1. INTRODUCTION

The Shipboard Scientific Party[1]

Leg 4 of the *Glomar Challenger* Deep Sea Drilling Project in the Atlantic and Caribbean began in Rio de Janeiro on January 27, 1969. During this cruise fifteen holes were drilled at nine sites, the locations of which are shown in Figure 1. The selection of sites and the drilling and coring objectives for each site were based largely upon the recommendations of the JOIDES Atlantic Advisory Panel (JOIDES, 1967a, 1967b). Two sites, 25 and 30, were added to the original plan at the discretion of the scientific party while the cruise was in progress. Although the objectives for the individual sites were more or less unrelated to one another, collectively, they were, to enhance knowledge of basins adjacent to continental margins, to investigate sea-floor spreading and the nature of the transverse fractures in the Mid-Atlantic Ridge, to study the geology of island arcs and trenches, and to explore the geologic history of the Caribbean.

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The track began in Rio de Janeiro and ran northeastward along the continental margin, then northwestward across the Guiana Basin to the Mid-Atlantic Ridge, and skirted the island arc of the Lesser Antilles. After a two-day supply stop in San Juan, Puerto Rico, the cruise continued northward across the Puerto Rico Trench and then southward to investigate the Venezuelan Basin and related features in the Caribbean. A summary of the drilling results for Leg 4 is given in Table 1.

TABLE 1
Summary of Holes Drilled on Leg 4

Hole	Latitude	Longitude	Dates of Drilling	Water Depth (m)	Penetration (subbottom) (m)	Number of Cores	Meters Cored	Amount of Core Recovered (m)	Per Cent Recovery
23	6° 08.75′S	31° 02.60′W	Feb. 1-4 , 1969	5079	208	9	72.5	22.70	31.3
24	6° 16.30′S	30° 53.53′W	Feb. 4-6 , 1969	5148	234	4	36.6	5.20	14.2
24A	6° 16.58′S	30° 53.46′W	Feb. 6-8 , 1969	5148	558	4	35.1	3.30	9.6
25	0° 31.00′S	39° 14.40′W	Feb. 10-11, 1969	1916	66	9	64.0	25.38	39.9
25A	0° 31.00′S	39° 14.40′W	Feb. 11 , 1969	1916	77	3	19.8	2.70	13.8
26	10° 53.55′N	44° 02.57′W	Feb. 14-15, 1969	5169	9	1	9.1	0.00	0.0
26A	10° 53.55′N	44° 02.57′W	Feb. 16-20, 1969	5169	483	5	43.3	13.60	31.3
27	15° 51.39′N	56° 52.76′W	Feb. 24-26, 1969	5251	475	7	55.8	29.20	52.5
27A	15° 51.39′N	56° 52.76′W	Feb. 26-27, 1969	5251	81	5	45.7	31.10	68.3
28	20° 35.19′N	65° 37.33′W	Mar. 3-7 , 1969	5521	404	9	64.6	13.90	21.5
29	14° 47.11′N	69° 19.36′W	Mar. 9-10, 1969	4247	230	20	164.6	85.60	52.1
29A	14° 47.11′N	69° 19.36′W	Mar. 10-11, 1969	4247	86	5	45.7	3.40	7.2
29B	14° 47.11′N	69° 19.36′W	Mar. 11-12, 1969	4247	231	10	86.3	52.45	61.0
29C	14° 47.11′N	69° 19.36′W	Mar. 12-14, 1969	4247	248	3	18.3	1.38	7.1
30	12° 52.92′N	63° 23.00′W	Mar. 16-17, 1969	1218	430	16	132.9	61.70	44.6
31	14° 56.60′N	72° 01.63′W	Mar. 19-21, 1969	3369	325	10	91.4	40.90	45.0

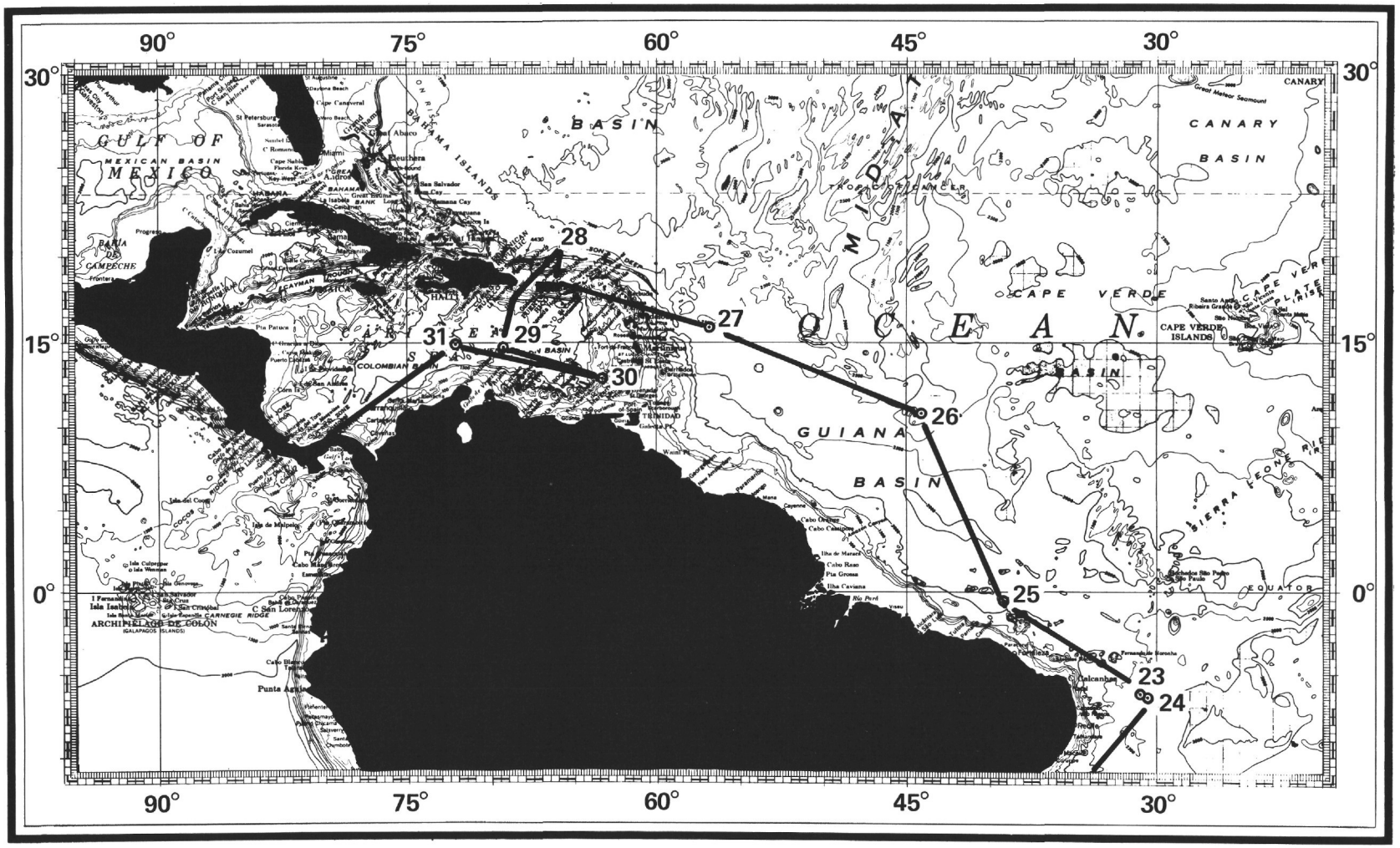

Figure 1. *Generalized track and site locations Leg IV. Topography from* THE WORLD. *U.S. Navy Hydrographic Office H. O. Misc. 15, 254-7.*

SUMMARY OF DRILLING OPERATIONS AND RESULTS

Holes 23, 24 and 24A

These holes, about 10 miles apart, are located at the foot of the continental rise in the western Brazil Basin. Hole 23 is located at latitude 6° 08.75′S, longitude 31° 02.60′N; Hole 24 is located at latitude 6° 16.30′S, longitude 30° 53.53′W; and Hole 24A is located at latitude 6° 16.58′S, longitude 30° 53.46′W.

The objectives at this site were to sample and date the basement rock, the intermediate reflecting horizons, and to determine the nature of the sedimentary fill of the western Brazil Basin at this continental margin location.

TABLE 2A
Cores Recovered from Hole 23
(Using a Diamond Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	5098-5108	0-9	7.6
2	5152-5161	53-62	1.2
3	5161-5170	62-72	3.4
4	5211-5220	112-122	9.1
5	5220-5229	122-131	0.6
6	5229-5238	131-140	0.0
7	5283-5288	184-190	0.5
8	5288-5297	190-199	0.0
9	5297-5307	199-208	0.3
		Total	22.7

Cores Recovered from Hole 24
(Using a Diamond Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	5361-5371	198-208	0.3
2	5371-5380	208-217	0.0
3	5380-5389	217-226	0.0
4	5389-5398	226-235	4.9
		Total	5.2

Cores Recovered from Hole 24A
(Using a Tungsten Carbide Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	5661-5669	503-511	0.3
2	5669-5678	511-520	0.3
3	5699-5708	540-550	0.9
4	5708-5717	550-558	1.8
		Total	3.3

Results

Three holes were necessary because of technical difficulties and adjustment of the objectives as drilling proceeded.

At Hole 23, about 200 feet (61 meters) of Pleistocene, Pliocene and late Middle Miocene strata containing tests of planktonic foraminifera and calcareous nannofossils were penetrated before entering a sereis of barren reddish zeolitic clays lacking useful plankton fossils. Coring resumed at about 370 feet (113 meters) revealing a sequence of turbidite sands and clays. The clays lack calcareous plankton, but contain some Radiolaria. The sands contain abundant planktonic foraminifera and calcareous nannoplankton, all of basal Miocene age. No cherts were encountered, and it is thought that one of the Miocene turbidite sands may represent the intermediate reflecting horizon. A thin layer of basalt, possibly associated with a nearby small seamount, was penetrated at a depth of approximately 600 feet (183 meters), which may correspond to another reflecting horizon. Beacon failure and a stuck core barrel caused abandonment of this hole.

At Holes 24 and 24A, located about 10 miles southeast of Site 23, a similar sequence of strata was penetrated to a greater depth. Coring was started at a depth of about 650 feet (198 meters) and again revealed basal Miocene turbidites, with calcareous fossils occurring only in the sandy beds. Cores taken between 1650 feet (503 meters) and 1830 feet (558 meters) were devoid of calcareous plankton fossils, but contain Radiolaria of probable Campanian (Upper Cretaceous) age. A sample of basalt was recovered in the lowest core at about 1830 feet (558 meters). Operations at this site were terminated due to a twist-off of the bottom hole assembly.

Holes 25, 25A

The site is located on a nearly continuous 1000 kilometer long ridge at the base of the continental slope

off northeastern Brazil. This feature, with crest depths of about 100 fathoms, has been surveyed by ships of Lamont-Doherty Geological Observatory (Hayes and Ewing, 1968). Holes 25 and 25A are located at latitude 0° 31.00′S, longitude 39° 14.40′W.

The objectives at this site were to determine the age and nature of the basement rock forming the ridge.

TABLE 2B
Cores Recovered from Hole 25
(Using a Tungsten Carbide Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	1937-1946	0-9	9.10
2	1946-1955	9-18	3.00
3	1955-1964	18-27	8.20
4	1964-1974	27-37	5.00
5	1977-1983	37-46	0.00
6	1983-1992	46-55	0.00
7	1992-1996	55-59	0.08
8	1996-2001	59-64	0.00
9	2001-2004	64-67	0.00
		Total	25.38

Cores Recovered from Hole 25A
(Using a Tungsten Carbide Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	1976-1985	39-48	2.7
2	1985-1995	48-58	0.0
3	1995-1996	58-59	0.0
		Total	2.7

Results

Drilling at this site terminated about 200 feet (61 meters) below the sediment surface due to loss of the bottom hole assembly. Good recovery was obtained in the upper 110 feet (33.5 meters) in foraminiferal oozes of Pleistocene to Upper Miocene age. At about 160 feet (49 meters), Middle Miocene ooze rests on a fragmental shallow water algae limestone.

Hole 26

The Vema Fracture Zone, a narrow east-west trending trough cutting through the Mid-Atlantic Ridge was first described by Lamont-Doherty Geological Observatory (Heezen *et al.*, 1964) and later surveyed by a Scripps Institution of Oceanography – Woods Hole Oceanographic Institution team (Van Andel *et al.*, 1967). Holes 26 and 26A are located at latitude 10° 53.55′N, longitude 44° 02.57′N.

The objectives at this site were to obtain evidence pertaining to the geologic development of the Fracture Zone and its relation to the Ridge and sea-floor spreading in the area.

TABLE 2C
Cores Recovered from Hole 26
(Using a Tungsten Carbide Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	5186-5195	0-9	0

Cores Recovered from Hole 26A
(Using a Tungsten Carbide Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	5282-5291	96-105	3.4
2	5291-5300	105-114	2.0
3	5415-5424	229-238	1.8
4	5587-5596	401-410	0.3
5	5663-5669	477-483	6.1
		Total	13.6

Results

Three holes were attempted, but only the second produced samples suitable for study. Cores were taken intermittently to a depth of 1586 feet (483 meters). All of the sediments are late to late middle Pleistocene in age. The deposits are a series of turbidites with a variety of organic and mineral components presumably derived from the Amazon, with little apparent contribution from the Ridge. Some beds consist almost entirely of plant debris and may be up to several centimeters thick. A rate of sedimentation of about one

foot per 250 years would indicate that the area must be rapidly filling by deposits from turbidity currents which cross the Demerara Plain.

Holes 27, 27A

In the western part of the Atlantic Basin, about 250 miles east of the Lesser Antilles Island Arc, reflection profiler measurements obtained by Lamont-Doherty Geological Observatory and the British Hydrographic Office provide the principal data on the sub-surface geology for this site. The selection of the site was based partly on the unusual nature of the basement which has a great deal more roughness and relief than is common near the continental margins. Holes 27 and 27A are located at latitude 15° 51.39′N, longitude 56° 52.76′W.

The objectives at this site were to determine the age and nature of the rough basement and to relate the geology of the site to ocean floor spreading and the development of island arcs. It was also considered an important location for paleontological sampling as a link between Caribbean fauna and the faunal provinces eastward in the Atlantic and Mediterranean.

TABLE 2D
Cores Recovered from Hole 27
(Using a Diamond Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	5337-5346	84-93	9.1
2	5394-5403	141-150	4.0
3	5489-5498	235-244	3.0
4	5498-5507	244-254	4.3
5	5622-5631	369-378	5.5
6	5707-5716	454-463	2.4
7	5727-5728	474-475	0.9
		Total	29.2

Cores Recovered from Hole 27A
(Using a Diamond Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	5279-5298	25-34	9.1
2	5298-5307	45-54	3.2
3	5307-5316	54-63	3.0
4	5316-5325	63-72	9.1
5	5325-5335	72-81	6.7
		Total	31.1

Results

Two holes were drilled; the first terminated in Eocene radiolarian deposits, and the second attempted to date the upper part of the sequence. Strata are almost barren of fossils above 770 feet (235 meters). Very poor planktonic foraminiferal assemblages from 300 feet (91 meters) and 470 feet (143 meters) suggest Pleistocene or Pliocene and Pliocene or Miocene ages, respectively. The first beds which have been accurately dated lie at a depth of 800 feet (244 meters) and are basal Miocene; the planktonic foraminifera are most abundant in turbidite sands which occur at this depth, but nannoplankton occur throughout the clays. Oligocene nannoplankton are an important constituent of greenish clays at 1200 feet (366 meters). At 1500 feet (457 meters) laminated tan to blue-gray clays with interbedded bentonites are strongly reminiscent, both lithologically and in faunal and floral content with the Oceanic Formation of Barbados. The hole was terminated in a moderately hard calcareous radiolarian-rich bentonitic clay, similar to the hard beds near the base of the Oceanic Formation, exposed on the east slopes of Mount Hillaby, Barbados. It seems evident that the hard radiolarian-rich calcareous bentonitic clay corresponds to the basement reflector seen in profiler records of this region. Two intermediate reflectors may be: 1) two thin turbidites between 220 feet (67 meters) and 230 feet (70 meters,) recovered during the second drilling and coring operation, and 2) minor turbidite beds at 775 to 815 feet (236 to 248 meters). In any case, the intermediate reflectors have no obvious relation to the widespread horizons known in the North Atlantic.

Hole 28

The site is located on the outer ridge north of the north wall of the Puerto Rico Trench, about 150 miles north of San Juan. Hole 28 is located at latitude 20° 35.19′N, longitude 65° 37.33′W.

The objectives at this site were to sample the layered structures and prominent reflectors in this area, to determine their relationship to Horizons A and B in the North American Basin, and to determine from the paleontologic record the possible history of subsidence in this area.

Results

Good core recovery was attained only in the upper part of the hole. The upper 500 feet (152 meters) of sediment consist of reddish clays devoid of plankton fossils. A core taken at 550 to 580 feet (168 to 177 meters) contains abundant Middle Eocene nannoplankton and Radiolaria and consists of green-gray clay

TABLE 2E
Cores Recovered from Hole 28
(Using a Diamond Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	5593-5603	59-68	0.0
2	5603-5612	68-77	4.6
3	5703-5710	169-176	7.6
4	5710-5720	176-185	0.5
5	5770-5779	236-245	0.3
6	5810-5814	276-280	0.0
7	5814-5817	280-283	0.3
8	5879-5888	345-354	0.3
9	5934-5938	400-404	0.3
		Total	13.9

with a fragment of limestone at the base of the core. The bit apparently was damaged in cutting through chert at about 600 feet (183 meters), and recovery below this level was poor; the samples obtained suggest alternating hard chalks, clays, and siliceous limestones. These extend to a depth of perhaps 1100 feet (335 meters) and seem to be entirely Middle Eocene, with possibly some Lower Eocene represented at the lowest part of the section. Samples from the center bit used during drilling from about 1160 feet (353 meters) to about 1310 feet (399 meters) contained planktonic foraminifera and calcareous nannoplankton of Cenomanian age. A single sample from 1310 feet (399 meters) consisted of green clays with Cretaceous Radiolaria. The barren strata in the upper part of the hole suggest deposition in deep water below the zone of carbonate compensation. The assumption of deposition of shallow water sediments on the outer ridge of the Puerto Rico Trench could not be substantiated. The thickness of 500 feet (168 meters) for recent-Middle Eocene sediments contrasts sharply with the thickness of 600 feet (183 meters) for the Middle Eocene alone and does not seem to be consistent with the 150 feet (46 meters) available for the Lower Eocene, Paleocene and Upper Cretaceous Stages above the Cenomanian. It is suggested that hiatuses may exist in the section, but they cannot be precisely determined from the materials recovered.

Holes 29, 29A, 29B, 29C

This site is located in the central part of the Venezuela Basin. Reflection profiler records have shown a widespread distribution of flat-lying sediments of uniform

TABLE 2F
Cores Recovered from Hole 29
(Using a Tungsten Carbide Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	4284-4293	0-9	4.6
2	4293-4302	9-18	4.6
3	4302-4311	18-27	0.9
4	4311-4321	27-37	5.2
5	4321-4330	37-46	0.8
6	4330-4339	46-55	0.3
7	4401-4410	117-126	0.9
8	4410-4419	126-135	0.9
9	4419-4428	135-144	9.1
10	4428-4437	144-153	7.6
11	4437-4446	153-162	0.6
12	4446-4456	162-172	9.1
13	4459-4468	175-184	0.6
14	4468-4477	184-193	9.1
15	4477-4486	193-202	9.1
16	4486-4495	202-211	9.1
17	4495-4504	211-220	9.1
18	4504-4509	220-225	3.7
19	4509-4510	225-226	0.3
20	4510-4513	226-230	0.0
		Total	85.6

Cores Recovered from Hole 29A
(Using a Tungsten Carbide Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	4325-4334	41-50	0.2
2	4334-4343	50-59	1.1
3	4343-4352	59-68	0.3
4	4352-4361	68-77	0.9
5	4361-4370	77-86	0.9
		Total	3.4

TABLE 2F – *Continued*
Cores Recovered from Hole 29B
(Using a Tungsten Carbide Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	4341-4350	57-66	9.10
2	4352-4361	68-77	4.90
3	4362-4371	78-87	3.00
4	4371-4381	87-97	6.40
5	4381-4390	97-106	6.10
6	4390-4399	106-115	0.60
7	4399-4408	115-124	0.15
8	4408-4417	124-133	9.10
9	4502-4511	218-227	9.10
10	4511-4515	227-231	4.00
		Total	52.45

Cores Recovered from Hole 29C
(Using a Diamond Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	4513-4520	230-236	0.80
2	4520-4526	236-242	0.50
3	4526-4532	242-248	0.08
		Total	1.38

thickness, called the Carib Beds (acoustically transparent sediments above and below the reflecting "A" Horizon), indicating a long and tranquil sedimentary environment. Holes 29, 29A, 29B and 29C are located at latitude 14° 47.11'N, longitude 69° 19.36'W.

The objectives at this site were to recover a complete stratigraphic record of the Tertiary and older strata which might be present and to determine the age and nature of the reflecting Horizons "A" and "B".

Results

Through the use of multiple holes, continuous coring was achieved to a hard Middle Eocene chert, but penetration of this layer proved impossible. Calcareous nannoplankton and planktonic foraminifera are abundant in the surficial strata to a depth of 100 feet (30.5 meters) (Pleistocene-Pliocene). Between 100 feet (30.5 meters) and 200 feet (61 meters) the sediments are barren clays. Some calcareous nannoplankton are present between 200 feet (61 meters) and 300 feet (91 meters) but the planktonic foraminifera are either absent or largely dissolved. Good calcareous plankton assemblages occur in chalky materials at about 350 feet (107 meters), dated as Lower Miocene. Immediately beneath this, barren zeolitic clays occur, but their exact thickness could not be determined. From 400 feet (122 meters) to about 750 feet (229 meters) the sediment consists of uniform pure radiolarian ooze of lower Upper Eocene and Middle Eocene age. Pumice and ash occur at several levels. Below 750 feet (229 meters) cherts and cherty limestones impeded and finally terminated drilling. Drilling records would suggest that the cherty layers are separated by softer beds, probably radiolarian ooze. Logging records also bear this out. The record of plankton fossils at this locality is surprisingly incomplete. Most of the Miocene part of the section was apparently deposited below the level of carbonate compensation. A major hiatus appears to exist between the Lower Miocene and lower part of the Upper Eocene. The Upper Eocene-Middle Eocene radiolarian ooze is a valuable discovery; previously, no continuous sequence of this age had been found.

The age of Horizon "A" is the same as that of Horizon A in the North American Basin, as determined on previous legs. Both in-pipe and open hole logging were accomplished at this site, and correlations with lithology and physical properties were found.

Hole 30

Site 29, which bottomed in an impenetrable chert zone of Middle Eocene age, did not contain the hoped-for complete Tertiary section; therefore, a decision was made by the shipboard scientific staff to drill at a shallower site more likely to have remained above the carbonate compensation depth during the Tertiary, yet remote from terrestrial sources of sediment and shallow-water deposits. The Aves Ridge in the eastern Caribbean, with crestal depths of 400 to 500 fathoms, separating the Venezuela Basin from the Grenada Basin, appeared to satisfy these requirements and was within one and a half days travel from Site 29. A drill site on the Aves Ridge had been proposed to the Atlantic Advisory Panel by Harry Hess, and the reflection profiler and track data which he supplied were available to guide the *Glomar Challenger* to the location of Site 30. Hole 30 is located at latitude 12° 52.92'N, longitude 62° 23.00'W.

The objectives of this site were to recover a stratigraphic sequence with abundant calcareous plankton fossils to improve knowledge of the Miocene and Pliocene in the Caribbean and to investigate the geologic history of the Aves Ridge.

TABLE 2G
Cores Recovered from Hole 30
(Using a Tungsten Carbide Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	1271-1280	50-59	7.0
2	1280-1289	59-69	5.2
3	1328-1337	108-117	5.2
4	1337-1347	117-126	1.8
5	1385-1394	164-174	3.0
6	1394-1399	174-178	4.6
7	1481-1490	260-269	1.5
8	1539-1548	318-327	1.8
9	1586-1596	366-375	3.7
10	1596-1605	375-384	3.0
11	1605-1614	384-393	7.6
12	1614-1623	393-402	4.6
13	1623-1628	402-407	3.0
14	1628-1633	407-412	1.5
15	1633-1642	412-421	7.0
16	1642-1651	421-430	1.2
		Total	61.7

Results

The upper 1000 feet (305 meters) of sediment are made up of soft clays rich in calcareous plankton fossils and ranging from Pleistocene–about 800 feet (244 meters) thick–through Pliocene. Between 1000 feet (305 meters) and 1400 feet (427 meters), more indurated Miocene siltstones were extensively cored. The Middle Miocene strata between 1300 feet (396 meters) and 1400 feet (427 meters) are essentially globigerina ooze or globigerina sand, and the basal strata are rather hard. Although ash beds are found in the lower parts of the section, volcanic materials seem to have been particularly important sediment constituents in the Pleistocene, the Pleistocene sedimentation rate being about twenty times that of the Miocene and Pliocene. Nothing is known with certainty about the provenance of the volcanic materials, but the persistent westerly ocean currents from the nearby Lesser Antilles suggest that they, as well as the Aves Ridge itself, may be involved. Strong surface currents (probably extending to the bottom) severely hindered the ship's dynamic positioning system and eventually led to abandonment of this site before a planned second hole could be made.

Hole 31

This site is located about 180 miles west of Site 29, in a region of rough faulted topography in the southeastern part of the Beata Rise, which separates the Venezuela and Colombia Basins. Extensive piston coring by Lamont-Doherty Geological Observatory in the scarp area has revealed outcrops of pre-Pleistocene beds as old as Lower Eocene, exposed by faulting (Talevani *et al.*, 1966). J. L. Worzel, aboard the Lamont-Doherty *R/V Vema*, obtained a reflection profiler record across the area just prior to the arrival of *Glomar Challenger*, suggesting this drilling location at the downthrow side of a fault scarp where Horizon "A" appeared absent.

The objective at this site was to penetrate and sample beneath Horizon "A".

TABLE 2H
Cores Recovered from Hole 31
(Using a Diamond Bit)

Core	Drill String (m)	Penetration (m)	Core Recovered (m)
1	3395-3404	0-9	9.1
2	3427-3436	32-41	0.3
3	3456-3465	60-69	9.1
4	3465-3474	69-79	2.7
5	3474-3483	79-88	1.5
6	3483-3492	88-97	3.0
7	3492-3501	97-106	1.5
8	3550-3559	155-164	2.7
9	3607-3616	212-221	3.4
10	3665-3674	270-279	7.6
		Total	40.9

Results

Ten cores were taken in the upper 100 feet (350 meters) of sediment. In contrast to Site 29, all of the strata were apparently deposited above the carbonate-compensation level except around 350 feet (107 meters), where the tests of pelagic foraminifera have been largely dissolved (Lower Pliocene). The upper part of the drilled section [to 600 feet (183 meters)], including Pleistocene, Pliocene, Upper and Middle Miocene beds, exhibits a normal rate of deposition for globigerina ooze. The strata between 680 feet (207 meters) and about 1000 feet (305 meters) are indurated chalk of Lower Miocene age, and must represent deposits laid down with a considerably higher rate of sedimentation. The drilling terminated at a depth of 1066 feet (325

meters) due to a lodged center bit and broken wire line. The apparent absence of Horizon "A" indicated by profiler records could not be verified.

EXPLANATORY NOTES

Responsibility of Authorship

The authorship of each chapter of this report is designated below the title of the chapter. Authorship of the major chapters of the shipboard report is indicated to be "The Shipboard Scientific Party," which consisted of Richard G. Bader, William E. Benson, Hans M. Bolli, Robert D. Gerard, William W. Hay, William R. Riedel, W. Thomas Rothwell, Jr., Michael H. Ruef, and Fred L. Sayles.

Actual preparation of the manuscripts for this report was the responsibility of certain individuals, and where appropriate those responsible for particular sections of chapters are indicated by their initials. Specialized reports by the shipboard paleontologists and shipboard geochemist are presented as separate chapters.

Responsibility for several sections of these explanatory notes must rest in part with the Leg 3 shipboard scientific party whose report we have extensively plagiarized.

Site Surveys

The Research Vessel *Vema* of Lamont-Doherty Geological Observatory preceded the *Glomar Challenger* to a number of the localities to be drilled and carried out extensive surveys at Sites 23, 24, 27 and 29. At each of these, the *R/V Vema* obtained underway topographic, magnetic, gravity, seismic reflection and seismic refraction records. Piston cores and bottom photographs were obtained at specific stations within each of the above site areas. Primary navigation control for all of these survey measurements was provided by satellite navigation methods. Dennis Hayes was chief scientist aboard the *R/V Vema* during the surveys at Sites 23, 24, 25 and 27. J. L. Worzel was chief scientist for the survey operations at Site 29, and provided additional information for site 31.

Sonic depth measurements given for the sites utilized the GIFFT Precision Graphic Recorder set for a constant sound velocity of 800 fathoms per second. The recorded depths were corrected for speed of sound calculated for specific ocean areas according to Matthews (1939) and for the depth of the hull-mounted echo-sounding transducer (3 fathoms).

Basis for Numbering Sites and Holes

Throughout this volume the term "site" has been used to refer to a location where drilling operations were carried out and core samples obtained. In most cases a single positioning beacon was used at each site. The drill string was lowered to the ocean floor and spudded into the sediment at least once at each site. At any site, each penetration of the bottom which produced samples is termed a "hole." The sites are numbered in sequence, from 23 at the beginning of the leg to 31 at the end of the leg. The first hole at each site bears the site number only, but subsequent holes at the same site are designated by the site number followed by a capital letter, starting with A, and continuing with B, C, D, etc. as additional penetrations of the bottom were achieved.

Basis for Numbering Cores and Sections

All cores are numbered sequentially in each hole, from first to last, whether any recovery was achieved or not. Cores brought on board were usually enclosed in a 9.1-meter long plastic liner. After the liner was pulled out of the core barrel, it was cut into 150 centimeter long sections, starting at the base. These sections were labelled consecutively, with the uppermost section containing sediment designated Section 1 and the numbers increasing toward the base. In a few rare instances, more than 9 meters of sediment were obtained, so that more than the standard six sections were obtained; in this case, the uppermost section was labeled Section 0, denoting its position above Section 1.

Some cores were taken without a plastic liner, and were extruded from the core barrel into a split liner cradled in a tray on deck using a piston. These cores have a slightly greater diameter than the standard cores taken with a liner, hence, not all of the standard measurements of physical properties could be made.

Samples were numbered before being processed, using the system recommended in the Core Description Manual of May 1968. Thus, Sample 4-25-1-6: 2 cm was taken on Leg 4, in the first hole at Site 25, from the sixth section of the first core, and represented the material between the top and a depth of 2 centimeters in that section.

A core catcher about 20 centimeters long was attached to the lower end of the metal core barrel. Samples recovered from the core catcher were designated by the abbreviation "CC." Core catcher samples were usually examined immediately by the shipboard paleontologists for a rapid determination of the age of the material. In some instances, the core catcher samples represent the only material recovered by a core barrel.

Handling of Cores

Upon arrival, the base of each core was sampled by the paleontologists for a rapid age determination. Nannoplanktonic foraminiferal preparations were made immediately, and the age determined within five minutes

while the drill pipe was held open pending a decision whether to drill an interval or to core. After removal from the core barrel, the core was cut into sections as described above, sealed, and labeled. Then the sections were brought into the core laboratory where the following operations were carried out:

1) Weighing of the core section to record gross recovery,

2) GRAPE analysis to determine bulk density variations,

3) Gamma ray counting for natural radioactivity,

4) X-ray photography to record sedimentary structures,

and in suitable sections measurements of sonic velocity and thermal conductivity were carried out.

After the physical measurements had been made, the core liner was cut almost through by an electric saw, final splitting of the liner and the end caps were done with a knife to minimize disturbance. Soft cores were then split into halves using a taut wire. Compacted or partially lithified sediments were split using a band saw. This was a time-consuming procedure, and in some instances lithified sections were left unsplit until their arrival at the Core Repository at Lamont.

To permit orientation of all sections from a single core, each plastic liner was marked with a single groove along the length on one side and a double groove along the length on the other; these markings were on the liner prior to its insertion into the core barrel. Splitting of the cores was done perpendicular to the plane of the liner marks. The half of the core with the single longitudinal groove was designated the working half and that with the double longitudinal groove was designated the archive half of the core. Penetrometer readings of the working half were made to give a measure of the degree of consolidation of the sediment, and samples were taken for grain size analysis, X-ray mineralogy, interstitial water chemistry, and total carbonate content determination by shore laboratories. The working half was then sent to the paleontology laboratory, where samples for shipboard and shore-based studies of the calcareous nannoplankton, foraminifera, and radiolarians were taken, along with oriented samples for paleomagnetic studies if disturbance of the core was not a serious problem.

The archive half was used for description. The cut surface was smoothed with a spatula to bring out the sedimentary features. The color, texture, structure, and composition of the various lithologic units within a section were described and any unusual features noted. A smear slide was made, usually at 75 centimeters if the core was uniform; if distinct lithologies were present, smear slides were made from as many of these as time permitted. After description in the Core Laboratory, the archive half was sent to the photographer.

After the paleontologist had finished with the working half and the archive half had been photographed, both halves were stored in refrigerated core vans.

Subsequently, the cores were shipped to New York and are now deposited in the Deep Sea Drilling Project Core Repository at Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York.

Unusually soft cores (termed "soupy") and some lithified cores were not split, but were opened at the end after physical measurements were made. The sample taken from the end was used to describe the color and texture, and for age determination by the paleontologists. In some cores, only a few hard rocks were recovered. These were numbered consecutively from the top down, and when possible oriented vertically by an arrow pointing upward. Small chips of mud were placed in plastic boxes or bags, sealed, and labeled with a description of their origin, whether from the core catcher, plug bit, bumper subs, or outside of the drill pipe.

Basis for Age Determinations

The shipboard paleontologists decided not to use stage names in reference to the age of Cenozoic sediments recovered on Leg 4. Planktonic foraminifera, calcareous nannofossils, radiolarians, and in some instances benthonic foraminifera were used to determine the age of the sediments. The most precise determinations used in this volume are in terms of biostratigraphic zones, as discussed in each of the detailed paleontological reports. The zones are considered equivalent to subdivisions of epochs in the Tertiary or of stages in the Cretaceous according to an arbitrary scheme prepared for the calcareous microfossils at the beginning of the leg (Figure 2), which, to the best of our knowledge, conforms with the usage in the time stratigraphic framework reproduced as Appendix 1. Insufficient information was available to permit integration of Cenozoic radiolarian zones into this scheme—but see Figure 3 of the radiolarian chapter in this volume. Planktonic foraminifera were considered definitive in determining the age of the sediment whenever they were present in abundance. If the plnaktonic foraminifera were absent, poorly preserved, or otherwise nondiagnostic, the calcareous nannoplankton or radiolarians were used as definitive of the age.

Physical Properties and Geochemical Measurements

The data on the physical properties of the sediments cored and the chemical data from the interstitial solutions are summarized in graphical form in the section for

		PLANKTONIC FORAMINIFERAL ZONE	CALCAREOUS NANNOPLANKTON ZONE
PLEISTOCENE		*Globorotalia truncatulinoides truncatulinoides*	*Emiliania huxleyi*
			Gephyrocapsa oceanica
			Gephyrocapsa caribbeanica
PLIOCENE	L	*Globoquadrina altispira altispira/ Globorotalia tosaensis*	*Discoaster brouweri*
			Sphenolithus abies
	M	*Globoquadrina altispira altispira*	*Discoaster surculus*
	E	*Globorotalia margaritae*	
MIOCENE	L	*Globorotalia dutertrei*	*Scyphosphaera amphora*
		Globorotalia acostaensis	*Discoaster hamatus*
	M	*Globorotalia menardii*	
		Globorotalia mayeri	*Catinaster coalitus*
		Globorotalia fohsi robusta	*Discoaster kugleri*
		Globorotalia fohsi lobata	
		Globorotalia fohsi fohsi	*Sphenolithus heteromorphus*
		Globorotalia fohsi peripheroronda	
	E	*Praeorbulina glomerosa*	*Helicopontosphaera ampliaperta*
		Globigerinatella insueta	
		Catapsydrax stainforthi	*Sphenolithus belemnos*
		Catapsydrax dissimilis	*Discoaster druggi*
		Globigerinoides primordius	*Triquetrorhabdulus carinatus*
OLIGOCENE	L	*Globorotalia kugleri*	*Sphenolithus ciperoensis*
		Globigerina ciperoensis ciperoensis	*Sphenolithus distentus*
	M	*Globorotalia opima opima*	
		Globigerina cf. venezuelana	*Sphenolithus predistentus*
		Globigerina ampliaperta	
	E	*Cassigerinella chipolensis/ Pseudohastigerina micra*	*Reticulofenestra laevis*
			Cyclococcolithus margaritae
			Ericsonia subdisticha
EOCENE	L	*Globorotalia cerroazulensis*	*Isthmolithus recurvus*
		Globigerapsis mexicana	

Figure 2. *Biostratigraphic zones used in this volume.*

		PLANKTONIC FORAMINIFERAL ZONE	CALCAREOUS NANNOPLANKTON ZONE
EOCENE	L	*Truncorotaloides rohri*	*Discoaster tani nodifer*
		Orbulinoides beckmanni	
	M	*Globorotalia lehneri*	*Chiphragmalithus quadratus*
		Globorotalia kugleri	
		Hantkenina aragonensis	*Discoaster sublodenosis*
	E	*Globorotalia palmerae*	*Discoaster lodoensis*
		Globorotalia aragonensis	*Marthasterites tribrachiatus*
		Globorotalia formosa formosa	*Discoaster binodosus*
		Globorotalia aequa	*Marthasterites contortus*
PALEOCENE	L	*Globorotalia velascoensis*	*Discoaster multiradiatus*
		Globorotalia pseudomenardii	*Heliolithus riedeli*
			Discoaster gemmeus
	M	*Globorotalia pusilla pusilla*	*Heliolithus kleinpelli*
		Globorotalia angulata	*Fasciculithus tympaniformis*
	E	*Globorotalia incinata*	*Cruciplacolithus tenuis*
		Globorotalia trinidadensis	
		Globorotalia pseudobulloides	
		Globigerina eugubina	*Markalius astroporus*
MAESTRICHTIAN		*Abathomphalus mayaroensis*	*Nephrolithus frequens*
			Lithraphidites quadratus
		Globotruncana gansseri	*Chiastozygus initialis*
		Globotruncana lapparenti tricarinata	*Tetralithus aculeus*
CAMPANIAN		*Globotruncana calcarata*	
		Globotruncana stuarti	
SANTONIAN		*Globotruncana fornicata*	*Kamptnerius magnificus*
		Globotruncana concavata	*Kamptnerius punctatus*
CONIACIAN		*Globotruncana schneegansi*	*Arkhangelskiella ethmopora*
TURONIAN		*Globotruncana helvetica*	*Marthasterites furcatus*
		Praeglobotruncana gigantea	*Tetralithus pyramidus*
CENOMANIAN		*Rotalipora cushmani*	*Corollithion exiguum*
		Rotalipora reicheli	*Chiastozygus cuneatus*
		Rotalipora brotzeni	*Staurolithites orbiculofenestrus*
		Rotalipora appeninica appeninica	

Figure 2. *(Continued).*

each site. The chemical data are also presented in tabular form in Table 1, Chapter 26. The analog data (gamma ray attenuation porosity evaluator–referred to as GRAPE, and natural gamma radiation) are presented as continuously recorded data with the detailed core logs (*1:10.16* scale). Density, water content, natural gamma and penetrometer data are presented in conjunction with graphic lithologic summaries of the sites. The details of the methods of measurement for these and other physical properties have been extensively discussed in the Reports on Legs 2 (Peterson *et al.*, 1970) and 3 (Maxwell *et al.*, 1970).

The density data used were measured by sampling the core with a cut-off 1 cubic centimeter syringe and weighing a measured volume of sediment. This was thought to be the most accurate density determination for the range of sediment encountered. A weighing error of approximately ± 1 per cent from the instability of the ship was determined. The error in volume measurement is impossible to assess accurately, but probably does not exceed 5 per cent; hence, the probable error in the density measurements is on the order of ± 5 per cent. Water content measurements rely solely on weight determinations, and errors should not exceed ± 1 per cent.

The natural gamma data are presented minus the background level for an empty core liner. All of the various types of data are presented in the graphs as mean values for each core (most involve one measurement or more per section) unless a recognizable lithologic break has been cored. In the latter case, several values across the break are plotted.

The GRAPE unit did not function accurately on Leg 4; electrical calibration did not prove possible. To minimize errors, the instrument was set to read accurately for water. Densities, as compared with other density calculations, agree within 0.05 gm/cc up to a density of about 1.80 gm/cc. At densities greater than 1.80 gm/cc the error becomes increasingly large up to 10 to 15 per cent for aluminum (P = 2.70 gm/cc). Porosities measured with the GRAPE instrument were generally 10 per cent greater than those calculated from water content-volume data.

The chemical data presented include carbonate (CO_2) where available, Eh, *p*H and total salinity. Carbonate analysis was made utilizing a gas chromatograph; 0.2 milliliter samples were acidified in glass vacutainers, and the evolved gas was analyzed. The samples were stored in sealed syringes with essentially no gas phase (less than 0.02 milliliter) for periods ranging from 10 to 20 days prior to analysis. The accuracy of the carbonate data appears to be only slightly better than ± 10 per cent. The *p*H measurements were made with a Beckman *p*H meter and a combination glass and calomel electrode. A platinum electrode used in conjunction with a calomel reference electrode was utilized for the Eh measurements; values are corrected to hydrogen (H_2) reference electrode potentials. Beckman *p*H buffers were used for *p*H standardization. Total salinities in parts per thousand were measured with a temperature-compensated Goldberg refractometer (American Optical Co.). Salinities are accurate to 0.3 ppt.

As the chemical data from each hole are often few (2 to 6 samples), discussion of the significance of these data are presented only in the cruise synthesis.

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