithologies: Nannofossil-bearing claystone, black (5Y 2.5/1). Claystone is finely laminated, not burrowed, and contains 7–8% organic carbon (up to 30% in smear slides?). Thin to very thin graded beds in Sections 2 and 3, graded from fine silt to clay with minor to moderate bioturbation in the top few mm, are interpreted as turbidites. Clayey nannofossil chalk, olive gray (5Y 4/2) and dark olive gray (5Y 3/2). Chalk is laminated to very thinly bedded, with local moderate bioturbation. Nannofossil content increases downcore to Section 3, 113 cm, with the lowest 35 cm black claystone again.

Minor lithologies: Laminae and small lenses of ash-bearing carbonate, grayish *brown (2.5Y 5/2), gray (N 5/0), and olive gray (5Y 4/2);* volcanic glass is prominent in some smear slides but absent in others. Laminae may contain up to 20% nannofossils. Laminae are 2–10 mm thick and generally have sharp bases and tops. Carbonate forms up to 10% in parts of each section. Igneous fragments in Section 1, 0–28 cm. Dropstones, diorite, medium gray, massive with medium-grained subhedral plagioclase.

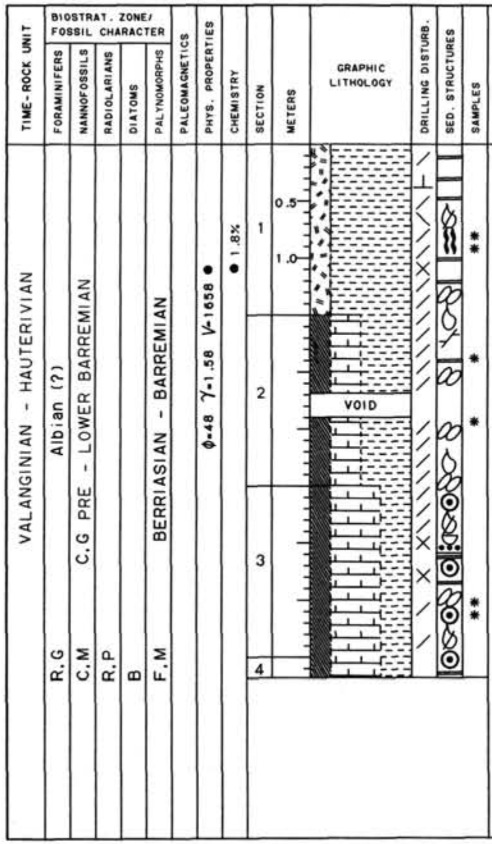
Macrofossil remains include belemnites in Section 1, 127 cm, and Section 3, 55 cm; one tiny pyritized ammonite in Section 2, 35 cm; and *Inoceramus* fragments in all sections.

SMEAR SLIDE SUMMARY (%):

	1, 30 D	1, 76 M	2, 35 M	2, 95 D	2, 112 M	3, 60 D
TEXTURE:						
Silt	10	15	18	10	89	—
Clay	90	85	82	90	11	—
COMPOSITION:						
Quartz	2	3	7	2	—	1
Feldspar	3	3	1	Tr	Tr	Tr
Mica	—	—	Tr	—	—	Tr
Clay	70	72	41	45	10	37
Volcanic glass	—	—	—	—	80	—
Calcite/dolomite	—	—	—	—	—	2
Accessory minerals:						
Pyrite	3	7	—	3	—	—
Heavy minerals	—	—	1	Tr	—	3
Foraminifers	—	—	5	5	—	—
Nannofossils	22	—	30	15	10	50
Plant debris	—	15	15	30	—	7



SITE 692 HOLE B CORE 9R CORED INTERVAL 2943.9-2953.6 mbsl; 68.8-78.5 mbsf



LITHOLOGIC DESCRIPTION

CARBONATE-BEARING MUDSTONE, ORGANIC- AND NANNOFOSSIL-BEARING MUDSTONE, and ORGANIC-BEARING MUDDY NANNOFOSSIL CHALK

Major lithologies: Carbonate-bearing mudstone, black (5Y 2.5/1 or 2). Organic- and nannofossil-bearing mudstone, black (5Y 2.5/2) to dark olive gray (5Y 3/2). Organic-bearing muddy nannofossil chalk, dark olive (5Y 3/3). Moderate bioturbation in the middle and base of Section 3. Primary structures include a scoured base and a thinly graded bed.

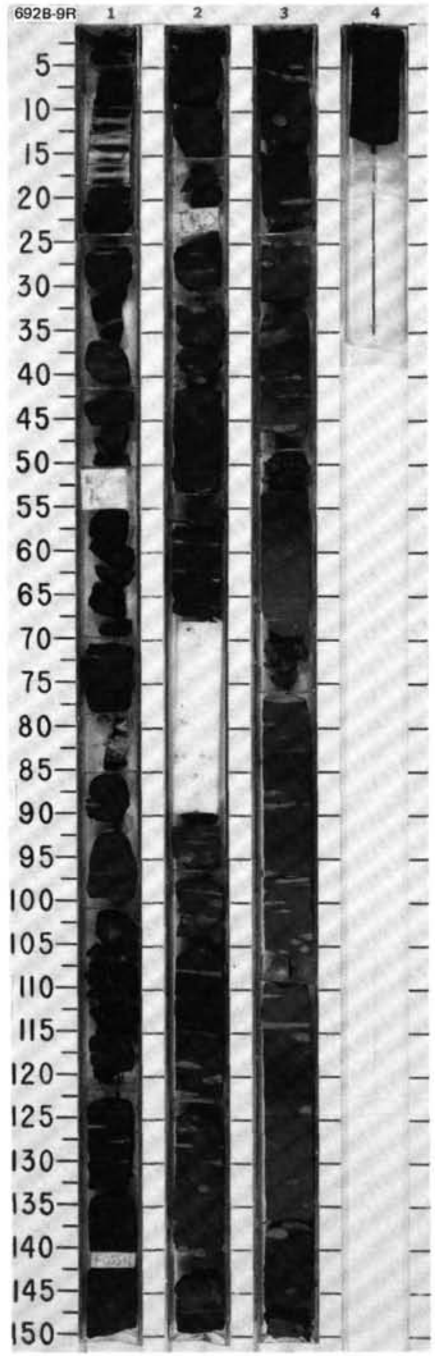
Minor lithology: Carbonate, light olive grayish brown (2.5Y 5/3), as lenticular layers, small lenses, and laminae. Nannofossil content is as high as 17%, with less than 4% organic matter; some lenticular layers contain pyrite nodules. Laminae are between 1 and 10 mm thick and have sharp boundaries. Small normal faults displace carbonate layers at the base of Section 3. Devitrified volcanic ash layers are also present as thin laminae.

Nannofossil and organic carbon content increase to base of core. High nannofossil content found in olive gray (5Y 3/2) and dark olive (5Y 3/3) color zones. All lithologies contain alternate black (5Y 2.5/1) and olive brown (2.5Y 4/4) laminae.

Inoceramus identified at Section 1, 70 cm, and minor amount of shell debris, probably bivalves, at Section 3, 27, 40, and 123-33 cm.

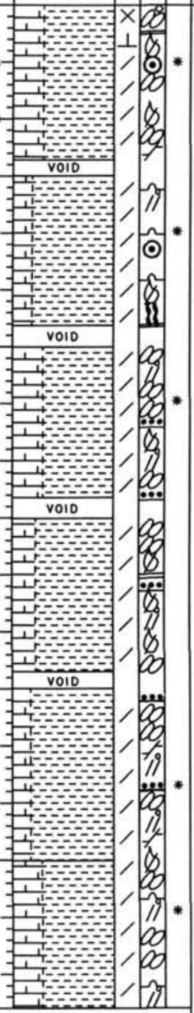
SMEAR SLIDE SUMMARY (%):

	1, 82 M	1, 91 D	2, 39 M	2, 96 D	3, 104 M	3, 109 D
TEXTURE:						
Silt	11	26	15	32	24	71
Clay	89	74	85	68	76	29
COMPOSITION:						
Quartz	1	Tr	3	3	Tr	2
Feldspar	—	1	—	—	Tr	1
Mica	—	—	—	1	—	—
Clay	89	64	85	50	76	29
Volcanic glass	—	20	—	—	—	—
Accessory minerals:						
Opaques	10	—	4	3	4	—
Nannofossils	—	5	4	25	17	50
Plant debris/ organic matter	—	10	4	18	3	18



SITE 692 HOLE B CORE 10R CORED INTERVAL 2953.6-2963.3 mbsl; 78.5-88.2 mbsf

TIME-ROCK UNIT	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	PALYNOMORPHS	PALEOMAGNETICS	PHYS. PROPERTIES	CHEMISTRY	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURB.	SED. STRUCTURES	SAMPLES
VALANGINIAN - HAUTERIVIAN		C, M; PRE - LOWER BARREMIAN (?); F, P	B	F, M	BERRIASIAN - BARREMIAN; R, P		ϕ=58 γ=1.87 V=1739 ●; ϕ=55 γ=2.14 V=1768●	30.1% ●; ● 26.7%	1, 2, 3, 4, 5, 6	0.5, 1.0	VOID, VOID, VOID, VOID			*



LITHOLOGIC DESCRIPTION

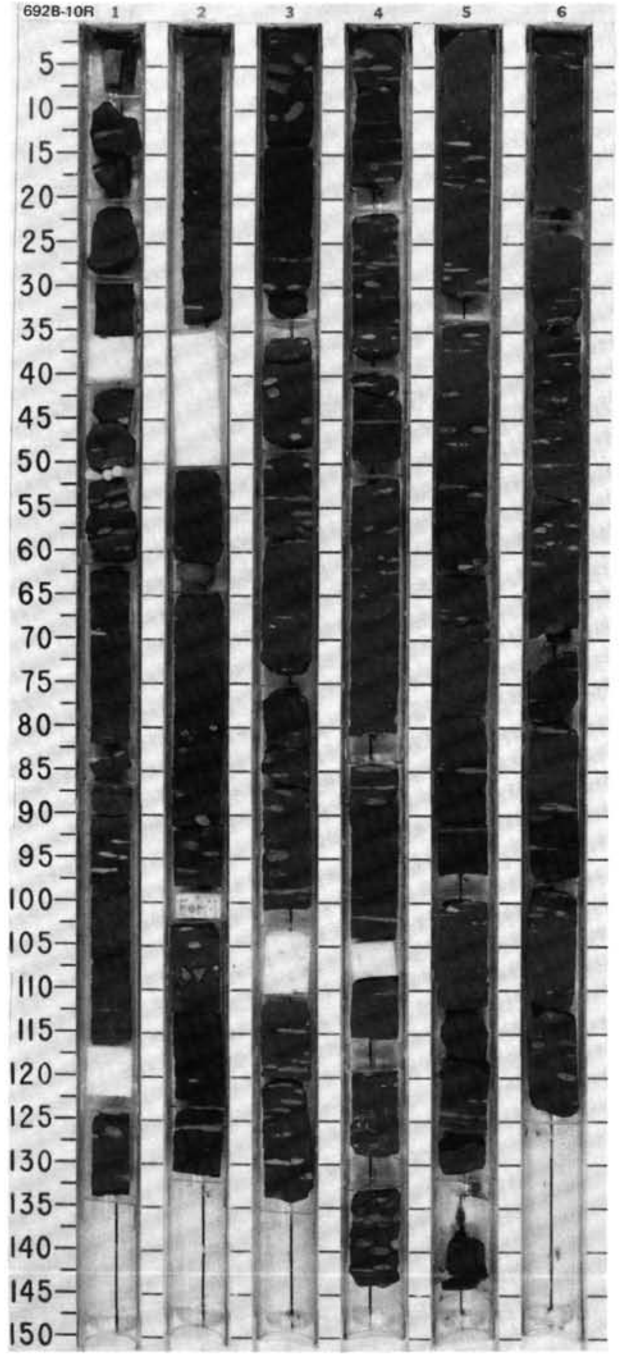
CARBONATE-BEARING NANNOFOSSIL CLAYSTONE and ASH- AND NANNOFOSSIL-BEARING CLAYSTONE

Major lithologies: Carbonate-bearing nannofossil claystone. Ash- and nannofossil-bearing claystone. Both dark olive gray (5Y 3/2), olive gray (5Y 4/2), and black (5Y 2.5/1). The ash clasts are pale olive (5Y 6/4) and grayish brown (2.5Y 5/2), and occur as thin layers (<1 mm to ~1 cm) and as rounded, oblong, and imbricate clays. The percentage of nannofossils within the claystone varies widely and is roughly correlated with color. Nannofossils are more abundant in the lighter intervals.

Shell fragments and bedding structures are abundant throughout this core. Shell fragments include gastropods, bivalves, and one ammonite (2–42 cm). They occur with parts of the shell intact, with the shell pyritized, and as casts. The sediment commonly parts along shell-rich layers. Bedding structures include fine-scale laminations, microfaults, graded bedding, and folded bedding. Some thin, dark, wavy, clay-like material is interpreted as water escape structures, as a folded and slumped interval, or as a folded water escape structure.

SMEAR SLIDE SUMMARY (%):

	1, 45 D	2, 54 D	3, 54 D	5, 75 D	6, 50 D
TEXTURE:					
Silt	20	12	5	14	7
Clay	80	88	95	86	93
COMPOSITION:					
Quartz	—	2	Tr	—	Tr
Mica	Tr	4	—	Tr	—
Clay	49	60	61	64	54
Volcanic glass	4	Tr	Tr	Tr	2
Accessory minerals:					
Opaques	8	2	3	10	2
Foraminifers	Tr	Tr	—	—	—
Nannofossils	28	20	28	19	30
Diatoms	—	Tr	—	—	—
Plant debris	9	10	—	6	10
Calcispheres	2	2	—	1	2
Organic carbon	—	—	8	—	—



SITE 692 HOLE B CORE 11W CORED INTERVAL 2929.9-2963.3 mbsl; 54.8-88.2 mbsf

TIME-ROCK UNIT: VALANGINIAN - HAUTERIVIAN

BIOSTRAT. ZONE/FOSSIL CHARACTER: NANNOFOSSILS: C,M PRE-LOWER BARREMIAN; DIATOMS: B; F,M BERRIASIAN - BARREMIAN

SECTION: 1, 2

LITHOLOGIC DESCRIPTION

WASH CORE

Sediment similar to that recovered in 113-692B-7R-10R.

SITE 692 HOLE B CORE 12R CORED INTERVAL 2963.3-2973.0 mbsl; 88.2-97.9 mbsf

TIME-ROCK UNIT: VALANGINIAN - HAUTERIVIAN

BIOSTRAT. ZONE/FOSSIL CHARACTER: NANNOFOSSILS: C,M BENNIASIAN - UPPER HAUTERIVIAN; RADIOLARIANS: B; DIATOMS: B; PALYNOMORPHS: R,P BERRIASIAN - BARREMIAN

PHYS. PROPERTIES: γ-1.85 V-1762 φ-43; γ-1.87 φ-55.5

CHEMISTRY: 1.7%; 1.9%

SECTION: 1, 2, 3

LITHOLOGIC DESCRIPTION

CARBONATE- AND NANNOFOSSIL-BEARING CLAYEY MUDSTONE

Major lithology: Carbonate- and nannofossil-bearing clayey mudstone, dark olive gray (5Y 3/2) with pale olive (5Y 6/3) lenses of volcanic ash. Lighter layers contain fossil fragments, coccoliths, and calcispheres. The pore-water escape structures seen in 113-692B-10R are also present in this core.

Minor lithology: Volcanic ash, Section 2, 35-45 cm, light gray (5YR 7/1), very fine grained and recrystallized.

SMEAR SLIDE SUMMARY (%):

	1, 20 D	1, 100 D	2, 39 M	3, 53 D
TEXTURE:				
Sand	Tr	10	—	8
Silt	40	30	20	40
Clay	60	60	80	52
COMPOSITION:				
Quartz	5	12	4	15
Mica	4	2	—	—
Clay	60	60	80	32
Volcanic glass	10	12	6	5
Calcite/dolomite	1	—	2	—
Accessory minerals	—	—	—	22
Opaque	—	8	8	5
Nannofossils	15	2	Tr	20
Plant debris	5	4	—	—
Calcispheres	—	—	—	1

SITE 692 HOLE B CORE 13W CORED INTERVAL 2963.3-2973.0 mbsl; 88.2-97.9 mbsf

BIOSTRAT. ZONE/FOSSIL CHARACTER: NANNOFOSSILS: C,G; RADIOLARIANS: B; DIATOMS: R,P; PALYNOMORPHS: B

SECTION: 1, 2

LITHOLOGIC DESCRIPTION

DRILLING SAND

Drilling-induced graded clay to gravel, but dominantly angular sand. Overall color is black. Most of the coarse fraction, Section 1, 4-7 cm, is fragments of Cretaceous shales.