5. SITE 402/HOLE 402A

The Shipboard Scientific Party[1]
With a Special Contribution by
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SITE DATA

Position: 47°52.48′N, 08°50.44′W

Water Depth (sea level): 2339.5 corrected meters, echo-sounding

Bottom Felt at: 2355.5 meters, drill pipe

Penetration: 469.5 meters

Number of Cores: 40 (402-5; 402A-35)

Total Core Recovery: 179.69 meters

Percentage Core Recovery: 48 per cent

Oldest Sediment Cored:
Depth sub-bottom: 469.5 meters
Nature: Calcareous mudstone
Age: Early Aptian
Basement: Not reached

Principal Results: Site 402 is located on the upper slope of the northern continental margin of the Bay of Biscay (Figure 1). The main objectives were to establish the presence or absence of shallow water Upper Cretaceous beds, and to penetrate pre-Aptian syn-rift sediments and the upslope equivalent of the deep water Albian-Aptian carbonaceous mudstones penetrated in Hole 400A.

Three lithological units were distinguished: Unit 1 (0-175.0 m) is composed of Quaternary to middle Miocene nannofossil ooze and siliceous nannofossil chalk of late Eocene age, deposited in a bathyal or upper-slope environment. The base of the unit is defined by a hiatus of at least 51 m.y. between the Albian and middle Eocene. Unit 2 (175-232 m) is Albian in age and consists of extremely lithified limestones exhibiting sound velocities up to 3 km/s. The main facies include vuggy bioclastic limestones, silicified limestones with large sponge spicules, and a fine-grained micritic limestone indicating deposition in a shelf environment. Unit 3 (232.0-469.5 m) consists of carbonaceous marly limestone, carbonaceous calcareous mudstone, and carbonaceous marly calcareous chalk of Albian and Aptian age. Two major depositional sequences recognized in these beds reflect changing environments in shallow water depths conditioned by the balance between a large terrigenous input and subsidence of the margin following rifting.

The Albian/Aptian section may have been deposited as part of a delta complex built on the subsiding shelf. The terrigenous black shale sediments may have been derived by reworking of coastal plain sediments colonized by abundant vegetation. Reduction in the supply of terrigenous material in late Albian time may indicate inundation of the source by rising sea level. The abnormal lithification of the Albian sediments just below the hiatus is ascribed to precipitation of silica from silica-enriched interstitial water. The middle Eocene sediments are characterized by abundant silica and a deep water fauna indicative of deposition in bathyal conditions. The deep water fauna is contaminated by a displaced shelf fauna and flora containing species indicative of nearshore conditions. This evidence of reworking may indicate erosion of the shelf, perhaps associated with the global early-middle Eocene regression and/or tectonic deformation at that time.

BACKGROUND AND OBJECTIVES

Site 402 is situated in the half-graben behind the tilted outer edge of the fault block on which Site 401 was drilled. The originally proposed site (intended penetration was 900 m) was designed to (1) compare the depth and environment of deposition of Albian-Aptian carbonaceous limestones postulated to underlie the site with the shallow water limestones dredged near to, and drilled at, Site 401, and with the carbonaceous limestones drilled at Hole 400A; (2) penetrate a more complete Cretaceous section to examine the change in margin paleoenvironment between the Upper and Lower Cretaceous and the nature of the "Cenomanian" unconformity; and (3) for biostratigraphic purposes, sample a Cenozoic section not subject to dissolution.

Although immediate approval to drill Site 401 to a depth of 400 meters had been given by the Deep Sea Drilling Project, penetration at the proposed Site 402 was restricted to 400 meters, with continuous coring, pending a further safety review to be held in the United States. Because Site 401 was completed before this review had begun, it became necessary to review the objectives and priorities of proposed Site 402 against alternative sites while bearing in mind the results of Sites 400 and 401.

At Site 401, a substantial part of the Neogene was absent, due to erosion or non-deposition, but the thick Paleogene section displayed little evidence of dissolution. Minor hiatuses were present in the Eocene and Paleocene. Maestrichtian to upper Campanian chalks rested unconformably on Lower Cretaceous shallow water limestones. At both

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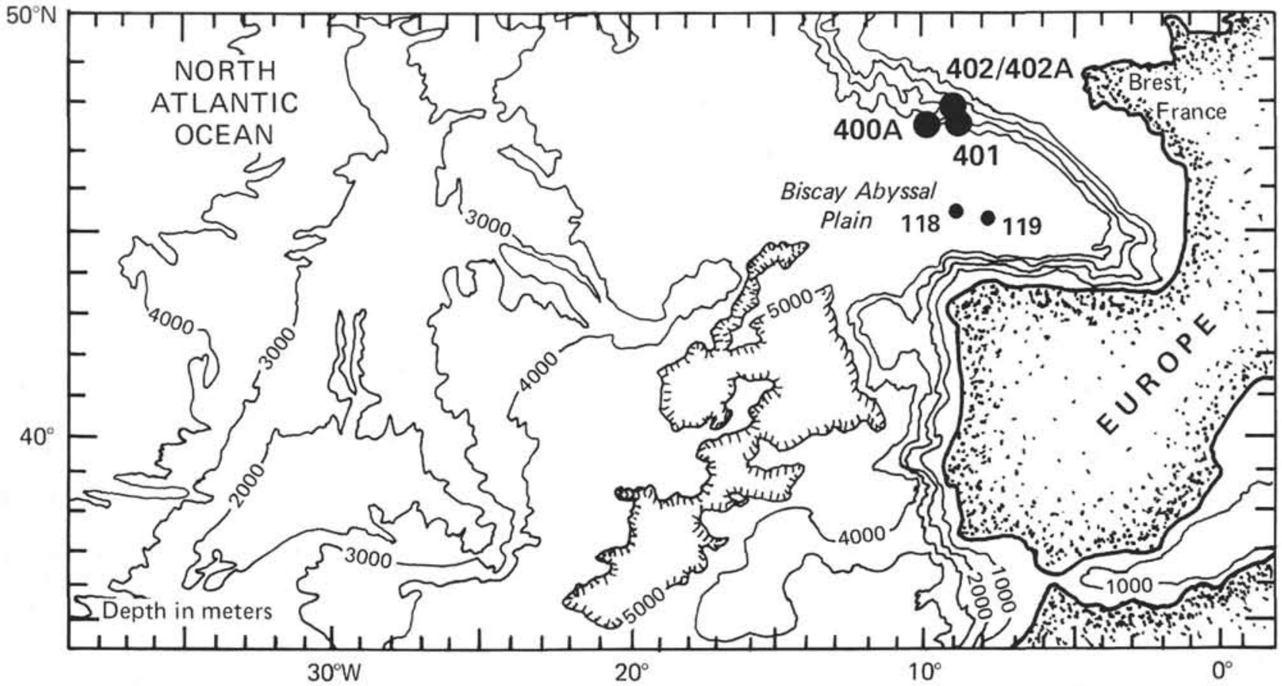

Figure 1. *General map of Biscay showing locations of Holes 400A, 401, 402A, 118, and 119.*

Sites 400 and 401 the hiatus, of about 30 m.y., separated deep water chalks and deep water carbonaceous limestones on the one hand and deep water chalks and shallow water limestones on the other. The tectonic and/or oceanographic nature of the event responsible for such a prolonged hiatus affecting shallow and deep environments equally was unclear, but was obviously fundamental to understanding the evolution of the margin. The question of the environment of deposition of the Albian-Aptian carbonaceous limestones remained open because the contemporaneus shallow water limestones at Site 401 could have been deposited on top of a fault block surrounded by deep water.

In terms of the overall priorities of passive margin drilling, these results suggested that the scientific objectives of Site 402 should be:

1) to establish the depositional environment of pre-Aptian sediments possibly deposited contemporaneously with rifting;

2) to penetrate the upslope equivalent of the Albian/Aptian carbonaceous limestones and thereby establish the paleoenvironment on the young margin;

3) to compare the subsidence history of three sites separated in depth and distance from the continent/ocean boundary; the site might also provide a link between the well documented uplift, regression, and transgression recorded on the adjacent shelf and the deep-sea geological record;

4) to examine the paleoceanographic significance and nature of the Cenomanian unconformity by establishing the presence of absence of a shallow water Upper Cretaceous section;

5) to compare the facies of Tertiary and Cretaceous sediments deposited at an upslope site with those penetrated at Sites 400 and 401;

6) to correlate well log data with seismic, lithologic, and physical properties data.

In view of the results obtained at Site 401, it was considered unlikely that these objectives could be fully met at the site proposed due to its structurally isolated position and uncertain paleodepth. Further, a substantial 900-meter penetration was required at the site. It was therefore decided to drill Site 402 at a previously proposed upslope site (Figure 2). Drilling at the site offered the opportunity of penetrating, at a shallower depth, the Upper Cretaceous and a substantial part of the Lower Cretaceous, possibly deposited in shallower water depths.

The section IPP line OC301 across the upper slope through Site 402 (Figures 3a, b) shows a large half-graben infilled with thick sediments which thin toward the edge of the fault block. A prominent unconformity, nearly cut by the canyon at SP400, can be correlated with the Cenomanian unconformity drilled at the previous sites. The attitude of the reflectors within the underlying pre-Cenomanian sequence is suggestive of tilting, accompanied by contemporaneous faulting. These sediments thin and nearly pinch out over the edge of the fault block where they are overlain by a much greater thickness of Tertiary sediments. Because there was no evidence of structural closure beneath the canyon, it was decided in consultation with DSDP to drill Site 402 in the canyon. This would avoid drilling a thick Tertiary section and would enable deep penetration of the key Cretaceous section. Estimated total penetration was 900 meters.

SITE APPROACH AND DRILLING OPERATIONS

Site 402 was situated in the easily identifiable axis of an approximately north-south-trending canyon on the slope north of Shamrock canyon (Figure 3a, b). The approach to the site involved heading along 336 degrees from Site 401

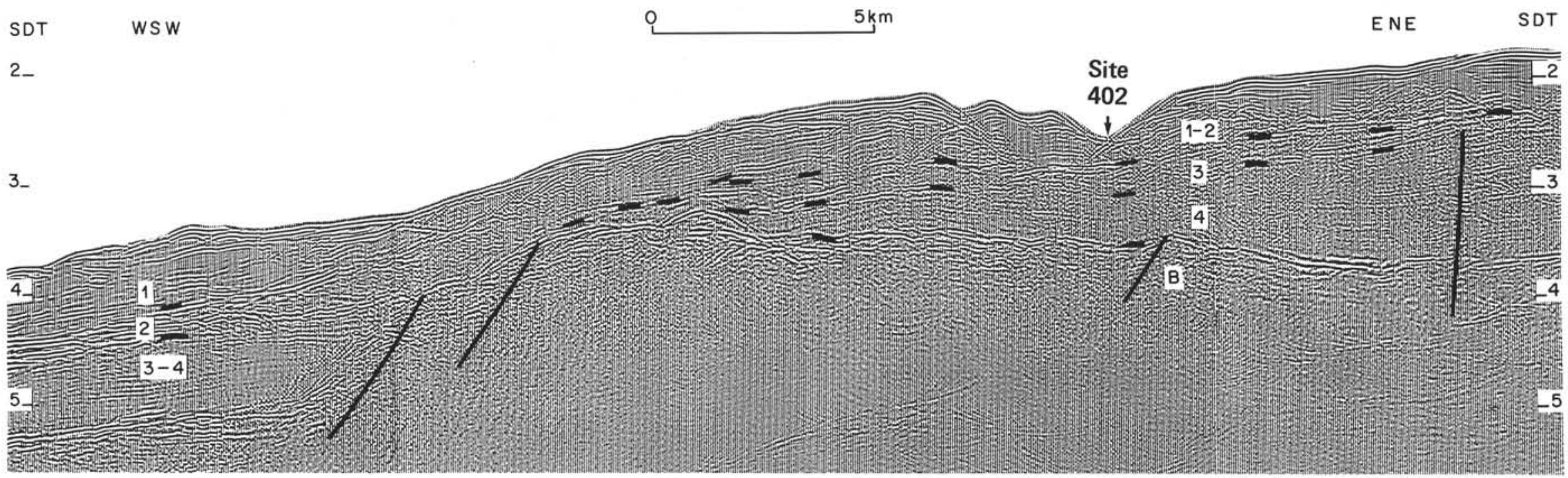

Figure 2. *Multichannel seismic profile IFP-CNEXO OC301 through Holes 402/402A.*

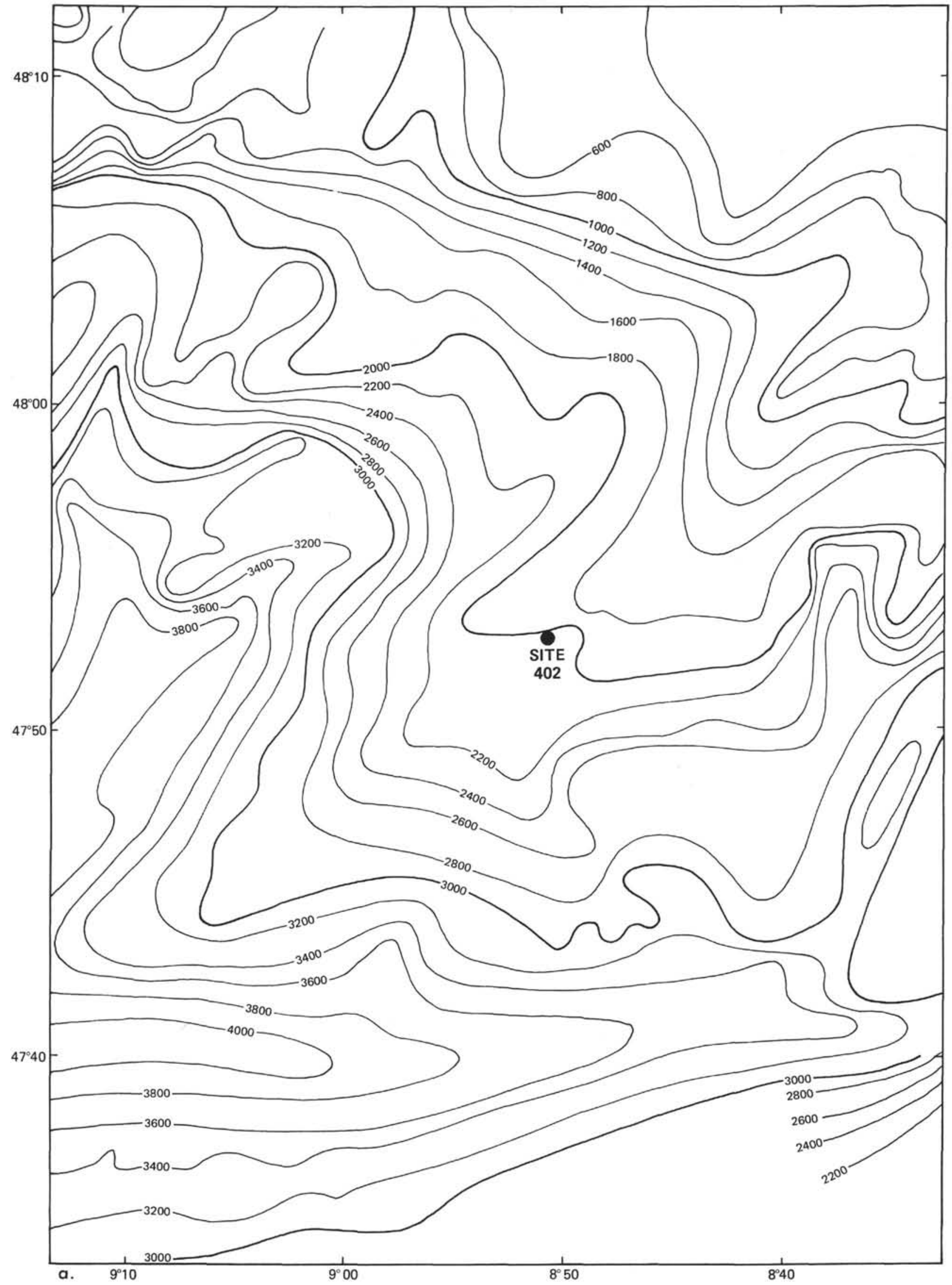

Figure 3a. *Bathymetry in the vicinity of Holes 402/402A.*

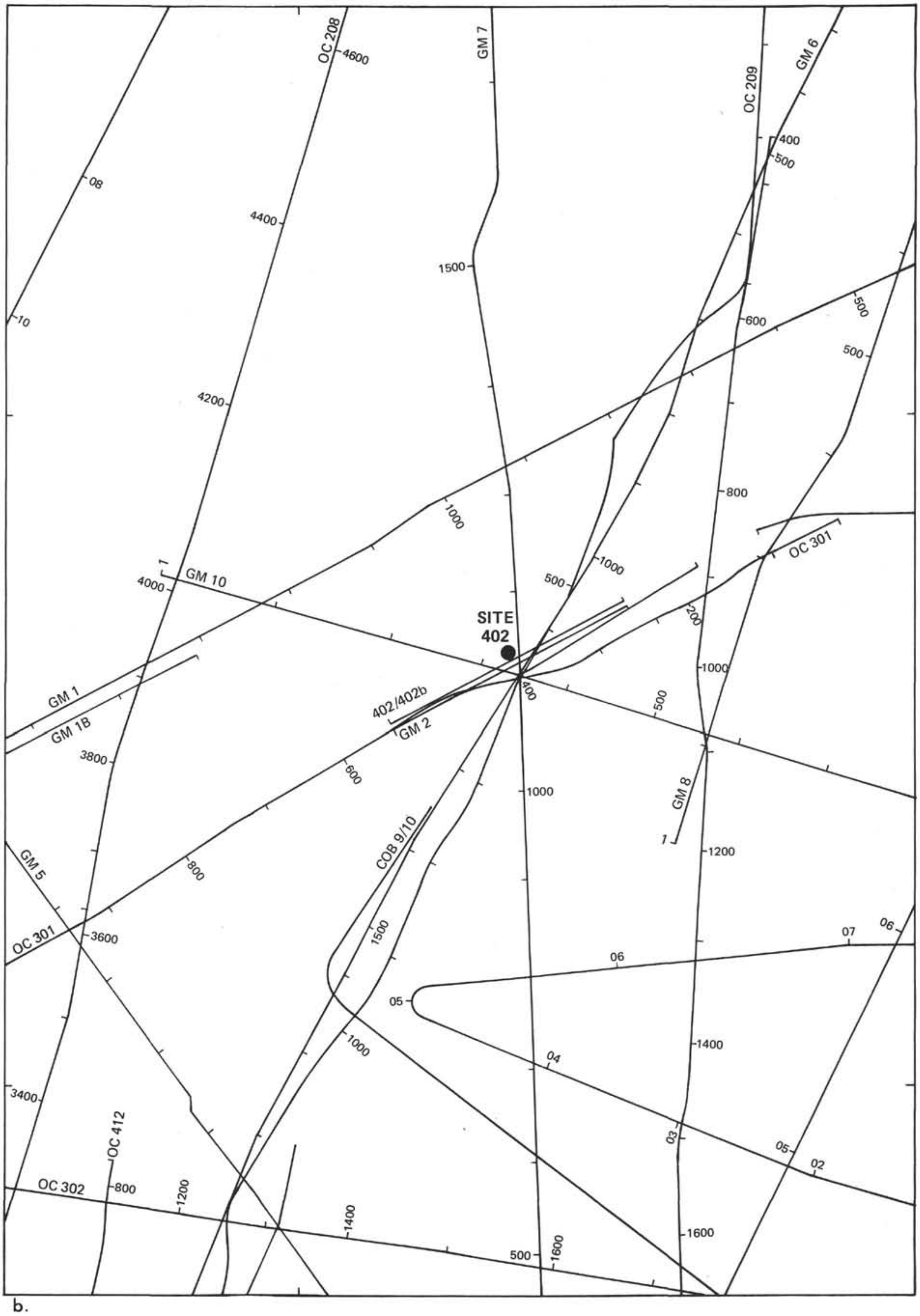

Figure 3b. *Location of seismic profiles.*

(0915 hours on 10 June) before turning along 074 degrees to follow the control seismic line IFP 301 (Figure 4). The axis of the canyon was crossed at 1330 hours on 10 June and at 1349 hours, the vessel executed a Williamson turn to port to return to the site.

At 1427 hours, the 16-kHz beacon was dropped while crossing the canyon axis; the vessel was positioned by 1530 hours and the bit was finally spudded at 0215 hours on 11 June at 2355.5 meters below the derrick floor (Table 1). At this time, a 4.5-meter core of Pleistocene nannofossil ooze and clay was cut at the mud line prior to washing down to a depth of 2397.5 meters. A second core was then cut prior to running a heat flow measurement at 2407.0 meters. The hole was then washed to 2435.5 meters before cutting a third core and taking another heat flow measurement at 2445.0 meters. The hole was again washed to 2473.5 meters and a third heat flow measurement taken at 2486.0 meters. This core yielded middle Eocene sediments. At 1845 hours, fragments of the seal on the float valve were discovered in Core 5. It was therefore decided to trip the whole string and replace the flapper valve section rather than risk drilling ahead.

Hole 402A was spudded at 0555 hours on 12 June and washed to the TD of 137 meters achieved in Hole 402 (Table 2). The hole was cored continuously thereafter and the heat flow measurements made at 2521.0 meters. Between 165.5 and 175.0 meters sub-sea, the drilling rate decreased abruptly with a marked decline in core recovery from around 9 meters to less than 1 meter. The change coincided with the appearance of highly lithified limestones. Fifteen barrels of mud were spotted at 1920 hours to clean the hole, but recovery remained less than 5 meters until the base of the lithified limestones was reached at about 232 meters. An inclinometer measurement on Core 19 (317.0 m sub-sea) gave a value of 2 degrees and a further 15 barrels of mud were spotted at 0000 hours on 14 June. Cores 27 through 29 yielded less than 1 per cent recovery, but Cores 30 to 35 at TD yielded in excess of 5 meters of recovery. The drilling rate progressively slowed from 45 minutes to cut Core 29 to 210 minutes to cut Core 35. As Cores 33 through 35 had already penetrated the important facies change associated with the lower Aptian, drilling was terminated and preparations began for logging. Between 1130 and 1305 hours on 15 June, the hole was cleaned with

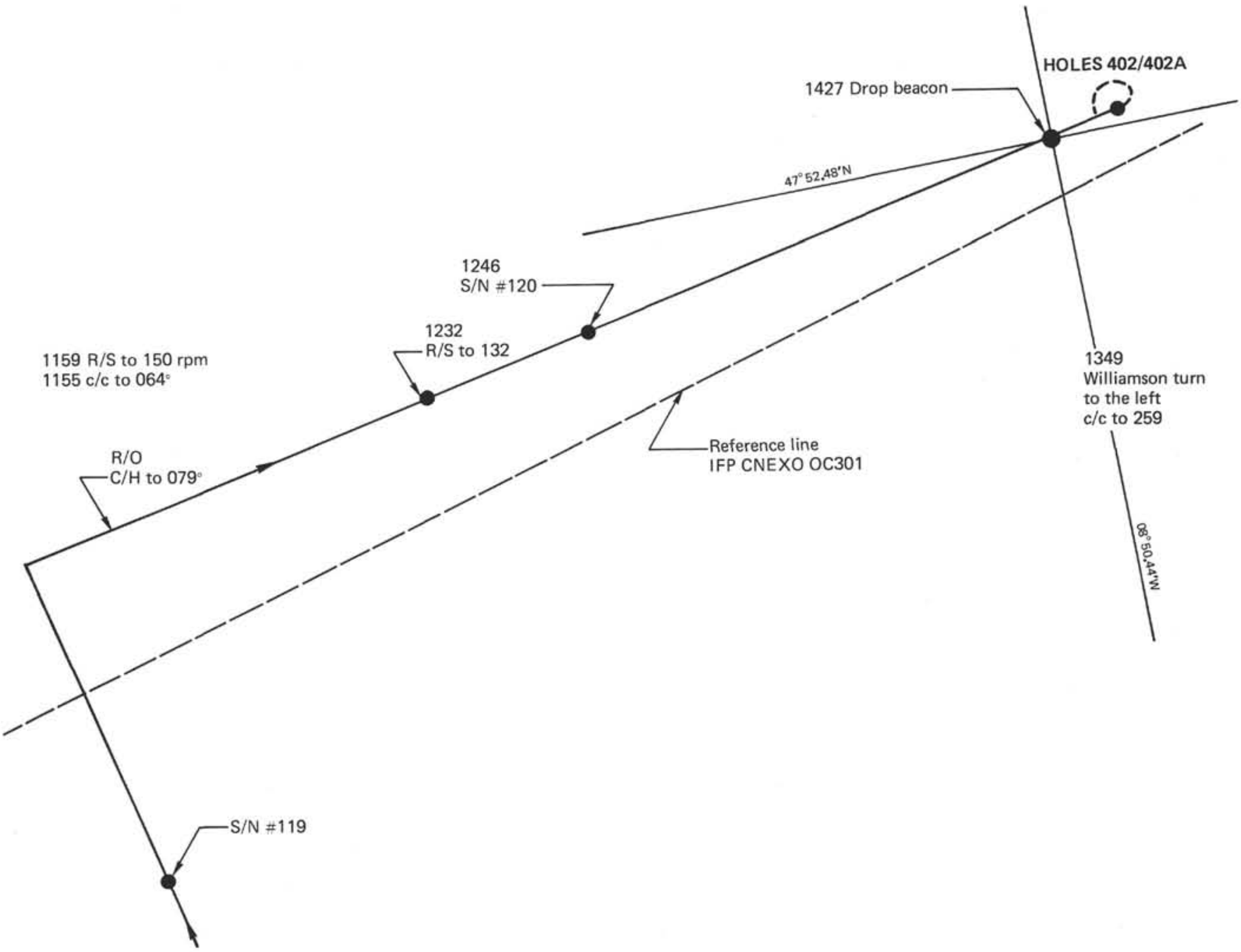

Figure 4. *Approach of* Glomar Challenger *to Holes 402/402A.*

TABLE 1
Coring Summary, Hole 402

Core	Date (June 1976)	Time	Depth From Drill Floor (m)		Depth Below Sea Floor (m)		Length Cored (m)	Length Recovered (m)	Recovery (%)
1	11	0255	2355.5	2359.5	0	4.0	4.0	4.0	100
2	11	0715	2397.5	2407.0	42.0	51.5	9.5	1.02	11.0
3	11	1045	2435.5	2445.0	80.0	89.5	9.5	1.07	18.0
4	11	1527	2473.5	2483.0	118.0	127.5	9.5	0.04	0.4
5	11	1825	2483.0	2492.5	127.5	137.0	9.5	5.43	57.0
Total							42.0	12.19	29.0

a mud pile and wiped. The pipe was run back in and mud spotted prior to running in the bit release tool. The bit was released successfully and by 1615 hours the hole was filled with mud. The pipe was pulled to 2466.5 meters prior to logging; the gamma/sonic/caliper logging tool was run in the hole at 1715 hours and cleared the end of the pipe without incident. By 0830 hours on 16 June, after several attempts, the logging was completed. At 1320 hours on 16 June, the vessel departed for Site 403.

LITHOLOGY

The 469.5-meter-thick section drilled at Holes 402/402A comprises 175 meters of foraminifer nannofossil ooze, marly nannofossil ooze, siliceous marly nannofossil ooze, and siliceous nannofossil chalks of Pleistocene to late Eocene age, underlain by 57 meters of well-lithified Albian limestone. These overlie 209 meters of "black shales" of Albian to Aptian age. The basal 28.5 meters consist of

TABLE 2
Coring Summary, Hole 402A

Core	Date (June 1976)	Time	Depth From Drill Floor (m)		Depth Below Sea Floor (m)		Length Cored (m)	Length Recovered (m)	Recovery (%)
1	12	0945	2492.5	2502.0	137.0	146.5	9.5	8.96	94.5
2	12	1056	2502.0	2511.5	146.5	156.0	9.5	0.92	9.68
3	12	1158	2511.5	2521.0	156.0	165.5	9.5	9.62	100.0
4	12	1435	2521.0	2530.5	165.5	175.0	9.5	4.89	51.5
5	12	1558	2530.5	2540.0	175.0	184.5	9.5	1.84	19.4
6	12	1735	2540.0	2549.5	184.5	194.0	9.5	0.76	8.0
7	12	1920	2549.5	2559.0	194.0	203.5	9.5	0.12	1.3
8	12	2132	2559.0	2568.5	203.5	213.0	9.5	0.5	5.3
9	12	2304	2568.5	2578.0	213.0	222.5	9.5	0.87	9.2
10	13	0030	2578.0	2587.5	222.5	232.0	9.5	1.1	11.6
11	13	0302	2587.5	2597.0	232.0	241.5	9.5	5.72	60.2
12	13	0437	2597.0	2606.5	241.5	251.0	9.5	2.94	30.9
13	13	0615	2606.5	2616.0	251.0	260.5	9.5	4.03	42.4
14	13	0800	2616.0	2625.5	260.5	270.0	9.5	4.65	49.0
15	13	0957	2625.5	2635.0	270.0	279.5	9.5	8.07	84.9
16	13	1200	2635.0	2644.5	279.5	289.0	9.5	2.89	30.4
17	13	1413	2644.5	2654.0	289.0	298.5	9.5	3.26	34.3
18	13	1627	2654.0	2663.5	298.5	308.0	9.5	5.75	60.5
19	13	1854	2663.5	2672.5	308.0	317.0	9.0	5.8	64.4
DRLD			2672.5	2673.0	317.0	317.5	0.5	–	
20	13	2135	2673.0	2682.5	317.5	327.0	9.5	5.35	56.3
21	13	2357	2682.5	2692.0	327.0	336.5	9.5	9.65	100
22	14	0229	2692.0	2701.5	336.5	346.0	9.5	8.78	92
23	14	0447	2701.5	2711.0	346.0	355.5	9.5	9.12	96
24	14	0650	2711.0	2720.5	355.5	365.0	9.5	6.4	67
25	14	0915	2720.5	2730.0	365.0	374.5	9.5	6.68	70.3
26	14	1125	2730.0	2739.5	374.5	384.0	9.5	1.18	12
27	14	1342	2739.5	2749.0	384.0	393.5	9.5	0.04	0.4
28	14	1525	2749.0	2758.5	393.5	403.0	9.5	0	0
29	14	1706	2758.5	2768.0	403.0	412.5	9.5	0.03	0.3
30	14	1855	2768.0	2777.5	412.5	422.0	9.5	8.37	88
31	14	2055	2777.5	2787.0	422.0	431.5	9.5	9.0	95
32	14	2347	2787.0	2796.5	431.5	441.0	9.5	9.52	100
33	15	0337	2796.5	2806.0	441.0	450.5	9.5	8.76	92
34	15	0650	2806.0	2815.5	450.5	460.0	9.5	4.90	51
35	15	1115	2815.5	2825.0	460.0	469.5	9.5	7.03	74
Total							332.5	167.5	50

upper to lower Aptian limestone and marly limestone. Washed cores in the 28.5-meter interval between the upper Eocene and Pleistocene contain Pliocene and middle Miocene sediment. It is therefore probable that a hiatus (of about 6 m.y.) occurs between the middle Miocene and the Pliocene. A second hiatus occurs between middle Miocene and upper Eocene (21 m.y.), and a major one (51 m.y.) separates the middle Eocene and Albian. Paleo-environmental indicators and lithology indicate a shallow water origin for the sediment constituting the black shales and the superimposed limestones. From lithology, physical properties, and logging, three units and six sub-units are distinguished (Figure 5, Table 3).

Unit 1

This unit consists principally of soft calcareous mud, marly foraminifer nannofossil ooze, and foraminifer nannofossil ooze; two sub-units have been distinguished on the basis of the occurrence of abundant siliceous biogenic components and lesser detrital materials in the lower part of the unit. The carbonate contents exhibit a decreasing trend from 70 per cent at the top to about 50 per cent at the base of Sub-unit 1B.

Sub-Unit 1A

The top 50 cm of Sub-unit 1A consists of a yellowish gray bioturbated foraminifer nannofossil ooze. Below this level, the sediments are mostly homogeneous grayish olive to olive-gray calcareous mud or foraminifer nannofossil ooze of Pleistocene age. Carbonate contents range from 24 to 65 per cent and average 33 per cent. Approximate composition of these sediments is: quartz (40%); clay minerals (18%); unspecified carbonate (10%); nannofossils (12%); foraminifers (20%). Clay minerals include kaolinite (15%); illite (40%); illite-montmorillonite (0-30%); montmorillonite (0-40%); chlorite (15%). The average texture is sand (30%); silt (40%); clay (30%).

Textural variations appear in Core 1 as gritty layers of marly foraminifer nannofossil ooze. In Core 2 (70-100 cm) there is evidence of a graded deposit associated with gritty layers; in Core 3, Section 1 (100-150 cm) color changes from grayish olive to pale olive are associated with laminations and apparent size grading. Some scattered ice-rafted gravels coated with black manganese oxide are present throughout the sub-unit.

Sub-Unit 1B

The change from greenish gray marly nannofossil ooze to grayish green siliceous marly nannofossil chalk occurs in Core 5 near the top of the sub-unit. The carbonate content ranges from 70 per cent at the top to about 50 per cent at the base of the sub-unit, where the siliceous biogenic content increases from 10 to 20 per cent. Nannofossils usually exceed 10 per cent and reach 80 per cent in the interbedded nannofossil chalks with a concomitant decrease to about 5 per cent of the siliceous components. Clay minerals comprise illite (0-15%), illite-montmorillonite (0-30%), and montmorillonite which averages about 85 per cent. The coarse fraction of this sub-unit is rich in siliceous biogenic components (sponge spicules, diatoms, radiolarians) as well as benthic and planktonic foraminifers and glauconite.

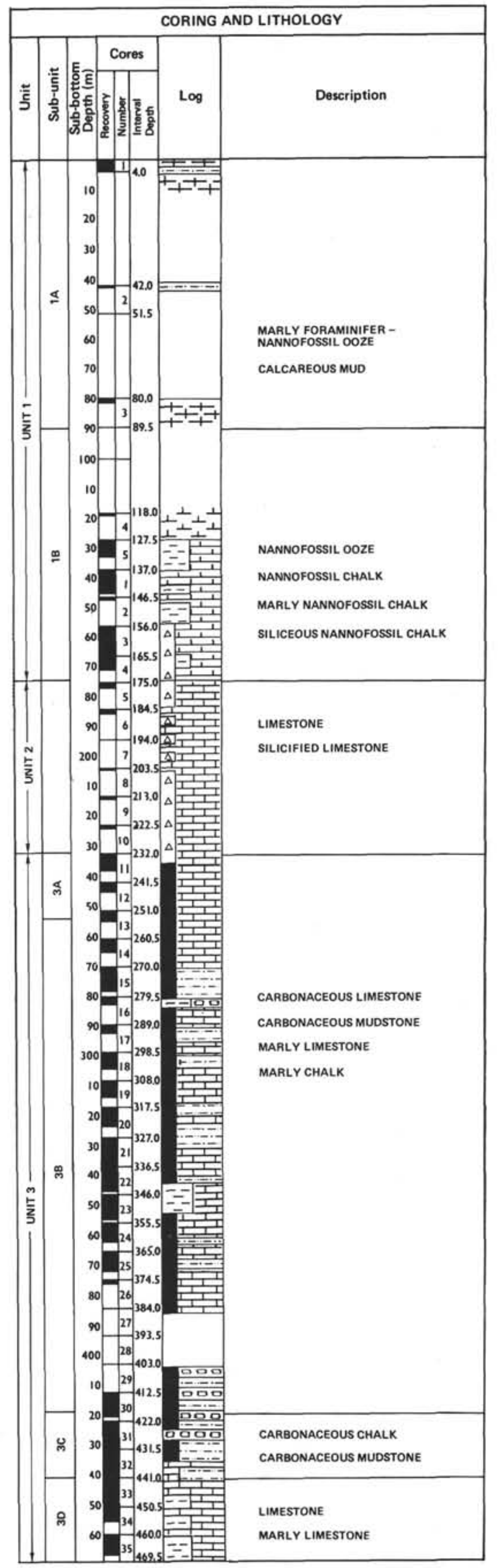

Figure 5. *Lithologic summary of Holes 402/402A.*

TABLE 3
Lithologic Units, Holes 402/402A

Unit	Sub-Unit	Cores	Depth (m)	Lithology	Age
1	1A	Hole 402 1-3	0-89.5	Foraminiferal nannofossil ooze, calcareous mud	Pleistocene
			HIATUS		
	1B	Hole 402 4-5 Hole 402A 1-4	89.5-175	Marly nannofossil ooze to siliceous marly nannofossil chalk	Late Eocene
			HIATUS		
2		Hole 402A 5-11	175-232	Limestone, siliceous limestones, calcareous claystone	Late Albian
3	3A	Hole 402A 11-13	232-254	Carbonaceous marly limestone	Late Albian
	3B	Hole 402A 14-29	254-419	Marly limestone, carbonaceous calcareous mudstone, marly calcareous chalk	Albian ? to late Aptian
	3C	Hole 402A 30-32	419-441	Carbonaceous marly calcareous chalk, carbonaceous calcareous mudstone	Late Aptian
	3D	Hole 402A 33-35	441-469.5	Limestone, marly limestone	Late to early Aptian

Sedimentary structures include slight to moderate bioturbation in which scattered pyritic minerals replace the burrow infillings. Rare coarser layers, a few millimeters thick, with sharp top and bottom boundaries, appear to be rich in detrital components, mainly quartz (Sample 402A-2-1, 8 cm). Pebbles of sandstone and chert (Core 402A-2, Section 1, 80-100 cm) occur sporadically. In Sample 402A-1-3, 56-60 cm two small pebbles of white limestone and a green calcareous mudstone containing silicified sponge spicules occur in a matrix of marly calcareous chalk. The matrix includes also an echinoid spine (more than 1 cm long), sandstone debris, glauconite, and large benthic foraminifers, some of which are arenaceous. A silicified limestone pebble in Sample 402A-2-1, 80-85 cm contains abundant siliceous sponge spicules, benthic foraminifers, and glauconite. It appears to be of late Albian age and representative of a shallow water facies.

Unit 2

Unit 2, in marked contrast to Unit 1, consists of well-lithified limestones, exhibiting mainly three facies (see Dupeuble, this volume, for detailed study of the microfacies).

Facies 1 (Figure 6a) consists of siliceous and/or silicified limestone and is rich in monaxon sponge spicules and, as minor components, algae and echinoderm debris. Facies 2 (Figure 6b) consists of limestone with algae as the major component and with a substantial amount of echinoderm remains. Facies similar to both of the above are known from the Aquitaine Basin. Facies 3 consists of a micritic limestone, with numerous *Pithonella ovalis* and *Calcisphaerula* (Figure 6c). This facies corresponds in character to the "Aturian facies" in the Aquitaine Basin where it occurs from upper middle Albian to the top of the Coniacian. Facies 1 occurs in part of Cores 5, 7, 8 and is exclusive in Cores 9 and 10. The 90-cm-thick section recovered in Core 9 is characterized by well-developed layering, most of the spicules lying in the bedding planes. The sponge spicules consist either of opal or are recrystallized. Facies 2 is present in the first 80 cm of the unit and in Samples 6-1, 50-80 cm, 8-1, 0-30 cm. Facies 3 is restricted to a small interval in Sample 6-1, 15-45 cm. The clay fraction of these rocks comprises illite-montmorillonite (20%) and a high content of clinoptilolite and opal.

The lithified constitution of Unit 2 is well characterized in the $\gamma\gamma$, neutron, and sonic logs. Density increases progressively to a maximum at 210 meters sub-bottom, then decreases abruptly. Extensive porosity (45%) is also characteristic of this level.

Unit 3

A variety of lithologies comprise the 237.5 meters of Unit 3, but it is characterized by carbonaceous marly limestone, carbonaceous calcareous mudstone, and carbonaceous marly calcareous chalk in some beds of which organic carbon occurs in quantities from 1 per cent to as much as 2.5 per cent. This unit is referred to, throughout this volume, as the "black shales." Four sub-units are recognized, based mainly on changes in the carbonate:terrigenous ratio, and to the character of sedimentary structures such as laminations and bioturbations. Sub-unit 3A consists mainly of carbonaceous marly limestone where the carbonate contents average 40 per cent. Rhythmic variations from lighter to darker shades and intense bioturbation is characteristic of this sub-unit. Sub-unit 3B has lesser carbonates (30%) and more terrigenous material, resulting in a chalky appearance. Sedimentary structures herein include well-developed laminations on a millimetric scale; bioturbation is slight to intense. The base of the sub-unit is characterized by the occurrence of mud, gravel, abundant scattered shell debris, and small-scale slumps. The histogram of dark layer thicknesses in Sub-unit 3B shows two modes of which the

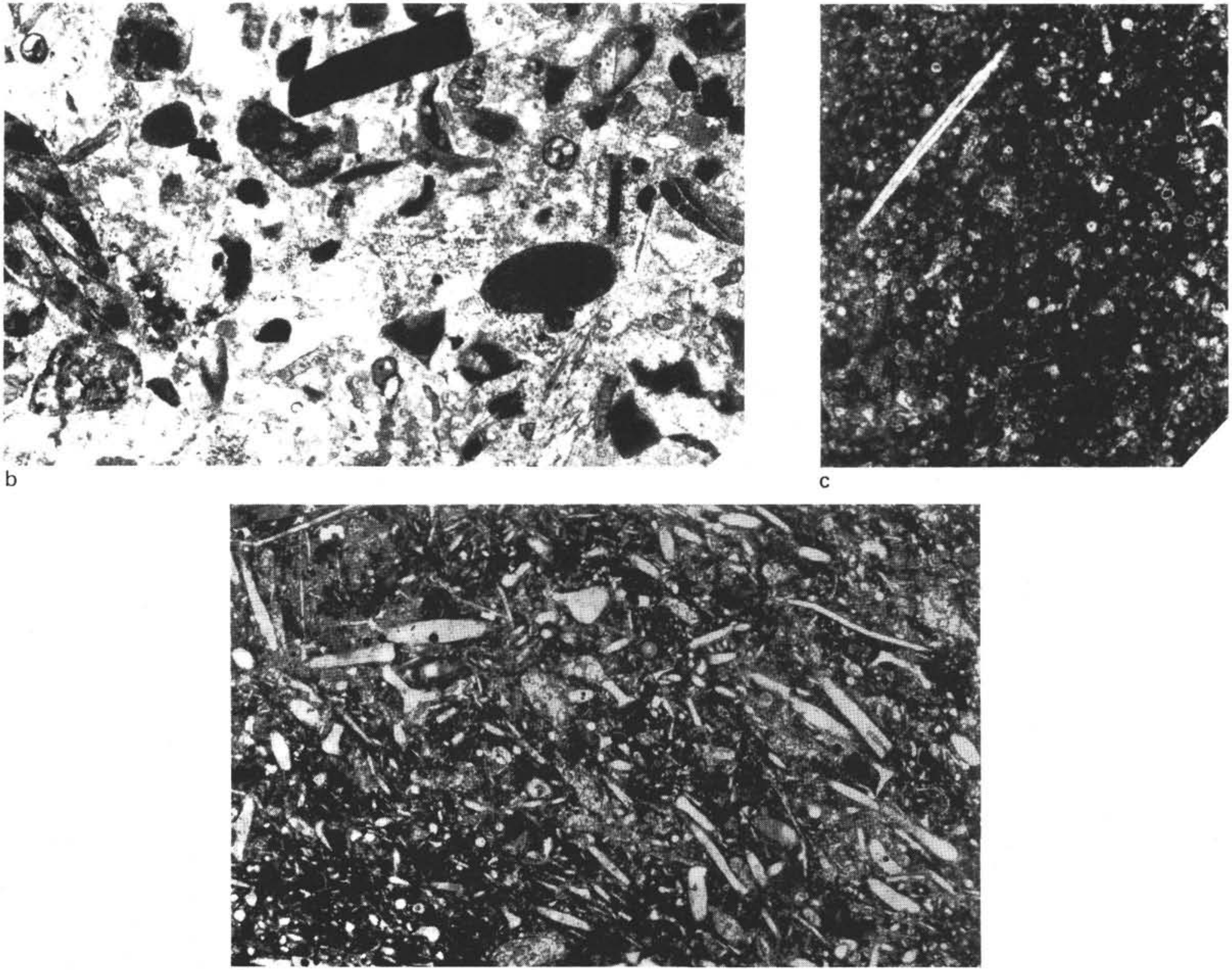

Figure 6. *(a) Photomicrographs of siliceous limestone rich in monaxon sponge spicules (Sample 5-1, 140-143 cm). (b) Photomicrograph of algal limestone containing echinoderma (Sample 8-1, 50-80 cm). (c) Photomicrograph of micritic limestone of "Arturian" facies containing numerous* Pithonella ovalis *and* Calcisphaerula *(Sample 6-1, 16-20 cm).*

major is 100 cm thick and the minor 250 cm. Sub-unit 3C, mainly calcareous mudstone, contains even less carbonate (average 25%) but the highest organic carbon content of any of the sub-units. Sedimentary structures in the sub-unit include layers of thin mollusk shells and chondrite-like burrows. Sub-unit 3D shows marked increase in the carbonate content (5-60%). Sedimentary structures are restricted to bioturbation.

Sub-Unit 3A

In this olive-gray to olive-black carbonaceous marly limestone, carbonate content averages 40 per cent. The minimum value (27%) is observed in Core 11, the maximum (61%) in Core 13. Quartz content is inverse to that of the carbonate, ranging between 5 and 15 per cent and reaching a maximum in Cores 11 and 14. Nannofossils, dominantly nannoconids, are rare, and the few coccoliths are small and fragile. Siliceous sponge spicules account for up to 10 per cent. The clay fraction is dominated by montmorillonite (30-70%) and clinoptilolite (15-40%); opal (5-30%) and kaolinite are subordinate. The coarse fraction (>44 μm) is rich in quartz (average 50%), unspecified carbonate (35%), and sponge spicules (10%), with minor components of heavy minerals (1-3%), glauconite (1-4%), and siderite (0-5%).

Sedimentary structures are rare and include slight evidence of burrowing. In Section 13-2, glauconite and quartz-bearing coarser laminae, 2 to 3 millimeters thick, occur.

Sub-Unit 3B

Sub-unit 3B is composed of carbonaceous calcareous mudstone, carbonaceous marly limestone and lighter, olive-gray, marly calcareous chalk. From Cores 15 to 21, the carbonate content averages around 30 per cent, increasing to about 40 per cent in the interval between Cores 21 to 26. Quartz shows an inverse trend, averaging about 20 per cent in the upper part of the sub-unit and only 10 per cent in the lower part. Foraminifers and siliceous sponge spicules are rare; nannofossils, although rare, are present in quantity from 1 to 10 per cent. Organic carbon content (0.5-1.5%) seems to correlate positively with the terrigenous fraction (quartz and clay minerals). In the clay fraction, montmorillonite is dominant (20-70%, average 50%); kaolinite and illite constitute about 20 to 25 per cent near the top of the unit and decline downward. Chlorite occurs in Cores 17 to 20 but is absent below; clinoptilolite averages about 5 to 10 per cent throughout the sub-unit, but reaches a peak concentration of 50 per cent in Core 18. Opal is also well represented (5-30%), the maximum value being in the top of the sub-unit. The coarse fraction is composed mainly of quartz (average 50%) and unspecified carbonate (40%); glauconite is a minor constituent of this fraction (3-5% in Cores 11-15). Some of these grains are well rounded. Siderite is a significant constituent of this fraction in Sample 23, CC. Sponge spicules are less abundant than in Sub-unit 3A (0-5%), reaching 10 per cent in Core 25 at the base of the sub-unit where the spicules appear particularly well rounded. Ammonites occur in the interval between Cores 22 and 25.

Color variations from light (olive-gray) to dark (olive-black to brownish black) occur throughout the sub-unit. The thickness of the darker layers which contain a higher content of organic carbon, decreases toward the top, averaging approximately 100 cm. On the criteria of laminations (from textural differentiation on a millimeter scale), burrowing, the occurrence of mud gravels, and scattered or layered shell debris, one can distinguish two lithologies in Sub-unit 3B. Cores 15 to 20 contain less organic matter, are well laminated, slightly to intensely bioturbated, and tiny mollusk shell debris occur sporadically. Cores 21 to 26, in contrast, contain higher percentages of carbonaceous material and microlaminations are frequent, particularly in darker calcareous mudstones. Bioturbation is less abundant, mud gravels and particularly numerous tiny mollusk shell debris occur throughout. There is also some indication of slumping as in Sample 21-3, 80-100 cm, in the form of overturned layers; other examples can be found in Samples 22-1, 30-40 cm and 22-4, 10-30 cm. Small-scale sedimentary structures (Figure 7) include single silty layers made of quartz, glauconite, unspecified carbonates and exhibit cross-bedding, and sets of laminae, 3 to 5 cm thick. A burrow in Sample 19-1, 55-76 cm cuts, without much disturbance, through one of these intervals, indicating that the laminae may have been well indurated shortly after deposition. Ripple marks about 4 cm in wavelength and 1 cm in amplitude (Figure 8) are, in some places, present on top of the laminae set.

Sub-unit 3B was subsequently divided into sub-units 3B1 and 3B2 (de Graciansky et al., this volume) between Cores 22 and 23 based on more detailed determinations of $CaCO_3$, quartz, and organic carbon contents and sedimentary structures (Figure 26).

Sub-Unit 3C

This sub-unit consists dominantly of interbedded olive-gray, carbonaceous, marly, calcareous chalk and brownish black, carbonaceous, calcareous mudstone. It has been separated from the previous sub-unit on the basis of trend toward increased content of clay and organic matter. The average carbonate content of the sub-unit is 25 per cent, consisting mainly of unspecified debris, some of which is magnesium calcite. Up to 5 per cent of the rock is nannofossils. They comprise abundant, well-preserved coccoliths and relatively few and badly preserved nannoconids. Average quartz content is 20 per cent. The sub-unit si also characterized by the highest organic carbon value (2.5%) of the black shales. In the clay fraction, montmorillonite is dominant (50-70%, with higher values toward the base of the sub-unit); kaolinite (10-35%), illite (0-20%), and mixed layer clays (illite-montmorillonite) comprise the remainder. In the coarse fraction quartz is dominant, accompanied by some chalcedony (1-3%). Mica and heavy minerals are significant (0-5%), as are fish debris (average 5%) and planktonic foraminifers (5-15%). Ammonites occur in Cores 31 and 32.

Alternations from lighter (olive-gray) to darker (brownish black) sediments occur throughout the sub-unit reflecting change in organic matter content. The "modal" thickness of the dark layers is about 100 cm; the two thickest beds are

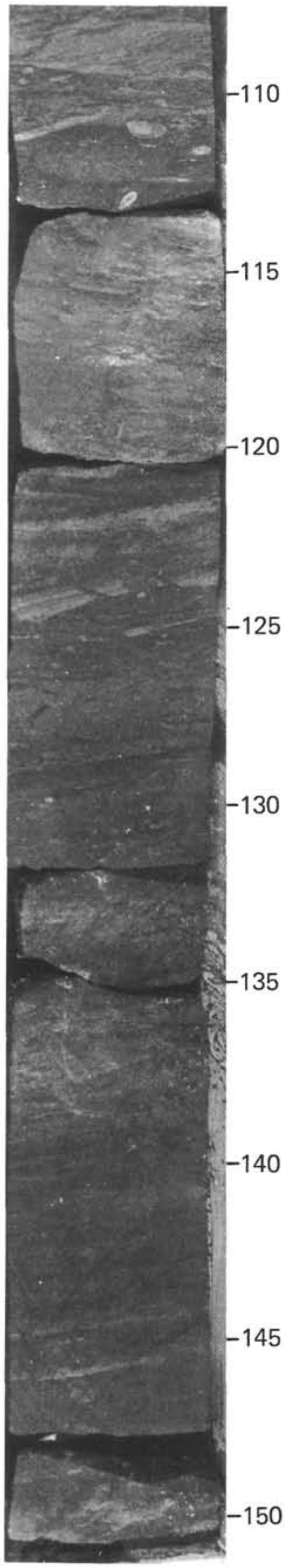

Figure 7. *Flaser structure and ripple marks (Sample 18-2, 110-150 cm).*

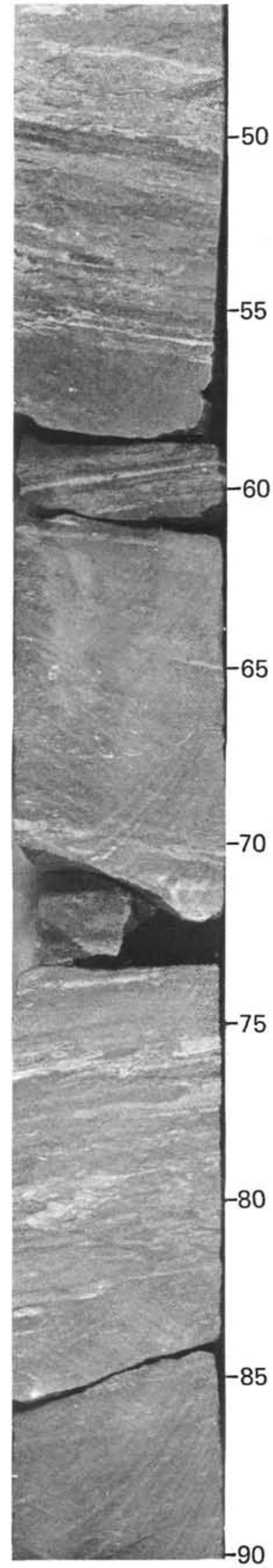

Figure 8. *Ripple marks (Sample 19-3, 45 cm).*

410 cm (Core 30) and 370 cm (Cores 31-32). Microlaminations are characteristic of most of the calcareous mudstones, whereas slight to moderate bioturbation appears throughout the olive-gray carbonaceous marly chalk; chondrites and *Zoophycos* are the most common burrows. Both types were lacking in the overlying sub-unit. Thin layers of mollusk shell debris occur, mostly in the carbonaceous calcareous mudstone.

Sub-Unit 3D

The sub-unit consists dominantly of greenish gray limestones and dark greenish gray marly limestones. The top is marked by a sharp increase in the carbonate content from 30 to about 90 per cent, but carbonate averages about 60 per cent and consists mostly of unspecified carbonates and nannofossils. Nannoconids are very abundant in sediments from Core 34 and Sample 35, CC. Concentrations of the fine silt-sized carbonates (Mg calcite) occur in ellipsoidal aggregates about 2mm in diameter. Other constituents include quartz (3-8%), pyrite (5%), and zeolite (3%). The coarse fraction is characterized by the abundance of planktonic foraminifer fragments, but low quartz.

Core 33 contains the lowest occurrence of the darker carbonaceous mudstone. The remainder of the sub-unit is light colored (dominantly greenish gray). Some well-developed sporadic clusters of pyrite (larger than 1 cm) are present, such as Sample 33-2, 128-133 cm which is organic rich. Burrowing is ubiquitous and laminations poorly developed.

BIOSTRATIGRAPHY

Sediments of Pleistocene, late Eocene, and Aptian-Albian age were recovered from Holes 402/402A. Discontinuous coring to 89.5 meters sub-bottom produced Pleistocene foraminifer oozes containing evidence of glacial-interglacial climatic fluctuations. Pliocene, Miocene, and Oligocene sediments were recovered only from the washdown core, taken somewhere between 89.5 and 118 meters sub-bottom suggesting that an incomplete, strongly condensed Neogene section is present. Cores 4 and 5 (118-137.5 m) recovered siliceous nannofossil ooze of late to middle Eocene age.

Hole 402A was washed down to 137 meters sub-bottom to continue from where the first hole at Site 402 had been abandoned (Figure 9). Cores 1 to 4 recovered further siliceous nannofossil ooze of late Eocene age; the planktonic foraminifers of Sample 4, CC indicate latest middle Eocene age, Zone P.13. This sequence is rich in well-preserved planktonic foraminiferal and nannofossil assemblages of high diversity. The nannofossil faunas, in contrast to those of Sites 400 and 401, contained an abundance of species commonly associated with neritic or nearshore deposits. Benthic foraminifers are rare, consisting of bathyal species, with common admixtures of shelf and shelf-edge species.

An important hiatus, encompassing Late Cretaceous to middle Eocene time, lies between Cores 4 and 5, an interval of at least 55 million years.

Cores 5 to 10 are hard, bioclastic limestones of late Albian age in a facies similar to the Albian epicontinental

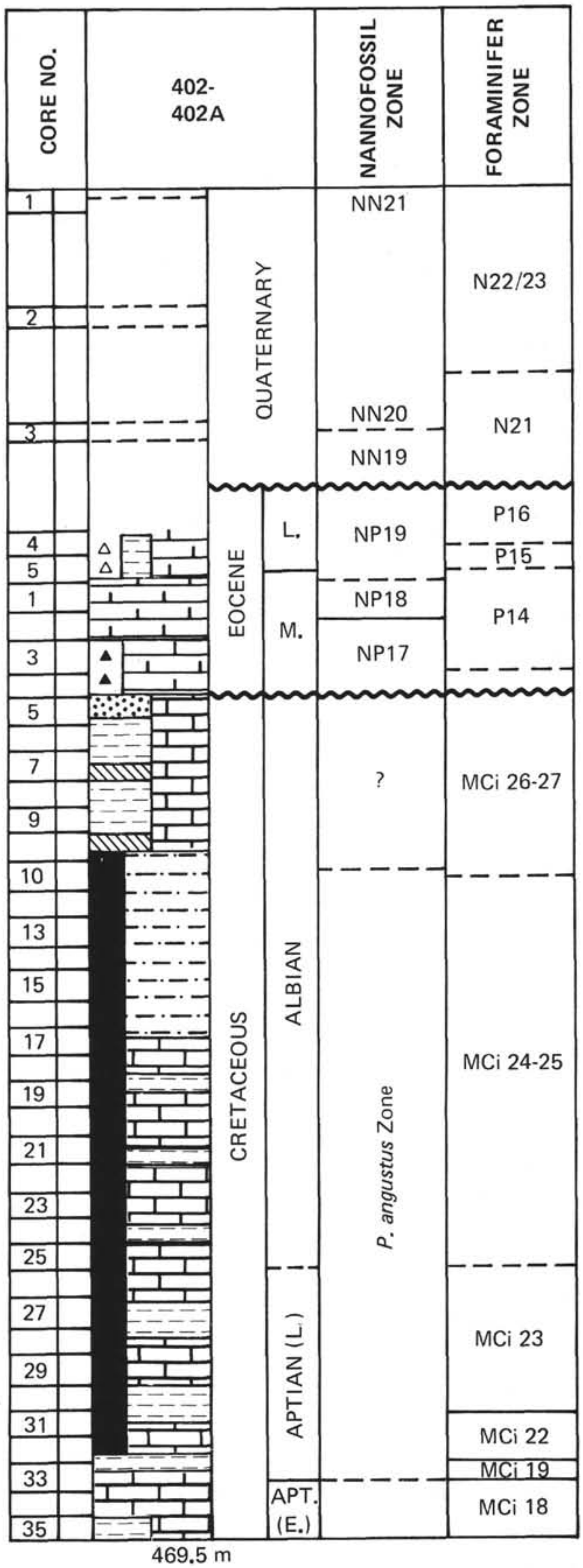

Figure 9. *Biostratigraphic summary, Holes 402/402A.*

deposits in southwestern France. Algae, echinoderms, bryozoa, foraminifers, and especially sponge spicules are common in this limestone. Below Core 10, the sediments are less indurated but contain few or no planktonic foraminifers. Cores 11 to 25 contain a poorly dated sequence of lower to upper Albian detrital sediments. The Albian/Aptian boundary was determined by palynomorphs to lie between Cores 26 and 27.

Below Core 27, planktonic foraminifers occur in increasing downward abundance, permitting location of the Gargasian/Bedoulian boundary between Cores 33 and 34. The entire Albian-Aptian sequence appears to have been deposited in a shallow water, nearshore environment. Planktonic foraminifers are scarce, being altogether absent in lower Albian sediments; benthic foraminifers present indicate neritic environments and, within the lower Albian, of restricted environments; pelecypods and gastropods are common to abundant; where nannoplankton is present, nannoconids are dominant or abundant; ostracodes, where present, are indicative of neritic, shallow seas. Ammonites of lower Albian age were found in the interval of Cores 22 to 25 and of lower upper Aptian age in Cores 31 and 32.

Foraminifers

The Pleistocene sediments of Cores 1, 2, and 3 of the first hole at Site 402 contained planktonic foraminiferal assemblages indicative of oscillations of the overlying water masses between interglacial and glacial conditions. *Globorotalia truncatulinoides*, the Pleistocene marker species, was present only within the interglacial assemblages; glacial assemblages could not be age dated with confidence. Intercalated within the foraminiferal ooze are layers of nearly pure and coarse foraminiferal sand. Because these sands contained, among the normal bathyal benthic foraminifers, such shelf-edge species as *Bulimina marginata* and *Cibicides lobatulus*, they are probably evidence of downslope mass movement, perhaps turbidites.

Washdown to 118 meters sub-bottom missed, probably, a Miocene and Oligocene section because disoriented material from the washdown core contained foraminiferal species of those ages.

Upper Eocene sediments, encountered in Cores 4 and 5 of Hole 402 and Cores 1, 2, and 3 of Hole 402A consist of siliceous nannofossil ooze containing abundant and mostly well-preserved planktonic foraminifers. Sample 4, CC yielded *Globorotalia cerroazulensis* s.s., and the *Globorotalia increbescens* to *Globigerina ampliapertura* transition, assigning it to Zones P.17-P.16. Samples 402-5, CC and 402A-1, CC contain no species which permitted a more precise determination than Zones P.15-P.16.

The upper Eocene-middle Eocene boundary lies within Core 2 of Hole 402A, the core catcher of which yielded a fauna containing, among others, *Truncorotaloides rohri*, *T. topilensis*, and *Globorotalia lehneri* and thus cannot be younger than Zone P.14. The faunas of Core 3 are essentially identical, but Sample 4, CC contains, in addition, *Globigerinatheca kugleri*, assigning it to Zone P.13 of the middle Eocene.

The Eocene planktonic foraminifers of Holes 402/402A are noteworthy for their great diversity. Fifteen to 20 species are commonly present in any one sample. Although the low latitude index species are commonly absent, such richness compares with Eocene and modern tropical and subtropical faunas and contrasts sharply to the 10 or fewer species of planktonic foraminifers that can be found in the Bay of Biscay today.

The benthic foraminifers of the Eocene sediments are generally well preserved but rare. In all but a few samples, a mixed fauna of bathyal and shelf-edge species was found. Species of *Gyroidina*, *Stilostomella*, *Nuttallides*, *Cibicidoides*, *Pleurostomella*, etc. are all indicators of deep water, but species of *Trifarina*, *Gavelinella*, *Rosalina*, and *Cibicides* occur usually in a shelf or shelf-edge environment or in neritic seas. Downslope mass movement apparently happened more frequently during Eocene times than during the Pleistocene when such faunal mixtures occurred only in less frequent intercalations within the normal sedimentary sequence.

A hiatus of at least 55 m.y. separates the middle Eocene sediments of Sample 4, CC from the Albian deposits in Core 5.

The limestones contained in Cores 5 to 10 had to be examined in thin sections. For the most part, they contain abundant sponge spicules and algal debris. At some levels the siliceous cement imparts a great hardness to the rock. A few specimens of small *Barkerinidae* and *Hedbergella* sp., cf. *H. washitensis* were recognized in some thin sections. This facies is similar to the Albian microfacies of the northern border of the flysch basin in southwestern France. A second microfacies, a bioclastic limestone, contains echinoderm remains and variable amounts of algal debris, principally of *Lithophyllum amphiroeformis*. In Sample 5-1, 12 cm, where algae are rare, two sections of what are probably *Hedbergella washitensis* are present; Sample 8-1, 3 cm contains *Hensonia lenticularis*. This facies too is known from the upper Albian of southwestern France and indicates a shelf-type environment. A third microfacies is restricted to hard, white limestone in Sample 6-1, 15-45 cm. Thin sections show abundant *Pithonella ovalis* and some *Calcisphaerula* sp., cf. *C. innominata*. Such a facies, also known from the Albian to Upper Cretaceous of southwestern France, is indicative of an outer-shelf or upper-slope deposit. The entire indurated limestone sequence is probably of late Albian age. Cores 5 and 6 may be of uppermost Albian (Vraconian) age.

Cores 11 to 25 contain detrital sediment and yield few, small, and mostly heavily encrusted foraminifers; planktonic foraminifers are rare to absent but gastropod and pelecypod remains are common to abundant.

Some benthic foraminifers in Sample 11-3, 107-109 cm (*Pleurostomella subnodosa*, *Epistomina* sp., cf. *Epistomina spinulifera*) and in Sample 13-2, 14-17 cm (*Epistomina cretosa*) suggest a middle Albian age. Cores 14 to 17, in addition to the above-mentioned benthic foraminifers, yielded also a few small specimens of *Hedbergella planispira*. Cores 18 to 23 contained no planktonic foraminifers and only encrusted benthic forms, in addition to gastropod and pelecypod fragments and echinoderm spines. Sample 24-1, 130-133 cm contains a better preserved and diversified fauna of benthic foraminifers, among them *Gyroidina primitiva*, *Pleurostomella* *subnodosa, Osangularia utaturensis,* and *Lenticulina cephalotes.* This assemblage may indicate an early Albian age.

Within Sample 26-1, 72-74 cm planktonic foraminifers reappear, principally *Ticinella bejaouaensis*, indicative of the *Ticinella bejaouaensis* Zone (MCi 23) of latest Aptian to earliest Albian age. This zone continues to Sample 31-4, 59-63 cm, wherein *Hedbergella trocoidea* is often common. The Aptian/Albian boundary probably lies between Cores 24 and 26. The *Hedbergella trocoidea* Zone (MCi 22) of late Aptian age is present from Samples 31-5, 96-101 cm to 32, CC. Three specimens of *Planomalina cheniourensis* in Sample 33-2, 55-57 cm, may indicate the *Globigerinelloides algerianus* Zone (MCi 21).

The *G. ferreolensis* Zone (MCi 20) was not identified.

The *Schackoina cabri* Zone (MCi 19) of late Aptian (early Gargasian) age occurs between Samples 33-3, 109-113 cm and 33, CC. Present in these samples are *Schackoina cabri, S. pustulans, Globigerinelloides gottisi*, and *G. duboisi*. The boundary between lower and upper Aptian can thus be placed between Samples 33, CC and 34-1, 18-21 cm, the latter of which does not contain *Schackoina*.

From Samples 34-1, 18-21 cm to 35, CC rare and small planktonic foraminifers such as *G. duboisi, G. gottisi,* and *Hedbergella infracretacea* and the benthic forms *Globorotalites* sp., cf. *G. aptiensis,* and *Lenticulina ouachensis* were recovered. Such species fix the age of these deposits at early Aptian (late Bedoulian).

The planktonic foraminifers (often small) within the Aptian sequence appear to represent an outer-shelf or possibly an upper-slope environment. Rapid detrital and organic matter influx occurred during early and middle Albian time, shoaling the sea to the point of it being a restricted, shallow water environment in which gastropods and pelecypods were abundant. Detrital influx diminished during late Albian time, and continued subsidence allowed outer-shelf environmental conditions to reappear.

Nannofossils

Pleistocene sediments are recovered in Cores 1, 2, and 3 (0-89.5 m) at Site 402. The *Emiliania huxleyi* Zone (NN 21) is determined in Core 1, and the *Gephyrocapsa oceanica* Zone (NN 20) in Core 2 and in Sample 3-1, 76-77 cm.

Samples 3-1, 122-123 cm to 3, CC belong to the *Pseudoemiliania lacunosa* Zone (NN 19). The sediments in general contain abundant, well-preserved nannofossils but occasionally are strongly diluted with terrigenous material. Diatoms and reworked Cretaceous species are present.

Upper Eocene sediments are present from Samples 4, CC to 5, CC. The *Isthmolithus recurvus/Sphenolithus pseudoradians* Zone (NP 19/NP 20) is present from Samples 4, CC to 5-1, 106-107 cm and the *Chiasmolithus oamaruensis* Zone (NP 18) from Samples 5-2, 9-10 cm to 5, CC. Therein are numerous siliceous microfossils and well-preserved to slightly etched calcareous nannofossils. *Braarudosphaera bigelowi, Micrantholithus basquensis, M. angulosus, M. vesper,* and *Pemma rotundum* are frequent. The abundance of these species is typical for upper Eocene deposits and, in general, is considered that they indicate a nearshore environment. Discoasters are scarce in the uppermost part of the Eocene section, which suggests a decrease of water temperatures.

Hole 402A was washed down to 137.0 meters sub-bottom. The *Isthmolithus recurvus/Sphenolithus pseudoradians* Zone (NP 19/NP 20) was determined in Core 1, Section 1. Core 1, Section 2 and Core 2, Section 1 contain the *Chiasmolithus oamaruensis* Zone (NP 18), and Samples 2, CC to 4, CC contain the *Discoaster saipanensis* Zone (NP 17) of late Eocene age. Siliceous microfossils and well-preserved to slightly etched nannofossils are numerous. The coccoliths are often slightly etched whereas the discoasters are slightly overgrown.

The upper Eocene section is underlain by Lower Cretaceous sediments. The hiatus represents an interval of at least 56 m.y. In Cores 5 and 6 only a few nannofossils are present such as *Nannoconus truitti, Watznaueria barnesae,* and *Parhabdolithus infinitus;* a precise age determination is not possible.

The *Parhabdolithus angustus* Zone of late Aptian/early Albian age is determined from Samples 11-1, 4-6 cm to 33-2, 88-90 cm. This sequence is distinguished by the occurrence of nannoconids which become frequent in several layers, whereas other nannofossils are often less abundant, pointing to an inverse relationship between the two groups.

The *Chiastozygus litterarius* Zone of early Aptian age is present from Samples 34-1, 30-32 cm to 3, CC containing *Chiastozygus litterarius, Micrantholithus hoschulzi* and *Conusphaera mexicana.* The sediments are rich in well-preserved to slightly overgrown nannofossils. Nannoconids are abundant, indicating the influence of a shallow water environment.

Dinoflagellates

Sparse assemblages of well-preserved dinoflagellate cysts were recovered from samples from Site 402. Sample 402-1-2, 86-89 cm yielded a typical upper Quaternary assemblage dominated by *Operculodinium centrocarpum* (Deflandre and Cookson) Wall with *Bitectatodinium tepikiense* Wilson, comparable to the present day "North Atlantic Drift" assemblage of Reid and Harland (in press). Assemblages from Samples 402-2-1, 41-43 cm and 402-3-1, 66-68 cm contain a mixture of Quaternary species together with such reworked upper Eocene species as *Areosphaeridium multicornutum* Eaton and *Hystrichosphaeridium asterium* Eaton. In contrast, Sample 402-5-2, 62-64 cm produces a rich, well-preserved assemblage of dinoflagellate cysts including *Cyclonephelium spinetum* Eaton, *Pentadinium laticinctum* Gerlach, *Phthanoperidinium tritonium* Eaton, and *Wetzeliella (Rhombodinium) perforata* Jan Du Chêne and Chateauneuf. The last-mentioned species signifies an assignment to the *W. (R.) perforata* Zone of Costa and Downie (1976) which encompasses NP Zones 17-20. This is in broad agreement with the nannofossil and planktonic foraminiferal evidence.

Two samples from Hole 402A yielded moderately rich, well-preserved dinoflagellate assemblages. The first, Sample 402A-1-3, 77-81 cm, contains *Distatodinium craterum* Eaton and *D. ellipticum* (Cookson) Eaton which indicate an age of late Eocene to late Oligocene. The second, Sample 402A-2-1, 43-46, yields *Homotryblium floripes* (Deflandre and Cookson) Stover, *Emmetrocysta urnaformis* (Cookson) Stover, and *Wetzeliella* (*Wetzeliella*) *coleothrypta* Williams and Downie, species that are indicative of the late Eocene. These ages are consistent with the evidence from calcareous micropaleontology. Little or no contamination was noted for the samples from this site.

Marine Aptian/Albian Palynology of Hole 402A[2]

The Aptian/Albian samples examined from Samples 11-4, 105-108 cm to 35-3, 69-72 cm yielded relatively rich and diverse dinocyst assemblages. Sporomorphs, consisting of bisaccate pollen grains and spores, are abundant. Microforaminifers are abundant in many of the samples and acritarchs, although never abundant, are consistently present. Preservation is good in all cases.

The Aptian/Albian sequence at Hole 402A is particularly difficult to date because of the paucity of stratigraphically restricted species of known range and because of extensive reworking. Aptian reworking into Albian is obvious, but reworking within the Aptian is not possible to identify. The occurrence of *Ctenidodinium elegantulum* in the Samples 34-3, 35-38 cm to 35-3, 69-72 cm and the single occurrence of *Pseudoceratium pelliferum* in Sample 31-6, 15-19 cm suggest a limited amount of reworking of pre-Aptian strata into the Aptian. Dating was mainly by comparing dinocyst ranges at this site with ranges in the more easily datable Hole 400A. Details are to be found elsewhere in this volume (Davey).

Samples 11-4, 105-108 cm to 25-5, 5-8 cm are of Albian age, but further refinements are not possible. Sample 26-1, 9-14 cm contains the earliest stratigraphic occurrence of *Hapsocysta peridictya*, and this can be correlated to Section 67-0 of Hole 400A. On this criterion the Aptian/Albian boundary is placed above Section 26-1. This dating is substantiated by the distribution of *Lecaniella foveata* which has an earliest occurrence in Sample 30-6, 60-63 cm (Hole 402A); Sample 68-2, 24-26 cm (Hole 400A); and in the upper part of the upper Aptian in southern England. Lower in the sequences the earliest occurrence of *Codoniella psygma* and the peak abundance of *Oligosphaeridium verrucosum* occur in Sample 32-7, 0-4 cm (Hole 402A) and in Section 70-0 (Hole 400A) indicating that the former sample is of early-late Aptian age. This correlation is substantiated by the earliest occurrence of *Ovoidinium diversum* which is in Sample 32-7, 0-4 cm (Hole 402A) and Sample 71-1, 111-113 cm (Hole 400A).

Dinocysts, bisaccate pollen grains, spores, and microforaminifers are abundant in the majority of samples analyzed. Organic debris is also abundant and consists mainly of non-carbonized, terrestrially derived tracheidal and cuticular material. Thus the organic content of these samples most closely resembles that of the sapropelic mudstones at Hole 400A with the exceptions that microforaminifers are almost absent there and that spores are relatively rare. The increased abundance of these two constituents is characteristic of an environment of deposition dominated and relatively close to the landmass and probably on the continental shelf. This "nearshore" depositional environment is again indicated by the consistent abundance of peridinacean dinocysts, including the genera *Ovoidinium* and *Subtilisphaera*, and by the consistent presence of the acritarch genus Micrhystridium.

[2]Contribution by J. R. Davey, Institute of Geological Sciences, Ring Road, Halton, Leeds, England.

PHYSICAL PROPERTIES

Determinations of physical properties (in addition to downhole logs for spontaneous potential, gamma-ray, formation density, neutron porosity, sound speed, and resistivity) involved 71 samples from 470 meters of hole for an average of one sample per 6.6 meters. The introduction to this volume includes discussion of purpose and procedures for these measurements and related calculations.

The ranges of determinations on cores include: coring time (0.5-22.1 min/m), sound speed (1.6-4.2 km/s), wet bulk density (1.68-2.56 g/cm), sound impedance (2.7-10.4 units), porosity (16-60%), and water content (8-35%). The data are presented in Table 4 and Figure 10 and in depth plots on the superlogs in the pocket of this volume.

Core measurements and downhole logs (closely coordinated by eight sound speed markers at 176, 185, 272, 330, 348, 367, 448, and 455 m sub-bottom) suggest that composition (in terms of $CaCO_3$) and cementation (mainly silica) strongly influence the physical properties, including seven potential seismic reflectors at sub-bottom depths in meters of about 100, 175, 213, 270, 345, 365, and 440. The following discussion concerns each of three sub-bottom depth intervals, 0 to 175, 175 to 235, and 235 to 470 meters.

Physical properties on the top interval (0-175 m), although represented by sparse data in the upper part, suggest control by compaction and $CaCO_3$ content including a probable seismic reflector at 100 to 115 meters. From 0 to 80 meters, compaction reasonably explains increases in sound speed and wet bulk density where the porosity and water content decrease with depth and the $CaCO_3$ content fluctuates in the 20 to 60 per cent range. Between 120 and 170 meters, the sound speed and wet bulk density decrease parallel with a decrease of $CaCO_3$ from 80 to 40 per cent, where the porosity and water content increase. A high sound speed and impedance seems probable in the 100 to 115 meter interval where wash cores indicate $CaCO_3$ content ranging up to 95 per cent and the gamma-ray shows a minimum content.

Based primarily on the downhole logs, the 175 to 235 meter depth interval demonstrates extreme variations in physical properties, apparently related primarily to lithology and to silicification, including probable seismic reflectors at the top (175) and in the middle (213).

Cementation and composition reasonably control the physical properties in the bottom interval (235-470 m) including increasing sound speed anisotropy in the upper part and probable seismic reflectors at 270, 345, 365, and 440 meters. Although the sound impedance increases that suggest seismic reflectors at 345, 365, and 440 meters coincide with $CaCO_3$ highs, the sound impedance high at 270 meters coincides with a $CaCO_3$ low, thus suggesting some other control.

The potential seismic reflector at 270 meters reasonably results from cementation as suggested by the abrupt increase

TABLE 4
Physical Property Summary, Holes 402/402A

Sample (Interval in cm)	Depth Sub-Bottom (m)	Strength Vane Shear (g/cm^2) Original	Strength Vane Shear (g/cm^2) Re-Mold	Sound Velocity (km/sec) (Hamilton Frame) ∥ to Beds	⊥ to Beds	Anisotropy ∥-⊥ + or -	Anisotropy ∥-⊥ / ⊥ %	C°	Wet Bulk Density (g/cm^3) GRAPE 2 Minute ∥ to Beds	GRAPE 2 Minute ⊥ to Beds	Syringe (wt./vol.)	Chunk (wt./vol.)	Sound Impedance [g/(cm^3/sec)] 10^5 GRAPE Density	Wt./vol. Density	Porosity (%) GRAPE	Porosity (%) Wt. H_2O Vol.	H_2O (%)	CO_3 (%)	Lithology
Hole 402																			
1-1, 29-30	.295										1.93					60.33	31.28		limy mud
1-1, 126-128	1.27			1.67				20											limy mud
1-1, 135-137	1.36																		limy mud
1-2, 16-22	1.69			1.70				19			1.82			3.09		53.77	29.56		limy mud
1-2, 140-150	2.95										1.68					59.52	35.39		limy mud
1-3, 48-56	3.52	.30	12	1.65				20			1.69			2.79		59.98	35.44		limy mud
2-1, 55-63	42.59			1.81				20			1.99			3.60		40.51	20.38		limy mud
3-1, 76-84	80.8			1.85				20			2.06			3.81		39.97	19.36		limy mud
5-2, 73-76	129.75			1.61	1.55	+0.06	0.04	20	1.79	1.74		1.78	2.84	2.87		53.31	30.03	53	siliceous marly chalk
5-2, 140-150	130.45											1.82				50.19	27.58		siliceous marly chalk
5-4, 58-64	132.61			1.74	1.70	+0.04	0.02	20	1.83	1.87		1.85	3.22	3.22		48.04	25.93	62	siliceous marly chalk
Hole 402A																			
1-2, 58-63	137.76			1.80	1.63	+0.17	0.10	22	1.86	1.87		1.82	3.67	3.28		51.21	28.12		chalk
1-2, 140-150	139.96											1.84				48.93	26.61		chalk
1-5, 115-118	144.17			1.66	1.66	0.0	0.0	22	1.80	1.85		1.81	3.03	3.00		49.57	27.36	60	chalk
2-1, 10-15	146.63			1.69	1.67	+0.02	0.01	22	1.84	1.80		1.83	3.08	3.09		49.04	26.80	54	chalk
3-2, 2-6	157.9			1.64	1.63	+0.01	0.01	22				1.73		2.84		52.82	30.61	46	siliceous chalk
3-5, 72-74	162.73			1.61	1.62	+0.01	0.01	22	1.68	1.71		1.68	2.73	2.70		55.92	33.33	33	siliceous chalk
4-2, 146-150	168.48			1.65	1.63	+0.02	0.01	22	1.69	1.71		1.71	2.81	2.82		55.42	32.50	?	siliceous chalk
4-3, 70-73	169.22			1.64	1.62	+0.02	0.01	22	1.69	1,69		1.70	2.77	2.79		55.28	32.45	36	siliceous chalk
5-1, 84-104	175.94		I	4.07				22	2.56				10.42						limestone
6-1, 0-10	184.55			2.40				22	1.93			1.88	4.63	4.51		37.41	19.92	25	claystone
6-1, 15-45	184.8		II	4.23				22	2.40			2.39	10.15	10.11		15.54	6.50	?	limy claystone
10-1, 8-12	222.6			3.75				22	2.15			1.97	8.06	7.39		22.47	11.39	?	siliceous claystone
11-1, 70-74	232.72			2.15	2.02	+0.13	0.06	22	1.98	1.99		1.98	4.28	4.26		40.69	20.55	26	mudstone
11-3, 130-134	236.32			2.16	2.04	+0.12	0.06	22	1.95			2.00	4.21	4.32		40.34	20.19	23	carbonaceous mudstone
12-1, 128-132	242.8			1.99	1.93	+0.06	0.03	22	1.97	1.99		1.96	3.94	3.90		43.36	22.18	25	carbonaceous mudstone
12-2, 0-10	243.05											1.93				45.33	23.54		carbonaceous mudstone
12-2, 92-95	243.94			2.13				22	1.95	1.93		1.99	4.13	4.24		40.46	20.30	24	carbonaceous mudstone
13-2, 67-70	253.19			2.21	2.12	+0.09	0.04	22	2.02	2.06		2.06	4.51	4.55		36.56	17.71	38	carbonaceous mudstone
14-1, 64-68	261.16			2.28	2.18	+0.10	0.05	22	2.02	2.04		2.01	4.63	4.58		37.04	18.40	30	carbonaceous mudstone
14-3, 98-100	264.49			2.10	1.93	+0.17	0.09	22	2.00	2.06		2.00	4.26	4.20		40.52	20.27	15	carbonaceous mudstone
15-2, 76-80	272.28		III	2.60	2.43	+0.17	0.07	22	2.11	2.16		2.08	5.55	5.41		31.19	14.99	19	carbonaceous mudstone
15-5, 1-5	276.03			2.52	2.25	+0.27	0.12	22	2.07	2.13		2.06	5.29	5.19		35.17	17.11	20	carbonaceous mudstone
16-1, 96-98	280.47			2.55	2.24	+0.31	0.14	22	2.07	2.07		2.04	5.28	5.20		31.57	15.47	20	carbonaceous mudstone
17-2, 93-95	291.44			2.63	2.42	+0.21	0.09	22	2.05	2.10		2.06	5.46	5.42		32.28	15.69	26	limestone
18-2, 110-112	301.11			2.61	2.46	+0.15	0.06	22	2.04	2.07		2.05	5.36	5.35		34.42	16.76	15?	carbonaceous marly limestone
18-3, 140-150	302.95											2.06				35.58	17.31	?	carbonaceous marly limestone
18-4, 34-36	303.35			2.60	2.34	+0.26	0.11	22	2.04	2.07		2.05	5.34	5.33		30.66	14.97	22	carbonaceous marly limestone
19-2, 110-112	310.61			2.61	2.46	+0.15	0.06	22	2.08			2.06	5.38	5.38		32.19	15.63	22	carbonaceous marly limestone
19-4, 34-36	312.85			2.60	2.34	+0.26	0.11	22	2.04			2.07	5.30	5.38		32.21	15.58	33	carbonaceous marly limestone
20-2, 85-87	319.86			2.55	2.36	+0.19	0.08	22	2.14			2.10	5.46	5.36		31.79	15.17	21	interbedded
20-4, 45-48	322.47			2.30	2.21	+0.09	0.04	22	2.08			1.93	4.78	4.44		34.32	16.53	24	interbedded mudstone limestone
21-2, 144-149	329.97		IV	2.80	2.62	+0.18	0.07	22	2.06	2.15		2.09	4.84	4.81		30.52	14.58	26	interbedded mudstone limestone
21-5, 11-14	333.13			2.44	2.28	+0.16	0.07	22	2.02	1.99		2.07	4.89	5.05		33.09	15.97	?	interbedded mudstone limestone
22-2, 45-48	338.47			2.58	2.50	+0.08	0.03	22	2.13	2.12		2.04	5.48	5.26		31.68	15.53	21	interbedded mudstone limestone
22-4, 101-104	342.03			2.73	2.47	+0.26	0.11	22	2.02	2.06		2.07	5.57	5.65		29.68	14.36	23	interbedded mudstone limestone
22-6, 11-14	344.13			2.53	2.41	+0.12	0.05	22	2.10	2.08		2.05	5.29	5.19		34.69	16.92	33	limestone
23-2, 54-57	348.06		V	3.00	2.68	+0.32	0.12	22	2.18			2.18	6.54	6.54		27.13	12.43	46	marly carbonaceous limestone
23-5, 79-82	352.81			2.51	2.22	+0.29	0.13	22	2.05			2.05	5.16	5.16		35.01	17.10	22	marly carbonaceous limestone
23-5, 140-150	353.45											2.07				32.85	15.86	26	marly carbonaceous limestone
24-2, 85-88	357.87			2.22	2.00	+0.22	0.11	22	2.04	2.05		2.05	4.54	4.55		38.43	18.73	?	marly carbonaceous limestone
24-4, 99-101	361.00			2.59	2.41	+0.18	0.07	22	2.09	2.07		2.09	5.39	5.41		31.86	15.25	25	marly carbonaceous limestone
25-2, 50-53	367.02		VI	2.72	2.47	+0.25	0.10	22	2.51	2.41		2.40	6.69	6.53		26.17	10.89	14	marly carbonaceous limestone
25-4, 137-140	370.89			2.38	2.19	+0.19	0.09	22	2.16	2.14		2.11	5.12	5.02		33.76	15.99	25	marly carbonaceous limestone
26-1, 56-59	375.08			2.22	2.10	+0.12	0.06	22	2.11	2.11		2.10	4.68	4.66		35.28	17.01	27	marly carbonaceous limestone
30-2, 84-87	414.86			2.04	1.95	+0.09	0.05	22	2.02	1.97		2.01	4.07	4.10		41.62	20.76	27	mudstone
30-5, 79-82	419.31			2.07	1.94	+0.13	0.09	22	2.04	2.06		2.00	4.24	4.14		39.90	19.94	19	carbonaceous mudstone
30-5, 140-150	419.95											2.01				40.20	20.00		carbonaceous mudstone
31-2, 8-11	423.60			1.97	1.91	+0.06	0.03	22	2.06			2.02	4.06	3.98		41.50	20.50		carbonaceous mudstone
31-4, 9-12	426.61			2.07	1.99	+0.08	0.04	22	2.13			2.08	4.41	4.31		36.95	17.78		carbonaceous mudstone
32-2, 79-82	433.81			2.01	1.93	+0.08	0.04	22	2.15	2.09		2.10	4.26	4.22		36.28	17.28	18	carbonaceous mudstone
32-5, 62-65	438.14			2.21	2.09	+0.12	0.06	22	2.17	2.17		2.16	4.80	4.77		32.31	14.95		carbonaceous mudstone
33-2, 12-15	442.64			2.28	2.16	+0.12	0.06	22	2.16	2.19		2.15	4.96	4.90		35.14	16.36	24	carbonaceous mudstone
33-2, 91-94	443.43			2.66	2.51	+0.15	0.06	22	2.40	2.39		2.32	6.37	6.17		24.87	10.39		limestone
33-5, 88-91	447.90		VII	2.98	2.87	+0.11	0.04	22	2.50	2.43		2.37	6.56	6.30		20.81	8.77		marly limestone
34-1, 32-35	450.84			2.38	2.27	+0.11	0.05	22	2.27	2.30		2.27	6.78	5.40		27.17	11.97		marly limestone
34-3, 146-149	454.98		VIII	2.81	2.71	+0.10	0.04	22	2.38	2.40		2.39	6.72	6.72		20.03	8.37	65	marly limestone
35-2, 78-81	462.30			2.54	2.34	+0.20	0.09	22	2.36	2.34		2.34	5.97	5.94		24.27	10.39	53	marly limestone
35-4, 52-55	465.04			2.41	2.21	+0.20	0.09	22	2.28	2.32		2.28	5.54	5.49		26.63	11.66		marly limestone
35-4, 139-150	465.95							22				2.33				25.93	11.11	50	marly limestone
35-5, 81-84	466.83			2.40	2.17	+0.23	0.11	22	2.32	2.34		2.29	5.59	5.50		26.61	11.63	45	marly limestone

in sound speed anisotropy (9-31%) as well as sound speed (2.0-2.4 km/s perpendicular to the sediment layers) where the per cent $CaCO_3$ generally remains the same or decreases between depths of 235 and 270 meters. This same interval shows an increase in wet bulk density, consistent with decreases in porosity and water content.

Close agreement (within a few per cent) of core measurements with downhole logs (for both wet bulk density and sound speed perpendicular to the sediment layers) indicate the anisotropy in sound speed is *not* related to unloading in bringing the cores to the surface. Furthermore, use of the higher sound speeds (those

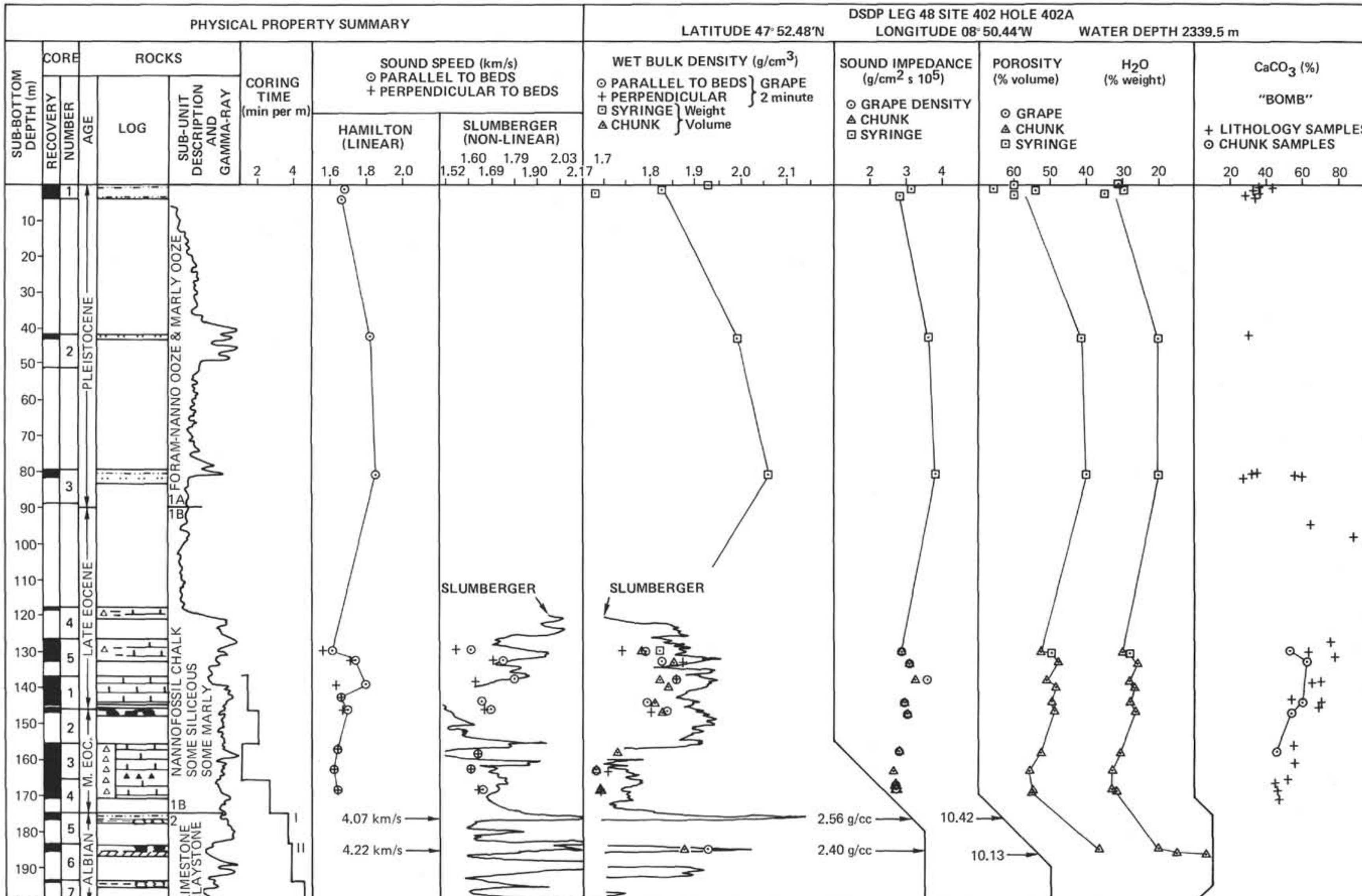

Figure 10. *Physical properties.*

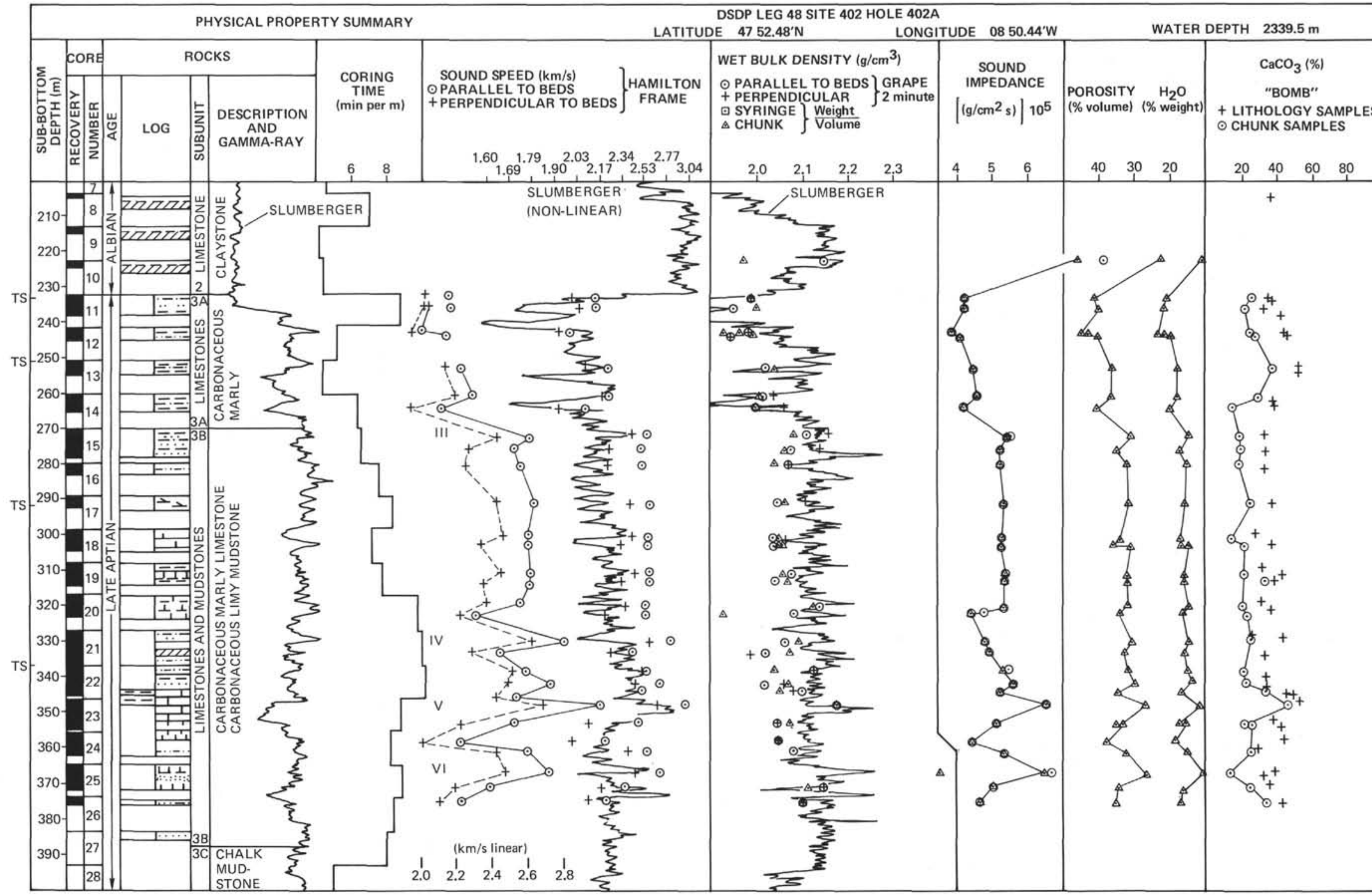

Figure 10. *Continued*

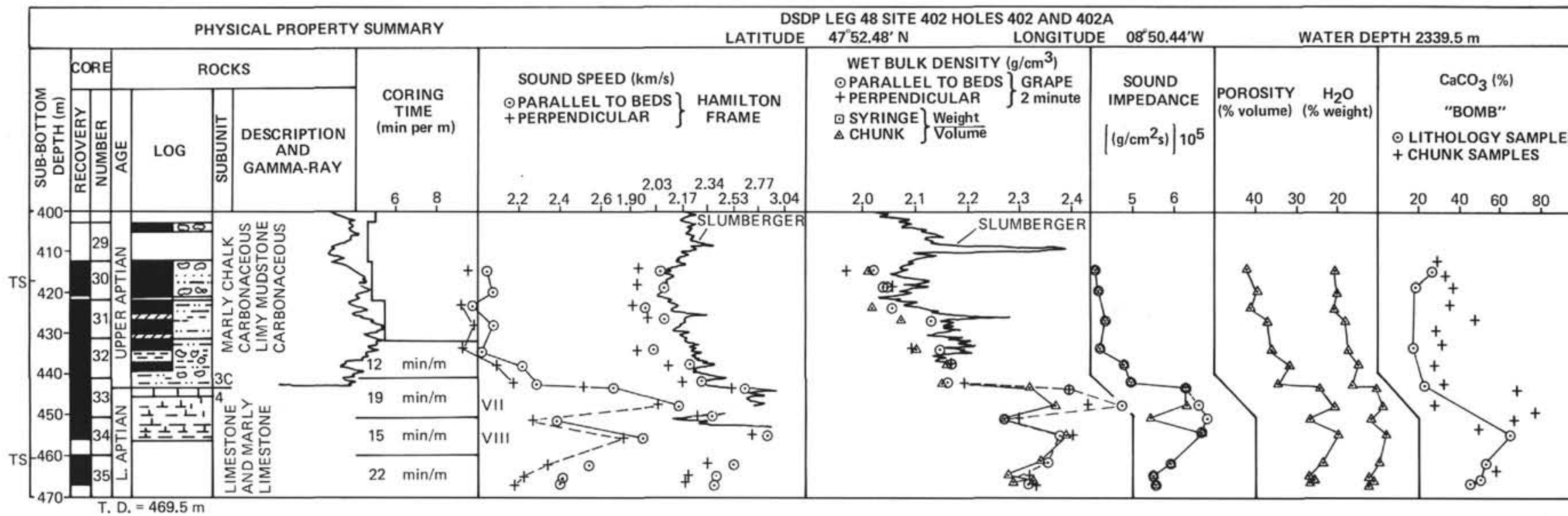

Figure 10. *Continued.*

measured parallel to the beds) for seismic analysis apparently would cause 10 to 20 per cent error for this particular rock sequence between depths of 270 and 370 meters.

Comparison of the Aptian/Albian sequence at Site 402 with similar rocks of the same age at Site 400 indicates much greater lithification at a shallower depth at the former site. Although the percentages of $CaCO_3$ for the two sites differ by less than 5 per cent, the bulk densities at Site 402 averaged 2.05 compared to 1.9 at Site 400 and the sound speeds measured on cores at Site 402 average 2.4 km/s compared to 1.9 km/s at Site 400. The sound speed anisotropy at Site 402 ranges from 10 to 30 per cent compared with the 5 to 10 per cent range exhibited by the rocks at Site 400. Porosity and water content average only 30 and 15 per cent, respectively, at Site 402 compared to 45 and 25 per cent, respectively, for the porosity and water content at Site 400.

Possible explanations for the obviously greater lithification of the Aptian/Albian rocks at Site 402 relative to similar rocks of the same age at Site 400 include a much greater load of sediment that was subsequently removed during the Cenomanian hiatus; the subaerial exposure responsible for this removal also would have promoted the lithification. A more probable explanation involves the stratigraphic relationships wherein siliceous Eocene sediment lies unconformably on the Aptian/Albian rocks at Site 402 in contrast to Upper Cretaceous chalk lying unconformably on the Aptian/Albian rocks at Site 400.

CORRELATION OF SEISMIC PROFILES WITH DRILLING RESULTS

Holes 402/402A are located in the axis of a canyon cutting the upper continental slope of the northern Bay of Biscay at shotpoint 400, on the IFP-CNEXO multichannel seismic profile OC301. Following completion of DSDP Leg 48, new multichannel seismic profiles run by IFP-CNEXO-CEPM (GMG, GM7, GM10) and by IOS (CM14) completed the coverage. In addition, a high-resolution multichannel seismic profile GEOM 402 (Figure 11) was run by IFP which gave a more detailed picture of the site area. This profile has been used for correlating the drilling results with the seismic reflection data.

As shown on profile OC301 (Figure 2) the continental margin in this area is underlain by a succession of tilted blocks and half-grabens downfaulted to the south. Several seismic units and reflectors can be distinguished.

Seismic Unit A: The canyon in which Holes 402/402A were drilled cuts through this unit. Two sub-units can be distinguished separated by an erosional surface dissected by a succession of buried canyons. Sub-unit A1 infilled these old canyons either completely, or partially, as at Site 402. For convenience, the erosional surface is called reflector 1. Sub-unit A2 is strongly eroded (perhaps totally, immediately southeast of the site) and at its base, northwest of the site, a series of strong, discontinuous reflectors is present which may be related to chert beds. Its lower boundary is a strong, continuous reflector called 2. At the site location, where reflector 1 is not clearly seen, reflector 2 lies at 0.220 s below the sea bottom. Beyond the canyon, the total thickness of seismic Unit A is about 0.500 s (two-way time) i.e., close to 525 meters, using a mean interval velocity of 2.1 km/s derived from the seismic profiles.

Seismic Unit B: The top of the unit is well defined by reflector 2 and its base by the strong and relatively continuous reflector 3. At the site, reflector 3 is at 0.480 s below sea bottom. Unit B, the thickness of which is 0.260 seconds at the site, thins considerably upslope and thickens downslope as far as the crest of the tilted block where it is completely cut out (eroded?) by the overlying unit. Two features which appear on the high-resolution section must be emphasized. Within seismic Unit B, oblique reflectors are present between the two sub-parallel reflectors 2 and 3, suggesting progradation of the sediments inside Unit B. Reflector 3 is affected by small faults which do not affect reflector 2. The faulting implies that the tectonic activity related to the rifting of the margin ended during deposition of Unit B.

Seismic Unit C: The unit is 1.3 s thick and contains numerous, continuous reflectors which pinch out toward the crest of the tilted block. Their attitude indicates contemporaneous deposition with the tilting of the block, i.e., during the rifting of the margin. The base of the unit is defined by the strong reflector 4, at 1 s (two-way time) below the sea bottom. The thickness of the unit at the site is 0.520 s (two-way time), i.e., around 700 to 800 meters using interval velocities of 2.9 to 3.0 km/s derived from the seismic profiles.

Seismic Unit D: This unit comprises the acoustic basement. In contrast to Site 400, reflectors are rare and discontinuous within the basement. Interval velocities of more than 4 km/s suggest that they may be pre-rift platform carbonates.

The correlation of seismic reflectors with the drilled section is based on the results of the velocity and density logging runs made on this hole and the generation of a synthetic seismogram (Figure 12) from these data. Because logging data were not available for the top and the base of the hole, the synthetic seismogram has been computed over these depths using velocity and density values measured on cores.

The most serious change observed on both logs and cores occurs at the level of Core 5 between 175 and 184.5 meters where siliceous upper Albian limestones underlie middle Eocene siliceous nannofossil chalks (Figure 13). Sonic velocity increases sharply from about 1.8 km/s to more than 3 km/s creating a sharp increase in acoustic impedance. The seismogram shows that a strong reflection must occur at around 0.220 meters below the sea bottom in close agreement with reflector 2 of the seismic profile. The high velocity layer extends to 222 meters depth where there is a sharp decrease in velocity and impedance. However, the change occurs too closely to reflector 2 for a reflector to be clearly delineated on the seismic profile at the frequencies used. Reflector 1 cannot be located exactly within the canyon axis. It must be situated about 0.100 s below the sea bottom between the Pleistocene cored to 89.5 meters and the upper Eocene cored from 118 meters. Several hiatuses and erosional events of different ages may exist there.

Below the high velocity layer of late Albian age, there is a thick, relatively homogeneous section of Albian-late

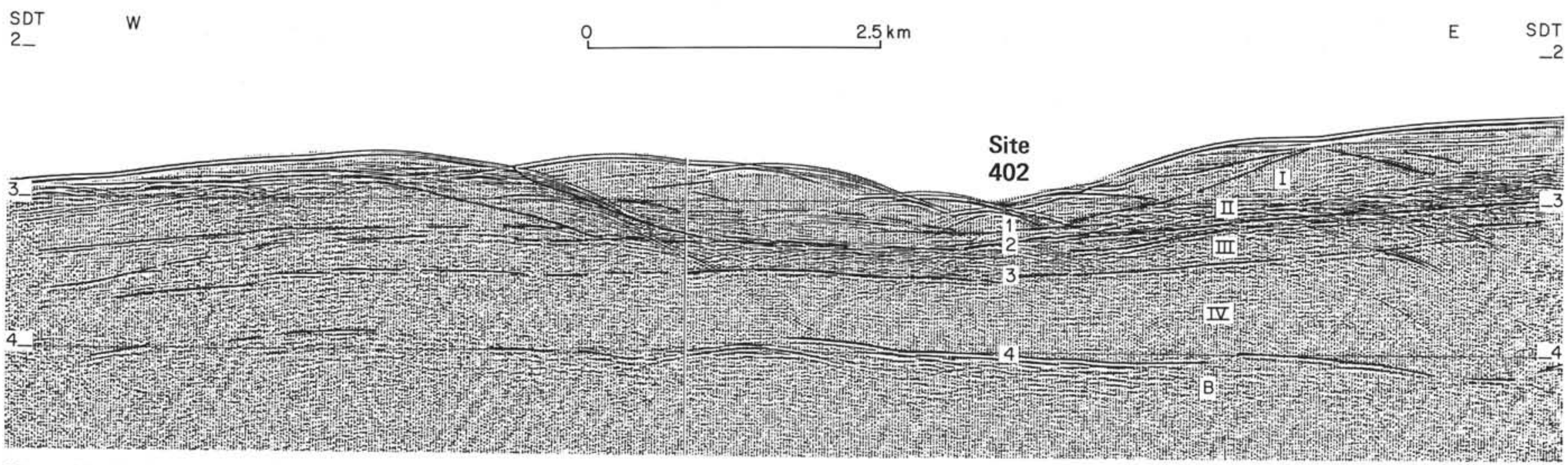

Figure 11. *High-resolution multichannel seismic profile IFP-CNEXO GEOM 402 through Holes 402/402A.*

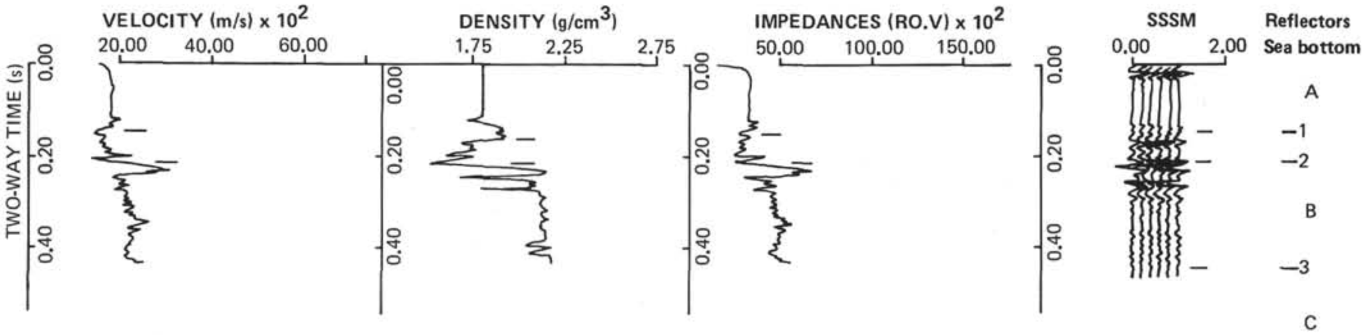

Figure 12. *Synthetic seismogram, Hole 402A.*

Aptian age. Densities are around 2.2 g/cm³ and velocities around 2.5 km/s.

In the basal part, at 443 meters, is a sharp increase in coring time, in density (2.3-2.4 g/cm³) and in velocity (3 km/s) that corresponds to the top of a limestone of upper-lower Aptian age. This change must create a reflection at about 0.450 meters below sea bottom, but it is not indicated on the seismogram, as logging could not be recorded to the bottom of the hole. This reflection probably corresponds to reflector 3 as defined above; i.e., the top of thick syn-rift seismic Unit C of Early Cretaceous age (Figure 14).

In conclusion, it is important to emphasize the value of generating synthetic seismograms from downhole logs in correlating drilling results with seismic reflections observed on both high-resolution and normal multichannel seismic profiles.

DOWNHOLE LOGGING

D. Mann

The following logs were run:

1) Borehole compensated sonic log/gamma-ray/caliper (BHCS/GR/CAL),

2) Induction 6FF40/electric log/short normal/SP (IES/SN/SP),

3) Compensated neutron/formation density/gamma-ray (CNL/FDC/GR).

No caliper log was recorded on the density/neutron run, and the curve displayed on the analog prints has been traced from the sonic run. It should be noted that the caliper jammed on one sonic run at just below 2550.0 meters.

The sonic log exhibits considerable cycle skipping especially over the interval 2520.0 to 2551.0 meters. The density/neutron curves also suffer from "wash-out" down to 2551.0 meters. Nonetheless, the relative deflections on the density-neutron curves provide valuable quantitative information in correlating with the core results. The SP proved characterless, suggesting that the mud filtrate and interstitial water have similar salinities.

All depths quoted refer either to depths marked on the logging runs using the density/neutron as the base log or to their equivalent sub-sea bottom depths.

In the discussion of the lithological units and sub-units, the geological and depth data have been taken from the DSDP Leg 48 Initial Core Description. Figure 14 is a composite of the main logging curves correlated against the cores and the generalized stratigraphy of the site.

The excellent correlation between the lithological units and logs is shown in Figure 15 wherein a double arrow has been used to indicate artificial depth discrepancies. Other logging breaks which may have lithological significance are also marked in the depth column.

Although the logs and physical properties data correlate reasonably well, cores and logs cannot be easily reconciled over the first 230.0 meters due to discontinuous coring.

Interpretation

Sub-Unit 1A (2358.0-2447.5 m [0-89.5 m])

The gamma-ray log, recorded through the drill pipe was the only log recorded over this interval and gave a sea-bed depth of 2358.0 meters. Within the sub-unit, two increases in gamma-ray intensity are present. From initial values of 10 API units, the gamma ray increases between 2384.3 and 2392.3 meters (26.3-34.3 m) and from 2421.3 to 2425.5 meters (63.3-67.5 m). Although there is no core over these intervals, the increased intensity may reflect higher clay mineral content.

Sub-Unit 1B (2447.5-2533.0 m [89.5-175.0 m])

Entry into the hole from the drill stem is recorded at 2463.0 meters (105.0 m) by the deflection of the gamma-ray log.

Between 2463.0 and 2507.0 meters (105.0-149.0 m), the section appears lithologically homogeneous and consists of siliceous marly nannofossil chalk and siliceous nannofossil chalk. Harder beds interbedded with more friable beds are inferred from the caliper log between 2501.0 and 2507.0 and may correspond to horizons rich in detrital components and pebbles (e.g., Hole 402A, Cores 1-3). Between 2507.0 and 2521.0 meters (149.0-163.0 m), the marly nannofossil chalks and siliceous nannofossil chalks are associated with more uniform log characteristics.

A significant change in lithification is shown by the logs at 2521.0 meters (168.0 m). This change does not correspond to the change from ooze to chalk which occurs between Cores 2 and 3 and is marked on the logs by a less abrupt change in hole size, bulk density, and porosity. The change observed at 163.0 meters may reflect increased silicification of the marly nannofossil chalks.

Unit 2 (2533.0-2590.0 m[175.0-232.0 m])

The base of the strongly lithified section of limestone and claystone comprising Unit 2 is shown on the logs at 2584.0

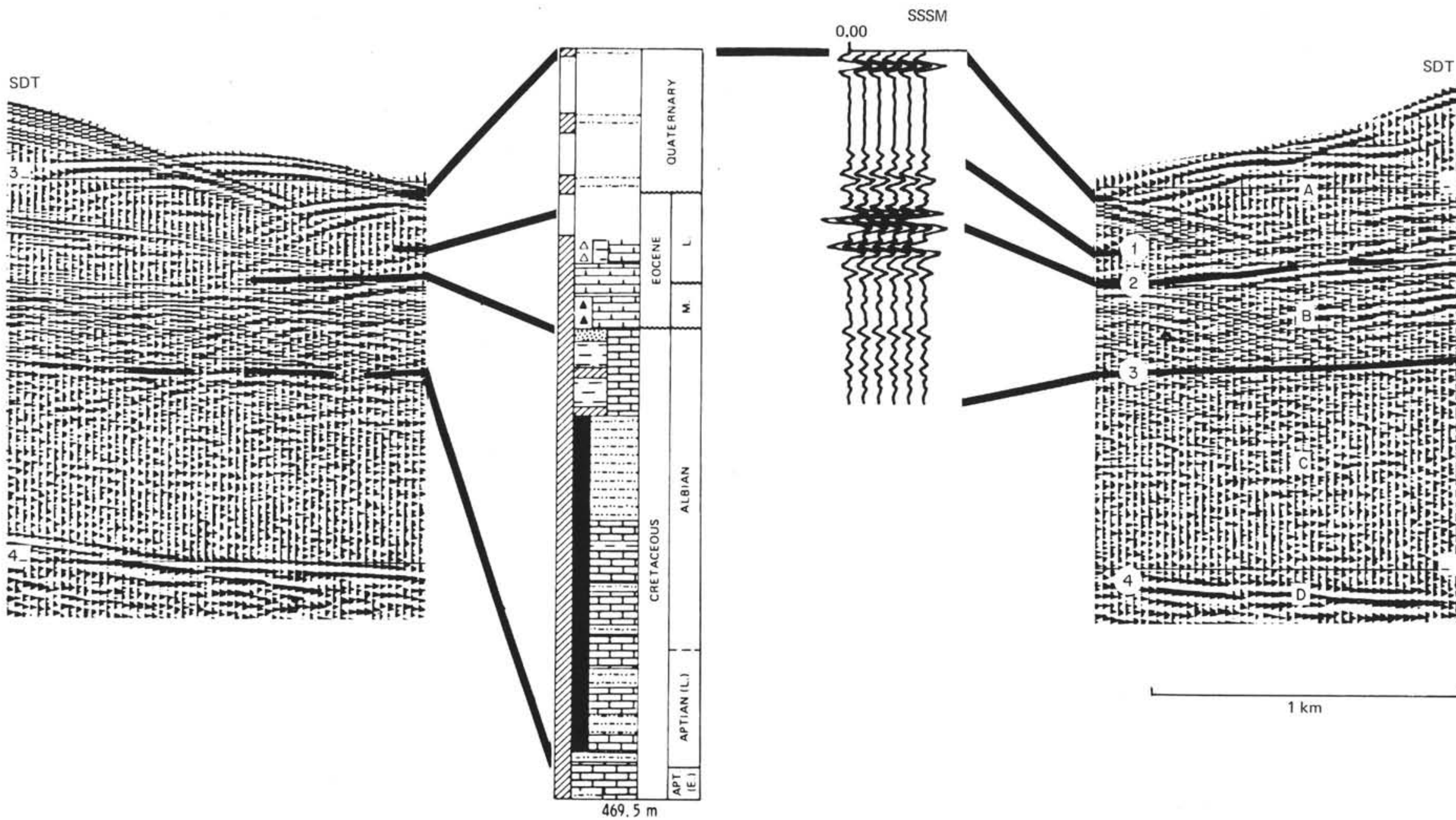

Figure 13. *Correlation of seismic reflectors on high-resolution seismic profile GM402 with synthetic seismogram and results of Holes 402/402A.*

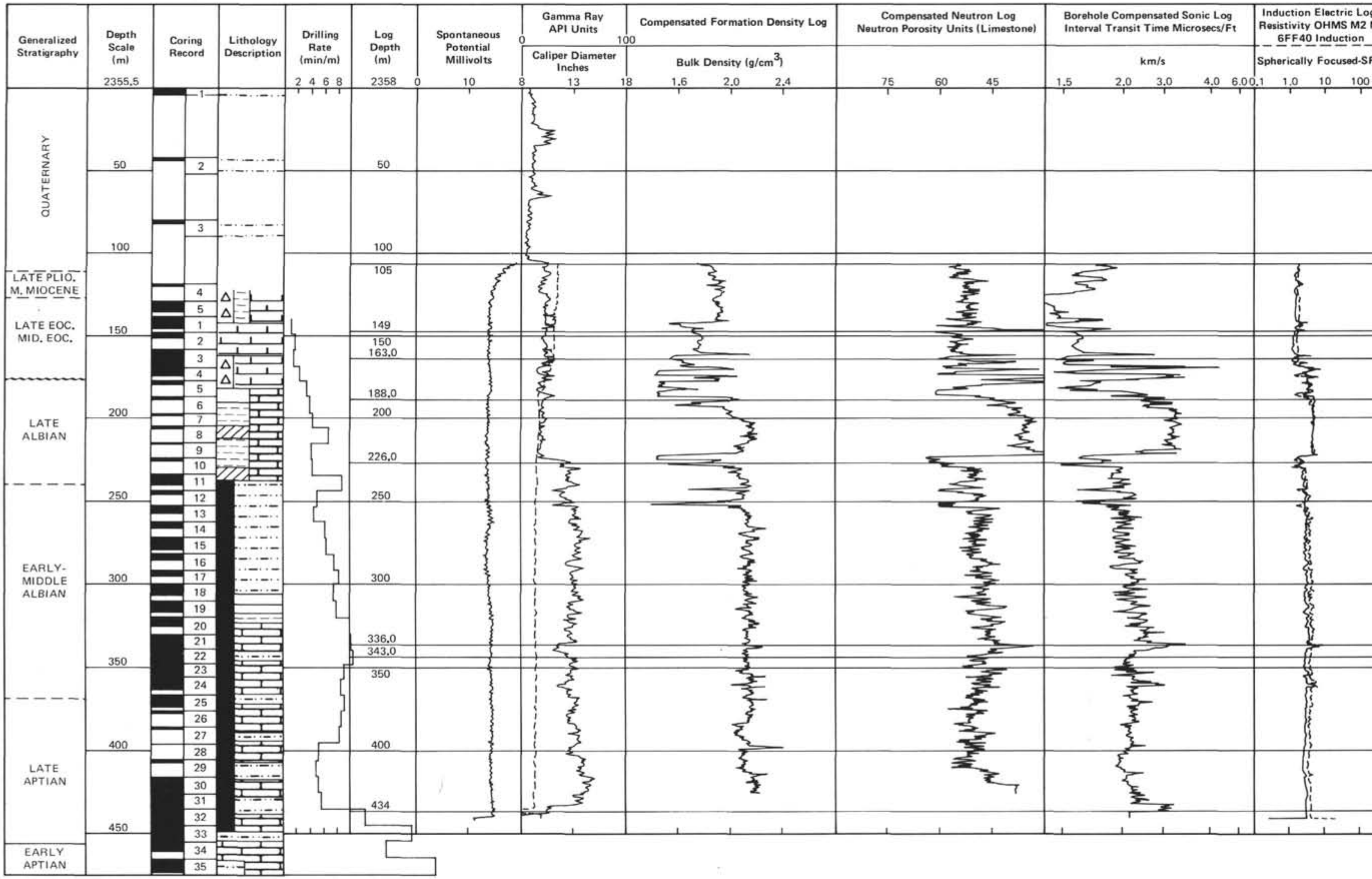

Figure 14. *Correlation of seismic reflectors, Hole 402A.*

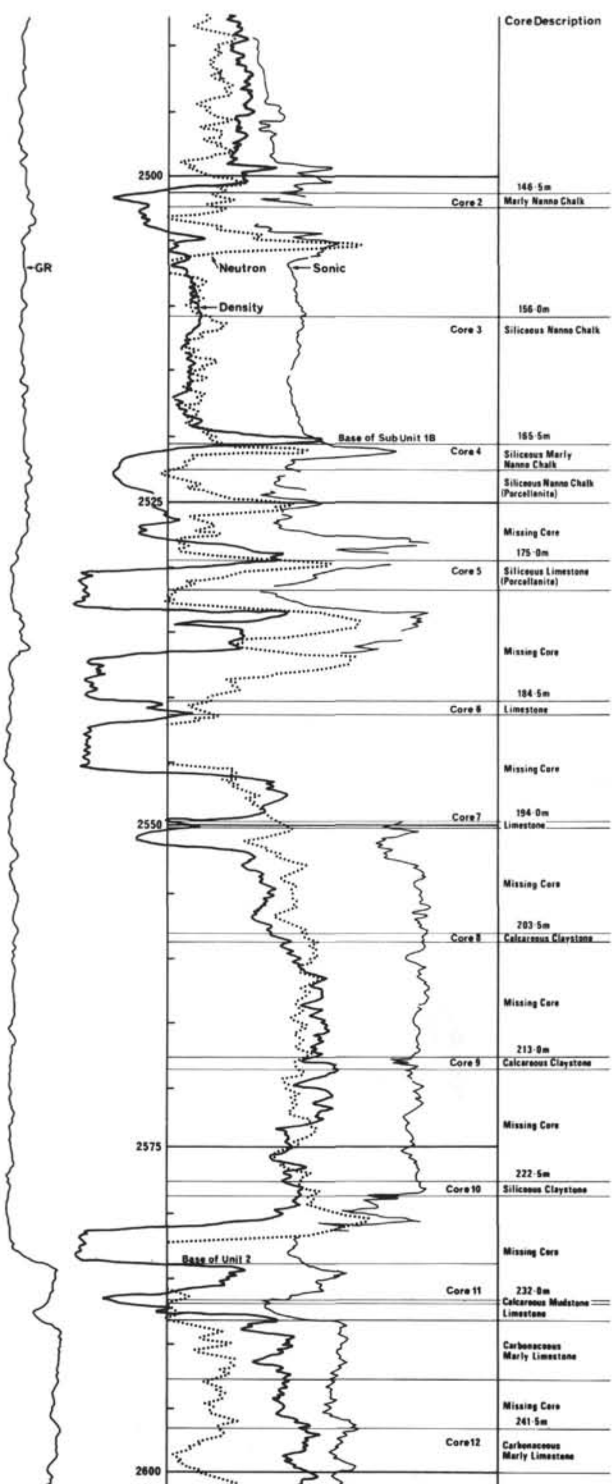

Figure 15. *Generalized stratigraphy of Holes 402/402A, well logs, and principal logging breaks.*

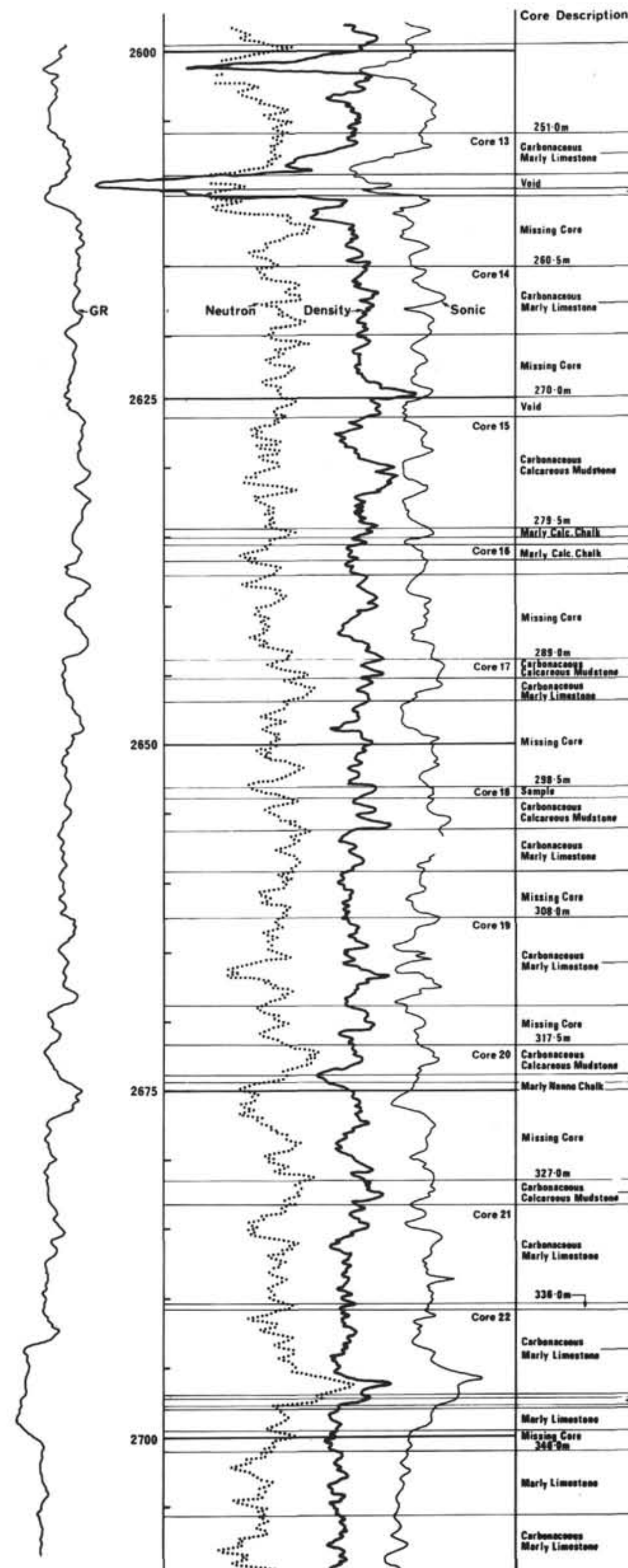

Figure 15. *(Continued).*

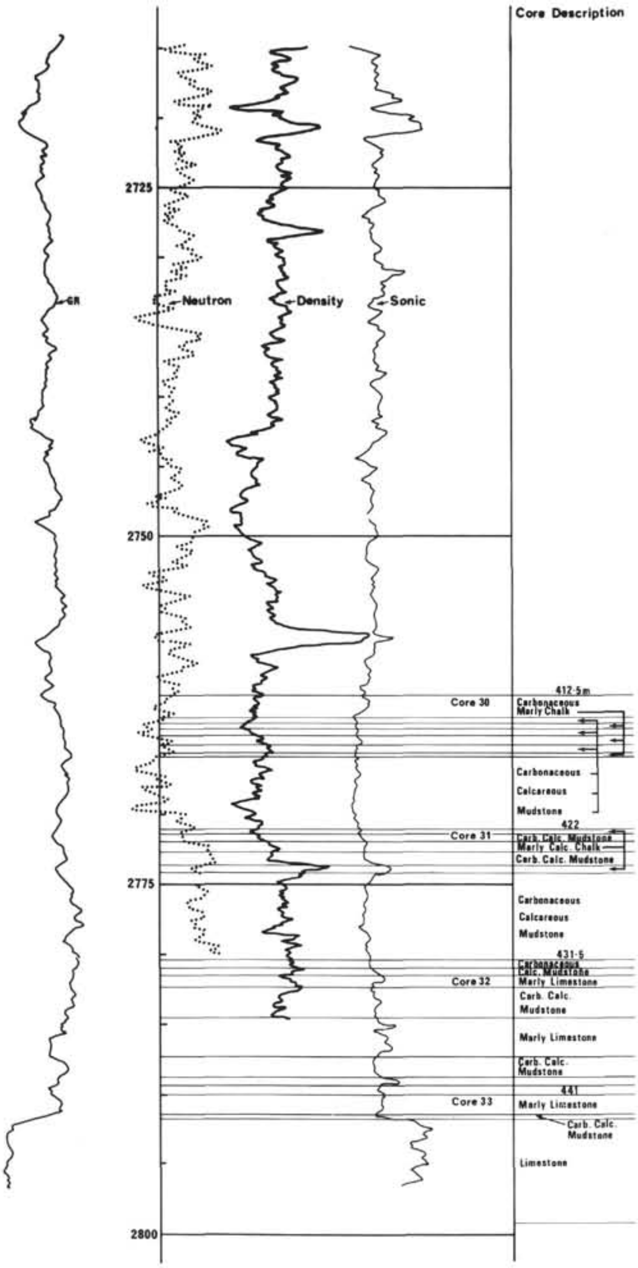

Figure 15. *(Continued).*

meters (226.0 m) and is defined by a sharp increase in gamma-ray intensity to nearly 50 API units. Two distinct subdivisions are present within Unit 2. Between 2521.0 and 2546.0 (163.0-188.0 m), the logs suggest an interbedded sequence in which tight limestone interbeds are separated by more porous friable beds. The whole of this section is washed out. The more porous material appears to have been preferentially washed out, leaving the harder layers unsupported and tending to break off in fragments. In support of this interpretation, the caliper log shows excursions close to hole size that occur exactly opposite the harder interbeds. Between 2536.0 and 2546.0 meters (178.0-188.0 m), the intense cycle skipping shown on the sonic log suggests that the zone is fractured, although the poor hole conditions reduce the reliability of this conclusion. The break at 2546.0 meters is also shown on the caliper log as a sharp reduction in hole size.

Between 2546.0 and 2584.0 meters (188.0-226.0 m) the uniformity of the logs suggests a more homogeneous lithology which consists predominantly of calcareous claystone and siliceous claystone. Although the section is washed out towards the base, the change from this lithology to the underlying carbonaceous marly limestone of Sub-unit 3A is clearly marked by a sharp increase in the gamma-ray log from 18 to 46 API units. The log suggests a probable hard stringer between 2549.0 and 2552.0 meters (191-194.0 m) which may correlate with the hard limestone recovered in Core 7.

Figure 14 shows the correlation between cores and logs. In the section of poor core recovery (Cores 8-11), few physical properties measurements were made and the strongest support for the correlation is given by the exact match between gamma-ray curve and the break between the limestone and carbonaceous limestone in Core 11. The correlation between cores and logs at greater depths is consistent with this best fit.

Sub-Unit 3A (2590.0-2638.0 m [232.0-254.0 m])

The top of this sub-unit is defined by the gamma log break at 2584.0 (226.0 m). The base of the unit at 254.0 meters is defined by an increase in the gamma log from an average of 40 API units to in excess of 50 API units. The sub-unit consists principally of carbonaceous marly limestone. Although clay mineral content lies in a similar range to the overlying unit, excursions in the gamma-ray curve indicate substantial variations are present. For example, three distinct limestone breaks at 2587.0 meters (229.0 m), 2601.0 meters (243.0 m), and 2610.0 meters (252.0 m) are each accompanied by a dip in the gamma-ray curve. Density/neutron curves in this interval are characterized by wider separation of the density and neutron readings indicating an increase in the bound water content.

Sub-Unit 3B (2614.0-2766.0 m [254.0-419.0 m])

The sub-unit consists of interbedded calcareous mudstone, carbonaceous marly mudstone, carbonaceous marly limestone, and marly calcareous chalk. In the interval from 2694.0 to 2701.0 meters (336.0-343.0 m) there is a considerable drop in the gamma ray indicating increasing carbonate at the expense of clay. There is some evidence of a minor logging break on the density log where the density decreases from a median value of 2.15 g/cm^3 to lower values. However, this pick does not conform with the core log correlation given above and below this depth.

Below 2742.0 meters, the sonic log only records the deepest log data as the other logs were unable to reach TD due to infill or bridging. Discrepancies are apparent in the gamma-ray log recorded in the density/neutron, sonic, and induction logging runs, and the density/neutron/gamma-ray log is considered unreliable below 2760.0 meters (402.0 m).

Both sonic and gamma-ray curves show a sharp change in lithology at 2791.5 meters (433.5 m) which corresponds to the relatively pure Aptian limestone recovered in Core 33 (441.0 m) (Figure 14) and the drilling break recorded at the same depth.

Crossplots

A detailed description of the construction and use of crossplots in well log analysis was given in the Site 401 Report and will not be repeated here.

The crossplots have been divided into convenient depth zones based on their logging characteristics and a final composite prepared for all zones to illustrate the general variation within the well.

Density Versus Sonic "Z" Plot (gamma-ray relative intensity superimposed)

These plots show the greater reliability of discrimination of the sonic log especially where the borehole is caved; the hole is badly washed out to a depth of 2584.0 meters (226.0 m).

The plot of Figure 16 includes Units 1B and 2 from 2463.0 to 2483.0 meters (105.0-125.0 m).

The plot of Figure 17 includes the depth range 2523.0 to 2546.0 meters (165.0-188.0 m). The plot shows the considerable scatter of points due to poor borehole conditions. The plot has been shown to conveniently identify the source of the scattered values on the composite plot shown in Figure 15.

The plot of Figure 18 includes the depth range 2546.0 to 2583.0 meters (188.0-225.0 m). The numeral 1 indicates the onset of the lithified sequence before a more consistent set of values is obtained. The numeral 2 identifies the more consistent set of values associated with the calcareous claystone sequence from this depth range. The washed out zone is identified by the numeral 3 and the higher gamma-ray readings towards the base of the Unit 2 by the numeral 4.

The plot of Figure 19 covers the depth range 2583.0 to 2621.0 meters (225.0-263.0 m).

The crossplot of Figure 20 covers the depth range 2621.0 to 2777.0 meters (263.0-419 m) and shows the downward continuation of the carbonaceous calcareous mudstone facies.

Figure 21 includes the entire depth range from 2463.0 to 2777.0 meters (105.0-419.0 m) and is a composite of Figures 16 to 20 that shows the groupings of the main lithologies encountered downhole. The highest relative gamma-ray readings (10) relate to values at 2777.0 meters. The limestone bed at 2757.0 meters is shown by points that plot on the density scale around 2.3 to 2.4 g/cm³ and gamma-ray values of 4 and 5.

Density Versus Neutron "Z" Plot (gamma-ray relative intensity superimposed)

The plot shown in Figure 22 is a composite of all zones between 2463.0 and 2777.0 meters (105.0-419.0 m) and includes the principal lithologies and their depths (cf. Figure 21).

Density Versus R_t (induction) Plot (gamma-ray relative intensity superimposed)

The plot shown in Figure 23 is a composite of all zones between 2463.0 and 2777.0 meters (105.0-419.0 m), although the resolution is less due to the limited range of the induction log. The plot emphasizes the value of cross plotting techniques even with a restricted logging suite.

Due to poor hole conditions, points on the lithoporosity "Z" plot exhibited severe scatter and no reliable interpretation could be made.

Conclusions

1) The caliper curve was unreliable over much of the hole and this added to the difficulty of matching core to log depths.

2) No meaningful information could be derived from the SP log.

3) All logs confirm the interbedded nature of the carbonaceous limestones below 2584.0 meters.

4) The sonic versus density crossplot proved to be the most discriminating of the crossplots.

5) Due to infill or bridging, the logs were unable to reach terminal depth. To maximize the logging data, the logs should be recorded while being run downhole in addition to uphole runs.

SEDIMENTATION RATES

Because Site 402 is located in a canyon cutting a spur directly linked with the continental shelf, sedimentation rates for the Quaternary and Miocene/Pliocene are not representative; seismic profiles at the site show intense scouring and infilling during this period. Thus, the Pleistocene sequence (NN 19 to NN 21) of 90 meters recovered from Site 402 represents infilling of the canyon.

In the core taken during washing (an interval of 28.5 m after Core 3), an undisturbed section of lower Pliocene underlain by middle Miocene (NN 5 to NN 7) was recovered. A hiatus, which includes the upper Miocene and a part of the middle Miocene, can be assumed; it has been observed also in cores taken in Hole 402A. Because it is known that on the Armorican margin the canyons were active from late Miocene to early Pliocene, it is probable that this hiatus is due to erosion processes in the canyon.

Upper Eocene sediments (NP 19/NP 20 to P.16/P.17) were recovered in Core 4 (118.0 to 127.5 m), thus, in addition to the lower Pliocene/middle Miocene hiatus, there is a hiatus also between the middle Miocene and the upper Eocene in this short washed interval.

The sedimentation rate for the upper Eocene sequence reaches 12 m/m.y. A major hiatus of about 58 m.y. lies between the upper Eocene (NP 17 to P.16/P.17) and the Lower Cretaceous (Albian). The Aptian/Albian boundary lies within the foraminiferal Zone MCi 23, probably between Core 24 and Core 26, the determination being based on foraminifers, pollen, and spores.

SUMMARY AND CONCLUSIONS

Holes 402/402A were drilled in a canyon on the upper slope of the northern continental margin of the Bay of Biscay in 2339.5 meters depth and bottomed at 469.5 meters below sea bottom, in lower Aptian limestones.

Multichannel seismic surveys made before and after the leg by IFP-CNEXO and CEPM shows a series of tilted and rotated fault blocks downthrown to the south beneath the margin. The profiles show an acoustic basement surface below which rare reflectors are interpreted as pre-rift Mesozoic platform carbonates (Figures 2, 24). The acoustic

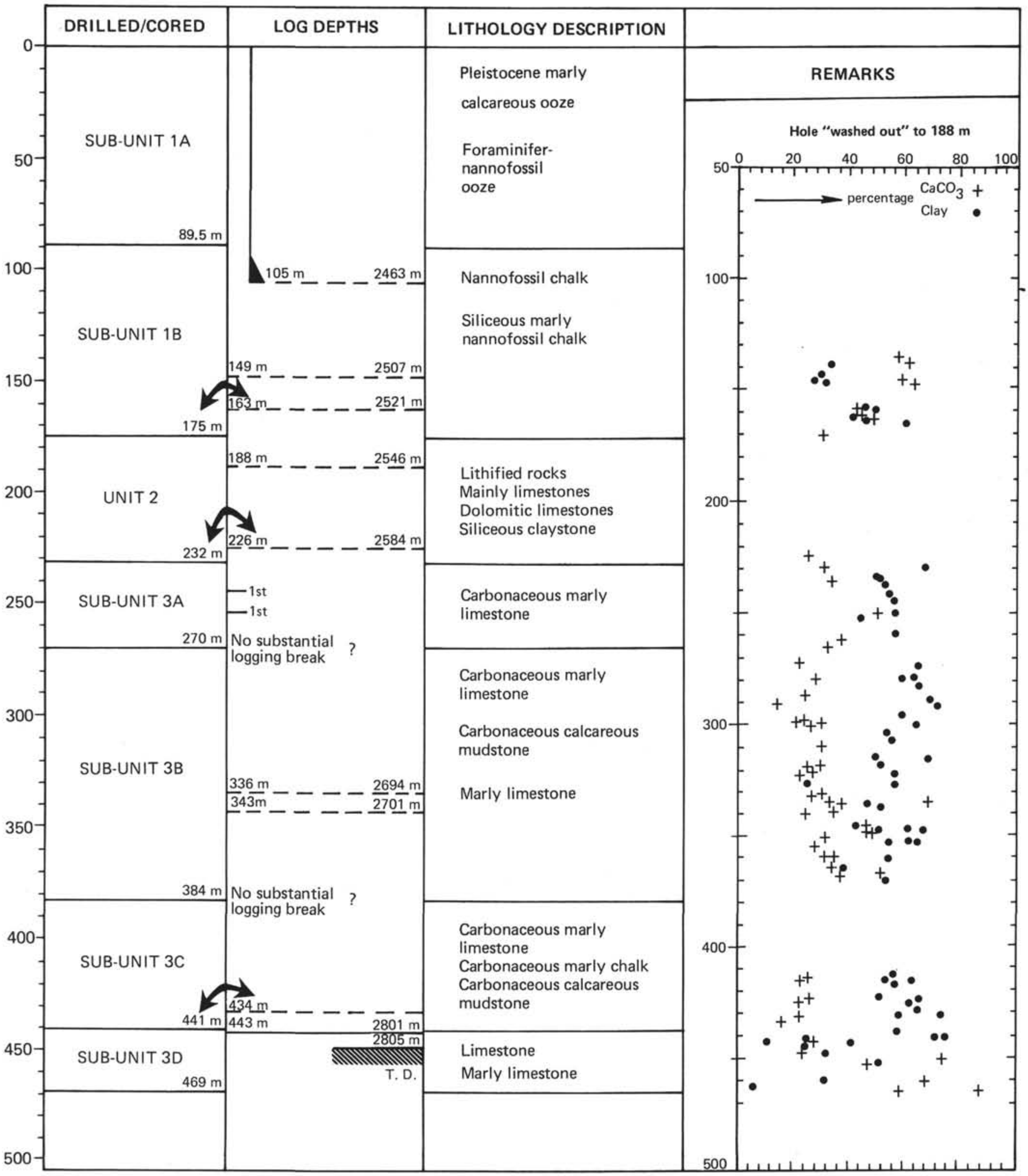

Figure 16. *Correlation of lithologic units and logging breaks, Holes 402/402A.*

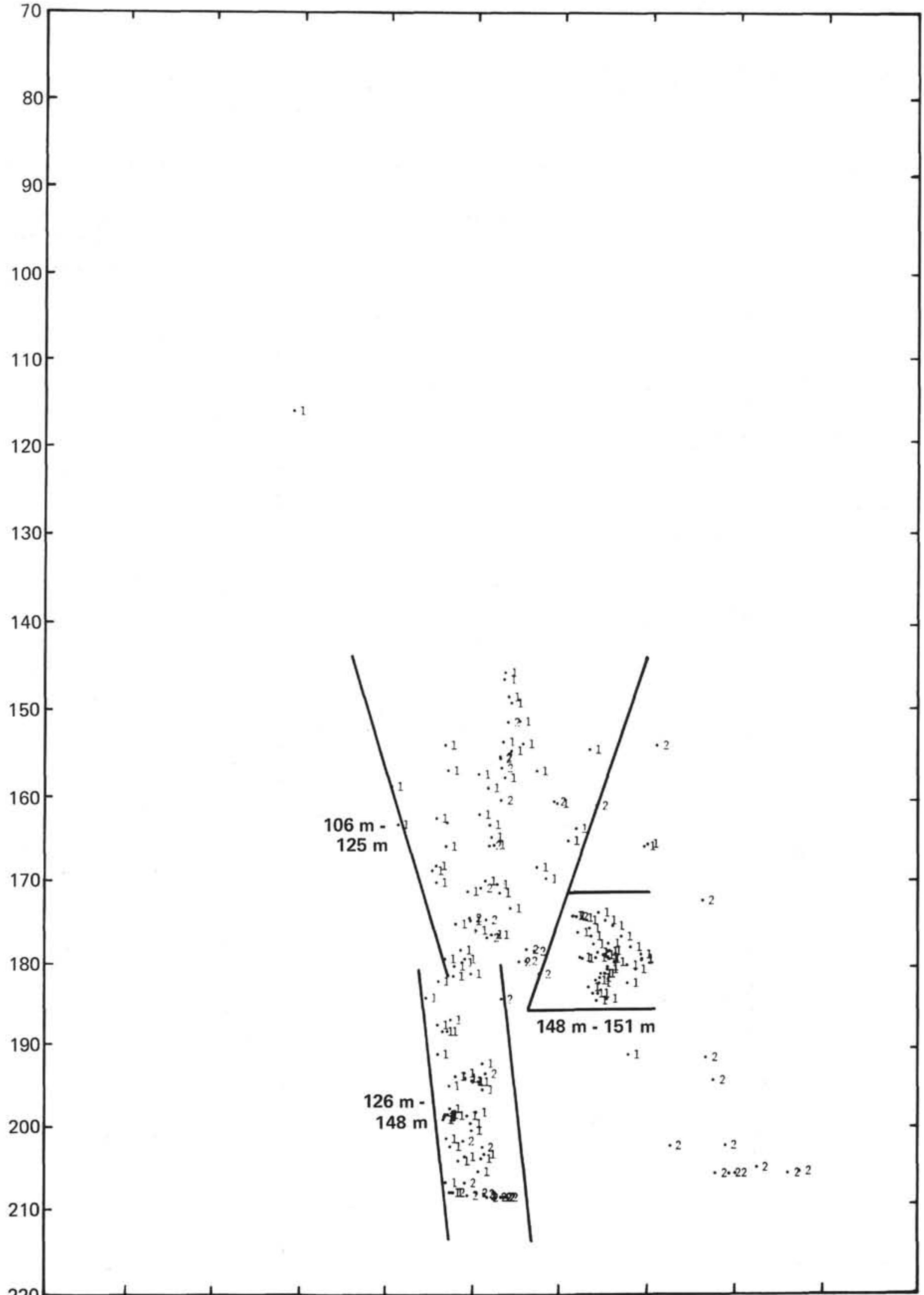

Figure 17. *Density versus sonic "Z" plot–gamma-ray relative intensity superimposed, Units 1B and 2 (2463.0 to 2483.0 m, 105.0 to 125.0 m).*

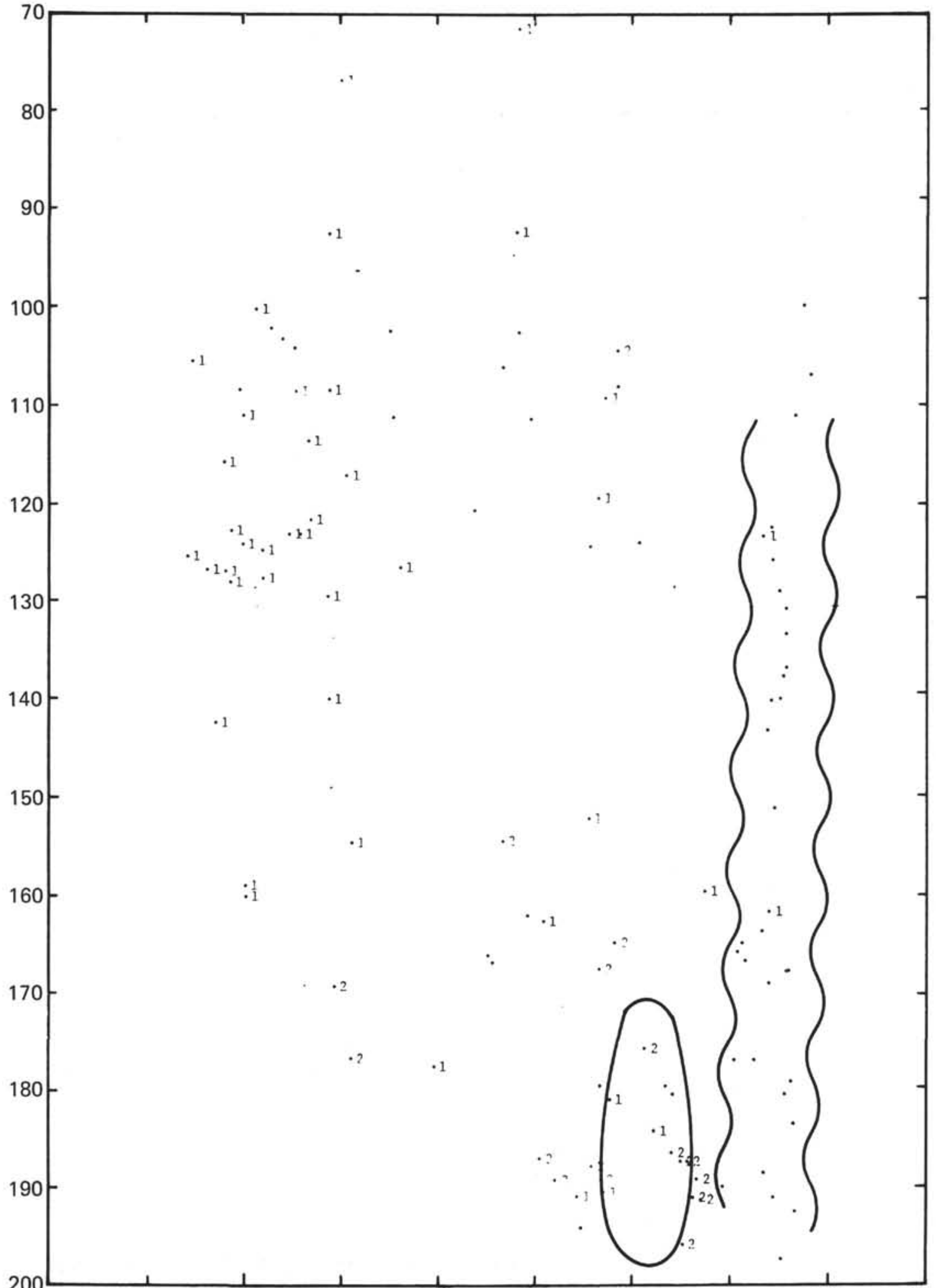

Figure 18. *Density versus sonic "Z" plot–gamma-ray relative intensity superimposed (2533.0 to 2546.0 m, 165.0 to 188.0 m).*

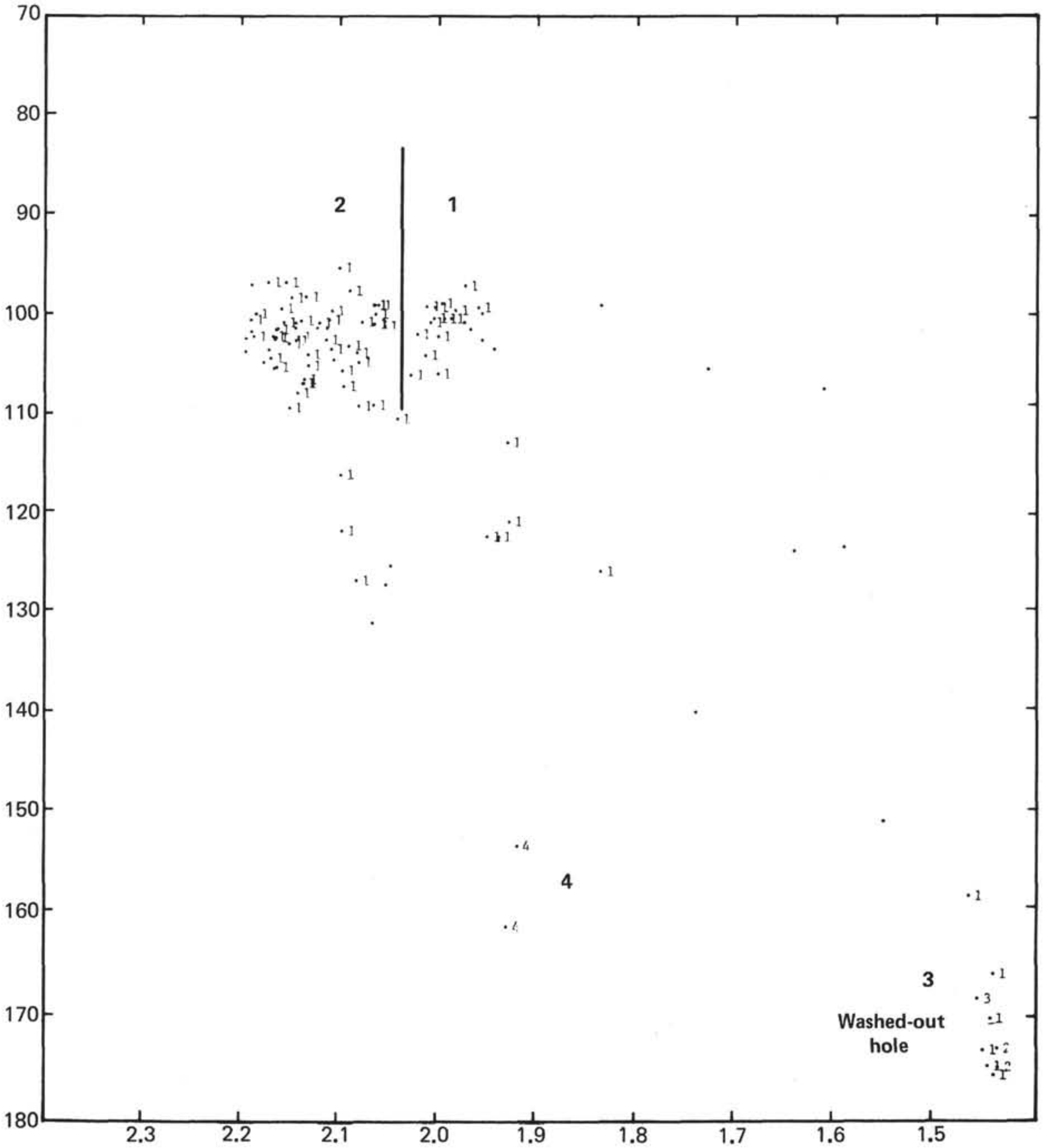

Figure 19. *Density versus sonic "Z" plot–gamma-ray relative intensity superimposed (2546.0 to 2583.0 m, 188.0 to 225.0 m).*

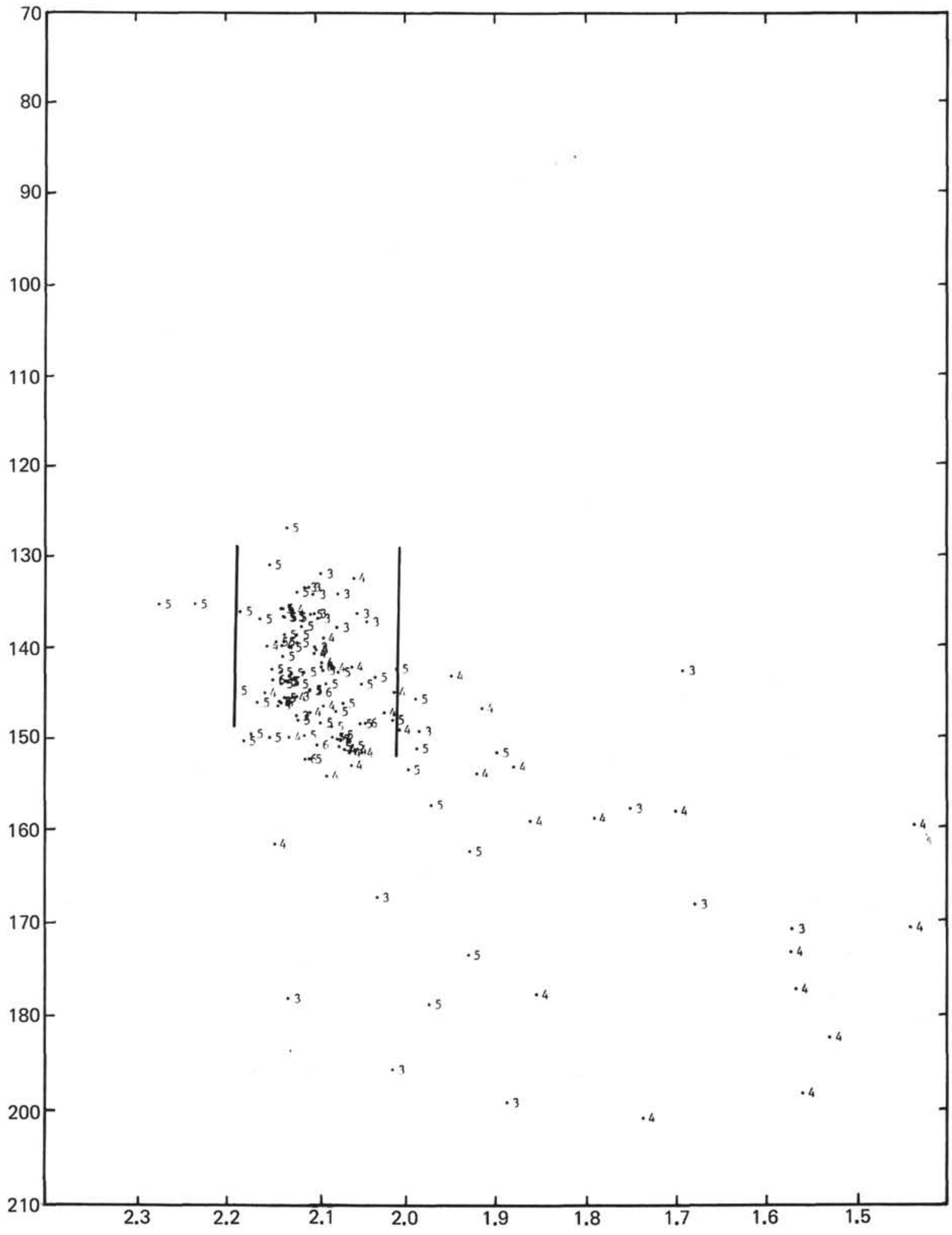

Figure 20. *Density versus sonic "Z" plot–gamma-ray relative intensity superimposed (2583.0 to 2621.0 m, 225.0 to 263.0 m).*

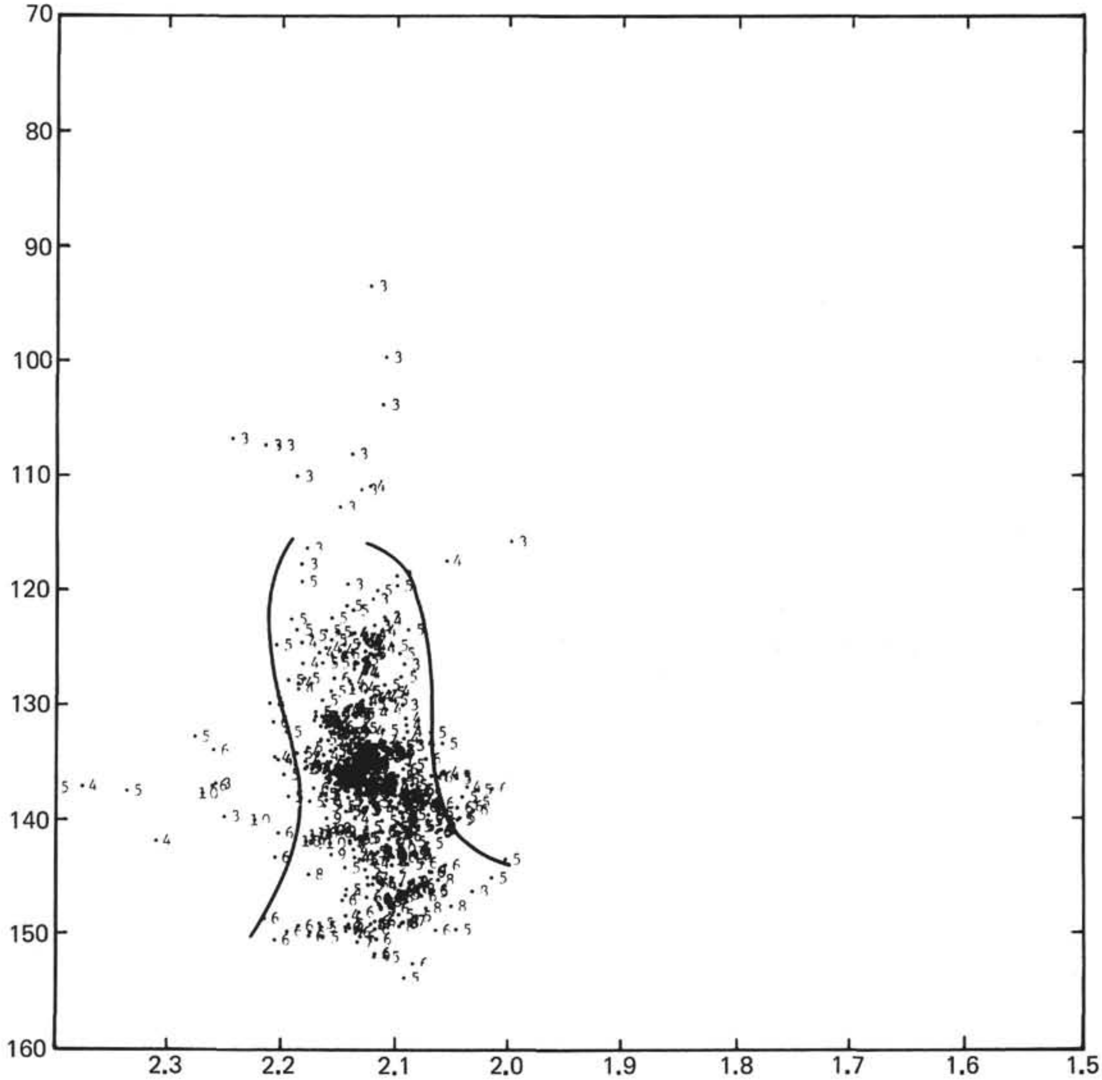

Figure 21. *Density versus sonic "Z" plot–gamma-ray relative intensity superimposed (2621.0 to 2777.0 m, 263.0 to 419.0 m.)*

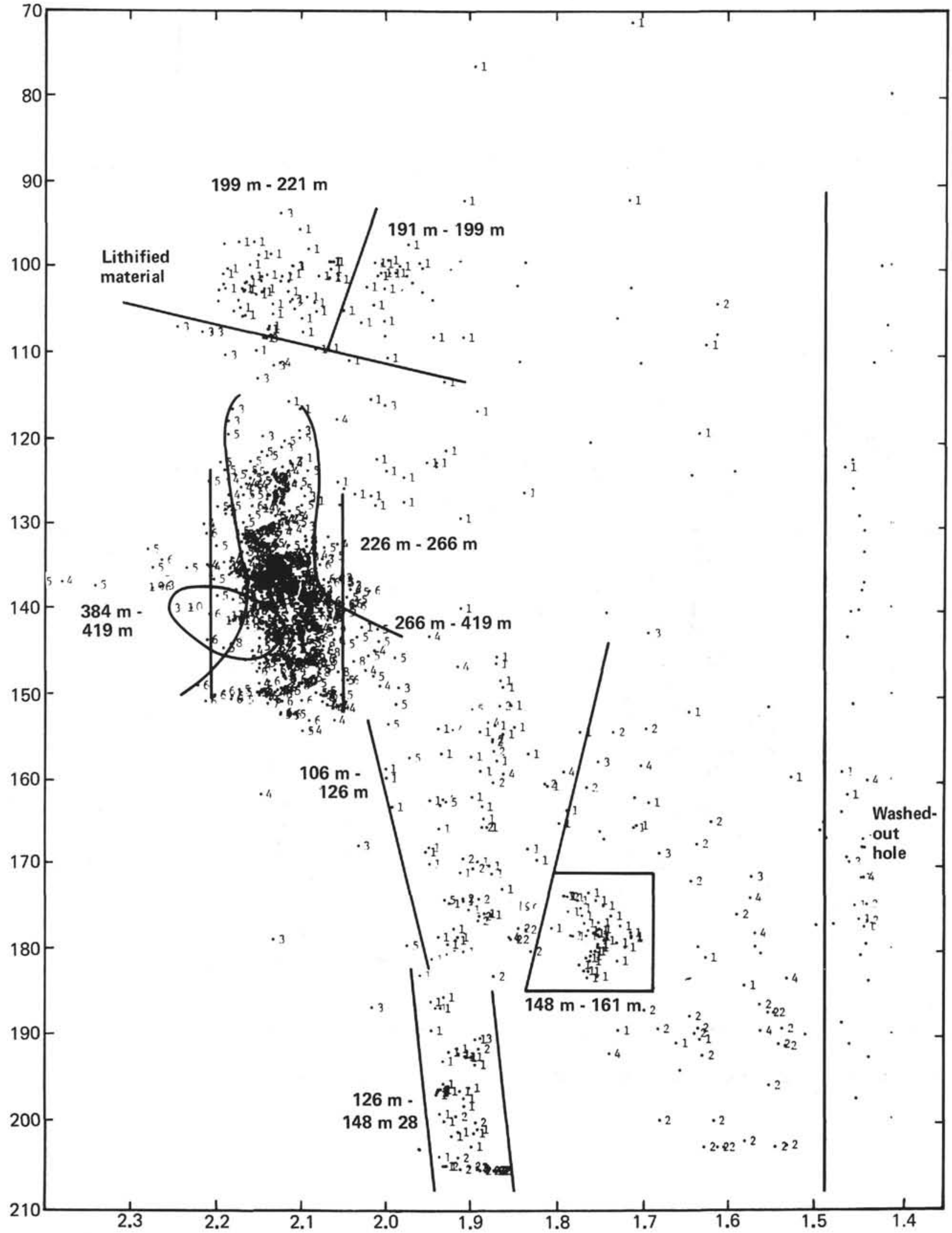

Figure 22. *Composite density versus sonic "Z" plot–gamma-ray relative intensity for the interval 2463.0 to 2777.0 meters (105.0 to 419.0 m).*

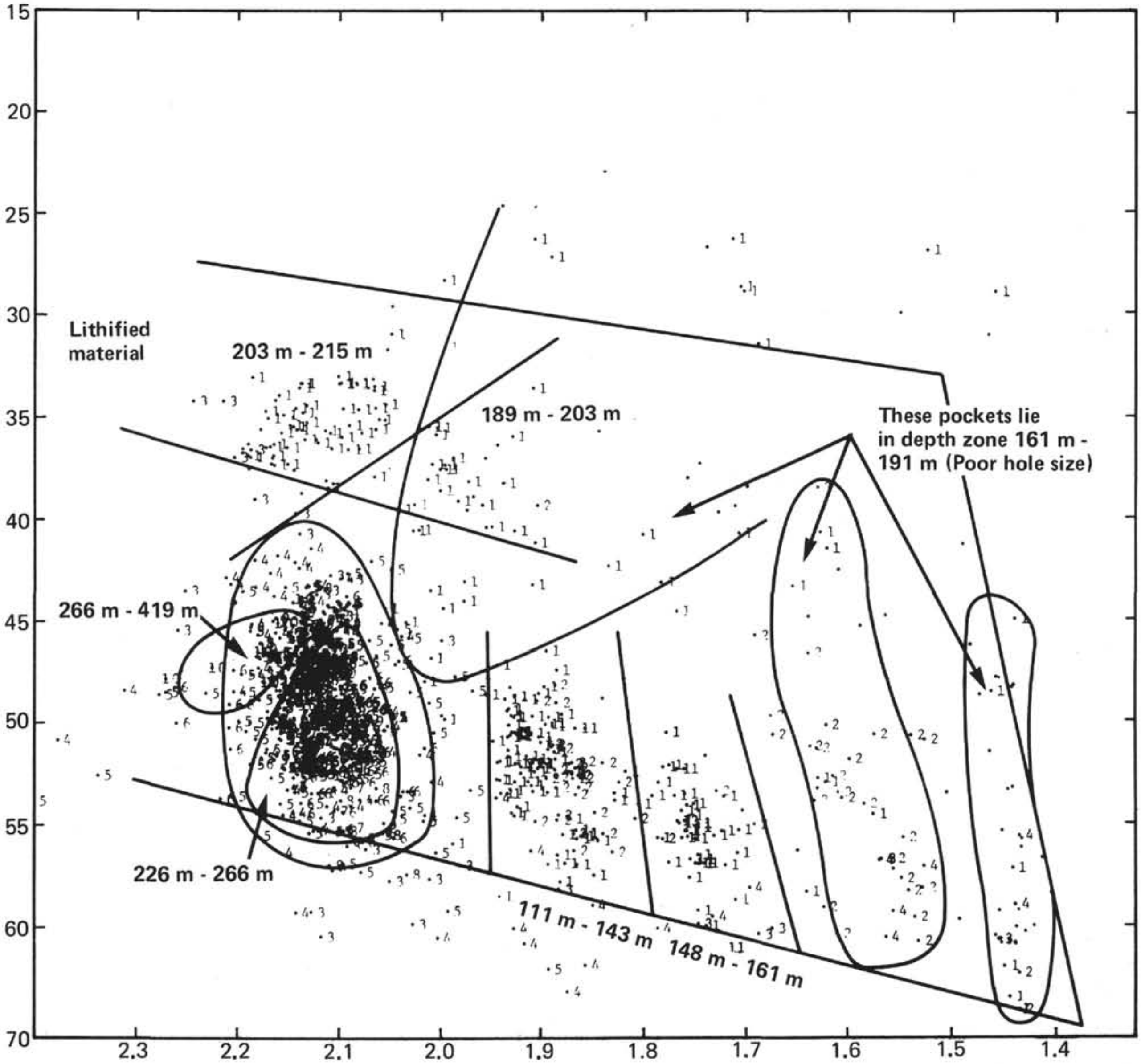

Figure 23. *Composite density versus neutron "Z" plot–gamma-ray relative intensity superimposed for the interval 2463.0 to 2777.0 meters (105.0 to 419.0 m).*

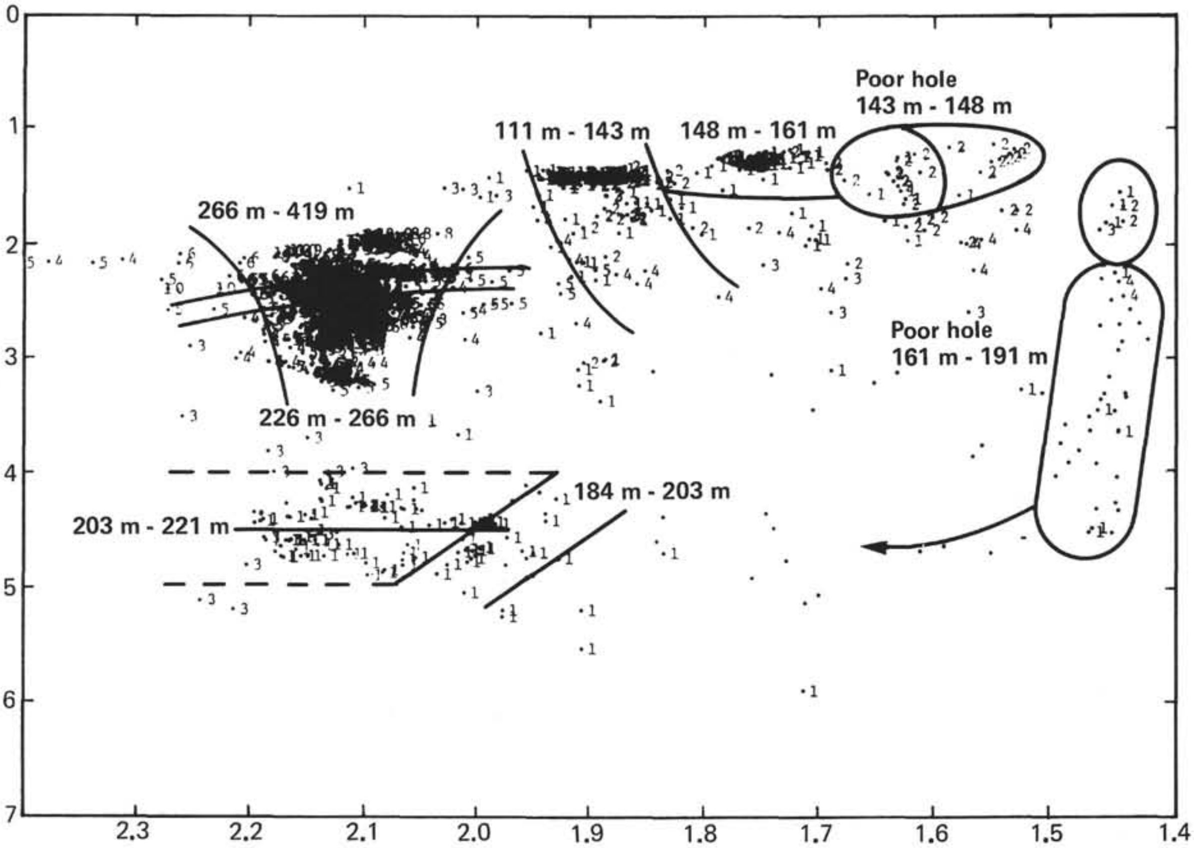

Figure 24. *Composite density versus R_t (induction) plot – gamma-ray relative intensity superimposed for the interval 2463.0 to 2777.0 meters (105.0 to 419.0 m).*

basement is overlain by a thick sequence of sediments deposited contemporaneously with tilting of the block. These sediments reach 1500 meters thickness at the axis of the half-graben, are 700 to 800 meters beneath Hole 402A, but pinch out completely on the crest of the fault block to the south.

The syn-rift sediments are separated from the overlying sequence by reflector 3. The overlying sequence thins upslope and oblique internal reflectors suggest progradation (Figure 11). Displacement of the base of the unit, but not its top, by several small faults suggests that normal faulting related to rifting terminated in Aptian time. The highly lithified top Albian (reflector 2) is directly overlain by Eocene beds. The unconsolidated Cenozoic sediments have been affected by intense erosion resulting in cutting and infilling of submarine canyons. The sedimentary section penetrated at the site has been divided into three units based on major breaks in the lithology, physical properties data and the downhole logs.

Unit 1 (0-175 m, Cores 1-5 in Hole 402, Cores 1-4 in Hole 402A) consists mainly of calcareous mud, marly foraminifer nannofossil ooze and foraminifer nannofossil ooze. Two sub-units have been recognized on the basis of abundant biogenic siliceous components and a decrease of detrital material in the lower part of the unit.

Sub-unit 1A (0-89.5 m) consists of olive-gray calcareous mud or foraminifer nannofossil ooze of Pleistocene age in which carbonate contents range from 24 to 65 per cent and average 33 per cent. Quartz content is 40 per cent and the clay minerals consist of kaolinite (15%), illite (40%), mixed layer clays (0-30%), smectite (0-40%), and chlorite (15%) (Blanc et al., Debrabant et al., both, this volume). Variations in the planktonic foraminiferal assemblages indicate fluctuating ocean surface water masses in response to glacial and interglacial conditions. Intercalated pure coarse foraminiferal sands that contain, among the normal bathyal benthic foraminifers, shelf-edge species and reworked Cretaceous nannofossils. This may indicate erosion at the shelf edge during low sea level stances and downslope sediment movement.

Sub-unit 1B (89.5-175 m) was not cored over the interval 89.5 to 118 meters, but the nannofossil ooze of the washed core recovered after drilling this interval was of early Pliocene and middle Miocene age, with a distinct hiatus between them. This suggests that an incomplete or extremely condensed Neogene section overlies the siliceous nannofossil ooze of late to late middle Eocene age recovered below 118 meters. The development of the condensed Neogene sequence may be related either to the formation of the canyons or to widespread erosional events resulting from circulation changes recorded at the other sites. The principal lithology of the late to middle Eocene section is siliceous nannofossil chalk characterized by a decrease in carbonate content from 70 per cent to 50 per cent at the base. The clay mineral suite consists of illite (0-15%), mixed layer clays (0-30%), and smectite (85%). Nannofossils comprise as much as 80 per cent of the interbedded nannofossil chalks. The coarse fraction is rich in siliceous biogenic components such as sponge spicules, diatoms, and radiolarians. Sedimentary structures include slight to moderate bioturbation and rare thin bands rich in quartz. Sandstone and chert pebbles occur sporadically as well as pebbles of shallow water Albian limestones. Well-preserved planktonic foraminifers and nannofossils of high diversity are abundant. Rare benthic foraminifers indicate bathyal conditions although contaminated by displaced shelf-edge species. Significantly, the nannoflora suggest a nearshore environment. The evidence of erosion and nearby land may reflect global regression perhaps accentuated locally by the Eocene compression well known in western Europe and evidenced on the Biscay margin (Montadert et al., this volume). The sedimentation rate was 12 m/m.y. (Figure 25, in back pocket of this volume). The base of the unit is defined by a hiatus of at least 55 m.y. between the Albian and middle Eocene.

Unit 2 (175-232 m, Cores 5-10) in marked contrast to Unit 1, consists of extremely lithified limestones exhibiting sound velocities up to 3 km/s. Three facies types have been recognized from thin section study. At the top is a bioclastic limestone with abundant echinoderm remains and some algae fragments. Below, the most common facies consists of limestones containing abundant sponge spicules and rare algae *(Lithothamnium)*. A third facies found only in a short interval of Core 6, Section 1, is a micritic limestone with *Pithonella ovalis* and calcisphaeres. All these facies are well known in the Albian in southwest France (Aquitaine). They indicate deposition in an outer-shelf environment in probable late Albian time.

Unit 3 (233-469.5 m, Cores 11-35) consists of carbonaceous marly limestone, carbonaceous calcareous mudstone, and carbonaceous marly calcareous chalk. Division into sub-units is based on changes in carbonate and terrigenous components as well as on the character of sedimentary structures. Principal lithologic and paleontologic variations are summarized in Figure 26.

Sub-unit 3A (232.0-254.0 m, Cores 11-13) consists of olive-gray to olive-black carbonaceous marly limestone with an average carbonate content of 40 per cent. Several hardgrounds with depressions infilled with glauconite occur in Core 11, Section 3. The quartz content ranges from 5 to 15 per cent and the clay fraction is dominated by smectite (30-70%) with subordinate kaolinite and illite. Clinoptilolite ranges from 15 to 40 per cent. Siliceous sponge spicules range up to 10 per cent. A middle Albian age is indicated by benthic foraminifers in the absence of planktonic foraminifers. The nannoflora is distinguished by the occurrence of common nannoconids but rare coccoliths. Fragments of pelecypods are also present. Some graded bedding is visible although it is intensely bioturbated. Organic carbon, of terrestrial origin, averages 1 per cent.

Sub-unit 3B (254.0-419.0 m, Cores 14-29) is composed of carbonaceous calcareous mudstone, carbonaceous marly limestone, and olive-gray marly calcareous chalk. In the abundant clay fraction, smectite is dominant (20-70%), kaolinite and illite constitute about 25 per cent with rare chlorite. Clinoptilolite and opal-CT, respectively, average 5 to 10 per cent and 5 to 30 per cent. Cores 11 to 25 contain few small encrusted benthic foraminifers; planktonics are rare or absent. Benthic foraminifers indicate a middle to lower Albian age. The Albian/Aptian boundary occurs below Core 25 according to ammonites (Renz, this volume). Below, planktonic foraminifers reappear and agglutinated foraminifers are present. Nannoconids occur throughout the sub-unit with variable abundance, whereas coccoliths increase in abundance from top to bottom (from Core 20 downwards).

This sub-unit, originally defined on board, was subsequently divided into two parts (de Graciansky et al., this volume) based on more detailed determinations of $CaCO_3$, quartz, and organic carbon contents and sedimentary structures (Figure 26). The boundary lies between Cores 22 and 23. It corresponds to the boundary between two cycles, B1 and B2, with increase of $CaCO_3$ from bottom to top (from 20-30% to 50-70%), and simultaneous decrease of terrigeneous content (quartz from 25% to less than 10%, organic carbon from 2% to 0.5-1%). The top cycle is composed mainly of bioturbated, graded sequences severely contorted by slumping. The lower part is more regularly stratified and comprises also graded bedded sequences. Ammonites, *Inoceramus,* and sponge spicules are common.

Sub-unit 3C (419.0-441.0 m, Cores 30-32) consists of interbedded olive-gray carbonaceous marly calcareous chalk and brownish black carbonaceous calcareous mudstone. Compared to Sub-unit 3B, organic carbon (2-3%) is higher and carbonate content lower (10-20%). The clay mineral suite is the same as in Sub-unit 3B, but zeolite and opal-CT are absent. Burrowing is intense. Coccoliths are abundant; nannoconids are of variable abundance. Planktonic foraminifers reappear, and indicate a late Aptian age; primitive agglutinates are common. Fish debris, ammonites, and *Inoceramus* are present. Diagenetic siderite is widespread in the coarser layers. From a sedimentological point of view, this sub-unit must be considered as the base of the lower cycle B2.

Sub-unit 3D (441.0-469.5 m, Cores 33-35) consists mainly of greenish gray marly limestone characterized by a high carbonate content of 60 to 80 per cent; the limestones may be the cause of reflector 3. There is a concomitant decrease in quartz and clay minerals. Organic carbon content is low (0.5%) compared to Sub-unit 3C. Burrowing is intense. Planktonic foraminifers are small but abundant and indicate an early Aptian age. Primitive agglutinates and benthic foraminifers are frequent and the nannoflora is composed mainly of abundant large nannoconids and coccoliths of variable abundance. Deposition of the whole Aptian sequence took place in an outer-shelf environment.

Depositional History

The oldest sediments at Site 402 comprise the acoustic basement below reflector 4 and are interpreted as Jurassic (?) platform carbonates deposited prior to rifting of the margin. These sediments are overlain by a thick, faulted sequence of presumed Early Cretaceous (pre-Aptian) age deposited in a half-graben. Deposition contemporaneous to the tilting is indicated by the thinning of the sequence over the crest of the tilted block. The overlying interval between reflectors 2 and 3 comprises the Aptian/Albian sequence drilled at Hole 402A. Unlike the interval below, the attitude of the reflectors is indicative of progradation rather than

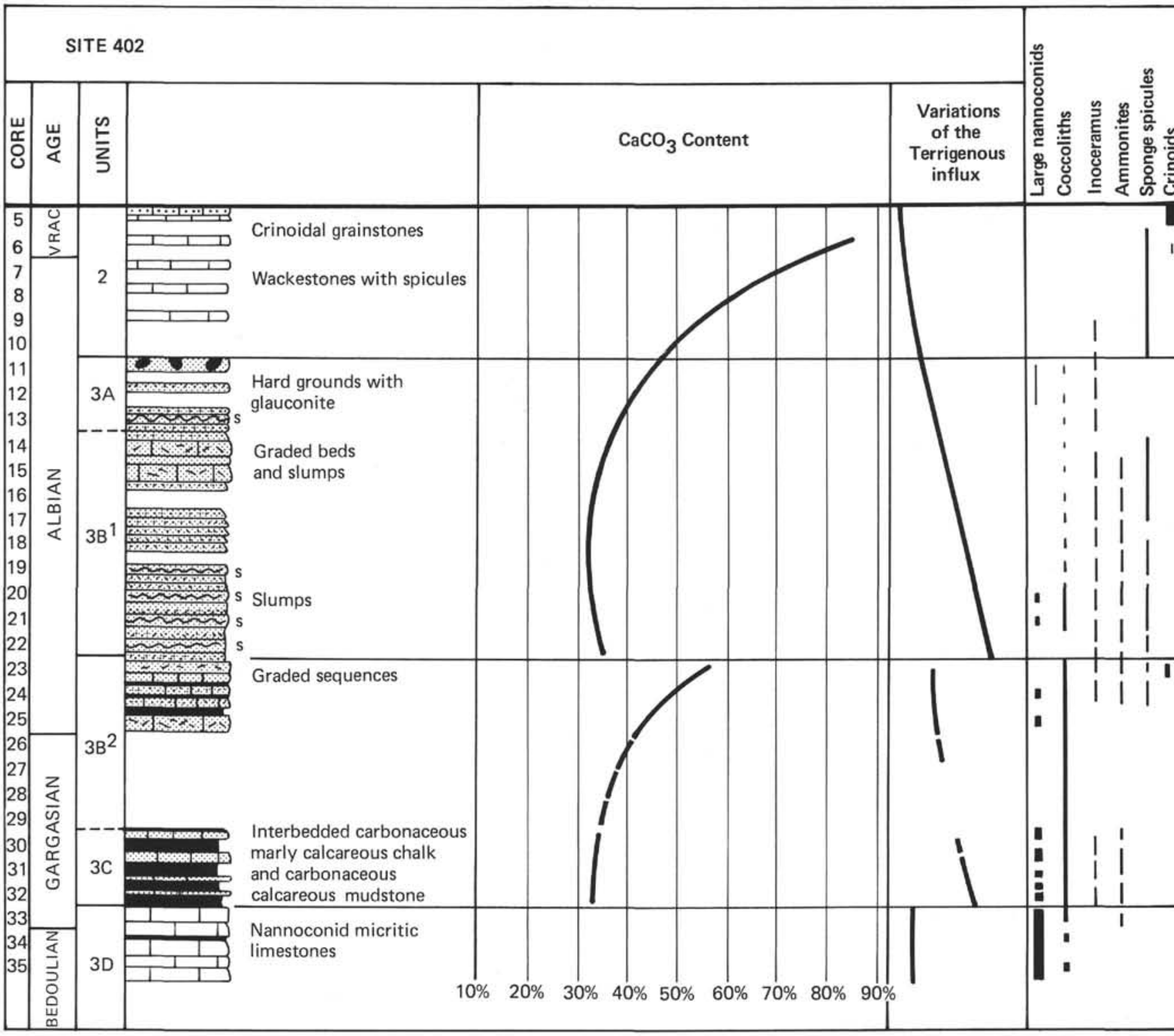

Figure 26. *Principal lithologic and paleontologic variations of the stratigraphic section in Holes 402/402A.*

syn-depositional tilting, although the lower part of the unit is affected by normal faults. Evidently, rifting ceased during Aptian time.

Three major depositional sequences (Figure 26) can be recognized in the Albian/Aptian sediments: (1) the lower Aptian limestones (Sub-unit 3D, Cores 33-35); (2) the upper Aptian/lowermost Albian "black shale" sequence (Sub-units 3C, 3B2, Cores 33-23); and (3) the lower-upper Albian "black shale" sequence and silicified carbonates (Sub-units 3B1-3B2, Cores 5-22).

The early Aptian carbonates are composed (80% biogenic, pelagic carbonates) mainly of large nannoconids together with a few ammonites, *Inoceramus,* and planktonic foraminifers. Relatively shallow water disposition may be indicated by rare dwarfed planktonic foraminifers. The benthic foraminifers also are small and "primitive" agglutinated foraminifers are common. At the time of their deposition, which corresponds to the end of rifting of the margin, the paleogeography may have been complex, with small basins delimited by crests of tilted blocks. Deposition of the carbonaceous calcareous mudstones in late Aptian time (Sub-unit 3C) marked a major change in the environment. High clay and quartz content, 2 to 3 per cent of terrestrially derived organic matter, and the low carbonate content (10-20%) indicate a significant influx of terrigenous sediments from the adjacent land. A concomitant change to more open conditions is indicated by abundant planktonic foraminifers and coccoliths of normal size. Agglutinated and calcareous benthic foraminifers, fish debris, gastropods, and pelecypods (*Inoceramus*) are present. This change may be linked with the thermal subsidence of the margin initiated after spreading had begun in the Bay of Biscay, but more probably it has a greater significance and is associated with the late Aptian transgression. The transgression associated with these events resulted in reworking of low-lying coastal plain deposits injecting plant debris, clay, etc. into the new open sea. It is the base of a sequence which ends at the top of Core 23 (lower Albian). A new sequence begins with Core 22 (lower Albian).

The paleontologic and sedimentologic evolution observed reflects changing environments conditioned by the balance between large terrigenous input, regressions and transgressions, and regional subsidence of the margin following the end of rifting during Aptian time. The two sequences may represent two superimposed prograding sedimentary units controlled by two transgression-regression cycles, one beginning in the lowermost Gargasian and the other one in the lower Albian. The rate of sedimentation was high enough (24 m/m.y., Figure 25), especially in the Albian, to keep pace with the subsidence rate. Thus the first deposited sediments in the sequence are hemipelagic, ammonite-, and nannofossil-bearing clays whereas the later ones consist of an outer shelf, biogenic, coarse deposit containing crinoidal grainstones (de Graciansky et al., this volume). In such a model, the water depth during black shale deposition could not have been greater at Site 402 than the thickness of the thicker sedimentary talus, i.e., around 200 meters (without correction for compaction). Supporting of this model, the oblique seismic reflectors indicate progradation (Figure 11).

The terrigenous black shale sediments may have been derived by reworking of low lying coastal plain sediments colonized by abundant vegetation. Batten (this volume) shows that the abundant miospores are dominated by the pollen grains of gymnosperms. Further, the occurrence of triradiate spores of great diversity, megaspores, cuticle fragments, woody tissues, acritarchs, and peridinacean cysts indicates nearshore deposition. Reworking is also demonstrated by the occurrence of Albian/Aptian palynomorphs. Oxidation of the organic matter may have taken place on land or during reworking.

The development of the black shale facies may be the result of a combination of several factors. A warm, subtropical climate may have favored growth of gymnosperms on flat-lying coastal plains. Transgression associated with the subsidence of the margin at the onset of spreading resulted in erosion, reworking, and seaward transport of plant and terrigenous debris. Reduction in the supply of terrigenous material in upper Albian time may indicate inundation of the source by rising sea level or, alternatively, the transport path bypassed Site 402. The upper Albian limestones were evidently deposited in open-shelf conditions. Finally, it should be noted that the black shales of Site 400 were contemporaneously deposited in 2000 meters depths.

A hiatus of 55 m.y. separates Albian and middle Eocene beds at Site 402. At Sites 400 and 401, in contrast, a Cenomanian/Santonian hiatus is present and Campanian/Paleocene chalks, absent at Site 402, are represented. At Hole 400A, the hiatus separates deep water Albian carbonaceous chalks and deep water Campanian chalks; at Site 401, the hiatus separates outer-shelf upper Aptian chalks and bathyal Campanian chalks. The origin of a prolonged hiatus affecting sediments deposited in deep and shallow environments is not clear, but two mechanisms may have operated at Site 402. The Cenomanian/Turonian hiatus, which is known in many parts of the Atlantic, corresponds in time with the well-known global transgression of that time. The global sea level rise may have resulted in a more vigorous circulation throughout the water column resulting in the hiatus magnified by erosion of the black shale. Further episodes of non-deposition and/or erosion may have taken place until middle Eocene time. It should be noted that the Albian beds below the hiatus are extremely lithified. Such lithification is often ascribed to removal of overburden following subaerial uplift. However, evidence of the uplift and subsequent subsidence is not observed on the seismic profile. In this case, the lithification may have arisen by precipitation of silica-enriched interstitial water (derived from the Eocene cherts or Albian sponge spicules?) in the porous Albian limestones.

In the middle to upper Eocene sediments, carbonate increases upward from 40 to 70 per cent whereas biogenic siliceous components, chiefly diatoms, radiolarians, and sponge spicules, decrease. Because calcareous microfossils are well preserved, and benthic foraminifers are rare, carbonate dissolution has not affected the fauna, indicating that the sediments were deposited above the CCD probably in bathyal depths. The high silica production during the middle Eocene time, also noted at other sites, may be connected with the change in water circulation and decrease in water temperature noted by Létolle (this volume). Of interest is the contamination of the deep water fauna by shallow water fauna displaced from the shelf. The rich nannoflora include species indicative of a nearshore environment (Müller, this volume). Reworked Cretaceous microfossils and Albian pebbles suggest renewed erosion. These changes may reflect erosion of the shelf following the global, early-middle Eocene regression, perhaps accentuated by the Eocene deformation observed on the adjacent European continent. A condensed Neogene section of 20 meters, probably containing several hiatuses, overlies the upper Eocene. These inferred hiatuses may have the same origins as those observed at other sites. The Pliocene and Pleistocene sections represent the fill of the canyon cut in the Cenozoic deposits. Although the site data do not allow definition of the age of the canyons, it is generally agreed that they were cut in Pliocene/Quaternary time as a consequence of glacio-eustatic fluctuations of sea level.

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