3. SITE 111[1]

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Location: Orphan Knoll at the edge of the continental rise northeast of Newfoundland.

Position: 50° 25.57′ N, 46° 22.05′ W; (satellite navigation).

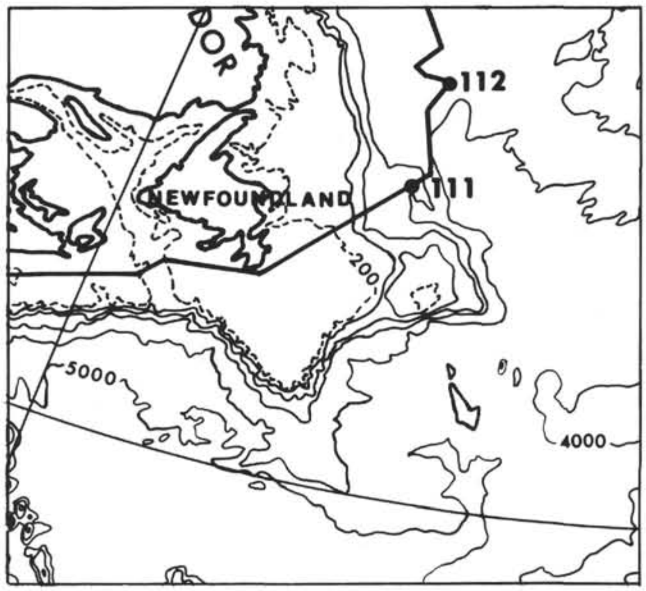
Depth of water: 1797 meters (corrected).

Total penetration: 250 meters.

SITE BACKGROUND AND OBJECTIVES

Introduction

Orphan Knoll is a pronounced submarine feature at the foot of the continental rise and bounded on its northeast side by the 4000-meter deep abyssal plain of the Labrador Basin. It lies isolated on the ocean floor some 550 kilometers northeast of Newfoundland and 350 kilometers north of Flemish Cap (Figure 1). The knoll is about 75 kilometers in breadth and is elongated in a northwest-southeast direction between 49°45′ N and 51°30′ N.



The knoll appears to be a small piece of continent separated from its parent block in the early stages of sea-floor spreading and continental drift either by differential sinking or lateral movement. The name "Orphan Knoll" is considered appropriate for such a small continental remnant that now lies abandoned, isolated and generally neglected. The name first appeared on Canadian Charts 802 and 800A in 1970 and 1971, respectively (Canadian Hydrographic Service).

Bathymetry

The knoll was noted as early as 1917 on British Admiralty Chart 2060A as a single 970 fathom sounding. It appears in more detail on the recent GEBCO collected sounding sheet #27 (Deut. Hydro. Inst., 1964), though here the contours are severely distorted by the inclusion of less reliable data.

Up until the compilation that appears in this presentation, the U.S. Hydrographic Office Chart BC 0510N (1965), a contoured chart, had the most accurate portrayal of the feature.

The knoll consists of two parts connected by a ridge (Figure 2). The larger southern portion is the shallowest rising to less than 1800 meters; the smaller northern extension is much deeper lying at depths of greater than

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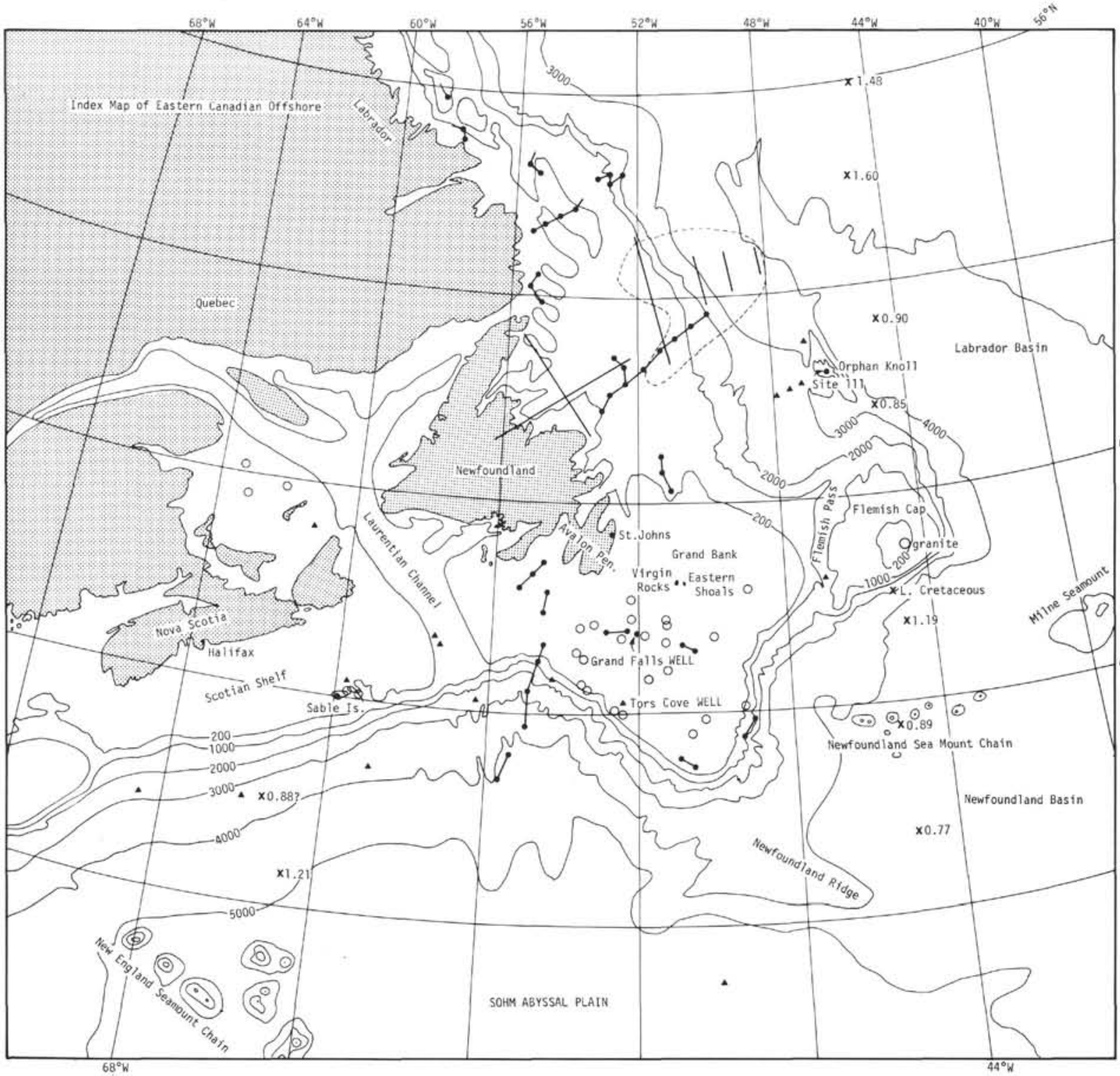

Figure 1. *Index map of the area around Site 111 including the Grand Banks showing general bathymetry as taken from the Canadian Hydrographic Service's Chart 800A. Contour interval 1000 meters except on shelf. Various reported diapiric structures are shown as solid triangles. Lamont seismic refraction lines are shown as solid circles connected by bars (Mayhew* et al., *1970). Reported core holes of commercial companies are shown as open circles. Reported commercial wells are shown as solid circles. Heat flow sites are shown as an "X" with the value noted (Langseth* et al., *1970). A Lower Cretaceous dredge site is shown southeast of Flemish Cap as well as granite core site on top of the Cap. The outlined area at 52°N, 50°W is the area of detailed study by Fenwick* et al. *(1968), and the long solid lines in the area are crustal seismic refraction experiments run by Dalhousie University, Halifax.*

2400 meters. The western edges of both sections are semicircular in outline with the northeastern margins being nearly linear and extremely steep, falling directly to the abyssal plain. The northeast margin has steep slopes of 30 to 40 degrees while the more gentle southwest margin has slopes of 5 to 10 degrees and is separated from the Newfoundland and Flemish Cap shelves by waters 2800 to 3400 meters deep.

From collected sounding sheets of the U.S. Naval Oceanographic Office, kindly provided by F. M. Edvalson, and from the GEBCO plotting sheet #27 of collected soundings one can estimate the approximate northern extent of the feature (Figure 2). The extension of the Knoll to the southeast as a gradually deepening ridge is estimated from the collected soundings sheets, and has been extended to Flemish Cap on the new Canadian Chart #802 (Canadian Hydrographic Service 1970).

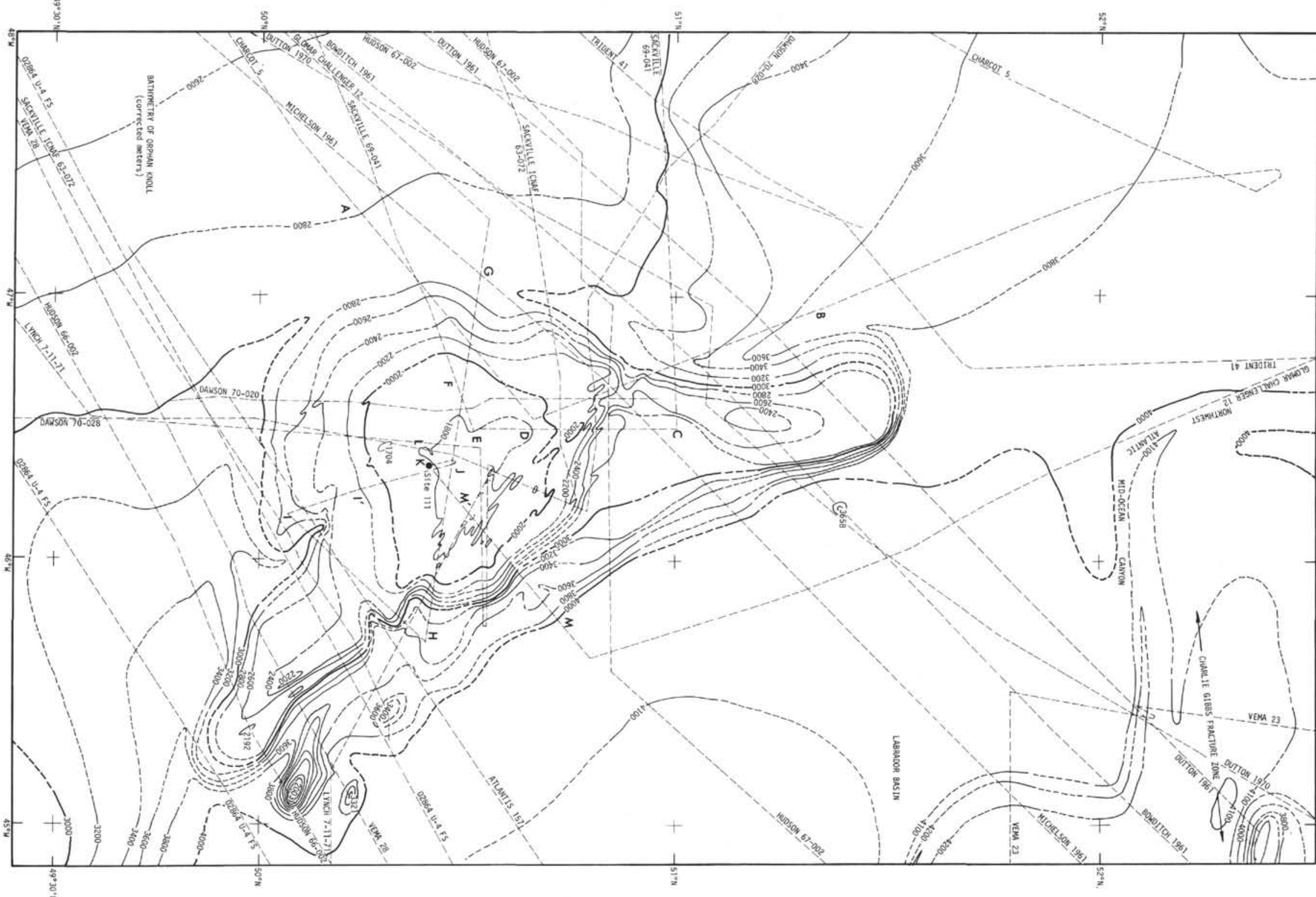

Figure 2. *Bathymetry of Orphan Knoll in corrected meters. Contour interval 200 meters except over Labrador Basin where interval is 100 meters. Solid contours indicate that the contour is defined, while presumed contours are shown as broken lines. The sources of information indicated by ship's tracks. Tracks indicated only by figures are from the U.S. Navy collected sounding sheets and the quality is completely unknown. The exact northwest and southeast extension of the feature is unknown. The minimum soundings to the top of some of the more pronounced peaks are indicated. Letters shown refer to profiles referenced in the text and in the following figures. The Northwest Atlantic Mid-ocean Canyon is relocated from the work of Heezen* et al. *(1969).*

The rather flat upper surface of the knoll between 50° and 51° N is interrupted by a series of bathymetric highs that are seen on most profiles (Figures 6 and 10) and rise in places to depths of 1498 meters. When these highs are plotted they can be interpreted as several continuous ridges parallel to the northeast margin, and they have been contoured as such in Figure 2.

Magnetics

The preliminary total magnetic intensity map (Figure 3) incorporates no correction for diurnal or secular variations, and some of the crossovers are rather poor (up to 75 gamma). However the data do indicate a somewhat linear positive zone lying along the northeast edge of the knoll and lying over the small expansion of the knoll north of 51° N. Otherwise the magnetic field is smooth over the Orphan Knoll and does not indicate the southwest edge of the feature. There is no obvious relationship between the magnetic field and the long narrow ridges that run along the northeast edge of the southern portion of the knoll.

Scientific Work Available Over Orphan Knoll

The first research ship to cross the feature appears to have been Atlantis gathering bathymetry in 1949 (Heezen *et al.*, 1959, P. 68).

Dutton, Bowditch and Michelson crossed the northern portion of the Orphan Knoll in 1961 gathering magnetics (Avery, 1963). The ICNAF cruise of Sackville 63-072 in 1963 (ICNAF, 1968) traversed the knoll twice gathering bathymetry as did Hudson 66-002 and 67-002 in 1966 and 1967, respectively.

There was no deliberate work over Orphan Knoll until 1969 when Sackville 69-041 (Grant, in preparation) and Charcot 5 (Olivet *et al.*, 1970a; Le Pichon *et al.*, 1971) did magnetic and continuous seismic profiling traverses across the feature. Olivet *et al.* noted the apparently fault bounded margins, and Le Pichon *et al.* interpreted the area south of the western extension of the Gibbs Fracture Zone as foundered continent. Two Russian workers have made interpretations of surficial geology and morphology of the area (Grabovskiy, 1966; Ravachev, 1968).

Related Studies

To the west of Orphan Knoll (Figure 1), Fenwick *et al.* (1968) surveyed in some detail a band of high intensity magnetic anomalies that trend at a low angle across the bathymetric contours from the shelf edge at 53° N, 53° W into deeper water at 51°30′ N, 46° W. Fenwick also ran four crustal seismic refraction lines outlining the transition from oceanic to continental crust in the area. Grant (1968, in preparation) has done a considerable amount of survey work on the shelf of Labrador and has shown that the sediments generally prograde into deeper water, except between 52° and 53° N where beds are truncated at the shelf edge.

North and east of the knoll was the area of concern of Mayhew in his PhD thesis (Mayhew, 1969). He placed Anomaly 32 (78 million years) just east of the knoll and also just east of Flemish Cap (as do Pitman *et al.*, 1971, and Pitman and Talwani, in press). Mayhew made no interpretation of the positive magnetic anomaly that lies over the northern and eastern portion of Orphan Knoll. Olivet *et al.* (1970 a, b) have mapped the Gibbs Fracture Zone in considerable detail from the mid-Atlantic Ridge west to the base of the continental rise. The fracture zone in its buried westernmost extension has a slight east-northeast orientation relative to the east-west orientation of the main fracture zone (Figure 1). This change in orientation is interpreted to reflect a transform fault related to early opening of the Labrador Sea (Le Pichon *et al.*, 1971).

Southwest of the area, Dainty *et al.* (1966), Sheridan and Drake (1968) and Mayhew *et al.* (1970) have written extensively on the continuation of the Appalachians seaward. However, their analyses did not reach the area of Orphan Knoll. Williams (1964) has written a comprehensive review of Appalachian geology in northeast Newfoundland.

South of the drilling site the Grand Banks of Newfoundland and Flemish Cap are the scene of intense activity by the commercial oil companies. Flemish Cap was ignored by Bullard *et al.* (1965) in their reconstruction of the Atlantic but it has attracted considerable interest since then. An early overflight (Hood and Godby, 1965) showed a central core of high intensity, short wavelength magnetic anomalies that indicated a shallow basement with thicker sediments to the west. Grant (in press) has interpreted profiler work and shown sedimentary beds prograding outwards from a seismically hard central core and being truncated at the shelf edge. He has also found Flemish Pass to be symmetrically flanked by two buried ridges and has found that the shelf-edge sediments on the north of Grand Bank prograde evenly into deeper water.

The Bedford Institute (Pelletier, 1969) has cored a 6-inch cylinder of granite at 46° 51′ N, 44° 32′ W on the crest of the Flemish Cap (Figure 1) which has yielded an age of 592 ± 20 million years (Pelletier, personal communication), and this seems to relate the intrusion to the Holyrood granite of the Avalon Peninsula. The same cruise also dredged what was thought to be quartzite in place on the crest of Flemish Cap. Carbonates have been dredged in 1481 meters (uncorrected) at 46° 33.7′ N and 44° 25.2′ W (Gilbert, 1967) (Figure 1); these are thought to be outcrop samples and are Lower Cretaceous in age (Sen Gupta and Grant, 1971). The only other known basement outcrops are the Virgin Rocks and the related Eastern Shoals that were studied by Lilly (Lilly, 1965; Lilly and Williams, 1965; Lilly, 1966a, b and, Lilly and Deutsch, 1967) and related to the Conception Group of the Avalon Peninsula (late Precambrian in age).

Also in this area Grant (in press) has reported a diapiric structure in Flemish Pass (Figure 1). King and MacLean (1970) and Keen (1970) have reported diapiric structures on the Nova Scotian Shelf. Watson and Johnson (1970) along with Emery *et al.* (1970) and Webb (in press) have reported deep-water diapirs south of the Grand Banks and east of the Scotian Shelf. Pautot *et al.* (1970) have reported diapiric structures in deep water southwest and northwest of Orphan Knoll; these diapirs, however, are not convincing and appear to be basement highs. None of Grant's extensive work on the Labrador shelf has recorded diapiric structures anywhere north of the Grand Banks area to Hudson Strait.

The obvious salt diapirism in the south has prompted a spate of off-shore commercial drilling beginning with the

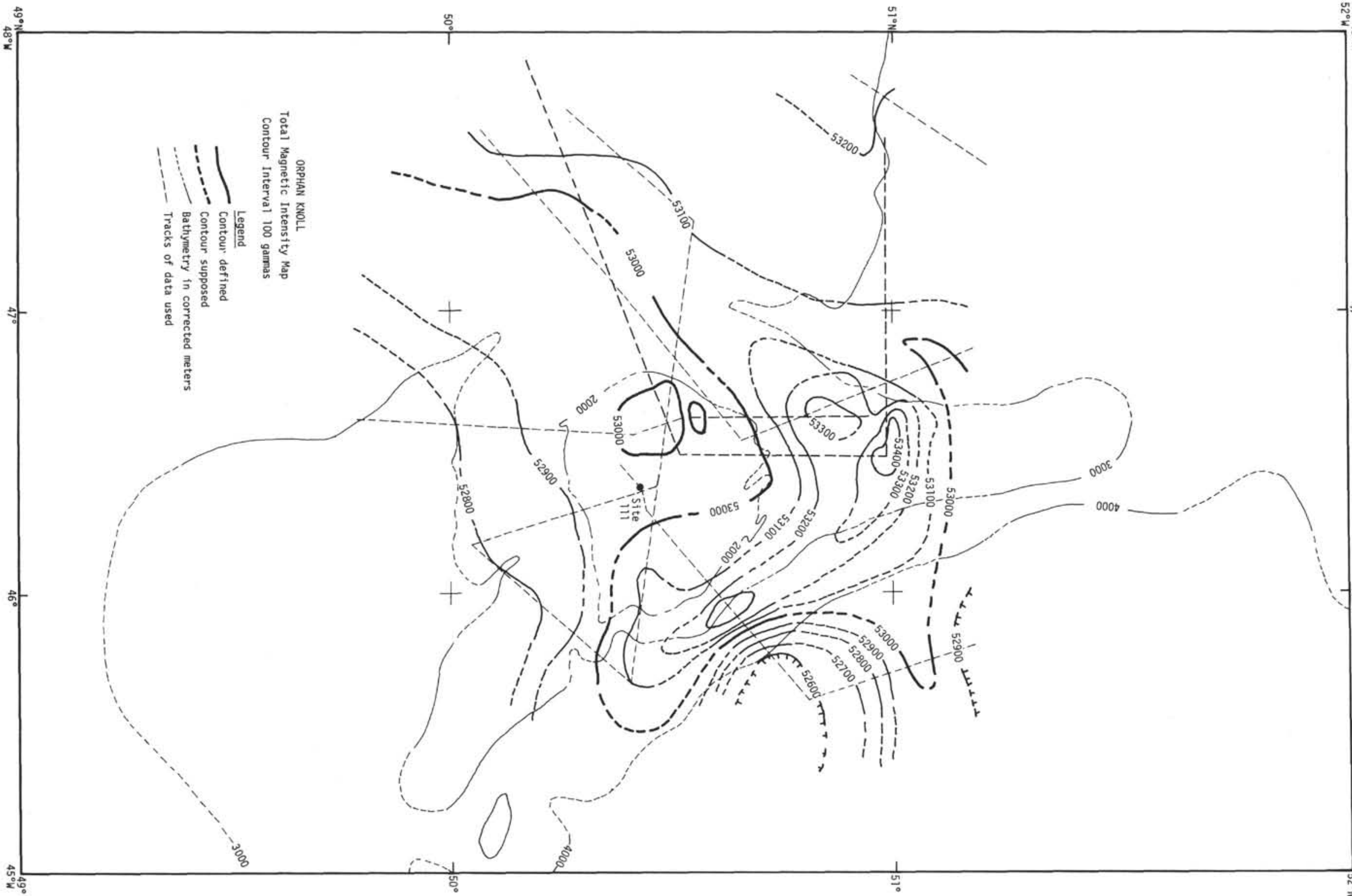

Figure 3. *A preliminary total magnetic intensity map of Orphan Knoll. The ship's tracks along which data was used are shown. No correction was made for secular or diurnal variation. The data is separated by at most one year. A pronounced positive anomaly is seen to parallel the northeast margin of the knoll. It is not directly related to the linear ridge structures and may be related to "basement" rocks being brought closer to the surface in the northeast during the mid Jurassic-Cretaceous orogenic period.*

Caldrill 1 coring program in 1965 (Swift and Evans, 1966; Magnusson, 1965); some of the sites are shown on Figure 1. Exploration began slowly in 1966 with AMOCO drilling the Grand Falls well and the Tors Cove well (Pan American Petroleum Corp., 1967a, 1967b). Both wells cut a mainly clastic section for about 1600 meters and the latter well, Tors Cove, over a diapiric structure, bottomed in salt of probable Jurassic age (Bartlett, 1969; Bartlett and Smith, 1971). The other well drilled in 1967 by Mobil Oil on Sable Island was a deep test that cut 4600 meters of a mainly clastic section and bottomed in the Lower Cretaceous to Upper Jurassic (Monro and Brusset, 1968; Magnusson, in press). Bartlett (in press) and Smith (in press) have correlated the stratigraphy between the Sable Island and Grand Banks wells. Austin and Howie (in press) have presented a general review of the offshore geology of eastern Canada; again, the area of Orphan Knoll is unknown and not referred to.

The DSDP drilling site was originally chosen by the Atlantic Advisory Panel on the basis of Charcot's Flexotir continuous seismic profile provided by CNEXO (Figure 4). Just before Leg 12 began the Sackville 69-041 seismic profiling record was made available by the Bedford Institute (Figures 5 and 8). However, these two records (with related magnetics) were the only data over the proposed site available to Glomar Challenger prior to Leg 12. An analysis of these records in conjunction with those of Glomar Challenger is presented later. Objectives of the site may be summarized as:

a. To sample if possible the "crystalline basement" and determine whether Orphan Knoll is foundered continental remnant or a piece of elevated oceanic crust,

b. To sample and date the layers overlying "basement" and to establish their biostratigraphy and lithology,

c. To investigate and identify the prominent seismic reflectors, and

d. To establish the time of the change from nonglacial to glacial sedimentation.

SURVEY DATA

On the passage to Orphan Knoll Glomar Challenger crossed the glacially dissected shelf of northeast Newfoundland, ran over the shelf edge, down a rather rough continental slope, then down a long, uniformly gentle continental rise, sloping from 2300 meters north of Grand Bank to 2800 meters at the western margin of Orphan Knoll. Only one iceberg was sighted on radar during the passage.

This traverse confirmed Grant's suggestion (in press) that the shelf sediments prograde evenly into deeper water, though the roughness seen by Glomar Challenger on the slope may be slump debris (Appendix III). The traverse down the continental rise crossed a thick sequence of what is probably continentally-derived sediment that masked any deeper basement reflectors, such as Charcot obtained (Pautot *et al.*, 1970). These beds appear to prograde evenly down slope, though there is some evidence of wedging out and terminating of beds against minor unconformities (Appendix III). Up to 1.7 seconds of sediment is known over basement southwest of the knoll from Charcot's traverse (Pautot *et al.*, 1970, and Hyndman, personal communication).

The uncertainty of the exact position of the track of Sackville, whose seismic record was used to define the general site location, required that the Glomar Challenger make a more detailed survey than would normally have been necessary. It was also necessary to tie the Sackville and Charcot seismic records together for correlation of reflectors seen on the top of Orphan Knoll.

Thus an approach was made to Orphan Knoll from the west in order to cross through the possible site suggested by the Atlantic Advisory Panel from the Charcot data and, as well, to cross through the general site location chosen from the Sackville data (line G-H, Figure 2). The positioning of the traverse was not easily controlled because of the wide spacing of satisfactory satellite fixes. The traverse continued across the Knoll and was followed by an approach to the general site location from the south. Some difficulty was encountered as a result of fog conditions and concern over possible ice which necessitated continual variations in speed. On the northward track, a suitable site was selected on the basis of the seismic record, the gear recovered and the ship brought back to the chosen site by dead reckoning (Figure 2). The crossing of the site was at about 8 knots and the return at 4 knots, slowing to zero to drop the beacon.

After completion of Holes 111 and 111A, another traverse was made by steaming about 10 kilometers southwest of the beacon then making a return traverse across the site to the northeast and continuing across the northeast edge of Orphan Knoll onto the abyssal plain before turning to the north for Site 112. This post-drilling traverse was interrupted 7 minutes after it began when the ship lost power and drifted north for 35 minutes before the traverse resumed to a point 10 kilometers southwest of the site (Figure 2).

Analysis of Seismic Profiles

The main seismic subdivisions may be seen on the photo of the records of Charcot in Figure 4 (track A-B, Figure 2), on the small portion of Sackville's record in Figure 5 (track D-E-F, Figure 2), on the complete traverse from west to east made by Glomar Challenger in Figure 6 (track G-H, Figure 2), and on the north-south compilation in Figure 8 made from data of Sackville (track C-E, Figure 2) and Glomar Challenger (track J-I, Figure 2). The continuous seismic record made on leaving Site 111 is seen in Figure 10 (track K-L-M, Figure 2). The corresponding interpretations of these five records are seen in the drawings of Figures 4, 5, 7, 9 and 10.

A rather jagged "basement", possibly crystalline in nature is best seen in Charcot's profile (labeled 1 in Figure 4) where the low frequency Flexotir profiling system usually had several seconds of penetration. The apparent diapiric structures that rise through all horizons to form the pronounced ridge structures on the relatively flat upper surface of the Knoll are labeled 2 in the line interpretations. They have no obvious magnetic signature on either of the two complete traverses (Figures 6 and 8). The narrow ridge structures may cause the small positive peak in the magnetic anomaly profile gathered on leaving the site (Figure 10). Just south of Site 111 there is a similar structure that punctures all horizons and appears as a small bathymetric high (Figure 8). One can clearly see a slight

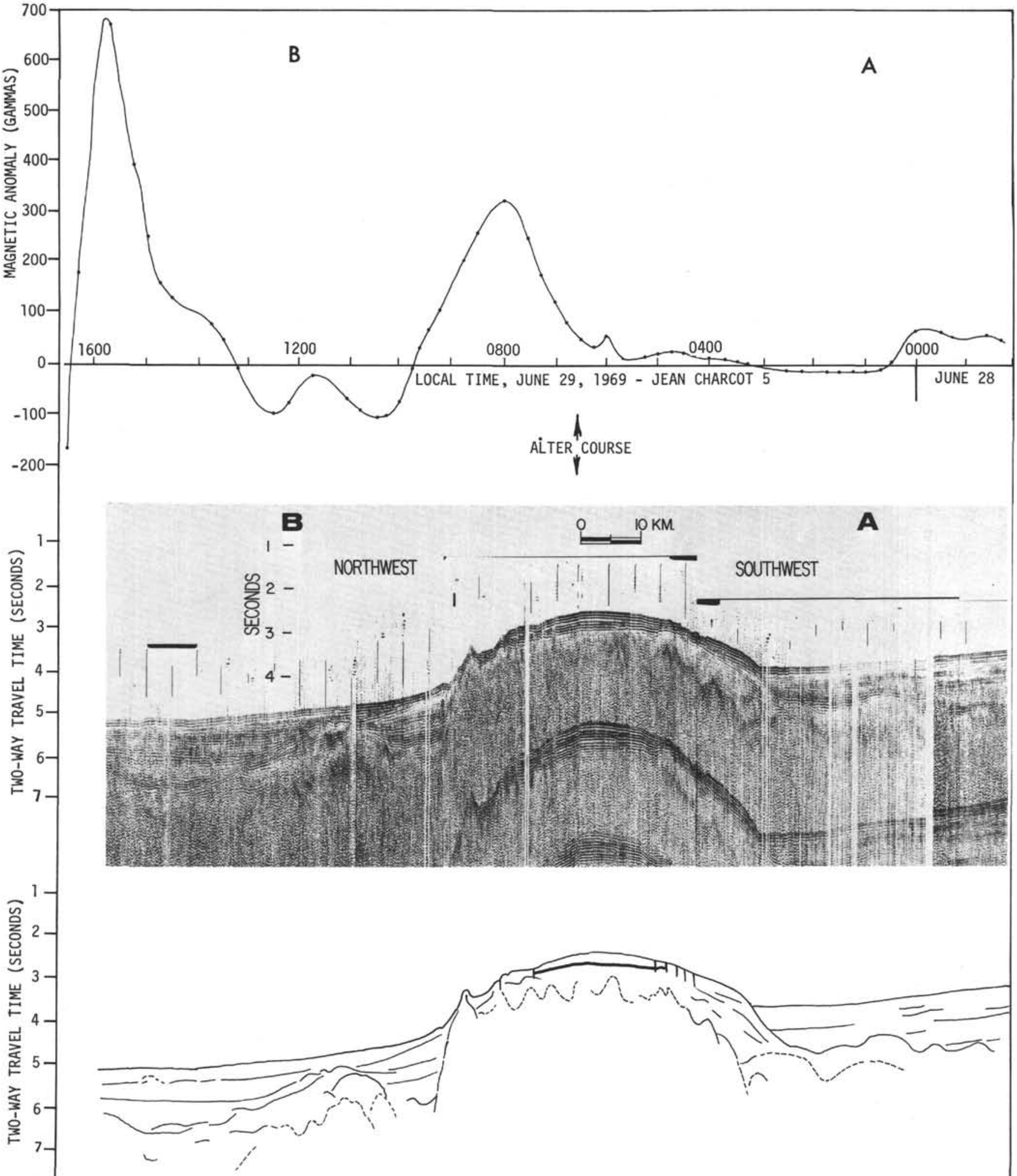

Figure 4. *Continuous seismic profile along line A-B (Figure 2) of* Jean Charcot *5 across Orphan Knoll with the magnetic anomaly above and the line interpretation below (vertical exaggeration about 20:1). Note that the southwest margin of the knoll is not seen in the magnetic anomaly trace. Two of the diapirs of Pautot* et al. *(1970) are seen at 0030 and 1100. The top of the Cenomanian (layer 4) is clearly seen as a prominent reflector. A number of small normal faults are seen to penetrate to the upper surface. Probable turbidites with near-horizontal layering are banked up on the northwest and southwest. Note: In Le Pichon* et al. *(1971) the magnetics over Orphan Knoll are misplaced by about 1.5 hours.*

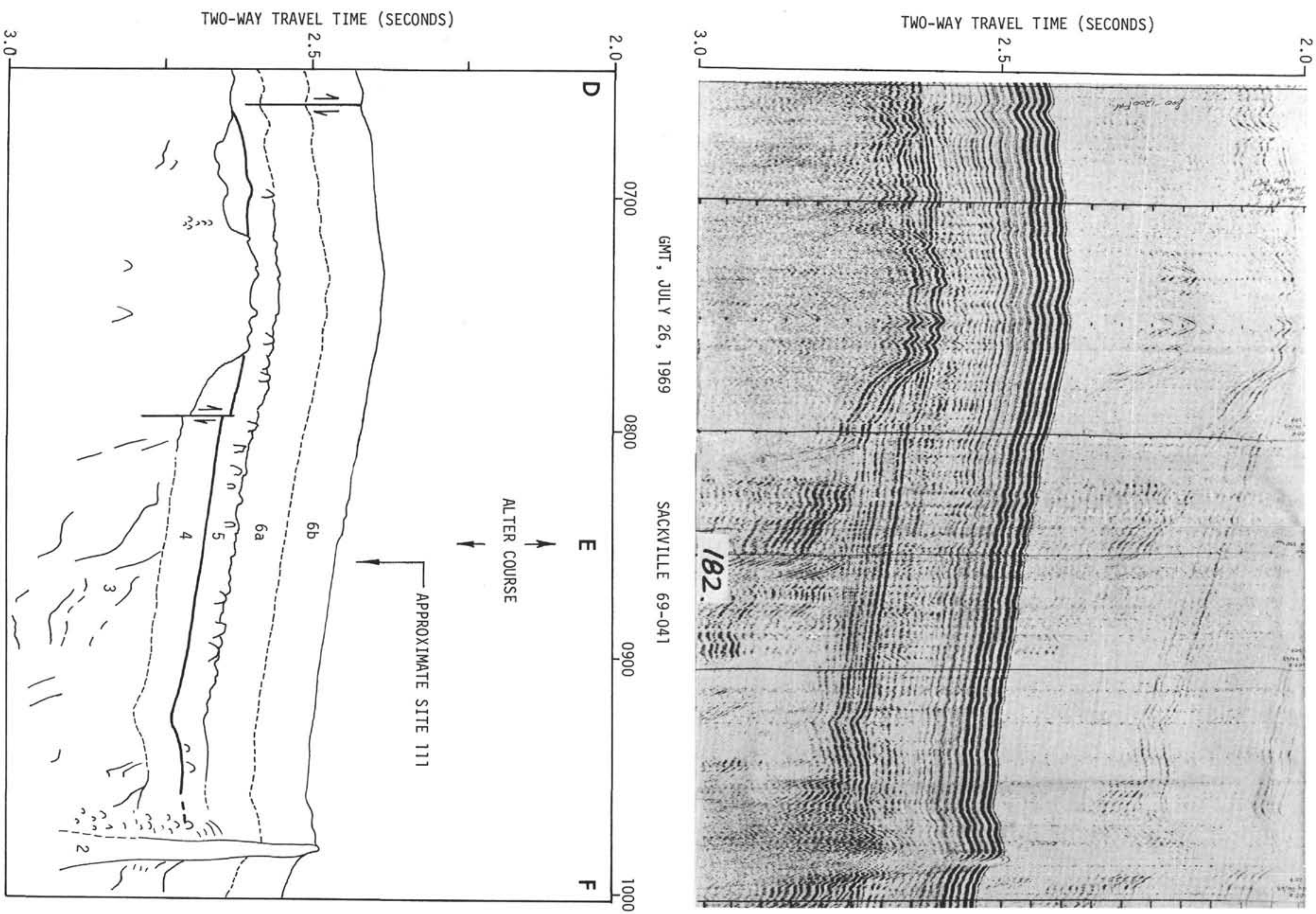

Figure 5. *Continuous seismic profile along line D-E-F (Figure 2) of* Sackville *69-041 across Orphan Knoll with the line interptetation below (vertical exaggeration about 30:1). The clear reflecting horizon on top of the Cenomanian (layer 4) is seen to abut against "basement" highs (layer 1). A "narrow ridge structure" (layer 2) is seen penetrating the complete section to the sea bottom. At 0640 a small normal fault is expressed in the bottom topography. The small hyperbolae that seem to mark layer 5 are clearly seen here.*

upturning of all reflectors on both sides of this feature down to at least layer 4.

Layer 3 is rather indistinct on the Charcot record, but shows quite well on the Sackville record (Figure 5) as a series of westward dipping beds that terminate with angular unconformity against overlying beds. The record made on departure from Site 111 also clearly shows these beds dipping westward (Figure 10). As the vessel made a slow turn of 180 degrees to port, southwest of the site, a small anticlinal structure in these beds was traversed (Figure 10). Its strike appears to be approximately north-south.

The dipping beds are overlain by a near flat-lying series of beds (layer 4); these beds are generally less than 0.1-second thick and wedge out against "basement" (Figure 5).

The top of layer 4 is marked by a very distinct reflector that is near horizontal and occasionally disrupted by small vertical faults and by some warping possibly associated with post-depositional intrusion of the ridge structures or associated with differential compaction of layer 4 around the ridge structures. The reflector at the top of layer 4 is very easy to distinguish on all types of seismic profiles, and terminates against the "basement" highs and the ridge structures (Figures 6 and 8). The reflector is not seen beyond the steep edge of Orphan Knoll.

Layer 5 is quite thin and is not easily distinguished on the Charcot record but can be seen on higher frequency records as an even coating over layer 4 and over some of the "basement" highs that interrupt layer 4 (Figure 5). Layer 5 is also interrupted by the narrow ridge structures and appears on records of Glomar Challenger (Figures 6 and 7) to wedge out on the "basement" highs. The upper surface of layer 5 is rather indistinct and is marked by a series of small hyperbolae (Figure 5). This layer is also cut by small vertical faults that appear to pass to the upper surface of the knoll (Figure 5) and to clearly control some low bathymetric relief (Figure 6).

Layer 6 is everywhere present, except on the ridge structures and steep edges of the knoll to the northeast. It is divided into two subdivisions: 6a being the seismically transparent lowermost part, and 6b the uppermost part of the section (Figure 5). Layer 6 appears conformable with underlying beds and structures, and is apparently draped over the knoll as one would expect with pelagic sedimentation. The small normal faults mentioned earlier cut this layer and are occasionally seen in the bottom bathymetry (Figure 5).

The steep apparently fault-bounded edges of the Orphan Knoll are seen in the two traverses (Figures 6 and 8) with the prograding sediment from the continent to the west infilling against the western margin of the feature. Northwest of the feature over 2 seconds of sediment was seen on the CHARCOT record (Figure 4).

This record also shows that the northernmost "diapir" of Pautot *et al.* (1970) is simply the subbottom record of the Orphan Knoll "basement" as Charcot brushed the buried edge of the feature. The sharp western margin of the feature apparently is not recorded in the west-east magnetic traverse (Figure 6).

The geophysical and bathymetric data gathered by Glomar Challenger have been combined with data gathered by the Canadian vessels Hudson and Sackville, as well as Dawson which kindly profiled over the site shortly after drilling. Data gathered by the U.S. vessels Bowditch, Dutton, Michelson, Spar and Lynch, also data gathered by the Lamont-Doherty Geological Observatory on Vema and Atlantis, some data from Trident of the University of Rhode Island and data from Charcot of Centre National de l'Exploitation des Oceans (CNEXO) have been incorporated into the bathymetric and magnetic compilations, (Figures 2 and 3).

Some of the data from the above cruises is unpublished and we thank T. Calderwood of the Bedford Institute, J. I. Ewing and B. C. Heezen of the Lamont-Doherty Geological Observatory, M. J. Keen and R. D. Hyndman of Dalhousie University, D. C. Krause of the University of Rhode Island, X. Le Pichon of CNEXO, and G. A. Young, F. M. Edvalson and G. L. Johnson of the U.S. Naval Oceanographic Office for their most sincere and truly international cooperation in providing the data. Certain of the data have been published by Avery (1963), Heezen *et al.* (1959), ICNAF (1968) and Le Pichon *et al.* (1971).

DRILLING OPERATIONS

Drilling operations started at 0445 hours on June 25 in a water depth of 1797 meters (corrected). A Christensen 1927 diamond bit was used below 8 drill collars and 3 bumper subs. The drill bottomed at 1430 hours and a surface core was taken. Of 9 meters cored, 5 meters were recovered which included the water/sediment interface (Core 1).

Drilling proceeded easily to 94 meters when a core was recovered of stiff Pleistocene glacial clay (Core 2). This sediment included a large number of pebble-sized glacial erratics which may have contributed to the irregular progress of drilling and to torquing up of the drill string.

At 189 meters, Core 3 was cut. It was intended to be above the strong seismic reflector; however, as soon as coring started, a very hard layer was encountered which, when recovered, turned out to be a shallow water, calcareous sandstone. A short section of glauconitic sands and another sandstone were obtained in the core, all of Cretaceous age. Continuous coring was then attempted in a succession of three more cores, (Cores 4, 5 and 6), but each time very hard layers were encountered interbedded with softer sediments. The high pump pressure needed to cut the hard layers unfortunately washed away the softer layers so only hard rock fragments were obtained mainly from the core catcher. Most of these had been rolled and ground in the course of coring.

After Core 6, an attempt was made to drill down and core at 50 meter intervals in order to reach a crystalline basement rock. To avoid coring while drilling, a center bit was dropped. However after 30 meters further penetration, another very hard layer was encountered and little progress was being made. The center bit was recovered and found to contain two small chips wedged in the water vents, one of granite and one of quartzite. The center bit was worn flat. Encouraged to believe we were near basement, a core was taken which produced a short section of apparently nonfossiliferous, graded, black sandstone over shale (Core 7).

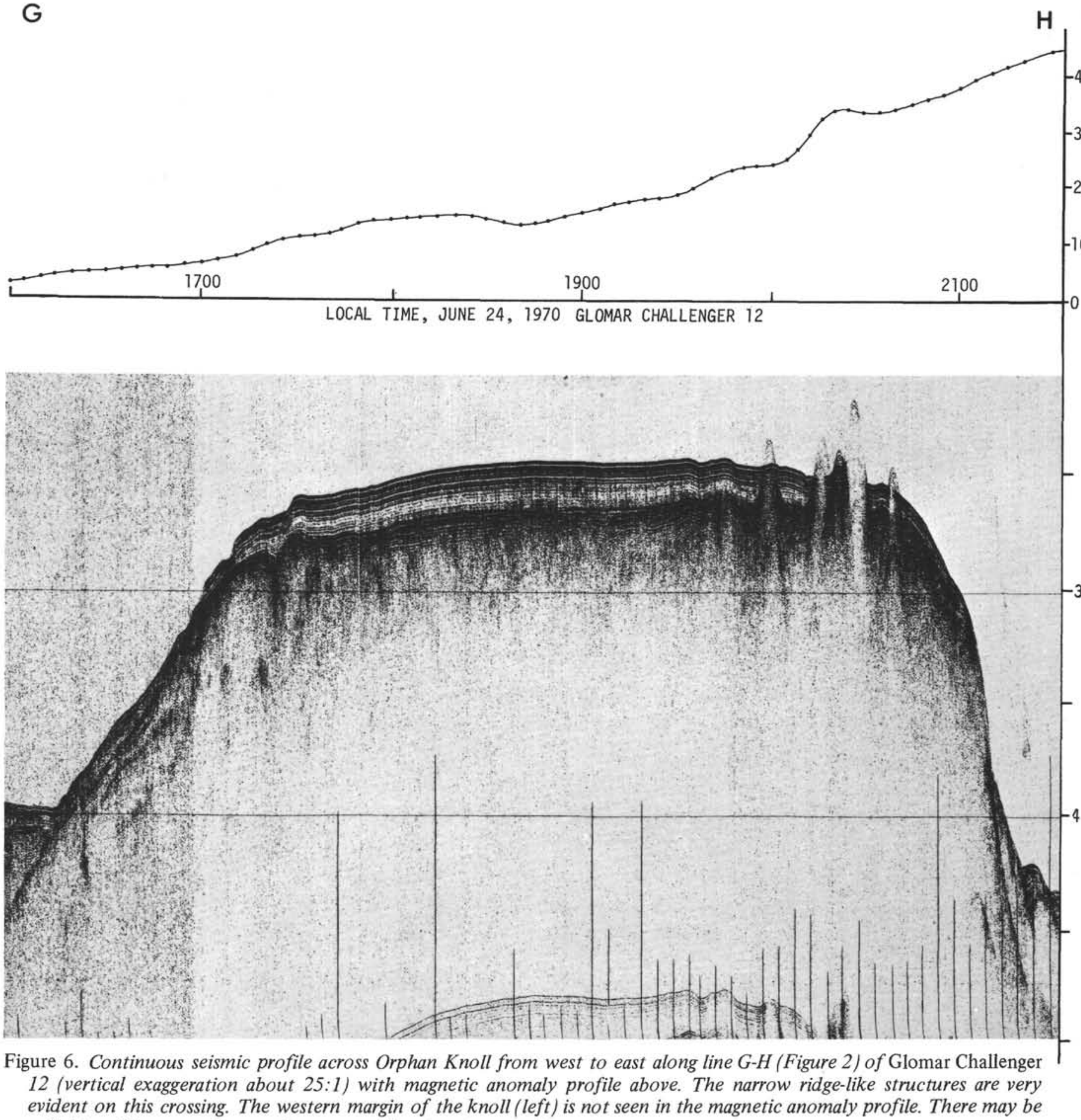

Figure 6. *Continuous seismic profile across Orphan Knoll from west to east along line G-H (Figure 2) of* Glomar Challenger *12 (vertical exaggeration about 25:1) with magnetic anomaly profile above. The narrow ridge-like structures are very evident on this crossing. The western margin of the knoll (left) is not seen in the magnetic anomaly profile. There may be a slight positive anomaly over the narrow ridge structures on the east.*

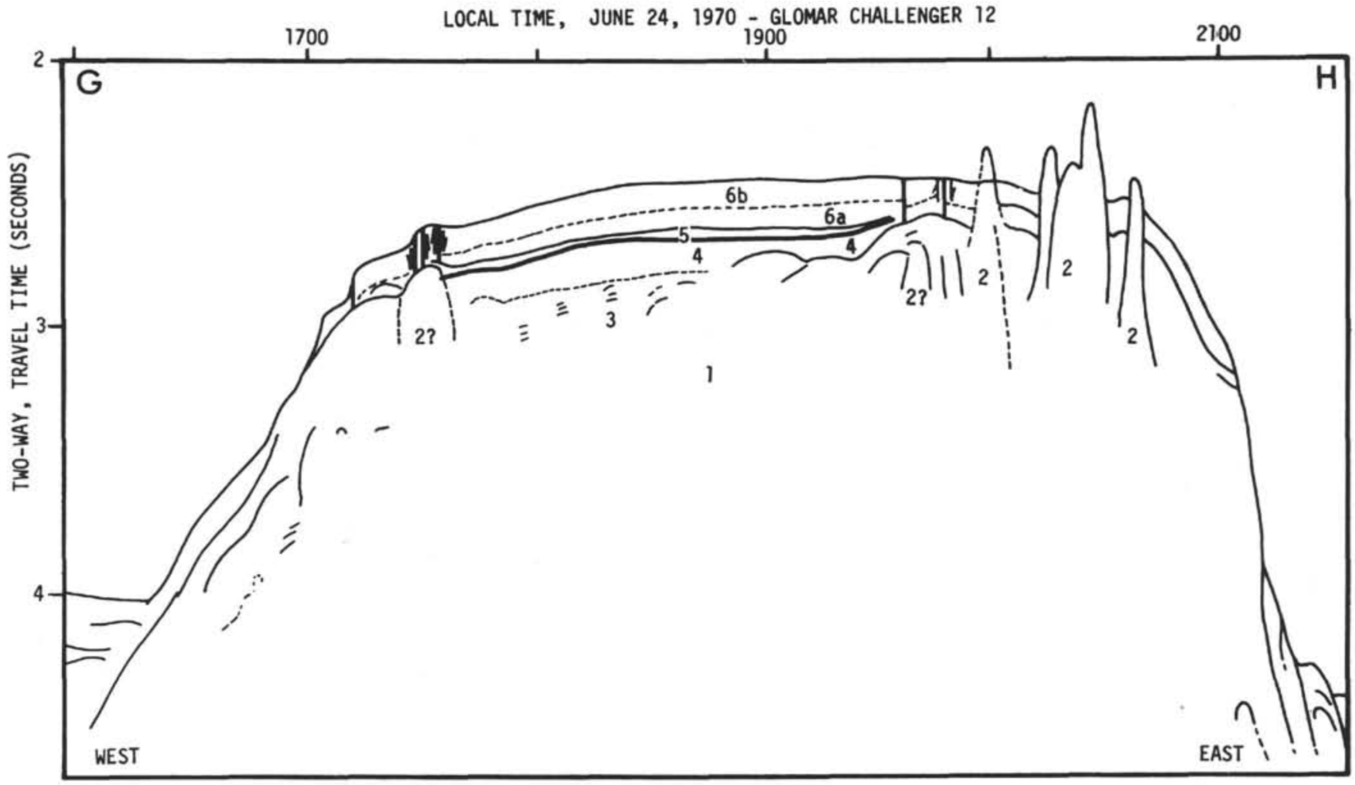

Figure 7. *Line interpretation of the west-to-east traverse of Orphan Knoll by* Glomar Challenger *12 (line G-H, Figure 2). It is not clear whether a buried ridge-like structure (layer 2) was seen on the western margin. A series of small normal faults above the possible structure have upraised a low bathymetric ridge on the ocean floor (see Figure 26).*

The apparent absence of any Tertiary sediments in the seven cores taken and the inability to drill further without changing the bit, led us to decide to withdraw from the hole to mud line, and to re-enter the bottom in order to drill another hole and to attempt to recover what appeared to be a highly compressed Tertiary section. Only 5 minutes elapsed between withdrawal and re-entry so there was no significant difference in hole position.

Hole 111A was entered at about 2000 hours on June 26 and drilled ahead to 105 meters with no coring. A continuous series of 12 cores were then taken from 105 to 199 meters when a calcareous sandstone horizon was sampled which could be correlated with that from Hole 111. During this series of cores, a number of hard horizons were encountered, some of which appeared to be exceptionally stiff clay, others chert or sandstone. Some cores had a good recovery, others were very poor, due presumably to the need for using a high circulation and pump pressure to cut the hard layers and the subsequent washing out of the softer layers. The rate of cutting was lower than on Hole 111 at the equivalent depth, due to the wear on the bit which was seen to be severe on recovery. The hole was finished at 2030 hours, June 27, the drill string inboard and secured by 0300 hours, June 28, and the passage to Site 112 was begun immediately.

In 19 cores, 142 meters were cut and a total of 74 meters recovered (52 per cent). Throughout the operation, the weather varied from rain to sunshine, from fog to snow, the wind varying from 15 to 20 knots from the southeast. No ice was sighted while on the site. A 13.5kHz beacon was successfully used for the first time during the three days on the site.

TABLE 1
Cores Cut at Site 111

Hole	Core No.	Interval Cored (meter Subbottom)	Core Recovered (meters)
111	1	0-5	5.50
111	2	94-103	7.40
111	3	189-198	1.70
111	4	198-204	0.12
111	5	204-213	CC only
111	6	213-222	CC only
111	7	249-250	0.67
111A	1	105-114	8.20
111A	2	114-120	5.20
111A	3	120-125	5.00
111A	4	125-134	4.40
111A	5	134-143	7.20
111A	6	143-152	4.00
111A	7	152-161	8.70
111A	8	161-164	2.80
111A	9	164-173	1.60
111A	10	173-182	3.80
111A	11	182-190	7.80
111A	12	190-199	0.50

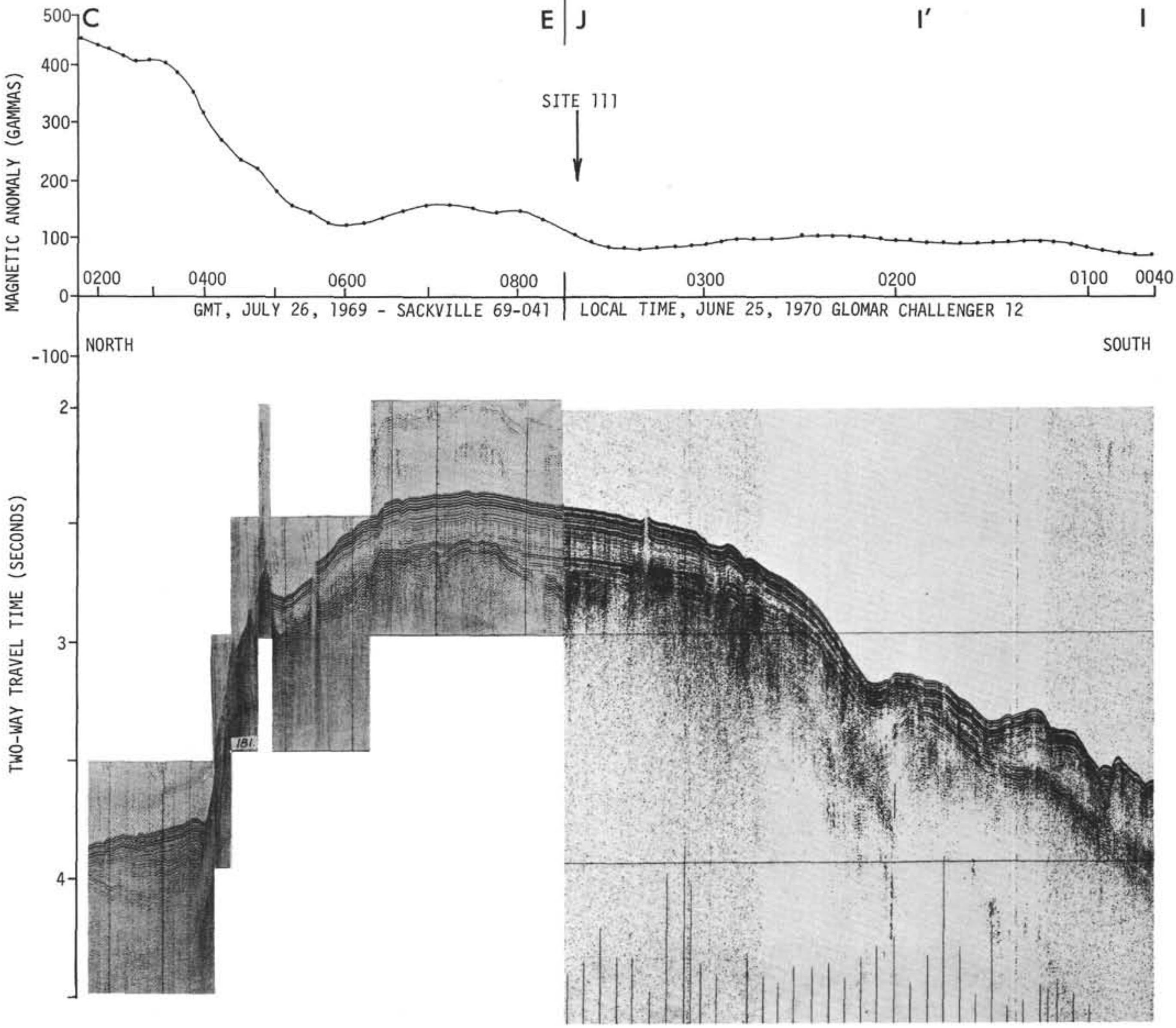

Figure 8. *Composite seismic profile across Orphan Knoll from north to south along lines C-E and J-I (Figure 2) of* Sackville *69-041 and* Glomar Challenger *12, respectively (vertical exaggeration between 25:1 and 30:1). Composite magnetic anomaly profile is in upper part of figure. A narrow ridge structure is seen south of Site 111 with upturned beds abutting it. Normal faulting is clearly seen to result in topographic expression on the sea floor. The magnetic anomaly profile of* Sackville *was estimated graphically and matched to that of* Glomar Challenger. *The southern margin of the knoll and the narrow ridge-like structures are not seen in the magnetic anomaly profile. Arrow marks Site 111.*

LITHOLOGY

General

The gross features of the lithology were examined visually on board ship and the broad features of the composition defined by examination of smear slides. Samples were subsequently analyzed for grain size distribution (Appendix B and Figure 11) and carbonate content (Appendix C). Additional special reports on the petrography of selected samples from the hard rocks were prepared by H. Nelson (ESSO, Calgary) and by N. P. James and J. C. Hopkins (McGill University). P. Hacquebard (Geological Survey of Canada), and T. W. Bloxam and G. Kelling (University of Wales) examined the carbonaceous material. These contributions will be found at the end of this general account of the rocks sampled on Orphan Knoll.

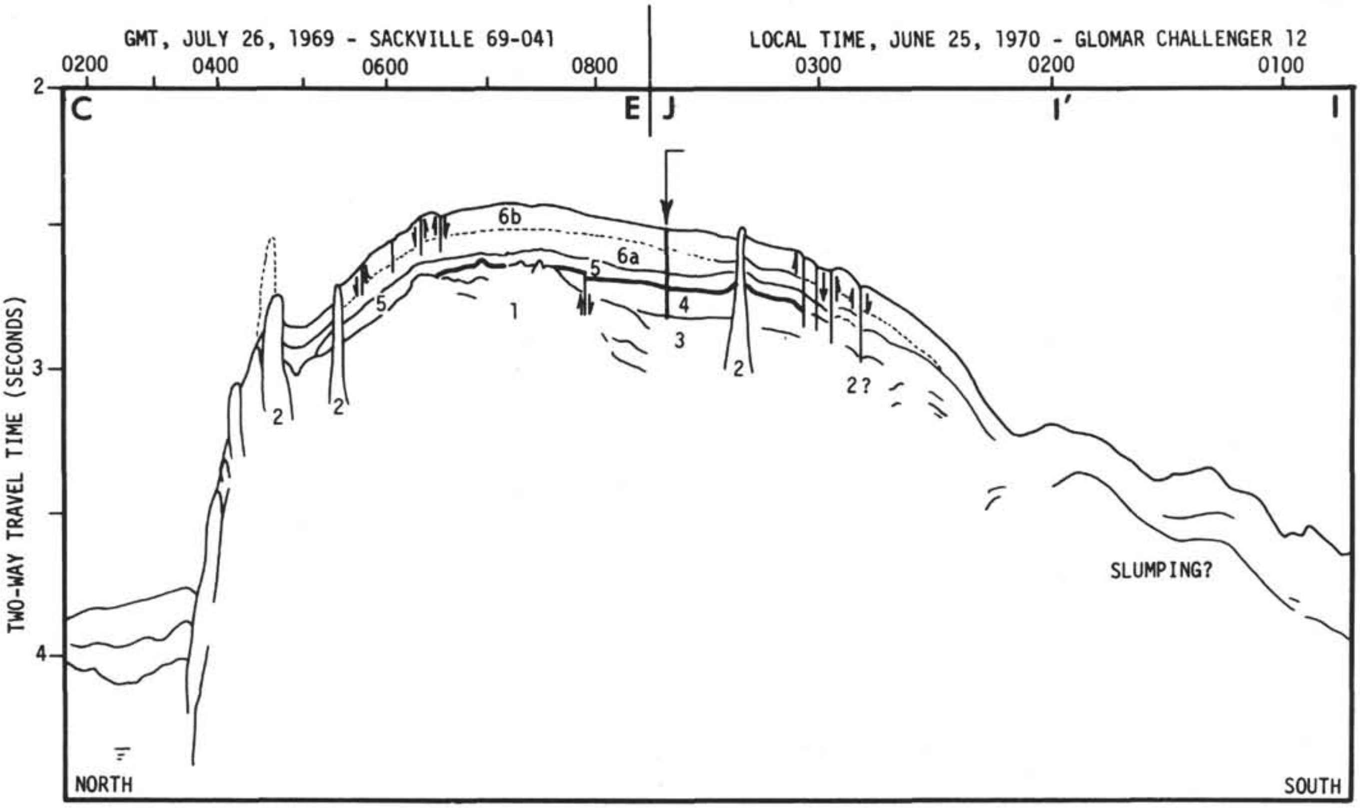

Figure 9. *Line interpretation of the composite seismic profile across Orphan Knoll (vertical exaggeration between 25:1 and 30:1). Two sections of Cenomanian shallow-water carbonates (layer 4) are separated by a "basement" high (layer 1) that existed as an island in Cenomanian times. On the north, a side echo from an even higher ridge structure is shown as a dotted peak. There appears to have been some slumping on the south.*

The sediments cored on the top of Orphan Knoll range from coarse, graded sandstone to zeolitic clays, glacial silty clays and soft chalks.

The succession can be divided into five sections:

Sediments	Approximate subbottom depth (m)
Glacial clays alternating with foraminiferal oozes.	
	146
Nannoplankton marls and zeolitic clays.	
	179
Soft chalks.	
	189
Calcarenites, carbonate sands and shelly limestones.	
	249
Coarse, graded sandstones and shales.	

Coarse Sandstones and Shales

The coarse, graded sandstones and shales forming the bottom of the section cored are represented by Core 111-7, which was taken from a depth of 249 to 250 meters below the seabed. This core shows a graded bed, 64 centimeters thick in the cored section, overlying about 3 centimeters of soft gray shale which could be the top of another graded bed (Plate 1).

The graded bed ranges from very coarse sandstone at the base, up through sandy siltstones to laminated, clayey siltstone at the top. The bed is dark gray in color and the coarse sandstone at the base has several black laminations, up to 3 millimeters in thickness, composed of carbonaceous material. Distributed through the coarse sandstone are hard, black particles of coal. There are also abundant rock fragments. The lamination in the core dips at an angle of about 20 degrees, and since the base of the sandstone, where it abuts the shale, also appears to dip, this dip is probably secondary (tectonic) in origin rather than being a primary depositional feature. The air gun record taken when steaming away from the site yields further evidence on this point (see below). In addition to the secondary dip, there is also cross bedding and, in the upper, silty part of the graded bed, some suggestion of convolute lamination.

Thin-section analysis was made of a sample of the coarse sandstone from the interval 54 to 61 centimeters from the bottom of Core 111-7 by H. Nelson (Calgary). His findings are reported separately.

The conclusions which can be drawn from both our general observations and from Nelson's more detailed studies are as follows:

(1) The composition indicates that the sandstones are composed of material derived from a nearby sedimentary terrain consisting of a succession of shales and sandstones, with some coaly interbeds. A further contribution was made by outcropping strata of shallow-water carbonates. The age of the eroded source beds may be Late Paleozoic.

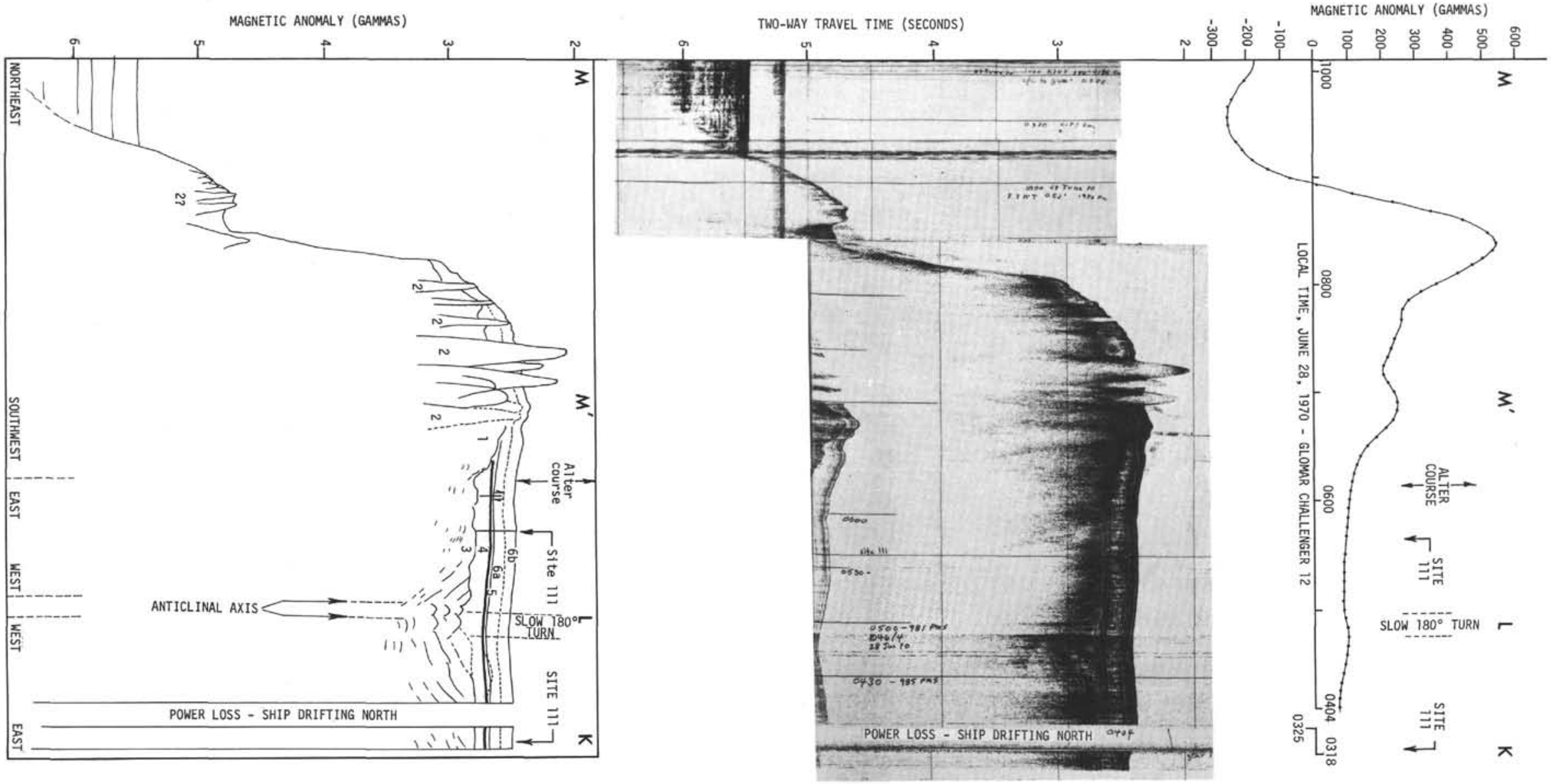

Figure 10. *Continuous seismic profile along lines K-L and L-M (Figure 2) made by* Glomar Challenger *12 on leaving Site 111. Magnetic anomaly profile is above, and line interpretation is below (vertical exaggeration about 25:1). Shortly after leaving Site 111 on a westerly course a half-hour power loss occurred. The Jurassic sandstones (layer 3) can be clearly seen to dip to the west. The dip reverses in the profile because the ship did a slow 180° turn to port from 0442 to 0456. At Site 111 the seismic section indicates the top of layer 6b, 6a, 5, 4, and 3 at 0.0, 0.10, 0.18, 0.21 and 0.29 seconds, respectively. The first multiple at 0645 can be used to discern structure. The positive bump on the magnetic anomaly profile at 0645 may result from the bodies giving rise to the narrow ridge structures (layer 2).*

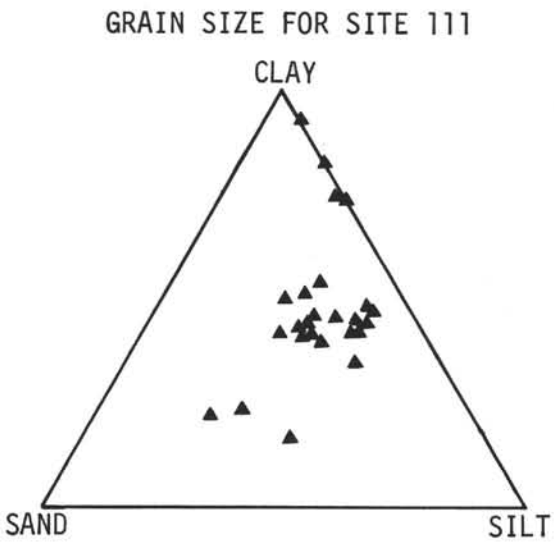

Figure 11. *Grain size of samples from Site 111.*

(2) The general appearance of the sandstone cored in Core 7 is that of a very immature sediment which was clearly laid down under high, but fluctuating, energy conditions. The nature of the lithic constituents precludes extensive reworking and the immature aspect, together with the graded bedding, suggests rapid "dumping," such as may occur in environments as diverse as braided streams and turbidites. There is no evidence from the nature of the sediment to indicate whether we have sampled a fluvial deposit or perhaps a marine deposit, although positive marine indications, like glauconite or autochtonous skeletal material, are absent. Paleontological studies (*q.v.*) indicate this to be a nonmarine deposit of Bajocian age.

The coal was examined both by P. A. Hacquebard (Geological Survey of Canada) and by T. W. Bloxam and G. Kelling (University of Wales). It was found to be a high rank anthracite, almost certainly of Paleozoic age. The distinct absence of similar coals from the Atlantic Provinces of Canada leads to the interesting suggestion that the coal may be derived from a source lying to the east. Corroborating evidence for such a speculation comes from Bloxam and Kelling's observation (*q.v.*) that the Orphan Knoll coal has a germanium content similar to that of South Wales anthracite. (On a pre-drift reconstruction of the North Atlantic Ocean, Orphan Knoll comes very close to the southwestern part of the British Isles; see Chapter 20.)

The hard, graded sandstone of Core 7 is separated from the overlying formations by an angular unconformity. This is suggested by the dipping laminations in Core 7 and is shown very clearly in the seismic profiler record at a depth between 245 and 250 meters below the seabed (Figure 10).

Calcarenites, Carbonate Sands and Limestones

Cores 111-3, 4, 5 and 6, and Core 111A-12 (about 190 to 220 meters below seabed) sampled the upper part of the stratigraphic sequence overlying the graded sandstone. Most of these cores consisted of only a few fragments of rock, and drilling was hard all the way. The rock fragments recovered consisted of fine-grained shelly limestones, compact carbonate sands and calcarenites. The sediments are classed as sandy silts on the basis of texture and have a carbonate content greater than 50 per cent. The sand fraction of the samples studied consisted mostly of "glauconitized" foraminifera, broken and corroded foraminifera and a lot of sugary-looking, recrystallized carbonate material.

A more thorough examination by James and Hopkins (McGill University) recorded echinoid fragments, shell fragments, foraminiferal tests, micro-crystalline pelletoids, "glauconite," detrital quartz and feldspar. These grains are either well-cemented with sparry calcite or contain up to 20 per cent micrite matrix within any one sample. These observers also noted some variation in composition: The lower portion of the section (Cores 111-5 and 6) is relatively richer in detrital quartz and feldspar, granular foraminifera, coarse skeletal fragments and micro-crystalline pelletoids (altered algae and foraminifera?). The "glauconite" is green, often botryoidal (cores or internal molds of foraminifera). The sand is clean and well cemented. The upper portion (111-3 and 4, and 111A-12) on the other hand contains relatively more planktonic foraminifera and ostracods in a muddy sand. The "glauconite" is a brown-green in color and most commonly associated with skeletal fragments. The sand contains less cement and is more porous. There appeared to be little mineral material, but this is clearly concentrated in the finer fractions. Quartz and feldspar are found as accessory minerals and the predominant clay minerals are chlorite and illite.

As reported above, "glauconite" is common in all of the samples studied. X-ray studies of samples from Core 111-3 showed only quartz and calcite, however; and studies of "glauconite" from other parts of the section revealed only an indeterminate mixture of clay minerals. Hence, it is possible that the green material which forms the very obvious casts of foraminifera in many of the samples is not a true glauconite, but only a semi-amorphous aggregate of iron-rich clay minerals.

The calcarenites at the top of the section have been broken up and recemented to form "conglomerates" consisting of subspherical rounded pebbles of calcarenite (up to 5 centimeters in diameter) in a muddy, fine-grained, chalky matrix (Plate 1). The pebbles appear to be of the same composition as the underlying material. In this upper part of the section the "glauconite" particles can be seen oxidizing and altering to yellow limonite, and all of the pebbles in the "conglomerate" have a yellow-brown weathered rim which James and Hopkins (*q.v.*) have shown to be enriched in phosphate. The top surface of the conglomerate in both 111-3 and 111A-12 is covered with a blue-black crust which has been shown to be enriched in iron and manganese. A similar coating can also be seen on some of the pebbles in the "conglomerate". It is clear therefore that following deposition of the calcarenites, there was a considerable period of nondeposition.

Soft Chalks

Resting on the manganese pavement is a soft chalk ooze in many respects comparable to chalk successions found on land (James and Hopkins). The ooze may be as much as 10 meters thick and was sampled in 111A-11 (182 to 190 meters below seabed). This is a core of soft friable brown-white chalk, partially lithified, for there are some very hard beds, and partially creamy and unlithified. The carbonate content of the chalks is greater than 90 per cent, and texturally they fall into the sand-silt-clay category. Most of the carbonate is coccoliths. The sand fraction of the sediments consists mostly of foraminifera, mostly whole with surface detail preserved, although they have the chalky appearance which suggests recrystallization. Echinoderm spines, ostracods and *Inoceramus* shell fragments are also common. The noncarbonate fraction of the sediments consists of minor amounts of quartz and feldspar, "glauconite," and some arenaceous foraminifera.

The chalk shows burrow mottling throughout. There are many small disconformities cutting the mottles horizontally. This suggests that deposition was not continuous and took place on a carbonate shelf, remote from land.

Nannoplankton Marls and Zeolitic Clays

Above the chalks is a sequence of green-gray nannoplankton clays and silty clays (111A-8, 9 and 10). These clays are about 20 meters thick. Most of the section, however, consists of a very hard, friable calcareous clay, having a soapy feeling to the touch and a carbonate content ranging from 20 to 30 per cent. Examination of smear slides shows a great abundance of calcareous nannoplankton and a few foraminifera. The sand fraction, which is generally only one or two per cent of total sediment, contains only benthonic foraminifera, a few broken and corroded planktonic foraminifera and some fish teeth. Shell fragments and other evidence of a shallow water environment are absent. It must be presumed, then, that between deposition of the underlying chalk and deposition of these clays, the knoll was further isolated from terrigenous influence and sank from outer shelf to bathyal depths. In some places, the clays have been lithified (silicified) into a very hard "cherty" mudstone and the softer sediment can be seen grading into the mudstone bands.

Overlying these clays is a sequence of creamy zeolitic clays (111A–6 and 7) containing some nannofossils completely without foraminifera or any other coarse components. The top of these clays is marked by a thin bed of "glauconite" sand lying at about 145 meters below the seabed (Plate 2 and frontispiece). The complete absence of coarse fraction, biogenic or otherwise, is puzzling. As stated above, presumably by this point in its history, Orphan Knoll had reached more or less its present position, isolated from the continental shelf and submerged beneath 2000 meters of water. This would explain the absence of a terrigenous component in the sediments; however, it does not explain the absence of any coarse biogenous material. Even in the absence of calcareous remains, one would expect to find phosphatic fossils such as fish teeth. The normal sediment accumulating at this location at the present time is foraminiferal ooze (see later section).

There are two possible interpretations. Either there was a complete absence of marine life other than nannoplankton in the waters surrounding Orphan Knoll at the time of accumulation of the zeolitic clays, or the larger biogenic components have been chemically removed. In view of our knowledge of the distribution of life in the oceans at the present time, the first explanation seems unlikely, so we are obliged to accept the latter and assume that the larger biogenous components have been removed chemically.

The "glauconitic" sand, like the phosphatic pavement recorded earlier in the succession, indicates a long period of nondeposition or an extremely low sedimentation rate.

Glacial Clays and Pelagic Deposits

Above the "glauconite" sand is a succession of normal pelagic, foraminifera-rich sediments (Plate 2). These foraminiferal oozes fall into the sand-silt-clay category on the basis of texture and have a carbonate content greater than 70 per cent. The sand fraction consists entirely of foraminifera, many of which are broken, and irregular green lumps of "glauconite". The "glauconite" grains may be reworked from the "glauconite" sands below, or may have been formed contemporaneously with deposition of the pelagic sediment.

About 1 meter above the "glauconite" sand, these pelagic deposits change abruptly in color from a creamy, pale green to olive gray, and the clay content increases from about 20 to more than 40 per cent. About 50 centimeters above the color boundary the sediment is a silty clay with abundant terrigenous material, mica flakes, pyrite lumps, and small pebbles. The color change is considered to mark the onset of extensive glaciation in the region. From here (about 145 meters depth) up to the present seabed, the section consists entirely of mixed ice-rafted detritus (Plate 3) and pelagic material interbedded with, towards the base of the section, "dirty" foraminiferal sands which presumably represent relatively warmer periods when ice-rafted material was usually not brought into the region. A mineralogic change is also detected at the onset of glaciation. X-ray minerology samples (Fig. 12) taken in Core 6 show an increase of quartz and mica and a decrease in calcite content in the glacial silty clays.

Petrographic Analysis of the Sandstone from Orphan Knoll

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Calgary, Alberta

Introduction

The following summarizes the results of a thin section analysis of a sandstone sample (111-7-1, 54 to 61 centimeters) from Orphan Knoll taken by *Glomar Challenger* from a depth 249 to 250 meters below seabed. The sample was passed on to me by J. E. van Hinte, with the objective of determining the composition of the component grains.

According to the core description, Core 7 consisted of 3 centimeters of grayish shale, overlain by a 64-centimeter graded bed ranging from coarse-grained sandstone at the base, through sandy siltstone, to laminated mudstone at the top. The interval is believed to be of Middle Jurassic (Bajocian) age (Pocock, this volume). The thin section was prepared from the coarse sandy zone.

The writer wishes to acknowledge his indebtedness to A. S. Ruffman, who read the initial report and provided helpful comments. The results of his X-ray and scanning electron-microscope analyses, which he kindly placed at

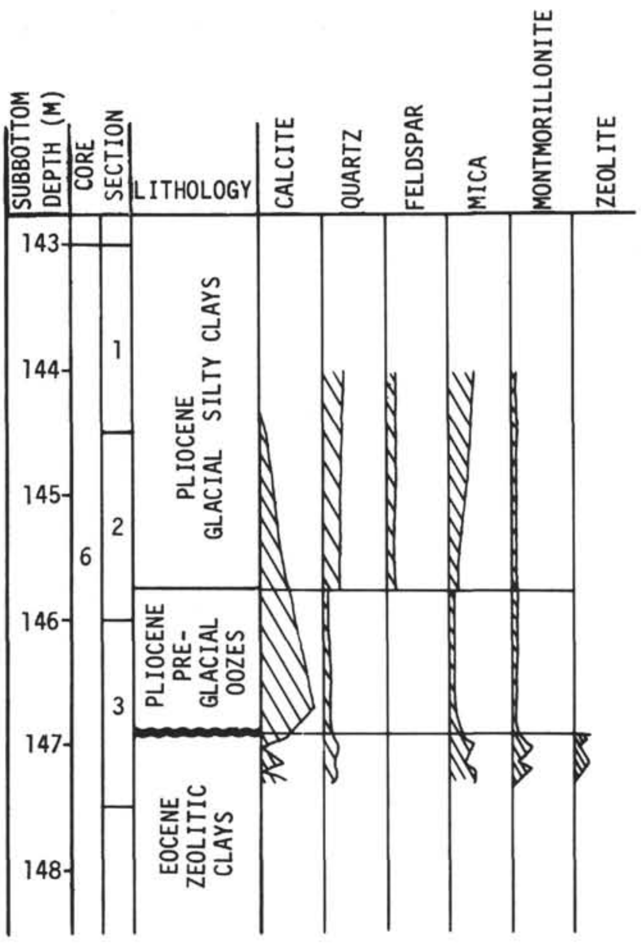

Figure 12. *X-ray mineralogy of Core 6, Hole 111A.*

this writer's disposal, form an important supplement to the optical description.

Composition

The composition determined by point-count under the petrographic microscope (200 counts) is tabulated in Table 2. The analysis shows the rock to be a muddy, lithic sandstone, composed preponderantly of rock fragments. Mineral grains, like quartz or feldspar, play only a very minor role.

Among the lithic components, fragments of argillite (35 per cent) and sandstone (23 per cent) predominate. The argillites occur as subrounded to rounded grains ranging from 0.5 to 1.5 millimeters in size and include shale, silty to fine sandy shale, carbonaceous shale and rare grains of phyllitic shale rich in mica.

The sandstone fragments, which are of about equal size as the argillites, include two types. Most common is a micaceous variety composed of fine-grained quartz, minor feldspar, chert, and variable amounts of muscovite as well as some bleached biotite. The absence of a true granoblastic fabric and the tendency of the mica flakes to be roughly parallel-oriented suggest that the mica flakes are of detrital rather than diagenetic origin. However, some slight recrystallization can be noted, suggesting incipient metamorphism in the provenance area.

In addition to the micaceous sandstone, there are a few grains of quartzitic sandstone. These differ only in that they are lacking in micaceous matrix material, and are transitional with the micaceous variety by an increase in mica content. In hand specimen, the fragments of both varieties display a notoriously poor induration which supports the view that the parent beds were not affected by any metamorphic alteration of significance.

The remaining lithic components consist of subordinate quantities of carbonate (6.5 per cent), siliceous rock fragments (6 per cent), coal (3 per cent) and rare volcanic rock fragments (0.5 per cent). The carbonate grains range in size from about 0.2 to 0.8 millimeters, and include fragments of both micritic and skeletal-micritic limestone. The micritic (or crypto-crystalline) fragments are variably argillaceous and fine-sandy, and seem to have been derived from very shallow, perhaps intertidal, mud flat deposits. The fossil remnants in the skeletal varieties are monocrystalline grains believed to be echinoid relicts, and suggest derivation from shallow marine deposits. Some loose skeletal debris present in the sample evidently were derived from the same source beds. All carbonate grains are rimmed with a dark coating which was caused by peripheral alteration either during transport or subsequent deposition.

The coal occurs in splintery fragments ranging from 0.3 to 3 millimeters in size, often displaying a fine "woody" striation. The fragments evidently are of detrital origin, and were introduced together with the other clastic components.

The table further shows that quartz is of minor importance only, making up no more than 5.5 per cent. The mineral occurs mainly in the size range 0.06 to 0.20 millimeters, which is significantly smaller than that of the lithic components and identical to the size ranges found in the sandstone fragments. This suggests that the detrital quartz grains were derived from the same source. Detrital feldspar grains are virtually absent in the analyzed sample.

The interstices between the grainy components are largely infilled with muddy matrix (15 per cent). The mud is crowded with minute spherulites of siderite which measure about 0.005 to 0.010 millimeter in size and in places constitute the principal component, forming a loose, finely granular coating around the sand grains. In addition, small specks of carbonaceous matter are present. Most of the remaining pore space is infilled with patches of calcite cement (4 per cent). Both the calcite and siderite are considered to be of diagenetic origin. They may have been derived from admixed ferruginous and micritic matter present in the mud itself, or possibly, the carbonate was introduced by circulating waters from skeletal limestone beds that are known to occur a few feet higher up in the section.

Fabric

As indicated above, the size of the component grains varies significantly and is dependent on grain type. The rock fragments generally occur as coarse grains and may range up to pebble size, whereas the mineral constituents are fine- to medium-grained. Consequently, the overall sorting is moderate to poor. Similarly, the rounding varies with the nature of the constituents and is best developed in the fairly soft argillite and sandstone fragments, and poorest in the brittle coal.

The porosity of the rock is practically completely destroyed by a combination of (1) infilling with matrix mud, (2) compaction, welding the softer elements together, and (3) diagenetic redistribution in the form of cement.

Lithification

The calcite and siderite appear to constitute the main agents responsible for the lithification of the sandstone. This is clearly demonstrated by the findings of a scanning electron microscope study by A. S. Ruffman, the results of which are reproduced on Plates 4 and 5. A survey across the broken sample surface revealed only grains covered with a drusy-like growth of secondary calcite crystals, besides a few grains that may have been broken (e.g., the coal fragment in Plate 5, Figure A.) The author concludes that the sandstone is weakly bound by the calcite cement, and when fractured breaks around the individual grains. The calcite appears mostly as a drusy-like growth of unoriented anhedral crystals, but occasionally euhedral crystals or an acicular growth form are encountered. These findings underline the important role of the carbonate in the lithification of this rock. However, in view of the petrographic observations it seems to the present writer that the drusy-like anhedral crystals are actually siderite rather than calcite, and that calcite is limited to the more sparsely occurring euhedral crystals and acicular growth forms. Hence, the lithification would be effected principally by the recrystallized sideritic mud.

Associated Lithologies

Apart from the coarse-grained sandstone described in the foregoing pages (111-7-1, 54 to 61 centimeters), a brief examination was carried out on four additional thin sections from the same core. The thin sections, prepared by the Geological Survey of Canada's labs in Ottawa, are from the following intervals: (1) a fine-grained sandstone, 20 to 23 centimeters; (2) a coarse-grained sandstone, 53 to 55 centimeters; (3) a very fine-grained sandstone, 62 to 64 centimeters; and (4) a piece of soft clay at 64 centimeters.

Point-counts were made on the coarse-grained (53 to 55 centimeters) and fine-grained (20 to 23 centimeters) samples, and the results incorporated in Table 2. The data show the coarse-grained sample to be very similar in composition to the one described above in detail, the main difference being only a higher percentage of coal fragments. The fine-grained sample, on the other hand, shows a significant increase in quartz grains and a simultaneous decrease in lithic components, notably sandstone and argillite fragments. Moreover, the composition of the matrix differs in that it contains a considerable percentage of very small dolomite rhombs, measuring about 3 to 5 microns, and which apparently were derived from dolomitized micrite occurring in the mud. No point-count was made on the very fine-grained sandstone (62 to 64 centimeters) but the same trends were observed, especially with regard to the significant content of dolomitized micrite in the mud fraction.

The fourth sample, referred to as soft clay (at 64 centimeters), is under the microscope a finely-sandy micritic mudstone of which the matrix again consists of a mixture of clay minerals and dolomitized micrite. The micrite content varies somewhat in alternating laminae, but on the whole makes up nearly half of the total matrix material. The sand fraction (15 per cent) consists primarily of quartz, together with accessory mica, a few larger carbonate relicts and a trace of chert. The largest grains are about 0.07 millimeter in size.

In summary, the additional samples indicate that the composition of the graded sandstone bed varies and is influenced to a considerable degree by grain size. The nature of the supplied detritus, however, remains essentially unchanged. The most notable feature is the appearance of significant quantities of micrite in the mud fraction of the finer grained varieties. Photomicrographs of the different lithologies are shown on Plates 6 and 7.

X-ray Analyses

X-ray powder diffraction diagrams essentially verify the above presented optical description. Analyses were carried out and interpreted by A. S. Ruffman on three samples, all from Core 111-7-1: (1) a fine-grained sandstone from the interval 20 to 23 centimeters, (2) a coarse-grained sandstone from 53 to 55 centimeters, (3) a very fine-grained sandstone from 62 to 64 centimeters.

The main constituents identified in each sample are quartz, albite, muscovite and kaolinite. Furthermore, a high proportion of calcite is found in the coarser-grained samples (1) and (2), but not in the finer-grained sample (3). The latter appears to contain also a small percentage of chlorite, in addition to the mentioned foliaceous minerals kaolinite and muscovite. The presence of siderite is indicated in all three samples, but the diffraction lines are incomplete, suggesting that this mineral occurs in small quantities only.

Comparison of the diagrams with one another indicate a decrease in quartz with finer grain size and an increase in clay mineral content. The optical investigations reveal that most of the quartz does not occur as single grains but forms an integral part of lithic fragments, particularly micaceous sandstone. Whereas the proportion of these lithic fragments diminishes with decreasing grain size, that of single quartz grains actually increases. (Compare Sample 3 with Samples 1 and 2, Table 2.) The same can be said for the feldspar (albite) content which is also largely controlled by the quantity of the feldspar-bearing micaceous sandstone fragments. The identified calcite is present mainly as carbonate fragments, and to a lesser extent as interstitial cement. In the very fine-grained sample (62 to 64 centimeters), carbonate fragments are practically absent and no secondary cement was introduced, apparently owing to the rock's low permeability. The bulk of the identified clay minerals and mica evidently is located in the mud fraction, which increases in significance with decreasing grain size.

Final Comments

1. The composition indicates that the clastics were derived from a nearby sedimentary terrain consisting of a succession of shales and sandstones, with some coaly interbeds. A further contribution was made by outcropping strata of shallow-water carbonates. The age of the eroded source beds possibly is Late Paleozoic.

2. The fabric suggests that the clastics were laid down under rather high, but fluctuating, energy conditions enabling entrapment of significant quantities of mud. The majority of the lithic constituents would not have survived prolonged reworking. The immature aspect, together with the reported graded bedding, suggests rapid "dumping", as may occur in environments as diverse as braided streams and turbidites.

3. An important indication as to the environmental conditions may be provided by the associated finer-grained beds which contain appreciable amounts of dolomitized micrite. Micrite is not an ordinary constituent of the muddier sections of point bars or braided streams, at least not in a truly terrestrial setting. Micritic mudstones are known to be common products of sedimentation in very shallow, coastal mud flats, or possibly in shallow embayments. The combination of poor sorting, high suspension load and graded structure, as well as the association with interbedded finer-grained micritic rock types, seems to indicate that the clastics were laid down by a system of braided distributaries in a coastal plain environment.

Report on Carbonaceous Material from Orphan Knoll

P. A. Hacquebard, Geological Survey of Canada,
Ottawa, Ontario

Location, Nature and Age of Sample

The sample submitted for study came from a core taken from 249 to 250 meters below the seabed from Orphan Knoll (water depth 1797 meters). The interval sampled was 54 to 61 centimeters from the top of 111-7-1. The rock is a coarse, graded sandstone, loosely consolidated, dark gray in color, with carbonaceous material. Palynological assemblages from samples a few centimeters above and below the sample studied here were determined by S. A. J. Pocock (Imperial Oil Enterprises Ltd.) to be Middle Jurassic (Bajocian) in age (see later report).

Result of Coal Petrological Study

The carbonaceous matter is of detrital origin and consists of (predominantly) angular fragments that vary in size between 1.5 and 3.5 millimeters in the largest diameter, and 0.03 and 0.2 millimeters in the shortest diameter. The average length is 1.14 millimeters, and the average width is 0.73 millimeter. Observations on polished surfaces with reflected light and oil immersion objective (at 375X magnification) has shown that the material is indeed coal. The presence of a few fragments of fusinite with distinct cellular structure indicates origin from woody tissues. Apart from the fusinite, the remainder—or the coaly material—consists entirely of the constituent vitrinite, which is common to all hard coals, regardless of their age or rank.

As an inorganic constituent, the presence of finely disseminated pyrite can be mentioned, as well as a few particles of a very highly reflective substance, which may be sphalerite.

Reflectance measurements carried out on the vitrinite component of 25 different fragments gave an average per cent maximum reflectance of 5.40. According to the correlation diagram of K. Kotter (1960) this figure can be equated with a volatile matter content that lies between 2 and 3 per cent. A coal of anthracitic rank, close to being a meta-anthracite is therefore represented. Coaly materials of such high rank are not known from the Paleozoic in the Atlantic Provinces, with the exception of one small occurrence at Lepreau on Bay of Fundy, 22 miles SW of Saint John, N. B. (Hacquebard and Donaldson, 1970). This occurrence is in a fault zone and has little areal extent.

The only known Mesozoic coal in the Atlantic region has been found in the Musquodoboit River Valley and near Shubenacadie in Nova Scotia. This coal is a lignite, and considerably lower in rank than the Paleozoic coals that have such widespread distribution (Lin, 1970).

As regards the age of the coaly fragments, a palynological dating cannot be given, because spores and pollen can no longer be isolated from coals of such high rank. However, in view of its high rank, a Paleozoic origin of these detrital fragments appears to be more likely than a Mesozoic one.

Germanium Content of Anthracite from Orphan Knoll

T. W. Bloxam and G. Kelling, University of Wales,
Swansea, United Kingdom

Fragments of anthracite found in a coarse sandstone of Jurassic age recovered in 111-7-1 were received for study. The anthracite sample was crushed, extracted and analysed spectroscopically for germanium, a trace element which appears to be more sensitive to provenance factors than most. Although the small size of the sample rendered analysis difficult, the germanium content was established at 3.0 ppm. (±0.5). This value is close to the average values for South Wales anthracites (about 4.5 ppm.) and considerably smaller than the values for bright coals from northern Britain (Bethell, 1962). Germanium values for coals from the Pennsylvanian of Nova Scotia are also much higher (9 to 15 ppm; Hawley, 1955), while those for the anthracties of the Appalachian coalfields average 6 ppm. (Zubovic *et al.*, 1960). Derivation of this sample from a source similar to the coalfields of Southern Britain thus appears to be a distinct possibility, although a single analysis cannot be regarded as sufficient proof.

Lithology and Correlation of Cretaceous Limestones from Orphan Knoll

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Introduction

Seven samples of limestone from the cored Albian-Cenomanian and Maestrichtian portion of the sequence were submitted to the authors for petrographic and mineralogic examination. The Cretaceous section under investigation is briefly outlined below.

Review of Preliminary Results

Albian and Cenomanian: Mostly core-catcher fragments of fine-grained shelly limestones, compact carbonate sands and dolomitic calcarenites. (Samples 111-3-2, 42 to 43 centimeters; 111-4-CC; 111-5-CC; 111-6-CC and 111A-12-CC.)

TABLE 2
Point-Count Results, Sandstone Samples 111-7-1

COMPOSITION (in per cent):	#1 54-61 cm		#2 53-55 cm		#3 20-23 cm	
Quartz		5.5		3.0		26.5
Feldspar				0.5		2.0
Sandstone fragments (total)		23.0		31.0		5.0
Micaceous sandstone	20.5		27.0		3.5	
Quartzitic sandstone	2.5		4.0		1.5	
Argillites (total)		35.0		33.5		13.5
Shale	20.0		19.0		8.0	
Silty shale	10.0		10.5		0.5	
Carbonaceous shale	3.0		2.0		3.0	
Phyllitic shale	2.0		1.0		1.5	
Sideritic mudstone			1.0		0.5	
Siliceous rock fragments (total)		6.0		3.0		4.0
Chert	2.0		1.5		1.5	
Siliceous shale	4.0		1.5		2.5	
Carbonate rock fragments (total)		6.5		4.5		6.0
Micritic-skel. limestone	4.0		3.5		1.5	
Skeletal fragments	2.5		1.0		4.5	
Volcanic rock fragments		0.5				
Coal fragments		3.0		10.0		4.0
Matrix (total)		15.0		9.0		39.0
Mud, including specks of Carbonaceous matter (est.)	12.0		6.0		27.0	
Siderite spherulite (est.)	3.0		3.0		2.0	
Dispersed dolomite rhombs (est.)					10.0	
Calcite cement		4.0		4.5		
Voids		1.5		1.0		
		100.0		100.0		100.0
Average Grain Size (in mm)		0.8		0.9		0.08

NOTE: Thin section of Sample 1 (N 1331) prepared at Imperial Oil Ltd, Calgary. The petrographic description on the foregoing pages refers essentially to this sample. Thin sections of Samples 2 and 3 prepared at GSC, Ottawa; point counts were made to obtain some insight into variability and influence of grain size.

Cenomanian-Maestrichtian contact: The top of the Cenomanian is marked by a hardground of Cenomanian calcarenites broken into rounded pebbles set in a calcarenite matrix and overlain by a manganese (?) crust. Yellow limonite rims on the glauconite grains and pebbles suggests a period of nondeposition on a turbulent well-oxygenated sea bed. (Sample 111A-12-1, 3 to 7 centimeters.)

Maestrichtian: Soft chalk ooze with partially lithified hard layers. (Sample 111A-11-CC.)

Objectives of This Study

The samples were examined with the following objectives in mind:

a. To provide a petrographic (optical and X-ray) description of the sediments.

b. To document lithologic evidence for shallow water depositional environments.

c. To establish the nature of the Cenomanian-Maestrichtian contact and determine its origin.

d. To compare the lithologic sequence on Orphan Knoll with other known Cretaceous sediments from northeastern North America and western Europe.

Petrology and Mineralogy

All the samples were routinely X-rayed to determine carbonate mineralogy. Without exception calcite (with less than 4 mole per cent $MgCO_3$) is the only carbonate mineral present. Dolomite, previously reported from shipboard examination was not confirmed in these samples.

Albian-Cenomanian

Sediments throughout the Albian-Cenomanian show little variation in composition. The sediments are moderately-sorted, sparite-cemented calcarenites (Plate 8A) to poorly-sorted muddy calcarenites with up to 15 per cent porosity (Plate 8B). The cement is calcite and occurs as a drusy mosaic in the granular spaces and as epitaxial rims on single crystal allochems. The mud is fine-grained microspar (Folk, 1965) of interlocking crystals averaging 6 to 10 microns in size. The sand-sized fraction is dominated by skeletal fragments and cryptocrystalline peloids with accessory glauconite pellets and terrigenous quartz and feldspar grains.

The most conspicuous skeletal fragments are echinoderm plates, spines and larger articulated segments, all of which have a strong affinity for epitaxial rim cement. Pelecypod and ostracod detritus is present but occurs in relatively small amounts. Foraminifera are common as globose radial hyaline, uniseriate and biseriate granular forms in which the chambers are filled with mud, calcite cement or glauconite. Subspherical to irregularly shaped cryptocrystalline peloids composed of micrite range from 0.02 to 0.06 millimeters in size. Peloids in general are a multigenetic group of grains (McKee and Gutschick, 1969) and may be formed by fecal agglutination, erosion of muddy sediments or micritization of skeletal grains. In these rocks, many of the peloids are probably fecal in origin but in some, remnant reticulate textures suggestive of calcareous algae are seen. Foraminifera are occasionally affected by the same process, but can readily be distinguished from the peloids by their shape.

The ubiquitous glauconite pellets are apple green to green brown in color and range in size from 0.3 to 0.6 millimeter being somewhat coarser than the other grains. The pellets may be botryoidal with v-shaped tension cracks or homogeneous ellipsoid and a slightly darker green. Glauconite also fills and replaces foraminifera, pelecypod valves, and in one case a small flake of mica.

The fine-sand terrigenous fraction is dominated by angular quartz and feldspar. Biotite and muscovite occur in accessory amounts. Smaller shard-like fragments with low birefringence are also present and appear to be devitrified glass. X-ray diffractograms of the predominantly silt-sized fraction of the insoluble residue (0.008 to 0.062 millimeter) from two samples (111-4-CC, 111-5-CC) indicate the presence of clinoptilolite which was readily identified from the main peaks at 9.00Å, 7.94Å and the dual peaks at 3.96Å and 3.90Å. Deer *et al.* (1962, p. 384) note that clinoptilolite in sediments occurs chiefly as an alteration product of volcanic glass. Diffraction patterns of the clay-sized fraction (less than 0.008 millimeter) in the same samples (111-4-CC, 111-5-CC) indicate that the dominant clay mineral is illite with subordinate chlorite.

Top of the Cenomanian

The Cenomanian-Maestrichtian contact is marked by a series of subspherical nodules up to 5 centimeters in diameter, each of which has a dark rim that is continuous between adjacent nodules. The major internal part of the nodules is sparite calcarenite similar to that of the Cenomanian (Plate 9A). The peripheral dark coating comprises two discontinuous layers. The layer immediately adjacent to the limestone core, where both layers are present, is grain-supported calcite prisms (*Inoceramus* ?), glauconite pellets and terrigenous grains (Plate 9B). The outer layer contains small globose planktonic foraminifera, glauconite pellets, terrigenous grains and occasional prisms (Plate 9C). The dark brown color of the coating is due to a brown subtranslucent material which forms the matrix of the outer (foraminiferal) layer and occurs as a first stage cement followed by calcite in the prism layer (Plate 9B). In the outer layers the dark coating may replace entire glauconite pellets, and in both the outer layers and the nodules it commonly rims glauconite.

Staining the rock slab with acidified ammonium molybdate (Mann, 1950) yielded a positive phosphate reaction in both the dark cement and altered portion of the glauconite pellets. Material from the brown coatings of the nodule was concentrated by hand picking small chips of the crushed rock. X-ray diffraction of some of these indicates a dominance of quartz, calcite and glauconite. The remaining chips were leached of carbonate in 1N acetic acid and the residue passed through 230 mesh to remove the quartz and glauconite sand. The fines were ground and X-rayed (Figure 13) and quartz, goethite and carbonate apatite identified. Goethite was confirmed by its transformation to hematite upon heating at 350°C for one hour following the method of Rooksby (1961). The carbonate apatite yields a very similar diffraction pattern to an artificial carbonate apatite containing slightly in excess of 20 wt % carbonate prepared by Le Geros *et al.* (1967). The same authors report that increasing substitution limits the size of the crystallite which may form. This may explain the very finely divided nature of the apatite in the coatings. King *et al.* (1970) have found very fine crystals of apatite in Cenomanian sandstone on the Scotian Shelf north of Sable Island.

Iron and manganese were determined by atomic absorption for different parts of the slabbed rock and the thin 'manganese' crust found above the nodular layer. (Location of samples and the results of the analyses are given in Figure 14). Iron is concentrated in the goethite of the brown coating and presumably the 'manganese' crust. The location of the manganese is uncertain, and as it occurs in relatively minor amounts it may be substituted as a cation in goethite, apatite or calcite. It may also be present as relatively small amounts of free oxide.

The matrix surrounding the coated nodules is a chalky biomicrite with abundant planktonic foraminifera and is texturally similar to the Maestrichtian above. It differs in that glauconite and terrigenous grains are abundant (Plate 9D).

The glauconite is similar in form (botryoidal grains, altered terrigenous grains and skeletal chamber filling) to that in the Albian-Cenomanian below, and there is no sign of significant abrasion of the botryoidal glauconite pellets. Some of the glauconite pellets are rimmed with phosphate. Terrigenous grains are medium and, less commonly, coarse sand and include larger strained quartz, volcanic rock fragments and small aligned plagioclase laths, pelites with incipient schistosity, and low grade schistose fragments of sandstone and siltstone in which lineated grains can be seen with sericitic micas between.

Maestrichtian

The Maestrichtian sample is a light buff, mottled foraminiferal marl (Plate 8D). The mottling is due to patches of light brown micrite, with scattered foraminifers, interspersed with areas rich in foraminifera. The latter are dominantly planktonic, radial hyaline forms. Glauconite is absent in this sample and only three terrigenous grains (quartz) are present. Diffraction patterns of the insoluble residue (scarcely any acid insoluble grains larger than 0.062 millimeter were obtained) indicate that montmorillonite is the only clay present, contrasting with the underlying Albian and Cenomanian.

The rock is very friable indicating weak cementation of the micrite, and only a few of the original pore spaces are filled with sparry calcite. Although most of the

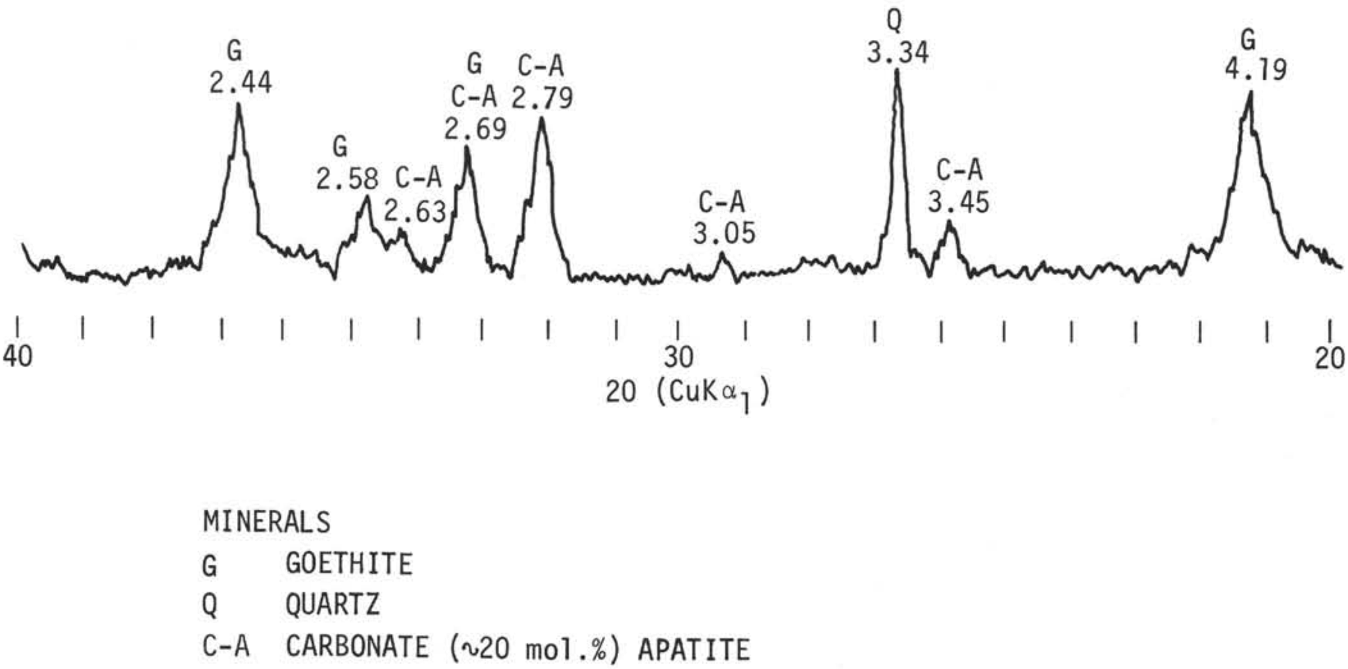


Figure 13. *X-ray diffraction (Cu, Kα radiation) pattern from acid insoluble residue of brown nodule coating (area B in Figure 14) at the Cenomanian-Maestrichtian contact (Sample 12-111A-12-1, 3-7 cm). Numbers below the mineral notation are the values of the peaks in angstrom units (Å).*

foraminiferal chambers are empty, some are filled with a crystalline, weakly birefringent material of low relief that is possibly a zeolite. The mineral could not be concentrated sufficiently from the small sample available to confirm the mineralogy by X-ray diffraction.

Environment of Deposition

Albian and Cenomanian

Sediments of the Albian and Cenomanian yield little that is diagnostic of a particular sedimentary environment. The fine grain size, associated carbonate mud matrix, abundant planktonic foraminifera and lack of abraded grains testifies to the tranquility of the bottom during deposition. Sparite calcite cement in some sands suggests local winnowing under ephemeral turbulence. Glauconite indicates a relatively low rate of sedimentation but cannot be used to indicate depth. Cloud (1955) and Porrega (1967) have noted the wide range of temperature and depth conditions under which glauconite is forming today. The well-sorted accessory terrigenous fraction may well be of wind-blown origin. The presence of clinoptilolite and volcanic glass, as well as the angularity of grains, lends further support to an ash-fall or wind-blown origin.

Cenomanian-Maestrichtian Contact

The following features of the deposit at the Cenomanian-Maestrichtian boundary suggest special conditions of formation:

a. Apatite and goethite, uncommon in the limestone below, are concentrated in the pebble coatings.

b. Similarity between the calcarenite within the pebbles and the underlying Cenomanian limestone; similarity between the matrix around the pebbles and the overlying Maestrichtian.

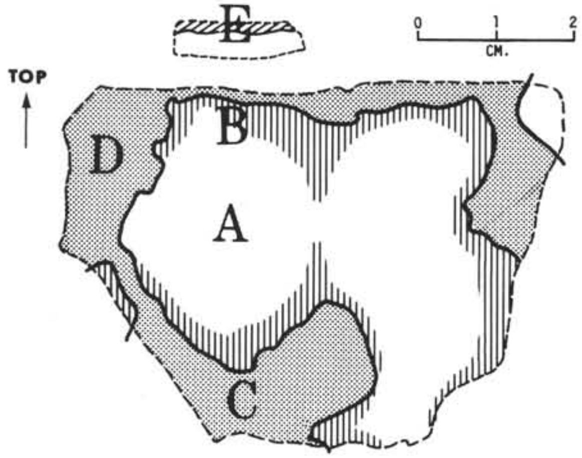
c. Concentration of large and varied terrigenous grains in the 'low energy matrix' around the pebbles.

d. Location of the deposit at a major hiatus.

Limestone nodules formed by submarine erosion of partially lithified sediment have been reported from a number of modern locations (Fischer and Garrison, 1967). The upper surface of lithified crusts associated with some of these nodules are discolored by a black or brownish stain of iron and manganese oxides.

Phosphatization of *Globigerina* ooze, followed by deposition of a ferruginous manganese crust with finely divided apatite has been reported from the Sylvania Guyot by Hamilton and Rex (1959). Bromley (1967) believes that phosphatic nodules coated with iron and manganese from a number of modern localities were phosphatized in shallower waters but received their iron and manganese coatings at a greater depth. This appears to be borne out by observations of the modern current-swept Blake Plateau where, in an area of no sedimentation, phosphate nodules are forming in shallow waters (approximately 200 to 400 meters) and are succeeded in deeper waters (approximately 400 to 800 meters) by manganese pavement and nodules (Pratt and McFarlin, 1966).

By analogy it appears that the nodular horizon on Orphan Knoll represents submarine lithification of Cenomanian calcarenite followed by phosphatization and accretion during the succeeding hiatus. The iron and manganese crust then formed when the area subsided into deeper water. The exact time of phosphatization cannot be determined because of the uncertain age of the fauna in the coatings (prisms and foraminifera) which differ from the



LEGEND	AREA	CHEMICAL ANALYSES Mn(PPM)	Fe(PPM)
CENTRE OF NODULE	*A*	180	12,500
COATING OF NODULE	*B*	723	105,000
MATRIX BETWEEN NODULES	*C*	880	29,800
BLACK "MANGANESE" CRUST	*D*	765	36,800
OUTLINE OF ROCK CHIP	*E*	1250	131,000

Figure 14. *Oriented sketch of the nodular limestone from the Cenomanian-Maestrichtian contact showing the distribution of iron and manganese in selected areas (Sample 12-111A-12-1, 3-7 cm). Sample E is a graphic representation of several small chips (total about 1 gm), each of which is coated with a thin black crust (up to 0.5 mm thick) on their upper surface. These chips were taken from the 'manganese' crust. See Plate 19 for photograph.*

Cenomanian fauna in the nodules. The matrix around the pebbles may be the same age or younger than the outside coatings of the pebbles. Its chalky nature probably reflects deposition under tranquil deeper conditions, the large and varied terrigenous grains having accumulated as a lag deposit during the preceding hiatus.

Comparative Stratigraphy

Eastern North America

Upper Cretaceous sediments are known from three test holes on the eastern Canadian continental margin (Howie, 1970). A relatively complete section is present in the Sable Island test on the Nova Scotian Shelf and one test on the Grand Banks southeast of Newfoundland (Grand Falls well). The 1610 meters of Upper Cretaceous sediments from the outer edge of the Nova Scotian Shelf appear to consist of mainly marine glauconitic terrigenous sand and shale with only minor limestone. The comparable section of 590 meters of Middle to Upper Cretaceous sediment on the Grand Banks have been investigated in more detail (Bartlett and Smith, 1971). Here, in the Cenomanian portion of the sequence, is gray glauconitic sandstone, shale, mudstone and minor coal, and this is separated from the remaining Upper Cretaceous by an unconformity. Overlying this unconformity are calcareous sandstones, with coarse rounded quartz grains, oysters and wood fragments which grade up into argillaceous and slightly glauconitic chalks, that in turn grade into argillaceous marls and dark gray mudstones at the top of the Upper Cretaceous. The third test hole (Tors Cove), also on the Grand Banks, penetrates an abbreviated Upper Cretaceous section above a Jurassic? diapir. This diapir is overlain by 16.5 meters of limestone of uncertain age that is succeeded by mudstone and marl deposits equivalent to the upper part of the Upper Cretaceous in the Grand Falls hole.

Greenland

In the Cretaceous section of eastern Greenland (Donovan, 1960), Albian and lower Cenomanian black shales and minor sandstones are overlain by upper Turonian sandstones and conglomerates. These coarse clastics, representing an important period of erosion, are succeeded by more coarse clastics with both marine animal and land plant fossils.

Western Europe

General. The boundary between the Upper and Lower Cretaceous in most of western Europe is marked by a profound lithologic change. The Lower Cretaceous (Albian and older) is dominated by glauconitic sandstones and shales deposited during the intermittent transgression following a long period of nonmarine deposition. The Upper Cretaceous (Cenomanian to Maestrichtian) is characterized by thick massive chalk deposits. Maestrichtian chalk is rare in England but small remnants are known from Ireland (Bennison and Wright, 1969).

The transgression at the beginning of the chalk deposition was initiated in the south and east (*op. cit.*). In the typical thick chalk succession of southern England, the youngest underlying greensands are late Albian in age. In the marginal facies to the west in Ireland, however, the lithologic change is transitional and the green sands range up into the Cenomanian and Campanian with extensive chalk deposition not occurring until late in the Campanian. These marginal facies contain many examples of erosion and nondeposition (Rayner, 1967).

Specific Examples. Several of the British areas exhibit features within the Upper Cretaceous lithologic succession that are pertinent to the sequence found at Orphan Knoll.

The Lower Chalk (Cenomanian) of southern England is a quartz-rich, glauconitic muddy chalk (*op.cit.*) in which the basal beds are conglomeratic and commonly contain phosphate nodules. Locally this Lower Chalk may contain abundant glauconite or grade into a thin calcareous sandstone.

In the base of the Middle Chalk (Lower Turonian) in southern England extensive hardgrounds are found (*op. cit.*). Many of these surfaces are glauconitized and phosphatized, a sequence of alteration that Bromley (1967) attributes to progressive shallowing over sea floor highs.

In northern Ireland (Hancock, 1961), the lowermost Cretaceous (Cenomanian) rests with marked unconformity on Jurassic to Triassic sandstones and clays. The lower Cenomanian is glauconitic calcarenite with gray marl matrix and scattered phosphate nodules. This sequence grades into the upper Cenomanian alternating hard and soft beds of gray, glauconitic, slightly sandy, argillaceous limestones. Succeeding Turonian time appears to have been a period of nondeposition and minor erosion. This unconformity is overlain by Senonian to Upper Campanian lithologies which grade from coarse sandstones at the base to sandy chalks at the top. Phosphatized shell fragments are common in the basal sands. These sands and chalks are in turn separated from the overlying Upper Campanian-Maestrichtian chalk by another unconformity which contains pebbles coated and impregnated with phosphate (Bromley, 1967). These conglomerates are locally derived and occasionally stained with manganese.

Clays in the English Chalk Sequence. Clays from the Upper and Middle Chalk (Turonian to Senonian) throughout south and east England are characterized by the dominance of montmorillonite and mica in subequal proportions (Weir and Catt, 1965). It is only in the less pure Lower Chalk (Cenomanian) that other clay minerals appear (Young, 1965). Detailed analyses of a borehole succession in Sussex by Young (*op.cit.*) indicates that clay minerals in the upper Cenomanian are mostly illite with minor chlorite and kaolinite and only trace amounts of montmorillonite. In the lowest Cenomanian montmorillonite and illite are again present in subequal amounts.

Analyses of the clays of the Maestrichtian, where present, could not be found in the literature. This is unfortunate because if the upward sequence of increasing purity of the Upper Cretaceous reported above were to culminate in a dominance of montmorillonite in the Maestrichtian, an interesting parallel with Orphan Knoll could be drawn. It will be recalled that clays from the Albian-Cenomanian samples of Orphan Knoll are illite with subsidiary chlorite, while the clay fraction of the Maestrichtian sample is montmorillonite.

Summary. Cenomanian sediments of the Canadian continental shelf and Greenland are mainly fine-grained glauconitic terrigenous clastics which are only occasionally calcareous and grade up into a dominantly mudstone-siltstone sequence. Despite difficulties in correlation due to the apparent lack of zonal control and small amount of published data, it appears that the lithology of these Cretaceous sections does not greatly resemble that of Orphan Knoll. In both of these areas, and at Orphan Knoll, however, there is an unconformity at the top of the Cenomanian succession which marks a significant change in deposition.

Although the present distance between localities is considerable, the Cretaceous lithological succession at Orphan Knoll shows marked similarities to the Cretaceous sequence of England and Ireland. However, prior to the late Cretaceous, Orphan Knoll was adjacent to the continental shelf of northwest Europe (see Chapter 20). The similarity between the Cenomanian glauconite-rich marls with hard and soft layers and capped by a phosphatized hardground both in Ireland and Orphan Knoll is striking. The approximate westward increasing time span represented by the unconformity at the top of the Cenomanian (full sequence in England; Turonian absent in Ireland; Turonian and Senonian absent at Orphan Knoll) suggests strong localization of deposition in western Europe after Cenomanian and gradual spreading of the chalk seas westward. The length of time represented by the unconformity at Orphan Knoll suggests that the Knoll was peripheral to this action.

In connection with the apparent lithologic similarities it is interesting to note that preliminary investigation of the pelecypods from the Upper Cretaceous of Orphan Knoll suggests that one of the identifiable forms is *Plicatula* cf. *guritis*. This "appears to be a European species without close allies among the Albian-Cenomanian *Plicatula* forms of the Atlantic and Gulf regions of North America" (Jeletzky, 1970).

PHYSICAL PROPERTIES

The physical properties are only defined fairly continuously in the interval 94 to 190 meters. Within this interval the measured parameters generally reflect the varied lithologies recovered in the cores, but care is needed in their interpretation since some low density values are due to highly disturbed cores, and the trend lines added to the density, porosity and impedance plots take this into account. Similarly low gamma counts occur in 111A-3-1 to 111A-3-3, 111A-5-1 to 111A-5-4 and 111A-8-2 due to disrupted cores.

The late Pliocene and Pleistocene glacial clays (1.75-2.0 gm/cc) exhibit increasing firmness with depth according to the penetrometer. Pebbles in the clays show up as sharp peaks on the GRAPE density plots. These clays have a high gamma activity mostly in the range 1800 ± 400 counts due to the large proportion of terrigenous material (less than 15 per cent carbonate according to twenty-one spot samples); but obvious decreases in activity occur in 111A-4-2, 111A-5-4, 111A-5-5 and 111A-6-2 where foraminiferal sands are encountered (the minimum at 111A-4-3 is of unknown origin since this section was not split). The sands also have a lower density (1.7-1.8 gm/cc) due to the hollow foraminiferal tests. An even sharper increase in gamma activity to 2000 counts occurs near the base of Core 111A-6 associated with a 10 to 15 per cent carbonate content of the creamy zeolitic clay containing phillipsite, according to laboratory measurements of Honjo at Woods Hole Oceanographic Institution (see Chapter 12). A similar narrow band of high activity (2000 counts) occurs at the base of 111A-7-6 coincident with a black clay suggesting that this too represents a hiatus in deposition. The underlying marls (1.55-1.65 gm/cc) continue to show high gamma activity (maximum 2300 counts), whereas, at their base the chalk oozes of Core 111A-11 (1.7-1.95 gm/cc) have very low activity due to their high carbonate content (greater than 93 per cent). These oozes increase in density, velocity and firmness downwards in the upper part of Core 11 indicating increasing lithification. The yellowish glauconitic sandy silt of 111-3-2 (2.2-2.4 gm/cc) lying at the base of this sequence has a maximum gamma count of 1700. Bands of dolomitic limestone within the silt are indicated by lower gamma counts of up to 1400.

Depth of Reflectors

It seems reasonable to correlate the main seismic reflector at Site 111 (0.29 second) with the hard layer encountered during drilling which proved to be a graded Bajocian sandstone. Of the other reflectors, the one at 0.21 second seems to result from the increase in impedance associated with the chalk ooze at about 180 meters, while that at 0.18 second might result from the change from higher density clays to lower density sands at 142 meters. These data are summarized in Figure 15.

PALEONTOLOGY AND BIOSTRATIGRAPHY

General

Stratigraphic units recovered include glacial Pleistocene and Pliocene, preglacial Pliocene, Upper Miocene, Eocene, Maestrichtian, Cenomanian, Albian and Middle Jurassic (Bajocian). The site bottomed in carbonaceous coarse sands and sandy clays of Middle Jurassic (Bajocian) age; these are believed to be of continental origin. Among the significant results obtained from a preliminary examination of the cores at this site are the following:

1. The contact between glacial/preglacial sediments cored (111A-6-2). A tentative date of mid-Pliocene (*ca.* 3 million years B.P.) has been determined (on the basis of micro-paleontologic analysis) for the age of initiation of glaciation in the North Atlantic.

2. A complete stratigraphic sequence from Upper Miocene to Upper Pliocene (*ca.* 5.5 to 2.8 million years) is preserved in a glauconitic chalk sequence containing a tropical to subtropical microfaunal and floral assemblage. Extremely low sedimentation rates—on the order of 0.04 cm/1000yrs.—have been calculated for this carbonate interval.

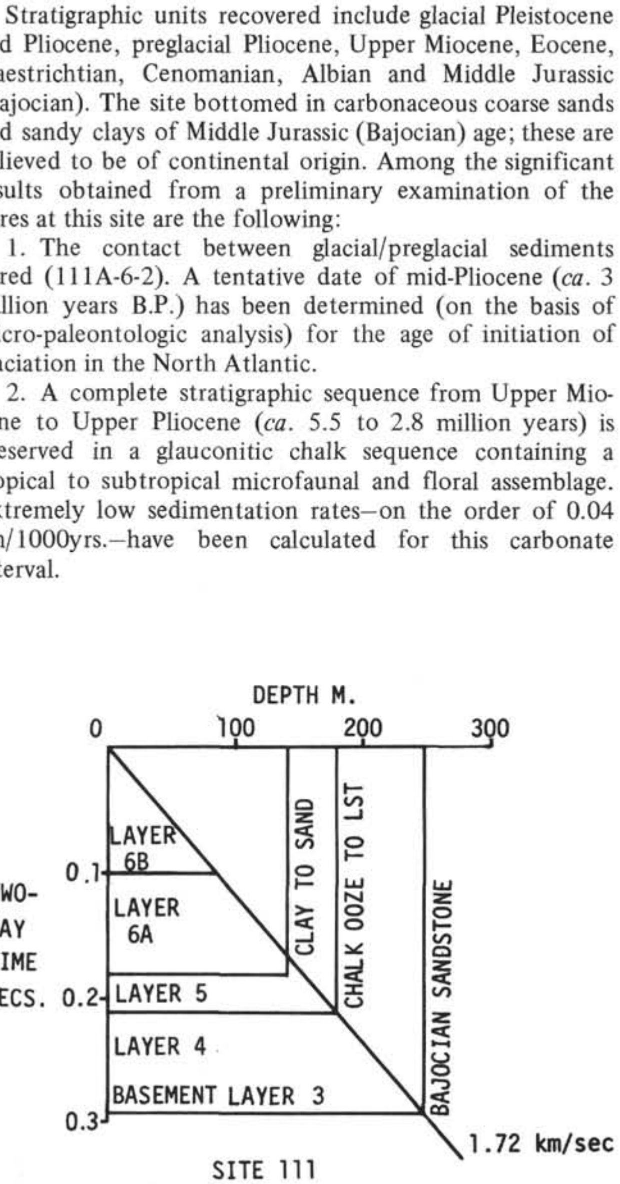


Figure 15. *Two-way travel times below the sea-bed of observed reflections plotted against the downhole depth of horizons believed to have given rise to these reflections. The mean velocity to the deepest reflection associated with a definite depth is given close to the line representing this velocity.*

3. A significant unconformity occurs between Upper Miocene glauconitic chalk and Upper Eocene zeolitic clays (111A-6-3). The unconformity is marked by a 2-centimeter band of glauconite at the contact. The Eocene is represented by a sequence of yellowish zeolitic clays which contain glauconite and hematite grains.

4. An abrupt change in lithology from Lower Eocene zeolitic clays to cream-colored pelagic oozes of Maestrichtian age occurs between Core 10 and 11 in Hole 111A. Although the presence of some Paleocene sediments is suspected, none were recovered.

5. A marked unconformity exists between Lower Maestrichtian chalks and Cenomanian glauconitic calcarenites (111-3).

6. Hole 111 terminated in carbonaceous coarse gray sands and sandy clays of Middle Jurassic age (see separate report on palynological dating of this material).

Significant paleontological aspects of the marine Cenozoic and Mesozoic units which were recovered will be discussed below.

Discussion

Cenozoic Foraminifera

In hole 111, two cores were recovered from the Pleistocene (Core 1: 0 to 5 meters; Core 2: 94-103 meters). Hole 111A was cored continuously from 105 to 199 meters. Cores 1 (105 to 114 meters), 2 (114 to 120 meters), and 3 (120 to 125 meters) are of Pleistocene age. The boundary between the Pliocene and Pleistocene is placed between Core 1 and 2 in Hole 111A.

The Pleistocene foraminiferal assemblages of Cores 1 and 2 in Hole 111 and of Cores 1, 2 and 3 in Hole 111A are characterized by sparse, relatively low diversity faunas containing *Globigerina bulloides*, *G. pachyderma* and *Globorotalia inflata*. *Globigerina pachyderma* is predominantly dextrally coiled in the three cores from the lower part of the Pleistocene in Hole 111A, and predominantly sinistrally coiled in the two younger cores in Hole 111. This tendency toward predominantly dextral coiling in the lower part of the Pleistocene and predominantly sinistral coiling in the younger parts of the Pleistocene is a trend which is repeated at several of the other sites in the North Atlantic. *Globorotalia truncatulinoides*, *Globoquadrina dutertrei*, and *Globigerinoides conglobata* occur in some of the samples as accessory species. Most of the samples contain glacially rafted detritus (quartz and various igneous and metamorphic minerals), and the presence of *G. sacculifera* and even *Pulleniatina obliquiloculata* (111-2-5, 117 to 118 centimeters) is indeed anomalous.

Characteristic benthonic foraminifera include: *Eggerella bradyi*, *Sigmoilopsis schlumbergeri*, *Pyrgo murrhyna*, *Pyrgo lucernula*, *Uvigerina hollicki*, *Uvigerina peregrina*, *Eponides tener*, *Eponides umbonatus*, *Melonis pompilioides*, *M. barleeanum*, *Gyroidina neosoldanii*, *Hoeglundina elegans*, and *Planulina bradii*.

The Pliocene/Pleistocene boundary was determined on the basis of the extinction of discoasters between Core 3 and 4 (*ca.* 125 meters) in Hole 111A. It is probable that the entire Pliocene is represented by the stratigraphic interval between 125 meters (between Cores 3 and 4) and *ca.* 146.5

meters (within Section 3, Core 6, Hole 111A). Cores 4 (below Section 1, 126.5 to 134 meters), 5(134 to 143 meters), and a part of Core 6 (143 to 152 meters) are of Late Pliocene age and consist, as above, of dark gray sandy clays with abundant ice-rafted debris. At 145 meters (within Core 6, Hole 111A) an abrupt change in lithology occurs from glacially transported sands and clays (above) to a cream-colored glauconitic ooze composed of planktonic foraminifera and coccoliths. A rich planktonic foraminiferal fauna containing numerous tropical-subtropical elements (*Globorotalia miocenica, G. multicamerata, G. limbata, G. tumida, Sphaeroidinellopsis seminulina, S. subdehiscens, Globoquadrina altispira*) occurs in this ooze. By plotting the known ranges of these forms against the paleomagnetically derived time-scale it is possible to estimate the approximate age of this boundary at about 3 million years B.P. Thus we have for the first time an independent estimate for the age of the initiation of glaciation in the North Atlantic region based on microfaunal evidence.

Because of the unique occurrence of Late Miocene and Pliocene tropical and subtropical marine planktonic foraminiferal species at this high latitude (54°N) and the strongly condensed nature of the stratigraphic sequence, Core 6, Hole 111A has been studied in somewhat greater detail than is normal for the initial reports. The stratigraphic distribution of various taxa in Core 6 is shown in Appendix D of this chapter. The dominant faunal element throughout Core 6 is *Globigerina atlantica*. This large robust granular-textured form has been found to be the dominant element in all Late Miocene and Pliocene cores taken in the North Atlantic on Leg 12. A marked diminution in diversity is seen in the upper part of Core 6 (Sections 1 and 2) following the initiation of glaciation in the Labrador Sea. *Globigerina atlantica* continues upwards with *Globigerina bulloides* and *Globorotalia inflata*. *Globigerina pachyderma* appears in minor quantities in the earliest glacial sediments of Late Pliocene age. However, it does not assume a quantitatively significant distribution until near the Pliocene-Pleistocene boundary, at which time it appears to replace *Globigerina atlantica*. This situation has been observed repeatedly at various sites in the North Atlantic. Core 5(134 to 143 meters) in Hole 111A consists predominantly of ice-rafted detritus. However, various anomalous faunal elements such as several species of the genus *Globigerinoides*, as well as *Globorotalia miocenica* and *Globorotalia exilis* occur in some of the samples from this core. These samples may indicate a return to moderately mild conditions in the Late Pliocene. Reworking of older material does not appear feasible inasmuch as none of the quantitatively more abundant tropical-subtropical planktonic species, which became extinct at or near the contact between glacial and preglacial sediments occur here in Core 5. On the contrary, *Globorotalia miocenica, Globorotalia exilis* and *Globigerinoides obliqua* are known to range up to the Pliocene/Pleistocene boundary in tropical regions. It is likely that the occurrences of these forms in Core 5 represent temporary incursions into this region of warmer waters, and that their absence in younger horizons is due to increasing severity of the climate in the Labrador Sea.

The Miocene/Pliocene boundary has been determined in 111A-6-3, at about 66 to 68 centimeters based on the nearly simultaneous disappearance of *Globoquadrina dehiscens* and the first appearance of *Globorotalia tumida*. *Globorotalia conomiozea* and *Globorotalia conoidea* appear to have become extinct at about the same level in this hole, although a sporadic occurrence of *G. conoidea* was observed in the lower part of Section 2 at a level about 3 to 3.2 million years old (see Figure 16). Sinistrally coiled *Globigerina atlantica* appears in abundance near the Miocene/Pliocene boundary as well.

A diverse benthonic foraminiferal fauna occurs throughout the Late Miocene and Pliocene preglacial glauconitic chalks but does not extend above 111A-5-5, 144 to 145 centimeters. Common faunal elements here include *Cibicidoides pseudoungeriana, C. cicatricosa, C. robertsoniana, Laticarinina halophora, Reussella simplex, Cassidulina subglobosa*, and most of the species mentioned above as occurring in the Pleistocene. The significant differences are that whereas the benthonic foraminifera are common in the Late Miocene to mid-Pliocene they are sporadic to rare in the Late Pliocene and Pleistocene glacial sequence. Sediments of late Middle to Early Eocene age are present in the lower part of Core 6; Cores 7 (152 to 161 meters), 8 (161 to 164 meters), 9 (164 to 173 meters), and 10 (173 to 182 meters) are of Early Eocene age. Only partial recovery was achieved in Core 10, and Core 11 contains hard calcareous ooze of Maestrichtian age. The lower part of Core 6 and Cores 7 through 10 contain an apparently exceedingly condensed section of Middle and Lower Eocene zeolitic clay sediments. Planktonic foraminiferal faunas suggest that the lower part of Core 6 may be of Middle Eocene age, whereas, calcareous nannoplankton suggest that Upper Eocene is present immediately below the disconformity at 111A-6-3, 90 to 92 centimeters. Cores 8 through 10 are of Early Eocene age and contain several species of *Acarinina, Pseudohastigerina wilcoxensis, Globigerina patagonica*, and *Globorotalia subbotinae*. Of perhaps greater interest here is the benthonic foraminiferal fauna which exhibits a pronounced similarity to that occurring in Lower Eocene sediments of northwestern Europe. Such forms as *Vaginulinopsis decorata, Anomalinoides acuta, Anomalinoides grosserugosa, A. limbata, A. praespissiformis, Cibicidoides acutimargo, C. hercegovinensis, Gaudryina* sp. cf. *G. hiltermanni, Nuttallides truempyi, Oridorsalis ecuadorensis* and *Osangularia pteromphalia* have been found. The benthonic forms listed above are characteristic of relatively deep water facies in the Early and Middle Eocene of northwestern Europe. Several elements occur in the Mediterranean region as well. The relatively rich planktonic foraminiferal fauna, the presence of the benthonic forms listed above, including various species of *Stilostomella*, indicate that Orphan Knoll lay at considerable depth (bathyal) during the Early Eocene (comparable to its present depth, perhaps), and suggests that the major sinking of Orphan Knoll occurred during Paleocene time.

Mesozoic Foraminifera and Ostracoda

General

The Mesozoic section at Site 111 consists of three distinct stratigraphic units:

(1) Maestrichtian outer neritic foraminiferal ooze or chalk;

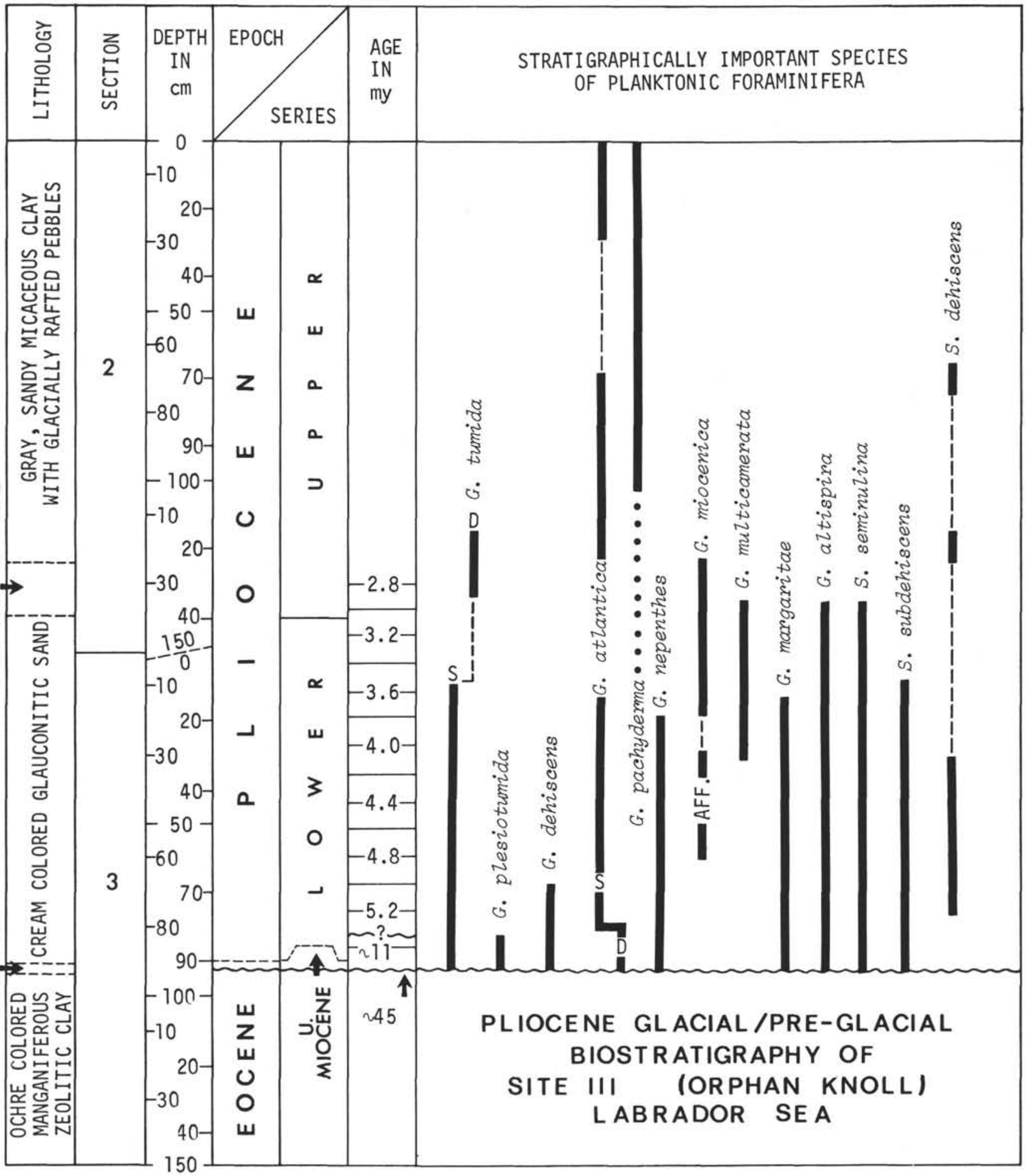


Figure 16. *Pliocene glacial/pre-glacial biostratigraphy of Site 111 (Orphan Knoll) Labrador Sea. (Core 6, sections 2 and 3).*

(2) Cenomanian/Albian shallow marine sandy carbonate–calcareous sandstone;

(3) Bajocian nonmarine sandstone, conglomerate and shale.

Cores 3, 4, 5 and 6 of Hole 111 are Cenomanian/Albian in age; Core 7 at the bottom of this hole is Middle Jurassic. In Hole 111A the Maestrichtian chalk was recovered in Core 11, and the Cenomanian/Albian was found in Core 12 (Figure 17).

Contacts

The top of the Mesozoic was not recovered. Core 10 of the second hole is entirely of Early Eocene age, whereas all of the immediately succeeding core, 11, is Maestrichtian.

Cores 10 and 11 do not have 100 per cent recovery. If all of Core 10 is shifted toward the top of the core barrel and all of core 11 is shifted toward the bottom of its core barrel, a gap of 5.4 meters is left between the two cores. This is the maximum thickness of unrecovered section; the minimum unrecovered section is zero meters, in that case the contact between the two units lies exactly at the base of Core 10. Extrapolating a minimum Early Eocene sedimentation rate (0.5 cm/1000 y) over the maximum gap (5.4 meters), one can conclude that the oldest possible sediment overlying the Maestrichtian is latest Paleocene. Late Paleocene faunal elements were found in the water collected from the core barrel at the base of 111A-10, whereas Maestrichtian foraminifers were found as contaminants in the core-catcher sample of Core 10. For these reasons the uppermost Paleocene can be considered to be present, but it is almost certain that Middle and Lower Paleocene are absent.

The contacts between the three Mesozoic units were not recovered. Examinations of water from the core barrels, the presence of a hardground, and the drilling rate records all suggest that the three units are in unconformable contact with one another and that no other Mesozoic stages are represented in the column.

The seismic records indicate that the Maestrichtian-Cenomanian contact is a disconformity whereas the Cretaceous-Jurassic contact is an angular unconformity. The Cretaceous-Jurassic contact has been drawn immediately above Core 7, because at that level a break in drilling rate occurred.

It seems reasonable to assume a sedimentation rate close to 1 cm/1000 yrs for the Cenomanian shallow marine sediments. This seems to be confirmed by the 15 meters representing the oldest part of that stage (possibly about 2 million years). Down section the amount of clastics increases, and sedimentation rates probably are higher. On this basis one could estimate that the Cretaceous, immediately overlying the Jurassic, is about 6 million years older than the beginning of the Cenomanian (or end of the Albian) and is of Early Albian age.

Unfortunately, it was technically impossible to drill below the Jurassic of Core 7, but the presence of immature reworked Upper Paleozoic elements in this core strongly suggests that the Jurassic, in its turn, unconformably overlies Paleozoic sediments.

Maestrichtian

Hole 111: Water sample from barrel of Core 3 (189 to 198 meters); small sample scraped off core liner above recovered Core 3; small sample of soft material collected from between hardened parts of the top of Core 3.

Hole 111A: Core 11 (182 to 190 meters), recovery 7.8 meters.

All normally recovered Maestrichtian consist of a uniform white foraminiferal ooze or chalk. No contacts with other units were recovered. Combining the data from both holes, the total thickness of the Maestrichtian cannot exceed 19.5 meters and probably is close to the 7.8 meters recovered.

The microfauna is very rich in planktonic and benthonic foraminifera; the planktonics outnumber the benthonics in number of specimens. Ostracods are very rare. Among the benthonic foraminifera, the "classic marker genera" *Stensiöina, Bolivinoides, Neoflabellina* and *Osangularia* are present and make possible the recognition of zonations made in temperate areas. At the same time the presence of both single and double-keeled globotruncanids together with *Rugoglobigerina* and Heterohelicidae, as well as *Pseudotextularia elegans* (incl. *fructicosa*) allows for detailed correlation with tropical planktonic foraminiferal zonations. Although many planktonic foraminifera are present, their morphology is not as voluptuous as in the Tethys, which suggests that the water was somewhat cooler than in tropical areas.

The top of the recovered ooze is of Late Maestrichtian age (*Globotruncanella mayaroensis* Zone). The very latest Maestrichtian may be absent; the reduction in globotruncanids and relative increase of rugoglobigerinids and heterohelicids found in sections of that age elsewhere is not recognizable here. The base of the recovered section is of Early Maestrichtian age (*Globotruncana gansseri* Zone). In Figure 17 the range of age diagnostic fossils is given. For two samples a specimen count was made using a sample-split on fractions coarser than 150 microns. This yielded the following results. In Sample 111A-11-1, 137 to 140 centimeters, 1530 planktonic foraminifers were counted against 94 benthonics, giving a plankton/benthos ratio of 16, or 94 per cent plankton. Continued collecting of benthonic foraminifers and of ostracods lead to a total of 194 (98 per cent) and 4 specimens, respectively: a benthonic foraminifer/ostracod ratio of 48.5. The total foraminifer/ostracod ratio is close to 800. The 194 specimens of benthonic foraminifera represent 33 species; the most dominant species (a gavelinellid) makes up less than 10 per cent of the fauna.

In Sample 111A-11-6, 147 to 150 centimeters, the following results were obtained: plankton/benthos ratio (1330/170) of 7.8 i.e. 88.7 per cent plankton. The benthonic foraminifer/ostracod ratio (276/9) is 30.6 i.e. 97 per cent foraminifers. The total foraminifer/ostracod ratio is 341. The number of benthonic foraminiferal species is twenty-seven, the dominant one (*Osangularia*) does not exceed 10 per cent of the fauna.

These data suggest that the upper sample represents outer neritic or upper bathyal deposition (200 to 500 meters), whereas, the lower sample probably was somewhat shallower (150 to 350 meters).

The unconformities above and below suggest that long periods of nondeposition followed (13 million years) and preceded (30 million years) deposition of the Maestrichtian on Orphan Knoll. Apparently, during part of the Maestrichtian, current velocities decreased and permitted deposition. Analogous with the Pliocene, higher at this site, one could speculate that a period of cooling caused this significant but temporary change in the circulation of the ocean water. This would be in agreement with paleotemperature data as compiled by Lowenstam (1954) for the Late Cretaceous.

Cenomanian

Hole 111: Core 3 (189 to 198 meters) recovery 1.7 meters; Core 4 (198 to 204 meters) recovery 0.12 meters.

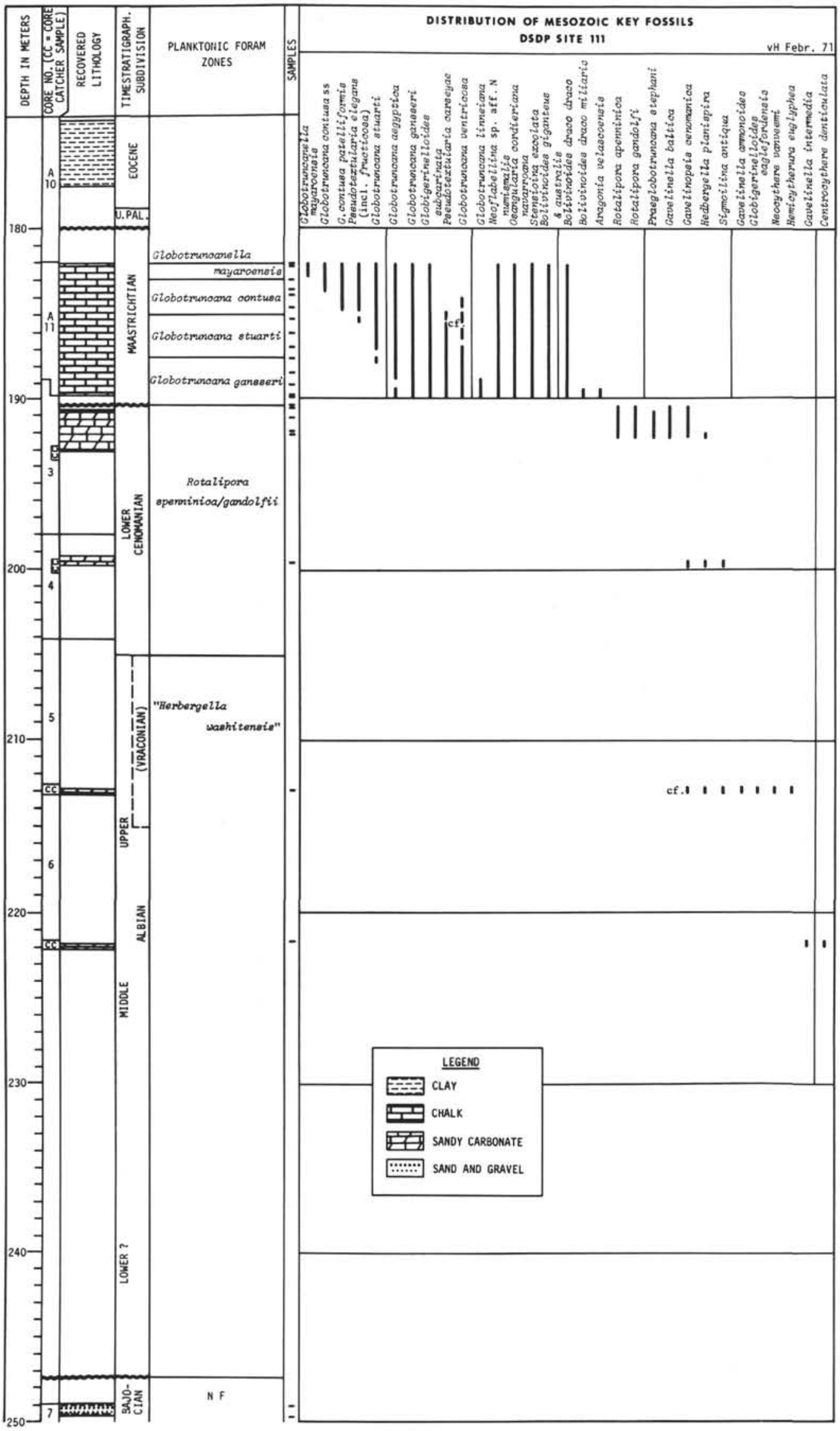


Figure 17. *Selected species of foraminifera and ostracods used in age determination of Mesozoic cores at Site 111.*

Hole 111A: Core 12 (190 to 199 meters) recovery 0.5 meters, fragments only.

The top of the Cenomanian sandy limestone as recovered in Core 3 is a hardground covered by a manganese crust. Small patches of material from the core barrel above it yielded Maestrichtian and younger fossils as did the sediment from a water sample collected from the barrel when opened. A sample from the soft material in between the hardened parts at the top of the core yielded Cenomanian and Maestrichtian fossils. No Campanian, Santonian, Coniacian or Turonian faunal elements were found. It is practically certain that the top of the Cenomanian as seen in Core 3 is actually the top, and that Maestrichtian is directly overlying it.

The planktonic foraminiferal fauna with *Rotalipora apenninica* (Renz) and *Rotalipora gandolfii* Luterbacher and Premoli Silva is characteristic for the Lower Cenomanian. Specimens are relatively small and not well developed. Their preservation is white and chalky; also, many specimens are present as glauconitic casts. *Hedbergella* sp. cf. *H. delrioensis* (Carsey) is common and *Praeglobotruncana stephani* (Gandolfi) is rare.

The benthonic foraminiferal fauna is dominated by the NW European marker *Gavelinopsis cenomanica* (Brotzen). Other forms present are *Gavelinella baltica* Brotzen, a few arenaceous species, rare miliolids, some other calcareous forms, and undeterminable glauconitic casts.

The ostracod assemblage is similar to the one figured by Oertli (1963) as typical for the French Cenomanian.

The microfauna as a whole is the same as described from NW Europe, at least in the preliminary investigation no endemic elements were encountered. Because of the solution of tests and casting with glauconite, quantitative data on the core should be considered with caution. Nevertheless, a general idea can be obtained from the material; some results of countings are presented below.

The uppermost sample (taken from between the hardened pieces at the top of Core 3) yielded 51 foraminiferal specimens of which 36 (70.5 per cent) are planktonic. A crushed sample of the hard fragments yielded 30 planktonics (86 per cent) and 5 benthonics.

The softer material lower in the core provided more and, in part, better preserved specimens and therefore results are more reliable. Of 605 benthonic foraminifers and 239 planktonic foraminifers (28.3 per cent of all foraminifers) 104 ostracods were found (11 per cent of foraminifera plus ostracods) in sample 111-3-2, 14 to 17 centimeters. Of the benthonic foraminifers, 582 are calcareous and 123 are arenaceous, and a total of 18 different species is present. *G. cenomanica* dominates the fauna (65 per cent) followed by *Gavelinella baltica* (7.4 per cent), *Marsonella trochus* (d'Orbigny) (5.3 per cent) and *Textularia* sp.; *Gaudryina* spp. and *Arenobulimina* sp. account for another 14.7 per cent. For sample 111-3-2, 135.5 to 138 centimeters, these numbers are comparable. Here a total of 16 benthonic species was found, and *G. cenomanica* dominates with 57 per cent.

The above data and the presence of oysters, echinoderms, coproliths, gastropods, and miliolids suggests deposition in shallow water, probably inner-middle neritic (shallower than 100 meters), and cool.

Of Core 4 the core-catcher sample is the only sample available for study of free specimens. A total of 17 foraminifers was collected from the hard limestone after it was crushed; five of these (29 per cent) are planktonic. *Gavelinopsis cenomanica* dominates the benthonic fauna with 50 per cent. Most specimens are glauconite casts, a few *Gavelinopsis* specimens still have their test, but it is strongly recrystallized. The material is too poor to say more than that it is probably an impoverished form of Core 3.

Albian

Hole 111: Core 5 (204 to 213 meters) core-catcher sample; Core 6 (213 to 222 meters) core-catcher sample.

It is most unfortunate that the only materials recovered from this interesting part of the stratigraphic section are the core-catcher samples.

Crushing of the hard sandy limestone fragments of Core 5 yielded a small, but age-diagnostic microfauna. Here, 180 foraminifera and 17 ostracods were collected.

The planktonic foraminiferal fauna has two species only: *Hedbergella planispira* (Tappan) and *Globigerinelloides eaglefordensis* (Moremann) (= *Planomalina caseyi* Bolli, Loeblich and Tappan from the British Gault). The 30 specimens (17 per cent of the total foraminiferal fauna) are relatively well preserved.

The benthonic foraminiferal fauna is dominated (33 per cent) by a *G. cenomanica–Gavelinella intermedia* (Berthelin) transitional form. The next most frequent species is *Arenobulimina presslii* (Reuss) with 9 per cent. Approximately24 different species are present; 15 per cent of this benthonic foraminiferal fauna is arenaceous.

The ostracod assemblage (11 per cent of benthonic foraminifers and ostracods) is very characteristic, despite the fact that many specimens were broken in the process of crushing the rock. Present are the Albian forms *Neocythere vanveeni* Mertens, *Hemicytherura euglyphea* Kaye, *Cytherelloidea btaterensis* Bischoff, *Alatacythere robusta langi* Kaye, and *Isocythereis* sp. and a *Cythereis* resembling *Cythereis reticulata* Jones and Hinde.

Planktonic and benthonic foraminifers as well as ostracods indicate an Albian age. The foraminiferal assemblage is very similar to the one found in the uppermost Albian (Vraconian) in its type region in France ("Marnes de Brienne"). The fauna also shows affinities with the Grayson Formation of Texas. *Cytherelloidea btaterensis* has been described from the Middle East, but all the other ostracods are found in the Northwest European (British) Albian.

The depositional environment of the sediments of Core 5 probably was cool shallow marine, inner to middle neritic (less than 100 meters water depth).

All that was recovered from Core 6 are a number of hard pieces of sandy limestone in the core catcher. Thin sections did not reveal any age-diagnostic information, but fossils could be collected from crushed material. Although only 5 foraminiferal and 3 ostracod specimens are found, the presence of *Gavelinella intermedia* (Berthelin) and *Centrocythere denticulata* Mertens is sufficient to conclude that the core is of Late or Middle Albian age. Other foraminifera present are *Valvulineria* sp. and *Lenticulina* sp., and one specimen of the ostracod *Cytherella* was found. This fauna most probably lived in very shallow marine water (inner neritic and not deeper than 30 meters).

Jurassic

Core 7 (249 to 250 meters) of Hole 111 did not yield foraminifera or Ostracoda. The age of the core was determined by means of spores and pollen and is reported separately.

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Calcareous Nannoplankton

With the exception of a few samples of the glacial clays, Pleistocene and Late Pliocene, Early Cretaceous and the continental? sandstone at the bottom of Hole 111, all samples at Site 111 contained coccoliths.

Pleistocene

The only sample from Core 111-1 contains a fairly rich assemblage of coccolith species still living in the North Atlantic. The presence of *Emiliania huxleyi* could not be proved by SEM studies on this sample, however, the core is believed to belong in the *E. huxleyi* Zone or high in the *Gephyrocapsa oceanica* Zone. *Gephyrocapsa oceanica, G. aperta, Helicopontosphaera kamptneri, H. sellii, Umbilicosphaera mirabilis, Scapholithus fossilis, Aspidorhabdus stylifer, Pontosphaera scutellum, Emiliania huxleyi* (?) and *Coccolithus pelagicus* were found. Several varieties of *Coccolithus pelagicus* appear: one with a small central opening. The small plates covering the central area are arranged in concentric ellipses, and the elements of the distal shield are rounded.

Most other Pleistocene cores (111-2, 111A-1, 2, 3 and upper part of 4) contain a poorer assemblage than the one described above. However, foraminiferal sand intercalations in the glacial clays show the same assemblage, including also *Pseudoemiliania lacunosa*, but lacking *Emiliania huxleyi* and *Gephyrocapsa oceanica*. In Cores 111-2 and 111A-1, another variety of *Coccolithus pelagicus* with a cross spanning over the central opening occurs. This form might be assigned to *Cruciplacolithus neohelis. Cyclococcolithus macintyrei* is only present in the foraminiferal sand layers that are believed to represent warmer times in the glacial cycles.

Pliocene

The youngest discoasters were found together with the youngest ceratoliths in Sample 111A-4-2, 11 centimeters, in a foraminiferal sand intercalation in the glacially-rafted clays and silts. In this sample, the only discoaster present is *Discoaster brouweri*. It was therefore assigned to the *D. brouweri* Zone. The Pliocene/Pleistocene boundary is drawn between this sample and the sample just above, in which discoasters are absent. The absence of discoasters in the overlying samples may be due to the dilution effect of the glacial material, where the coccolith content is very small and discoasters even more unlikely to be detected. The Pliocene/Pleistocene boundary, therefore, may have been set too low. This is also indicated by the presence above this boundary of *Cyclococcolithus macintyrei* which, in lower latitudes with little or no glacial deposits, seldom occurs in the Pleistocene.

The Pliocene in Hole 111A occurs in two main lithologies: glacially-rafted clays and silts and foraminiferal sands, the latter as intercalations in the glacial sequence and at the base of the Miocene-Pliocene sequence. In the clays, coccoliths are rare or missing, and discoasters are very rare, missing, or represented only by fragments. The foraminiferal sands contain a richer flora, however, discoasters represent far less than 1 per cent of the total flora. Thus, the assignment to the current zones within the Pliocene must be considered tentative, as it is based mainly on discoasters and ceratoliths, that also are rare.

Two species, *Sphenolithus abies* and *Reticulofenestra pseudoumbilica*, disappear at the onset of glaciation (a smaller, similar form to *R. pseudoumbilica*, however, continues). This indicates their dependence on better conditions than those indicated at the beginning of the glaciation. As the latest occurrence of *R. pseudoumbilica* is used for the definition of the upper boundary of the *R. pseudoumbilica* Zone. This means that this boundary is probably younger in areas where the influence of the glaciation came later. (This may be true for most of the zones from the Miocene to the Pleistocene whether based on first or last occurrences!)

In Figure 18 the distribution of the most important species is listed. The assemblages of the other samples are given in the core summary sheets at the end of the chapter on Site 111.

The zones distinguished in 111A-6-2 and 3 in the Pliocene (see Figure 19) are represented only by tens of centimeters of sediment each. The thickness of the interval from the top of the *Discoaster quinqueramus* Zone to the top of the *Reticulofenestra pseudoumbilica* Zone measures 70 centimeters which is comparable to the section on the Blake Plateau (Gartner, 1969), where the same interval is represented by *ca*. 250 centimeters. The figures for the interval from the top of the *R. pseudoumbilica* Zone to the top of the *Discoaster brouweri* Zone are *ca*. 1500 centimeters for Site 111 and 100 centimeters for the Blake Plateau. The sedimentation rates in the Blake Plateau core were almost the same during the Pliocene and most of the Pleistocene (the Late Pleistocene is missing), while on Orphan Knoll, it was extremely low before the onset of glaciation about 3 million years ago. The figure for the glacial part of the Pliocene is probably composed of the higher sedimentation rate in the glacial clays and of a lower rate for the foraminiferal sands. In the Pleistocene, where probably fewer foraminiferal sands are intercalated, the sedimentation rate mounts to a figure otherwise attained by turbidites or contour current sedimentation.

Miocene

The Miocene is represented by 30 centimeters of glauconitic, greenish to light gray ooze. The Miocene-Pliocene boundary has been placed at the top of the *Discoaster quinqueramus* Zone, defined by the last occurrence of this species. Also present is the *Discoaster*

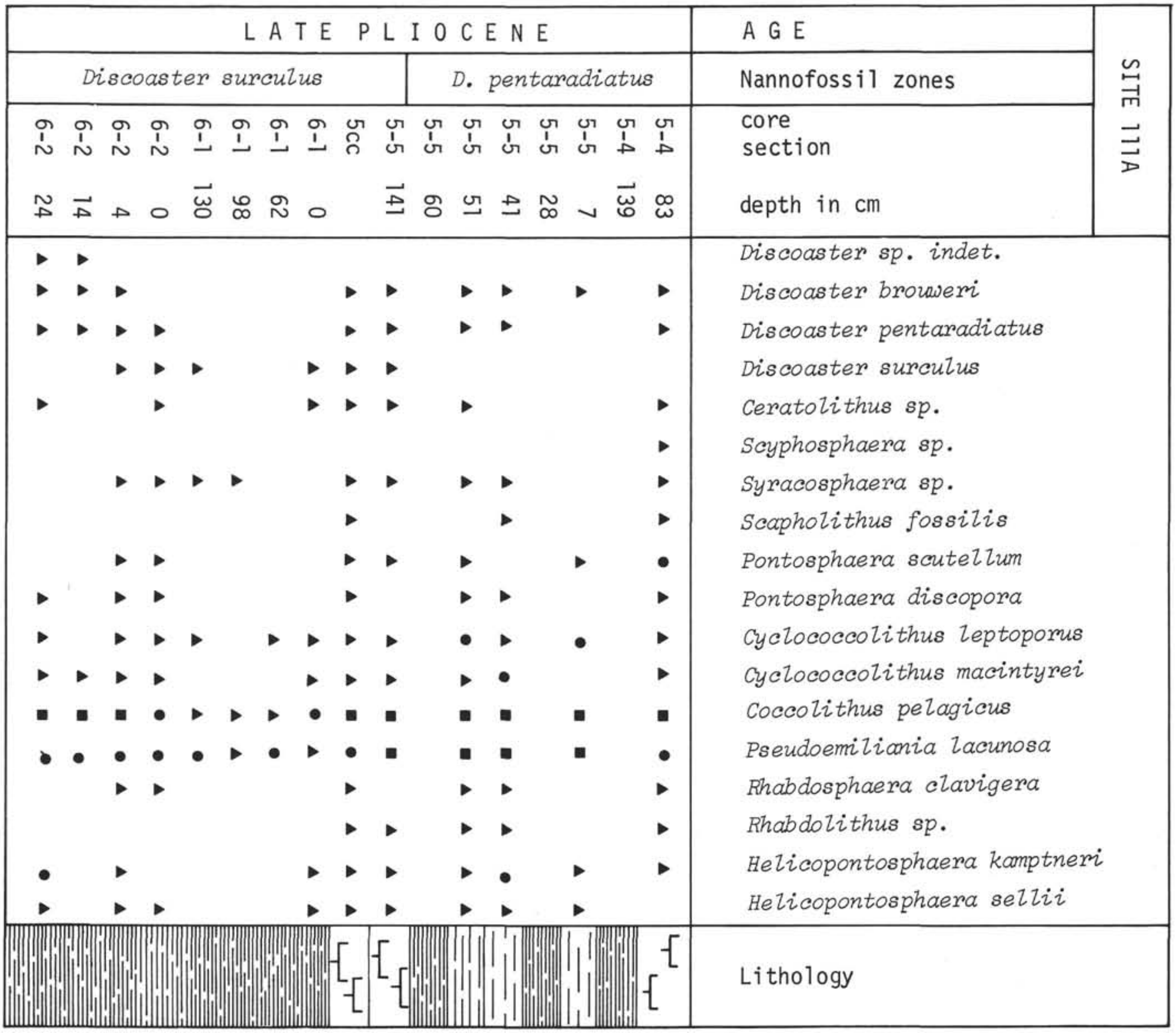

Figure 18. *Distribution of calcareous nannofossils in glacial Late Pliocene of Site 111. The flora is richer in the foraminiferal sand intercalations and the lighter clays, where the calcium carbonate content is higher than in the dark gray clays. The dark clays in the lower part of the section are richer than those in the higher part.*

neohamatus Zone, while the assignment of the lowermost sample above the underlying Late Eocene sediments to the *Discoaster hamatus* Zone is questionable.

The assemblages are listed in the graphical core summaries and the stratigraphically important species in the appendix. Compared to the Pliocene assemblages they show more abundant discoasters and include *Triquetrorhabdulus rugosus*. Although *Catinaster coalitus* was not found, a few specimens of *Catinaster calyculus* were detected in the lowermost Miocene sample (111-6-3, 88 centimeters). This is a further reason to assign this sample to the *D. hamatus* Zone, as *C. calyculus* is typical for the Middle Miocene, as well as *Discoaster bollii* which also occurs in this sample. With the assumption of 11 million years for the top of the *Discoaster hamatus* Zone, the rate of sedimentation in the Late Miocene has been only 0.005 cm/1000 years.

Eocene

Eocene sediments are separated from the Miocene ones only by a glauconitic layer, about 2 centimeters in thickness. No reworking seems to have taken place from the Eocene into the Miocene.

In the uppermost 10 centimeters of Eocene, *Isthmolithus recurvus* occurs together with *Discoaster saipanensis* and a sphenolith similar to *S. predistentus*, indicating a Late Eocene age for those samples. In the next 10-centimeter interval, another zone is represented. The assemblage of Middle Eocene age lacks all the forms that can be used in

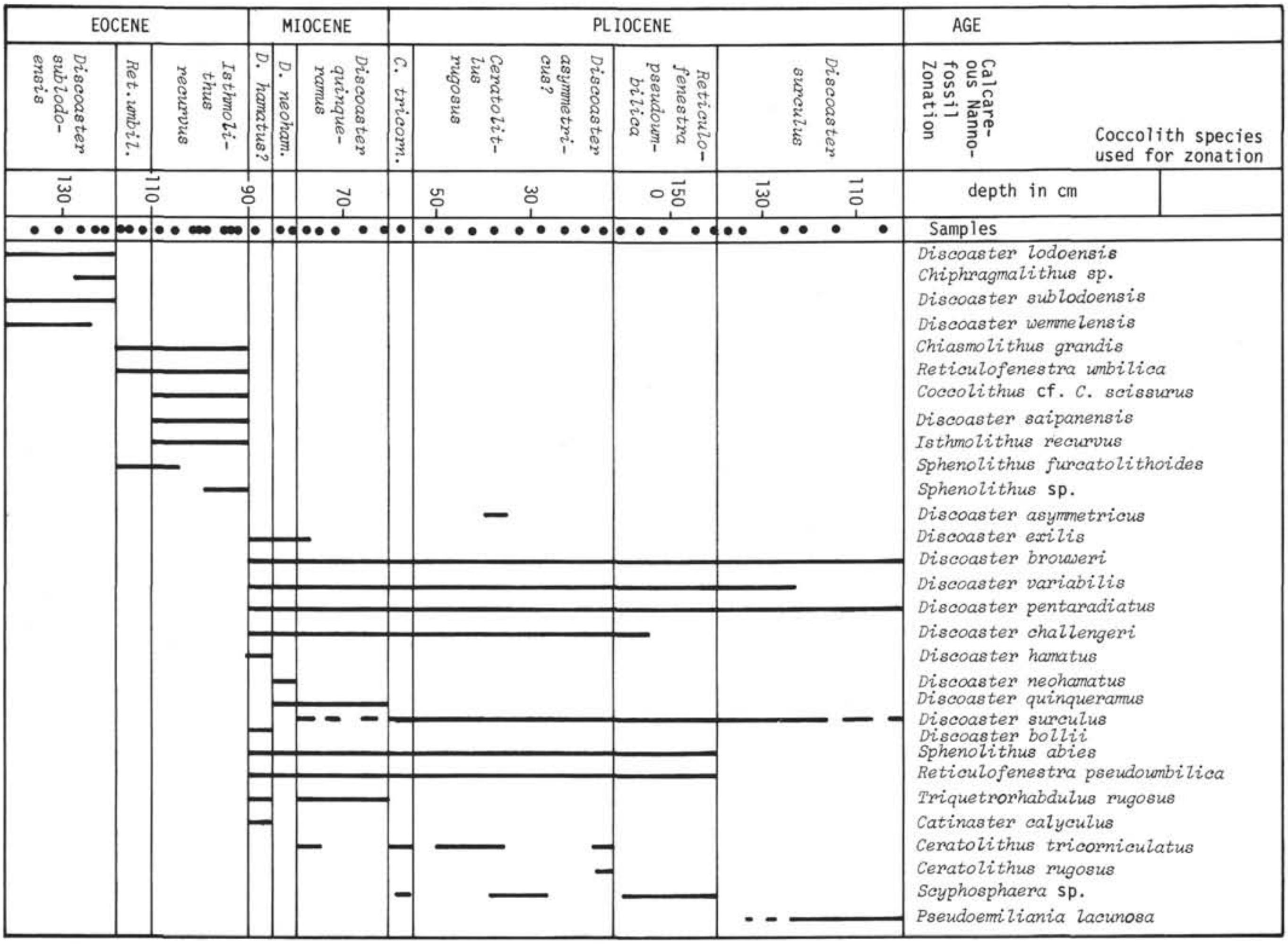

Figure 19. *Distribution of calcareous nannofossils in 111A-6-2 and 3 (Eocene, Miocene and Pliocene).*

lower latitudes to define zones within this interval (*Pemma papillatum, Bramletteius serraculoides, Hayella situliformis, Clathrolithus spinosus*). It can therefore only be assigned to the *Discoaster tani nodifer* Zone s.l. The absence of members of the genus *Nannotetrina* indicates that the sequence could be in a higher part of this zone. A hiatus is probable between this zone and the sediments in the *I. recurvus* Zone, as well as with the underlying sediments that can be placed in the *Discoaster sublodoensis* Zone. This is supported by changes in lithology and concentration of manganese (?) between the zones.

The *Discoaster sublodoensis* Zone is present in 111A-6-3 and 111A-7. In Cores 111A-8 and 9, the *Discoaster lodoensis* Zone is present, while the *Marthasterites tribrachiatus* Zone was found in 111A-10. The assemblages of the two latter zones can be compared to other high latitude floras from Denmark (See Table 4, Chapter 15).

Paleocene?

Lowermost Eocene or Late Paleocene seems to be present in Hole 111A. *Discoaster multiradiatus* has been found, together with some less distinct early Eocene or late Paleocene forms in greenish-gray clay-clasts above the 0.5-meters thick Cenomanian limestone recovered in Core 12, which underlies a quite complete sequence of Maestrichtian in Core 11. The clasts probably got into the core by a drilling accident; yet, they give some information about what is missing between the actually cored and the recovered sediments.

Maestrichtian and ? Campanian

Coccoliths of Late Maestrichtian age were only found in water that came up on top of Core 11, Hole 111A. *Nephrolithus frequens*, the index form for Late Maestrichtian in high latitudes, is not present; and only a few specimens of *Tetralithus murus*, the index forms for Late Maestrichtian in lower latitudes, were found. The actual top of the same core contains no coccoliths characteristic for the Late Maestrichtian.

Core 111A-11 consists of a coccolith chalk that contains an assemblage similar to the one found in the Late Cretaceous chalk of Northern Europe. The uppermost 5 sections contain an assemblage with: *Arkhangelskiella cymbiformis, Kamptnerius magnificus, Prediscosphaera cretacea, P. spinosa, Braarudosphaera bigelowi, Cretarhabdus conicus, C. crenulatus, Cribrosphaerella ehrenbergi, Cylindralithus gallicus, Eiffellithus turriseiffeli, Lithraphidites quadratus, Lucianorhabdus cayeuxi, Microrhabdulus decoratus, Micula* *staurophera, Tetralithus obscurus, Ahmuellerella octoradiata, Glaukolithus fessus, Markalius reinhardtii, Biscutum constans, Marthasterites inconspicuus* and *Watznaueria barnesae*. Section 6 has a similar assemblage, however, without *Lithraphidites quadratus*, but including *Reinhardtites anthophorus, Tetralithus nitidus, Dodekapoderhabdus noelae, Broinsonia parca* and *Tetralithus aculeus*. This assemblage represents Late Campanian or Early Maestrichtian.

? Albian-Cenomanian

The coccoliths in 111-3 to 5 and 111A-12 have only been studied superficially, as they are rare and their preservation in the hard limestone is too poor to justify further study at this stage of the investigations. None of the short-range species were found; however, typical Senonian forms are absent, whereas forms ranging throughout most of the Late Cretaceous are present. No coccoliths were found in Core 6.

Jurassic

The core assigned to the Jurassic (111-7) by pollen analysis contains no coccoliths.

Radiolaria

The only occurrence of diagnostic radiolarians at Site 111 is in the Lower Eocene in 111A-8 to 10. Here, however, they are very rare, and all are corroded but not to the extent that makes their identification impossible. The few sponge spicules present likewise are corroded.

The most abundant and varied (5 to 10 species) assemblages are in samples from 111A-9-CC and 111A-10-1. The most well-developed assemblage occurs in 111A-10-1, 102 to 105 centimeter, in a clay immediately underlying a thin layer of green chert. Diagnostic radiolarians of Eocene age include *Lophocyrtis biaurita* (Ehrenberg), *Phormocyrtis striata* Brandt, *Podocyrtis papalis* Ehrenberg, (?) *Sethochytris babylonis* (Clark and Campbell), *Spongasteriscus cruciferus* Clark and Campbell, and *Amphicraspedum murrayanum* Haeckel.

Jurassic Palynomorphs from 12-111-7-1, 4-5 cms and 66-67 cms

Stanley A. J. Pocock, Imperial Oil Enterprises, Ltd., Calgary

Abstract

Core samples from the above locality and depth contain Upper Paleozoic spores associated with thermally-altered organic matter, and Jurassic palynomorphs accompanied by relatively unaltered organic matter. It is concluded that the samples are of Jurassic, probably Bajocian, age (*ca.* 170 million years; Howarth, 1964), and that the Paleozoic fossils have been reworked.

Introduction

In the autumn of 1970 two samples from 111-7-1 were submitted to the author by J. van Hinte to determine if they contained palynomorph assemblages that could assist in dating the section. The samples from 4 to 5 centimeters and 66 to 67 centimeters were relatively small (less than 5 grams), but could be seen to contain minute fragments of a coaly material which might conceivably yield fossil plant remains. Both samples were crushed, washed in 52 per cent hydrofluoric acid for two hours to remove silica and silicates, and the organic material then concentrated and removed by flotation in a zinc bromide solution of specific gravity 1.8. In order to minimize possible laboratory inflicted damage to the residues, no further treatment was carried out, and slides were prepared from the organic concentrate by polyvinyl alcohol smear method, using Canada balsam as cement. Both samples yielded organic residues sufficiently rich in palynomorphs to permit detailed study and the reaching of significant conclusions.

Results

The organic residues from the two samples examined are essentially similar and may be considered together. These residues are composed of three distinct fractions:

a. Coal fragments.

b. Upper Paleozoic spores and associated, moderately altered, organic matter.

c. Jurassic spores and pollen with associated, fairly fresh, organic matter.

Coal Fragments

Coal fragments appear to represent a fairly high rank coal. They are completely opaque and yield no identifiable organized plant remains on maceration.

Upper Paleozoic Spores and Associated Organic Matter

This fraction comprises about 45 per cent of the total insoluble organic matter in the samples. It includes much translucent to opaque cuticular and woody tissue, including scalariform tracheids, and many spores. The latter are generally poorly preserved, but Densospores are recognizable, together with abundant flanged *Lycospora*. This association indicates Late Paleozoic age, probably Late Mississippian or Pennsylvanian. All of this organic material is of a neutral gray shade, indicating that it has been subject to some thermal alteration.

Jurassic Spores, Pollen and Associated Organic Matter

This fraction is slightly less abundant than the Upper Paleozoic fraction discussed above. It is pale brown to yellow and has suffered little thermal alteration. It is, however, corroded, probably due to oxidation at the time of sedimentation. Fossils are not abundant in this material, but a number of distinctive species were recorded by scanning several slides. These included:

Dictyotriletes crateris (Balme) Pocock
Deltoidospora minor (Couper) Pocock
Classopollis classoides Pflug
Exesipollenites tumulus Balme
Callialasporites dampieri (Balme) Sukh Dev
Osmundacidites wellmanii Couper
Bennettiteaepollenites lucifer Thierg
Paleoconiferus asaccatus Bolkh.

This assemblage is Jurassic in age. Since *Paleoconiferus asaccatus* has only previously been recorded from the Lower and Middle Jurassic and *Bennettiteaepollenites lucifer* from the Middle Jurassic, it is reasonable to assign it a Middle Jurassic age. As a whole, the assemblage is closely similar to that recovered from the Lower Deltaic Series of Yorkshire (Couper, 1958) and the upper member of the Gravelbourg Formation of Saskatchewan, Canada (Pocock, 1970). These strata are of Early Bajocian age, and it appears that such an age assignment for the above assemblage is probable.

With regard to depositional environment, it should be noted that no marine species were recorded and no sapropelic material, which normally occurs in marine sediments, was seen. A nonmarine depositional environment may therefore be postulated.

Conclusions

The sediment from both samples is of Middle Jurassic, probably Early Bajocian age. Within this sediment occur fragments of rock, possibly fine-grained micaceous sandstone, (A. Ruffman, personal communication), carrying palynomorph assemblages of Late Paleozoic, probably Late Mississippian or Pennsylvanian, age. Fragments of fairly high rank coal, derived from an unknown source, are also present and, like the Paleozoic spores, are concluded to be reworked. This evidence would seem to suggest that deposition of plant material and eroded rock fragments took place in a low lying, possibly somewhat swampy, region which received much of its water from a well-drained upland source that supported a fairly rich vegetation and was, in part, undergoing active sub-aerial erosion. During Jurassic time, Upper Paleozoic strata, including coal seams, must have been exposed over part of this source area to account for the reworked Upper Paleozoic material in the Jurassic sediments.

Mesozoic Macrofossils: Site 111

J. A. Jeletzky, Geological Survey of Canada, Ottawa

Identifications

12-111A-12-1, 18-20 cm

Unoriented limestone (large shell); *Plicatula* cf. *gurgitis* Pictet and Roux, 1853 (one somewhat fragmentary specimen consisting of a partly exfoliated right valve and an almost completely rock covered left valve).

Age and Correlation:

Plicatula gurgitis Pictet and Roux, 1853 appears to be diagnostic of the Albian rocks of England, France, Switzerland and northern Germany. It may locally ascend into the Cenomanian rocks (especially in northern Germany), but seems to be largely replaced by *Plicatula inflata* Sowerby in this stage. The presence of *Plicatula* cf. *gurgitis* is suggestive of the Albian (?late Albian) age of that part of the core from which Sample 12-11A-12-1 was recovered. The Cenomanian age of this sample cannot be ruled out, however, because of a poor preservation of the only identifiable specimen available and the ?rare presence of *P. gurgitis* in the Cenomanian rocks of northwestern Europe.

The *Plicatula* ex gr. *gurgitis-inflata* appears to be a European species group without close allies among the Albian-Cenomanian *Plicatula* forms of the Atlantic and Gulf regions of North America. The presence of a form comparable with this European stock in shallow water deposits of 111A, separated from the North American shelf by waters 2800 to 3400 meters deep (*Geotimes*, Vol. 15, No. 9, 1970, p. 10), lends some color to the recently published (*ibid.* p. 10) suggestion that "Orphan Knoll" is: "a piece of the continent [?European continent] abandoned in the proximity of Newfoundland in the early stages of sea-floor spreading."

So far as I could determine, all Cretaceous representatives of *Plicatula* and its subgenera are shallow water forms (mostly shelf parts of epicontinental seas) restricted to a littoral-to-neritic environment. None of them appears to be attributable to the bathyal, let alone abyssal, environment. I would suggest a depth of less than 100 fathoms for Sample 12-111A-12-1. I can find no signs of transport or mixing of fauna in Sample 12-111A-12-1, particularly as the only specimen of *Plicatula* cf. *gurgitis* has its valves closed in a life-like position.

12-111-4-1, 7-12 cm

Oriented slice of glauconitic limestone (oyster?); Gastropod fragment resembling *Pteropoma raritanum* (Richards 1943) but not identifiable definitively even to the genus.

Age and Correlation:

Cannot be dated.

12-111-3-1, 15-18 cm
12-111-3-2, 141-142 cm
12-111-4-CC
12-111-6-CC
12-111A-11-CC
12-111A-12-CC

Various gastropods, pelecypods, (pectenids, exogyrids), and serpulid worm tubes occur, but neither taxonomic nor age determination is possible due to the fragmentary nature of the fossils.

ESTIMATED RATES OF SEDIMENTATION

The Pliocene/Pleistocene boundary (2 million years) is drawn on paleontological data at about 125 meters (111A-4-1 and 2). This yields an average Pleistocene sedimentation rate of 6.2 cm/1000 yrs (Figure 20).

Between 145 and 146 meters (to be more precise 111A-6-2, between 124 and 139 centimeters), a marked lithologic change occurs from a glauconitic chalk (below 139 centimeters) to gray, sandy-gravely clays with icerafted detritus (above 124 centimeters). This lithologic change (and the accompanying faunal and floral change) heralds the onset of glaciation in the Northern Atlantic. A level at 130 centimeters has been dated paleontologically at 2.8 million years. Additional levels have been dated by paleontologic means as follows:

111A-6-3, 18 centimeters; 3.7 million years
111A-6-3, 67 centimeters; 5.0 million years.

Calculations between and among these dated levels indicate a relatively constant rate of sedimentation of about 0.04 cm/1000 yrs (=0.4 mm/1000 yrs) (Figure 21). This is, to our knowledge, the lowest documented rate of sedimentation recorded in deep-sea carbonates. The fact that this extremely low rate of sedimentation occurs in a carbonate

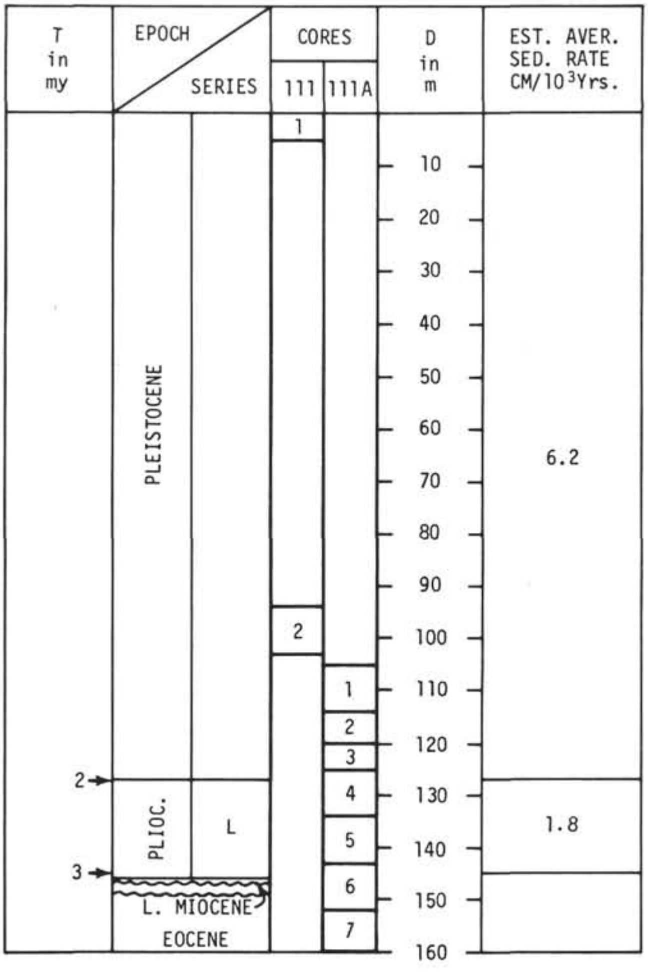

Figure 20. *Estimated average rates of sedimentation for the Late Pliocene and Pleistocene at Site 111 (Orphan Knoll).*

section atop a topographic high is all the more remarkable. Some interesting data are indicated below:

At a sedimentation rate of about 0.04 cm/1000 yrs:

(1) each 4 centimeters of section represents about 100,000 years.

(2) Over 2 million years of time/sediments are compressed into slightly less than 1 meter.

An average rate of sedimentation of about 1 cm/1000 years calculated for the Lower Eocene at Site 111 on the following basis:

111A-6-3, 121 centimeters: top *D. sublodoensis* Zone: age 49 million years

111A-10: *M. tribrachiatus* Zone: age 52 million years.

An estimated rate for the Albian-Cenomanian of 0.7 cm/1000 years is based on approximate correlation of absolute ages and biostratigraphic zones as given in Figure 2, Chapter 2 (Basis for Age Determinations) (Figure 22).

No correction for natural consolidation was applied because there did not seem to be an appreciable systematic density gradient down the hole.

DISCUSSION

Introduction

Nineteen cores were recovered at Site 111. Total core recovery was approximately 74 meters out of 142 meters cored. Stratigraphic units recovered include Pleistocene, Pliocene, Miocene, Eocene, Cretaceous (Maestrichtian, Cenomanian, Albian) and Jurassic. The site bottomed in carbonaceous coarse sands and sandy clays of Bajocian age; these are believed to be of continental origin.

The most significant information which was obtained at this site concerns the following:

(a) The boundary between glacial and pre-glacial sediments; and pre-glacial Pliocene biostratigraphy.

(b) Four definite, and a possible fifth, unconformities in the sedimentary sequence.

(c) Contrast in lithologic types encountered and its bearing on the depositional history at this site.

The discussion that follows will deal with the unconformities and will then go on to treat the stratigraphic succession from the oldest to the youngest rocks, then review the sinking history of the Orphan Knoll, and finally consider the place of Orphan Knoll in a reconstruction of Laurasia. The significance of the narrow ridge structures is discussed at length elsewhere (Ruffman, in preparation), and more detail is available on certain aspects of the biostratigraphy and sinking history in Ruffman and van Hinte (in press).

At Site 111 on Orphan Knoll all the objectives set for the hole were essentially attained, except that of obtaining samples of crystalline "basement". Orphan Knoll was established to be a foundered block of continental material; the prominent seismic reflectors were identified; and, the biostratigraphy and lithology of virtually the whole section was determined, including the onset of glacial material.

Unconformities

Four definite unconformities have been encountered at this site.

(1) Late Miocene/Late Eocene. At approximately 147 meters a distinct unconformity occurs marked by a thin (2 centimeters) glauconitic sand layer. Late Eocene zeolitic clays (dated at about 38 million years) are overlain by Late Miocene calcareous sediments (*ca.* 10 to 11 million years). The hiatus in deposition thus represents approximately 30 million years. The strongly condensed sequence within the Eocene suggests a possible further disconformity separating Upper and Lower Eocene and representing about 10 million years time.

(2) Early Eocene/Late Maestrichtian. There appears to have been about a 5-meter interval between the lowest Eocene recovered (zeolitic clays at 177.5 meters) and the first Cretaceous (i.e., Late Maestrichtian calcareous ooze at 182.2 meters). Within this interval it is possible that lowest Eocene and perhaps a part of the Paleocene are present in a condensed section. However, it is unlikely that the total Paleocene is present at this site, and a hiatus has been drawn for this reason separating Lower Eocene from Upper

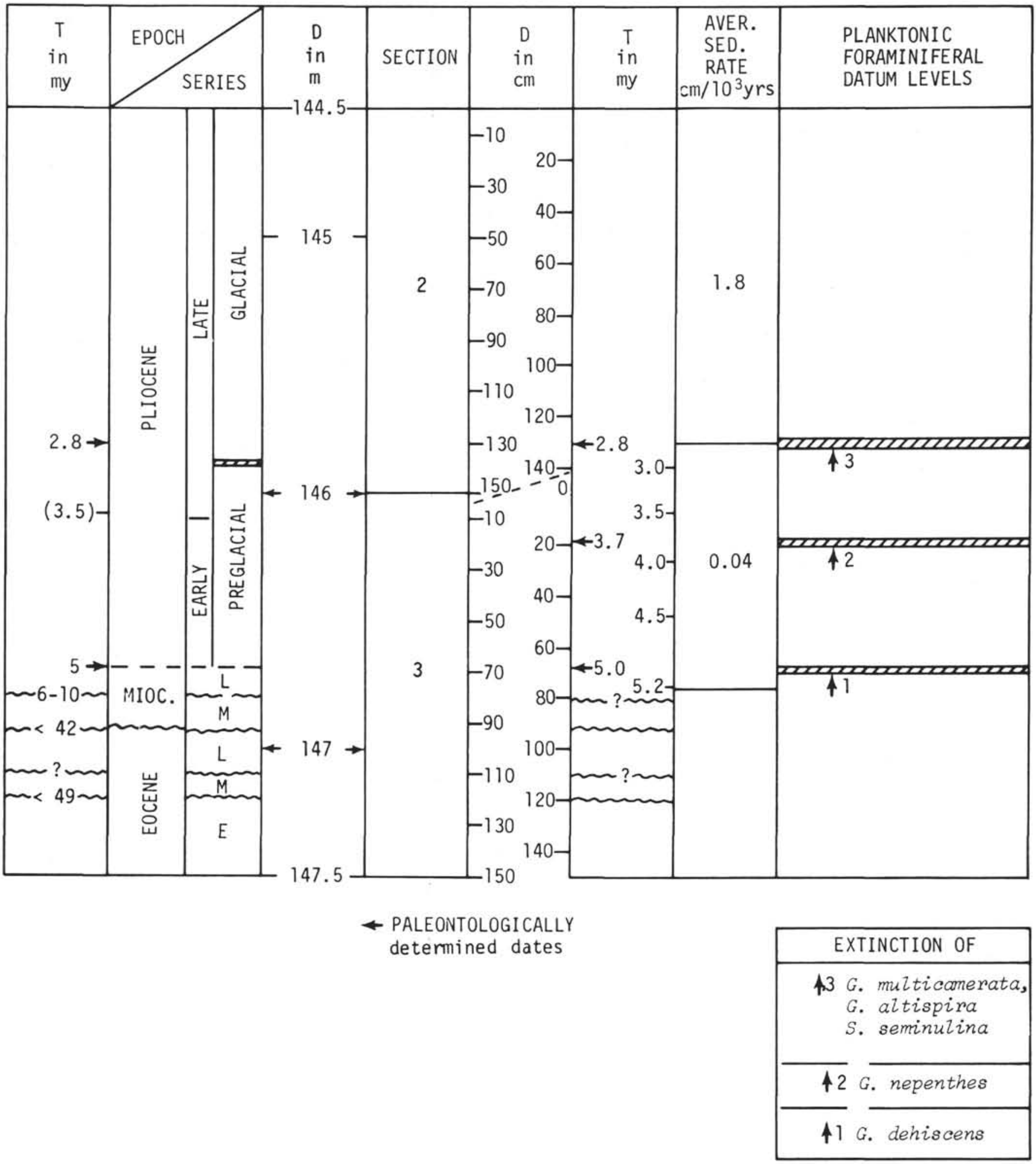

Figure 21. *Estimated average rates of sedimentation in Early Pliocene of Site 111 (Orphan Knoll), Core 6, Sections 2 and 3.*

Maestrichtian at about 180 meters. The estimated lapse in time represented by this unconformity is about 13.5 million years.

(3) Late Maestrichtian/Middle Cenomanian. A manganese encrusted calcarenite occurs at about 189 meters, immediately below calcareous oozes of Late Maestrichtian age. Approximately 30 million years are represented by this hiatus.

(4) Albian-Jurassic (Bajocian). Dating of Core 111-6 at 213 to 222 meters, gives an Albian age. The base of the

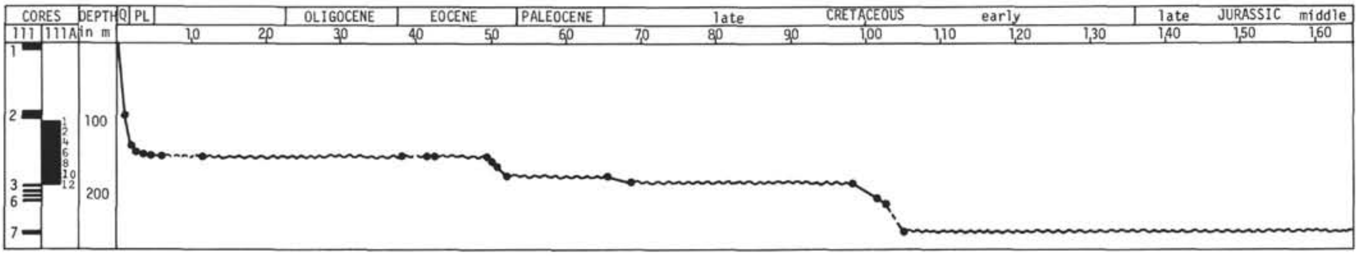

Figure 22. *History of sedimentation at Site 111 (Orphan Knoll).*

Albian section represented here is thought to be at about 105 million years. The age of the underlying Bajocian sandstone is approximately 170 million years. The unconformity therefore spans 64 million years.

"Basement"

The age and nature of the crystalline basement is not known because the drill hole was terminated above this horizon in a Jurassic sandstone. However, it is thought that much older rocks, possibly including crystalline basement, outcrop along the steep northeast margin of Orphan Knoll. These rocks are almost certainly Paleozoic in age because they underlie the Jurassic sandstones and because the Jurassic sandstone contains reworked and thermally metamorphosed carboniferous spores that may be related to the anthracite and, therefore, also locally derived. Dredging along this steep northeast slope will further elucidate this question.

Narrow Ridge Structures (Layer 2)

The narrow ridge-like structures that border the northeast margin of the Orphan Knoll could be surface expressions of diapiric intrusions of evaporites, erosional remnants of igneous dikes or possibly high-standing remnants of resistant sedimentary strata. Figure 23 shows the presently known distribution of the pronounced hills, some of which stand 300 meters above the relatively flat upper surface of the knoll.

It is not thought that diapirs of evaporites could produce such narrow structures (less than 3 kilometers wide) and rise to such pronounced heights above the upper surface of the knoll without being cut down by erosion. The bathymetric expression of other deep sea diapirs seems to be limited to less than 200 meters and the structures are often 6 to 11 kilometers in diameter (Ewing *et al.* 1969; Watson and Johnson, 1970).

As was mentioned earlier, it is not believed that the diapirs of Pautot *et al.* (1970) are evaporitic intrusions. Thus it is assumed that no diapirs occur on the continental margins north of Flemish Pass on the North American margin, and only one diapir is known north of the French shelf on the European margin (Pautot *et al.*, 1970). The suggestion is that the narrow, shallow and saturated saline sea that existed between Africa and North America and which laid down an evaporite sequence in Triassic to Jurassic times was no longer restricted nor was depositing evaporites by the time rifting had progressed between Europe and North America to the extent that an intra-continental ocean was developed in middle to late Cretaceous times. (Ruffman and van Hinte, in press).

The apparent linear trend of the features along the northeast margin of Orphan Knoll suggests that they are eroded remnants of either dikes or upturned resistant sedimentary strata. The features have no definite magnetic signature which is unexpected if they are diabase dikes and related to other known Triassic-Jurassic dikes intruded during the initial rifting phase (May, 1971). However, their orientation parallel to the linear northeast margin of the main part of the knoll and their obvious intrusive nature makes the dike explanation most attractive. If the ridges are eroded remnants of sedimentary strata this might account for the lack of any pronounced magnetic signature. In any case the features are believed to be made of rock older than the Bajocian sandstone recovered at the bottom of the hole.

It is now known the narrow ridge-like structures extend the full length of the southern portion of Orphan Knoll (Figure 23) since Vema 28 crossed a similar ridge structure that broke the surface on the southeast extension of the knoll (J. I. Ewing, personal communication). Recent dredging on the ridge structures by Lynch appears at this time to be inconclusive and will be reported on elsewhere (Ruffman, in preparation).

Jurassic Sandstone (Layer 3)

Although only 67 centimeters of the lowermost Bajocian sandstone was recovered, it has proved most interesting. Both the petrologic and paleontological investigations have suggested either a nonmarine or very shallow coastal environment; this along with the presence of immature sediments and anthracite fragments has confirmed the suspected continental nature of the Orphan Knoll block.

The westward apparent dip seen in the lowermost sandstone on the *Challenger* seismic record (Figure 10) can also be discerned on the seismic reflection profiles of *Charcot* and *Sackville*. Using a standard structural diagram and structural contours, the average strike and dip of the Jurassic sandstone formation in the general area west and north of the drilling site is approximately 296° and 6-1/2°SW, respectively (assuming a velocity of sound in the sandstone of 3 km/sec). The small anticlinal structure (Figure 10) has an approximate strike of 178°. Both the westward dip and the anticlinal structure are thought to be the result of post-depositional tectonic movement. This is perhaps in part confirmed by the very approximate isopach

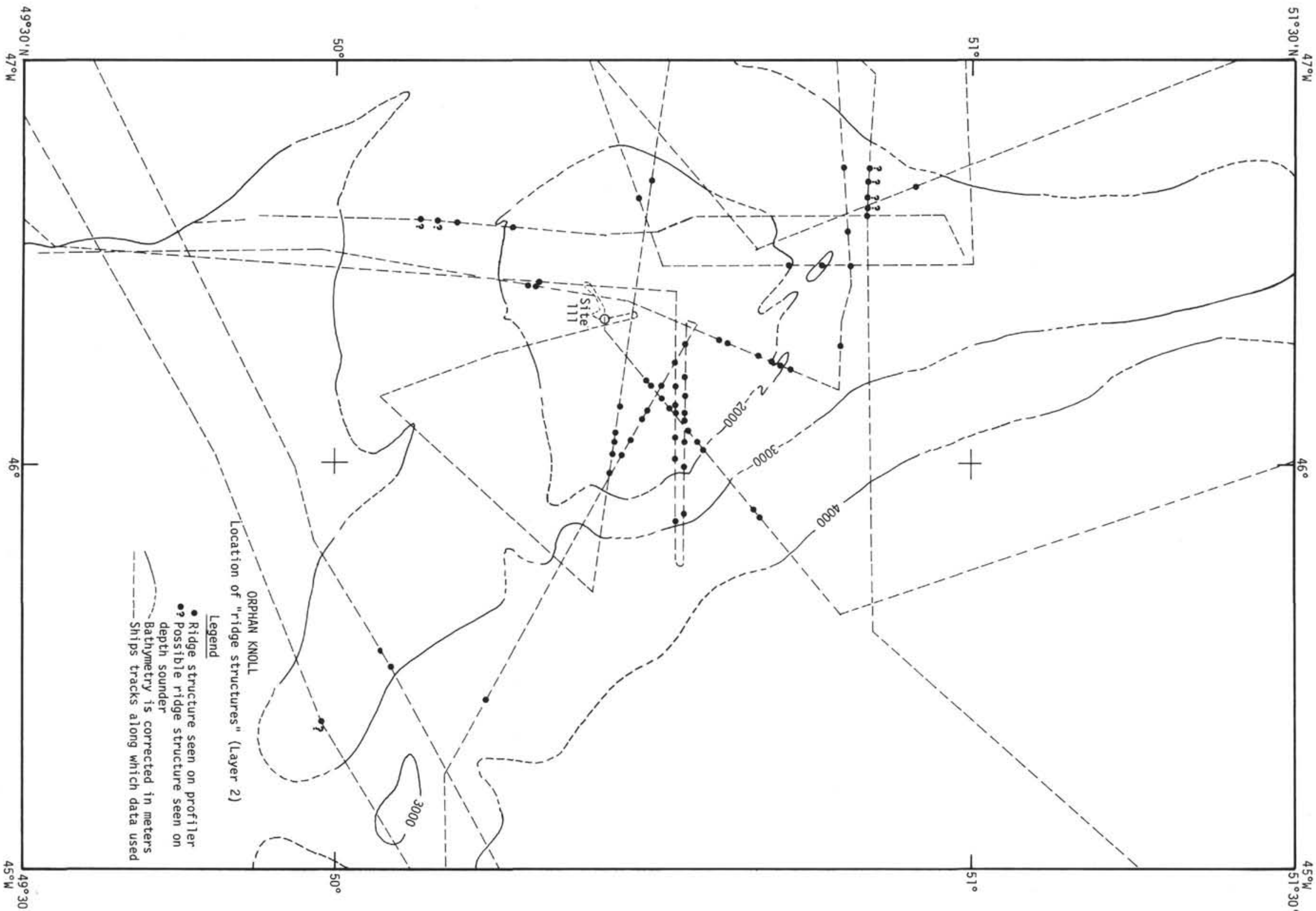

Figure 23. *The location of known "ridge structures" superimposed on simplified bathymetry of Orphan Knoll. Peaks seen on seismic profiles or in some cases only on depth sounders. The peaks are shown as circles, but it is believed that they are in most cases linear ridges.*

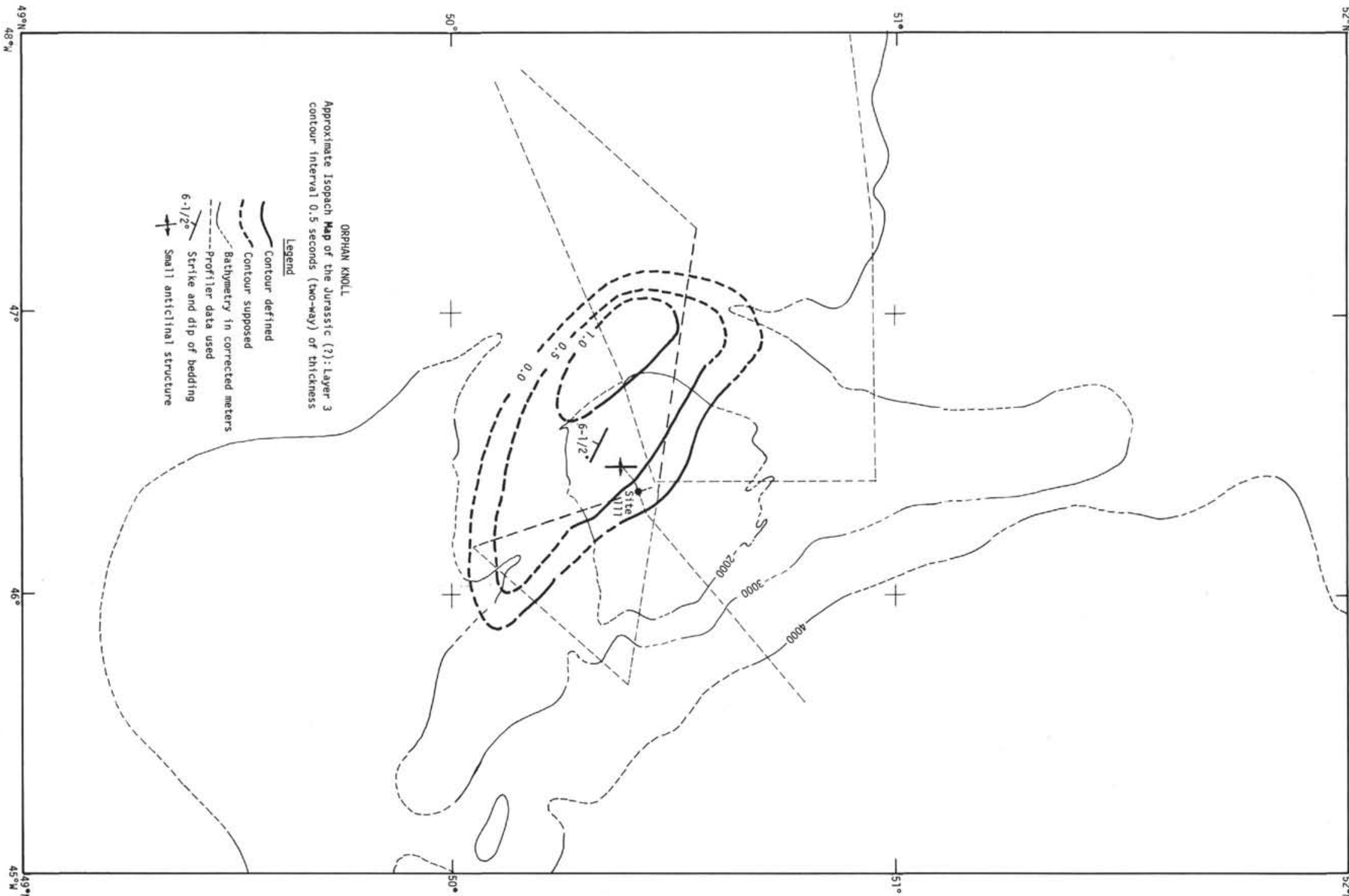

Figure 24. *An approximate isopach map of the lowermost seismic layer identified in Hole 111 (layer 3). The horizon was dated at Site 111 as Jurassic (Bajocian) from 67 centimeters of core recovered at the bottom of the hole. The tectonically deformed bedding dips at a low angle to the southwest. The whole body has been deformed then peneplaned between the Jurassic and early Albian.*

of the lowermost sandstone (Figure 24) where the main mass of the body lies on the southwest half of the knoll and appears to extend beneath the sea floor close to the southwest wall of the feature. The isopach is drawn quite generally and based mainly on the seismic reflection profile of *Charcot*. The map (Figure 24) should be thought of as the thickness of a peneplaned sequence overlying a hypothetical crystalline basement

Albian-Cenomanian Basin (Layer 4)

The Albian-Cenomanian basin has been interpreted on the isopach map (Figure 25) to have linear margins on the northeast and southwest. The linear margins could result from post-depositional uplift and subsequent erosion (possibly associated with diapirs or dike intrusion). However, the preferred interpretation is that the Albian-Cenomanian carbonates were deposited in a shallow basin contained between islands of Jurassic or older rock on the top of the knoll. The islands may be fault-bounded blocks possibly uplifted in association with earlier intrusion of the dikes or diapirs. The islands explain the source of occasional terrestrial material found in the Albian-Cenomanian limestones. As Orphan Knoll continued to sink, the islands would become submerged and terrestrial material would die out upwards in the section and be restricted to minor windblown amounts in the Maestrichtian (as was found).

The margins of the Albian-Cenomanian basin are also marked by small normal faults seen on the seismic profile records (Figure 5). These faults are post-depositional and result from differential compaction of younger sediments over the islands of Albian-Cenomanian times. The faults give rise to two ridges of less than 50 meters relief (Figure 6) that traverse the surface of Orphan Knoll (Figure 26). The low ridges have been interpreted on Figure 26 to be subparallel and parallel to the northeast margin of the southern portion of the knoll, parallel to the trend of the narrow ridge structures (Figures 2 and 23), and parallel to the interpreted trend of the small normal faults.

Post-Cenomanian Sedimentation (Layers 5, 6a and 6b)

All post-Cenomanian sediments deposited on Orphan Knoll were pelagic with a marked ice-rafted component introduced in the Pliocene-Pleistocene. The isopach map of the post-Cenomanian sediments (Figure 27) reflects their pelagic nature. The sediment body mantles the whole of the knoll except the narrow ridges. It is thickest on the flat central parts of the knoll and wedges out toward the periphery where the slopes become too steep to permit accumulation.

However the rain of pelagic material was not constant nor was it continual. Marked gaps in the record occur between the Eocene and Upper Miocene, as well as apparently between the Maestrichtian and Lower Eocene. There is an extremely low sedimentation rate with minor gaps in the Eocene. The gaps do not represent times of active erosion since, so far as can be seen in the seismic profiles, all internal stratification within the pelagic section appears to be parallel to the upper surface of the knoll. Similarly, the 2-centimeter glauconite band that separates Eocene from Upper Miocene appears to be indicative of quiet conditions over a period of time following an interval of nondeposition or active erosion (see frontispiece).

However, the gaps in the record present a puzzle. They appear to represent periods of nondeposition, hence disconformities, associated with a changing current regime that during certain periods accelerated deep currents over Orphan knoll and prevented sedimentation.

The apparent cessation of sedimentation or very low rate of sedimentation between the Maestrichtian and Lower Eocene may be related to an increase of current velocities over the knoll associated with the main sinking of Orphan Knoll, and related to the development of the Labrador Sea triple point and accelerated opening of the Denmark Straits and Norwegian Sea subsequent to 60 million years ago (see Chapter 20). It appears that the main opening of the Atlantic north of 47°, beginning about 60 million years ago, had a marked effect on deep sea sedimentation on the western margins of the North Atlantic, since a similar major hiatus between the Cretaceous and Middle Tertiary has been recorded on Leg 11 at Sites 99, 101 and 105 (Ewing *et al.*, 1970). The cessation of deposition from Upper Eocene to Middle(?) and upper Miocene is presumably also related to an acceleration of current velocities over the knoll, but is more difficult to relate to a known physical event. (It is also possible to suggest in view of recent work (Bader *et al.*, 1971) that the lack of Paleocene sediments resulted from an exceptionally shallow carbonate compensation depth.

In fact the very low sedimentation rates represented in the Eocene and Miocene would suggest that only a very slight change in current velocity was needed during this period to move from conditions of deposition to nondeposition. Hence, from the Maestrichtian to Miocene one might speculate that the same relative current conditions held over Orphan Knoll until the Pliocene, when there was a major change in current patterns that led to higher sedimentation rates and eventually to the development of a Labrador current analogue and a great contribution of ice-rafted material. The paleontological evidence suggests that a Gulf Stream analogue with a warmer water fauna probably passed over Orphan Knoll during the Tertiary until displaced southward to its present position south of 45°N during the Pliocene.

At 145 meters, the time of the development of a Polar Faunal Realm and the introduction of ice-rafted debris has been placed at 3 million years in the Upper Pliocene, and is earlier in this chapter interpreted as, "the age of the initiation of glaciation in the North Atlantic region" (see frontispiece). This event occurs at Site 111 just prior to the extinction of *Globoquadrina altispira, Sphaeroidinellopsis seminula, S. subdehiscens* and *Globorotalia multicamerata*, and it appears that their extinction is directly related to the onset of glaciation. In Chapter 13 a detailed analysis of the Pliocene-Pleistocene glaciation in the North Atlantic is presented. Suffice to say at this point that Orphan Knoll has provided one of the first complete deep sea sections of the Pliocene-Pleistocene glaciation and for the first time has given an independent estimate for the initiation of glaciation in the North Atlantic based on microfaunal evidence. This has lent considerable support to the "longscale" school of glacial chronology.

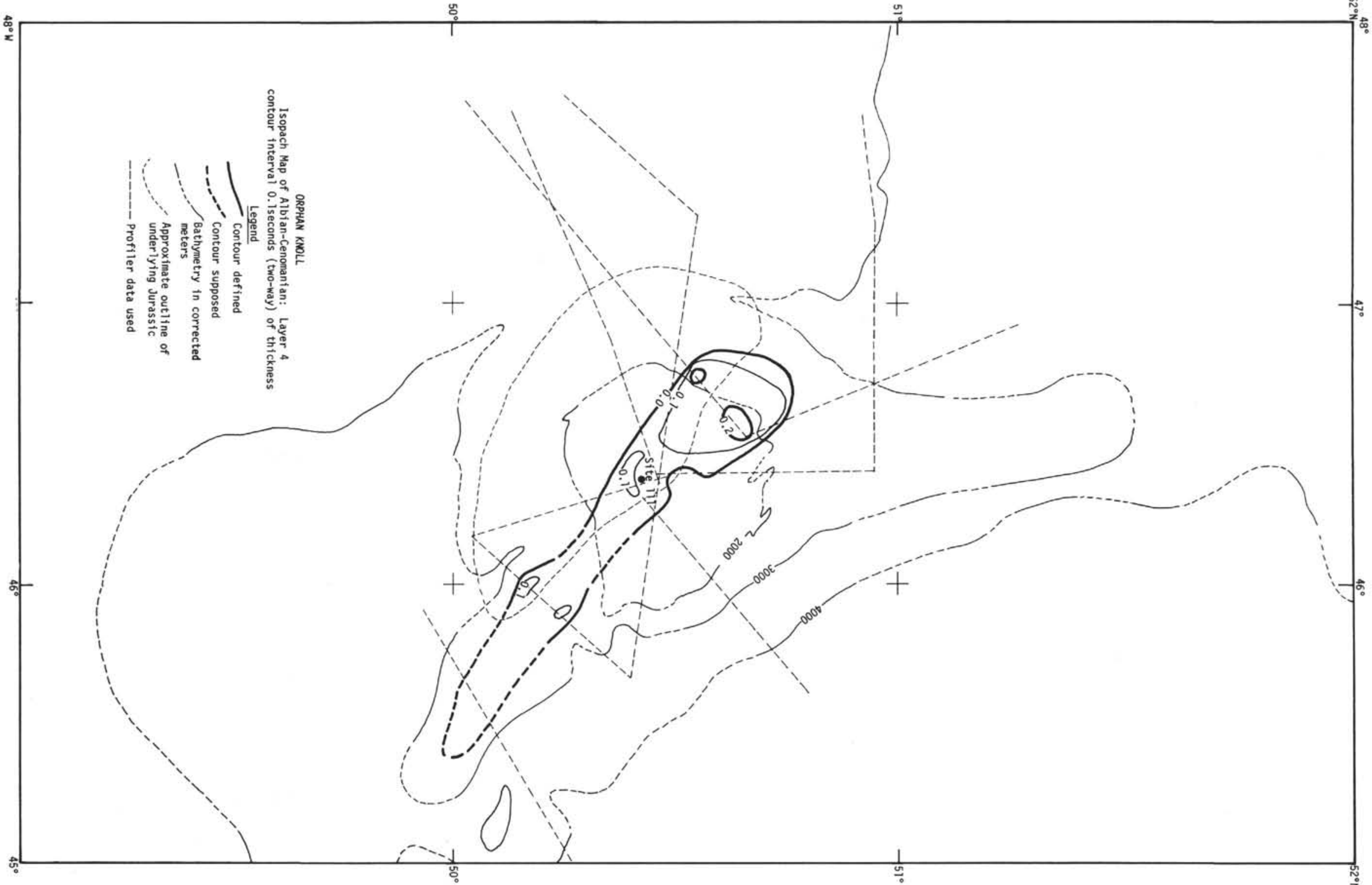

Figure 25. *An isopach map of the Albian-Cenomanian carbonates (layer 4). The shallow-water carbonates are interpreted to have been deposited between long linear islands whose margins may be in part fault-controlled.*

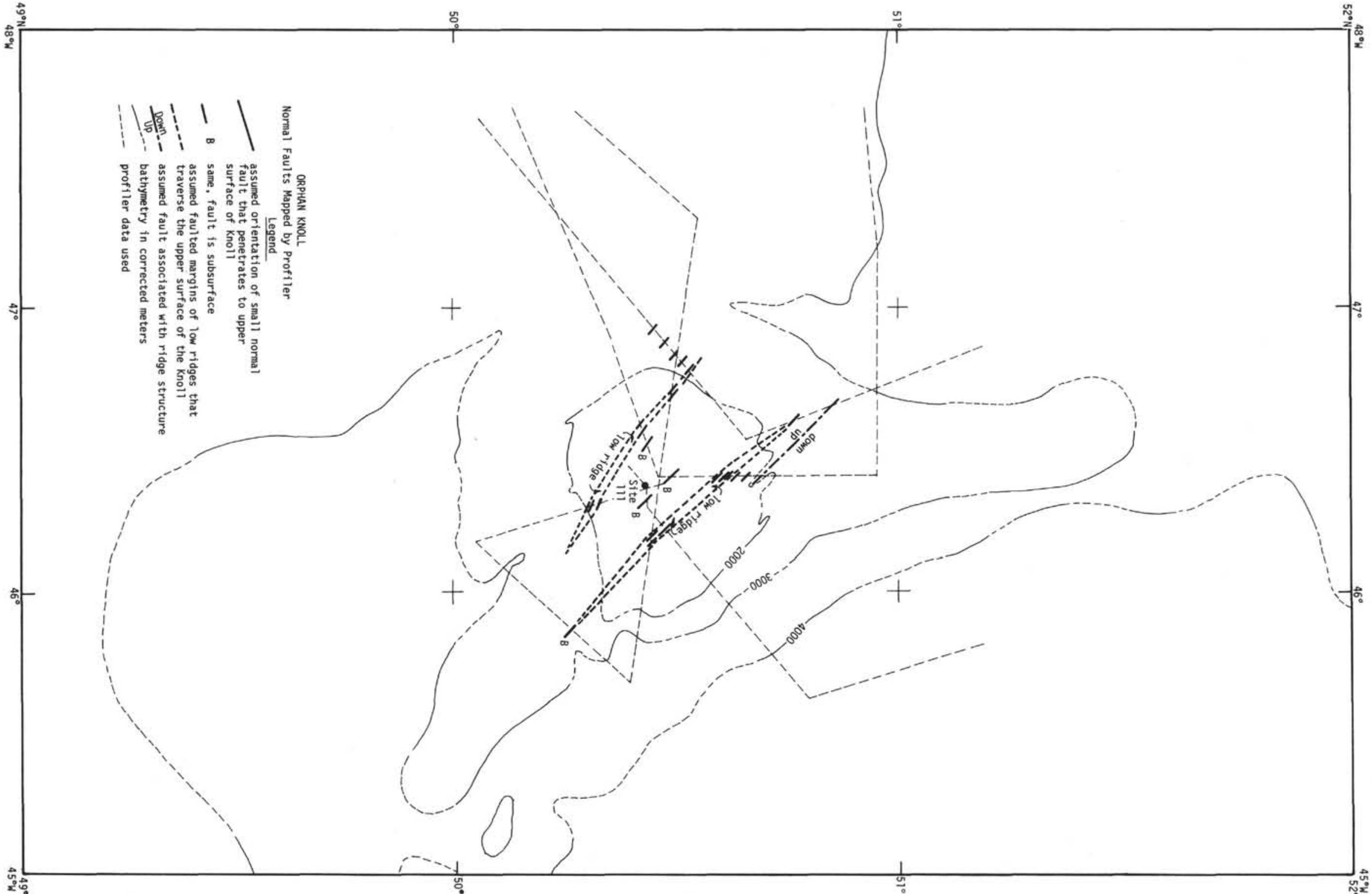

Figure 26. *Small normal faults seen on the profiler records. When a fault was seen on a seismic profile its orientation was unknown. In this diagram the faults are interpreted to be interrelated thus a NW-SE orientation is estimated. The faults often reach the surface of the knoll and have affected the topography in a number of places. The bathymetric effects are interpreted to form two low linear ridges that parallel the trend of the narrow ridge structures. The low ridges may in fact be directly related to the ridge structures either through differential compaction being greater off the side of the features or through faulting associated with the intrusion of underlying ridge structures. Low ridges have less than 50 meters relief; often are only a few meters in height.*

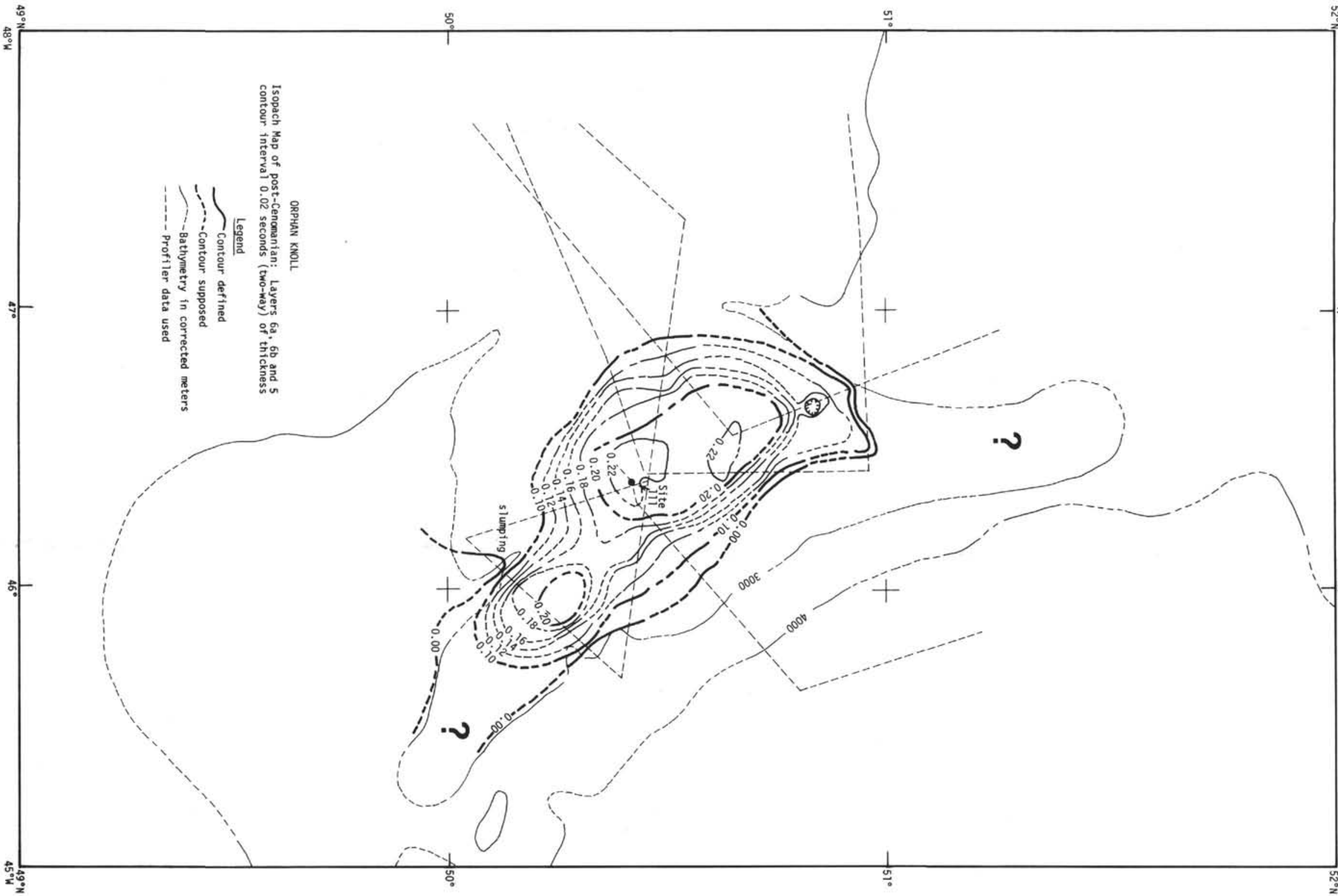

Figure 27. *Isopach map of post-Cenomanian sediments (layers 6b, 6a, 5). All sediment lying above the pronounced reflector at the top of layer 4 was included. This isopach ignores the narrow ridge structures that rise through all horizons. The isopach suggests that the sediments were simply draped over the knoll by means of pelagic sedimentation.*

A note of caution should perhaps be introduced here since the above mentioned glacial-nonglacial horizon could simply be the result of a persistent change of an already existing ice-laden Pliocene surface current pattern. Icebergs are not necessarily associated exclusively with a continental icecap. It is possible, but unlikely that the onset of glacially derived material on Orphan Knoll 3 million years ago may only represent the increased activity of mountain glaciers in Greenland and Baffin Island and the associated increased calving of icebergs in fjords rather than the initiation of a continental icecap. Perforce a continental icecap must be preceded by a period of greatly reactivated mountain glaciation, which alone would greatly increase the numbers of icebergs and the amount of ice-rafted material rained down over the Labrador Sea floor.

Geological History of Orphan Knoll

Orphan Knoll is a piece of continental crust originally embedded in the heart of the supercontinent of Laurasia 200 million years ago. The crystalline basement of the knoll is unknown but is not thought to be rock of high magnetic susceptibility because the magnetic map does not reflect the basement topography (Figure 3).

Coal measures were laid down near the drilling site during the Carboniferous (?); and later when the whole area was metamorphosed by the Hercynian(?) orogeny, the coal was transformed to anthracite. From this point to the present the geological history of Orphan Knoll is essentially a sinking history of the knoll as outlined in Figure 28.

Following the models of Schneider (1969) and Sleep (1969; in press) on the evolution of continental margins, at some point in the Triassic or early Jurassic a general thermal upwarping of the areas of incipient rifting ocurred east of Newfoundland and the Labrador coast and included Orphan Knoll. There may have been some dike intrusion during this period in the area of incipient rifting which is one explanation for the narrow ridge-like structures seen on Orphan Knoll. The Triassic-Jurassic was mainly a period of sub aerial erosion and nonmarine deposition in the area of Site 111. The earlier metamorphic coal measures and other Paleozoic rocks were eroded and redeposited as a series of fluvial deposits close to sea level. In Bajocian times (170 million years ago) anthracite-rich, graded, lithic sands were deposited on a coastal plain at Site 111. They were later loosely indurated by a carbonate cement.

After deposition of the Jurassic sand there was a long hiatus in deposition (65 to 70 million years) during which the knoll was first uplifted somewhat in the east, then peneplaned, leaving some pronounced ridges standing high mainly along the northeast margin. The ridges are either earlier dikes or older resistant formations. A low dip of about 6-1/2° SW was imposed upon the Jurassic during this minor tectonic activity as well as some other minor structure. It appears most likely that it was during this long hiatus that actual separation of the Orphan Knoll from the continents occurred, and the knoll has stood isolated from the contribution of terrestrial sedimentation through to the present.

The narrow ridges, as well as some of the other "basement" rock, stood as islands when in the Lower Cretaceous the knoll had subsided to the extent that it was covered in Albian times by up to 30 meters of water. By extrapolation downward through unsampled section, the earliest Cretaceous on top of the Jurassic was not much older than early Albian(?). The deposition of these shallow water limestones (Aptian ?–Cenomanian) between the islands may mark the time of development of the first marine separation between Europe and North America.

The Orphan Knoll sank without tilting from the early Cretaceous to the early Tertiary. During the Albian-Cenomanian very minor subsidence occurred and the water depth in the Cenomanian was still less than 100 meters (still inner neritic). The geological section here was, correspondingly, entirely composed of calcarenites, carbonate sands and shelly limestones, all glauconite-rich. The sedimentation rate was 0.7 cm/1000 yr.

Sedimentation ceased during the late Cretaceous though subsidence probably continued at about 0.84 cm/1000 yr. A phosphatized nodular or conglomerate horizon developed on top of the lithified Cenomanian calcarenite during the earlier part of this long hiatus of about 26 million years. Sometime later, perhaps in deeper water, a manganese-rich goethite coating developed over the thin "conglomerate" horizon.

When sedimentation recommenced it was in the Maestrichtian, and the knoll had sunk to outer neritic or upper bathyal depths and all islands were submerged. Chalk seas had invaded, and chalk filled the interstices between the conglomerate-like nodules. This was followea by a thin horizon of Maestrichtian chalk at about 0.3 cm/1000 yr. Sedimentation apparently ceased again. There were some indications of Paleocene sediments but no core recovery up the hole until the Lower Eocene–indicating a hiatus of 13.5 million years or a highly compressed Paleocene section.

Deposition began again in the Lower Eocene with an average deep sea pelagic rate of 1 cm/1000 yr and continued to the Upper Eocene when the rate dropped sharply to 0.005 cm/1000 yr. The Eocene nonnoplankton marl and silty clays graded upwards into yellow zeolitic clays and were topped by a 2-centimeter glauconite band that represents a long hiatus of 32 million years.

The fauna of the Eocene sediments are not diagnostic of their depth of deposition, but are thought to be at least middle bathyal and more likely deeper. It is entirely possible that the Orphan Knoll had already sunk to present levels by the time Eocene sedimentation occurred. Thus the minimum rate of subsidence during the Paleocene is 4.2 cm/1000 yr, while the favored interpretation is that all of the remaining sinking occurred during the hiatus of 13 million years at a rate of 15.5 cm/1000 yr.

When sedimentation resumed, the knoll was essentially at its present depth and all sediments from the Miocene to the present were simply stacked on the upper surface. Thus, on Figure 28 the upper surface of the knoll is shown to get shallower from the Miocene to the present as sediment was added.

A very thin Upper Miocene–Lower Pliocene foraminiferal ooze was deposited at 0.04 cm/1000 yr over the glauconite band. The upper part of these oozes was a gray ooze that recorded in a 15-centimeter transition zone (see

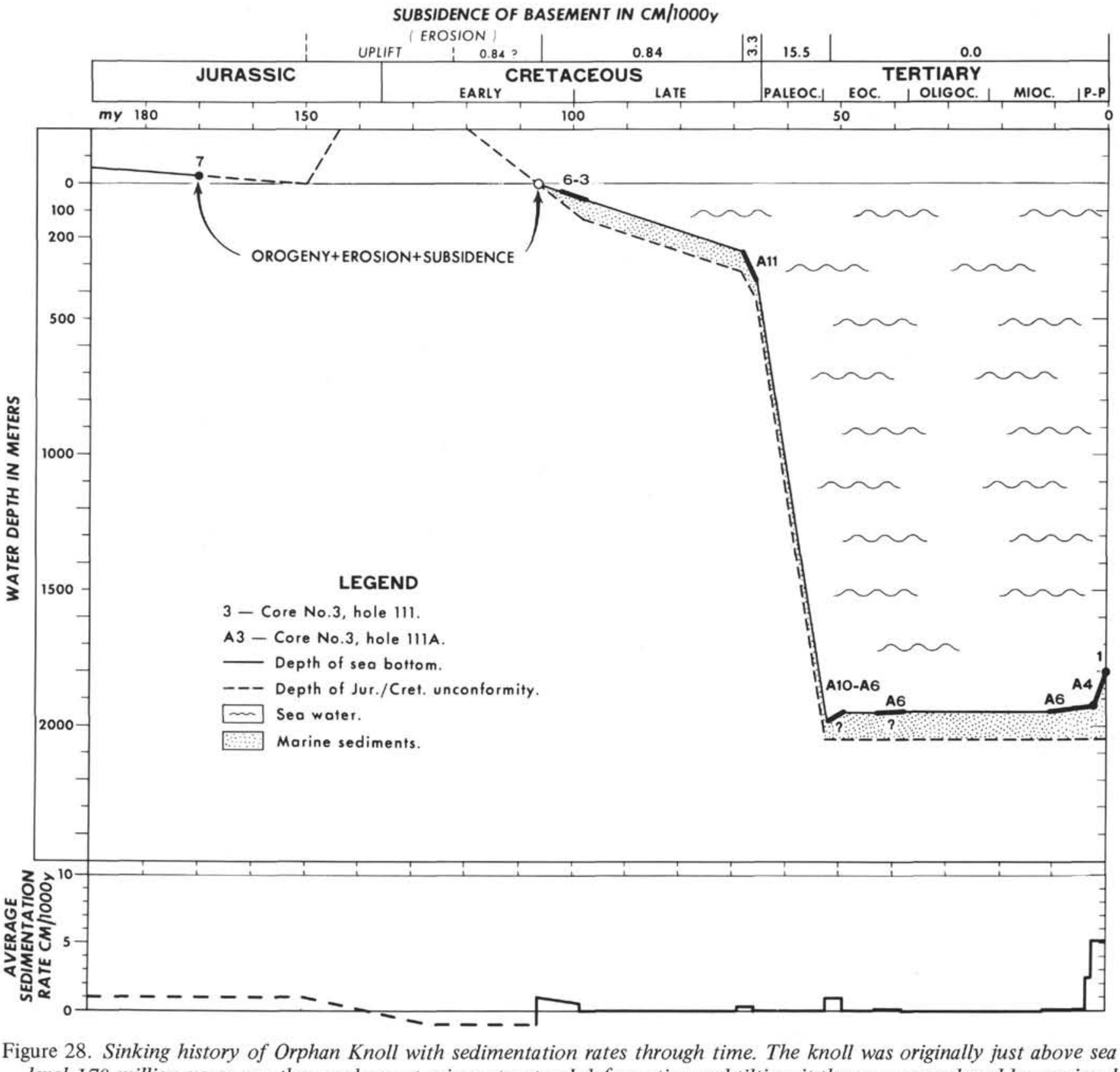

Figure 28. *Sinking history of Orphan Knoll with sedimentation rates through time. The knoll was originally just above sea level 170 million years ago then underwent minor structural deformation and tilting; it then was peneplaned by erosional forces. In early Albian it sank below sealevel and began to receive shallow water marine sedimentation. The main sinking occurred in the Paleocene, and the knoll has probably remained at the same depth ever since with pelagic sedimentation and lately glacial debris adding to the upper surface some 190 meters of sediment to bring it to its present depth of about 1800 meters. The sedimentation rates show the large increase of material during the recent glacial period and that the knoll only has 34 of the last 170 million years recorded in the stratigraphic column.*

frontispiece) the dramatic change from nonglacial to glacial conditions. Between this point 3 million years ago and the present, 145 meters of sediment with a high glacial content was added to the knoll at an average rate of 6.2 cm/1000 yr. The addition of ice-rafted material continues at the present time.

Thus of 170 million years of time represented at Orphan Knoll, we only have 34 million years actually recorded in cored sediment and 136 million years lost during four major unconformities (Figure 28). Subsidence of at least 2047 meters has occurred since the Bajocian with the major sinking in the Paleocene.

Reconstruction of North Atlantic

When Bullard *et al.* (1965) constructed their computer fit of the North American, Greenland and European coasts (Figure 29) little was known of the detailed coastal structure of the components of the jigsaw puzzle. The original fit assumed the two kidney-shaped banks, Hatton and Rockall, were contiguous, whereas Leg 12 has shown along with other evidence (see Chapter 8, this volume) that the whole of Rockall Plateau should probably be considered a single continental block. Similarly, as earlier discussed, Flemish Cap is now known to be continental, and Galicia Bank along the Vigo and Oporto Seamounts appear to be part of a large submarine extension of the Iberian continental block (Black *et al.*, 1964).

In the fit (Bullard *et al.*, 1965) one can see that Porcupine Bank was an area of overlap and a considerable underlap exists between Newfoundland and south England (Figure 29). The positions of Flemish Cap, Galicia Bank and Orphan Knoll are also shown. It is evident that the 590 million-year old granites of Flemish Cap and the shallow water Cretaceous carbonates of Galicia Bank present an absolutely incompatible overlap, as do the overlap of Orphan Knoll's Jurassic sands into the Devonian of Cornwall. Clearly the 1965 fit of Bullard et al. now needs refinement.

In Chapter 20 of this volume is presented a series of reconstructions showing the closure between Europe and North America to about Anomaly 31 at 72 million years. The reconstruction at 72 million years is reproduced here (Figure 30), and Orphan Knoll (Site 111) is shown. A recent fit by LePichon *et al.* (in press) is available but it has a severe overlap problem with Flemish Cap, Galicia Bank and Spain—though it does have room for Orphan Knoll.

The intriguing suggestion seen quite well on Figure 30 is that with Orphan Knoll being a continental block, perhaps

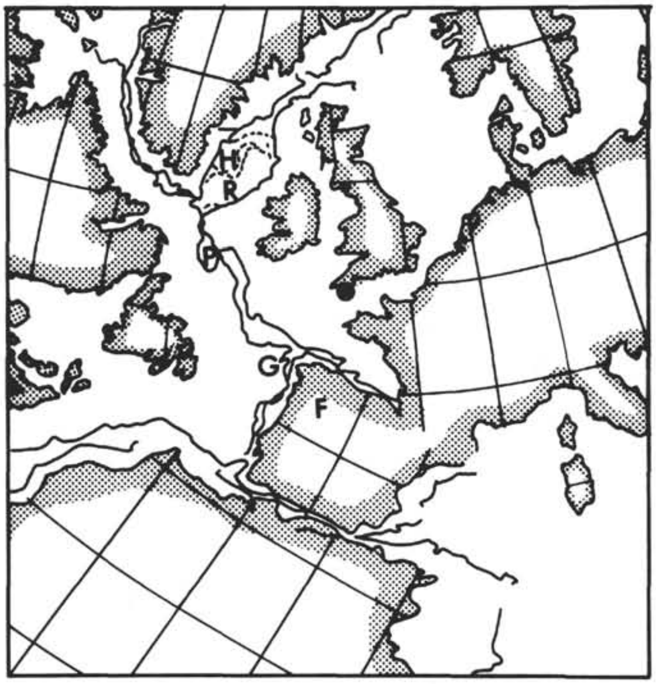

Figure 29. *The fit of Europe and North America from Bullard* et al. *(1965) showing Orphan Knoll as a black dot overlapping onto the Devonian of Cornwall. Rockall Bank (R) and Hatton Bank (H) are shown fitted together eliminating the Hatton-Rockall Basin. Porcupine Bank (P), and Galicia Bank (G) are both shown overlapping onto North America. Flemish Cap (F) is shown badly overlapping onto northern Spain. These overlaps are now known to generally involve rock of a predrift age, and this along with other data make the above large overlaps unacceptable.*

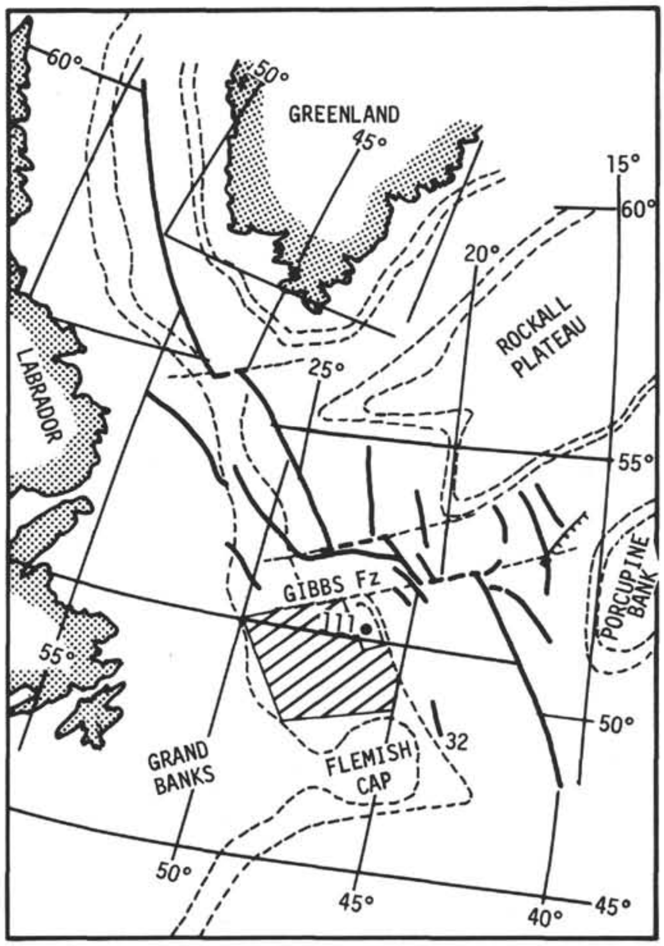

Figure 30. *A reconstruction of the North Atlantic at 72 million years taken from Chapter 20 of this volume. The black stripes represent linear magnetic anomalies on the ocean floor; transform faults are indicated as heavy dashed lines with their older extensions as a lighter dashed line. The estimated shelf edge and bottom of the continental slope are shown as dashed lines paralleling the continental margins. The shaded area west and south of Orphan Knoll (Site 111) is thought to be a vast area of subsided continental crust or possibly an area of primaeval oceanic crust now deeply buried by turbidite sequences.*

the whole shaded area may, indeed, all be subsided continental material with only the Knoll left standing high. In 1968, Kroenke and Wollard argued that there was a large deep sedimentary basin north of the Grand Banks. They based this on their studies of the *Eltanin* 2 magnetic and gravity data. The three southernmost aeromagnetic profiles of Hood and Bower (1971), which all cross the shaded area of Figure 30, tend to substantiate the above proposals. There appears to be a distinct lack of the oceanic type of magnetic anomalies over the shaded area on Hood and Bower's profiles and on those of *Eltanin* and *Glomar Challenger.*

If the above suggestion that a large area of continent has subsided is incorrect, then Orphan Knoll must have moved approximately due east during the initial rifting process before the spreading center jumped eastward and left the Knoll as an isolated block. If such is the case, then beneath the turidites to the west of the Knoll should lie an ancient spreading center and an associated strip of "ocean" floor bounded on the north and south by transform faults striking approximately east-west. The Charlie-Gibbs Fracture Zone could be one of these faults (Olivet *et al.*, 1970 a, b; Olivet *et al.*, in press).

The evidence for either suggestion is rather inadequate at the moment. Besides the above magnetic evidence, the bathymetry of the region (Figure 2) and a cursory correlation with the magnetic studies of Fenwick *et al.* (1968), would tend to support our suggestion that between Orphan Knoll and the North American continent lies a vast area of continental crust that has subsided in the order of 4000 meters. Any such major subsidence must have involved profound modifications to the base of the crust if the area is presently in isostatic equilibrium. These modifications are probably intimately associated with the initial rifting of a continental block prior to initiation of a process of ongoing continental drift.

ADDENDUM

Dredging from the USNS *Lynch,* in the summer of 1971 recovered shallow-water Devonian limestone believed to be from the narrow ridge-like structures (Layer 2). These samples have been reported on in Ruffman and van Hinte (in preparation), and the note was submitted to *Nature* in April, 1972. The ridges now appear to be erosional remanants of steeply dipping massive limestone beds. The continental nature of the Knoll is therefore further substantiated. Orphan Knoll appears to have been a relatively positive element lying close to sea level from at least the Devonian to the Early Paleocene, a period of about 300 million years.

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PLATE 1

Figure A — Core 7, Hole 111 (Orphan Knoll, 249 to 250 meters subbottom). Graded bed, sharp base on silty shale, gradational top. Coal . in coarse sandstone is Mississipian. (Photo J. v. Hinte, courtesy Imperial Oil Enterprises Ltd.).

Figure B — Core 3, Hole 111 (Orphan Knoll, 189 to 198 meters subbottom). Top of Cenomanian. Hardground in glauconitic calcarenite. (*ca.* × 1.5) (Photo J. v. Hinte, courtesy Imperial Oil Enterprises Ltd.).

PLATE 1

PLATE 1B

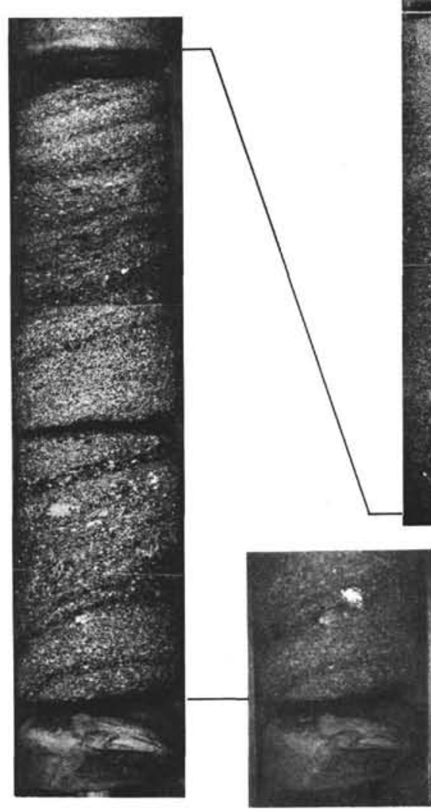


PLATE 1A

PLATE 2

Sections of Core 6, Hole 111A (Orphan Knoll, 143 to 152 meters subbottom).

PLATE 2

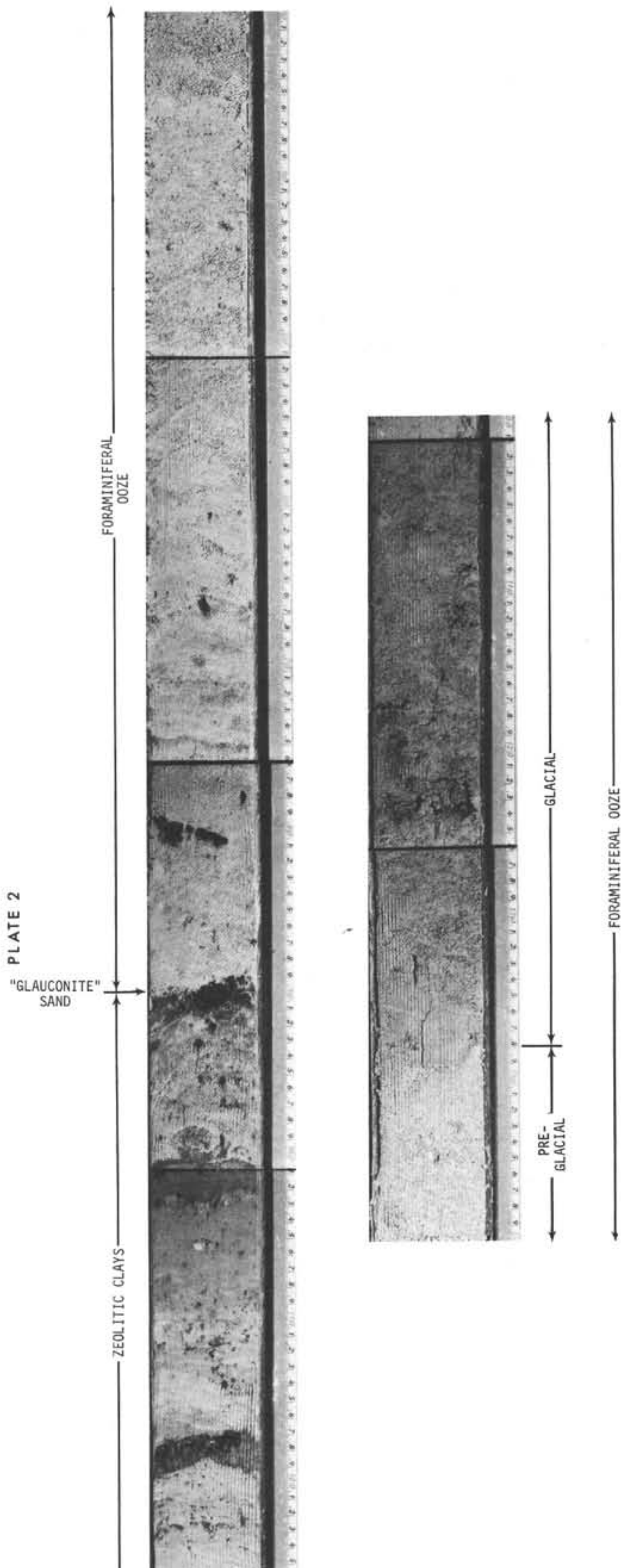

FORAMINIFERAL OOZE
"GLAUCONITE" SAND
ZEOLITIC CLAYS
GLACIAL
PRE-GLACIAL
FORAMINIFERAL OOZE

PLATE 3

Explanation

Quartz grains exhibiting evidence of glacial transport. Three specimens are figured (Figure 1, 4 and 7) and enlargements of each are shown below. All specimens are from 111-6-2, 139 to 140 centimeters, at the level at which glacially transported quartz grains first appear at this site. Specimens have been photographed by S. Honjo, H. Okada and K. Harada (W.H.O.I.) on a JEOLCO JSM-U3 scanning electron microscope.

Figure 1	Glacially transported quartz grain, X 11.
Figure 2	Enlargement of scalloped area in upper right corner of Figure 1, X 851.
Figure 3	Same, X 2553. Note sharply defined ridges and grooves which are evidence of glacial "plucking" and grinding.
Figure 4	Glacially transported quartz grain, X 77.
Figure 5	Same, X 426.
Figure 6	Same, X 1785. The mechanically gouged ridges and grooves in this specimen appear to have been subsequently smoothed, perhaps by aqueous transport, and the pitted surface suggests subsequent chemical corrosion.
Figure 7	Glacially transported quartz grain, X 296.
Figure 8	Same, X 1080.
Figure 9	Same, X 4467. The mechanically gouged ridge and groove system on this specimen is broader than that developed in the two specimens shown to the left on this plate. White bar indicates 10μ. Black bar indicates 100μ.

PLATE 3

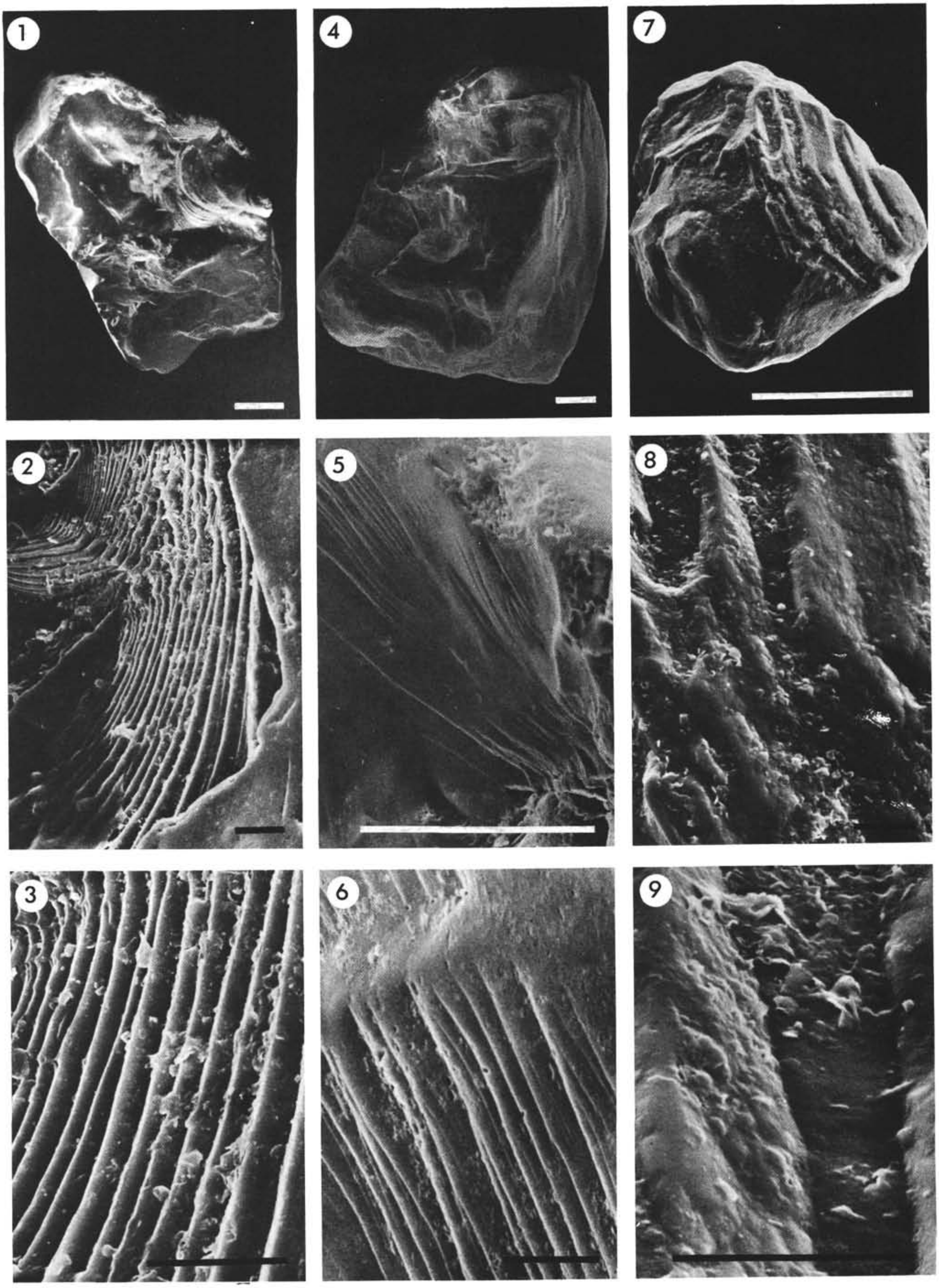


PLATE 4
SCANNING ELECTRON MICROSCOPE PHOTOGRAPHS OF CORE 7, HOLE 111

The photographs and descriptions presented on Plates 5 and 6 were prepared by A. Ruffman and kindly made available for incorporation in this report.

The pictures were taken of the broken surface of the sandstone (12-111-7-1, 55 centimeters) using a JEOLCO JSM-2 scanning electron microscope. The sample was cemented to a standard copper mount using silver paint. The sample was uncoated.

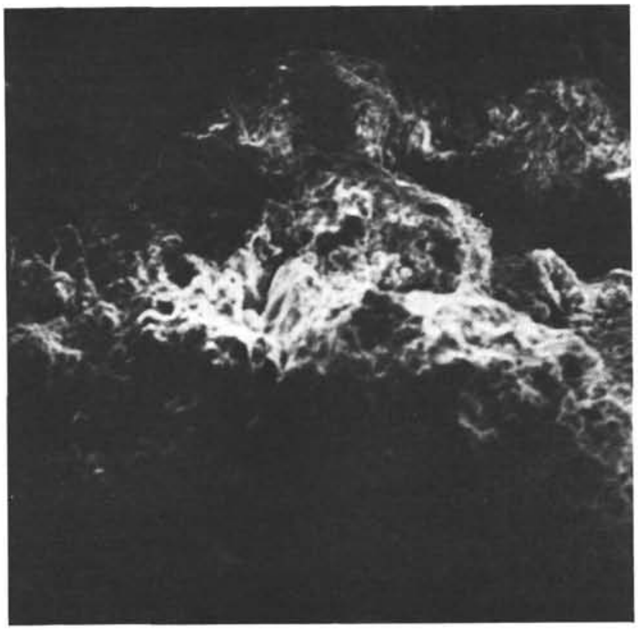
Figures A-D These four photos A to D are a sequence taken at magnification of 100X, 300X, 1000X and 3000X respectively.

Photo A shows an oblique view of a broken surface of the sandstone. Three grains can be seen more or less in line, each standing somewhat rounded but this may in fact be only apparent because of the coating of other mineralization. The surface of the grains appear to be covered with a drusy-like growth of crystals and hence has a rough appearance.

In photos B to D we come progressively closer and closer and are able to discern in C and D the familiar euhedral forms of calcite crystal growth. These photos also indicate the nature of the porosity of the rock. The porosity of the original sandstone is severely reduced by the secondary growth of calcite and exists presently only in spaces between the secondary calcite crystals.

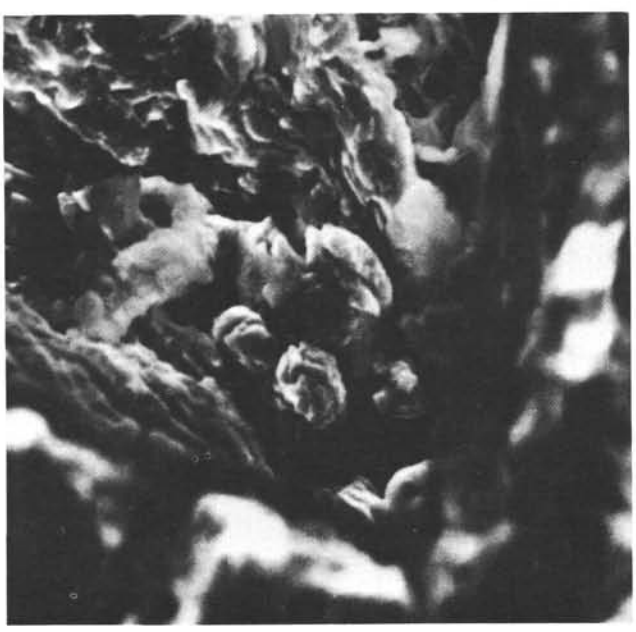
PLATE 4

SCALE: LENGTH OF BAR = 25 MICRON



A

B



C

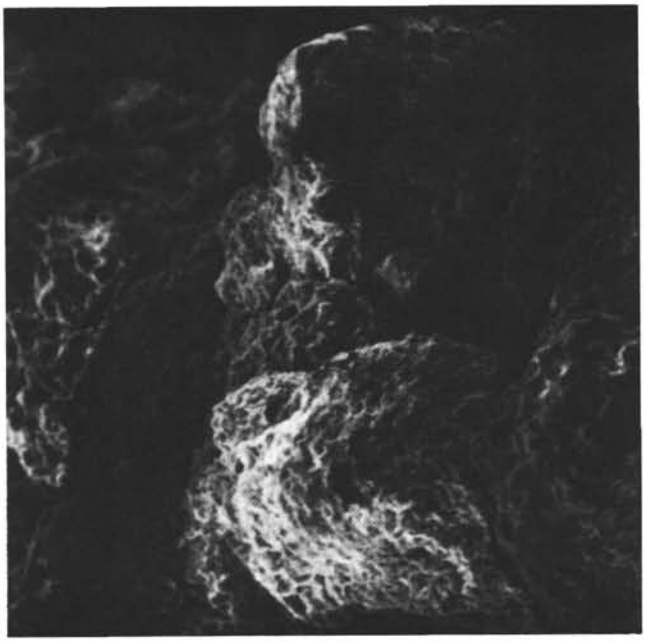
D

PLATE 5
SCANNING ELECTRON MICROSCOPE PHOTOGRAPHS OF CORE 7, HOLE 111

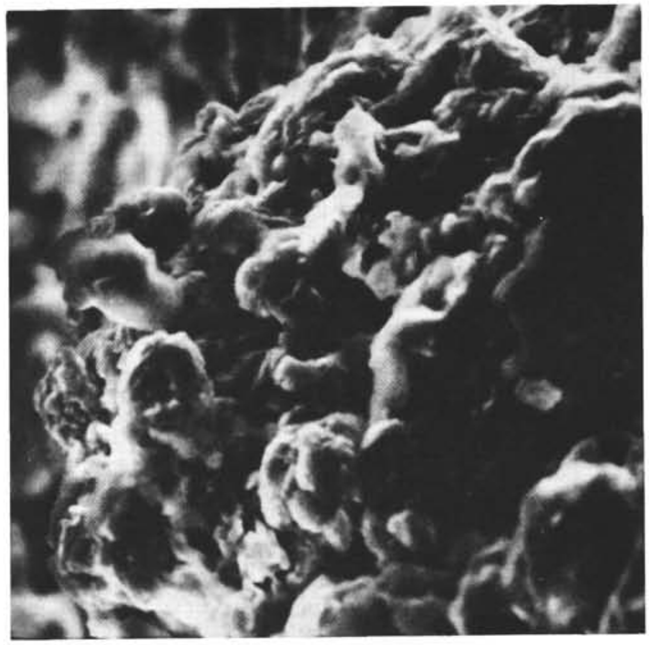
Photo A	This photo at 100X magnification shows a general aspect of the broken surface of the rock. One somewhat rounded grain is quite evident in the foreground with a dark pore space just above it. To the left a flat elongated grain can be seen. This may be a fragment of coal (anthracite) showing a flat fracture plane. Again the drusy-like calcite growth over the entire grains is evident.
Photos B and C	These two enlargements (1000X) show essentially anhedral calcite growth over the surface of a grain. This type of calcite growth is the most common and was seen everywhere on the sample's broken surface.
Photo D	This shot at 300X shows the general aspect of an area where the secondary calcite appears to have a fibrous nature. This type of growth was not common.

PLATE 5

SCALE: LENGTH OF BAR = 25 MICRON

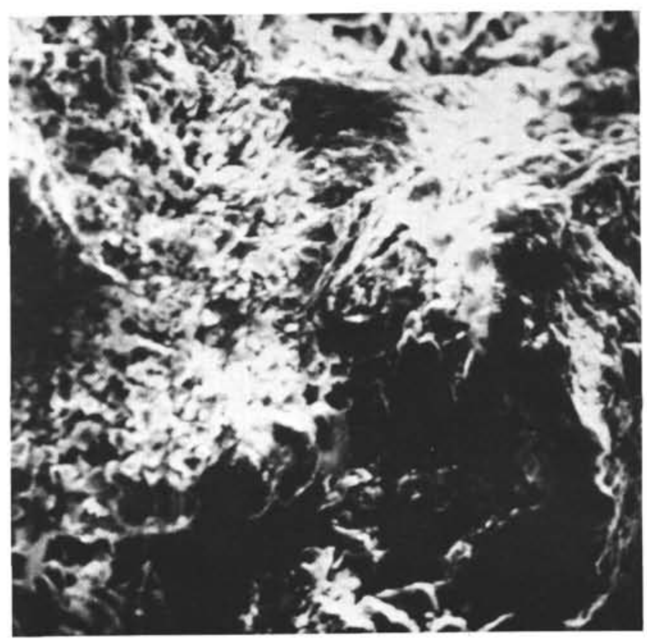


A



B

C



D

PLATE 6

PHOTOMICROGRAPHS OF CORE 7, HOLE 111

Figure A — Sample 54-61 cm (crossed nicols)
This overall view shows the sandstone to be composed mainly of lithic grains, including quartzitic sandstone, micaceous sandstone and variably silty argillites. In addition, a few smaller grains of quartz and carbonate are present, together with fragments of coal, all set in a matrix of carbonaceous mud.

Figure B — Sample 54-61 cm (crossed nicols)
In this view, grains of argillite predominate. The dark grain at top center is silicified carbonaceous shale. Below that, a fragment of skeletal carbonate rimmed with a coating of sideritic mud.

Figure C — Sample 53-55 cm (plane light)
The large grain in center is a fragment of fine grained micaceous sandstone. Note that it contains two dark laminae with fine coal fragments. The coal is believed to be of the same age as the large detrital coal fragments in the upper right corner, and probably was initially deposited as plant debris which subsequently became carbonized together with the coaly beds.

Figure D — Sample 53-55 cm (crossed nicols)
Detail view of the micaceous sandstone fragment shown in the previous photomicrograph. The mica flakes appear to be essentially of detrital origin and are most abundant in the coaly laminae, suggesting settling from suspension together with the plant debris.

Figure E — Sample 54-61 cm (crossed nicols)
The components include a large fragment of fine-grained skeletal-micritic limestone (left) and of micaceous sandstone (upper right). Remaining grains are argillite, coal and a trace quartz.

Figure F — Sample 54-61 cm (crossed nicols)
This photomicrograph depicts two types of carbonate grains, both rimmed with a dark coating: (1) a fragment of micritic limestone, and (2) a skeletal fragment. The space between the grains is infilled with calcite cement. Cement as well as coating contain small spherulites of siderite. Other components include quartzitic sandstone, micaceous sandstone and argillite.

PLATE 6

SCALE: LENGTH OF BAR = 0.5 MM

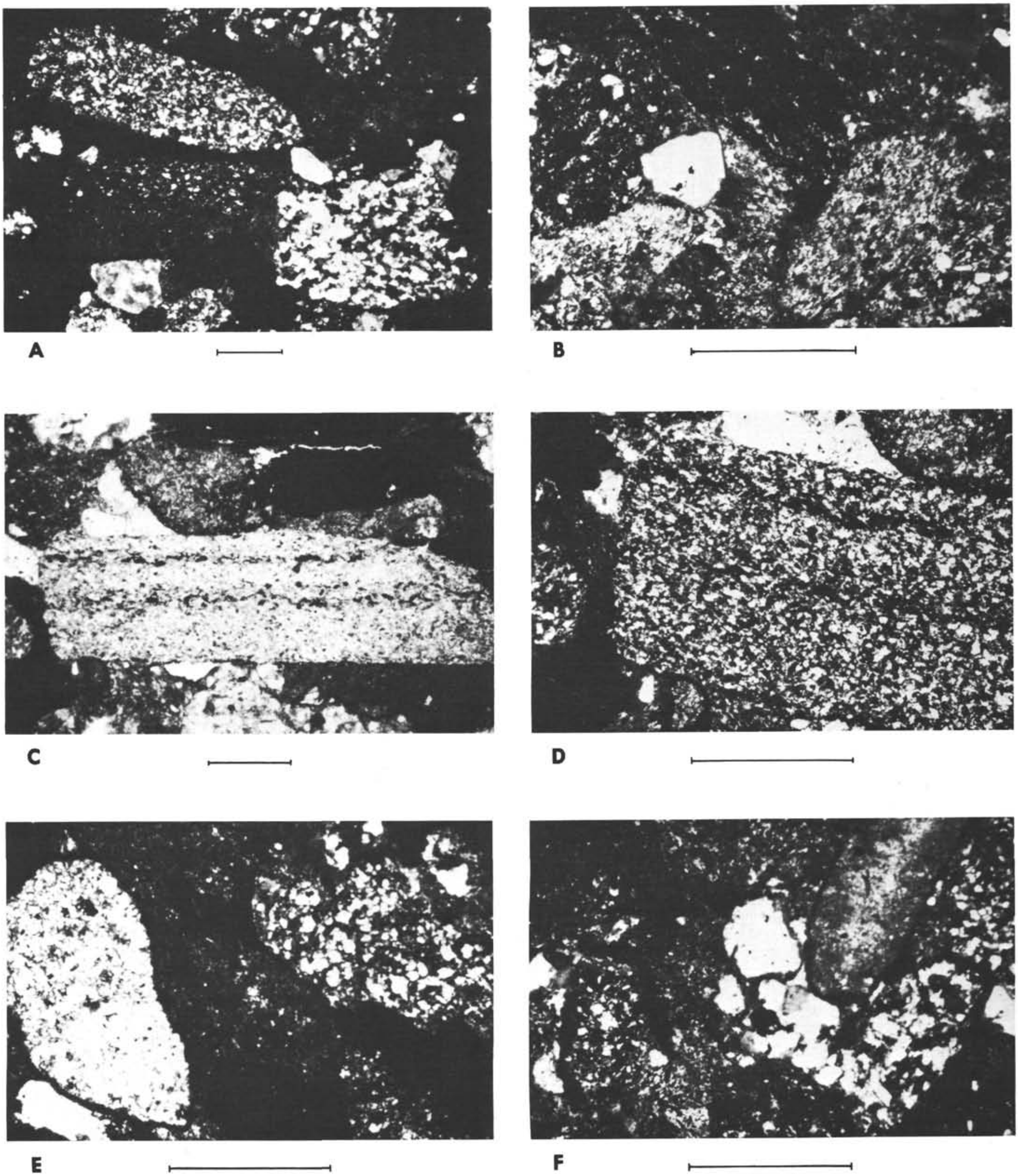


PLATE 7
PHOTOMICROGRAPHS OF CORE 7, HOLE 111

Figure A — Sample 53-55 cm (crossed nicols)
This close-up depicts one of the rare single feldspar grains (twinned plagioclase) that were observed in the sediment, together with a large fragment of argillite. Interstices are infilled with variably carbonaceous sideritic mud (abundant spherulites just south and west of feldspar crystal) and calcite cement (partially replacing the feldspar).

Figure B — Sample 54-61 cm (crossed nicols)
Quartz, like feldspar, is rather sparse in the sediment. Some crystals exhibit remarkably sharp euhedral outlines, as the one portrayed here (gray). Possibly these grains are of diagenetic origin, but it seems more likely that they were derived as euhedral grains from the source area and were only little affected by the transport.

Figure C — Sample 53-55 cm (crossed nicols)
The carbonate fragment in this photomicrograph displays a finely fibrous texture, as is common in skeletal debris derived from Mollusks (Gastropods or Pelecypods). Fragments like these testify to the organic origin of the carbonate. Other components include argillite and micaceous sandstone.

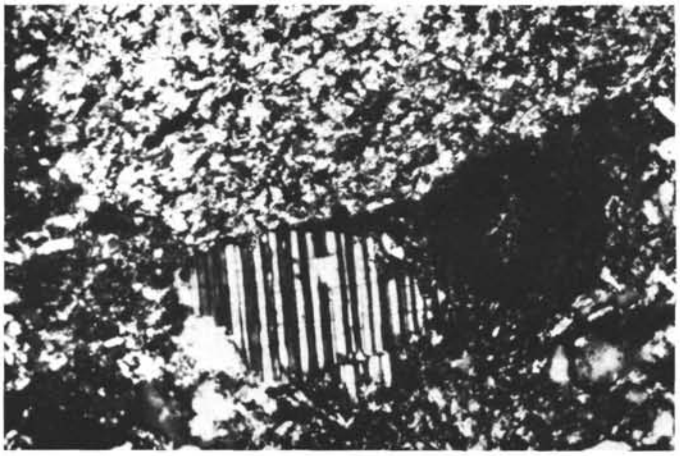
Figure D — Sample 20-23 cm (crossed nicols)
The fine-grained sandstone is made up of essentially the same components as the coarse-grained varieties portrayed above, but the proportion of the components differs. Quartz grains are most plentiful, whereas rock fragments are sparser. Note also carbonate fragments (center, and to southwest). Dispersed throughout the muddy matrix are numerous minute dolomite grains.

Figure E — Sample 64 cm (crossed nicols)
The rock is a finely sandy micritic mudstone and is composed of matrix material containing floating quartz grains, mica flakes and other mineral remnants. The matrix consists of an intimate mixture of clay minerals and minute carbonate grains in about equal proportion.

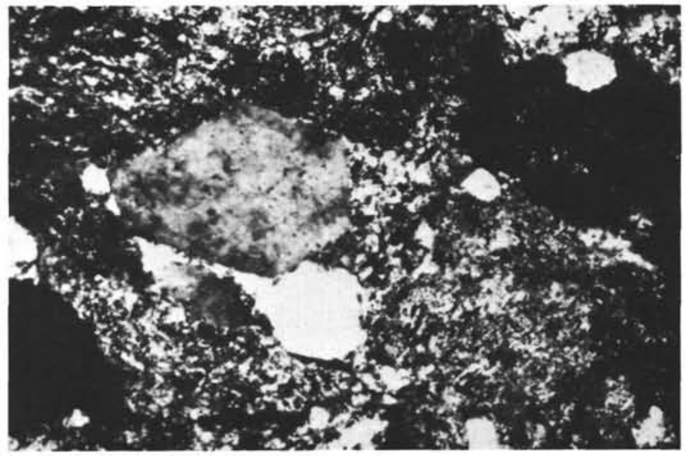
Figure F — Sample 64 cm (crossed nicols)
Close-up of the same sample as portrayed in E. This detailed view of the matrix shows the admixed carbonate grains to consist of very small dolomite rhombs, about 3-5 micron in size. The rhombs in all likelihood result from dolomitized micrite particles which occurred throughout the mud. A larger grain of detrital carbonate is seen northeast of the center.

PLATE 7

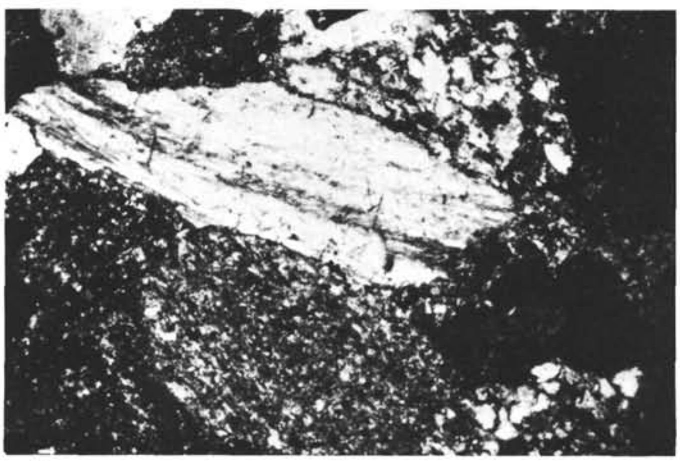
SCALE: LENGTH OF BAR = 0.5 MM



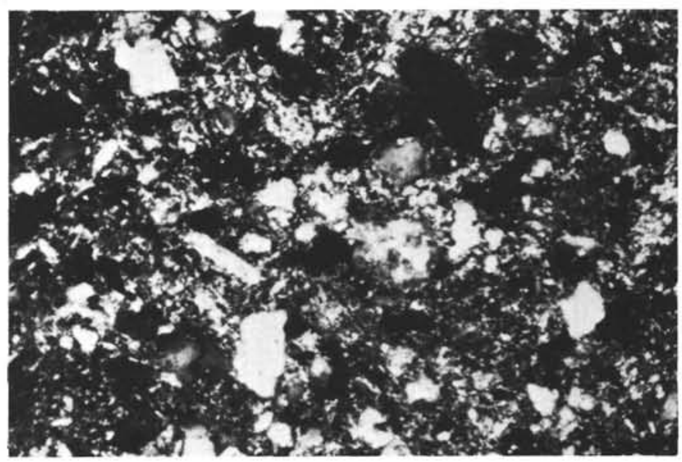
A



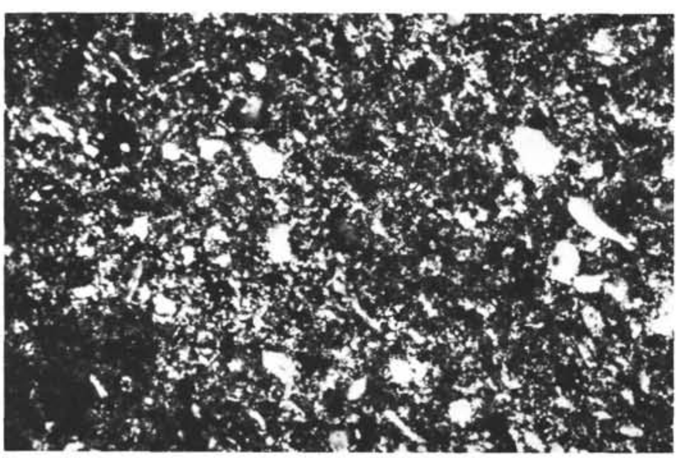
B



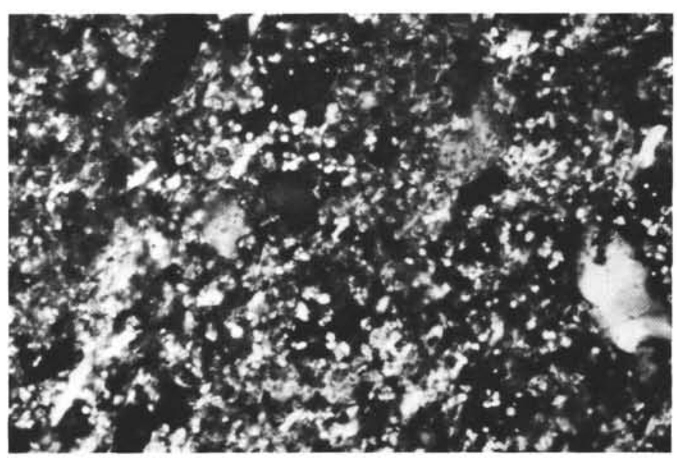
C



D



E



F

PLATE 8
PHOTOMICROGRAPHS OF ALBIAN-CENOMANIAN AND MAESTRICHTIAN LIMESTONES HOLES 111 AND 111A, ORPHAN KNOLL

Figure A	Sample 111-4-CC (plain light, scale bar 1.0 mm). Cenomanian limestone, clean very fine-grained calcarenite tightly cemented by sparry calcite, typical of the Albian-Cenomanian lithology. Note allochems, mainly foraminifera and microcrystalline peloids.
Figure B	Sample 111-5-CC (crossed nicols, scale bar 0.2 mm). Albian limestone, echinoid fragment enlarged by precipitation of epitaxial calcite cement. Note smaller glauconite pellet.
Figure C	Sample 111-3-2, 42 cm. (plain light scale bar 1.0 mm). Cenomanian limestone, muddy very fine-grained calcarenite. Note sparry calcite in leached skeletal fragments.
Figure D	Sample 111A-11-CC (plain light, scale bar 0.2 mm). Maestrichtian foraminiferal marl. Note lack of large terrigenous grains and sparite calcite cement. Foraminiferal chambers empty except for occassional linings of clay minerals.

PLATE 8

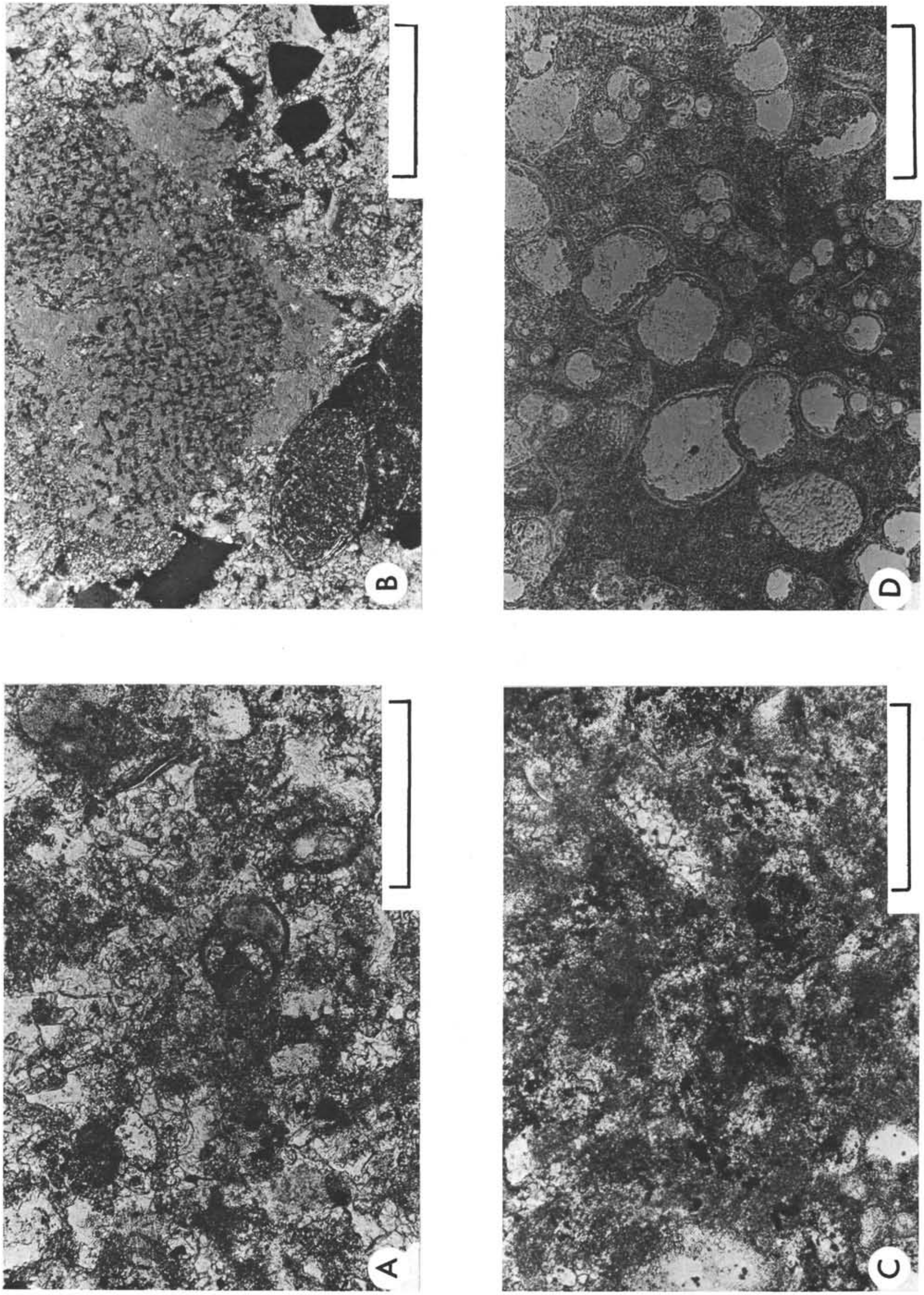


PLATE 9
PHOTOMICROGRAPHS OF NODULAR HORIZON AT
CENOMANIAN-MAESTRICHTIAN CONTACT,
SAMPLE 111A-11-CC, HOLE 111A, ORPHAN KNOLL

Top	Macroscopic view of pebbles and location of subsequent photomicrographs (see Figure 14 for sketch).
Figure A	Plain light, scale bar 0.2 mm. Well-sorted, tightly cemented calcarenite making up the center of each nodule. Note similarity to Cenomanian calcarenite in Plate 8A.
Figure B	Plain light, scale bar 0.2 mm. Calcarenite towards the periphery of nodule. Note cement between allochems, the second stage of which is brown scalenohedra, succeeded in places by clear sparry calcite.
Figure C	Plain light, scale bar 0.2 mm. Periphery of nodule coating. Note relatively large allochems, especially prisms of calcite, in a dark brown cement, which is dominantly goethite and carbonate-apatite.
Figure D	Plain light, scale bar 0.2 mm. Sediment between nodules, large terrigenous grains in a planktonic foraminiferal marl matrix. Note similarity between this matrix and the Maestrichtian marl in Plate 8D.

PLATE 9

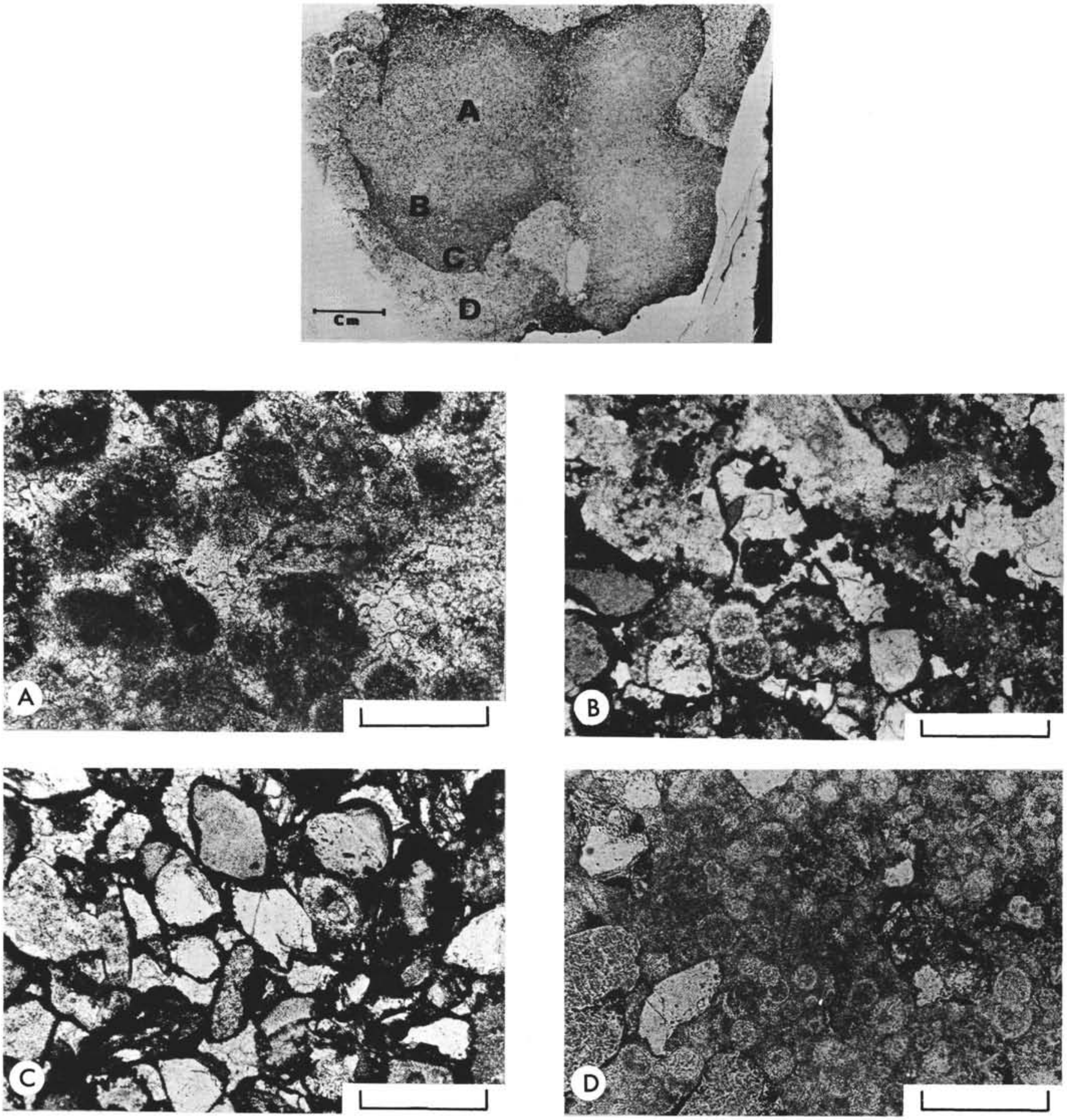


PLATE 10
SHORE LABORATORY REPORT ON
MESOZOIC PLANKTONIC FORAMINIFERIDA

Figure 1 *Racemiguembelina* sp.
This form appears to be a new species derived from *Pseudotextularia intermedia* de Klasz and is not directly related to *Racemiguembelina fructicosa* (Egger). Site 111A, Core 11, Section 2: 76-79 cms. Late Maestrichtian: *Abathomphalus mayaroensis* Subzone. Marker = 200 microns.

Figure 2 *Pseudotextularia intermedia* de Klasz
This species is a consistently good marker for the base of the *Abathomphalus mayaroensis* Subzone both in DSD and land based samples. It seems to be restricted to the lower part of the zonal unit. Site 111A, Core 11, Section 2: 76-79 cms. Late Maestrichtian: *Abathomphalus mayaroensis* Subzone. Marker = 200 microns.

Figure 3 *Pseudotextularia elegans* (Rzehak) transitional to *P. intermedia* de Klasz. Note lobate nature of next to last chamber. Site 111A, Core 11, Section 2: 76-79 cms. Late Maestrichtian: *Abathomphalus mayaroensis* Subzone. Marker = 200 microns.

Figure 4 *Planoglobulina acervulinoides* (Egger)
Site 111A, Core 11, Section 2: 76-79 cms. Late Maestrichtian: *Abathomphalus mayaroensis* Subzone. Marker = 200 microns.

Figures 5, 6 *Abathomphalus mayaroensis* (Bolli)
Spiral and umbilical views of separate specimens. Site 111A, Core 11, Section 2: 76-79 cms. Late Maestrichtian: *A. mayaroensis* Subzone. Marker in Figure 5 = 200 microns; marker in Figure 6 = 100 microns.

PLATE 10

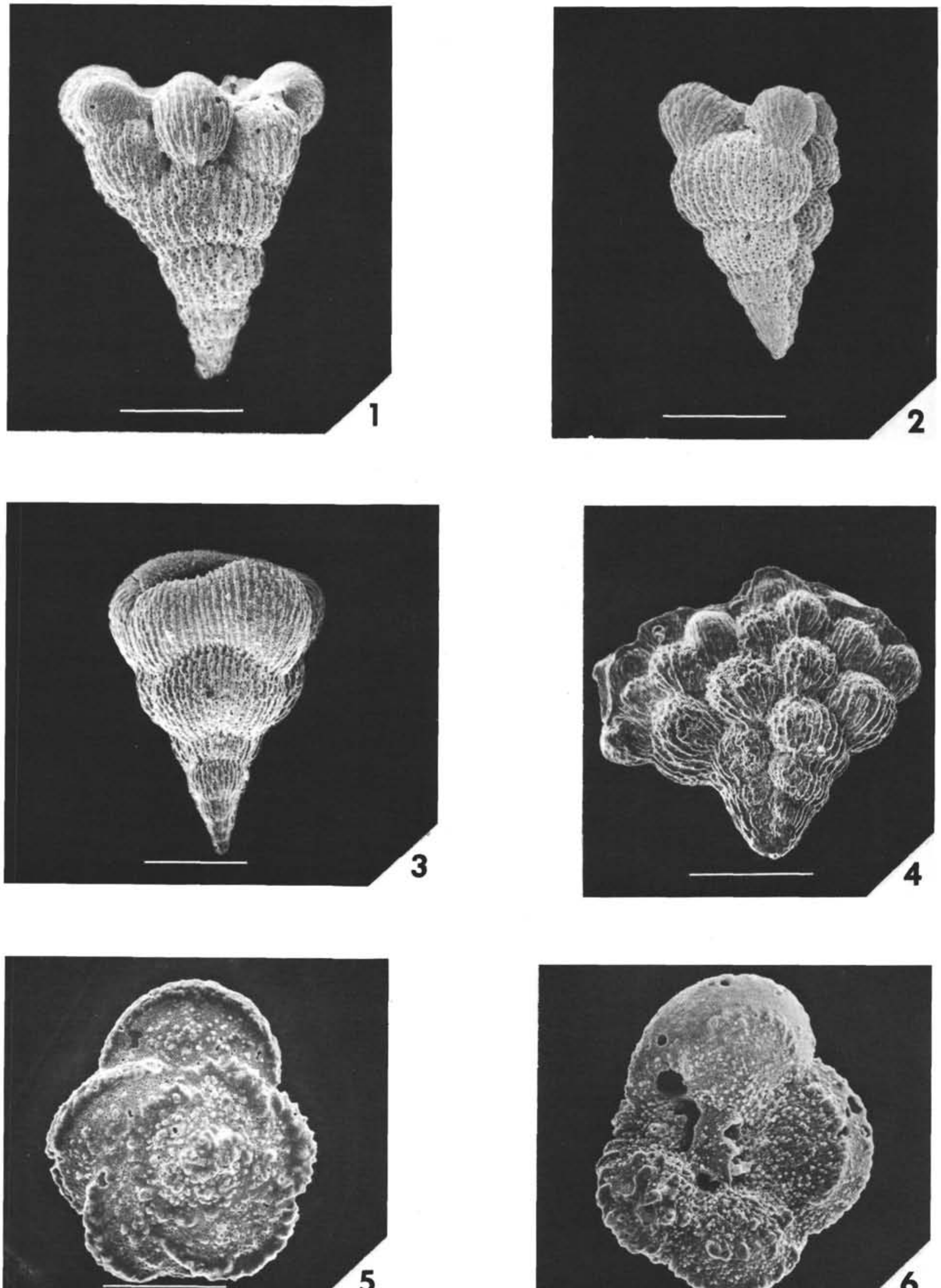
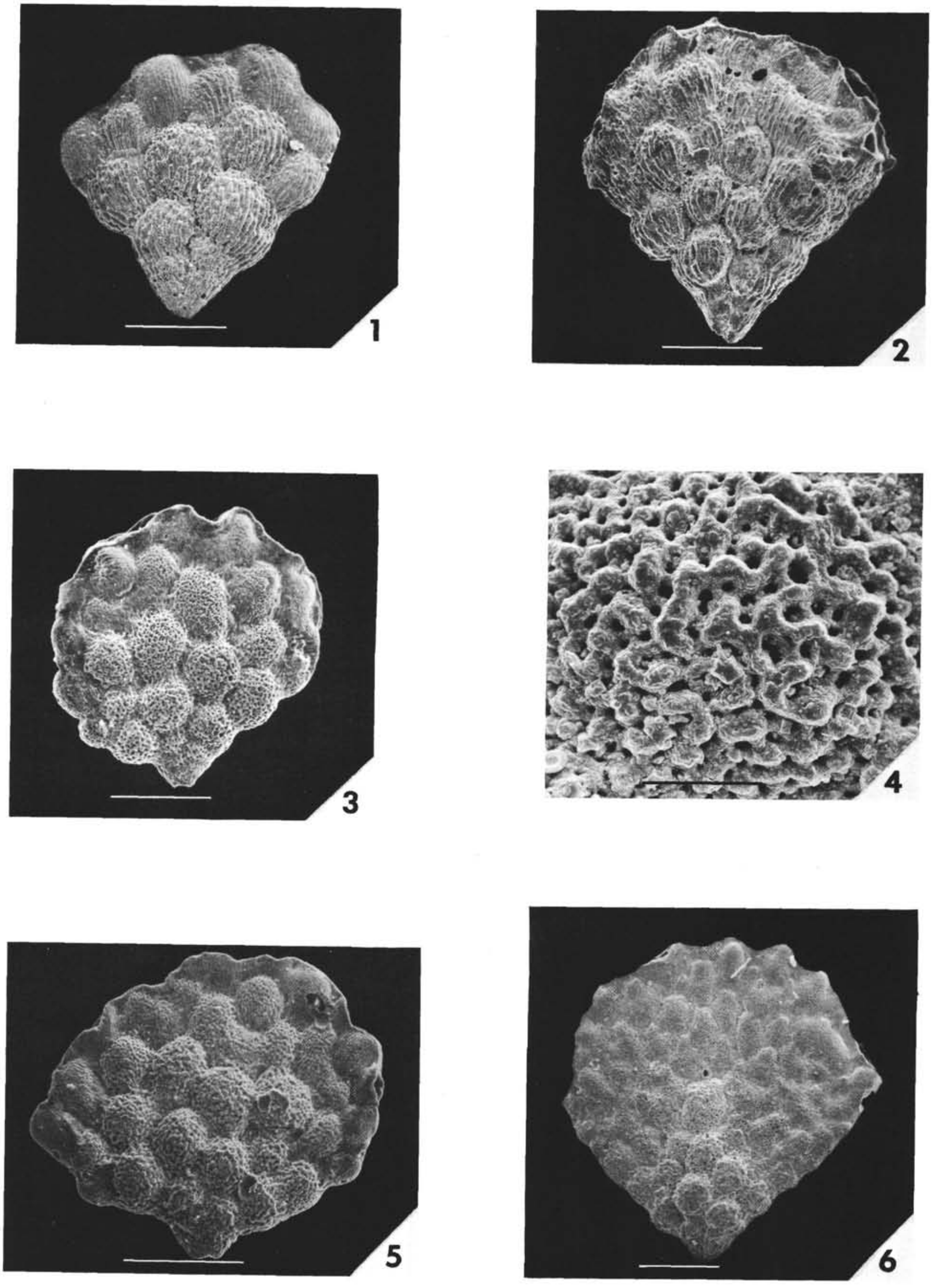


PLATE 11
SHORE LABORATORY REPORT ON
MESOZOIC PLANKTONIC FORAMINIFERIDA

Figure 1	*Planoglobulina brazoensis* Martin Site 111A, Core 11, Section 2: 76-79 cms. Late Maestrichtian: *A mayaroensis* Subzone. Marker = 200 microns.
Figure 2	*Planoglobulina acervulinoides* (Egger) Site 111A, Core 11, Section 2: 76-79 cms. Late Maestrichtian: *A. mayaroensis* Subzone. Marker = 200 microns.
Figures 3-5	*Ventilabrella manuelensis* Martin Note fan-shaped test with vermicular ornamentation (Figure 4). Site 111A, Core 11, Section 6: 77-80 cms. Latest Campanian: *G. calcarata* Zone. This species is a good marker for the late Campanian and early Maestrichtian: *G. elevata* Subzone, *G. calcarata* Zone to *R. subcircumnodifer* Subzone, *R. subpennyi* Zone. Markers = 200 microns in Figures 3 and 5; marker in Figure 4 = 40 microns.
Figure 6	*Ventilabrella multicamerata* de Klasz Note vermicular ornamentation and arrow head shape of test. Site 111A, Core 11, Section 2: 76-79 cms. Late Maestrichtian: *A. mayaroensis* Subzone. Marker = 200 microns.

PLATE 11



APPENDIX A. SHIPBOARD SMEAR SLIDE OBSERVATIONS

Site Hole	Core	Section	Interval (cm)	Sand	Silt	Clay	Quartz	Feldspar	Pyroxene	Chlorite	Dark Mica	Light Mica	Dark Glass	Light Glass	Palagonite	Glauconite	Phosphorite	Pyrite	Auth. Carb.	Barite	Phillipsite	Other Zeolite	Micronodules	Other Minerals	Abundance	Estimated Carbonate	Foraminifera	Calcareous Nannofossils	Diatoms	Radiolaria	Sponge Spicules	Plant Debris	Fish Debris	Lithology and Comments
111	1	CC		C	A	A	D	R	R	R	R	R														30	R	A			R	R		Gravelly silty clay on smear slide. Acid residue showing 80% quartz, angular to subrounded; less than 10% feldspar, pyroxene and mica; rest are heavy minerals; also silicified ? Ordovician Chitinozoa.
111	2	CC		R	R	D	A		R	R								R								30		C						Clayey mud; many quartz grains show solution rims.
111	2	1	20	R	D	C	X				X													X	C									Fine silty clay; mostly rock flour composed of fine grains of mixed detrital minerals.
111	2	2	70	C	A	A	C																	X	D									Mostly rock flour with some grains fine quartz sand; other minerals include clays silty clay.
111	2	3	10		A	D	A																			50		R						Silty clay.
111	2	3	70	R	A	D	C																	X	C									Fine silty clay; mostly quartz grains, some green amphibole, rutile; other minerals detrital.
111	2	4	41	C	A	C	A																											Fine silty sand; mostly quartz grains some green amphibole.
111	2	4	123	R	A	A	C																					R	R					Silty clay.
111	2	5	115	C	A	A	A																			35	R	C						Marl; sandy mud with nannofossils and rare foraminifera; mostly broken foraminifera, blue-green amphibole, quartz, calcite.
111	2	5	115	A	D	C	C	R	R									R								40	R	R						Clayey, sandy silt.
111	2	6	86	C	R		C		R		A															90	D							Silty fine sand planktonic foraminifera, all sand-sized, plus a few benthonics; quartz common; greenish mica abundant; hornblende and heavy minerals rare; other minerals include greenish quartzite fragments.
111	3	CC		C	A	C	C									C											C	R						Some calcite rhombs.
111	3	1	105	R	D	A	R																		R	80	A							Clayey silt; benthonic foraminifera and aggregates of calcite main components; few quartz grains, blue-green amphibole, rutile.
111	3	1		C	A	C	C																	X	C									Rutile fragments very common; no glauconite.
111	3	1		A	C		C								R			C						X		65	A	A						Silty calcareous sand with many calcareous nannofossils, planktonic, foraminifera; other minerals include common hematite.

D = Dominant, 65+%; A = Abundant, 41%-65%; C = Common, 16%-40%; R = Rare, 0%-15%.

Site Hole	Core	Section	Interval (cm)	Sand	Silt	Clay	Quartz	Feldspar	Pyroxene	Chlorite	Dark Mica	Light Mica	Dark Glass	Light Glass	Palagonite	Glauconite	Phosphorite	Pyrite	Auth. Carb.	Barite	Phillipsite	Other Zeolite	Micronodules	Other Minerals	Abundance	Estimated Carbonate	Foraminifera	Calcareous Nannofossils	Diatoms	Radiolaria	Sponge Spicules	Plant Debris	Fish Debris	Lithology and Comments
111	3	1	112	D	C		C		R			R							A							70	R				R			Thin section of 2 cm large pebble with brown rim and matrix. Pebble and matrix of same composition, intrasparite, slightly micritic with few biogens (plankton and benthonic foraminifera); carbonate matrix micritic to sparry. Acid residue: 70% quartz, angular, 10% glauconite, rounded, partly foraminiferal-pseudomorphs or altered into limonite (20%). Few hornblende grains.
111	3	2	137	C	D	A	A					R														30	R	A						Clayey silt with small amount of glauconite.
111	3	2	54	R	D	R	C				R	R				C								X		70	R	R						Carbonate silt with glauconite and quartz. Acid residue mostly quartz, mica-rare, glauconite–abundant, many foraminifera carbonate (?dolomite)–common, sponge spicules present; glauconite appears to be bleached.
111	6	CC		A	A	R	C					R				C			C							80	R							Very hard calcarenite.
111	7	CC			C	A	C																			10								Silty clay; silt is calcitic; other minerals include rare tourmaline.
111	7	1	54	A	D	A	D		C		C																							Sandy silt; quartz mostly, but about 5-10% colored minerals.
111	7	1	10		A	A	C	C			R															15								Silty clay; feldspars altering to clay minerals; no fossils; rare altered mica.
111	7	1	40	C	D	C												C								20		R						Silty sand with pyrite.
111	8	CC		R	C	D	A																					A						Silty clay.
111A	1	CC		C	A	A	C	R	R	R								C								20	R	R						Silty sandy clay, dark grey.
111A	1		110	R	D	A	C	R	R	R	R	R						R								15	R	C						Sandy clayey silt, dark gray.
111A	1	1		R	A	A	C	R																				R						Silty clay.
111A	1	4	70	R	A	A	C	R								R												R						Silty clay.
111A	1	5	47	R	C	R	C	R																										Clayey sandy silt.
111A	1	5	70	R	R	A	D									R												C						Sandy silty clay; possible broken foraminiferal chambers giving uniaxial positive interference figure.
111A	1	6	75	R	R	D	A	R								R						A						R						Zeolitic clay.
111A	2	CC		R	C	A	C	R	R	R		R				C		C						X		10	R	R						Silty clay with glauconite (reworked from cretaceous with typical glauconitized foraminifera; other minerals-dolomite (?).

APPENDIX A – *Continued*

Site Hole	Core	Section	Interval (cm)	Sand	Silt	Clay	Quartz	Feldspar	Pyroxene	Chlorite	Dark Mica	Light Mica	Dark Glass	Light Glass	Palagonite	Glauconite	Phosphorite	Pyrite	Auth. Carb.	Barite	Phillipsite	Other Zeolite	Micronodules	Other Minerals	Abundance	Estimated Carbonate	Foraminifera	Calcareous Nannofossils	Diatoms	Radiolaria	Sponge Spicules	Plant Debris	Fish Debris	Lithology and Comments
111A	2	1	108	C	C	A	C			R								R						X		10		R						Sandy silty clay; other minerals include rare hornblende and other heavy minerals.
111A	2	2	5	C	C	A	D			R								R			R					10	R	R						Sandy silty clay.
111A	2	3	75	C	C	A	C	R		R	C	C				R						R		X		10	R	X						Sandy silty clay; other minerals include rare hornblende.
111A	2	4	75	C	C	A	A			R	R	R						R				C		X		15	R	R						Sandy silty clay; unsorted glacial debris, other minerals include common hornblende.
111A	3	CC		R	A	D	R	R	R	R	R	R				X		R								10	R	R						Silty clay.
111A	3	1	106	R	C	D	D			R		R										R		X		5	X	X						Silty clay; clay lumps, other minerals include rare hornblende.
111A	3	1	138	C	D	R	A	R		R				R							R			X		30	R	A						Sandy silt; other minerals include hornblende (R).
111A	3	2	75	C	A	D	A	R																X		5								Silty sandy clay; other minerals include hornblende (R).
111A	3	3	75	C	A	D	A	R	R															X		5								Clayey silt; other minerals include hornblende (R).
111A	3	3	135	C	C	D	A	R	R																	5								Sandy silty clay; other minerals include hornblende (R).
111A	3	4	75	C	C	A	A	R														R				5								Sandy silty clay; other minerals include hornblende (R).
111A	4	CC		R	D	C	R		R								R		R							90	A	A						Clayey sandy silt, gray.
111A	4	1	100	C	C	D	A			R	R	R												X			R							Sandy silty clay, other minerals include heavy minerals (R).
111A	4	2	50	A	D	R	D	R	A	R						R		R				R				60	C	D						Sandy nannofossil marl.
111A	4	2	94		C	D																					R	R						Silty clay.
111A	4	2	145	R	D	R	R	R			R										R					10	R							Clayey silt.
111A	5	CC		R	D	A	C	R	R	R		R				R		C						X		15	R	C						Clayey sandy silt; glauconitic, other minerals include dolomite (?).
111A	5	1	75	C	A	R	D	R														R		X		30	A	A						Sandy silt; other minerals include hornblende (C).
111A	5	4	91	R	C	C	R																			80	A	D						Nannofossil marl.
111A	5	4	120	A	C	C	D											C				R		X			X	R						Sandy clay; other minerals include hornblende (C).
111A	5	5	46	D	A	R	D	R		R														X		30	C	A						Silty sand; other minerals include hornblende (R).
111A	5	5	75	R	R	D	D					R						R						X		10	R	R						Silty sandy clay; other minerals include hornblende (R).
111A	6	CC				D															A						R	C						Pelagic, zeolite clay with nannofossils, yellow-light gray.
111A	6	2	10	R	R	D	D			C												R				60	R	D						Silty clay.
111A	6	2	40	R	D	A	D																			60	C	D						Clayey silt marl.
111A	6	2	145	C	A	R	R			R						R											A	D						Sandy silt; foraminifera partially glauconitized.

Site Hole	Core	Section	Interval (cm)	Sand	Silt	Clay	Quartz	Feldspar	Pyroxene	Chlorite	Dark Mica	Light Mica	Dark Glass	Light Glass	Palagonite	Glauconite	Phosphorite	Pyrite	Auth. Carb.	Barite	Phillipsite	Other Zeolite	Micronodules	Other Minerals	Abundance	Estimated Carbonate	Foraminifera	Calcareous Nannofossils	Diatoms	Radiolaria	Sponge Spicules	Plant Debris	Fish Debris	Lithology and Comments
111A	6	3	60	C	D	C	R									R										60	A	D						Silty nannofossil-foraminiferal marl.
111A	6	3	102	R	R	D								A							D			X		5								Zeolitic, shardy clay (montmorillonite); zeolites are twinned; other minerals include montmorillonite (D).
111A	6	3	103	R	R	D								R				R			D					5								Zeolitic montmorillonite clay.
111A	6	3	133	R		D								R							D			X		30	X	D						Zeolitic nannofossil clay; manganese burrows and nodules; other minerals include (?) dolomite rhombs.
111A	7	CC			C	D															A			X		15		A						Pelagic, zeolitic nannofossil clay; other minerals rare.
111A	7	4	143	R	A	D															A					30	R	A						Zeolitic nannofossil clay.
111A	8	1	100	R	D	C	X														R			X		70	R	D						Clayey silt; nannofossil marl; other minerals include rare clays.
111A	8	2	125	R	D	A															C					65	R	D						Nannofossil marl.
111A	9	1	12	R	D	R	C														C						R	C						Cherty nannofossil marl; phillipsite is somewhat corroded.
111A	9	1	45	C		C	R									R										80	A							Has many foraminifera, both silicified and carbonate.
111A	9	1	120	X	A	C				R											C	R				50	R	A						Clayey nannofossil marl.
111A	10	CC			D	A	R														C					70	R	D						Silty nannofossil marl ooze with zeolites.
111A	10	1		R	A	A	R														C			X		60	R	A						Silty clay; nannofossil marl; other minerals include common clays.
111A	10	2	10	X	A	A															C			X		50	R	A						Silty nannofossil clay; other minerals include abundant clays.
111A	10	4	40		D	A															C					40	R	D						Zeolitic nannofossil marl.
111A	10	4	139	R	A	A															C					50	R	A						Zeolitic nannofossil marl.
111A	11	CC		R	D	C	R																	X		95	C	D						Slightly silicified nannofossil chalk ooze.
111A	11	1	143	R	D	C	R									X						X				90	C	D						Nannofossil chalk.
111A	11	3	15		D	R																				90	C	D						Chalk ooze; other minerals include *Inoceramus* fragments (C).
111A	11	4	15	R	D	C	R																	X		90	C	A						Nannofossil chalk ooze; other minerals include chalcedony (C).
111A	11	5	40	C	D	R	R																			80	C	D						Nannofossil chalk ooze; other minerals include *Inoceramus* fragments (R).
111A	11	5	100	R	A	C	R																			90	R	A						Nannofossil chalk ooze; other minerals include shell fragments (*Inoceramus*).
111A	11	6	75	C	D	R	R																	X		90	C	D						Nannofossil chalk ooze; other minerals include chalcedony (C) and *Inoceramus* fragments (R).
111A	12	1			D	A				R											A					30	R	A						Zeolitic clayey nannofossil marl ooze.

APPENDIX B. GRAINSIZE DETERMINATIONS ON SAMPLES FROM SITE 111[1]

Hole	Core	Section	Interval	Per Cent Sand	Per Cent Silt	Per Cent Clay	Classification
111	2	3	29.0	10.1	44.8	45.1	Silty clay
111	2	4	25.0	13.5	43.1	43.5	Silty clay
111	2	5	25.0	8.8	43.2	48.1	Silty clay
111	3	2	24.0	40.0	43.4	16.6	Sandy silt
111A	1	1	99.0	13.7	42.9	43.4	Silty clay
111A	1	2	24.0	15.9	42.5	41.7	Clayey silt
111A	1	3	38.0	13.7	44.8	41.5	Clayey silt
111A	1	4	24.0	15.2	42.9	41.9	Clayey silt
111A	1	5	25.0	11.2	44.4	44.4	Clayey silt
111A	1	6	25.0	13.2	44.4	42.4	Clayey silt
111A	2	1	90.0	25.4	33.5	41.1	Sand-silt-clay
111A	2	2	25.0	25.3	32.1	42.6	Sand-silt-clay
111A	2	3	25.0	27.6	33.1	44.3	Sand-silt-clay
111A	2	4	25.0	16.0	38.2	45.8	Silty clay
111A	3	3	130.0	8.0	45.3	46.7	Silty clay
111A	3	4	24.5	7.0	45.2	47.0	Silty clay
111A	4	1	69.0	18.0	47.2	34.8	Clayey silt
111A	4	2	25.0	46.4	29.8	23.7	Sand-silt-clay
111A	5	4	123.0	15.3	30.9	53.8	Silty clay
111A	5	5	23.0	22.3	38.3	39.4	Sand-silt-clay
111A	6	1	76.0	23.2	35.7	41.1	Sand-silt-clay
111A	6	2	24.0	12.8	42.1	45.1	Silty clay
111A	6	3	24.0	54.1	23.9	21.9	Sand-silt-clay
111A	8	2	110.0	0.2	18.2	81.7	Clay
111A	10	1	121.0	0.0	27.1	72.9	Silty clay
111A	10	2	0.0	0.1	26.3	73.6	Silty clay
111A	10	3	24.0	0.0	7.6	92.3	Clay
111A	10	4	99.0	2.1	24.1	73.9	Silty clay
111A	11	2	24.0	24.5	26.0	49.5	Sand-silt-clay
111A	11	3	24.0	29.7	29.0	41.3	Sand-silt-clay
111A	11	4	23.0	20.9	33.2	46.0	Sand-silt-clay
111A	11	5	24.0	19.8	28.9	51.3	Silty clay

[1] Analyses carried out under the supervision of G. W. Bode and R. E. Boyce Scripps Inst. of Oceanography.

APPENDIX C. CARBON-CARBONATE DETERMINATIONS ON SAMPLES FROM SITE 111[1]

Hole	Core	Section	Top Interval	Hole Depth	Total Carbon	Organic Carbon	$CaCO_3$	Hole	Core	Section	Top Interval	Hole Depth	Total Carbon	Organic Carbon	$CaCO_3$
111	2	3	15.0	97.2	1.6	0.4	10	111A	1	5	15.0	111.2	1.6	0.5	12
111	2	4	15.0	98.7	1.8	0.4	12	111A	1	6	4.0	112.5	1.6	0.0	14
111	2	5	15.0	100.2	1.6	0.5	10	111A	2	1	80.0	114.8	1.5	0.0	13
111	3	2	15.0	190.6	6.5	0.0	53	111A	2	2	15.0	115.7	2.1	0.4	14
111A	1	1	119.0	106.2	1.6	0.4	10	111A	2	3	14.0	117.1	1.4	0.5	8
111A	1	2	14.0	106.6	1.7	0.4	11	111A	2	4	15.0	118.7	1.0	0.4	5
111A	1	3	14.0	108.1	1.8	0.4	12	111A	3	3	140.0	124.4	1.6	0.6	9
111A	1	4	15.0	109.7	1.7	0.4	11	111A	3	4	31.0	124.8	1.7	0.6	9

[1] Analyses carried out under the supervision of G. W. Bode and R. E. Boyce, Scripps Inst. of Oceanography.

APPENDIX C – *Continued*

Hole	Core	Section	Top Interval	Hole Depth	Total Carbon	Organic Carbon	$CaCO_3$	Hole	Core	Section	Top Interval	Hole Depth	Total Carbon	Organic Carbon	$CaCO_3$
111A	4	1	50.0	125.5	1.0	0.4	5	111A	9	1	14.0	164.1	3.4	0.2	27
111A	4	2	14.0	126.6	4.2	0.1	34	111A	10	1	125.0	174.3	2.9	0.2	22
111A	5	4	7.0	138.6	0.6	0.4	2	111A	10	2	14.0	174.6	3.3	0.1	26
111A	5	5	15.0	140.1	0.4	0.3	1	111A	10	3	14.0	176.1	2.5	0.1	20
111A	6	1	59.0	143.6	0.8	0.4	3	111A	10	4	79.0	178.3	2.4	0.1	19
111A	6	2	14.0	144.6	1.3	0.2	9	111A	11	2	14.0	183.6	11.3	0.1	94
111A	6	3	15.0	146.1	8.8	0.1	72	111A	11	3	14.0	185.1	11.2	0.0	93
111A	7	6	132.0	160.8	2.3	0.2	17	111A	11	4	14.0	186.6	11.4	0.0	95
111A	8	1	105.0	162.1	3.6	0.2	28	111A	11	5	14.0	188.1	11.4	0.1	94
111A	8	2	14.0	162.6	3.7	0.2	30	111A	11	6	14.0	189.6	10.7	0.0	88

[1]Analyses carried out under the supervision of G. W. Bode and R. E. Boyce, Scripps Inst. of Oceanography.

APPENDIX D. LISTS OF SELECTED PLANKTONIC AND AGE DETERMINATIONS

W. A. Berggren

Hole 111

Sample 12-111-1, CC:
PF: *Globigerina pachyderma* (predominantly sinistral), *G. bulloides, Globorotalia inflata, G. hirsuta, G. truncatulinoides, Globigerinita quinqueloba.*
BF: *Sigmoilopsis schlumbergeri, Karreriella novangliae, Eggerella bradyi, Planulina bradii, Hoeglundina elegans, Elphidium* sp. cf. *E. lessonii.*
Also present: Glacially-rafted debris.
Age: Pleistocene (glacial).

Sample 12-111-2-1, 8.5-9.5 cm:
PF: *Globigerina bulloides* (dominant), *G. pachyderma* (predominantly sinistral), *Globigerinita quinqueloba, Globorotalia inflata, G. scitula, G. truncatulinoides, Globigerinoides conglobata, Globoquadrina dutertrei, Orbulina universa.*
BF: Only in finer fractions and relatively rare.
Also present: Glacially-rafted debris.
Age: Pleistocene (glacial).

Sample 12-111-2-1, 19.0-21.0 cm:
PF: *Globigerina bulloides, G. pachyderma, Globorotalia inflata, Globigerinita quinqueloba, Globoquadrina dutertrei, Globigerinoides rubra, G. sacculifera.*
BF: Rare, including *Uvigerina peregrina, Dentalina* sp.
Also present: glacially-rafted debris.
Age: Pleistocene (glacial).

Sample 12-111-2-2, 143.5-145.5 cm:
PF: *Globigerina bulloides, G. pachyderma, Globoquadrina dutertrei, Globorotalia inflata, G. puncticulata, G. hirsuta, Globigerinoides rubra, G. sacculifera.*
BF: Not common, but including *Pyrgo murrhyna, Eponides tener, Uvigerina hollicki, Dentalina* sp.
Also present: Glacially-rafted debris.
Age: Pleistocene (glacial).

Sample 12-111-2-3, 137.0-139.5 cm:
PF: *Globigerina bulloides, G. pachyderma, Globoquadrina dutertrei, Globorotalia inflata, Globigerinita quinqueloba.*
BF: *Eponides tener* (common), *Elphidium* sp., *Stilostomella* spp.
Also present: Ice-rafted debris.
Age: Pleistocene (glacial).

Sample 12-111-2-4, 146.0-148.0 cm:
PF: *Globigerina pachyderma, G. bulloides, Globigerinita quinqueloba, Globorotalia inflata, G. hirsuta, Globigerinoides rubra.*
BF: Abundant nodosariids, *Eponides tener* (common), *Nonion* sp.
Also present: Ice-rafted debris.
Age: Pleistocene (glacial).

Sample 12-111-2-5, 117-118 cm:
PF: *Globigerina bulloides, G. pachyderma, Globorotalia inflata, G. hirsuta, Globoquadrina dutertrei, Globigerinoides rubra, Pulleniatina obliquiloculata* (rare).
BF: Relatively diverse, including *Uvigerina hollicki, Gyroidina soldanii, Melonis pompilioides, M. barleeanum.*
Also present: Ice-rafted debris.
Age: Pleistocene (glacial).

Sample 12-111-2-5, 145-148 cm:
Essentially same fauna as preceding sample above; benthonic diversity less.

Sample 12-111-2-6, 12.5-15.0 cm:
PF: Planktonic fauna common, including *Globorotalia inflata* (abundant, dominant), *Globigerina bulloides, G. pachyderma, Globoquadrina dutertrei, Globorotalia hirsuta.*
BF: As above.
Also present: Ice-rafted debris.
Age: Pleistocene (glacial).

Sample 12-111-2-6, 83.5-85.5 cm:
PF: Rich planktonic assemblage, including *Globorotalia inflata* (dominant), *Globoquadrina dutertrei, Globigerina bulloides, G. pachyderma* (predominantly dextral), *Globorotalia crassaformis, G. hirsuta, G. menardii, G. truncatulinoides, Globigerinoides conglobata, Sphaeroidinella dehiscens.*
BF: Uncommon, including *Eggerella bradyi, Eponides umbonatus.*
Note: This is a coccolith-foraminiferal ooze; ice-rafted detritus forms a minor component of the residue.
Age: Pleistocene (probably interglacial).

Sample 12-111-2-6, 115-116 cm:
PF: *Globigerina bulloides, G. pachyderma, Globoquadrina dutertrei, Globorotalia inflata, G. crassaformis.*
BF: Sparse, including *Uvigerina hollicki, Hoeglundina elegans.*
Also present: Abundant ice-rafted debris.
Age: Pleistocene (glacial).

Sample 12-111-2, core catcher:
PF: Essentially as in preceding sample above.
BF: Essentially as above but with greater diversity, including *Stilostomella bradyi, S. antillea*, nodosariids, *Pyrgo lucernula*.
Also present: Abundant ice-rafted debris.
Age: Pleistocene (glacial).
Remarks: All Samples listed above contain abundant ice-rafted debris (quartz sand, igneous and metamorphic mineral suites, mica, and so forth); the lone exception is Sample 12-111-2-6, 83.5 to 85.5 centimeters which is a coccolith-foraminiferal ooze. Species of the genus *Globigerinoides* are rare, but persistent, in most of the samples above and their presence in generally temperate faunal associations is interesting.

Hole 111A

Sample 12-111A-1-1, 72-74 cm (top of core):
PF: Relatively rich planktonic fauna, including *Globigerina pachyderma* (predominantly dextral), *Globoquadrina dutertrei, Globigerina bulloides, Globorotalia inflata, G. hirsuta, G. truncatulinoides conglobata, Pulleniatina obliquiloculata, Sphaeroidinella dehiscens, Hastigerina siphonifera.*
BF: Negligible.
Also present: Abundant ice-rafted detritus.
Age: Pleistocene (glacial).

Sample 12-111A-1-2, 140.0-142.5 cm:
PF: Poor fauna, low diversity, including *Globigerina pachyderma, G. bulloides, G. inflata.*
BF: Poor fauna, low diversity, including *Gyroidina soldanii, Cassidulina* sp.
Also present: Abundant ice-rafted detritus.
Age: Pleistocene (glacial).

Sample 12-111A-1-3, 146.0-148.5 cm:
PF and BF: Essentially same as for preceding sample above.
Age: As above.

Sample 12-111A-1-4, 142.0-144.5 cm:
PF and BF: Essentially same as above.
Age: As above.

Sample 12-111A-1-5, 138.0-140.5 cm:
PF and BF: Essentially same as above.
Also present: Abundant manganese nodules.
Age: Pleistocene (probably interglacial).

Sample 12-111A-1-6, 132.0-134.5 cm:
PF: Sparse, low diversity fauna, including *Globorotalia inflata, Globigerina pachyderma, G. bulloides.*
BF: Sparse, low diversity fauna, including *Cassidulina* sp.
Also present: Abundant ice-rafted detritus.
Age: Pleistocene (glacial).

Sample 12-111A-1, core catcher:
PF: *Globigerina bulloides, G. pachyderma* (dextral), *Globorotalia inflata, G. hirsuta, G. truncatulinoides, G. crassaformis, Globigerinoides rubra, Orbulina universa.*
BF: Low diversity fauna, including common *Dentalina filiformis, Dentalina* spp.
Also present: Abundant ice-rafted detritus.
Age: Pleistocene (glacial).

Sample 12-111A-2-1, 137.0-138.5 cm:
All data as in above sample 12-111A-1-6.

Sample 12-111A-2-2, 140.0-142.5 cm:
All data as in preceding sample.

Sample 12-111A-2-3, 140.0-142.5 cm:
PF: As above, plus *Globorotalia crassaformis, Orbulina universa, Globigerinoides rubra.*
BF: As above, plus *Uvigerina hollicki, Gyroidina neosoldanii, Oolina* sp., *Quinqueloculina* sp.
Also present: Abundant ice-rafted detritus.
Age: Pleistocene (glacial).

Sample 12-111A-2-4, 130.0-132.5 cm:
Virtually barren of microfossils (foraminifera).

Sample 12-111A-2, core catcher:
PF: Sparse, low diversity fauna, including *Globigerina bulloides, G. pachyderma* (dextral), *Globorotalia inflata, G. hirsuta.*
Also present: Abundant ice-rafted detritus.
Age: Pleistocene (glacial).

Sample 12-111A-3-1, 144.5-146.0 cm:
PF: Sparse, low diversity fauna, including *Globigerina bulloides, G. pachyderma* (dextral), *Globorotalia crassaformis, G. inflata, Orbulina universa.*
BF: Sparse, low diversity fauna, including *Sigmoilopsis schlumbergeri, Hoeglundina elegans.*

Sample 12-111A-3-2, 132.0-134.5 cm:
All data essentially as above.

Sample 12-111A-3-4, 146-149 cm:
PF Sparse, relatively low diversity fauna, including *Globigerina bulloides, G. pachyderma* (dextral), *Globorotalia crassaformis, G. hirsuta, G. inflata, Orbulina universa.*
BF: Virtually barren.
Also present: Abundant ice-rafted detritus.
Age: Pleistocene (glacial).

Sample 12-111A-3, core catcher:
All data as above.

Sample 12-111A-4-1, 145-148 cm:
PF: Sparse, low diversity, including *Globigerina bulloides, G. pachyderma* (dextral), *Globorotalia crassaformis, Orbulina universa.*
BF: Rare, including *Karreriella bradyi.*
Also present: Abundant ice-rafted detritus.
Age: Pliocene-Pleistocene (glacial).

Sample 12-111A-4-2, 141.5-144.0 cm:
PF: Sparse fauna consisting solely of *Globigerina atlantica.*
BF: Sparse, including *Eponides tener, Pyrgo* sp.
Also present: Abundant ice-rafted detritus.
Age: Late Pliocene.

Sample 12-111A-4, core catcher:
PF: Rich fauna, including *Globigerina atlantica* (dominantly sinistral and including 5 and 6 chambered forms). (This form constitutes over 95 percent of the total planktonic fauna.) *Globigerina bulloides, Globorotalia crassaformis, Globigerinoides conglobata, G. sacculifera, Orbulina universa, Sphaeroidinella dehiscens.*
BF: Includes *Eponides tenera, Pullenia* sp., dentalinids, nodosariids.
Also present: Abundant ice-rafted detritus.
Age: Late Pliocene.

Sample 12-111A-5-2, 140-143 cm:
PF: Rich, diversified assemblage, including *Globigerina bulloides, Globigerina atlantica, Globorotalia inflata, G. puncticulata, G. crassaformis, G. miocenica, Globigerinoides rubra, G. sacculifera, G. obliqua.*
BF: Sparse, including *Pyrgo lucernula,* nodosariids, dentalinids.
Also present: Ice-rafted detritus.
Age: Late Pliocene.
Remarks: This sample contains the highest (*i.e.*, youngest, occurrence of *Globorotalia miocenica* and *Globigerinoides obliqua* in Hole 111A. Specimens of several species of the genus *Globigerinoides* are quite common in this sample and may indicate a return to moderately mild conditions (see below).

Sample 12-111A-5-3, 144.5-147.0 cm:
PF: Essentially same as above, plus *Globorotalia exilis* and *G. menardii.* (dextral).
BF: Sparse, including *Karreriella bradyi.*
Also present: Ice-rafted debris.

Age: Late Pliocene.
Remarks: This sample contains the highest (*i.e.*, youngest, occurrence of *Globorotalia exilis*.

Sample 12-111A-5-4, 14-15 cm:
PF: Essentially same as the above save for (apparent) absence of *Globorotalia exilis* and *G. menardii*.
BF: Sparse, including *Uvigerina* sp.
Also present: Ice-rafted detritus.
Age: Late Pliocene.

Sample 12-111A-5-4, 136.5-137.5 cm:
This sample is barren of foraminifera. It is composed solely of ice-rafted detritus (quartz sand, various igneous and metamorphic rock fragments, etc.).

Sample 12-111A-5-5, 7-8 cm:
All data as in Sample 12-111A-5-4, 88 to 89 centimeters.

Sample 12-111A-5-5, 144-145 cm:
PF: *Globigerina atlantica* (dominant, abundant), *G. bulloides, Globorotalia miocenica, G. scitula, G. crassaformis, Globigerinoides conglobata, G. rubra, G. sacculifera, Sphaeroidinella dehiscens, Orbulina universa.*
BF: Relatively diverse fauna, including *Karreriella bradyi, K.* sp. *Cassidulina subglobosa, Cibicidoides pseudoungeriana, C. robertsoniana, Ehrenbergina trigona, Rectoglandulina* sp. cf. *R. comatula, Eponides tener.*
Also present: Coarse grained ice-rafted debris less common than in samples above; in fine fraction, quartz sand abundant.
Age: Late Pliocene.

Sample 12-111A-5, core catcher:
All data same as preceding sample with exception of apparent absence of *Globorotalia miocenica.*
Remarks: The samples from Core 5 are characterized generally by rich planktonic foraminiferal faunas dominated by *Globigerina atlantica.* The scattered but persistent presence of *Globorotalia miocenica* as high as Sample 12-111A-4-1, 145 to 148 centimeters, is evidence of the Late Pliocene age of this core. The faunal association, however, is rather anomalous. The relatively diverse benthonic foraminiferal fauna, characteristic of Core 6 below, does not extend above Sample 12-111A-5-5, 144 to 145 centimeters (*i.e.*, the lower part of Core 5, Section 5).

Because of its stratigraphic importance, Core 6 has been studied in considerable detail (in particular the lower part of Section 2 and Section 3). Following is a list of the samples which have been examined and which form the basis for the stratigraphic ranges of planktonic foraminiferal species presented in Figure 31:

Sample 12-111A-6-1, Top
12-111A-6-1, 143-145.5 cm

Sample 12-111A-6-2, Top
12-111A-6-2, 4-5 cm
12-111A-6-2, 11-12 cm
12-111A-6-2, 21-22 cm
12-111A-6-2, 34-35 cm
12-111A-6-2, 44-45 cm
12-111A-6-2. 54-55 cm
12-111A-6-2, 64-65 cm
12-111A-6-2, 74-75 cm
12-111A-6-2, 84-85 cm
12-111A-6-2, 94-95 cm
12-111A-6-2, 104-105 cm
12-111A-6-2, 114-115 cm
12-111A-6-2, 121.5-122.5 cm
12-111A-6-2, 126-127 cm
12-111A-6-2, 129-131 cm
12-111A-6-2, 134-135 cm
12-111A-6-2, 145-146 cm

Sample 12-111A-6-3, Top
12-111A-6-3, 7-8 cm
12-111A-6-3, 12-14 cm
12-111A-6-3, 17-18 cm
12-111A-6-3, 23-25 cm
12-111A-6-3, 29-30 cm
12-111A-6-3, 33-35 cm
12-111A-6-3, 39-40 cm
12-111A-6-3, 43-45 cm
12-111A-6-3, 49-50 cm
12-111A-6-3, 58.5-59.5 cm
12-111A-6-3, 63.5-64.5 cm
12-111A-6-3, 68.5-69.5 cm
12-111A-6-3, 77.5-78.5 cm
12-111A-6-3, 83-85 cm
12-111A-6-3, 87-88 cm
12-111A-6-3, 90-91 cm
12-111A-6-3, 91-92 cm
12-111A-6-3, 92-93 cm

Samples below this depth are discussed in the usual manner in the section below.

Remarks: A significant unconformity occurs between 90 and 92 centimeters in Section 3, and separates upper Eocene sediments from upper Miocene/Pliocene sediments. Upper Miocene and Pliocene sediments (containing a tropical-subtropical water microfauna) are overlain by sediments of glacial origin. A transitional interval occurs between 124 and 139 centimeters in Section 2. Evidence of the first ice rafted detritus occurs within this interval. As can be seen from Figure 31 several significant extinctions occur within this core. In particular, the extinction of *Globoquadrina altispira, Sphaeroidinella seminulina, Globorotalia multicamerata* at about 130 centimeters in Section 2 is similar to that seen in tropical areas of the Atlantic and Pacific Oceans. An age estimate of 2.8 million years has been made for this level in accordance with evidence from paleomagnetic stratigraphy. *Globigerina nepenthes* disappears between the sample at 17-18 centimeters and 12 to 14 centimeters in Section 3. This level is assigned an age of 3.7 million years in accordance with evidence from paleomagnetic stratigraphy. *Globoquadrina dehiscens* disappears at 65 centimeters in Section 3 at a level estimated to be about 5 million years. This agrees well with recent evidence (Saito, personal communication) that *Globoquadrina dehiscens* disappears at about 5 million years, and forms a reliable criterion for determination of the Miocene/Pliocene boundary. Several important observations can be made regarding the stratigraphic interval encompassed by Core 6.

1) A diverse keeled globorotalid fauna occurs throughout the Late Miocene and pre-glacial Pliocene section.
2) In the lower part of Section 3 (between 60 and 90 centimeters) *Globorotalia conoidea* and *Globorotalia conomiozea* form distinctive elements in the globorotalid fauna. Forms assigned to *Globorotalia plesiotumida* also occur in this interval.
3) *Globotoralia tumida* appears above 70 centimeters in Section 3 and is uniformly sinistral. At 12-14 centimeters in Section 3, it disappears temporarily and reappears at the base of Section 2. Its coiling in the upper part of its range is uniformly dextral. A change from sinistral to dextral coiling in *Globorotalia tumida* has been shown by Saito to occur at about 3.6 to 3.7 million years ago, roughly coincident with the extinction of *Globigerina nepenthes.*
4) *Globorotalia crassaformis* appears slightly above the disappearance of *Globigerina nepenthes,* which is consistent with evidence elsewhere of its first appearance in the mid-Pliocene.
5) *Globorotalia inflata* appears for the first time in this sequence within the transitional interval heralding the onset of glaciation about 3 million years ago.
6) A marked diminution in species diversification is evident within and above the transitional interval between the cream-colored, glauconitic foraminiferal sand below and the gray, sandy, micaceous clay with glacially-rafted pebbles above. A few forms (such as *Globigerinoides conglobata, G. obliqua, Globorotalia crassaformis, G. crassula,* and *G. praehirsuita* range up into the lower part of the sediments of the glacial origin. In Section 1, however, species diversity has been considerably reduced and the faunas here consist almost exclusively of *Globigerina atlantica* and *G. pachyderma* with sporadic occurrences of *Globigerina bulloides* and *Globotalia inflata.*

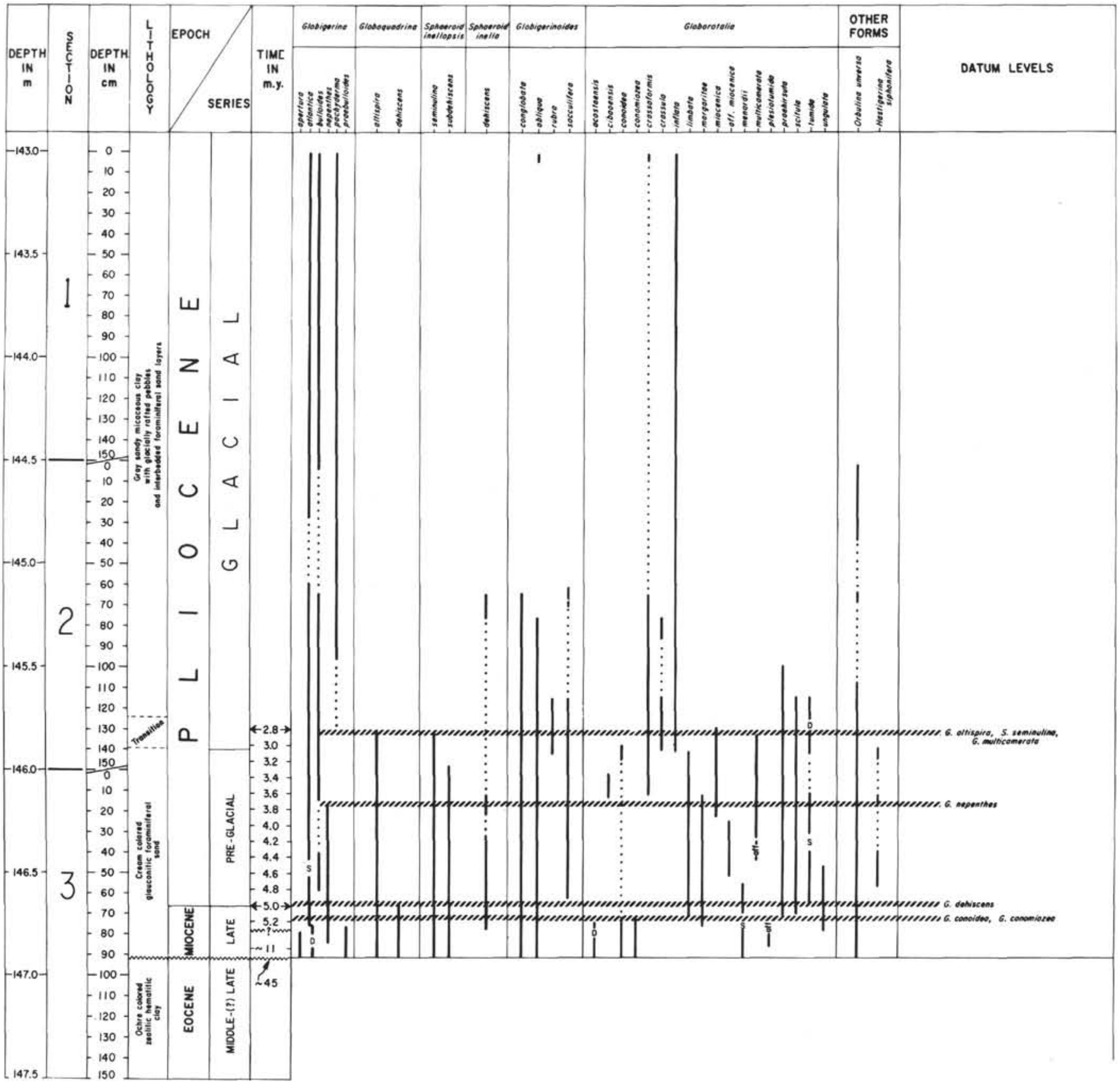


Figure 31. *Foraminiferal stratigraphy for Appendix D.*

7) The dominant faunal element throughout these samples is a species identified here as *Globigerina atlantica.* This form exhibits considerable morphologic variation, and it has been impossible to consistently separate this into more than a single form. Between 70 and 90 centimeters in Section 3, (that is, in the Upper Miocene sediments) this species exhibits dextral coiling, whereas, above 70 centimeters, it coils sinistrally (<95%).

Sample 12-111A-6-3, 97-98 cm:
PF: Extremely sparse (few specimens) including *Acarinina* sp., *Globigerinita* sp. cf. *G. pera.*
BF: Extremely sparse (few specimens).
Also present: Shark teeth.
Age: Middle Eocene.
Remarks: Broken tests of planktonic foraminifera indicate solution.

Sample 12-111A-6-3, 98.5-99.5 cm:
All data same as for preceding sample.

Sample 12-111A-6-3, 109-111 cm:
PF: Sparse fauna, including *Globigerinita* sp. cf. *G. pera, Acarinina densa, Truncorotaloides collactea, Globigerapsis index.*
BF: *Osangularia pteromphalia* (=? *O. mexicana), Anomalinoides grosserugosa, Pleurostomella bellardii, P.* sp., *Stilostomella curvatura, Karreriella* sp., *Pullenia* sp., *Siphonia* sp., *Uvigerina* sp.
Also present: Abundant manganese showing, in some instances, overgrowth and replacement of benthonic foraminiferal tests; solution effects also apparent.
Age: Middle Eocene.

Sample 12-111A-6-3, 129-131 cm:
PF: *Pseudohastigerina wilcoxensis, Globigerina* sp.
BF: *Nuttallides truempyi, Oridorsalis ecuadorensis, Ammodiscus* sp., *Bulimina* sp., *Angulogerina* sp., *Cibicides* sp., *Nonion* sp.

Also present: Abundant manganese nodules.
Age: Eocene (Early to early Middle).

Sample 12-111A-6-3, 138-140 cm:
All data essentially same as in preceding sample above; fauna sparser.

Sample 12-111A-6, core catcher:
PF: No planktonic fauna, only fragments.
BF: *Nuttallides truempyi, Oridorsalis ecuadorensis,* scattered fragments.
Also present: Abundant manganese nodules.
Age: Eocene.
Note: Core 7 was contaminated by drilling almost in its entirety with abundant Pliocene planktonic and benthonic foraminiferal faunas similar to those listed from Core 6 above. Most of these samples contain Eocene faunal elements in the fine fraction, but it is extremely difficult to separate and distinguish them from Pliocene contaminants in a consistent manner. The following samples have been examined and found to be contaminated:

12-111A-7-1, 30-32 cm (=top core)
12-111A-7-1, 143-145.5 cm
12-111A-7-2, 0-2 cm (top section)
12-111A-7-2, 144-147 cm
12-111A-7-3, 0-2 cm (top section)
12-111A-7-3, 143-146 cm
12-111A-7-4, 0-2 cm (top section)
12-111A-7-4, 136-139 cm
12-111A-7-5, 0-2 cm (top section)
12-111A-7-5, 143-146 cm
12-111A-7-6, 0-2 cm (top section

Sample 12-111A-7, core catcher:
PF: *Globigerina patagonica, Pseudohastigerina wilcoxensis.*
BF: *Vaginulinopsis decorata, Lenticulina* sp., *Nuttallides truempyi, Oridorsalis ecuadorensis.*
Age: Eocene (probably Early).

Sample 12-111A-8-1, 20-22 cm (top core):
PF: *Globigerina patagonica, Acarinina angulosa, A. broedermanni, A. pentacamerata, Pseudohastigerina wilcoxensis.*
BF: *Vaginulinopsis decorata, Anomalinoides acuta, Gavelinella limbata, Anomalinoides praespissiformis, Cibicidoides acutimargo, C. hercegovinensis, Gaudryina* sp. cf. G. *hiltermanni, Bolivinopsis sp., Osangularia* sp., *Nuttallides truempyi, Oridorsalis ecuadorensis, Gyroidina* sp., *Aragonia* sp., *Nonion* sp., *Bulimina grata, G.* sp., *Cassidulina* sp.
Age: Early Eocene.

Sample 12-111A-8-1, 145-148 cm:
Data same as for preceding sample above.

Sample 12-111A-8-2, 0-2 cm (top section 2):
Data same as above.

Sample 12-111A-8-2, 143-145 cm:
Data same as above.

Sample 12-111A-8, core catcher:
Data same as above.
Also present: High concentration of phosphorite granules.
Age: Early Eocene.

Sample 12-111A-9, core catcher:
PF: *Acarinina pentacamerata* (=*A. gravelli*), *A.* cf. *broedermanni, Globigerina patagonica.*
BF: *Lenticulina* sp., *Anomalinaides grosserugosa, Osangularia pteromphalia,* (=? *O. mexicana*), *Nuttallides truempyi, Cibicidoides acutimargo, Pleurostomella* sp., *Recurvoides* sp., *Cornuspira* sp., *Bulimina* sp.
Age: Early Eocene.

Sample 12-111A-10-1, 147-150 cm:
Fauna essentially similar to above; specimens preserved mostly in fine fraction.
Age: Early Eocene.

Sample 12-111A-10-2, 145-151 cm:
Data same as preceding.
Age: Early Eocene.

Sample 12-111A-10-3, 147-150 cm:
PF: Rare, including *Globigerina patagonica, Acarinina pentacamerata, A.* sp.
BF: Sparse, including *Oridorsalis ecuadorensis, Cibicidoides hercegovinensis, C. acutimargo, Nuttallides truempyi;* common in fine fraction but difficult to identify.
Age: Early Eocene.

Sample 12-111A-10-4, 148-151 cm:
PF: *Globigerina patagonica, Acarinina pentacamerata, A. triplex, Globorotalia subbotinae.*
BF: *Anomalinoides grosserugosa, Cibicidoides hercegovinensis, Osangularia pteromphalia* (=? *O. mexicana*), *Nuttallides truempyi, Oridorsalis ecuadorensis, Gaudryina* sp. cf. *G. hiltermanni, Neoconorbina* sp., *Bolivinopsis* sp., *Bulimina* sp.
Also present: Shark teeth and other fragments.
Age: Early Eocene.

Sample 12-111A-10, core catcher:
PF: *Globigerina patagonica, Acarinina pentacamerata, A. soldadoensis, A. triplex, A. acarinata, Globorotalia lensiformis.*
BF: *Cibicidoides hercegovinensis, Anomalinoides grosserugosa, Gyroidina* sp., *Bulimina* sp., *Neoconorbina* sp., *Nuttallides truempyi, Osangularia pteromphalia* (=? *O. mexicana*), *Oridorsalis ecuadorensis.*
Age: Early Eocene.
Remarks: The stratigraphically distinctive forms in Cores 8, 9, and 10 include, *i. al., Acarinina soldadoensis, A. pentacamerata, A. triplex, Cibicidoides hercegovinensis, C. acutimargo, Anomalinoides grosserugosa, Oridorsalis ecuadorensis, Nuttallides truempyi, Vaginulinopsis decorata,* and *Gaudryina* sp. cf., *G. hiltermanni.* The presence of *G. subbotinae* and *G. lensiformis* in Core 10 indicates that this core is equivalent to Zone P7. The benthonic forms listed above are characteristic of relatively deep-water facies in the Early and Middle Eocene of northwestern Europe. Several elements occur in the Mediterranean region as well. The relatively rich planktonic foraminiferal fauna, the presence of the forms listed above, and various species of *Stilostomella* indicate that Orphan Knoll lay at considerable depth during the Early Eocene (comparable to its present depth perhaps), and suggest the major sinking of Orphan Knoll occurred during Paleocene time.

APPENDIX E. LISTS OF SELECTED MESOZOIC PLANKTONIC AND BENTHONIC FORAMINIFERA AND OSTRACODA, AND CONCLUSIONS ON AGE AND ENVIRONMENT

J. E. van Hinte

Hole 111

Sample 12-11103-(core barrel water):
This sample is a sieve residue of water collected from the core barrel at the top of the core.

Planktonic Foraminifera: *Globigerina pachyderma* (Ehrenberg), *G. bulloides* d'Orbigny, *Globorotalia inflata* (d'Orbigny), Eocene globigerinids and acarinids, *Globotruncana arca* (Cushman), *G. fornicata* Plummer, *G. contusa* (Cushman), *G. gansseri* Bolli, *G. stuarti* (de Lapparent), *G. stuartiformis* Dalbiez, *G. aegyptiaca* Nakkady, *G. rosetta* (Carsey), *Globigerinelloides messinae biforaminata* (Hofker), *Globotruncanella havanensis* (Voorwijk), *Heterohelix* sp., *Pseudotextularia elegans* (Rzehak).

Remarks: The absence of Cenomanian forms suggests that the top of the Cenomanian as recovered, is the top indeed. No evidence of Senonian older than Maastrichtian.

Sample 12-111-03-(material scraped from core liner above recovered core):
PF: *Globotruncana arca, G. rosetta, Globigerinelloides messinae* (Brönnimann) *Heterohelix* spp.

Remarks: No evidence for Senonian other than Maastrichtian.

Sample 12-111-03-01, 130-135 cm:
This is a small sample of soft material scraped from between the hardened parts at the top of the core. The washed residue consists of carbonate crystals, glauconite grains, coated (phosphate?) grains, and some angular fine quartz. Rare gastropod casts and pelecypod chips are present. Also, there are glauconite casts of Cenomanian foraminifers and normally preserved Maastrichtian foraminifers.

PF: *Hedbergella* sp., *Praeglobotruncana* sp., *Rotalipora gandofii* Luterbacher & Premoli-Silva, *Rotalipora appenninica* (Renz).
BF: *Gavelinopsis cenomanica* (Brotzen), *Gavelinella baltica* Brotzen, *Marsonella trochus* (d'Orbigny), *Gaudryina* sp., *Valvulineria* sp.
Age: Early Cenomanian.
Environment: Middle neritic?

Sample 12-111-03-01, 136-137 cm:
In the sample there were spatic limestone fragments with abundant glauconite; the hard fragments did not fall apart easily and therefore little fauna was recovered; most as glauconite casts.

Four thin-sections of the sample show: very glauconitic, fine (150μ) sandy, (5%) recrystallized micritic-skeletal limestone. The rare foraminifers seen in the sections have their wall preserved, or are present as glauconite casts only.

PF: *Hedbergella* sp., *Rotalipora* sp., *Praeglobotruncana stephani* (Gandolfi) (in thin-section).
BF: *Conorboides* ? sp., *Dentalina* sp., *Valvulineria* sp., polymorphinid.
Other: Echinoderm fragments, a shark tooth and *Bairdia* sp.
Age: Early Cenomanian
Environment: Middle Neritic?

Sample 12-111-03-02, 14-17 cm:
The washed residue of the glauconitic, sandy carbonate consists of carbonate crystals, glauconite, and in the finer fractions, much quartz (<150μ). Foraminifera are abundant and ostracods are common. The former occur either as glauconite casts or are normally preserved. Pelecypods and echinoderms are common; some coproliths are present.

PF: *Hedbergella* sp. cf. *H. delrioensis* (Carsey), *Praeglobotruncana stephani*, the *Rotalipora* population of small specimens is dominated by relatively high-spired forms (*R. greenhornensis* (Morrow)) whereas most others are of the *R. gandolfii* type, very few being flat as *R. apenninica* or loosely coiled like *R. evoluta* Sigal (glauconite casts only).
BF: *Gavelinopsis cenomanica, Gavelinella baltica, Marssonella trochus, "Gaudryina"* spp., *Textularia* sp., *Arenobulimina* sp., *Gyroidinoides* sp., *Lenticulina* spp., *Patellina subcretacea* Cushman & Alexander, *Vaginulina* sp., *Quinqueloculina "antiqua."*
Ostracoda: *Cytherella* sp., *Cytherelloidea* sp., *Bairdia* sp., *"Cythereis"* sp.
Age: Early Cenomanian
Environment: Middle or Inner Neritic.

Sample 12-111-03-02, 135.5-138 cm:
The same as above.

Sample 12-111-03, core catcher:
The same as above with *Hedbergella planispira* (Tappan).

Sample 12-111-04, core catcher:
The washed residue consists of aggregate carbonate grains, glauconite (5-10%), mica and quartz (1-5%) and a cast of a gastropod phoetus. The microfauna is extremely poor and practically all specimens are glauconite casts and determinations, therefore, have to be questionable.

Thin sections show a very fine sandy (5-10%, 50-190μ) glauconitic recrystallized detrital-micritic limestone with very few discernible skeletal elements of macro- and microfossils.

PF: *Hedbergella planispira, Rotalipora* sp.
BF: *Gavelinopsis cenomanica, Sigmoiline antiqua* Franke, *Quinqueloculina "antiqua", Marssonella trochus.*
Age: Early Cenomanian.
Environment: Shallow marine, inner neritic?

Sample 12-111-05, core catcher:
The washed residue of the crushed material consists of limestone fragments, glauconite, pyrite, quartx, and some mica; the finest fraction consisting almost entirely of quartz and 10 percent mica. Pelecypod, gastropod, and each echinoderm fragments are common fish remains, and bryozoans are rare. Foraminifers are rare, and Ostracoda are rare and broken.

Thin sections show a glauconitic, very fine sandy (10-20%) micritic-skeletal limestone, recognizable skeletal parts are pelecypods, echinoderms and foraminifers.

PF: *Hedbergella planispira, Globigerinelloides eaglefordensis* (Moreman).
BF: *Gavelinopsis cenomanica – Gavelinella intermedia* (Berthelin) transitional population, *Gavelinella ammonoides* (Reuss), *Tristix* sp., *Vaginulina* sp., *Lenticulina* spp., *polymorphinids, Valvulineria* sp., several arenaceous species amongst which *Arenobulimina presslii* (Reuss).
Ostracod: *Neocythere vanveeni* Mertens, *Hemicytherura euglyphea* Kaye, *Cytherelloides* sp. cf. *C. btaterensis* Bischoff, *Alatacythere robusts langi* Kaye, *Cynthereis* sp. cf. *C. reticulata* Jones & Hinde, *Isocythereis* sp.
Age Late Albian (Vraconian).
Environment: Shallow marine (inner to middle neritic).

Sample 12-111-06, core catcher:
The washed residues of crushed material consist of sandy carbonate fragments, some glauconite, quartz and mica.

The thin sections show a recrystallized, very sandy (20-40; <175μ) glauconitic micritic-skeletal limestone.

PF: none found
BF: one specimen of *Gavelinella intermedia*, three *Lenticulina* sp. and one *Valvulineria* sp.
Ostracod: two specimens of *Centrocythere denticulata* Mertens and a *Cytherella* sp.
Age: Late or Middle Albian
Environment: Shallow marine (inner neritic.)

Samples 12-111-07-01, 4-5 cm and 66-67 cm.
The washed residues consist of lithic fragments, quartz, mica and coal. No fossils over than the coal.

Samples 12-111A-11-1, 137-140 and 145-150 cm:
The washed residue of the white ooze consists of foraminifera with some pelecypod (among others, *Inoceramus*) and echinoderm fragments.

PF: *Globotruncana stuarti* (de Lapparent), *G. stuartiformis* Dalbiez, *G. gansseri* Bolli, *G. rosetta* (Carsey), *G. falsostuarti* Sigal, *G. contusa contusa* (Cushman), *G. contusa patelliformis* Gandolfi, *G. arca* (Cushman), *G. aegyptiaca* Nakkady, *Globotruncanella mayaroensis* (Bolli), *G. havanensis* (Voorwijk), *Planoglobulina multicamerata* de Klasz, *P. acervalinoides* (Egger), *Pseudoguembelina punctulata* (Cushman), *P. excolata* Cushman, *Pseudotextularia elegans* (Rzehak) (includes forms referred to as *P. fructicosa* by some authors) *Heterohelix striata* (Ehrenberg), *Gublerina pseudotessera* (Cushman), *Globigerinelloides messinae messinae* (Bronnimann), *G. messinae subcarinata* (Bronnimann), *G. messinae biforaminata* (Hofker), *Rugoglobigerina rugosa* (Plummer).
BF: *Allomorphina allomorphinoides* White, *Angulogavelinella gracilis* (Marsson), *Bolivina incrassata gigantea* Wicher, *Bolivinoides draco draco* (Marsson), *Euvigerina* sp., *Eponides* sp., *Frondicularia striatula* Reuss, *F. goldfussi* Reuss, *Gavelinella* spp., *Gyroidina* sp., *Lenticulina* spp., *Loxostomum gemmum* (Cushman), *Marsonella* sp., *Neoflabelina* sp. aff. *N. numismalis* (Wedekind), nodosarids spp., *Osangularia navarroana* Cushman, polymorphinids spp., *Praebulimina carseyae* (Plummer), *Pullenia americana* Cushman, *Reussella* sp., *Spiroplectammina* sp., *Stensiöina* sp. aff. *altissima* Hofker, *S. excolata* (Cushman), verneuilinids spp.
Ostracoda: Very rare Cytheridae, *Bairdia* sp. and *Cytherella* sp.
Age: Late Maestrichtian.

Environment: Relatively deep marine (outer neritic or upper bathyal).

Sample 12-111A-11-2, 2-5 cm:
The washed residue of the ooze consists dominantly foraminifera with less than 5 per cent of *Inoceramus* and a few other pelecypod fragments.
PF: Like above.
BF: Like above.
Ostracoda: Like above.
Age: Late Maestrichtian.
Environment: Relatively deep marine (outer neritic or upper bathyal).

Sample 12-111A-11-2, 73-76 cm:
The washed residue of the ooze consists of foraminifera and 5 to 10 per cent *Inoceramus* fragments.
PF: Differs from samples above in lacking *Globotruncanella mayaroensis*.
BF: Practically the same as above.
Ostracoda: Like above.
Age and Environment: As above.

Sample 12-111A-11-2, 130-131 cm:
Inoceramus makes up 5 per cent of the washed residue.
PF: Like the above, but with *Globotruncana tricarinata* (Quereau) and without *G. contusa* s. s.
BF: Like above, now with a *Bolivinoides* sp. of the *peterssoni-paleocenicus* group.
Ostracoda: Like above, with a *Krithe* sp.
Age and Environment: As above.

Sample 12-111A-11-3, 3-6 cm:
About 5 per cent of the washed residue is made up by *Inoceramus* and other megafossil fragments.
PF: The same as above, with *G.* sp. cf. *G. ventricosa* White (too narrow a keelband for being without a cf.).
BF: The same as above.
Ostracoda: Like above without *Krithe* sp.
Age and Environment: Like above.

Sample 12-111A-11-3, 78-81 cm:
More than 50 per cent of the washed residue is made up by *Inoceramus* fragments.
PF: Essentially the same as above, but specimens generally smaller; the following species were seen at the preliminary examination: *Globotruncana stuarti, G. stuartiformis, G. contusa patelliformis* (rare), *G. scitula, G. gansseri, G. arca, G. rosetta, G. falsostuarti, G. tricarinata, G.* sp. cf. *G. ventricosa, Rugoglobigerina rugosa, Globotruncanella havanensis, Planoglobulina* sp. cf. *P. glabrata, Pseudotextularia elegans, Gublerina pseudotessera, Globigerinelloides messinae messinae, G. messinae subcarinata, G. messinae biforaminata.*
BF: The same as above, *Bolivinoides decoratus giganteus* Hiltermann and Koch is the *Bolivinoides* species found in this sample.
Ostracoda: Like above.
Age: Late Maestrichtian.
Environment: Relatively deep marine (outer neritic–bathyal); the large proportion of *Inoceramus* in this sample, together with the somewhat smaller size of the planktonic foraminiferal specimens, might point to cooler water.

Sample 12-111A-11-4, 0-3 cm:
More than 50 per cent of the washed residue is made up by *Inoceramus* fragments.
PF: The same as above, in addition *G. aegyptiaca* was found; no *G. contusa* s.l.
BF: The same as above, but impoverished, no *Bolivinoides*.
Age and Environment: Like above.

Sample 12-111A-11-4, 76-79 cm:
More than 50 per cent of the washed residue is made up by *Inoceramus* fragments.
PF: Like above; the *Pseudotextularia* still had a fructicose specimen in the sample above, but none was found in this sample and the *Pseudotextularia* present is referred to as *P. carseyae* (Plummer).
BF: Like above, with a *Bolivinoides* of the *B. peterssoni-paleocenicus* group.
Age and Environment: Like above.

Sample 12-111A-11-5, 9-12 cm:
Inoceramus fragments made up 25 to 35 per cent of the washed residue.
PF: Like above, *G. stuarti* becomes very rare.
BF: Like above, *Bolivinoides* sp. cf. *B. peterssoni* Brotzen.
Ostracoda: Like above.
Age and Environment: Like above.

Sample 12-111A-11-5, 72-75 cm:
More than 50 per cent of the washed residue is fragments of *Inoceramus*.
PF: Like above, but without *G. stuarti* and with *G. ventricosa*.
BF: Like above, with *Bolivinoides* sp. cf. *B. peterssoni* and *B. australis* Edgell.
Ostracoda: Like above.
Age: Early Maestrichtian.
Environment: Probably like above.

Sample 12-111A-11-6, 3-6 cm:
Twenty to thirty per cent of the washed residue is *Inoceramus*, other pelecypod fragments are also common, echinoderm remains are rare.
PF: Like above, the fauna is dominated by *G. arca*.
BF: Like above, somewhat richer. In addition to the two forms of *Bolivinoides* listed above here also *B. draco draco* is found.
Ostracoda: Like most samples above, rare Cytheridae and *Cytherella*.
Age and Environment: Like above, slightly warmer water (?).

Sample 12-111A-11-9, 72-75 cm:
About 5 to 10 per cent of the washed residue now consists of *Inoceramus* fragments; in addition some echinoderm spines and fish teeth are found.
PF: Mostly the same as above, *Globotruncana gansseri* is very rare and primitive; *G. linneiana* (d'Orbigny) is present, but rare. As in the sample above the fauna is dominated by *G. arca*.
BF: Like above, also the same *Bolivinoides* species.
Age and Environment: Like above.

Sample 12-111A-11-6, 147-150cm:
Inoceramus fragments are present but constitute less than 1 per cent of the washed residue; some other pelecypod fragments and echinoderms are found as well. The core-catcher sample of a core can be contaminated with younger fossils, therefore the fossils found in this sample are listed as being the lowest reliable sample of the core:
PF: *Globotruncana arca* and *G. rosetta* dominate the planktonic foraminiferal fauna, followed by *G. scitula, G. ventricosa* and *G. tricarinata; G. linneiana* is rare and so is the single-keeled form *G. stuartiformis; G. gansseri* is very rare, and *G. aegyptiaca* occurs as a rare variant of *G. ventricosa*; others present are: *Rugoglobigerina rugosa, Globotruncanella havanensis, Globigerinelloides messinae messinae, G. messinae subcarinata, G. messinae biforaminata, Pseudotextularia carseyae, Pseudoguembelina excolata* (very rare), *Heterohelix striata, Gublerina pseudotessera, Hedbergella monmouthensis* (Olsson), Planoglobulina sp. cf. *P. glabrata.*
BF: *Bolivinoides draco draco* and (less) *B. draco miliaris* Hiltermann and Koch (length/breadth of *B. draco* s.l.=1.25;n=7), *B. delicatulus delicatulus, G.* sp. cf. *B. paleocenicus* (differs from *B. paleocenicus* (Brotzen) in having one sutural lobe rather than two or three; ditters from *B. watersi* (Cushman) in being much wider having a L/B index of 1.45 (n=17, 1.61-1.12)). Apart from this relatively rich *Bolivinoides*

assemblage other interesting benthonics are present: *Aragonia velascoensis* (Cushman), *Stensiöina excolata* (Cushman), *Neoflabellina* sp. aff. *N. numismalis*, *Osangularia cordieriana navarroana* (Cushman) (dominates larger fraction), *Reussella szajnochae* Grzybowski, *Gavelinopsis* sp., lagenids, arenaceous forms.

Ostracoda: *Cytherella* sp., *Bairdia* sp., *Pterygocythere alata* (Bosquet), *Curfsina minor* (van Veen), "*Cythereis*" *nodulosa* (Bosquet).

Age: Early Maestrichtian.

Environment: Marine, outer neritic–upper bathyal.

Sample 12-111A-11, core catcher:
The same as above.

Sample 12-111A-12, gray clay pebble on top of core:
The washed residue of this small sample contains Maestrichtian and Eocene foraminifera.

Sample 12-111A-12, core catcher:
The washed residue of a hard piece of sandy glauconitic limestone yielded glauconite casts of *Hedbergella*, *Rotalipora*, gavelinellids, biserial forms and miliolids. Maestrichtian and Eocene foraminifers are present as contaminants.
Thin sections show a recrystallized micritic skeletal limestone that is glauconitic and very fine sandy (silty) (<5%); foraminifera are rare in the sections and occur as glauconite casts as well as with the original tests.

Age: Cenomanian.

Environment: Shallow marine.

APPENDIX F. COCCOLITH SPECIES AND STRATIGRAPHIC ASSIGNMENT OF SITE 111

David Bukry

Hole 111

Cenozoic

12-111-2-6, 114-116 cm; depth 102 m:
Coccolithus pelagicus (Wallich), *Coccolithus* sp. [small].

Upper Cretaceous

12-111-3-2, 136-137 cm; depth 191 m:
Apertapetra gronosa (Stover), *Biscutum* sp., *Eiffellithus turisseiffeli* (Deflandre), *Lithastrinus floralis* Stradner, *Parhabdolithus embergeri* (Noël), *Prediscosphaera* sp., *Watznaueria barnesae* (Black), *Zygodiscus* sp. cf. *Z. stenopus* (Stover).

Hole 111A

Lower Pleistocene
(*Coccolithus doronicoides* Zone)

12-111A-1A-1, 144-146 cm; depth 106 m:
Coccolithus pelagicus, *Cyclococcolithina leptopora* (Murray and Blackman), *Emiliania annula* (Cohen).

12-111A-3A-1, 141-143 cm; depth 120 m:
Coccolithus doronicoides Black and Barnes, *C. pelagicus*, *Cyclococcolithina leptopora*, *C. macintyrei* (Bukry and Bramlette), *Discolithina japonica* Takayama, *Emiliania annula*, *Helicopontosphaera kamptneri* Hay and Mohler, *H. sellii* Bukry and Bramlette, *Syracosphaera* sp.

Series unknown

12-111A-3A-4, 144-145 cm; depth 125 m:
Barren.

12-111A-4A-1, 143-144 cm; depth 126 m:
Barren

Lower Pleistocene
(*Coccolithus doronicoides* Zone)

12-111A-4A-2, 145-146 cm; depth 128 m:
Coccolithus doronicoides, *C. pelagicus*, *Emiliania annula*, *Helicopontosphaera kamptneri*

12-111A-5A-1, 142-143 cm; depth 135 m:
Coccolithus doronicoides, *C. pelagicus*, *Cyclococcolithina leptopora*, *Rhabdosphaera clavigera* Murray and Blackman.

Upper Pliocene
(*Discoaster brouweri* Zone)

12-111A-6A-1, 141-142 cm; depth 144 m:
Coccolithus doronicoides, *C. pelagicus*, *Cyclococcolithina leptopora*, *C. macintyrei*, *Discoaster* sp. cf. *D. brouweri* Tan, *Discoaster* sp. aff. *D. exilis* Martini and Bramlette [webbed rays].

12-111A-6A-2, 38-39 cm; depth 144 m:
Ceratolithus rugosus Bukry and Bramlette, *Coccolithus pelagicus*, *Cyclococcolithina leptopora*, *C. macintyrei*, *Discoaster pentaradiatus* Tan, *D. surculus* Martini and Bramlette, *Discolithina* sp.

Lower Pliocene
(*Ceratolithus rugosus* Zone)

12-111A-6A-2, 146-147 cm; depth 145 m:
Ceratolithus rugosus, *C. tricorniculatus* Gartner, *Coccolithus pelagicus* [abundant], *Cyclococcolithina leptopora*, *C. macintyrei*, *Discoaster brouweri*, *D. pentaradiatus*, *Discoaster* sp. cf. *D. surculus*, *D. variabilis variabilis* Martini and Bramlette, *Discolithina japonica*, *D. multipora* (Kamptner ex Deflandre) *s.l.*, *Helicopontosphaera kamptneri*, *H. sellii*, *Reticulofenestra pseudoumbilica* (Gartner), *Rhabdosphaera* sp. cf. *R. procera* Martini, *Scyphosphaera intermedia* Deflandre, *Sphenolithus neoabies* Bukry and Bramlette.

Upper Miocene
(*Discoaster quinqueramus* Zone)

12-111A-6A-3, 74-75 cm; depth 146 m:
Ceratolithus tricorniculatus [rare], *Coccolithus pelagicus*, *Cyclococcolithus leptopora*, *C. macintyrei*, *Discoaster berggreni* Bukry, *D. braarudii* Bukry, *D. brouweri s.l.*, *D. pentaradiatus*, *D. quinqueramus* Gartner, *D. surculus*, *D. variabilis variabilis*, *Helicopontosphaera granulata* Bukry and Percival, *H. kamptneri*, *Reticulofenestra pseudoumbilica*.

Middle Eocene
(*Discoaster sublodoensis* Zone)

12-111A-6A-3, 135-136 cm; depth 147 m:
Campylosphaera dela (Bramlette and Sullivan), *Chiasmolithus grandis* (Bramlette and Riedel), *Cyclococcolithina formosa* (Kamptner), *Cyclolithella bramlettei* (Hay and Towe), *Discoaster barbadiensis* Tan, *D. distinctus* Martini, *D. lodoensis* Bramlette and Riedel, *D. sublodoensis* Bramlette and Sullivan, *D. wemmelensis* Acuthan and Stradner, *Reticulofenestra samodurovi* (Hay, Mohler, and Wade).

Lower Eocene
(*Discoaster lodoensis* Zone)

12-111A-8A-2, 143-144 cm; depth 164 m:
Campylosphaera dela, *Chiasmolithus grandis*, *C. solitus* Bramlette and Sullivan, *Coccolithus crassus* Bramlette and Sullivan, *Cyclolithella bramlettei*, *Discoaster cruciformis* Martini, *D. elegans* Bramlette and Sullivan, *D. lodoensis*, *D. nonaradiatus* Klumpp, *Discoasteroides kuepperi* Stradner, *Ellipsolithus lajollanensis* Bukry and Percival, *Helicopontosphaera* sp. cf. *H. lophota* (Bramlette and Sullivan), *H. seminulum* (Bramlette and Sullivan), *Reticulofenestra* sp. aff. *R. umbilica* [structurally similar species, but two zones lower than typical first occurrence], *Rhabdosphaera* sp. cf. *R. perlonga* (Deflandre), *Sphenolithus radians* Deflandre, *Syracosphaera fimbriata* (Bramlette and Sullivan), *Syracosphaera* sp., *Transversopontis pulcheroides* (Sullivan), *Zygolithus dubius* Deflandre.

Lower Eocene
(*Tribrachiatus orthostylus* Zone)

12-111A-10A-1, 146-147 cm; depth 174 m:
Campylosphaera dela, Chiasmolithus grandis, Cyclolithella bramlettei, Discoaster elegans, D. lodoensis, Discoasteroides kuepperi, Discolithina plana Bramlette and Sullivan, *Helicopontosphaera seminulum, Lophodolithus nascens, Syracosphaera fimbriata, Transversopontis pulcher* (Deflandre), *Tribrachiatus orthostylus* Shamrai [*nom. subst. pro Discoaster tribrachiatus* Bramlette and Riedel], *Zygolithus dubius.*

Upper Cretaceous [Maestrichtian]
(*Lithraphidites quadratus* Zone)

12-111A-11A-4, 143-144 cm; depth 187 m:
Apertapetra gronosa, Arkhangelskiella cymbiformis Vekshina, *Biscutum testudinarium* Black and Barnes, *Braarudosphaera bigelowi* (Gran and Braarud), *Cretarhabdus conicus* Bramlette and Martini, *C. crenulatus* Bramlette and Martini, *Cribrosphaera ehrenbergii* Arkhangelsky, *Cylindralithus gallicus* Bramlette and Martini, *Eiffellithus turriseiffeli, Kamptnerius magnificus* Deflandre, *Lithraphidites quadratus* Bramlette and Martini, *Lucianorhabdus cayeuxi* Deflandre, *Marthasterites inconspicuus* Deflandre, *Microrhabdulus decoratus* Deflandre, *M. stradneri* Bramlette and Martini, *Micula decussata* Vekshina, *Prediscosphaera cretacea cretacea* (Arkhangelsky), *P. cretacea lata* Bukry, *P. spinosus* Bramlette and Martini, *Watznaueria barnesae.*

Upper Cretaceous [Campanian]
(*Tetralithus gothicus trifidus* Zone)

12-111A-11A-6, 138-139 cm; depth 190 m:
Arkhangelskiella cymbiformis, Biscutum testudinarium, Broinsonia parca (Stradner), *Cretarhabdus crenulatus, Cribrosphaera ehrenbergii, Cylindralithus gallicus, Eiffellithus turriseiffeli, Kamptnerius magnificus, Microhabdulus decoratus, Micula decussata, Prediscosphaera cretacea cretacea, Tetralithus aculeus* (Stradner), *T. gothicus trifidus* Stradner and Papp, *Watznaueria barnesae, Zygodiscus meudini* Bukry.

APPENDIX G. SHORE LABORATORY REPORT ON MESOZOIC PLANKTONIC FORAMINIFERIDA – LEG 12

E. A. Pessagno, Jr. and J. F. Longoria T.

12-111A-11-1, 142-143 cm:
Abathomphalus mayaroensis (Bolli)
Abathomphalus intermedius (Bolli)
Globotruncana contusa s.s. (Cushman)
Globotruncana conica White
Globotruncana stuarti s.s. (de Lapparent)
Globotruncana stuartiformis Dalbiez
Globotruncana elevata Brotzen
Globotruncana arca (Cushman)
Globotruncana fornicata Plummer (reworked)
Globotruncana linneiana (d'Orbigny) (reworked)
Globotruncana hilli Pessagno (reworked)
Globotruncanella nothi (Bronnimann and Brown)
Globotruncanella havanensis (Voorwijk)
Globotruncanella sp. cf. *G. petaloidea* (Gandolfi)
Archaeoglobigerina sp.
Racemiguembelina sp.
Ventilabrella multicamerata de Klasz
Heterohelix punctulata (White)
Pseudotextularia elegans (Rzehak)
Globigerinelloides multispina (Lalicker)

Biostratigraphic determination: *A. mayaroensis* Subzone (upper part with reworked specimens from the *G. elevata* Subzone or *R. subcircumnodifer* Subzone. Latest Maestrichtian with reworked late Campanian or early Maestrichtian.

12-111A-11-2, 76-79 cm:
Abathomphalus intermedius (Bolli)
Abathomphalus mayaroensis (Bolli)
Globotruncanella havanensis (Voorwijk)
Globotruncana gansseri Bolli
Globotruncana contusa (Cushman)
Globotruncana patelliformis Gandolfi
Globotruncana stuarti s.s. (de Lapparent)
Globotruncana stuartiformis Dalbiez
Globotruncana arca (Cushman)
Globotruncana linneiana (d'Orbigny) (reworked)–Campanian to early Maestrichtian element
Globotruncana lapparenti s.s. Brotzen (reworked)–Santonian to early Maestrichtian element
Globotruncana hilli Pessagno (reworked)–late Campanian to early Maestrichtian element
Globigerinelloides multispina (Lalicker)
Globigerinelloides volutus (White)
Pseudotextularia elegans (Rzehak)
Pseudotextularia intermedia de Klasz
Ventilabrella multicamerata de Klasz
Ventilabrella manuelensis Martin
Pseudoguembelina costulata (Cushman)

Biostratigraphic determination: *A. mayaroensis* Subzone (lower part) with reworked specimens from the *G. elevata* Subzone or *R. subcircumnodifer* Subzone. Latest Maestrichtian with reworked late Campanian or early Maestrichtian.

12-111A-11-3, 76-77 cm:
Globotruncana stuarti s.s. (de Lapparent)–late Maestrichtian element
Globotruncana patelliformis Gandolfi–late Maestrichtian element
Globotruncana ventricosa White–definitive Campanian element
Globotruncana hilli Pessagno–first occurrence, *G. calcarata* Zone
Globotruncana plummerae Gandolfi
Globotruncana elevata (Brotzen)
Globotruncana fornicata Plummer
Globotruncana linneiana (d'Orbigny)
Globotruncana lapparenti s.s. Brotzen
Globotruncana arca (Cushman)
Globotruncana stephensoni Pessagno
Globotruncana rosetta (Carsey)
Globotruncana sp. aff. *G. churchi* Martin
Globotruncanella havanensis (Voorwijk)
Archaeoglobigerina sp. (cf. *R. pennyi* of Berggren, 1962)
Pseudotextularia elegans (Rzehak)

Biostratigraphic determination: *G. contusa-stuartiformis* Assemblage Zone (undifferentiated) with reworking of *G. elevata* Subzone, *G. clacarata* Zone. Late Maestrichtian with reworking of latest Campanian.

This sample could also be regarded as latest Campanian with stratigraphic infiltration of late Maestrichtian elements.

12-111A-11-4, 71-74 cm:
Globotruncana ventricosa White
Globotruncana hilli Pessagno
Globotruncana elevata (Brotzen)
Globotruncana stuartiformis Dalbiez
Globotruncana rosetta (Carsey)
Globotruncana fornicata Plummer
Globotruncana plummerae Gandolfi
Globotruncana arca (Cushman)
Archaeoglobigerina sp (cf. *R. pennyi* of Berggren, 1962)
Globotruncanella petaloidea (Gandolfi)
Globigerinelloides volutus (White)
Rugoglobigerina rugosa (Plummer)
Heterohelix globulosa (Ehrenberg)
Heterohelix striata (Ehrenberg)
Heterohelix pulchra (Brotzen)
Pseudotextularia elegans (Rzehak)
Ventilabrella manuelensis Martin

Biostratigraphic determination: *G. elevata* Subzone, *G. calcarata* Zone. Latest Campanian.

12-111A-11-5, 78-81 cm:
Globotruncana ventricosa White
Globotruncana hilli Pessagno
Globotruncana nothi (Bronnimann and Brown)
Globotruncana fornicata Plummer

Globotruncana linneiana (d'Orbigny)
Globotruncana arca (Cushman)
Globotruncana elevata (Brotzen)
Globotruncanella havanensis (Voorwijk)
Globotruncanella petaloidea (Gandolfi)
Rugoglobigerina rugosa (Plummer)
Ventilabrella manuelensis Martin
Pseudotextularia elegans (Rzehak)
Globigerinelloides volutus (White)
Archaeoglobigerina sp. (cf. *R. pennyi* of Berggren)

Biostratigraphic determination: *G. elevata* Subzone, *G. calcarata* Zone. Latest Campanian.

12-111A-11-6, 77-80 cm:
Globotruncana ventricosa White
Globotruncana hilli Pessagno
Globotruncana linneiana (d'Orbigny)
Globotruncana lapparenti Brotzen
Globotruncana arca (Cushman)
Globotruncana fornicata *Plummer*
Globotruncana plummerae Gandolfi
Globotruncana sp. cf. *G. churchi* Martin
Globotruncana elevata (Brotzen)
Globotruncana stuartiformis Dalbiez
Archaeoglobigerina sp. (cf. *R. pennyi* Bronnimann of Berggren, 1962)
Pseudotextularia elegans (Rzehak)
Ventilabrella manuelensis Martin
Globotruncanella havanensis (Voorwijk)
Globigerinelloides multispina (Lalicker)

Biostratigraphic determination: *G. elevata* Subzone, *G. calcarata* Zone. Latest Campanian.

Summary

The shore laboratory samples from Hole 111A, Core 11 indicate that Sections 1 and 2 are latest Maestrichtian in age and are assignable to the *Globotruncana contusa-stuartiformis* Assemblage Zone, *Abathomphalus mayaroensis* Subzone. Section 3 is likewise regarded as late Maestrichtian. However, on the basis of the available data, it can only be placed in the *G. contusa-stuartiformis* Assemblage Zone (undifferentiated). Reworked specimens from the late Campanian portions of the *Globotruncana fornicata-stuartiformis* Assemblage Zone are present in Sections 1, 2 and 3. Reworked specimens from the late Campanian in Section 3 nearly mask late Maestrichtian markers, such as, *Globotruncana stuarti* s.s. and *Globotruncana patelliformis* Gandolfi.

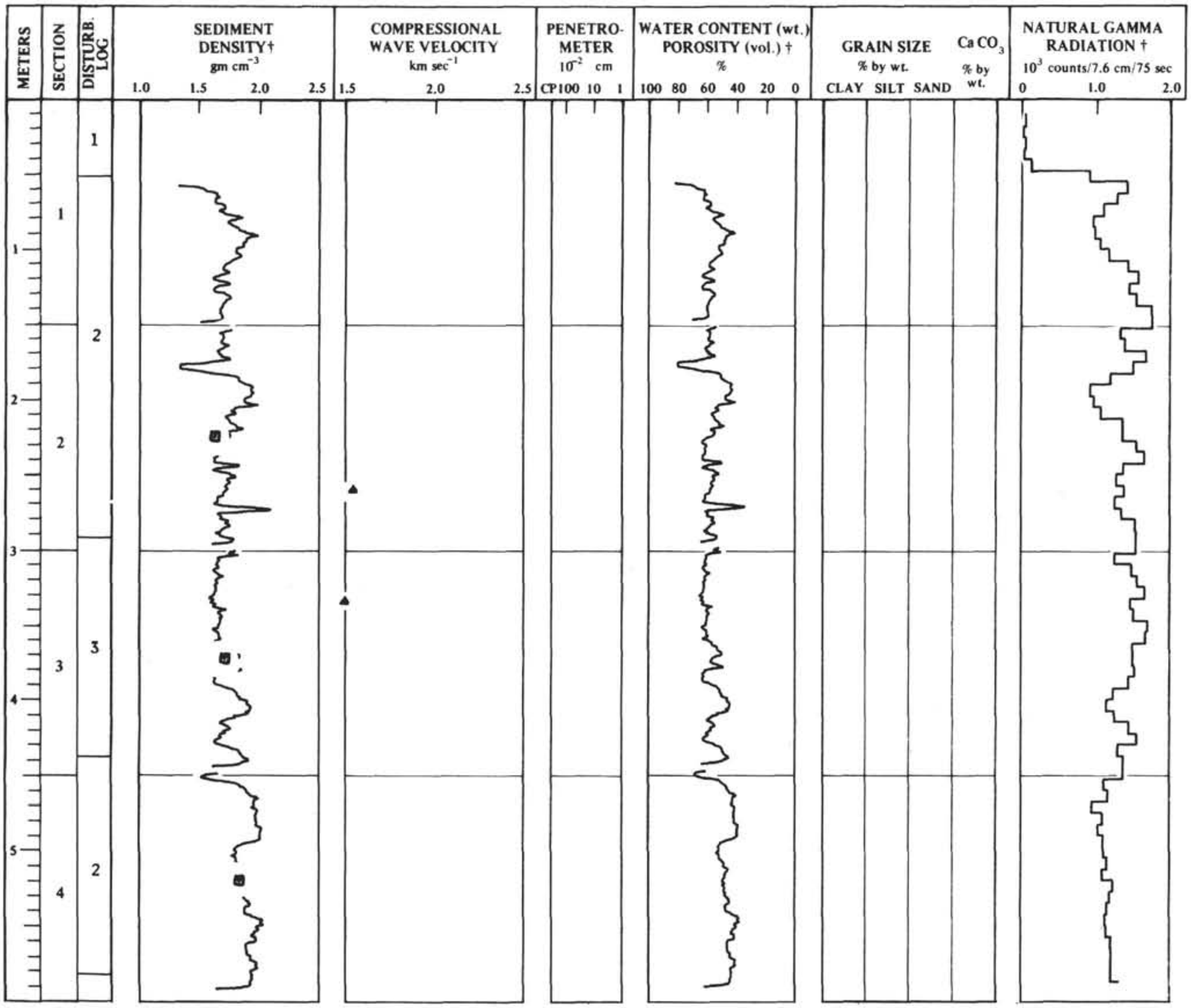
Sections 4, 5 and 6 are assignable to the latest Campanian: *G. fornicata-stuartiformis* Assemblage Zone, *G. elevata* Subzone, *G. calcarata* Zone. The association of *Globotruncana ventricosa* White, *Globotruncana hilli* Pessagno, *Globotruncanella havanensis* (Voorwijk), *Globotruncana nothi* (Bronnimann and Brown), etc., is clearly indicative of the *G. calcarata* Zone and a latest Campanian age.

It would appear that a disconformity and hiatus exists between Section 3 (76 to 77 centimeters) and Section 4 (71 to 74 centimeters) with late Maestrichtian strata resting on latest Campanian strata. All of the *R. subcircumnodifer* Subzone and possibly all of the *G. gansseri* Subzone are missing.

The planktonic foraminiferal assemblage shows a strong Tethyan or southern Boreal overprint. It is surprising, for example, to find an abundance of such forms as *Abathomphalus mayaroensis* (Bolli) and *Abathomphalus intermedius* (Bolli) at this high a latitude. In spite of this strong Tethyan overprint, some Tethyan elements, such as *Racemiguembelina fructicosa* (Egger) and *Pseudotextulaira deformis* (Kikoine), which are abundant in late Maestrichtian strata of the southern part of the Boreal Faunal Province and in the Tethyan Faunal Province are absent. Furthermore, species of *Rugoglobigerina* s.s. are rare or absent in the Campanian-Maestrichtian assemblage at Site 111. Such specimens of *Rugoglobigerina* that are present lack strongly developed costellae. *Rugoglobigerina* s.s. is profusely abundant in the Campanian and Maestrichtian strata of the Tethyan Faunal Province and in the southern part of the Boreal Faunal Province.

HOLE 111

CORE 1



†Adjusted data, see Chapter 2

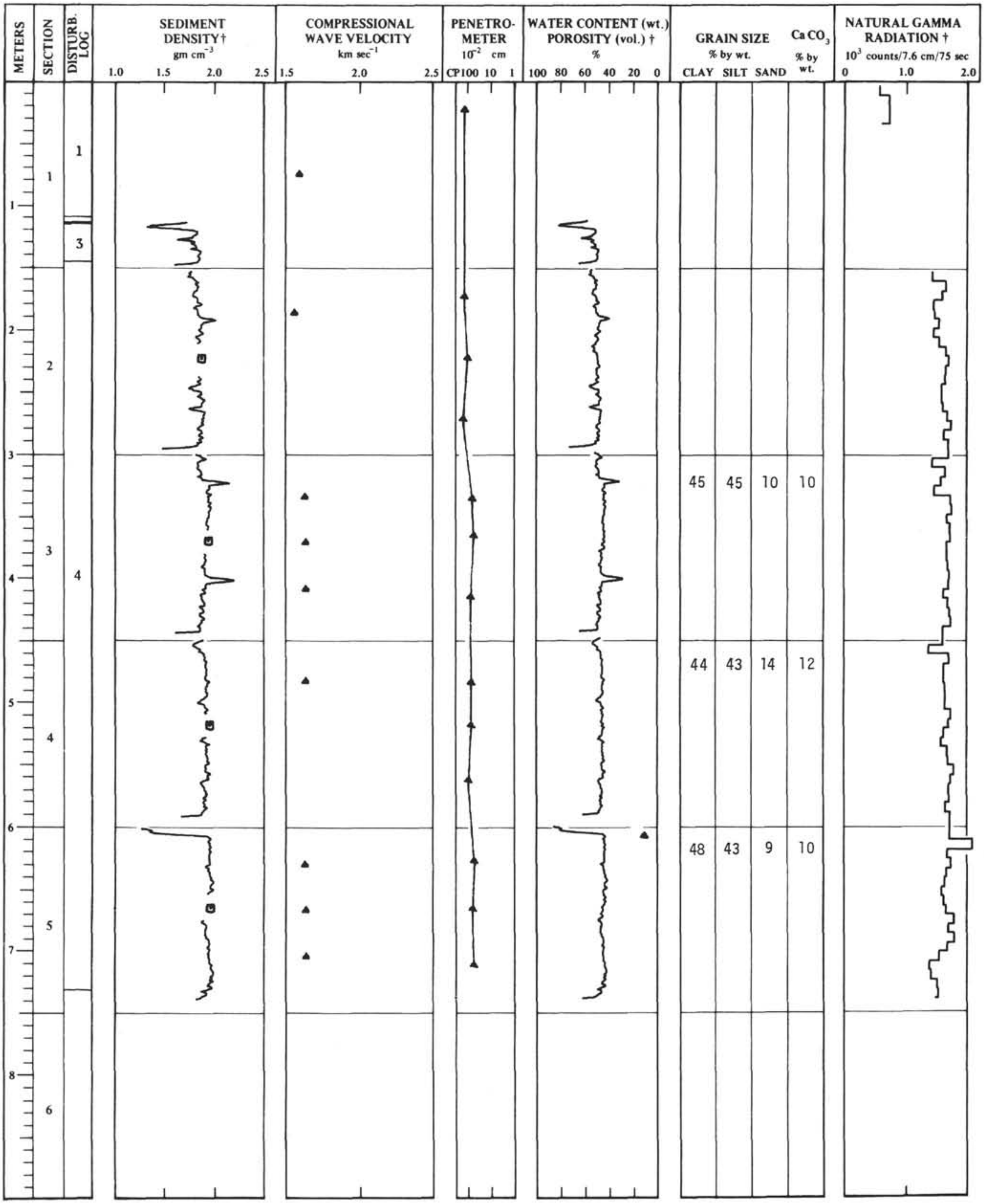
HOLE 111 0 TO 5 m

CORE 1

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
0–6	1, 2, 3, 4	EMPTY		2.5Y6/2 Light, grayish-brown very soft and watery, completely disturbed, sticky silty clay with some small pebbles. X-ray mineralogy (bulk) Calcite 26.4 Dolomite 11.2 Qtz. 23.2 Plag. 20.4 Kaol. 2.3 Mica 13.8 Amphibole 2.7 Amorph. 47.8		*Globorotalia truncatulinoides*	PLEISTOCENE
6	CC		R N F	Thin sandy layer, mostly forams.	**Core Catcher:** No radiolarians Foram fauna: *Globigerina pachyderma, G. bulloides, Globorotalia inflata, G. hirsuta, G. truncatulinoides* Flora: *Gephyrocapsa aperta, G. oceanica Helicopontosphaera kamptneri, H. sellii, Coccolithus pelagicus, Umbilicosphaera mirabilis, Syracosphaera* sp., *Scapholithus fossilis, Emiliania huxleyi, Aspidorhabdus stylifer, Pontosphaera scutellum.*	*Emiliania huxleyi*	

HOLE 111

CORE 2



†Adjusted data, see Chapter 2

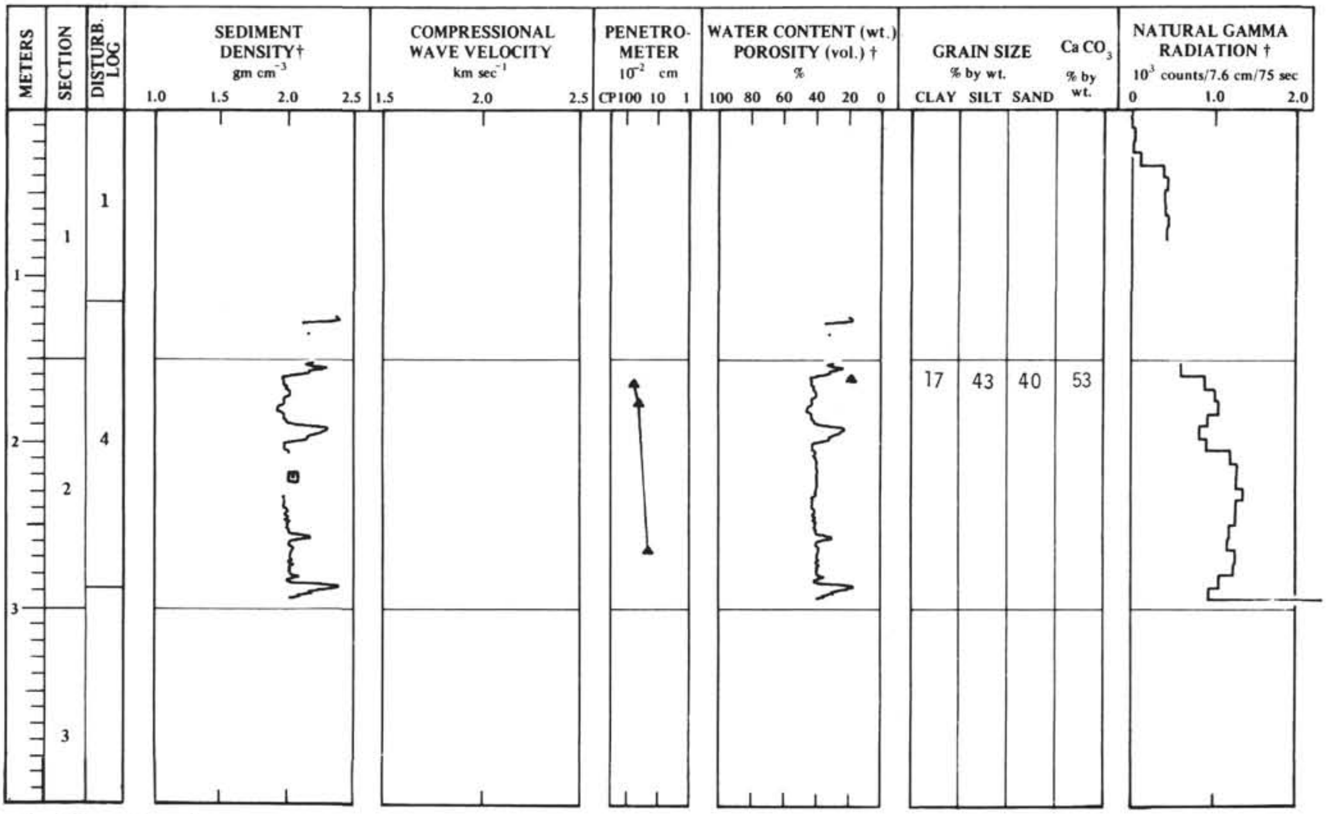
HOLE 111 94 TO 103 m

CORE 2

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
0–1.5	1	EMPTY	N N,F	5Y7/1 Disturbed gray, fine silty clay. 5Y5/1	Flora: *Coccolithus pelagicus, Gephyrocapsa aperta, Pontosphaera discopora,* Fauna: *Globigerina bulloides, G. pachyderma Globorotalia inflata, G. scitula, G. truncatulinoides, Globigerinoides conglobata*	*Pseudoemiliania lacunosa* / *Globorotalia truncatulinoides*	PLEISTOCENE
1.5–3	2		F N	5Y5/2 to 5Y6/2 Disturbed, gray silty clay with pebbles.	Fauna: *Globigerina bulloides, G. pachyderma, Globoquadrina dutertrei, Globorotalra inflata, G. puncticulata, G. hirsuta* Flora: *Coccolithus pelagicus, Pontosphaera discopora, P. sutellum, Helicopontosphaera kamptneri, H. sellii, Cyclococcolithus leptoporus, Pseudoemiliania lacunosa, Thoracosphaera* sp., *Gephyrocapsa aperta*		
3–4.5	3		F N	5Y4/1 Dark gray fine silty clay with small pebbles. Apparently not much disturbed but small patches of silt 1-2mm across are seen throughout the core. Pebbles include limestone, acid and basic igneous rocks and a few chert chips. Coarse fraction is almost entirely mineral and rock fragments with a few broken and corroded forams.	Fauna as above. Flora: *Coccolithus pelagicus, Helicopontosphaera kamptneri, H. sellii, Cyclococcolithus leptoporus, Pseudoemiliania lacunosa, Syracosphaera* sp.		
4.5–6	4		F	X-ray mineralogy (bulk) Calcite 3.9 Dolomite 6.8 Qtz. 32.0 K-feldsp. 3.9 Plag. 11.5 Kaol. 2.2 Mica 33.9 Chlor. 2.4 Mont. 1.5 Amphiboli 1.8 Amorphous 52.6	Fauna as above.		
6–7.5	5		N N,F	5Y5/2 Sandy silt, mainly forams. 5Y4/1	Flora similar to above. Flora similar to above plus *Cyclococcolithus macintyrei.* Fauna as above and rare *Pulleniatina obliquiloculata.*		
7.5–9	6	EMPTY	N,F R N,F N,F	5Y5/1 5Y4/1 5Y6/1 Foram sand. 5Y5/1 5Y6/1 Foram sand.	Flora similar to above. Fauna similar to above. No radiolarians. Flora similar to above. Fauna as above plus *G. menardii, G. crassaformis, Sph. dehiscens.* Flora similar to above. Fauna as above, but without keeled globorotaliids.		
	CC		R N F		Radiolaria very rare, silicified. Flora similar to above. Fauna as above.		

HOLE 111

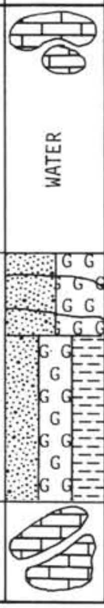
CORE 3



†Adjusted data, see Chapter 2

HOLE 111 189 TO 198 m

CORE 3

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
1 2	1 2 CC		N,R F F N F F N F N N F	Calcarenite conglomerate. Clasts 3-4 cm diameter with brown, weathered margin. Glauconite grains seen altering to limonite. Uppermost piece of calcaranite has a manganese crust 5mm think. 10YR6/6 — 5Y7/2 Glauconitic, sandy silt, becoming more clay rich towards base. Upper parts oxidized to a yellow color. Layers and fragments of "hard ground also occur. X-ray mineralogy (bulk) Calcite 35.0 Qtz. 28.0 Plag. 3.7 Mica 31.6 Mont. 1.7 Amorph. 52.0	Water above core. Fauna: *Globotruncana* sp. plus rare undiagnostic radiolarians. Flora: *Prediscosphaera cretaceae, Micula staurophora, Cribrosphaerella ehrenbergi, Lucianorhabdus cayeuxi, Watznaueria barnesae, Arkhangelskiella cymbiformis, Eiffellithus turriseiffeli, Biscutum constans, Markalium inversus, Ahmuellerella octoradiata, Cylindralithus gallicus, Kamptnerius magnificus, Braarudosphaera bigelowi, Reinhardtites anthophorus, Tranolithus* sp.* Core samples. Flora: *Eiffellithus turriseiffeli, Watznaueria barnesae, Coccolithites ficula, Zygolithus ponticulus, Biscutum constans, Prediscosphaera* sp. *Watznaueria barnesae, Zygolithus ponticulus, Prediscosphaera cretacea, Biscutum constans, Staurolithites matalosus, Cribrosphaerella ehrenbergi.* Fauna: *Rotalipora gandolfii, R. appenninica, Gavelinopsis cenomanica*	*Rotalipora gandolfii*	UPPER CRETACEOUS (LWR CENOMANIAN - MAESTRICHTIAN)
				Core Catcher: Lumps of calcarenite.	**Core Catcher:** Fauna: *Rotalipora* spp., *Gavelinopsis cenomanica* Flora similar to above.	As	above

*The top-water contains a flora of Early Maastrichtian age, contaminated by Eocene coccoliths.

HOLE 111 198 **TO** 204 **m**

CORE 4

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
1	1		N	12 cm of hard calcarenite.	Water: *Watznaueria barnesae*		
		SECTIONS 2-6 EMPTY			Fauna: *Rotalipora* sp. *Hedbergella planispira, Gavelinopsis cenomanica* Flora: *Watznaueria barnesae, Tranolithus exiguus, Cretarhabdus decorus, Prediscosphaera* sp. *Zygolithus tractus Eiffellithus turriseiffeli, Rhabdolithus splendens, Arkhangelskiella* sp.	*R. gandolfii*	UPPER CRETACEOUS (LWR CENOMANIAN)
	CC		N F	Pieces of hard calcarenite.			

HOLE 111 204 **TO** 213 **m**

CORE 5

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
		SECTIONS 1-6 EMPTY			Fauna: *Hedbergella planispira, Globigerinelloides eaglefordensis, Gavelinella intermidiacenomanica, Neocythere vanveeni*	*H. washiteesis* Zone	CRETACEOUS (UPPER ALBIAN)
	CC		F N	Core catcher sample only: Pieces of fine grained gray clayey limestone.	Flora: *Watznaueria barnesae, Zygolithus erectus, Eiffellithus turriseiffeli Biscutum* sp.		

HOLE 111 213 TO 222 m

CORE 6

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
	CC		F N R	Core catcher sample only: Fragments of hard calcarenite.	Fauna: *Gavelinella intermedia, Centrocythere denticulata* No radiolarians No coccoliths		CRETACEOUS - (ALBIAN)

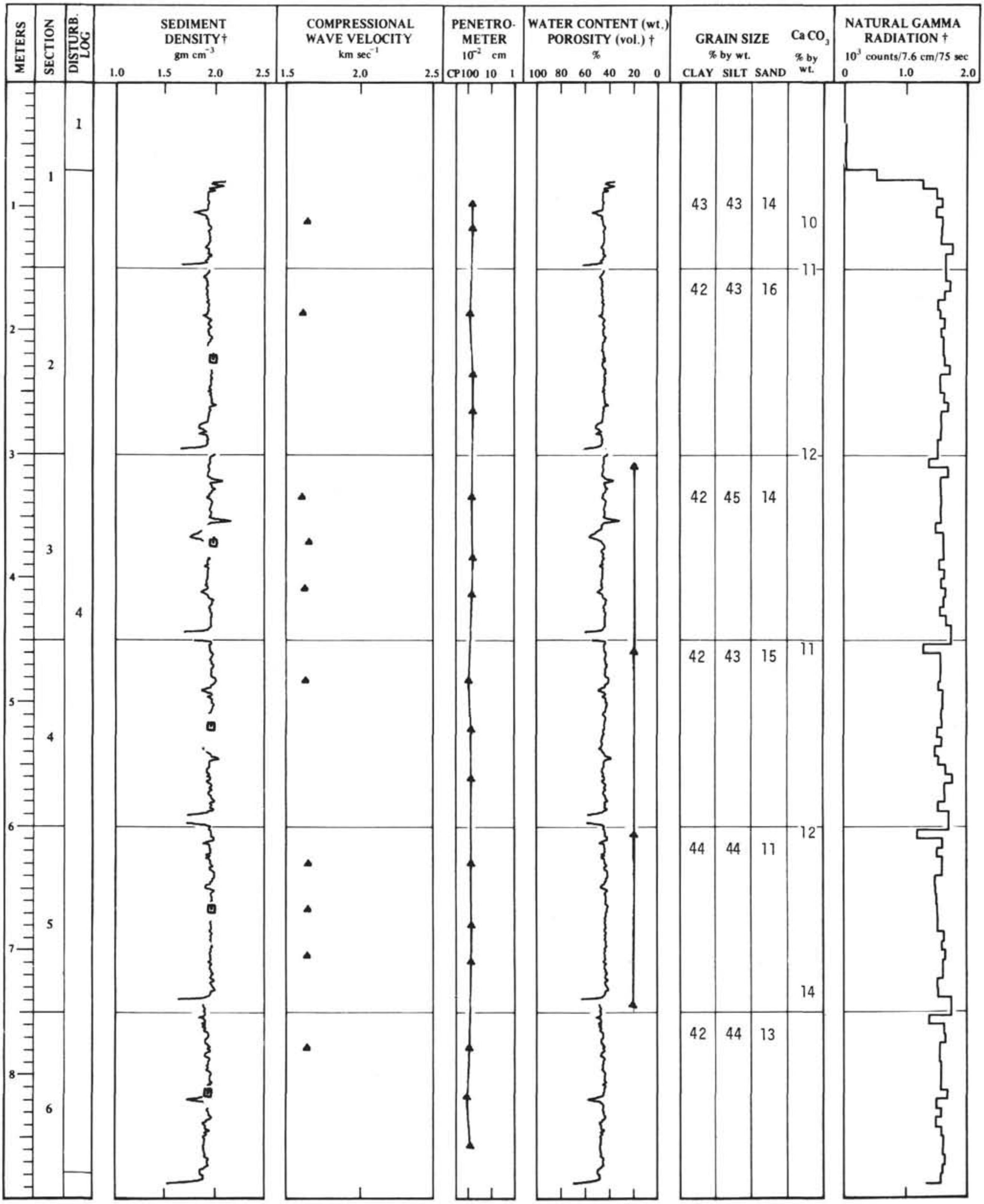
HOLE 111 249 TO 250 m

CORE 7

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
1	1		R	Graded bed of sandstone ranging from clayey siltstone at top to coarse sandstone at base. Some sign of convolute bedding. Coarser part has fine streaks and laminae of coal. Underlying the sandstone is a soft, laminated gray clay.	No radiolarians. Palynomorphs, acritarchs present. Flora: See palynology report in text.		
	CC		N				
				Core Catcher: Some smears of gray clay.	**Core Catcher:** No coccoliths		

HOLE 111A

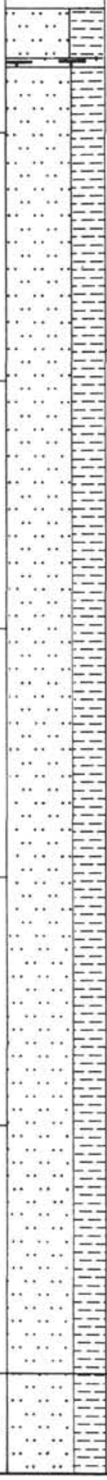
CORE 1



†Adjusted data, see Chapter 2

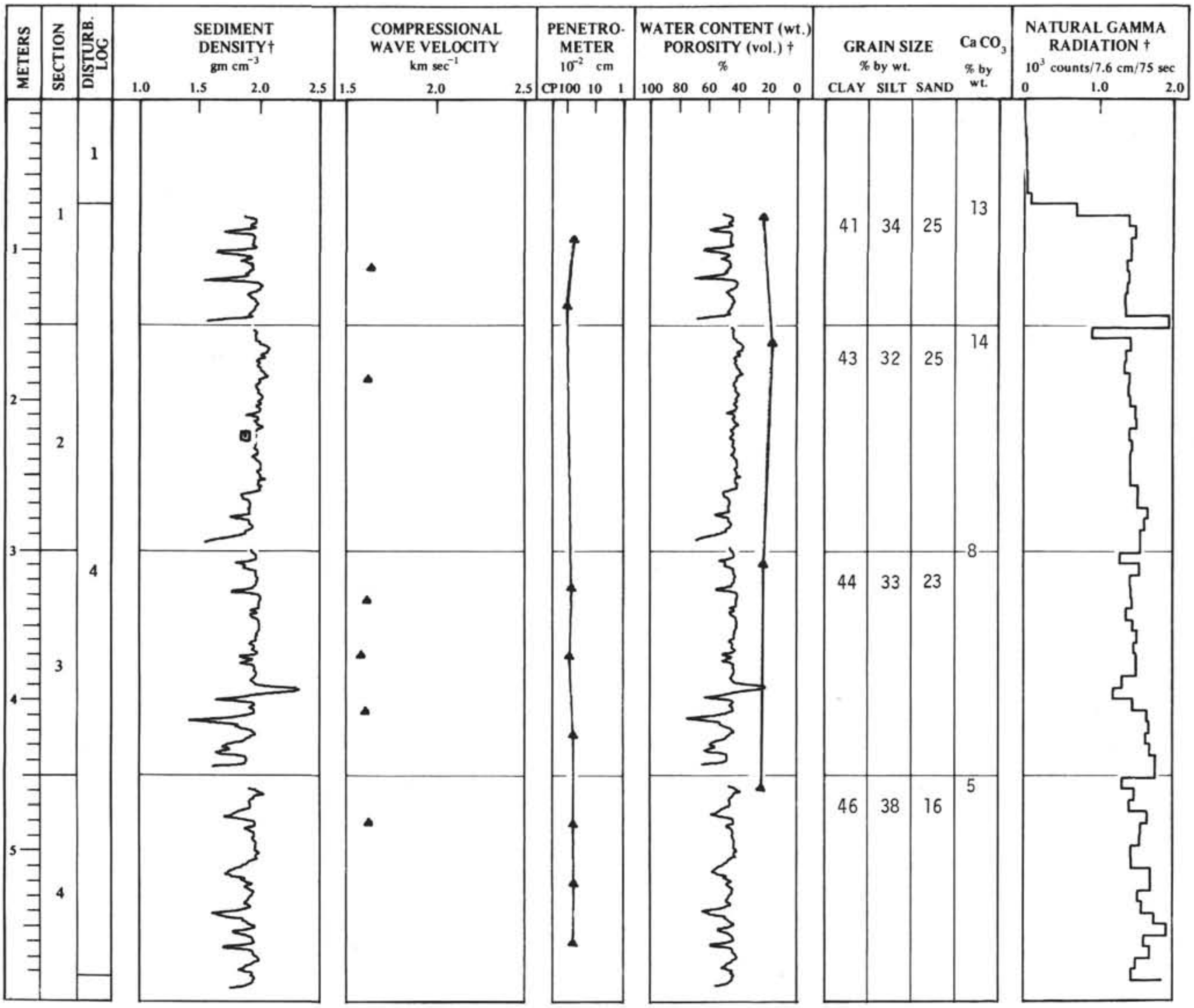
HOLE 111 A 105 TO 114 m

CORE 1

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
0–1.5	1	EMPTY 	N,F	5Y4/1 Foram sand.	Flora: *Coccolithus pelagicus, Cyclococcolithus leptoporus, Gephyrocapsa* sp., *Helicopontosphaera kamptneri, Pseudoemiliania lacunosa* Fauna: *Globigerina pachyderma, G. bulloides, Globoquadrina dutertrei, Globorotalia truncatulinoides, G. hirsuta, G. inflata, Pulleniatina obliquiloculata, Sphaeroidinella dehiscens*	*Pseudoemiliania lacunosa* / *Globorotalia truncatulinoides*	PLEISTOCENE
1.5–3	2		N		Flora similar to above		
			F		Fauna similar to above		
3–4.5	3		N	Uniform stiff gray clayey silt with siltier patches up to 2mm across, scattered through core. Many small pebbles of granite, limestone, quartzite, etc. Coarse fraction is practically all mineral grains and rock fragments with some broken and corroded forams. X-ray mineralogy (bulk) Calc. 5.9 Dolo. 5.3 Qtz. 31.4 Plag. 13.3 Kaol. 1.1 Mica 35.9 Chlor. 3.0 Mont. 2.2 Amphibole 1.9 Amorph. 57.2	Flora similar to above		
			F		Fauna similar to above		
4.5–6	4		N		Flora similar to above		
			F		Fauna similar to above		
6–7.5	5		N		Flora similar to above		
			F		Fauna similar to above		
7.5–9	6		N	5Y5/1	Flora similar to above plus reworked Eocene coccoliths and discoasters (*Discoaster lodoensis, D. kuepperi, Sphenolithus radians, Discolithus pulcher*		
			F		Fauna: *Globorotalia inflata, Globigerina pachyderma, G. bulloides*		
	CC		N,F R		Flora similar to above Fauna: *Globigerina bulloides, G. pachyderma, Globorotalia inflata, G. truncatulinoides, G. crassaformis* No radiolarians		

HOLE 111A

CORE 2



†Adjusted data, see Chapter 2

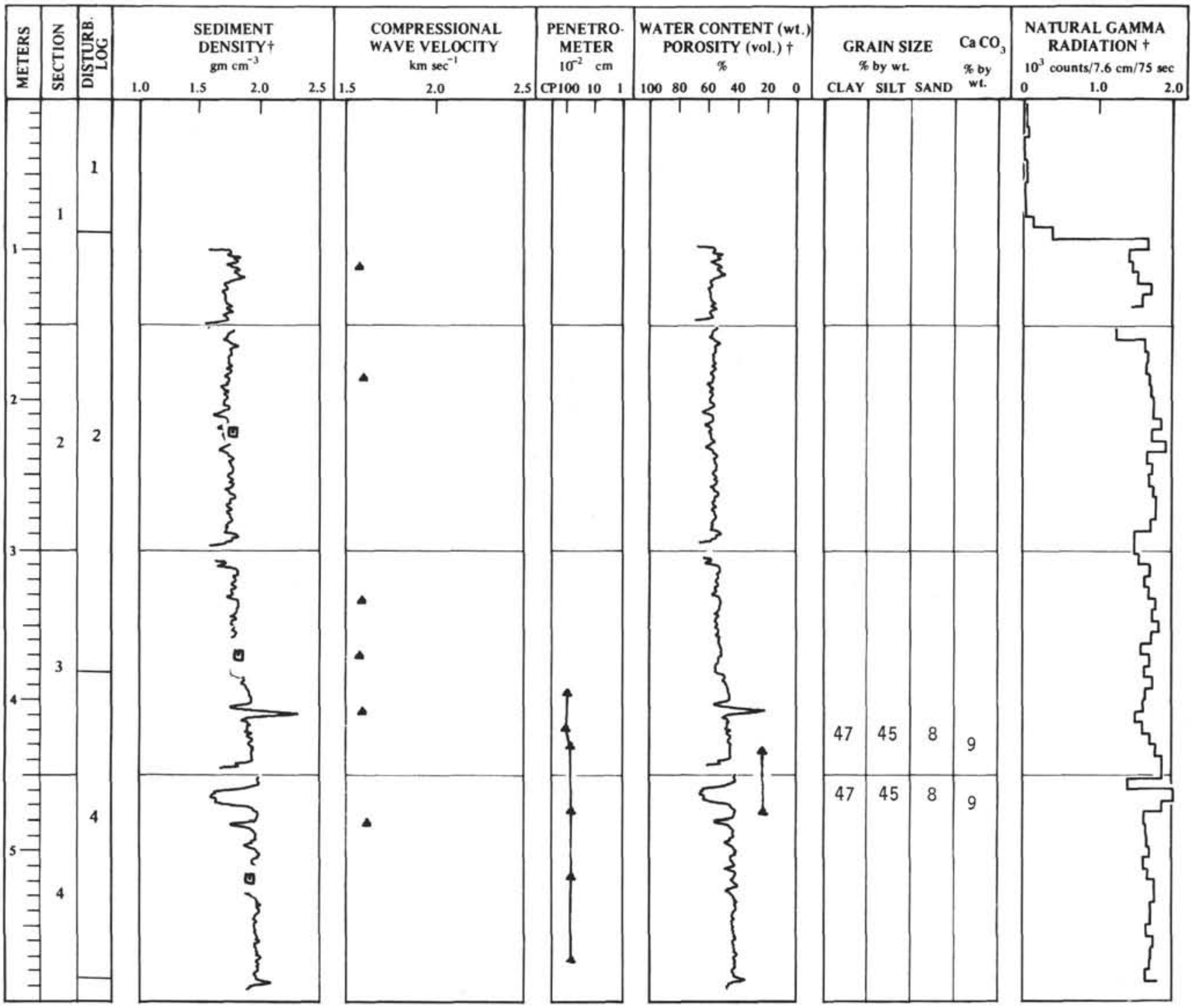
HOLE 111 A   114 **TO** 120 **m**

CORE 2

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
0–1	1	EMPTY	N F		Flora: *Coccolithus pelagicus, Cyclococcolithus leptoporus, Gephyrocapsa* sp. *Helicopontosphaera kamptneri, Pseudoemiliania lacunosa, Pontosphaera discopora* Fauna: *Globigerina bulloides, G. pachyderma, Globorotalia inflata* Flora similar to above	*Pseudoemiliania lacunosa*	PLEISTOCENE
2	2		N F	5Y5/1 to 5Y4/1 Uniform stiff gray silty clay with occasional pebbles and silty patches (as Core 111A-1). Pebbles are mostly limestone with some pebbles of metamorphic rocks. Coarse fraction is practically all mineral material with many lumps of pyrite and pyritised worm tubes. Some forams. Mica flakes are common and conspicuous in Sections 3 and 4. X-ray mineralogy (bulk) Calcite 6.3 Dolo. 3.3 Qtz. 34.4 Plag. 11.1 Kaol. 3.8 Mica 34.6 Chlor. 1.9 Mont. 4.6 Amorphous 62.7	Fauna similar to above Flora similar to above		
3–4	3		N F		Fauna similar to above plus *G. crassaformis, O. universa*		
5	4		N F		Flora similar to above Essentially barren		
	CC		N F		**Core Catcher:** Flora similar to above Faunal diversity low; *G. bulloides, G. pachyderma, G. inflata, G. hirsuta*		

HOLE 111A

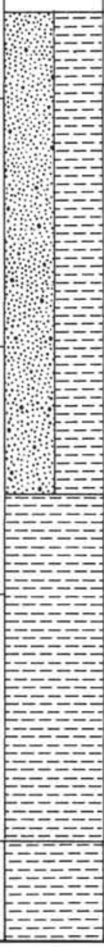
CORE 3



†Adjusted data, see Chapter 2

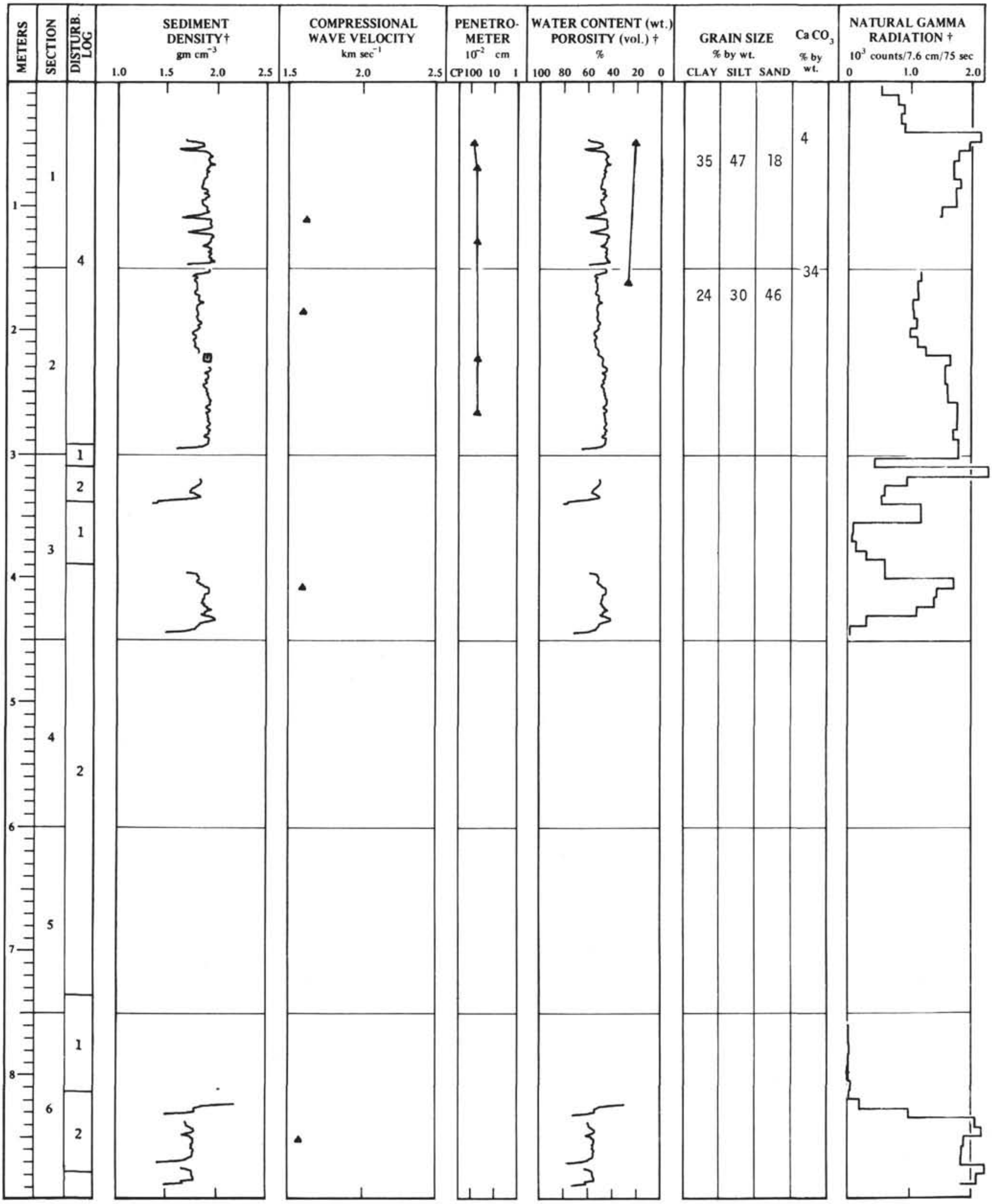
HOLE 111 A 120 **TO** 125 **m**

CORE 3

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
0–1	1	EMPTY			Flora: *Coccolithus pelagicus*, *Cyclococcolithus leptoporus*, *Gephyrocapsa* sp. *Helicopontosphaera kamptneri*, *H. sellii*, *Pseudoemiliania lacunosa*, *Pontosphaera discorpora*, *Syracosphaera* sp.	*Pseudoemiliania lacunosa*	PLEISTOCENE
1–1.5	1		N, F		Fauna sparse, *Globigerina bulloides*, *G. pachyderma*, *Globorotalia inflata* Flora similar to above		
1.5–3	2		N, F	5Y4/1 The upper part of this core, down to 90cm in Section 3, is completely disrupted by drilling and consists of irregular lumps of stiff gray clay in a watery matrix of gray sandy silt. Below 90cm in Section 3 the core consists of uniform stiff gray clay with scattered pebbles, similiar to cores 1 and 2 (111A).	Fauna similar to above		
3–4.5	3		N	X-ray mineralogy (bulk) Calcite 1.3 Dolo. 4.3 Qtz. 32.6 K-feldsp. 2.3 Plag. 8.8 Mica 43.0 Chlor. 2.5 Mont. 5.1 Amorph. 59.2	Flora similar to above		
4.5–6	4		N, F		Flora similar to above Fauna: *Globigerina pachyderma*, *G. bulloides*, *Globorotalia crassaformis*, *G. hirsuta*, *G. inflata*		
	CC		N, F		**Core Catcher:** Flora similar to above Fauna similar to above		

HOLE 111A

CORE 4



†Adjusted data, see Chapter 2

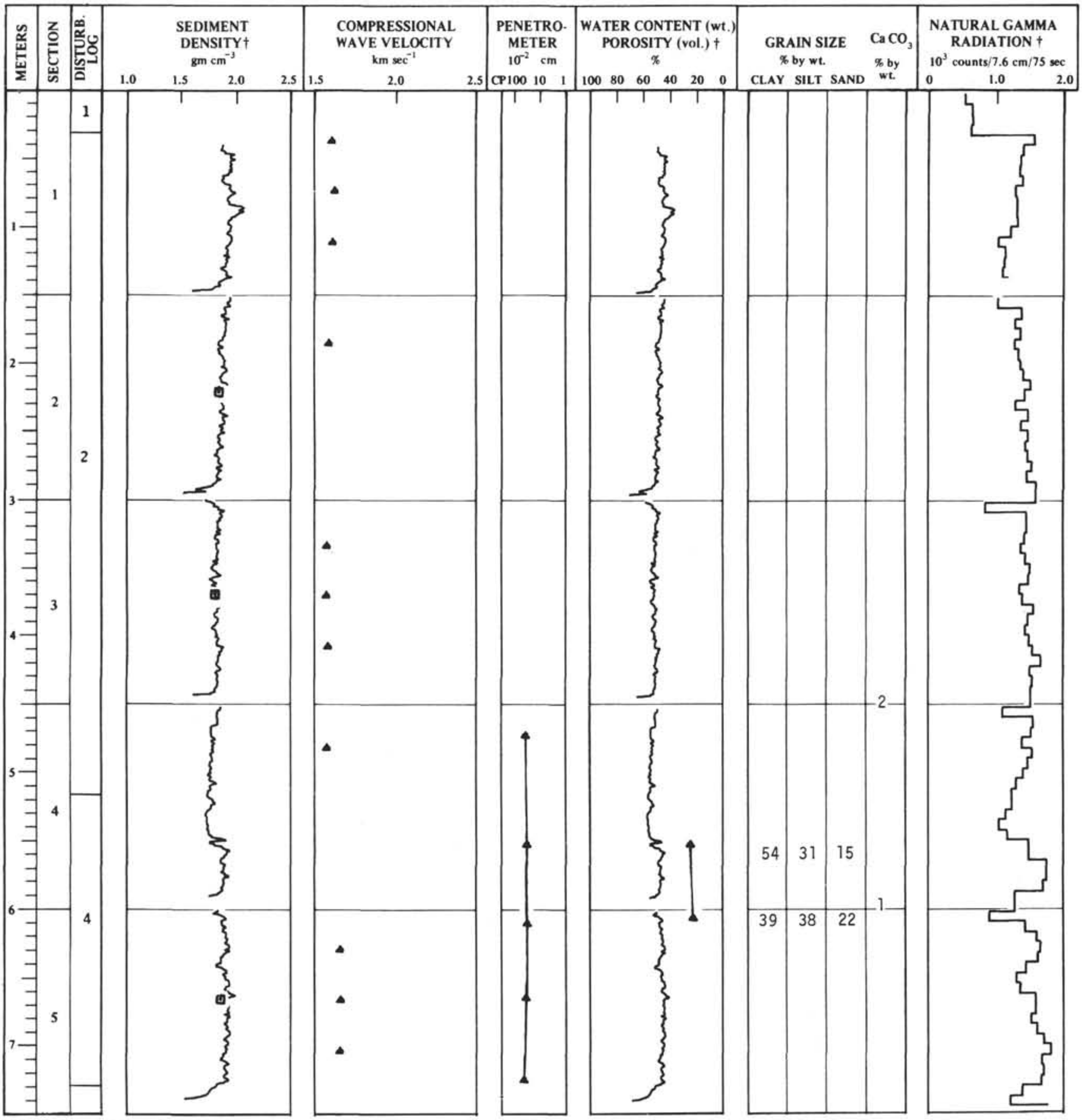
HOLE 111 A 125 TO 134 m

CORE 4

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
0–1.5	1	EMPTY	N F	5Y4/1 Uniform dark gray clay with silty patches and occasional pebbles.	Flora: *Coccolithus pelagicus, Gephyrocapsa* sp., *Cyclococcolithus leptoporus, Helicopontosphaera sellii, Pseudoemiliania lacunosa* Fauna: *Globigerina bulloides, G. pachyderma, Globorotalia crassaformis*	*P. lacunosa*	PLEISTOCENE
1.5–3	2		N F	5Y6/1 Light olive gray foram sand. Coarse fraction almost all forams, few mineral grains. N4/N5 N3 Gray stiff clay similar to Section 1. 5Y4/1 5Y6/1 X-ray mineralogy (bulk) Dolo. 2.2 Qtz. 33.4 K-feldsp. 4.2 Plag. 12.7 Kaol. 3.2 Mica 36.1 Chloro. 2.1 Mont. 6.1 Amphibole 1.4 Amorph. 56.2	Flora: *Coccolithus pelagicus, Cyclococcolithus leptoporus, C. macintyrei, Discoaster brouweri, Syracosphaera* sp. *Rhabdosphaera clavigera, Helicopontosphaera kamptneri, H. sellii, Pontosphaera discopora, P. scutellum, Pseudoemiliania lacunosa, Thoracosphaera* sp., *Scapholithus fossilis, Ceratolithus rugosus* Sparse Fauna: *Globigerina atlantica*	*Discoaster brouweri*	PLIOCENE
3–4.5	3	SECTION NOT OPENED					
4.5–7.5	4, 5	EMPTY					
7.5–9	6	SECTION NOT OPENED				*Discoaster pentaradiatus*	
	CC		N F		Flora similar to above plus *Discoaster pentaradiatus* Fauna: *Globigerina atlantica, G. bulloides, Globorotalia crassaformis, Globigerinoides conglobata, G. sacculifera, Sphaeroidinella dehiscens*		

HOLE 111A

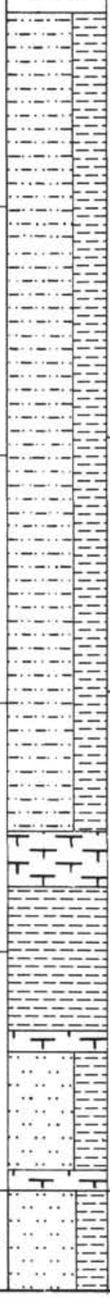
CORE 5



†Adjusted data, see Chapter 2

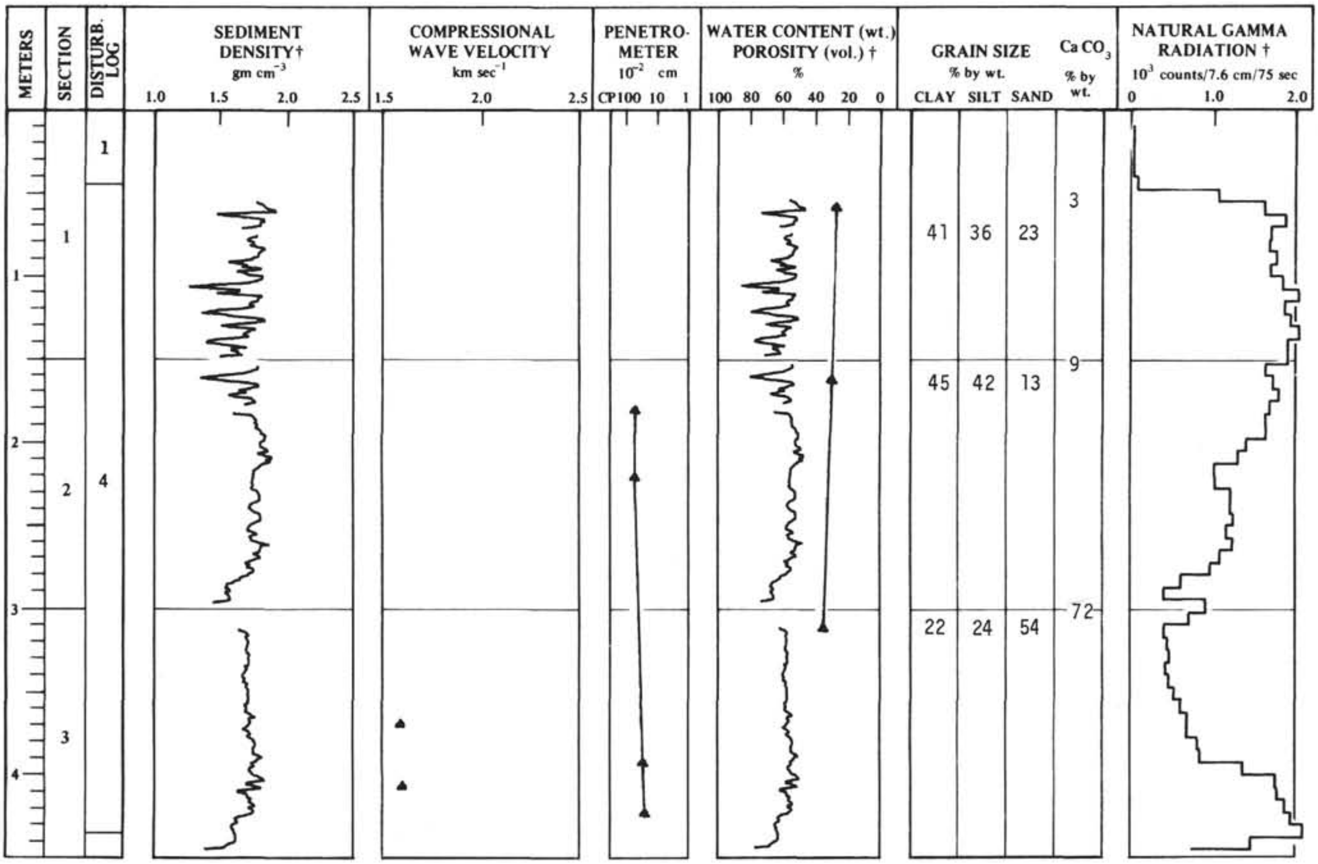
HOLE 111 A   134 **TO** 143 **m**

CORE 5

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
0–1.5	1	EMPTY 	N N N		Flora: *Coccolithus pelagicus, Cyclococcolithus leptoporus, Pseudoemiliania lacunosa, Discoaster brouweri, Helicopontosphaera kamptneri, H. sellii, Pontosphaera scutellum, Scapholithus fossilis* Flora similar to above	*Discoaster pentaradiatus*	PLIOCENE
1.5–3	2		N N F N	The top four sections of this core, down to 80cm in Section 4, are completely disrupted by drilling and consist of irregular rounded lumps of gray uniform clay in a watery silty clay matrix. X-ray mineralogy (bulk) Dolo. 1.7 Qtz. 31.5 K. feldsp. 4.6 Plag. 10.7 Kaol. 4.0 Mica 36.1 Chlor. 2.0 Mont. 9.2 Amorph. 64.9	Flora similar to above Flora similar to above Fauna: *Globigerina bulloides, G. atlantica, Globoratalia inflata, G. puncticulata, G. crassaformis, G. miocenica, Globigerimoides rubra, G. sacculifera, G. obliqus* Flora similar to above		
3–4.5	3		N N F		Flora similar to above Flora similar to above Fauna as above plus *Globoratalia exilis, G. menardii*		
4.5–6	4		N,F N N N	5GY6/1 Foraminiferal sand with limestone and red quartzite pebbles. 5Y4/1 Dark gray clay with black reduced horizons.	Flora similar to above Fauna as above: *G. exilis & G. menardii* apparently absent. Flora similar to above plus *Discoaster pentaradiatus, Ceratolithus rugosus, Syracosphaera* sp., *Cyclococcolithus macintyrei, Pontosphaera discopora, Scyphosphaera* sp. No coccoliths		
6–7.5	5		N N N N N N,F	5Y4/2-5/1 Olive gray foram sand. 5Y4/1 Gray clay with silty patches and abundant mica flakes. 5Y5/1 Foram sand.	Flora similar to above No coccoliths Flora similar to above Flora similar to above No coccoliths		
	CC		R N F		Flora similar to above plus *Discoaster surculus* Fauna: *Globigerina atlantica, G. bulloides, Globorotalia miocenica, G. scitula, G. crassaformis, Globigerinoides sacculifera, G. rubra, Sphaeroidinella dehiscens* **Core Catcher:** No radiolarians. Flora similar to above Fauna similar to above: *G. miocenica* apparently absent	*Discoaster surculus*	

HOLE 111A

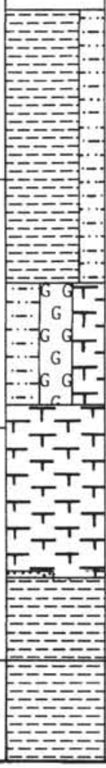
CORE 6



†Adjusted data, see Chapter 2

HOLE 111 A 143 **TO** 152 **m**

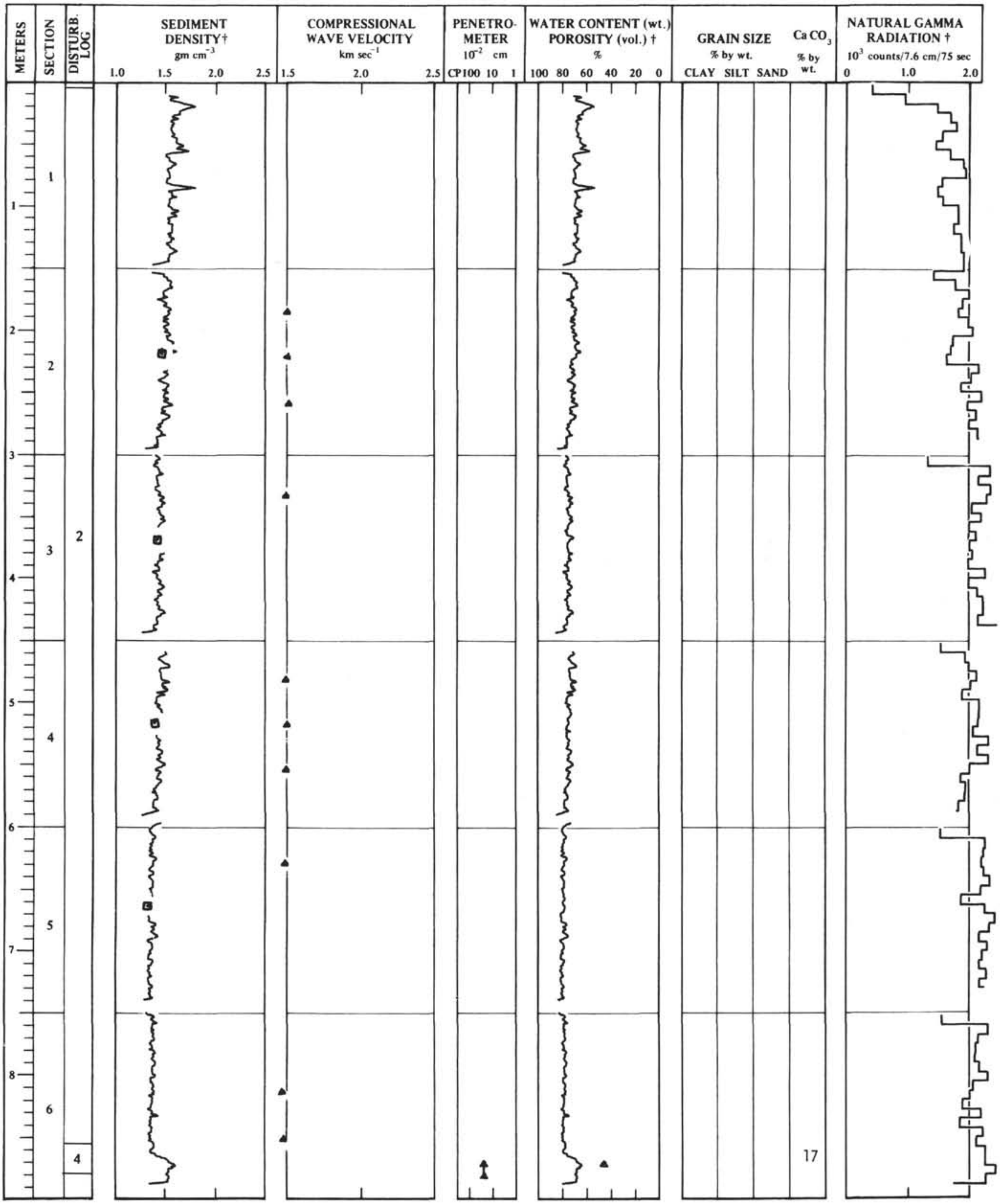
CORE 6



METERS	SECTION	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
0–1.5	1	N,F; N; N; N; F	EMPTY (top). 5Y4/1: Uniform gray clay; small pebbles and silty patches, mica flakes, etc., common.	Flora: *Discoaster brouweri, D. surculus, Coccolithus pelagicus, Cyclococcolithus leptoporus, Pontosphaera scutellum, Helicopontosphaera kamptneri, H. sellii, Pseudoemiliania lacunosa* Flora similar to above Flora similar to above	*Discoaster surculus*	PLIOCENE
1.5–3	2	N,F; N,F; N,F; N,F; N,F; N,F; N,F; N,F; N,F; N,F	5Y6/2, 5Y7/1: Glauconitic silty foram ooze. 5Y6/2: Light olive gray ooze.	For flora descriptions see section sheet. For Faunal description see section sheet.		
3–4.5	3	N,F; N,F; N,F; N,F; N,F; N,F; N,F; R N,F; R N,F; R N,F; N,F; N,F	10Y8/2, 5Y7/1: Creamy, pale green foram ooze. 5Y6/2 5G3/2: 1cm bed of glauconite sand. 10YR6/6, 5Y7/4: Below glauconite sand: 10cm creamy clay. 2cm brownish yellow oxidized clay. 14cm irregularly laminated clay. 3cm dark, reduced layer. 20cm pale yellow clay, irregularly laminated.	For Flora descriptions see section sheet. No radiolarians. For Faunal description see section sheet.		UP.&MID.(?) MIOCENE
	CC	R; N; F	X-ray mineralogy - see text.	**Core Catcher:** No radiolarians *Discoaster lodoensis, D. sublodoensis, D. wemmelensis, D. barbadiensis, Ericsonia ovalis, Chiasmolithus eograndis* No planktonic foram. fauna, only fragments; BF: *Nuttallides truempyi, oridorsalis ecuadorensis*	*D. sublodoensis*	EOCENE; E. EOCENE

HOLE 111A

CORE 7



†Adjusted data, see Chapter 2

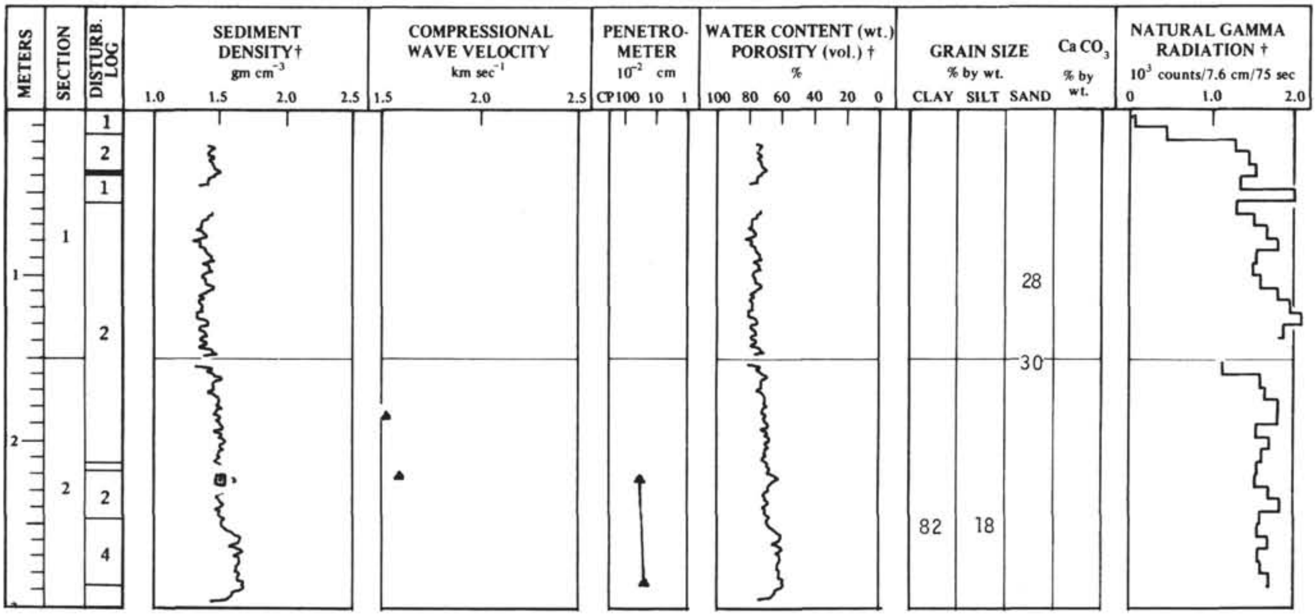
HOLE 111 A 152 **TO** 161 **m**

CORE 7

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
	1	EMPTY	N N N		Flora: *Discoaster lodoensis*, *D. kuepperi*, *D. wemmelensis*, *Neococcolithus dubius*, *N. protenus*, *Sphenolithus radians*, *Ericsonia ovalis*, *Chiasmolithus eograndis*, *Transversopontis pulcher*, *T.* cf. *exilis*, *Markalius inversus*, *Discolithina plana*, *Cyclococcolithus lusitanicus*, *Toweius* sp., *Thoracosphaera* sp.	*Discoaster sublodoensis*	LOWER EOCENE
1	2		N N		Flora similar to above		
2, 3	3		N	The upper part of this core has been completely disrupted by drilling and consists of irregular lumps of gray clay (? cavings) and smooth clays similar to the bottom part of Core 6. The matrix is a soft, watery glauconitic sand.	Flora similar to above		
4	4		N N		Flora similar to above		
5, 6	5		N N	X-ray mineralogy (bulk) Calc. 34.1 Qtz. 11.6 Plag. 1.2 Kaol. 4.8 Mica 29.0 Mont. 13.9 Clin. 5.4 Amorph. 83.9	Flora similar to above		
7, 8	6		N		Flora similar to above		
			N	5Y 7/3 — Creamy zeolitic clay 10Y 6/2 — Smooth olive clay Black clay	Flora similar to above		
			N		Flora similar to above		
	CC		N R		Flora similar to above No radiolarians		

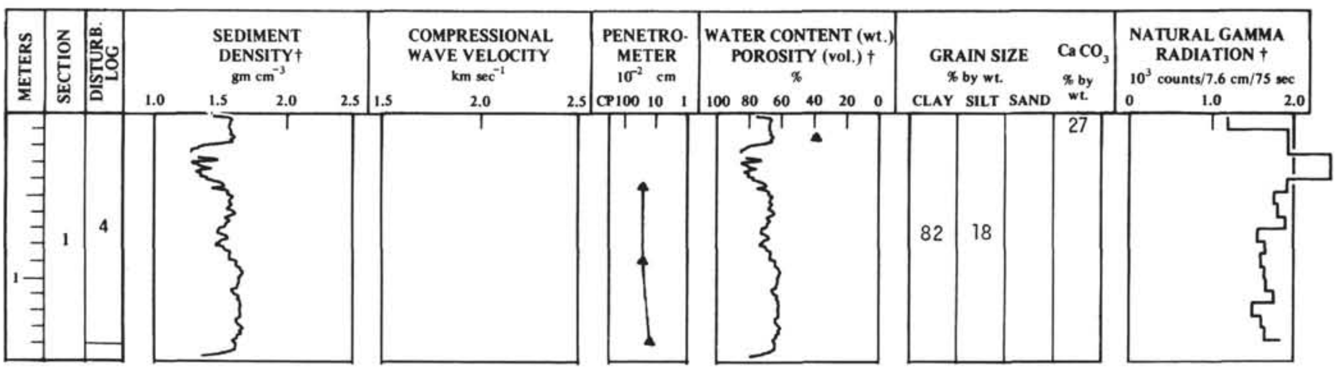
HOLE 111A

CORE 8



HOLE 111A

CORE 9



†Adjusted data, see Chapter 2

HOLE 111 A — 161 TO 164 m

CORE 8

METERS	SECTION	LITHOL.	SAMPLES		LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
1, 2	1	EMPTY	N N,F F N,F		Most of this core has been completely disrupted by drilling.	Flora: *Discoaster lodoensis, D. kuepperi, D. barbadiensis, D. currens, D. binodosus hirundinus, Ericsonia ovalis, Cyclococcolithus dubius, N. protenus, Transversopontis pulcher, Toweius* sp., *Sphenolithus radians, Discolithina exilis, Koczyia scissura, Cruciplacolithus delus, Chiasmolithus solitus, C. eograndis, Helicopontosphaera seminulum, Lophodolithus nascens, Reticulofenestra umbilica* Fauna: *Globigerina patagonica, Ac. angulosa, Ac. broedermanni, Ac. pentacamerata, Ps. wilcoxensis*	*Discoaster lodoensis*	LOWER EOCENE
	2		N	5GY 6/1	Plug of apparently undisturbed greenish gray clay.	Flora similar to above		
					Laminated greenish gray nannoplankton marl.			
			R N,F	5Y 6/1	Light olive gray laminated nannoplankton marl.	No radiolarians Flora similar to above Fauna similar to above		
	CC		R N F		X-ray mineralogy (bulk) Calc. 43.7 Qtz. 5.2 Mica 15.8 Mont. 32.1 Clin. 3.2 Amorph 69.1	**Core Catcher:** Radiolarians very rare, corroded. Flora similar to above Fauna similar to above		

HOLE 111 A — 164 TO 173 m

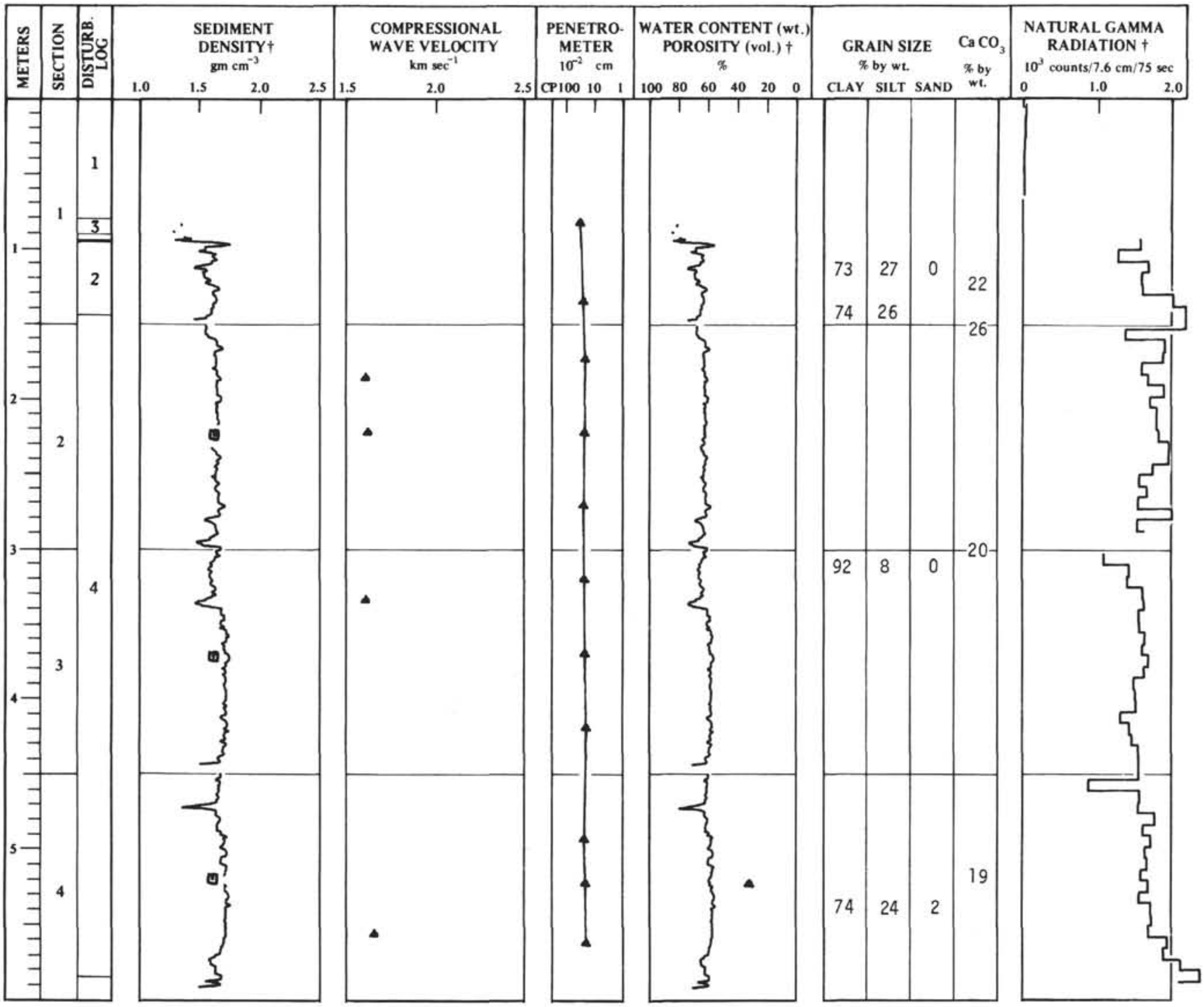
CORE 9

METERS	SECTION	LITHOL.	SAMPLES		LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
1	1		R N R R N R	5GY 6/1	Friable, hard greenish-gray nannoplankton marl. The marl is laminated and moderately mottled with green, yellow, and black streaks and laminae. X-ray mineralogy (bulk) Calc. 43.7 Qtz. 4.1 Mica 14.0 Mont. 35.5 Clin. 2.7 Amorph. 66.5	Flora: *Discoaster lodoensis, D. kuepperi, D. elegans, D. binodosus hirundinus, D. barbadiensis, Neococcolithes dubius, N. protenus, Cruciplacolithus delus, Chiasmolithus solitus, C. eograndis, Helicopontosphaera lophota, H. seminulum, Discolithina* sp, *Transversopontis pulcher, Cyclococcolithus lusitanicus, Ericsonia ovalis, Sphenolithus radians, S. moriformis, Toweius* sp. * Radiolarians very rare, corroded.	*Discoaster lodoensis*	LOWER EOCENE
	CC		R N F			**Core Catcher:** Radiolarians rare, corroded. *Podocyrtis papalis, Lophocyrtis biaurita, Spongasteriscus cruciferus.* Flora similar to above plus *Marthasterites tribrachiatus, Lophodolithus mochloprous, L. reniformis* Fauna: *Ac. pentacemerata, A.* cf. *broedermanni Gl. patagonica*	*Marthasterites tribrachiatus*	

*Contamination by younger material: *Coccolithus pelagicus, Reticulofenestra umbilica*

HOLE 111A

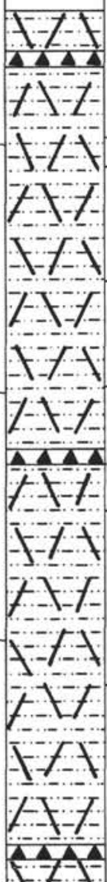
CORE 10



†Adjusted data, see Chapter 2

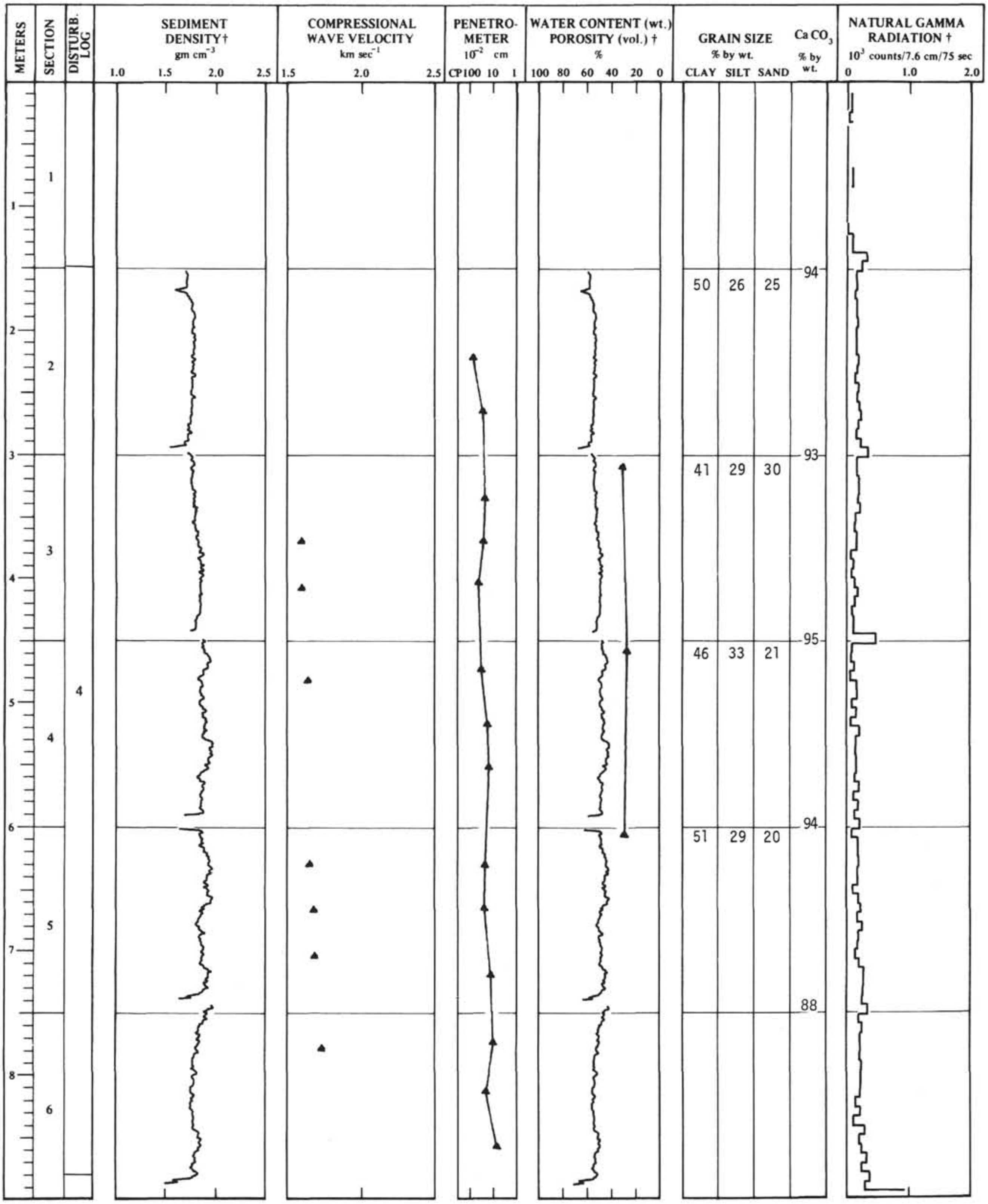
HOLE 111 A 173 **TO** 182 **m**

CORE 10

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
1	1	EMPTY 	N, R, R	5BG5/2 Cherty mudstone layer 5BG5/2	Radiolarians rare, corroded. *Lophocyrtis blaurita, Spongasteriscus cruciferus, Phormocyrtis striata, Amphicraspedum marrayanum, (?) Lychnocanium bellum, (?) Sethochytris babylonis* group. Flora: *Discoaster lodoensis, D. kuepperi, D. barbadiensis, D. binodosus binodosus, Marthasterites tribrachiatus, Ericsonia ovalis, Cyclococcolithus lusitanicus, Toweius* sp. *Neococcolithes dubius, N. protenus, Transversopontis exilis, Chiasmolithus solitus, C. eograndis, Markalius inversus, Spheno lithus radians* Fauna similar to 111A-9-CC	*Marthasterites tribiachiatus* / *Globorotalia formosa*	LOWER EOCENE
2	2		F, R N, N, R, N, F	Grayish blue-green hard laminated nannoplankton marls and cherty mudstones. The marls grade into the mudstones which appear to have to have lithified in place. The marls are slightly mottled and laminated with streaks of red, gray and yellow gray. Coarse fraction of marls includes corroded forams and fish teeth.	No radiolarians Flora similar to above Fauna similar to above		
3, 4	3		N, R N, N,F	Cherty mudstone layer 5GY6/1 X-ray mineralogy (bulk): Calc. 62.8; Qtz. 8.3; Mica 17.4; Clin. 11.4; Amorph. 73.7	Flora similar to above No radiolarians Flora similar to above		
5	4		N, R, N,F	5Y5/6 Light olive brown marl grading down into 10Y6/2 pale olive marl.	Fauna and Flora similar to above Flora similar to above No radiolarians Flora similar to above Fauna: *Globigerina patagonica, Ac. pentacomerata, A. triplex, Globorotalia subbotinae*		
	CC		R N F		**Core Catcher:** No radiolarians Flora similar to above. Flora: *G. patagonica, Ac. pentacamerata, A. soldadoensis, A. triplex, A. acarinata, G.' tensiformis.*		

HOLE 111A

CORE 11



†Adjusted data, see Chapter 2

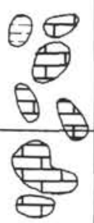
HOLE 111 A 182 **TO** 190 **m**

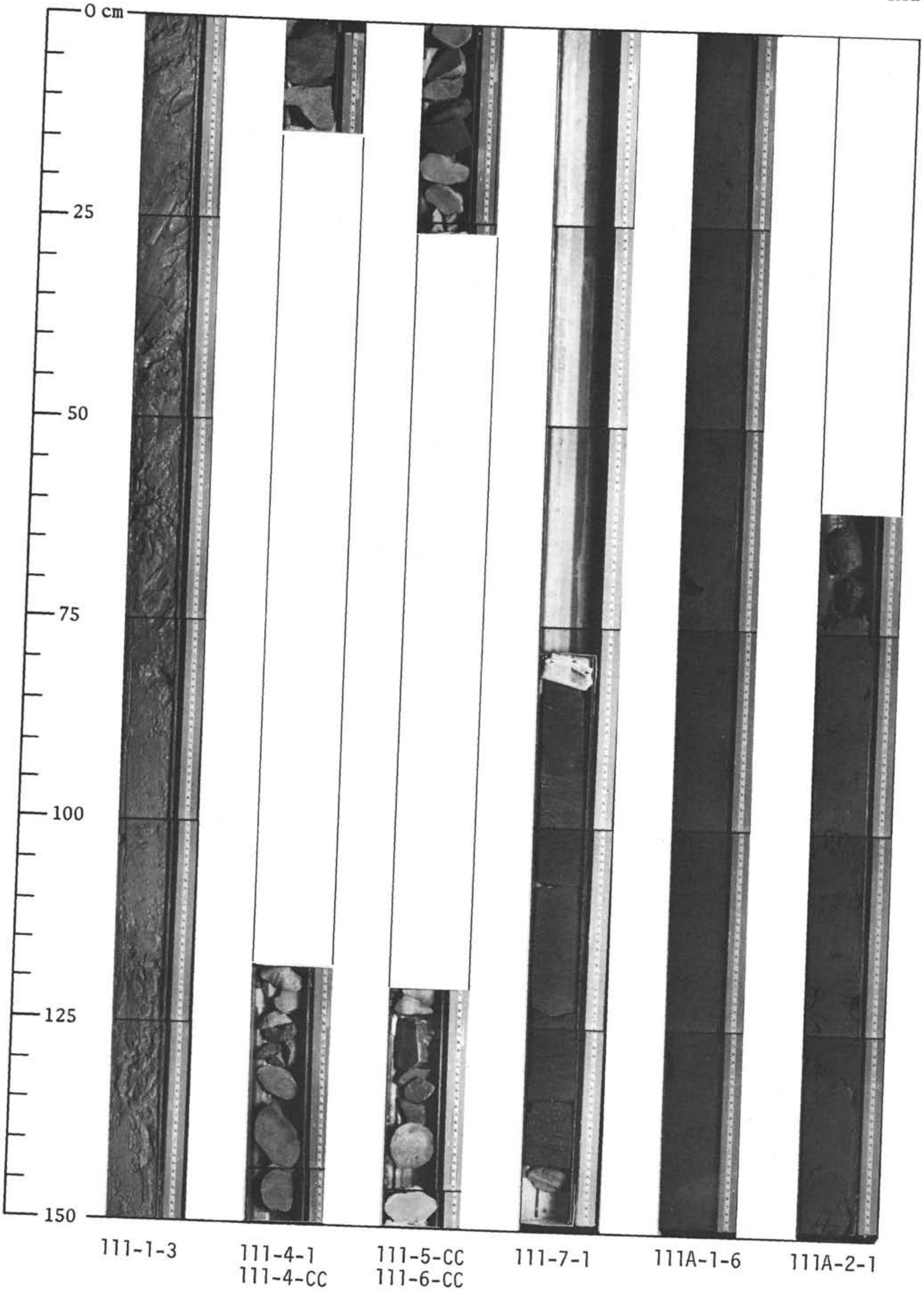
CORE 11

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
0–1.5	1	EMPTY	N, F, N F, F, N	10YR 8/2 and 2.5Y 8/2	Water: *Tetralithus murus, Arkhangelskiella cymbiformis, Prediscosphaera cretacea, P. spinosa, Cylindralithus gallicus, Kamptnerius magnificus, Micula staurophora, Ahmuellerella octoradiata, Tetralithus obscurus.* Top of core: as above, less *T. murus*, and with *Lithraphidites* sp. Contamination by Eocene coccoliths and even Paleocene (*Discoaster* cf. *gemmeus*). Fauna: *Globotruncanella mayaroensis, Globotruncana aegyptiaca, G. gansseri, G. contusa* s.s., *G. stuarti* s.s., *Pseudotextularia elegans, Bolivinoides giganteus, B. draco*	*G. mayaroensis* Zone	UPPER MAASTRICHTIAN
1.5–3	2		F, F, NF		Fauna: *Globotruncana contusa* s.l., *G. stuarti* s.s., *G. aegyptiaca, G. gansseri, Ps. elegans, Bolivinoides giganteus, B. draco* s.s. Flora: *Prediscosphaera cretacea, P. spinosa, Cribrosphaerella ehrenbergi, Micula staurophora, Kamptnerius magnificus, Cylindralithus gallicus, Braarudosphaera bigelowi, Lithraphidites carniolensis, Watznaueria barnesae, Lucianorhabdus cayeuxi, Glaukolithus fessus, Tetralithus obscurus, Microrhabdulus decoratus, Ahmuellerella octoradiata, Eiffellithus turriseiffeli, Arkhangelskiella cymbiformis*	*G. contusa* Zone; *Arkhangelskiella cymbiformis*	
3–4.5	3		F, N F	Moderately mottled chalk ooze with occasional Inoceramus prisms. A lithified and a creamy nonlithified chalk seem to be interbedded but this could be an artifact produced by drilling. Many small disconformities cut the mottles horizontally. The coarse fraction is largely forams but digestion in acid reveals quartz grains and arenaceous forams. X-ray mineralogy (bulk) Calc. 99.5 Qtz. 0.5 Amorph. 26.0			
4.5–6	4		F, N F	10YR 8/2 and 2.5YR 7/2	Flora similar to above Fauna: *Globotruncana stuarti* s.s., *G. aegyptiaca, G. gansseri, Ps. carseyae* Flora similar to above	*G. stuarti* Zone	CRETACEOUS
6–7.5	5		F, N F		Fauna: *Globotruncana aegyptiaca, G. gansseri, G. ventricosa, Bolivinoides draco* s.s., *B. draco miliaris, B. australis, Osangularia navarroana, Aragonia velascoensis* Flora similar to above plus *Reinhardtites anthophorus, Dodekapodorapdus noelae, Broinsonia parca*	*G. gansseri* Zone; *Reinhardtites anthophorus*	LOWER MAASTRICHTIAN
7.5–9	6		F, N F				
	CC		N, R, N		Flora similar as above No radiolarians. Fauna as above Flora similar as above		

HOLE 111 A 190 **TO** 199 **m**

CORE 12

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
1	1		N		Contamination with ?Paleocene (Discoaster multiradiatus)		
2, 3	2						
4	3						
5, 6	4						
7	5						
8	6			Core 12 consists of 14 pieces of rock: 1 gray piece of clay and 13 pieces of hard calcarenite. One of the pieces of calcarenite has a manganese crust, (cf Core 111-3).	Gray clay pebble on top of core yielded Maastrichtian and Eocene microfauna. Other rocks: Fauna: *Rotalipora* spp., *Hedbergella* sp., Gavelinopsis cenomanica.	*R. gandolfii* Zone	CRETACEOUS (CENOMANIAN)
	CC		F N R		Flora: *Watznaueria barnesae, Cretarhabdus conicus, C. crenulatus, Parrhabdolithus embergeri* No radiolarians.		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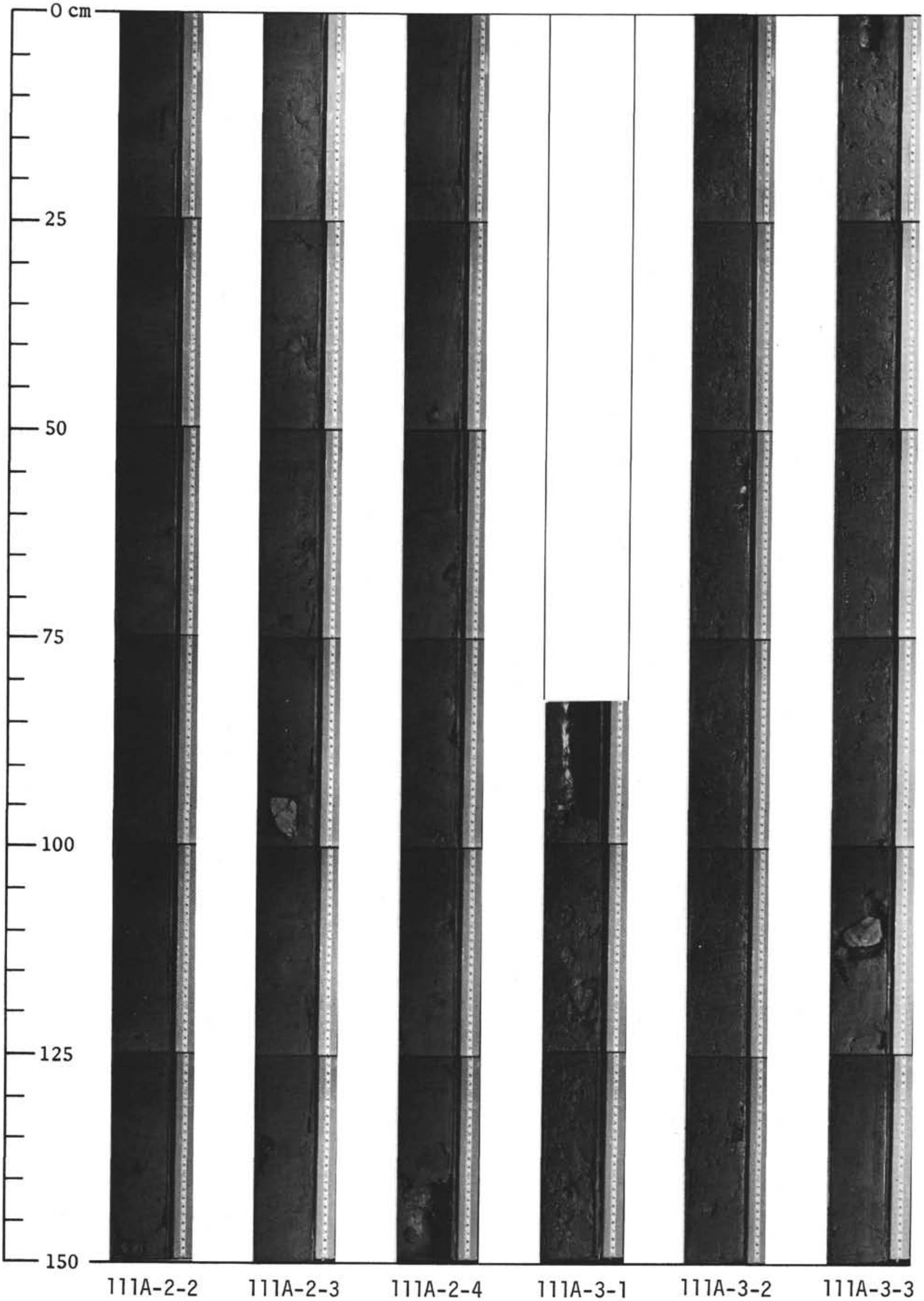
111-4-1
111-4-CC
111-5-CC
111-6-CC
111-7-1
111A-1-6
111A-2-1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111A-2-3
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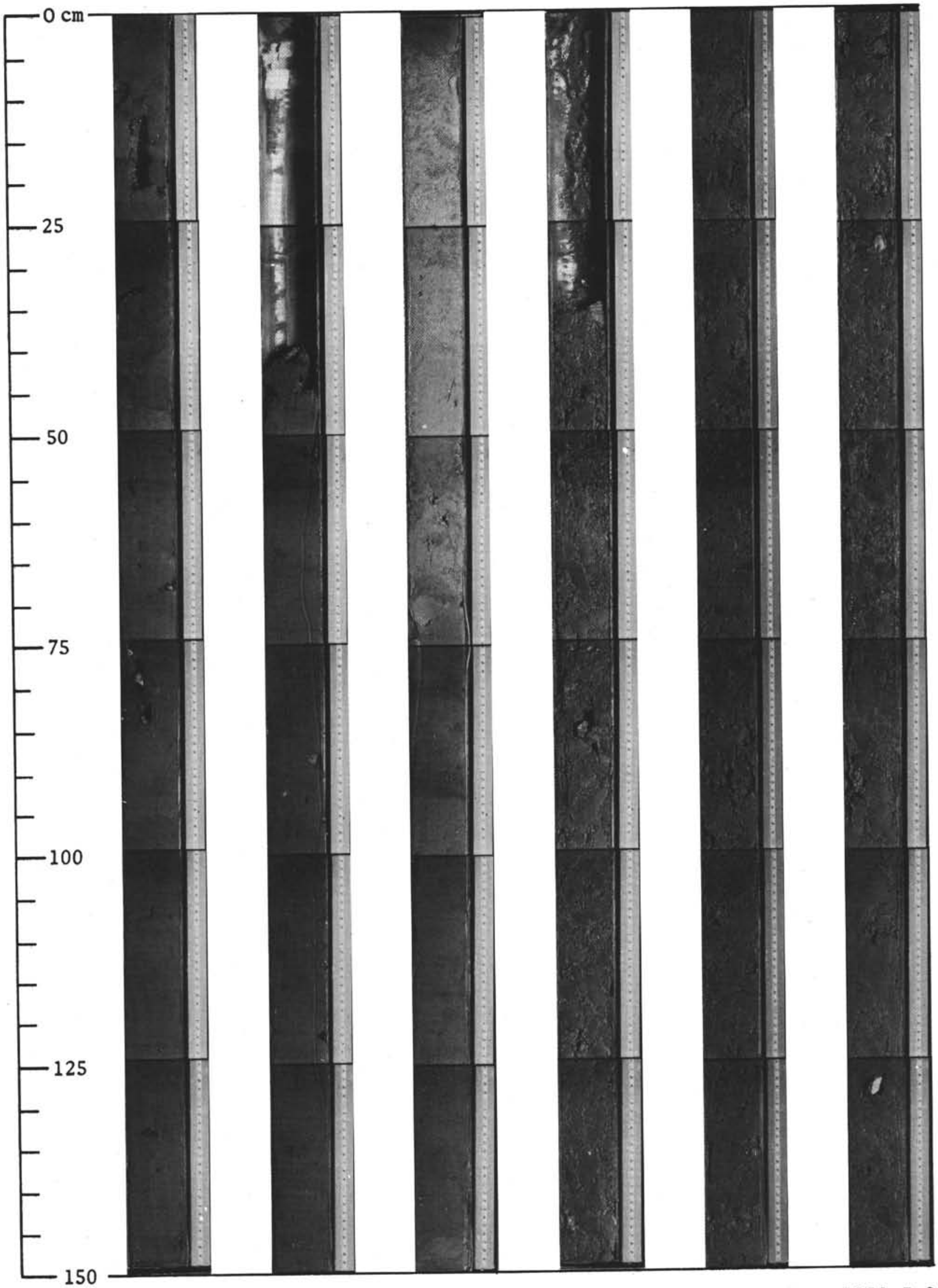
111A-3-1
111A-3-2
111A-3-3



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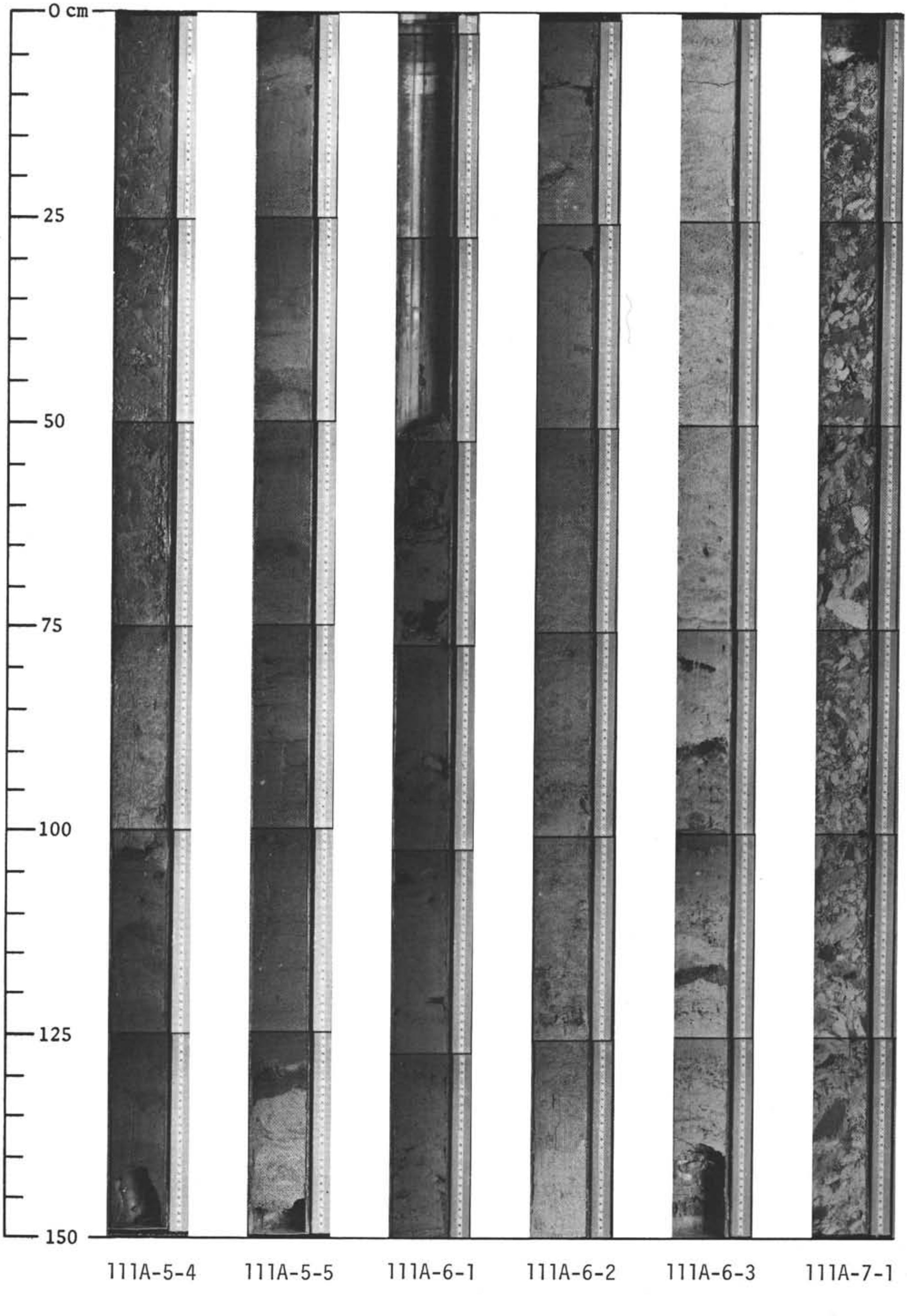
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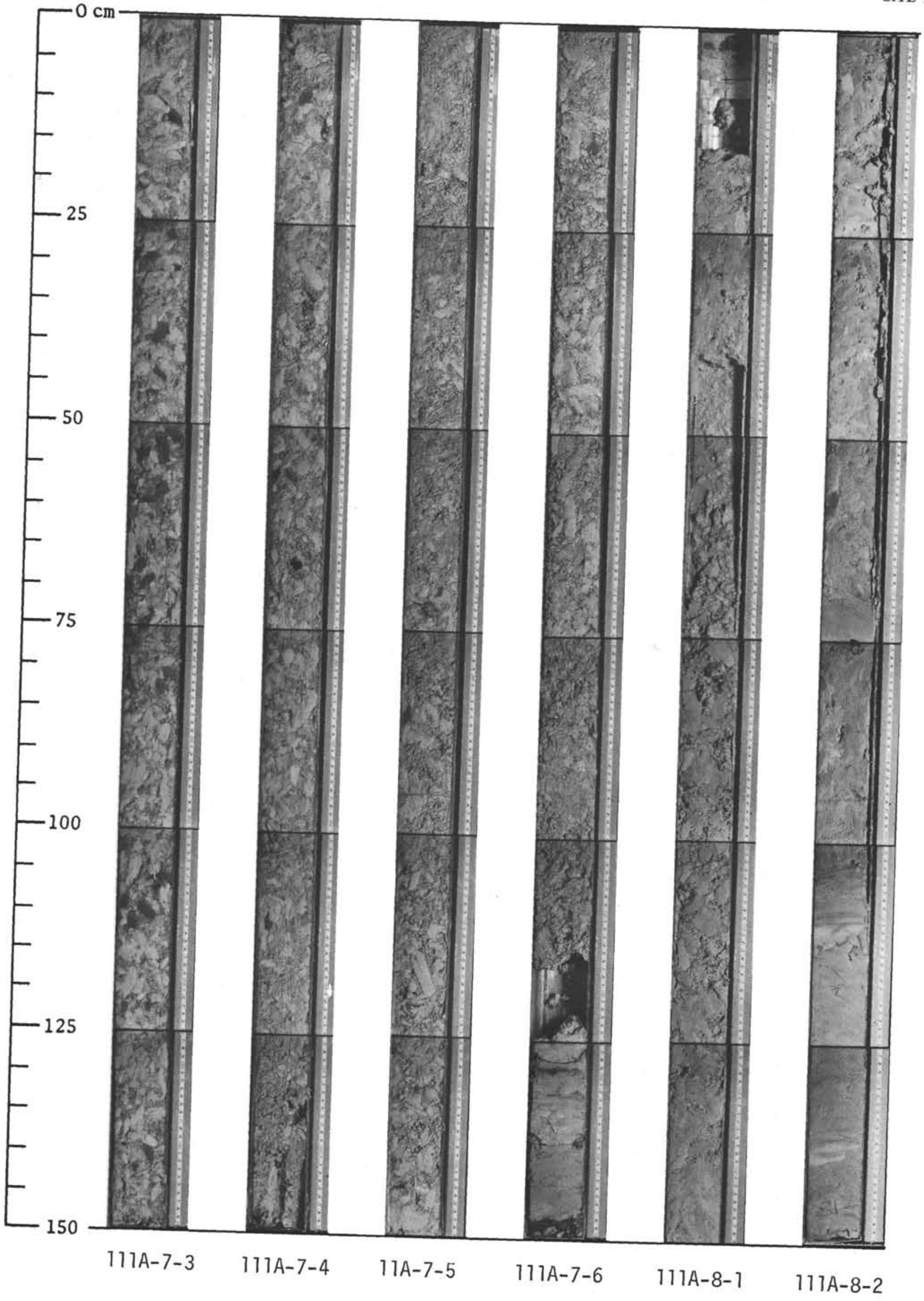
111A-6-2
111A-6-3
111A-7-1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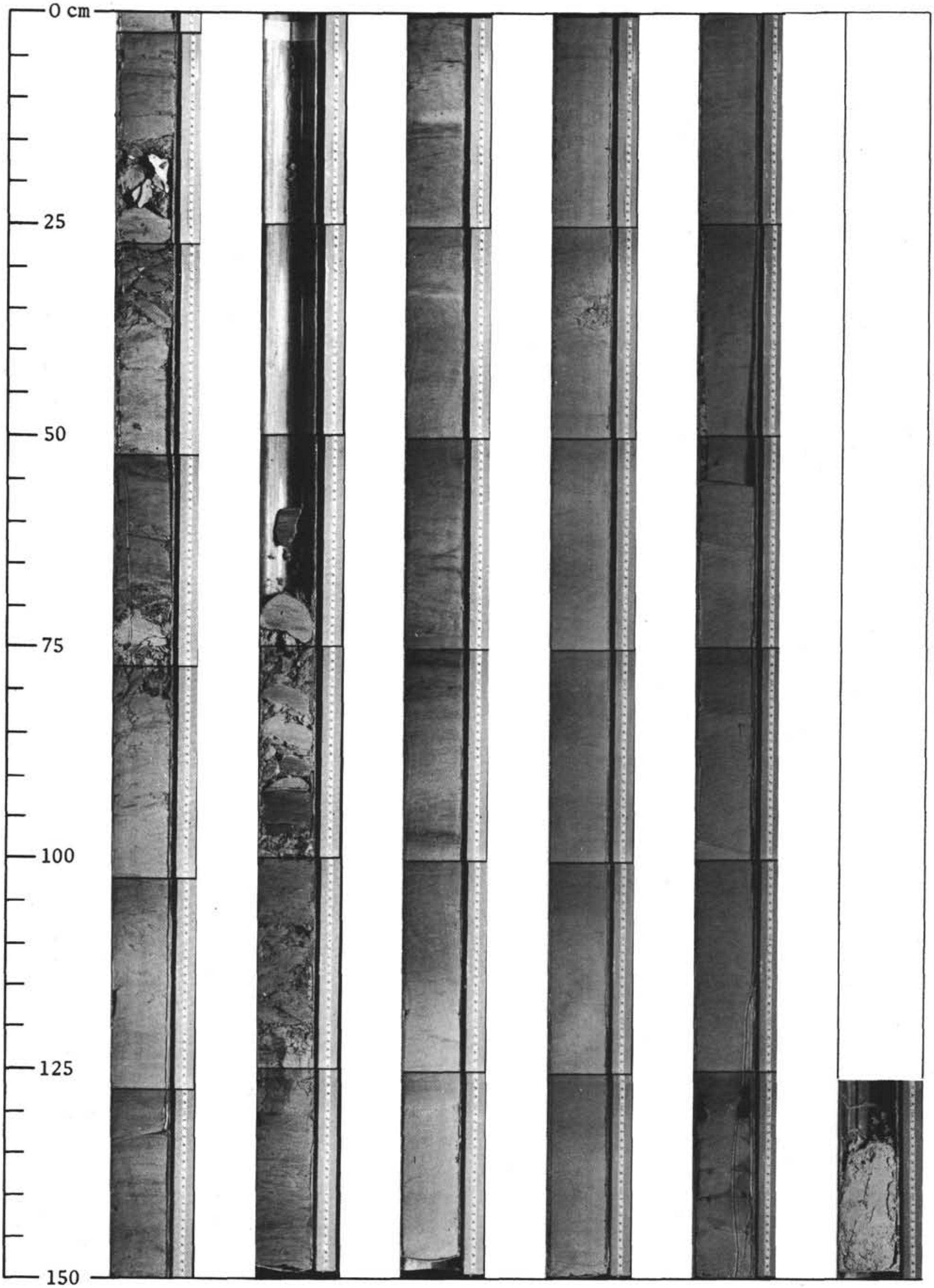
111A-7-6
111A-8-1
111A-8-2



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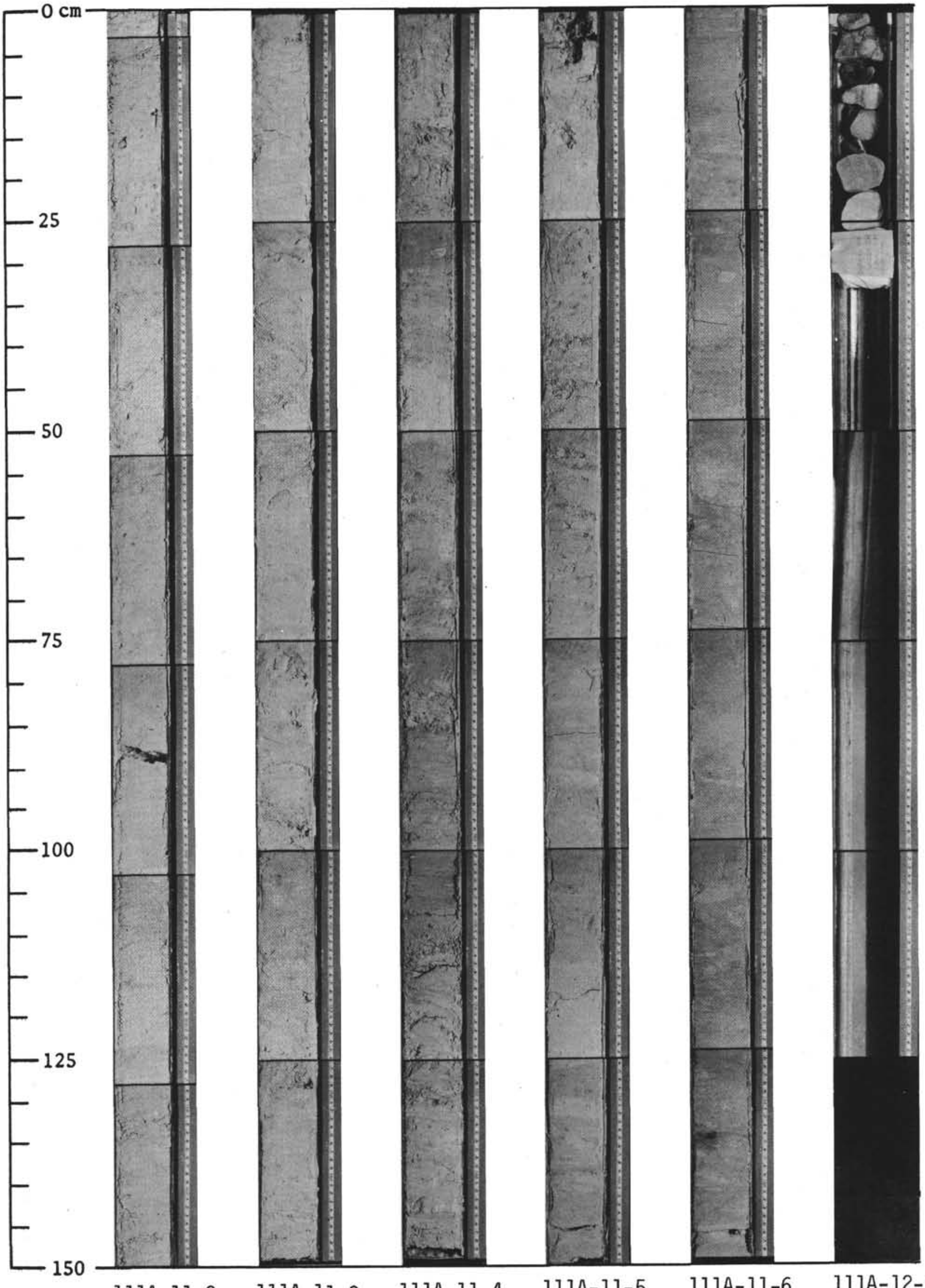
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111A-11-3
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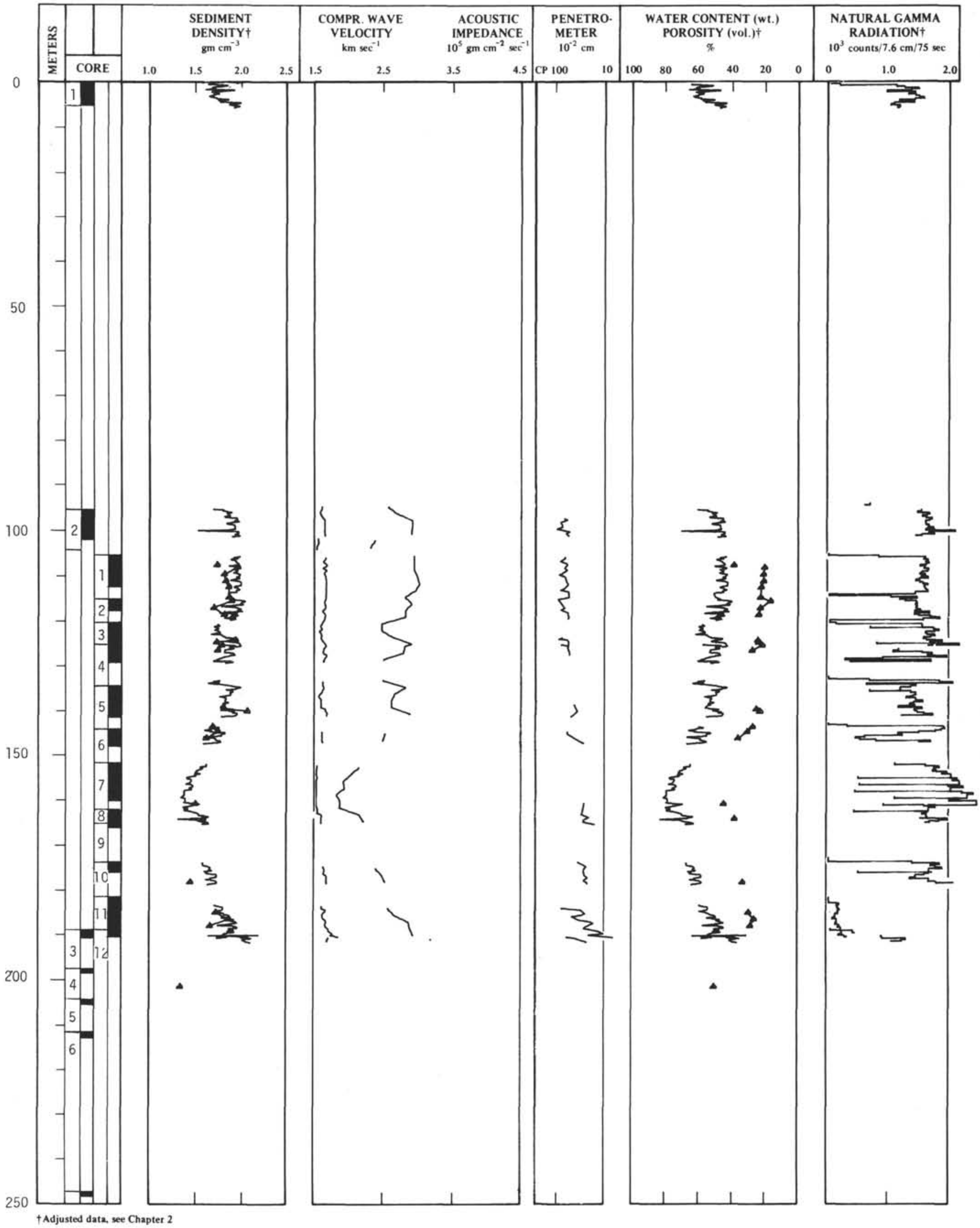
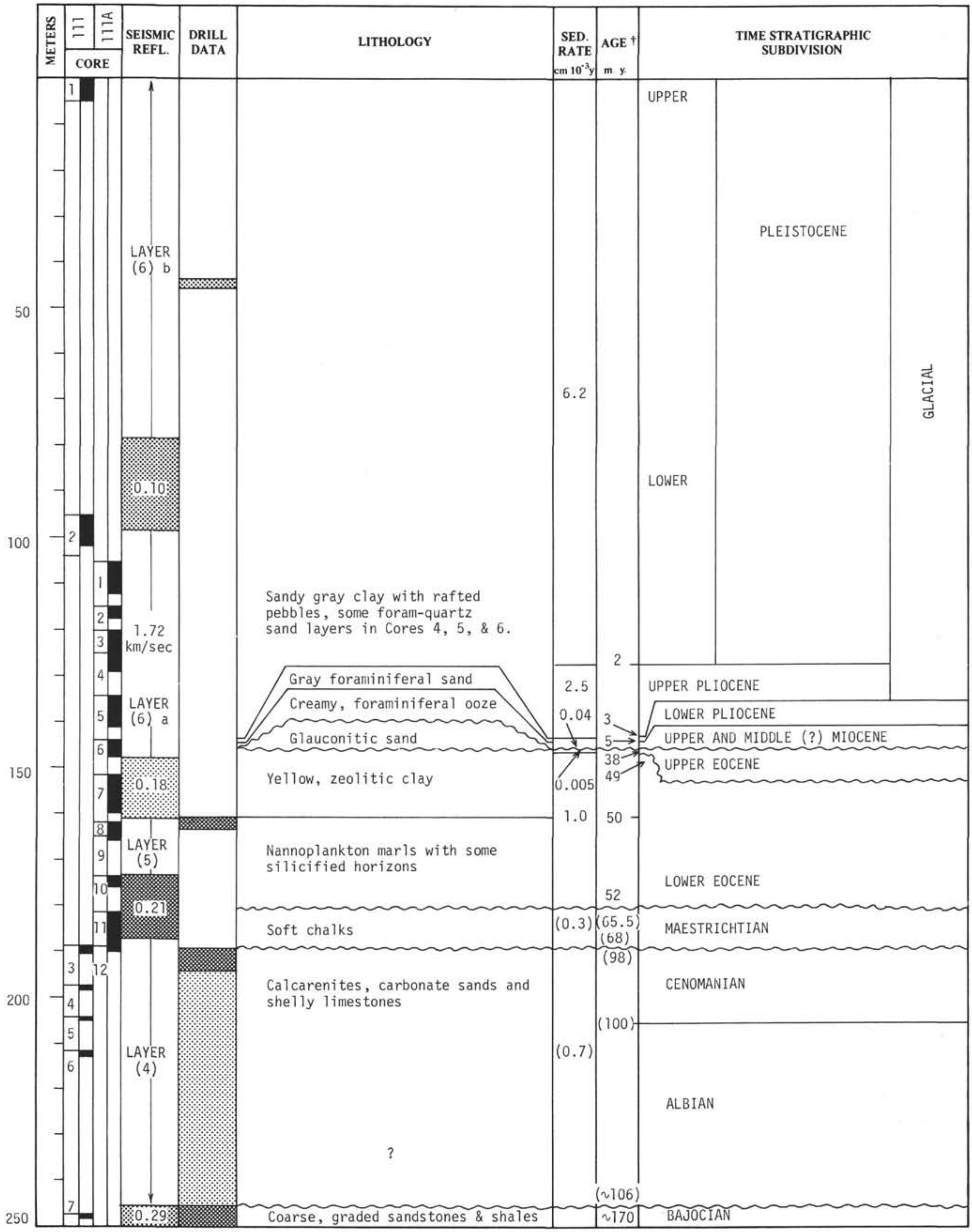
111A-11-5
111A-11-6
111A-12-1

SITE 111 0m TO 250m



†Adjusted data, see Chapter 2

SITE 111 0 TO 250 m



†See Chapter 2 (explanatory notes)