7. SITE 9951

Shipboard Scientific Party²

HOLE 995A

Position: 31°48.210'N, 75°31.343'W

Start hole: 1400 hr, 20 November 1995

End hole: 1315 hr, 26 November 1995

Time on hole: 149.50 hr (6.23 days)

Seafloor (drill pipe measurement from rig floor, mbrf): 2789.8

Total depth (drill pipe measurement from rig floor, mbrf): 3494.4

Distance between rig floor and sea level (m): 11.3

Water depth (drill pipe measurement from sea level, m): 2778.5

Penetration (mbsf): 704.6

Coring totals:

Type: APC Number: 18 Cored: 163.2 m Recovered: 168.6 m (103.3%)

Type: XCB Number: 56 Cored: 530.1 m Recovered: 374.41 m (70.6%) Type: PCS

Number: 9 Cored: 9.0 m Recovered: 4.56 m (50.7%)

Formation:

Unit I: 0–13.4 mbsf; Holocene to late Pleistocene; light greenish gray foraminifer-bearing nannofossil-rich clay and nannofossil clay Unit II: 13.4–131.9 mbsf; late Pleistocene to late Pliocene; greenish gray

diatom-rich nannofossil-rich clay and nannofossil-rich clay Unit III: 131.9–704.6 mbsf; late Pliocene to late Miocene; dark greenish gray diatom-bearing nannofossil-rich clay and claystone

HOLE 995B

Position: 31°48.217'N, 75°31.336'W

Start hole: 1520 hr, 26 November 1995

End hole: 0800 hr, 3 December 1995

Time on hole: 166.5 hr (6.94 days)

Seafloor (drill pipe measurement from rig floor, mbrf): 2788.2

Total depth (drill pipe measurement from rig floor, mbrf): 3488.2

Distance between rig floor and sea level (m): 11.3

Water depth (drill pipe measurement from sea level, m): 2776.9

Penetration (mbsf): 700.0

Coring totals:

Type: APC Number: 3 Cored: 27.3 m Recovered: 27.86 m (102.1%)

Type: XCB Number: 9 Cored: 75.1 m Recovered: 31.83 m (42.4%) Type: PCS Number: 2 Cored: 2.0 m

Recovered: 1.58 m (79.0%)

Formation:

Cores were recovered only from limited intervals (see "Operations" section, this chapter). Lithologies are similar to those in Hole 995A.

Principal results: At Site 995, we recovered a 700-m-thick sedimentary sequence that is dominantly composed of clay and nannofossils. Three major lithologic units were identified, primarily based on downhole variations in carbonate contents and diatom and nannofossil abundances. Unit I (0-13.4 mbsf; Holocene to late Pleistocene) comprises light greenish gray, foraminifer-bearing nannofossil-rich clay and nannofossil clay, with carbonate contents as much as 50 wt%. The greenish gray nannofossil-rich clays in Unit II (13.4-131.9 mbsf; late Pleistocene to late Pliocene) contain abundant diatoms and have lower nannofossil contents (average 10%) than those in Unit I. The upper part of Unit II (Subunit IIA) contains foraminifer-rich winnowed layers that indicate deposition by contour currents. Unit III (131.9-704.6 mbsf) extends to the bottom of the hole and comprises an upper Pliocene to upper Miocene sequence of monotonous dark greenish gray diatom-bearing nannofossil-rich clay and nannofossil-bearing clay and claystone, with average CaCO3 contents of 15 wt%

Nannofossil biostratigraphy indicates that the sequence recovered at Site 995 is mostly continuous except for a short hiatus within the uppermost Miocene between 570 and 580 mbsf. The sedimentation rates for the Quaternary (60 m/m.y.) and lower Pliocene (150 m/m.y.) sequences are almost identical to those at Site 994. However, the rate for the upper Pliocene (110 m/m.y.) is ~17% higher than at Site 994. Because of the presence of a hiatus, we could not obtain a sedmintation rate for the upper Miocene sequence. The age of the oldest sediments cored at Site 995 (704.6 mbsf) is estimated to be 6.1 Ma. A magnetostratigraphy was determined for Hole 995A, despite remanences of <0.5 mA/m. Major chron boundaries were recognized as follows: C2An/C2r (Gauss/Matuyama) at 136 mbsf, C2Ar/C2An (Gilbert/Gauss) at 295–320 mbsf, C3n/C2Ar at 320–350 mbsf, C3r/C3n at 545–580 mbsf, and C3An/C3r (Anomaly 5/Gilbert) at 620–635 mbsf.

Methane/ethane ratios decrease with depth and reach a minimum of 146 at 699.4 mbsf. Higher molecular weight hydrocarbons are present in <10 ppm concentrations from 171.2 to 699.4 mbsf, and heptane occurs in the lower sections of Hole 995A, suggesting that a small amount of thermally mature gas has migrated to the site. The TOC contents of the sediments are near 1%, and the organic matter is immature, containing both terrestrial and marine components.

¹Paull, C.K., Matsumoto, R., Wallace, P.J., et al., 1996. Proc. ODP, Init. Repts., 164: College Station, TX (Ocean Drilling Program).

²Shipboard Scientific Party is given in the list of participants that precedes the Table of Contents.

Interstitial-water geochemical data from Site 995 are remarkably similar to those found at Site 994. In particular, a zone of anomalously low interstitial-water chloride concentrations (as low as 466 mM) occurs between 195 and 440 mbsf. The zone of anomalous chloride values is coincident with the zone of anomalously low sediment temperatures measured on the catwalk after recovery, suggesting that gas hydrate recently decomposed in these cores. These results imply that sites 3 km apart possess similar vertical distributions and amounts of gas hydrate.

Eleven WSTP runs from 78.7 to 200.2 mbsf were made at Site 995. The recovered samples contain 0.1%–94% interstitial water, with the proportion of interstitial water decreasing with increasing depth. After correction for the effects of dilution by borehole water, the WSTP samples indicate that in situ chloride concentrations are generally comparable to those measured for water squeezed from whole-round core samples recovered from corresponding depths.

The PCS was successfully deployed 11 times at Site 995. Gas samples taken from the PCS are largely composed of methane, with small amounts (~1%) of CO₂. The amount of methane recovered from several PCS cores exceeds that expected from methane saturation of the interstitial waters at in situ pressures. Because some of these same cores were recovered above the base of gas hydrate stability in the zone associated with the erratic interstitial-water chloride concentrations, the "excess" gas probably is derived from decomposition of methane hydrate.

Physical properties data for sediments from Hole 995A are nearly coincident with those found at Site 994. The data do not reveal major differences that could account for the remarkable lateral variability in the strength of the BSR between the sites. The data also show a 390-m-thick interval (220–610 mbsf) in which the wet bulk density values are constant as a function of depth, an unusual observation in sediments undergoing normal compaction.

Rock magnetism defines a trend of magnetite-greigite-pyrite conversion in which greigite develops within the first 20 mbsf in response to bacterial oxidation of organic material and is progressively reduced to pyrite downhole. Below this, a second generation of greigite extends downward to \sim 260–300 mbsf, approximately coinciding with the zone of high gas hydrate concentration inferred from interstitial-water chloride values. This sequence of reduction steps is similar to that documented at Site 994.

Twenty in situ temperature measurements were attempted at Site 995 using the Adara APC temperature shoe, the WSTP, and a new prototype temperature probe, the DVTP. Based on 15 successful deployments of the temperature tools, the geothermal gradient is estimated at $33.5 \pm 0.9^{\circ}$ C/km between 0 and 381 mbsf. Taking into account vertical variations in thermal conductivity, the average heat flow from 0 to 381 mbsf is 34.2 ± 1.7 mW/m², which is 35% lower than previous measurements from this region (Ruppel et al., 1995). Extrapolation of the thermal gradient to 440 mbsf, the depth of the BSR at Site 995, yields a temperature of 18.3°C. This is well within the experimentally determined pressure-temperature stability field for methane hydrate.

Vertical seismic profiling was conducted at depths of 144–664 mbsf during two lowerings of the three-component WHOI borehole seismometer in Hole 995B. Walkaway VSPs were shot by the *Cape Hatteras* and recorded at eight depths from 176 to 680 mbsf. A stacked record section shows clear downgoing first arrivals and upgoing reflections, including a strong reflection from the BSR. The intersection of the downgoing first arrival and the upgoing BSR reflection indicates that the BSR is located at 440 ± 10 mbsf. A preliminary *P*-wave velocity model shows that compressional velocity reaches a maximum of 1850 m/s at 400 mbsf. Velocities decrease below this depth, reaching a minimum of ~1550 m/s at 590 mbsf, suggesting the presence of free gas.

A complete suite of wireline logs (natural gamma, electrical resistivity, *P*-wave sonic, neutron porosity, bulk density, geochemical, Formation MicroScanner, and the LDEO-SST) was run in Hole 995B from 130 to 630 mbsf. Preliminary analysis of the *P*-wave acoustic and electrical resistivity logs shows a pattern similar to that at Site 994, with low acoustic velocities (~1600 m/s) in the top of the hole that begin to increase at 220 mbsf to a maximum of 1900 m/s at 450 mbsf before decreasing again to 1600 m/s at 600 mbsf. The zone from 220 to 450 mbsf has higher electrical resistivities than are found either above or below. The electrical resistivity and *P*-wave acoustic velocity measurements are consistent with the presence of gas hydrate in the zone from 220 to 450 mbsf and with the presence of free gas in the section below 450 mbsf.

BACKGROUND AND OBJECTIVES

Site 995 was the first site during Leg 164 at which drilling penetrated below the base of the gas hydrate stability zone and through a strong BSR. The site is located on the southern flank of the Blake Ridge, 3.0 km northeast of Site 994 and within the same stratigraphic interval as Site 994 (Fig. 1). However, a strong BSR is present at Site 995 at 0.53 s sub-bottom, which is not observed at Site 994 (Fig. 2). Sites 994 and 995 are coupled sites that were intended to establish the nature of BSRs and to understand the causes of profound differences in acoustic characteristics (Fig. 2) within essentially the same materials.

The geologic setting of Site 995 is similar to that of Site 994. Both sites are on the southern flank of the Blake Ridge, a Neogene sediment drift (Tucholke and Mountain, 1979). Previous drilling (e.g., DSDP Leg 11, Sites 102, 103, and 104; Shipboard Scientific Party, 1972; DSDP Leg 76, Site 533; Gradstein and Sheridan, 1983) has shown that this sediment drift is largely composed of fine-grained nannofossil-bearing hemipelagic sediments.

The water depth at Site 995 (2778.5 m) is 20 m shallower than at Site 994. The seismic reflection profile along which Sites 994 and 995 are located shows that the reflectors are essentially parallel to the seafloor and that the stratigraphic units are continuous between the sites (Fig. 2). Although a few minor normal faults may occur within this zone, the offsets are nominal.



Figure 1. Bathymetry and location of Site 995 on the Blake Ridge. The location of the seismic reflection profile (CH-06-92, Line 31) shown in Figure 2 is indicated with the bold line.



Figure 2. Seismic reflection profile (CH-06-92, Line 31) across Sites 994, 995, and 997. The location of the survey line is shown in Figure 1.

A very strong reflector is obvious at 0.53 s sub-bottom in seismic reflection profiles over Site 995 (Fig. 1). This reflector is laterally continuous upslope to the regionally traceable reflector that is identified as the BSR in this area (see Dillon et al., this volume) because (1) it is observed to cross other reflectors on the northern flank of the Blake Ridge, (2) where presumably stratal boundaries are crossed by the identified BSR, they are more reflective below and less reflective above the identified BSR, and (3) the identified BSR occurs at greater sub-bottom depths as the water depth increases (Fig. 2). Thus, the level of the identified BSR mimics the crest of the Blake Ridge (Fig. 2). The continuity of the BSR is lost at ~0.8 km north of Site 994 as it is traced downslope from Site 995 toward Site 994.

Another reflector, or top of a group of reflectors, is seen at both Sites 995 and 994 at ~0.62 and 0.64 s sub-bottom, respectively. These reflectors are ~0.1 s below the identified or projected position of the BSR at these sites. Another significant feature observed in seismic reflection profiles is a zone that is relatively free of distinct reflections (blanking zone) that extend from ~0.25 s downward to the BSR (0.53s) at Site 995. A similar zone of low internal reflectivity occurs at Site 994, but it continues to 0.64 s sub-bottom at Site 994 (well below the projected level of the BSR at Site 994).

Site 995 was drilled for comparison with Site 994, where there is no BSR. The specific objectives were:

 To assess the nature and origin of the BSR in the Blake Ridge area. Most models for the origin of the BSR (see "Introduction chapter," this volume) infer that the BSR results from (1) an acoustic impedance contrast associated with the base of a gas hydrate-bearing zone, (2) the top of a gas-bearing zone that is below the base of the gas hydrate stability zone, or (3) a combination of the two. The origin of the BSR would be clarified by comparing the nature of sediments from above and below the BSR at Site 995 and with the sediments from the same interval at Site 994.

- 2. To recover data on in situ characteristics of the sediments to (1) estimate the total amount of gas hydrate at this site, (2) establish the sources of gases associated with the gas hydrate (e.g., in situ-produced microbial gases, migrated and concentrated microbial gas, or migrated thermogenic gases), and (3) recover natural gas hydrate samples to determine the structure, composition and volumetric ratio of gas to water.
- 3. To assess lateral variations in the amount of gas trapped within and below gas hydrate-bearing sediments. Comparative studies of Sites 994 and 995 will provide insight into the utility of acoustic techniques for establishing the amount of gas hydrate in adjacent marine sediment sequences with and without a BSR.
- 4. To measure the temperature gradient to assess the relationship between the theoretical stability of methane gas hydrate, the inferred position of the base of the gas hydrate stability zone, and the position of the BSR.

OPERATIONS

Hole 995A

The ship was moved 3.0 km northeast of Site 994 to the Global Positioning System (GPS) coordinates for Site 995 (prospectus site BRH-6), and a Datasonics 354M beacon was dropped at 0749 hr on 20 November. A near-seafloor water sample was taken with the PCS tool at 2693.7 m below sea level (mbsl) (~84.8 m above the seafloor). After several water cores were obtained using an incorrect precision depth recorder setting, Hole 995A was spudded at 1400 hr on 20 November (Table 1). The water depth was 2778.5 mbsf, based on recov-

Table 1. Coring summary for Site 995.

	Date		1.444	Length	Length	
1.000	(Nov.	Time	Depth	cored	recovered	Recovery
Core	1995)	(UTC)	(mbsf)	(m)	(m)	(%)
164-995A-						
1H	20	1915	0.0 - 1.7	1.7	1.70	100.0
2H	20	2020	1.7 - 11.2	9.5	9.27	97.6
3H	20	2105	11.2-20.7	9.5	9.71	102.0
4H	20	2330	20.7-30.2	9.5	9.87	104.0
5H	21	0020	30.2-39.7	9.5	9.94	104.0
6H	21	0125	39.7-49.2	9.5	9.92	104.0
7H	21	0210	49.2-58.7	9.5	9.99	105.0
8H	21	0300	58.7-68.2	9.5	10.12	106.5
9P	21	0350	68.2-69.2	1.0	1.00	100.0
10H	21	0505	69.2-78.7	9.5	10.28	108.2
11H	21	0715	78.7-88.2	9.5	9.85	103.0
12H	21	0800	88.2-97.7	9.5	10.65	112.1
13H	21	0905	97.7-107.2	9.5	10.15	106.8
14H	21	1120	107.2-116.7	9.5	10.23	107.7
15H	21	1205	116.7-126.2	9.5	9.99	105.0
16H	21	1325	126.2-135.7	9.5	10.65	112.1
17H	21	1410	135.7-145.2	9.5	9.58	101.0
18P	21	1500	145.2-146.2	1.0	0.70	70.0
19H	21	1725	146.2-155.7	9.5	10.02	105.5
20H	21	1835	155.7-165.2	9.5	6.68	70.3
21X	21	2215	165.2-174.8	9.6	5.79	60.3
22X	21	2310	174.8-184.4	9.6	6.80	70.8
23X	22	0015	184.4-194.0	9.6	7.40	77.1
24X	22	0120	194.0-203.7	9.7	3.01	31.0
25X	22	0225	203.7-213.3	9.6	6.17	64.3
26X	22	0325	213.3-222.9	9.6	1.75	18.2
27P	22	0430	222.9-223.9	1.0	1.00	100.0
28X	22	0715	223.9-233.1	92	9 19	99.9
29X	22	0830	233.1-242.7	9.6	2.93	30.5
30X	22	0945	242 7-252 3	96	640	66.6
31X	22	1235	252.3-261.9	9.6	8 41	87.6
32X	22	1410	261 9-271 5	96	2.64	27.5
33X	22	1520	271.5-281.1	9.6	5.63	58.6
34X	22	1750	281.1-290.7	9.6	1.44	15.0
35X	22	2050	290.7-300.3	9.6	5 50	57.3
36P	22	2155	300 3-301 3	1.0	0.75	75.0
37X	22	2320	301 3-310.0	87	0.34	3.9
38X	23	0100	310.0-319.6	96	0.23	24
39X	23	0415	319 6-329 3	9.7	3.01	31.0
40X	23	0625	329 3-339 0	97	2.84	29.3
41X	23	0815	339 0-348 6	9.6	1 72	17.9
42X	23	1110	348 6-358 2	9.6	5.76	60.0
43X	23	1245	358 2_367 9	0.7	7 35	75.8
AAX	23	1420	367 0 377 5	0.6	2 38	35.2
45P	23	1515	377 5 378 5	1.0	0.58	58.0
46Y	23	1640	378 5 387 1	8.6	7.21	85.0
404	23	2020	387 1_306 8	0.0	7.10	73.2
48P	23	2115	306.8 307.9	1.0	0.23	23.0
40X	23	2300	307 8, 406 4	2.6	6.47	25.0
50X	24	0045	406.4-416.0	0.0	0.47	05.8
518	24	0415	416.0 425.6	9.0	9.20	95.0
520	24	0415	410.0-425.0	9.0	0.18	18.0
52P	24	0035	423.0-420.0	1.0	0.18	105.0
538	24	1025	420.0-433.2	0.6	9.03	105.0
34A	24	1025	435.2-444.9	9.1	1.54	11.1

	Date	Time	Danth	Length	Length	Dagouany
Core	1995)	(UTC)	(mbsf)	(m)	(m)	(%)
core	1775)	(010)	(most)	(111)	(111)	(~)
55X	24	1200	444.9-454.5	9.6	3.17	33.0
56X	24	1345	454.5-464.2	9.7	4.18	43.1
57X	24	1535	464.2-473.8	9.6	6.11	63.6
58X	24	1715	473.8-483.5	9.7	5.40	55.7
59X	24	1915	483.5-493.1	9.6	4.37	45.5
60P	24	2020	493.1-494.1	1.0	0.09	9.0
61X	24	2205	494.1-502.7	8.6	7.94	92.3
62X	24	2355	502.7-512.3	9.6	6.61	68.8
63X	25	0140	512.3-522.0	9.7	5.49	56.6
64X	25	0350	522.0-531.6	9.6	8.48	88.3
65X	25	0545	531.6-541.2	9.6	5.14	53.5
66X	25	0735	541.2-550.8	9.6	7.15	74.5
67X	25	0910	550.8-560.4	9.6	6.00	62.5
68X	25	1050	560.4-570.0	9.6	9.52	99.1
69X	25	1235	570.0-579.6	9.6	3.87	40.3
70P	25	1330	579.6-580.6	1.0	0.03	3.0
71X	25	1510	580.6-589.2	8.6	8.85	103.0
72X	25	1655	589 2-598 8	9.6	1.51	15.7
73X	25	1850	598 8-608 4	9.6	8 29	86.3
74X	25	2050	608 4-618 0	9.6	2.93	30.5
758	25	2245	618 0-627 6	96	73	76.10
768	25	0045	627 6 637 3	0.7	2.03	20.9
778	26	0245	637 3-646 0	0.6	4.74	40.4
798	26	0505	646.0-656.5	0.6	1.41	14.7
70X	26	0725	656 5 666 1	9.6	3.07	32.0
19A	26	0020	666 1 675 7	9.6	5.29	56.0
OUA	20	1125	675 7 695 4	9.0	0.31	06.0
01A	20	1135	695 4 605 0	9.1	9.51	90.0
82A 83X	26	1525	695.0-704.6	9.6	9.29	96.8
Coring totals	20	1020	07010 10110	702.3	547.57	78.0
164 005P						
11	26	2035	00.83	83	8 27	00.6
211	26	2035	160 25 5	0.5	0.27	100.0
211	20	0115	100.0 100.5	0.5	10.06	105.0
AW	27	1140	100.5 235.0	125.5	0.50	(Wash core)
5V	27	1245	225.0.244.6	125.5	0.30	(wash core)
SA 6V	27	1245	233.0-244.0	9.0	0.26	28.6
70	27	1915	244.0-254.2	9.0	2.75	20.0
/P	27	1015	200 5 214 2	1.0	0.95	180.0
ON	27	1920	309.3-314.3	4.0	9.09	189.0
94	27	2030	314.5-319.1	4.8	0.00	0.0
TUP	27	2125	319.1-320.1	1.0	0.05	05.0
11X	28	0545	410.0-417.8	1.8	5.47	70.1
12X	28	0725	417.8-427.4	9.0	3.12	32.5
13X	28	0900	427.4 437.0	9.0	4.53	47.2
14X	28	1040	437.0-446.6	9.0	0.00	0.0
15X	28	1225	446.6-456.3	9.7	6.59	67.9
Coring totals				104.4	61.27	58.7
Washing total	S			125.5	0.50	
Combined tot	als			229.9	61.77	

Notes: UTC = Universal Time Coordinated. An expanded version of this coring summary table that includes lengths and depths of sections, sampling comments, and locations of water-sampling temperature probe (WSTP) measurements is included on CD-ROM in the back pocket of this volume.

empty core liners and was present on the tools at the top of the liner.

The Davis/Villinger Temperature Probe was run for the first time af-

ery of a mudline. Eighteen APC cores (164-995A-1H through 20H) were taken from 0 to 165.2 mbsf, with 163.2 m cored and 168.6 m recovered (103% recovery). Two PCS cores (164-995A-9P and 18P) were taken in the APC hole, with a total of 2.0 m cored and 1.70 m recovered (85% recovery). Cores were oriented from Core 164-995A-3H. Adara temperature tool measurements were taken with a 10-min burial time at Cores 164-995A-2H, 4H, 6H, 10H, 13H, 16H, and 20H.

When liners were removed from the core barrel, gas voids were noted in the cores. Expansion of gas caused some cores to selfextrude from both the tops and bottoms of the liner. The core liner split along its full length on Core 164-995A-17H (145.2 mbsf), after which gassy core safety precautions were followed. APC coring was terminated when Core 164-995A-20H was a partial stroke, requiring 50,000 lb overpull, and the liner was crunched in the inner core barrel and had to be pumped out.

Cores 164-995A-21X through 83X, including nine PCS cores (see below), were taken from 165.2 to 704.6 mbsf. Very large gas voids were common, and core recovery was reduced by extensive extrusion of sediments from the core liners. Mud smeared the length of nearly

ter Cores 164-995A-20H and 33X and successfully recorded data during both runs (see "In Situ Temperature Measurements" section, this chapter). WSTP temperature and water samples were taken after Cores 164-995A-3H, 10H, 13H, 18P, 27P, 30X, 34X, 38X, 41X, and 46X. Nine PCS cores were taken at Cores 164-995A-9P, 18P, 27P, 36P, 45P, 48P, 52P, 60P, and 70P, with a total of 9.0 m cored and 4.56 m recovered (50.7% recovery). In addition, a borehole water sample was taken with the PCS after Core 164-995A-51X. The new PCS push-in-type shoes were run as deeply as possible on Hole 995A to establish their practical range of use, which appears

on Hole 995A to establish their practical range of use, which appears to be down to ~380 mbsf (in moderately indurated claystones requiring XCB drilling at 18,000 lb weight on bit [wob]). The shoes were pushed in with 5,000–18,000 lb weight to a depth of ~0.7 m (depending on the extension sub and formation induration) and then rotated at 10–40 rpm for 2 min to penetrate an additional ~0.3 m. The new PCS rotary auger-type bit was run three times in Hole 995A. The optimum parameters appeared to be 15,000 lb wob at 40 rpm with 150 A torque, circulating 200 gpm at 475–550 psi (to clean the larger bit). After drilling to 704.6 mbsf, Hole 995A was terminated. The hole was displaced with gel mud and the pipe was pulled, with the bit clearing the seafloor at 1308 hr on 26 November.

Hole 995B

The ship was moved 20 m north-northeast in dynamic positioning mode, and Hole 995B was spudded at 1520 hr on 26 November. The water depth was 2776.9 mbsf, based on recovery of a mulline. A single mulline core (164-995B-1H) was taken from 0 to 8.3 mbsf. The hole was drilled from 8.3 to 16.0 mbsf, and Core 164-995B-2H was taken from 16.0 to 25.5 mbsf. The hole was drilled from 25.5 to 100.0 mbsf, and Core 164-995B-3H was taken from 100.0 to 109.5 mbsf. A WSTP temperature measurement and water sample were taken, and the hole was then drilled ahead from 109.5 to 155.0 mbsf. The WSTP was run a second time, after which the hole was drilled from 155.0 to 200.0 mbsf. A third WSTP run was made, and the hole was then drilled ahead with a wash barrel to 235.0 mbsf.

Cores 164-995B-5X and 6X were taken from 235.0 to 254.2 mbsf (16% recovery) in an unsuccessful attempt to recover gas hydrate (gas hydrate was recovered from approximately this depth at Site 994). The hole was drilled ahead with a center bit to 308.5 mbsf. Core 164-995B-7P was taken from 308.5 to 309.5 mbsf. Two XCB half-length cores (164-995B-8X and 9X) were taken from 309.5 to 319.5 mbsf in an effort to obtain better recovery in the suspected gas hydrate–bearing zone (Hole 995A had 3% recovery at this depth). The two half-length cores had 94% recovery. Core 164-995B-10P was taken from 319.5 to 320.5 mbsf by pushing in the shoe (no rotation or circulation) and recovered 0.65 m of core. A center bit was used to drill from 320.5 to 410.0 mbsf. Five XCB cores (164-995B-11X through 15X) were taken from 410.0 to 456.3 mbsf. The hole was then drilled with a center bit from 456.3 to 700.0 mbsf.

A 35-bbl sepiolite mud sweep was circulated and a wiper trip was made to 100 mbsf to condition the hole for logs. A maximum overpull of 20,000 lb was encountered pulling out of the hole, with a maximum drag of 40,000 lb at 530 mbsf while running in. The hole was reamed from 530 to 700 mbsf with 25 m of fill on the bottom. The hole was displaced with sepiolite/seawater mud sweep. The pipe was pulled back to 106 mbsf, and the conical side-entry sub (CSES) was rigged up.

At 1130 hr on 28 November, the *Cape Hatteras* arrived on location to conduct a two-ship W-VSP experiment (see "Geophysics" section, this chapter). The WHOI triaxial VSP tool was run and had to be pumped out of the pipe with 250 gpm at 500 psi. The W-VSP was conducted for 27.75 hr with the *Cape Hatteras*. The VSP tool was clamped at 72-m intervals from 176 to 680 mbsf. The *Cape Hatteras* then conducted a seismic survey in the area before returning to Beaufort, N.C. The pipe was run in to 683 mbsf, and a ZO-VSP was run at 8-m station spacing from 662 to 144 m in 22 hr using the ship's guns. The VSP clamping arm stopped working, and the tool was pulled. A kink was found in the logging cable. About 50 m of logging cable was cut off, the cable was reheaded, and the VSP logs were finished at 0900 hr on 1 December.

A DITE/SDT/NGT/LDEO-TLT log was run from 337 to 660 mbsf without the CSES. The pipe was then pulled to 135 mbsf, and the logs were continued to 135 mbsf. HLDT/CNT-G/NGT, GLT, and FMS logs were run to 660 mbsf without problems. The LDEO-SST also was deployed. The logs required 41.5 hr. Hole 995B was then terminated, the pipe was pulled, and the bit cleared the rotary table on the rig floor at 1150 hr on 3 December.

LITHOSTRATIGRAPHY

Introduction

Hole 995A at Site 995 was continuously cored to 704.6 mbsf, and a nearly complete Holocene to uppermost Miocene section was recovered. Intermittent coring in Hole 995B recovered a few short intervals of sediment ranging in age from Holocene to early Pliocene. Three lithostratigraphic units are recognized in Hole 995A on the basis of sediment composition, primarily variations in the nannofossil, diatom, and total carbonate contents. Color-reflectance measurements (VIS 400–700 nm) also exhibit changes corresponding to unit boundaries (Fig. 3).

Unit I

Interval: 164-995A-1H-1, 0 cm, through 3H-2, 65 cm Age: Holocene to late Pleistocene Depth: 0–13.4 mbsf

Unit I consists of interbeds of light gray (5Y 6/1 to 5Y 5/1) and light greenish gray to greenish gray (5G 6/1 to 5/1 and 5GY 6/1 to 5/1) foraminifer-bearing nannofossil clay and foraminifer-bearing nannofossil-rich clay. The subtle color changes appear to be caused primarily by downhole variations in the biogenic carbonate content. To a lesser extent, trace amounts of disseminated glauconite give some intervals a more greenish hue. Unit I is subdivided into two subunits on the basis of overall color and sediment composition.

Subunit IA

The uppermost 20 cm of the section (interval 164-995A-1H, 0–20 cm; 0–0.2 mbsf) consists of brown (10YR 5/3) bioturbated foraminifer-bearing nannofossil silty clay. A 1-cm-thick darker band (interval 164-995A-1H-1, 19–20 cm; 0.19–0.20 mbsf) marks the base of this subunit. Subunit IA in Hole 995A is equivalent to Subunit IA in Holes 994A, 994B, and 994C (Fig. 8, "Site 994" chapter, this volume).

Subunit IB

Subunit IB extends from 0.20 to 13.4 mbsf (interval 164-995A-1H-1, 20 cm, through 3H-2, 65 cm) and consists primarily of alternating beds of light greenish gray to greenish gray (5GY 6/1 to 5GY 5/1 and 5G 6/1 to 5G 5/1) bioturbated foraminifer-bearing nannofossilrich clay, nannofossil-rich clay, and nannofossil clay. Total carbonate content (expressed as weight percentage CaCO₃; see "Organic Chemistry" section, this chapter) ranges from 25 to 50 wt%.

The top of this subunit is characterized by a slightly bioturbated gray (5Y 5/1) to dark gray (N4) foraminifer-bearing nannofossil-rich clay (interval 164-995A-1H-1, 20 cm, through 2H-2, 40 cm [0.2–3.65 mbsf]) with a sharp, angular, basal contact. The rest of the subunit consists of lighter greenish gray, moderately to intensely bioturbated, foraminifer-bearing nannofossil and nannofossil-rich clay. Bioturbation is most intense at the lithologic contacts where burrows are filled with the overlying sediment. Bioturbation is less obvious in the slightly darker gray to greenish gray (5Y 5/1 and 5GY 5/1) nannofossil-rich clay. Beds of medium-grained foraminifer ooze, as thick as 5 cm, occur in both the darker and lighter clay (i.e., intervals 164-995A-2H-3, 84–91 cm, and 2H-6, 50–55 cm) and commonly exhibit irregular, scoured bases. Medium-grained foraminifer ooze also occurs as burrow infillings (i.e., intervals 164-995A-2H-4, 116–120 cm, and 2H-5, 23–26 and 75–80 cm).

Unit II

Interval: 164-995A-3H-2, 65 cm, through 16H-5, 75 cm Age: late Pleistocene to late Pliocene Depth: 13.4–131.9 mbsf

The top of Unit II is placed at the base of the lowermost bed of light greenish gray nannofossil clay (5GY 6/1 and 5Y 6/1) in Unit I and is coincident with decreases in nannofossil abundance, total carbonate content, and color reflectance (Fig. 3). The sediments consist primarily of greenish gray (5Y 5/1 and 5GY 5/1) nannofossil-rich clay and nannofossil-bearing clay. Some intervals are also foramini-



Figure 3. Composite stratigraphic section for Site 995 showing core recovery, a simplified summary of lithology, lithologic unit boundaries, and age. Also shown are the total carbonate contents expressed as CaCO₃ weight percentage (see "Organic Geochemistry" section, this chapter) and color reflectance of sediments across the visible spectrum (VIS 400–700 nm) down Hole 995A. Lithologic symbols are explained in Figure 2 of the "Explanatory Notes" chapter (this volume).

fer bearing. The total carbonate content ranges from 8 to 68 wt% (see "Organic Chemistry" section, this chapter). This unit is subdivided into Subunits IIA and IIB on the basis of carbonate contents, bed thicknesses, and nannofossil and diatom abundances. Average carbonate content is higher in Subunit IIA (33 wt%) than in Subunit IIB (17 wt%). Below 40 mbsf (Cores 164-995A-6H through 16H), gas expansion has disrupted the sediment and created numerous voids and horizontal expansion cracks.

Subunit IIA

Subunit IIA extends from 13.4 to 48.25 mbsf (interval 164-995A-3H-2, 65 cm, through 6H-6, 105 cm) and consists predominately of interbedded bioturbated gray and greenish gray (5Y 5/1 and 5GY 5/1) nannofossil-rich clay. Individual beds are decimeters to meters thick. Total carbonate content ranges from 14 to 68 wt% (Fig. 3; see "Organic Chemistry" section, this chapter). The highest carbonate contents are found in dolomite-rich beds in intervals 164-995A-5H-5, 45–150 cm (41.07–42.12 mbsf); 6H-1, 132–144 cm (42.95–43.07 mbsf); 6H-3, 21–28 cm (48.0–48.07 mbsf); 6H-6, 78–90 cm (48.6–48.72 mbsf); and in beds and burrows of medium-grained foraminifer ooze similar to those observed in Unit IB (Fig. 4).

Three beds of reddish gray (5YR 6/1) foraminifer-rich nannofossilrich clay, ranging in thickness from 7 to 30 cm, occur in intervals 164-995A-5H-1, 37–44 cm (30.57–30.64 mbsf); 5H-3, 80–110 cm (34.0– 34.30 mbsf); and 5H-4, 72–88 cm (35.42–35.58 mbsf). These beds resemble the graded weak red (2.5YR 5/2) foraminifer-bearing nannofossil-rich clay bed in interval 164-994C-2H-1, 46–62 cm (see "Lithostratigraphy" section, "Site 994" chapter, this volume). At Site 995, however, these reddish units are less distinct, more gray in color, and not graded.

Subunit IIB

Subunit IIB extends from 48.25 to 131.9 mbsf (interval 164-995A-6H-6, 105 cm, through 16H-5, 75 cm) and is marked by the consistent



Figure 4. Winnowed bed of coarse-grained foraminifer ooze (70–83 cm) with scoured base (interval 995A-4H-2, 65–90 cm; 22.85–23.10 mbsf).

downhole appearance of diatoms (Fig. 5). This subunit consists of interbeds of greenish gray (5GY 5/1, 5Y 5/1, and 5GY 4/1) diatom-rich nannofossil-rich clay and slightly lighter colored greenish gray (5GY 5/1 and 6/1) nannofossil-rich clay, and nannofossil-bearing clay. The thicknesses of individual beds range from 0.5 to 9.0 m. Interbeds are less abundant than in Subunits IB and IIA. Total carbonate content

Figure 5. Downhole mineralogical variation of the major sediment constituents, based on visual estimation in smear slides.

ranges from 8 to 33 wt%, with maximum values associated with beds of foraminifer ooze (intervals 164-995A-8H-1, 30–34 cm, and 13H-5, 55–60 cm) and dolomite (interval 164-995A-10H-4, 63–66 cm; Fig. 3; see "Organic Geochemistry" section, this chapter). Bioturbation varies from slight to moderate throughout this unit.

Two 5-cm-thick winnowed beds of medium-grained foraminifer ooze occur at intervals 164-995A-8H-1, 30–34 cm (59.0–59.04 mbsf), and 13H-5, 55–60 cm (104.3–104.35 mbsf). These winnowed beds are probably similar in origin to the common beds of foraminifer ooze found in Subunits IB and IIA. Pyrite nodules and pyritized burrows occur in Section 164-995A-11H-1 at 30 cm (79.0 mbsf), 75 cm (79.45 mbsf), and 105 cm (79.75 mbsf), and at 11H-2, 60 cm (80.8 mbsf). Disseminated sulfides are continuously present (3% to 5% by smear-slide estimates) below 78.70 mbsf.

One dolomite-rich nodule is observed in interval 164-995A-10H-2, 36-41 cm (70.06–71.1 mbsf). A light brownish gray (10YR 6/2) dolomite-rich bed (Fig. 6) is found in interval 164-995A-10H-4, 63-66 cm (74.33–74.36 mbsf). Two centimeter-sized dolomite-rich nodules (Fig. 5) occur in interval 164-995A-10H-4, 20-30 cm, and at 10H-2, 39 cm (73.9–74.0 and 71.09 mbsf, respectively). Because Section 164-995A-10H-4 has experienced flowage associated with drilling disturbance (see whole-core photo in Section 4, this volume), these nodules and the dolomite bed have been displaced upward and cannot be considered in place.

Unit III

Interval: 164-995A-16H-5, 75 cm, through 83X-CC, 19 cm Age: late Pliocene to late Miocene Depth: 131.9–704.6 mbsf

Unit III is a 572.7-m-thick succession of homogeneous dark greenish gray to dark gray (5GY 4/1 to 5Y 4/1) diatom- and nannofossil-bearing clay and claystone and diatom-bearing nannofossilrich clay and claystone. The top of this unit (164-995A-16H-5, 75 cm; 131.9 mbsf) is marked by a significant drop in total carbonate content (see "Organic Geochemistry" section, this chapter), nannofossil abundance, and color reflectance (Fig. 3). Increases in the abundance of clay and diatoms coincide with this boundary. Total carbonate content ranges from 8 to 30 wt% (Fig. 3; see "Organic Geochemistry" section, this chapter). The variations in CaCO₃ correlate closely with the downhole abundances of nannofossils. Bioturbation is slight to moderate throughout this unit.

The sediments exhibit gradual lithification downhole, with the transition from clay to claystone occurring at ~416 mbsf. The sediment becomes distinctly more fissile with depth. High-angle to vertical fractures first appear in Section 164-995A-24X-1, 20 cm (194 mbsf), and are rare to the base of Core 164-995A-48X (397.8 mbsf). Fractures are common to abundant from Core 164-995A-9X to the bottom of the hole. Individual fractures are commonly traceable across several successive drilling biscuits, which suggests that they are primary structures and were not created by drilling disturbance (see "Lithostratigraphy" section, "Site 994" chapter, this volume).

Sediments within intervals 164-995A-16H-5, 0 cm, to 31X-1, 0 cm (131.9 to 252.3 mbsf), and 59X-1 to 79X-1 (464.2 to 656 mbsf) are diatom-bearing clay and diatom-rich clay. Total carbonate and

nannofossil contents in these intervals range from 8 to 20 wt%. In contrast, sediments in intervals 164-995A-31X-1, 0 cm, through 57X-1, 0 cm (252.3–464.2 mbsf), and 79X-1, 0 cm, through 83X-CC, 19 cm (656.0–704.6 mbsf), are characterized by nannofossil-bearing clay and nannofossil-rich clay and claystone. Total carbonate and nannofossil contents range from 10 to 30 wt%.

Foraminifers are concentrated within burrows and some laminae at 164-995A-35X-4, 44 cm (295.20 mbsf), in Section 40X-1 (329.30–330.64 mbsf), and in interval 50X-6, 55–70 cm (414.45–414.60 mbsf), as well as in the more diatom-rich intervals 62X-2, 98–105 cm (504.92–504.99 mbsf), and 62X-3, 12–18 cm (505.56–505.62 mbsf), and at 65X-2, 52 cm (533.62 mbsf), 65X-3, 127 cm (535.87 mbsf), 66X-2, 45 cm (542.42 mbsf), and 66X-4, 25 cm (545.11 mbsf). Two clay-rich carbonate layers occur in intervals 164-995A-71X-6, 141–143 cm (588.75–588.77 mbsf), and 71X-CC, 47–49 cm (589.31–589.33 mbsf). Discontinuous carbonate-rich laminae are present in the interval 164-995A-81X-5, 77–78 cm, and at 94 and 98 cm (682.47–682.48, 682.64, and 682.68 mbsf, respectively); in interval 81X-6, 44–48 cm, and at 85 and 100 cm (683.64–683.68, 684.05, and 684.20 mbsf, respectively); and throughout Sections 164-995A-82X-2, 3, and 4 (685.98–690.48 mbsf).

Sediment Composition Based on Smear-Slide and XRD Analyses

The dominant mineral components of Unit I are clay minerals, calcite, and quartz (Fig. 7). Feldspars and dolomite are minor components (Fig. 7; Table 2). The biogenic calcareous constituents (Fig. 5) consist of nannofossils (15%–40%) and minor amounts of foraminifers. Siliceous microfossils are represented by diatoms (<5%), sponge spicules, and silicoflagellates. Clay minerals and nannofossils make up most of the clay-sized fraction. Quartz and feldspars dominate the silt fraction. Abundances of quartz and feldspar, as shown by XRD, indicate that they are underrepresented in smear slides and may be present in the clay-sized fraction (Fig. 7). Sand-sized particles generally comprise less than 5% of the sediment and are composed largely of foraminifers and, to a lesser extent, pteropods. On the basis of smear-slide estimates, concentrations of foraminifers reach 50% in foraminifer-ooze beds and foraminifer-filled burrows. Disseminated

Figure 6. Slightly indurated dolomitic bed (63–66 cm; 74.33–74.36 mbsf). Drilling disturbance has caused flowage through the center of the core, resulting in upward displacement of the central portion of this bed; thus, nei-ther the nodules nor the bed should be considered in place (interval 164-995A-10H-4, 56–68 cm; 74.26–74.38 mbsf).

Figure 7. Downhole mineralogical variation of the major sediment constituents, based on XRD analysis. Quartz, calcite, and dolomite contents are expressed in weight percentage (see "Explanatory Notes" chapter, this volume). The relative abundances of clays, feldspars, pyrite, and siderite are given as integrated peak intensities.

Table 2. Main diffraction peak areas, d-values, and weight percent proportions for minerals identified in samples from Hole 995A.

Core, section, interval (cm)	Depth (mbsf)	Quartz (101) peak area	Clay 4.4–4.6 Å peak area	Feldspars 3.26–3.18 Å peak area	Calcite (104) d-value (Å)	Calcite (104) peak area	Dolomite (104) d-value (Å)	Dolomite (104) peak area	Aragonite (111) peak area	Siderite (104) peak area	Pyrite (200) peak area	K-spar 3.27 Å peak area	Plagioclase 3.21 Å peak area	Quartz* (wt%)	Calcite* (wt%)	Dolomite* (wt%)
164-995A-																
2H-2, 70-71	3.95	9,468	2,315	2.045	3.035	21,104	2.886	736	1.848			1,406	2,055	7	55	1
2H-3, 88-89	5.68	18,297	2,491	2,243	3.037	15,346	2.892	1.885	429			736	1,814	13	33	2
2H-4, 61-62	6.96	7,863	2,208	2,043	3.035	18,300	2.888	1.133	2,881			2,135	2,207	6	44	1
3H-2, 80-81	13.55	12,675	2,611	4,932	3.035	15.266	2.886	1.601	480				4,156	9	33	1
3H-5, 80-81	18.10	13,435	2,558	6.211	3.036	12,119	2.893	1,440				1.798	4,926	10	23	1
4H-2, 60-61	22.80	9,871	2,075	4,441	3.034	18,505	2.895	4,804	1,807			1,712	2,627	7	44	5
4H-4, 60-61	25.80	11.178	2,513	7.354	3.034	7.621	2.893	2,450			634	1,080	2,466	8	12	2
5H-2, 79-80	31.00	12,002	2,494	8,376	3.035	7.647	2.894	2,450			1,121	1,931	5,226	9	12	2
5H-4, 79-80	37.00	18,947	2,288	3,124	3.032	4,964	2.899	24,200			673	831	2,102	14	7	25
5H-7, 39-40	39.59	10,946	2,470	6,426	3.034	9,303	2.900	1,093			1,093			8	16	1

Note: K-spar = potassium feldspar. * = percentages (wt%) for quartz, calcite, and dolomite are calculated using the calibration curves described in the "Lithostratigraphy" section of the "Explanatory Notes" chapter (this volume).

Only part of this table is produced here. The entire table appears on the CD-ROM (back pocket).

dolomite rhombs (15–30 μ m) make up 1%–2% of the bulk mineralogy (Fig. 5). The d-spacing of the (104) diffraction peak ranges from 2.886 to 2.892 Å (Table 2), which is close to the d-spacing of stoichiometric dolomite (2.886 Å). Glauconite is present in trace amounts.

Clay minerals, calcite, and quartz also are the dominant mineral components in Unit II (Figs. 5, 7; Table 2). Clay mineral content increases sharply at the boundary between Units I and II. Nannofossil abundances (15%) are generally less than in the Unit I. Foraminifer contents reach as much as 45% in foraminifer ooze beds. Diatom contents may reach 15%, but on average remain below 5%. As in Unit I, quartz and feldspars generally occur in the silt-sized fraction, which also contains siliceous microfossils, foraminifers, dolomite, siderite, and pyrite. Quartz shows an overall increase within this unit, whereas contents of feldspars decrease toward the boundary with Unit III. Both K-feldspar and plagioclase were identified on the X-ray diffractograms (Table 2). Dolomite, siderite, pyrite, and feldspars are minor components of Unit II. The clay-sized fraction is dominated by clay minerals and nannofossils.

The first appearance of pyrite in XRD patterns occurs at 26 mbsf, although disseminated sulfides resembling pyrite are continuously observed in smear slides from 164-995A-2H-5, 77 cm (8.67 mbsf). Within this unit, there is a general downward increase in disseminated sulfides and carbonate rhombs. Disseminated carbonate rhombs, $5-15 \mu m$ in diameter, are common but generally make up only 1%– 3% of the bulk sediment. Dolomite is dominant in nodules and thin beds (intervals 164-995A-6H-1, 138–142 cm; 6H-3, 21–28 cm; and 6H-6, 78–90 cm) in Subunit IIA (Fig. 8) but occurs only in trace amounts in Subunit IIB. The d-spacing of the (104) diffraction peak ranges from 2.886 to 2.903 Å, which is indicative of compositions reflecting both stoichiometric and nonstoichiometric dolomite. Siderite becomes the dominant diagenetic carbonate phase below 89.17 mbsf but remains low in abundance throughout Unit II.

In Unit III, clay minerals, calcite, and quartz are the major mineral components, whereas dolomite, siderite, pyrite, and feldspars represent minor components (Fig. 7; Table 2). Nannofossil abundance ranges from 5% to 20%. Diatom content varies systematically in Unit III, exhibiting high values (5%-20%) in two intervals: 164-995A-16H-5 through 31X-1 (131.9-252.3 mbsf) and 57X through 79X (464.2-656 mbsf). Clay minerals and nannofossils make up most of the clay-sized fraction. Quartz (averaging 12% by XRD estimates) and feldspars (estimated 1%-2% by smear-slide observation) vary little in abundance throughout this unit. Diagenetic carbonate rhombs are disseminated throughout the sediment, and their abundances range from 2% to 8% based on smear-slide estimations (Fig. 5). These rhombs probably correspond to siderite because XRD analyses indicate that dolomite only occurs in trace amounts, whereas siderite becomes the dominant authigenic phase below 50 mbsf (Fig. 7). Siderite occurs in carbonate-rich laminae in intervals 995A-81X-5, 75-

Figure 8. Clayey dolomite-rich bed (81–89 cm) containing ~20% authigenic carbonate rhombs (interval 164-995A-6H-6, 73–93 cm; 47.93–48.13 mbsf).

94 cm, and 81X-6, 44-100 cm (682.45-682.64 and 683.64-684.20 mbsf). Siderite is disseminated within the sediment in higher concentrations (12% to 15%) in Cores 164-995-31X, 39X, and 42X (Fig. 5). On the basis of smear-slide estimates, pyrite is consistently present in minor amounts (<5%, as estimated from smear slides).

Discussion

Site 995 is located on the Blake Ridge only 3.0 km from Site 994 (see "Background and Objectives" section, this chapter). The sediments and lithologic units at this site, therefore, are very similar to those of Site 994 (see "Lithostratigraphy" section, "Site 994" chapter, this volume). Deposition is dominated by hemipelagic accumulation of biogenic and terrigenous sediments, modified and reworked by contour currents associated with the Western Boundary Undercurrent (WBUC) (Heezen et al., 1966). As at Site 994 (see "Lithostratigraphy" section, "Site 994" chapter, this volume), long-distance transport of sediment is indicated by the reddish grav (5YR 6/1) nannofossilrich clay found within Unit II at 30.6, 34.0, and 35.4 mbsf. These reddish sediments were apparently derived from the Carboniferous red beds of eastern Canada during Pleistocene glacial periods and then transported southward by the WBUC (Needham et al., 1969). These exotic red sediments are more diluted at Site 995 than at Site 994 and are apparently equivalent to the gray lutite with rose-colored hue described by Heezen et al. (1966). Fluctuations in nannofossil content of interbeds in the upper 130 m of this section probably reflect changes in the flux of terrigenous components and/or in carbonate productivity associated with glacial-interglacial climatic changes. This is evidenced by the brown nannofossil clay of Subunit IA, which apparently records the decrease of terrigenous sediment supply to the Atlantic in response to Holocene sea-level rise (see "Lithostratigraphy" section, "Site 994" chapter, this volume). Increased diatom abundances in Unit III suggest higher productivity, and/or enhanced WBUC flow, during late Miocene to early and late Pliocene times.

GAS HYDRATE

Although a strong and distinct BSR occurs at Site 995 (~0.54 s below the seafloor), we did not confidently identify gas hydrate in any of the recovered cores. However, the extensive set of chemical and thermal data indicates that gas hydrate is present within a significant section of the cored sequence at Site 995. Based on this evidence, we conclude that disseminated gas hydrate had largely dissociated during core inspection and was so fine grained that it was difficult to visually detect.

Initial Core Inspections

All cores were inspected on the catwalk for indications of gas hydrate, such as the presence of white nodules, fizzing sediment, or unusually cold spots. The following cores are the only ones in which the presence of gas hydrate was suspected on the basis of these initial inspections.

When Sections 164-995A-29X-1 and 29X-2 were inspected on the catwalk, a through-the-liner temperature probe showed a 4.5° C reading. The liners in both sections of the core were split so that half of the liner could be removed. Thus, the surface of the core could be examined although the sediment itself was not split. Temperature probe measurements were made every few centimeters along these sections. Most of the core was determined to have temperatures in the 9°-11°C range. However, three zones of distinctly colder temperatures were found: interval 164-995A-29X-1, 60-70 cm, ranged from 5.6° to 4.3° C; interval 29X-1, 135-142 cm, was as cold as 3.8° C; and interval 29X-2, 13-17 cm, was as cold as 7.5° C. Several pieces of the core from these zones were cut out and broken apart for hand inspection. A few submillimeter-sized white specks were seen on the fresh surfaces. However, frequent white specks also were noted during the lithologic description of cores from this depth interval (lithologic Unit III; see "Lithostratigraphy" section, this chapter). Thus, gas hydrate was not identified with confidence.

During the initial inspection of Core 164-995A-30X on the catwalk, a through-the-liner temperature probe showed a 1°C reading in Section 164-995A-30X-1. This section was opened immediately (as described above for Core 164-995A-29X), and a transect of thermal measurements was run down the core. Figure 9 shows the result of the 20 measurements along Section 164-995A-30X-1 (242.7–244.2 mbsf). Section 30X-1 exhibited obvious and prominent temperature anomalies for the interval 60–110 cm, with a minimum value of 1°C, whereas the background value is estimated to be 10°–12°.

Core 164-995A-32X also had somewhat low temperature readings (7°C) on the catwalk, and Section 164-995A-32X-1 was opened immediately for closer inspection (as described above for Cores 164-995A-29X and 30X). The sediments were very cold to the touch, and when broken open, the broken surfaces appeared somewhat shiny, as if frozen. The sediment in contact with the liner was soupy (<1-cmthick zone) but was not fizzing. One 10-cm interval (164-995A-32X-1, 133-150 cm; 263.2 to 263.5 mbsf) of this "frozen" core was cut out and placed in a pressure vessel (Fig. 10, "Explanatory Notes" chapter, this volume). After the core material was allowed to come room temperature (~20°C), the pressure did not increase, but the sediments inside the vessel became softer and partly soupy after the 10hr experiment. From these observations, we infer that the "frozen" sediments were not frozen by gas hydrate but by water-ice, and if gas hydrate was initially present in this sediment it had decomposed and cooled the core to below the freezing point of water before core inspection.

Core Slab Temperature Measurements

Surface temperatures of 20-cm-long slab samples were measured from interval 164-995A-2H-5, 135–155 cm (~9.2 mbsf), down to interval 56X-2, 130–150 cm (457.12 mbsf), in an attempt to observe low-temperature anomalies that might be caused by gas hydrate dissociation (see "Gas Hydrate" section, "Explanatory Notes" chapter, this volume). Temperature anomalies were not confidently detected within any of the 36 measured slabs (Table 3). Several slabs showed variable temperature distributions, but the fluctuations were less than 3°C, which could be a result of core surface irregularities. The lack of obvious temperature anomalies within the slab samples from Site 995 may suggest that either the spotlike low-temperature anomalies were weakened, homogenized, and erased during core cutting and splitting processes or that the entire 20-cm-long slab was uniformly cooled as a result of dissociation of homogeneously distributed gas

Figure 9. Temperature measurement vs. depth along Section 164-995A-30X-1 shortly after being split to examine for gas hydrate. Temperatures were measured from the top to the bottom of the core.

hydrate. A 20-cm slab may not be long enough to adequately sample temperature anomalies along the core.

Downhole Profile of Core Temperatures

Catwalk core temperatures (see "Gas Hydrate" section, "Explanatory Notes" chapter) were measured on 27 selected cores from Hole 995A and six cores from Hole 995B (Tables 4, 5; Fig. 10). The scarcity of data between 280 and 370 mbsf was due to poor core recovery. Also included in Figure 10 are the initial temperatures of cores that were used in the gas-collection chamber experiments (see "Gas Hydrate" section, "Site 994" chapter, this volume) (Table 6). Although these temperatures were measured with a different technique and at a different time after core recovery, the majority of the data cluster near $12.5^{\circ} \pm 2^{\circ}$ C, and strong low-temperature anomalies are evident for the intervals between 250-270 and 350-450 mbsf. Temperature anomalies coincide with two zones of pronounced negative chloride anomalies (see "Inorganic Geochemistry" section, this chapter). It is notable that low-temperature anomalies and negative chloride anomalies exhibit good positive correlation (see "Inorganic Geochemistry" section, this chapter). The lower limit of the deeper anomaly zone matches well with the decrease in electrical resistivity and acoustic velocity data recorded by downhole logging (see "Downhole Logging" section, this chapter). The anomalously low core temperatures measured for cores from the zone of gas hydrate occurrence may either indicate areas where gas hydrate has recently decomposed or areas where the effects of adiabatic gas expansion were concentrated during core recovery.

Gas-Collection Chambers

The volumes of gas that evolved from sediments while they warmed to room temperature were measured by placing 1.5-m whole-core sections into sealed chambers, referred to as gas-

Table 3. Average and minimum temperatures for individual slab samples from Hole 995A.

	Temp	erature	
Core	Average (C°)	Minimum (C°)	Depth (mbsf)
64-995A-			
2H	12.3	11.6	10.2
3H	15.1	14.4	19.7
4H	13.2	12.3	29.2
5H	12.6	12.0	38.7
6H	12.3	11.7	48.2
7H	12.8	12.1	57.7
8H	12.6	12.1	67.2
10H	14.9	13.9	77.7
11H	12.5	11.7	87.2
12H	12.9	12.3	96.7
13H	13.1	12.4	106.2
14H	13.4	12.5	115.7
15H	14.1	13.4	125.2
16H	14.8	14.1	134.7
17H	16.1	15.3	144.2
19H	14.2	13.2	154.7
21X	12.5	11.3	173.8
22X	14.1	13.4	183.4
23X	12.0	11.2	193.0
25X	11.4	10.4	212.3
26X	14.1	13.1	221.9
30X	11.0	9.7	251.3
31X	11.9	10.9	260.9
33X	14.0	11.9	280.1
35X	12.8	11.8	299.3
42X	12.3	11.1	357.2
43X	12.0	10.7	366.9
47X	13.3	12.0	395.8
49X	14.0	13.0	405.4
53X	12.5	11.1	434.2
54X	14.0	12.3	443.9
55X	14.7	14.0	453.5
56X	15.0	14.0	463.2

collection chambers (see "Gas Hydrate" section, "Explanatory Notes" chapter, this volume). Table 6 gives the total measured volume of gas that evolved from individual core sections and the calculated volumes of gas that evolved per liter of interstitial water, based on measured water contents (see "Physical Properties" section, this chapter).

Measurable volumes of evolved gas first occur in core sections from below the base of the sulfate reduction zone (see "Inorganic Geochemistry" section, this chapter). Although the values rise erratically, the general pattern is an increase in gas volume downward throughout the APC cores (Fig. 11). These are minimum values for the cores, which expanded considerably before they were received on the catwalk and were observed to release gas before they could be placed in the chambers. However, the concentration of gas in these cores dropped abruptly when APC coring was terminated and XCB coring started (i.e., Section 164-995A-21X-1). The data suggest that the abrupt decrease in gas concentrations at depths >160 mbsf is an artifact of the XCB coring process. However, the amounts of gas that are measured in the upper 160 mbsf with the gas-collection tubes are small in comparison with the amount of methane that is required to saturate the waters under in situ conditions (see Fig. 22, "Site 994" chapter, this volume).

Hydrate Occurrence

Gas hydrate that is inferred to exist at Site 995 is thought to occur as fine-grained, pore-filling accumulations that are widely dispersed in the host sediments rather than as concentrated nodules that are large enough to survive the coring process.

BIOSTRATIGRAPHY

Nannofossil biostratigraphy was studied only in Hole 995A. Out of 83 cores from this hole, nine were PCS cores. Although sediments were recovered successfully in most of the PCS cores, nannofossils from these materials were not studied, and the shipboard biostratigraphy was restricted to the remaining 18 APC and 56 XCB cores. In

Table 4. Average and minimum temperatures	of	cores	from	Holes	995A
as measured on the catwalk immediately after	rec	covery			

		Temp	erature	
Core	Measurements	Average (C°)	Minimum (°C)	Depth (mbsf)
164-995A				
32X	13	10.2	8.5	271.5
44X	3	9.5	9.0	377.5
46X	8	11.4	9.9	387.1
53X	5	10.0	9.6	435.2
54X	10	8.4	5.2	444.9
55X	7	10.4	8.6	454.5
56X	9	12.0	10.1	464.2
57X	7	11.6	11.0	473.8
58X	5	12.6	11.3	483.5
61X	7	13.8	13.3	502.7
62X	4	14.4	13.1	512.3
63X	4	13.7	13.0	522.0
64X	4	13.3	12.3	531.6
67X	3	14.1	13.8	560.4
68X	5	13.1	12.3	570.0
69X	4	13.3	12.1	579.6
71X	3	14.0	13.3	589.2
74X	3	14.6	14.5	618.0
75X	3	13.0	12.1	627.6
76X	3	15.1	14.6	637.3
77X	5	14.3	13.1	646.9
78X	3	15.8	13.9	646.1
79X	3	12.9	12.7	666.1
80X	4	14.9	13.9	675.7
81X	12	13.1	12.5	684.6
82X	4	12.6	11.3	695.0
83X	5	13.3	12.0	704.6

Table 5. Temperatures of cores from Hole 995B as measured on the catwalk immediately after recovery.

$ \begin{array}{c c c c c c c c c c c c c c c c c c c $						
164-995B- $12X$ 424.4 11.6 $6X$ 245.2 9.9 $12X$ 425.0 13.0 $6X$ 245.5 9.3 $12X$ 425.0 13.0 $6X$ 245.5 9.3 $12X$ 425.0 13.0 $6X$ 245.8 11.6 $12X$ 425.6 9.5 $6X$ 246.1 8.6 $12X$ 426.2 8.6 $6X$ 246.7 10.4 $12X$ 426.2 8.6 $6X$ 247.3 10.2 $12X$ 426.5 8.4 $6X$ 247.3 10.2 $12X$ 426.8 9.7 $6X$ 247.3 10.2 $12X$ 426.8 9.7 $6X$ 247.3 10.2 $12X$ 426.8 9.7 $6X$ 310.7 13.0 $13X$ 432.8 8.8 $8X$ 311.3 12.8 $13X$ 434.0 12.7	Core	Depth (mbsf)	Temperature (C°)	Core	Depth (mbsf)	Temperature (C°)
6X244.910.712X424.713.86X245.29.912X425.013.06X245.59.312X425.311.26X245.811.612X425.97.16X246.18.612X425.97.16X246.710.412X426.58.46X247.09.412X426.89.76X247.09.412X426.89.76X247.09.412X426.89.76X247.013.013X432.512.88X310.113.413X432.512.88X310.414.213X433.110.18X311.013.213X433.710.08X311.312.813X434.313.18X313.116.813X434.612.78X313.710.413X435.512.68X314.010.413X435.512.68X314.69.613X436.112.28X315.89.315X447.313.38X316.710.715X447.611.58X315.89.315X447.313.38X316.710.715X447.611.58X315.89.315X447.313.38X316.710.715X448.216.	164-995B-			12X	474.4	11.6
bx 245.2 9.0 $12X$ 424.7 13.0 6X 245.5 9.3 $12X$ 425.0 13.0 6X 245.8 11.6 $12X$ 425.6 9.5 6X 246.1 8.6 $12X$ 425.6 9.5 6X 246.8 10.2 $12X$ 426.2 8.6 6X 247.0 9.4 $12X$ 426.5 8.4 6X 247.0 9.4 $12X$ 426.5 8.4 6X 247.0 9.4 $12X$ 426.5 8.4 6X 247.3 10.2 $12X$ 427.1 13.3 8X 310.4 14.2 $13X$ 432.8 8.8 8X 310.7 13.0 $13X$ 433.1 10.4 8X 311.3 12.8 $13X$ 433.1 10.4 8X 311.6 13.1 $13X$ 434.0 12.4 8X 313.1 16.8 $13X$ 434.6 12.7 8X 313.4 17.7 $13X$ 434.6 12.7 8X 314.0 10.4 $13X$ 435.5 12.6 8X 314.6 9.6 $13X$ 435.5 12.6 8X 314.6 9.6 $13X$ 436.4 11.8 8X 315.8 9.3 $15X$ 476.6 11.9 8X 316.1 15.0 $15X$ 447.6 11.5 8X 316.1 15.0 $15X$ 447.6 11.5 8X 316.7 1	6V	244.0	10.7	122	124.7	12.9
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8χ 310.1 13.4 13χ 432.5 12.8 8χ 310.4 14.2 13χ 432.5 12.8 8χ 310.7 13.0 13χ 433.1 10.1 8χ 311.0 13.2 13χ 433.4 10.4 8χ 311.3 12.8 13χ 433.4 10.4 8χ 311.3 12.8 13χ 433.4 10.4 8χ 312.2 12.8 13χ 434.3 13.1 8χ 313.1 16.8 13χ 434.6 12.7 8χ 313.1 16.8 13χ 434.6 12.7 8χ 313.7 10.4 13χ 435.2 12.6 8χ 314.0 10.4 13χ 435.2 12.6 8χ 314.6 9.6 13χ 436.1 12.2 8χ 314.5 8.7 13χ 436.1 12.2 8χ 314.6 9.6 13χ 436.1 12.2 8χ 314.5 8.7 13χ 436.1 12.2 8χ 316.1 15.0 15χ 447.3 13.3 8χ 316.1 15.0 15χ 447.6 11.5 8χ 317.0 11.5 15χ 448.2 16.5 8χ 317.0 11.5 15χ 449.1 13.2 8χ 317.0 11.5 15χ 449.1 13.2 8χ 317.0 11.5 15χ 450.0 <td< td=""><td>6X</td><td>247.3</td><td>10.2</td><td>12X</td><td>427.1</td><td>13.3</td></td<>	6X	247.3	10.2	12X	427.1	13.3
8X310.414.213X432.88.88X310.713.013X433.110.18X311.013.213X433.710.08X311.613.113X433.410.48X311.613.113X434.012.48X312.212.813X434.313.18X313.116.813X434.612.78X313.417.713X434.612.78X313.410.413X435.212.68X314.010.413X435.512.68X314.69.613X436.112.28X314.69.613X436.112.28X314.58.713X436.112.28X315.58.713X436.411.88X315.58.713X436.411.58X316.115.015X447.313.38X316.115.015X447.611.58X316.710.715X448.216.58X317.011.515X448.512.68X317.611.315X450.013.48X318.210.715X449.113.28X317.611.315X450.013.48X318.210.715X449.113.28X316.715X450.013.4 </td <td>8X</td> <td>310.1</td> <td>13.4</td> <td>13X</td> <td>432.5</td> <td>12.8</td>	8X	310.1	13.4	13X	432.5	12.8
8χ 310.7 13.2 13χ 433.1 10.1 8χ 311.0 13.2 13χ 433.4 10.4 8χ 311.3 12.8 13χ 433.4 10.4 8χ 311.6 13.1 13χ 434.0 12.4 8χ 312.2 12.8 13χ 434.0 12.4 8χ 312.2 12.8 13χ 434.3 13.1 8χ 313.1 16.8 13χ 434.9 12.4 8χ 313.7 10.4 13χ 435.2 12.6 8χ 314.0 10.4 13χ 435.5 11.9 8χ 314.6 9.6 13χ 436.1 12.2 8χ 314.6 9.6 13χ 436.7 11.9 8χ 315.8 9.3 15χ 447.3 13.3 8χ 316.1 15.0 15χ 447.6 11.5 8χ 316.7 10.7 15χ 448.2 16.5 8χ 317.0 11.5 15χ 449.1 13.2 8χ 317.6 11.3 15χ 449.1 13.2 8χ 318.5 18.2 15χ 450.0 13.4 8χ 318.5 18.2 15χ 450.0 13.4 8χ 317.9 11.2 15χ 449.1 13.2 8χ 317.6 11.3 15χ 450.0 13.4 8χ 318.5 18.2 15χ 450.0 <t< td=""><td>8X</td><td>310.4</td><td>14.2</td><td>13X</td><td>432.8</td><td>8.8</td></t<>	8X	310.4	14.2	13X	432.8	8.8
baxb	8X	310.7	13.0	138	433.1	10.1
3x 311.3 13.2 $13x$ 433.4 10.0 $8x$ 311.6 13.1 $13x$ 433.7 10.0 $8x$ 312.2 12.8 $13x$ 434.3 12.4 $8x$ 313.1 16.8 $13x$ 434.3 12.7 $8x$ 313.4 17.7 $13x$ 434.9 12.4 $8x$ 313.7 10.4 $13x$ 435.5 12.6 $8x$ 314.0 10.4 $13x$ 435.5 12.6 $8x$ 314.3 9.0 $13x$ 435.8 11.9 $8x$ 314.6 9.6 $13x$ 436.4 11.8 $8x$ 314.6 9.6 $13x$ 436.4 11.8 $8x$ 315.5 8.7 $13x$ 436.7 11.9 $8x$ 315.8 9.3 $15x$ 447.3 13.3 $8x$ 316.1 15.0 $15x$ 447.6 11.9 $8x$ 316.7 10.7 $15x$ 448.2 16.5 $8x$ 316.7 10.7 $15x$ 448.2 16.5 $8x$ 317.0 11.5 $15x$ 449.7 17.1 $8x$ 317.6 11.3 $15x$ 449.7 17.1 $8x$ 318.5 18.2 $15x$ 450.0 13.4 $8x$ 412.4 9.6 $15x$ 450.6 14.1 $11x$ 413.0 9.1 $15x$ 451.5 12.3 $11x$ 413.6 7.3 $15x$ 451.5	ev	311.0	12.0	122	422.4	10.1
3X 311.5 12.6 $13X$ 435.7 12.4 $8X$ 312.2 12.8 $13X$ 434.0 12.4 $8X$ 312.2 12.8 $13X$ 434.3 13.1 $8X$ 313.1 16.8 $13X$ 434.3 13.1 $8X$ 313.1 16.8 $13X$ 434.9 12.4 $8X$ 313.7 10.4 $13X$ 435.2 12.6 $8X$ 314.0 10.4 $13X$ 435.2 12.6 $8X$ 314.0 10.4 $13X$ 435.5 11.9 $8X$ 314.6 9.6 $13X$ 436.1 12.2 $8X$ 314.6 9.6 $13X$ 436.1 12.2 $8X$ 314.6 9.6 $13X$ 436.7 11.9 $8X$ 315.8 9.3 $15X$ 447.3 13.3 $8X$ 316.1 15.0 $15X$ 447.6 11.5 $8X$ 316.7 10.7 $15X$ 448.2 16.5 $8X$ 317.0 11.5 $15X$ 448.2 16.5 $8X$ 317.0 11.2 $15X$ 449.1 13.2 $8X$ 317.9 11.2 $15X$ 449.1 13.2 $8X$ 318.2 10.7 $15X$ 449.1 13.2 $8X$ 318.2 10.7 $15X$ 449.1 13.2 $8X$ 316.4 8.7 $15X$ 450.0 13.4 $8X$ 316.7 $15X$ 450.0 13.4 <td>ov</td> <td>211.2</td> <td>10.2</td> <td>134</td> <td>422.4</td> <td>10.4</td>	ov	211.2	10.2	134	422.4	10.4
δX 311.0 13.1 $13X$ 434.0 13.1 $8X$ 312.2 12.8 $13X$ 434.3 13.1 $8X$ 313.1 16.8 $13X$ 434.6 12.7 $8X$ 313.4 17.7 $13X$ 434.9 12.7 $8X$ 313.4 17.7 $13X$ 434.9 12.7 $8X$ 314.0 10.4 $13X$ 435.5 12.6 $8X$ 314.3 9.0 $13X$ 435.5 12.6 $8X$ 314.3 9.0 $13X$ 436.1 12.2 $8X$ 314.9 8.3 $13X$ 436.1 12.2 $8X$ 315.5 8.7 $13X$ 436.1 11.8 $8X$ 315.5 8.7 $13X$ 436.4 11.8 $8X$ 315.5 8.7 $13X$ 436.4 11.5 $8X$ 316.1 15.0 $15X$ 447.6 11.5 $8X$ 316.1 15.0 $15X$ 447.6 11.5 $8X$ 317.0 11.5 $15X$ 448.2 16.5 $8X$ 317.0 11.5 $15X$ 448.2 16.5 $8X$ 317.9 11.2 $15X$ 449.1 13.2 $8X$ 318.2 10.7 $15X$ 449.1 13.6 $8X$ 318.2 10.7 $15X$ 449.1 13.2 $8X$ 317.9 11.2 $15X$ 450.0 13.4 $8X$ 318.2 10.7 $15X$ 450.0	01	311.5	12.0	15A	433.1	10.0
8x 312.2 12.8 $13x$ 434.3 12.7 8x 313.1 16.8 $13x$ 434.3 12.7 8x 313.4 17.7 $13x$ 434.9 12.4 8x 313.7 10.4 $13x$ 435.2 12.6 8x 314.0 10.4 $13x$ 435.5 12.6 8x 314.0 10.4 $13x$ 435.5 12.6 8x 314.6 9.6 $13x$ 435.8 11.9 8x 314.6 9.6 $13x$ 436.1 11.8 8x 315.5 8.7 $13x$ 436.7 11.9 8x 315.8 9.3 $15x$ 447.6 11.9 8x 316.1 15.0 $15x$ 447.6 11.9 8x 316.7 10.7 $15x$ 448.2 16.5 8x 317.0 11.5 $15x$ 448.5 12.6 8x 317.6 11.3 $15x$ 449.1 <td>87</td> <td>311.0</td> <td>13.1</td> <td>13X</td> <td>434.0</td> <td>12.4</td>	87	311.0	13.1	13X	434.0	12.4
8X 313.1 16.8 13X 434.6 12.4 8X 313.4 17.7 13X 434.9 12.4 8X 313.7 10.4 13X 435.2 12.6 8X 314.0 10.4 13X 435.2 12.6 8X 314.0 10.4 13X 435.2 12.6 8X 314.4 9.0 13X 435.8 11.9 8X 314.4 9.6 13X 436.1 12.2 8X 314.4 9.6 13X 436.1 12.2 8X 314.5 8.7 13X 436.4 11.8 8X 315.5 8.7 13X 436.7 11.3 8X 316.1 15.0 15X 447.3 13.3 8X 316.1 15.0 15X 447.9 12.4 8X 316.7 10.7 15X 448.2 16.5 8X 317.0 11.5 15X 448.1 13.2 8X 317.9 11.2 15X 449.1 <td>8X</td> <td>312.2</td> <td>12.8</td> <td>13X</td> <td>434.3</td> <td>13.1</td>	8X	312.2	12.8	13X	434.3	13.1
8X 313.4 17.7 13X 434.9 12.4 8X 313.7 10.4 13X 435.2 12.6 8X 314.0 10.4 13X 435.5 12.6 8X 314.3 9.0 13X 435.8 11.9 8X 314.6 9.6 13X 436.1 12.6 8X 314.6 9.6 13X 436.4 11.8 8X 315.5 8.7 13X 436.7 11.9 8X 315.8 9.3 15X 447.3 13.5 8X 316.1 15.0 15X 447.6 11.5 8X 316.7 10.7 15X 448.2 16.6 8X 317.3 11.2 15X 448.8 14.7 8X 317.6 11.3 15X 449.1 13.2 8X 318.5 18.2 15X 449.7 17.1 8X 318.5 18.2 15X 450.0 13.4 8X 318.5 18.2 15X 450.6 <td>8X</td> <td>313.1</td> <td>16.8</td> <td>13X</td> <td>434.6</td> <td>12.7</td>	8X	313.1	16.8	13X	434.6	12.7
8X 313.7 10.4 13X 435.2 12.6 8X 314.0 10.4 13X 435.2 12.6 8X 314.0 10.4 13X 435.5 12.6 8X 314.6 9.6 13X 435.8 11.9 8X 314.6 9.6 13X 436.1 12.2 8X 314.9 8.3 13X 436.4 11.9 8X 315.8 9.3 15X 447.3 13.3 8X 316.1 15.0 15X 447.6 11.9 8X 316.7 10.7 15X 444.2 16.5 8X 317.0 11.5 15X 448.2 16.5 8X 317.6 11.3 15X 449.1 13.2 8X 317.9 11.2 15X 449.4 13.6 8X 318.5 18.2 15X 450.0 13.4 8X 318.5 18.2 15X 450.0 13.4 8X 318.5 18.2 15X 450.6 <td>8X</td> <td>313.4</td> <td>17.7</td> <td>13X</td> <td>434.9</td> <td>12.4</td>	8X	313.4	17.7	13X	434.9	12.4
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	8X	313.7	10.4	13X	435.2	12.6
8X 314.3 9.0 13X 435.8 11.9 8X 314.6 9.6 13X 436.1 11.2 8X 314.6 9.6 13X 436.1 11.8 8X 315.5 8.7 13X 436.7 11.9 8X 315.5 8.7 13X 436.7 11.9 8X 315.8 9.3 15X 447.3 13.3 8X 316.1 15.0 15X 447.9 12.4 8X 316.7 10.7 15X 448.2 16.5 8X 317.0 11.5 15X 448.8 14.7 8X 317.6 11.3 15X 449.1 13.2 8X 317.9 11.2 15X 449.7 17.1 8X 318.5 18.2 15X 450.0 13.4 8X 412.4 9.6 15X 450.6 14.1 11X 413.0 9.1 15X	8X	314.0	10.4	13X	435.5	12.6
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	8X	314.3	9.0	13X	435.8	11.9
8x314.98.313x436.411.88x315.58.713x436.711.38x315.58.713x436.711.58x315.89.315x447.611.58x316.115.015x447.611.58x316.48.715x447.912.48x316.710.715x448.216.58x317.011.515x448.512.68x317.311.215x448.512.68x317.911.215x449.113.28x317.911.215x449.113.68x318.210.715x449.113.68x318.215x450.013.48x412.49.615x450.013.48x412.79.615x450.313.211x413.39.315x451.812.111x413.67.315x452.412.411x413.96.115x453.012.411x414.510.415x453.613.911x415.110.115x453.613.911x416.31.415x454.514.711x416.31.415x455.114.711x416.31.415x455.714.211x416.31.415x455.714.2<	8X	314.6	9.6	13X	436.1	12.2
8x 315.5 8.7 $13x$ 436.7 11.9 $8x$ 315.8 9.3 $15x$ 447.3 13.3 $8x$ 316.1 15.0 $15x$ 447.3 13.3 $8x$ 316.1 15.0 $15x$ 447.9 12.4 $8x$ 316.7 10.7 $15x$ 448.2 16.5 $8x$ 316.7 10.7 $15x$ 448.2 16.5 $8x$ 317.0 11.5 $15x$ 448.2 16.5 $8x$ 317.0 11.5 $15x$ 448.5 14.7 $8x$ 317.6 11.3 $15x$ 449.4 13.2 $8x$ 317.6 11.3 $15x$ 449.4 13.2 $8x$ 318.5 18.2 $15x$ 450.0 13.4 $8x$ 318.5 18.2 $15x$ 450.0 13.4 $8x$ 412.4 9.6 $15x$ 450.6 14.1 $11x$ 413.0 9.1 $15x$ 451.5 12.3 $11x$ 413.6 7.3 $15x$ 452.1 11.5 $11x$ 413.6 7.3 $15x$ 453.0 12.4 $11x$ 414.5 10.4 $15x$ 453.6 13.9 $11x$ 414.5 10.4 $15x$ 453.6 13.9 $11x$ 416.3 1.4 $15x$ 453.6 13.9 $11x$ 416.3 1.4 $15x$ 455.7 14.2 $11x$ 416.3 1.4 $15x$ 455.7	8X	314.9	83	13X	436.4	11.8
bitbitbitbitbitbitbit8X315.89.315X447.313.38X316.115.015X447.611.58X316.115.015X447.912.48X316.710.715X448.216.58X317.011.515X448.216.58X317.011.515X448.113.28X317.611.315X449.113.28X317.911.215X449.113.68X318.210.715X449.113.68X318.215X450.013.48X318.215X450.013.48X412.49.615X450.313.211X412.79.615X450.313.211X413.39.315X451.512.311X413.67.315X453.012.411X414.510.415X453.012.411X414.510.415X453.613.911X415.110.115X453.613.911X415.49.715X454.514.711X416.31.415X455.414.711X416.31.415X455.414.711X416.65.615X455.414.811X416.65.615X455.714.2<	88	315.5	87	13X	436.7	11.0
3X 316.3 9.3 $13X$ 447.5 11.5 $8X$ 316.1 15.0 $15X$ 447.6 11.5 $8X$ 316.7 10.7 $15X$ 447.6 11.5 $8X$ 316.7 10.7 $15X$ 448.2 12.4 $8X$ 317.0 11.5 $15X$ 448.2 12.6 $8X$ 317.3 11.2 $15X$ 448.8 14.7 $8X$ 317.6 11.3 $15X$ 449.1 13.2 $8X$ 317.6 11.3 $15X$ 449.7 17.1 $8X$ 317.6 11.2 $15X$ 449.7 17.1 $8X$ 318.2 10.7 $15X$ 449.7 17.1 $8X$ 318.5 18.2 $15X$ 450.0 13.4 $8X$ 412.4 9.6 $15X$ 450.6 14.1 $11X$ 413.0 9.1 $15X$ <td>ev.</td> <td>315.9</td> <td>0.7</td> <td>15%</td> <td>430.7</td> <td>12.2</td>	ev.	315.9	0.7	15%	430.7	12.2
δX 316.1 15.0 $15X$ 447.6 12.4 $8X$ 316.7 10.7 $15X$ 447.9 12.4 $8X$ 316.7 10.7 $15X$ 448.2 16.5 $8X$ 317.0 11.5 $15X$ 448.2 16.5 $8X$ 317.0 11.5 $15X$ 448.2 16.5 $8X$ 317.0 11.5 $15X$ 448.5 14.7 $8X$ 317.6 11.3 $15X$ 449.4 13.2 $8X$ 317.9 11.2 $15X$ 449.4 13.6 $8X$ 318.5 18.2 $15X$ 449.7 17.1 $8X$ 318.5 18.2 $15X$ 450.0 13.4 $8X$ 412.4 9.6 $15X$ 450.6 14.1 $11X$ 413.0 9.1 $15X$ 451.5 12.3 $11X$ 413.6 7.3 $15X$ 451.8 12.1 $11X$ 413.6 7.3 $15X$ 452.1 11.5 $11X$ 414.5 10.4 $15X$ 453.0 12.4 $11X$ 414.5 10.4 $15X$ 453.6 13.9 $11X$ 415.1 10.1 $15X$ 453.6 13.9 $11X$ 416.3 1.4 $15X$ 454.5 14.7 $11X$ 416.3 1.4 $15X$ 455.4 14.6 $11X$ 416.3 1.4 $15X$ 455.7 14.2 $11X$ 416.3 1.4 $15X$ 455.7 <	on	216.1	9.5	154	447.5	15.5
3λ 316.4 8.7 15λ 447.9 16.5 8χ 316.7 10.7 15χ 448.2 16.5 8χ 317.0 11.5 15χ 448.2 16.5 8χ 317.3 11.2 15χ 448.8 11.3 8χ 317.9 11.2 15χ 449.4 13.6 8χ 317.9 11.2 15χ 449.4 13.6 8χ 318.2 10.7 15χ 449.4 13.6 8χ 318.2 10.7 15χ 449.7 13.4 8χ 412.4 9.6 15χ 450.3 13.2 11χ 413.3 9.3 15χ 451.5 12.3 11χ 413.6 7.3 15χ 453.0 12.4 11χ 414.5 10.4 15χ 453.0 12.4 11χ 414.5 10.4 15χ </td <td>04</td> <td>216.4</td> <td>15.0</td> <td>154</td> <td>447.0</td> <td>11.5</td>	04	216.4	15.0	154	447.0	11.5
8x 316.7 10.7 $15x$ 448.2 16.6 $8x$ 317.0 11.5 $15x$ 448.5 12.6 $8x$ 317.3 11.2 $15x$ 448.2 16.6 $8x$ 317.6 11.3 $15x$ 449.1 13.2 $8x$ 317.9 11.2 $15x$ 449.4 13.6 $8x$ 318.5 18.2 $15x$ 449.7 17.1 $8x$ 318.5 18.2 $15x$ 450.0 13.4 $8x$ 412.4 9.6 $15x$ 450.6 14.1 $11x$ 413.0 9.1 $15x$ 451.5 12.3 $11x$ 413.0 9.1 $15x$ 452.1 11.5 $11x$ 413.0 9.1 $15x$ 452.1 12.4 $11x$ 413.0 9.1 $15x$ 453.0 12.4 $11x$ 414.5 10.4 $15x$ </td <td>84</td> <td>310.4</td> <td>8.7</td> <td>15X</td> <td>447.9</td> <td>12.4</td>	84	310.4	8.7	15X	447.9	12.4
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	8X	316.7	10.7	15X	448.2	16.5
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	8X	317.0	11.5	15X	448.5	12.6
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	8X	317.3	11.2	15X	448.8	14.7
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	8X	317.6	11.3	15X	449.1	13.2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	8X	317.9	11.2	15X	449.4	13.6
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	8X	318.2	10.7	15X	449.7	17.1
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	8X	318.5	18.2	15X	450.0	13.4
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	8X	412.4	9.6	15X	450.3	13.2
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	11X	412.7	9.6	15X	450.6	14.1
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	11X	413.0	9.1	15X	451.5	12.3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	11X	413.3	03	15X	451.8	12.1
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	111	413.6	73	15%	452.1	11.5
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	112	413.0	6.1	154	452.1	12.4
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	112	413.9	0.1	154	452.4	12.4
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	IIX	414.2	1.5	15X	453.0	12.4
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	IIX	414.5	10.4	15X	453.3	13.0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	11X	414.8	9.5	15X	453.6	13.9
11X 415.4 9.7 15X 454.2 16.0 11X 415.7 9.8 15X 454.5 14.7 11X 416.0 9.0 15X 454.5 14.7 11X 416.0 9.0 15X 455.1 13.0 11X 416.3 1.4 15X 455.1 13.0 11X 416.6 5.6 15X 455.4 14.8 11X 416.9 3.3 15X 455.7 14.2 11X 417.2 6.0 15X 456.0 13.5 11X 417.2 9.0 0 15X 456.0 13.5	IIX	415.1	10.1	15X	453.9	15.2
11X 415.7 9.8 15X 454.5 14.7 11X 416.0 9.0 15X 454.8 13.6 11X 416.3 1.4 15X 455.1 13.0 11X 416.3 1.4 15X 455.4 14.8 11X 416.6 5.6 15X 455.4 14.8 11X 416.9 3.3 15X 455.7 14.2 11X 417.2 6.0 15X 456.0 13.5 11X 417.2 9.0 15X 456.0 13.5	11X	415.4	9.7	15X	454.2	16.0
11X 416.0 9.0 15X 454.8 13.6 11X 416.3 1.4 15X 455.1 13.0 11X 416.6 5.6 15X 455.1 14.8 11X 416.9 3.3 15X 455.7 14.2 11X 417.2 6.0 15X 456.0 13.5 11X 417.2 9.0 15X 456.0 13.5	11X	415.7	9.8	15X	454.5	14.7
11X 416.3 1.4 15X 455.1 13.0 11X 416.6 5.6 15X 455.4 14.8 11X 416.9 3.3 15X 455.7 14.2 11X 417.2 6.0 15X 455.7 14.2 11X 417.2 6.0 15X 456.0 13.5	11X	416.0	9.0	15X	454.8	13.6
11X 416.6 5.6 15X 455.4 14.8 11X 416.9 3.3 15X 455.7 14.2 11X 417.2 6.0 15X 456.0 13.5 11X 417.2 9.0 15X 456.0 13.5	11X	416.3	1.4	15X	455.1	13.0
11X 416.9 3.3 15X 455.7 14.2 11X 417.2 6.0 15X 456.0 13.5 11X 417.2 6.0 15X 456.0 13.5	11X	416.6	5.6	15X	455.4	14.8
11X 417.2 6.0 15X 456.0 13.5	11X	416.9	33	15X	455 7	14.2
11X 4175 90	11X	417.2	60	15X	456.0	13.5
	11X	4175	9.0	154	450.0	15.5

addition to the core-catcher samples, some section samples were examined to refine zonal identification as much as possible.

A continuous sequence of nannofossil zones and subzones was observed from the Holocene to the upper Miocene in Hole 995A, which was similar to Hole 994C. However, a short hiatus was detected in the upper Miocene in the Hole 995A, correlatable to the major portion of Subzone CN10a and to the top part of Subzone CN9b (Fig. 12). Nannofossils are abundant throughout the examined samples, except in Sample 164-995A-30X-CC (249.1 mbsf) in which poorly preserved nannofossils are sporadic. Although the depths are slightly different, a similar reduction in nannofossil abundance, induced by an increase of diatoms and other siliceous particles, was observed in three samples at Hole 994C (183.7–197.8 mbsf), and the ages of these samples are identical (the upper part of Subzone CN12a is of late Pliocene age).

Preservation of nannofossils is mostly good for the upper sequences down to Sample 164-995A-15H-CC (126.2 mbsf) and becomes generally moderate, with a few well-preserved and rare poorly preserved intervals intercalated for the remainder of the hole. As was the case for Hole 994C, dissolution of nannofossils at this hole is weak, even in the moderately preserved nannofloras, but overgrowth was observed from much higher levels than at the previous site (236 vs. 520 mbsf). Overgrowth is light throughout; discoasters show

Figure 10. Temperatures of the sediments shortly after they were recovered from Site 995 vs. recovery depth. Plus signs = temperatures measured through the liner on the catwalk, solid triangles = temperatures measured after splitting, and solid circles = initial temperatures when the core sections were placed into the gas-collection chambers.

Table 6. Volumes of gas collected from 1.5-m whole-core sections as they warmed to room temperature inside the gas-collection chambers.

Core, section	Depth to top of section (mbsf)	Insertion temperature (°C)	Gas evolved (mL)	Estimated porosity	Gas/pore water ratio (mL/L)
164-995A-					
2H-2	12.7	10.2	0	69.3	0
3H-4	22.2	14.5	0	69.0	0
4H-2	31.7	11.9	0	68.7	0
5H-2	41.2	10.5	210	68.4	17
6H-2	50.7	11.9	650	68.1	54
7H-2	60.2	12.9	800	67.8	66
8H-3	69.7	12.1	0	67.5	0
10H-2	80.2	14.9	660	67.2	54
11H-2	89.7	11.7	460	66.9	37
12H-4	99.2	12.4	0	66.7	0
13H-2	108.7	12.1	907	66.4	73
14H-3	118.2	13.8	650	66.1	52
16H-4	137.7	12.6	1625	65.5	130
19H-3	157.2	12.8	610	64.9	48
21X-2	176.3	10.3	50	64.3	3
31X-3	253.2	9.6	60	62.0	4
33X-3	273.0	11.4	0	61.4	0
42X-3	351.6	10.6	0	59.0	0
51X-2	417.5	3.8	0	57.0	0
53X-3	429.6	11.0	0	56.7	0
54X-3	438.2	11.0	75	56.4	5
67X-3	558.0	14.5	0	52.8	0
68X-4	563.4	14.1	220	52.6	14
71X-3	583.6	13.6	200	52.0	12
73X-3	601.8		200	51.4	12
80X-1	666.1		0	49.5	0
81X-2	677.2		130	49.2	7
83X-2	696.5	12.6	120	48.6	7
164-995B-					
3H-1	108.3	14.5	255	66.4	20
3H-2	109.8	13.7	1050	66.4	85
3H-3	111.3	13.9	772	66.3	62
3H-4	112.8	14.1	813	66.3	66
3H-5	114.3	13.8	410	66.2	33

Note: - = not available.

slight to moderate overgrowth, and placoliths are little affected by recrystallization.

Hole 995A contained generally rare to few Cretaceous to Paleogene nannofossils, as well as ascidian spicules, in many samples (as did Hole 994C). However, reworking of Neogene nannofossils is more intense at Hole 995A than at Hole 994C, making zonal identi-

Figure 11. Plot of volume of gas evolved per liter of interstitial pore water for core sections as they warmed to room temperature in gas-collection chambers. The total amount of gas was corrected by the porosity of the cores to give the milliliters of gas per liter of pore water. Solid circles = measurements on APC cores. Open circles = XCB core measurements.

fication more difficult. The datum events described in this chapter, particularly those of the last occurrences, are likely to be modified by post-cruise study. Most of the reworked Neogene specimens are not much older than the samples' ages, with a rough age difference well less than 1 m.y.

Because the floral assemblages are identical to those of Site 994, the floral character will not be repeated here, except a few new findings observed at this hole.

Pleistocene

The upper 14 cores of Hole 995A contain Pleistocene nannofloras. Samples 164-995A-1H-1, 0–1 cm, and 1H-CC yielded dominant *Emiliania huxleyi*, indicating a Holocene or latest Pleistocene age (<0.085 Ma). Samples 164-995A-2H-3, 75–76 cm, and 2H-4, 70 cm, contain common and few *E. huxleyi*, respectively, whereas in Sample 164-995A-2H-5, 70 cm, no *E. huxleyi* was observed. The base of the uppermost Pleistocene Zone CN15, therefore, occurs in the lower part of Core 164-995A-2H.

Pseudoemiliania lacunosa was not found in Samples 164-995A-2H-CC and 3H-1, 70 cm, but is common in Samples 164-995A-3H-2, 75–76 cm, and 3H-CC. Thus, Samples 164-995A-2H-5, 70 cm, through 3H-1, 70 cm, were assigned to Subzone CN14b, and the base of this subzone was tentatively placed within the upper two sections of Core 164-995A-3H. Rejuvenation of medium to large *Gephyrocapsa*, including typical *Gephyrocapsa oceanica*, was identified in Sample 164-995A-6H-3, 120–121 cm; therefore, Samples 164-995A-3H-2, 70 cm, through 6H-3, 120–121 cm, are assignable to Subzone CN14a. The last occurrence (LO) of *Reticulofenestra asanoi* occurs in Sample 164-995A-6H-1, 70 cm.

Sample 164-995A-6H-4, 70 cm, through 8H-2, 108–110 cm, belongs to the "small *Gephyrocapsa*" Zone, and the interval between Samples 164-995A-6H-4, 70 cm, and 13H-CC was assigned to lower Pleistocene Subzone CN13b. The LOs of *Helicosphaera sellii* and *Calcidiscus macintyrei* were observed in Samples 164-995A-8H-3, 108–110 cm, and 11H-5, 108–110 cm, respectively, but these LOs may be erroneous because of reworking. The first occurrence (FO) of *Gephyrocapsa caribbeanica* (1.8 Ma) was tentatively identified in Sample 164-995A-13H-CC.

Figure 12. Biostratigraphic hole summaries of Hole 995A.

Pliocene

Although few to rare specimens of *Discoaster brouweri* were observed in Cores 164-995A-13H and 14H, the taxon becomes more abundant and its presence consistent from Sample 164-995A-15H-4, 108–110 cm, downward. Therefore, Samples 164-995A-14H-1, 8–10 cm, through 15H-3, 48–50 cm, were tentatively assigned to upper Pliocene Subzone CN13a. The LO of *Umbilicosphaera* sp. A, which

was observed within Subzone CN13a in Hole 994C, seems to occur at the top of Subzone CN13a in this hole.

Samples 164-995A-15H-4, 108–110 cm, through 16H-3, 8–10 cm, belong to Subzone CN12d. Although *Discoaster pentaradiatus* is consistently common from the next sample (164-995A-16H-4, 5–7 cm) downward, the interval assignable to Subzone CN12d seems too short, if this is the true LO of this taxon. Also, considering the possibility of reworking, the base of Subzone CN12d was not determined in this shipboard study. The LOs of *Discoaster surculus* (top of Subzone CN12b) and *Discoaster tamalis* (top of Subzone CN12a) were tentatively identified in Samples 164-995A-22X-3, 75 cm, and 25X-4, 4–8 cm, respectively.

Because Samples 164-995A-34X-CC and 35X-CC are devoid of *Reticulofenestra pseudoumbilica*, its common presence in corecatcher samples of Cores 164-995A-31X through 33X is a result of reworking. The rare specimens found in Samples 164-995A-37X-CC and 38X-1, 22–23 cm, also were considered to be reworked. Core 164-995A-38X recovered only 23 cm of sediment, and the core catcher was empty. However, a piece of sediment was found sticking to the inner wall at the bottom of the core liner. Examination of this sample yielded common specimens of *R. pseudoumbilica*. Because this taxon is consistently common to abundant from Sample 164-995A-39X-1, 10–12 cm, downward, the LO of *R. pseudoumbilica* (top of Subzone CN11b) is within the nonrecovered sections of Core 164-995A-38X.

The FO of *D. tamalis* (base of Subzone CN11b: 3.9 Ma) is in Sample 164-995A-40X-CC; Cores 164-995A-39X and 40X, as well as the lower portion of Core 38X, therefore belong to Subzone CN11b.

Rare specimens of *Amaurolithus delicatus*, which are sporadic in Cores 164-995A-40X through 46X, are reworked specimens, and the LO of this taxon seems to be in Sample 164-995A-51X-2, 70–71 cm. The interval between Samples 164-995A-41X-1, 10–12 cm, and 50X-CC, therefore, was assigned to Subzone CN11a. The FO of typical *P. lacunosa* (4.2 Ma) was identified in Sample 164-995A-44X-CC.

Cores 164-995A-51X through 69X-CC belong to lower Pliocene to upper Miocene Zone CN10 (4.4-5.6 Ma). As was the case at Hole 994C, Discoaster asymmetricus is rare in the CN10 nannoflora, and Subzones CN10d and CN10c were combined in this report. The LO of Ceratolithus acutus (top of Subzone CN10c) is in Sample 164-995A-57X-4, 8-10 cm, and rare specimens of the taxon are present consistently down to Sample 164-995A-68X-CC. The interval between these samples, therefore, is assignable to Subzone CN10b, and the Pliocene/Miocene boundary lies in the lower part of this interval. Although Ceratolithus armatus was observed only in the upper interval of Subzone CN10b at Hole 994C, its occurrence almost overlaps with that of C. acutus. A slight difference between the stratigraphic distributions observed here is that C. armatus persists a little longer after the disappearance of C. acutus. As found at Hole 994C, rare specimens of Ceratolithus atlanticus were again observed in some samples of this subzone.

Miocene

Samples 164-995A-69X-1, 8–10 cm, through 69X-CC contain no *C. acutus* or *Discoaster quinqueramus* and, therefore, belong to uppermost Miocene Subzone CN10a. *Discoaster berggrenii* also was not observed in this sample. The next sample (164-995A-71X-1, 8–10 cm) and all the samples examined below it, however, consistently yielded common to few *D. berggrenii* and *D. quinqueramus*, a clear indication of Zone CN9 nannoflora. Because the interval (maximum 8.73 m) assignable to Subzone CN10a at this hole is too short compared to that of Hole 994C (minimum 48.10 m), a hiatus exists at this hole, corresponding to the major portion of Subzone CN10a as well as the uppermost part of Subzone CN9b.

Cores 164-995A-71X through 83X contain nannoflora of Subzone CN9b. A. delicatus and Triquetrorhabdulus farnsworthii occur consistently throughout this interval. The lowest seven cores of this hole yielded rare but continuous Amaurolithus amplificus, and the LO of this taxon (5.9 Ma) is between Samples 164-995A-76X-CC and 77X-1, 18–19 cm. Rare specimens identifiable to Amaurolithus ninae and to C. atlanticus also occur in these cores.

Sedimentation Rate

Sedimentation rates calculated from the calcareous nannofossil datum events increase with depth in Hole 995A (Fig. 13). Sedimentation rates for the upper (0–0.46 Ma), middle (0.46–0.98 Ma), and lower (0.98–1.8 Ma) Quaternary sections are calculated as 29, 60, and 80 m/m.y., respectively (Fig. 4). These rates are similar to those of Hole 994C, and the average rate for the entire Quaternary (60 m/m.y.) is slightly lower than that at Hole 994C (68 m/m.y.).

The sedimentation rate for the upper Pliocene is 104 m/m.y. in Hole 995A, which is 17% higher than at Hole 994C. Because the sedimentation rate curves are closely parallel for the lower upper to lower lower Pliocene between these two holes, there is a strong possibility that sediment was winnowed or a series of short hiatuses occurred during the late late Pliocene (2.5–1.8 Ma) at Hole 994C (Fig. 4).

As mentioned earlier, a hiatus exists within the uppermost Miocene sequence (between 573.86 and 580.68 mbsf). As there is only one datum event (LO of *A. amplificus:* 5.9 Ma) detected below this hiatus, a sedimentation rate cannot be calculated for the upper Miocene sequence recovered at this hole. Because the rates are similar in the overlying sequences (except the upper upper Pliocene), the values are expected to be similar between the upper Miocene sequences

Figure 13. Age-depth relationships of biostratigraphic markers of calcareous nannofossils in Hole 995A (solid line) and Hole 994C (dashed line). Horizontal error bar at the bottom of the figure indicates the range of *Amaurolithus amplificus*.

of Holes 994C and 995A. By adopting the rate of 303 m/m.y. from Hole 994C, the bottom age of Hole 995A was calculated as 6.14 Ma. This age is within the chronological range of *A. amplificus* (5.9–6.4 Ma), which was found in the last core catcher of this hole. The duration of the Miocene hiatus in Hole 995A was estimated as 5.72 to 5.44 Ma (Fig. 13).

PALEOMAGNETISM Magnetostratigraphy

Paleomagnetic measurements at Hole 995A were carried out with the pass-through cryogenic magnetometer, following the procedures outlined in the "Explanatory Notes" chapter (this volume). We measured the NRM on the cores that were taken with the APC (Cores 164-995A-1H through 20H) and demagnetized them under an AF of 20 mT to determine the direction of the stable component of remanence. Routine measurement of remanence was abandoned for the subsequent XCB cores (164-995A-21X through 83X) because they were highly biscuited during drilling. To supplement magnetostratigraphic results from the routine demagnetization and to construct a magnetostratigraphy for the XCB cores, 47 discrete samples were AF demagnetized in 5-mT steps up to 55 mT.

Between 10 and 70 mbsf, NRM shows sawtooth-shaped fluctuations in intensity between 10 and 0.1 mA/m, with peaks of extremely high intensity (>1000 mA/m) at 87 and 120 mbsf (Fig. 14). Each abrupt increase in NRM intensity occurs at the top of a core, and intensity decreases toward the bottom of the core, suggesting that the fluctuations are a result of contamination from drill-pipe rust. The NRM declination is very scattered, and the inclination is generally steeply downward (near +90°), suggesting that a core-barrel overprint was acquired during coring.

After demagnetization at 20 mT, intensity is generally less than 1 mA/m and more constant downhole than the NRM intensity, although the fluctuations resulting from rust contamination can still be seen (Fig. 15). The inclination after 20-mT demagnetization shifts toward lower inclinations and shows negative and positive intervals through the section. The decrease in intensity and inclination suggests that the demagnetization removed the core-barrel overprint. The declination after 20-mT demagnetization is less scattered than that of NRM. Before Tensor tool orientation, demagnetized declinations are generally grouped around 180°, relative to the x-axis direction defined by the double-line fiducial mark in the center of the core liner on the working half of the cores. Orientation of declination relative to geographic north (see "Paleomagnetism" section, "Explanatory Notes" chapter, this volume) produces a distinct break at the top of each core (Fig. 16); this is most readily explained by a bias in the relative responses of the x- and y-axis sensors in the cryogenic magnetometer to the very weak remanence surviving after demagnetization (see "Paleomagnetism" section, "Explanatory Notes" chapter, this volume).

Progressive AF demagnetization of the discrete samples shows that the steeply downward-inclined drilling-induced components can be removed from most samples, leaving a stable component of remanence at 5–10 mT (Fig. 17). After the removal of the overprint, typical progressive demagnetization up to 55 mT follows a linear demagnetization path converging on the origin of the Zijderveld plot (Fig. 17). This indicates a single, stable component that is interpreted as the primary remanence, from which magnetic polarity can be determined (e.g., normal polarity from the sample of Fig. 17A and reverse polarity from the sample of Fig. 17B). The stepwise demagnetization of the discrete samples suggests that a magnetostratigraphy can be constructed for the APC-cored interval in Hole 995A.

Polarities determined from analyses of the discrete samples correlate well with the inclination data obtained from the 20-mT demagnetization of the continuous core sections in the cryogenic magnetometer (Fig. 18), indicating that the cryogenic magnetometer record reveals the primary magnetization. Based on the inclination and polarity data with the constraint of the nannofossil datums (see "Biostratigraphy" section, this chapter), polarity chron boundaries were determined on the APC section. The lower boundary of the C1r.1n (Jaramillo normal chron) is at 61 mbsf, the upper and lower boundaries of the C2n (Olduvai normal chron) are at 98 and 107 mbsf, respectively, and the C2An/C2r boundary (Gauss/Matuyama boundary) is at 136 mbsf. The polarity boundary between C1n and C1r (Brunhes/Matuyama boundary) is poorly constrained, and the position of the upper boundary of the Jaramillo normal chron could not be determined. According to the nannofossil biostratigraphy (see "Biostratigraphy" section, this chapter) the C1n/C1r boundary should lie near 40 mbsf.

Figure 14. NRM declination (referred to arbitrary core coordinates), inclination, and intensity for Hole 995A.

Figure 15. Declination (core coordinates), inclination, and intensity for Hole 995A after 20-mT demagnetization.

Discrete sample analysis also allowed recognition of the approximate position of major chron boundaries in the interval cored with the XCB (Fig. 19). The C2Ar/C2An (Gilbert/Gauss) boundary is between 295 and 320 mbsf, the C3n/C2Ar between 320 and 350 mbsf, the C3r/C3n between 545 and 580 mbsf, and the C3An/C3r (Anomaly 5/Gilbert) between 620 and 635 mbsf.

As was the case for Site 994, rock-magnetic analysis (see below) suggests that authigenic minerals dominate the remanence at Site 994. Consequently, although detrital remanence (DRM) may make some contribution, the primary remanence at Site 994 is probably post-depositional (PDRM). The lag between sediment deposition and acquisition of PDRM is not clear, but the PDRM is probably dominated by magnetite produced during early diagenesis between 0 and 2 mbsf. Consequently, the magnetostratigraphy at Site 994 may be offset downhole from the depositional history (i.e., nannofossil biostratigraphy) by as much as 2 m.

Magnetic Susceptibility

Measurement of magnetic susceptibility of whole-core sections from Hole 995A using the MST produced a very similar record to that observed at Site 994 (see "Paleomagnetism" section, "Site 994" chapter, this volume). Susceptibility increases from $\sim 10 \times 10^{-5}$ (all susceptibilities are in volume-normalized SI terms) at the mudline to $\sim 40 \times 10^{-5}$ at 2 mbsf, presumably reflecting bacterial authigenesis of magnetite (Fig. 20). Susceptibility drops sharply below 2 mbsf to ~20 $\times 10^{-5}$, then recovers to $\sim 30 \times 10^{-5}$ at 3 mbsf. A similar pair of peaks in the shallow susceptibility record also may be present at Site 994, but the lower peak was obscured at Site 994 by core breaks and whole-round sampling. Susceptibility declines sharply below 3 mbsf to reach values of 3-4 x 10-5 by 4 mbsf, probably as a result of bacterially mediated reduction of magnetite to iron sulfides. Superimposed on this diagenetic trend is a series of smaller spikes (e.g., at ~0.4 and 1.0 mbsf), which presumably represents depositional laminae enriched in magnetite.

Susceptibility begins to increase at ~75 mbsf, reaching a local maximum of $\sim 13 \times 10^{-5}$ at 83 mbsf, before returning to $\sim 6-8 \times 10^{-5}$ at 90 mbsf. This local maximum roughly coincides with an increase in pyrite concentrations identified in XRD samples (see "Lithostratigraphy" section, this chapter). Susceptibility continues downhole with a background value of $\sim 6-8 \times 10^{-5}$, with similar small cyclic variations on a 1- to 5-m scale to those seen at Site 994 (see "Paleomagnetism" section, "Site 994" chapter, this volume).

As at Site 994, susceptibility increases slightly to $\sim 10-12 \times 10^{-5}$ below ~ 560 mbsf, within the upper Miocene part of the sequence.

Rock Magnetism

Saturation Isothermal Remanence

Patterns observed at Site 994 in the distribution of SIRM normalized for susceptibility (i.e., SIRM/k) were confirmed at Site 995 (Fig. 21). Both the log-linear decrease in the background value of SIRM/k, extending from 20 mbsf to total depth in Hole 995A, and the zone of anomalously high SIRM/k, extending from ~60 mbsf to ~260–300 mbsf, are more clearly defined at Site 995 than at Site 994.

Very high values of SIRM/k (>10 kA/m) characterize the high susceptibility interval above 4 mbsf. As at Site 994, these presumably reflect the presence of a substantial proportion of SD grains. The shallowest sample, at 0.5 mbsf, has an $S_{-0.3T}$ ratio of 0.99, indicating that magnetite dominates the magnetic mineralogy. However, a sample at 2.18 mbsf, within the zone of reduced susceptibility between 2 and 3 mbsf, has a lower value of $S_{-0.3T}$ (Fig. 22), indicating an increased proportion of a higher coercivity phase. It is likely that magnetic sulfide authigenesis has already commenced at this shallow sub-bottom depth.

Four other samples with SIRM/k values >10 kA/m and $S_{-0.3T}$ values >0.98 were measured at Site 995. Two of these were from the in-

Figure 16. Declination data oriented to geographic coordinates with the Tensor tool for Hole 995A after 20-mT demagnetization.

Figure 17. Representative Zijderveld, stereo, and intensity demagnetization plots for (A) Sample 164-995A-2H-1, 48–50 cm (2.18–2.20 mbsf), and (B) Sample 164-995A-15H–1, 62–64 cm (117.32–117.34 mbsf). Demagnetization increases in 5-mT steps to 55 mT for (A) and 45 mT for (B). Zijderveld plot: solid circles = projection on the horizontal plane; open circles = projection on the vertical plane. Stereo plot: solid circles = the lower hemisphere. Declination is with respect to core coordinates.

Figure 18. Inclination after 20-mT demagnetization with pass-through magnetometer and polarity data determined from Zijderveld diagram analysis of discrete samples from Hole 995A, correlated to the revised geomagnetic polarity time scale of Cande and Kent (1995). Solid circles and zones = normal polarity, open circles and zones = reverse polarity, question marks (?) = less certain polarity, and bars = unsuccessful analyses. J = Jaramillo, and O = Olduvai.

terval below 600 mbsf, in the upper Miocene sequence, where a series of similar samples was measured at Site 994. However, at Site 995, samples from 84 and 458 mbsf gave similar high SIRM/k and $S_{-0.3T}$ values. Coercivity studies at Site 994 indicated that these samples are dominated by SD magnetite. These samples probably represent local intervals of decreased reduction, resulting in less complete reduction of magnetite to iron sulfides.

Coercivity

Coercivity at Site 995 was analyzed through acquisition of pIRM and pARM (see "Paleomagnetism" section, "Explanatory Notes" chapter, this volume).

Studies of pIRM for samples below the horizon of rapid magnetite reduction at 3-4 mbsf define three coercivity populations (Fig. 23A): the first, distributed around 50-100 mT; the second, around 400 mT; and the third, around 1000-1200 mT. Magnetite saturates at <200 mT (Thompson and Oldfield, 1986), so the two high-coercivity populations must represent phases other than magnetite. Greigite is indicated at Site 995 by the presence of its 2.98 Å peak in XRD analysis of Samples 164-995A-3H-2, 80 cm, 25X-2, 105 cm, 37X-1, 9 cm, and 81X-6, 84 cm; pyrrhotite may be indicated by a less welldeveloped peak at 2.05 Å in these samples. SD greigite may be responsible for the pIRM peak at 400 mT. Because greigite is a ferrimagnet, however, it is unlikely to be the source of the pIRM peak at 1000-1200 mT. Pyrrhotite, which is antiferromagnetic over certain Fe:S ratios, could be responsible for the 1000-1200 mT peak. Alternatively, some detrital hematite may have survived throughout the sequence, as reported for greigite-bearing sediments by Reynolds et al. (1994).

Sample 164-995A-2H-1, 21-23 cm (1.92 mbsf), is defined by a single pIRM peak at 100 mT (Fig. 23B), indicating the dominance of

Figure 19. Columns showing core number and recovery and polarity data determined from Zijderveld diagram analysis of discrete samples from Hole 995A, correlated to the revised geomagnetic polarity time scale of Cande and Kent (1995). Symbols are the same as in Figure 18.

Figure 20. Susceptibility determined on the MST in Hole 995A (shown at three different scales).

Figure 21. SIRM/k vs. sub-bottom depth, Hole 995A.

Figure 22. S_{-0.3T} vs. sub-bottom depth, Hole 995A.

magnetite in the magnetic mineralogy within the initial zone of magnetite authigenesis above 2 mbsf.

As at Site 994, pARM of samples within the first meter below the seafloor reveals a moderately broad, slightly left-skewed coercivity spectrum with a peak coercivity of 35 mT (Fig. 24A). This spectrum is typical of a mixture of grain sizes of a mineral with coercivity in the magnetite range. The peak coercivity indicates that the dominant magnetite grain size is in the MD to pseudo-single-domain (PSD) range, typical of detrital magnetites. Microbial magnetite has usually been reported in the single-domain size range. Hence it is likely that detrital magnetite makes up a significant proportion of the magnetic mineralogy in the first meter below scafloor.

Many samples from below the magnetite reduction horizon have pARM spectra that are bimodal, with peaks at 15 and 35–55 mT, suggesting two populations of magnetic minerals (Fig. 24B). Others are distinctly left skewed, with a single peak at 15 mT. The left skewing of the pARM coercivity spectra may be explained by the dissolution of SD and PSD magnetite (which constitutes the fine-grained fraction less than ~10 μ m in size). Development of a new, high-coercivity

Figure 23. Acquisition of pIRM at Site 995. Each histogram block represents pIRM acquired between the previous applied field step and the step indicated, divided by the log of the width of the applied field step (e.g., pIRM at 100 mT = $(IRM_{100 \text{ mT}} - IRM_{50 \text{ mT}})/\log (100-50)$. A. Samples below 4 mbsf, showing three peaks in their coercivity spectra. B. Sample 164-995A-2H-1, 21–23 cm (1.92 mbsf), with a single peak.

Figure 24. Acquisition of pARM at Site 995. A. Sample 164-995A-1H-1, 50–52 cm (0.51 mbsf). B. Samples from below 4 mbsf, showing bimodal or highly left-skewed stability spectra.

peak may be explained by the growth of SD greigite in significant proportions in many samples.

Thermal Demagnetization of Isothermal Remanence

Thermal demagnetization of mIRM (see "Paleomagnetism" section, "Explanatory Notes" chapter, this volume, for details of technique) also indicates the presence of two or more magnetic phases at Site 995 (Fig. 25). One phase (or group of phases), distinguishable in all samples below ~10 mbsf, has an unblocking temperature between ~250° and 300°C and includes grains with coercivities ranging from 200 to 400 and possibly 1200 mT. The apparent blocking temperature of this phase may reflect decomposition of greigite, which is metastable, oxidizes rapidly on heating in air, and completely decomposes at

Figure 25. Thermal demagnetization of mIRM for samples from Site 995. Three orthogonal components of isothermal remanence, at 200, 400, and 1200 mT, were imparted before thermal demagnetization. The remanence after each demagnetization step in each of the three orthogonal directions is plotted.

~300°C (Roberts and Turner, 1993; Roberts, 1994; Musgrave et al., 1995). A second phase, which is saturated by IRM at 200 mT, unblocks between 550° and 600°C, corresponding to the Curie point of magnetite.

Summary of Rock-Magnetic Analysis

Evidence for the presence of greigite, and possibly pyrrhotite, is provided by coercivity and thermal demagnetization analyses at Site 995. Magnetic sulfides form part of a sequence of reduction steps that are delineated by changes in magnetic susceptibility, the background log-linear trend in SIRM/k, and the $S_{-0.3T}$ ratio. The same sequence was noted at Site 994 (see "Paleomagnetism" section, "Site 994" chapter, this volume, for a detailed discussion). Initial detrital magnetite deposition is followed by (1) authigenic (presumably microbial) generation of SD magnetite and magnetic sulfides within the first few meters below seafloor, (2) further reduction to remove most magnetite (and almost all magnetite in the fine-grained SD range) below ~4 mbsf, and (3) an apparently highly uniform, continued reduction of the magnetic iron sulfides toward pyrite downhole.

Superimposed on this trend is an interval of anomalously high SIRM/k between ~60 and 260-300 mbsf, which we interpret as the result of the development of a second generation of magnetic sulfides in the upper part of the gas hydrate stability zone. As at Site 994, this interval corresponds to a zone of downhole-decreasing interstitialwater chlorinity (see "Inorganic Geochemistry" section, this chapter) in a manner closely analogous to Sites 889 and 890 from Leg 146 (Shipboard Scientific Party, 1994). High SIRM/k in the interval of downhole-decreasing chlorinity at Sites 889 and 890 was associated with the presence of substantial proportions of greigite, which was demonstrated through a variety of shore-based rock-magnetic analyses (Housen and Musgrave, 1996). Alkalinity at both Sites 994 and 995 also exhibits an inflection between two distinct trends at ~250-260 mbsf. The alkalinity trend between 250 and 100 mbsf shows a positive anomaly above a linear gradient, which may imply bacterial activity over this interval. Bacterial authigenesis of greigite in response to the availability of methane (both as hydrate and as free gas or in solution) has been proposed previously (Musgrave et al., 1995; Housen and Musgrave, 1996).

DOWNHOLE TOOLS AND SAMPLING

Pressure Core Sampler

The PCS was deployed 13 times at Site 995 (Table 7). The objective for 11 of these runs was to collect sediment, interstitial water, and gas at in situ pressure; the objective for two of these runs was to collect only borehole water and gas at in situ pressure. An asterisk (*) is used throughout this text to denote the two runs in which coring was not an objective.

The general procedure for collecting gas samples from the PCS is discussed in the "Downhole Tools and Sampling" sections, "Explanatory Notes" and "Site 994" chapters, this volume. A fundamental difference between gas sampling at Sites 994 and 995 was that the PCS-M was purged with He (at 14 psi) before collection of gas samples at Site 995. The first (and sometimes subsequent) gas samples collected from the PCS-M, therefore, contain significant quantities of He. In addition, Core 164-995A-70P was not placed on ice.

Two water samples were collected from Core 164-995A-18P through the PCS-M. The first of these two samples (~8 mL) was collected at relatively high pressure (~600 psi) along with gas; the second of these samples was collected at low pressure (~14 psi). Methane hydrate should dissociate in seawater at 0°C at ~430 psi (Dickens and Quinby-Hunt, 1994). Therefore, the water collected from the PCS at pressures greater than 430 psi might have a component of formation water before gas hydrate dissociation.

Gas Release Experiments

Core 164-995A-9P (68.2 mbsf) was the first PCS core in ODP history to recover a complete 1-m core of sediment at in situ pressure (cf. Pettigrew, 1992, and Westbrook, Carson, Musgrave, et al., 1994). However, because sediment at this depth is gassy and poorly consolidated, a substantial portion of the core was extruded into the manifold and gas experiments could not be conducted on Core 164-995A-9P.

The amount of gas that evolved from the remaining 12 PCS cores and water samples (Table 7) ranges between 85 mL (Core 164-995A-52P*) and 4215 mL (Core 164-995A-27P). These total gas volumes primarily represent mixtures of air, CH₄, and CO₂ (Table 8). The amount of air does not exceed 175 mL in any PCS run. The amount of CO₂ also is relatively small (Table 8). Therefore, large volumes of gas from the PCS (>350 mL) are predominantly composed of CH₄.

Most of the air in the PCS is released at high pressure. In contrast, most of the CH_4 in the PCS is released at relatively low pressure (<600 psi). Therefore, the first gas sample taken from the PCS always has a higher proportion of air to CH_4 relative to subsequent gas samples (Table 8).

Air is the predominant gas in the PCS runs (164-995A-0P* and 52P*) designed to collect only water and gas (Table 8). The two unidentified gases observed in PCS cores from Site 994 (see "Downhole Tools and Sampling" section, "Site 994" chapter, this volume) also are present in PCS cores from Site 995. In addition, higher hydrocarbons (particularly isobutane and normal heptane) are enriched in the first gas splits of certain PCS runs.

Time-pressure-volume plots for the 12 PCS cores (Fig. 26A–L) show the same general features as those from Site 994 (see "Downhole Tools and Sampling" section, "Site 994" chapter, this volume). There is an initial time interval over which pressure in the PCS decreases in a roughly exponential pattern and no gas is released from the PCS. This time interval represents cooling of the PCS from an initial temperature toward 0°C in the ice bath. There is a pronounced drop in pressure when the PCS is first opened to the PCS-M. As evident from the composition of gas samples (G_1) taken immediately af-

Table 7. Description of PCS deployment at Site 995.

			Pressure	š		Core		Total gas
Core	Depth (mbsf)	Expected (psig)	Observed (psig)	Hydrostatic (%)	Cutting shoe	recovered (cm)	Manifold design	released (mL)
164-995A-								
0P*	-73.0	3970	2760	70	(Push-in)	0.00*	PCS-M3B	140
9P	68.2	4177	4128	99	Push-in	1.00	PCS-M3B	_
18P	145.2	4290	3180	74	Push-in	0.70	PCS-M4	555
27P	222.9	4404	4049	92	Push-in	1.00	PCS-M4	4215
36P	300.3	4517	4740	105	Push-in	0.75	PCS-M4	1430
45P	377.5	4631	4535	98	Push-in	0.58	PCS-M4	4210
48P	396.8	4659	4700	101	Push-in	0.23	PCS-M4	985
52P*	423.7	4698	4830	103	(Push-in)	0.00*	PCS-M4	85
52P	425.6	4701	4788	102	Auger	0.18	PCS-M4	2635
60P	493.1	4800	4240	88	Auger	0.09	PCS-M4	1310
70P	579.6	4927	3656	74	Auger	0.03	PCS-M4	285
164-995B-								
7P	308.5	4529	2776	61	Push-in	0.93	PCS-M4	2330
10P	320.1	4546	3266	72	Push-in	0.65	PCS-M4	980

Notes: The water depth at Hole 995A is 2779 m. Expected pressure is the hydrostatic pressure assuming a pressure gradient of 1.467 psi/m. Observed pressure is that first recorded at the PCS sampling station. * = Cores 995A-0P and 52P were deployed as blank (water) PCS runs that were not intended to recover core (see text). (Push-in) = cutting shoe was not applied because these samples were taken in water, not in sediment. — = below detection.

Table 8. Gas com	position of samples	from the PCS at Site 995.

Core	Sample, analysis	C ₁ (ppmv)	C ₂ (ppmv)	C ₃ (ppmv)	i-C ₄ (ppmv)	n-C ₄ (ppmv)	i-C ₅ (ppmv)	n-C ₅ (ppmv)	<i>i</i> -C ₆ (ppmv)	n-C ₆ (ppmv)	n-C ₇ (ppmv)	N ₂ (vol%)	O ₂ (vol%)	CO ₂ (ppmv)
164-995A-														
0P*	G ₁ -G	204												
9P	G ₁ -N	8,100	. 1	23	5	0.4	0.3							
18P	G1-G	719,300	25	13										
18P	G ₁ -N	652,400	18	14	8.4	1	5	0.3						
27P	G ₁ -N	19,400	4	1	0.4		0.4					12.4	3.0	1600
27P	G ₂ -N	837,000	158	21	2.7	0.2	1.3	0.2				8.8	1.9	10,700
27P	G ₃ -N	953,700	173	5	3	0.6	1.8	0.2				0.3	< 0.1	10,400
27P	G ₄ -N	952,500	180	5	3	0.5	2.2					0.2	< 0.1	8,900
27P	G-N	914,100	170	6	3.7	0.6	3.7					3.5	0.4	12,300
27P	G ₆ -N	912,100	173	7	5	0.9	5.6	0.5				3.0	0.5	24,700

Notes: Gas samples taken from the PCS are designated (e.g., G₁) in the order in which they were collected (see Fig. 26). Letters following the sample number refer to the shipboard analytical instrument used for gas analyses: G = GC3, and N = NGA (see "Organic Geochemistry" section, "Explanatory Notes" chapter, this volume). * = PCS was lowered only to collect a water sample and not for coring.

Only part of this table is produced here. The entire table appears on the CD-ROM (back pocket).

ter opening the PCS (Table 8; Fig. 26), the drop in pressure results from the release of air. There is a late time interval (when pressure is <600 psi) over which pressure fluctuates with time. This time interval is when nearly all the CH₄ is released from the PCS (Table 8; Fig. 26). Except for PCS runs with only air, this time interval also is when most of the total gas volume is released (Fig. 26).

Sediment samples from the PCS cores were squeezed using conventional techniques to obtain interstitial water (see "Inorganic Geochemistry" section, "Explanatory Notes" chapter, this volume). These waters from the PCS cores (Table 9) are similar in composition (after correcting for seawater contamination) to those from APC and XCB cores at the same depth (see "Inorganic Geochemistry" section, this chapter). The water surrounding the cores (in the inner and outer chambers of the PCS) is borehole water. Water collected from PCS run 164-995A-52P* also is borehole water.

The water sample collected at high pressure from Core 164-995A-18P (145.67 mbsf) has a Cl⁻ concentration of 506 mM and a NH_4^+ concentration of 400 μ M (Table 9). The Cl⁻ value is significantly less than that of seawater and is similar to Cl⁻ values obtained from the WSTP at the same depth (see "Water-Sampling Temperature Probe" below). However, this water sample is not formation water because the NH_4^+ concentration is too low for this depth (see "Inorganic Geochemistry" section, this chapter). Chloride and NH_4^+ concentrations in the low-pressure water sample from Core 164-995A-18P are similar to seawater (Table 9).

The physical properties of sediment from the PCS cores (Table 10) generally are similar to those from APC and XCB cores at the same depth (see "Physical Properties" section, this chapter). An ex-

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ception is the high water content in Samples 164-995A-27P, 79-81 cm, and 52P, 10-12 cm.

Preliminary Interpretations

Gas volumes and compositions were determined for multiple sediment cores at in situ pressure at Site 995. Thus, a major objective of Leg 164 was accomplished at Site 995 (see "Introduction" chapter, this volume). Together with similar results achieved using the PCS at Site 997, volumes of CH_4 recovered from the PCS provide fundamental constraints on the amount of gas hydrate and free gas in the sediment of the Blake Ridge.

Two important observations at Site 995 were (1) that the outer chamber of the PCS contains only borehole water and (2) that borehole water contains no gas other than air. This indicates that CH_4 evolved from the PCS comes only from pore water captured in the inner (sampling) chamber (i.e., CH_4 is not at elevated concentrations in the borehole water). On PCS runs with incomplete (<1 m) core recovery, the void in the inner (sampling) chamber of the PCS also contains borehole water. Thus, all available evidence indicates that gas evolved from the PCS (other than air) or He comes from the sediment core in the PCS, and not the surrounding borehole water.

Preliminary estimates on the amount of CH_4 in pore space of sediment at Site 995 can be made using sediment porosity (see "Physical Properties" section, this chapter), volumes of sediment in the PCS, and the amount of CH_4 released from the PCS. These calculations indicate that the pore space of sediment in PCS cores contains between 40 and 930 mM/L CH_4 . The lower values are from cores <140 mbsf

Figure 26. PCS time-pressure-volume plots. A. Core 164-995A-0P*. B. Core 164-995A-18P. C. Core 164-995A-27P. D. Core 164-995A-36P. E. Core 164-995A-45P. F. Core 164-995A-45P. F. Core 164-995A-45P. G. Core 164-995A-52P*. H. Core 164-995A-52P. I. Core 164-995A-60P. J. Core 164-995A-70P. K. Core 164-995B-7P. L. Core 164-995B-10P. The volume represents the cumulative gas volume collected in the manifold bubbling chamber. G = times of gas sampling. * = The PCS was lowered to collect only borehole water and gas at in situ pressure, not for coring.

and between 300 and 330 mbsf; the higher values are from other depth intervals. It is suggested that the interstitial waters from cores that evolve greater than 200 mM/L CH_4 are saturated with respect to CH_4 (see Duan et al., 1992).

ter correction). In addition, preliminary calculations indicate that the interstitial waters of Core 164-995A-27P were saturated with respect to CH_4 .

Several lines of evidence indicate that Core 164-995A-27P contained gas hydrate in the interval between 71 and 89 cm. This interval had a mousse-like appearance, an extremely high dry water content (93.18%), and a low interstitial-water Cl⁻ concentration (486 mM af-

Water-Sampling Temperature Probe

The WSTP was deployed on 11 occasions at Site 995 at depths ranging from 78.70 to 200.25 mbsf (Table 11). Water samples from

Table 9. Chemistry of water samples from the PCS at Site 995.

Core, interval (cm)	Depth (mbsf)	Notes	pH	Alk (mM)	Sal (g/kg)	Cl- (mM)	Cl-* (mM)	Mg ²⁺ (mM)	Ca ²⁺ (mM)	SO4 ²⁻ (mM)	PO ₄ ³⁻ (μM)	NH4 ⁺ (μM)	SiO ₂ (µM)	K ⁺ (mM)	Sr ²⁺ (μM)
164-995A-															
9P. 35-50	68.55	IW	7.98	23.0	32.0	545	536	27.9	3.0	6.1	37	4,664	723	13.7	109
18P. 47-61	145.67	IW	7.52	74.9	32.0	514	513	19.3	2.4	0.3	173	10,309	733	13.4	77
18P	145.67	Manifold, HP				506						400			
18P	145.67	Manifold, LP				555						830			
27P. 28-42	223.18	IW	8.07	99.9	33.8	501	501	15.6	1.3	0.2	121	17,119	631	16.8	59
27P, 71-89	223.61	IW, mousse-like			35.0	548	486	37.1	6.4	19.5	42	11.758	607	14.8	90
36P, 9-24	300.39	IW	7.40	59.3	35.0	543	512	29.5	4.3	13.5	56	15,970	667	14.4	95
45P. 13-33	377.63	IW	8.03	80.1	33.0	533	525	12.9	1.4	4.1	47	22,590	538	17.8	53
45P	377.50	Outer chamber			1949	571						1.000000000			
48P. 0-23	396.80	IW	7.90	87.5	32.5	535	529	14.7	2.0	3.4	48	20,710	720	15.1	77
52P	423.70	Inner chamber				579			-						
164-995B-															
7P. 57-77	309.07	IW	7.47	107.9	33.0			15.2	1.5	0.0	106	17.650	767	14.3	66
10P, 43-56	319.53	IW	7.66	75.1	33.0	504	486	17.6	1.8	5.7	66		596	14.5	

Notes: Alk = alkalinity, and Sal = salinity. IW = interstitial water, HP = high pressure, and LP = low pressure. * = values have been corrected for seawater contamination (see "Inorganic Geochemistry" section, "Site 994" chapter, this volume). The depth listed for Core 164-995A-52P, a water core, is the bottom of the pipe depth at this core.

Table 10. Physical properties of sediment samples from the PCS, Hole 995A.

Core	Depth	Water co	ter content (%)		nsity (g/c	m ³)	Porosity	Void	
interval (cm)	(mbsf)	Wet	Dry	Bulk	Grain	Dry	(%)	ratio	
164-995A-									
9P, 83-85	69.03	48.23	93.18	1.49	2.72	0.77	70.28	2.47	
18P. 5-7	145.25	41.53	71.04	1.66	2.82	0.97	67.26	1.96	
18P, 32-34	145.52	43.23	76.16	1.64	2.77	0.93	69.13	2.06	
27P. 8-10	222.98	33.70	50.84	1.81	2.64	1.20	59.58	1.31	
27P, 27-29	223.17	33.27	49.87	1.86	2.74	1.24	60.34	1.33	
27P, 59-61	223.49	37.47	59.91	1.71	2.67	1.07	62.58	1.56	
27P. 79-81	223.69	48.27	93.32	1.55	2.72	0.80	72.98	2.48	
45P, 36-38	377.86	32.54	48.24	1.77	2.69	1.19	56.27	1.27	
48P. 4-6	396.84	32.90	49.03	1.80	2.74	1.21	57.95	1.31	
52P, 10-12	425.70	42.98	75.37	1.61	2.76	0.92	67.73	2.03	

the WSTP contain various proportions of interstitial water, borehole water (surface seawater pumped down the hole), and undisplaced coil water (initial water in the WSTP sampling coil).

A primary objective of these WSTP experiments at Site 995 was to determine Cl⁻ concentrations of in situ interstitial water (see "Inorganic Geochemistry" section, this chapter). A 1000-ppm Li⁺ solution was used to fill the sampling coil. The proportion of interstitial water, borehole water, and undisplaced coil water then was estimated via analyses of Li⁺ and SO₄²⁻. The assumptions behind this approach are that interstitial and coil waters contain no SO₄²⁻ and that interstitial and borehole waters contain no Li⁺ (see "Downhole Tools and Sampling" section, "Explanatory Notes" chapter, this volume).

Two observations support the validity of this approach. Analyses of seawater and interstitial water from whole-round intervals indicate that neither of these waters contain Li⁺ concentrations above 0.3 ppm. Analyses of borehole water and seawater show that these two waters are essentially identical except for NH₄⁺ concentrations. An experimental check also supports this method. Lithium and SO₄^{2–} concentrations suggest that WSTP Samples 164-995A-47X and 995B-4W₂ contain 99.6% and 99.1% seawater, respectively. The concentration of Cl⁻ shows that these two samples are indistinguishable from seawater.

The water samples from the WSTP contain between 0.1% and 94% interstitial water (Table 12). Two observations concerning these samples are that (1) the proportion of interstitial water generally decreases with depth (Fig. 27) and (2) the estimated concentration of Cl⁻ in the interstitial water generally is similar (within 1 standard deviation) to the Cl⁻ measured on water squeezed from whole-round intervals from the same depth (see Fig. 33, "Inorganic Geochemistry" section, this chapter).

The concentrations of Ca²⁺, Mg²⁺, and K⁺ (after correction for dilution by coil water) are intermediate between seawater and interstitial water (see "Inorganic Chemistry," section, this chapter). However, WSTP water samples are depleted in Ca²⁺ and Mg²⁺ relative to interstitial water squeezed from whole-round intervals.

Preliminary Interpretations

The most important result regarding the chemistry of WSTP water samples is that the Cl⁻ concentrations (after correction for contamination) generally are similar to that of interstitial waters squeezed from whole-round intervals. The implication of this observation is discussed in the "Inorganic Geochemistry" section, this chapter. Sample 164-995A-14H (107.2 mbsf) contains significantly lower Cl⁻ concentrations than those of interstitial waters squeezed from whole-round intervals. We offer no explanation for this observation, but note that the Cl⁻ concentration of Sample 164-995B-4W₁ (at a close depth, 109.5 mbsf) is similar to those of interstitial waters squeezed from whole-round intervals.

Sediment compaction (water content reduction) at Site 995 increases with depth. The decreasing proportion of interstitial water obtained by the WSTP with respect to depth probably is related to this compaction (i.e., it is more difficult for the tool to extract in situ water from compact sediment).

The depletion in Ca^{2+} and Mg^{2+} likely reflects precipitation of carbonate during CO_2 degassing (see "Inorganic Chemistry" section, this chapter). Thus, the degassing effect on pore-water concentrations appears to be more pronounced for WSTP samples than for squeezed whole-round samples. One explanation is that there is a sudden drop

Table 11. Description of WSTP deployment at Site 995.

	Depth	Water	type (mL)
Core	(mbsf)	Coil	Overflow
164-995A-			
4H	20.7	0	NR
11H	78.7	10	NR
14H	107.2	10	NR
19H	146.2	0	NR
28X	223.9	10	NR
31X	252.3	20	6
35X	290.7	25	0
39X	319.6	NR	NR
42X	348.6	10	75
47X	387.1	10	NR
164-995B-			
4W1	109.5	10	400
$4W_2$	155.0	12	120
4W2	200.0	10	1200

Note: NR = not recorded. The WSTP was run at three different depths within the washed interval designated as Core 164-995B-4W (see Table 1).

in pressure when interstitial water flows across the filter in the WSTP.

ORGANIC GEOCHEMISTRY

The shipboard organic geochemistry program at Site 995 included analyses of volatile hydrocarbons; determinations of inorganic carbon, total nitrogen, total carbon, total sulfur; and Rock-Eval pyrolysis (for a description of methods see "Explanatory Notes" chapter, this volume).

Volatile Hydrocarbons

Headspace Gas

Concentrations of methane (C₁), ethane (C₂), and propane (C₃) were measured from every core using the standard ODP headspacesampling technique (Table 13). The C₁ concentration increases from 136 to 113,400 μ L/kg between 14 and 52 mbsf. From 52 to 139 mbsf, the C₁ concentration decreases to ~20,000 μ L/kg. At greater depths, the concentration of C₁ remains constant at ~10,000 μ L/kg. C₂ concentrations are low (0–10 μ L/kg) in the upper 290 mbsf, but they increase to values of 117 μ L/kg down to 700 mbsf (Fig. 28).

Carbon dioxide (CO₂) concentrations in headspace gas of selected samples (Table 13) were determined with the Natural Gas Analyzer (NGA). Concentrations of CO₂ are highest from 200 to 450 mbsf and then decrease with depth. A maximum value of 750 μ L/kg occurs at 384 mbsf. The same downhole trend is observed for alkalinity in interstitial water (see Table 18, "Inorganic Geochemistry" section, this chapter).

Free-Gas Samples

Concentrations of C₁, higher molecular weight hydrocarbons, and CO₂ were measured for free gas in voids using the NGA (Table 14). There is a decrease in the C₁/C₂ ratio with depth, from ~39,000 to ~1,200 (Fig. 29). Concentrations of propane through heptane were usually below 10 ppm (Table 14). Concentrations of CO₂ vary widely and comprise 0%–20% of the free gas. Some of this variance results from air contamination; there is no apparent relation between CO₂ concentration and depth. There are also trace amounts of several unidentified compounds (Fig. 30).

Gas-Collection Chamber Samples

Concentrations of C_1 and higher molecular weight hydrocarbons were determined for gas released from the gas-collection chambers (Table 15). The C_1 concentrations of these gases are ~1 order of magnitude higher than C_1 concentrations in depth-coincident headspace samples.

Organic Carbon, Total Nitrogen, and Total Sulfur

The TOC content of sediment from 0 to 119 mbsf is typically below 1% and averages 0.72% (Table 16; Fig. 31). A maximum value of 1.77% was found at a depth of 542 mbsf. The average TOC content of sediment from 119 to 686 mbsf is 1.32%. The C/N ratio is below 10 for most samples and nearly uniform from 119 to 686 mbsf (Fig. 31). Most measured hydrogen indices (HI) from Rock-Eval pyrolysis range from 135 to 361. The average T_{max} is 420°C (Table 17). Oxygen indices (OI) are between 107 and 263. The total sulfur content varies from 0.24% to 2.60% (Table 16).

Discussion

The C1 concentration of the headspace gas within the SO42- reduction zone (>21 mbsf) is low (21-36 µL/kg). Highest concentrations of C1 occur between 43 and 52 mbsf (~114,000 µL/kg). Sediment below this depth has a lower C1 headspace concentration. Methanogenesis below the SO42- reduction zone is likely responsible for high C1 concentration. Some portion of that C1 may migrate upward and be oxidized in the SO42- reduction zone. Thus, sediment below the most active C1 generation zone (which extends down to ~150 mbsf based on methane concentration vs. depth curve; Fig. 28) contains a largely residual pool of microbially generated C1. Comparable concentration vs. depth profiles have been observed at other ODP sites (e.g., at Site 688 [Kvenvolden and Kastner, 1990]). The occurrence of C4 through C6 hydrocarbons is more likely related to diagenesis than to thermal generation, as suggested by the greater concentration of the isoalkanes relative to the n-alkanes (Schaefer and Leythaeuser, 1987).

High concentrations of CO_2 are probably from the degassing of pore water that is laden with bicarbonate. A close relationship between alkalinity and CO_2 concentrations in the free gas is observed (see "Inorganic Geochemistry" section, this chapter). Alkalinity (HCO₃⁻) production may, among other sources, result from the microbial decomposition of organic matter.

Preliminary CNS analysis of the organic matter from Site 995 sediments below 105 mbsf indicate a marine origin (C/N ratios <10). However, sources other than organic nitrogen (e.g., ammonia) may contribute to the overall nitrogen content lowering the C/N ratio. Low HI values (mostly <300 mg/gC) and high OI values (mostly >100 mg/gC) from Rock-Eval pyrolysis suggest a type II-III kerogen. The calculated HI value (Langford and Blanc-Valleron, 1990) for the whole sample set is 344 mg/g rock. This suggests that a mixture of marine and terrestrial organic matter is present. The average Tmax value of 420°C is indicative of a low maturity organic matter. An increase of the T_{max} values with depth from 410° to 430°C indicates the approach to the zone of thermogenesis. However, this maturity stage is inconsistent with the present-day borehole maximum temperature. Variations in the mass accumulation rate (MAR) of the TOC (see "Synthesis and Significance" section, this chapter) are roughly parallel to those of noncarbonate terrigenous matter rather than to marine carbonate fractions.

Table 12. Chemistry of water samples from the WSTP and proportion of seawater, coil water, and interstitial water at Site 995.

	Deat	1.14		<i>C</i> 11-	1.0	co 2-			W.A.	24	C . 24	N	Vater type (%)	C1-*	1
Core	(mbsf)	(ppm)	(%)	(mM)	(%)	(mM)	10 (%)	(mM)	(mM)	(mM)	(mM)	Coil	Seawater	Interstitial	(mM)	(%)
164-995A-																
Coil water		969.4	0.6	140	0.32	0.00										
11H	78.7	132.0	0.7	513	0.18	18.20	0.87	3.1	9.8	37.4	5.4	13.6	60.8	25.6	552	3.2
14H	107.2	18.7	0.8	519	0.18	13.34	2.32	4.3	10.4	26.2	3.0	1.9	44.5	53.6	482	3.1
28X	223.9	109.3	0.7	512	0.18	18.88	0.79	8.2	11.9	36.7	5.2	11.3	63.1	25.6	509	3.2
31X	252.3	354.7	0.6	406	0.18	12.39	1.95	6.2	7.8	25.3	4.4	36.6	41.4	22.0	521	5.7
35X	290.7	950.8	0.6	145	0.18	0.00	150.68	0.0	0.0	0.2	0.2	98.1	0.0	1.9	447	59.8
39X	319.6	5.9	1.2	572	0.18	29.05	1.96	4.1	11.7	51.3	9.7	0.6	97.0	2.4	358	152.3
42X	348.6	4.9	1.2	568	0.18	26.04	0.95	10.0	11.9	45.5	9.1	0.5	86.9	12.6	502	10.5
47X	387.1	3.0	1.3	579	0.18	29.84	0.62	2.1	10.8	55.0	10.6	0.3	99.6	0.1	1037	1006.3
164-995B-																
Coil water		1056.0	0.7	152	0.28	0.00										
1W	109.5	3.4	1.2	530	0.18	1.69	3.19	6.1	10.8	25.5	3.0	0.3	5.6	94.1	528	0.3
2W	155.0	2.5	2.2	579	0.18	29.69	0.95	2.3	10.1	54.7	10.8	0.2	99.1	0.7	582	212.9
3W	200.0	4.2	0.5	567	0.18	25.17	0.82	5.5	12.0	46.6	8.9	0.4	84.0	15.6	507	7.1
Seawater		0		580	0.18	29.95	0.18	~0.00	10.84	56.12	10.9					

Notes: The initial coil water is distilled water with ~1000 ppm LiCl. The seawater concentration for SO₄²⁻ is taken from Millero and Sohn (1992) for a Cl⁻ value of 580 mM. * = measurements have been corrected for dilution by seawater and coil water.

Figure 27. The proportion of interstitial water in Site 995 WSTP water samples with respect to depth.

INORGANIC GEOCHEMISTRY

Site 995 is the second site of a drilling transect across the Blake Ridge. The transect grades from a flank site without an underlying BSR (Site 994) to a flank site with a strong BSR, (Site 995) and then, finally, to a site located on the crest of the drift deposit with a very strong BSR and strong seismic reflections below the BSR (Site 997). Of particular importance to Leg 164 objectives is how the interstitialwater chemistry (in particular, Cl⁻) varies across this transect.

Sediment from Site 995 was sampled for interstitial waters replicating the high sampling frequency and strategy of Site 994 (see "Inorganic Geochemistry" section, "Site 994" chapter, this volume). At Site 995, 133 interstitial water samples were analyzed (Table 18). Surface seawater and waters from 11 WSTP (or Barnes Tool) runs also were analyzed. The analyses of these latter samples, as well as water samples recovered from PCS runs at Site 995, are presented in the "Downhole Tools and Sampling" section (this chapter).

Two additional studies were conducted at Site 995 in response to observations at Site 994:

 Fifty-four whole-round intervals used for squeezing were measured for temperatures on the catwalk to assess any correlation between core temperature and Cl⁻ concentration. Core temperature was measured by inserting a temperature probe through a drill hole in the core liner.

 Four whole-round intervals from Site 995 were split into replicate samples and squeezed at different times to evaluate storage effects. Stored samples were trimmed to prevent seawater contamination and tightly wrapped in plastic bags to prevent evaporation. The stored samples were squeezed 25–68 hr after they were recovered.

Geochemical Similarity to Site 994

The interstitial-water chemistry at Site 995 (Table 18) is very similar to that of Site 994. Downhole profiles of all interstitial species (Figs. 32, 33) show the same general trends as those seen at Site 994, although there are slight differences in absolute concentrations. For example, alkalinity and PO_4^{3-} concentrations are higher (~10% and 30%, respectively) at Site 995, and NH_4^+ concentrations are lower (~7%) at Site 995. The downhole Cl⁻ profile is described below; thorough descriptions of overall trends for the other species are presented in the "Inorganic Geochemistry" section of the "Site 994" chapter (this volume).

Chloride

The Cl⁻ profiles at Sites 994 and 995 are very similar (Fig. 33). Chloride concentration increases with depth from ~557 mM near the sediment-water interface to 563 mM at 16 mbsf. The Cl⁻ gradient above 16 mbsf at Site 995 is ~0.5 mM/m. Chloride steadily decreases below this depth to a value of 519 mM at ~190 mbsf. Between ~190 and 438 mbsf, there is a zone of significant Cl⁻ variation. There is a baseline concentration of ~500 mM with superimposed Cl⁻ excursions to significantly lower values (to 438 mM). The depth zones 190 to 270 mbsf and 340 to 438 mbsf contain most of the Cl⁻ excursions to fresher values. Chloride values below 438 mbsf average ~515 mM.

Corrected Cl⁻ concentrations from the WSTP water samples (see "Downhole Tools and Sampling" section, this chapter) are broadly consistent (within analytical uncertainty) with baseline concentrations of the interstitial-water values from corresponding depths (Fig. 33).

Temperature Measurements

The temperatures of whole-round intervals taken on the catwalk (Table 19) are correlated (r = 0.80) with interstitial-water Cl⁻ concen-

Table 13. Composition of headspace gas in sediment from Hole 995A.

Core, section	Depth (mbsf)	CO ₂ (ppmv)	C ₁ (ppmv)	C ₂ (ppmv)	C ₃ (ppmv)	<i>i</i> -C ₄ (ppmv)	n-C ₄ (ppmv)	i-C ₅ (ppmv)	n-C ₅ (ppmv)	i-C ₆ (ppmv)	n-C ₆ (ppmv)	C1/C2	C1/C2+	CO2 (µL/kg wet sediment)	C ₁ (µL/kg wet sediment)	C ₂ (µL/kg wet sediment)	C ₃ (µL/kg wet sediment)
164-995A-																	
1H-1	0.00	NA	3.2			NA	NA	NA	NA	NA	NA			NA	21	0	0
2H-3	4.80	NA	3.2	0.1		NA	NA	NA	NA	NA	NA	53	53	NA	22	0	0
3H-3	14.30	NA	28.1	0.4		NA	NA	NA	NA	NA	NA	70	70	NA	136	2	0
4H-3	23.70	NA	4,200	1.0		NA	NA	NA	NA	NA	NA	4,170	4,170	NA	16,600	4	0
5H-3	33.20	NA	23,600	1.5		NA	NA	NA	NA	NA	NA	15,700	15,700	NA	68,100	4	0
6H-3	42.70	NA	29,200	2.0		NA	NA	NA	NA	NA	NA	14,600	14,600	NA	114,000	8	0
7H-3	52.20	NA	31,000	2.0		NA	NA	NA	NA	NA	NA	15,500	15,500	NA	113,000	7	0
8H-1	58.70	NA	17,100	2.0		NA	NA	NA	NA	NA	NA	8,530	8,530	NA	49,600	6	0
10H-4	73.70	NA	17,000	1.4		NA	NA	NA	NA	NA	NA	12,200	12,200	NA	79,200	7	0
11H-4	83.20	NA	23,400	1.5		NA	NA	NA	NA	NA	NA	15,600	15,600	NA	75,200	5	0

Notes: C_1 through C_6 = the alkanes: methane, ethane, propane, butane, pentane, and hexane. Iso- and normal configurations of butane, pentane, and hexane are designated with *i*- and *n*- prefixes. C_1/C_2 = the methane/ethane ratio, and C_1/C_{2+} = the ratio of methane/ Σ (C_2 through C_6). NA = not analyzed.

Only part of this table is produced here. The entire table appears on the CD-ROM (back pocket).

Figure 28. Concentration of C_1 , C_2 , C_3 , and CO_2 in sediments (headspace gas) and in free gases collected in syringes from Site 995.

Table 14.	Composition o	f free gas collected	in syringes from	sediment from Site	995.

Core, section	Depth (mbsf)	O ₂ (ppmv)	N ₂ (ppmv)	C ₁ (ppmv)	CO ₂ (ppmv)	C ₂ (ppmv)	C ₃ (ppmv)	i-C ₄ (ppmv)	n-C ₄ (ppmv)	i-C5 (ppmv)	n-C ₅ (ppmv)	<i>i-</i> C ₆ (ppmv)	n-C ₆ (ppmv)	C1/C2	C1/C2+
164-995A-															
6H-6	47.70	NA	NA	911.300	NA		23.0	5.0	0.4	0.3					31,800
8H-1	59.20	NA	18,000	936,400	NA	53	10.7	6.0	0.5	0.4				17,600	13,200
12H-2	89.13	0	6,000	943,300	25,600	24	10.7	6.3	0.7	1.4				39,300	21,900
12H-6	95.18	0	3,000	948,700	22,600	49	11.7	7.1	0.9	1.9				19,400	13,400
13H-2	99.70	186,000	752,000	10,100	500		21.0	0.1		0.4					469
14H-2	109.20	0	5,000	827,200	24,300	56	30.0	8.8	1.2	3.4				14,700	8,310
14H-3	110.70	18,000	89,000	980,600	31,500	48	13.2	9.4	1.2	3.3				20,300	13,000
15H-6	124.70	0	1,000	942,700	31,800	29	15.6	12.7	1.6	6.6	0.2	0.1		32,300	14,300
16H-5	131.58	0	1,000	956,000	18,100	27	27.8	12.6	1.6	7.4	0.3	0.2		35,800	12,500
17H-6	143.70	0	1,000 -	942,700	44,700	57	14.8	9.4	1.2	3.3				16,500	11,000

Notes: Oxygen (O₂) and nitrogen (N₂) concentrations are included as a guide to the amount of air contamination in each sample. C₁ through C₆ = the alkanes: methane, ethane, propane, butane, pentane, and hexane. Iso- and normal configurations of butane, pentane, and hexane are designated with *i*- and *n*- prefixes. C₁/C₂ = the methane/ethane ratio, and C₁/C_{2*} = the ratio of methane/ Σ (C₂ through C₆). NA = not analyzed.

Only part of this table is produced here. The entire table appears on the CD-ROM (back pocket).

trations (Fig. 34). As suspected from observations at Site 994, samples from Site 995 with anomalously low Cl⁻ concentrations were significantly colder than other samples. sented storage effects (e.g., CO_2 degassing and carbonate precipitation) rather than intrahole variability.

Sample Storage Effects

Concentrations of some species were observed to vary between two holes at Site 994 (see "Inorganic Geochemistry" section, "Site 994" chapter, this volume). We assumed that this difference repreConcentration differences in K^+ , Mg^{2+} , Ca^{2+} , and Sr^{2+} were observed between stored and unstored replicate samples (Table 20). The changes in these species are qualitatively similar to the changes observed between Holes 994D and 994C. Chloride concentrations also increase by an average of 1.3%. The increase in Cl⁻ likely reflects sample evaporation (as also indicated by the presence of water droplets inside of the sealed bags).

Figure 29. C_1 and C_2 concentrations and C_1/C_2 and C_1/C_2 ratios of free gas collected in syringes from Site 995. Samples containing more than 5% oxygen were not included.

Preliminary Interpretations

Chloride and Hydrate Occurrence at Site 995

The downhole decrease in Cl⁻ concentrations at Site 995 is related to gas hydrate decomposition (see "Inorganic Geochemistry" section, "Site 994" chapter, this volume). Thus, the similarity of the Cl⁻ profiles at Sites 994 and 995 implies that the distribution of gas hydrate at the two locations is similar. The observation further implies that zones of concentrated hydrate are laterally continuous over 3 km (the distance between Sites 994 and 995).

Chloride excursions between 190 and 438 mbsf at Site 994 were interpreted as intervals where the greatest concentrations of gas hydrate occur (see "Inorganic Geochemistry" section, "Site 994" chapter, this volume). Gas hydrate dissociation during core retrieval should dilute interstitial water with fresh water. Because gas hydrate dissociation also is an endothermic reaction (e.g., Sloan, 1990), the surrounding host sediment will be cooled during core retrieval. The observed positive correlation between interstitial-water Cl⁻ concentrations and catwalk temperatures at Site 995 provides compelling evidence that the Cl⁻ excursions between 190 and 456 mbsf indeed represent the greatest concentrations of gas hydrate.

In principle, "background" Cl⁻ values that are lower than seawater (such as observed at Sites 994 and 995 between 190 and 440 mbsf) could represent either in situ Cl⁻ concentrations or Cl⁻ values after significant gas hydrate dissociation during core retrieval (e.g., Kvenvolden and Kastner, 1990). Analyses of water from the WSTP suggest that in situ interstitial-water Cl⁻ concentrations are similar to "background" Cl⁻ concentrations. Thus, significant freshening of interstitial water does not occur during core retrieval. However, the large uncertainty in the WSTP Cl⁻ concentrations does not preclude some freshening of interstitial water and the existence of a small amount of gas hydrate that is uniformly distributed within this section.

The significance of the BSR in terms of gas hydrate presence and free-gas abundance has been actively discussed in recent geophysical literature (e.g., Minshull and White, 1989; Miller et al., 1991; Hyndman and Spence, 1992; Singh et al., 1993; Bangs et al., 1993; Katzman et al., 1994; MacKay et al., 1994). VSP experiments at Site 995 place the BSR at 440 ± 10 mbsf (see "Geophysics" section, this chapter). The BSR at Site 995, therefore, is coincident with the base of the lower zone of Cl⁻ excursions and presence of hydrate (Fig. 33).

However, the above observation does not necessarily imply that the BSR is defined by the presence of gas hydrate or that concentrated gas hydrate causes a BSR. Indeed, because the downhole Cl⁻ profiles strongly suggest that the distribution of hydrate is the same at both Sites 994 and 995, a fundamental question is why there is no BSR at Site 994. A working hypothesis is that the BSR occurs because of the presence of free gas rather than gas hydrate (e.g., Minshull and White, 1989; Singh et al., 1993; Bangs et al., 1993) and that there is no free gas below 440 mbsf at Site 994.

PHYSICAL PROPERTIES

Physical properties data were collected on both whole-round and split sections of cores recovered at Site 995. GRAPE wet bulk density, magnetic susceptibility, and NGR activity were measured on all undisturbed unsplit sections using the MST. Because of separation of the sediments from the liner, PWL data could be collected only to 40 mbsf. The DSV was used to measure *P*-wave velocities at discrete intervals in split sections recovered shallower than 60 mbsf. Undrained shear strength and unconfined compressive strength were measured in APC cores and in biscuits in XCB cores using the vane shear apparatus and pocket penetrometer, respectively. Index properties were determined from samples collected in one to three sections per core. Thermal conductivity data were obtained at a resolution of one per section in APC cores. Gas expansion, drilling and coring disturbance, Table 15. Composition of gases from Site 995 collected in gas-collection chambers.

Core, section	Depth (mbsf)	O ₂ (ppmv)	N ₂ (ppmv)	C ₁ (ppmv)	CO ₂ (ppmv)	C ₂ (ppmv)	C ₃ (ppmv)	<i>i</i> -C ₄ (ppmv)	n-C ₄ (ppmv)	<i>i</i> -C ₅ (ppmv)	n-C ₅ (ppmv)	<i>i</i> -C ₆ (ppmv)	n-C ₆ (ppmv)	C1/C2	C1/C2+
164-995A-															
7H-6	51.20	131,000	535,000	248,000	7,400	12	3	1.5						20,700	14,800
10H-1	71.20	160,000	650,000	114,900	4,500	5	2	0.8						23,900	15,700
11H-2	80.70	137,000	570,000	229,100	9,200	9	3	2		0.7	0.5			24,400	14,400
13H-3	99.70	109,000	460,000	370,100	18,700	14	6	3.8	0.4	1.2	0.1			27,400	14,800
14H-5	109.20	1,000	5,000	104,100	33,200	56	26		1.2					1,860	1,250
14H-6	110.70	118,000	494,000	323,500	22,800	11	5	3.5	0.4	1.5				29,100	15,000
16H-2	127.15	117,000	493,000	326,100	23,200	12	6	4.9	0.7	2.8				26,700	12,300
16H-2	127.15	50,000	228,000	562,500	39,700	24	10	8.6	0.8					23,200	12,900
16H-4	130.15	125,000	523,000	293,000	20,600	11	5	4.3	0.5	2.4				26,200	12,500
19H-6	147.58	1,000	519,000	199,800	19,600	10	5	5	0.5	8.2	0.2			19,400	6,800

Notes: Oxygen (O₂) and nitrogen (N₂) concentrations are included as a guide to the amount of air contamination in each sample. C₁ through C₆ = the alkanes: methane, repane, butane, pentane, and hexane. Iso- and normal configurations of butane, pentane, and hexane are designated with *i*- and *n*- prefixes. C₁/C₂ = the methane/ethane ratio, and C₁/C₂₊ = the ratio of methane/ Σ (C₂ through C₆).

Only part of this table is produced here. The entire table appears on the CD-ROM (back pocket).

Table 16. Carbonate, carbon, nitrogen, and sulfur contents in sediment from Site 995.

Core, section, interval (cm)	Depth (mbsf)	Inorganic carbon (wt%)	CaCO ₃ (wt%)	Organic carbon (wt%)	Total nitrogen (wt%)	C/N	Total sulfur (wt%)
164-995A-				2.000 A			1.0.10
2H-2, 70-71	3.95	5.41	45.1	NA	NA	NA	NA
2H-3, 88-89	5.68	4.61	38.4	0.20	0.00	NA	0.24
2H-4, 61-62	6.96	6.00	50.0	NA	NA	NA	NA
3H-2, 80-81	13.55	3.17	26.4	NA	NA	NA	NA
3H-5, 80-81	18.1	2.67	22.2	0.56	0.01	NA	0.49
4H-2, 60-61	22.8	5.83	48.6	NA	NA	NA	NA
4H-4, 60-61	25.8	1.67	13.9	0.34	0.01	NA	0.66
5H-1, 59-60	32.29	1.80	15.0	NA	NA	NA	NA
5H-5, 59-60	35.29	6.05	50.4	NA	NA	NA	NA
5H-7, 39-40	39.59	2.05	17.1	0.71	0.01	NA	0.90

Note: NA = not analyzed.

Only part of this table is produced here. The entire table appears on the CD-ROM (back pocket).

and the possible breakdown of gas hydrate prevented meaningful tests from being performed on some core sections. All index properties, thermal conductivity, strength, and DSV data for Site 995 are available on CD-ROM (back pocket).

Index Properties

Wet bulk density, porosity, and grain density (Fig. 35) determined using gravimetric methods (see "Index Properties" in the "Physical Properties" section of the "Explanatory Notes" chapter, this volume) show well-defined trends with depth in the hole. Wet bulk density increases from ~1.45 g/cm³ near the seafloor to 1.95 g/cm³ at the bottom of the hole, with localized minima at 70, 100, and 155 mbsf. In the interval of 330–610 mbsf, bulk density is nearly constant. Wet bulk density increases with depth below 610 mbsf. In general, the wet bulk density values obtained using gravimetric methods correlate well with the high-resolution GRAPE data.

Water contents measured using both wet and dry methods show a gradual change as a function of depth, with values decreasing linearly from 142% to 33% (dry) and from 59% to 25% (wet) with increasing depth. Between 84 and 132 mbsf, water content increases from 37% to 42%, with a sharp offset in the trend at 115 and 132 mbsf.

Porosity values generally decrease from 80% to 48% with depth in the hole, but the decrease in porosity is less pronounced than that in the water contents. Grain density obtained using the dry method remains uniform as a function of depth, with deviations of less than ± 0.1 g/cm³ from the average value of 2.7 g/cm³.

The major difference between the index properties of sediments recovered from PCS cores and those collected in adjacent APC or XCB cores is relatively higher water contents (wet and dry) and sometimes porosity. The increased water content of the PCS sediments may be more closely related to the core recovery technique than to in situ conditions. The index properties of sediments collected from the PCS are reported in Table 21 but are not shown in Figure 35.

Acoustic Velocity

P-wave velocities (Fig. 36) were measured with the PWL on unsplit sections recovered from 0 to 200 mbsf, but realistic values were obtained only when sediments completely filled the liner (0–40 mbsf). In the interval from 0 to 28 mbsf, *P*-wave velocities are distributed around an average of 1.5 km/s, with some scattered peaks occurring at 10, 13, 23, and 27 mbsf. At depths of 30–36 mbsf, velocity decreases, reaching a minimum of 1.46 km/s. The scattered nature of the velocity data makes it difficult to determine the true *P*-wave velocity at depths >30 mbsf.

Acoustic velocities were also measured with the DSV frame on split sections of cores recovered between 0 and 60 mbsf. The DSV data generally correlate with the PWL results and are consistent with decreasing velocity between 30 and 37 mbsf.

Undrained Shear Strength

Undrained shear strength values obtained with a pocket penetrometer and the vane shear apparatus vary from 24.5 to 220 kPa and from 3.4 to 159.5 kPa, respectively, with a progressive increase as a function of depth. The plot (Fig. 35) shows an offset in the strength values at 90 mbsf, the same depth at which the wet bulk density values have a local maximum. Stiff carbonate layers at 41 and 48 mbsf produce localized strength increases. A strength maximum also occurs at 142 mbsf, at the same depth at which a pronounced, localized increase in wet bulk density occurs.

Natural Gamma Radiation

NGR data (Fig. 35) were filtered with a 5-m-wide boxcar function to eliminate high-frequency variations. NGR values are nearly constant as a function of depth, varying in a narrow range from 4 to 12 cps. The only significant change in NGR occurs between 180 and 230 mbsf, where the values increase from 7 to 10 cps. NGR gently increases with depth from 340 mbsf to the bottom of the hole.

Thermal Conductivity

Thermal conductivity varies between 0.8 and 1.32 W/(m·K) in APC cores recovered from Hole 995A (Fig. 37). The greatest scatter in the data occurs between 0 and 40 mbsf. Deeper than 40 mbsf, conductivity averages 1.0 ± 0.1 W/(m·K), with significant departures

Figure 31. Contents of carbonate, total organic carbon, and C/N ratios in sediment from Site 995. A C/N ratio of 10 or lower is indicative of marine organic matter; ratios higher than 20 are representative for terrestrial organic matter.

Table 17. Rock-Eval analysis of sediment from Hole 995A.

Core, section,	Depth							
interval (cm)	(mbsf)	T _{max}	S_1	S_2	S_3	PI	HI	01
164-995A-								
6H-2, 21-22	41.41	417	0.52	4.55	2.49	0.10	309	169
8H-3, 102-103	62.72	388	0.21	0.41	2.20	0.34	37	203
10H-5, 55-56	75.75	416	0.14	1.10	2.60	0.11	87	206
12H-5, 54-55	93.67	464	0.08	1.49	2.08	0.05	188	263
15H-5, 54-55	123.24	420	0.22	3.46	2.26	0.06	245	160
19H-5, 54-55	152.12	409	0.65	3.50	2.31	0.16	221	146
23X-5, 44-45	190.84	418	0.12	1.66	1.96	0.07	146	173
28X-2, 44-45	225.84	409	0.59	3.04	2.02	0.16	255	169
31X-5, 44-45	258.74	412	0.40	2.56	2.00	0.14	234	183
33X-2, 44-45	273.44	414	0.41	2.82	2.36	0.13	223	187
35X-4, 43-44	295.76	406	2.64	2.82	2.43	0.48	195	168
37X-1, 9-10	301.39	417	0.40	3.34	2.07	0.11	233	144
39X-CC, 35-36	322.32	414	0.18	1.72	2.37	0.09	135	186
42X-3, 45-46	352.05	421	0.15	3.15	2.39	0.05	180	136
45P-1, 47-48	377.97	421	0.20	3.98	2.19	0.05	361	199
49X-2, 55-56	399.85	420	0.29	3.12	2.38	0.09	271	206
50X-5, 55-56	412.95	424	0.09	1.42	2.24	0.06	125	198
51X-2, 44-45	417.94	423	0.20	2.69	1.52	0.07	231	131
53X-5, 45-46	433.05	425	0.42	3.29	1.72	0.11	263	137
54X-2, 44-45	437.15	426	0.35	4.23	1.82	0.08	311	133
55X-2, 45-46	446.85	432	0.15	2.09	1.54	0.07	190	140
58X-2, 55-56	474.71	425	0.26	3.46	1.57	0.07	290	131
61X-2, 54-55	495.51	431	0.13	2.95	1.50	0.04	220	111
63X-2, 53-54	513.28	420	0.31	2.83	1.78	0.10	239	150
65X-2, 46-47	533.56	413	0.92	5.48	1.98	0.14	320	115
66X-2, 44-45	542.41	425	0.39	5.20	1.78	0.07	293	100
67X-1, 54-55	551.34	425	0.30	3.21	1.83	0.09	189	108
71X-2, 51-52	581.99	419	0.87	4.03	1.80	0.18	307	137
73X-3, 52-53	601.56	421	0.48	3.57	1.77	0.12	262	130
77X-3, 45-46	639.47	445	0.23	3.02	1.53	0.07	258	130
78X-1, 54-55	647.44	431	0.20	3.59	1.46	0.05	262	106
79X-2, 45-46	657.77	422	0.07	1.75	1.57	0.04	182	163
81X-2, 42-43	677.62	425	0.69	5.52	1.65	0.11	360	107
82X-2, 39-40	686.27	434	0.14	2.88	1.40	0.05	257	125

Notes: T_{max} = temperature (°C) at which the maximum amount of hydrocarbons is generated from the kerogen during pyrolysis; S_1 = quantity of free hydrocarbons in the rock samples, in mg/g rock; S_2 = quantity of hydrocarbons produced by kerogen cracking, in mg/g rock; S_3 = quantity of organic CO₂ produced during pyrolysis of the rock, in mg/g rock; PI = production index, calculated as S_1/S_1+S_2 ; HI = hydrogen index, calculated as S_2/TOC ; and OI = oxygen index, calculated as S_3/TOC .

from the mean value concentrated between 70 and 90 mbsf. A high value (1.3 W/[m·K]) recorded at 39 mbsf cannot be simply explained.

Physical Properties Units

Five units were delineated based on trends in the physical properties data (Fig. 35). Unit A extends from 0 to 40 mbsf and is characterized by a general increase in wet bulk density with depth, reaching a maximum of 1.82 g/cm^3 at 39 mbsf. The increase in bulk density is accompanied by a corresponding decrease in porosity and both wet and dry water contents. Unit B (40–77 mbsf) is distinguished from Unit A by a progressive decrease in wet bulk density observed in both index properties and GRAPE data. Within Unit B, wet bulk density, porosity, and water contents decrease with depth. Unit C (77–175 mbsf) has increasing water content as a function of depth (apart from the top 6 m), with values ranging from 35% to 45% (wet) and from 54% to 83% (dry). Both the wet and dry water content curves are offset at ~115 and 132 mbsf. Strength increases with depth to 140 mbsf within Unit C but abruptly decreases between 140 and 158 mbsf. On the basis of physical properties measurements, Unit D (175 to 615 mbsf) is the most uniform part of the sedimentary section, with wet bulk densities first increasing as a function of depth to 330 mbsf and

Table 18. Interstitial-water chemistry data for Site 995.

Core, section, interval (cm)	Depth (mbsf)	Water (mL)	pН	Alk (mM)	Sal (g/kg)	Cl- (mM)	Cl-* (mM)	Mg ²⁺ (mM)	Ca ²⁺ (mM)	SO4 ²⁻ (mM)	PO4 ³⁻ (µM)	NH4 ⁺ (μM)	SiO ₂ (µM)	K* (mM)	Sr ²⁺ (µM)
164-995A-															
1H-1, 145-152	1.45	45	7.6	4.6	34.5	555	555	50.8	9.7	26.4	17	185	427	11.8	93
2H-1, 145-150	3.15	50	7.9	5.5	34.0	557	557	48.4	7.8	22.8	21	475	604	13.2	93
2H-2, 145-150	4.70	50	7.7	6.2	34.0	559	559	48.3	7.3	21.1	19	597	556	12.4	94
2H-3, 145-150	6.25	45	7.6	7.1	34.0	561	561	46.6	7.0	19.3	19	816	546	12.5	99
2H-4, 145-150	7.80	34	7.8	8.0	33.0	559	559	46.5	6.4	17.6	20	910	576	12.4	96
2H-6, 0-5	9.45	45	7.9	8.0	33.0	560	560	44.0	5.3	15.5	19	1.086	556	12.2	96
3H-1, 153-158	12.73	50	8.0	11.0	32.5	562	562	40.7	4.6	11.2	31	1,453	702	13.0	101
3H-2, 153-158	14.28	45	8.2	12.8	32.5	562	562	38.9	4.2	9.2	29	1,453	733	12.6	103
3H-3, 145-150	15.75	50	8.1	13.5	32.5	563	563	37.8	4.0	6.9	32	1,642	780	12.8	106
3H-4, 145-150	17.25	50	8.3	14.8	32.5	562	562	36.3	3.7	5.2	33	1,878	746	12.7	105

Notes: Alk = alkalinity, and Sal = salinity. Cl^{-*} = values are corrected for seawater contamination (see "Inorganic Geochemistry" section, "Site 994" chapter, this volume). All other concentrations are uncorrected.

Only part of this table is produced here. The entire table appears on the CD-ROM (back pocket).

Figure 32. Concentration vs. depth profiles for various chemical species in interstitial waters at Site 995. Values have not been corrected for seawater contamination (see "Inorganic Geochemistry" section, "Site 994" chapter, this volume). Most excursions seen on the profiles are from Hole 995B, where storage effects in the measurements have been noted.

then remaining relatively constant to 615 mbsf. The boundary between Unit D and Unit E (615-703 mbsf) corresponds to a change in slope of the wet bulk density curve.

Discussion

The physical properties units generally do not correlate with lithostratigraphic units in the uppermost portion of the hole, but some variations in wet bulk density and porosity can possibly be linked to changes in carbonate concentration and diatom abundance, respectively. For example, the high concentration of carbonate at ~40 mbsf correlates with a peak in the wet bulk density curve at the same depth. The cage-like structure of diatoms can increase the amount of void space in sediments, and the relative abundance of diatoms within lithostratigraphic Unit II may offer a partial explanation for the fact that porosity does not decrease between 85 and 150 mbsf.

Figure 33. Chloride concentration profiles for interstitial waters at Sites 994 and 995. Note the similarly of the profiles. All Cl⁻ values have been corrected for seawater contamination (see "Inorganic Geochemistry" section, "Site 994" chapter, this volume). WSTP samples are shown as open squares, with error bars indicating the uncertainty associated with the correction for mixing with seawater.

The most uniform physical properties units (D and E) correlate with lithostratigraphic Unit III, a homogeneous, nannofossil-rich claystone. Index properties are nearly constant between 330 and 610 mbsf, an unusual observation in sediments undergoing normal compaction. The presence of in situ gas and/or diffuse gas hydrate within the sediments may contribute to decreasing the effective vertical stress available to drive compaction.

For the most part, the physical properties data for Holes 994C and 995A are nearly coincident. Physical properties data reveal no major differences that could account for the remarkable lateral variability in the strength of the BSR between Sites 994 and 995. If lateral variations in BSR strength can be attributed to localized distribution of biogenic methane and/or fluid advection, then physical properties measurements would not be expected to detect such processes or their effects in recovered cores.

GEOPHYSICS

Vertical Seismic Profile Experiment Design

Zero-offset and walkaway VSP data were acquired in Hole 995B in two lowerings of the Geospace Model WLS-1100 three-component borehole seismometer (see "Operations" section, this chapter). Eight W-VSPs shot by the *Cape Hatteras* were recorded at 72-m intervals from depths of 680–176 mbsf, and a 66-station ZO-VSP was acquired at 8-m intervals from 662 to 144 mbsf (Table 22). The experiment design was similar to that of the VSP experiment in Hole 994D (see Fig. 45, "Site 994" chapter, this volume). During the ZO-VSP, 10–30 shots each of the 300-in³ Bolt PAR1500 air gun and the 400-in³ Seismic Systems P400 water gun were fired at each depth.

Data and Processing

Data were recorded as at Site 994 (see "Geophysics" section, "Site 994" chapter, this volume) with the following changes. To suppress the 60-Hz noise, shot times were randomized at intervals of 10 ms. Because this effectively reduced the 60-Hz noise on stacking, no

Table 19. Chloride concentrations and sediment temperatures of interstitial-water samples.

Core, section,	Temperature	CI-
interval (cm)	(°C)	(mM)
164-995A-		
31X-2, 135-150	8.0	496
31X-5, 135-150	10.3	507
32X-1, 118-133	8.6	505
33X-4, 88-103	12.3	503
34X-1, 106-121	13.8	502
35X-1 130-150	93	506
35X-3 130-150	10.6	505
42X 1 130-150	10.0	487
42X-1, 130-150	12.2	507
42A-5, 150-150	7.0	402
45A-1, 150-150	12.2	493
46X-5, 130-150	12.3	510
46X-5, 122-142	12.7	501
47X-2, 130–150	11.1	497
47X-4, 130–150	12.8	495
49X-2, 130-150	8.4	486
49X-4, 130-150	10.9	506
50X-2, 130-150	11.8	484
50X-5, 130-150	14.8	508
51X-2, 130-150	3.4	452
53X-2, 130-150	8.8	483
53X-5 130-150	8.2	482
54X-2 130-150	8.8	481
54X-5, 100-120	12.8	501
55V 1 120 150	10.1	506
56V 1 120 150	10.1	507
56X 2 120 150	11.0	500
50X-5, 150-150	15.4	509
58X-2, 130-150	13.9	512
59X-2, 130-150	12.5	512
64X-4, 130–150	13.4	512
68X-3, 130–150	13.7	513
71X-4, 130–150	14.3	516
72X-1, 110-131	11.8	515
74X-2, 101-121	14.6	524
75X-4, 130-150	14.3	514
76X-2, 0-32	15.4	521
77X-3, 130-150	15.6	517
78X-1, 105-125	16.8	519
79X-2, 130-150	12.7	516
80X-3 130-150	15.3	516
81X-5, 130-150	13.7	515
87X-5, 150-150	13.1	516
02A-3, 4/-/3	15.1	515
63A-7, 0-20	15.0	515
6X-1, 120-150	9.1	458
8X-2 120-150	11.2	503
8X-3 135-150	87	473
8X-4 135-150	10.4	511
8X-5 135-150	12.8	408
118 4 0 20	2.0	490
117-4, 0-20	2.0	447
12X-1, 120-150	9.5	482
12X-2, 121-131	13.3	490
13X-1, 130-150	10.0	492
12V 2 120 150	12.6	503
13A-2, 120-150	A 44 1 10	
15X-2, 120-150 15X-2, 111-116	13.9	500

Note: Temperature was measured as soon as possible after core retrieval using a probe inserted into whole-round intervals collected for interstitial water.

Figure 34. Graph of chloride (Cl⁻) concentration and sediment temperature. Temperature was measured as soon as possible after core retrieval using a probe inserted into whole-round section samples collected for interstitial water.

Table 20. Chemical analyses of unstored and stored samples showing the difference between measurements made at different times after core collection.

Core, section, interval (cm)	Storage time (hr)	Cl- before (mM)	Cl [−] after (mM)	Cl- change (%)	K ⁺ before (mM)	K* after (mM)	K ⁺ change (%)	Mg ²⁺ before (mM)	Mg ²⁺ after (mM)	Mg ²⁺ change (%)	Ca ²⁺ before (mM)	Ca ²⁺ after (mM)	Ca ²⁺ change (%)	Sr ²⁺ before (µM)	Sr ²⁺ after (µM)	Sr ²⁺ change (%)
164-995A- 81X-5, 120-150	68	515	523	1.6	13.12	16.24	23.7	14.21	9.36	-34.1	5.83	1.78	-69.5	148	109	-26.4
164-995B- 8X-2, 120-150 11X-2, 120-150 15X-3, 120-150	36 32 25	503 507 501	512 508 509	1.8 0.2 1.6	14.37 18.16	16.29 17.86	13.4 -1.6	16.64 10.99	17.13 8.78	2.9 -20.1	2.38 0.92	1.6 0.73	-32.6 -20.8	82 47 100	76 35 37	-7.3 -25.5 -63
Average change (%)			1.2			5.9			-8.6			-26.7			-31.9

Figure 35. Physical properties data from Hole 995A. IP = index properties data. The grain density data were calculated using the dry method (see "Physical Properties" section, "Explanatory Notes" chapter, this volume). NGR = natural gamma radiation in average counts per second. NGR data have been smoothed using a boxcar filter. Physical properties units are shown on the left; lithostratigraphic units, on the right.

Table 21. Index	properties of s	ediment samples	from Hole 995A.

		Water	Water	Density				
Core, section, interval (cm)	Depth (mbsf)	content (wet%)	content (dry%)	Bulk (g/cm ³)	Grain (g/cm ³)	Dry (g/cm ³)	Porosity (%)	Void ratio
164-995A-								
1H-1, 8-10	0.08	55.59	125.17	1.44	2.74	0.64	77.98	3.35
1H-1, 77-79	0.77	58.60	141.52	1.40	2.72	0.58	80.16	3.76
1H-1, 134-136	1.34	40.17	67.14	1.64	2.72	0.98	64.43	1.78
2H-1, 38-40	2.08	52.38	109.98	1.46	2.67	0.69	74.52	2.87
2H-2, 66-68	3.91	52.25	109.43	1.46	2.67	0.70	74.36	2.86
2H-4, 104-106	7.39	40.92	69.27	1.60	2.70	0.95	63.98	1.83
2H-6, 74-76	10.19	45.54	83.61	1.60	2.80	0.87	71.00	2.28
3H-2, 72-74	13.47	46.66	87.46	1.47	2.72	0.78	66.81	2.32
3H-4, 74-76	16.54	49.09	96.44	1.42	2.67	0.72	68.03	2.51
3H-6, 52-54	19.32	45.99	85.14	1.49	2.78	0.80	66.69	2.31

Only part of this table is produced here. The entire table appears on the CD-ROM (back pocket).

notch filter was applied to the data. High signal-to-noise ratios were observed at all stations (Fig. 38).

Preliminary Results

A stacked air gun section shows clear downgoing first arrivals as well as numerous upgoing reflections, including one that corresponds to the BSR (Fig. 39). The depth of the BSR is defined by the intersection of its reflection with the downgoing arrival at 440 ± 10 mbsf.

Figure 36. Acoustic velocity data obtained on whole-round core sections with the PWL (solid circles) and on split sections with the DSV (open squares). In the interval from 0 to 27 mbsf, the data sets are coincident. Below 30 mbsf, scattered values yield a velocity of ~1.45 km/s.

Figure 37. Thermal conductivity measurements obtained in sediments recovered in APC cores from Hole 995A. Error bars indicate analytical uncertainties.

A preliminary velocity-depth function was produced by inverting the air gun first-arrival times using a weighted, damped, least-squares inversion that weights mean traveltimes by the inverse of their standard error. Average picking errors on prestack traces were ± 0.0008 (1 standard deviation). The velocity-depth curve in Figure 40 was produced by assigning equal weight to fitting the traveltime data and to producing a smooth velocity-depth function. Velocities increase gradually from 150 to 400 mbsf, then decrease to a minimum of ~1550 m/s at 590 mbsf.

A plot of two-way traveltime vs. depth (Fig. 41) for Site 995 was produced by doubling the observed one-way traveltimes of first arrivals on the stacked VSP section and adding 4 ms to account for the

Table 22. Depths of vertical seismic profile stations, type of VSP, and number of air gun shots used in traveltime calculations.

Depth	Walkaway/	Number of air
(mbsf)	zero-offset	gun shots
144	ZO	31
152	ZO	26
160	ZO	23
168	ZO	14
176	ZO + W	11
184	20	17
200	20	15
208	70	16
216	ZO	24
224	ZO	15
232	ZO	20
240	ZO	15
248	ZO + W	18
256	20	12
204	20	50
280	20	17
288	70	15
296	ZO	16
304	ZO	18
312	ZO	30
320	ZO + W	17
328	ZO	20
336	ZO	17
344	20	20
352	20	22
368	ZO	11
376	zo	18
384	ZO	20
392	ZO + W	20
400	ZO	12
408	ZO	13
416	20	18
424	20	12
440	20	17
448	ZO	12
456	ZO	18
464	ZO + W	13
472	ZO	13
480	ZO	12
488	ZO	12
496	ZO	14
512	20	18
520	20	16
528	70	21
536	ZO + W	15
544	ZO	16
552	ZO	15
560	ZO	16
568	ZO	29
576	ZO	23
584	20	10
600	20	31
608	$70 \pm W$	15
616	20 + 1	11
624	ZO	12
640	ZO	11
648	ZO	15
656	ZO	16
664	ZO	22
680	W	

Note: - = no air gun shots.

depth of the guns. The resulting plot provides a direct means of relating two-way traveltime on surface seismic data to depth.

Discussion

Before discussing the implications of the VSP results for interpretations of the distribution of hydrate and free gas in the sediment column beneath Site 995, two caveats should be mentioned. First, the preliminary velocity-depth function of Figure 40 represents an average velocity structure for seismic wavelengths of 15–30 m, derived via an inversion procedure that minimizes vertical velocity gradients. As such, the fine-scale structure responsible for vertical-incidence reflections (e.g., the BSR) is not represented in this result. Second, a rigorous error analysis has not yet been conducted, so caution should be exercised in interpreting minor features of the velocity-depth curve (e.g., the peak at 290 mbsf).

The first-order interpretation of the velocity model of Figure 40 is that the increasing velocities above 420 mbsf are the combined result of decreasing porosity with depth and the addition of gas hydrate, whereas the rapid decrease from 430 to 590 mbsf indicates the presence of free gas. The anomalously low velocity of ~1520 m/s at 590 mbsf almost certainly indicates that several percent of the pore fluid volume is occupied by free gas at that depth.

The depth to the BSR can be determined in two ways from the VSP results: (1) by direct observation of the intersection of the BSR reflection with the downgoing first arrival at 440 ± 10 mbsf and (2) by depth conversion of the vertical-incidence seismic data using the velocities obtained by the VSP. The latter approach, shown in Figure 42, yields an estimate of 450 mbsf. The BSR thus arises from an impedance contrast located ~20–30 m below the peak seismic velocity of 1820 m/s at 420 mbsf. This observation is consistent with an interpretation of the BSR as arising from a thin zone of free gas just beneath the BGHS. The offset between the peak seismic velocity and the BSR suggests that the greatest concentration of gas hydrate occurs 20–30 m above the BGHS.

Comparison of the velocity-depth functions derived for Sites 994 and 995 shows that velocities at both sites are lowest at 550–600 mbsf, suggesting the greatest concentration of free gas at that depth. At Site 995, however, velocities are lower from 430 to 550 mbsf than at Site 994, suggesting that more free gas exists at shallower levels at Site 995 than at Site 994.

DOWNHOLE LOGGING Introduction

The primary objective of the downhole logging program at Site 995 was to obtain in situ physical property and geochemical data

Figure 38. Air gun shots recorded on the vertical component of a clamped geophone at 512 mbsf in Hole 995B, showing clear downgoing arrivals.

Figure 39. Stacked VSP section for Hole 995B created by filtering data from 10 to 150 Hz and stacking common depth gathers. A clear upgoing event that corresponds to the BSR reflection intersects the downgoing arrivals at 440 \pm 10 mbsf.

Figure 40. A. Observed traveltimes of downgoing first arrivals (open circles) and traveltime fit calculated from velocity-depth model (solid line) in Hole 995B. B. Velocity-depth function for Hole 995B computed by weighted, damped least-squares inversion of first-arrival times using a smoothness constraint. Velocities increase gradually from 150 to 400 mbsf and decrease to a

Figure 41. Two-way traveltime vs. depth from VSP measurements (open circles) and from integrated sonic log velocities (dashed line) in Hole 995B. This plot provides a means of correlating two-way traveltime on verticalincidence seismic sections to depth.

from an area where a BSR exists. Site 995 was part of a multihole transect (Sites 994, 995, and 997) designed to penetrate below the base of the gas hydrate stability zone within the same stratigraphic interval over a relatively short distance on the Blake Ridge. Site 995 was selected as a transition location from an area of no BSR (Site 994) to an area with a strong BSR (Site 997).

At Site 995, Hole 995B was logged with five different tool strings: (1) the seismic stratigraphic combination, (2) the lithoporosity combination, (3) the GLT, (4) the LDEO-SST, and the (5) Formation MicroScanner (for more detail on the logging runs, see "Operations" section, this chapter). The Schlumberger seismic stratigraphic and lithoporosity tool strings were run over the interval from 134.0 mbsf (base of drill pipe) to 639.0.0 mbsf, and the depth interval between 135.0 mbsf (base of drill pipe) to 634.5 mbsf was logged with the GLT. In addition to the normal acquisition of capture-t neutron geochemical data, a series of 19 inelastic neutron geochemical measurements were made. The LDEO-SST also was deployed in Hole 995B, and the depth interval from 136.0 to 658.7 mbsf was successfully logged. The final borehole surveys in Hole 995B consisted of two runs of the Schlumberger Formation MicroScanner within the depth interval between 145.0 and 658.7 mbsf. Hole 995B penetrated a total of 700.0 m of sediment (total hole depth); borehole bridging prevented logging below 658.7 mbsf. Because of borehole stability problems at Site 994, the CSES was deployed before logging Hole 995B.

Log Quality

The quality of the log measurements at Site 995 was moderately degraded by the size and rugosity of the borehole. The caliper log in Hole 995B (Fig. 43) shows borehole diameters greater than the 43.7-cm (17.2 in) maximum range of the caliper for a significant portion of the hole. The NGT, HLDT, and CNT-G tools are particularly sus-

Figure 42. Comparison of (A) interpreted ZO-VSP velocity-depth function for Hole 995B to (B) the seismogram stack from seven adjacent traces around Site 995, converted to depth using an average subseafloor seismic velocity of 1650 m/s (determined from VSP results). The BSR is a bright reflection at 450 mbsf.

ceptible to adverse effects from large and irregular hole diameters. The NGT logs from Hole 995B were not significantly affected by the size of the borehole. However, the apparent gamma-ray well-log measurements near 210 and 400 mbsf are affected by changes in the size of the borehole (discussed later in this section). The HLDT, which is an excentered device, has a caliper arm that forces the tool against the wall of the borehole. If the hole is larger than the maximum reach (43.7 cm) of the caliper arm, the density tool may lose contact with the formation. In general, the density log in Hole 995B yields useful data; however, the density log measurements are degraded within the depth interval between 135 and 240 mbsf because of borehole size effects. Data from the density log have been used for porosity calculations (see "Porosity Calculations," this section). The CNT-G is severely affected by enlarged boreholes and has been disregarded in our initial interpretation (see "Porosity Calculations," this section). The sonic velocity (SDT/LSS) and resistivity (DITE-SFL) logs provided useful information in Hole 995B; however, both of these devices may be affected by the presence of gas hydrate. The GLT provides useful information; however, the GLT measurements also have been degraded by the enlarged borehole conditions. Data from the GLT have been used sparingly in our initial interpretation because of the need for standard shore-based processing.

The seismic stratigraphic and lithoporosity surveys in Hole 995B were recorded at cable speeds that yield high-resolution data (425 and 275 m/hr, respectively). The GLT was run at a cable speed of 183 m/hr. The LDEO-SST was recorded at a 335 m/hr cable speed, whereas the Formation MicroScanner was run at a cable speed of 550 m/hr. A summary of the logging tool strings used during Leg 164 and discussion of their measurement principles are provided in the

Figure 43. Caliper logs recorded from the HLDT in Hole 995B.

"Downhole Logging" section, "Explanatory Notes" chapter (this volume).

Shipboard data editing was limited to depth shifting and the removal of some out-of-range data. Establishing consistent depths for each of the logs was accomplished by correlating the natural gammaray logs. The absolute depths, relative to seafloor, for all logs were fixed by identifying the gamma-ray signal associated with the seafloor and depth shifting the log data appropriately. The natural gamma-ray log pick for the seafloor in Hole 995B is 2786 mbsl. Because the logs were measured from the dual elevator stool, which is located 11.4 m above sea level, the actual log-determined water depth at Hole 995B was 2774.6 mbsl, which is 2.3 m less than the water depth of 2776.9 m (zero core depth) determined by the drillers. Outof-range log measurements were removed from our working log database. These deletions were limited to data from within the drill pipe or near the bottom of the hole.

Logging Units

The description of the logged interval in Hole 995B is divided into three logging units on the bases of obvious changes in the natural gamma-ray (NGT), bulk density (HLDT), sonic velocity (LSS/SDT), and electrical resistivity measurements (DITE-SFL) (Fig. 44). The elemental yield data from the geochemical log (GLT) also was evaluated for lithologic changes (Fig. 45). Elemental yield data (uranium, thorium, and potassium) from the natural gamma-ray spectrometry tool (NGT) has been used to assess the mineralogy of the sediments in the delineated logging units (Fig. 46).

Log Unit 1 (134.0 mbsf [base of pipe] to 193.0 mbsf)

This interval between the base of the pipe (134.0 mbsf) and 193.0 mbsf is characterized by relatively low gamma-ray, density, velocity, and resistivity log values. Near the base of Unit 1 (below 178.0 mbsf), all of the recorded logs are significantly affected by the enlarged borehole. The resistivity log shows an upward step in value at the boundary between Units 1 and 2 (Fig. 44), whereas the density log reveals a significant reduction in the recorded bulk densities at the same boundary. The acoustic velocity ramps up more gradually across the boundary between Units 1 and 2. The gamma-ray log from Hole 995B (Fig. 45) does not show a significant change in value at the boundary between Units 1 and 2 (depth of 193.0 mbsf).

Elemental yield data depicted in Figure 45 reveal no significant changes at the boundary between Units 1 and 2. Within Unit 1, the weight percentage of potassium (K) is relatively low and remains constant. The elemental lithology indicator ratios LIR [Si/(Si+Ca)] and IIR [Fe/(Si+Ca)] are used to assess the relative amounts of carbonate, silica, and clay. Decreases in LIR suggest the increasing presence of carbonates, whereas increasing values indicate more silica. Increases in IIR suggest the presence of more clays. Within Unit 1, IIR remains relatively constant, suggesting little changes in clay content. LIR in Unit 1 also remains relatively constant, indicating little change in carbonate or silica content. Potassium and thorium (Th) elemental yields (Fig. 46) reveal that the clays in Unit 1 of Hole 995B are predominately montmorillonites and some illites. Photoelectric data from the formation density device in Hole 995B also indicate that the clays are dominantly montmorillonites.

Log Unit 2 (193.0-450.0 mbsf)

Unit 2 is characterized by increasing velocities (1.60 km/s at the top of the unit to more than 1.90 km/s at the bottom) with depth. The electrical resistivity log reveals a small increase of ~0.1 Ω m from the top to the bottom of Unit 2. The resistivity log also reveals two conspicuous high electrical resistivity intervals between 218 and 242 mbsf. Both the acoustic velocity and resistivity logs are characterized by a distinct baseline shift to relatively higher values throughout Unit 2. At the base of Unit 2, across the boundary into Unit 3, the acoustic velocity and resistivity logs are affected by significant changes in hole size within the upper 100 m of Unit 2 and, again, near the depth of 400 mbsf. In general, however, the natural gamma-ray log is nearly constant throughout Unit 2, whereas the density log shows an increase in bulk density from ~1.5 g/cm³ at 200.0 mbsf to nearly 1.8 g/cm³ at the base of Unit 2.

Relative to Unit 1, the gamma-ray logs (Fig. 45) from Unit 2 in Hole 995B reveal a more variable lithologic section. The relative amount of K is elevated within Unit 2 in comparison to Unit 1. Changes in K concentrations may suggest changes in the clay content; however, the IIR elemental ratios for this interval do not indicate a change in the clay content. Analyses of the LIR elemental ratios

Figure 44. Log data from Hole 995B. Data shown include natural gamma-ray log data from the NGT, bulk density data from the HLDT, acoustic velocity data from the LSS, and deep-reading electrical resistivity data from the DITE. Also shown are the depths of logging Units 1, 2, and 3.

suggest that there is a slight increase in the relative carbonate content of the sediments in Unit 2, with the highest amounts being detected near the base of the unit. Analyses of K and Th elemental yields (Fig. 46) suggest that the clays are dominantly montmorillonites.

Log Unit 3 (450.0-658.7 mbsf [end of log run])

Unit 3 is characterized by consistently lower velocities and resistivities with respect to Unit 2. An anomalous low velocity interval is seen from 536 to 622 mbsf; velocities within this anomalous interval decrease to 1.55 km/s, which suggests the presence of a highly attenuating, possibly free gas-bearing zone. The electrical resistivity, natural gamma-ray, and density logs show slightly increasing values with depth in Unit 3.

Porosity Calculations

Sediment porosities can be calculated from numerous borehole measurements. At Site 995, we have attempted to use data from the CNT-G, HLDT, LSS/SDT, and DITE-SFL logs to calculate sediment porosities. Most standard techniques for calculating log-derived porosities have been developed for lithified "clean" sandstone and carbonate systems with little or no clay fraction. Log porosity calculate

tions in unconsolidated clay-rich marine sediments are often severely hampered by adverse borehole conditions and the lack of previous quantitative studies.

Neutron Porosity Calculations

The CNT-G measures the amount of hydrogen within the pore space of a sedimentary sequence, which is largely controlled by the amount of water that is present. The CNT-G has two pairs of detectors that indirectly measure both epithermal (intermediate energy level) and thermal (low energy) neutrons, which provide two independent porosity measurements. The recorded neutron porosity log data from Hole 995B reveal an average thermal porosity of ~50%, whereas the epithermal porosity averages ~100%. The thermal and epithermal porosity logs are calibrated to read 50% and 100%, respectively, in water (no sediment). Therefore, it is likely that the neutron log in Hole 995B only detected the hydrogen in the borehole waters, so the porosity data from the neutron log is of no value.

Density Porosity Calculations

The HLDT measurements of bulk density (ρ_b) from Hole 995B (Fig. 47) were used to calculate sediment porosities (\emptyset) using the

Figure 45. GLT data from Hole 995B. Data shown include the total gamma-ray (SGR) and computed gamma-ray (CGR = SGR – uranium concentration) measurements. Potassium concentrations are shown in weight percentage. LIR and IIR are lithology indicator ratios. Also shown is the depth of the boundary between logging Units 1, 2, and 3.

standard relationship $\emptyset = (\rho_b - \rho_m)/(\rho_w - \rho_m)$ (Schlumberger, 1989). Water density (ρ_w) and grain density (ρ_m) were assumed to be 1.05 and 2.65 g/cm³, respectively, based on index properties measurements of recovered core (see "Physical Properties" section, this chapter). The resulting porosity calculations yielded values ranging from 55% to near 85% (Fig. 47). Sensitivity to variations in grain density (ρ_m) were evaluated over the range from 2.60 to 2.85 g/cm³; calculated porosities varied by less than 4%. The unreasonably high density log-derived porosities above 210 mbsf in Hole 995B appear to be caused by the enlarged borehole. The effect of the enlarged borehole can be removed from the measured density data, but this correction will require extensive shore-based reprocessing.

Acoustic Velocity Porosity Calculations

The empirical Wyllie time-average equation (Schlumberger, 1989) was used to calculate porosities (\emptyset) from the measured acoustic well-log velocities (t_{log}) (Fig. 48). In the standard time-average relationship $\emptyset = (t_{log} - t_m)/(t_w - t_m)$, water velocity (t_w) and matrix velocity (t_m) were assumed to be 1.50 and 3.40 km/s, respectively. The resulting velocity porosity calculations yielded unreasonably high values ranging from 60% to 90%. Sensitivity to variations in matrix

velocity (t_m) was evaluated over the range of 3.40–4.37 km/s; calculated porosities varied by less than 4% and remained out of the range of expected values. Several workers have shown that the observed velocity behavior of unlithified marine sediments is not always consistent with the prediction of the time-average equation. An additional concern at Site 995 is the presence of gas hydrate and free gas below the gas hydrate stability zone. The occurrence of gas hydrate often is associated with significantly higher acoustic velocities and apparent decreases in porosities calculated from the acoustic data. On the other hand, free gas will yield lower acoustic velocities and apparent increases in acoustic calculated porosities. Because of the limitations of available velocity-porosity mathematical relations and because of the potential occurrence of gas hydrate and free gas, we have not used the acoustic velocity data from Site 995 to calculate porosities.

Electrical Resistivity Porosity Calculations

One approach to obtaining porosities from well logs is to use the electrical resistivity logs (Fig. 48) and Archie's relationship between the resistivity of the formation (R_i) and porosity (\emptyset): $R_t/R_w = a \, \emptyset^{-m}$, where *a* and *m* are parameters to be determined and R_w is the resis-

Figure 46. Lithology crossplot (modified from Schlumberger, 1989) of potassium and thorium elemental concentrations from the GLT in Hole 995B. All of the K-Th data from the logged interval (135.0-634.5 mbsf) are shown.

Figure 47. Bulk density (RHOB) log data and density-derived porosities for Hole 995B.

tivity of the pore waters (Archie, 1942). We have used this relationship by assuming a pore-water salinity of seawater (32 ppt) and calculating the resistivity of seawater (R_w) as a function of temperature in the formation using Arp's formula (Schlumberger, 1989) and a geothermal gradient of 3.85°C/100 m (seabed temperature of 3°C). To determine the parameters a and m, we used the measured log resistivities and the porosities measured in the Physical Properties Laboratory (Fig. 47) (see "Physical Properties" section, this chapter) for the depth intervals 140-200 mbsf and 575-650 mbsf. We determined linear trends for the log resistivities and core-derived porosities in these two intervals from which we calculated representative resistivities and porosities. From these representative values, we calculated the slope, m, and the intercept, $\ln a$, of the function $\ln (R_t/R_w)$ $= -m \ln \emptyset + \ln a$. Given these parameters (a = 0.9; m = 2.7), we then calculated porosity from the resistivity log using Archie's relationship. The result of this calculation is the porosity log shown in Figure 48. The calculated resistivity porosities should be considered "apparent" porosity values because we have assumed that all of the void space within the sediments is filled with water with the same salinity as seawater (32 ppt), which may not be true. The Archie parameters (a and m) calculated for Hole 995B are within the normal range of expected values (Schlumberger, 1989).

In Hole 995B, we see decreasing porosities with depth (Fig. 48), although this is not the normal exponential consolidation trend that would be expected if the pore space decreased with depth primarily from the weight of increasing overburden; instead, we see an almost linear porosity decrease. Relative to Units 1 and 3, Unit 2 exhibits a baseline shift to higher resistivities and lower calculated resistivity porosities. The assumption that all of the pore space within the sediments of Unit 2 is filled with water with the same salinity as seawater (32 ppt) may be invalid. Some of the pore space in Unit 2 may be occupied by gas hydrate, which exhibits very high electrical resistivities and would contribute to an apparent reduction in resistivity-derived porosities. However, the resistivity porosity log in Figure 48 is the best downhole-derived porosity log from Site 995.

A comparison between core and log measurements of bulk density and porosity was made with the data from Site 995 (Fig. 49). Laboratory-derived core porosities are similar to the resistivity logderived porosities. However, within the upper part of the hole (above 300 m) the core porosities are consistently greater than the log values. Core measurements from Hole 995A and log measurements from Hole 995B of bulk density are similar; however, the core-measured densities are generally greater than the downhole measurements. At Site 994 (see "Downhole Logging" section, "Site 994" chapter, this volume), we thought that the low downhole-measured bulk densities were caused by enlarged hole sizes. However, the consistency between the downhole density measurements at Sites 994 and 995 suggests that the density logs are accurately measuring in situ densities.

The density- and resistivity-derived porosities for Hole 995B are anomalous for a "normal" marine stratigraphic section. As shown in Figure 50, the density- and resistivity-derived porosities exhibit an almost-linear decrease with depth. The apparent discrepancies between the two log porosity plots in Figure 50 are due to borehole size effects discussed earlier in this section. To further evaluate the log porosity trends at Site 995, we have generated a theoretical porosity profile for the Blake Ridge sedimentary section (Fig. 50). To construct this theoretical porosity profile, we have used a series of sediment compaction relations developed by Hamilton (1976) that assume a sediment mixture of pelagic clay, calcareous ooze, and terrigenous material. In general, the theoretical porosity profile is similar to the log-calculated porosities within the upper 300 m of Hole 995B. However, within the lower portion of Hole 995B (below 450 mbsf) there is a significant difference between the theoretical and logcalculated porosities, thus revealing a potentially undercompacted sedimentary section.

Figure 48. Log data used to calculate porosities in Hole 995B. Data shown include bulk density (RHOB) data from the HLDT, acoustic velocity data from the LSS, deep-reading electrical resistivity (IDPH) data from the DITE, and porosity as calculated from the resistivity log. Also shown are the depths of logging Units 1, 2, and 3.

Gas Hydrate

Collett et al. (1984, 1988), Mathews (1986), and Prensky (1995) have provided a comprehensive review of gas hydrate well-log evaluation techniques. Confirmed natural gas hydrate occurrences are generally characterized by the release of unusually large concentrations of methane during drilling and an increase in log-measured acoustic velocities and electrical resistivities. Gas hydrate-bearing stratigraphic sections exhibit relatively high electrical resistivities because some of the available pore space is filled with a solid nonconductor (i.e., gas hydrate) (Pearson et al., 1983). Because hydrate is an electrical insulator, its presence in a stratigraphic section can be electrically detected and quantified. Gas hydrate-bearing horizons also exhibit rapid acoustic velocities because some volume of the pore space is occupied by solid gas hydrate that is characterized by acoustic velocities nearly twice that of water (reviewed by Prensky, 1995). As discussed in the "Downhole Logging" section in the "Explanatory Notes" chapter (this volume), other well-log measurements, including bulk density, neutron porosity, and natural gamma ray, are not significantly affected by the presence of gas hydrate.

In comparison to logging Units 1 and 3 in Hole 995B, logging Unit 2 (193.0-450.0 mbsf) is characterized by a distinct stepwise increase in both electrical resistivity (increase of ~0.2 \Omegam) and acoustic velocity (increase of ~0.2 km/s) (Fig. 51). In addition, the deepreading resistivity device (RILD) reveals two anomalously high resistivity units from 218 to 242 mbsf. For the purpose of this discussion, we have further subdivided logging Unit 2 into four additional units: 2A, 2B, 2C, and 2D (Fig. 51). The two anomalously high resistivity units have been identified as logging Units $2A_1$ and $2A_2$ (Fig. 51). In comparison, the resistivity log values are almost constant in logging Unit 2B, whereas the acoustic velocities increase with depth over the same interval. However, both the electrical resistivity and acoustic velocities increase with depth in Units 2C and 2D. Further comparisons show that the high electrical resistivity nature of Units 2A1 and 2A2 do not correlate to any apparent velocity anomalies. Examination of the natural gamma-ray and bulk density logs (Fig. 44)

Figure 49. Comparisons of laboratory-derived index property measurements with downhole bulk density measurements and electrical resistivity-derived porosity calculations for Site 995. The continuous line shows the downhole log data. The laboratory data are shown as discrete point measurements.

reveals no apparent lithologic causes for the observed velocity and resistivity increases in Unit 2. The above observations are consistent with a material of increased resistivity and acoustic velocity, but similar density, that partially replaces some of the pore water in Unit 2. The depth of the boundary between Units 2 and 3 (450.0 mbsf) is in rough accord with the predicted base of the methane hydrate stability zone (see "Gas Hydrate" section, this chapter).

Similar to our observations at Site 994, one conclusion that can be made is that logging Unit 2 in Hole 995B contains some amount of gas hydrate. However, an alternative hypothesis suggests that porewater salinity changes could account for the observed electrical resistivity log responses. Geochemical analyses of recovered cores at Site 995 have revealed the presence of pore water with relatively low chloride concentrations (see "Inorganic Geochemistry" section, this chapter). This may indicate that logging Unit 2 contains waters with relatively low salt concentrations that will contribute to an increase in the measured electrical resistivities. However, because the acoustic log is not affected by changes in pore-water salinities, it appears to refute the hypothesis that salinity changes are contributing to the anomalous acoustic velocity and resistivity properties of logging Unit 2. To further evaluate the effect of pore-water salinity on the measured log values at Site 995, we have attempted to quantify the observed changes in electrical resistivity in Unit 2 with respect to potential pore-water salinity changes. We have determined that accounting for the high resistivities (1.40 Ω m) observed in Unit 2A₁ (Fig. 51) would require the pore waters to be diluted, relative to a seawater baseline of 32 ppt, by almost 72% (to ~9 ppt NaCl). The resistivity response observed in Unit 2C would require a 50% reduction of the pore-water salt relative to an assumed seawater-salinity baseline (to ~16 ppt NaCl). These required pore-water salinity changes of 50% and 72% are greater than the maximum observed chloride

Hamilton porosity

ōn

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Figure 50. Log-calculated density and resistivity-derived porosities from Hole 995B. Also shown is a theoretical porosity profile for the Blake Ridge sedimentary section (developed from Hamilton, 1976).

Figure 51. Log data used to calculate potential gas hydrate amounts in Hole 995B. Data shown include acoustic velocity data from the LSS and deepreading electrical resistivity data from the DITE. Also shown are the depths of logging Units 1, 2 (2A, $2A_1$, $2A_2$, 2B, 2C, and 2D), and 3. Listed beside the electrical resistivity log trace are the calculated gas hydrate amounts (percentage of pore space occupied by gas hydrate).

changes measured in the recovered cores (see "Inorganic Geochemistry" section, this chapter.

Electrical resistivity log data can be used to quantify the amount of gas hydrate in a stratigraphic sequence (see "Downhole Logging" section, "Explanatory Notes" chapter, this volume). For the purpose of discussion, we have assumed that the anomalously high resistivities and velocities measured in logging Unit 2 of Hole 995B are caused by the presence of in situ gas hydrate. The DITE-SFL measurements of deep electrical resistivity (R_i) from Hole 995B (Fig. 51) were used to calculate water saturations (S_w) [gas hydrate saturation (S_h) is equal to $(1.0 - S_w)$] using the following modified Archie relationship: $R_t/R_o = S_w^{-n}$ (Schlumberger, 1989), where R_o is the resistivity of the sedimentary section if it contained only water ($S_w = 1.0$), R_t is the resistivity of the hydrocarbon-bearing intervals (log values), and n is an empirically derived parameter. This modified Archie relationship is based on the following logic: If the pore space of a sediment is 100% saturated with water, the deep-reading resistivity device will measure the resistivity of the 100% water-saturated sedimentary section (R_a) . This measured R_a value is considered to be a relative baseline from which hydrocarbon saturations can be determined within nearby hydrocarbon-bearing intervals. To determine R_{o} for logging Unit 2 in Hole 995B, we have used the measured deep resistivities from Units 1 and 3, which are assumed not to contain a significant amount of hydrocarbons ($S_w = 1.0$), to project an R_a trend line for Unit 2 (Fig. 51). Laboratory experiments of different sediment types have yielded a pooled estimate for n of 1.9386 (reviewed by Pearson et al., 1983). Now knowing R_t , R_o , and n it is possible to use the modified Archie relationship to estimate gas hydrate saturation $(S_h$ -fraction of the total pore space that is occupied by gas hydrate). We calculated S_h for Units 2A₁ and 2A₂ to both be 20% (Fig. 51). The resistivity-derived Sh for Unit 2C averages 7.9%, which probably accounts for the baseline resistivity log shift observed throughout all of Unit 2. The lower 52 m of Unit 2 (Unit 2D) is characterized by slightly higher resistivity log values, which suggest a relative increase in gas hydrate content. Resistivity log calculations do indicate higher S_h in Unit 2D, with an average value of 9.7%. The resistivity-derived S_h values in Unit 2D range from 7.7% to 11.6%.

Carbon (C) and oxygen (O) elemental yield data were obtained with the GLT in Hole 995B for the purpose of calculating gas hydrate saturations. Inelastic neutron measurements were made at a series of 19 stations (5-min stationary measurements) in Hole 995B (Table 23). The inelastic stations were located both within and below the zone of expected gas hydrate occurrence (logging Unit 2 and 3). The measured C/O ratios ranged from 0.020 to 0.043, which are within the expected range for marine sediments (Table 23). Further analyses of this data are beyond the scope of this initial log interpretive phase.

Temperature

The LDEO-TLT was deployed on the Schlumberger seismic stratigraphic tool string in Hole 995B (Fig. 52). During the process of drilling, cold seawater is circulated in the hole, cooling the formation surrounding the borehole. Once drilling ceases, the temperature of the formation gradually rebounds to its equilibrium temperature. The available borehole temperature data cannot be easily used to assess the nature of the thermal rebound in Hole 995B because only one temperature survey was conducted. The plot of vertical temperature gradient in Figure 52 reveals several gradient changes that were caused by borehole temperature anomalies. These anomalous temperature zones in Hole 995B may indicate gas flowing into the well bore.

Acoustic Velocities

The LSS from Hole 995B was integrated over the range of the logging run (134.0-639.0 mbsf) to produce a graph of two-way traveltime vs. depth (Fig. 53). A two-way traveltime for the water bottom of 3.73 s was determined from site survey seismic records, and velocities were linearly interpolated between the seafloor velocity of 1500 m/s and the first log velocity at 134.0 mbsf. The resultant traveltime depth curve (Fig. 53) is coincident with one obtained independently from the VSP data (see "Geophysics" section, this chapter).

Lamont-Doherty Dipole Shear Tool

The deployment of the Lamont-Doherty dipole shear tool in Hole 995B yielded compressional and shear wave velocity data. Figure 54 contains a partial log of the compressional and shear wave velocities measured with the dipole shear tool in Hole 995B. Because this was the first deployment of the LDEO-SST, the selection of shear wave arrivals was not yet automated. Therefore, the results in Figure 54 are a sample of the data that will be forthcoming after shore-based processing.

IN SITU TEMPERATURE MEASUREMENTS

The primary goal of the in situ temperature program at Site 995 was to determine the thermal conditions in the gas hydrate stability zone at a location with a strong BSR. In addition, the in situ temperature measurements constrain the amount of heat available for low-temperature diagenetic processes and microbial incubation, and they can be used to evaluate the role of advection in the local transport of heat. A final goal of the in situ temperature program was the estimation of heat flow for comparison with the results of a traditional heat-flow survey at the same location (Ruppel et al., 1995).

Sampling Strategy

In Hole 995A, the Adara tool was used to measure in situ temperatures at 20–30 m vertical spacing during APC operations between 0 and 170 mbsf. The WSTP tool was deployed from 20 to 390 mbsf in Hole 995A, with measurements obtained at 30–60 m spacing at APC depths (shallower than 170 mbsf) and at 20–30 m spacing deeper in the hole. Three additional WSTP measurements were made in Hole 995B. The prototype DVTP tool (see "Explanatory Notes" chapter, this volume) was deployed twice in Hole 995A at depths of 165.2 and 290.7 mbsf, respectively. The results of the 20 Adara, WSTP, and DVTP measurements attempted at Site 995 are summarized in Table 24. Fifteen of the attempted in situ measurements were successful.

Table 23. Carbon-oxygen elemental ratios as measured with the GLT in Hole 995B.

Depth (mbsf)	Well-log depth (mbrf)	Carbon/oxyger ratio
221.0	3007.0	0.022
225.9	3011.9	0.025
234.9	3020.9	0.037
238.9	3024.9	0.021
339.0	3125.0	0.022
349.0	3135.0	0.031
414.0	3200.0	0.036
438.9	3224.9	0.037
449.0	3235.0	0.042
454.0	3240.0	0.043
463.9	3249.9	0.020
488.9	3274.9	0.033
513.9	3299.9	0.031
524.0	3310.0	0.036
534.1	3320.1	0.022
593.9	3379.9	0.038
599.1	3385.1	0.025
604.1	3390.1	0.040
614.1	3400.1	0.029

Figure 52. Temperatures recorded with the LDEO-TLT on the downward run of the Schlumberger seismic stratigraphic tool string in Hole 995B. Also plotted is the vertical temperature gradient for the downward portion of the logging run.

APC Adara Measurements

The Adara bottom-water temperature (BWT) of $2.9^{\circ}-3.0^{\circ}$ C used as a baseline for all in situ temperature records was obtained during a 10-min mudline stop on descent before Core 164-995A-4H. The six Adara runs for in situ temperatures (Cores 164-995A-4H through 20H) included a 5-min mudline stop during descent, 10–12 min in the bottom of the hole, and a 2–3 min mudline reading on ascent.

Figure 55 shows the portion of the Adara records that includes the mudline stops, penetration, and pullout. Frictional heating on penetration ranged from 1° to 9°C, with the frictional pulse generally increasing with the depth of the measurements. In some cases (e.g., Core 164-994C-10H), the thermal equilibration curve was overprinted by small temperature perturbations caused by heaving of the ship.

Figure 53. Two-way traveltime calculated from the acoustic velocity log in Hole 995B.

WSTP Measurements

The WSTP tool was used at both APC and XCB depths at Site 995. The deployment of the WSTP at APC depths (shallower than 170 mbsf) in Hole 995A provided an opportunity for direct comparison of the equilibrium temperature values obtained using the Adara and WSTP tools. The WSTP also was deployed three times between 100 and 200 mbsf in Hole 995B, yielding additional, independent constraints on in situ temperatures in this depth range in Hole 995A.

The WSTP was always deployed in the combined water sampling and temperature mode at Site 995. WSTP runs in Hole 995A included a 2- to 3-min descending mudline stop, a 10-min thermal equilibration interval at the bottom of the hole, and a second mudline stop on ascent. Sampling of pore fluids was timed to begin ~10 min after penetration. Because the primary objective of the WSTP program in Hole 995B was the sampling of pore waters, mudline stops were abandoned, and water sampling commenced within 1 min of the tool's penetration into the sediments.

Mudline, penetration, and pullout records for WSTP deployments that did not result in cracking of the formation or thermistor failure are shown in Figure 56. Frictional heating pulses are missing from all records, but pullout forces were in all cases sufficiently high to infer that the tool was probably firmly embedded in the bottom of the hole during the runs.

DVTP Measurements

The prototype Davis/Villinger Temperature Probe was deployed at the switch from APC to XCB operations (165.2 mbsf) and again at 290.7 mbsf. The first run included a 10-min mudline stop, 15 min in the bottom of the hole, and a 5-min stop at the mudline on ascent. The duration of the descending mudline stop and the equilibration interval were reduced for the second deployment.

The DVTP records shown in Figure 57 indicate that more than one penetration occurred during both deployments of the tool. At 165.2 mbsf, the formation probably was not firm enough to support the weight of the probe, which episodically sank farther into the sediments as the run continued. At 290.7 mbsf, the temperature record reveals two distinct penetrations, with the probe in the borehole for more than 3 min between the penetrations. Because the DVTP is de-

Figure 54. Compressional and shear wave acoustic logs measured with the LDEO-SST in Hole 995B.

coupled from the wireline at bottom of the hole, the explanation for the pullout and subsequent repenetration of the probe is not obvious. applied to render these data usable for the determination of equilibrium temperatures.

Corrections

The DVTP and WSTP data required substantial corrections (Table 24) to bring the BWT recorded by these tools into agreement with the value measured by the more reliable Adara tool. The corrections were applied to the raw resistance (WSTP) or logger (DVTP) data before the conversion to temperatures. Six of the 10 successful WSTP deployments at Site 995 required corrections of at least 1200 counts over the 30,000 count range of the thermistors. Because of the nonlinear dependence of temperature on resistance, a correction of this magnitude changes equilibrium temperatures by -0.5° C in the range from 5° to 10°C but by nearly -2° C in the range from 15° to 20°C.

The two thermistors near the tip of the DVTP tool (see "Explanatory Notes" chapter, this volume) recorded resistances that were grossly off scale even before deployment. A correction of 7900 units was applied to produce a match between the mudline temperatures recorded by Thermistor 1 (probe tip) in the DVTP and by the Adara tool. Data logged by Thermistor 2 (30 cm from the probe tip) exceeded 0 counts only during handling on deck, and no correction could be

Equilibrium Temperatures

Standard ODP software was used to process the Adara and WSTP records for Hole 995A. Because tool-specific software was not yet available for the DVTP, equilibrium temperatures could only be estimated based on the shape of the equilibration curves. For the WSTP and Adara tools, the equilibrium temperature is determined by fitting synthetic temperature-time curves to the recorded data. The choice of penetration records and initial and final equilibration records primarily controls the quality of the equilibrium temperature estimates. Of secondary importance is the choice of a thermal conductivity value, here taken as 1.0 W/(m-K) for all analyses.

For the high-quality in situ measurements, the temperature data recorded in the bottom of the hole are asymptotic to the equilibrium temperature values given in Table 24. The equilibrium temperature is given by the y-intercept of the synthetic curve that best fits the observations in temperature vs. $F(\alpha,t)$ space, where F is a function of the nondimensional probe parameter (α) and the inverse of time since penetration (t) in the standard formulation used for all deep-sea tem-

Table 24. In situ temperature measurements in Holes 9	195A and 995B.
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Core	Depth (mbsf)	Tool	Equil. T ^a (°C)	K ^b (W/[m·K])	Correction (counts)	Comments
164-995A-						
2H	0	Adara				Electronics failed
4H	20.7	WSTP				Thermistor leaked (#203)
4H	30.2	Adara	4.8 ± 0.25	1.04		Reference mulline $T = 2.9^{\circ} - 3.0^{\circ} \text{C} \pm 0.5^{\circ} \text{C}$
6H	49.2	Adara	5.2 ± 0.25	1.07		
10H	78.7	Adara	7.3 ± 0.50	0.93		Unsteady in-bottom record
11H	78.7	WSTP	5.4 ± 0.50	0.93	+2800	Mudline T offset by $+2.4^{\circ}$ C
13H	107.2	Adara	7.2 ± 0.25			1.03
14H	107.2	WSTP	6.2 ± 0.50	1.03	+2800	Recorder began to fail: thermistor wet (#203)
16H	135.7	Adara	8.2 ± 0.25	1.19		
20H	165.2	Adara	9.3 ± 0.25	1.00		
21X	165.2	DVTP	8.4 ± 0.75	1.00	+7900	First deployment of new tool; multiple penetrations; thermistors off scale; switch to XCB coring
28X	223.9	WSTP	11.6 ± 0.25	0.94	+290	Recorder replaced; new thermistor (#208)
31X	269.1	WSTP			+290	Bad penetration
34X	290.7	DVTP	12.4 ± 0.75	0.94	+7900	Two penetrations; thermistors off scale
35X	300.3	WSTP			+450	High drift
39X	319.6	WSTP	13.9 ± 0.50	0.94	+650	Thermistor drifting (apparent)
42X	348.6	WSTP	15.2 ± 0.50	0.94	+1200	Thermistor drifting (apparent)
47X	387.1	WSTP	16.2 ± 0.50	0.94	+1200	
164-995B-						
4W1	109.5	WSTP	7.0 ± 0.50	1.03	+1200	Thermistor drifting (apparent)
4W2	155	WSTP				Tool in borehole water
4W2	200	WSTP	10.0 ± 0.50	0.94	+1500	Thermistor drifting (apparent)

Notes: Adara = Adara APC temperature shoe; WSTP = water-sampling temperature probe; and DVTP = Davis/Villinger Temperature Probe. T = temperature. The WSTP was run at three different depths within the washed interval designated as Core 164-995B-4W (see Table 1).

^aThe equilibrium temperature was determined by trial-and-error minimization of the misfit between the synthetic equilibration curve and the recorded data in temperature vs. $F(\alpha,t)$ space. The errors are assigned subjectively based on the magnitude of the correction applied to the data, the degree of in-bottom disturbance, and the tool used. ^bK indicates the average, uncorrected thermal conductivity value used to convert from depth to resistance. Because no laboratory thermal conductivity data are available for sediments

recovered deeper than 210 mbsf at Sites 994 or 995, a value of 0.94 W/(m·K) was adopted for all in situ temperatures measured deeper than 200 mbsf.

Figure 55. Raw temperature vs. time records from the Adara tool for the period between the descending and ascending mulline stops. Dashed lines = equilibrium temperature determined by fitting synthetic curves to the equilibration record, assuming thermal conductivity of 1 W/(m·K). The mudline temperature reading was taken before Core 164-995-4H.

Figure 56. Corrected temperature vs. time records from the WSTP for the period between the ascending and descending mulline stops. Data obtained in both Holes 995A and 995B are shown. Dashed lines = equilibrium temperatures determined by fitting synthetic curves to the equilibration record, assuming thermal conductivity of 1 W/(m·K).

the DVTP. Dashed lines = estimated equilibrium temperatures.

Figure 57. Corrected temperature vs. time data from

perature measurements (Bullard, 1954). Figure 58 illustrates the relationship between temperature vs. time and temperature vs. $F(\alpha,t)$ for one of the WSTP measurements.

Equilibrium temperatures obtained from the in situ measurements are shown as a function of depth in Figure 59A. The average geothermal gradient is 33.5 ± 0.9 mK/m, if the data are weighted based on the magnitude of the estimated errors. The errors (Table 24) were determined subjectively, based on the stability of the equilibration record (lack of perturbations during the time in the bottom of the hole), tool performance, and the magnitude of the applied correction. The magnitude of the errors is likely to decrease with further analysis.

Heat Flow

Heat flow, given by the product of thermal conductivity and the geothermal gradient, can be estimated from the in situ equilibrium temperature measurements and the thermal conductivity values measured on board (Fig. 37). After averaging, the laboratory thermal con-

ductivity data were corrected to seafloor temperature and pressure (hydrostatic) conditions (Ratcliffe, 1960). No laboratory data were available for cores recovered deeper than 140 mbsf at Site 995, and the conductivity values obtained between 140 and 210 mbsf in Hole 994C were, therefore, assumed to apply at comparable depths at Site 995.

A

13.9

13.3

3400

Variations in thermal conductivity were explicitly incorporated into the heat-flow calculations by converting depths to resistances using the standard formulation of Bullard (1939). The slope of the temperature vs. resistance curve (Fig. 59B) yields a direct measure of heat flow, which averages $34.2 \pm 1.7 \text{ mW/m}^2$ between the seafloor and 387.1 mbsf. There appears to be no change in heat flow with depth, and estimated heat at Site 995 is more than 25% lower than that determined by a traditional heat-flow survey conducted at the same location ($48.4 \pm 1.7 \text{ mW/m}^2$; Ruppel et al., 1995).

Discussion

Site 995 is characterized by a geothermal gradient almost 8% lower than that determined at Site 994 ($36.4 \pm 1.3 \text{ mK/m}$). The regression equation corresponding to the best-fit line is given by $T(z) = (3.60^{\circ} \pm$ 0.15° C) + (0.0335° ± 0.001°C/m)z, where z is depth in meters and T is temperature in °C. The regression equation was calculated by weighting the data in proportion to the inverse of the squared errors. At the estimated depth of the BSR at Site 995 (450 mbsf), temperatures determined from the average geotherms are 20.1° and 18.7°C at Sites 994 and 995, respectively. The higher temperatures at Site 994, where no BSR is present, are consistent with the hypothesis that a phenomenon associated with the presence of the BSR causes refraction of heat away from the area overlain by the BSR, effectively insulating sediments below the BSR. Advection of heat may contribute to maintaining lateral variations in thermal regimes between Sites 994 and 995.

SYNTHESIS AND SIGNIFICANCE

Site 995 was located on the southern flank of Blake Ridge 3 km upslope of Site 994 in the area of an extremely well-developed and distinct BSR at 0.54 s below seafloor. A sedimentary section with a total thickness of 704.5 m was recovered without experiencing any drilling problems associated with passing through the level of the BSR.

Sedimentation and Diagenesis

Lithology and Sedimentation Rates

The sediments at Site 995 are similar to those from Site 994 in both age and lithology. The section was divided into three lithologic units similar to the units at Site 994. The upper two units (0-132 mbsf) are Pleistocene and latest Pliocene in age and are characterized

Figure 59. A. Equilibrium temperatures as a function of depth. Triangles = Adara data, squares = WSTP data, and circles = the results of DVTP measurements. Errors, indicated by distance between short vertical bars, are given in Table 24. B. Equilibrium temperature as a function of resistance. The slope of the curve is a direct measure of heat flow, and the data were weighted by the inverse of the squared errors to determine the average heatflow value of 34.2 mW/m2.

by alternations of dark greenish gray nannofossil-rich clay and more carbonate-rich beds of lighter greenish gray nannofossil-rich clay. Beds of coarse-grained foraminifer ooze and reddish brown terrigenous muds are rare but indicate contour-current activity. Unit III (132-705 mbsf) is a monotonous dark-greenish gray nannofossil-rich clay and claystone of late Pliocene to late Miocene age that is moderately to intensively bioturbated.

Carbonate contents are generally higher (20-40 wt%) in Units I and II (0-132 mbsf) than in Unit III (15-30 wt%; 132-705 mbsf). Smear-slide estimates of diatom abundance indicate that samples from the intervals between 40 and 220 mbsf frequently contain more than 10% diatoms. An individual sample contained as much as 35% diatoms (164-995A-8H-6, 67 cm; 66.87 mbsf). The interbeds of Units I and II apparently correlate with a shallow reflective zone (<0.1 s sub-bottom) in seismic reflection profiles across Site 995 (Fig. 1).

No major changes in lithology (see "Lithostratigraphy" section, this chapter) or physical properties (see "Physical Properties" section, this chapter) were identified in Unit III throughout the interval where the distinct BSR occurs (i.e., 440 ± 10 m; see "Geophysics" section, this chapter). The only change that was observed to be coinSedimentation rates at Site 995 are almost identical to those of Site 994. However, ~30 m more sediment accumulated at Site 995 in the late Pliocene than at Site 994 during this period (Fig. 13). This difference appears to be compensated by a short hiatus (~0.3 m.y.) within the uppermost Miocene sequence. During the time span represented by this hiatus at Site 995, sediments ~60 m thick accumulated at Site 994.

Sediment Accumulation Rates

The MARs of carbonate and noncarbonate fractions are generally similar between Sites 994 and 995 (Fig. 65, "Site 994" chapter, this volume, and Fig. 60, this chapter). At both sites, the MAR in the upper Miocene section exceed 30 g/cm² per 10³ yr, which is about 10 times greater than the late Quaternary rate. The MAR of total organic carbon demonstrates dramatic downhole increases from <0.05 g/cm² per 10³ yr in the Pleistocene sequence to 0.5 g/cm² per 10³ yr in the upper Miocene sequence (Fig. 61). Organic geochemistry data (C/N, HI, and OI) suggest a mixture of terrestrial and marine organic matter.

Diagenetic Dolomite and Siderite

Dolomite is common in the interval between 25 and 45 mbsf. The dolomite occurs either as small indurated dolomite nodules or beds or as semi-indurated beds. Small disseminated dolomite rhombs also occur down to 110 mbsf, but dolomite becomes rare in the Pliocene to Miocene sections. The dolomite distribution patterns are similar at Sites 994 and 995.

Closely spaced interstitial pore-water sampling through the upper 30 mbsf at Site 995 characterized the geochemical changes through the sulfate reduction zone in unprecedented detail. Sulfate concentrations decrease linearly with depth to the base of the sulfate reduction zone, which is estimated to be at 21 mbsf. The linear profile indicates that sulfate consumption is concentrated at the base of the sulfate reduction zone (Borowski et al., 1996). Concentrated anaerobic methane oxidation will cause a local increase in the alkalinity, which may result in the precipitation of carbonate. The decreases in the Ca+ and Mg+ concentrations support this hypothesis. The concentration of dolomite in the upper Pleistocene sequence may result from the reduced Quaternary sedimentation rate. If the zone where anaerobic methane oxidation is actively occurring represents a balance between upward diffusion of methane and downward diffusion of sulfate (Borowski et al., 1996), the low sedimentation rates will have concentrated the diagenetic effects associated with methane oxidation on these strata for a longer period of time.

Siderite first appears at 85 mbsf at Site 995, and its concentration increases downhole throughout Unit III. One discrete siderite nodule was observed at 637.7 mbsf in the upper Miocene section. The amounts of disseminated siderite (Fig. 7), the downhole distribution, and the depth of discrete siderite nodules are nearly identical between Sites 995 and 994. Diagenetic siderite seems to be a common element of gas hydrate–bearing sediments in Blake Ridge area, implying a genetic relationship with the formation/decomposition of gas hydrate (Matsumoto, 1989).

Detection and Indications of the Presence of Gas Hydrate Direct Sampling

Site 995 was intentionally drilled where a strong BSR occurs (see Fig. 1). Although gas hydrate was not actually observed in cores from Site 995 (see "Gas Hydrate" section, this chapter), proxy measurements indicate it was present throughout much of the section between 195 and 450 mbsf.

Figure 60. Mass accumulation rates for both carbonate and noncarbonate fractions calculated from the sedimentation rates, shipboard density, and porosity measurements for Hole 995A. Carbonate contents were determined from a XRD peak of calcite so that diagenetic dolomite and siderite were excluded from the carbonate fraction. The noncarbonate fraction appears to be composed mainly of terrigenous materials with subordinate diatoms.

Figure 61. Total organic carbon content and mass accumulation rates for Hole 995A.

Proxy Measurements

The presence of gas hydrate within the Site 995 sediments is inferred on the basis of the following observations (Table 25):

1. The cores from Site 995 were observed to evolve large amounts of gas in a similar fashion to what was observed at Site 994 (see "Synthesis and Significance" section, "Site 994" chapter, this volume). Gas evolution may have caused the low core recovery (Fig. 62). Although these qualitative indicators of the presence of gas do not require that gas hydrate be present in the sediment before coring, they do indicate that significant amounts of gas occur throughout the sedimentary section below ~20 mbsf.

2. PCS data (see "Downhole Tools and Sampling" section, this chapter) indicate that the sediments below 200 mbsf contain methane concentrations that are at or exceeding methane saturation in seawater. Because there is no acoustic indication that gas bubbles exist above 440 mbsf and because the only known additional source for methane (beyond what can be dissolved in seawater) is the decomposition of gas hydrate, we concluded that gas hydrate occurred in two PCS samples (Cores 164-995A-27P [225.5 mbsf] and 45P [376.5 mbsf]). Moreover, the data from PCS cores taken from below 440 m indicate that the concentrations of methane in the interstitial waters are three to five times the saturation values (see "Downhole Tools and Sampling" section, this chapter). Thus, gas bubbles should occur below the BGHS at Site 995.

3. Acoustic data also may indicate that gas is present at depths below 450 mbsf. ZO-VSP data from Site 995 indicate that after a gradual increase in velocity from 150 to 400 mbsf, the velocities drop below 400 mbsf to a low of about 1550 m/s at 590 mbsf (Fig. 40). Sonic logs also increase downhole from ~1580 m/s at the base of the drill pipe (~160 mbsf) to a local maximum at 440 mbsf (Fig. 51). Below 450 mbsf, sonic velocities decrease to <1600 m/s ~600 mbsf. Such low velocity values indicate the presence of gas bubbles.

4. Both the general freshening trend of the interstitial waters and the intersample variation in the interstitial-water chloride concentrations between 195 and 438 mbsf suggest that gas hydrate is present in this interval (see "Inorganic Geochemistry" section, this chapter, and "Synthesis and Significance" section, "Site 994" chapter, this volume). Interstitial-water compositions are naturally modified by diffusion so that in a relatively static sedimentary sequence only small changes in chloride concentrations occur between adjacent samples. Thus, the relative amplitude of the chloride anomalies are proportional to the amount of gas hydrate that dissociated within the sample during core recovery.

5. Core temperatures upon recovery on the catwalk were quite variable. Low temperature anomalies are interpreted as indicating areas where gas hydrate decomposition had occurred recently or where large volumes of gas evolved and expanded during core recovery. Temperatures below 10°C were only observed in the interval between 251.3 and 432.8 mbsf (see "Gas Hydrate" section, this chapter). Observations of the core temperatures and the interstitial-water chlorinities on the same samples show a reasonable correlation between these two proxy measurements (Fig. 34) with the samples with the lowest temperatures having the lowest chloride concentrations.

6. Data from downhole logs also are interpreted as indicating the presence of gas hydrate in the interval between 193 and 450 mbsf. Both the velocity and electrical resistivity logs are distinctly offset in this zone; however, there is no obvious observed change in either the lithologic description or the physical properties data from this interval that explains these offsets. Thus, the discrepancy between the in situ observations made with the logs and the analysis of the recovered material is potentially related to some property that is different in situ than in the recovered cores (e.g., the presence of gas hydrate).

Defining the Zone of Gas Hydrate Occurrence

The depth to the top and the base of the zone of gas hydrate occurrence at Site 995 was measured using both interstitial-water chloride anomalies and downhole-logging data (Table 25; Fig. 63). The base of the zone of gas hydrate occurrence was also measured with ZO-VSP data. Interstitial-water chloride anomalies established whether gas hydrate occurred within a given sample. The occurrence of the highest and lowest chloride anomalies establish the minimum range in the gas hydrate distribution zone. Because data on the temperature of the recovered cores indicate that the distribution of gas hydrate is rather patchy, the lack of an interstitial-water chloride anomaly in individual samples does not confidently determine the limit of the zone. Thus, the top of this zone might be higher and its base lower because of the distribution of the samples. In Table 25, we indicate that the boundaries of the gas hydrate-bearing zone extend from the last distinctive interstitial-water chloride anomaly sample that lies along the chloride baseline (see "Gas Hydrate Estimates," below). Shipboard analysis of the ZO-VSP data indicated that the base of the gas hydrate both with the direct-arrival data and with acoustic modeling (see "Geophysics" section, this chapter), assuming that the BSR coincides with the base of gas hydrate. Well-logging estimates of the position of the top and bottom of the gas hydrate-bearing zone are picked as discrete boundaries. However, these techniques all agree within the range of error of the respective measurements.

Discrepancy Between Observed and Predicted Base of Gas Hydrate Stability

The direct sampling, shipboard temperature measurements, chlorinity anomalies, and downhole-logging data all suggest that gas hydrate occurred at least intermittently within a zone between 195 and 450 mbsf. The inferred gas hydrate-bearing zone does not extend to the experimentally predicted BGHS (541–577 mbsf; Fig. 64) as estimated with the experimental data and measured geothermal gradient at Site 995 (see "In Situ Temperature Measurements" section, this chapter). Why the discrepancy exists is unclear, and several possible explanations need to be considered:

- The base of the inferred occurrence zone is a fossil depth to the BGHS that reflects conditions during a previous sea-level stand or bottom-water temperature regime (Paull et al., 1991).
- Experimental data do not adequately characterize the behavior of natural gas hydrate, especially in fine-grained sediments.
- Gas hydrate actually existed below 465 mbsf, but we did not detect it.

Gas Hydrate Estimates

Preliminary estimates of the amount of gas hydrate in the sediments at Site 995 were made in the following ways:

1. Estimates of the amounts of gas hydrate that existed in the seafloor before the sediments were recovered from Site 995 are made by assuming that diffusive equilibration prohibits significant and nonsystematic interstitial-water chloride concentrations from occurring between closely spaced samples. Thus, chloride spikes are only a result of gas hydrate decomposition during sample recovery. To produce an estimate of the interstitial-water salinity through the zone between 195 and 460 mbsf (Fig. 65A), where erratic chloride values were measured, a polynomial was fit to the relatively smooth chloride data above 195 m and below 460 m. All but two of the measured chloride concentrations in this zone have lower values than the calculated in situ values, some significantly lower. The difference between the calculated in situ chloride concentrations and the measured chloride concentrations were used to establish the relative chlorinity anomaly that is associated with each sample (Fig. 65B).

The calculated chloride anomalies enable the amount of gas hydrate that occurred in these samples to be estimated. Corrections for the porosity of the samples were made with best values through the shipboard physical properties data (see "Physical Properties" section, this chapter) that exist throughout this interval. The estimated volume percentage of the samples that was occupied by gas hydrate had a skewed distribution, ranging to as much as 8.4 vol% (at 418.8 mbsf) and having a mean value of 1.8 ± 1.8 vol% and a median value of 0.9 vol% for all the interstitial-water samples that were collected between 195 and 460 mbsf (Fig. 65C). However, these are considered to be minimum estimates because the baseline used to calculate these values may be lower than the actual in situ interstitial-water chlorinities and because gas expansion during core recovery may result in lower core recovery from the more gas hydrate-rich samples.

2. Calculations of the percentage of gas hydrate that is required to explain the observed changes in the well-logging electrical resistivities (Fig. 51) indicate that the general trend through this interval (between 193 and 450 mbsf) can be explained by the pervasive addition of as much as 7.9 vol% gas hydrate in the pore spaces (or ~4 vol% of the bulk volume). The same calculation indicates that the most concentrated horizon (~220 mbsf) contains as much as 20 vol% gas hydrate in the pore space (~10 vol% of the bulk volume). The independent estimation of the amounts of gas hydrate from different data sets (chloride anomalies and logging data) has given very similar esti-

Table 25. Top and	base of gas	hydrate d	listribution.
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Chloride anomaly depth (mbsf)		Zero-offset VSP depth (mbsf)	Logging depth (mbsf)	Experimental depth (mbsf)
Site 995 (d	lepth of water = 2778.5 mbs):		
Top Base	190.25–195.35 438.0–465.12	440 ± 10 (DM)-450.0 (AM)	193.0 450.0	54 (SW)-577 (PW)

Note: DM = direct measurements of first arrival, AM = acoustic modeling, SW = based on experiments in seawater, and PW = based on experiments in pure water.

Figure 62. Plot showing the percentage recovery from APC and XCB coring (circles and dashed line) in Hole 995A smoothed with a five-point average (solid line).

mates of the percentage of gas hydrate contained in the sediments between ~195 and 450 mbsf. Unlike at Site 994, the electrical resistivity logs show increasing gas hydrate concentrations (ranging from 7.7 to 11.6 vol% of the pore space) near the base of the higher electrical resistivity zone (i.e., from 390 to 450 mbsf).

Habit of Natural Gas Hydrate Occurrences

The distribution of shipboard core-temperature measurements and the interstitial-water chlorinities indicate that significant variations in the amount of gas hydrate occur on the centimeter to meter scale. However, the hydrate that was in the recovered sediments is inferred to have been finely grained and dispersed within the available pore space.

Nature of the BSR

Correlations between traveltimes measured in the ZO-VSP data indicate that the BSR occurs at 440 ± 10 mbsf. No significant change in either lithology or physical properties measurements occurred at this depth. Essentially, the section below 132 mbsf at Site 995 is indistinguishable from the section below 132 mbsf at Site 994 (see "Site 994" chapter, this volume).

Figure 64. The zone of CH_4 hydrate stability in the marine environment lies between the sediment-water interface and the intersection of the geotherm with the CH_4 hydrate-water equilibrium curve (after Kvenvolden and McMenamin, 1980). At Site 995, the sediment-water interface is 2799 mbsl; the geotherm is $2.85^{\circ} + 0.0386^{\circ}$ C/mbsf. The depth of intersection for the CH_4 hydrate-water equilibrium curve in pure water (compiled in Sloan, 1990) occurs at ~577 mbsf; the depth of intersection for the CH_4 hydratewater equilibrium curve in seawater (Dickens and Quinby-Hunt, 1994) occurs at ~541 mbsf. Depths along the equilibrium curves assume a hydrostatic pressure gradient of 0.010 MPa/m (1.467 psi/m). Note that dissolved ions shift the CH_4 hydrate-water equilibrium curve such that the zone of CH_4 hydrate stability is shallower than expected from consideration of the CH_4 -pure water system, and that incorporation of trace gases (e.g., CO_2 , H_2S , and C_2) into the hydrate lattice has the opposite effect.

Both the sonic log and the VSP data indicate that decreasing interval velocities occur near the depth of the BSR (~440 mbsf). Decreasing velocity without a change in the sediment density will produce a negative polarity reflection. The BSR here is a negative polarity reflection that is presumably related to the decrease in sonic velocity. The change in sediment velocity may be related to either changes in the amount of gas hydrate or the presence of free-gas bubbles below ~440 mbsf. Although both types of acoustic data indicate that gas bubbles are present at greater depths, simple shipboard analysis of the Figure 65. A. The interstitial-water chlorinity profile at Site 995 indicates a distinct freshening with depth that is highlighted by a zone of low and erratic values between 200 and 450 mbsf. A polynomial fit to the data above and below the 200–450 mbsf zone is indicated. B. Chlorinity anomalies are interpreted with respect to the polynomial. C. The percentage of gas hydrate by volume is calculated by assuming that the chloride anomalies (B) are solely produced by gas hydrate decomposition during core recovery and corrected by porosity using a linear fit to the porosity data in the physical properties section.

absolute velocities does not require that the gas be present immediately below the BSR.

PCS data, coupled with core temperature and chlorinity anomalies data, resolve this issue. The concentrations of gas measured by the PCS required that there must either be hydrate or gas bubbles in the samples from below 493.1 mbsf (i.e., Cores 164-995A-60P and 70P; see "Downhole Tools and Sampling" section, this chapter). However, core temperature and interstitial-water chloride data indicate that there was no gas hydrate below 465 mbsf (Table 25). Thus, gas bubbles exist beneath the BSR at Site 995.

Conclusion

Although no gas hydrate was recovered from Site 995, the interstitial-water chlorinity anomalies, anomalously cold temperatures in the recovered cores, and patterns in the downhole-log data indicate that gas hydrate occupies (on average) between ~1 and 4 vol% or more of the sediment section from 195 to 450 mbsf, with several intervals containing as much as 10 vol% gas hydrate. The gas hydrate is inferred to be finely dispersed within the homogenous sediments. All of the inferred gas hydrate occurs well above the predicted base of gas hydrate stability at this site. The BSR is apparently associated with first occurrence of free gas. Higher sediment velocities also occur in the interval above the BSR. Sediment velocities continue to decrease from the BSR (440 ± 10 mbsf) to minimum values of <1600 m/s at ~600 mbsf that are consistent with the existence of gas bubbles in the sedimentary section for more than 150 m below the BSR.

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NOTE: Core-description forms ("barrel sheets") and core photographs can be found in Section 4, beginning on page 337. Forms containing smear-slide data can be found in Section 5, beginning on page 599.

SHORE-BASED LOG PROCESSING HOLE 995B

Bottom felt: 2785 mbrf Total penetration: 700 mbsf Total core recovered: 139.4 m (61.8%)

Logging Runs

Logging string 1: DITE/SDT/NGT/LDEO-TLT Logging string 2: HLDT/CNT-G/NGT Logging string 3: AACT/GST/NGT Logging string 4: LDEO-SST Logging string 5: FMS/GPIT/NGT (2 passes) A wireline heave compensator was used to counter ship heave.

Bottom-Hole Assembly

The following bottom-hole assembly depths are as they appear on the logs after differential depth shift (see "Depth Shift" section) and depth shift to the seafloor. As such, there might be a discrepancy with the original depths given by the drillers on board. Possible reasons for depth discrepancies are ship heave, the use of the wireline heave compensator, and drill string and/or wireline stretch.

DITE/SDT/NGT: Bottom-hole assembly at ~133 mbsf. HLDT/CNT-G/NGT: Bottom-hole assembly at ~133 mbsf. AACT/GST/NGT: Bottom-hole assembly at ~133 mbsf. FMS/GPIT/NGT: Did not reach the bottom-hole assembly.

Processing

Depth shift: Original logs have been interactively depth shifted with reference to the NGT from the AACT/GST/NGT run and to the seafloor (-2786 m). This amount corresponds to the depth of the seafloor as seen on the logs and differs 1.0 m from the "bottom felt" depth given by the drillers.

Gamma-ray processing: Data have been processed to correct for borehole size and type of drilling fluid.

Acoustic data processing: The array sonic tool was operated in the standard depth-derived borehole compensated, long (8-10-10-12 ft) spacing mode. The logs have been processed to eliminate some of the noise and cycle skipping experienced during the recording.

Geochemical processing: The elemental yields recorded by the GST tool represent the relative contribution of only some of the rockforming elements (iron, calcium, chlorine, silicon, sulfur, hydrogen, gadolinium, and titanium—the last two computed during geochemical processing) to the total spectrum. Because other rock-forming elements are present in the formation (such as aluminum, potassium, and so on), caution is recommended in using the yields to infer lithologic changes. Instead, ratios (see file acronyms.doc on CD-ROM in back pocket, this volume) are more appropriate to determine changes in the macroscopic properties of the formation. A list of oxide factors used in geochemical processing includes the following:

 $SiO_2 = 2.139$ $CaCO_3 = 12.497$ $FeO^* = 1.358$ $TiO_2 = 1.668$ $K_2O = 1.205$ $Al_2O_3 = 1.889$ FeO^* Computed of

FeO* Computed using an oxide factor that assumes a 50:50 combination of Fe₂O₃ and FeO factors.

Quality Control

Invalid spikes were recorded by the density tool at 211, 213, 218–219, 224.5 344.5, and 402 mbsf.

Data recorded through bottom-hole assembly, such as the gammaray and neutron porosity data above 133 mbsf, should be used only qualitatively because of the attenuation on the incoming signal. Invalid gamma ray spikes were recorded at 115–120 and 128–133 mbsf on the DITE/SDT/NGT run.

Hole diameter was recorded by the hydraulic caliper on the HLDT tool (CALI) and the caliper on the FMS string (C1 and C2).

The results of geochemical processing are presented along with the calcium carbonate measurements performed on board. FACT = quality control curve in geochemical processing. Accuracy of the estimates is inversely proportional to the magnitude of the curve.

Details of standard shore-based processing procedures are found in the "Explanatory Notes" chapter (this volume). For further information about the logs, please contact:

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Hole 995B: Natural Gamma Ray Logging Data

Hole 995B: Natural Gamma Ray Logging Data (cont.)

Hole 995B: Natural Gamma Ray-Density-Porosity Logging Data

Caliper Potassium 0 20 wt.% 5 in. 0 Computed Gamma Ray Depth (mbsf) Neutron PorosityDensity Correction00%0-0.25g/cm³0.25 Depth (mbsf) Thorium 0 Recovery API units 100 100 0.25 -3 12 ppm Core Bulk Density g/cm³ Photoelectric Effect0barns/e10 **Total Gamma Ray** Uranium 0 6 API units 2.5 0 100 1 10 -9 ppm 3 no core recovery 3 300 300 8X /WW/T 9X Mr Mummun MUNNIN M 350 350 23212 MANNAN MANNAN 1-1--1 400 400 MMM 11X 12X N-V-M 13X 14X 450 450 15X

Hole 995B: Natural Gamma Ray-Density-Porosity Logging Data (cont.)

Hole 995B: Natural Gamma Ray-Density-Porosity Logging Data (cont.)

Hole 995B: Natural Gamma Ray-Density-Porosity Logging Data (cont.)

Hole 995B : Natural Gamma Ray-Resistivity-Sonic Logging Data (cont.)

Hole 995B : Natural Gamma Ray-Resistivity-Sonic Logging Data (cont.)

Hole 995B : Natural Gamma Ray-Resistivity-Sonic Logging Data (cont.)

Hole 995B: Geochemical Logging Data

Hole 995B: Geochemical Logging Data (cont.)

