7. SITE 591: LORD HOWE RISE, 31°S[1]

Shipboard Scientific Party[2]

HOLE 591

Date occupied: 19 December 1982

Date departed: 20 December 1982

Time on hole: 38 hr.

Position: 31°35.06′S; 164°26.92′E

Water depth (sea level; corrected m, echo-sounding): 2131

Water depth (rig floor; corrected m, echo-sounding): 2141

Bottom felt (m, drill pipe): 2142.2

Penetration (m): 283.1

Number of cores: 31

Total length of cored section (m): 283.1

Total core recovered (m): 278.21

Core recovery (%): 98.3

Oldest sediment cored:
Depth sub-bottom (m): 283.1
Nature: Nannofossil ooze
Age: Early late Miocene

Basement: Not reached

HOLE 591A

Date occupied: 20 December 1982

Date departed: 22 December 1982

Time on hole: 37 hr.

Position: 31°35.06′S; 164°26.92′E

Water depth (sea level; corrected m, echo-sounding): 2131

Water depth (rig floor; corrected m, echo-sounding): 2141

Bottom felt (m, drill pipe): 2142.9

Penetration (m): 284.6

Number of cores: 30

Total length of cored section (m): 284.6

Total core recovered (m): 233.15

Core recovery (%): 81.9

Oldest sediment cored:
Depth sub-bottom (m): 284.6
Nature: Nannofossil ooze
Age: Early late Miocene
Measured velocity (km/s): 1.656 km/s at 249 m
Shear strength: 145 g/cm^2 at 248 m;
greater than 250 g/cm^2 below

Basement: Not reached

HOLE 591B

Date occupied: 23 December 1982

Date departed: 24 December 1982

Time on hole: 31 hr.

Position: 31°35.06′S; 164°26.92′E

Water depth (sea level; corrected m, echo-sounding): 2131

Water depth (rig floor; corrected m, echo-sounding): 2141

Bottom felt (m, drill pipe): 2141.5

Penetration (m): 500.4

Number of cores: 24

Total length of cored section (m): 229.8

Total core recovered (m): 130.86

Core recovery (%): 56.9

Oldest sediment cored:
Depth sub-bottom (m): 500.4
Nature: Foraminifer-bearing nannofossil chalk
Age: Latest early Miocene
Measured velocity (km/s): 2.218 km/s at 495 m
Shear strength: 222 g/cm^2 at 294 m; greater values below

Basement: Not reached

Principal results: Site 591 consists of three holes. Hole 591 was cored continuously with the hydraulic piston corer (HPC) from 0–283.1 m sub-bottom; Hole 591A was cored continuously with the HPC from 0–246.5 m and rotary cored with the extended core barrel (XCB) from 246.5–284.6 m; and Hole 591B was cored continuously using conventional rotary coring from 270.6–500.4 m sub-bottom. Cores recovered with the first HPC are relatively undisturbed; those using the second HPC are slightly more disturbed because of rough sea conditions. The cores recovered using conventional rotary coring exhibit mixed quality: quite disturbed in the upper part of the section, although recovery was high; moderate recovery in the middle part of the sequence; and good quality cores with moderate to low recovery rates in the lowest part of the sequence. The extended core barrel did not function successfully at this site.

The sequence is made up of one lithostratigraphic unit represented mostly by foraminifer-bearing nannofossil ooze or foramin-

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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).

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ifer-rich nannofossil ooze. Site 591 is a continuous sequence from the late early Miocene (17 m.y. ago) to the Quaternary. The HPC part of the sequence is from early late Miocene (11 m.y. ago) to the Quaternary. The biostratigraphy is complete with no apparent hiatuses. A paleomagnetic polarity stratigraphy has been identified down to the late Gilbert Chron (about 3.5 m.y. ago).

The sequence is divided into three subunits based on changes in color and the relative abundance of foraminifers and calcareous nannofossils, and on the degree of lithification. The sedimentary sequence is similar to that at Site 590, but there are even more spectacular sedimentation rates within the early Pliocene: 131 m/m.y. These high rates are due to the high productivity of calcareous biogenic material occurring in the late Neogene at three sites in this area (590, 591, and 206). It is possible that the particularly high biogenic productivity in this area is related to the poorly known Subtropical Divergence that crosses the Tasman Sea at the latitude of these sites. Rates are much lower at the sites drilled to the north of Lord Howe Rise (Site 588) and to the south (Site 592). We have dismissed the possibility that the high sedimentation rates in the Pliocene are due to secondary reworking of material from elsewhere. This is because of the isolated location of Site 591, near the crest of a spur of Lord Howe Rise, and because clearly reworked material is absent from the section.

Diagenetic alteration of the microfossil sequence took place in younger sediments than at Site 590, because Site 591 has higher sedimentation rates. Foraminiferal recrystallization is already well advanced in the lower middle Miocene sediments, and calcareous nannofossils exhibit signs of overgrowths in lower Pliocene sediments. The higher rates of sedimentation at Site 591 have allowed finer stratigraphic resolution than at Site 590. A number of evolutionary sequences within the planktonic foraminifers are clearly exhibited in this expanded sequence.

Site 591 provides excellent opportunities for high-resolution microfossil and stable isotopic work in the upper Miocene through Quaternary section, which is well preserved. Radiolarians, diatoms, and silicoflagellates are persistently but rarely present throughout the entire section.

Benthic foraminifers are well represented in the late Miocene to Quaternary. Site 591 is intermediate in vertical depth profile (2131 m) between Sites 590 and 206. Benthic faunas typical of upwelling zones appear in the middle Miocene. Important faunal differences exist between Sites 591 and 590, reflecting different paleoceanographic histories at these different water depths. The paleoceanographic changes include both upward and downward migrations of some forms of benthic foraminifers.

Site 591 exhibits a valuable tephrochronology, based on many volcanic ash layers and inferred altered ash layers. There is an important Quaternary peak in activity, low activity in the Pliocene and late Miocene, high activity in the early late Miocene to late early Miocene. The mid-Neogene peak may extend through the middle Miocene, but core recovery was poor in this interval.

BACKGROUND AND OBJECTIVES

Site 591 lies near the crest of a southern spur of the eastern part of the Lord Howe Rise (Fig. 1). The spur extends outward into the New Caledonia Basin and is surrounded by turbidite fill to the east and south. The western edge of the spur is, in its northern part, separated from the main part of the Lord Howe Rise by a valley that slopes southward, leading toward a ponded turbidite sequence which slopes toward the level of the New Caledonia Basin. Thus the crest of the spur on which Site 591 is located is isolated from any influences of sediment transportation from the main part of the Lord Howe Rise. The seismic profile (Fig. 2) exhibits a relatively simple transparent layer about 520 m thick above a distinct reflector which is considered to represent the regional unconformity associated with the Eocene/Oligocene boundary.

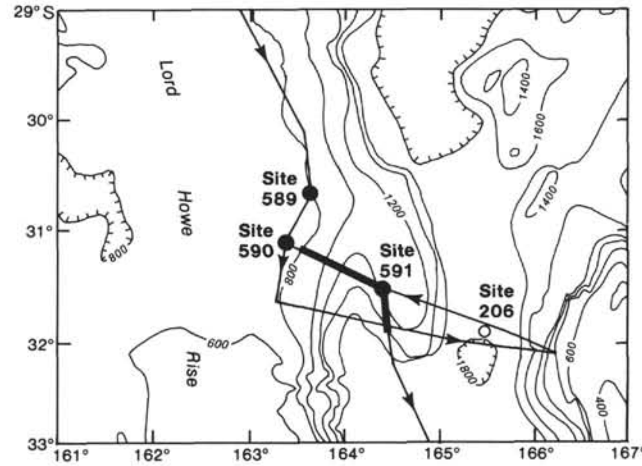

Figure 1. Regional bathymetry (fathoms) around Site 591, after Mammerickx et al. (1974). *Glomar Challenger* Leg 90 track shown; heavy portion locates water gun seismic profile illustrated in Fig. 2.

Site 591 was selected to provide a Neogene–late Paleogene stratigraphic succession at water depths intermediate (about 2200 m) between Sites 590 (1299 m) and 206 (3196 m). A site at this intermediate depth is required to study changes in the vertical water mass structure of the southwest Pacific Ocean during the Neogene. These three sites, in combination, will provide an opportunity to carry out detailed studies of changes in the intermediate water masses between 1000 and 3000 m water depth. Site 591 is located midway between Sites 590 and 206, providing a compact suite of sites.

Determining the vertical temperature gradient of past oceans represents a problem that has not been studied in detail. Keigwin et al. (1979) examined the thermal structure of the Pacific Ocean for the early Pliocene, using sediment cores from water depths between 1000 and 4500 m and oxygen isotopic analyses of benthic foraminifers. This study demonstrated an approximate 1‰ difference in $\delta^{18}O$ between cores taken at 1000 m and those from 3000 m, representing a 3°C vertical temperature difference through the intermediate water masses. A major goal of Site 591, as with the other sites in the depth traverse, was to provide a continuous sequence of high stratigraphic resolution through the Neogene, which would allow us to compare and contrast the $\delta^{18}O$ and temperature gradients between selected intervals of time (see Kennett, this volume). For instance, we were interested in determining whether any changes occurred in the character of the vertical temperature gradient during the middle Miocene paleoceanographic event, when considerable ice accumulated on east Antarctica (Shackleton and Kennett, 1975; Kennett, 1978; Woodruff et al., 1981); during the terminal Miocene event, when a distinct shift in $\delta^{13}C$ occurred in the deep-sea sediment record 6.2 m.y. ago (Loutit and Kennett, 1979; Vincent et al., 1980; Haq et al., 1980), perhaps related to a major change in oceanic turnover rates (Bender and Keigwin, 1979); and during the late Pliocene, about 3 m.y. ago, when Northern Hemisphere ice sheets began to form (Shackleton and Opdyke, 1977).

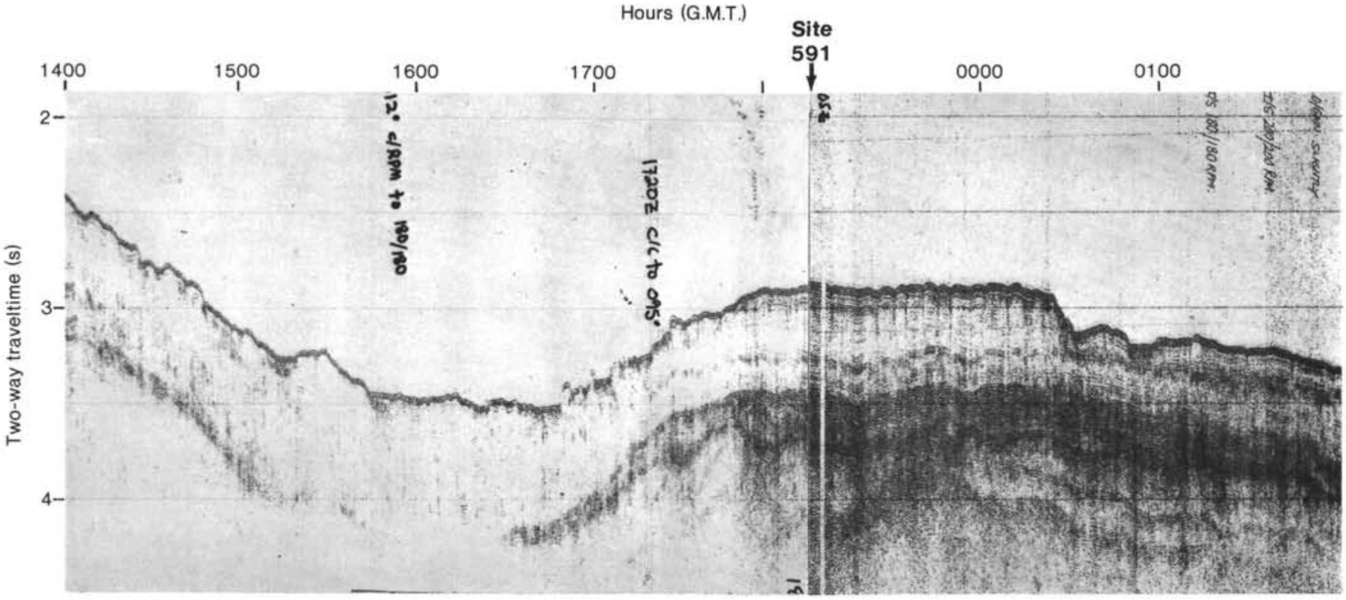

Figure 2. Water gun seismic profile (*Glomar Challenger*) near Site 591; bandpass filter 50–160 Hz.

Changes in $\delta^{13}C$ were also to be examined through the Neogene at the different water depths offered by the sites in this traverse. It has been determined that differences in $\delta^{13}C$ values represent valuable fingerprints of bottom waters.

The vertical depth traverse also was intended to provide a valuable opportunity to examine changes in benthic foraminiferal assemblages within the intermediate water masses during the Neogene. Benthic foraminifers are particularly valuable tracers of change in bottom-water characteristics through time (Douglas and Woodruff, 1981). They either migrate, evolve, or become extinct in response to bottom-water changes. The cores in the southwest Pacific depth traverse were expected to allow foraminiferal changes to be evaluated within a framework of paleodepths. This, in turn, should provide valuable data on the evolution of the intermediate water mass and allow comparisons with the stable isotopic data.

Site 591 is located at 2130 m, above the foraminiferal lysocline, and calcareous microfossil preservation was expected to be of high quality. Like Site 590, this site is located in waters transitional between the warm subtropical and temperate water masses and is of potential importance in correlating stratigraphic sequences of these areas. Because Site 590 was marked by very high sedimentation rates in the middle Miocene and younger sequences, high overburden pressure created much recrystallization of the microfossils in the middle and early Miocene. This has a potentially detrimental effect upon stable isotopic values. It was hoped that the calcareous microfossils through the early Neogene sequence at Site 591 would be less recrystallized and thus more useful for analyses of stable isotopes.

The final location of SW-6 (Site 591) changed during Leg 90. Originally SW-6 was to be located at a similar depth about 1° of latitude further north on the slope of the Lord Howe Rise. The original position was located on an Australian Bureau of Mineral Resources seismic profile which is of poor resolution but was the best available in the region. During the breakdown of the shipboard positioning computer, a useful survey conducted near Site 206 with the excellent water gun profiling system of the *Glomar Challenger* provided high-resolution data of the upper part of the sediment column. It was discovered that areas between about 1900 m and 2900 m on the slope of the rise exhibit heavily slumped topography. This seems also to be the case in the original area proposed for Site SW-6 drilling. A new area favorable for SW-6 objectives was discovered on the spur of the Lord Howe Rise, in unslumped terrain, exhibiting apparently uncomplicated stratigraphy and with a sediment thickness of 520 m down to the inferred regional unconformity separating the Eocene and Oligocene.

The drilling plans at Site 591 were to take two hydraulic piston cores and to rotary core (XCB) continuously through the Neogene sequence to the upper Oligocene sequence.

OPERATIONS

Site 591 (new SW-6): Downslope of Central Lord Howe Rise

The ship was positioned over the beacon with some difficulty because wind, current, and swell were all present from different directions. A combination variable length (VL) HPC–XCB bottom-hole assembly (BHA) was made up and run to the seafloor. Hole 591 was spudded at 1150 hr., 19 December, with a mud line core which verified the water depth as 2142 m (Table 1).

Piston coring proceeded using the 9.5-m VLHPC with only two shear pins. A nearly perfect series of cores was taken to a total depth of 283.1 m BSF in gradually stiffening carbonate ooze. Favorable conditions of vessel motion, repeated full stroke of the piston corer, and excellent core quality made this an exceptionally well preserved cored sequence which was marked by greater than

Table 1. Coring Summary, Site 591.

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 591							
1	19	1215	2142.2-2145.6	0.0-3.4	3.4	3.38	99+
2	19	1318	2145.6-2155.2	3.4-13.0	9.6	9.72	100+
3	19	1410	2155.2-2164.8	13.0-22.6	9.6	9.52	99+
4	19	1503	2164.8-2174.4	22.6-32.2	9.6	9.47	99+
5	19	1605	2174.4-2184.0	32.2-41.8	9.6	8.82	92
6	19	1705	2184.0-2193.6	41.8-51.4	9.6	9.57	100
7	19	1805	2193.6-2203.2	51.4-61.0	9.6	9.12	93
8	19	1900	2203.2-2212.8	61.0-70.6	9.6	8.98	98
9	19	1950	2212.8-2222.4	70.6-80.2	9.6	9.44	100+
10	19	2055	2222.4-2232.0	80.2-89.8	9.6	9.65	100+
11	19	2150	2232.0-2241.6	89.8-99.4	9.6	9.16	95
12	19	2310	2241.6-2251.2	99.4-109.0	9.6	9.56	99.5
13	19	2350	2251.2-2260.5	109.0-118.3	9.3	9.19	98.8
14	20	0050	2260.5-2269.8	118.3-127.6	9.3	9.67	100+
15	20	0200	2269.8-2279.1	127.6-136.9	9.3	9.64	100+
16	20	0300	2279.1-2288.4	136.9-146.2	9.3	9.63	100+
17	20	0400	2288.4-2297.7	146.2-155.5	9.3	9.71	100+
18	20	0450	2297.7-2307.0	155.5-164.8	9.3	9.29	100+
19	20	0600	2307.0-2316.5	164.8-174.3	9.5	9.55	100+
20	20	0700	2316.5-2326.0	174.3-183.8	9.5	9.59	100+
21	20	0740	2326.0-2335.5	183.8-193.3	9.5	9.47	99.7
22	20	0843	2335.5-2344.9	193.3-202.7	9.4	8.55	90.9
23	20	0940	2344.9-2354.3	202.7-212.1	9.4	9.50	100+
24	20	1035	2354.3-2363.7	212.1-221.5	9.4	8.63	91.8
25	20	1145	2363.7-2373.3	221.5-231.1	9.6	9.73	100+
26	20	1245	2373.3-2382.9	231.1-240.7	9.6	8.76	91
27	20	1345	2382.9-2392.5	240.7-250.3	9.6	9.71	100+
28	20	1445	2392.5-2402.0	250.3-259.8	9.5	9.11	95
29	20	1615	2402.0-2411.5	259.8-269.3	9.5	8.93	94
30	20	1730	2411.5-2416.5	269.3-274.3	5.0	4.40	88
31	20	1900	2416.5-2425.3	274.3-283.1	8.8	8.76	99
					283.10	278.21	98.3
Hole 591A							
1	20	2052	2140.9-2150.1	0.0-9.2	9.2	9.16	100
2	20	2150	2150.1-2159.7	9.2-18.8	9.6	8.73	90.9
3	20	2300	2159.7-2169.3	18.8-28.4	9.6	6.40	66.6
4	20	2340	2169.3-2178.9	28.4-38.0	9.6	8.30	86.4
5	21	0055	2178.9-2188.5	38.0-47.6	9.6	8.67	90.3
6	21	0200	2188.5-2198.1	47.6-57.2	9.6	8.44	87.9
7	21	0245	2198.1-2207.7	57.2-66.8	9.6	9.28	96.6
8	21	0350	2207.7-2217.3	66.8-76.4	9.6	7.92	82.5
9	21	0445	2217.3-2226.9	76.4-86.0	9.6	7.34	76.4
10	21	0540	2226.9-2236.5	86.0-95.6	9.6	6.92	72.0
11	21	0645	2236.5-2246.1	95.6-105.2	9.6	7.95	82.8
12	21	0745	2246.1-2255.4	105.2-114.5	9.3	8.61	92.5
13	21	0840	2255.4-2264.7	114.5-123.8	9.3	8.55	91.9
14	21	0940	2264.7-2274.0	123.8-133.1	9.3	9.20	95.8
15	21	1040	2274.0-2283.3	133.1-142.4	9.3	9.39	100+
16	21	1140	2283.3-2292.6	142.4-151.7	9.3	8.77	94
17	21	1240	2292.6-2301.9	151.7-161.0	9.3	9.24	99
18	21	1340	2301.9-2311.4	161.0-170.5	9.5	8.86	93
19	21	1440	2311.4-2320.9	170.5-180.0	9.5	8.79	92
20	21	1540	2320.9-2330.4	180.0-189.5	9.5	8.27	87
21	21	1040	2330.4-2339.8	189.5-198.9	9.4	9.31	99
22	21	1745	2339.8-2349.2	198.9-208.3	9.4	9.48	100+
23	21	1900	2349.2-2358.6	208.3-217.7	9.4	9.25	98
24	21	2030	2358.6-2368.2	217.7-227.3	9.6	8.29	86
25	21	2130	2368.2-2377.8	227.3-236.9	9.6	8.18	85
26	21	2235	2377.8-2387.4	236.9-246.5	9.6	8.41	87.6
27	22	0100	3387.4-2396.9	246.5-256.0	9.5	7.31	76.9
28	22	0445	2396.9-2406.4	256.0-265.5	9.5	0.0	0.0
29	22	0545	2406.4-2415.9	265.5-275.0	9.5	0.0	0.0
30	22	0645	2415.9-2425.5	275.0-284.6	9.6	4.13	43
					284.6	233.15	81.9
Hole 591B							
1	23	0600	2411.5-2421.1	270.6-280.2	9.6	3.69	38.4
2	23	0645	2421.1-2430.7	280.2-289.8	9.6	9.48	98.7
3	23	0730	2430.7-2440.3	289.8-299.4	9.6	7.42	77.2
4	23	0820	2440.3-2449.7	299.4-308.8	9.4	7.08	73.7
5	23	0905	2449.7-2459.1	308.8-318.2	9.4	5.00	52.0
6	23	1000	2459.1-2468.5	318.2-327.6	9.4	7.86	81.8
7	23	1045	2468.5-2478.1	327.6-337.2	9.6	9.00	93.7
8	23	1130	2478.1-2487.7	337.2-346.8	9.6	2.17	22.6
9	23	1235	2487.7-2497.3	346.8-356.4	9.6	2.69	28.0
10	23	1335	2497.3-2506.9	356.4-366.0	9.6	4.31	44.9
11	23	1435	2506.9-2516.5	366.0-375.6	9.6	1.63	17.0
12	23	1535	2516.5-2526.1	375.6-385.2	9.6	2.51	26.1
13	23	1620	2526.1-2535.7	385.2-394.8	9.6	3.24	33.7
14	23	1740	2535.7-2545.3	394.8-404.4	9.6	2.21	23.0
15	23	1840	2545.3-2554.9	404.4-414.0	9.6	4.11	42.8
16	23	1935	2554.9-2564.5	414.0-423.6	9.6	0.49	5.1
17	23	2040	2564.5-2574.1	423.6-433.2	9.6	5.06	52.7
18	23	2140	2574.1-2583.7	433.2-442.8	9.6	8.70	90.6
19	23	2240	2583.7-2593.3	442.8-452.4	9.6	7.86	81.9
20	23	2340	2593.3-2602.9	452.4-462.0	9.6	7.74	80.6
21	24	0045	2602.9-2612.5	462.0-471.6	9.6	4.68	48.7
22	24	0145	2612.5-2622.1	471.6-481.2	9.6	7.98	83.1
23	24	0245	2622.1-2631.7	481.2-490.8	9.6	9.71	100+
24	24	0345	2631.7-2641.3	490.8-500.4	9.6	6.24	65.0
					229.80	130.86	56.9

98% recovery. The hole was terminated despite continued full stroke when excessive pullout loads endangered the coring tool.

Hole 591A

The bit was pulled to the mud line and the vessel was offset 100 ft. in preparation for a repeat piston core sequence. The new hole was spudded at 2012 hr., 20 December. Cores were staggered to overlap those from Hole 591. Rougher weather resulted in poorer core quality and recovery in the repeat piston core sequence. Again full stroke was achieved on all cores.

Piston coring was stopped at 246.5 m BSF to avoid excess overpull. The XCB was then deployed a total of six times. Each of the six attempts resulted in a severely shattered liner which created much difficulty in removing the liners and/or cores from the core barrels.

Additional problems were encountered when several of the XCB core barrels did not land at their proper latch-in point above the bit. Each seemed to become stuck at a position 70–80 m above its normal landing point and required repeated jarring by the wireline to become free. No immediate cause for or solution to this phenomenon could be found.

Both these problems led to the termination of Hole 591A, and the pipe was tripped to allow us to change over to the standard rotary system and inspect the BHA. Subsequent inspection of all BHA components including disassembly and servicing of the bumper subs failed, however, to reveal why the barrels had become stuck.

During the pipe trip the vessel was subjected to a severe combination of wind, swell, and current. In an attempt to hold the roll to a minimum for safety of personnel on the rig floor while pulling out of the hole, the vessel was allowed to wander about 3 mi. from the beacon. When we returned to the beacon the adverse conditions made positioning exceedingly difficult unless the ship's heading was such that the rolls made running in the hole unsafe. After the ship spend 7 hr. seeking optimum positioning while waiting on the weather, the wind abated enough to allow the vessel to position in automatic with a safe level of vessel motion.

Hole 591B

A short-hook-up BHA, spaced out for standard rotary drilling, was run back to the seafloor and the bit was washed to 270.6 m BSF to begin rotary coring. After the wash barrel was retrieved, 24 rotary cores were taken to a depth of 500.4 m BSF (Table 1). At this point fossils were too badly preserved to be valuable for analyses so the hole was terminated.

Core quality was mediocre and recovery was below average, largely because of unfavorable sea conditions and vessel motion. The pipe was tripped, the rig secured for sea, and the ship was underway for second-priority Site SW-3 at 0950 hr., 24 December 1982.

LITHOSTRATIGRAPHY

The sedimentary sequence recovered at Site 591 is a calcareous biogenic facies that constitutes a single lithostratigraphic unit. The basic color of the sediment is light gray, with greenish gray interbeds. The main biogenic components are calcareous nannofossils and foraminifers (Fig. 3). Biosiliceous components are occasionally present in trace amounts, and increase slightly in abundance below Core 591-27 and throughout Hole 591B. Siliceous components consist mainly of fragments of radiolarians, diatoms, and sponge spicules, and silicoflagellates appear in Cores 591-21 and 591A-23.

Nonbiogenic components comprise a very small proportion of the sediment. Quartz, feldspars, mica, possible heavy minerals, and micritic carbonate are generally present. Micritic carbonate significantly increases below Core 591B-18. Trace quantities of clear volcanic glass occur throughout the sequence. Ash layers are present in Cores 591-2, 591-5, 591-10 and possibly 591-13, and in 591A-1 and possibly 591A-2 (Fig. 4). Pockets of volcanic glass also occur in Core 591A-25. Zeolites are present in trace amounts in Cores 591-2 and 591-4. Palagonite is also present in Cores 591-31 and 591A-3. Light greenish gray laminae are common and often associated with underlying gray laminae of iron sulfides. These laminae (Fig. 4) may represent alteration products of devitrified volcanic glass. These paired color bands occur more frequently above 80 m BSF (Cores 591-1 to 591-9 and 591A-1 to 591A-8), as well as in Hole 591B below Core 591B-3 (Fig. 4). Authigenic iron sulfides occur within burrows and foraminifer tests, and as finely dispersed gray pockets, halos, and laminae throughout the sequence. Pyrite nodules are present in Hole 591B.

The sequence at Site 591 is divided into three subunits based on color, on the relative abundance of foraminifers and calcareous nannofossils, and on the degree of lithification (Fig. 5).

Subunit IA extends from the seafloor to 0.62 m sub-bottom in Hole 591 and to 0.50 m in Hole 591A. This subunit is late Quaternary in age. The sediment is yellowish gray to pale yellowish brown and consists of a foraminifer-bearing nannofossil ooze. Subunit IA corresponds to the zone of oxidation.

Subunit IB extends from the base of the oxidized layer to 289.8 m sub-bottom (Quaternary to upper Miocene). The sediments, light gray in color, range from a foraminifer-bearing nannofossil ooze to a nannofossil ooze. Greenish gray levels are frequent in this subunit and contain slightly more foraminifers (5 to 10%) than light gray oozes.

Subunit IC extends from 289.8 m sub-bottom to the bottom of Hole 591B (500.4 m sub-bottom). This subunit is late Miocene to early Miocene in age. The sediments, very light gray to light greenish gray, range from a foraminifer-bearing nannofossil chalk to a nannofossil chalk.

Bioturbation in Hole 591 is important in Cores 591-7 and 591-8, and Cores 591-9 to 591-31 are slightly to moderately bioturbated. The entire sequence in Hole 591A is slightly to moderately bioturbated, with the exception of Core 591A-13, which is extremely bioturbated. Sediments in Hole 591B are moderately bioturbated in Cores 591B-4 and 591B-5, as well as in 591B-15 to 591B-24. Many burrows—gray, light greenish gray, and grayish yellow green—are present. Examples of Planolites-like burrows are apparent in the three holes. Zoophycos-like burrows are common below Core 591B-3. Flaser-type structures appear below Core 591B-16. Microfractures are present in Cores 591B-5 to 591B-7 and in 591B-12.

The sediment becomes more indurated with depth. Sediment above 290 m sub-bottom is an ooze and becomes progressively stiffer with depth, especially below 155 m (soft to stiff). Sediment below 290 m (Core 591B-3) is chalk, with clear recrystallization below 300 m (Core 591B-4). Sediment becomes very hard and recrystallization is widespread below 443 m (591B-19).

The first section of Cores 591-1 to 591-12 is generally soupy or very disturbed. Sections 1 to 3 of Cores 591-12 to 591-24 are slightly to very disturbed. Cores 591-24 to 591-31 are undisturbed. All cores in Hole 591A are soupy or disturbed in the first section. Cores 591A-5 to 591A-9 are moderately to very disturbed in Sections 1 to 4, and Cores 591A-9 to 591A-13 and 591A-18 to 591A-30 are slightly to very disturbed in Sections 1 and 2. Cores 591B-1, 591B-2 and 591B-8 to 591B-13 are very disturbed and consist of biscuits of sediment surrounded by a slurry of soft ooze introduced during the coring process.

PHYSICAL PROPERTIES

Combining Holes 591A and 591B yields a continuously cored section with good recovery, nearly 500 m long, from which numerous physical properties were obtained. Gravimetric, sonic velocity, and shear strength measurements were systematically performed at small intervals along the HPC cores and most sections were run through the continuous GRAPE scanning apparatus (see Introduction for specific techniques). Grain densities were determined by standard gravimetric analyses and the results are shown in Figure 6A. Below a depth of 300 m, the data were obtained from solid chunk samples rather than from sediment-filled cylinders (Boyce, 1976). The grain densities are quite uniform at this level and are consistent with calcareous sediments ($CaCO_3$ grain density = 2.71 g/cm^3). The carbonate content of these sediments is quite high (Fig. 6B). At shallower depths, however, the grain density varies erratically. It appears that the chunk method used with lithified samples is more accurate and reliable than the cylinder technique which is employed for soft, easily deformable sediments.

The GRAPE porosity data are plotted versus depth in Figure 7A, where the GRAPE wet-bulk densities have been converted to porosities by assuming an average grain density of 2.691 g/cm^3. The results are averaged across each meter of depth, and these mean values are depicted by a solid line. The porosity profile of Hole 591 coincides well with that of the adjacent Holes 591A and 591B (Fig. 7B).

All of the acoustic velocity and shear strength measurements were made on split cores, parallel to bedding. The P-wave velocity results are plotted versus depth in Figure 7C. This information, when combined with the GRAPE porosity profile, yields a relationship between compressional velocity and porosity (Fig. 7D). A sharp increase in this property is observed as the sediment porosity approaches 53%.

Similarly, shear strength is plotted versus depth in Figure 7E, where a sudden rise in its magnitude is seen to occur at approximately 250 m. At a depth of 290 m, lith-

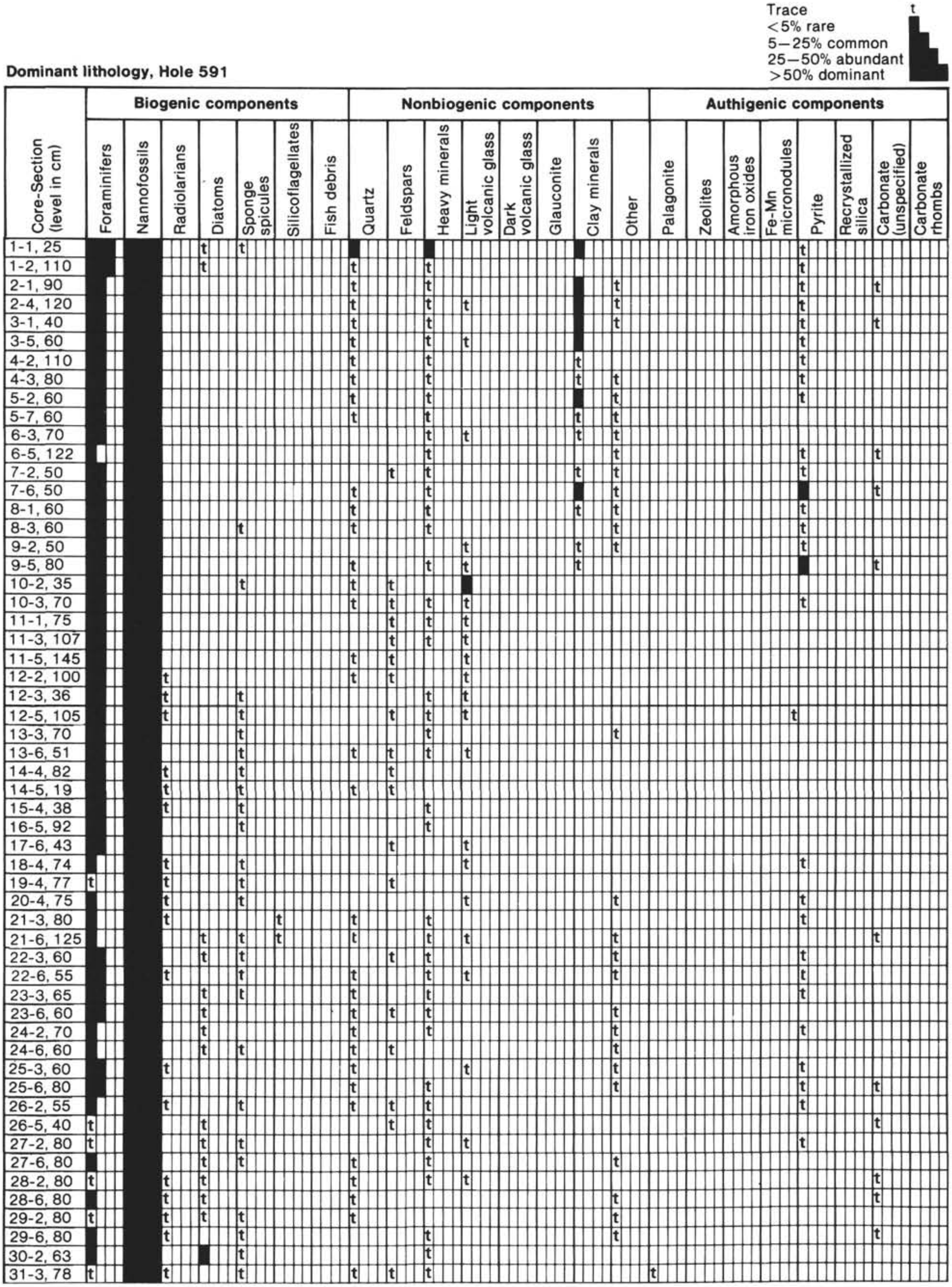

Figure 3. Smear slide summary, Site 591.

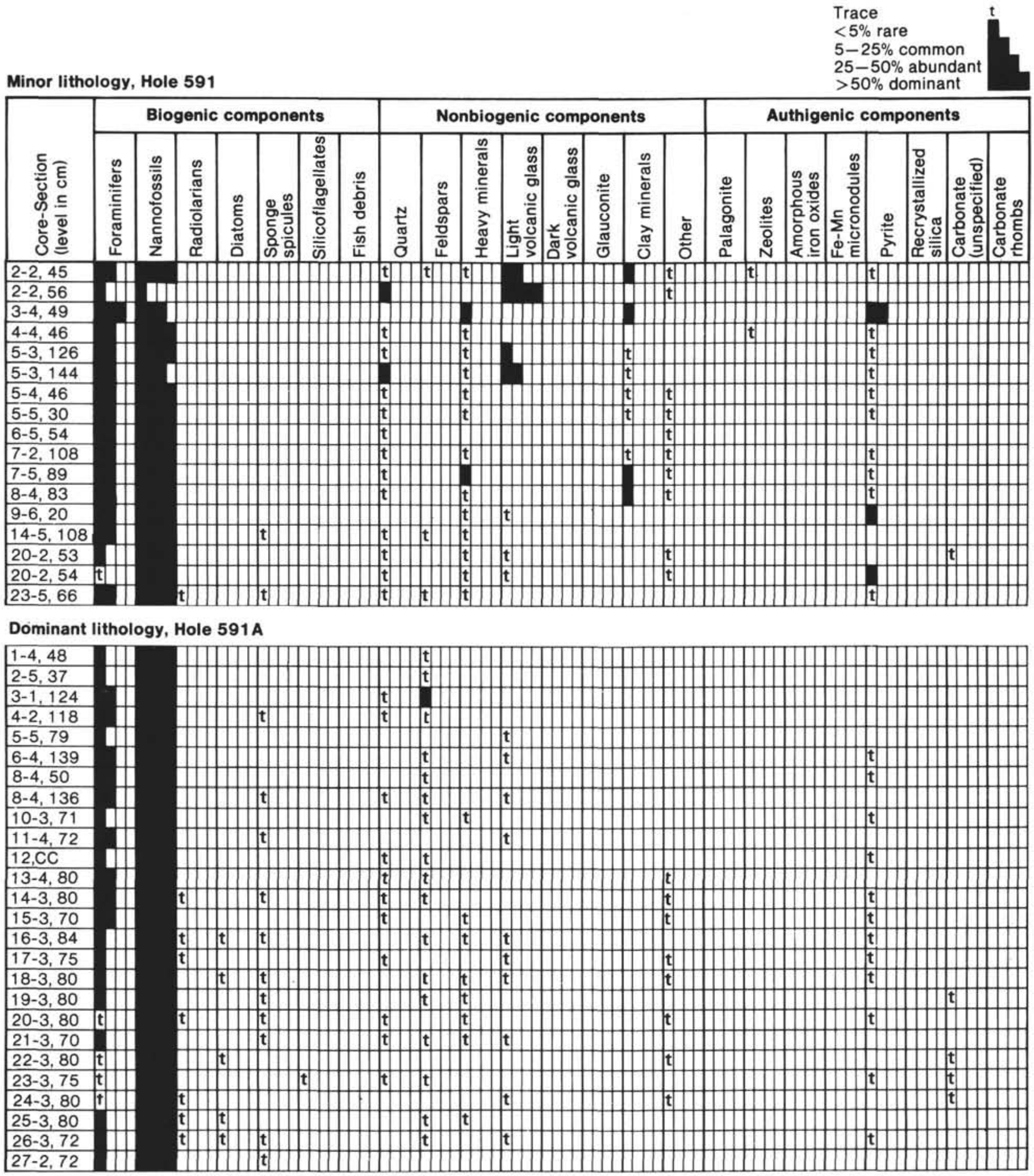

Figure 3. (Continued).

ification prevents further testing as the shear strength progresses beyond the range of the Wykeham-Farrance vane device. These data depict the same behavior as that described by the acoustic velocity results of Figure 7D. The shear strength increases dramatically as a declining porosity approaches 53% (Fig. 7F).

A relationship between acoustic impedance and depth can be established by combining the compressional velocity results with the GRAPE wet-bulk density profile (Fig. 7G). A more detailed presentation and analysis of the physical properties results for Site 591 is reported by Morin (this volume).

SEISMIC STRATIGRAPHY

Figure 8 illustrates a portion of the shipboard water gun seismic profile collected during the approach to Site 591. Five acoustic units have been identified (A–E), equivalent to the regional acoustic units of Willcox et al.,

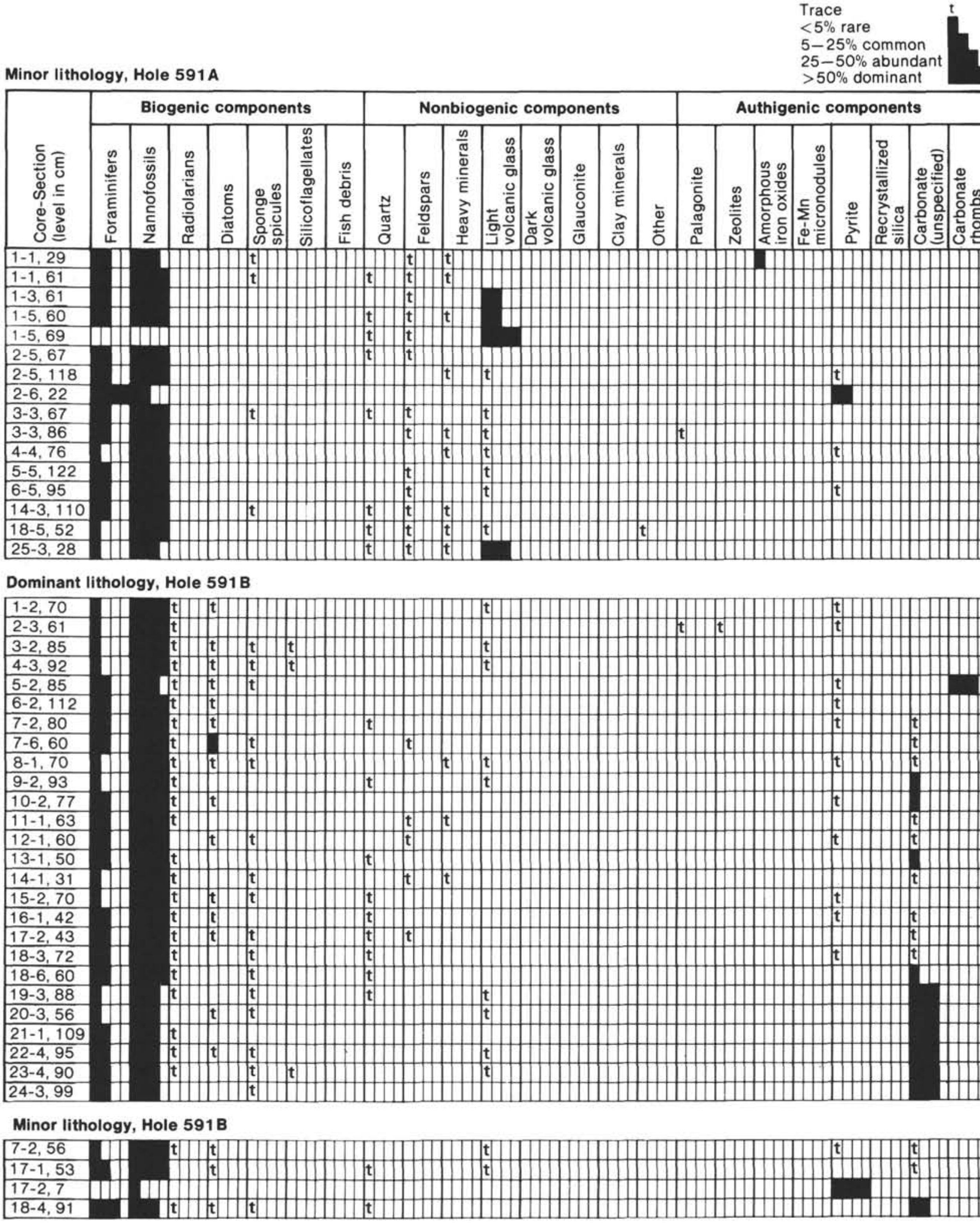

Figure 3. (Continued).

1980. These are correlated in part with the lithology of the site (lithostratigraphic Subunits IA, IB, and IC).

The five acoustic units are identical to those described in the Seismic Stratigraphy section for Site 590, with the exception that Unit E at Site 591 may represent acoustic basement, and not the graben-filling low-amplitude unit described earlier. Some obvious erosion has occurred immediately to the northwest of the site, with uppermost reflectors below the reflected wave form showing evidence of truncation. However the actual site locality, at a slightly shallower water depth, appears to overlie a relatively complete stratigraphic sequence.

Site 591 was drilled to a total depth of 500.4 m, through acoustic Unit A into acoustic Unit B. The sedimentary section comprises three lithostratigraphic subunits (IA, IB, and IC), ranging in age from Quaternary to latest early Miocene. Subunit IA is too thin to be shown on Figure 8. Lithologies range from foraminifer-bearing nannofossil ooze or nannofossil ooze to foraminifer-bearing nannofossil chalk, with the ooze/chalk boundary occurring at a sub-bottom depth of approximately 290 m.

The most significant observation from the data outlined above is the gradation from ooze to chalk, which occurs within the upper Miocene. This occurs approximately 40 m above the selected upper boundary of acoustic Unit B, assuming an interval velocity of 2000 m/s averaged from shipboard velocimeter measurements. The greater amplitudes observed near the top of acoustic Unit B are considered to be due at least in part to variations in the degree of induration of sediments observed within lithostratigraphic Unit IC.

BIOSTRATIGRAPHY

Site 591 was drilled with the objective of recovering a deep-water Neogene section that could be combined with those from Sites 590 (1299 m) and 206 (3196 m) to form a depth traverse through the three major bottom-water types in this area of the Tasman Sea. The planktonic biostratigraphies and faunas were expected to be very similar to those at Site 590, which is located only about 100 km to the west.

Three holes were cored at Site 591. Hole 591 contains 31 cores and includes sediments of Quaternary through late Miocene age. Hole 591A repeated the section at Hole 591. Hole 591B overlapped in part with the upper Miocene section at Hole 591, then recovered Miocene sediment down to the uppermost lower Miocene. The nannoplankton and planktonic foraminiferal zones are shown in Figure 9.

The planktonic foraminiferal faunas at Site 591 are well preserved through the Pliocene and upper Miocene; below that point preservation deteriorates rapidly and by the lower middle Miocene most forms are recrystallized. In the few lower Miocene cores, many species are barely recognizable because of recrystallization and cementation. The faunas are identical to those from nearby Site 590; however, three biostratigraphic zones not recognized at Site 590 were recovered at Site 591. These are the lower Pliocene *Globorotalia sphericomiozea* Zone, the *Orbulina suturalis* Zone, and the *Praeorbulina glomerosa curva* Zone of the early middle Miocene. The identification of these zones is attributed to the very high sedimentation rates at Site 591.

Calcareous nannoplankton were very abundant and were preserved throughout the section; however, their preservation was, in general, worse than at Site 590. Overgrowths occur in the Pliocene, and the Miocene discoasters are difficult to recognize. As with the foraminifers, preservation deteriorated rapidly toward the bottom of the hole. The biostratigraphy of the section was the same as at Site 590.

Benthic foraminiferal faunas are well preserved from the Quaternary through the upper Miocene, but below that faunas are impoverished; in the middle Miocene, recrystallization of the individuals increases and by the lower Miocene few if any forms could be recognized because of recrystallization and cementation. The benthic faunas contain many of the same species found at site 590; however, an indigenous element was recognized.

Radiolarians, diatoms, and silicoflagellates were found in most cores throughout the section; they were rare to common down to the lower middle Miocene.

Planktonic Foraminifers

Zones

The following zones were identified at Site 591; the zonal boundary markers are shown below:

Globorotalia truncatulinoides Zone
  L. A. *Globorotalia tosaensis*
Globorotalia truncatulinoides-G. tosaensis Zone
  I. A. *G. truncatulinoides*
Globorotalia tosaensis Zone
  I. A. *G. tosaensis*
Globorotalia inflata Zone
  I. A. *G. inflata*
Globorotalia crassaformis Zone
  I. A. *G. crassaformis*
Globorotalia puncticulata Zone
  I. A. *G. puncticulata*
Globorotalia sphericomiozea Zone
  L. A. *G. conomiozea*
Globorotalia conomiozea Zone
  I. A. *G. conomiozea*
Globigerina nepenthes Zone
  L. A. *Neogloboquadrina continuosa*
Neogloboquadrina continuosa Zone
  L. A. *Globorotalia mayeri*
Globorotalia mayeri Zone
  L. A. *G. peripheroacuta*
Globorotalia fohsi s.l. Zone
  I. A. *G. peripheroacuta*
Orbulina suturalis Zone
  I. A. *O. suturalis*
Praeorbulina glomerosa curva Zone
  I. A. *P. glomerosa*
Globorotalia miozea Zone

Faunas

The preservation of the abundant planktonic foraminiferal faunas was good down to the early late Miocene *N. continuosa* Zone, but in this zone and sporadically down through the middle Miocene into the lower Miocene the preservation deteriorated; this poor preservation is especially true for the lowermost middle Miocene and down into the lower Miocene.

As expected, the species content of the zones was almost identical to those at Site 590.

Benthic Foraminifers

Benthic foraminifers were examined from all core catchers from Holes 591 and 591B. Benthic faunas are well preserved in the Quaternary, Pliocene, and upper

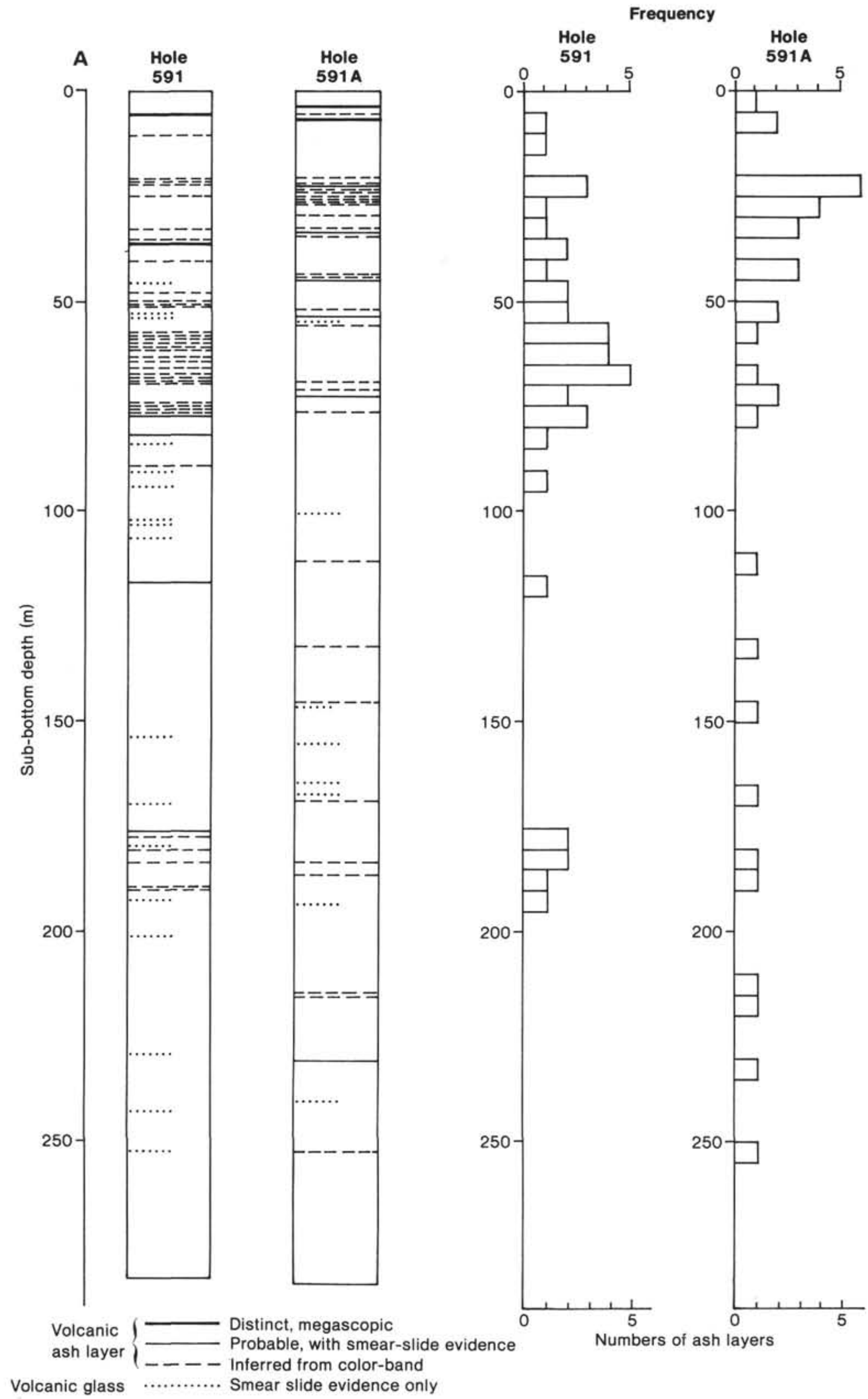

Figure 4. A. Horizons and histograms of distinct, megascopic volcanic ash layers (thick lines) and possibly devitrified ash layers (thin or broken lines) of Holes 591 and 591A are shown. Thickness of each layer is more than 1.0 cm and is typically several centimeters. Single, very thin laminae less than 1 mm thick are omitted. B. A compiled histogram showing the frequency of ash layers at Site 591, with careful correlation between Holes 591 and 591A. Because of relatively poor recovery in Hole 591B, a normalization is also shown as "ash-layer density" (m^{-1}), which is the averaged number of ash layers in every 10-m interval (Holes 591 and 591A) or in every core (Hole 591B).

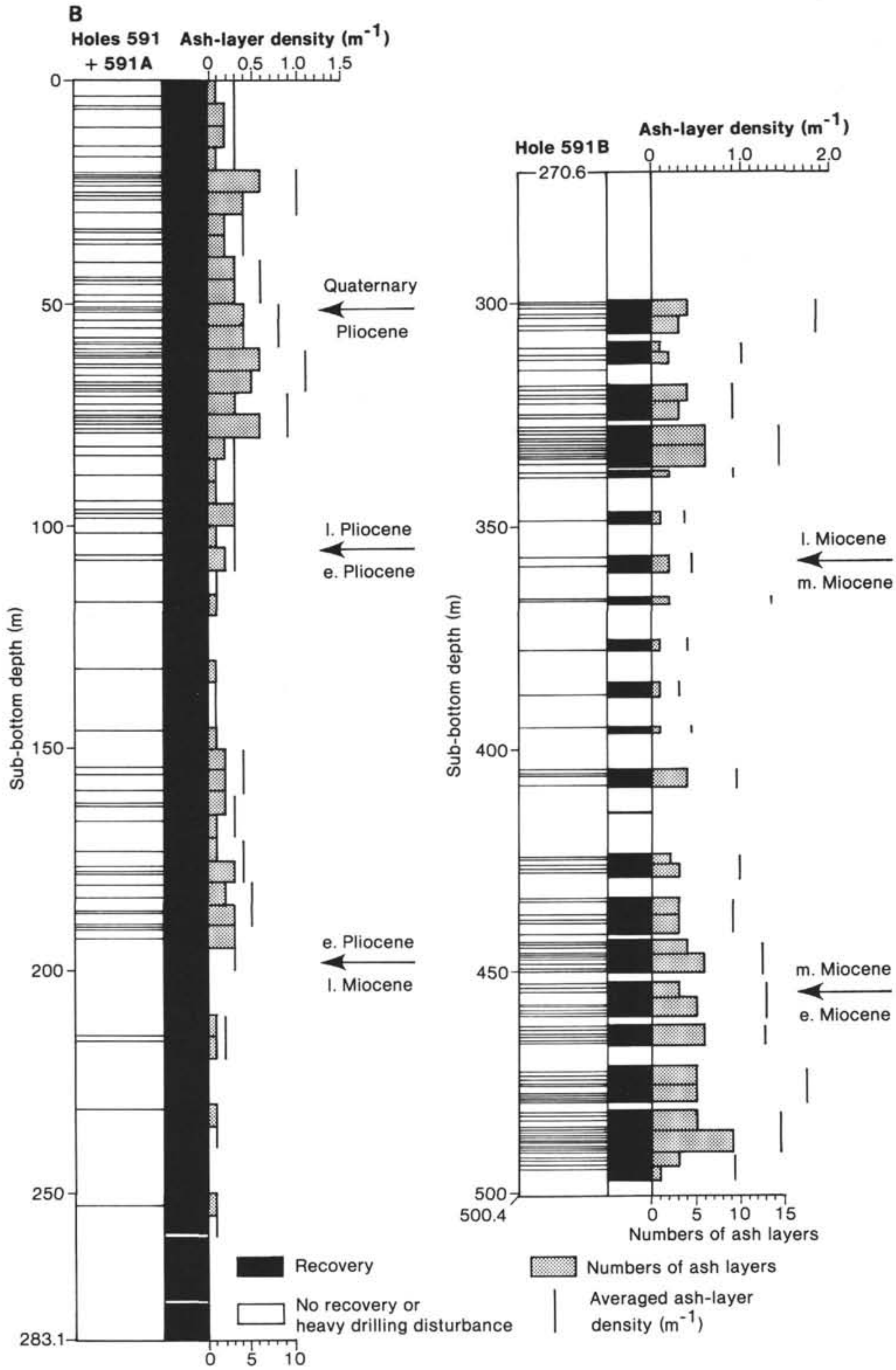

Figure 4. (Continued).

Miocene sediments; however, faunas are impoverished, and the preservation of several taxa deteriorates below the upper Miocene. Recrystallization was first noticed in the mid-middle Miocene; by the lower Miocene few if any individuals could be recognized because of the cementation of the carbonates.

Benthic faunas at Site 591 contain many of the same species found at the shallower Site 590, but did reveal an indigenous element consisting of several miliolid species, *Favocassidulina fava, Uvigerina pygmaea, Angulogerina angulosa*, and *Epistominella exigua.* The species that occurred very rarely at Site 591, including *Bolivinopsis*

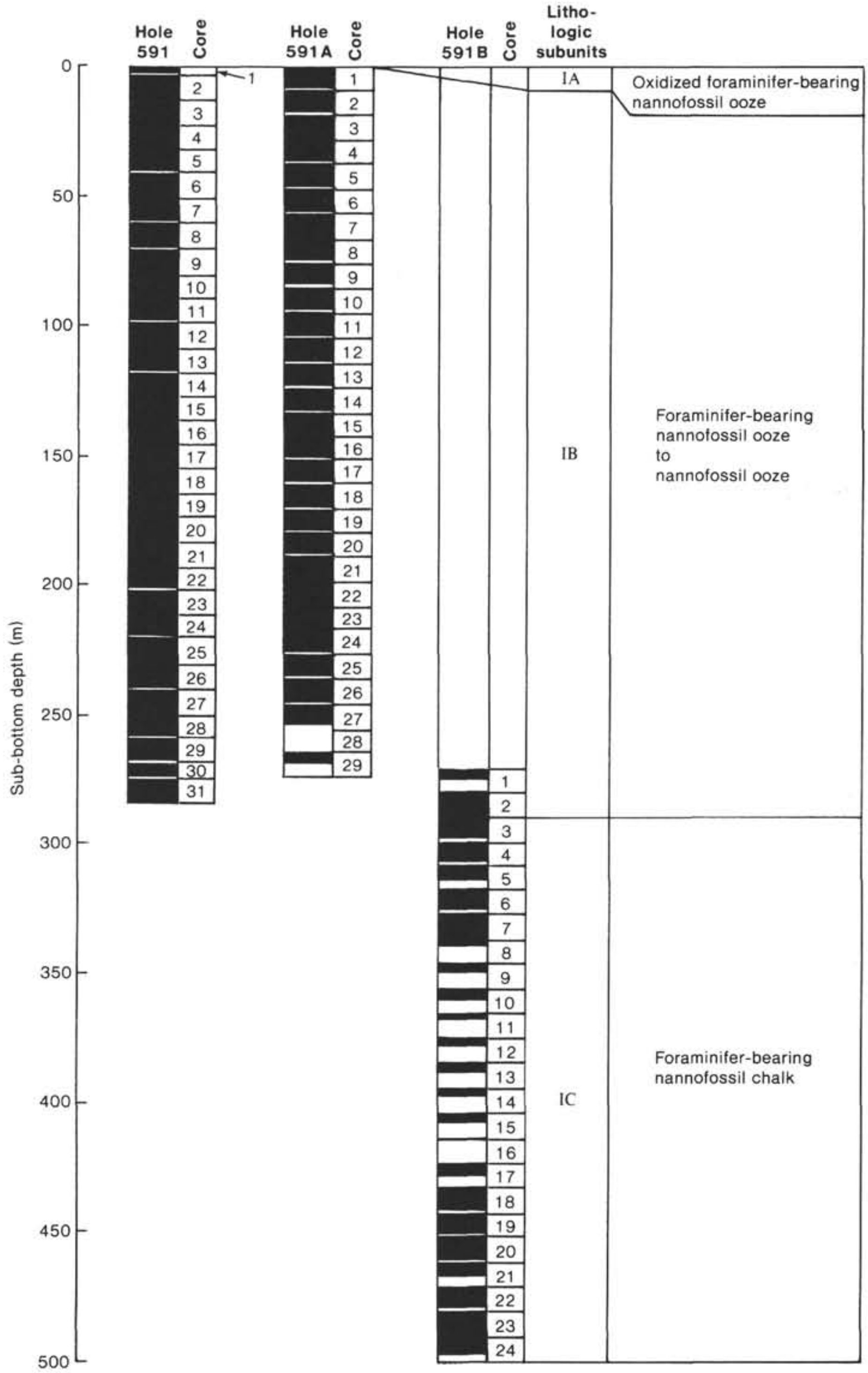

Figure 5. Lithostratigraphy of Site 591 (recovery in black).

praelonga, Pleurostomella alternans, Rectuvigerina multistriata, and *Cibicidoides rugosus*, to name only a few, were those which were common and typical of the shallower Site 590.

Because of the poor preservation, little could be derived from the lower to mid-middle Miocene faunas at Site 591 (591B-16 to 591B-24,CC). Species resistant to dissolution are the same as found at the other sites. *Cibicidoides tuxpamensis* does not range above the *Globorotalia fohsi* s.l. Zone as it does at other sites. The first increase in the size of faunas that is not attributable to the vagaries of preservation occurs in 591B-12,CC, in the *Globorotalia mayeri* Zone. The six new entrants appearing at this time are all also found in abundance in the Pliocene at Site 590, but are most typical and abundant at sites underlying upwellings.

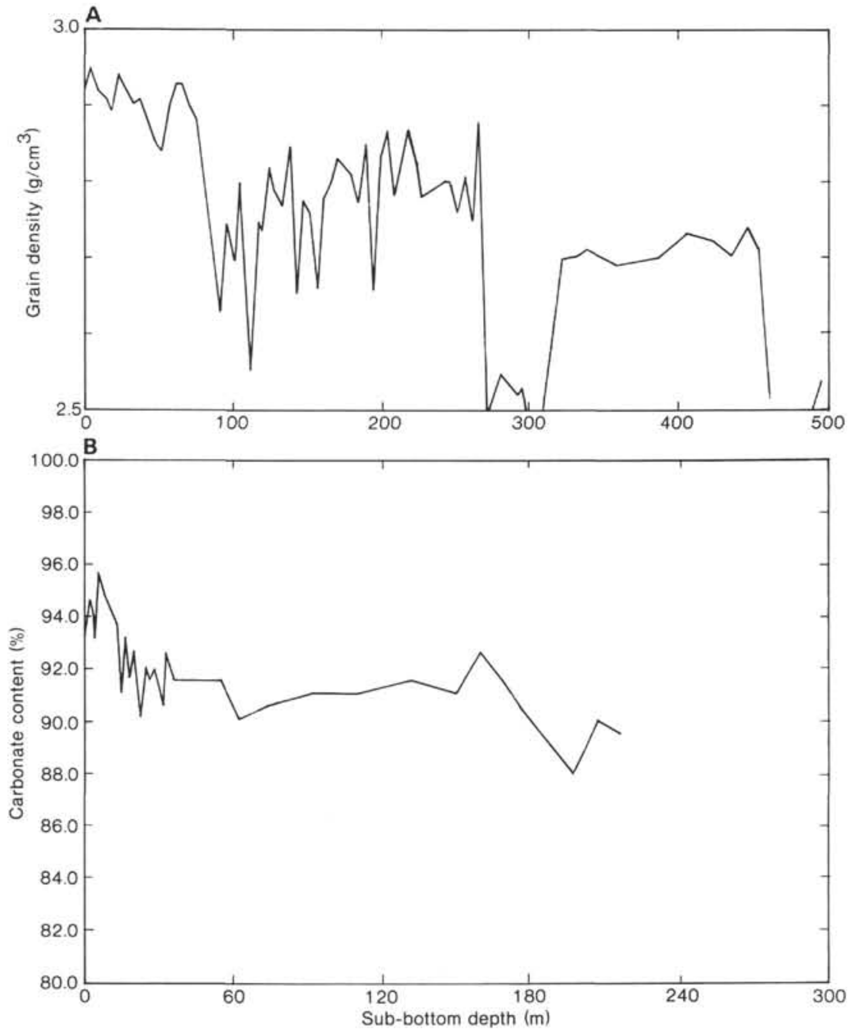

Figure 6. Grain density (A) and carbonate content (B) versus sub-bottom depth for Site 591.

At the base of the *Neogloboquadrina continuosa* Zone (591B-8,CC; 591-30 to 591-31,CC), large numbers of miliolid fragments and two species, *Pyrgo murrhina* and *Quinqueloculina seminulina*, occur for the first time. Faunas through the remainder of the Miocene are dominated by the miliolids and, in the *Globigerina nepenthes* Zone, by *Uvigerina hispido-costata*. This type of miliolid–uvigerinid fauna, including also *Melonis pompilioides* and several taxa more typical of Site 590, disappears at the top of the Miocene, but reappears in this area during the *Globorotalia tosaensis* Zone and continues into the Quaternary.

At the top of the Miocene (*Globorotalia conomiozea* Zone, 591-22,CC through 591-21) preservation deteriorates and the depleted benthic faunas contain only the most dissolution-resistant species and some miliolid fragments.

Lower Pliocene faunas (591-20,CC to 591-14) are well preserved and diverse; typical taxa include *Oridorsalis umbonatus, Heterolepa kullenbergi, P. murrhina*, and *Bulimina alazanensis*. The transition to the glacial fauna (*G. crassaformis/G. inflata*) shows a change in coarse-fraction content. Species changes include only the reintroduction of species already present in the Miocene at this site and variations in abundances of species common in the Pliocene. The miliolids decrease markedly in number through this interval.

The most obvious change in faunal content of the Pliocene occurs in the *G. tosaensis* Zone (591-10 to 591-9,CC) and in the *G. tosaensis–G. truncatulinoides* overlap interval (591-8 to 591-5,CC), when faunas again resemble those of the upper Miocene and include, as well, several species typical of shallower sites, such as *Anamalinoides globulosa, Cibicidoides pseudoungerianus, Cassidulina laevigata*, and *Pullenia quadriloba*.

Whereas most of the appearances/disappearances throughout this section are not considered to have been evolutionary events, it is interesting that the first appearance of *Uvigerina peregrina* occurs later at Site 591 (in the *G. puncticulata* Zone) than it did at the shallow Site 590, where it first occurs in the upper Miocene. This suggests that a form not generally associated in the Quaternary or Pliocene with intermediate waters first appeared at these shallower depths. The descent of uvigerinids from upper bathyal to deeper areas occurred several times during the history of the group.

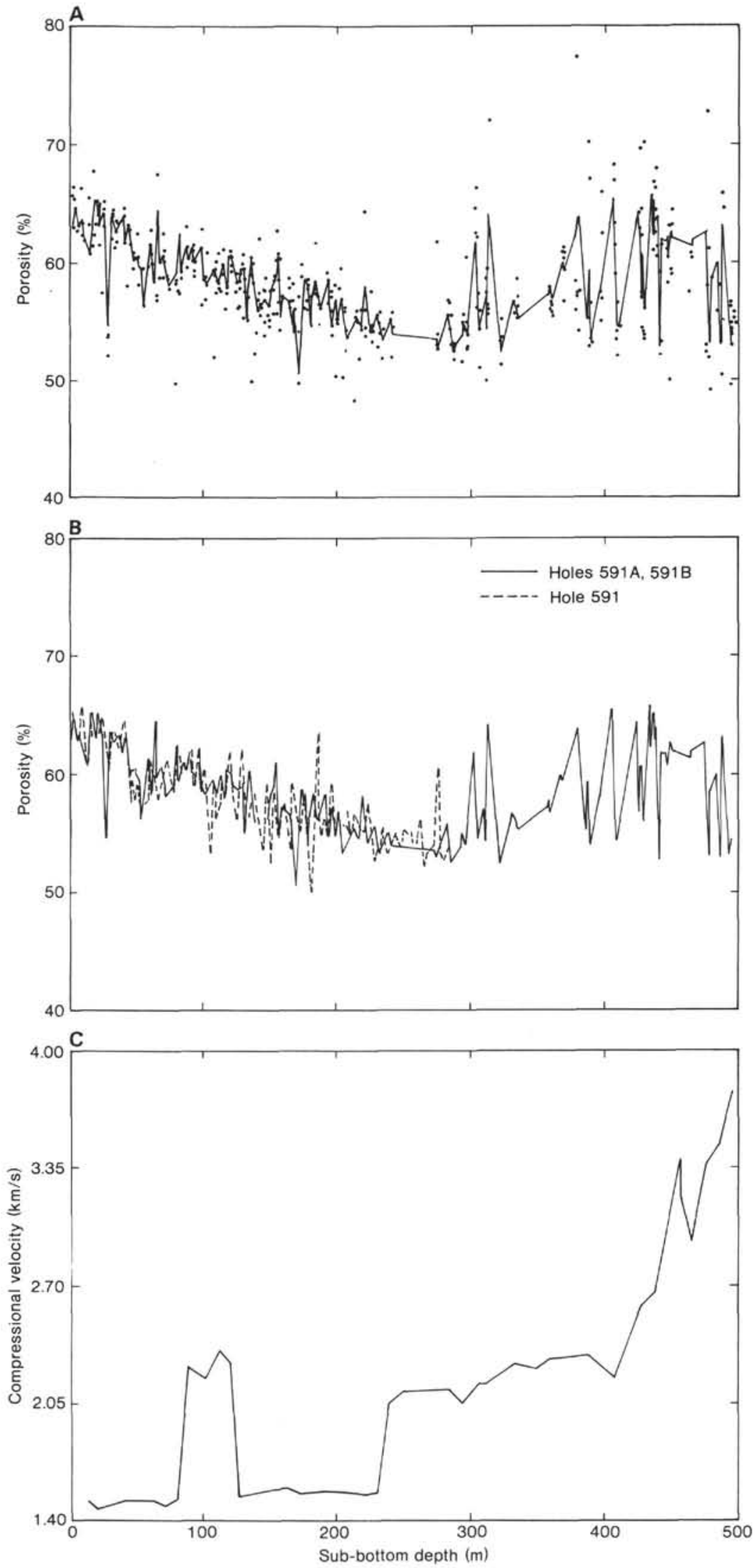

Figure 7. A. GRAPE porosity versus sub-bottom depth for Hole 591A. B. GRAPE porosity versus sub-bottom depth for Holes 591, 591A, and 591B. C. Compressional velocity versus sub-bottom depth for Site 591. D. Porosity versus compressional velocity for Hole 591A. E. Shear strength versus sub-bottom depth for Hole 591A. F. Porosity versus shear strength for Hole 591A. G. Acoustic impedance versus sub-bottom depth for Hole 591A.

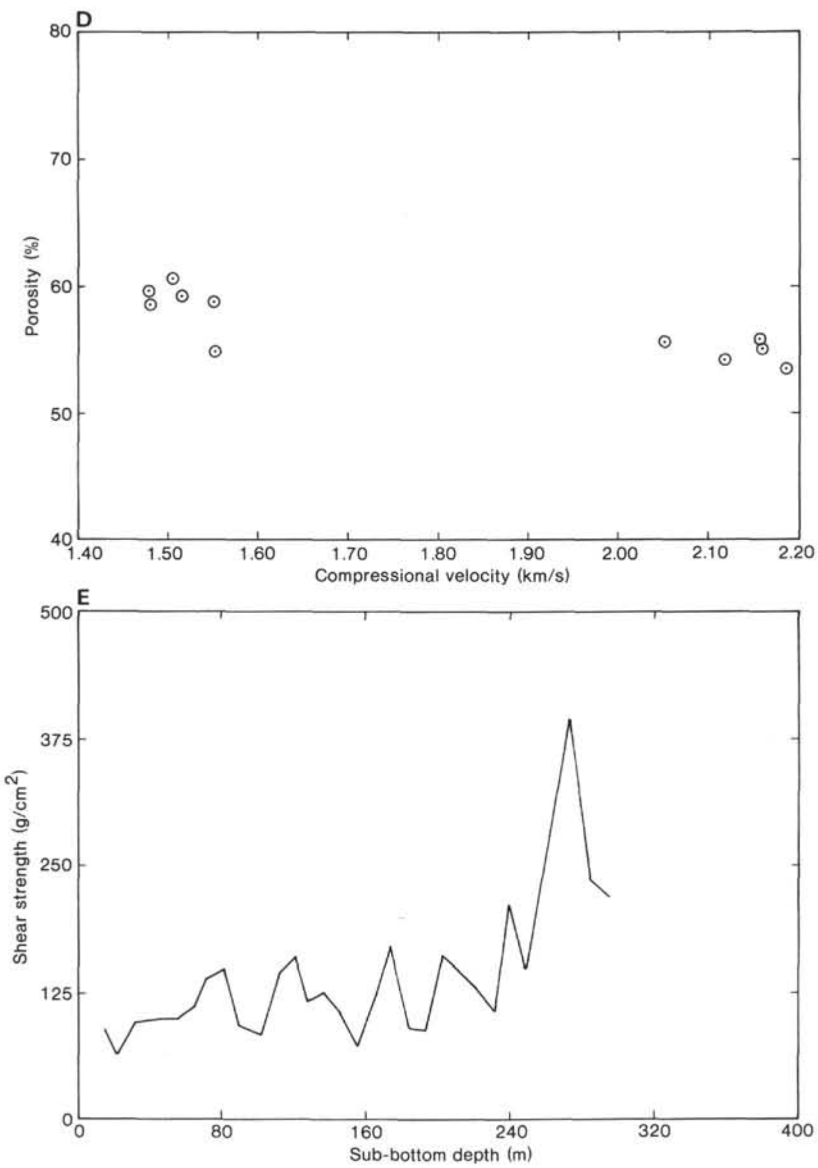

Figure 7. (Continued).

Calcareous Nannoplankton

Core-catcher samples along with sufficient additional samples to determine zonal boundaries accurately were examined for calcareous nannoplankton. All of the zonal indicators are present, with the exception of *Helicosphaera ampliaperta*. The upper boundary of the *Helicosphaera ampliaperta* Zone (NN4) is determined instead by the first occurrence of *Discoaster exilis*. Calcareous nannoplankton are abundant throughout the section at Site 591. Preservation is good in the Quaternary and Pliocene. In the Miocene, preservation deteriorates from moderate to poor, and in particular most of the discoasters are heavily overgrown.

Hole 591

Thirty-one cores were recovered from Hole 591, providing a complete nannoplankton zonation from late Quaternary to late Miocene.

Quaternary

Samples 591-1,CC to 591-2-3, 3–4 cm are placed in the late Pleistocene *Gephyrocapsa oceanica* Zone (NN20). Sample 591-2-5, 3–4 cm contains *Emiliania ovata* and is placed in the upper subzone of the early Pleistocene *Emiliania ovata* Zone (NN19b). The presence of *E. ovata* together with *Calcidiscus macintyrei* in Samples 591-5-5, 3–4 cm to 591-6,CC places these samples in the lower subzone of the *E. ovata* Zone (NN19a).

Pliocene

The presence of *Discoaster brouweri* in Samples 591-7-1, 3–4 cm to 591-8-1, 3–4 cm places these samples in the late Pliocene *Discoaster brouweri* Zone (NN18). The late Pliocene *D. pentaradiatus* Zone (NN17) is represented only by Sample 591-8-3, 3–4 cm, based on the last occurrence of *Discoaster pentaradiatus*. The late Pliocene *D. surculus* Zone (NN16) is located by the last oc-

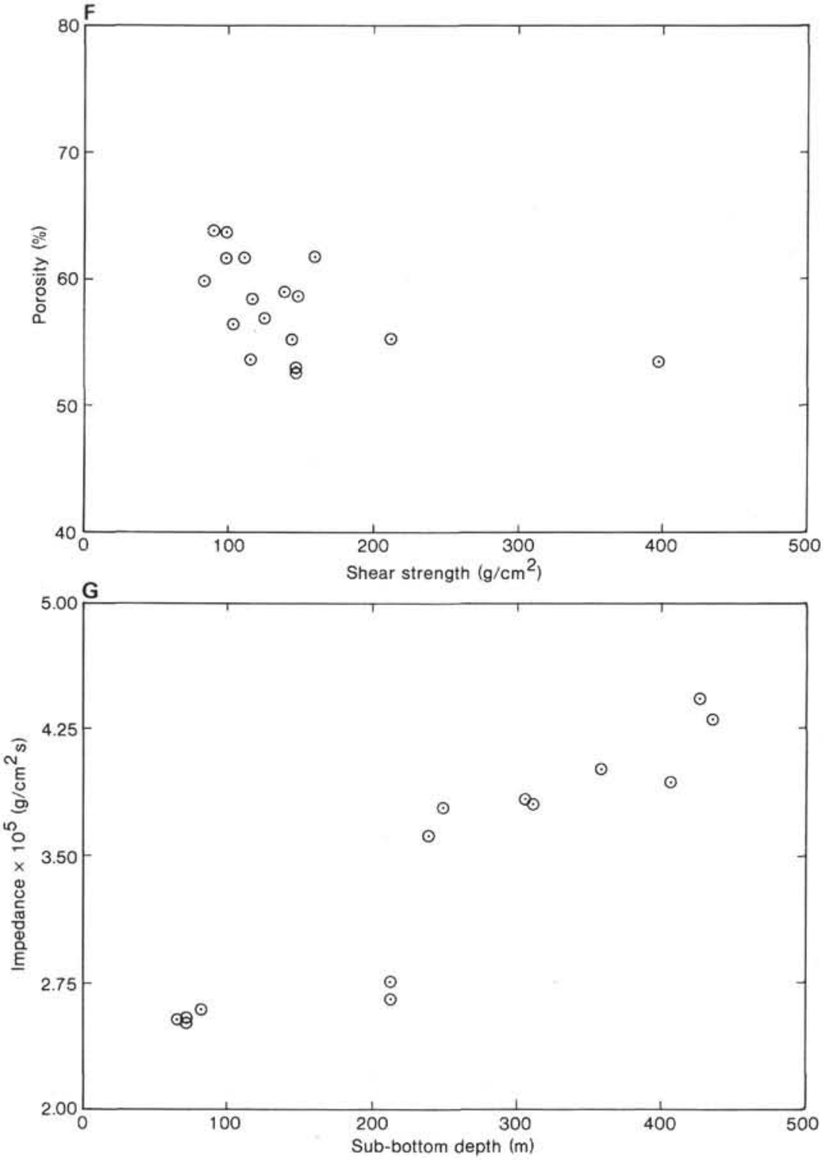

Figure 7. (Continued).

currence of *D. surculus* in Samples 591-8-5, 3–4 cm to 591-12-3, 3–4 cm, above the last occurrence of *Reticulofenestra pseudoumbilica*.

Samples 591-12-5, 3–4 cm to 591-16,CC above the last occurrence of *Amaurolithus tricorniculatus*, are placed in the early Pliocene *Reticulofenestra pseudoumbilica* Zone (NN15). The co-occurrence of *D. asymmetricus* and *A. tricorniculatus* in Samples 591-17-1, 21–22 cm to 591-20,CC places these samples in the early Pliocene *Discoaster asymmetricus* Zone (NN14). The first occurrence of *Ceratolithus rugosus* in Sample 591-21-5, 3–4 cm places this sample and the overlying Sample 591-21-1, 3–4 cm in the early Pliocene *Ceratolithus rugosus* Zone (NN13).

Miocene

Samples 591-24-3, 3–4 cm, the last occurrence of *D. quinqueramus*, to 591-28-3, 3–4 cm, the first occurrence of *A. primus*, are placed in the upepr subzone of the late Miocene *D. quinqueramus* Zone (NN11b). Samples 591-28-5, 3–4 cm to 591-31,CC, the deepest core at Hole 591, are placed in the lower subzone of the *Discoaster quinqueramus* Zone (NN11a).

Hole 591A

Only the 31 core-catcher samples from the hole were examined, because this hole duplicated the zonation of Hole 591.

Hole 591B

Miocene

The first occurrence of *D. quinqueramus* in Sample 591B-4,CC places Samples 591B-1,CC to 591-4,CC in the lower subzone of the late Miocene *Discoaster quinqueramus* Zone (NN11a). The interval from Samples

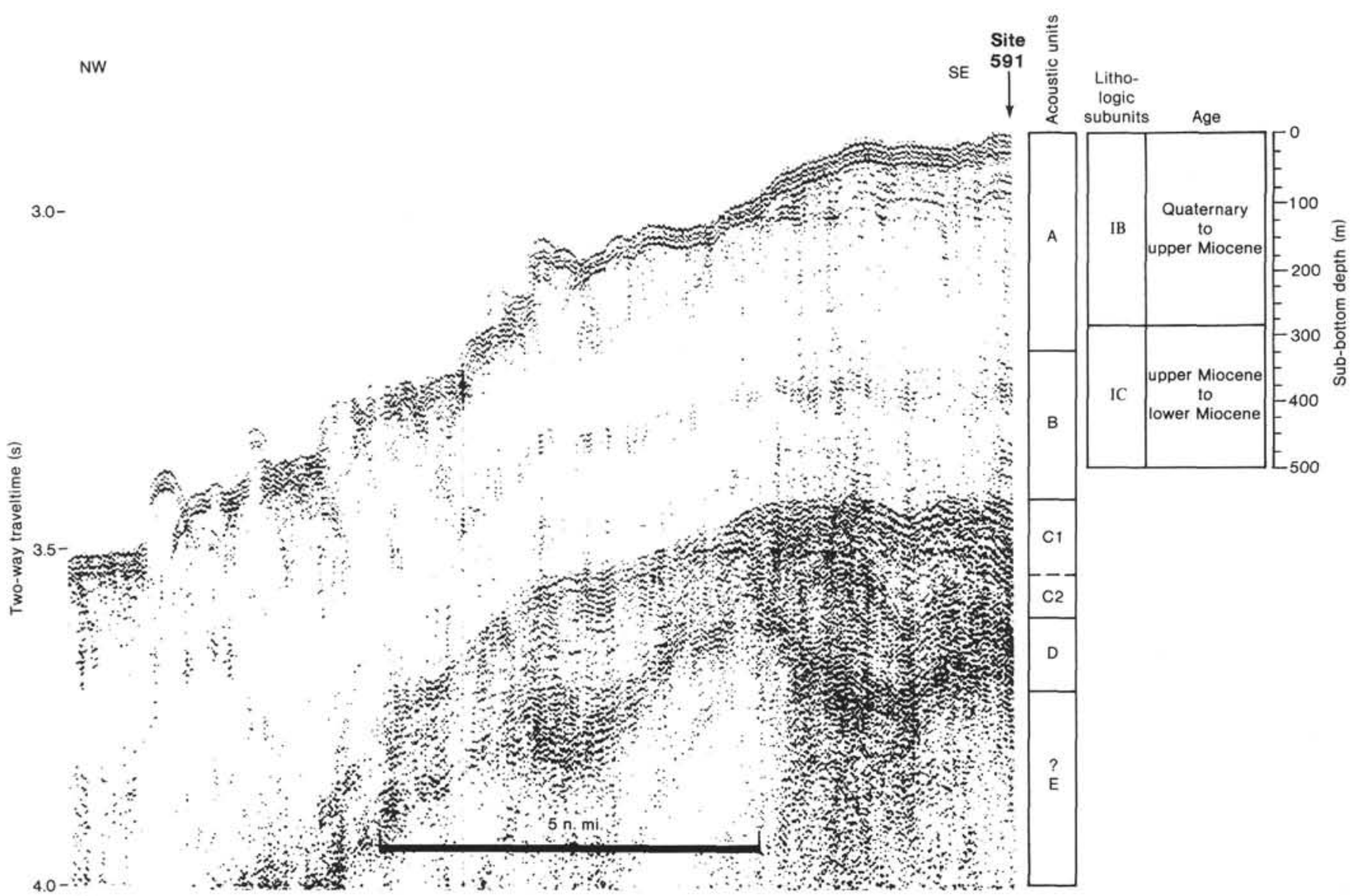

Figure 8. Comparison of acoustic units A–E with lithostratigraphic Subunits IA (not shown), IB, and IC cored at Site 591; shipboard water gun seismic profile, collected during site approach; depths in meters estimated by assuming a sediment sound velocity of 2000 m/s.

591B-5-1, 3–4 cm to 591B-9-2, 4–5 cm, above the last occurrence of *D. hamatus* in Sample 591B-9,CC, is placed in the late Miocene *D. calcaris* Zone (NN10). The range of *D. hamatus* in Samples 591B-9,CC to 591B-11-1, 4–5 cm places these samples in the middle Miocene *D. hamatus* Zone (NN9). Sample 591B-11,CC is placed in the middle Miocene *Catinaster coalitus* Zone (NN8). The interval from Samples 591B-12-1, 3–4 cm to 591B-12,CC, the first occurrence of *D. kugleri*, is placed in the middle Miocene *D. kugleri* Zone (NN7). The interval from Samples 591B-13-1, 3–4 cm to 591B-18-5, 3–4 cm, above the last occurrence of *Sphenolithus heteromorphus* in Sample 591B-18,CC, is placed in the middle Miocene *D. exilis* Zone (NN6). The presence of *S. heteromorphus* together with *D. exilis* in Samples 591B-18,CC to 591B-23,CC places these samples in the middle Miocene *Sphenolithus heteromorphus* Zone (NN5). Sample 591B-24,CC possibly belongs in the early Miocene *Helicosphaera ampliaperta* Zone (NN4).

Diatoms and Silicoflagellates

Diatoms and silicoflagellates occur in fair numbers throughout most of the section, but the occurrences are heavily masked by vast numbers of foraminifers and calcareous nannoplankton. Fragments of diatoms and silicoflagellates were noted in several routine smear slides from the late Pliocene down to the middle Miocene.

The residue of an acid-treated sample (591B-5,CC) of late Miocene age (nannoplankton Zone NN10) included representatives of the diatom genera *Hemidiscus, Thalassiosira*, and *Coscinodiscus*. The silicoflagellate assemblage of this particular sample is dominated by members of the *Dictyocha fibula* group (forms with horizontal apical bar) and *Distephanus polyactis*. Present also are *D. crux, D. speculum*, and *Mesocena circulus*. They are associated with sponge spicules and endoskeletal dinoflagellates.

Radiolarians

Fragments of radiolarians were found in smear slides from various levels, indicating the presence of this fossil group throughout most of the drilled section. In the residue of the acid-treated Sample 591B-5,CC radiolarians are rather common, but were not investigated in detail.

PALEOMAGNETISM

Preliminary NRM results were generally similar to those from previous sites. Sedimentation rates are somewhat higher than in nearby Site 590 and there was no evidence of a viscous component of magnetization. A magnetic polarity stratigraphy can be traced down to the end of the Gilbert Chron which is reproduced in the Hole 591A.

Hole 591 was subsampled at three specimens per section, Hole 591A at two specimens per section, and rota-

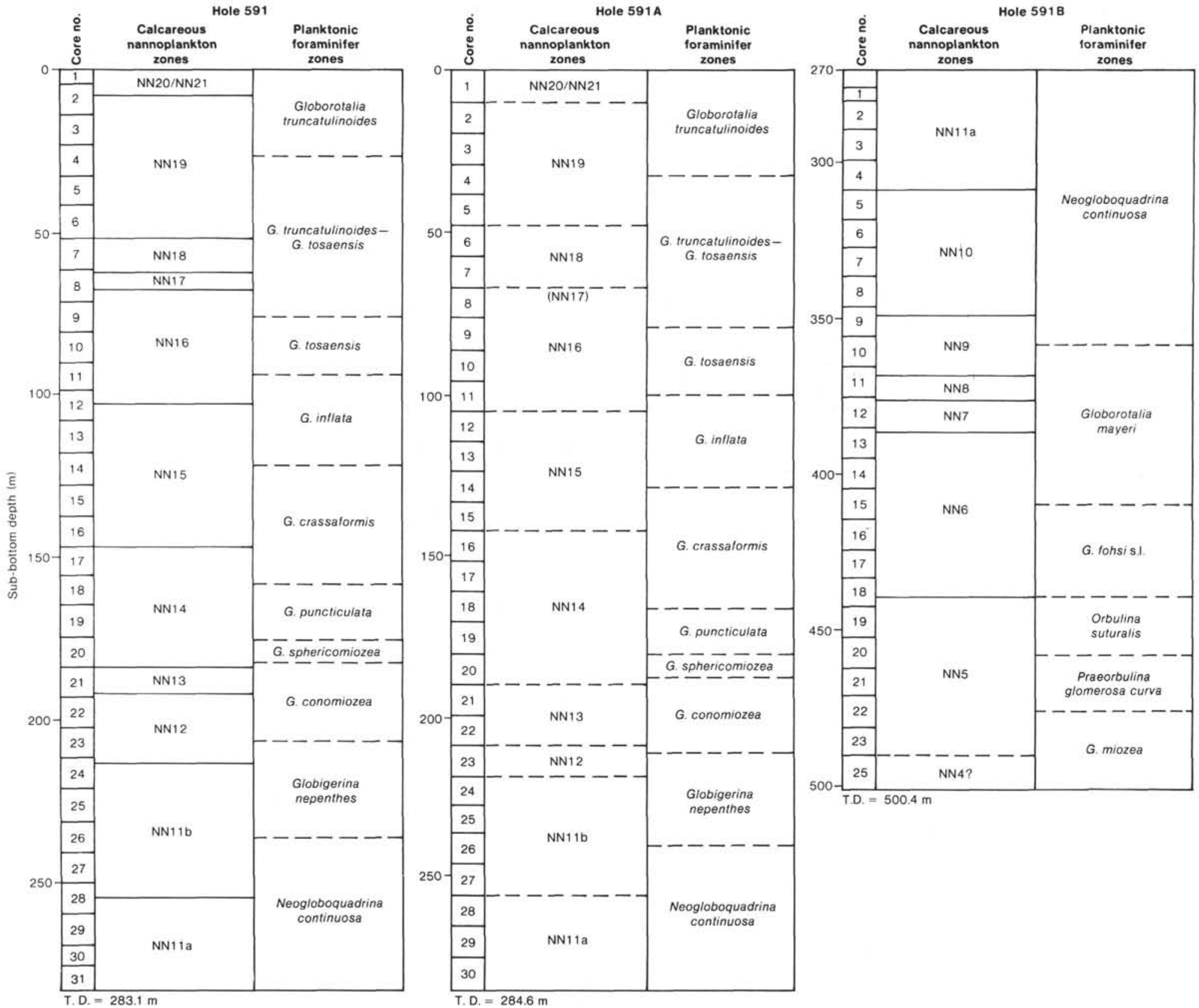

Figure 9. Correlation between calcareous nannoplankton and foraminifer zones in Hole 591, 591A, and 591B (radiolarians, though present in small numbers, were not investigated).

ry-drilled Hole 591B at one specimen per section. Apparent success rates with the Kuster orientation tool were 55 and 58% for Holes 591 and 591A. Laboratory NRM measurements have been completed on three specimens per section for the upper three cores from Holes 591 and 591A, and one specimen per section for the remaining cores from these two holes. The mean hole statistics are:

	Hole 591	Hole 591A
Geometric mean intensity (μG)	0.066	0.059
Scalar mean inclination ($\pm$1 s.d.)	$-9.1 \pm 43.7°$	$-7.2 \pm 44.0°$
Axial dipole inclination	-50.9	
Mean angle between repeats	6.1°	6.7°

The ubiquitous and surficial high-intensity zone (1 to 10 μG) is almost completely confined to the first core in each hole. From about 5–20 m sub-bottom depth intensities are typically 0.1 μG and thereafter remain consistently low (typically a few $\times$ 10^{-2} μG). There is a general trend toward lower intensity with increasing depth. High-intensity spikes noted in Hole 591 are listed in Table 2.

The quality of the paleomagnetic record deteriorates increasingly as a function of depth and cannot be interpreted in terms of polarities with any confidence below about 110 m sub-bottom depth (the upper part of the Gilbert Chron, about 3.5 m.y. ago). The polarity stratigraphy for Hole 591 (Fig. 10) is duplicated in the adjacent HPC Hole 591A.

To assess the magnetic stability of these sediments, partial AF demagnetization tests were run on seven specimens from Hole 591 (Table 3). More strongly magnetized specimens where chosen deliberately, because the weaker ones rapidly became immeasurable when demagnetized. The upper sediments which preserve a polarity record give stable directions in fields up to at least 400 Oe (40 mT) and median destructive fields in the range 215 to 310 Oe (21.5 to 31 mT). Lower in the section median destructive fields ranged from 120 to 155 Oe, and directional stability was poorer—consistent directions were observed up to peak AF's of about 200 Oe. There was no evidence for a soft viscous component in any of the specimens, which agrees with the fact that the mean inclination for the section does not have a significant negative bias. Without a more extensive study it is not possible to establish the scale of any chemical overprinting:

Table 2. High-intensity spikes at Site 591.

Sample (level in cm)	Depth (m)	Intensity (μG)
591-1-2, 80	2.30	7.419
591A-4-5, 40	34.80	2.371
591-8-1, 80	61.80	0.586
591-12-6, 75	107.65	0.597
591A-12-6, 40	113.10	0.248
591A-15-3, 40	136.50	0.234
591-16-4, 75	142.15	0.210
591-16-5, 75	143.65	0.273
591A-19-2, 40	172.40	0.369
591-20-3, 75	178.05	0.187
591A-20-1, 40	180.40	0.896
591A-24-3, 40	221.10	0.122
591-28-4, 75	255.55	0.168
591-28-5, 75	257.05	0.170

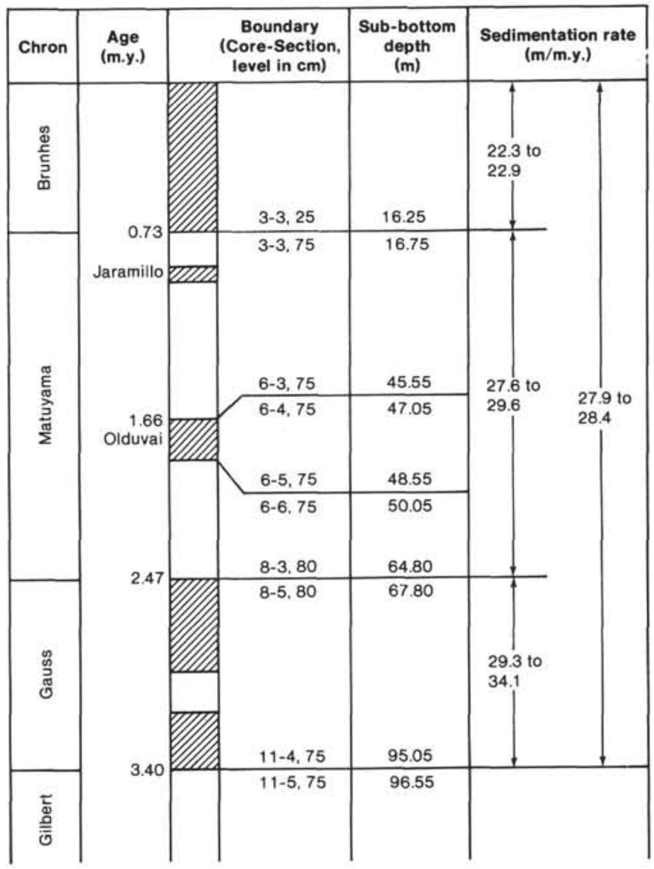

Figure 10. Magnetic polarity stratigraphy for the upper part of Hole 591.

Table 3. Summary of partial AF demagnetization results for Hole 591.

Core-Section (level in cm)	Depth (m)	J_o (μG)[a]	MDF (Oe)	AF stability range (Oe)	Inclination variation
1-1, 25	0.25	5.395	255	0–400	±5°
2-2, 125	6.15	1.544	310	0–400	±5°
3-1, 125	14.25	0.364	215	0–500	±6°
3-4, 75	18.25	0.191	120	0–200	±14°
				0–500	±24°
12-6, 75	107.65	0.424	120	0–150	±13°
20-3, 75	178.05	0.179	155	0–300	±6°
28-5, 75	257.05	0.165	135	0–500	±25°

Note: The range of demagnetizing field for a given range of inclination variation is shown in the last two columns.
[a] Initial NRM intensity.

the present indication is that the remanence is essentially single-component and sufficiently stable to preserve a record of polarity reversals. Since measurements on the very weakly magnetized material are reproducible, the scatter in the data cannot be attributed predominantly to instrumental noise.

SEDIMENTATION RATES

Sedimentation rates (Fig. 11) are based on calcareous nannoplankton boundaries and their absolute ages, as indicated in the Introduction. For better comparison, intervals taken for calculating the sedimentation rates are the same as for the previous sites.

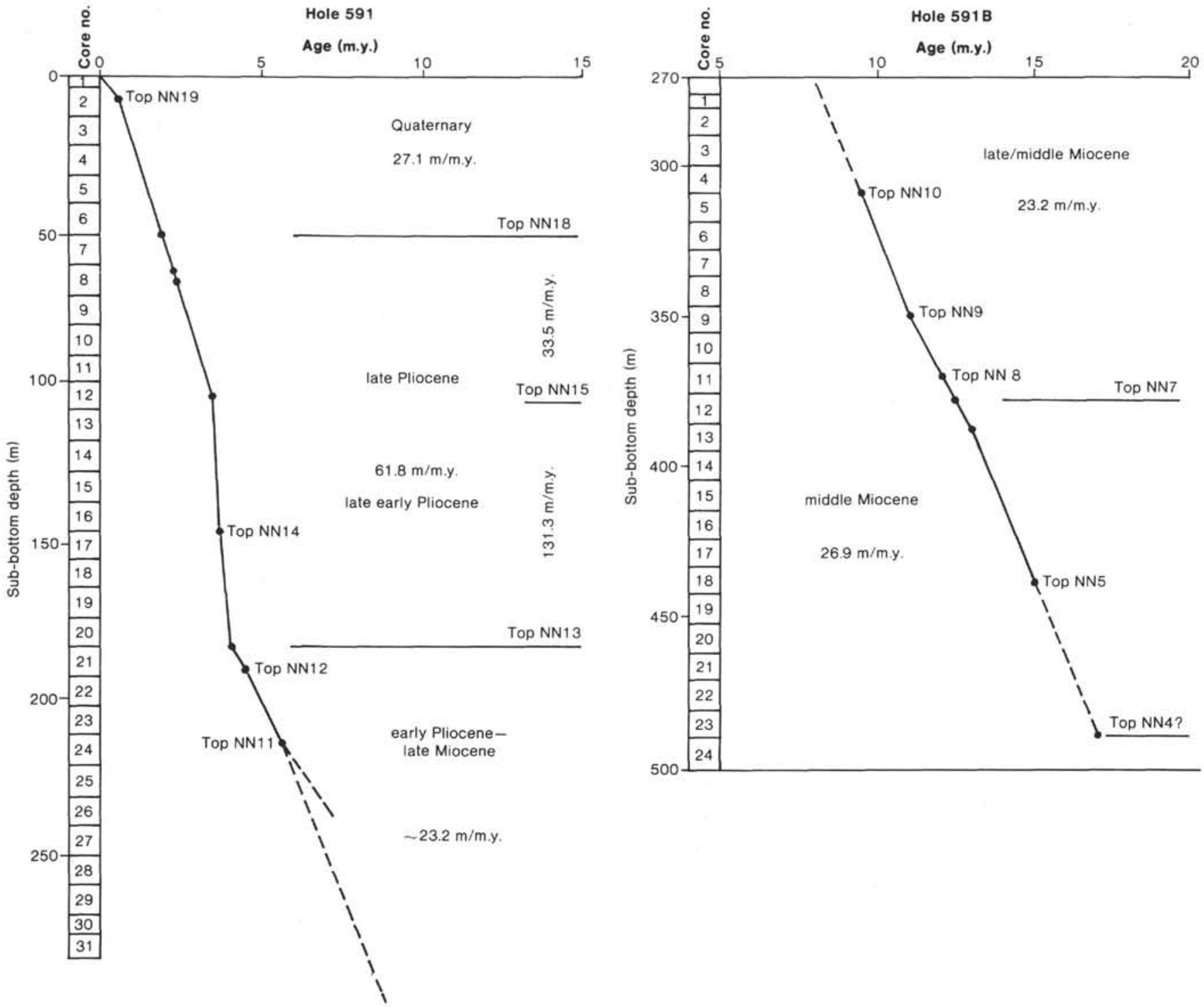

Figure 11. Sedimentation rates and datum levels in Holes 591 and 591B.

In the middle Miocene (Hole 591B, NN4 top to NN7 top), the sedimentation rate is based on four datum levels and is 26.9 m/m.y. for indurated calcareous sediments with minor siliceous constituents (Fig. 11B).

In the late middle Miocene to early Pliocene interval (Hole 591B, NN7 top, to Hole 591, NN13 top), the sedimentation rate is 23.2 m/m.y. and similar to that of the middle Miocene (Fig. 11A, B). This rate is based on seven datum levels.

Then a remarkable increase in the sedimentation rate occurs in the late early to late Pliocene, similar to that of Site 590. The sedimentation rate of calcareous sediments (foraminifer-bearing nannofossil ooze) for the entire interval between NN13 top and NN18 top in Hole 591 is 61.8 m/m.y., and is based on six datum levels. The strongest increase is found during deposition of Zones NN14 and NN15 (between 4.1 and 3.5 m.y. ago), where it increases to 131.3 m/m.y. In the late Pliocene (Hole 591, NN15 top to NN18 top), the sedimentation rate slows to 33.5 m/m.y. (Fig. 11A).

In the Quaternary (Hole 591, above NN18 top) the sedimentation rate drops further to a value of 27.1 m/m.y., which, however, is well above the 17.2 m/m.y. at Site 590.

SUMMARY AND CONCLUSIONS

Site 591 lies near the crest of a southern spur of the eastern part of the Lord Howe Rise at 31°35.06′S, 164°26.92′E and at a water depth of 2131 m. The spur extends outward into the New Caledonia Basin and is surrounded by turbidite fill to the east and south. The western edge of the spur is, in its norther part, separated from the main part of Lord Howe Rise by a valley that slopes southward, leading toward a ponded turbidite sequence which slopes toward the level of New Caledonia Basin. Thus the crest of the spur on which Site 591 is located is largely isolated from any influences of sediment transportation from the main part of Lord Howe Rise. The seismic profile exhibits a relatively simple transparent layer about 520 m thick above a distinct reflector which is considered to represent the regional unconformity associated with the Eocene/Oligocene boundary.

Site 591 was selected to provide a Neogene–late Paleogene stratigraphic succession at water depths intermediate (about 2200 m) between Site 590 (1299 m) and Site 206 (3196 m). A site at this intermediate depth was required to study changes in the vertical water mass structure of the southwest Pacific Ocean during the Neogene. These three sites, in combination, will provide an opportunity to carry out detailed studies of changes in the intermediate water masses between 1000 and 3000 m water depth. Site 591 is located midway between Sites 590 and 206, providing a compact suite of sites. Northward movement of the Indo-Australian Plate has carried Site 591 about 4–5° of latitude from about 35°S in the early Miocene to its present-day position near 31°30′S. Thus the Neogene sedimentary history at this site has been related in part to its northward movement away from the temperate region and the zone of westerly winds.

Site 591 consists of three holes: Hole 591 was continuously cored with the HPC from 0–283.1 m sub-bottom; Hole 591A was continuously cored with the HPC from 0–246.5 m and rotary cored with the XCB from 246.5–284.6 m; and Hole 591B was continuously cored using conventional rotary coring from 270.6–500.4 m sub-bottom. Cores recovered with the first HPC are relatively undisturbed; those using the second HPC are slightly more disturbed because of rough sea conditions. The cores recovered using conventional rotary coring exhibit mixed quality; quite disturbed in the upper part of the section although recovery was high; moderate recovery in the middle part of the sequence; and good quality cores with moderarte to low recovery rates in the lowest part of the sequence. The extended core barrel did not function successfully at this site.

The sequence is made up of one lithostratigraphic unit represented mostly by foraminifer-bearing nannofossil ooze or foraminifer-rich nannofossil ooze. Site 591 is a continuous sequence from the late early Miocene (17 m.y.) to the Quaternary. The HPC part of the sequence is complete from early late Miocene (11 m.y.) to the Quaternary. The biostratigraphy is complete with no apparent hiatuses. A paleomagnetic polarity stratigraphy has been identified down to the late Gilbert Chron (about 3.5 m.y.). Like Site 590, this site exhibits high sedimentation rates (uncorrected) ranging from 23 m/m.y. to 131 m/m.y.

Biosiliceous components are occasionally present in trace amounts, and exhibit slightly higher abundances in the early Miocene to early late Miocene. Siliceous components consist mainly of fragments of radiolarians, diatoms, and sponge spicules, and silicoflagellates appear in the latest Miocene (Cores 591-21 and 591A-23).

Nonbiogenic components comprise only a very small proportion of the sediment. Micritic carbonate significantly increases near the bottom of the section in the early and early middle Miocene. In the middle middle Miocene, trace quantities of clear volcanic glass occur throughout the sequence. Ash layers are present at certain intervals as well as very common light greenish gray laminae which possibly represent devitrified layers of volcanic ash. These laminae are commonly associated with underlying gray laminae of iron sulfides.

The sequence at Site 591 is divided into three subunits based on color, on the relative abundance of foraminifers and calcareous nannofossils and on the degree of lithification (Fig. 12).

Subunit IA extends from the seafloor to 0.62 m sub-bottom in Hole 591 and to 0.50 m in Hole 591A. This subunit is late(?) Quaternary in age. The sediment is yellowish gray to pale yellowish brown and consists of a foraminifer-bearing nannofossil ooze. Subunit IA corresponds to the zone of oxidation which was found in all of our sites.

Subunit IB extends from the base of the oxidized layer to 289.8 m sub-bottom (Quaternary to upper Miocene). The sediments, light gray in color, range from a foraminifer-bearing nannofossil ooze to a nannofossil ooze. Frequent greenish gray levels occur within this subunit, which contain slightly more foraminifers than the dominant light gray oozes.

Subunit IC extends from 289.8 m sub-bottom to the bottom of Hole 591B (500.4 m sub-bottom). This subunit is upper Miocene to lower Miocene in age. The sediments, very light gray to light greenish gray, range from a foraminifer-bearing nannofossil chalk to a nannofossil chalk. Clear recrystallization occurs below 300 m. Sediment becomes very hard and recrystallization is widespread below 452 m (earliest middle Miocene).

Diagenetic alteration of the microfossil sequence appears at Site 591 in younger sediments than at Site 590, because of the higher sedimentation rates at Site 591. Foraminifer recrystallization is already well advanced by the early middle Miocene, and calcareous nannofossils exhibit signs of overgrowths by the early Pliocene. The higher rates of sedimentation at Site 591 have allowed finer stratigraphic resolution than at Site 590. The planktonic faunas are identical to those from nearby Site 590; however, three biostratigraphic zones not recognized at Site 590 were recovered at Site 591. These are the early Pliocene *Globorotalia sphericomiozea* Zone, the *Orbulina suturalis* Zone of the early middle Miocene, and the *Praeorbulina glomerosa curva* Zone of the early Miocene. The presence of these relatively thin zones is attributed to very high sedimentation rates at Site 591.

Radiolarians, diatoms, and silicoflagellates were present but uncommon in most cores throughout the section. They are common in the coarse fractions of sediments younger than early middle Miocene. The greater water depth of Site 591 somehow favors the preservation of some of the siliceous biogenic fraction compared with the nearby, shallower-water Site 590, which has almost no siliceous biogenic components. A number of evolutionary sequences within the planktonic foraminifers are clearly exhibited in this expanded sequence which, in general, provides excellent opportunities for high-resolution microfossil and stable isotopic work, particularly in the well-preserved upper Miocene through Quaternary section.

Site 591 is intermediate in its vertical depth profile (2131 m) between Sites 590 and 206; thus the benthic foraminifers are of considerable interest. Benthic fora-

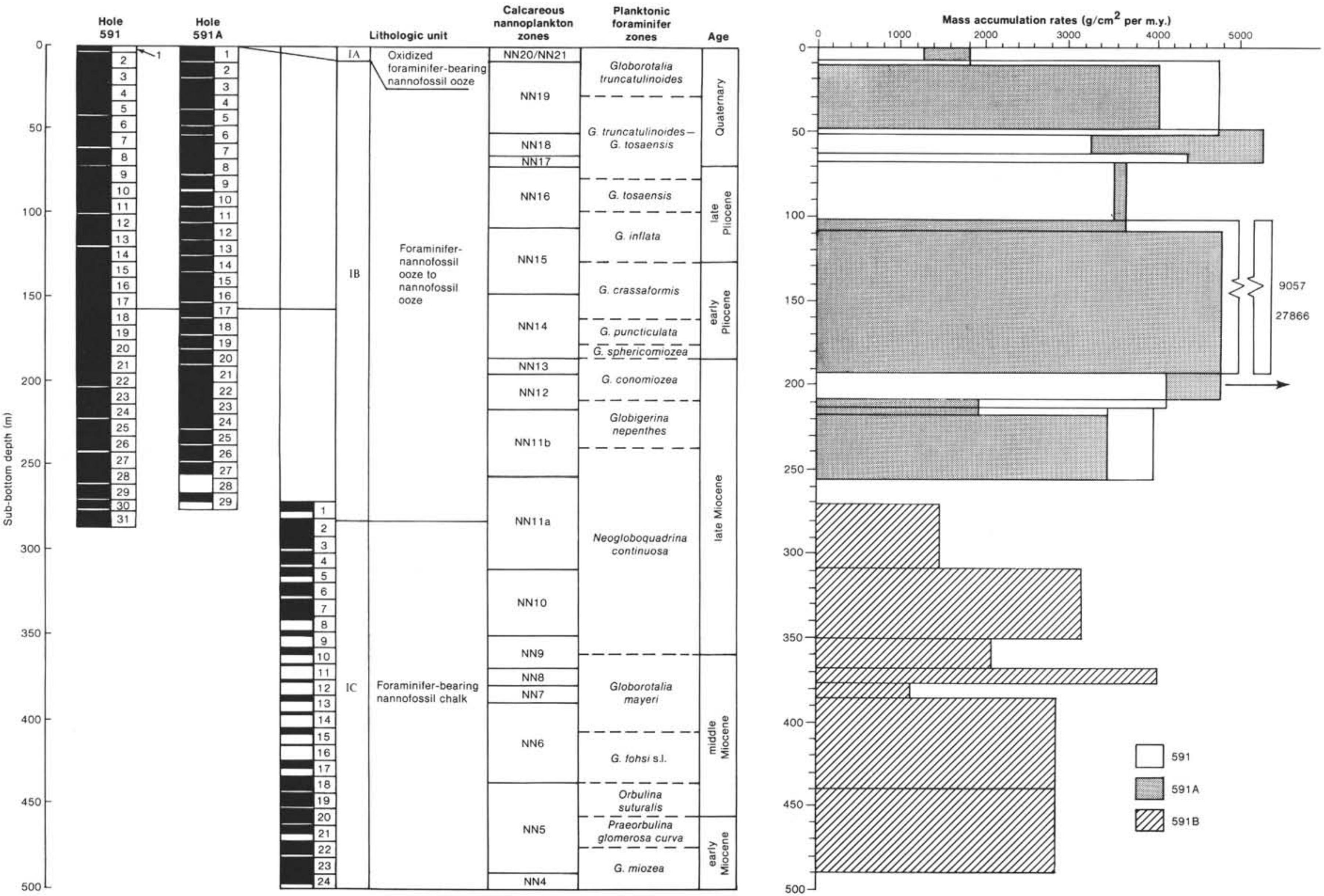

Figure 12. Summary lithology, biostratigraphy, and mass accumulation rates at Site 591 (recovery in black).

miniferal faunas are well preserved from the Quaternary through the late Miocene; earlier than that, faunas are impoverished; in the middle Miocene, recrystallization of the individuals increases and by the early Miocene few, if any, forms could be recognized because of the recrystallization and cementation. The benthic faunas contain many of the same species found at Site 590; however, some important differences reflect distinct paleoceanographic histories at these different water depths. The paleoceanographic changes include both upward and downward migration of some benthic foraminifers. Assemblages typical of upwelling zones appear in the middle Miocene.

Site 591 exhibits a valuable tephrochronology based on many layers and laminae which are inferred to be altered volcanic ash layers. These are compiled in Figure 4 for each of the three holes. Figure 4B shows a compilation for all Site 591 holes and also provides average ash layer densities per unit of core. These data clearly show that there have been a number of episodes of volcanic explosivity separated by more quiescent intervals. Intervals of more active volcanism are as follows: 17–14 m.y., latest early Miocene to middle Miocene; 10.5–9 m.y., early late Miocene; 5.4–4 m.y., latest Miocene to early Pliocene; 1.8–0.5 m.y., early to middle Quaternary.

Middle Miocene volcanic explosivity may be more extensive, but this is difficult to determine because of poor core recovery throughout this interval. The episodes of increased explosive volcanicity are separated by periods of relative quiescence, which include much of the Pliocene and late Miocene. This history is similar to that compiled by Kennett et al. (1977) for the southwest Pacific region and is also similar to the trends exhibited in a global compilation.

Paleoenvironmental History of Site 591

The Neogene sediments at Site 591 were deposited in a paleoenvironmental setting similar to that of nearby Site 590. Both of these sites exhibit similar stratigraphic records and paleoenvironmental histories. However, the greater water depth of Site 591 and its location upon an isolated spur of Lord Howe Rise have created a number of important paleoceanographic differences, especially in the intermediate waters.

During the late early to middle Miocene, the site was located about 4 to 5° of latitude further south than its present-day position near 31°35′S. This would have placed it within the zone of westerly winds and in temperate latitudes, a reconstruction which is supported by the distinctly temperate planktonic foraminifer assemblages in the early Neogene. Foraminifer-bearing nannofossil oozes were laid down during this time interval as well as in the early late Miocene. During the early middle to early late Miocene, siliceous biogenic materials were preserved in the sequence, although they are fairly uncommon. At other times they are much less common. Their increased abundance during the interval must reflect decreased dissolution. Sedimentation rates were moderately high during the late early to middle Miocene, with values of between 23 and 27 m/m.y.

Explosive volcanicity seems to have been quite intense in the source region between 17 and 14 m.y. ago, judging from the large number of volcanic ash layers. This episode of increased volcanicity may have continued through the middle Miocene, but poor core recovery prevented comparable analysis.

During the late middle Miocene, a number of new benthic foraminiferal species appeared, heralding important changes in bottom waters at this site. These changes occurred later than the well-known earlier middle Miocene changes known from other areas (Woodruff et al., 1981) that have been linked to bottom-water changes that took place during the accumulation of the east Antarctic ice sheet.

During the early late Miocene, the mode of sedimentation changed to more pure nannofossil oozes, which lasted until the mid-early Pliocene. Rates of sedimentation remained much the same at about 23 m/m.y.

The benthic foraminifer assemblages show important changes in the early late Miocene when miliolids become more important. they showed further change during the latest Miocene, when the assemblage became dominated by dissolution-resistant forms. This low-diversity assemblage heralds further important changes in the character of the bottom waters; it is associated with increased global glaciation. This represents the time of the Messinian "salinity crisis" of the Mediterranean Basin. The latest Miocene planktonic foraminiferal assemblages at Site 591 are typically cool, as they are also at Site 590. More foraminifer-rich sediments were laid down during a number of brief intervals during the latest Miocene, perhaps reflecting greater winnowing activity of bottom currents.

In this region the late Miocene is bracketed near the beginning and end with episodes of increased explosive volcanicity. These occur at about 10.5 to 9 and 5.4 to 4 m.y. ago, respectively. These episodes are separated by an especially quiescent period.

The beginning of the Pliocene is marked by a return of warmer-water planktonic foraminiferal assemblages. By the middle early Pliocene, sediment deposition again changed from rather pure nannofossil ooze to foraminifer-bearing nannofossil oozes. At the same time, there occurred a remarkable increase in sedimentation rates to 131 m/m.y. during the interval between 4 and 3.5 m.y. This increase almost certainly is created by an important increase in biogenic productivity. Explosive volcanic activity seem to have been relatively quiet during this interval, although the extremely high biogenic sedimentation rates may have masked any such activity.

During the late Pliocene, sedimentation rates decreased markedly to a still high rate of 33 m/m.y. This does not seem to coincide with any distinct change in the lithofacies. Explosive volcanism remained quiescent. As at all other sites, the benthic foraminiferal assemblages at Site 591 changed during the late Pliocene, when forms were reintroduced that had occurred through the Miocene. The earliest of these events were associated with global climatic changes about 3 m.y. ago related to major global climate cooling. Further and more important changes occurred later in the late Pliocene, probably in response to the initiation of Northern Hemisphere ice-sheet formation.

By the Quaternary, rates of sedimentation had further decreased to 27 m/m.y. Explosive volcanic activity was further renewed at this site in the Quaternary, as in many other circum-Pacific area.

As at other sites cored during Leg 90, the youngest sediments form an oxidized veneer at and close to the ocean floor.

The sedimentation rates calculated for Site 591 are mostly rather normal for carbonate biogenic oozes in shallow waters. The Pliocene rates of 131 m/m.y. are, however, extremely high and unexpected. High rates (57 m/m.y.) also mark the Pliocene of Site 590. We consider that these high rates are due to high productivity of calcareous biogenic material, a phenomenon now known in the late Neogene at three sites in this area (590, 591, and 206). It is possible that increased biogenic productivity is related to the poorly known Subtropical Divergence that crosses the Tasman Sea at the latitude of these three sites. Rates are much lower at the sites drilled to the north of Lord Howe Rise (Site 588) and to the south (Site 592). However, high rates have also been repeated for the Pliocene (early Pliocene, 40 m/m.y.; late Pliocene, 51 m/m.y.) of Site 289 on the Ontong-Java Plateau (Andrews, Packham, et al., 1975). We have now dismissed the possibility that the high sedimentation rates in the Pliocene are due to secondary reworking of material from elsewhere. This is due to the isolated location of Site 591 near the crest of a spur of Lord Howe Rise and to an absence of any clearly reworked material in the section.

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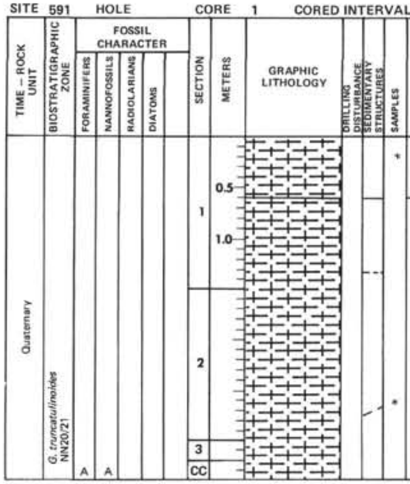
SITE 591 HOLE CORE 1 CORED INTERVAL 0.0–3.4 m



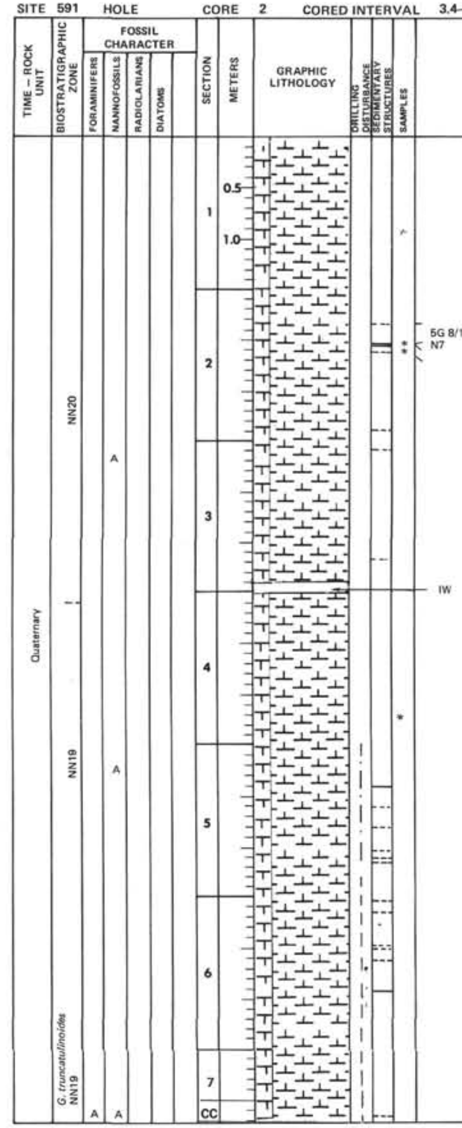
LITHOLOGIC DESCRIPTION

FORAMINIFER NANNOFOSSIL OOZE, yellowish gray (5Y 8/1, top 62 cm) and very light gray (N8), soft, with burrow mottles of moderate yellow green (5GY 7/4) spotted by iron sulfides of light gray (N6–N7).

SMEAR SLIDE SUMMARY:

	1, 25	2, 110
	D	D
Texture:		
Sand	C	R
Silt	C	A
Clay	D	D
Composition:		
Quartz	R	T
Heavy minerals	R	T
Clay	R	–
Pyrite	T	T
Foraminifers	A	A
Calc. nannofossils	D	D
Diatoms	T	T
Sponge spicules	T	–

SITE 591 HOLE CORE 2 CORED INTERVAL 3.4–13.0 m



LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8) to white (N9), soft, with light greenish gray (5GY 8/1) zone and double colored bands of greenish (5GY 8/1) and light (N7) gray.

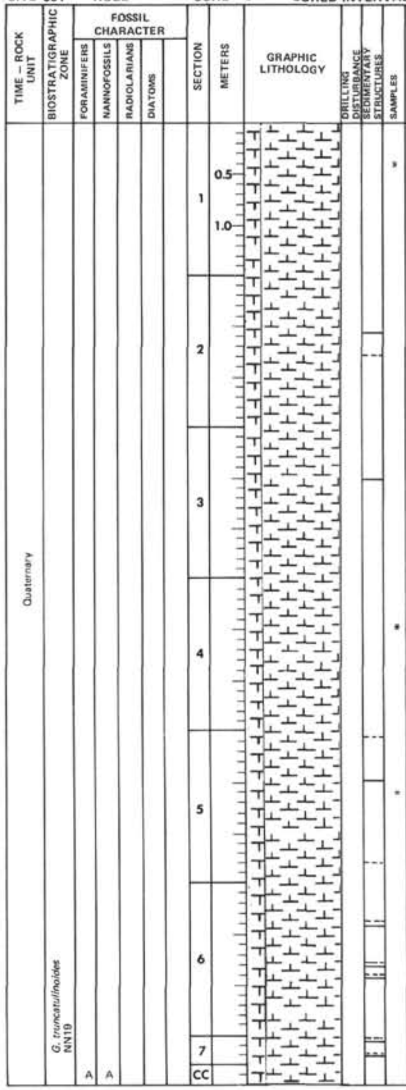
Ash layer (totally 25 cm in thickness) at about 55 cm of Section 2, clear, light gray (N7), 4 cm in thickness.

Light gray (N7) or light greenish gray (5GY 8/1) laminae occur in the lower part of the core (Sections 5, 6).

SMEAR SLIDE SUMMARY:

	1, 90	2, 45	2, 56	4, 120
	D	M	M	D
Texture:				
Sand	T	T	C	T
Silt	C	R	A	R
Clay	D	D	R	D
Composition:				
Quartz	T	T	R	T
Mica	T	T	T	T
Heavy minerals	T	T	–	T
Clay	R	R	–	R
Volcanic glass	–	C	D	T
Pyrite	T	T	–	T
Zeolite	–	T	–	–
Carbonate unspec.	T	–	–	–
Foraminifers	C	C	R	C
Calc. nannofossils	D	D	R	D

SITE 591 HOLE CORE 3 CORED INTERVAL 13.0–22.6 m



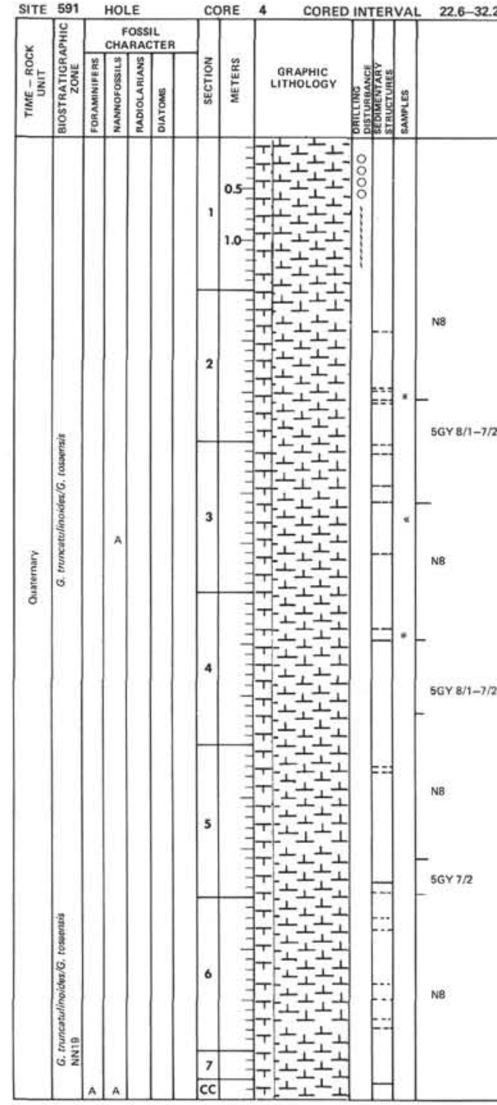
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, soft, very light gray (N8) predominant, with gray (N6–7) or grayish yellow green (5GY 7/2) burrow mottles. Two-tone colored laminae common in the lower sections. Dots and/or specks of iron sulfides.

SMEAR SLIDE SUMMARY:

	1, 40	4, 49	5, 60
	D	M	D
Texture:			
Sand	T	C	R
Silt	C	C	C
Clay	D	A	D
Composition:			
Quartz	T	–	T
Mica	T	–	–
Heavy minerals	T	R	T
Clay	R	R	R
Pyrite	T	C	T
Carbonate unspec.	T	–	–
Foraminifers	C	A	C
Calc. nannofossils	D	A	D

SITE 591 HOLE CORE 4 CORED INTERVAL 22.6–32.2 m



LITHOLOGIC DESCRIPTION

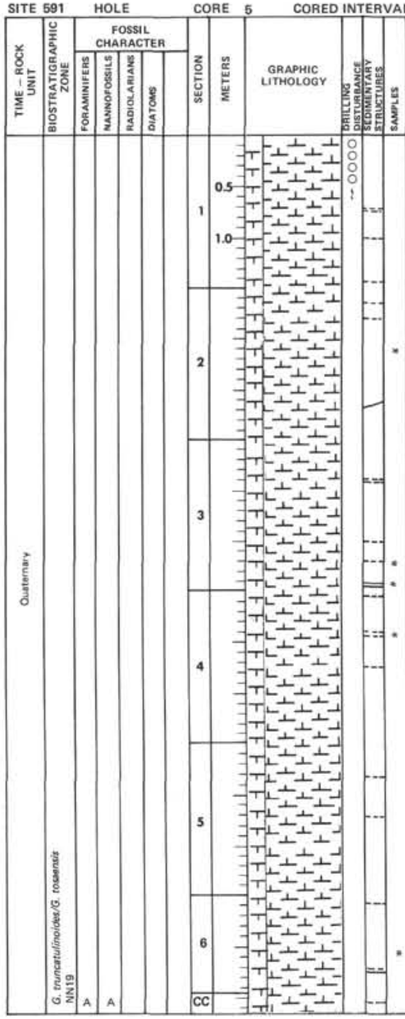
FORAMINIFER-BEARING NANNOFOSSIL OOZE, soft, color alternation of greenish gray (5GY 7/2–5GY 8/1) and very light gray (N8), no significant difference of composition between the two colors.

Commonly, mottles and specks of gray (N6–N7) and yellowish to greenish gray (5GY 7/2 to 5GY 8/1); dark gray (N4–6) iron sulfides dots and streaks.

SMEAR SLIDE SUMMARY:

	2, 110	3, 80	4, 46
	D	D	M
Texture:			
Sand	R	T	R
Silt	C	R	R
Clay	D	D	D
Composition:			
Quartz	T	T	T
Mica	–	T	–
Heavy minerals	T	T	T
Clay	T	T	–
Pyrite	T	T	T
Zeolite	–	–	T
Foraminifers	C	C	C
Calc. nannofossils	D	D	D

SITE 591 HOLE CORE 5 CORED INTERVAL 32.2–41.8 m



LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, predominantly very light gray (N8) and partly grayish yellow green (5GY 7/2), soft.

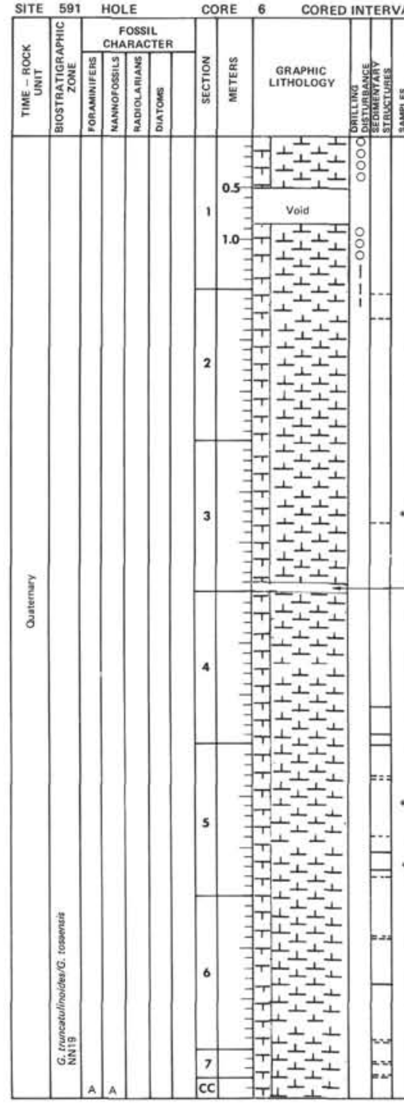
Two-tone colored bands of light gray (N7) and light greenish gray (5G 8/1) are common throughout.

Volcanic ash layer at the bottom of Section 3, clear dark greenish gray (5GY 6/2).

SMEAR SLIDE SUMMARY:

	2, 60	3, 126	3, 144	4, 46	6, 60
	D	M	M	M	D
Texture:					
Sand	R	R	C	T	T
Silt	R	R	C	R	C
Clay	D	D	A	D	D
Composition:					
Quartz	T	T	R	T	T
Mica	T	–	–	T	T
Heavy minerals	T	T	T	T	T
Clay	R	T	T	T	T
Volcanic glass	–	R	C	–	–
Pyrite	T	T	T	T	–
Foraminifers	C	C	C	C	C
Calc. nannofossils	D	D	A	D	D

SITE 591 HOLE CORE 6 CORED INTERVAL 41.8–51.4 m



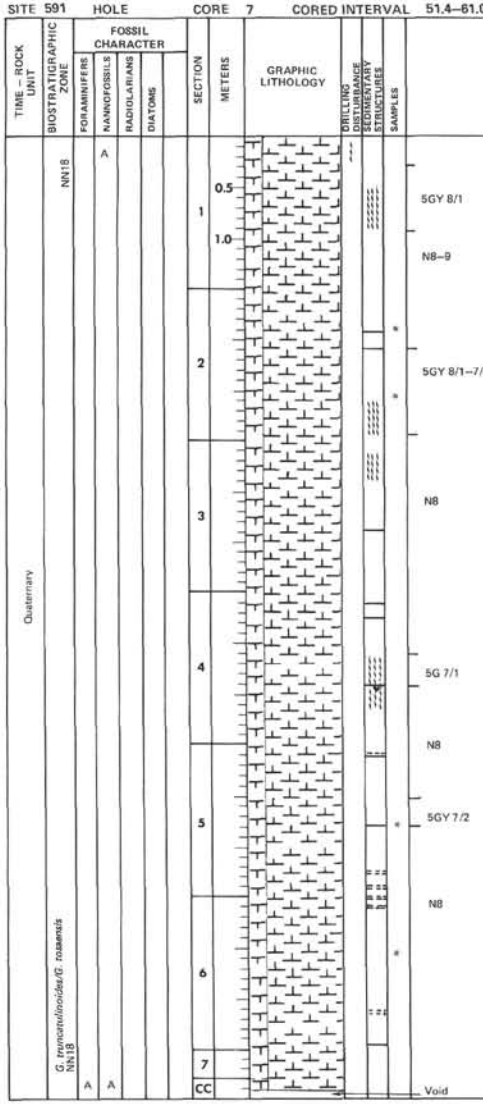
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, soft; color: alternation of predominant very light gray (N8) and light greenish gray (5GY 7/2–8/1) with numerous laminae, both lighter and darker; and with band, streaks and specks of iron sulfides of dark gray (N4–6).

SMEAR SLIDE SUMMARY:

	3, 70	5, 54	5, 122
	D	M	D
Texture:			
Sand	T	R	T
Silt	R	C	C
Clay	D	D	D
Composition:			
Quartz	–	T	–
Mica	T	T	T
Heavy minerals	T	–	T
Clay	T	–	–
Volcanic glass	T	–	–
Pyrite	–	–	T
Carbonate unspec.	–	–	T
Foraminifers	C	C	R
Calc. nannofossils	D	D	D

SITE 591 HOLE CORE 7 CORED INTERVAL 51.4–61.0 m



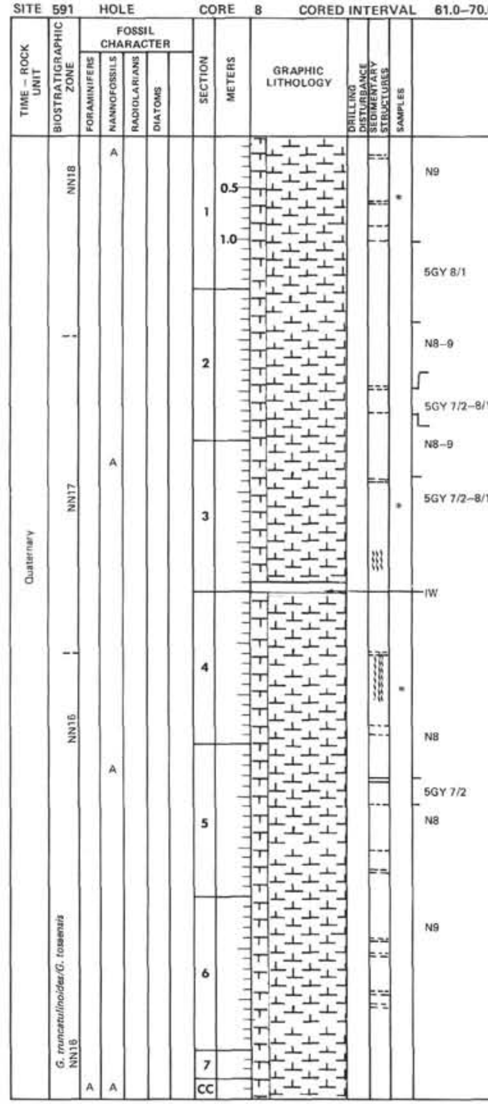
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, soft, predominantly very light gray (N8), but partially greenish gray (5GY 7/2–8/1) where bioturbation is present. Moderately bioturbated, especially at the middle of Section 4 (lots of mud chunks).

SMEAR SLIDE SUMMARY:

	2, 50	2, 108	5, 89	6, 50
	D	M	M	D
Texture:				
Sand	T	T	R	T
Silt	C	C	R	C
Clay	D	D	D	D
Composition:				
Quartz	–	T	T	T
Feldspar	T	–	–	–
Mica	T	T	T	T
Heavy minerals	T	T	R	T
Clay	T	T	R	R
Pyrite	T	T	T	R
Carbonate unspec.	–	–	–	T
Foraminifers	C	C	C	C
Calc. nannofossils	D	D	D	D

SITE 591 HOLE CORE 8 CORED INTERVAL 61.0–70.6 m



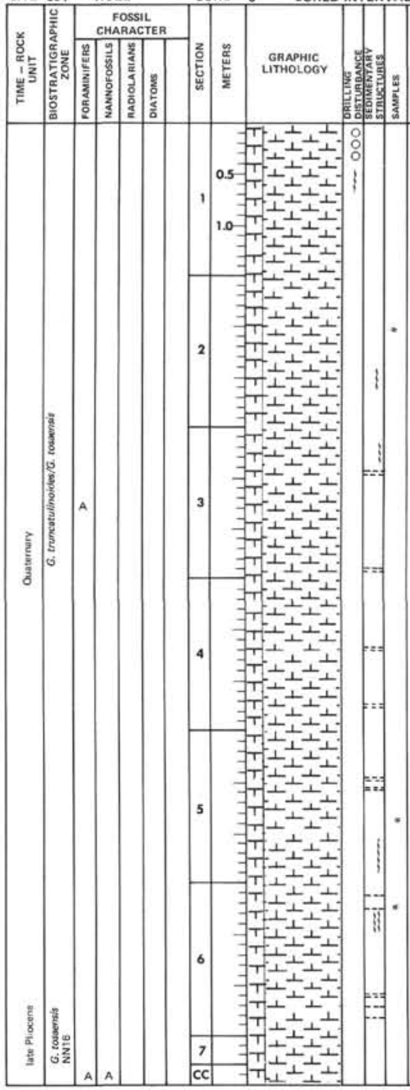
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, soft; color alternation of very light gray (N8–N9) and greenish gray (5GY 7/2–5GY 8/1); with burrow mottles and pyritized specks. Double colored laminae common.

SMEAR SLIDE SUMMARY:

	1, 60	3, 60	4, 83
	D	D	M
Texture:			
Sand	R	R	T
Silt	R	R	C
Clay	D	D	D
Composition:			
Quartz	T	T	T
Mica	T	T	T
Heavy minerals	T	T	T
Clay	T	–	R
Pyrite	T	T	T
Foraminifers	C	C	C
Calc. nannofossils	D	D	D
Sponge spicules	–	T	–

SITE 591 HOLE CORE 9 CORED INTERVAL 70.6–80.2 m



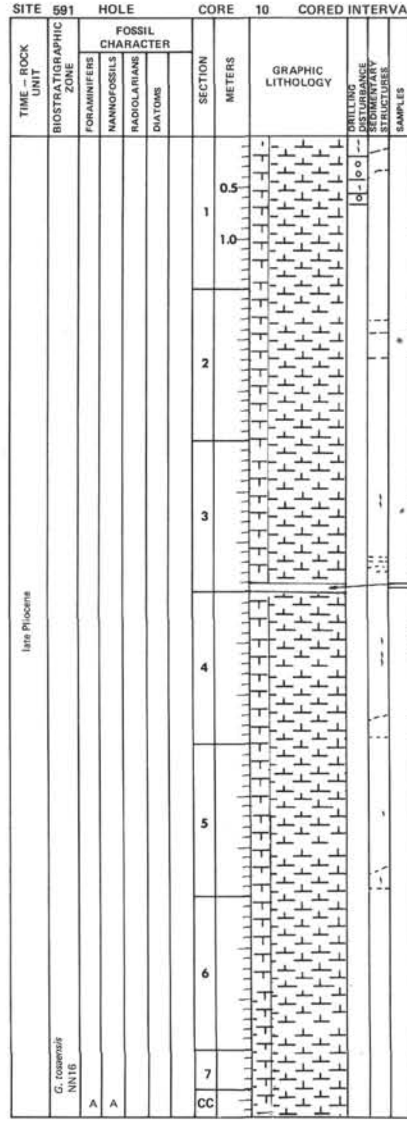
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8) to light greenish gray (5GY 8/1), soft, with burrow mottles (yellowish gray [5Y 8/1]) and several laminae of two-tone color of light greenish gray (5G 8/1) and light gray (N7). Pyritized specks common.

SMEAR SLIDE SUMMARY:

	2, 50	5, 80	6, 20
	D	D	M
Texture:			
Sand	R	R	R
Silt	C	C	R
Clay	D	D	D
Composition:			
Quartz	–	T	–
Mica	T	–	–
Heavy minerals	–	T	T
Clay	T	T	–
Volcanic glass	T	T	T
Pyrite	T	R	R
Carbonate unspec.	–	T	–
Foraminifers	C	C	C
Calc. nannofossils	D	D	D

SITE 591 HOLE CORE 10 CORED INTERVAL 80.2–89.8 m



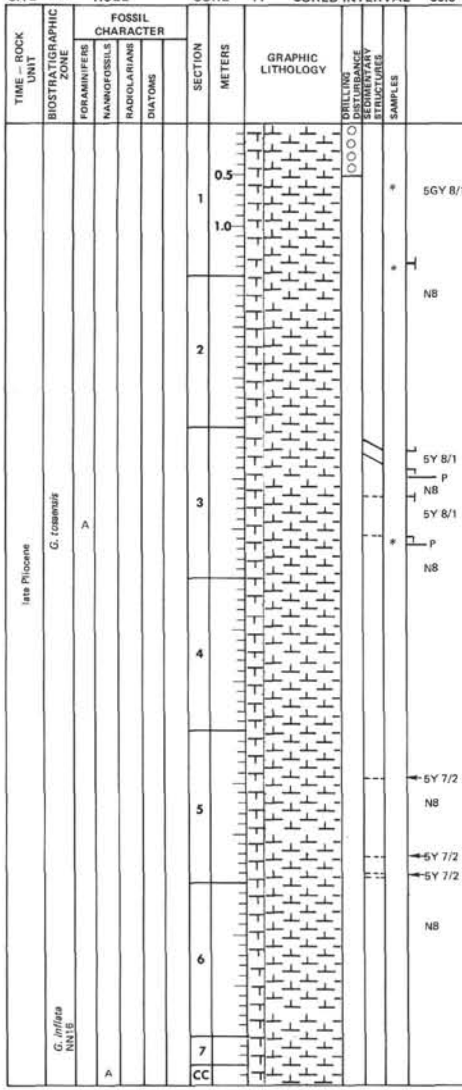
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, light greenish gray (5GY 8/1) to light grayish green (5G 8/1), soft, with swirls, streaks, and halos of various shades of grayish purple (5P 4/2) of iron sulfide. *Planolites* burrows are only identifiable burrows but mottles are common.

SMEAR SLIDE SUMMARY:

	2, 35	3, 70
	D	D
Composition:		
Quartz	T	T
Feldspar	–	T
Volcanic glass	R	T
Pyrite	–	T
Foraminifers	C	C
Calc. nannofossils	D	D
Sponge spicules	T	–

SITE 591 HOLE CORE 11 CORED INTERVAL 89.8–99.4 m



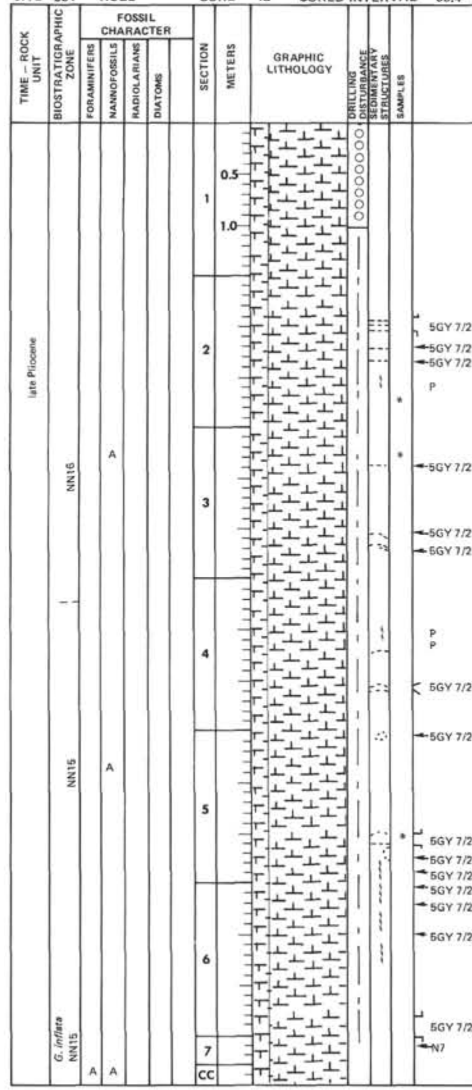
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, light greenish gray (5GY 8/1) grading to very light gray (N8). Soft and homogeneous with streaks of grayish purple (5P 4/2) iron sulfide throughout. Iron sulfide bands become horizontal by Section 3. Mottles of yellowish gray (5Y 7/2) and thin laminae (<2 mm) are common. A few *Planolites* occur.

SMEAR SLIDE SUMMARY:

	1, 75	1, 145	3, 107
	D	D	D
Composition:			
Quartz	–	T	–
Feldspar	T	T	T
Heavy minerals	T	–	T
Volcanic glass	T	–	T
Foraminifers	C	C	C
Calc. nannofossils	D	D	D

SITE 591 HOLE CORE 12 CORED INTERVAL 99.4–109.0 m



LITHOLOGIC DESCRIPTION

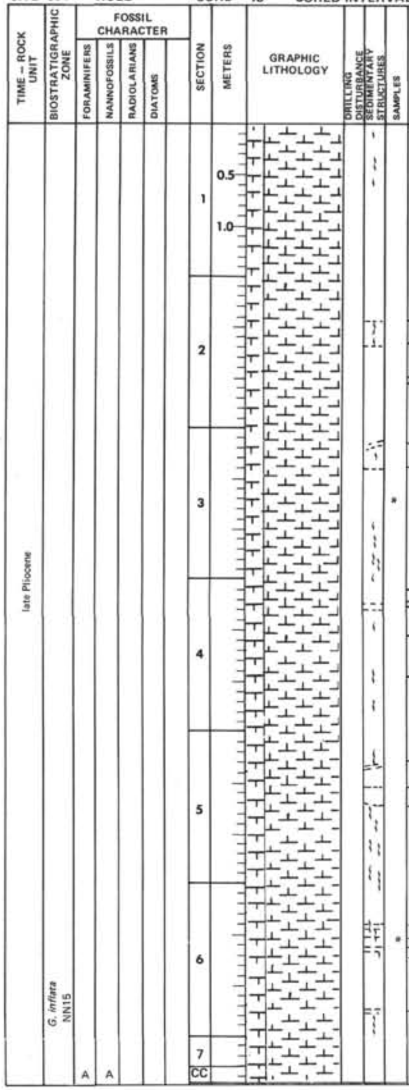
FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous. Faint mottles of grayish yellow green occur scattered throughout. Streaks of iron sulfide become bands <2 mm thick and horizontal by Section 3.

Interbeds, and mottles of dark yellowish green (5GY 7/2) contains possible volcanic glass.

SMEAR SLIDE SUMMARY:

	2, 100	3, 36	5, 105
	D	D	D
Composition:			
Quartz	T	–	–
Feldspar	T	–	T
Heavy minerals	–	T	T
Volcanic glass	T	T	T
Pyrite	–	–	T
Foraminifers	C	C	C
Calc. nannofossils	D	D	D
Radiolarians	T	T	T
Sponge spicules	–	T	T

SITE 591 HOLE CORE 13 CORED INTERVAL 109.0–118.3 m



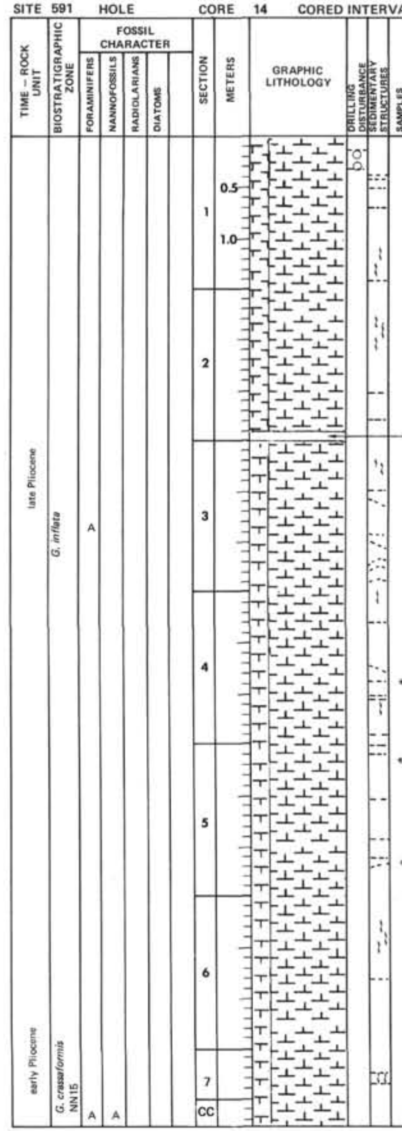
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), soft to stiff. Common blebs, streaks, and thin laminae (< 2 mm) of iron sulfide. Burrow mottles of grayish yellow green (5GY 7/2) and interbeds of same color occur scattered throughout. Burrow mottles become more apparent with depth. Possible ash layers (< 1 mm thick) occur at Section 6, 50 and 62 cm.

SMEAR SLIDE SUMMARY:

	3, 70	6, 51
	D	D
Composition:		
Feldspar	–	T
Mica	T	T
Heavy minerals	T	T
Volcanic glass	–	T
Foraminifers	C	C
Calc. nannofossils	D	D
Sponge spicules	T	T

SITE 591 HOLE CORE 14 CORED INTERVAL 118.5–129.6 m



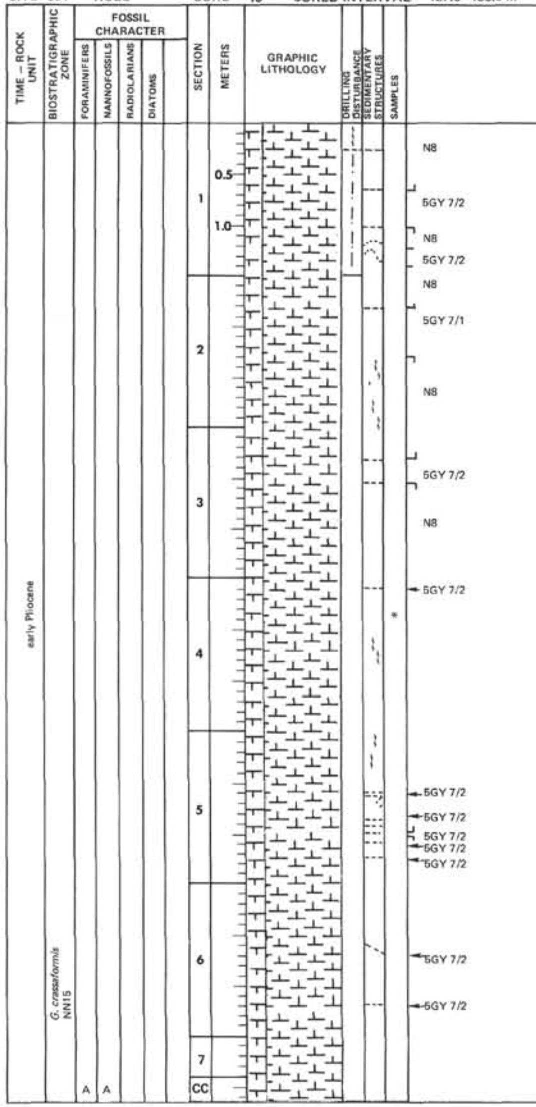
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), soft, with streaks and laminae (< 2 mm) of iron sulfide. Laminae and interbeds of light grayish yellow green (5GY 8/2) occur throughout. Burrow mottles are conspicuous and a few planolites occur. A few pale yellowish green (10GY 7/2) laminae.

SMEAR SLIDE SUMMARY:

	4, 82	5, 19	5, 108
	D	D	M
Composition:			
Quartz	–	T	–
Feldspar	T	T	T
Heavy minerals	–	–	T
Foraminifers	C	C	C
Calc. nannofossils	D	D	D
Radiolarians	–	T	–
Sponge spicules	T	T	T

SITE 591 HOLE CORE 15 CORED INTERVAL 127.6–136.9 m



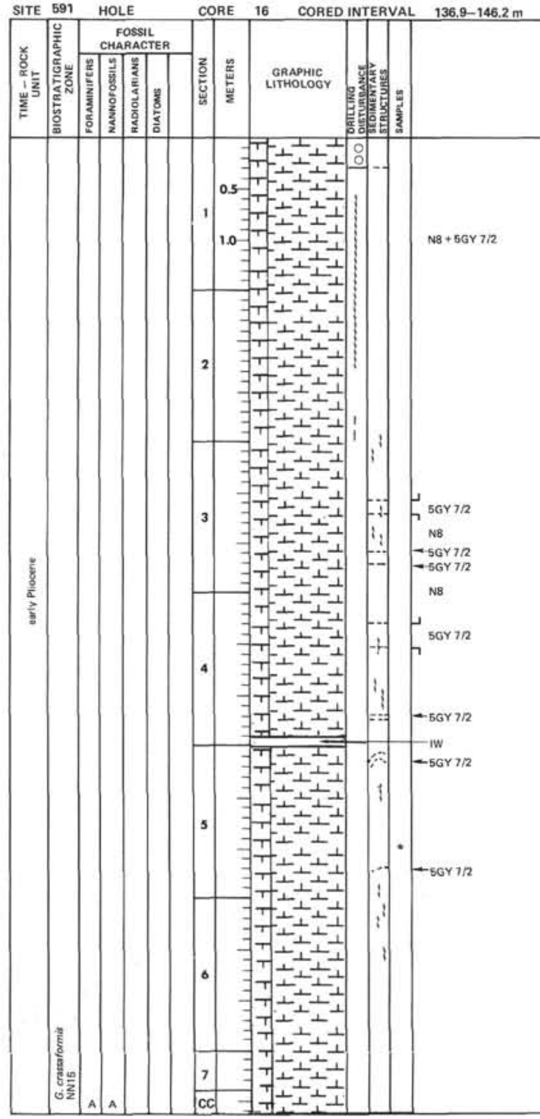
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8) with interbeds and burrow mottles of grayish yellow green (5GY 7/2), soft, with streaks and blebs of iron sulfide scattered throughout.

SMEAR SLIDE SUMMARY:

	4, 38
	D
Composition:	
Heavy minerals	T
Foraminifers	C
Calc. nannofossils	D
Radiolarians	T
Sponge spicules	T

SITE 591 HOLE CORE 16 CORED INTERVAL 136.9–146.2 m



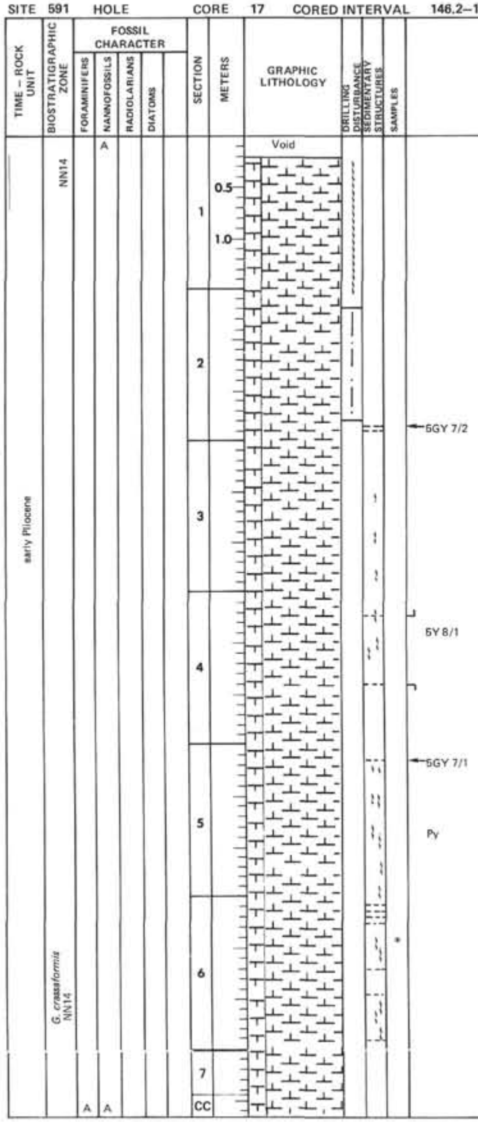
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8) with mottles of grayish yellow green (5GY 7/2) and interbeds of same. Specks, streaks, and a few burrow outlines of medium light gray (N4) scattered throughout. Sections 1 and 2 badly disturbed by coring.

SMEAR SLIDE SUMMARY:

	5, 92
Composition:	D
Heavy minerals	T
Foraminifers	C
Calc. nannofossils	D
Sponge spicules	T

SITE 591 HOLE CORE 17 CORED INTERVAL 146.2–155.5 m



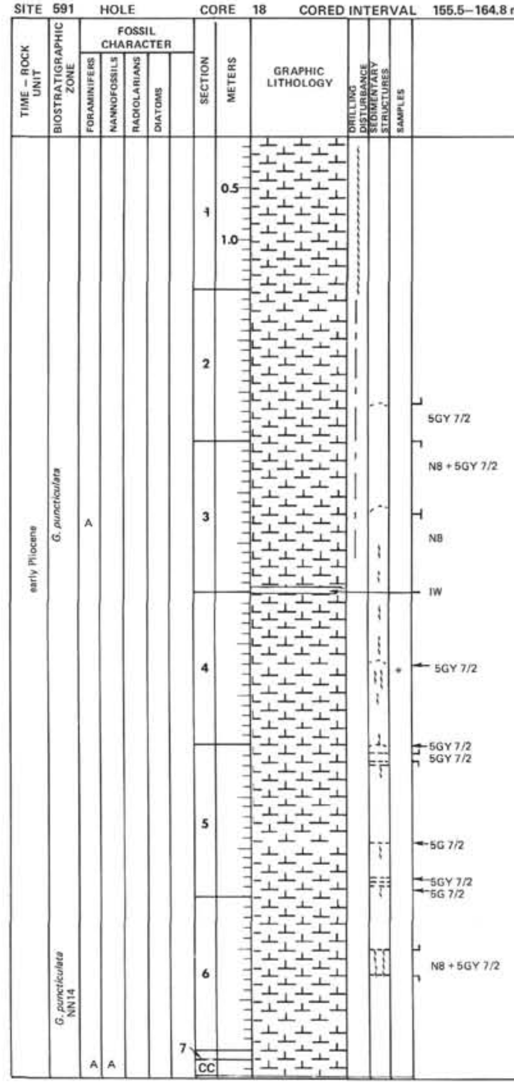
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8) with mottles and zones of grayish yellow green (5GY 7/2). Iron sulfide streaks, medium dark gray (N4) common. H_2S odor released when split. Yellowish gray interbed at Section 4, 25–83 cm.

SMEAR SLIDE SUMMARY:

	6, 43
	D
Composition:	
Feldspar	T
Volcanic glass	T
Foraminifers	C
Calc. nannofossils	D

SITE 591 HOLE CORE 18 CORED INTERVAL 155.5–164.8 m



LITHOLOGIC DESCRIPTION

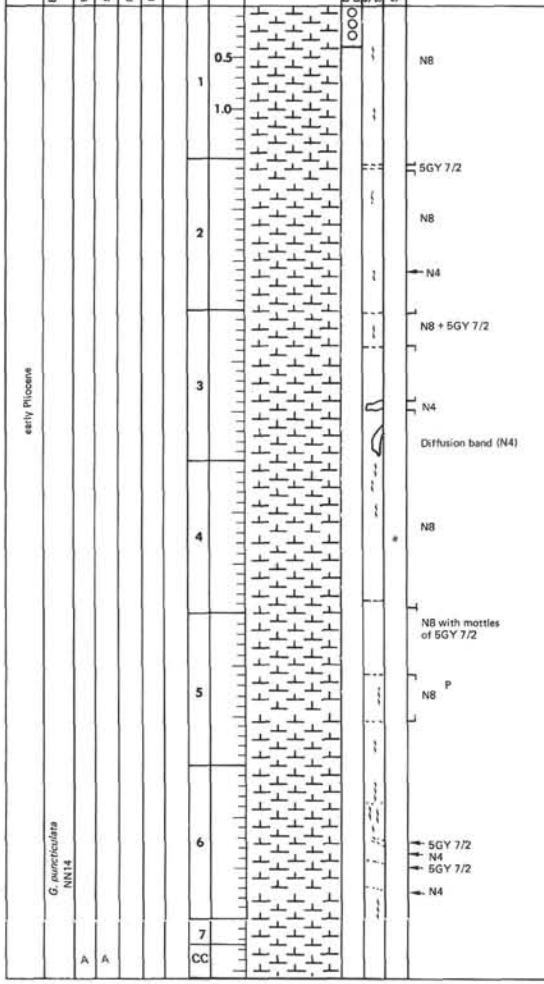
NANNOFOSSIL OOZE, very light gray (N8), soft, with streaks and laminae of medium dark gray (N4) iron sulfide throughout. Mottles and thin (<2 mm) laminae of grayish yellow green (5GY 7/2) common. Two thin (<1 mm) very subtle pale green (5G 7/2) laminae occur in Section 5.

SMEAR SLIDE SUMMARY:

	4, 74
Composition:	
Volcanic glass	T
Pyrite	T
Foraminifers	R
Calc. nannofossils	D
Radiolarians	T
Sponge spicules	T

SITE 591 HOLE CORE 19 CORED INTERVAL 164.8–174.3 m

TIME – ROCK UNIT | BIOSTRATIGRAPHIC ZONE | FOSSIL CHARACTER: FORAMINIFERS, NANNOFOSSILS, RADIOLARIANS, DIATOMS | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | SAMPLES | LITHOLOGIC DESCRIPTION



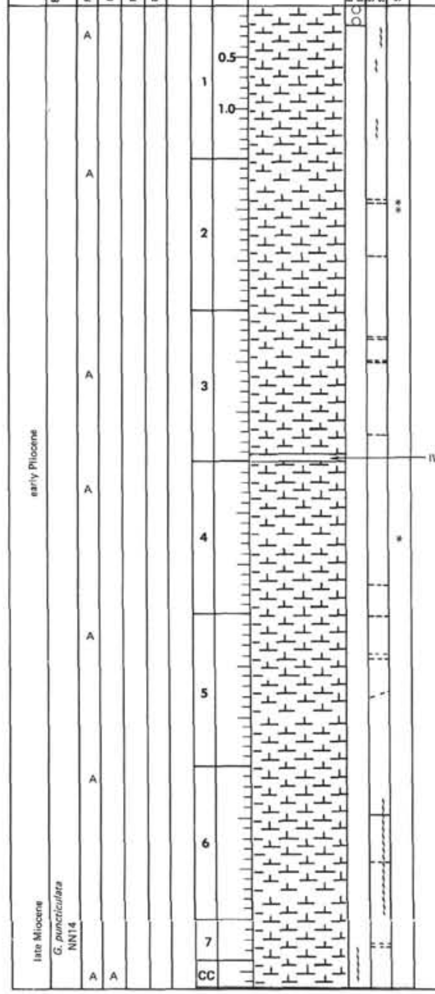
NANNOFOSSIL OOZE, very light gray (N8), soft, with streaks and thin laminae of medium dark gray (N4) iron sulfides common throughout. Mottles and zones of grayish yellow green (5GY 7/2) scattered throughout. Dark volcanic glass in insoluble residue at Section 5, 147 cm.

SMEAR SLIDE SUMMARY:

	4, 72
	D
Composition:	
Feldspar	T
Foraminifers	T
Calc. nannofossils	D
Radiolarians	T
Sponge spicules	T

SITE 591 HOLE CORE 20 CORED INTERVAL 174.3–183.8 m

TIME – ROCK UNIT | BIOSTRATIGRAPHIC ZONE | FOSSIL CHARACTER: FORAMINIFERS, NANNOFOSSILS, RADIOLARIANS, DIATOMS | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | SAMPLES | LITHOLOGIC DESCRIPTION



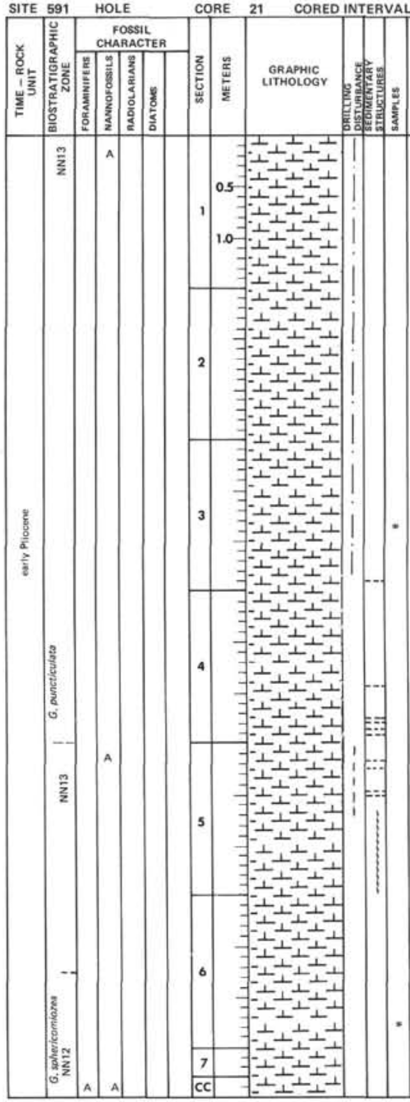
NANNOFOSSIL OOZE, very light gray (N8), soft, with streaks, spots, and thin laminae of light gray (N7) iron sulfides common throughout. Burrow mottles of light greenish gray (5GY 8/1) scattered throughout.

Double-color (laminae) bands of light greenish gray (5G 8/1) and light gray (N7) occur.

SMEAR SLIDE SUMMARY:

	2, 53	2, 54	4, 75
	M	M	D
Texture:			
Sand	T	T	T
Silt	T	T	T
Clay	D	D	D
Composition:			
Quartz	T	T	–
Mica	T	T	T
Heavy minerals	T	T	–
Volcanic glass	T	T	T
Pyrite	–	R	T
Carbonate unspec.	T	–	–
Foraminifers	R	T	R
Calc. nannofossils	D	D	D
Radiolarians	–	–	T
Sponge spicules	–	–	T

SITE 591 HOLE CORE 21 CORED INTERVAL 183.8–193.3 m



LITHOLOGIC DESCRIPTION

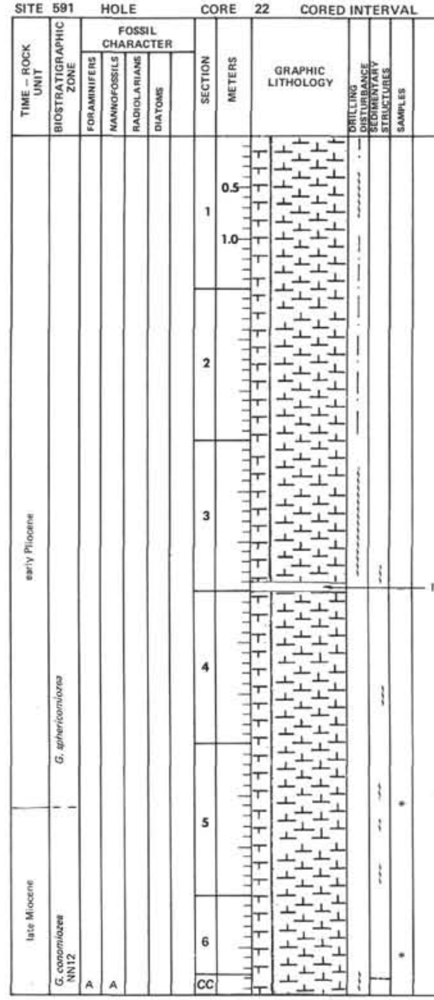
NANNOFOSSIL OOZE, very light gray (N8), soft, slightly to moderately deformed by drilling.

Light greenish gray (5GY 8/1) and light gray (N7) mottles scattered.

SMEAR SLIDE SUMMARY:

	3, 80	6, 125
	D	D
Texture:		
Sand	T	R
Silt	T	R
Clay	D	D
Composition:		
Quartz	T	T
Mica	–	T
Heavy minerals	T	T
Volcanic glass	–	T
Pyrite	T	–
Carbonate unspec.	–	T
Foraminifers	R	R
Calc. nannofossils	D	D
Diatoms	–	T
Radiolarians	T	–
Sponge spicules	–	T
Silicoflagellates	T	T

SITE 591 HOLE CORE 22 CORED INTERVAL 193.3–202.7 m



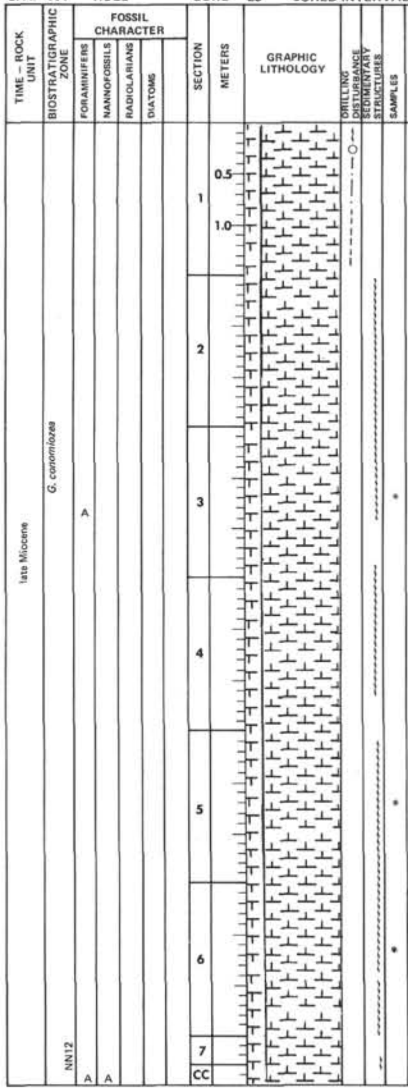
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, soft; very light gray (N8), upper half; light greenish gray (5GY 8/1), lower; with mottles of yellowish gray (5Y 8/1) and light gray (N6–N7).

SMEAR SLIDE SUMMARY:

	5, 60	6, 55
	D	D
Composition:		
Quartz	–	T
Feldspar	T	–
Mica	T	T
Heavy minerals	T	T
Volcanic glass	–	T
Pyrite	T	T
Foraminifers	C	C
Calc. nannofossils	D	D
Diatoms	T	–
Radiolarians	–	T
Sponge spicules	T	T

SITE 591 HOLE CORE 23 CORED INTERVAL 202.7–212.1 m



LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), soft, with burrow mottles of light gray (N6–N7) and yellowish gray (5GY 8/1–5GY 7/2).

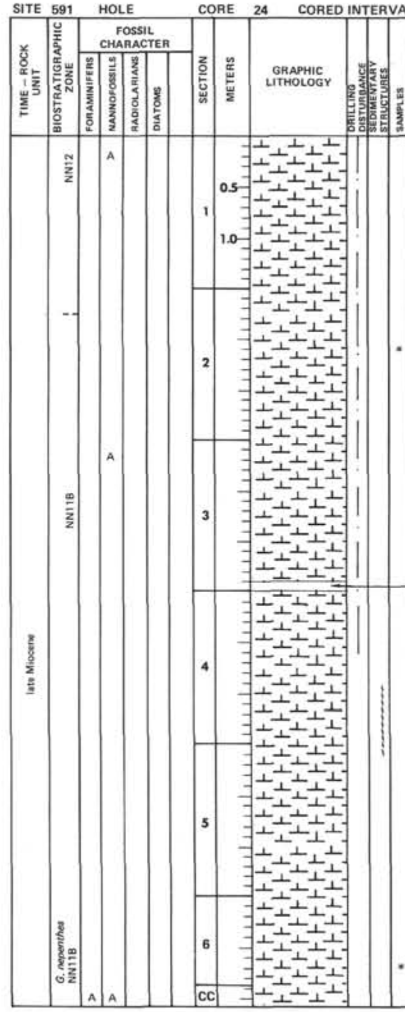
Accessory pyrite of medium gray (N4).

Moderately bioturbed.

SMEAR SLIDE SUMMARY:

	3, 65	5, 66	6, 60
	D	M	D
Texture:			
Sand	T	T	T
Silt	R	R	R
Clay	D	D	D
Composition:			
Quartz	T	T	T
Feldspar	–	T	T
Mica	–	–	T
Heavy minerals	T	T	T
Pyrite	T	T	–
Foraminifers	C	C	C
Calc. nannofossils	D	D	D
Diatoms	T	–	T
Radiolarians	–	T	–
Sponge spicules	T	T	–

SITE 591 HOLE CORE 24 CORED INTERVAL 212.1–221.5 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft, with mottles of pale olive (10Y 6/2) and light gray (N7) in color.

SMEAR SLIDE SUMMARY:

	2, 70	6, 60
	D	D
Texture:		
Sand	T	T
Silt	R	R
Clay	D	D
Composition:		
Quartz	T	T
Feldspar	–	T
Mica	T	T
Heavy minerals	T	–
Pyrite	T	–
Foraminifers	R	R
Calc. nannofossils	D	D
Diatoms	T	T
Sponge spicules	–	T

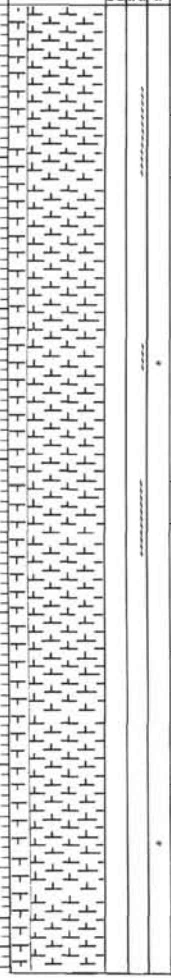
IW

Light greenish gray (5GY 8/1) bioturbation

SITE 591 HOLE CORE 25 CORED INTERVAL 221.5–231.1 m

TIME-ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS
late Miocene	G. nepenthes NN11B	A	A			1, 2, 3, 4, 5, 6, 7, CC	0.5, 1.0

GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | SAMPLES



LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8) to light greenish gray (5GY 8/1), soft, with burrow mottles of yellowish gray (5Y 7/2) and medium to light gray (N5 to N7), and with iron sulfides of dark gray (N4).

Mixed by bioturbation.

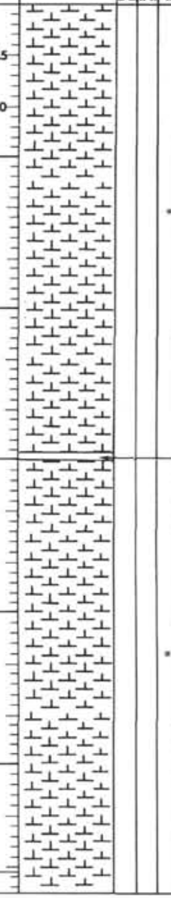
SMEAR SLIDE SUMMARY:

	3, 60	6, 80
	D	D
Texture:		
Sand	R	T
Silt	R	R
Clay	D	D
Composition:		
Quartz	T	T
Mica	T	T
Heavy minerals	–	T
Volcanic glass	T	–
Pyrite	T	T
Carbonate unspec.	–	T
Foraminifers	C	C
Calc. nannofossils	D	D
Radiolarians	T	–

SITE 591 HOLE CORE 26 CORED INTERVAL 231.1–240.7 m

TIME-ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS
late Miocene	N. continuosa	A				1, 2, 3, 4, 5, 6	0.5, 1.0
	N. continuosa NN11B	A	A			CC	

GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | SAMPLES



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft, with mottles of grayish yellow green (5GY 7/2); almost totally bioturbated.

SMEAR SLIDE SUMMARY:

	2, 55	5, 40
	D	D
Texture:		
Sand	T	T
Silt	R	R
Clay	D	D
Composition:		
Quartz	T	–
Feldspar	T	T
Heavy minerals	T	T
Pyrite	T	–
Carbonate unspec.	–	T
Foraminifers	R	T
Calc. nannofossils	D	D
Diatoms	–	T
Radiolarians	T	–
Sponge spicules	T	–

SITE 591 HOLE CORE 27 CORED INTERVAL 240.7–250.3 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES
late Miocene	*N. continuosa* NN11B	A	A			1–7, CC	0.5, 1.0				* (Sections 2, 6)

LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8) and partly light greenish gray (5GY 8/1), soft, almost totally bioturbed.

SMEAR SLIDE SUMMARY:

	2, 80	6, 80
	D	D
Texture:		
Silt	T	R
Clay	D	D
Composition:		
Quartz	T	T
Mica	–	T
Heavy minerals	T	T
Volcanic glass	T	–
Pyrite	T	–
Foraminifers	T	R
Calc. nannofossils	D	D
Diatoms	T	T
Sponge spicules	T	T

SITE 591 HOLE CORE 28 CORED INTERVAL 250.3–259.8 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES
late Miocene	NN11B		A			1–3	0.5, 1.0				* (Section 2)
	NN11A		A			4–6					IW (top of Section 4); * (Section 6)
	N. continuosa NN11A	A	A			CC					

LITHOLOGIC DESCRIPTION

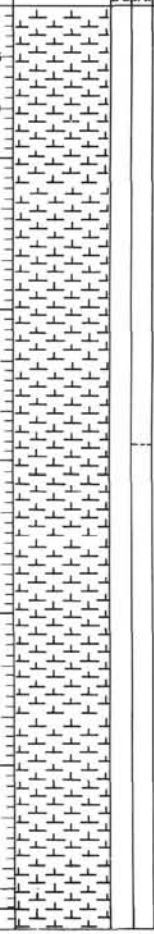
NANNOFOSSIL OOZE, very light greenish gray (5GY 8/1), soft, almost totally bioturbated.

SMEAR SLIDE SUMMARY:

	2, 80	6, 80
	D	D
Texture:		
Sand	–	T
Silt	R	T
Clay	D	D
Composition:		
Quartz	T	T
Mica	–	T
Heavy minerals	T	–
Volcanic glass	T	–
Carbonate unspec.	T	T
Foraminifers	T	R
Calc. nannofossils	D	D
Diatoms	T	T
Radiolarians	T	T

SITE 591 HOLE CORE 29 CORED INTERVAL 259.8–269.3 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES
late Miocene	*N. continuosa* NN11A	A	A			1, 2, 3, 4, 5, 6, CC	0.5, 1.0				* (Section 2), * (Section 6)



LITHOLOGIC DESCRIPTION

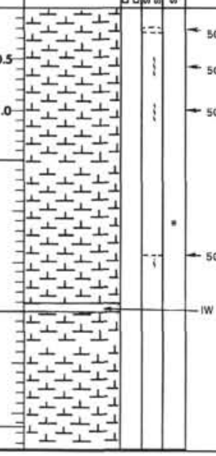
NANNOFOSSIL OOZE, very light gray (N8), soft, almost totally bioturbated, with burrow mottles (rim of light gray [N7] and core of grayish yellow green [5GY 7/2]).

SMEAR SLIDE SUMMARY:

	2, 80	6, 80
	D	D
Texture:		
Sand	T	T
Silt	T	R
Clay	D	D
Composition:		
Quartz	T	–
Mica	T	T
Heavy minerals	–	T
Carbonate unspec.	–	T
Foraminifers	T	R
Calc. nannofossils	D	D
Diatoms	T	–
Radiolarians	T	T
Sponge spicules	T	T

SITE 591 HOLE CORE 30 CORED INTERVAL 269.3–274.3 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES
late Miocene	*N. continuosa* NN11A	A	A			1, 2, 3, CC	0.5, 1.0				* (Section 2)



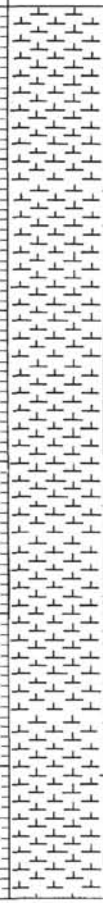
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), stiff, with mottles and faint interbeds of grayish yellow green (5GY 7/2). Streaks of medium dark gray (N4) iron sulfide.

SMEAR SLIDE SUMMARY:

	2, 63
	D
Composition:	
Foraminifers	R
Calc. nannofossils	D
Diatoms	R
Sponge spicules	T

SITE 591 HOLE CORE 31 CORED INTERVAL 274.3–283.1 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES	LITHOLOGIC DESCRIPTION
late Miocene	*N. continuosa* NN11A	A	A			1, 2, 3, 4, 5, 6, CC	0.5, 1.0				* (section 3)	

Section 1: 5GY 7/2

Section 2: Diffusion band

Section 3: 5GY 7/2

Sections 4–5: N8 + 5GY 7/2 intermixed

Section 6: 5GY 7/2; 5GY 7/2

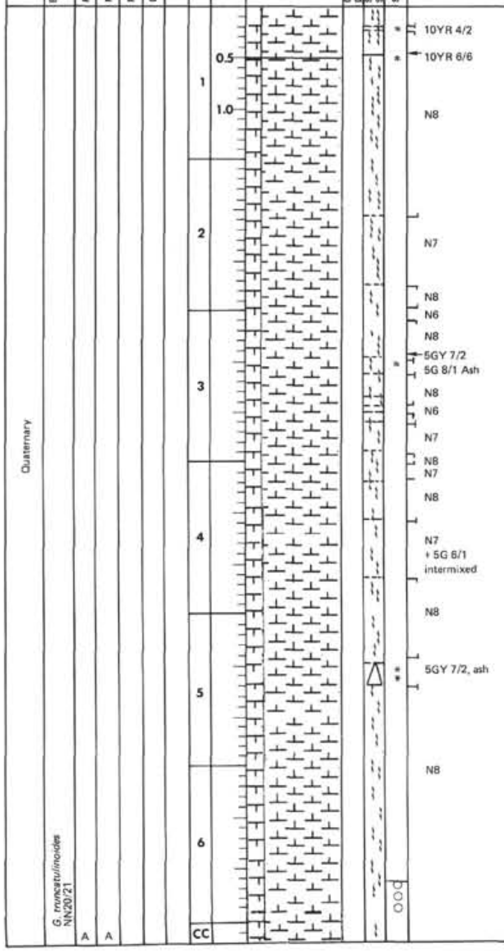
NANNOFOSSIL OOZE, very light gray (N8), soft, homogeneous, with streaks of medium dark gray (N4) iron sulfide common throughout. Faint mottles of grayish yellow green (5GY 7/2) rare to common.

SMEAR SLIDE SUMMARY:

	3, 71
	D
Composition:	
Quartz	T
Feldspar	T
Palagonite	T
Foraminifers	T
Calc. nannofossils	D
Radiolarians	T
Sponge spicules	T

SITE 591 HOLE A CORE 1 CORED INTERVAL 0.0–9.2 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES	LITHOLOGIC DESCRIPTION



FORAMINIFER-BEARING NANNOFOSSIL OOZE, pale yellowish brown (10YR 6/4), soft, intensely bioturbated, with bioturbated interbed of dark yellowish brown (10YR 4/2). Sequence has various faint hues of yellow browns (10YR). Contact with underlying FORAMINIFER-BEARING NANNOFOSSIL OOZE is sharp with a distinct band (2 mm thick) of dark yellowish orange (10YR 6/6).

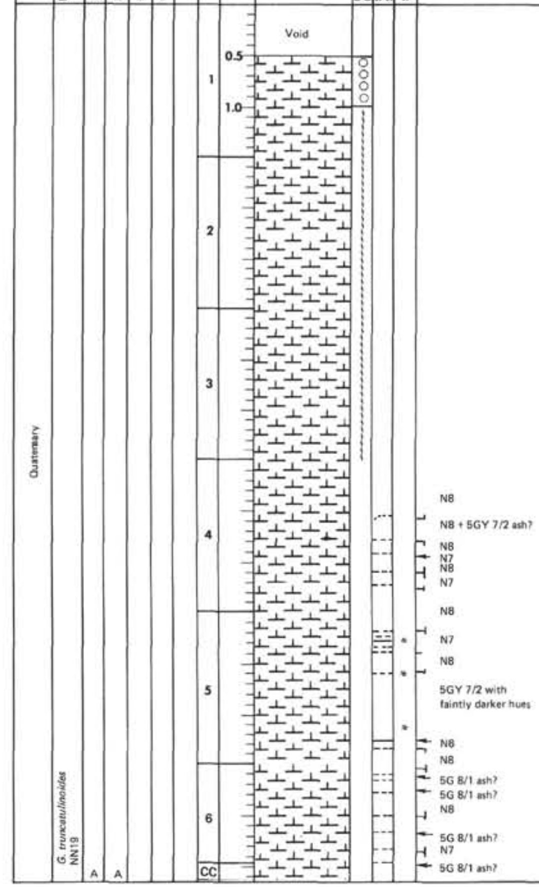
FORAMINIFER-BEARING NANNOFOSSIL OOZE, light gray (N7) and very light gray (N8) color cycles, soft, intensely bioturbated. Streaks of dark gray (N3) iron sulfides common throughout. A few mottles of grayish yellow green (5GY 7/2) occur. Color cycles become medium light gray (N6) in Section 3. Fining upward interbed occurs in Section 5 with coarse-grained, ash-rich base.

SMEAR SLIDE SUMMARY:

	1, 29	3, 61	4, 48	5, 60	5, 69
	M	D	D	M	M
Composition:					
Quartz	–	–	–	–	T
Feldspar	T	T	T	T	T
Heavy minerals	T	–	–	T	–
Volcanic glass	–	C	–	C	A
Foraminifers	C	C	R	C	–
Calc. nannofossils	A	A	A	A	–
Sponge spicules	T	–	–	–	–

SITE 591 HOLE A CORE 2 CORED INTERVAL 9.2–18.8 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES	LITHOLOGIC DESCRIPTION

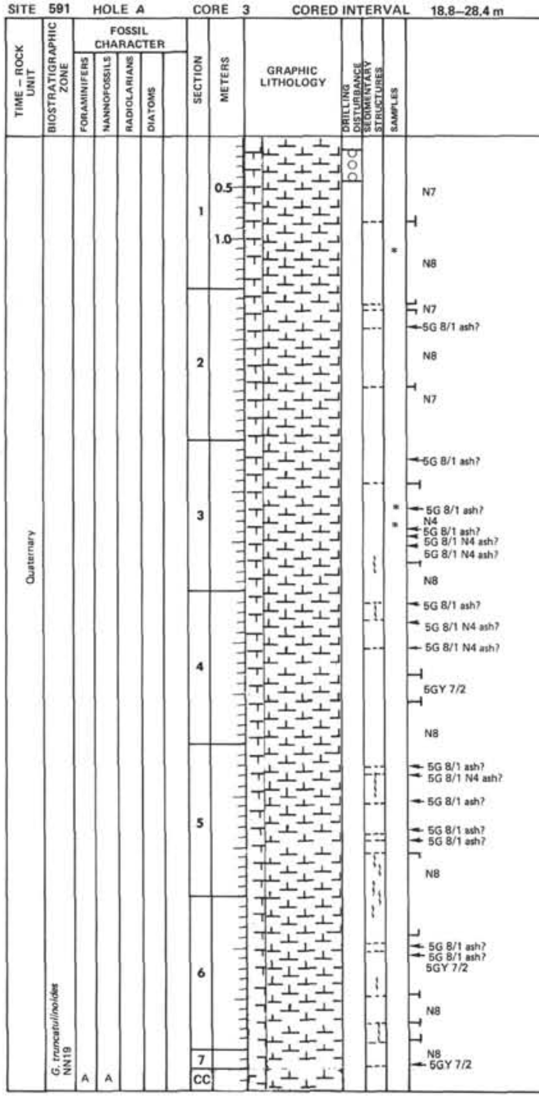


NANNOFOSSIL OOZE, alternations of very light gray (N8) and light gray (N7), soft, streaks of medium dark gray (N4) iron sulfides throughout. Several thin zones of ash(?), light greenish gray (5G 8/1). Several zones of grayish yellow green (5GY 7/2) with mottles.

SMEAR SLIDE SUMMARY:

	5, 37	5, 67	5, 118	6, 22
	D	M	M	M
Composition:				
Quartz	–	T	–	–
Feldspar	T	T	–	–
Heavy minerals	–	–	T	–
Volcanic glass	–	–	T	–
Pyrite	–	–	T	C
Foraminifers	R	C	C	D
Calc. nannofossils	D	D	D	C

SITE 591 HOLE A CORE 3 CORED INTERVAL 18.8–28.4 m



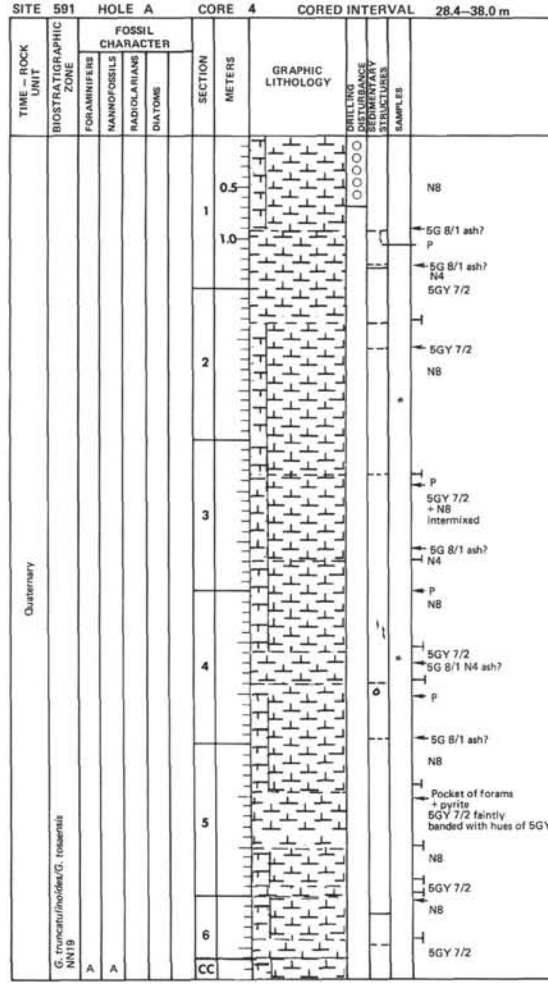
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE cycles of light gray (N7) and very light gray (N8) with very faint hues of (5G) throughout. Medium dark gray (N4) iron sulfide streaks and laminae common. Mottles common. Doublets of light greenish gray (5Y 8/1) above a band of (N4) very common from Section 3 down. Pockets of forams, pyrite, cemented by anhydrite(?) occur in Sections 3, 4, and 5.

SMEAR SLIDE SUMMARY:

	1, 124	3, 67	3, 86
	D	M	M
Composition:			
Quartz	T	T	–
Feldspar	R	T	T
Heavy minerals	–	–	T
Volcanic glass	–	T	T
Palagonite	–	–	T
Foraminifers	C	C	C
Calc. nannofossils	D	D	D
Sponge spicules	–	T	–

SITE 591 HOLE A CORE 4 CORED INTERVAL 28.4–38.0 m



LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (5GY 7/2) alternating with NANNOFOSSIL OOZE, grayish yellow green (N8), soft, homogeneous, mottled, common medium dark gray (N4) streaks of iron sulfide. Doublets of pale greenish gray (5G 8/1) and medium dark gray (N4) may be altered ash. Small pockets of forams, pyrite and aragonite(?) occur in Section 5.

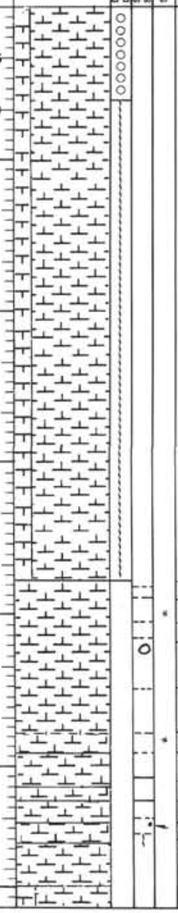
SMEAR SLIDE SUMMARY:

	2, 118	4, 76
	D	D
Composition:		
Quartz	T	–
Feldspar	T	–
Heavy minerals	–	T
Volcanic glass	–	T
Pyrite	–	T
Foraminifers	C	R
Calc. nannofossils	D	D
Sponge spicules	T	–

SITE 591 HOLE A CORE 5 CORED INTERVAL 38.0–47.6 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS
Quaternary	*G. truncatulinoides/G. tosaensis* NN19	A	A			1, 2, 3, 4, 5, 6, CC	0.5, 1.0

GRAPHIC LITHOLOGY · DRILLING DISTURBANCE · SEDIMENTARY STRUCTURES · SAMPLES



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8) alternating with FORAMINIFER-BEARING NANNOFOSSIL OOZE, grayish yellow green (5GY 7/2), soft, mottled, common streaks of iron sulfide of medium dark gray (N4) and several doublets of altered ash(?) of light greenish gray (5G 8/1) and medium dark gray (N4). Two pockets of forams and pyrite at Section 5, 32 cm and Section 6, 57 and 65 cm. Chemical diffusion bands common.

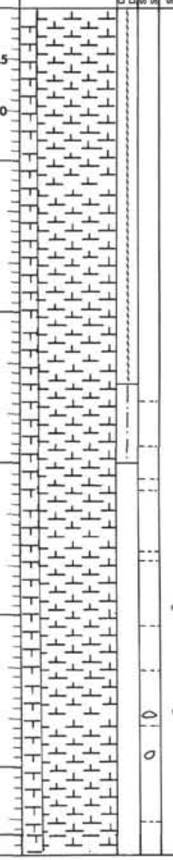
SMEAR SLIDE SUMMARY:

	5, 7	5, 122
	D	D
Composition:		
Feldspar	–	T
Volcanic glass	T	T
Foraminifers	R	C
Calc. nannofossils	D	D

SITE 591 HOLE A CORE 6 CORED INTERVAL 47.6–57.2 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS
Quaternary	*G. truncatulinoides/G. tosaensis* NN18	A	A			1, 2, 3, 4, 5, 6, CC	0.5, 1.0

GRAPHIC LITHOLOGY · DRILLING DISTURBANCE · SEDIMENTARY STRUCTURES · SAMPLES



LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, alternating very light gray (N8) and grayish yellow green (5GY 7/2), soft, with streaks of medium dark gray (N4) iron sulfide, and doublets of altered ash(?) light greenish gray (5G 8/1) and (N4). Pockets of forams and pyrite in Sections 5 and 6.

SMEAR SLIDE SUMMARY:

	4, 13	5, 95
	D	D
Composition:		
Feldspar	T	T
Volcanic glass	T	T
Pyrite	T	T
Foraminifers	C	C
Calc. nannofossils	D	D

SITE 591 HOLE A CORE 7 CORED INTERVAL 57.2–66.8 m

TIME – ROCK UNIT: Quaternary

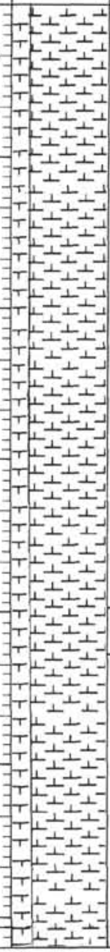
BIOSTRATIGRAPHIC ZONE: *G. truncatulinoides/G. tosaensis* NN18

FOSSIL CHARACTER: FORAMINIFERS A; NANNOFOSSILS A; RADIOLARIANS; DIATOMS

SECTION: 1, 2, 3, 4, 5, 6, 7, CC

METERS: 0.5, 1.0

GRAPHIC LITHOLOGY



DRILLING DISTURBANCE; SEDIMENTARY STRUCTURES; SAMPLES

5G 8/1 N4 ash?

P

N8

5GY 7/2

N8

LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8) and grayish yellow green (5GY 7/2), soft, homogeneous with common streaks of medium dark gray (N4) iron sulfide. Altered ash(?) doublet of light greenish gray (5G 8/1 and N4) in Section 5. Mottles rare.

SITE 591 HOLE A CORE 8 CORED INTERVAL 66.8–76.4 m

TIME – ROCK UNIT: Quaternary

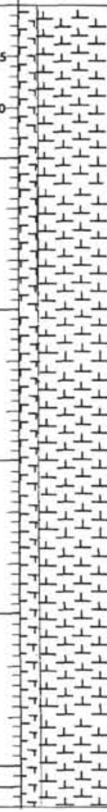
BIOSTRATIGRAPHIC ZONE: *G. truncatulinoides/G. tosaensis* NN18

FOSSIL CHARACTER: FORAMINIFERS A; NANNOFOSSILS A; RADIOLARIANS; DIATOMS

SECTION: 1, 2, 3, 4, 5, 6, CC

METERS: 0.5, 1.0

GRAPHIC LITHOLOGY



DRILLING DISTURBANCE; SEDIMENTARY STRUCTURES; SAMPLES

N4

N4

5GY 7/2

Pocket of forams + pyrite

N8

5GY 7/2 + N4

N8

P

Chemical diffusion bands

5G 8/1 N4 ash?

N8

5GY 6/2

5G 8/1 N4 ash?

N8

P

P

5GY 7/2

N8

5GY 7/2

5G 8/1 N4 ash?

LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8) and grayish yellow green (5GY 7/2 and 5GY 6/2), stiff, with streaks of medium dark gray (N4) iron sulfide throughout. Pocket of forams and pyrite in Section 1 and light greenish gray (5Y 8/1) and medium dark gray (N4) doublets of altered ash(?) in Sections 3, 4, and 5. Rare *Planolites*-like mottles and some chemical diffusion bands of iron sulfide.

SMEAR SLIDE SUMMARY:

	4, 50	4, 136
	D	D
Composition:		
Quartz	–	T
Feldspar	T	T
Volcanic glass	–	T
Pyrite	T	–
Foraminifers	C	C
Calc. nannofossils	D	D
Sponge spicules	–	T

SITE 591 HOLE A CORE 9 CORED INTERVAL 76.4–86.0 m

TIME – ROCK UNIT: late Pliocene

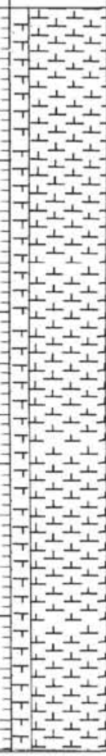
BIOSTRATIGRAPHIC ZONE: *G. tosaensis* NN16

FOSSIL CHARACTER: FORAMINIFERS A; NANNOFOSSILS A; RADIOLARIANS; DIATOMS

SECTION: 1, 2, 3, 4, 5, CC

METERS: 0.5, 1.0

GRAPHIC LITHOLOGY



DRILLING DISTURBANCE / SEDIMENTARY STRUCTURES / SAMPLES

N8
N4
N4 5GY 7/2
N4
N8
N4
N8 + 5GY 7/2
N8
N4
N8
5GY 7/2
N8
5GY 7/2
N4
N8
N8 + N4 intermixed
5GY 7/2

LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8) alternating with grayish yellow green (5GY 7/2). Several thin laminae and common streaks of medium dark gray (N4) iron sulfide.

SITE 591 HOLE A CORE 10 CORED INTERVAL 86.0–95.6 m

TIME – ROCK UNIT: late Pliocene

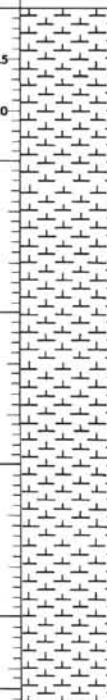
BIOSTRATIGRAPHIC ZONE: *G. tosaensis* NN16

FOSSIL CHARACTER: FORAMINIFERS A; NANNOFOSSILS A; RADIOLARIANS; DIATOMS

SECTION: 1, 2, 3, 4, 5, CC

METERS: 0.5, 1.0

GRAPHIC LITHOLOGY



DRILLING DISTURBANCE / SEDIMENTARY STRUCTURES / SAMPLES

N8
5GY 7/2
5GY 7/2 + N4
P
*
N8
Pockets of forams and pyrite
5GY 7/2 with hues of 5G and N4
N8 with mottles of 5GY 7/2

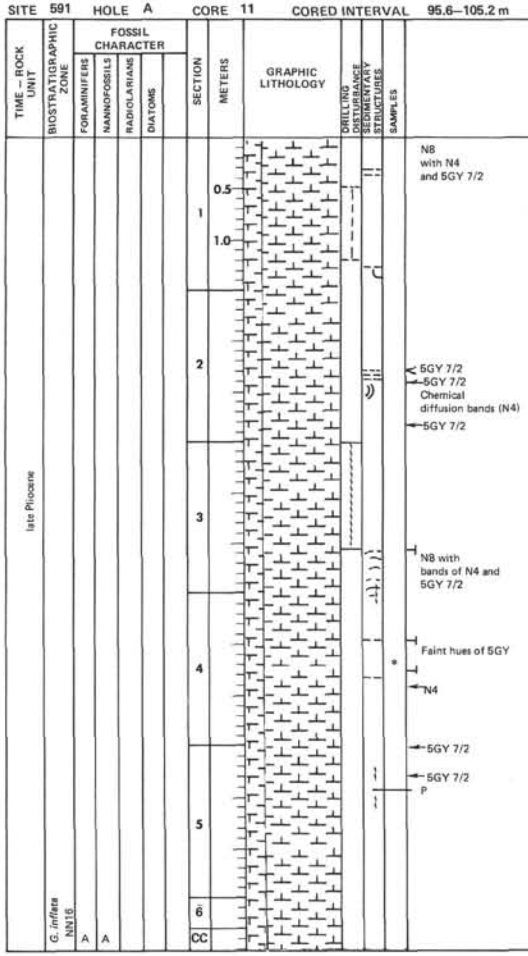
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N4) and grayish yellow green (5GY 7/2) with common streaks and laminae of medium dark gray (N4) iron sulfide. A pyrite concretion occurs in Section 3 and pockets of forams and pyrite occur in Section 4. Entire sequence is mottled.

SMEAR SLIDE SUMMARY:

	3, 71
	D
Composition:	
Feldspar	T
Heavy minerals	T
Pyrite	T
Foraminifers	R
Calc. nannofossils	D

SITE 591 HOLE A CORE 11 CORED INTERVAL 95.6–105.2 m



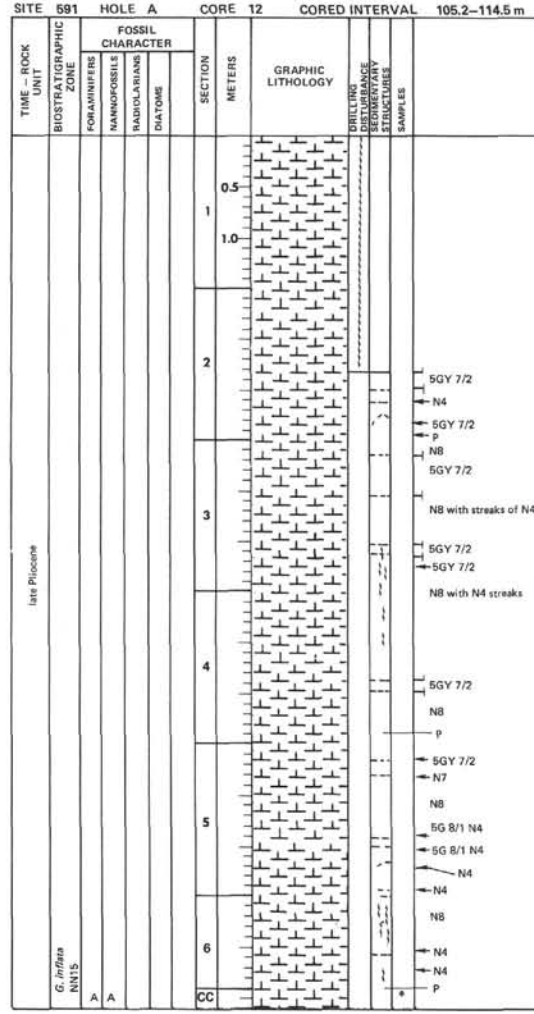
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8) with zones of intermixed medium dark gray (N4) and grayish yellow green (5GY 7/2). Streaks of N4 common. Faint hues of 5GY common. Mottles of 5GY 7/2 common. Thin laminae of N4 occur

SMEAR SLIDE SUMMARY:

	4, 72
Composition:	
Volcanic glass	T
Foraminifers	C
Calc. nannofossils	D
Sponge spicules	T

SITE 591 HOLE A CORE 12 CORED INTERVAL 105.2–114.5 m



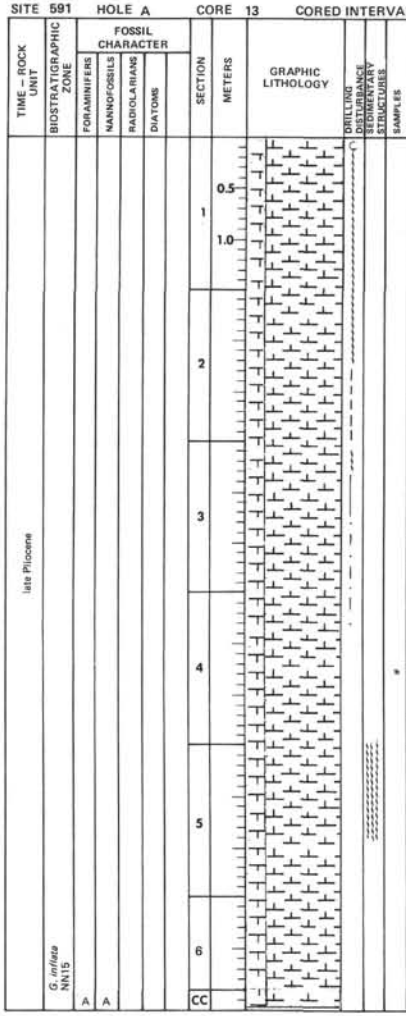
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft to firm, homogeneous except for common streaks of medium dark gray (N4) iron sulfide, thin bands of N4, grayish yellow green (5GY 7/2) and light greenish gray (5G 8/1). Large *Planolites*-like mottles of 5GY 7/2 commonly occur below Section 4. Bioturbation is common and distinctive.

SMEAR SLIDE SUMMARY:

	CC D
Composition:	
Feldspar	T
Pyrite	T
Foraminifers	R
Calc. nannofossils	D

SITE 591 HOLE A CORE 13 CORED INTERVAL 114.5–123.8 m



LITHOLOGIC DESCRIPTION

N8
5GY 7/2
N8
5GY 7/2
5GY 8/1
N8
5GY 8/1
N8

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

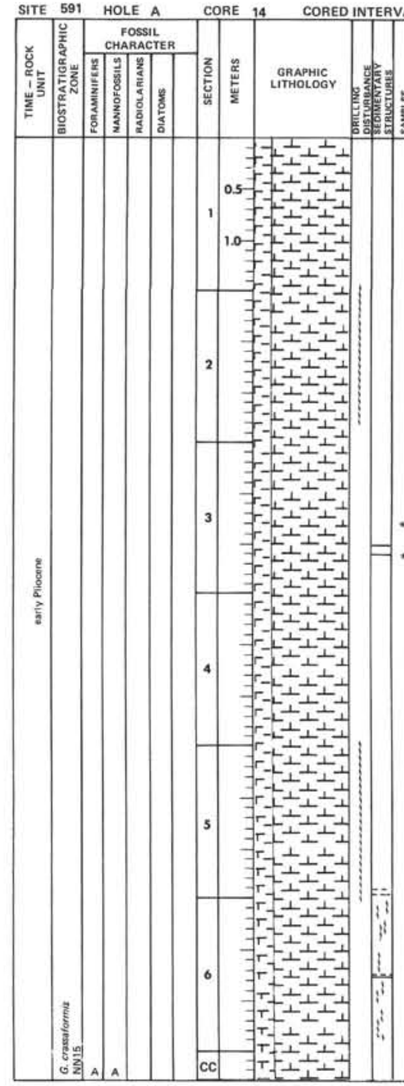
Specks, streaks, and thin bands of iron sulfides (dark to light gray [N4–N6]) and mottles of burrows (grayish yellow green [5GY 7/2]) common.

Total bioturbation.

SMEAR SLIDE SUMMARY:

	4, 80
	D
Texture:	
Sand	T
Silt	R
Clay	D
Composition:	
Quartz	T
Feldspar	T
Mica	T
Foraminifers	C
Calc. nannofossils	D

SITE 591 HOLE A CORE 14 CORED INTERVAL 123.8–133.1 m



LITHOLOGIC DESCRIPTION

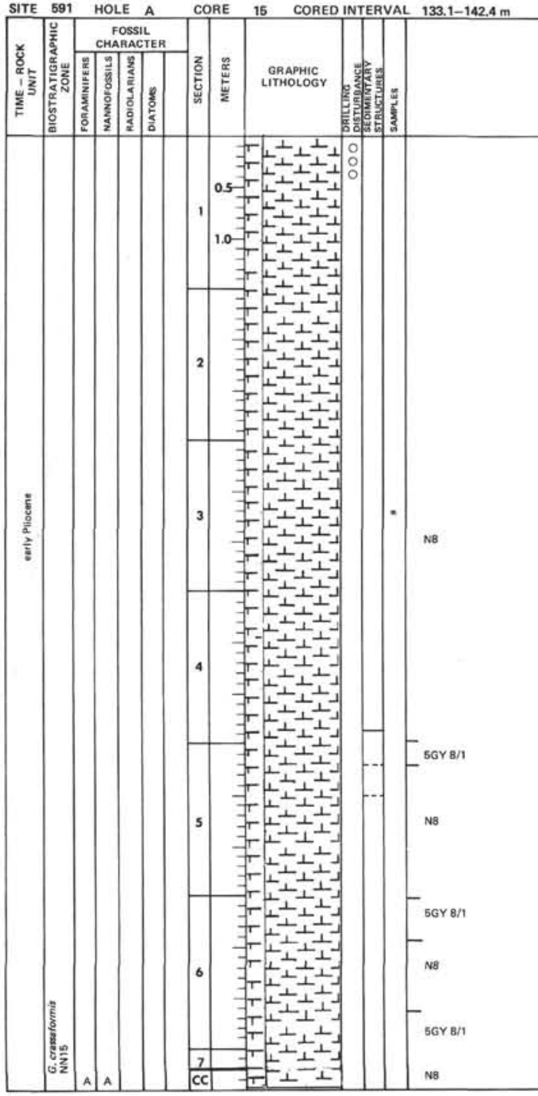
N8
5GY 8/1
N8

FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), firm, totally bioturbated.

SMEAR SLIDE SUMMARY:

	3, 80	3, 110
	D	M
Texture:		
Sand	T	R
Silt	C	R
Clay	D	D
Composition:		
Quartz	T	T
Feldspar	T	T
Mica	T	–
Heavy minerals	–	T
Pyrite	T	–
Foraminifers	C	C
Calc. nannofossils	D	D
Radiolarians	T	–
Sponge spicules	T	T

SITE 591 HOLE A CORE 15 CORED INTERVAL 133.1–142.4 m



LITHOLOGIC DESCRIPTION

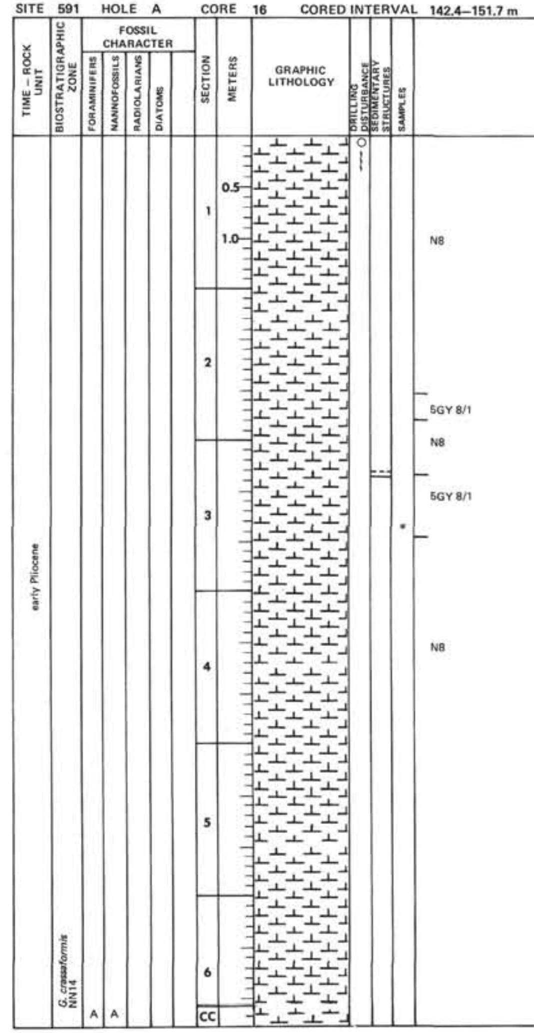
FORAMINIFER-BEARING NANNOFOSSIL OOZE, very light gray (N8), firm, homogenized by multiple (superposed) bioturbation, specks and streaks of iron sulfides (dark to light gray [N4–N6]) are common.

Planolites-like mottles commonly occur throughout the core.

SMEAR SLIDE SUMMARY:

	3, 70
	D
Texture:	
Sand	T
Silt	R
Clay	D
Composition:	
Quartz	T
Mica	T
Heavy minerals	T
Pyrite	T
Foraminifers	C
Calc. nannofossils	D
Sponge spicules	T

SITE 591 HOLE A CORE 16 CORED INTERVAL 142.4–151.7 m



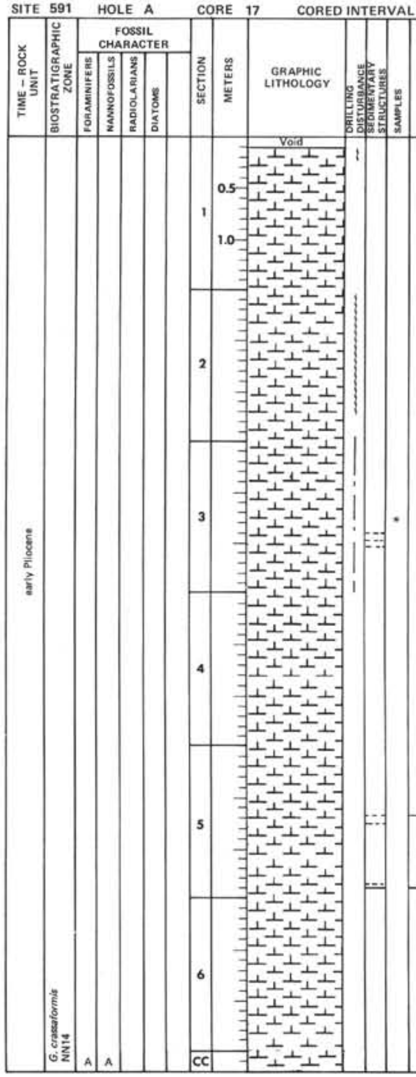
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, totally bioturbated *Planolites*-like mottles are superposed.

SMEAR SLIDE SUMMARY:

	3, 84
	D
Texture:	
Sand	T
Silt	R
Clay	D
Composition:	
Feldspar	T
Heavy minerals	T
Volcanic glass	T
Pyrite	T
Foraminifers	R
Calc. nannofossils	D
Diatoms	T
Radiolarians	T
Sponge spicules	T

SITE 591 HOLE A CORE 17 CORED INTERVAL 151.7–161.0 m



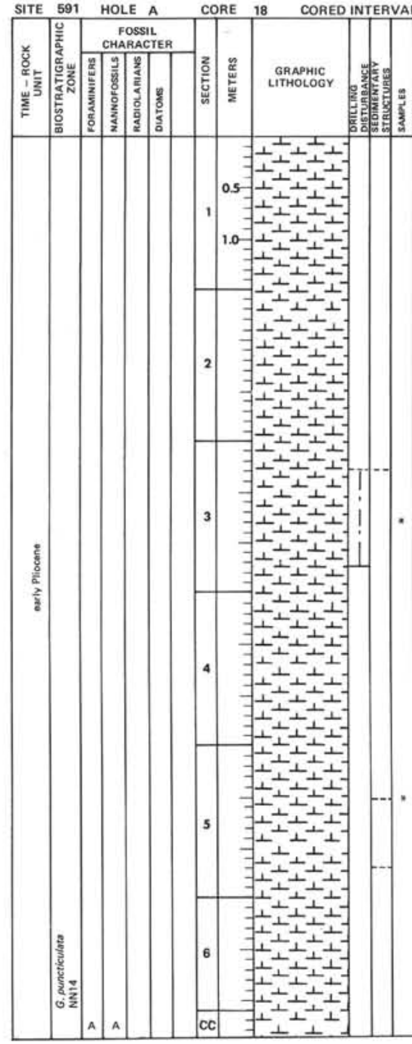
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, homogeneous except for pyritized rims of trace fossils.

SMEAR SLIDE SUMMARY:

	3, 75
	D
Texture:	
Sand	T
Silt	T
Clay	D
Composition:	
Quartz	T
Mica	T
Volcanic glass	T
Pyrite	T
Foraminifers	R
Calc. nannofossils	D
Radiolarians	T

SITE 591 HOLE A CORE 18 CORED INTERVAL 161.0–170.5 m



LITHOLOGIC DESCRIPTION

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

Grayish yellow green (5GY 7/2) colored mottles common (total bioturbation).

SMEAR SLIDE SUMMARY:

	3, 80	5, 52
	D	M
Texture:		
Sand	T	T
Silt	R	R
Clay	D	D
Composition:		
Quartz	–	T
Feldspar	T	T
Mica	T	T
Heavy minerals	T	T
Volcanic glass	T	T
Pyrite	T	–
Foraminifers	R	R
Calc. nannofossils	D	D
Diatoms	T	–
Sponge spicules	T	–

SITE 591 HOLE A CORE 19 CORED INTERVAL 170.5–180.0 m

TIME – ROCK UNIT | BIOSTRATIGRAPHIC ZONE | FOSSIL CHARACTER: FORAMINIFERS, NANNOFOSSILS, RADIOLARIANS, DIATOMS | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | SAMPLES

early Pliocene

G. puncticulata
NN14

A A

Sections: 1, 2, 3, 4, 5, 6, CC

Meters: 0.5, 1.0

N8

5GY 8/1

N8

5GY 8/1

Void

LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, homogeneous.

Grayish yellow green (5GY 7/2) colored mottles with light gray (N6–N7) rims are common.

SMEAR SLIDE SUMMARY:

	3, 80
	D
Texture:	
Sand	T
Silt	R
Clay	D
Composition:	
Feldspar	T
Heavy minerals	T
Carbonate unspec.	T
Foraminifers	R
Calc. nannofossils	D
Sponge spicules	T

SITE 591 HOLE A CORE 20 CORED INTERVAL 180.0–189.5 m

TIME – ROCK UNIT | BIOSTRATIGRAPHIC ZONE | FOSSIL CHARACTER: FORAMINIFERS, NANNOFOSSILS, RADIOLARIANS, DIATOMS | SECTION | METERS | GRAPHIC LITHOLOGY | DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | SAMPLES

late Miocene

G. conomiozea
NN14

A A

Sections: 1, 2, 3, 4, 5, 6, CC

Meters: 0.5, 1.0

Void

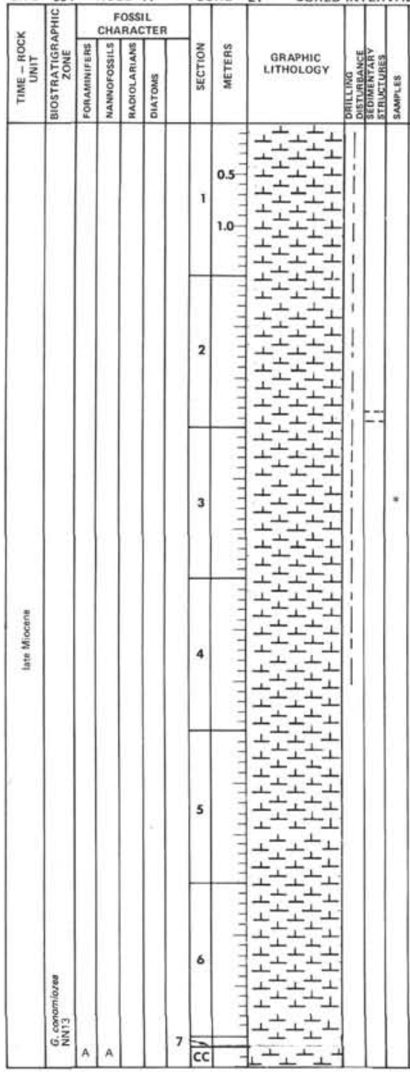
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8). Homogeneous, firm, with laminae of light gray (N6–N7) and light greenish gray (5G 8/1 to 5GY 7/2–8/1), almost totally bioturbated.

SMEAR SLIDE SUMMARY:

	3, 80
	D
Texture:	
Silt	R
Clay	D
Composition:	
Quartz	T
Mica	T
Heavy minerals	T
Pyrite	T
Foraminifers	T
Calc. nannofossils	D
Radiolarians	T
Sponge spicules	T

SITE 591 HOLE A CORE 21 CORED INTERVAL 189.5–198.9 m



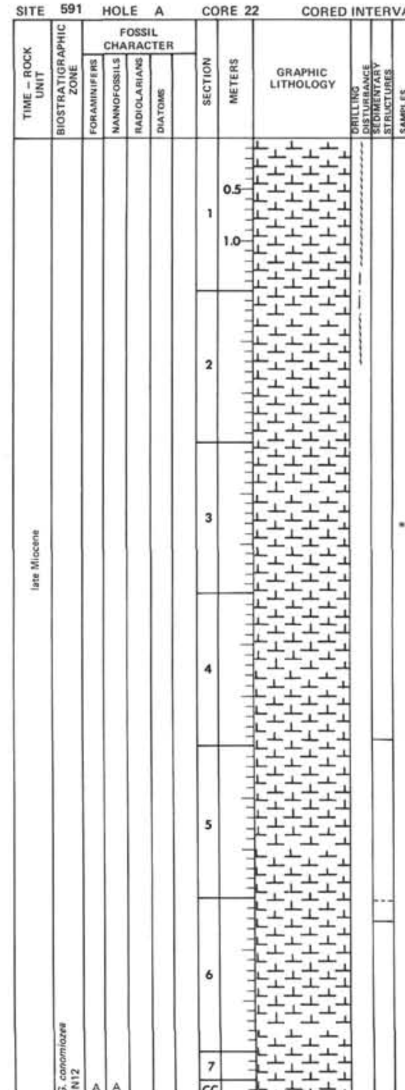
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, homogeneous with specks, streaks, and mottles of medium gray (N6) and light greenish gray (5GY 8/1) to grayish yellow green (5GY 7/2), completely bioturbated.

SMEAR SLIDE SUMMARY:

	3, 20
	D
Texture:	
Sand	T
Silt	R
Clay	D
Composition:	
Quartz	T
Feldspar	T
Heavy minerals	T
Volcanic glass	T
Foraminifers	R
Calc. nannofossils	D
Sponge spicules	T

SITE 591 HOLE A CORE 22 CORED INTERVAL 198.9–208.3 m



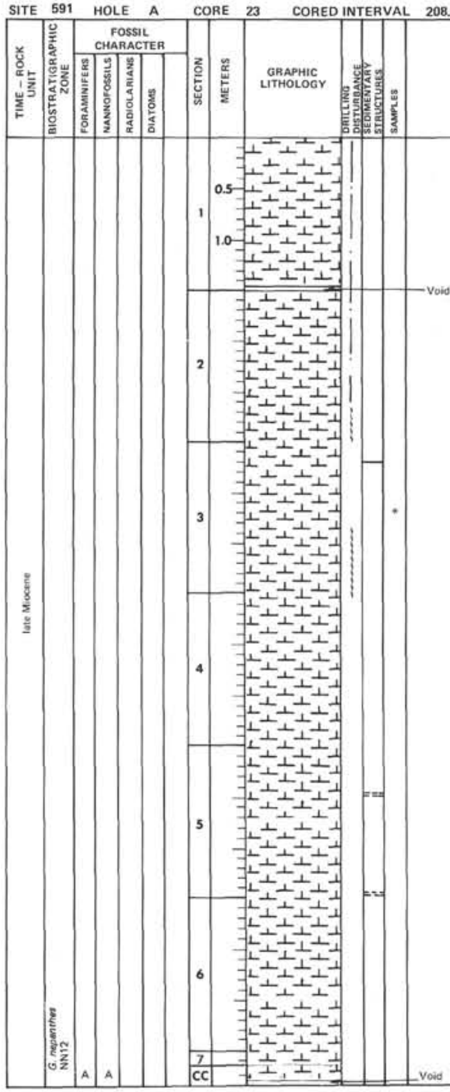
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, bioturbated and homogeneous pyritization of margin of large *Planolites*-like burrows (medium light to light gray [N5–N7]).

SMEAR SLIDE SUMMARY:

	3, 80
	D
Composition:	
Mica	T
Carbonate unspec.	T
Foraminifers	T
Calc. nannofossils	D
Diatoms	T

SITE 591 HOLE A CORE 23 CORED INTERVAL 208.3–217.7 m



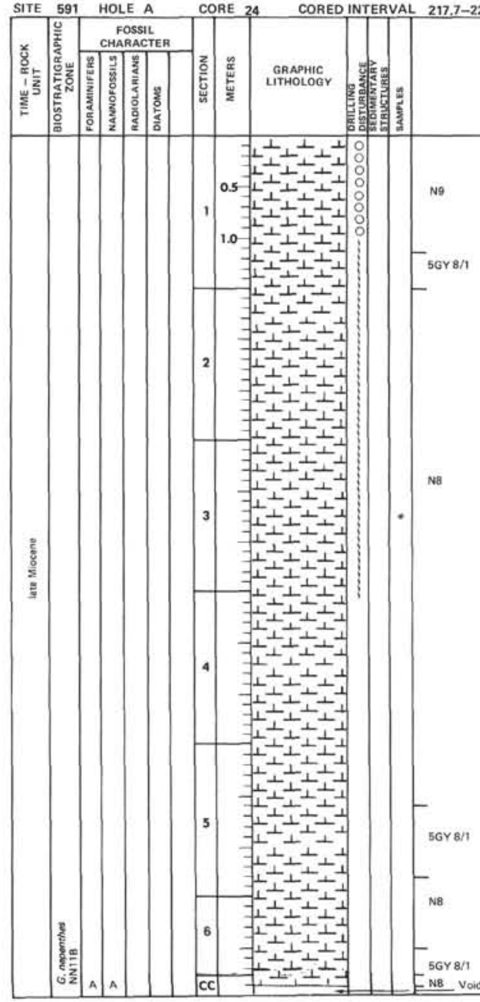
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, very homogeneous except for superposed trace fossils of giant *Planolites*-like burrows and others, and for specks and streaks of iron sulfides (medium to light gray [N6–N7]).

SMEAR SLIDE SUMMARY:

	3, 75
	D
Texture:	
Silt	T
Clay	D
Composition:	
Pyrite	T
Carbonate unspec.	T
Foraminifers	T
Calc. nannofossils	D
Silicoflagellates	T

SITE 591 HOLE A CORE 24 CORED INTERVAL 217.7–227.3 m



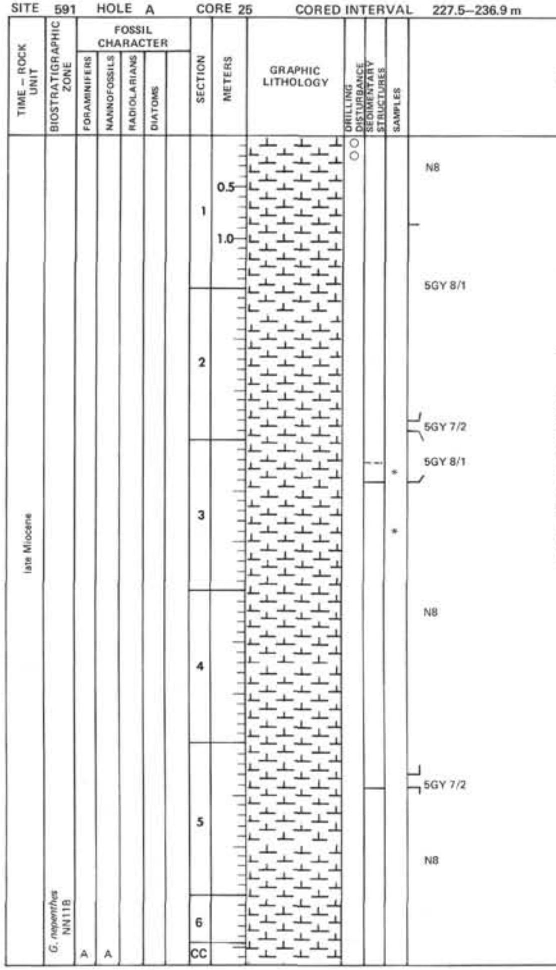
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, predominantly, very light gray (N8) and partly light greenish gray (5GY 8/1), firm but very disturbed by coring.

SMEAR SLIDE SUMMARY:

	3, 80
	D
Texture:	
Sand	T
Silt	T
Clay	D
Composition:	
Mica	T
Volcanic glass	T
Carbonate unspec.	T
Foraminifers	T
Calc. nannofossils	D
Radiolarians	T

SITE 591 HOLE A CORE 25 CORED INTERVAL 227.5–236.9 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8) to light greenish gray (5GY 8/1), firm.

Homogeneous due to bioturbation.

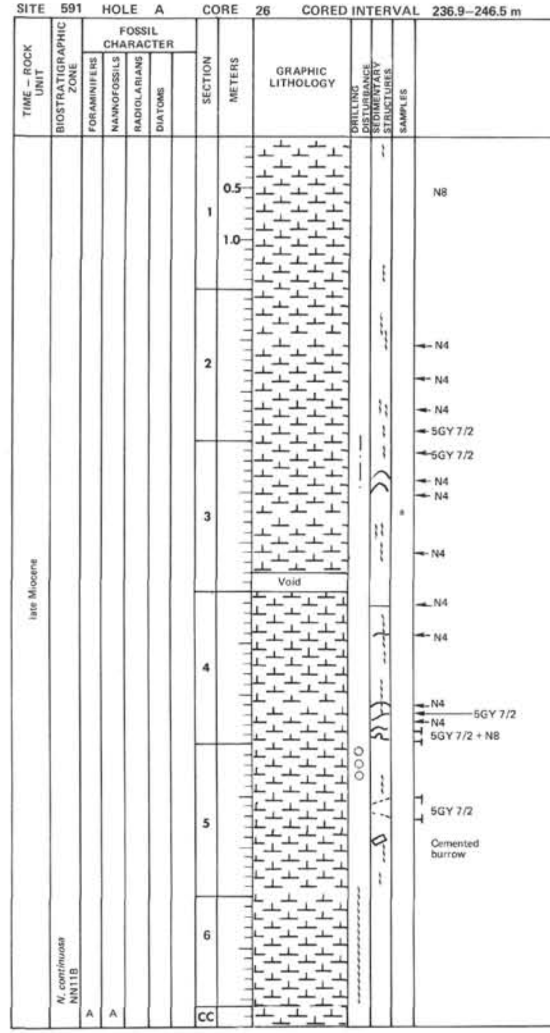
Specks of iron-sulfides of medium to light gray (N4–N7) and mottles or bands of grayish yellow green (5GY 7/2) to light greenish gray (5GY 8/1) are common.

Occasionally, small pockets including volcanic glass occur (grayish olive [10Y 4/2]) at about 30 cm in Section 3.

SMEAR SLIDE SUMMARY:

	3, 28	3, 80
	M	D
Texture:		
Sand	C	T
Silt	C	R
Clay	A	D
Composition:		
Quartz	T	–
Feldspar	T	T
Heavy minerals	T	T
Volcanic glass	A	–
Foraminifers	R	R
Calc. nannofossils	A	D
Diatoms	–	T
Radiolarians	–	T

SITE 591 HOLE A CORE 26 CORED INTERVAL 236.9–246.5 m



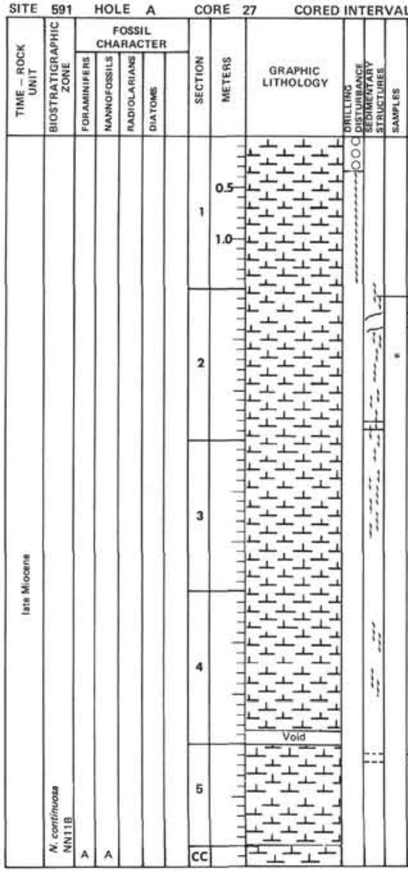
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), soft to stiff, homogeneous, with streaks of medium dark gray (N4) iron sulfide and mottles of grayish yellow green (5GY 7/2). Bioturbation common. Cemented burrow (celestite?) in Section 5.

SMEAR SLIDE SUMMARY:

	3, 72
Composition:	
Feldspar	T
Volcanic glass	T
Pyrite	T
Foraminifers	R
Calc. nannofossils	D
Diatoms	T
Radiolarians	T
Sponge spicules	T

SITE 591 HOLE A CORE 27 CORED INTERVAL 246.5–256.0 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, bioturbation moderate, common mottles of grayish yellow green (5GY 7/2), common streaks and thin laminae of medium dark gray (N4) iron sulfide.

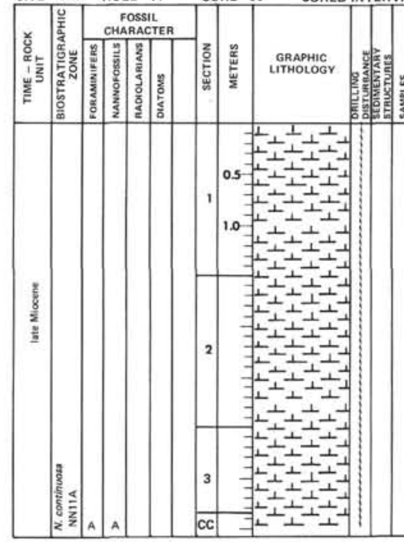
SMEAR SLIDE SUMMARY:

	2, 72
	D
Composition:	
Foraminifers	R
Calc. nannofossils	D
Sponge spicules	T

Core 28, 256.0–265.5 m: no recovery.

Core 29, 265.0–275.0 m: no recovery.

SITE 591 HOLE A CORE 30 CORED INTERVAL 275.0–284.5 m



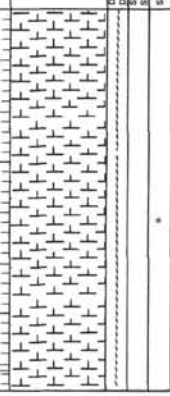
LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8) with streaks of medium dark gray (N4) iron sulfide and grayish yellow green (5GY 7/2) throughout.

Core totally wrecked by the coring procedure and splitting, thus a detailed description is impossible.

SITE 591 HOLE B CORE 1 CORED INTERVAL 270.6–280.2 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES
late Miocene	*N. continuosa* NN11A	A	A			1	0.5, 1.0				
						2					*
						3					
						CC					



LITHOLOGIC DESCRIPTION

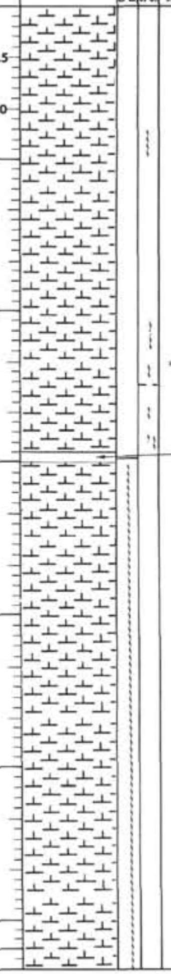
NANNOFOSSIL OOZE, very light gray (N8), firm, homogenized by rotary coring, streaks of medium dark gray (N4) and blobs of grayish yellow green (5GY 7/2) scattered throughout.

SMEAR SLIDE SUMMARY:

	2, 69
	D
Composition:	
Volcanic glass	T
Pyrite	T
Foraminifers	R
Calc. nannofossils	D
Diatoms	T
Radiolarians	T

SITE 591 HOLE B CORE 2 CORED INTERVAL 280.2–289.8 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FOSSIL CHARACTER: FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES
late Miocene	*N. continuosa* NN11A	A	A			1	0.5, 1.0				
						2					
						3					* ← N4
											— IW
						4					
						5					
						6					
						7					
						CC					



LITHOLOGIC DESCRIPTION

NANNOFOSSIL OOZE, very light gray (N8), firm, homogeneous with a few streaks of medium dark gray (N4) iron sulfide. Severe drilling disturbance below Section 3. Small nodule of CHERT, light gray (N7) at Section 5, 145 cm – working half.

SMEAR SLIDE SUMMARY:

	3, 61
	D
Composition:	
Palagonite	T
Pyrite	T
Zeolite	T
Foraminifers	R
Calc. nannofossils	D
Radiolarians	T

SITE 591 HOLE B CORE 3 CORED INTERVAL 289.8–299.4 m

TIME – ROCK UNIT: late Miocene

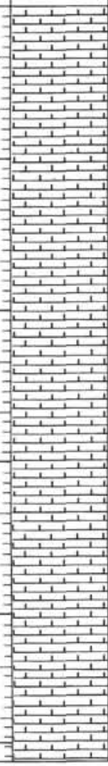
BIOSTRATIGRAPHIC ZONE: N. continuosa NN11A

FOSSIL CHARACTER: FORAMINIFERS A; NANNOFOSSILS A; RADIOLARIANS; DIATOMS

SECTION: 1, 2, 3, 4, 5, CC

METERS: 0.5, 1.0

GRAPHIC LITHOLOGY



DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | SAMPLES: *

LITHOLOGIC DESCRIPTION

NANNOFOSSIL CHALK, very light gray (N8) with blebs of medium dark gray (N4) iron sulfides. Core is broken into "biscuits" and "drilling soup" throughout. Nannofossils show overgrowths.

SMEAR SLIDE SUMMARY:

	2, 85
	D
Composition:	
Volcanic glass	T
Foraminifers	R
Calc. nannofossils	D
Diatoms	T
Radiolarians	T
Sponge spicules	T
Silicoflagellates	T

SITE 591 HOLE B CORE 4 CORED INTERVAL 299.4–308.8 m

TIME – ROCK UNIT: late Miocene

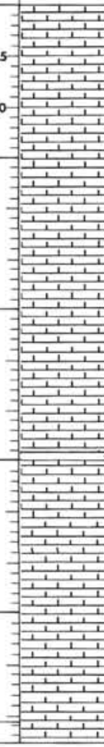
BIOSTRATIGRAPHIC ZONE: N. continuosa NN11A

FOSSIL CHARACTER: FORAMINIFERS A; NANNOFOSSILS A; RADIOLARIANS; DIATOMS

SECTION: 1, 2, 3, 4, 5, CC

METERS: 0.5, 1.0

GRAPHIC LITHOLOGY



DRILLING DISTURBANCE | SEDIMENTARY STRUCTURES | SAMPLES

5G 8/1
5G 8/1
5G 8/1
5G 8/1
5G 8/1
5G 8/1
5G 8/1
5G 8/1 N4
5G 8/1
5G 8/1
5G 8/1
5G 8/1 N4
5G 8/1 N4
5G 8/1
5G 8/1 N4
5G 8/1 N4
5G 8/1
5G 8/1
IW
5G 8/1
N4
5G 8/1 N4
5G 8/1
5G 8/1
5G 8/1 N4
5G 8/1
5G 8/1
5G 8/1
5G 8/1

LITHOLOGIC DESCRIPTION

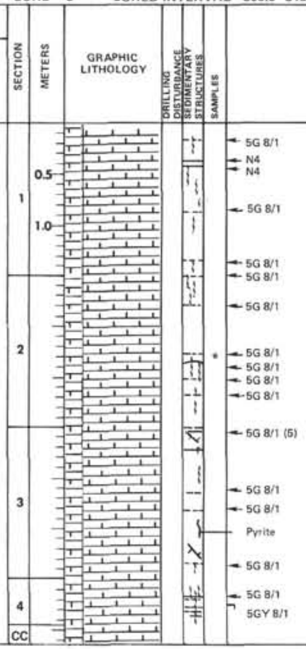
NANNOFOSSIL CHALK, very light gray (N8), with common streaks, pods, and diffusion bands of medium dark gray (N4) iron sulfide. Altered ash(?) of light greenish gray (5G 8/1) color is common in very faint bands. Often a band of N4 is beneath the 5G 8/1. Burrows are very common and include *Zoophycos* and *Planolites*.

SMEAR SLIDE SUMMARY:

	3, 92
	D
Composition:	
Volcanic glass	T
Foraminifers	R
Calc. nannofossils	D
Diatoms	T
Radiolarians	T
Sponge spicules	T
Silicoflagellates	T

SITE 591 HOLE B CORE 5 CORED INTERVAL 308.8–318.2 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS
late Miocene	NN10		A		
	N. continuosa NN10	A	A		



LITHOLOGIC DESCRIPTION

ENTIRE CORE BROKEN INTO BISCUITS SURROUNDED BY GROUND-UP SEDIMENT.

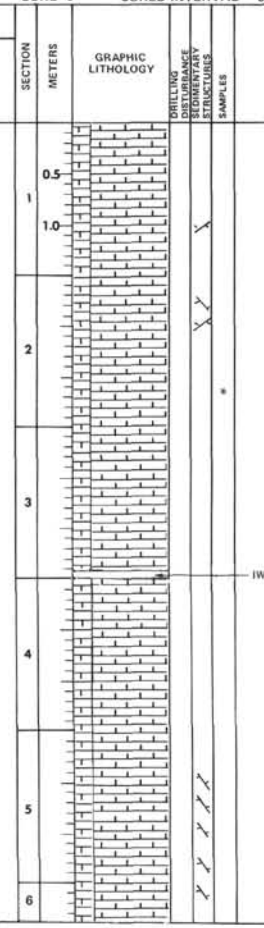
FORAMINIFER-BEARING NANNOFOSSIL CHALK, very light gray (N8) grading to light greenish gray (5GY 8/1) in Section 4. Bioturbation very evident with *Zoophycos* and *Planolites* common. Altered ash(?) light greenish gray (5GY 8/1) very common as thin bands. Microfaults occur in Section 3.
common, typically medium dark gray (N4).

SMEAR SLIDE SUMMARY:

Composition:	2, 85
Pyrite	T
Carbonate unspec.	A
Foraminifers	C
Calc. nannofossils	A
Diatoms	T
Radiolarians	T
Sponge spicules	T

SITE 591 HOLE B CORE 6 CORED INTERVAL 318.2–327.6 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS
late Miocene	*N. continuosa* NN10	A	A		



LITHOLOGIC DESCRIPTION

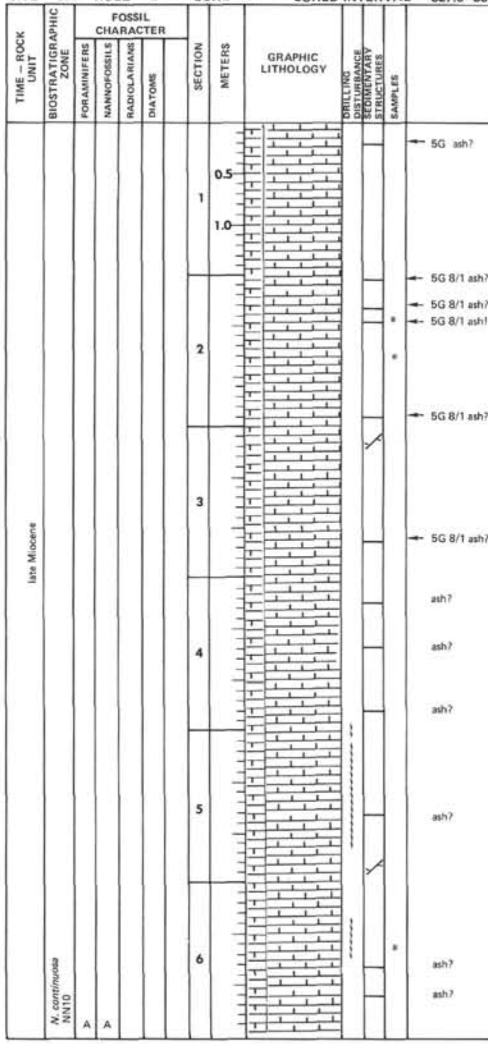
FORAMINIFER-BEARING NANNOFOSSIL CHALK, very light gray (N8), firm, with lots of light greenish gray (5G 8/1) and medium dark gray (N4) bands of pyrite and iron sulfides. Microfaults with about 15 mm sepatation (normal dip-slip) are common.

Bioturbation very evident with *Zoophycos* and *Planolites*-like common to abundant.

SMEAR SLIDE SUMMARY:

Composition:	2, 112 D
Foraminifers	C
Calc. nannofossils	D
Diatoms	T
Radiolarians	T

SITE 591 HOLE B CORE 7 CORED INTERVAL 327.6–337.2 m



LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL CHALK, very light gray (N8), firm with lots of light greenish gray (5G 8/1) thin laminae and paired color band of 5G 8/1 and light gray (N7).

Light greenish gray bands composed of parallel laminae, possibly altered from ash.

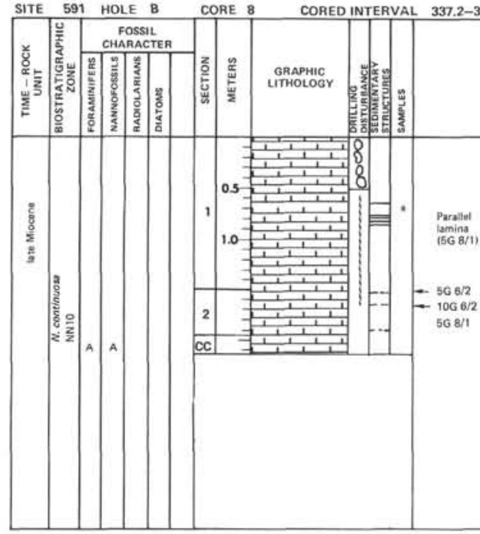
Bioturbation common (*Zoophycos*, *Planolites*-like, etc.).

Iron sulfides halo chains common.

SMEAR SLIDE SUMMARY:

	2, 56	2, 80	6, 60
	M	D	D
Texture:			
Sand	T	T	T
Silt	C	C	C
Clay	D	D	D
Composition:			
Quartz	–	T	–
Feldspar	–	–	T
Volcanic glass	T	–	–
Pyrite	T	T	–
Carbonate unspec.	T	T	T
Foraminifers	R	C	C
Calc. nannofossils	D	D	D
Diatoms	T	T	R
Radiolarians	T	T	T
Sponge spicules	–	–	T

SITE 591 HOLE B CORE 8 CORED INTERVAL 337.2–346.8 m



LITHOLOGIC DESCRIPTION

NANNOFOSSIL CHALK, very light green (N8) to white (N9), soft (due to coring) to firm.

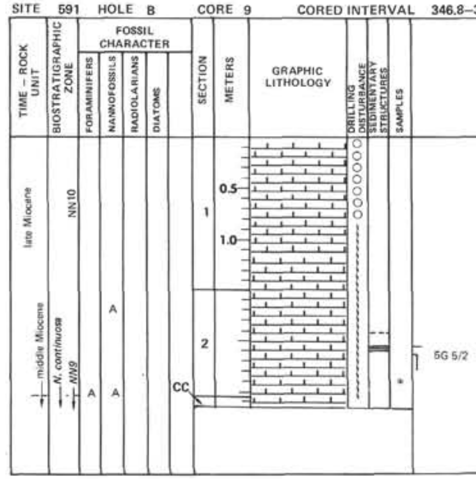
Bioturbed structure (burrows) are less abundant than in Core 7.

Parallel pale green (10G 6/2) thin laminae remarkable. remarkable.

SMEAR SLIDE SUMMARY:

	1, 70
	D
Texture:	
Sand	T
Silt	R
Clay	D
Composition:	
Heavy minerals	T
Volcanic glass	T
Pyrite	T
Carbonate unspec.	T
Foraminifers	R
Calc. nannofossils	D
Diatoms	T
Radiolarians	T
Sponge spicules	T

SITE 591 HOLE B CORE 9 CORED INTERVAL 346.8–356.4 m



LITHOLOGIC DESCRIPTION

Very disturbed by coring, poor recovery.

NANNOFOSSIL CHALK, very light gray (N8), predominantly soft by coring except for biscuits of firm sediment with parallel lamination of thin grayish green (5G 5/2) laminae.

SMEAR SLIDE SUMMARY:

	2, 93
	D
Texture:	
Sand	T
Silt	C
Clay	D
Composition:	
Quartz	T
Volcanic glass	T
Carbonate unspec.	R
Foraminifers	R
Calc. nannofossils	D
Radiolarians	T

SITE 591 HOLE B CORE 10 CORED INTERVAL 356.4–366.0 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES	LITHOLOGIC DESCRIPTION
middle Miocene	*G. mayeri* NN9	A	A			1, 2, 3	0.5, 1.0				*	5G 7/2; 5G 7/2; IW; 5G 8/1; 5G 7/2

Very disturbed by coring.

FORAMINIFER-BEARING NANNOFOSSIL CHALK, very light gray (N8) to white (N9) with thin lamina of pale green (5G 7/2) to light greenish gray (5G 8/1).

SMEAR SLIDE SUMMARY:

	2, 77
	D
Texture:	
Sand	T
Silt	R
Clay	D
Composition:	
Pyrite	T
Carbonate unspec.	R
Foraminifers	C
Calc. nannofossils	D
Diatoms	T
Radiolarians	T

SITE 591 HOLE B CORE 11 CORED INTERVAL 366.0–375.6 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES	LITHOLOGIC DESCRIPTION
middle Miocene	NN9		A			1	0.5, 1.0				*	
	G. mayeri NN8	A	A			CC						

FORAMINIFER-BEARING NANNOFOSSIL CHALK, very light gray (N8), originally firm, with parallel thin laminae of pale green (5G 7/2).

SMEAR SLIDE SUMMARY:

	1, 63
	D
Texture:	
Sand	T
Silt	C
Clay	D
Composition:	
Feldspar	T
Heavy minerals	T
Carbonate unspec.	T
Foraminifers	C
Calc. nannofossils	D
Radiolarians	T

SITE 591 HOLE B CORE 12 CORED INTERVAL 375.6–385.2 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES	LITHOLOGIC DESCRIPTION
middle Miocene	NN7		A			1	0.5, 1.0				*	IW
	G. mayeri NN7	A	A			2, CC						

FORAMINIFER-BEARING NANNOFOSSIL CHALK, very light gray (N8) to white (N9), naturally firm, very disturbed by coring with very thin laminae of dusky green (5G 3/2).

SMEAR SLIDE SUMMARY:

	1, 60
	D
Texture:	
Sand	T
Silt	R
Clay	D
Composition:	
Feldspar	T
Pyrite	T
Carbonate unspec.	T
Foraminifers	C
Calc. nannofossils	D
Diatoms	T
Sponge spicules	T

SITE 591 HOLE B CORE 13 CORED INTERVAL 385.2–394.8 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS	GRAPHIC LITHOLOGY	DRILLING DISTURBANCE	SEDIMENTARY STRUCTURES	SAMPLES	LITHOLOGIC DESCRIPTION
middle Miocene	NN6		A			1, 2	0.5, 1.0				*	
	G. mayeri NN6	A	A			3, CC						

FORAMINIFER-BEARING NANNOFOSSIL CHALK, very light greenish gray (5GY 8/1–N9), biscuits with very thin laminae of grayish green (5G 5/2) and pyrite and iron sulfides of grayish purple (5P 4/2).

SMEAR SLIDE SUMMARY:

	1, 50
	D
Texture:	
Sand	T
Silt	C
Clay	D
Composition:	
Quartz	T
Carbonate unspec.	R
Foraminifers	C
Calc. nannofossils	D
Radiolarians	T

SITE 591 HOLE B CORE 14 CORED INTERVAL 394.8–404.4 m

TIME – ROCK UNIT: middle Miocene

BIOSTRATIGRAPHIC ZONE: *G. mayeri* NN6

FOSSIL CHARACTER: FORAMINIFERS A; NANNOFOSSILS A

SECTION: 1, 2, CC

METERS: 0.5, 1.0

GRAPHIC LITHOLOGY: IW

LITHOLOGIC DESCRIPTION

NANNOFOSSIL CHALK, very light gray (N8); firm biscuits and soft slurry, very disturbed by coring and poor recovery; with thin laminae of light greenish gray (5G 8/1) and grayish blue (5PB 5/2), pyrite specks, burrows of *Zoophycos* and *Chondrites*, etc.

SMEAR SLIDE SUMMARY:

	1, 31
Texture:	
Sand	T
Silt	R
Clay	D
Composition:	
Feldspar	T
Heavy minerals	T
Carbonate unspec.	T
Foraminifers	R
Calc. nannofossils	D
Radiolarians	T
Sponge spicules	T

SITE 591 HOLE B CORE 15 CORED INTERVAL 404.4–414.0 m

TIME – ROCK UNIT: middle Miocene

BIOSTRATIGRAPHIC ZONE: *G. fohsi* s. l. NN6

FOSSIL CHARACTER: FORAMINIFERS A; NANNOFOSSILS A

SECTION: 1, 2, 3, CC

METERS: 0.5, 1.0

ash?
ash?
ash?
ash?

LITHOLOGIC DESCRIPTION

NANNOFOSSIL CHALK, very light gray (N8), firm, moderate drilling disturbance, with lots of trace fossils and green laminae. *Zoophycos*- and *Planolites*-like burrows are present.

SMEAR SLIDE SUMMARY:

	2, 70 D
Texture:	
Sand	R
Silt	R
Clay	D
Composition:	
Quartz	T
Pyrite	T
Foraminifers	R
Calc. nannofossils	D
Diatoms	T
Radiolarians	T
Sponge spicules	T

SITE 591 HOLE B CORE 16 CORED INTERVAL 414.0–423.6 m

TIME – ROCK UNIT: middle Miocene

BIOSTRATIGRAPHIC ZONE: *G. fohsi* s. l. NN6

FOSSIL CHARACTER: FORAMINIFERS A; NANNOFOSSILS A

SECTION: 1

LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL CHALK, very light gray (N8) to light gray (N7), completely bioturbed with dense piles of burrow lenses.

SMEAR SLIDE SUMMARY:

	1, 62 D
Texture:	
Sand	T
Silt	R
Clay	D
Composition:	
Quartz	T
Pyrite	T
Carbonate unspec.	T
Foraminifers	C
Calc. nannofossils	D
Diatoms	T
Radiolarians	T

SITE 591 HOLE B CORE 17 CORED INTERVAL 423.6–433.2 m

TIME – ROCK UNIT: middle Miocene

BIOSTRATIGRAPHIC ZONE: *G. fohsi* s. l. NN6

FOSSIL CHARACTER: FORAMINIFERS A; NANNOFOSSILS A

SECTION: 1, 2, 3, 4

METERS: 0.5, 1.0

ash?!
ash?
ash??
N7 ash?
N7 ash?
ash?

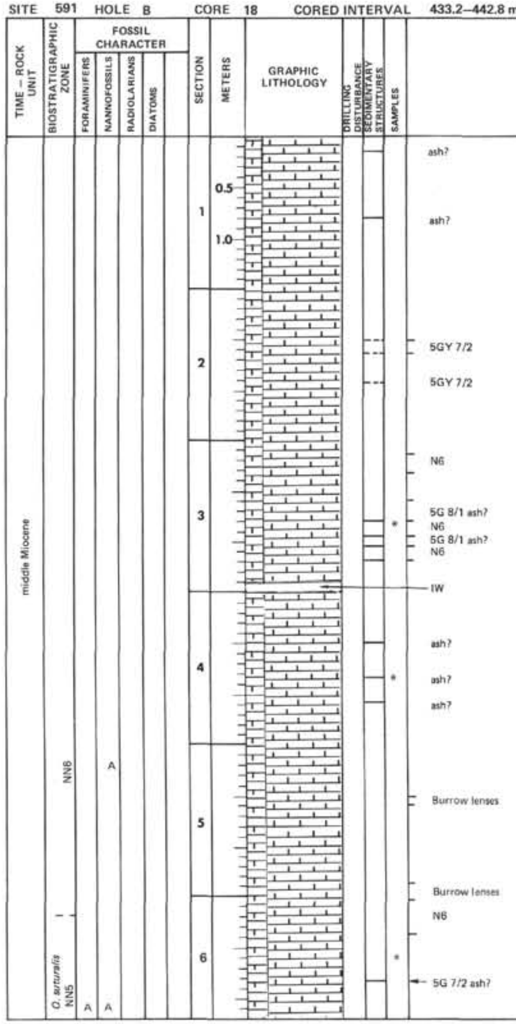
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL CHALK, very light gray (N8) with a few zones of burrow lenses of light gray (N8), firm, with several zones of fine intervals of parallel laminae (grayish green [5G 5/2]).

SMEAR SLIDE SUMMARY:

	1, 53 M	2, 7 M	2, 43 D
Texture:			
Sand	T	–	T
Silt	R	–	R
Clay	D	–	D
Composition:			
Quartz	T	–	T
Feldspar	–	–	T
Volcanic glass	T	–	–
Pyrite	–	D	–
Carbonate unspec.	T	–	T
Foraminifers	C	–	C
Calc. nannofossils	D	R	D
Diatoms	T	–	T
Radiolarians	–	–	T
Sponge spicules	–	–	T

SITE 591 HOLE B CORE 18 CORED INTERVAL 433.2–442.8 m



LITHOLOGIC DESCRIPTION

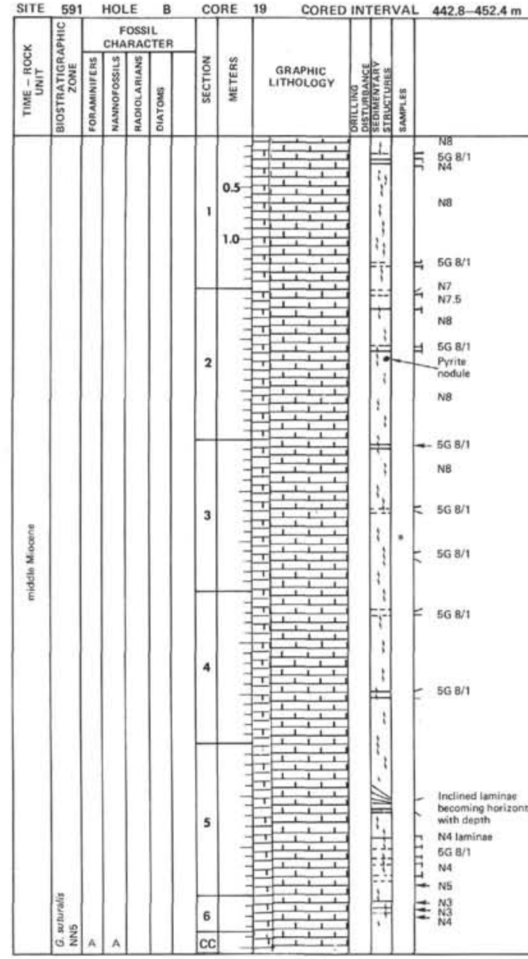
FORAMINIFER-BEARING NANNOFOSSIL CHALK, predominantly, very light gray (N8) to white (N9) with chemically changed zones of light gray (N7) to medium gray (N6). Parallel laminae of grayish green (5G 7/2) and burrow lenses typically gray (N6) common.

Bioturbation distinct.

SMEAR SLIDE SUMMARY:

	3, 72	4, 91	6, 60
	D	M	D
Texture:			
Sand	T	R	R
Silt	C	C	C
Clay	D	A	D
Composition:			
Quartz	T	T	T
Pyrite	T	–	–
Carbonate unspec.	T	C	R
Foraminifers	C	A	C
Calc. nannofossils	D	A	D
Diatoms	–	T	–
Radiolarians	T	T	T
Sponge spicules	T	T	T

SITE 591 HOLE B CORE 19 CORED INTERVAL 442.8–452.4 m



LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL CHALK, very light gray (N8) with cycles of light greenish gray (5G 8/1), very hard, entire sequence is moderately bioturbated with *Zoophycos*- and *Planolites*-like burrows. The (5G 8/1) interbeds are beginning to show flaser type structure. Pyrite nodules rare.

SMEAR SLIDE SUMMARY:

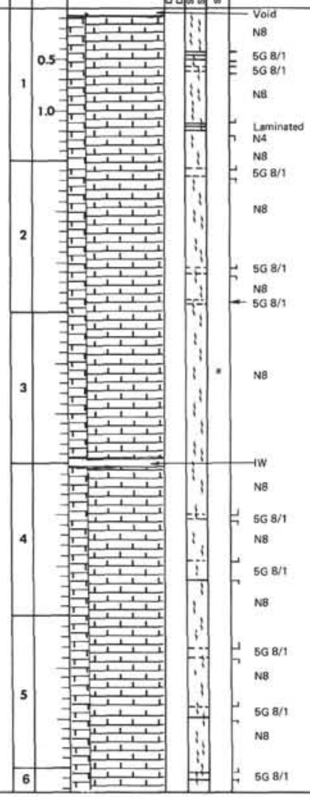
	3, 88
	D
Composition:	
Quartz	T
Volcanic glass	T
Carbonate unspec.	A
Foraminifers	C
Calc. nannofossils	A
Radiolarians	T
Sponge spicules	T

SITE 591 HOLE B CORE 20 CORED INTERVAL 452.4–462.0 m

TIME-ROCK UNIT: middle Miocene

BIOSTRATIGRAPHIC ZONE: *P. glomerosa curva* NN5

FOSSIL CHARACTER: Foraminifers A; Nannofossils A



LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL CHALK, very light gray (N8) with cyclic interbeds of very light greenish gray (5G 8/1) that are bioturbated and show flaser beds. Very hard almost limestone. Bioturbation throughout with *Zoophycos*- and *Planolites*-like burrows. Finely laminated colors in 5G hues in Section 1.

SMEAR SLIDE SUMMARY:

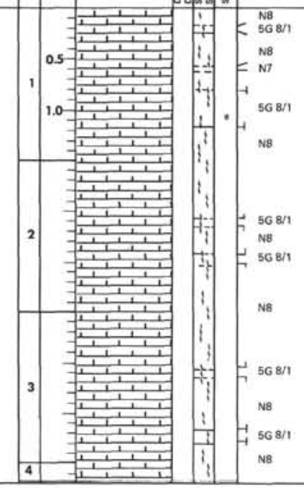
	3, 57
	D
Composition:	
Volcanic glass	T
Carbonate unspec.	A
Foraminifers	C
Calc. nannofossils	A
Diatoms	T
Sponge spicules	T

SITE 591 HOLE B CORE 21 CORED INTERVAL 462.0–471.6 m

TIME-ROCK UNIT: middle Miocene

BIOSTRATIGRAPHIC ZONE: *P. glomerosa curva* NN5

FOSSIL CHARACTER: Foraminifers A; Nannofossils C



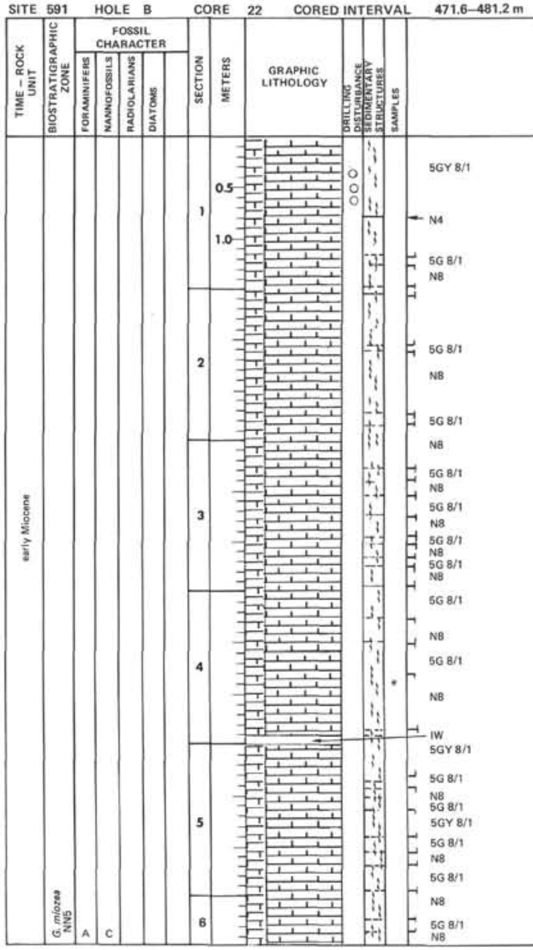
LITHOLOGIC DESCRIPTION

NANNOFOSSIL CHALK, very light gray (N8) with cyclic interbeds of various hues of light greenish gray (5G 8/1). Bioturbated throughout with *Planolites*-like and *Zoophycos* burrows. Very hard. A few pods of pyrite.

SMEAR SLIDE SUMMARY:

	1, 109
	D
Composition:	
Carbonate unspec.	A
Foraminifers	R
Calc. nannofossils	A
Radiolarians	T

SITE 591 HOLE B CORE 22 CORED INTERVAL 471.6–481.2 m



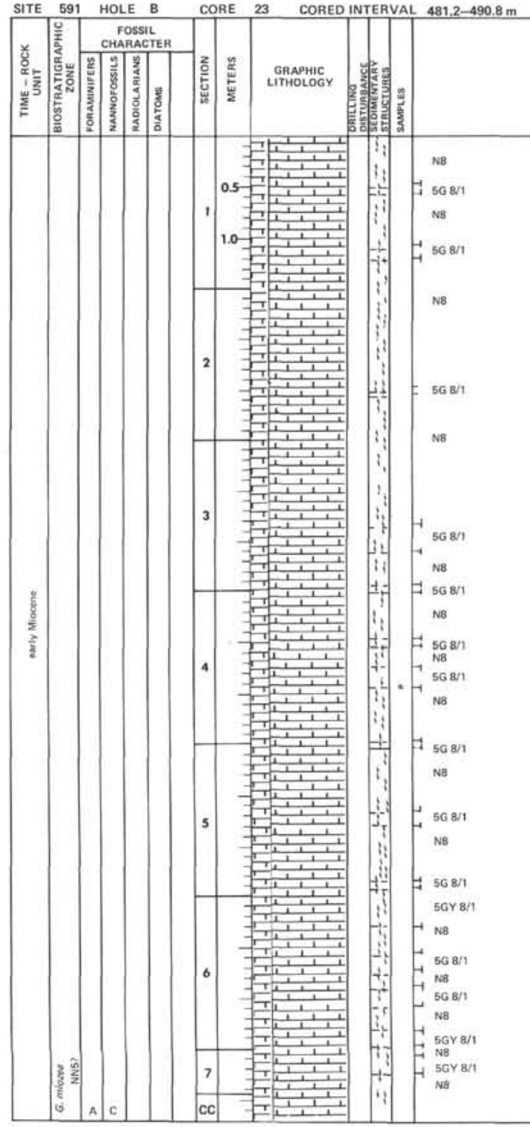
LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL CHALK, alternating cycles of light greenish gray (5GY 8/1 and 5G 8/1) and very light gray (N8), very hard. Bioturbated throughout. Flaser structures developed in (5G 8/1) interbeds. Iron sulfide bands rare.

SMEAR SLIDE SUMMARY:

	4, 95
	D
Composition:	
Volcanic glass	T
Carbonate unspec.	A
Foraminifers	C
Calc. nannofossils	A
Diatoms	T
Radiolarians	T
Sponge spicules	T

SITE 591 HOLE B CORE 23 CORED INTERVAL 481.2–490.8 m



LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL CHALK, very light gray (N8) with alternating light greenish gray (5GY 8/1 and 5G 8/1). Iron sulfide streaks and spots common. Totally bioturbated and extremely hard – almost limestone.

Flaser structure developed in some (5G 8/1) interbeds.

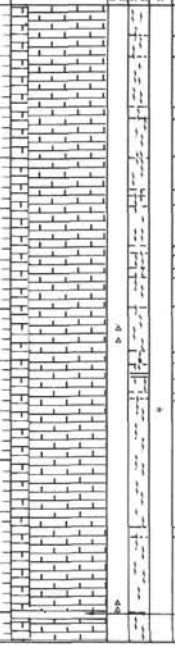
SMEAR SLIDE SUMMARY:

	4, 90
	D
Composition:	
Volcanic glass	T
Carbonate unspec.	A
Foraminifers	C
Calc. nannofossils	A
Radiolarians	T
Sponge spicules	T

SITE 591 HOLE B CORE 24 CORED INTERVAL 490.8–500.4 m

TIME – ROCK UNIT	BIOSTRATIGRAPHIC ZONE	FORAMINIFERS	NANNOFOSSILS	RADIOLARIANS	DIATOMS	SECTION	METERS
lower Miocene?	*G. miozea* NN4?	A	C			1, 2, 3, 4, 5	0.5, 1.0

GRAPHIC LITHOLOGY / DRILLING DISTURBANCE / SEDIMENTARY STRUCTURES / SAMPLES



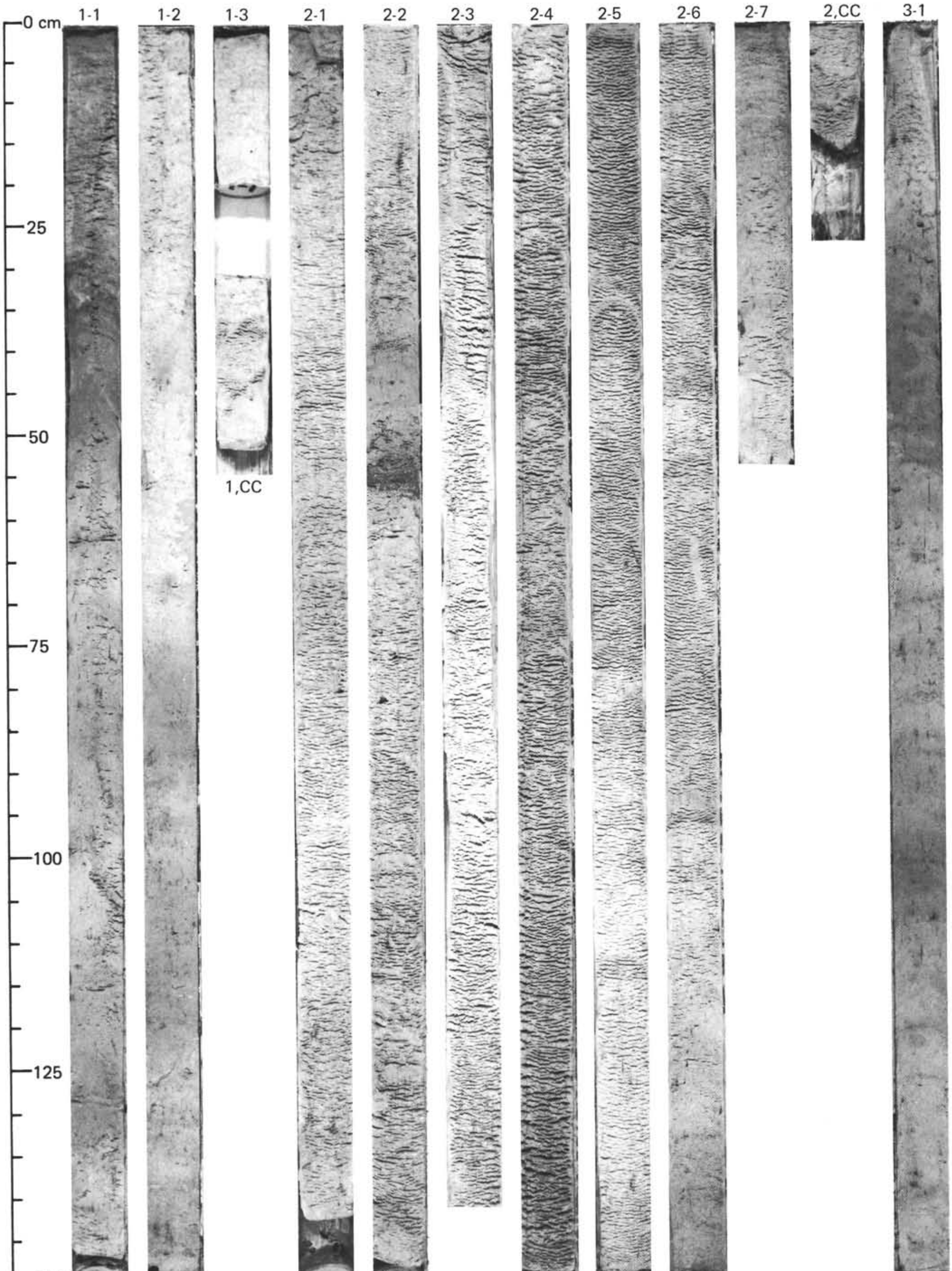
N8
5G 8/1 + N8
N8
5G 8/1
N8
5GY 8/1
5G 8/1
5G 8/1
5GY 8/1
5G 8/1
5G 8/1
5GY 8/1
5GY 8/1
5G 8/1 Flasers
5G 8/1
5G 8/1
5GY 8/1
5G 8/1 Flasers
5GY 8/1
IW

LITHOLOGIC DESCRIPTION

FORAMINIFER-BEARING NANNOFOSSIL CHALK, very light gray (N8), light greenish gray (5GY 8/1 and 5Y 8/1) interbedded. Very hard and almost a limestone. Thoroughly bioturbated and a few zones show flaser structures. *Zoophycos* very rare. All contacts between interbeds are gradational, burrowed but horizontal.

SMEAR SLIDE SUMMARY:

	3, 99
	D
Composition:	
Carbonate unspec.	A
Foraminifers	C
Calc. nannofossils	A
Sponge spicules	T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2,CC
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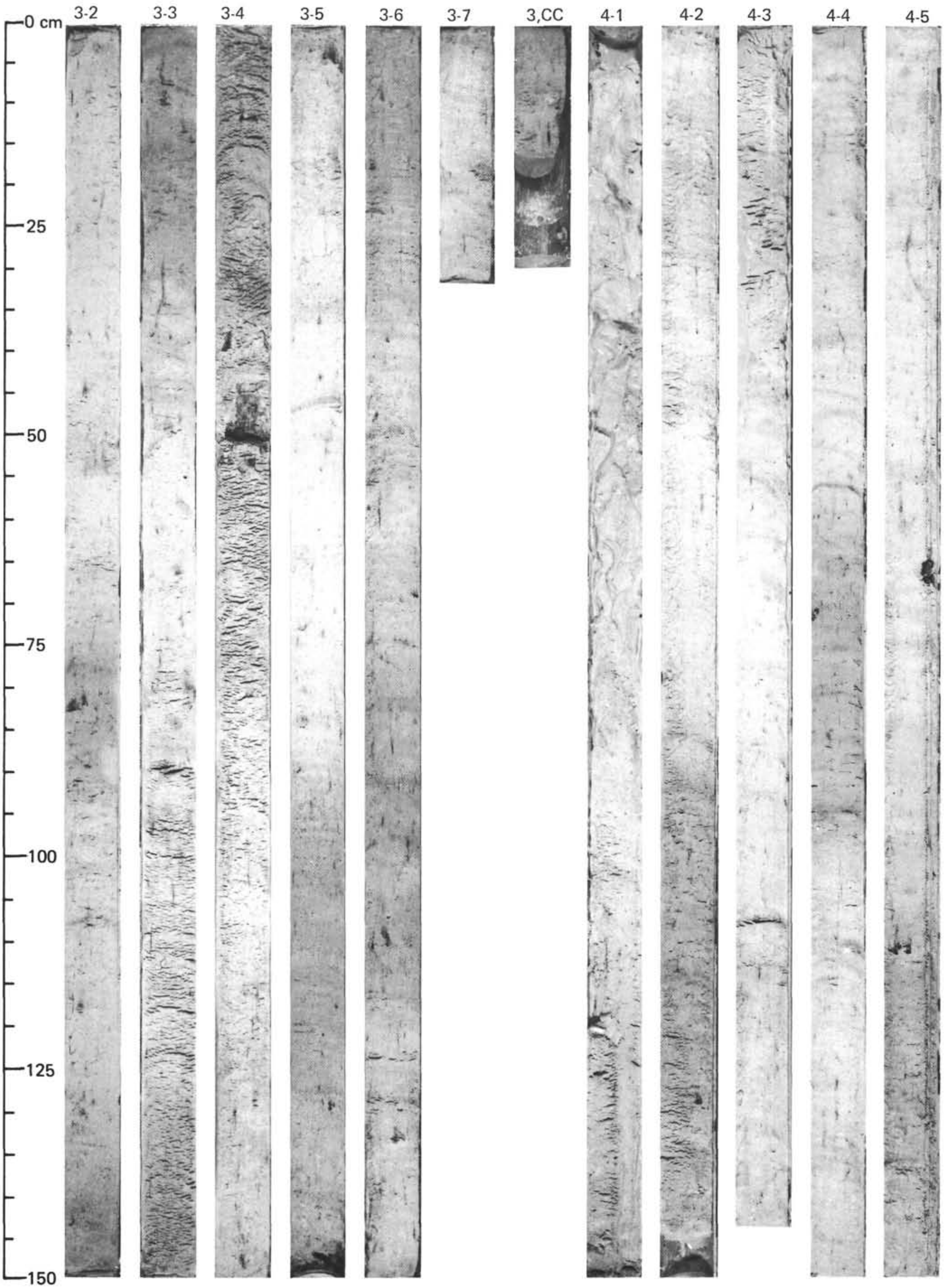
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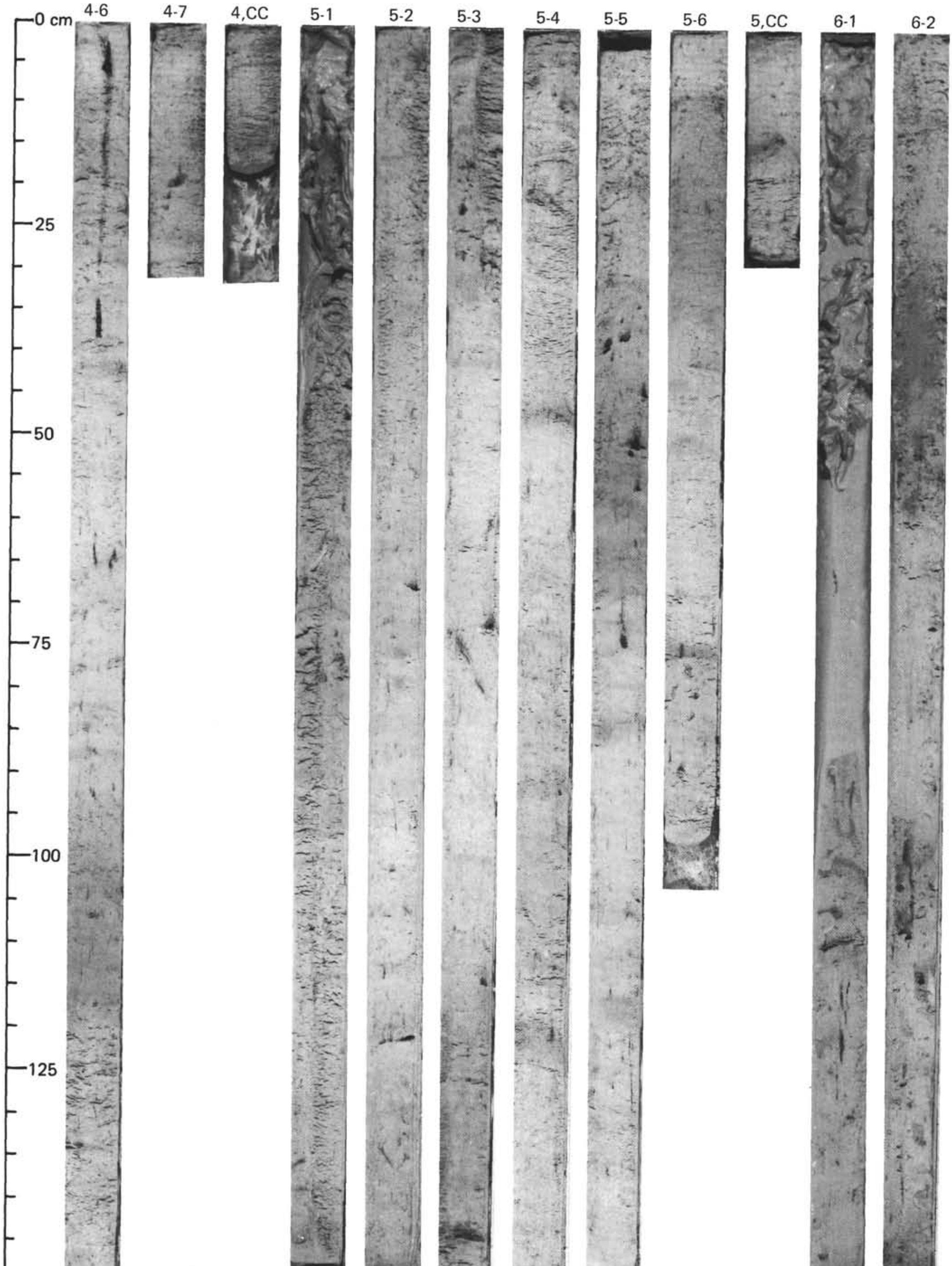
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6-1
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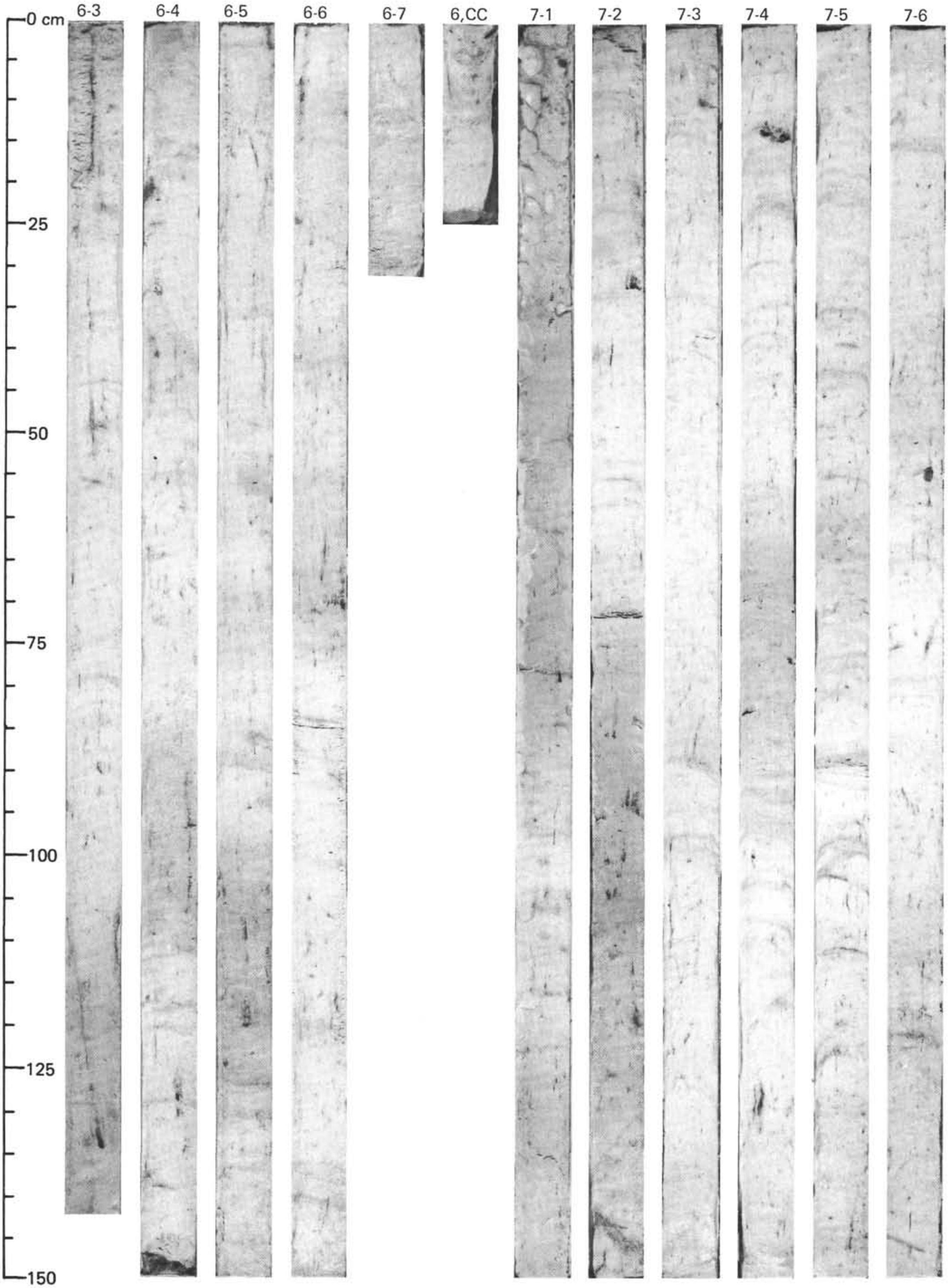
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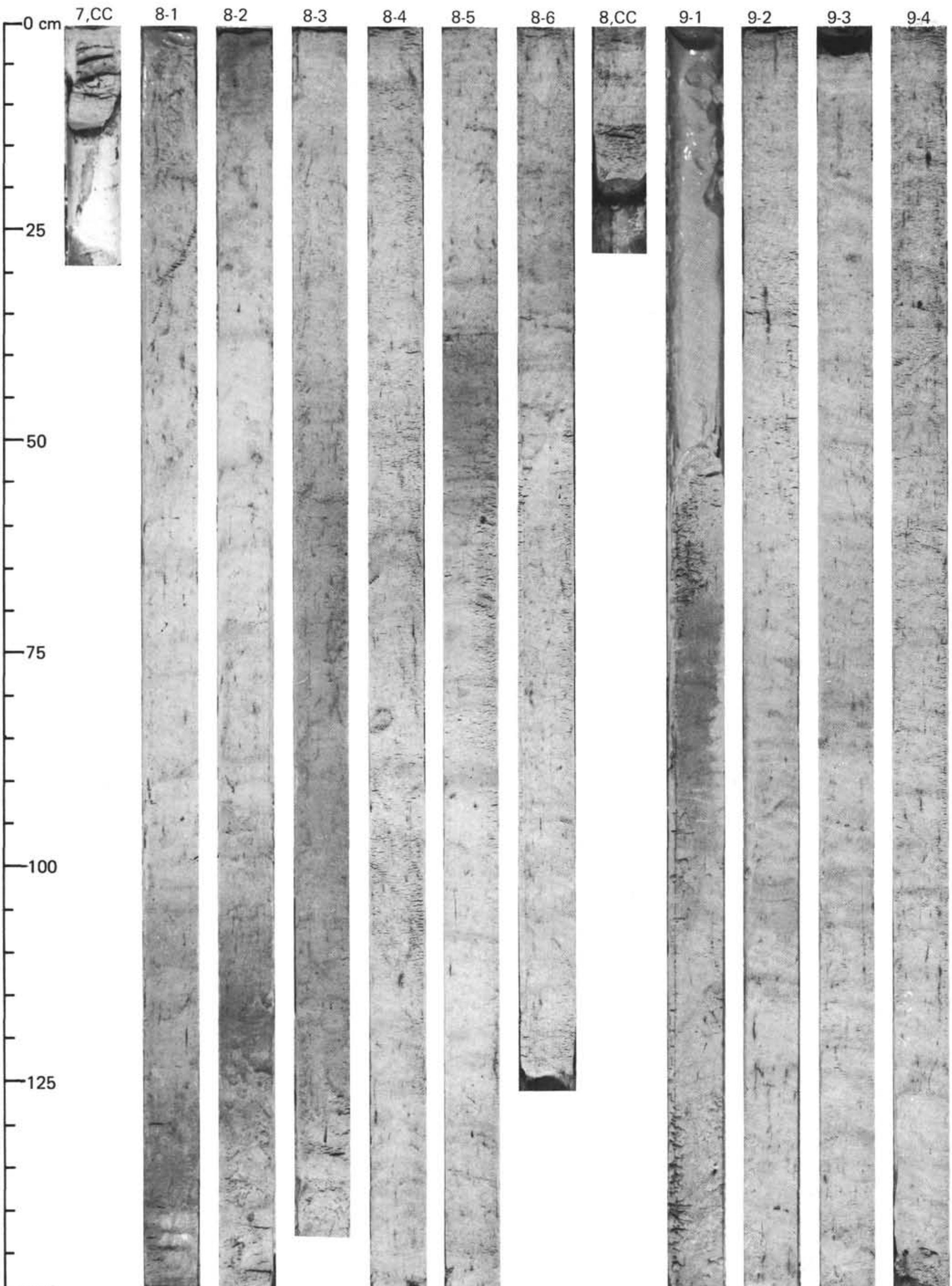
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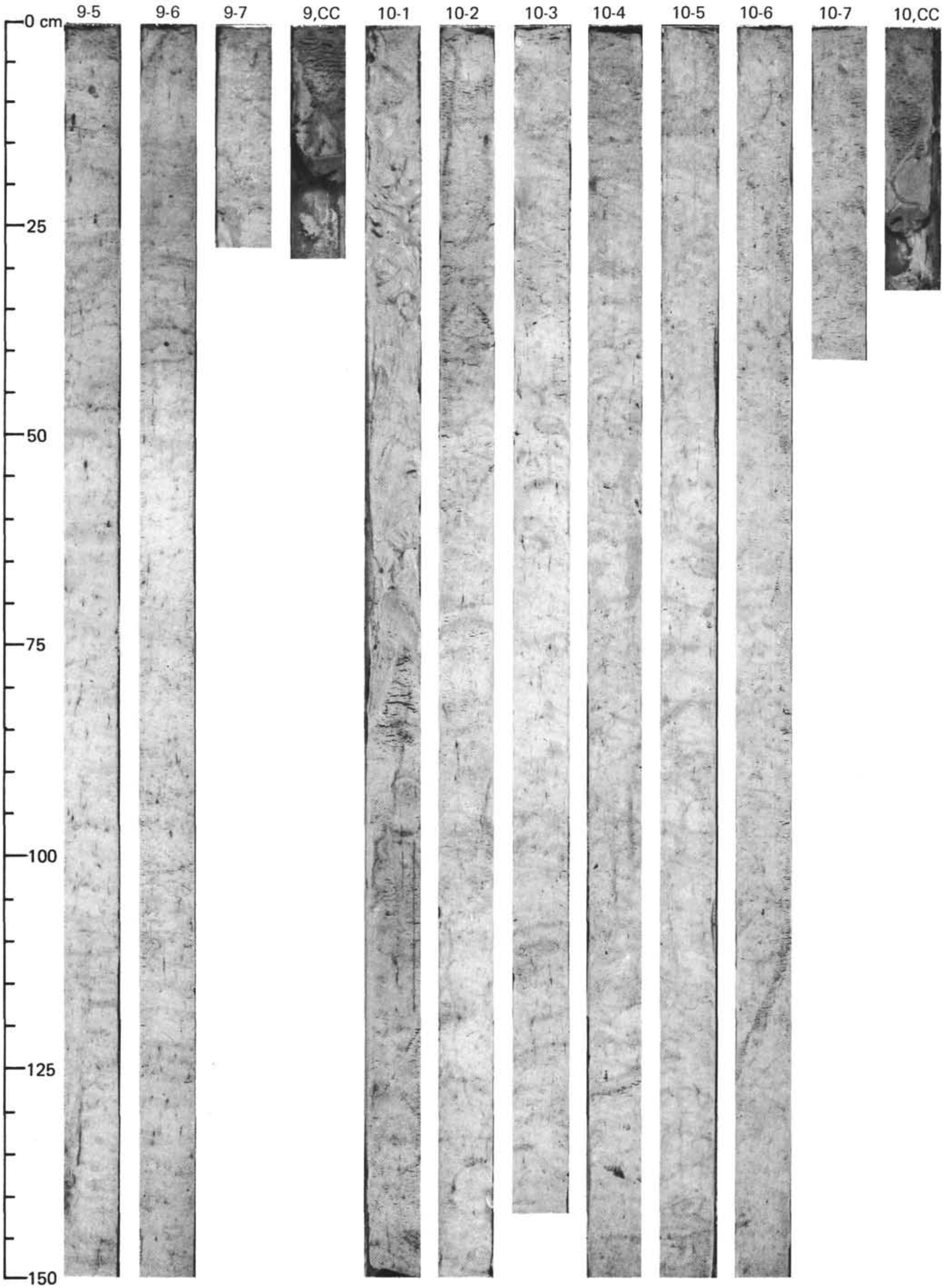
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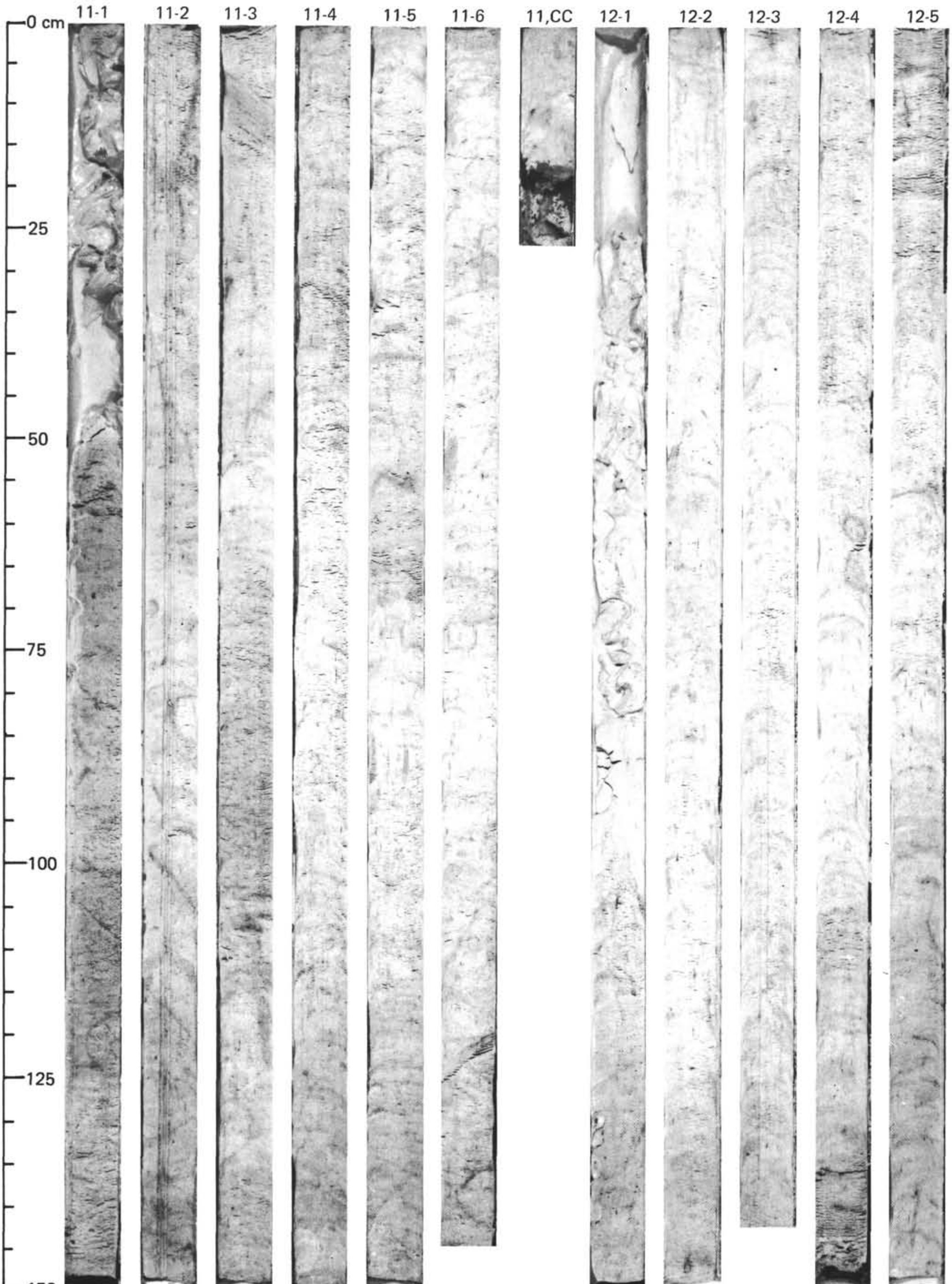
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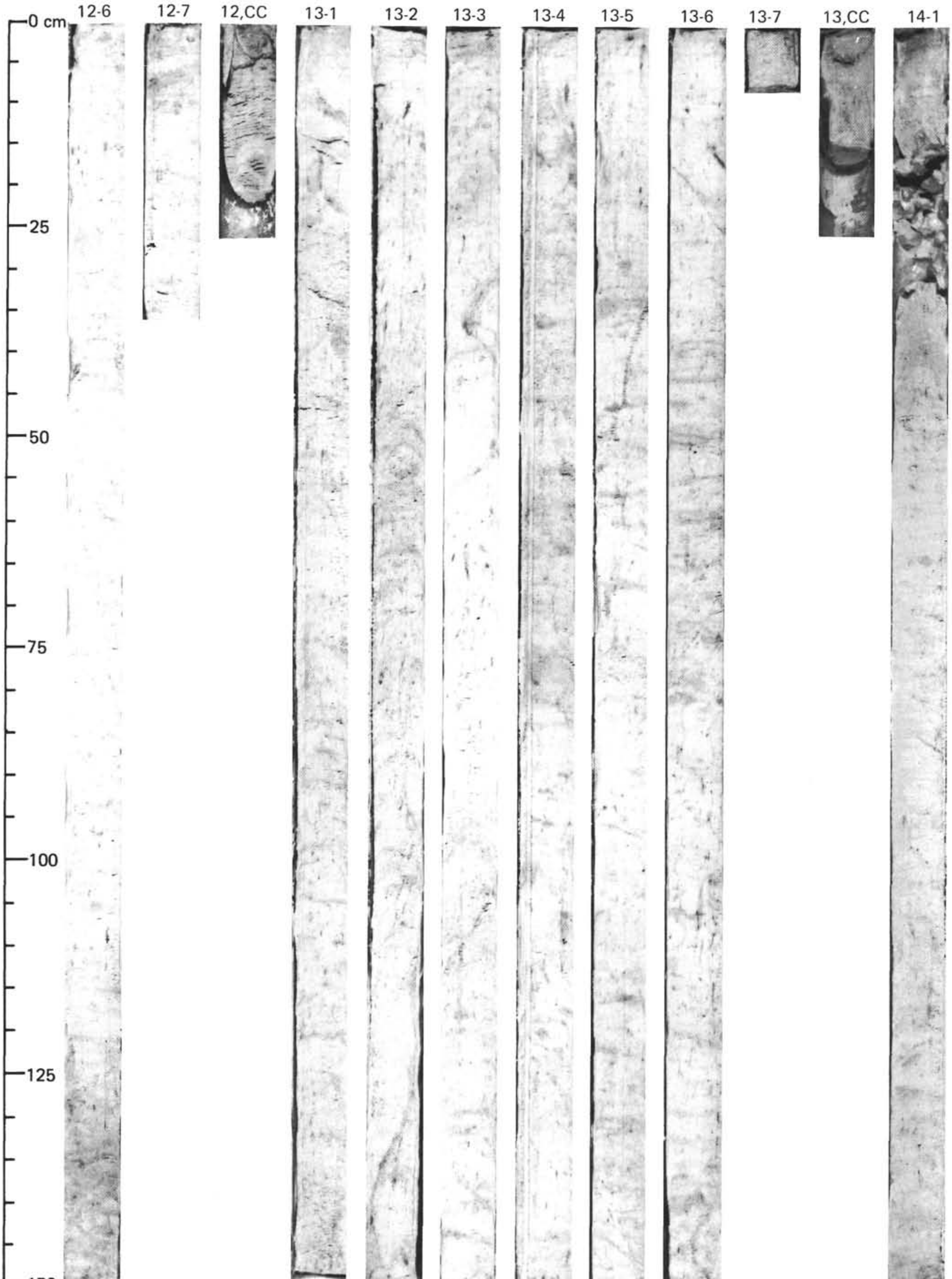
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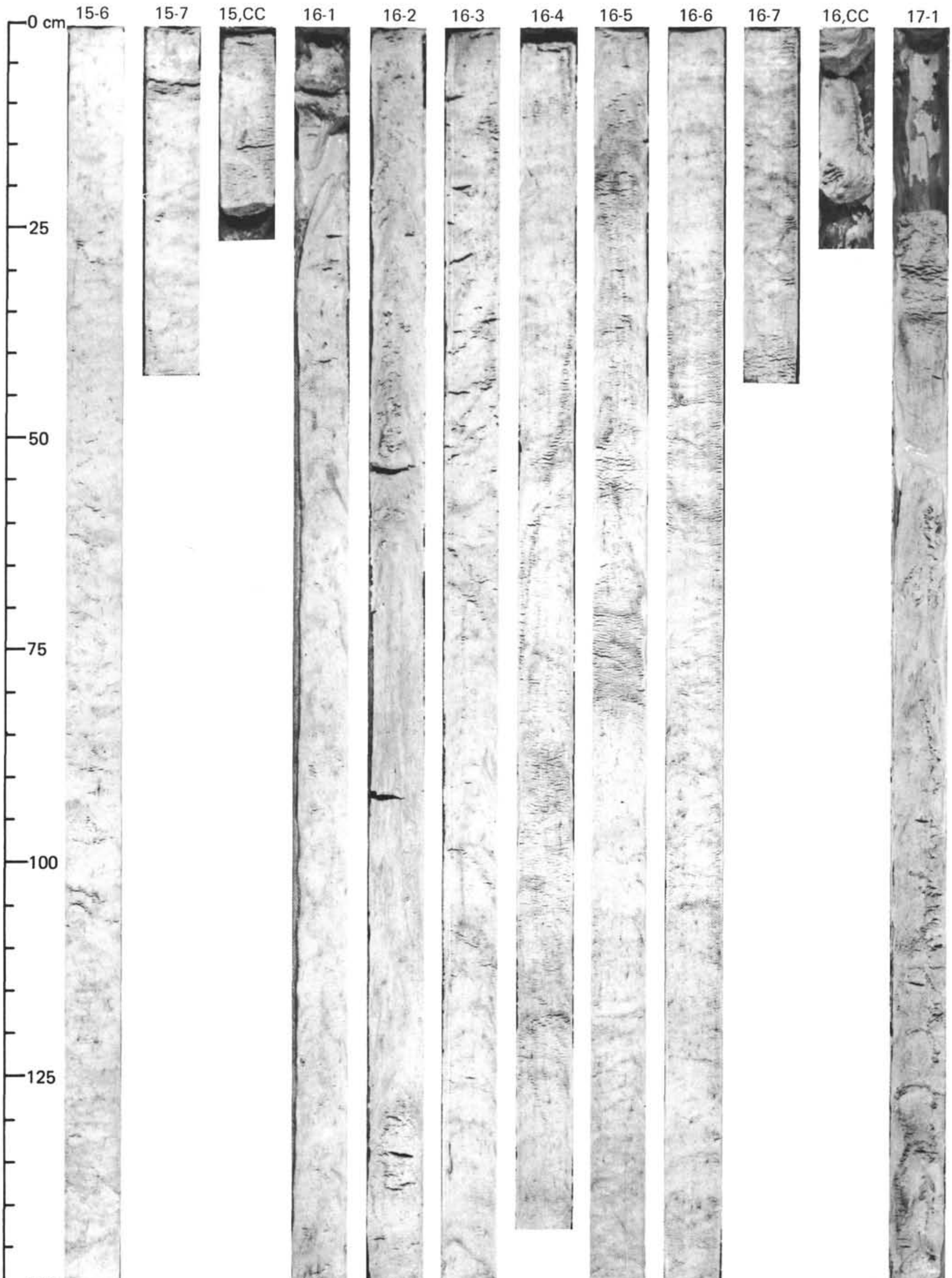
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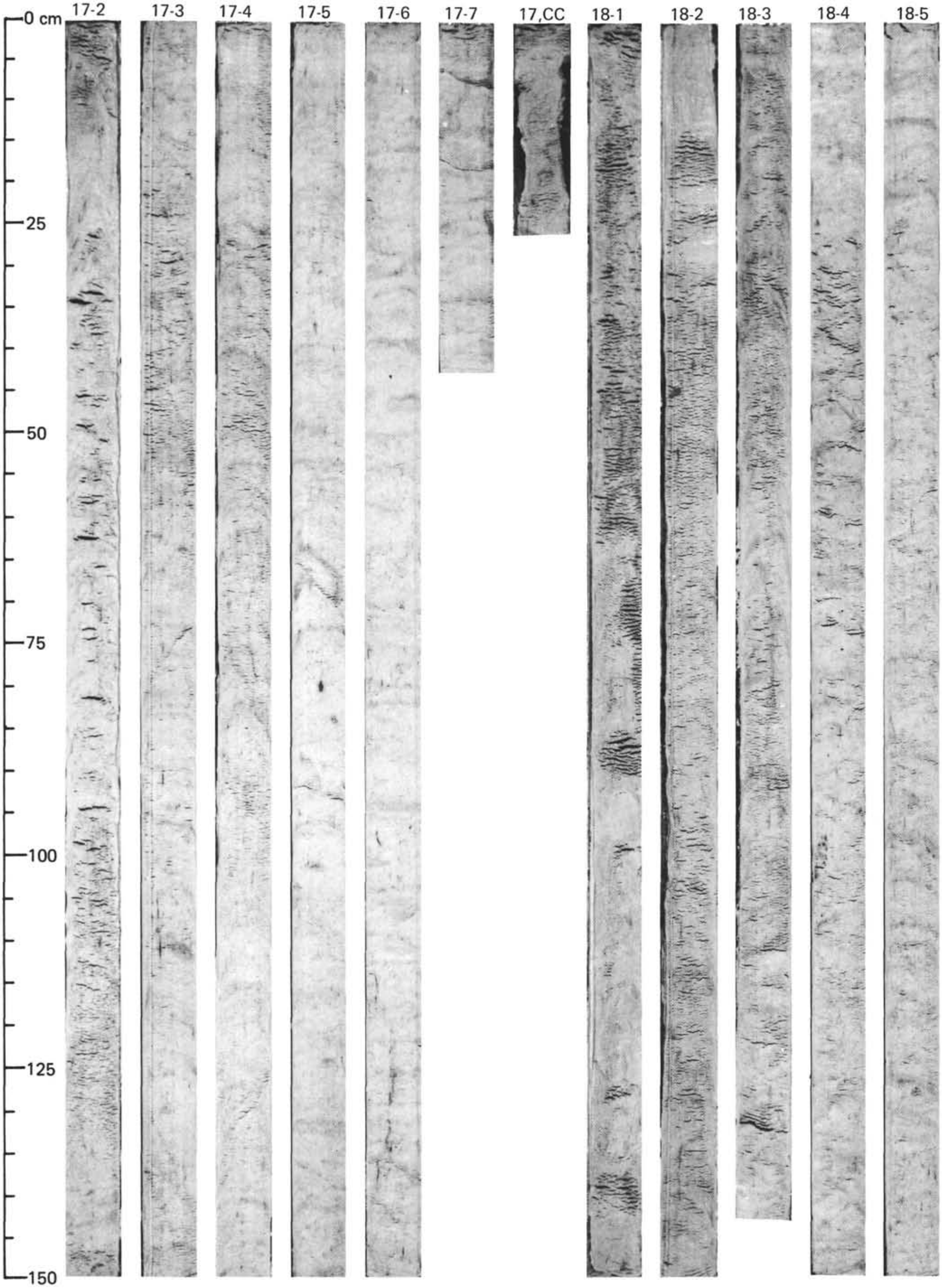
16,CC
17-1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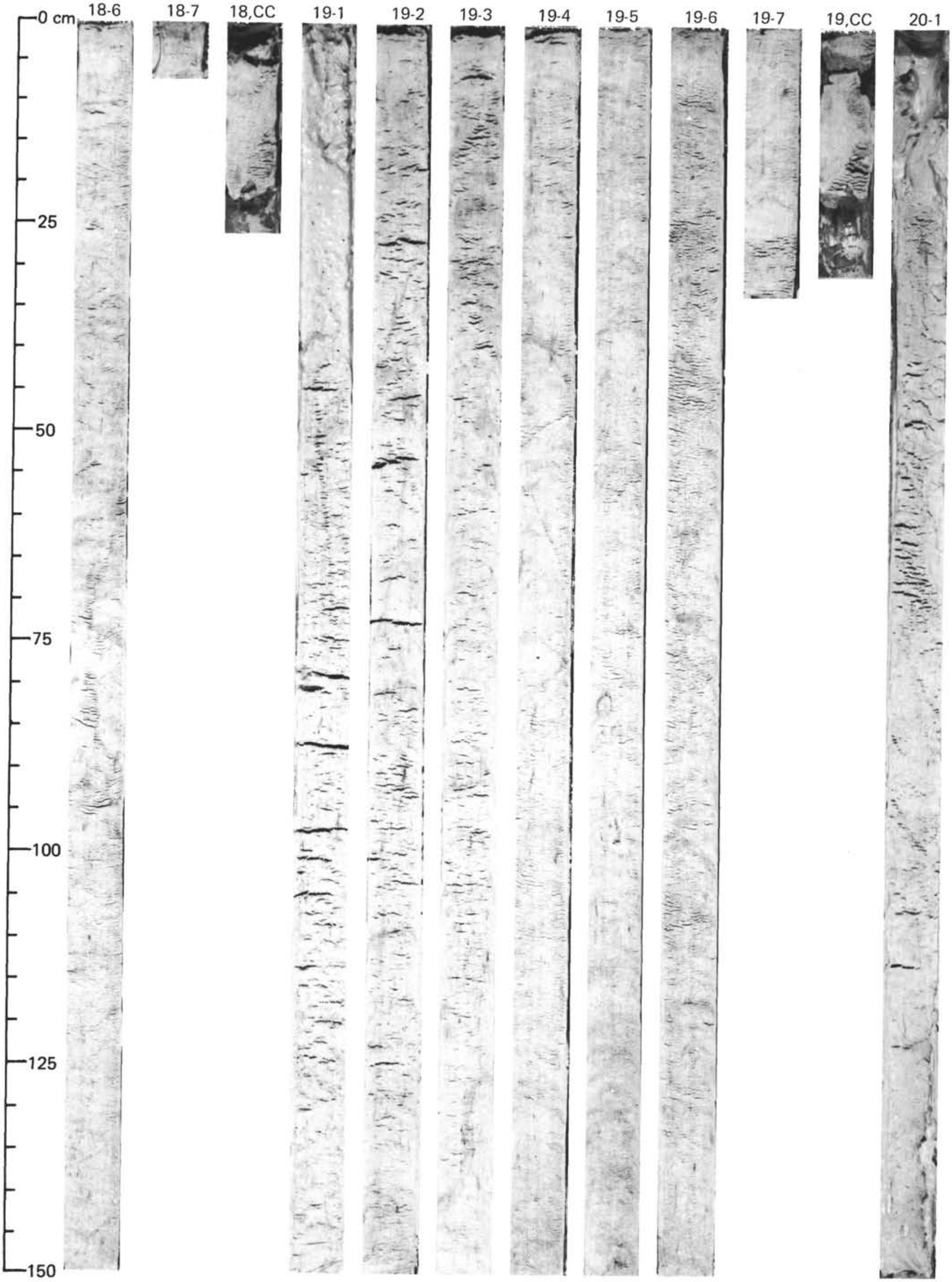
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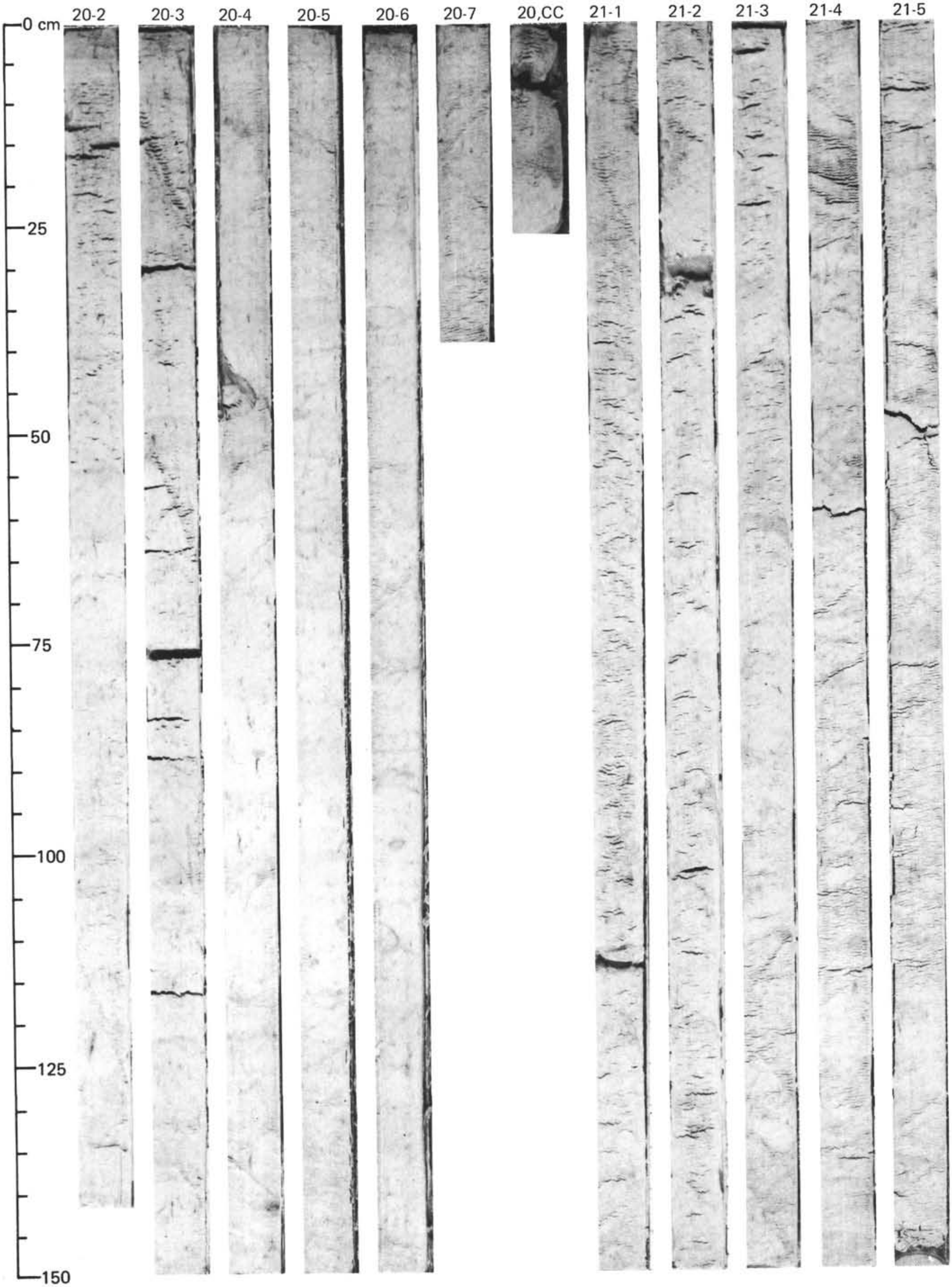
19,CC
20-1



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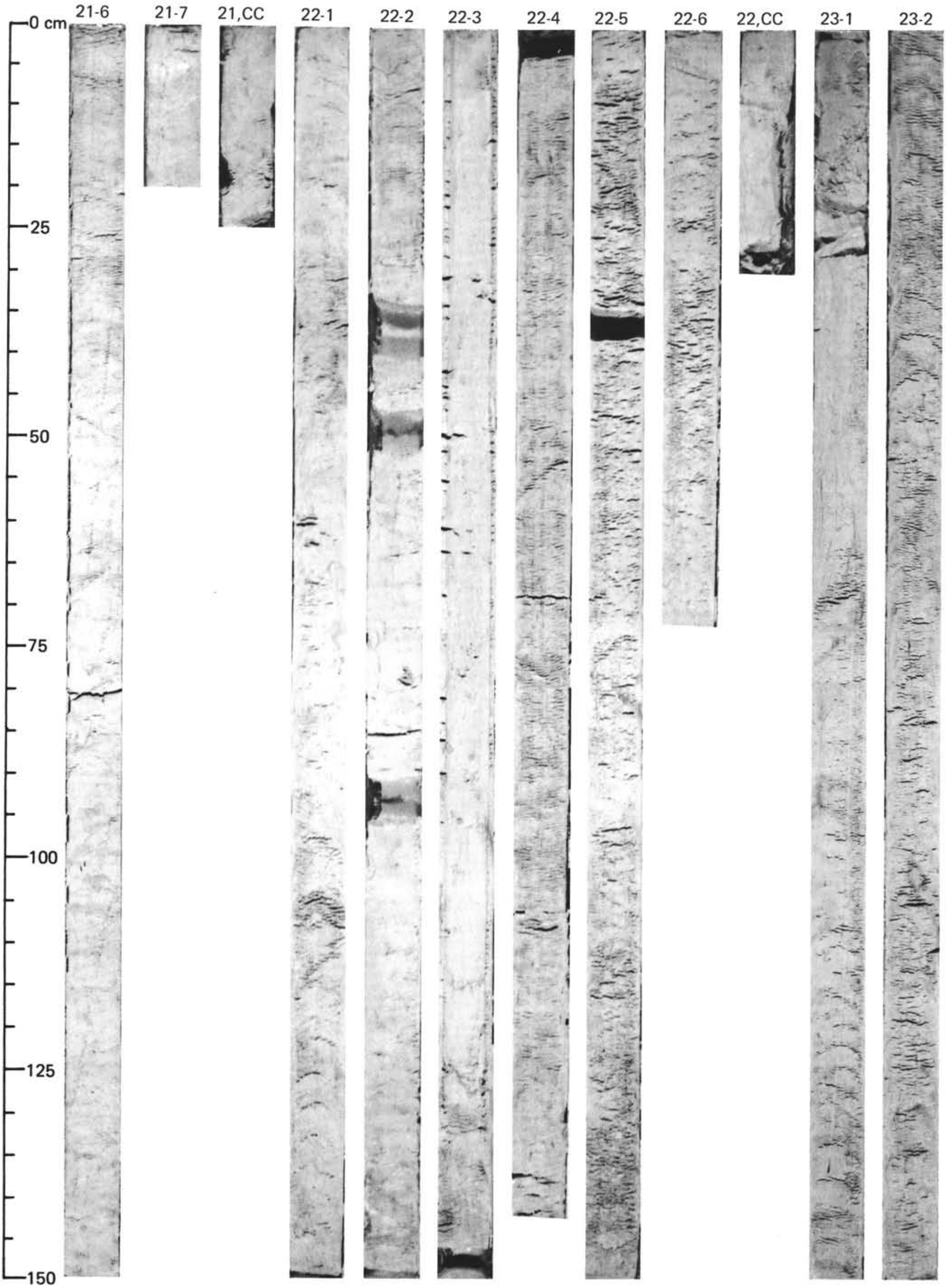
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22,CC
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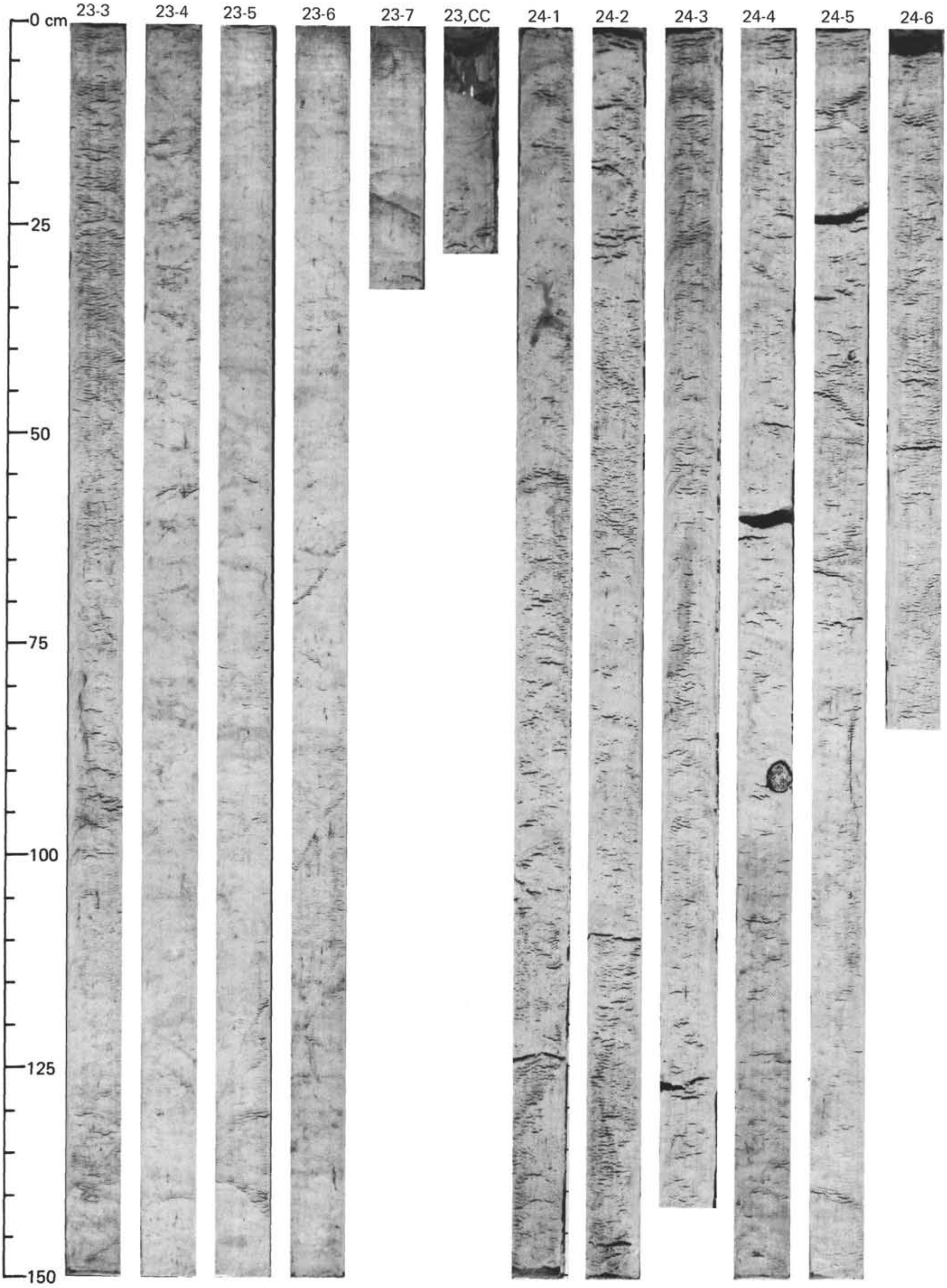
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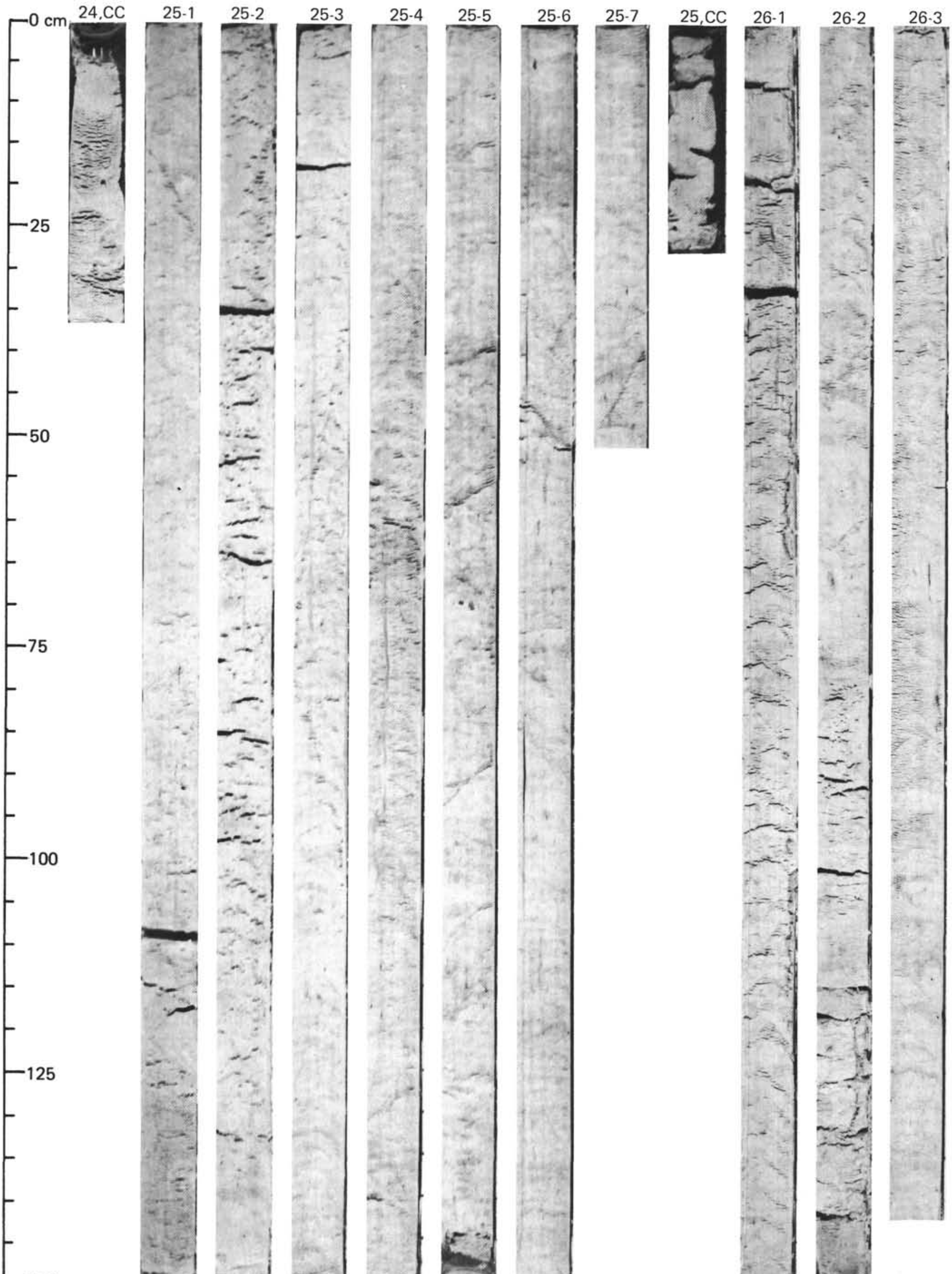
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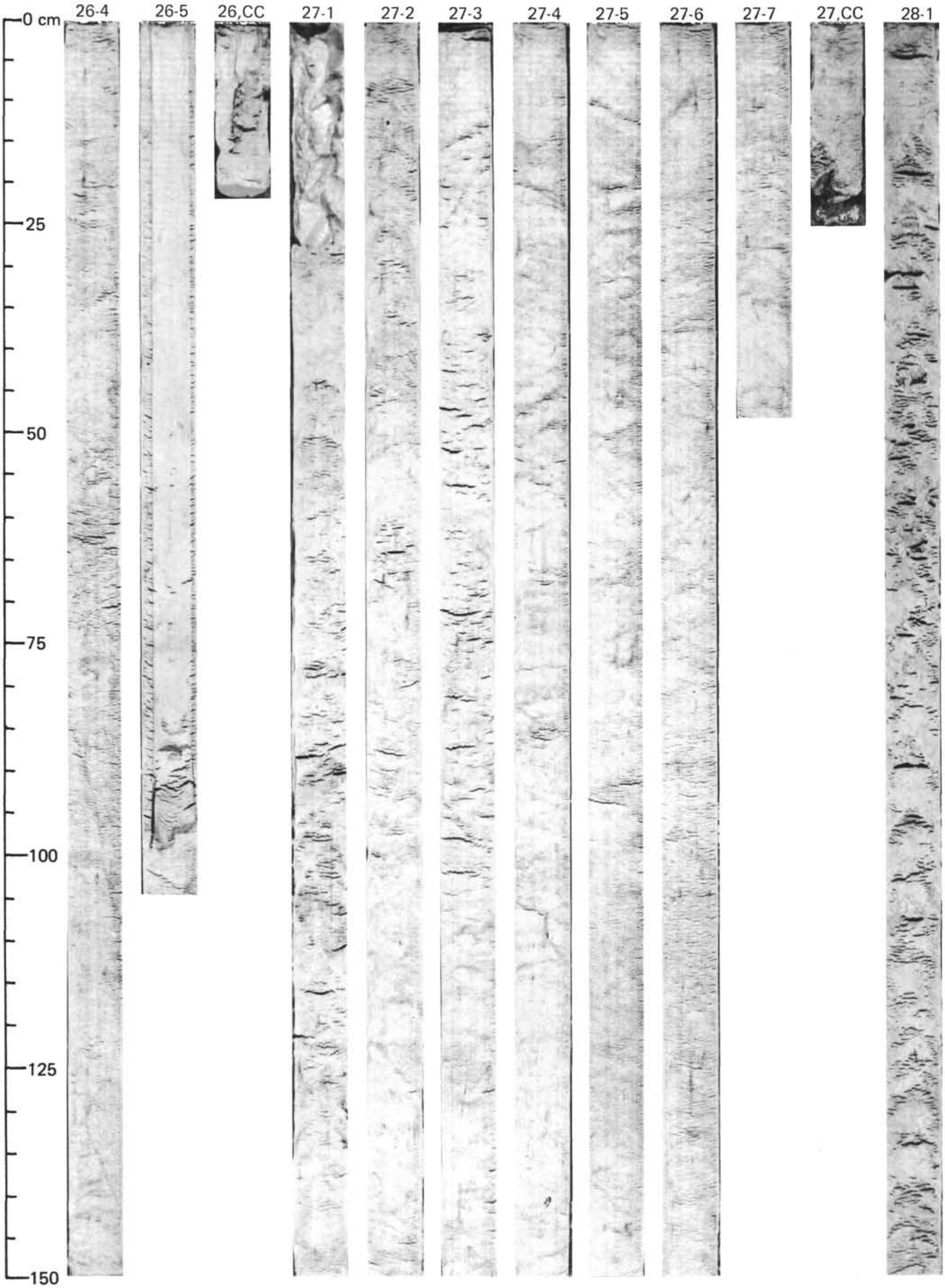

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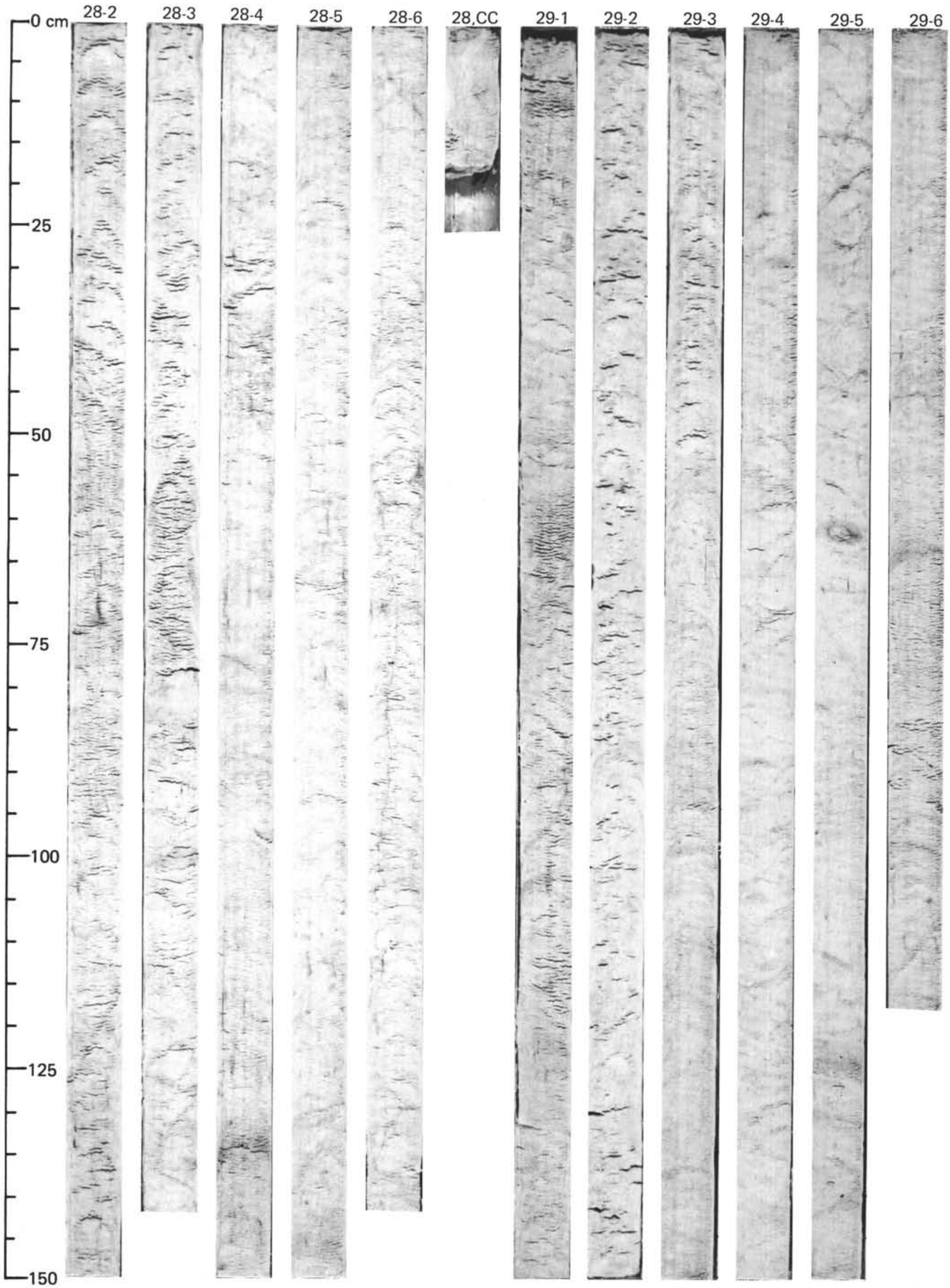
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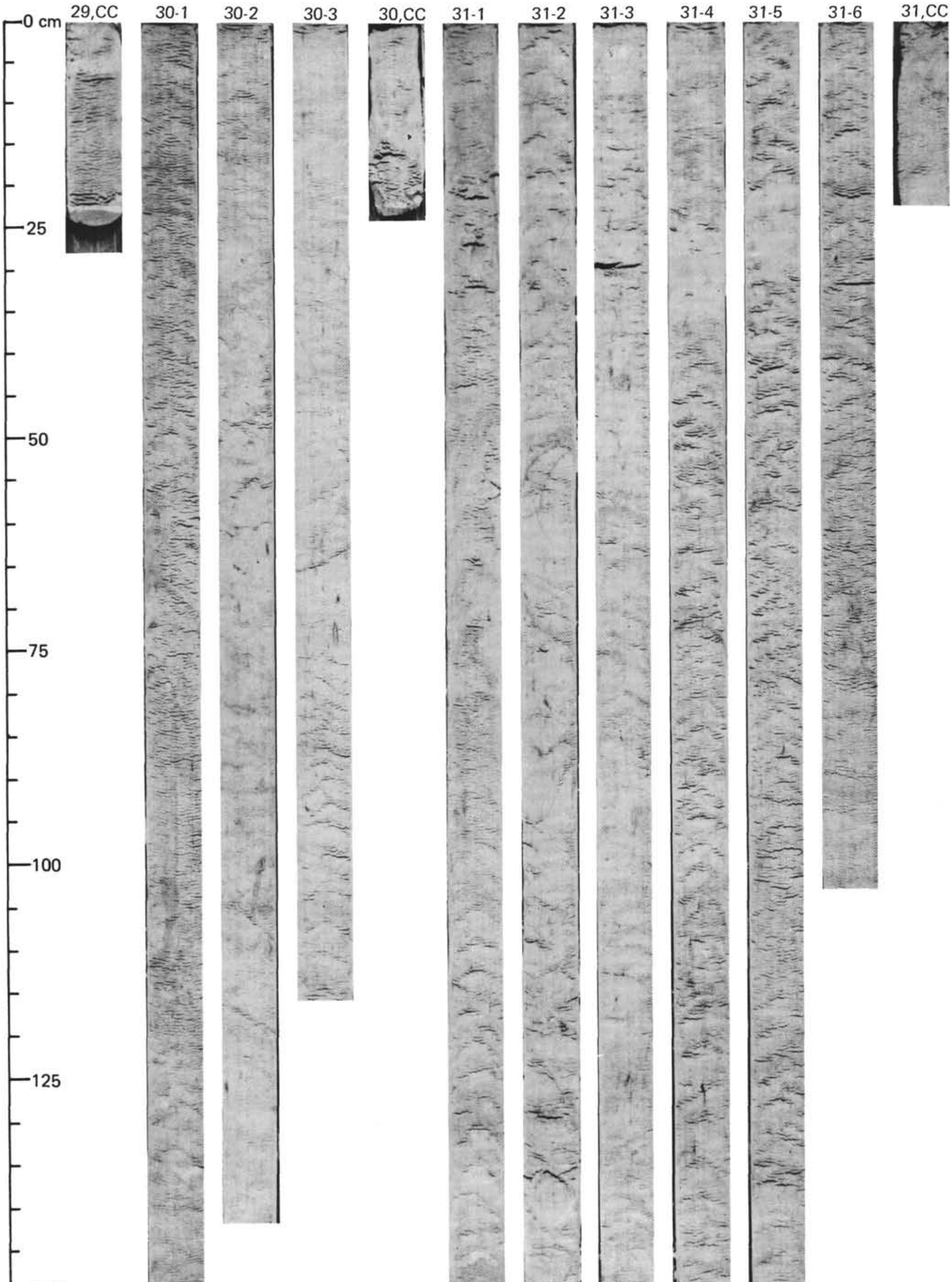
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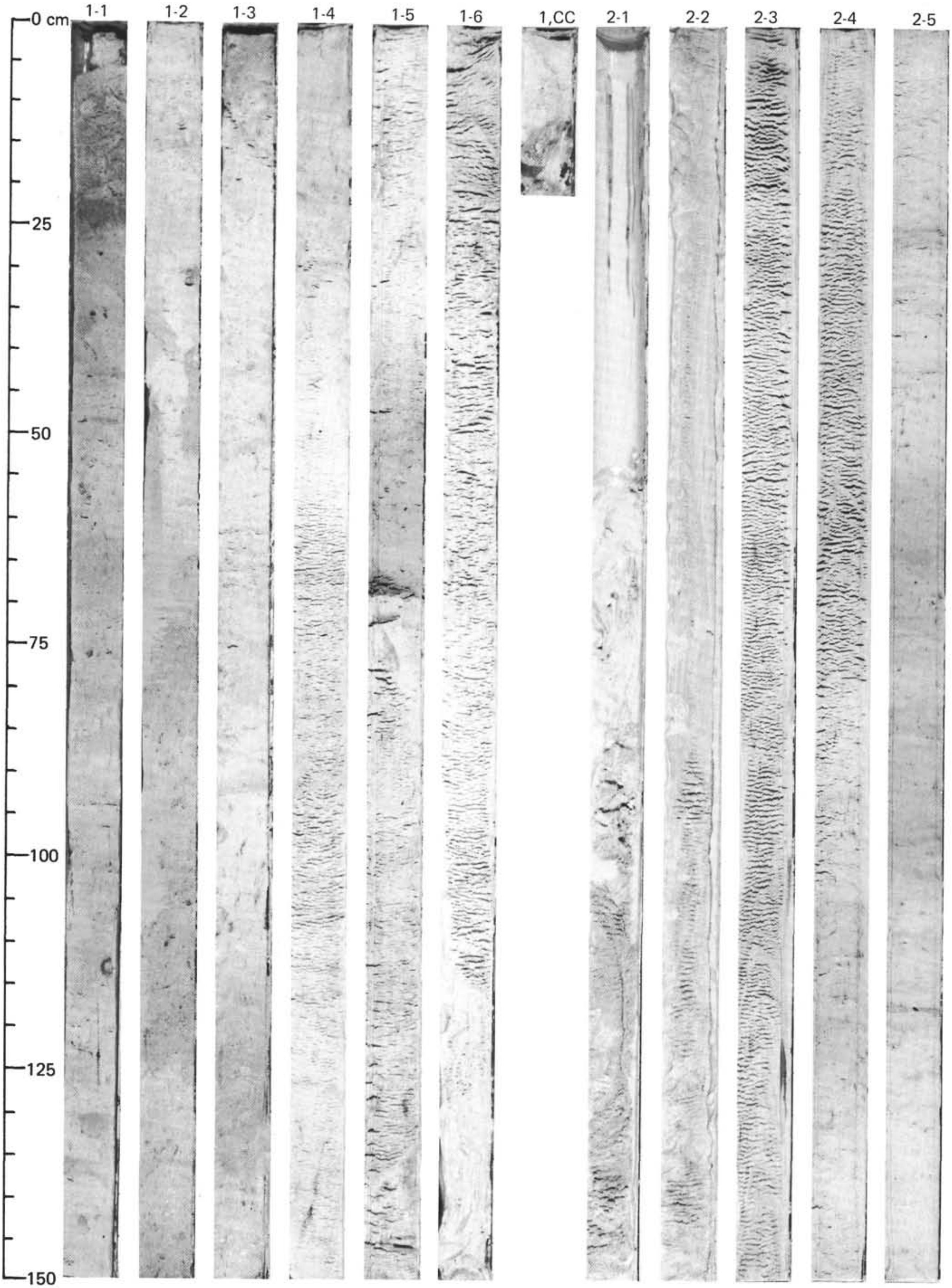
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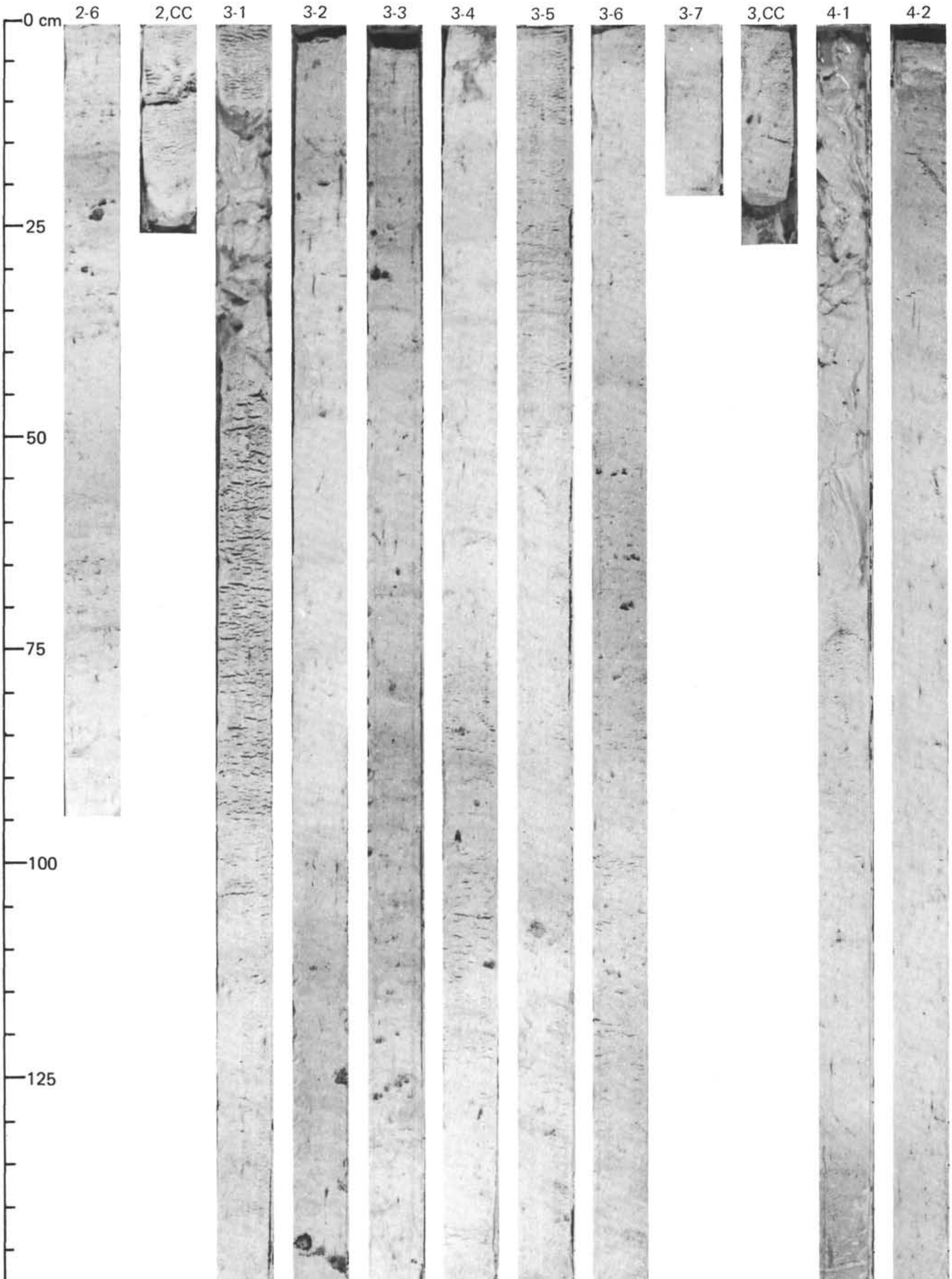
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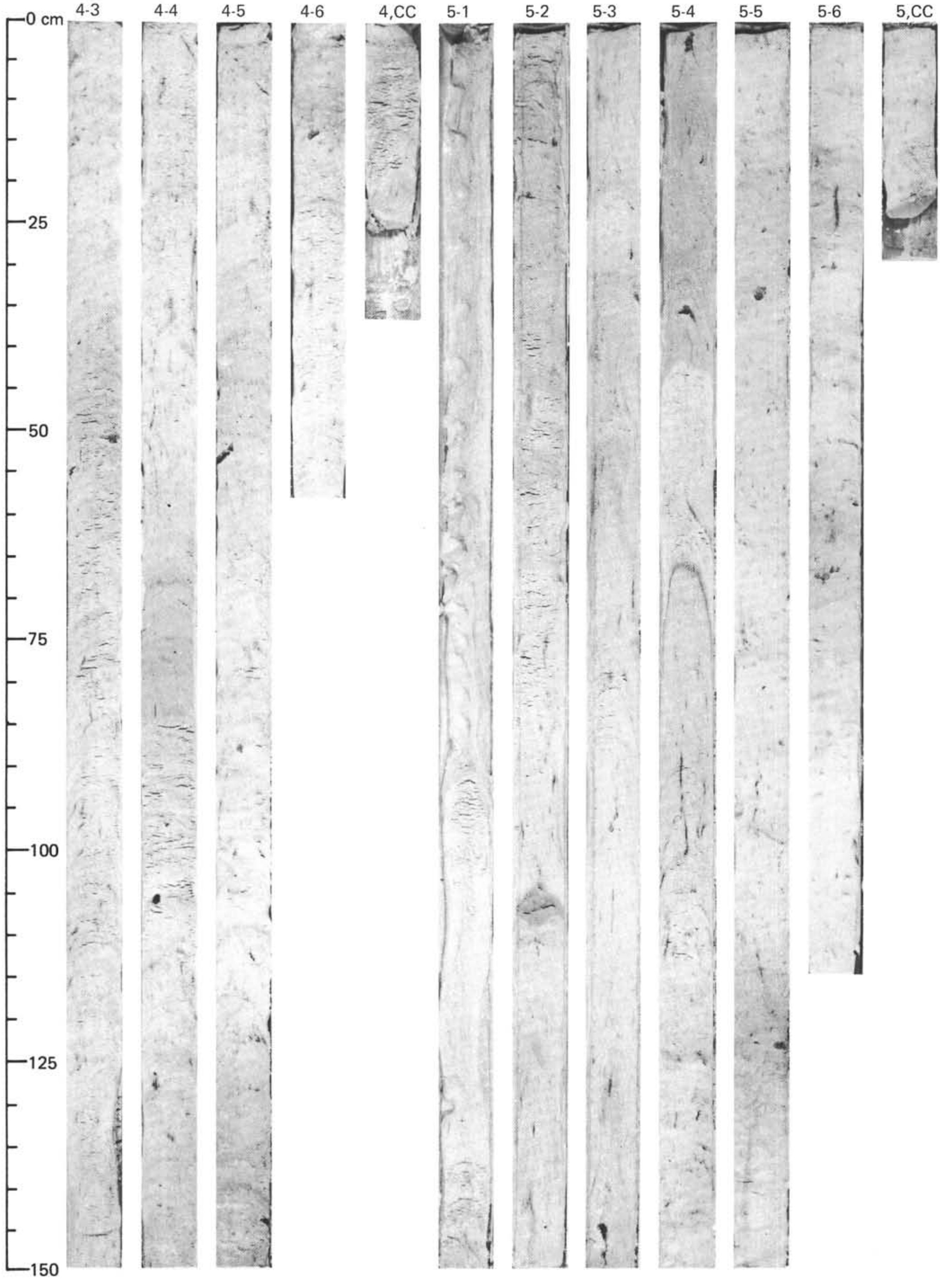
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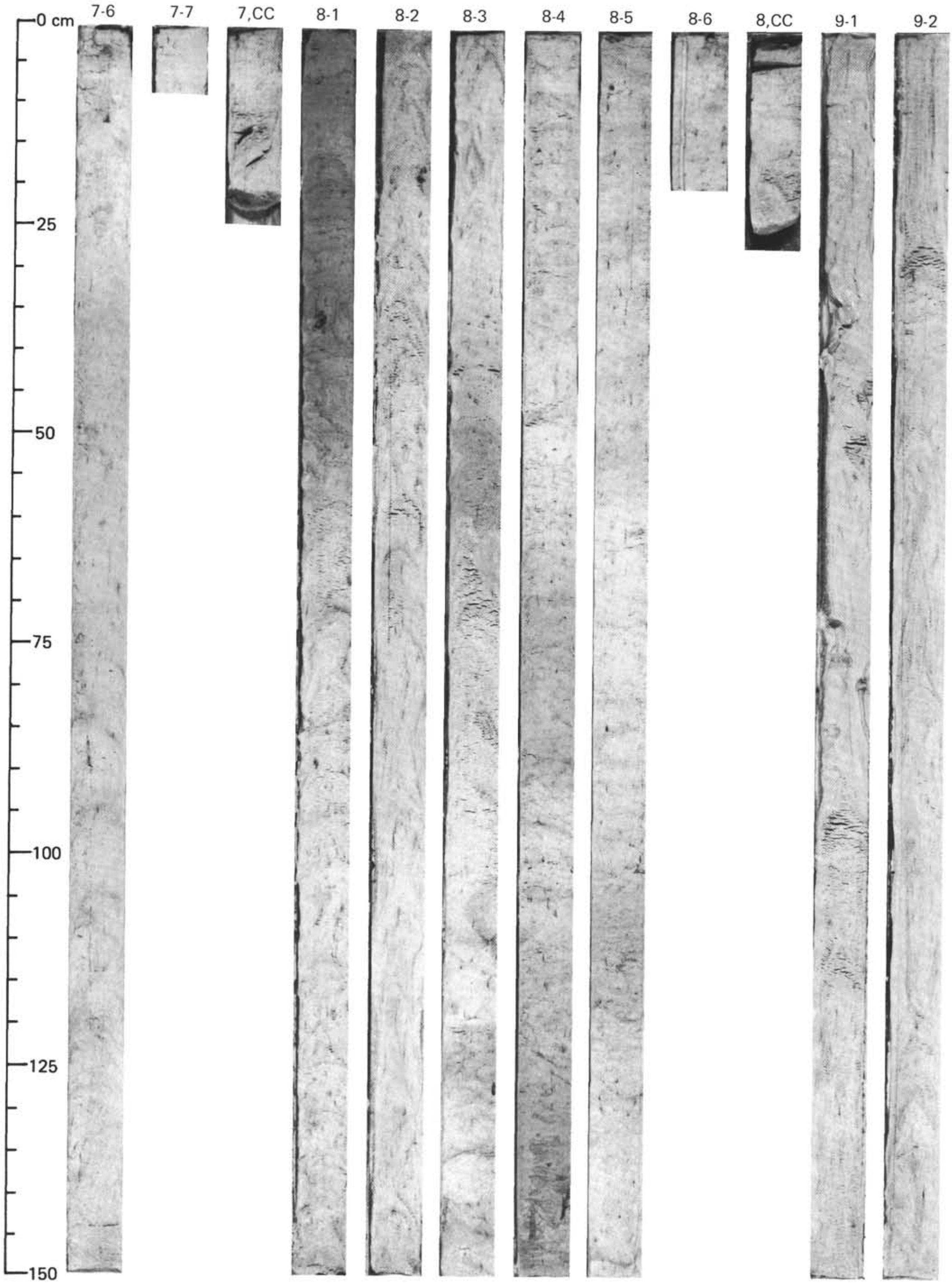
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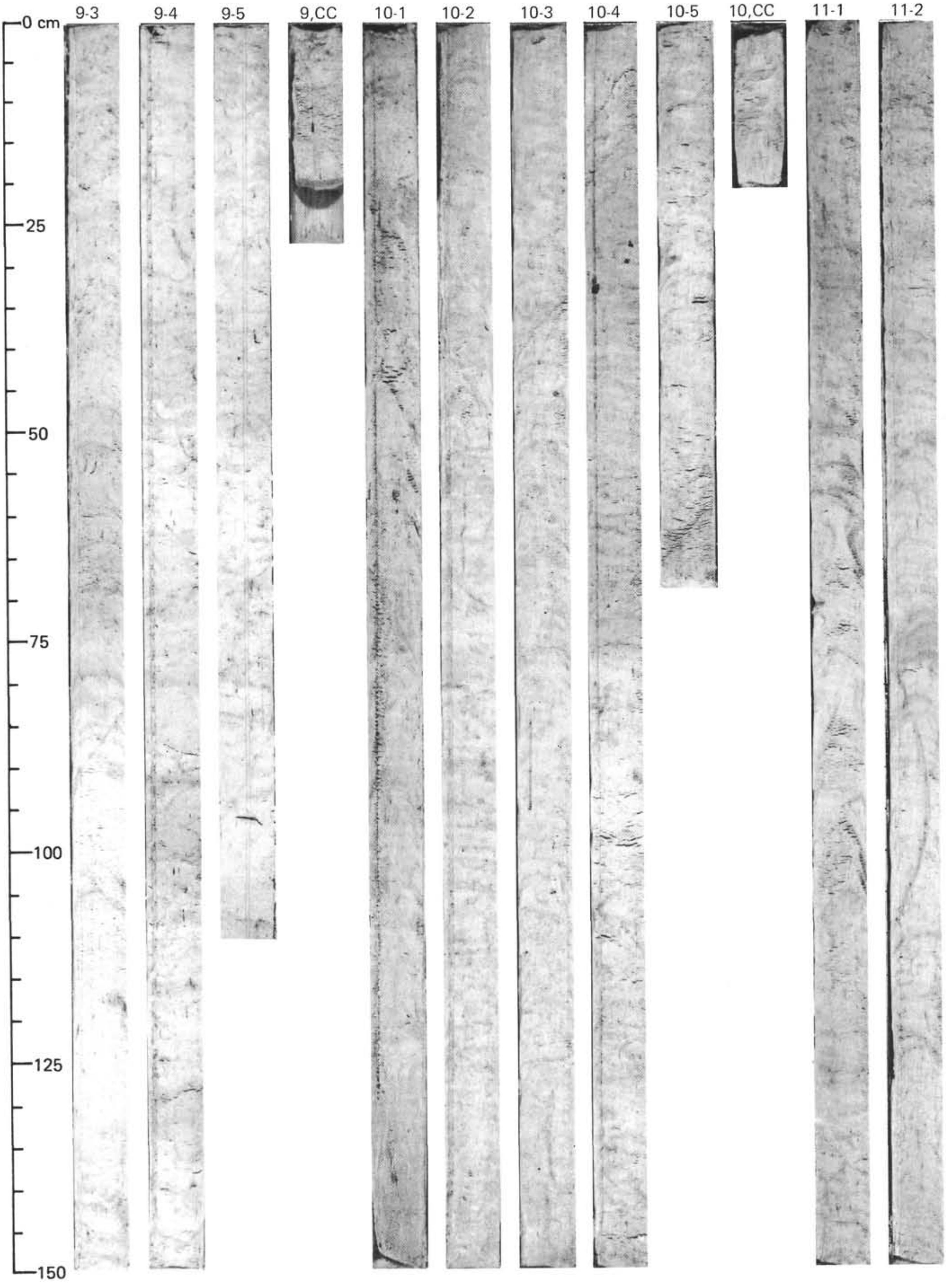
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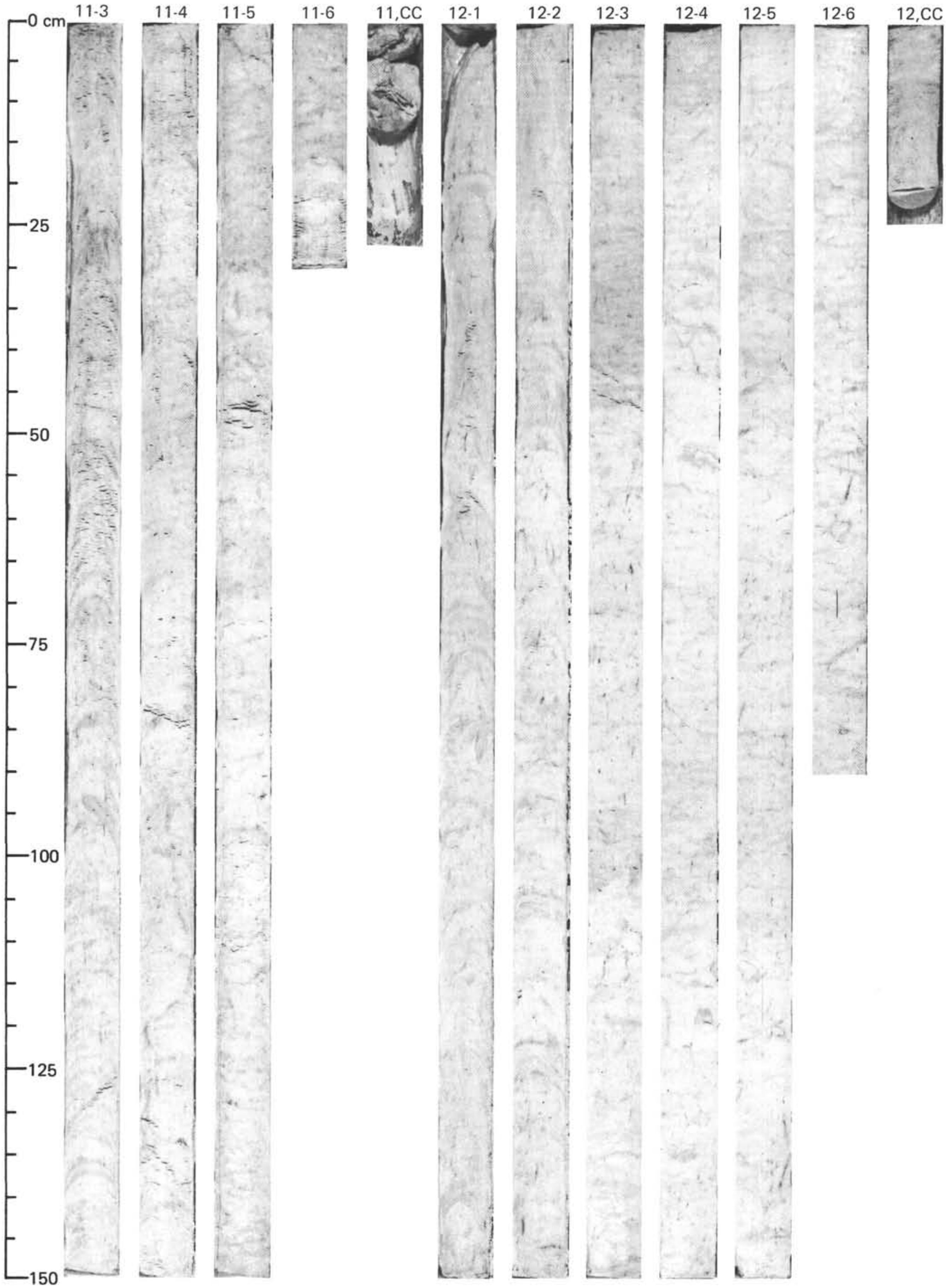
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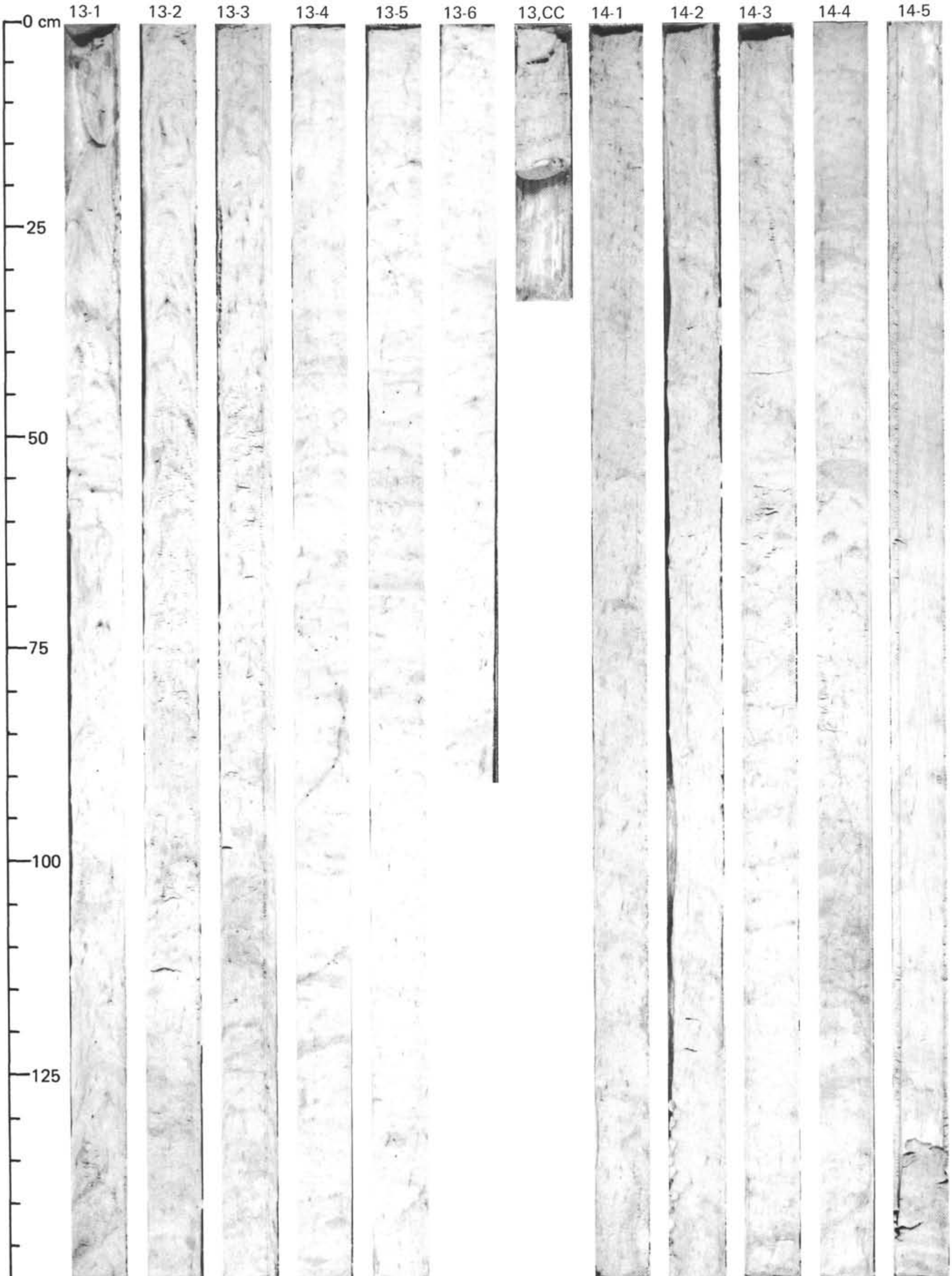
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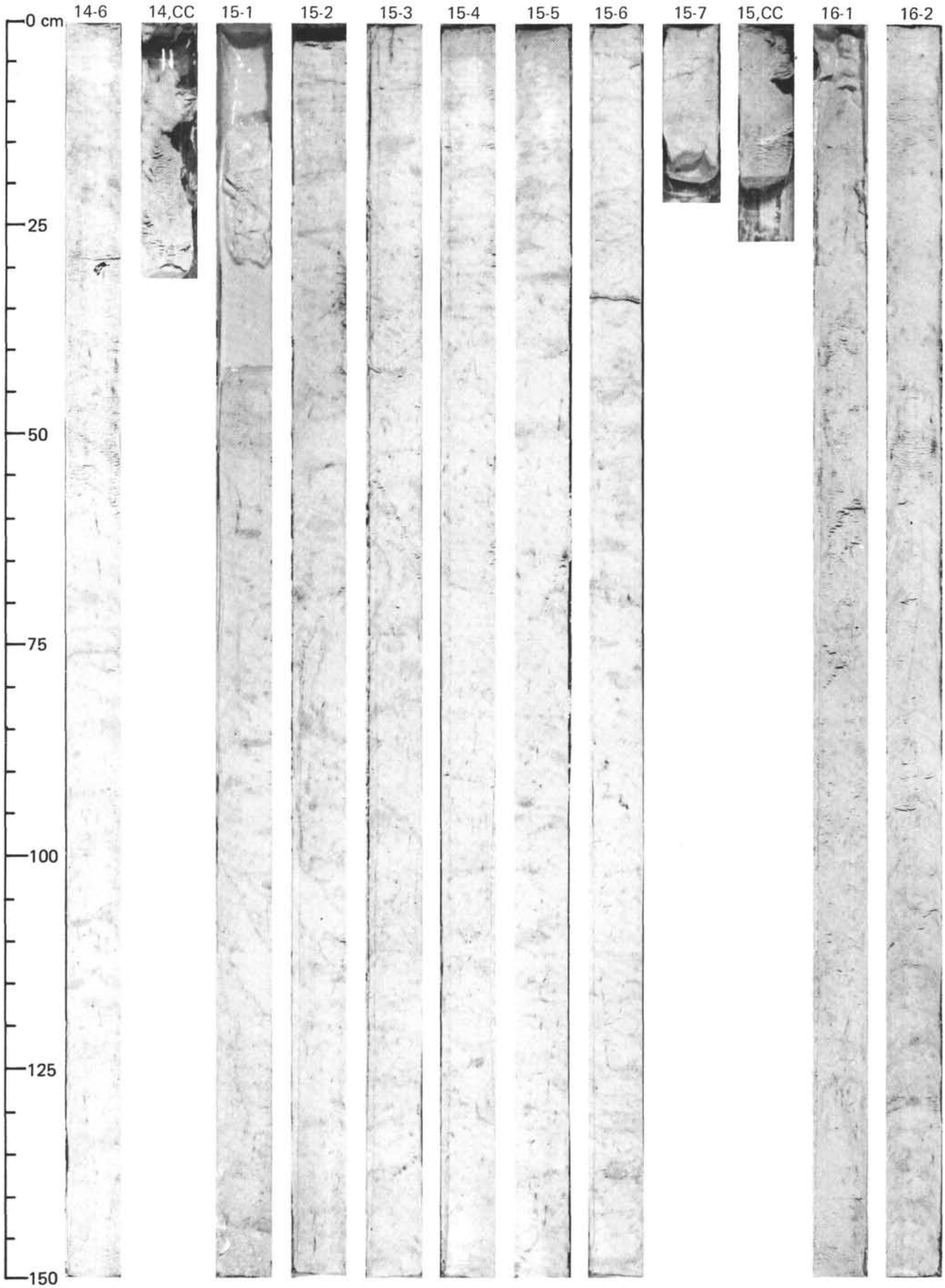
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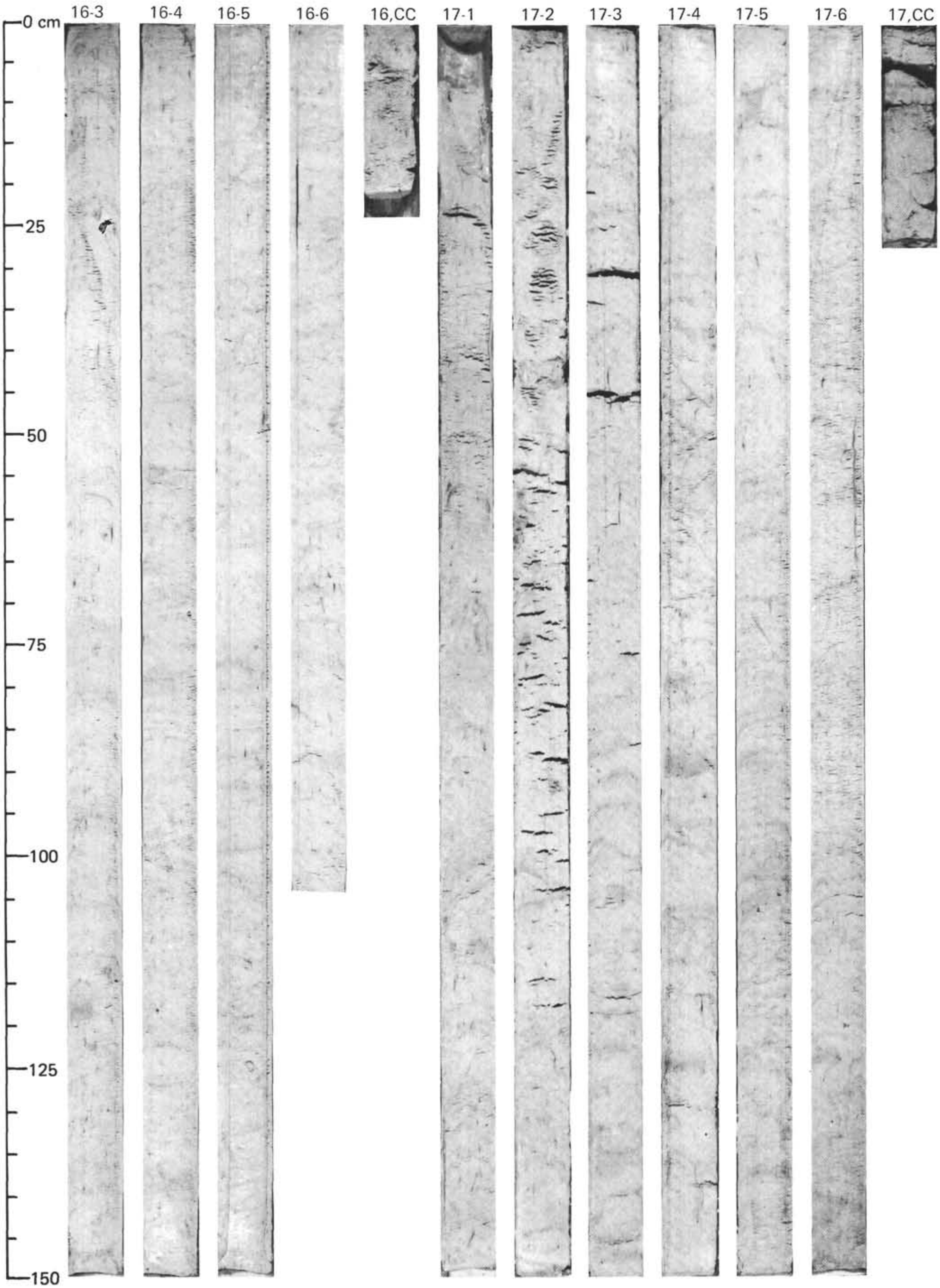
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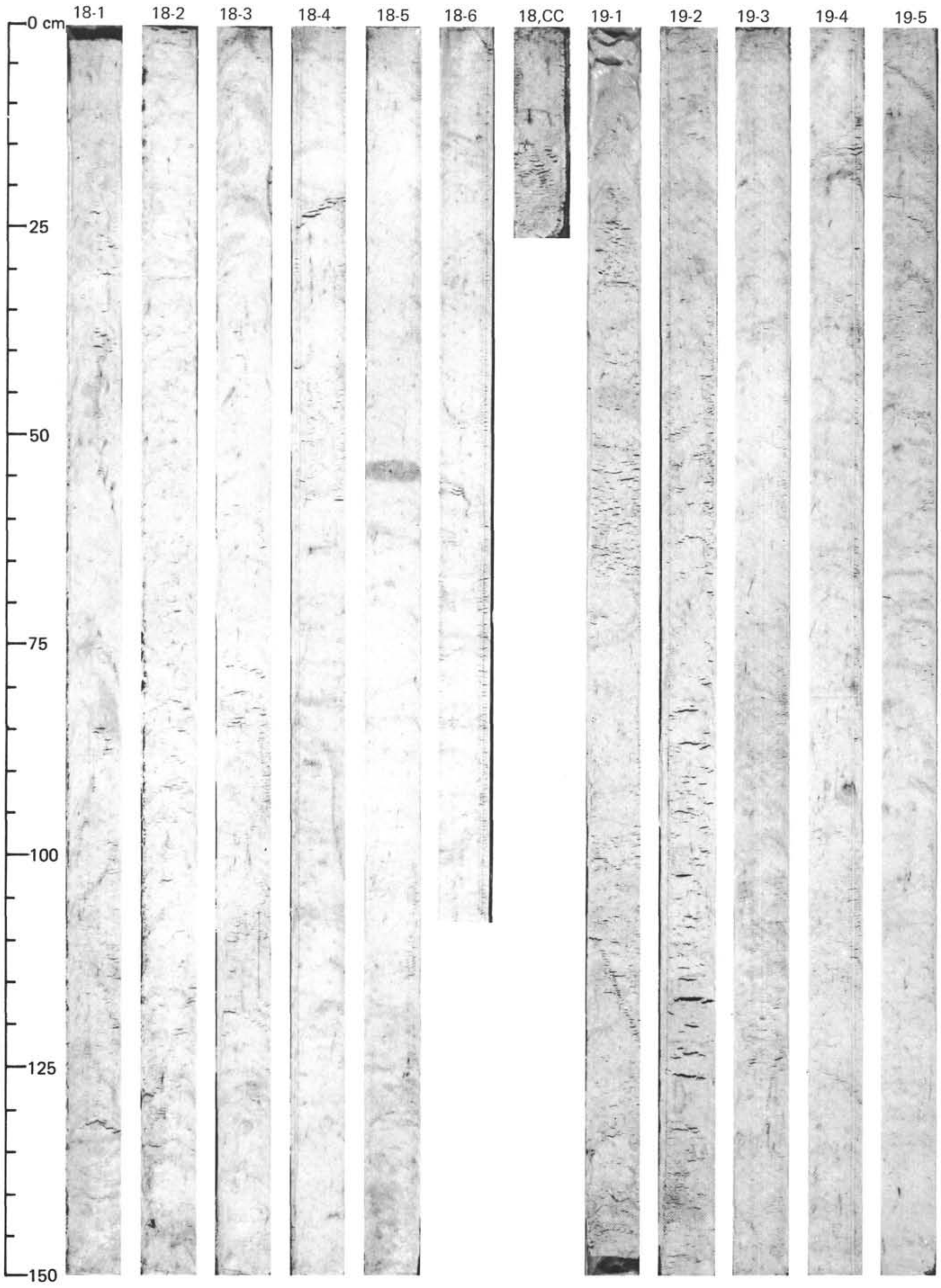
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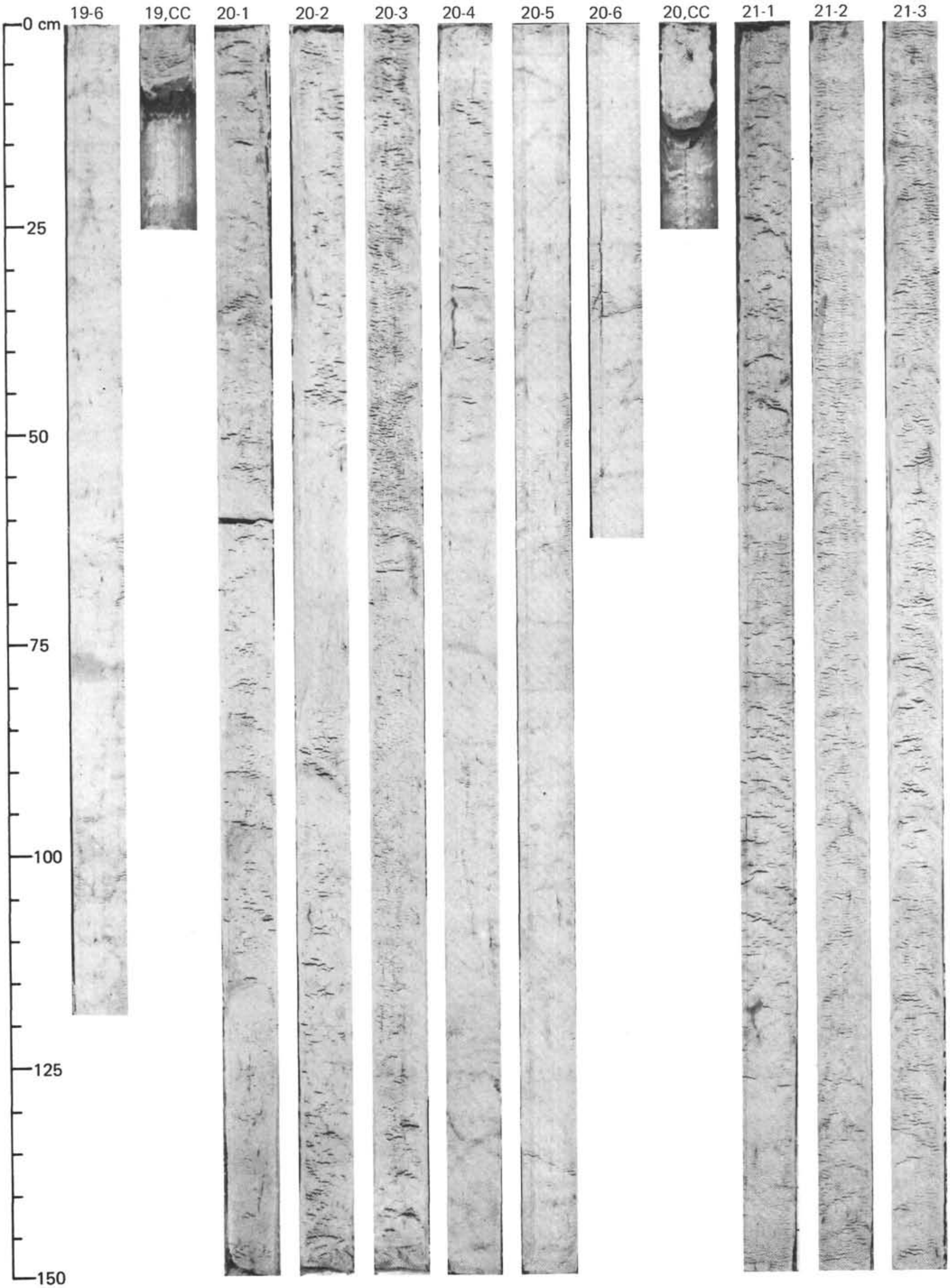
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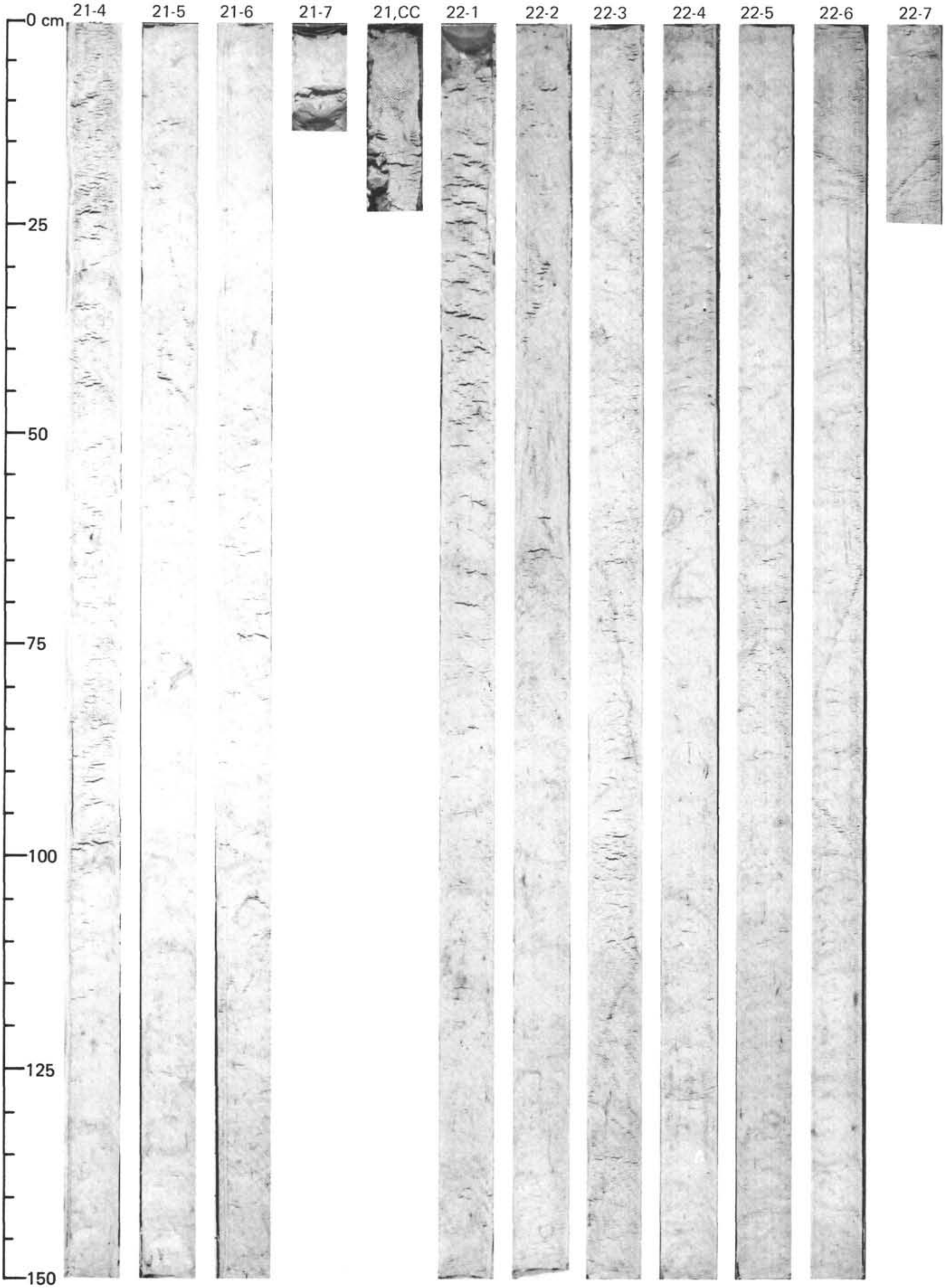
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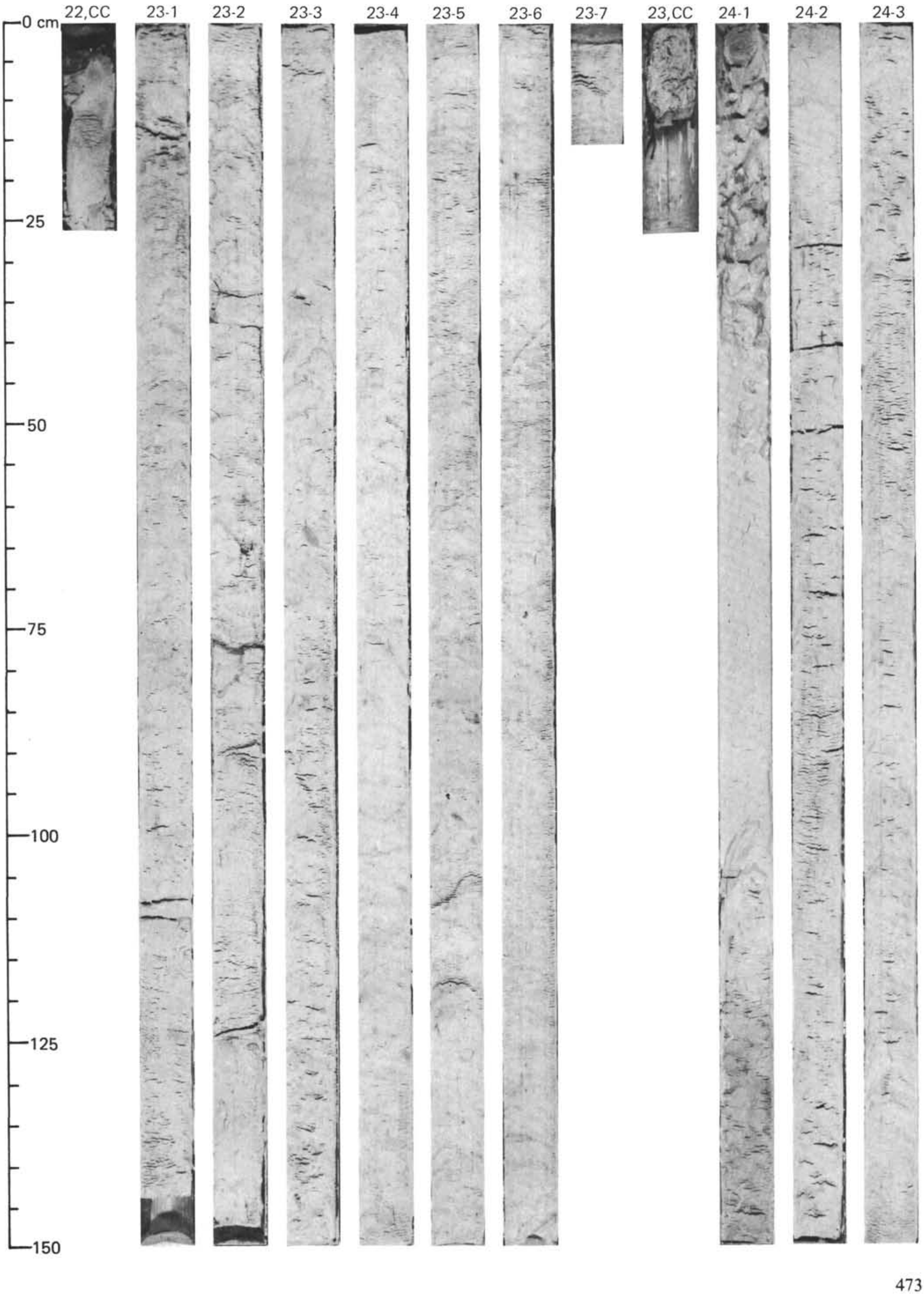
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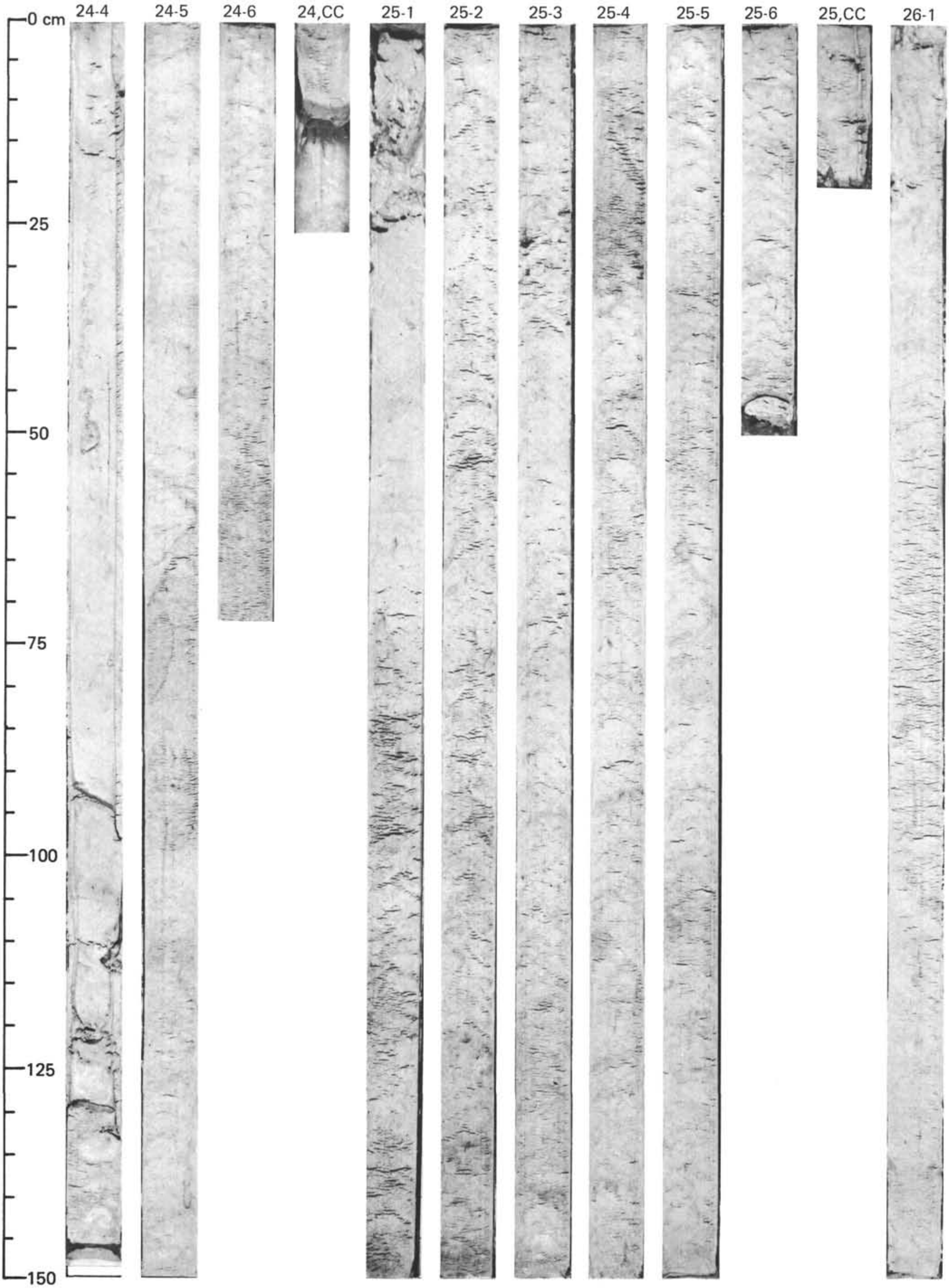

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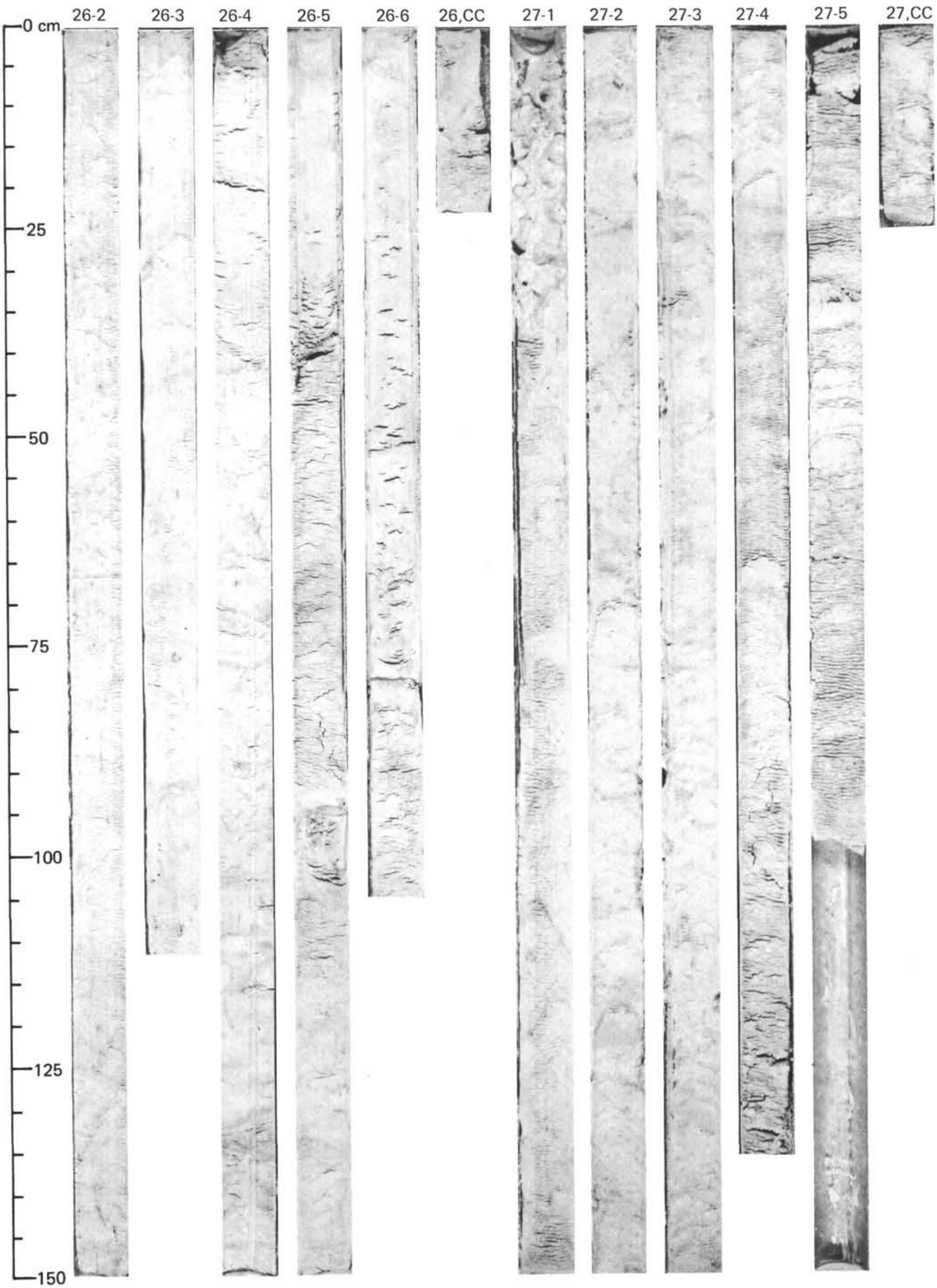
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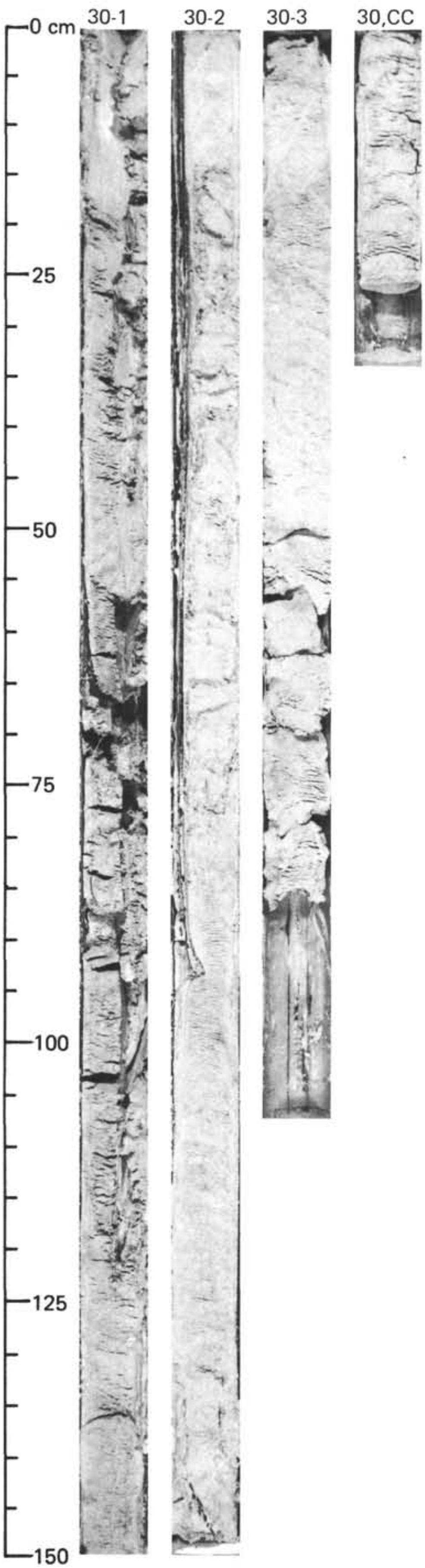
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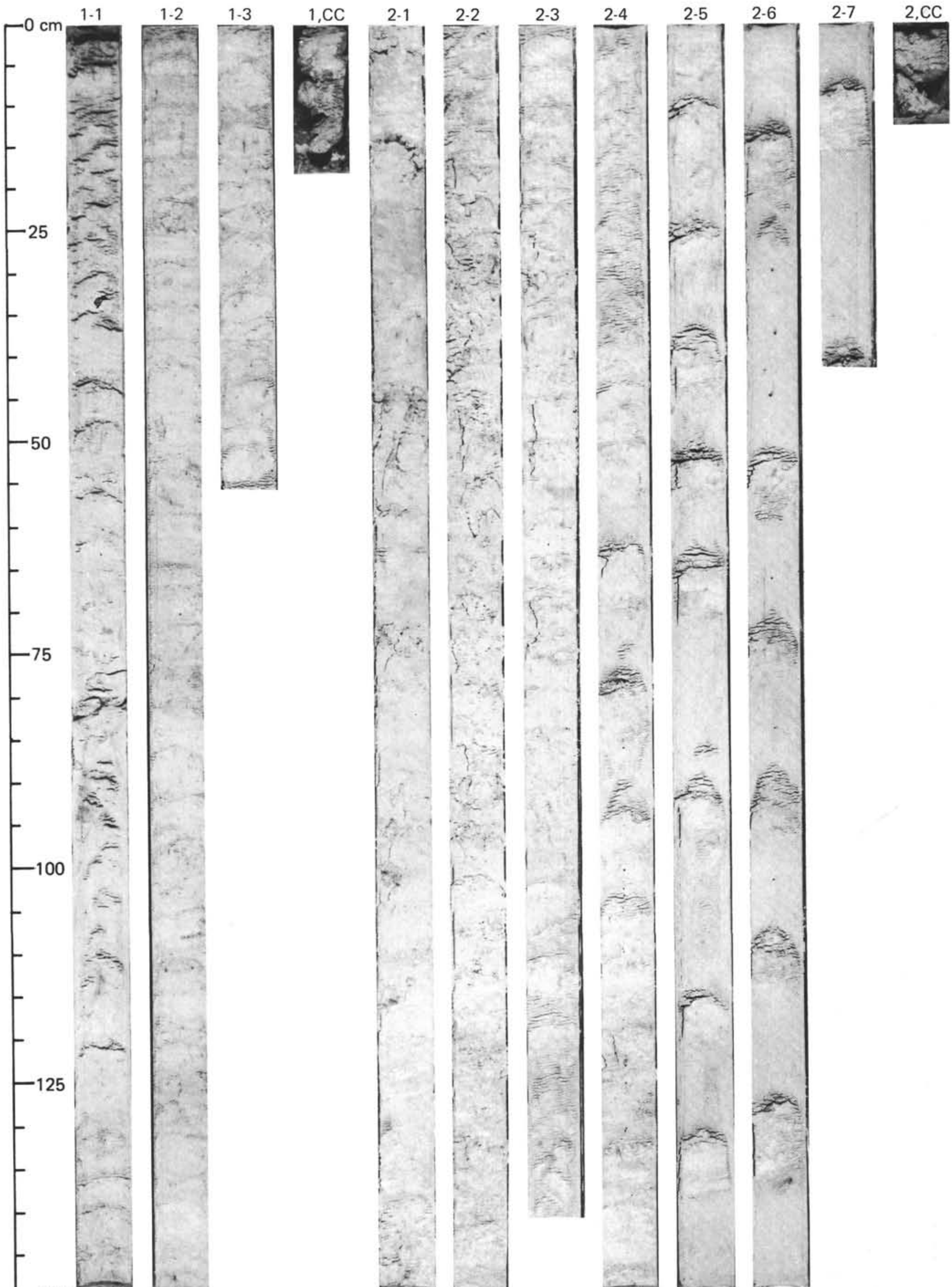
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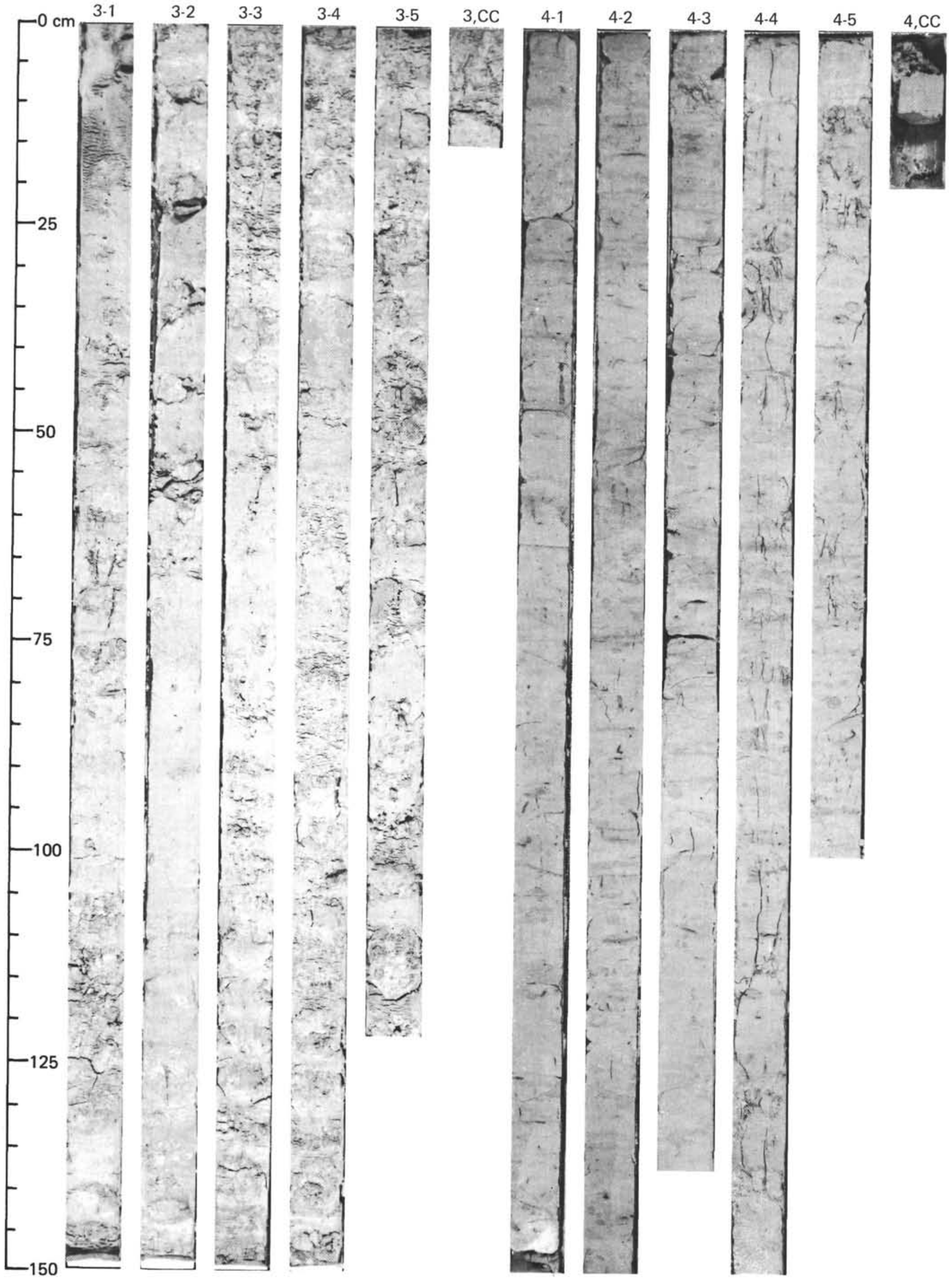
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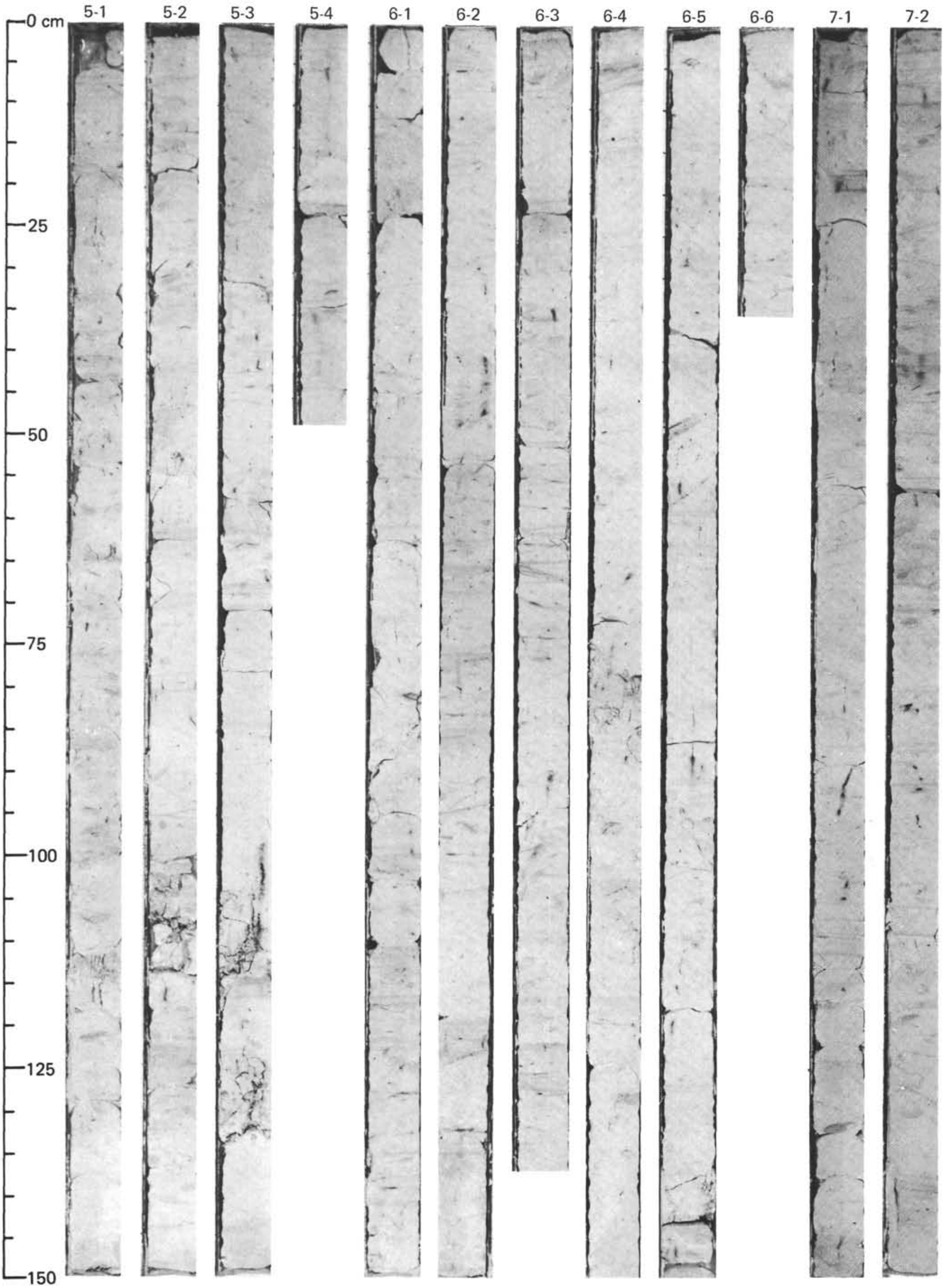
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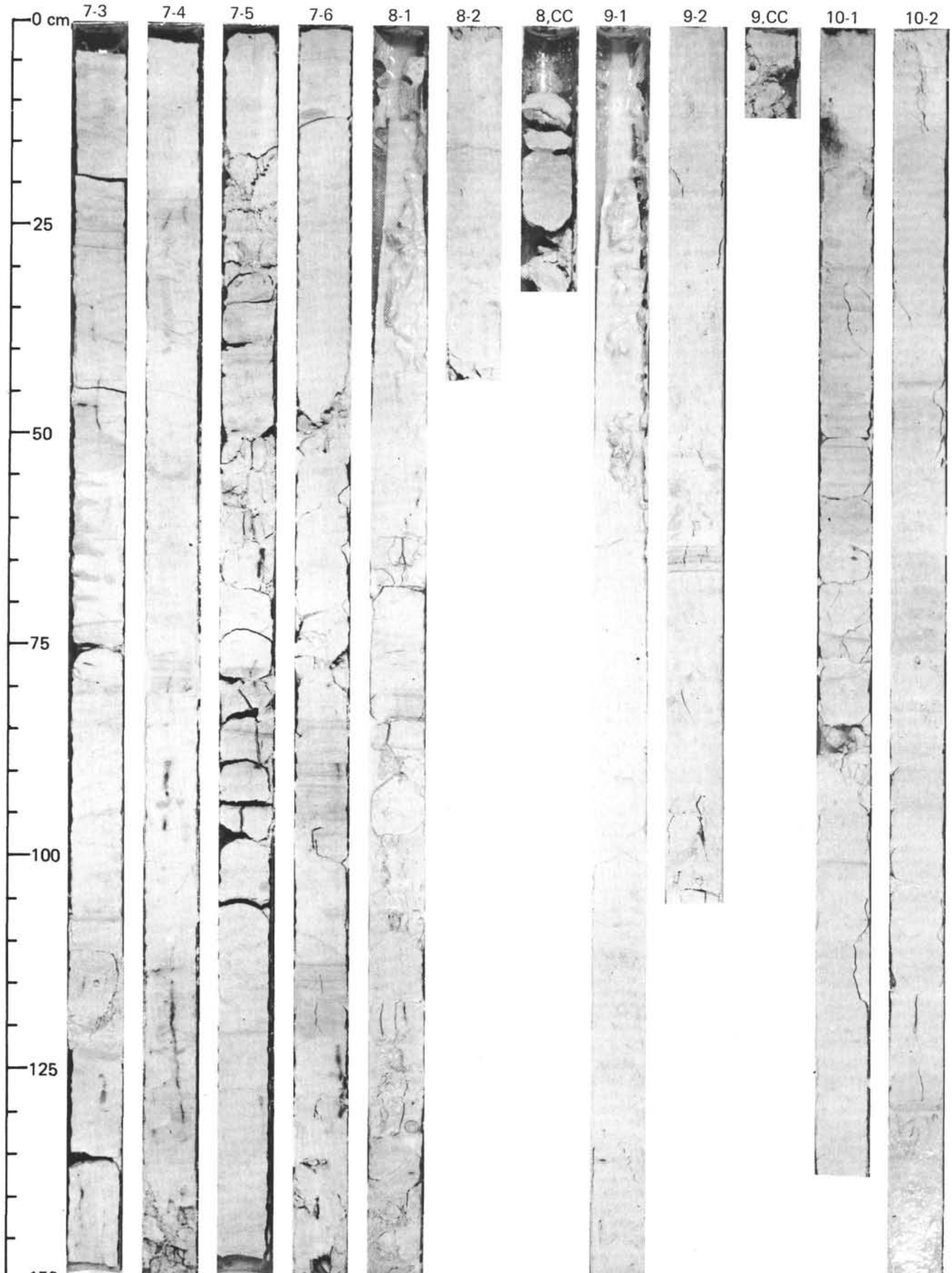
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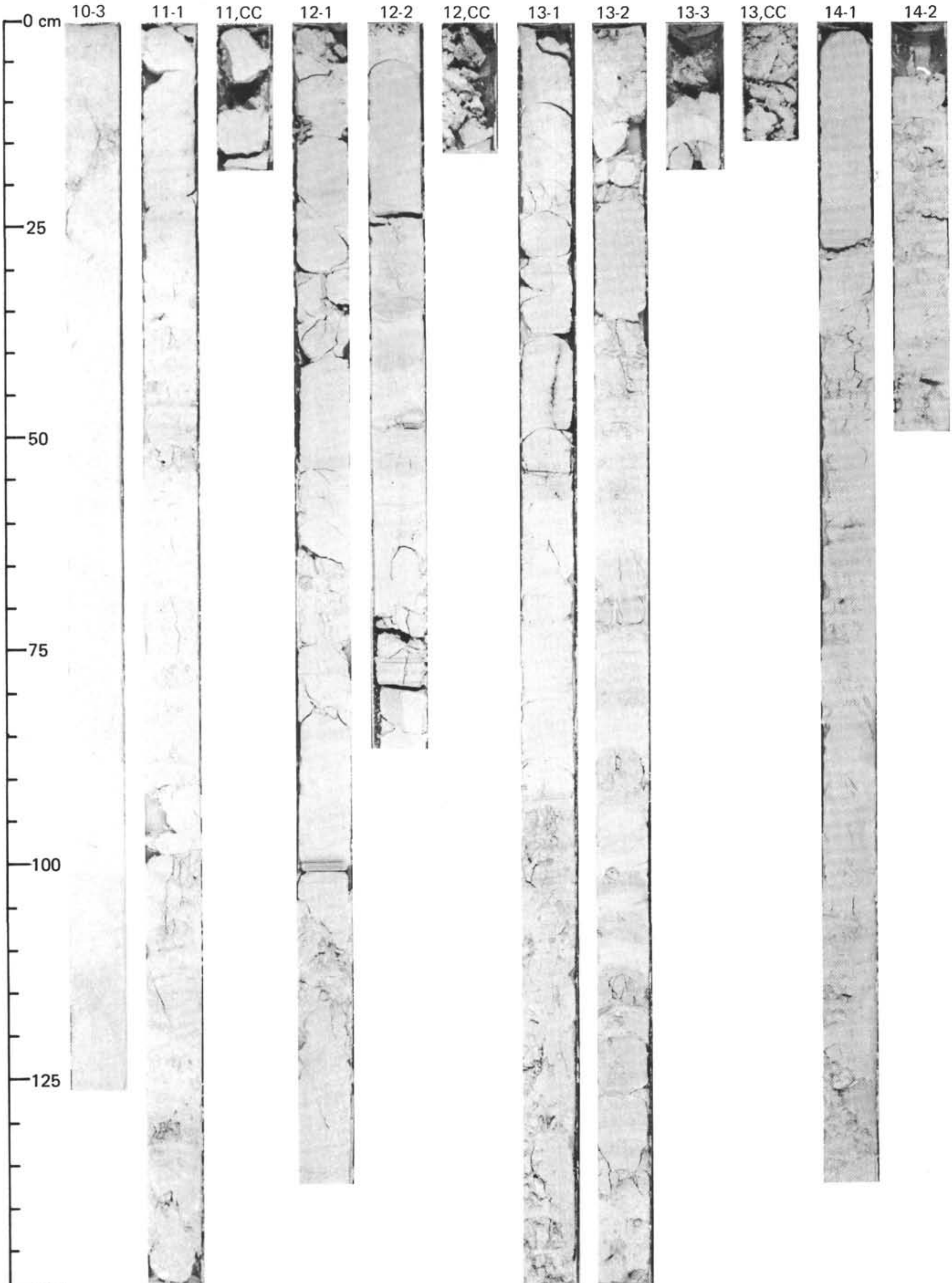

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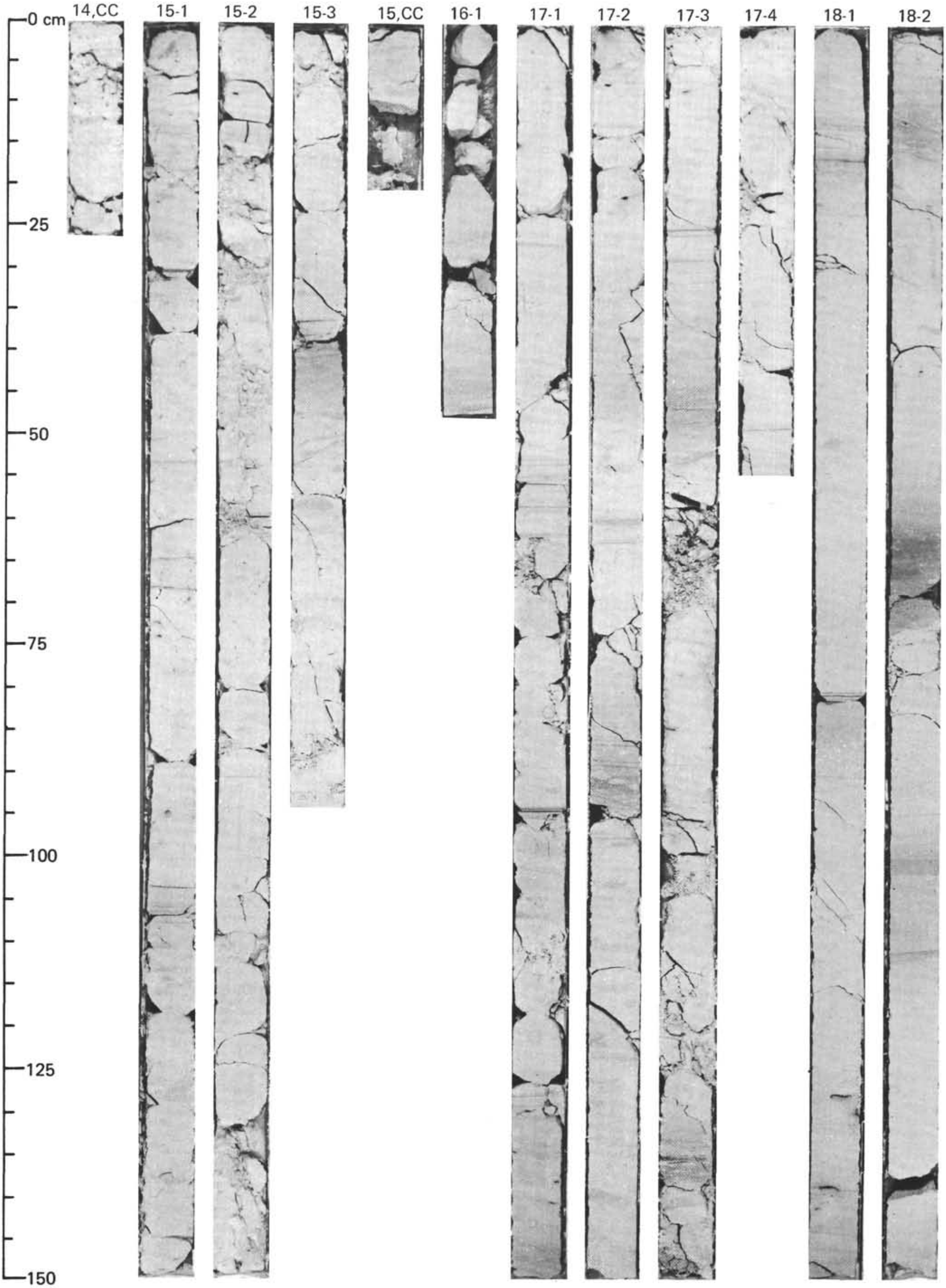
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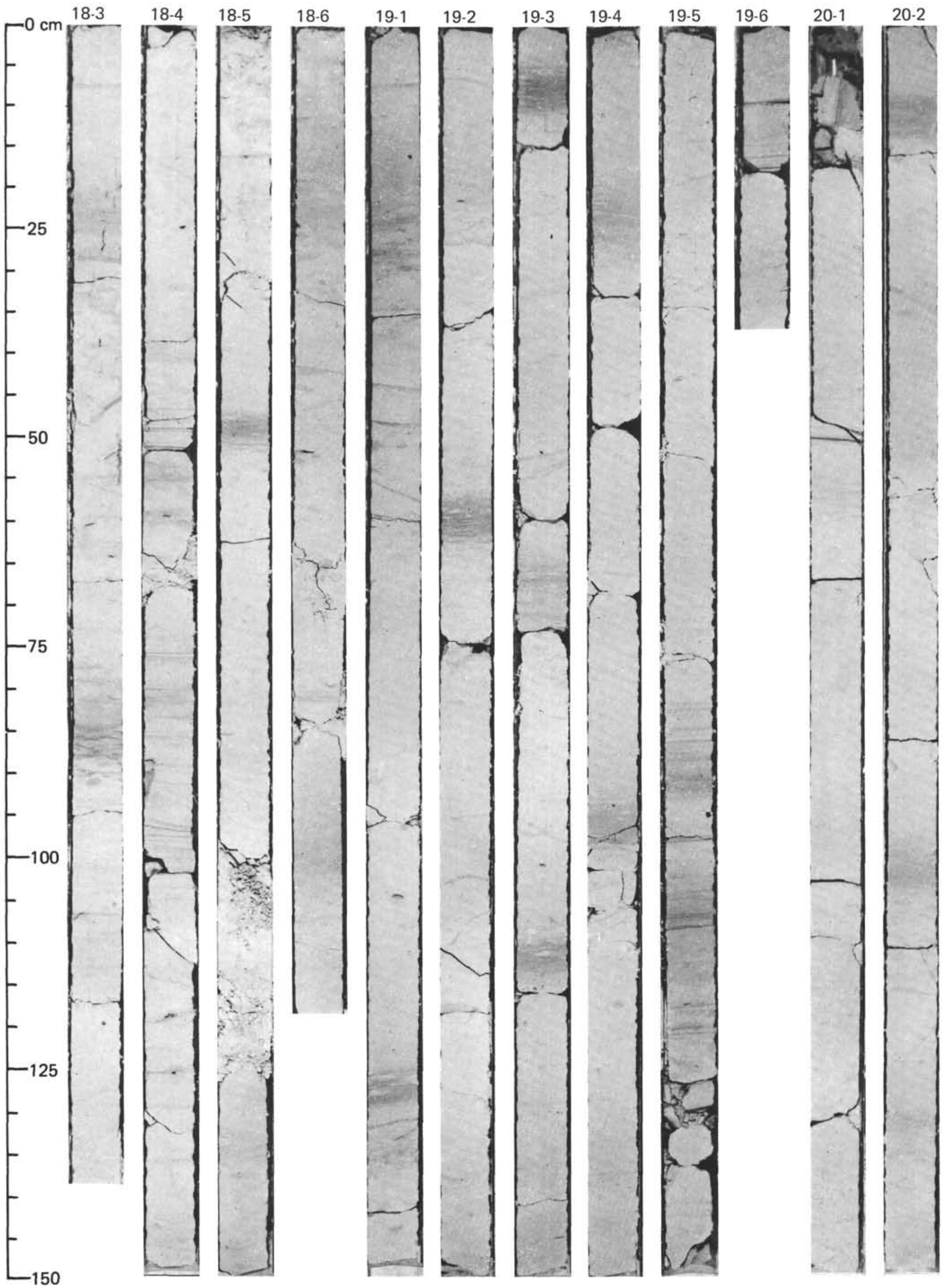

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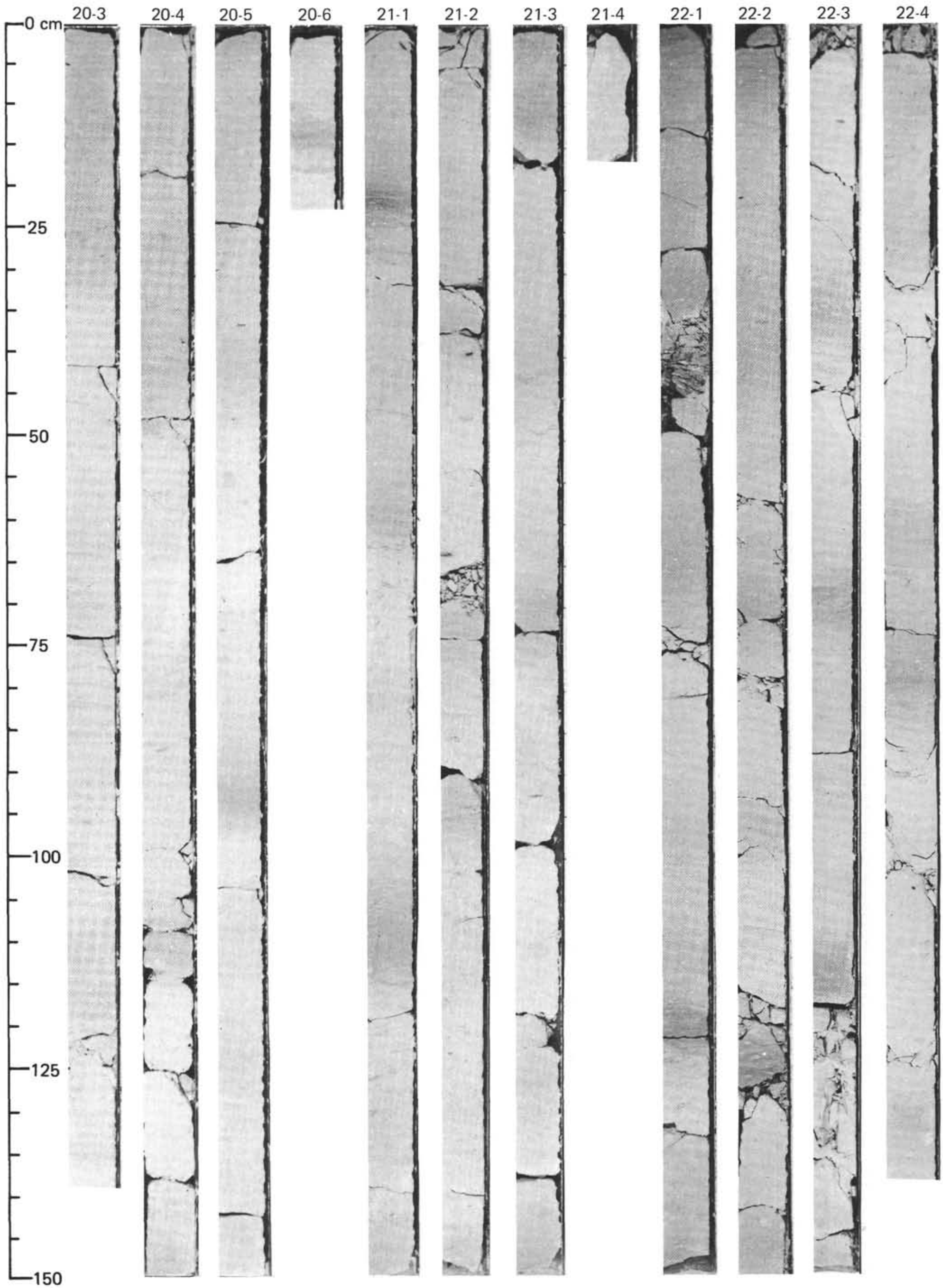
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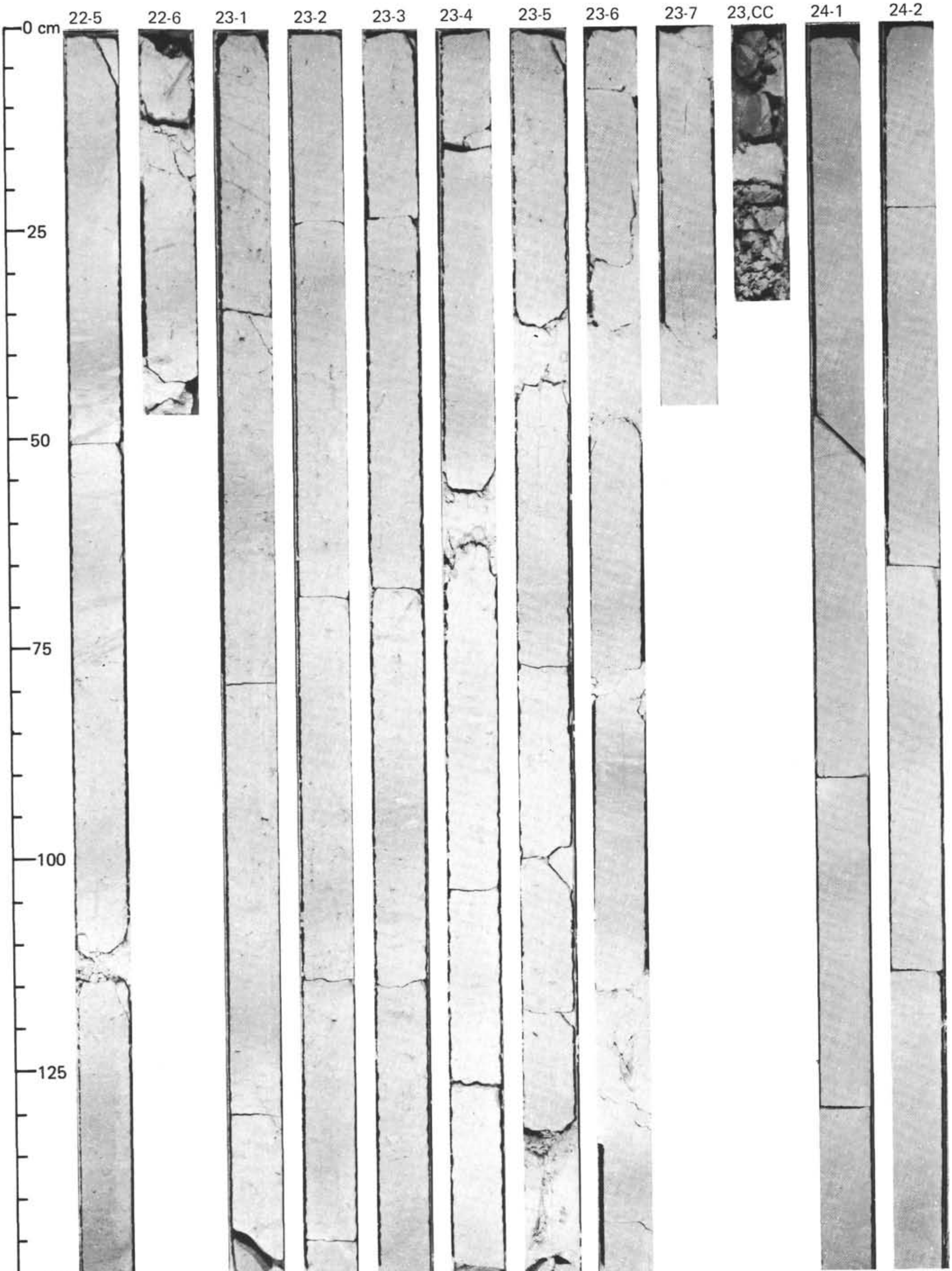
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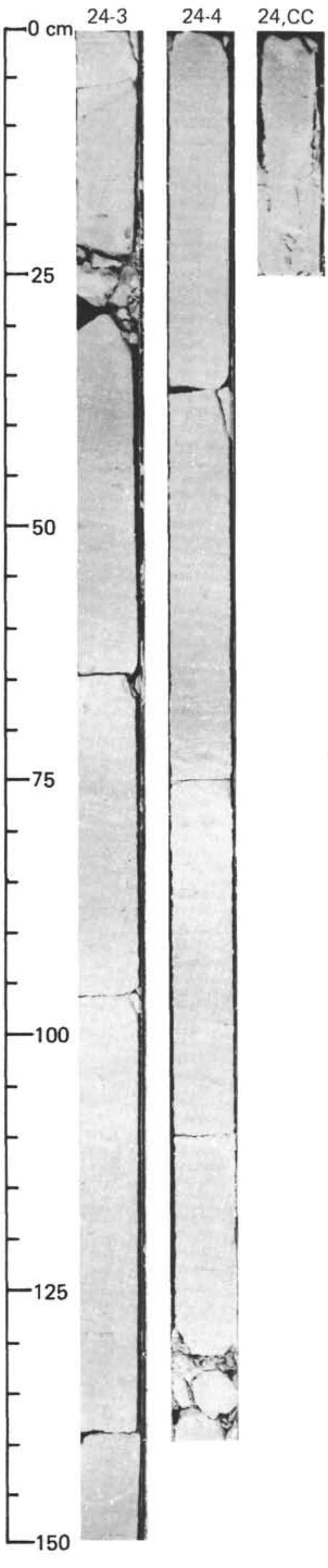
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