2. CAPE BASIN CONTINENTAL RISE— SITES 360 AND 361

The Shipboard Scientific Party[1]

SITE DATA—360

Position: 35°50.75′S, 18°05.79′E (Upper Continental Rise, west of Cape Agulhas, South Africa)

Water Depth: 2949 corrected meters, echo sounding, 2967 meters, drill pipe measurement.

Number of Holes: 1

Number of Cores: 50

Penetration: 839.5 meters

Total Length of Cored Section: 475 meters

Total Core Recovered: 278.1 meters

Percentage Core Recovery: 58.6%

Oldest Sediment Cored:
Depth sub-bottom: 839.5 meters
Nature: Marly nannofossil chalk
Age: middle Eocene
Velocity: 2.43 km/sec

Basement:
Depth sub-bottom: ≈ 4 km (not reached)

Principal Results: A continuous section was penetrated from the Pliocene into the middle Eocene, consisting predominantly of biogenic oozes, chalks, and marly chalks. The deposition is sharply pelagic in nature with episodes of especially high productivity during the late Miocene around 6 m.y., during the middle Miocene at 13 m. y., during the early Miocene at 22 m. y., and during the early Oligocene at 36 m. y. The planktonic foraminifers are for the most part of the cool-temperate type characteristic of the Austral, New Zealand biogeographic province. The earliest major cooling was initiated in the middle part of the late Eocene. Selective carbonate dissolution occurred within the late and middle Miocene and again in the Eocene. An acoustic unit consisting of what may be long-wavelength apparent upslope-migrating sediment dunes correlates to the significantly more marly Eocene section containing thin silty and sandy beds which have been highly bioturbated. The influence of bottom currents on this sediment unit was apparently very subtle, for there are no detectable stratigraphic gaps. The currents promoted the dilution of the biogenic sediments more by accelerating the infusion of terrigenous mud than by the erosional removal of sediment or the condensation of the lithologic column by winnowing. In fact, the stratigraphic intervals which in many other DSDP sites are characterized by hiatuses are here precisely the intervals of peak rates of accumulation. Alternatively, the crumpled internal reflectors may have resulted from slumping, for which there is evidence in the cores. Reflector D of Emery et al. (1975), although not reached by the drill string, has an extrapolated age of earliest Eocene to latest Paleocene.

SITE DATA—361

Position: 35°03.97′S, 15°26.91′E (Lower Continental Rise, west of Cape Agulhas, South Africa)

Water Depth: 4549 corrected meters, echo sounding, 4547.5 meters, drill pipe measurement

Number of Holes: 1

Number of Cores: 49

Penetration: 1314 meters

Total Length of Cored Section: 465.5 meters

Total Core Recovered: 222.1 meters

Percentage Core Recovery: 47.7%

Oldest Sediment Cored:
Depth sub-bottom: 1314 meters
Nature: Calcite-cemented sandstone and sapropelic shale
Age: early Aptian (by fauna) to late Barremian (by paleomagnetism)
Velocity: 3.64 km/sec

Basement:
Depth sub-bottom: 1350 to 1400 meters as estimated by reflection profile.
Nature: basalt as inferred by fragments in deepest core

Principal Results: A continuous stratigraphic section was penetrated from the upper Eocene to at least as far down as lower Aptian, the younger Cenozoic having been stripped away by recent erosion. The hole was abandoned following the destruction of the drill bit some 50-100 meters from acoustic basement. Extrapolation of sediment accumulation rates would give this basement, situated on the Mesozoic magnetic anomaly M-4 lineation, a Barremian age. Surficial Eocene mud, calcareous mud, marly nannofossil ooze, and chalk directly overlie Paleocene pelagic clay. The abrupt contact between the carbonate-rich and carbonate-poor strata corresponds to Reflector D. The Maestrichtian through Albian interval is comprised of non-carbonate terrigenous shale with intercalated sandy mudstones and siltstones interpreted as a distal fan turbidite facies deposited in its entirety beneath the carbonate compensation depth. Sediment accumulation rates range from 13 to 20 m/m. y. The Aptian interval is considerably more sandy and highly carbonaceous. The pelagic component throughout is a minutely laminated dark sapropelic shale deposited under euxinic conditions. Thick clastic beds contain wood fragments up to 8 cm in length, much bituminous material, reworked flat pebbles of coaly substances, amber, gas-escape deformation structures, and silicic volcanic sand grains all redeposited in massive quartz-rich turbidites of an interpreted moderately

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deep proximal fan to fan-valley environment sterile to indigenous benthic life. Many of the massive sands are calcite cemented and have compressional-wave velocities exceeding 4 km/sec. These Aptian-age sandstones correlate with Reflector AII of Emery et al. (1975). Sedimentation rates in the Aptian section exceed 50 m/m.y. Calibration of the Cape Basin magnetic lineations confirms an initial opening of the South Atlantic during the late Valanginian to early Hauterivian stage of the Early Cretaceous.

BACKGROUND AND OBJECTIVES

From a structural and morphological point of view, the continental margin of southwestern Africa is a middle-aged "pull-apart" or "passive-type" margin which was initially created during the breakup of the supercontinent of Gondwanaland in the Mesozoic (Wegener, 1929; DuToit, 1937). This margin (Figure 1) thus contains the classical components of both the shallow-subaqueous continental regime and the oceanic domain—that is, a shelf area, in places extensively built out by progradation, a moderately steep and occasionally canyon-dissected slope, and a broad continental rise prism leading seaward to a basin-centered abyssal plain (Heezen and Tharp, 1961; Simpson and Needham, 1967).

Sedimentary Configuration

By far, the greatest volume of sediment on the eastern South Atlantic is concentrated within the continental rise prism (Leyden et al., 1971; Bryan and Simpson, 1971; Dingle, 1973; Renard and Mascle, 1974; Emery et al., 1975). Three major units (Figure 2) can be recognized in this sediment wedge separated one from another by regionally extensive internal seismic horizons termed Reflectors D and AII of Emery et al. (1975). The bounding horizons can be followed breadthwise from the lower continental slope to the Lower Continental Rise and lengthwise from the Agulhas Fracture Zone (Francheteau and Le Pichon, 1972; Scrutton and du Plessis, 1973) to the Walvis Ridge (Connary, 1972; Barnaby, 1974; Goslin et al., 1974). In addition to the above-mentioned horizons, a morphologically irregular and highly diffracting acoustic basement can be recognized. On many of the normal-incidence seismic profiles the acoustic basement can be traced from the basin axis in a landward direction beneath the Continental Rise sediment prism to a position near the mid-rise where its relief becomes subdued and where it eventually attenuates and is lost beneath the increasing sediment overburden.

Almost without exception all sedimentary layers of Acoustic Units I and III of the Continental Rise, as seen in the reflection profiles, thin in the seaward direction. However, not all of the reflecting horizons are continuous across the rise. The deepest horizons of Acoustic Unit III below Horizon AII progressively pinch out against the acoustic basement as does Horizon AII itself. The shallowest horizons of Acoustic Unit I above Horizon D are in many instances truncated by what appears to be a youthful erosion surface in the mid-rise region. Hence both the deepest and shallowest layers of sediment accentuate the prism-like geometry of the Continental Rise. In fact, the strata of Acoustic Unit II bounded by Horizons AII and D are, by contrast, the only ones to reveal a marked uniform thickness in cross-section and are generally the most continuous on a regional scale (Figure 3).

Based almost exclusively on an analysis of the available seismic reflection profiles, Emery et al. (1975) suggested that: (1) the strata younger than Horizon D with a velocity less than 2 km/sec might be of Neogene age; (2) those between Horizons D and AII with velocities of 2.0 to 3.0 km/sec might be Paleogene in age; and (3) those between Horizon AII and acoustic basement with velocities of 3.0 to 3.8 km/sec might be Mesozoic (mostly Cretaceous) in age.

Isopachs of sediment thickness of Acoustic Unit III (Figure 4) between basement and Horizon AII depict a major depocenter beneath the Upper Continental Rise along the entire margin seaward and south of the Orange River, indicating a strong phase of deposition (probably predominantly clastic) during the initial widening of the South Atlantic. Isopachs of the sediment thickness of Acoustic Unit I above Horizon D reveal a dominance of accumulation in a narrow belt along the upper continental rise as compared to either the slope or shelf, with particularly significant deposits having formed immediately east of Agulhas Bank.

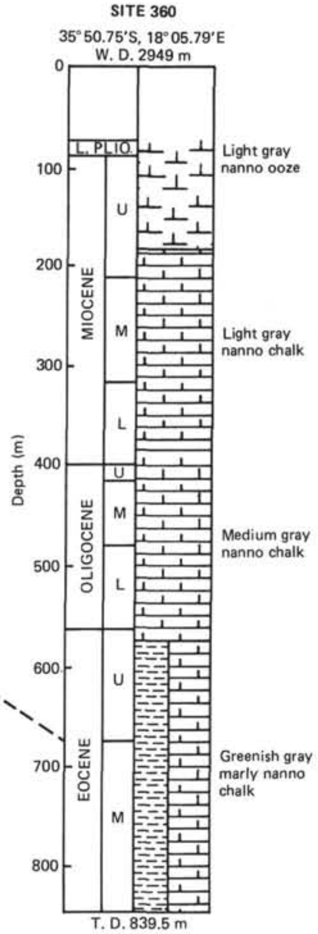
Magnetic Anomaly Patterns

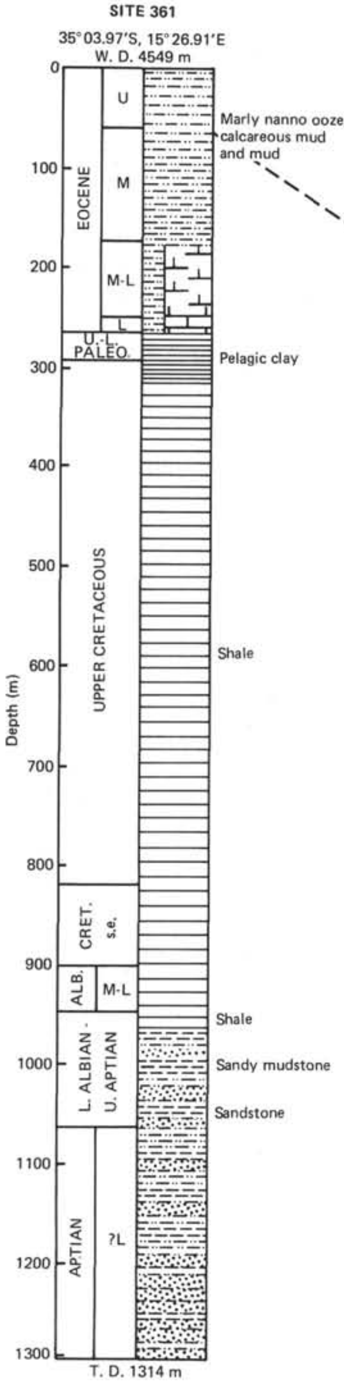
The Continental Rise sedimentary wedge of the eastern South Atlantic has been built out over a basement layer which possesses recognizable magnetic lineations (Larson and Ladd, 1973). These magnetic stripes (Figure 5), known as the Cape Basin lineations, extend from the Agulhas Fracture Zone northwards to the vicinity of the Walvis Ridge and have recently been traced in considerable detail over long distances by Rabinowitz (1976). These lineations have been correlated to anomalies M-O to M-13 of the Mesozoic sequence of Larson and Pitman (1975). The proposed correlations, if correct, imply the initial creation of oceanic crust within the Cape Basin in the Early Cretaceous at approximately 125 to 130 m. y. ago.

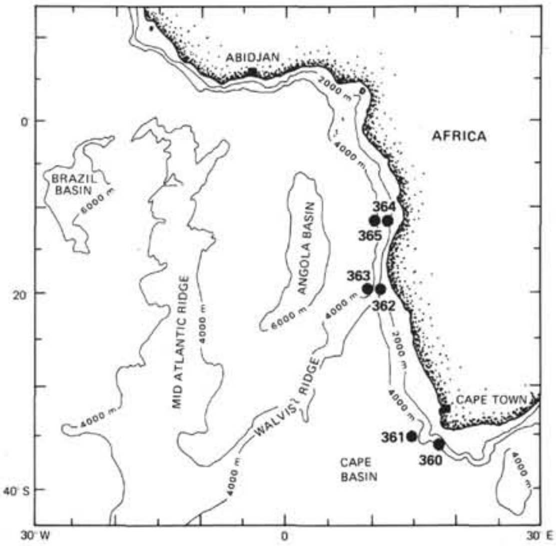
Earlier investigations of Simpson and Du Plessis (1968) and Mascle and Phillips (1972) did not reveal these oriented anomalies along the African margin; instead they mapped the region of the Cape Basin west of Cape Town as a magnetic smooth zone. An additional confusion was generated when the region of the proposed Cape Basin lineations was referred to by Mascle and Phillips (1972) as a "marginal smooth zone." This is a nomenclature for a magnetic province similar to that used to describe the Agulhas Bank which is floored by the continental continuation of South Africa (Ludwig et al., 1968; Talwani and Eldholm, 1973; Dingle, 1973; du Plessis and Simpson, 1974; Rabinowitz, 1976).

In a subsequent study with new magnetic traverses of R/V *Atlantis II*, Emery et al. (1975, p. 28) persisted in claiming "the existence of a marginal smooth zone in the Cape Basin that extended from about Lat. 24°S to Lat. 38°S." Even though these investigations point out the existence of several large positive anomaly trends (> 500 gammas) associated spatially with the continental shelf edge and the upper slope, they apparently do not accept the continuity of the greater part of the Cape Basin lineations, and, as a matter of record state (p. 22) that "the anomalies M-1 to M-10 observed by Larson and Ladd (1973) do not extend along the west margin of southern Africa."

The alternative explanation of Emery et al. (1975, p. 25) is that their "marginal smooth zone" (which actually cuts obliquely across the seaward part of the Cape Basin linea-


SITE 360
35°50.75'S, 18°05.79'E
W. D. 2949 m
Depth (m)
0
100
200
300
400
500
600
700
800
L. PLIO.
MIOCENE
U
M
L
OLIGOCENE
U
M
L
EOCENE
U
M
Light gray nanno ooze
Light gray nanno chalk
Medium gray nanno chalk
Greenish gray marly nanno chalk
T. D. 839.5 m


SITE 361
35°03.97'S, 15°26.91'E
W. D. 4549 m
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
EOCENE
U
M
M-L
L
U.-L. PALEO.
UPPER CRETACEOUS
CRET. s.e.
ALB. M-L
L. ALBIAN - U. APTIAN
APTIAN ?L
Marly nanno ooze, calcareous mud and mud
Pelagic clay
Shale
Shale
Sandy mudstone
Sandstone
T. D. 1314 m


ABIDJAN
AFRICA
BRAZIL BASIN
6000 m
2000 m
4000 m
364
365
363
362
ANGOLA BASIN
6000 m
MID ATLANTIC RIDGE
WALVIS RIDGE
CAPE TOWN
361
360
CAPE BASIN
0°
20°
40° S
30° W
0
30° E

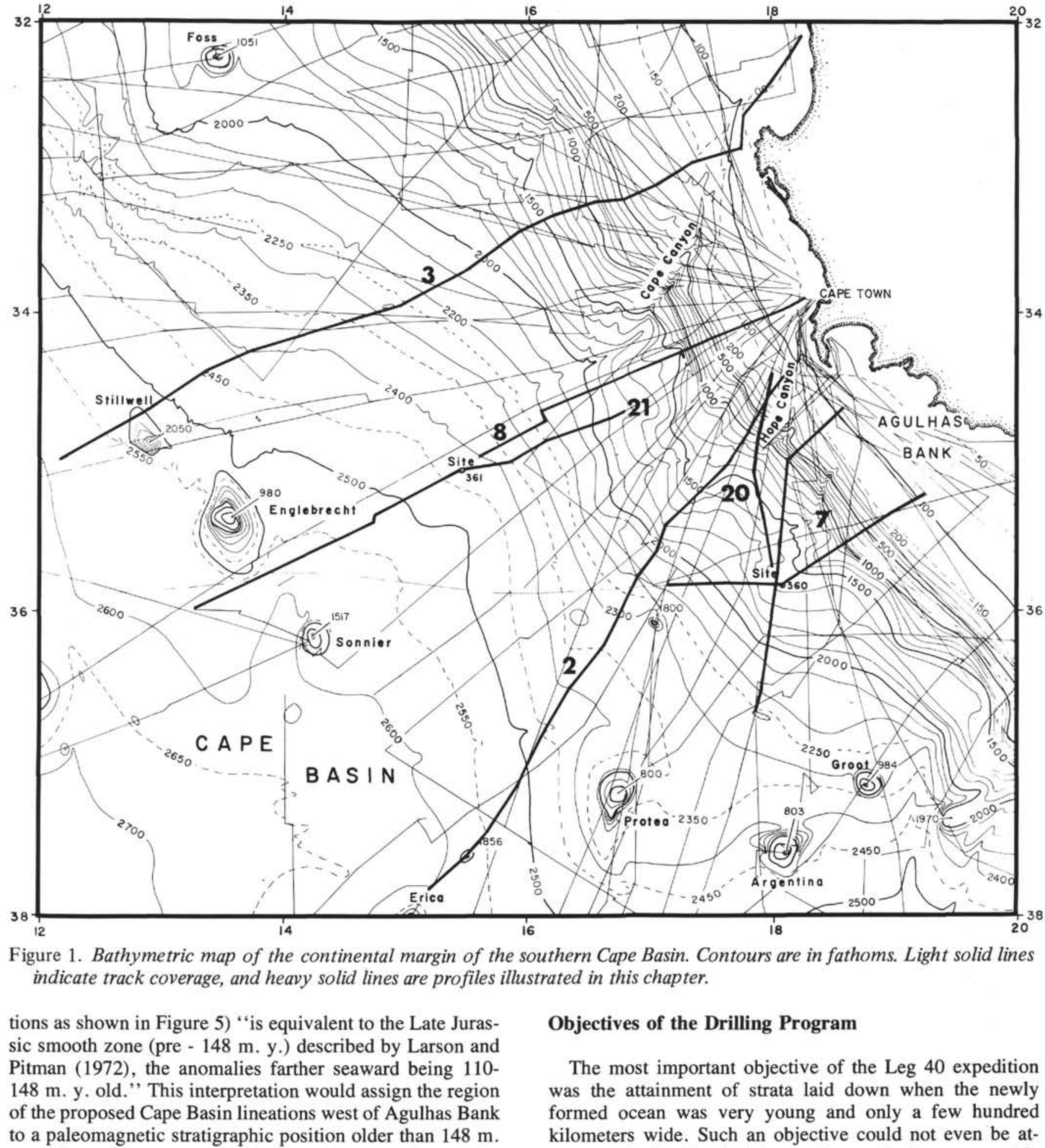


Figure 1. *Bathymetric map of the continental margin of the southern Cape Basin. Contours are in fathoms. Light solid lines indicate track coverage, and heavy solid lines are profiles illustrated in this chapter.*

tions as shown in Figure 5) "is equivalent to the Late Jurassic smooth zone (pre - 148 m. y.) described by Larson and Pitman (1972), the anomalies farther seaward being 110-148 m. y. old." This interpretation would assign the region of the proposed Cape Basin lineations west of Agulhas Bank to a paleomagnetic stratigraphic position older than 148 m. y. and would correspondingly date "the opening of the South Atlantic south of Lat. 20°S in middle Jurassic time about 165 m. y. ago" (p. 25, Emery et al., 1975).

Hence two very different age estimates have been offered[2] or the formation of oceanic crust within the Cape Basin.

Objectives of the Drilling Program

The most important objective of the Leg 40 expedition was the attainment of strata laid down when the newly formed ocean was very young and only a few hundred kilometers wide. Such an objective could not even be attempted in the North Atlantic due to the insurmountable thickness of sediments beneath the Continental Rise far in excess of the sub-bottom penetration capability of *Glomar Challenger*. Such an objective had been attempted once and achieved successfully in the very youthful Gulf of Aden, where at DSDP Site 231 (Fisher, Bunce, et al., 1974) oceanic tholeiitic basalt had been recovered beneath 12-13 m. y. old nannofossil ooze at a distance of less than 100 km from the continental edge.

The attainment of such a goal in the southern South Atlantic Ocean was very attractive because: (1) there existed

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[2] The Emery et al. (1975) paper was made available as a preprint prior to the Leg 40 campaign and its data and the interpretations were used for the planning of the drilling and coring program.

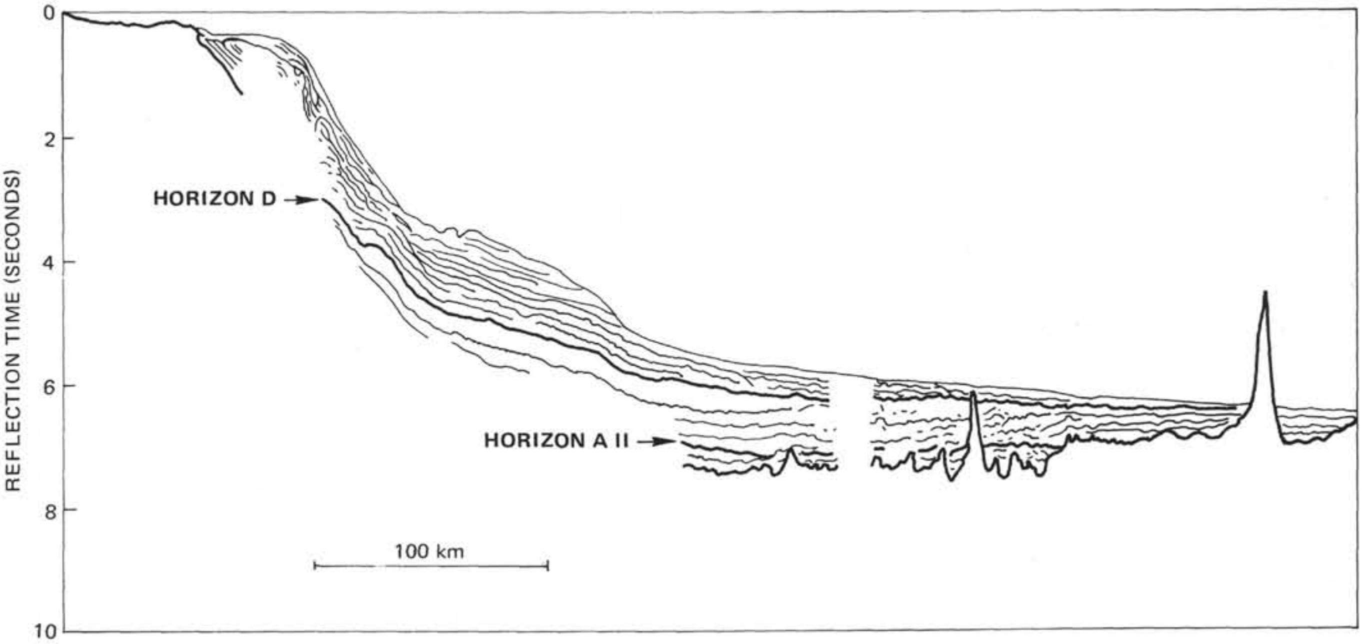


Figure 2. *Line tracing of profile 8 of Emery et al. (1975) which transects the continental margin and displays the three major acoustic units described in the text.*

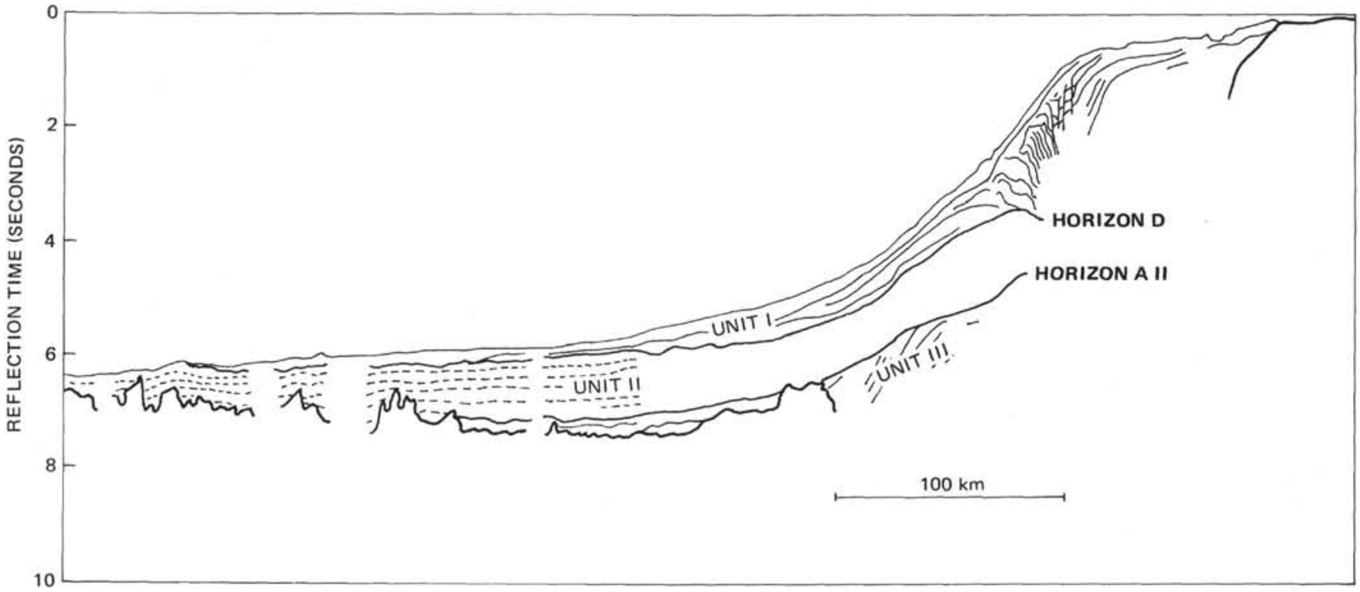


Figure 3. *Line tracing of profile 3 of Emery et al. (1975) illustrating the uniform thickness of Acoustic Unit II beneath the continental slopes and rise.*

the strong likelihood that the nature and composition of the basal sediments within the Cape Basin region would have been different than the astonishingly pure biogenic oozes of the Gulf of Aden as the consequence of a much higher paleolatitude for South Africa in the Mesozoic accompanied by a cooler and more humid climatic regime, (2) the entire South Atlantic would have been narrow and semi-restricted by high-standing sills and barriers unlike the open-embayment situation of the Gulf of Aden, (3) the paleogeography at the time of the fragmentation of Gondwanaland still remained quite poorly defined, particularly in respect to the regions from which marine waters and their accompanying flora and fauna might have been expected to have migrated from at the time of their entrance into the embryonic South Atlantic rift zone. Furthermore, there was, as already outlined, a considerable uncertainty as to the age itself of the pull-apart of South Africa from South America, leading to the development of the oceanic environment, transgressive through time in a northward direction.

An additional major objective of Leg 40 drilling was to search in the basal sedimentary layers for the possibility of evaporite deposits of a like nature to those detected northward of the Walvis Ridge beneath and seaward of the coasts

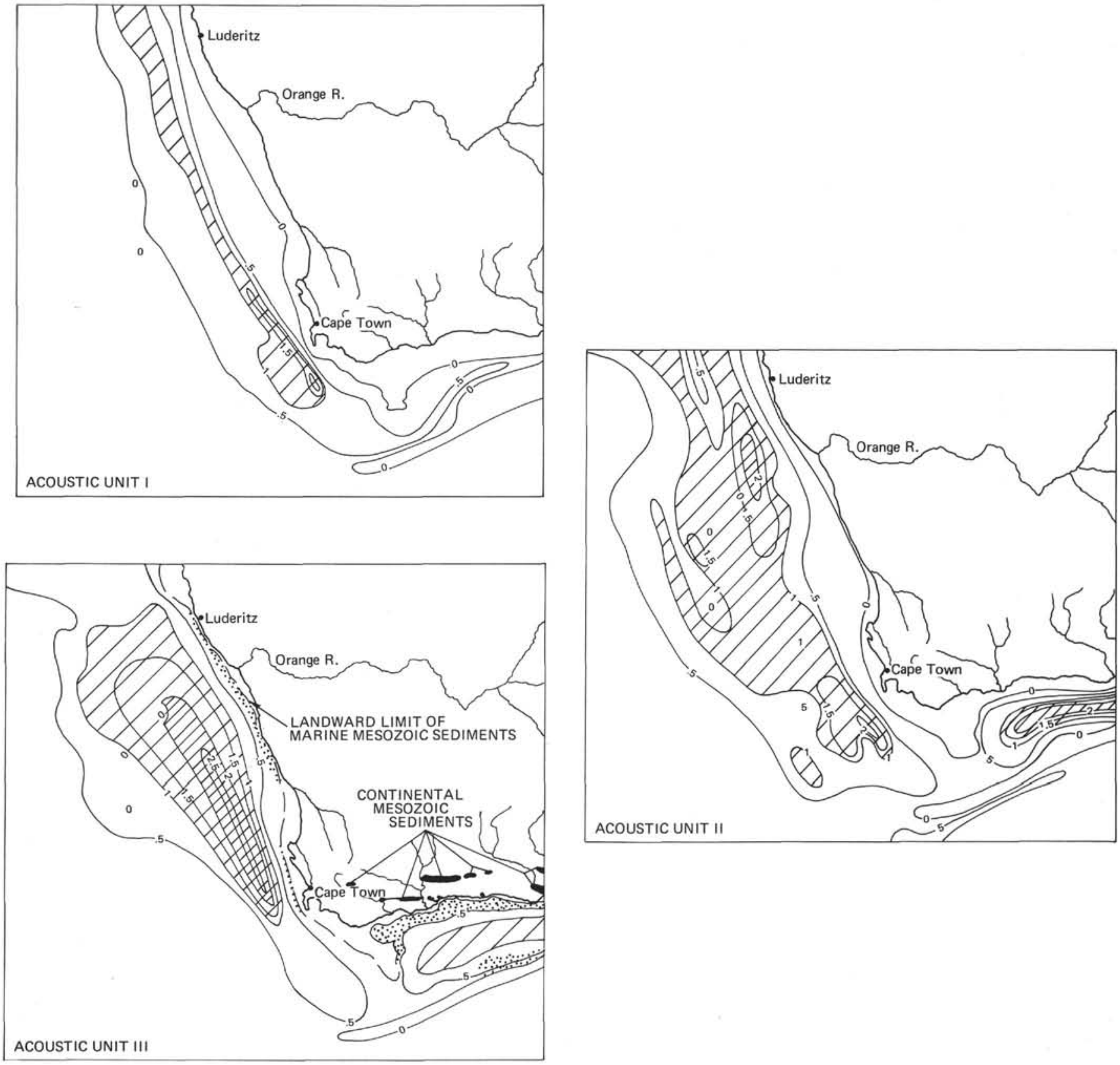


Figure 4. *Isopach diagrams of sediment thickness of the three main acoustic units (adapted from Emery et al., 1975).*

of Brazil in South America and Gabon, Congo Cabinda, Zaire, and Angola in Africa. Although no diapiric structures had been discovered south of the Walvis Ridge, precious few outcrops of Mesozoic sediments existed off South Africa (Haughton, 1969; Dingle, 1969, 1971, 1973; Rigassi and Dixon, 1972; Winter, 1973) from which the nature of the early opening environment could be assessed, especially in deep water settings.

Besides emphasis on the oldest sedimentary strata, there was a need to probe carefully the younger deposits especially above Horizon D, which thin so markedly in the downslope direction and which reveal sub-surface bedforms (Figure 6) resembling abyssal antidunes (Fox et al., 1968) or sediment waves (Hollister et al., 1974; Jacobi et al., 1975). Undulating strata in a similar stratigraphic position exist on the southwestern end of the Walvis Ridge (Emery et al., 1975, fig. 44A). It was anticipated that their lithologic and biogenic makeup would provide an additional calibration of the extent of the activity of bottom-water circulation in the past, possibly as related to climatic deterioration and the onset of an intensified deep-ocean thermohaline circulation during the early Cenozoic (Kennett et al., 1972, 1975; Berggren and Hollister, 1974).

The cause of the observed seaward thinning of the different units of the Continental Rise prism required explanation. Possible answers included (1) more vigorous current activity on the Lower Rise than on the Upper Rise which inhibited deposition of sediment particles or caused their removal by erosion; (2) progressive downslope dispersal of terrigenous clastic deposits transported in suspension by

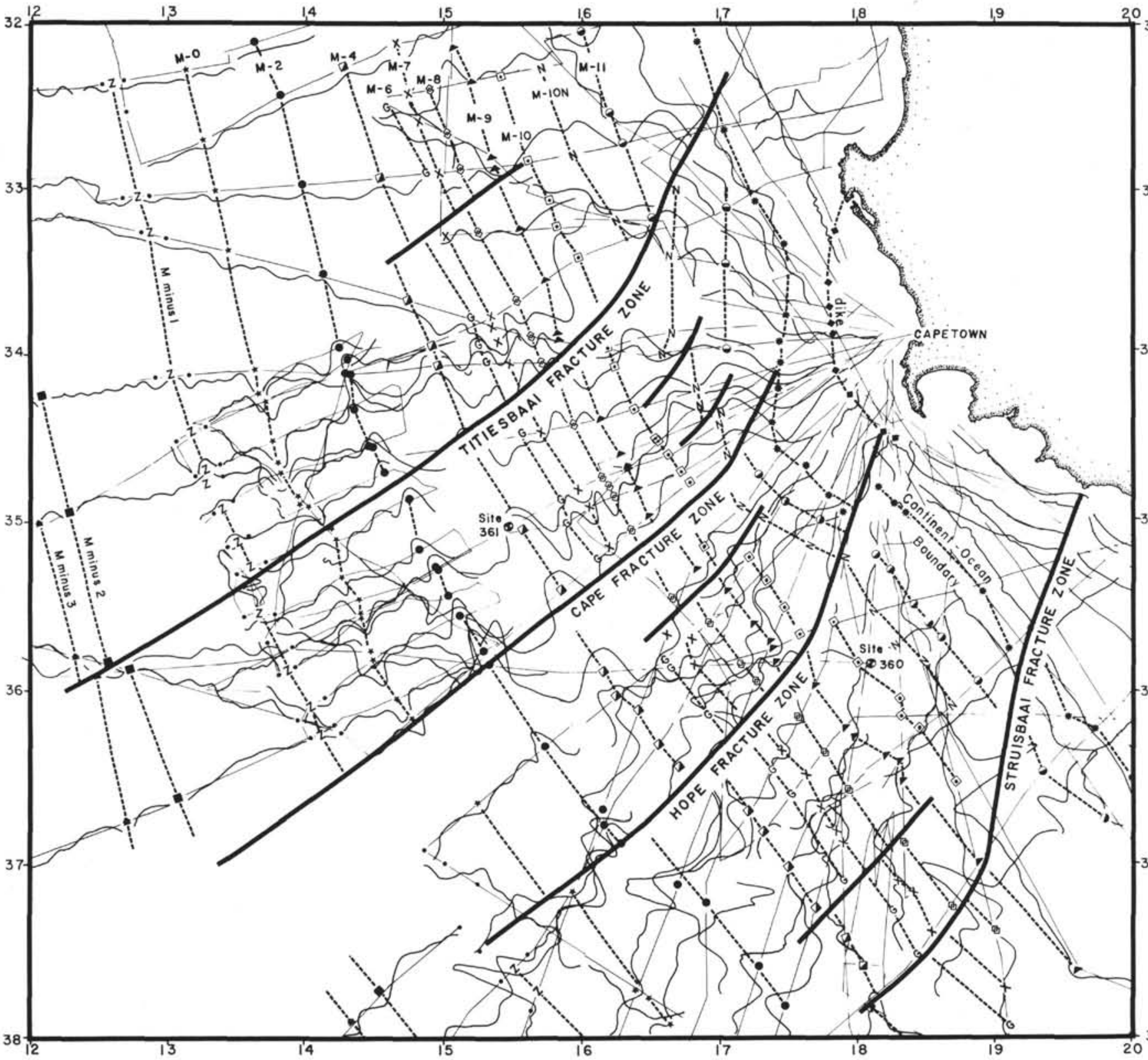


Figure 5. *Magnetic anomaly lineations in the southern Cape Basin. Dotted lines indicate coverage, with selected profiles illustrated by solid lines. The lineations are offset by several fracture zones. Anomaly G is considered to correspond approximately with the ocean/continent boundary. Stippled patterns delineate the "marginal smooth zones" of Emery et al. (1975), which cut obliquely across the mapped lineations.*

gravity-propelled density flows; (3) selective destruction of a predominant biogenic carbonate sediment supply as a function of the water depth dependence on calcite solubility; and (4) decreasing productivity of shell-secreting plankton with increasing distance seaward from a coastal zone of upwelling and associated high fertility.

Strategy

Two sites were scheduled in order to realize the stated objectives and satisfy the technical limitation of continental margin penetrations. Together they would form a composite section. The first site (360) would be targeted in a relatively shallow water (< 3000 m) above the level of marked carbonate dissolution at a location optimum for sampling the post-Horizon D sequence in an area where it reached an appreciable thickness (hopefully to assure stratigraphic completeness of the section). The second site (361) would be positioned in deeper water with much of the younger section already penetrated at the first site either missing or considerably thinned. The second site would have the prime purpose of reaching the pre-Horizon AII sequence, determine its lithology and environmental significance, and stratigraphically define the oldest sediments above basement over a key magnetic lineation.

Site 360

The first site (360) was therefore placed on the Upper Continental Rise immediately to the west of Agulhas Bank

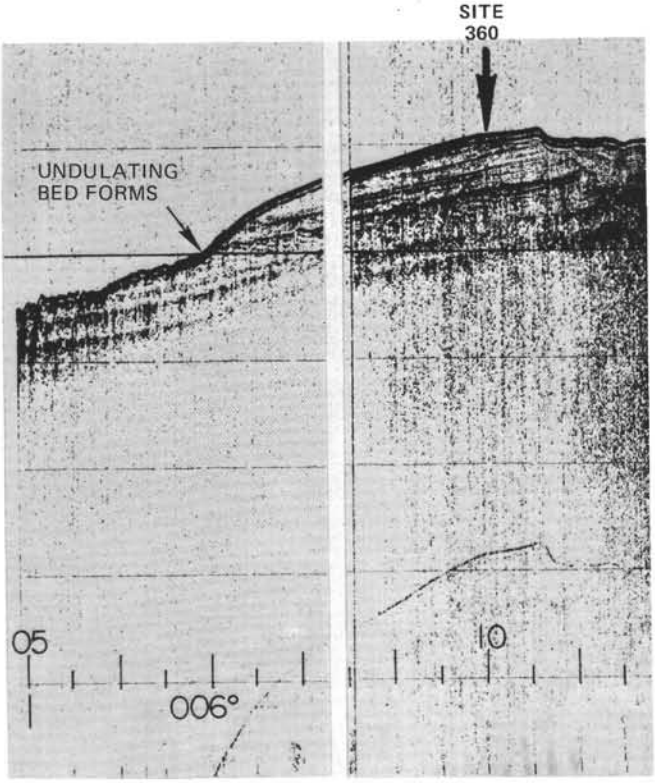


Figure 6. *Subsurface bedforms beneath the South African continental rise on profile 8 of Emery et al. (1976),* Robert D. Conrad *profile 2298. The undulating bedforms belong to lower part of Acoustic Unit I and resemble large-scale sediment waves.*

and almost directly south of Cape Town where the sediment isopachs of Acoustic Unit I above Horizon D show an impressive thickness along a contiguous belt. The actual site (Figure 7) was picked at 0940 hours, 10 January, on seismic reflection profile 2298 of Cruise 13 R/V *Robert D. Conrad* where it intersected at right angles a second line at a position of 1600 hours, 2 November, on profile 2079. In the region of the Upper Continental Rise the aforementioned subsurface bedforms are exceptionally well expressed and the sedimentary horizons are generally conformable.

Five acoustic subunits can be recognized on the seismic profiles above Horizon D at approximately 1.10 seconds below the sea floor.

Table 1 lists the subunits, their boundary seismic horizons (given the name of colors used to interpret the profiles), and the position of these horizons below the sea floor in units of travel time for the various reflection profiles.

Subunit IA is a relatively thin and acoustically transparent surficial cap of sediment preserved in the vicinity of this site from the erosion which is prevalent in the Upper Continental Rise. Subunit IB is weakly stratified and strongly comformable body which like Subunit IA has also been removed by erosion from much of the Continental Rise profile. The basal strata of the conformable, uniformly bedded sediments are again acoustically stratified and are represented in Subunit IC. Its lower limit defines an important reflecting horizon referred to as reflector blue.

TABLE 1
Acoustic Boundary Designations at Site 360

Base of Acoustic Unit	Seismic Reflector	Travel Time Sub-Bottom (sec)
IA	Pale Green	0.23
IB	Turquoise	0.44
IC	Blue	0.54
ID	Red (not reached)	0.93
IE	Horizon D (not reached)	1.10

An interval of undulating bedforms resembling abyssal antidunes or sediment waves is apparent in Subunit ID whose base is identified by a strong, somewhat diffuse reflecting interface referred to as reflector red. The acoustically transparent Subunit IE lies between reflector red and Horizon D of Emery et al. (1975). Horizon D has been calibrated by lateral correlation to 0600 hours, 28 February, on profile 8 (Figure 2) of *Atlantis II* Cruise 67, published in fig. 6 of Emery et al (1975). This location on profile 8 is considered in our site report the stratotype location for the definition of Horizon D in the southern Cape Basin region.

Site 361

The second site (361) was targeted on the Lower Continental Rise at a depth of approximately 4.5 km where the post-reflector-D sequence is very much attenuated in thickness. The location (Figure 8) at 0300 hours, 11 April, on reflection profile 441 of Cruise 22 of R/V *Vema* was chosen after completing the Site 360 drilling; it was adjusted to permit an overlap of the reflector red to Horizon D stratigraphic interval not previously obtained as a consequence of the premature abandonment of Site 360.

Three main acoustic units and two subunits can be recognized (Table 2) at Site 361. Unit I extends to 0.30 sec. beneath the sea floor. Bounded at its base by Horizon D of Emery et al. (1975), Unit I is primarily acoustically transparent in the vicinity of the site, as it is a lateral continuation of Unit IE of Site 360. Some stratification is seen, however, in the uppermost part of Acoustic Unit I. A shallowly buried erosion surface crops out very near to Site 361 and is referred to as reflector brown (Figure 8). Horizon D is especially well defined on the seismic reflection profile and converges with the sea floor in the down-dip direction, eventually cropping out in an erosional moat around the base of Englebrecht Seamount.

TABLE 2
Acoustic Boundary Designations at Site 361

Base of Acoustic Unit	Seismic Reflector	Travel Time Sub-Bottom (sec)
I	Horizon D	0.32
II	Horizon AII	1.04
III	Acoustic Basement	>1.28

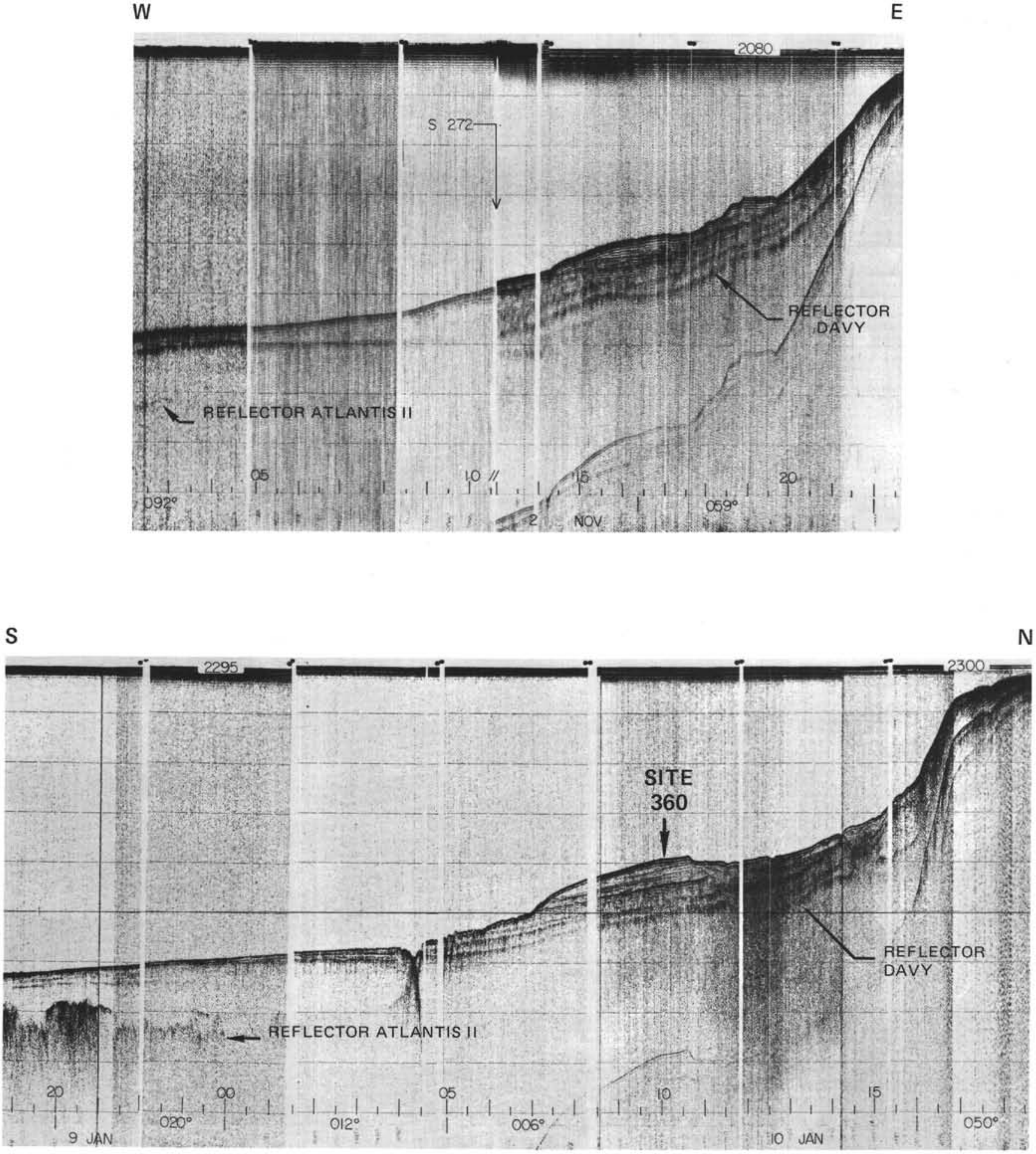


Figure 7. *Seismic reflection profiles extending south to north and west to east through Site 360. Rabinowitz et al. 1976, lines 27 and 120. These are* Robert D. Conrad *profiles 2079 and 2298 respectively. Particular reflecting interfaces are identified in the line drawings and are discussed in the text. The profiles are located in Figure 9.*

Acoustic Unit II is also rather transparent, although some faint undulating stratification is discernible in the seismic profiles. The base of Unit II is represented by Horizon AII, considered here the top of a 0.25 sec thick band of strongly reverberant reflecting interfaces. Horizon AII has been calibrated by correlation to 1400 hours, 28 February, on profile 8 (Figure 2) of *Atlantis II*, Cruise 67, published in fig. 6 of Emery et al. (1975). This location on profile 8 is considered herein the stratotype location for the definition of Horizon AII in the southern Cape Basin region. Acoustic Unit III lies between Horizon AII and the morphologically irregular acoustic basement, interpreted as basaltic layer 2

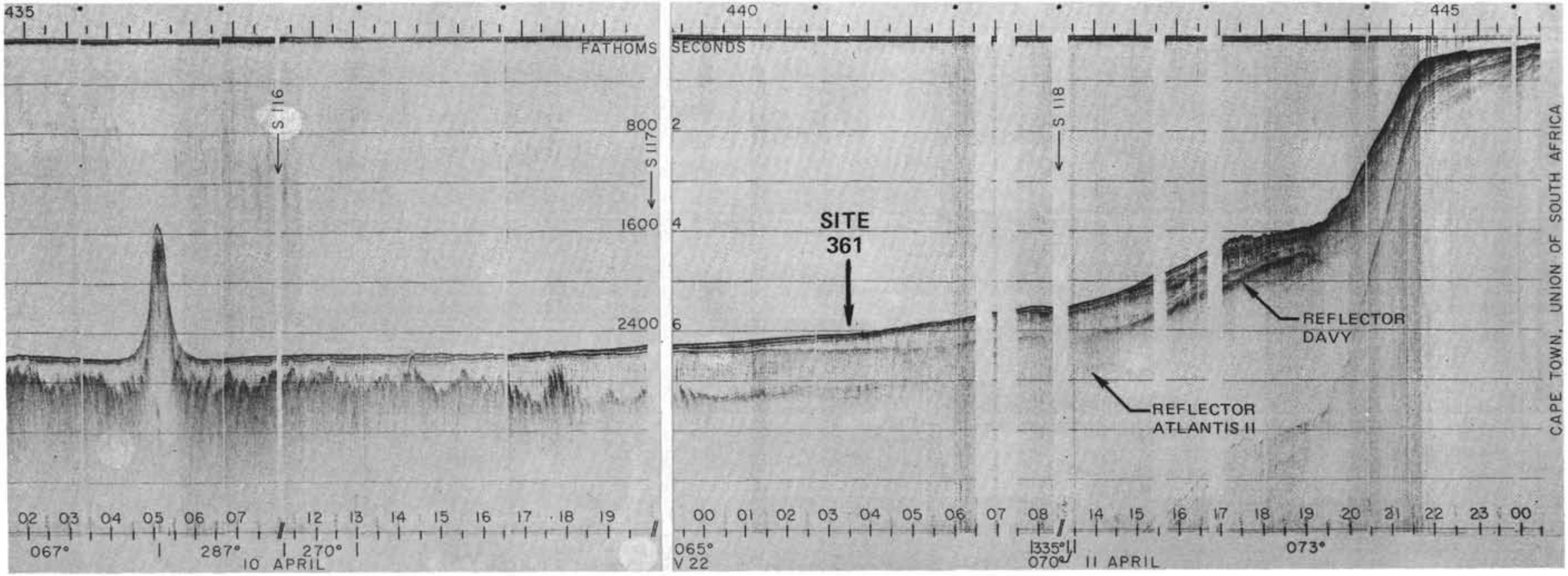


Figure 8. *Seismic reflection profile extending northeast to southwest through Site 361 (Rabinowitz, et al., 1976, line 25,* Vema *Cruise 22 profile 441). Particular reflecting interfaces are identified in the line drawing and are discussed in the text. The location of the profile is given in Figure 10.*

of the oceanic crust. Acoustic basement is not especially clear beneath the site location on the *Vema* profile, although it is readily discernible about 40 km to the southwest at 2330 hours, 10 April. The top of the acoustic basement has been picked shipboard with a travel time of 1.35 sec or greater for the site location.

Horizon AII merges with acoustic basement in the vicinity of magnetic anomaly M-O. Near the region of pinch out on profile 440 of *Vema* 22, this acoustic interface is offset by faults and is tilted northeastward as a series of rotated blocks, possibly associated with basement tectonics of the mid-ocean ridge. Near the site Horizon AII is slightly undulating and contains small niches which resemble the box-shaped cross-section of deep-sea channels and fanvalleys. Internal reflectors within the reverberant interval below Horizon AII are laterally discontinuous.

OPERATIONS

Approach to Site 360

Site 360 was approached during the evening of 20 December, 1974 on a heading of 157° so as to intersect the *Robert D. Conrad* reflection profiles at the selected target (Figure 1). *Glomar Challenger's* speed was reduced at 2120 hours to prepare for a jettisoning of the acoustic beacon deployed for dynamic positioning. The release of the beacon (while still underway and continuing the seismic profiling) took place at 2130 hours with an echo-sounding reading of 1581 tau (= 2949 m). The seismic profile was then continued for an additional one-half mile before changing course back to the site location. Information on Site 360 cores is given in Table 3. A long chisel (insert type) 4-cone F93C core bit was made up at the bottom of the coring assembly. We anticipated sedimentary formations with relatively low compressive strength and no indurated stringers of chert. The core bit was selected to provide moderately high penetration rates if the formations were to become excessively shaly.

Spudding in at Site 360

The first detectable contact with the seabed was at 1150 hours on 21 December with a drill string length of 2977 meters measured from the rig floor (situated 10 m above sea level). Due to the uncertainties in the continued performance of the dynamic positioning system and the presence of relatively high-amplitude swell trains from several directions, coring was suspended until the bottom-hole assembly (drill collars and collapsible bumper subs) was sufficiently buried to assure its stability and integrity if the vessel were to take an off-hole excursion. Continuous back-to-back coring commenced with Cores 1 through 4 cut without circulation of fluids through the bit face. The first noticeable resistant interval was felt while cutting the lower half of Core 6 at approximately 135 meters sub-bottom. Other thin resistant zones were encountered at 155, 164, and 190 meters. The penetration rate increased appreciably for Core 13 suggesting the presence of a somewhat sandier lithology which was more easily washed aside with the circulation fluids.

Technical Difficulties

Dynamic-positioning problems occurred while finishing the cutting of Core 18. The bridge recorded an offset from the beacon which may have exceeded 300 meters, and the entire system was judged quite shaky and unreliable in both manual and semi-automatic modes. Correspondingly we decided to lay down the power sub and pull the drill string free of the subsurface of the sea floor. Fortunately repairs were made before the hole was completely cleared. Some 90 meters of pipe had been removed allowing for the possibility of uphole contamination in Core 19.

Change to Intermittent Coring

Because of accumulating down time and the realization that we had passed through the critical late Miocene stratigraphic interval, we decided to recover every other 9.5-meter interval from Core 19 onwards.

An appreciable change in the nature of the formation was noticed while cutting Core 22. All cores were now being obtained with a constant circulation of 5 to 10 strokes per minute. During the late evening of 22 December the wind commenced to gust above 30 knots and occasionally above 40 knots with the swell rising to 6 meters.

Another major formation change causing moderate torquing and accompanied by bouncing of the drill bit was encountered at 435 meters in Core 28, followed by an abrupt switch back into something much less brittle. Hard intervals were again seen during the cutting of Core 29, followed by significant torquing for the last 3 meters of Core 30. The highest bit weight yet was used to penetrate this level. At this time a significant overall decrease in the penetration rate was realized culminating in Core 34.

One small soft spot was apparent at 533 meters in the middle of Core 33 followed immediately by moderate torquing. The last brief easy penetration was seen at 562-564 meters in the work interval between Cores 34 and 35. Core 35 jammed and it took two runs on the overshot to retrieve it. Core 36 was cut back to back to 35 to explore this major increase in formation induration thought to correspond to the passage through reflector blue and to the transition into Acoustic Unit ID.

Christmas Day was ushered in with the retrieval of Core 39 and progress continued at a steady pace through semi-indurated chalks of Eocene age. On the following day, however, a check of a high rpm reading of the No. 2 bow thruster revealed that this propulsion unit was freewheeling due to a disconnection from the thruster propeller. The weather, which had been unsettled for days, became a critical factor now that position-holding capabilities were reduced. At mid-morning of 27 December, the ship's meteorologist recommended a termination of drilling operations in light of a rapidly approaching low pressure front detected on the satellite photos of cloud coverage. Therefore we abandoned the hole some 300 meters short of Reflector D. A mud line punch core was attempted on the trip out of the hole, but yielded no recovery. The drill string was pulled in rapidly. Deteriorating weather conditions and a full gale hit at the time the ship was secured for transit back to Cape Town to effect repairs to the bow thruster. Some hours

TABLE 3
Coring Summary, Site 360

Core	Date (December 1974)	Time	Depth From Drill Floor (m)	Depth Below Sea Floor (m)	Length Cored (m)	Length Recovered (m)	Per Cent Recovery
1	21	1310	3056.5 – 3066.0	79.5 – 89	9.5	6.9	73
2	21	1425	3066.5 – 3075.0	89 – 98.5	9.5	9.5	100
3	21	1530	3075.5 – 3085.0	98.5 – 108	9.5	8.8	93
4	21	1650	3085.0 – 3094.5	108 – 117.5	9.5	6.24	66
5	21	1800	3094.5 – 3104.0	117.5 – 127.0	9.5	9.5	100
6	21	2000	3104.0 – 3135.0	127.5 – 136.5	9.5	9.5	100
7	21	2120	3135.0 – 3123.0	136.5 – 146.0	9.5	8.8	93
8	21	2240	3123.0 – 3132.5	146 – 155.5	9.5	4.45	47
9	21	2355	3132.5 – 3142.0	155.5 – 165	9.5	9.5	100
10	22	0055	3142.0 – 3151.5	165 – 174.5	9.5	4.7	50
11	22	0400	3151.5 – 3161.0	174.5 – 184	9.5	9.2	97
12	22	0515	3161.0 – 3170.5	184 – 193.5	9.5	7.15	75
13	22	0620	3170.5 – 3180.0	193.5 – 203	9.5	8.98	95
14	22	0725	3180.0 – 3189.5	203 – 212.5	9.5	6.35	67
15	22	0830	3189.5 – 3199.0	212.5 – 222	9.5	2.85	30
16	22	0940	3199.0 – 3208.5	222 – 231.5	9.5	4.8	51
17	22	1100	3208.5 – 3218.0	231.5 – 241	9.5	3.5	37
18	22	1210	3218.0 – 3227.5	241 – 250.5	9.5	2.8	29
19	22	1755	3237.0 – 3246.5	260 – 269.5	9.5	5.15	54
20	22	1910	3256.0 – 3265.5	279 – 288.5	9.5	6.65	70
21	22	2025	3275.0 – 3284.5	298 – 307.5	9.5	9.15	96
22	22	2155	3294.0 – 3303.5	317 – 326.5	9.5	7.45	78
23	23	2315	3313.0 – 3322.5	336 – 345.5	9.5	5.6	59
24	23	0225	3332.0 – 3341.5	355 – 364.5	9.5	2.2	23
25	23	0700	3351.0 – 3360.5	374 – 383.5	9.5	3.0	32
26	23	0900	3370.0 – 3379.5	393 – 402.5	9.5	1.73	18
27	23	1225	3389.0 – 3398.5	412 – 421.5	9.5	5.65	60
28	23	1410	3408.0 – 3417.5	431 – 440.5	9.5	3.85	41
29	23	1610	3427.0 – 3436.5	450 – 459.5	9.5	5.22	50
30	23	1745	3446.0 – 3455.5	469 – 478.5	9.5	4.0	42
31	23	1950	3465.0 – 3474.5	488 – 497.5	9.5	9.5	100
32	23	2230	3484.0 – 3493.5	507 – 516.5	9.5	5.55	58
33	24	0110	3503.0 – 3517.5	526 – 535.5	9.5	6.4	67
34	24	0435	3522.0 – 3531.5	545 – 554.5	9.5	9.5	100
35	24	1035	3541.0 – 3550.5	564 – 573.5	9.5	4.15	43.7
36	24	1416	3550.5 – 3560.0	573.5 – 583	9.5	6.15	64.7
37	24	1815	3569.5 – 3579.0	592.5 – 602	9.5	1.95	20.5
38	24	2210	3588.5 – 3598.0	611.5 – 621	9.5	1.25	13.2
49	25	0230	3607.5 – 3617.0	630.5 – 640	9.5	4.15	43.7
40	25	0730	3626.5 – 3636.0	649.5 – 659	9.5	2.35	24.7
41	25	1245	3645.5 – 3655.0	668.5 – 678	9.5	2.85	30.0
42	25	1710	3655.0 – 3664.5	678 – 687.5	9.5	5.95	62.6
43	25	2215	3674.0 – 3683.5	697 – 706.5	9.5	2.30	24.2
44	26	9230	3693.0 – 3702.5	716 – 725.5	9.5	3.05	32.1
45	26	0810	3712.0 – 3721.5	735 – 744.5	9.5	7.37	77.6
46	26	1250	3731.0 – 3740.5	754 – 763.5	9.5	6.05	63.7
47	26	1720	3750.0 – 3759.5	773 – 782.5	9.5	2.15	22.6
48	26	2220	3769.0 – 3778.5	792 – 801.5	9.5	6.7	70.5
49	27	0440	3788.0 – 3797.5	811 – 820.5	9.5	4.0	42.1
50	27	1205	3807.0 – 3816.5	830 – 839.5	9.5	3.15	53.2

later gusts exceeded 80 knots and the *Challenger* took rolls in excess of 20°.

Approach to Site 361

Site 361 was approached during the evening of 4 January, 1975 on a track parallel to and some 10 miles south of the *Vema* 22-04 seismic profile (Figure 1). At 2150 hours, *Glomar Challenger* was headed to the west to intersect the *Vema* profile at the targeted site. The vessel slowed to half speed at 2357 hours and dropped the positioning beacon at 0005 hours, 5 January. Satellite fixes obtained while on station placed the site about 1 mile south of 0305 hours, 11 April on the *Vema* line and just to the west of the central axis of anomaly M-4 magnetic lineation. The sea-floor depth from echo-sounding is 4549 corrected meters, corresponding to 2421 tau. The approach seismic profile is shown on Figure 10. Information related to the depth below the sea floor and the length of the Site 361 cores is given in Table 4.

Spudding In

The initial touchdown of the drill string occurred in the mid-afternoon of 5 January with a measurement of 4557.5 meters from the rig floor. A standard bottom-hole assembly had been made up. A long chisel, 4-cone 93CJS drill bit with journal bearings was selected to provide optimum penetration rates in the expected terrigenous mudstone and shales, and to give long rotation life for the anticipated deep penetration to Horizon AII.

TABLE 4
Site 361 Coring Summary

Core	Date (January 1975)	Time	Depth From Drill Floor (m)	Depth Below Sea Floor (m)	Length Cored (m)	Length Recovered (m)	Percent Recovery
1	5	1740	4859 – 4598.5	31.5 – 41.0	9.5	5.05	53
2	5	2005	4617.5 – 4627	60 – 69.5	9.5	1.75	18
3	5	2355	4655.5 – 465.0	98.0 – 107.5	9.5	2.0	21
4	6	0300	4693.5 – 4703	136.0 – 145.5	9.5	1.5	16
5	6	0530	4731.5 – 4741	174.0 – 183.5	9.5	5.6	59
6	6	0745	4760.0 – 4769.5	202.5 – 212	9.5	3.9	41
7	6	1045	4788.5 – 4798	231 – 240.5	9.5	1.25	13
8	6	1300	4807.5 – 4817	250 – 259.5	9.5	5.2	54.7
9	6	1455	4817 – 4826.5	259.5 – 267	9.5	7.95	84
10	6	1630	4826.5 – 4836	269 – 278.5	9.5	8.35	88
11	6	1805	4836 – 4845.5	27815 – 288	9.5	8.75	92
12	6	2025	4855 – 4864.5	297.5 – 307	9.5	7.45	78
13	6	2222	4883.5 – 4893	326 – 335.5	9.5	1.25	13
14	7	0105	4921.5 – 4931	364 – 373.5	9.5	2.65	27.9
15	7	0400	4959.5 – 4969	402 – 411.5	9.5	3.0	31.6
16	7	0720	4997.5 – 5007	440 – 449.5	9.5	2.4	25.3
17	7	1010	5035.5 – 5045	478 – 487.5	9.5	2.0	21.0
18	7	1315	5083 – 5092.5	525.5 – 535	9.5	2.0	21.0
19	7	1615	3130.5 – 5140	573 – 582.5	9.5	4.80	50.0
20	7	1900	5178.0 – 5187.5	610.5 – 620	9.5	5.35	56.0
21	7	2225	5225.5 – 5235	669 – 677.5	9.5	4.9	52
22	8	0145	5273 – 5282.5	715.5 – 725	9.5	6.0	63
23	8	0530	5320.5 – 5330	763 – 792.5	5.8	5.8	61
24	8	0900	5368 – 5377.5	810.5 – 820	9.5	5.85	62
25	8	1350	5415.5 – 5425	858.0 – 867.5	9.5	9.5	100
26	8	1945	5463.0 – 5425	905.5 – 915	9.5	7.95	84
27	9	0045	5510.5 – 5520	953 – 962.5	9.5	4.9	52
28	9	0500	5559 – 5567.5	1000.5 – 1010	9.5	7.9	83
29	9	0910	5586.5 – 5596	1029 – 1038.5	9.5	8.0	84
30	9	1145	5596 – 5605.5	1038.5 – 1045	9.5	4.6	48
31	9	1600	5605.5 – 5616	1048 – 1057.5	9.5	5.0	53
32	9	2050	4516 – 5624.5	1057.5 – 1067	9.5	9.4	99
33	10	0005	4624.5 – 5634	1067 – 1076.5	9.5	3.7	39
34	10	0300	5634 – 5643.5	1076.5 – 1086	9.5	4.8	51
35	10	0520	5643.5 – 5653	1086 – 1095.5	9.5	3.6	38
36	10	0820	5653 – 5662.5	1095.5 – 1105	9.5	4.15	44
37	10	1040	5662.5 – 5672	1105 – 1114.5	9.5	3.0	32
38	10	1310	5672 – 5681.5	1114.5 – 1124	9.5	3.8	40
39	10	1535	5681.5 – 5691	1124 – 1133.5	9.5	4.4	46
40	10	1845	5700.5 – 5710	1143 – 1152.5	9.5	5.45	57
41	10	2200	5719.5 – 5729	1162 – 1171.5	9.5	5.6	59
42	11	0140	5738.5 – 5748	1181 – 1190.5	9.5	3.0	32
43	11	0600	5757.5 – 5767	1200 – 1209.5	9.5	6.3	66
44	11	0845	5776.5 – 5786	1219 – 1228.5	9.5	4.5	47
45	11	1215	5799.5 – 5805	1238 – 1247.5	9.5	5.9	62
46	11	1615	5814.5 – 5824	1257 – 1266.5	9.5	3.75	39
47	11	2105	5824 – 5833.5	1266.5 – 1276	9.5	3.95	42
48	12	0320	5843 – 5852.5	1285.5 – 1295	9.5	3.0	32
49	12	1230	5862 – 5871.5	1304.5 – 1314	9.5	0.2	2.1

While washing in the lowermost drill collars, a resistant layer was encountered at 25 meters sub-bottom, most likely corresponding to an indurated pavement on the erosion surface detected at 0.040 sec on the *Vema* profile. Core 1 was cut at 30 to 39.5 meters with very slow rotation, using strong circulation in order to make headway through additional hard stringers. Similar resistant zones were also encountered in Core 2.

Judging from the drilling characteristics the first significant formation change was encountered in the middle of Core 5 at a depth of approximately 178 meters. A second and even more pronounced change was detected at the base of Core 8 when drilling slowed markedly for a brief period while penetrating resistant interface. Immediately below 259 meters the formation washed away very easily with only 5 strokes per minute (spm) of circulation. This drilling break correlated with the passage of the drill bit into Horizon D.

Encounter with Sands

Steady penetration continued down through Core 13 before additional weight was placed on the drill bit to increase the drilling rate. Drilling characteristics suggested that loose sand layers occurred in Core 14. A significant slowing down was observed at 404 meters sub-bottom in Core 15, followed once more by massive sands which were quickly penetrated by washing. The first indurated sandstones (with compressional-wave velocities of ~ 4 km/sec) were discovered in Core 17 and are thought to correspond with a relatively weak reflector seen at 0.54 sec on the *Glomar Challenger* reflector profile. Hard and brittle stringers were met at 535, 560, and 580 meters. The latter interface drilled like a cemented pavement giving some bit bounce and observable torquing. Similar levels appeared at 672 meters while cutting Core 21, at 704 meters, at 720 meters, at 724 meters while cutting Core 22, at 760 meters, 771 meters while cutting Core 23, at 910 meters while cutting Core 26, and at 930 meters. Extremely difficult headway was made encountering numerous indurated levels from 942 meters or down through Core 27 to a depth of 1000 meters.

Suddenly at 1000 meters the penetration rapidly increased and Core 28 was cut in less than 10 minutes. The possibility of massive loose sands became of concern and 100 barrels of heavy mud was circulated to form a wall cake and hopefully prevent caving in of this strata. Relatively rapid penetration continued accompanied by a few thin resistant stringers until a major formation change was detected at 1030 meters, followed with wild bouncing of the bit, and a significantly enhanced torquing of the drill stem.

First Signs of Gaseous Hydrocarbon

At this point, gas was detected in Core 28, and its appearance associated with rapid penetration raised the spectre of overpressured shale. Samples were taken for the gas chromatograph. Technical difficulties with this instrument led to temporary suspension of drilling after Core 30 reached the deck, until we could properly monitor the hydrocarbon situation.

The amount of gas was small, causing only the end caps of the liners to bulge slightly. Nevertheless the methane-to-ethane ratio was below 300, a figure which previous legs had used as an arbitrary cutoff value below which no further penetration was attempted.

After a long consultation among the shipboard geochemists, the operations manager, the drilling supervisor, the ship's master, and the chief scientists, we decided to proceed very cautiously with back-to-back coring from Core 30 downwards. An additional 150 barrels of drilling mud was inserted to assist the removal of downhole debris and any additional caveins which might be created by the gaseous zone. Progress was slow, but steady, and the prognosis that the formation change to carbonaceous shales and massive sandstones corresponded to Horizon AII gave the scientific party much encouragement that a principal objective had now been achieved.

Further encouragement came at 1086 meters sub-bottom when the trend in the ratio of methane to ethane began to reverse itself and increase back to a more comfortable range of > 400. When the ratio reached 500 in Core 39, the coring program was switched from a continuous mode to one core every 19 meters.

Sands and sandstones were recovered in many of the cores, some of the beds containing large pieces of wood and coaly fragments. The weather remained clear, with a freeze breeze. Multiple swell patterns produced a slight roll.

Penetration rates varied from slow (< 10 m/hour) in Cores 30 to 36 to moderate (> 20 m/hour) in Cores 37, 38, and 44. Very slow penetration began with Core 46 and continued into Core 49 when every indication suggested that the drill bit had shed most or all of its cones by failure of the journal bearings. The hole was abandoned at this point with 1314 meters penetration. The percentage of core recovery remained surprisingly high, above 30 per cent, up until the last core attempt.

LITHOLOGY

Site 360 Lithologic Descriptions

Site 360 yielded sediments that range in age from lower Pliocene to middle Eocene, and reached a sub-sea floor depth of 839.5 meters. Coring began at 79.5 meters, was continuous to 250.5 meters. Below this level, coring was intermittent with alternate coring and washing on a 9.5-meter interval to the bottom of the hole. The non-continuous sampling interval and low core recovery in some core barrels resulted in a retrieval of approximately 33 per cent of the stratigraphic column.

The sedimentary sequence of Site 360 has been divided into stratigraphic units on the basis of composition, color, and sedimentary structures (Table 5). Compositional percentages are based on visual estimations of the frequency of major components in smear slides and have been verified by shore-based analyses of carbonate percentage and grain size. These appear on the barrel sheets at the end of this chapter. Also, coarse fractions (> 63μm) of all core-catcher samples prepared by the paleontologists were studied with a binocular microscope for content and fossil preservation.

Unit 1: Nannofossil Ooze (79.5-181 m)

Lithologic Unit 1 consists of approximately 100 meters of nannofossil ooze with minor amounts of foraminiferal nannofossil ooze and marly nannofossil ooze. The ooze is typically light gray with minor amounts of yellow-gray and greenish gray. At 160 meters, stiff ooze is intercalated with softer material; by 170 meters it is stiff throughout. The nannofossil ooze averages about 75 per cent calcareous nannofossils, 20 per cent clay minerals, and minor to trace amounts of foraminifers, sponge spicules, radiolarians, fish fragments, pyrite, quartz, and glauconite. Pyrite occurs as small black patches of disseminated microscopic-size crystals that smear upon cutting of the core, producing black streaks. It also occurs as larger, brassy yellow nodules and as tubes that attain a length of up to 4 cm. Placoliths are the most abundant nannofossil; locally, discoasters contribute significantly to the sediment. Coccospheres are present in nearly all samples and are abundant in many. The coarse fraction (greater than 63 μm in diameter) is dominated by planktonic foraminifers which average greater than 95 per

TABLE 5
Lithologic Units of Site 360

Unit	Dominant Lithology	Depth in Section (m)	Thickness (m)	Age
1	Nannofossil ooze	79.5-181 (Cores 1-11)	101.5	Lower Pliocene-upper Miocene
2	Nannofossil chalk	181-388 (Cores 12-25)	207	Upper Miocene-lower Miocene
3	Nannofossil chalk	388-568 (Cores 26-35)	180	Lower Miocene upper Eocene
4	Marly nannofossil chalk	568-839.5 (Cores 36-50)	271.5	Upper Eocene-middle Eocene

cent of this size fraction. Material present in the coarse fraction but not recognized in the smear slides includes: echinoid fragments, ostracodes, and iron oxyhydroxides.

The ooze throughout Lithologic Unit 1 is homogeneous and lacks well-defined bedding. Faint color variations in the form of mottles occur throughout most of the unit.

The contact between the soft ooze of Lithologic Unit 1 and the more compacted chalk of Unit 2 is gradational. The boundary was placed between Cores 11 and 12 at the top of the first major zone of semi-indurated sediment although chalk and marly nannofossil ooze are intercalated throughout the next 10 meters. Lithologic Unit 1 comprises the stratigraphic interval from upper Miocene to lower Pliocene. The nearby surface piston core (*Vema* 29-96) at a water depth of 3422 meters has a similar lithology of nannofossil ooze and suggests an extension of this unit upward into the Quaternary.

Unit 2: Nannofossil Chalk (181-388 m)

Unit 2 consists of 207 meters of nannofossil chalk that is typically light gray, very light gray, or light bluish gray. The chalk averages 75 per cent nannofossils, 12-15 per cent clay minerals, with trace amounts of planktonic foraminifers, carbonate fragments, sponge spicules, pyrite, quartz, mica, and glauconite. Fish fragments are conspicuously more abundant in Lithologic Unit 2 than in the overlying Unit 1. Pyrite occurs as small nodules, tubes, black patches of disseminated crystals, and thin black pyrite-rich laminae. Quartz is subangular to angular. Placoliths dominate the nannofossils; coccospheres occur throughout the unit. Planktonic foraminifers dominate the coarse fraction ($>63\mu m$ in diameter) averaging greater than 95 per cent of the total sample. Present in this fraction but not reported in the smear slides are echinoid fragments, pteropods, radiolarians, ostracodes, and heavy minerals.

Burrows are the most striking lithologic characteristic of Lithologic Unit 2 (Figure 9). Mottling occurs in some cores, but burrowing is more widespread and much more distinctive than in Lithologic Unit 1. The burrows are typically infilled with a slightly coarser and darker material. Lighter colored burrow fillings do also occur. *Zoophycos* burrows are the most common followed by Rind burrows and *Teichichnus*. *Chrondrites,* Halo burrows, and Composite burrows are present but not common.

The chalks of Lithologic Unit 2 are distinguished from the ooze of Lithologic Unit 1 primarily by the greater degree of lithification. Also, Lithologic Unit 1 is characterized by mottling whereas distinct burrows are the most prominent sedimentary structure of Lithologic Unit 2. Lithologic Unit 2 ranges comprises the stratigraphic interval from lower to upper Miocene.

Unit 3 — Nannofossil Chalk (388-568 m)

Unit 3 consists predominantly of 180 meters of nannofossil chalk with minor intercalations of marly nannofossil chalk. It is typically light gray to medium light gray with laminae of olive-gray and greenish gray. Compositionally, Lithologic Unit 3 is rich in calcareous nannofossils, averaging approximately 75 per cent of the unit, with clay minerals making up about 20 per cent. Foraminifers, quartz, pyrite, heavy minerals, and undifferentiated carbonate occur in minor amounts. Coccospheres are present in most samples. The coarse fraction (greater than 63 μm in diameter) is generally more abundant than in Lithologic Units 1 and 2 and shows the presence of the following constituents not reported in the smear slides: echinoid fragments, sponge spicules, fish fragments, ostracodes, glauconite, micarb fragments, and mica. As in Lithologic Units 1 and 2, the tests of foraminifers dominate the coarse fraction, averaging over 95 per cent of the total except in three cores, two that contain calcareous mud aggregates and a third that contains up to 20 per cent quartz. Benthic foraminifers are a minor component.

Two prominent sedimentary structures distinguish this unit from the units above and below: laminated bedding and penecontemporaneous deformational structures (Figures 10, 11, and 12). Secondary structures in the form of microfaulting offset many of the laminations. Laminations vary from laminated to thinly laminated; alternating light and dark colors make the laminations stand out. Small faults offsetting these laminated strata show an average dip of 40° from horizontal. The soft-sediment deformation includes folded layers as well as zones with subrounded clasts set in a less indurated matrix. These are interpreted to be the result of slumping. Slump structures are prominent in five cores. Slump structures in Core 26 are characterized by intensive deformation with subrounded fragments set in a nannofossil chalk matrix. Cores 27, 31, and 33 are characterized by flow structures. They are typically offset by numerous normal microfaults. Core 32 is of special interest because of the large-scale folding present and which unlike other cores, shows reverse faulting of the laminae.

Lithologic Unit 3 can be distinguished from the units above and below by the laminated nature of the sediment. Lithologic Unit 3 is slightly darker in color than Lithologic Unit 2, but much lighter than underlying Lithologic Unit 4. Lithologic Unit 3 extends upwards from the upper Eocene into the lower Miocene.

Unit 4 — Marly Nannofossil Chalk (568-839.5 m)

Unit 4 consists of approximately 270 meters of greenish gray marly nannofossil chalk. Calcareous nannofossils make up about 40 per cent of the sediment, clay minerals 55 per cent, and quartz 3 per cent. Significant to trace amounts of foraminifers, pyrite, glauconite, fish remains, authigenic carbonate, heavy minerals, and mica are present. Scattered thin laminae of coarse clastic silt and fine sand occur throughout the unit. These laminae are rich in quartz, heavy minerals, and glauconite. Minor constituents include: plagioclase, microcline, zircon, tourmaline, garnet, epidote, chlorite, and muscovite. Coarse fraction studies (greater than 63 μm in diameter) also show the presence of echinoid remains, sponge spicules, and radiolarians. As in Lithologic Unit 2, benthic foraminifers and fish remains are a conspicuous component especially in Core 42 and below where carbonate contents drop below 35 per cent. Incomplete disaggregation of the chalk results in many carbonate mud aggregates in some Lithologic Unit 4 coarse fractions. Except for these mud aggregates, planktonic foraminifers dominate all but selected levels that contain appreciable amounts of quartz (up to 80% of the coarse fraction).

Extreme bioturbation produces the most striking features of this unit. *Zoophycos* are the most common type of burrow, but most all types are present.

Figure 9a. *Examples of bioturbation in Lithologic Unit 2, Core 17-3, 67-75 cm.*

Lithologic Unit 4 can be distinguished from the overlying unit by: (1) a much more terrigenous and clastic nature in both the coarse fraction and fine fraction, (2) lack of laminations, (3) intensified burrowing, and (4) darker color. Its stratigraphic range is from the middle to upper Eocene.

Coarse Fraction Analysis

Coarse fractions (63 μm to 180 μm and greater than 180 μm) of all core-catcher samples were studied. The total sand-size fraction is small, generally less than 5 per cent of the total sediment and often less than 2 per cent. Except for discrete horizons in Lithologic Units 3 and 4, planktonic foraminifers account for more than 80 per cent of the total coarse fraction, and often more than 90 per cent followed by quartz (generally less than 5%, but sometimes as great as 60%) glauconite (≤1%), benthic foraminifers (≤1%), echinoid fragments (≤0.5%), sponge spicules (≤0.5%), fish debris (≤0.5%), and heavy minerals (≤0.5%) making up the remainder. Quartz and heavy minerals are present only in the 63 to 180 μm fraction.

Shipboard investigations show that two major zones of high fragmentation of the tests of planktonic foraminifers and thus probably of selective partial dissolution of their calcite chamber walls can be distinguished: (1) Cores 36 through 48 and (2) Cores 10 through 22.

In both of these inferred partial dissolution phases, the percentage of planktonic foraminifer fragments (in the coarse fraction) is greater than 40 per cent, and, may reach

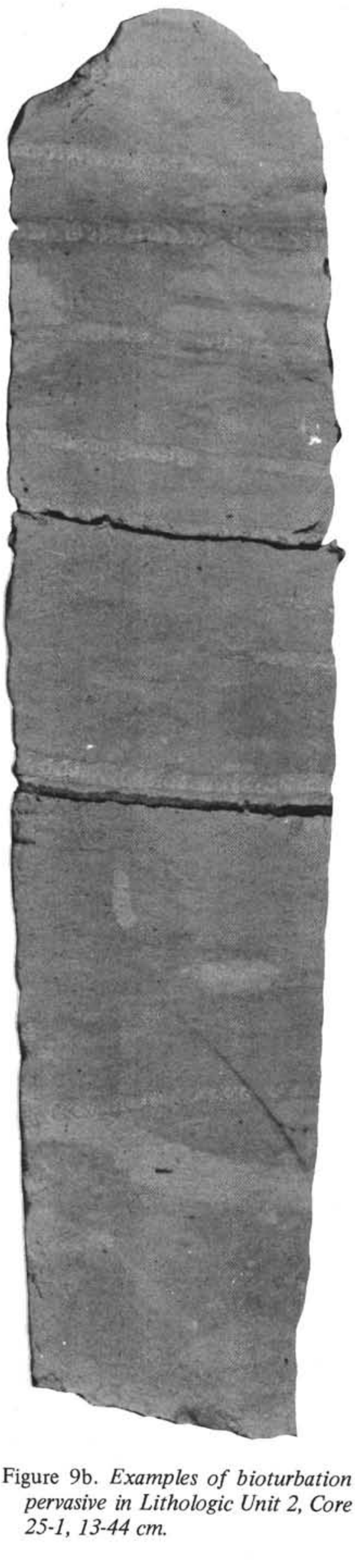


Figure 9b. *Examples of bioturbation pervasive in Lithologic Unit 2, Core 25-1, 13-44 cm.*

Figure 10. *Finely laminated bedding characteristic of inclined bedding restricted to Lithologic Unit 3. Example is from Site 360, Sample 27-4, 108-122 cm.*

70 per cent, which is higher than the fragmentation of planktonic foraminifers at their lysocline level. These intervals of high fragmentation are also accompanied by a marked enrichment in fish remains (up to 5% of the coarse fraction) and are characterized by a uniformly diminished sand-sized component. Total carbonate content may still be as great as 75 per cent, indicative of the greater resistance to dissolution of the nannofossil skeletons as compared to the planktonic foraminifers. There appears to be no direct correlation of higher concentrations of benthic foraminifers (enriched in Cores 42 to 48) and dissolution phases, since they are not as especially conspicuous in Cores 10 to 22.

Site 361 Lithologic Descriptions

Site 361 was drilled to a sub-sea floor depth of 1314 meters and yielded sediments that range in age from upper Eocene to lower Aptian and possibly slightly older. Coring

Figure 11. *Penecontemporaneous microfaulting and inclined bedding restricted to Lithologic Unit 3. Example is from Site 360, Sample 27-4, 108-122 cm.*

Figure 12a. *Slump structures observed in Lithologic Unit 3, Site 360, Core 33-3, 105-120 cm.*

Figure 12b. *Slump structures observed in Lithologic Unit 3, Site 360, Core 29-2, 115-122 cm.*

began at 31.5 meters, was intermittent from 31.5 to 250 meters, continuous from 250 to 288 meters, intermittent from 288 to 1029 meters, continuous from 1029 to 1133 meters, and then intermittent to 1314 meters. Forty-nine cores were collected, containing 231.1 meters of sediment. These sediments represent 18 per cent of the section ultimately penetrated.

The sediments have been subdivided into four lithologic units on the basis of composition, texture and sedimentary structures (Table 6). The unit numbers continue from those of Site 360, permitting an integrated sequence to be made for the two Cape Basin sites. Compositional percentages are based on visual estimations of smear-slide components and the results of shore-laboratory measurements of carbonate content and grain size. Coarse fractions (63 to 180 μm and >180 μm) of each core-catcher sample were examined, as were thin sections cut from sandstones of Lithologic Unit 7.

TABLE 6
Lithologic Units of Site 361

Unit	Dominant Lithology	Depth in Section (m)	Thickness (m)	Age
4a	Mud Calcareous mud Marly nannofossil ooze	0-263.5 (Cores 1-9)	263.5	Upper Eocene-upper Paleocene
5	Pelagic clay	263.5-316.5 (Cores 9-12)	53	Upper Paleocene-Maestrichtian
6	Shale	316.5-1001 (Cores 13-28)	684.5	Maestrichtian-upper Aptian
7	Sapropelic shale Sandy mudstone Sandstone	1001-1314 (Cores 28-49)	313	Upper Aptian-lower Aptian

Unit 4a: Mud, Calcareous Mud, Marly Nannofossil Ooze

Unit 4a is dominantly composed of mud, calcareous mud, and marly nannofossil ooze with minor amounts of marly nannofossil chalk and calcareous clay (one 20-cm-thick bed). The unit has a minimum thickness of 263.5 meters, based on the lithologies encountered in piston cores V22-115 (4718 m), V27-211 (4508 m), and RC13-247 (4832 m) located at approximately the same water depth on the Lower Continental Rise. The stratigraphic position of Cores 1 to 9 of Lithologic Unit 4a extends from the upper Eocene to upper Paleocene and is correlatable, chronologically, with part of Lithologic Unit 4 at Site 360.

The marly nannofossil oozes are typically light brown or yellowish brown in Cores 1 to 4, grading to bluish gray, greenish gray, and orange-pink in Cores 5 to 8. Bedding of the unit is mostly massive, with minor laminated zones. Color mottles are only significant in Core 1, and burrowing is most marked in Cores 1, 8, and 9; the chalks are more intensely burrowed than the oozes.

The ooze averages 55 per cent nannofossils, 35 per cent clay minerals, and 7 per cent quartz, with minor (<1%) or trace amounts of a variety of components (see Barrel Sheets at the end of the chapter). The ooze becomes progressively firmer with depth, and is ultimately a marly nannofossil chalk in Cores 8 and 9. The chalk becomes less quartzose with depth and obtains a carbonate content approaching 70 per cent. It has appreciably less clastic material than in the overlying sequence.

Muds and calcareous muds are mostly light brown and brownish to greenish gray. Their average composition is 50 per cent clay, 35 per cent quartz, 8 per cent nannofossils, 3 per cent heavy minerals, and 2 per cent feldspar, plus minor and trace amounts of the same components found in the oozes and chalks. Heavy minerals present include zircon, garnet, epidote, opaques, chlorite, tourmaline, and sphene. Examination of the coarse fraction shows that quartz ranges from <10 per cent to 90 per cent and glauconite pellets from 5 per cent to 40 per cent in the 63 to 180 μm size fraction; quartz is less abundant (10-50%) in the >180 μm fraction, and glauconite is more abundant. Well-preserved benthic and planktonic foraminifers are present.

Fish remains average about 3 per cent in Cores 1 to 7 and reach 25 per cent of the coarse fraction in Core 8. The boundary between Lithologic Unit 4a and Lithologic Unit 5 is in Section 3, Core 9, at the top of the uppermost pelagic clay.

Unit 5: Pelagic Clay

Unit 5 consists of 43.5 meters of pelagic clay, with one minor 80-cm-thick bed of marly nannofossil chalk in the top of Core 10. This unit is typically moderate brown, with minor yellowish brown and greenish gray colors. There is no apparent bedding; burrowing occurs only in Core 9 and the upper part of Core 10. The pelagic clay averages 77 per cent clay, 11 per cent quartz, 4 per cent zeolite, 2 per cent fish remains, 3 per cent iron oxides, and 1 per cent nannofossils, and also contains a variety of minor (<1%) and trace components. The coarse fraction of this unit is largely similar to that of Unit 4a, although fish remains are more abundant in Unit 5. Foraminifers are rare in the >180 μm size fraction and only sparsely present in the 63 to 180 μm fraction. The foraminifers show considerable variation in preservation. Euhedra of authigenic barite occur in some abundance in the coarse fraction (0.5% to 20%). Manganese nodules are found in Core 12 (Figure 13).

The boundary between Lithologic Unit 5 and Lithologic Unit 6 is placed below the last pelagic clay arbitrarily at 316.5 meters, halfway between Cores 12 and 13.

Unit 6: Shale

Unit 6 consists of 684.5 meters of shales, relatively thin cross-bedded and parallel-bedded fine sands (Figure 14), with minor amounts of sandy mudstones, one bed of marly nannofossil chalk (Core 26), and two beds of sandstone

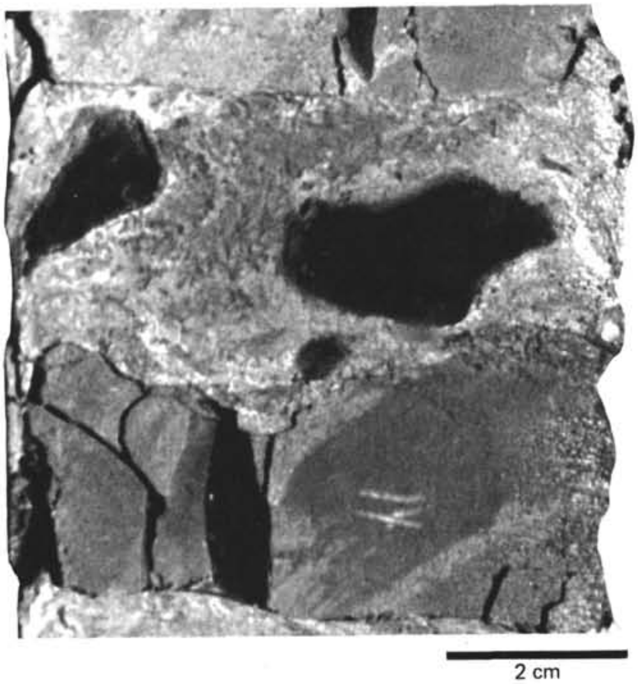


Figure 13. *Manganese nodules within pelagic clay of Lithologic Unit 5. Example is from Site 361, Sample 12-2, 65-72 cm.*

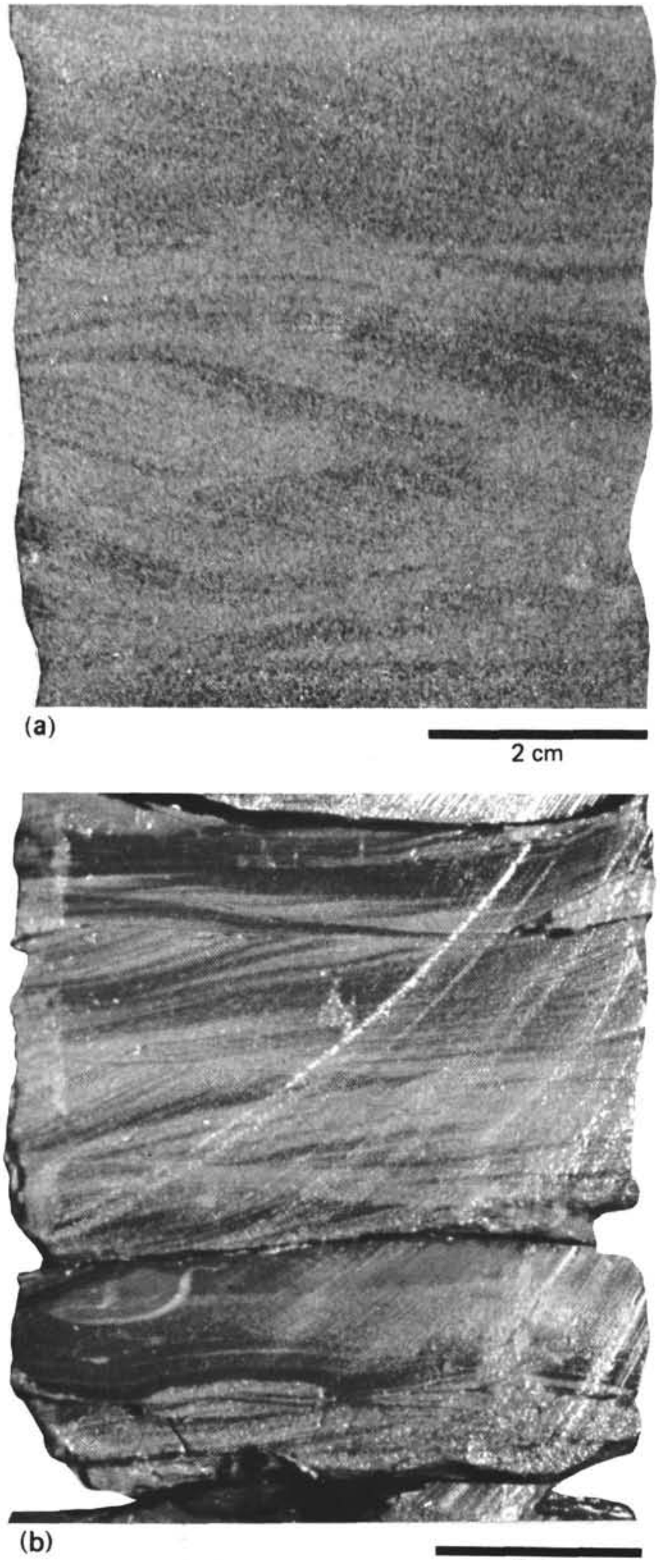


Figure 14. *Cross-bedding and parallel bedding observed in Lithologic Unit 6. Examples are: (a) Site 361, Core 15-2, 76-82 cm and (b) Site 361, Core 24-1, 102-109 cm.*

(Cores 17 and 19). The shales are, compositionally, layers of mostly grayish or greenish black mudstones alternating with reddish mudstones and/or claystones. The cyclic alteration of red and grayish shales, especially marked in the upper and lower cores of this unit, is probably the result of fine variations in the proportions of silt to clay, the result of cycles or pulses of bottom currents that brought terrigenous material southward, apparently from the Orange River delta (see Natland, this volume). Sandy mudstones are only common in the upper part of this unit (Cores 13 and 14).

A distinctive characteristic of the shales is the abundance of parallel- and cross-bedded fine sand and silt laminae in the mudstones (see Kagami, this volume). Minor convolute bedding and flow structures are also present. Burrowed areas are scattered throughout the unit. Calcareous concretions are present throughout the lower half of the section, as, to a lesser extent, are pyrite concretions and pyrite laminae. The frequency of pyritic and calcareous concretions appears to increase in a downward direction in the section, which corresponds to a decrease in the number of cross- and parallel-bedded laminae.

The shales are composed of an average of 70 per cent clay, 20 per cent quartz, 2 per cent zeolite, 1 per cent iron oxides, and other minor and trace components. Heavy minerals, which average about 0.5 per cent, include zircon, epidote, garnet, tourmaline, opaques, monazite (?), barite (?), apatite, and piedmontite. The sandy mudstones are considerably richer in heavy minerals (average 3%), which include epidote, zircon, garnet, leucoxene, tourmaline, sphene, biotite, chlorite, opaques, and staurolite (?). Nannofossils are absent or present in only trace amounts. The coarse fraction shows the presence of sand-sized dolomite grains in Core 14 (Section 2, 137 cm) and Core 16 (core catcher). Most of the grains appear to be dolomitized foraminifers and radiolarians. The coarse fraction of one sample (Core 19) showed an abundance of pyrite (25%), although pyrite generally makes up less than 1 per cent of this unit.

The boundary between Lithologic Unit 6 and Lithologic Unit 7 is placed at 1001 meters where abundant carbonaceous material, a characteristic component of Unit 7, first appears. Carbonaceous material is found in only trace amounts down to Core 28, where it suddenly becomes abundant (3% in Section 4 and up to 11% in Section 6).

Unit 7: Sapropelic Shale, Sandy Mudstone, and Sandstone

Unit 7 consists of a minimum thickness of 313.5 meters of sapropelic shales, sandy mudstones, and sandstones, with minor amounts of mudstones, siltstones, and one 40-cm-thick contorted bed of marly nannofossil chalk (Core 40).

The shales are typically black to dark gray, the sandy mudstones greenish gray to greenish black, and the sandstones bluish gray to greenish gray. The minor siltstones and mudstones are also predominantly gray and greenish gray in color. Bedding of clastic layers in Lithologic Unit 7 is generally massive, with thin sandy laminae and minor graded bedding. In contrast to Lithologic Unit 6, cross-bedding is very rare and burrowing is absent.

The shales and sandy mudstones are distributed throughout the unit, with little noticeable change in composition. The sandstones, which are well indurated by calcite and clay cement, occur more frequently in the lower cores. The distinctive characteristic of this unit is the abundant carbonaceous material found in all lithologies (with the exception of the one chalk layer). Pyrite is also more abundant in this unit than in any of the younger ones.

Shales average 35 per cent quartz, 35 per cent clay, 15 per cent carbonaceous material, 6 per cent pyrite, 2 per cent feldspar, and 2 per cent nannofossils. Sandy mudstones average 55 per cent quartz, 25 per cent clay, 10 per cent carbonaceous material, 3 per cent feldspar, and 2 per cent pyrite. The sandstones average 55 per cent quartz, 8 per cent clay, 4 per cent carbonaceous material, 3 per cent feldspar, 2 per cent pyrite, and 2 per cent rock fragments (the remaining portion of the sandstones is calcite and/or clay cement). Minor and trace components are noted on the Barrel Sheets and the end of this chapter. Heavy minerals are most abundant (0.6%) in the sandy mudstones, but are still much less abundant than in Lithologic Unit 6. They include zircon, chlorite, garnet, sphene, apatite, opaques, and tourmaline.

Nannofossils are fairly common (2%) in the shales, but occur in only trace amounts in the sandy mudstones and sandstones. Five isolated and widely separated calcareous laminae, ranging from 2 mm up to 4 mm in thickness, were found in the shales and mudstones. These are very largely (45-100%) composed of nannofossils with low species diversity, probably representing sudden, brief blooms of nannoplankton (see Noël and Melguen, this volume).

Pyrite laminae and concretions are characteristic features of this unit, especially from Core 28 down to 34. The carbonaceous material consists of algal material, palynomorphs (see McLachlan and Pieterse, this volume), terrestrial ligneous debris and wood fragments (see Brown, this volume), the latter ranging from silt-size up to chips 7 cm long. Modal size of the carbonaceous material is estimated to be coarse sand to granule size. Some layers (up to 4 cm thick) contain carbonaceous debris in such abundance as to best be called "sapropelic coal" (see Raynaud and Robert, this volume). Methane is found throughout this unit and is clearly related to the bacterial decomposition of the plant debris.

Mineralogy of Lithologic Unit 7 Sand Grains

A total of 15 thin sections of sandstones in Lithologic Unit 7 was examined to determine the nature of the source of these coarse sediments.

The dominant component in all the sandstones is quartz, usually less than 1 mm in size. It is chiefly angular to subangular, but some grains are rounded, and it includes both strained (undulose extinction) and unstrained types. Quartz forms 80-95 per cent of the detrital sand grains in the rocks. It is greatest in proportion in the most indurated rocks and least in those with a clay matrix.

The remainder of the sand grains are (1) lithic grains of various rock types, (2) mineral grains, and (3) chips and grains of plant material. Identification of the lithic grains is inhibited by extensive alteration to clays, zeolites, and quartz, usually interlocked in a finely crystalline mesh or mosaic, and by the formation of pyrite on grain surfaces and in cracks and cavities within the grains. To assist the interpretation of these grains in thin section, several hundred grains of materials other than quartz were hand picked from coarse fractions (>0.42 mm) of sandstones from the lowest cores in the unit (46-48) and from a black shale recovered in the core catcher of the last core (49) and the bit. These were classified by appearance, sorted, set into casting resin, and made into additional thin sections. From visual appearance under the binocular microscope and from the thin sections, it now appears that many of the lithic grains in the sandstone may be volcanic in origin.

The following minerals (in addition to quartz) identified in thin section form sand grains in the rocks: plagioclase, microcline, sanidine, biotite, brown amphibole, muscovite, hypersthene, augite, magnetite, tourmaline, zircon, glaucophane, and pyrite. Of the mafic minerals, biotite is most abundant, followed by brown amphibole, but neither is more abundant than about 1 per cent. Pyroxenes are most abundant in the coarser, least-indurated sandstones; possibly a function of sorting, but are still less frequently seen than micas. Glaucophane was found only in one thin section, in which it is very rare. Feldspars are fairly common (up to 2-3% in some sections), and it is likely their proportion is underestimated since many altered grains were probably originally feldspar. Alkali feldspars are more abundant than plagioclase. The plagioclase is usually sodic (An_{25-35}).

In addition to mineral fragments, the following rock types were identified in thin section: concretionary calcite, shale, quartzite, quartz-biotite schist, and several fine-grained pyritized microcrystalline varieties, which probably were originally silicic volcanic glass.

GEOCHEMICAL MEASUREMENTS

Site 360—Gas Contents

Neither hydrocarbon gas components nor oil staining were detected in cores from Site 360. Only Cores 1 and 4, those cut from beds of Pliocene and upper Miocene nannofossil foraminifer ooze, showed indication of containing any gas.

Once split in the core lab, Core 1 exuded the faint, but unmistakable, odor of H_2S. Core 4 contained enough pressure to cause a slight bulge in the end cap after sealing. Analysis, however, of both Cores 1 and 4 showed the pressure was mainly caused from air pressure that was induced during recovery.

Not surprisingly, pyrite was found to be common throughout the section. Any H_2S produced may react with the colloidal hydrated iron oxides in the local sediments to form finely divided ferrous sulfide. This hydrated ferrous sulfide ($FeS \cdot nH_2O$), or hydrotroilite, is subsequently altered into the more stable disulfides, marcasite as well as pyrite. Many bottom waters—e.g., in the Black Sea, that are rich in H_2S—also contain high concentrations of CO_2. However, the H_2S is likely to be removed by reaction with any dissolved iron salts to produce sulfides, resulting in proportionately higher concentrations of CO_2.

Site 361—Gas Contents

The first appearance of gas at Site 361 was noted in Core 28 which was cut from strata of Aptian age at a sub-sea depth beginning at 1000.5 meters. Gas causing faint to mild effervescence was found in virtually every core recovered in the subsequent 304-meter interval that ended with effective destruction of the drill bit. If gas was not apparent before the core was sectioned, it became so either immediately after capping the core sections or when nearing ambient temperature and becoming confined under sufficient pressure to cause the end caps to bulge slightly. This natural process could be accelerated by heating the core with a hot airgun. Gas samples were drawn from each core to monitor concentrations and compositional trends.

On an air-free basis, the gases were found to consist primarily of methane with small amounts of ethane. While the ratio of these two components should remain constant in a given sample, they should be regarded as minimum individual indications of the total concentration of the in situ gas because of contamination. For example, carbon dioxide was consistently detected in concentrations too high to be attributed solely to air contamination (i.e., 1000-1500 ppm versus 300 ppm expected in air). The methane/ethane ratio as a function of depth is shown in Figure 15. The gases are interpreted to have been generated in situ by diagenetic processes that are taking place within the sediments.

Under limitations of shipboard lab equipment, the most significant parameter in terms of hydrocarbon genesis is the ratio of methane to ethane. In general, the lower this ratio, the greater the indication of proximity (in a temporal as well as stratigraphic sense) to mature petroleum or petroleum-derived natural gas.

The shipboard manual of chemical procedures unequivocally states that: ''If the interstitial gases contain ethane, this is cause for stopping the drilling'' (Waterman, 1972). Similarly, but less emphatically, the JOIDES Advisory Panel on Pollution Prevention and Safety (1972) says, ''drilling should be stopped immediately whenever hydrocarbons are encountered in concentrations markedly above normal base-level and under circumstances suggesting possibilities of substantial petroleum accumulations.'' The Panel acknowledges, however, that ''it is difficult, if not impossible, to put a usable quantitative figure on what constitutes a base level of hydrocarbon concentration above which the situation becomes dangerous, especially since the degree of dilution in the material examined is essentially not known. If, however, as drilling progresses, there is a pronounced increase of hydrocarbons (particularly light paraffin hydrocarbons common in matured petroleum), this should be looked on as a serious warning sign.'' However, ''it is difficult to spell out quantitatively what constitutes a dangerous level because of the many possibly influencing factors, *and the decision must be left in large part to the common sense and experience* of those in charge of the operations'' (emphasis added). ''Certainly, visible oil-staining or pronounced hydrocarbon gas bubbling from cores should call for abandonment of the hole.''

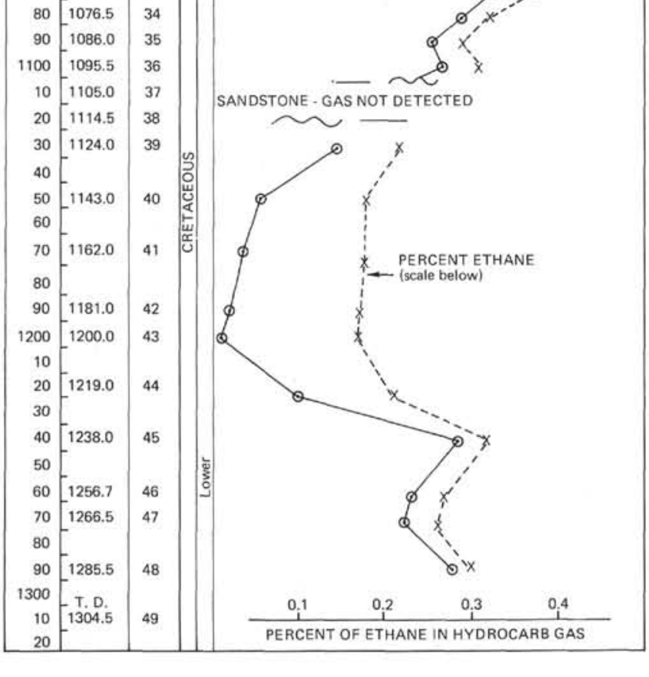


Figure 15. *Ratio of methane to ethane in Lithologic Unit 7 of Site 361 showing inversion below Core 33.*

The concentration when ethane in a gas reaches the hypothetical danger level has not been fixed or even defined within reasonable limits. Nevertheless, if an increasing trend of ethane develops, then drilling should proceed with caution only if experienced shipboard scientists and operations people are able fully to weigh the interrelated variables of lithologic sequence, depth, temperature gradient, and the possible historical effects of paleo-overburden and temperature.

PHYSICAL PROPERTIES

Introduction

The mass physical properties of soft and indurated sediments which were routinely recorded onboard *Glomar Challenger* are: color, water content, bulk density, porosity, shear strength, and sonic velocity. From these basic data, information regarding consolidation characteristics, pore volume-overburden-pressure relationships, and sound velocity gradients can be derived. The latter, sound velocity gradients, provide a means by which to correlate seismic profiles with the lithologies recovered. Shear strength data are used by geologists as a quantitative measure of induration and of sediment sensitivity of remolded samples.

Site 360 offered an excellent opportunity to understand physical property variations as a function of burial depth since a nearly complete section was obtained. As the gross lithology was largely homogeneous with a consistent high carbonate content to a depth of 570 meters, the effects of overburden pressure can be assumed to be a more or less direct function of depth without added stratigraphic variables. In general, the physical properties of the sediment (Figure 16) maintain a positive correlation with each other and with the major lithologic and acoustic changes.

Site 361 presented an interesting situation where sediments of a post-upper Eocene stratigraphic position were absent, except for perhaps the uppermost 25 meters which were not cored. Measurements of the physical properties of the Site 361 sediment column (Figure 17) were expected to

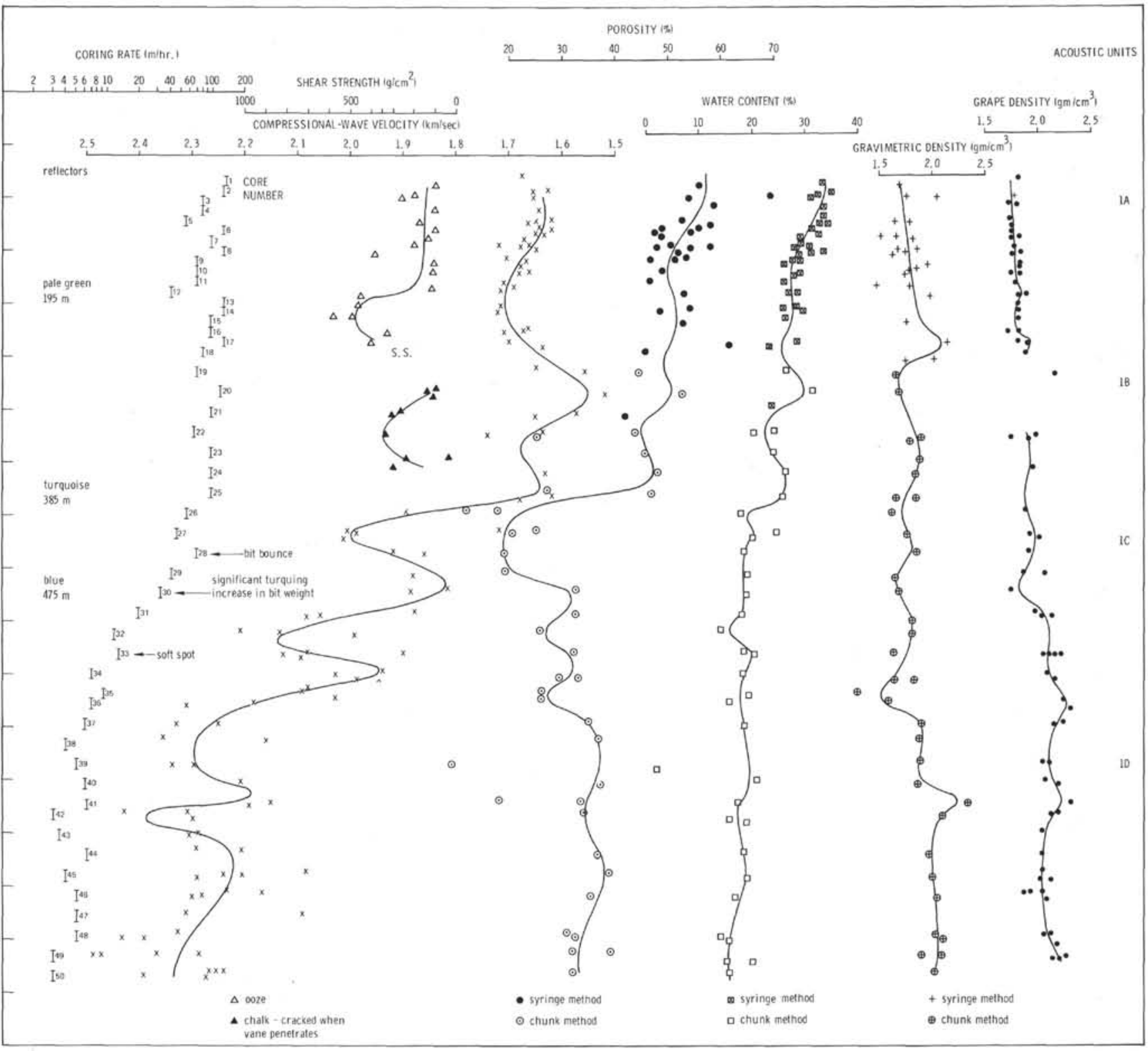


Figure 16. *Downhole variations in physical properties at Site 360 and the inferred level of key seismic reflecting interfaces separating the various acoustic units.*

shed light on whether the present outcropping or shallow subcropping of Eocene strata occurred as the consequence of a massive erosion of a once-thick Cenozoic (and perhaps complete) sequence comparable to Site 360, or by the removal of a formerly condensed section which may never have had an overburden of more than a hundred or so meters, and which for the most part may have been deposited below the calcite compensation depth.

Site 360

Gamma Ray Attenuation Porosity Evaluation

The GRAPE system consists of a drive train which carries a sample material between a shielded gamma ray source (Ba^{133}) and a shielded scintillation detector. This unit was operated chiefly in an analog mode which used a computer to calculate an apparent wet-bulk density from the measured parameters (Boyce, 1974; and Evans and Cotteral, 1970).

Two major hindrances for onboard reduction of GRAPE data were the uncertainty of the sample diameter and the lack of an accurate measurement of grain density. With these two problems in mind, an attempt was made to estimate wet bulk densities from the analog records. The results of these measurements have been plotted in apposition with bulk density determined by syringe and rock chunk techniques. As discussed by Bennett and Keller (1973) and by Bader, Gerard, et al. (1970), water-content-volume data from the syringe technique may be in error by as much as 10 per cent. For this reason, very few syringe samples were taken. The water contents and bulk densities measured below 250 meters were measured by the chunk method of Boyce (1974). The range of error for the syringe technique probably accounts for the large scatter of measured bulk density in the upper 250 meters.

The bulk density as determined by the GRAPE shows moderately little scatter. The values are not very different

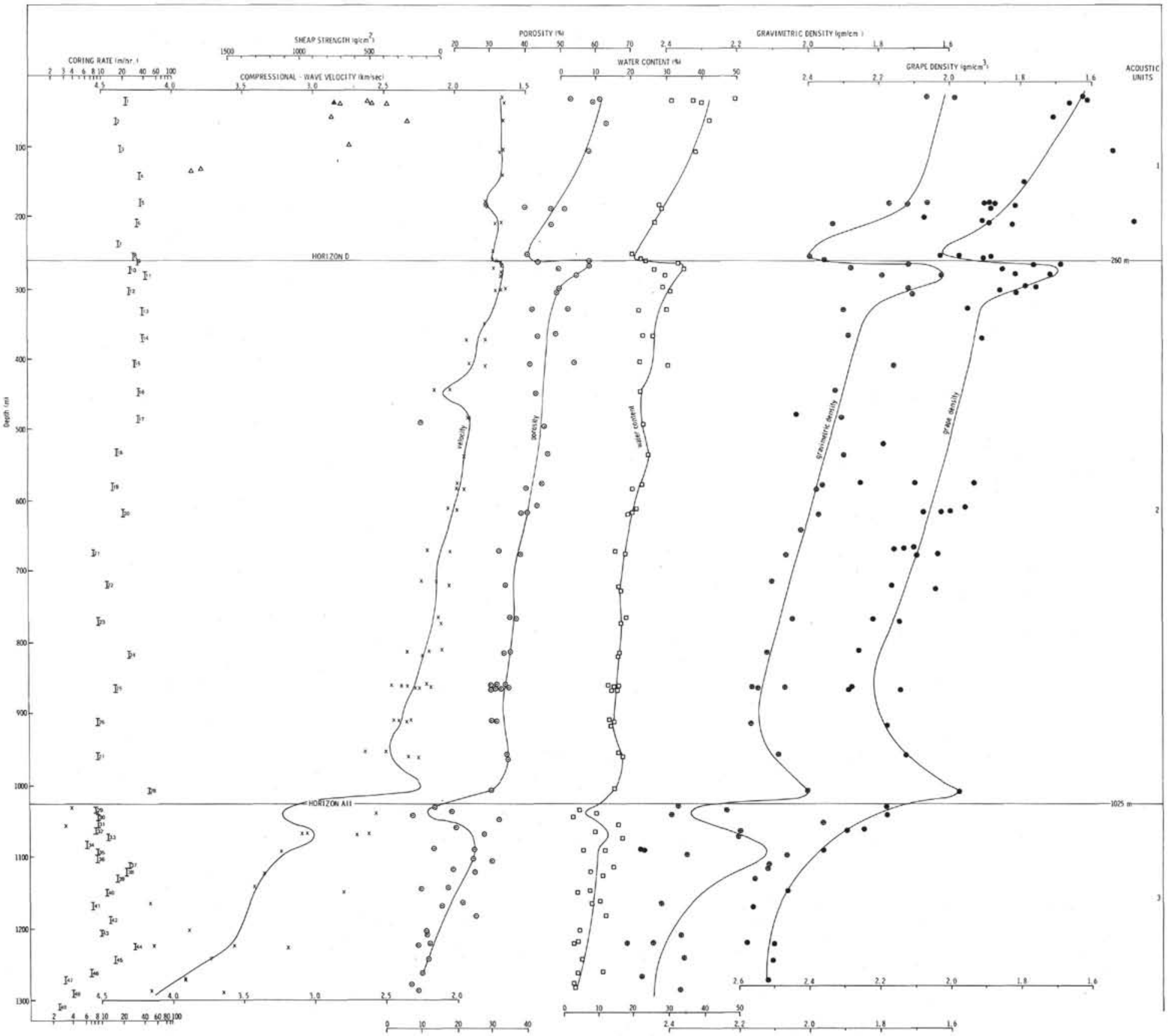


Figure 17. *Downhole variations in physical properties at Site 361 and the inferred level of seismic reflecting Horizons D and AII of Emery et al. (1975).*

from the measured bulk densities, and in general, bulk density increases with depth from values of ~1.75 g/cm³ at 100 meters to 2.1 g/cm³ at 800 meters. The curves illustrate this trend except at 565 meters, where the measured bulk density decreases and the GRAPE bulk density increases. The plot of porosity with depth shows a large reduction in porosity between 360 and 400 meters. This reduction, however, does not show up in the bulk-density plots.

Sonic Velocity

The Hamilton Frame velocimeter was used in its standard configuration as described by Boyce (1973a). This system, which uses a compressional sound wave of 300 kHz, is provided with a dial micrometer for measuring the distance traveled and an oscilloscope display to measure the time delay.

At Site 360, the upper 288 meters of sediment were too soft and soupy to be handled without being further deformed. The velocity of these samples was measured through the longitudinally split core liner. Average corrections of 0.256 cm liner thickness and 1.180 microseconds time delay were used in calculating these velocities. All velocities after Core 20 were measured on samples removed from the liner, thus requiring no correction.

A summary of Site 360 sonic velocities is presented in Figure 16. An attempt to fit a weighted curve through the data leads to some fairly large velocity gradients and inversions. The correlation of these gradients with the acoustic units is shown and is discussed later in this chapter. One of the best correlations of sonic velocity with the other mass physical parameters occurs at the base of Acoustic Unit IB. At this level the porosity also decreases rather sharply. Within Acoustic Unit IA there is a lithologic break at 184 meters, where the formation changes from an ooze to a chalk; however, the sonic velocity shows no major change even though this change can be correlated with seismic reflector pale green (Figure 7). The mean measured velocities for the various cores corresponding to each of the acoustic units are listed in Table 7. The average measured velocity of each unit increases with depth.

Shear Strength

A Wykeham-Ferrance motorized shear vane was installed in order that the vane could penetrate split cores parallel to bedding. A four-bladed vane (diameter = 1.278 cm, height = 1.2785 cm) was used with a known torque being applied at a rate of about 65° per minute. When the vane is inserted into a sediment, torque is applied to the vane axis until it shears about a surface area which approximates that of the cylindrical area calculated with the diameter and height of the vane (Boyce, 1973b).

TABLE 7
Site 360 Mean Compressional Wave Velocities

Acoustic Unit	Cores	Mean Velocity (km/sec)
IA	1 to 12	1.66
IB	13 to 25	1.67
IC	26 to 30 (pars)	1.89
ID	30 (pars) through 50	2.21

Although the upper sediment encountered at Site 360 was a calcareous ooze, the vane shear test was run on this material. A general increase in shear strength with depth was found as shown in Figure 16. Below Core 17, at 240 meters, the lithology was a hard chalk which cracked with penetration of the vane. Even though these values are plotted on Figure 19, they do not represent shear strength but the amount of torque required to crush a disturbed sample. In the interval from 80 meters to 235 meters, the shear strength ranges from 23 to 591 g/m². Over this interval, the water content has a very small range, 35 per cent to 27 per cent, with an average of 29.79, with one point of 11.90 outside the given range. There is a gradual reduction of water content with depth but the total reduction is only 8 per cent. The increase in shear strength at 190 meters may represent either a partial cementation occurring with the transformation of ooze to chalk at the boundary of Lithologic Units 1 and 2, or the effect of increased overburden pressure.

Site 361

Gamma Ray Attenuation Porosity Evaluation

Bulk density values obtained at Site 361 comply with the general trend of reduction with depth found at Site 360. This relationship is illustrated through both gravimetric and GRAPE measurement. In general, the GRAPE studies gave values which were higher than those obtained from the gravimetric method.

While the bulk density over the entire range increases with depth, there are variations which are accounted for by changes in rock type, degree of induration, and amount of cementation. As illustrated in Figure 17, the bulk density-depth relationship is nearly linear between Cores 1 and 21 (670 m). Beginning at Core 21, interbedded red and gray shales were recovered. The red shales have a slightly higher bulk density than the gray. A difference between the types of shale was also manifested by different sound velocities. Below 950 meters, sandstones and mudstones comprise a significant portion of the section. The sandstones can easily be differentiated by measuring densities and other physical properties. Highly dense calcite and silica cemented sandstones varied in bulk density from 2.35 to 2.60. The dirty sandstones or mudstones with a clay matrix and partial cementation had densities ranging from 2.2 to 2.3. The loose sandstones had densities which varied between 2.15 and 2.2, similar to those derived for the shales. Although the presence of gas was noted in this section, the physical properties were not appreciably altered because of the indurated nature of the sediments.

The GRAPE measurements of Cores 35, 38, and 45 exhibit very high bulk densities (>2.6). This probably was due to the "tightness" of the sandstone from almost complete cementation. Core 35, Section 3, exhibited the highest bulk density, 2.89, in a 0.5-meter continuously recovered section of sandstone. This may have been an area of differential cementation or a concentration of high density minerals.

The bulk density and porosity plots of Figure 17 display normal trends with depth. Although Eocene sediments were not penetrated until a depth of 560 meters at Site 360, at Site 361 sediment of the same age was encountered at a depth of less than 30 meters. The Eocene sediment of Site 361 had similar porosities and densities as the near-surface Pliocene nannofossil oozes of Site 360. Estimates of maximum overburden pressures from consolidation tests to be published elsewhere suggest that Site 361 may originally have had a maximum of 80-100 meters of sediment overlying the Eocene deposits. This apparent thinning of the Tertiary sediment wedge between Sites 360 and 361 may be the result of dissolution since biogenic sediments form a major component of the continental rise prism at Site 360 nearer to the continent.

The porosity and bulk density of sandstones recovered below 950 meters are directly related to the matrix content and degree of cementation. The porosity values of these sandstones range from 10 to 20 per cent. The cleanest-appearing sands were completely cemented and had the least porosity and greatest bulk density. The mudstones or dirty sandstones with clay and partial calcite cement were more porous but still much less so than in their depositional state. The loose sandstone or mudstone had low porosity because of the large amount of clay matrix.

Sonic Velocity

The major breaks in the acoustic velocity profile correspond to changes in the acoustic units (Figure 17). Mean velocities for each acoustic unit are presented in Table 8.

In general, there is a linear increase in velocity as a function of depth. Several abnormal velocities of 4.0 to 5.0 km/sec were measured in calcite concretions or stringers recovered between 475 and 725 meters. In Acoustic Unit II, the velocities of a series of interbedded red and gray shales were compared, and the red yielded velocities which were about 0.2 km/sec greater than the gray. The red shales also showed a higher bulk density. Acoustic Unit III was composed of interbedded sandstones and shales. The velocity of the sandstones ranged from 2.5 to 4.7 km/sec. The velocities of the shales of this unit were 2.2 to 2.4. The shales in the upper part of the Acoustic Unit III contained gas which caused the sediment to dilate and greatly attenuated the sonic energy being transmitted through them, making the velocity measurements somewhat difficult to determine.

Shear Strength

A Wykeham-Ferrance vane shear was used to measure shear strength in selected cores beginning at a depth of 32 meters and continuing to 268 meters. The sediment tested varied from a marly nannofossil ooze to an abyssal red clay. The vane shear tests for this site were terminated after the failure of the vane. In Figure 17, one can see that the shear strength for the upper sediments ranged from 230 g/cm² to 3700 g/cm². The shear strength at Site 361 was as great in the shallow samples as it was in the deeper samples retrieved from Site 360. These values are much greater than typical near-surface sediments of similar lithology and depth as tested by Rocker (1974) and by Keller and Bennett (1973). These high values further confirm that overburden has been removed. Remolded shear strength were measured and sensitivity was calculated. In general, the sensitivity decreases with depth.

TABLE 8
Site 361 – Mean Compressional Wave Velocities

Acoustic Unit	Cores	Mean Velocity (km/sec)
I	1 through 8	1.69
II	9 through 28	2.232
III	29 through 49	3.61[a]

[a]This mean is high because the velocity of the interbedded shales could not be accurately measured.

As shown by Figure 17, the water content decreases from 40 to 20 per cent in the upper 250 meters. High water contents below 1050 meters were found in the coarser mudstones with clay matrix.

BIOSTRATIGRAPHY AND PALEONTOLOGY

General Remarks, Site 360

Site 360 was cored continuously from 79.5 to 250.5 meters and alternately drilled and cored at 9.5-meter intervals from 250.5 meters to bottom at 839.5 meters. A lower Pliocene to middle Eocene section was penetrated, containing abundant to common planktonic foraminifers, infrequent benthic foraminifers, and calcareous nannoplankton throughout. The carbonate compensation depth affected these faunas and floras to varying degrees. In particular the planktonic foraminifers suffered major dissolution in the Paleogene part of the section (Toumarkine, this volume).

The planktonic foraminifer association is predominantly of the cooler water Austral-New Zealand type, but with warmer water forms also present at many levels. This allowed for the application of both the Austral-New Zealand and the tropical zonal scheme for dating the sediments (Jenkins, this volume, Fig. 2 for the Neogene, and Toumarkine, this volume, Fig. 3 for the Paleogene). The calcareous nannoplankton assemblages confirm the colder Austral-New Zealand environment throughout the section. Although it is often difficult to recognize certain zones because of the more monotonous colder water faunas/floras and because of often strong dissolution effects, it appears from both the planktonic foraminifer and calcareous nannoplankton distribution that the penetrated sequence represents continuous sedimentation without noticeable hiatuses.

Biostratigraphy, Site 360

For a general planktonic foraminiferal and calcareous nannoplankton zonation of the section, and correlation of the zonal schemes applied, reference is made to Table 9.

Pliocene

Based on the presence of the index fossil *Globorotalia margaritae*, Cores 1 and 2 (79.5-98.5 m) are assigned to the lower Pliocene. This is in agreement with the nannoplankton evidence.

Miocene

Cores 3 to 26, except for the core catcher which is upper Oligocene (98.5-402.5 m), are Miocene on the basis of both planktonic foraminifer and calcareous nannoplankton evidence. In the upper Miocene (95.5-231.5 m) both the Austral, New Zealand and the tropical planktonic foraminiferal

TABLE 9
Correlation of Pliocene to Eocene Calcareous Nannoplankton and Planktonic Foraminiferal Zones in Site 360

AGE		CALCAREOUS NANNOPLANKTON ZONES		DEPTH BELOW SEA FLOOR IN METERS	CORE	AUSTRAL-NEW ZEALAND PLANKTONIC FORAMINIFERAL ZONES (Jenkins 1966, 1967, 1975)	TROPICAL PLANKTONIC FORAMINIFERAL ZONES (Bolli 1957, 1966, 1973)		AGE
PLIOCENE	L	Amaurolithus tricorniculatus	Ceratolithus acutus	79,5- 89	1	Globorotalia puncticulata	Globorotalia margaritae	L	PLIOCENE
				89 - 98,5	2				
MIOCENE	U		Triquetrorhabdulus rugosus	98,5-108	3	Globorotalia conomiozea	Neogloboquadrina dutertrei	U	MIOCENE
		Discoaster quinqueramus	Amaurolithus primus	108 -117,5	4				
				117,5-127	5				
				127 -136,5	6		Globorotalia acostaensis		
				136,5-146	7				
				146 -155,5	8				
				155,5-165	9	Globorotalia miotumida			
				165 -174,5	10				
			Discoaster berggrenii	174,5-184	11				
				184 -193,5	12				
		Discoaster calcaris		193,5-203	13				
				203 -212,5	14				
	M	Discoaster hamatus		212,5-222	15		Globorotalia menardii	M	
		Catinaster coalitus		222 -231,5	16		Globorotalia mayeri Globigerinoides ruber Globorotalia fohsi robusta Globorotalia fohsi lobata Globorotalia fohsi fohsi		
				231,5-241	17	Globorotalia mayeri mayeri			
		Discoaster kugleri		241 -250,5	18				
				260 -269,5	19				
				279 -288,5	20	Orbulina suturalis	Globorotalia fohsi peripheroronda		
		Discoaster exilis		298 -307,5	21				
	L	Sphenolithus belemnos / Discoaster druggii		317 -326,5	22	Praeorbulina glomerosa curva	Praeorbulina glomerosa Globigerinatella insueta	L	
				336 -345,5	23	Globigerinoides trilobus trilobus	Globigerinita stainforthi to Globigerinita dissimilis		
				353 -364,5	24				
		Triquetrorhabdulus carinatus		374 -383,5	25	Globigerina woodi connecta			
OLIGOCENE	U			393 -402,5	26	Globoquadrina dehiscens	G. primordius G. kugleri		
				412 -421,5	27	Globigerina euapertura	Globigerina ciperoensis ciperoensis	U	OLIGOCENE
		Sphenolithus ciperoensis		431 -440,5	28		Globorotalia opima opima	M to L	
				450 -459,5	29				
	M	Sphenolithus distentus / Sphenolithus predistentus		469 -478,5	30				
				488 -497,5	31		Globigerina ampliapertura to Cassigerinella chipolensis / Pseudohastigerina micra		
	L	Helicosphaera reticulata		507 -516,5	32	Globigerina angiporoides			
		Ericsonia subdisticha		526 -535,5	33	Globigerina brevis			
				545 -554,5	34				
				564 -573,5	35				
EOCENE	U	Sphenolithus pseudoradians		573,5-583	36	Globigerina linaperta	Globorotalia cerroazulensis s.l. to Globigerinatheka semiinvoluta	U	EOCENE
		Isthmolithus recurvus		592,5-602	37				
				611,5-621	38				
				630,5-640	39				
	M	Chiasmolithus oamaruensis		649,5-659	40				
		Reticulofenestra umbilica		668,5-678	41				
				678 -687,5	42	Globigerinatheka luterbacheri	Truncorotaloides rohri to Globorotalia lehneri	M	
				697 -706,5	43				
				716 -725,5	44				
				735 -744,5	45	Globigerinatheka cf. index			
				754 -763,5	46				
				773 -782,5	47		Globorotalia lehneri to Hantkenina aragonensis		
		Nannotetrina fulgens		792 -801,5	48				
				811 -820,5	49	Pseudogloboquadrina primitiva			
				830 -839,5	50				

zones are recognizable, but the tropical zones become more difficult to distinguish in the middle and lower Miocene (231.5-402.5 m). This applies in particular to the suite of the *Globorotalia fohsi* Subzone. As in the Mediterranean area, only *Globorotalia fohsi peripheroronda*, the early form of the evolutionary sequence, is present here.

While the *Praeorbulina glomerosa* Zone could be recognized with the zonal marker present in Sample 25-5, 61-63 cm, the tropical *Globigerinatella insueta* index fossil for the upper lower Miocene, was not seen. *Globorotalia kugleri* and *Globigerinoides primordius*, characteristic of the basal lower Miocene Zone, occur in Sample 26-1, 136-139 cm.

Oligocene

In addition to the boreal zonal scheme, the interval from Samples 26,CC to 35-2, 134-136 cm (412 - ca.567 m) can in part also be subdivided by means of the tropical planktonic foraminiferal zones. The Eocene-Oligocene boundary is difficult to determine using the Austral-New Zealand zonal scheme. On the basis of warmer water forms it is here placed in Core 35 between Sections 2 and 3 above the extinction level of *Hantkenina*. On the basis of calcareous nannoplankton, the Eocene-Oligocene boundary (marked by the extinction of *Discoaster saipanensis*) is also in Core 35, between Section 3 and the core catcher. The presence of *Globigerina ciperoensis ciperoensis* and *Globorotalia opima opima* allows recognition of the upper Oligocene zones of these names. The intervals comprising the middle to lower Oligocene *Globigerina ampliapertura* and *Cassigerinella chipolensis/Hastigerina micra* zones could not, however, be distinguished from each other.

Eocene

The Eocene planktonic foraminiferal faunas from Sample 35-3, 11-14 cm to Core 50 (ca. 567-839.5 m) are strongly affected by dissolution and are composed mainly of cool to temperate water species. This allows only a tentative application of the tropical zonal scheme, whereas the less detailed boreal zones proved to be more useful. Based on the extinction of the spinose planktonic foraminiferal species, it was possible to restrict the middle/upper Eocene boundary to the interval between Sample 42-2, 58-60 cm and the base of Core 41. The oldest sample recovered, 50, CC, is based on planktonic foraminifers, lower middle Eocene, *Globorotalia lehneri* or *Hantkenina aragonensis* Zone. The calcareous nannoplankton was less affected by dissolution, allowing recognition of a continuous sequence of zones from the upper Eocene *Sphenolithus pseudoradians* to the lower middle Eocene *Nannotetrina fulgens* Zone.

Paleontology, Site 360

The dominant faunal/floral elements consist of planktonic foraminifers and calcareous nannoplankton. In comparison, benthic foraminifers constitute only a very minor portion. Other microfossils, such as ostracodes and radiolarians occur in small numbers at certain intervals. Fish denticles are recognized in sediments particularly affected by dissolution, such as in the Eocene. Diatoms are absent throughout the section.

Planktonic and benthic foraminifers and calcareous nannoplankton were investigated in some detail and reported on in the following contributions of this volume:

Neogene planktonic foraminifers (Jenkins)
Paleogene planktonic foraminifers (Toumarkine)
Neogene benthic foraminifers (Cameron)
Paleogene benthic foraminifers (Proto Decima and Bolli)
Neogene and Paleogene calcareous nannoplankton (Proto Decima, Medizza, and Todesco)

Planktonic Foraminifers

Planktonic foraminifers are abundant to common throughout the section, with the exception of some intervals in the upper and middle Eocene where the faunas were strongly affected by dissolution. Elsewhere, preservation is mostly good.

The Neogene fauna (Sample 1-35-2, 134-136 cm, 79.5-ca.567 m) is dominated by boreal Austral, New Zealand species such as *Globigerina bulloides, G. woodi woodi, G. woodi connecta, Globorotalia miozea miozea, G. miozea conoidea, G. pachyderma, G. conomiozea*, and *G. puncticulata*. Also present are more cosmopolitan forms such as *Globorotalia margaritae, Globorotalia fohsi peripheroronda, Globigerinoides bisphaerica, Globigerina nepenthes, Orbulina suturalis universa*. But more distinctly temperate to warm-water forms such as *Globorotalia menardii, G. humerosa, Pulleniatina obliquiloculata primalis* also occur together with the more boreal species.

This somewhat unusual faunal association of boreal, cosmopolitan, and temperate to warm-water species points to ecological conditions where these temperature-controlled groups overlapped either in the sense that all species were present together, or that they alternated to some degree as a result of annual temperature fluctuations, or followed somewhat more extended but still short climatic rhythms. Another though less likely explanation for these faunal associations may be that either the boreal or the more warm-water faunal components were carried in by currents.

Paleogene: Because of the strong dissolution effects particularly in the upper and upper middle Eocene, where some levels are almost totally devoid of planktonic foraminifers, it is assumed that certain more delicately built species became destroyed; therefore the preserved species association is not fully representative of the total fauna originally living in the waters above Site 360. As in the Neogene, the Paleogene planktonic foraminiferal fauna is strongly influenced by cool water masses and therefore shows close affinities to the Austral, New Zealand faunas. This, together with dissolution effects resulted in an impoverishment in the number of species present, and is manifested by the absence or strong reduction of numerous Eocene species including the zonal markers *Cribrohantkenina, Globigerinatheka semiinvoluta*, and *Orbulinoides beckmanni*.

The temperate to cool-water environment in the Eocene is also demonstrated by the relative frequency of several thick-shelled *Globigerinatheka* species, in particular the large-sized *G. subconglobata luterbacheri* and *G. index index*. The warmer water form *G. semiinvoluta* is conspicuously absent. The occurrence almost to the top of the Eocene of the abundant *Globigerinatheka* subspecies *luterbacheri* and *index* signifies a more boreal environment. This follows from their distribution in higher latitudes, e.g., in the North Sea Basin and in New Zealand, whereas in lower latitudes (e.g., Caribbean area) these same species (*luterbacheri*) are either absent or were already extinct within the lower upper Eocene *Globigerinatheka semiinvoluta* Zone (Mediterranean). For further observations at Site 360 on the stratigraphically and ecologically significant *Globigerinatheka*, reference is made to Toumarkine (this volume).

Benthic Foraminifers

Though benthic foraminifers occur very infrequently compared with the planktonic forms, their numbers in the samples prepared were found sufficient to investigate the occurrence of genera and species more closely, to record their distribution in the section, and to correlate their occurrences with the planktonic foraminiferal zonal schemes. Benthic foraminifers as a rule show more resistance to dissolution than do their more delicately built planktonic counterparts. In the Pliocene to Oligocene part of the section, where dissolution is weak to moderate, it is assumed that a complete faunal assemblage is present. In the upper and upper middle Eocene where dissolution is strong, even benthic species seem to have become victims of dissolution. Their preservation in this interval, or parts of it, is therefore considered incomplete.

Calcareous Nannoplankton

Abundant nannofossil assemblages ranging in age from the lower Pliocene *Ceratolithus acutus* Subzone to the middle Eocene *Nannotetrina fulgens* Zone were encountered at this site.

The preservation of the specimens is moderate throughout except for some samples in Cores 42 to 44 that contain poorly preserved nannofloras only. Discoasters are rare in the lower Pliocene and lower Oligocene, frequent in the remainder of the section, but particularly well preserved in the Miocene. The rosette *Discoaster barbadiensis*, however, is generally scarce in the upper Eocene. *Chiasmolithus oamaruensis* and *Isthmolithus recurvus* are very abundant in Cores 34, 35, 36 of upper Eocene and lower Oligocene age; *Neococcolithes dubius* is very frequent in the middle Eocene part of the sequence. The abundance here of these forms, which are extremely rare or absent in tropical waters, and the general scarcity of the genus *Sphenolithus* and *Discoaster barbadiensis*, furnish indications for temperate water conditions. The range of *Chiasmolithus oamaruensis* in this sequence differs from that of Mediterranean regions and is the same as known for New Zealand. Near-shore indicators such as *Braarudosphaera, Micrantholithus, Pemma* are characteristically totally absent. In the middle/lower Oligocene the abundance of the holococcolith *Zygrablithus bijugatus* seems to suggest a basin less than 1000 meters deep.

The presence of *Ceratolithus acutus* in the upper part of the section is indicative of lower Pliocene. The Oligocene/Miocene boundary falls between the last occurrence of *Helicosphaera recta* in Core 28, Section 3, and the first occurrence of *Discoaster druggii* in Core 24. The last occurrence of *Discoaster saipanensis* is in Sample 35,CC. The Eocene/Oligocene boundary based on this event is placed in Core 35 between Section 3 and the core catcher. Frequent *Nannotetrina cristata* and *Chiasmolithus gigas*, suggesting a middle Eocene age, characterize the assemblages at the bottom of the site.

Radiolarian and Opal Phytoplankton Remains

Infrequent radiolarians are present in most samples investigated from Cores 1 to 13. The species *Stichocorys delmontensis, Ommatartus penultimus*, and *O. antepenultimus* suggest an upper Miocene age. Fairly common radiolarians occur in the middle Eocene Sample 43-2, 33-35 cm.

Reference is made to Pisias and Moore (this volume) where the two species *Ommatartus tetrathalmus* and *O. antepenultimus* from Site 360 are illustrated on Plate 1.

All samples investigated from Cores 1 to 50 proved to be void of opal phytoplankton, sponge spicules, and phytolites.

General Remarks, Site 361

The section at Site 361 is complementary to Site 360 where drilling penetrated Pliocene to middle Eocene sediments. Site 361 begins stratigraphically in the lower equivalent of that section with a stratigraphic overlap of about 150 meters in the upper and middle Eocene. Below this overlap, some 50 meters of Paleocene and about 1000 meters of Upper and Lower Cretaceous sediments were cored. A sub-bottom depth of 1314 meters was reached. Cores were spaced at 19- to 38-meter intervals throughout the hole; only between 250 and 288 meters (lower Eocene-Paleocene) and 1029 and 1133.5 meters (Lower Cretaceous) were cores taken continuously. The coring/drilling ratio in the Eocene between 31.5 and 250 meters was mostly 1:2 and 1:3, in the Cretaceous between 288 and 1029 meters it was 1:3 and 1:4, and in the Cretaceous of the lower part of the hole, between 1133.5 and 1314 meters it was 1:1.

The Eocene-Paleocene sediments (Cores 1-11) contain planktonic and benthic foraminifers and calcareous nannoplankton, but the faunas and floras, in particular the planktonic foraminifers, are strongly affected by dissolution throughout most of this interval.

With the exception of Cores 14 and 27, the Cretaceous (Cores 12-49) is void of planktonic foraminifers. Benthic foraminifers are also rare and only a very poor arenaceous deep-water assemblage occurs in Cores 20 to 28.

In contrast to the foraminifers, calcareous nannoplankton is more abundant, though the fossils are often poorly preserved, especially in the Eocene-Paleocene Cores 1 to 10. The upper part of the Cretaceous section (Cores 12-25) contains highly impoverished floras allowing only for a general Cretaceous dating. More abundant but still comparatively rare are the calcareous nannoplankton assemblages of Cores 26 to 49. They indicate a middle Albian to lower Aptian age through this interval.

In marked contrast to the foraminifers, pollen, spores, and dinoflagellates occur in considerable numbers in most of the Cretaceous Cores 13 to 49. Further, wood fragments and cuticles are frequent to abundant in the shales, sandy shales, and sands of Cores 27 to 49.

Ichthyoliths have been investigated from the Paleocene Core 9 to the Cretaceous Core 25 (Doyle et al., this volume). Radiolarians are absent in the Paleogene and scarce in the Cretaceous. No diatoms were seen in 90 samples prepared from Cores 1 to 48.

Biostratigraphy, Site 361

Eocene

The general planktonic foraminiferal and calcareous nannoplankton zonation is presented in Table 10.

Cores 1 to 8 (31.5-259.5 m): planktonic foraminifers are very strongly affected by dissolution throughout most of the interval; in some of the samples investigated the whole fauna has virtually disappeared (Toumarkine, this volume, Fig. 4). For most of the column, the poor preservation prevented exact dating or zonal subdivision on this faunal group. The interval from Core 5 to Sample 7, CC contains a number of typical index forms that allow assigning of a middle-lower Eocene age. But planktonic foraminifers are so scarce in this interval that no zonal subdivisions can be given.

Calcareous nannofossils, which are mostly poorly preserved and in some samples altogether absent, allow for better dating and zoning of most cores than is possible with planktonic foraminifers. From their distribution it is assumed that a complete Eocene sequence is present at Site 361. Extensive dissolution, however, has much reduced its thickness. That makes the recognition of the full distribution of the floras impossible.

Paleocene

Cores 9 to 11 (259.5-288.0 m): dissolution strongly reduced the preservation of calcareous microfossils in this interval, making dating tentative or impossible. Again, calcareous nannofossils are better preserved, allowing for the distinction of upper Paleocene in the upper part of Core 9, and of lower Paleocene in Core 10.

Cretaceous

Cores 12 to 49 (297.5-1314.0 m): dating of the Cretaceous is here almost exclusively based on calcareous nannoplankton, spores, pollen, and dinoflagellates. Planktonic foraminifers were recorded only in two cores. In Section 14-2, from 137-141 cm, a Campanian-lower Maestrichtian planktonic foraminiferal assemblage mixed with Lower Cretaceous forms occurs amongst a radiolarian fauna. A thin section of a concretion in Section 27-2 at 35 cm shows lower Aptian planktonic foraminifers which are probably reworked.

Fragments of a giant questionable *Inoceramus* sp. occur in Sample 15, CC. Several species of such forms are known from the Coniacian-Campanian. Such an age range is in fair agreement with the planktonic foraminifers in Sample 14-2, 137-141 cm which indicate Campanian-lower Maestrichtian.

The calcareous nannofossils of Cores 12 to 25 are very scarce. These cores contain *Watznaueria*, allowing a general Cretaceous age to be assigned. Based on calcareous nannoplankton, Cores 26 to 49 fall into the middle Albian to lower Aptian *Prediscosphaera cretacea* (Core 26), *Parhabdolithus augustus* (27-32), and *Chiastozygus litterarius* (32-49) zones. The scarce and poorly preserved radiolarians offer little towards biostratigraphic dating. An exception is a well-preserved specimen of *Eucyrtis micropora* in Sample 28-6, 61-63 cm which has a range from Valanginian to lower Aptian.

On the basis of pollen, spores, and dinoflagellates, McLachlan and Pieterse (this volume) subdivide the Cretaceous interval as follows: Cores 12-24, Maestrichtian to Cenomanian; Cores 25-26, no determination (barren); Cores 27-48, Albian-Aptian.

A profound floral change takes place between Cores 24 and 27. With Cores 25 and 26 barren, it is not possible to locate this change through the Upper/Lower Cretaceous boundary more precisely. Based on the palynomorph distribution, McLachlan and Pieterse see no reason to assume depositionary gaps for the Cenomanian-Maestrichtian interval. By comparison of wells drilled on the Agulhas Bank, where microfaunas suggest a widespread regression within the upper Maestrichtian, however, they leave the possibility open that part of the Maestrichtian could be missing. Because reliable index pollen and spores are rare, McLachlan and Pieterse base their Cretaceous subdivision more on the accompanying dinoflagellates. Davey (this volume), who studied the dinocysts and acritarchs of the Site 361 Cretaceous, arrives at the following age interpretations which slightly differ from those of McLachlan and Pieterse, and also from the ages based on calcareous nannoplankton: Cores 13-20, Senonian-lower Maestrichtian; Cores 21-24, Turonian; Cores 25-26, barren; Cores 27-48, Aptian, with the lower/upper Aptian boundary between Samples 33-3, 117-118 cm and 32-2, 117-119 cm. No Cenomanian or Albian was identified by Davey. According to him Cores 12 to 24 are difficult to date within the Upper Cretaceous because exact dinoflagellate ranges are still unknown.

Paleontology

The Eocene/Paleocene faunas and floras of Site 361 (Cores 1-11) are greatly reduced by dissolution. As a consequence, fish debris is present particularly in samples strongly affected by dissolution. The Cretaceous (Cores 12-49) has extremely rare foraminifers or none at all. Calcareous nannofossils are more frequent, but are still fairly rare and in some intervals absent. Pollen, spores, and dinoflagellates are frequent in the Cretaceous. Ichthyoliths are present and have been studied in the Cores 9 to 25, Paleocene to upper Cretaceous. Several fragments of an *Inoceramus* sp. indet. up to 6 cm in length were recovered from the core catcher of Core 15 (Matsumoto, supplement volume).

The following faunal/floral groups of Site 361 are treated in special contributions in this volume and supplement volume:

Paleogene planktonic foraminifers (Toumarkine)
Paleogene benthic foraminifers (Proto Decima and Bolli)
Paleogene and Cretaceous calcareous nannoplankton (Proto Decima, Medizza, and Todesco)
Cretaceous radiolarians (Foreman)
Pollen, spores, dinoflagellates (McLachlan and Pieterse)
Dinoflagellates (Davey)
Plant fragments, cuticles (Brown)
Ichthyoliths (Doyle, Dunsworth, and Riedel)
Inocerami (Matsumoto).

Planktonic Foraminifers

Paleogene: The planktonic foraminifers in the upper Eocene to Paleocene Cores 1 to 11 are so strongly affected by dissolution that only a few of the more resistant forms are

TABLE 10
Correlation of Upper Eocene to Aptian Calcareous Nannoplankton and Planktonic Foraminiferal Zones in Site 361

AGE		CALCAREOUS NANNOPLANKTON ZONES	DEPTH BELOW SEA FLOOR IN METERS	CORE	AGE			
					PLANKTONIC FORAMINIFERA	MARINE PALYNOMORPHS (Davey)		PALYNOMORPHS (McLachlan & Pieterse)
EOCENE	U	Sphenolithus pseudoradians/ Isthmolithus recurvus	31,5- 41	1	UPPER EOCENE			
		Chiasmolithus oamaruensis	60 - 69,5	2				
	M		98 - 107,5	3				
			136 - 145,5	4				
		Nannotetrina fulgens/ Discoaster sublodoensis mixed	174 - 183,5	5	MIDDLE EOCENE			
		Discoaster sublodoensis	202,5- 212	6	LOWER EOCENE (Globorotalia palmerae equivalent)			
	L		231 - 240,5	7				
		Discoaster lodoensis Discoaster binodosus Tribrachiatus contortus	250 - 259,5	8				
PALEOCENE	U	Discoaster multiradiatus Discoaster nobilis	259,5- 269	9				
	L	Cruciplacolithus tenuis	269 - 278,5	10	LOWER EOCENE to PALEOCENE			
			278,5- 288	11				
CRETACEOUS	U		297,5- 307	12				MAASTRICHTIAN to CENOMANIAN
			326 - 335,5	13		LOWER MAASTRICHTIAN to SENONIAN		
			364 - 373,5	14	L. MAASTRICHTIAN - CAMPANIAN			
			402 - 411,5	15				
			440 - 449,5	16				
			478 - 487,5	17				
			525,5- 535	18				
			573 - 582,5	19				
			610,5- 620	20				
			668 - 677,5	21		TURONIAN		
			715,5- 725	22				
			763 - 772,5	23				
			810,5- 820	24				
			858 - 867,5	25				
ALBIAN		Prediscosphaera cretacea	905.5- 915	26				
	M	Parhabdolithus angustus	953 - 962,5	27		U	APTIAN	ALBIAN
	L		1000,5-1010	28				
			1029 -1038,5	29				
APTIAN	U		1038,5-1048	30				
			1048 -1057,5	31				
			1057,5-1067	32				
	L	Chiastozygus litterarius	1067 -1076,5	33		L		
			1076,5-1086	34				
			1086 -1095,5	35				
			1095,5-1105	36				
			1105 -1114,5	37				APTIAN
			1114,5-1124	38				
			1124 -1133,5	39				
			1143 -1152,5	40				
			1162 -1171,5	41				
			1181 -1190,5	42				
			1200 -1209,5	43				
			1219 -1228,5	44				
			1238 -1247,5	45				
			1257 -1266,5	46				
			1266,5-1276	47				
			1285,5-1295	48				
			1304,5-1314	49				

the major part of the planktonic foraminiferal fauna. Keeled *Globorotalia* are very rare, exceptions are *Globorotalia* present in the investigated samples. Among them is *Globigerina primitiva* which in some samples constitutes *aragonensis caucasica* in Samples 6, CC to 7, CC, indicating uppermost lower Eocene. Core 1 contains a mixed fauna of uppermost Eocene and middle Eocene. Dissolution is extremely strong in Cores 2 to 4 and 8 and 9, where virtually no planktonic foraminifers remained preserved (Toumarkine, this volume, Figures 4 and 5).

Cretaceous: Planktonic foraminifers were recorded only from two samples. Sample 14-2, 137-141 cm contains *Globotruncana linneiana, G. hilli, G. lapparenti, G. arca, G. morozowa, G.* cf. *fornicata, G. havanensis, G. mattsoni, Heterohelix globulosus,* and *H. planatus*, indicating a Campanian age. In the same sample the Aptian species *Hedbergella occulta, H. excelsa, H.* cf. *gorbachikae, Globigerinelloides ferreolensis*, and *G. gottisi* also occur. In a thin-sectioned concretion from Sample 27-2, 35 cm *Hedbergella occulta, H. excelsa, H. sigali,* and *Globigerinelloides gottisi*, a fauna of lower Aptian character, were tentatively identified. These faunas are isolated occurrences in a facies apparently not favorable for planktonic foraminifers. They are therefore considered redeposited.

According to McLachlan and Pieterse (this volume), chitinous linings of microforaminifers are present in nearly all Cretaceous samples investigated for palynomorphs. Most specimens have a coiled chamber arrangement, few are uniseral or biseral. No generic or specific determinations have been attempted Their continuous presence shows that living conditions must have been favorable, but that their $CaCO_3$ tests later became dissolved.

Benthic Foraminifers

Paleogene: Though dissolution is very pronounced, benthic foraminifers are present in most of the upper Eocene-Paleocene samples investigated (Cores 1-11). Like the Eocene faunas of Site 360, it is assumed that also here some of the benthic species were victims of dissolution. In core-catcher samples of Cores 3 and 9, both benthic and planktonic foraminifers are totally absent as a result of dissolution. *Stainforthia ryani* is described as a new species from the core-catcher sample of Core 6. Reference is made to Proto Decima and Bolli (this volume).

Cretaceous: A primitive, dwarfed, and very scarce arenaceous fauna occurs in Cores 20 to 28. The genera *Bathysiphon, Ammodiscus, Glomospira,* and ? *Trochammina* are present. The association is indicative of a deep-water fauna. Their scarce occurrence and small size point to rather unfavorable bottom conditions.

Calcareous Nannoplankton

Nannoplankton assemblages of upper Eocene to lower Paleocene and middle Albian to lower Aptian age were encountered at Site 361. Poorly preserved upper Eocene nannofossils are present in Cores 1 and 2. Cores 3 and 4 are barren except for the core catcher of Core 4 that is similar to Core 5 samples. Cores 5, 6, and 7 contain moderately preserved assemblages of middle Eocene age, with the middle-lower Eocene *Discoaster sublodoensis* Zone present in Core 7. The interval from the top of Core 8 to Core 9, Section 2, represents a complete, but strongly condensed sequence of lower Eocene and upper Paleocene nannoplankton zones. The first appearance of *Discoaster multiradiatus* occurs in Core 9, Section 2. A very interesting evolution of the *Tribrachiatus* group is recorded from Core 8. A barren interval in the lower part of Core 9 separates the upper Paleocene from the lower Paleocene *Cruciplacolithus tenuis* Zone present in Core 10, Section 2. Samples contaminated from above and barren samples characterize the lower part of Cores 10 and 11.

Cores 12 to 25 contain very rare, small *Watznaueria* that allow only for a general Cretaceous age. The *Prediscosphaera cretacea* (Core 26), *Parhabdolithus angustus* (Cores 27-32), and *Chiastozygus litterarius* (Cores 32-49) zones of middle Albian to lower Aptian age have been recognized in the poor nannoflora associations from Core 26 to the bottom of the hole.

Radiolarians

Cretaceous: Radiolarians are absent in most samples examined. When present, they are usually rare and poorly preserved. In some samples they occur in two states of preservation, an indication of mixing and/or reworking.

Marine Palynomorphs

Cretaceous: Fairly rich assemblages of dinocysts and acritarchs occur in most of the Cretaceous Cores 12 to 48 of Site 361. They are described, illustrated, and their distribution shown in this volume by Davey, and McLachlan and Pieterse.

The Lower Cretaceous assemblages are comparable to those of both Australia and Europe; those of the Upper Cretaceous correlate better with Australian associations.

Davey is of the opinion that typical marine conditions prevailed in the photic zone during the deposition of most of the Cretaceous sediments. He considers bottom conditions during most of the Aptian-Turonian to have been anaerobic.

The following new taxa are proposed by Davey from Site 361: *Australisphaera* gen. nov., *A. verrucosa* sp. nov., *Aiora perforare* sp. nov., and *Cyclonephelium distinctum* subsp. *longispinatum* subsp. nov.

Pollen, Spores

Cretaceous: With the exception of Cores 12, 25, and 26 the Cretaceous of Site 361 is rich in pollen and spores. They were studied together with the dinoflagellates by McLachlan and Pieterse (this volume). Two distinct floral associations can be distinguished. One characterizes the Lower Cretaceous sapropelic interval, Cores 27 to 49, with a low species diversity and dominated by a *Classopollis* local plant community. The other, with a marked phytoplankton increase and high species diversity characterizes the Upper Cretaceous Cores 12 to 24. These marked floral differences in the Lower and Upper Cretaceous are regarded as having been caused by a number of factors, in particular climate and provenance. The low diversity flora may be interpreted to reflect an unfavorable climate and/or a supply from a restricted area or plant community. In contrast, the high diversity floras indicate a more favorable climate and supply from a wider area with more diverse plant communities.

Wood Fragments and Cuticles

Cretaceous: The sapropelic Cores 27 to 49 are rich to very rich in wood fragments and cuticles. Their occurrence in Cores 30, 31, 36, and 45 was investigated by Brown (supplement volume). The wood fragments, one reaching about 8 cm in length, proved too poorly preserved for a systematic study. The cuticles of leaves and leafy stems represent at least nine different taxa of gymnospermous leaves. One new species, the conifer *Pagiophyllum maritimum*, is described. *Pagiophyllum* produces the *Classopollis* pollen shown by McLachlan and Pieterse to be the dominating form in the Lower Cretaceous Cores 27 to 49.

The Lower Cretaceous flora of Site 361, dominated by conifers and cycadeoids, resembles the floras that occurred at that time around the opening South Atlantic. It is regarded as a near-shore community that grew not far from Site 361.

Ichthyoliths

Paleocene-Upper Cretaceous: Ichthyoliths have been investigated by Doyle et al. (supplement volume) from Cores 9 to 11 (Paleocene) and Cores 12-16, 22, and 25 (Upper Cretaceous). Of biostratigraphic interest is a substantial change in Ichthyolith assemblages between the upper Paleocene Core 9 and the lower Paleocene Core 10, Section 2. Marked changes in the assemblages also occur between Sections 2 and 6 of Core 10, and between the Upper Cretaceous Cores 16 and 25.

Inocerami

The fragments that occur in Sample 15, CC and measure up to 6.5 cm belong to a giant questionable *Inoceramus* sp. indet. Several species of giant Inocerami, as large as 30 cm, are known from the Upper Cretaceous Coniacian to Campanian.

SEDIMENTATION AND ACCUMULATION RATES, SITES 360 AND 361

General Remarks

Sedimentation rates represent an interval thickness for increments of time, using the geochronology established in the introductory chapter of this volume. Sedimentation rates have been calculated primarily using calibrated nannofossil data corresponding to zonal boundaries. When applicable, selected foraminiferal datums have been used and these appear as asterisks on the related diagrams. For the Cretaceous of Site 361 some general age assignments have been taken from the palynology report of Davey (this volume) in support of a uniform sedimentation rate from Cores 26 to 14 due to the absence of any further stratigraphic resolution for this interval.

Accumulation rates have also been calculated, to correct for differential post-burial compaction of older strata. Downhole trends in porosity and gravimetric bulk density have been smoothed and used as inputs to the accumulation rate calculation. In some sequences, such as alternating limestones and shales, these properties vary considerably. Apart from initial selection of representative samples, no attempt has been made to "weight" these trends to lithologic types. Accumulation rates are expressed for both the total bulk sediment and the carbonate fraction, except in the Early Cretaceous section of Site 361 where much of the carbonate occurs as diagenetic cement.

Sedimentation and accumulation rates were derived from the slope of the age versus depth plots, and these derivatives amplify both the errors and imprecisions in the geochronology used and the inaccuracy of the original biostratigraphic correlations. Where zonal boundaries occur between cores, these are arbitrarily placed at the mid-point of uncored intervals. The curves are interpolated at 1-m.y. intervals. The effect of doing this rather than using the base of each microfossil zone as a datum is both to narrow the peaks and increase their amplitude.

Site 360

An age versus depth curve for Site 360 is presented in Figure 18, along with the calcareous nannofossil zonation of Table 9, the calculated sedimentation and accumulation rates, the content of calcium carbonate, and the per cent sand, silt, and clay.

The mean sedimentation rate is 18.4 ±16.7 m/m. y., the mean bulk accumulation rate is 26.8 $\pm 26.6 \times 10^2$ g/cm^2/m.y., and the mean carbonate content is 67.2 ±13 per cent.

Five pronounced maxima are apparent in the sedimentation and accumulation rate curves of Site 360; namely at 6.5, 13.5, 22.5, 36.5, and 42.5 million years. The maxima stand out very clearly from the background accumulation rates of approximate 7 to 12×10^2 g/cm^2/m. y., being five to ten times greater in magnitude. Four of these maxima of the southern Cape Basin coincide almost precisely with accumulation rate maxima in sites from the equatorial Pacific as indicated in fig. 31 of van Andel et al. (1975). However, the maximum at 28 to 32 m. y. recorded in many of the Pacific boreholes is absent at Site 360. There is no consistent correspondence between the magnitude of the accumulation rate and the per cent carbonate of the sediment, nor is there any consistent correlation to the degree of carbonate dissolution as evidenced by fragmentation of foraminiferal tests. For example, the interval of generally lower carbonate values (50 to 60%) in Cores 11 through 15 of Neogene age corresponds to low carbonate accumulation rates (6 to 8×10^2 g/cm^2/m.y.), whereas the lower carbonate values (25 to 50%) in Cores 39 through 50 of Paleogene age correspond to much higher carbonate accumulation rates (35 to 40×10^2 g/cm^2/m. y.). Likewise the interval of inferred carbonate dissolution in Cores 10 through 22 is characterized by both low and high rates of accumulation as does the inferred dissolution in Cores 36 through 48.

One obvious feature is the much greater contribution made by non-carbonate components in Cores 38 and below than at any level in the younger part of the Cenozoic section. This interval has a strong supply of non-carbonate components and corresponds to the generally lower carbonate contents of Eocene age. Since the accumulation rate of the carbonate component in this Eocene interval is no smaller than that detected in the other accumulation-rate maxima, the lower carbonate percentage is explained primarily as the result of a significant dilution by an enhanced non-carbonate component even though dissolution effects are

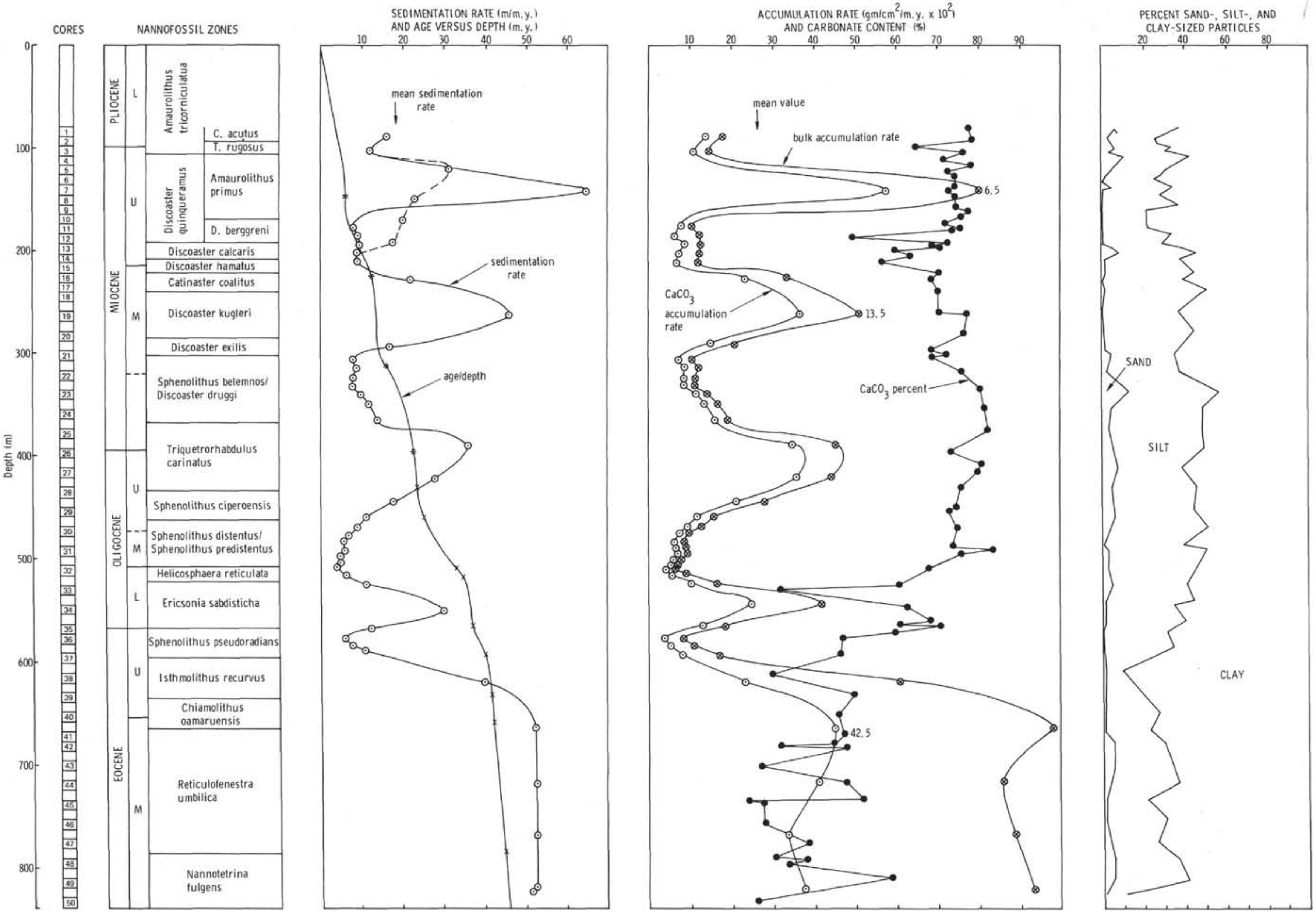


Figure 18. *Biostratigraphic zonation, sedimentation rates, accumulation rates, carbonate contents, and sediment textures at Site 360, Upper Continental Rise.*

pronounced, for example, in Cores 41, 43, 44, and 45 (Toumarkine, this volume). This non-carbonate component is interpreted to be fine-grained clay of terrigenous origin as indicated by the relatively large per cent of the clay-sized fraction in the Eocene sequence.

Another interesting observation is the occurrence of an increased sand-sized fraction at intervals of Neogene age corresponding to low or decreasing accumulation rates (e.g., Cores 3, 4, 14, and 23). This relationship suggests that the sand fraction (consisting almost entirely of the tests of planktonic foraminifers) may have been enriched by winnowing and the partial removal of finer grained material at times of more vigorous bottom-water circulation.

Late Miocene Sedimentation Rates

The extremely high sedimentation rate corresponding to 6.5 m.y. is based on the anomalously thick *Amaurolithus primus* nannofossil zone whose base in Core 10 has been assigned an age of ~6.6 m. y. (Bukry, 1973, 1975). The base of this zone (defined by the first appearance of *A. primus* is practically coincident in the Mediterranean outcrops with the first appearance of *Globorotalia conomiozea* (Rio et al., 1976; d'Onofrio et al., 1975). At Site 360 the *G. conomiozea* appearance occurs in Core 8 (Jenkins, this volume) some 20 meters above the *A. primus* datum. Paleomagnetic correlations proposed by Ryan et al. (1974) place the *G. conomiozea* inferred evolutionary appearance in New Zealand sections (see Kennett and Watkins, 1974) in Paleomagnetic Epoch 6 with an age assignment of ~6.3 m. y. In southeastern Spain, the first appearance of *G. conomiozea* is detected in a 30-meter stratigraphic level overlying the Barqueros volcanics (Mein et al., 1973) which have been radiometrically dated at ~6.9 m. y. (Montenat et al., 1975; van Couvering et al., in press).

The base of the *Triquetrorhabdulus rugosus* nannofossil zone (located in Core 3) is defined by the last appearance of *Discoaster quinqueramus* and has been placed in the middle of Paleomagnetic Epoch 5 at ~5.6 m. y. (Ryan et al., 1974; Bukry, 1975).

Hence there is considerable supporting evidence that the interval from Cores 3 to 10 was deposited in a relatively brief interval of time. However, the possibility does exist that both the *A. primus* and *G. conomiozea* made their first entrances into the South Atlantic prior to their appearance (perhaps ecologically controlled?) in the Mediterranean. To cover this possibility an alternate sedimentation rate curve (dashed line) has been calculated based on a connection of the age/depth curves from the base of the *D. quinqueramus* nannofossil zone directly to the base of the *T. rugosus* Zone. This interpretation retains the late Miocene sedimentation rate maximum, but reduces its magnitude to a value comparable with the other maxima at 22.5 and 36.5 m. y., respectively.

Site 361

The rates of sedimentation and accumulation for Site 361 are plotted in Figure 19 along with an age/depth curve, the nannofossil zonal boundaries of Table 10, the carbonate content, per cent organic carbon, and the per cent sand, silt, and clay. The mean sedimentation rate for the entire section is 16.8 ±10.0 m/m. y., and the mean accumulation rate is 27.8 ±23.1 k × 10^2 g/cm^2/m.y. The mean carbonate content for the Eocene is 12.8 ±16.2 per cent.

The biostratigraphic resolution is sufficient to reveal a more or less uniform sedimentation rate for the Eocene section followed by an abrupt slowdown and possible brief hiatus in the upper Paleocene corresponding to the top of the pelagic clays of Lithologic Unit 5.

Biostratigraphic resolution is not adequate to infer anything but a uniform rate of 15 m/m. y. for the Upper Cretaceous down to the Albian where calcareous nannofossils are once again present.

Sedimentation rates increase in the Albian and upper Aptian and are estimated at 45 m/m. y. in the lower Aptian. The rates for the lower Aptian have been calculated with the assumption of a basement depth of 1400 meters and a basal age equivalent to 120 m. y. by correspondence to magnetic anomaly M-4 as presented in Table 6 of the introductory chapter of this volume. If the entire interval of Cores 32 through 49 has a lower Aptian stratigraphic position, then the net sedimentation rate may have exceeded 70 m/m.y.

Although the maximum accumulation rate of the carbonate component of the Eocene section at Site 361 (20 × 10^2 g/cm^2/m.y.) is not as great as that of Site 360 (35 to 40 × 10^2 g/cm^2/m. y.), its magnitude is significant considering that the paleodepth of the Lower Continental Rise site was approximately 1 km greater than that of the Upper Continental Rise site.

The very rapid accumulation rates in the lower Albian and Aptian correspond with the interval of high organic carbon contents, some exceeding 10 per cent by weight. Much of the organic matter consists of plant and wood debris entrained in massive sand and silt beds. Its preservation is likely to have been enhanced by the high-speed burial associated with deposition by grain flows and in this process the organic carbon would have escaped serious depletion by oxidation.

CORRELATION OF REFLECTION PROFILES WITH DRILLING RESULTS

The combined drilling at Sites 360 and 361 penetrated all three principal sedimentary acoustic units of the continental margin of the Cape Basin but failed to reach acoustic basement. The reflecting interfaces between the main acoustic units are calibrated as follows:

1) Horizon D (Emery et al., 1975) at the base of Acoustic Unit I corresponds to an abrupt lithologic break at Site 361 between overlying nannofossil ooze (77% $CaCo_3$) in Core 8 and pelagic clay ($CaCO_3$ nil) in Core 9. The break has been placed at approximately 259 to 260 meters sub-bottom by a significant change in drilling characteristics (previously described) and by correlation to abrupt inversions in various physical-property gradients illustrated in Figure 18. Horizon D has a stratigraphic position between the uppermost Paleocene and lowermost Eocene with a minimum estimated age of ~53 m. y. Biostratigraphic control is not sufficient to determine if a small hiatus is present. Strata above and below Horizon D are conformable and the Horizon itself is a crisp reflector as shown in Figure 8.

2) Horizon AII (Emery et al., 1975) at the base of Acoustic Unit II corresponds to a rather sudden transition from predominantly non-carbonate shale (in Core 28, above) to

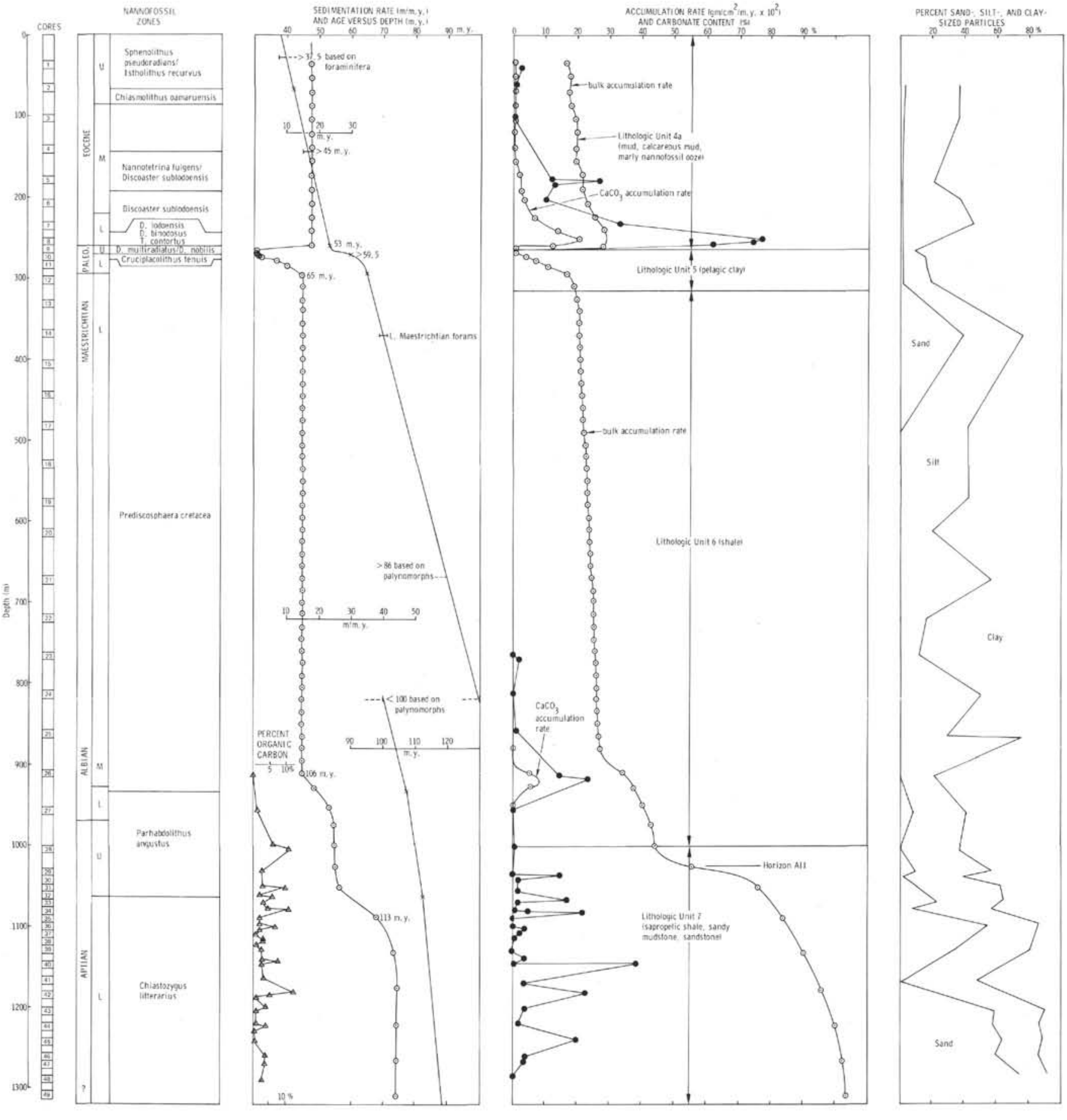


Figure 19. *Biostratigraphic zonation, sedimentation rates, accumlation rates, carbonate contents, organic carbon contents, and sediment textures at Site 361, Lower Continental Rise.*

shale interbedded with thick, calcite-cemented sandy mudstones and siltstones (Core 29, below). The boundary is provisionally located at 1030 meters sub-bottom by correlation to drilling characteristics (enhanced torquing and appreciable bit bounce) generally produced by the brittle nature of the mudstone and siltstone. Thick cemented layers are observed in Core 30, where compressional wave velocities exceed 4.5 km/sec as compared to 2.25 km/sec for the shale in Core 28. A significant increase in bulk density is also measured (ranging from 2.0 g/cm³ in Core 28 to 2.4 g/cm³ in Core 29). Horizon AII has a stratigraphic position in the upper Aptian, with an age estimate of approximately 110 m. y.

Site 360

The subunits of Acoustic Unit I at Site 360 are shown in Figure 20 where they are correlated to the lithologic column. The acoustic boundaries are listed in Table 11. The base of Acoustic Unit IA corresponds to reflector pale green and is assigned a depth of ~195 meters sub-bottom. This level in the borehole is marked by an appreciable increase in the sand-sized component first detected in Core 13, by an

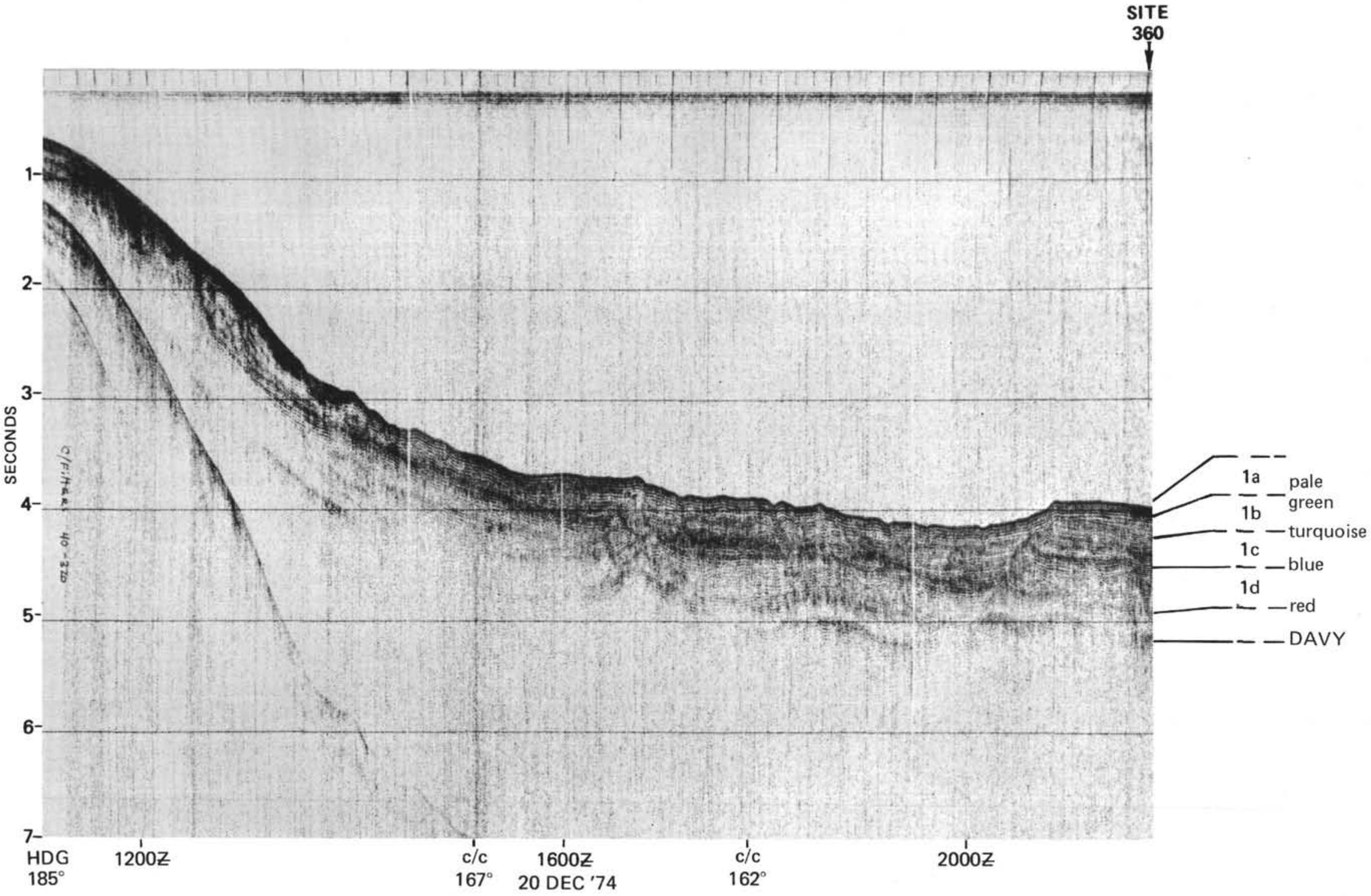


Figure 20. *Correlation of acoustic units and reflecting horizons of the* Glomar Challenger *approach profile to Site 361 to the recovered lithologic column.*

TABLE 11
Acoustic Boundaries at Site 360 and Their Lithologic, Stratigraphic, and Chronostratigraphic Position

Base of Acoustic Unit	Seismic Reflector	Travel Time Sub-bottom[a] (sec)	Depth (m)	Interval Velocity (km/sec)	Measured Mean Velocity (km/sec)	Stratigraphic Position	Estimated Age (m.y.)
1A	Pale green	0.230	195	1.695	1.666	Upper Miocene	9.5
1B	Turquoise	0.440	385	1.809	1.67	Lower Miocene	22.5
1C	Blue	0.535	475	1.895	1.89	Middle Oligocene	27.0
1D	Red	0.925	Not reached	---	2.21	Middle Eocene	47.0

[a] Measured at 0940 hours 10 January on ROBERT D. CONRAD profile 2298.

associated increase in the drilling rate, and by an increase in the measured shear strength. Reflector pale green has a stratigraphic position in the upper Miocene.

The base of Acoustic Unit IB corresponds to reflector turquoise. Its assigned depth of ~385 meters sub-bottom coincides with a significant increase in the measured compressional wave velocity from 1.63 km/sec in Core 25 to 1.90 km/sec in Core 26, a decrease in porosity, and a decrease in the carbonate content. Reflector turquoise has a stratigraphic position in the lowermost Miocene.

The base of Acoustic Unit IC corresponds to reflector blue, located at a depth of 475 meters sub-bottom. Another velocity increase occurs at this level ranging from 1.82 km/sec in Core 30 to 2.08 km/sec in Core 31. The stratigraphic position of reflector blue is middle Oligocene. The highest carbonate content of the entire section drilled appears at this stratigraphic position.

The base of Acoustic Unit ID lies below the deepest depth penetrated at Site 360. By using the measured compressional wave velocities in cores from Unit ID, the base of the unit has an extrapolated depth of 905 meters. Further linear extrapolations of the age versus depth curve to this level produces a middle Eocene age for reflector red, giving a stratigraphic position similar to that of the widespread Reflector A in the northwest Atlantic Ocean.

Site 361

The main acoustic units at Site 361 are shown in Figure 21 where they are correlated to the lithologic column. The acoustic boundaries at Site 361 are listed in Table 12. As previously discussed, Horizon D corresponds to the top of the pelagic clay of Lithologic Unit 5 at 259-260 meters sub-bottom and Horizon AII to the interbedded indurated sandy mudstones and siltstones of Lithologic Unit 7 at 1030 meters.

Acoustic basement was not penetrated in the Cape Basin. Extrapolation of the depth of the acoustic basement is difficult to make because the measured velocities are biased towards high values as the result of not being able to make satisfactory measurements in shales which had experienced significant dilation from expansion of entrained gaseous hydrocarbons. If a reasonable mean velocity of 3.0 km/sec is applied to Acoustic Unit III, its base can be estimated at >1390 meters sub-bottom. In further discussion in this chapter, the basement depth is rounded off to 1400 meters.

Acoustic Character of the Various Units

The weakly stratified character of Acoustic Units IA and IB is explained by the more or less homogeneous nature of the nannofossil ooze and nannofossil chalk of Lithologic Units 1 and 2. These formations exhibit only minor changes in carbonate content and lack distinct bedding.

The stratified nature of Acoustic Unit IC, on the other hand, is primarily attributed to a very distinct laminated bedding with sharp bedding contacts. The near conformable base of Unit IC occurs at an interval of very low accumulation rates ($<10 \times 10^2$ g/cm^2/m. y.) and may correspond to a brief undetected hiatus induced by sea-floor erosion.

The stratified and undulating nature of Acoustic Unit ID seems to match best with the enhanced terrigenous component (especially below 600 m) prevalent sometimes as discrete thin laminae of coarse clastic silt and fine sand. Carbonate contents fluctuate over a wider range than in overlying units possibly as the consequence of dissolution cycles, and a rhythmically bedded nature is consistently present, although somewhat smeared out by pervasive bioturbation across bedding planes. The undulating bedforms seen on the seismic profiles might have been constructed by the same dynamic processes which supplied the terrigenous material.

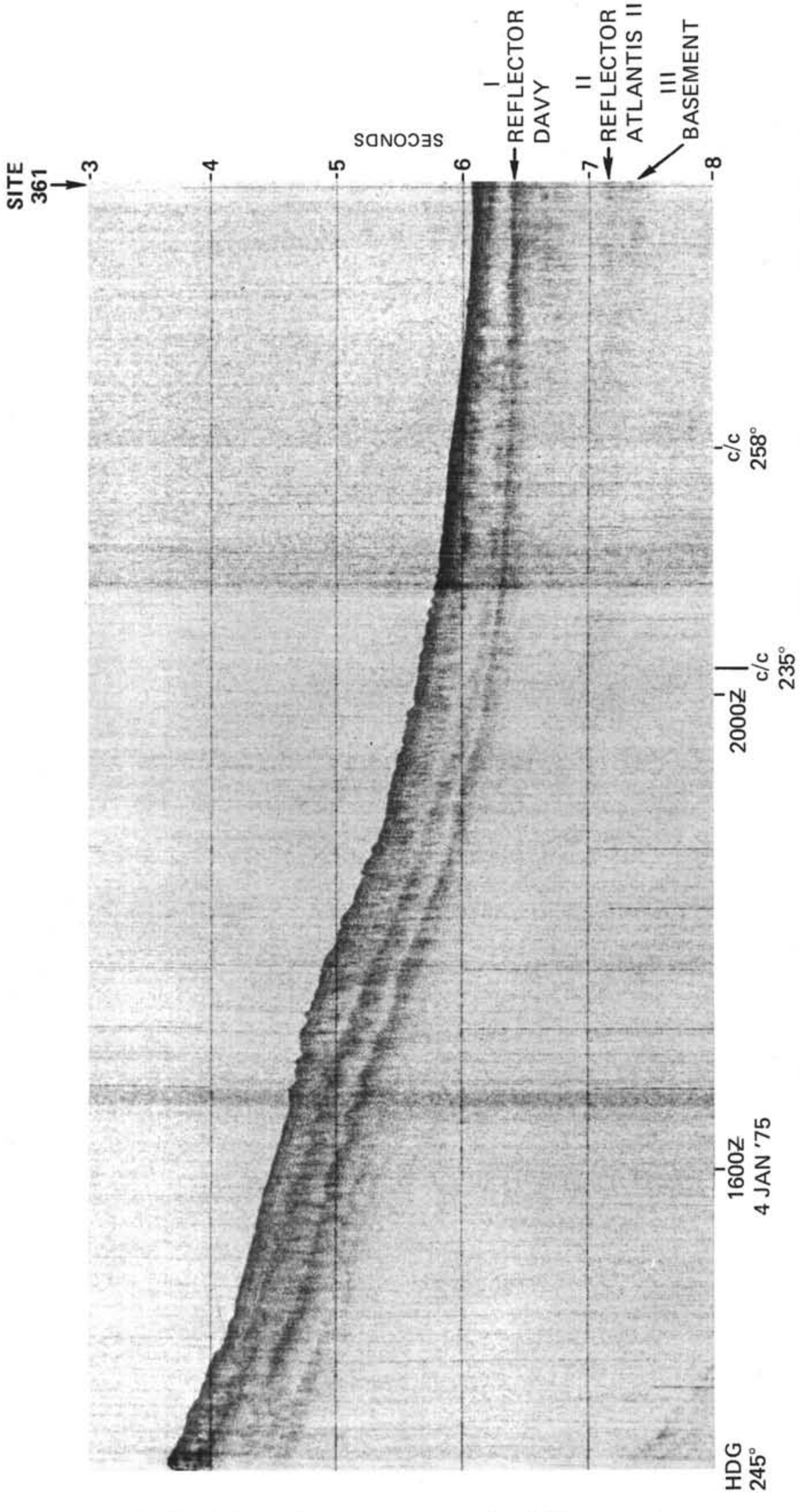
The transparent character of Acoustic Unit I on the Lower Continental Rise is more difficult to explain, considering the range of carbonate contents from essentially nil near the surface to more than 75 per cent at the base. Bedding, in Acoustic Unit I, however, is mostly massive, with only minor laminated zones.

The crisp nature of Horizon D throughout the Lower Continental Rise is at present thought to be the product of the extremely sharp lithologic change from nannofossil ooze to pelagic clay. The pelagic clay, with its low rate of accumulation, is furthermore considered the residue from strong dissolution below the Paleocene CCD.

Horizon D becomes less sharp and more diffuse in the upslope direction as can be seen in the reflection profiles near Site 360. The diffuse nature is attributed to the fact that these sites are near the Paleocene lysocline so that the carbonate gradient in the sediment column is less severe, thereby generating a more gradual impedance change.

The convergence of reflector red and Horizon D in the downslope direction may also be explained as the effect of partial carbonate dissolution in the stratigraphic interval, seeing that the CCD is generally somewhat elevated in other oceans such as the Pacific and Atlantic during Eocene time (Hay, 1970; Berger, 1972; Berger and von Rad, 1972; Ramsay, 1974; van Andel et al., 1975).

The faint undulating nature of Acoustic Unit II results from the numerous intercalated thin cross-bedded fine sands, silts, and sandy mudstones in shale. Cyclic alternation of color is common, but impedance contrasts would be



expected to be minor, except for the few indurated stringers, first encountered in Core 17.

Several of the lithified horizons correspond to faint reflecting interfaces within Acoustic Unit II.

The highly reverberant nature of Horizon AII and the generally strong stratification of Acoustic Unit III are caused by the large acoustic impedance contrasts between the much thicker cemented sandy mudstones, sandstones,

TABLE 12
Acoustic Boundaries at Site 361 and Their Lithologic, Stratigraphic, and Chronostratigraphic Position

Base of Acoustic Unit	Seismic Reflector	Travel Time Sub-bottom[a] (sec)	Depth (m)	Interval Velocity (km/sec)	Measured Mean Velocity (km/sec)	Stratigraphic Position	Estimated Age (m.y.)
1	Horizon D	0.320	259-260	1.621	1.69	Uppermost Paleocene Lowermost Eocene	53
2	Horizon AII	1.035	1030	2.155	2.232	Upper Aptian	110
3	Acoustic basement	>1.275	Not reached	---	3.61[b]	Barremian	120

[a] Measured at 0305 hours, 1 April on VEMA profile 441.
[b] This mean is high because the velocity of the interbedded shales could not be acurately measured.

and siltstones and the interbedded compacted shales of Lithologic Unit 7.

The interfingering and ponding of Acoustic Units II and III lithologies around topographic highs and within depressions of the basement further substantiate that the bulk of the sediment was laid down by sediment suspensions above the sea floor, including both tenuous suspension in nepheloid layers and concentrated suspension and grain flows in gravity-driven density currents.

The diffractive nature and irregular morphology of the upper surface of the acoustic basement is consistent with it being composed of piles of extrusive basalts characteristic of layer 2 of the oceanic crust.

SUMMARY AND CONCLUSIONS

The composite stratigraphic section of the Cape Basin provided by the two sites shows an evolution of sediment types reflecting alterations in the physical setting, the tectonic and erosional history of the adjacent continental margin, increasing water depths, significant oceanographic events,and continued climatic change.

Age and Geometry of Initial Opening

The initial opening of the South Atlantic appears from Figure 5 to pre-date magnetic anomaly M-11. According to both the revised time scale of Larson and Hilde (1975), and the Cretaceous time scale of van Hinte (1976), anomaly M-11 has a chrono-stratigraphic position equivalent to the late Valanginian stage of the early Cretaceous with an age assignment of approximately 126 to 128 m.y. B.P.

The South Atlantic west of Agulhas Bank had opened to a half-width of some 220 km by the time the oceanic crust underlying Site 361 was generated through a process of axial accretion at the crest of the mid-oceanic ridge. According to the fracture zone traces delineated in Figure 5, the earliest opening was strongly oblique to the strike of the continental edge. A major reorganization in direction followed sometime between the formation of anomalies M-10N and M-10. The reorganization may have been worldwide in extent, as suggested by changes in the strike of the Hawaiian lineations and the Mendocino Fracture Zone in the North Pacific (Hilde et al., 1976, their fig. 2 and 5) and by changes in the geometry of the Keathly lineations in the North Atlantic (H. Schouten, personal communication to W.B.F. Ryan).

Age of Oldest Sediments

The oldest biostratigraphically datable sediments recovered by drilling at Site 361 are early Aptian in age according to their association with the *Chiastozygus litterarius* nannofossil zone. Magnetic polarity measurements on the drill cores (Keating and Helsley, this volume) locate reversely magnetized intervals. These intervals of reversed polarity are interpreted as corresponding to magnetic anomalies M - minus 2 (early Albian) for Core 27, M-0, and M-1 (early Aptian) for Cores 39, 43, and 46. According to the Mesozioc time scale of Chapter 1 (this volume), the normal polarity at the base of Site 361 could be expected to correlate with anomaly M-2 and might thereby place the lowermost cores within the Barremian stage. However, a more refined magnetic stratigraphy will be required to confirm this assignment.

Early Cretaceous Water Depths

The oldest lithologic unit penetrated at Site 361 is Aptian in age. It consists of bituminous shale interbedded with coarse sandstones. Because of its age, Lithologic Unit 7 could have been deposited no further seaward than anomaly M-minus 1. Figure 25 provides a reconstructed cross-section for the M-minus 1 isochrone along a schematic transect striking west from South Africa and passing through Site 361. The paleodepth of the sea floor and basement surface are computed from the age-depth empirical curve of Sclater et al. (1971) taking into consideration isostatic loading of the basement by Unit 7 and older strata.

Unit 7 can be seen to have lapped against the flank of the Mid-Atlantic Ridge at the time it was deposited. As previously noted on Figure 5, Acoustic Unit III (bounded at its upper surface by Horizon AII) pinches out against the rough acoustic basement between anomalies M-0 and M-2. The reconstruction cross-section provides evidence that this pinch-out probably resulted from a ponding of continentally derived and gravity-transported sediments against the elevated eastern flank of the Mid-Atlantic Ridge at that time.

Although the exact depth of Site 361 in late Aptian time can be debated, it is significant to note that Site 361 is located within the deepest part of the bathymetric transect[3]. Today the Cape Basin has a somewhat anomalously shallow elevation (of perhaps 300 to 400 m) when compared to theoretical age/depth curves. Although it is not known when this anomalous elevation occurred, it is unlikely to have been acquired at the Early Cretaceous ridge crest since the

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[3] In fact, the location of the site was purposely chosen at the anomaly M-4 isochrone so that it would have occupied a basinal setting at the time of late Aptian evaporite deposition north of Walvis Ridge. The significance of the evaporites will be discussed in Chapter 4, this volume.

Argentine Basin on the opposite side of the South Atlantic is now anomalously deep by an equivalent amount. In fact, the observed truncation of post-Horizon D top-set sediments beneath the modern continental shelf of South Africa (Dingle et al., 1972) can be best explained by a regional uplift of the eastern South Atlantic in post-Mesozoic time.

Regardless of the absolute value of the paleodepth of Site 361 in the late Aptian, the age-depth reconstruction implies a former depositional setting seaward of the then-existing continental slope. We therefore conclude that the massive sandstone and muddy sandstone layers of Lithologic Unit 7 were derived from the rifted margin of South Africa and were essentially transported downslope to the site location by turbidity currents and other associated grain-flow and suspension-flow mechanisms before becoming ponded on the floor of the Cape Basin.

Provenance of the Sandstones and Shales of Lithologic Unit 7

At the close of the Barremian, only some 11 to 13 million years had passed since Africa and South America were rifted and began drifting apart. Hence the African margin was youthful and most likely possessed narrow and steep marginal escarpments of fault origin like those that border the modern Red Sea and Gulf of Aden.

The mineral composition of the Unit 7 sandstones (see Natland, this volume: Siesser and Bremner, this volume) suggests two types of source rock: (1) a predominant granitic and high-grade metamorphic terrane, and (2) a minor, silicic volcanic terrane.

Granitic and Metamorphic Sources

Much of the undulose quartz, microcline, tourmaline, and zircon observed in smear slides and thin sections, and the chemistry of the sandstones (Natland, this volume) point toward a granite provenance. Rose quartz is also present, suggestive of veins or pegmatites. Schist and quartzite fragments, plus frequently observed biotite, amphibole, and muscovite grains, originate from a metamorphic highland.The west coast of southern Africa is predominantly granitic and high-grade metamorphic in character (Martin, 1965; Kröner, 1974; Kröner and Jackson, 1974) and hence is a likely candidate for these materials. Orthoquartzites have been sampled from Pleistocene age sediments in piston core *Vema* 19-234 (137 m) from the continental shelf immediately southwest of the Cape of Good Hope. Granulite facies metamorphic rocks of this portion of Africa supplied the hypersthene observed in the sandstones.

The most unusual mineral observed in Unit 7 sandstones is glaucophane, which typically occurs in high-pressure, low-temperature metamorphic (blueschist) terranes. The southern extension of the Pan-African Orogenic Belt below Damaraland on the west coast of South Africa includes ophiolites and metamorphic rocks indicative of plate-tectonic style orogeny 550-560 m.y. ago (Kröner, 1973). This belt may have blueschist rocks within it (Kröner, personal communication to J.H. Natland) although they have been little studied. Glaucophane was also reported with biotite in smear slides of predominantly carbonate rocks dredged from 2700 meters on the north side of the Walvis Ridge (Pastouret and Goslin, 1974).

Silicic Volcanic Source

The most diagnostic volcanic material is sanidine, a high-temperature feldspar which occurs as individual sand grains and as phenocrysts in altered vitrophyric sand grains. Sanidine is a common mineral in silicic volcanic rocks, hence we infer a small silicic volcanic contribution to Unit 7 sediments. It is possible that some of the quartz and biotite may also be volcanic in origin, based on their occurrence in some lithic sand grains observed in thin sections and their typical occurrence in silicic volcanic rocks.

The location of the source which provided the silicic volcanic component to Unit 7 sandstones is not obvious. At present, there are no unmetamorphosed Aptian or older silicic volcanic rocks exposed in western South Africa, although there are local exposures of Jurassic Karroo dolerites. Only the volcanic complexes of Damaraland east of Walvis Bay (Messum, Cape Cross, Okonjeje, Paresis, etc.) dated at about 130 m.y. (Marsh, 1973) could have formed an Aptian source of silicic volcanics to the Cape Basin, but they are too far north to have added sediments to the coarse clastic deposits drilled at Site 361 near the southern tip of Africa. Drainage from the interior of Africa may have carried sediments derived from Karroo dolerites, but these are not evident in thin sections nor in the chemistry of the sandstones (Natland, this volume). In any event, only minor amounts of intermediate composition lavas and trachytes are associated with the Karroo Basin dolerites (Haughton, 1969). No rhyolitic to dacitic flows and tuffs, nor shallow granitic stocks and plugs which could have been the cores of silicic volcanoes, are found south of Cape Cross in the Damaraland belt, nearly 1500 km north of Site 361. The extreme angularity of quartz grains as well as detrital volcanic grains indicates a short distance of transport, or very rapid transport, for all components of the Site 361 sandstones. Their composition suggests a source dominated by Cape or older granites (Natland, this volume). Sources within the Paleozoic Cape Fold Belt (Figure 1) and the Proterozoic Kheis granites and associated metamorphic complexes are postulated (or, less likely, possible counterparts on the Falkland Plateau which was situated nearby to the south in Aptian time [Rabinowitz and La Brecque, in press]).

It seems plausible that during and immediately after the continental rupture accompanying the opening of the South Atlantic, silicic volcanic complexes formed along the fault structures of the continental portion of the rift, mainly by melting of continental crust. They would have been analogous to basalt-rhyolite volcanoes of Somalia and the southern Arabian Peninsula adjacent to the Gulf of Aden today (Beydoun, 1970; Gass, 1970), and in some respects, to the Damaraland complexes which are mainly silicic, but have gabbroic central stocks (Martin et al., 1960), and which may have been contiguous with the South African-Atlantic Coast complexes proposed here. The date of the Damaraland activity, ~130 m.y., coincides well with the inferred date of opening of the South Atlantic Ocean, as suggested by the identification of Magnetic Anomaly M-11 in Figure 5. The igneous complexes which provided components of Site 361 sandstones thus may have been near the continental margins roughly paralleling the coasts. The agent of crustal melting could have been basalt magma, by analogy with the basalt-rhyolite complexes of southwest Africa, the Scottish Hebrides, and other continental rift occurrences. Erosion of the uplifted blocks and cooling of the lithosphere may then have carried the erosional remnants of the silicic volcanoes below sea level to be buried by continental margin sediments. The nearly submerged complex at Cape Cross, western Damaraland, may be an example of this process continuing today.

Implications of the Sapropelitic Facies

Lithologic Unit 7 contains both organic carbon-rich sandstones and carbon-rich shales. The carbon in the sandstones exists as lithic fragments of bituminous material transported for the most part to the depositional site along with the other clastic components. The noted occurrence of calcareous benthic foraminifers in Samples 361-31-4, 129-131 cm, and 361-32-2, 117-119 cm (see MacLachlan and Pieterse, this volume) is confined to graded sandstone intervals and opens the possibility that the tests of the foraminifers were retransported from shallower settings on the margin. Pollen and spores from the carbonaceous material are low in species diversity — an observation which has been interpreted by MacLachlan and Pieterse (this volume) to reflect a harsh climate of some sort (cold or low rainfall) or a supply of spores and pollen from a restricted area or plant community such as that which might be expected in a narrow coastal belt at the base of still rugged marginal escarpments.

The shale interbeds are characterized by a considerable amount of amorphous sapropelic matter as especially typified in Core 28 (see Reynaud and Robert, this volume). Although some of the shale belongs to the finer upper parts of graded layers, and hence contains considerable amounts of fine-grained organic material derived from land (brown ligneous debris, fusinite, and pollen grains), some of the shale is minutely laminated and has the lithologic appearance of pelagic-type deposition. In these beds, a varve-like texture is accentuated by thin white laminae of nannofossil marlstone (see Noël and Melguen, this volume). Upon drying and oxidizing in air, the split surfaces of the shale cores become studded with tiny euhedryal crystals of gypsum. Some of the varve laminae expand and pull apart as the result of gypsum crystal formation, leaving the core trays with detached millimeter-thin wafers having their surfaces coated white by the nannofossil films. The calcium sulfate indicates the presence of considerable amounts of previously unoxidized or only partly oxidized sulfur bound up in organic molecules within the sapropelic material.

The distribution of sapropelic sediment is confined to Lithologic Unit 7. Although some dark-colored shale is present in the lower one-third of Unit 6, carbon contents are generally well below 1 per cent by weight, as contrasted to the greater than 3.5 per cent average in both clay-cemented sandstones and shales from Unit 7.

Explanations of the carbon enrichment of Unit 7 include:

1) greater supply of plant and associated material due to more extensive terrestrial erosion;

2) greater preservation of land-derived organic material due to rapid rates of burial (greater than 70×10^2 g/cm^{2}m.y.;

3) greater preservation due to rapid rates of burial resulting from extensive marine productivity;

4) greater preservation due to either a total absence of oxygen or a significant reduction in its content with the overlying water mass in contact with the sea bed.

Explanations 1 and 2 might seem satisfactory to account for the organic matter found within the massive sandstone and sandy mudstone layer, but do not account for the abundant finely dispersed sapropelic matter found with the varve-like shale.

Explanation 3 has difficulty in shedding light on why biogenic skeletal components of Unit 7 are not more enriched in the shales especially as to siliceous faunas which usually adapt to high fertility situations along belts of coastal upwelling (Goll and Bjorklund, 1974). It is possible, however, that the calcareous tests of planktonic organisms have been selectively dissolved after burial as the consequence of carbonate extraction under strongly reduced conditions. The acid-resistant chitinous linings of the initial chambers of benthic foraminifers have been described in numerous samples by MacLachlan and Pieterse (this volume). Planktonic foraminifers of moderately good preservation were noted in abundance in thin calcareous sandstone beds in Core 27. It is hypothesized that they were shed from a high-standing seamount to the west on the mid-oceanic ridge such as Englebrecht. This particular volcanic peak was created on crust corresponding to magnetic anomaly M minus 1 whose age corresponds well with the biozone of Core 27. Although we attribute the preservation of foraminifer tests to a rapid allochthonous input by turbidity currents to a site lying below the lysocline but above the level of total dissolution, the absence of abundant radiolarians is curious in a high-fertility situation.

Explanation 4 related to oxygen depletion seems perhaps the most plausible. Anoxic environments have in fact been postulated to account for several other occurrences of carbonaceous shales of Cretaceous age, particularly at DSDP sites in the North Atlantic (Lancelot et al., 1972; Saunders et al., 1973) but also within shallow epeiric seas.

The cause of oxygen depletion has been attributed to an intensification of the oxygen-minimum zone usually found at the base of the ocean thermocline (Arthur, 1976). The development of anoxic environments at Site 361 requires an expansion of the oxygen-minimum right down to the axis of the then existing Cape Basin and hence might be better viewed as the development of an actual abyssal stagnation of the type that has occurred intermittently within the semi-enclosed Mediterranean, Red, and Black seas during the Quaternary.

Evidence of the formation of hydrogen sulfide-rich bottom waters as a product of abyssal stagnation is difficult to elucidate, but might be indicated in the pervasive abundance of iron-sulfides within Lithologic Unit 7 (see Siesser, this volume). Pyrite and marcasite sometimes comprise up to 10 per cent or more of the total bulk weight of the finely laminated varve-like facies.

The inferred abyssal stagnation of the South Atlantic might very well have been a local oceanographic event, since the geometric reconstruction to the anomaly M minus 1 isochron (Figure 5) shows rather a tight closure to the south between the Agulhas Bank and Falkland Plateau as well as to the north across the then existing Walvis-São Paulo Ridge complex. The Aptian South Atlantic was indeed comparable in size and depth to the present eastern Mediterranean Sea which underwent a basin-wide stagnation as recently as 9000-7000 years B.P. (Olausson, 1961, McCoy, 1974).

Stagnation would imply trapped bottom waters, isolated from the surface by a density stratification. The more effective stratification would be that caused by local high-salinity bottom water since it would not be particularly vulnerable to geothermal heating from the underlying igneous substratum. High salinity bottom waters could be generated from arid coastal lagoons, or instead might have been derived by means of brine-reflux from the hypersaline Angola-Brazil Basin passing either over carbonate reefs capping the Walvis-São Paulo barrier ridge or through a permeable basement formation such as that present in young layer 2 of the oceanic crust (see further discussions in Chapter 4, this volume). The authigenic mineral assemblage illite-kaolinite-phillipsite in Unit 7 sandstones appears to require high-salinity bottom waters (Natland, this volume).

Additional hypotheses as to the possible cause of abyssal stagnation in the Cape Basin and discussion of the inferred pattern of oceanic circulation during the Aptian are given in greater detail by Natland (this volume).

Implications of the Sedimentary Succession

A definite succession occurs in the texture and mineralogy of the Cretaceous sediments. The succession suggests first of all changes in the geometry of the submarine sedimentary apron and secondly in the sites of sediment input and manner of subaqueous transport.

Lithologic Units 7 and 6

The coarse turbidites and carbonaceous shales of Lithologic Unit 7 were deposited along the axis of the Cape Basin. To the west was the elevated crest of the Mid-Atlantic Ridge, and to the east the marginal escarpments of continental Africa. Unit 7 was thus part of a distal deep-sea fan deposit.

Unit 6, on the other hand, is a sequence of alternately bedded Albian to Maestrichtian red or gray shales and siltstones. Massive coarse graded sandstones similar to those of Unit 7 do not occur. With respect to Unit 7, Unit 6 shows three other important changes:

1) finely cross-laminated siltstones are predominant (Kagami, this volume);

2) bottom conditions were well oxygenated;

3) the provenance, though still dominantly granitic, included basaltic and/or andesitic components as well (Natland, this volume).

These changes are most probably related to the following developments in structure and oceanographic conditions which occurred toward the end of the Aptian or in the early Albian:

1) a shift in the locus of most rapid ocean floor subsidence to the west, as the African margin and Mid-Atlantic Ridge crest drew further apart;

2) a decline in the relief of source regions of clastic materials;

3) an end to deposition of evaporites in the Angola Basin to the north, probably coinciding with a ridge crest jump in the Angola Basin which may have formed a gap in the Walvis-São Paulo Ridge barrier (see discussion in Chapter 4, this volume);

4) sliding of the Falkland Plateau past the tip of southern Africa;

5) cessation of anoxic conditions at Site 361.

Decline in source-region relief and the build-up of the continental margin prism during the Aptian would have tended to diminish the supply of coarse turbidites to Site 361. However, the provenance change between Unit 7 and Unit 6 indicates that an additional factor had come into play, namely the rearrangement of the route of supply of sediments, bringing a basaltic and andesitic component to Site 361 for the first time, as well as a more diverse pollen assemblage (MacLachlan and Pieterse, this volume).

Natland (this volume) also proposed that sedimentary structures within Unit 6 were the result primarily of bottom currents and suggested that they flowed from north to south across the continental margin prism, bringing with them sediments with a partly basaltic source. This source was inferred to be the delta of the Orange River which drains Karroo basalts and older andesitic terranes. Using sedimentary structures to distinguish fine sediments deposited by turbidity currents from those sculpted by bottom currents (contourites) is not easy. The flow regimes of turbidity currents and contour currents might both produce graded bedding and finely cross-laminated layers in the right circumstances. Hollister and Heezen (1973) place great emphasis on the identification of placers in contourites in contrast with the more massive and poorly-sorted sandstones of turbidites. But it is not clear that this is always diagnostic. Natland (this volume) described placered finely cross-laminated siltstones from Unit 6. Furthermore, massive poorly sorted sandstones characterize Unit 7, but are absent in Unit 6. In the final analysis, perhaps the only way to prove that Unit 6 sediments are contourites would be to demonstrate that the flow direction was parallel to the continental slope using sedimentary structures and perhaps magnetic inclinations. This has not yet been done. Lacking this, the evidence for contourites is mainly suggestive or permissive. It is:

1) There was a change in provenance between Unit 7 and Unit 6 to what are most likely northerly sources with a basaltic component;

2) Within Unit 6, several cores contain a more varied pollen assemblage than in Unit 7, also explainable by derivation from a more northerly (temperate) source (other explanations, i.e., wind patterns, climate, etc. are possible here however);

3) The change in the style of sedimentation between Unit 7 and Unit 6 was abrupt. Not only did massive sandstones stop reaching Site 361, but, most critically, a distinct change occurred in the fine-grained sediments. The finer grained silts and shales of Unit 7 are discrete horizontal beds with sharp, flat, very regular contacts. They are almost perfectly parallel-bedded, a major evidence for deposition in stagnant bottom waters. Within even the lowermost cores of Unit 6, however, parallel bedding is absent. There are invariably at least small changes in inclinations of beds from one to the next, and partial or complete truncation of beds is common. Typically the dip of beds varies by 5-15° and the surfaces of beds are irregular. Some factor in addition to the existence of

turbidity currents is required to explain this difference between Unit 6 and Unit 7. This factor we infer to be bottom currents.

4) The top of Unit 7 coincides with Horizon AII and defines a wedge-shaped pile of sediments (Acoustic Unit III) thickening landward. Unit 6 comprises the bulk of Acoustic Unit II which is uniform in thickness (Figure 3), a feature that we would not expect if the sediments of Unit 6 were the distal portions of turbidites.

5) Within Unit 6, there are many examples of apparent mixing of fine reddish muds with grayish silty muds. This mixing can be very dispersed. One would not expect such a color contrast to be produced by size sorting within a turbidity current. Instead it is most likely that the reddish color developed in sea floor muds which had a long residence time within oxygenated bottom waters. These were then mixed by bottom currents with coarser sediments poor but not lacking in clay, but which had a shorter residence time on the sea floor.

Making this picture more attractive is the notion that ocean-floor subsidence, now slowed at Site 361 and more rapid to the west, would allow the depth to the top of the sediment column at Site 361 actually to become shallower, since the rate of sediment upbuilding would soon approach and then surpass the rate of subsidence. Turbidites formerly deposited in the deepest parts of the Cape Basin would begin to bypass Site 361 and be channeled farther westward. The site, having changed from a distal-fan to a mid-continental-rise setting, would then plausibly be in the path of a thermohaline current either spilling from the Angola Basin, or produced by excess evaporation in the northern part of the Cape Basin, as proposed by Natland (this volume). Such a current would have been eastward-intensified by the Coriolis effect, and in the vicinity of Site 361, would have been channeled into whatever narrow gap existed to allow waters to escape the South Atlantic between Southern Africa and the Falkland Plateau.Site 361, then, was a place likely to have had currents given the type of thermohaline circulation proposed here. Vigorous near-bottom circulation is a plausible consequence of the opening of the Cape Basin to Indian Ocean waters, of the deepening of the Angola Basin, and of the postulated break in the Walvis Ridge (see discussion in Chapter 3, this volume).

It is possible that some of the basaltic component of Unit 6 could have come from seamounts west of Site 361 (Ewing, Vema, Protea, etc.) which probably were formed at or shortly after the ridge-crest jump in the South Atlantic about M (−1) time (late Aptian). However, there are no preserved volcanic ashes in Unit 6, and the evidence for a basaltic component to Unit 6 persists throughout the unit, spanning the Late Cretaceous. This basaltic component is also thoroughly mixed with continent-derived quartz, feldspar, and clays wherever it is seen. We thus favor a persistent continental source for the basaltic component.

Cessation both of a supply of terrigenous silt and of bottom currents occurred rather abruptly within a 19-meter interval between Cores 13 and 12 in the Late Cretaceous. The Cretaceous-Tertiary boundary is marked at Site 361 by the deposition of brick-red pelagic clay containing manganese oxide micronodules and abundant fish debris. This coincides in time with periods of tranquil deposition at Site 364 in the Angola Basin, Site 356 on the São Paulo Plateau (Supko, Perch-Nielsen, et al., 1977), and Site 363 on Walvis Ridge (see Summary and Conclusions, Chapter 4, this volume). The Mediterranean-type circulation system we have proposed evidently broke down at this time, probably a consequence of widening and deepening of all sills within and at the ends of the South Atlantic. The worldwide rise in the calcite compensation depth proposed by Worsley (1974) is inferred by Melguen (this volume) to be the reason why no carbonates were deposited at Site 361 at this time. Toward the end of the Paleocene and through the Eocene, however, moderately to poorly-preserved foraminifers and nannofossils were deposited within marly oozes, calcareous muds, and muds, implying a deeper CCD.

Coring at Site 361 commenced at 32 meters sub-bottom in the *Isthmolithus recurvus* Zone of the upper Eocene after washing through a major unconformity at 25 meters sub-bottom. Measurements of the physical properties of the Site 361 sediment column (Figure 17) demonstrate that the present outcropping or shallow subcropping of Eocene strata occurred by the removal of a thinner sediment section than the 840 meters of Eocene and younger strata cored at Site 360. Site 361 was and is much deeper than Site 360, hence the Cenozoic section may have been condensed because it was largely deposited below the CCD. Sound velocities average 1.68 km/sec for Units 4a and 5, and reach a maximum of 4.1-4.7 km/sec in the cemented sandstones of Unit 7.

A variety of factors made much of Site 361 difficult to date. Within Unit 7, both diagenetic dissolution of calcite (Natland, this volume) and a possible shallow calcite compensation depth (Melguen, this volume) reduced the nannofossil population to sporadic occurrences of the more resistant species. Unusual surface-water conditions are implied by the occurrence only of dwarfed specimens of primitive arenaceous benthic foraminifers, and no planktonic foraminifers.

Within Unit 6, only the lowest two cores could be dated using nannofossils. All other cores contained only highly impoverished floras. Foraminifers were equally undiagnostic. Site 361 was apparently quite close to the calcite compensation depth throughout the Late Cretaceous.

Much of Unit 5 also proved undatable because of poor preservation or lack of calcareous microfossils. Here again, Site 361 was at or below the calcite compensation depth.

Both foraminifers and nannoplankton are abundant in the upper Eocene to upper Paleocene, the nannoflora in particular providing good markers for dating this interval. By contrast, the planktonic foraminifers consist largely of more boreal, longer ranging forms. The Aptian planktonic foraminiferal assemblages recognized in Section 27-2 and as reworked forms in Core 14-2 show strong affinities to those known from Mexico, France, and Spain, providing evidence for a likely water-mass circulation between the South Atlantic Cape Basin and the Tethys at that time.

We must now shift our attention to Site 360 to complete our history of the southern Cape Basin. The site is both shallower and closer to the continental shelf than Site 361. It is therefore no surprise that both the supply of terrigenous sediments and calcareous sediments to Site 360 was greater in the Eocene than to Site 361 (Figures 18 and 19). The acoustic unit below 0.54 seconds consists of what might be long-wavelength apparent upslope-migrating sediment dunes. This corresponds with Eocene and lower Oligocene marls and highly bioturbated thin silty and sandy terrigenous beds. The influence of bottom currents on this sediment, if they existed, must have been very subtle, since there are no detectable biostratigraphic gaps. Winnowing and removal of the sediment were minor. Perhaps the currents that formed the dunes, if these indeed are dunes were mainly responsible for supply of terrigenous material to dilute the carbonate component.

On the other hand, it is possible that the crumpled internal reflectors of this acoustic unit were the result of slumping, specifically the formation of slope-parallel slump blocks only tens of meters wide, but perhaps up to several kilometers long. Lonsdale (1975) described similar slump blocks from the Samoan archipelagic apron and made a number of specific comparisons to occurrences on lower continental rises. We here summarize his point of view. Ballard (1966) proposed that a province of hummocks covering 32,000 sq/km east of Cape Hatteras had formed by progressive slumping on slopes of less than 1°. Others have opposed this view, arguing that such hummocks are depositional waveforms resulting from a steady bottom current (e.g., Heezen and Schneider, 1968; Fox et al., 1968; Rona, 1969). Hollister et al. (1974) described linear erosional furrows, paralleling currents, on the Bahama outer ridge, an area they considered equivalent to the province east of Cape Hatteras in that it, too, is traversed by the Western Boundary Undercurrent.

In short, there is little way to tell from profiler records that bent internal reflectors correspond to dunes, slump blocks, or erosional furrows. At Site 360, where we have actual samples of the sediments, we have virtually no evidence for erosion, nor any sedimentary structures suggestive of dunes. The top of the acoustic unit occurs near the bottom of Lithologic Unit 3, which has abundant thin silty laminations, but none of the highly sorted and finely cross-laminated siltstones that characterize contourities. Most of the acoustic unit is represented by Lithologic Unit 4, which is heavily bioturbated and lacks even thin laminations. Instead, the top 70 meters of the acoustic unit (represented by Cores 30-33) is characterized by microfaulting, burrows offset by shear planes, and soft-sediment deformation structures which are primary evidence for slumping (Figures 11 and 12). Similar structures may have been obliterated in deeper cores by intensive bioturbation.

One of the factors which apparently promotes the slump-block mechanism is sediments with low shear strength. Slumping occurs on the Samoan apron in large part because of layers of bentonitic mud derived from subaerial weathering of the Samoan Islands and from halmyrolysis of volcanic glass (Lonsdale, 1975). In the Eocene and Oligocene, terrigenous clay was a greater component of Site 360 sediments than at any time since. This may have contributed to lower near-surface sediment shear strength. Bulk accumulation rates also dropped with the decline in terrigenous input, thereby reducing the rate of application of stress to near-surface sediments and allowing more time for cementation processes to work.

It would appear, then, that the best evidence we have from the cores suggests that the characteristic acoustic signature of this interval of sediments was produced by slumping, not by currents.

Post-Oligocene sedimentation at Site 360 has been mainly biogenous, resulting in a thick sequence of calcareous oozes and chalks. Several peaks in the $CaCO_3$ accumulation rate have occurred since the Eocene (Figure 18). These correspond with periods of reduction in the preservation of planktonic foraminifers (Melguen, this volume) and nannofossils (Noël and Melguen, this volume). Noël and Melguen interpret them to reflect shoaling of the CCD throughout the South Atlantic.These peaks are compared with similar peaks at Sites 362 and 363 at the end of the Summary and Conclusions section of Chapter 4 (this volume). There, alternatives to the shallow-CCD hypothesis are also considered.

Based on the floral and faunal evidence, the closely cored section at Site 360 (intermittently coring one, washing one) represents a stratigraphically fairly continuous sequence. It is well dated by nannoflora. The planktonic foraminiferal fauna of Site 360, in particular the Neogene, shows strong affinities to the colder-water Austral, New Zealand associations (Jenkins, this volume, and Toumarkine, this volume). However, subtropical/tropical species are often present together with the colder water forms, thus allowing closer dating than is possible using the longer ranging boreal species alone. The planktonic foraminifers of the Eocene largely lack the marker species of the warm water areas. The dating of these sediments is therefore based almost exclusively on the nannofloras.

Sound velocities average 1.66 km/sec in Lithologic Unit 1 to 2.2 km/sec inLithologic Unit 4. Reflector D of Emergy et al. (1975), although not reached by the drill string, has an extrapolated age of earliest Eocene to latest Paleocene.

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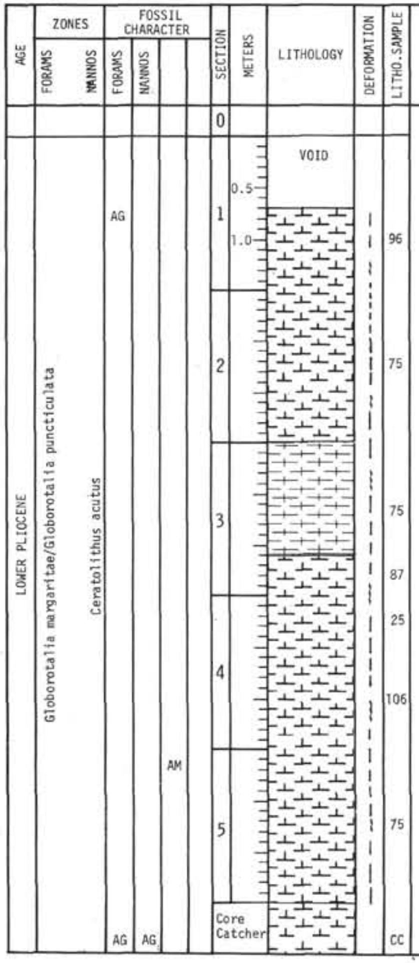
Site 360 Hole Core 1 Cored Interval: 79.5-89.0 m



LITHOLOGIC DESCRIPTION

5GY 8/1

5Y 8/1
mottles

5GY 8/1

5GY 8/1

5Y 8/1
mottles

5GY 8/1

Nannofossil ooze with minor foraminiferal nannofossil ooze. Light greenish gray (5GY 8/1). Slightly to moderately mottled with yellow gray (5Y 8/1) mottles. Pyrite appears as small, black specks, micronodules, and tubes. Coccospheres present in some smear slides. Many large forams fragmented.

<u>NANNOFOSSIL OOZE</u>
SS 1-96, 3-86, 4-25, 5-75, CC
65-85% Nannos
2-5% Forams
5-20% Clay
T- 5% Sponge spicules
0-1% Pyrite
T Rads

<u>FORAMINIFERA NANNOFOSSIL OOZE</u>
SS 2-75, 3-75, 4-106
60-75% Nannos
10-15% Forams
<10% Clay
T-5% Sponge spicules
T-5% Pyrite
T Mica

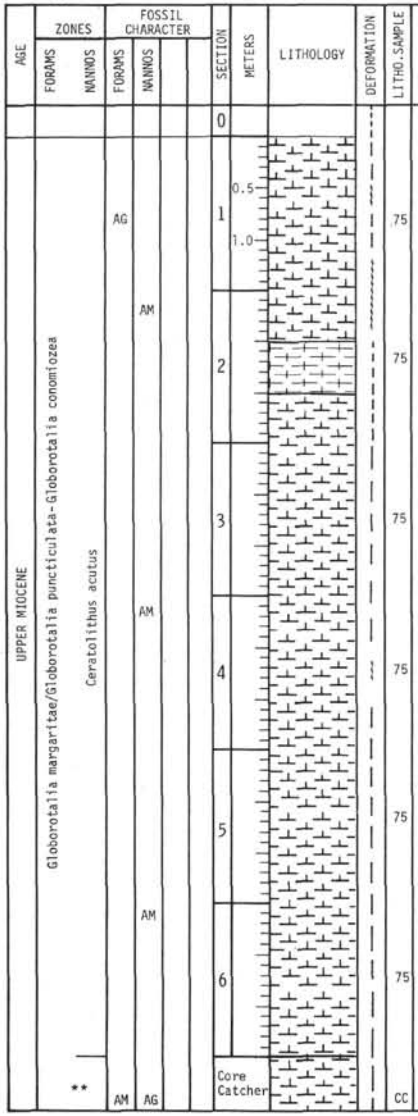
<u>TEXTURE (Average from SS)</u>
5% Sand
15% Silt
80% Clay

Carbonate Bomb: 4-30 to 31 cm = 93% $CaCO_3$

<u>Carbon-Carbonate (DSDP)</u>
4-20 (9.6, 0.2, 78)

<u>Grain Size (DSDP)</u>
4-58 (6.6, 31.0, 62.5)

Site 360 Hole Core 2 Cored Interval: 89.0-98.5 m



LITHOLOGIC DESCRIPTION

N8

5GY 8/1

5Y 8/1

5GY 8/1

5GY 8/1
5Y 8/1
mottles

5GY 8/1
5Y 8/1
mottles

Nannofossil ooze with minor foraminiferal nannofossil ooze. Light greenish gray (5GY 8/1) with yellow gray (5Y 8/1) mottles. Pyrite same as in Core 1. Coccospheres numerous.

<u>NANNOFOSSIL OOZE</u>
SS 1-75, 2-75, 4-75, 5-75, 6-75
65-80% Nannos
2- 8% Forams
10-25% Clay
1- 3% Sponge spicules
T Pyrite
T- 2% Quartz
T Mica
T Rads

<u>FORAMINIFERA NANNOFOSSIL OOZE</u>
SS 3-75
70% Nannos
10% Forams
15% Clay
5% Sponge spicules
T Pyrite
1% Quartz
T Mica

<u>TEXTURE (Average from SS)</u>
5% Sand
15% Silt
80% Clay

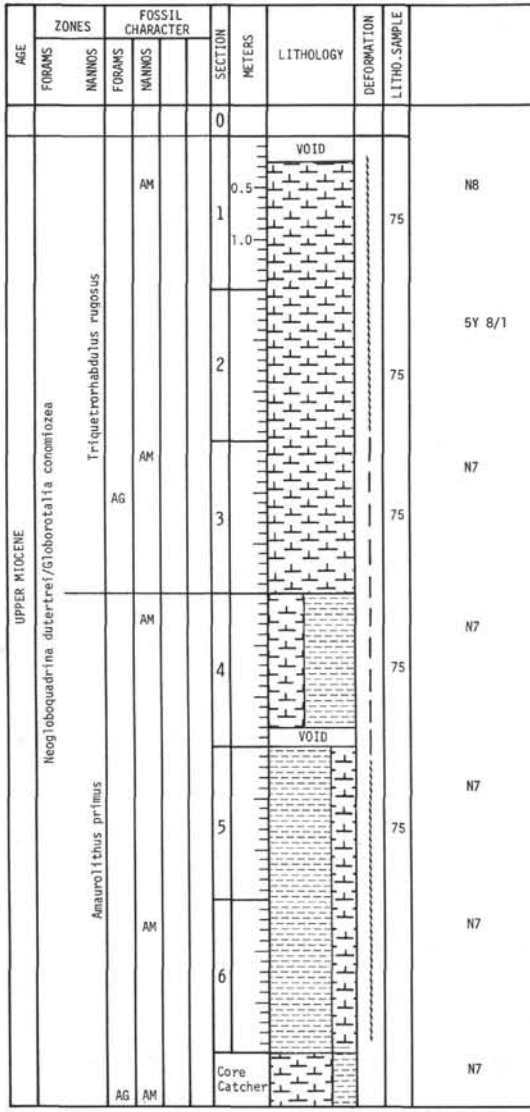
Carbonate Bomb: 4-30 to 31 cm = 71% $CaCO_3$

<u>Carbon-Carbonate (DSDP)</u>
4-20 (9.7, 0.2, 79)
6-20 (8.5, 0.6, 66)

<u>Grain Size (DSDP)</u>
4-58 (3.0, 23.7, 73.3)
6-58 (5.2, 21.7, 73.1)

**Triquetrorhabdulus rugosus
Explanatory notes in Chapter 1

Site 360 Hole Core 3 Cored Interval: 98.5-108.0 m



LITHOLOGIC DESCRIPTION

Nannofossil ooze with minor marly nannofossil ooze. Light gray (N7) with yellow gray (5Y 8/1) mottled.

NANNOFOSSIL OOZE
SS 1-75, 2-75, 3-75
65-75% Nannos
1- 5% Forams
15-30% Clay
T Rads
T Sponge spciules
T Pyrite
T Quartz
T Mica

MARLY NANNOFOSSIL OOZE
SS 4-75, 5-75, CC
55-60% Nannos
2% Forams
40% Clay
T- 1% Rads
T Sponge spicules
T Pyrite
T Quartz
T Mica

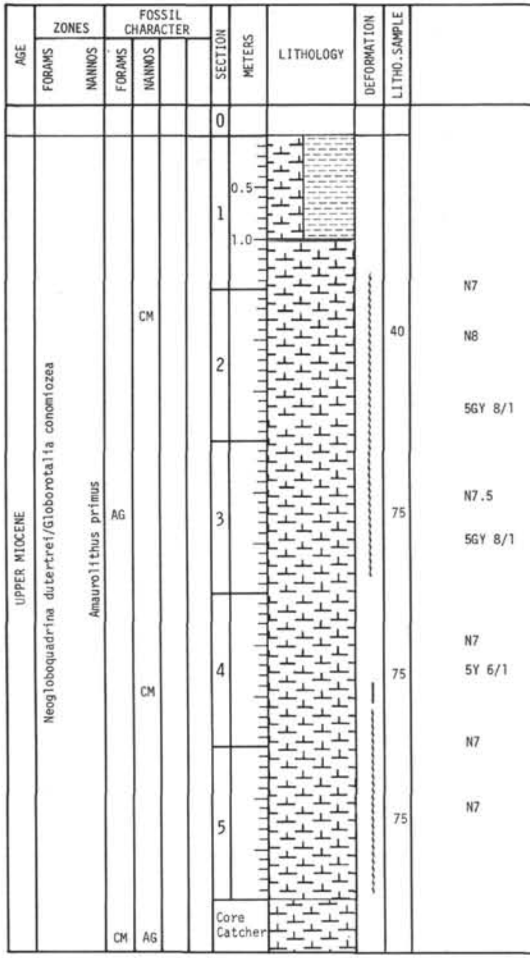
Texture (Average from SS)
1% Sand
10% Silt
89% Clay

Carbonate Bomb: 4-30 to 31 cm = 57% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (9.1, 0.2, 74)
6-20 (9.4, 0.2, 77)

Grain Size (DSDP)
4-58 (6.0, 27.9, 66.1)
6-55 (3.7, 28.3, 68.0)

Site 360 Hole Core 4 Cored Interval: 108.0-117.5 m



LITHOLOGIC DESCRIPTION

Nannofossil ooze with minor marly nannofossil ooze. Very light gray (N8) with streaks and mottles of light gray green (5GY 8/1). Moderately to intensely disturbed.

NANNOFOSSIL OOZE
SS 2-40, 3-75, 4-75
60-70% Nannos
20-30% Clay
1- 2% Forams
T Sponge spicules
T Pyrite
0- 2% Quartz
T Mica

MARLY NANNOFOSSIL OOZE
SS 1-75, 3-58
50% Nannos
40% Clay
2- 6% Forams
1- 2% Rads
T Quartz

TEXTURE (Average from SS)
2% Sand
11% Silt
87% Clay

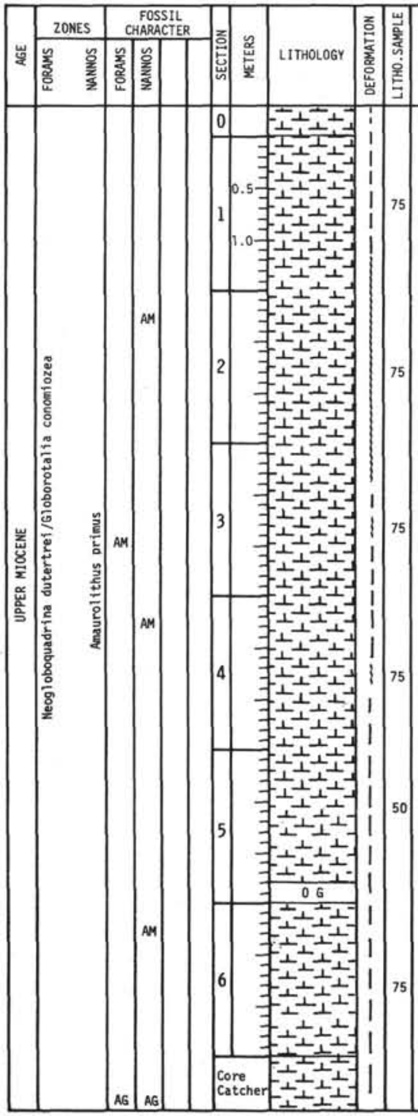
Carbonate Bomb: 3-30 to 31 cm = 75% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (8.8, 0.2, 72)

Grain Size (DSDP)
2-58 (11.1, 31.7, 57.2)

Explanatory notes in Chapter 1

Site 360 Hole Core 5 Cored Interval: 117.5-127.0 m



LITHOLOGIC DESCRIPTION

N8

N8

N7

N8

N7

5G 8/1

5GY 8/1

5G 8/1

N8

Light gray (N7) to very light gray (N8) nannofossil ooze. Slightly to moderately mottled throughout with light greenish gray (5G 8/1) and greenish gray (5GY 6/1) mottles. Pyrite present as small nodules and tubes.

<u>NANNOFOSSIL OOZE</u>
SS 1-75, 2-75, 3-75, 4-75, 5-50, 6-75
75-80% Nannos
10-20% Clay
0- 5% Forams
T Rads
0- 2% Sponge spicules
T Pyrite
0- 1% Quartz
T Mica

<u>TEXTURE (Average from SS)</u>
1% Sand
13% Silt
86% Clay

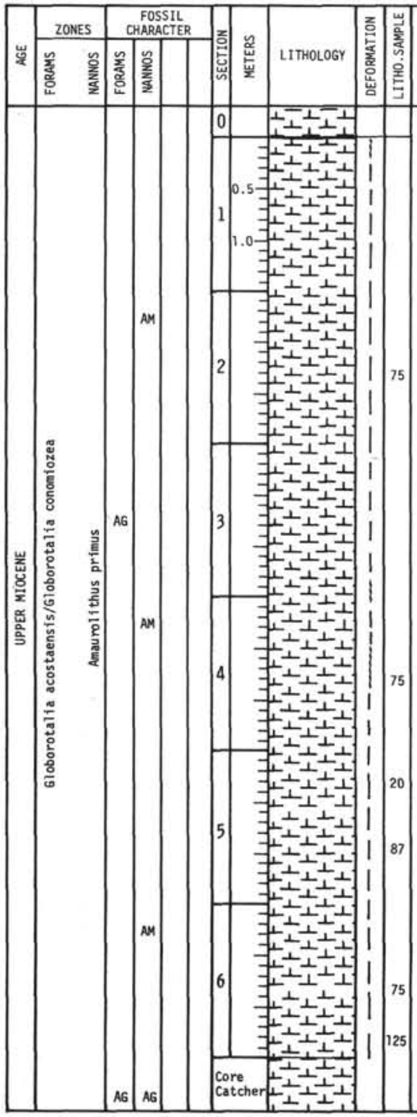
Carbonate Bomb: 4-30 to 31 cm = 83% $CaCO_3$

<u>Carbon-Carbonate (DSDP)</u>
4-20 (9.7, 0.3, 79)
6-20 (9.1, 0.3, 74)

<u>Carbon-Carbonate (OG)</u>
5-130 (9.2, 0.2, 75)
5-150 (-.3, 0.2, 76)

<u>Grain Size (DSDP)</u>
4-58 (6.0, 29.4, 64.6)
6-58 (4.0, 26.5, 69.6)

Site 360 Hole Core 6 Cored Interval: 127.5-136.5 m



LITHOLOGIC DESCRIPTION

N7

5GY 8/1

N7.5

N8

N8

N7.5

5Y 6/1

N7.5

N7.5
5Y 6/1
(mottles)

5Y 6/1

Light gray (N7) to very light gray (N8) nannofossil ooze. Slightly mottled throughout. Pyrite tubes up to 1 cm long. Coccospheres abundant.

<u>NANNOFOSSIL OOZE</u>
SS 2-75, 3-75, 4-75, 5-20, 5-87, 6-75, 6-125
70-85% Nannos
1- 3% Forams
10-20% Clay
T Pyrite
T- 2% Quartz

<u>TEXTURE (Average from SS)</u>
2% Sand
14% Silt
84% Clay

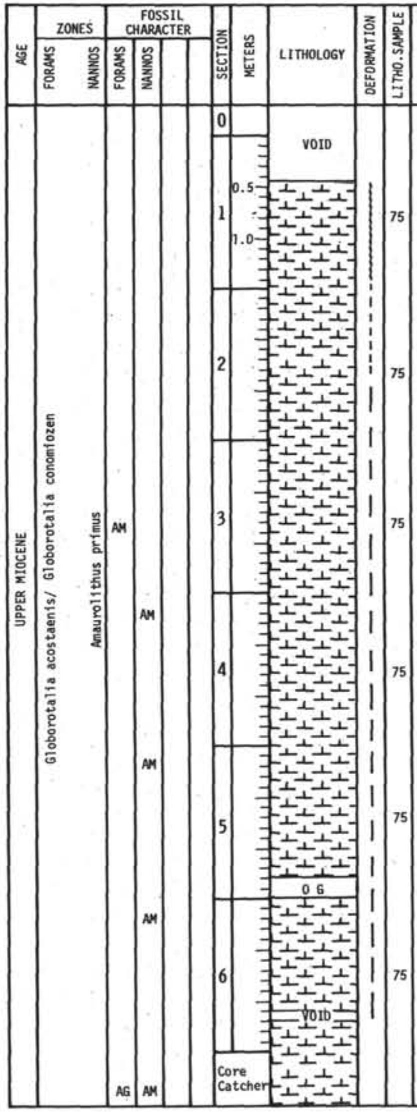
Carbonate Bomb: 3-30 to 31 cm = 89% $CaCO_3$

<u>Carbon-Carbonate (DSDP)</u>
4-20 (9.1, 0.1, 75)
6-20 (9.2, 0.2, 75)

<u>Grain Size (DSDP)</u>
4-58 (2.3, 27.9, 69.9)
6-58 (1.2, 24.9, 73.8)

Explanatory notes in Chapter 1

Site 360 Hole Core 7 Cored Interval: 136.5-146.0 m



LITHOLOGIC DESCRIPTION

N7.5

5Y 6/1 mottles

N8

5GY 6/1 mottles

N8

N8

5GY 6/1 mottles

N8

N8

Nannofossil ooze. Very light gray (N8) with mottles of light olive gray (5Y 6/1). Thin layers (1-4 cm) of very firm ooze. Pyrite less abundant but larger. One tube 4 cm x 1/2 cm. Coccospheres common.

NANNOFOSSIL OOZE
SS 1-75, 2-75, 3-30, 3-70, 4-75, 5-75, 6-75
50-80% Nannos
1-12% Forams
10-35% Clay
T- 3% Sponge spicules
T- 1% Pyrite
T- 2% Quartz

TEXTURE (Average from SS)
3% Sand
15% Silt
82% Clay

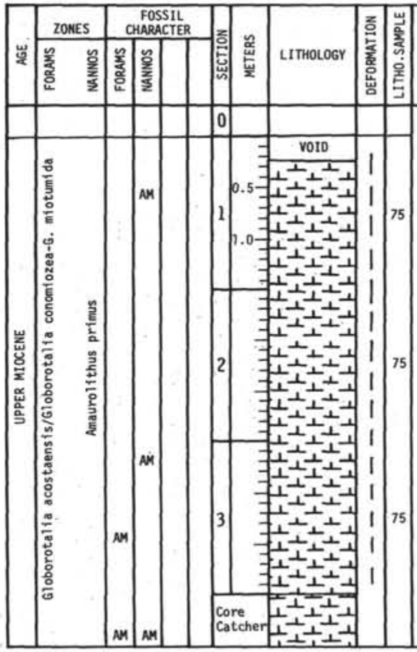
Carbonate Bomb: 5-30 to 31 cm = 74% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (9.1, 0.0, 75)
6-20 (8.9, 0.2, 73)

Carbon-Carbonate (OG)
5-130 (9.1, 0.2, 73)
5-150 (9.0, 0.2, 73)

Grain Size (DSDP)
4-58 (4.9, 29.9, 65.2)
6-58 (0.9, 33.0, 66.0)

Site 360 Hole Core 8 Cored Interval: 146.0-155.5 m



LITHOLOGIC DESCRIPTION

N7

N8

N7

N8

5GY 6/1 mottles

Nannofossil ooze. Light gray (N7) and very light gray (N8) with mottles of greenish gray (5GY 6/1). Sections 1 and 2 have 2-15 cm layers of very firm ooze. Section 3 is firm throughout. Pyrite nodules. Coccospheres abundant.

NANNOFOSSIL OOZE
SS 1-75, 2-75, 3-75
50-70% Nannos
25-40% Clay
1- 5% Forams
1- 2% Sponge spicules
T Rads
1- 2% Quartz
1- 2% Authigenic carbonate

TEXTURE (Average from SS)
2% Sand
15% Silt
83% Clay

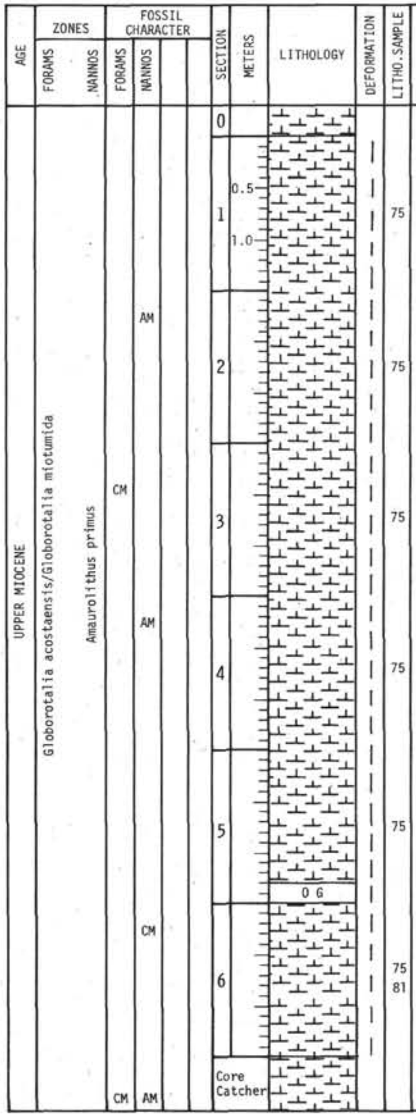
Carbonate Bomb: 3-30 to 31 cm = 80% $CaCO_3$

Carbon-Carbonate (DSDP)
3-20 (9.2, 0.1, 75)

Grain Size (DSDP)
3-58 (0.5, 28.8, 70.6)

Explanatory notes in Chapter 1

Site 360 Hole Core 9 Cored Interval: 155.5-165.0 m



LITHOLOGIC DESCRIPTION

N8
N8
N8
N8
N8
N8
N8

Very light gray nannofossil ooze. Very firm layers 5-10 cm thick start in Section 1, increase until they comprise 1/3 of Sections 4 and 5, and disappear in Section 6. Slightly mottled throughout. Pyrite-rich black streaks common. Coccospheres abundant.

NANNOFOSSIL OOZE
SS 1-75, 2-75, 3-75, 4-75, 5-75, 6-75
75-80% Nannos
10-30% Clay
1- 5% Forams
T- 2% Sponge spicules
T Pyrite
T Quartz
T Mica

TEXTURE (Average from SS)
1% Sand
9% Silt
80% Clay

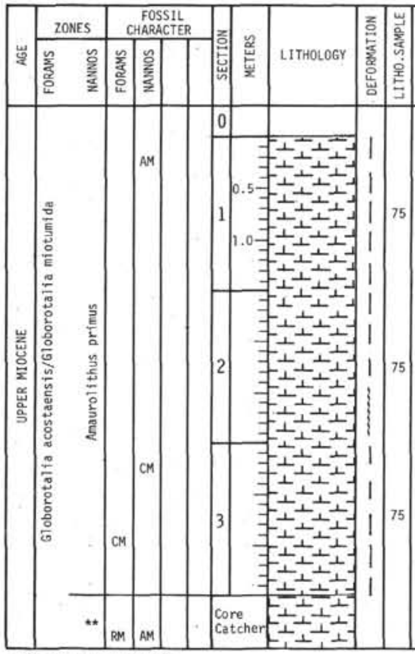
Carbonate Bomb: 4-30 to 31 cm = 48% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (9.2, 0.1, 75)
6-20 (incomplete; leave space)

Carbon-Carbonate (OG)
5-130 (9.6, 0.1, 78)
5-150 (9.5, 0.2, 78)

Grain Size (DSDP)
4-58 (0.5, 37.6, 61.9)
6-28 (1.0, 22.1, 76.9)

Site 360 Hole Core 10 Cored Interval: 165.0-174.5 m



LITHOLOGIC DESCRIPTION

N8
5GY 6/1 mottles
N8
N8

Very light gray (N8) nannofossil ooze with mottles of greenish gray (5GY 6/1). Ooze very firm throughout.

NANNOFOSSIL OOZE
SS 1-75, 2-75, 3-75
80% Nannos
10-20% Clay
1- 2% Forams
T Sponge spicules
1- 2% Authigenic carbonate
T Pyrite
1- 2% Quartz
T Mica
T Heavies

TEXTURE (Average from SS)
1% Sand
9% Silt
90% Clay

Carbonate Bomb: 3-30 to 31 cm = 80% $CaCO_3$

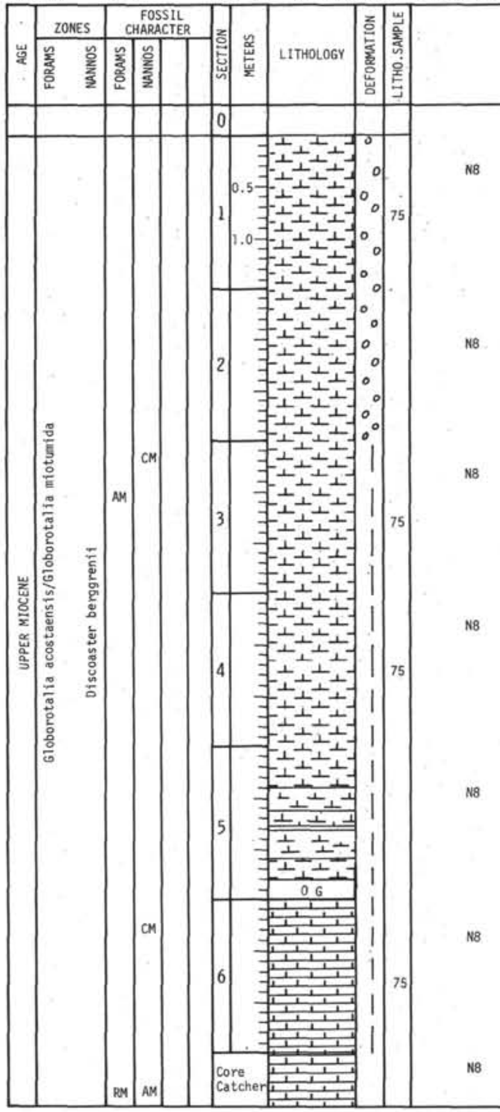
Carbon-Carbonate (DSDP)
2-20 (9.4, 0.1, 77)

Grain Size (DSDP)
2-58 (1.0, 22.1, 76.9)

**Discoaster berggrenii

Explanatory notes in Chapter 1

Site 360 Hole Core 11 Cored Interval: 174.5-184.0 m



LITHOLOGIC DESCRIPTION

Nannofossil ooze with lesser amount of nannofossil chalk. Very light gray with sparse mottles of greenish gray (5GY 6/1). Thin layers become very firm in Section 4, are 3-10 cm chalk layers in Section 5, and become more numerous and thicker making up most of Section 6. Minor pyrite present as fine-grained black patches. Coccospheres common.

NANNOFOSSIL OOZE AND NANNOFOSSIL CHALK
SS 1-75, 3-75, 4-75, 6-75
60-85% Nannos
10-35% Clay
1- 3% Forams
T Sponge spicules
T- 2% Authigenic carbonate
T- 1% Pyrite
T Quartz

TEXTURE (Average from SS)
1% Sand
11% Silt
88% Clay

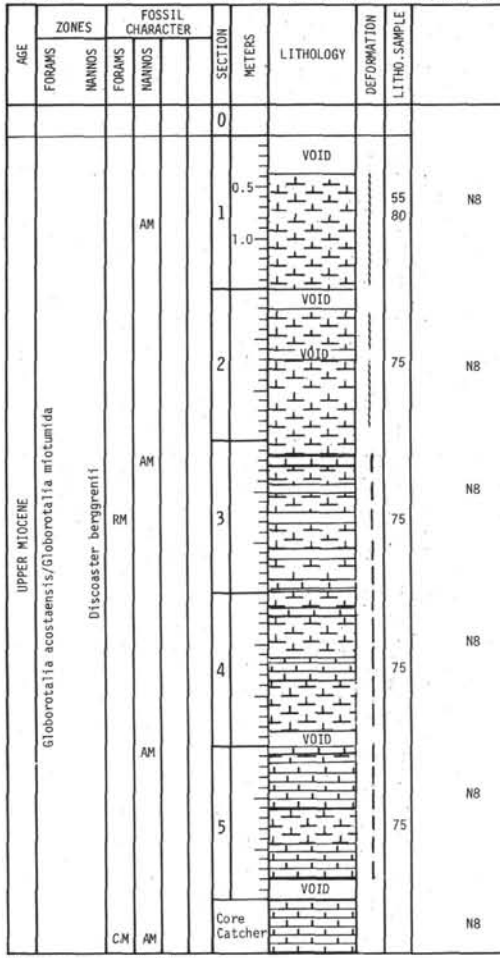
Carbonate Bomb: 4-30 to 31 cm = 62% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (8.9, 0.1, 73)
6-20 (8.9, 0.1, 73)

Carbon-Carbonate (OG)
5-130 (9.3, 0.2, 76)
5-150 (9.0, 0.2, 74)

Grain Size (DSDP)
4-58 (1.3, 27.2, 71.5)
6-58 (1.2, 27.6, 71.3)

Site 360 Hole Core 12 Cored Interval: 184.0-193.5 m



LITHOLOGIC DESCRIPTION

Nannofossil ooze and nannofossil chalk with minor marly nannofossil ooze. Very light gray (N8 and N7.5) throughout. Slightly mottled. Nannofossil ooze is dominant in Sections 1 and 2; chalk becomes abundant in Sections 3 and 4 and makes up most of Section 5. Pyrite occurs as tubes and small nodules (<1/2 cm). Quartz increases over earlier cores.

NANNOFOSSIL OOZE AND NANNOFOSSIL CHALK
SS 1-55, 2-80, 3-75, 4-75, 5-75
75-80% Nannos
10-20% Clay
1- 2% Forams
T- 1% Sponge spicules
T- 5% Authigenic carbonate
T- 1% Pyrite
T- 5% Quartz

SS 1-55 has 40% clay and would be a marly nannofossil ooze.

TEXTURE (Average from SS)
<1% Sand
12% Silt
88% Clay

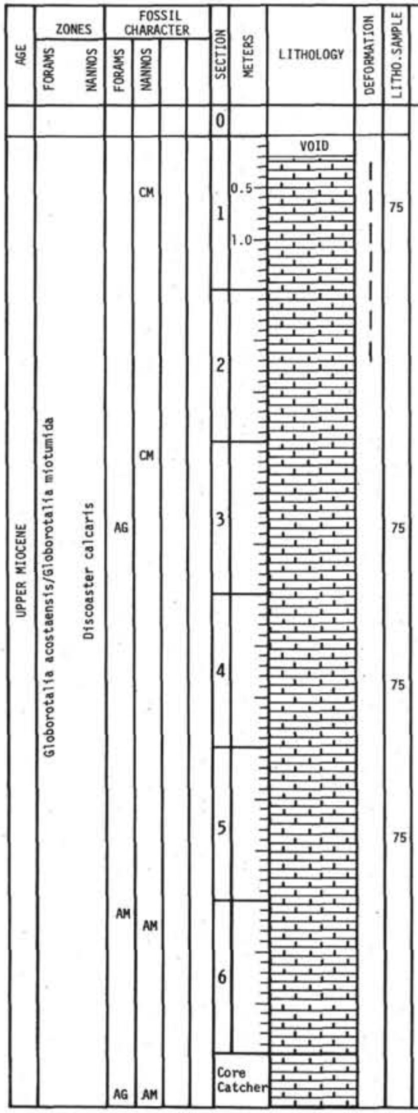
Carbonate Bomb: 3-30 to 31 cm = 61% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (6.2, 0.2, 50)

Grain Size (DSDP)
4-58 (1.2, 33.8, 65.0)

Explanatory notes in Chapter 1

Site 360 Hole Core 13 Cored Interval: 193.5-203.0 m



LITHOLOGIC DESCRIPTION

N7.5

5B 7/1

5B 7/1

5B 7/1

5B 7/1

5B 7/1

5GY 8/1 mottles

5B 7/1

Light bluish gray (5B 7/1) nannofossil chalk slightly mottled with light greenish gray (5GY 8/1). Minor burrowing in Sections 3, 4, 5 and 6.

NANNOFOSSIL CHALK
SS 1-75, 2-75, 3-75, 4-75, 5-35, 5-75, 6-75
80-85% Nannos
10-15% Clay
1- 5% Forams
2- 3% Authigenic carbonate
T Sponge spicules
T Pyrite
T Quartz

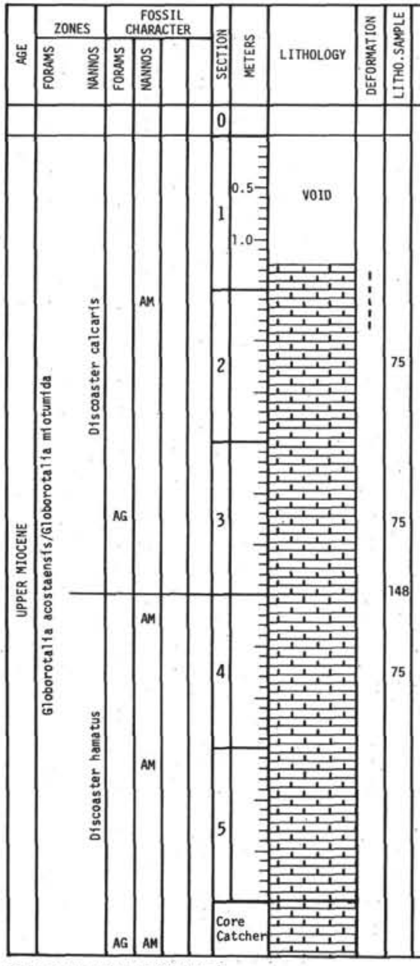
TEXTURE (Average from SS)
T Sand
10% Silt
90% Clay

Carbonate Bomb: 6-30 to 31 cm = 73% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (8.9, 0.1, 73)
6-20 (8.8, 0.1, 72)

Grain Size (DSDP)
4-58 (2.8, 27.4, 69.9)
6-58 (6.0, 34.2, 59.7)

Site 360 Hole Core 14 Cored Interval: 203.0-212.5 m



LITHOLOGIC DESCRIPTION

5B 7/1

5B 7/1

5B 7/1

5B 7/1

5B 7/1

Light bluish gray (5B 7/1) nannofossil chalk. Slightly mottled throughout. Scattered Zoophycus and Teichichnus burrows with somewhat sandy appearing infillings. Coccospheres common.

NANNOFOSSIL CHALK
SS 2-75, 3-75, 4-75
80% Nannos
10% Clay
2- 5% Forams
T Sponge spicules
2- 3% Authigenic carbonate
1- 2% Quartz
T Pyrite
T Mica

TEXTURE (Average from SS)
1% Sand
15% Silt
84% Clay

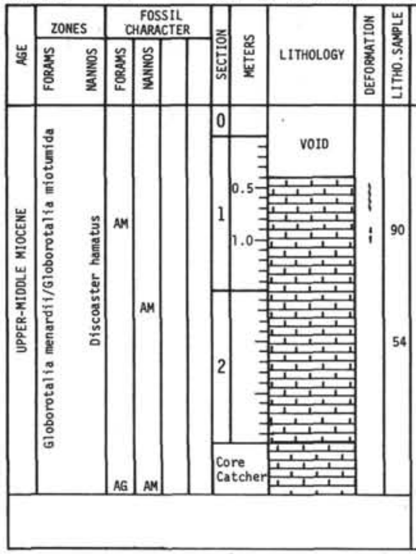
Carbonate Bomb: 3-30 to 31 cm = 62% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (7.8, 0.1, 64)

Grain Size (DSDP)
4-58 (7.8, 38.7, 53.5)

Explanatory notes in Chapter 1

Site 360 Hole Core 15 Cored Interval: 212.5-222.0 m



LITHOLOGIC DESCRIPTION

Light bluish gray (5B 7/1) nannofossil chalk. Section 1 and the upper 85 cm of Section 2 show slight mottling and only a few burrows. Both increase markedly in the lower 65 cm of Section 2.

5B 7/1

5B 7/1

NANNOFOSSIL CHALK
SS 1-90, 2-54
75-80% Nannos
10-20% Clay
T Forams
3- 5% Authigenic carbonate
2- 3% Quartz
T Pyrite
T Plant debris

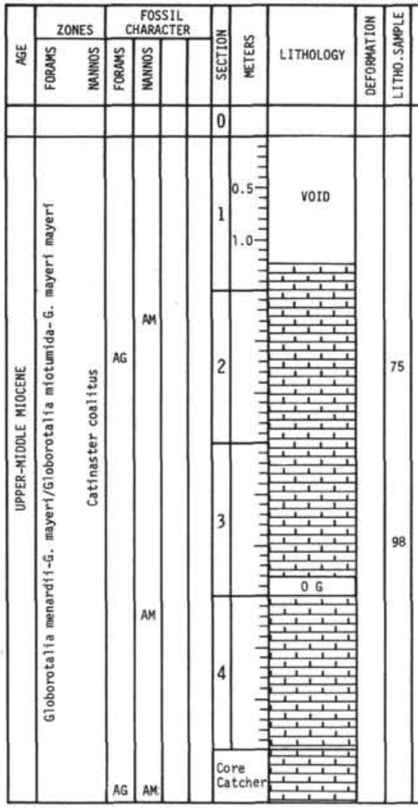
TEXTURE (Average from SS)
T Sand
10% Silt
90% Clay

Carbonate Bomb: 2-30 to 31 cm = 67% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (6.9, 0.1, 57)

Grain Size (DSDP)
1-129 (1.6, 35.8, 62.6)

Site 360 Hole Core 16 Cored Interval: 222.0-231.5 m



LITHOLOGIC DESCRIPTION

Light bluish gray (5B 7/1) nannofossil chalk. Numerous mottles of light olive gray (5Y 6/1). Heavily burrowed in Sections 1 and 2, lightly burrowed in Section 3. A few horizontal seams 1-2 mm thick of black, pyrite-rich material.

5B 7/1

5B 7/1

5B 7/1

5B 7/1

NANNOFOSSIL CHALK
SS 2-75, 3-98
80% Nannos
10% Clay
1- 5% Forams
3- 5% Authigenic carbonate
2- 3% Quartz
T Pyrite

TEXTURE (Average from SS)
T Sand
10% Silt
90% Clay

Carbonate Bomb: 3-30 to 31 cm = 70% $CaCO_3$

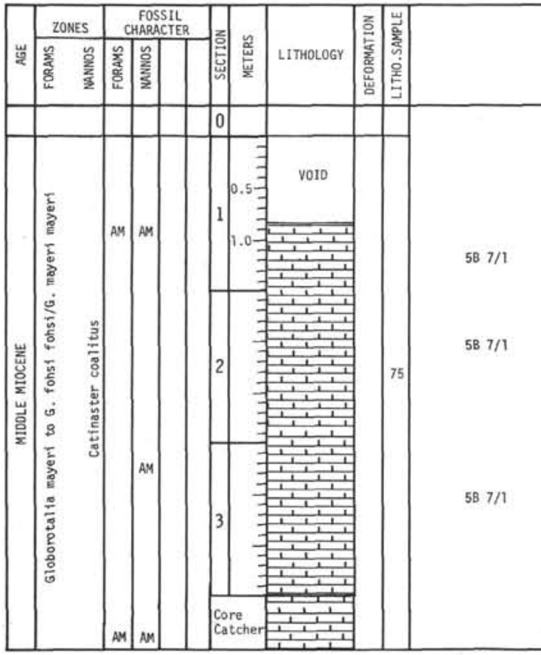
Carbon-Carbonate (DSDP)
4-20 (8.6, 0.1, 71)

Carbon-Carbonate (OG)
3-130 (8.6, 0.1, 71)
3-150 (8.7, 0.1, 71)

Grain Size (DSDP)
4-109 (2.3, 42.0, 55.7)

Explanatory notes in Chapter 1

Site 360 Hole Core 17 Cored Interval: 231.5-241.0 m



LITHOLOGIC DESCRIPTION

Light bluish gray (5B 7/1) nannofossil chalk. Heavily mottled and burrowed throughout. Burrows are infilled with coarser appearing material.

NANNOFOSSIL CHALK
80% Nannos
10-15% Clay
T Forams
T Sponge spicules
T Pyrite
T Quartz
1 Authigenic carbonate

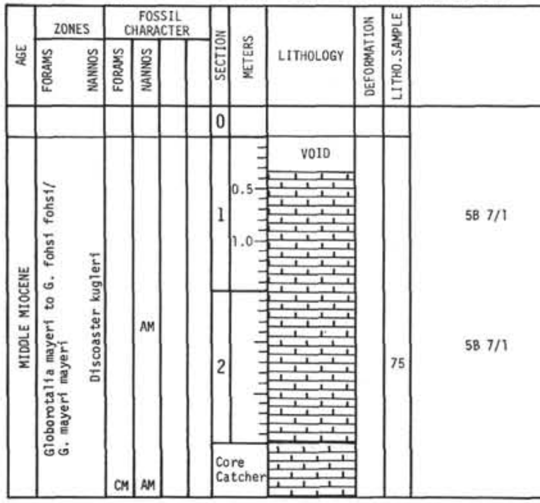
TEXTURE (Average from SS)
1% Sand
15% Silt
84% Clay

Carbonate Bomb: 3-30 to 31 cm = 79% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (8.4, 0.1, 69)

Grain Size (DSDP)
3-58 (0.6, 38.9, 60.5)

Site 360 Hole Core 18 Cored Interval: 241.0-250.5 m



LITHOLOGIC DESCRIPTION

Light bluish gray (5B 7/1) nannofossil chalk. Heavily mottled and burrowed throughout. Thin (1 mm) black seams of pyrite abundant.

NANNOFOSSIL CHALK
SS 2-75
80% Nannos
20% Clay
T Forams
T Pyrite
T Quartz

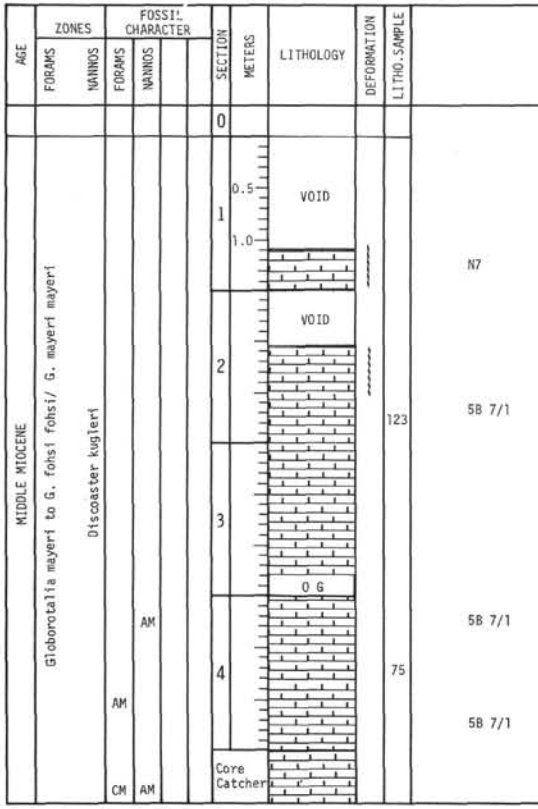
TEXTURE (Average from SS)
1% Sand
20% Silt
79% Clay

Carbonate Bomb: 2-30 to 31 cm = 67% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (8.6, 0.1, 71)

Grain Size (DSDP)
2-58 (1.8, 50.5, 47.7)

Site 360 Hole Core 19 Cored Interval: 260.0-269.5 m



LITHOLOGIC DESCRIPTION

Light bluish gray (5B 7/1) nannofossil chalk. Moderately to heavily burrowed throughout. Burrows filled with coarser material in some cases.

NANNOFOSSIL CHALK
SS 2-123, 4-75
80-90% Nannos
5-15% Clay
T Forams
T Authigenic carbonate
1- 5% Quartz
T Pyrite

TEXTURE (Average from SS)
2% Sand
15% Silt
83% Clay

Carbonate Bomb: 3-35 to 36 cm = 78% $CaCO_3$

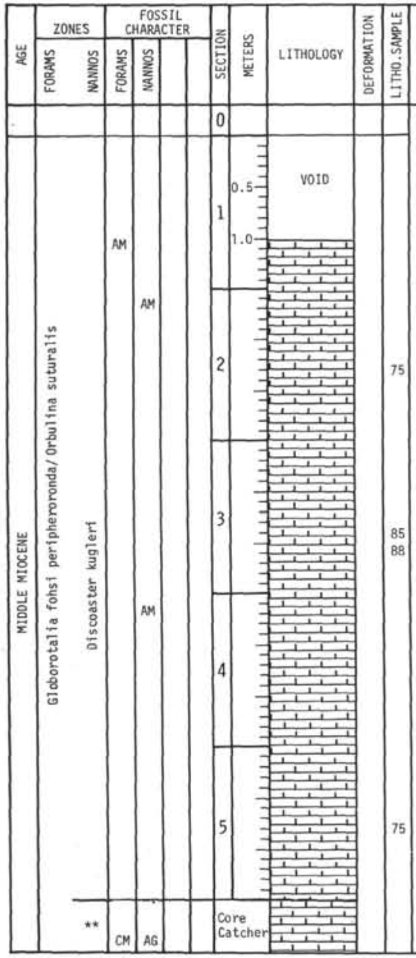
Carbon-Carbonate (DSDP)
4-20 (9.4, 0.1, 78)

Carbon-Carbonate (OG)
3-130 (8.7, 0.1, 71)
3-150 (9.4, 0.1, 77)

Grain Size (DSDP)
4-58 (0.6, 37.7, 61.7)

Explanatory notes in Chapter 1

Site 360 Hole Core 20 Cored Interval: 279.0-288.5 m



LITHOLOGIC DESCRIPTION

5B 7/1

Light bluish gray (5B 7/1) nannofossil chalk. Intensively burrowed showing Zoophycus, Teichichnus, and Rind burrows. Minor shearing - perhaps from drilling.

NANNOFOSSIL CHALK
SS 2-75, 3-85, 3-88, 5-75
80-90% Nannos
5-15% Clay
T Forams
1- 3% Quartz
T Pyrite
T Authigenic carbonate

TEXTURE (Average from SS)
1% Sand
10% Silt
89% Clay

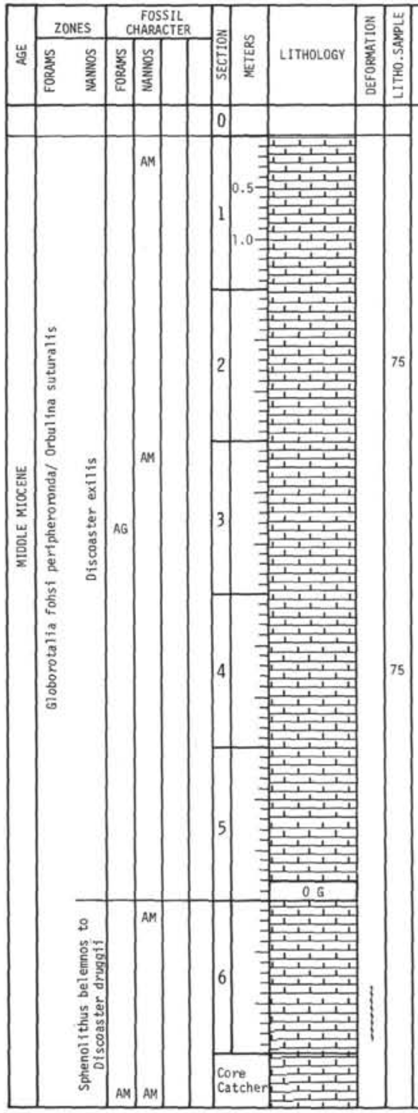
Carbonate Bomb: 4-30 to 31 cm = 71% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (9.4, 0.1, 77)

Grain Size (DSDP)
4-58 (1.6, 44.9, 53.5)

**Discoaster exilis

Site 360 Hole Core 21 Cored Interval: 298.0-307.5 m



LITHOLOGIC DESCRIPTION

5B 7/1

Light bluish gray (5B 7/1) nannofossil chalk. Upper half of Sections 2, 3 and 4 heavily burrowed. The rest of core more lightly burrowed. Zoophycos type most common; Teichichnus, Rind burrows, and Composite burrows all present. Smear slides show presence of coccospheres.

5B 7/1

NANNOFOSSIL CHALK
SS 2-75, 4-75
85% Nannos
10% Clay
1- 2% Forams
1- 2% Authigenic carbonate
T Pyrite
T Mica
T Heavy minerals

TEXTURE (Average from SS)
1% Sand
20% Silt
79% Clay

Carbonate Bomb: 3-30 to 31 cm = 72.8% $CaCO_3$

5B 7/1

Carbon-Carbonate (DSDP)
4-20 (8.3, 0.1, 69)
6-20 (8.3, 0.1, 69)

Carbon-Carbonate (OG)
5-130 (8.9, 0.1, 73)
5-150 (8.4, 0.1, 69)

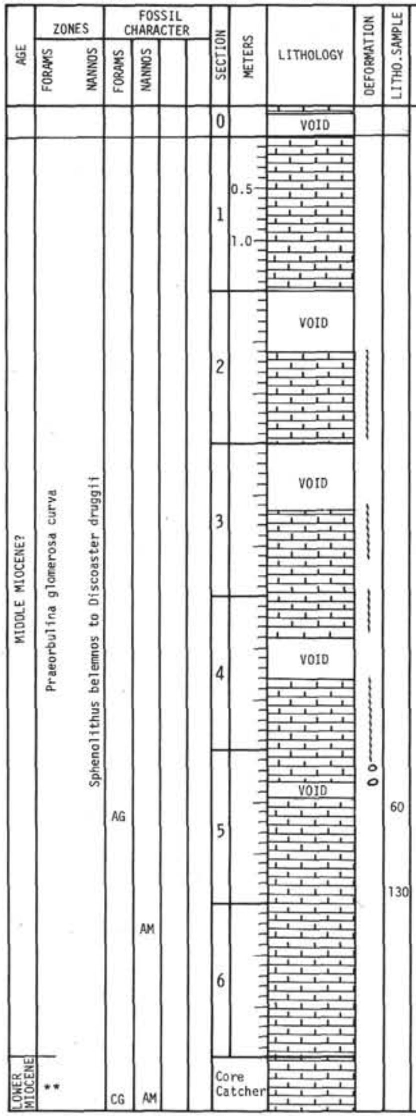
Grain Size (DSDP)
4-58 (2.8, 34.4, 62.8)
6-58 (5.1, 30.9, 64.0)

5B 7/1

5B 7/1

Explanatory notes in Chapter 1

Site 360 Hole Core 22 Cored Interval: 317.0-326.5 m



LITHOLOGIC DESCRIPTION

5B 7/1

Nannofossil chalk. Light bluish gray (5B 7/1) until 90 cm of Section 5. The lower 2 meters are various shades of yellows, browns, and grays. Color differences are seen as distinct beds and as patches or mottles. Some color changes are gradational, others sharp. Minor burrowing present in Sections 5 and 6.

5B 7/1

NANNOFOSSIL CHALK
SS 5-60, 5-130
80% Nannos
10% Clay
1% Forams
T Pyrite
3% Quartz
T Heavy minerals
1% Carbonate unspecified

5B 7/1

TEXTURE (Average from SS)
5% Sand
40% Silt
55% Clay

Carbonate Bomb: 5-30 to 31 cm = 71.4% $CaCO_3$

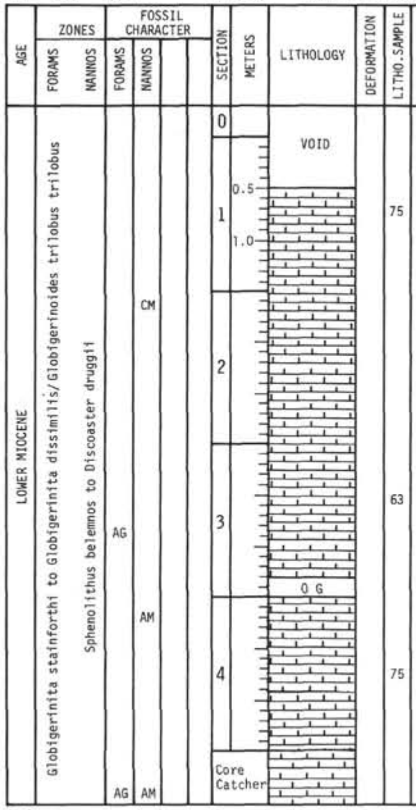
Carbon-Carbonate (DSDP)
5-51 (9.2, 0.0, 76)

Grain Size (DSDP)
6-58 (3.2, 35.0, 61.8)

5B 7/1
5GY 8/1
10YR 5/4
5B 7/1
5YR 4/4
10YR 8/2
5Y 8/1
5YR 4/4
5Y 8/1
5B 7/1
10YR 6/6

**Globigerinatella insueta/ Globigerinoides trilobus trilobus

Site 360 Hole Core 23 Cored Interval: 336.0-345.5 m



LITHOLOGIC DESCRIPTION

Nannofossil chalk. Very pale orange (10YR 8/2) and grayish orange (10YR 7/4) with minor zones of white (N9). Zoophycos and Rind burrows common.

NANNOFOSSIL CHALK
SS 1-75, 3-63, 4-75
85% Nannos
10% Clay
3- 5% Forams
T Quartz
T Pyrite
T Heavy minerals

TEXTURE (Average from SS)
2% Sand
48% Silt
50% Clay

Carbonate Bomb: 1-90 to 91 cm = 80.9% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (9.8, 0.1, 81)

Carbon-Carbonate (OG)
3-130 (9.7, 0.1, 81)
3-150 (9.7, 0.0, 81)

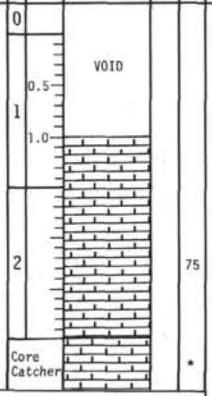
Grain Size (DSDP)
4-58 (14.8, 43, 42.3)

10YR 8/2
10YR 8/2
N9
10YR 7/4
10YR 7/4
N9
10YR 8/2
10YR 7/4
N9
10YR 7/4
10YR 7/4
N9
10YR 8/2
10YR 7/4
N9
10YR 8/2
10YR 8/2

Explanatory notes in Chapter 1

Site 360 Hole Core 24 Cored Interval: 355.0-364.5 m

AGE	ZONES FORAMS	ZONES NANNOS	FOSSIL CHARACTER FORAMS	FOSSIL CHARACTER NANNOS
LOWER MIOCENE	Globigerinita stainforthi to Globigerinita dissimilis/ Globigerinoides trilobus trilobus	Sphenolithus belemnos to Discoaster druggii	AG AG	AM AM



LITHOLOGIC DESCRIPTION

N9

N9

Nannofossil chalk with 3 soft, slightly coarser layers that average 10-12 cm thick. The white (N9) chalk is slightly burrowed.

NANNOFOSSIL CHALK
SS 2-75, CC
85% Nannos
10% Clay
3% Forams
T Quartz
T Pyrite
1 Carbonate unspecified

TEXTURE (Average from SS)
3% Sand
55% Silt
42% Clay

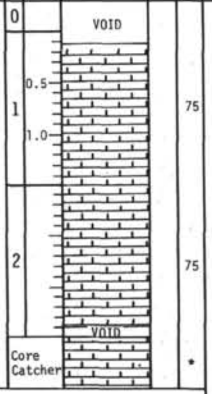
Carbonate Bomb: 2-30 to 31 cm = 85.4% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (10.0, 0.1, 82)

Grain Size (DSDP)
2-58 (4.6, 44.0, 51.4)

Site 360 Hole Core 25 Cored Interval: 374.0-383.5 m

AGE	ZONES FORAMS	ZONES NANNOS	FOSSIL CHARACTER FORAMS	FOSSIL CHARACTER NANNOS
LOWER MIOCENE	Globigerinita stainforthi to Globigerinita dissimilis/ Globigerina woodi connecta	Triquetrorhabdulus carinatus	AG AG	CM AM AM



LITHOLOGIC DESCRIPTION

N9

N9

N9

White (N9) nannofossil chalk. Excellent examples of Zoophycos burrows present in upper part of Section 1. A few burrows are present throughout core.

NANNOFOSSIL CHALK
SS 1-75, 2-75, CC
88% Nannos
10% Clay
1- 2% Forams
T Carbonate unspecified
T Heavy minerals
T Pyrite

TEXTURE (Average from SS)
1% Sand
60% Silt
39% Clay

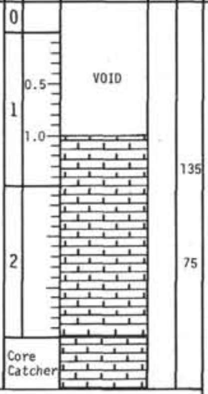
Carbonate Bomb: 2-38 to 40 cm = 83.3% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (10.0, 0.0, 83)

Grain Size (DSDP)
2-58 (3.6, 45.3, 51.1)

Site 360 Hole Core 26 Cored Interval: 393.0-402.5 m

AGE	ZONES FORAMS	ZONES NANNOS	FOSSIL CHARACTER FORAMS	FOSSIL CHARACTER NANNOS
LOWER MIOCENE	Globigerinoides primordius to Globorotalia kugleri/Globigerina woodi connecta	Triquetrorhabdulus carinatus	AG	AM
UPPER OLIGOCENE	G. ciperoensis ciperoensis/ Gq. dehiscens		AM	AM



LITHOLOGIC DESCRIPTION

N7

5Y 8/1

N9
5Y 8/1
N9

5Y 8/1
N9
5Y 8/1

Nannofossil chalk. Yellow gray (5Y 8/1), very light gray (N7), with lesser amounts of white (N9). Core shows evidence of soft-sediment deformation. Rounded clasts set in a matrix and clearly not disturbed by drilling appear to be the result of slumping. Zoophycos and Composite burrows are present in large numbers in the undisturbed horizons of the core and also in the rounded clasts of the slumped part.

NANNOFOSSIL CHALK
SS 1-135, 2-75
80% Nannos
10% Clay
3- 5% Forams
1- 2% Carbonate unspecified
T- 1% Quartz
T Pyrite

TEXTURE (Average from SS)
5% Sand
50% Silt
45% Clay

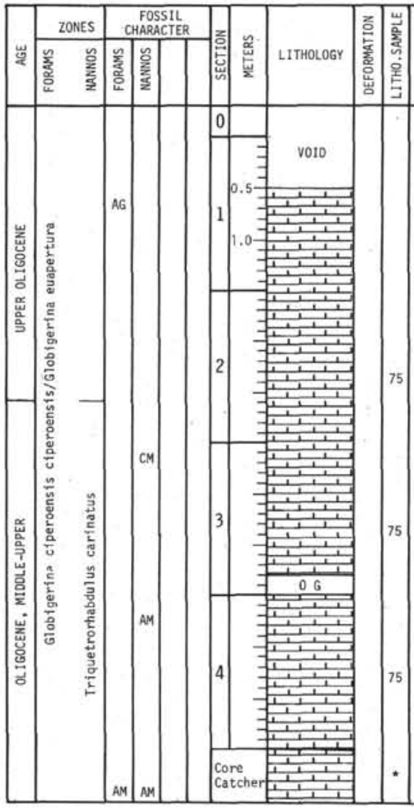
Carbonate Bomb: 2-31 to 32 cm = 67.7% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (8.8, 0.1, 73)

Grain Size (DSDP)
2-58 (6.3, 43.7, 50.0)

Explanatory notes in Chapter 1

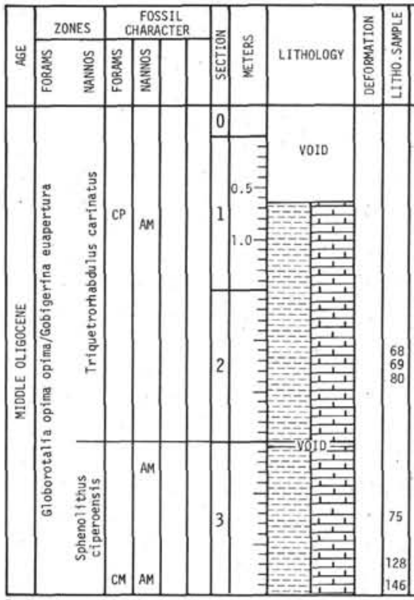
Site 360 Hole Core 27 Cored Interval: 412.0-421.5 m



LITHOLOGIC DESCRIPTION

5B 7/1	Nannofossil chalk. Numerous shades of gray, including light bluish gray (5B 7/1), bluish white (5B), pinkish gray (5YR 8/1), yellow gray (5Y 8/1), and very light gray (N8). Intensive burrows in Sections 1 and 2 with lesser burrowing in 3 and 4. Sections 3 and 4 show thinly laminated, laminated, and thinly stratified bedding. Microfaulting with offsets up to 1 cm is very common in Sections 3 and 4.
5B 5YR 8/1	NANNOFOSSIL CHALK SS 2-75, 3-75, 4-75, CC
	95% Nannos
N9	T Clay
	2- 5% Forams
	1% Quartz
N9	T Heavy minerals
	1% Carbonate unspecified
	T Fish remains
5YR 8/1	
	TEXTURE (Average from SS)
	2% Sand
	58% Silt
5YR 8/1	40% Clay
	Carbonate Bomb: 2-29 to 30 cm = 66.1% $CaCO_3$
5YR 8/1	Carbon-Carbonate (DSDP)
5B 7/1	4-20 (9.6, 0.0, 80)
	Carbon-Carbonate (OG) 3-130 (9.7, 0.0, 81)
N8	3-150 (9.7, 0.0, 81)
	Grain Size (DSDP) 4-60 (7.6, 31.8, 60.5)
N8	
N8	

Site 360 Hole Core 28 Cored Interval: 431.0-440.5 m

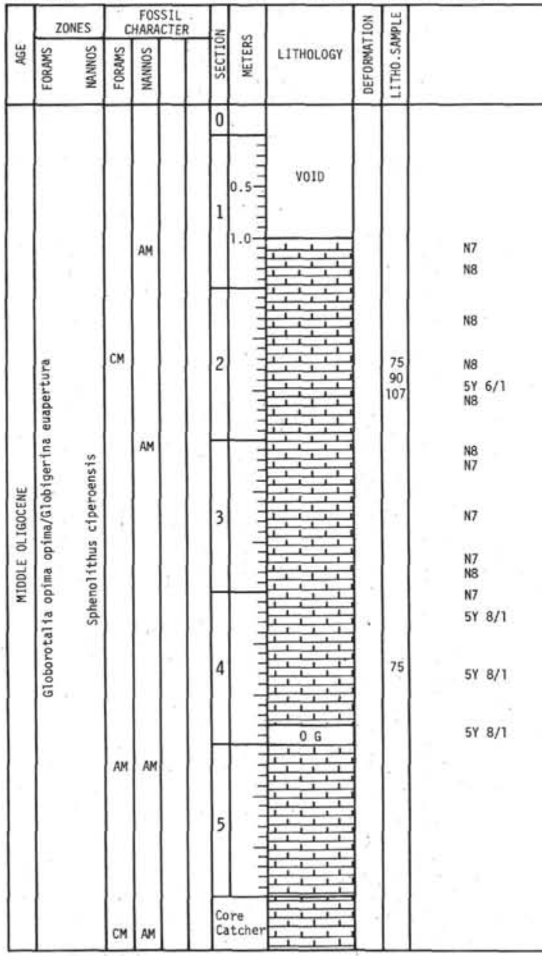


LITHOLOGIC DESCRIPTION

	Marly nannofossil chalk. Light bluish gray (5B 7/1) with lesser bluish white (5B 9/1) and white (N9). Most of core intensely burrowed (Zoophycos, Composite and Rind burrows; where not burrowed, sediment is laminated and has numerous microfaults offsetting lamina.
5GY 8/1	MARLY NANNOFOSSIL CHALK SS 2-60, 2-69, 2-80, 3-75, 3-128, 3-146
	60% Nannos
	T Forams
	40% Clay
5B 7/1	T Quartz
	TEXTURE (Average from SS)
	T Sand
5B 9/1	60% Silt
5B 7/1	40% Clay
	Carbonate Bomb: 2-3 to 4 cm = 74.3% $CaCO_3$
N9	
	Carbon-Carbonate (DSDP)
5B 7/1	3-29 (9.1, 0.1, 76)
	Grain Size (DSDP)
5B 7/1	3-74 (4.9, 41.8, 53.3)
5B 9/1	

Explanatory notes in Chapter 1

Site 360 Hole Core 29 Cored Interval: 450.0-459.5 m



LITHOLOGIC DESCRIPTION

Nannofossil chalk. Light gray (N7), very light gray (N8), and yellow gray (5Y 8/1). Burrowing is the most noticable feature. Some layers up to 35 cm thick are heavily burrowed. All the rest, except for 10 cm of thinly laminated strata, shows moderat burrowing. Many types of burrows are present including Zoophycos, Chrondrites, Rind burrows, and Composite burrows.

NANNOFOSSIL CHALK
SS 2-75, 2-90, 2-107, 4-75, CC
80-85% Nannos
4- 6% Forams
10-15% Clay
2% Quartz
2% Carbonate unspecified

TEXTURE (Average from SS)
5% Sand
40% Silt
55% Clay

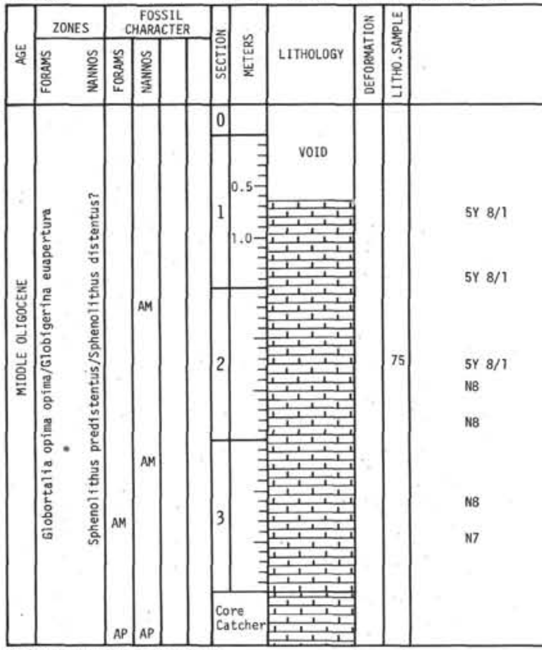
Carbonate Bomb: 3-45 to 46 cm = 64.8% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (9.1, 0.1, 75)

Carbon-Carbonate (OG)
4-130 (8.9, 0.1, 73)
4-150 (8.9, 0.1, 73)

Grain Size (DSDP)
4-58 (6.3, 39.4, 54.3)

Site 360 Hole Core 30 Cored Interval: 469.0-478.5 m



LITHOLOGIC DESCRIPTION

Nannofossil chalk. The first 2 meters are yellow gray (5Y 8/1), the rest very light gray (N8) with minor light gray (N7). Most of core shows moderate burrowing with Zoophycos the most common type. In section 2, the burrows are offset by shear planes.

NANNOFOSSIL CHALK
SS 2-75, CC
85% Nannos
10% Clay
3% Quartz
T Mica
T Heavy minerals
T Pyrite
T Authigenic carbonate
1% Forams

TEXTURE (Average from SS)
2% Sand
50% Silt
48% Clay

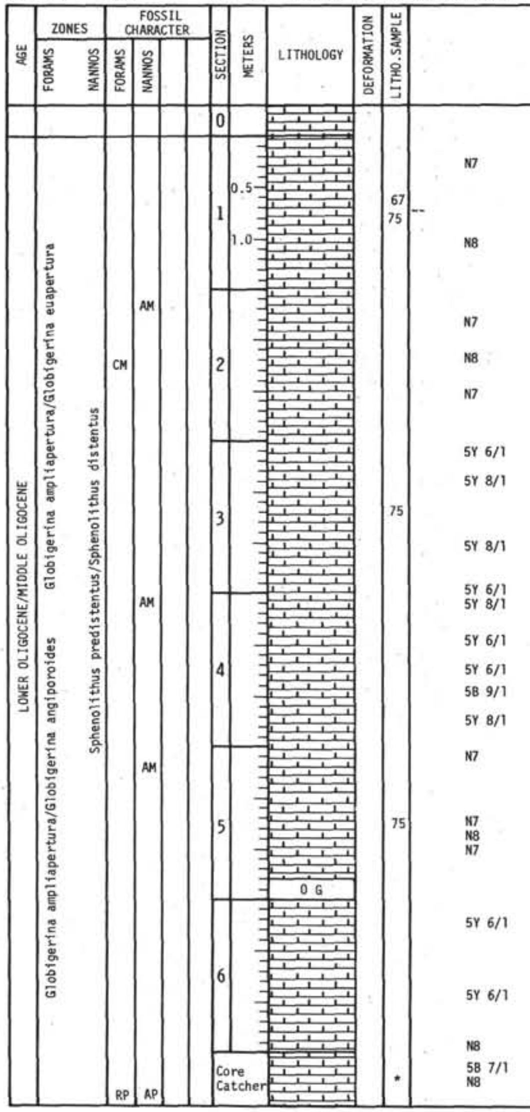
Carbonate Bomb: 2-29 to 30 cm = 76.3% $CaCO_3$

Carbon-Carbonate (DSDP)
2-73 (9.1, 0.0, 75)

Grain Size (DSDP)
2-22 (4.2, 47.6, 48.1)

Explanatory notes in Chapter 1

Site 360 Hole Core 31 Cored Interval: 488.0-497.5 m



LITHOLOGIC DESCRIPTION

Nannofossil chalk. Light gray (N7) to very light gray (N8) with lesser amounts of light bluish gray (5B 7/1), yellow gray (5Y 8/1), and light olive gray (5Y 6/1). Intensive burrowing throughout most of core with Zoophycos, Chondrites, Composite and Rind burrows recognizable. In Sections 1 and 6, laminated to thinly laminated strata show microfaulting and evidence of soft-sediment deformation.

NANNOFOSSIL CHALK
SS 1-67, 1-75, 3-75, 5-75, CC
85% Nannos
10% Clay
1% Forams
T Pyrite
T Mica
T Quartz
T Heavy minerals

TEXTURE (Average from SS)
T Sand
50% Silt
50% Clay

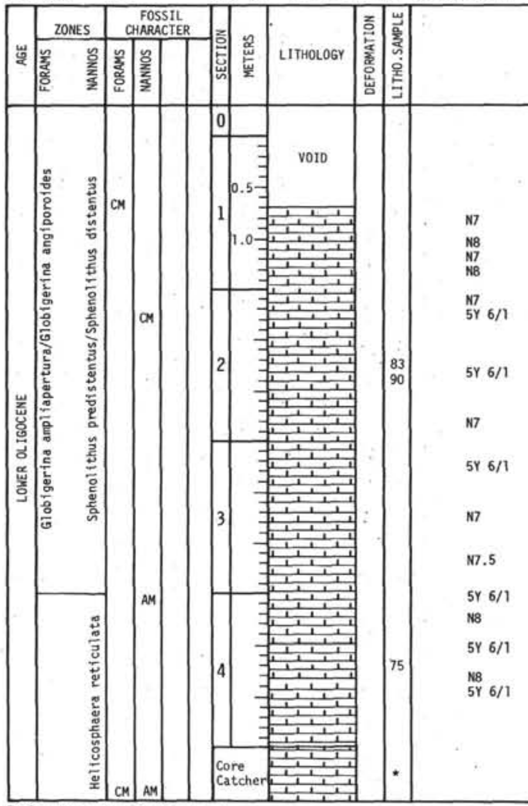
Carbonate Bomb: 4-27 to 28 cm = 74.9% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (9.0, 0.1, 74)
6-20 (8.0, 0.1, 76)

Carbon-Carbonate (OG)
5-130 (9.2, 0.1, 76)
5-150 (9.6, 0.1, 79)

Grain Size (DSDP)
4-58 (0.9, 38.9, 60.2)
6-58 (3.4, 48.0, 48.7)

Site 360 Hole Core 32 Cored Interval: 507.0-516.5 m



LITHOLOGIC DESCRIPTION

Nannofossil chalk. Light gray (N7) to very light gray (N8) with lesser amounts of light olive gray (5Y 6/1). The entire core shows evidence of burrowing; some areas are heavily burrowed. Zoophycos are most common type but Composite burrows also present. The lowermost 20 cm of Section 3 shows soft-sediment deformation.

NANNOFOSSIL CHALK
SS 2-83, 2-90, 4-75, CC
85% Nannos
12% Clay
1% Forams
1% Quartz
T Pyrite
T Plant debris
T Authigenic carbonate

TEXTURE (Average from SS)
T Sand
60% Silt
40% Clay

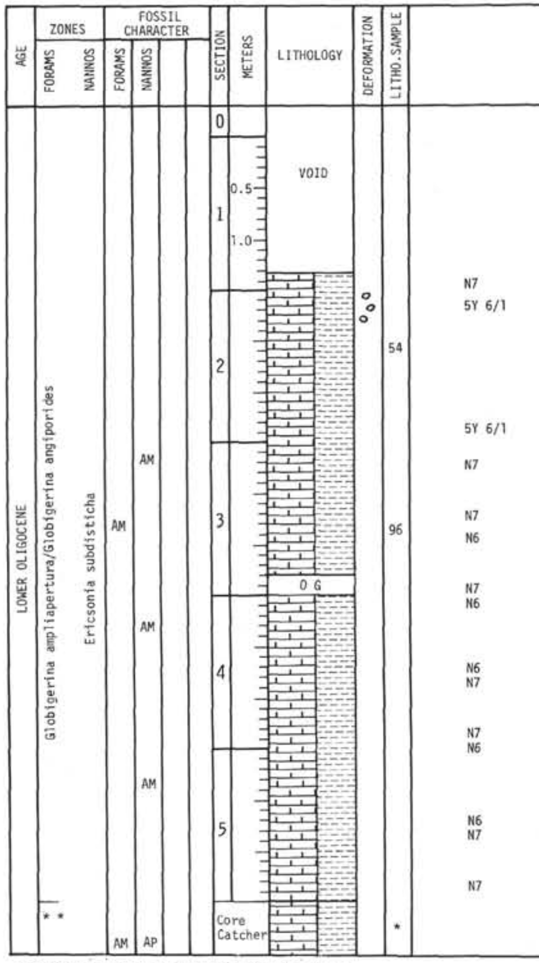
Carbonate Bomb: 2-34 to 35 cm = 66.1% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (8.2, 0.1, 68)

Grain Size (DSDP)
4-58 (2.6, 43.8, 53.6)

Explanatory notes in Chapter 1

Site 360 Hole Core 33 Cored Interval: 526.0-535.5 m



LITHOLOGIC DESCRIPTION

Marly *nannofossil chalk*. Medium gray (N6) to light gray (N7) sediments with lesser amount of light olive gray (5Y 6/1). Moderate to intense burrowing; Zoophycos and Rind burrows most common. The lower part of Section 3 and the upper part of Section 4 show soft-sediment deformation. A thinly laminated layer in the same section of core shows microfaulting.

MARLY NANNOFOSSIL CHALK
SS 2-54, 3-96, CC
48% Nannos
50% Clay
1% Forams
T Quartz
T Pyrite
T Heavy minerals

[Sandy layer at 3-96 shows very abundant quartz.]

TEXTURE (Average from SS)
1% Sand
30% Silt
69% Clay

Carbonate Bomb: 4-23 to 24 cm = 27.9% $CaCO_3$

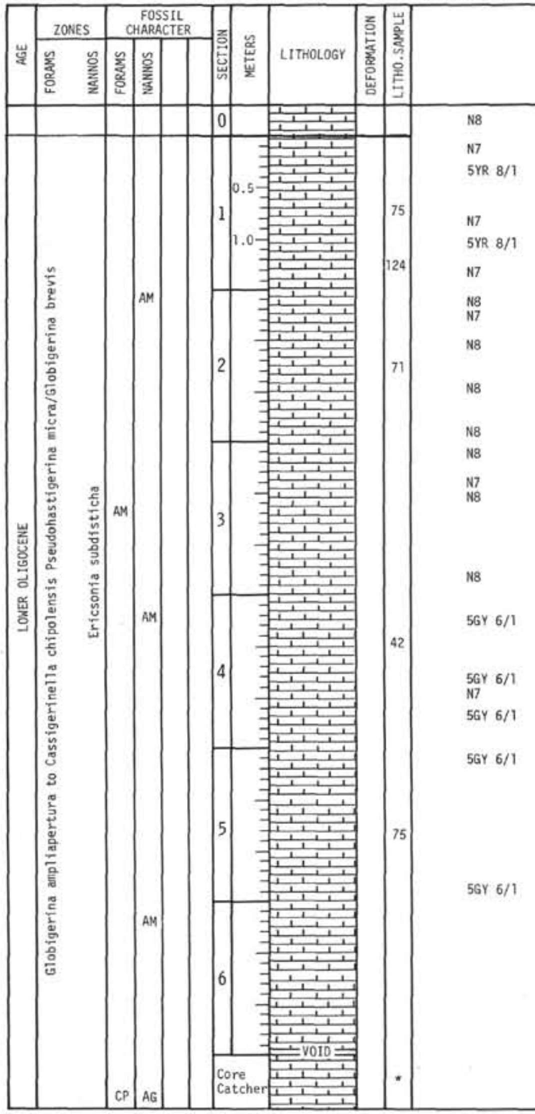
Carbon-Carbonate (DSDP)
4-20 (4.0, 0.1, 32)

Carbon-Carbonate (OG)
3-130 (7.4, 0.1, 61)
3-150 (7.5, 0.1, 62)

Grain Size (DSDP)
4-58 (5.0, 35.9, 59.1)

**Globigerina ampliapertura/ Globigerina brevis

Site 360 Hole Core 34 Cored Interval: 545.0-554.5 m



LITHOLOGIC DESCRIPTION

Nannofossil chalk. The upper half of the core is typically light gray (N7) to very light gray (N8), the lower half is mostly greenish gray (5GY 6/1). Rind burrows, Zoophycos, and Chondrites all common in the intensely burrowed core.

NANNOFOSSIL CHALK
SS 1-75, 1-124, 2-71, 4-42, 5-75, CC
65-75% Nannos
1- 2% Forams
20% Clay
2- 3% Quartz
T Pyrite
T Glauconite
T Mica
1- 2% Authigenic carbonate

TEXTURE (Average from SS)
T Sand
60-70% Silt
30-40% Clay

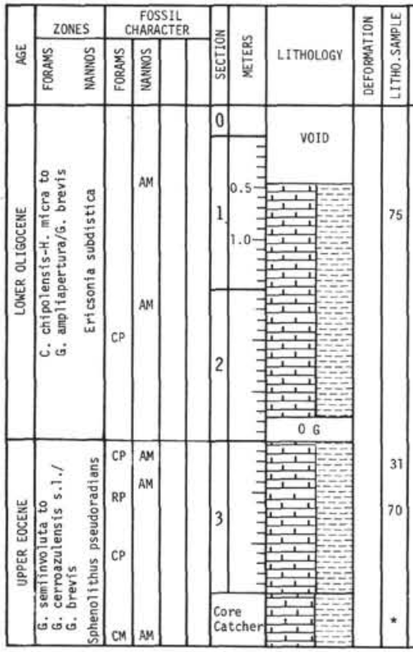
Carbonate Bomb: 5-3 to 4 cm = 26.2% $CaCO_3$
1-0 to 1 cm = 60.5% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (7.7, 0.1, 63)
6-20 (4.1, 0.1, 63)

Grain Size (DSDP)
4-58 (2.2, 43.2, 54.7)
6-58 (2.1, 32.9, 65.0)

Explanatory notes in Chapter 1

Site 360 Hole Core 35 Cored Interval: 564.0-573.5 m



LITHOLOGIC DESCRIPTION

5G 6/1
5G 6/1
N7
5G 6/1
N7
5G 6/1
5G 6/1
N7
N7
5G 6/1
N7
N7
5G 6/1

Marly nannofossil chalk. Greenish gray (5G 6/1) alternating with light gray (N7). Moderately to intensely burrowed throughout with Zoophycos, Rind burrows and Composite burrows.

MARLY NANNOFOSSIL CHALK
1-75, 3-31, 3-70, CC
40% Nannos
55% Clay
1- 3% Quartz
T Pyrite
1% Authigenic carbonate
1% Forams

TEXTURE (Average from SS)
T Sand
40% Silt
60% Clay

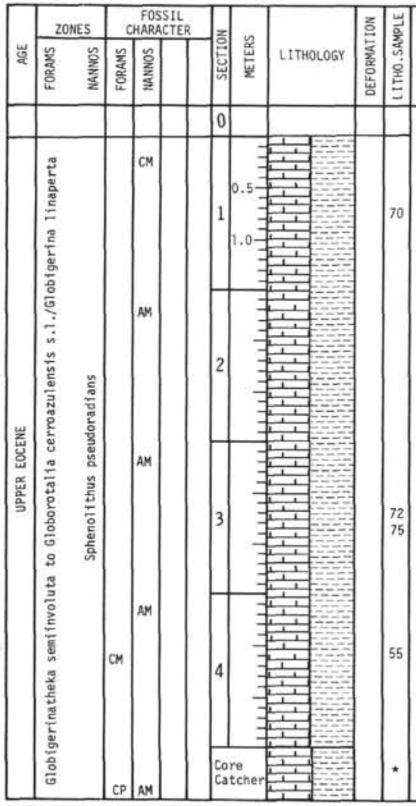
Carbonate Bomb: 2-38 to 39 cm = 41.9% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (8.4, 0.1, 69)

Carbon-Carbonate (OG)
2-130 (7.4, 0.1, 61)
2-150 (8.6, 0.1, 71)

Grain Size (DSDP)
3-58 (1.8, 39.8, 58.4)

Site 360 Hole Core 36 Cored Interval: 573.5-583.0 m



LITHOLOGIC DESCRIPTION

5G 6/1
5G 6/1
5GY 6/1
5G 6/1
5G 6/1
5Y 6/1
5Y 6/1
5GY 6/1
5GY 6/1
N7

Marly nannofossil chalk. Greenish gray (5GY 6/1) and light olive gray (5G 6/1) with minor light gray (N7). Moderate to intense burrowing.

MARLY NANNOFOSSIL CHALK
SS 1-70, 3-72, 3-75, 4-55, CC
40% Nannos
55% Clay
3% Quartz
T Pyrite
1% Authigenic carbonate
1% Forams

[4-75 is sandy with 40% Quartz.]

TEXTURE (Average from SS)
5% Sand
50% Silt
45% Clay

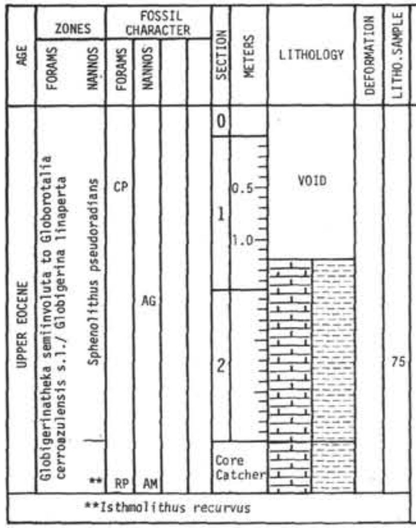
Carbonate Bomb: 1-30 to 31 cm = 27.9% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (5.7, 0.1, 47)

Grain Size (DSDP)
4-58 (0.7, 30.6, 68.6)

Explanatory notes in Chapter 1

Site 360 Hole Core 37 Cored Interval: 592.5-602.0 m



LITHOLOGIC DESCRIPTION

N6
5GY 6/1
5GY 6/1
5GY 6/1

Marly nannofossil chalk. Greenish gray (5GY 6/1) with minor medium light gray (N6). Moderate to intense burrowing throughout.

MARLY NANNOFOSSIL CHALK
SS 2-75
55% Nannos
44% Clay
T Forams
T Quartz
T Heavy minerals
T Pyrite

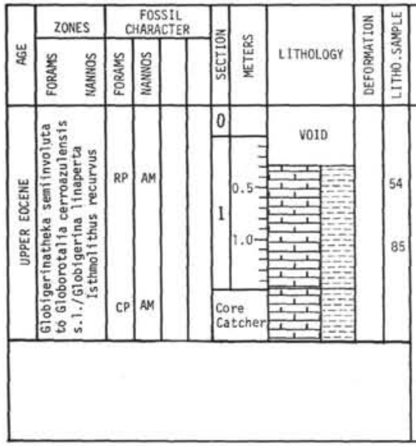
TEXTURE (Average from SS)
1% Sand
29% Silt
70% Clay

Carbonate Bomb: 2-66 to 67 cm = 37.2% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (5.7, 0.1, 47)

Grain Size (DSDP)
2-58 (0.8, 34.9, 64.3)

Site 360 Hole Core 38 Cored Interval: 611.5-621.0m



LITHOLOGIC DESCRIPTION

5GY 6/1

Marly nannofossil chalk. Greenish gray (5GY 6/1) with 5 cm pale yellow brown (10YR 6/3). Burrowed throughout.

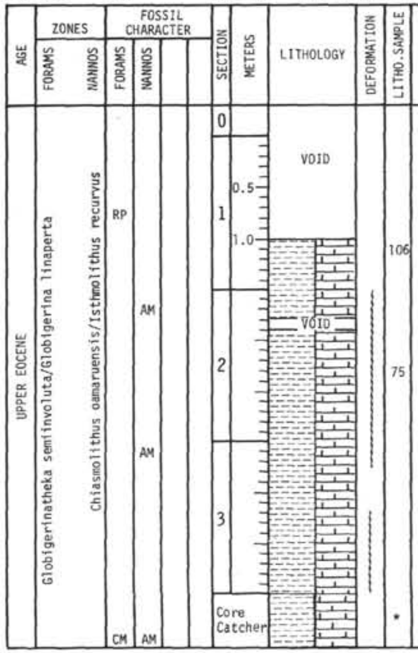
MARLY NANNOFOSSIL CHALK
SS 1-54, 1-85
50% Nannos
44% Clay
5% Quartz
1% Pyrite
T Forams

TEXTURE (Average from SS)
2% Sand
50% Silt
48% Clay

Carbon-Carbonate (DSDP)
1-34 (3.7, 0.1, 30)

Grain Size (DSDP)
1-58 (2.0,7.8, 90.2)

Site 360 Hole Core 39 Cored Interval: 630.5-640.0 m



LITHOLOGIC DESCRIPTION

5G 6/1
5G 6/1
5G 6/1

Marly nannofossil chalk. Greenish gray (5G 6/1). Most of core badly fragmented. Rest shows intensive burrowing.

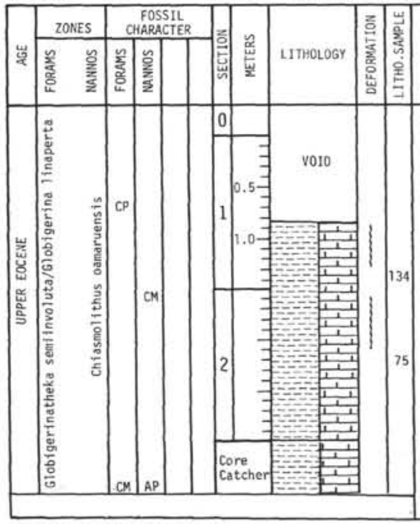
MARLY NANNOFOSSIL CHALK
SS 1-105, 2-75, CC
30-60% Nannos
30-60% Clay
2- 3% Quartz
T- 1% Authigenic carbonate
1% Pyrite
1% Fish remains

TEXTURE (Average from SS)
3% Sand
40% Silt
57% Clay

Carbonate Bomb: 2-10 to 11 cm = 30.2% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (6.1, 0.1, 50)

Site 360 Hole Core 40 Cored Interval: 649.5-659.0 m



LITHOLOGIC DESCRIPTION

5GY 6/1
5GY 6/1

Greenish gray (5GY 6/1) marly nannofossil chalk. Moderately burrowed with Zoophycos and Rind burrows (where not too fragmented).

MARLY NANNOFOSSIL CHALK
SS 1-134, 2-75, CC
60% Nannos
38% Clay
2% Quartz
T Mica
T Pyrite
T Authigenic carbonate

TEXTURE (Average from SS)
1% Sand
60% Silt
39% Clay

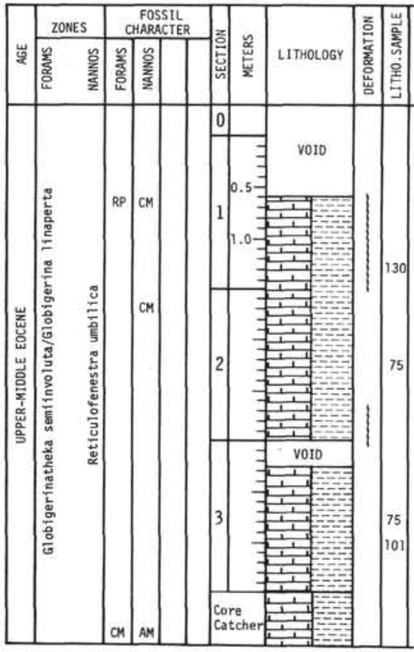
Carbonate Bomb: 1-83 to 84 cm - 41.9% $CaCO_3$

Carbon-Carbonate (DSDP)
1-84 (5.7, 0.1, 46)

Grain Size (DSDP)
2-88 (0.7, 27.1, 72.2)

Explanatory notes in Chapter 1

Site 360 Hole Core 41 Cored Interval: 668.5-678.0 m



LITHOLOGIC DESCRIPTION

5G 6/1
5G 6/1
5G 6/1

Marly nannofossil chalk. Greenish gray (5GY 6/1 and 5Y 6/1) color. Heavily burrowed with Zoophycos and Rind burrows most common. A black lens rich in detrital minerals occurs at 3-101.

MARLY NANNOFOSSIL CHALK
SS 1-130, 2-75, 3-75, 3-101, CC
40% Nannos
55% Clay
1% Quartz
T Mica
T Heavy minerals
T Glauconite
T-5% Pyrite
2% Authigenic carbonate
T Forams

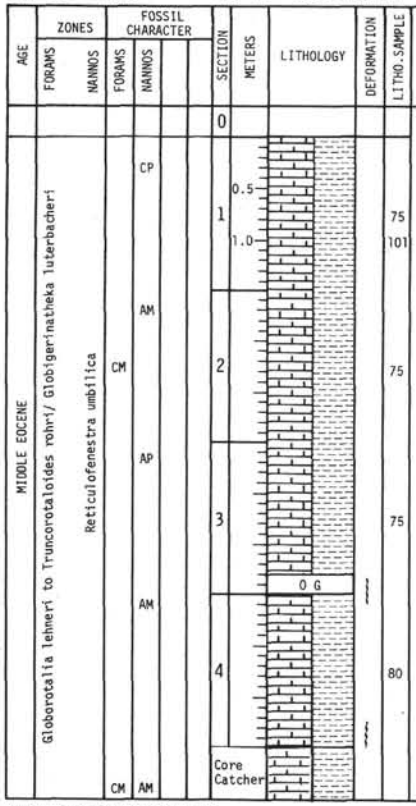
TEXTURE (Average from SS)
1% Sand
39% Silt
60% Clay

Carbonate Bomb: 1-72 to 73 cm = 29.1% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (5.7, 0.1, 47)

Grain Size (DSDP)
2-58 (0.9, 21.1, 78.1)

Site 360 Hole Core 42 Cored Interval: 678.0-687.5 m



LITHOLOGIC DESCRIPTION

5GY 6/1
5GY 6/1
N7
5GY 6/1
5GY 6/1
5GY 6/1

Marly nannofossil chalk; well-indurated. Greenish gray (5Y 6/1 and 5GY 6/1) with minor amount of light gray (N7). Intensely burrowed throughout. Two thin sandy layers recognized.

MARLY NANNOFOSSIL CHALK
SS 1-75, 2-75, 3-75, 4-80, CC
40% Nannos
58% Clay
T Quartz
T Mica
T Heavy minerals
T Pyrite
1% Authigenic carbonate

Carbonate Bomb: 1-35 to 36 cm = 36.1% $CaCO_3$

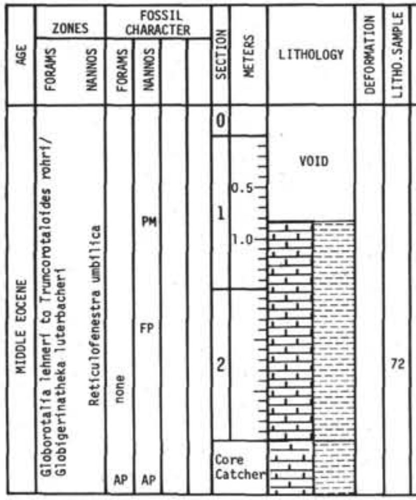
Carbon-Carbonate (DSDP)
4-20 (6.0, 0.1, 49)

Carbon-Carbonate (OG)
3-130 (5.3, 0.1, 43)
3-150 (4.0, 0.1, 32)

Grain Size (DSDP)
4-58 (5.7, 26.8, 67.5)

Explanatory notes in Chapter 1

Site 360 Hole Core 43 Cored Interval: 697.0-706.5 m



LITHOLOGIC DESCRIPTION

5G 6/1

5G 6/1

Greenish gray (5G 6/1) marly nannofossil chalk. Indurated. Moderately burrowed throughout. A large Zoophycos burrow occurs at 2-101.

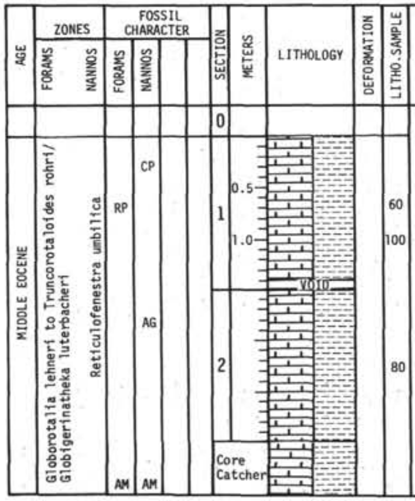
MARLY NANNOFOSSIL CHALK
SS 2-72
40% Nannos
60% Clay
T Quartz
T Authigenic carbonate

TEXTURE (Average from SS)
T Sand
20% Silt
80% Clay

Carbonate Bomb: 1-105 to 106 cm = 39.0% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (3.4, 0.1, 27)

Site 360 Hole Core 44 Cored Interval: 716.0-725.5 m



LITHOLOGIC DESCRIPTION

Greenish gray (5G 6/1) marly nannofossil chalk. Moderately burrowed throughout. More intense burrowing locally. One thin sandy layer observed.

MARLY NANNOFOSSIL CHALK
SS 1-60, 1-100, 2-80
30% Nannos
67% Clay
2% Quartz
1% Authigenic carbonate

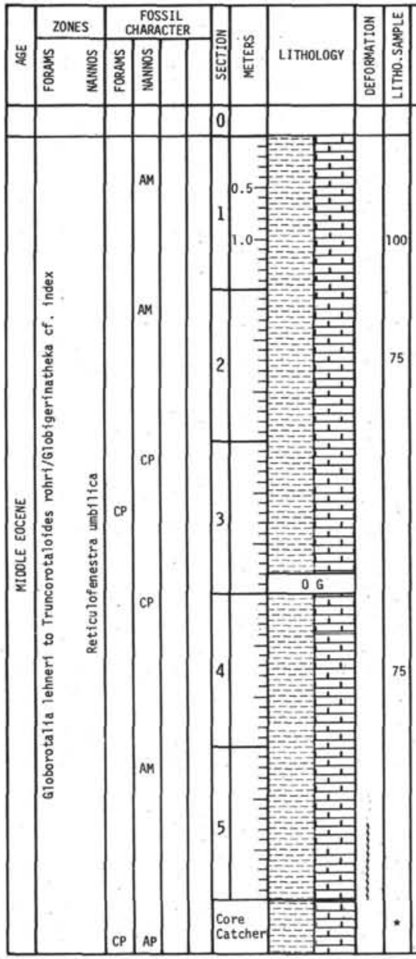
TEXTURE (Average from SS)
T Sand
20% Silt
80% Clay

Carbonate Bomb: 1-33 to 35 cm = 31.2% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (5.9, 0.1, 48)

Grain Size (DSDP)
2-68 (3.8, 33.7, 62.4)

Site 360 Hole Core 45 Cored Interval: 735.0-744.5 m



LITHOLOGIC DESCRIPTION

5G 6/1

5G 6/1

5G 6/1

5G 6/1

5G 6/1

Nannofossil chalk and marly nannofossil chalk. Greenish gray (5G 6/1) color. Moderate to heavy burrowing throughout. Zoophycos and Rind burrows most abundant. Several darker, heavily burrowed zones. One sandy lamina occurs at 4-102.

MARLY NANNOFOSSIL CHALK AND NANNOFOSSIL CHALK
SS 1-100, 2-75, 4-75, CC
30-70% Nannos
25-65% Clay
3- 5% Quartz
1% Pyrite

Carbonate Bomb: 1-43 to 44 cm = 30.6% $CaCO_3$

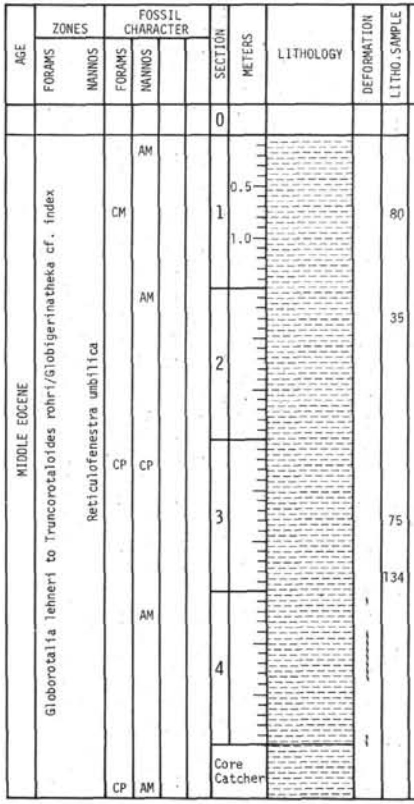
Carbon-Carbonate (DSDP)
4-20 (3.5, 0.1, 28)

Carbon-Carbonate (OG)
3-130 (5.2, 0.1, 42)
3-150 (3.0, 0.1, 24)

Grain Size (DSDP)
4-58 (0.9, 22.3, 76.9)

Explanatory notes in Chapter 1

Site 360 Hole Core 46 Cored Interval: 754.0-763.5 m



LITHOLOGIC DESCRIPTION

5G 6/1

5G 6/1

5G 6/1

5G 6/1

Greenish gray (5G 6/1) calcareous claystone. Moderately to intensely burrowed. Some darker zones appear to be most intensely burrowed. Very well-formed Zoophycos burrows in this core: Section 4 is softer and is deformed.

CALCAREOUS CLAYSTONE
SS 1-80, 2-35, 3-75, CC
20% Nannos
75% Clay
2- 3% Quartz
1% Pyrite
T Fish remains

[SS 3-134 is sandy layer containing 50% Quartz, 10% Pyrite, and 40% Clay.]

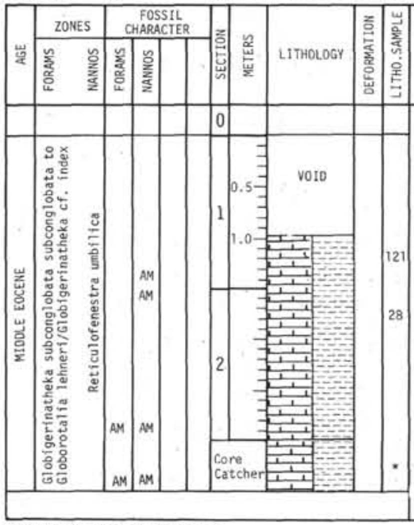
TEXTURE (Average from SS)
1% Sand
25% Silt
74% Clay

Carbonate Bomb: 2-32 to 33 cm = 10.6% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (3.5, 0.1, 28)

Grain Size (DSDP)
4-58 (1.0, 29.7, 69.3)

Site 360 Hole Core 47 Cored Interval: 773.0-782.5 m



LITHOLOGIC DESCRIPTION

5GY 6/1
10YR 4/2
minor
10YR 4/2
minor

5GY 6/1
10YR 4/2
minor
10YR 4/2
minor

Marly nannofossil chalk. Most greenish gray with small zones of grayish red (10R 4/2). Slightly burrowed throughout.

MARLY NANNOFOSSIL CHALK
SS 1-121, 2-28, CC
35% Nannos
50% Clay
10% Quartz
1% Pyrite
2% Authigenic carbonate
T Forams

TEXTURE (Average from SS)
1% Sand
58% Silt
42% Clay

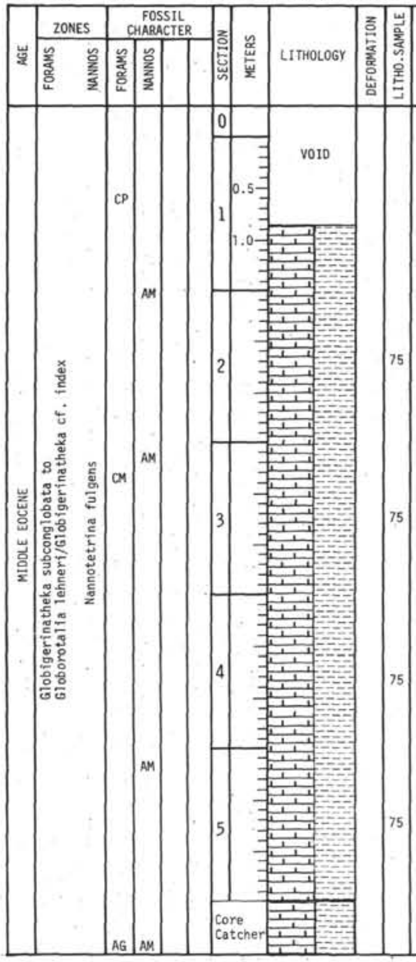
Carbonate Bomb: 2-15 to 16 cm = 45.3% $CaCO_3$
1-108 to 109 cm = 31.2% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (4.8, 0.1, 39)

Grain Size (DSDP)
2-58 (2.7, 23.7, 73.5)

Explanatory notes in Chapter 1

Site 360 Hole Core 48 Cored Interval: 792.0-801.5 m



LITHOLOGIC DESCRIPTION

Greenish gray (5G 6/1) marly nannofossil chalk with minor patches of grayish red (10R 4/2). Moderately burrowed throughout. Some intensely burrowed zones are darker in color. Numerous sandy layers .5 to 1 cm thick occur in core.

5G 6/1
10YR 4/2 minor

MARLY NANNOFOSSIL CHALK
SS 2-75, 3-75, 4-75, 5-75
30-35% Nannos
60-65% Clay
3% Quartz
2- 3% Authigenic carbonate
2% Pyrite
T Mica
T Forams

5G 6/1
10YR 4/2 minor

TEXTURE (Average from SS)
T Sand
45% Silt
55% Clay

Carbonate Bomb: 2-17 to 18 cm = 26.5% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (4.2, 0.1, 34)

5G 6/1

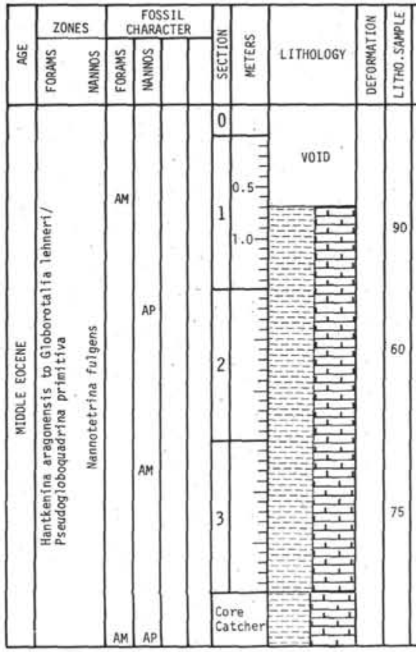
Carbon-Carbonate (DSDP)
3-130 (3.7, 0.1, 30)
3-150 (4.7, 0.1, 38)

Grain Size (DSDP)
4-58 (4.7, 32.5, 62.7)

5G 6/1
5B 9/1
minor

5G 6/1

Site 360 Hole Core 49 Cored Interval: 811.0-820.5 m



LITHOLOGIC DESCRIPTION

Marly nannofossil chalk. Greenish gray (5G 6/1) with a few darker laminations and lenses (5B 9/1). The core is burrowed throughout. Zoophycos and Composite burrows well preserved. The darker layers appear to be associated with more intense burrowing.

5G 6/1

MARLY NANNOFOSSIL CHALK
SS 1-90, 2-60, 3-75
55-65% Nannos
25-30% Clay
3- 5% Quartz
3- 5% Authigenic carbonate
T Mica
T Forams
T Glauconite

5G 6/1

TEXTURE (Average from SS)
T Sand
60% Silt
40% Clay

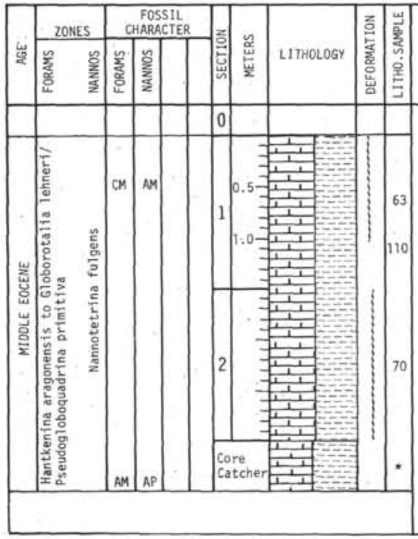
Carbonate Bomb: 1-130 to 131 cm = 65.3% $CaCO_3$

5G 6/1

Carbon-Carbonate (DSDP)
2-20 (7.2, 0.1, 59)

Grain Size (DSDP)
2-58 (5.0, 35.6, 59.5)

Site 360 Hole Core 50 Cored Interval: 830.0-839.5 m



LITHOLOGIC DESCRIPTION

Marly nannofossil chalk and calcareous claystone. Core disturbed by drilling. A few sandy layers and moderate burrowing present in less disturbed part.

5G 6/1

MARLY NANNOFOSSIL CHALK AND CALCAREOUS CLAYSTONE
SS 1-63, 1-110, 2-70, CC
20-35% Nannos
55-70% Clay
2- 3% Quartz
2- 3% Authigenic carbonate
T- 1% Pyrite
T- 1% Forams

5G 6/1

TEXTURE (Average from SS)
1% Sand
44% Silt
55% Clay

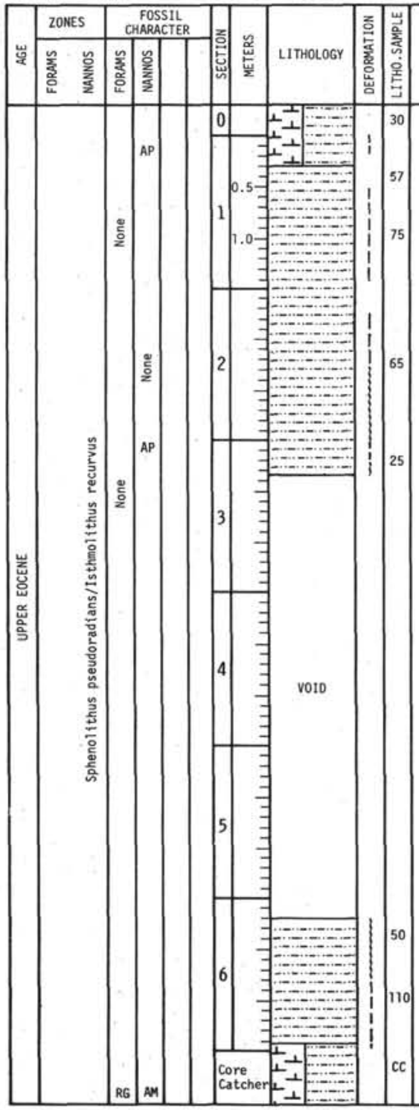
Carbonate Bomb: 1-105 to 107 cm = 16.5% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (3.3, 0.2, 26)

Grain Size (DSDP)
2-58 (0.6, 10.7, 88.7)

Explanatory notes in Chapter 1

Site 361 Hole Core 1 Cored Interval: 31.5-41.0 m



LITHOLOGIC DESCRIPTION

10YR 5/4
5YR 8/4 (minor)
10YR 8/4
5BG 5/2
5BG 7/2 (minor)
5YR 8/4
5YR 6/4
5G 8/1 (minor)
5YR 6/4
5YR 6/4
5B 6/1 (minor)
5YR 6/1

MUD AND CALCAREOUS MUD

Light brown (5YR 6/4) and light brownish gray (5YR 6/1); minor yellow brown (10YR 5/2-10YR 5/4), grayish blue green (5BG 5/2), pale blue green (5BG 7/2), light greenish gray (5G 8/1) and very pale orange (10YR 8/2) patches and layers. Moderate to intense mottling in Sections 1-3, and slight burrowing in Section 1.
Heavy minerals: Zircon, Epidote, Chlorite, Tourmaline, Amphibole, Garnet.
Feldspars: Microcline, Plagioclase.

MINERALOGY
SS 1-75, 2-65, 3-25, 6-50, 6-110
20-26% Quartz
0- 4% Feldspar
T Mica
0- 3% Heavy minerals
40-65% Clay
0- 4% Chlorite
0- 2% Glauconite
T Pyrite
0- 1% Authigenic carbonate
0- 2% Iron oxide
5-15% Nannos
T Fish remains

TEXTURE (Average from SS)
11% Sand
21% Silt
68% Clay

MARLY NANNOFOSSIL OOZE

Moderate yellowish brown (10YR 5/4) and moderate orange (5YR 8/4), slightly burrowed.
Heavy minerals: Zircon, Apatite.

MINERALOGY
SS 0-30, CC
10-15% Quartz
T- 2% Feldspar
T Mica
T Heavy minerals
40% Clay
0- 2% Chlorite
T Dolomite
T- 2% Iron oxide
40-45% Nannos
T Fish remains
0- 1% Authigenic carbonate

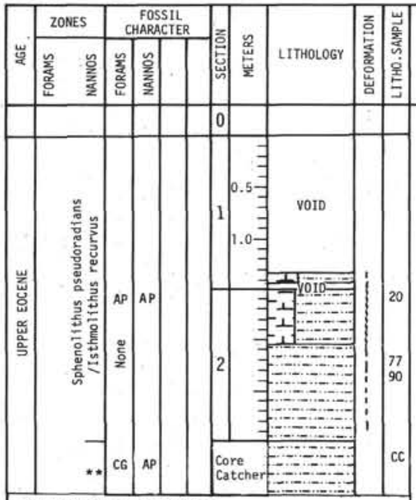
5YR 6/1
5YR 6/4
5B 6/1
10YR 8/2 (minor)

TEXTURE (Average from SS)
5% Sand
40% Silt
55% Clay

Carbonate Bomb: 6-29 to 30 cm = 13.9% $CaCO_3$

Carbon-Carbonate (DSDP)
6-39 (0.6, 0.2, 3)

Site 361 Hole Core 2 Cored Interval: 60-69.5 m



**Chiasmolithus oamaruensis

LITHOLOGIC DESCRIPTION

MARLY NANNOFOSSIL OOZE

Light brown (5YR 6/4) with minor zones of 5G 6/1. Heavy minerals include Epidote, Zircon, Iron oxides, Chlorite, Tourmaline, Pyroxene, Sphene.
Feldspars: Microcline, Orthoclase, Plagioclase.

MINERALOGY
SS 2-20
5YR 6/4 12% Quartz
1% Feldspar
5YR 6/4 T Mica
1% Heavy minerals
50% Clay
T Dolomite
5G 6/1 35% Nannos

TEXTURE (Average from SS)
10YR 6/2 6% Sand
5G 6/1 8% Silt
86% Clay

MUD AND CALCAREOUS MUD

Pale yellowish brown (10YR 6/2) with thin layers of greenish gray (5G 6/1). Heavy minerals include Epidote, Zircon, Opaques, Chlorite, Sphene, Tourmaline, Iron oxides.

MINERALOGY
SS 2-90, CC
23-30% Quartz
2- 3% Feldspar
T Mica
2- 3% Heavy minerals
48-70% Clay
T Glauconite
0- 1% Authigenic carbonate
0-15% Nannos

TEXTURE (Average from SS)
15% Sand
18% Silt
68% Clay

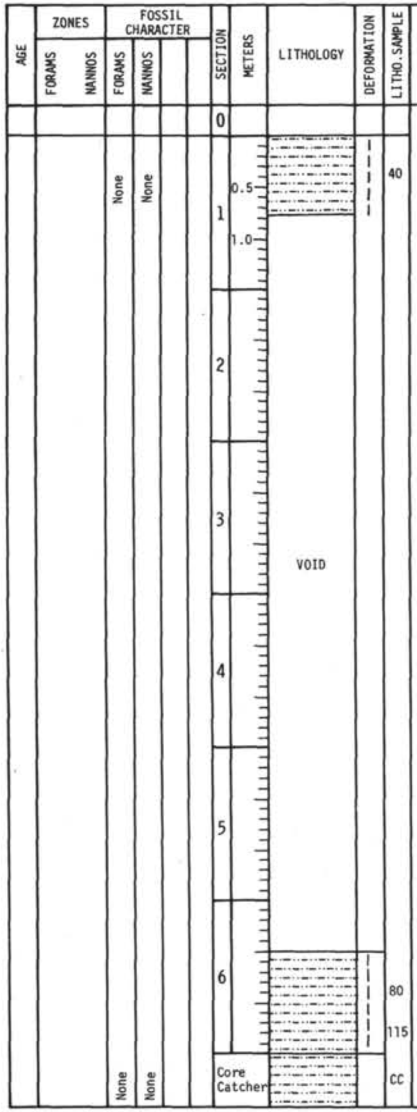
Carbonate Bomb: 2-105 to 106 cm = 9.6% $CaCO_3$

Carbon-Carbonate (DSDP)
2-30 (0.2, 0.2, 0)
2-68 (2.1, 34.3, 63.6)

Grain Size (DSDP)
2-68 (2.1, 34.3, 63.6)

Explanatory notes in Chapter 1

Site 361 Hole Core 3 Cored Interval: 98.0-107.5 m



LITHOLOGIC DESCRIPTION

5G 6/1
5YR 6/4
5G 6/1

MUD
Light brown (5YR 6/4) and greenish gray (5G 6/1) with minor layers of pale blue green (5BG 7/2). Heavy minerals include Chlorite, Epidote, Iron oxides, Zircon, Goethite(?).

MINERALOGY
SS 1-40, 6-80, CC
30-40% Quartz
0- 3% Feldspar
T Mica
2- 6% Heavy minerals
54-65% Clay
T Glauconite
0- 1% Authigenic carbonate
T Fish remains

TEXTURE (Average from SS)
12% Sand
31% Silt
57% Clay

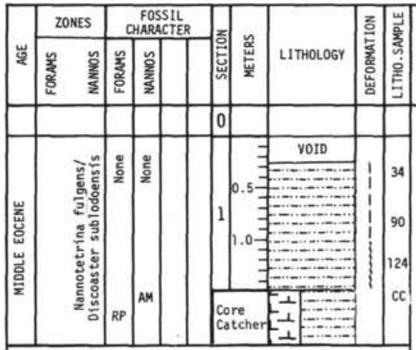
Carbonate Bomb: 1-5 to 6 cm = 9.6% $CaCO_3$

Carbon-Carbonate (DSDP)
1-20 (0.2, 0.2, 0)

Grain Size (DSDP)
6-88 (2.3, 32.4, 65.3)

5YR 6/4

Site 361 Hole Core 4 Cored Interval: 136.0-145.5 m



LITHOLOGIC DESCRIPTION

5B 7/1
5YR 6/4
5G 6/1

MUD
Light brown (5YR 6/4) and greenish gray (5G 6/1), with very minor light bluish gray (5B 7/1) and very pale orange (10YR 8/2) zones.
Heavy minerals: Chlorite, Opaques, Epidote, Zircon, Garnet.
Feldspars: Microcline, Plagioclase.

MINERALOGY
1-90, 1-125
60-70% Quartz
3- 4% Feldspar
T Mica
2- 4% Heavy minerals
15-32% Clay
T Dolomite
0- 1% Authigenic carbonate
0- 6% Nannos

TEXTURE (Average from SS)
25% Sand
47% Silt
28% Clay

MARLY NANNOFOSSIL OOZE
Light brown (5YR 6/4).
Heavy minerals: Chlorite, Epidote, Garnet, Opaques.

MINERALOGY
CC
8% Quartz
1% Feldspar
1% Heavy minerals
50% Clay
T Pyrite
T Dolomite
40% Nannos

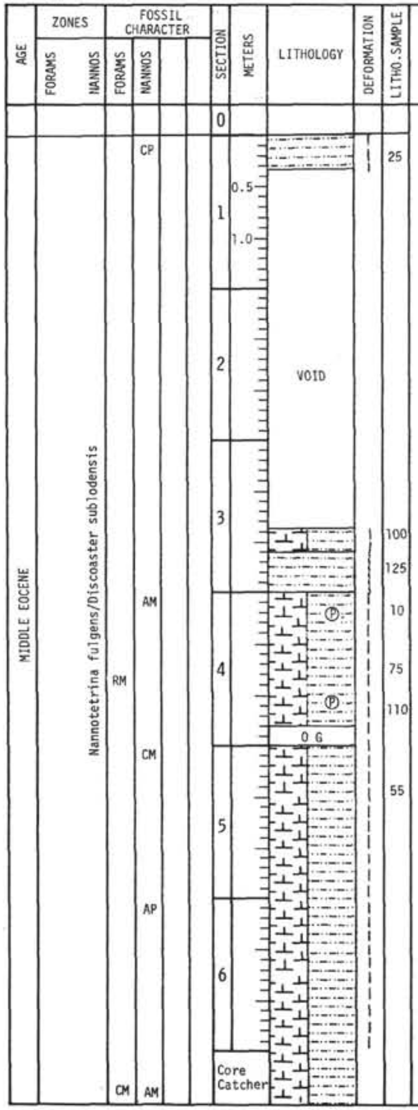
TEXTURE
5% Sand
30% Silt
65% Clay

Carbonate Bomb: 1-123 to 124 cm = 13.0% $CaCO_3$

Carbon-Carbonate (DSDP)
1-42 (0.2, 0.2, 0)

Explanatory notes in Chapter 1

Site 361 Hole Core 5 Cored Interval: 174.0-183.5 m



LITHOLOGIC DESCRIPTION

5G 6/1

CALCAREOUS MUD
Greenish gray (5G 6/1).
Heavy minerals: Chlorite, Epidote, Opaques, Zircon.

MINERALOGY
SS 1-25, 3-125
40% Quartz
1- 2% Feldspar
0% Mica
4- 6% Heavy minerals
22-30% Clay
T Authigenic carbonate
20-25% Nannos
T Fish remains

TEXTURE (Average from SS)
27% Sand
39% Silt
34% Clay

5B 7/1
5G 4/1
5B 7/1
5G 6/1
5G 6/1
5B 7/1
(minor)
5G 6/1

MARLY NANNOFOSSIL OOZE
Light bluish gray (5B 7/1) and greenish gray (5G 6/1). Thinly laminated, with scattered pyrite patches and glauconite layers (especially in Sections 4 and 5).
Heavy minerals: Epidote, Opaques, Zircon, Tourmaline, Chlorite, Garnet.

MINERALOGY
SS 3-100, 4-10, 4-75, 5-55, 6-60, CC
2-20% Quartz
0- 1% Feldspar
T Mica
0- 3% Heavy minerals
0- 1% Fish remains
30-45% Clay
0- 3% Glauconite
0- 3% Pyrite
T Forams
40-63% Nannos

TEXTURE (Average from SS)
8% Sand
29% Silt
63% Clay

Carbonate Bomb: 4-5 to 6 cm = 46.2% $CaCO_3$

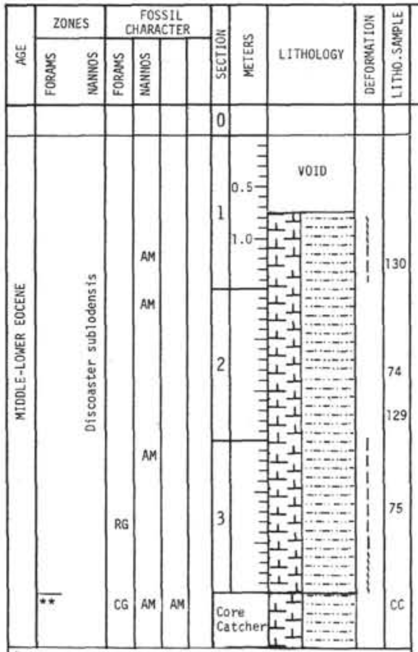
Carbon-Carbonate (DSDP)
6-20 (1.6, 0.1, 13)

Carbon-Carbonate (OG)
4-130 (1.6, 0.1, 12)
4-150 (3.6, 0.2, 28)

Grain Size (DSDP)
6-88 (0.1, 19.5, 80.3)

Ⓟ = Pyrite nodule

Site 361 Hole Core 6 Cored Interval: 202.5-212.0 m



** Globorotalia palmerae equivalent

LITHOLOGIC DESCRIPTION

MARLY NANNOFOSSIL OOZE
Light bluish gray (5B 7/1) and medium bluish gray (5B 5/1). Thinly laminated throughout. Firmer zone in Section 2. Minor glauconite lenses in Section 2.
Heavy minerals: Epidote, Opaques, Zircon, Chlorite, Sphene.
Feldspars: Microcline, Plagioclase.
A pyritic sand layer (SS 2-129) contains 20% spheroidal to irregular pyrite grains.

5B 7/1
5B 7/1
5B 5/1
5B 5/1

MINERALOGY
SS 1-130, 2-74, 3-75, CC
8-12% Quartz
T- 1% Feldspar
T- 1% Mica
T- 1% Heavy minerals
17-46% Clay
0- 1% Glauconite
0- 2% Pyrite
T Dolomite
0- 1% Authigenic carbonate
0- 2% Forams
35-63% Nannos
T Fish remains
T Sponge spicules

TEXTURE (Average from SS)
7% Sand
40% Silt
53% Clay

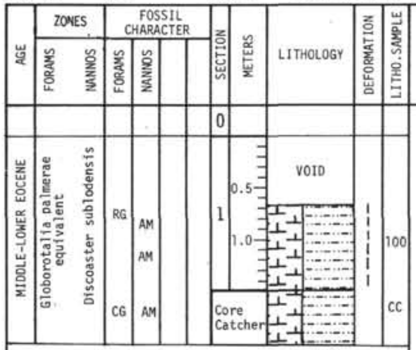
Carbonate βomb: 1-103 to 104 cm = 17.3% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (1.5, 0.2, 10)

Grain Size (DSDP)
3-104 (1.1, 35.3, 63.7)

Explanatory notes in Chapter 1

Site 361 Hole Core 7 Cored Interval: 231.0-240.5 m



LITHOLOGIC DESCRIPTION

5B 5/1 (minor)

5B 7/1

MARLY NANNOFOSSIL OOZE
Light bluish gray (5B 7/1).
Heavy minerals: Chlorite, Zircon, Epidote, Garnet, Opaques, Kyanite(?).

MINERALOGY
SS 1-100, CC
2- 5% Quartz
T Feldspar
T Mica
1- 2% Heavy minerals
30-32% Clay
T Glauconite
T Pyrite
T Forams
60-65% Nannos
T Fish remains

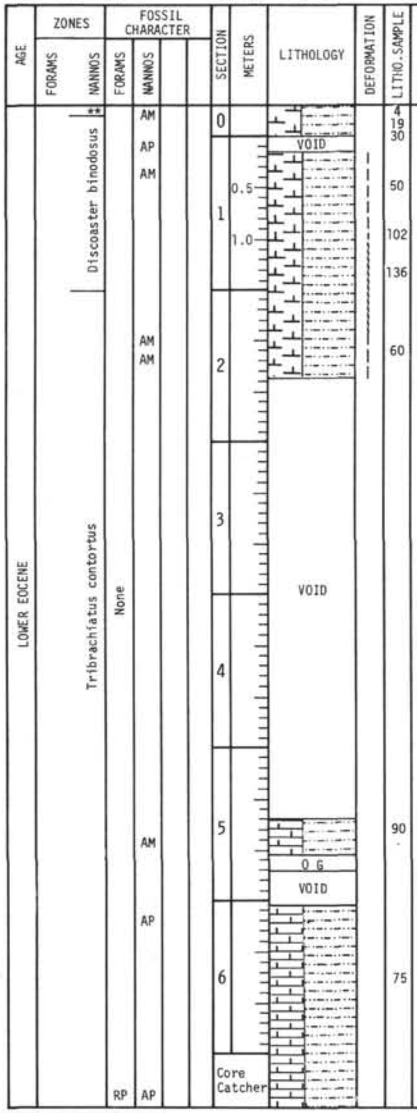
TEXTURE (Average from SS)
2% Sand
38% Silt
61% Clay

Carbonate Bomb: 1-64 to 65 cm = 16.8% $CaCO_3$

Carbon-Carbonate (DSDP)
1-82 (4.1, 0.1, 33)

Grain Size (DSDP)
1-119 (0.2, 44.2, 55.7)

Site 361 Hole Core 8 Cored Interval: 250.0-259.5 m



LITHOLOGIC DESCRIPTION

5YR 8/4
6B 5/1 (minor)
5B 9/1

5YR 7/2

10R 8/2
5YR 8/4

5YR 3/4
(mottling)

5YR 8/4
5BG 5/2
(minor)

MARLY NANNOFOSSIL OOZE AND MARLY NANNOFOSSIL CHALK
Moderate orange pink (5YR 8/4), very pale orange (10YR 8/2), and grayish orange pink (5YR 7/2), with minor medium bluish gray (5B 5/1), bluish white (5B 9/1), moderate brown (5YR 3/4) and grayish blue green (5BG 5/2) in patches and zones. Marked mottling in Sections 1 and 2, and intensive burrowing in Sections 5 and 6. Heavy minerals: Chlorite, Opaques, Zircon, Iron oxide.

MINERALOGY
SS 0-4, 0-30, 1-50, 2-60, 5-90, 6-75, CC
0- 3% Quartz
T Feldspar
T Mica
T Heavy minerals
17-43% Clay
T Pyrite
0- 6% Dolomite
0-20% Authigenic carbonate
T Forams
52-80% Nannos

TEXTURE (Average from SS)
T Sand
27% Silt
69% Clay

Carbonate Bomb: 6-30 to 31 cm = 64.9% $CaCO_3$

Carbon-Carbonate (DSDP)
6-20 (7.5, 0.0, 62)

Carbon-Carbonate (OG)
5-109 (9.1, 0.1, 75)
5-129 (9.2, 0.1, 76)

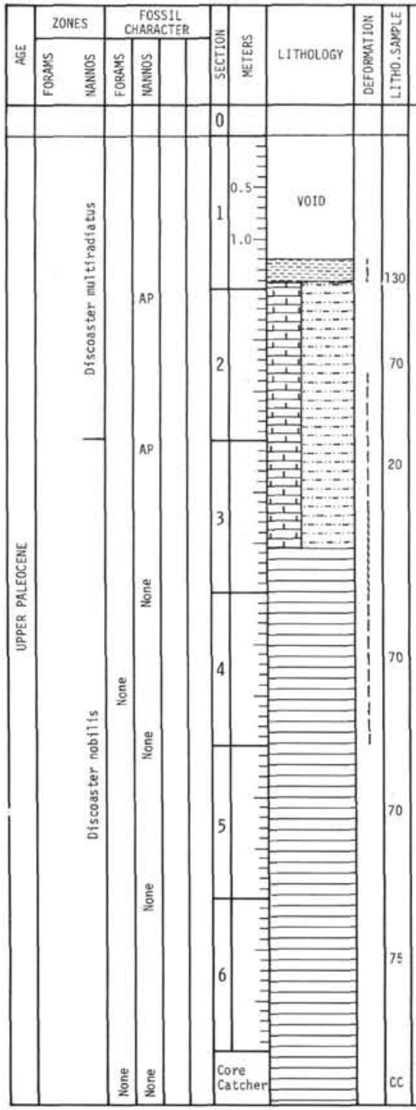
5YR 8/4
10YR 8/2

5YR 8/4

10YR 8/2

**Discoaster lodensis
Explanatory notes in Chapter 1

Site 361 Hole Core 9 Cored Interval:259.5-269.0 m



LITHOLOGIC DESCRIPTION

5YR 5/6
5YR 6/4
5YR 5/6
N8 (minor)
N7 (minor)
N8 (minor)
5YR 4/4
5YR 4/4
5YR 4/4
5G 6/1
(minor)
5YR 4/4
5G 6/1
(minor)

CALCAREOUS CLAY
Light brown (5YR 5/6). Intensely burrowed.

MINERALOGY
SS 1-130
T Quartz
1% Mica
80% Clay
2% Authigenic carbonate
15% Nannos

TEXTURE
0% Sand
10% Silt
90% Clay

MARLY NANNOFOSSIL CHALK
Light brown (5YR 5/6-5YR 6/4), with minor light gray (N7-N8) zones. Intensely burrowed.

MINERALOGY
SS 2-70, 3-20
1- 2% Quartz
T Heavy minerals
58-66% Clay
T Zeolites
T Forams
32-40% Nannos
T Fish remains
T- T Iron oxide

TEXTURE (Average from SS)
0% Sand
28% Silt
73% Clay

PELAGIC CLAY
Moderate brown (5YR 4/4) with greenish gray (5G 6/1) patches.
Heavy minerals: Zircon, Epidote, Chlorite

MINERALOGY
SS 4-70, 5-70, CC
11-28% Quartz
T Feldspar
74-84% Clay
T- 1% Zeolites
T- 2% Fish remains
2- 6% Iron oxide

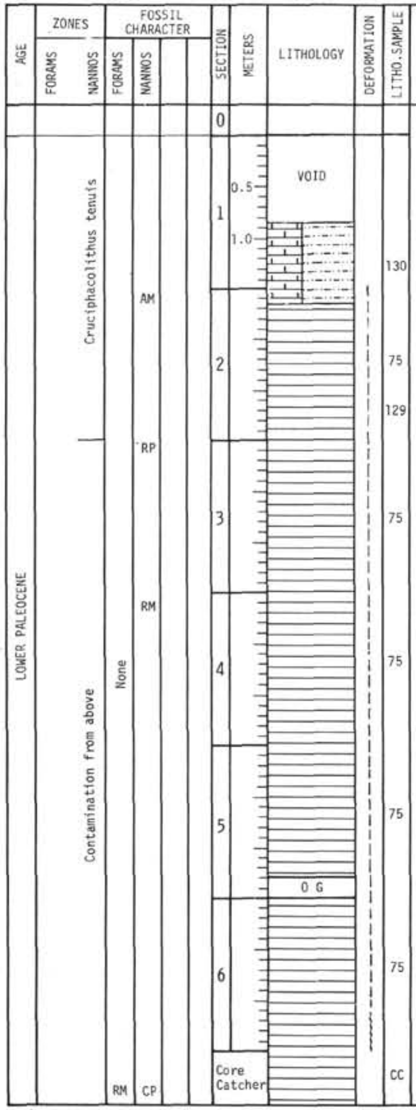
TEXTURE (Average from SS)
2% Sand
18% Silt
80% Clay

Carbonate Bomb: 5-29 to 30 cm = 10.1% $CaCO_3$

Carbon-Carbonate (DSDP)
5-20 (0.2, 0.1, 1)
6-20 (0.2, 0.1, 1)

Grain Size (DSDP)
4-68 (0.0, 7.8, 92.2)
6-68 (0.1, 10.8, 89.1)

Site 361 Hole Core 10 Cored Interval: 269.0-278.5 m



LITHOLOGIC DESCRIPTION

5YR 4/4
5YR 5/6
5YR 4/4
5G 6/1
(minor)
5YR 4/4
5YR 4/4
5YR 4/4-
6YR 4/2
5G 6/1
(minor)
6YR 4/4-
10YR 4/2

MARLY NANNOFOSSIL CHALK
Moderate brown (5YR 4/4), burrowed.
Heavy minerals: Chlorite, Zircon, Opaques.

MINERALOGY
SS 1-130
21% Quartz
2% Feldspar
1% Heavy minerals
38% Clay
2% Iron oxides
36% Nannos
T Fish remains

TEXTURE (Average from SS)
8% Sand
32% Silt
60% Clay

PELAGIC CLAY
Moderate brown (5YR 4/4) to dark yellowish brown (10YR 4/2). Minor greenish gray (5G 6/1) layers. Burrowing only in Section 2.
Heavy minerals: Epidote, Opaques, Tourmaline, Garnet.

MINERALOGY
SS 2-76, 3-75, 4-75, 5-75, 6-75, CC
5-16% Quartz
0- 2% Feldspar
T Mica
0- 1% Heavy minerals
72-85% Clay
T Pyrite
T Dolomite
T Authigenic carbonate
0- 3% Iron oxides
0- T% Forams
0-17% Nannos
T- 5% Fish remains

TEXTURE (Average from SS)
2% Sand
19% Silt
79% Clay

Carbonate Bomb: 4-29 to 30 cm = 11.1% $CaCO_3$

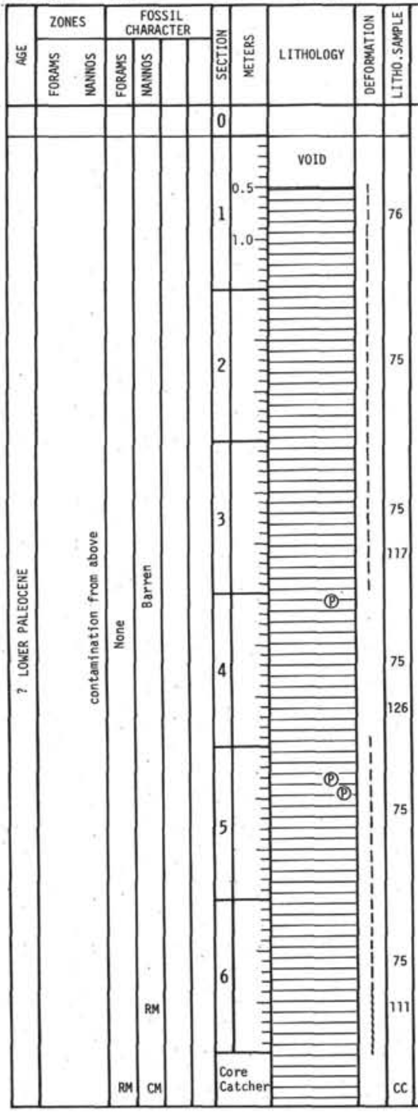
Carbon-Carbonate (DSDP)
4-20 (0.2, 0.0, 1)
6-20 (0.1, 0.1, 0)

Carbon-Carbonate (OG)
5-130 (0.1, 0.1, 0)
5-150 (0.1, 0.1, 0)

Grain Size (DSDP)
4-88 (0.3, 14.5, 85.3)
6-88 (0.1, 15.4, 4.5)

Explanatory notes in Chapter 1

Site 361 Hole Core 11 Cored Interval: 278.5-288.0 m



LITHOLOGIC DESCRIPTION

5YR 4/4
5YR 4/4
5YR 4/4
5G 6/1 (minor)
5G 6/1 (minor)
5YR 4/4
10YR 2/2 (minor)
5G 6/1 (minor)
5YR 4/4
5G 6/1 (minor)
5YR 4/4
5G 6/1 (minor)
10YR 7/4 (mottling)

PELAGIC CLAY
Moderate brown (5YR 3/4-5YR 4/4) with minor, but distinctive greenish gray spherical patches - some have darker brown rims around the patches. Minor pyrite.
Heavy minerals: Zircon, Epidote, Opaques, Barite.

MINERALOGY
SS 1-76, 2-75, 3-75, 4-75, 5-75, 6-75, CC
5-15% Quartz
0- 1% Feldspar
T Mica
T- 1% Heavy minerals
72-88% Clay
0- 6% Zeolite
T Authigenic carbonate
2- 4% Iron oxide
T Nannos
2- 4% Fish remains

TEXTURE (Average from SS)
1% Sand
18% Silt
81% Clay

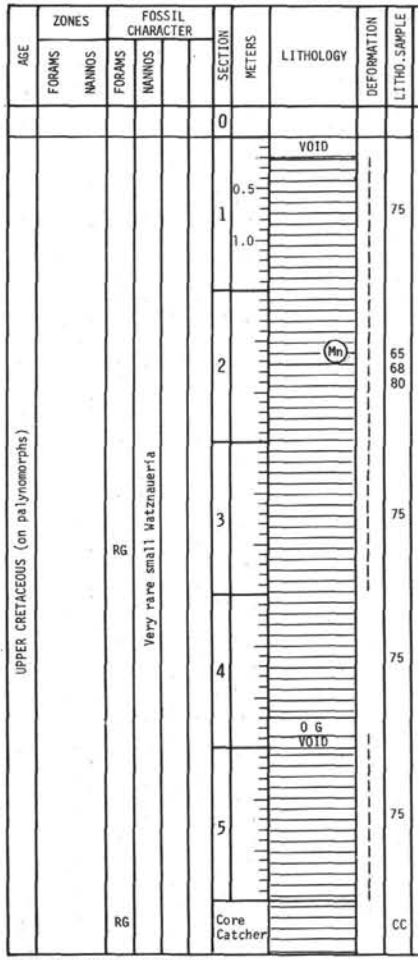
Carbonate Bomb: 4-30 to 31 cm = 8.2% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (0.1, 0.0, 0)
6-20 (0.0, 0.1, 0)

Grain Size (DSDP)
4-99 (0.1, 16.2, 83.7)
6-85 (0.1, 16.7, 83.2)

Ⓟ = Pyrite nodule

Site 361 Hole Core 12 Cored Interval: 297.5-307.0 m



LITHOLOGIC DESCRIPTION

5YR 3/4
5YR 3/4
5YR 4/4
N3 (minor)
5YR 4/4
5YR 4/4
5G 6/1 (minor)
5YR 3/4-
5YR 4/4
5G 6/1 (minor)

PELAGIC CLAY
Moderate brown (5YR 3/4-5YR 4/4), with minor patches of greenish gray (5G 6/1). Two-cm-diameter manganese nodule at 2-70, in 10-cm layer of brownish gray zeolitic mudstone.
Heavy minerals: Zircon, Epidote.

MINERALOGY
SS 1-75, 2-80, 3-75, 4-75, CC
5-11% Quartz
T Feldspar
T Mica
T- 1% Heavy minerals
67-79% Clay
3-15% Zeolite
2- 8% Iron oxide
3- 5% Fish remains

TEXTURE (Average from SS)
1% Sand
24% Silt
75% Clay

Carbonate Bomb: 1-53 to 54 cm = 10.6% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (0.1, 0.0, 0)

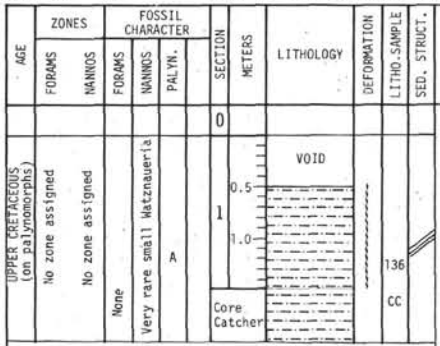
Carbon-Carbonate (OG)
4-120 (0.1, 0.1, 0)
4-140 (0.1, 0.1, 0)

Grain Size (DSDP)
4-88 (0.0, 18.5, 81.5)

Ⓜ = Manganese nodule

Explanatory notes in Chapter 1

Site 361 Hole Core 13 Cored Interval: 326.0-335.5 m



LITHOLOGIC DESCRIPTION

5BG 5/2

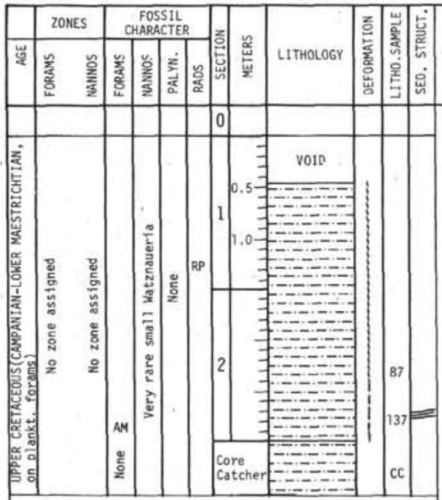
SANDY MUDSTONE
Grayish blue green (5BG 5/2). Minor cross-bedded sands.

MINERALOGY
1-136, CC
25-60% Quartz
2- 3% Feldspar
T- 1% Mica
0- 1% Heavy minerals
16-48% Clay
0- 6% Zeolite
8-10% Iron oxide
9-10% Chlorite

TEXTURE (Average from SS)
40% Sand
27% Silt
34% Clay

Carbonate Bomb: 1-105 to 107 cm = 9.6% $CaCO_3$

Site 361 Hole Core 14 Cored Interval: 364.0-373.5 m



LITHOLOGIC DESCRIPTION

10R 4/2
5BG 5/2
10R 4/2
5GY 4/1
5GY 2/1
10Y 9/2
(minor)

CHLORITIC SANDY MUDSTONE AND SANDY MUDSTONE
Grayish blue green (5BG 5/2), grayish red (10R 4/2) and greenish black (5GY 2/1). Thin horizontal and cross-bedded sands, especially marked in Section 2. A 5-cm laminated zone, rich in forams, occurs at 2-137.

MINERALOGY
SS 2-75, CC
35-38% Quartz
0- 2% Feldspar
0- 1% Mica
T- 2% Heavy minerals
10-15% Clay
15% Zeolite
5% Iron oxide
0- 3% Fish remains
20-27% Chlorite

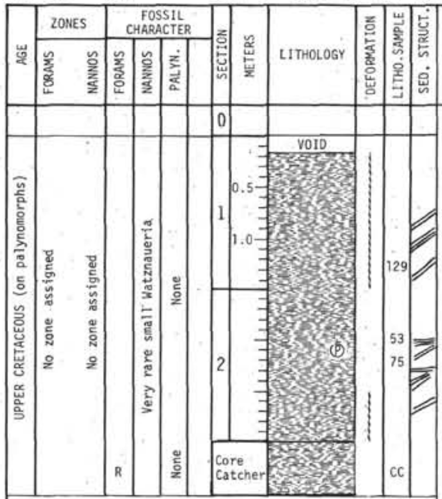
TEXTURE (Average from SS)
55% Sand
29% Silt
16% Clay

Carbonate Bomb: 2-45 to 46 cm = 8.7% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (0.1, 0.1, 0)

Grain Size (DSDP)
2-56 (38.8, 38.6, 22.7)

Site 361 Hole Core 15 Cored Interval: 402.0-411.5 m



LITHOLOGIC DESCRIPTION

5GY 4/1
5B 7/1
10R 3/4
5B 5/1
10R 3/4
5B 7/1

SHALE
Alternating light bluish gray (5B 7/1) to medium bluish gray (5B 5/1) mudstone, and dark reddish brown (10R 3/4) claystone. Paralleland cross-bedded silts and fine sands in mudstones. Minor pyrite. (?)Ioceramus found in core catcher (fragment). Chloritic mudstone at 2-75.

MINERALOGY
SS 2-75, CC
5-30% Quartz
T Mica
T Heavy minerals
15-87% Clay
T Pyrite
20-35% Zeolite
2- 3% Iron oxide
T Fish remains
0-30% Chlorite

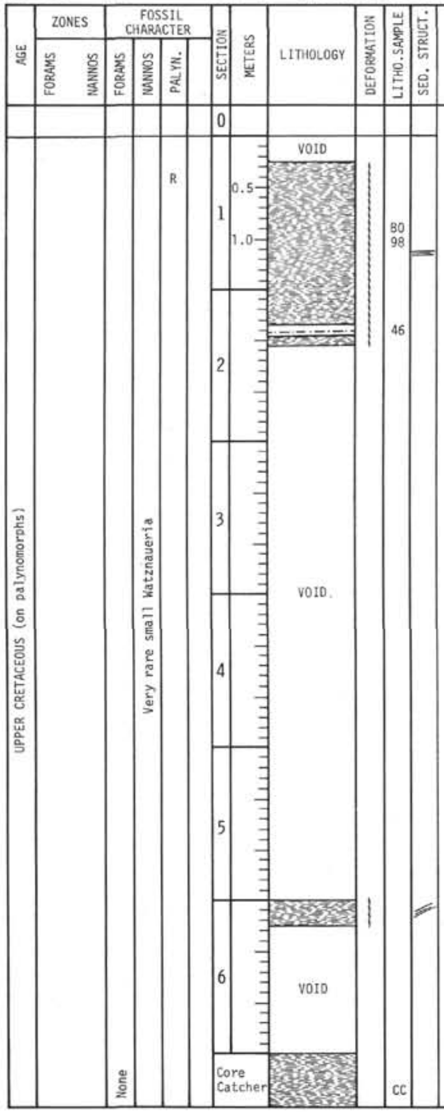
TEXTURE (Average from SS)
3% Sand
28% Silt
65% Clay

Carbonate Bomb: 2-45 to 47 cm = 9.6% $CaCO_3$

Carbon-Carbonate (DSDP)
1-34 (0.1, 0.1, 0)
Ⓟ = Pyrite nodule

Explanatory notes in Chapter 1

Site 361 Hole Core 16 Cored Interval: 440.0-449.5 m



LITHOLOGIC DESCRIPTION

5GY 2/1
10R 3/4
5B 5/1
10R 3/4
5G 4/1
10R 4/2
5G 4/1

SHALE
Dark greenish gray (5G 4/1), greenish black (5GY 2/1), and medium bluish gray (5B 5/1) mudstones, alternating with dark reddish brown (10R 3/4) and grayish red claystones and mudstones. Parallel and cross-bedded silts and fine sands in mudstones. Burrowing in Section 1.
Heavy minerals: Barite(?), Zircon, Epidote.

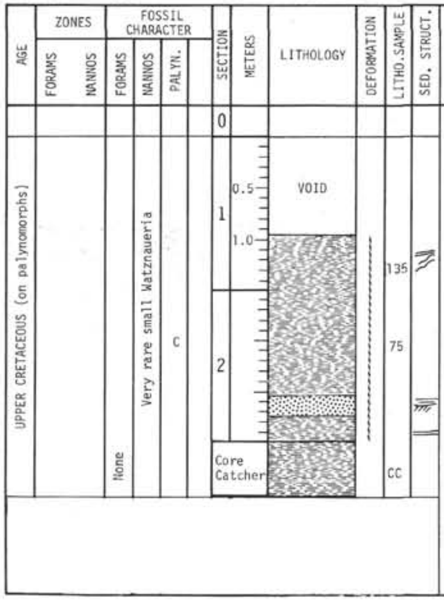
MINERALOGY
SS 1-80, CC
8-10% Quartz
T Heavy minerals
84-89% Clay
0% Dolomite
T Zeolite
0% Authigenic carbonate
1- 2% Iron oxide
0- 1% Fish remains
1- 2% Chlorite

TEXTURE (Average from SS)
4% Sand
8% Silt
88% Clay

Carbonate Bomb: 1-39 to 40 cm = 10.0% $CaCO_3$

Carbon-Carbonate (DSDP)
2-31 (0.1, 0.1, 0)

Site 361 Hole Core 17 Cored Interval: 478.0-487.5 m



LITHOLOGIC DESCRIPTION

N3
N3
N3

SHALE
Dark gray (N3) mudstones. Parallel and cross-bedded fine sands and silts.
Heavy minerals: Zircon.

MINERALOGY
SS 1-135, 2-75, CC
10-15% Quartz
T Heavy minerals
82-83% Clay
T- 2% Zeolite
2- 4% Iron oxide
T Nannos
T Fish remains
0- 1% Chlorite

TEXTURE (Average from SS)
T Sand
15% Silt
84% Clay

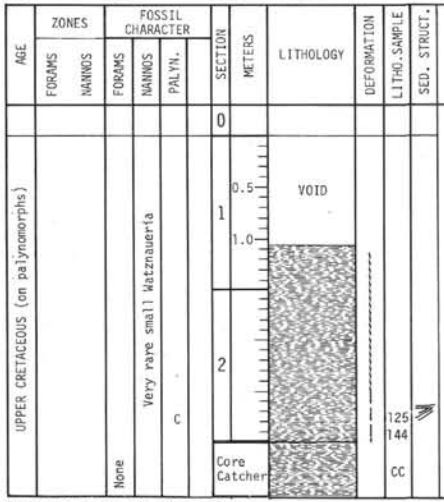
SANDSTONE
Dark gray (N3). Laminated, very fine grained.

Carbonate Bomb: 1-104-105 cm = 8.1% $CaCO_3$

Carbon-Carbonate (DSDP)
1-145 (0.2, 0.2, 0)

Grain Size (DSDP)
1-101 (0.1, 42.5, 57.4)

Site 361 Hole Core 18 Cored Interval: 525.5-535.0 m



LITHOLOGIC DESCRIPTION

N3
5B 6/1
(minor)
5GY 4/1-
5Y 4/1
N3

SHALE
Dark gray (N3), dark greenish gray to olive gray (5Y 4/1-5GY 4/1) mudstones and zeolitic mudstones. Mottled. Fine-sand laminations in places.
Heavy minerals: Epidote, Phosphorite.

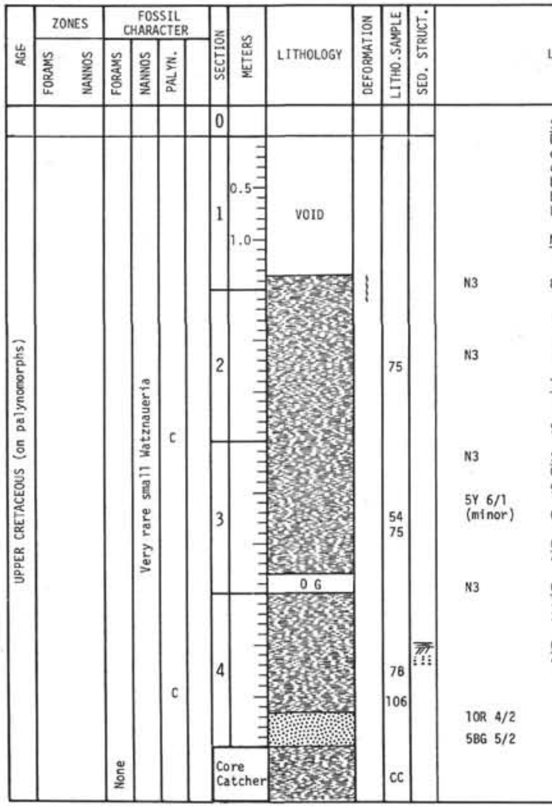
MINERALOGY
SS 2-125, 2-144, CC
5-10% Quartz
T- 1% Heavy minerals
71-80% Clay
0-20% Zeolite
2- 5% Iron oxide
0- 4% Nannos
0- 3% Fish remains
0- 1% Chlorite

TEXTURE (Average from SS)
1% Sand
22% Silt
77% Clay

Carbonate Bomb: 1-129 to 130 cm = 9.0% $CaCO_3$

Explanatory notes in Chapter 1

Site 361 Hole Core 19 Cored Interval: 573.0-582.5 m



LITHOLOGIC DESCRIPTION

SHALE

Dark gray (N3), mudstones, alternating with dark gray (N3) and grayish red (10R 4/2), claystones. Minor parallel and cross-bedded fine sands and silts. Slightly burrowed.
Heavy minerals: Zircon, Epidote.

MINERALOGY
3- 5% Quartz
T Heavy minerals
86-93% Clay
T- 5% Zeolite
0- T% Authigenic carbonate
1- 3% Iron oxide
0- 7% Nannos
0- 1% Fish remains

TEXTURE (Average from SS)
0% Sand
9% Silt
91% Clay

SANDSTONE

Grayish red (10R 4/2) and grayish blue green (5BG 5/2) calcareous sandstone.

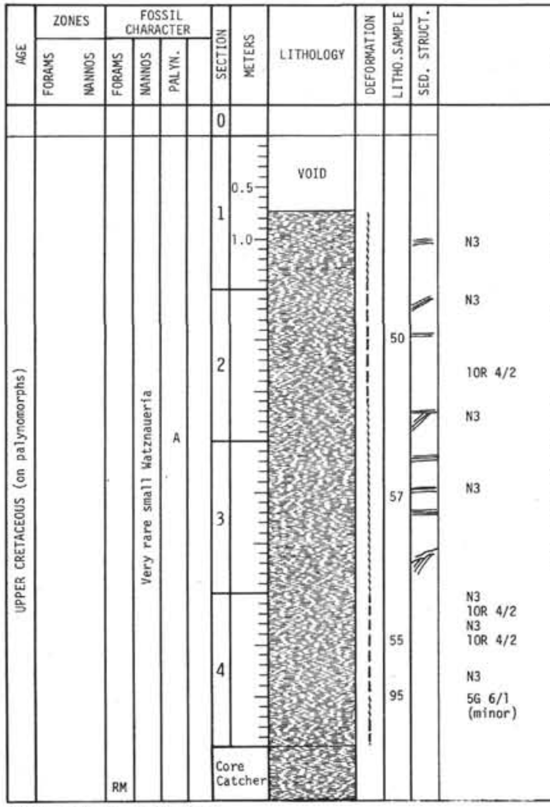
Carbonate Bomb: 2-15 to 16 cm = 7.6% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (2.1, 1.9, 2)

Carbon-Carbonate (OG)
3-130 (0.6, 0.6, 0)
3-150 (0.8, 0.9, 0)

Grain Size (DSDP)
4-88 (0.1, 42.5, 57.4)

Site 361 Hole Core 20 Cored Interval: 610.5-620.0 m



LITHOLOGIC DESCRIPTION

SHALE

Dark gray (N3) mudstones alternating with grayish red (10R 4/2) claystones. Parallel and cross-bedded silts and fine sands in mudstones. Minor thin convolute laminae. Slightly burrowed.
Heavy minerals: Zircon, Garnet, Epidote.

MINERALOGY
SS 2-5, 3-57, 4-55, 4-94
6-22% Quartz
T Mica
0- 1% Heavy minerals
63-86% Clay
T Pyrite
2- 8% Zeolite
0- 5% Iron oxide
T- 1% Fish remains

TEXTURE (Average from SS)
5% Sand
16% Silt
79% Clay

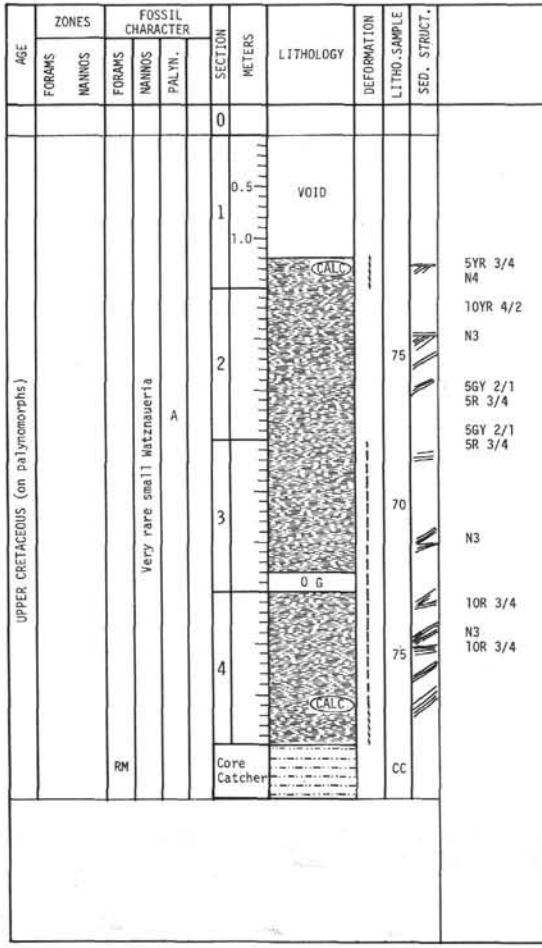
Carbonate Bomb: 2-69 to 71 cm = 8.1% $CaCO_3$

Carbon-Carbonate (DSDP)
3-23 (0.5, 0.5, 0)

Grain Size (DSDP)
4-20 (0.3, 20.2, 79.5)

Explanatory notes in Chapter 1

Site 361 Hole Core 21 Cored Interval: 668.0-677.5 m



LITHOLOGIC DESCRIPTION

SHALE
Dark gray (N3-N4) to greenish black (5GY 2/1) mudstones, alternating with dusky red (5YR 3/4), dark reddish brown (10R 3/4), and grayish red (10R 4/2) claystones and mudstones. Parallel and cross-bedded fine sands and silts. Minor calcareous concretions. Slightly burrowed.

MINERALOGY
SS 2-75, 3-70, 4-75
8-11% Quartz
0- 1% Feldspar
T Heavy minerals
83-90% Clay
0- 2% Iron oxide
T- 2% Zeolite
0- 7% Fish remains

TEXTURE (Average from SS)
0% Sand
13% Silt
88% Clay

SANDY MUDSTONE
Heavy minerals: Epidote, Zircon, Leugoxene, Garnet, Tourmaline, Sphene, Staurolite(?), Biotite.

MINERALOGY
SS CC
60% Quartz
4% Heavy minerals
20% Clay
10% Opaques
1% Pyrite
5% Chlorite

TEXTURE
50% Sand
30% Silt
20% Clay

Carbonate Bomb: 2-63 to 64 cm = 9.5% $CaCO_3$

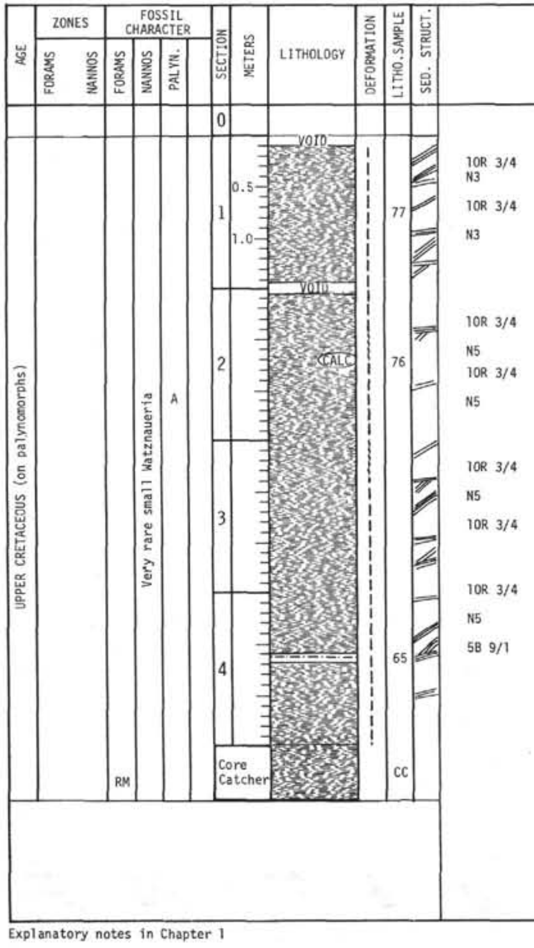
Carbon-Carbonate (DSDP)
3-95 (0.1, 0.1, 0)

Carbon-Carbonate (OG)
3-130 (0.2, 0.2, 0)
3-150 (0.2, 0.2, 0)

Grain Size (DSDP)
3-20 (0.1, 56.6, 43.3)

(CALC) = Calcareous concretion

Site 361 Hole Core 22 Cored Interval: 715.5-725.0 m



LITHOLOGIC DESCRIPTION

SHALE
Dark gray (N3) to medium dark gray (N5), mudstones, alternating with dark reddish brown (10R 3/4) claystones and mudstones. Gray mudstones occasionally grade into sandy mudstones. Parallel and cross-bedded silts and fine sands. Minor calcareous concretions. Slightly burrowed.

MINERALOGY
SS 1-77, CC
8-12% Quartz
T Feldspar
T Heavy minerals
75-80% Clay
5-10% Iron oxide
0- 7% Zeolite
T Nannos
T Fish remains

TEXTURE (Average from SS)
0% Sand
18% Silt
83% Clay

SANDY MUDSTONE
Bluish white (5B 9/1).
Heavy minerals: Epidote, Zircon, Tourmaline, Opaques, Chlorite, Sphene, Leucoxene.

MINERALOGY
71% Quartz
1% Feldspar
8% Heavy minerals
15% Clay
1% Iron oxide
1- 2% Pyrite
1% Zeolite
T Fish remains

TEXTURE
20% Sand
65% Silt
15% Clay

Carbonate Bomb: 3-63 to 64 cm = 6.6% $CaCO_3$

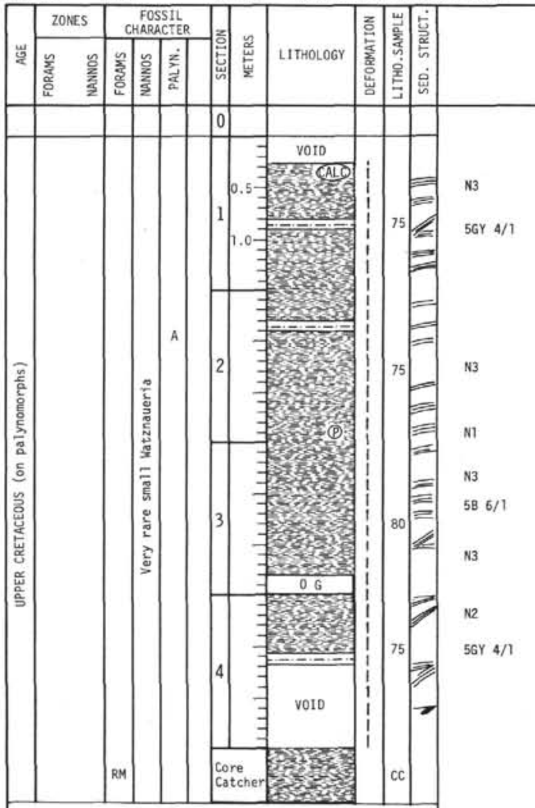
Carbon-Carbonate (DSDP)
4-20 (0.2, 0.2, 0)

Grain Size (DSDP)
4-88 (0.0, 15.9, 84.1)

(CALC) = Calcareous concretion

Explanatory notes in Chapter 1

Site 361 Hole Core 23 Cored Interval: 763.0-772.5 m



LITHOLOGIC DESCRIPTION

SHALE
Dark gray to black (N1-N3) mudstones, alternating with claystones of the same general color. Mudstones occasionally grade into sandy mudstones. Parallel and cross-bedded fine sands and silts. Slight burrowing minor calcareous concretions and pyrite.
Heavy minerals: Tourmaline, Zircon, Epidote, Opaques.

MINERALOGY
SS -75, 3-80, 4-75, CC
5-68% Quartz
0- 1% Feldspar
0- 2% Mica
T- 3% Heavy minerals
15-92% Clay
0- 5% Chlorite
0- 3% Pyrite
0- 5% Zeolite
0- 3% Fish remains

TEXTURE (Average from SS)
15% Sand
31% Silt
54% Clay

SANDY MUDSTONE
Dark greenish gray (5GY 4/1).
Heavy minerals: Epidote, Zircon, Tourmaline, Opaques.

MINERALOGY
SS 1-75
76% Quartz
2% Feldspar
3% Heavy minerals
15% Clay
1% Pyrite
T Zeolite
7% Chlorite
2% Fish remains

TEXTURE
40% Sand
40% Silt
20% Clay

Carbonate Bomb: 1-41 to 42 cm = 7.6% $CaCO_3$

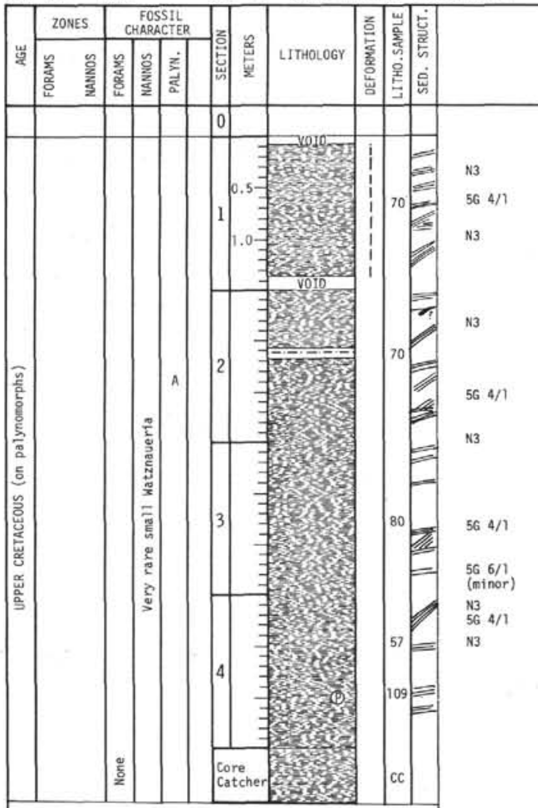
Carbon-Carbonate (DSDP)
4-20 (0.3, 0.1, 2)

Carbon-Carbonate (OG)
3-130 (1.2, 1.1, 0)
3-150 (0.5, 0.6, 0)

Grain Size (DSDP)
4-88 (0.0, 12.4, 87.5)

(CALC) = Calcareous concretion

Site 361 Hole Core 24 Cored Interval: 810.5-820.0 m



LITHOLOGIC DESCRIPTION

SHALE
Dark gray (N3) and dark greenish gray (5G 4/1) mudstones alternating with dark gray (N3) claystones. Mudstones grade into sandy mudstones. Parallel and cross-bedded fine sands and silts. Minor pyrite.
Heavy minerals: Zircon, Chlorite, Tourmaline, Opaques, Epidote.

MINERALOGY
SS 2-70, 3-80, 4-57, CC
20-45% Quartz
T- 3% Feldspar
0- 1% Mica
T- 1% Heavy minerals
T Authigenic carbonate
47-75% Clay
0- 1% Pyrite
1- 3% Zeolite
T Glauconite
T Plant debris

TEXTURE (Average from SS)
0% Sand
33% Silt
67% Clay

SANDY MUDSTONE
Dark greenish gray (5G 4/1).
Heavy minerals: Zircon, Epidote, Tourmaline

MINERALOGY
SS 1-70
58% Quartz
2% Feldspar
1% Mica
1% Heavy minerals
20% Clay
15% Chlorite
T Zeolite
2% Fish remains
T Plant debris

TEXTURE
60% Sand
15% Silt
25% Clay

Carbonate Bomb: 1-34 to 35 cm = 6.5% $CaCO_3$

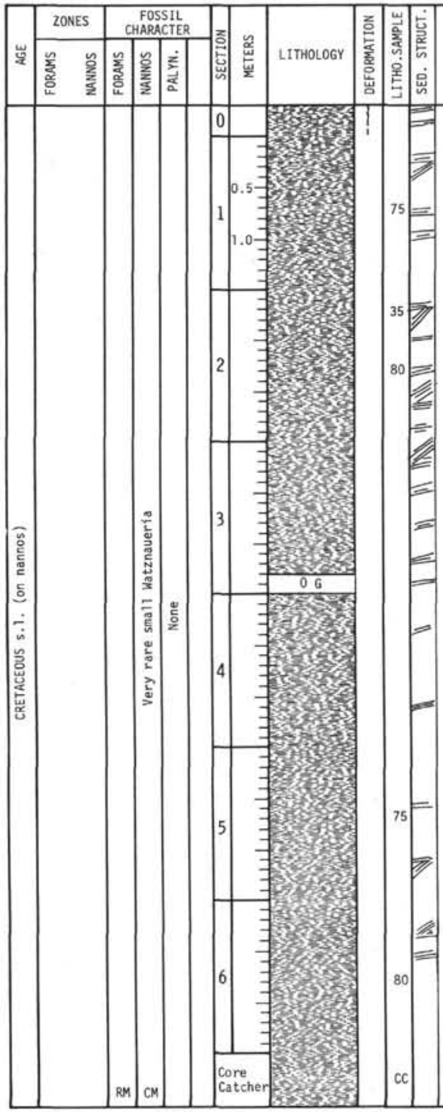
Carbon-Carbonate (DSDP)
4-26 (0.0, 0.0, 0)

Grain Size (DSDP)
4-84 (1.6, 49.5, 48.9)

Ⓟ = Pyrite nodule

Explanatory notes in Chapter 1

Site 361 Hole Core 25 Cored Interval: 858.0-867.5 m



LITHOLOGIC DESCRIPTION

5B 5/1
5R 3/4
5B 5/1
5R 3/4
5B 7/1
(minor)
5R 3/4
5B 5/1
5R 3/4
5B 8/1
5B 5/1
5R 3/4
5B 5/1
5R 3/4
5B 5/1
5R 3/4
5B 5/1
5R 3/4
5B 5/1
5R 3/4
5B 5/1

SHALE
Medium bluish gray (5B 5/1) mudstones, alternating with dusky red (5R 3/4) claystones. Parallel and cross-bedded fine sands and silts in the mudstones. Heavy minerals: Zircon, Epidote, Opaques, Monazite(?).

MINERALOGY
SS 1-75, 2-35, 2-80, 5-75, 6-80, CC
9-50% Quartz
0- 5% Feldspar
0- 1% Mica
T- 1% Heavy minerals
15-90% Clay
0- 1% Chlorite
0-30% Authigenic carbonate
0- 7% Pyrite

TEXTURE (Average from SS)
8% Sand
39% Silt
52% Clay

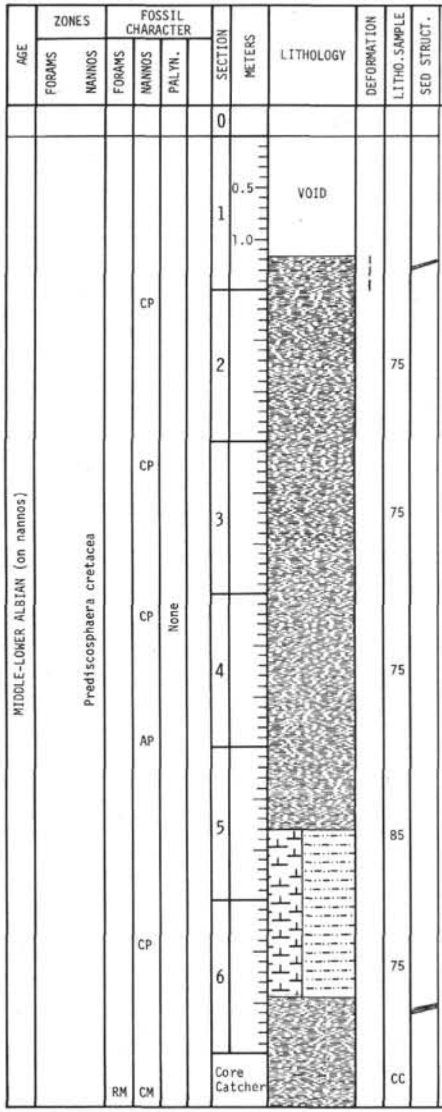
Carbonate Bomb: 1-22 to 23 cm = 8.2% $CaCO_3$

Carbon-Carbonate (DSDP)
4-22 (0.2, 0.0, 1)
6-22 (0.1, 0.1, 1)

Carbon-Carbonate (OG)
3-130 (0.2, 0.1, 1)
3-150 (0.2, 0.1, 1)

Grain Size (DSDP)
4-71 (0.0, 30.0, 70.0)
6-90 (0.1, 77.3, 22.6)

Site 361 Hole Core 26 Cored Interval: 907.5-915.0 m



LITHOLOGIC DESCRIPTION

5R 3/4
5G 6/1
5B 5/1
5B 7/1
(minor)
5R 3/4
5B 5/1
10R 3/4
5B 7/1
5B 7/1
5B 7/1
(minor)
10R 3/4
5B 5/1
(minor)
10R 4/6
5B 5/1
5B 5/1-
5B 7/1
10R 3/4

SHALE
Dusky red (5R 3/4) and medium bluish (5B 5/1). Burrowed.
Heavy minerals: Zircon, Epidote, Opaques, Garnet, Apatite, Sphene, Piedmontite.

MINERALOGY
SS 2-75, 3-75, 4-75, CC
1-40% Quartz
T Heavy minerals
0- 1% Mica
53-95% Clay
T- 4% Nannos
0- 5% Feldspar

TEXTURE (Average from SS)
0% Sand
11% Silt
89% Clay

MARLY NANNOFOSSIL CHALK
Medium bluish gray (5B 5/1). Intensely burrowed.

MINERALOGY
SS 5-85, 6-75
25-30% Quartz
35-45% Clay
30-35% Nannos

(minor)

TEXTURE (Average from SS)
0% Sand
45% Silt
55% Clay

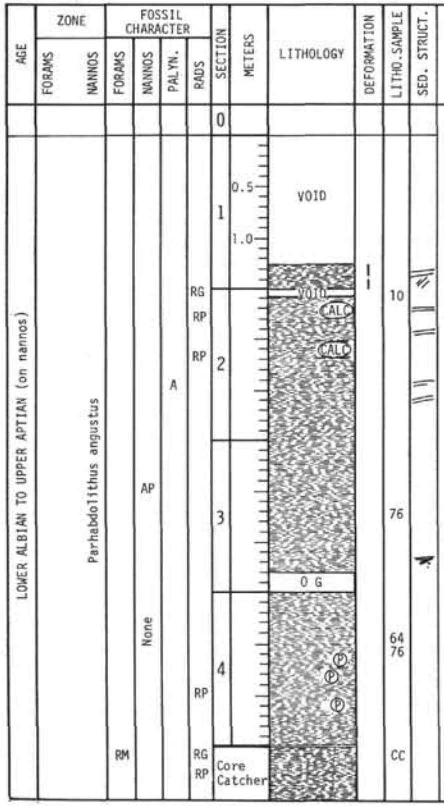
Carbonate Bomb: 5-12 to 13 cm = 17.3% $CaCO_3$

Carbon-Carbonate (DSDP)
4-103 (1.8, 0.1, 15)
6-19 (2.9, 0.1, 24)

Grain Size (DSDP)
4-88 (0.0, 24.1, 75.9)
6-82 (0.1, 21.5, 78.5)

Explanatory notes in Chapter 1

Site 361 Hole Core 27 Cored Interval: 953.0-962.5 m



LITHOLOGIC DESCRIPTION

SHALE
Dark gray (N3) and greenish black (5G 2/1). Minor bluish gray (5B 5/1-5B 7/1). Minor carbonaceous debris. Pyrite laminae (thin) and calcareous concretions. Composition of concretion at 2-10: 5% Quartz, 5% Clay, 90% Authigenic carbonate.

MINERALOGY
SS 3-76, 4-76, CC
15-60% Quartz
0- 2% Feldspar
1% Mica
T- 2% Heavy minerals
37-82% Clay
T Pyrite
T Zeolite

TEXTURE (Average from SS)
8% Sand
33% Silt
62% Clay

Carbonate Bomb: 4-28 to 29 cm = 7.4% $CaCO_3$

Carbon-Carbonate (DSDP)
4-14 (0.3, 0.1, 1)

Carbon-Carbonate (OG)
3-130 (0.7, 0.6, 0)
3-150 (0.9, 1.0, 0)

Grain Size (DSDP)
4-93 (7.4, 34.1, 58.5)

(CALC) = Calcareous concretion

Ⓟ = Pyrite nodule

5B 5/1-
5B 7/1

5G 2/1

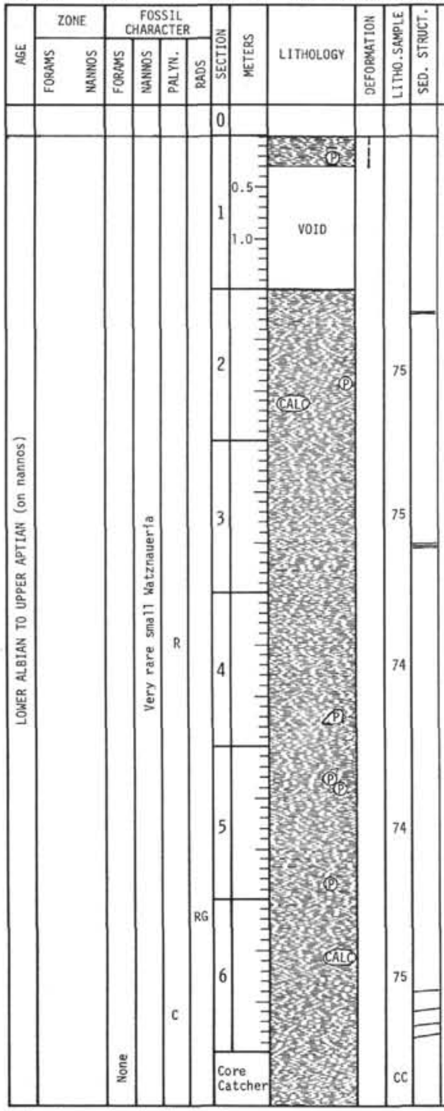
N3
5B 7/1
(minor)

N3

5B 5/1

5G 2/1

Site 361 Hole Core 28 Cored Interval: 1000.5-1010.0 m



LITHOLOGIC DESCRIPTION

SHALE
Grayish black (N2) to dark gray (N3). Richly carbonaceous in places.

MINERALOGY
SS 2-75, 3-75, 6-75
20% Quartz
0- 2% Feldspar
T Mica
T Heavy minerals
62-75% Clay
T Iron oxide
1- 6% Pyrite
0-15% Plant debris

TEXTURE (Average from SS)
0% Sand
27% Silt
72% Clay

Laminae and concretions of pyrite; calcareous concretions.

Carbonate Bomb: 5-14 to 15 cm = 4.6% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (3.5, 3.3, 1)
6-20 (11.0, 10.9, 1)

Grain Size (DSDP)
4-63 (0.0, 36.9, 63.1)

(CALC) = Calcareous concretion

Ⓟ = Pyrite nodule

N2

Thin calcareous layer
N2

N3

Fine sand

N3
Loading structures

Loading structure(?)

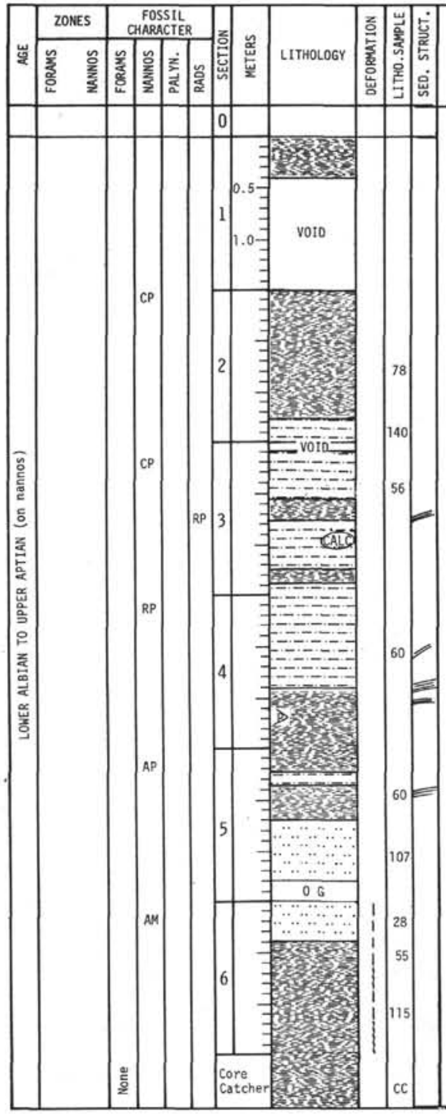
N3

N3
Loading structure

5B 7/1
(minor)
Thin pyrite laminae

Explanatory notes in Chapter 1

Site 361 Hole Core 29 Cored Interval: 1029.0-1038.5 m



LITHOLOGIC DESCRIPTION

N1
N1
N4
N4
N1
N1
5G 2/1
N1
N3
N1
N3
N1
Thin laminae
N1
N3
N1
5G 2/1
N1
5B 5/1 (minor)
Thin laminae, rich in nannos

SHALE
Black (N1). Richly carbonaceous. Heavy minerals: Tourmaline, Chlorite, Opaques.

MINERALOGY
SS 5-60, 6-55

T Heavy minerals	40-65% Quartz
T Authigenic carbonate	0- 1% Mica
2- 4% Feldspar	10-29% Clay
10-25% Plant debris	1-10% Nannos

TEXTURE (Average from SS)
0% Sand, 74% Silt, 26% Clay

SANDY MUDSTONE
Dark gray (N3-N4), greenish black (5G 2/1). Richly carbonaceous. Heavy minerals: Zircon, Opaques, Chlorite, Garnet, Apatite, Tourmaline.

MINERALOGY

2% Heavy minerals	1- 2% Mica
50-80% Quartz	0- 2% Nannos
0- 5% Feldspar	9-15% Clay
0- 1% Authigenic carbonate	2% Pyrite
4-20% Plant debris	

TEXTURE (Average from SS)
50% Sand, 38% Silt, 12% Clay

SILTSTONE
Greenish black (5G 2/1). Richly carbonaceous. Heavy minerals: Chlorite.

MINERALOGY
SS 5-107, 6-28

75-85% Quartz	T- 1% Mica
3- 5% Feldspar	5-10% Clay
T Heavy minerals	1- 3% Pyrite
T Glauconite	T Nannos
1- 7% Plant debris	

TEXTURE (Average from SS)
17% Sand, 75% Silt, 8% Clay

Carbonate Bomb: 4-29 to 30 cm = 8.2% $CaCO_3$

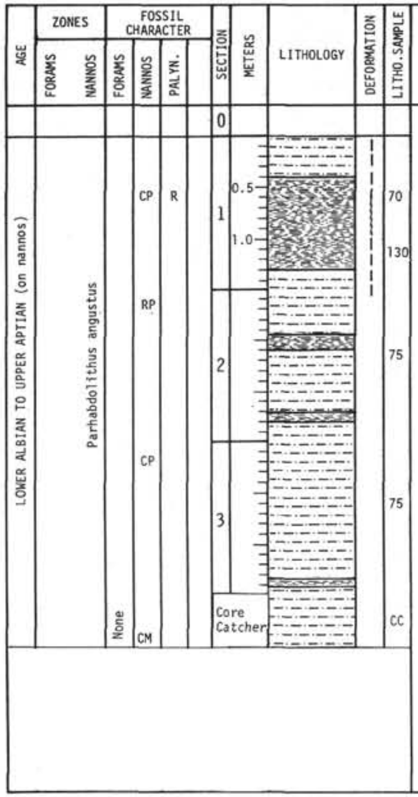
Carbon-Carbonate (DSDP)
4-20 (2.5, 2.5, 0)
6-20 (16.2, 14.6, 14)

Carbon-Carbonate (OG)
5-130 (5.9, 6.1, 0)
5-150 (0.9, 0.8, 0)

Grain Size (DSDP)
4-88 (10.0, 47.2, 42.8)
6-88 (0.2, 44.9, 54.9)

(CALC) = Calcareous concretion
Ⓟ = Pyrite nodule

Site 361 Hole Core 30 Cored Interval: 1038.5-1048.0 m



LITHOLOGIC DESCRIPTION

5G 4/1
N1
5G 4/1
5G 4/1
N3
Coal layer
N1
N4

SHALE
Black (N1) to dark gray (N3). Carbonaceous. Heavy minrals: Zircon, Garnet, Chlorite, Epidote, Tourmaline.

MINERALOGY
SS 1-70, 1-130, 2-75
10-58% Quartz
1- 4% Feldspar
0- 1% Mica
0- 1% Heavy minerals
0- 1% Authigenic carbonate
15-62% Clay
1- 8% Pyrite
T Nannos
10-25% Plant debris

TEXTURE (Average from SS)
13% Sand
53% Silt
34% Clay

SANDY MUDSTONE
Dark greenish gray (5G 4/1) to medium dark gray (N4). Calcareous. Richly carbonaceous. Thin coal layer in Section 2. Heavy minerals: Zircon, Garnet, Sphene.

MINERALOGY
SS 3-75
50% Quartz
5% Feldspar
1% Heavy minerals
30% Clay
3% Pyrite
1% Authigenic carbonate
T Nannos
10% Plant debris

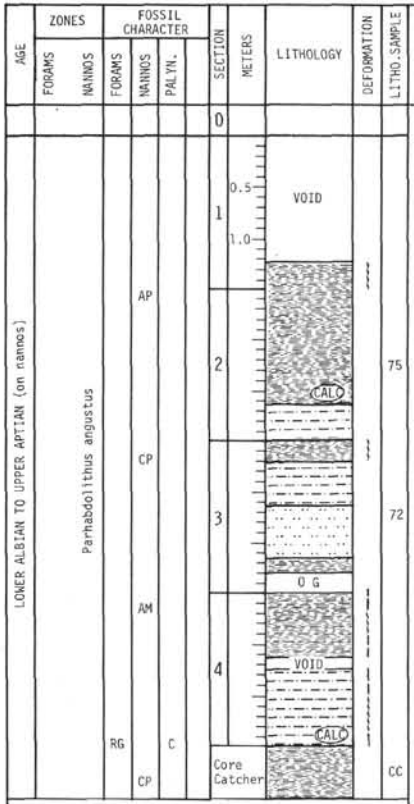
Carbonate Bomb: 2-29 to 30 cm = 7.3% $CaCO_3$

Carbon-Carbonate (DSDP)
1-104 (2.7, 2.5, 2)

Grain Size (DSDP)
2-120 (3.1, 36.5, 60.3)

Explanatory notes in Chapter 1

Site 361 Hole Core 31 Cored Interval: 1048.0-1057.5 m



LITHOLOGIC DESCRIPTION

5G 4/1
N1
N1
5GY 2/1
5GY 2/1
Incipient concretion?
5GY 2/1
Slump
Ripple marks
N1
5G 4/1

SHALE
Black (N1) to dark greenish gray (5G 4/1). Calcareous concretions. Richly carbonaceous. Slightly burrowed. Heavy minerals: Zircon. Dolmite spheroids and pollen (CC).

MINERALOGY
SS 2-75, 4-90, CC
35-52% Quartz
3- 5% Feldspar
T Mica
T- 1% Heavy minerals
30-42% Clay
T Authigenic carbonate
T Glauconite
2- 3% Pyrite
0-12% Dolomite
0- 1% Zeolite
0- 1% Nannos
10-15% Plant debris

TEXTURE (Average from SS)
7% Sand
56% Silt
38% Clay

SILTSTONE
Greenish black (5GY 2/1). Thinly laminated, ripple marks. Heavy minerals: Zircon.

MINERALOGY
SS 3-72
65% Quartz
5% Feldspar
T Mica
T Heavy minerals
10% Clay
20% Authigenic carbonate
T Nannos
5% Plant debris

TEXTURE
5% Sand
85% Silt
10% Clay

Carbonate Bomb: 2-30 to 31 cm = 8.2% $CaCO_3$

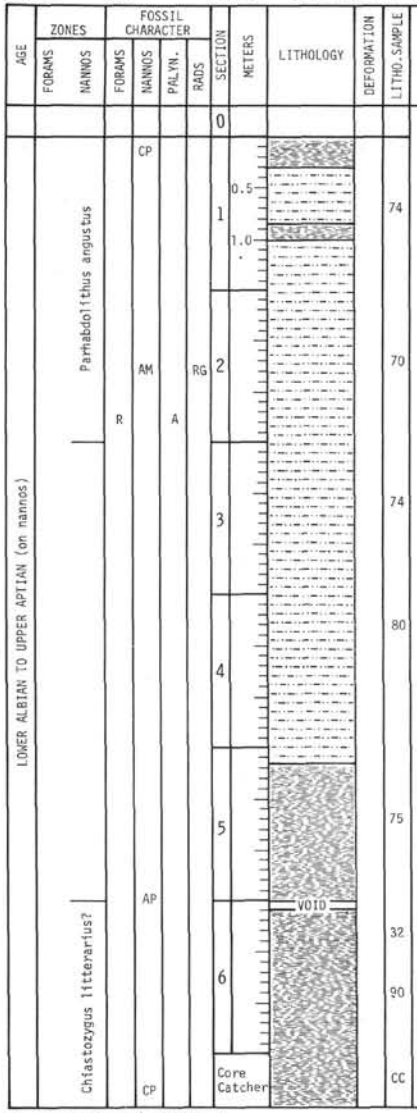
Carbon-Carbonate (DSDP)
4-20 (5.1, 5.0, 1)

Carbon-Carbonate (OG)
3-130 (3.8, 3.7, 1)
3-150 (10.1, 10.0, 1)

Grain Size (DSDP)
4-82 (9.6, 54.6, 36.8)

(CALC) = Calcareous concretion

Site 361 Hole Core 32 Cored Interval: 1057.5-1067.0 m



LITHOLOGIC DESCRIPTION

N1
N1
5G 2/1
Flow structures
N1
5G 4/1
5G 4/1
Flow structures
Flow structure
5G 2/1
5G 2/1
5G 2/1
N3
N3
N3
10YR 7/4 (minor)

MUDSTONE
Greenish black (5G 2/1) to dark greenish gray (5G 4/1). Richly carbonaceous. Granule-size plant debris. Flow structures. Calcareous in places. Heavy minerals: Zircon, Chlorite, Tourmaline.

MINERALOGY
1-75, 2-70, 3-74, 4-80
20-53% Quartz
1- 5% Feldspar
T Mica
T Heavy minerals
20-73% Clay
0- 4% Pyrite
0- 7% Glauconite
T- 1% Dolomite
T Zeolite
T-10% Authigenic carbonate
T- 3% Nannos
5-10% Plant debris

TEXTURE (Average from SS)
21% Sand, 38% Silt, 41% Clay

SHALE
Black (N1) to dark gray (N3). Slightly calcareous, minor fine sand laminae. Richly carbonaceous. Pollen.

MINERALOGY
SS 5-75, 6-32, CC
12-20% Quartz
T- 1% Feldspar
T Mica
T Heavy minerals
44-60% Clay
1- 3% Pyrite
0- 3% Authigenic carbonate
T Zeolite
4- 9% Nannos
10-30% Plant debris

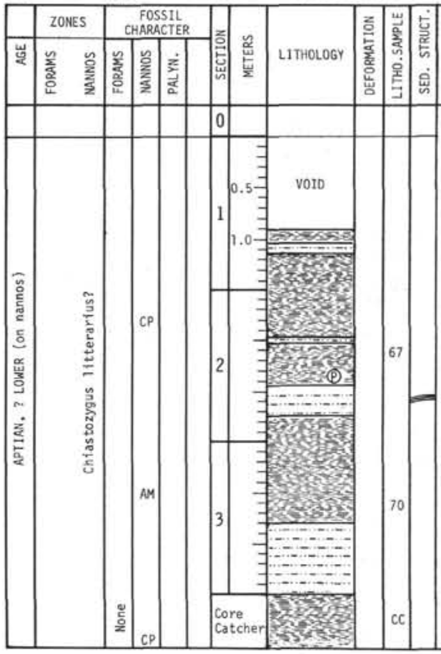
TEXTURE (Average from SS)
1% Sand, 45% Silt, 54% Clay

Carbonate Bomb: 1-36 to 38 cm = 9.1% $CaCO_3$

Carbon-Carbonate (DSDP)
4-22 (2.6, 2.3, 3)
6-17 (7.7, 5.6, 17)

Explanatory notes in Chapter 1

Site 361 Hole Core 33 Cored Interval: 1067.0-1076.5 m



LITHOLOGIC DESCRIPTION

N1

Pyrite laminae

N1

Microfault

10YR 7/4 (minor)

Flow structure

5G 4/1

SHALE
Black (N1). Thin layers of carbonaceous mudstone. Pyrite laminae and concretions. Heavy minerals: Zircon, Tourmaline, Chlorite.

MINERALOGY
SS 2-67, CC
20-40% Quartz
0- 2% Feldspar
T Mica
T Heavy minerals
43-65% Clay
4- 8% Pyrite
0- 3% Nannos
T Fish remains
8-10% Plant debris

TEXTURE (Average from SS
3% Sand, 40% Silt, 57% Clay

MUDSTONE
Dark greenish gray (5G 4/1). Thinly laminated to massive. Richly carbonaceous. Minor flow structures.

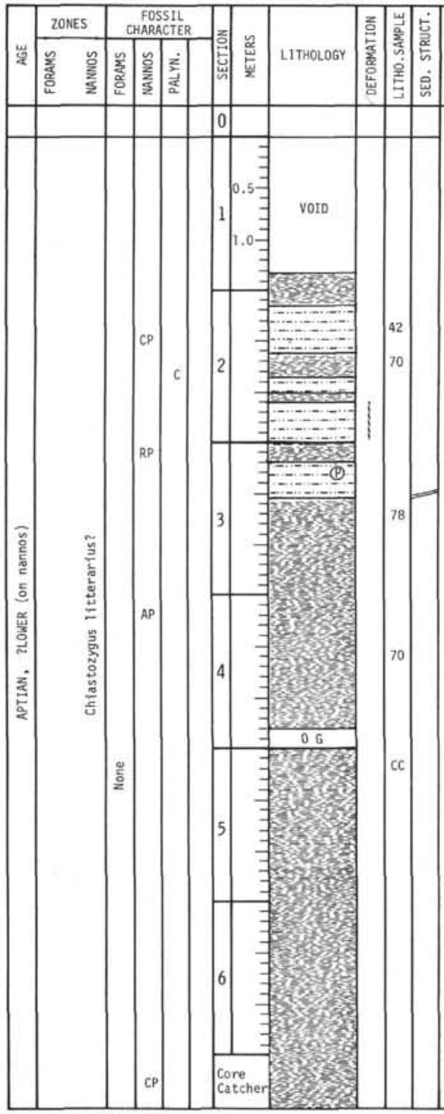
Carbonate Bomb: 3-22 to 23 cm = 22.7% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (4.6, 3.2, 1)

Grain Size (DSDP)
2-84 (23.0, 41.7, 35.3)

Ⓟ = Pyrite nodule

Site 361 Hole Core 34 Cored Interval: 1076.5-1086.0 m



LITHOLOGIC DESCRIPTION

N1

Calcareous layer (2 cm) (nanno chalk)
N3
N3

N3
Very thin calcareous layers
pyrite laminae
N1
Fine sands

Pyrite laminae

Pyritized

N1

SHALE
Black (N1). Carbonaceous.

MINERALOGY
SS 2-70, 3-78, 4-70
10-48% Quartz
0- 5% Feldspar
T Mica
T Heavy minerals
25-62% Clay
2- 5% Pyrite
T Zeolite
T Authigenic carbonate
1-15% Nannos
10-15% Plant debris

TEXTURE (Average from SS)
7% Sand
45% Silt
48% Clay

MUDSTONE
Dark gray (N3). Massive, minor thin laminae. Richly carbonaceous. Thin calcareous layers. Pyrite laminae and concretions.

Carbonate Bomb: 2-23 to 24 cm = 7.7% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (4.3, 3.9, 3)

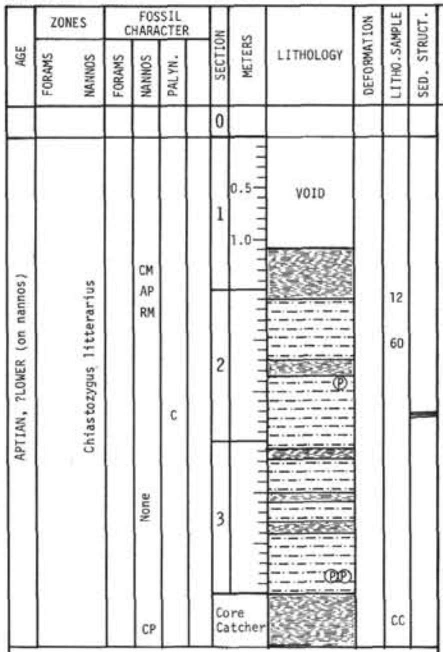
Carbon-Carbonate (OG)
4-130 (11.3, 10.7, 5)
4-150 (9.5, 6.9, 22)

Grain Size (DSDP)
3-48 (8.0, 49.7, 42.3)

Ⓟ = Pyrite nodule

Explanatory notes in Chapter 1

Site 361 Hole Core 35 Cored Interval: 1086.0-1095.5 m



LITHOLOGIC DESCRIPTION

Calcareous layer 10YR 7/4
5YR 2/1
5B 5/1
N1
Loading structure 5G 2/1
Pyrite laminae
5G 2/1
N1
5B 5/1

SHALE
Black (N1) to brownish black (5YR 2/1).

MINERALOGY
SS 2-12, CC
15-60% Quartz
1- 2% Feldspar
T- 1% Mica
T Heavy minerals
20-55% Clay
2- 3% Pyrite
0-10% Authigenic carbonate
0-10% Nannos
4-15% Plant debris

TEXTURE (Average from SS)
8% Sand
52% Silt
40% Clay

SANDY MUDSTONE -
Medium bluish gray (5B 5/1) to greenish black (5G 2/1). Massive. Minor thin laminae. Richly carbonaceous. Pyrite concretions.
Heavy minerals: Zircon.

MINERALOGY
SS 2-60
55% Quartz
2% Feldspar
1% Mica
20% Clay
1% Pyrite
15% Authigenic carbonate
1% Nannos
5% Plant debris

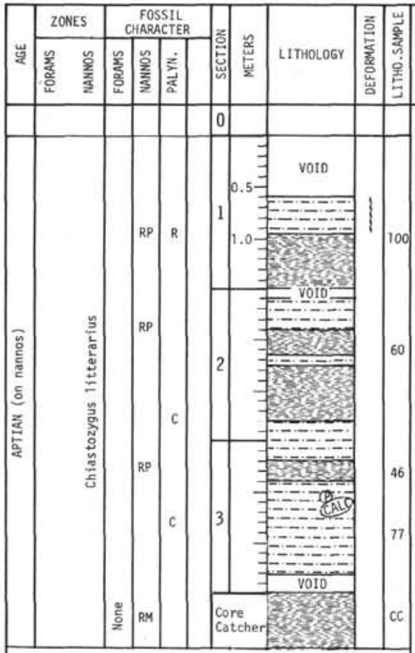
TEXTURE (Average from SS)
40% Sand
30% Silt
20% Clay

Carbonate Bomb: 2-126 to 127 cm = 6.4% $CaCO_3$

Carbon-Carbonate (DSDP)
2-145 (1.6, 1.6, 0)

Ⓟ = Pyrite nodule

Site 361 Hole Core 36 Cored Interval: 1095.5-1105.0 m



LITHOLOGIC DESCRIPTION

5B 5/1
N1
N1
5G 2/1
N1
5B 5/1
Intraformational conglomerate

SHALE
Black (N1). Richly carbonaceous.
Heavy minerals: Garnet, Zircon.

MINERALOGY
SS 1-100, 2-60, 3-46, CC
25-57% Quartz
0- 4% Feldspar
T Mica
T Heavy minerals
15-35% Clay
3- 6% Pyrite
0- 1% Zeolite
0- 3% Authigenic carbonate
T-22% Nannos
15-20% Plant debris

TEXTURE (Average from SS)
13% Sand
75% Silt
35% Clay

SANDY MUDSTONE
Medium bluish gray (5B 5/1) to greenish black (5G 2/1). Mostly massive. Richly carbonaceous. Calcareous and pyritic concretions.

Carbonate Bomb: 2-48 to 49 cm = 8.2% $CaCO_3$

Carbon-Carbonate (DSDP)
2-20 (2.5, 2.5, 0)

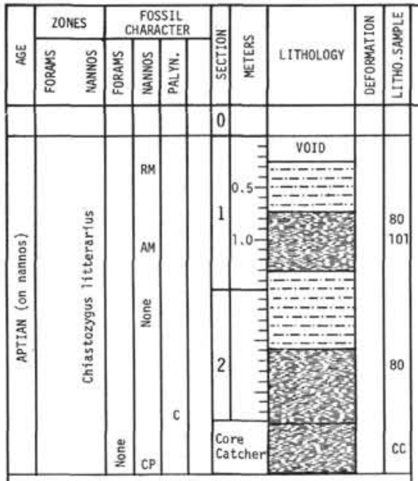
Carbon-Carbonate (OG)
3-130 (6.7, 6.7, 0)
3-150 (2.5, 2.0, 4)

Grain Size (DSDP)
2-80 (54.7, 31.0, 14.4)

Ⓟ = Pyrite nodule
(CALC) = Calcareous concretion

Explanatory notes in Chapter 1

Site 361 Hole Core 37 Cored Interval: 1105.0-1114.5 m



LITHOLOGIC DESCRIPTION

5B 5/1

N1
Thin white laminae
100% Nannos
5B 2/1

5G 2/1

N1

SHALE
Black (N1). Very thin fine sand laminae. Carbonaceous.

MINERALOGY
SS 1-80, 2-80, CC
10-40% Quartz
T- 3% Feldspar
T Mica
T Heavy minerals
30-50% Clay
4-27% Pyrite
0- 1% Zeolite
T- 3% Nannos
10-25% Plant debris

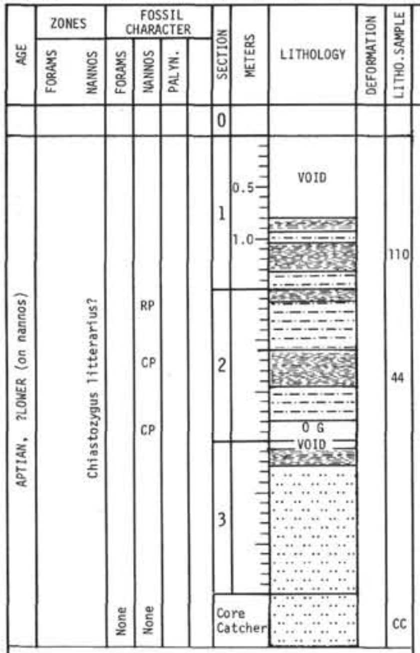
TEXTURE (Average from SS)
5% Sand
45% Silt
50% Clay

SANDY MUDSTONE
Medium bluish gray (5B 5/1) to greenish black (5G 2/1). Richly carbonaceous.

Carbonate Bomb: 1-45 to 46 cm = 7.3% $CaCO_3$

Carbon-Carbonate (DSDP)
1-46 (1.1, 0.7, 3)

Site 361 Hole Core 38 Cored Interval:1114.5-1124.0 m



LITHOLOGIC DESCRIPTION

5G 4/1
5YR 2/1
N1
5G 2/1
5G 2/1
N1
N3
5B 5/1

SHALE
Black (N1). Carbonaceous.

MINERALOGY
SS 1-110
35% Quartz
2% Feldspar
T Mica
T Heavy minerals
30% Clay
10% Pyrite
T Zeolite
4% Nannos
20% Fish remains

TEXTURE
5% Sand
45% Silt
50% Clay

SANDY MUDSTONE
Dark greenish gray (5G 4/1) to dark gray N3. Mostly massive, some thin laminae. Richly carbonaceous.

SILTSTONE
Medium bluish gray (5B 5/1). Calcareous.

MINERALOGY
SS CC
43% Quartz
2% Feldspar
T Mica
T Heavy minerals
5% Clay
1% Pyrite
45% Authigenic carbonate
3% Plant debris

TEXTURE
15% Sand
75% Silt
10% Clay

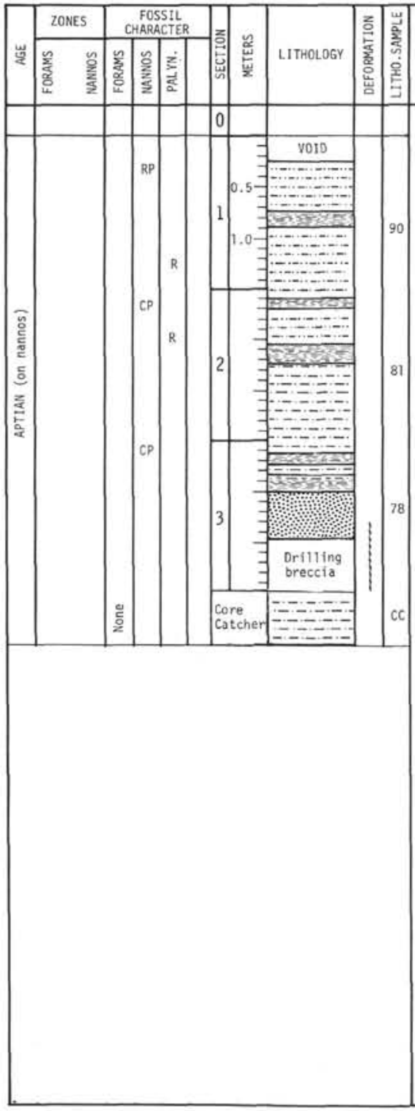
Carbonate Bomb: 2-36 to 37 cm = 8.2% $CaCO_3$

Carbon-Carbonate (DSDP)
3-75 (4.7, 0.4, 36)

Carbon-Carbonate (OG)
2-130 (2.8, 2.6, 1)
2-150 (3.0, 2.8, 1)

Explanatory notes in Chapter 1

Site 361 Hole Core 39 Cored Interval: 1124.0-1133.5 m



LITHOLOGIC DESCRIPTION

5G 4/1
N1
5G 2/1
5GY 4/2
N1
5G 2/1
5G 4/1
N1
N1
5G 2/1

MUDSTONE
Dark greenish gray (5G 4/1) to greenish black (5G 2/1). Massive, carbonaceous. Some graded bedding.

MINERALOGY
SS 1-90
40% Quartz
3% Feldspar
T Mica
T Heavy minerals
39% Clay
3% Pyrite
6% Zeolite
T Nannos
10% Plant debris

TEXTURE
25% Sand
32% Silt
43% Clay

SANDY MUDSTONE
Greenish black (5G 2/1) to dark greenish gray (5G 4/1). Massive, with some fine sand laminae. Richly carbonaceous.
Heavy minerals: Zircon, Tourmaline.

MINERALOGY
SS 2-81, CC
45% Quartz
1% Feldspar
T- 1% Mica
T Heavy minerals
35-38% Clay
2-10% Chlorite
1% Pyrite
0- 4% Zeolite
0- 1% Nannos
2-12% Plant debris

TEXTURE (Average from SS)
33% Sand
26% Silt
41% Clay

SANDSTONE
Greenish black (5G 2/1), massive, slightly carbonaceous.
Heavy minerals: Zircon, Garnet.

MINERALOGY
SS 3-78

70% Quartz	3% Pyrite
1% Feldspar	4% Authigenic carbonate
1% Mica	8% Plant debris
12% Clay	

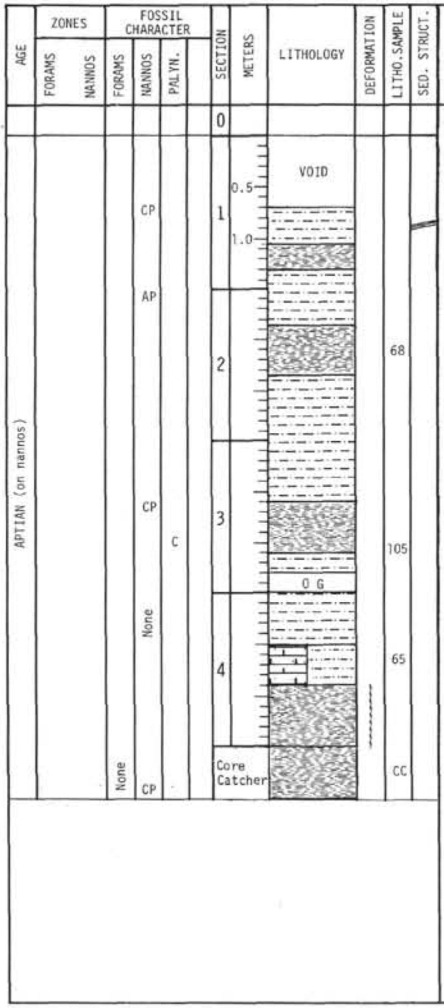
TEXTURE
45% Sand, 40% Silt, 15% Clay

Carbonate Bomb: 1-39 to 40 cm = 8.2% $CaCO_3$

Carbon-Carbonate (DSDP)
3-24 (2.1, 2.3, 0)

Grain Size (DSDP)
3-88 (35.4, 48.0, 16.7)

Site 361 Hole Core 40 Cored Interval: 1143.0-1152.5 m



LITHOLOGIC DESCRIPTION

N1
N1
N3
N1
5G 4/1
5G 5/1
5YR 2/1
5G 2/1
5G 5/1
10YR 7/4
microfaulting
N1

SHALE
Black (N1), minor brownish black (5YR 2/1). Carbonaceous.

MINERALOGY
SS 2-68, 3-105, CC
35-45% Quartz
T- 1% Feldspar
T Mica
T Heavy minerals
33-38% Clay
2-15% Pyrite
0- 3% Zeolite
7-20% Plant debris

TEXTURE (Average from SS)
5% Sand
57% Silt
39% Clay

SANDY MUDSTONE
Dark greenish gray (5G 4/1) to medium bluish gray (5B 5/1). Mostly massive, but thinly laminated in places.

MARLY NANNOFOSSIL CHALK
Grayish orange (10YR 7/4). Slump folding.

MINERALOGY
SS 4-65
20% Quartz
T Feldspar
T Mica
T Heavy minerals
18% Clay
1% Pyrite
50% Authigenic carbonate
10% Nannos
T Plant debris

TEXTURE
0% Sand
70% Silt
30% Clay

Carbonate Bomb: 4-5 to 6 cm = 7.5% $CaCO_3$

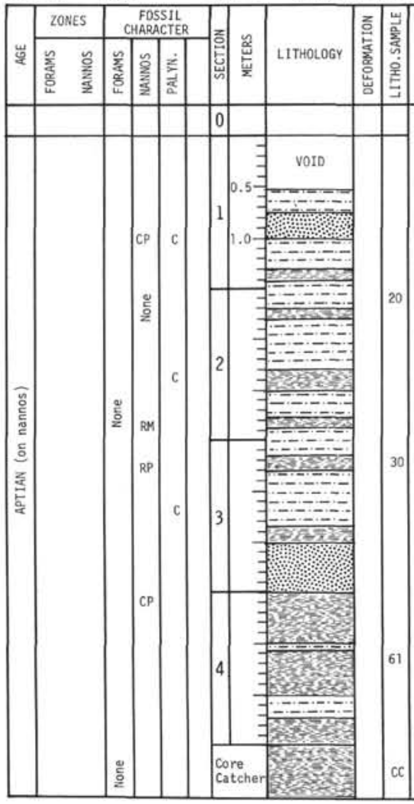
Carbon-Carbonate (DSDP)
2-76 (3.4, 2.9, 4)
4-54 (8.6, 3.3, 44)

Carbon-Carbonate (OG)
3-130 (1.3, 1.2, 1)
3-150 (7.6, 7.5, 0)

Grain Size (DSDP)
2-138 (40.7, 42.9, 16.4)

Explanatory notes in Chapter 1

Site 361 Hole Core 41 Cored Interval: 1162.0-1171.5 m



LITHOLOGIC DESCRIPTION

5G 4/1
5B 5/1
5GY 2/1
N1
5GY 2/1
N3
5GY 2/1
5YR 2/1
N1
5YR 2/1
N1
5G 4/1
5B 5/1
N1
N1
5G 2/1

SHALE
Black (N1) to dark gray (N3). Minor brownish black (5YR 2/1). Calcareous spheroids (40-60 m) in core catcher. Heavy minerals: Zircon, Garnet, Tourmaline.

MINERALOGY
SS 2-20, 4-61, CC
30-45% Quartz
0- 2% Feldspar
23-40% Clay
2- 7% Pyrite
1- 3% Authigenic carbonate
T- 1% Nannos
20-25% Plant debris

TEXTURE (Average from SS)
13% Sand
50% Silt
38% Clay

SANDY MUDSTONE
Dark greenish gray (5G 4/1) to greenish black (5GY 2/1). Massive, richly carbonaceous.

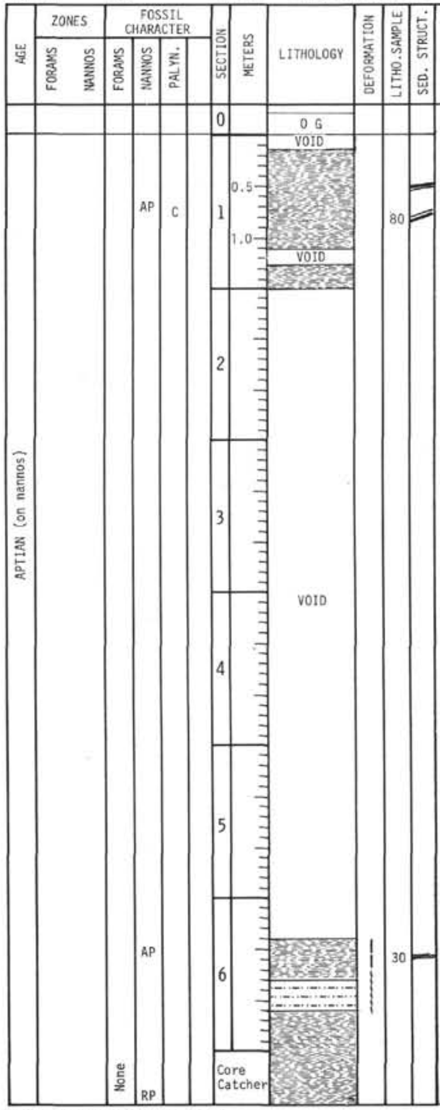
SANDSTONE
Medium bluish gray (5B 5/1). Well indurated by carbonate cement.

Carbonate Bomb: 2-15 to 16 cm = 8.0% $CaCO_3$

Carbon-Carbonate (DSDP)
4-20 (3.7, 3.3, 4)

Grain Size (DSDP)
4-88 (1.1, 47.1, 51.8)

Site 361 Hole Core 42 Cored Interval: 1181.0-1190.5 m



LITHOLOGIC DESCRIPTION

N1
10YR 7/4
(minor)
N1

N1
10YR 8/2
(minor)
N4
N1

SHALE
Black (N1), with minor grayish orange (10YR 7/4) and very pale orange (10YR 8/2) thin laminae of marly nannofossil chalk (45-47% nannos). Carbonaceous.

MINERALOGY
SS CC
30% Quartz
1% Feldspar
T Mica
T Heavy minerals
51% Clay
2% Pyrite
T Nannos
15% Plant debris

TEXTURE
20% Sand
28% Silt
52% Clay

MUDSTONE
Medium dark gray (N4). Finely laminated.

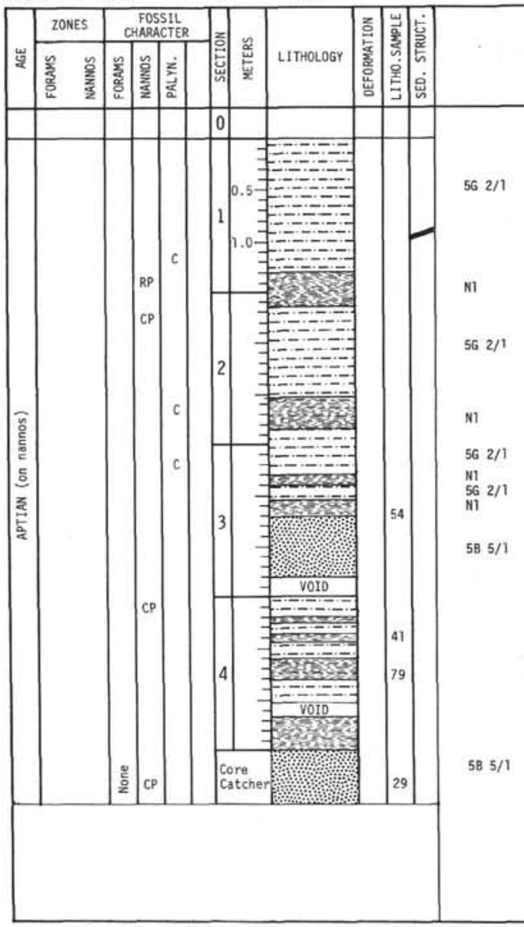
Carbonate Bomb: 1-34 to 35 cm = 16.5% $CaCO_3$

Carbon-Carbonate (DSDP)
1-20 (16.1, 13.4, 23)

Carbon-Carbonate (OG)
0-0 (5.6, 4.6, 8)
0-20 (2.6, 1.2, 12)

Explanatory notes in Chapter 1

Site 361 Hole Core 43 Cored Interval: 1200.0-1209.5 m



LITHOLOGIC DESCRIPTION

SHALE
Black (N1). Carbonaceous. Fine sand laminae. Pollen.
Heavy minerals: Zircon, Epidote, Chlorite, Tourmaline, Opaques.

MINERALOGY
SS 3-54, 4-41, 4-79
28-46% Quartz
0- 5% Feldspar
T Mica
0- 2% Heavy minerals
20-40% Clay
6-10% Pyrite
T Zeolite
0-12% Authigenic carbonate
1- 2% Nannos
15-20% Plant debris

TEXTURE (Average from SS)
15% Sand
46% Silt
36% Clay

SANDY MUDSTONE
Greenish black (5G 2/1). Mostly massive. Richly carbonaceous.

SANDSTONE
Medium bluish gray (5B 5/1). Calcareous cement - well-indurated.

MINERALOGY
SS 5-29
50% Quartz
T Mica
T Chlorite
50% Authigenic carbonate (as cement)
3% Plant debris

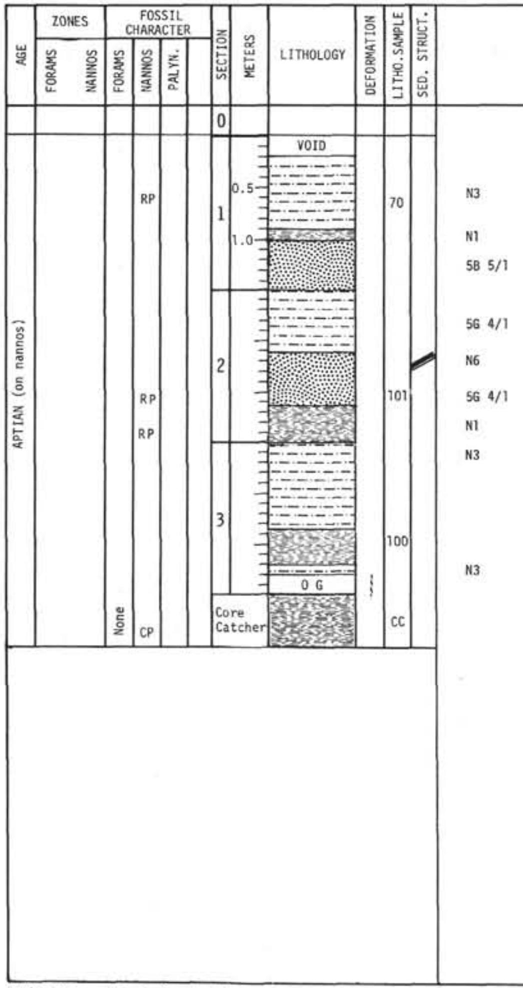
TEXTURE
60% Sand
40% Silt
0% Clay

Carbonate Bomb: 2-89 to 91 cm = 18.4% $CaCO_3$

Carbon-Carbonate (DSDP)
2-49 (4.2, 3.7, 4)
3-4 (1.1, 0.8, 2)

Grain Size (DSDP)
3-6 (60.6, 29.1, 10.4)

Site 361 Hole Core 44 Cored Interval: 1219.0-1228.5 m



LITHOLOGIC DESCRIPTION

SHALE
Black (N1). Carbonaceous. Heavy minerals: Zircon, Tourmaline.

MINERALOGY
SS 3-100, CC

46-47% Quartz	T Mica
2- 3% Feldspar	25-30% Clay
T Heavy minerals	4-15% Pyrite
T Zeolite	T Nannos
10-15% Plant debris	

TEXTURE (Average from SS)
15% Sand, 55% Silt, 30% Clay

SANDY MUDSTONE
Dark gray (N3) to dark greenish gray (5G 4/1). Richly carbonaceous. Heavy minerals: Zircon, Tourmaline.

MINERALOGY
SS 1-70

55% Quartz	T Mica
3% Feldspar	24% Clay
T Heavy minerals	4% Pyrite
T- 1% Zeolite	T Nannos
15% Plant debris	

TEXTURE
50% Sand, 25% Silt, 25% Clay

SANDSTONE
Medium bluish white (5B 5/1), medium light gray (N6), and dark greenish gray (5G 4/1). Well-indurated by calcite cement. Cross-bedding in Section 2. Slightly carbonaceous.

MINERALOGY

45% Quartz	2% Feldspar
4% Authigenic carbonate (as cement)	T Mica
	4% Pyrite
5% Plant debris	24% Clay
T Heavy minerals	

TEXTURE (Non-carb. only)
55% Sand, 35% Silt, 10% Clay

Carbonate Bomb: 3-70 to 72 cm = 9.4% $CaCO_3$

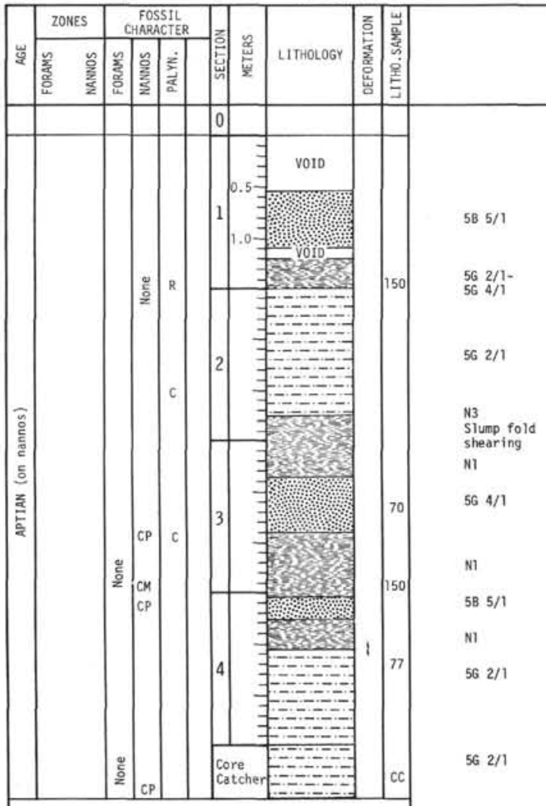
Carbon-Carbonate (DSDP)
3-13 (1.4, 1.3, 1)

Carbon-Carbonate (OG)
3-130 (3.6, 3.7, 0)
3-150 (1.7, 1.6, 1)

Grain Size (DSDP)
3-0 (58.3, 29.9, 11.8)

Explanatory notes in Chapter 1

Site 361 Hole Core 45 Cored Interval: 1238.0-1247.5 m



LITHOLOGIC DESCRIPTION

SHALE
Black (N1) to dark gray (N3) minor greenish black (5G 2/1) to dark greenish gray (5G 4/1). Carbonaceous, sandy.

MINERALOGY
SS 1-150, 3-150
30-55% Quartz
3- 4% Feldspar
T Mica
T Heavy minerals
20-37% Clay
0- 2% Chlorite
10% Pyrite
T- 4% Nannos
8-15% Plant debris

TEXTURE (Average from SS)
12% Sand, 57% Silt, 31% Clay

SANDY MUDSTONE
SS 4-77, CC
51% Quartz
4% Feldspar
T Mica
T Heavy minerals
25% Clay
3% Pyrite
T Authigenic carbonate
T- 1% Nannos
15% Plant debris

TEXTURE
48% Sand, 26% Silt, 26% Clay

SANDSTONE
Medium bluish gray (5B 5/1) to dark greenish gray (5G 4/1). Calcite cement (Sections 1 and 2). Slightly carbonaceous.

MINERALOGY
SS 3-70

75% Quartz	4% Pyrite
5% Feldspar	T Zeolite
T Mica	T Nannos
T Heavy minerals	5% Plant debris
10% Clay	
2% Rock fragments	

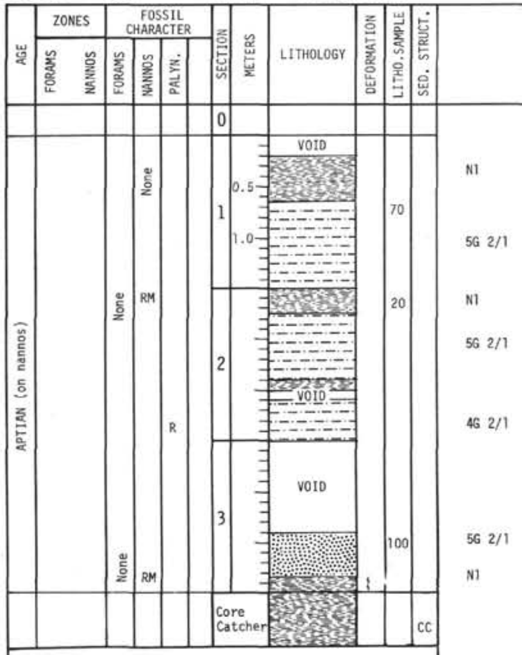
TEXTURE
60% Sand, 30% Silt, 10% Clay

Carbonate Bomb:
1-123 to 124 cm = 26.4% $CaCO_3$

Carbon-Carbonate (DSDP)
1-123 (2.6, 0.3, 20)

Grain Size (DSDP)
3-52 (64.9, 23.7, 11.4)

Site 361 Hole Core 46 Cored Interval: 1257.0-1266.5 m



LITHOLOGIC DESCRIPTION

SHALE
Black (N1). Carbonaceous. Heavy minerals: Zircon, Chlorite, Tourmaline.

MINERALOGY
SS 2-20
40% Quartz
6% Feldspar
T Mica
T Heavy minerals
30% Clay
5% Pyrite
T Nannos
17% Plant debris

TEXTURE
1% Sand, 67% Silt, 32% Clay

SANDY MUDSTONE
Greenish black (5G 2/1). Richly carbonaceous. Heavy minerals: Tourmaline, Epidote, Chlorite.

MINERALOGY
SS 1-70
60% Quartz
10% Feldspar
T Mica
T Heavy minerals
15% Clay
4% Rock fragments
3% Pyrite
T Nannos
8% Plant debris

TEXTURE
45% Sand, 40% Silt, 15% Clay

SANDSTONE
Greenish black (5G 2/1).

MINERALOGY
SS 3-100
50% Quartz
10% Feldspar
T Mica
T Heavy minerals
10% Clay
10% Rock fragments
3% Pyrite
10% Authigenic carbonate
T Nannos
5% Plant debris

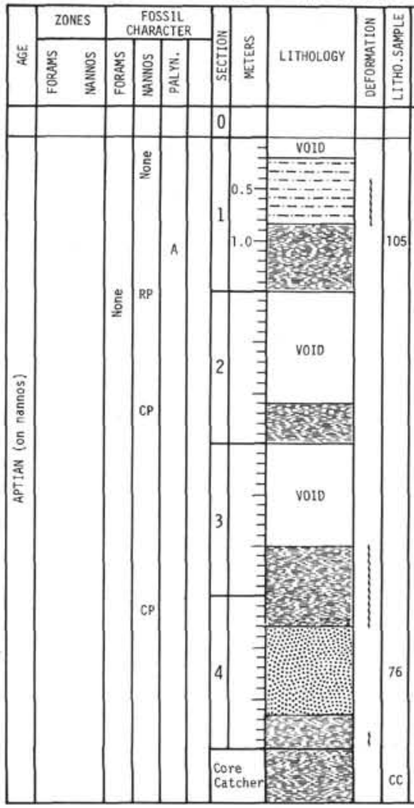
Carbonate Bomb: 2-0 to 1 cm = 6.0% $CaCO_3$

Carbon-Carbonate (DSDP)
1-60 (4.5, 4.0, 4)

Grain Size (DSDP)
2-44 (60.4, 26.3, 13.3)

Explanatory notes in Chapter 1

Site 361 Hole Core 47 Cored Interval: 1266.5-1276.0 m



LITHOLOGIC DESCRIPTION

N3
N1
N1
N1
5B 5/1
N3

SHALE
Black (N1) to dark gray (N3). Carbonaceous, sandy in places.

MINERALOGY
SS 1-105
30% Quartz
3% Feldspar
T Mica
T Heavy minerals
35% Clay
3% Rock fragments
10% Pyrite
T Zeolite
4% Nannos
15% Plant debris

TEXTURE
10% Sand, 50% Silt, 40% Clay

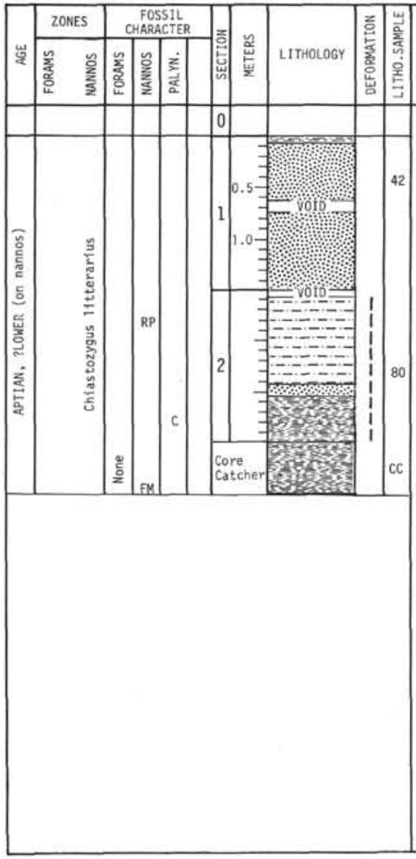
SANDY MUDSTONE
Dark gray (N3). Carbonaceous.

SANDSTONE
Medium bluish gray (5B 5/1). Well-indurated, calcite cement. Only a trace of carbonaceous material.

Carbonate Bomb: 1-90 to 91 cm = 7.4% $CaCO_3$

Carbon-Carbonate (DSDP)
1-65 (4.3, 3.8, 4)

Site 361 Hole Core 48 Cored Interval: 1285.5-1295.0 m



LITHOLOGIC DESCRIPTION

N1
5B 5/1
Shaley, flow structure N3
N1

SHALE
Black (N1). Carbonaceous. Pyrite spheres, probably test infillings.

MINERALOGY
SS CC
25% Quartz
3% Feldspar
T Heavy minerals
45% Clay
10% Pyrite
1% Zeolite
2% Nannos
12% Plant debris

TEXTURE
5% Sand, 48% Silt, 47% Clay

SANDSTONE
Medium bluish gray (5B 5/1). Calcareous. Vague laminae. Mostly calcite-cemented quartz grains.

SANDY MUDSTONE
Dark gray (N3). Thin shale layers. Richly carbonaceous.

MINERALOGY
SS 2-80
40% Quartz
5% Feldspar
T Mica
T Heavy minerals
35% Clay
5% Rock fragments
3% Pyrite
T Nannos
10% Plant debris

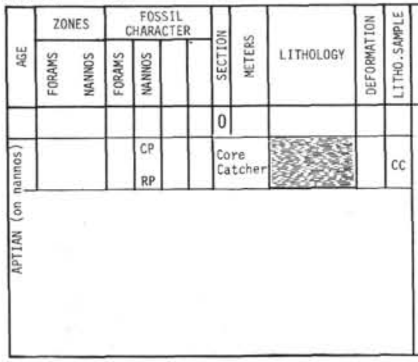
TEXTURE
35% Sand, 28% Silt, 37% Clay

Carbonate Bomb: 2-127 to 128 cm = 10.7% $CaCO_3$

Carbon-Carbonate (DSDP)
2-65 (3.0, 3.0, 0)

Grain Size (DSDP)
1-106 (75.2, 16.4, 8.4)

Site 361 Hole Core 49 Cored Interval: 1304.5-1314.0 m



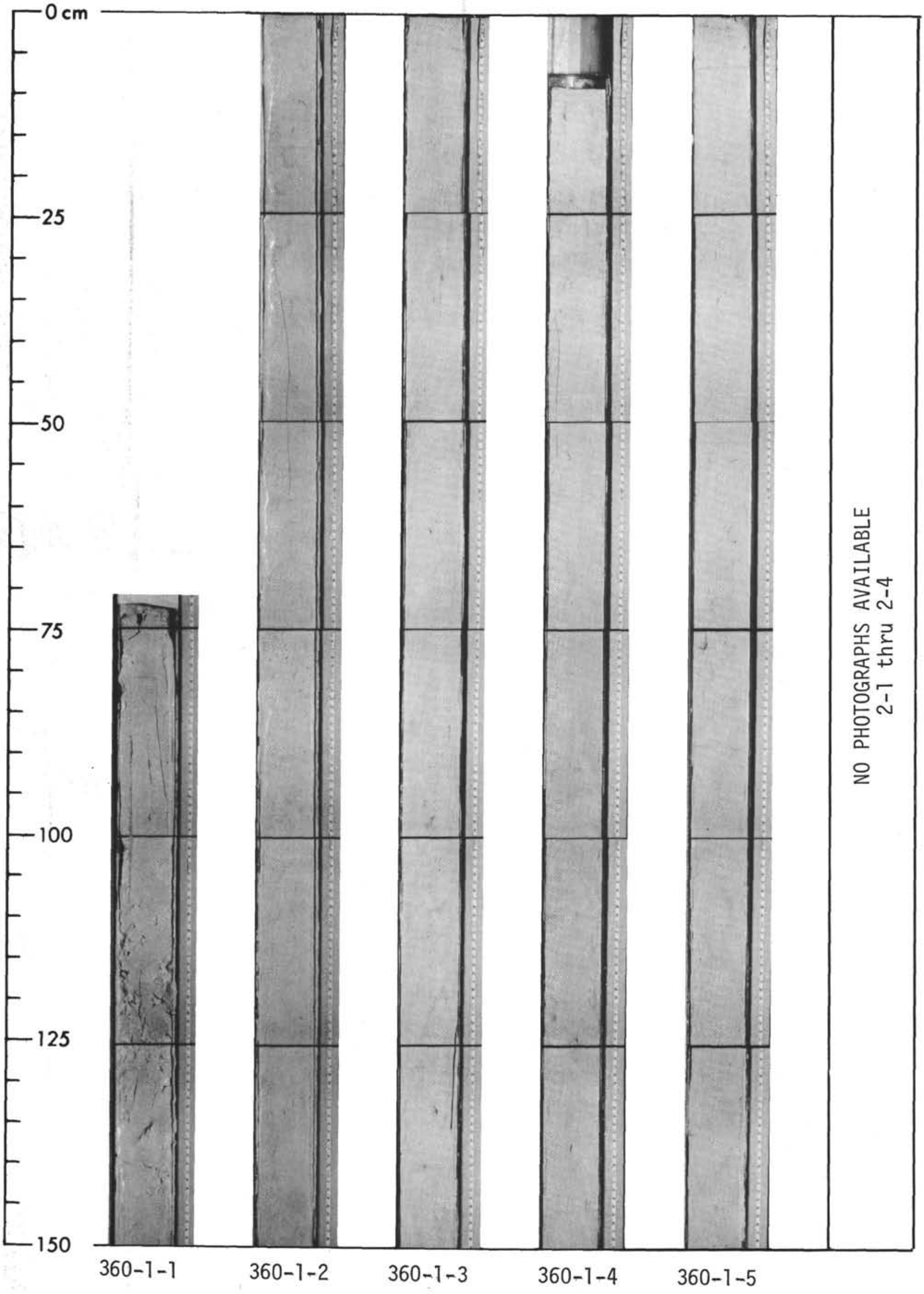
LITHOLOGIC DESCRIPTION

N1

SHALE
Black (N1). Carbonaceous.

MINERALOGY
SS CC
25% Quartz
3% Feldspar
T Heavy minerals
50% Clay
10% Pyrite
T Zeolite
T Authigenic carbonate
T Nannos
10% Plant debris

Explanatory notes in Chapter 1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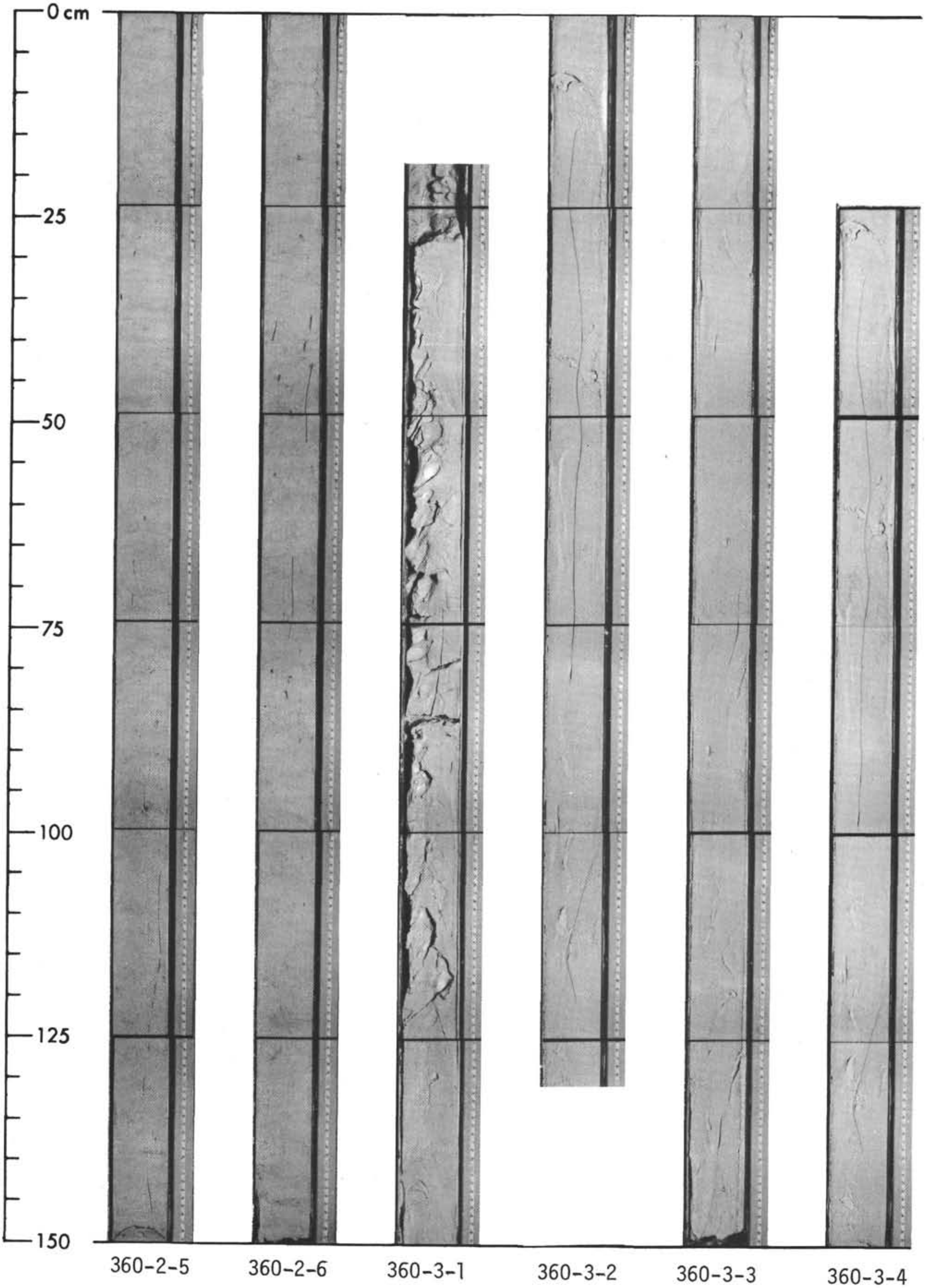
NO PHOTOGRAPHS AVAILABLE
2-1 thru 2-4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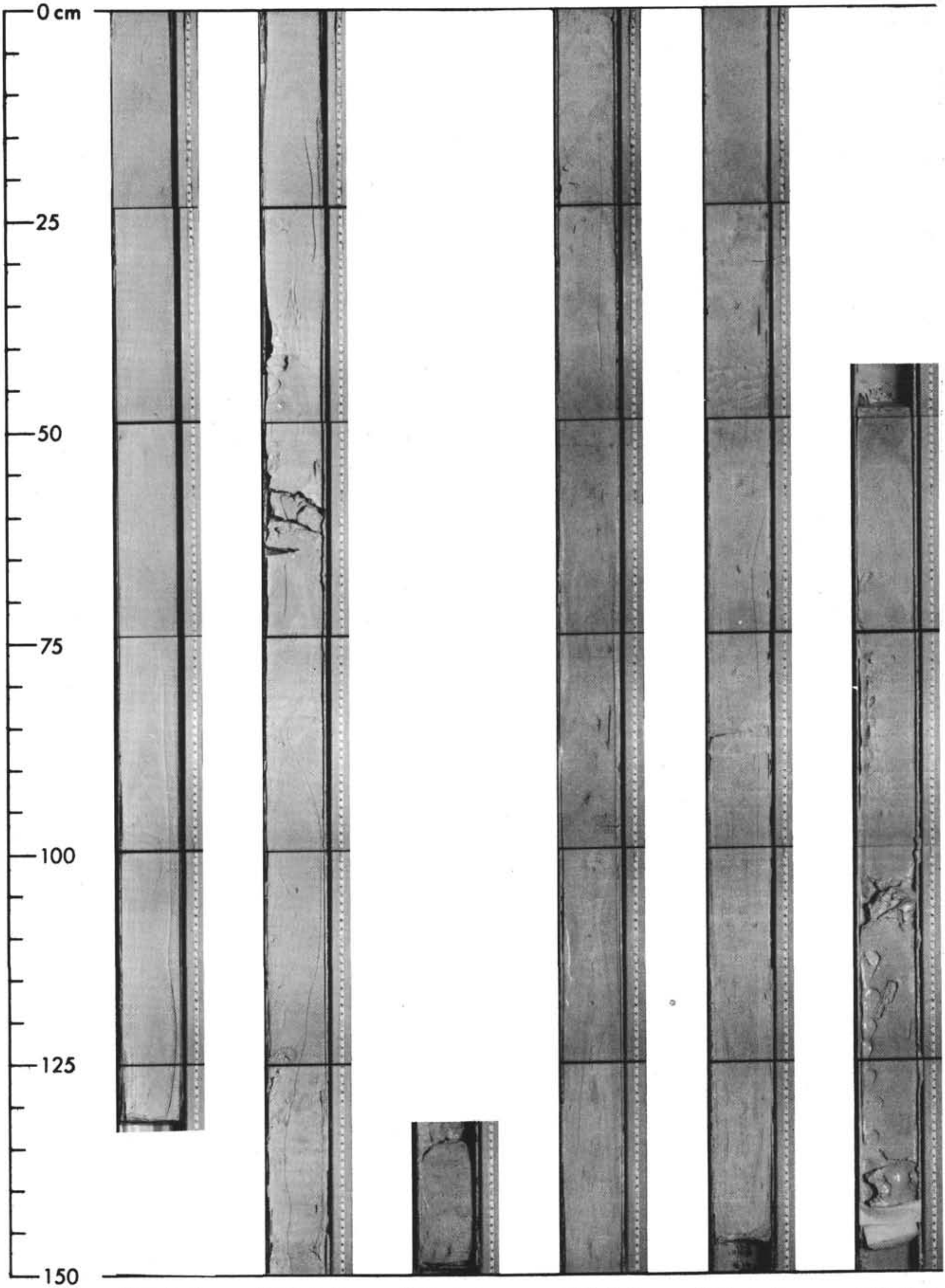
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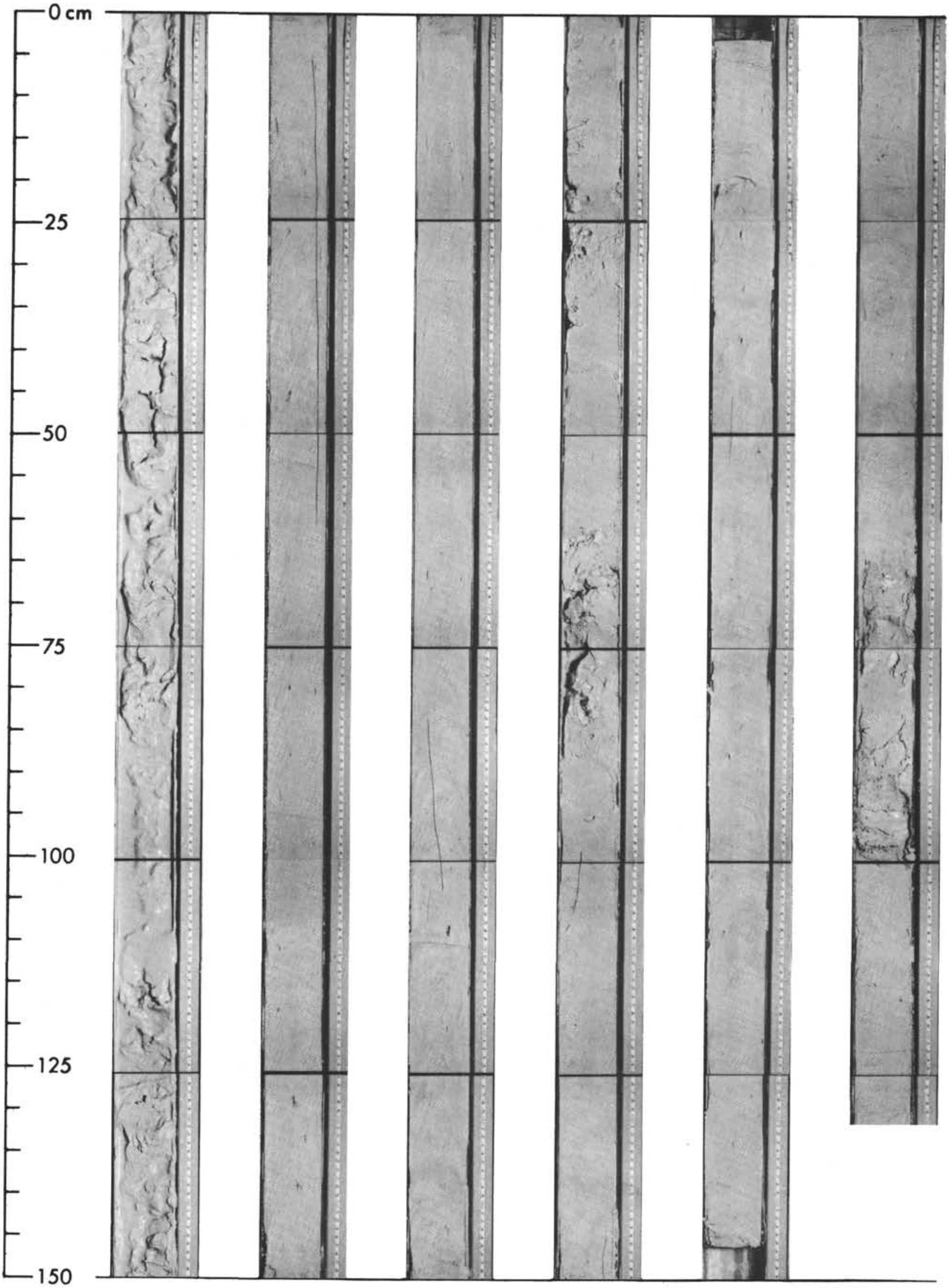
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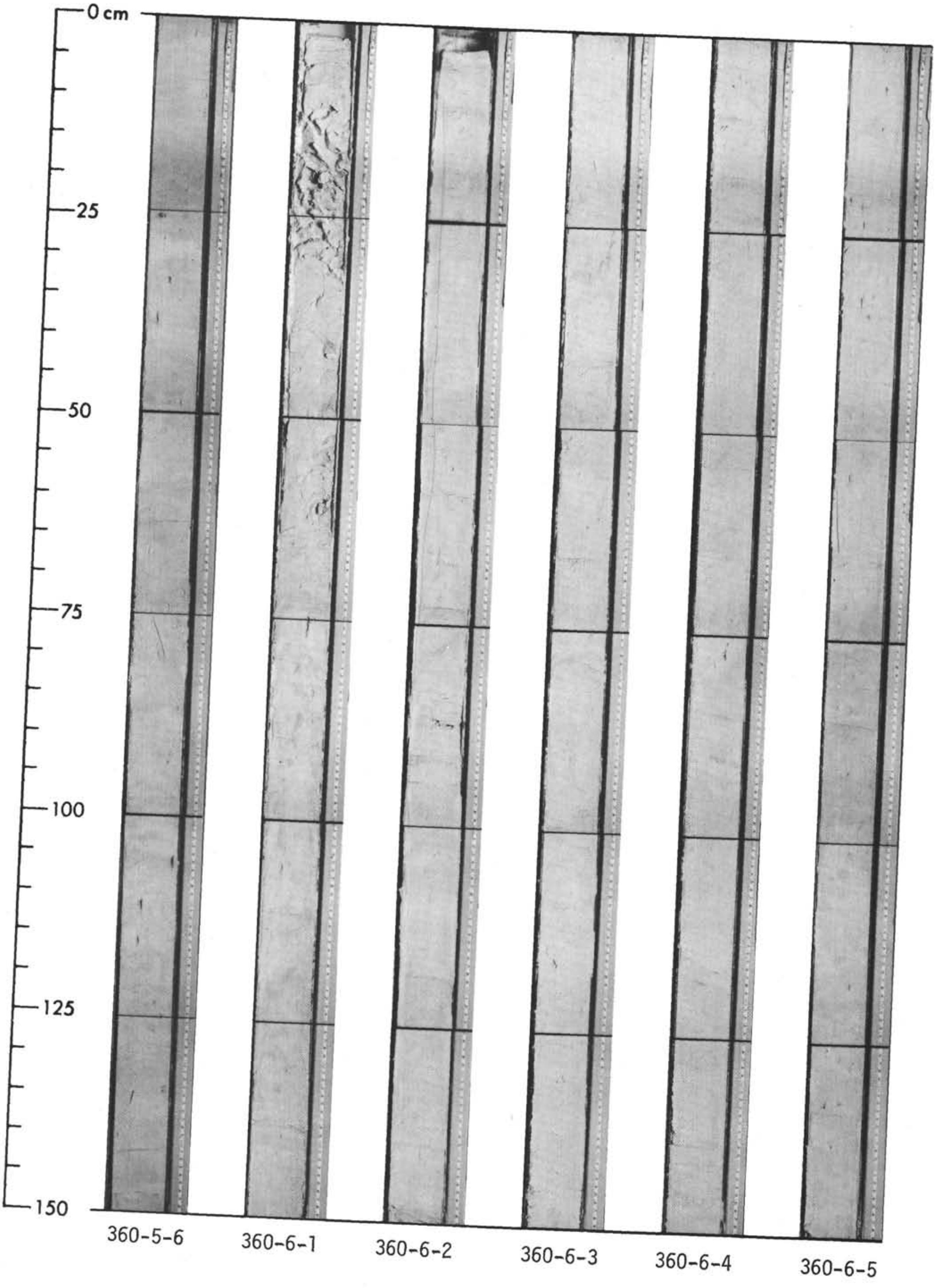
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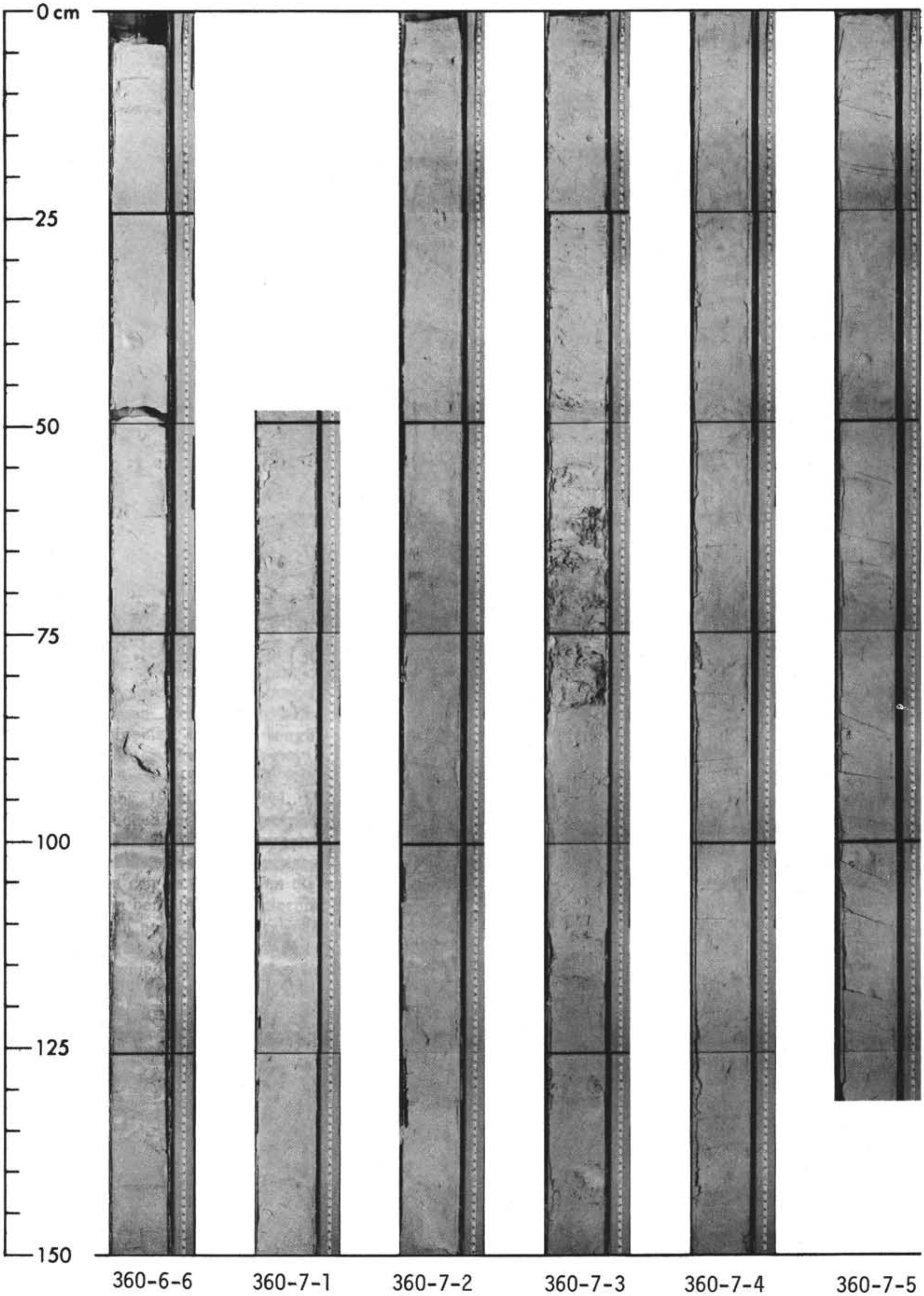
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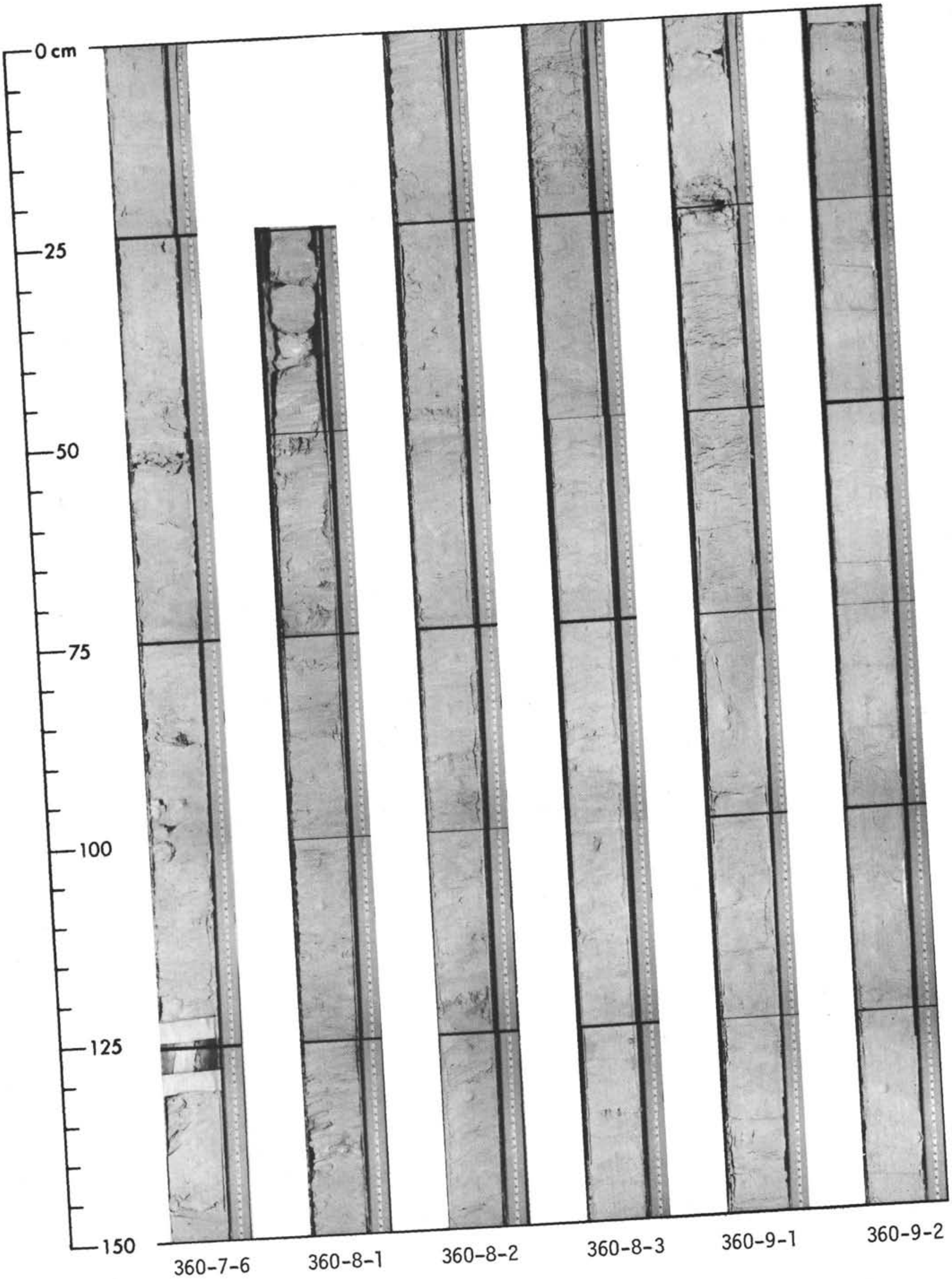
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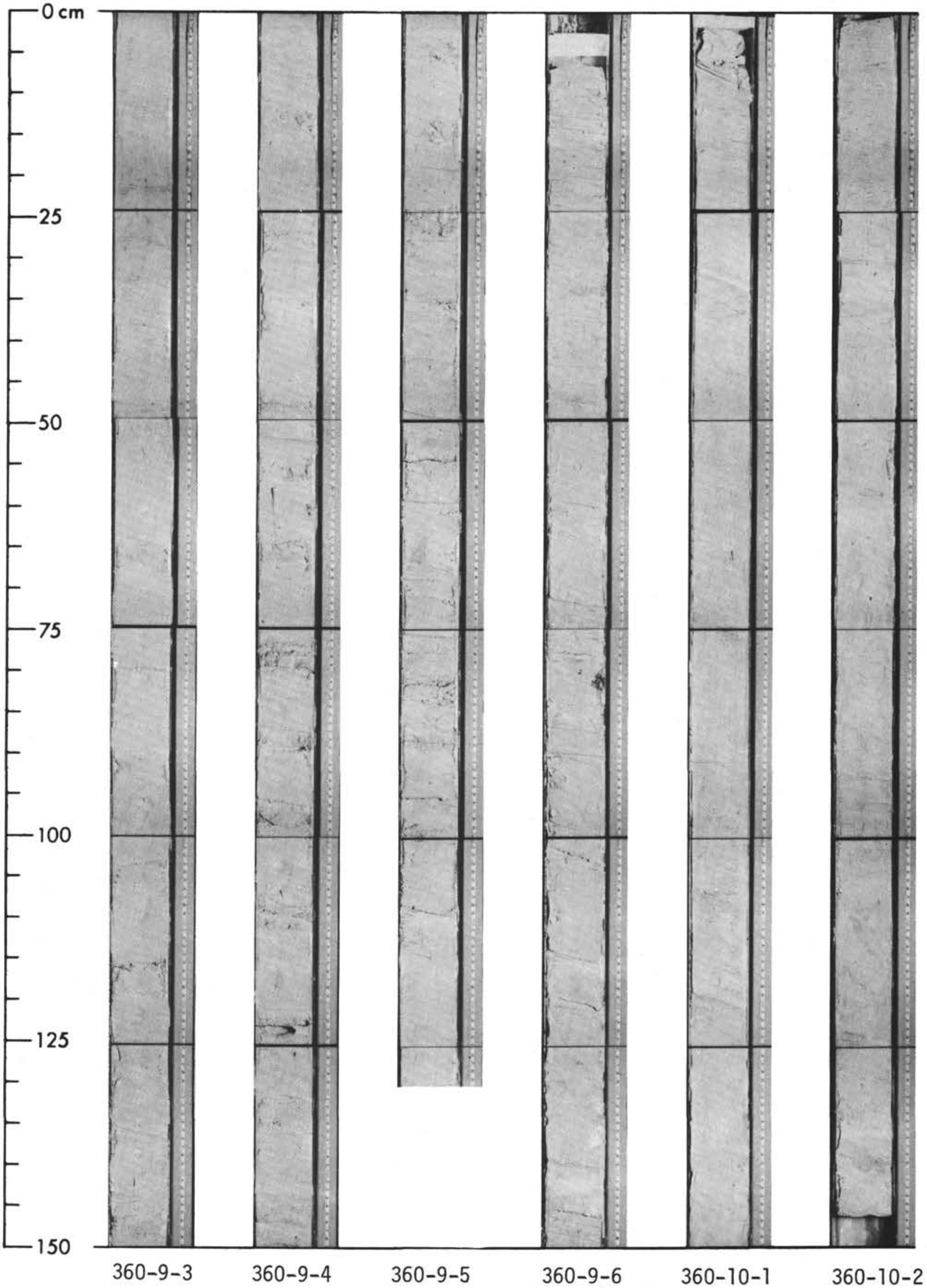
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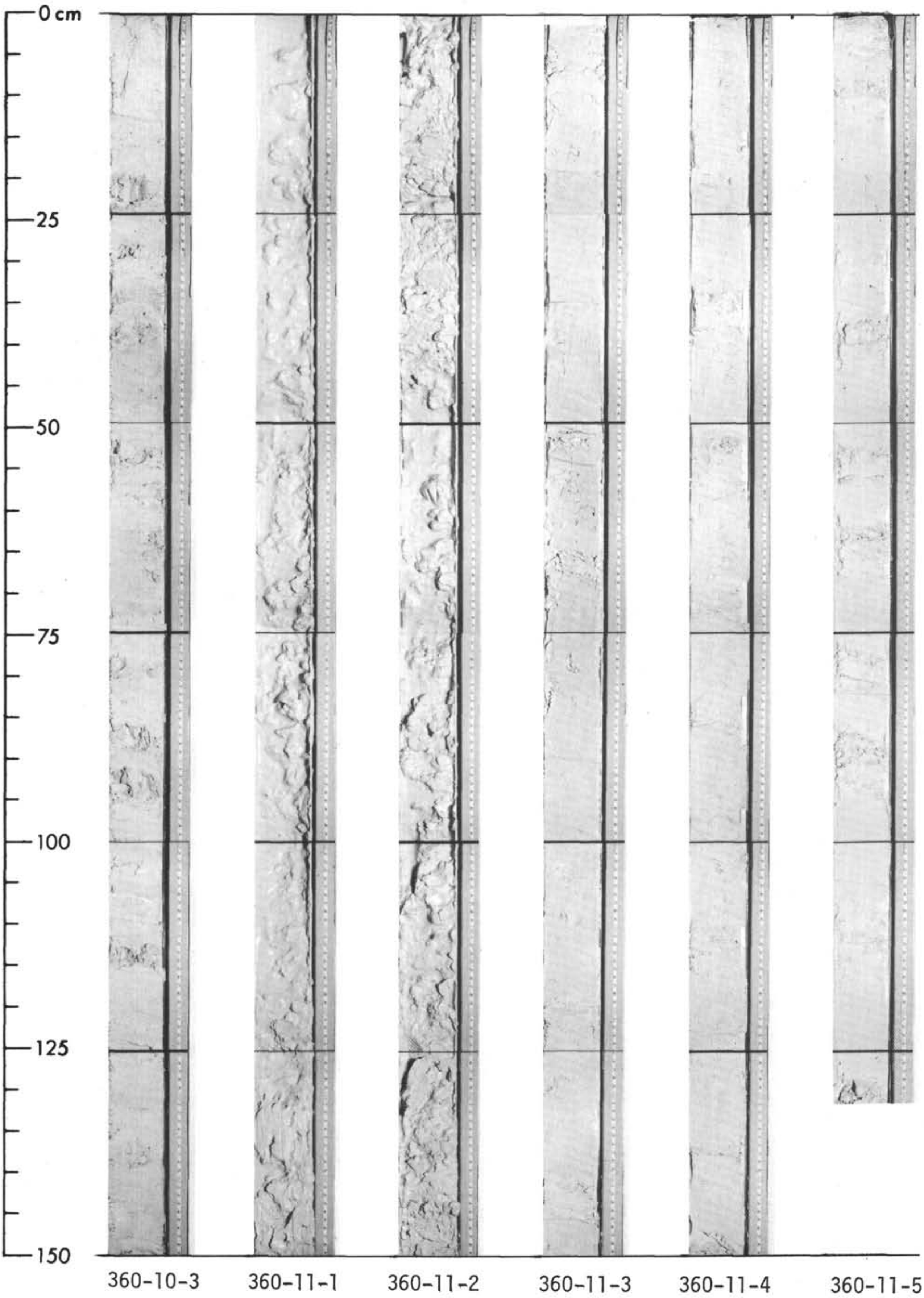
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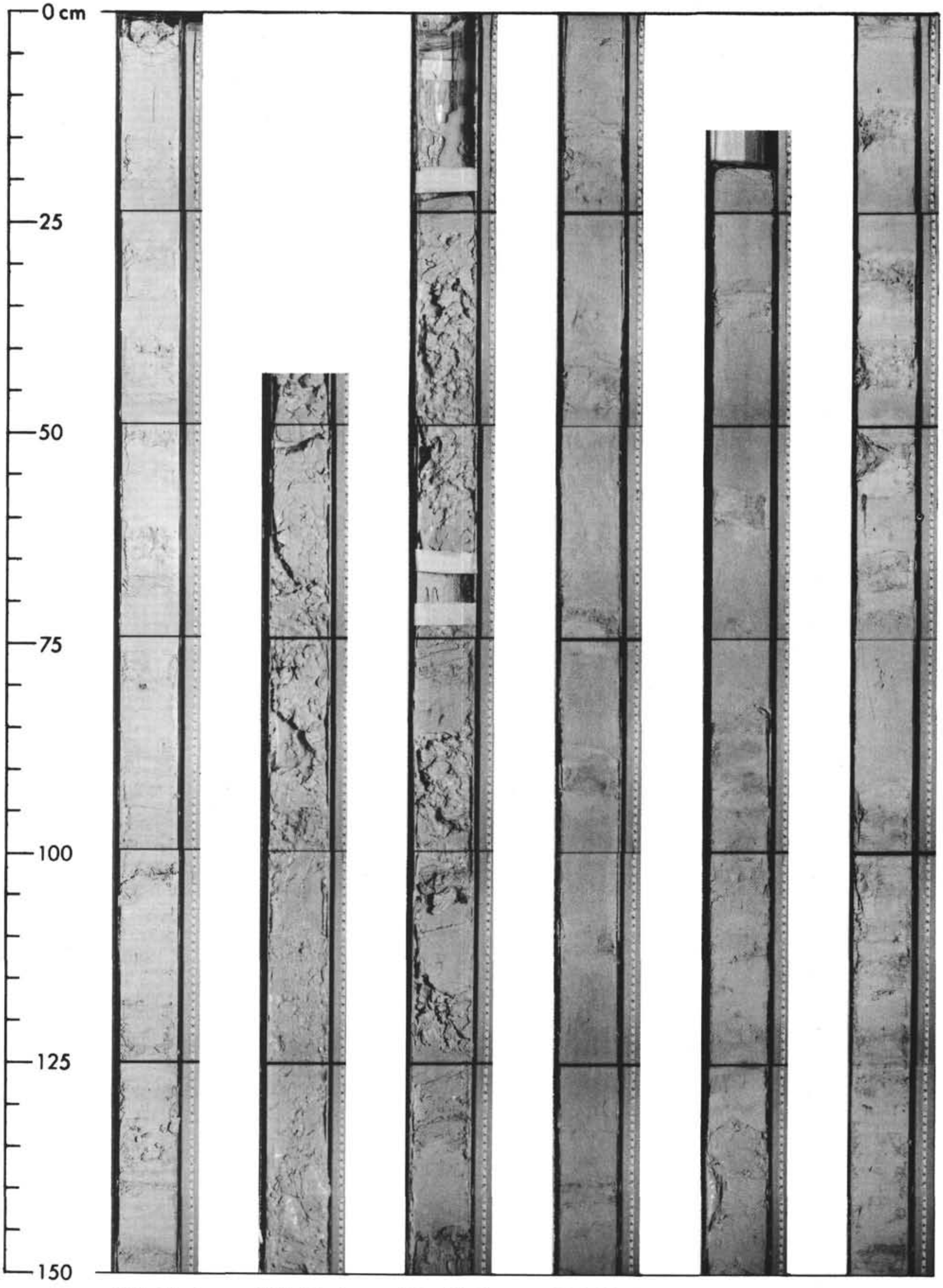
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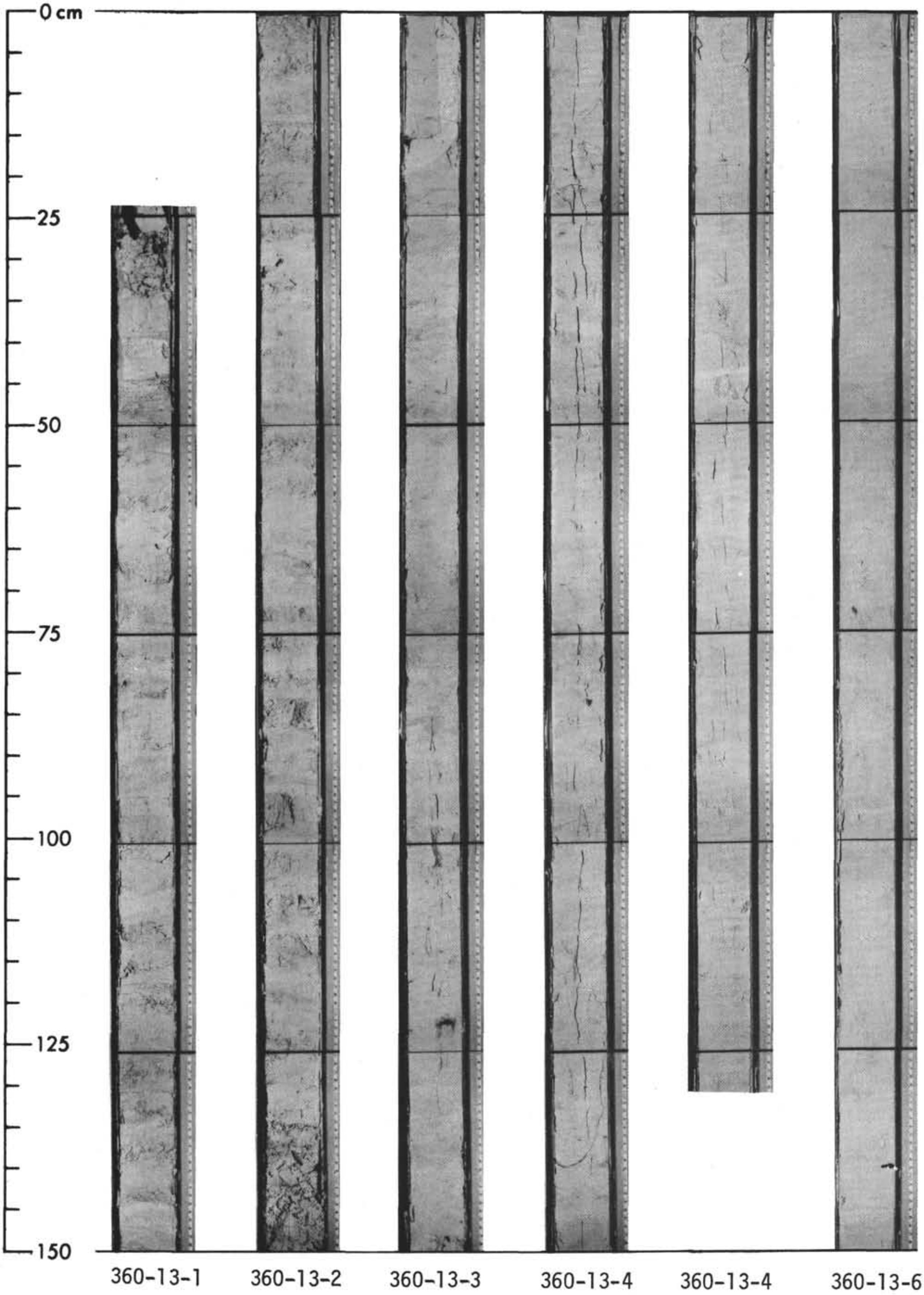
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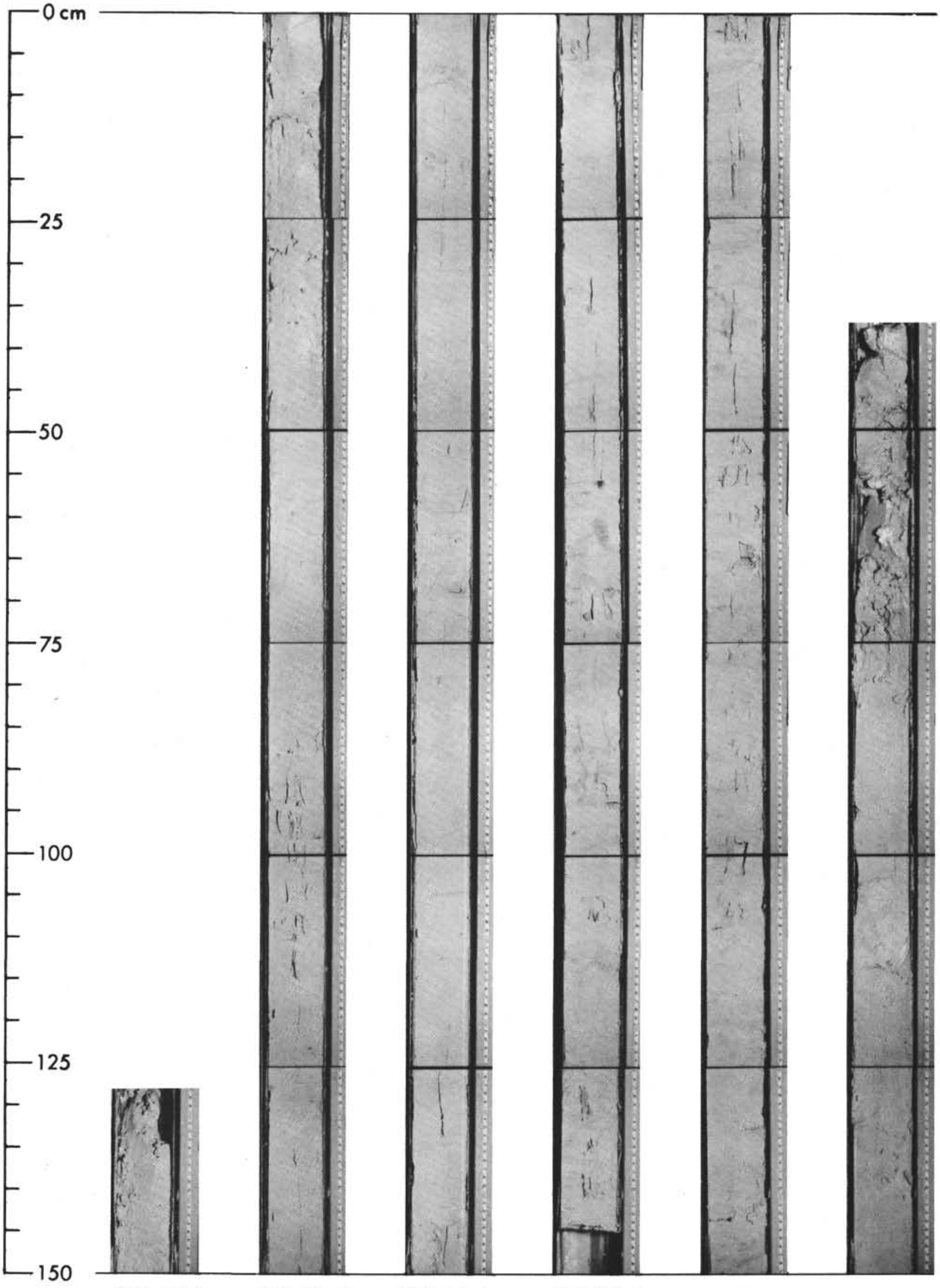
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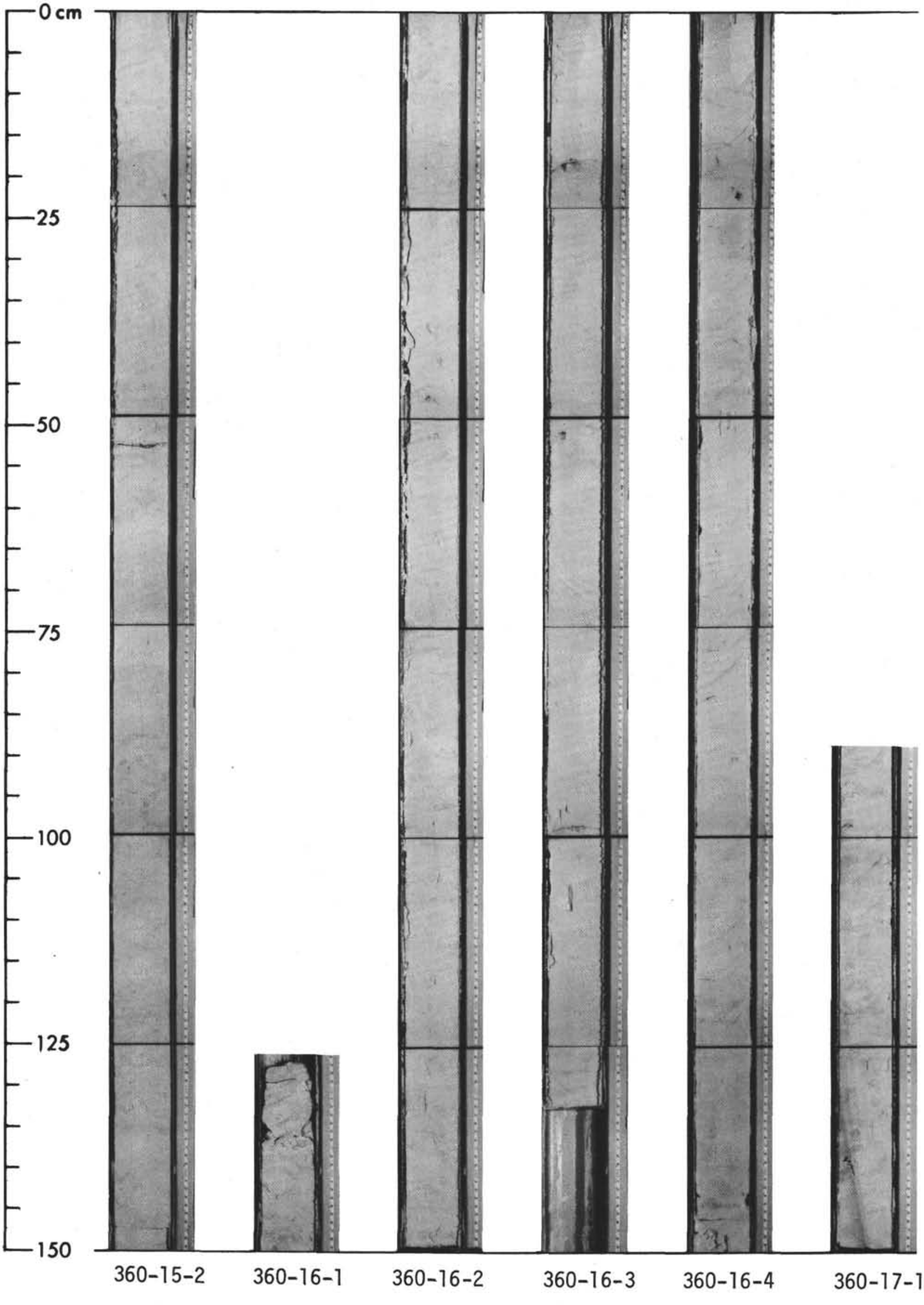
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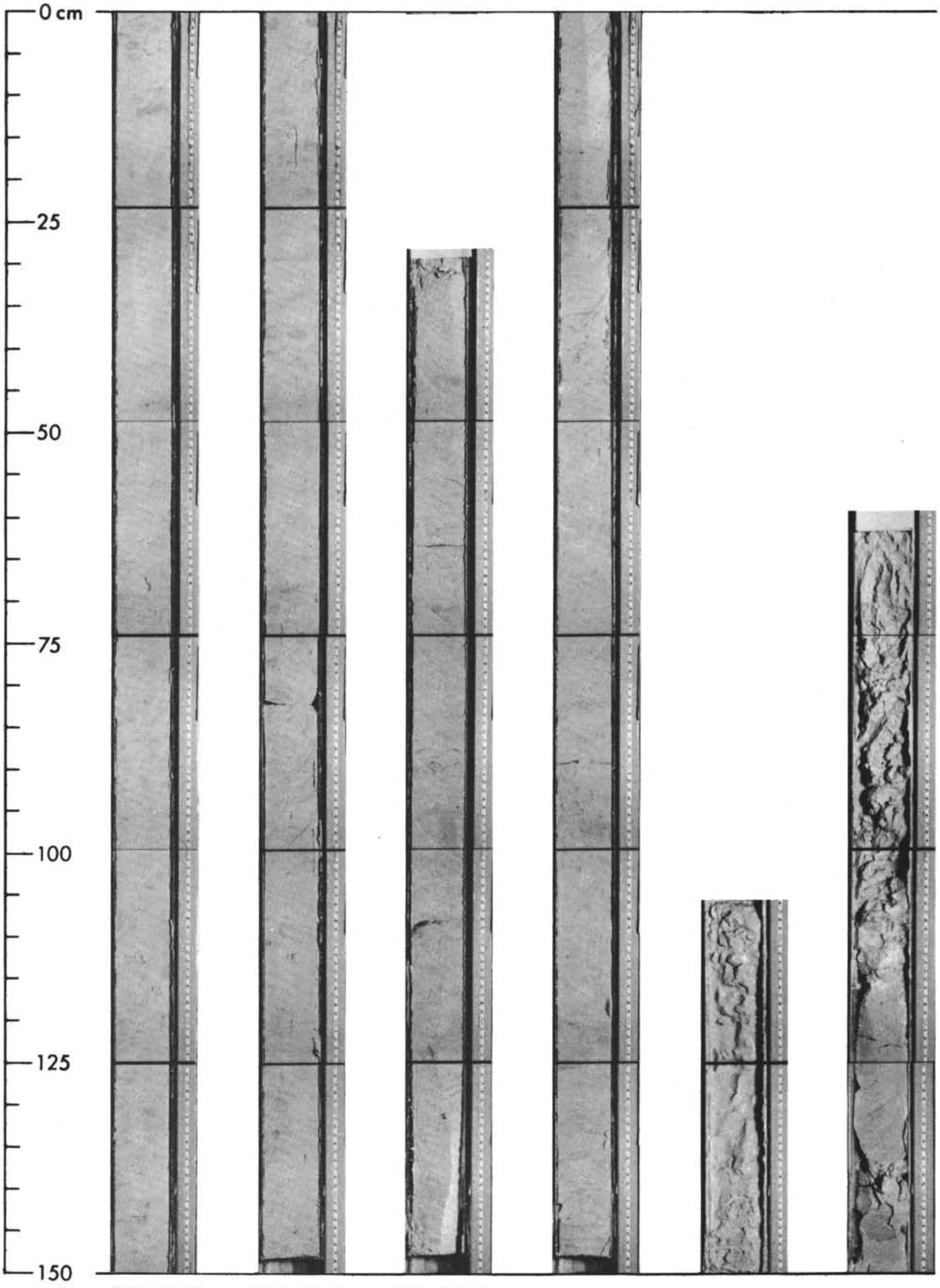
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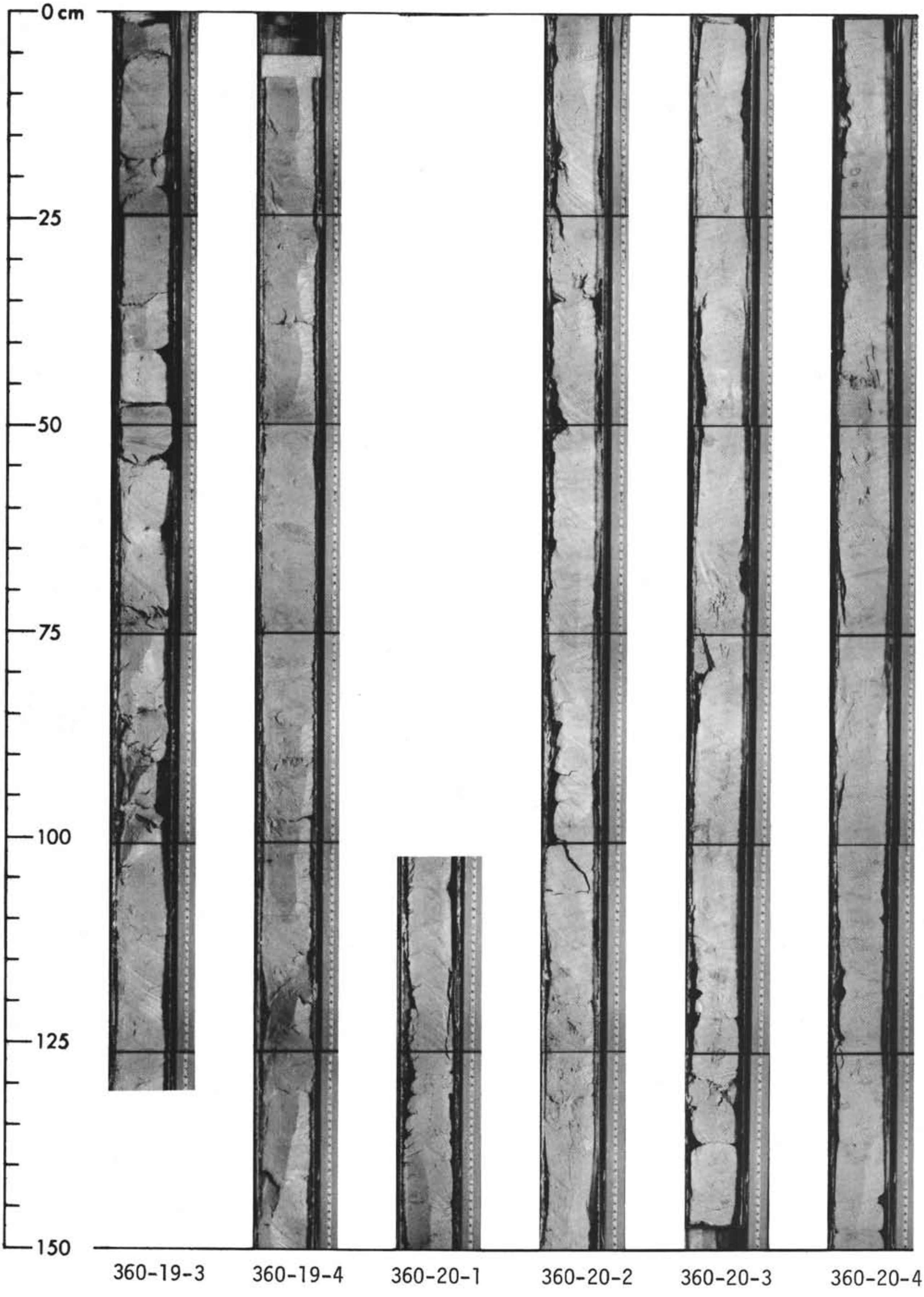
360-19-2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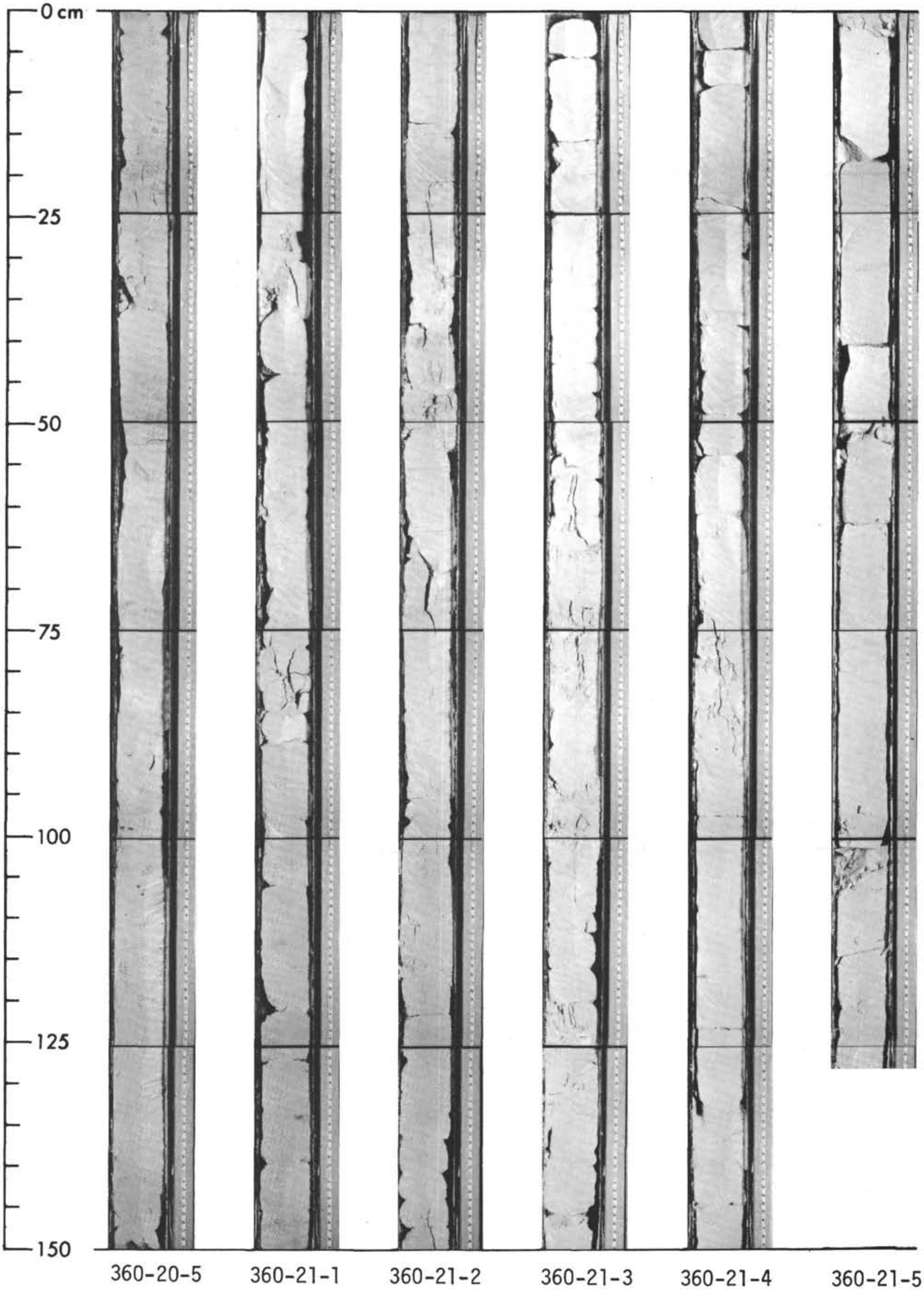
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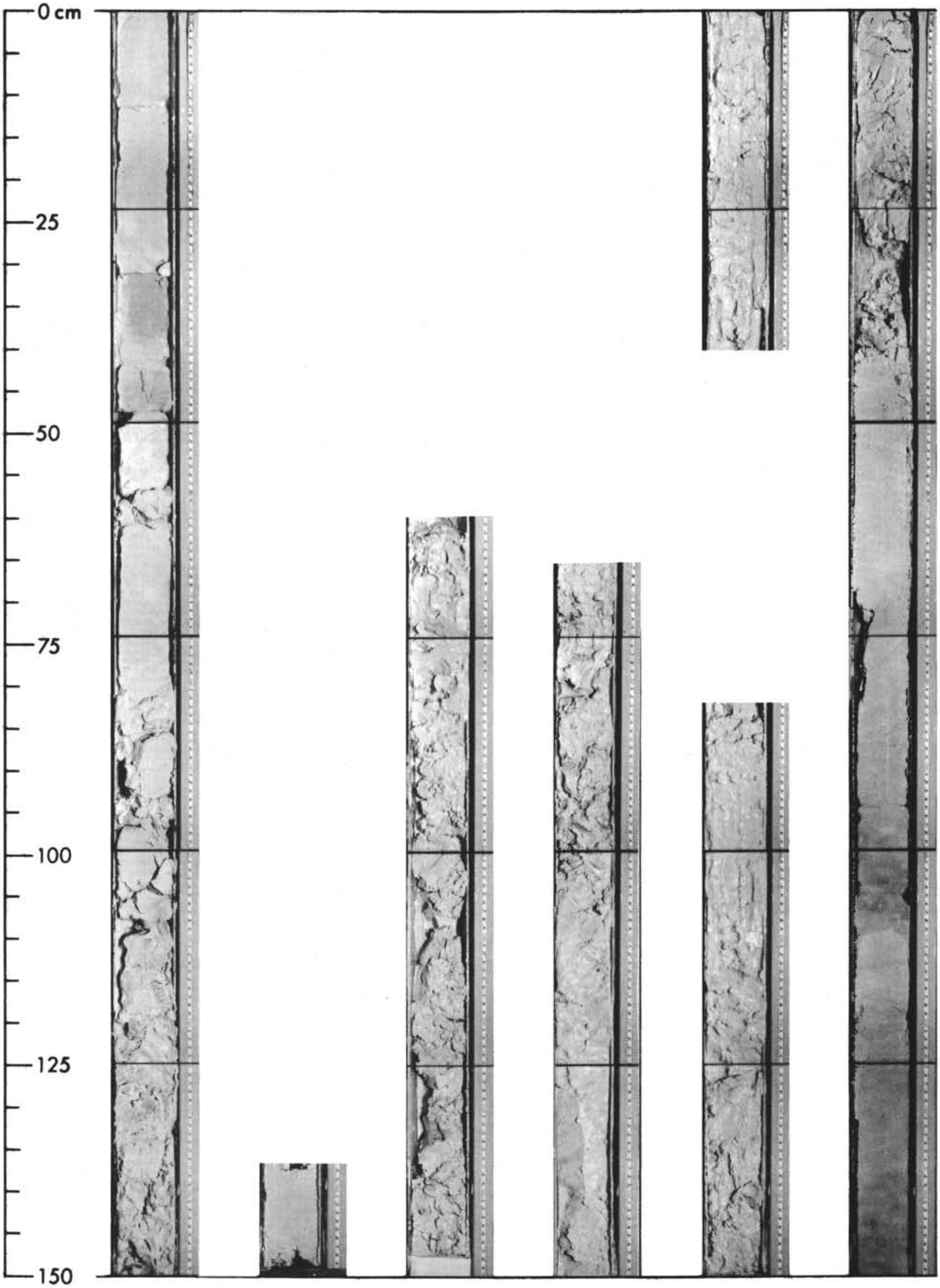
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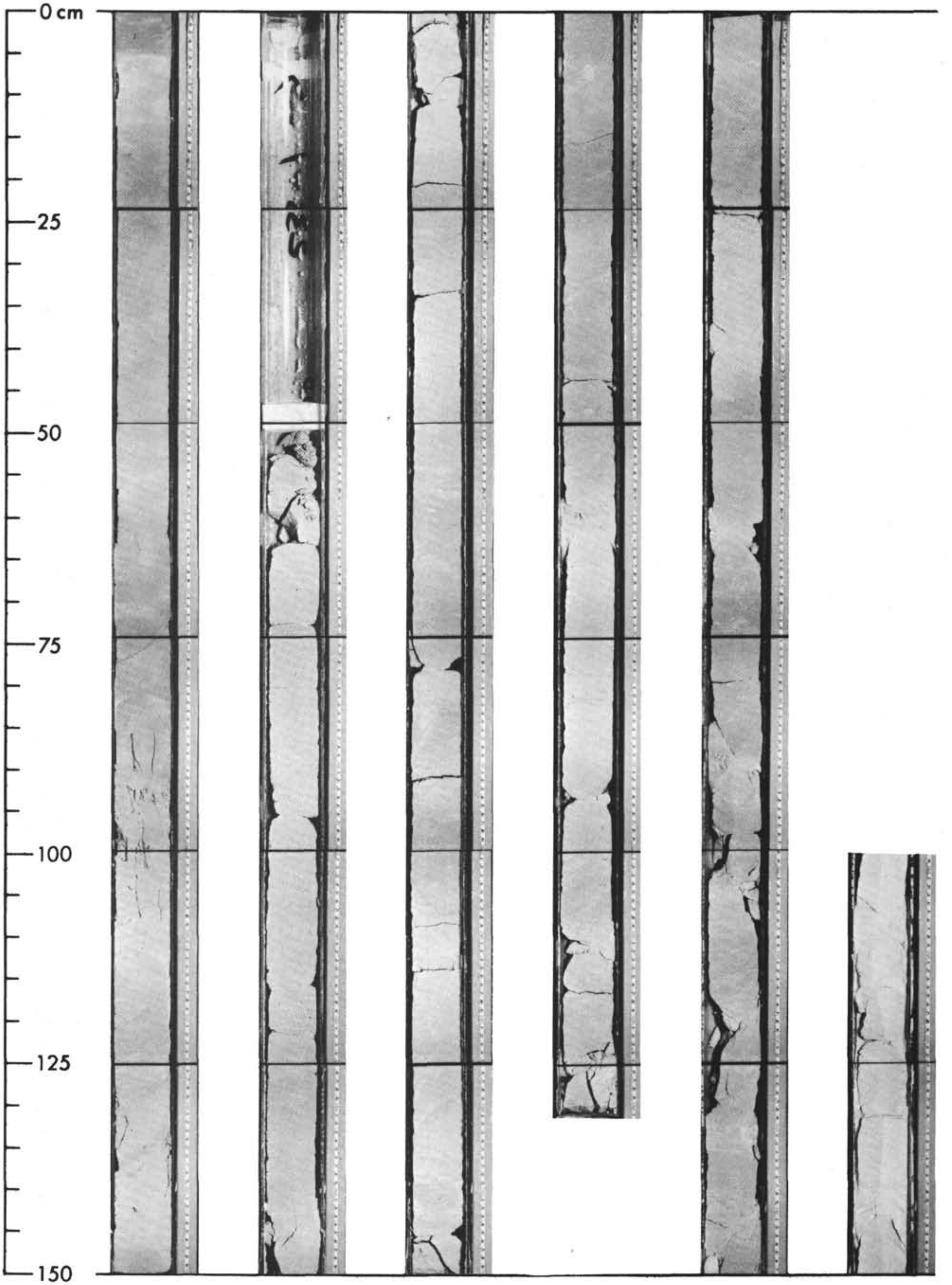

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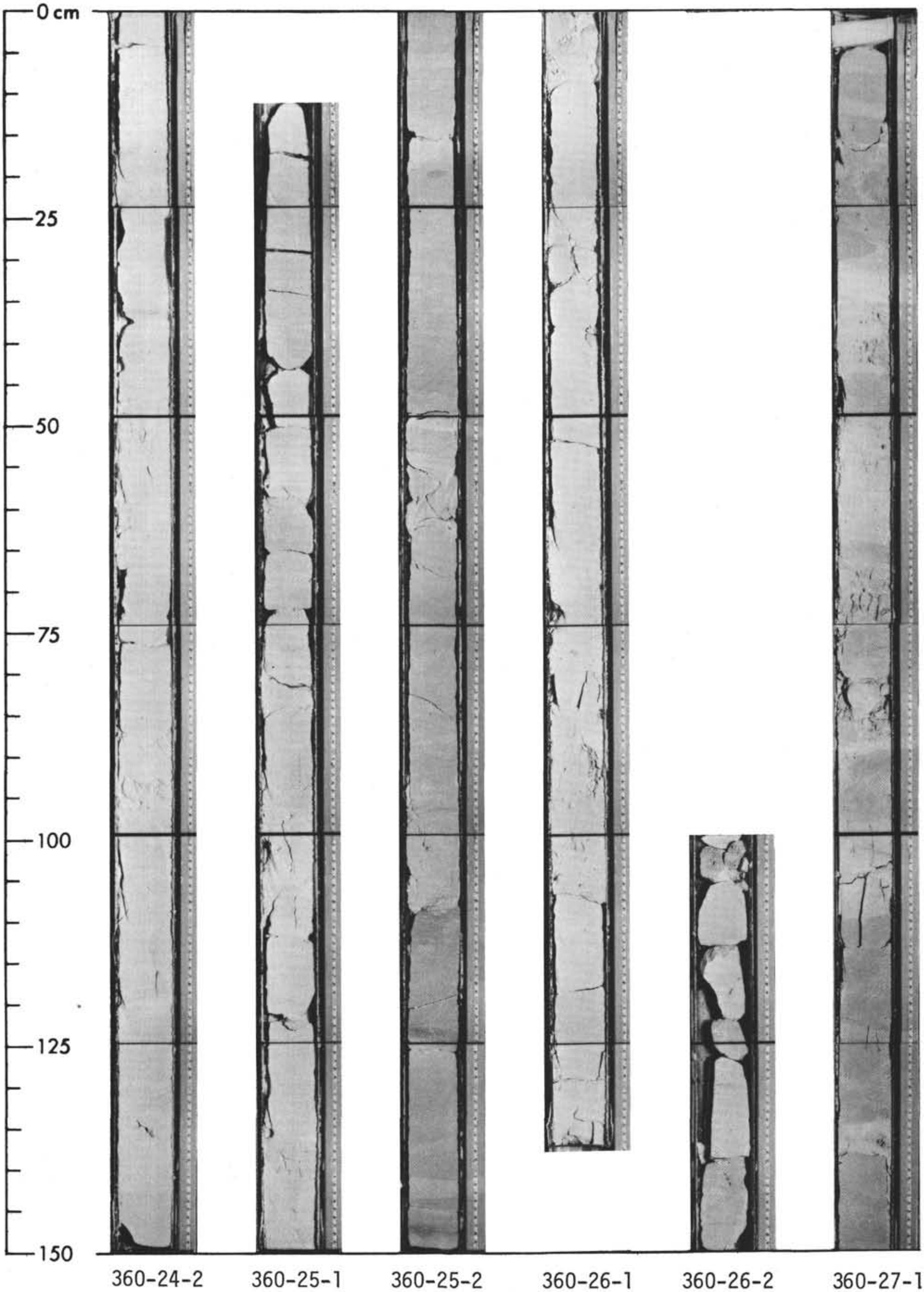
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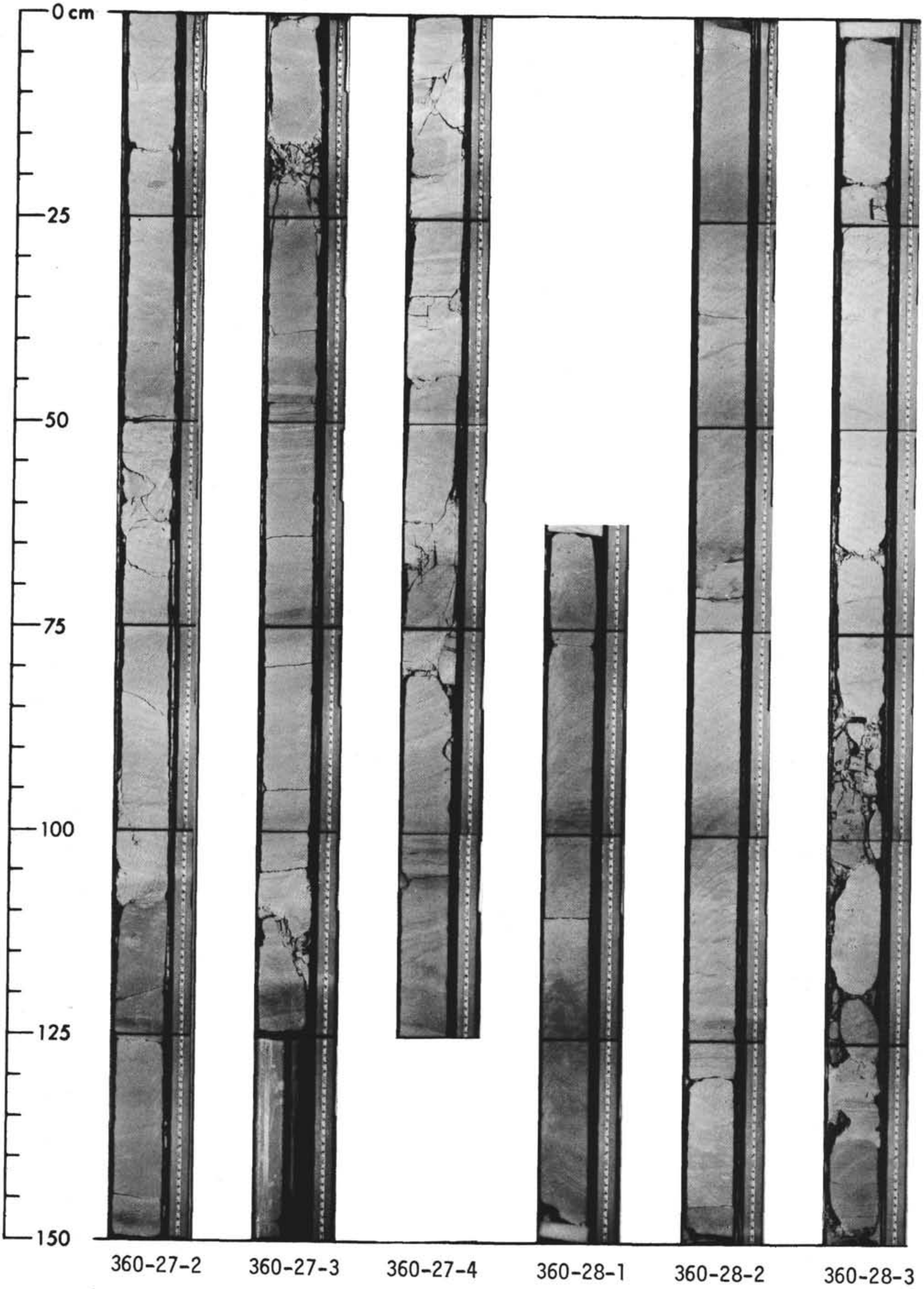
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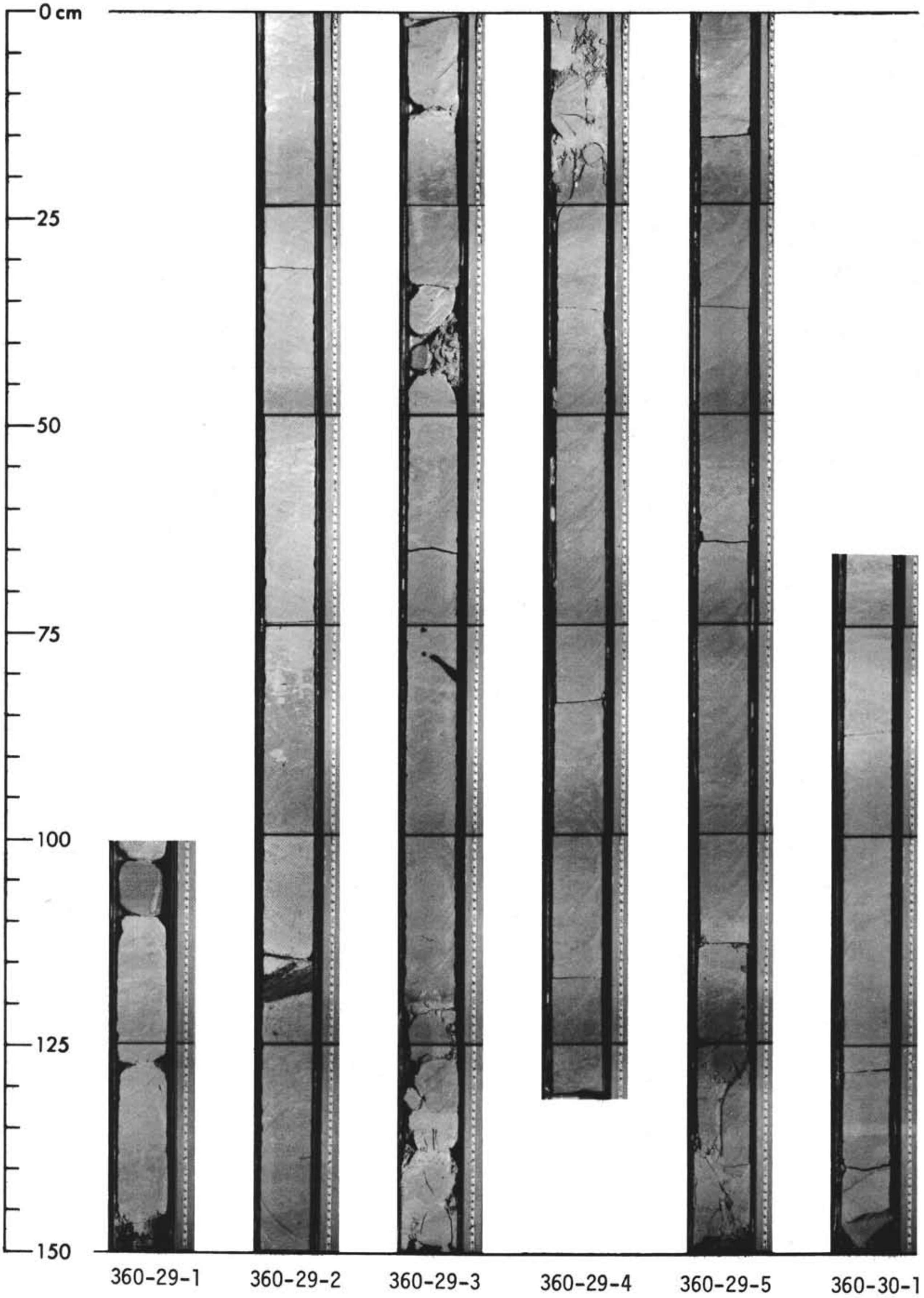
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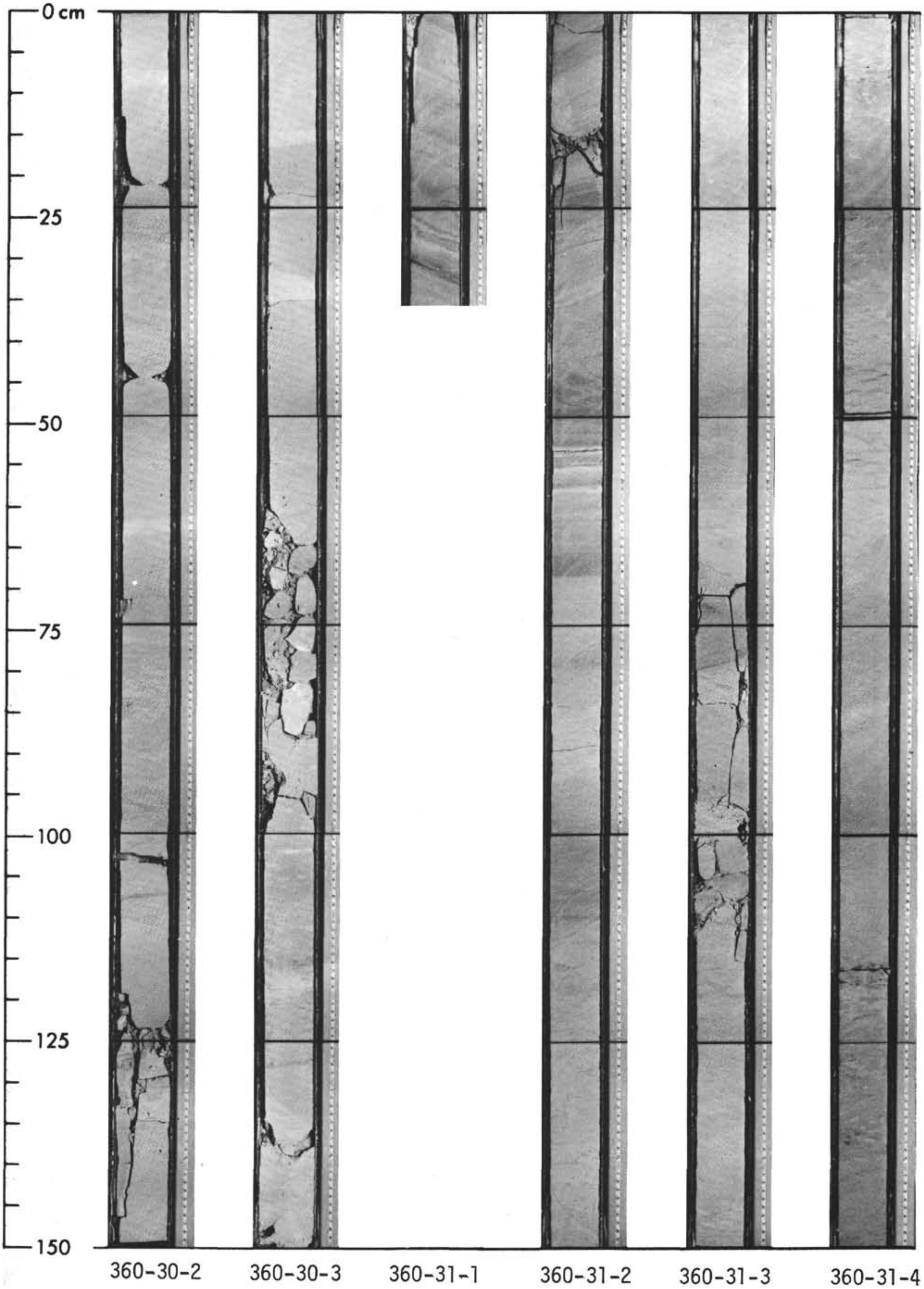
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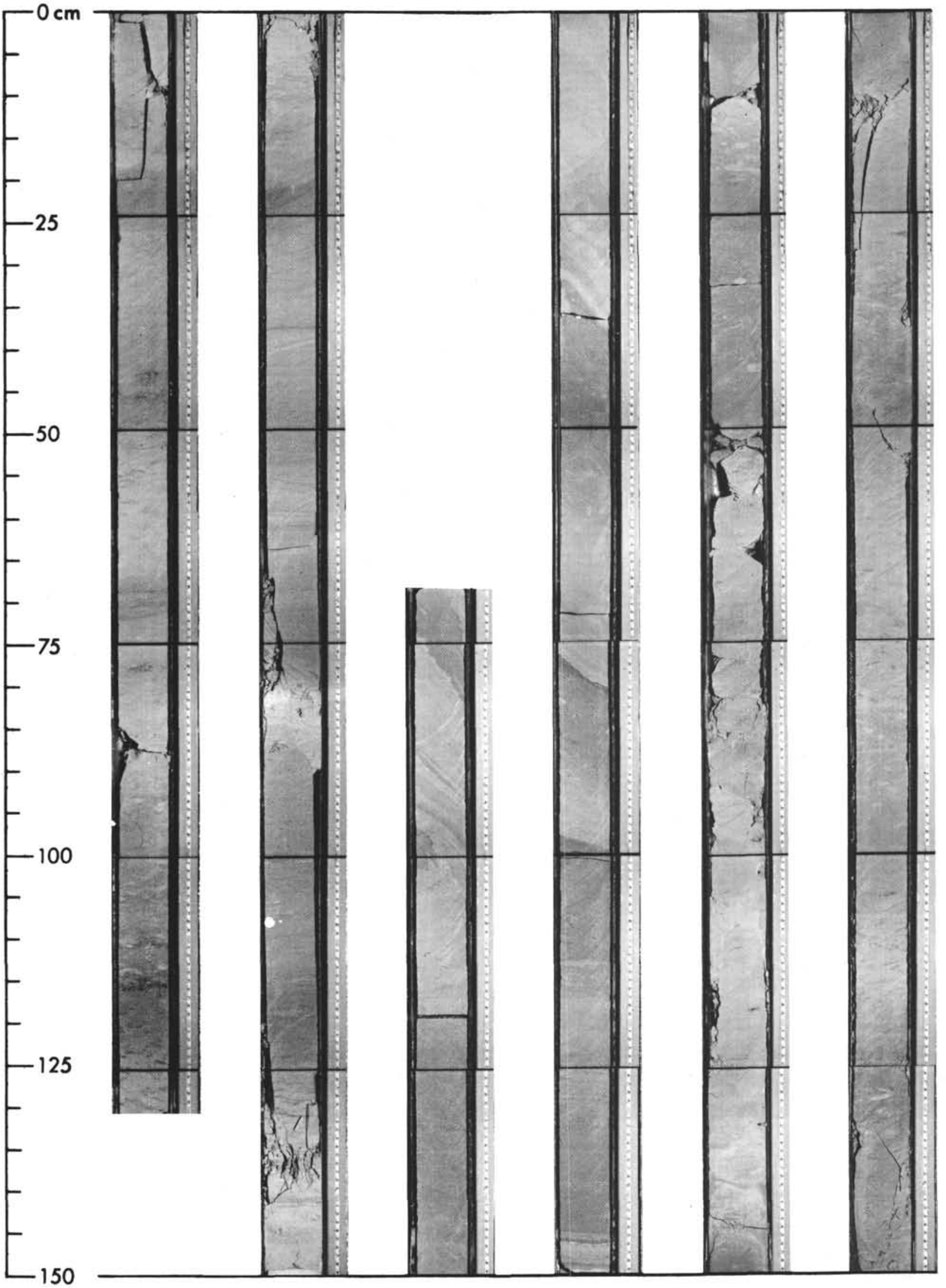
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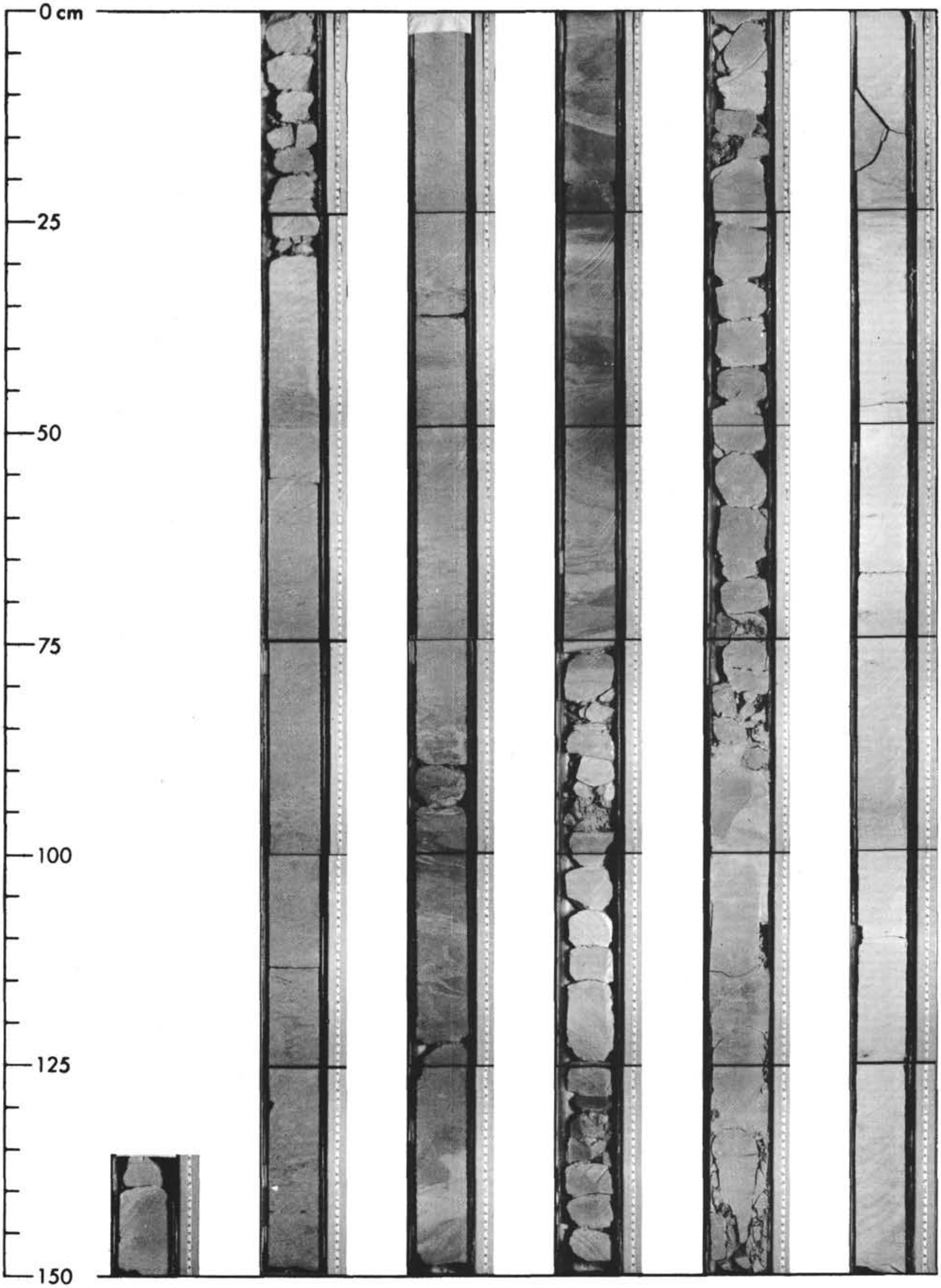
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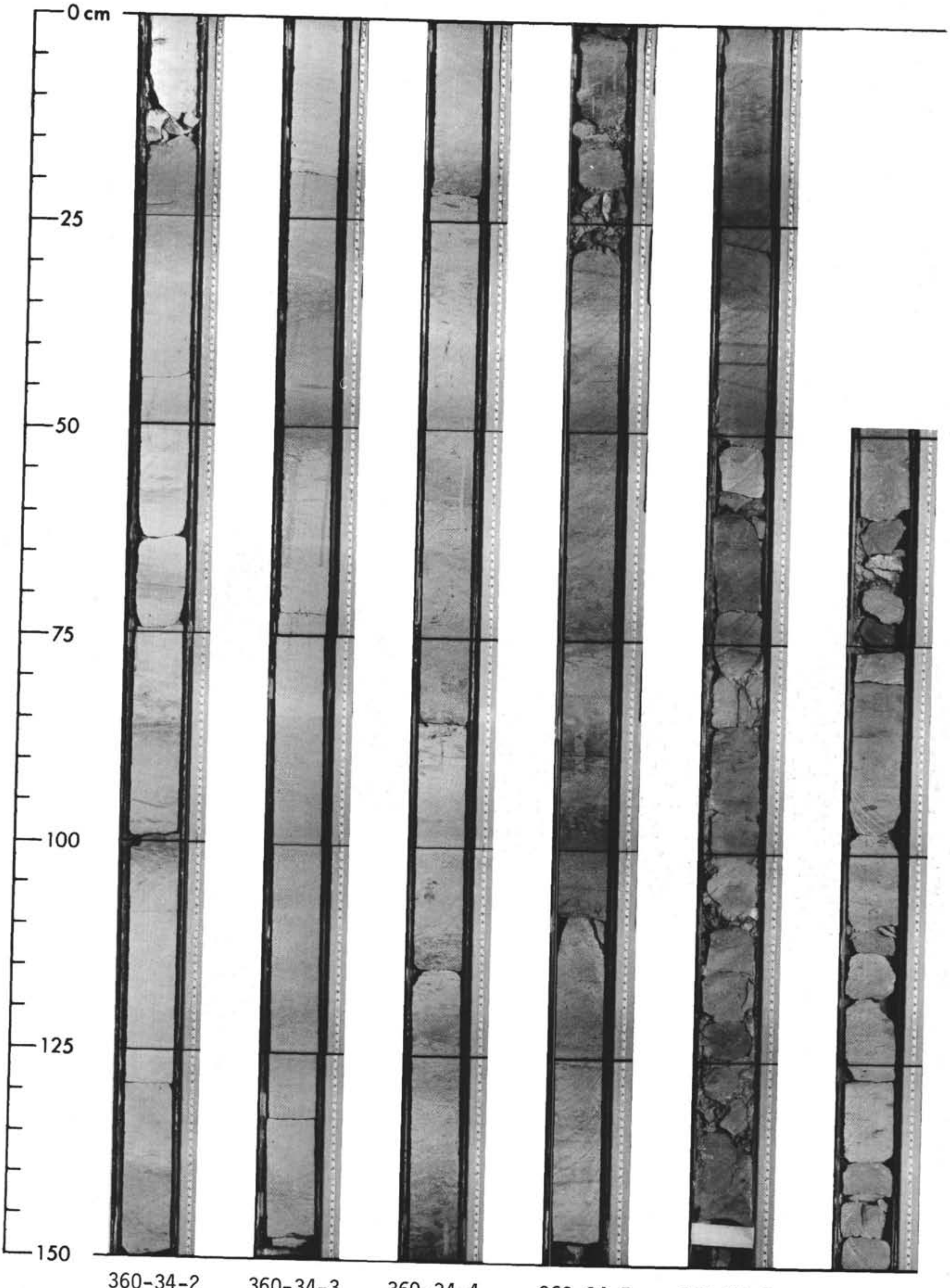
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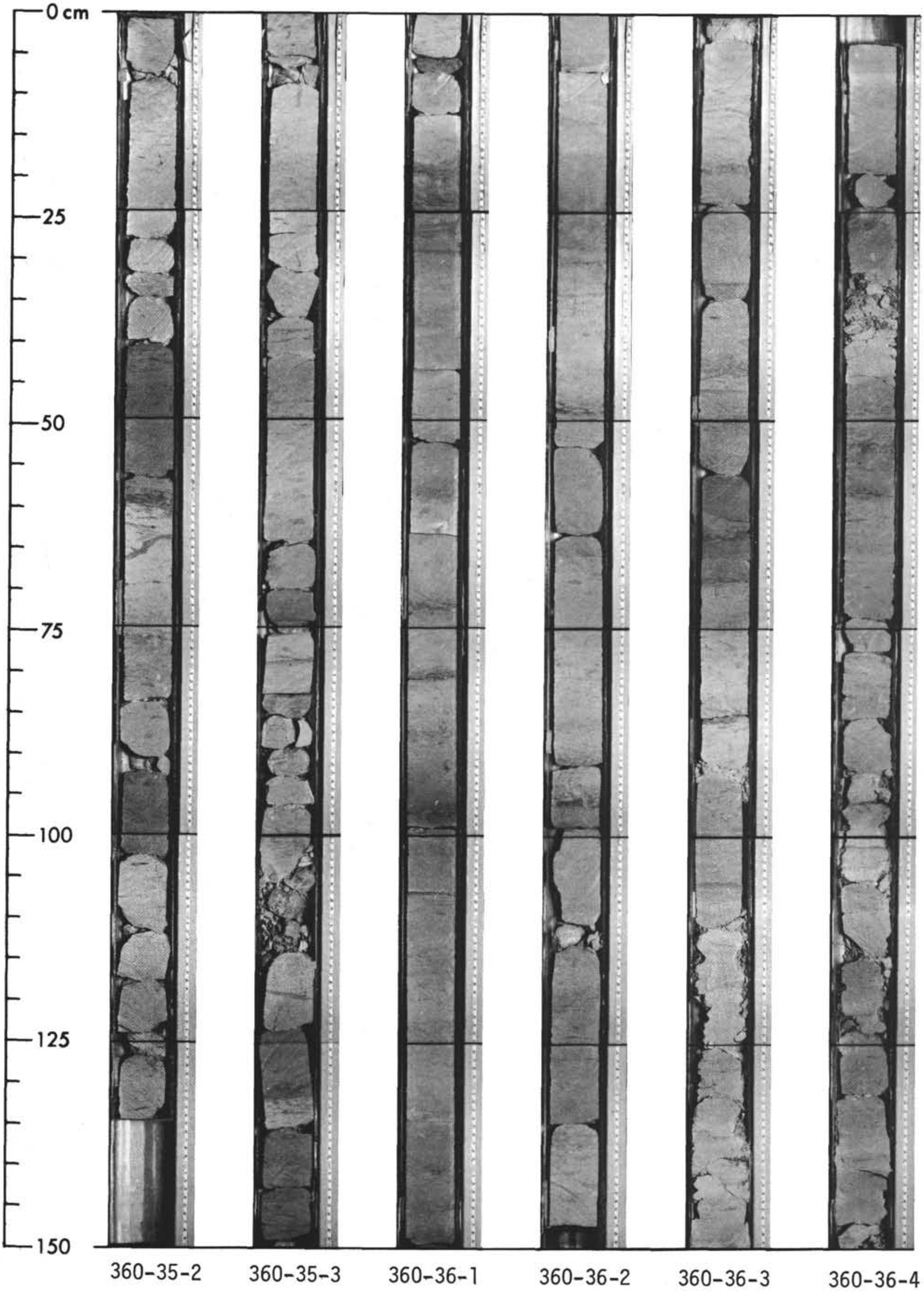
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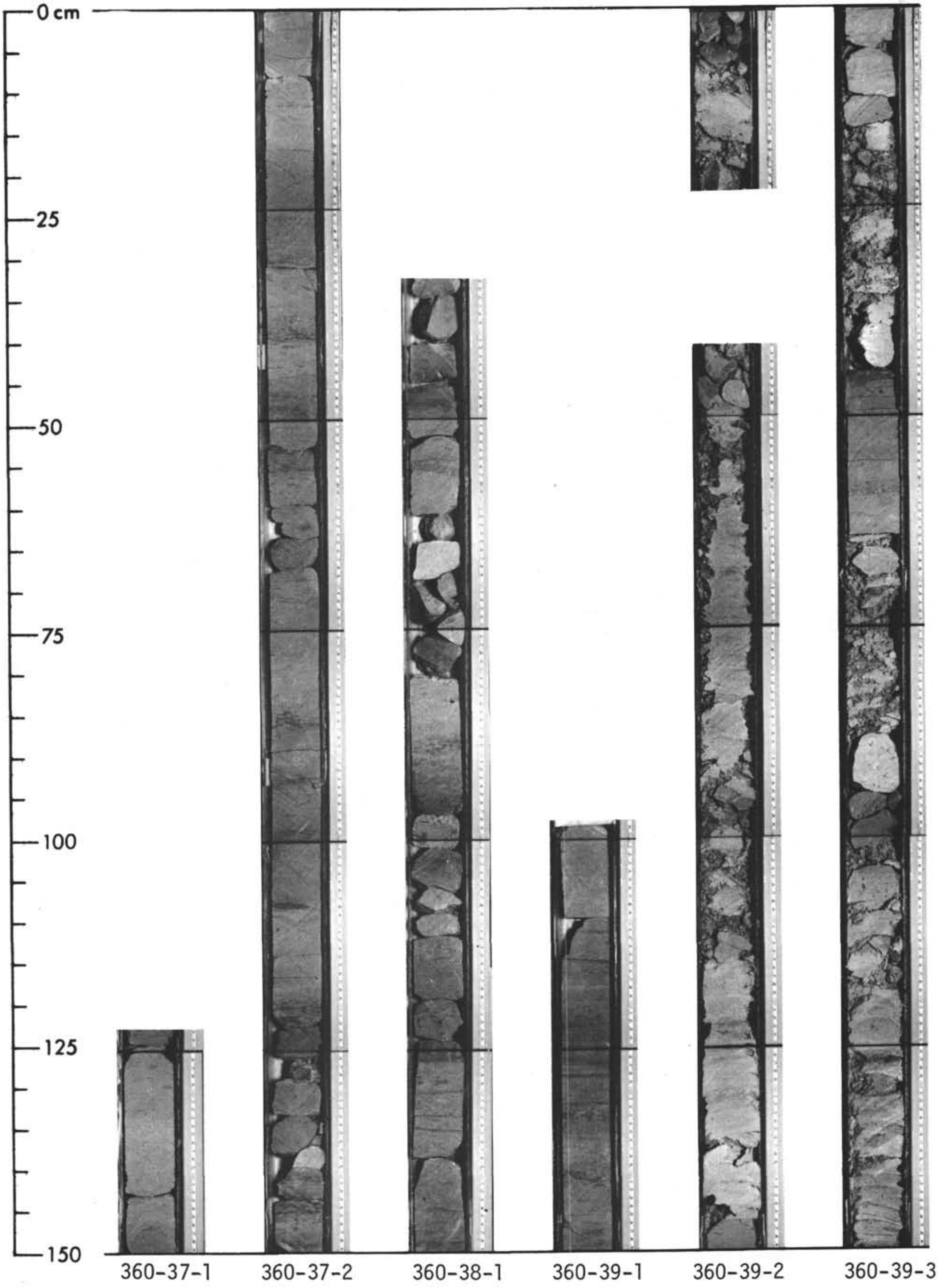
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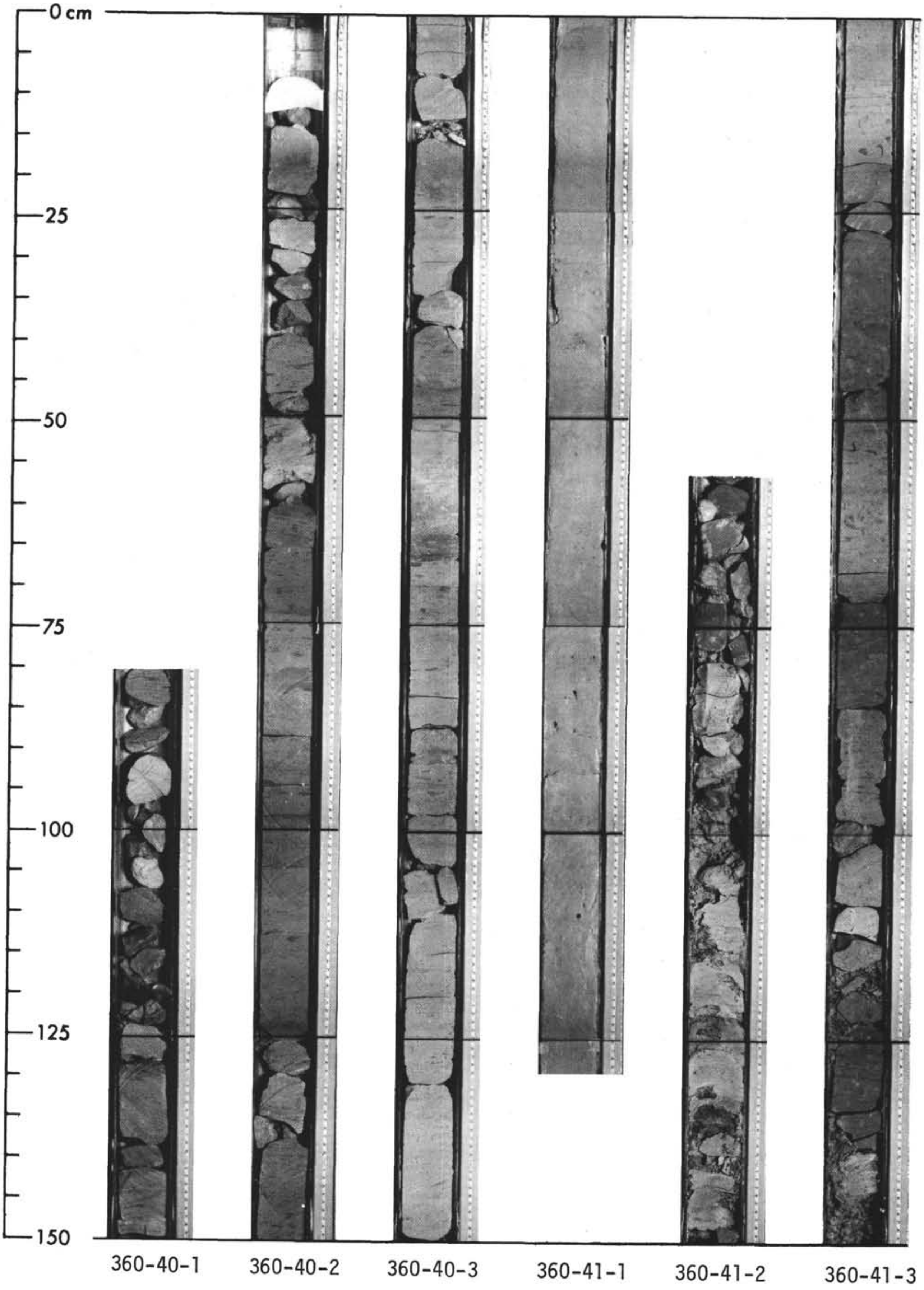
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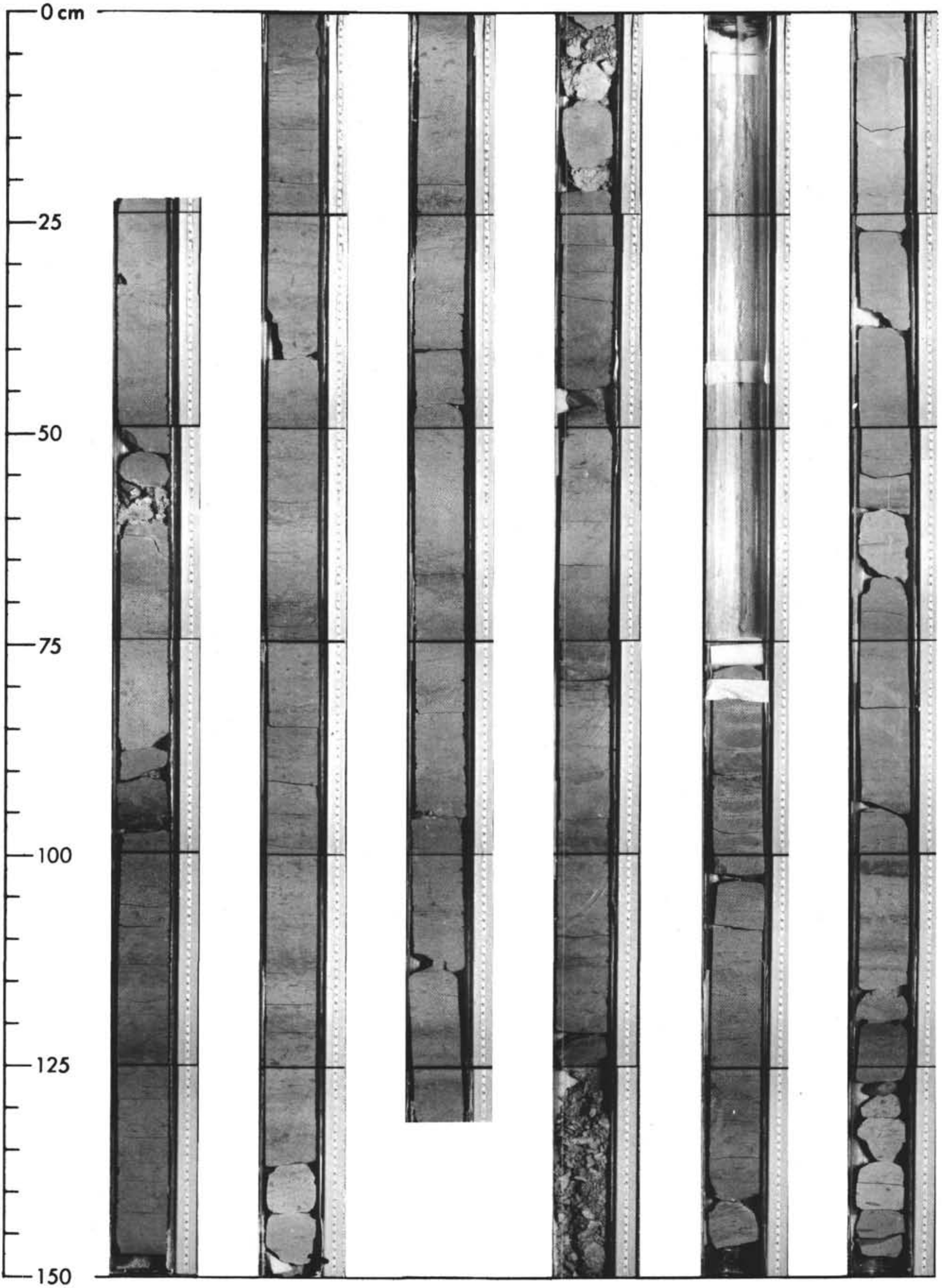
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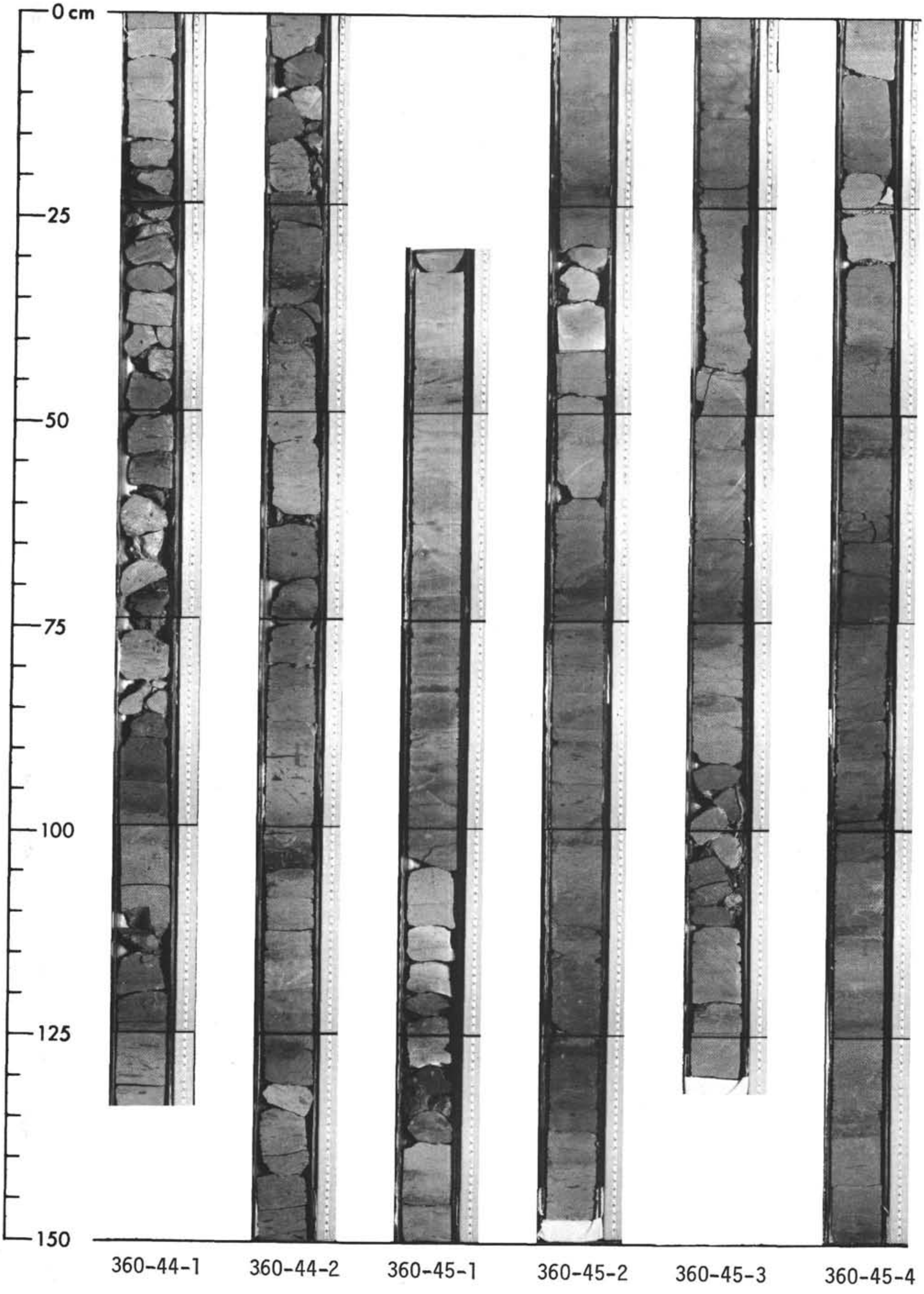
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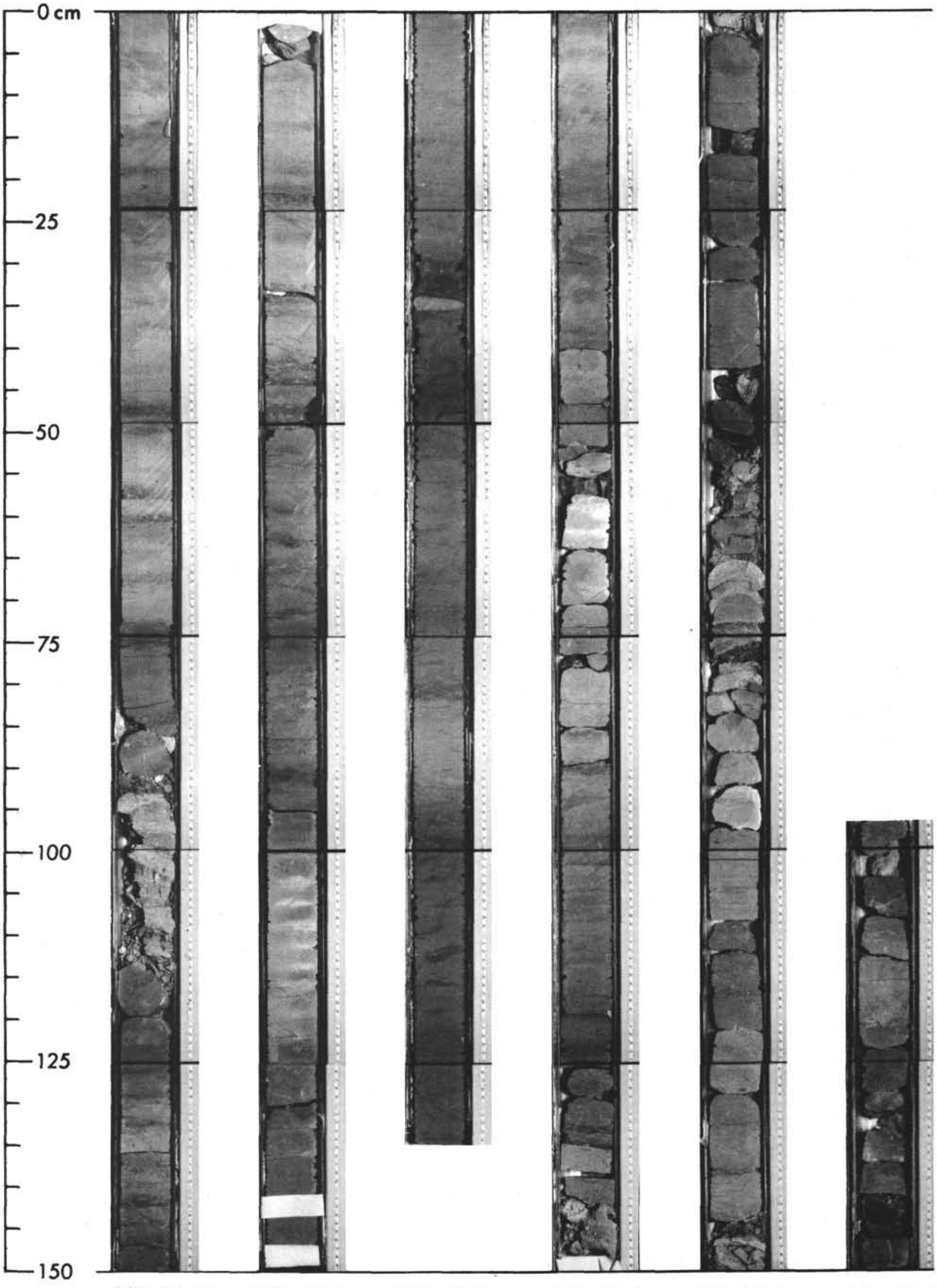
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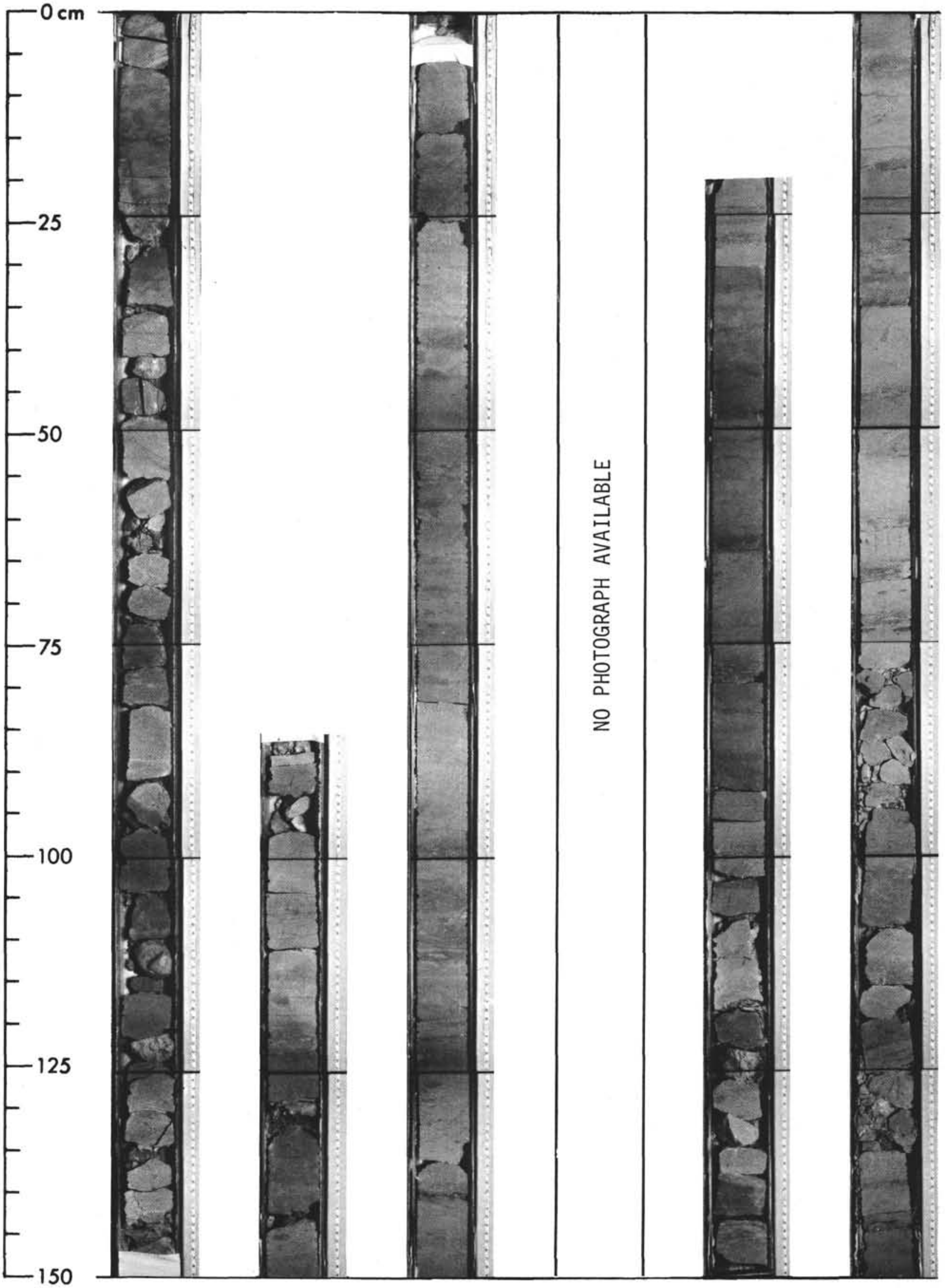
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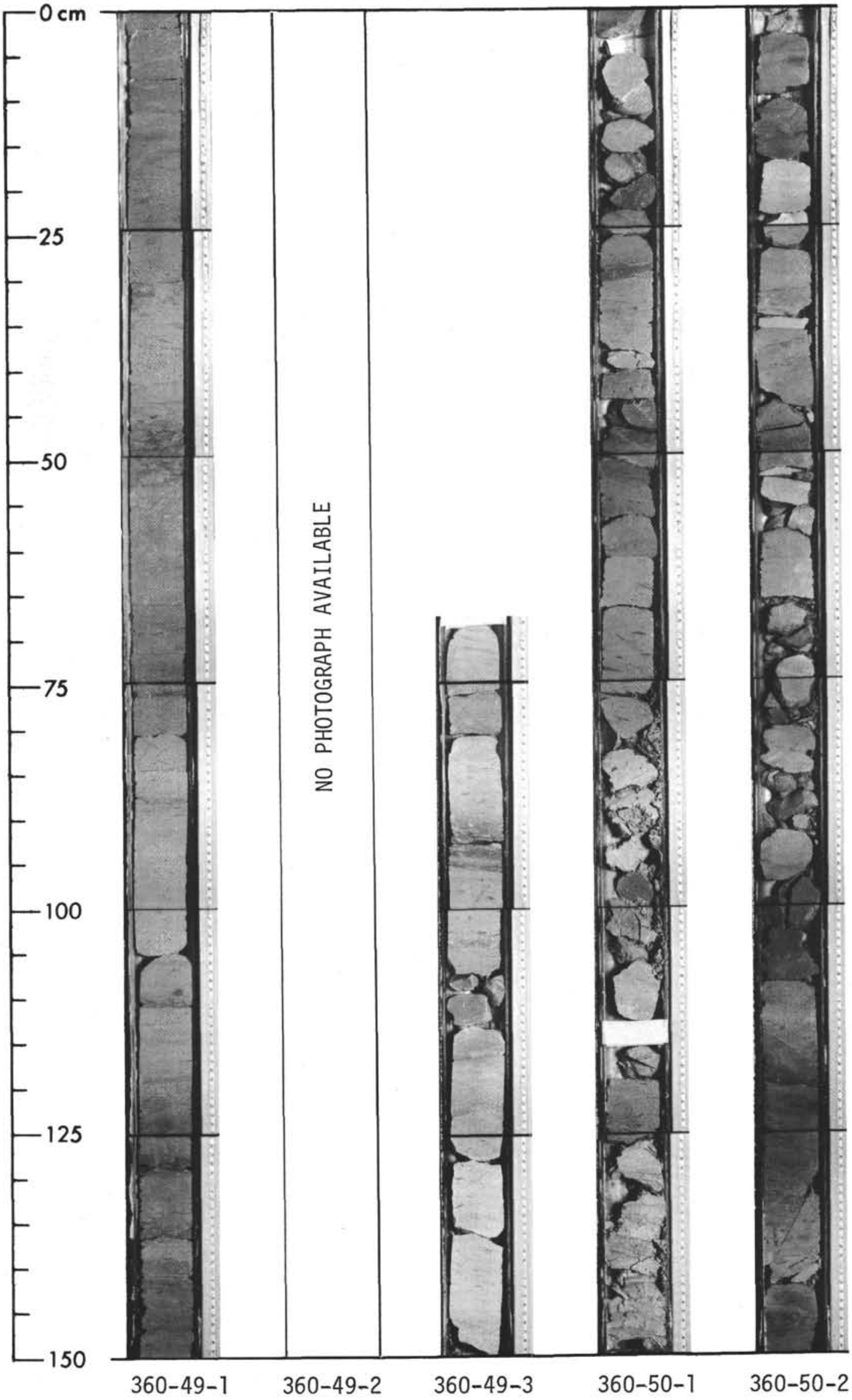
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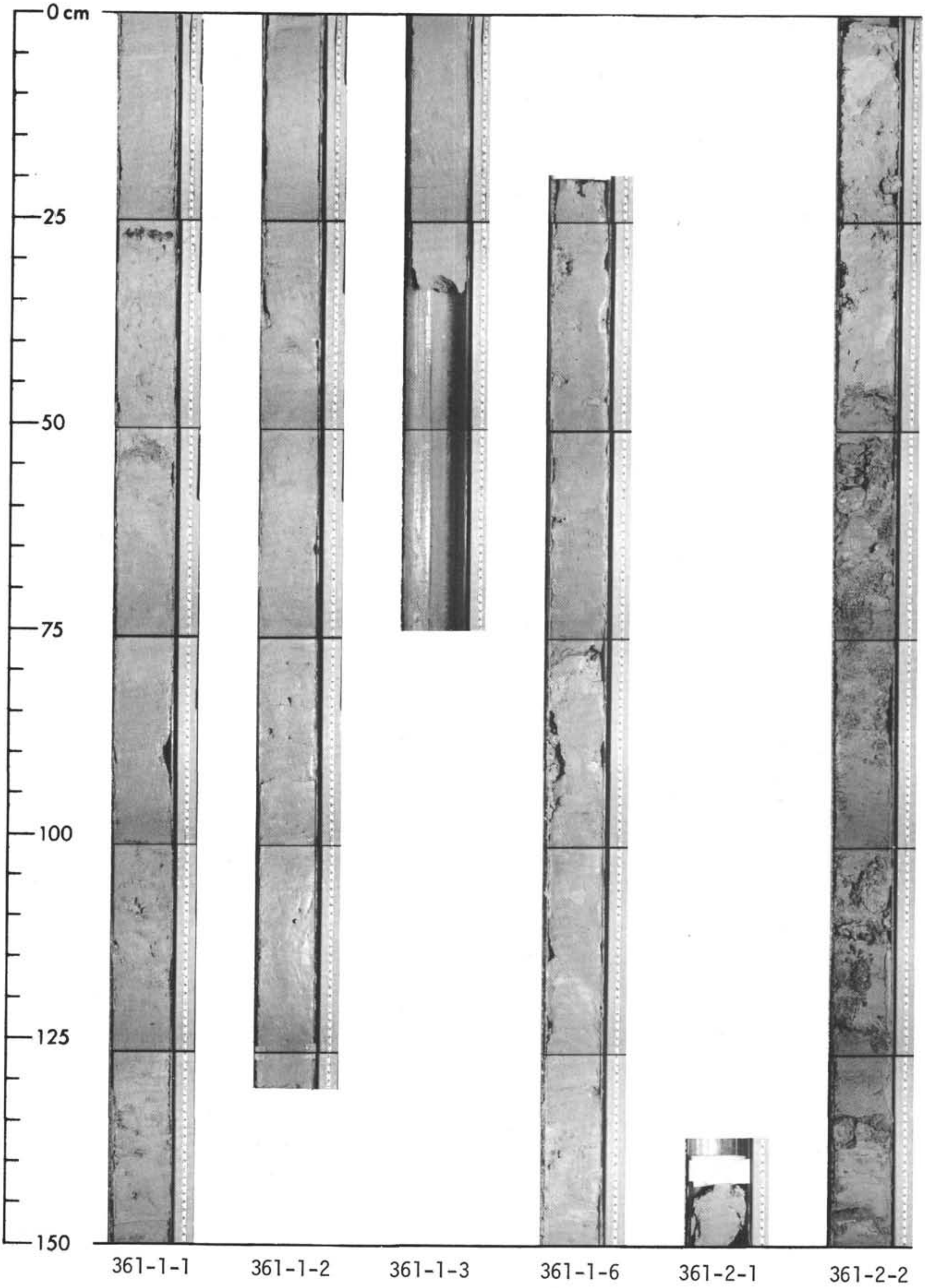
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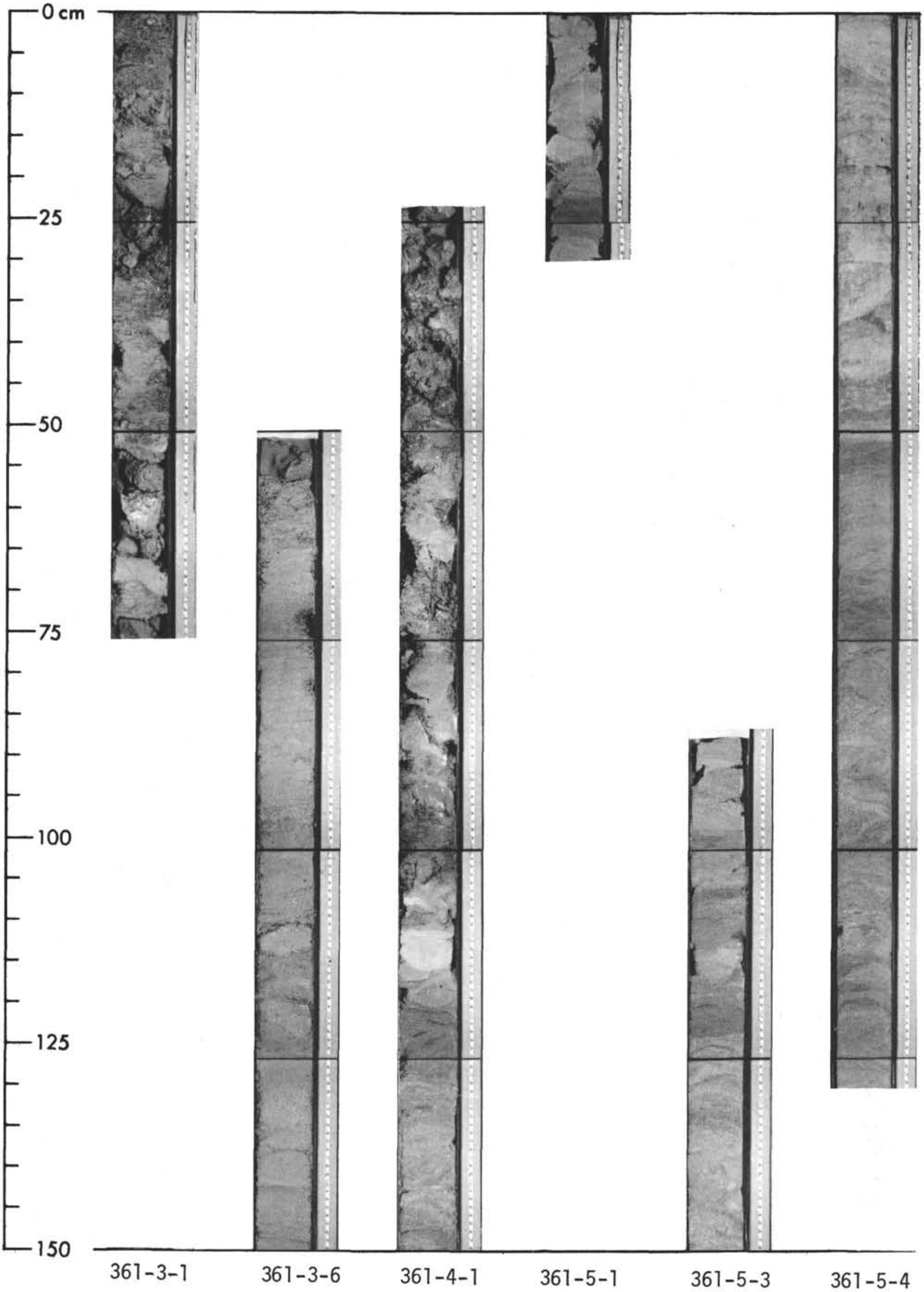
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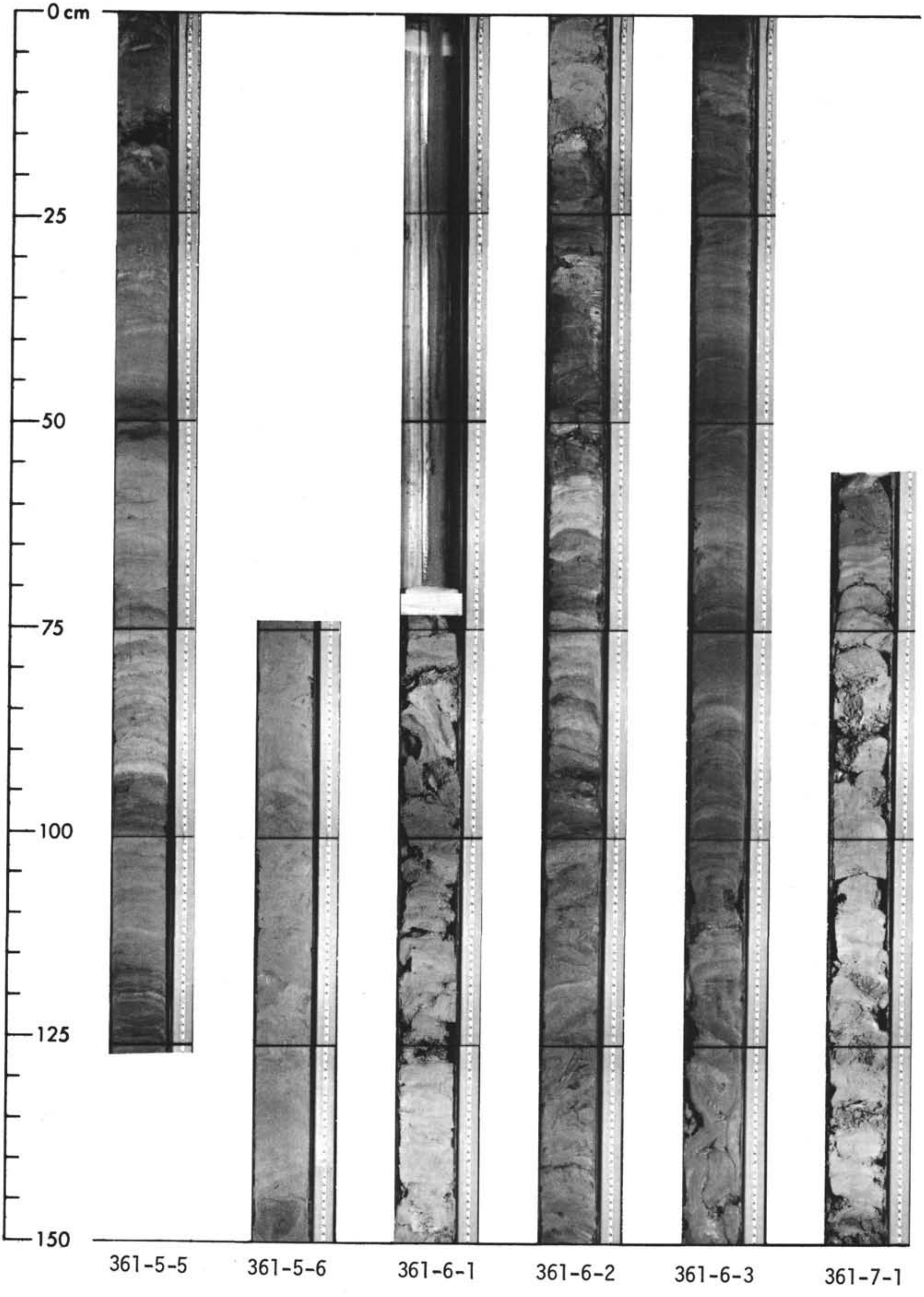
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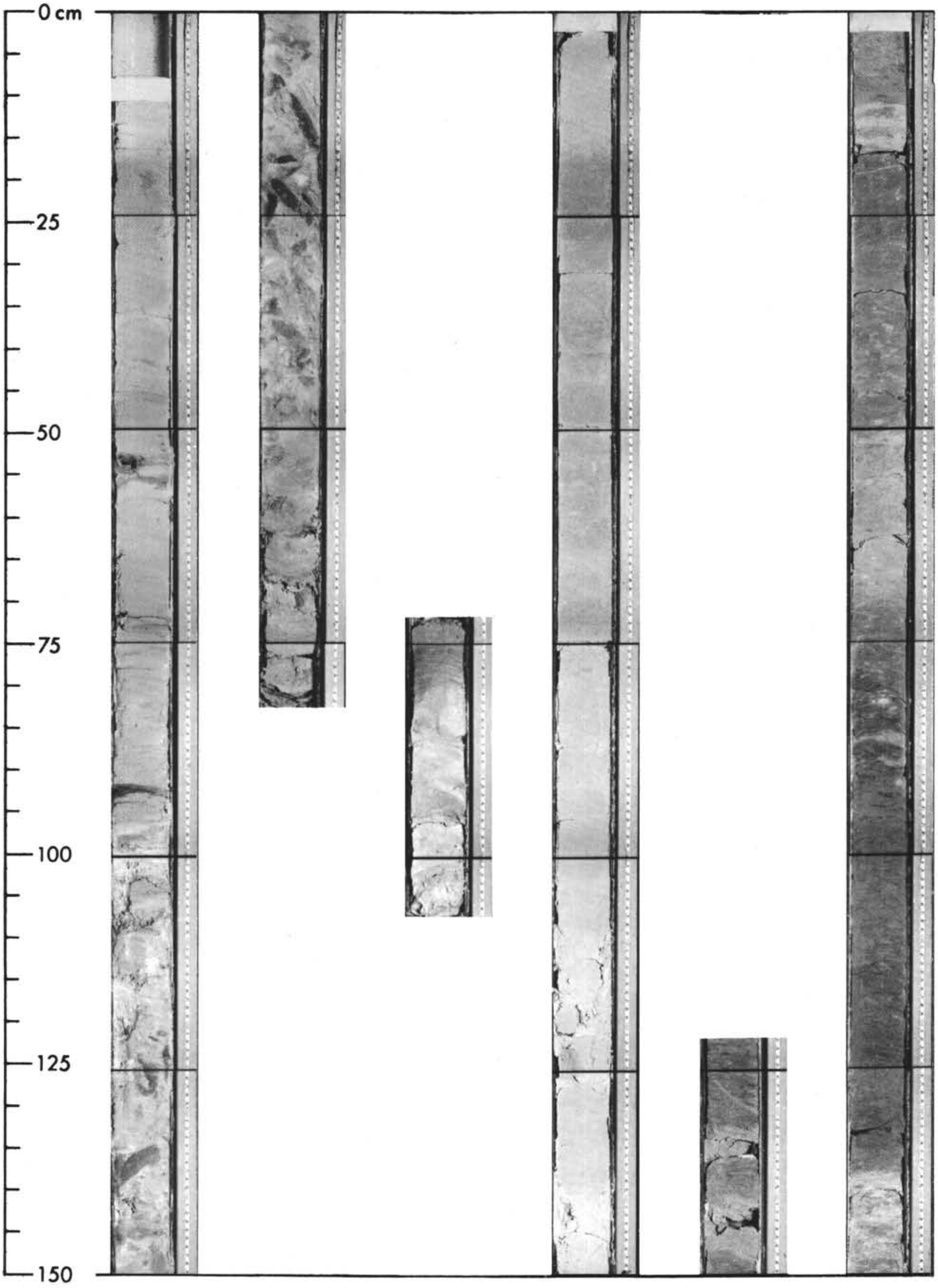
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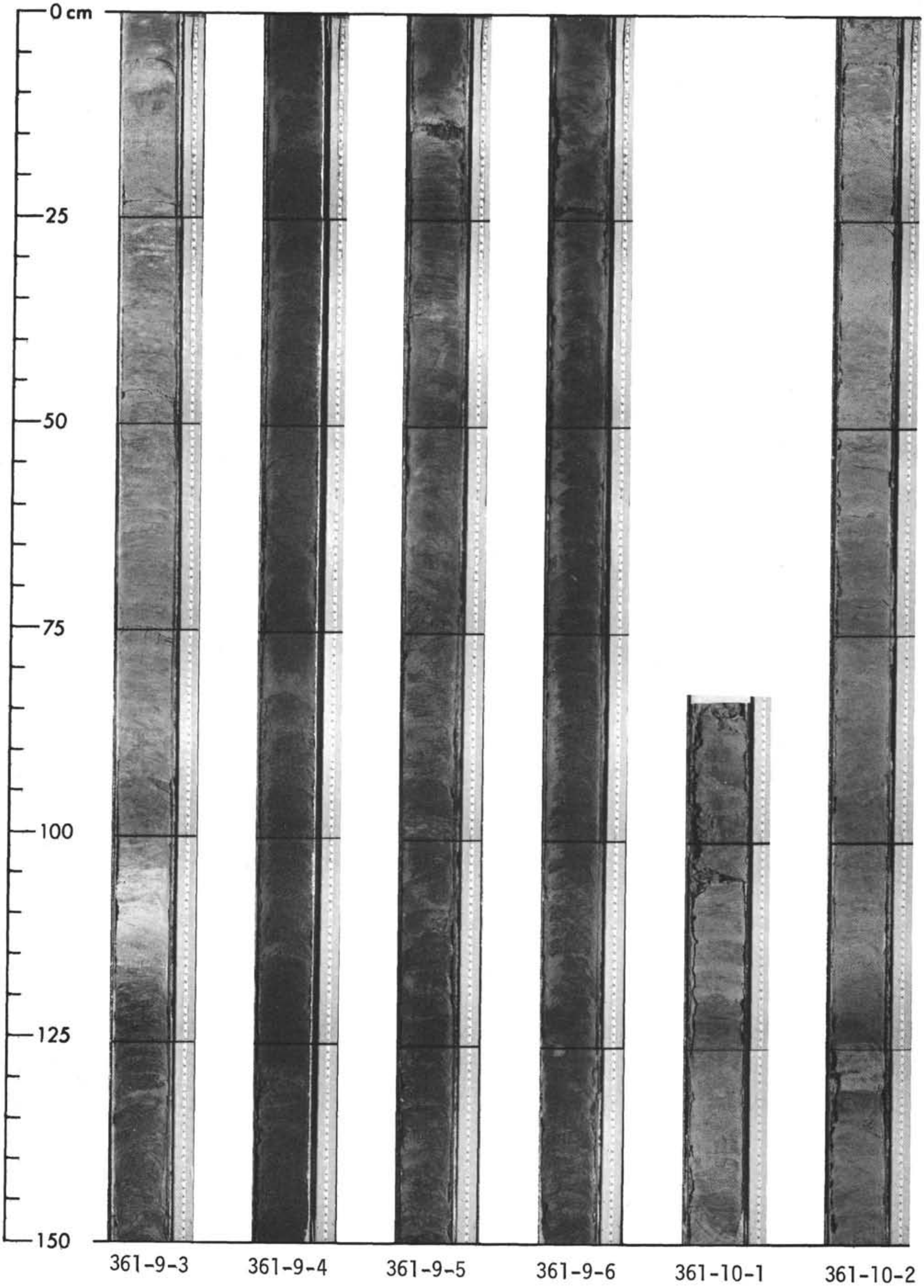
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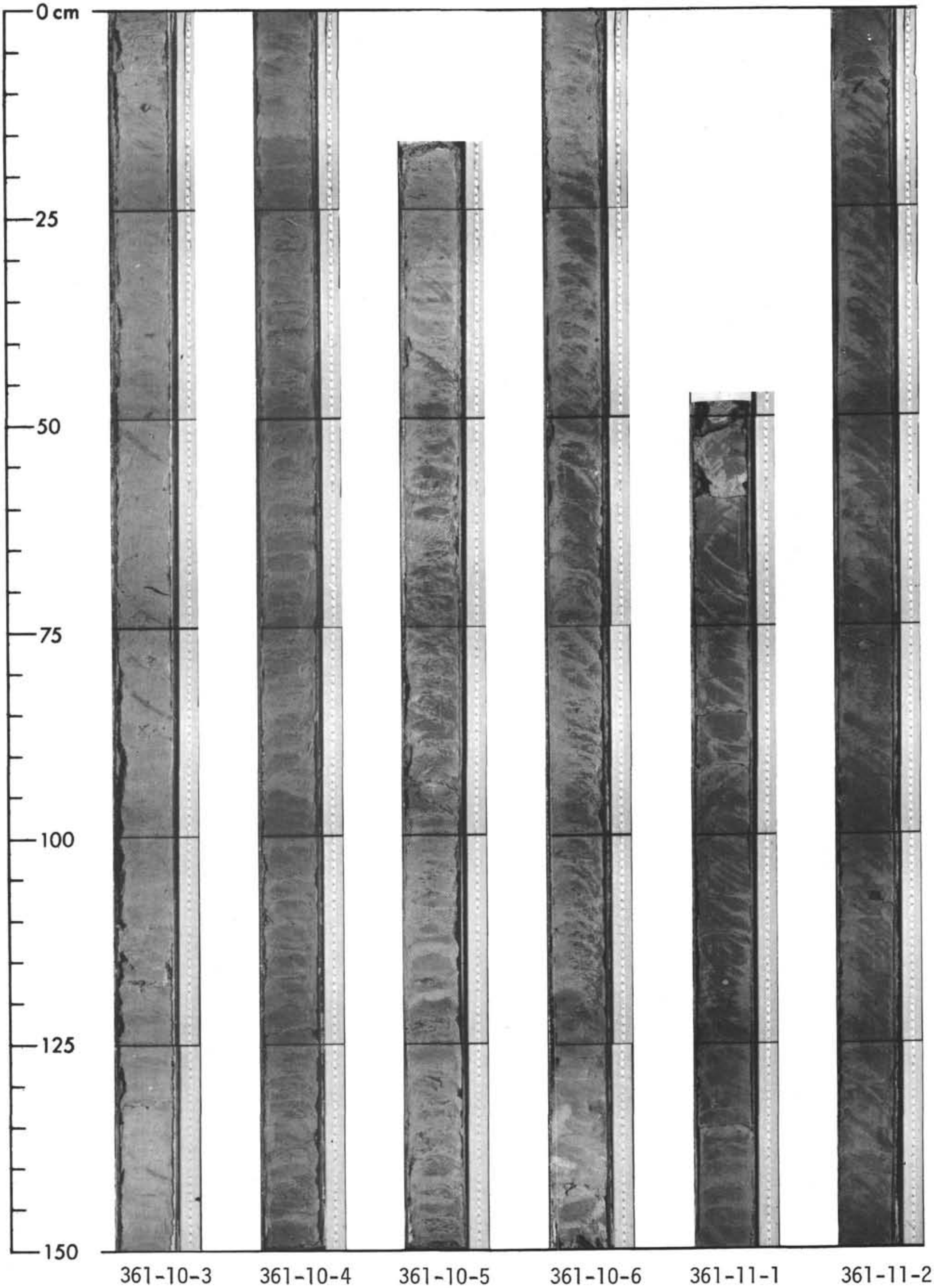
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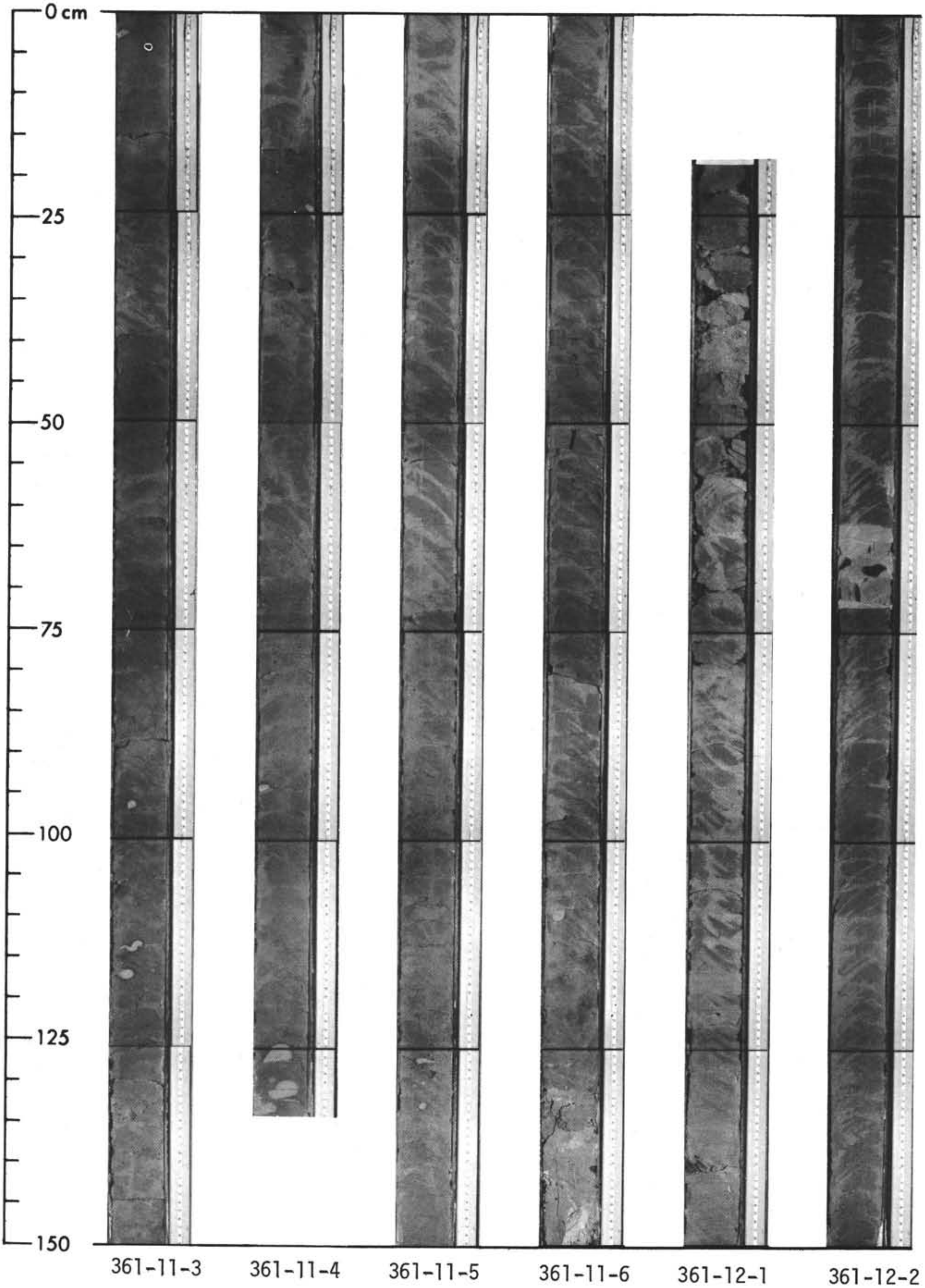
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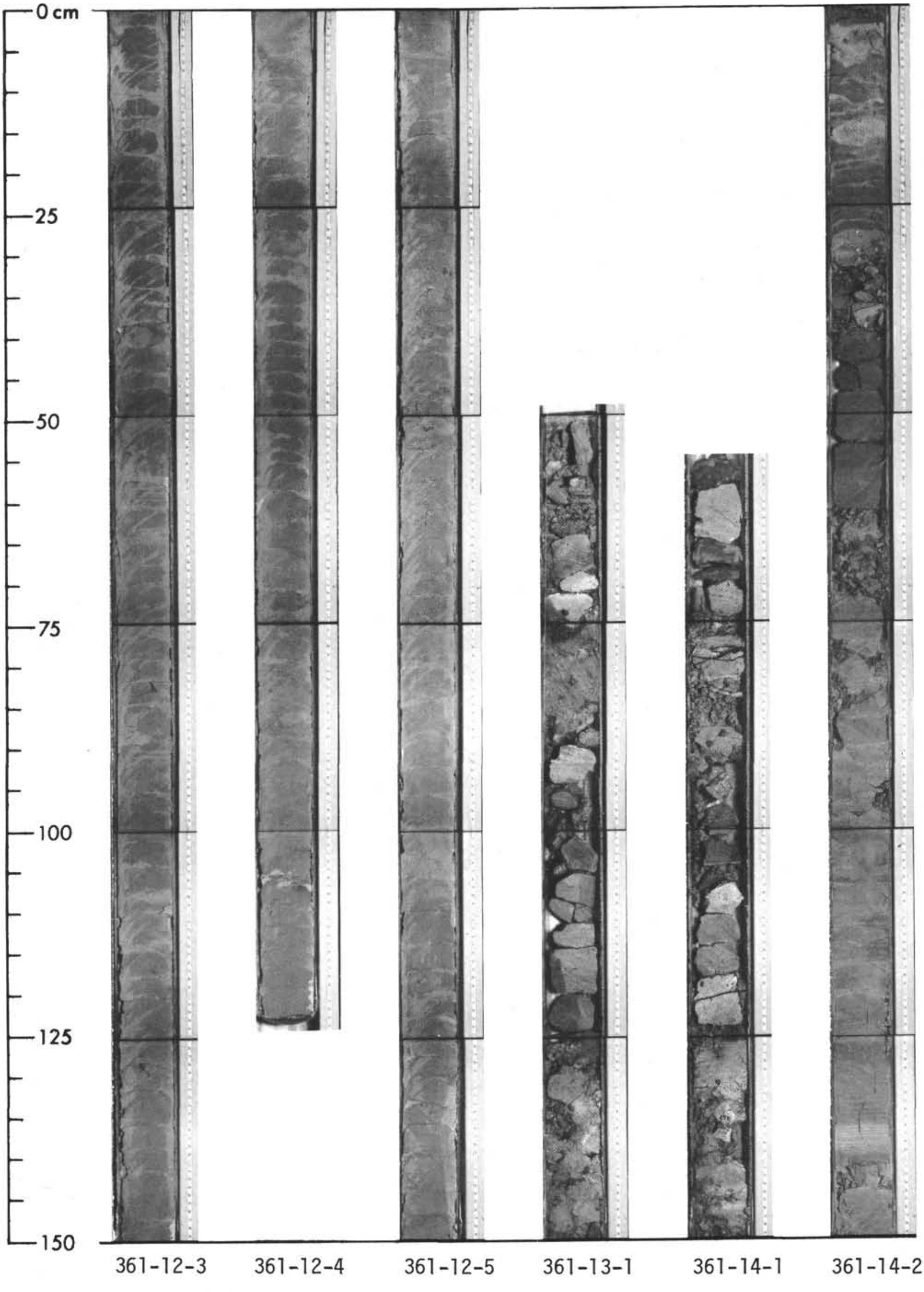
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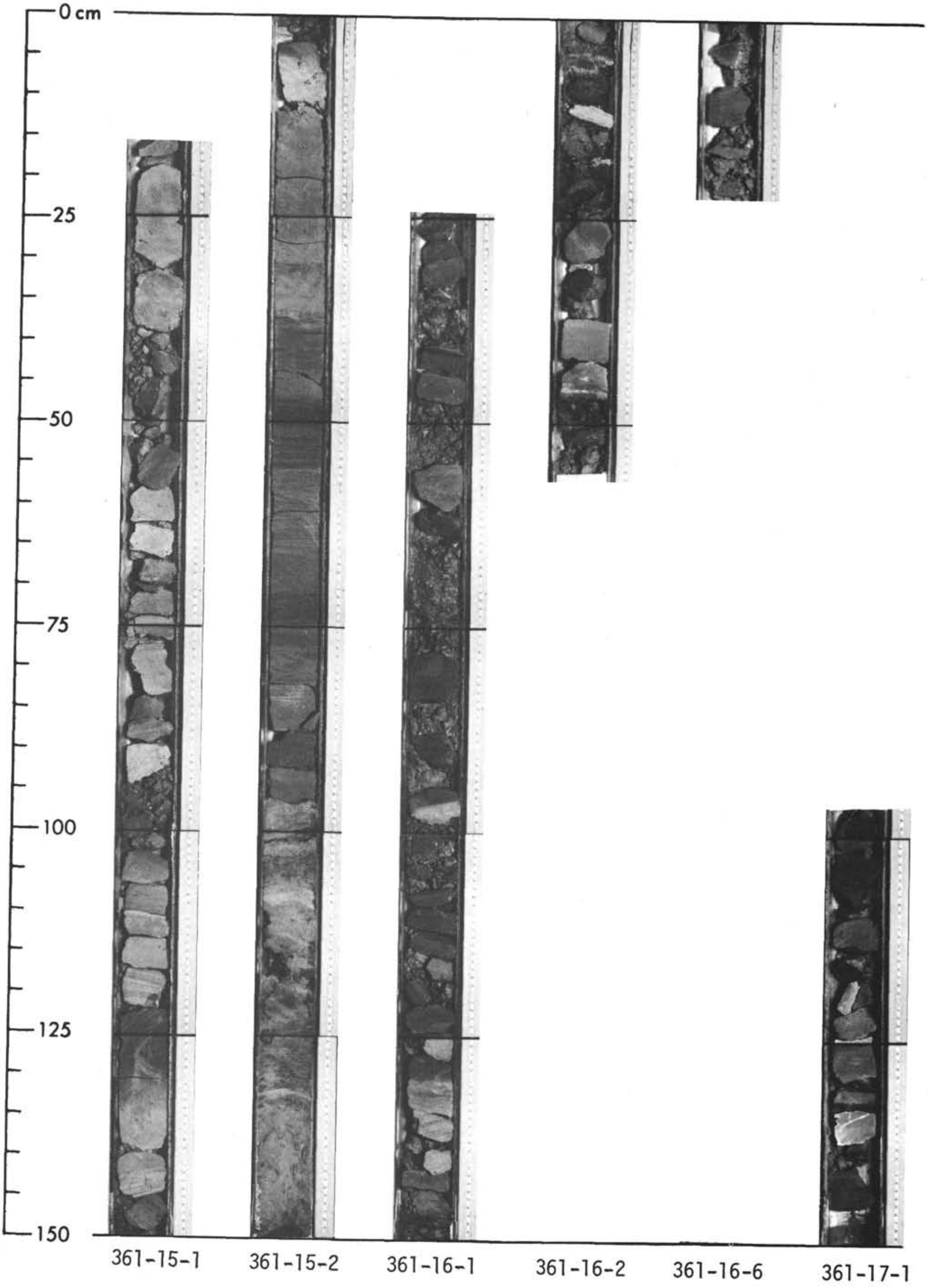
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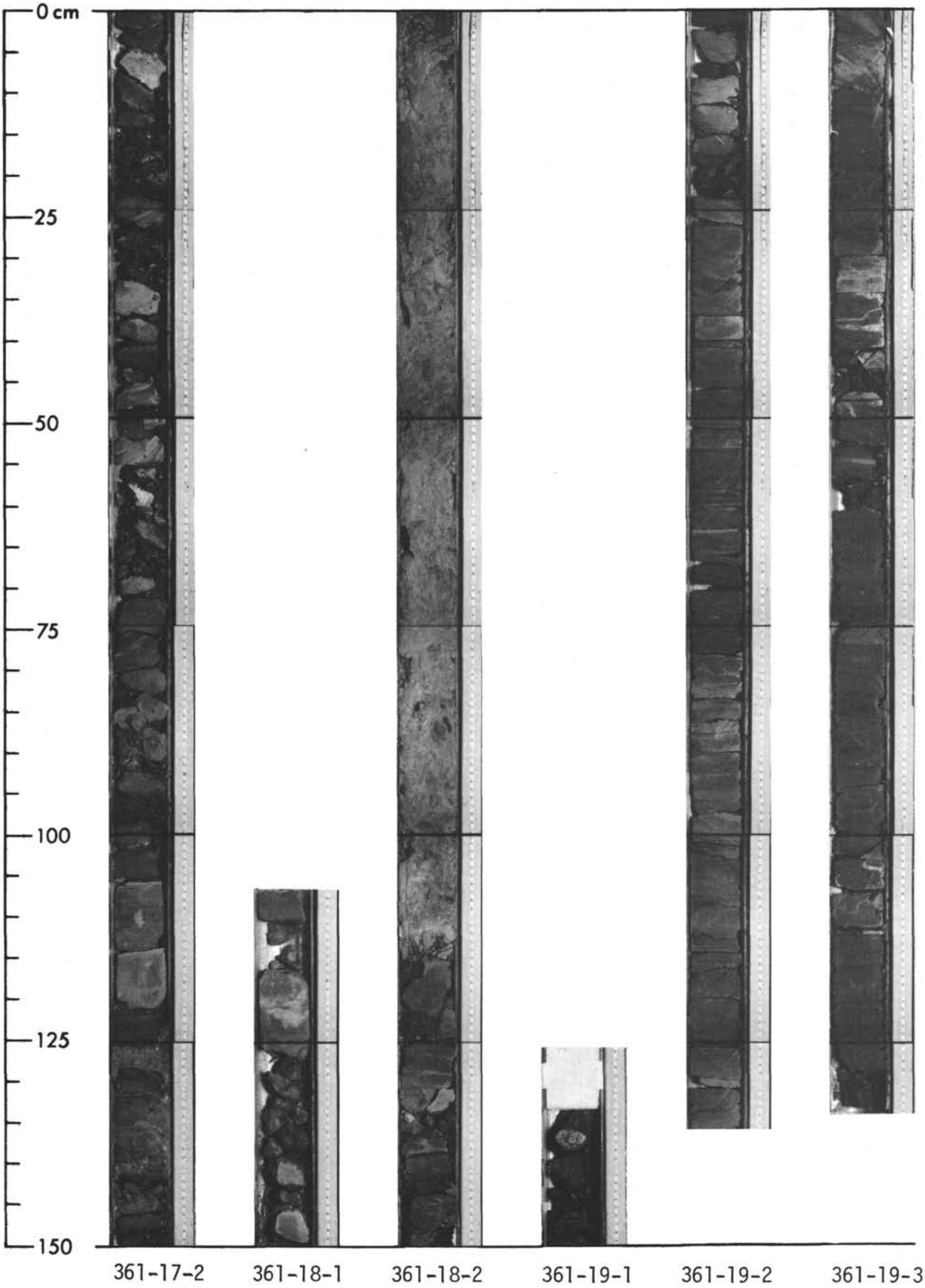
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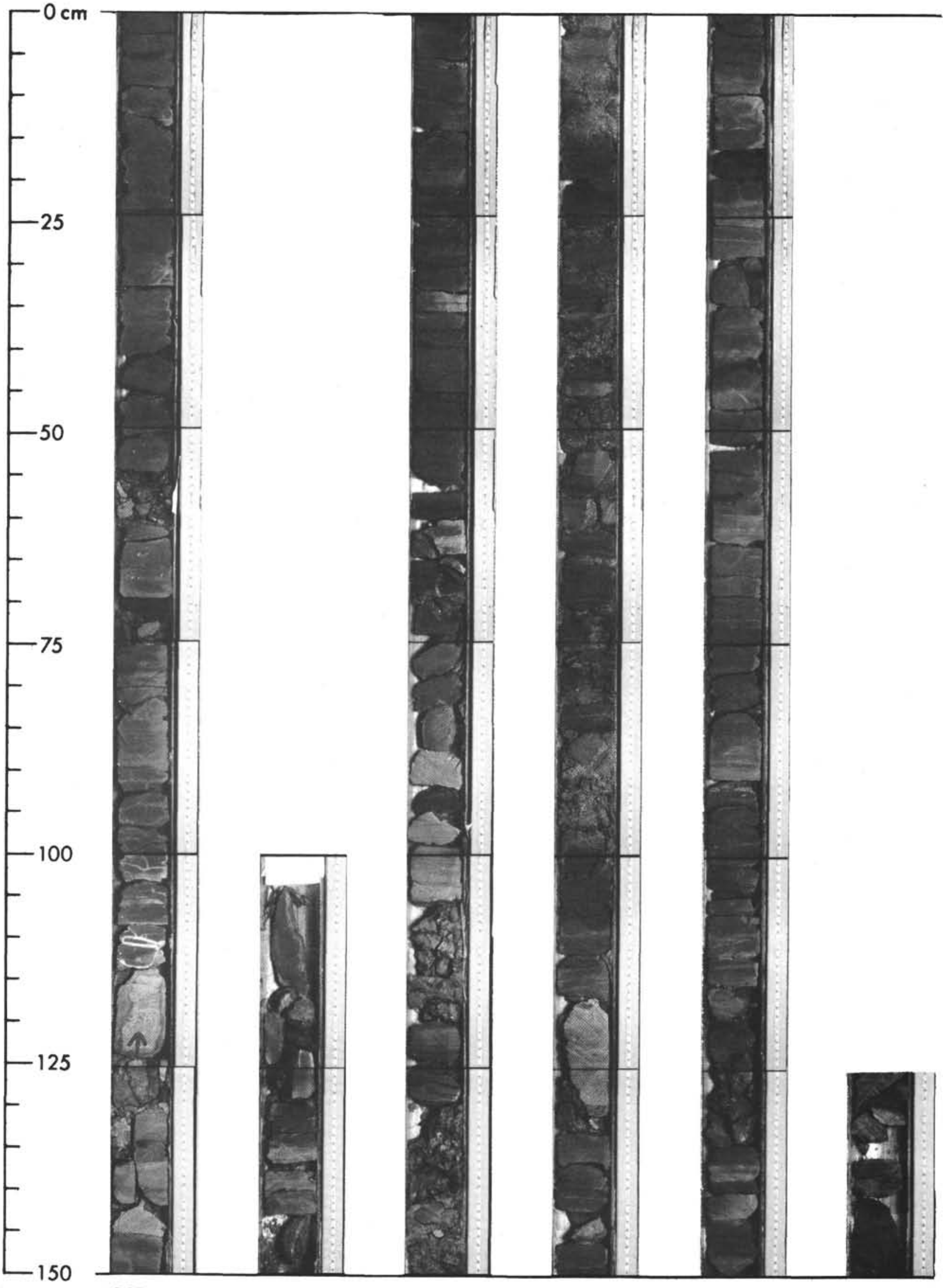
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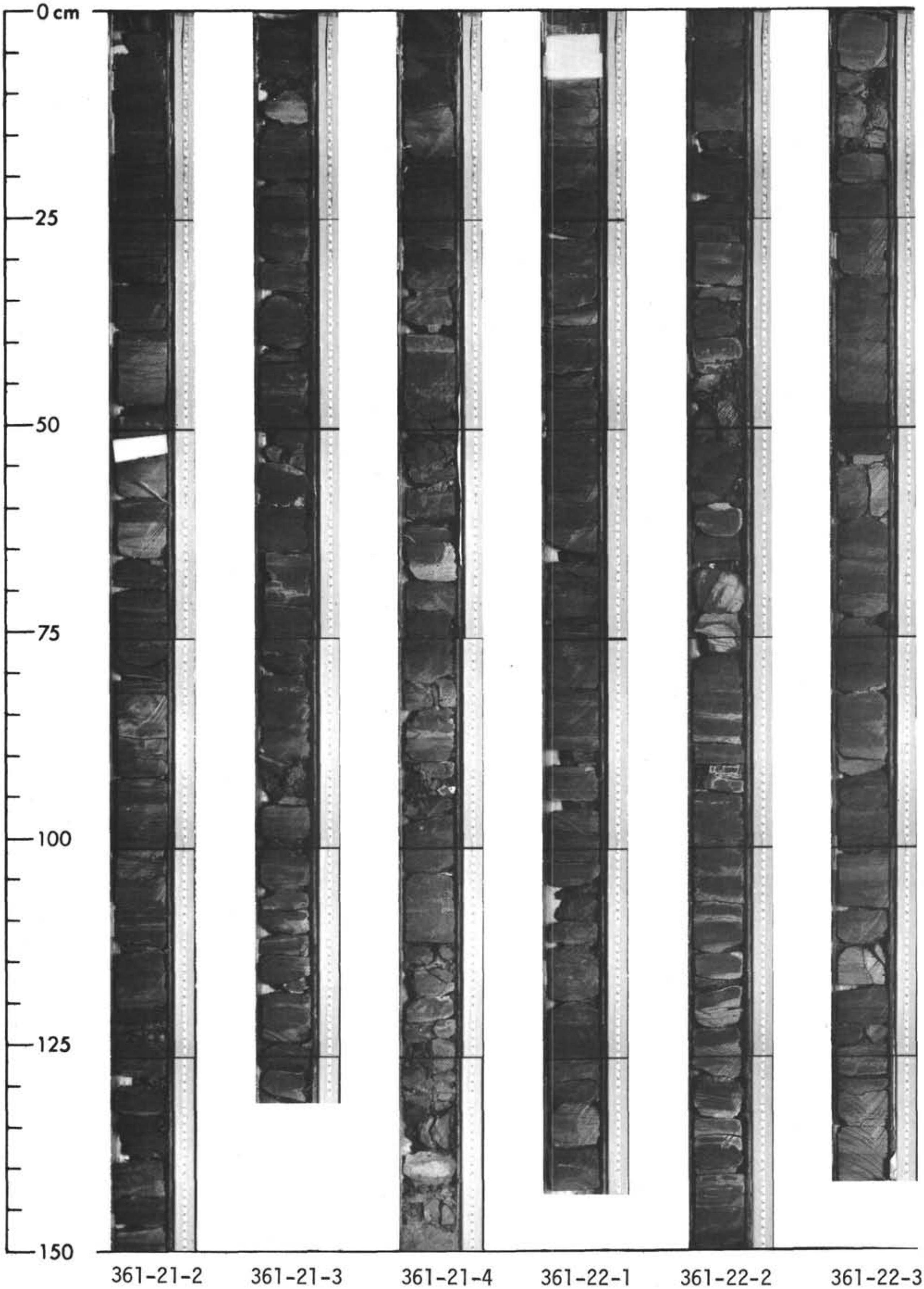
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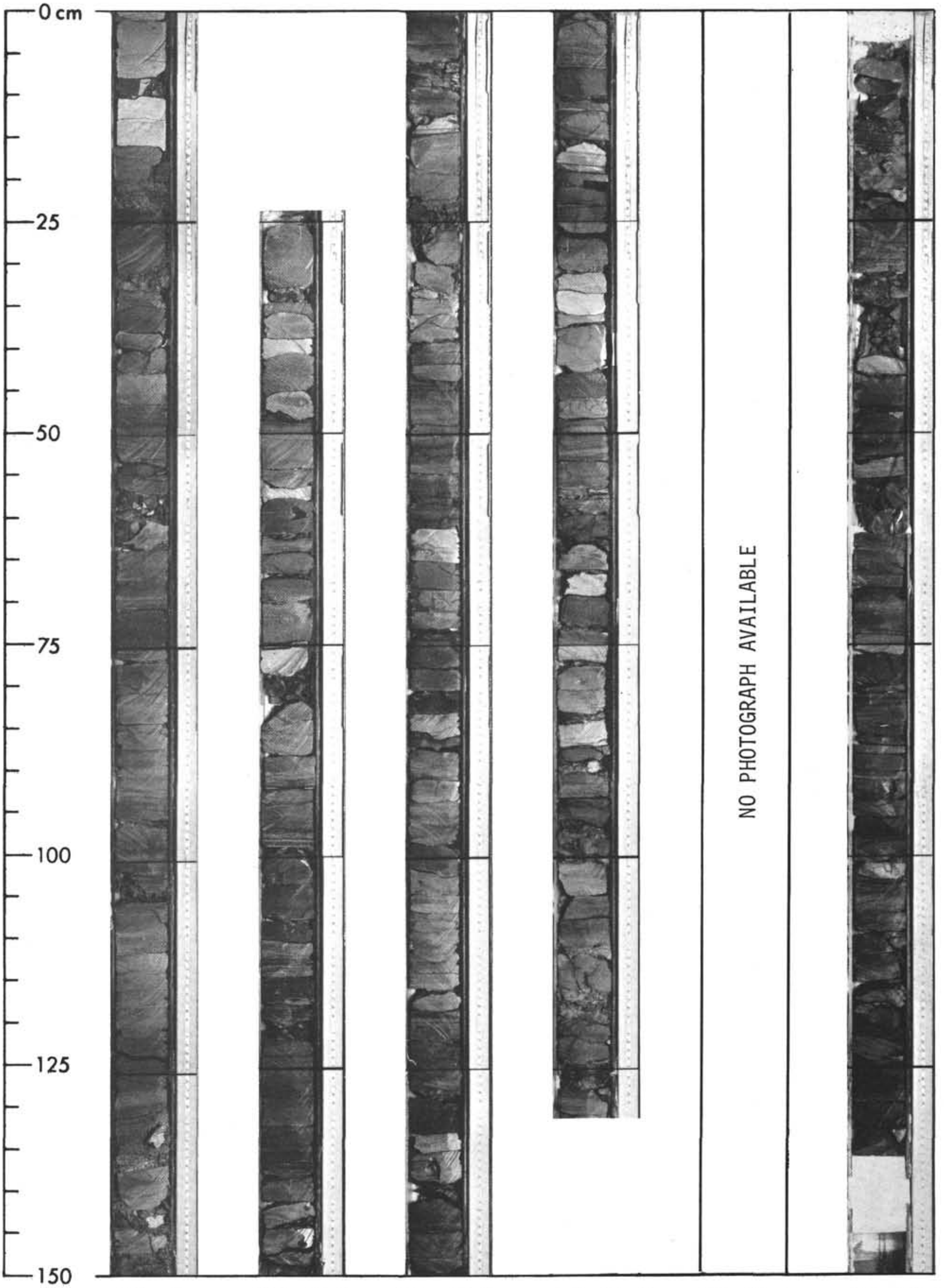

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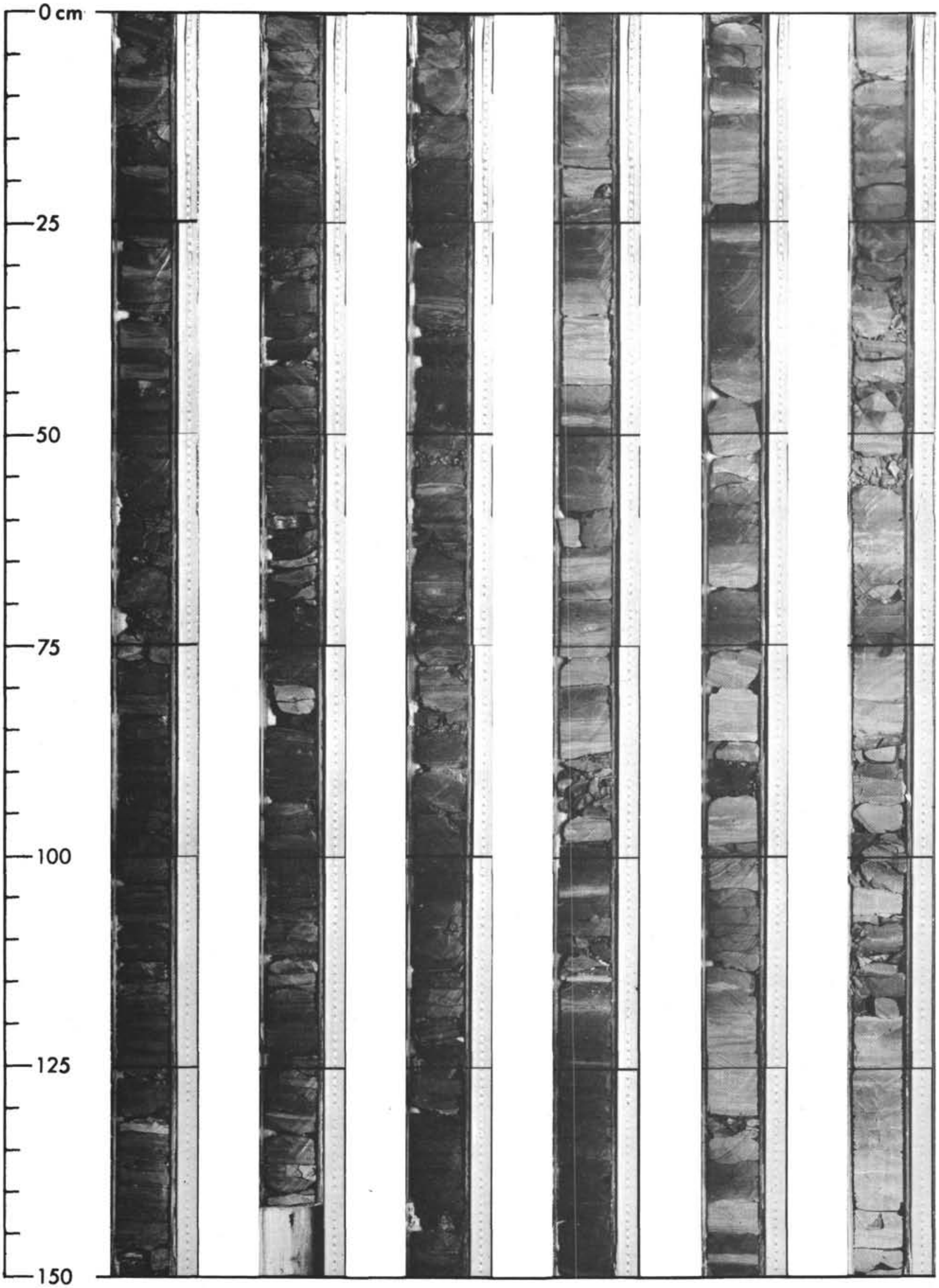
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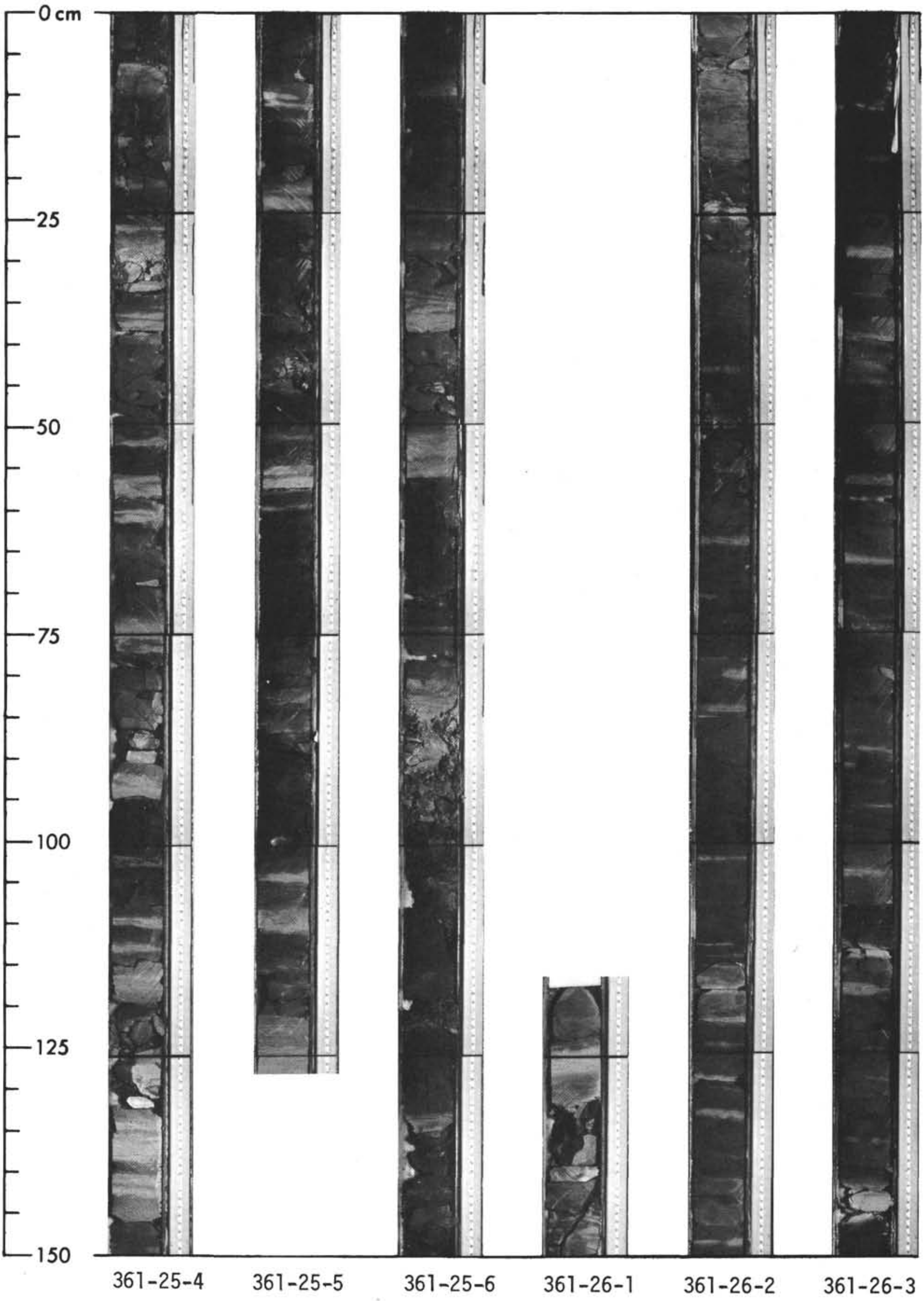
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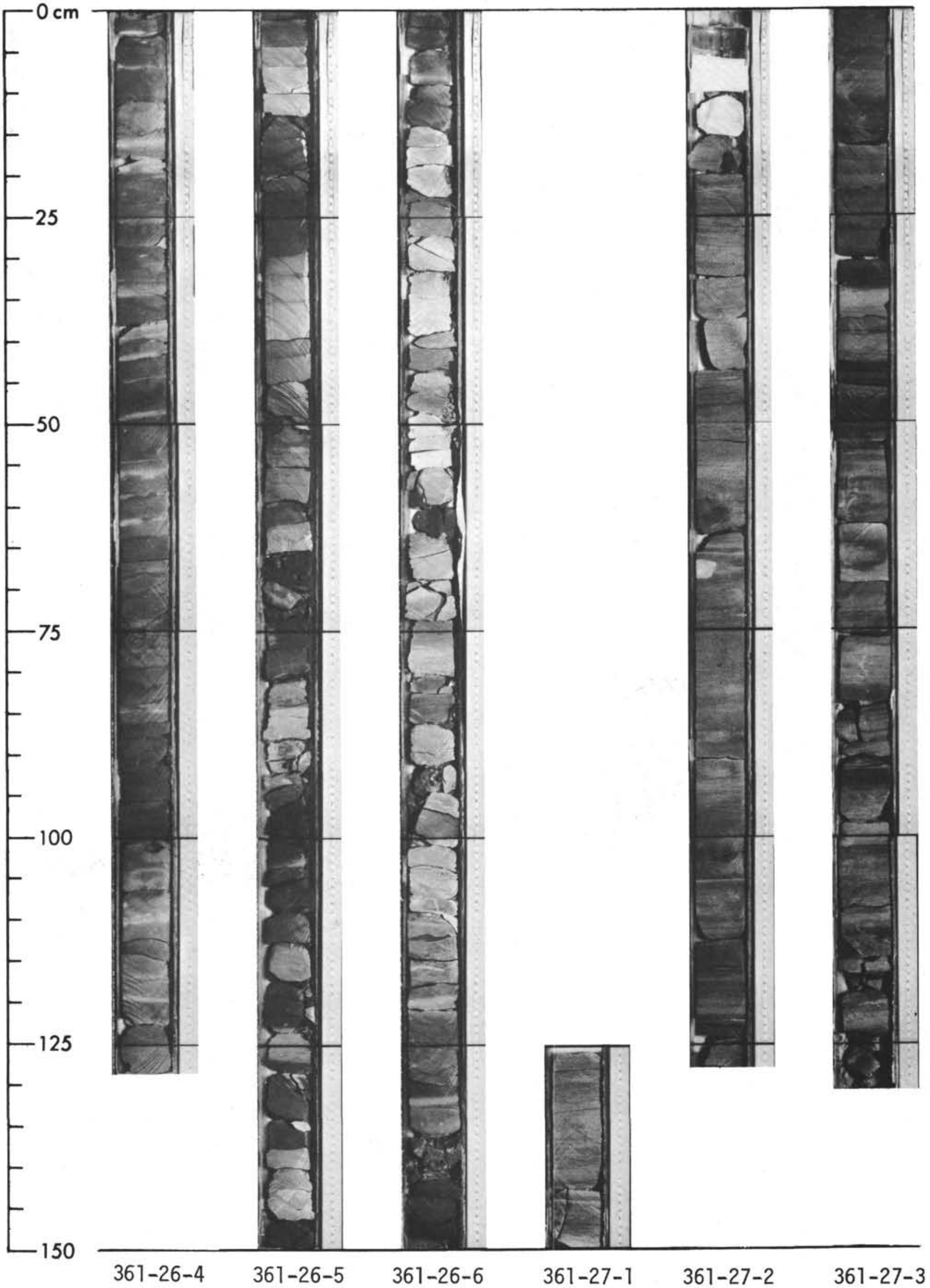
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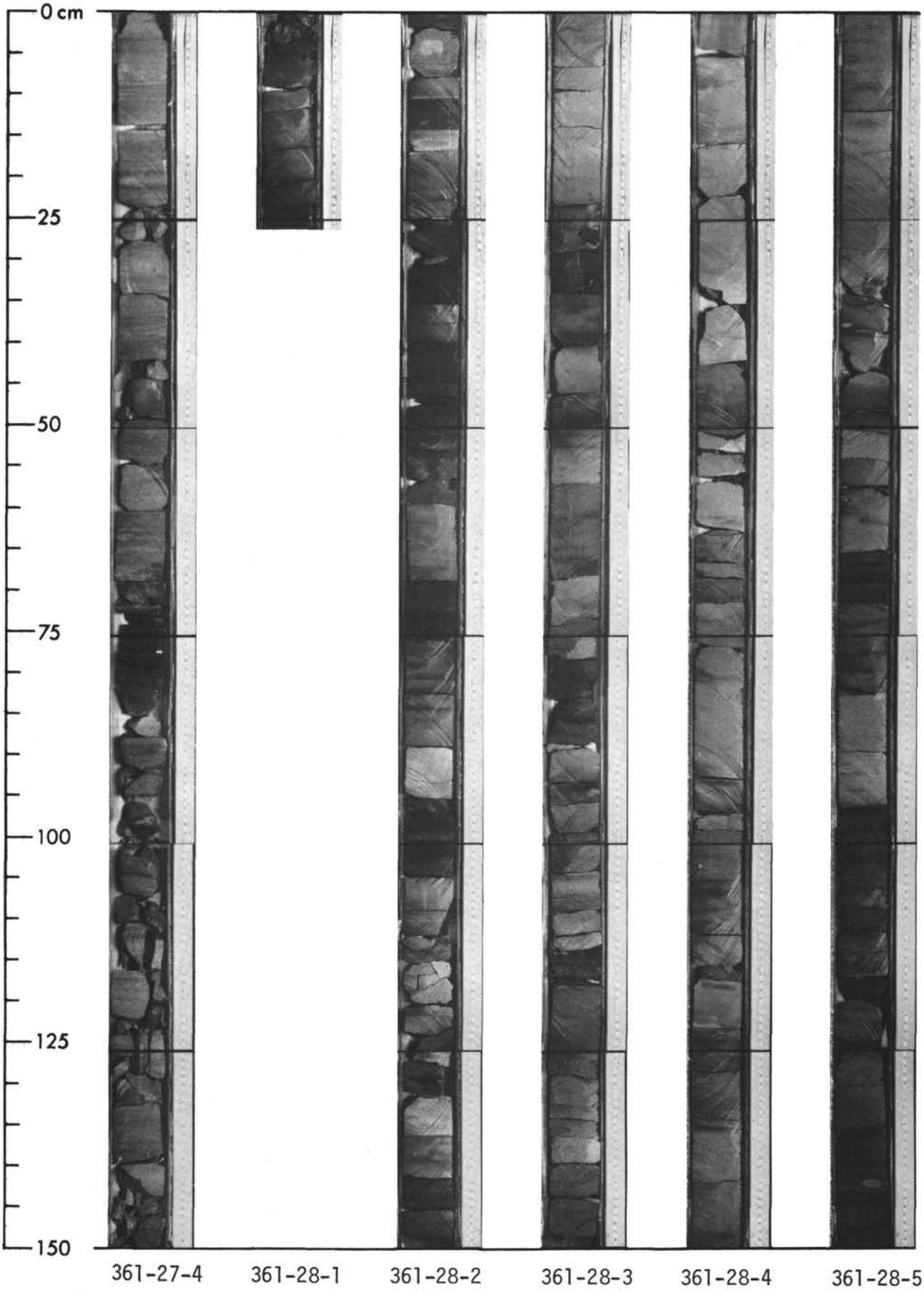
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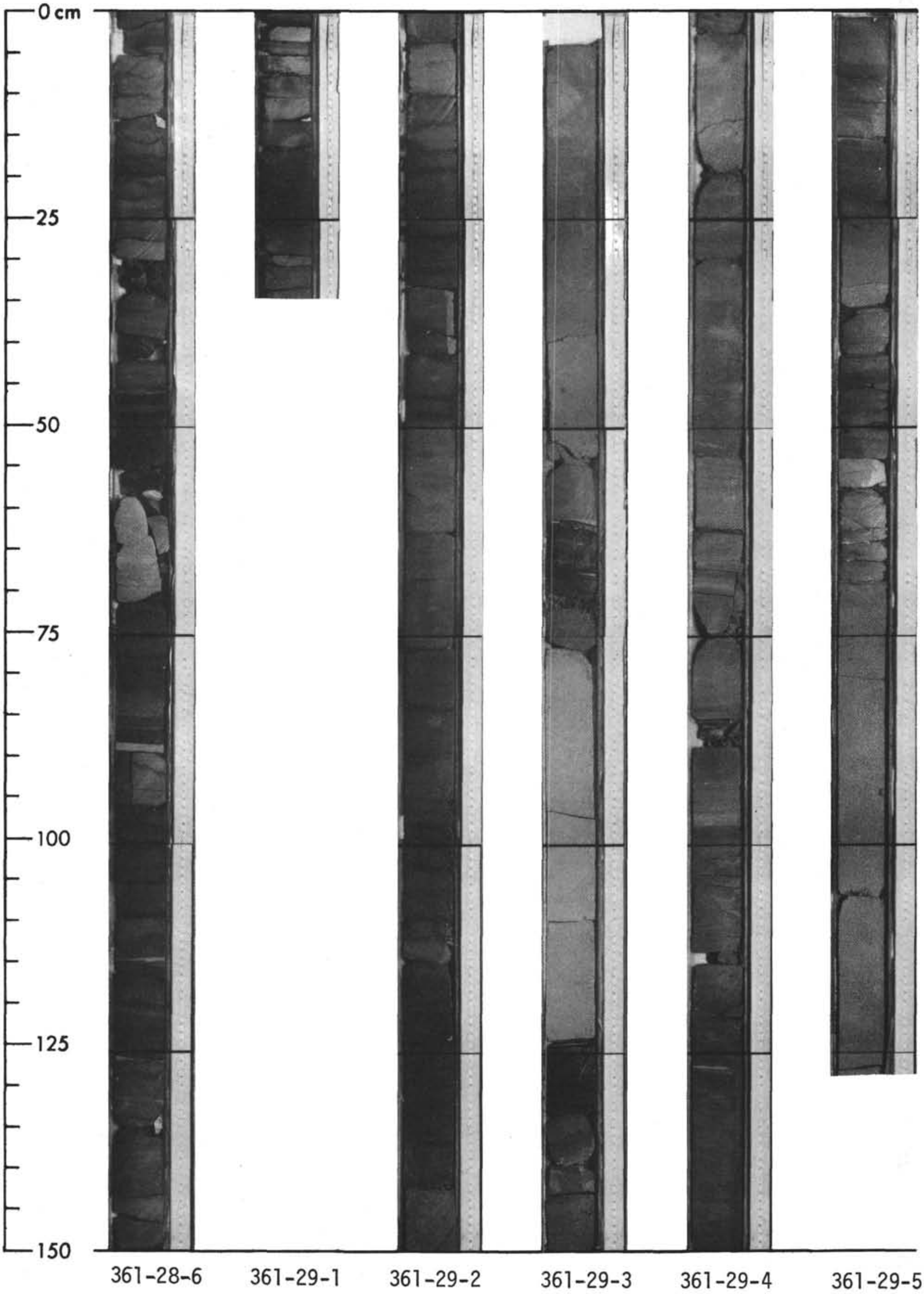
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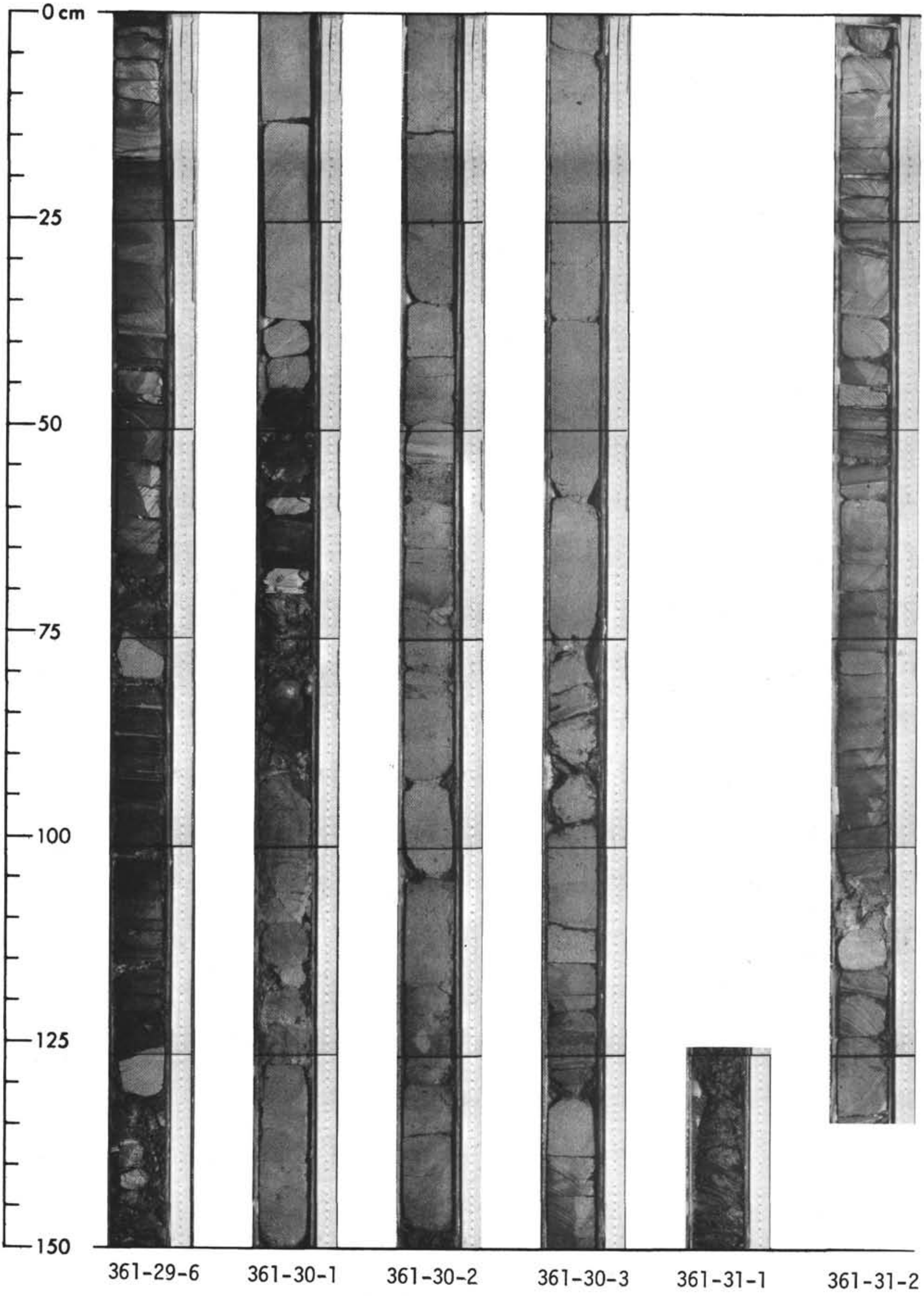
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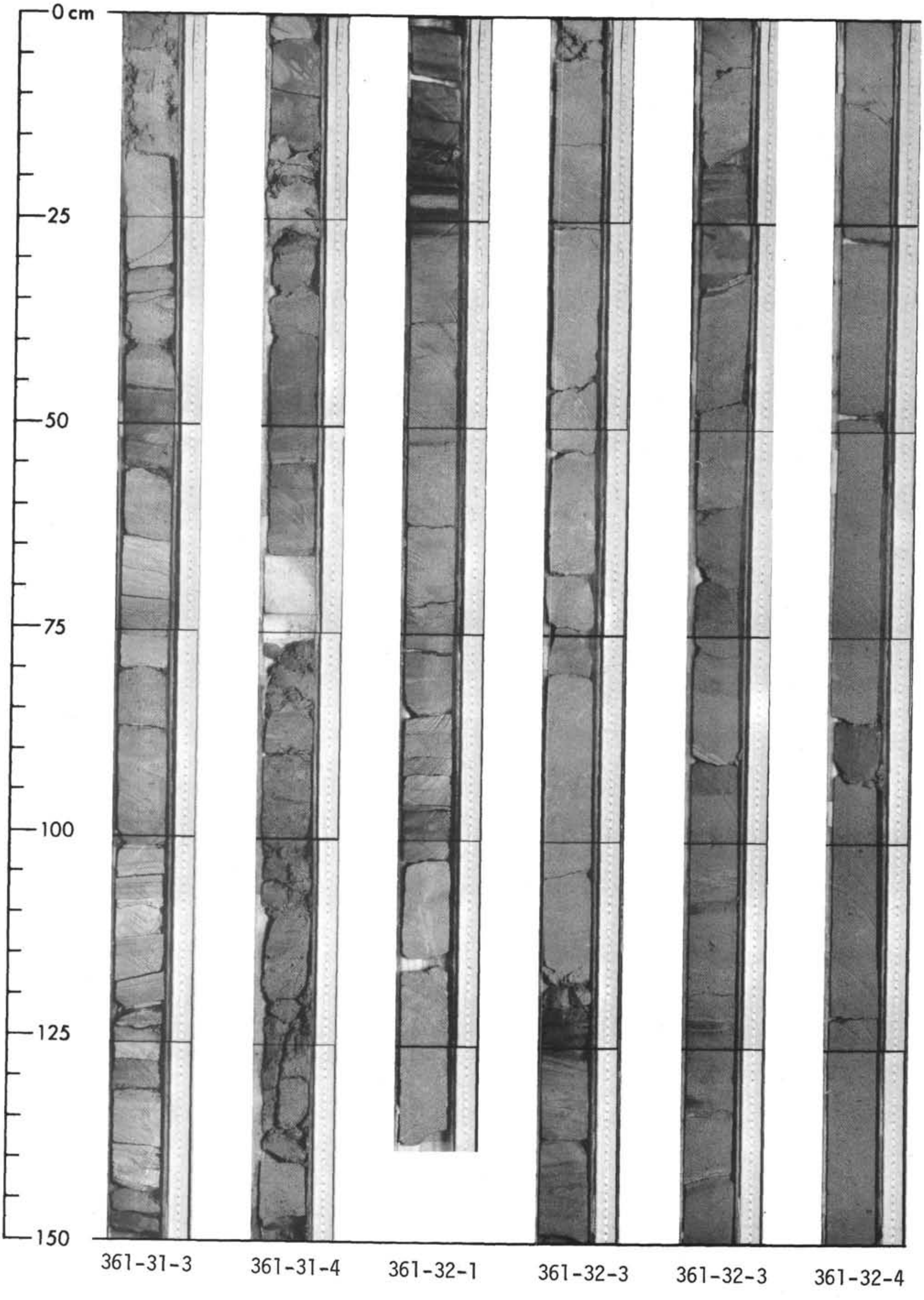
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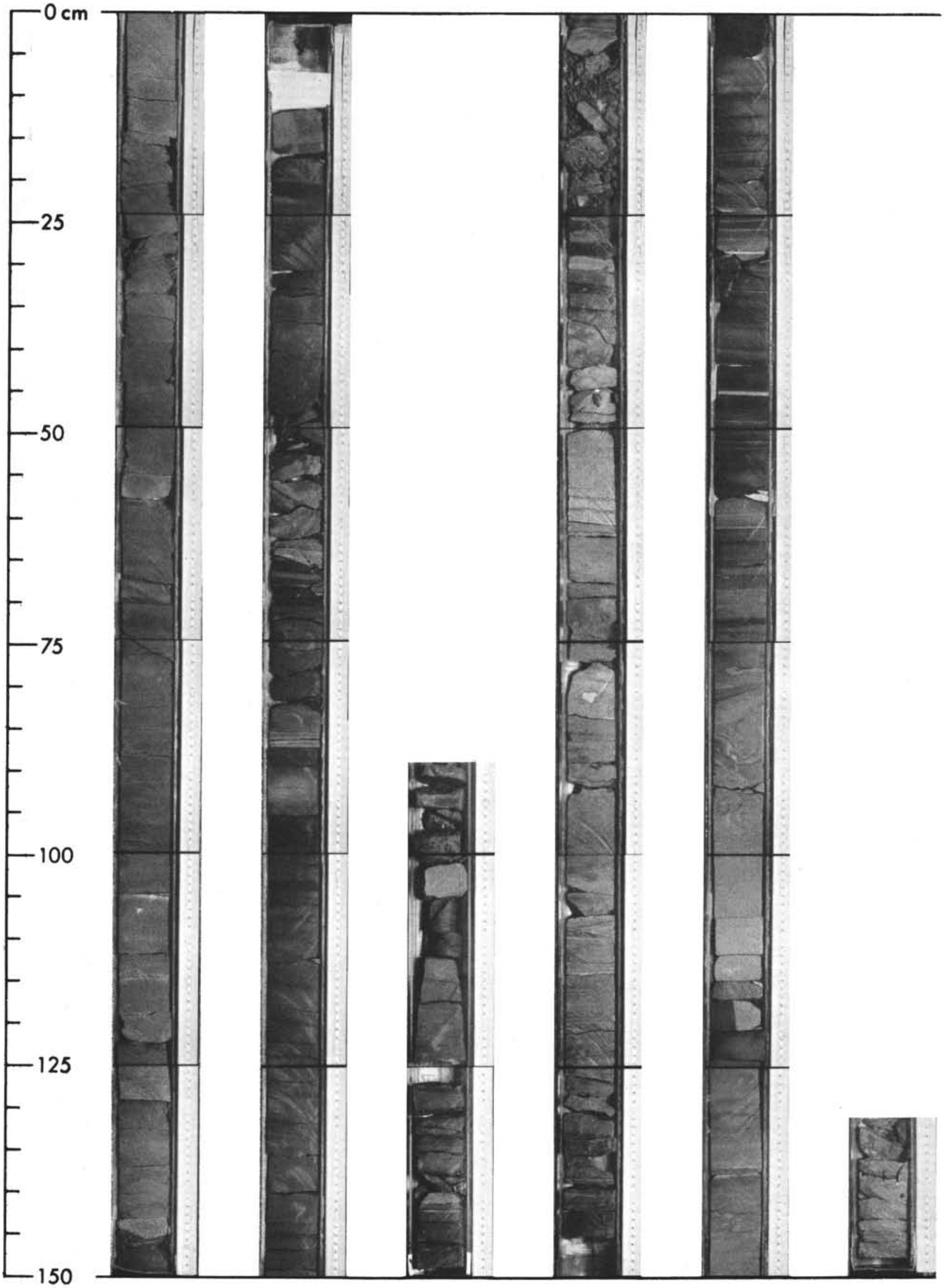
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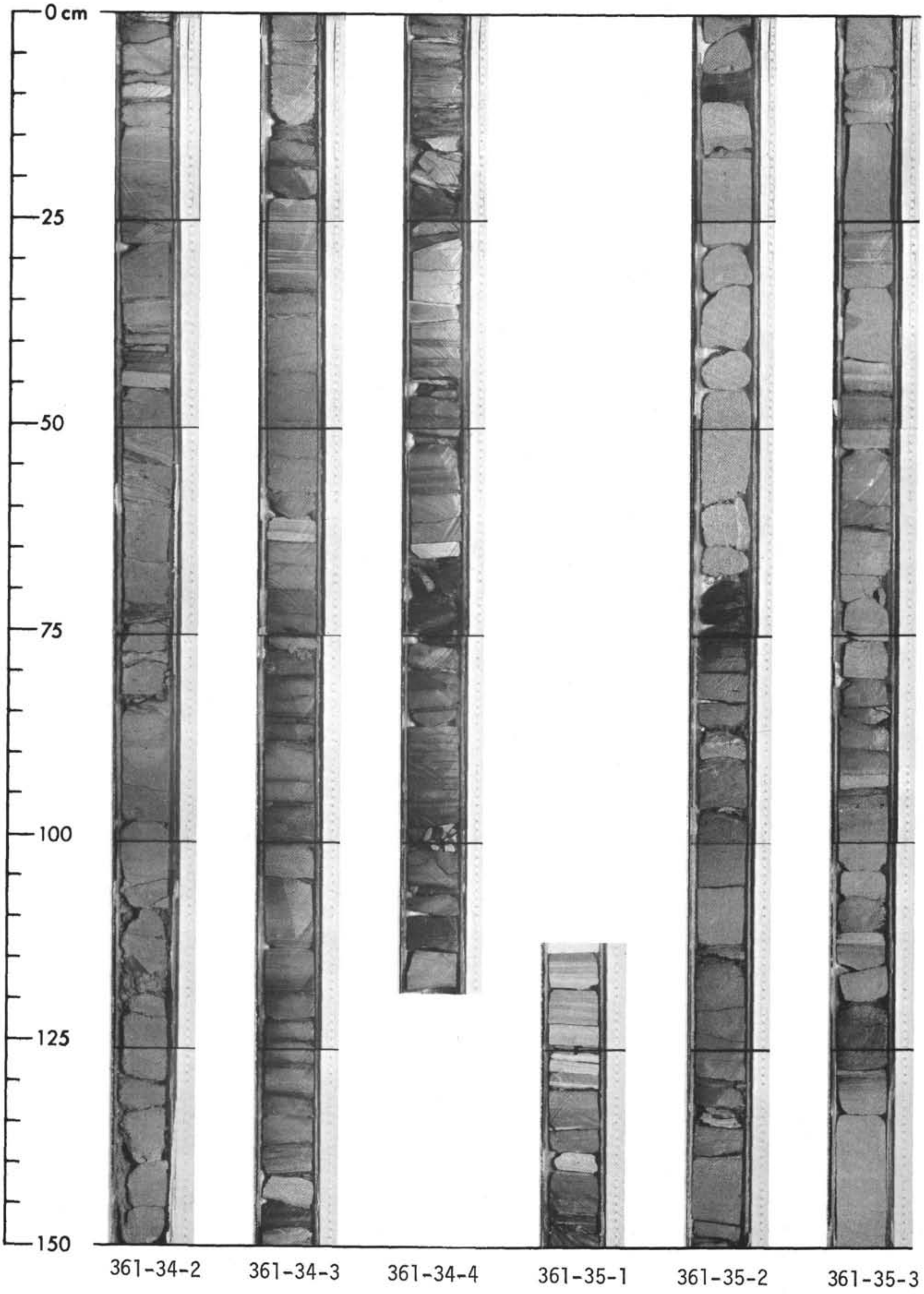
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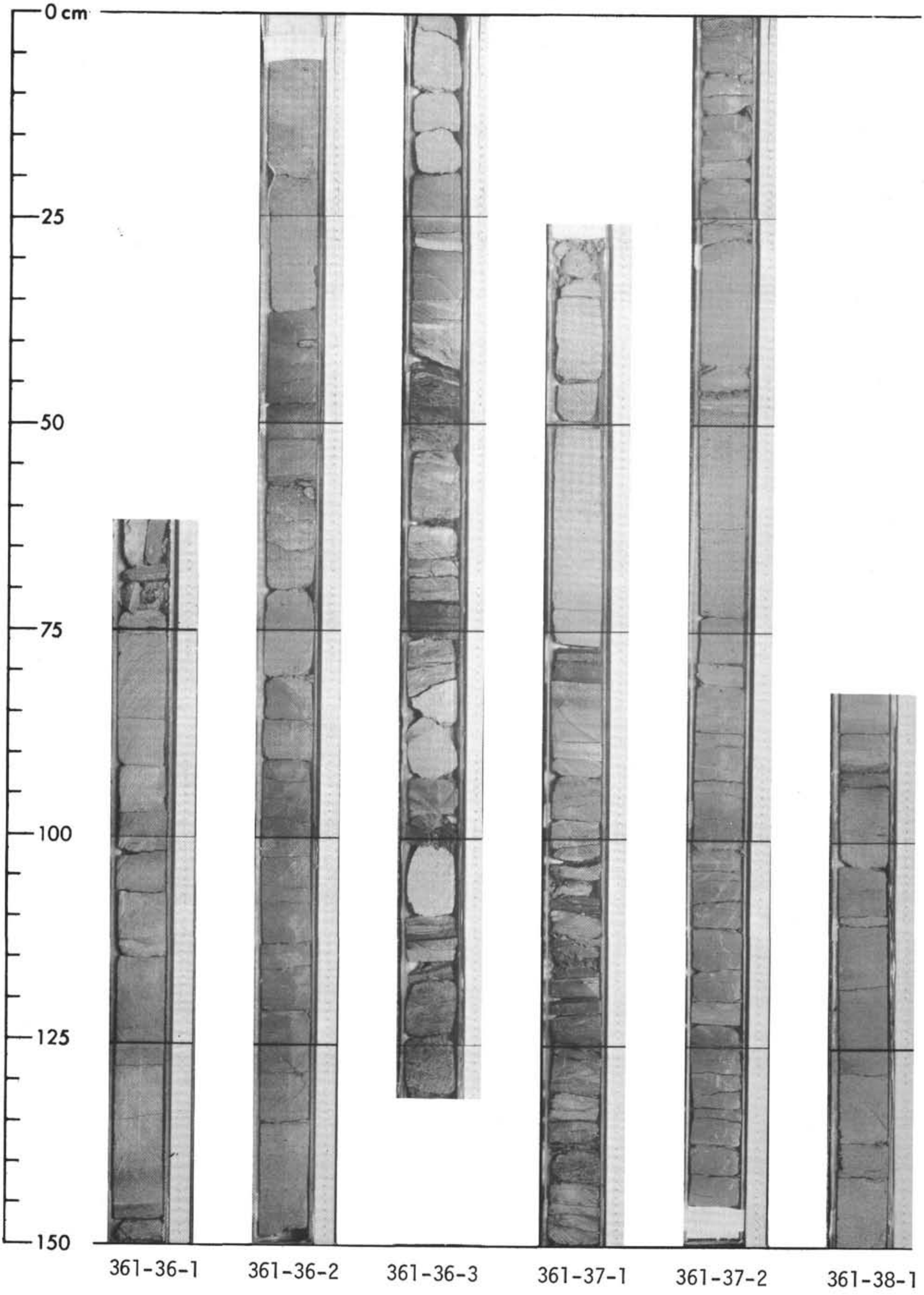
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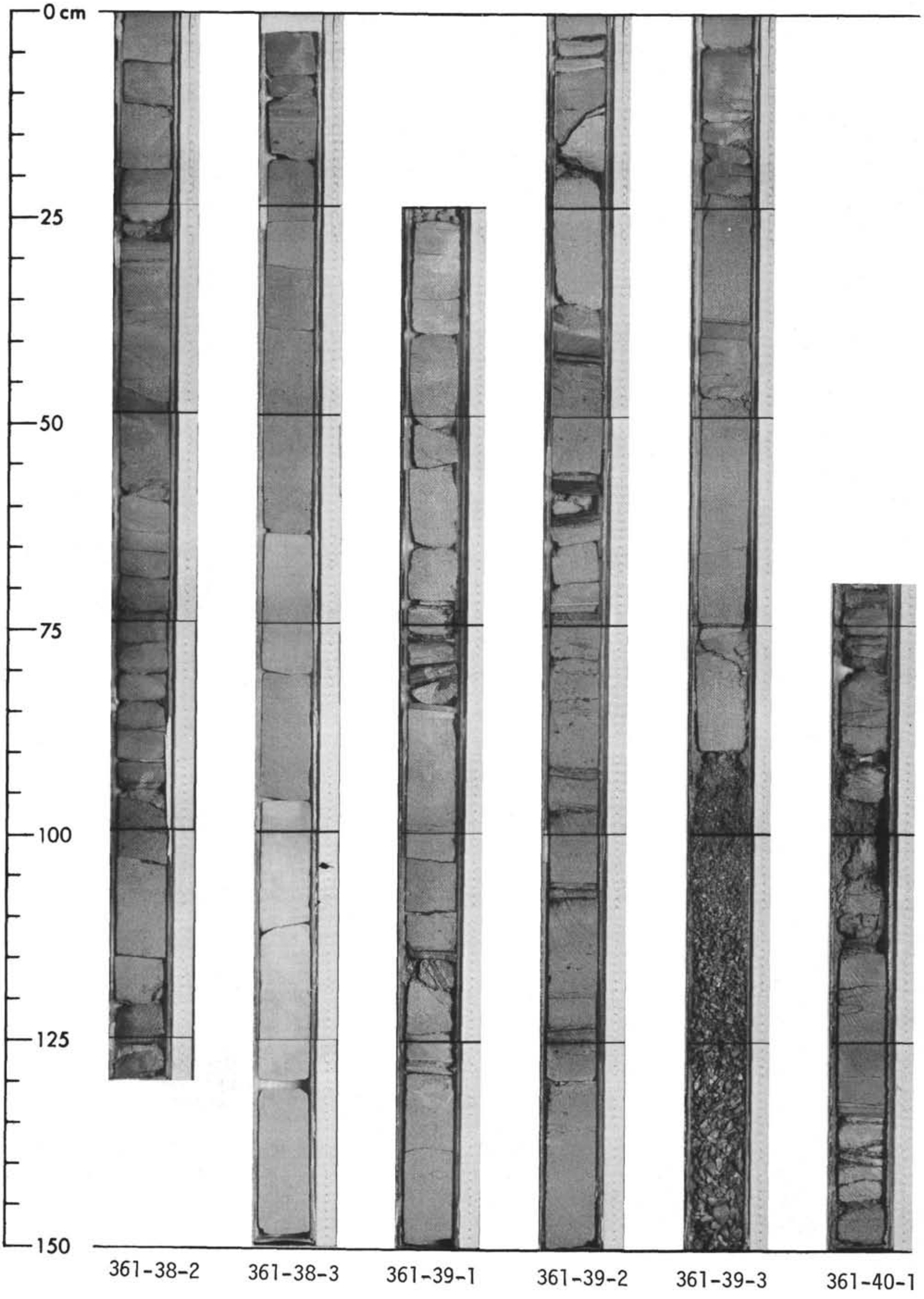
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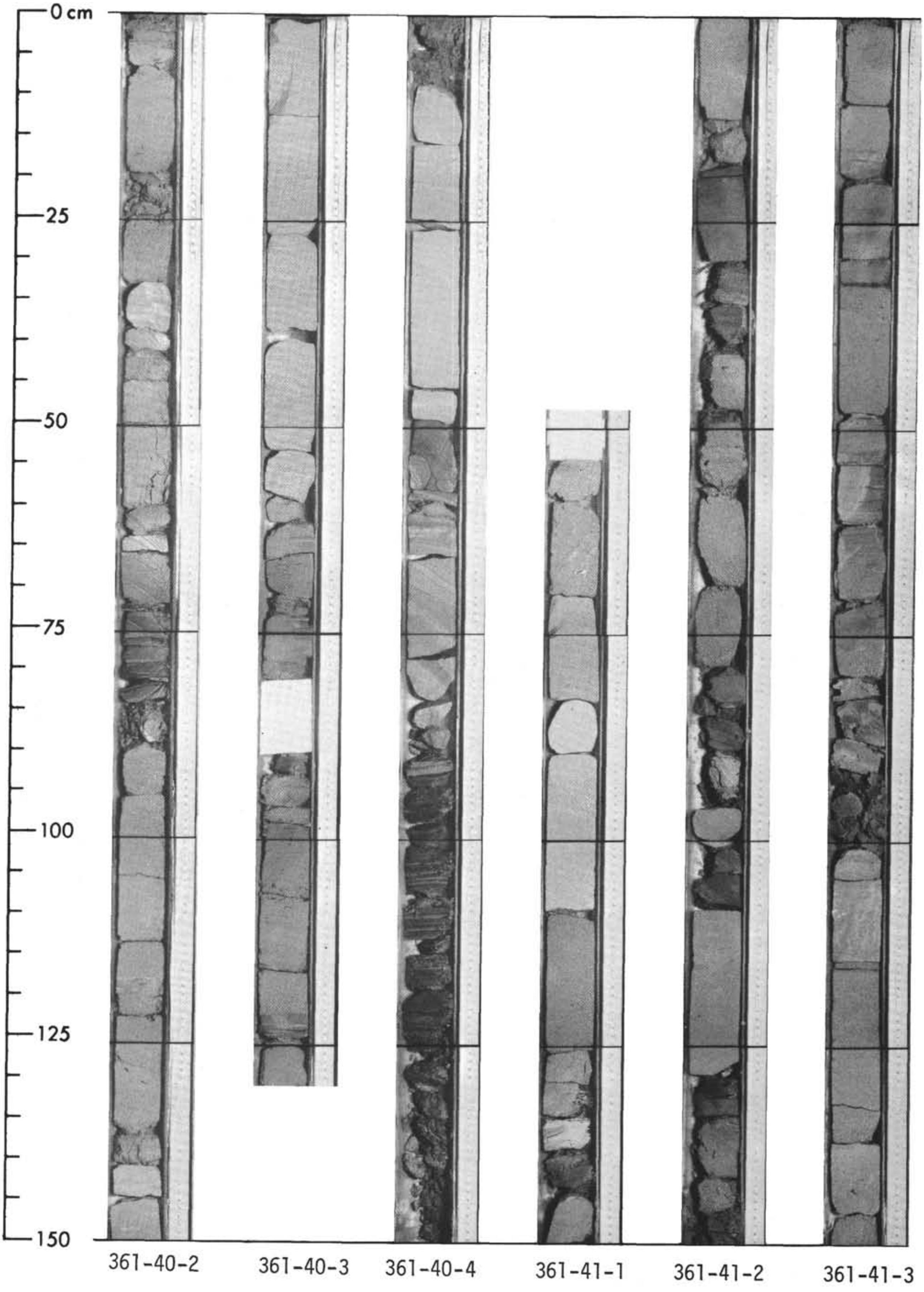
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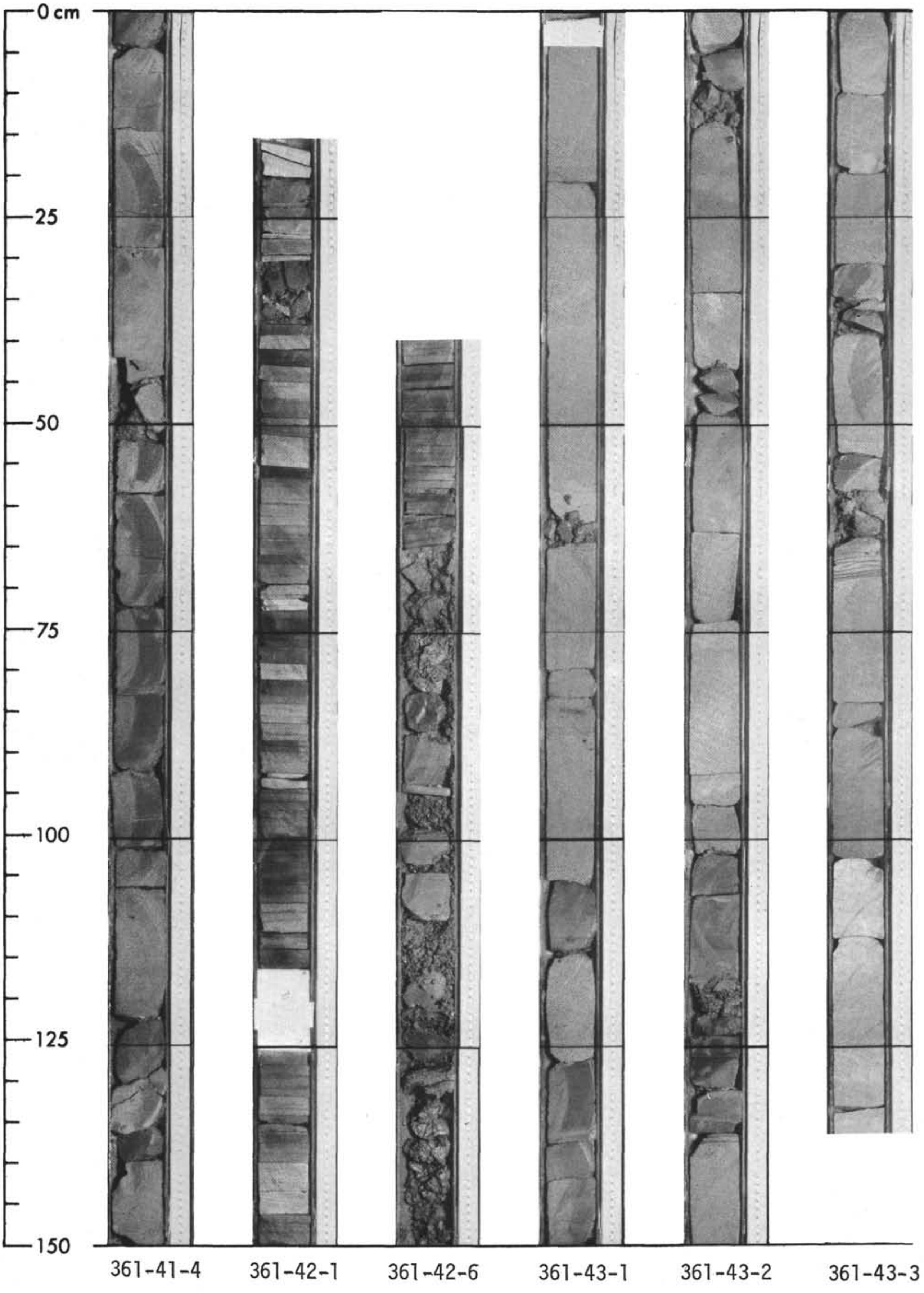
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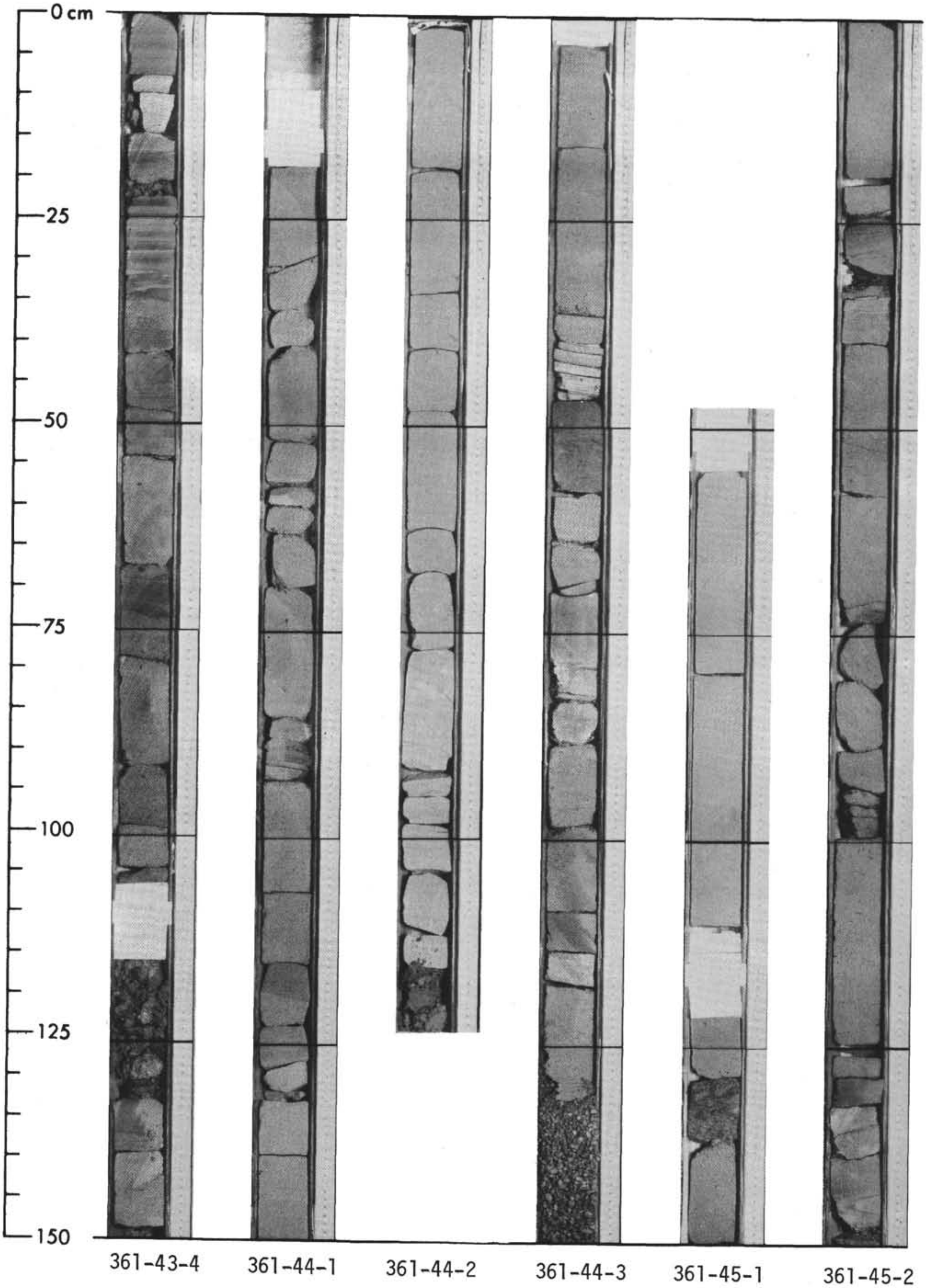
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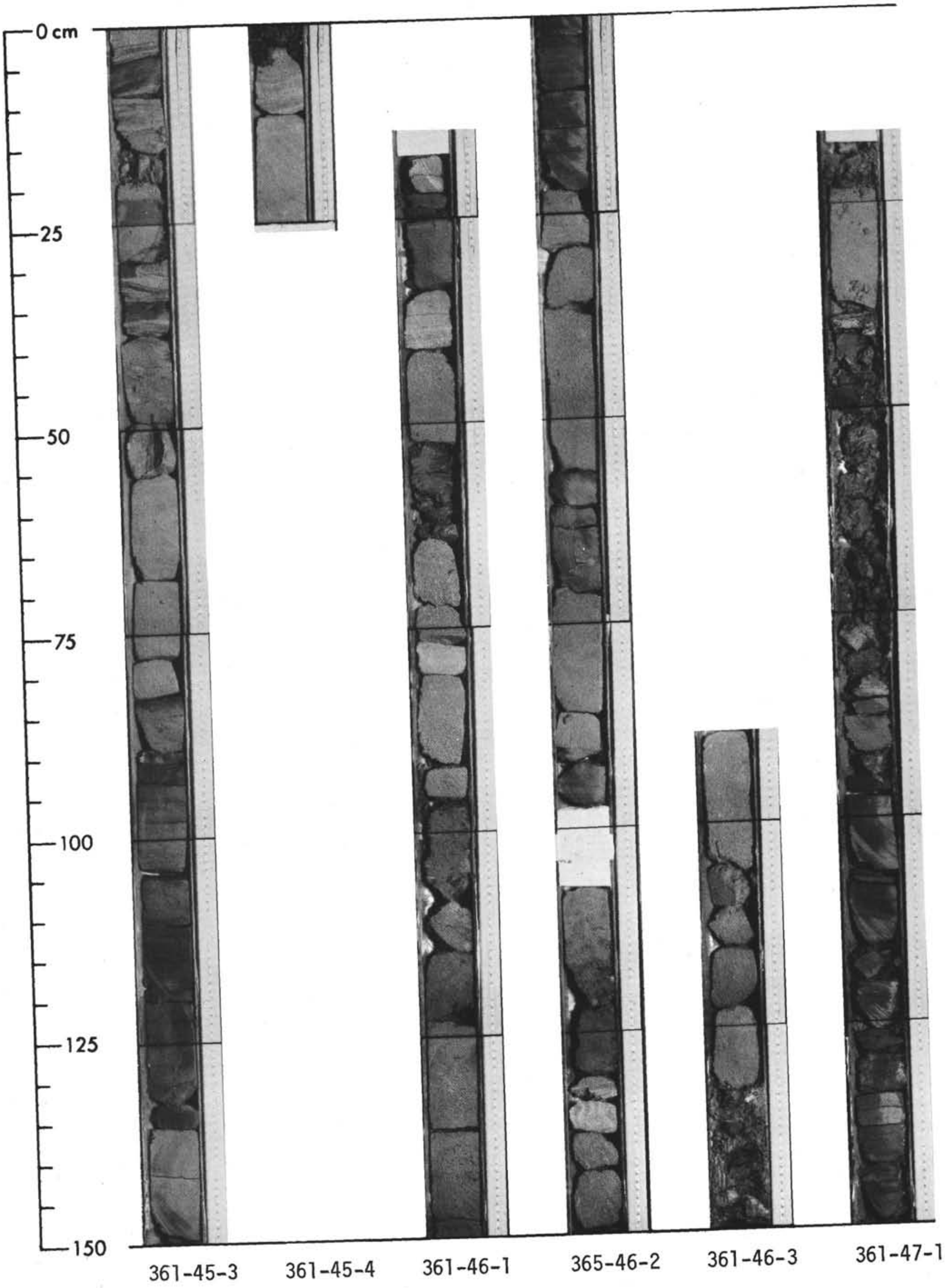
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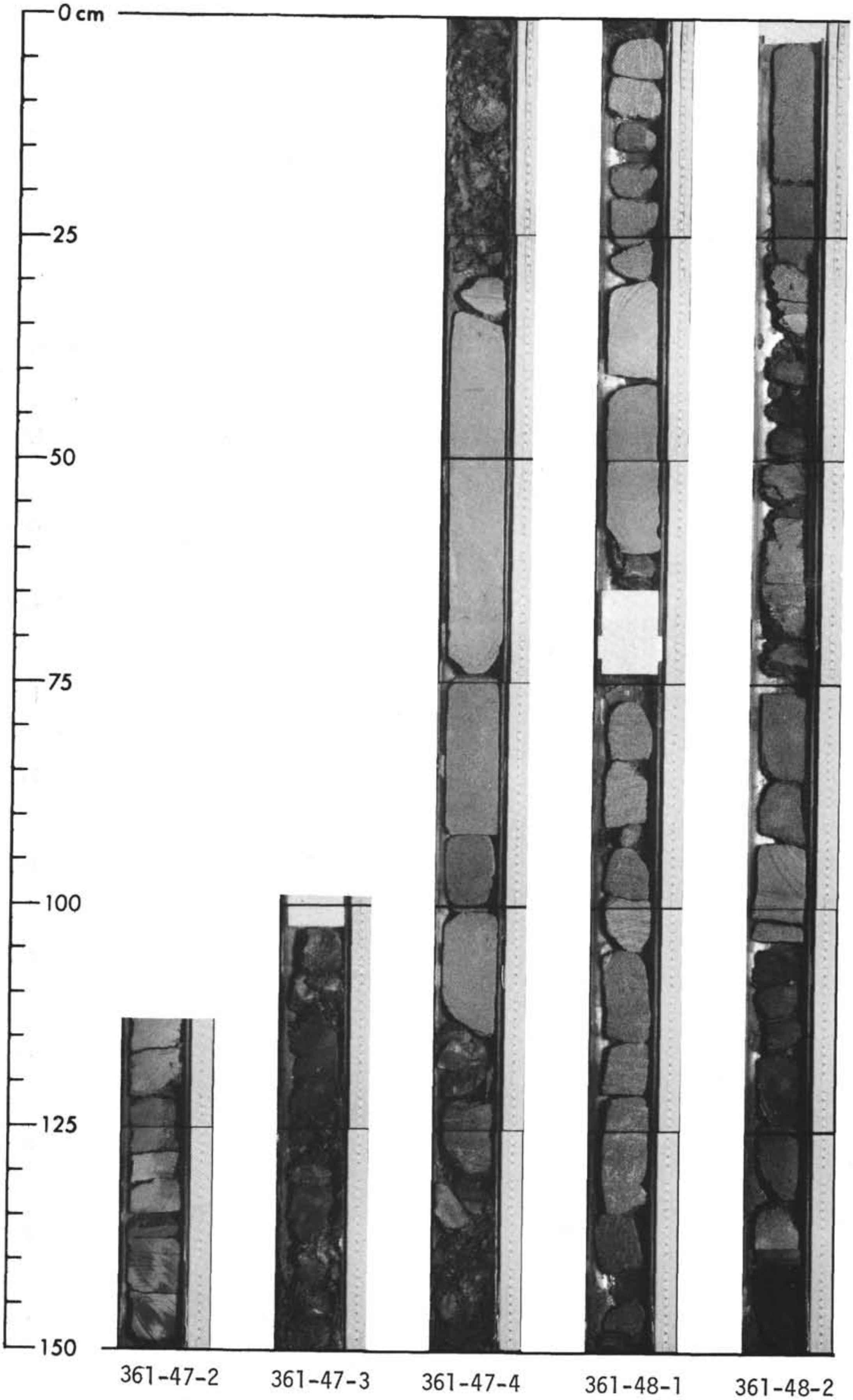
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