9. SITE 593: CHALLENGER PLATEAU[1]

Shipboard Scientific Party[2]

HOLE 593

Date occupied: 28 December 1982

Date departed: 30 December 1982

Time on hole: 2 days, 16 hr.

Position: 40°30.47′S; 167°40.47′E

Water depth (sea level; corrected m, echo-sounding): 1068

Water depth (rig floor; corrected m, echo-sounding): 1078

Bottom felt (m, drill pipe): 1079

Penetration (m): 571.5

Number of cores: 60

Total length of cored section (m): 571.5

Total core recovered (m): 468.21

Core recovery (%): 81.9

Oldest sediment cored:
Depth sub-bottom (m): 571.5
Nature: Nannofossil chalk
Age: Late Eocene
Measured velocity (km/s): 2.340 km/s at 554 m

Basement: Not reached

HOLE 593A

Date occupied: 30 December 1982

Date departed: 1 January 1983

Time on hole: 25 hr.

Position: 40°30.47′S; 167°40.47′E

Water depth (sea level; corrected m, echo-sounding): 1068

Water depth (rig floor; corrected m, echo-sounding): 1078

Bottom felt (m, drill pipe): 1080.3

Penetration (m): 496.8

Number of cores: 27

Total length of cored section (m): 257.3

Total core recovered (m): 227.71

Core recovery (%): 88.5

Oldest sediment cored:
Depth sub-bottom (m): 496.8
Nature: Nannofossil chalk
Age: Latest Oligocene

Basement: Not reached

Principal results: Site 593 is located on the Challenger Plateau, a western extension of the New Zealand Plateau. The western part of the Challenger Plateau provides a shallow-water pedestal of 270 km distant from the nearest land mass of northern South Island, New Zealand. This setting has allowed accumulation of an uncomplicated Paleogene–Neogene pelagic ooze sequence with virtually no terrigenous sedimentary influences. Site 593 is a reoccupation of Site 284, cored during Leg 29 of DSDP.

Site 593 consists of two holes continuously cored to a maximum sub-bottom depth of 571.5 m. Hole 593 was cored with the hydraulic piston corer (HPC) from 0 to 245.1 m sub-bottom and continued to a total depth of 571.5 m with the extended core barrel (XCB). Hole 593A was continuously cored with the HPC from 0 to 209.3 m sub-bottom, then washed down to 448.8 m and cored with the XCB to 496.8 m to recover the Oligocene/Miocene transition. This interval was poorly cored in the first hole.

Site 593 is an apparently continuous stratigraphic sequence from the late Eocene (42 m.y.) to the Quaternary. A paleomagnetic polarity stratigraphy has been identified to the middle of the Gauss Chron (3.2 m.y.).

The general facies is a foraminiferal-bearing nannofossil ooze that grades into nannofossil ooze and nannofossil chalk with depth. Only traces of biosiliceous sediments occur in a few intervals. The section has been divided into two units of earliest Oligocene to Recent age.

Unit I is subdivided into four units:

Subunit IA, of late Quaternary age, represents a veneer (0–6 m) of yellow gray foraminifer-bearing nannofossil ooze within the oxidized zone near the seafloor.

Subunit IB, a thick (6–393 m) sequence of Quaternary to middle Miocene age, is a rather monotonous light-colored foraminifer-bearing nannofossil ooze to nannofossil ooze.

Subunit IC, a thin (393 to 418 m) early middle Miocene sequence, is an oxidized sediment zone of pale orange color.

Subunit ID, is a thick (418 to 545.5 m) sequence of nannofossil ooze of early middle Miocene to earliest Oligocene age.

Unit II is a thin (545.5 to 571.5 m) sequence of lithified volcanogenic turbidites and pyroclastics emplaced at the Eocene/Oligocene boundary and probably derived from nearby "Lalitha Pinnacle." The volcanogenic rocks are underlain by nannofossil chalk at the base of the hole. This chalk contains many thin laminae of altered volcanic glass, indicating an episode of active explosive volcanism.

Site 593 is a fine, complete stratigraphic succession in southern temperate waters with abundant, well-preserved planktonic foraminifers except in the volcanogenic material. Calcareous nannofossils are abundant throughout, but not well preserved below the Pliocene. An excellent succession of the benthic foraminifers is preserved.

Planktonic foraminiferal zonations are typically temperate in character. A number of calcareous nannofossil zones are missing

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[1] Kennett, J. P., von der Borch, C. C., et al., *Init. Repts. DSDP*, 90: Washington (U.S. Govt. Printing Office).

[2] James P. Kennett (Co-Chief Scientist), Graduate School of Oceanography, University of Rhode Island, Narragansett, RI 02882; Christopher C. von der Borch (Co-Chief Scientist), School of Earth Sciences, Flinders University of South Australia, Bedford Park, South Australia 5042; Paul A. Baker, Department of Geology, Duke University, Durham, NC 27708; Charles E. Barton, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI 02882 (present address: Bureau of Mineral Resources, Geology, and Geophysics, P.O. Box 378, Canberra, A.C.T., Australia); Anne Boersma, Microclimates, Inc., 404 RR1, Stony Point, NY 10980; Jean-Pierre Caulet, Laboratoire de Géologie, Muséum National d'Histoire Naturelle, 43 Rue Buffon, 75005, Paris, France; Walter C. Dudley, Jr., Natural Sciences Division, College of Arts and Sciences, University of Hawaii at Hilo, Hilo, Hawaii 96720; James V. Gardner, Pacific-Arctic Branch of Marine Geology, U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025; D. Graham Jenkins, Department of Earth Sciences, Open University, Walton Hall, Milton Keynes, MK7 6AA, Buckinghamshire, United Kingdom; William H. Lohman, Marathon Oil Co., Denver Research Center, P.O. Box 269, Littleton, CO 80160; Erlend Martini, Geologisch-Paläontologisches Institut, Johann-Wolfgang-Goethe Universität, Senckenberg-Anlage 32-34, D-6000 Frankfurt am Main, Federal Republic of Germany; Russell B. Merrill, Deep Sea Drilling Project A031, Scripps Institution of Oceanography, La Jolla, CA 92093 (present address: Ocean Drilling Project, Texas A&M University, College Station, TX 77843-3469); Roger Morin, Department of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139 (present address: U.S. Geological Survey, Denver Federal Center, Denver, CO 80225); Campbell S. Nelson, Department of Earth Sciences, University of Waikato, Private Bag, Hamilton, New Zealand; Christian Robert, Laboratoire de Géologie Marine, Centre Universitaire de Luminy, Case 901, 13288 Marseille Cedex 09, France; M. S. Srinivasan, Department of Geology, Banaras Hindu University, Varanasi 221 005, India; Rüdiger Stein, Geologisch-Paläontologisches Institut, Universität Kiel, 2300 Kiel, Federal Republic of Germany (present address: Institute of Petroleum and Organic Geochemistry (ICH-5), Kernforschungslage Jülich GmbH, P.O. Box 1913, 5170 Jülich, Federal Republic of Germany); Akira Takeuchi, Department of Earth Sciences, Faculty of Science, Toyama University, Gohuku 3190, Toyama 930, Japan.

because the warm-water marker forms are rare or absent. All epoch boundaries are well represented between the Eocene/Oligocene and the Pliocene/Pleistocene boundaries. The Oligocene/Miocene boundary coincides with a more lithified ooze layer. The Eocene/Oligocene boundary coincides with the volcanogenic sequence (Unit II) with no apparent break in sedimentation. Evidence from the seismic profiles suggest that the volcanic rocks resulted from a single episode of submarine extrusion. These volcanics are approximately coeval with extensive volcanism in New Zealand, including the Deborah volcanics of South Canterbury. A number of volcanic pinnacles with seismic character similar to that of "Lalitha Pinnacle" occur over the Challenger Plateau, indicating widespread volcanism at that time.

The middle Miocene oxidized ooze (Subunit IC) was deposited between 15.5 and 15 m.y., immediately preceding the time of major ice-sheet growth on east Antarctica. It is, therefore, possible that it reflects important paleoceanographic changes at an oceanographic front in the Southern Ocean tied to this glacial evolution. The oxidized sediment contains a temporary benthic foraminiferal fauna that is typical of oxygen-rich waters.

The late early Pliocene (4–3 m.y.) is marked, as in other Leg 90 sites, by an episode when enhanced carbonate productivity caused extremely high sedimentation rates.

BACKGROUND AND OBJECTIVES

Site 593 is located on the Challenger Plateau, a western extension of the New Zealand Plateau (Figs. 1 and 2). The Challenger Plateau is effectively a topographic extension of the Lord Howe Rise and its western part provides a shallow-water pedestal 270 km distant from the nearest land mass of northern South Island, New Zealand. This setting has allowed the accumulation of an uncomplicated sequence of Neogene pelagic ooze with virtually no terrigenous sedimentary influences.

Site 593 is a reoccupation of Site 284, which was cored during Leg 29 of the Deep Sea Drilling Project in April, 1973 (Kennett, Houtz, et al., 1975). Site 284 was added very near the end of Leg 29 when it became apparent that two spare days could be made available for an additional site. Because no formal safety panel reviews had been made, coring was restricted to the upper 208 m lest hydrocarbons occur below this depth. Site 284 is a valuable middle late Miocene to Quaternary sequence of calcareous oozes, located in cool-temperate waters. The site has provided material for a wide variety of paleoceanographic and biostratigraphic studies (e.g. Shackleton and Kennett, 1975; Kennett and Vella, 1975; Kennett et al., 1979; Hornibrook, 1982).

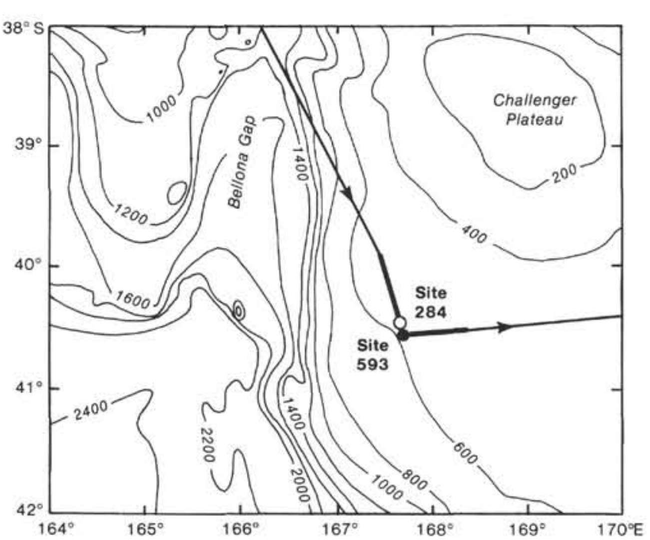

Figure 1. Regional bathymetry (fathoms) around Site 593; after Mammerickx et al. (1974); *Glomar Challenger* Leg 90 track shown; heavy portion locates water gun seismic profile illustrated in Fig. 2.

Because Site 284 had been shown to contain an excellent late Neogene section, is was decided to recore this location using the HPC and the XCB. It was hoped that a pair of hydraulic piston cores would provide a better-quality sequence for higher-resolution biostratigraphic and paleoceanographic studies. Also the section needed to be extended to include as much of the Neogene as possible. The seismic profile record (Fig. 2) shows that the first distinct reflector lies at about 500 m. This may be the regional Eocene/Oligocene hiatus (or Oligocene/Miocene, as at Site 592). Therefore a major objective at Site 593 was to core the entire Neogene sequence. Because sedimentation rates were known to be high (about 40 m/m.y.) at this location, this sequence was expected to provide material for high-resolution stratigraphic studies.

Site 593 is located in the present-day cool-temperate water mass, about midway between transitional water masses north of New Zealand and subantarctic waters to the south. That this lies within the west wind drift was made apparent by a population of about 70 albatrosses that welcomed our ship when it reached the roaring forties!

Significant paleoceanographic changes have been documented for this latitude (Kennett and Vella, 1975; Shackleton and Kennett, 1975) although no major water mass boundary migrated across the location of Site 284 during the late Neogene. All documented paleoceanographic oscillations have been confined within the temperate water mass.

The scientific objectives of Site 593 were much the same as the other sites in the southwest Pacific latitudinal traverse: to understand, using a variety of analytical approaches, the Neogene paleoceanographic evolution of the South Pacific and its relations with global paleoenvironmental change; to develop a tephrochronology and to study the diagenetic history of the sediment column.

OPERATIONS

Site 592 to Site 593

The pipe was pulled out of the hole, the rig floor made secure for sea, and the vessel was under way for Site 593 at 1242 hr., 27 December. The trip south was made in pleasant weather. As had become customary, a direct approach was made and the 13.5 kHz beacon was dropped on the first pass at 1632 hr., 28 December. The transit took 27.9 hr. and covered 264.8 n. mi. at an average 9.5 knots.

Site 593 (SW-2): Challenge Plateau

The routine short hook-up BHA for both XCB and variable length (VL)HPC work was made up and run to the shoot-off point for the first piston core attempt. A good mudline core was recovered, establishing the water

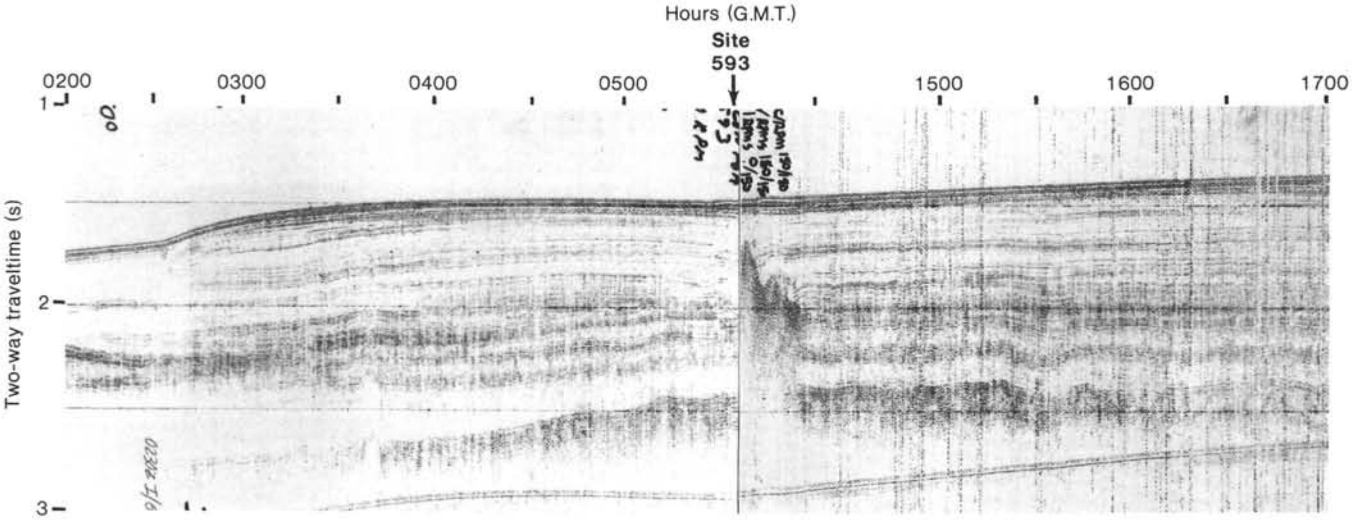

Figure 2. Water gun profile (*Glomar Challenger*) near Site 593; bandpass filter 40–160 Hz.

depth at 1079 m, thus spudding Hole 593 at 2155 hr., 28 December (Table 1).

Using the 9.5-m VLHPC with two shear pins, coring progressed easily through unusually soft carbonate ooze. Full stroke of the piston corer was achieved on all cores. At Core 593-22 (206.7 m BSF) a crumpled liner indicated that the adhesive properties of the sediment were becoming significant. Two cores later the barrel could not be withdrawn with 30,000 lb. overpull and was partially washed over to free it; piston coring was then terminated.

The XCB coring tools were then rigged up and deployed. After some initial fine-tuning on the troublesome XCB latch good results were achieved for the next 24 cores.

At Core 593-49 shattered liners reappeared. In each off-numbered core of the next three, recovery was marginal because the liner was shattered, which suggested that one of the two XCB tools being alternated was faulty. However, no obvious problem was discovered. To deal with the problem, the remaining cores in the hole were taken by running the XCB tools in on the wire line. By this means good cores with liners intact were achieved for the rest of the hole. Core 593-51 became stuck in the pipe before reaching the bit and could not be worked loose with the wire line until after the interval had been drilled, so no core was recovered.

Starting with Core 593-58 at about 550 m BSF, a 10-m interval of very hard volcanogenic turbidites was encountered and was cored successfully using the XCB soft-formation cutting shoes.

The hole was terminated at 571.5 m BSF when the sediments of the Eocene objective were reached.

The bit was pulled to the mudline and the vessel offset 100 ft. north by 100 ft. west in preparation for the repeat piston core sequence.

Hole 593A

Hole 593A was spudded with a mudline piston core at 2337 hr., 30 December (Table 1). Piston coring continued as in the previous hole with no difficulties at all up to Core 593A-22 at 209.3 m BSF. At this point no further cores in the piston corer "zone" were desired. Next the XCB was deployed and washed to 448.8 m BSF in order to recover the section which lost during the interlude of shattered liners and associated poor recovery in the first hole. Each of the five XCB cores was taken by running in on the wire line. Recovery was good through the boundary except for Core 593A-24 which, apparently, suffered a slight blockage and recovered only 3.15 m. The hole was terminated after the fifth XCB core at a total depth of 496.8 m BSF. The pipe was then pulled out of the hole and the bit arrived on deck just 15 min. after the start of the New Year, 1983.

LITHOSTRATIGRAPHY

The sequence recovered at Site 593 represents two lithostratigraphic units. Unit I has been subdivided into four subunits based on color and composition (Table 2).

Unit I

The general facies of Site 593 is a foraminifer-bearing nannofossil ooze that grades into a nannofossil ooze and a nannofossil chalk with depth. The transition to reduced abundances of foraminifers, from about 15 to about 5% (smear-slide estimates only), occurs around 110 m sub-bottom depth. The facies is predominantly calcareous nannofossils with very subordinate foraminifers. Other components, such as quartz and feldspar grains, volcanic glass, and pyrite(?), only occur in trace abundances (<1%) (Fig. 3). Micritic carbonate occurs in persistent abundances of 5 to 10% from 323 m sub-bottom to total depth, but the sediment does not become chalk until 562 m. The only biogenic silica found were traces (less than 1%) of sponge spicules in a zone from about 249 to 296 m sub-bottom.

Subunit IA (Hole 593: 0–1.5 m; Hole 593A: 0–6 m; late Quaternary)

This subunit recognized by its yellowish gray (5Y 7/2) color, is foraminifer-bearing nannofossil ooze. The contact with underlying Subunit IB is gradational over about

Table 1. Coring summary, Site 593.

Core no.	Date (Dec. 1982)	Time	Depth from drill floor (m) Top Bottom	Depth below seafloor (m) Top Bottom	Length cored (m)	Length recovered (m)	Percentage recovered
Hole 593							
1	28	2220	1079.9–1085.0	0.0–5.1	5.1	5.09	99.8
2	28	2300	1085.0–1094.6	5.1–14.7	9.6	8.81	91.7
3	28	2348	1094.6–1104.2	14.7–24.3	9.6	9.21	95.9
4	29	0035	1104.2–1113.8	24.3–33.9	9.6	8.86	92.2
5	29	0100	1113.8–1123.4	33.9–43.5	9.6	9.02	93.9
6	29	0135	1123.4–1133.0	43.5–53.1	9.6	9.11	94.9
7	29	0210	1133.0–1142.6	53.1–62.7	9.6	9.22	96.0
8	29	0255	1142.6–1152.2	62.7–72.3	9.6	3.11	32.3
9	29	0340	1152.2–1161.8	72.3–81.9	9.6	8.17	85.1
10	29	0355	1161.8–1171.4	81.9–91.5	9.6	0.0	0.0
11	29	0425	1171.4–1181.0	91.5–101.1	9.6	7.75	80.7
12	29	0500	1181.0–1190.6	101.1–110.7	9.6	9.52	99.1
13	29	0540	1190.6–1200.2	110.7–120.3	9.6	9.39	97.3
14	29	0615	1200.2–1209.8	120.3–129.9	9.6	9.45	98.4
15	29	0635	1209.8–1219.4	129.9–139.5	9.6	9.41	98.0
16	29	0720	1219.4–1229.0	139.5–149.1	9.6	9.38	97.7
17	29	0800	1229.0–1238.6	149.1–158.7	9.6	9.51	99.0
18	29	0830	1238.6–1248.2	158.7–168.3	9.6	8.93	93.0
19	29	0910	1248.2–1257.8	168.3–177.9	9.6	9.67	100+
20	29	0945	1257.8–1267.4	177.9–187.5	9.6	9.52	99.1
21	29	1015	1267.4–1277.0	187.5–197.1	9.6	9.70	100+
22	29	1115	1277.0–1286.6	197.1–206.7	9.6	6.13	64
23	29	1200	1286.6–1296.2	206.7–216.3	9.6	9.61	100+
24	29	1250	1296.2–1305.8	216.3–225.9	9.6	9.18	96
25	29	1410	1305.8–1315.4	225.9–235.5	9.6	9.54	99
26	29	1500	1315.4–1325.0	235.5–245.1	9.6	8.48	88
27	29	1550	1325.0–1334.6	245.1–254.7	9.6	9.69	100+
28	29	1650	1334.6–1344.2	254.7–264.3	9.6	7.87	82
29	29	1730	1344.2–1353.8	264.3–273.9	9.6	7.88	82
30	29	1800	1353.8–1363.4	273.9–283.5	9.6	7.12	74
31	29	1840	1363.4–1373.0	283.5–293.1	9.6	7.45	78
32	29	1925	1373.0–1382.6	293.1–302.7	9.6	6.80	71
33	29	1945	1382.6–1392.2	302.7–312.3	9.6	7.08	74
34	29	2100	1392.2–1401.8	312.3–321.9	9.6	6.36	66
35	29	2145	1401.8–1411.4	321.9–331.5	9.6	6.92	72
36	29	2230	1411.4–1421.0	331.5–341.1	9.6	5.53	58
37	29	2320	1421.0–1430.6	341.1–350.7	9.6	6.64	69
38	30	0030	1430.6–1440.2	350.7–360.3	9.6	9.46	98
39	30	0115	1440.2–1449.8	360.3–369.9	9.6	8.86	92
40	30	0200	1449.8–1459.4	369.9–379.5	9.6	7.91	82
41	30	0240	1459.4–1469.0	379.5–389.1	9.6	9.71	100+
42	30	0335	1469.0–1478.6	389.1–398.7	9.6	8.53	89
43	30	0400	1478.6–1488.2	398.7–408.3	9.6	9.15	95
44	30	0530	1488.2–1497.8	408.3–417.9	9.6	8.77	91
45	30	0615	1497.8–1507.4	417.9–427.5	9.6	9.75	100+
46	30	0700	1507.4–1517.0	427.5–437.1	9.6	9.65	100+
47	30	0755	1517.0–1526.6	437.1–446.7	9.6	8.55	89
48	30	0905	1526.6–1536.2	446.7–456.3	9.6	7.96	83
49	30	1000	1536.2–1545.8	456.3–465.9	9.6	0.69	7
50	30	1040	1545.8–1555.4	465.9–475.5	9.6	9.15	95
51	30	1135	1555.4–1565.0	475.5–485.1	9.6	0.0	0
52	30	1235	1565.0–1574.6	485.1–494.7	9.6	4.99	52
53	30	1335	1574.6–1584.2	494.7–504.3	9.6	5.01	52
54	30	1435	1584.2–1593.8	504.3–513.9	9.6	7.08	74
55	30	1525	1593.8–1603.4	513.9–523.5	9.6	9.56	100
56	30	1620	1603.4–1613.0	523.5–533.1	9.6	9.31	97
57	30	1730	1613.0–1622.6	533.1–542.7	9.6	9.62	100+
58	30	1845	1622.6–1632.2	542.7–552.3	9.6	4.21	44
59	30	1955	1632.2–1641.8	552.3–561.9	9.6	6.60	67
60	30	2055	1641.8–1651.4	561.9–571.5	9.6	8.58	89
					571.50	468.21	81.9
Hole 593A							
1	30	2355	1080.3–1088.0	0.0–7.7	7.7	7.66	99.0
2	31	0035	1088.0–1097.6	7.7–17.3	9.6	8.62	89.8
3	31	0115	1097.6–1107.2	17.3–26.9	9.6	6.90	71.9
4	31	0200	1107.2–1116.8	26.9–36.5	9.6	8.61	89.7
5	31	0230	1116.8–1126.4	36.5–46.1	9.6	8.15	84.9
6	31	0320	1126.4–1136.0	46.1–55.7	9.6	9.46	98.5
7	31	0355	1136.0–1145.6	55.7–65.3	9.6	8.55	89.0
8	31	0430	1145.6–1155.2	65.3–74.9	9.6	8.22	85.6
9	31	0510	1155.2–1164.8	74.9–84.5	9.6	9.52	99.1
10	31	0610	1164.8–1174.4	84.5–94.1	9.6	8.88	92.5
11	31	0635	1174.4–1184.0	94.1–103.7	9.6	8.76	91.2
12	31	0730	1184.0–1193.6	103.7–113.3	9.6	8.85	92.1
13	31	0800	1193.6–1203.2	113.3–122.9	9.6	8.83	91.9
14	31	0835	1203.2–1212.8	122.9–132.5	9.6	9.04	94.1
15	31	0920	1212.8–1222.4	132.5–142.1	9.6	8.79	91.5
16	31	1000	1222.4–1232.0	142.1–151.7	9.6	9.14	95.5
17	31	1040	1232.0–1241.6	151.7–161.3	9.6	9.54	99.3
18	31	1110	1241.6–1251.2	161.3–170.9	9.6	9.32	97.0
19	31	1150	1251.2–1260.8	170.9–180.5	9.6	9.36	97
20	31	1250	1260.8–1270.4	180.5–190.1	9.6	9.41	98
21	31	1315	1270.4–1280.0	190.1–199.7	9.6	8.71	91
22	31	1400	1280.0–1289.6	199.7–209.3	9.6	8.79	92
Wash to 448.8 m BSF							
23	31	1755	1529.1–1538.7	448.8–458.4	9.6	6.16	64
24	31	1830	1538.7–1548.3	458.4–468.0	9.6	3.15	33
25	31	1920	1548.3–1557.9	468.0–477.6	9.6	8.19	85
26	31	2007	1557.9–1567.5	477.6–487.2	9.6	7.50	78
27	31	2105	1567.5–1577.1	487.2–496.8	9.6	9.60	100
					257.30	227.71	88.5

Table 2. Lithostratigraphy at Site 593.

Lithologic units	Core Section	Sub-bottom depth (m)	Description	Age
IA	1 1A[a]	0.0–1.5 0.0–6.0	Yellowish gray (oxidized) foraminifer-bearing nannofossil ooze	late Quaternary
IB	2 to 42-3 1A[a] to 27	1.5–393.5 6.0–>496.8	Light gray to white foraminifer-bearing nannofossil ooze to nannofossil ooze	late Quaternary to middle Miocene
IC	42-4 to 44	393.8–418.0	Pale orange to yellow gray (oxidized) nannofossil ooze	middle Miocene
ID	45 to 58-2	418.0–545.5	White nannofossil ooze	early middle Miocene to earliest Oligocene
II	58-3 to 60	545.5–>571.5	Interbedded lithified volcanogenic turbidites and light greenish gray to white nannofossil chalk	late Eocene

[a] Cores from Hole 593A; All others from Hole 593.

5 cm. Subunit IA represents the upper oxidized layer and correlates with a similar subunit at Sites 586, 588, 589, 590, 591, and 592. The relatively high content of foraminifers is probably the result of winnowing.

Subunit IB (593: 1.5–393.5 m; 593A: 6.0 to more than 496.8 m; late Quaternary to middle Miocene)

Subunit IB is a light gray (N6) to white (N9) foraminifer-bearing nannofossil ooze that grades into a nannofossil ooze with depth. It is distinguished by its color from overlying Subunit IA and underlying Subunit IC. Subunit IB is mottled and burrowed and has ubiquitous streaks, blebs, and diffusion bands of iron sulfides(?). Four distinct, very light gray (N5–N7) ash beds are found at 21.5, 27.7, 29.5, and 29.60 m sub-bottom. Unusual pockets of foraminifers and pyrite(?) occur between 15 and 178 m sub-bottom. Small zones of cemented nodules occur between 100 and 110 m sub-bottom. The cement may be either gypsum, found at this same sub-bottom depth at Site 284 (Kennett, Houtz, et al., 1975), or possibly celestite. Numerous very thin (less than 1 mm) laminae of pale green hues (5G) occur throughout this subunit. These thin laminae may represent altered volcanic glass.

Subunit IC (593: 393.8–418.0 m sub-bottom; middle Miocene)

Subunit IC is distinguished from two overlying and underlying subunits by its distinctive pale orange (10YR 8/2) color but is lithologically identical to the surrounding subunits. The upper contact is quite sharp but the lower contact is gradational and varies in color from very pale orange (10YR 8/2) through yellowish gray (5Y 8/1) to light greenish gray (5GY 8/1) with depth.

Subunit ID (593: 418.0–545.5 m sub-bottom; early middle Miocene to earliest Oligocene)

Subunit ID is a white (N9) nannofossil ooze that is identical in lithology to the lower part of Subunit IB. Subunit ID is defined by its stratigraphic position below the easily recognized pale orange Subunit IC.

Between about 475 and 485 m sub-bottom in Hole 593 and about 455 and 468 m sub-bottom in Hole 593A

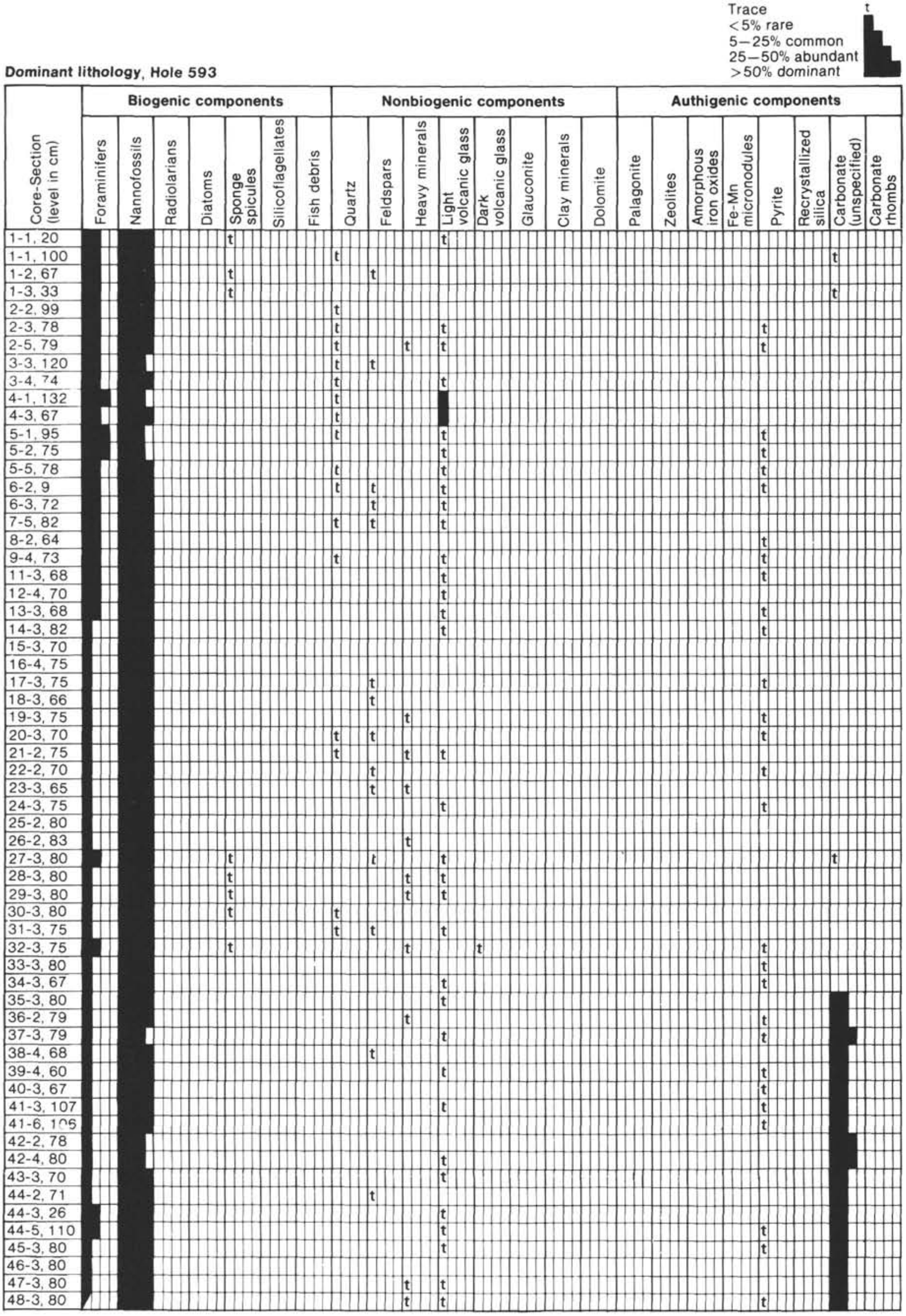

Figure 3. Smear slide summary, Site 593.

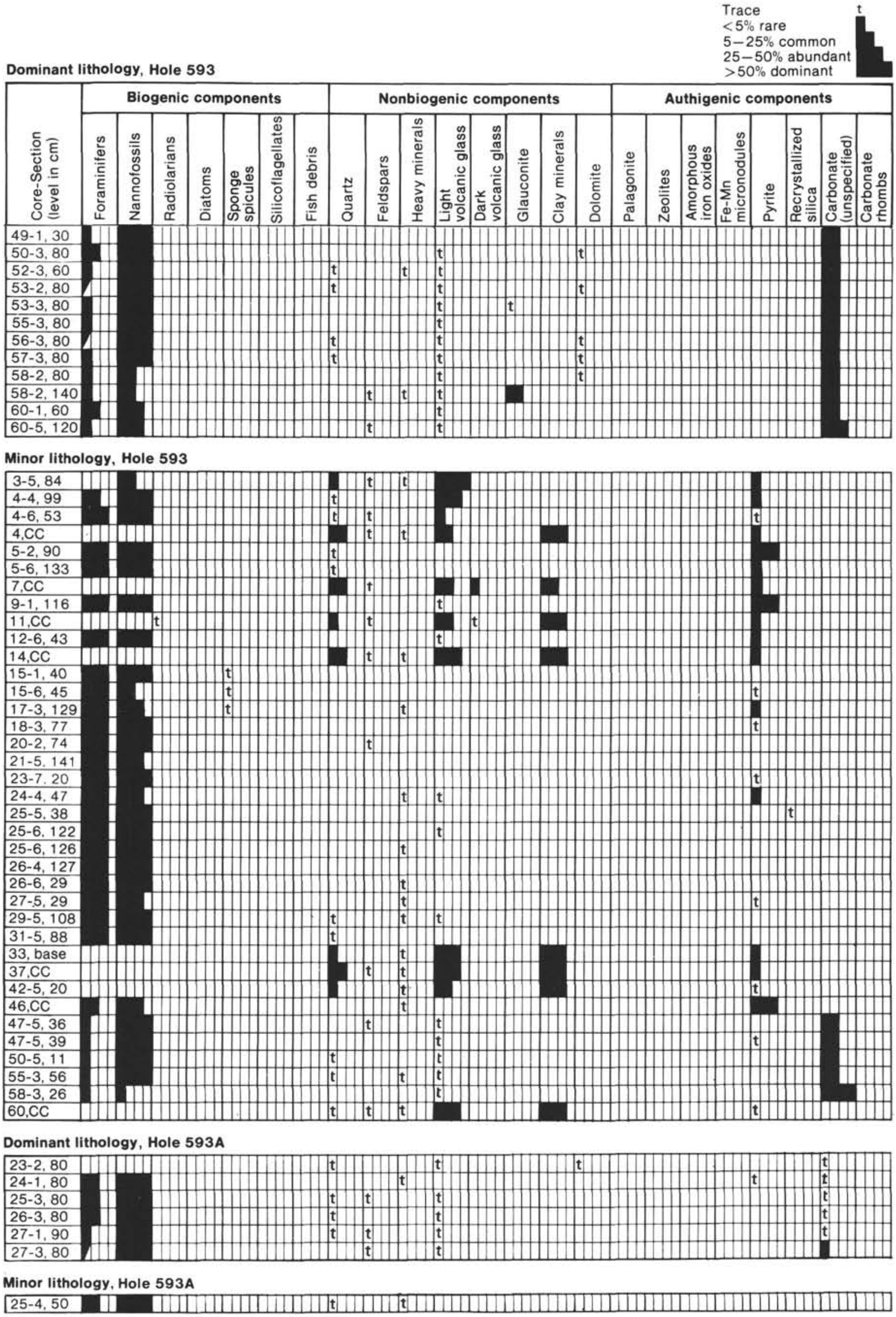

Figure 3. (Continued).

there occurs a zone that proved difficult to recover. The material recovered is composed of very homogeneous, firm, nannofossil ooze, indistinguishable from the sediment above and below. This zone occurs across the Miocene/Oligocene boundary, but the significance of the lack of recovery is unknown.

Unit II (593: 545.5–571.5 m; early late Eocene)

Unit II is composed of interbedded, lithified volcanogenic turbidites and light greenish gray (5GY 7/2) or white (N9) foraminifer-bearing nannofossil chalk to nannofossil chalk. The turbidites are grayish olive green (5GY 3/2) to dark gray (N4) and occur as a sequence of very fine- to coarse-grained packets. Some individual turbidites display good examples of Bouma A and B divisions (coarse massive, graded, to finely laminated) (Fig. 4) which generally dominate Bouma D and E divisions (very fine-grained).

The interbedded nannofossil chalk is identical in lithology to the overlying pelagic subunits but additionally has many thin (less than 2 mm thick), very pale green (10G 8/1) laminae that appear to be altered volcanic ash. The upper contact with Subunit ID is very sharp.

Discussion

The lithofacies at Site 593 is a thick sequence from the early late Eocene to Holocene that represents remarkably consistent pelagic conditions. Curiously there was no evidence of preserved siliceous biogenic material, even though the area had relatively high biogenic productivity—a situation similar to that at Sites 587 through 592. Insoluble residues of bulk sediment yield very small quantities of quartz grains, light-colored volcanic glass, clays, and pyrite(?). No evidence was found of ice-rafted debris at this mid-latitude site, which supports the conclusions of Kennett, Houtz, et al. (1975) that the site has been north of the iceberg limit since the late Miocene and extends this observation back to the late Eocene.

The color change that distinguishes Subunit IC from the surrounding subunits represents a change from post-depositional reduced conditions (Subunit ID) to oxidized conditions (Subunit IC) and back to a post-depositional reduced state (Subunit IB). The event that caused the oxidized state of Subunit IC must have altered the balance between available dissolved oxygen supplied to the seafloor and available organic carbon supplied to the in-

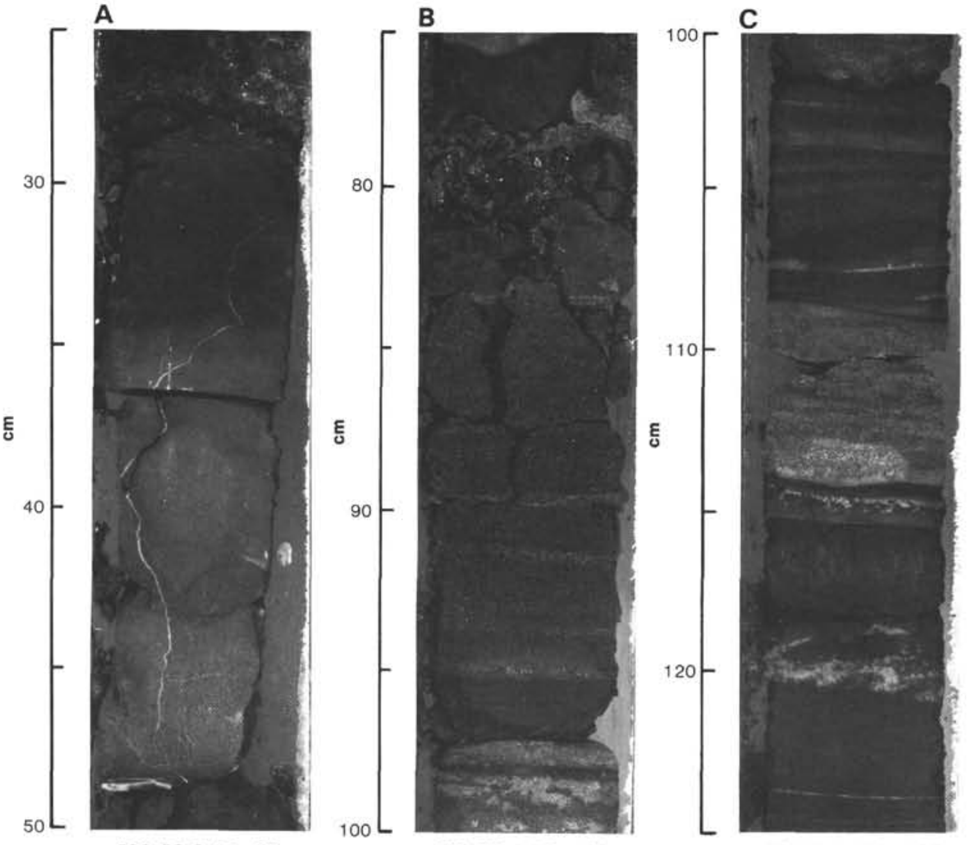

Figure 4. Examples of Bouma structures within lithostratigraphic Unit II, volcanogenic turbidites. A. Sharp basal contact at 48.5 cm with normally graded sequence beginning cross-bedded and laminated fine-grained, then at 28.5 cm the start of another packet. B. A coarse-grained, massive to bedded sequence, beginning at 95 cm, grading at 83 cm into fine-grained interbed, then at 75.5 cm another packet. C. A laminated, coarse-grained sequence at 115 cm, becoming massive and graded at 114 through 108.5 cm, then a rippled, fine-grained sequence through103.7 cm. Notice the erosional contact at 103.7 cm; coarse-grained silts have eroded into the finer-grained underlying material.

fauna and bacteria within the sediment. Compared to over- and underlying subunits, Subunit IC accumulated at a reduced sedimentation rate that allowed aerobic combustion of organic matter to greater burial depths. One possible explanation of this event would be the brief development or intensification of an oceanographic convergence not far to the south of Site 593 during this period. The effects of this convergence would have been relatively short-lived, because the sediment returns to a reduced state in Subunit IB. The surface oxidized zone (Subunit IA) may represent a similar phenomenon that reflects the flow of oxygen-charged Antarctic Intermediate Water from the Antarctic Convergence (Fig. 5).

The lithified volcanogenic turbidites and thin laminae of altered volcanic ash represents an episode of local volcanism in the late Eocene. The thin laminae of ash probably represents air-fall deposits and were regional precursors to the event or events that generated the turbidites. The internal structures of the individual flows, especially the dominant occurrence of Bouma A and B divisions compared to Bouma D and E divisions, suggest proximal rather than distal deposits (Walker, 1967). These observations imply that the source of the volcaniclastic material may have been nearby on the Challenger Plateau or, more likely, from "Lalitha Pinnacle," a buried volcanic "high" observed on the seismic profile to be near Site 593. The upper 115 m of the sequence is a foraminifer-bearing nannofossil ooze that probably represents an interval when bottom currents in this area were strong enough to winnow some nannofossils from the sediment, thereby increasing the relative abundance of foraminifers. The upper winnowed sequence at Site 593 is similar to the uppermost recovered sections at Sites 587 through 592 and probably coincides with a period of more intensive global oceanic circulation.

PHYSICAL PROPERTIES

The HPC cores recovered from Hole 593 were sampled for gravimetric evaluation using the standard cylinder technique on all of the cores except the final two, for which chunk samples were taken (Boyce, 1976). The GRAPE was employed on selected cores (see Introduction for details of experimental methods). Additional analyses of the physical properties results for Site 593 are reported by Morin (this volume).

The GRAPE saturated-bulk density results (points) are plotted versus depth in Figure 6A. These data are directly converted to sediment porosity by assuming a grain density of 2.691 g/cm^3. The corresponding GRAPE porosity results are presented versus depth in Figure 6B. Mean values of density and porosity across each meter interval are calculated and these averages are plotted as the solid lines. After initially declining through the upper 50 m, porosity remains relatively constant over the next 300 m. This unusual behavior is reflected in the bulk density data. The sediment column shows little or no evidence of systematic, lithostatic compaction within the depth interval of 50 to 350 m. At 550 m, the porosity

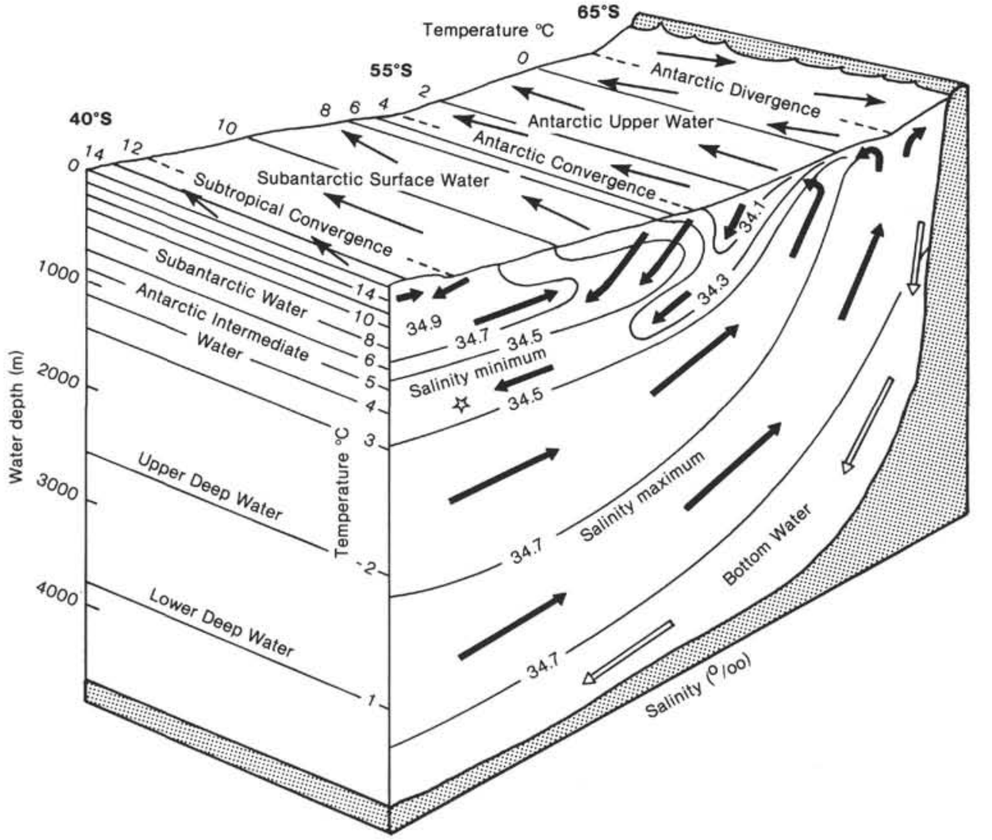

Figure 5. Schematic diagram of the vertical and horizontal structure of flow in the southern oceans (from Knox, 1970). Open star is approximate position of Site 593.

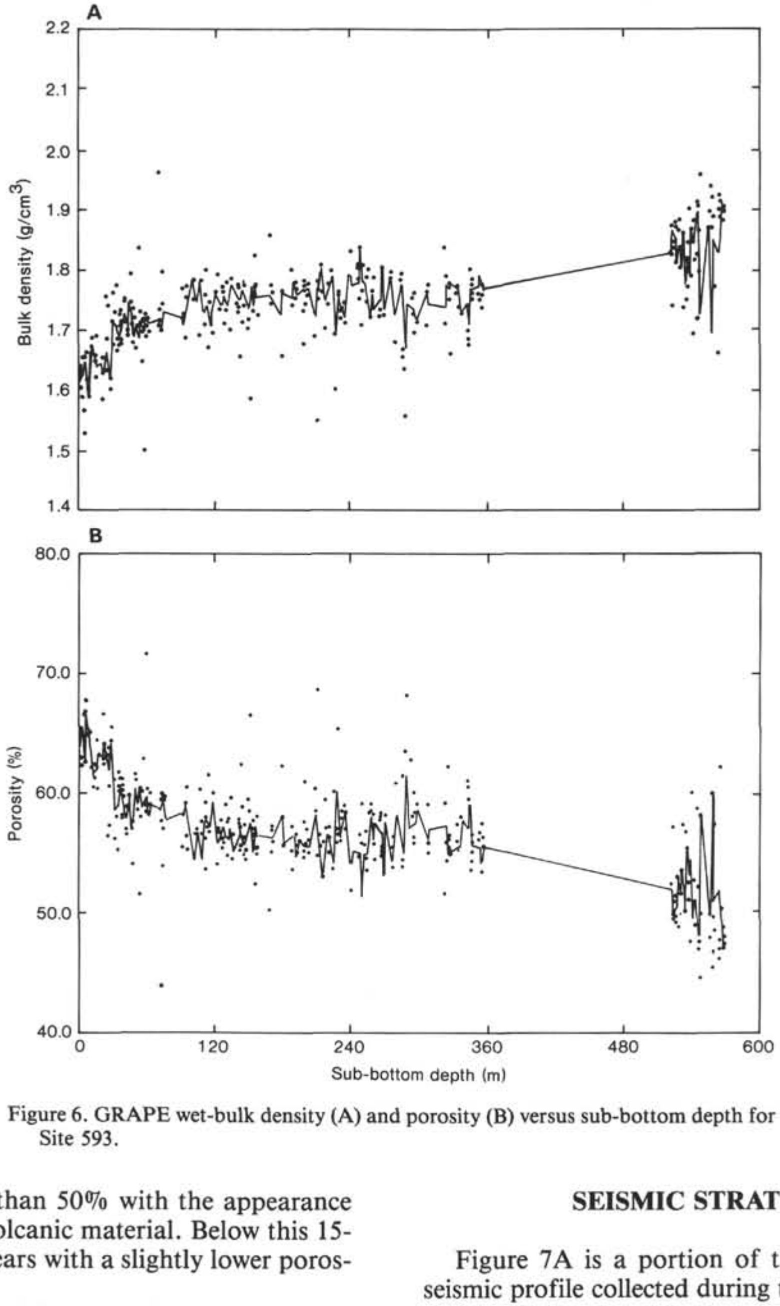

Figure 6. GRAPE wet-bulk density (A) and porosity (B) versus sub-bottom depth for Site 593.

finally decreases to less than 50% with the appearance of a layer of indurated volcanic material. Below this 15-m-thick zone, chalk appears with a slightly lower porosity.

A few chunk samples of the volcanic material was removed from Core 59 for preliminary evaluation. This material has a grain density of approximately 2.80 g/cm^3. Sonic velocity data for these samples were determined and the results show values which are slightly higher (faster) than those found for calcareous sediments of equivalent porosity. For the Core 59 samples, few measurements were performed both parallel and perpendicular to bedding, with the latter producing slightly lower velocities:

Section (level in cm)	Sonic velocity (km/s)	Orientation
1, 70	2.546	Parallel to bedding
2, 70	2.340	Parallel
5, 70	2.155	Perpendicular

SEISMIC STRATIGRAPHY

Figure 7A is a portion of the shipboard water gun seismic profile collected during the approach to Site 593. Figure 7B is a line drawing of the profile, illustrating a possible unconformity at a sub-bottom depth of 0.54 s. Six acoustic units (A–F) have tentatively been identified, and these are compared in part with lithostratigraphic Units IA, IB, IC, ID, and II.

Acoustic Unit A comprises relatively low amplitude parallel reflectors, some of which are separated by acoustically transparent intervals. Acoustic Unit B is a zone of closely spaced parallel reflectors of moderate amplitude. Acoustic Unit C includes an interval of closely spaced parallel reflectors which lie directly below an apparent angular unconformity separating B and C. Alternatively, Units C and B may simply converge in the vicinity of Site 593, at the expense of a somewhat more transparent unit between B and C, which can be seen to lens out or be removed by erosion about 5 n. mi. north of Site 593 (Fig. 7B).

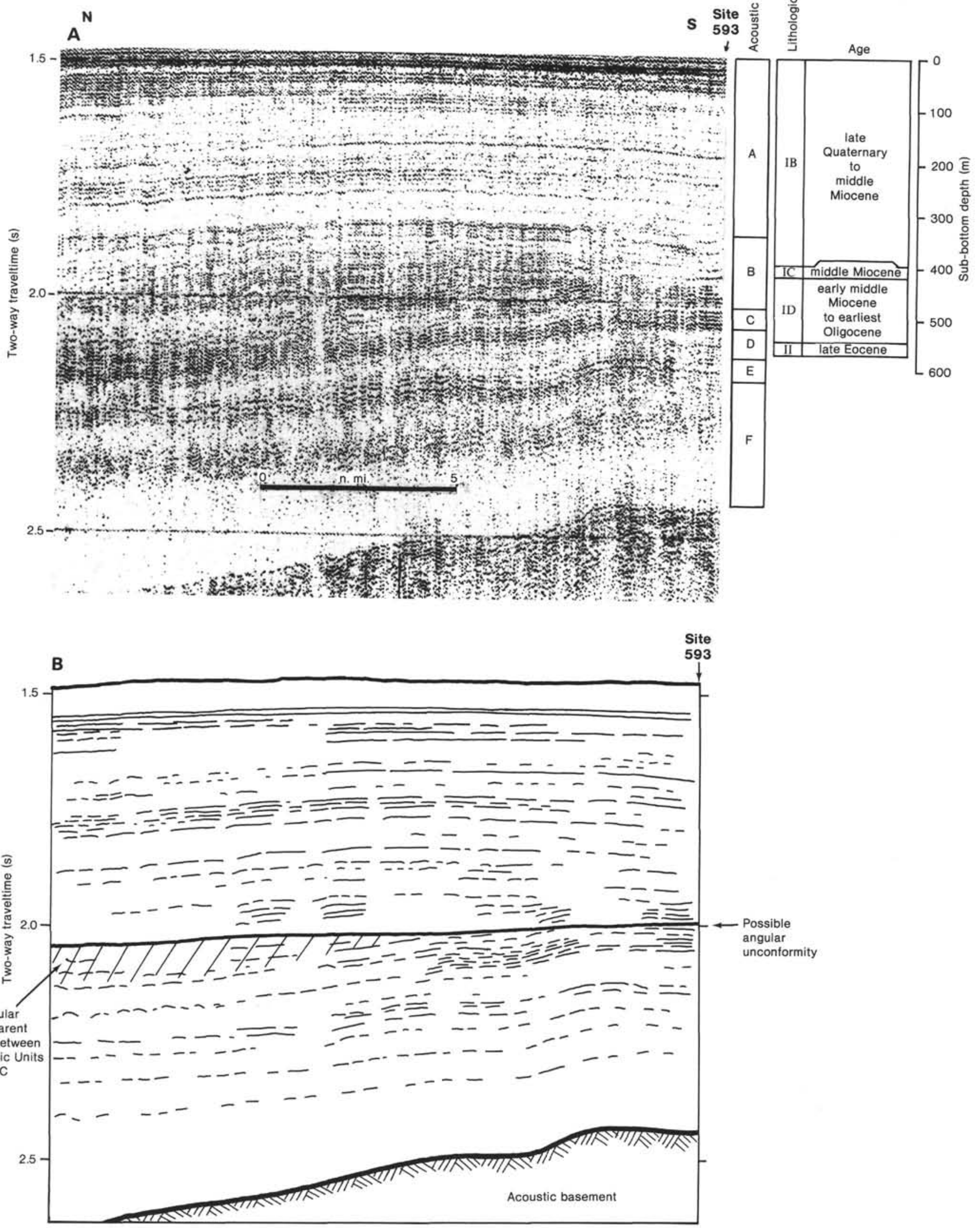

Figure 7. A. Comparison of acoustic Units A–F with lithological Units I and II. Shipboard water gun seismic profile, collected during site approach; depths in meters estimated by assuming a sediment sound velocity of 1800 m/s. B. Line drawing of seismic profile shown in A; note possible angular unconformity and lenticular transparent zone.

Acoustic Unit D is a relatively transparent zone of uniform thickness. This overlies Unit E, an interval of strong, parallel reflectors which are subparallel to those of Unit C.

Acoustic Unit F is a transparent unit which includes an irregular zone of diffuse reflectors. Unit F overlies acoustic basement at a sub-bottom depth of 0.97 s.

Site 593 was drilled to a total depth of 571.5 m. Two lithostratigraphic units (Units I and II) are identified, with Unit I being subdivided into four subunits. Basic lithology of Unit I is a foraminifer-bearing nannofossil ooze. Unit II comprises a sequence of interbedded, lithified, volcanogenic turbidites and minor chalks which coincide with the Eocene/Oligocene boundary.

The lithologic units column shown in Figure 7A arbitrarily correlates the upper Eocene lithologic Unit II with acoustic Unit D. However, it is equally likely that Unit II may be correlated with the relatively strong reflector of acoustic Unit E, or the closely spaced reflectors of acoustic Unit C. Either of these may represent the seismic signature of the volcanogenic turbidites of lithologic Unit II.

BIOSTRATIGRAPHY

At Site 593 a complete sequence of Quaternary to late Eocene age was recovered. Hole 593A duplicated the Quaternary to late Miocene and the early Miocene to late Oligocene interval.

Calcareous nannoplankton and foraminifers are common throughout the drilled succession with the exception of the volcanic sequence in Cores 593-58 and 593-59, where both fossil groups were found only sporadically as contamination from above. Radiolarians, diatoms, and silicoflagellates have not been found at this site. Nannoplankton and foraminiferal zones are correlated in Figures 8 and 9.

The zonations of the calcareous nannoplankton and the planktonic foraminifers are hampered by the lack of certain index species. Discoasters and some ceratoliths are rare or absent from the early Pliocene; this is also true for *Catinaster* and some *Discoaster* species in the middle Miocene and for sphenoliths in the middle and late Oligocene.

A remarkable change in color from yellow brown below to white above was noted in Core 593-42, approximately at the top of nannoplankton Zones NN4/NN5, that is, just prior to the extinction of *Sphenolithus heteromorphus*. Calculation of the sedimentation rates indicates a sudden increase from 9.7 to 48.4 m/m.y. at this level.

The Oligocene/Miocene boundary was placed in Core 593-50, as indicated by the boundary between nannoplankton Zones NP25 and NN1 and the base of the foraminiferal *Globoquadrina dehiscens* Zone. The Eocene/Oligocene boundary probably falls in the interval containing volcanic material in Cores 593-58 and 593-59. The first calcareous layers above contain nannoplankton of the early Oligocene Zone NP21 and a foraminiferal fauna of the *Globigerina brevis* Zone. Samples from within the volcanic sequence contain only some species

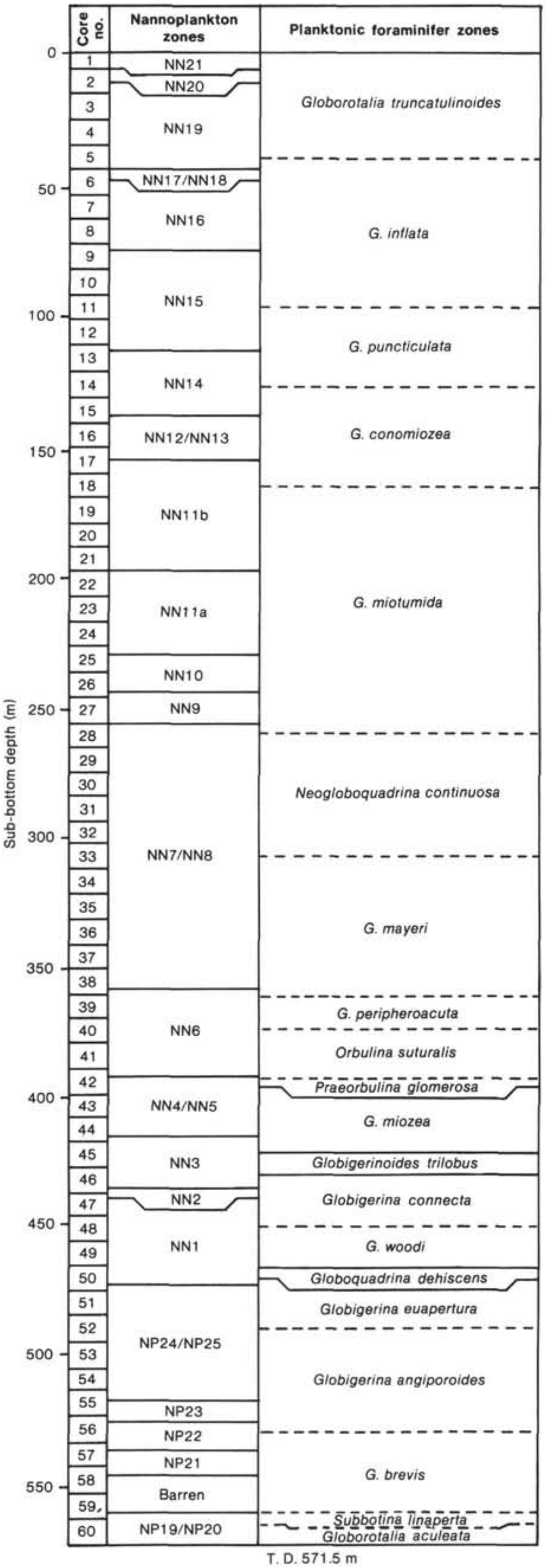

Figure 8. Correlation between calcareous nannoplankton and foraminiferal zones in Hole 593. Hole barren of radiolarians.

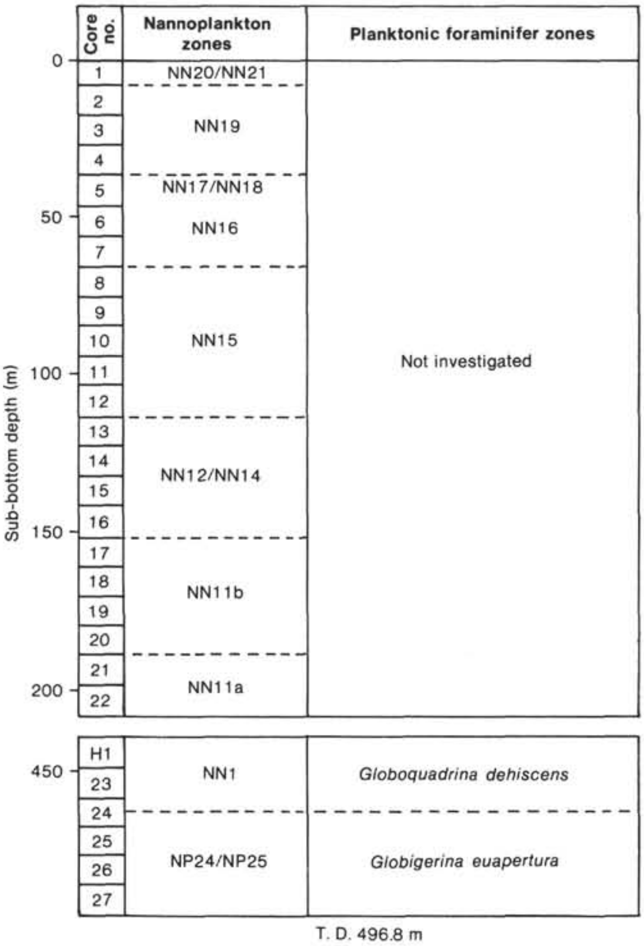

Figure 9. Correlation between calcareous nannoplankton and foraminiferal zones in Hole 593A. Hole barren of radiolarians.

without stratigraphic value and displaced nannoplankton and foraminifers from above, including Miocene and Quaternary species. Sample 593-59,CC could be placed in the late Eocene nannoplankton Zone NP19/NP20 and in the foraminiferal *Subbotina linaperta* Zone. Also reworked nannoplankton species like *Neococcolithus dubius* are present in samples from Core 60, probably in the same stratigraphic level as at Site 592. As the calculation of the sedimentation rate shows no obvious break at this level, a continuous sedimentation is assumed, and determining the absolute age of the volcanic material could provide useful data about the Eocene/Oligocene boundary.

As in Site 592, the Oligocene nannoplankton assemblages contain abundant *Zygrhablithus bijugatus*, indicating a shallow-water environment during this time interval. Data from the benthic foraminifers support this assumption.

Preservation of foraminifers and calcareous nannoplankton is good in the Quaternary and Pliocene, and for the foraminifers also in the Miocene and Oligocene. Preservation of the nannoplankton, however, is only moderate in the Miocene and is poor at certain levels through extensive calcite overgrowth, especially on discoasters and sphenoliths. In the Oligocene also, calcareous nannoplankton are commonly sturdy and exhibit considerable calcite overgrowths. In the late Eocene below the volcanic intercalation, preservation of the calcareous nannoplankton is moderate, but excellent foraminiferal preservation occurs in Sample 593-60,CC.

Planktonic Foraminifers

Zones

The following zones were identified at Site 593; the zonal boundary markers are shown below:

Globorotalia truncatulinoides Zone
  I. A. *G. truncatulinoides*
Globorotalia inflata Zone
  I. A. *G. inflata*
Globorotalia puncticulata Zone
  L. A. *G. conomiozea*
Globorotalia conomiozea Zone
  I. A. *G. conomiozea*
Globorotalia miotumida Zone
  L. A. *G. dehiscens*
Neogloboquadrina continuosa Zone
  L. A. *G. mayeri*
Globorotalia mayeri Zone
  L. A. *G. peripheroacuta*
Globorotalia peripheroacuta Zone
  I. A. *G. peripheroacuta*
Orbulina suturalis Zone
  I. A. *O. suturalis*
Praeorbulina glomerosa curva Zone
  I. A. *P. glomerosa curva*
Globorotalia miozea Zone
  I. A. *G. miozea*
Globigerinoides trilobus Zone
  I. A. *G. trilobus*
Globigerina connecta Zone
  I. A. *G. connecta*
Globigerina woodi Zone
  I. A. *G. woodi*
Globoquadrina dehiscens Zone
  I. A. *G. dehiscens*
Globigerina euapertura Zone
  I. A. *G. angiporoides*
Globigerina angiporoides Zone
  L. A. *G. brevis*
Globigerina brevis Zone
  I. A. *G. brevis*
Subbotina linaperta Zone
  L. A. *G. aculeata*
Globorotalia aculeata Zone

The *Globorotalia tosaensis* Zone and *G. truncatulinoides/G. tosaensis* Zones were not recognized at this site because of the low numbers of *G. tosaensis.* Because of the low numbers of *N. continuosa* and its gradation into *N. pachyderma* in the early late Miocene, it was decided to redefine the upper boundary of the *N. continuosa* Zone at the extinction of *Globoquadrina dehiscens.* This event is regarded as a good marker in the temperate water mass of the southwest Pacific; further north in the Pacific, *G. dehiscens* survived into the base of the N18 Zone at Site 289 (Srinivasan and Kennett, 1981). The *G.*

peripheroacuta Zone of middle Miocene age is recognized on the total range of the zone fossil.

Paleobiogeography

The planktonic foraminifers are abundant and well preserved from the Pleistocene through the Oligocene; faunas were less well preserved in the late Eocene but the lower core-catcher sample at the site produced an excellent fauna.

The late Eocene faunas show a progressive reduction in diversity toward the Eocene/Oligocene boundary; a lower diversity in the early Oligocene indicates cooler waters. Diversity increases toward the end of the Oligocene, which suggests a progressive warming, probably continuing through the early Miocene to the early part of the late Miocene in the lower *Globorotalia miotumida* Zone, where there is a marked change with the extinction of *Globigerinoides trilobus*. There probably was a warming in the late Miocene toward the top of the *Globorotalia miotumida* Zone to the base of the *G. conomiozea* Zone; this observation is based on the presence of *Globigerinella aequilateralis*. During the remaining late Miocene–early Pliocene, *G. aequilateralis* was not present in the area. For the remaining Pliocene to the Pleistocene, the surface water supported *G. aequilateralis* and the occasional *Globigerinoides ruber.*

Of importance at Site 593 is the presence of the short-ranging *Guembelitria samwelli* in the late Oligocene *Globigerina euapertura* Zone; its first appearance may have been a biogeographic response to the initiation of the Circum-Antarctic Current (Jenkins, 1974). Associated with *Guembelitria samwelli* is *Streptochilus pristinum,* and its presence here may also be associated with the initiation of the current.

Major Boundaries

Pliocene/Pleistocene: first appearance of *Globorotalia truncatulinoides*; because of the low numbers of *G. tosaensis*, it is not certain whether the first appearance of *G. truncatulinoides* is its first evolutionary appearance at this site.

Miocene/Pliocene: last appearance of *G. conomiozea*.

Oligocene/Miocene: the first appearance of *Globoquadrina dehiscens*.

Eocene/Oligocene: the extinction of *Globigerinatheka index*.

Benthic Foraminifers

Benthic foraminifers were examined from all core catchers at Site 593 in the fractions >63 μm. Benthics were very abundant in nearly all samples and their preservation remained good almost to the bottom of the hole; cementation was a slight problem in Cores 593-52 through 593-60. At many levels the benthics were fragmented. Dolomite occurs in Cores 593-23 and 593-53 to 593-55; free rhombs and crystals growing out of the foraminifers occur in Core 593-53.

Although the exact species composition of samples varied through the section, in general faunas contained large numbers of cibicidids and planulinids, with *Oridorsalis umbonatus, Bolivina* spp., and *Anomalinoides* spp. consistently present, but in smaller percentages. Uvigerinids become important at discrete intervals, but are consistently present only in the upper Eocene and upper Pliocene through Quaternary. Agglutinated genera are less abundant here than at other sites.

Along the Lord Howe Rise there is a north–south gradient in the abundances of several species. *Osangularia bengalensis, O. culter*, species of *Melonis, Rectuvigerina multistriata, Gyroidinoides nitidula, Uvigerina gemmaeformis, Anomalinoides globulosa*, and numerous other forms are less common in Site 593. Species more common at Site 593 than in sites to the north include not only the New Zealand endemic forms such as *Hopkinsina mioindex, Rotaliatina sulcigera,* and *Cibicidoides molestus,* but also *Bulimina aculeata, Uvigerina* aff. *mediterranea, Vulvulina haeringensis, Planulina marialana gigas,* and *P. harangensis*.

Eocene faunas (Cores 60–57) are generally similar to those at Site 592; there is a smaller proportion of large, ornamented cibicidids such as *C. molestus* and *Cibicides tholus* at Site 593, but a larger proportion of *Globocassidulina subglobosa* and *Uvigerina bortotara* and *U. rippensis-havanensis*. The distinctive species of *Vaginulinopsis* present at Site 592 were not found here.

Changes across the Eocene/Oligocene boundary (Cores 593-57 to 593-55) include the disappearance of *U. rippensis,* the first appearance of *Sphaeroidina bulloides,* and a change in dominance from cibicidids, particularly the larger ornamented types, to *Globocassidulina subglobosa*, which remains dominant through most of the Oligocene. In the basal Oligocene the striate bolivinids, *Martinottiella occidentalis* and *Cassidulina crassa,* first appear, and the hispido-costate uvigerinids are replaced by *Rectuvigerina multistriata* and, in Cores 593-53 to 593-52, the typical North Atlantic species *U. semivestita*. The first appearances of all these species agree with their proposed evolution in other parts of the world ocean.

Between Cores 593-50 and 593-52 (upper Oligocene, *Globigerina angiporoides/G. euapertura* Zones) the Circum-Antarctica Current is postulated to have developed. There is much breakage of the fossils in these two cores. Diversity of the benthics decreases (possibly because preservation was poorer) and several new species first occur at this site, including the important Neogene species *Heterolepa kullenbergi* and *U. pygmaea*.

Several of the typically Paleogene benthic species disappear during the early Miocene (Cores 593-49 to 593-40) at this site, including *Cibicidoides tuxpamensis, C. io,* and *Bulimina macilenta.* Lower Miocene faunas demonstrate little change in diversity, but contain distinctly fewer individuals than those of other times. The consistent presence of *Robulus* spp. through this interval is important, since it allows correlation with the dissolved faunas through this interval at Site 592. At both sites, then, the low numbers of benthics reflect some property of the environment, not just dissolution effects.

In the lowermost middle Miocene (Cores 593-43 to 593-42, *Praeorbulina glomerosa curva–Globorotalia miozea* Zones), there is a yellow, oxidized layer through the sediments. In this interval the character of the benthic fauna remains surprisingly constant. A few forms appear, including *Melonis barleeanum, Bolivina anastomosa,* and *Uvigerina auberiana.* However, the small, hispid uvigerinids occur in large numbers in Sample 593-42,CC and may be a reflection of the suggested oxidation of these levels. Such uvigerinids are typical of the shallowest and deepest parts of the oceanic water column, which are generally oxygen-rich.

The large change during the lower Miocene occurs in the *P. glomerosa curva* to *Orbulina suturalis* Zones. Both the diversity and abundance of benthics increase. The rectuvigerinids disappear temporarily and seven new entrants appear, at least four of which are cibicidids. *Nuttalides umbonifera*, a form correlated with deep water masses later in the Neogene, first occurs at this site.

The new, typically Pliocene–Quaternary benthic species first evolve in the mid-Miocene *Globorotalia* Zone (Cores 593-38 to 593-34). Such species as *Cassidulina carinata, Cibicidoides mundulus, C. cicatricosus,* and *Rectuvigerina spinea* first appear at this time, but disappear by the *Neogloboquadrina continuosa* Zone, only to reappear in the Pliocene.

The first pulse of miliolids, accompanied by the deep-water index, *Pullenia quinqueloba,* appears in the *G. miotumida* Zone (Cores 28 to 27). The only consistent occurrences of the more northerly species *Osangularia bengalensis* and less common *O. culter* occur throughout most of this zone.

Uvigerinids again appear at the top of the *G. conomiozea* Zone, as at other sites on this leg; however, at this site the species which mark the top of the Miocene are *Uvigerina auberiana* and *U. pygmaea,* both tiny species more typical of deeper waters and sites.

A larger change in benthic faunas and in the uvigerinids occurs, however, in the basal Pliocene (Cores 593-11 and 593-12). Benthic diversity drops, there is an influx of miliolids, and particularly of large, abraded spiroloculinids which may be redeposited from shallower water. *U. hispido-costata* occurs for the first time and continues to occur at this site through the course of the Pliocene and Quaternary.

The faunal changes associated with the development of Northern Hemisphere glaciation inferred between Cores 593-11 and 593-9 (*Globorotalia puncticulata/G. inflata* Zones) are less prominent than the changes that occur in the early Pliocene. Diversity drops, several species disappear, *Globocassidulina* increases in abundance, and *N. umbonifera* again appears in the faunas, albeit in small numbers.

Within the *Globorotalia inflata* Zone (Cores 593-7 to 593-4) miliolids become more important, *Bulimina aculeata* first occurs and becomes a prominent part of the faunas, and the deeper-water index, *P. quinqueloba,* occurs through most of the zone. Beginning in this zone there is a trend to lower diversity and higher dominance of the fewer species. This trend is accentuated in the Quaternary, when only a few species, including *Cassidulina carinata* and *B. aculeata*, are very abundant. *Epistominella exigua* appears in the Pleistocene (Sample 593-2,CC) at this site.

Calcareous Nannoplankton

Core-catcher samples and enough additional samples accurately to determine zonal boundaries were examined for calcareous nannoplankton. Some of the zonal indicators are absent at Site 593. Middle and late Oligocene zone-defining sphenoliths were not observed, and Zones NP24/NP25 could not be differentiated. The first occurrence of *Discoaster exilis* is used to define the top of the *Helicosphaera ampliaperta* Zone (NN4) instead of the last occurrence of *Helicosphaera ampliaperta.* The top of the *D. asymmetricus* Zone (NN14) is defined on the last occurrence of *Amaurolithus primus* instead of *A. tricorniculatus* in Hole 593. (*A. tricorniculatus* was observed at this level in Hole 593A.) The last occurrence of *D. neohamatus* is used instead of the first occurrence of *D. quinqueramus* to approximate the top of the *D. calcaris* Zone (NN10). *Catinaster coalitus* and *D. kugleri* were not observed at this site.

Calcareous nannoplankton are abundant throughout the section at Site 593. Most species are well preserved but most discoasters become progressively more overgrown with depth. Many early and middle Miocene sphenoliths are also overgrown.

Hole 593

Quaternary

Samples 593-1,CC and 593-2-3, 3–4 cm are above the last occurrence of *Pseudoemiliania lacunosa* and belong in the late Quaternary *Gephyrocapsa oceanica* Zone or *Emiliania huxleyi* Zone (NN20/NN21).

The upper part of the early Pleistocene *Pseudoemiliania lacunosa* Zone (NN19b) includes Samples 593-2-5, 3–4 cm to 593-3-1, 3–4 cm. The last occurrence of *Calcidiscus macintyrei* in Sample 593-3-3, 3–4 cm places this Sample 593-5,CC in the lower part of the *P. lacunosa* Zone (NN19a).

Pliocene

The last occurrence of *Discoaster brouweri* in Sample 593-6-1, 3–4 cm places this sample in the late Pliocene *Discoaster brouweri* Zone (NN18). The addition of *D. pentaradiatus* in Sample 593-6-2, 3–4 cm places this sample in the *D. pentaradiatus* Zone (NN17). The late Pliocene *D. surculus* Zone (NN16) includes Samples 593-6-3, 3–4 cm to 593-9-1, 3–4 cm, above the last occurrence of *Reticulofenestra pseudoumbilica* Zone (NN15) includes Samples 593-9-3, 3–4 cm. The early Pliocene *Reticulofenestra pseudoumbilica* in Sample 593-9-3, 3–4 cm to 593-13-1, 3–4 cm. *Amaurolithus tricorniculatus* was not observed in Hole 593. Instead, the last occurrence of *A. primus* in Sample 593-13-3, 3–4 cm is used to mark the top of the early Pliocene *Discoaster asymmetricus* Zone (NN14), which includes this sample to Sample 593-15-5, 3–4 cm. Samples 593-15,CC and 593-16,CC are placed in the combined *A. tricorniculatus/Ceratolithus rugosus* Zone (NN12/13). The boundary between these zones is defined by the first occurrence of *Ceratolithus rugosus*, which was not observed at this site.

Miocene

The last occurrence of *D. quinqueramus* in Sample 593-17-5, 3-4 cm and first occurrence of *A. primus* in Sample 593-22,CC places this interval in the upper subzone of the late Miocene *D. quinqueramus* Zone (NN11b). In the absence of *D. quinqueramus* below this level, the base of the lower subzone (NN11a) is placed between Samples 593-25-1, 3-4 cm and 593-25-3, 3-4 cm, the last occurrence of *D. neohamatus*, which approximates the first occurrence of *D. quinqueramus.* Samples 593-25-3, 3-4 cm to 593-26-5, 3-4 cm, above the last occurrence of *D. hamatus* in Sample 593-26,CC, are placed in the middle Miocene *D. calcaris* Zone (NN10). The range of *D. hamatus* from Samples 593-26,CC to 593-27,CC places these samples in the middle Miocene *D. hamatus* Zone (NN9).

Catinaster coalitus and *D. kugleri* were not observed at this site; therefore, boundaries between the middle Miocene Zones NN8, NN7, and NN6 cannot be determined. This unzoned interval includes Samples 593-28-1, 3-4 cm to 593-42-4, 99-100 cm. The last occurrence of *Sphenolithus heteromorphus* in Sample 593-42-5, 3-4 cm marks the top of the middle Miocene *Sphenolithus heteromorphus* Zone (NN5). In the absence of *Helicosphaera ampliaperta* at this site, the first occurrence of *D. exilis* in Sample 593-43,CC is used for the base of Zone NN5. Samples 593-44-1, 3-4 cm and 593-44-5, 3-4 cm, above the last occurrence of *S. belemnos* in Sample 593-44,CC, are placed in the early Miocene *Helicosphaera ampliaperta* Zone (NN4). The last occurrence of *Triquetrorhabdulus carinatus* is in Sample 593-46,CC. Therefore Samples 593-44,CC to 593-46-5, 3-4 cm are placed in the early Miocene *Sphenolithus belemnos* Zone (NN3). One sample, 593-46,CC, contains both *T. carinatus* and *D. druggi*, which places it in the early Miocene *D. druggii* Zone (NN2). Samples 593-47-1, 3-4 cm to 593-50-5, 3-4 cm, below the first occurrence of *D. druggii,* are placed in the early Miocene *Triquetrorhabdulus carinatus* Zone (NN1).

Oligocene

The last occurrence of *Zygrhablithus bijugatus* in Sample 593-5, 3-4 cm marks the top of the Oligocene. The last occurrence of *R. umbilica* in Samples 593-56-3, 3-4 cm to 593-57-5, 3-4 cm, above the last occurrence of *Cyclococcolithus formosus* in Sample 593-57-3, 3-4 cm, places these samples in the early Oligocene *H. reticulata* Zone (NP22). The early Oligocene *Ericsonia? subdisticha* Zone (NP21) extends down at least to Sample 593-58-2, 110-111 cm. The base of Zone NP21, the Oligocene/Eocene boundary, is within an interval from Samples 593-58-3, 13 cm to 593-59-4, 71-72 cm.

Eocene

The occurrence of *D. saipanensis* and *Cribrocentrum reticulatum* below or in Sample 593-59,CC and the occurrence of *Isthmolithus recurvus* down to Sample 593-60,CC places this interval in the late Eocene Zone NP19/NP20. From Sample 593-60-1, 6-7 cm downward reworked nannoplankton species from the late middle and early late Eocene, like *Neococcolithus dubius* and *Chiasmolithus solitus*, were noted.

Hole 593A

Core-catcher samples were examined through Core 22 with no significant differences between Holes 593 and 593A. The hole was washed down to 448.8 m sub-bottom. Samples 593A-23,CC to 593A-24-1, 3-4 cm are placed in the early Miocene *T. carinatus* Zone (NN1) by the presence of *T. carinatus* and the absence of *D. druggii.*

The occurrence of *Z. bijugatus* and *H. recta* in Sample 593A-24,CC places this sample in the late Oligocene *S. ciperoensis* Zone (NP25). The Oligocene/Miocene boundary is between Samples 593A-24-1, 3-4 cm and 593A-24,CC. Three additional cores were drilled below Core 24 and are of late Oligocene age.

Radiolarians, Diatoms, and Silicoflagellates

Radiolarians, diatoms, and silicoflagellates were not observed in the late Eocene to Recent sequence at this site.

PALEOMAGNETISM

The magnetic properties of sediments from Site 593 were generally similar to those from Site 592 except for an extended zone of high intensity from 360 to 455 m sub-bottom depth encompassing Subunit IC. Intensities were slightly higher than at Site 592. A polarity stratigraphy was obtained back to 3.3 m.y. ago.

Hole 593 was generally subsampled at three specimens per section and the first 11 cores from Hole 593A were subsampled at two or sometimes three specimens per section. The Kuster orientation tool has a success rate of 64% in Hole 593, with good agreement between drift (i.e., tilt) azimuths. Four cores from Hole 593A were oriented. Laboratory measurements for NRM have been completed on most specimens from Hole 593, and low-field susceptibility measurements have been made on Cores 593-1 to 593-24. Shipboard NRM measurements were made on the volcanogenic turbidite zone in Hole 593. The few shipboard measurements made on Hole 593A were consistent with results from Hole 593. NRM statistics for Hole 593, excluding the volcanogenic turbidite zone, are as follows:

Geometric mean intensity (μG) = 0.110
Scalar mean inclination (±1 s.d.) = +3.9 ±41.7°
Axial dipole inclination = −59.7°
Mean angle between repeats = 20.3° (55 repeats)

Low-field susceptibilities were marginally higher than for the corresponding units at Site 592:

Zone (Core-Section, level in cm)	Susceptibility
1-1, 10 to 1-1, 125	Weak positive
1-2, 10 to 6-3, 25	Diamagnetic
6-4, 25 to 14-4, 125	Weak positive (~1-3 μG/Oe)
14-5, 25 to 17-2, 25	Very weak positive (<1 μG/Oe)
14-7, 75 to 26-1, 75	Diamagnetic

The comment made in the Site 592 paleomagnetic report concerning the significance of diamagnetic (negative) susceptibilities is equally applicable here.

The magnetization of these carbonate oozes is extremely weak. Intensities fall from about 15 to about 0.4 μG in the uppermost half meter of pale brown oxidized sediment, thence to characteristically low values below the bottom of Core 593-1. The surficial high-intensity layer was absent from the top of Hole 593A. A region of uniformly high intensity (1.5 to 4 μG) spans Cores 593-41 through 593-46, preceded by a gradual increase starting at the bottom of Core 593-50 and terminating with a steady decline in Cores 593-40 and 593-39. The range of this zone is somewhat wider than that of the pale orange to yellow gray Subunit IC. It appears to correlate with similar zones at Sites 588 and 592 and marks a change in the sedimentological regime over a wide area during the early and middle Miocene. Stein and Sarnthein (this volume) propose that during this period Australia would have been at higher latitudes and exposed to strong westerly winds, resulting in an increase in eolian terrigenous material in sediments on the Lord Howe Rise. This would account for the high-intensity zone, but is not a convincing explanation of the fairly abrupt termination of the zone.

A magnetic polarity stratigraphy can be traced downward as far as the middle of the Gauss Chron at about 3.3 m.y. (Fig. 10). Deformation caused by coring was fairly common in the first eight cores from Hole 593. Despite this the Brunhes/Matuyama boundary and the Jaramillo Subchron appear to be well resolved. It was not possible to identify the Olduvai Subchron, and the lower part of the stratigraphy given in the figure is somewhat speculative. At greater depths, with the exception of the volcanogenic Unit II, directions are too scattered for a polarity interpretation to be made based on the NRM data.

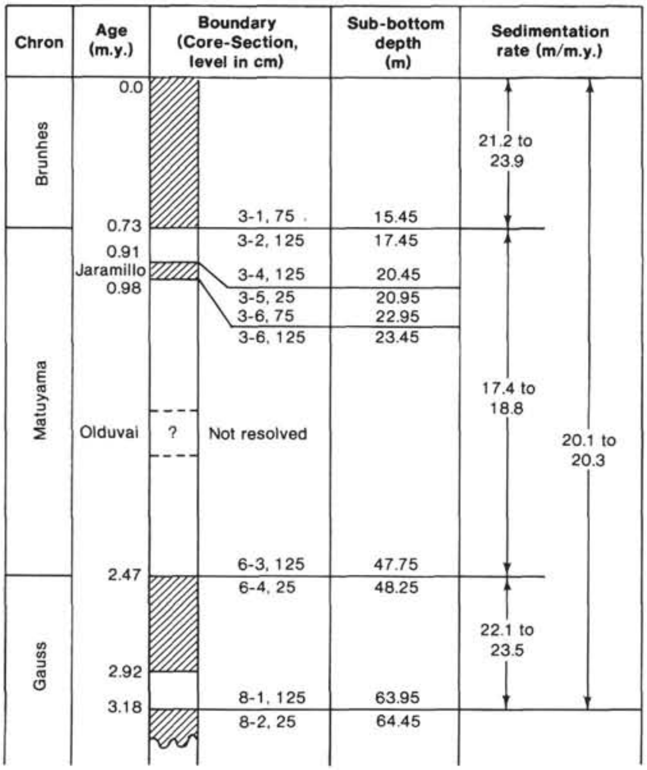

Figure 10. Magnetic polarity stratigraphy for the upper part of Hole 593.

It was surprising to find predominantly reversed (positive) inclinations for Cores 593-34 through 593-46. Much of this interval comprises the early and early middle Miocene high-intensity region in which directional data are highly reproducible. Furthermore, declinations in the high-intensity region were found to fall nearly always into the same quadrant for successive cores with positive inclinations, despite the fact that the azimuthal orientation of successive cores is expected to be random. It must be concluded therefore that the sediments in this region have acquired a large secondary remanence, either during or after coring. Partial AF demagnetization tests on this hole have yet to be performed.

Shipboard NRM measurements on the volcanogenic turbidite Unit II indicated reversed polarity throughout and magnetizations much less than would be expected for fresh volcanic material (Table 3). Lower intensities tended to be associated with the more fine-grained samples, which points to a greater degree of alteration in the fine-grained material.

SEDIMENTATION RATES

Sedimentation rates are calculated as outlined for the previous sites, but intervals used are subdivided if necessary or slightly changed according to datum levels available, especially in the early Miocene and middle to late Oligocene (Fig. 11). A few nannoplankton zones had to be combined, because some index species are missing at this southern high latitude.

In the late Eocene and Oligocene interval (nannoplankton Zones NP19/NP20 top to NP25 top) the sedimentation rate is only 4.6 m/m.y. (including the volcanic material in Cores 58 and 59). In the early to early middle Miocene (Zones NP25 top to NN5 top) the sedimentation rate is 9.7 m/m.y., based on five datum levels. At the top of nannoplankton Zone NN5 the sedimentation rate increases very suddenly to 48.4 m/m.y. in the middle Miocene (Zones NN5 top to NN8 top), at a level which is marked by change of color from yellow brown to white in the calcareous sediments (Core 593-42). In the late Miocene and early Pliocene (nannoplankton

Table 3. NRM data for the volcanogenic turbidite Unit II.

Core-Section (level in cm)	Intensity (μG)	Polarity[a]	Inclination	Comments
58-3, 30–32	6.94	R	15	Bedded, fine-grained, black
58-3, 72–74	14.91	R	50	Uniform, med.-grained, green/gray
59-1, 94–96	111.62	R	53	Bedded, fine/med., green/black
59-2, 132–134	~220.00	R	Pos.	Mottled, med./coarse, green/gray
59-3, 50–52	77.76	R	70	Bedded horiz., med., green/gray
59-3, 132–134	20.31	R	49	Fine, black/green
59-4, 128–130	0.32	R?	25	V. fine, black
59-5, 65–67	0.67	N?	−22	Reproducible med., green/gray
59-5, 100–102	1.61	R	9	Fine, half gray, half black laminated
59,CC 10–12	0.35	R?	Pos.	Med., gray (with CO_3)
60-2, 75–77	0.39	R?	−45	Burrowed, fine, pale gray

Note: Queries denote specimens too weak to be measured reliably.
[a] R = reversed, N = normal.

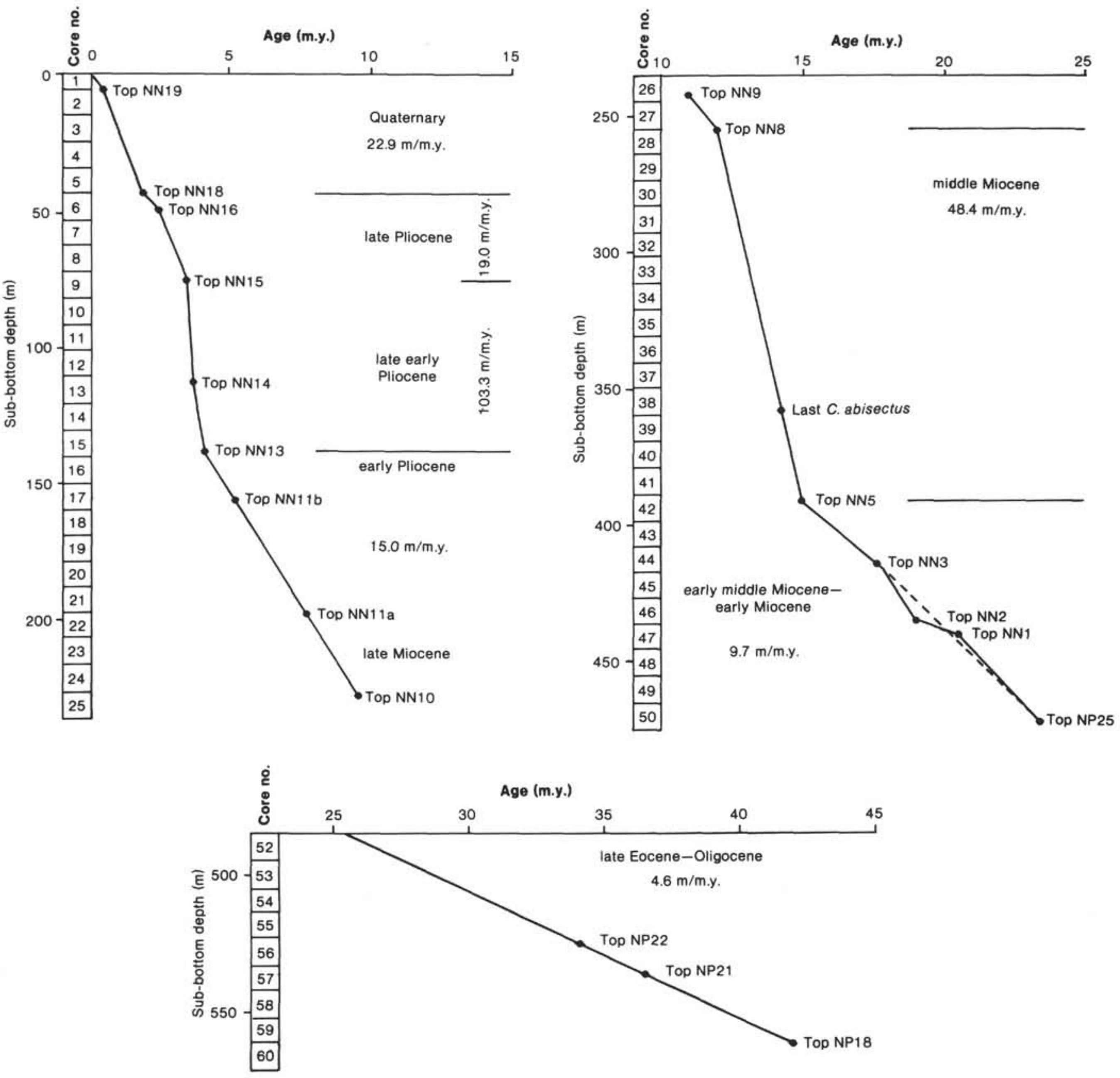

Figure 11. Sedimentation rates and datum levels in Hole 593.

Zones NN8 top to NN13 top) the sedimentation rate drops to 15.0 m/m.y., based on five datum levels.

As was true for previous sites, the sedimentation rate increases in the late early Pliocene (nannoplankton Zones NN14 and NN15), and is 103.3 m/m.y. In the late Pliocene (Zones NN16 to NN18) it drops again to 19.0 m/m.y., based on three datum levels. In the Quaternary (above nannoplankton Zone NN18 top), it increases slightly to 22.9 m/m.y., which is more than twice the amount of that at Site 592.

SUMMARY AND CONCLUSIONS

Site 593 is located on the Challenger Plateau, a western extension of the New Zealand Plateau, in a relatively shallow water depth of 1068 m at a position 40°30.47′S, 167°40.47′E. The Challenger Plateau is effectively a topographic extension of Lord Howe Rise and its western part provides a shallow-water pedestal 270 km distant from the nearest land mass of northern South Island, New Zealand. This setting has allowed accumulation of an uncomplicated Paleogene to Neogene pelagic ooze sequence with virtually no terrigenous sedimentary influences. Site 593 is a reoccupation of Site 284, which was cored during Leg 29 of the Deep Sea Drilling Project.

Site 593 consists of two holes continuously cored to a maximum sub-bottom depth of 571.5 m. Hole 593 was cored with the HPC from 0 to 254.1 m sub-bottom and continued to a total depth of 571.5 m with the XCB. Hole 593A was continuously cored with the HPC from 0 to 209.3 m sub-bottom, then washed down to 448.8 m and cored with the XCB to 496.8 m to recover the Oligocene/Miocene transition. This interval was poorly cored in the first hole.

Site 593 is an apparently continuous stratigraphic sequence from the late Eocene (42 m.y. ago) to the Quaternary (Fig. 12). The general facies is a rather monotonous foraminifer-bearing nannofossil ooze that grades into a nannofossil ooze and a nannofossil chalk with depth. The transition to reduced abundances of foraminifers, from about 15 to about 5%, occurs at about 110 m. The sediment is predominantly calcareous nannofossils with subordinate foraminifers. Other components, such as quartz and feldspar grains, volcanic glass, and pyrite(?), occur only in trace (<1%) abundances (Fig. 3). Micritic carbonate occurs in persistent abundances of 5 to 10% from 323 m to total depth, but the sediment does not become chalk until 562 m. The only biogenic silica found comprised traces (<1%) of sponge spicules in a zone from about 249 to 296 m.

The sequence at Site 593 has been divided into two units. Unit I has been subdivided into four subunits (Fig. 12):

Subunit IA, of late Quaternary age, is a yellow gray foraminifer-bearing nannofossil ooze and represents an upper oxidized layer, correlating with a similar subunit at most other sites. The relatively high content of foraminifers appears to be the result of winnowing.

Subunit IB, of late Quaternary to middle Miocene age, is a light gray foraminifer-bearing nannofossil ooze that grades into a nannofossil ooze with depth. It is distinguished by its much lighter color compared with overlying Subunit IA and underlying Subunit IC.

Subunit IC, of middle Miocene age, is distinguished from two overlying and underlying subunits by its distinctive pale orange color, but is otherwise homogeneous and identical in lithology to the surrounding subunits.

Subunit ID, of early middle Miocene to earliest Oligocene age, is a white nannofossil ooze that is identical in lithology to the lower part of Subunit IB. Subunit ID is defined by its stratigraphic position below the easily recognized pale orange Subunit IC.

Between about 475 and 485 m in Hole 593 and about 455 and 468 m in Hole 593A, there occurs a zone that was difficult to recover. It comprises very homogeneous, firm, nannofossil ooze, indistinguishable from the sediment above and below. This zone occurs across the Miocene/Oligocene boundary. The reason for lack of recovery is unknown.

Unit II, of late earliest Oligocene to early late Eocene age, is composed of interbedded, lithified volcanogenic turbidites and pyroclastic flows and light greenish gray or white foraminifer-bearing nannofossil chalk to nannofossil chalk. The turbidites are grayish olive green to dark gray and occur as a sequence of very fine- to coarse-grained packets.

The interbedded nannofossil chalk is identical in lithology to the overlying pelagic subunits but additionally contains many thin (<2 mm thick), very pale green laminae that appear to be altered volcanic ash. The upper contact with Subunit ID is very sharp.

Site 593 offers a very fine, complete biostratigraphic succession in southern temperate latitudes. A paleomagnetic polarity stratigraphy has been identified back to the middle of the Gauss Chron (3.2 m.y. ago). Calcareous nannoplankton and foraminifers are common throughout except in the volcanic sequence, where both fossil groups were found sporadically only as contamination from above. Radiolarians, diatoms, and silicoflagellates have not been found at this site. Correlations between nannoplankton and foraminiferal zones are shown in Figure 12.

Preservation of foraminifers is of high quality through the entire section except for the Eocene. Calcareous nannofossils are well preserved in the Quaternary and Pliocene, but only moderately so in the Miocene and poorly so at certain levels because of the extensive calcite overgrowth, especially on discoasters and sphenoliths. In the Oligocene, calcareous nannoplankton are commonly sturdy and also exhibit considerable calcite overgrowths. In the late Eocene below the volcanic intercalation, preservation is improved for the calcareous nannoplankton; Core 60 contains well-preserved nannoplankton and excellently preserved foraminifers.

The zonation of planktonic foraminifers is typically that of the temperate regions. However, the zonation of the calcareous nannofossils is much more generalized than is true at lower latitudes. Warm-water calcareous nannofossils become much less common at this site. A number of mid- to low-latitude zones cannot be recognized because certain index species are missing. Discoasters and some ceratoliths are rare or absent from the early Pliocene. In the middle Miocene, *Catinaster* and some discoasters are rare or absent, which is also true for sphenoliths in the middle and late Oligocene.

All of the epoch boundaries are well represented at Site 593, from the Eocene/Oligocene to the Pliocene/Pleistocene. Of particular interest at this site are the Oligocene/Miocene and the Eocene/Oligocene boundaries. The Oligocene/Miocene boundary was encountered in Core 593-59, as indicated by the boundary between nannoplankton Zones NP25 and NN1 and the base of the foraminiferal *Globoquadrina dehiscens* Zone. This boundary coincides with a much firmer nannofossil ooze/chalk zone that is otherwise homogeneous with the surrounding sediments. The significance of this layer is as yet unknown. The Eocene/Oligocene boundary falls in the interval containing volcanic material in Cores 593-58 and 593-59. The first calcareous layers above contain nannoplankton of the early Oligocene Zone NP21 and a foraminiferal fauna of the *Globigerina brevis* Zone. Samples from within the volcanic sequence contain only some species without stratigraphic value and displaced nannoplankton and foraminifers from above, including Miocene species. Sample 593-59,CC could be placed in the late Eocene nannoplankton Zone NP19/NP20 and in the foraminiferal *Subbotina linaperta* Zone. As the calculation of the sedimentation rate shows no obvious break at this level, a continuous sedimentation rate is assumed,

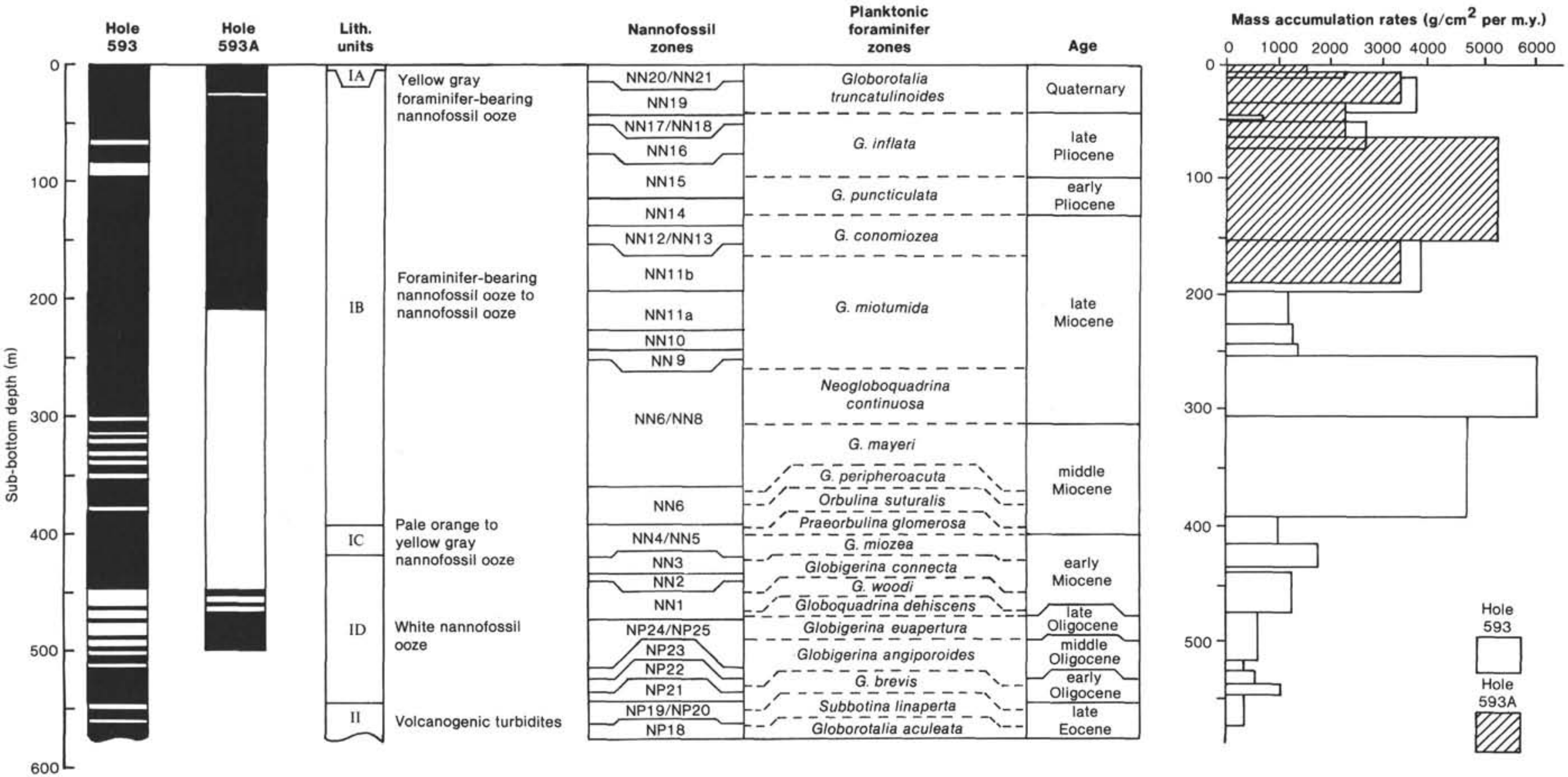

Figure 12. Summary lithology, biostratigraphy, and mass accumulation rates of Site 593 (recovery in black).

and the determination of a radiometric age for the volcanic material should assist with the dating of the Eocene/Oligocene boundary.

Paleoenvironmental History of Site 593

In general, the monotonous sedimentary sequence at Site 593 indicates a very consistent environment of deposition during the last 42 m.y., punctuated only by two major events at 38 m.y. ago and 15.5 to 15 m.y. ago and a minor event at 23.5 m.y. ago. The calcareous oozes were deposited in an oceanic environment at middle bathyal depths on the Challenger Plateau, with little evidence that the depth of the ocean floor changed. There was virtually no terrigenous input except for minor volcanic ash layers.

Nannofossil ooze (now chalk) was deposited during the late Eocene. The presence of many altered volcanic ash layers indicate that this was an active period of explosive volcanicity (42 to 38 m.y. ago).

This largely biogenic sedimentation was suddenly interrupted at the end of the Eocene (about 38 m.y. ago) by the deposition at the Eocene/Oligocene boundary of a 15-m layer of volcanogenic proximal turbidites, debris flows, and pyroclastic flows. These were deposited, probably rapidly, as a result of submarine volcanism at middle(?) bathyal depths, probably from "Lalitha Pinnacle," a small, now-buried volcanic pinnacle only 2 or 3 km from Site 593. Judging by seismic evidence, this volcanogenic deposit seems to have flowed several kilometers to the north of Site 593 and also seems to have been the only such event in this region during the Paleogene. The laminae of altered volcanic ash in the late Eocene probably represent air-fall deposits that were precursors to the submarine volcanic event that produced the pyroclastic deposits. Coeval volcanism occurred in the southern New Zealand region. The Deborah volcanics, South Canterbury, for instance, were also extruded at the time of the Eocene/Oligocene boundary. Similar volcanic pinnacles like "Lalitha" occur at other locations on the Challenger Plateau, and their structural relations with the sediments suggest that they were deposited at the same time, indicating that it was a period of widespread volcanism in the region.

Sedimentation continued over the Eocene/Oligocene boundary without break. The usual extinctions of planktonic foraminifers and calcareous nannoplankton index forms occurred. Benthic forms also show significant changes over this interval. White nannofossil oozes were deposited from the early Oligocene to the early middle Miocene. Sedimentation rates were noticeably low (4.6 m/m.y.) during the Eocene–Oligocene interval.

Other than some minor event leading to the deposition of a layer of hard ooze at the Oligocene/Miocene boundary, depositional conditions remained remarkably unchanged until the beginning of the middle Miocene. However, benthic faunas did evolve, indicating changes in bottom-water character.

Between 15.5 and 15 m.y. ago, there commenced deposition of a remarkable 25-m deposit of orange ooze which differs from the surrounding sediments only by its bright color. The top of this layer coincides with the upper boundary of NN5 and the subunit falls within the *Praeorbulina glomerosa curva* Zone; hence it is about 15.5 to 15 m.y. in age. The subunit thus seems to have immediately preceded the time of major ice build-up on Antarctica. The event that caused oxidation of this subunit must have altered the balance between available dissolved oxygen supplied to the seafloor and available organic carbon supplied to the infauna and bacteria within the sediment. It is possible that there was a brief development of a water mass front not far to the south of Site 593 that produced intermediate waters sufficiently highly oxygenated to prevent post-depositional reduction within the sediments. In the present day, oxygen-charged Antarctic Intermediate Waters are produced at the Antarctic Convergence and flow toward the north at about 1000 m water depth (Figs. 5 and 13). The middle Miocene episode was relatively short-lived because the sediment had returned to a reduced state by about 15 m.y. ago. The oxidized sediment layer may, therefore, represent a paleoceanographic change associated with the evolution of Antarctic glaciation. In this interval the character of the benthic fauna remains surprisingly constant. A few new forms occur, including *Melonis barleeanum, Bolivina anastomosa,* and *Uvigerina auberiana*. The small, hispid uvigerinids, however, occur in large numbers in Sample 593-42,CC and may be a reflection of the increased oxidation at that time.

Coincidentally, when deposition of the oxidized subunit ceased, sedimentation rates suddenly increased from 9.7 to 48.4 m/m.y. This increase may have resulted from increased biogenic productivity associated with stimulated circulation related to Miocene glaciation.

The large change occurs slightly later in the early Miocene (*P. glomerosa curva* to *Orbulina suturalis* zones). At this time, both the diversity and abundance of benthics increase. The rectuvigerinids disappear temporarily and seven new forms appear, at least four of which are cibicidids. *Nuttalides umbonifera*, a form correlated with deep water masses later in the Neogene, first occurs at this site.

High rates (48.4 m/m.y.) of sedimentation continued through the middle Miocene, with the deposition of relatively unchanging foraminifer-bearing nannofossil oozes to nannofossil oozes. These high rates diminished to 15 m/m.y. in the late Miocene to earliest Pliocene.

As in most of the sites drilled during Leg 90, there was a remarkable increase in sedimentation rates between 4 and 3 m.y. ago, in the late early Pliocene. Rates were 103 m/m.y. at Site 593. The paleoceanographic event that caused this increase remains unknown but was almost certainly related to increased biogenic productivity. Beginning near the end of this interval, the percentage of foraminifers in the sediments increased.

The foraminifer-bearing nannofossil ooze that occurred at 3 m.y. in the sequence probably represents an interval when bottom currents in this area were strong enough to winnow some nannofossils from the sediment. The occurrence of an upper winnowed sequence at Site 593 is similar to the uppermost recovered sections at Sites 587 through 592, and probably coincides with a period of more intensive global oceanic circulation, perhaps re-

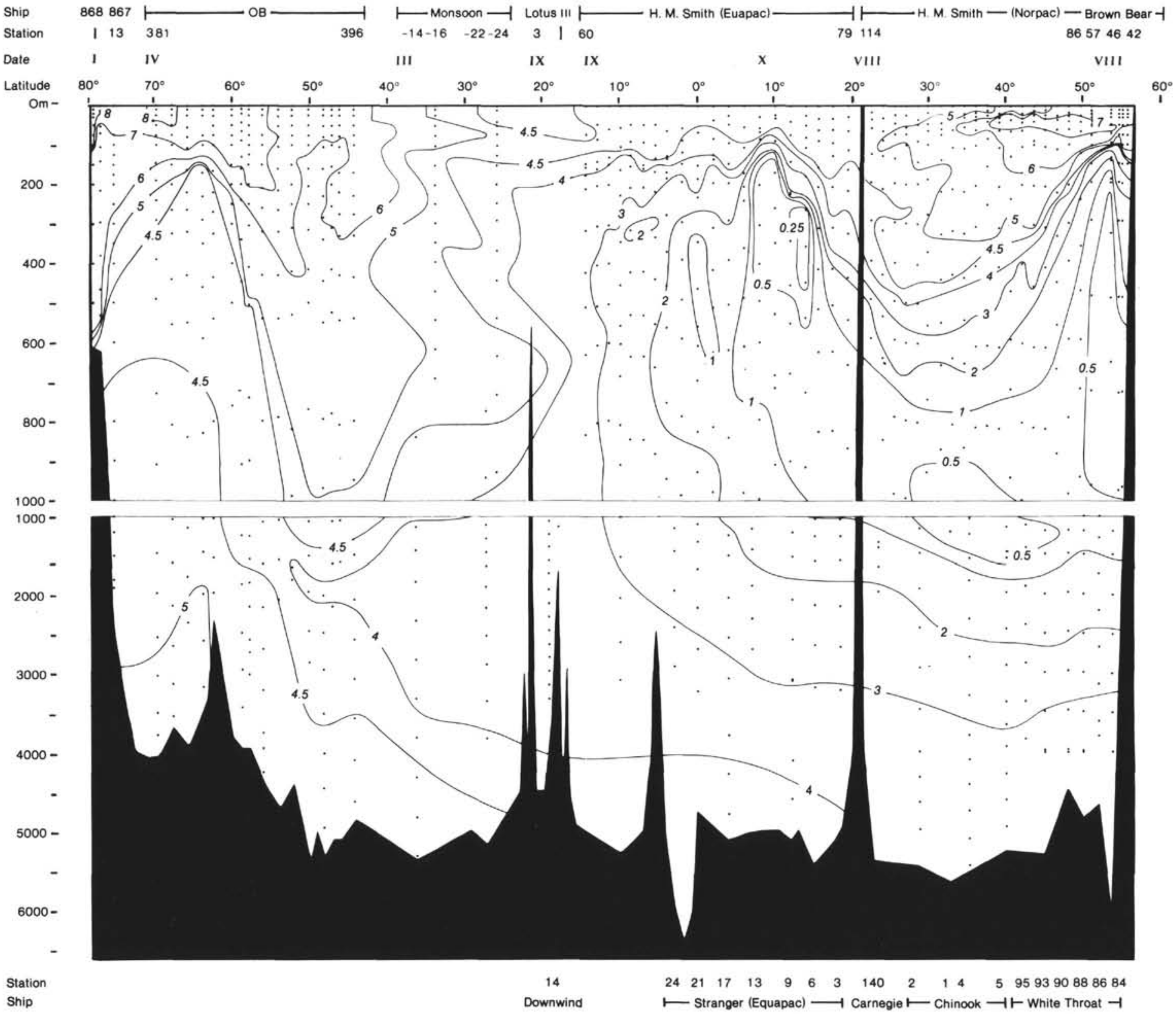

Figure 13. Dissolved-oxygen concentration (ml/l) along approximately 160°W from Antarctica to Alaska (reprinted with permission from Reid, 1965).

lated to the development of Northern Hemisphere glaciations. This led to a marked decrease in sedimentation rates (about 23 m/m.y.) through the late Pliocene to Quaternary.

The section terminates with the familiar late Quaternary veneer (0 to 6 m) of oxidized sediments.

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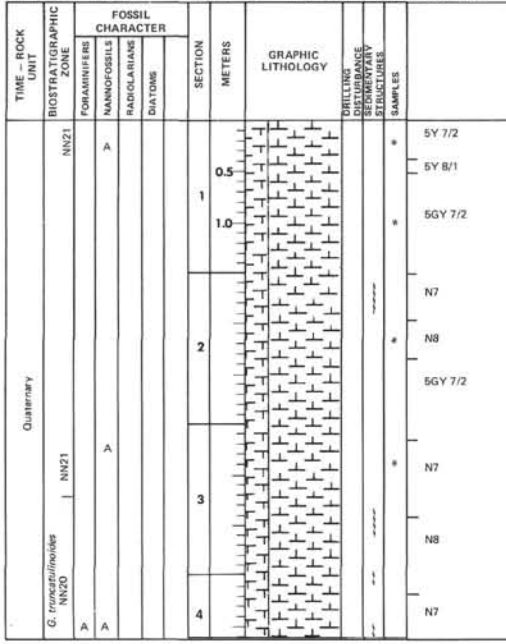
Date of Acceptance: 1 December 1983

SITE 593 HOLE CORE 1 CORED INTERVAL 0.0–5.1 m



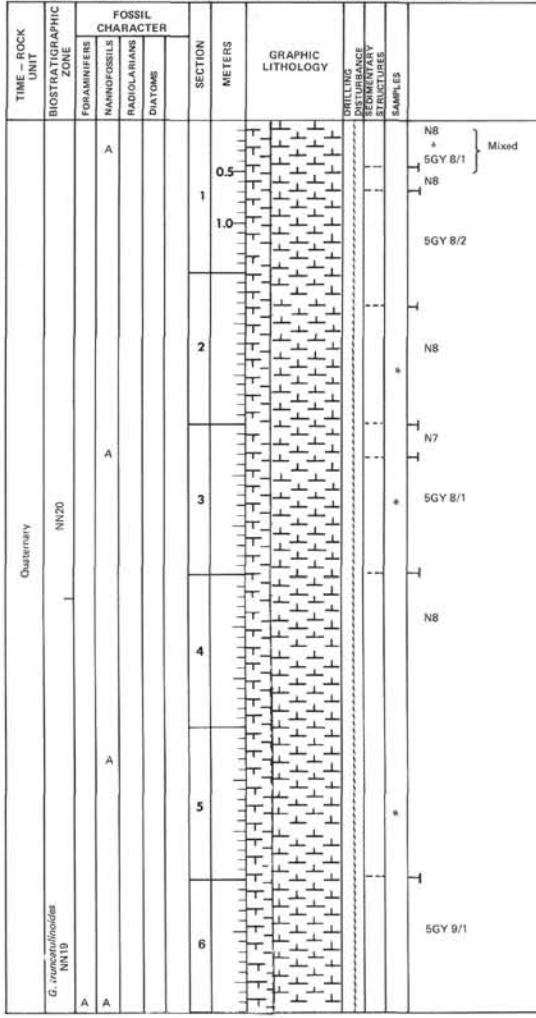
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, soft, yellowish gray (5Y 7/2 and 5Y 8/1) in the first 0.50 m of Section 1. Then, sediment shows alternating zones of grayish yellow green (5GY 7/2), light gray (N7), and very light gray (N8) oozes. Grayish yellow green (5GY 7/2) burrows are present.

SMEAR SLIDE SUMMARY:

	1, 20	1, 100	2, 67	3, 33
	D	D		D
Composition:				
Quartz	–	T	–	–
Feldspar	–	–	T	–
Volcanic glass	T	–	–	
Carbonate unspec.	–	T	–	T
Foraminifers	C	C	C	C
Calc. nannofossils	D	D	D	D
Sponge spicules	T	–	T	T

SITE 593 HOLE CORE 2 CORED INTERVAL 5.1–14.7 m



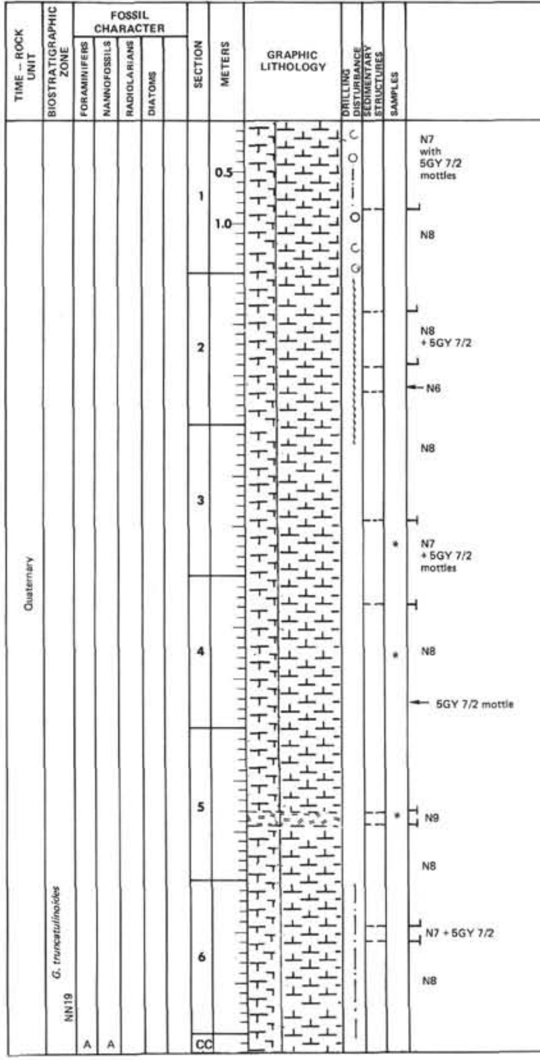
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), light gray (N7), light greenish gray (5GY 8/1), to very light greenish gray (5GY 9/1) interbeds, all with gradational contacts, soft. Mottles apparent in Sections 5 and 6, otherwise homogeneous. Coring disturbance throughout.

SMEAR SLIDE SUMMARY:

	2, 99	3, 78	5, 79
	D	D	D
Composition:			
Quartz	T	T	T
Heavy minerals	–	–	T
Volcanic glass	–	T	T
Pyrite	–	T	T
Foraminifers	C	C	C
Calc. nannofossils	D	D	D

SITE 593 HOLE CORE 3 CORED INTERVAL 14.7–24.3 m



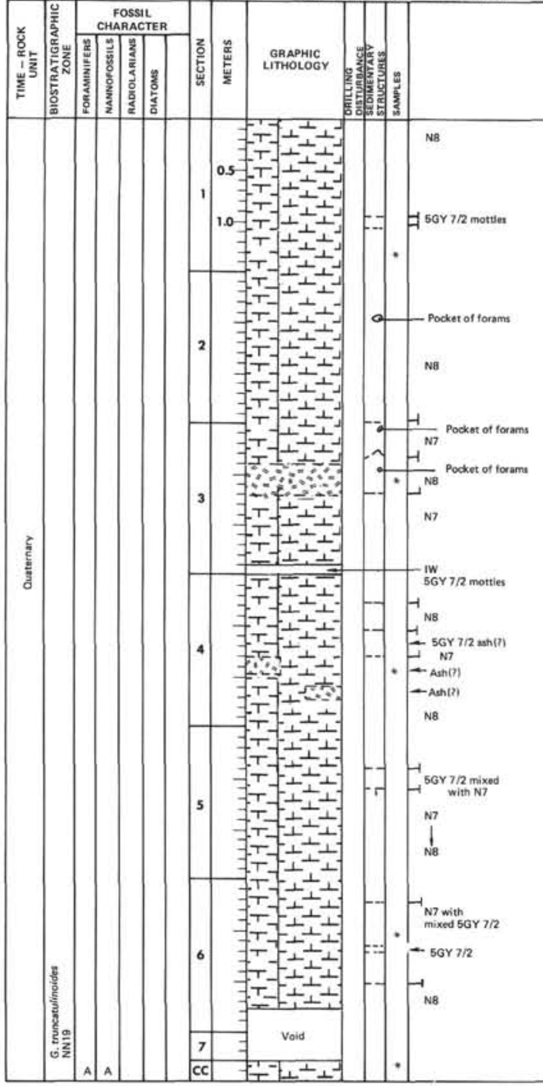
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, alternating colors of light gray (N7), very light gray (N8), medium gray (N5), with soft, generally homogeneous grayish yellow green (5GY 7/2) mottles. Pockets of ash-rich ooze at Section 2, 100 cm and Section 5, 78 to 88 cm.

SMEAR SLIDE SUMMARY:

	3, 120	4, 74	5, 85
	D	D	M
Composition:			
Quartz	T	T	R
Feldspar	T	–	T
Volcanic glass	–	T	D
Pyrite	–	–	T
Foraminifers	C	C	–
Calc. nannofossils	A	D	R

SITE 593 HOLE CORE 4 CORED INTERVAL 24.3–33.7 m



LITHOLOGIC DESCRIPTION

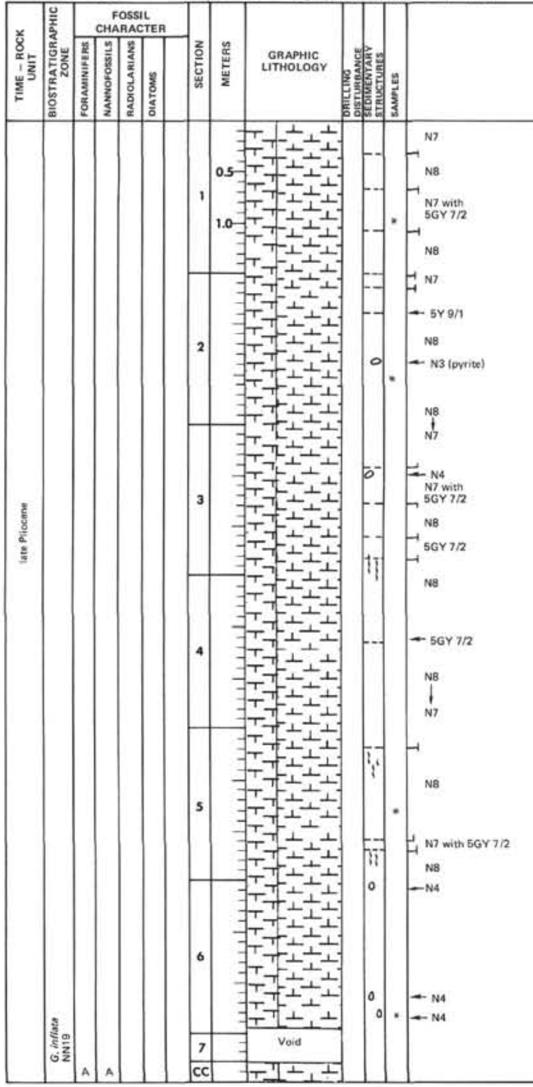
FORAMINIFER-BEARING NANNOFOSSIL OOZE TO FORAMINIFER NANNOFOSSIL OOZE, light gray (N7) and very light gray (N8) with mottles of grayish yellow green (5GY 7/2), soft. Pockets of foram-rich zones occur in Sections 2 and 3. Distinct ash occurs Section 3, 30–50 cm and indistinct ash(?) occurs in Section 4. Occasional streaks of iron sulfide(?), grayish yellow green (5GY 7/2) and light gray (N7) colored interbeds appear coarser grained than very light gray (N8) beds.

SMEAR SLIDE SUMMARY:

	1, 132	3, 27	4, 98	6, 53	CC[a]
	D	D	M	M	M
Composition:					
Quartz	T	T	T	T	C
Feldspar	–	–	–	T	T
Heavy minerals	–	–	–	–	T
Clay	–	–	–	–	A
Volcanic glass	R	R	A	R	C
Pyrite	–	–	R	T	R
Foraminifers	A	C	C	A	–
Calc. nannofossils	A	D	A	A	–

[a] insoluble residue

SITE 593 HOLE CORE 5 CORED INTERVAL 33.9–43.5 m



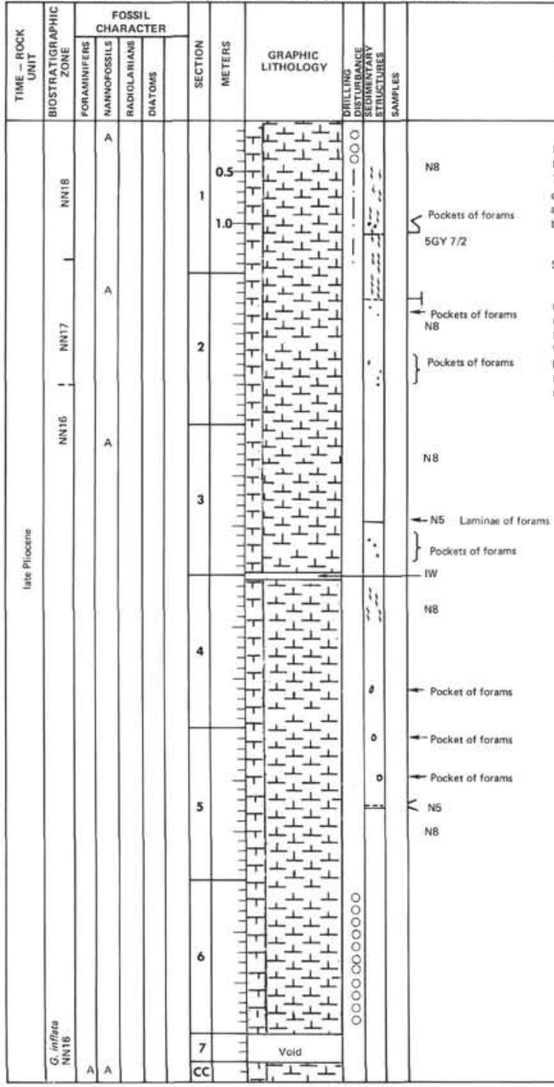
LITHOLOGIC DESCRIPTION

FORAMINIFER NANNOFOSSIL OOZE, light gray (N7) to very light gray (N8) with mottled zones of mixed grayish yellow green (5GY 7/2). Soft, streaks and laminae iron sulfides(?) and pods of medium dark gray (N4) of pyrite(?). Mottling common and a few *Planolites*-like burrows occur.

SMEAR SLIDE SUMMARY:

	1, 95	2, 75	2, 90	5, 78	6, 133
	D	D	M	D	M
Composition:					
Quartz	T	–	T	T	–
Volcanic glass	T	T	–	T	–
Pyrite	T	T	A	T	R
Foraminifers	A	A	C	C	C
Calc. nannofossils	A	A	A	D	A

SITE 593 HOLE CORE 6 CORED INTERVAL 43.5–53.1 m



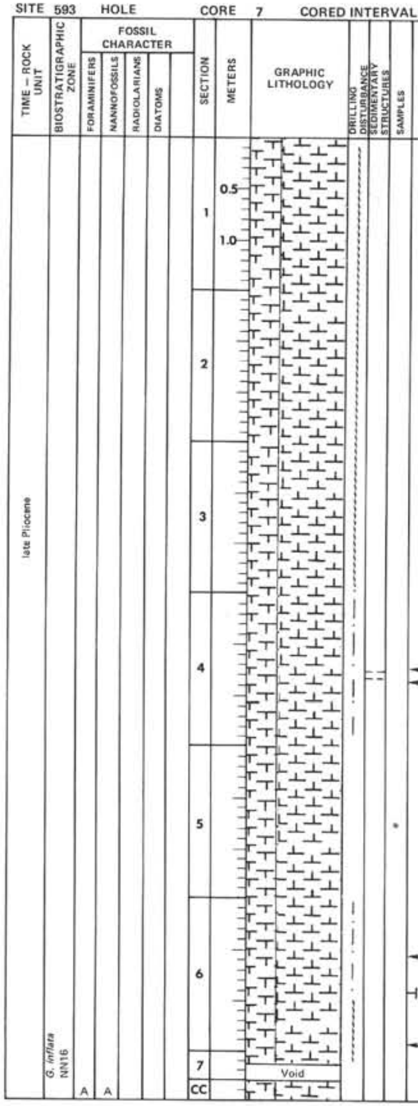
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8) with zones of grayish yellow green (5GY 7/2) mottling. Soft and homogeneous. Pockets of forams occur throughout the core. Rare tints of iron sulfides(?) and diffusion bands, especially in Section 3. Section 6 badly disturbed.

SMEAR SLIDE SUMMARY:

	2, 9	3, 72
	D	D
Composition:		
Quartz	T	–
Feldspar	T	T
Volcanic glass	T	T
Pyrite	T	–
Foraminifers	C	C
Calc. nannofossils	D	D

SITE 593 HOLE CORE 7 CORED INTERVAL 53.1–62.7 m



LITHOLOGIC DESCRIPTION

N8

5GY 7/2

5GY 7/2

N5

N8 with swirls of 5GY 7/2

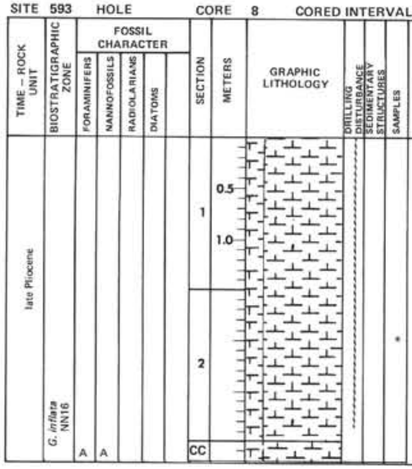
N5

FORAMINIFER-BEARING NANNOFOSSIL OOZE, severe coring disturbance throughout. Light to very light gray (N8), soft, homogeneous. Streaks of iron sulfides(?). Faint hues of grayish yellow green (5GY 7/2) in Section 4.

SMEAR SLIDE SUMMARY:

	5, 82 D
Composition:	
Quartz	T
Feldspar	T
Volcanic glass	T
Foraminifers	C
Calc. nannofossils	D

SITE 593 HOLE CORE 8 CORED INTERVAL 62.7–72.3 m



LITHOLOGIC DESCRIPTION

N8

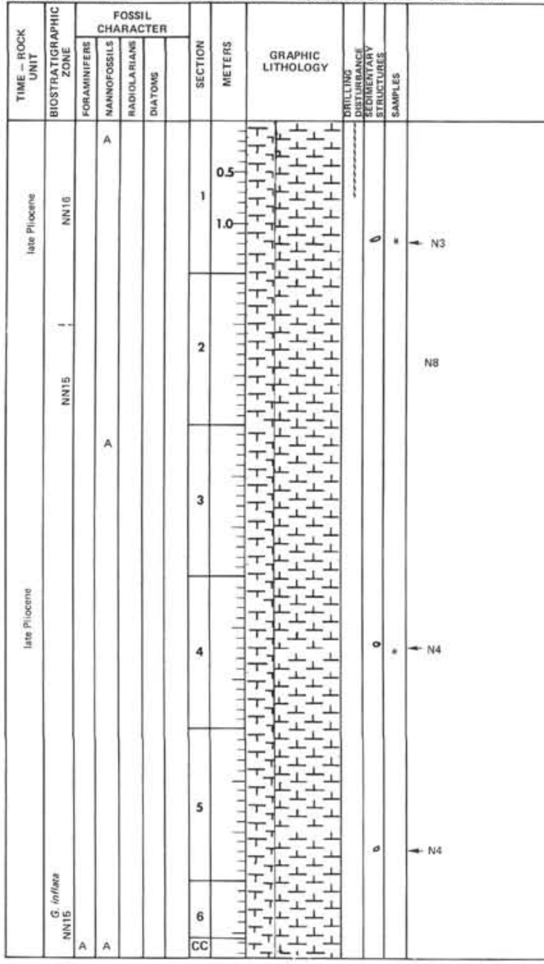
FORAMINIFER-BEARING NANNOFOSSIL OOZE, severe coring disturbance throughout core.

Very light gray (N8), soft, with streaks of medium dark gray (N4) throughout.

SMEAR SLIDE SUMMARY:

	2, 63 D
Composition:	
Pyrite	T
Foraminifers	C
Calc. nannofossils	D

SITE 593 HOLE CORE 9 CORED INTERVAL 72.3–81.9 m



LITHOLOGIC DESCRIPTION

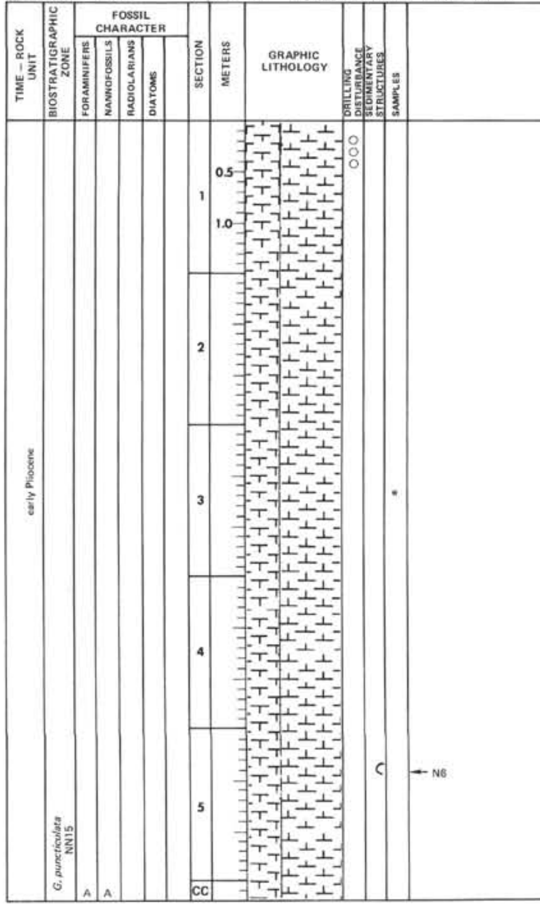
FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous with streaks and blebs of iron sulfide dark gray (N3) scattered throughout. Diffusion bands of iron sulfide faintly show in Section 4.

SMEAR SLIDE SUMMARY:

	1, 116	4, 73
	M	D
Composition:		
Quartz	–	T
Volcanic glass	T	T
Pyrite	A	T
Foraminifers	A	C
Calc. nannofossils	A	D

Core 10, 81.9–91.5 m: no recovery.

SITE 593 HOLE CORE 11 CORED INTERVAL 91.5–101.1 m



LITHOLOGIC DESCRIPTION

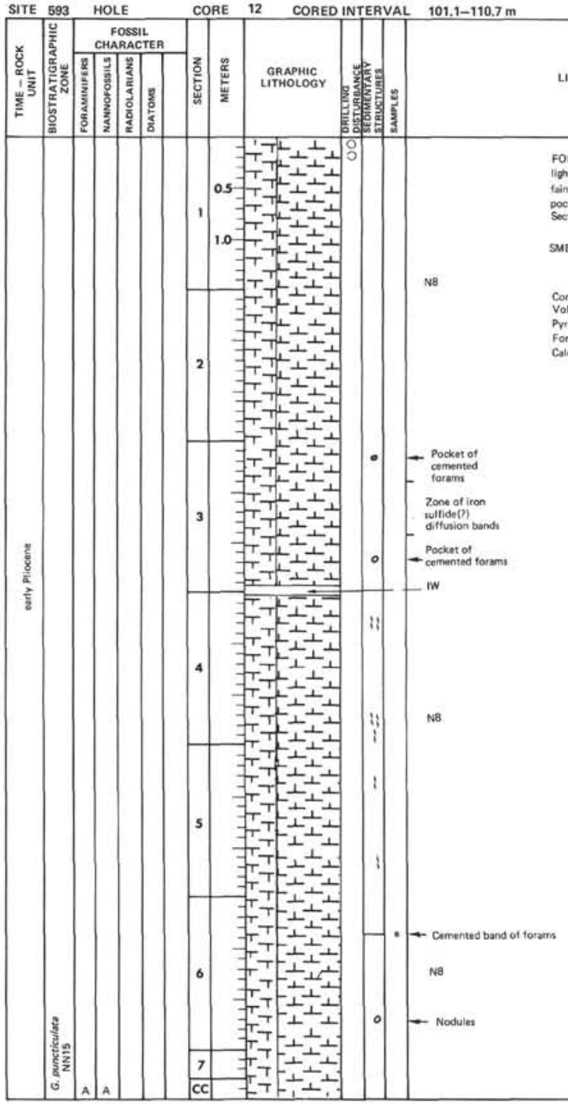
FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), soft, extremely homogeneous with only rare streaks and blebs of medium dark gray (N4) iron sulfide(?).

Nodule of cemented (celestite?) forams and pyrite(?) at Section 5, 40 cm.

SMEAR SLIDE SUMMARY:

	3, 68
	D
Composition:	
Volcanic glass	T
Pyrite	T
Foraminifers	C
Calc. nannofossils	D

SITE 593 HOLE CORE 12 CORED INTERVAL 101.1–110.7 m



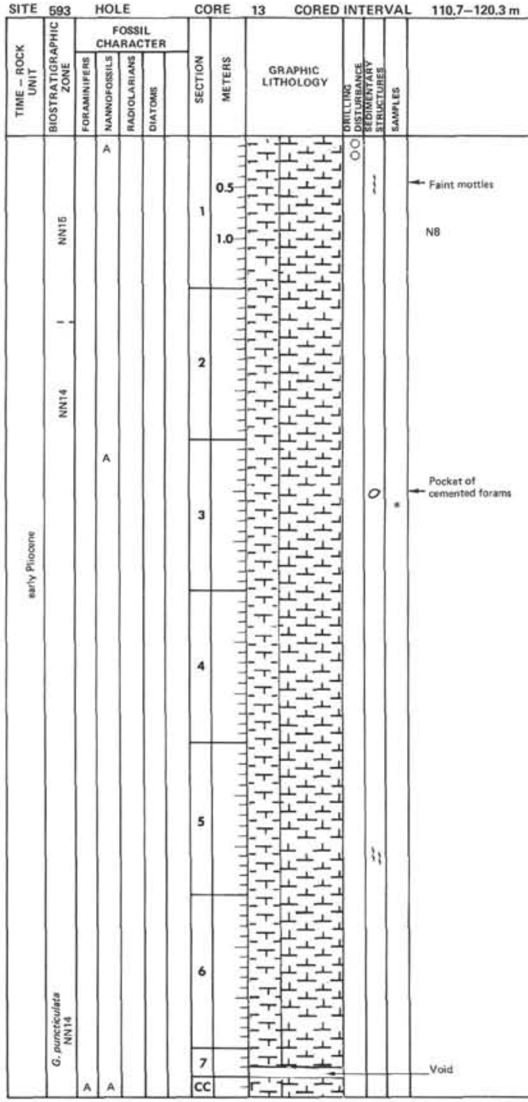
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), soft, very homogeneous with only a few faint iron sulfide(?) diffusion bands, and streaks. Several pockets of cemented (celestite or gypsum?) forams occur in Section 3, 30 cm; Section 3, 125 cm; and Section 6, 38 cm.

SMEAR SLIDE SUMMARY:

	4, 70	6, 43
	D	M
Composition:		
Volcanic glass	T	T
Pyrite	–	R
Foraminifers	C	A
Calc. nannofossils	D	A

SITE 593 HOLE CORE 13 CORED INTERVAL 110.7–120.3 m



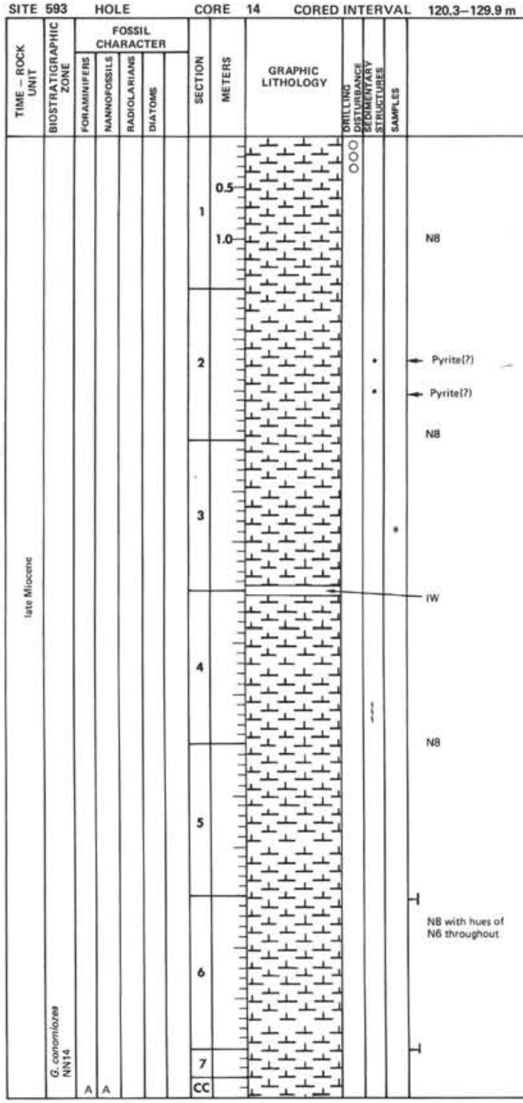
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous, with rare streaks of iron sulfide(?). Pocket of cemented forams at Section 3, 48–50 cm.

SMEAR SLIDE SUMMARY:

	3, 68
	D
Composition:	
Volcanic glass	T
Pyrite	T
Foraminifers	C
Calc. nannofossils	D

SITE 593 HOLE CORE 14 CORED INTERVAL 120.3–129.9 m



LITHOLOGIC DESCRIPTION

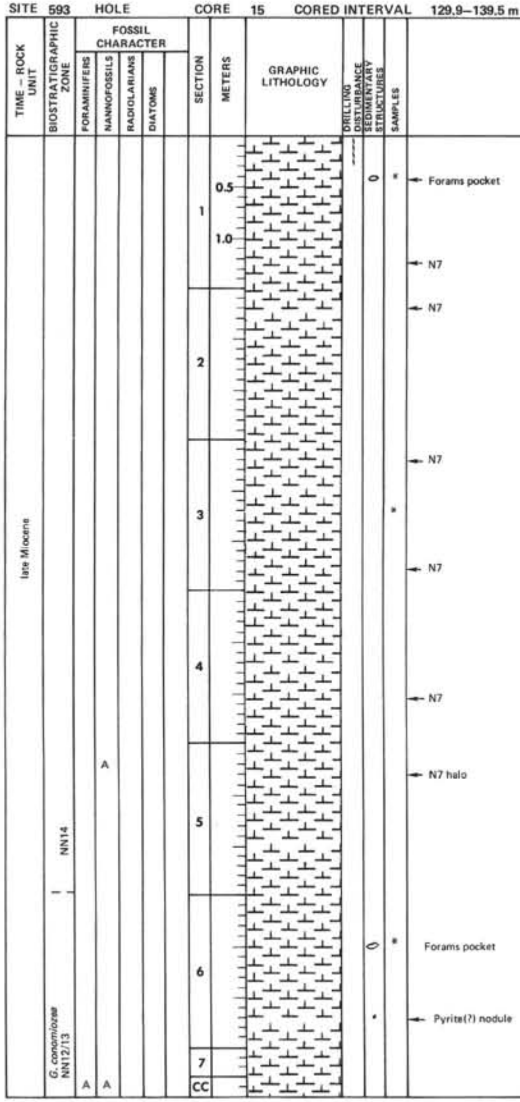
NANNOFOSSIL OOZE, very light gray (N8) with rare faint hues of medium light gray (N6) from iron sulfides(?). Soft and very homogeneous throughout.

Strong H_2S odor when split.

SMEAR SLIDE SUMMARY:

	3, 82
	D
Composition:	
Volcanic glass	T
Pyrite	T
Foraminifers	R
Calc. nannofossils	D

SITE 593 HOLE CORE 15 CORED INTERVAL 129.9–139.5 m



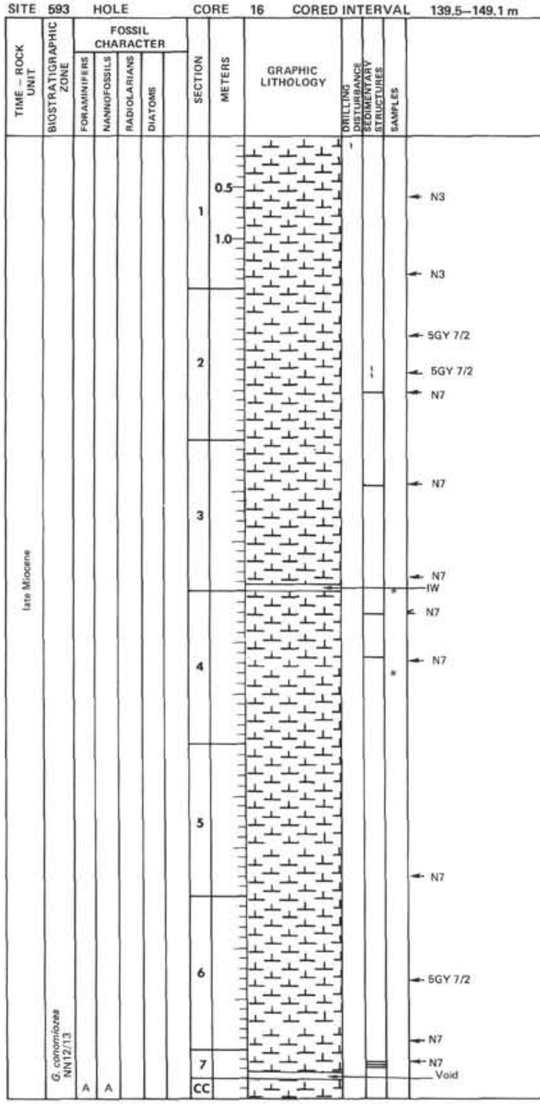
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous, with rare light gray (N7) laminae of iron sulfide.

SMEAR SLIDE SUMMARY:

	3, 70	1, 40	6, 45
	D	M	M
Texture:			
Sand	R	C	C
Silt	C	C	C
Clay	D	D	C
Composition:			
Pyrite	–	–	T
Foraminifers	R	C	A
Calc. nannofossils	D	D	C
Sponge spicules	–	T	T

SITE 593 HOLE CORE 16 CORED INTERVAL 139.5–149.1 m



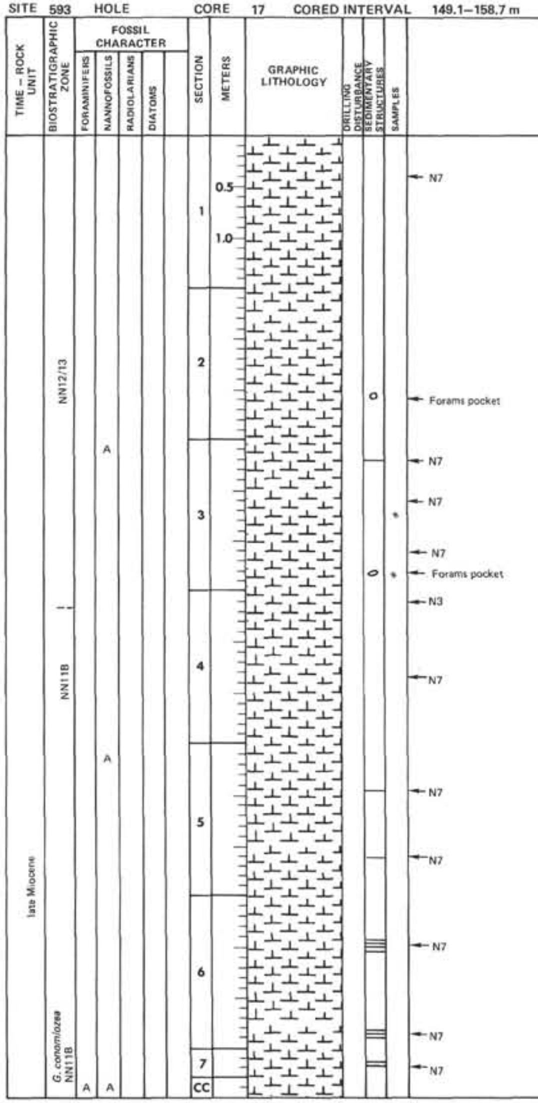
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous. Rare light gray (N7) laminae and dark gray (N3) fine accumulations of iron sulfide(?). Rare grayish yellow green (5GY 7/2) burrows.

SMEAR SLIDE SUMMARY:

	4, 75
	D
Texture:	
Sand	T
Silt	R
Clay	D
Composition:	
Foraminifers	R
Calc. nannofossils	D

SITE 593 HOLE CORE 17 CORED INTERVAL 149.1–158.7 m



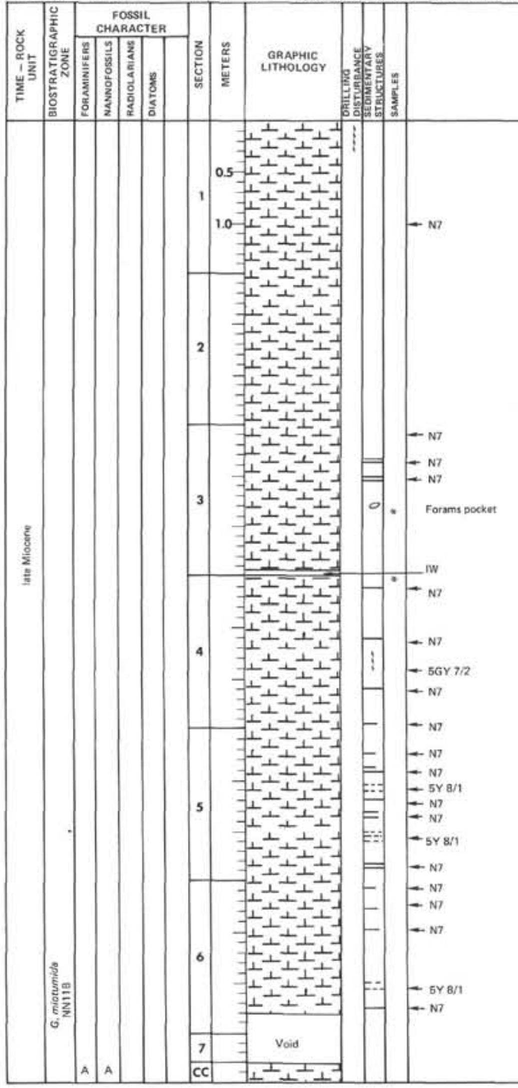
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous. Light gray (N7) laminae and rare dark gray (N3) fine accumulation of iron sulfide(?) are present. Pockets of foraminifers in Sections 2 and 3.

SMEAR SLIDE SUMMARY:

	2, 75	3, 129
	D	M
Texture:		
Sand	T	R
Silt	R	C
Clay	D	A
Composition:		
Feldspar	T	–
Heavy minerals	–	T
Pyrite	T	R
Foraminifers	R	C
Calc. nannofossils	D	A
Sponge spicules	–	T

SITE 593 HOLE CORE 18 CORED INTERVAL 158.7–168.3 m



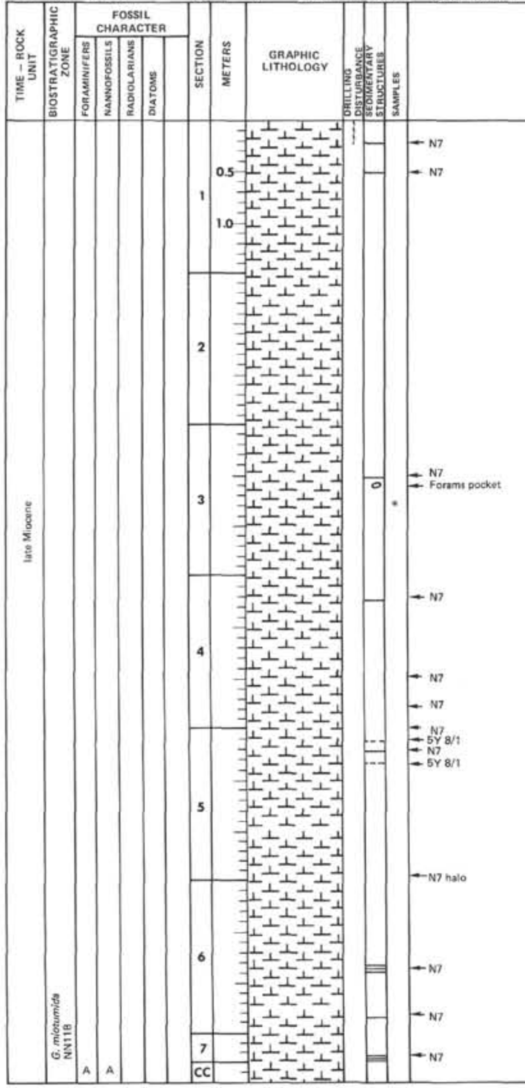
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous. Light gray (N7) laminae and dark gray (N3) fine accumulations of iron sulfide(?). Grayish yellow green (5GY 7/2) burrows, foraminifers pockets and discrete yellowish gray (5Y 8/1) laminae are present.

SMEAR SLIDE SUMMARY:

	3, 65	3, 77
	D	M
Composition:		
Feldspar	T	–
Pyrite	–	T
Foraminifers	R	R
Calc. nannofossils	D	D

SITE 593 HOLE CORE 19 CORED INTERVAL 168.3–177.9 m



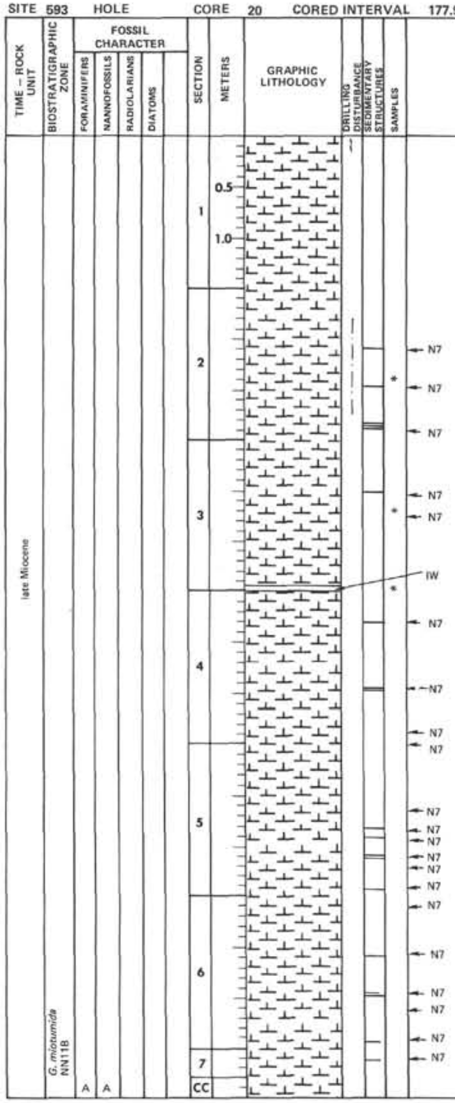
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous. Light gray (N7) laminae and dark gray (N3) fine accumulations of iron sulfide(?). Foraminifers pockets and discrete yellowish gray (5Y 8/1) laminae are present.

SMEAR SLIDE SUMMARY:

	3, 75
	D
Texture:	
Sand	T
Silt	R
Clay	D
Composition:	
Heavy minerals	T
Pyrite	T
Foraminifers	R
Calc. nannofossils	D

SITE 593 HOLE CORE 20 CORED INTERVAL 177.9–189.5 m



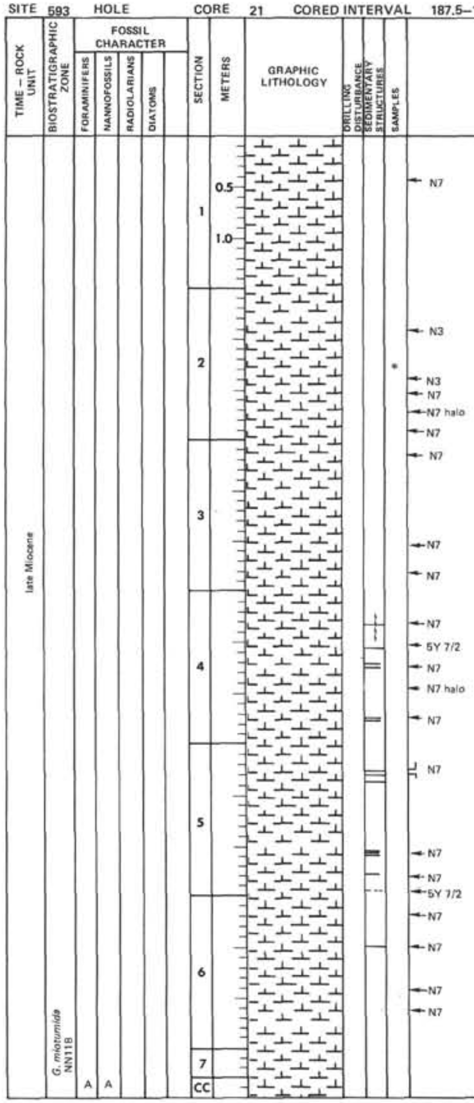
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous. Light gray (N7) laminae of iron sulfide(?) are present.

SMEAR SLIDE SUMMARY:

	3, 70	2, 74
	D	M
Texture:		
Silt	R	R
Clay	D	D
Composition:		
Quartz	T	–
Feldspar	T	T
Pyrite	T	–
Foraminifers	R	R
Calc. nannofossils	D	D

SITE 593 HOLE CORE 21 CORED INTERVAL 187.5–197.1 m



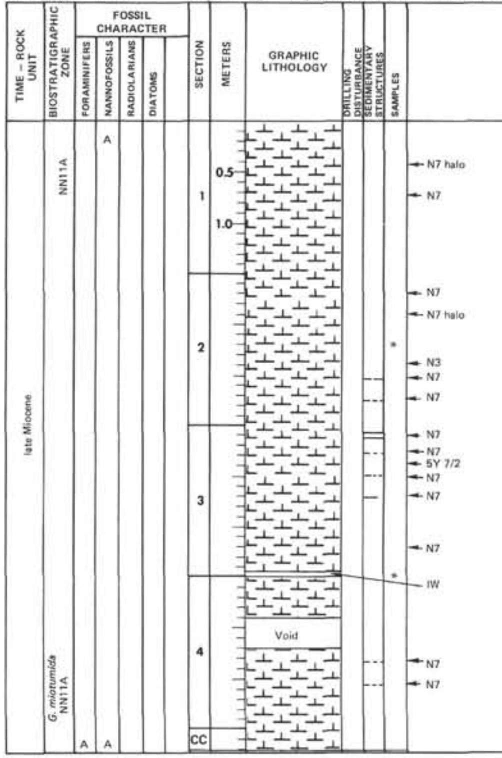
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous. Light gray (N7) laminae and dark gray (N3) fine accumulations of iron sulfide(?) are present, as well as rare yellowish gray (5Y 7/2) burrows and laminae.

SMEAR SLIDE SUMMARY:

	2, 75	5, 144
	D	M
Texture:		
Sand	–	A
Silt	R	A
Clay	D	A
Composition:		
Quartz	T	–
Heavy minerals	T	–
Volcanic glass	T	–
Foraminifers	R	A
Calc. nannofossils	D	A

SITE 593 HOLE CORE 22 CORED INTERVAL 197.1–206.7 m



LITHOLOGIC DESCRIPTION

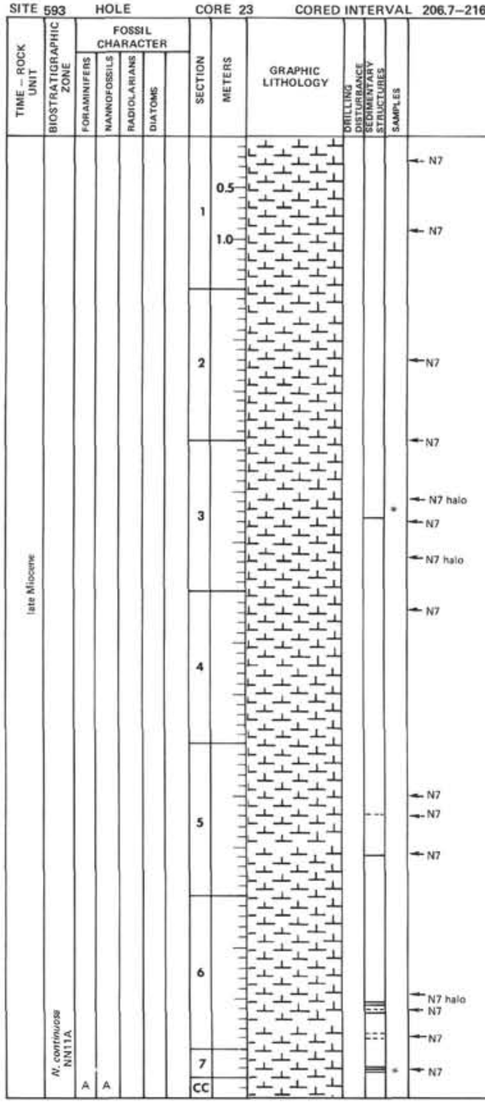
Non-oriented core.

NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous. Light gray (N7) laminae and dark gray (N3) fine accumulations of iron sulfide(?). Rare yellowish gray (5Y 7/2) burrows are present. Void in Section 4 between 0.40 and 0.70 m is due to drilling.

SMEAR SLIDE SUMMARY:

	2, 70 D
Texture:	
Sand	T
Silt	R
Clay	D
Composition:	
Feldspar	T
Pyrite	T
Foraminifers	R
Calc. nannofossils	D

SITE 593 HOLE CORE 23 CORED INTERVAL 206.7–216.3 m



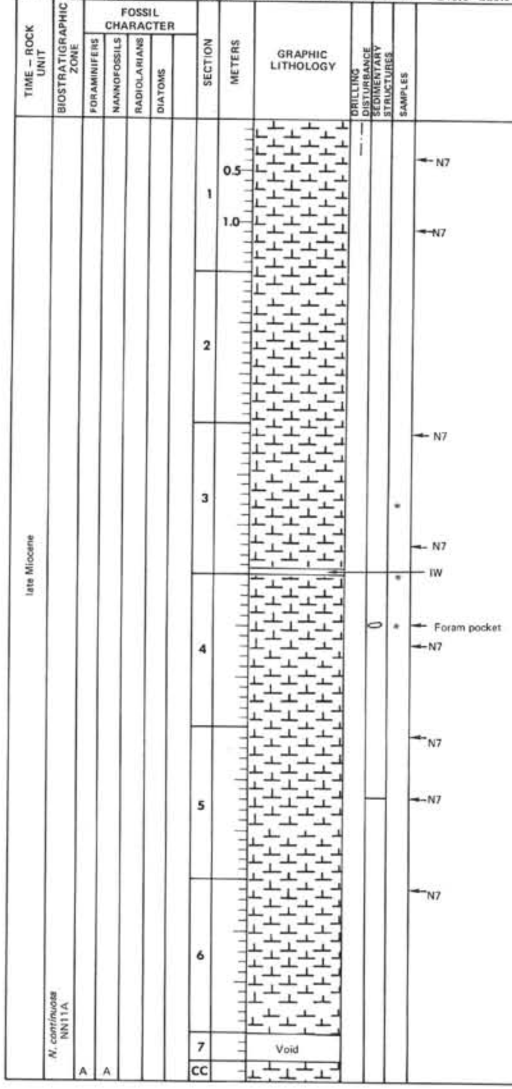
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, homogeneous, light gray (N7) laminae and halos of iron sulfide(?) occur throughout core.

SMEAR SLIDE SUMMARY:

	3, 65 D	7, 20 M
Texture:		
Silt	R	R
Clay	D	D
Composition:		
Feldspar	T	–
Heavy minerals	T	–
Pyrite	–	T
Foraminifers	R	R
Calc. nannofossils	D	D

SITE 593 HOLE CORE 24 CORED INTERVAL 216.3–225.9 m



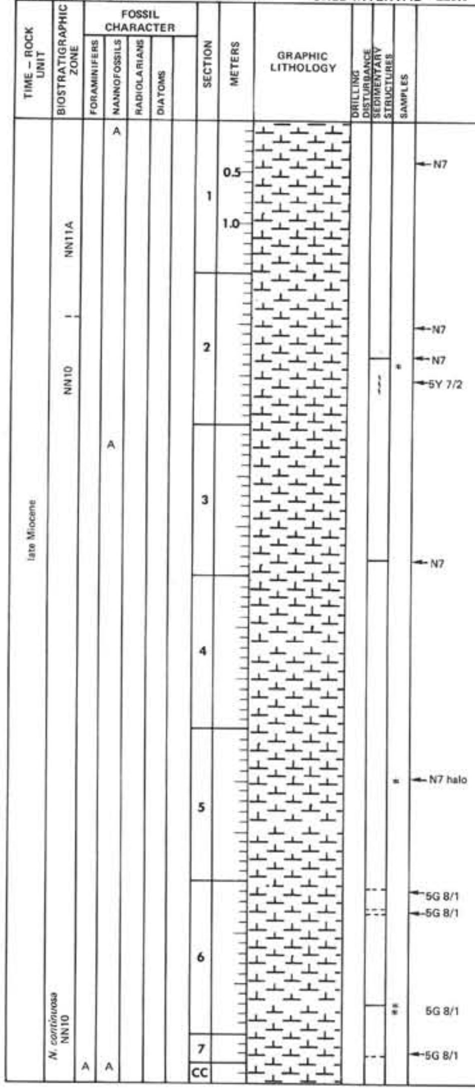
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, homogeneous. Light gray (N7) laminae of iron sulfide(?). Foraminifer pocket in Section 4.

SMEAR SLIDE SUMMARY:

	3, 75 D	4, 47 M
Texture:		
Sand	–	C
Silt	R	C
Clay	D	A
Composition:		
Heavy minerals	–	T
Volcanic glass	T	T
Pyrite	T	R
Foraminifers	R	A
Calc. nannofossils	D	A

SITE 593 HOLE CORE 25 CORED INTERVAL 225.9–235.5 m



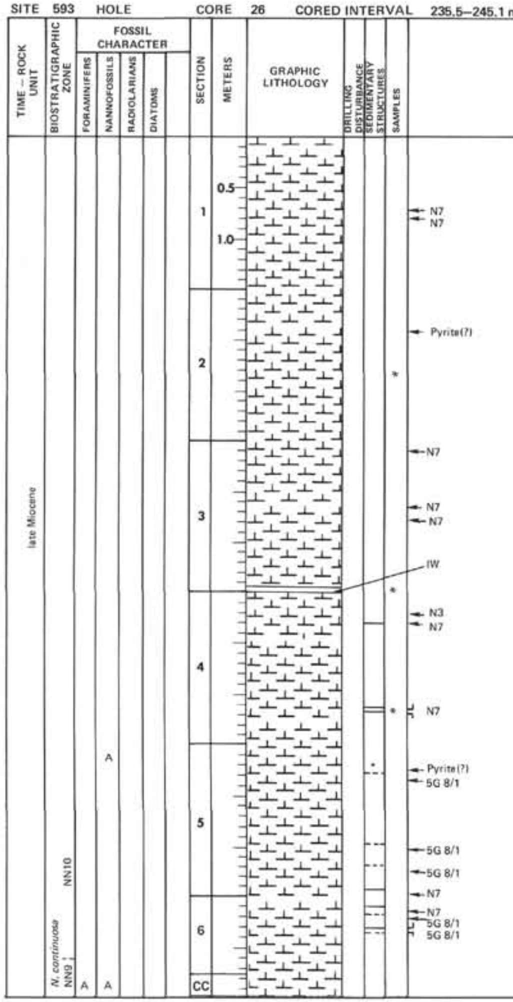
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, homogeneous. Light gray (N7) laminae of iron sulfide(?). Rare yellowish gray (5Y 7/2) burrows. Discrete light greenish gray (5G 8/1) laminae appear in Section 6.

SMEAR SLIDE SUMMARY:

	2, 86 D	5, 38 M	6, 122 M	6, 124 M
Texture:				
Sand	–	–	R	–
Silt	R	R	R	–
Clay	D	D	D	D
Composition:				
Heavy minerals	–	–	–	T
Volcanic glass	–	–	T	–
Carbonate unspec.	–	T	–	–
Foraminifers	R	R	C	R
Calc. nannofossils	D	D	D	D

SITE 593 HOLE CORE 26 CORED INTERVAL 235.5–245.1 m



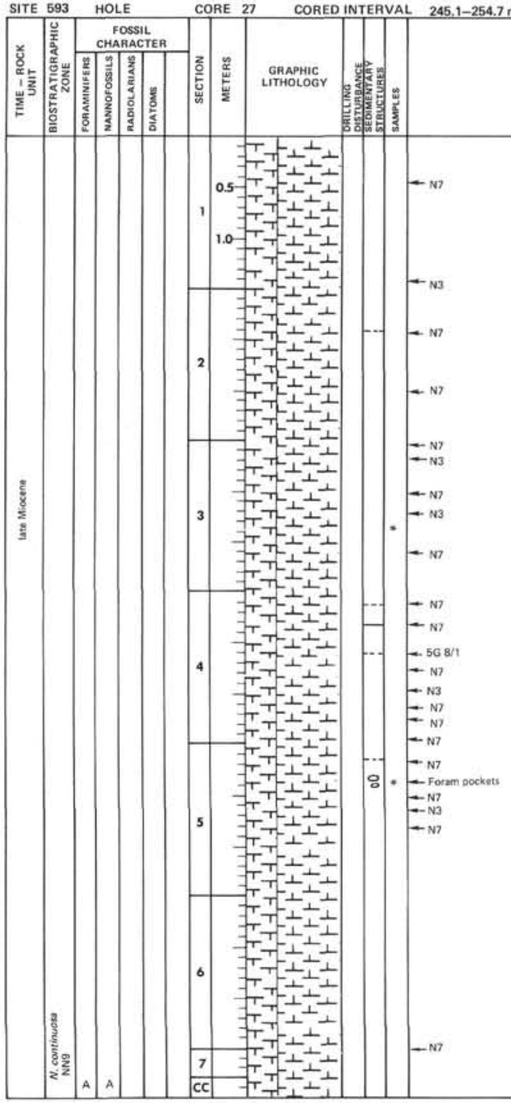
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N6), firm, homogeneous. Light gray (N7) laminae and dark gray (N3) fine accumulations of iron sulfide(?). Pyrite(?) nodules are present in Sections 2 and 5. Light greenish gray (5G 8/1) laminae are present in Sections 5 and 6.

SMEAR SLIDE SUMMARY:

	2, 83 D	4, 127 M	6, 29 M
Texture:			
Silt	R	R	C
Clay	D	D	D
Composition:			
Heavy minerals	T	–	T
Foraminifers	R	R	C
Calc. nannofossils	D	D	D

SITE 593 HOLE CORE 27 CORED INTERVAL 245.1–254.7 m



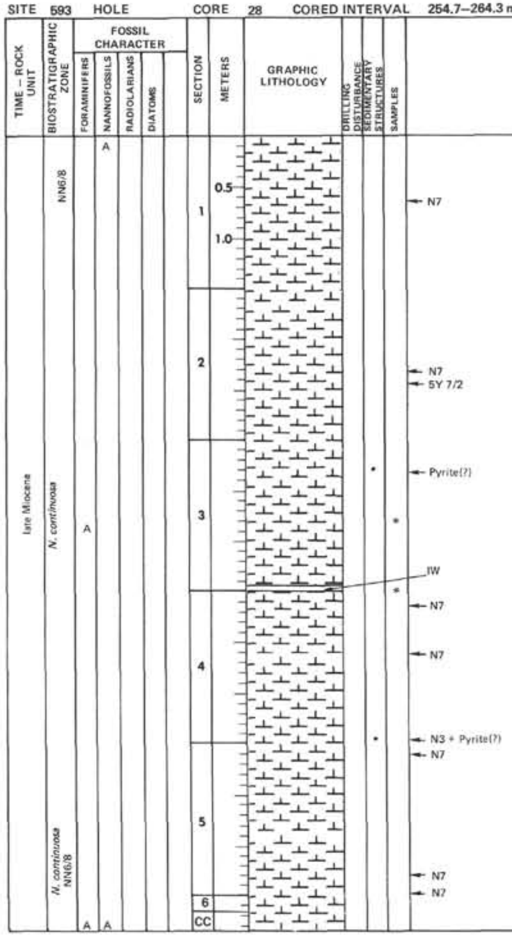
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), firm, homogeneous. Light gray (N7) laminae and dark gray (N3) fine accumulations of iron sulfide(?). Foraminifer pockets are present in Section 5.

SMEAR SLIDE SUMMARY:

	3, 80 D	5, 29 M
Texture:		
Sand	R	C
Silt	C	C
Clay	D	A
Composition:		
Feldspar	T	–
Heavy minerals	–	T
Volcanic glass	T	–
Carbonate unspec.	T	–
Foraminifers	C	A
Calc. nannofossils	D	A
Sponge spicules	T	–

SITE 593 HOLE CORE 28 CORED INTERVAL 254.7–264.3 m



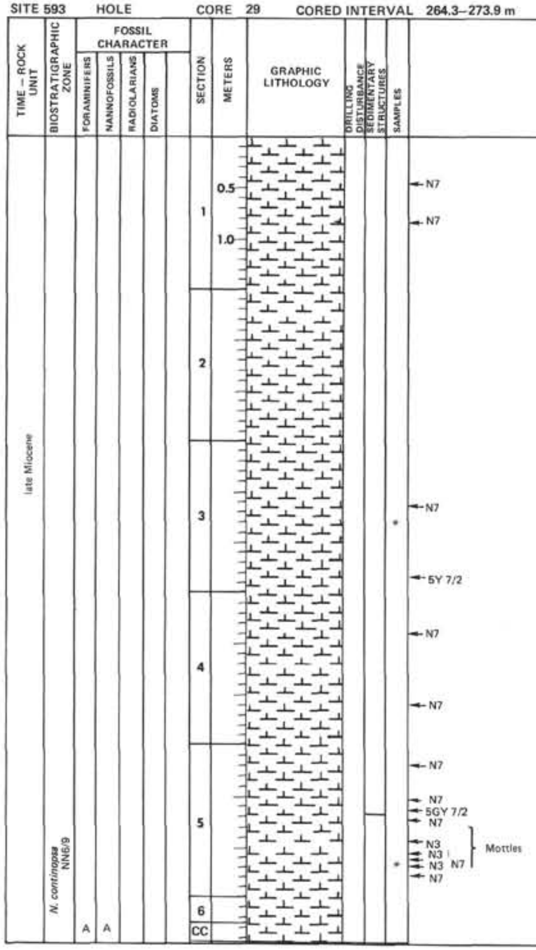
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, homogeneous. Light gray (N7) laminae and dark gray (N3) fine accumulations of iron sulfide(?). Pyrite(?) nodules in Sections 3 and 4.

SMEAR SLIDE SUMMARY:

	3, 80
	D
Texture:	
Silt	R
Clay	D
Composition:	
Heavy minerals	T
Volcanic glass	T
Foraminifers	R
Calc. nannofossils	D
Sponge spicules	T

SITE 593 HOLE CORE 29 CORED INTERVAL 264.3–273.9 m



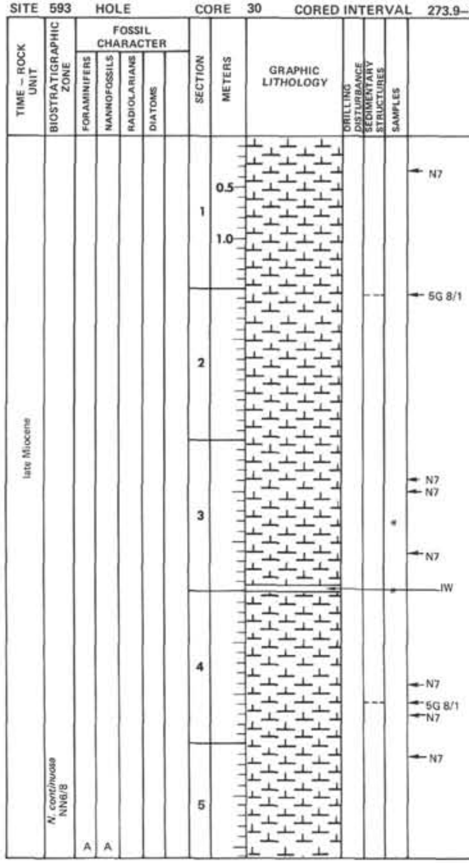
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, homogeneous. Light gray (N7) burrows and laminae, and dark gray (N3) fine accumulations of iron sulfide(?). Rare yellowish gray (5Y 7/2) and grayish yellow green (5GY 7/2) burrows.

SMEAR SLIDE SUMMARY:

	3, 80	5, 108
	D	M
Texture:		
Silt	R	R
Clay	D	D
Composition:		
Quartz	–	T/R
Heavy minerals	T	T
Volcanic glass	T	T
Foraminifers	R/C	R
Calc. nannofossils	D	D
Sponge spicules	T	–

SITE 593 HOLE CORE 30 CORED INTERVAL 273.9–283.5 m



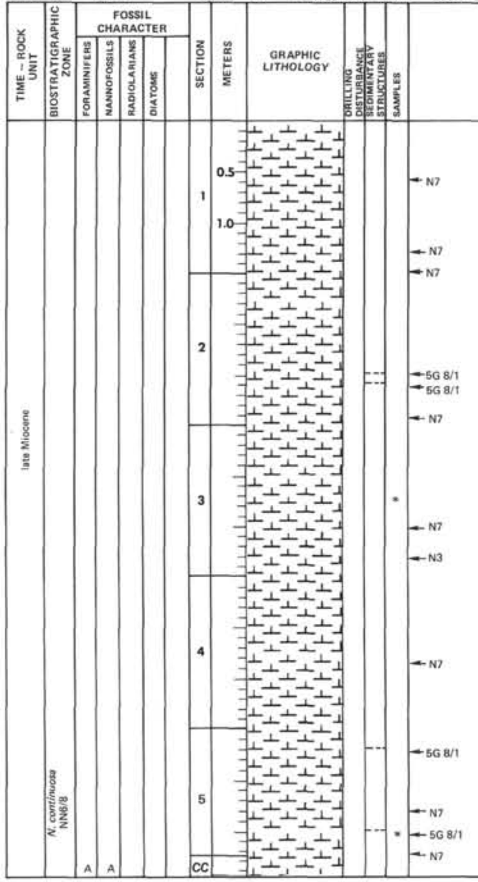
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, homogeneous. Light gray (N7) laminae and accumulations of iron sulfide(?). Discrete light greenish gray (5G 8/1) laminae in Sections 2 and 4.

SMEAR SLIDE SUMMARY:

	3, 80 D
Texture:	
Silt	R
Clay	D
Composition:	
Quartz	T
Foraminifers	R
Calc. nannofossils	D
Sponge spicules	T

SITE 593 HOLE CORE 31 CORED INTERVAL 283.5–293.1 m



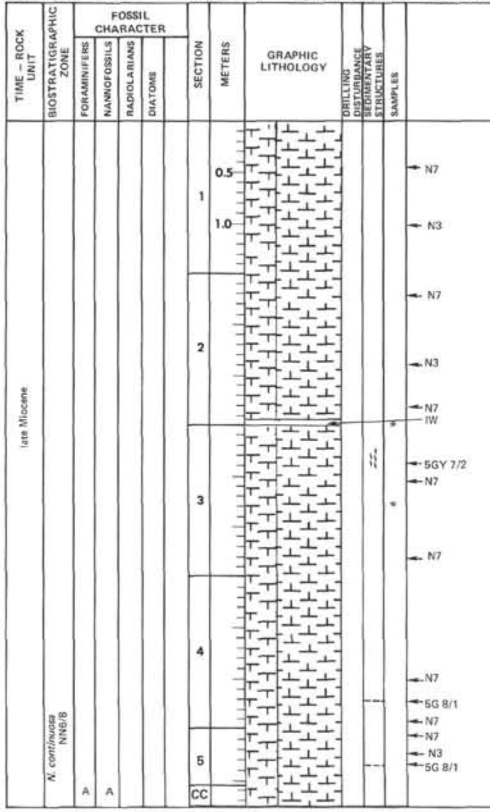
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, homogeneous. Light gray (N7) laminae and dark gray (N3) fine accumulations of iron sulfide(?). Discrete light greenish gray (5G 8/1) laminae are present.

SMEAR SLIDE SUMMARY:

	3, 75 D	5, 88 M
Texture:		
Silt	R	C
Clay	D	D
Composition:		
Quartz	T	T
Feldspar	T	–
Volcanic glass	T	–
Foraminifers	R/C	C
Calc. nannofossils	D	D
Radiolarians	–	?

SITE 593 HOLE CORE 32 CORED INTERVAL 293.1–302.7 m



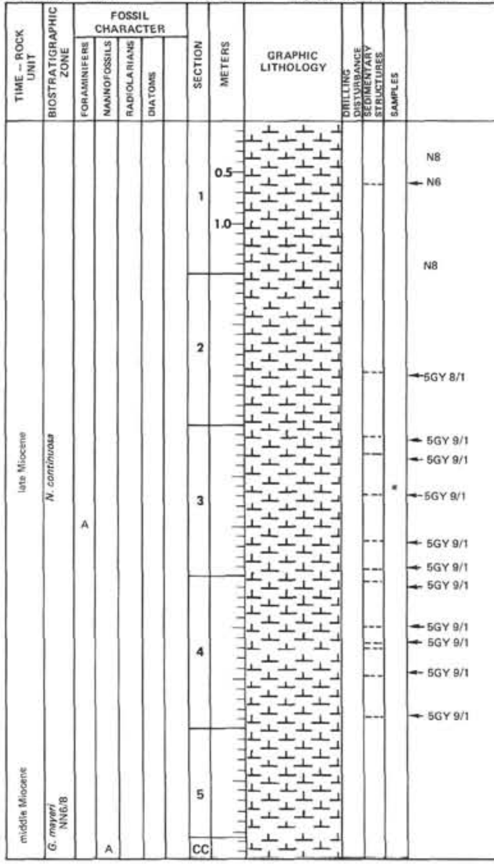
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), firm, homogeneous. Light gray (N7) and dark gray (N3) laminae of iron sulfide(?). Rare grayish yellow green (5GY 7/2) mottles are present in Section 3. Discrete light greenish gray (5G 8/1) laminae are present.

SMEAR SLIDE SUMMARY:

	3, 75
	D
Texture:	
Sand	T
Silt	R
Clay	D
Composition:	
Heavy minerals	T
Volcanic glass	T
Pyrite	T
Foraminifers	R/C
Calc. nannofossils	D
Sponge spicules	T

SITE 593 HOLE CORE 33 CORED INTERVAL 302.7–312.3 m



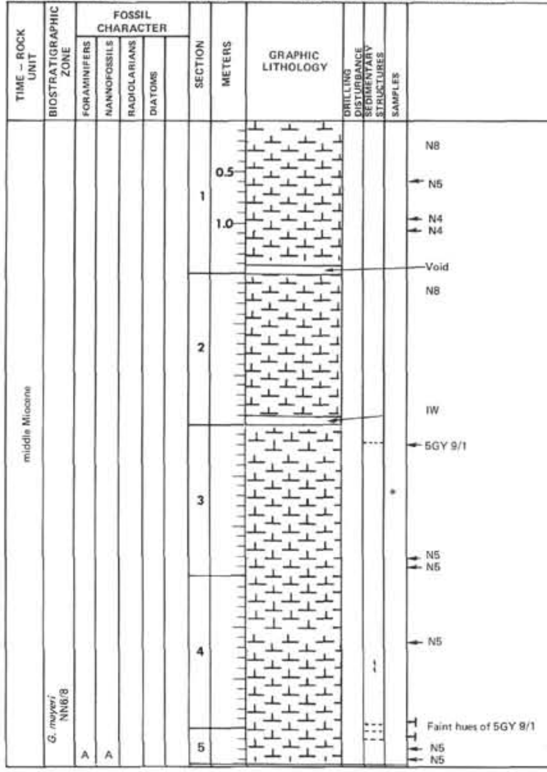
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft, very homogeneous with rare very faint bands of very light greenish gray (5GY 9/1) and streaks of iron sulfide(?).

SMEAR SLIDE SUMMARY:

	3, 60
	D
Composition:	
Pyrite	T
Foraminifers	R
Calc. nannofossils	D

SITE 593 HOLE CORE 34 CORED INTERVAL 312.3–321.9 m



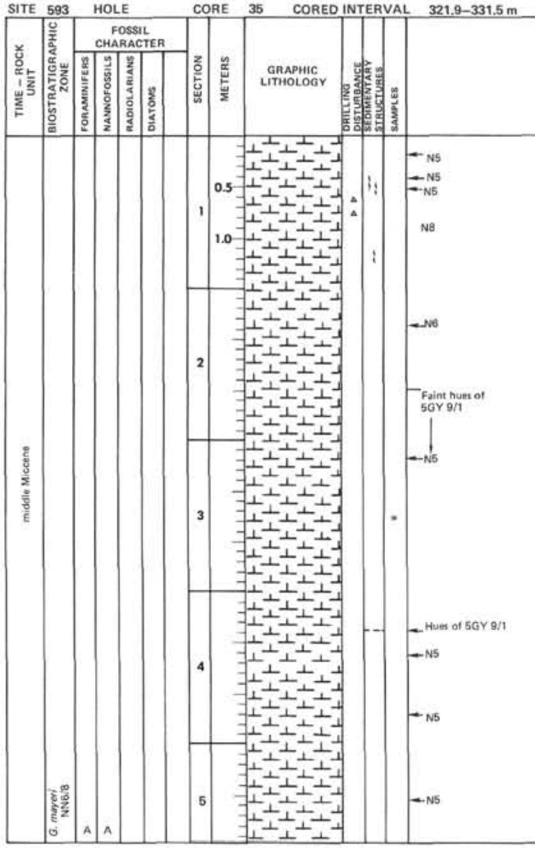
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous with a few spots of medium gray (N5) to medium dark gray (N4) iron sulfide(?) and very light greenish gray (5GY 9/1) hues.

SMEAR SLIDE SUMMARY:

	3, 67
Composition:	D
Volcanic glass	T
Pyrite	T
Foraminifers	R
Calc. nannofossils	D

SITE 593 HOLE CORE 35 CORED INTERVAL 321.9–331.5 m



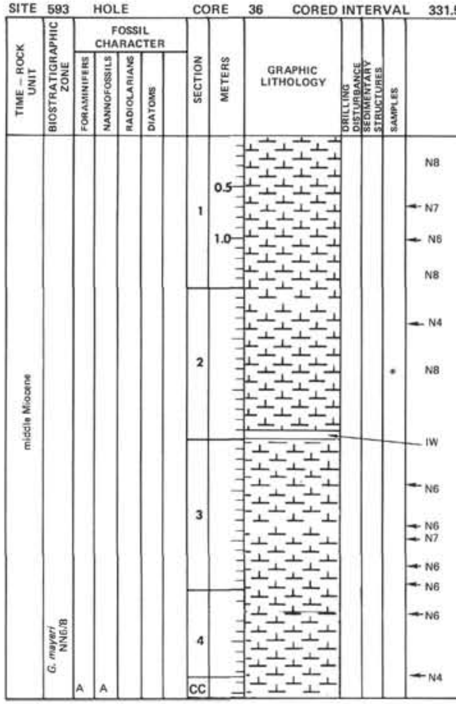
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft, very homogeneous. A few mottles(?) and streaks of medium gray (N5) iron sulfide(?). Some zones have faint hues of very light greenish gray (5GY 9/1) but the nature of the split surface precludes any accessment of sedimentary structures.

SMEAR SLIDE SUMMARY:

	3, 80
	D
Composition:	
Volcanic glass	T
Carbonate unspec.	C
Foraminifers	R
Calc. nannofossils	A

SITE 593 HOLE CORE 36 CORED INTERVAL 331.5–341.1 m



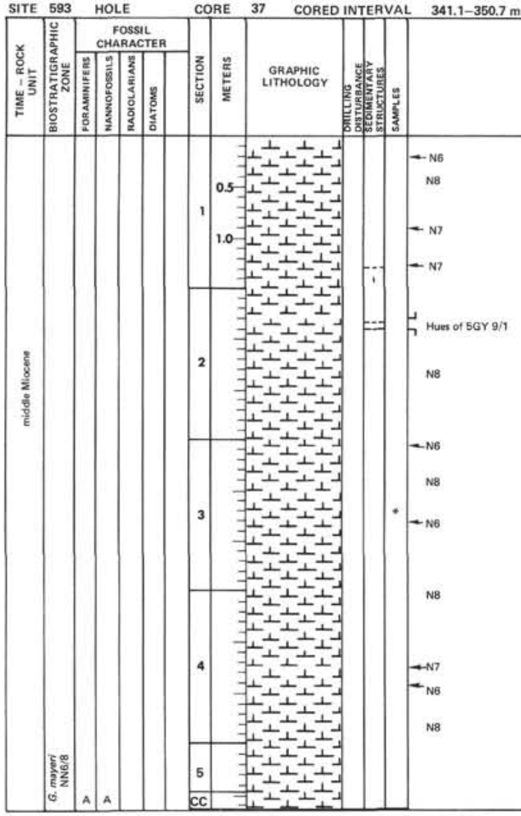
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous. Spots and streaks of various shades of gray (N7, N6, N4) iron sulfide(?). Impossible to describe sediment structures because surface was destroyed when split.

SMEAR SLIDE SUMMARY:

	2, 79
	D
Composition:	
Heavy minerals	T
Pyrite	T
Carbonate unspec.	C
Foraminifers	R
Calc. nannofossils	D

SITE 593 HOLE CORE 37 CORED INTERVAL 341.1–350.7 m



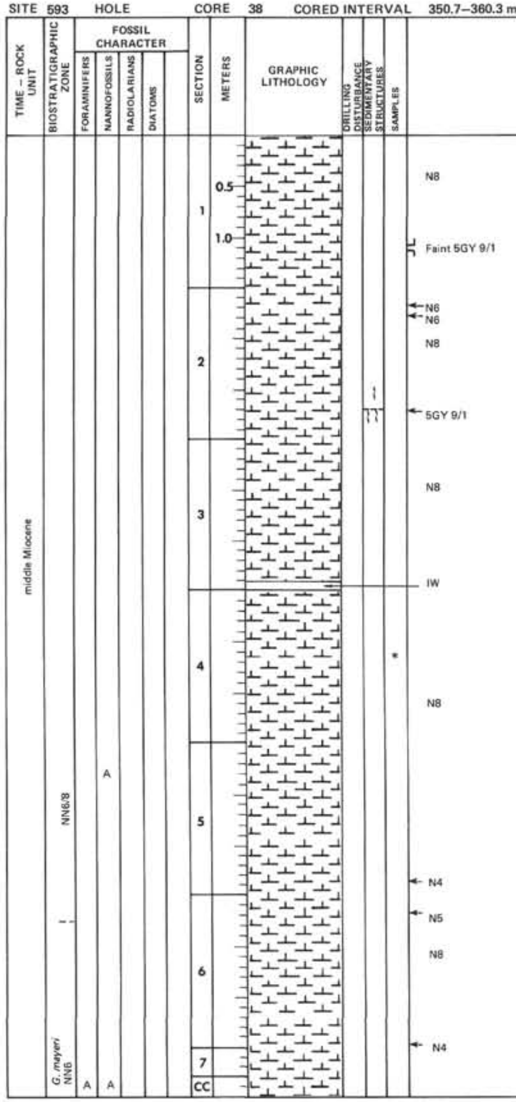
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft and homogeneous. Faint blobs and streaks of various grays (N7, N6). Zone of faint hues of very light gray green (5GY 9/1) in Section 2. Surface badly distorted by splitting.

SMEAR SLIDE SUMMARY:

	3, 79
	D
Composition:	
Volcanic glass	T
Pyrite	T
Carbonate unspec.	A
Foraminifers	R
Calc. nannofossils	A

SITE 593 HOLE CORE 38 CORED INTERVAL 350.7–360.3 m



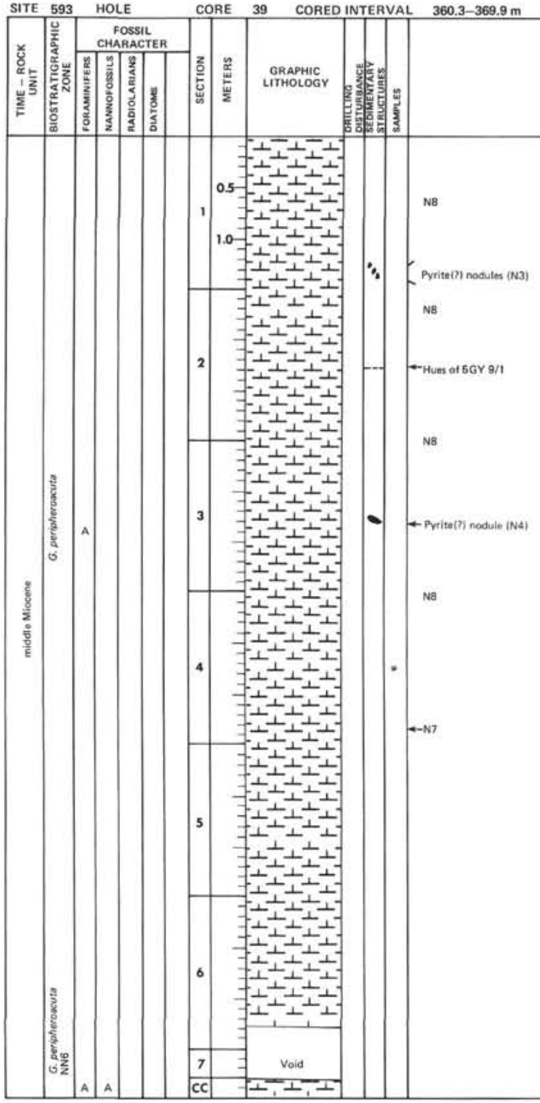
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft to stiff, homogeneous. A few zones of faint hues of 5GY 9/1 and several zones of grays (N6, N5, N4) of iron sulfides(?). Surface disrupted by splitting.

SMEAR SLIDE SUMMARY:

	4, 68
	D
Composition:	
Feldspar	T
Pyrite	T
Carbonate unspec.	C
Foraminifers	R
Calc. nannofossils	D

SITE 593 HOLE CORE 39 CORED INTERVAL 360.3–369.9 m



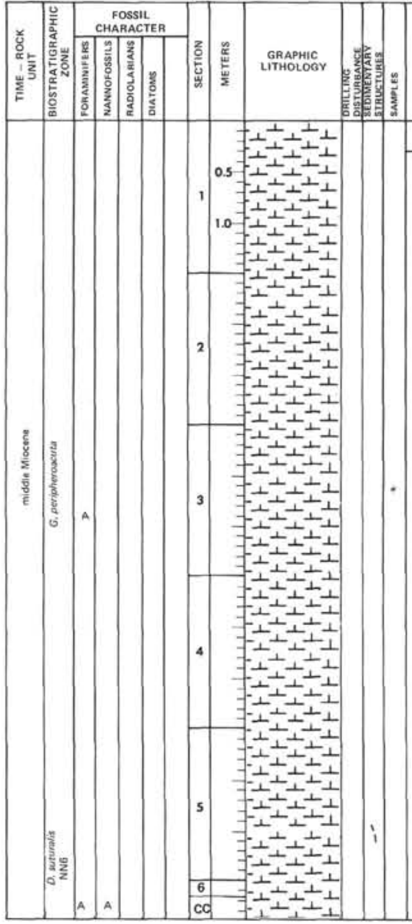
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft to firm, homogeneous. Streaks of medium gray (N4) iron sulfide(?). Nodules of pyrite(?) in Section 3, 75 cm and Section 1, 125 cm. Surface disrupted by splitting.

SMEAR SLIDE SUMMARY:

	4, 60
	D
Composition:	
Volcanic glass	T
Pyrite	T
Carbonate unspec.	C
Foraminifers	R
Calc. nannofossils	D

SITE 593 HOLE CORE 40 CORED INTERVAL 369.9–379.5 m



LITHOLOGIC DESCRIPTION

N7

N8

N8

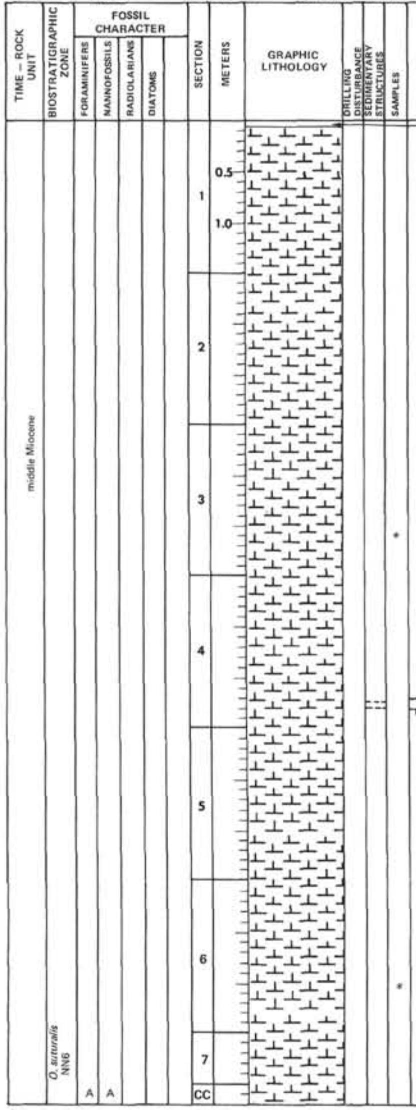
Iron sulfide(?) streaks

NANNOFOSSIL OOZE, very light gray (N8), stiff, very homogeneous. A few streaks of iron sulfide(?) in Section 5. Surface disrupted by splitting.

SMEAR SLIDE SUMMARY:

	3, 67
	D
Composition:	
Pyrite	T
Carbonate unspec.	C
Foraminifers	R
Calc. nannofossils	D

SITE 593 HOLE CORE 41 CORED INTERVAL 379.5–389.7 m



LITHOLOGIC DESCRIPTION

Void

N8

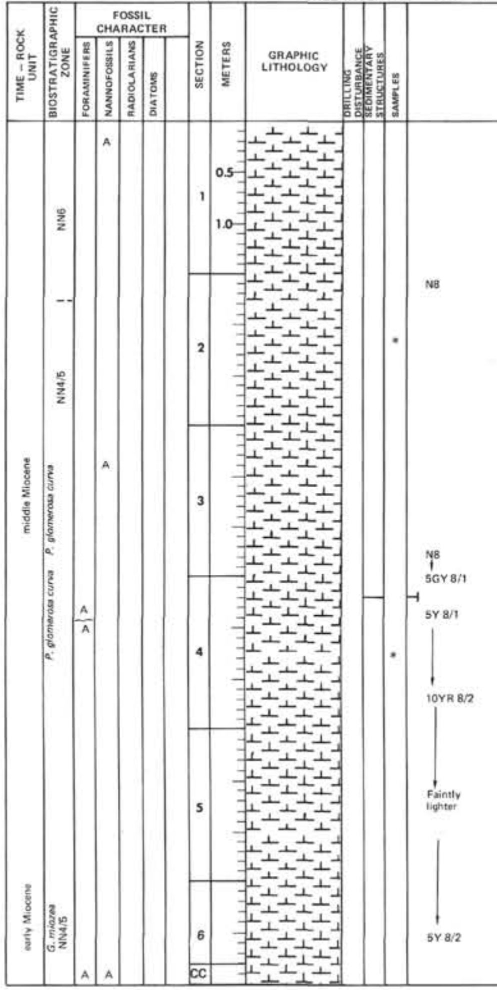
5B 7/1

NANNOFOSSIL OOZE, very light gray (N8), stiff, very homogeneous. Only very occasional iron sulfide(?) streaks. Surface disrupted by splitting.

SMEAR SLIDE SUMMARY:

	3, 107	6, 106
	D	D
Composition:		
Volcanic glass	T	T
Pyrite	T	T
Carbonate unspec.	C	C
Foraminifers	R	R
Calc. nannofossils	D	D

SITE 593 HOLE CORE 42 CORED INTERVAL 389.1–398.7 m



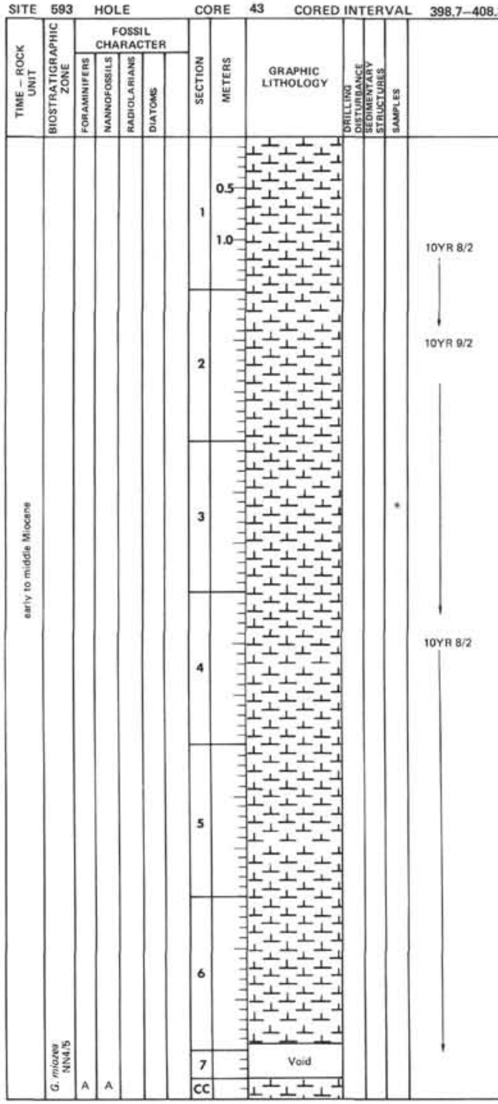
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8) overlying various hues of very pale orange (10YR 8/2), stiff, very homogeneous. Color boundary represents no change in lithology.

SMEAR SLIDE SUMMARY:

	2, 78	4, 80
	D	D
Composition:		
Volcanic glass	–	T
Carbonate unspec.	A	A
Foraminifers	R	R
Calc. nannofossils	A	A

SITE 593 HOLE CORE 43 CORED INTERVAL 398.7–408.3 m



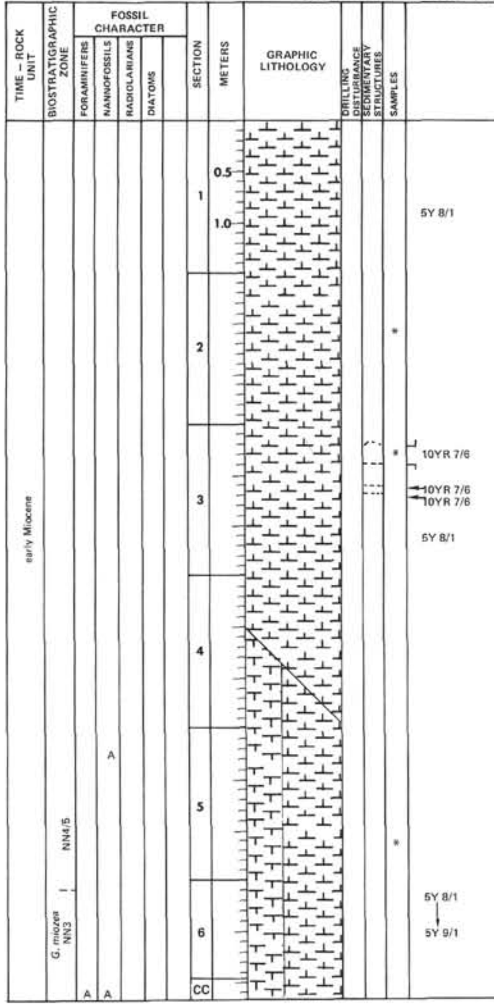
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very pale orange (10YR 8/2 and (10YR 9/2), stiff to firm, totally homogeneous and featureless.

SMEAR SLIDE SUMMARY:

	3, 70
	D
Composition:	
Volcanic glass	T
Carbonate unspec.	C
Foraminifers	R
Calc. nannofossils	D

SITE 593 HOLE CORE 44 CORED INTERVAL 408.3–417.9 m



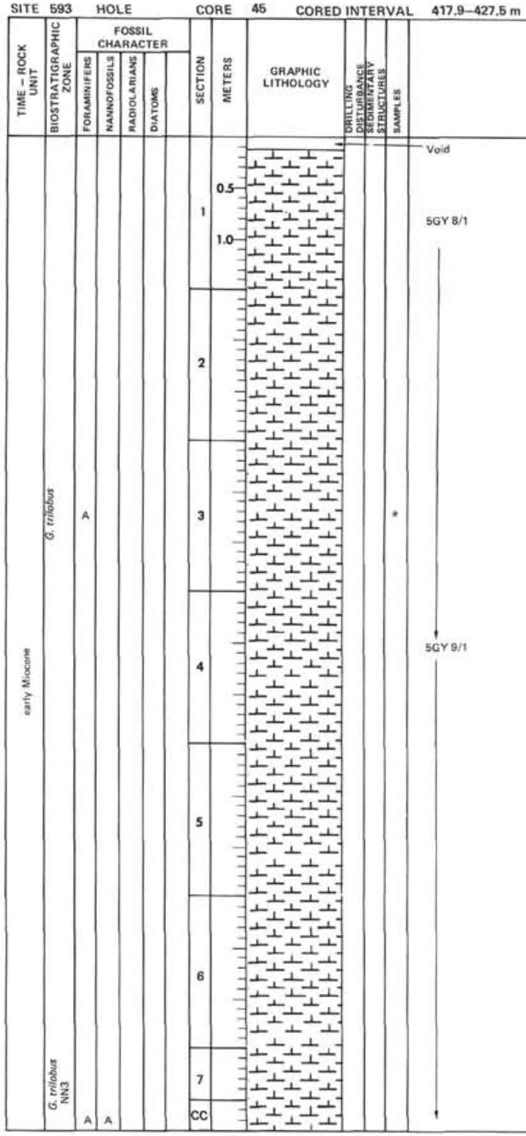
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, yellowish gray (5Y 8/1 to 5Y 9/1), stiff to firm, very homogeneous, essentially featureless except for pale yellowish orange (10YR 7/6) zones in Section 3. Facies becomes FORAMINIFER-BEARING NANNOFOSSIL OOZE by Section 5.

SMEAR SLIDE SUMMARY:

	2, 71 D	3, 26 M	5, 110 D
Composition:			
Feldspar	T	–	–
Volcanic glass	–	T	T
Pyrite	–	–	T
Carbonate unspec.	C	C	C
Foraminifers	R	C	C
Calc. nannofossils	D	D	D

SITE 593 HOLE CORE 45 CORED INTERVAL 417.9–427.5 m



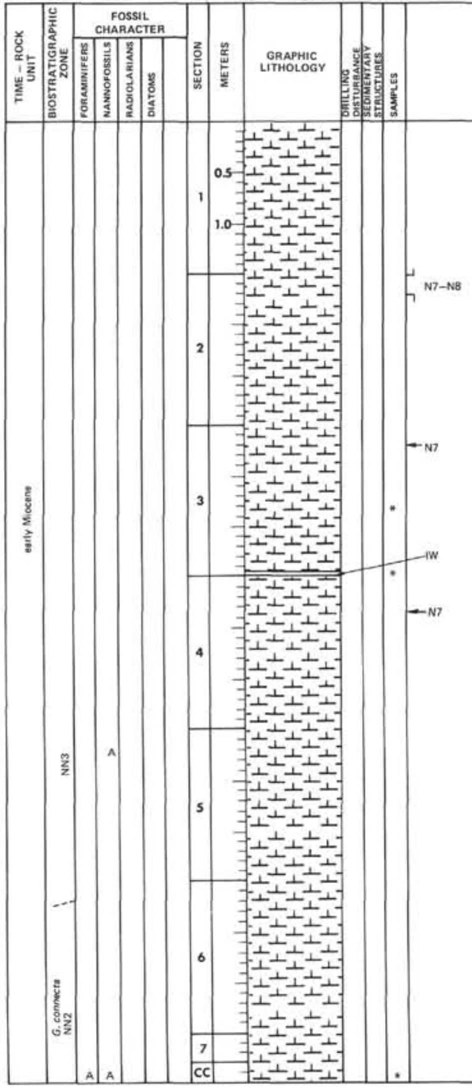
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, light greenish gray (5GY 8/1) to very light greenish gray (5GY 9/1), stiff, homogeneous, virtually featureless.

SMEAR SLIDE SUMMARY:

	3, 80 D
Composition:	
Volcanic glass	T
Pyrite	T
Carbonate unspec.	C
Foraminifers	R
Calc. nannofossils	D

SITE 593 HOLE CORE 46 CORED INTERVAL 427.5–437.1 m



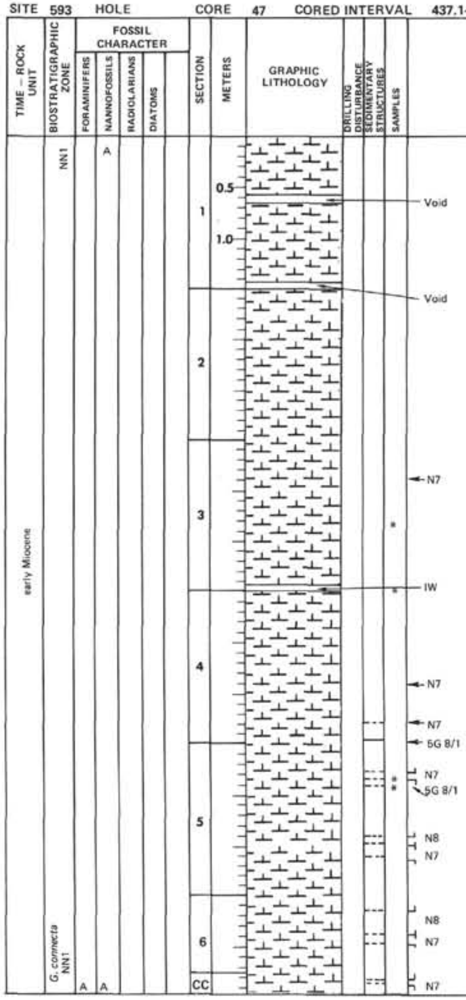
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, white (N9) to very light gray (N8), firm, homogeneous. Light gray (N8–N7) level in Section 2.

SMEAR SLIDE SUMMARY:

	3, 80	CC
	D	M
Texture:		
Sand	–	C
Silt	R	A
Clay	D	A
Composition:		
Heavy minerals	–	T
Pyrite	–	A
Carbonate unspec.	C	–
Foraminifers	R	C
Calc. nannofossils	D	A

SITE 593 HOLE CORE 47 CORED INTERVAL 437.1–446.7 m



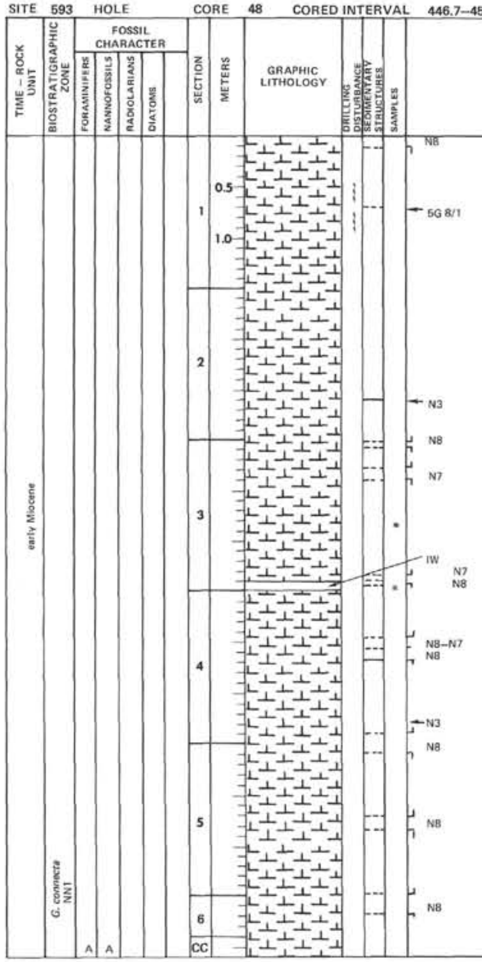
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, white (N9) to very light gray (N8), firm, homogeneous. Light gray (N7–N8) zones in Sections 5, 6, and CC. Discrete light greenish gray (5G 8/1) laminae in Sections 4 and 5. Voids in Section 1 are due to drilling and core handling.

SMEAR SLIDE SUMMARY:

	3, 80	5, 36	5, 39
	D	M	M
Texture:			
Silt	R	R	R
Clay	D	D	D
Composition:			
Feldspar	–	T	–
Heavy minerals	T	–	–
Volcanic glass	T	T	T
Pyrite	–	–	T
Carbonate unspec.	C	C	C
Foraminifers	R	R	R
Calc. nannofossils	D	D	D

SITE 593 HOLE CORE 48 CORED INTERVAL 446.7–456.3 m



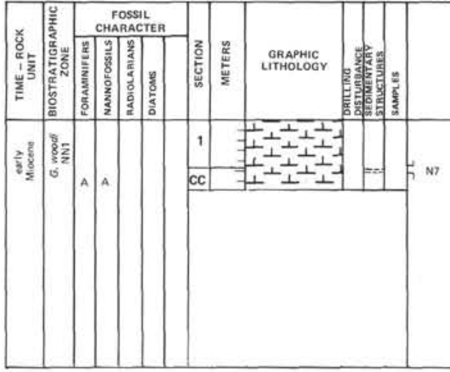
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, white (N9) to very light gray (N8), firm, homogeneous. Light gray (N7) to very light gray (N8), and dark gray (N3) levels of iron sulfide(?) are present.

SMEAR SLIDE SUMMARY:

	3, 80 D
Texture:	
Silt	T
Clay	D
Composition:	
Heavy minerals	T
Volcanic glass	T
Pyrite	T
Carbonate unspec.	C
Foraminifers	T/R
Calc. nannofossils	D

SITE 593 HOLE CORE 49 CORED INTERVAL 456.3–465.9 m



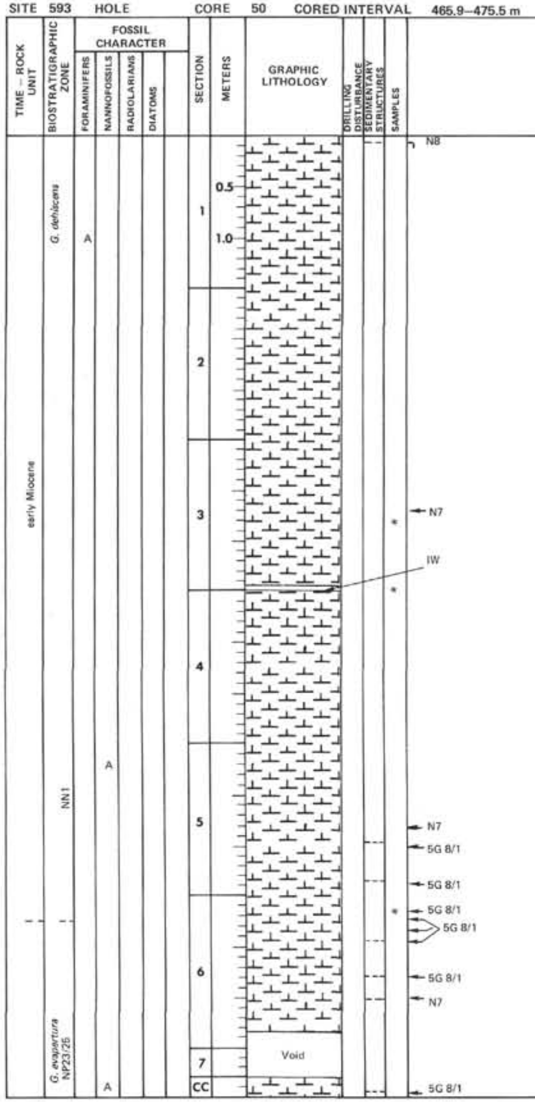
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, white (N9) to very light gray (N8), firm, homogeneous. Light gray (N7) level in Core Catcher.

SMEAR SLIDE SUMMARY:

	1, 30 D
Texture:	
Sand	R
Silt	D
Composition:	
Carbonate unspec.	C
Foraminifers	R/C
Calc. nannofossils	D

SITE 593 HOLE CORE 50 CORED INTERVAL 465.9–475.5 m



LITHOLOGIC DESCRIPTION

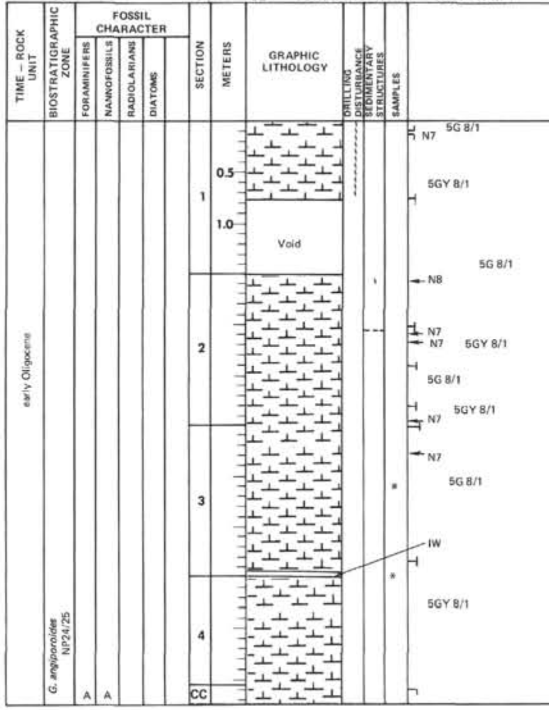
FORAMINIFER-BEARING NANNOFOSSIL OOZE, firm, homogeneous, white (N9) to light greenish gray (5GY 8/1). Rare light gray (N7–N8) laminae and light greenish gray (5G 8/1) burrows and laminae.

SMEAR SLIDE SUMMARY:

	3, 80	6, 11
	D	M
Texture:		
Sand	R	–
Silt	C	–
Clay	D	–
Composition:		
Quartz	–	T
Volcanic glass	T	T
Carbonate unspec.	C	C
Foraminifers	C	R
Calc. nannofossils	A	D
Dolomite	T	T

Core 51, 475.5–485.1 m: no recovery.

SITE 593 HOLE CORE 52 CORED INTERVAL 485.1–494.7 m



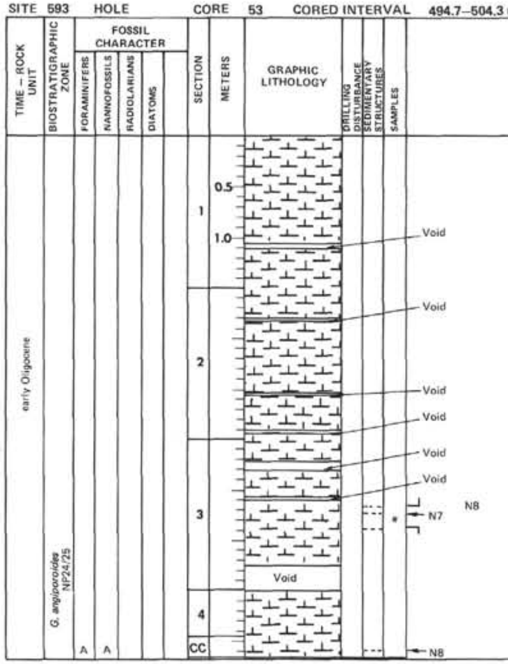
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, light greenish gray (5GY 8/1 to 5G 8/1), firm, homogeneous. Partly lithified in Sections 1 and 2. Rare light gray (N7 and N8) burrows and laminae.

SMEAR SLIDE SUMMARY:

	3, 80
	D
Texture:	
Silt	R
Clay	D
Composition:	
Quartz	T
Heavy minerals	T
Volcanic glass	T
Carbonate unspec.	C
Foraminifers	R
Calc. nannofossils	D

SITE 593 HOLE CORE 53 CORED INTERVAL 494.7–504.3 m



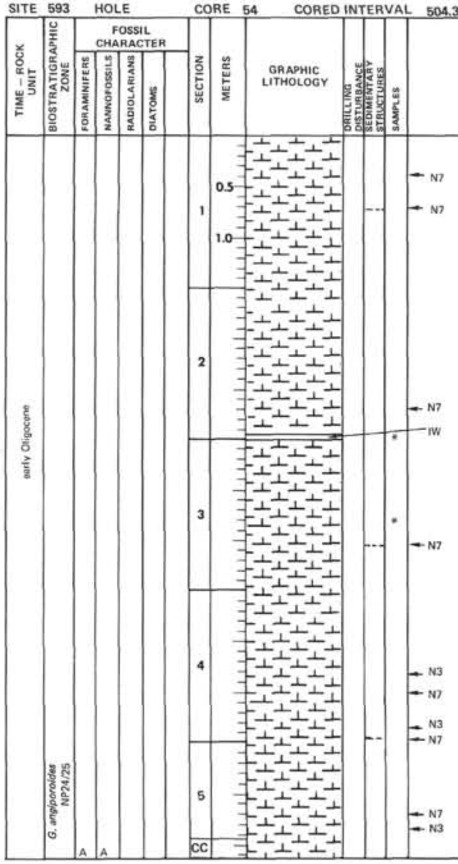
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, white (N9), firm, homogeneous. Very light gray (N8) level in Section 3. Rare light gray (N7) laminae. Voids are due to drilling and core handling.

SMEAR SLIDE SUMMARY:

	3, 80
	D
Texture:	
Silt	T
Clay	D
Composition:	
Quartz	T
Volcanic glass	T
Carbonate unspec.	C
Foraminifers	T/R
Calc. nannofossils	D
Dolomite	T

SITE 593 HOLE CORE 54 CORED INTERVAL 504.3–513.9 m



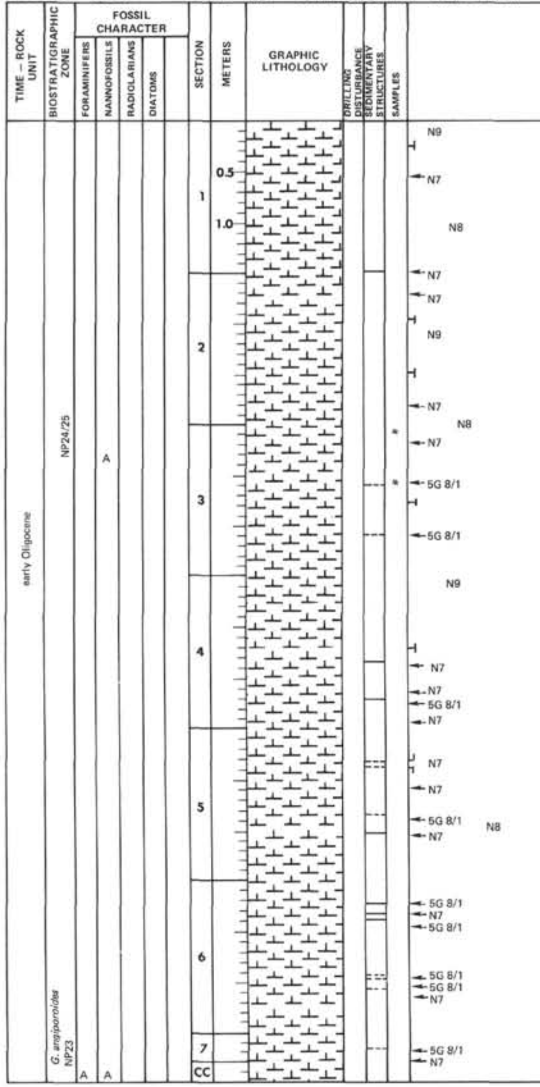
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, white (N9) to very light gray (N8), firm, homogeneous. Rare light gray (N7) and dark gray (N3) laminae.

SMEAR SLIDE SUMMARY:

	3, 80
	D
Texture:	
Silt	R
Clay	D
Composition:	
Volcanic glass	T
Glauconite	T
Carbonate unspec.	C
Foraminifers	R
Calc. nannofossils	D

SITE 593 HOLE CORE 55 CORED INTERVAL 513.9–523.5 m



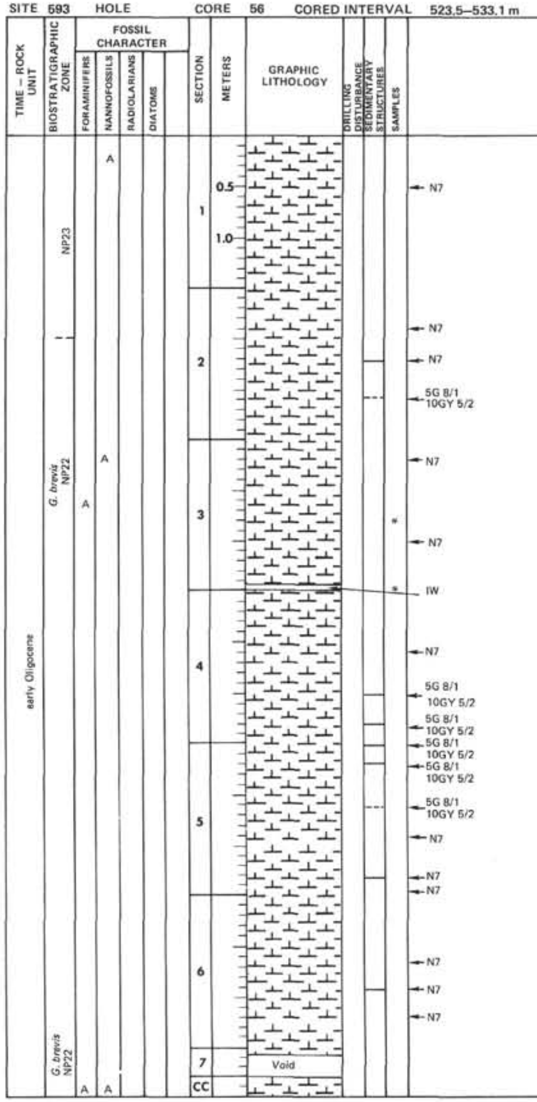
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, white (N9) to very light gray (N8), firm, homogeneous. Light gray (N7) laminae of iron sulfide(?). Discrete light greenish gray (5G 8/1) laminae below Section 2.

SMEAR SLIDE SUMMARY:

	3, 80 D	3, 56 M
Texture:		
Silt	R	R
Clay	D	D
Composition:		
Quartz	–	T
Heavy minerals	–	T
Volcanic glass	T	T
Carbonate unspec.	C	C
Foraminifers	R	R
Calc. nannofossils	D	D
Dolomite	–	T

SITE 593 HOLE CORE 56 CORED INTERVAL 523.5–533.1 m



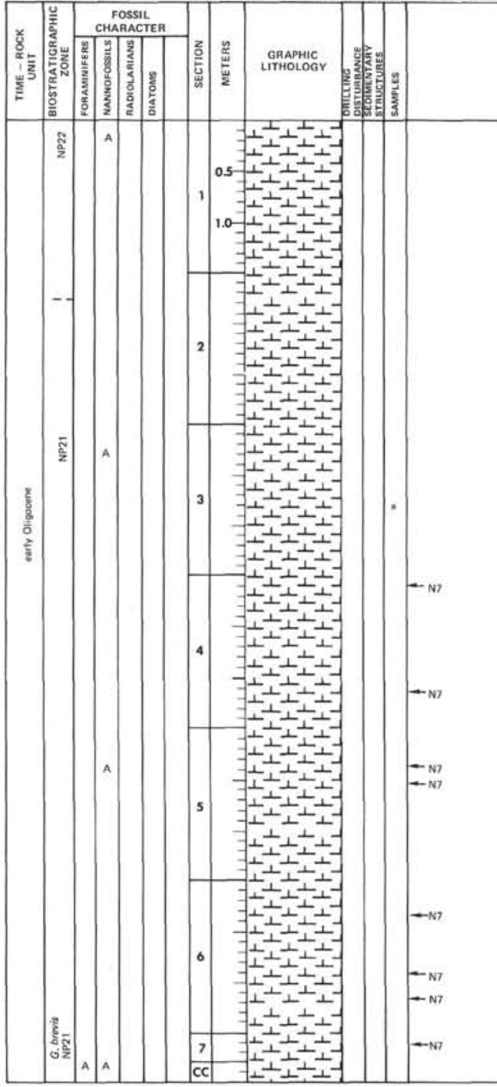
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8) to light greenish gray (5GY 8/1), homogeneous, with alternations of firm and stiff sediments. Light gray (N7) burrows and light gray (N7), light greenish gray (5G 8/1) to grayish green (10GY 5/2) laminae common.

SMEAR SLIDE SUMMARY:

	3, 80 D
Composition:	
Quartz	T
Heavy minerals	T
Carbonate unspec.	C
Foraminifers	T/R
Calc. nannofossils	D
Dolomite	T

SITE 593 HOLE CORE 57 CORED INTERVAL 533.1–542.7 m



LITHOLOGIC DESCRIPTION

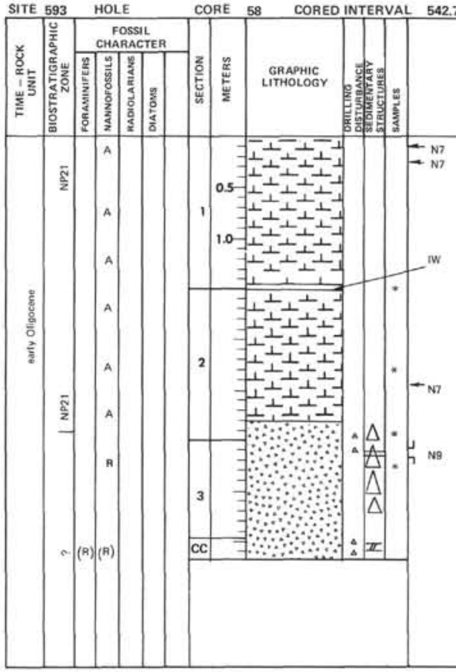
NANNOFOSSIL OOZE, homogeneous, with alternations of firm and stiff sediments. White (N9) to very light gray (N8).

Rare light gray (N7) burrows and laminae.

SMEAR SLIDE SUMMARY:

	3, 80
	D
Texture:	
Silt	R
Clay	D
Composition:	
Quartz	T
Heavy minerals	T
Volcanic glass	T
Carbonate unspec.	C
Foraminifers	R
Calc. nannofossils	D
Dolomite	T

SITE 593 HOLE CORE 58 CORED INTERVAL 542.7–552.3 m



LITHOLOGIC DESCRIPTION

Section 1, 0 cm through Section 2, 130 cm: NANNOFOSSIL OOZE, white (N9) to very light gray (N8), homogeneous, with alternations of firm and stiff sediment. Rare light gray (N7) laminae in Section 1 through Section 2, 129 cm.

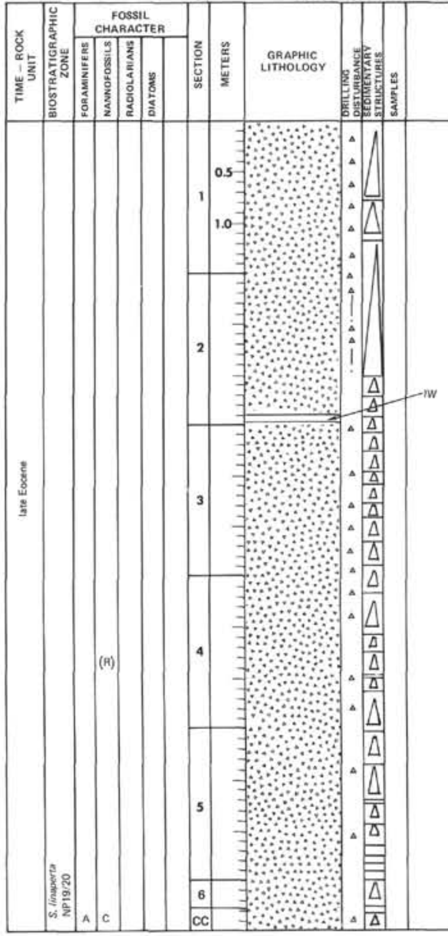
Section 2, 130 cm through Core Catcher: LITHIFIED VOLCANOGENIC TURBIDITES, grayish olive green (5GY 3/2) to dusky yellowish green (10GY 3/2) until 25 cm Section 3 then grayish olive green (5GY 3/2) to dark gray (N4). White (N9) veins of calcite are present. White (N9) laminae of nannofossil chalk in Section 3. Sediment generally normally graded. Cross-beddings are present in Core Catcher.

Cross-beddings are present in Core Catcher.

SMEAR SLIDE SUMMARY:

	2, 80	2, 140	3, 26
	D	D	M
Composition:			
Quartz	–	T	–
Feldspar	–	T	–
Heavy minerals	–	T	–
Clay	–	A	–
Volcanic glass	T	T	T
Glauconite	–	C	–
Carbonate unspec.	C	C	D
Foraminifers	R	R	R
Calc. nannofossils	C	C	R
Other	T	–	–

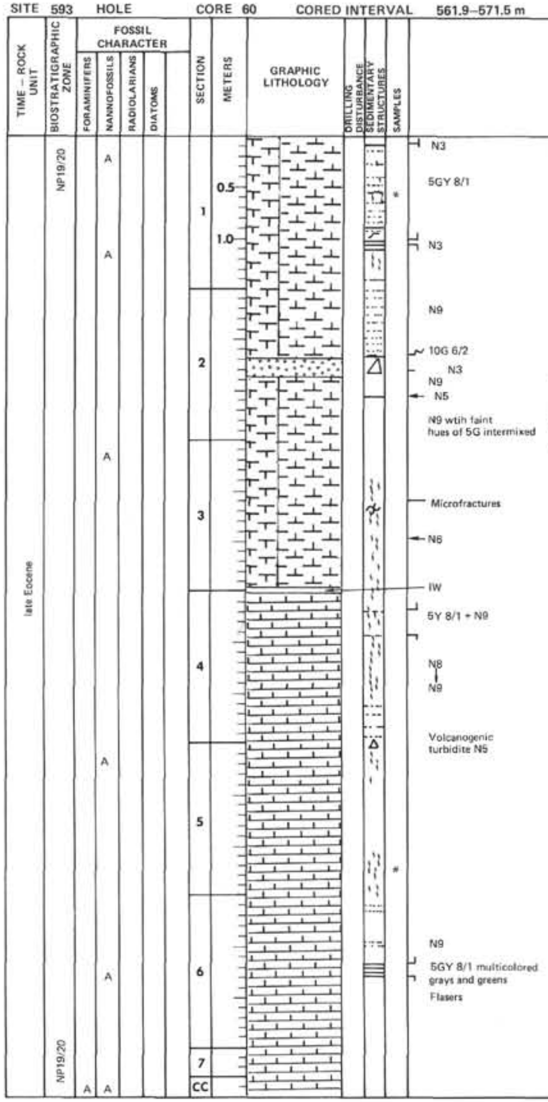
SITE 593 HOLE CORE 59 CORED INTERVAL 552.3–561.9 m



LITHOLOGIC DESCRIPTION

LITHIFIED VOLCANOGENIC TURBIDITES, predominantly grayish black (N2) with some grayish green (5GY) hues in coarser lithologies, hard (lithified), repetitive packets of upward-fining units involving breccia to sandstone to siltstone or sandstone to siltstone, several with Bouma sedimentary structure sequences (especially A, B, and E divisions). Siltstones are glassy (cf. obsidian) and detritus possibly of glassy rhyolite composition. Occasional calcite veining. Core retains stratigraphic entity, but all sections include brecciated material due to coring, and some biscuit structures.

SITE 593 HOLE CORE 60 CORED INTERVAL 561.9–571.5 m



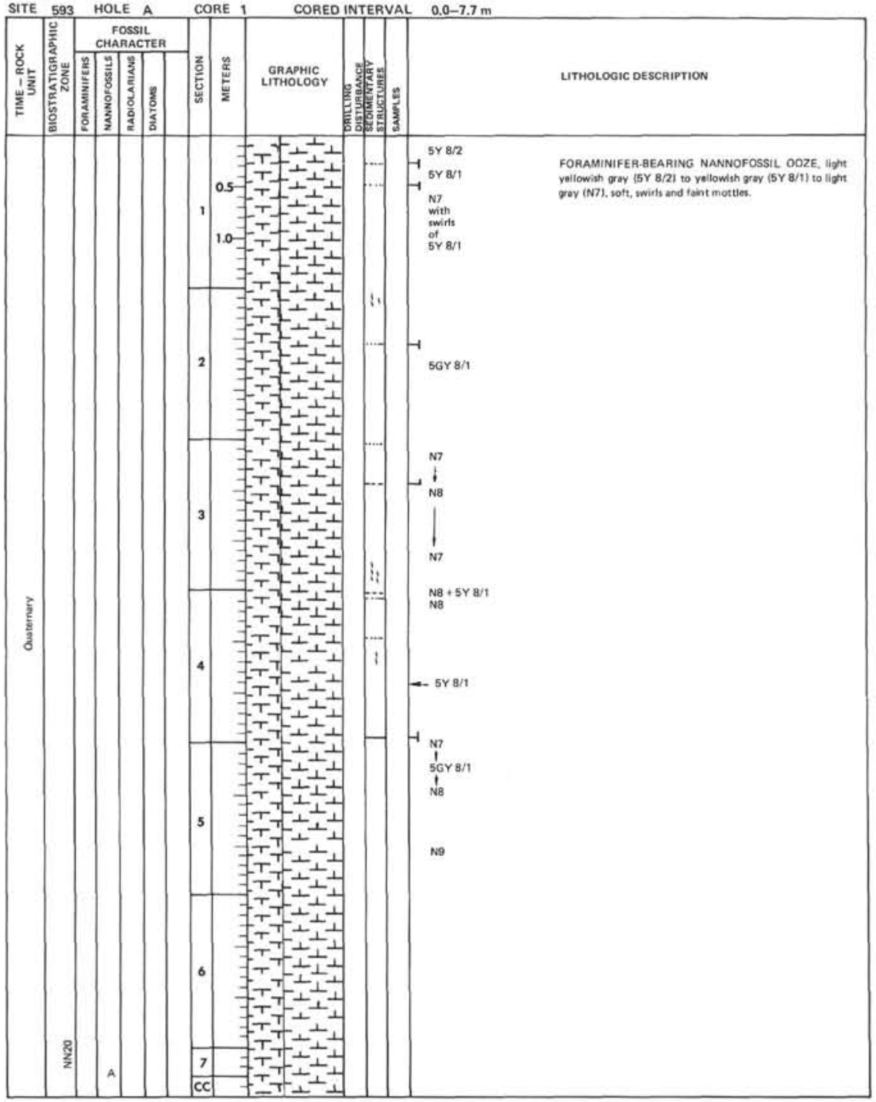
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL CHALK grading with depth to NANNOFOSSIL CHALK, light greenish gray (5GY 8/1) to white (N9), varies from stiff to hard (ooze to chalk), intensely burrowed. Numerous thin very pale green (10G 8/1) volcanic ash layers (indicated by •••••) in sedimentary structures column. Flaser-like beds common and *Zoophycus* burrows numerous; *Planolites* common. Volcanogenic turbidite, lithified at Section 2, 57 to 78 cm. Chalk below this turbidite is almost featureless. Microfractures in Section 3. Volcanogenic turbidite in bottom Section 4.

SMEAR SLIDE SUMMARY:

	1, 60	5, 120
	D	D
Composition:		
Feldspar	–	T
Volcanic glass	T	T
Carbonate unspec.	C	A
Foraminifers	C	R
Calc. nannofossils	A	A

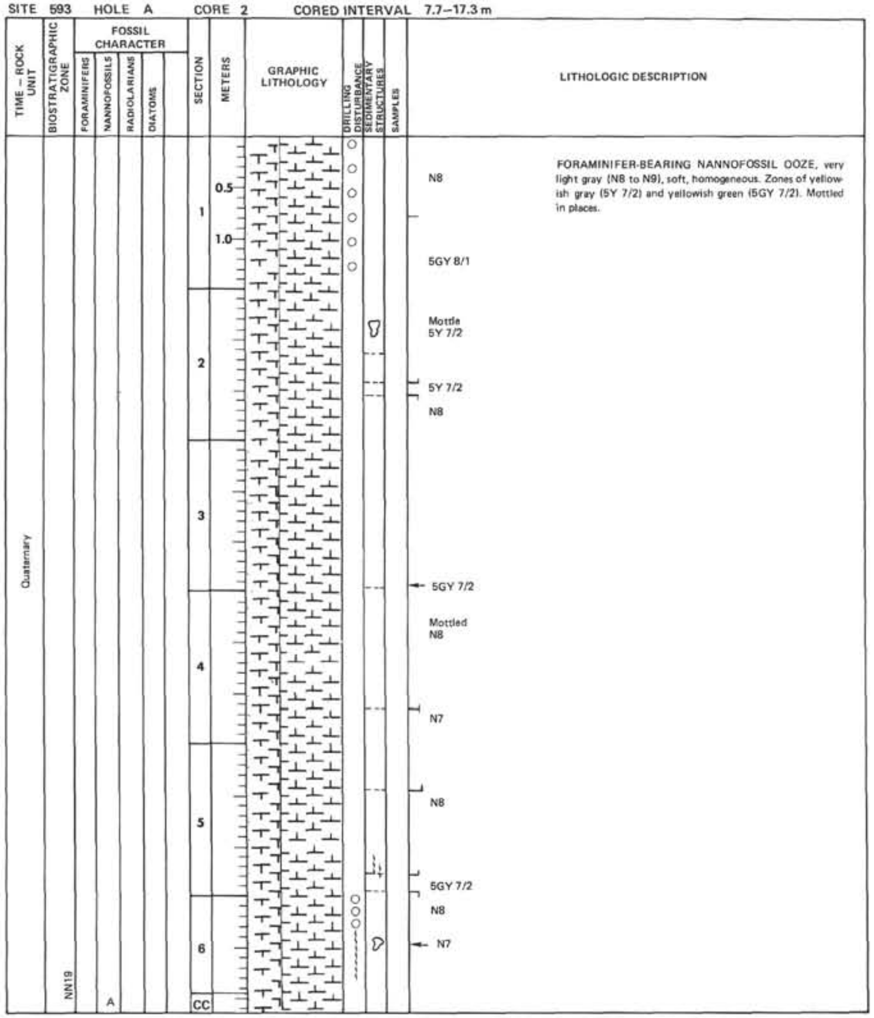
SITE 593 HOLE A CORE 1 CORED INTERVAL 0.0–7.7 m



LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, light yellowish gray (5Y 8/2) to yellowish gray (5Y 8/1) to light gray (N7), soft, swirls and faint mottles.

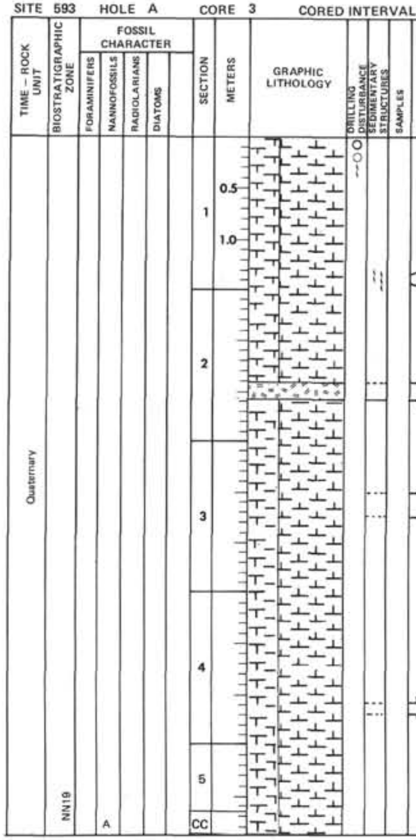
SITE 593 HOLE A CORE 2 CORED INTERVAL 7.7–17.3 m



LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8 to N9), soft, homogeneous. Zones of yellowish gray (5Y 7/2) and yellowish green (5GY 7/2). Mottled in places.

SITE 593 HOLE A CORE 3 CORED INTERVAL 17.3–26.9 m

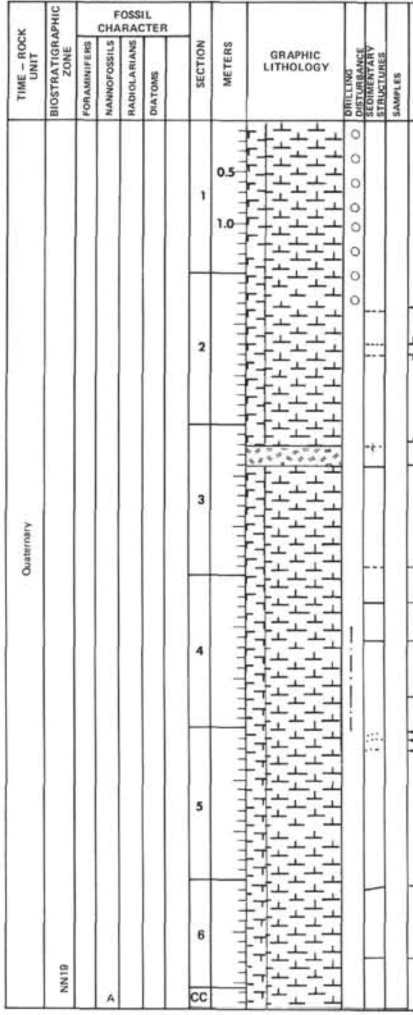


LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, soft, homogeneous with mottles of yellowish gray (5Y 8/1). Major lithology is very light gray (N8).

Ash in Sections 2, 3, and 4?

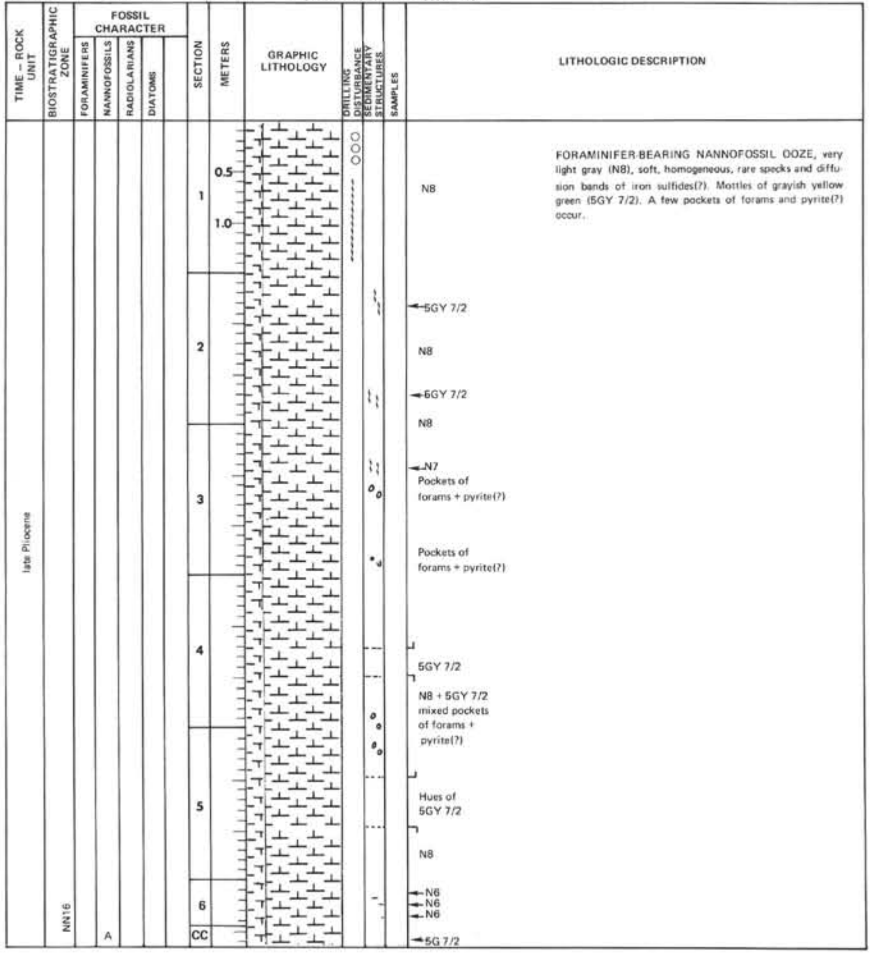
SITE 593 HOLE A CORE 4 CORED INTERVAL 26.9–36.5 m



LITHOLOGIC DESCRIPTION

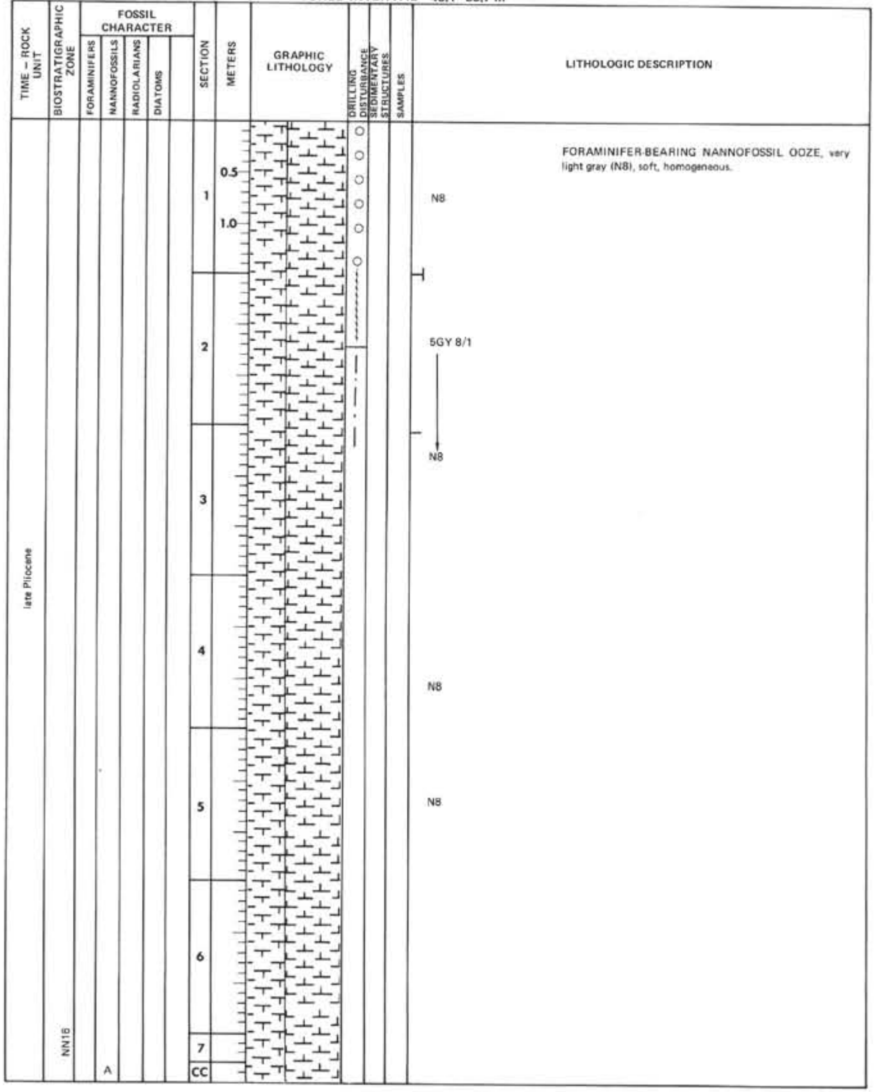
FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8) to light gray (N7), soft, homogeneous. Interbeds of grayish yellow green (5GY 7/2) and pockets of forams and pyrite(?) scattered throughout. Possible ash in Section 3.

SITE 593 HOLE A CORE 5 CORED INTERVAL 36.5–46.1 m



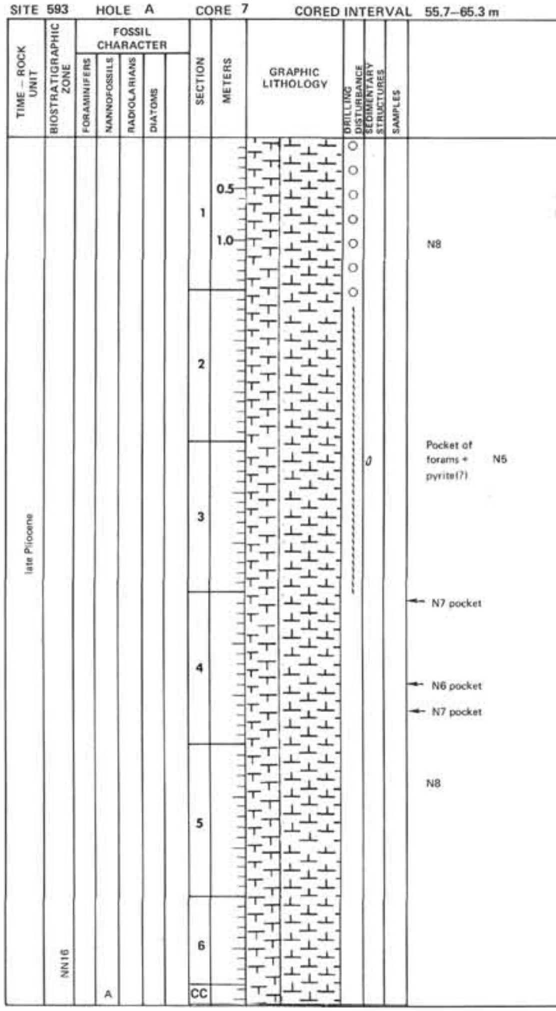
FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous, rare specks and diffusion bands of iron sulfides(?). Mottles of grayish yellow green (5GY 7/2). A few pockets of forams and pyrite(?) occur.

SITE 593 HOLE A CORE 6 CORED INTERVAL 46.1–55.7 m



FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous.

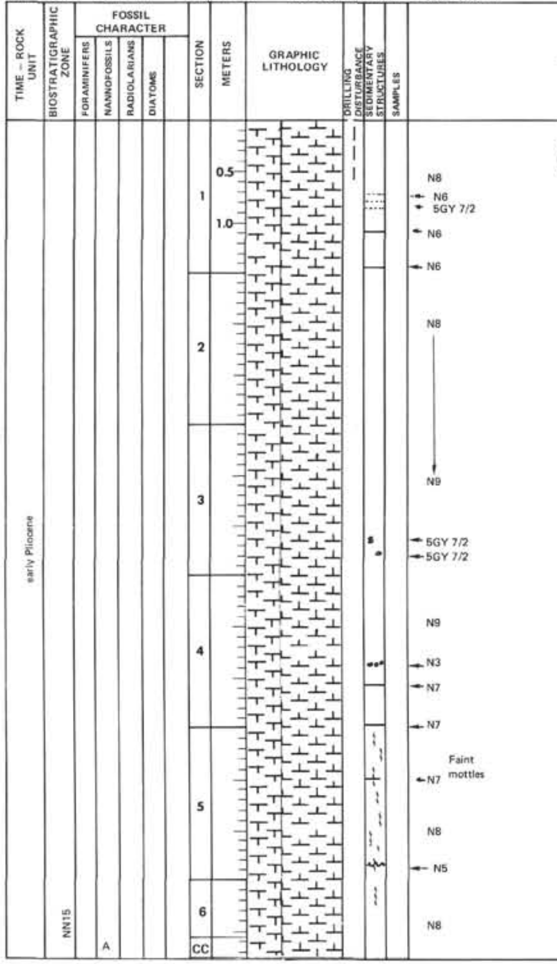
SITE 593 HOLE A CORE 7 CORED INTERVAL 55.7–65.3 m



LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), soft, severe coring disturbance in at least first 3 sections, homogeneous. Pocket of forams and pyrite(?) in Sections 3 and 4.

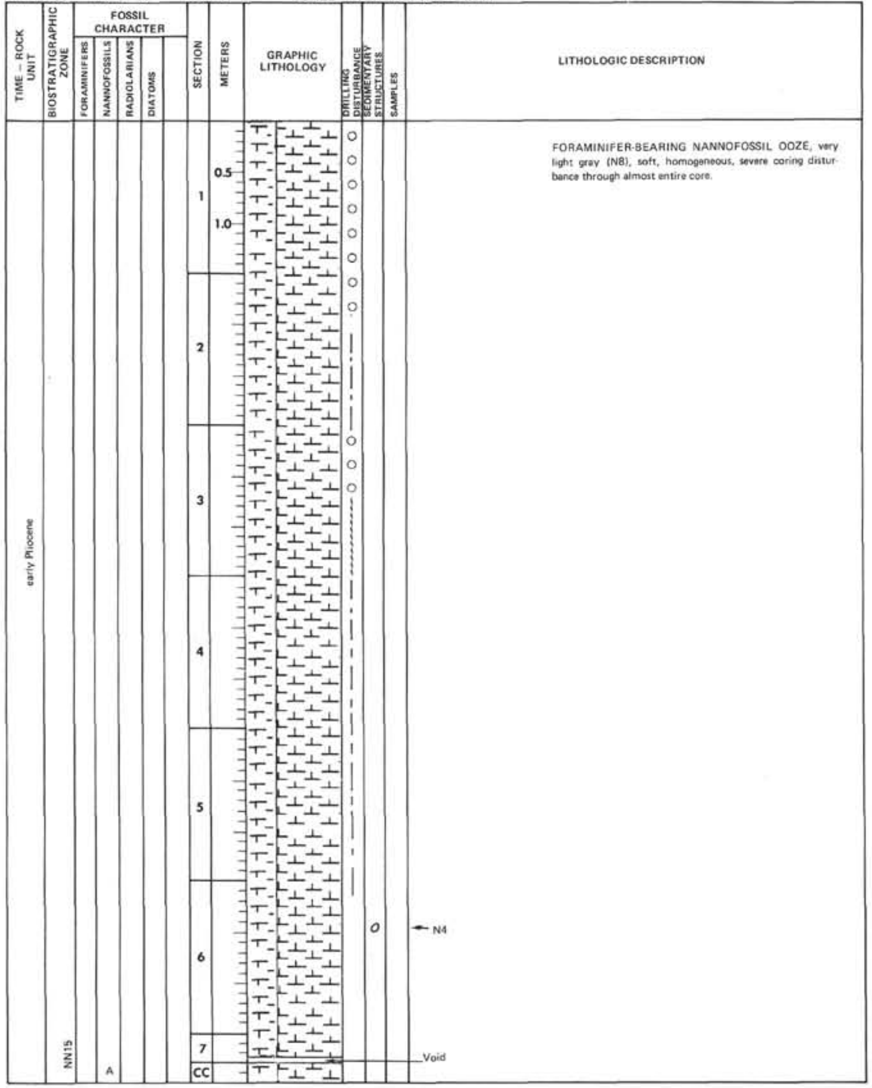
SITE 593 HOLE A CORE 8 CORED INTERVAL 65.5–74.9 m



LITHOLOGIC DESCRIPTION

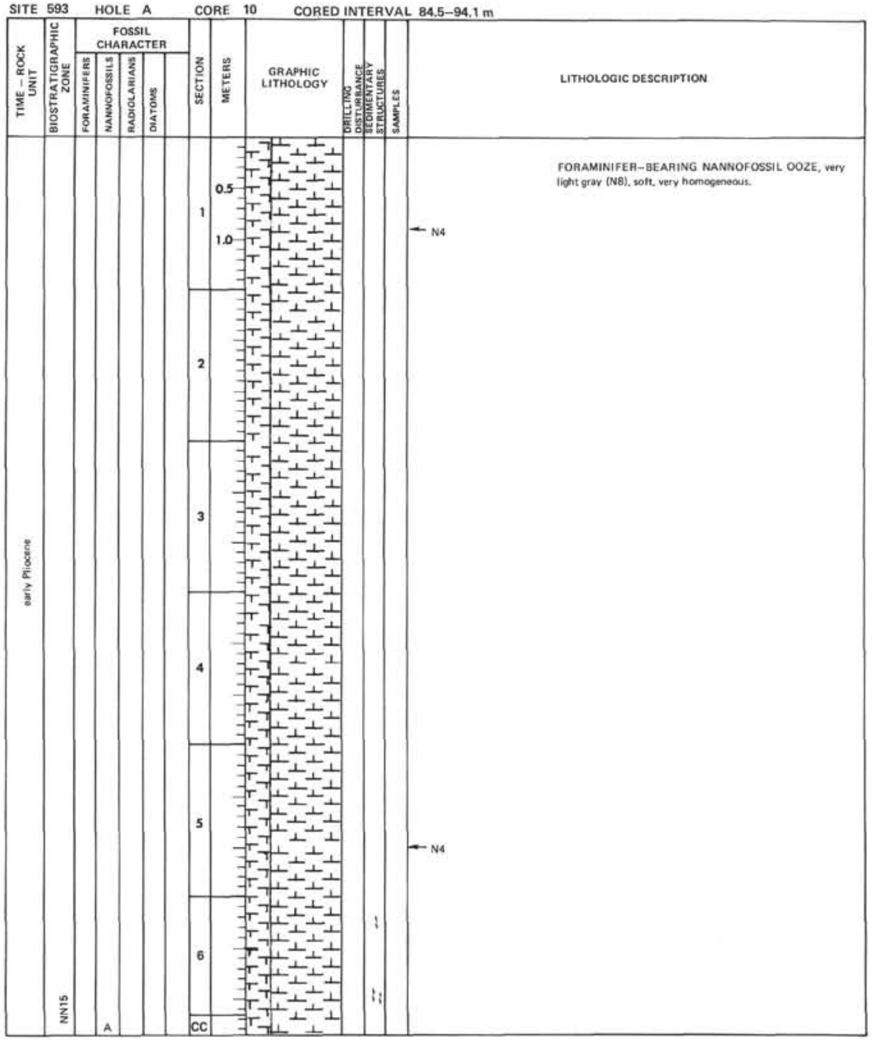
FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), soft, some dark (N6) blebs and streaks. Mottles faint but present, especially in Section 5.

SITE 593 HOLE A CORE 9 CORED INTERVAL 74.9–54.5 m



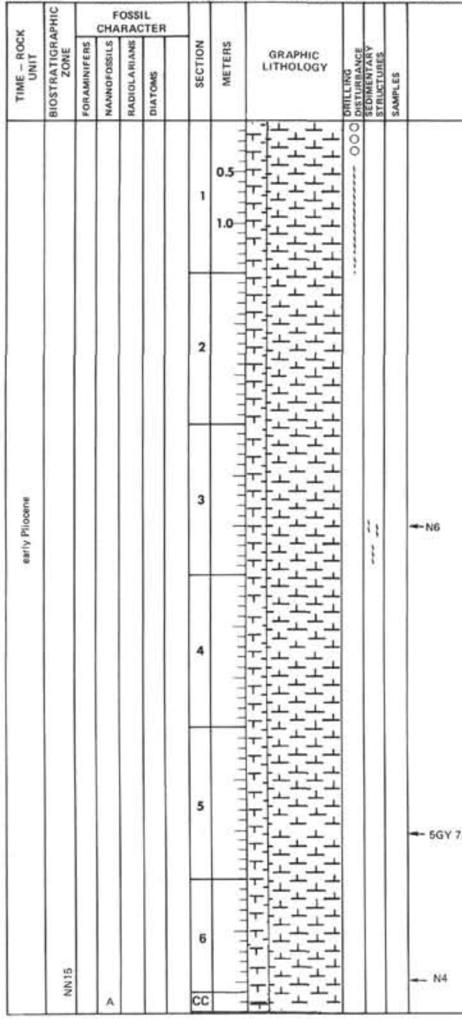
FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous, severe coring disturbance through almost entire core.

SITE 593 HOLE A CORE 10 CORED INTERVAL 84.5–94.1 m



FORAMINIFER–BEARING NANNOFOSSIL OOZE, very light gray (N8), soft, very homogeneous.

SITE 593 HOLE A CORE 11 CORED INTERVAL 94.1–103.7 m

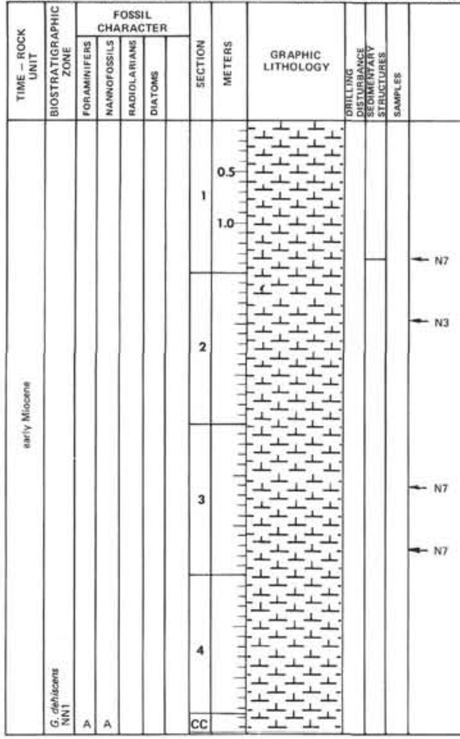


LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), soft, very homogeneous with only very rare iron sulfide(?) diffusion bands and pockets of grayish yellow green (5GY 7/2).

NOTE: 593A, Cores 12 through 22 have not been split – no core barrel sheets.

SITE 593 HOLE A CORE 23 CORED INTERVAL 448.8–458.4 m



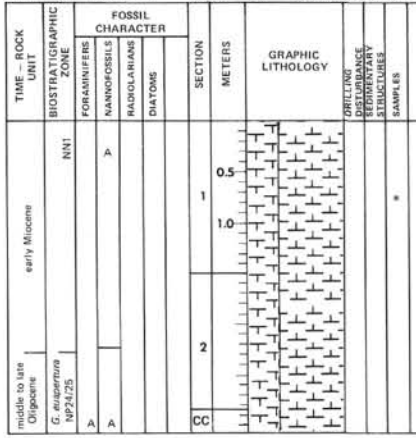
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, white (N9) to very light gray (N8), firm, homogeneous. Rare light gray (N7) and dark gray (N3) laminae.

SMEAR SLIDE SUMMARY:

	2, 80
	D
Texture:	
Silt	R
Clay	D
Composition:	
Quartz	T
Mica	T
Volcanic glass	T
Carbonate unspec.	T
Foraminifers	T
Calc. nannofossils	D

SITE 593 HOLE A CORE 24 CORED INTERVAL 458.4–468.0 m



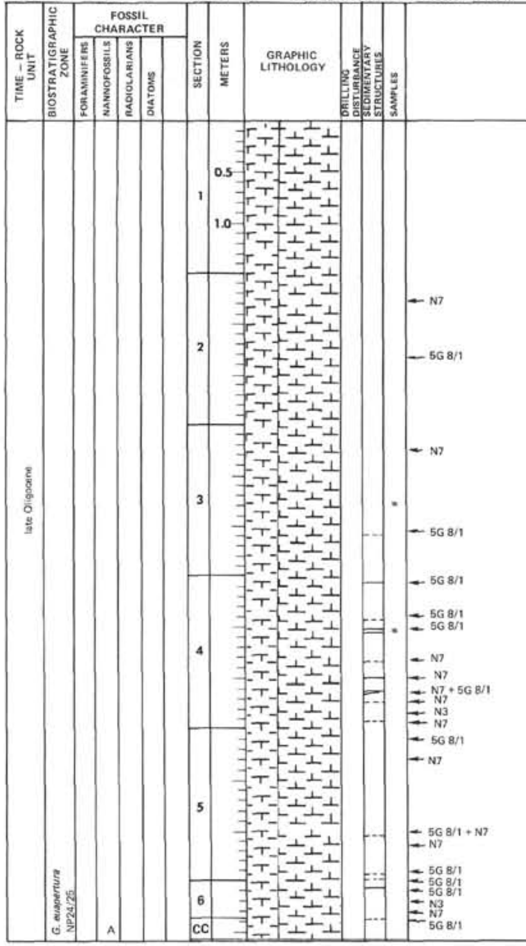
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, white (N9) to very light gray (N8), firm, homogeneous.

SMEAR SLIDE SUMMARY:

	1, 80
	D
Texture:	
Sand	R
Silt	C
Clay	D
Composition:	
Heavy minerals	T
Pyrite	T
Carbonate unspec.	R
Foraminifers	C
Calc. nannofossils	D

SITE 593 HOLE A CORE 25 CORED INTERVAL 468.0–477.6 m



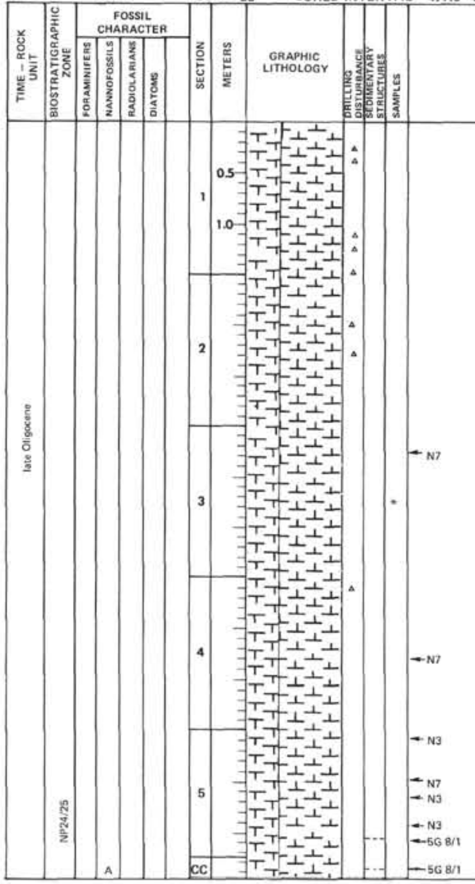
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, white (N9) to light greenish gray (5GY 8/1), firm to stiff, homogeneous. Light gray (N7) and dark gray (N3) and light greenish gray (5G 8/1) lamina are present.

SMEAR SLIDE SUMMARY:

	3, 80	4, 50
	D	M
Texture:		
Silt	C	C
Clay	D	D
Composition:		
Quartz	T	T
Feldspar	T	–
Volcanic glass	T	T
Carbonate unspec.	T	T
Foraminifers	C	C
Calc. nannofossils	D	D

SITE 593 HOLE A CORE 26 CORED INTERVAL 477.6–487.2 m



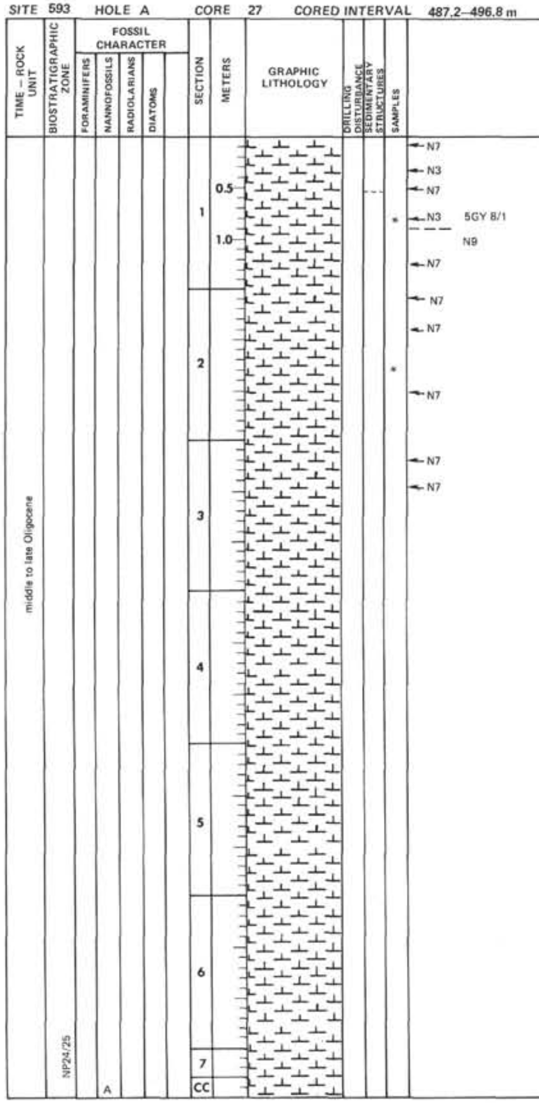
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, light greenish gray (5GY 8/1), homogeneous, firm to stiff, partly lithified. Rare light gray (N7), dark gray (N3) or light greenish gray (5G 8/1) laminae.

SMEAR SLIDE SUMMARY:

	3, 80
	D
Texture:	
Sand	R
Silt	C
Clay	A
Composition:	
Quartz	T
Mica	T
Volcanic glass	T
Carbonate unspec.	T
Foraminifers	C/A
Calc. nannofossils	A/D

SITE 593 HOLE A CORE 27 CORED INTERVAL 487.2–496.8 m

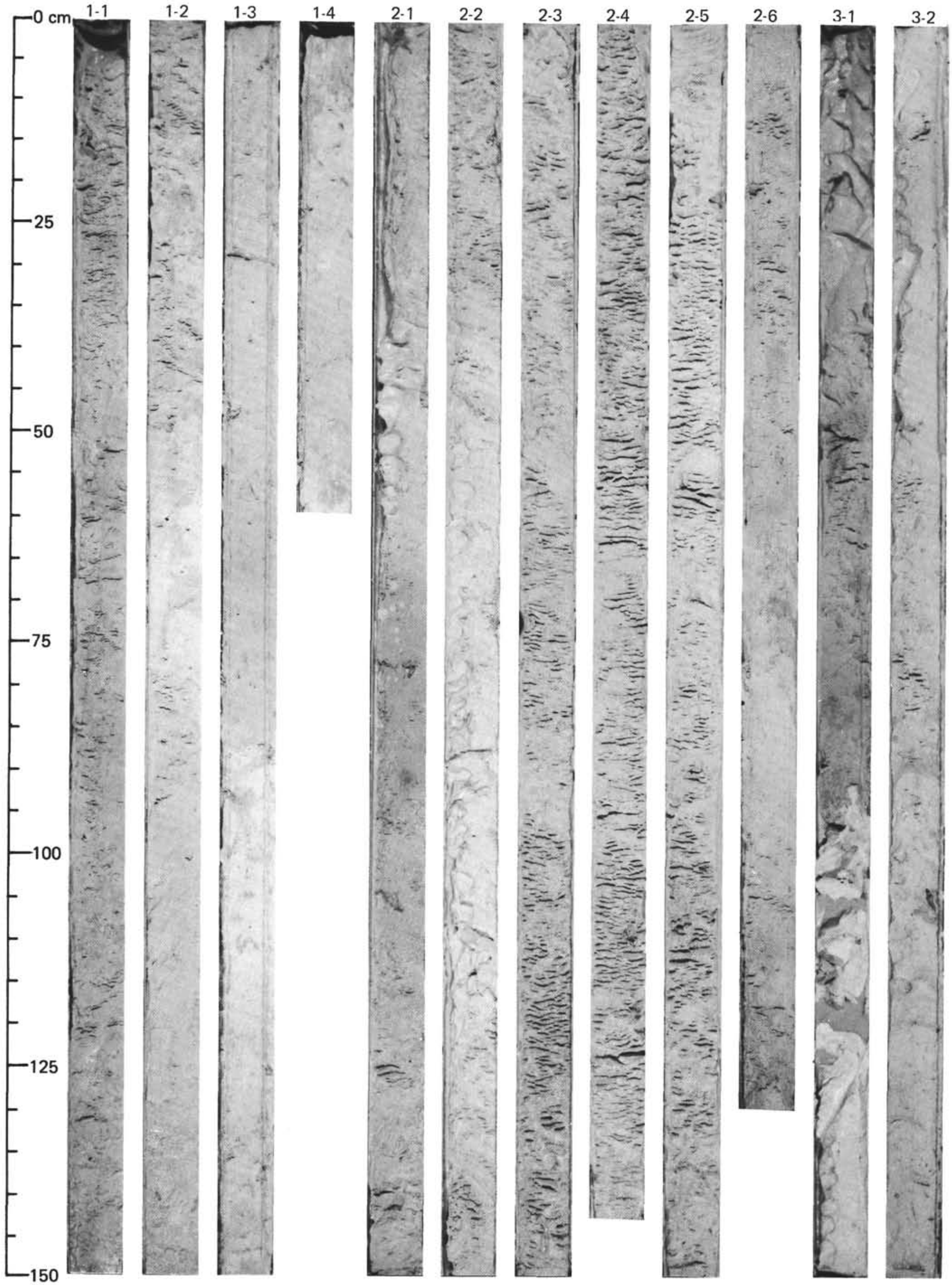


LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, light greenish gray (5GY 8/1) in Section 1 (0.95), then white (N9), homogeneous, firm to stiff. Light gray (N7) and dark gray (N3) laminae occur.

SMEAR SLIDE SUMMARY:

	1, 90	3, 80
	D	D
Texture:		
Silt	R	—
Clay	D	D
Composition:		
Quartz	T	—
Feldspar	T	T
Mica	T	—
Volcanic glass	T	T
Carbonate unspec.	T	R
Foraminifers	R/C	T/R
Calc. nannofossils	D	D
Dolomite	—	T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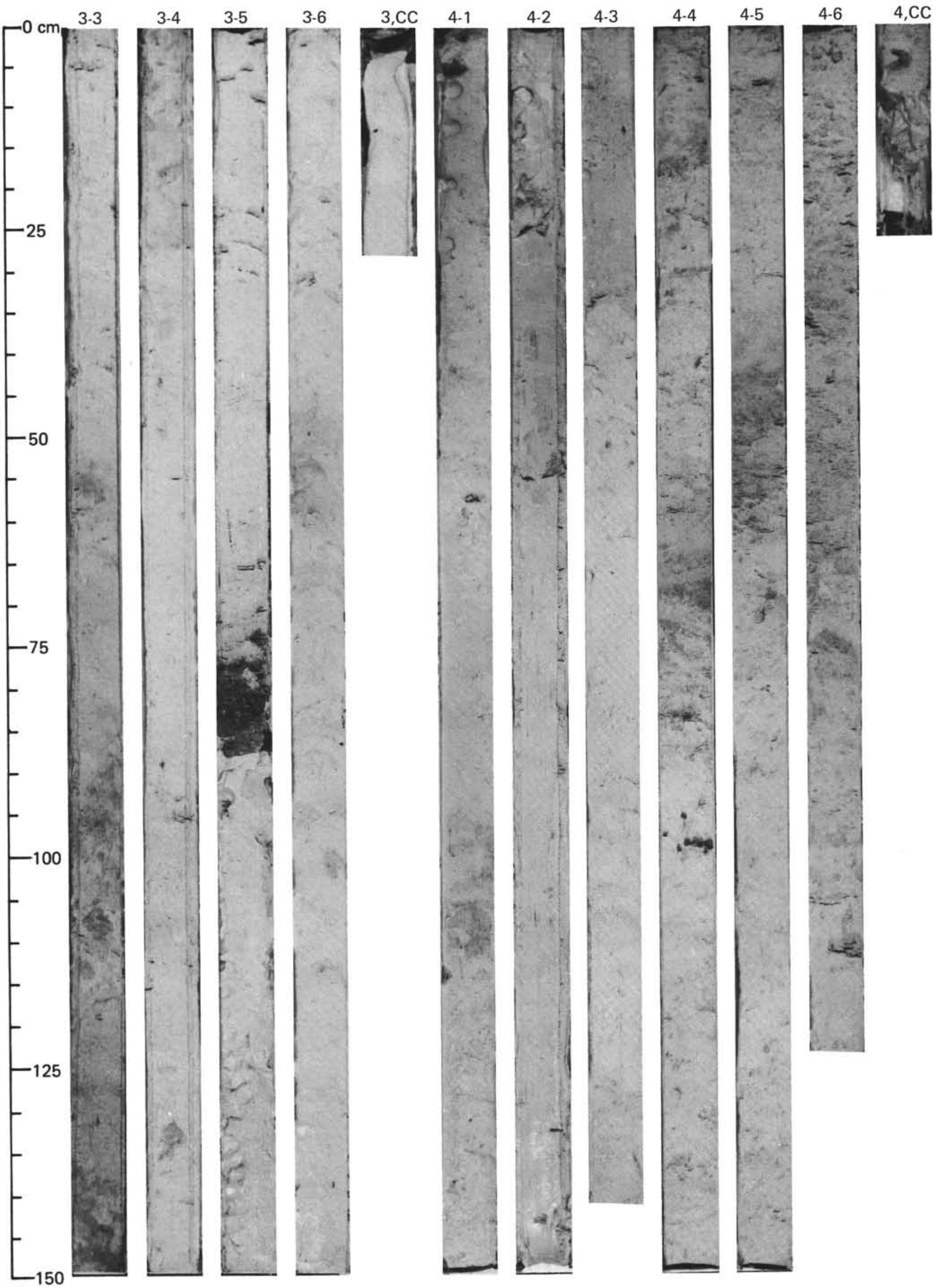
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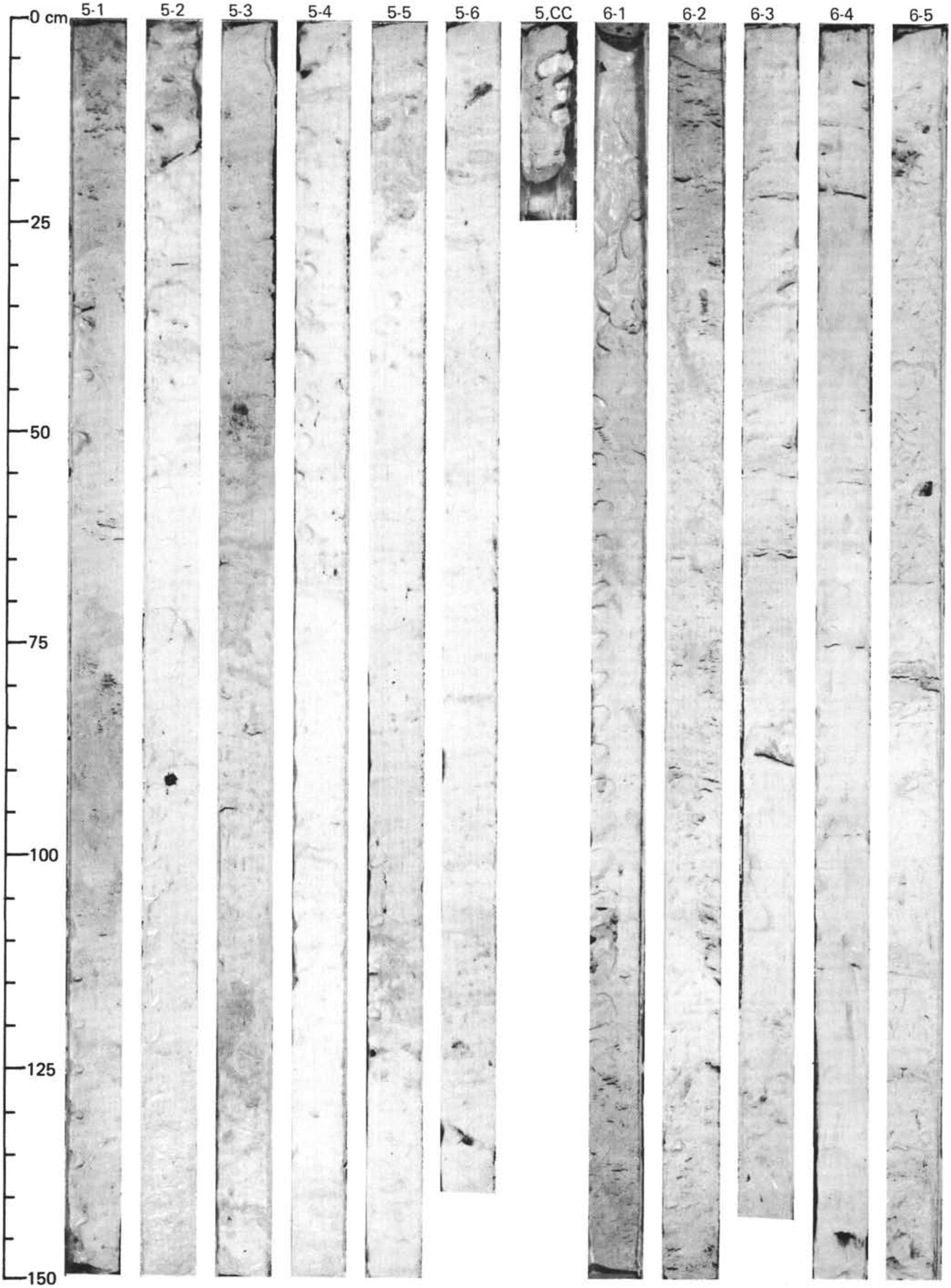
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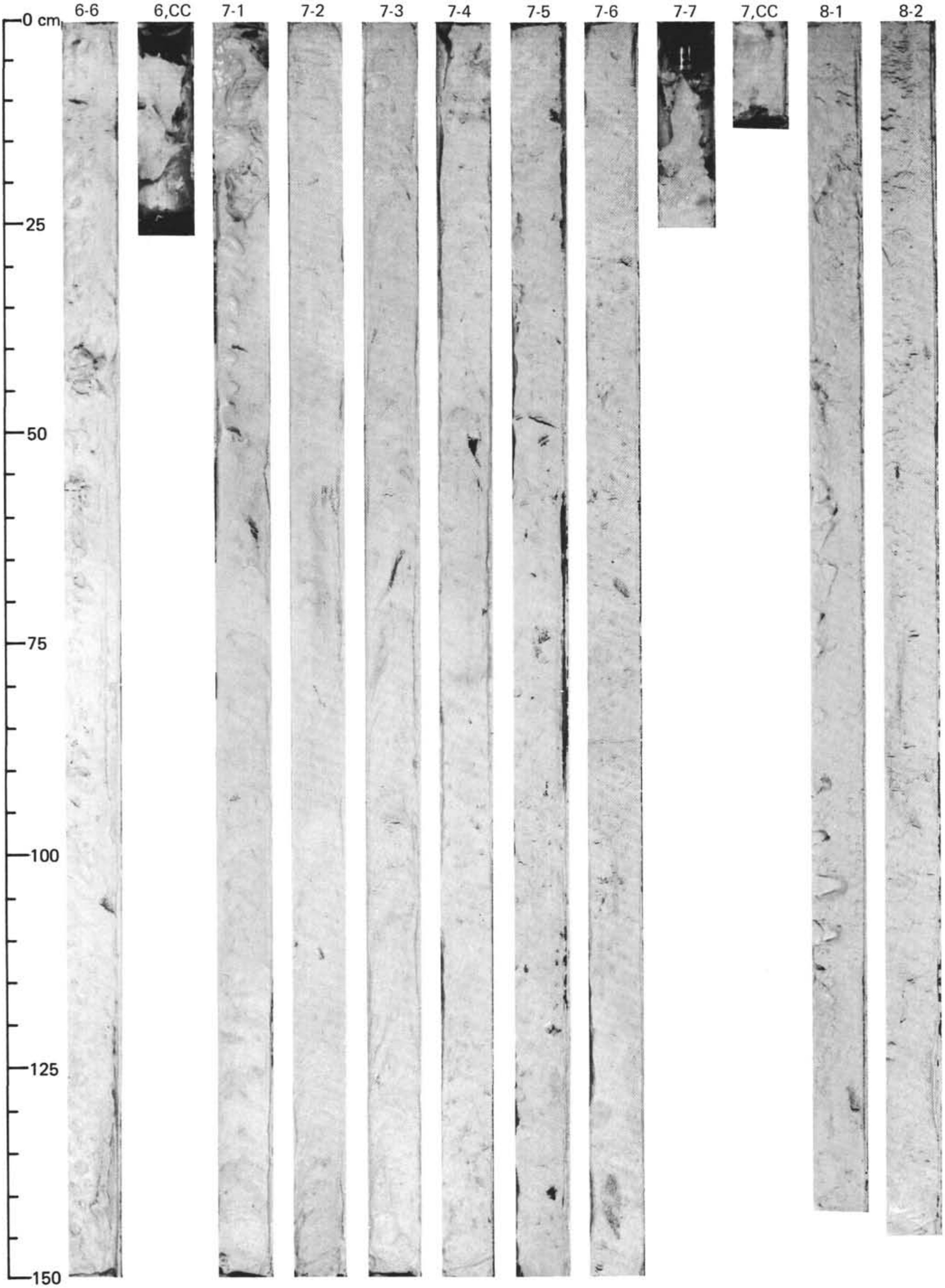
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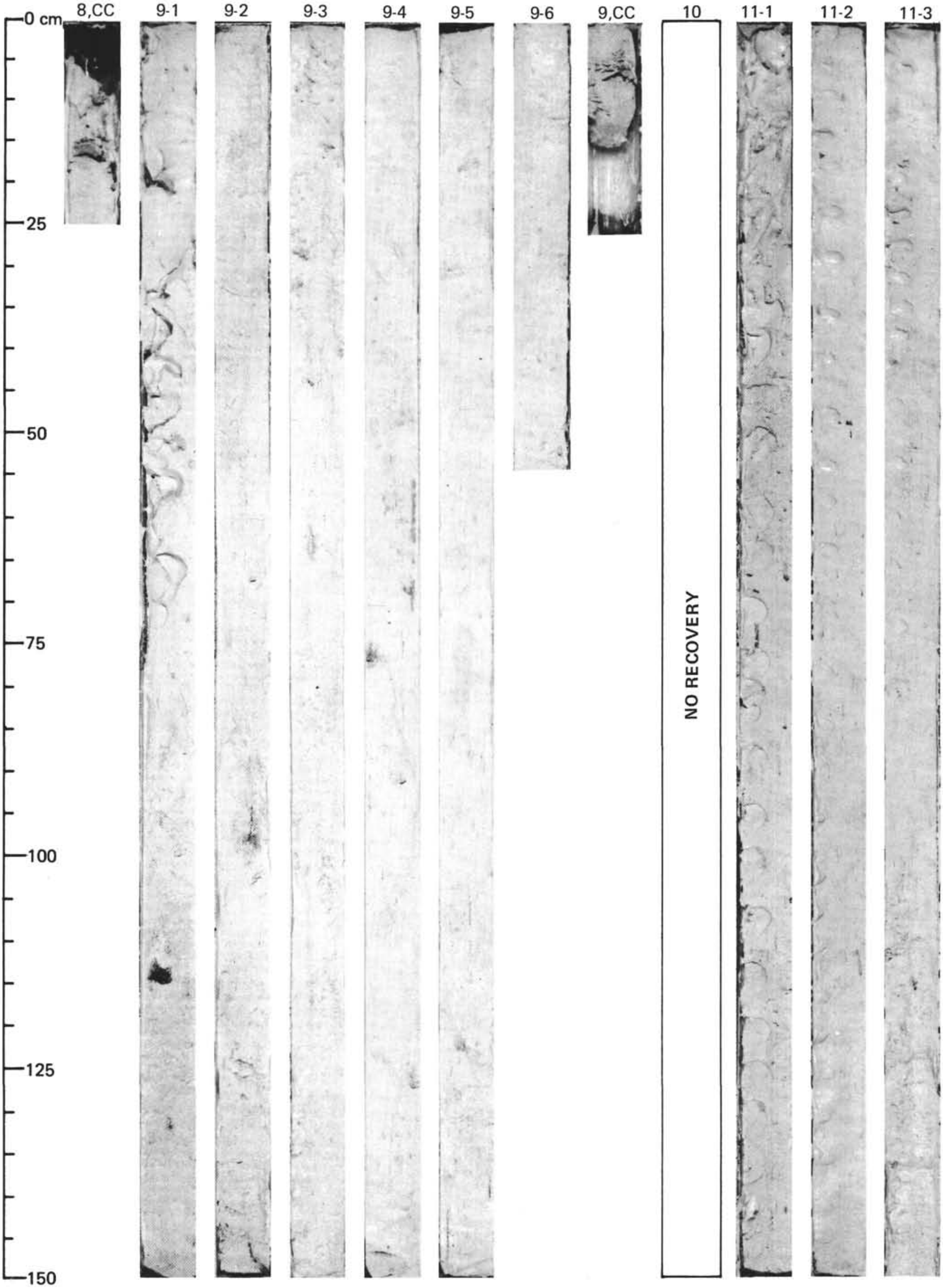
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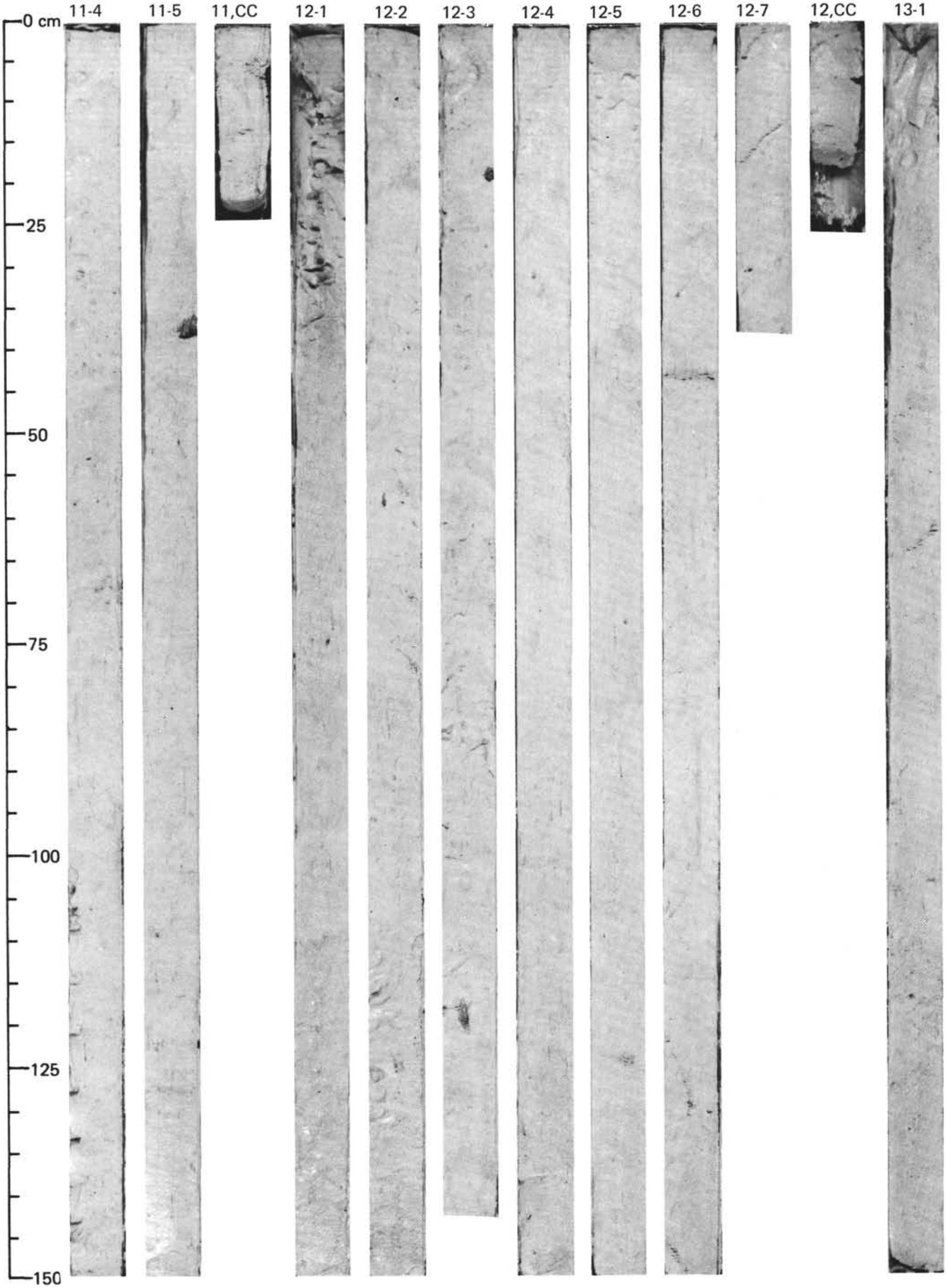
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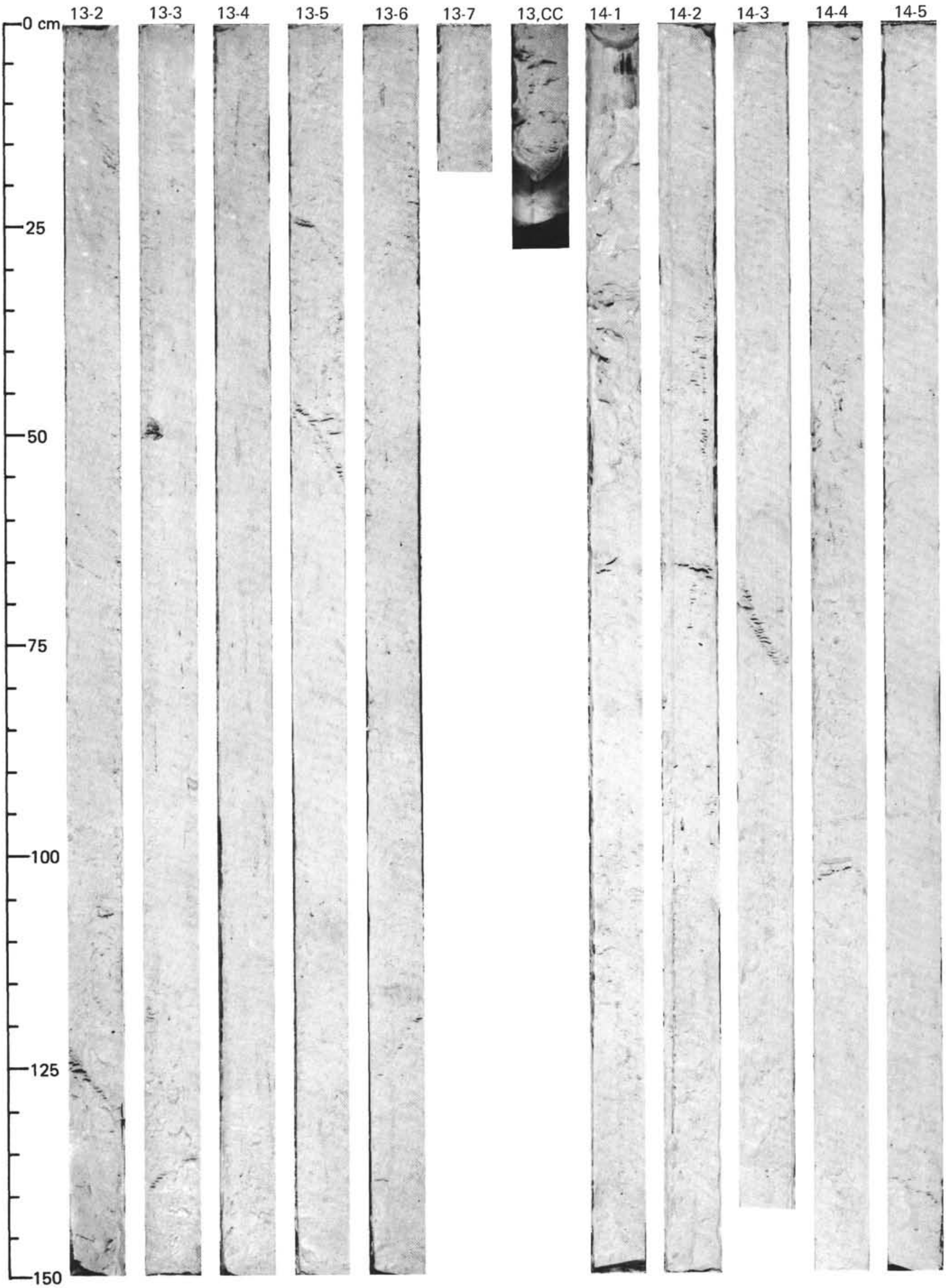
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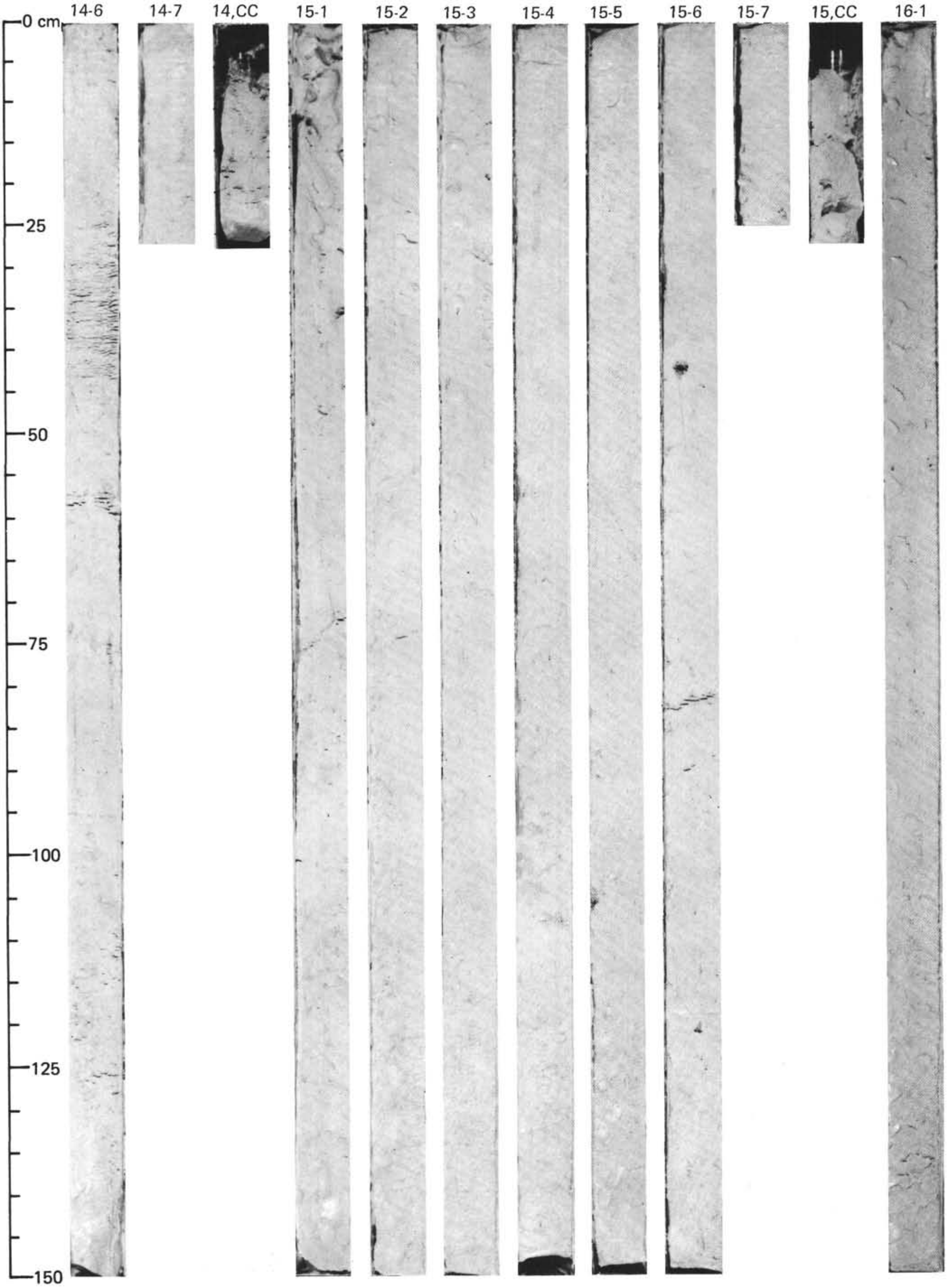
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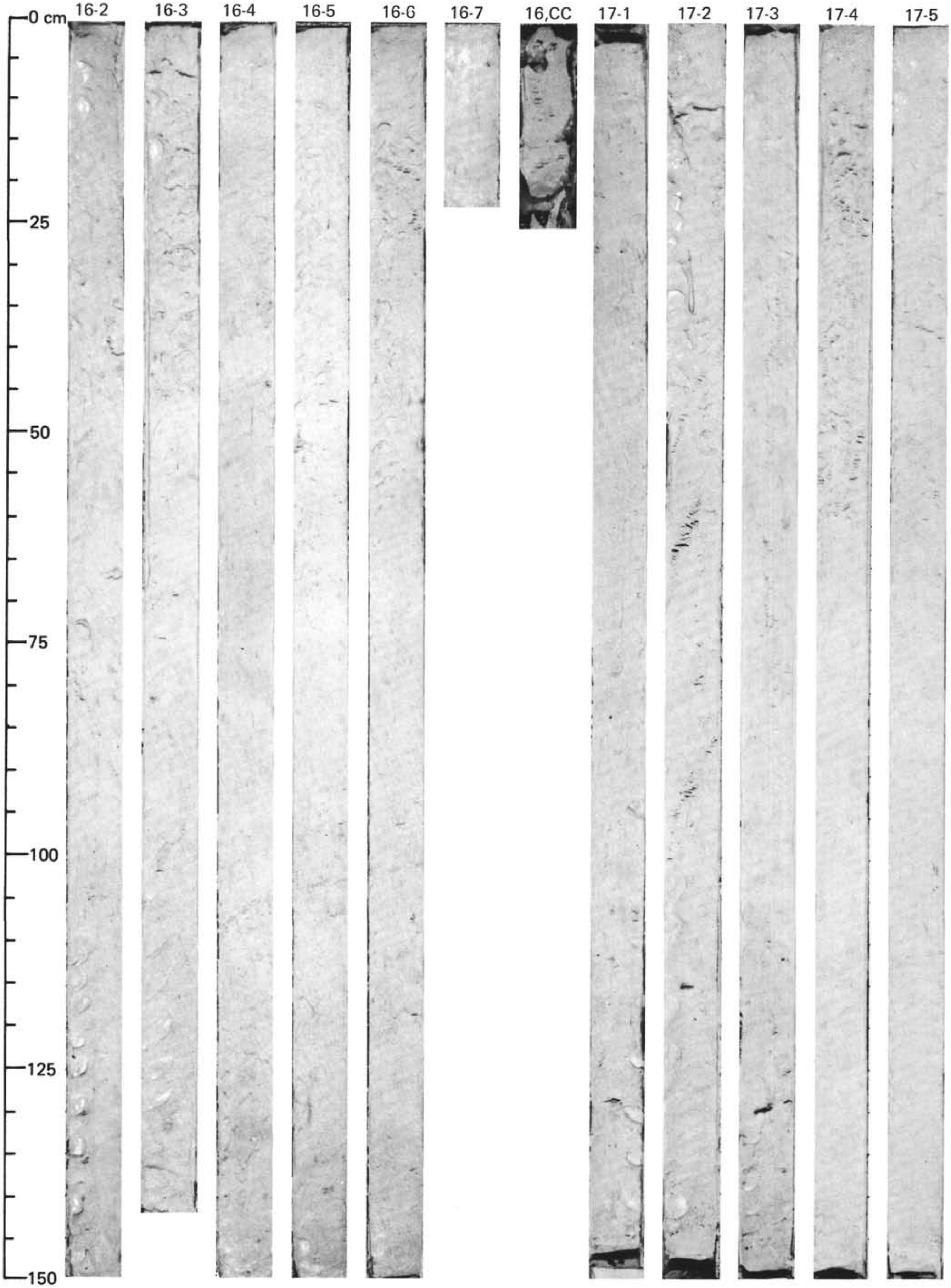
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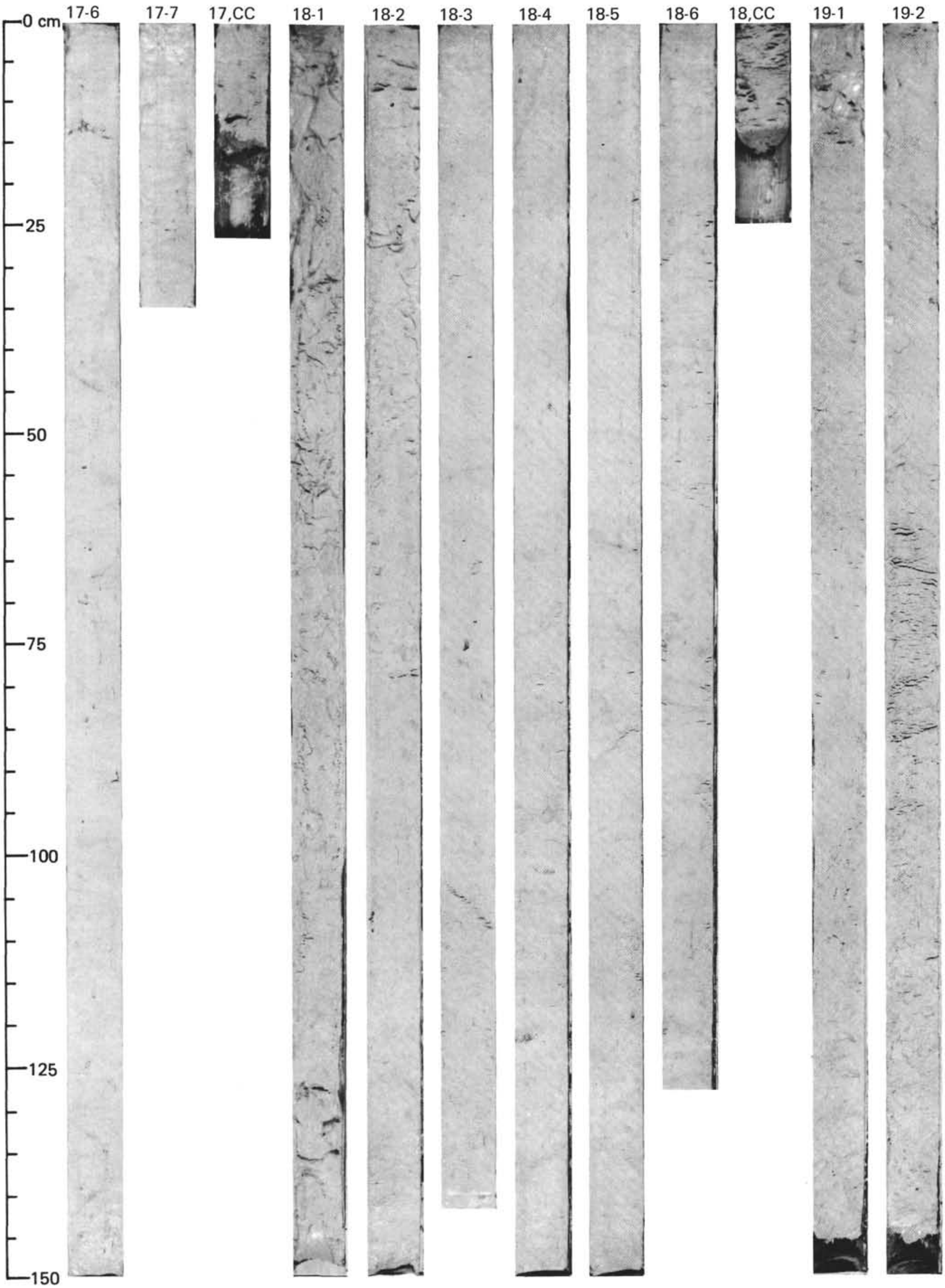
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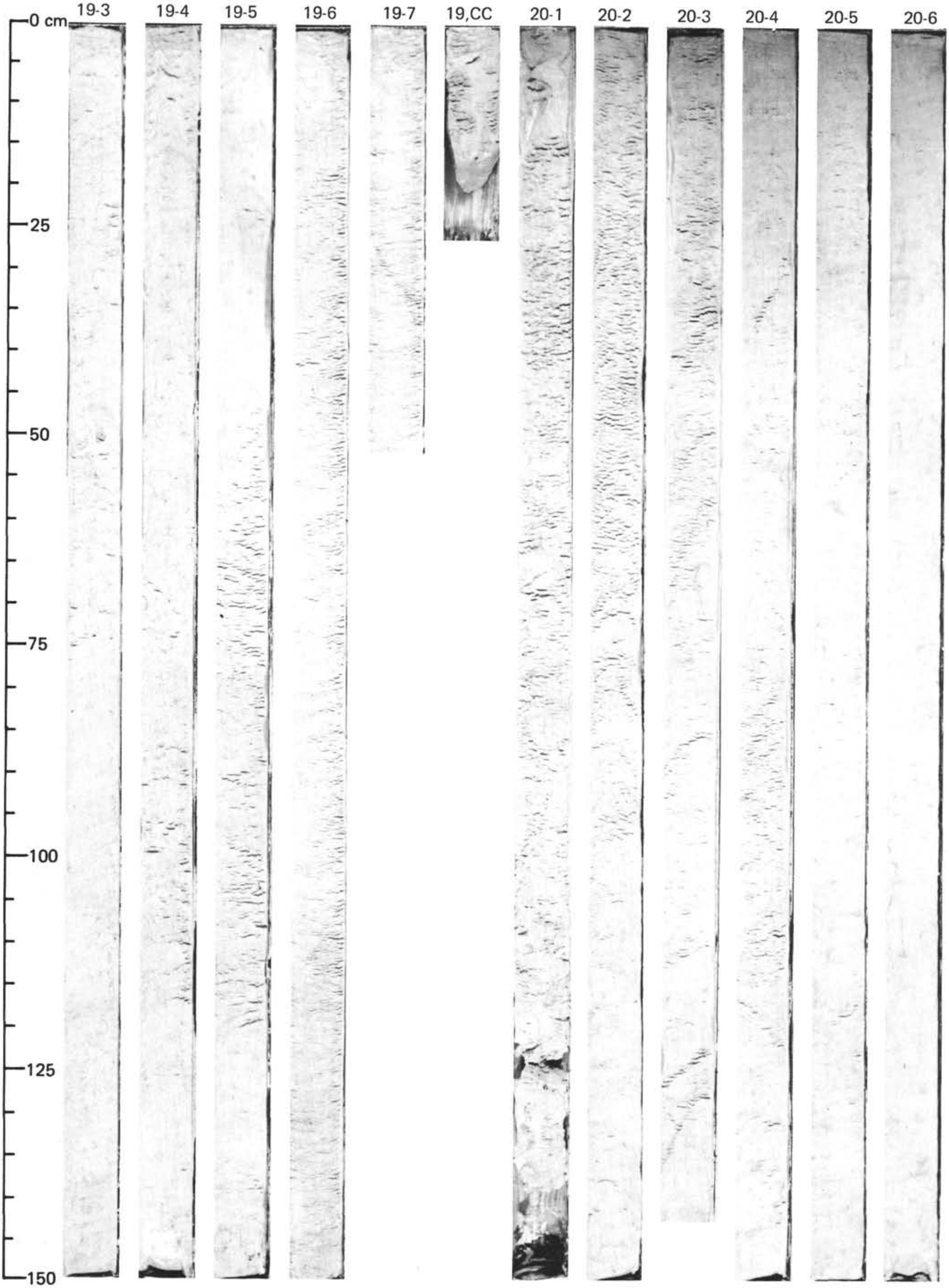
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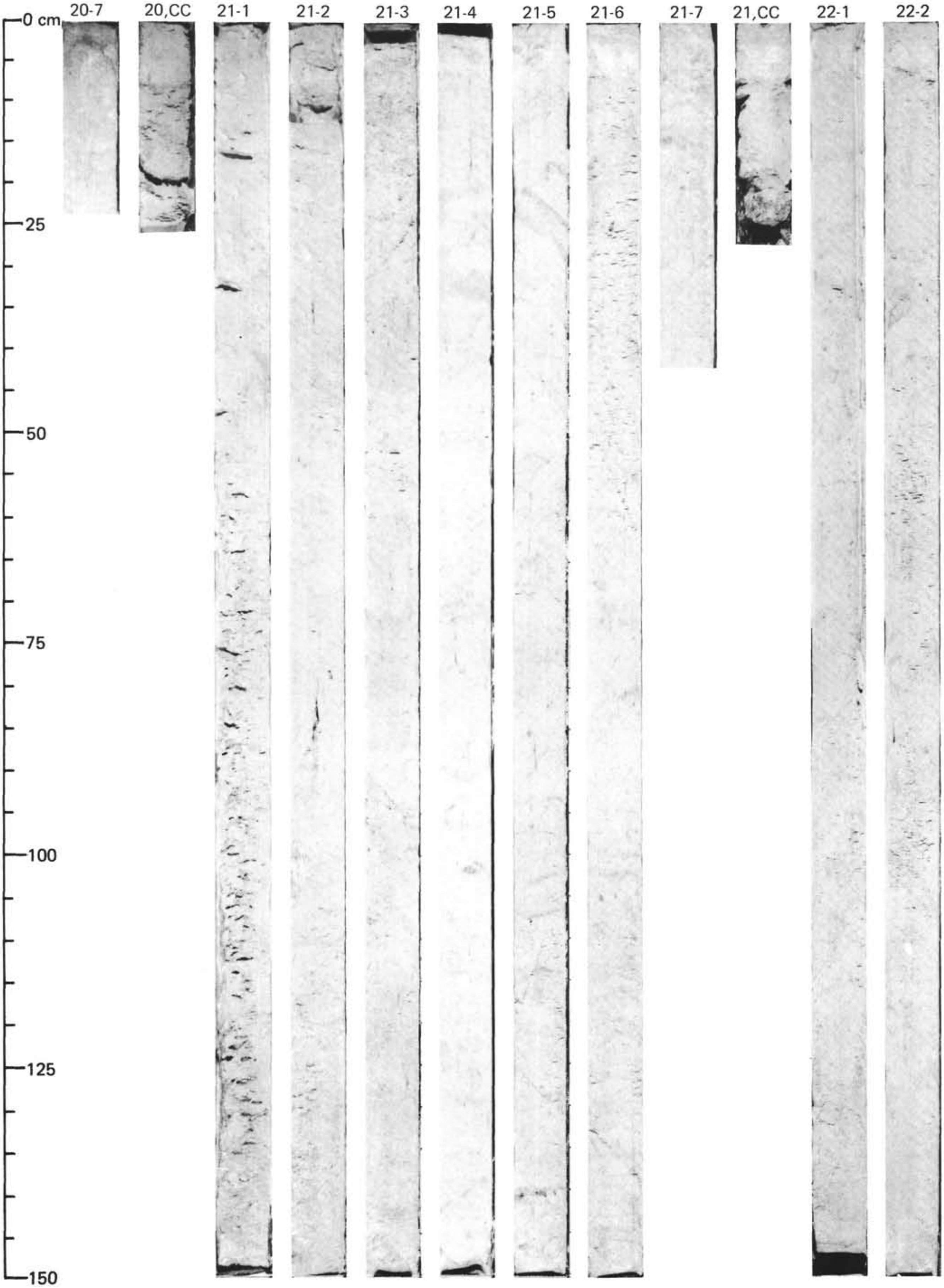
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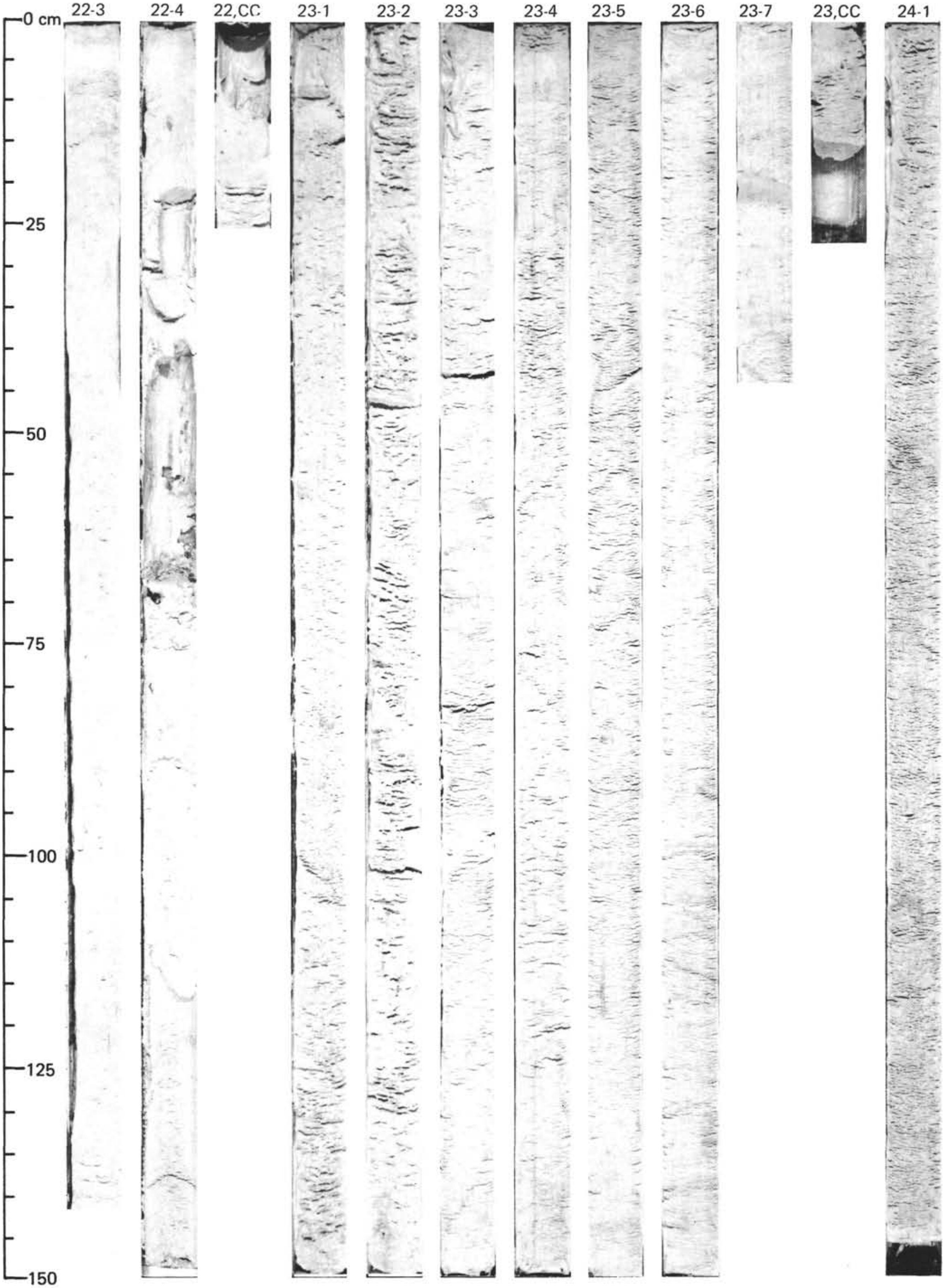
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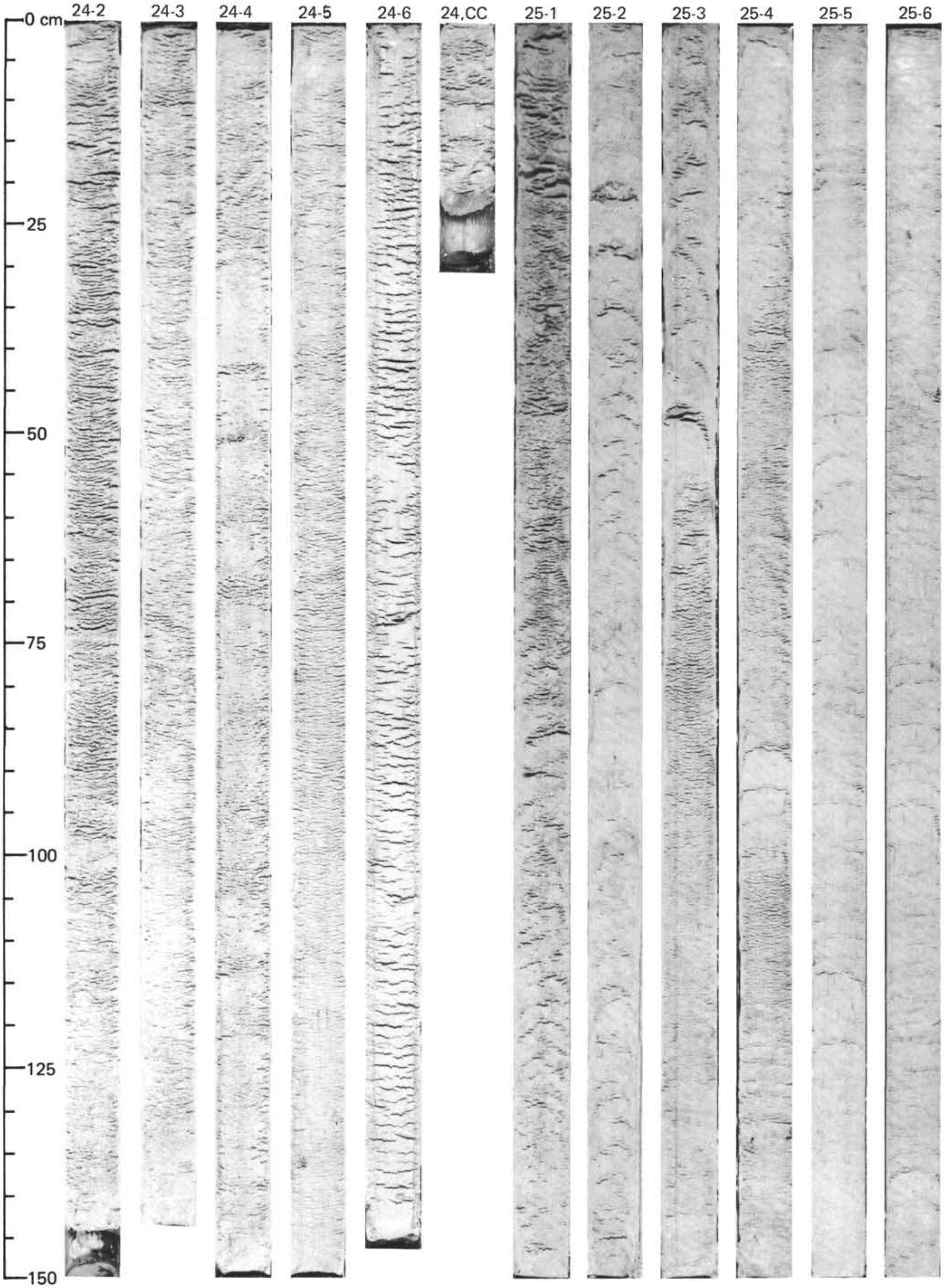
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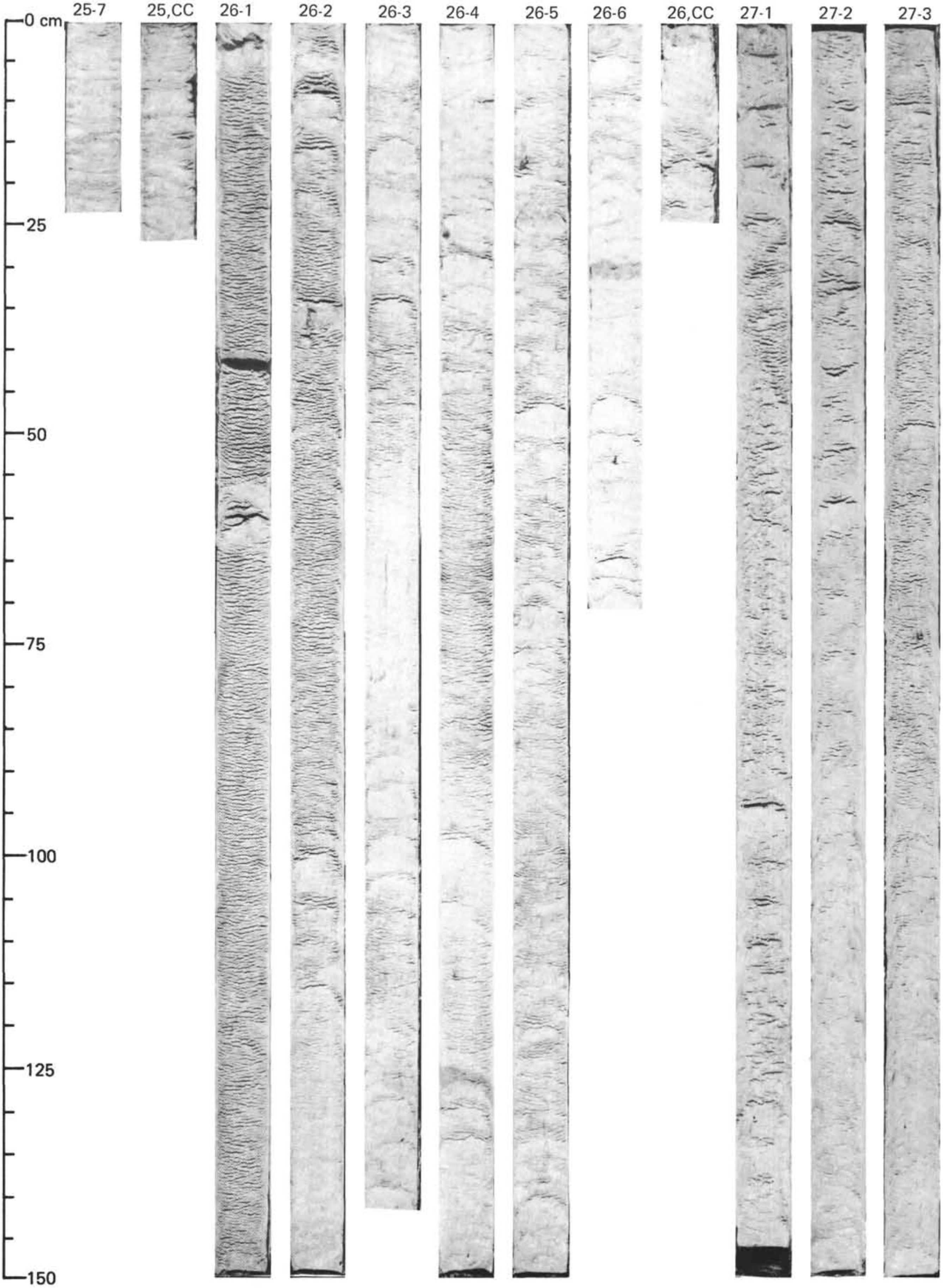
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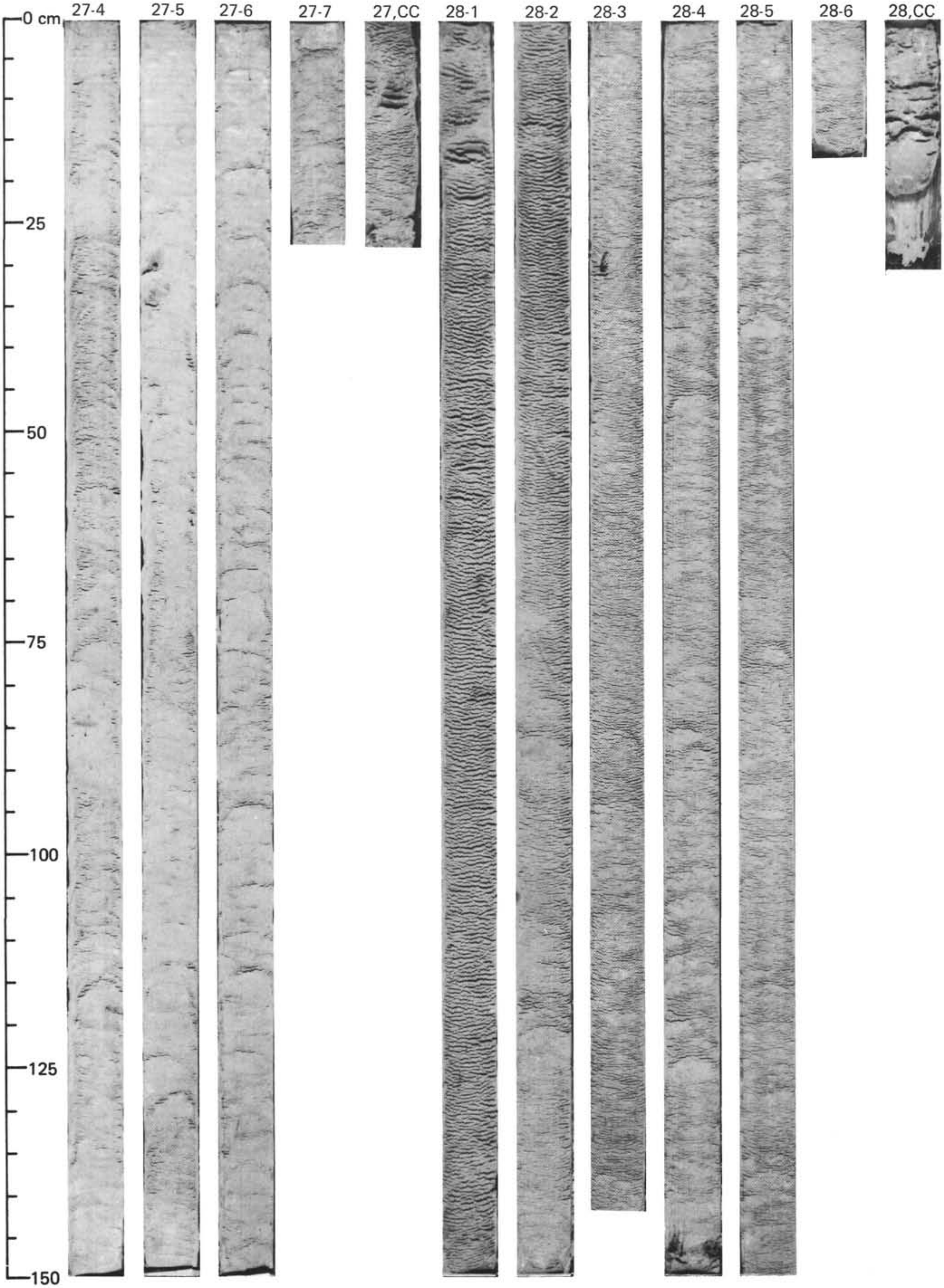
27-3


0 cm
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75
100
125
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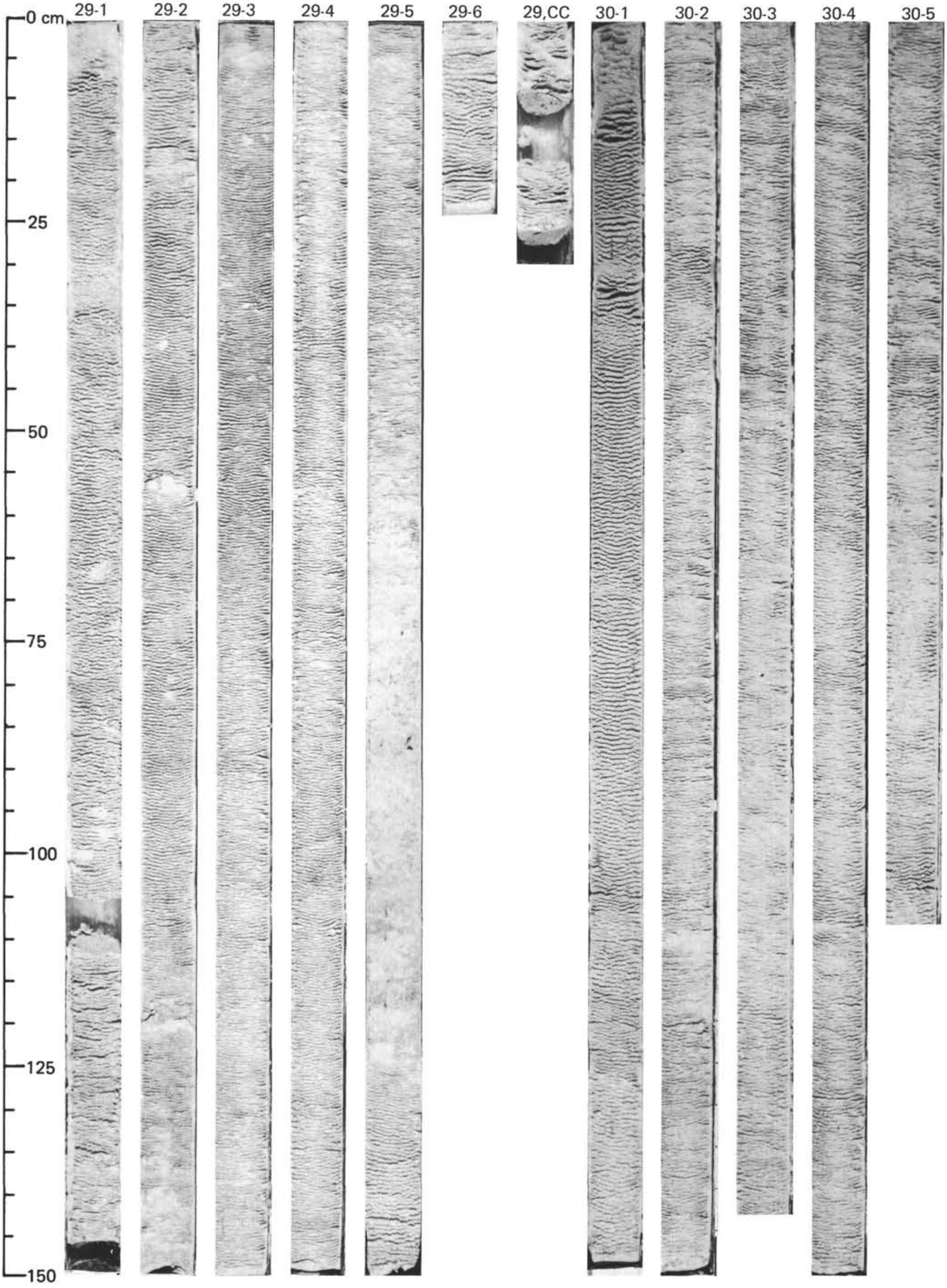
27-5
27-6
27-7
27,CC
28-1
28-2
28-3
28-4
28-5
28-6
28,CC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29-6
29,CC
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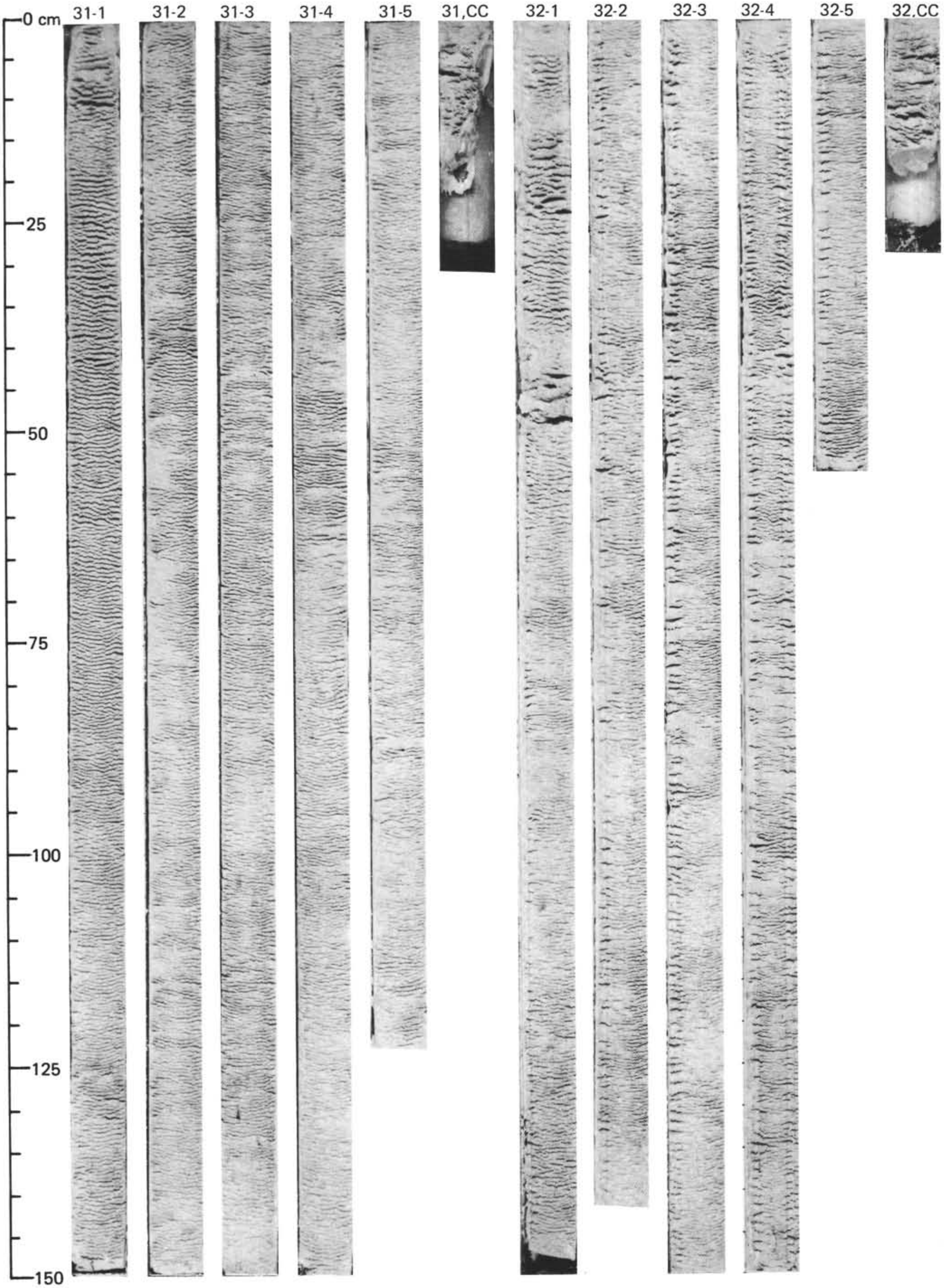
30-4
30-5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31-4
31-5
31,CC
32-1
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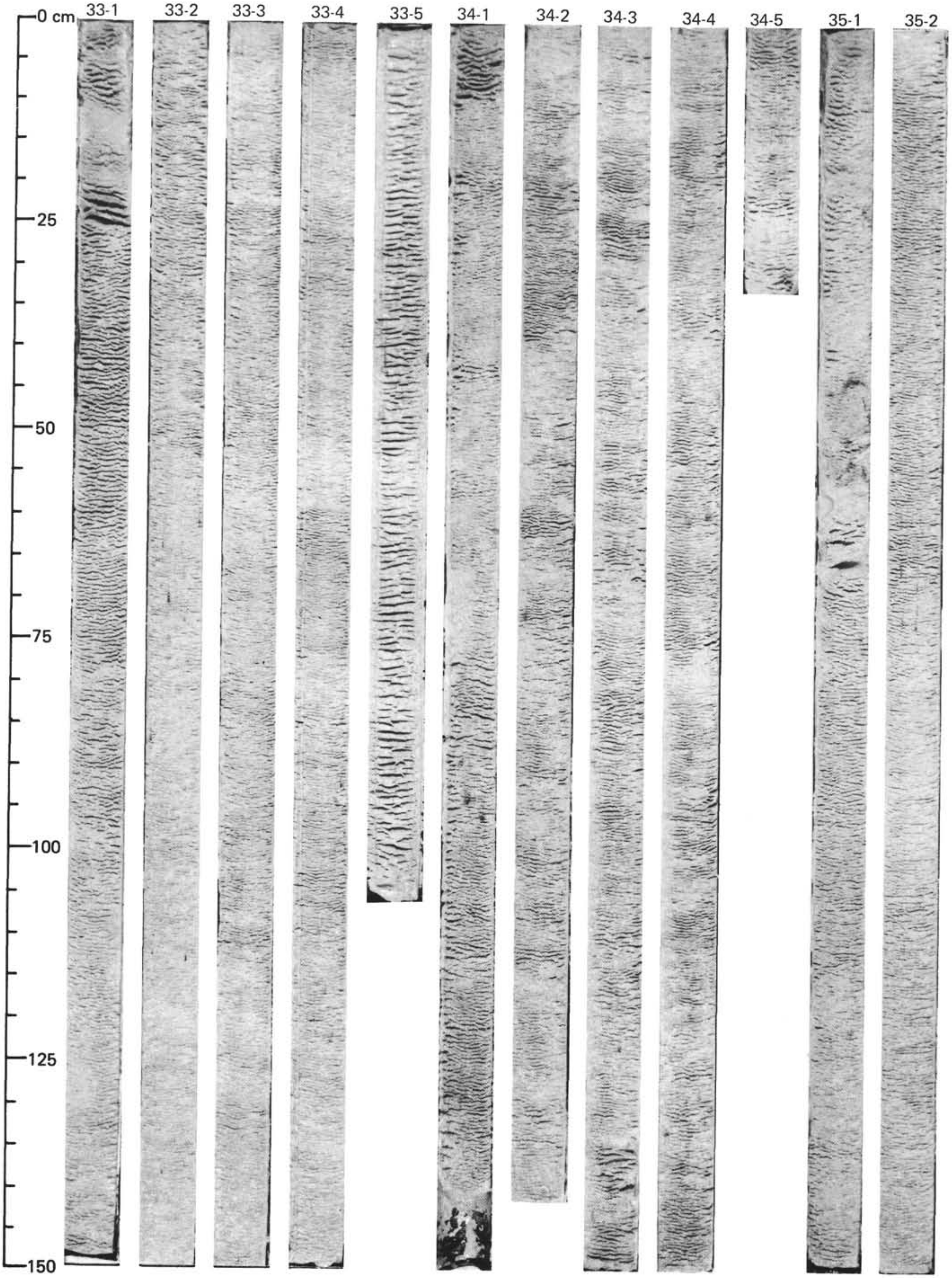
32-4
32-5
32,CC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33-4
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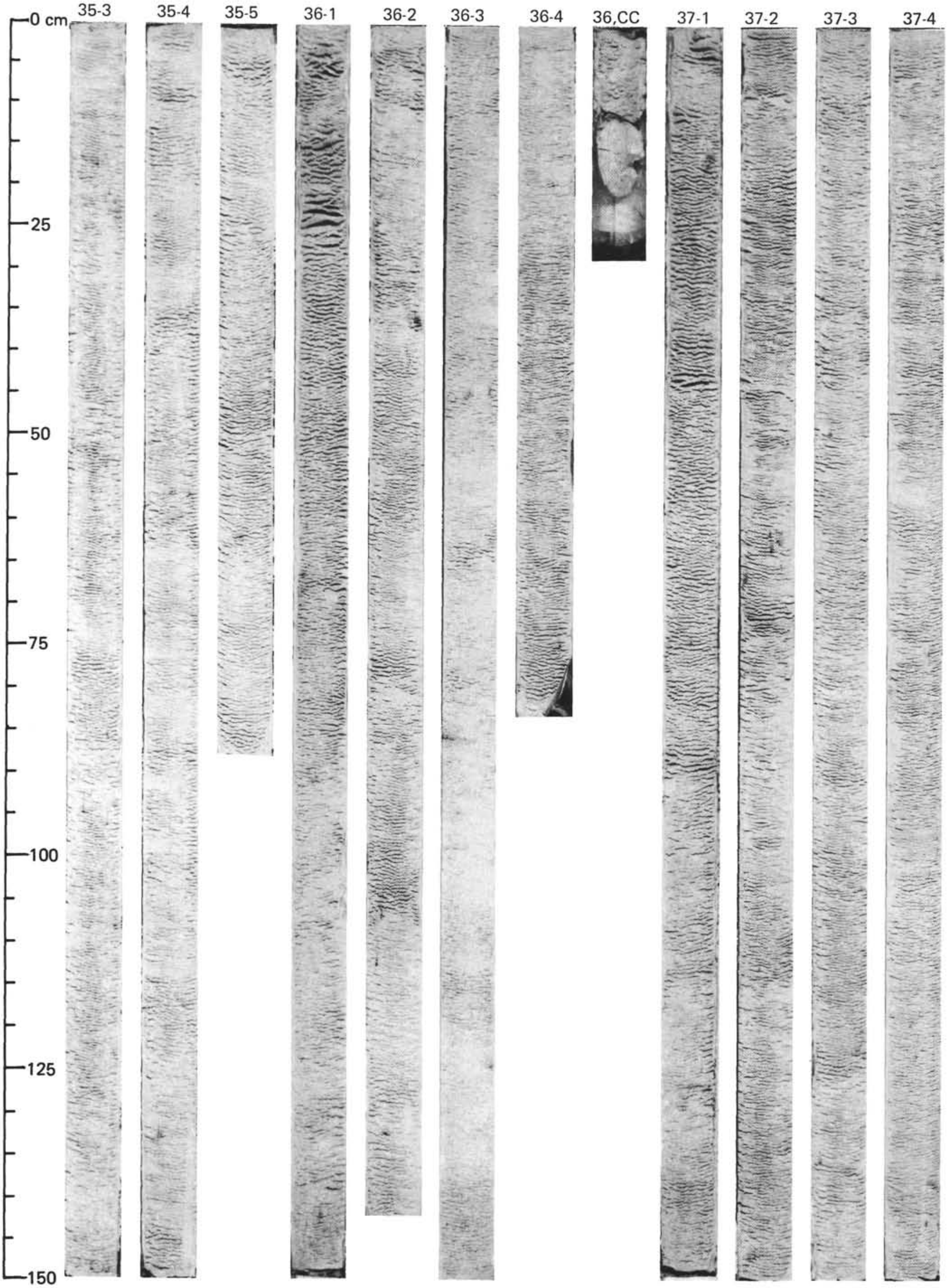
34-3
34-4
34-5
35-1
35-2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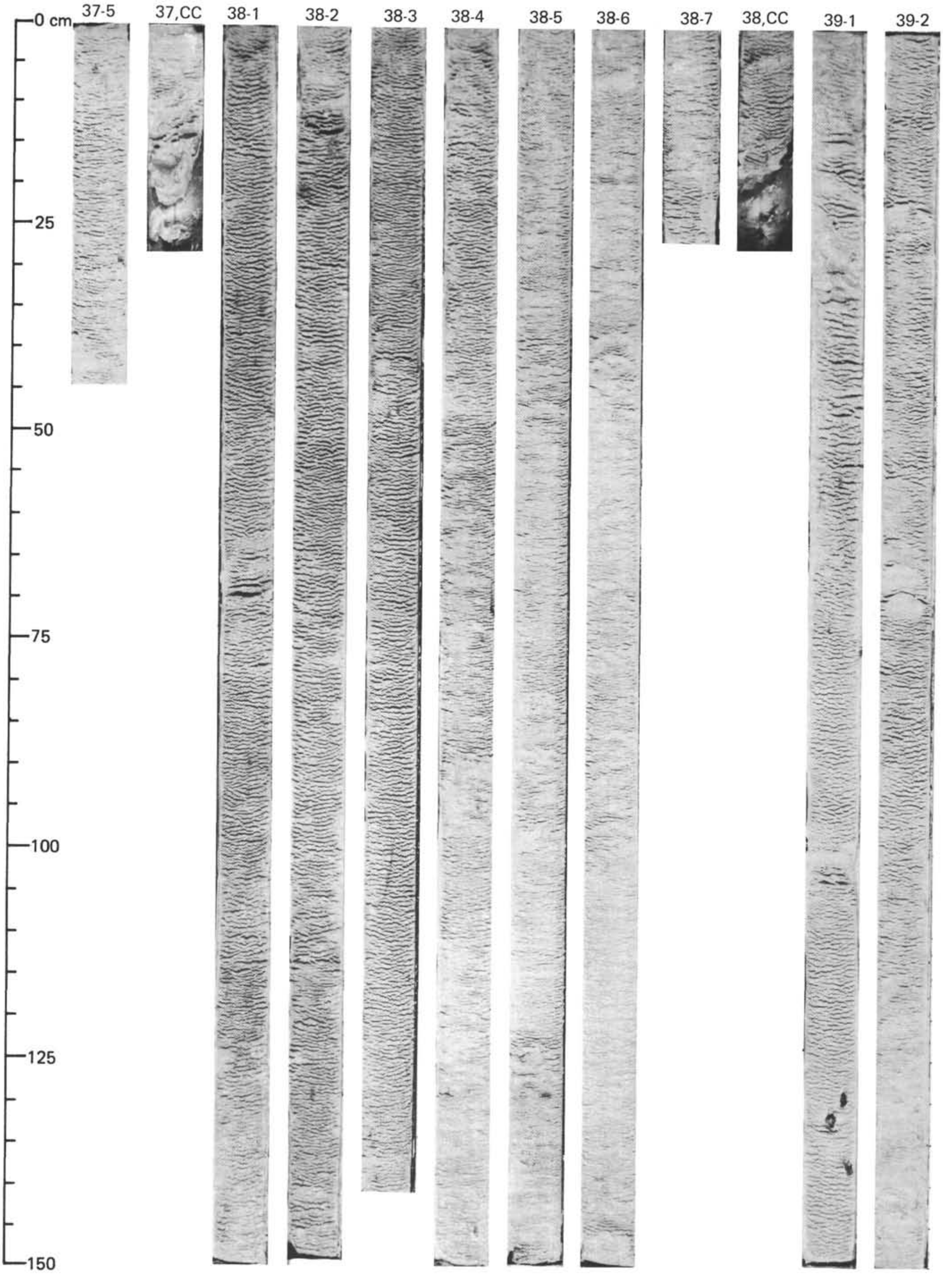
36-1
36-2
36-3
36-4
36,CC
37-1
37-2
37-3
37-4


0 cm
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75
100
125
150
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37,CC
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38-2
38-3
38-4
38-5
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38-7
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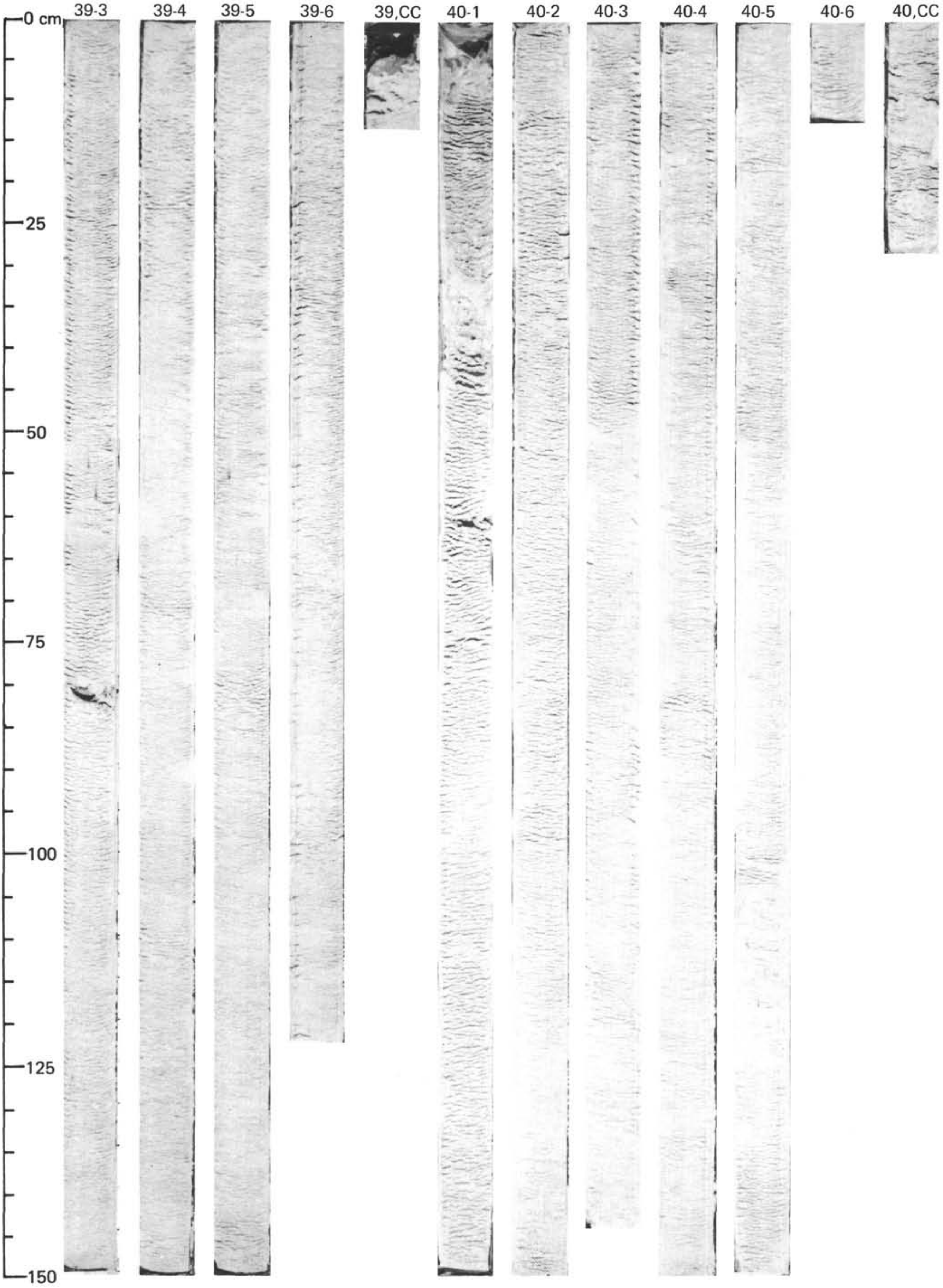
39-1
39-2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100
125
150
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39-4
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39-6
39,CC
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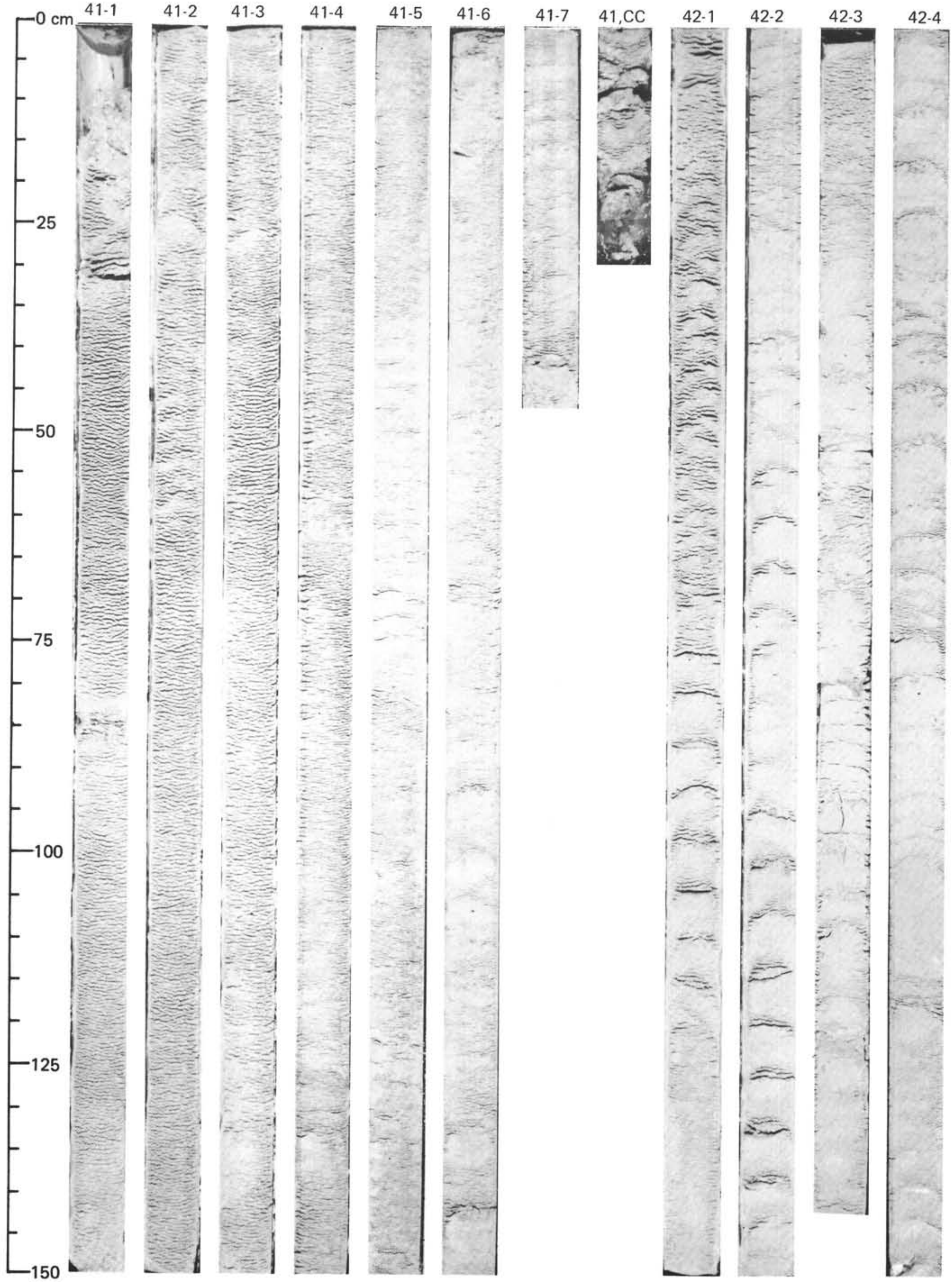
40-3
40-4
40-5
40-6
40,CC



0 cm
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75
100
125
150
41-1
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41-3
41-4
41-5
41-6
41-7
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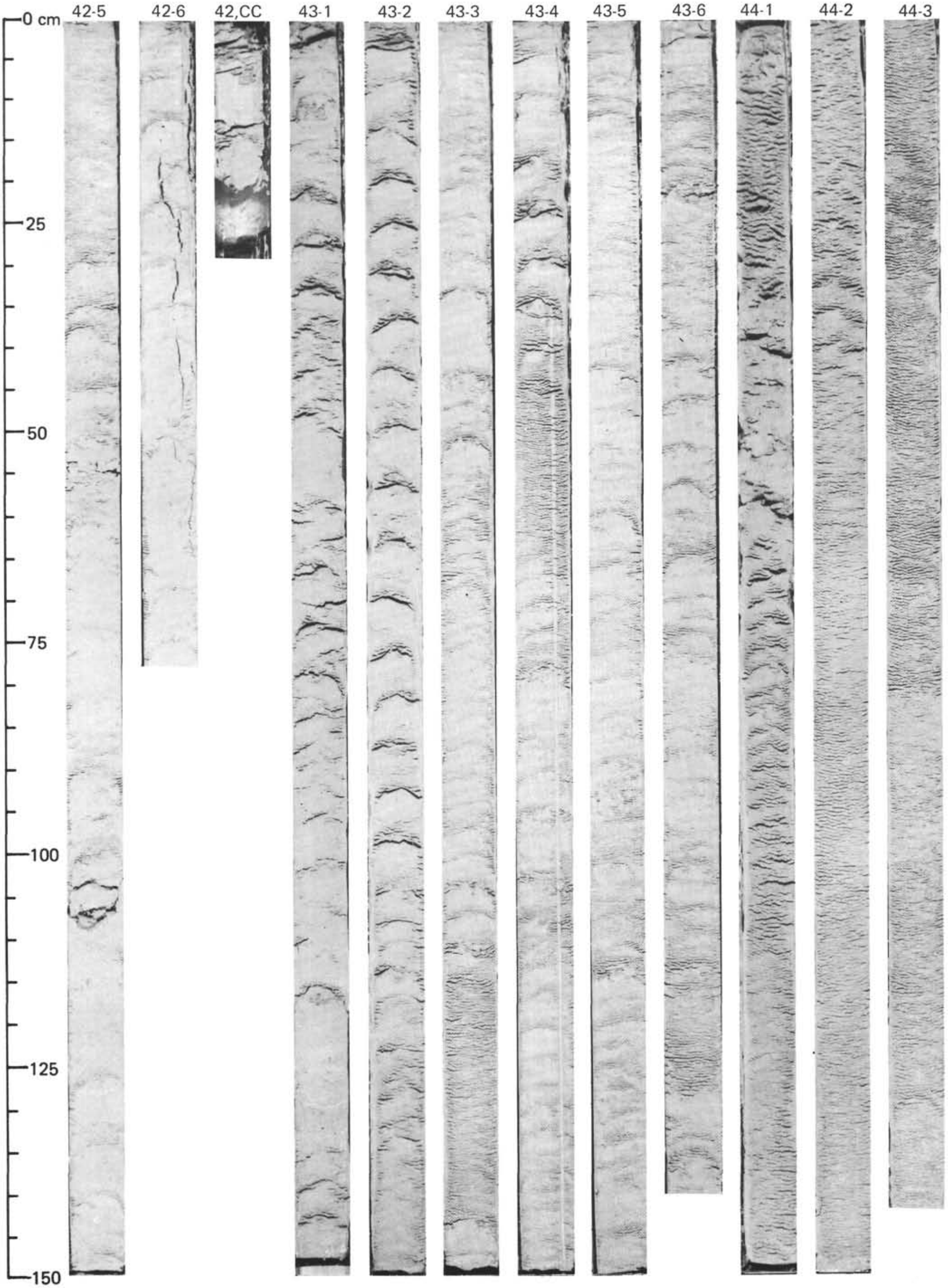
42-1
42-2
42-3
42-4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100
125
150
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42-6
42,CC
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43-5
43-6
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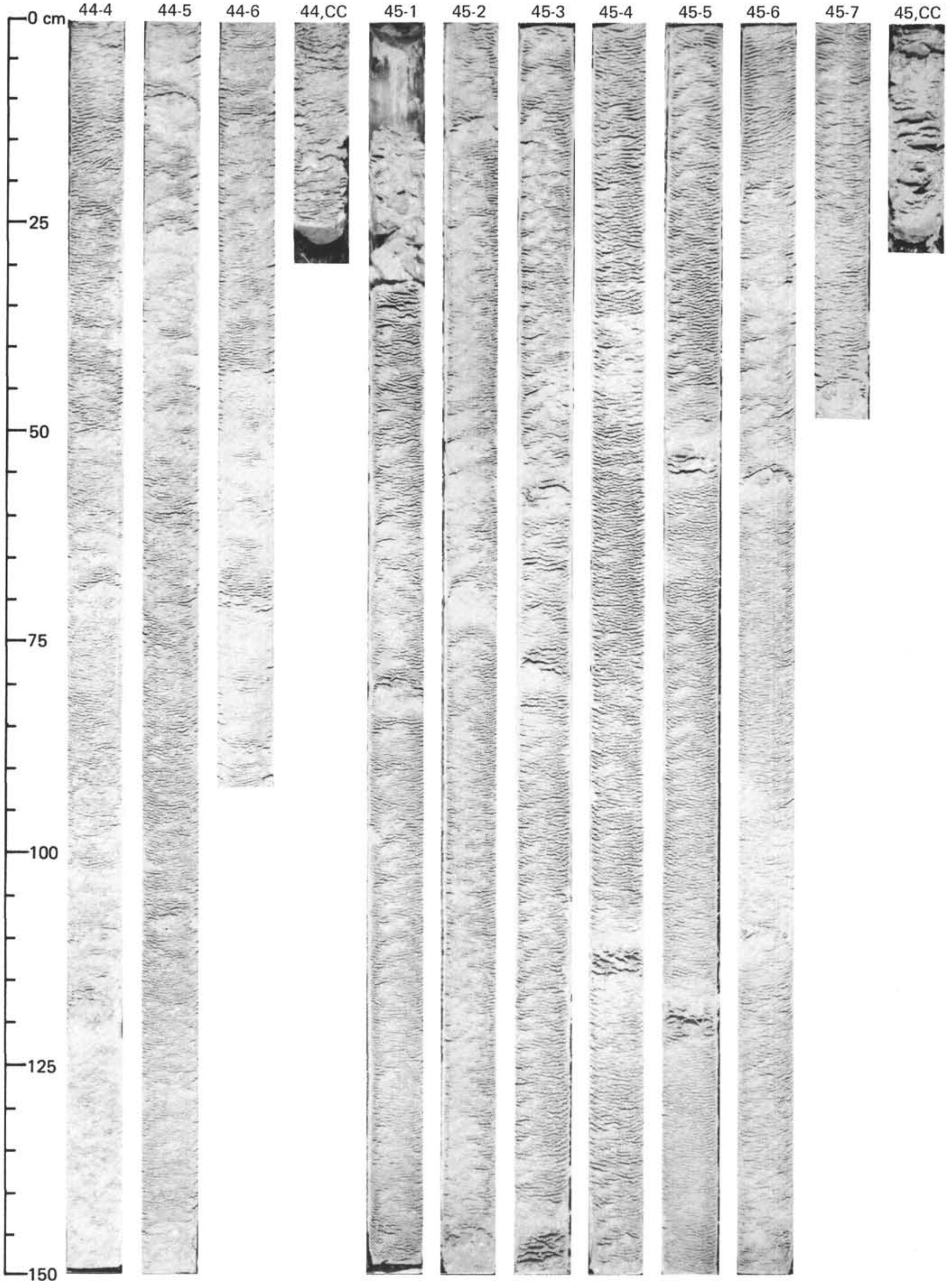
44-2
44-3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44-6
44,CC
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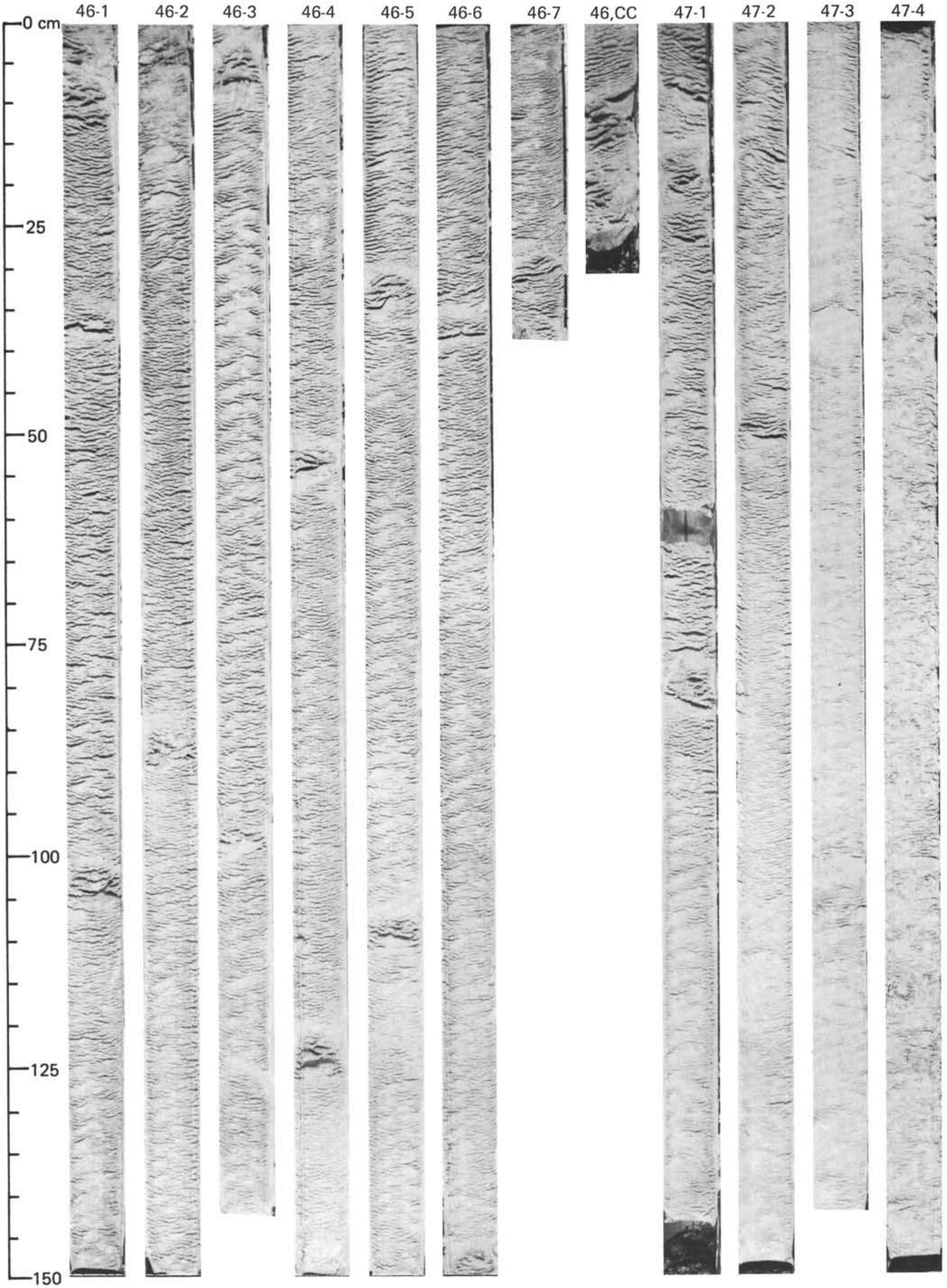
45-6
45-7
45,CC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75
100
125
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46-4
46-5
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46-7
46,CC
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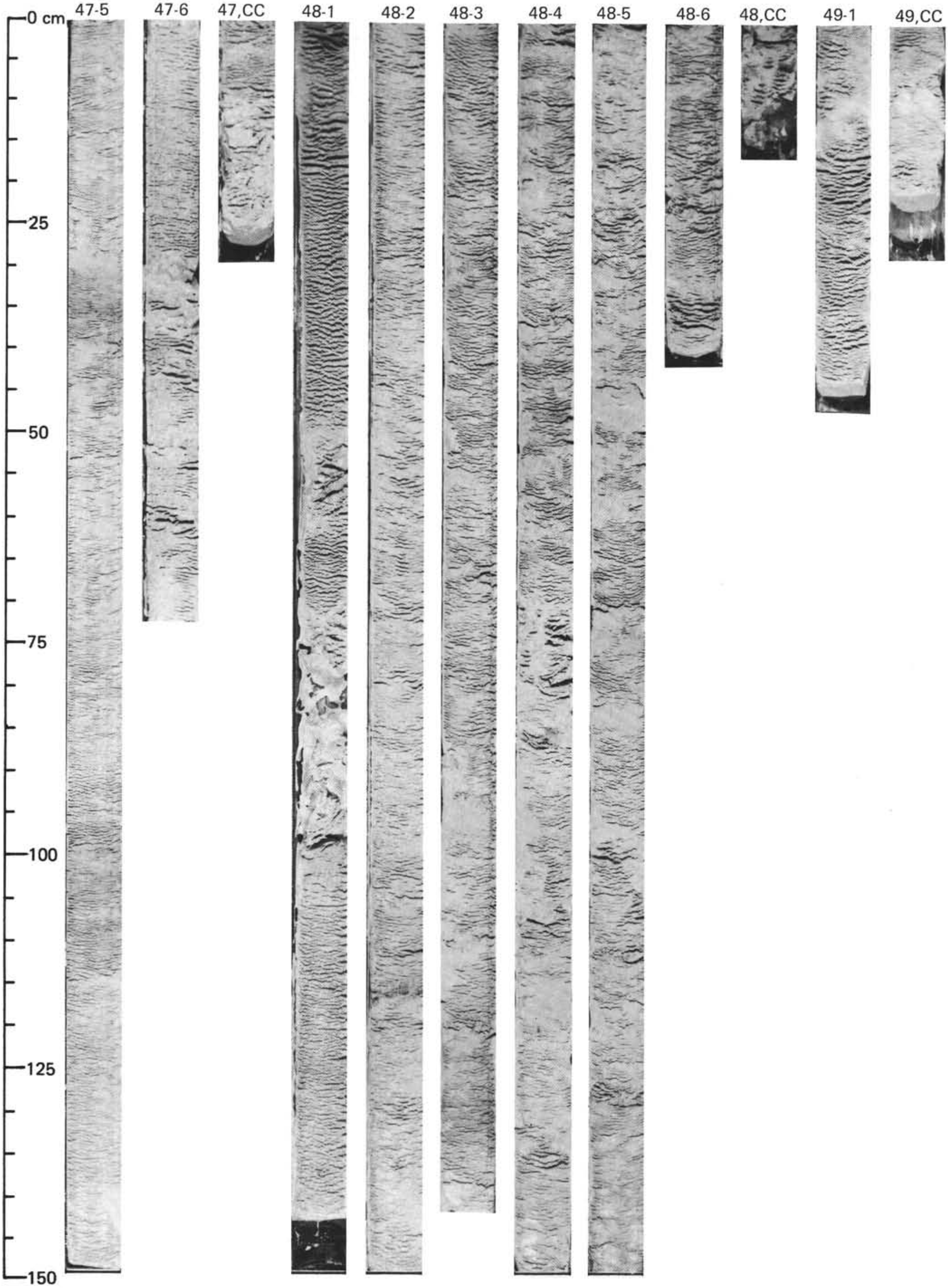
47-2
47-3
47-4


0 cm
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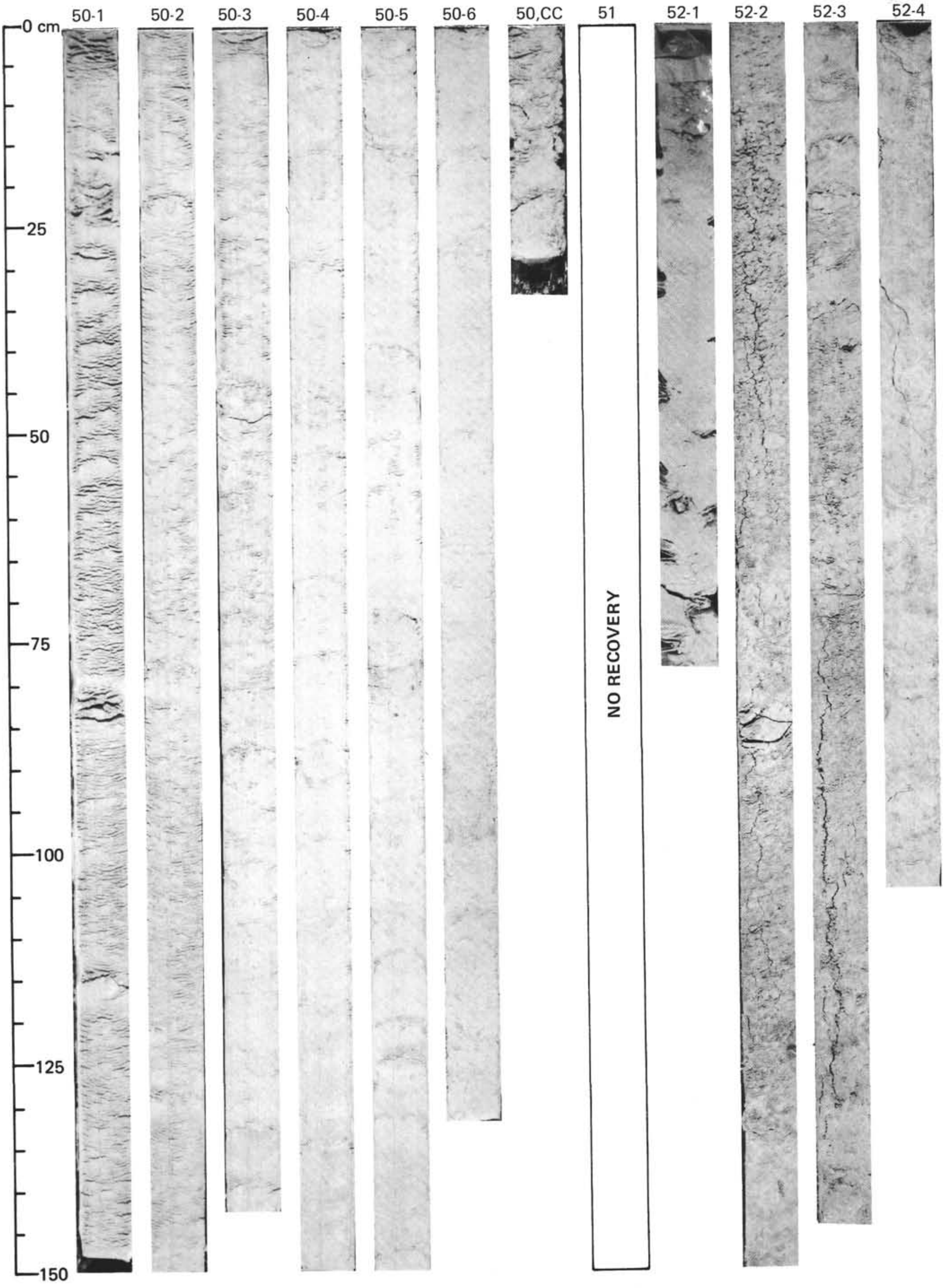
75
100
125
150
47-5
47-6
47,CC
48-1
48-2
48-3
48-4
48-5
48-6
48,CC
49-1
49,CC



0 cm
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125
150
50-1
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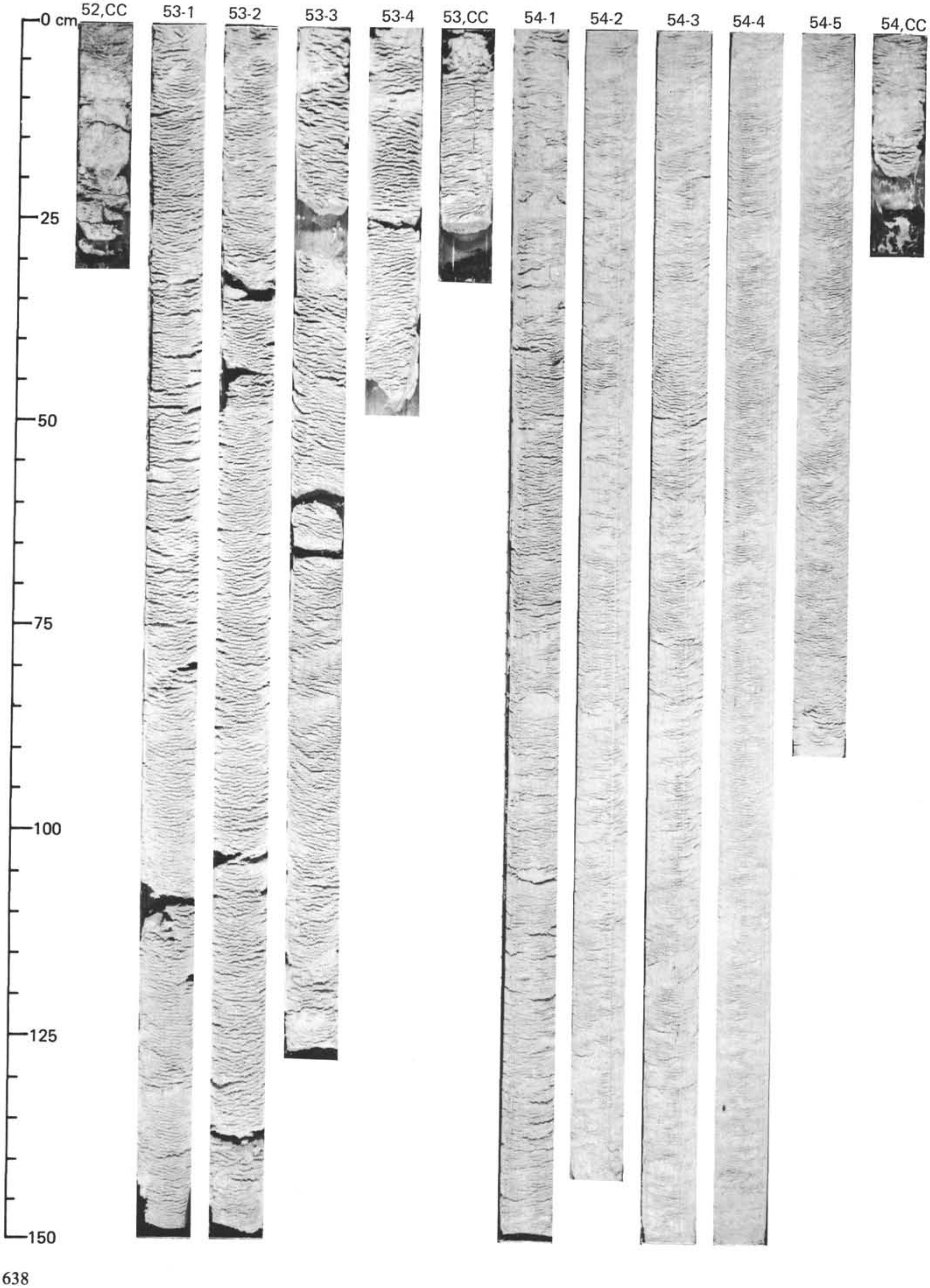
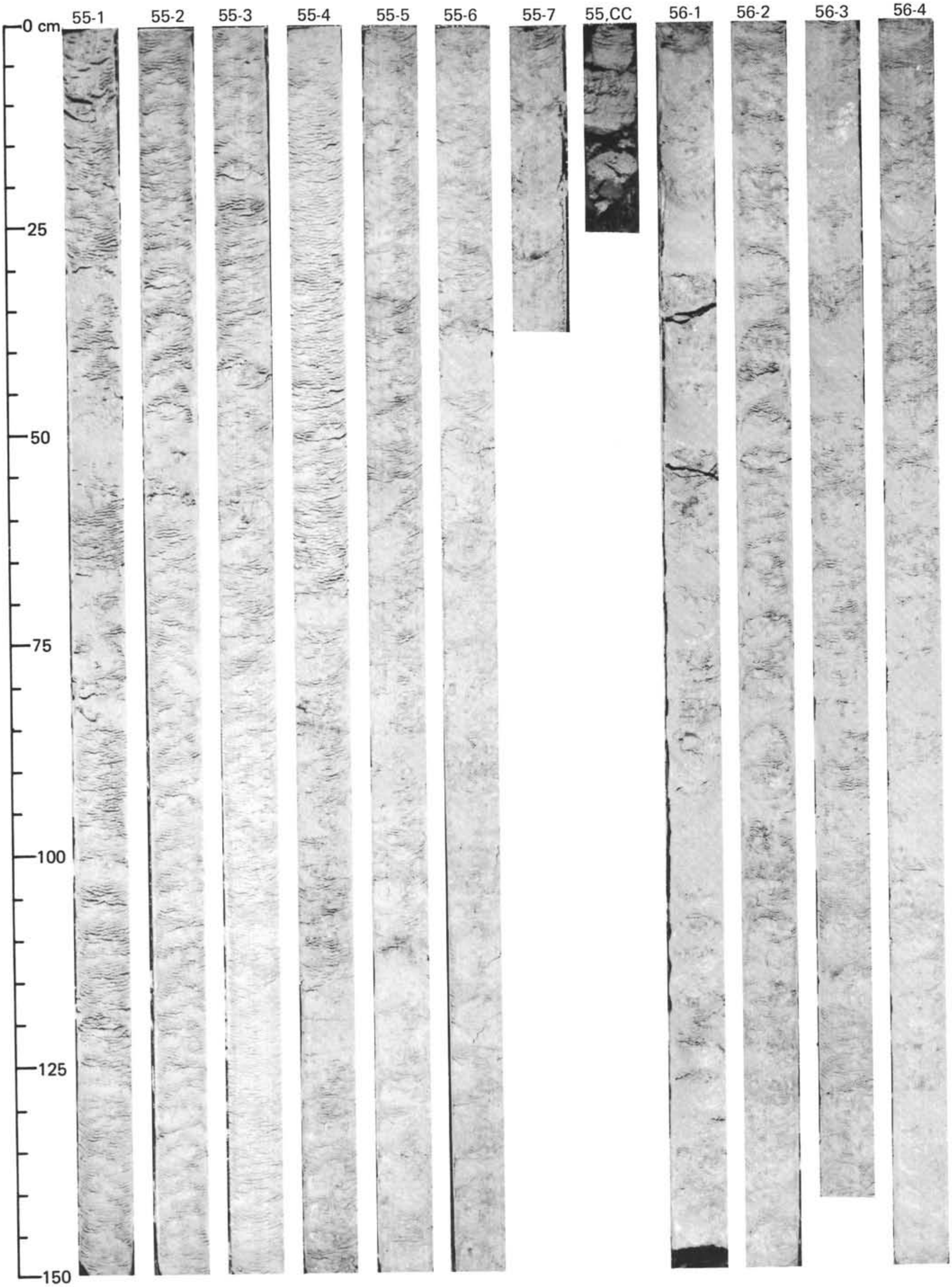
50-4
50-5
50-6
50,CC
51
52-1
52-2
52-3
52-4
NO RECOVERY


52,CC
53-1
53-2
53-3
53-4
53,CC
54-1
54-2
54-3
54-4
54-5
54,CC
0 cm
25
50
75
100
125
150


0 cm
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75
100
125
150
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55-3
55-4
55-5
55-6
55-7
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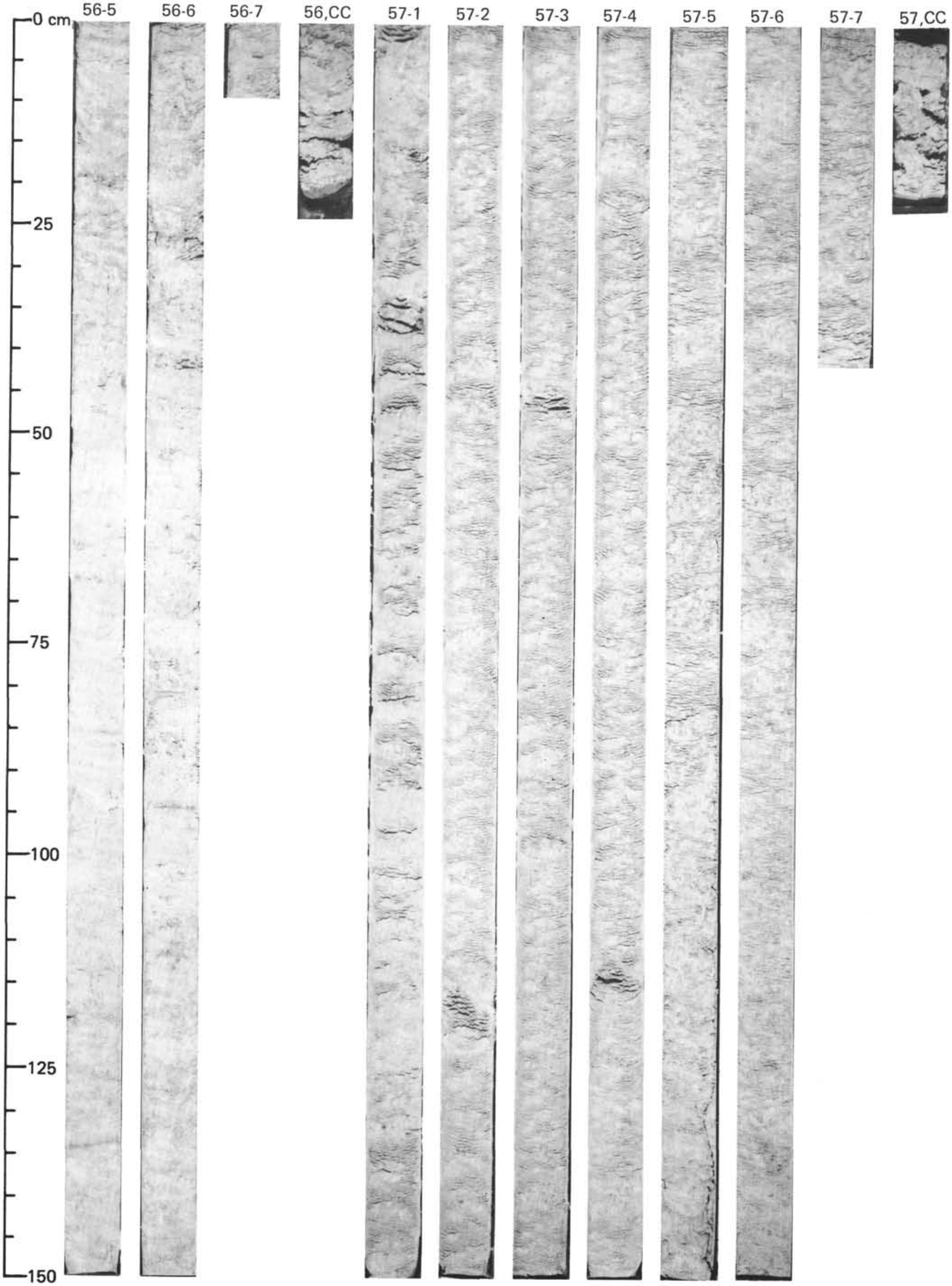
56-2
56-3
56-4


0 cm
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75
100
125
150
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56-6
56-7
56,CC
57-1
57-2
57-3
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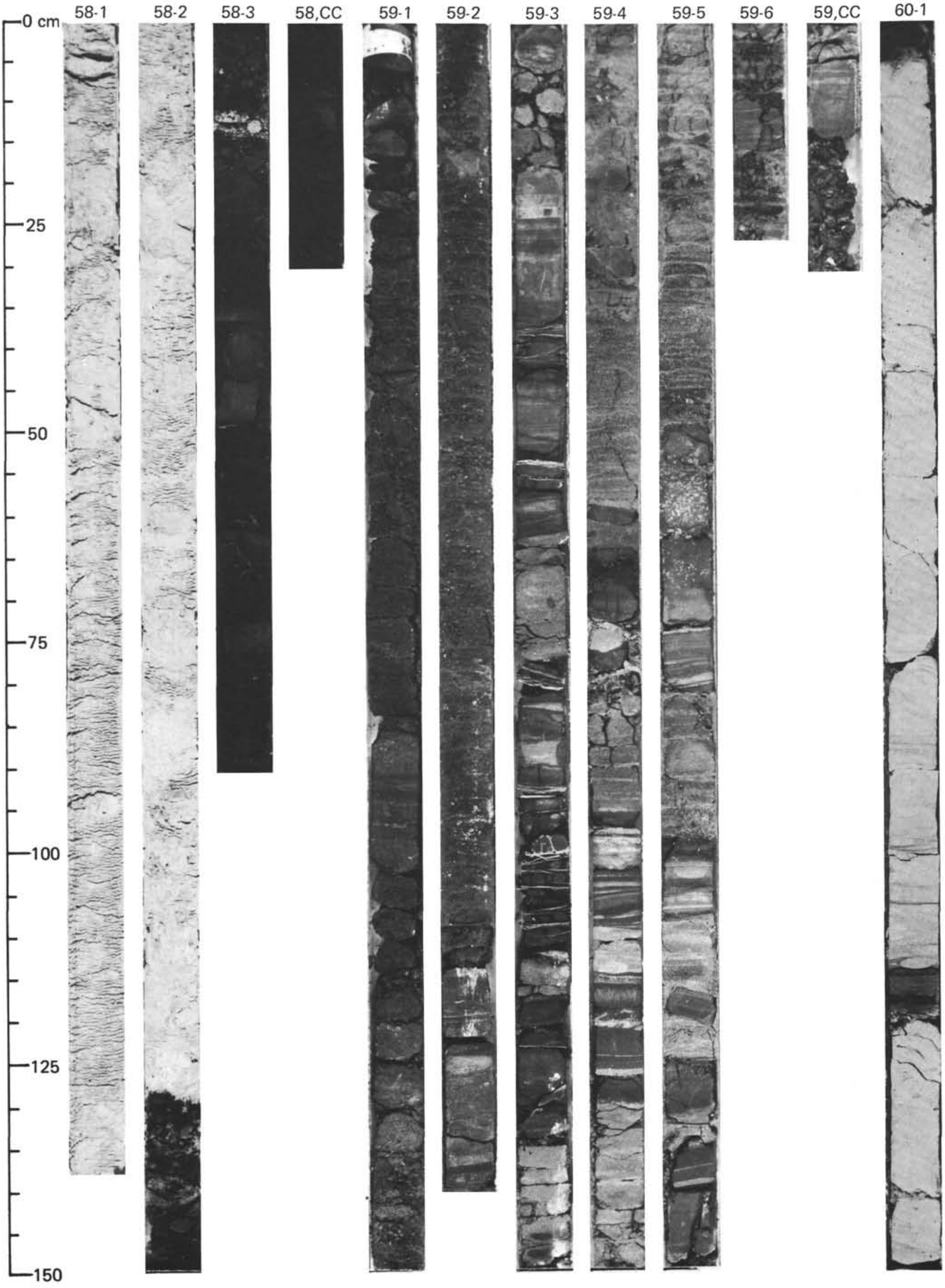
57-6
57-7
57,CC


0 cm
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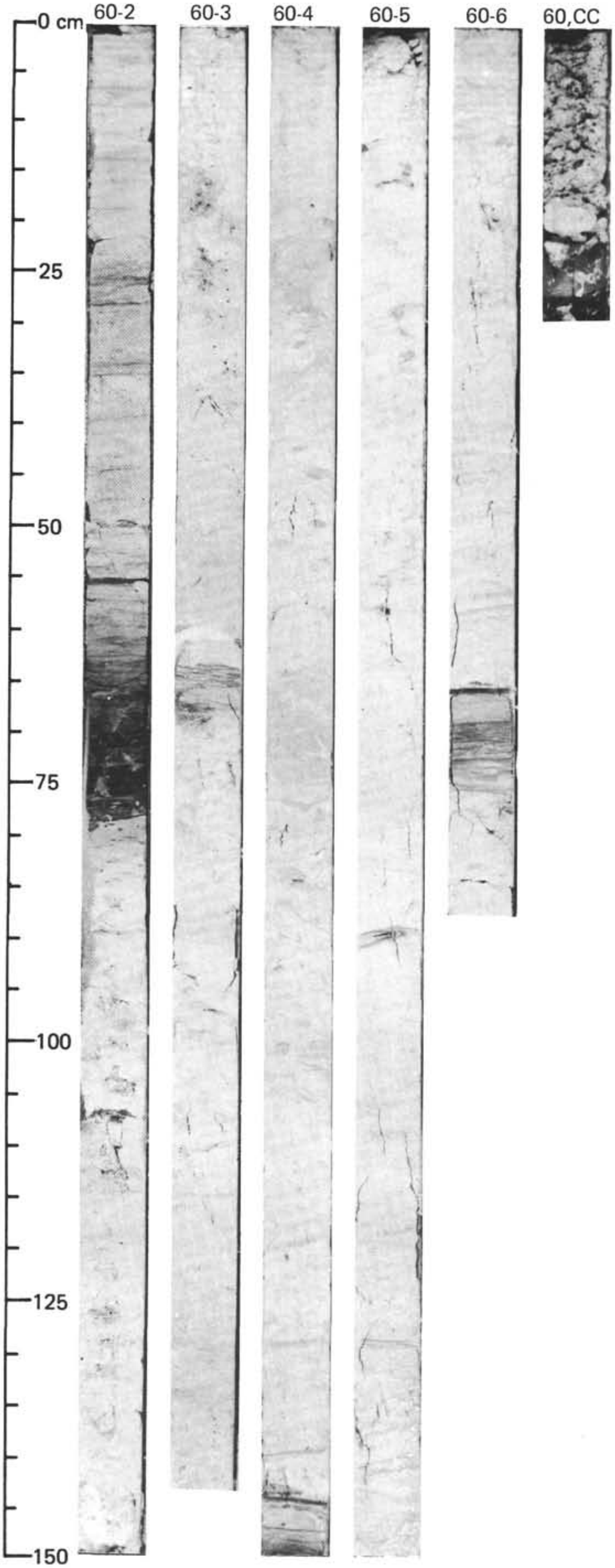
50
75
100
125
150
58-1
58-2
58-3
58,CC
59-1
59-2
59-3
59-4
59-5
59-6
59,CC
60-1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75
100
125
150
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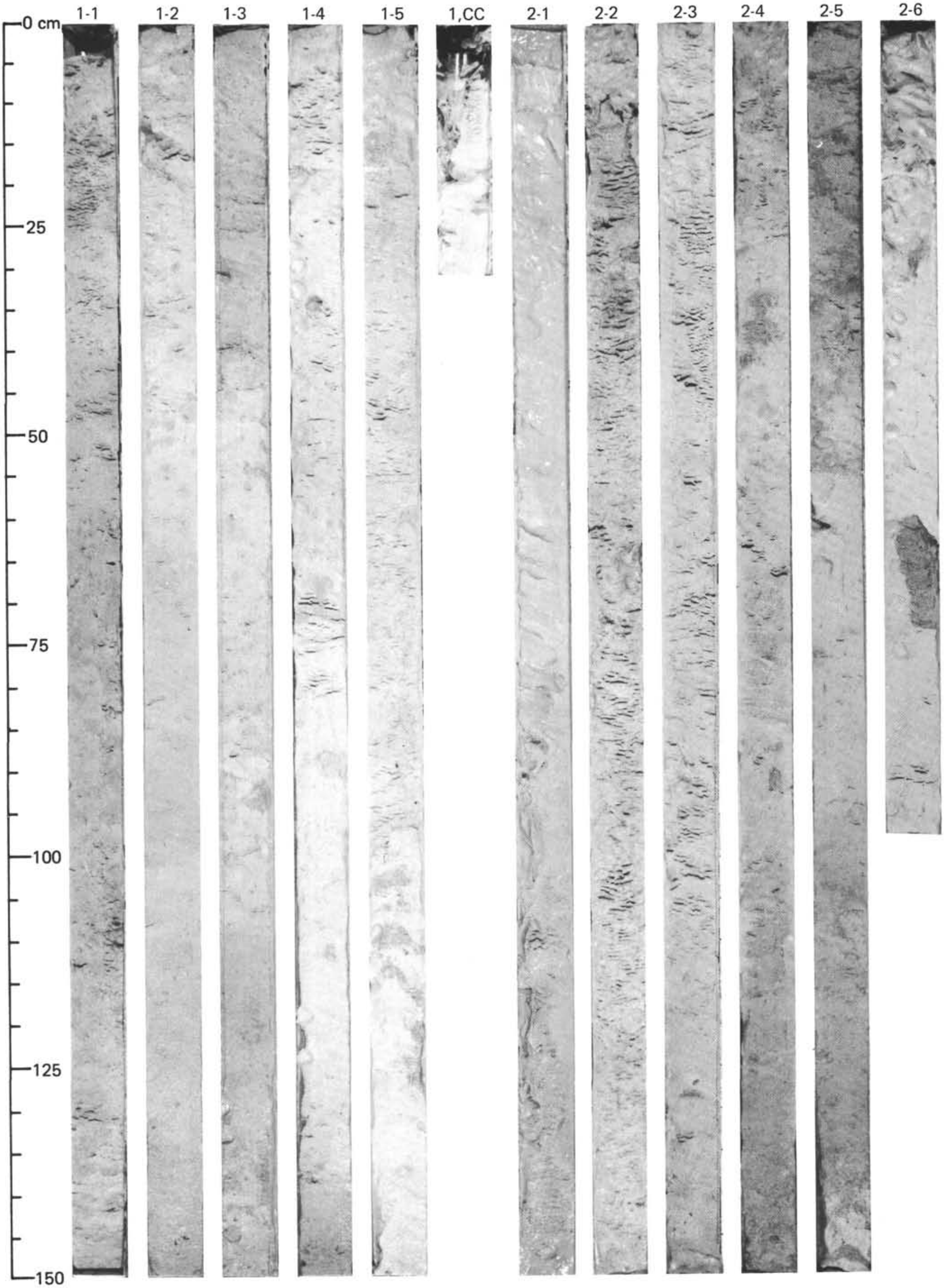
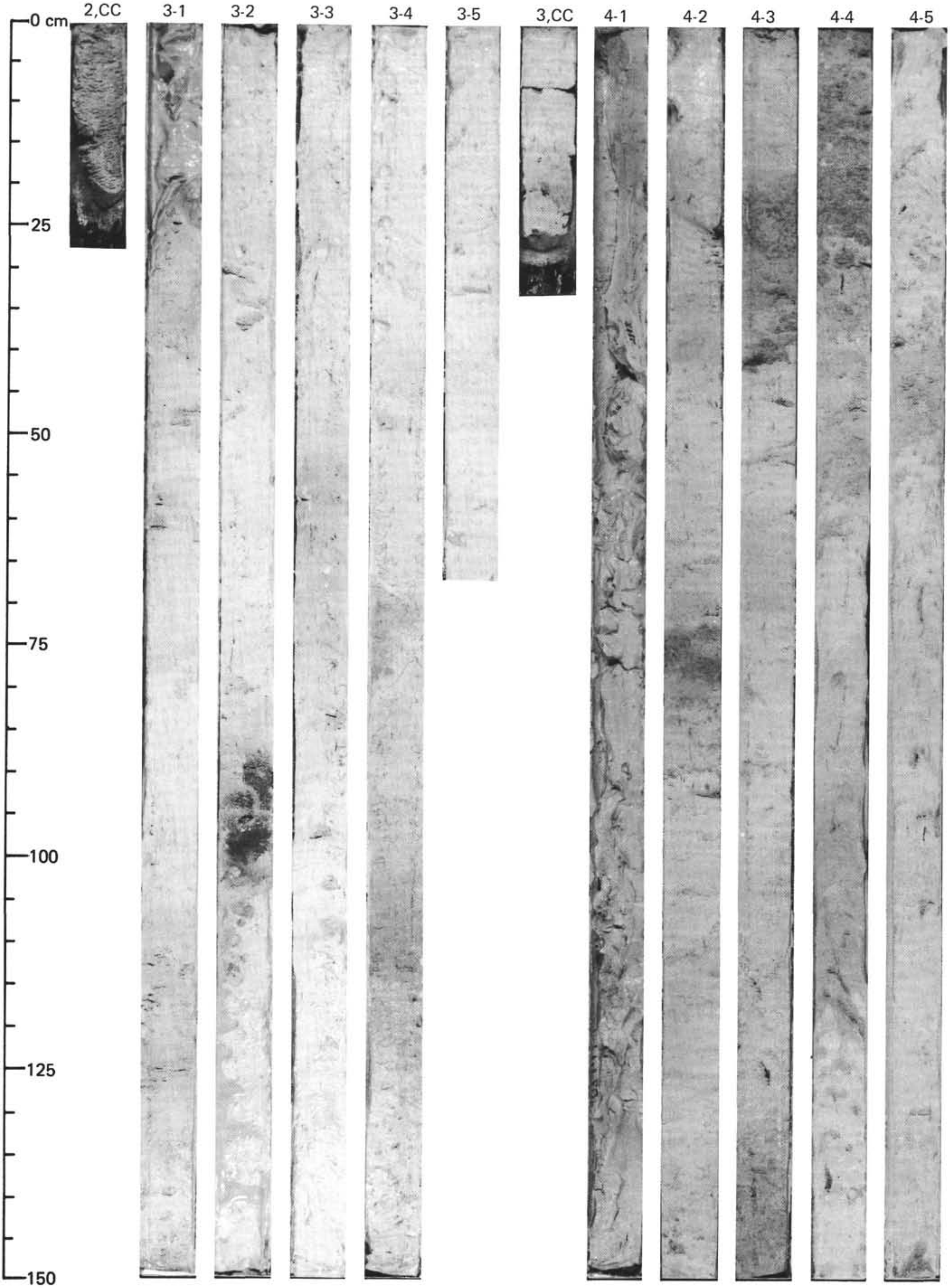
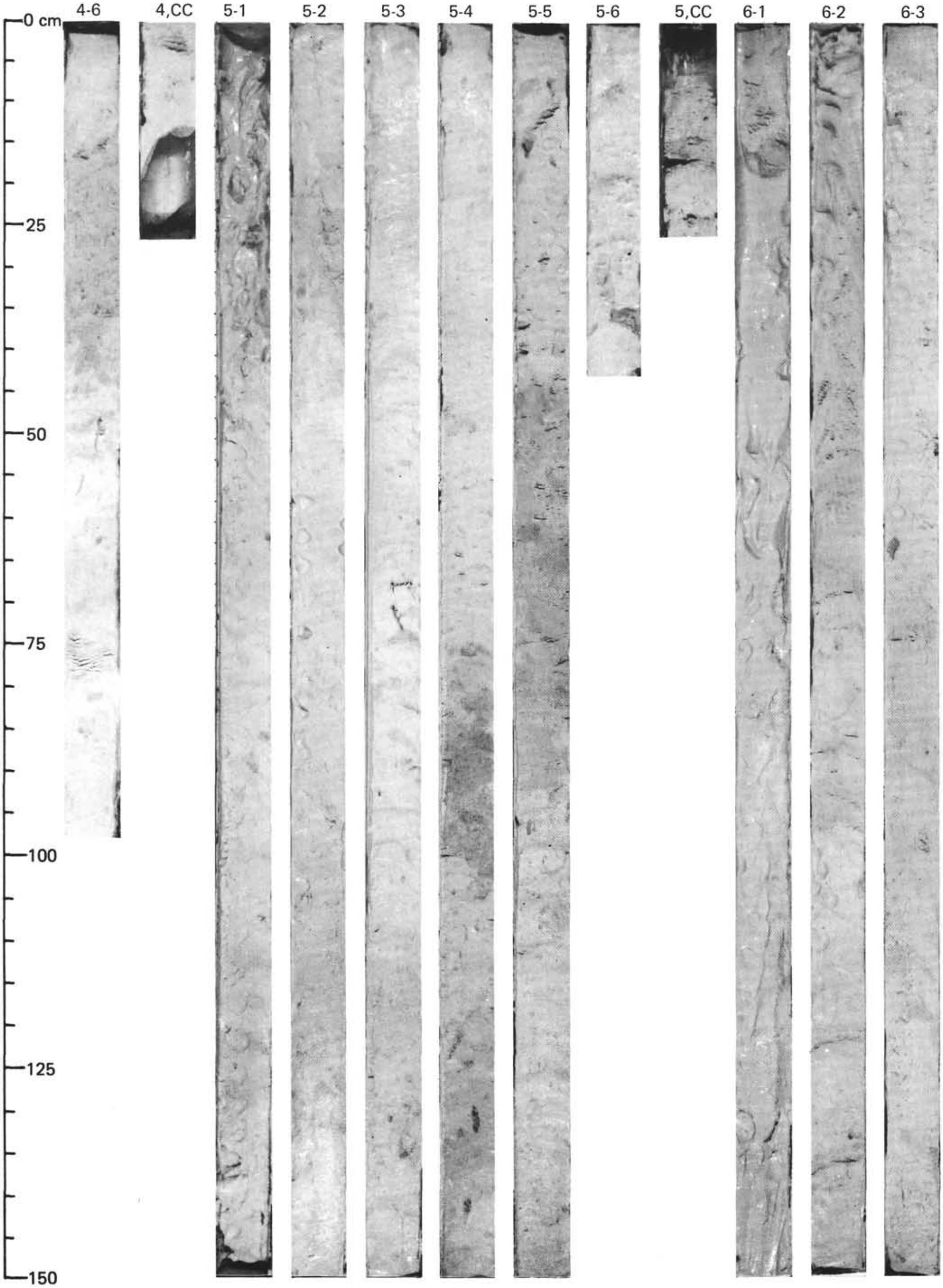
60-3
60-4
60-5
60-6
60,CC


1-1
1-2
1-3
1-4
1-5
1,CC
2-1
2-2
2-3
2-4
2-5
2-6
0 cm
25
50
75
100
125
150


0 cm
25
50
75
100
125
150
2,CC
3-1
3-2
3-3
3-4
3-5
3,CC
4-1
4-2
4-3
4-4
4-5


0 cm
25
50
75
100
125
150
4-6
4,CC
5-1
5-2
5-3
5-4
5-5
5-6
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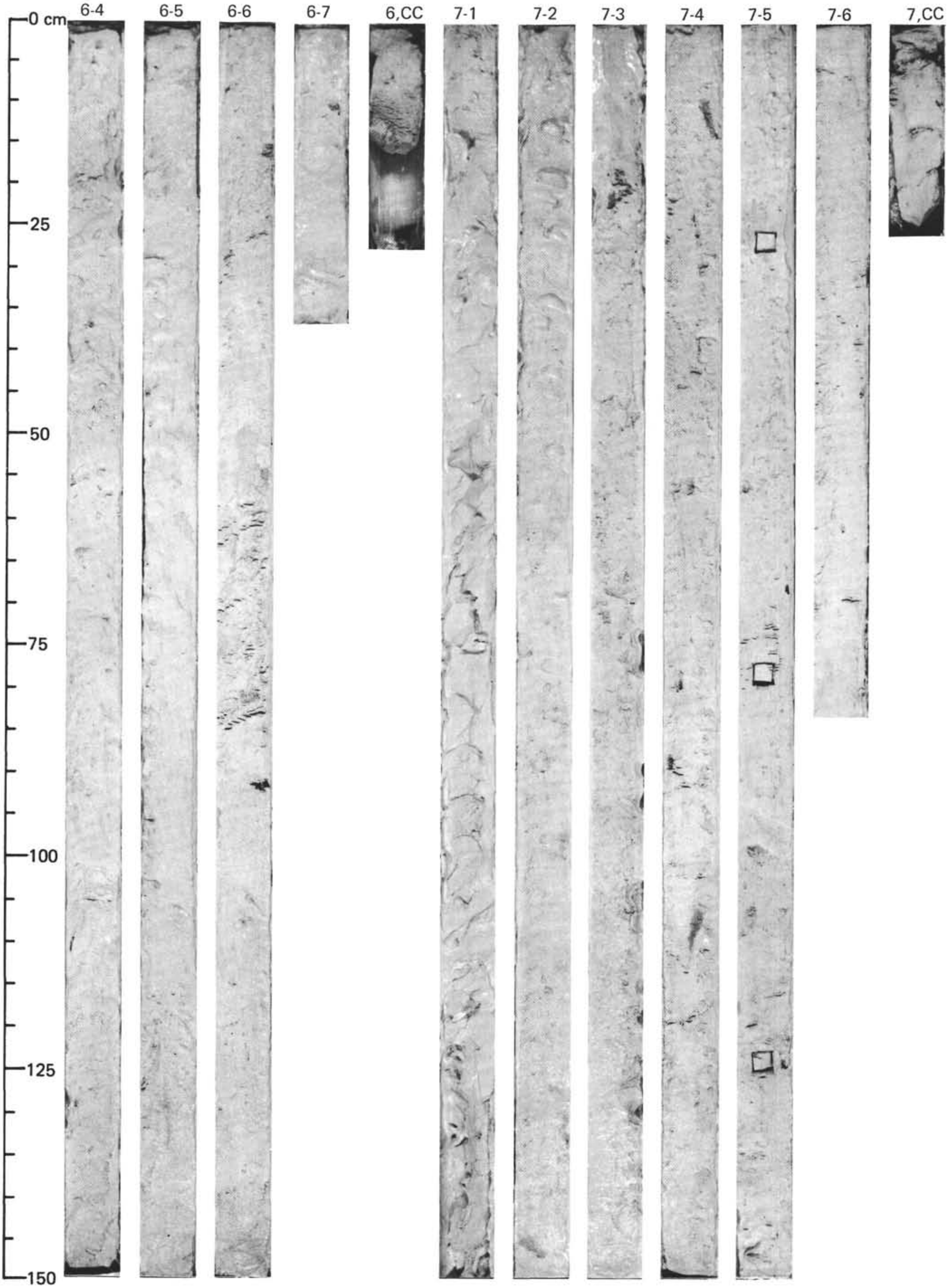
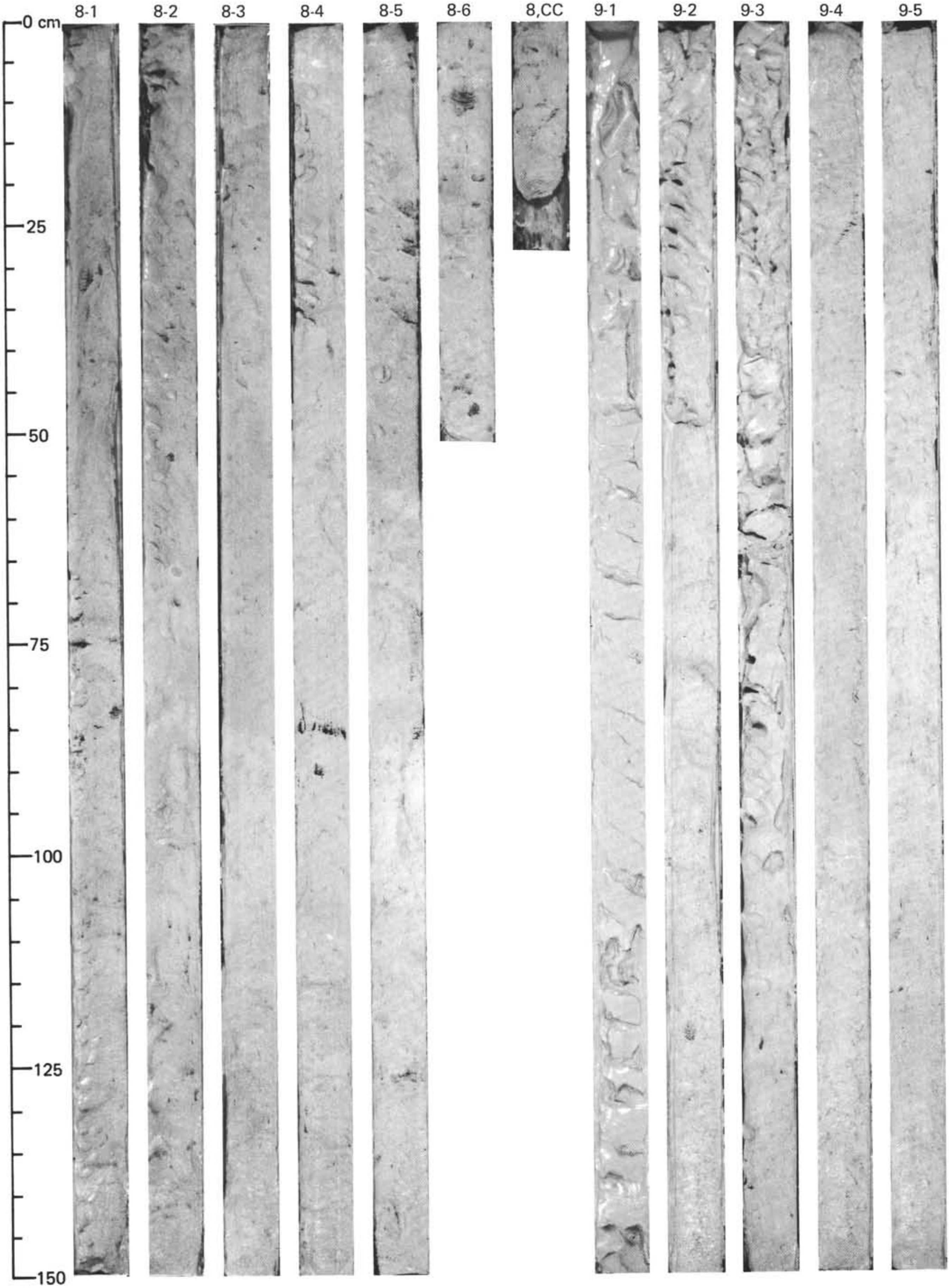
6-1
6-2
6-3


0 cm
25
50
75
100
125
150
6-4
6-5
6-6
6-7
6,CC
7-1
7-2
7-3
7-4
7-5
7-6
7,CC


0 cm
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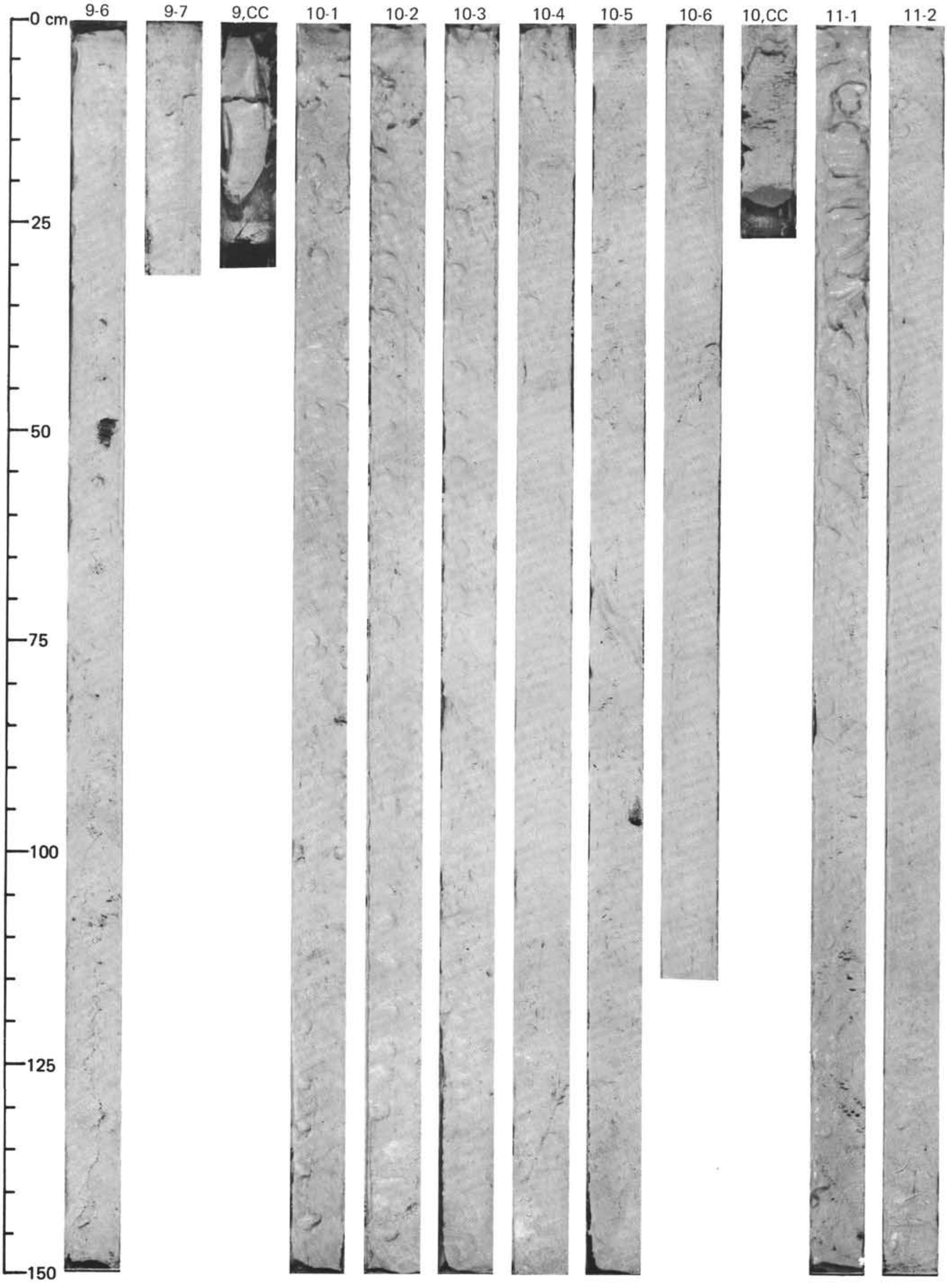
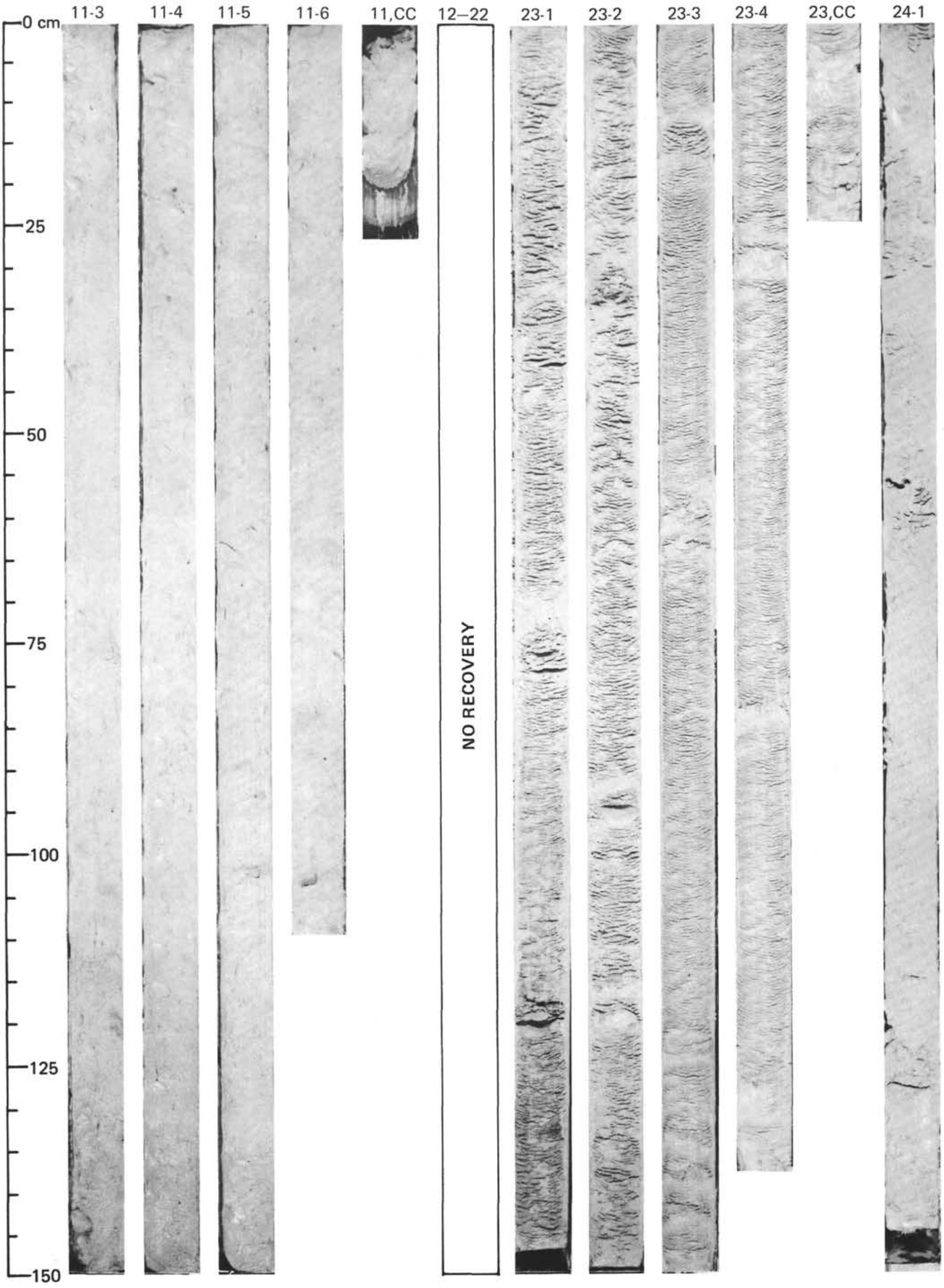
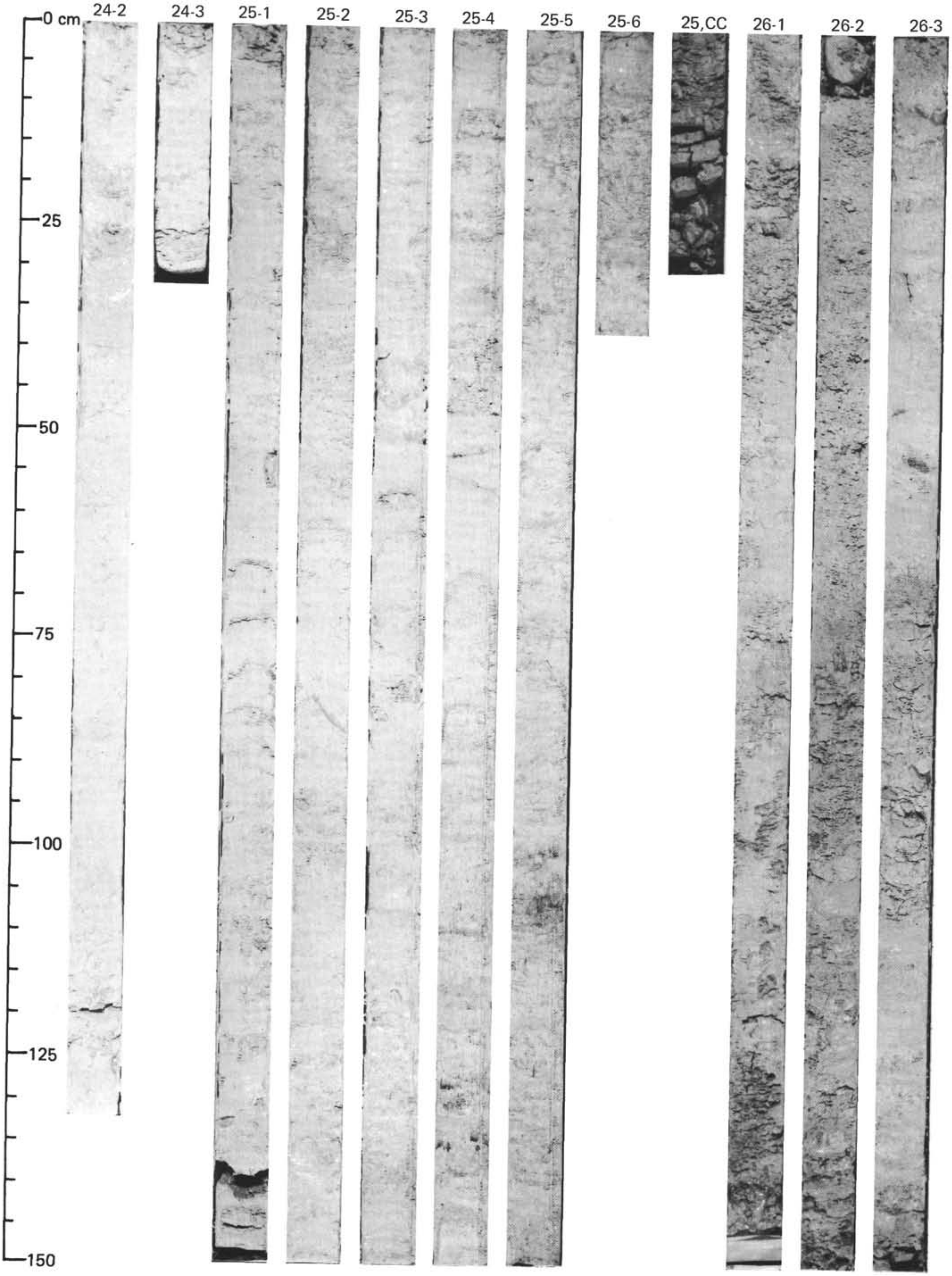
50
75
100
125
150
8-1
8-2
8-3
8-4
8-5
8-6
8,CC
9-1
9-2
9-3
9-4
9-5


9-6
9-7
9,CC
10-1
10-2
10-3
10-4
10-5
10-6
10,CC
11-1
11-2
0 cm
25
50
75
100
125
150


11-3
11-4
11-5
11-6
11,CC
12–22
23-1
23-2
23-3
23-4
23,CC
24-1
0 cm
25
50
75
100
125
150
NO RECOVERY


0 cm
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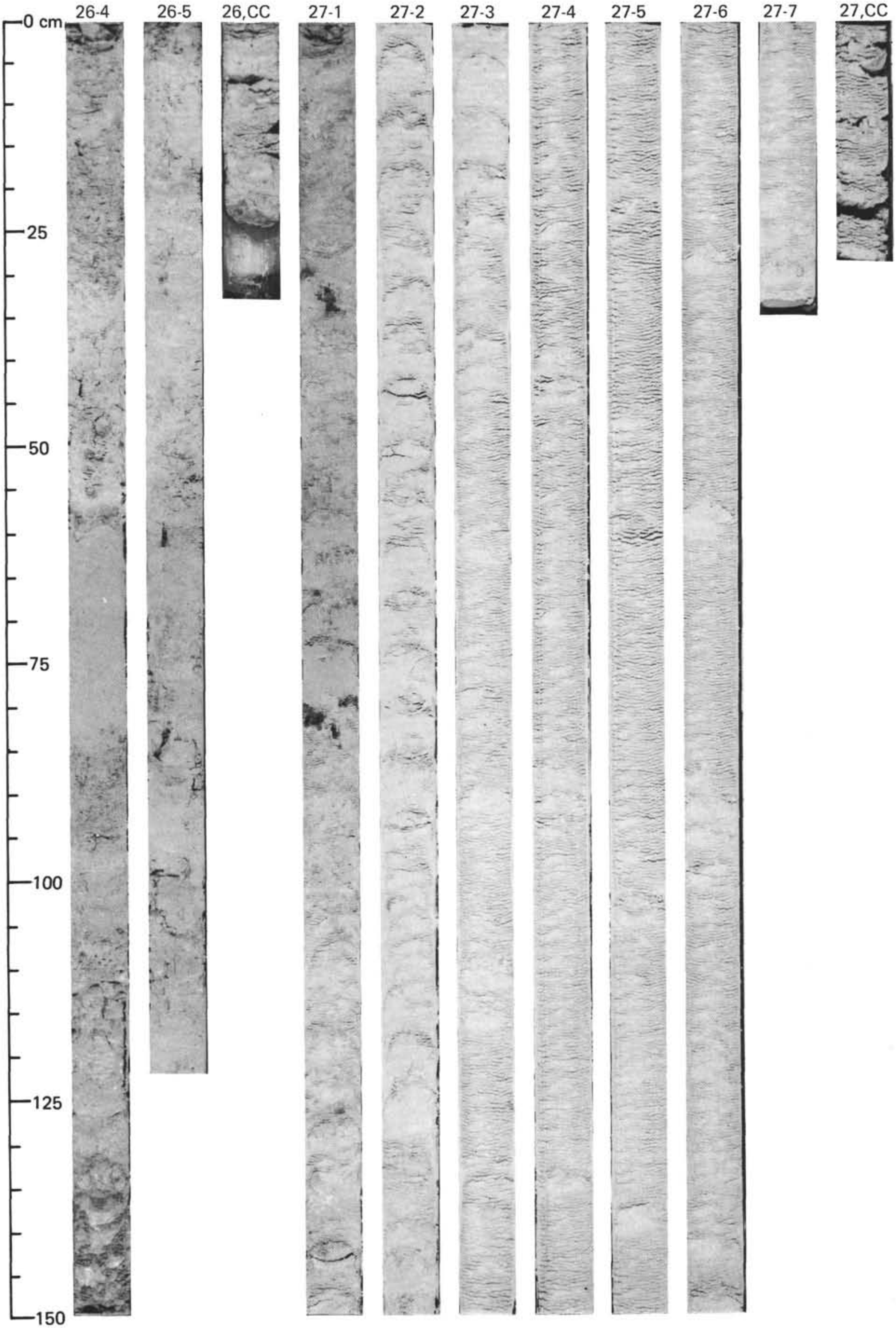
50
75
100
125
150
24-2
24-3
25-1
25-2
25-3
25-4
25-5
25-6
25,CC
26-1
26-2
26-3


26-4
26-5
26,CC
27-1
27-2
27-3
27-4
27-5
27-6
27-7
27,CC
0 cm
25
50
75
100
125
150