UNITED STATES DEPARTMENT OF INTERIOR

GEOLOGICAL SURVEY

Geological and Geochemical Data for Seamounts and Associated Ferromanganese Crusts in and near the Hawaiian, Johnston Island, and Palmyra Island Exclusive Economic Zones

by

James R. Hein, Frank T. Manheim, William C. Schwab,
Alice S. Davis, Charlaine L. Daniel, Robin M. Bouse,
Lisa A. Morgenson, Rosemary E. Sliney, David Clague,
George B. Tate, and David A. Cacchione

Open File Report 85-292

This report is preliminary and has not been reviewed for conformity with the U.S. Geological Survey editorial standards and stratigraphic nomenclature.

Menlo Park, California
1985

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Geological and Geochemical Data for Seamounts and Associated Ferromanganese Crusts in and near the Hawaiian, Johnston Island, and Palmyra Island Exclusive Economic Zones

INTRODUCTION

In this report we present shipboard and laboratory data for samples collected on R/V S.P. Lee cruise L5-83-HW which was designed to study seamounts and their associated Co-rich ferromanganese crusts. Detailed discussions and interpretations of the data are presented in two papers (Hein et al., 1985; Manheim et al., 1985). The cruise began in Hawaii on 29 October 1983 and ended in Pago Pago, American Samoa on 29 November 1983. Three of the largest seamount-ridge volcanic edifices in the central Pacific were surveyed: Necker Ridge, Horizon Guyot, and S.P. Lee Guyot (Fig. 1). Additional planned surveys in the Palmyra Island and Samoa Islands areas were curtailed as the result of equipment problems encountered during the survey of S.P. Lee Guyot. Three-quarters of Necker Ridge falls within the Hawaiian 200-mile Exclusive Economic Zone (EEZ) (Fig. 2). Horizon Guyot and S.P. Lee Guyot fall within the EEZ of the U.S. possessions Johnston Island and Palmyra Island-Kingman Reef, respectively.

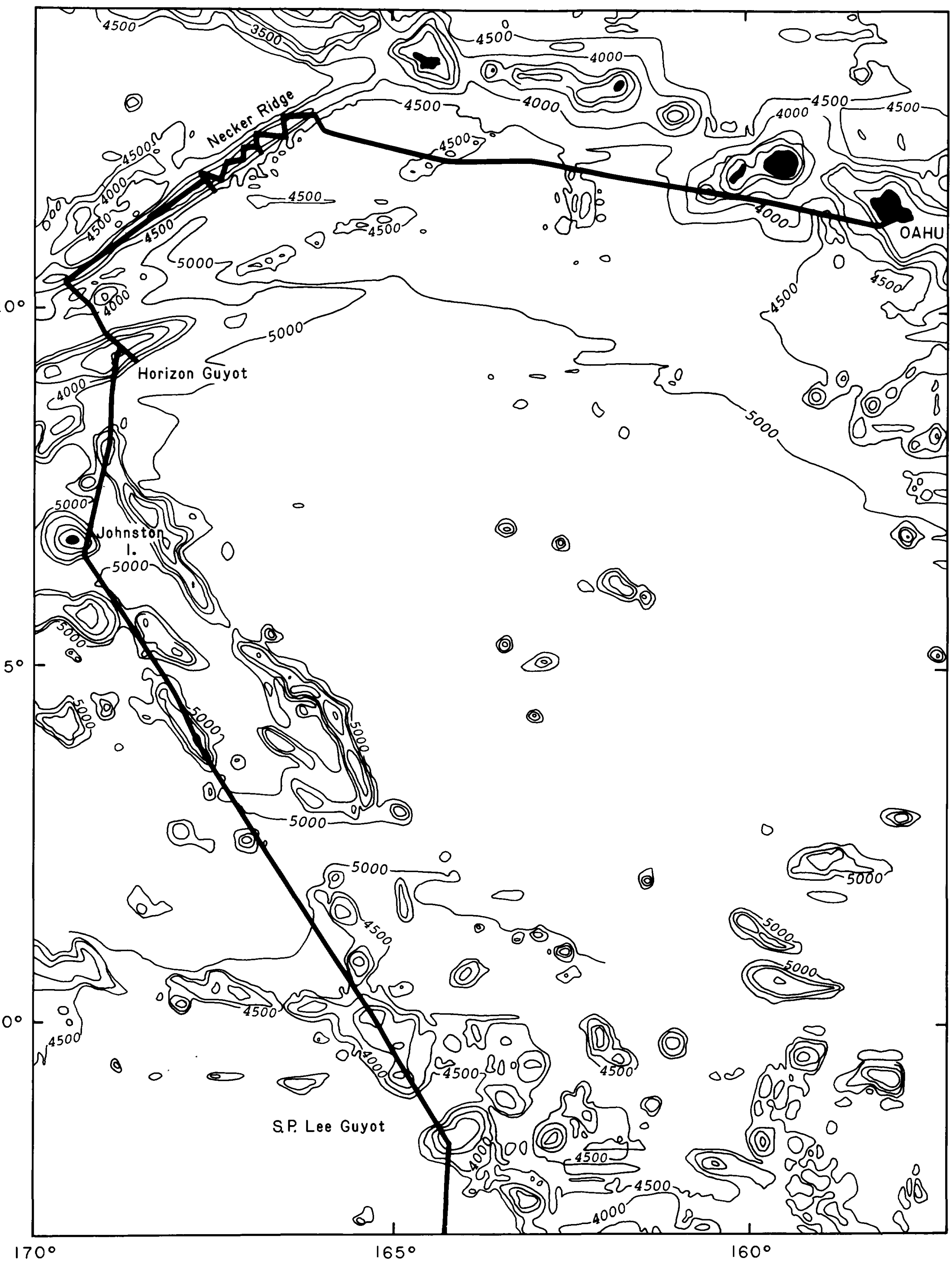
In addition, we present data for samples from two seamounts, Abbott and Colahan, located in the far northern part of the Hawaiian Ridge. These seamounts were sampled on S.P. Lee cruise L8-82-NP which was designed to study the volcanic history at the intersection of the Emperor-Hawaiian linear volcanic chains.

Data on ferromanganese crusts from these volcanic features compliment the information collected in the mid-Pacific Mountains and Line Islands (MIDPAC I and II) by the F. R. Germany's ship R/V Sonne under the direction of Professor Peter Halbach, Clausthal University (Fig. 2). The U.S. Geological Survey - F. R. Germany cooperative program was developed in order to determine the distribution of Co- and Pt-rich ferromanganese crusts, and to understand the origin and evolution of this mineral deposit, which contains in abundance the strategic metals manganese, cobalt, nickel, and platinum. The richest ores occur between about 500 and 2500-m water depth between about 5° and 20° north latitude, although other areas locally contain crusts enriched with cobalt or other metals. The technology needed to mine these crusts is being developed and many countries have expressed interest in the recovery of this resource, including U.S.A., F. R. Germany, Japan, Korea, China, and India.

EQUIPMENT AND RECORDS

On S.P. Lee cruise L5-83-HW to Necker Ridge, Horizon Guyot, and S.P. Lee Guyot, a total of 4500 km of 3.5 kHz and 12 kHz bathymetric data were collected along with 1300 km of single-channel, 80 cubic-inch airgun seismic-reflection profiles. The scientific crew (Table 1) also collected samples with large-diameter chain-bag dredges, hard-substrate piston cores, and gravity cores (Table 2). In addition, the sea floor was photographed with a still camera and video system. Four CTD-oxygen profiles were run to a water depth of 2400 m. A mooring, consisting of two current meters and a sediment trap, was placed atop Horizon Guyot and collected data for a 10-month period. Navigation was by Loran C and SAT-NAV, including the Global Positioning System (GPS).

Figure 1. Track line map of R/V S.P. Lee Cruise L5-83-HW, Honolulu to American Samoa. Bathymetric contours in meters.



Necker Ridge
OAHU
Horizon Guyot
Johnston I.
S.P. Lee Guyot
20°
15°
10°
170°
165°
160°
3500
4000
4500
5000

Figure 2. Station locations for R/V S.P. Lee Cruise L5-83-HW and for R/V Sonne Cruises MIDPAC I and II. S.P. Lee track line is also shown, as are the boundaries for the 200 mile exclusive economic zones of Hawaii, Johnston Island, and Palmyra Island-Kingman Reef. S.P. Lee cruise L8-82-NP stations are located to the northwest of the boundaries of this map. Bathymetric contours are in meters.

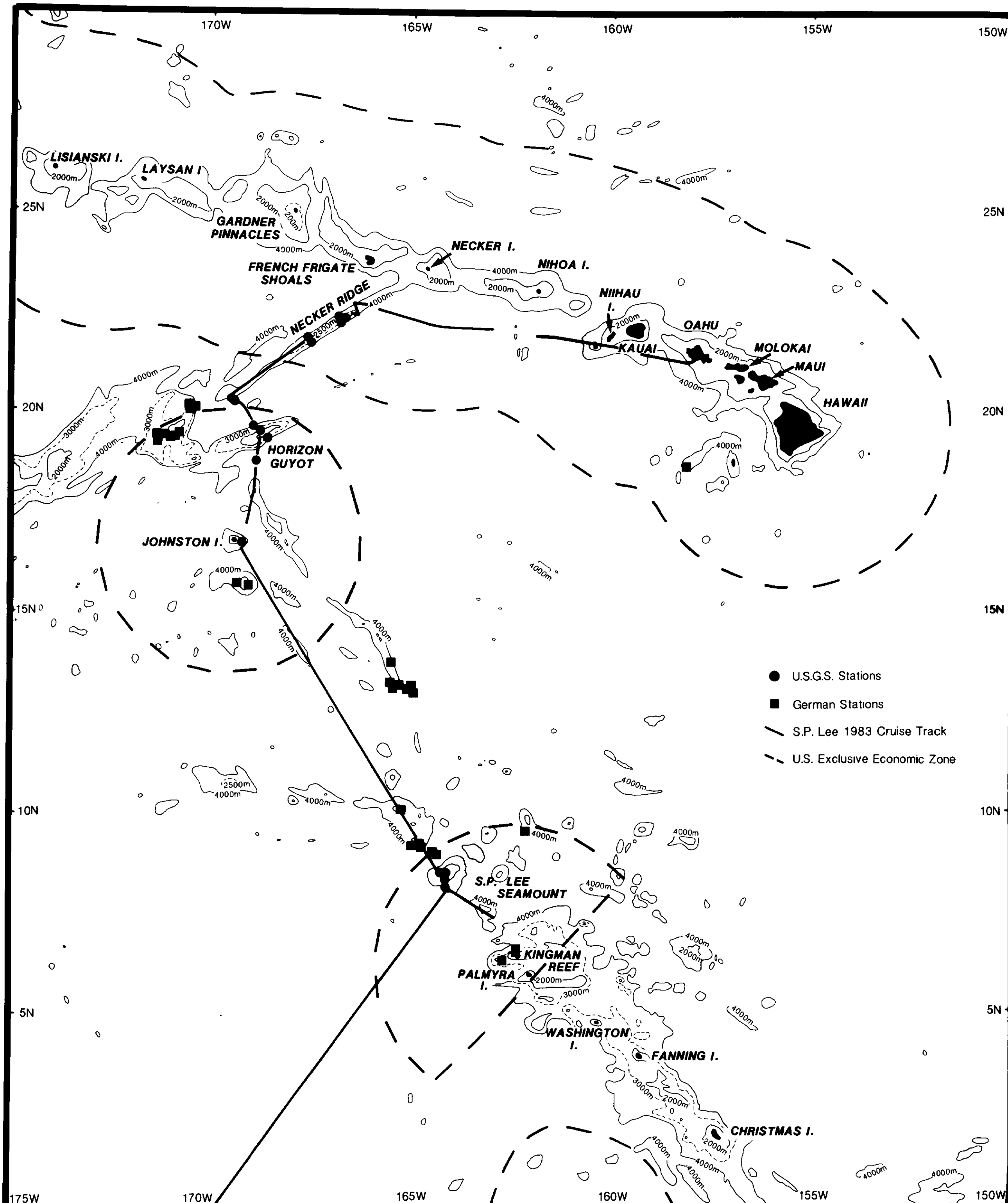

170W
165W
160W
155W
150W
175W
25N
20N
15N
10N
5N
LISIANSKI I.
LAYSAN I.
GARDNER PINNACLES
FRENCH FRIGATE SHOALS
NECKER I.
NIHOA I.
NIIHAU I.
KAUAI
OAHU
MOLOKAI
MAUI
HAWAII
NECKER RIDGE
HORIZON GUYOT
JOHNSTON I.
S.P. LEE SEAMOUNT
KINGMAN REEF
PALMYRA I.
WASHINGTON I.
FANNING I.
CHRISTMAS I.
U.S.G.S. Stations
German Stations
S.P. Lee 1983 Cruise Track
U.S. Exclusive Economic Zone

Table 1. Scientific Personnel, R/V S.P. Lee Cruise L5-83-HW.

James R. Hein	Co-chief Scientist, U.S.G.S., Menlo Park
Frank T. Manheim	Co-chief Scientist, U.S.G.S., Woods Hole
Bill C. Schwab	Geologist, U.S.G.S., Woods Hole
George B. Tate	Geologist, U.S.G.S., Menlo Park
Alice S. Davis	Geologist, U.S.G.S., Menlo Park
Joe L. Ritchey	Geologist, U.S. Bureau of Mines, Spokane
Vesna Marchig	Geologist, BGR, Hannover, F.R. Germany
Doris Puteanus	Geologist, University of Clausthal, F.R. Germany
Kaye L. Kinoshita	Chief Navigator, U.S.G.S., Menlo Park
Rosemay E. Sliney	Navigator, U.S.G.S., Menlo Park
Robin M. Bouse	Navigator, U.S.G.S., Menlo Park
Hank Chezar	Photographer, U.S.G.S., Menlo Park
John Robinson	Journalist, San Francisco
Kevin O'Toole	Mechanical Technician, U.S.G.S., Menlo Park
Jeff Stamfer	Mechanical Technician, U.S.G.S., Menlo Park
Mike Boyle	Electronics Technician, U.S.G.S., Menlo Park
Jim Nicholson	Electronics Technician, U.S.G.S., Menlo Park

Table 2. Summary of stations and dredge and core samples from R/V S.P. Lee Cruise L5-83-HW.

	Necker Ridge				Horizon Guyot			S.P. Lee Guyot
	Eastern	Central	Western	Total	North	South	Total	SW half
Dredges								
attempted	5	2	3	10	4	4	8	13
successful	2	2	2	6	3	3	6	8
Cores, Piston	3	1	0	4	0	3	3	0
Cores, Gravity	0	0	0	0	3	0	3	0
Camera - video	0	0	0	0	1	0	1	2
CTD-oxygen	0	0	0	0	1	1*	2	2
Total amount of sample (kg)	140	580	15	735	190	105	295	625
Range of water depths where crusts were recovered (m)	1985 to 4200	2100 to 2400	2400 to 4800	1985 to 4800	1500 to 4500	1750 to 3790	1500 to 4500	1125 to 2400

*A CTD station was taken off structure at 18°42.3'N, 168°55'W on the transit to Johnston Island. Two current meters and a sediment trap were deployed on Horizon Guyot at 19°26.9'N, 168°48.9'W in 1635 m of water and collected data for a 10 month period.

NECKER RIDGE

Sampling transects crossed the eastern, central, and western parts of the ridge (Fig. 3). Seismic-reflection lines were run both perpendicular to the ridge and along its crest (Fig. 4a-k, Lines 2 through 12). Ridge slope-angles range up to 20° and average about 12°. The ridge crest is more rugged in the northeast and becomes rounded and supports sediment ponds to 146-m thick in the southwest. Talus deposits and moating of abyssal deposits occur in different areas at the base of the ridge flanks (Fig. 4).

Recovered rocks are predominantly ferromanganese-oxide encrusted hyaloclastite and volcanic breccia, with minor basalt cobbles and phosphatized chalk and claystone (Table 3). The chemistry of the substrates varies widely depending on the lithology (Table 4), as does the chemistry of the crusts, which depends primarily on water depth and latitude (Table 5). For crusts collected at water-depths shallower than 2500 m, Mn averages 20.80%, Fe 20.11%, Co 0.648%, Ni 0.305%, and Cu 0.088% (Table 5-3).

Vernadite (δ-MnO_2) is the primary crystalline (89 to 100%) mineral present in all crusts (Table 6). Small amounts of quartz, feldspar, and apatite also occur in the crusts. Encrusting foraminifera occur on the crust surfaces and throughout the crusts. Substrate mineralogy is dominated by plagioclase, apatite, phillipsite, smectite, and pyroxene (Table 7).

The thickness of crusts varies from 5 mm to 70 mm, with a mean of about 25 mm. Sixty percent of rocks recovered appear to be broken from outcrops, 20 percent are cobbles and pebbles completely coated by thin crusts, 10 percent consist of ferromanganese nodules, similar in appearance to abyssal nodules, and 10 percent consist of substrate without crusts or crust without substrate. Based on 60 measurements from dredge 5, crusts on rocks broken from outcrop are twice as thick as those that surround talus cobbles.

Density, porosity, and other physical properties of the substrates, were determined by immersing the rock in water under 80 psi pressure for 24 hours, then weighing the rock (Table 8). Next substrates were dried at 110°C for 48 hours and reweighed. Volumes were measured with a pycnometer. Crusts were placed in fresh water immediately after collection on-board ship. Water loss was determined by overnight oven drying at 110°C (Tables 9-1 and 9-2), and grain densities were measured by micropycnometer techniques. Physical properties were computed from these parameters. Some additional dried samples were reconstituted to saturated condition by placing them in water under vacuum for 3-4 days, followed by the same procedure as above.

Figure 3. Sampling stations and seismic-reflection profiles along Necker Ridge. Line numbers are indicated and can be correlated with profiles in Figure 4. Contour interval is 200 fathoms (Chase and Menard, 1973).

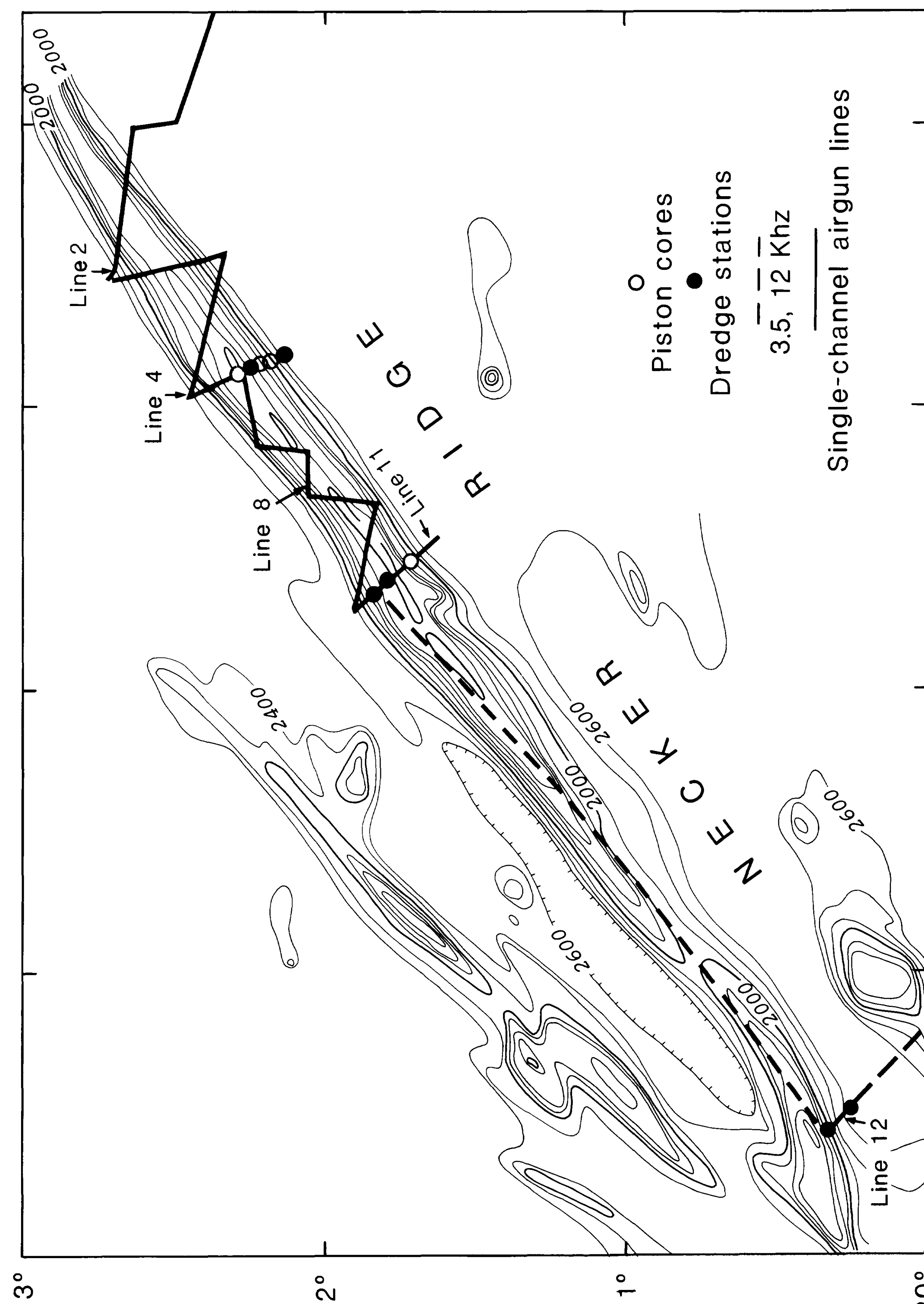

NECKER RIDGE
Line 2
Line 4
Line 8
Line 11
Line 12
Piston cores
Dredge stations
3.5, 12 Khz
Single-channel airgun lines
2000
2400
2600
23°
22°
21°
20°
170°
169°
168°
167°
166°

Table 3. Location and description of samples from Necker Ridge, Cruise L5-83-HW.

Sample No.[1]	Latitude (N)	Longitude (W)	Water Depth (m)	approximate Sample wt. (kg)	Crust Description	Substrate Description
1-D1	22°10.87' 22°12.17'	166°48.57' 166°47.08'	4200- 3950	5.5	Thin (0.5-3 mm) very smooth crusts evenly coat basalt cobbles. One crust on siltstone is botryoidal, dense, and brown on the top and smooth, porous, and black on the bottom.	Dark gray-brown, altered basalt pebbles and cobbles, few to moderate numbers of vesicles, olivine and plagioclase phyric with olivine replaced by Fe-hydroxides and plagioclase by clay minerals. Minor pale brown to brown siltstone.
4-PC1	22°10.87'	166°51.66'	3403	--	None	1 m white to pale brown stiff nannofossil mud.
5-PC2	22°12.48'	166°52.90'	2402	--	Smooth and botryoidal, thin (0.5-12 mm) crusts coating mostly phosphorite nuclei.	Foraminiferal sand overlying altered basalt and phosphorite pebbles.
6-PC3	22°15.35'	166°51.23'	1970	--	5-10 mm thick crust with mm-scale knobby surface coats hyaloclastite.	Foraminiferal sand mixed with crust chips overlying 25 mm hyaloclastite pebble.
7-D4	22°14.18' 22°14.26'	166°52.21' 166°52.79'	2100- 2050	--	None	White foraminiferal sand.
8-D5	22°18.98' 22°18.30'	166°53.93' 166°54.12'	2350- 2100	135	Dominantly smooth, porous in lows; many botryoidal, porous between botryoids; some granular and porous. On the basis of 60 measurements, crusts that completely surround rocks range in thickness from 1-38 mm and average 13 mm; crusts that coat only one surface of rocks (broken from outcrops) range from 5-45 mm and average 25 mm, all crusts together average 19 mm.	Yellow-brown hyaloclastite with angular to subrounded, highly altered basalt and palagonite clasts; encrusted conglomerate composed of rounded basalt clasts coated by mm-thick Mn-oxide and cemented by pinkish-brown phosphorite. Basalt is typically highly vesicular (~45%), highly altered, with olivine microphenocrysts pseudomorphed by Fe-hydroxides.
9-D6	21°43.10' 21°43.32'	167°34.69' 167°35.22'	2400- 2100	545	Dominantly smooth, layered crusts; botryoidal to knobby; 50% rocks partly encrusted, 25% completely encrusted, 25% without crusts, and <1% nodules. Partly coated rocks fall into two groups: those with crusts from 5-15 mm and those with 20-40 mm-thick crusts. Crusts range from 2-50 mm and average about 25 mm.	Yellow-green hyaloclastite; breccia of altered brown basalt and palagonite in clay mineral matrix; pinkish-brown breccia containing rounded basalt clasts coated with Mn-oxides in a phosphatized limestone cement; fractured and altered cobbles and boulders of basalt coated with Mn-oxide and fractures filled with nannofossil ooze. Basalt ranges from aphyric to olivine and plagioclase phyric, and from massive to highly vesicular. Minor clasts of bioturbated chalk and chert.
10-D7	21°47.89' 21°48.01'	167°37.41' 167°36.92'	2100	125	Dominantly thick, smooth, layered crusts; rare botryoidal crusts. 70% of rocks partly coated, 20% without crusts, 10% without substrate; crust thicknesses range from 10-45 mm and average 28-30 mm.	Yellowish to greenish brown hyaloclastite and broken pillow breccia with highly altered, olivine phyric clasts (to 15 cm) with palagonite rinds. Minor pale-brown phosphorite and Foraminifera-bearing chalk.
11-PC4	21°50.48'	167°39.99'	4123	--	1 mm or less-thick crusts on basalt pebbles.	28 cm brown, calcareous silty mud above 5 cm of stiff brown mud with altered basalt pebbles and crust chips.
12-D8	20°12.57' 20°11.88'	169°30.36' 169°31.15'	4800- 4500	10	Dominantly granular-porous surface; others botryoidal or smooth; 40% partly coated rocks, 30% pancake nodules with porous and smooth to knobby surfaces, nuclei of silty volcaniclastic mudstone, and crust thicknesses of 1-30 mm; 30% nodules, of bimodal size distribution: <1-4 cm and 8-15 cm, with nuclei of mudstone or basalt. Thickest crust is 45 mm, average 25 mm.	Green to brown volcanic breccia and conglomerate with highly altered, subrounded basalt pebbles; green-brown faintly laminated silt and claystone containing many crust chips.
14-D10	20°20.12' 20°19.99'	169°34.52' 169°34.30'	2400	7	8 rocks: 3 coated with crusts that vary from granular-porous to subtly botryoidal; 3 crusts without substrate are similar; 2 rocks without crusts. Thicknesses are 30-40 mm, average 35 mm.	Yellow-green hyaloclastite with orange-red palagonite and altered basalt clasts (to 8 cm) in clay mineral or limestone matrix. Nannofossil ooze fills fractures and euhedral calcite crystals and zeolites fill vugs.

[1] D and PC in sample numbers represent dredge and hard-substrate corer, respectively.

Table 4. Major oxides in weight percent: Necker Ridge substrate rocks, Cruise L5-83-HW.

	D1-1	D5-A3-9	D5-B3-11	D6-2	D6-A2	D6-A5-3	D6-A5-8	D7-A3	D7-A8-15	D8-A2	D10-A1
SiO_2	46.2	29.5	51.3	47.4	8.47	41.5	46.9	47.8	48.4	47.3	47.5
Al_2O_3	16.5	10.1	17.5	19.1	2.19	17.4	17.3	19.1	18.8	13.9	17.2
Fe_2O_3	10.6*	5.31	9.31	12.0*	1.31	15.9	14.8	12.8	13.0	11.9	13.4
FeO	--	<0.02	<0.02	--	<0.02	0.31	0.47	<0.02	<0.02	0.52	<0.02
MgO	7.47	1.58	2.60	1.62	0.66	1.32	2.34	2.42	2.21	4.06	2.26
CaO	8.56	24.3	1.95	7.83	45.1	9.28	3.06	4.65	4.05	3.99	3.07
Na_2O	2.63	1.90	2.45	3.38	1.13	2.98	2.46	2.49	2.41	4.07	2.50
K_2O	0.81	2.22	4.19	1.53	0.77	1.56	2.90	2.35	2.61	2.10	3.65
TiO_2	1.62	1.29	2.19	2.51	0.19	2.67	2.28	2.17	2.23	2.78	2.15
P_2O_5	0.25	14.4	0.70	0.67	28.0	2.47	0.29	0.15	0.17	0.22	0.80
MnO	0.15	0.36	0.14	0.08	0.24	0.08	0.07	0.12	0.12	0.55	0.19
H_2O^+	--	6.29**	8.54	--	3.23	4.80	8.06	8.53	8.50	9.73	8.83
CO_2	--	2.82	0.40	--	5.01	0.73	0.37	0.33	0.39	0.33	0.36
LOI (900°C)	5.06	6.84	7.62	3.94	6.18	4.99	7.07	6.45	6.29	8.09	7.06
Total	99.9	97.8	100.0	100.1	94.3	100.5	99.9	100.5	100.3	99.5	99.8
Lithology	Basalt	Volcanic breccia	Hyaloclastite	Basalt	Phosphatized volcanic breccia	Altered basalt	Hyaloclastite	Volcanic breccia	Hyaloclastite with zeolite cement	Volcanogenic mudstone, laminated	Volcanogenic breccia, zeolite cement

* Total Fe as Fe_2O_3.
** H_2O^+ represents total water present. Samples were dried at 105°C before analysis.
Totals based on LOI.
Analyses performed at U.S. Geological Survey analytical laboratories in Denver and Menlo Park.

Table 5-1. Chemistry of ferromanganese crusts, Necker Ridge, Cruise L5-83-HW. Hygroscopic water-free major oxides, weight percent, with sum. H_2O refers to chemically bound water determined by Penfield method. Sample type denotes sample chosen for analysis. Top generally refers to uppermost 5 mm of crust, or less. Total refers to entire thickness of crust. Bott. refers to crust between top 5 mm and substrate. Bott. F refers to black, friable and porous samples from underside of slabs. Analyses done by USGS-Reston.

SAMPLE	SiO_2	TiO_2	MnO_2	Al_2O_3	Fe_2O_3	Co_3O_4	Ni_3O_4	CuO	CaO	MgO	K_2O	Na_2O	P_2O_5	CO_2	H_2O+	Sum	Sample Type	Total Thickness (mm)
D1A-1	14.92	1.88	29.2	3.01	29.0	0.55	0.29	0.186	3.43	1.76	0.81	2.23	0.94	0.41	7.1	95.7	total	1-3
PC2A-2	15.67	2.45	27.7	3.89	27.0	0.65	0.46	0.284	3.63	1.79	0.82	2.27	0.85	0.5	8.6	96.7	total	4
PC3A-3	12.96	2.25	30.8	2.76	28.3	0.79	0.41	0.135	3.58	1.62	0.64	2.23	0.85	0.5	9.3	97.2	top	5-10
D5Bx-4	13.10	1.93	31.4	2.63	27.6	0.83	0.46	0.118	3.67	1.74	0.76	2.18	1.17	0.3	8.7	96.8	total	28
D5Cx-5	9.45	2.27	33.9	1.63	29.1	0.92	0.45	0.116	3.42	1.62	0.60	2.22	1.03	0.4	9.2	96.6	total	1-5
D6Ay-6	12.74	2.54	35.5	2.95	25.0	0.72	0.54	0.228	3.72	1.67	0.92	2.30	0.73	0.4	10.5	100.7	bott.	40
D6Ay-7	13.02	2.32	33.6	2.63	31.0	0.70	0.38	0.104	3.77	1.71	0.71	2.23	1.03	0.3	7.7	101.4	top	40
D6Ax-9	8.36	2.00	35.7	1.76	23.6	1.58	0.56	0.084	4.00	1.74	0.67	2.75	1.01	0.9	6.5	91.3	bott. F	4
D6Ax-8	15.75	1.88	29.8	3.21	29.4	0.74	0.31	0.043	3.82	1.66	0.86	2.39	1.12	0.5	9.3	100.9	top	4
D7Ax-10	8.53	3.19	38.8	1.46	27.5	1.38	0.45	0.050	3.58	1.94	0.75	2.66	0.89	0.4	7.3	99.0	bott. F	10-25
D7Fx-11	14.00	2.87	28.5	3.01	32.0	0.56	0.32	0.100	3.77	1.58	0.67	2.15	0.99	0.2	7.4	98.3	total	40
D7Fx-12	15.24	1.77	30.4	2.65	31.0	0.73	0.30	0.048	3.44	1.59	0.75	2.22	1.03	0.4	8.9	100.7	top	40
D8A-13	17.48	3.65	24.8	4.63	31.7	0.43	0.22	0.131	3.12	1.76	0.86	2.13	0.76	0.1	7.1	99.0	total	40
D8B-14	24.50	3.02	19.5	7.03	27.2	0.34	0.20	0.170	3.08	2.25	1.25	2.20	0.62	0.1	6.6	98.2	top	30
D8B-15	23.24	2.65	23.5	6.84	25.2	0.44	0.33	0.195	3.12	2.40	1.23	2.23	0.57	0.2	6.9	99.2	bott.	30
D8C-16	20.46	4.00	22.0	5.88	29.7	0.38	0.24	0.194	2.95	2.02	0.94	2.11	0.76	0.2	8.4	100.4	total	30
D10-17	11.57	2.03	33.3	1.76	31.5	0.82	0.34	0.051	3.36	1.66	0.64	2.29	0.96	0.2	7.7	98.3	top	30
D10-18	11.59	2.35	33.0	1.91	31.9	0.72	0.35	0.084	3.30	1.59	0.61	2.13	0.94	0.3	8.3	99.1	total	30
D10-19	8.32	2.87	38.4	1.46	27.7	1.20	0.46	0.094	3.93	1.74	0.67	2.34	1.12	0.5	8.1	99.0	bottom F	10

Table 5-2. Chemistry of ferromanganese crusts, Necker Ridge, Cruise L5-83-HW. Hygroscopic water-free major oxides, weight percent, with sum. *H_2O refers to chemically bound water computed by empirical relationship: $(Fe_2O_3 + MnO_2)/7$. Other is an empirical correction factor $(Fe_2O + MnO_2)/40$ to account for some minor constituents not included in table. For sample type and total thickness refer to Table 5-1. Analyses done by USGS-WH.

SAMPLE	SiO_2	TiO_2	MnO_2	Al_2O_3	Fe_2O_3	Co_3O_4	Ni_3O_4	CaO	MgO	K_2O	P_2O_5	H_2O-	H_2O+*	Other*	Sum
PC2A-2	15.23	2.35	27.0	5.39	26.2	0.68	0.42	3.23	1.72	0.74	0.87	5.5	7.6	1.33	92.9
PC3A-3	12.68	2.30	31.4	3.80	28.6	0.89	0.36	3.37	1.72	0.60	0.92	13.5	8.6	1.50	96.9
D5Cx-5	8.90	2.25	35.4	2.59	29.8	1.00	0.39	3.40	1.62	0.58	1.03	12.8	9.3	1.63	98.0
D6Ay-6	11.81	2.95	33.6	4.14	24.2	0.76	0.52	3.26	1.51	0.81	0.76	19.8	8.3	1.45	94.1
D6Ax-9	8.40	2.50	37.7	3.27	24.8	1.66	0.53	4.17	2.02	0.63	1.08	5.6	8.9	1.57	97.4
D7Fx-11	13.42	2.77	28.2	4.71	31.0	0.67	0.25	3.36	1.62	0.65	1.05	9.3	8.5	1.48	97.8
D8A-13	16.15	3.79	23.6	7.05	29.8	0.49	0.10	2.65	1.51	0.39	0.71	5.7	7.6	1.34	95.4
D8B-14	23.45	2.90	19.8	8.62	27.0	0.41	0.09	2.70	1.81	1.14	0.60	10.0	6.7	1.17	96.5
D10-17	10.96	1.92	31.7	2.14	29.8	0.90	0.27	2.93	1.49	0.59	0.96	8.3	8.8	1.54	94.2
D10-19	8.14	2.77	37.0	2.82	26.8	1.34	0.44	3.57	1.64	0.64	0.92	15.8	9.1	1.60	96.9

Table 5-3. Chemistry of ferromanganese crusts, Necker Ridge, Cruise L5-83-HW. Hygroscopic water-free major elements in weight percent. For sample type and total thickness refer to Table 5-1. Analyses by USGS-Reston.

SAMPLE	SiO_2	Ti	Mn	Al	Fe	Co	Cu	Ni	Ca	Mg	K	Na_2O	P	CO_2	H_2O-
D1A-1	14.92	1.13	18.44	1.59	20.25	0.405	0.149	0.213	2.45	1.06	0.67	2.23	0.41	0.41	6.20
PC2A-2	15.67	1.47	17.51	2.06	18.91	0.475	0.227	0.335	2.59	1.08	0.68	2.27	0.37	0.52	7.50
PC3A-3	12.96	1.35	19.44	1.46	19.77	0.581	0.108	0.301	2.56	0.98	0.53	2.23	0.37	0.53	10.50
D5Bx-4	13.10	1.16	19.86	1.39	19.32	0.611	0.094	0.338	2.62	1.05	0.63	2.18	0.51	0.37	8.40
D5Cx-5	9.45	1.36	21.46	0.86	20.35	0.678	0.093	0.333	2.44	0.98	0.50	2.22	0.45	0.47	10.10
D6Ay-6	12.74	1.52	22.45	1.56	17.47	0.533	0.182	0.400	2.66	1.01	0.76	2.30	0.32	0.49	17.60
D6Ay-7	13.02	1.39	21.24	1.39	21.71	0.516	0.083	0.281	2.69	1.03	0.59	2.23	0.45	0.37	14.80
D6Ax-8	15.75	1.13	18.83	1.70	20.54	0.547	0.034	0.228	2.73	1.00	0.71	2.39	0.49	0.51	12.40
D6Ax-9	8.36	1.20	22.56	0.93	16.52	1.165	0.067	0.413	2.86	1.05	0.56	2.75	0.44	0.91	5.60
D7Ax-10	8.53	1.91	24.54	0.77	19.21	1.013	0.040	0.330	2.56	1.17	0.62	2.66	0.39	0.45	6.30
D7Fx-11	14.00	1.72	17.99	1.59	22.41	0.409	0.080	0.237	2.69	0.95	0.56	2.15	0.43	0.29	7.20
D7Fx-12	15.24	1.06	19.22	1.40	21.68	0.539	0.038	0.222	2.46	0.96	0.62	2.22	0.45	0.49	14.70
D8A-13	17.48	2.19	15.67	2.45	22.17	0.319	0.105	0.159	2.23	1.06	0.71	2.13	0.33	0.17	6.20
D8B-14	24.50	1.81	12.30	3.72	19.03	0.252	0.136	0.147	2.20	1.36	1.04	2.20	0.27	0.15	4.90
D8B-15	23.24	1.59	14.86	3.62	17.65	0.324	0.156	0.245	2.23	1.45	1.02	2.23	0.25	0.25	10.50
D8C-16	20.46	2.40	13.90	3.11	20.80	0.278	0.155	0.177	2.11	1.22	0.78	2.11	0.33	0.21	10.10
D10-17	11.57	1.22	21.06	0.93	22.05	0.600	0.041	0.251	2.40	1.00	0.53	2.29	0.42	0.22	8.40
D10-18	11.59	1.41	20.83	1.01	22.29	0.529	0.067	0.259	2.36	0.96	0.51	2.13	0.41	0.30	11.20
D10-19	8.32	1.72	24.26	0.77	19.34	0.879	0.075	0.339	2.81	1.05	0.56	2.34	0.49	0.59	14.70

Table 5-4. Chemistry of ferromanganese crusts, Necker Ridge, Cruise L5-83-HW. Hygroscopic water-free major elements, weight percent. For sample type and total thickness refer to Table 5-1. Analyses by USGS-WH.

SAMPLE	SiO_2	Ti	Mn	Al	Fe	Co	Ni	Ca	Mg	K	P	H_2O^-
PC2A-2	15.23	1.41	17.06	2.85	18.32	0.497	0.306	2.31	1.04	0.61	0.38	5.52
PC3A-3	12.68	1.38	19.87	2.01	20.02	0.658	0.265	2.41	1.04	0.50	0.40	13.50
D5Cx-5	8.90	1.35	22.36	1.37	20.81	0.734	0.286	2.43	0.98	0.48	0.45	12.86
D6Ay-6	11.81	1.77	21.24	2.19	16.89	0.561	0.386	2.33	0.91	0.67	0.33	19.88
D6Ax-9	8.40	1.50	23.82	1.73	17.36	1.218	0.391	2.98	1.22	0.52	0.47	5.61
D7Fx-11	13.42	1.66	17.80	2.49	21.70	0.496	0.187	2.40	0.98	0.54	0.46	9.35
D8A-13	16.15	2.27	14.92	3.73	20.85	0.360	0.074	1.89	0.91	0.32	0.31	5.75
D8B-14	23.45	1.74	12.51	4.56	18.89	0.299	0.066	1.93	1.09	0.95	0.26	10.00
D10-17	10.96	1.15	20.03	1.13	20.87	0.665	0.196	2.09	0.90	0.49	0.42	8.38
D10-19	8.14	1.66	23.36	1.49	18.74	0.985	0.320	2.55	0.99	0.53	0.40	15.81

Table 5-5. Chemistry of ferromanganese crusts, Necker Ridge, Cruise L5-83-HW. Trace elements corrected for H_2O^- (hygroscopic moisture free basis), weight percent. For sample type and total thickness refer to Table 5-1. Analyses by USGS-Reston.

SAMPLE	Ba	Mo	Pb	Sr	V	Zn	Y	Ce	As	Cd	H_2O^-
D1A-1	0.127	0.017	0.181	0.127	0.056	0.063	0.014	0.159	0.018	0.00033	6.20
PC2A-2	0.172	0.019	0.172	0.140	0.060	0.084	0.014	0.091	0.016	0.00027	7.50
PC3A-3	0.167	0.031	0.178	0.145	0.065	0.072	0.016	0.096	0.020	0.00024	10.50
D5Bx-4	0.141	0.031	0.196	0.141	0.058	0.065	0.018	0.109	0.019	0.00030	8.40
D5Cx-5	0.177	0.043	0.189	0.177	0.070	0.066	0.025	1.112	0.031	0.00021	10.10
D6Ay-6	0.194	0.035	0.133	0.157	0.053	0.076	0.018	0.121	0.018	0.00025	17.60
D6Ay-7	0.164	0.035	0.187	0.152	0.061	0.069	0.021	0.115	0.022	0.00025	14.80
D6Ax-9	0.148	0.029	0.201	0.158	0.060	0.072	0.018	0.169	0.026	0.00031	5.60
D6Ax-8	0.106	0.029	0.171	0.136	0.058	0.054	0.019	0.113	0.021	0.00023	12.40
D7Ax-10	0.160	0.030	0.213	0.149	0.051	0.064	0.021	0.149	0.021	0.00033	6.30
D7Fx-11	0.183	0.028	0.183	0.150	0.057	0.074	0.021	0.107	0.019	0.00022	7.20
D7Fx-12	0.128	0.031	0.199	0.140	0.062	0.058	0.021	0.128	0.022	0.00026	14.70
D8A-13	0.170	0.015	0.138	0.117	0.053	0.063	0.019	0.181	0.018	0.00023	6.20
D8B-14	0.136	0.006	0.104	0.088	0.041	0.053	0.013	0.136	0.010	0.00022	4.90
D8B-15	0.145	0.010	0.110	0.090	0.043	0.055	0.013	0.145	0.012	0.00027	10.50
D8C-16	0.155	0.007	0.122	0.102	0.045	0.070	0.015	0.144	0.012	0.00028	10.10
D10-17	0.120	0.033	0.185	0.141	0.060	0.061	0.021	0.131	0.021	0.00026	8.40
D10-18	0.157	0.037	0.191	0.146	0.060	0.067	0.021	0.112	0.021	0.00029	11.20
D10-19	0.152	0.032	0.187	0.152	0.051	0.064	0.022	0.140	0.019	0.00035	14.70

Table 6. Mineral content of ferromanganese crusts, Necker Ridge, Cruise L5-83-HW.

Sample No.	Vernadite (%)	Plagioclase (%)	Quartz (%)	Apatite (%)	Others	Comments
D1-A1	99	0	1	0		Bulk
D5-A2	100					Bulk
D5-A3-1	98	1	1			Bulk
D5-A3-3-I	90	1	1	3	Todorokite (4%) Barite (1%)	Bulk
D5-A3-4	97	2	1			Bulk
D5-A3-5	97	2	2	0		Bulk
D5-A3-6	100?					inner crust
D5-A3-6	98		1		Anhydrite or Mordenite (1%)	outer crust
D5-A3-8	95	3	1	1		inner crust
D5-A3-8	98	1	1			outer crust
D5-A3-9	92		<1	4	K-spar (4%)	Bulk
D5-A3-10	89		1	10		granular
D5-A3-22	94		1	5		Bulk
D5-B3-7	94	4	2			Bulk
D5-B3-9	100	0	0	0		Bulk - very porous
D5-B3-13	98	1	1			porous, upper surface
D5-B3-13	97	3				crust on underside
D5-B3-13	97	2.5	0.5			inner crust
D5-B3-17	91		1	8		Bulk
D6-A1	98	2	1			outer crust
D6-A1	97	2	<1			1st layer (adjacent to outer crust)
D6-A1	99	1				2nd layer
D6-A1	96	3	1			3rd layer (adjacent to substrate)
D6-A1	100					porous underside
D6-B1	97	2	0	1		inner crust
D6-B1	97	1	2	0		outer crust
D7-A8-1	94	5	1	0		inner crust
D7-A8-1	96	3	1	0		outer crust
D8-A4-6	95	3	2	0	calcite?	Bulk
D10-B1	98	1	1	0		outer crust
D10-B1	97	2	1	0		inner crust

Percentages were determined by using the following weighting factors relative to quartz set as 1 : vernadite 75, plagioclase 2.8, apatite 3.1, calcite 1.65. We determined the vernadite weighting factor by mixing known amounts of a pure vernadite crust and quartz; other weighting factors are from Cook et al. (1975). The limit of detection for each mineral falls between 0.5 and 1.0 percent.

Table 7. Mineral content of substrates associated with ferromanganese crusts, Necker Ridge, Cruise L5-83-HW.

Sample No.	-----X - r a y Major	M i n e r a l o g y----- Moderate	Minor or Trace	Comments
D5-A2	Apatite		Quartz	White vein in basalt
D5-A2	Apatite Plagioclase		Smectite Pyroxene	Basalt
D5-A3-1	Plagioclase Apatite		Smectite	Gray basalt clast from phosphorite-cemented breccia
D5-A3-1	Plagioclase	Smectite	Apatite Goethite	Yellow-brown basalt clast from phosphorite-cemented breccia
D5-A3-1	Apatite		Quartz Plagioclase	White matrix from phosphorite-cemented breccia
D5-A3-1	Apatite		Quartz	Pink matrix from phosphorite-cemented breccia
D5-A3-1	Apatite		Quartz Calcite?	
D5-A3-1	Apatite			Basalt clast from phosphorite-cemented breccia
D5-A3-3	Apatite		Quartz?	White vein from volcanic breccia
D5-A3-3	Apatite	Plagioclase	Smectite	Volcanic breccia
D5-A3-4	Phillipsite Plagioclase	Smectite	Apatite	Pale brown sandstone matrix from volcanic breccia
D5-A3-4	Phillipsite Apatite	Smectite	Plagioclase Quartz	White sandstone matrix from volcanic breccia
D5-A3-9	Apatite		Smectite? Quartz?	Pink volcanic clast from volcanic breccia
D5-A3-9	Apatite		Quartz Smectite	White matrix of volcanic breccia
D5-A3-9	Plagioclase	Apatite	Smectite Pyroxene	Gray basalt clast from volcanic breccia
D5-A3-10	Plagioclase Apatite		Smectite Calcite	Green basalt clast from volcanic breccia
D5-A3-10	Apatite			White matrix from volcanic breccia
D5-A3-10	Apatite			Phosphorite

Table 7 cont.

Sample No.	-----X - r a y Major	M i n e r a l o g y----- Moderate	Minor or Trace	Comments
D5-A3-22	Apatite			White matrix in volcanic breccia
D5-A3-22	Quartz	Apatite Illite	Plagioclase Chlorite	Pale brown matrix in volcanic breccia
D5-A3-22	K-spar Smectite	Apatite		Yellow-brown basalt clast in volcanic breccia
D5-B3-7	Plagioclase Smectite		Pyroxene Phillipsite	White basalt clast from volcanic breccia
D5-B3-13	Plagioclase		Apatite Pyroxene Smectite	Gray basalt clast from volcanic breccia
D5-B3-17	Apatite			Phosphorite coating on volcanic breccia
D5-B3-17	Apatite Plagioclase			Basalt clast from volcanic breccia
D5-B3-17	Apatite			Phenocryst from volcanic breccia
D6-A1	Plagioclase		Smectite Apatite Calcite Pyroxene?	
D6-A2	Apatite		Plagioclase Smectite Phillipsite	Phosphorite from volcanic breccia
D6-A5-3	Plagioclase	Apatite	Quartz Pyroxene Smectite	Basalt
D6-A5-8	Plagioclase		Smectite	Hyaloclastite
D7-A3	Plagioclase		Smectite	Volcanic breccia
D7-A8-15	Phillipsite	Smectite Plagioclase	Apatite	Hyaloclastite with zeolite cement
D8-A2	Phillipsite Plagioclase	Smectite Pyroxene		Laminated mudstone
D10-A1	Phillipsite		Apatite Plagioclase Smectite	Volcanic breccia with zeolite cement

Table 8. Physical properties of substrate rocks from Necker Ridge, Cruise L5-83-HW. Weight fraction of water is fraction of dry solids. The grain density used to calculate columns 2, 3, and 5 is 2.9.

Sample No.	Wet Bulk Density (g/cc)	Dry Bulk Density (g/cc)	Total wt. fraction of Water (g/g)	Percent Porosity	Rock Type
D5-A3-9	2.26	1.91	0.182	35	Volcanic breccia
D6-A2	2.57	2.38	0.077	18	Phosphatized volcanic breccia
D6-A5-3	2.62	2.46	0.063	15	Altered basalt
D7-A3	2.11	1.68	0.258	43	Volcanic breccia

Table 9-1. Physical properties of crust samples from Necker Ridge, Cruise L5-83-HW. H_2O, ϕ (porosity), are expressed in weight and volume percent respectively, where water loss is determined by overnight oven drying at 110°C. Correction for sea-salt contribution is denoted by (*), assuming water is associated with brine with salinity 35.0 g/kg. Salt-free wet bulk density (P) and dry bulk density (D) are given in g/ml. Grain density (GD) refers to mineral matter dried at 110°C. Dredge stations are shown in parentheses under "Sample No."

Sample No.	H_2O-(wet)	H_2O-(wet*)	H_2O-(dry)	H_2O-(dry*)	ϕ	ϕ(*)	P	D(*)	GD	GD(*)
2 (D7)	33.4	33.8	50.2	51.7	66.0	66.4	1.98	1.29	3.87	4.10
4 (D7)	31.7	32.1	46.4	47.7	62.1	62.5	1.96	1.32	3.53	3.57
5 (D7)	25.7	25.9	34.6	35.4	52.0	52.3	2.02	1.48	3.13	3.21
6 (D5B1)	34.1	34.6	52.0	53.6	61.2	63.3	1.84	1.19	3.26	3.57
7 (D7)	29.3	29.6	41.4	42.5	58.3	58.6	1.99	1.38	3.37	3.50
9 (D5B1)	33.4	33.8	50.2	51.7	62.8	63.3	1.88	1.23	3.37	3.52
10 (D7)	30.0	30.3	42.9	44.0	61.1	61.4	2.04	1.40	3.66	3.82
12 (D5B1)	29.4	29.7	41.6	42.7	58.1	58.5	1.98	1.38	3.33	3.37
13 (D5B1)	33.2	33.6	49.7	51.2	62.9	63.3	1.89	1.24	3.41	3.44
14 (D5B1)	33.0	33.4	49.3	50.7	62.0	62.4	1.88	1.24	3.31	3.35
15 (D5B1)	33.3	33.7	49.9	51.5	62.8	63.2	1.88	1.23	3.38	3.41
17 (D5B1)	34.5	34.9	52.7	54.4	63.6	64.1	1.84	1.18	3.32	3.35
19 (D5B1)	32.1	32.4	47.1	48.4	58.8	59.2	1.83	1.22	3.03	3.05

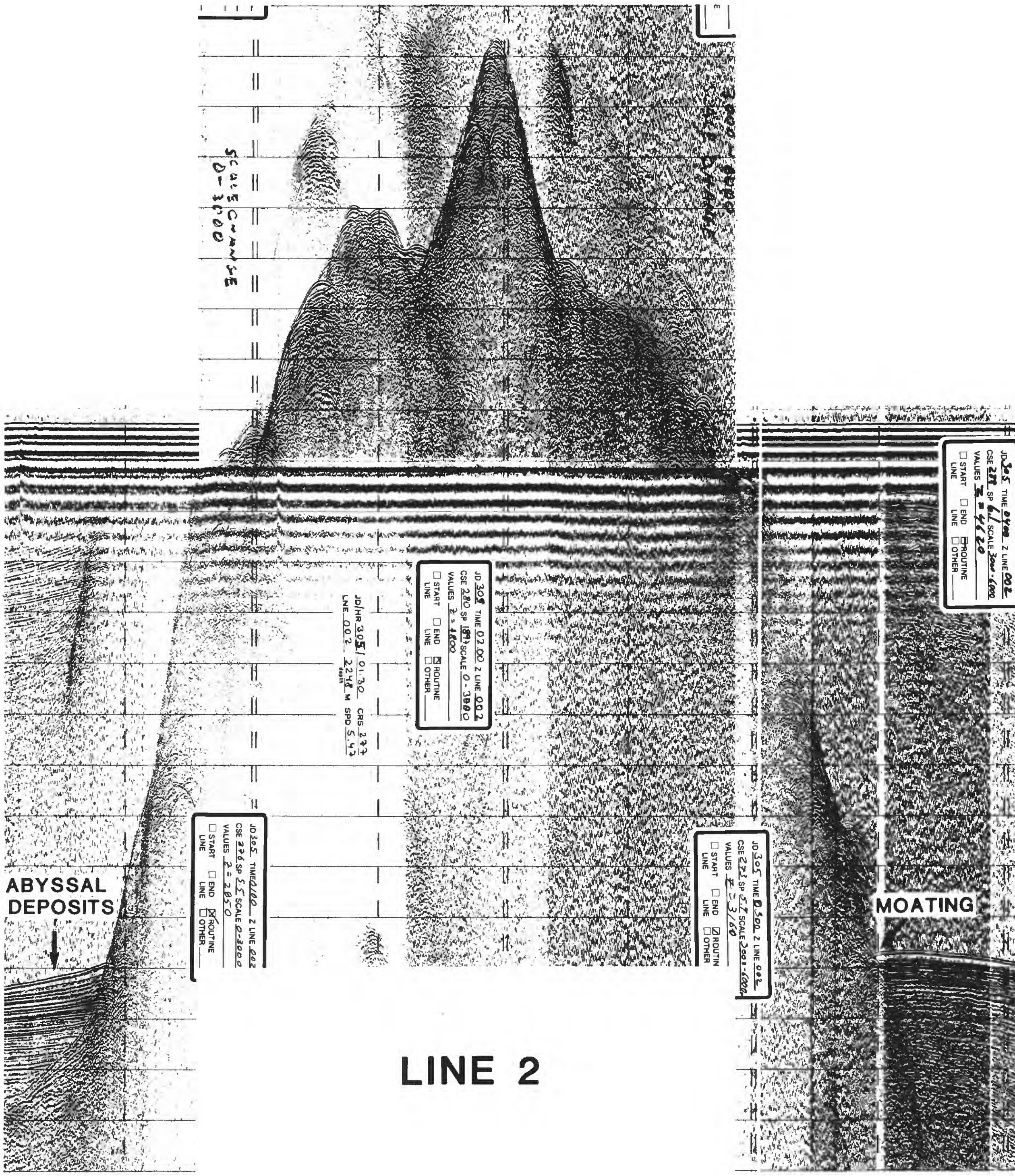
Four samples (4, 6, 15, and 17) are composite samples, taken from all layers of crust; 3 samples (2, 9, and 17) are scrapings from the top 1-2 mm of crust; 2 samples (13 and 14) are from just beneath the top layer; 2 samples (5 and 10) are from the central portion of the crust and represent a vitreous, coaly material about 5 mm in thickness; 2 samples (12 and 19) are from the bottom layers of crust, in contact with the substrate.

Table 9-2. Water content and ignition loss data for Necker Ridge, Cruise L5-83-HW. H. Mairs and K. Schmitz, analysts. H_2O on wet weight basis was established by loss on drying at 110°C. Dry weight basis means that starting material was air-dry powder, and all weight loss data are given as a weight percent of oven-dried sample (110°C) except hygroscopic moisture (H_2O). All data in weight percent.

Sample No.	Wet weight basis			Dry weight basis			
	H_2O^-	500°	1000°	H_2O	110-500°	500-1000°	110-1000°
D1B2	33.1	37.6	39.1				
PC3A	35.3	41.3	-				
D5Bx-4				14.4	8.69	5.95	14.6
D5B2	31.6	38.7	41.6				
D6Ay-7				16.8	9.06	5.79	14.8
D6A-4	30.7	39.3	42.4				
D7Ay-7				12.8	8.29	7.72	16.01
D7Fx-12				17.8	9.38	5.80	15.19
D7A6	39.2	45.7	49.3				
D8A-13				11.04	8.75	5.01	13.76
D8B-14				8.68	7.84	4.34	12.17
D8B-16				12.78	9.56	4.25	13.82
D10-18				12.97	9.72	6.17	15.89
D10B-3	33.7	41.0	44.8				

Figure 4. Single-channel, 80 cubic-inch airgun seismic-reflection profiles for lines 2 through 12 (4a through 4k), Necker Ridge. Note moating of abyssal deposits at the base of the ridge. The northeastern part of the ridge is rugged and supports little sediment in contrast to the southwestern part. Dredge and core locations are indicated on some profiles. The distance between each horizontal rule represents 150-m water depth.

4 a



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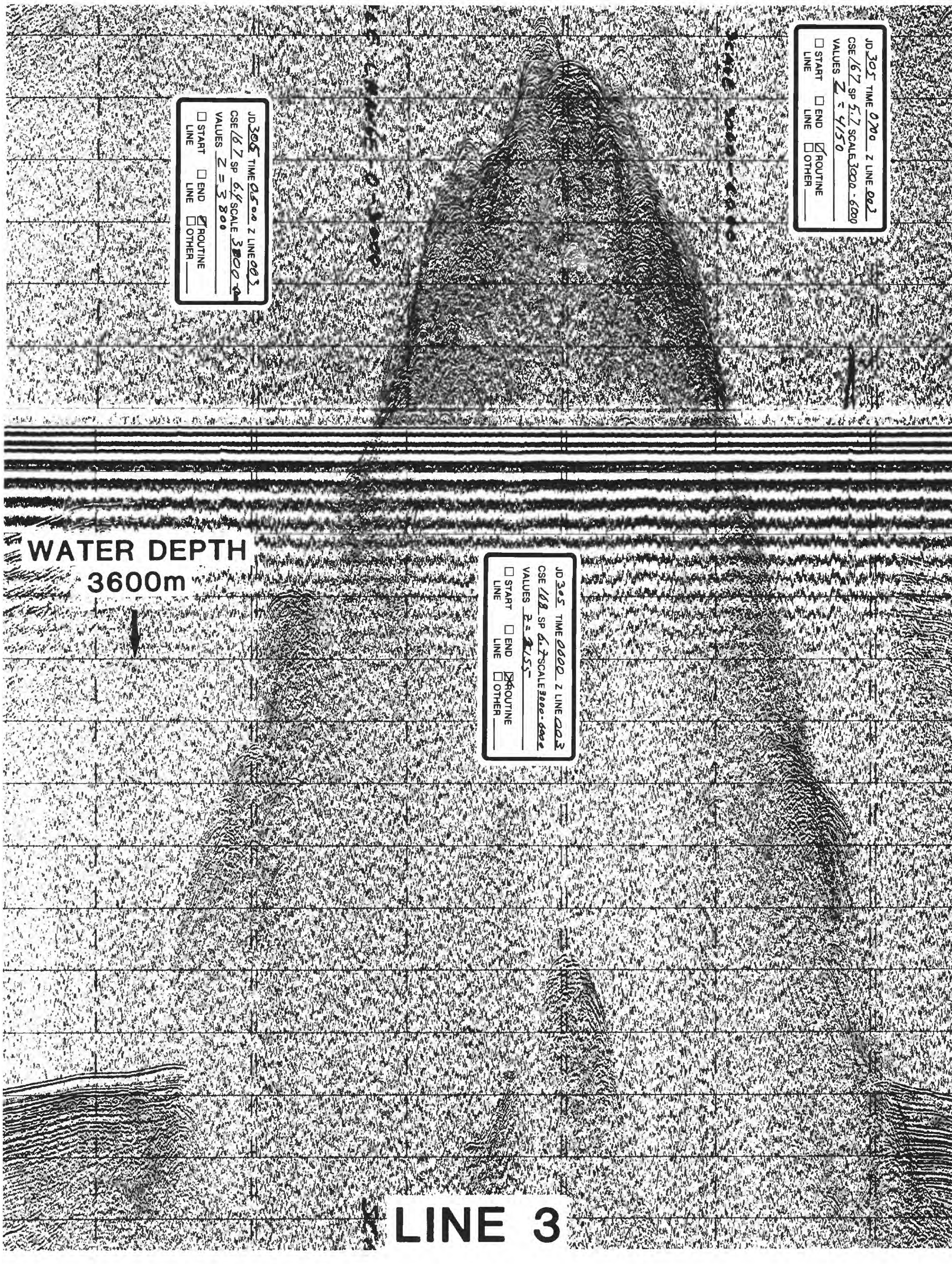
4 b



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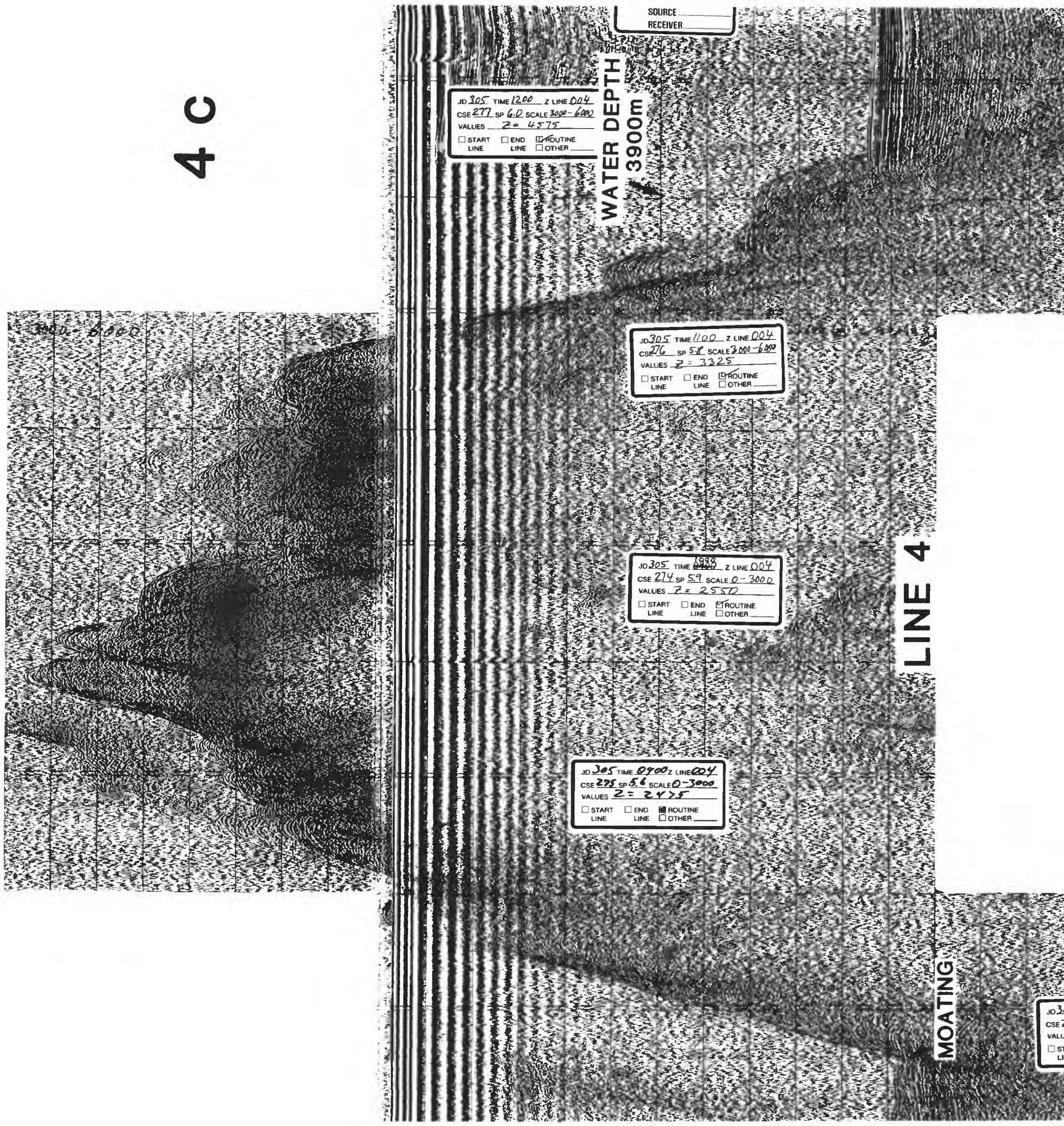

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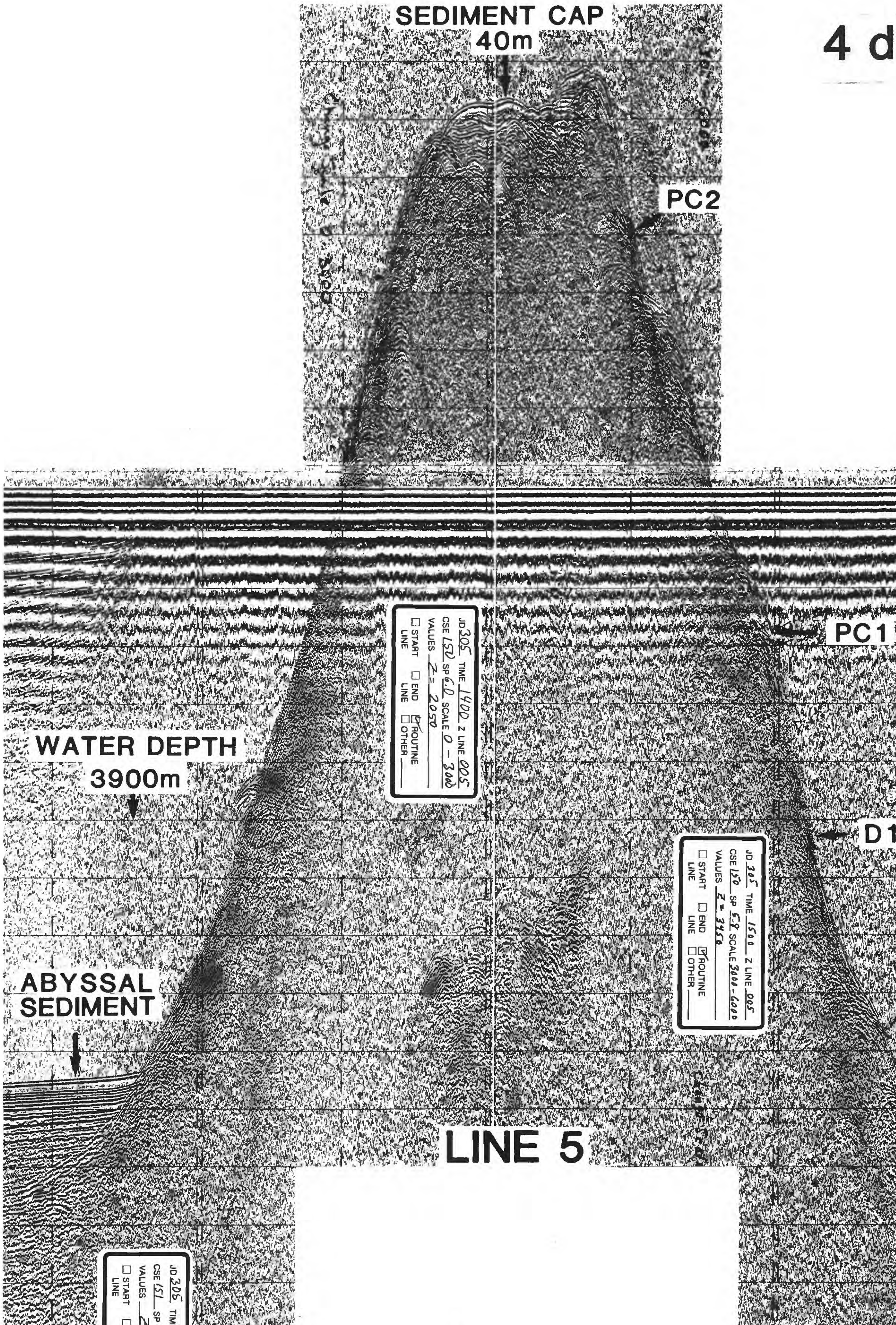
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WATER DEPTH
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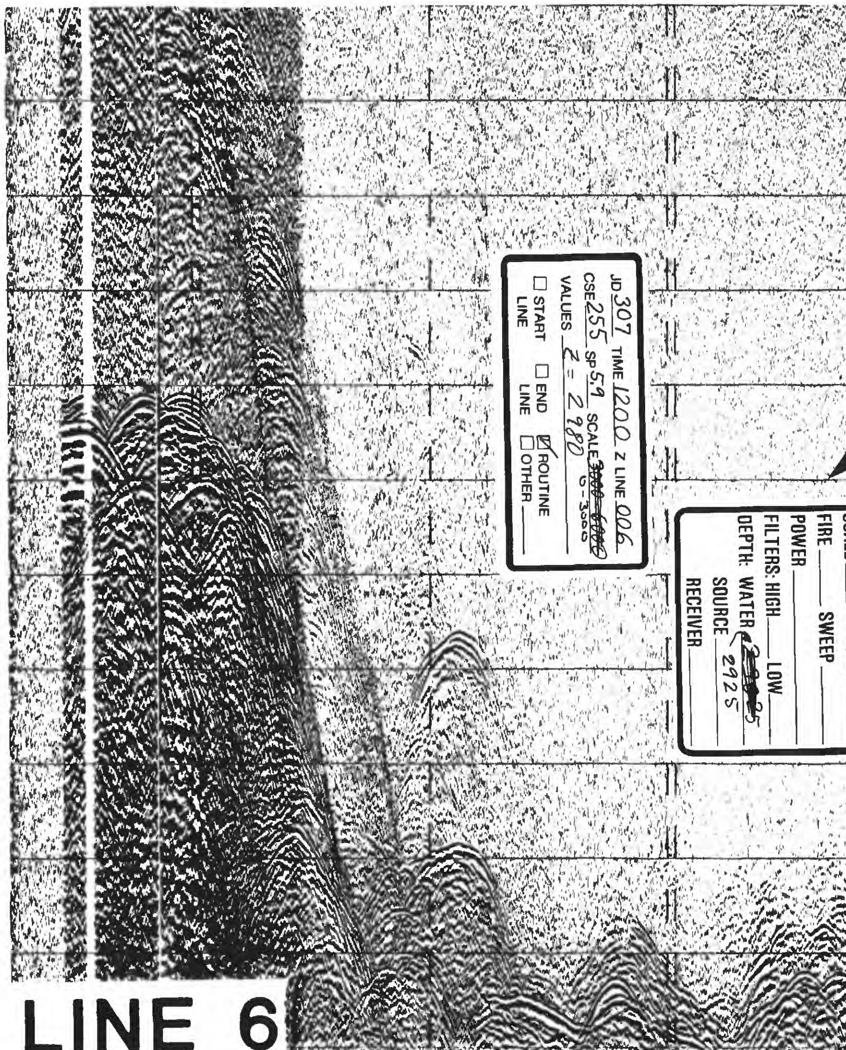
D1
ABYSSAL
SEDIMENT
LINE 5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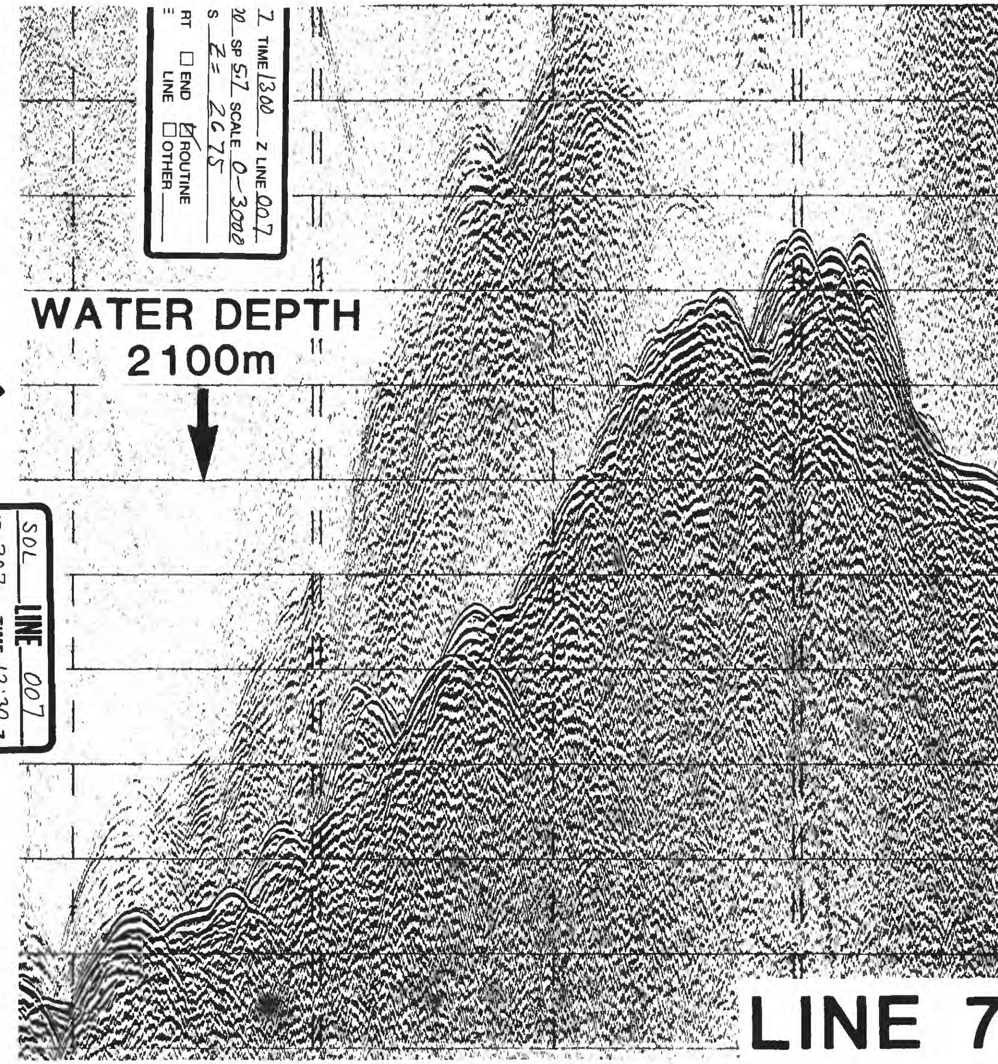
START LINE
END LINE
ROUTINE
OTHER

4 e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FILTERS: HIGH LOW
DEPTH: WATER 2925
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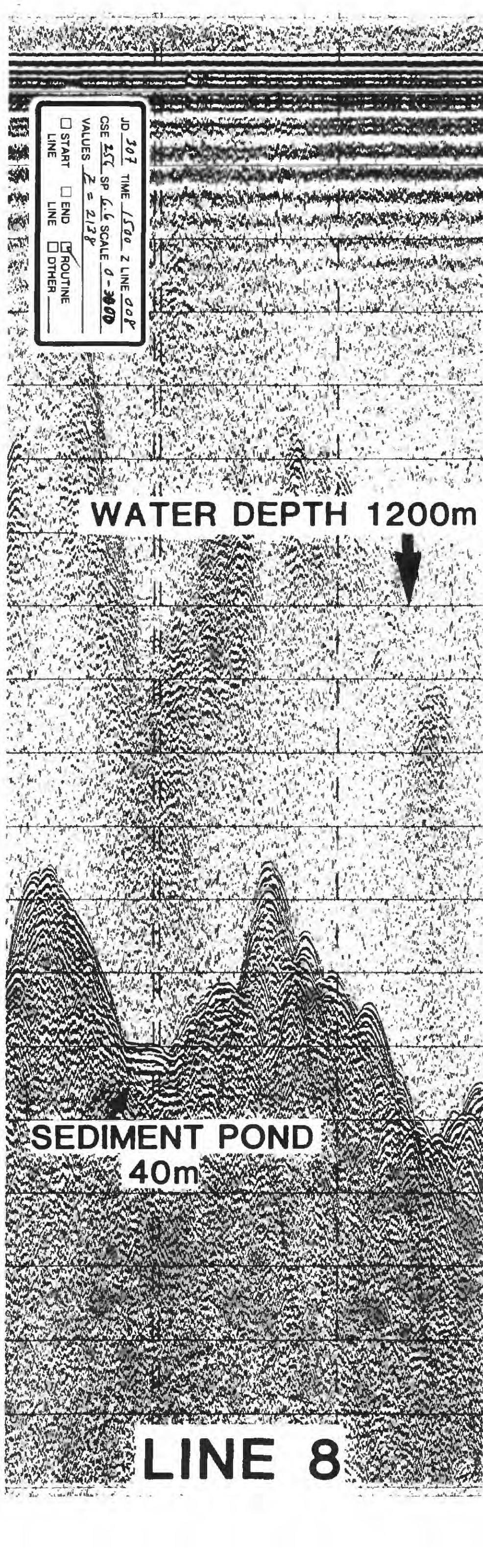
END LINE
ROUTINE
OTHER

4 f

4 g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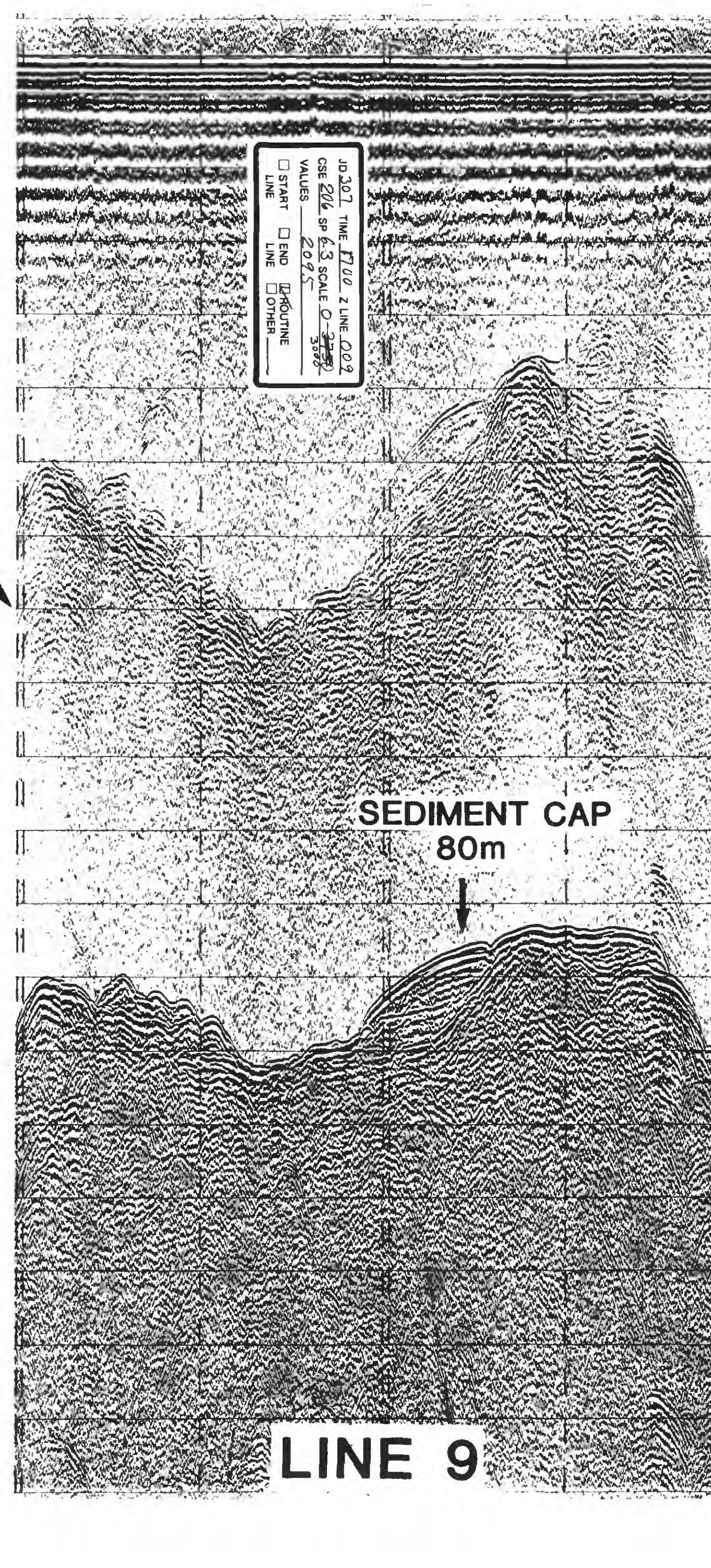
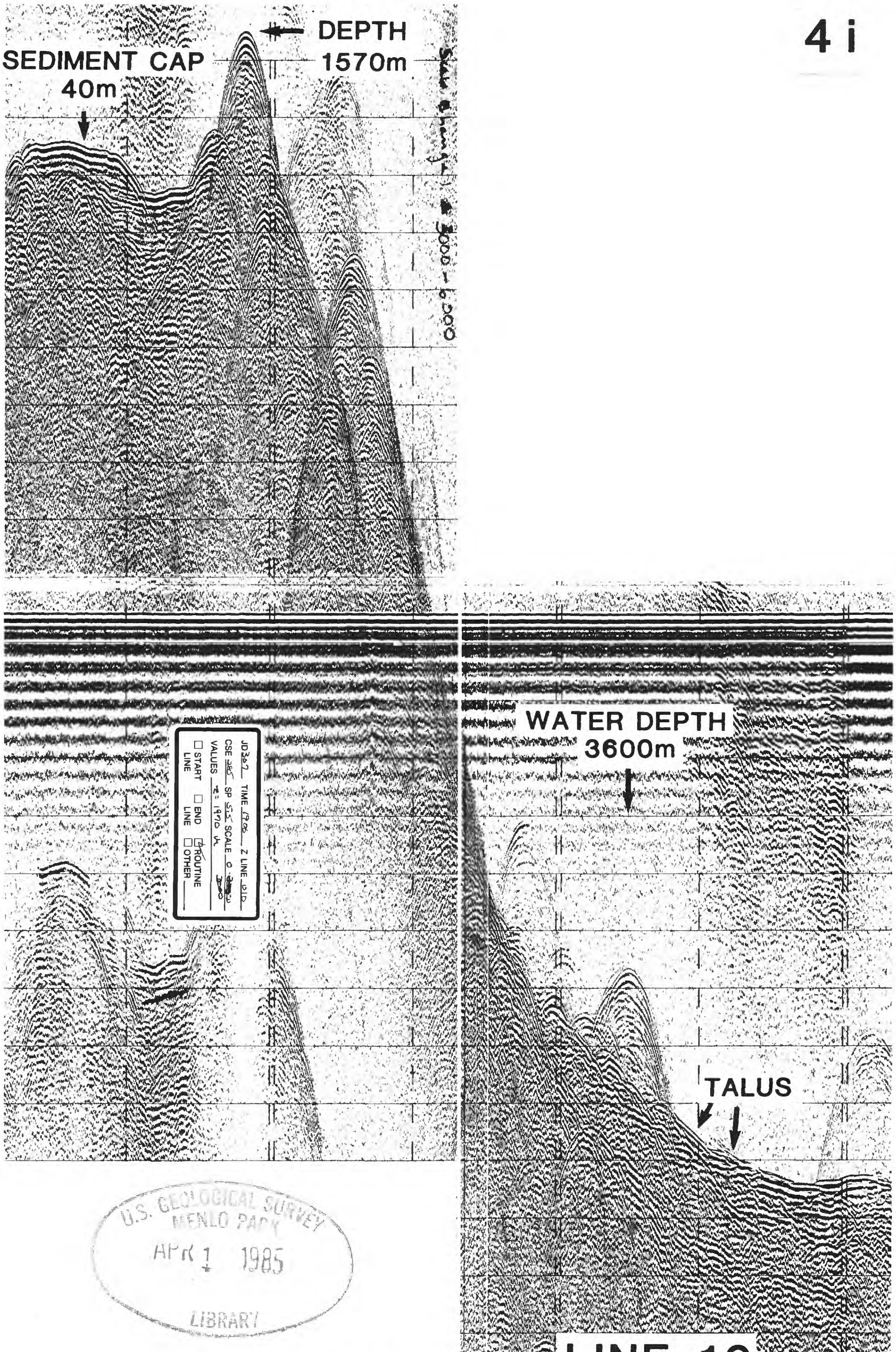
SEDIMENT POND
40m
LINE 8

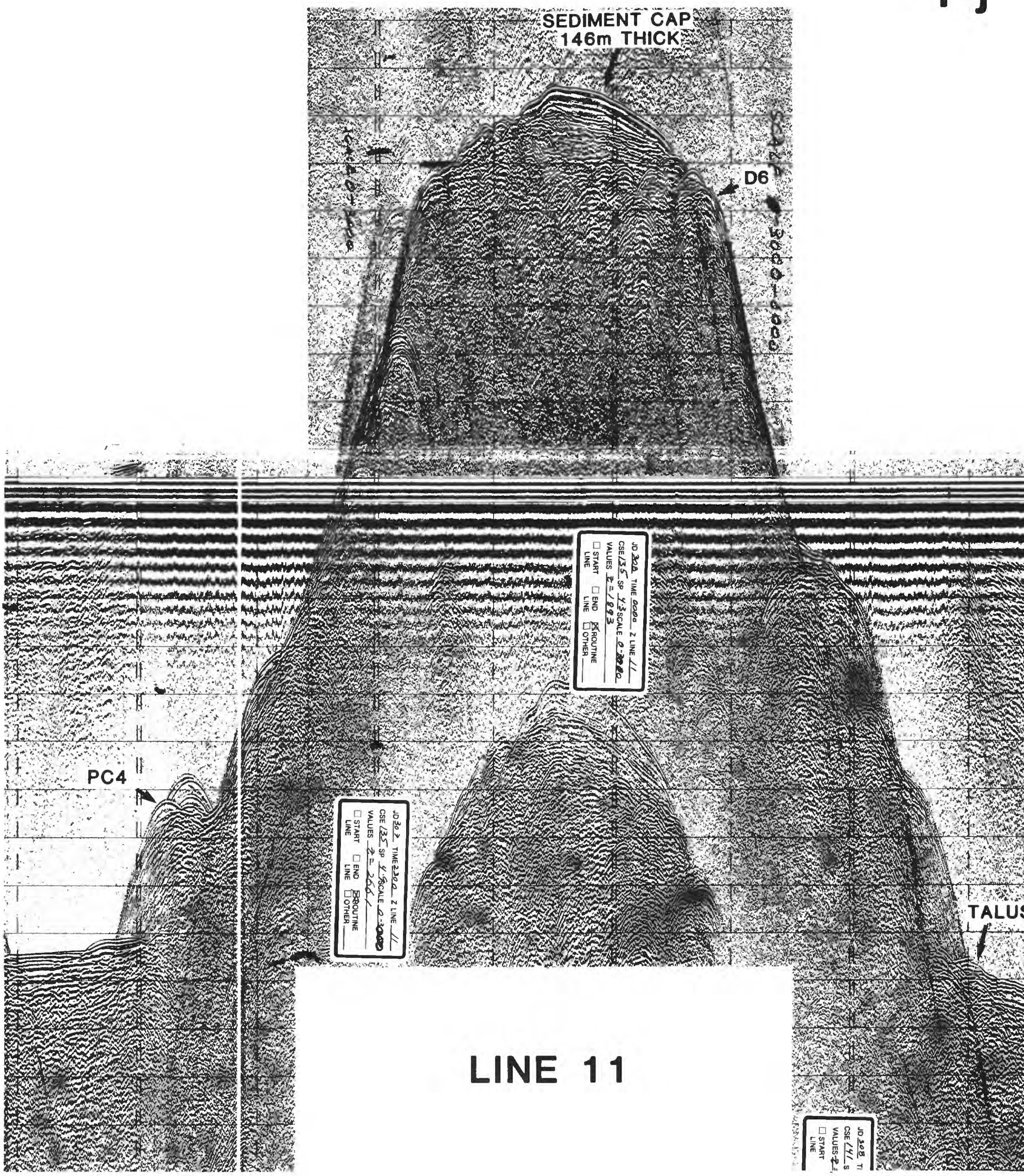
4 h

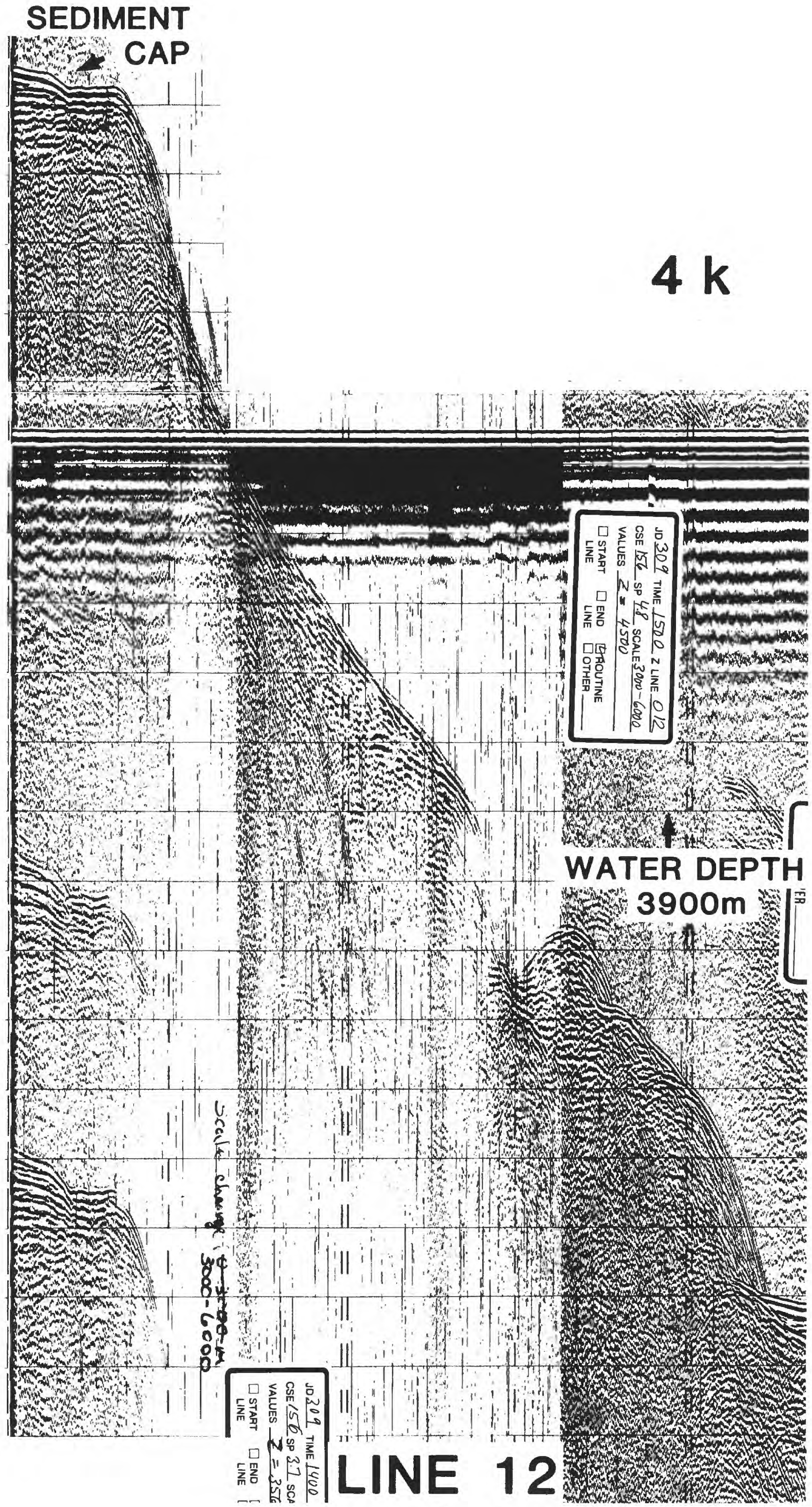

SEDIMENT CAP
80m
LINE 9

4 i


SEDIMENT CAP
40m
DEPTH
1570m
JD TIME Z LINE
CSE SP SCALE
VALUES
START LINE
END LINE
ROUTINE
OTHER
WATER DEPTH
3600m
TALUS
LINE 10

4 j




SEDIMENT CAP
4 k
WATER DEPTH 3900m
LINE 12

HORIZON GUYOT

A sampling transect crossed the central region of Horizon Guyot (Fig. 5). Two seismic-reflection profiles (Lines 13 and 14) crossed the guyot from north to south (Fig. 6a,b). Maximum slope gradients of the north and south flanks are 14° and 19°, respectively. A sediment cap up to 500-m thick rests atop the guyot (Deep Sea Drilling Project Site 171 on Figure 5).

Sediment from the cap spills over to the flanks as seen in the camera-video survey. Sediment commonly shows ripple marks and sand waves, attesting to vigorous current activity (Fig. 7-2 and 7-6). In places, manganese nodules line the troughs of the sand ripples (Fig. 7-6). Several densely-packed nodule fields were photographed (Fig. 7-4). A rough estimate from 900 bottom photographs, each displaying 2 to 3 m of seafloor on a side (Fig. 7), indicates that 50 percent of the upper flanks of the guyot (between 1770 m and 2800 m water depth) are sediment covered. All hard-substrates photographed were covered with ferromanganese crusts. Photographs show ubiquitous organisms living both on hard and soft substrates, including their tracks and trails (Fig. 7-5).

Two current meters were placed 10 and 180 m above the sea floor on a single mooring. The 10-m current meter flooded and no data were obtained. The 180-m current meter returned excellent data and showed variable-current speeds and directions with a maximum velocity of 30 cm/sec (Fig. 8 and appendix 5).

One set of CTD and oxygen profiles was taken over the guyot and one set in deep water to the south of the guyot. Both sets showed similar patterns (Fig. 9-1 through 9-10). The oxygen-minimum zone begins at about 500 to 600-m water depth.

Recovered rocks are mainly ferromanganese-encrusted volcanic breccia and hyaloclastite with minor basalt cobbles (Table 10). Some basalts contain abundant vesicles indicating eruption of volatile-rich magma in shallow water. One basalt cobble encloses several shallow-water limestone pebbles attesting to contemporaneous volcanism and reef growth. The chemistry of substrate rocks varies with lithology and with degree of impregnation by phosphorite and calcite (Table 13-6). Likewise, the substrate mineralogy reflects the lithology, amount of cementation, and degree of alteration of the volcanic clasts (Table 12).

Again, vernadite is the dominant (87 to 100 percent) mineral present in all crusts (Table 11). Minor quartz, plagioclase, calcite, and phosphorite (up to 12 percent) also occur. Crust chemistry also varies, especially with water depth (Table 13-1 through 13-5). For crusts collected at water-depths shallower than 2500 m, Mn averages 25.98%, Fe 16.65%, Co 0.743%, Ni 0.400%, and Cu 0.096% (Table 13-3).

Crusts vary in thickness up to 50 mm and average 15 mm (Table 10). Forty percent of encrusted rocks recovered were broken from outcrop; forty percent were completely encrusted cobbles, ten percent were not encrusted, and ten percent were ferromanganese nodules. Crust surfaces varied from smooth to knobby and botryoidal. Thicker crusts contained two distinct layers separated by a paper-thin layer of phosphorite. In polished sections crusts are laminated. Foraminifers occur throughout the crusts.

Density, porosity, and other physical properties were measured as discussed in the Necker Ridge section and are listed in Tables 14 and 15 for substrates and crusts, respectively.

JOHNSTON ISLAND

Seismic line 18 traversed part of the east flank of Johnston Island (Figs. 10 and 11). Only one dredge from 1400-m water depth was attempted, which recovered a calcite and smectite-cemented volcanic-breccia cobble (Fig. 10 and Table 16). Most volcanic clasts are highly altered to clay minerals, zeolites, and calcite but a few, relatively fresh, porphyritic clasts also occur (Table 17). A thin (less than 1 mm) crust of vernadite coats one surface (Table 17).

Figure 5. Sampling stations and camera and seismic-reflection profiles on Horizon Guyot. Deep Sea Drilling Project Sites 44 and 171 are indicated. Areas marked with A are the thickest sediment section detected by Lonsdale et al. (1972). Contour interval is 200 fathoms (Chase and Menard, 1973).

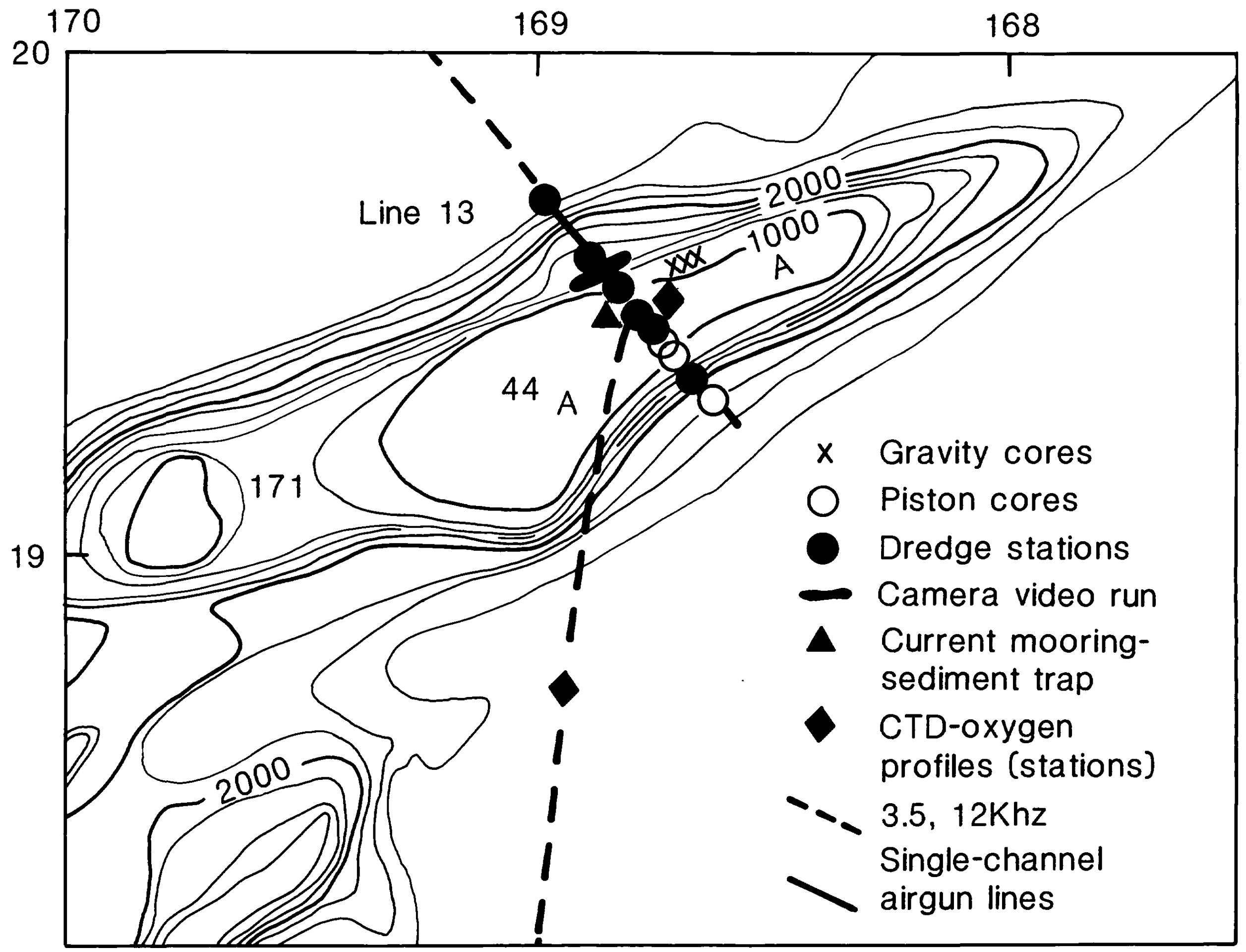
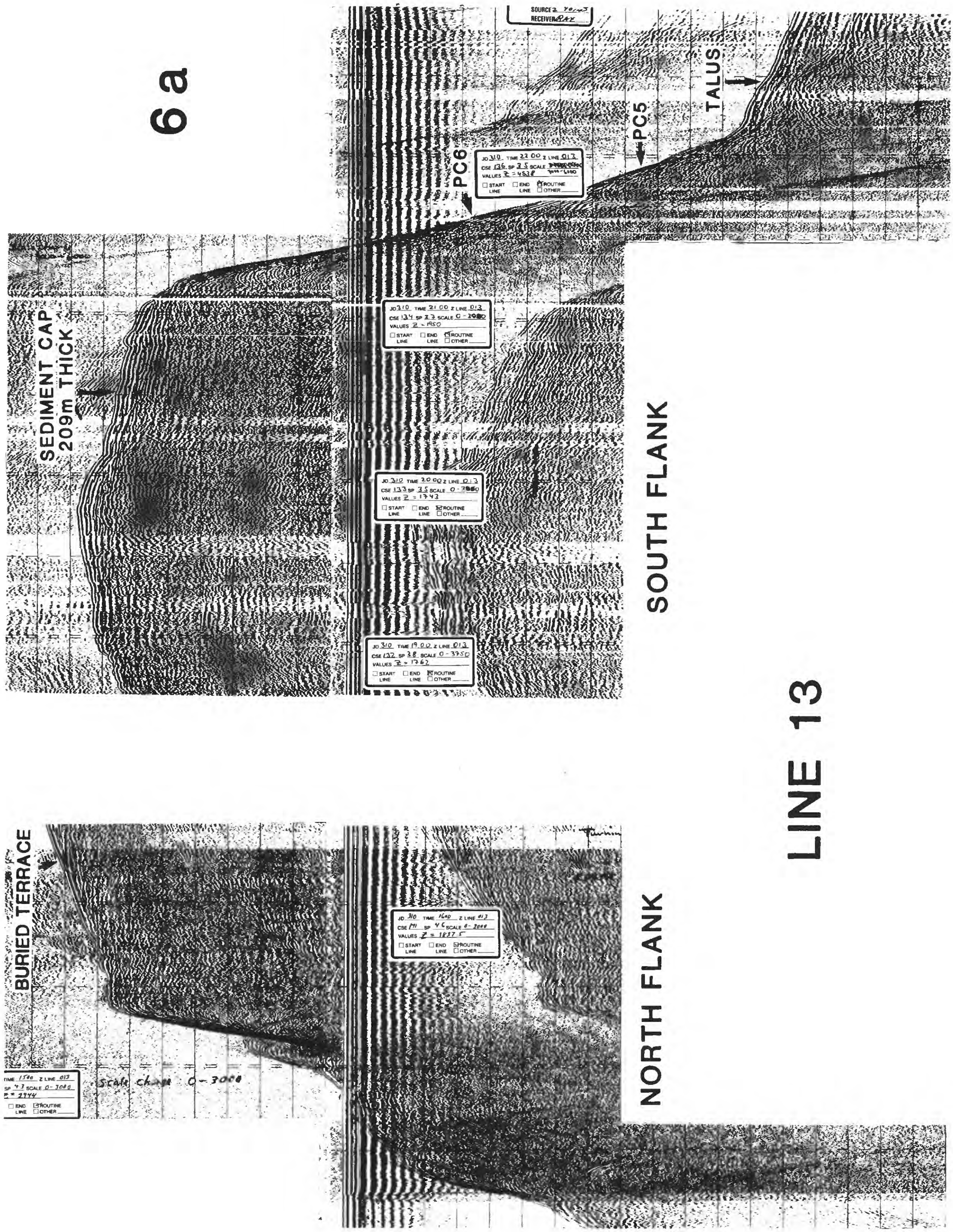

170
169
168
20
19
Line 13
2000
1000
A
44
A
171
2000
x Gravity cores
Piston cores
Dredge stations
Camera video run
Current mooring-
sediment trap
CTD-oxygen
profiles (stations)
3.5, 12Khz
Single-channel
airgun lines

Figure 6. Single-channel, 80 cubic-inch airgun seismic profiles of Horizon Guyot (Lines 13 and 14). A thick sediment cap buries a series of terraces. The lower south flank is drapped with talus. Location of piston cores 5 and 6 are shown. The distance between each horizontal rule represents 150-m water depth.


6a
LINE 13
SEDIMENT CAP
209m THICK
BURIED TERRACE
PC6
PC5
TALUS
SOUTH FLANK
NORTH FLANK

6 b

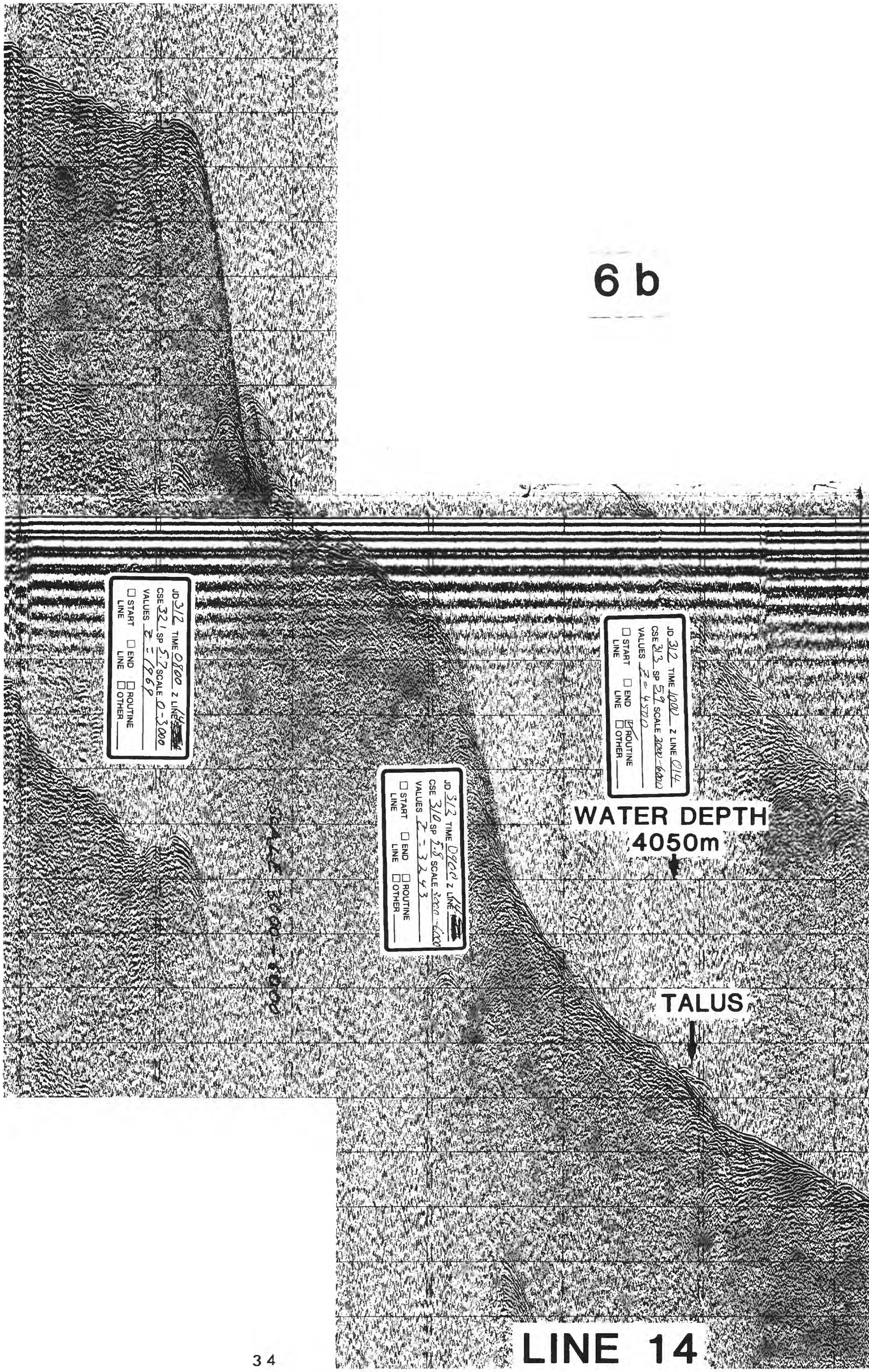
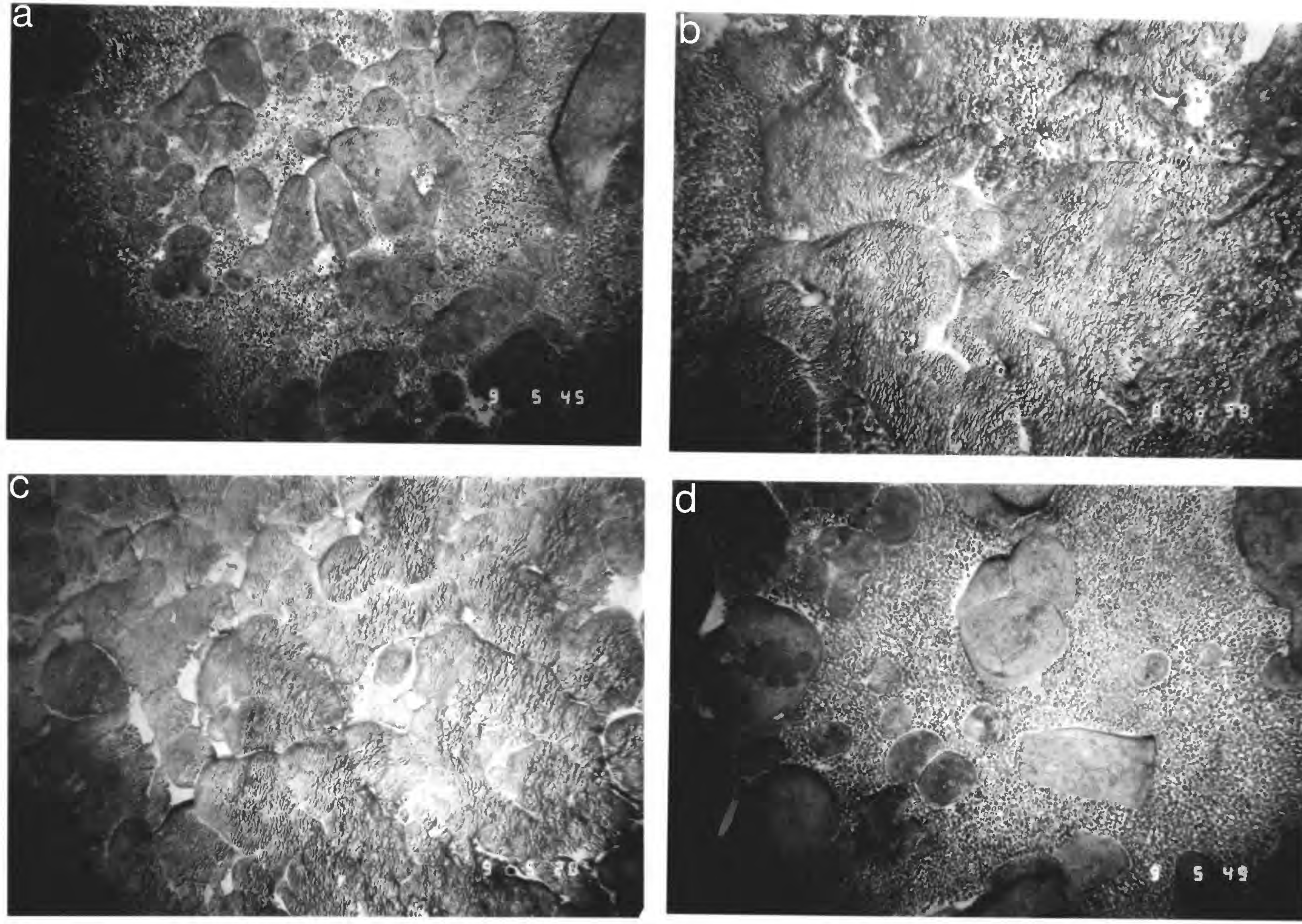


Figure 7. Bottom photographs of Horizon Guyot (7-1 through 7-6). Field of view varies between 2 and 3 m on a side, depth of water between 1770 and 2800 m. All depths given below are plus or minus 10 meters.

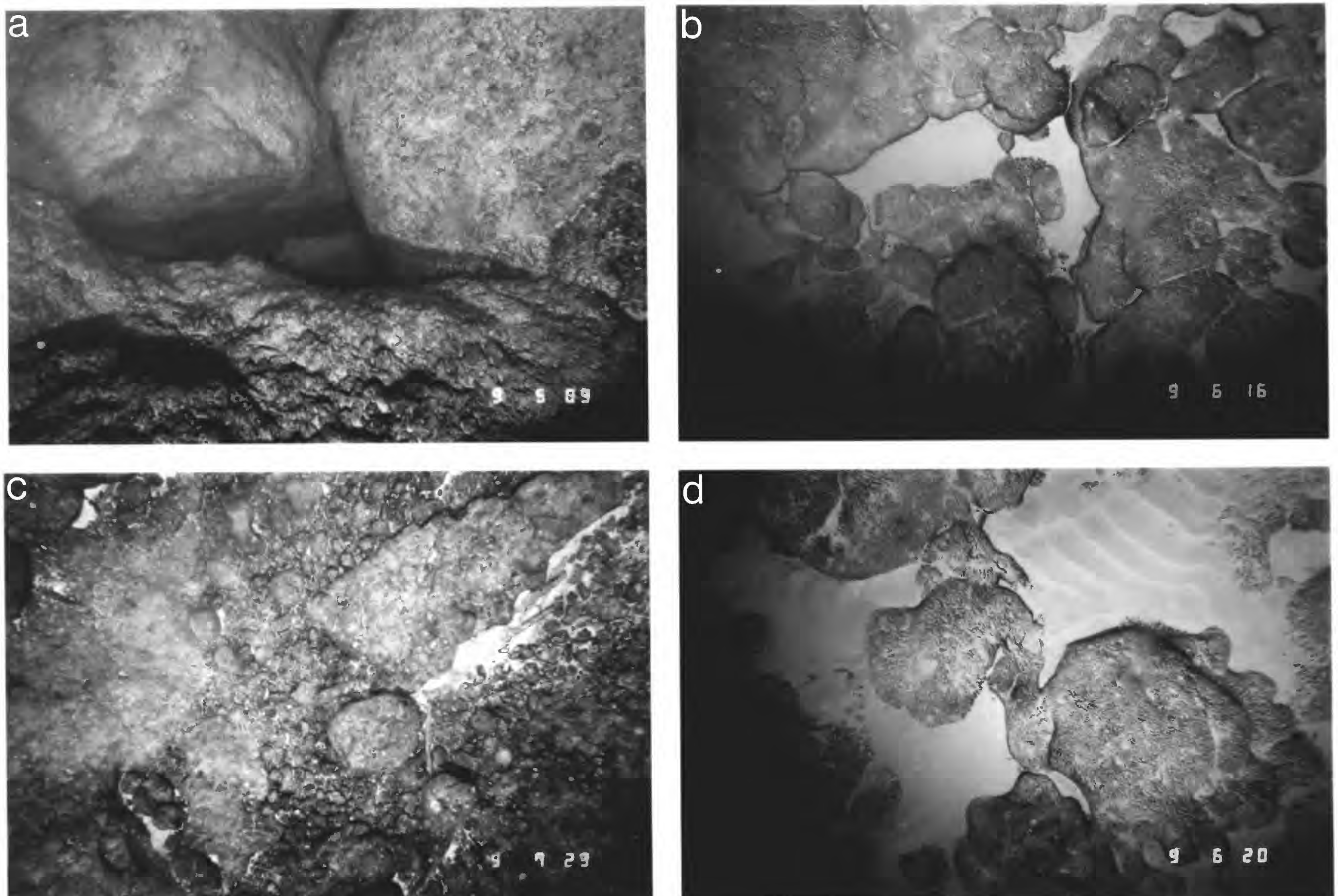
7-1. Seafloor completely covered with ferromanganese crusts (b,c), or seafloor covered with encrusted cobbles surrounded by nodules a, d (encrusted pebbles). Water depths are 1973, 1997, 1989, and 1965 meters respectively for a, b, c, and d.

35



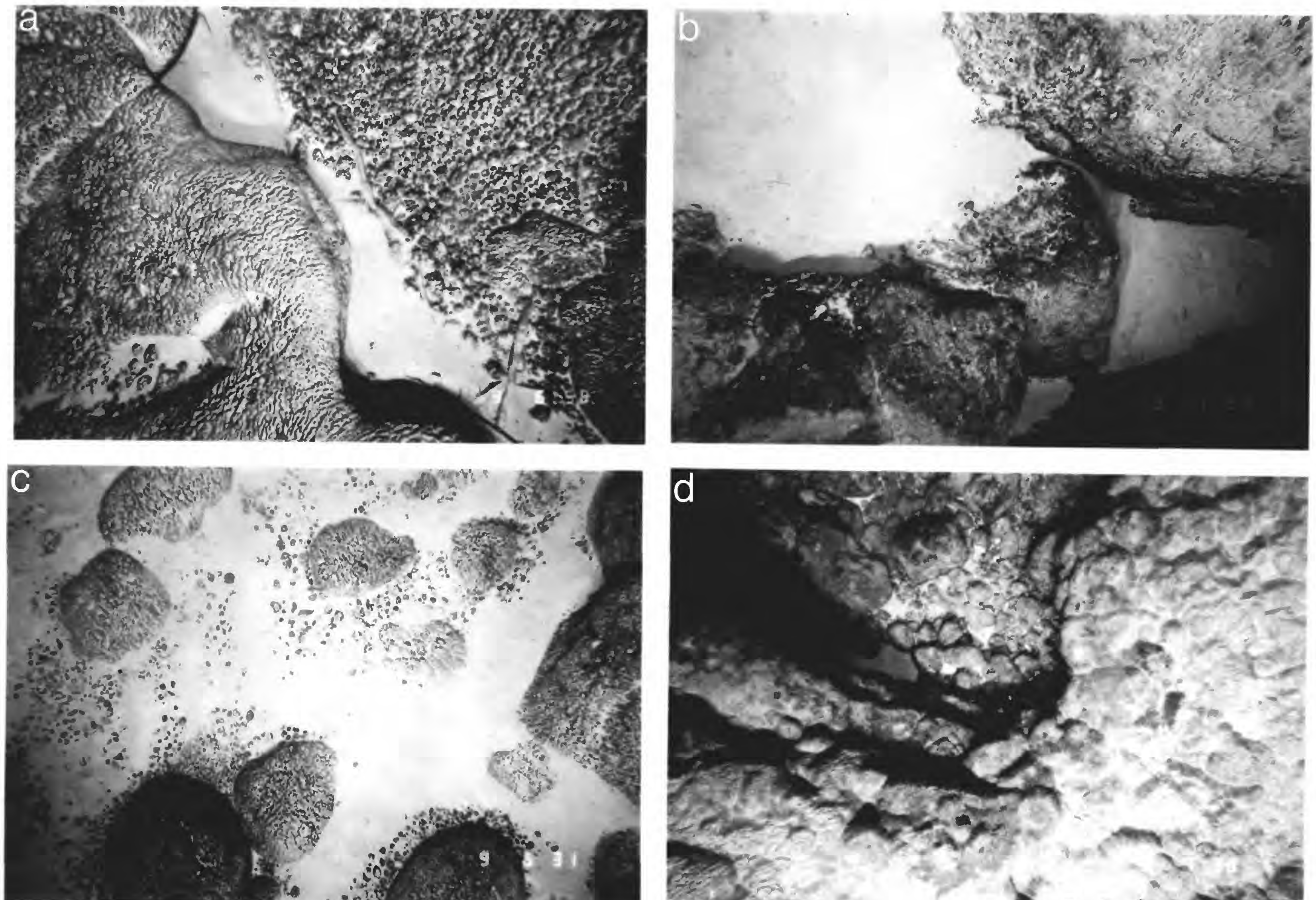
7-1

7-2. Rock outcrops encrusted with ferromanganese. Note both botryoidal and smooth surface textures. Water depths are 1973, 1965, 2552, and 1965 meters respectively for a, b, c, and d.



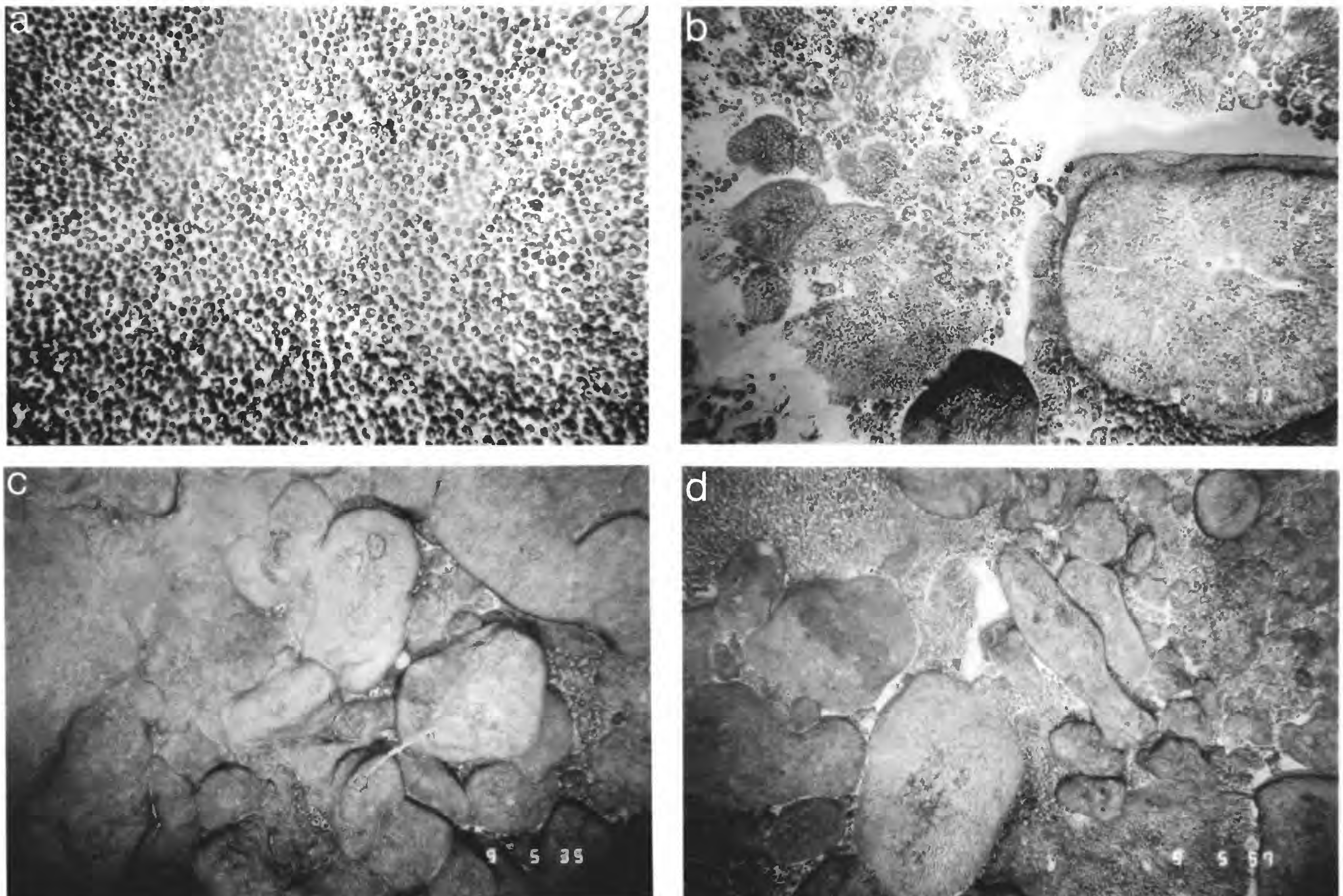
7-2

7-3. Ferromanganese encrusted outcrops surrounded by varying amounts of calcareous ooze. Note siphons of infauna in (a). Water depths are 1997, 1973, 1973, and 2486 meters respectively for a, b, c, and d.



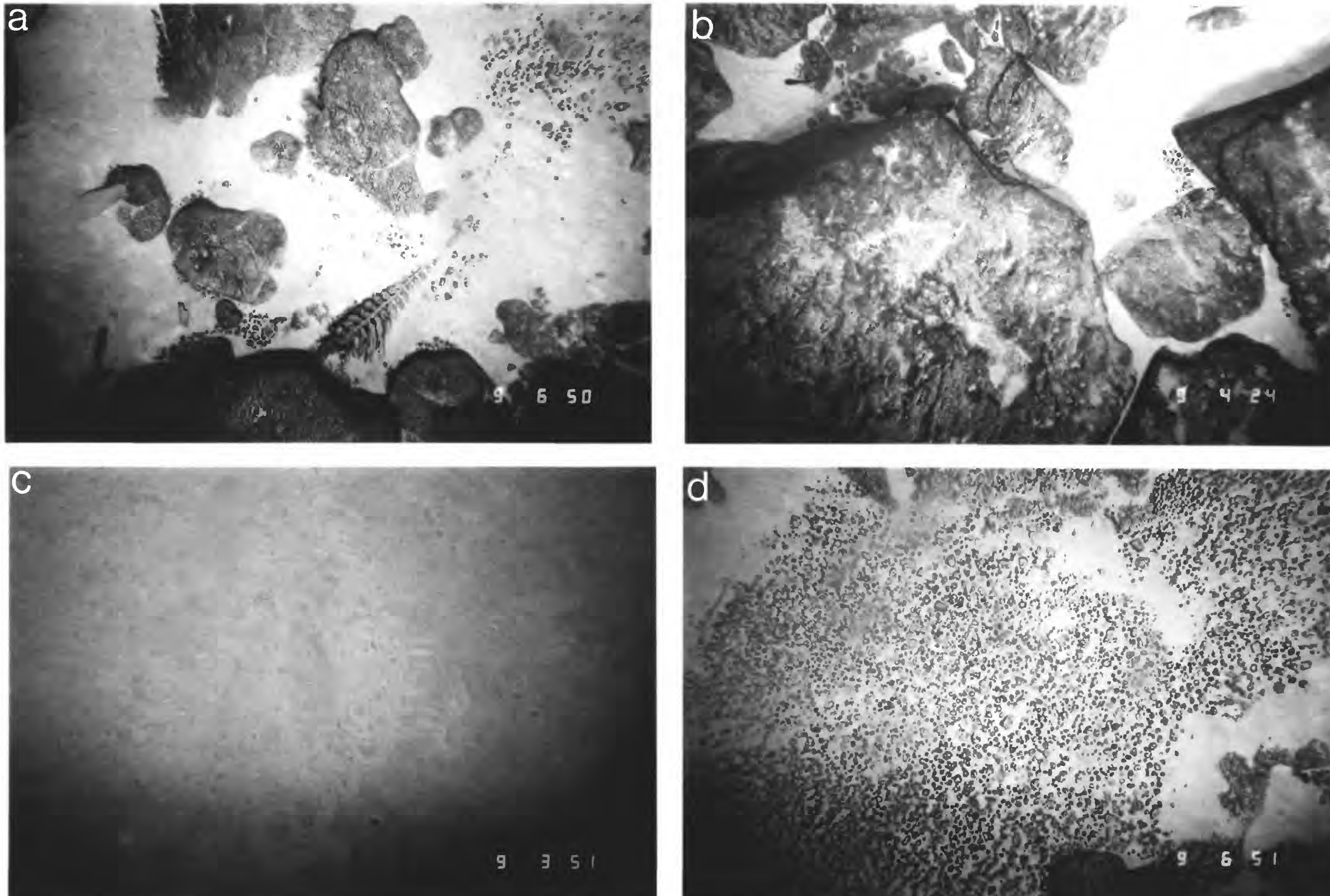
7-3

7-4. (a) nodule field, (b, c, d) rock outcrops encrusted with ferromanganese and surrounded by varying amounts of calcerous ooze. Crevices are floored with encrusted pebbles. Water depths are 1997, 1973, 1975, and 1970 meters respectively for a, b, c, and d.



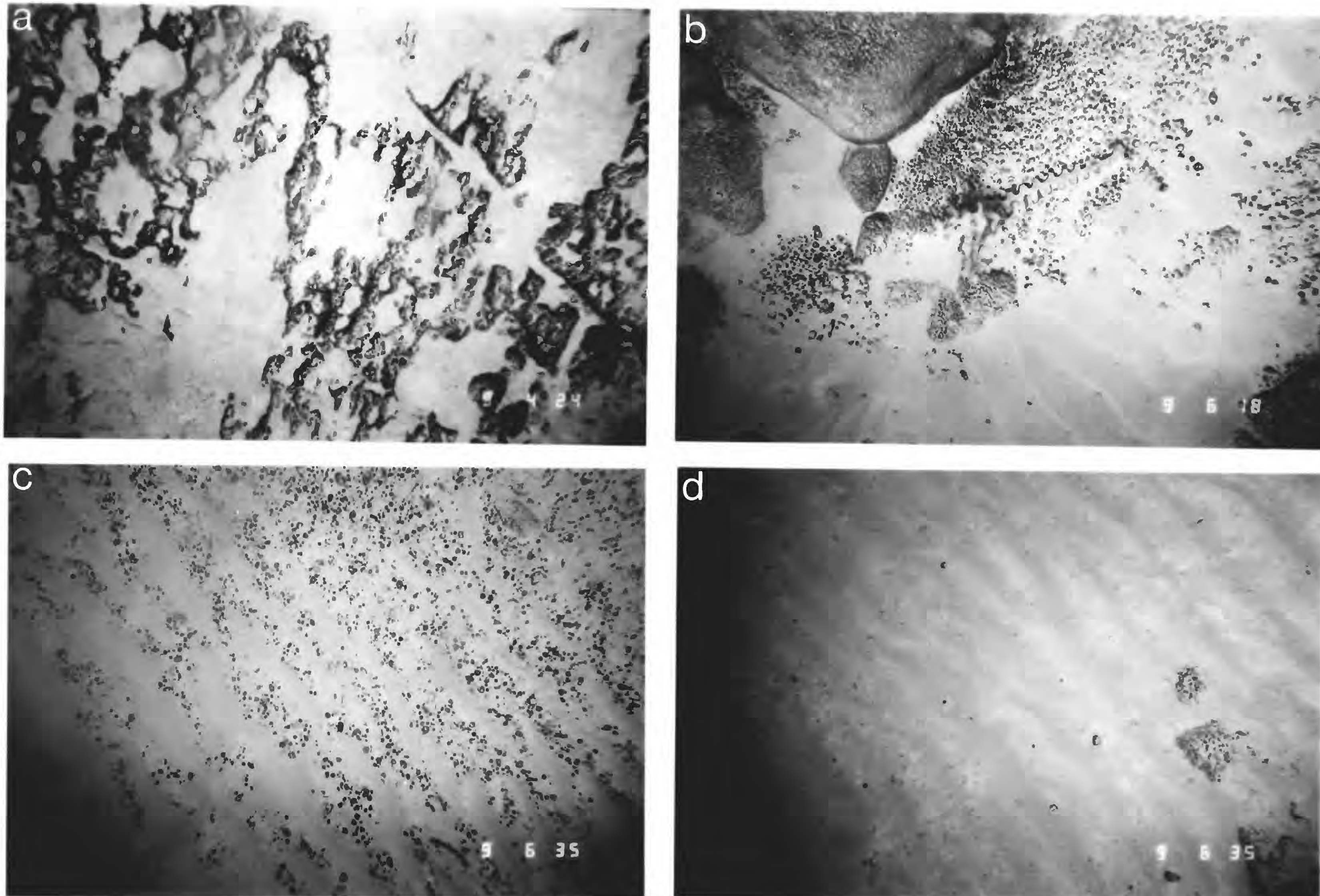
7-4

7-5. (a,b) ferromanganese encrusted cobbles and boulders.
(c) sediment covered sea floor showing trails of epifauna.
(d) nodule field (encrusted pebbles). Water depths are 2136, 2144, 2682, and 2138 meters respectively for a, b, c, and d.



7–5

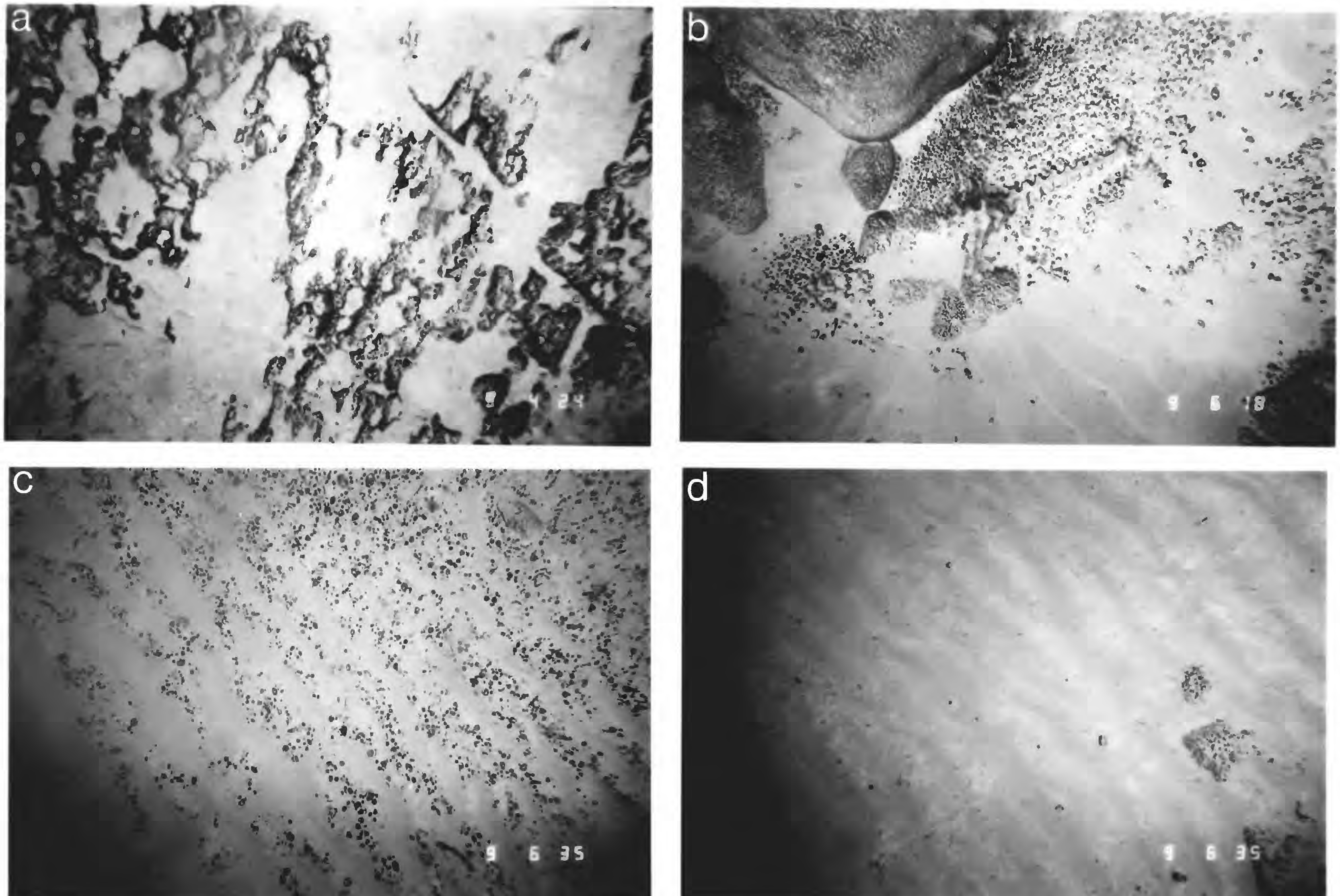
7-6. Mostly sediment covered sea floor showing ripple marks. In (c), nodules are aligned along troughs of sand ripples. Water depths are 2144, 1965, 1975, and 1975 meters respectively for a, b, c, and d.



7-6

Figure 8. Ten month current meter and temperature record for a site 180 m above the summit of Horizon Guyot (see Fig. 5 for location). The north-south and east-west components are in cm/sec. The maximum current velocity is 30 cm/sec (see also appendix 4).

3981



7-6

Figure 8. Ten month current meter and temperature record for a site 180 m above the summit of Horizon Guyot (see Fig. 5 for location). The north-south and east-west components are in cm/sec. The maximum current velocity is 30 cm/sec (see also appendix 4).

3981

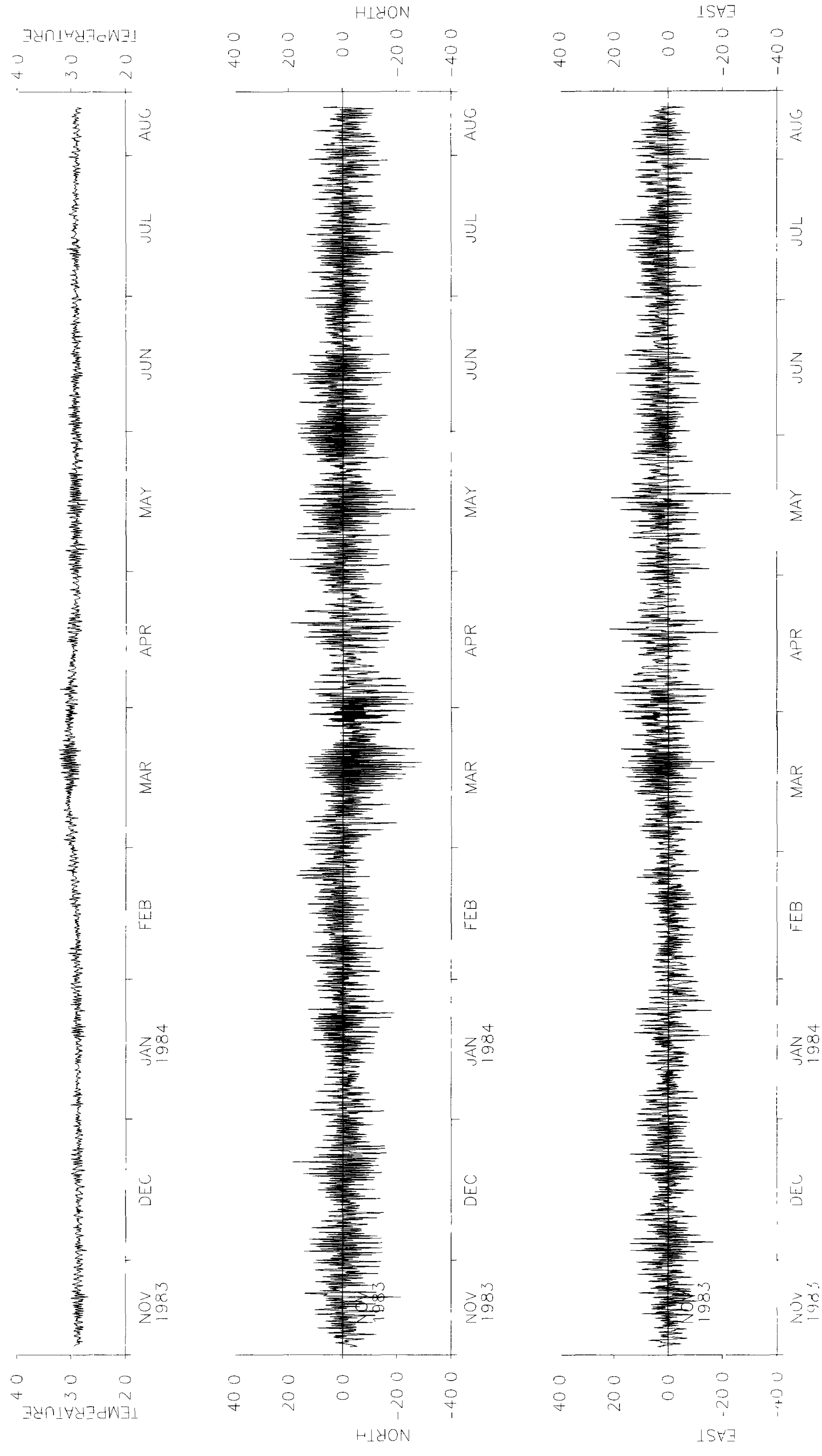
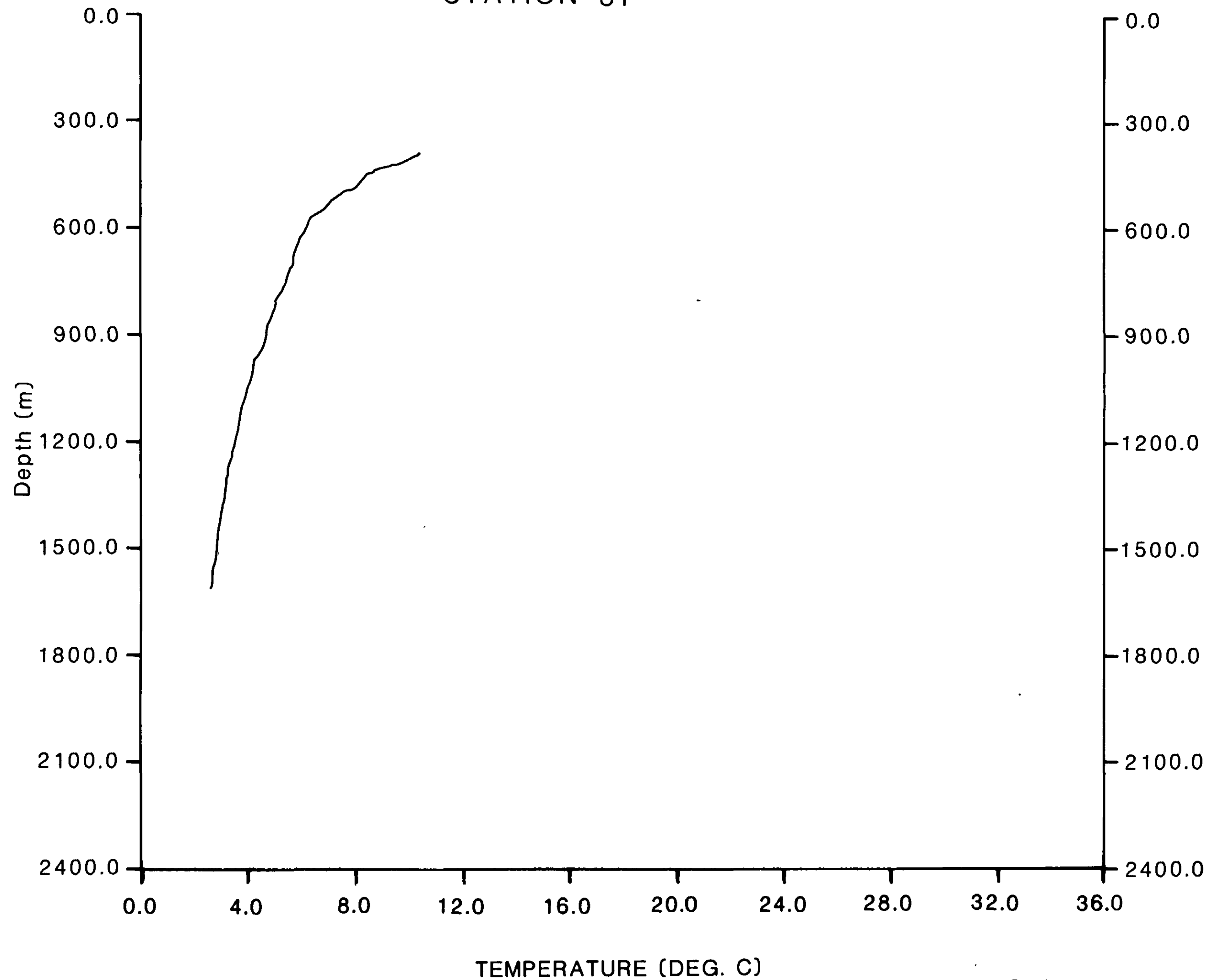

TEMPERATURE
NORTH
EAST
NOV 1983
DEC
JAN 1984
FEB
MAR
APR
MAY
JUN
JUL
AUG
40.0
20.0
0.0
-20.0
-40.0
4.0
3.0
2.0

Figure 9. Water column data for two Horizon Guyot stations, 31 which is on top of the guyot and 33 located to the south of the guyot (see Figure 5 for locations). 9-1 through 9-5 are respec-tively temperature, conductivity, salinity, Sigma-T, and oxygen for station 31; 9-6 through 9-10 are the same parameters for station 33.

L5-83-HW HORIZON GUYOT

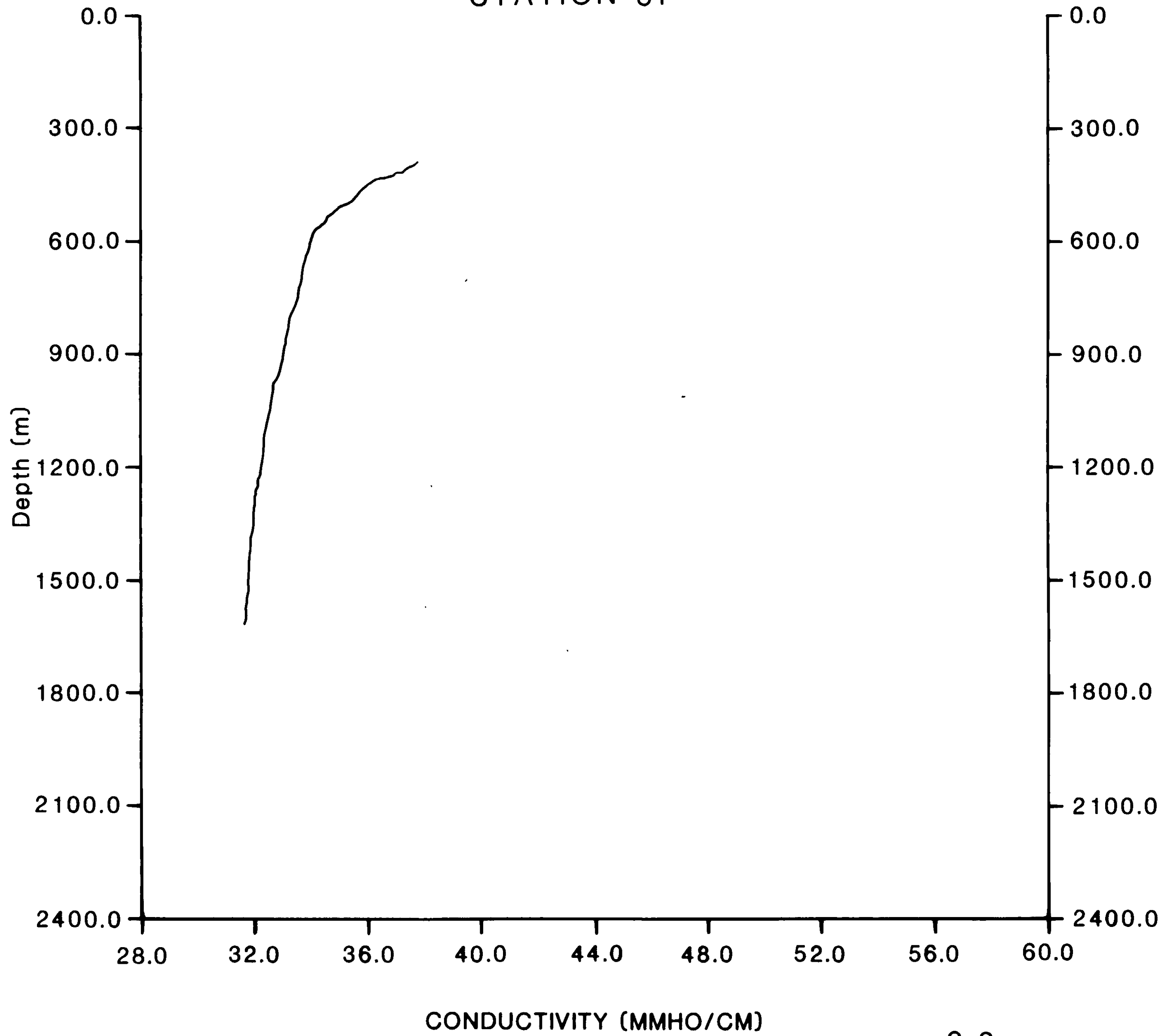
STATION 31



9-1

L5-83-HW HORIZON GUYOT

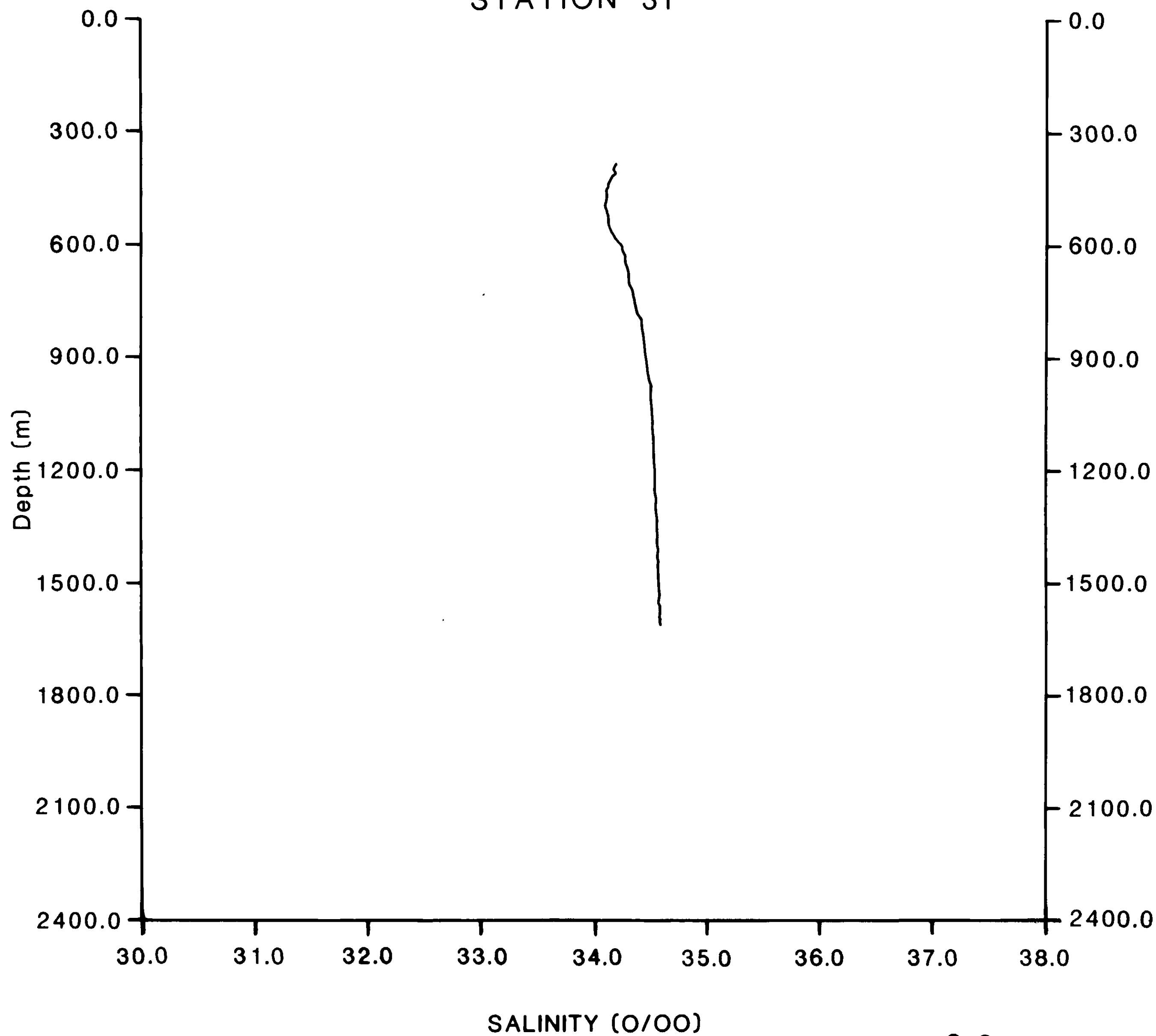
STATION 31



9-2

L5-83-HW HORIZON GUYOT

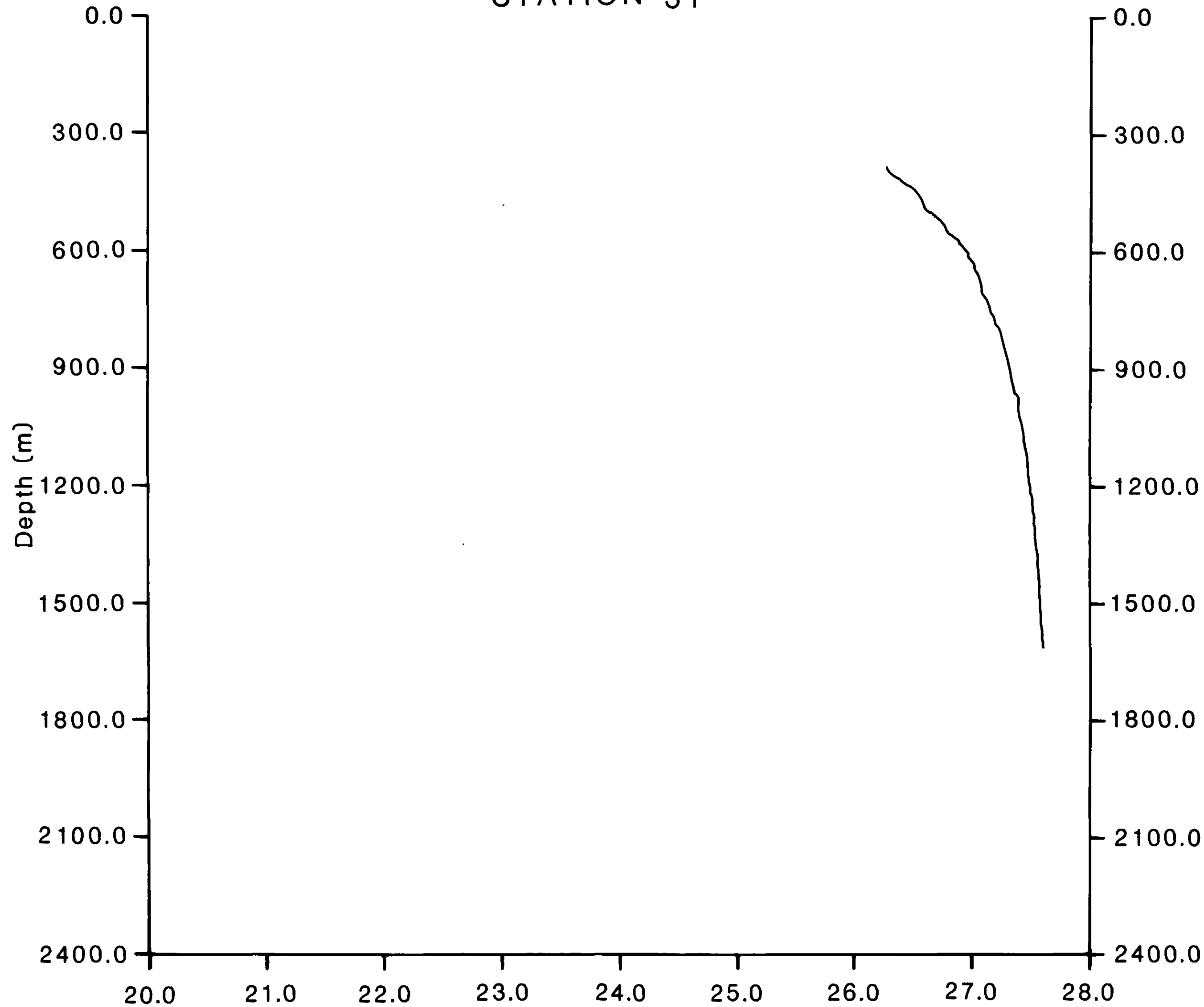
STATION 31



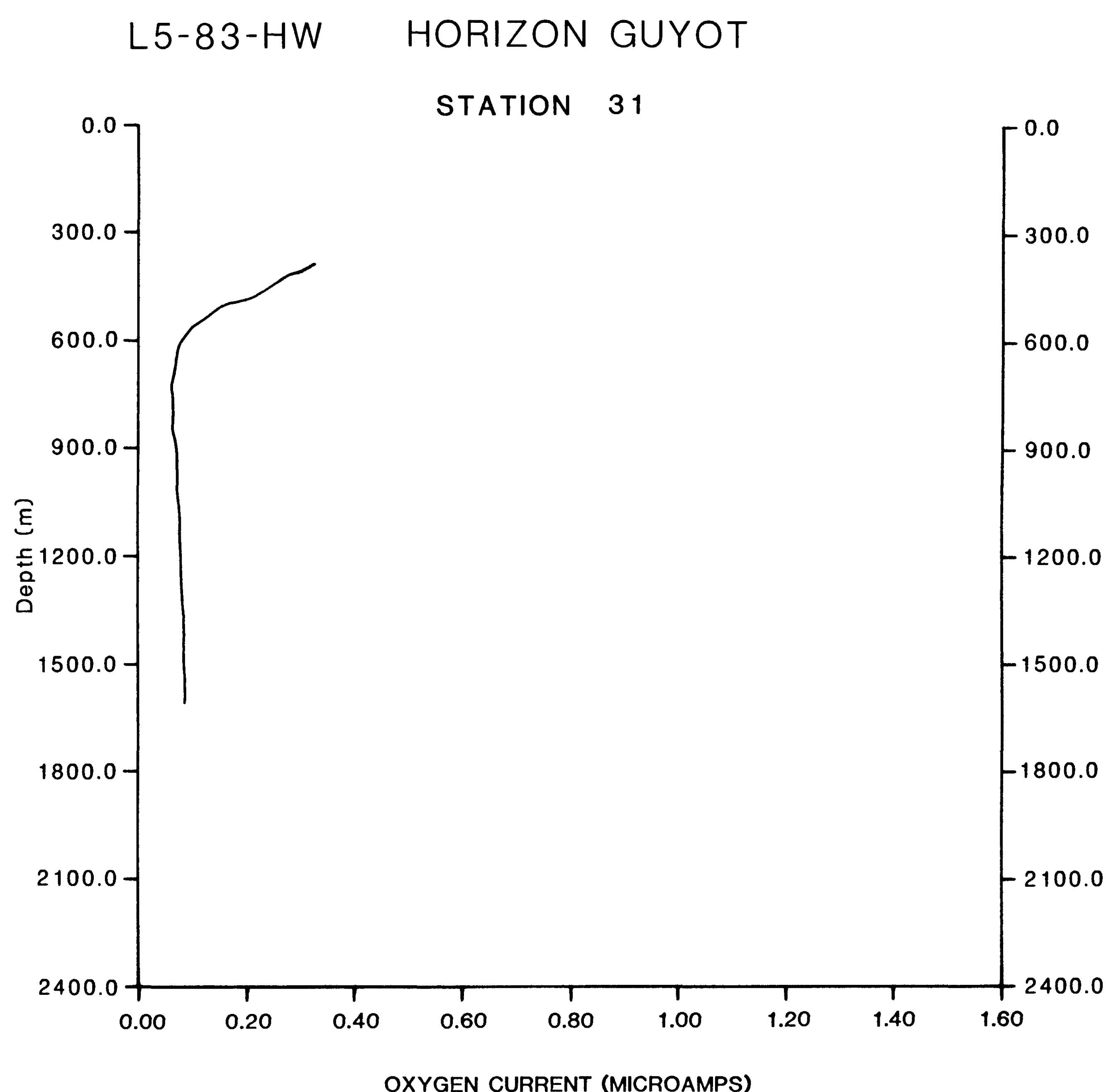
9-3

L5-83-HW HORIZON GUYOT

STATION 31



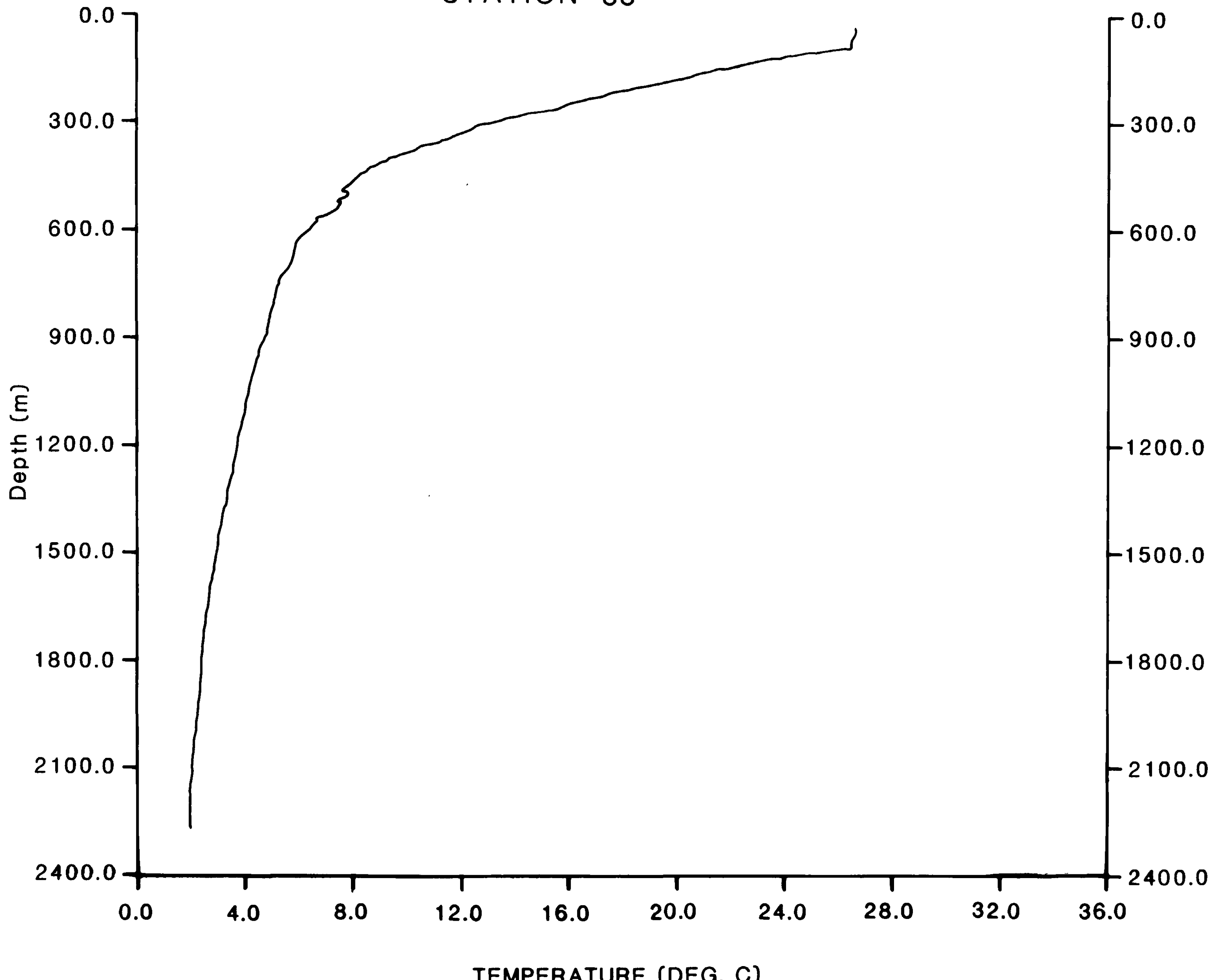
9-4


L5-83-HW HORIZON GUYOT
STATION 31
Depth (m)
0.0
300.0
600.0
900.0
1200.0
1500.0
1800.0
2100.0
2400.0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
OXYGEN CURRENT (MICROAMPS)

9-5

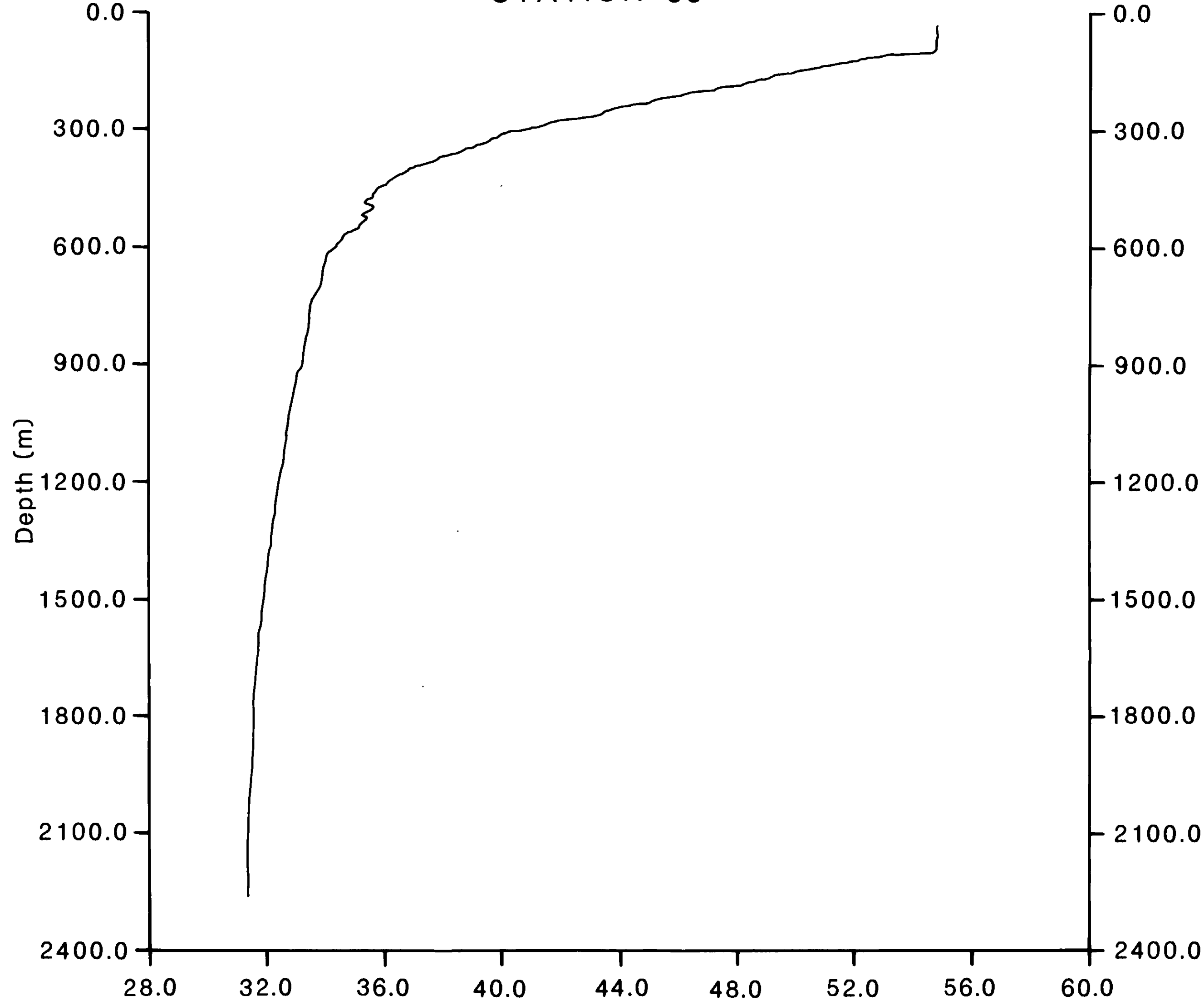
L5-83-HW HORIZON GUYOT

STATION 33

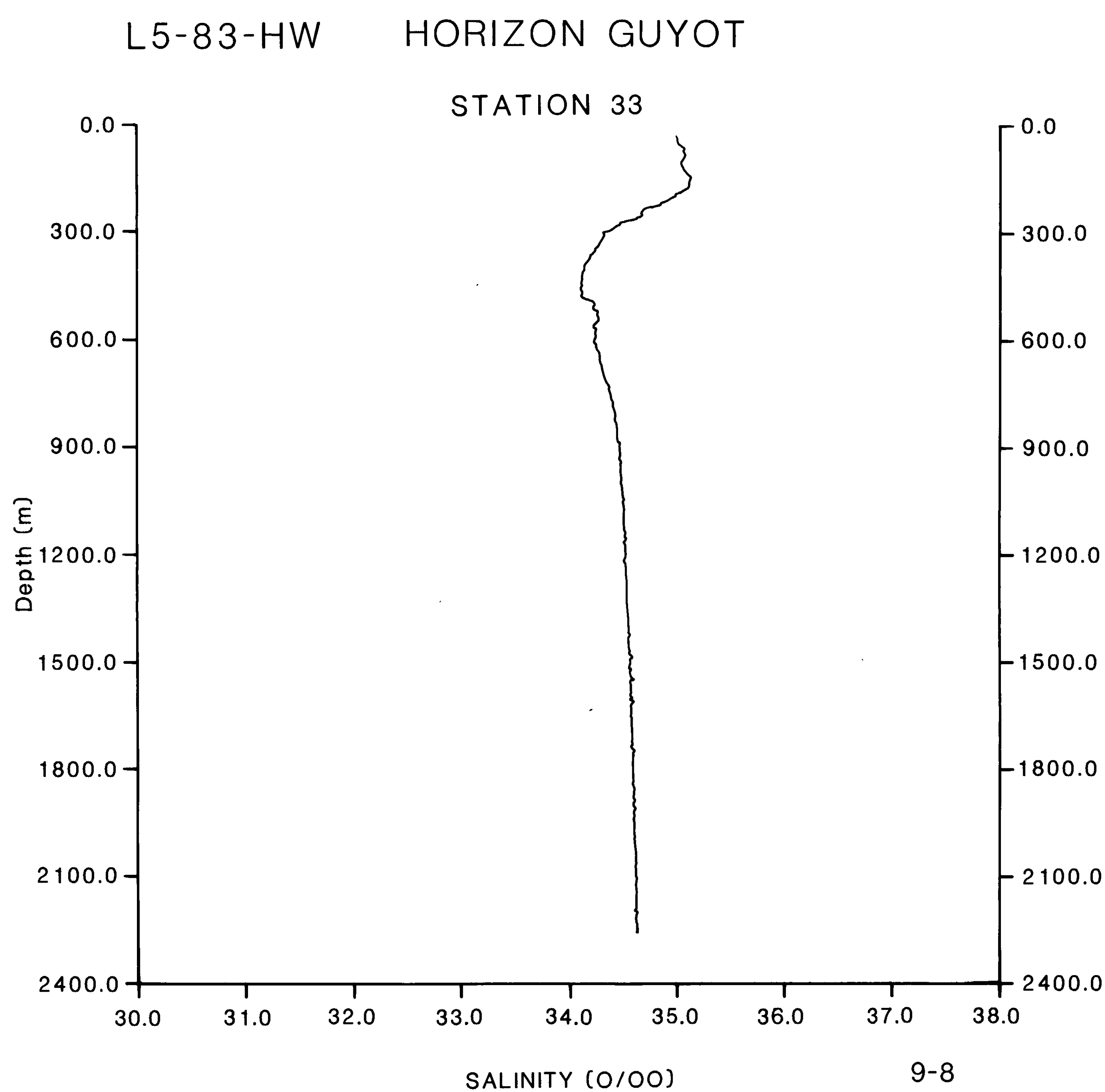


L5-83-HW HORIZON GUYOT

STATION 33

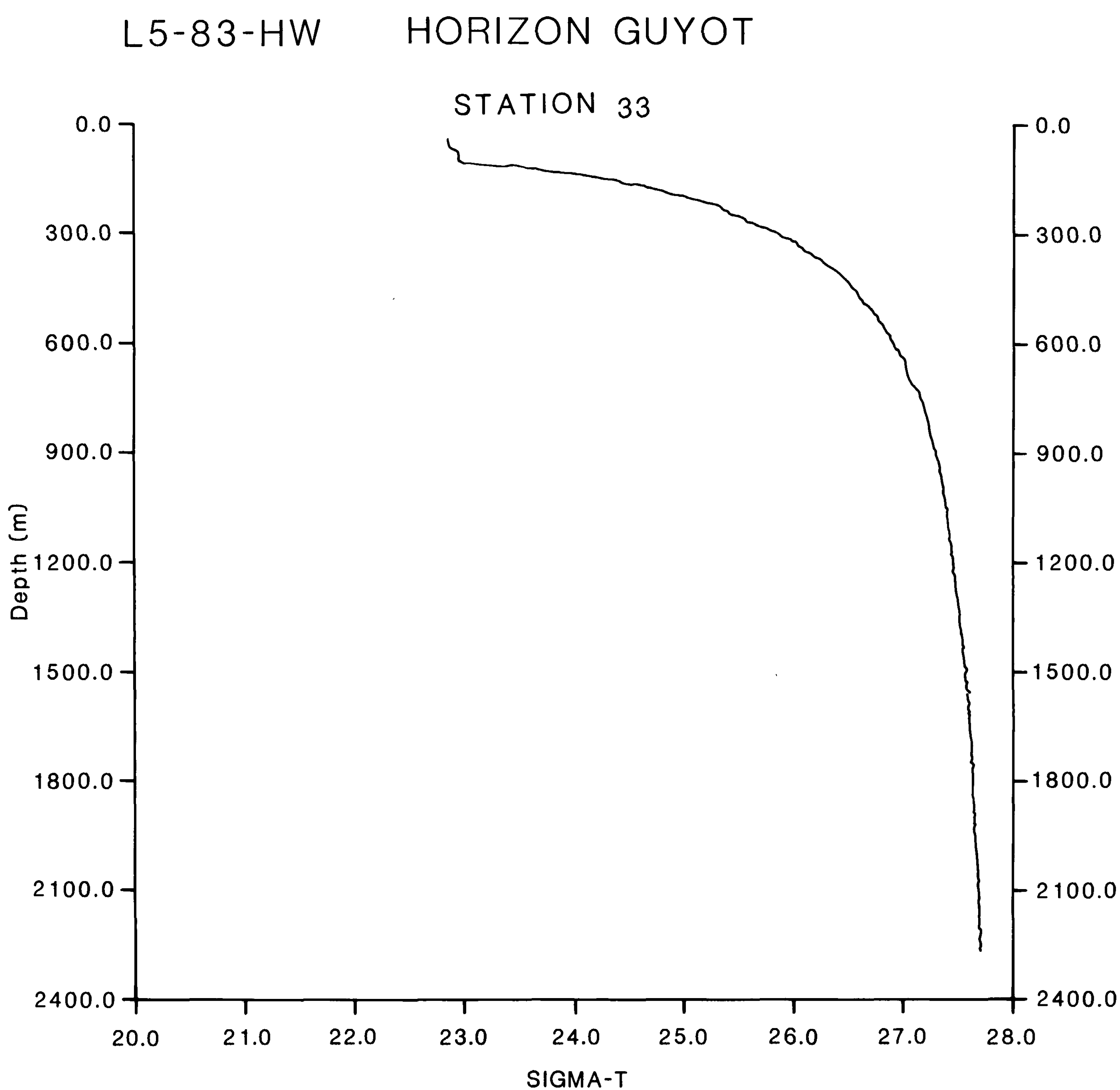


9-7



L5-83-HW HORIZON GUYOT
STATION 33
Depth (m)
0.0
300.0
600.0
900.0
1200.0
1500.0
1800.0
2100.0
2400.0
30.0
31.0
32.0
33.0
34.0
35.0
36.0
37.0
38.0
SALINITY (O/OO)

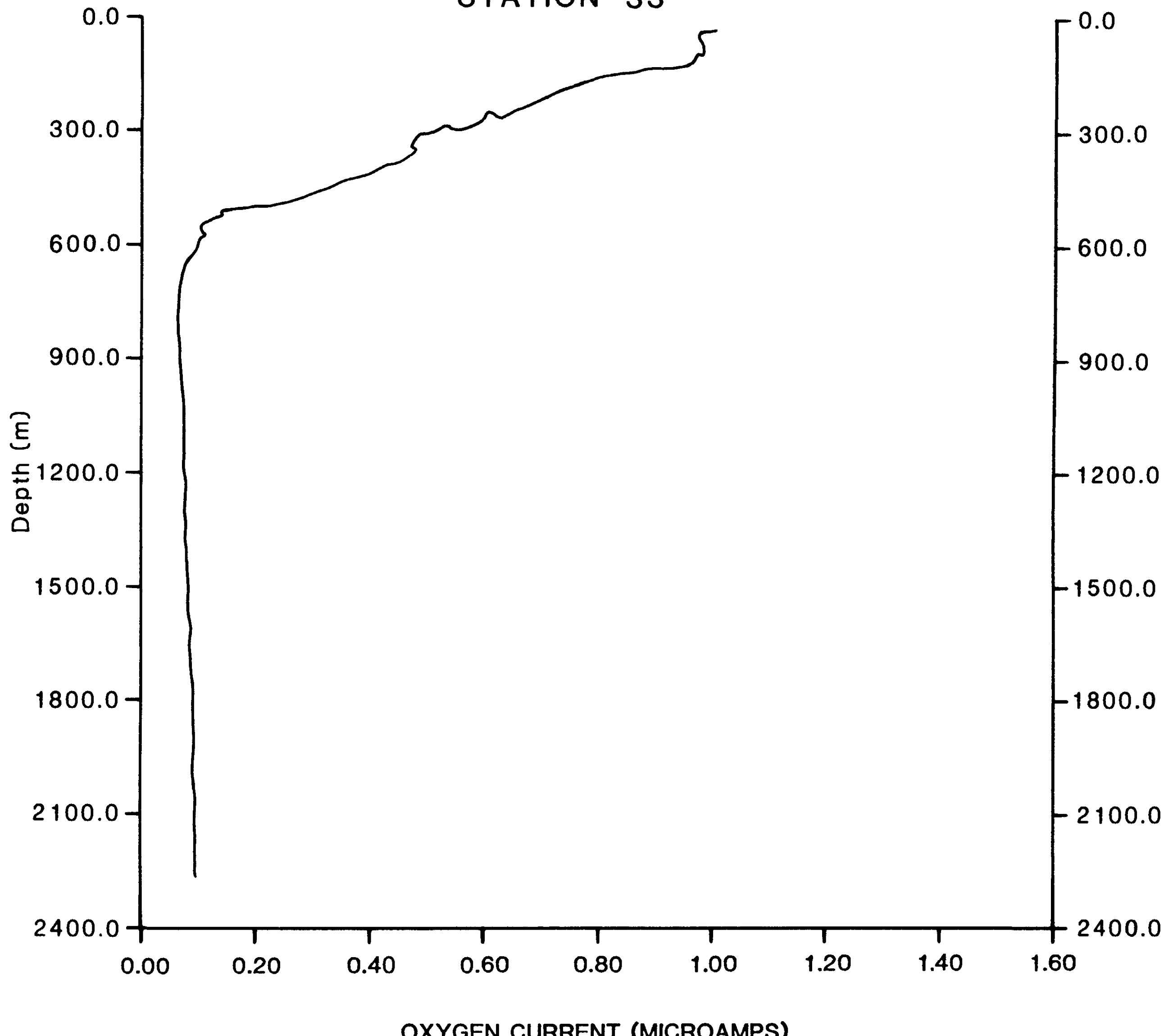
9-8


L5-83-HW HORIZON GUYOT
STATION 33
Depth (m)
0.0
300.0
600.0
900.0
1200.0
1500.0
1800.0
2100.0
2400.0
20.0
21.0
22.0
23.0
24.0
25.0
26.0
27.0
28.0
SIGMA-T

9-9

L5-83-HW HORIZON GUYOT

STATION 33



9-10

Figure 10. Sampling station and seismic-reflection line on Johnston Island. Contour interval is 200 fathoms (Chase and Menard, 1973).

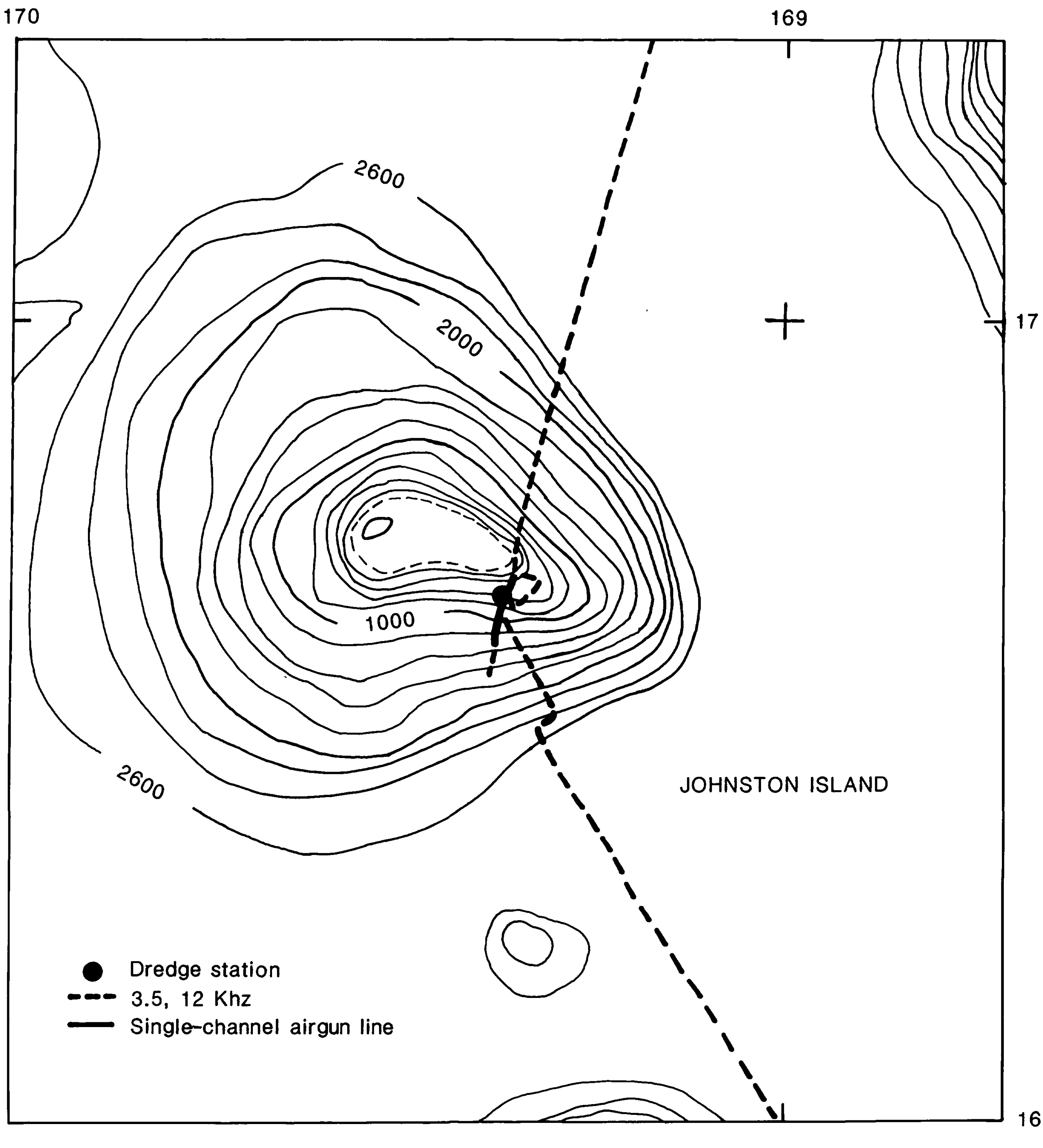

170
169
17
16
2600
2000
1000
2600
JOHNSTON ISLAND
Dredge station
3.5, 12 Khz
Single-channel airgun line

Figure 11. Single-channel, 80 cubic-inch airgun seismic profile of Johnston Island (Line 18). See Figure 10 for location of this line. The distance between each horizontal rule represents 150-m water depth.

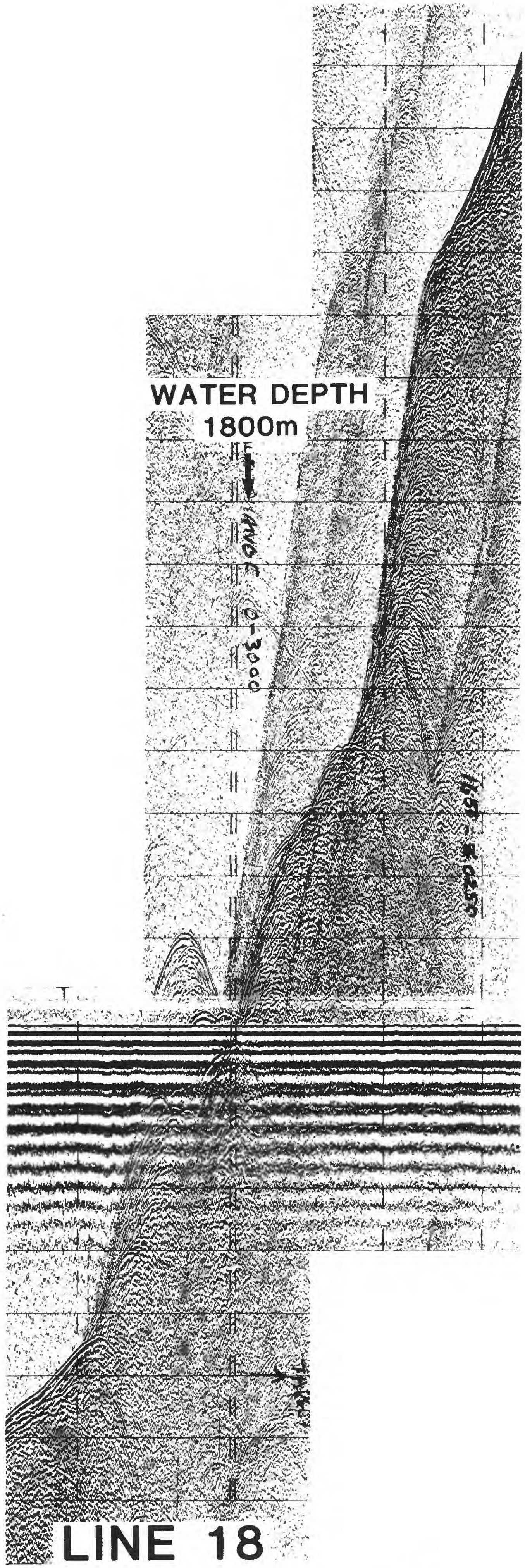

WATER DEPTH
1800m
LINE 18

Table 10. Location and description of samples from Horizon Guyot, Cruise L5-83-HW.

Sample No.[1]	Latitude (N)	Longitude (W)	Water Depth (m)	approximate Sample wt. (kg)	Crust Description	Substrate Description
15-PC5	19°19.09'	168°39.09'	4411	--	Paper thin coatings on some basalt pebbles.	0-5 cm highly vesicular, altered basalt pebbles, some hyaloclastite; 5-23 cm brownish-green silty volcaniclastic mud; 23-28 cm moderately vesicular altered basalt pebbles, some dusted with manganese; 28-40 cm, volcaniclastic silty mudstone; 40-50 cm highly vesicular altered basalt pebbles.
16-PC6	19°20.82'	168°39.5'	3622	--	Dusting of Mn-oxides on some basalt pebbles.	Gravel of highly vesicular basalt scattered through 40 cm of gray-green Foraminifera-rich nannofossil ooze.
17-PC7	19°20.25'	168°42.30'	2450	--	None	Pebbles of very highly altered basalt and volcanic breccia, with calcite and zeolite crystals in vugs and fractures. Fragments of marl.
18-D11	19°20.10' 19°21.48'	168°39.90' 168°41.87'	3791- 3700	7	75% partly coated rocks, 25% rocks without crusts. Crusts are mostly knobby to botryoidal, some with secondary smoothing of the botryoids (not due to dredging). Thicknesses are 2-4 mm, average 3 mm.	Yellow-green hyaloclastite with red-brown, angular, highly altered basalt and palagonite clasts; minor basalt cobbles are dark-gray, massive to sparsely vesicular, sparsely olivine and plagioclase phyric (pseudomorphed).
19-D12	19°22.14'	168°41.69'	2000	45	80% partly coated rocks, 20% rocks without crusts. Crusts mostly smooth or granular and porous, some with subdued botryoids. Thicknesses to 4 mm, average 3 mm.	Breccia and conglomerate composed of angular to subrounded basalt pebbles and cobbles; and loose basalt cobbles; basalt ranges from aphyric to sparsely olivine-plagioclase phyric, and from sparsely vesicular to amygdaloidal; amygdules to 3 cm are filled with coarse-grained calcite and zeolites. One basalt incorporates shallow-water limestone clasts.
20-D13	19°23.70'	168°43.08'	1850	--	None	Nannofossil-rich foraminiferal sand.
21-D14	19°30.19'	168°46.67'	1750-1800	55	50% partly, 50% completely coated with crusts. Surfaces mostly smooth and porous (90%), others irregular. Erosion and renewed growth of black oxides 1-50 mm, average 20 mm in thickness.	Reddish to yellow brown breccia with angular basalt clasts; angular basalt cobbles that are massive and aphyric; minor pale brown siltstone; foraminiferal sand.
22-D15	19°41.64' 19°40.54'	168°59.67' 168°59.02'	4500- 4300	1.5	3 pancake nodules; one laminated nodule is smooth and porous on the thin (6 mm) nodule bottom and botryoidal and porous on the thick (18 mm) upper crust surface, whereas the other nodules are just the opposite. Nodule rims are smooth. Thicknesses from 1-18 mm, average 8 mm.	Silty mudstone composed of altered glassy volcanic debris from nodule nuclei.
24-D17	19°33.20'	168°49.94'	2400	7	65% rocks partly coated, 35% completely coated. Crusts are botryoidal (reflect shape of clasts of the conglomerate) to smooth. Thicknesses 1-15 mm, average 10 mm.	Breccia and conglomerate with angular to well-rounded, highly altered, sparsely vesicular and sparsely olivine phyric basalt clasts.
25-D18	19°30.89' 19°29.69'	168°51.28' 168°51.91'	1799- 1780	180	10% partly, 90% completely encrusted, with subdued knobby to botryoidal crusts; some are smooth. Some have a porous outer layer (10 mm) and massive inner layer (25 mm). Thicknesses 2-40 mm, average 30 mm.	Breccia boulders and cobbles of angular basalt and pink-brown phosphorite clasts in white to pale brown calcareous matrix that has been replaced by phosphorite to varying degrees. Basalt clasts range from dark-gray massive aphyric to red-brown sparsely vesicular olivine (pseudomorphed) phyric.
28-GC2	19°28.16'	168°47.52'	1680	--	None	Nannofossil-rich foraminiferal sand.
29-GC3	19°26.14'	168°50.39'	1669	--	None	Nannofossil-rich foraminiferal sand.
30-GC4	19°25.57'	168°50.77'	1580	--	None	Nannofossil-rich foraminiferal sand.

[1]D, PC, GC in sample numbers represent dredge, hard-substrate corer, and gravity corer, respectively.

Table 11. Mineral content of ferromanganese crusts, Horizon Guyot, Cruise L5-83-HW.

Sample No.	Vernadite (%)	Plagioclase (%)	Quartz (%)	Apatite (%)	Others	Comments
D11-A4	100	0	0	0		Bulk
D12-A4	98	0	1	0	Calcite, Fe-hydroxide?	Bulk
D14-B2	98	1	1	0		Bulk
D15-B1	97	1	2	0		Bulk
D17-AX	97	1	1	1		Bulk
D18-A2	89			4	Todorokite (7%)	Mn matrix in conglomerate
D18-B3-1	87	0	1	12		inner crust
D18-B3-1	88	0	0	12		outer crust

Percentages were determined by using the following weighting factors relative to quartz set as 1 : vernadite 75, plagioclase 2.8, apatite 3.1, calcite 1.65. We determined the vernadite weighting factor by mixing known amounts of a pure vernadite crust and quartz; other weighting factors are from Cook et al. (1975). The limit of detection for each mineral falls between 0.5 and 1.0 percent.

Table 12. Mineral content of substrates associated with ferromanganese crusts, Horizon Guyot, Cruise L5-83-HW.

Sample No.	X-ray Mineralogy			Comments
	Major	Moderate	Minor or Trace	
D11-A6	Plagioclase Phillipsite	Smectite	Calcite?	Volcanic breccia
D12-A5	Calcite Phillipsite Plagioclase		Smectite	Matrix of volcanic breccia
D12-A7	Calcite		Phillipsite Plagioclase	Hyaloclastite, calcite cement
D18-A2	Plagioclase-labradorite	Pyroxene-diopside		Basalt clast in volcanic breccia
D18-A2	Goethite	Apatite	Quartz	Iron-rich clast from volcanic breccia

Table 13-1. Chemistry of ferromanganese crusts, Horizon Guyot, Cruise L5-83-HW. Hygroscopic water-free major oxides, weight percent, with sum. H_2O refers to chemically bound water determined by Penfield method. Sample type denotes sample chosen for analysis. Top generally refers to uppermost 5 mm of crust, or less. Total refers to entire thickness of crust. Bott. refers to crust between top 5 mm and substrate. Bott. F refers to black, friable and porous samples from underside of slabs. Analyses done by USGS-Reston.

SAMPLE	SiO_2	TiO_2	MnO_2	Al_2O_3	Fe_2O_3	Co_3O_4	Ni_3O_4	CuO	CaO	MgO	K_2O	Na_2O	P_2O_5	CO_2	H_2O+	Sum	Sample Type	Total Thickness (mm)
D11A-20	11.05	2.20	34.6	2.04	29.9	0.80	0.34	0.069	3.49	1.76	0.65	2.16	0.96	0.3	8.1	98.6	total	3
D12A-21	11.29	2.22	34.9	2.55	25.1	1.28	0.43	0.045	4.59	1.99	0.77	2.63	0.89	1.0	7.9	97.7	bott. F	3
D12A-22	9.92	1.80	36.2	1.85	26.4	1.00	0.44	0.051	5.21	1.71	0.67	2.36	0.99	1.6	8.5	98.9	total	4
D14A-23	11.60	1.95	37.7	1.85	28.0	1.06	0.45	0.071	3.68	1.74	0.69	2.39	0.89	0.4	7.3	99.9	top	10
D14A-24	2.17	1.68	51.6	0.42	17.1	1.03	0.76	0.211	7.78	1.84	0.67	2.29	2.45	0.7	7.9	98.8	bott.	10
D14A-25	7.27	1.92	44.1	1.32	21.9	1.24	0.65	0.140	6.03	1.81	0.72	2.34	1.74	0.7	7.4	99.3	total	20
D14A-26	13.07	1.98	39.2	1.85	27.1	1.24	0.54	0.068	3.65	1.77	0.74	2.24	0.78	0.4	7.7	102.5	top	10
D14A-27	2.99	1.95	50.2	0.51	20.7	1.03	0.63	0.089	6.99	1.77	0.64	2.37	1.97	0.7	8.5	101.2	bott.	20
D14A-28	7.98	2.00	43.4	1.44	23.7	1.14	0.66	0.080	4.54	1.79	0.71	2.36	0.94	0.5	7.5	98.9	total	30
D15B-29	18.53	2.74	27.1	4.95	28.5	0.42	0.55	0.354	2.80	2.14	0.96	2.24	0.71	0.3	7.2	99.6	top	9-18
D17A-30	10.11	2.02	37.3	1.98	27.6	1.04	0.49	0.118	3.61	1.77	0.70	2.35	1.01	0.3	7.9	98.6	total	10
D17B-31	13.13	2.12	33.7	3.02	23.0	0.73	0.49	0.278	3.60	1.82	0.77	2.22	0.89	0.5	8.8	95.2	total	10-15
D18-32	5.97	1.58	41.6	0.95	23.3	0.89	0.52	0.119	7.24	1.62	0.59	2.18	2.89	0.7	8.1	98.5	total	35
D18-33	4.70	1.58	42.8	0.79	21.3	0.88	0.57	0.274	8.74	1.62	0.60	2.19	3.51	0.8	7.1	97.6	top	15
D18-34	8.69	1.80	38.8	1.46	27.4	0.97	0.50	0.078	3.78	1.74	0.61	2.23	1.15	0.5	8.7	98.5	top	5
D18-35	3.45	1.43	44.6	0.60	19.4	0.85	0.59	0.153	8.58	1.62	0.59	2.11	0.89	0.8	8.3	94.2	bott.	10
D18-36	11.98	1.93	35.5	2.04	28.0	1.10	0.46	0.061	3.49	1.71	0.74	2.37	0.89	0.5	8.1	99.1	top	10
D18-37	2.79	1.50	46.0	0.70	20.9	0.68	0.54	0.085	8.30	1.59	0.59	1.97	3.02	0.8	8.4	98.1	bott.	15

Table 13-2. Chemistry of ferromanganese crusts, Horizon Guyot, Cruise L5-83-HW. Hygroscopic water-free major oxides, weight percent, with sum. *H_2O refers to chemically bound water computed by empirical relationship: $(Fe_2O_3 + MnO_2)/7$. Other is an empirical correction factor $(Fe_2O + MnO_2)/40$ to account for some minor constituents not included in table. For sample type and total thickness refer to Table 13-1. Analyses done by USGS-WH.

SAMPLE	SiO_2	TiO_2	MnO_2	Al_2O_3	Fe_2O_3	Co_3O_4	Ni_3O_4	CaO	MgO	K_2O	P_2O_5	H_2O-	H_2O+*	Other*	Sum
D12A-21	10.83	2.15	34.7	3.50	24.3	1.43	0.42	4.26	1.89	0.72	0.94	9.4	8.4	1.48	95.2
D14A-23	11.58	1.90	36.7	2.34	27.3	1.21	0.44	3.23	1.66	0.65	1.01	16.7	9.2	1.60	98.9
D14A-28	7.32	1.95	41.2	1.87	22.7	1.24	0.59	4.02	1.72	0.66	1.03	18.8	9.1	1.60	95.1
D15B-29	17.43	2.59	26.0	6.10	27.2	0.46	0.54	2.44	1.82	0.86	0.64	14.3	7.6	1.33	95.2
D17A-30	10.66	1.98	36.6	2.65	27.1	1.28	0.47	3.36	1.87	0.66	0.96	13.8	9.1	1.59	98.4
D18-32	6.59	1.53	39.7	1.02	22.6	0.96	0.49	6.54	1.74	0.54	2.80	14.4	8.9	1.56	95.1
D18-33	4.63	1.82	39.7	1.23	20.1	0.92	0.55	7.85	1.64	0.53	3.28	6.8	8.6	1.50	92.4
D18-35	3.95	1.38	42.6	0.62	18.9	0.89	0.61	7.80	1.76	0.53	3.25	10.2	8.8	1.54	92.7

Table 13-3. Chemistry of ferromanganese crusts, Horizon Guyot, Cruise L5-83-HW. Hygroscopic water-free major elements in weight percent. For sample type and total thickness refer to Table 13-1. Analyses by USGS-Reston.

SAMPLE	SiO_2	Ti	Mn	Al	Fe	Co	Cu	Ni	Ca	Mg	K	Na_2O	P	CO_2	H_2O-
D11A-20	11.05	1.32	21.88	1.08	20.91	0.585	0.055	0.249	2.49	1.06	0.54	2.16	0.42	0.35	7.70
D12A-21	11.29	1.33	22.03	1.35	17.54	0.942	0.036	0.317	3.28	1.20	0.64	2.63	0.39	1.09	8.80
D12A-22	9.92	1.08	22.88	0.98	18.48	0.732	0.041	0.326	3.72	1.03	0.56	2.36	0.43	1.69	11.30
D14A-23	11.60	1.17	23.80	0.98	19.61	0.777	0.057	0.334	2.53	1.05	0.57	2.39	0.39	0.44	16.40
D14A-24	2.17	1.01	32.64	0.22	11.97	0.761	0.169	0.556	5.56	1.11	0.56	2.29	1.07	0.78	17.30
D14A-25	7.27	1.15	27.86	0.70	15.28	0.912	0.112	0.480	4.31	1.09	0.60	2.34	0.76	0.72	18.90
D14A-26	13.07	1.19	24.78	0.98	18.92	0.909	0.054	0.398	2.61	1.07	0.61	2.24	0.34	0.47	19.70
D14A-27	2.99	1.17	31.71	0.27	14.48	0.761	0.071	0.461	4.99	1.07	0.53	2.37	0.86	0.76	19.90
D14A-28	7.98	1.20	27.43	0.76	16.58	0.835	0.064	0.486	3.24	1.08	0.59	2.36	0.41	0.56	19.80
D15B-29	18.53	1.64	17.11	2.62	19.95	0.306	0.283	0.401	2.00	1.29	0.80	2.24	0.31	0.35	15.30
D17A-30	10.11	1.21	23.59	1.05	19.32	0.764	0.094	0.359	2.58	1.07	0.58	2.35	0.44	0.38	11.00
D17B-31	13.13	1.27	21.33	1.60	16.06	0.539	0.222	0.363	2.57	1.10	0.64	2.22	0.39	0.51	14.70
D18-32	5.97	0.95	26.32	0.50	16.32	0.655	0.095	0.379	5.17	0.98	0.49	2.18	1.26	0.77	13.00
D18-33	4.70	0.95	27.05	0.42	14.89	0.646	0.219	0.416	6.24	0.98	0.50	2.19	1.53	0.82	8.70
D18-34	8.69	1.08	24.55	0.77	19.15	0.716	0.062	0.364	2.70	1.05	0.51	2.23	0.50	0.51	14.90
D18-35	3.45	0.86	28.20	0.32	13.60	0.624	0.122	0.434	6.13	0.98	0.49	2.11	0.39	0.85	10.30
D18-36	11.98	1.16	22.47	1.08	19.60	0.811	0.049	0.337	2.49	1.03	0.61	2.37	0.39	0.54	19.90
D18-37	2.79	0.90	29.06	0.37	14.65	0.499	0.068	0.395	5.93	0.96	0.49	1.97	1.32	0.87	14.00

Table 13-4. Chemistry of ferromanganese crusts, Horizon Guyot, Cruise L5-83-HW. Hygroscopic water-free major elements, weight percent. For sample type and total thickness refer to Table 13-1. Analyses by USGS-WH.

SAMPLE	SiO_2	Ti	Mn	Al	Fe	Co	Ni	Ca	Mg	K	P	H_2O-
D12A-21	10.83	1.29	21.91	1.85	17.01	1.049	0.309	3.04	1.14	0.60	0.41	9.45
D14A-23	11.58	1.14	23.19	1.24	19.09	0.889	0.324	2.31	1.00	0.54	0.44	16.78
D14A-28	7.32	1.17	26.03	0.99	15.86	0.912	0.431	2.87	1.04	0.55	0.45	18.87
D15B-29	17.43	1.55	16.41	3.23	19.05	0.338	0.397	1.74	1.10	0.71	0.28	14.39
D17A-30	10.66	1.19	23.12	1.40	18.94	0.939	0.348	2.40	1.13	0.55	0.42	13.82
D18-32	6.59	0.92	25.08	0.54	15.82	0.706	0.362	4.67	1.05	0.45	1.22	14.42
D18-33	4.63	1.09	25.09	0.65	14.03	0.676	0.408	5.61	0.99	0.44	1.43	6.87
D18-35	3.95	0.83	26.91	0.33	13.22	0.657	0.445	5.57	1.06	0.44	1.42	10.20

Table 13-5. Chemistry of ferromanganese crusts, Horizon Guyot, Cruise L5-83-HW. Trace elements corrected for H_2O^- (hygroscopic moisture free basis), weight percent. For sample type and total thickness refer to Table 13-1. Analyses by USGS-Reston.

SAMPLE	Ba	Mo	Pb	Sr	V	Zn	Y	Ce	As	Cd	H_2O^-
D11A-20	0.108	0.030	0.184	0.140	0.058	0.060	0.019	0.162	0.020	0.00032	7.70
D12A-21	0.109	0.032	0.164	0.142	0.053	0.059	0.018	0.142	0.020	0.00034	8.80
D12A-22	0.112	0.040	0.169	0.135	0.056	0.058	0.018	0.090	0.022	0.00038	11.30
D14A-23	0.143	0.041	0.191	0.155	0.061	0.062	0.019	0.113	0.022	0.00035	16.40
D14A-24	0.266	0.093	0.205	0.181	0.071	0.087	0.013	0.217	0.016	0.00052	17.30
D14A-25	0.197	0.062	0.184	0.160	0.060	0.073	0.016	0.160	0.020	0.00049	18.90
D14A-26	0.149	0.044	0.186	0.161	0.024	0.064	0.018	0.118	0.023	0.00038	19.70
D14A-27	0.274	0.083	0.237	0.187	0.073	0.079	0.011	0.237	0.021	0.00049	19.90
D14A-28	0.211	0.059	0.211	0.162	0.064	0.072	0.013	0.174	0.023	0.00045	19.80
D15B-29	0.153	0.012	0.129	0.105	0.047	0.076	0.036	0.153	0.017	0.00048	15.30
D17A-30	0.134	0.038	0.179	0.157	0.060	0.064	0.021	0.112	0.029	0.00032	11.00
D17B-31	0.152	0.023	0.175	0.140	0.052	0.077	0.015	0.107	0.022	0.00032	14.70
D18-32	0.206	0.065	0.218	0.183	0.071	0.071	0.019	0.160	0.024	0.00037	13.00
D18-33	0.208	0.067	0.219	0.175	0.066	0.075	0.017	0.164	0.021	0.00040	8.70
D18-34	0.152	0.048	0.199	0.164	0.068	0.069	0.019	0.108	0.032	0.00037	14.90
D18-35	0.234	0.075	0.234	0.189	0.069	0.080	0.016	0.200	0.022	0.00042	10.30
D18-36	0.149	0.041	0.187	0.162	0.062	0.062	0.018	0.114	0.031	0.00025	19.90
D18-37	0.267	0.084	0.267	0.197	0.077	0.070	0.017	0.244	0.020	0.00028	14.00

Table 13-6. Major oxides in weight percent: Horizon Guyot substrate rocks, Cruise L5-83-HW.

	D11-A6	D12-7	D12-A5	D12-A7	D14-1	D15-B2	D18-1
SiO_2	48.2	46.7	44.0	39.0	45.3	50.6	27.5
Al_2O_3	18.7	16.7	18.8	16.1	19.1	15.4	13.4
Fe_2O_3	12.9	11.4*	13.4	12.9	10.0*	8.03	7.67*
FeO	<0.02	--	<0.02	0.04	--	<0.02	--
MgO	2.46	6.28	1.51	2.16	4.11	2.34	0.37
CaO	3.93	8.55	3.76	9.86	8.72	2.21	21.5
Na_2O	2.66	2.98	4.02	3.23	2.70	4.07	1.14
K_2O	2.28	1.18	3.50	2.51	1.28	3.90	2.36
TiO_2	2.80	2.35	2.66	2.62	2.60	1.32	1.74
P_2O_5	0.14	0.41	0.32	0.31	1.02	0.68	13.23
MnO	0.20	0.13	0.07	0.09	0.13	1.24	0.29
H_2O^+	7.62**	--	10.87	8.40	--	12.54	--
CO_2	0.30	--	0.39	4.44	--	0.44	--
LOI (900°C)	5.73	3.92	7.60	10.88	5.23	9.74	8.29
Total	100.0	100.6	99.7	99.7	100.2	99.5	97.5
Lithology	Volcanic breccia zeolite cement	Basalt	Fine-grained matrix of a coarse-grained volcanic breccia with zeolite cement	Hyaloclas-tite calcite cemented	Basalt	Mudstone - interior of a pancake nodule	Volcanic breccia with phos-phorite cement

* Total Fe as Fe_2O_3.
** H_2O^+ represents total water present. Samples were dried at 105°C before analysis.
Totals based on LOI.
Analyses performed at U.S. Geological Survey analytical laboratories in Denver and Menlo Park.

Table 14. Physical properties of substrate rocks from Horizon Guyot, Cruise L5-83-HW. Weight fraction of water is fraction of dry solids. The grain density used to calculate columns 2, 3, and 5 is 2.9.

Sample No.	Wet Bulk Density (g/cc)	Dry Bulk Density (g/cc)	Total wt. fraction of Water (g/g)	Percent Porosity	Rock Type
D11-A6	2.18	1.78	0.223	39	Volcanic breccia with zeolite cement
D12-A5	2.04	1.56	0.302	47	Fine-grained matrix of a coarse-grained volcanic breccia with zeolite and calcite cement
D12-A7	2.12	1.70	0.251	42	calcite cemented hyaloclastite

Table 15. Water content and ignition loss data for Horizon Guyot, Cruise L5-83-HW. H. Mairs and K. Schmitz, analysts. Dry weight basis means that starting material was air-dry powder, and all weight loss data are given as a weight percent of oven-dried sample (110°C) except hygroscopic moisture (H_2O). All data in weight percent.

Sample No.	----------Dry weight basis----------			
	H_2O^-	110-500°	500-1000°	110-1000°
D12A-22	15.13	8.39	8.03	16.42
D14A-24	19.72	9.60	7.85	17.44
D14A-25	20.27	9.13	7.42	16.55
D14A-26	21.96	8.88	6.98	15.87
D14A-27	23.49	9.32	8.55	17.87
D17B-31	17.39	8.52	6.99	15.51
D18-34	17.91	9.24	7.00	16.25
D18-36	22.51	8.61	6.90	15.51
D18-37	15.78	10.6	6.32	16.92

Table 16. Location and description of samples from Johnston Island, Cruise L5-83-HW.

Sample No.	Latitude (N)	Longitude (W)	Water Depth (m)	Sample wt. (kg)	Crust Description	Substrate Description
34-D19	16°40.65' 16°40.86'	169°21.52' 169°21.45'	1400	1	Less than 1 mm, smooth, polished crust on one surface	Smectite and calcite cemented volcanic breccia. Clasts altered to clay minerals, zeolites, and calcite; non-vesicular, porphyritic. Botryoidal cement, with zeolite crystals in voids.

Table 17. Mineral content of ferromanganese crusts, Johnston Island, Cruise L5-83-HW.

Sample No.	Vernadite (%)	Plagioclase (%)	Quartz (%)	Apatite (%)	Others	Comments
D19-1	92	5			Calcite (3%)	Bulk

Percentages were determined by using the following weighting factors relative to quartz set as 1 : vernadite 75, plagioclase 2.8, apatite 3.1, calcite 1.65. We determined the vernadite weighting factor by mixing known amounts of a pure vernadite crust and quartz; other weighting factors are from Cook et al. (1975). The limit of detection for each mineral falls between 0.5 and 1.0 percent.

Mineral content of substrates associated with ferromanganese crusts, Johnston Island, Cruise L5-83-HW.

Sample No.	---X - r a y M i n e r a l o g y---- Major	Moderate	Minor or Trace	Comments
D19-1	Plagioclase	Smectite Mg-calcite	Pyroxene Phillipsite	Cement of volcanic breccia
D19-1	Plagioclase Pyroxene		Smectite	Altered volcanic clast from volcanic breccia
D19-1	Plagioclase Pyroxene		Smectite	Fresh volcanic clast from volcanic breccia

S.P. LEE GUYOT

Fifteen seismic-reflection lines criss-crossed the western half of S.P. Lee Guyot (Figs. 12, 14). Eight dredges returned samples from water depths between 1125 and 2400 m. A thick-sediment cap (300 m) contains up to four internal reflectors, which may be the result of chert horizons (Fig. 14). Buried terraces occur below the sediment cap. Lines 21 and 28 cross a small well-developed sediment slump (Fig. 14c and 14j). The flanks are rugged, showing many volcanic pinnacles that support little sediment (Fig. 13). Volcanic knobs dot the summit region. The northern lower flank is draped by a debris apron.

Camera-video runs recorded guyot flanks between 1200 to 2400 m and 1050 to 1800-m depth of water (Figs. 12, 15). A rough estimate from 850 bottom photographs, each displaying 2 to 3 m on a side of seafloor, indicates that 80 percent of the upper flanks are sediment covered (Fig. 15). Sediment commonly shows current ripples and sand waves (Fig. 15-4). Ubiquitous bottom-dwelling organisms are seen (Fig. 15-2). All rock surfaces are encrusted with ferromanganese oxides.

The CTD and oxygen profiles taken over the summit are remarkably different from ones taken over the northwest flank (Fig. 16-1 through 16-10). The oxygen-minimum zone begins at about 200 to 300-m water depth over the summit and 500 to 600-m over the north flank; that is 300-m shallower than the oxygen minimum over the summit of Horizon Guyot.

Most rocks recovered from S.P. Lee Guyot are volcaniclastic breccia, sandstone, and siltstone, all with a calcareous matrix or cement, and minor basalt cobbles (Table 18). Sedimentary rocks show evidence of gravity-flow deposition. Large blocks of phosphorite-replaced limestone were recovered. The chemistry of the substrate varies with the lithology and with the amount of calcite and apatite present (Table 19). Substrate mineralogy reflects the abundant phosphorites on S.P. Lee Guyot and the highly-altered volcaniclastic debris which produced smectite, phillipsite, and calcite (Table 20).

Vernadite is the dominant (60-100 percent) crust mineral except for one sample recovered from 1600-m water depth, whose mineralogy in addition to vernadite is 17 percent todorokite, and 22 percent apatite (Table 21); this sample may have some hydrothermal input, rather than being solely hydrogenous as are the other crusts studied. Quartz and plagioclase are rare, but apatite comprises up to 22 percent of the inner parts of some crusts. S.P. Lee Guyot crusts are the richest in cobalt of those we studied (Table 22). For crusts collected at water-depths shallower than 2500 m, Mn averages 28.29%, Fe 15.29%, Co 1.220%, Ni 0.529%, and Cu 0.053% (Table 22-3).

The average crust thickness is 8 mm, with a maximum thickness of 45 mm (Table 18). Thicknesses varied greatly within single-dredge hauls. On the average, about a third of rocks recovered were broken from outcrop and were coated with crusts. Forty-three percent supported no crusts, while 5 percent were crust fragments without substrate. Twenty percent had crusts encircling nuclei. Thicker crusts show two distinct generations of growth. Foraminifers occur throughout many crusts.

Density, porosity, and other physical properties are listed in Tables 23 and 24 for substrates and crusts, respectively.

Figure 12. Sampling stations and camera and seismic-reflection lines on S.P Lee Guyot. Deep Sea Drilling Project Site 165 is located. Contour interval is 200 fathoms (Chase and Menard, 1973).

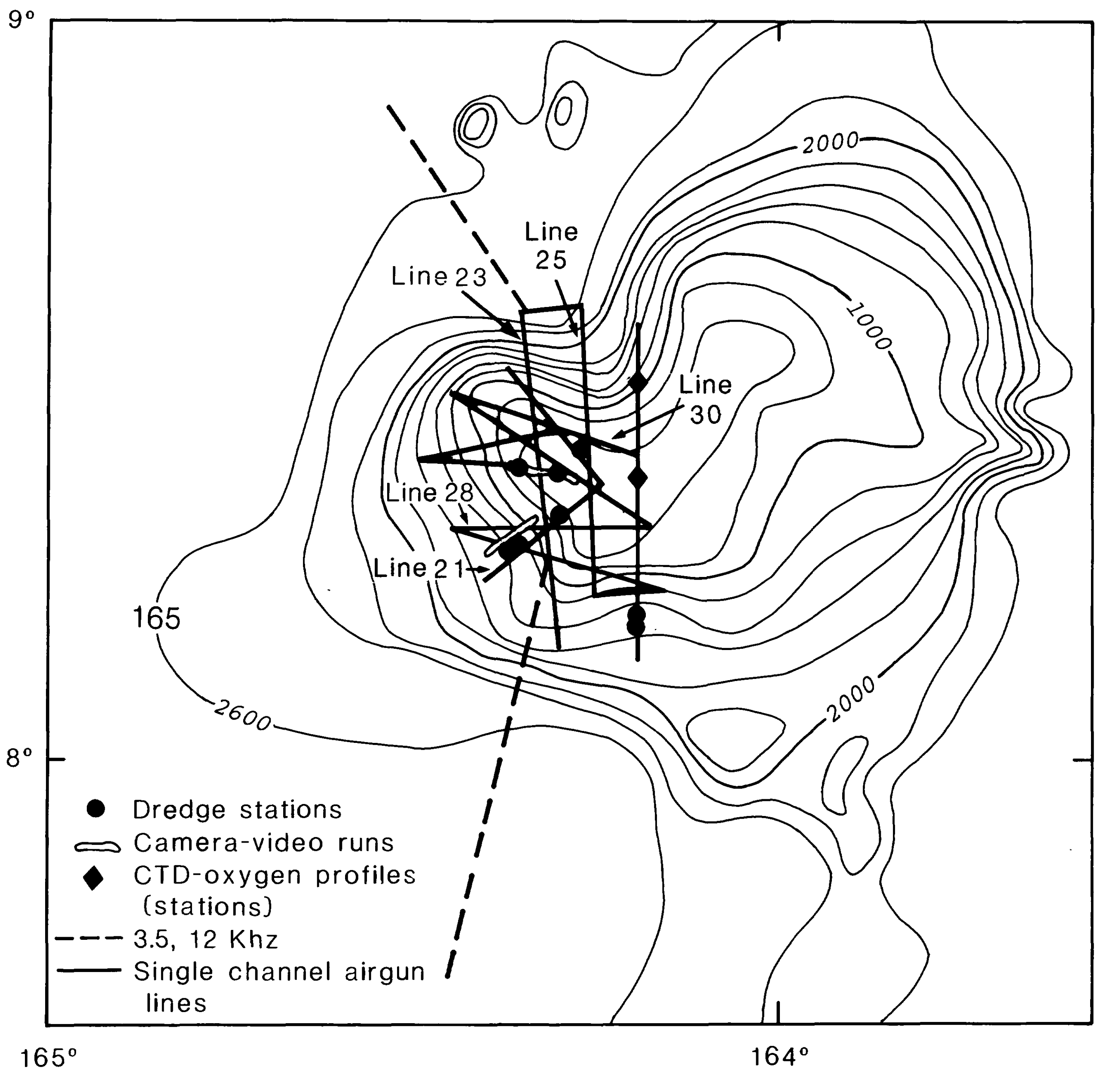

9°
8°
165°
164°
2000
1000
2000
2600
165
Line 25
Line 23
Line 30
Line 28
Line 21
Dredge stations
Camera-video runs
CTD-oxygen profiles (stations)
3.5, 12 Khz
Single channel airgun lines

Figure 13. Bathymetric map of west half of S.P. Lee Guyot based on seismic and bathymetric survey from Cruise L5-83-HW.

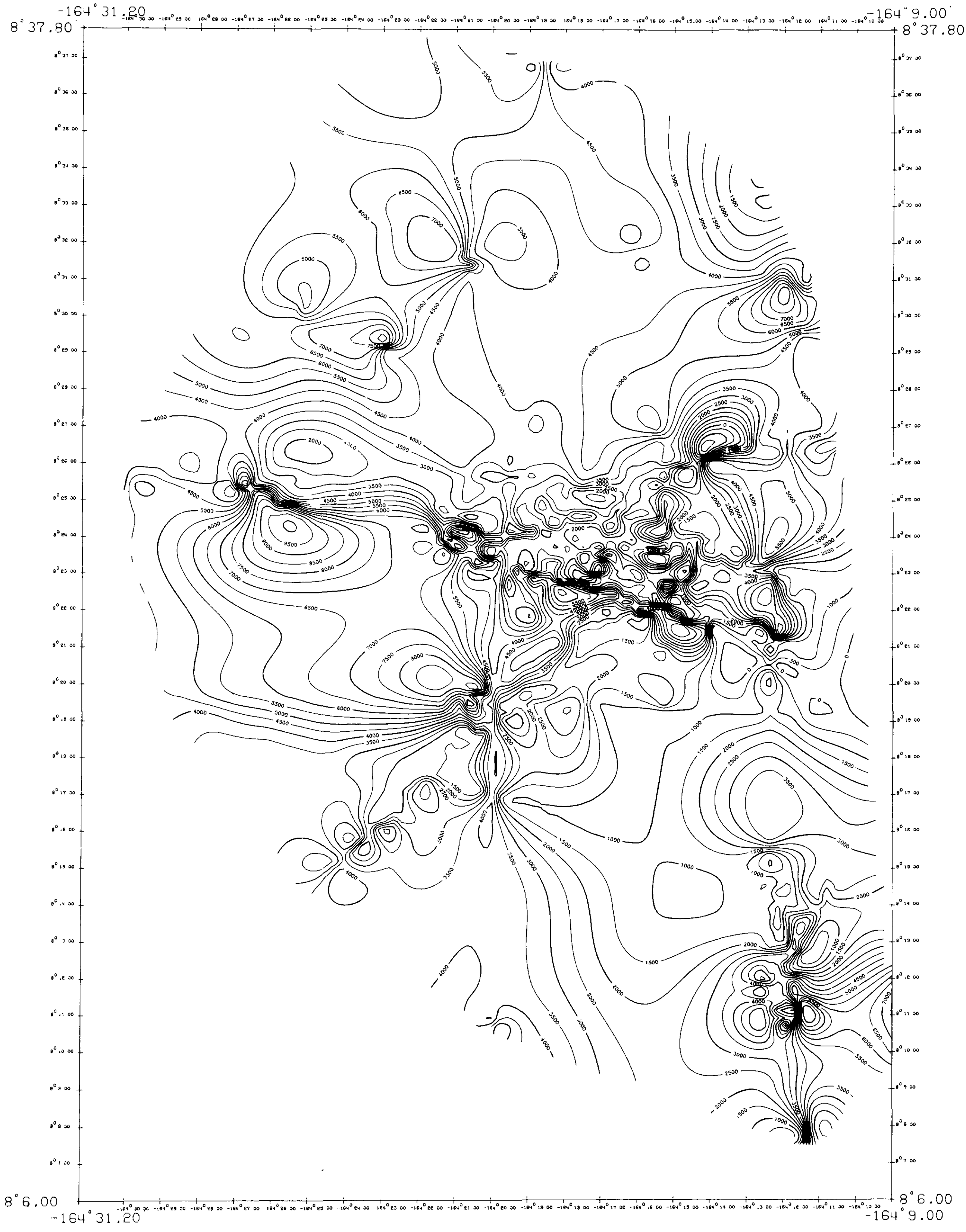
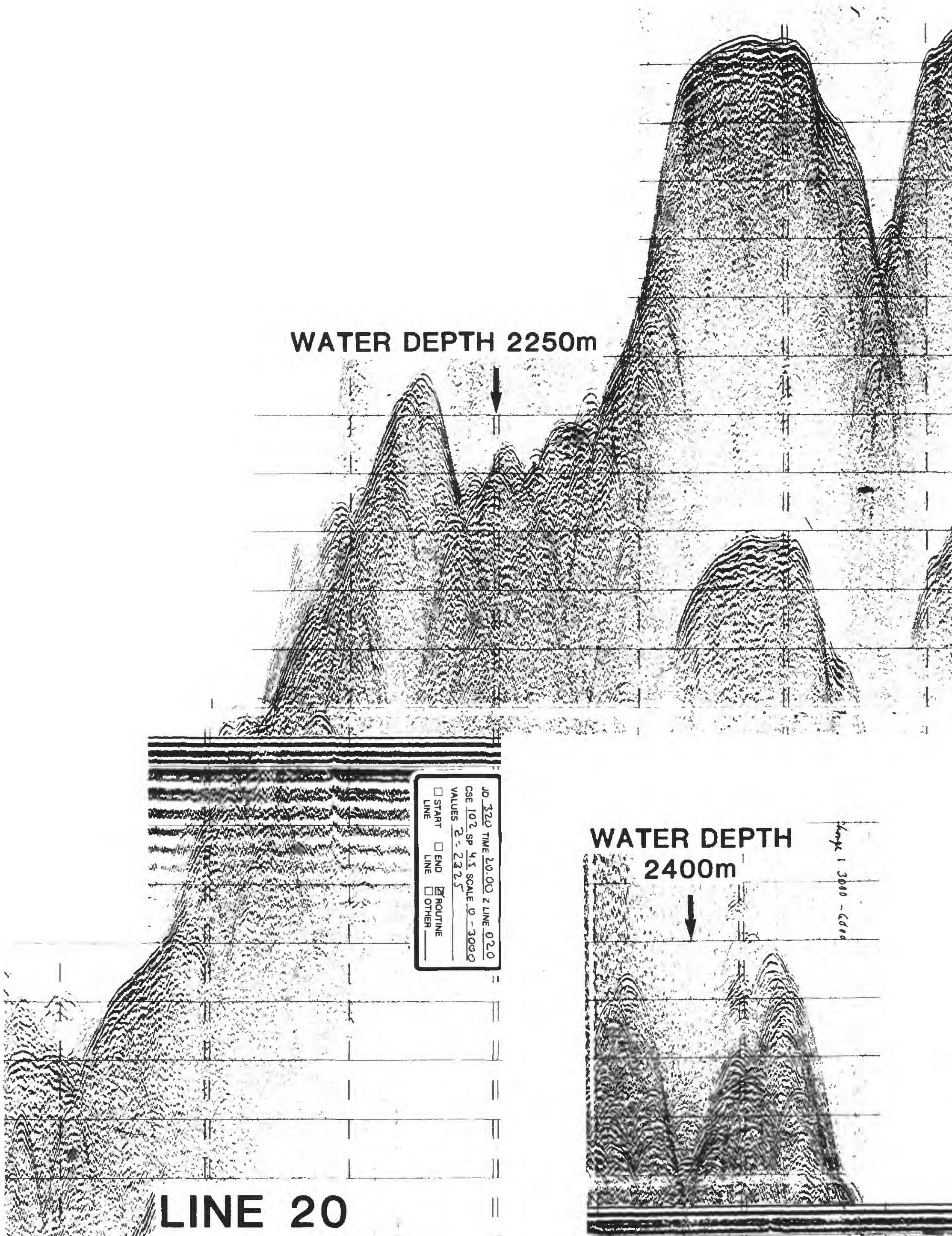
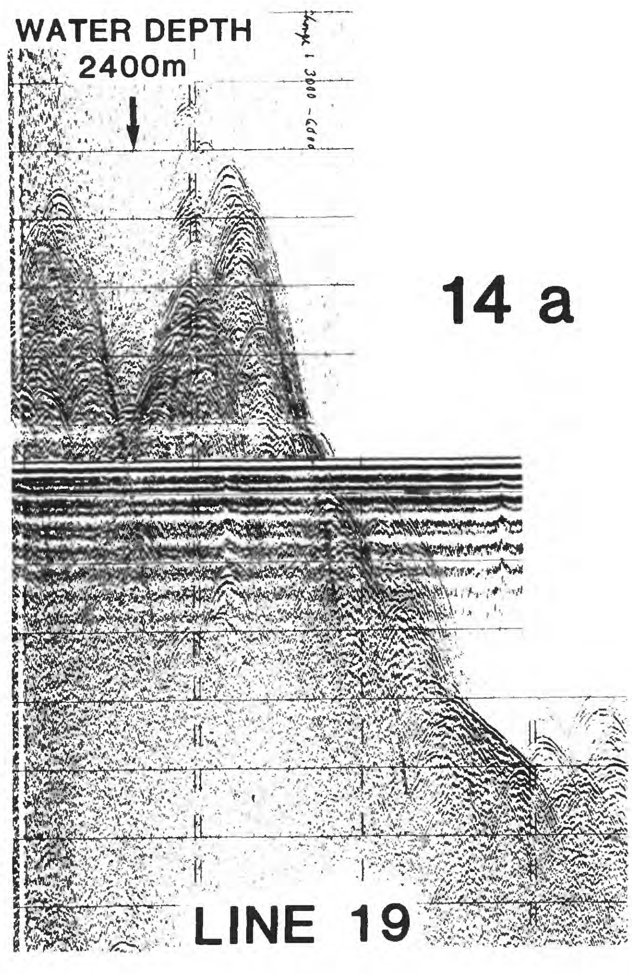

-164° 31.20
8° 37.80
-164° 9.00
8° 37.80
8° 6.00
-164° 31.20
8° 6.00
-164° 9.00

Figure 14. Single-channel 80 cubic-inch airgun seismic profiles of S.P. Lee Guyot (Lines 19 through 36). Note slump deposits and volcanic pinnacles, some of which penetrate through the sediment cap. The north flank shows a well-developed stepped morphology. On Line 28, a thick sediment cap slumped at the break in slope. Volcanic pinnacles are common on the flanks of the guyot. The distance between each horizontal rule represents 150 m.

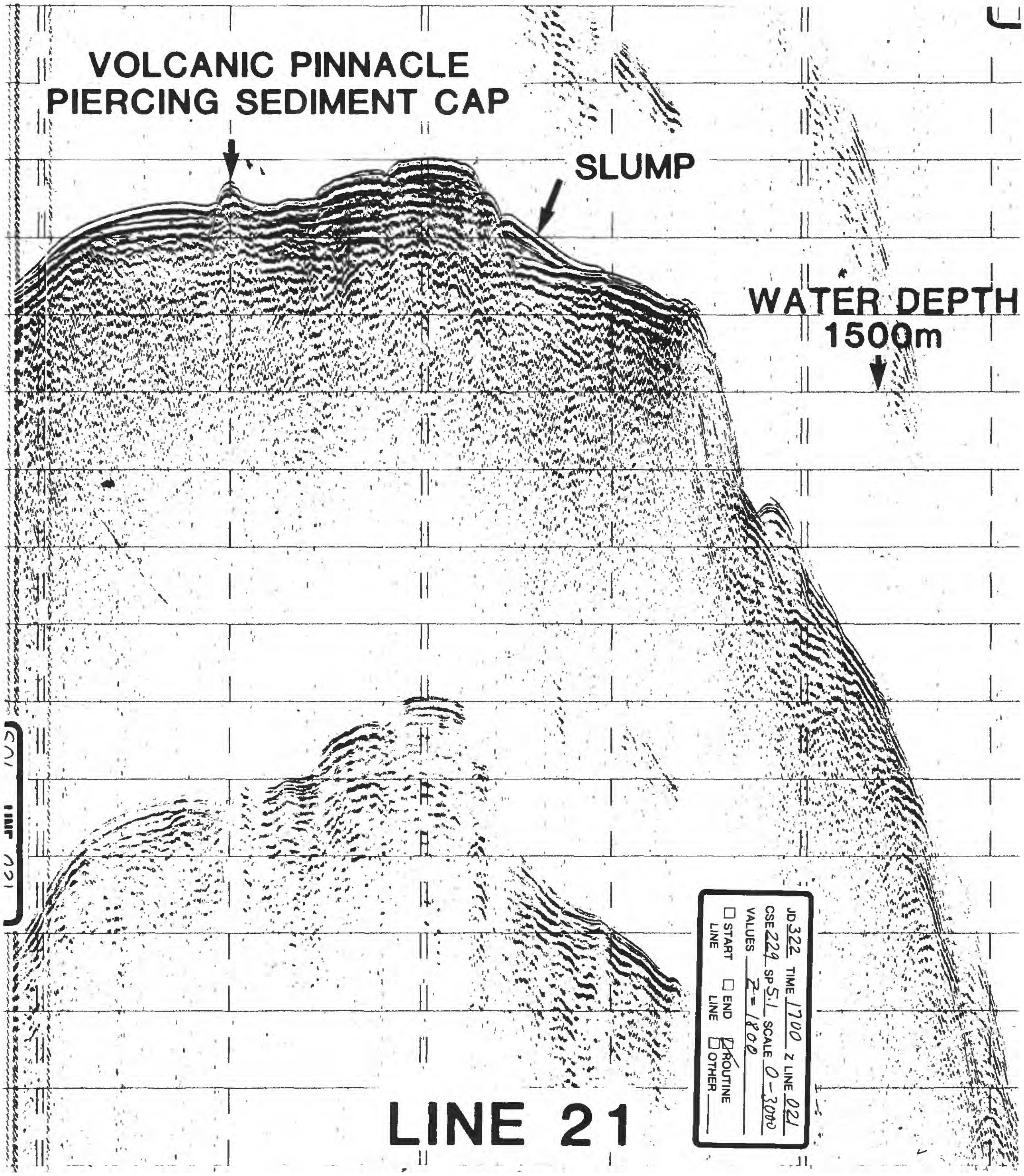
14 b



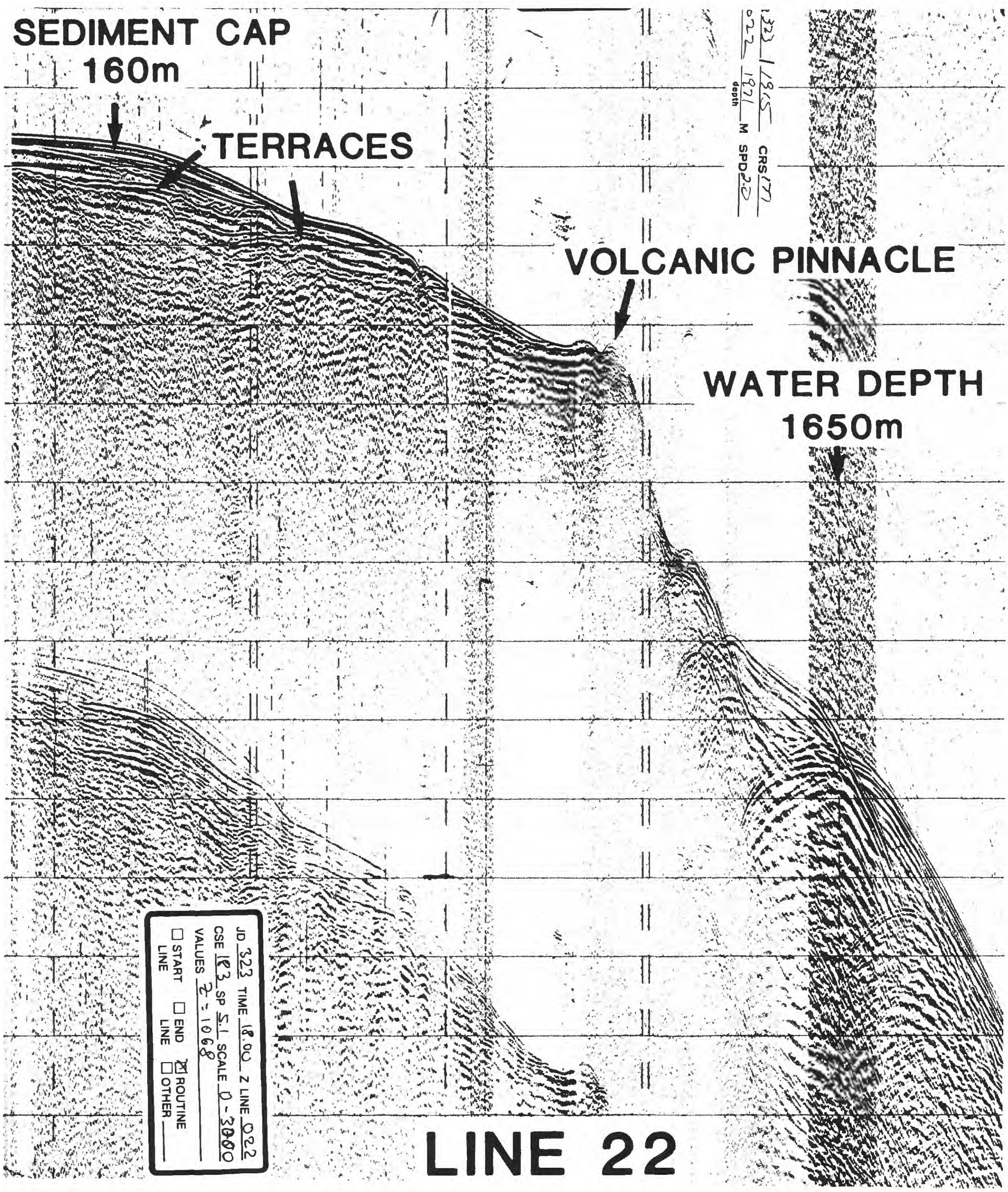
14 a



14 c

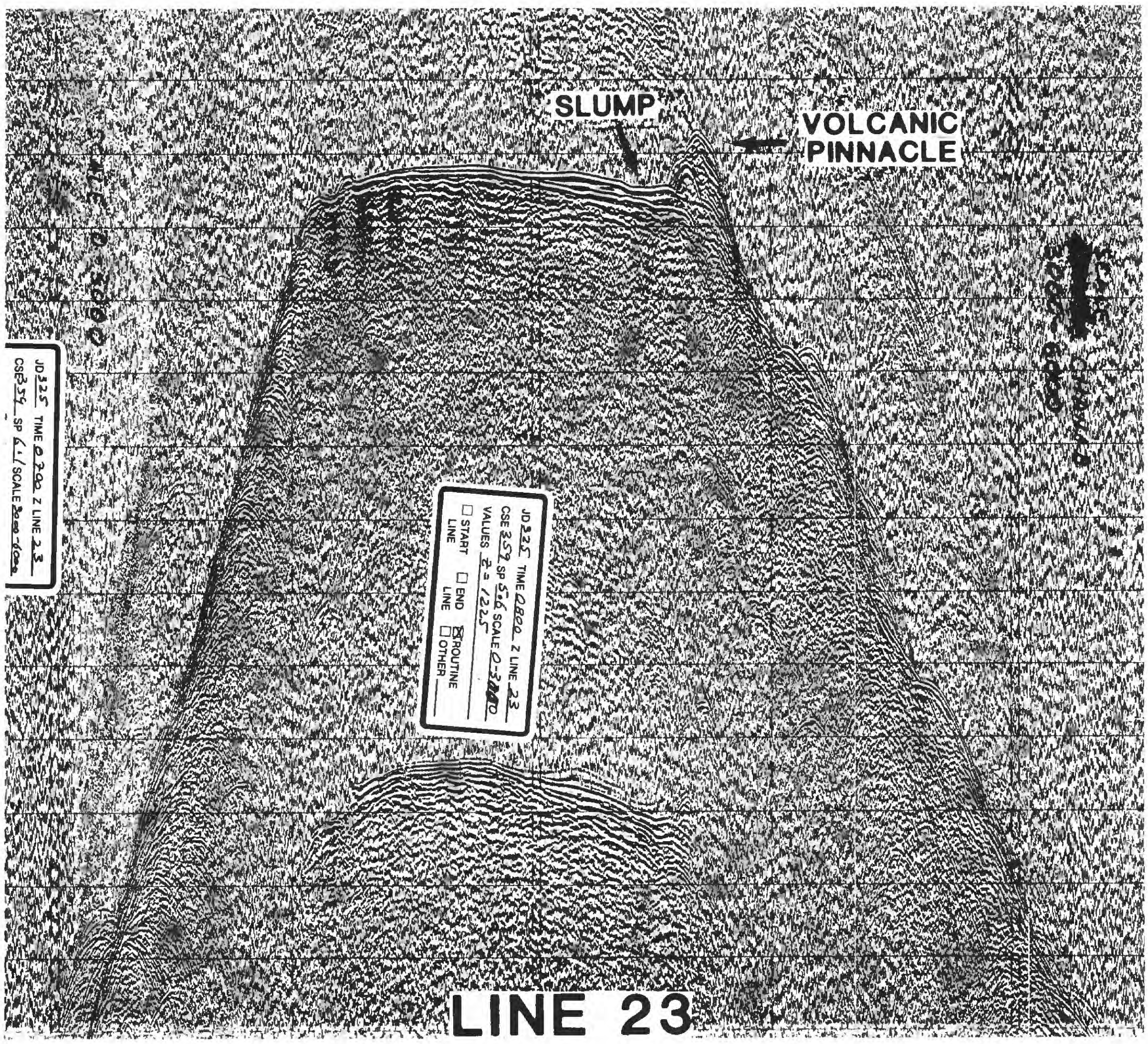

VOLCANIC PINNACLE
PIERCING SEDIMENT CAP
SLUMP
WATER DEPTH
1500m
LINE 21

14 d

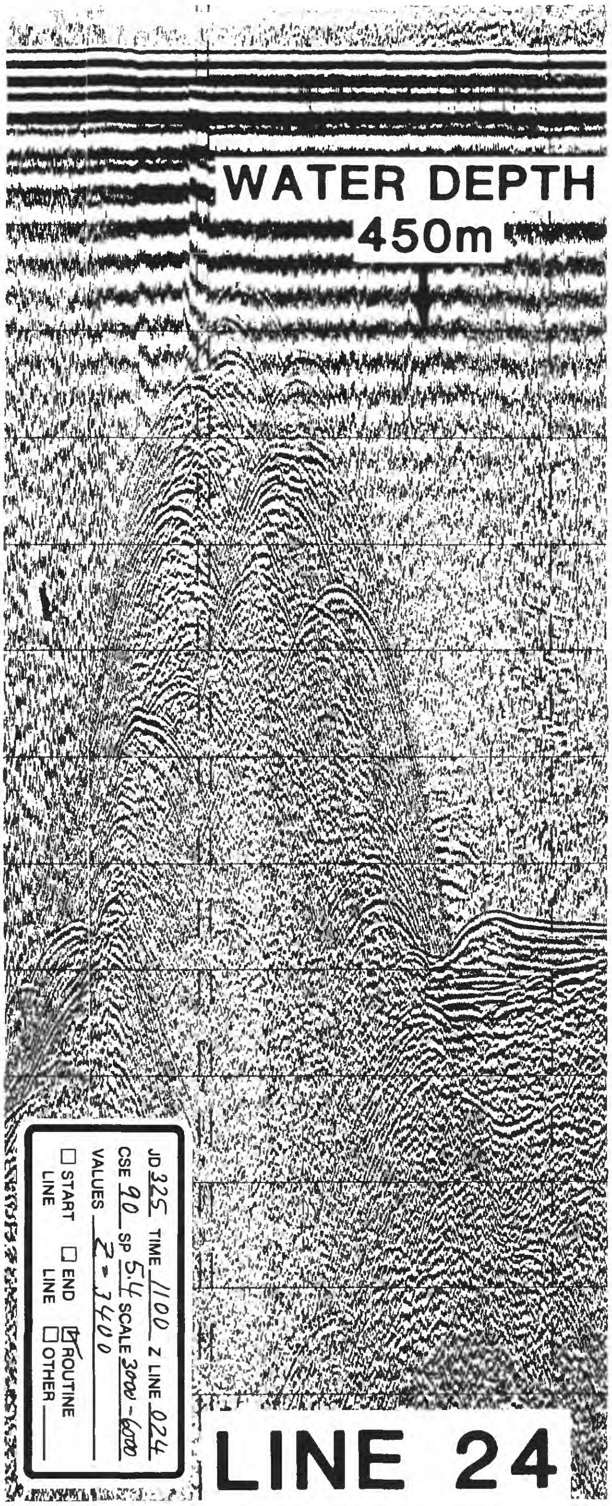


SEDIMENT CAP
160m
TERRACES
VOLCANIC PINNACLE
WATER DEPTH
1650m
LINE 22

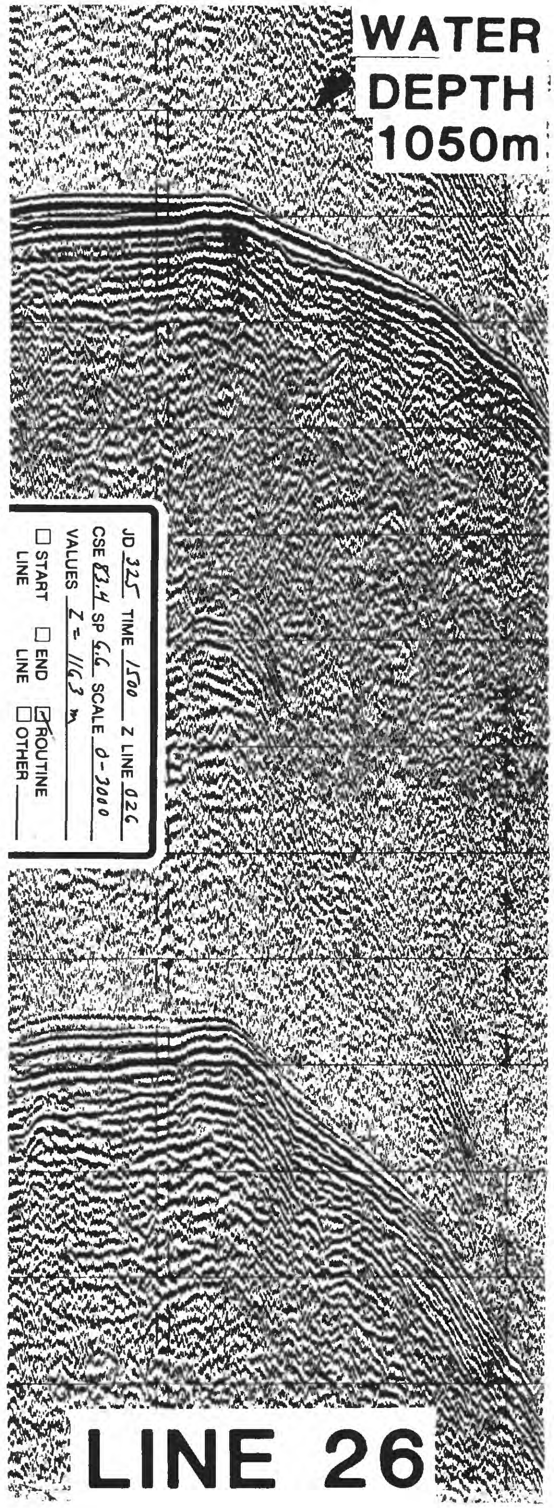
14 e



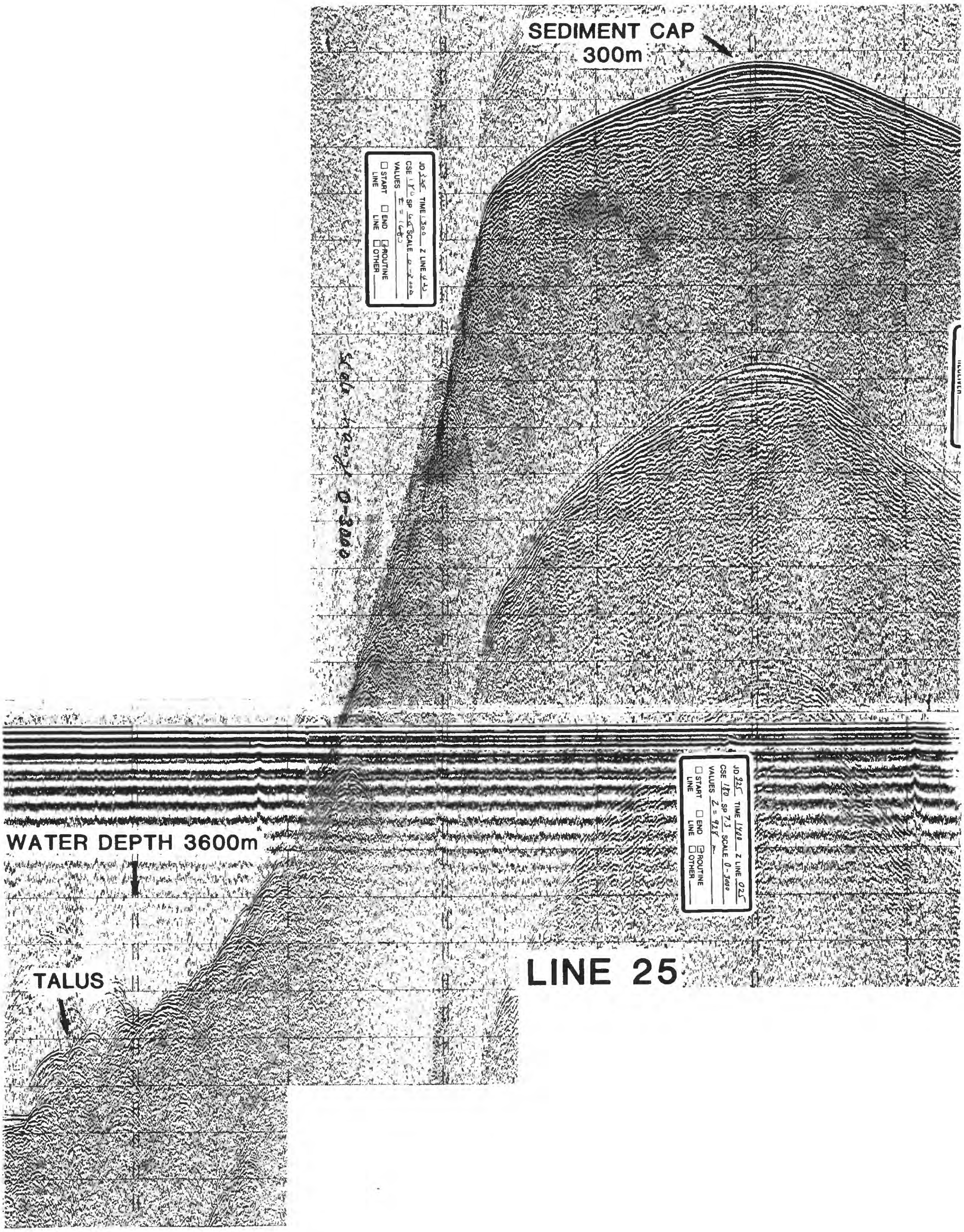
14 f



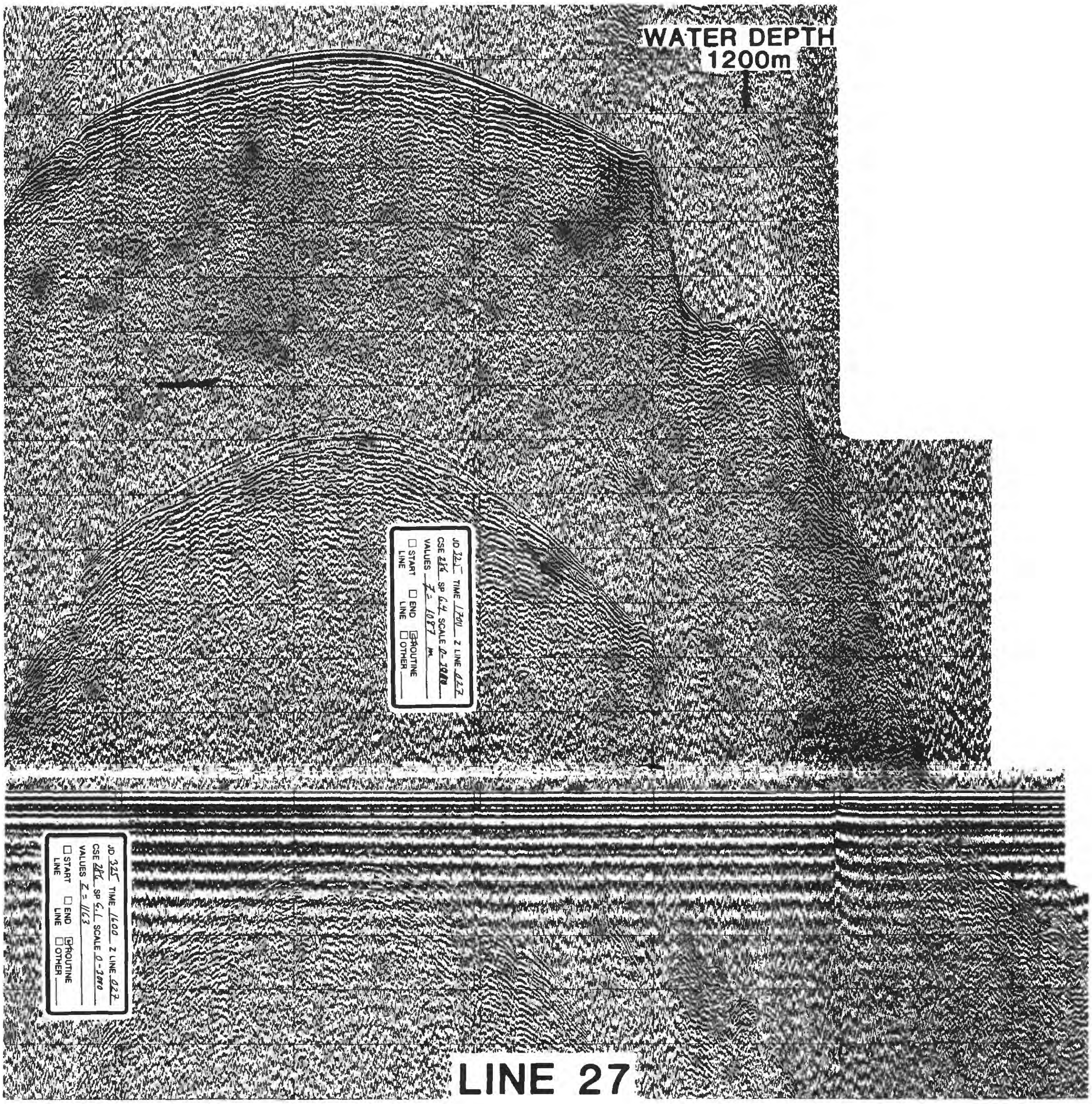
14 h



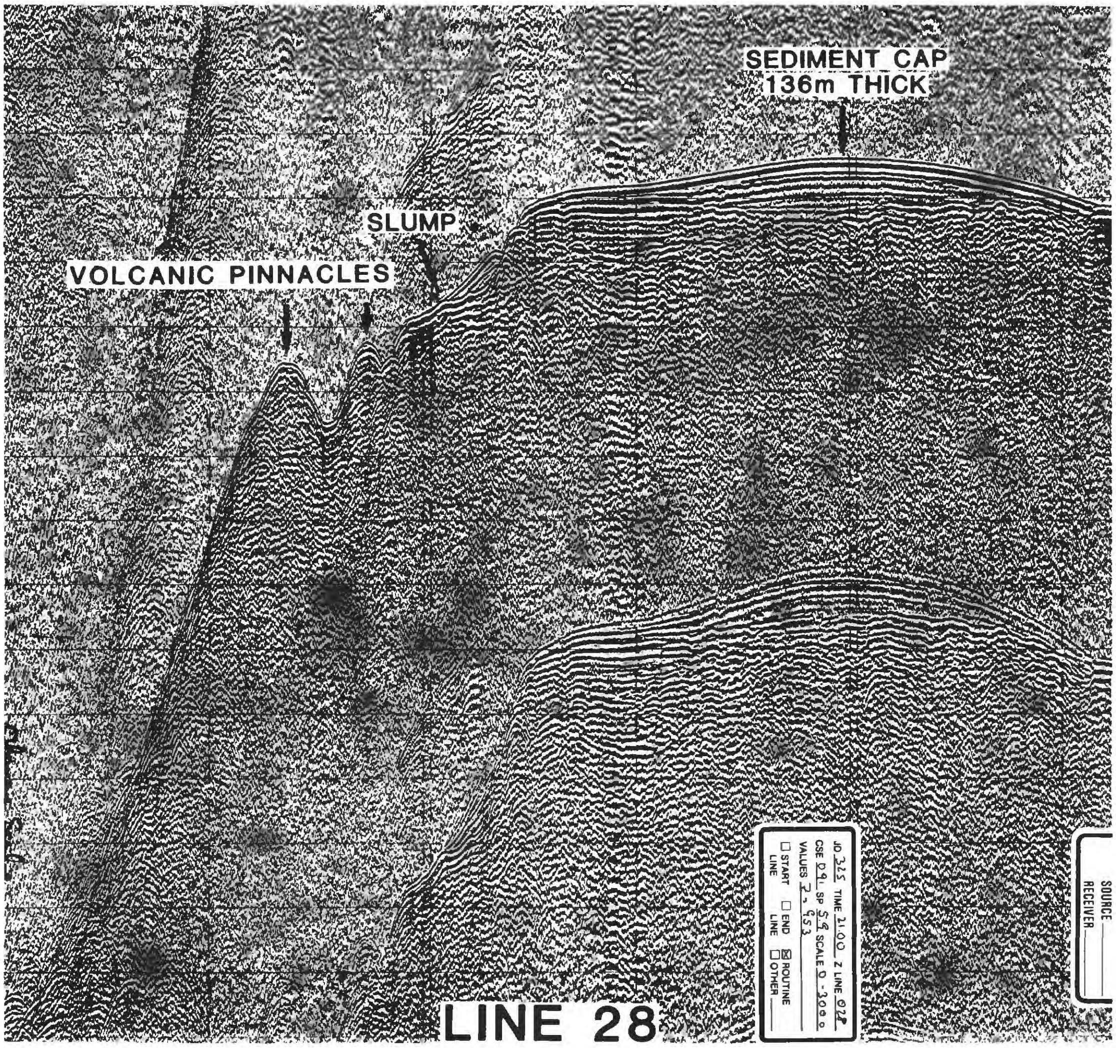
14 g



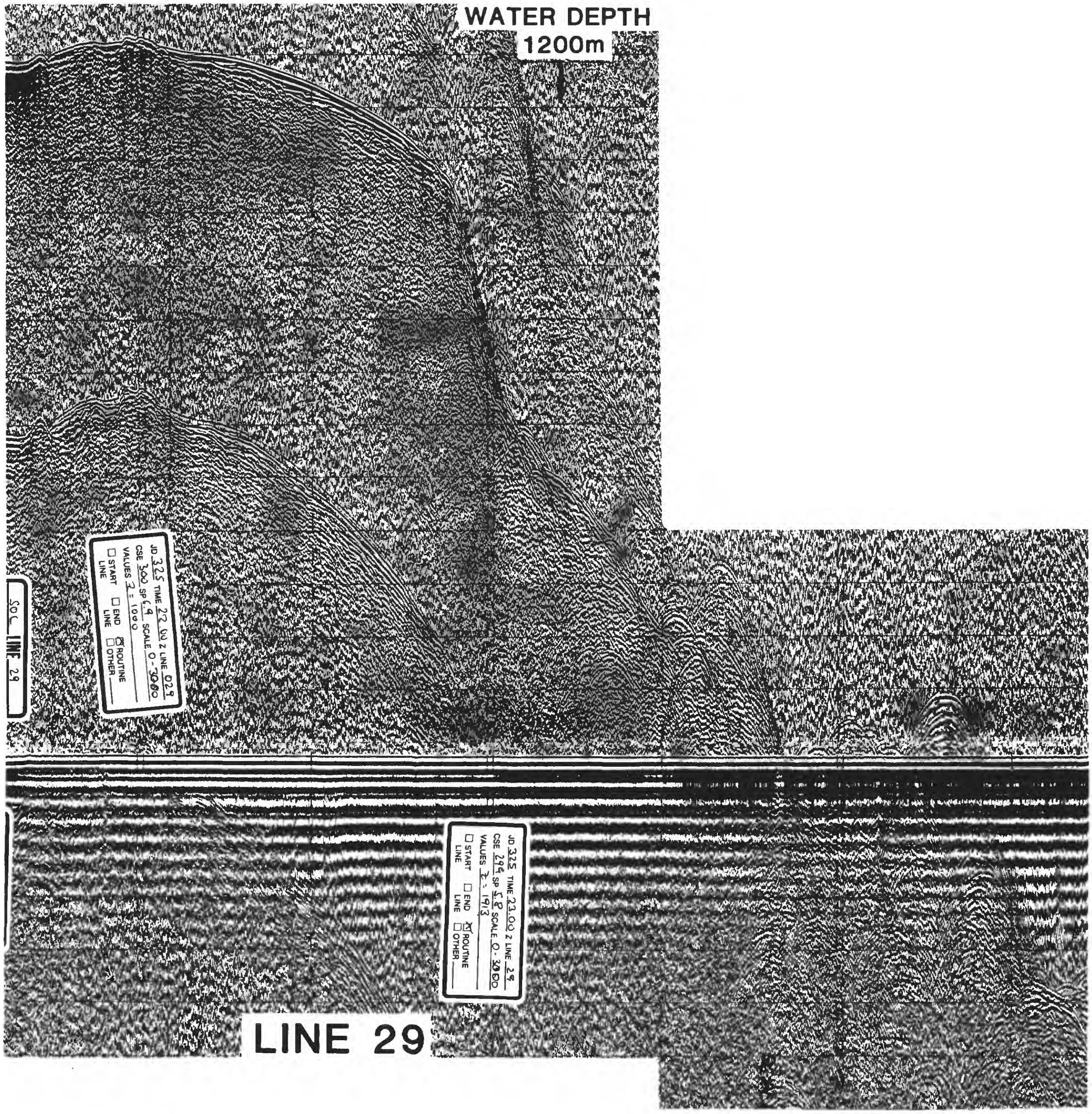
14 i

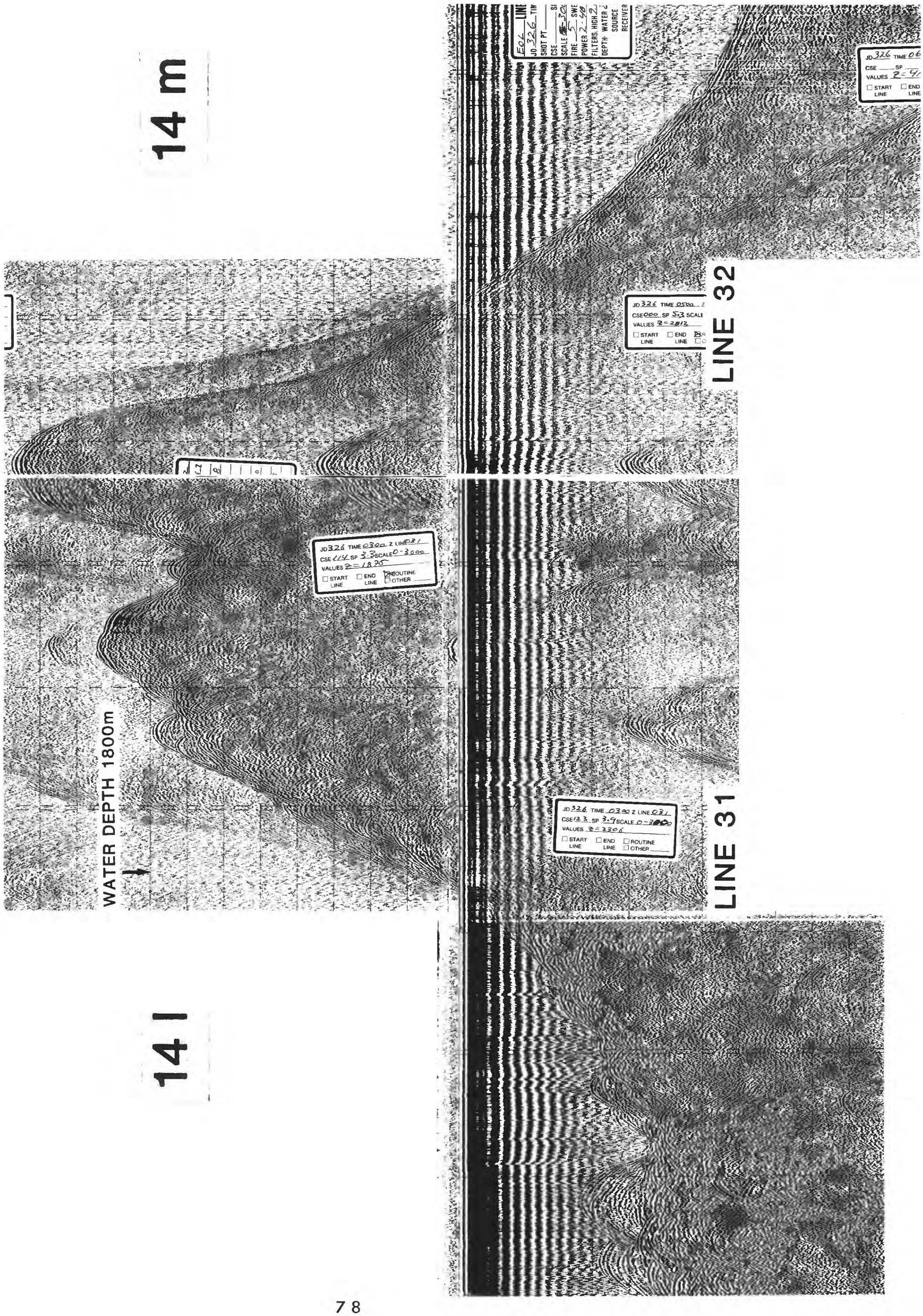


14 j

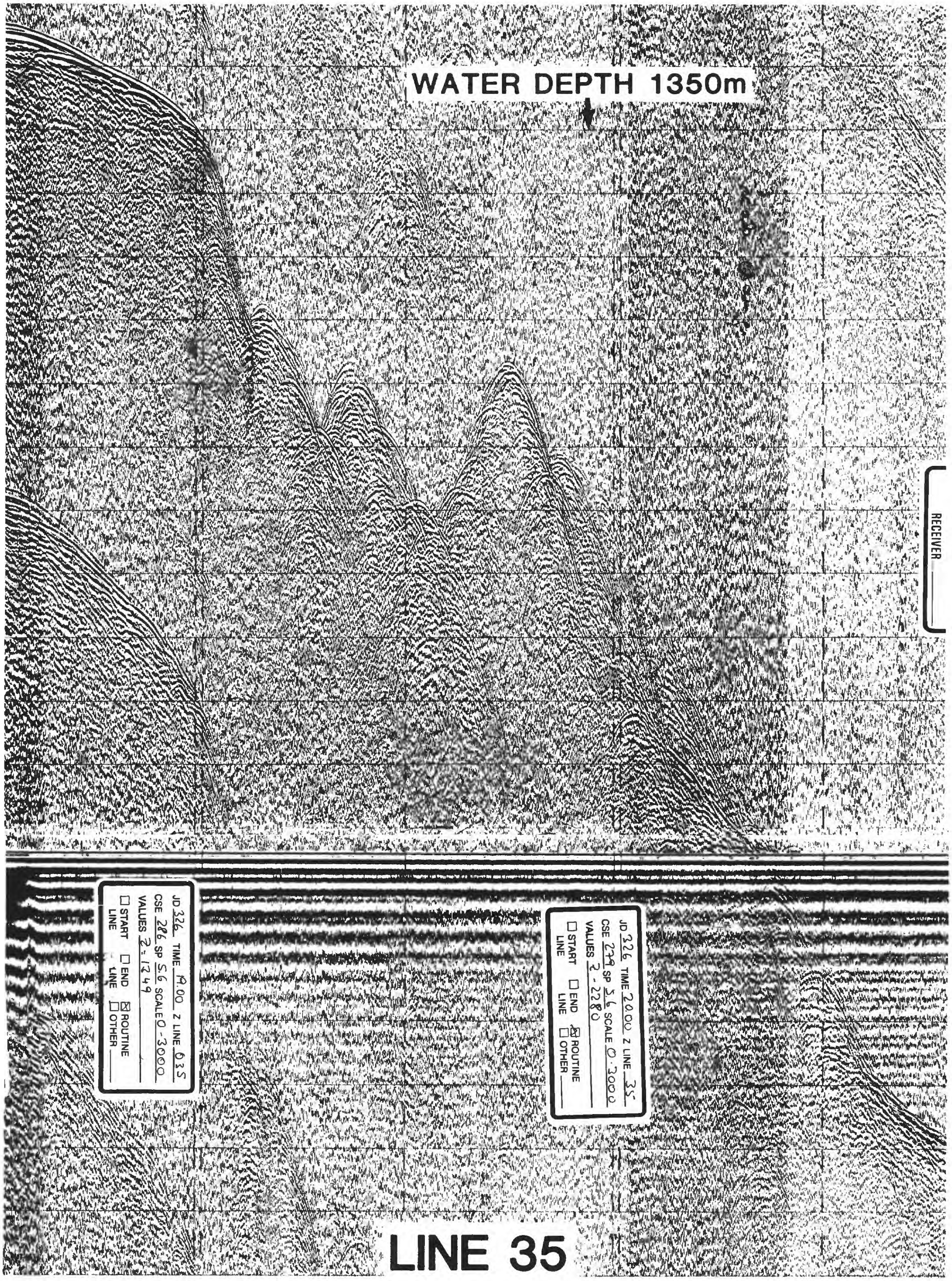


14 k




14 m
14 l
WATER DEPTH 1800m
LINE 31
LINE 32

14 n



14 o

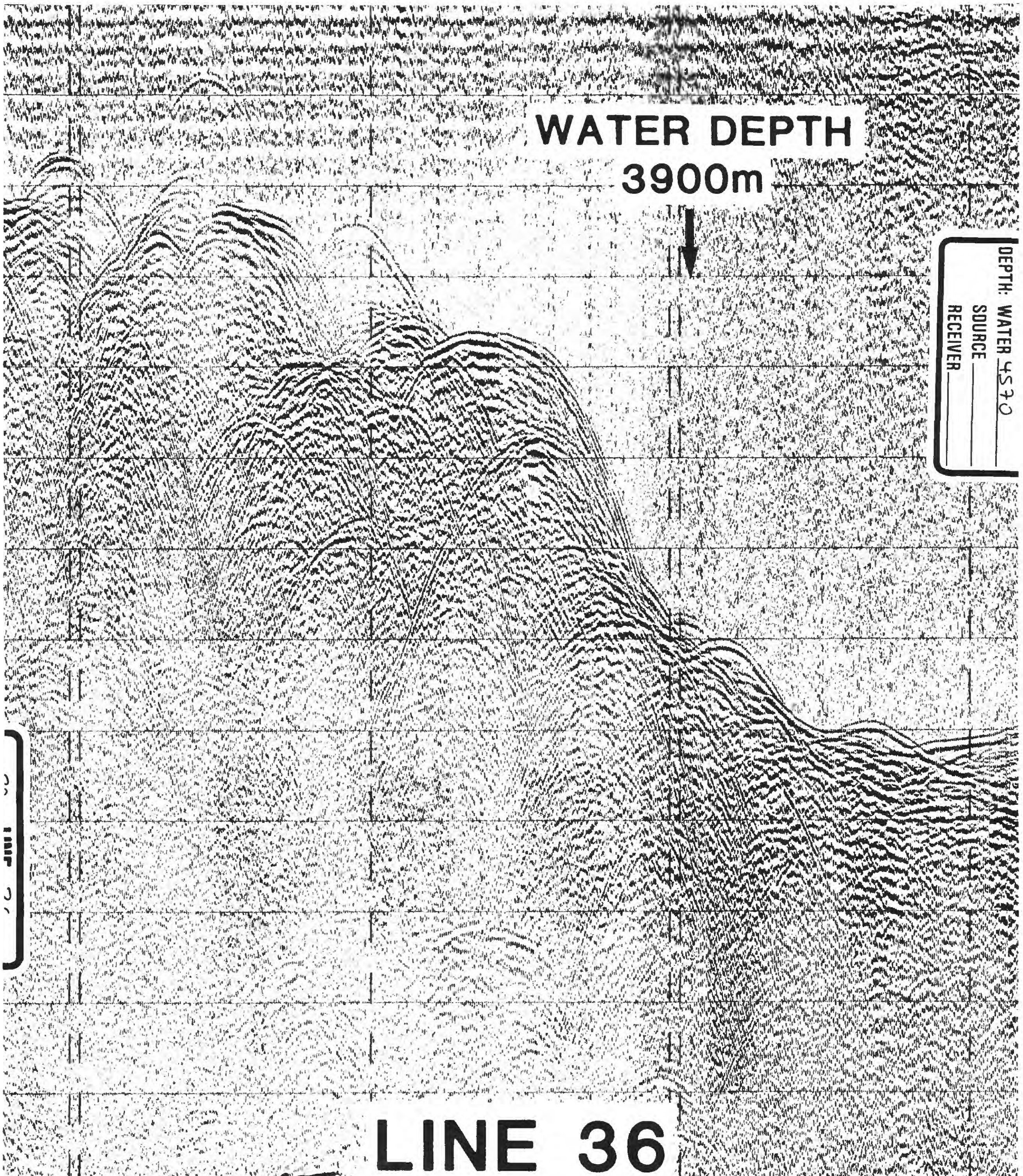
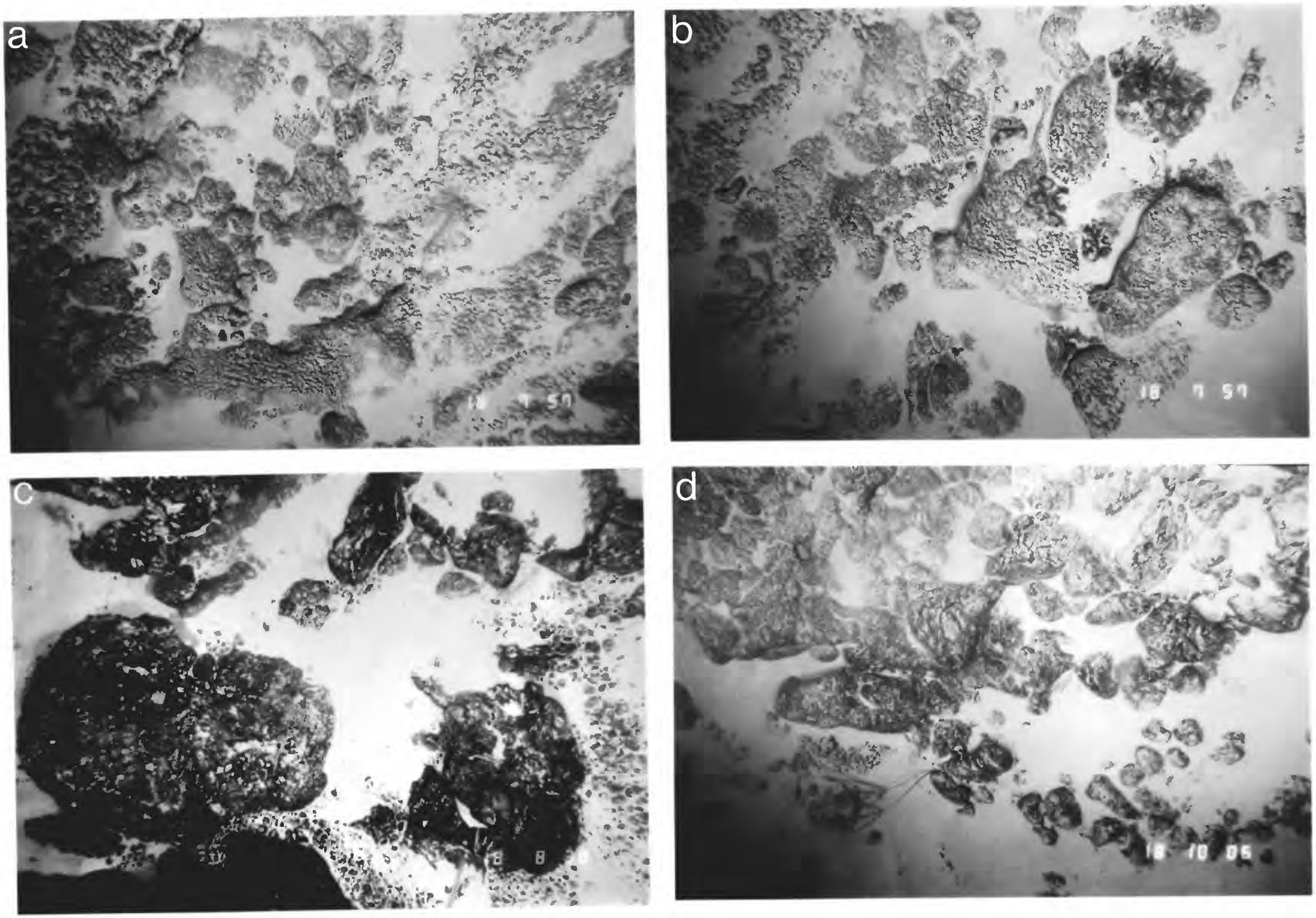


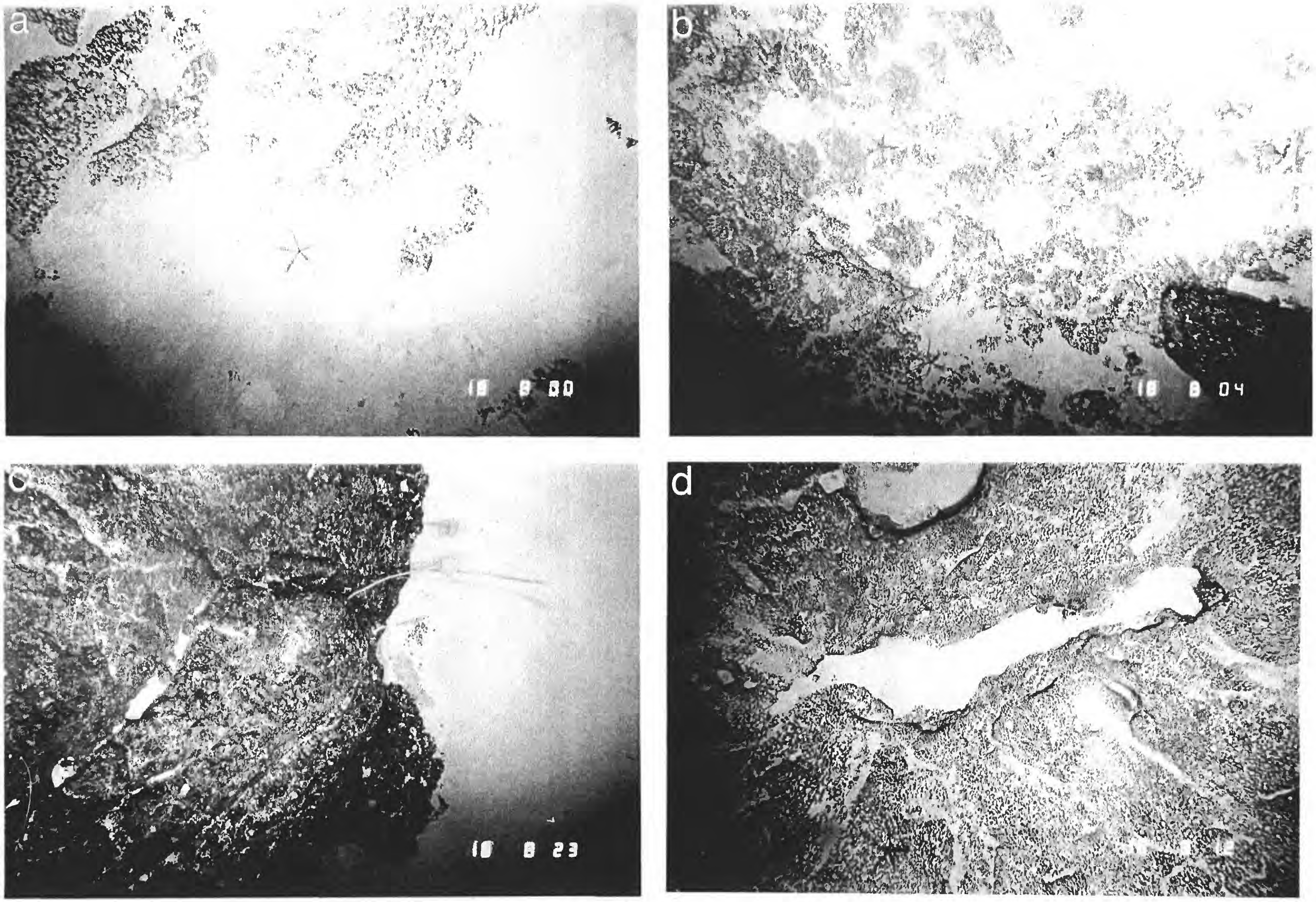
Figure 15. Bottom photographs of S.P. Lee Guyot (15-1 through 15-5). Field of view varies between 2 and 3 m on a side, depth of water between 1050 and 1800 m. All depths given below are plus or minus 10 meters.

15-1. Ferromanganese encrusted outcrops partly covered with calcareous ooze. Water depths are 1736, 1736, 1541, and 1296 meters respectively for a, b, c, and d.



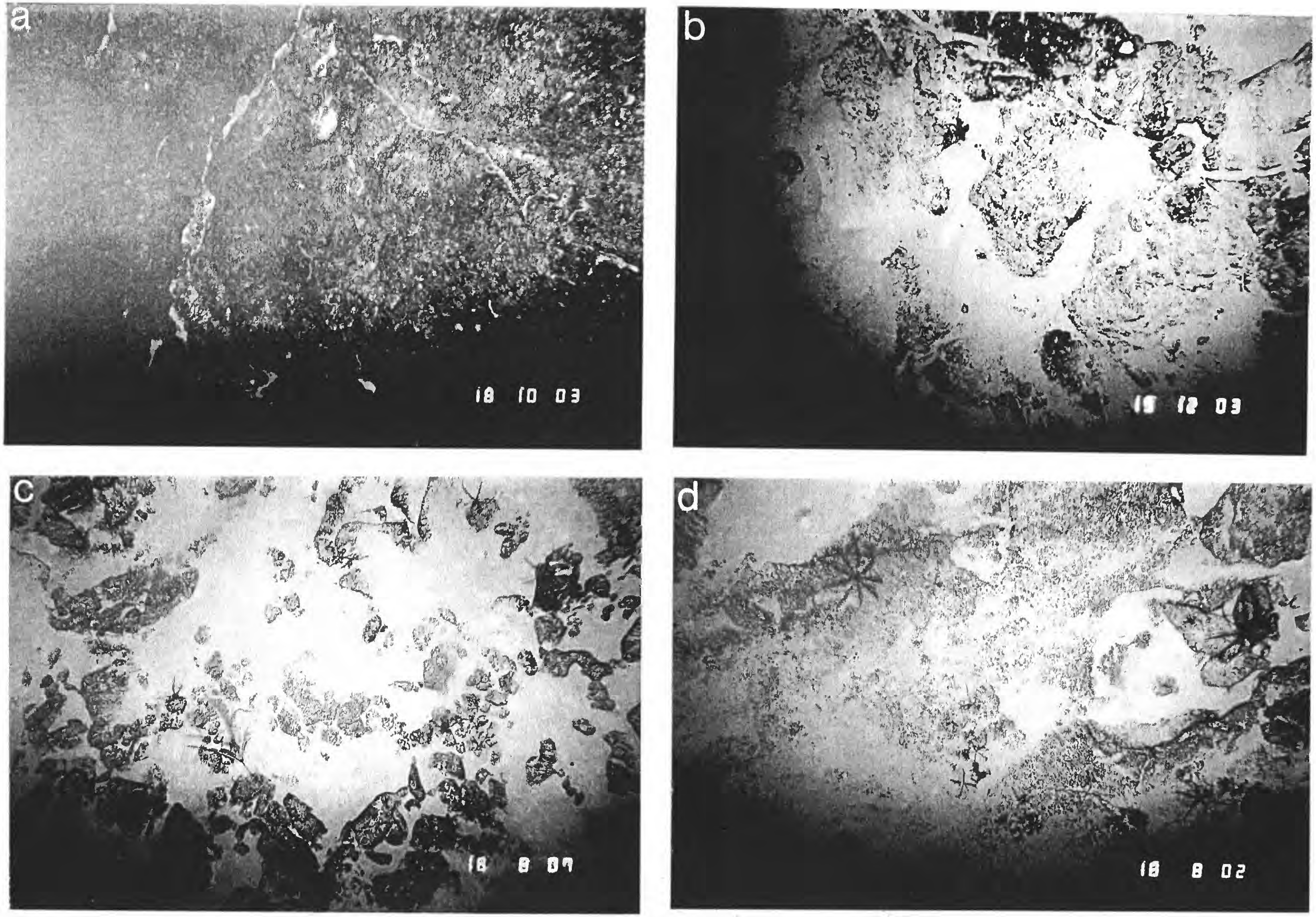
15-1

15-2. Ferromanganese encrusted outcrops, covered by varying degrees with calcareous ooze. Water depths are 1745, 1769, 1777, and 1712 meters respectively for a, b, c, and d.



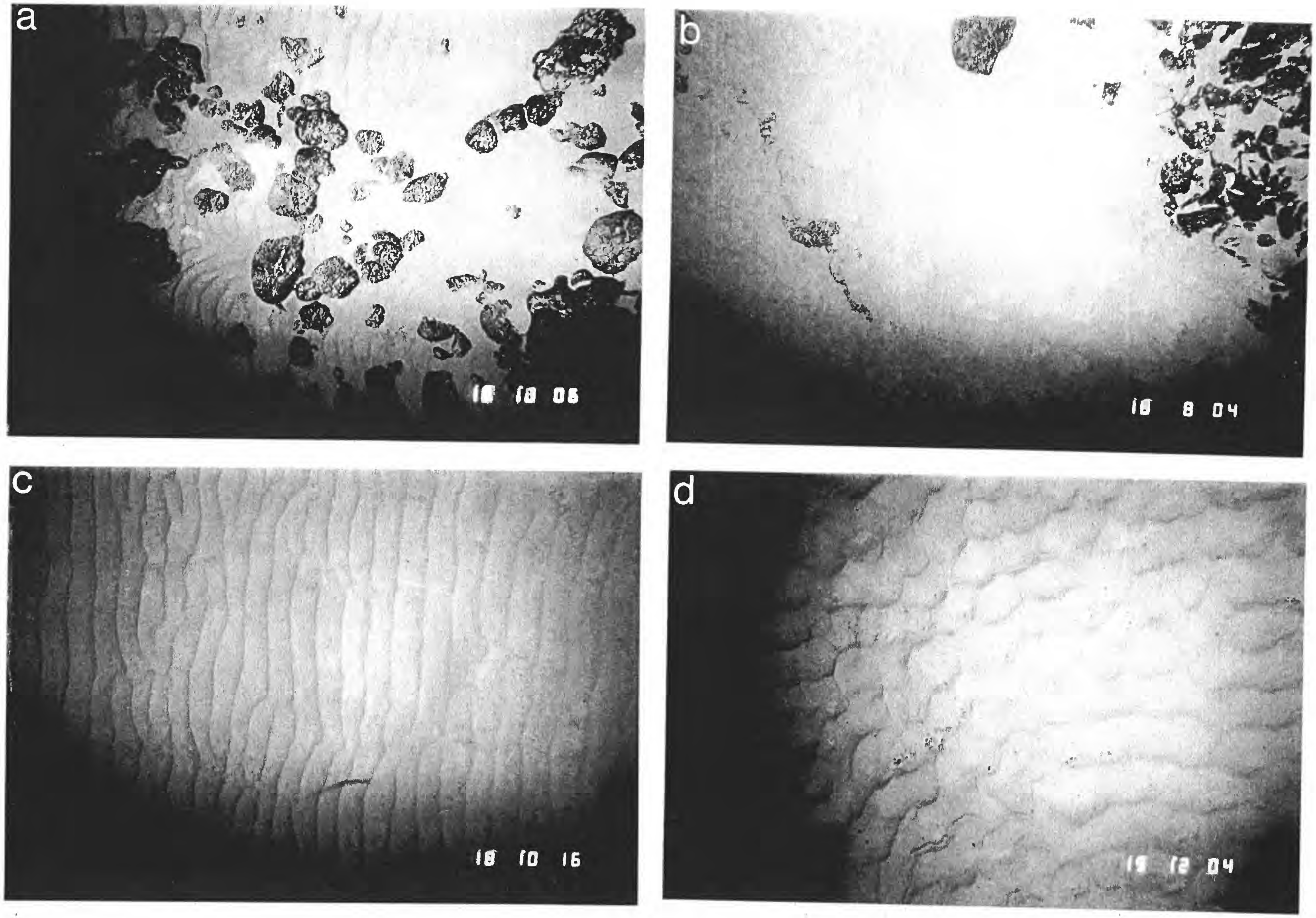
15-2

15-3. Seafloor partly to completely rock covered. In b, c, and d, only a thin sediment covers the outcrop. Many organisms in photos c and d. Water depths are 1296, 1133, 1753, and 1753 meters respectively for a, b, c, and d.



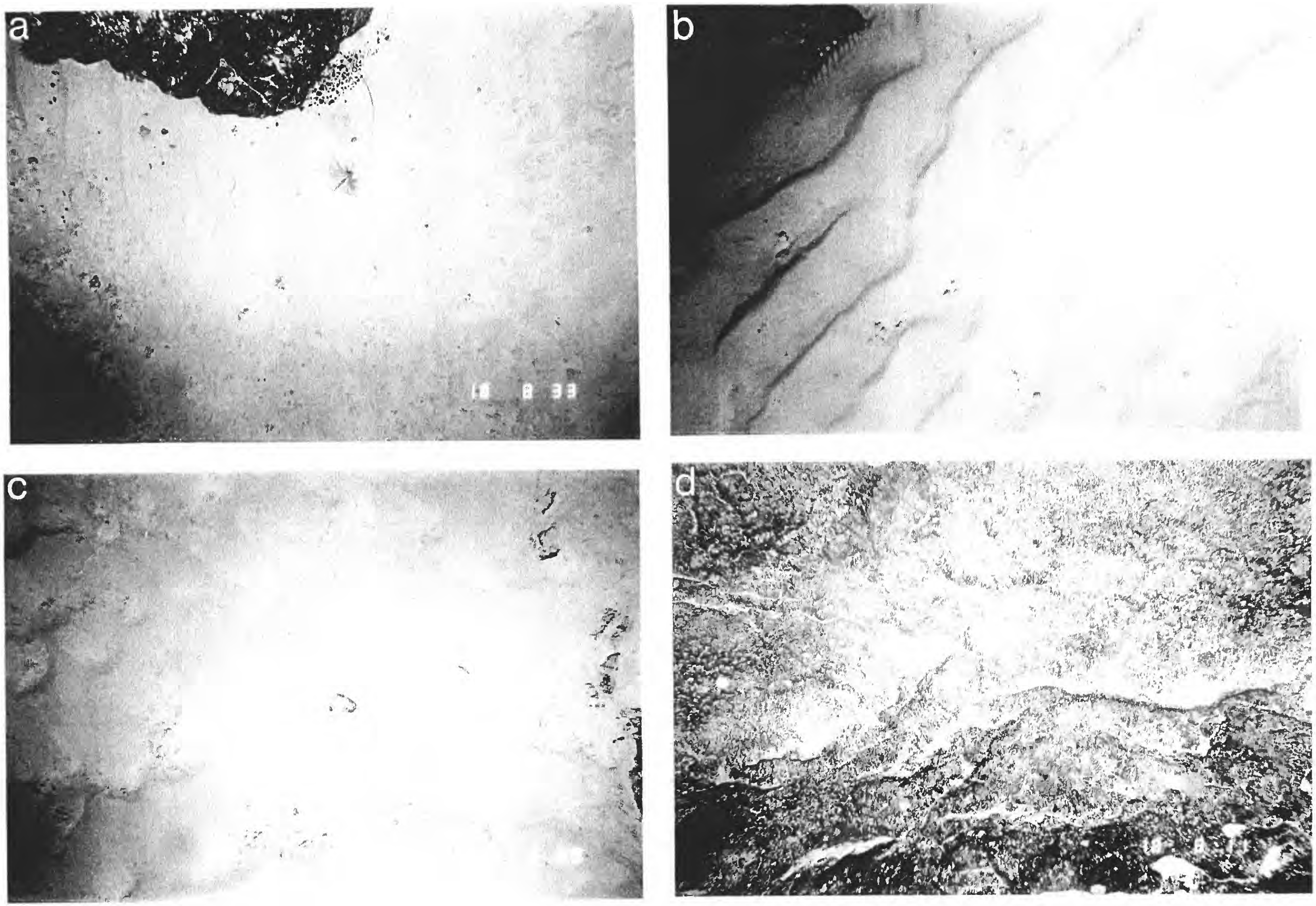
15-3

15-4. Currents are indicated by sand ripples. Long crested ripples occur in (c) and interference ripples in (d). Ferromanganese coated cobbles occur in (a), whereas a thin blanket of sediment covers a rock outcrop in (b). Water depths are 1296, 1769, 1696, and 1141 meters respectively for a, b, c, and d.



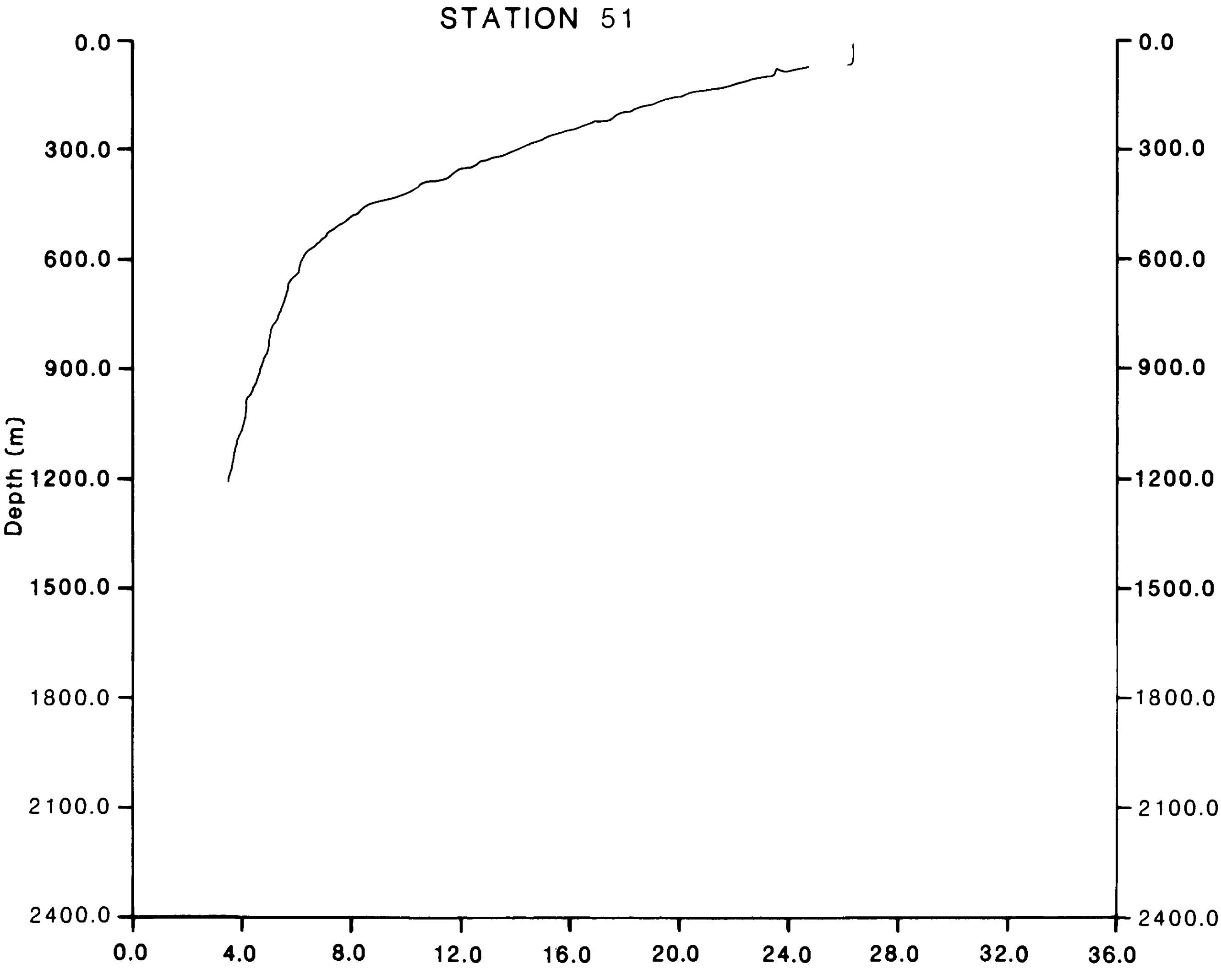
15-4

15-5. Currents indicated by sand ripples and by position of organism in (a). (d) shows a completely rock covered seafloor. Water depths are 1484, 1614, 1757, and 1736 meters respectively for a, b, c, and d.



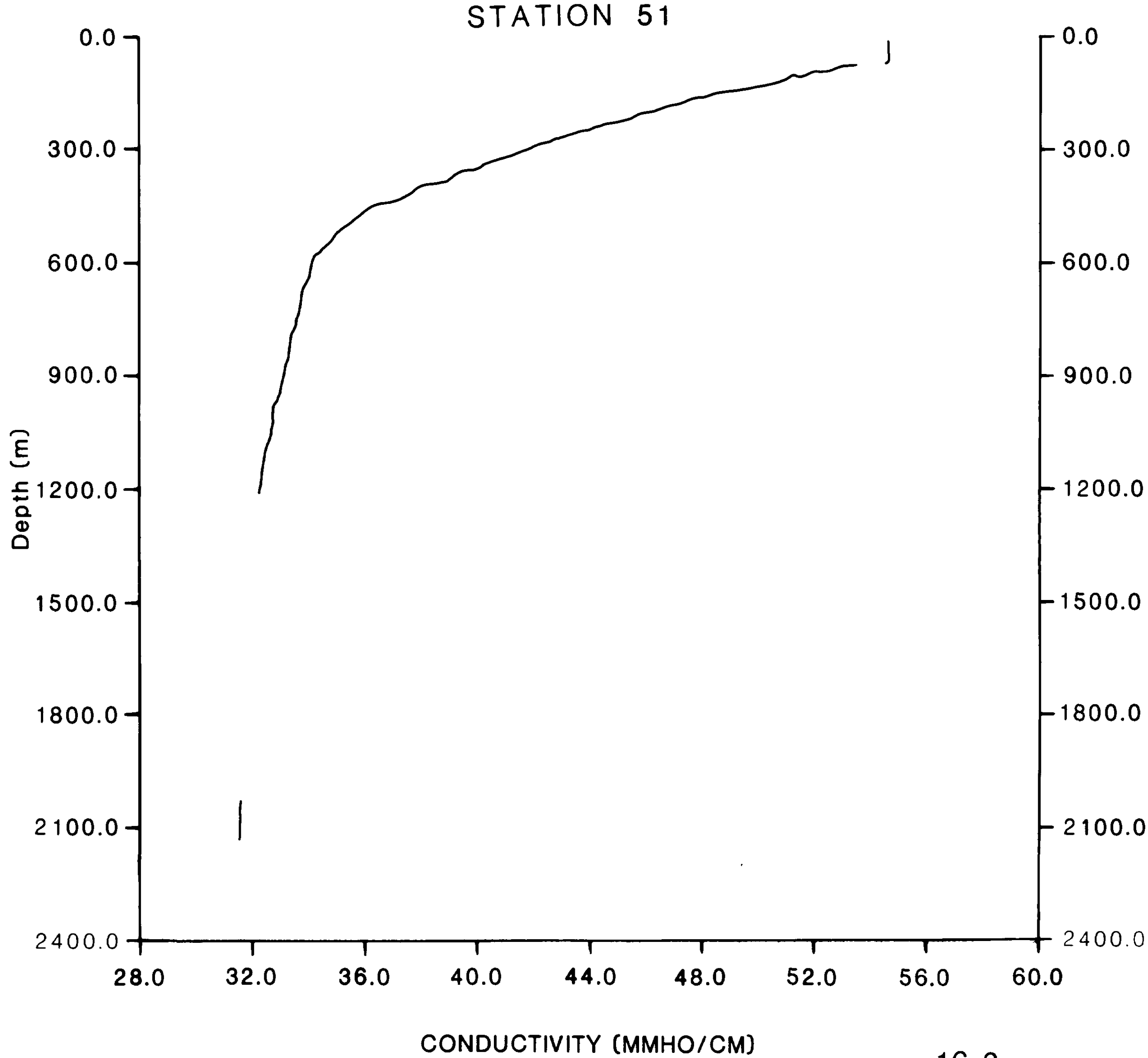
15-5

L5-83-HW S.P. LEE GUYOT



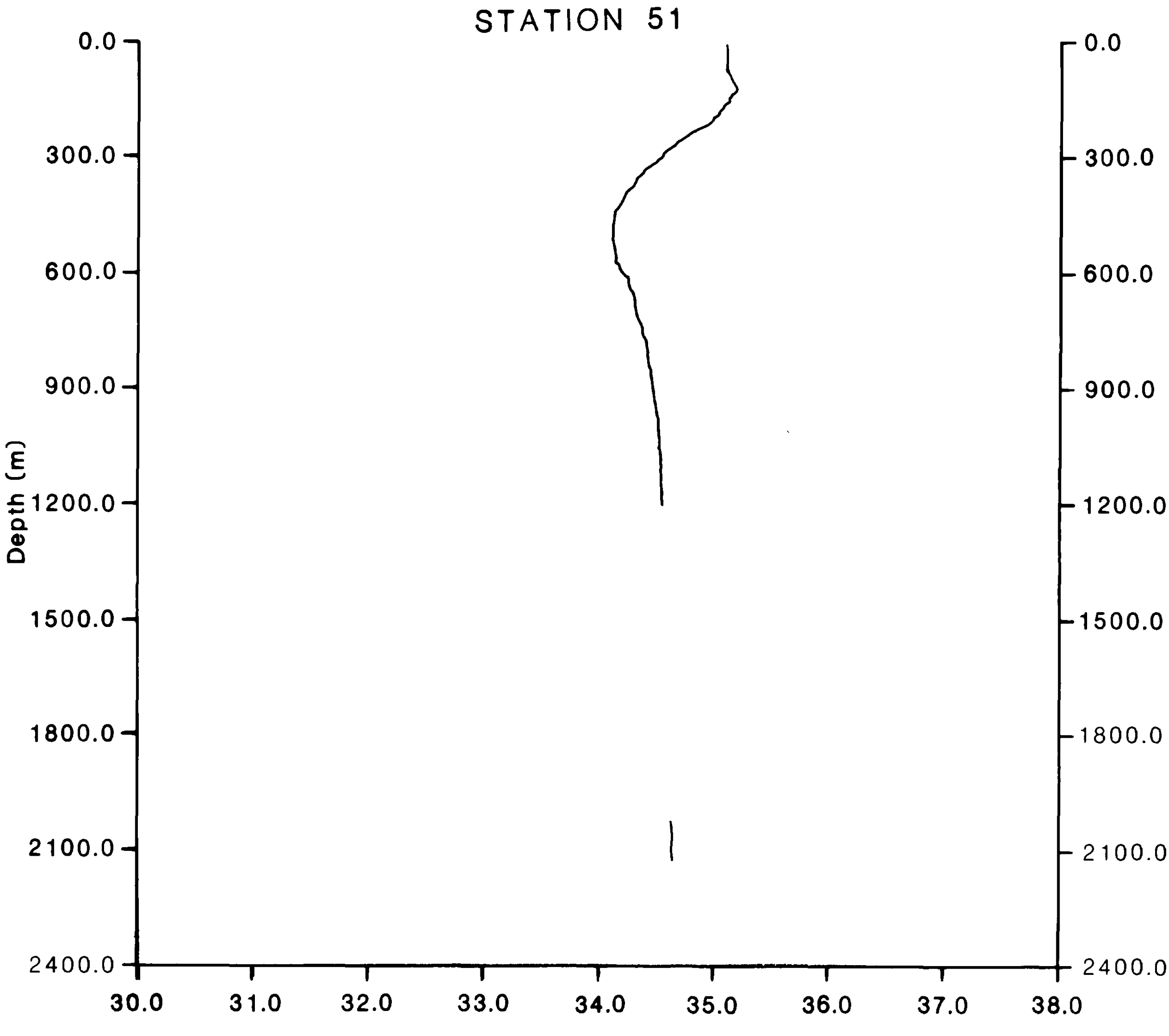
16-1

L5-83-HW S.P. LEE GUYOT



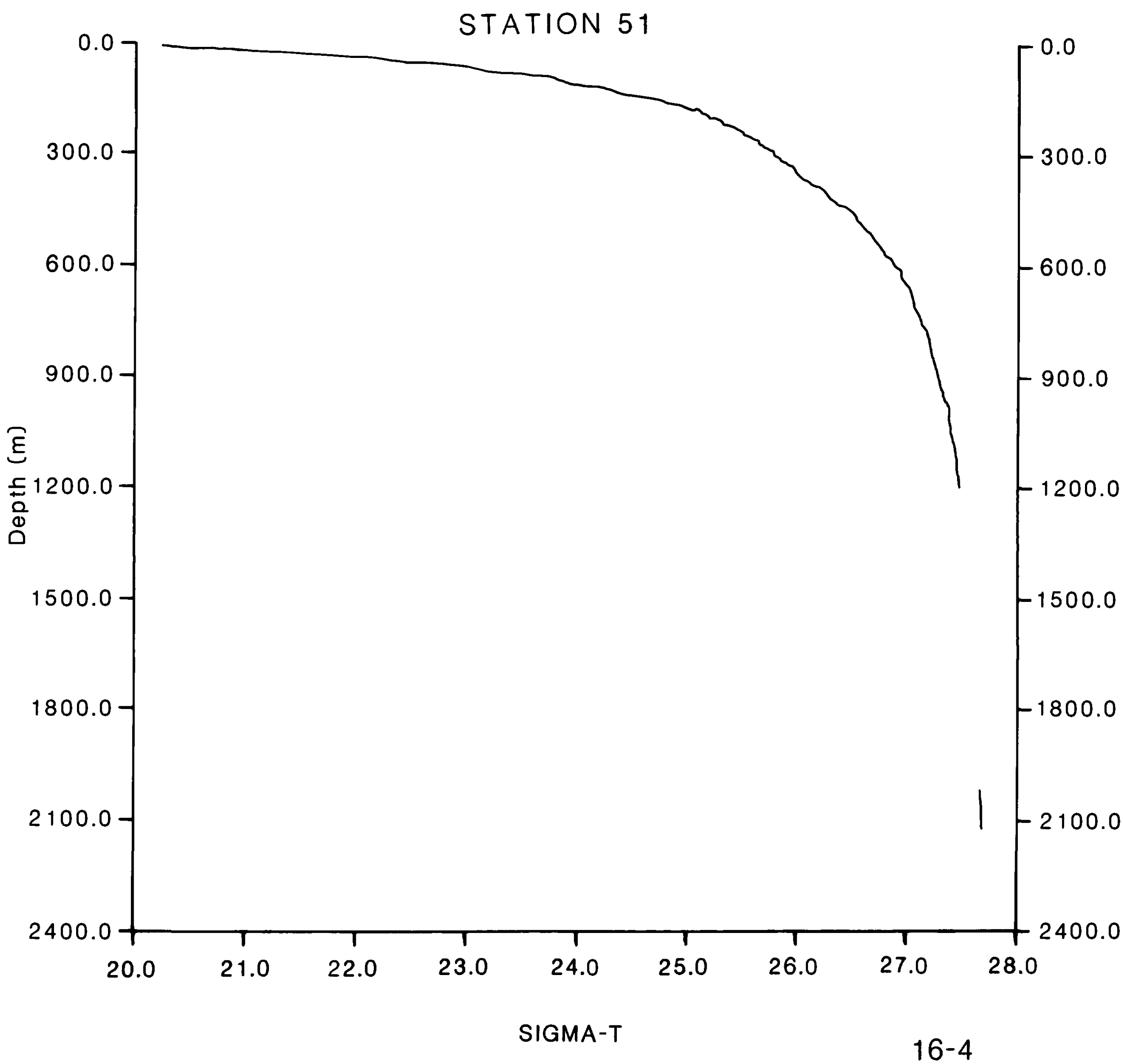
16-2

L5-83-HW S.P. LEE GUYOT

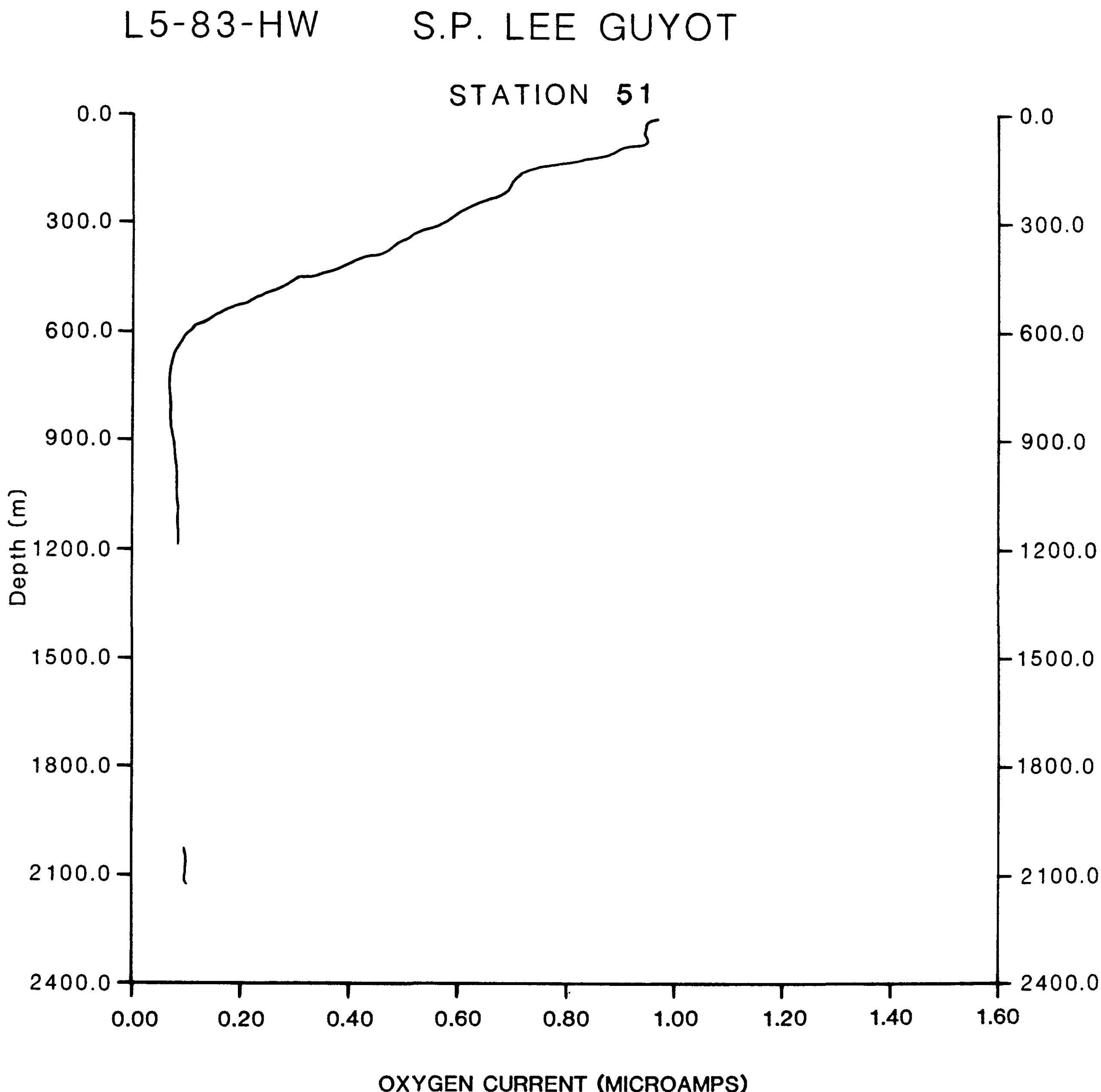


16-3

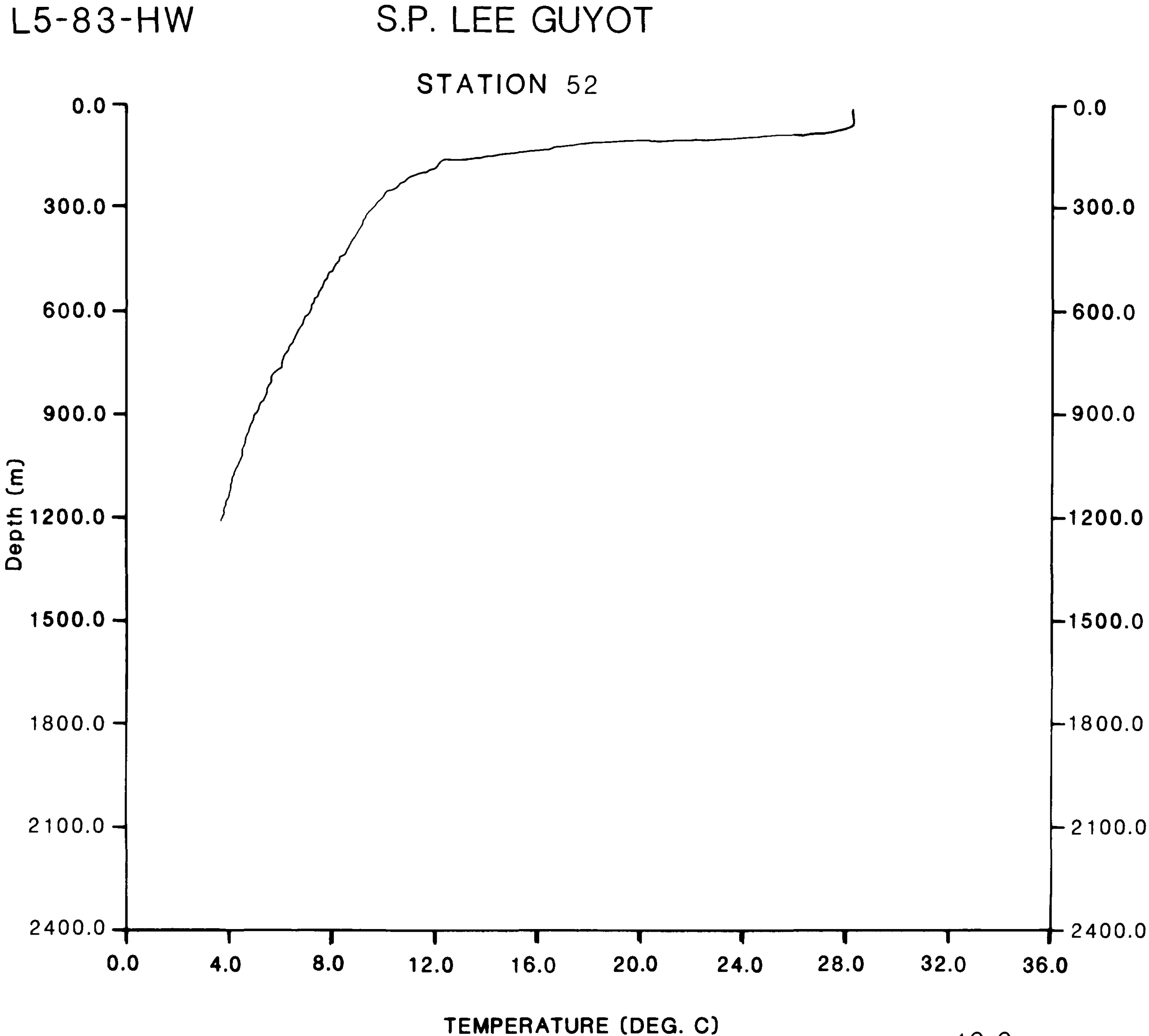
L5-83-HW S.P. LEE GUYOT



16-4


L5-83-HW S.P. LEE GUYOT
STATION 51
Depth (m)
0.0
300.0
600.0
900.0
1200.0
1500.0
1800.0
2100.0
2400.0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
OXYGEN CURRENT (MICROAMPS)

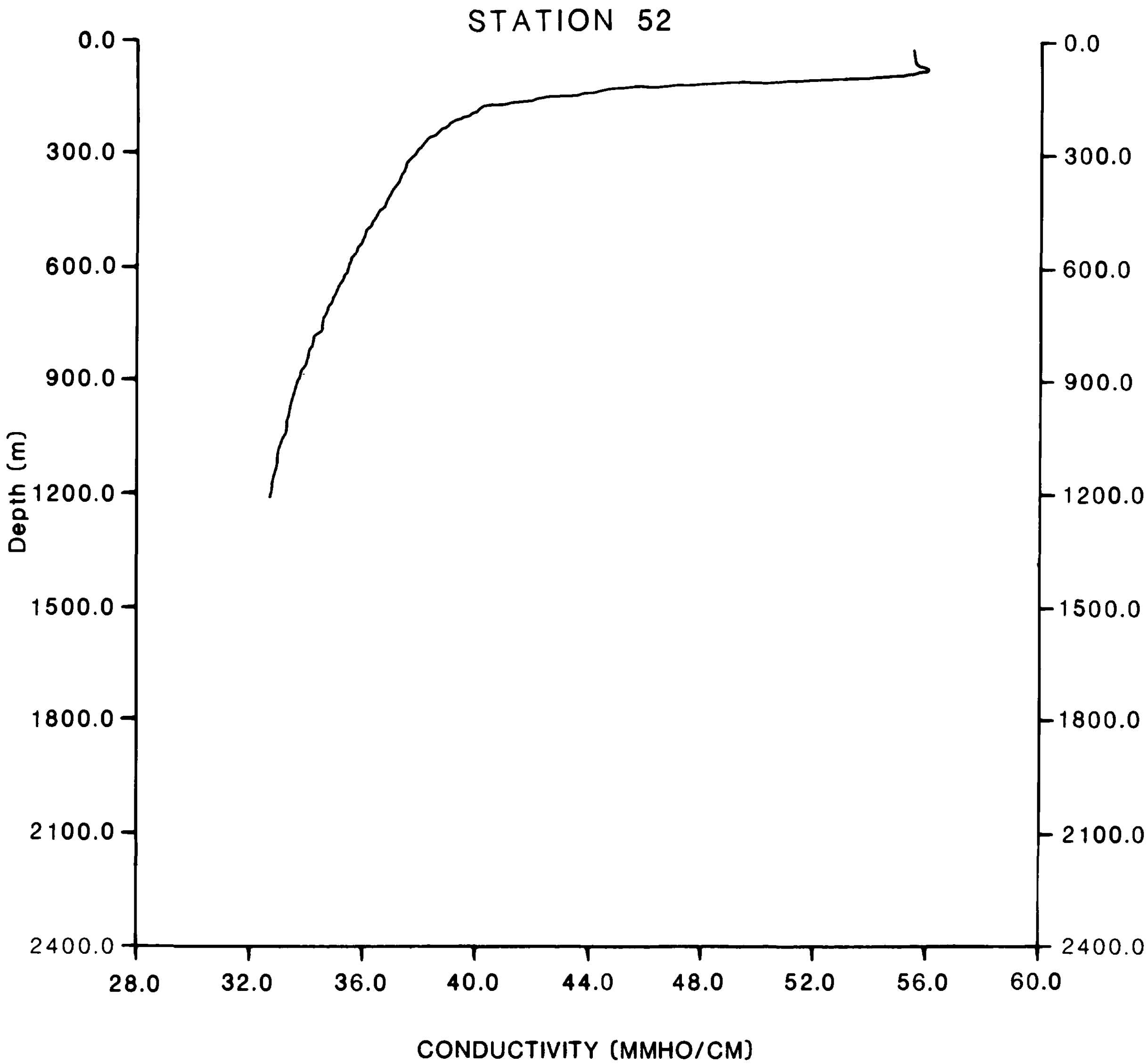
16-5



L5-83-HW
S.P. LEE GUYOT
STATION 52
0.0
300.0
600.0
900.0
1200.0
1500.0
1800.0
2100.0
2400.0
Depth (m)
0.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0
32.0
36.0
TEMPERATURE (DEG. C)

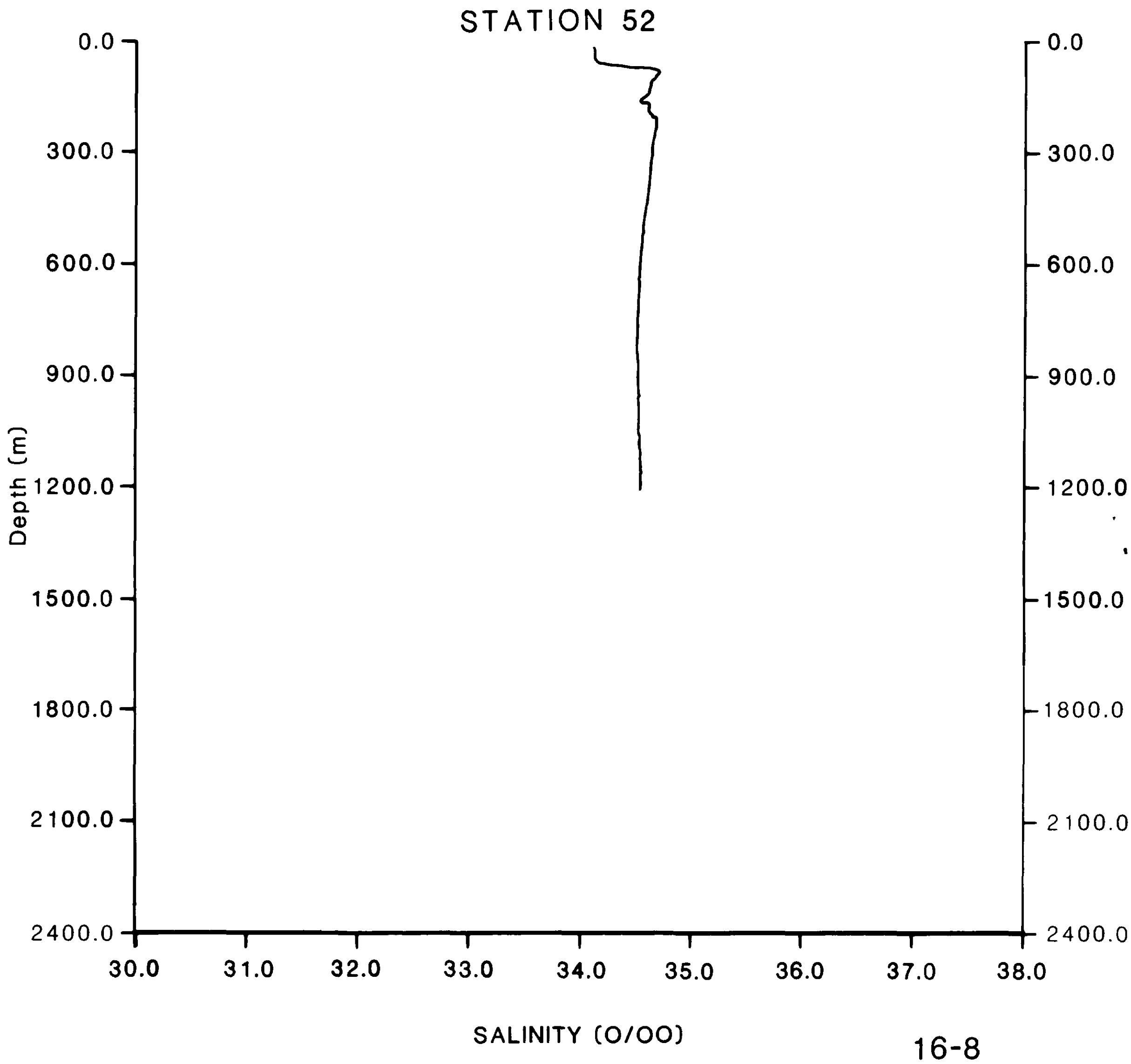
16-6

L5-83-HW S.P. LEE GUYOT

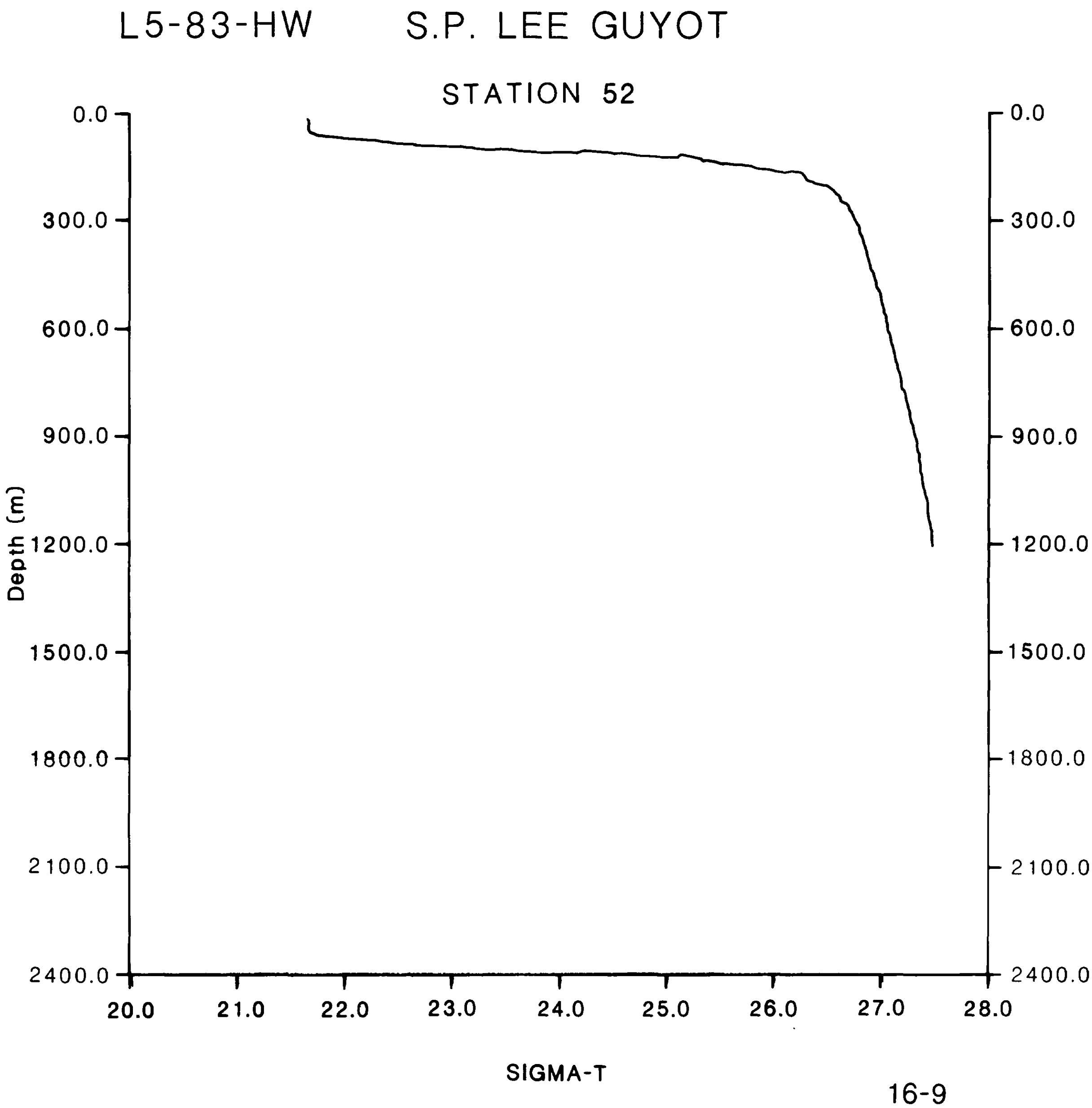


16-7

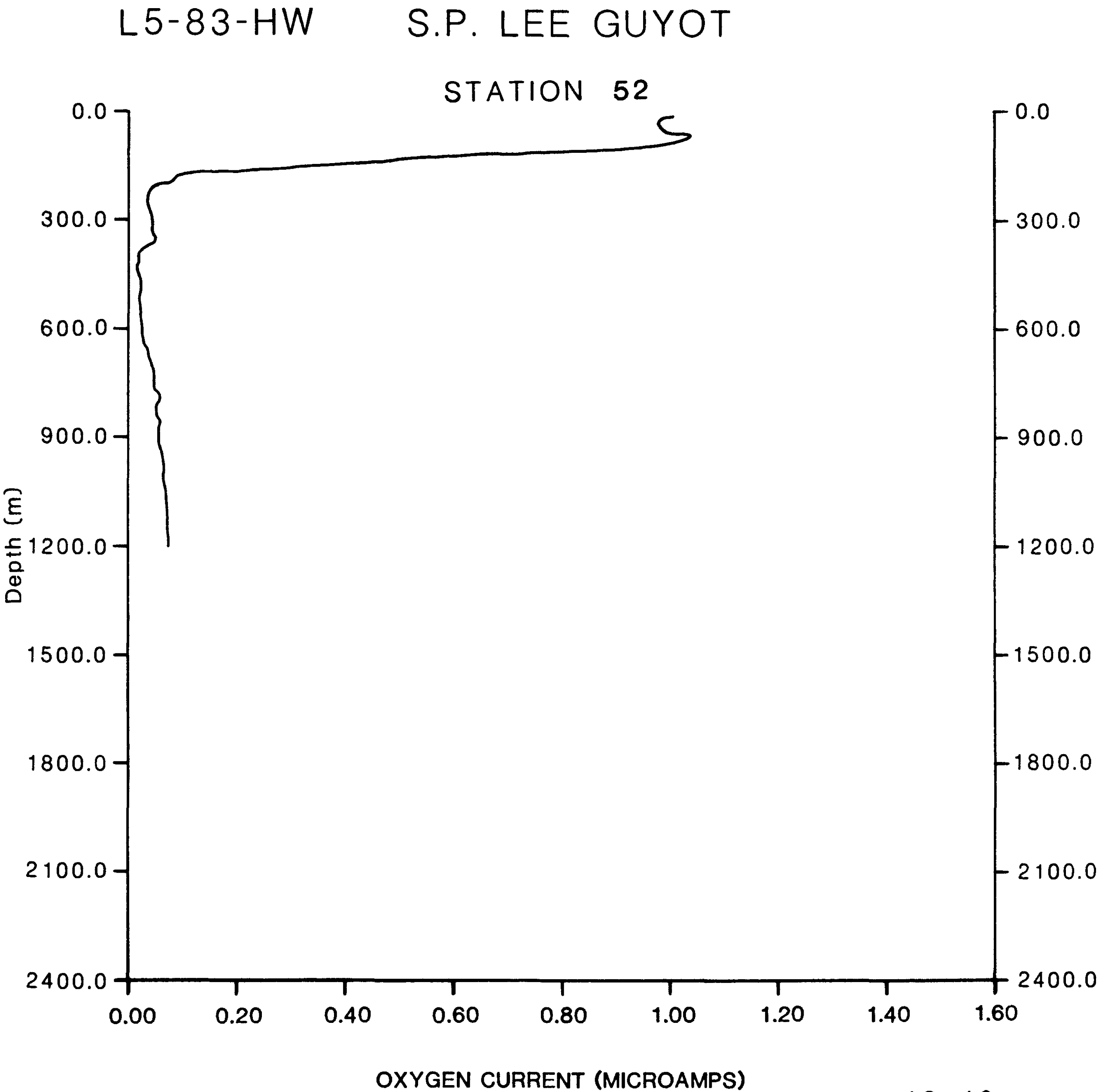
L5-83-HW S.P. LEE GUYOT



16-8


L5-83-HW S.P. LEE GUYOT
STATION 52
0.0
300.0
600.0
900.0
1200.0
1500.0
1800.0
2100.0
2400.0
Depth (m)
20.0
21.0
22.0
23.0
24.0
25.0
26.0
27.0
28.0
SIGMA-T

16-9


L5-83-HW S.P. LEE GUYOT
STATION 52
Depth (m)
0.0
300.0
600.0
900.0
1200.0
1500.0
1800.0
2100.0
2400.0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
OXYGEN CURRENT (MICROAMPS)

16-10

Table 18. Location and description of samples from S.P. Lee Guyot, Cruise L5-83-HW.

Sample No.	Latitude (N)	Longitude (W)	Water Depth (m)	approximate Sample wt. (kg)	Crust Description	Substrate Description
40-D23	8°24.84' 8°25.03'	164°17.36' 164°18.04'	1900- 1850	32	5% partly encrusted, 95% without crusts or with only dusting of Mn-oxide. Knobby to botryoidal, and smooth porous surfaces. Thicknesses 2-40 mm, average 20 mm for those rocks with crust.	Volcanic breccia, with calcite cement, and tuffaceous siltstone and sandstone showing graded bedding; hyaloclastite with orange-red palagonite clasts in greenish-gray clay-mineral matrix; basalt clasts are dark gray, fine-grained, olivine phyric, and are pseudomorphed by Fe-hydroxides and clay minerals.
41-D24	8°23.89'	164°21.52'	2400	32	10% partly encrusted, 90% without crusts or with only dusting of Mn-oxide. Botryoidal to granular and porous textures. Several stages of crust growth, erosion and regrowth. Thicknesses from <1-20 mm, average 6-8 mm.	Volcanic breccia with extremely altered red palagonite and basalt clasts in greenish clay mineral or pale brown phosphatized limestone cement; phosphatized carbonate siltstone and calcarenite with rare basalt pebbles; much reworking and animal borings in sedimentary rocks.
42-D25	8°23.35' 8°23.54'	164°17.61' 164°17.53'	1600	11	55% partly encrusted, 15% completely, and 30% without crusts. Surfaces are smooth to granular and porous. Thicknesses range from <1-20 mm, average 5 mm.	Pale to dark brown volcanic breccia, some with euhedral pyroxene crystals (cm-size) in poorly indurated calcareous siltstone and sandstone; basalt clasts and separate pebbles contain fresh euhedral clinopyroxene and olivine (pseudomorphed by calcite and clay minerals) phenocrysts in highly altered, red-brown glass groundmass.
45-D27	8°20.55'	164°19.02'	1150- 1125	225	95% completely and 5% partly encrusted; surfaces smooth to subtly botryoidal in lows. Thicknesses range from <1-30 mm and average about 10 mm.	Volcanic breccia, phosphorite, and siltstone and sandstone phosphatized to varying degrees; the silt-and-sandstone include minor well-rounded, highly altered basalt clasts and rare clinopyroxene crystals; abundant calcite and zeolite veins.
46-D28	8°18.47' 8°18.63'	164°20.73' 164°20.82'	1400	115	50% completely 30% partly encrusted; 20% crusts without substrate are massive on the inner part and porous on the outer layer. Surfaces are mostly smooth, others are botryoidal or granular and porous. Thicknesses are <1-40 mm, average 8-10 mm.	Volcanic breccia with well-rounded, extremely altered, vesicular basalt clasts, and abundant calcite and zeolite veins; volcaniclastic siltstone and sandstone.
47-D29	8°17.82' 8°18.69'	164°22.11' 164°21.04'	1700	70	60% partly encrusted, 40% without crusts; smooth, thin crusts follow the curves of the host rock. Thicknesses to 5 mm, average 2 mm.	White to pale brown phosphatized calcarenite; minor brown bioturbated volcaniclastic siltstone, and phosphorite; all with high water contents.
49-D31	8°11.64'	164°12.01'	1600- 1450	6	30% partly encrusted, 70% without crusts; one fragment of a thick (35 mm) crust without substrate is massive with a subdued knobby surface. Crusts are knobby to botryoidal. Thicknesses 1-35 mm, average 5-6 mm.	Volcanic breccia with reddish, highly vesicular, extremely altered rounded basalt clasts in white to brown phosphatized limestone cement; some clasts have large euhedral clinopyroxene crystals. Basalt and phosphorite pebbles.
50-D32	8°11.15' 8°11.00'	164°12.13' 164°12.00'	1800	135	70% partly encrusted, 30% without crusts. Irregular, porous crusts reflect the breccia surface. Thicknesses 1-7 mm, average 6 mm.	Volcaniclastic breccia, siltstone and sandstone (some with graded bedding); basaltic clasts are strongly altered and highly vesicular, some with phenocrysts of unaltered pyroxene and olivine pseudomorphed by calcite and clay minerals.

Table 19. Major oxides in weight percent: S.P. Lee Guyot substrate rocks, Cruise L5-83-HW.

	D23-9	D23-D3	D23-D4	D24-1A	D24-A3-6	D24-A3-9	D24-A3-16	D25-D	D25-10	D27-B1	D27-B5-9	D28-11
SiO_2	44.6	47.9	25.7	37.7	50.0	5.63	7.14	9.98	23.0	1.64	41.6	2.06
Al_2O_3	16.0	14.3	7.06	10.2	13.0	1.19	1.70	2.27	8.65	0.77	13.8	0.44
Fe_2O_3	13.1*	12.8	7.31	9.06	13.9	0.95	1.59	3.14	8.07	>76.1	10.2	1.03
FeO	--	0.16	<0.02	0.19	0.10	<0.02	<0.02	0.19	0.30	<0.02	0.87	<0.02
MgO	3.26	3.86	1.79	3.00	3.58	0.49	0.77	1.33	1.36	0.42	8.44	0.46
CaO	11.6	2.34	26.4	13.1	0.45	48.6	46.5	44.8	28.5	4.41	4.49	51.0
Na_2O	2.62	2.15	1.55	3.05	2.84	1.22	1.22	0.77	2.10	0.30	3.27	1.10
K_2O	1.59	2.80	2.09	2.56	2.76	0.43	0.40	0.58	1.26	0.10	2.28	0.15
TiO_2	3.71	3.92	1.66	2.38	4.32	0.02	0.45	0.56	1.93	0.14	2.58	0.26
P_2O_5	0.93	0.81	0.60	6.37	0.08	30.0	28.7	9.58	15.6	4.60	1.51	31.7
MnO	0.23	0.05	0.08	0.14	0.12	<0.02	0.03	<0.02	0.05	<0.02	0.23	0.24
H_2O^+	--	11.01**	7.24	7.04	11.69	2.57	2.87	2.25	6.06	10.44	11.51	2.59
CO_2	--	0.42	18.5	2.65	0.14	5.24	5.35	24.4	3.74	0.99	1.09	6.09
LOI (900°C)	2.60	8.87	25.50	9.54	8.42	6.65	6.51	25.49	7.24	11.63	10.32	7.05
Total	100.2	100.0	99.8	97.3	99.6	95.4	95.0	98.7	98.1	100.1	99.6	95.5
Lithology	Basalt	Volcani-clastic sandstone	Hyaloclas-tite calcite cement	Volcani-clastic mudstone	Volcanic breccia smectite and phillipsite cement	Phosphorite	Phosphorite	Volcanic breccia calcite cement	Volcanic breccia phillipsite and apatite cement	Iron-rich volcanic rock(?)	Volcanic breccia	Phosphorite

Table 19 cont.

	D28-A1	D29-A6	D29-A7	D29-A1	D31-1	D31-2	D31-10	D31-A1-1	D32-A1	D32-A2
SiO_2	16.8	8.09	11.1	0.79	39.4	8.60	32.9	31.8	42.3	35.0
Al_2O_3	6.85	2.60	3.51	<0.10	15.4	3.60	16.7	14.3	15.1	12.4
Fe_2O_3	6.08	4.10	4.36	0.00	16.0*	4.77	19.5	10.9	12.6	10.3
FeO	<0.01	0.36	0.19	0.77	--	0.30	3.11	2.32	0.41	1.12
MgO	0.87	0.88	1.01	0.51	5.42	0.76	2.83	2.17	3.41	2.03
CaO	35.0	42.7	40.1	51.3	12.0	39.8	4.89	9.76	4.26	13.0
Na_2O	2.06	1.62	1.78	1.34	1.72	1.37	2.06	2.50	2.43	2.53
K_2O	0.84	0.40	0.62	0.05	0.71	0.61	1.04	1.74	2.38	2.91
TiO_2	1.42	1.19	1.12	<0.02	5.13	1.45	6.70	4.34	4.32	3.66
P_2O_5	21.3	25.9	23.4	31.4	0.86	24.8	1.49	3.37	2.21	7.33
MnO	0.20	0.05	0.06	<0.02	0.15	0.20	0.10	0.18	0.14	0.14
H_2O^+	2.59	3.08	3.43	2.71	--	4.71	9.51	10.00	11.93	9.14
CO_2	7.20	5.67	6.27	3.83	--	4.99	0.42	3.48	0.80	1.74
LOI (900°C)	5.4	7.58	9.14	9.15	3.47	9.67	7.43	14.95	9.83	8.44
Total	96.8	95.5	96.4		100.3	95.9	98.8	98.3	99.4	98.9
Lithology	Phosphorite	Phosphorite (replaced clastic limestone)	Phosphorite (replaced pebbly, clastic limestone)	Volcanic breccia	Basalt	Phosphorite	Altered vesicular basalt	Volcanic breccia	Volcani-clastic sandstone	Volcanic breccia grain supported

* Total Fe as Fe_2O_3.
** H_2O^+ represents total water present. Samples were dried at 105°C before analysis.
Totals based on LOI.
Analyses performed at U.S. Geological Survey analytical laboratories in Denver and Menlo Park.

Table 20. Mineral content of substrates associated with ferromanganese crusts, S.P. Lee Guyot, Cruise L5-83-HW.

Sample No.	------X - r a y Major	Mineralogy------ Moderate	Minor or Trace	Comments
D23-D3	Plagioclase		Smectite Apatite	Sandstone
D23-D4	Mg-calcite		Phillipsite Smectite	Hyaloclastite, calcite cement
D24-A3-6	Phillipsite	Smectite	Chlorite?	Volcanic breccia
D24-A3-9	Apatite		Clinoptilolite/ Heulandite?	Phosphorite
D24-A3-16	Apatite			Phosphorite
D24-1A	Apatite Phillipsite Plagioclase Calcite	Smectite	Quartz Pyroxene?	Mudstone
D25-D	Calcite	Apatite	Plagioclase	Volcanic breccia
D25-10	Apatite	Phillipsite Plagioclase	Smectite	Volcanic breccia
D27-B1	Goethite	Apatite		Iron-rich volcanic rock(?)
D27-B5-9	Phillipsite	Smectite	Plagioclase	Volcanic breccia
D28-A1	Apatite	Plagioclase	Smectite	Phosphorite
D28-11	Apatite			Phosphorite
D29-A1	Apatite			
D29-A6	Apatite		Plagioclase	Phosphorite
D29-A7	Apatite		Phillipsite Plagioclase	Phosphorite
D31-A1-1	Plagioclase Calcite	Smectite Phillipsite	Apatite	Volcanic breccia
D31-2	Apatite		Plagioclase Smectite	Phosphorite
D31-10	Plagioclase Pyroxene		Smectite Phillipsite	Altered basalt
D32-A1	Plagioclase Smectite	Phillipsite Apatite		Sandstone
D32-A2	Phillipsite		Smectite Calcite Plagioclase	Volcanic breccia

Table 21. Mineral content of ferromanganese crusts, S.P. Lee Guyot, Cruise L5-83-HW.

Sample No.	Vernadite (%)	Plagioclase (%)	Quartz (%)	Apatite (%)	Others	Comments
D23-A1	100	0	0	0		inner crust
D23-A1	100	0	0	0		outer crust
D24-A2	100	0	0	0		Bulk
D25-B2	60	0	<1	22	Todorokite 17%	Bulk
D27-B1	89	0	0	11		inner crust
D27-B1	100	0	0	0		outer crust
D28	94	0	0	6		inner crust
D28	100	0	0	0		outer crust
D31-B	100	0	<1?	0		Bulk
D32-A1	97	0	<1?	1	Manjiroite?, Calcite? K-feldspar?	Bulk

Percentages were determined by using the following weighting factors relative to quartz set as 1 : vernadite 75, plagioclase 2.8, apatite 3.1, calcite 1.65. We determined the vernadite weighting factor by mixing known amounts of a pure vernadite crust and quartz; other weighting factors are from Cook et al. (1975). The limit of detection for each mineral falls between 0.5 and 1.0 percent.

Table 22-1. Chemistry of ferromanganese crusts, S.P. Lee Guyot, Cruise L5-83-HW. Hygroscopic water-free major oxides, weight percent, with sum. H_2O refers to chemically bound water determined by Penfield method. Sample type denotes sample chosen for analysis. Top generally refers to uppermost 5 mm of crust, or less. Total refers to entire thickness of crust. Bott. refers to crust between top 5 mm and substrate. "C" means sample is partly contaminated with substrate. Analyses done by USGS-Reston.

SAMPLE	SiO_2	TiO_2	MnO_2	Al_2O_3	Fe_2O_3	Co_3O_4	Ni_3O_4	CuO	CaO	MgO	K_2O	Na_2O	P_2O_5	CO_2	H_2O+	Sum	Sample Type	Total Thickness (mm)
D23-38	5.54	1.97	45.2	0.83	24.1	1.36	0.70	0.070	4.05	1.86	0.65	2.28	1.12	0.5	8.9	99.3	top	5
D23-39	5.70	2.15	40.2	1.02	26.7	1.02	0.55	0.078	4.48	1.69	0.57	2.01	1.42	0.6	8.7	96.9	total	3
D23-40	5.80	2.45	40.1	1.13	27.8	1.20	0.55	0.104	3.91	1.72	0.61	2.00	0.94	0.4	8.5	97.2	total	20
D24-41	7.04	1.78	40.9	1.13	24.8	1.12	0.61	0.094	3.96	1.74	0.67	2.20	1.05	0.3	7.6	95.2	total	30
D24-42	8.82	1.95	38.2	1.55	26.9	1.20	0.56	0.094	4.31	1.92	0.72	2.23	1.35	0.5	7.5	97.9	total	20
D25-43	5.90	1.73	39.0	1.55	21.9	1.63	0.77	0.090	7.50	2.30	0.60	2.25	3.67	0.9	7.8	97.8	total	10-15
D27-44	2.70	1.37	56.0	0.85	12.7	3.47	1.23	0.088	3.93	2.93	0.89	2.81	0.96	0.4	7.3	97.7	top	7
D27-45	2.52	1.67	44.7	0.47	20.0	1.66	0.46	0.041	7.94	1.91	0.65	2.31	3.85	0.8	8.3	97.4	total	10-15
D28-46	2.10	1.52	50.3	0.30	19.0	1.69	0.93	0.036	4.02	2.01	0.60	2.32	1.01	0.4	10.2	96.6	total	25
D28-47	2.32	1.47	48.0	0.51	20.4	1.45	0.80	0.045	4.80	1.82	0.59	2.32	1.33	0.5	9.7	96.3	bott.	3
D28-48	1.98	1.37	52.3	0.32	17.8	2.49	0.94	0.021	3.85	2.19	0.60	2.53	1.03	0.4	10.0	98.0	top	3
D31-50	3.32	1.58	47.8	0.62	20.6	1.97	0.62	0.054	3.86	1.82	0.69	2.54	1.12	0.4	8.5	95.7	top	5
D31-51	3.55	1.78	45.6	0.45	23.2	1.17	0.64	0.074	3.91	1.69	0.63	2.15	0.92	0.3	9.7	96.0	bott.	35
D32-52	8.80	2.03	38.3	1.97	20.2	1.80	0.70	0.045	4.05	1.84	0.94	2.67	1.17	0.7	8.3	93.6	top C	1-2

Table 22-2. Chemistry of ferromanganese crusts, S.P. Lee Guyot, Cruise L5-83-HW. Hygroscopic water-free major oxides, weight percent, with sum. *H_2O refers to chemically bound water computed by empirical relationship: $(Fe_2O_3 + MnO_2)/7$. Other is an empirical correction factor $(Fe_2O + MnO_2)/40$ to account for some minor constituents not included in table. For sample type and total thickness refer to Table 22-1. Analyses done by USGS-WH.

SAMPLE	SiO_2	TiO_2	MnO_2	Al_2O_3	Fe_2O_3	Co_3O_4	Ni_3O_4	CaO	MgO	K_2O	P_2O_5	H_2O-	H_2O+*	Other*	Sum
D23-38	5.91	1.85	43.0	1.10	23.3	1.43	0.73	3.54	1.82	0.59	0.92	18.4	9.5	1.66	95.4
D23-40	6.70	2.32	38.8	2.17	27.0	1.26	0.52	3.56	1.84	0.58	1.01	11.3	9.4	1.65	97.0
D24-42	8.57	1.77	35.7	1.91	25.2	1.35	0.56	3.79	1.69	0.64	1.26	5.3	8.7	1.52	92.8
D27-44	2.71	1.33	55.6	0.87	13.1	3.48	1.20	3.78	2.77	0.86	1.01	12.0	9.8	1.72	98.4
D28-46	2.66	1.50	49.3	0.49	19.1	1.65	0.94	3.82	1.81	0.59	0.85	10.3	9.8	1.71	94.4
D28-48	2.90	2.05	51.7	0.91	18.1	2.62	1.03	3.74	1.84	0.59	0.89	13.9	10.0	1.75	98.3

Table 22-3. Chemistry of ferromanganese crusts, S.P. Lee Guyot, Cruise L5-83-HW. Hygroscopic water-free major elements in weight percent. For sample type and total thickness refer to Table 22-1. Analyses by USGS-Reston.

SAMPLE	SiO_2	Ti	Mn	Al	Fe	Co	Cu	Ni	Ca	Mg	K	Na_2O	P	CO_2	H_2O-
D23-38	5.54	1.18	28.55	0.44	16.86	0.999	0.056	0.518	2.89	1.12	0.54	2.28	0.49	0.55	17.00
D23-39	5.70	1.29	25.41	0.54	18.64	0.748	0.062	0.403	3.20	1.02	0.47	2.01	0.62	0.60	15.80
D23-40	5.80	1.47	25.33	0.60	19.41	0.881	0.083	0.401	2.79	1.04	0.51	2.00	0.41	0.40	10.40
D24-41	7.04	1.07	25.86	0.60	17.35	0.820	0.075	0.452	2.83	1.05	0.56	2.20	0.46	0.37	4.90
D24-42	8.82	1.17	24.12	0.82	18.80	0.882	0.075	0.414	3.08	1.16	0.60	2.23	0.59	0.51	5.90
D25-43	5.90	1.04	24.67	0.82	15.34	1.201	0.072	0.568	5.36	1.39	0.50	2.25	1.60	0.91	6.80
D27-44	2.70	0.82	35.41	0.45	8.85	2.552	0.070	0.906	2.81	1.77	0.74	2.81	0.42	0.40	4.00
D27-45	2.52	1.00	28.28	0.25	13.98	1.219	0.033	0.336	5.67	1.15	0.54	2.31	1.68	0.82	4.90
D28-46	2.10	0.91	31.78	0.16	13.28	1.240	0.029	0.686	2.87	1.21	0.50	2.32	0.44	0.49	9.70
D28-47	2.32	0.88	30.37	0.27	14.30	1.064	0.036	0.587	3.43	1.10	0.49	2.32	0.58	0.53	9.80
D28-48	1.98	0.82	33.07	0.17	12.45	1.830	0.017	0.694	2.75	1.32	0.50	2.53	0.45	0.42	9.30
D31-50	3.32	0.95	30.23	0.33	14.39	1.450	0.043	0.454	2.76	1.10	0.57	2.54	0.49	0.46	9.70
D31-51	3.55	1.07	28.84	0.24	16.25	0.861	0.059	0.473	2.79	1.02	0.52	2.15	0.40	0.36	7.10
D32-52	8.80	1.22	24.19	1.04	14.15	1.326	0.036	0.512	2.89	1.11	0.78	2.67	0.51	0.72	10.30

Table 22-4. Chemistry of ferromanganese crusts, S.P. Lee Guyot, Cruise L5-83-HW. Hygroscopic water-free major elements, weight percent. For sample type and total thickness refer to Table 22-1. Analyses by USGS-WH.

SAMPLE	SiO_2	Ti	Mn	Al	Fe	Co	Ni	Ca	Mg	K	P	H_2O-
D23-38	5.91	1.11	27.16	0.58	16.28	1.053	0.539	2.53	1.10	0.49	0.40	18.40
D23-40	6.70	1.39	24.55	1.15	18.89	0.925	0.383	2.54	1.11	0.48	0.44	11.37
D24-42	8.57	1.06	22.55	1.01	17.61	0.993	0.412	2.71	1.02	0.53	0.55	5.34
D27-44	2.71	0.80	35.17	0.46	9.13	2.557	0.886	2.70	1.67	0.71	0.44	12.03
D28-46	2.66	0.90	31.17	0.26	13.38	1.215	0.691	2.73	1.09	0.49	0.37	10.30
D28-48	2.90	1.23	32.69	0.48	12.69	1.929	0.755	2.67	1.11	0.49	0.39	13.97

Table 22-5. Chemistry of ferromanganese crusts, S.P. Lee Guyot, Cruise L5-83-HW. Trace elements corrected for H_2O^- (hygroscopic moisture free basis), weight percent. For sample type and total thickness refer to Table 22-1. Analyses by USGS-Reston.

SAMPLE	Ba	Mo	Pb	Sr	V	Zn	Y	Ce	As	Cd	H_2O^-
D23-38	0.180	0.059	0.168	0.168	0.065	0.077	0.016	0.099	0.028	0.00035	17.00
D23-39	0.225	0.059	0.178	0.178	0.072	0.089	0.016	0.130	0.028	0.00026	15.80
D23-40	0.234	0.053	0.167	0.178	0.073	0.090	0.017	0.156	0.030	0.00027	10.40
D24-41	0.189	0.059	0.147	0.168	0.062	0.068	0.017	0.082	0.028	0.00028	4.90
D24-42	0.212	0.051	0.138	0.159	0.058	0.071	0.018	0.086	0.028	0.00032	5.90
D25-43	0.160	0.049	0.182	0.160	0.065	0.080	0.034	0.090	0.025	0.00042	6.80
D27-44	0.156	0.081	0.197	0.124	0.057	0.096	0.011	0.081	0.021	0.00094	4.00
D27-45	0.336	0.092	0.199	0.199	0.079	0.066	0.026	0.136	0.030	0.00035	4.90
D28-46	0.177	0.087	0.188	0.177	0.079	0.069	0.014	0.121	0.032	0.00043	9.70
D28-47	0.199	0.093	0.177	0.188	0.084	0.077	0.019	0.121	0.033	0.00046	9.80
D28-48	0.121	0.083	0.198	0.154	0.071	0.066	0.016	0.085	0.031	0.00054	9.30
D31-50	0.232	0.105	0.199	0.188	0.090	0.064	0.016	0.087	0.036	0.00046	9.70
D31-51	0.269	0.078	0.161	0.204	0.103	0.086	0.017	0.129	0.033	0.00037	7.10
D32-52	0.122	0.043	0.144	0.144	0.063	0.066	0.017	0.088	0.025	0.00040	10.30

Table 23. Physical properties of substrate rocks from S.P. Lee Guyot, Cruise L5-83-HW. Weight fraction of water is fraction of dry solids. The grain density used to calculate columns 2, 3, and 5 is 2.9.

Sample No.	Wet Bulk Density (g/cc)	Dry Bulk Density (g/cc)	Total wt. fraction of Water (g/g)	Percent Porosity	Rock Type
D23-D4	2.08	1.64	0.273	44	Calcite cemented hyaloclastite
D27-B5-9	2.04	1.56	0.303	47	Volcanic breccia
D31-10	2.22	1.84	0.203	37	Altered vesicular basalt

Table 24. Water content and ignition loss data for S.P. Lee Guyot, Cruise L5-83-HW. H. Mairs and K. Schmitz, analysts. H_2O on wet weight basis was established by loss on drying at 110°C. Dry weight basis means that starting material was air-dry powder, and all weight loss data are given as a weight percent of oven-dried sample (110°C) except hygroscopic moisture (H_2O). All data in weight percent.

Sample No.	Wet weight basis			----------Dry weight basis----------			
	H_2O^-	500°	1000°	H_2O	110-500°	500-1000°	110-1000°
D22B	32.2	40.4	43.4				
D23-B				20.15	11.0	6.70	17.70
D23-39				17.96	10.87	6.23	17.10
D24-41				9.77	9.71	6.03	15.74
D25-43				11.41	9.70	6.27	15.97
D27-45				6.71	9.34	7.15	16.49
D27	32.3	39.4	43.1				
D31-51				8.41	10.65	6.89	17.54

COLAHAN SEAMOUNT

Colahan Seamount is located at the northernmost end of the Hawaiian chain, just northwest of the U.S. EEZ boundary. Although Colahan Seamount is outside the EEZ, data from it should be comparable to seamounts at the northernmost end of the Hawaiian EEZ. Colahan Seamount was surveyed in 1971 on the Scripps Institution of Oceanography cruise Aries VII (Davies et al., 1971). A seismic profile showed rugged features and several peaks, the shoalest one supporting an actively-growing coral cap. A single dredge at the summit in water depths of 598 to 282 m recovered limestone and coral.

In 1982, R/V S.P. Lee cruise L8-82-NP dredged rocks in a single haul from 1920 to 1220-m water depth (Fig. 17). Rocks are both aphyric and phyric vesicular alkalic basalts, some containing amphibole (Table 25). Nearly all, of even the freshest lavas, are phosphatized, presumably as replacements of glass; most lavas have 2 to 5 weight percent P_2O_5 (Table 26). The low (average about 0.5%) P_2O_5 concentrations from fresh glass rinds on the basalt require the abundant apatite to be secondary. The age of the seamount is 37 to 40 m.y. old (Duncan and Clague, 1984).

Substrate mineralogy varies from relatively altered to unaltered basalts (Table 27). Fresh basalts are dominantly plagioclase or pyroxene; phillipsite and smectite are the dominant alteration products, some rocks being solely composed of these two minerals. Apatite occurs in varying amounts.

Ferromanganese crust mineralogy is dominated by vernadite (79 to 98 percent) with minor quartz and feldspar (less than 2 percent). Several crusts, however, contain todorokite (up to 12 percent) and phillipsite (up to 9 percent) (Table 28). The chemical composition of the crusts show relatively low Cu values and high Pb values (Table 29). For crusts collected at water-depths shallower than 2500 m, Mn averages 19.60%, Fe 12.09%, Co 0.44%, and Ni 0.34%.

Crusts average about 6 mm in thickness with a maximum of 15 mm (Table 25). Only 15 percent of the dredged rocks were encrusted with ferromanganese, the others contained only manganese stains.

ABBOTT SEAMOUNT

Abbott Seamount is located to the northwest of Colahan Seamount in the northern Hawaiian chain. Four seismic profiles were taken across Abbott Seamount in 1971 on the Aries VII expedition, which showed a relatively simple cone with a subsidiary cone on the lower northern flank (Davies et al., 1971). Abbott was surveyed in 1982, on the R/V S.P. Lee cruise L8-82-NP; bathymetric and seismic profiles, and two successful dredges were completed (Fig. 18; Duncan and Clague, 1984; Sager, 1984). Rocks recovered are vesicular basalts transitional between alkalic and tholeiitic (Table 25). As with Colahan Seamount, even the freshest Abbott Seamount basalts are phosphatized with P_2O_5 mostly between 2 and 4 percent (Table 30). Substrate mineralogy is primarily plagioclase, pyroxene, and apatite in the freshest rocks, with smectite and phillipsite becoming increasingly abundant with increasing alteration (Table 31). The age of the seamount is 36 to 41 m.y. old (Duncan and Clague, 1984).

Crust minerals are dominantly vernadite (95 to 100 percent) with minor quartz and plagioclase, which are more abundant in the inner crusts (Table 32). The chemical composition of the crusts shows low Cu values; the thickest crust has the lowest Fe and highest Cu values (Table 33). For crusts collected at water depths shallower than 2500 m, Mn averages 20.35%, Fe 11.26%, Co 0.61% and Ni 0.41%.

Crusts average about 10 mm in thickness with a maximum thickness of 57 mm. Most rocks recovered contained crusts greater than several millimeters (Table 25).

DISCUSSION

Most crusts studied are hydrogenous in origin; the elements that make-up the crusts precipitated from sea water. One crust from Necker Ridge, three from Colahan Seamount, and ferromanganese cement in a conglomerate from Horizon Guyot may have a hydrothermal input as suggested by the todorokite mineralogy. On the average Co, Ni, and Mn are richest in S.P. Lee Guyot crusts. These elements along with the mineral apatite increase in the crusts with decreasing latitude, that is from Necker Ridge to Horizon Guyot to S.P. Lee Guyot (see appendices 3 and 4). Only one Colahan crust contained apatite, and none from Abbott seamount contained apatite. Iron and the minerals quartz and feldspar show the opposite trend, decreasing with decreasing latitude. Even though the S.P. Lee Guyot crusts are among the richest analyzed for cobalt, the crusts are thin, averaging only 8 mm. This is partly the result of mass movement on the guyot flanks and of sedimentation. Mass movements abrade crusts or destroy them, and the growth process must begin again. Sedimentation covers the hard substrates necessary for initiation of growth of the crusts, and migrating sand can cover outcrops where crusts had already formed. (Hein et al., 1985).

Figure 17. Dredge stations, track line, and bathymetry of Colahan Seamount. The summit dredge is from Scripps Institution of Oceanography cruise Aries VII (Davies et al., 1971). Contour interval is 400 fathoms.

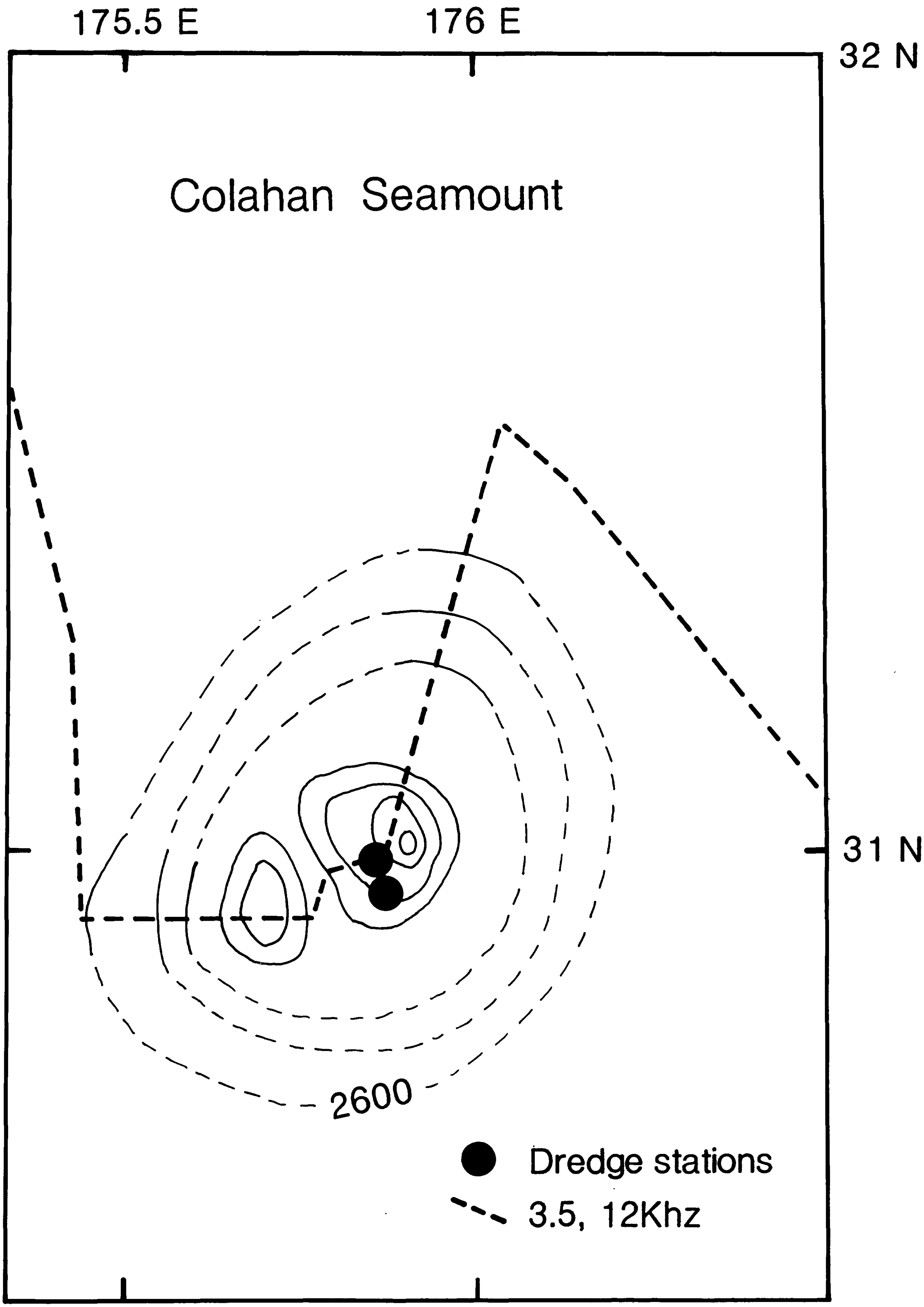

175.5 E
176 E
32 N
31 N
Colahan Seamount
2600
Dredge stations
3.5, 12Khz

Figure 18. Dredge stations (L8-82-NP) and bathymetry (Sager, 1984) for Abbott Seamount. Contour interval is 250 m.

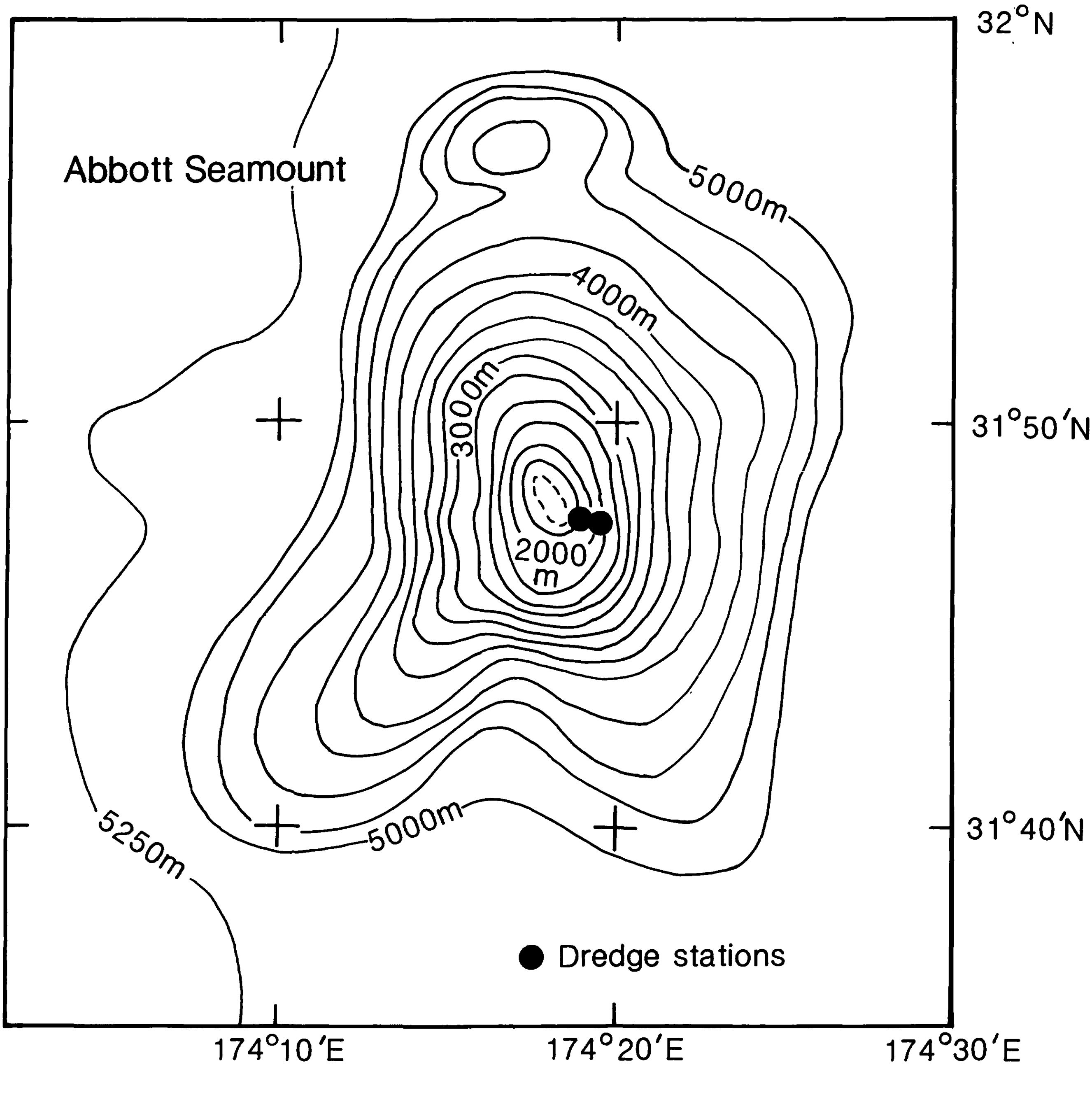

Abbott Seamount
5000m
4000m
3000m
2000
m
5250m
5000m
32°N
31°50′N
31°40′N
174°10′E
174°20′E
174°30′E
Dredge stations

Table 25. Location and description of samples from Colahan (D4) and Abbott (D2, D3) Seamounts, Cruise L8-82-NP, northernmost Hawaiian chain.

Sample No.	Latitude (N)	Longitude (E)	Water Depth (m)	Approximate Sample Wt. (kg)	Crust Descriptions	Substrate Descriptions
D4	30°59.2'	175°52.4'	1920-1220	90	32% of rocks have ferromanganese patina and are from talus deposits, 53% of rocks with patina were broken from outcrop; all rocks (15%) with thicker crusts were broken from outcrop. The thickest crust is 15 mm (one that is 25 mm is at least half phosphorite), average thickness 6 mm. Surfaces are botryoidal to smooth and highly fractured into chips.	Phosphatized, alkalic basalt (some contain amphiboles) comprise 92% of the rocks; volcanic breccia and volcaniclastic mudstone and sandstone comprise 8%. 85% of the rocks (84% = basalts, 1% = breccia) have a ferromanganese patina; 15% of the rocks (8% are basalts, 7% are breccias) have thicker ferromanganese crusts.
D2	31°47.5'	174°19.5'	2130-2000	8	Substrates broken from outcrop with crusts to 57 mm, average 12 mm. Crusts have botryoidal surfaces.	Phosphatized basalts transitional between tholeiitic and alkalic; thick ferromanganese crusts. Few fragments of coralline limestone.
D3	31°47.6'	174°19.0'	2130-1462	23	60% of rocks were broken from outcrop, 40% were from talus deposits. Crust up to 12 mm thick, average 8 mm. Most surfaces botryoidal, even with thin crusts, some are smooth.	90% phosphatized basalts transitional between tholeiitic and alkalic, some with relatively thick ferromanganese crusts; 10% volcanic breccia, some with thick crusts.

Table 26. Major oxides in weight percent: Freshest Colahan Seamount basalts, Cruise L8-82-NP.

	4-18	4-21	4-22	4-23	4-26	4-47	4-48	4-50	4-56	4-57	4-60	4-62	4-63	4-65	4-67	4-68
SiO_2	43.2	48.7	40.2	46.1	40.3	51.1	38.6	39.7	42.4	43.7	52.1	48.4	38.4	46.3	50.6	37.8
Al_2O_3	12.3	18.1	11.7	12.1	11.8	18.0	15.4	9.57	12.1	14.5	19.5	11.4	15.1	12.1	18.3	9.83
Fe_2O_3	11.8*	7.92	14.1	14.0	13.3	7.39	10.1	13.4	14.3	13.2	7.90	13.5	13.5	13.5	7.30	14.5
MgO	5.87	2.53	4.78	8.72	4.79	2.36	3.81	7.32	5.22	4.34	2.74	11.9	1.97	8.10	2.51	6.22
CaO	14.3	6.23	13.4	9.81	14.7	5.01	13.9	13.1	14.3	11.2	6.32	9.09	11.4	9.88	6.24	14.1
Na_2O	2.14	4.83	2.28	1.70	2.28	5.12	2.42	2.41	2.14	2.58	4.08	1.81	2.55	2.14	4.37	1.29
K_2O	0.69	3.24	0.70	0.76	0.76	3.40	1.53	2.01	0.54	1.02	2.57	0.59	1.72	0.65	2.82	1.46
TiO_2	3.35	2.43	3.13	2.05	3.01	2.13	3.40	2.88	2.07	3.67	2.37	1.96	3.91	2.00	2.10	3.00
P_2O_5	2.90	0.93	2.98	0.30	3.90	0.65	5.11	2.23	3.32	1.86	1.05	0.21	4.49	0.62	1.09	3.61
MnO	0.28	0.20	0.72	0.15	0.29	0.19	0.24	0.25	0.35	0.91	0.21	0.18	0.28	0.53	0.20	0.23
LOI (900°C)	3.29	4.22	4.17	4.90	4.04	4.49	4.79	7.35	3.96	3.54	1.34	1.50	6.25	4.77	4.53	7.88
Total	100.12	99.33	98.16	100.59	99.17	99.84	99.30	100.22	100.70	100.52	100.18	100.54	99.57	100.59	100.06	99.92

* Total Fe as Fe_2O_3.

Table 27. Mineral content of substrates associated with ferromanganese crusts, Colahan Seamount, Cruise L8-82-NP.

Sample No.	X-ray Mineralogy			Comments
	Major	Moderate	Minor or Trace	
D4-3	Phillipsite		Apatite Pyroxene Smectite Plagioclase	Volcanic breccia
D4-8	Phillipsite		Smectite	Cavity fill in basalt
D4-8	Phillipsite	Plagioclase	Apatite	Basalt
D4-38	Smectite		Plagioclase Chlorite?	Mudstone
D4-40	Apatite		Phillipsite	Phosphorite
D4-68	Pyroxene		Apatite	Basalt

Table 28. Mineral content of ferromanganese crusts, Colahan Seamount, Cruise L8-82-NP.

Sample No.	Vernadite (%)	Plagioclase (%)	Quartz (%)	Apatite (%)	Others	Comments
D4-8	95				Todorokite (5%)	outer crust
D4-8	79				Todorokite (12%) Phillipsite (9%)	inner crust
D4-8	90		1		Phillipsite (9%)	amygdule filling
D4-9	72		1	25	Todorokite (2%) Calcite (<1%)	bulk
D4-68	98	1.5	0.5		bulk	

Percentages were determined by using the following weighting factors relative to quartz set as 1 : vernadite 75, plagioclase 2.8, apatite 3.1, calcite 1.65. We determined the vernadite weighting factor by mixing known amounts of a pure vernadite crust and quartz; other weighting factors are from Cook et al. (1975). The limit of detection for each mineral falls between 0.5 and 1.0 percent.

Table 29. Chemical composition of bulk crusts from Colahan Seamount. Analysis by Atomic Adsorption, listed in weight percent and corrected for water content determined at 110°C.

	D4-42	D4-43	D4-68
Mn	23.26	22.84	19.71
Fe	15.15	13.83	11.88
Co	0.59	0.47	0.41
Ni	0.40	0.38	0.37
Pb	0.25	0.25	0.19
Cu (ppm)	260	320	250
Zn (ppm)	560	510	840
Crust thickness	2 mm	2 mm	<1 mm

Table 30. Major oxides in weight percent: Freshest Abbott Seamount basalts, Cruise L8-82-NP.

	2-1	2-2	2-3	3-9	3-10A	3-11	3-12
SiO_2	42.6	42.7	44.2	56.6	44.0	43.3	46.4
Al_2O_3	14.0	13.9	15.0	12.9	14.8	14.6	14.9
Fe_2O_3	12.2*	12.3	12.9	9.93	11.8	11.5	12.2
MgO	3.46	3.46	2.96	3.38	3.59	3.47	4.05
CaO	12.8	12.4	10.5	8.33	12.9	13.6	10.4
Na_2O	2.49	2.58	2.58	2.38	2.84	2.77	2.73
K_2O	0.71	0.81	0.66	0.58	0.50	0.51	0.68
TiO_2	3.33	3.43	3.65	2.86	3.38	3.30	3.47
P_2O_5	3.60	3.54	2.42	1.01	3.06	3.51	1.44
MnO	0.20	0.15	0.15	0.14	0.1	0.11	0.22
LOI (900°C)	4.64	4.85	5.46	2.65	3.22	3.55	3.76
Total	100.03	100.12	100.48	100.76	100.19	100.22	100.25

* Total Fe as Fe_2O_3.

Table 31. Mineral content of substrates associated with ferromanganese crusts, Abbott Seamount, Cruise L8-82-NP.

Sample No.	------X - r a y	M i n e r a l o g y------		Comments
	Major	Moderate	Minor or Trace	
D2-3	Smectite			Altered glass in basalt
D2-3	Plagioclase	Pyroxene Apatite		Basalt
D3-7	Plagioclase	Phillipsite Apatite	Smectite	Rind between basalt and Fe-Mn crust
D3-7	Smectite			Vesicle fill in basalt
D3-7	Plagioclase	Pyroxene Apatite	Smectite Phillipsite Quartz??	Basalt
D3-8	Phillipsite		Smectite Plagioclase	Matrix of volcanic breccia
D3-8	Smectite	Pyroxene? Plagioclase		Altered basalt clast from volcanic breccia
D3-8	Plagioclase	Pyroxene	Smectite Quartz?	Basalt fragment from volcanic breccia
D3-11	Apatite		Smectite Quartz?	Phosphate

Table 32. Mineral content of ferromanganese crusts, Abbott Seamount, Cruise L8-82-NP.

Sample No.	Vernadite (%)	Plagioclase (%)	Quartz (%)	Apatite (%)	Others	Comments
D2-3A	>99		<1			
D2-3B	>99		<1			
D2-3C	>99		<1?	<1?		
D3-7	95		2?		Halite (3%)	Bulk
D3-8	100					outer crust
D3-8	96	3	1?			inner crust

Percentages were determined by using the following weighting factors relative to quartz set as 1 : vernadite 75, plagioclase 2.8, apatite 3.1, calcite 1.65. We determined the vernadite weighting factor by mixing known amounts of a pure vernadite crust and quartz; other weighting factors are from Cook et al. (1975). The limit of detection for each mineral falls between 0.5 and 1.0 percent.

Table 33. Chemical composition of bulk crusts from Abbott Seamount. Analysis by Atomic Adsorption, listed in weight percent and corrected for water content determined at 110°C.

	D2-3	D3-7	D3-8	D3-11
Mn	24.00	23.81	23.78	20.29
Fe	11.01	12.70	12.34	14.77
Co	0.64	0.83	0.73	0.53
Ni	0.60	0.47	0.43	0.35
Pb	0.17	0.25	0.25	0.23
Cu (ppm)	920	220	280	360
Zn (ppm)	680	500	480	530
Crust thickness	55 mm	2 mm	10 mm	10 mm

Acknowledgments

We wish to thank the Captain and crew of the R/V S.P. Lee, and all those on the scientific staff. We thank Bill Winters, Homa Lee, Hank Chezar, Kaye Kinoshita, Sara Neil, Laura Benninger, Clint Steele, Marlene Noble, Joanne Thede, Candy Lane, and Bonnie Rose for laboratory and technical assistance.

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Appendix 1. Comparison of cobalt concentrations for analysis done by Bureau of Mines, USGS-WH, USGS-Reston, the German Geological Survey (FRG), and shipboard analysis (SH) on S.P. Lee data from Necker Ridge, Horizon Guyot, and S.P. Lee Guyot, Cruise L5-83-HW.

Sample	BOM	USGS-WH	USGS-RES	FRG	SH	MEAN (ex ship)	S.D.	C.V.
PC2A-2	0.56	0.50	0.48	0.46	0.51	0.50	0.043	8.6
PC3A-3	0.70	0.66	0.58	-	0.64	0.65	0.061	9.4
D5Bx-4	0.76	-	0.61	-	0.71	0.69	0.106	15.5
D5Cx-5	0.74	0.73	0.68	-	0.65	0.72	0.032	4.5
D6Ay-6	0.65	0.56	0.53	0.58	0.50	0.58	0.052	7.6
D6Ay-7	0.60	-	0.52	0.59	0.53	0.57	0.044	7.6
D6Ax-8	0.68	-	0.55	0.52	0.62	0.58	0.085	14.6
D6Ax-9	1.14	1.22	1.16	1.26	1.19	1.20	0.055	4.4
D7Ax-10	1.04	-	1.01	0.77	1.10	0.94	0.148	15.9
D7Fx-11	0.45	0.50	0.41	0.52	0.52	0.47	0.050	10.6
D7Fx-12	0.54	-	0.54	0.56	0.61	0.55	0.012	2.1
D8A-13	0.33	0.36	0.32	0.33	0.45	0.34	0.017	5.2
D8B-14	0.27	0.30	0.25	0.26	0.36	0.27	0.022	8.0
D8B-15	0.33	-	0.32	0.36	0.34	0.34	0.021	6.2
D8C-16	0.28	-	0.28	-	0.34	0.28	-	-
D10-17	0.65	0.67	0.60	-	0.68	0.64	0.036	5.6
D10-18	0.55	-	0.53	0.55	0.60	0.54	0.012	2.1
D10-19	0.93	0.99	0.88	0.94	0.98	0.93	0.045	4.8
D11A-20	0.62	-	0.59	-	0.61	0.60	0.0212	3.5
D12A-21	1.03	1.05	0.94	1.00	1.13	1.00	0.048	4.8
D12A-22	0.85	-	0.73	0.74	0.86	0.77	0.067	8.6
D14A-23	0.82	0.89	0.78	0.85	0.88	0.84	0.047	5.6
D14A-24	0.83	-	0.76	0.80	0.74	0.80	0.035	4.4
D14A-25	0.97	-	0.91	-	0.86	0.94	0.042	4.5
D14A-26	0.94	-	0.91	0.85	0.97	0.90	0.046	5.1
D14A-27	0.81	-	0.76	0.76	0.84	0.78	0.029	3.7
D14A-28	0.88	0.91	0.84	-	0.83	0.88	0.035	4.0
D15B-29	0.31	0.34	0.31	0.33	0.35	0.32	0.015	4.6
D17A-30	0.82	0.94	0.76	0.82	0.98	0.83	0.075	9.6
D17B-31	0.69	-	0.54	0.70	0.77	0.64	0.090	13.9
D18-32	0.73	0.71	0.66	0.70	0.75	0.70	0.029	4.2
D18-33	0.75	0.68	0.65	0.65	0.74	0.68	0.047	6.9
D18-34	0.75	-	0.72	0.72	0.90	0.73	0.017	2.4
D18-35	0.71	0.66	0.62	0.70	0.68	0.67	0.041	6.1
D18-36	0.87	-	0.81	0.84	1.11	0.84	0.03	3.6
D18-37	0.55	-	0.50	0.55	0.55	0.53	0.029	5.4
D23-38	1.14	1.05	1.00	1.02	1.29	1.05	0.062	5.9
D23-39	0.84	-	0.75	0.81	0.91	0.80	0.046	5.7
D23-40	1.01	0.93	0.88	0.88	1.05	0.92	0.061	6.6
D24-41	1.02	-	0.82	0.90	0.94	0.91	0.100	11.0
D24-42	0.96	0.99	0.88	0.90	1.03	0.93	0.051	5.5
D25-43	1.37	-	1.2	1.2	1.41	1.26	0.098	7.8
D27-44	3.02	2.56	2.55	2.68	2.48	2.70	0.220	8.1
D27-45	1.41	-	1.22	1.24	1.27	1.29	0.104	8.1
D28-46	1.41	1.22	1.24	1.14	1.19	1.25	0.113	9.1
D28-47	1.07	-	1.06	1.07	1.10	1.07	0.0058	0.54
D28-48	1.97	1.93	1.83	1.9	1.88	1.91	0.059	3.10
D31-50	1.47	-	1.45	1.45	1.58	1.46	0.0115	0.79
D31-51	0.86	-	0.86	0.87	0.88	0.86	0.0058	0.67
D32-52	1.39	-	1.33	1.26	1.49	1.33	0.065	4.9

Appendix 2. Station data for S.P. Lee samples.

SEQNO	LAT	LON	DEPTH	CRUISE	STATION	SAMP#
89011	22.181	-166.810	3950.	SPLEE L583HW	001	D1A-1
89012	22.181	-166.861	3403.	SPLEE L583HW	004	PC1
89013	22.208	-166.882	2402.	SPLEE L583HW	005	PC2A-2
89014	22.256	-166.854	1970.	SPLEE L583HW	006	PC3A-3
89015	22.316	-166.899	2350.	SPLEE L583HW	008	D5Bx-4
89016	22.316	-166.899	2350.	SPLEE L583HW	008	D5Cx-5
89017	21.718	-167.578	2400.	SPLEE L583HW	009	D6Ay-6
89018	21.718	-167.578	2400.	SPLEE L583HW	009	D6Ay-7
89019	21.718	-167.578	2400.	SPLEE L583HW	009	D6Ax-8
89020	21.718	-167.578	2400.	SPLEE L583HW	009	D6Ax-9
89021	21.796	-167.624	2100.	SPLEE L583HW	010	D7Ax-10
89022	21.796	-167.624	2100.	SPLEE L583HW	010	D7Fx-11
89023	21.796	-167.624	2100.	SPLEE L583HW	010	D7Fx-12
89024	21.841	-167.666	4123.	SPLEE L583HW	011	PC4
89025	20.209	-169.506	4500.	SPLEE L583HW	012	D8A-13
89026	20.209	-169.506	4500.	SPLEE L583HW	012	D8B-14
89027	20.209	-169.506	4500.	SPLEE L583HW	012	D8B-15
89028	20.209	-169.506	4500.	SPLEE L583HW	012	D8C-16
89029	20.335	-169.575	2400.	SPLEE L583HW	014	D10-17
89030	20.335	-169.575	2400.	SPLEE L583HW	014	D10-18
89031	20.335	-169.575	2400.	SPLEE L583HW	014	D10-19
53015	19.318	-168.651	4411.	SPLEE L583HW	015	PC5
53016	19.347	-168.658	3622.	SPLEE L583HW	016	PC6
53050	19.338	-168.705	2450.	SPLEE L583HW	017	PC7
53017	19.335	-168.665	3791.	SPLEE L583HW	018	D11A-20
53018	19.369	-168.695	2000.	SPLEE L583HW	019	D12A-21
53019	19.369	-168.695	2000.	SPLEE L583HW	019	D12A-22
53020	19.511	-168.835	1800.	SPLEE L583HW	021	D14A-23
53021	19.511	-168.835	1800.	SPLEE L583HW	021	D14A-24
53022	19.511	-168.835	1800.	SPLEE L583HW	021	D14A-25
53023	19.511	-168.835	1800.	SPLEE L583HW	021	D14A-26
53024	19.511	-168.835	1800.	SPLEE L583HW	021	D14A-27
53025	19.511	-168.835	1800.	SPLEE L583HW	021	D14A-28
53026	19.695	-168.995	4500.	SPLEE L583HW	022	D15B-29
53027	19.553	-168.832	2400.	SPLEE L583HW	024	D17A-30
53028	19.553	-168.832	2400.	SPLEE L583HW	024	D17B-31
53029	19.515	-168.855	1790.	SPLEE L583HW	026	D18-32
53030	19.515	-168.855	1790.	SPLEE L583HW	026	D18-33
53031	19.515	-168.855	1790.	SPLEE L583HW	026	D18-34
53032	19.515	-168.855	1790.	SPLEE L583HW	026	D18-35
53033	19.515	-168.855	1790.	SPLEE L583HW	026	D18-36
53034	19.515	-168.855	1790.	SPLEE L583HW	026	D18-37
53035	16.678	-169.359	1400.	SPLEE L583HW	034	D19-53
17006	8.41400	-164.289	1850.	SPLEE L583HW	040	D23-38
17007	8.41400	-164.289	1850.	SPLEE L583HW	040	D23-39
17008	8.41400	-164.289	1850.	SPLEE L583HW	040	D23-40
17009	8.39800	-164.359	2400.	SPLEE L583HW	041	D24-41
17010	8.39800	-164.359	2400.	SPLEE L583HW	041	D24-42
17011	8.38900	-164.294	1600.	SPLEE L583HW	042	D25-43
17012	8.35300	-164.317	1150.	SPLEE L583HW	045	D27-44

Appendix 2 cont.

SEQNO	LAT	LON	DEPTH	CRUISE	STATION	SAMP#
17013	8.35300	-164.317	1150.	SPLEE L583HW	045	D27-45
17014	8.30800	-164.346	1400.	SPLEE L583HW	046	D28-46
17015	8.30800	-164.346	1400.	SPLEE L583HW	046	D28-47
17016	8.30800	-164.346	1400.	SPLEE L583HW	046	D28-48
17017	8.29700	-164.369	1700.	SPLEE L583HW	047	D29-49
17018	8.23500	-164.207	1300.	SPLEE L583HW	048	D30
17019	8.19400	-164.200	1600.	SPLEE L583HW	049	D31-50
17020	8.19400	-164.200	1600.	SPLEE L583HW	049	D31-51
17021	8.18600	-164.202	1800.	SPLEE L583HW	050	D32-52

Appendix 3. Correlation coefficients for Necker Ridge, Horizon Guyot, and S.P. Lee Guyot, Cruise L5-83-HW. Samples represent top surfaces of crusts (younger generation) generally about 5 mm. N = 19.

Depth	Mn	Fe	Ni	Co	Cu	Mg	Ca	Al	Ti	K	P	Si	Na	CO_2	Ba	Mo	Pb	Sr	V	Zn	Y	Ce	As	Cd	H_2O^-	H_2O^+	Long.	Lat.	
1.00	-.75	.48	-.55	-.64	.50	-.05	-.33	.84	.86	.58	-.27	.76	-.52	-.55	-.29	-.72	-.73	-.72	-.44	-.32	.50	.67	-.68	-.34	-.16	-.42	-.52	-.43	Dept
	1.00	-.78	.87	.88	-.33	.39	.33	-.87	-.85	-.47	.27	-.95	.65	.34	.36	.92	.62	.57	.44	.57	-.41	-.54	.64	.75	-.14	.23	.69	-.77	Mn
		1.00	-.89	-.86	.00	-.67	-.33	.45	.56	-.06	-.25	.69	-.75	-.32	-.33	-.71	-.17	-.14	-.26	-.63	.52	.53	-.30	-.82	.42	-.06	-.70	.81	Fe
			1.00	.92	-.09	.70	.17	-.58	-.62	-.10	.10	-.76	.77	.24	.22	.71	.27	.17	.20	.75	-.29	-.57	.37	.92	-.22	.11	.72	-.80	Ni
				1.00	-.40	.66	-.07	-.63	-.71	-.10	.00	-.77	.88	.14	.14	.79	.34	.22	.31	.53	-.48	-.69	.45	.85	-.33	.17	.78	-.83	Co
					1.00	.11	.26	.46	.45	.28	.28	.32	-.39	.07	.31	-.36	-.32	-.35	-.29	.37	.40	.50	-.47	.03	-.01	-.41	-.40	.31	Cu
						1.00	-.18	.08	-.08	.49	-.24	-.18	.59	-.34	-.02	.25	-.25	-.49	-.16	.56	-.23	-.30	-.18	.82	-.49	-.28	.38	-.52	Mg
							1.00	-.40	-.41	-.33	.99	-.44	-.05	.68	.47	.38	.47	.45	.23	.24	-.22	.27	.06	.12	-.18	-.16	.02	-.05	Ca
								1.00	.89	.79	-.38	.94	-.41	-.49	-.30	-.82	-.83	-.82	-.54	-.34	.30	.40	-.74	-.41	-.07	-.38	-.51	.52	Al
									1.00	.60	-.39	.86	-.54	-.48	-.20	-.82	-.83	-.66	-.52	-.30	.39	.45	-.67	-.51	.05	-.42	-.51	.49	Ti
										1.00	-.34	.62	.15	-.36	-.24	-.45	-.84	-.80	-.48	-.11	.03	.07	-.60	.05	-.29	-.47	-.08	.01	K
											1.00	-.42	-.10	.67	.44	.34	.46	.44	.29	.19	-.11	.34	.07	.06	-.18	-.14	-.02	-.01	P
												1.00	-.55	-.46	-.40	-.91	-.69	-.70	-.61	-.50	.37	.47	-.70	-.60	.16	-.32	-.67	.72	Si
													1.00	.14	.01	.61	.09	.06	.32	.35	-.35	-.70	.35	.72	-.33	.10	.74	-.77	Na
														1.00	.34	.33	.40	.59	.30	.25	-.14	-.13	.38	.05	.25	.27	.28	-.19	CO_2
															1.00	.54	.29	.53	.40	.41	-.12	-.12	.35	.20	.06	-.16	-.24	-.25	Ba
																1.00	.62	.67	.62	.36	-.41	-.52	.72	.61	-.20	.24	.70	-.74	Mo
																	1.00	.75	.45	.21	-.23	-.13	.56	.22	.11	.29	.12	-.05	Pb
																		1.00	.55	.04	-.21	-.26	.81	-.03	.37	.36	.28	-.26	Sr
																			1.00	.06	-.16	-.35	.65	.09	-.21	.44	.52	-.42	V
																				1.00	-.10	-.28	.07	.77	-.12	-.10	.37	-.40	Zn
																					1.00	.50	-.15	-.17	.38	-.15	-.37	.37	Y
																						1.00	-.54	-.36	.02	-.51	-.74	.62	Ce
																							1.00	.16	.33	.54	.48	-.51	As
																								1.00	-.37	-.13	.53	-.66	Cd
																									1.00	.17	-.24	.27	H_2O^-
																										1.00	.45	-.21	H_2O^+
																											1.00	-.88	Long.
																												1.00	Lat.

Appendix 4. Correlation coefficients for crusts from Necker Ridge, Horizon Guyot, and S.P. Lee Guyot, Cruise L5-83-HW. Top refers to topmost layer of crusts, generally 5 mm (also referred to as "younger generation"). Total refers to total crust thickness. Generally speaking, coefficients >|.60| are significant at the 99% confidence limit or better. N for top is 19 and for total is 50. Elements correlated with latitude and longitude are at variable depth. Data for top 5 mm from Appendix 3.

	----------Mn versus--------					---Al versus---			---Ca versus---		
	Ni	Mo	Co	Cd	Zn	Si	Ti	K	P	CO_2	Cu
Top	.87	.92	.88	.75	.57	.94	.86	.62	.99	.67	.26
Total	.84	.93	.73	.70	.49	.95	.72	.85	.84	.63	.03

	--Depth (positive) versus--					----------Depth (negative) versus------------							
	Al	Ti	Si	K	Cu	Pb	Mn	Mo	As	Ni	Sr	Co	Zn
Top	.84	.86	.76	.58	.50	-.73	-.75	-.72	-.68	-.55	-.72	-.64	-.32
Total	.87	.73	.82	.69	.50	-.64	-.79	-.74	-.63	-.63	-.77	-.63	-.38

	---Longitude (positive) versus---						Longitude (negative) versus	
	Mo	Co	Mn	Ni	Na	Cd	Fe	Si
Top	.70	.78	.69	.72	.74	.53	-.70	-.67
Total	.49	.62	.46	.57	.17	.25	-.41	-.51

	Latitude (positive) versus			-----Latitude (negative) versus---					
	Fe	Si	Y	Co	Mn	Ni	Mo	Cd	Na
Top	.81	.72	.37	-.83	-.77	-.80	-.74	-.66	-.77
Total	.54	.58	.02	-.66	-.58	-.65	-.61	-.40	-.12

Interpretation: The elements Mn, Mo, Co, Ni, and Cd form a consistent affinity group, which is negatively correlated to the aluminosilicate elements Al, Si, Ti, and K. Ca and P are very closely correlated as apatite with lesser affinity to CO_2. Al, Ti, Si, K and Cu concentrations increase with depth, whereas Pb, Mn, Mo, As, Ni, Sr, and Co concentrations decrease with depth. Latitudinal and longitudinal relationships are pronounced in the youngest crust generation, with the Mn oxide group led by Co showing enrichment toward the equator.

Appendix 5. Statistical analysis of current meter data.

	East cm/sec	North cm/sec	Temperature °C
Mean	1.343	-0.855	2.923
Variance	35.327	54.196	0.6114E-02
Minimum	-23.243	-30.027	2.666
Maximum	24.669	20.648	3.265
Error about mean	0.144	0.178	0.1891E-02