Geotechnical Investigations in the Southern Beaufort Sea - Spring 1984

Compiled by

P.J. Kurfurst

Geological Survey of Canada

Contributing Authors

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1. Introduction (P.J. Kurfurst)

An extensive program of geotechnical investigations of frozen and unfrozen seabottom sediments was carried out in the spring of 1984 in the Southern Beaufort Sea between Pullen and Hooper Islands near Tuktoyaktuk, N.W.T. This area was chosen for detailed investigations because of the nearby proposed pipeline routes and the proximity of other study areas investigated in detail in previous years. The fieldwork, supported by a mobile "cat train" camp, started March 15 and was completed April 13, 1984. The program was entirely financed by the Office of Energy Research and Development funds.

The objective of the program was to provide data required for evaluation of the physical properties of the seabottom sediments and to correlate and compare them with their acoustic properties.

The work consisted of drilling, sampling, instrumenting and testing of 22 boreholes drilled through the ice and waster ranging from 1.77 m to 10.17 m in depth. The majority of boreholes (20) were drilled to the depths of approximately 20 m below seabottom, while two remaining boreholes (17+60A and 23+279) were drilled to the depths of 25 m and 40 m respectively as the geological and permafrost conditions required. The general location of the investigated area and the detailed locations of the boreholes are shown in Figure 1.

The multidisciplinary approach used throughout the program required participation of scientists and technical personnel from several agencies for the part of entire duration of the program. The participants included M.F. Nixon and P.J. Kurfurst from the Geological Survey of Canada - Terrain Sciences Division (GSC-TS), J.A. Hunter, S. Pullan, H.A. MacAuley, R.A. Gagné, R.A. Burns and R. Good from the Geological Survey of Canada -

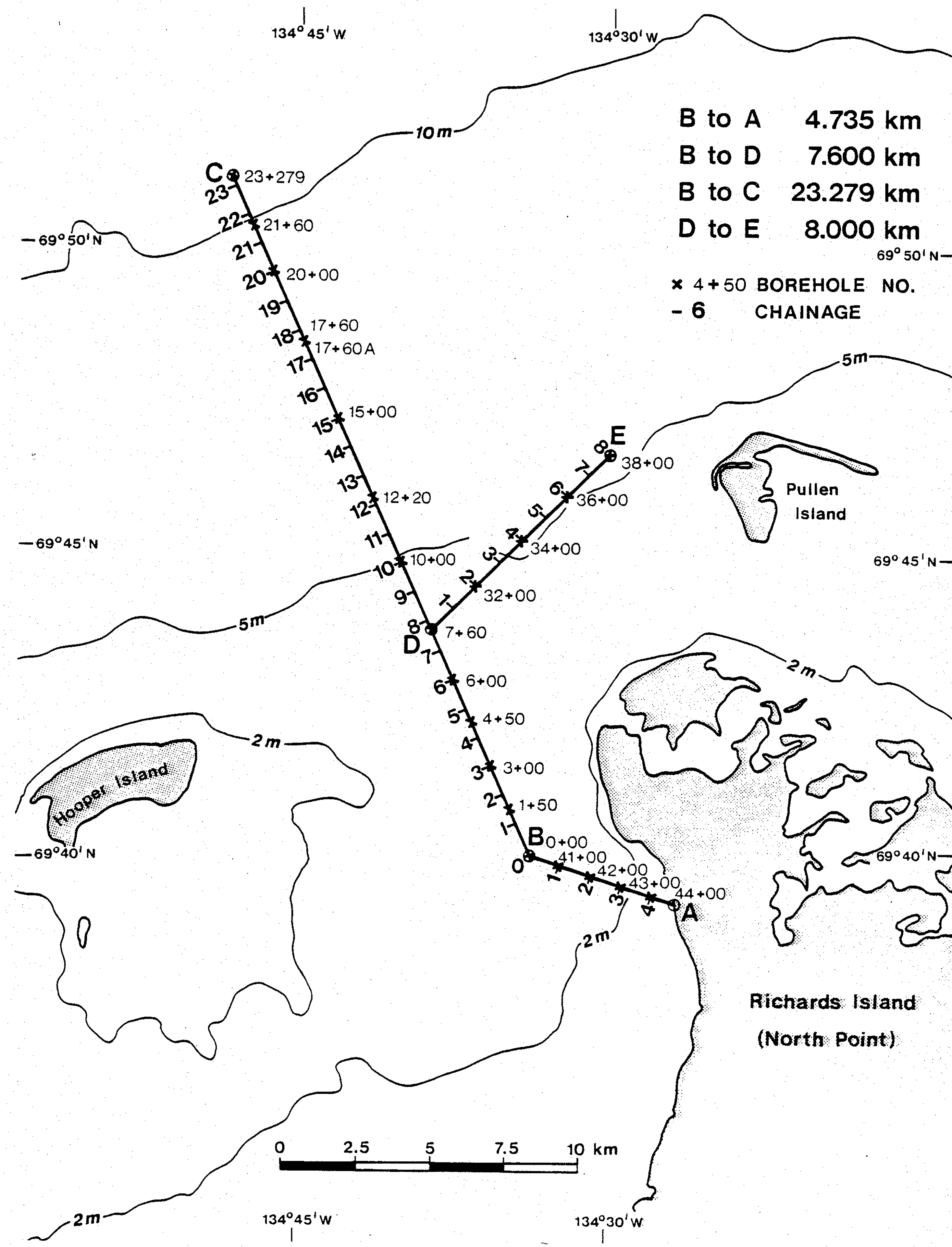


Figure 1: General location of the study area and boreholes

Resource Geophysics and Geochemistry Division (GSC-RGG), K. Moran, P. Hill and F.D. Jodrey from the Geological Survey of Canada - Atlantic Geoscience Centre (AGC), T.H.W. Baker from the National Research Council of Canada - Division of Building Research (NRCC), and J.L. Morack and W. Harrison from the University of Alaska - Department of Physics and Geophysical Institute.

The field studies were complemented by laboratory studies carried out both in the field and later on in the laboratories in Ottawa and Halifax. The program components included the following:

GSC-TS - Drilling, intermittent sampling, core logging, core temperature measurements, acoustic velocity measurements, and standard physical properties (moisture content, grain size, Atterberg limits).

GSC-RGG - Borehole location surveying, in-situ seabottom equilibrium temperature measurements, water temperature measurements, uphole seismic measurements and seabottom seismic refraction measurements.

GSC-AGC - Core stratigraphy with sedimentological, biostratigraphic and geochronological analyses, standard physical properties tests (moisture content, grain size, Atterberg limits, bulk density), strength parameters measurements (shear vane tests), CTD (conductivity, temperature and depth) water profiling and sampling.

NRCC - Strength parameters measurements (uniaxial compression tests), and thermal conductivity tests.

UA - Borehole heating and thermal conductivity tests.

The details of the program field data and some preliminary results are discussed in the following chapters.

2. Administration and Logistics Support (P.J. Kurfurst)

Consulting company Klohn Leonoff Ltd., with Foundex Exploration Ltd., and Beau-Tuk Marine Services Ltd. as subcontractors, was awarded a contract by the Department of Supply and Services on behalf of the Geological Survey of Canada to provide drilling, administrative and logistics support for the project. As prime contractors, Klohn Leonoff Ltd. supervised the operations of the subcontractors and was responsible for the administrative and logistics aspects of the project through the on-site manager present during the duration of the field operation. The manager's duties involved:

- supervision of camp and drilling staff provided by subcontractors;
- liaison with subcontractors and GSC project manager regarding schedules, staff changes, road construction and maintenance, and camp administration;
- liaison with Land Use Office inspectors to ensure that operations were carried out in accordance with the Land Use Permit;
- provided daily drilling and camp operation reports to GSC project manager;
- provided up to date costing for the program as required.

Beau-Tuk Marine Services Ltd. provided a camp and logistics support for the program. The camp included a kitchen trailer, a wash-house trailer, three bunk-house trailers, a laboratory trailer, a generator trailor and two fuel sloops. The sled-mounted trailers were pulled from Tuktoyaktuk to the Richards Island camp site by a D6 bulldozer and Cat 966 wheeled loader; these were also used to build and maintain roads to the drill sites and to serve the camp as required.

The camp support staff, which included a cook, a camp attendant, a mechanic, two heavy equipment operators and two polar bear monitors, was organized to support two 12-hour shift drilling programs.

3. Surveying (H. MacAulay)

The boreholes were positioned as shown in Figure 1. Co-ordinates at the shore end (A), at stations 0+000 (B) and 23+279 (C) were taken from Canadian Hydrographic chart 7604. Station 0+000 (B) was established on the ice by running a line from Geodetic Control Position "GROUW" on Richards Island, with the required angle turned from a sight on the Pullen Island Racon tower which straddles Geodetic Control Position No. 699039. The required angles were turned at station 0+000 (B) and chainage, marked by pickets at 100 metre intervals, proceeded from there to the shore end at (A) and subsequently, offshore to station 23+279 (C). The same procedure was used to branch traverse D (station 7+600) to E (station 38+000).

Check shots were taken at station 0+000 (B) sighting Hooper Island tower (Control Position No. 6599009), at station 7+600 (D) sighting on Hooper Island tower and Pullen Island Racon tower and at station 38+000 (E) sighting on Pullen Island Racon tower.

Azimuths and distances were provided by R. Morris, Geodetic Surveys, Surveys and Mapping Branch, E.M.R., prior to the survey, as were the co-ordinates of the boreholes subsequently to the survey.

Approximately 48 kilometers of line were chained in three and a half days using ski-doos for transport.

Table 1 summarizes latitude, longitude, northing and easting (UTM system) for all boreholes and line points.

4. Drilling and Sampling (P.J. Kurfurst)

Foundex Explorations Ltd. was the subcontractor responsible for the drilling operation. Twenty-two boreholes were drilled along three lines (AB, BC and DE) northeast of Hooper Island and west of Pullen Island.

TABLE 1

Borehole Co-ordinates

Point	Borehole	Latitude	Longitude	Northing	Easting
A		69 39 12.00	134 26 48.00	7727134.98	521472.56
	44+000	69 39 19.54	134 27 52.64	7727362.45	520773.78
	43+000	69 39 29.66	134 29 20.71	7727667.62	519821.90
	42+000	69 39 39.77	134 30 48.80	7727973.17	518870.14
	41+000	69 39 49.89	134 32 16.89	7728279.09	517918.50
B	0+000	69 40 00.00	134 33 45.00	7728585.40	516966.[illegible]3
	1+500	69 40 44.11	134 34 42.31	7729947.49	516340.14
	3+000	69 41 28.22	134 35 39.66	7731309.74	515713.65
	4+500	69 42 12.34	134 36 37.04	7732672.15	515087.51
	6+000	69 42 56.45	134 37 34.45	7734034.72	514461.73
D	7+600	69 43 43.50	134 38 35.73	7735488.31	513794.61
	10+000	69 44 54.08	134 40 07.74	7737668.97	512794.53
	12+200	69 45 58.77	134 41 32.14	7739668.29	51187[illegible].63
	15+000	69 47 21.11	134 43 19.69	7742213.32	510713.92
	17+600	69 48 37.56	134 44 59.65	7744577.09	509633.55
	20+000	69 49 48.14	134 46 32.01	7746759.49	508637.28
	21+600	69 50 35.19	134 47 33.62	7748214.70	507973.71
C	23+279	69 51 24.00	134 48 42.00	7749724.29	507238.58
	32+000	69 44 29.36	134 36 24.74	7736917.58	515192.46
	34+000	69 45 15.22	134 34 13.67	7738347.69	516589.46
	36+000	69 46 01.08	134 32 02.52	7739778.63	517985.61
E	38+000	69 46 46.95	134 29 51.29	7741210.41	519380.91

Locations of all the lines and boreholes are shown in Figure 1. The borehole numbers, their depths, sample diameter, ice thickness and ice and water depth are summarized in Table 2. Two 12-hour shifts ensured continuous and uninterupted drilling and sampling.

All boreholes were drilled using the HT-700 hydraulic rotary drill rig. To gain the access to the seabottom, a 30 cm diameter hole was augered through the ice which ranged in thickness from 135 to 190 cm. The drill rods and the drill bit were then lowered to the seabottom and rotated while pumping drilling fluid through the centre of the drill rods and out through the bit. The drilling fluid and cuttings were then carried up the outside of the drill rods and deposited on the ocean floor. When the desired sampling depth was reached, the drill string was pulled back 120 to 150 cm, a Shelby tube sample was inserted and the sample, approximately 60 cm long, was taken. The drilling fluid used was seawater pumped from below the sea ice. In intervals where loose sand or sloughing conditions were encountered, drilling muds (Zeogel or Kelgon) were used.

Shelby tube samples (63 mm or 76 mm I.D.) up to 60 cm in length were taken generally at 150 cm intervals. However, in boreholes 3+00, 4+50 and 6+00 the sampling interval was increased to 300 cm. In other boreholes, either in the top 3 m or where lithological change or permafrost were expected, the sampling interval varied between continuous samples and spacing up to 100 cm.

All samples retrieved by the drillers were passed immediately to the GSC staff working the shift. Temperature probe was immediately inserted in the bottom of the sample to record the sample temperature. Sample was

TABLE 2

Borehole Information

Borehole	Depth (m)	Sample Ø (mm)		Ice Thickness (cm)	Ice+Water Depth (cm)
		63	76		
44+00	19.65		X	165	177
43+00	19.50		X	155	222
42+00	20.25		X	160	280
41+00	19.80		X	140	300
0+00	19.20	X		180	292
1+50	20.70		X	168	333
3+00	20.70		X	153	385
4+50	19.50	X		163	409
6+00	19.40	X		165	430
7+50	20.10	X		180	447
10+00	19.50	X		190	530
12+20	19.35	X		135	580
15+00	19.50	X		160	713
17+60	19.50	X		170	810
17+60A	25.30		X	170	810
20+00	20.60		X	170	890
21+60	18.90		X	180	984
23+279	40.20		X	170	1017
32+00	19.50		X	170	500
34+00	20.40		X	155	513
36+00	19.20		X	190	536
38+00	19.35	X		155	590
Total	460.10	9	13		

then extruded into a split PVC casing, its length was measured and a brief soil type description, and presence of ground ice, when observed, were recorded. The sample was then photographed, sealed and transported to the camp laboratory for more detailed logging and testing.

Some selected Shelby tube samples were not extruded in the field. After recording the temperature at the bottom of the sample, it was sealed and transported to the camp laboratory for retention for future specialized tests in the Inuvik, Ottawa and Halifax laboratories. Table 3 shows the borehole number and the depth of undisturbed Shelby tube samples.

The sediments encountered ranged from clays and silts to sands. The drill logs showing soil types, sampled horizons and core temperatures, for all boreholes are presented in Appendix B.

The extruded Shelby tube samples received in the camp laboratory were either placed in the temperature controlled freezer (frozen samples) or in the low temperature environment (unfrozen samples). Samples were split along the length, measured, photographed and described in detail lithologically and for sedimentary structures. One side was sealed and peels of coarse grained samples were prepared for future detailed inspection. The other side was used for shear vane tests at 3 to 4 positions along the sample length and subsamples for moisture content determination and index testing (Atterberg limits, grain size, etc.) were selected, sealed and prepared for shipment. Selected samples of wood and peat were also sealed and shipped for radiocarbon dating analysis. Unconfined compression tests were carried out on selected suitable samples.

TABLE 3

Undisturbed Shelby Tube Samples

Borehole	Depth (m)
3+00	12.5
6+00	9.87
7+60	18.0
10+00	15.86
20+00	4.42
20+00	7.47
20+00	10.52
20+00	13.51
21+60	4.85
23+279	7.62
34+00	12.2
38+00	12.65
42+00	10.52
42+00	19.67
43+00	16.07
43+00	11.04
44+00	10.06

5. Core Temperature Measurements (P.J. Kurfurst)

Temperatures of the Shelby tube samples were measured and recorded, using an Atkins temperature probe and readout equipment. The probe was inserted in the bottom of the Shelby tube sample as soon as possible after its retrieval from the borehole. When negative temperature was expected or signs of ground ice were detected, temperature was also measured in several spots along the sample length after its extrusion from the Shelby tube.

The temperature probe and readout equipment were calibrated at NRCC after completion of the field operation, using a Guideline constant temperature bath. The calibration, carried out in the temperature range -12°C to +12°C, indicated a zero shift of +1.2 to 1.4°C. The field temperature measurements were then corrected accordingly.

All core temperature measurements were plotted on individual drill logs which are presented in Appendix B.

When compared to the more accurate temperature readings measured by the thermistor cables after the completion of the boreholes (see Chapter 6), the probe measurements are generally higher but show similar trend. This temperature difference is considered to be due to thermal disturbance of the sample caused by drilling and sampling, and by time delay between the sample recovery and the measurements.

Along line B-C (boreholes 0+00 to 23+279), only positive temperatures above 0°C were recorded in all samples from boreholes 0+00 to 10+00. Negative temperatures of 0°C and below were recorded in samples from boreholes 12+20 to 23+279, either in certain horizons or through the entire borehole.

Along line D-E (boreholes 32+00 to 38+00), all temperatures recorded were positive with the exception of top 1.5 m in boreholes 34+00, 36+00 and 38+00.

Temperatures recorded in samples from boreholes along line A-B (boreholes 41+00 to 44+00) varied from positive (entire borehole 42+00) to negative only in top 3 m (boreholes 41+00 and 43+00) to negative throughout most of the borehole length (borehole 44+00).

The range of temperatures recorded spanned from $+2.0^{\circ}C$ to $-1.3^{\circ}C$, with the exceptions of nearshore boreholes 43+00 and 44+00, where temperatures of $-2.4^{\circ}C$ were measured in the horizons including solid ice extending from the land.

6. Sub-seabottom Temperature Measurements (J.A. Hunter)

Installation and Measurement Procedure

Temperature cable installations were completed on most geotechnical boreholes (Fig. 1) shortly after completion of drilling. At many of the drill sites 5 cm diameter PVC casing was installed while the drill rig was on site and before pulling the drill casing. The PVC casing was used for uphole seismic measurements (see Chapter 8). After completion of the uphole survey, a 2.5 cm diameter steel casing was installed inside the PVC casing. The steel casing was filled with antifreeze and the temperature cable was then installed. Due to technical difficulties no temperature installations were completed in boreholes 17+60, 17+60A, 20+00 or 21+60.

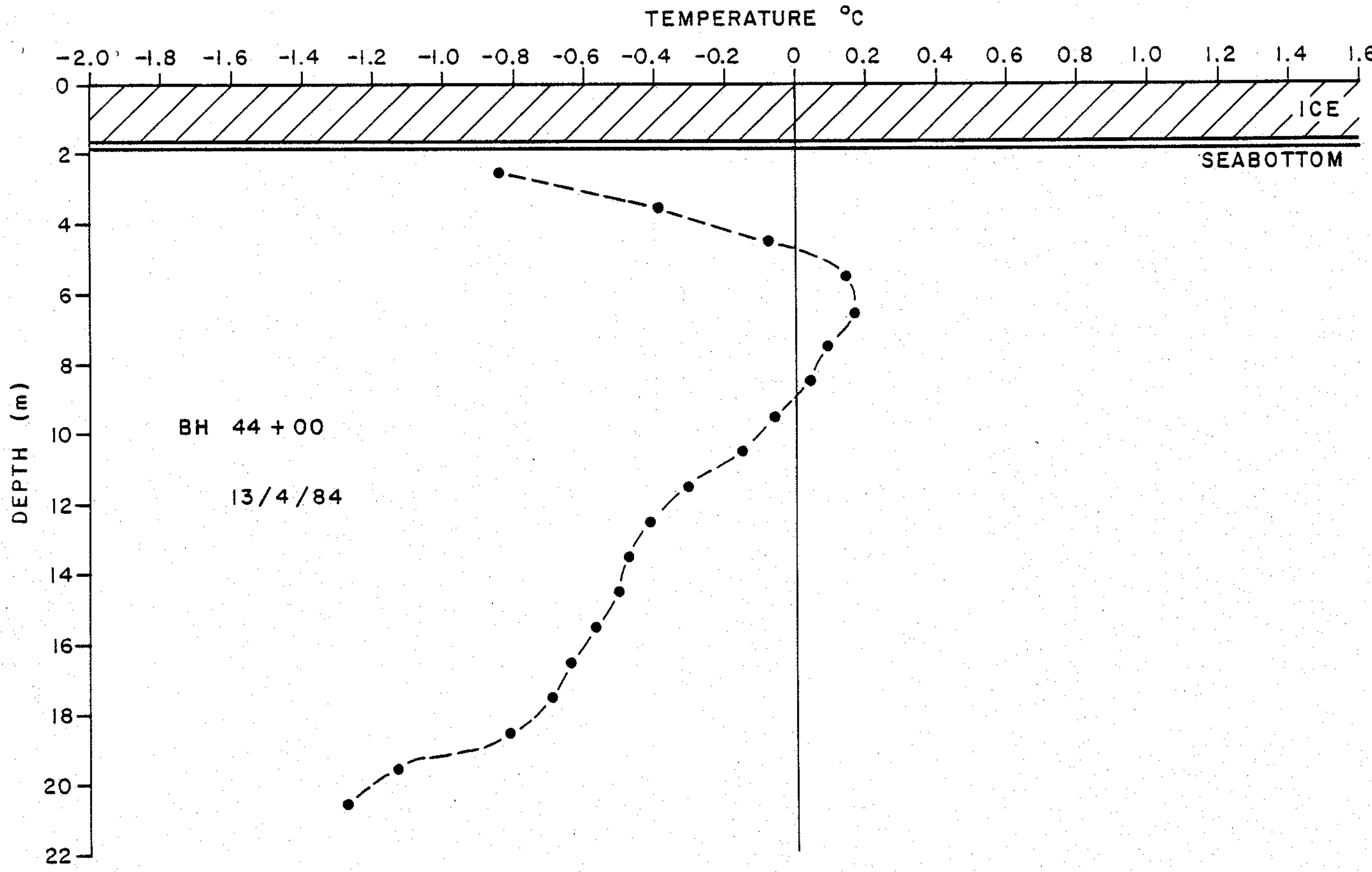
Each temperature cable consisted of 12 YSI thermistors ($\pm 0.05^{\circ}C$) spaced at 2 m intervals. After installation, temperatures were read at almost daily intervals until thermal equilibrium was reached and the cable removed. At some locations, leakage of antifreeze took place and the cables were frozen in position. At other locations where the cables were free to be moved, an intermediate set of readings was taken to obtain 1 metre spacing of temperature readings. In many locations wide variations in readings in the first few metres below seabottom were observed. These variations continued throughout the duration of the experiment and it is suspected that thermal convection was taking place in the borehole outside the casing.

Temperature Data

Figure 2 sho s the equilibrium temperature-depth plots. The inshore boreholes display a thermal maximum at depth which reflects the effect of the previous summer's outflow of warm water from the Mackenzie River. Data from borehole 44+00 (Figure 2a) shows an anomalously lower temperature regime compared with those from the boreholes further offshore. It is suggested tha+ the cold permafrost conditions of land permafrost, as well as the bottom-fast ice inshore of this borehole, result in the overall reduction of temperatures.

It is thought that the amount of warm Mackenzie River water and the residence time of this water in contact with the seabottom are factors affecting the shape of the temperature-depth plots. Figure 3 is a plot of maximum observed subbottom temperature vs water depth for the boreholes examined. Subbottom temperatures do not exceed $0^{o}C$ for boreholes drilled in greater than 6 m water depth.

The temperature-depth curves taken at this time of year probably represent the maximum winter time cooling effect from the incursion of cold salt-water.



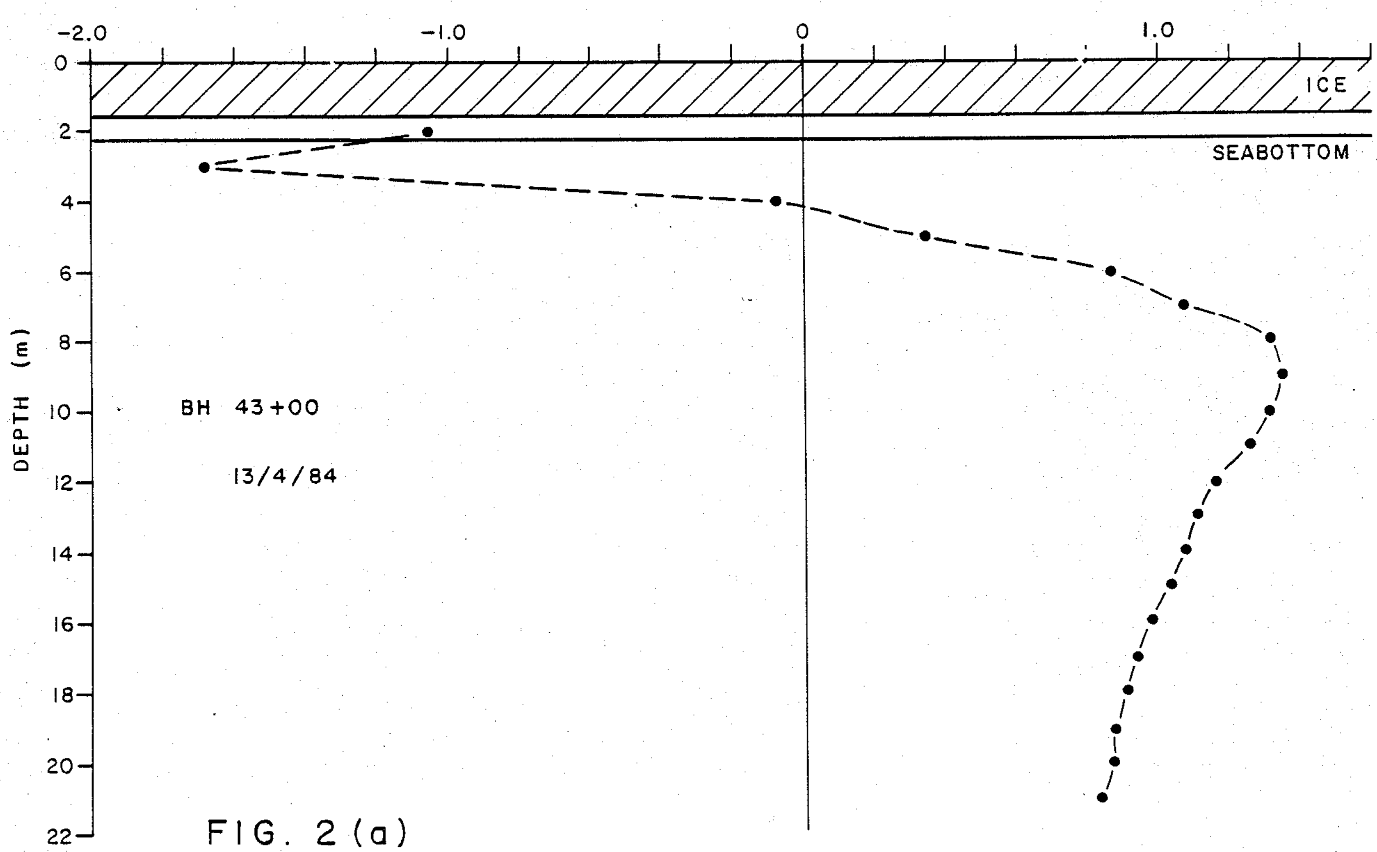


FIG. 2 (a)

Figure 2 a - j: Equilibrium temperature vs depth plots

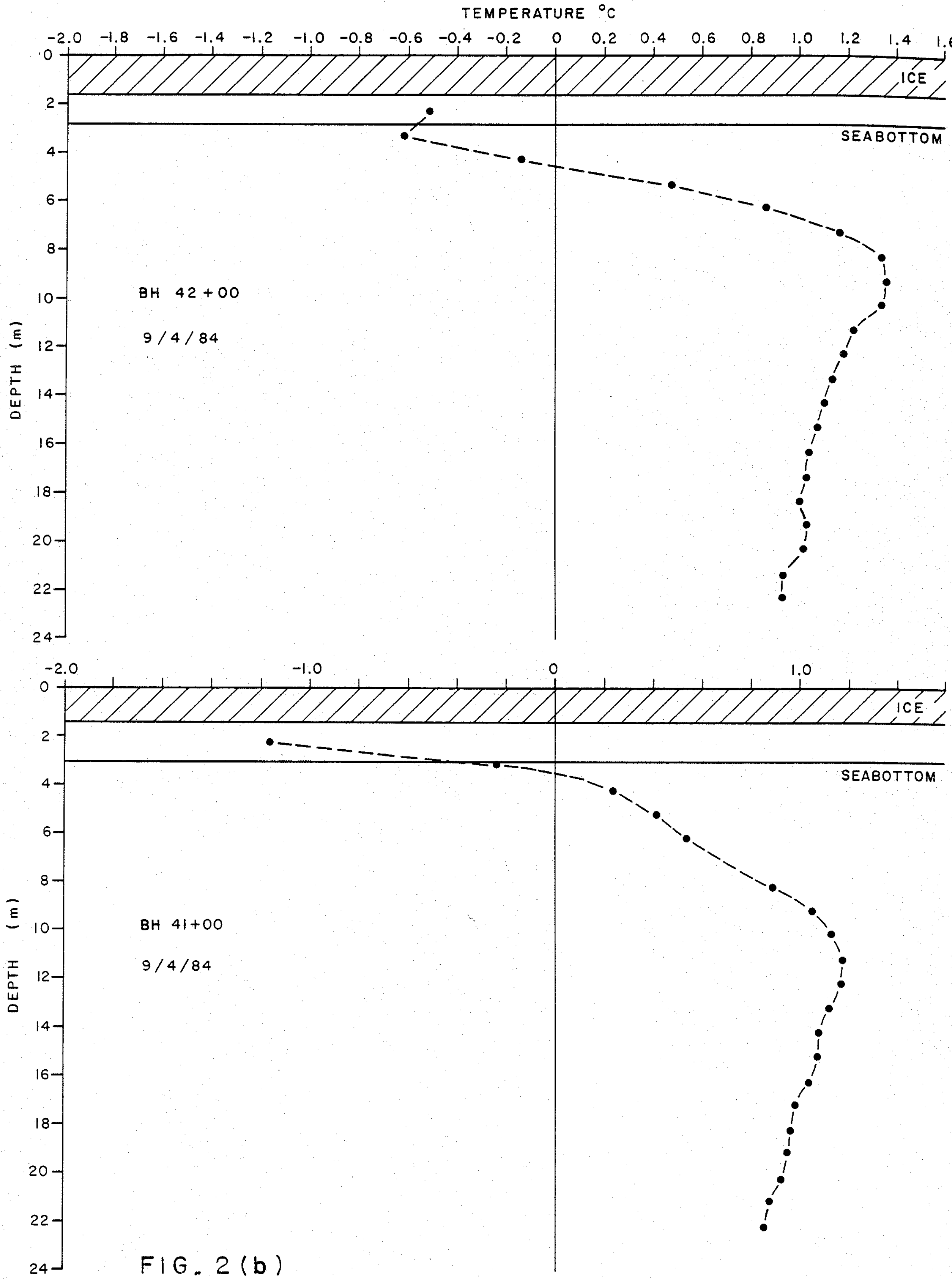

TEMPERATURE °C
-2.0 -1.8 -1.6 -1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6
ICE
SEABOTTOM
BH 42+00
9/4/84
DEPTH (m)
0 2 4 6 8 10 12 14 16 18 20 22 24
-2.0 -1.0 0 1.0
ICE
SEABOTTOM
BH 41+00
9/4/84
DEPTH (m)
0 2 4 6 8 10 12 14 16 18 20 22 24

FIG. 2 (b)

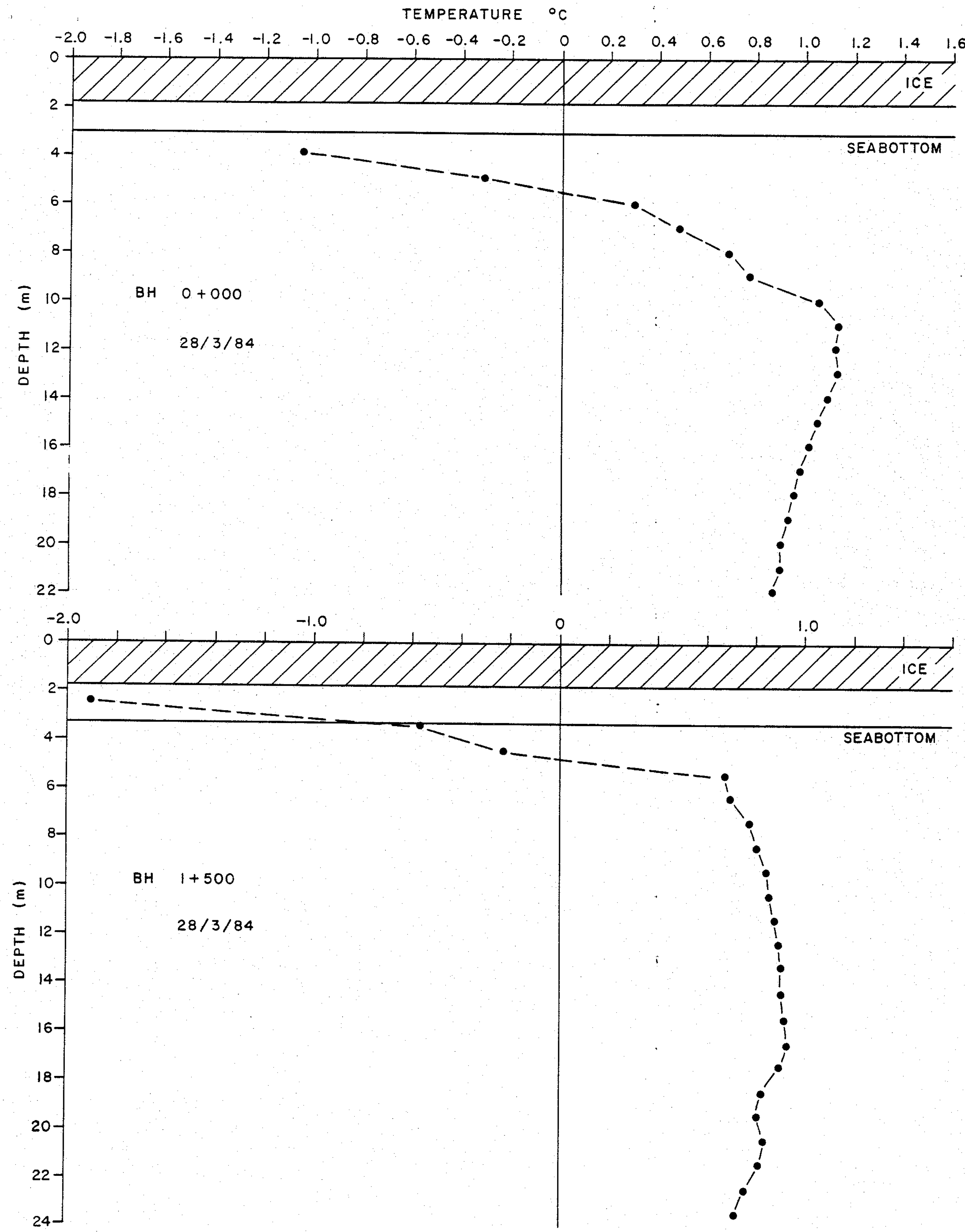
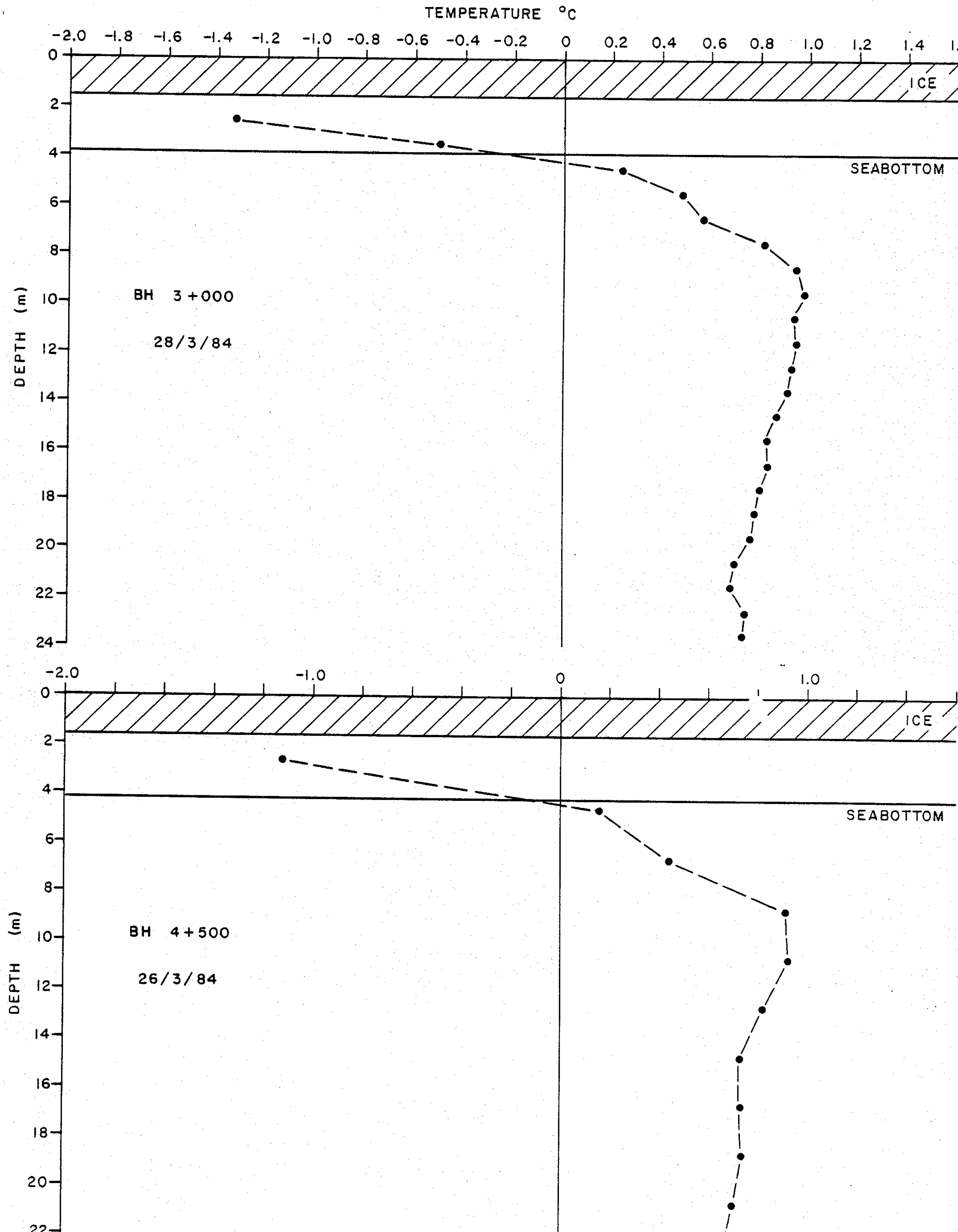

TEMPERATURE °C
-2.0
-1.8
-1.6
-1.4
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
ICE
SEABOTTOM
DEPTH (m)
0
2
4
6
8
10
12
14
16
18
20
22
BH 0+000
28/3/84
-2.0
-1.0
0
1.0
ICE
SEABOTTOM
DEPTH (m)
24
BH 1+500
28/3/84

FIG. 2(c)


TEMPERATURE °C
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-1.8
-1.6
-1.4
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
ICE
SEABOTTOM
DEPTH (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
BH 3+000
28/3/84
-2.0
-1.0
0
1.0
ICE
SEABOTTOM
DEPTH (m)
BH 4+500
26/3/84

FIG. 2(d)

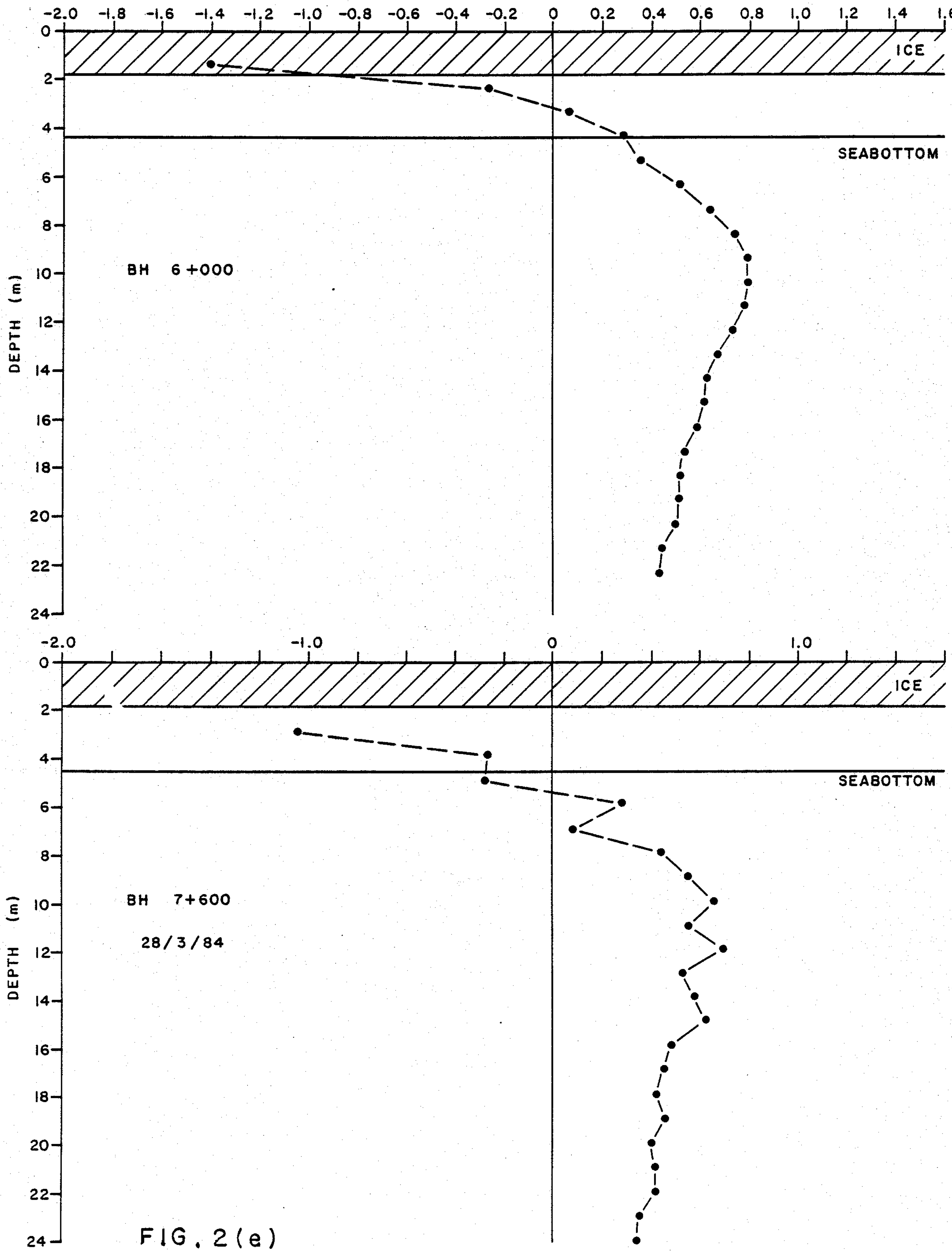
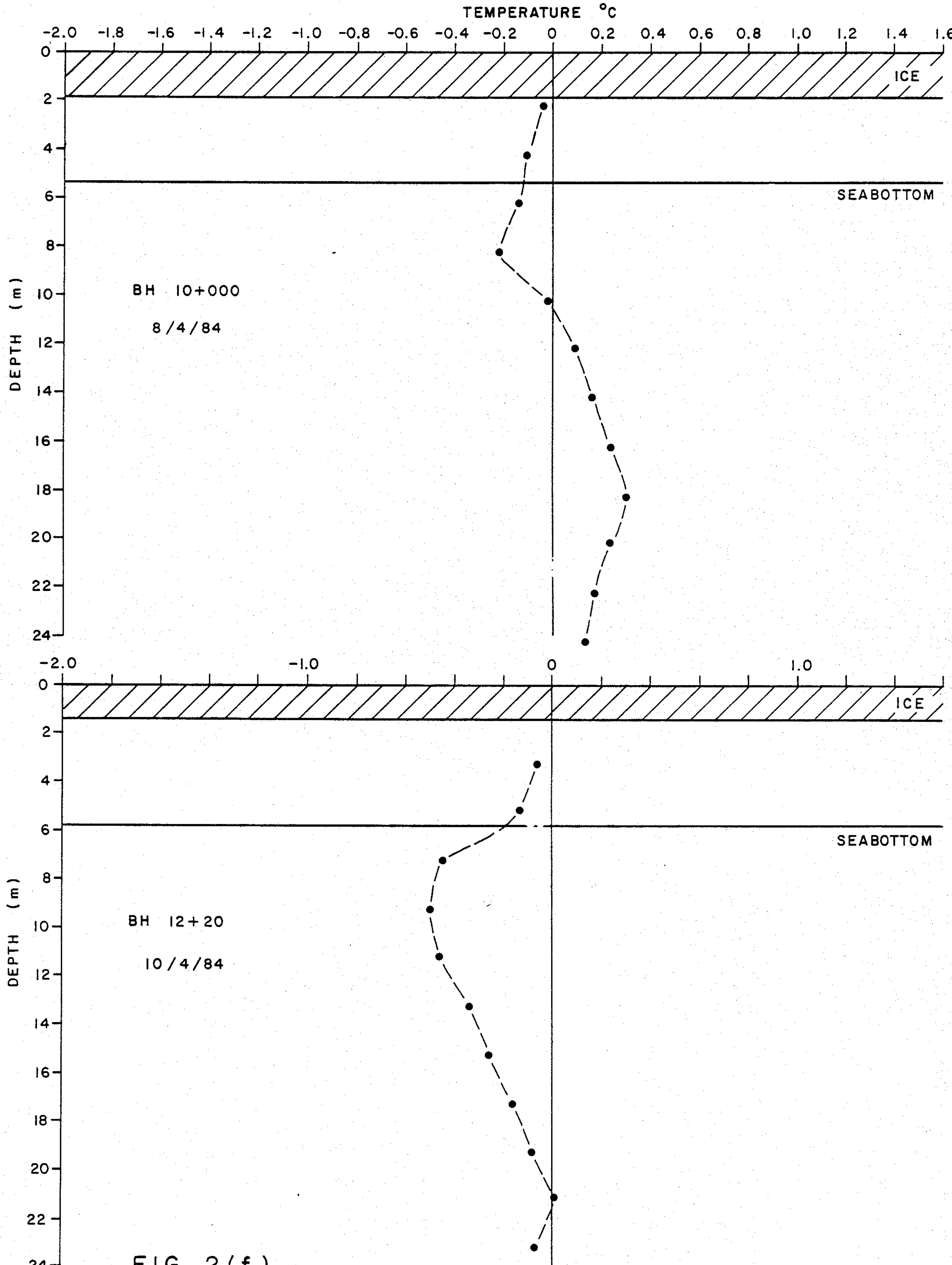

-2.0 -1.8 -1.6 -1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6
ICE
SEABOTTOM
DEPTH (m)
0 2 4 6 8 10 12 14 16 18 20 22 24
BH 6+000
-2.0 -1.0 0 1.0
ICE
SEABOTTOM
DEPTH (m)
0 2 4 6 8 10 12 14 16 18 20 22 24
BH 7+600
28/3/84

FIG. 2(e)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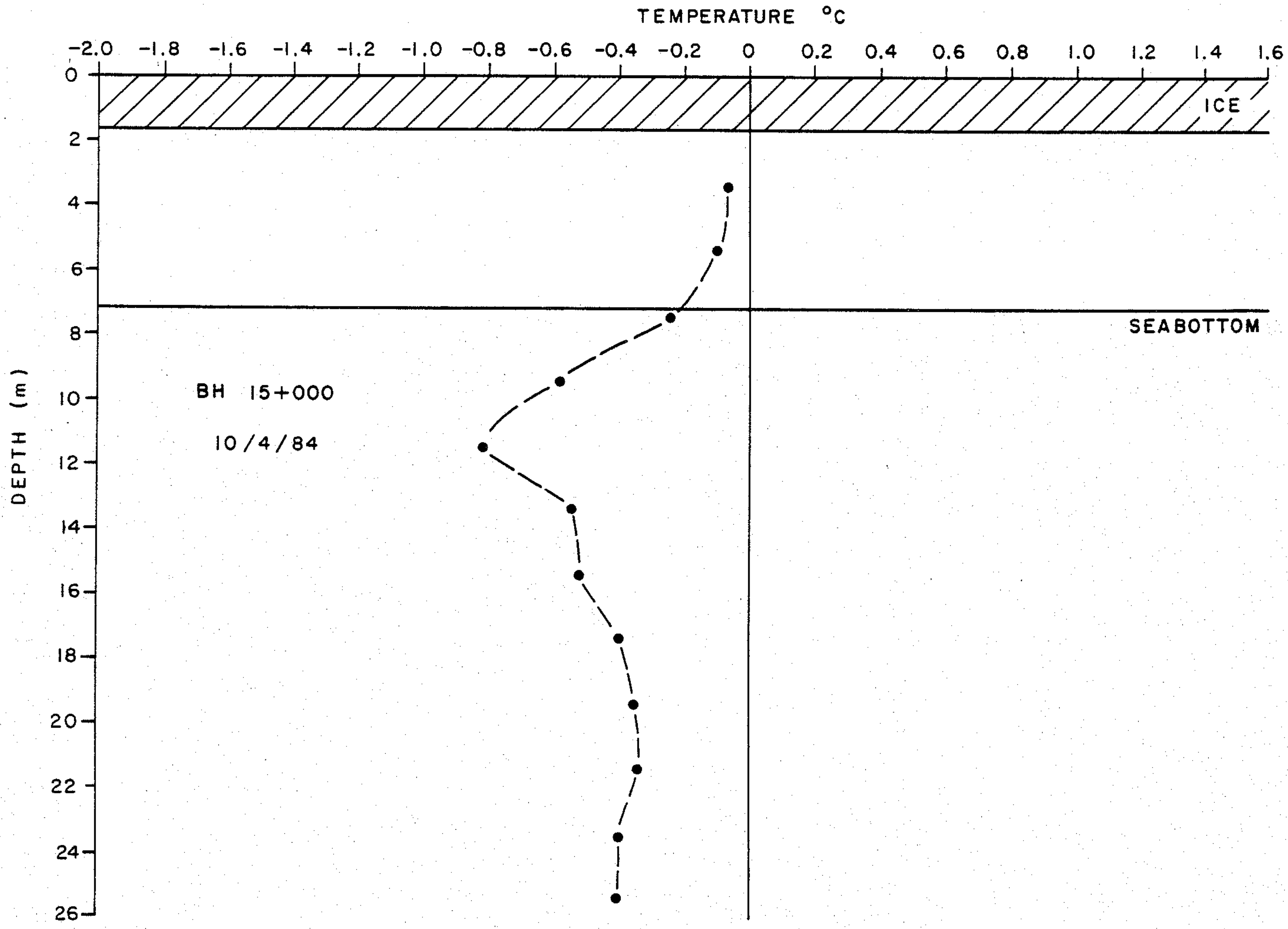
ICE
SEABOTTOM
DEPTH (m)
0 2 4 6 8 10 12 14 16 18 20 22 24
BH 10+000
8/4/84
-2.0 -1.0 0 1.0
ICE
SEABOTTOM
DEPTH (m)
0 2 4 6 8 10 12 14 16 18 20 22 24
BH 12+20
10/4/84

FIG. 2(f)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-1.6
-1.4
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
ICE
SEABOTTOM
DEPTH (m)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
BH 15+000
10/4/84

FIG. 2(g)

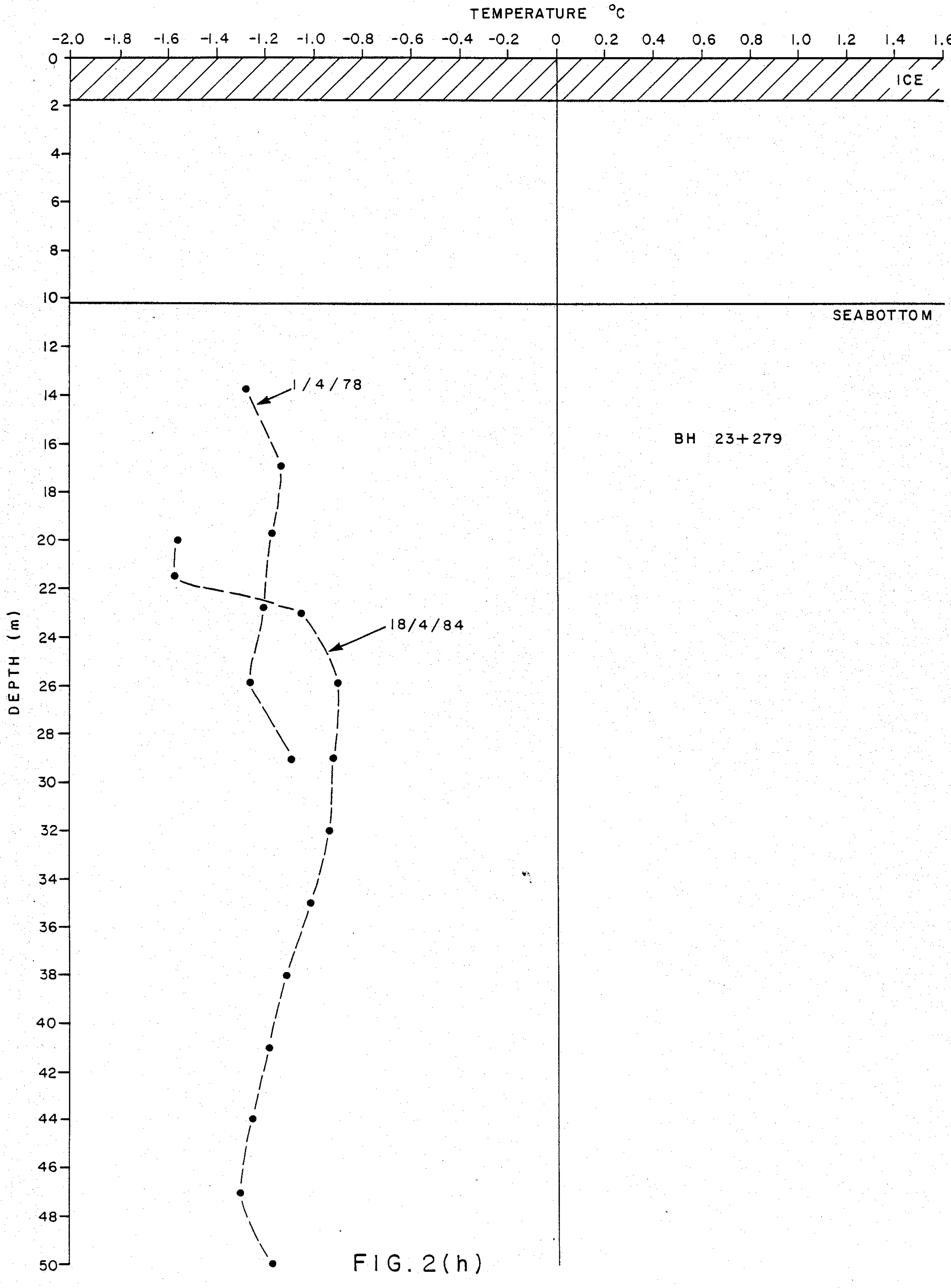
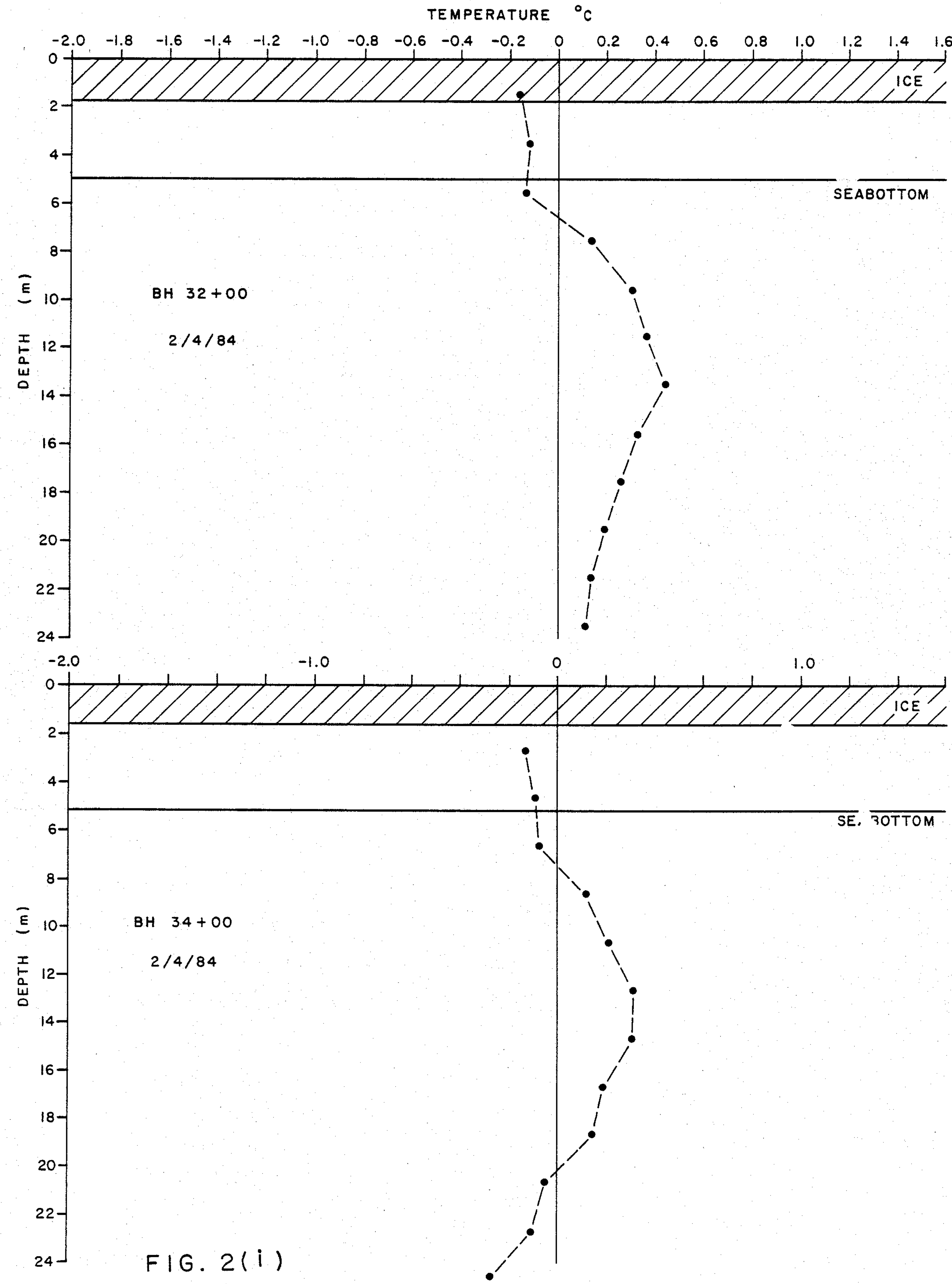

TEMPERATURE °C
-2.0 -1.8 -1.6 -1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6
ICE
SEABOTTOM
1/4/78
18/4/84
BH 23+279
DEPTH (m)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50

FIG. 2(h)


TEMPERATURE °C
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0 2 4 6 8 10 12 14 16 18 20 22 24
DEPTH (m)
ICE
SEABOTTOM
BH 32+00
2/4/84
-2.0 -1.0 0 1.0
0 2 4 6 8 10 12 14 16 18 20 22 24
DEPTH (m)
ICE
SEABOTTOM
BH 34+00
2/4/84

FIG. 2(i)

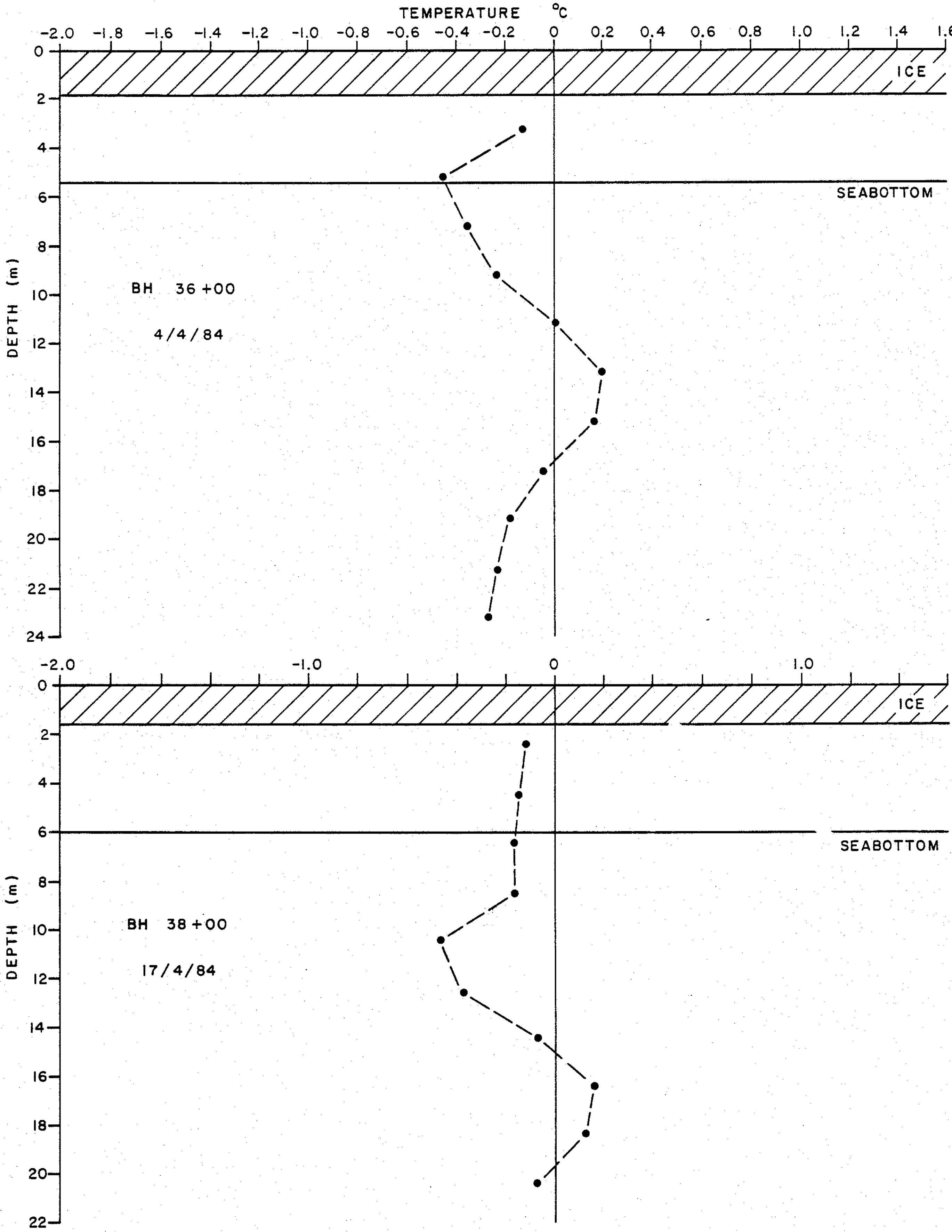

TEMPERATURE °C
-2.0 -1.8 -1.6 -1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6
0 2 4 6 8 10 12 14 16 18 20 22 24
DEPTH (m)
ICE
SEABOTTOM
BH 36+00
4/4/84
-2.0 -1.0 0 1.0
0 2 4 6 8 10 12 14 16 18 20 22
DEPTH (m)
ICE
SEABOTTOM
BH 38+00
17/4/84

FIG. 2(j)

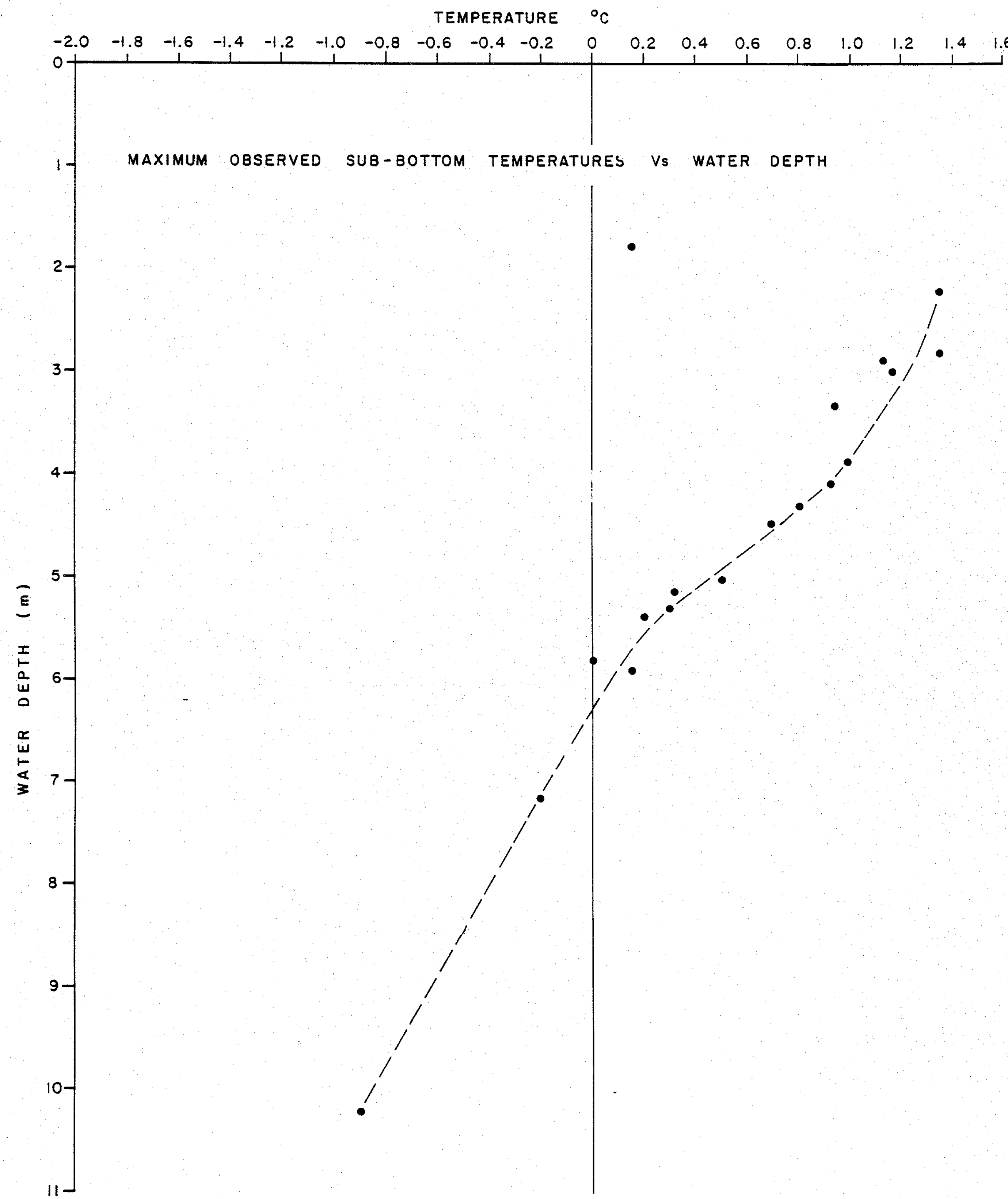


FIG. 3 : Maximum observed sub-bottom temperature vs water depth plot

Figure 4 shows the temperature sections for the three line segments with the strong thermal gradients near the shoreline as well a thermal maximum persisting at a depth of aopproximatley 6 m.

7. Water Temperature Measurements (J.A. Hunter)

Figure 5 shows the sections of water temperature measurements made at borehole locations on April 9. All measurements were made within a 24-hour period; some minor fluctuations in the isotherms may result from tidal variations between measurements times at locations. Temperatures were measured using a temperature cable consisting of 12 YSI thermistors; measurements were made at 0.5 m depth intervals.

All observed water temperatures were below 0^{o}C. The largest temperature gradients were observed in the 4 to 6 m water depth range. Temperatures in the -0.1^{o}C range suggest considerable mixing of Mackenzie River water with salt water; temperatures in the range of -1.5^{o}C indicate predominantly salt water (in adjacent survey areas, sea water temperatures of -1.8^{o}C have been observed in 10 m water depth in April).

8. Uphole Seismic Measurements (J.A. Hunter)

Seismic velocity measurements were made in PVC-cased boreholes immediately after the completion of drilling. Two types of downhole dectors were used; boreholes 41+00 to 44+00 were shot using a Mark Products P-38 hydrophone suspended in the water filled borehole. All other boreholes were shot using an OYO 3-component wall-lock geophone clamped to the PVC casing. The seismic source in all cases was a seismocap detonated at 2 m water depth adjacent to the borehole. First arrival times vs shot-detector distance are shown in Figure 6. The velocities indicated are those obtained

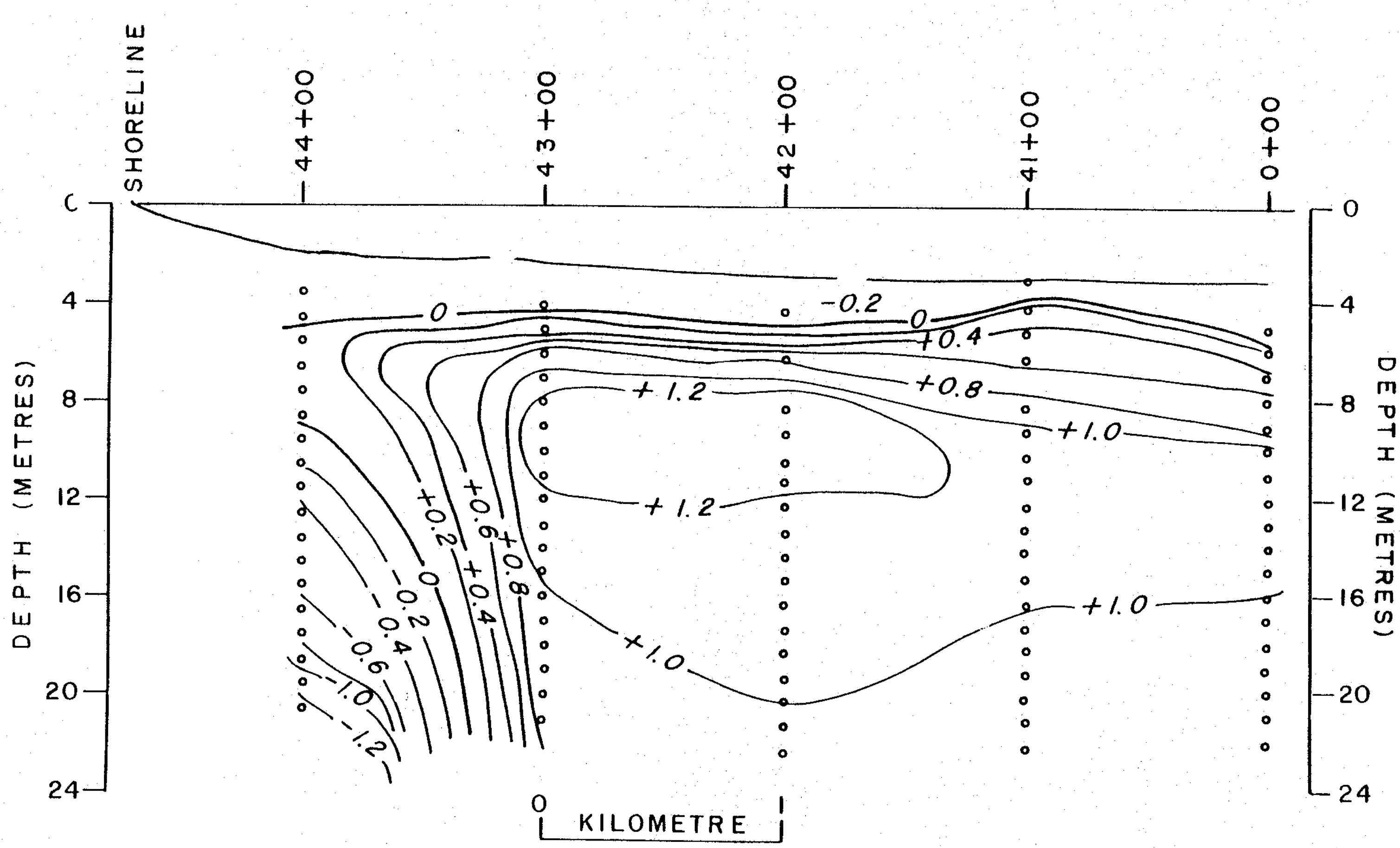


FIG. 4(a)

Figure 4 a - c:Sub-bottom temperature distribution along drill lines

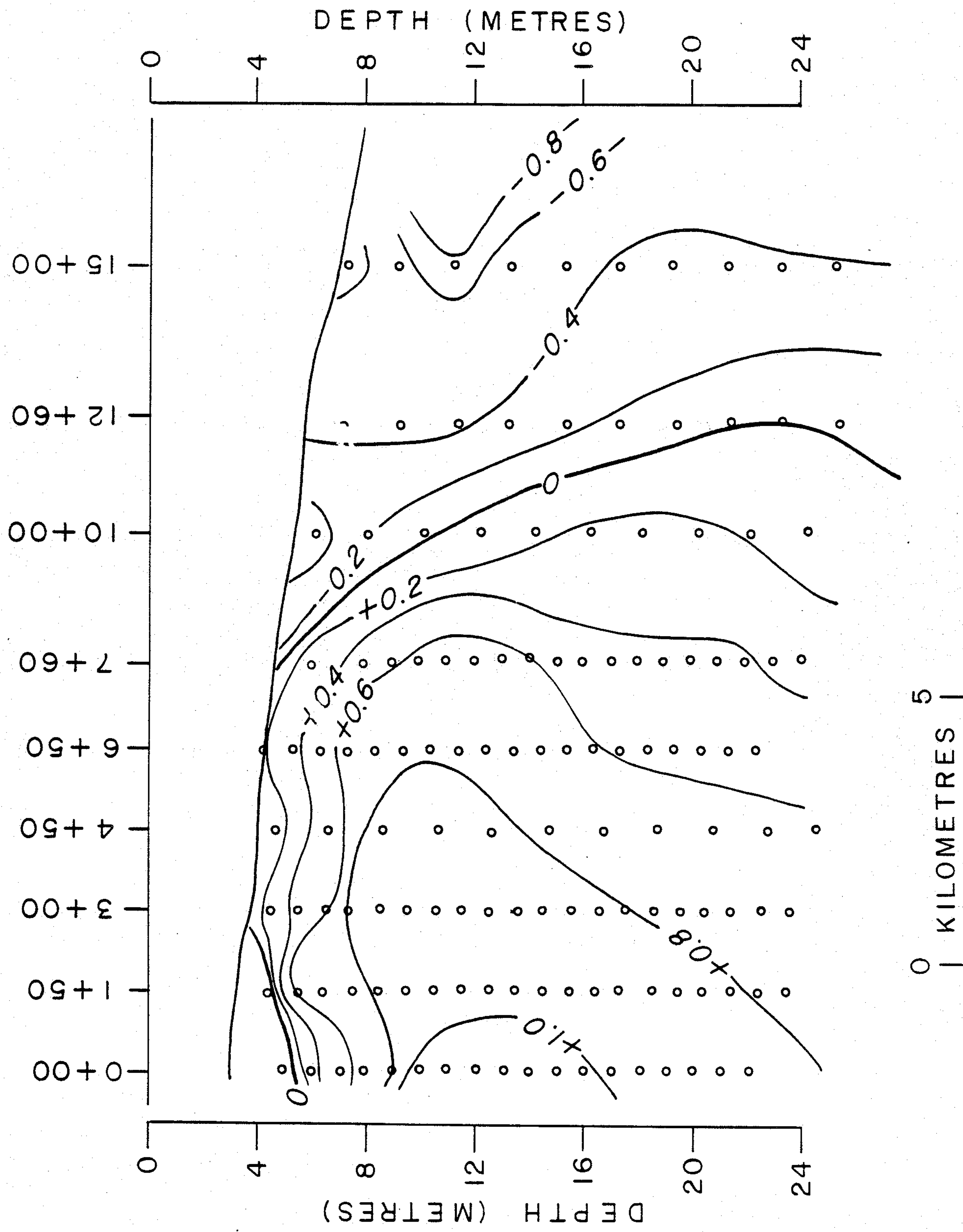

DEPTH (METRES)
0
4
8
12
16
20
24
15+00
12+60
10+00
7+60
6+50
4+50
3+00
1+50
0+00
-0.8
-0.6
-0.4
-0.2
0
+0.2
+0.4
+0.6
+0.8
+1.0
0
KILOMETRES
5

FIG. 4(b)

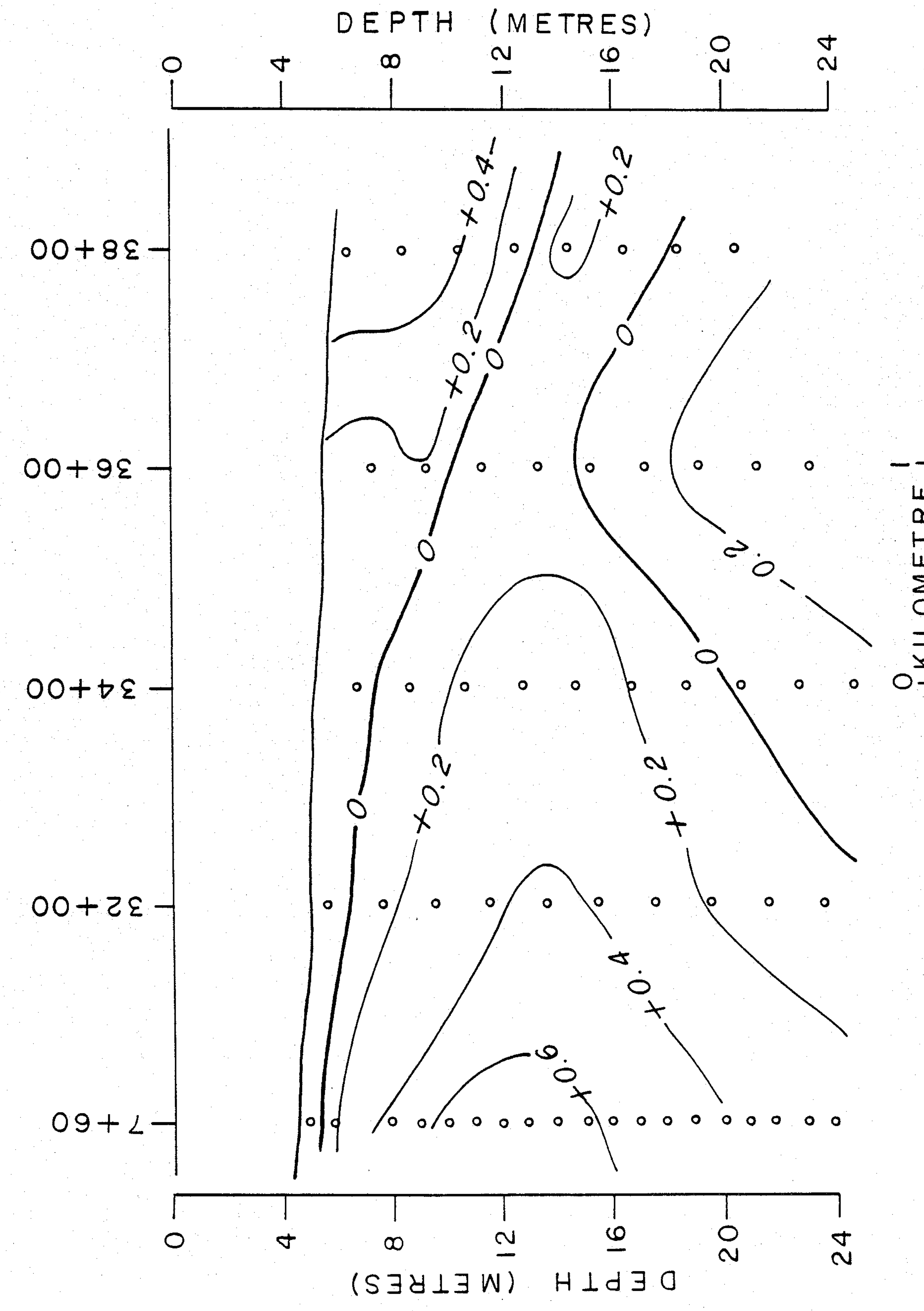

DEPTH (METRES)
0
4
8
12
16
20
24
38+00
36+00
34+00
32+00
7+60
+0.4
+0.2
0
-0.2
+0.6
0 KILOMETRE 1

FIG. 4(c)

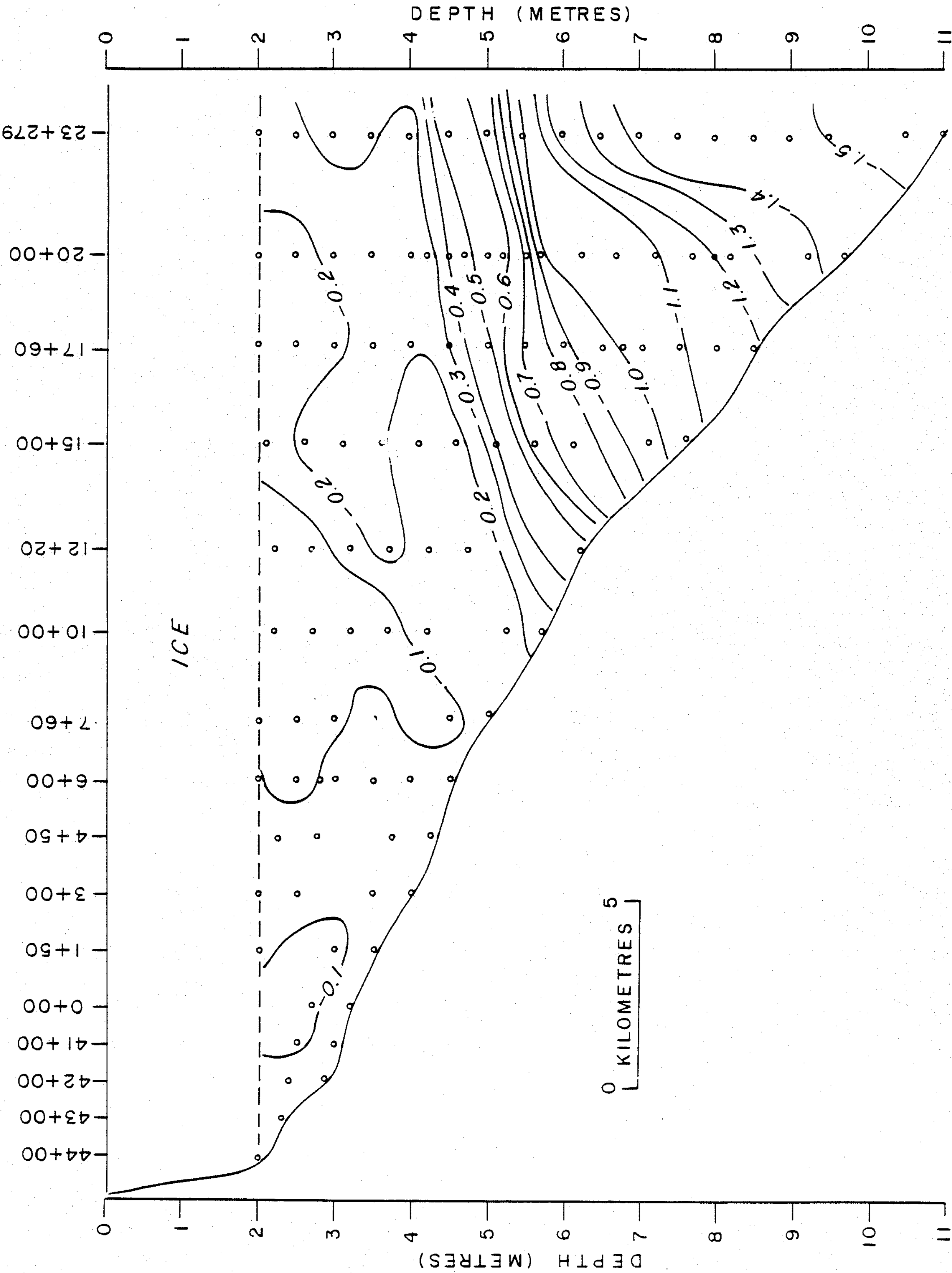


FIG. 5(a):Water temperature measurements

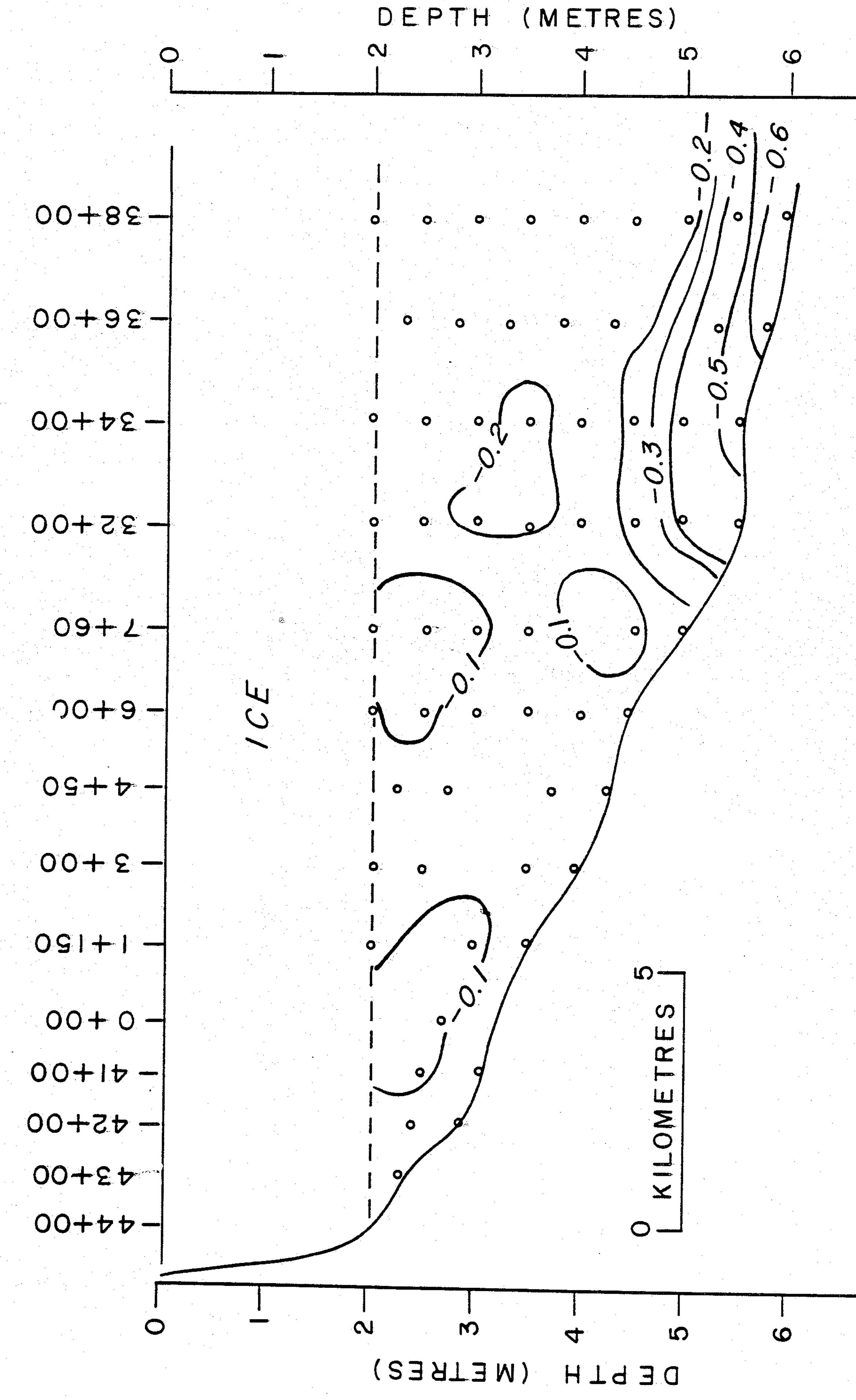


FIG. 5(b): Water temperature measurements

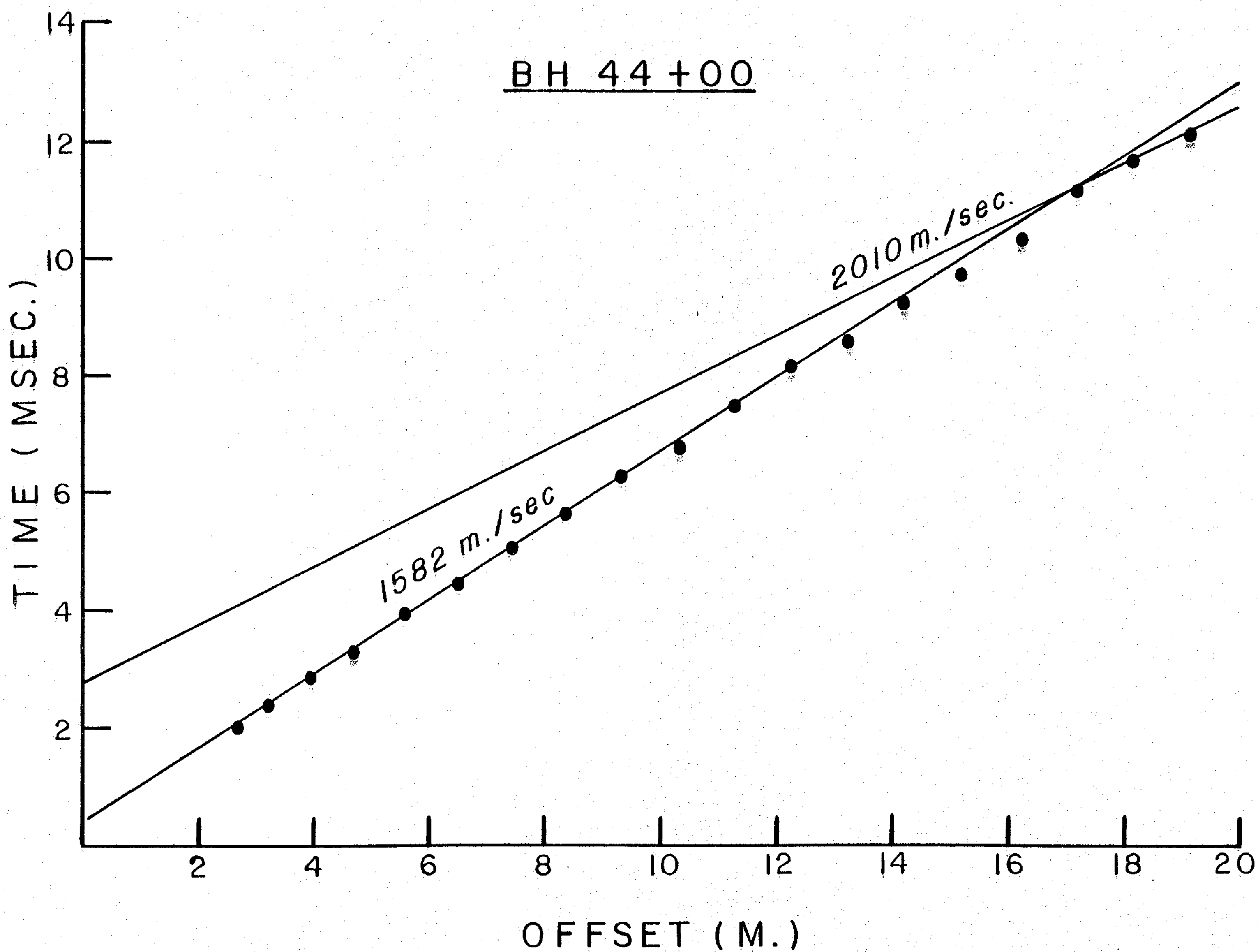


Figure 6 a - o: First arrival time vs shot detector distance plots

FIG. 6(g)

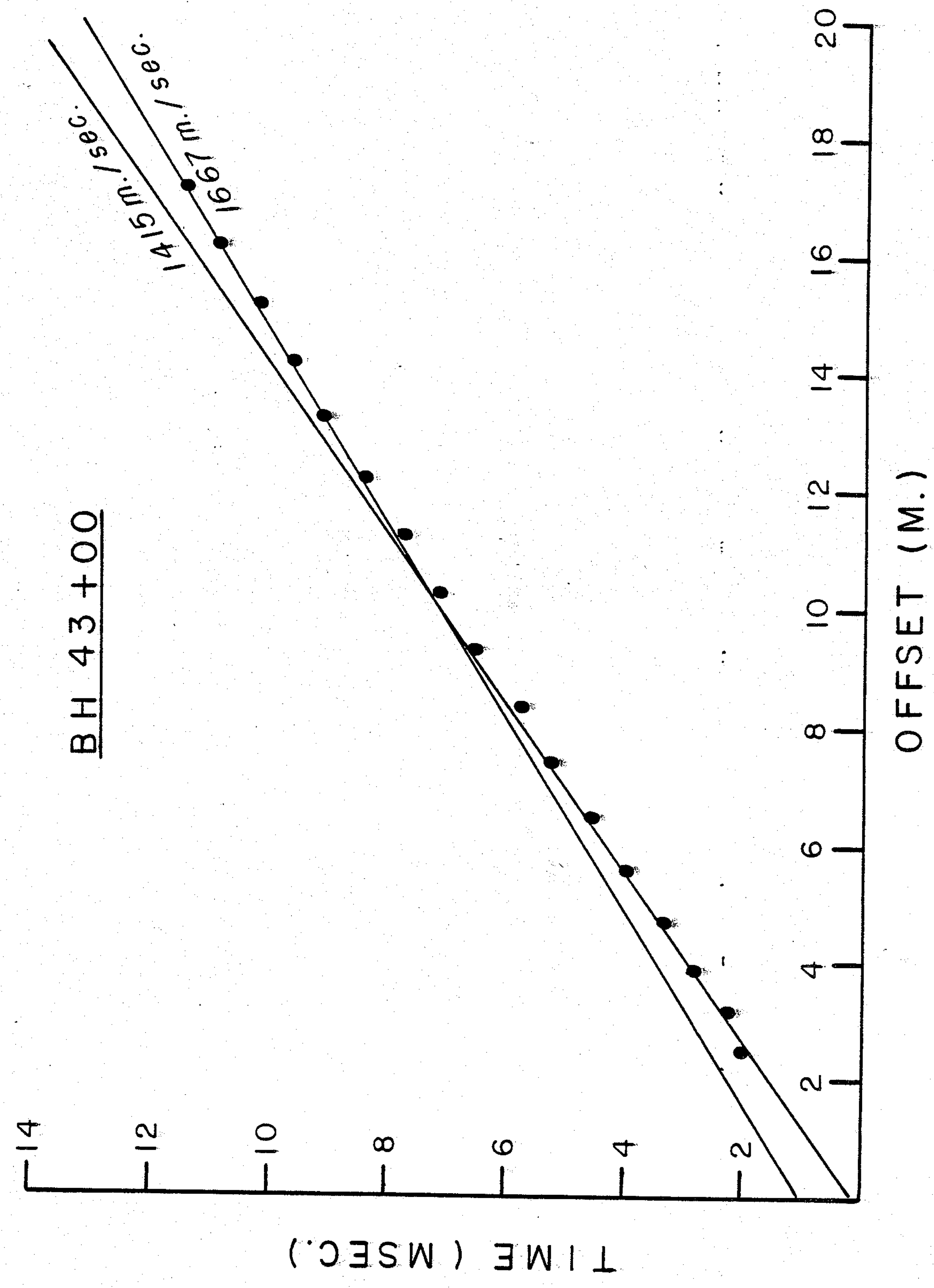

BH 43+00
1415 m./sec.
1667 m./sec.
TIME (MSEC.)
OFFSET (M.)
2
4
6
8
10
12
14
16
18
20

FIG. 6(b)

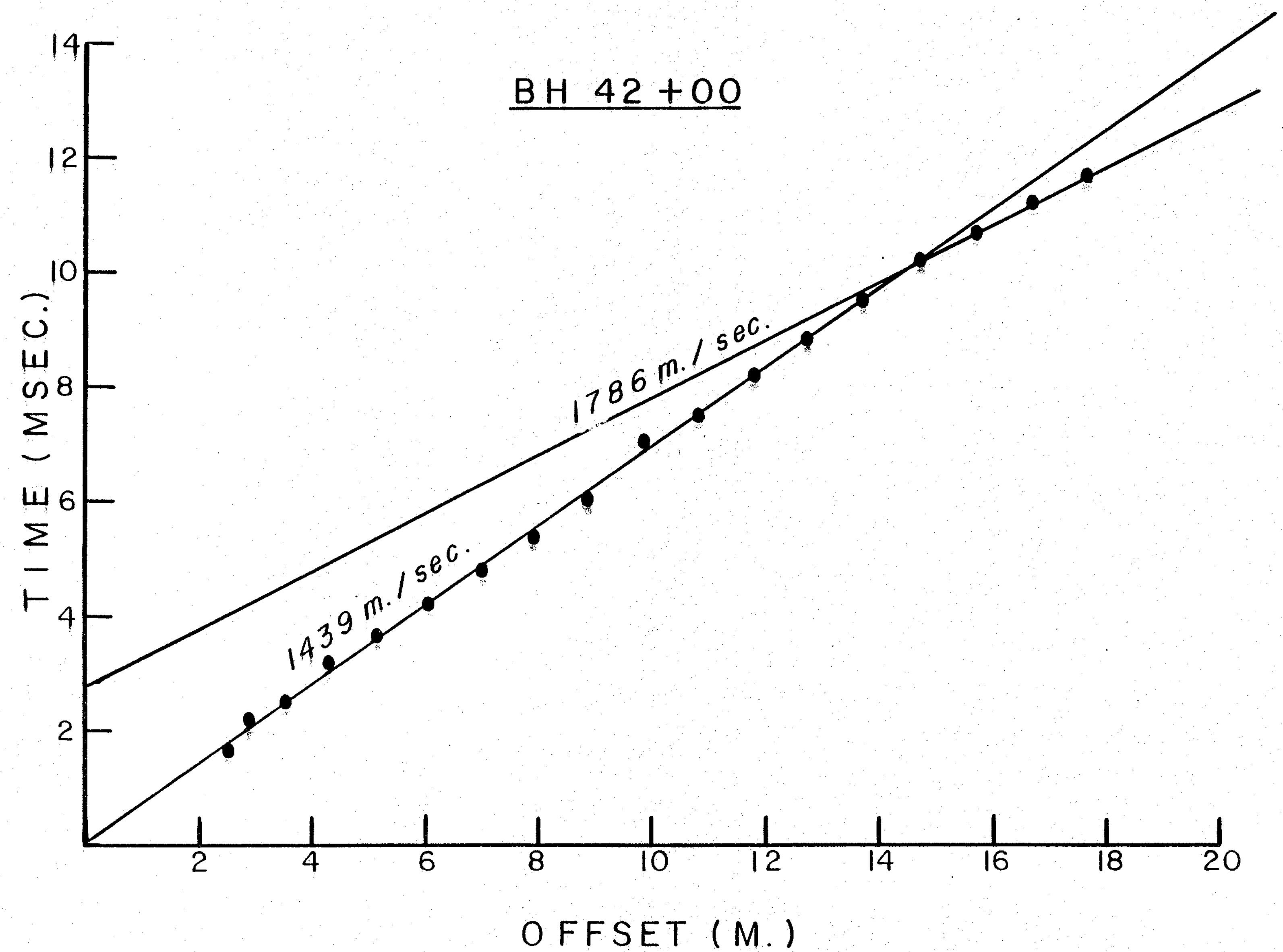

BH 42 +00
TIME (MSEC.)
14
12
10
8
6
4
2
1786 m./sec.
1439 m./sec.
2
4
6
8
10
12
14
16
18
20
OFFSET (M.)

FIG. 6(c)

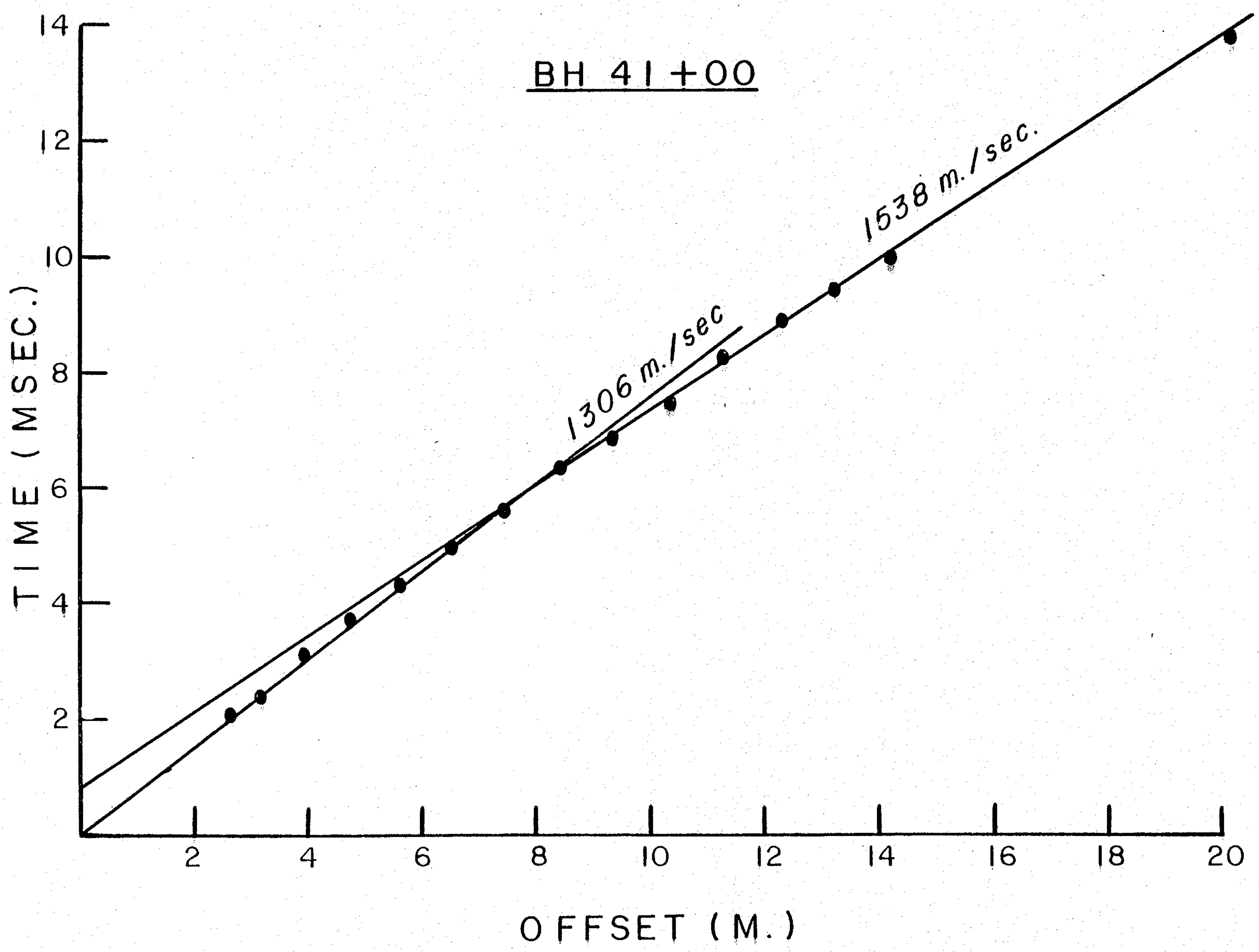

BH 41+00
1306 m./sec
1538 m./sec.
TIME (MSEC.)
OFFSET (M.)
2
4
6
8
10
12
14
16
18
20

FIG.6(d)

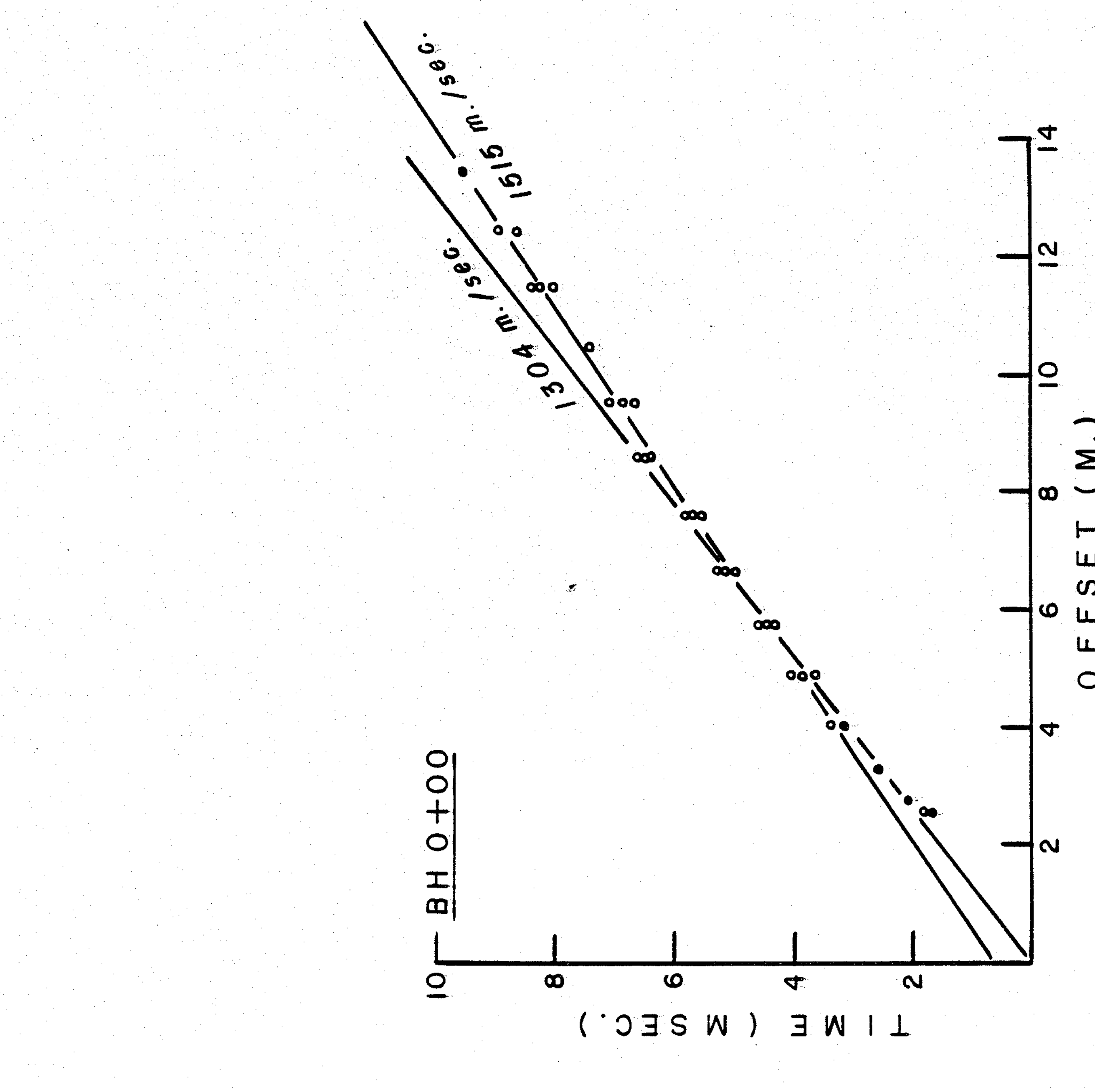


FIG. 6(e)

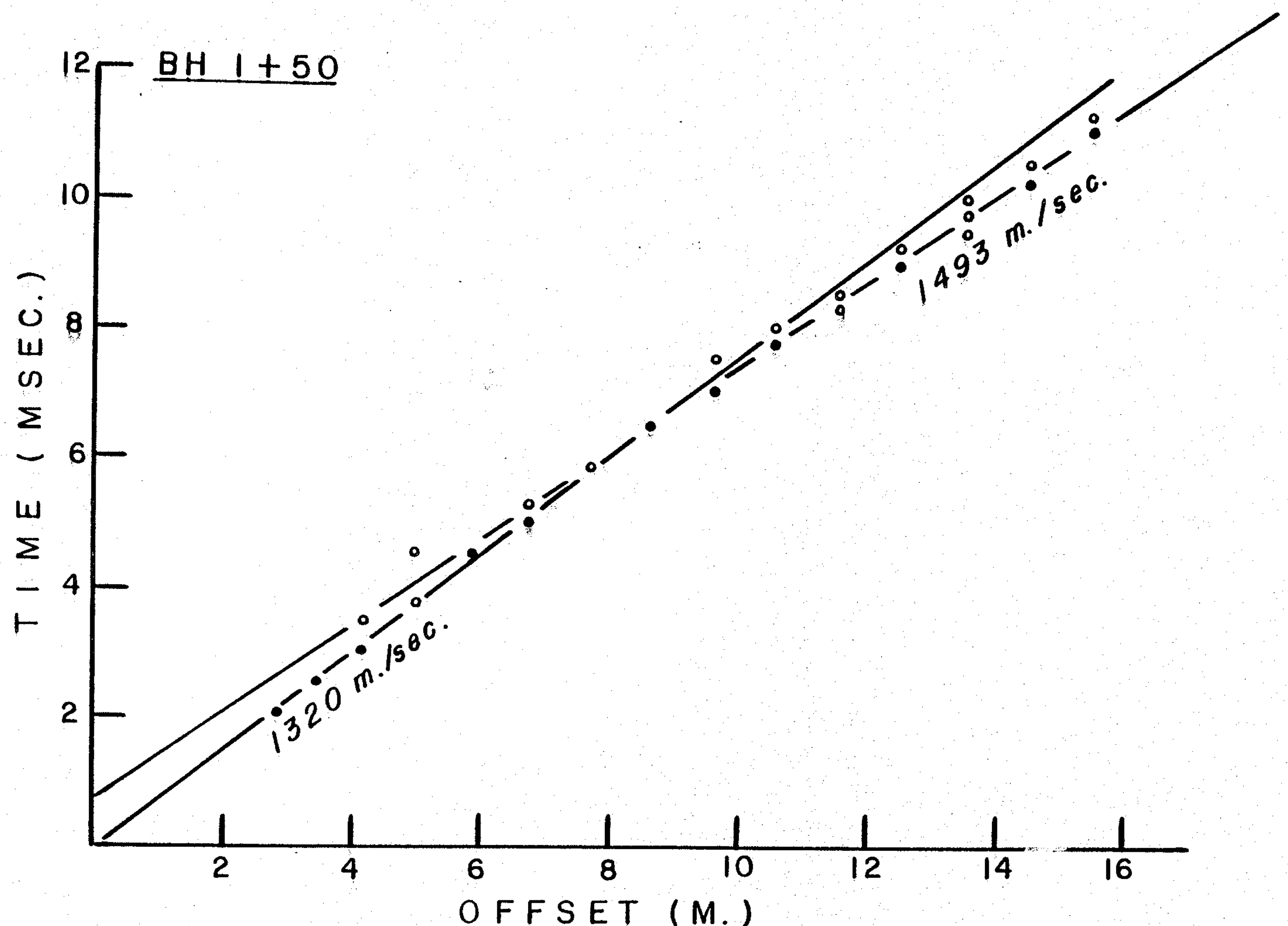

BH 1+50
TIME (MSEC.)
12
10
8
6
4
2
OFFSET (M.)
2
4
6
8
10
12
14
16
1320 m./sec.
1493 m./sec.

FIG. 6(f)

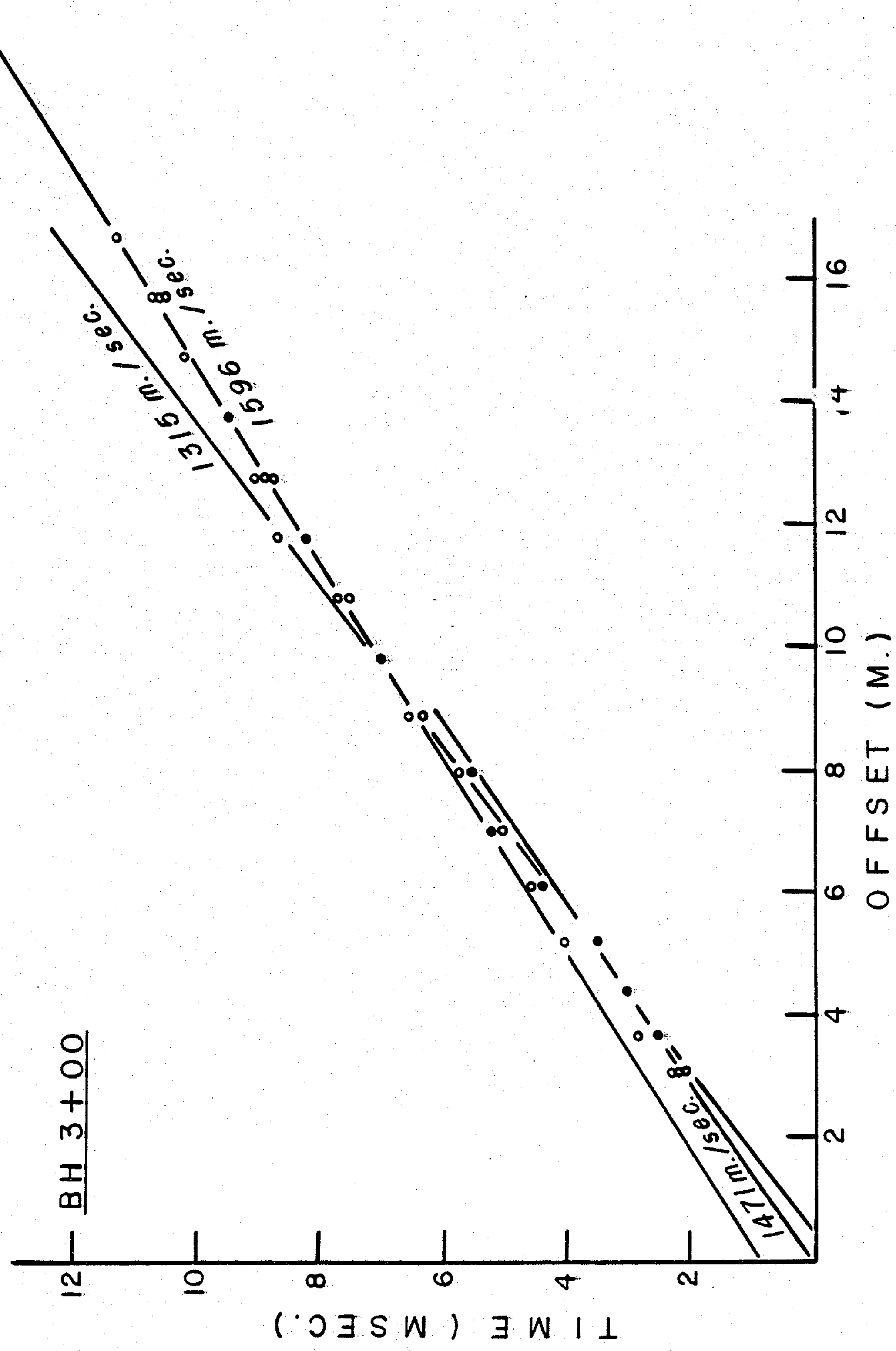

BH 3+00
TIME (MSEC.)
12
10
8
6
4
2
OFFSET (M.)
2
4
6
8
10
12
14
16
1471 m./sec.
1315 m./sec.
1696 m./sec.

FIG. 6(g)

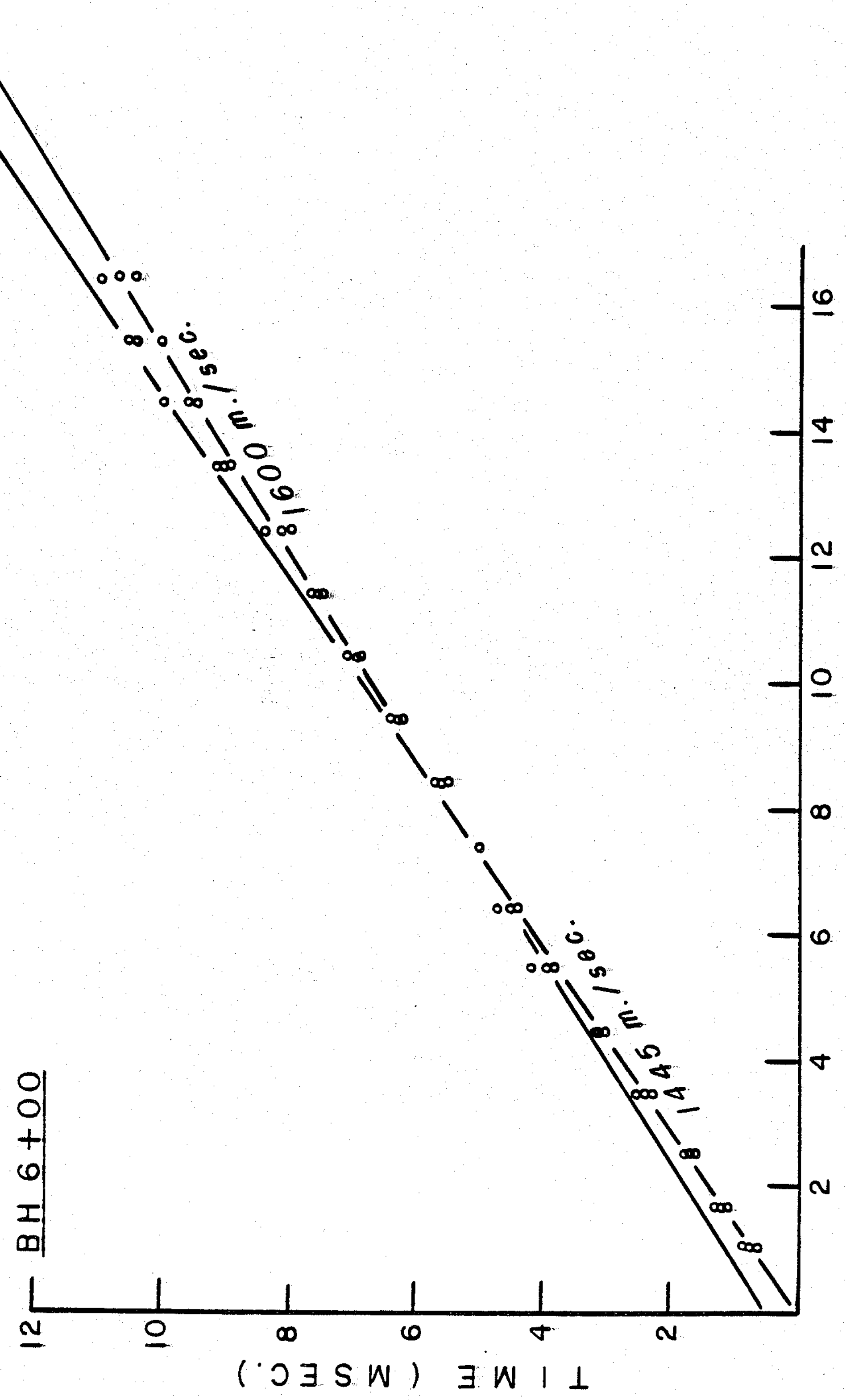

BH 6+00
1600 m./sec.
1445 m./sec.
OFFSET (M.)
TIME (MSEC.)
2
4
6
8
10
12
14
16
2
4
6
8
10
12

FIG. 6(h)

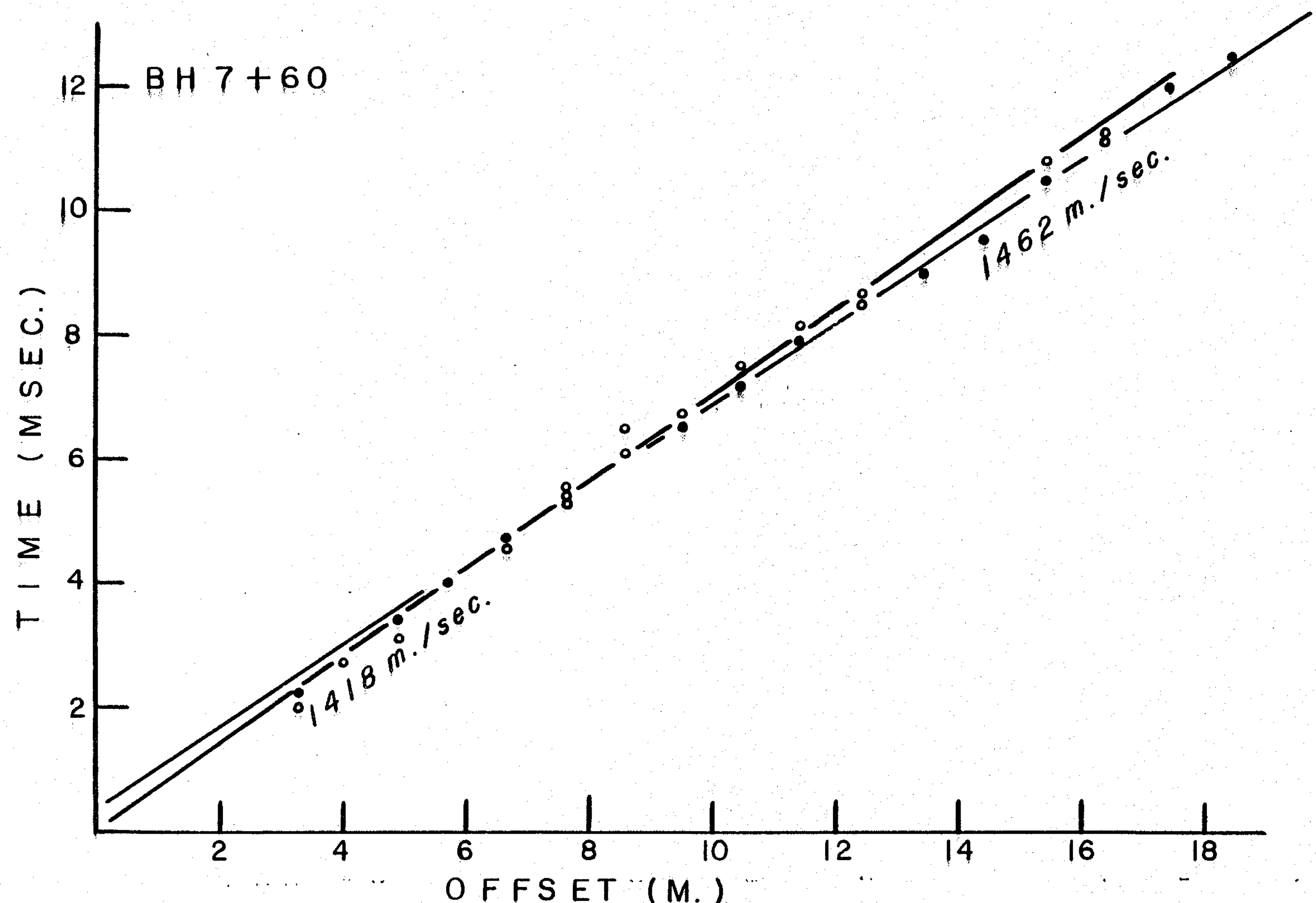

BH 7+60
TIME (MSEC.)
OFFSET (M.)
1418 m./sec.
1462 m./sec.
2
4
6
8
10
12
14
16
18

FIG. 6(i)

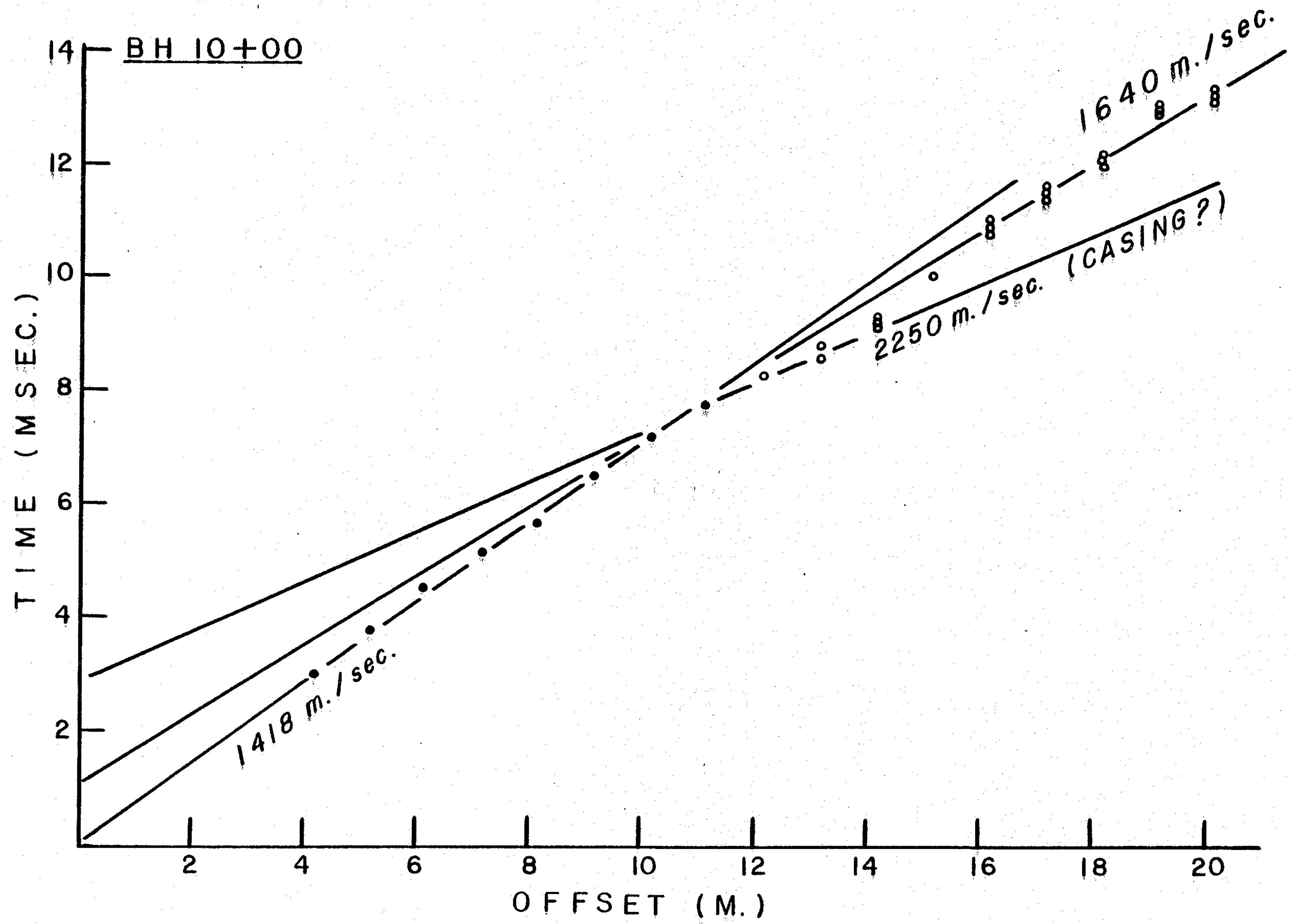

BH 10+00
TIME (MSEC.)
OFFSET (M.)
1418 m./sec.
2250 m./sec. (CASING?)
1640 m./sec.
14
12
10
8
6
4
2
2
4
6
8
10
12
14
16
18
20

FIG. 6(j)

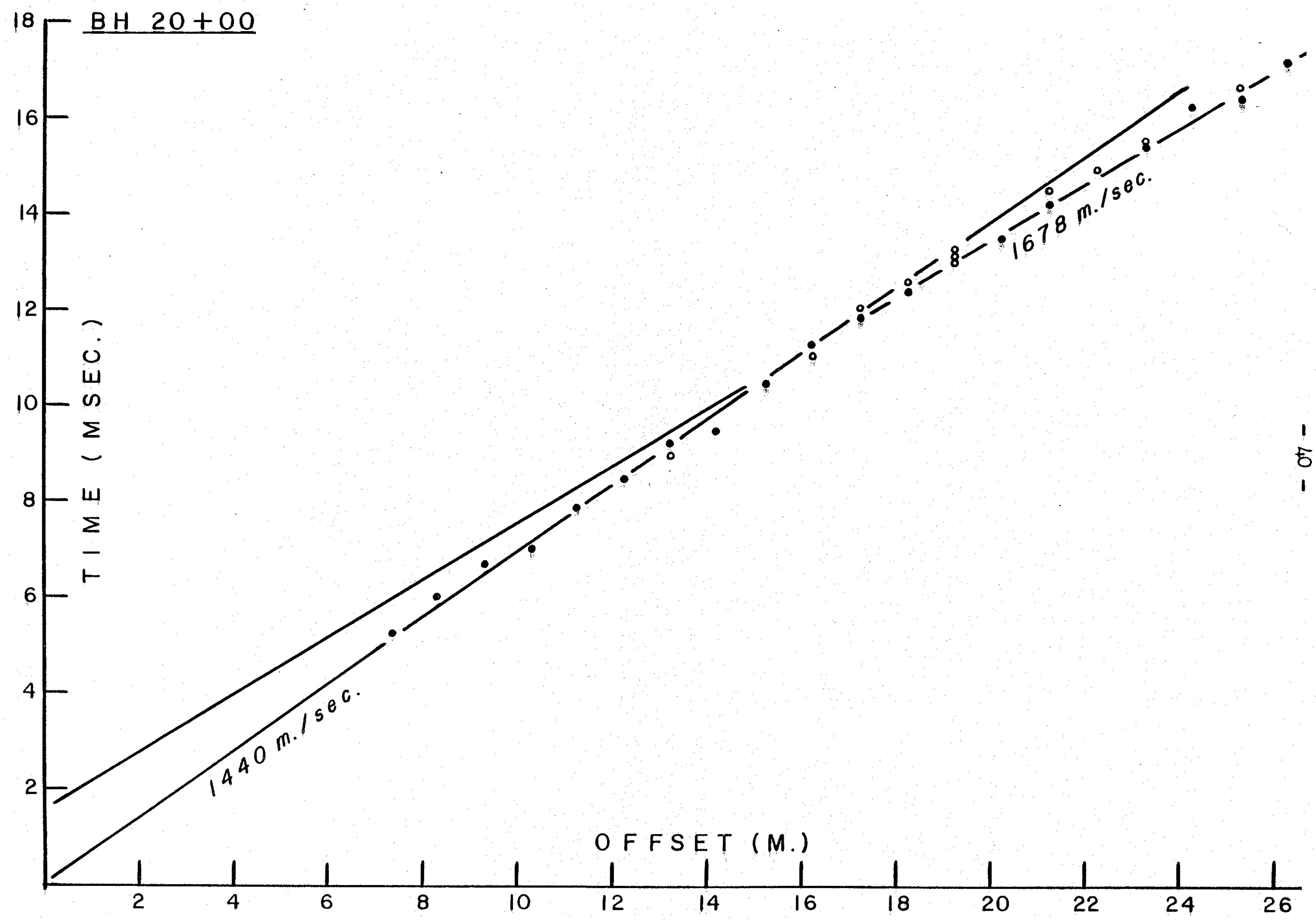

BH 20+00
TIME (MSEC.)
OFFSET (M.)
1440 m./sec.
1678 m./sec.
18
16
14
12
10
8
6
4
2
2
4
6
8
10
12
14
16
18
20
22
24
26

FIG. 6(k)

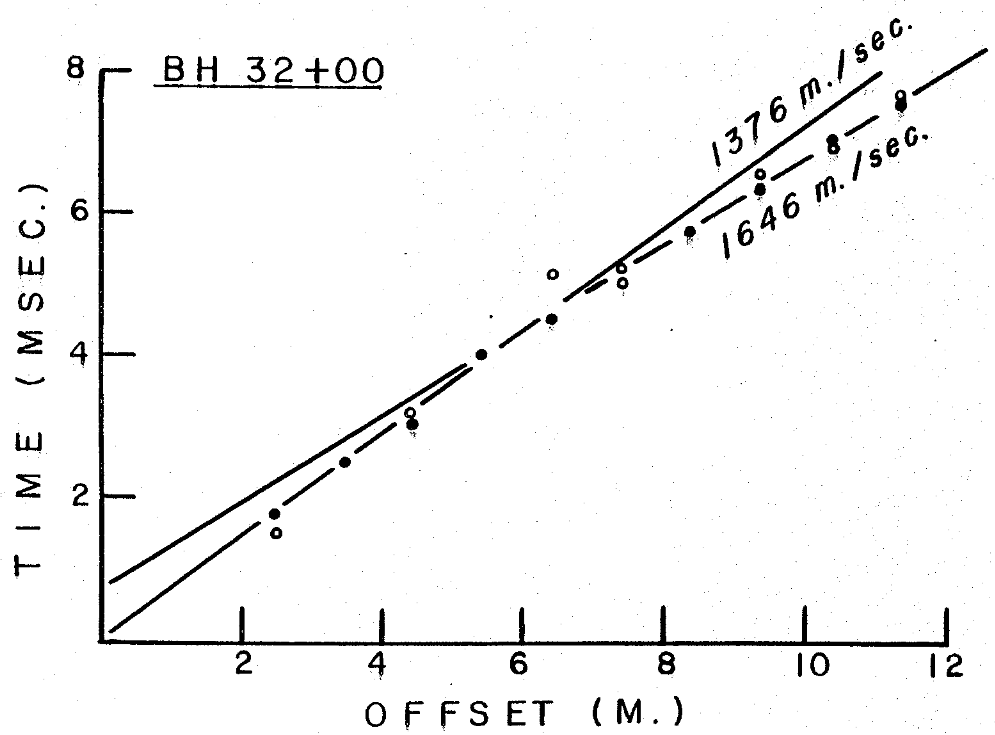


FIG. 6(1)

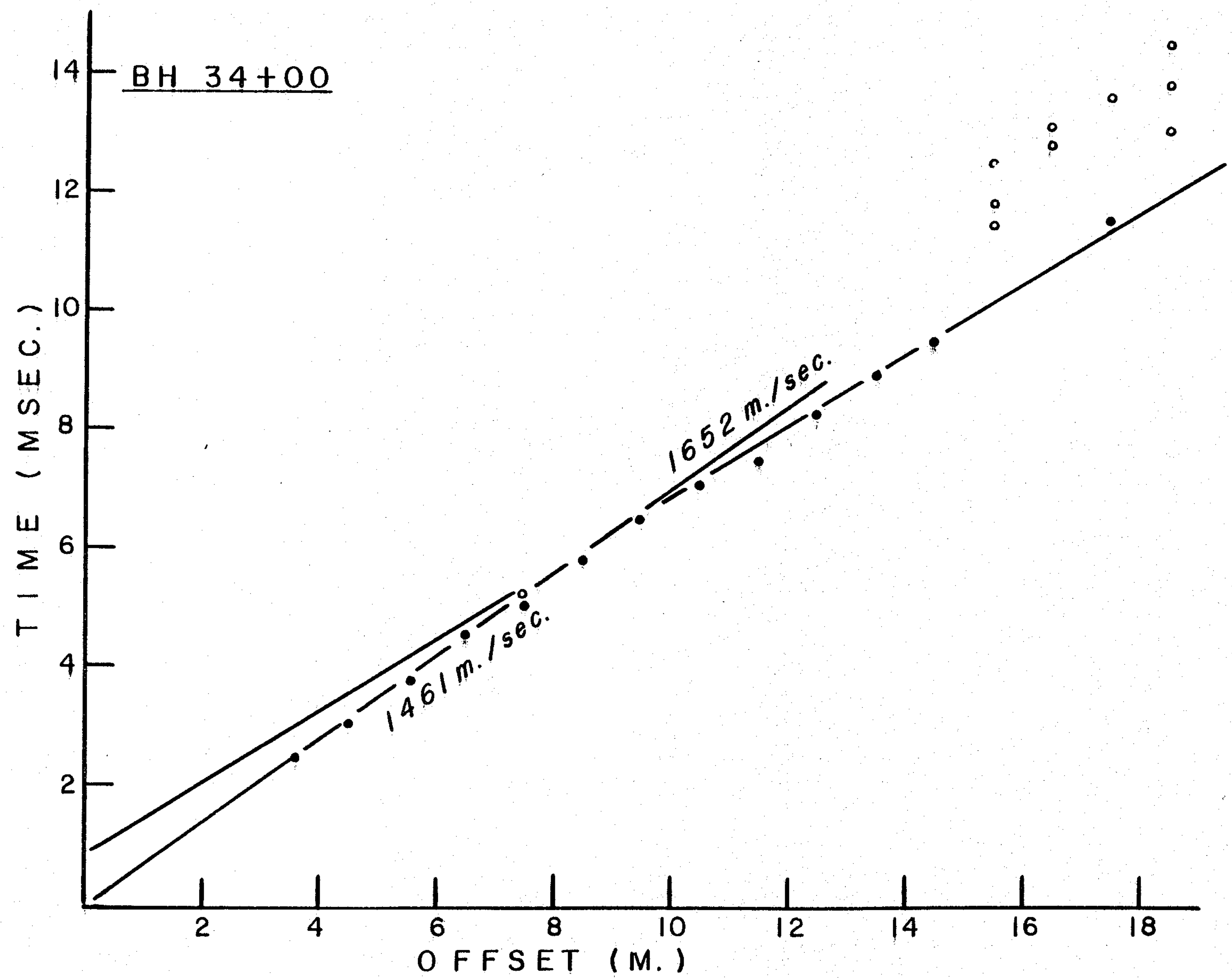

BH 34+00
TIME (MSEC.)
OFFSET (M.)
1652 m./sec.
1461 m./sec.
14
12
10
8
6
4
2
2
4
6
8
10
12
14
16
18

FIG. 6(m)

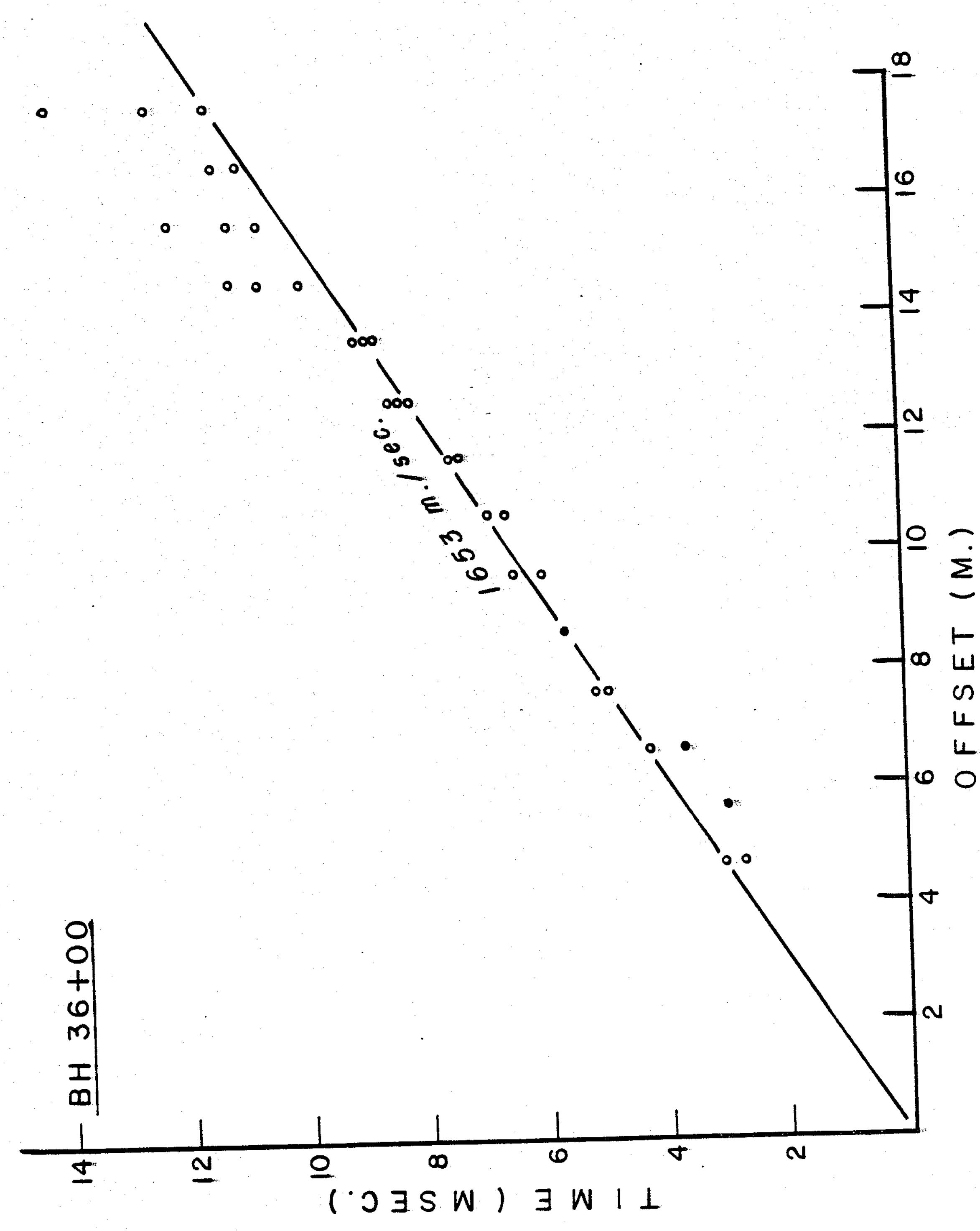


FIG. 6(n)

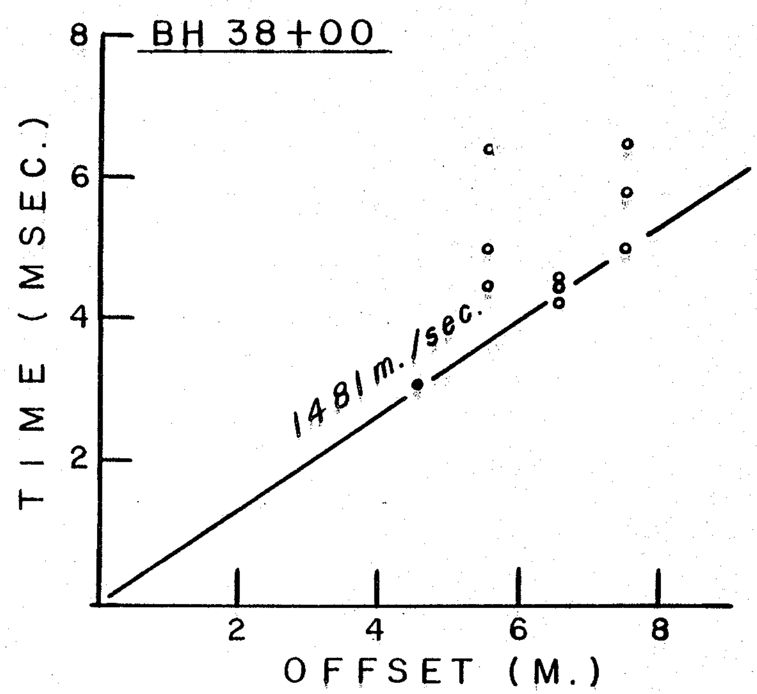


FIG. 6(o)

from an interpreter's best-fit line and should be considered as only preliminary. Most velocities were in the range of 1300-1650 m/sec.

9. Seabottom Seismic Refraction Measurements (J.A. Hunter)

Seabottom seismic refraction measurements were made at each borehole location by deploying a 12 channel hydrophone (Mark Products P-44) array on the seabottom. Seismocaps were detonated off each end of the array to obtain a reversed profile. The depth of penetration with the refraction technique is limited by the onset of the refraction wave through the sea ice; hence it was determined that in-shore locations with only a couple of metres of water beneath the ice would not provide adequate seabottom data and only the deepwater sites were shot.

Figure 7 shows the time-distance plots of first arrivals for the sites examined. Shown also are the best-fit velocity lines through the data; such velocity determination should be considered as preliminary. All seabottom velocities were observed to be in the range of 1450-1550 m/sec.

10. Borehole Heating and Thermal Conductivity (J.L. Morack, W. Harrison)

Two of the boreholes drilled (4+50 and 36+00) were electrically heated and their temperature responses were monitored, enabling a determination of the equilibrium temperatures and thermal conductivities to be made.

The difficulty of obtaining thermally and mechanically undisturbed soil samples during subsea permafrost investigations has led the University of Alaska to the development of a method of in-situ measurements. The approach is particularly valuable in reconnaissance jet-drilling and probling investigations when no soil samples are obtained at all. A

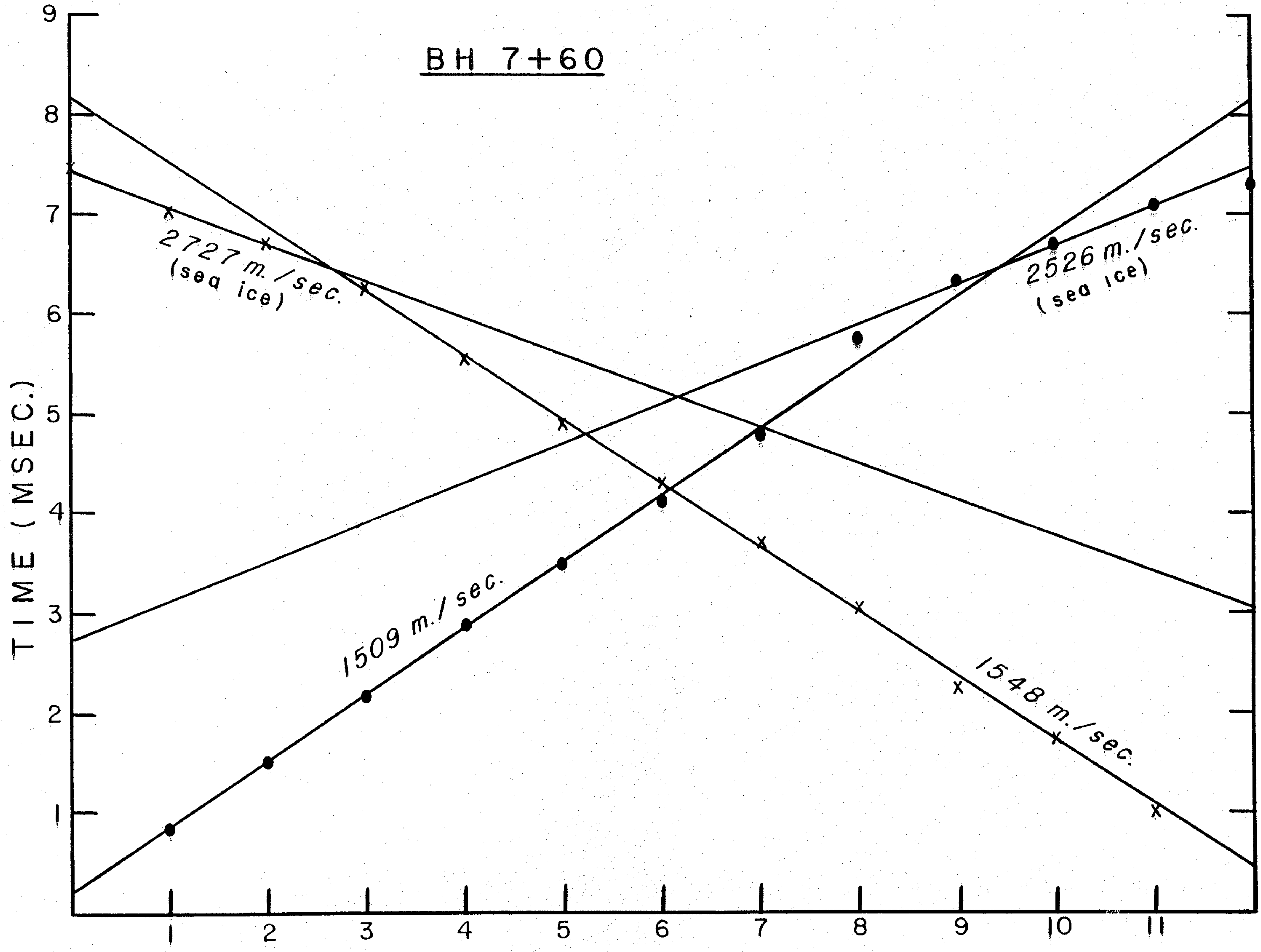
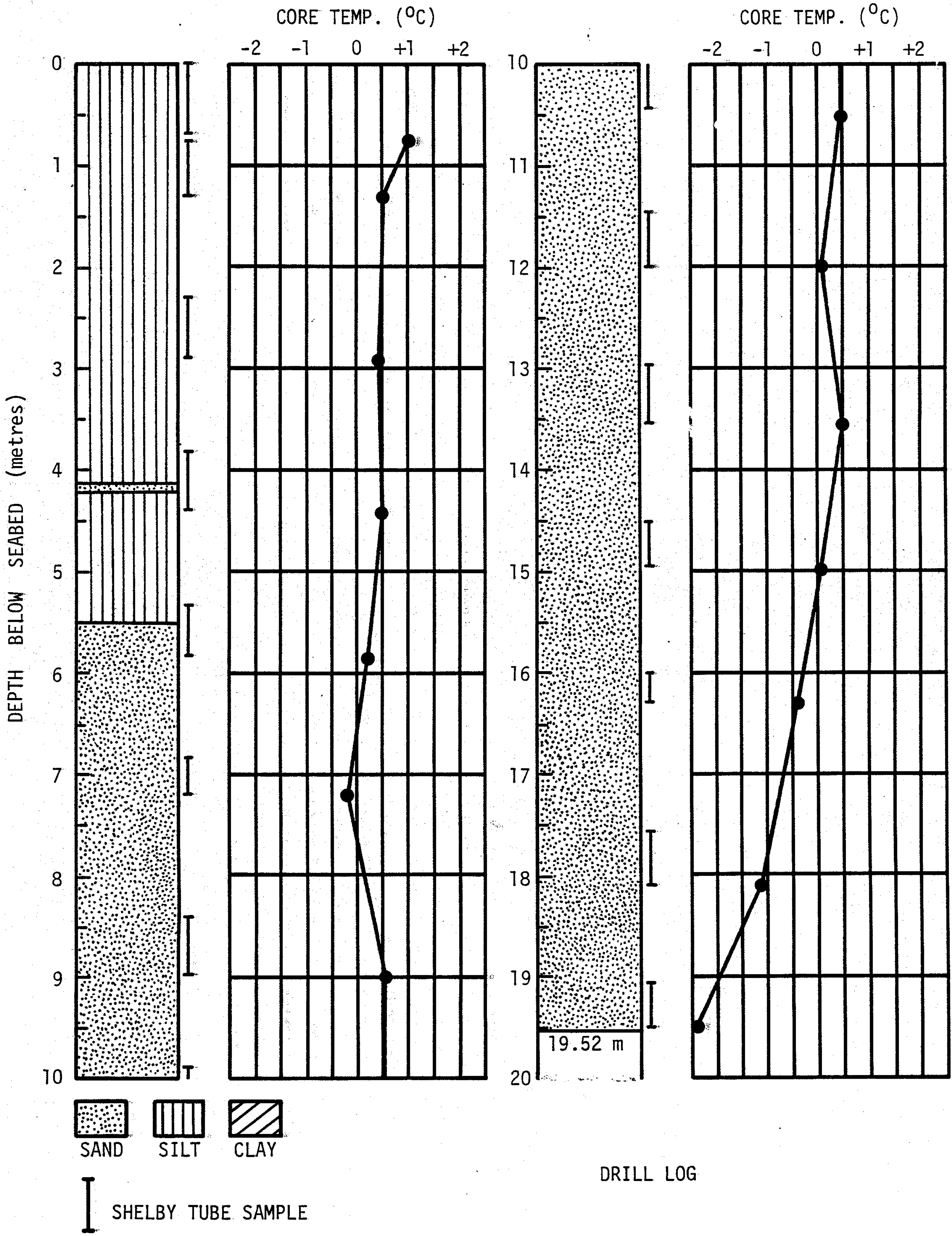


FIG. 7(a)

Figure 7 a - k: Time vs distance plots of first arrivals

BOREHOLE: 44+00
DATE: 27-03-84

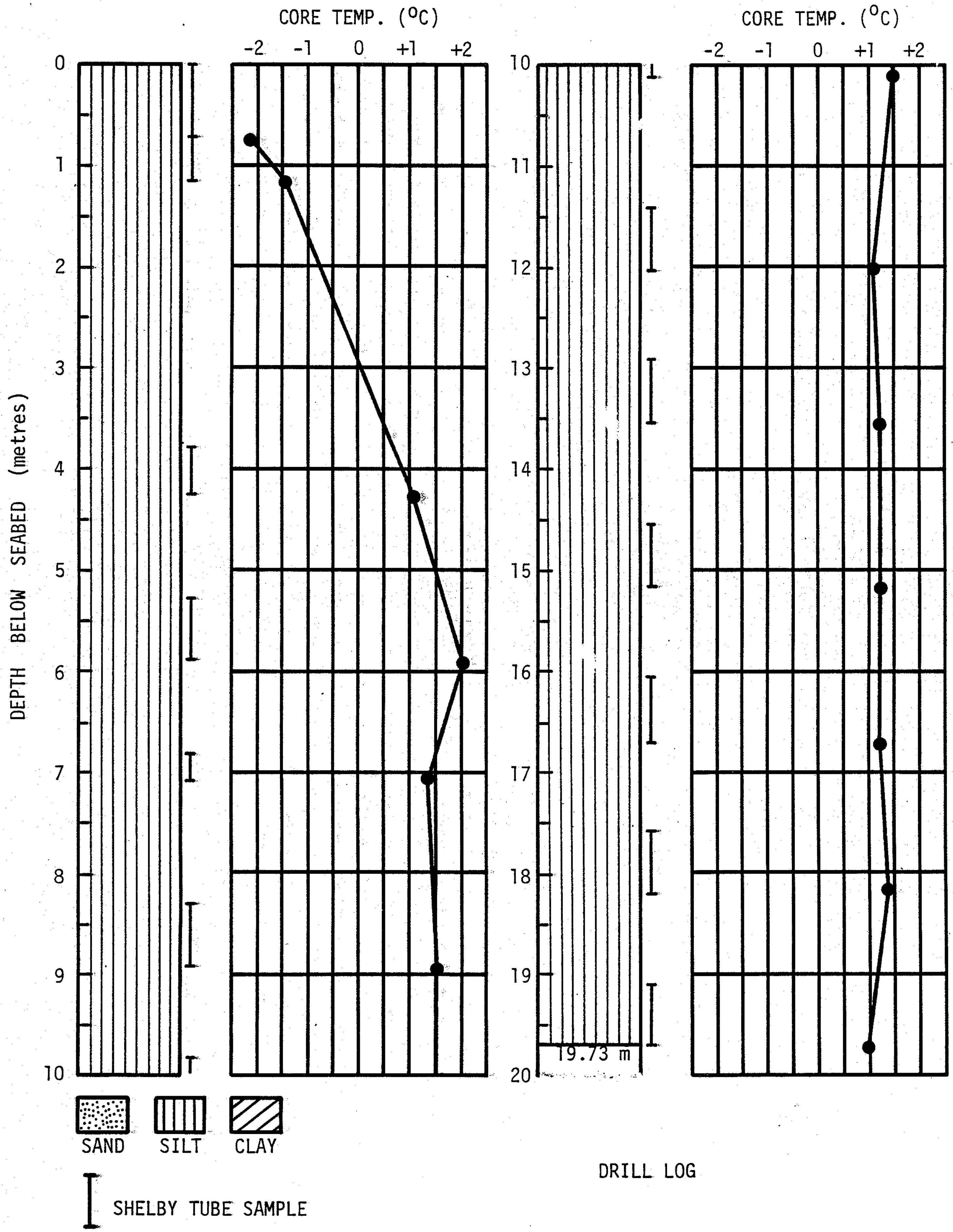
ICE: 165 cm
ICE & WATER: 177 cm



DRILL LOG

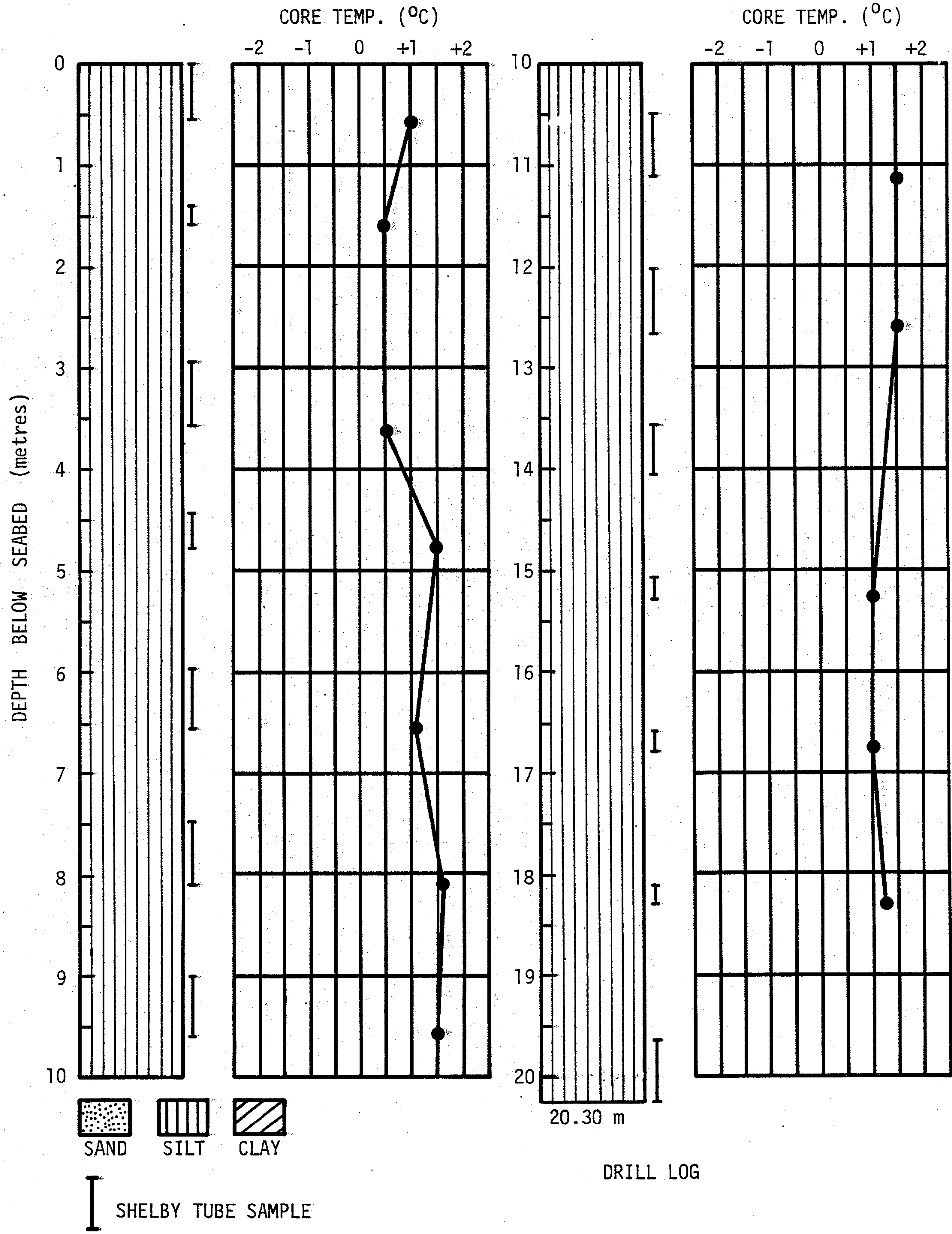
BOREHOLE: 43+00
DATE: 27-03-84

ICE: 155 cm
ICE & WATER: 222 cm



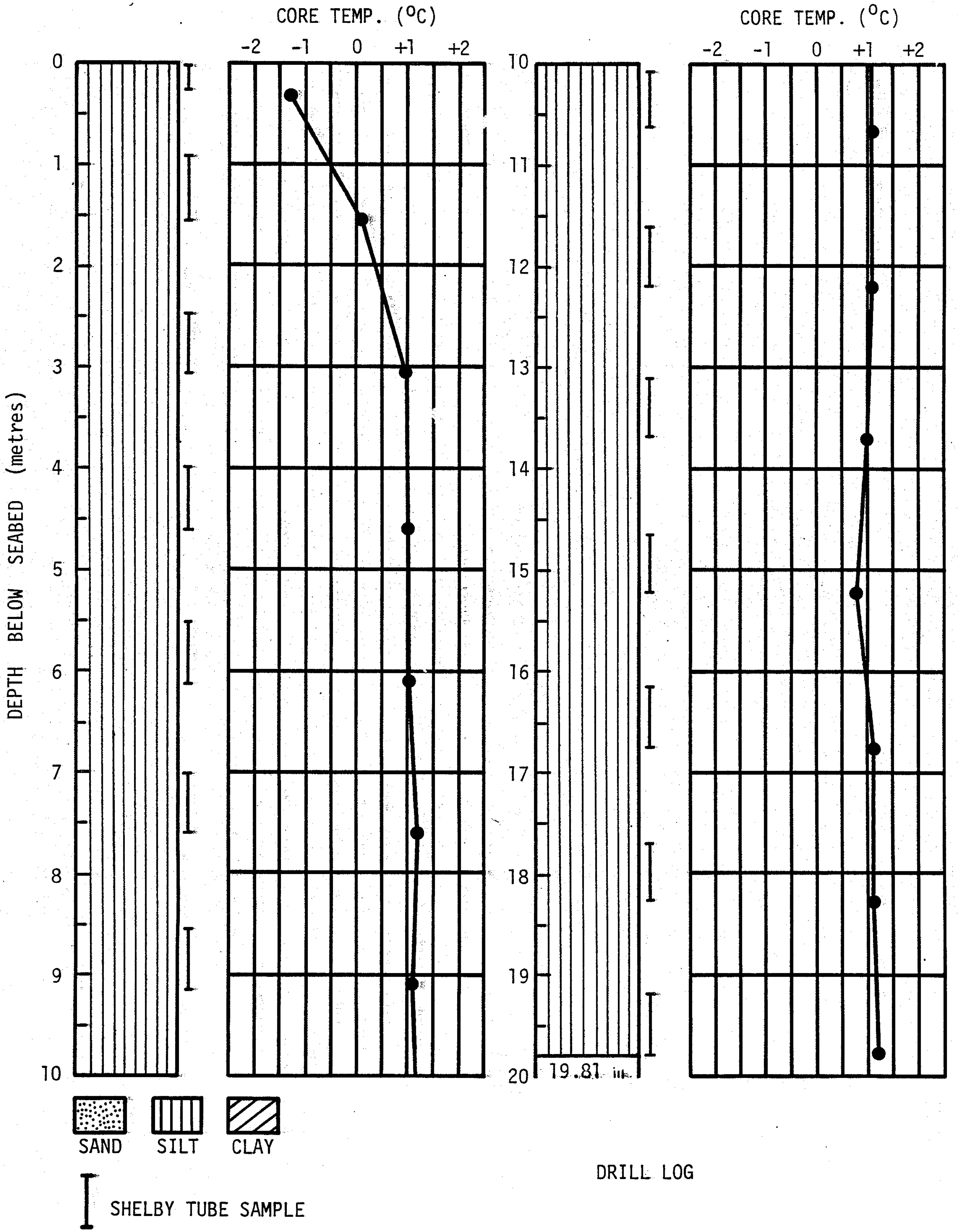
BOREHOLE: 42+00
DATE: 27-03-84

ICE: 160 cm
ICE & WATER: 280 cm



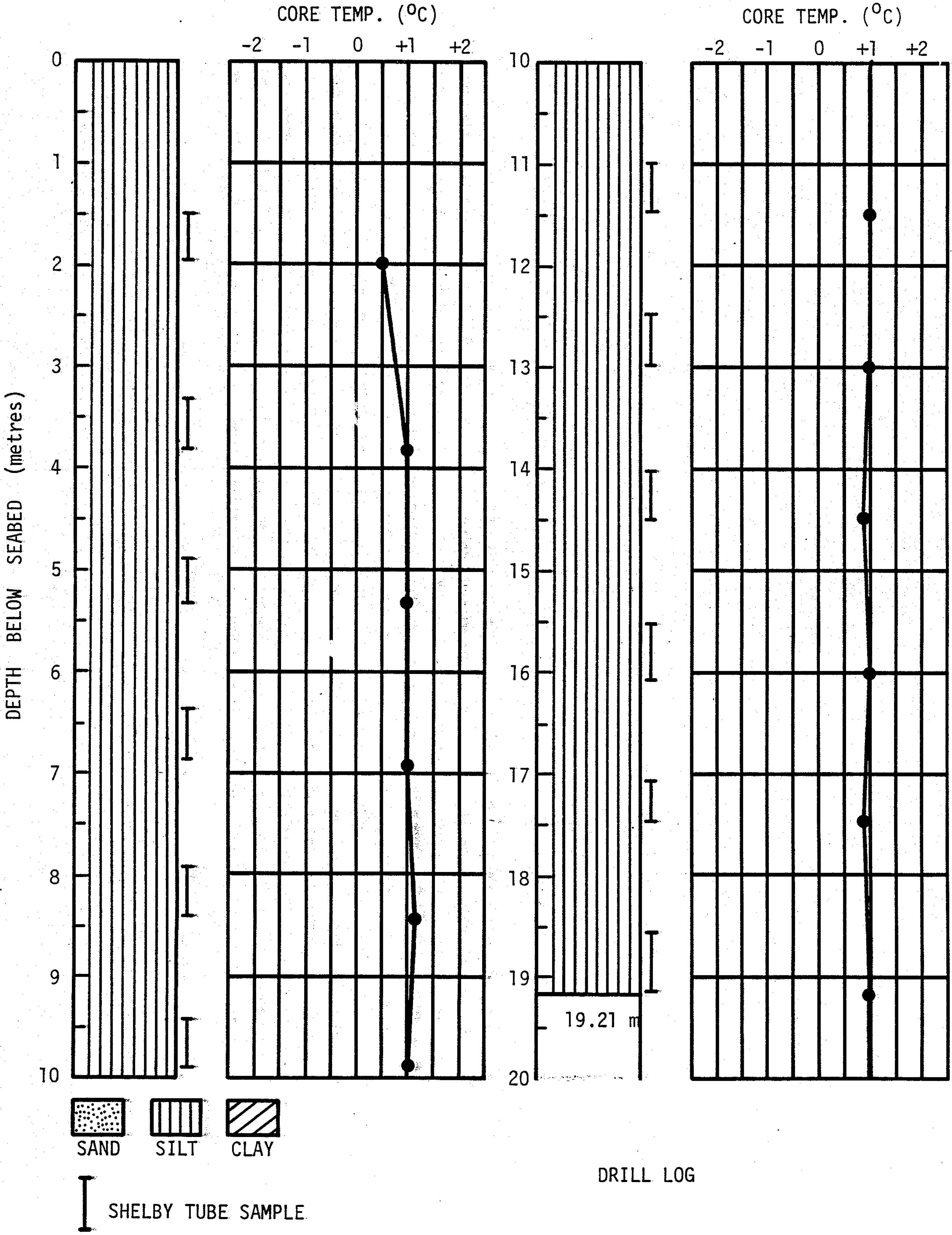
BOREHOLE: 41+00
DATE: 27-03-84

ICE: 140 cm
ICE & WATER: 300 cm



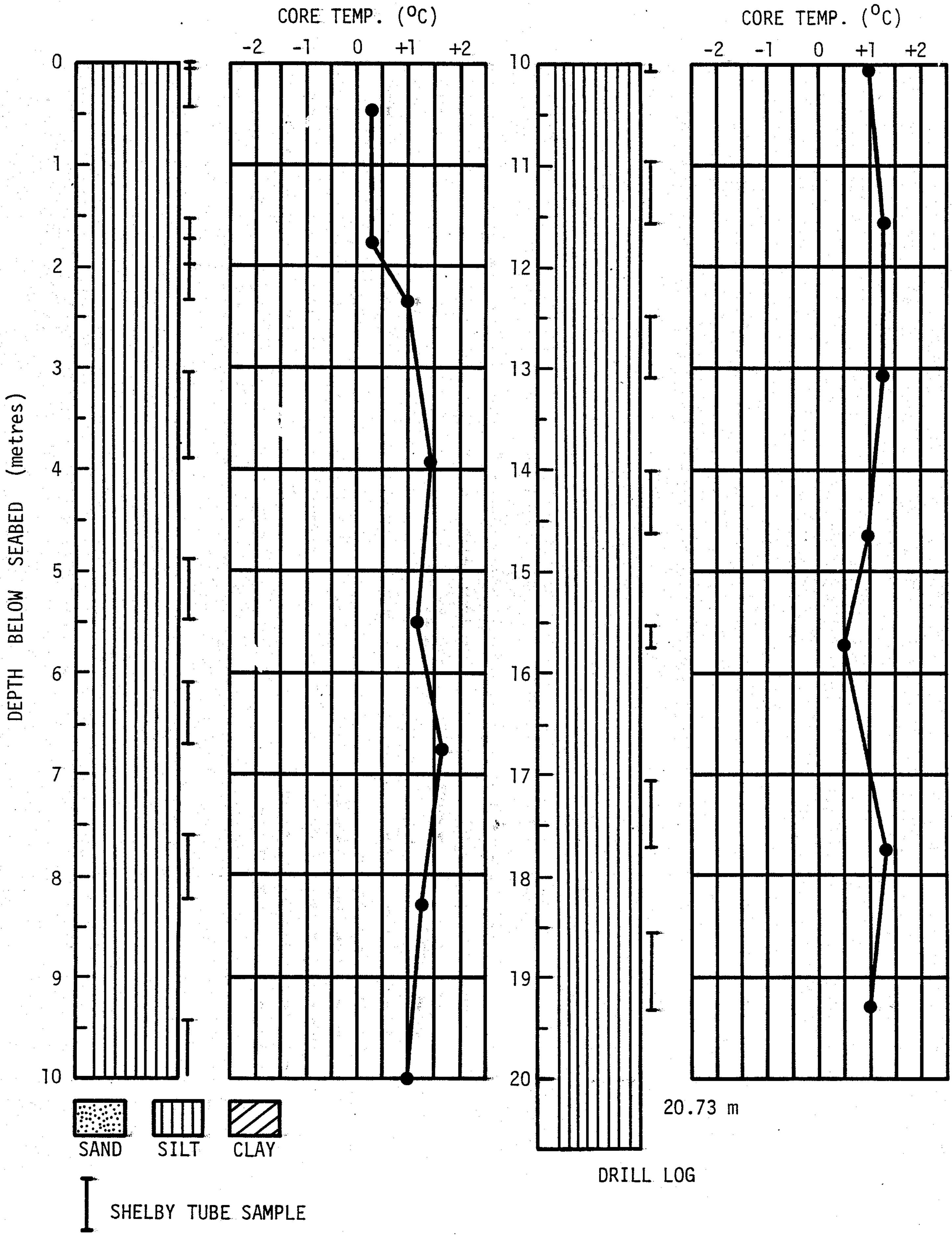
BOREHOLE: 0+00
DATE: 18-03-84

ICE: 180 cm
ICE & WATER: 292 cm



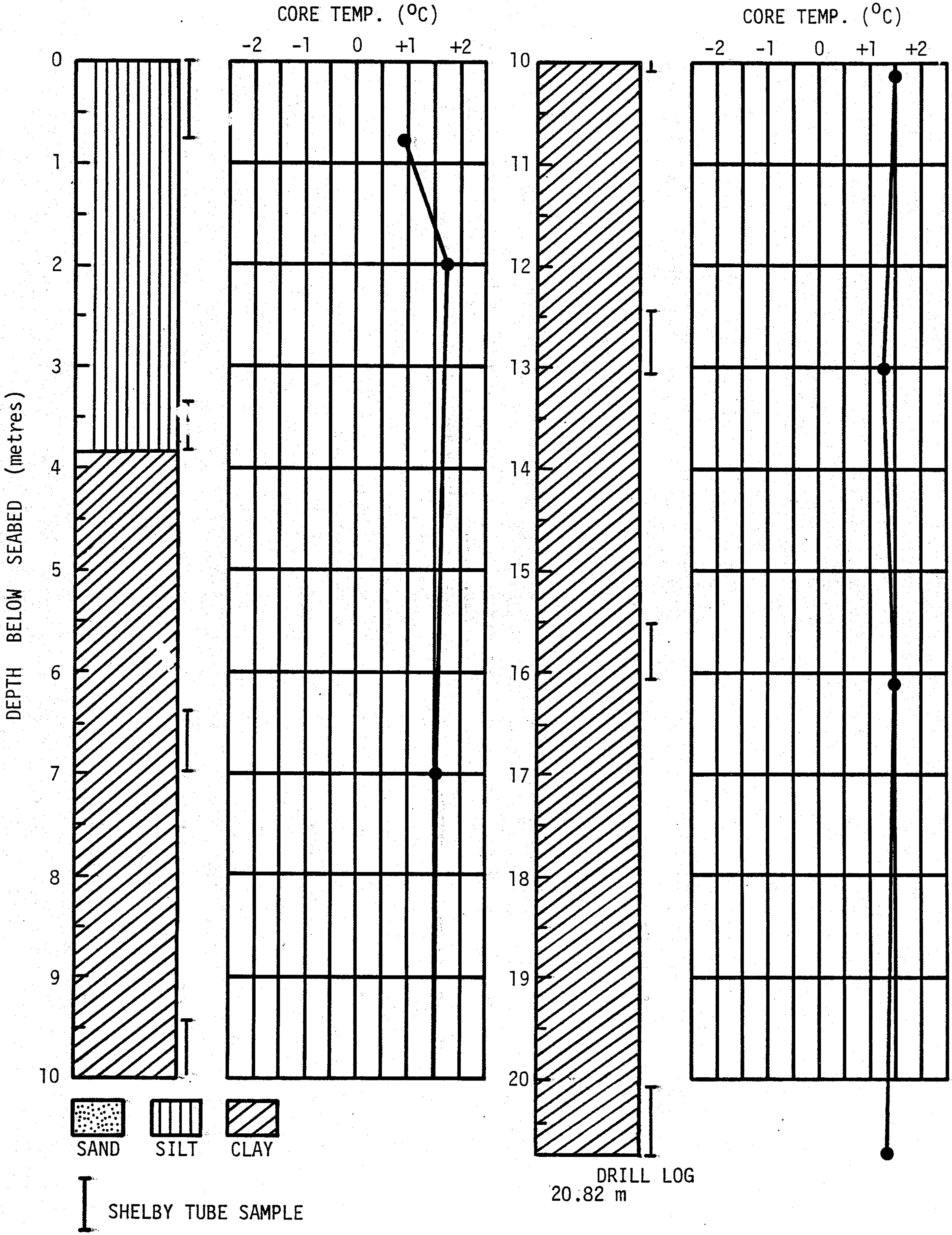
BOREHOLE: 1+50
DATE: 18-03-84

ICE: 168 cm
ICE & WATER: 333 cm



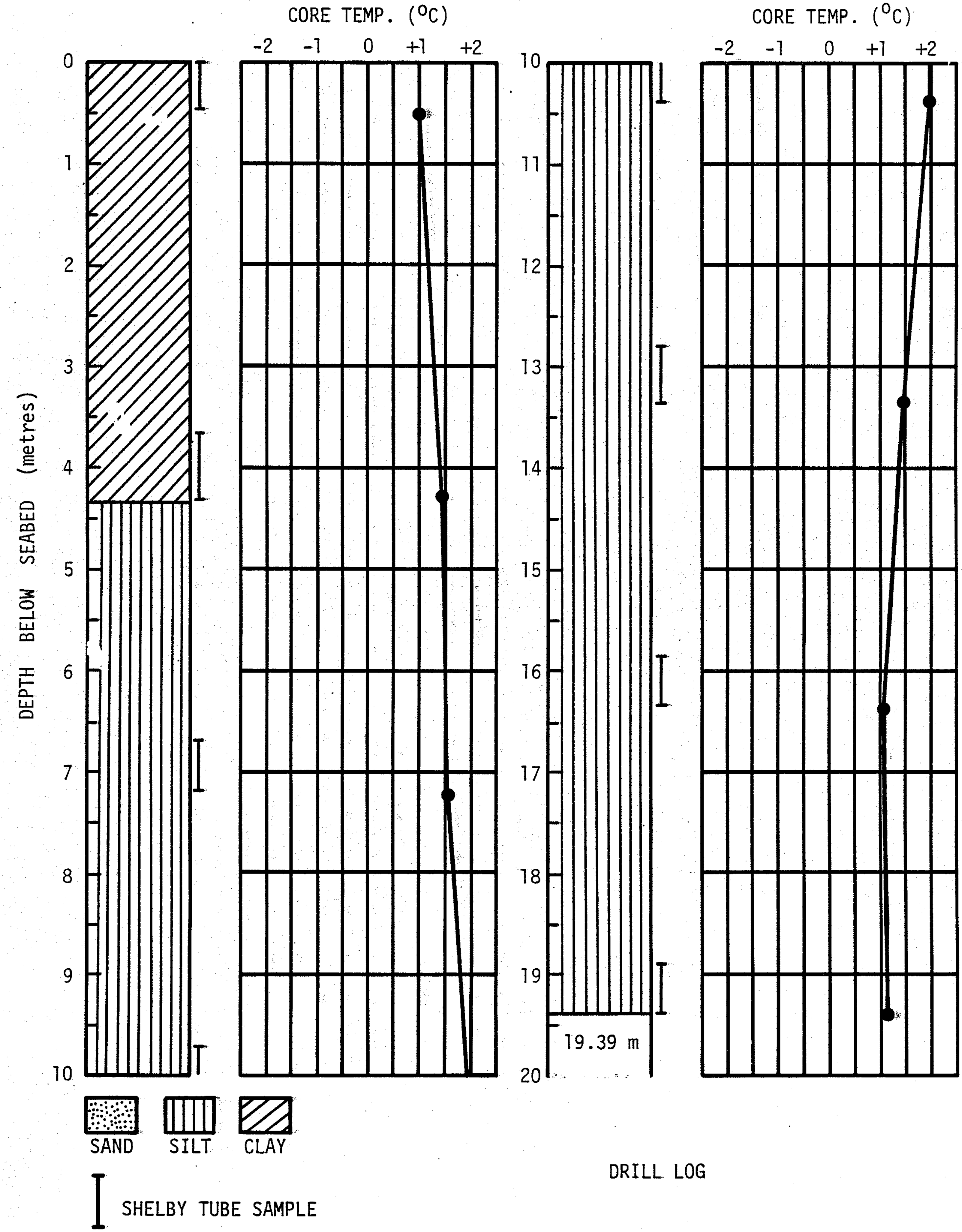
BOREHOLE: 3+00
DATE: 19-03-84

ICE: 153 cm
ICE & WATER: 385 cm



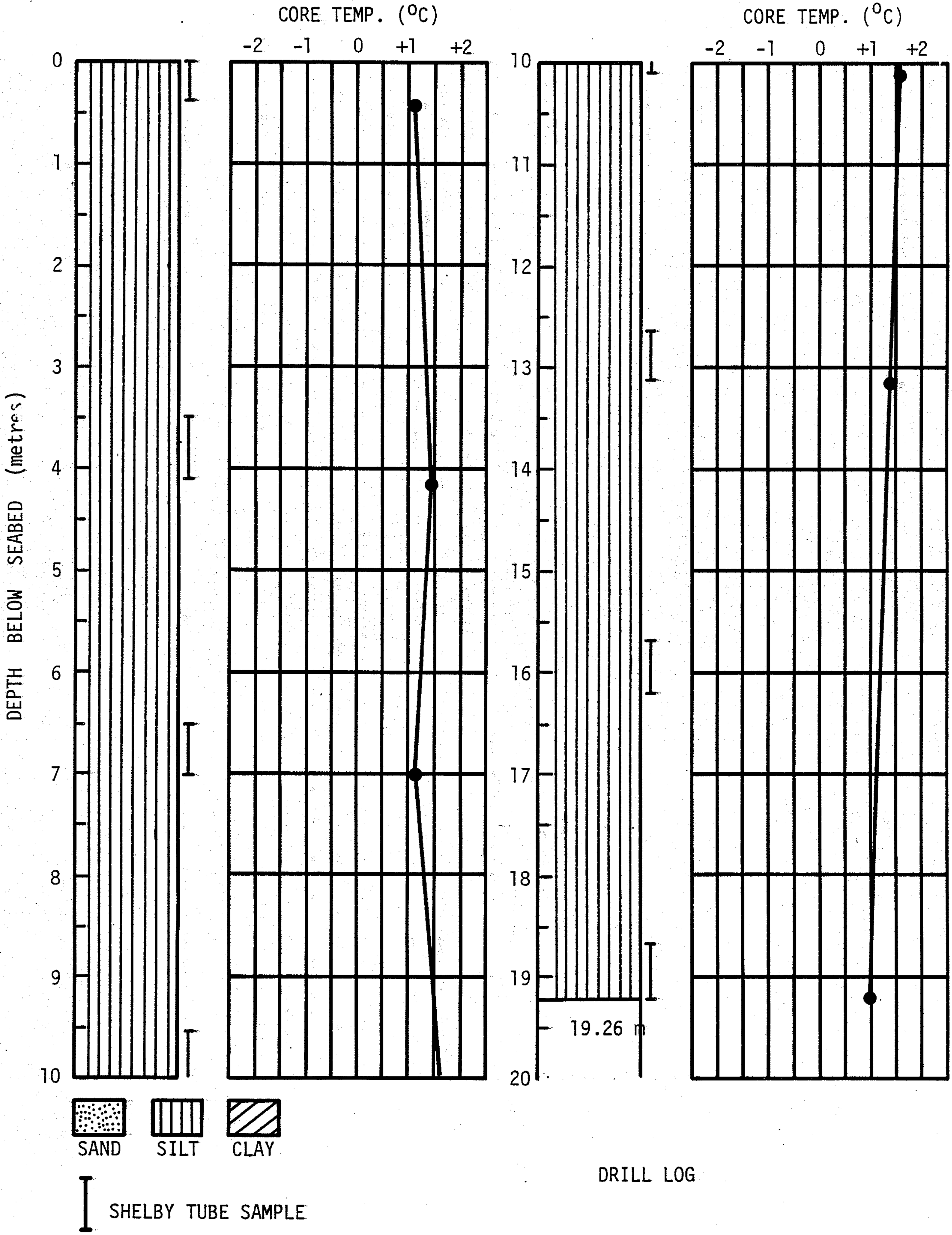
BOREHOLE: 4+50
DATE: 19-03-84

ICE: 163 cm
ICE & WATER: 409 cm



BOREHOLE: 6+00
DATE: 19-03-84

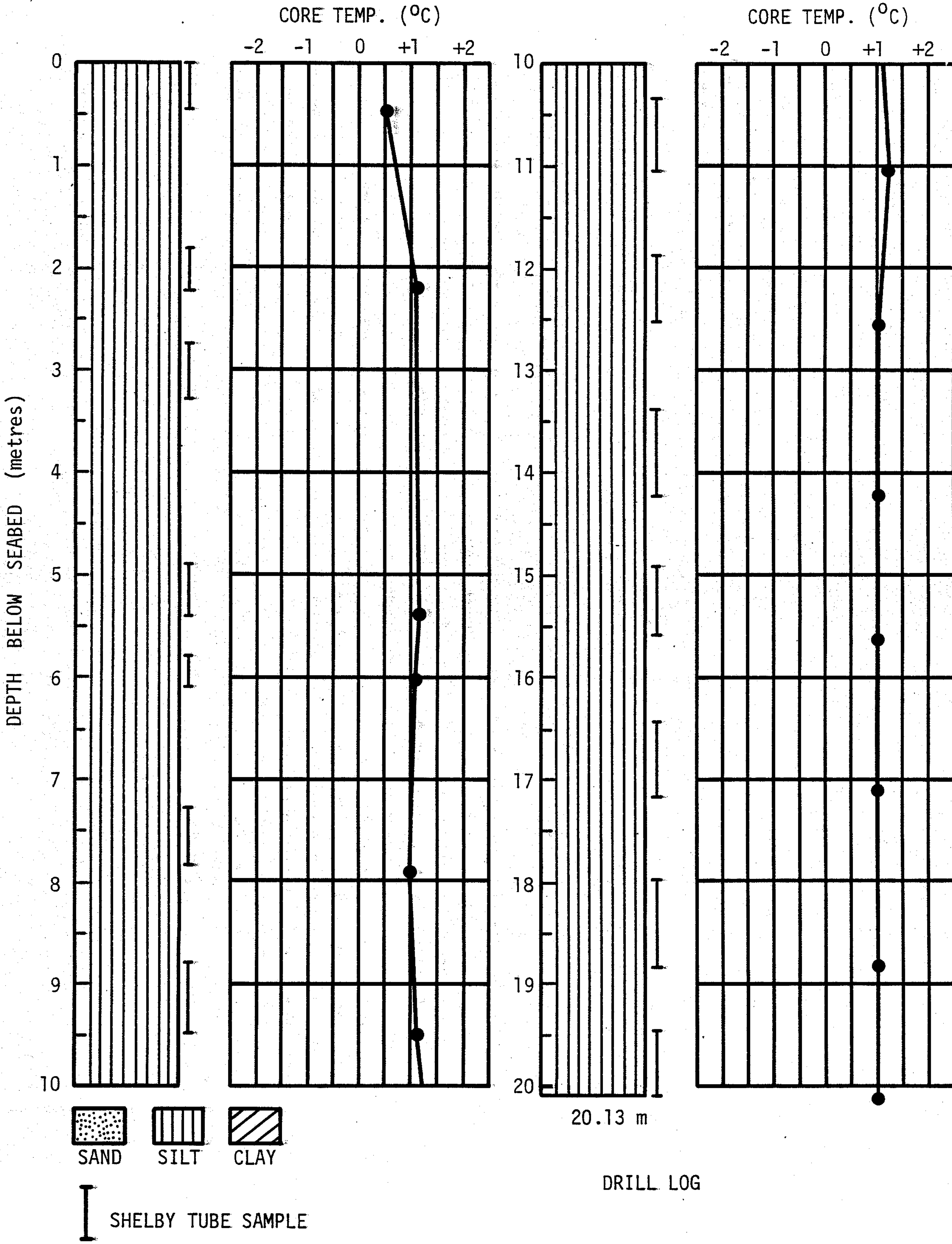
ICE: 165 cm
ICE & WATER: 430 cm



DRILL LOG

BOREHOLE: 7+60
DATE: 19, 20-03-85

ICE: 180 cm
ICE & WATER: 447 cm



DRILL LOG

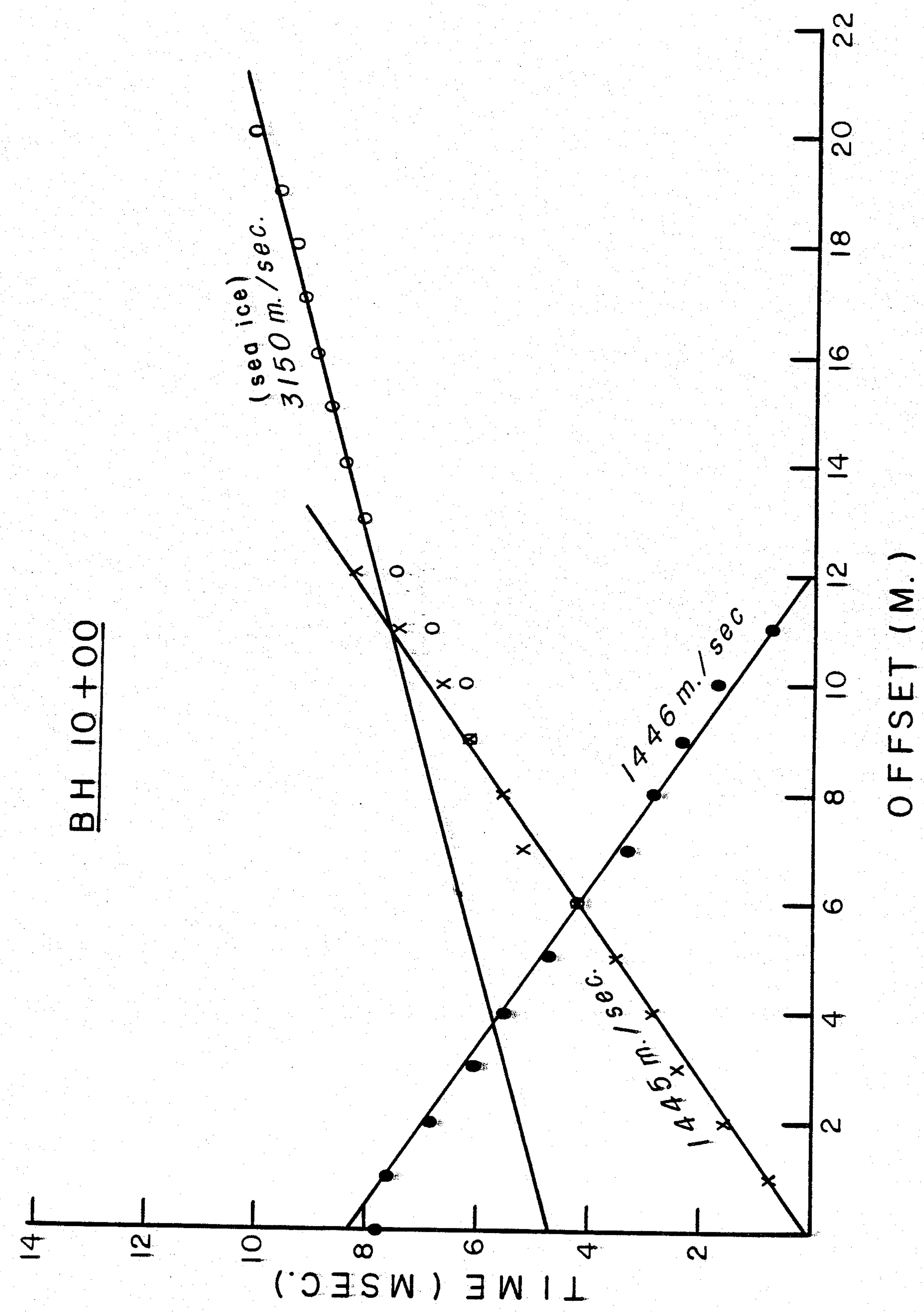

BH 10+00
TIME (MSEC.)
OFFSET (M.)
14
12
10
8
6
4
2
22
20
18
16
14
12
10
8
6
4
2
(sea ice)
3150 m./sec.
1446 m./sec
1445 m./sec.

FIG.7(b)

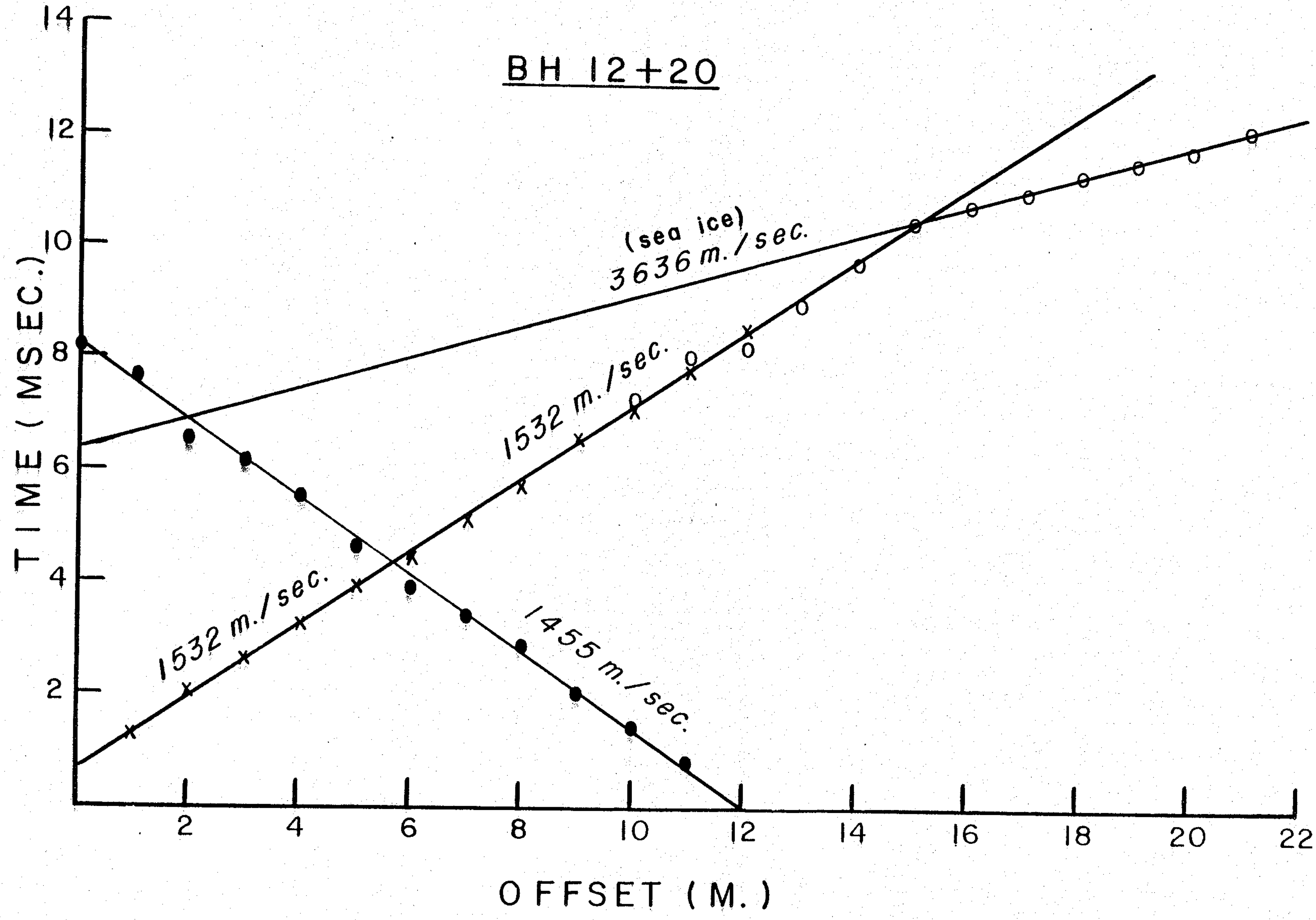

BH 12+20
(sea ice)
3636 m./sec.
1532 m./sec.
1532 m./sec.
1455 m./sec.
TIME (MSEC.)
OFFSET (M.)
14
12
10
8
6
4
2
2
4
6
8
10
12
14
16
18
20
22

FIG. 7(c)

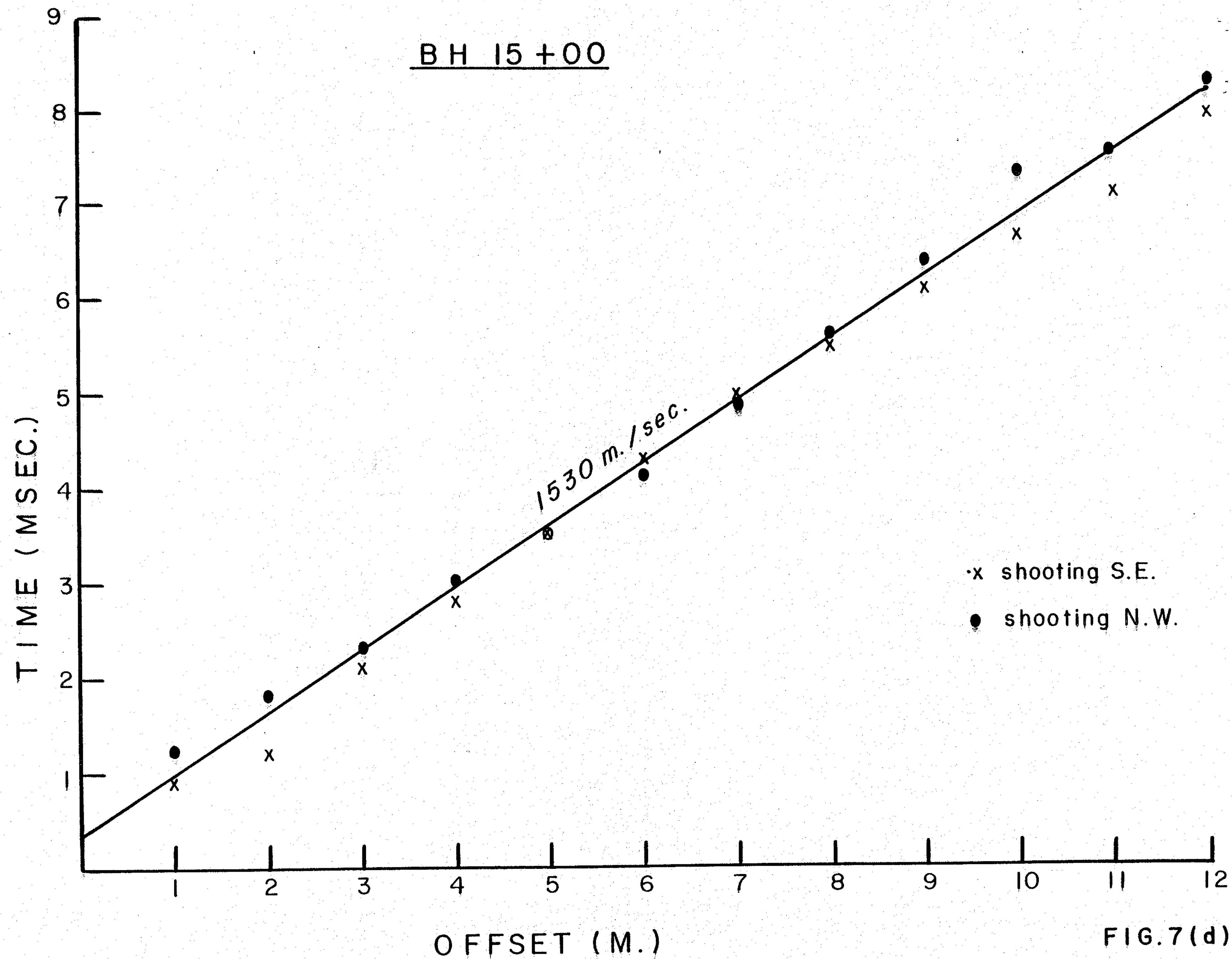

BH 15+00
TIME (MSEC.)
9
8
7
6
5
4
3
2
1
OFFSET (M.)
1
2
3
4
5
6
7
8
9
10
11
12
1530 m./sec.
x shooting S.E.
shooting N.W.

FIG. 7(d)

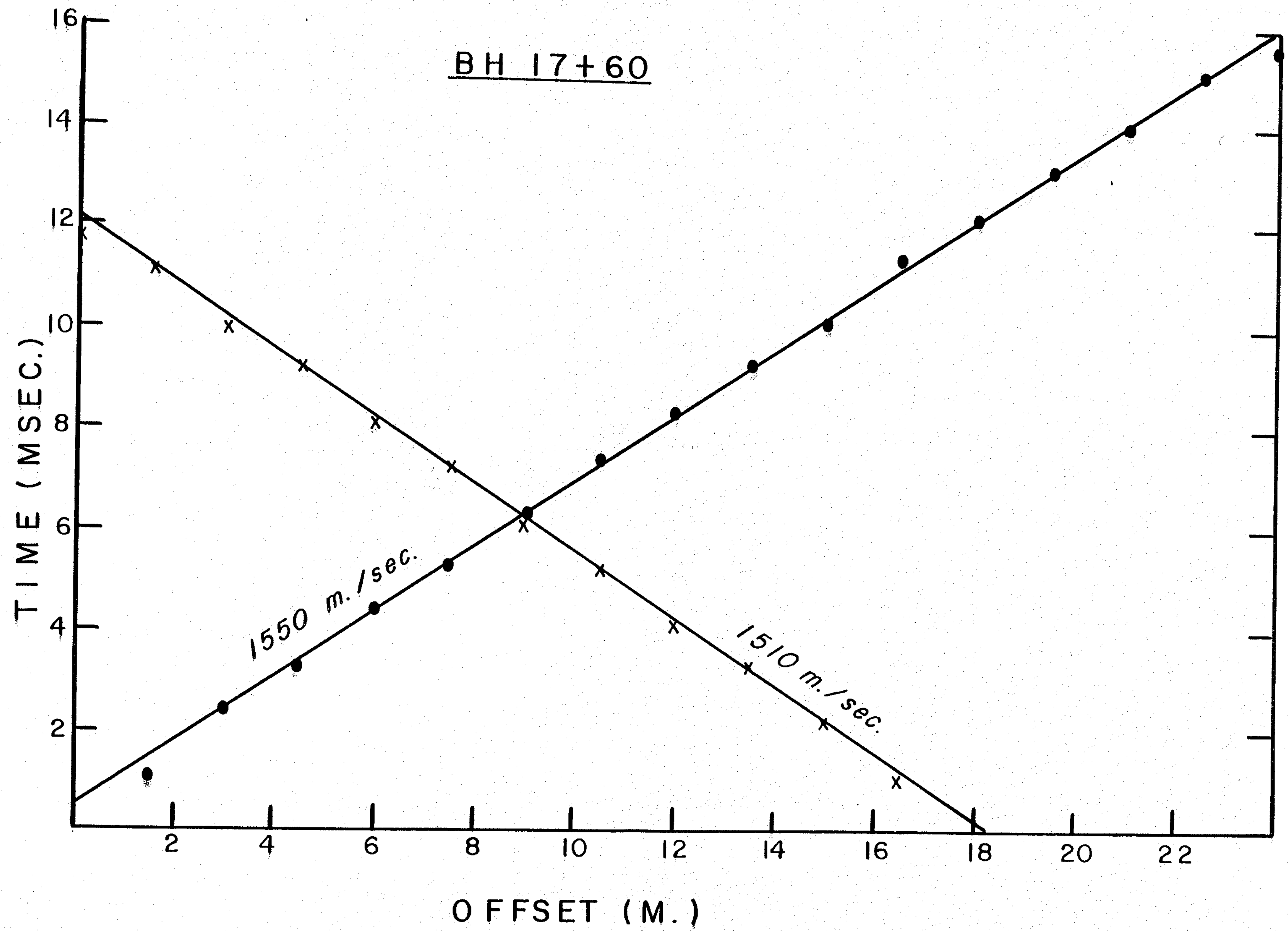

BH 17+60
TIME (MSEC.)
OFFSET (M.)
1550 m./sec.
1510 m./sec.
16
14
12
10
8
6
4
2
2
4
6
8
10
12
14
16
18
20
22

FIG.7(e)

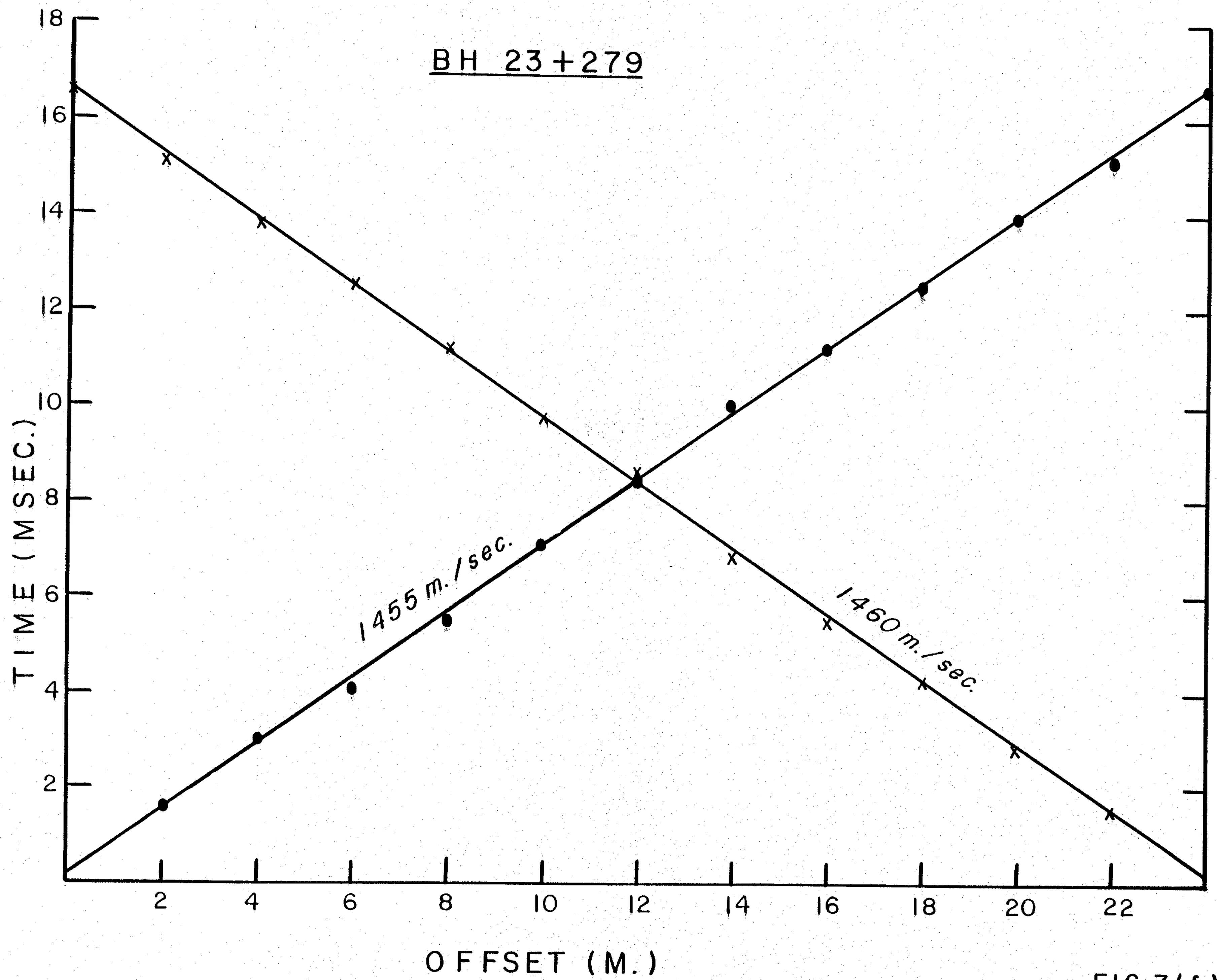

BH 23+279
TIME (MSEC.)
18
16
14
12
10
8
6
4
2
OFFSET (M.)
2
4
6
8
10
12
14
16
18
20
22
1455 m./sec.
1460 m./sec.

FIG. 7(f)

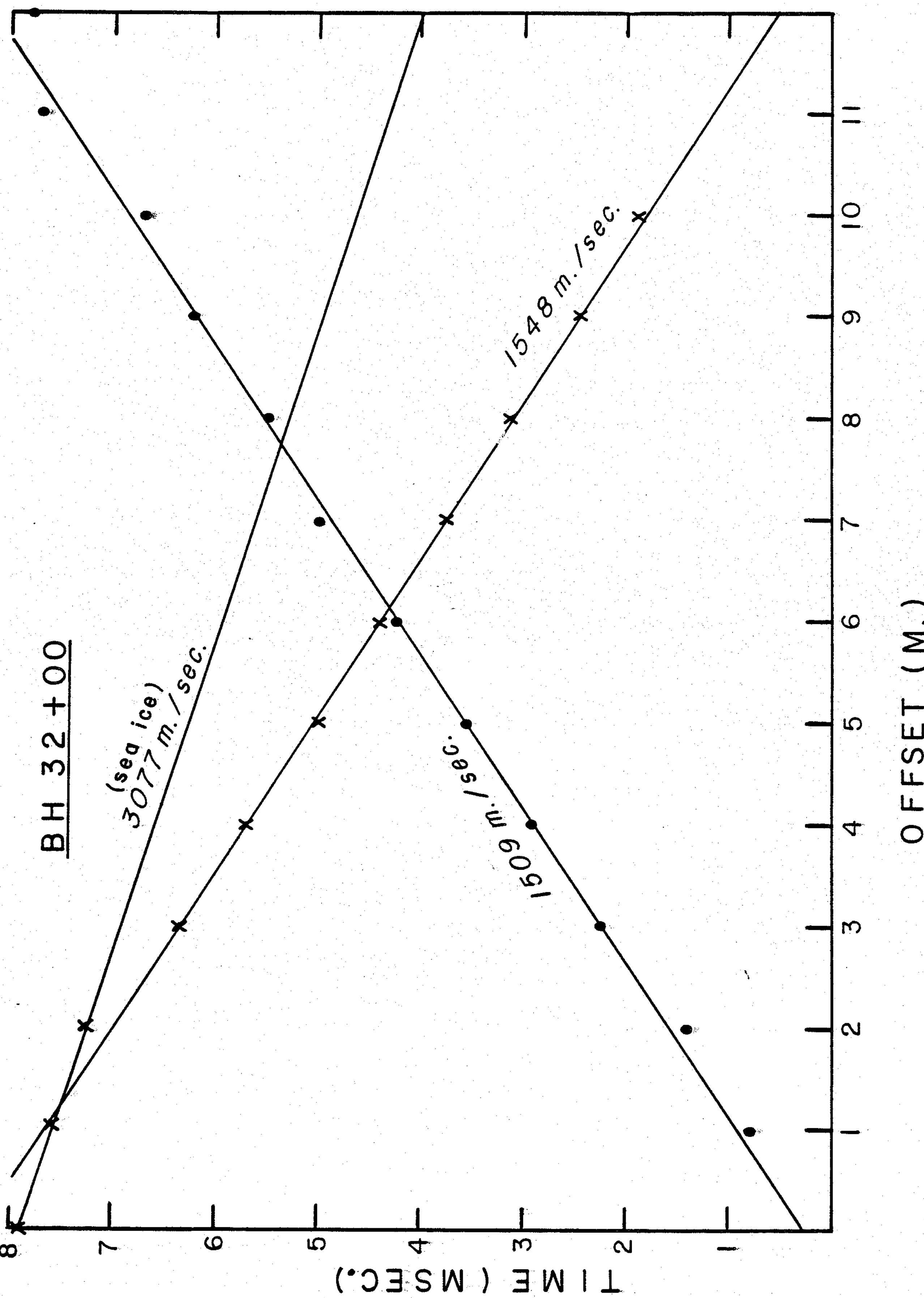

BH 32+00
(sea ice)
3077 m./sec.
1548 m./sec.
1509 m./sec.
TIME (MSEC.)
OFFSET (M.)
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
11

FIG.7(g)

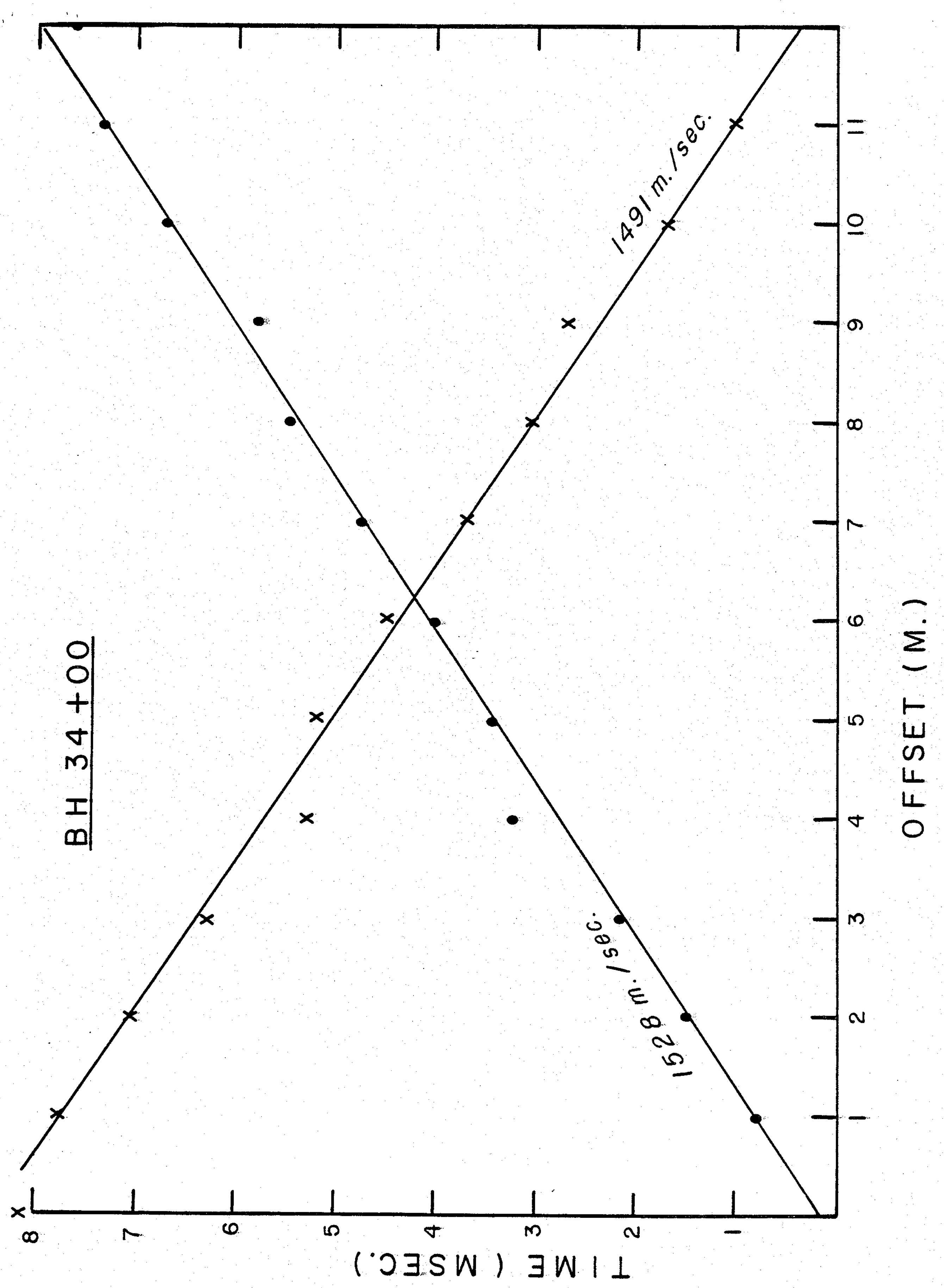

BH 34+00
1491 m./sec.
1528 m./sec.
TIME (MSEC.)
OFFSET (M.)
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
11

FIG.7(h)

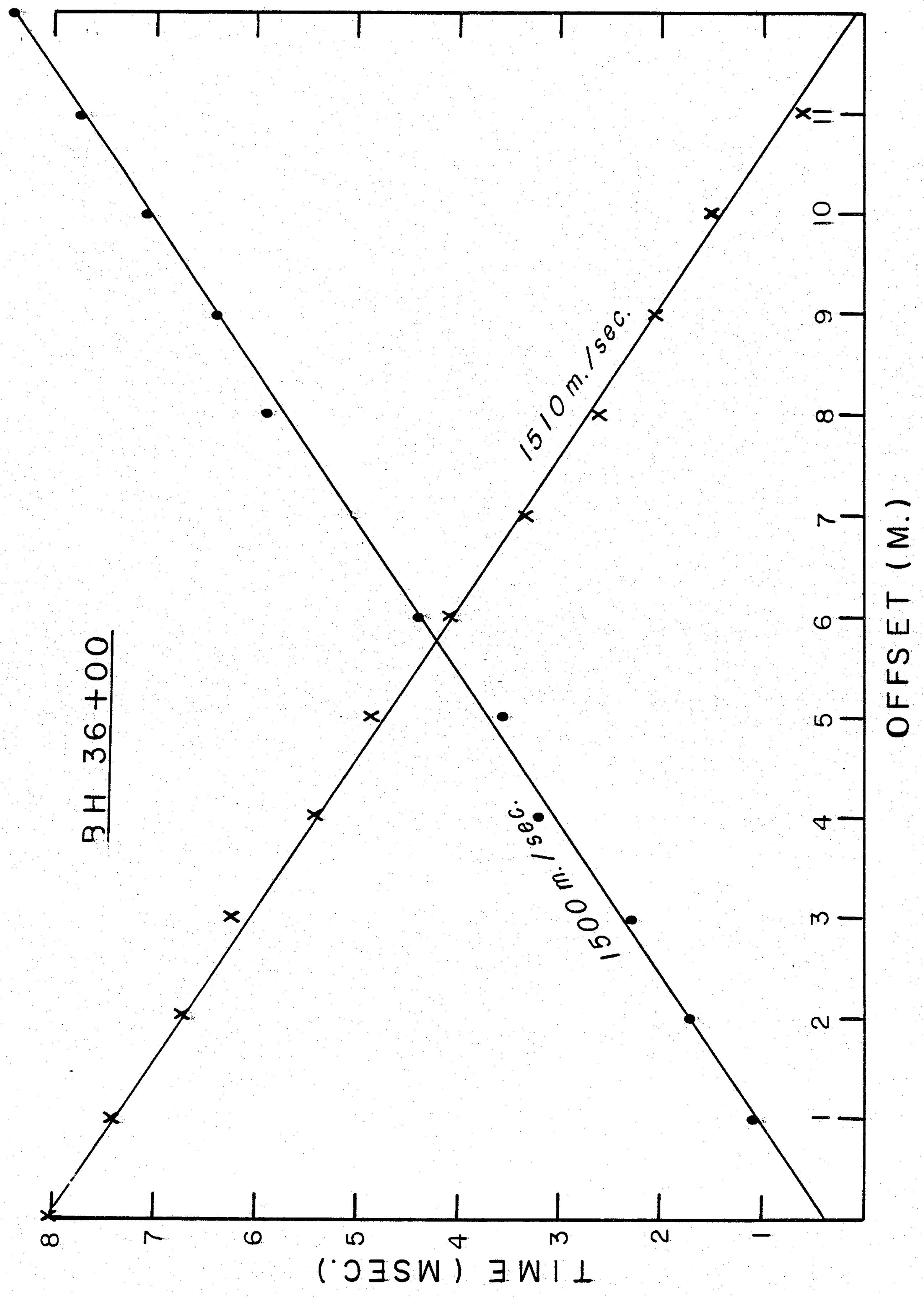


FIG. 7(i)

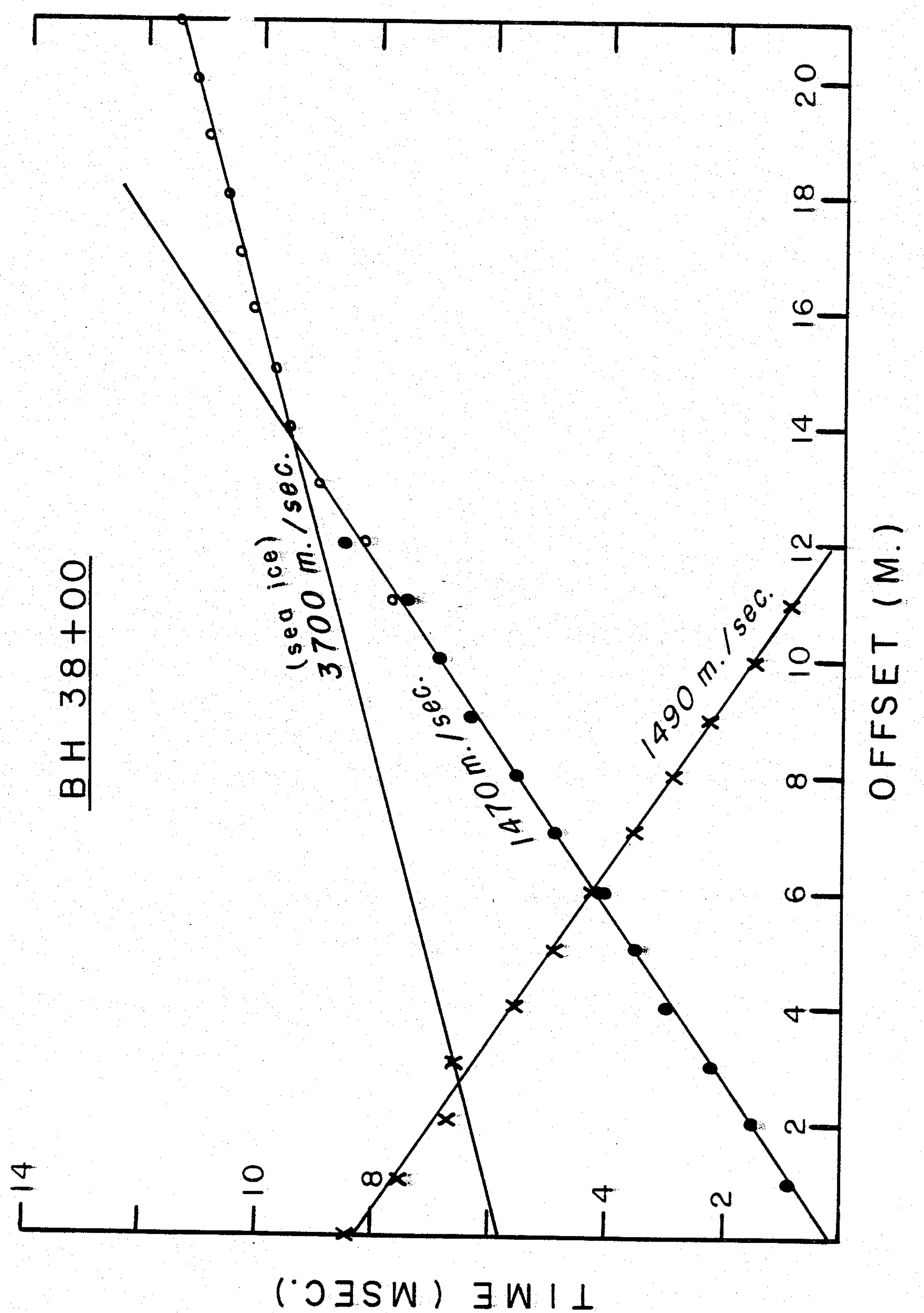

BH 38+00
TIME (MSEC.)
OFFSET (M.)
14
10
8
4
2
2
4
6
8
10
12
14
16
18
20
(sea ice)
3700 m./sec.
1470 m./sec.
1490 m./sec.

FIG.7(j)

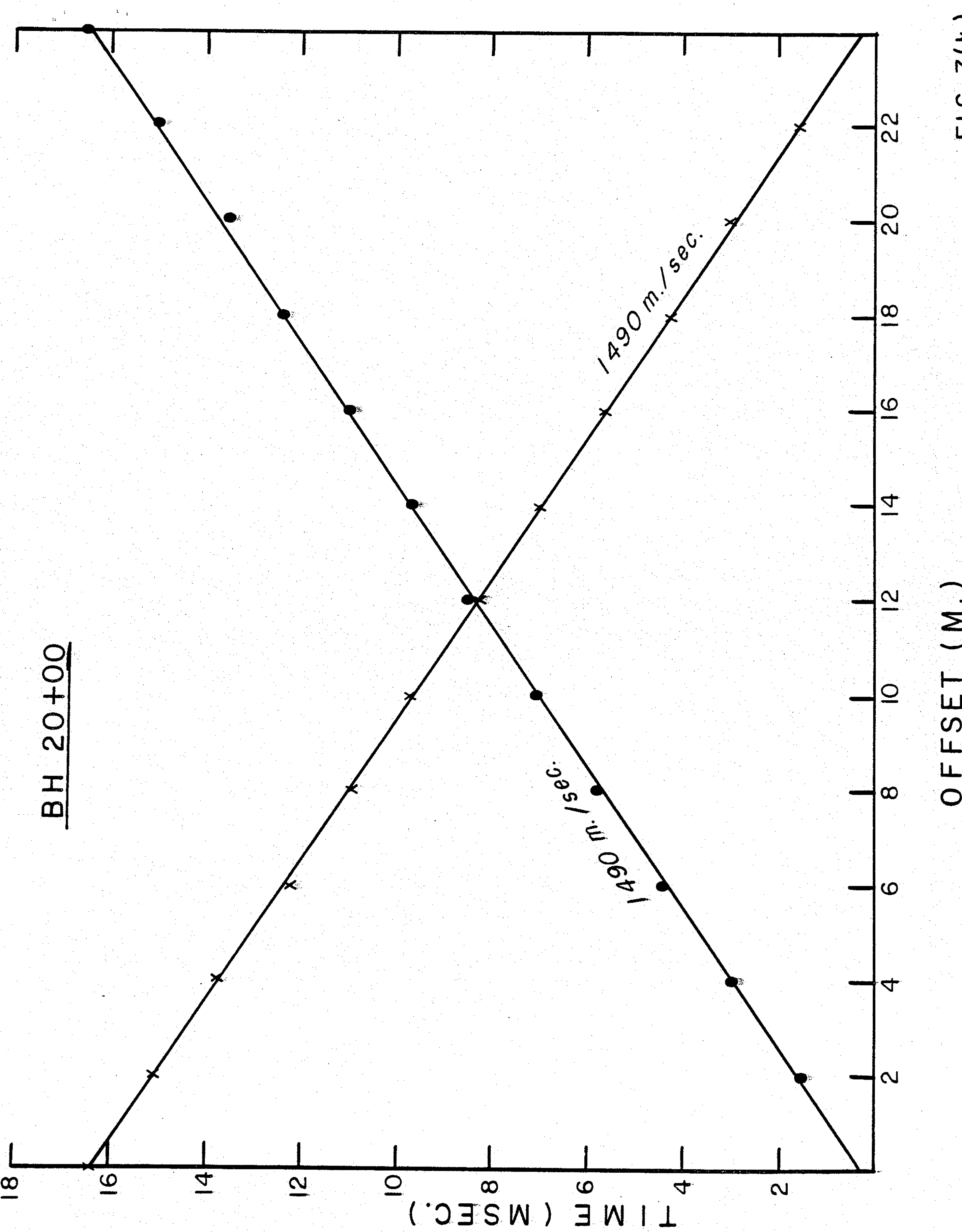

BH 20+00
1490 m./sec.
1490 m./sec.
TIME (MSEC.)
18
16
14
12
10
8
6
4
2
OFFSET (M.)
2
4
6
8
10
12
14
16
18
20
22

FIG. 7(k)

particularly unique problem in subsea materials is that it is often difficult to tell from the drilling or from samples taken whether ice is present in situ. If the borehole is repeatedly logged for temperature after completion, this question can sometimes be resolved by an interpretation of the rate of return of the borehole to temperature equilibrium, but clearly a better approach is desirable.

Method

The method used is to supply a known amount of energy per unit length of the borehole, using a long electrically heated wire, and to study the temperature response. The interpretation is simplest if the heating is carried out after temperature equilibrium has become re-established after drilling, but in some cases this is not essential. If no ice is present, the approach to equilibrium after heating can usually be interpreted to give the thermal conductivity as a function of depth. A smaller and different temperature response indicates the presence of ice. The method is most effective in smaller diameter boreholes, because the time required to obtain interpretable results varies approximately as the square of the borehole diameter.

This in situ method is still in its developmental phase, and it is therefore of special interest to compare thermal conductivity measured by this technique with that measured on samples by laboratory methods. The GSC samples taken in this study provide an ideal opportunity for this comparison because they appear to be relatively undisturbed.

Theory

The theory is based on the temperature response, ΔT, on the axis of a long and instantaneous heat source of strength (energy per length) Q:

$$\Delta T = \frac{Q}{4\pi k}\ \frac{1}{t} \tag{1}$$

where k is thermal conductivity and t is elapsed time. If the source has a finite duraction s, and if ΔT is measured for $t > s$, equation (1) leads to

$$\Delta T = \frac{1}{4\pi k}\int_0^s \frac{P(\tau)}{t-\tau}\, d\tau \tag{2}$$

where P is power per length, and t is measured from the time heating begins. If P is constant,

$$\Delta T = \frac{P}{4\pi k}\ \ln \frac{t}{t-s} \tag{3}$$

Experimental Results

A preliminary analysis of the data from thermistor #11 in borehole 4+50 has been made. This thermistor is located approximately 17 m below the seabed (21 m below the top of the sea ice). The borehole was heated for 7.0 hours with an average power of 33 ± 3 watts/m. Figure 8 shows a plot of equation 3 for 11 days beginning shortly after the heating was terminated. The data becomes linear after approximately 1 hour. A linear best fit of the data gives a value of 1.64°C for the slope and a

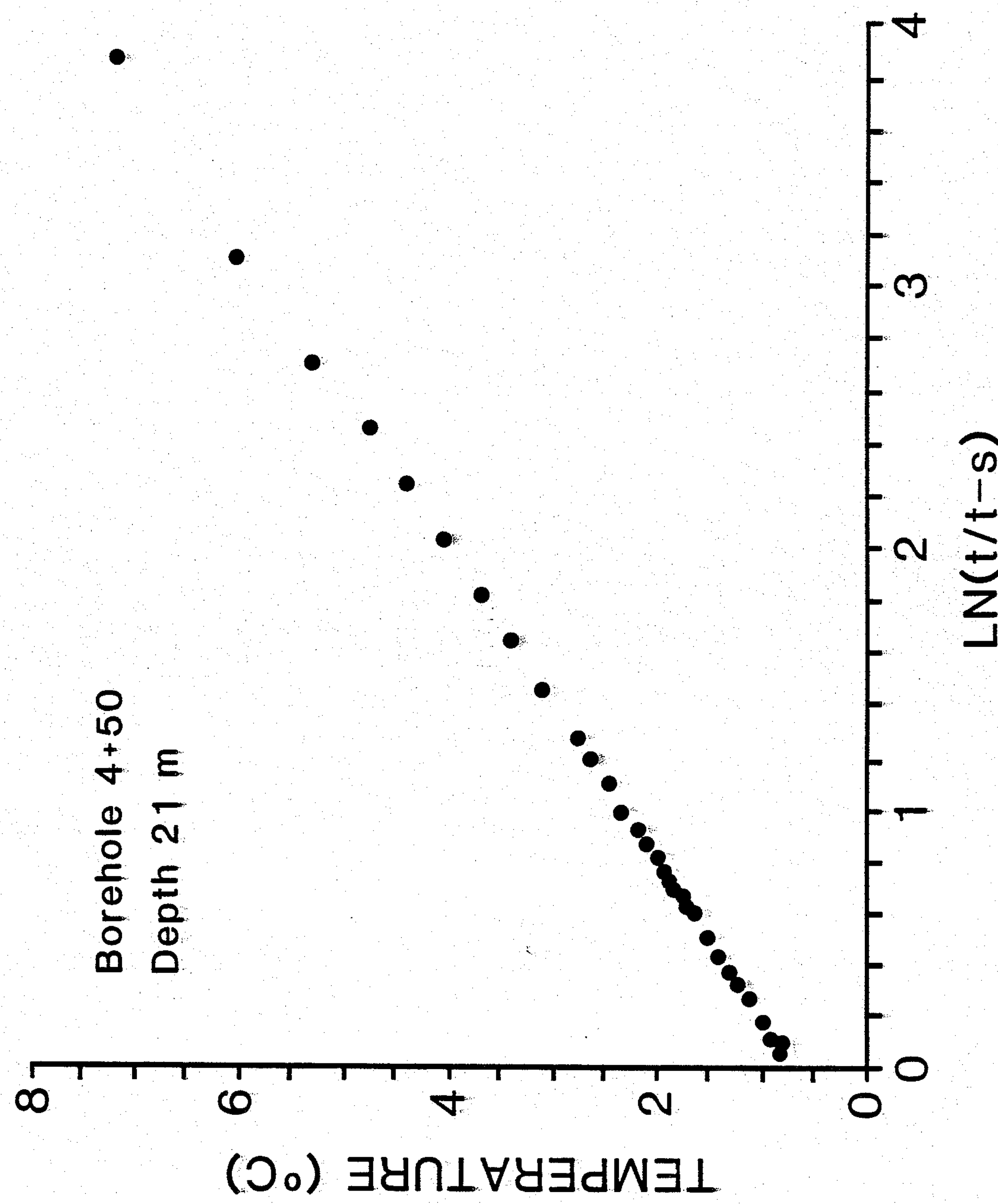


Figure 8: Thermal conductivity plot

value of 1.60 ± .16 W/mk for the thermal conductivity of the material. This value agrees well with values measured in the laboratory on similar samples. The intercept of the best fit line is .67°C which is the extrapolated equilibrium temperature of the material.

Although these results are preliminary, the method clearly works. The technique of monitoring the temperature response after the heat is turned off is rather time consuming. The temperature was also monitoried during the heating period and it is hoped that these data can be used to give the same information more rapidly.

11. Acoustic Velocity Tests (P.J. Kurfurst)

Acoustic velocity measurements were made in the field on the representative samples from various boreholes. Nine unfrozen samples from 8 boreholes and five frozen samples from four boreholes represented a variety of materials ranging from silty clays to sands.

Compressional and shear wave velocity measurements were attempted either at the drill site immediately after the recovery of the samples or — in the later stages of the field program — in the field laboratory at the camp. All measurements were made using an OYO Sonic viewer 5217A with two pairs of transmitters and receivers measuring the compressional and shear wave velocity independently. However, only compressional wave first arrival times were picked up. No first arrival times of the shear waves were discernable, probably due to low frequency range of the transmitter.

The samples were transported to the GSC laboratory in Ottawa, where the measurements will be repeated in the cold room at the conditions approximating those in the field.

Table 4 shows the sample and borehole identification, compressional velocity, soil type, and frozen and unfrozen state. Most velocities were in the range of 1350-1800 m/sec. for unfrozen samples and around 2000 m/sec for frozen samples.

12. Lithological and Stratigraphic Logging (P. Hill)

Lithologies

Based on the preliminary field logs, several distinct fine-grained lithologies can be identified. The detailed sedimentological logs for each borehole are shown in Figure 9, Table 5 lists the key to the sedimentological logs. Laminated and bioturbated silt and clay were the predominant lithologies. The laminae were generally thin (in the mm range) and bioturbation was highly variable, ranging from minor disruption to complete destruction of the laminae. In general, silt was more abundant than clay. In some cores, the silt laminae reached several centimetres in thickness and were noticeably graded (fining upwards), with sharp bases and thin clay tops, as shown in the upper 6 m of borehole 10+00 (Fig. 9b).

The graded sand beds, fining upwards into silt and clay intervals, were present only rarely. Ripple cross-lamination was sometimes observed in the graded sand intervals, while in other sections floating sand and silt ripples with a mud drape were a common lithology. These structures were most commonly observed in core intervals immediately overlying thick sand units.

TABLE 4

Acoustic Velocities

Borehole Number	Depth (m)	Comp. velocity (m/sec)	Soil Type	Frozen/ Unfrozen
10+00	10.24-10.37	1775	Clayey silt	Unfrozen
17+60A	6.90- 7.02	2045	Clayey silt	Frozen
20+00	6.38- 6.50	1556	Clayey silt with sandy layers	Unfrozen
21+60	3.42- 3.57	1770	Clayey silt	Unfrozen
32+00	15.86-16.03	1402	Sandy silt	Unfrozen
34+00	9.67- 9.77	1381	Clayey silt	Unfrozen
38+00	14.48-14.59	1366	Silt with organic material	Unfrozen
41+00	0 - 0.12	1983	Clayey silt	Frozen
41+00	19.65-19.79	1734	Clayey silt	Unfrozen
42+00	9 - 0.14	1155?	Clay	Unfrozen
42+00	13.93-14.07	1840	Clayey silt	Unfrozen
43+00	0.56- 0.72	—	Clayey silt	Frozen
43+00	1.00- 1.11	2048	Clayey silt	Frozen
44+00	19.42-19.52	—	Sand	Frozen

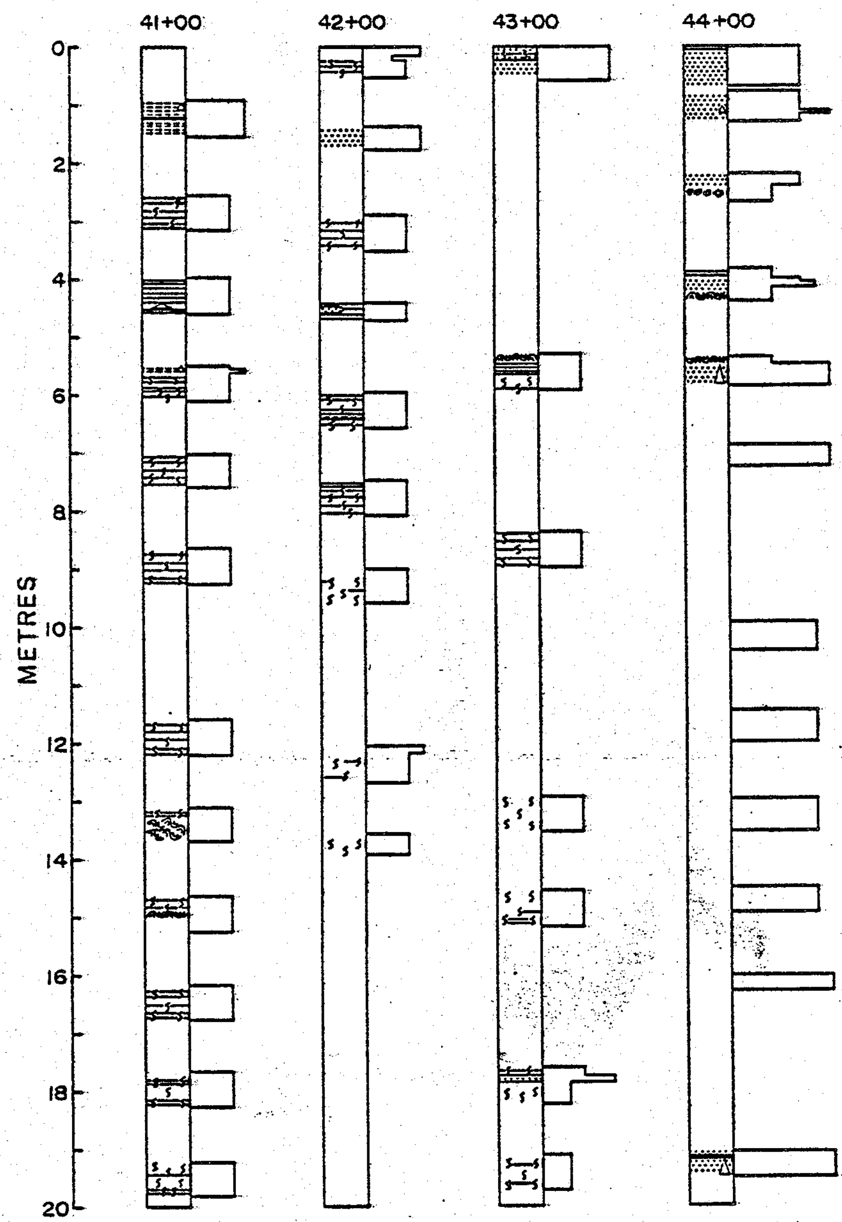


Figure 9a - d: Sedimentological logs

Figure 9a

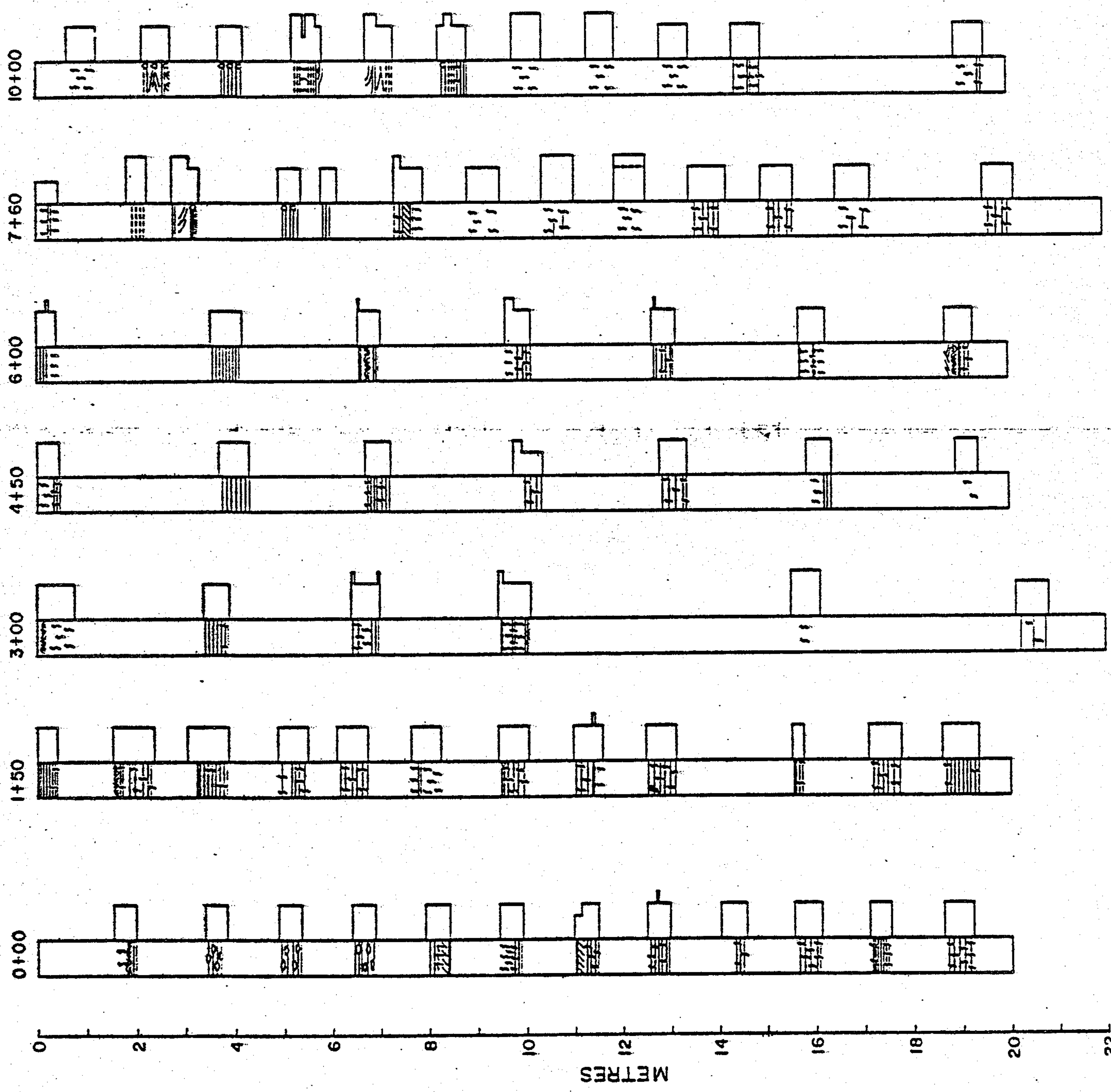


Figure 9b

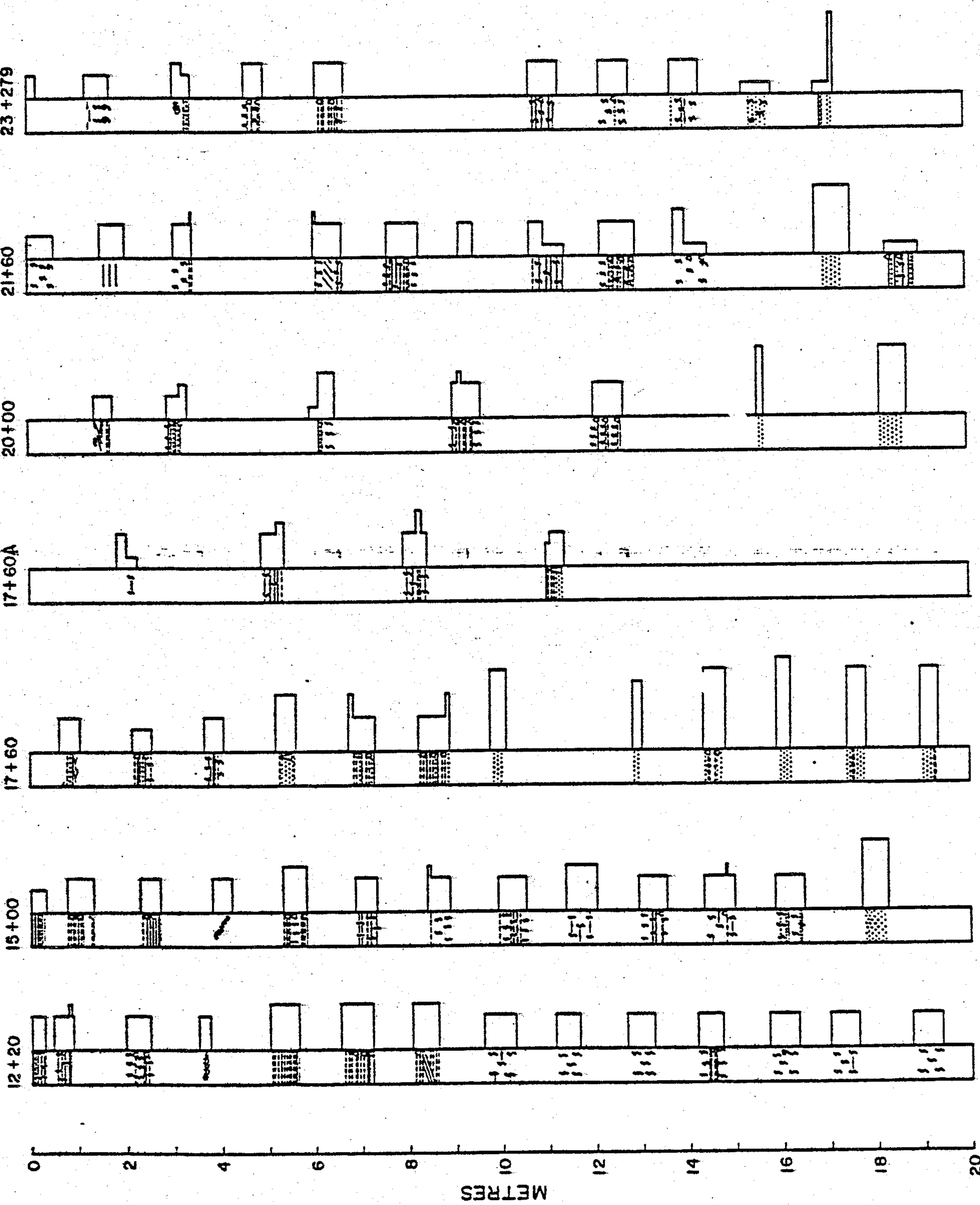

23+279
21+60
20+00
17+60A
17+60
15+00
12+20
0
2
4
6
8
10
12
14
16
18
20
METRES

Figure 9c

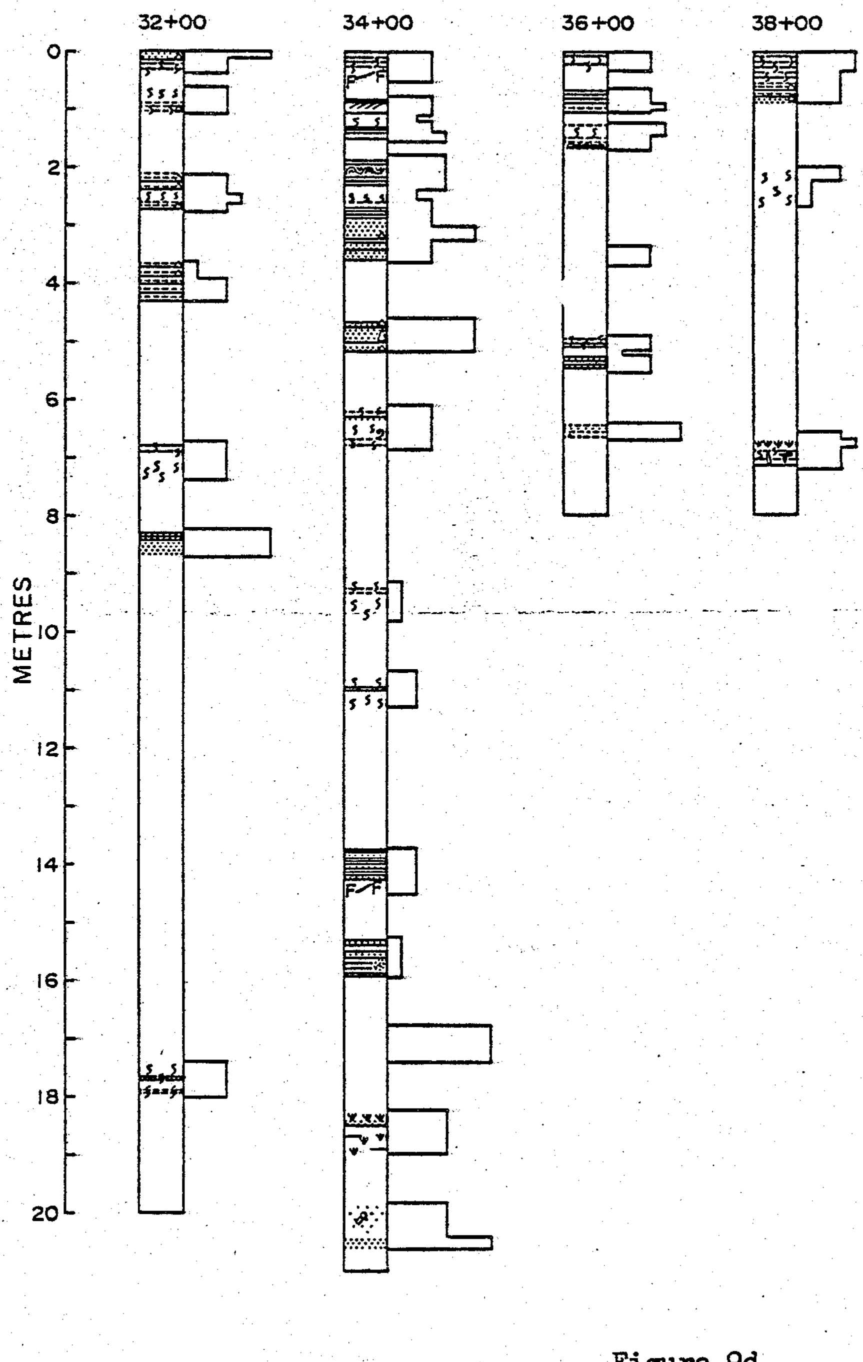
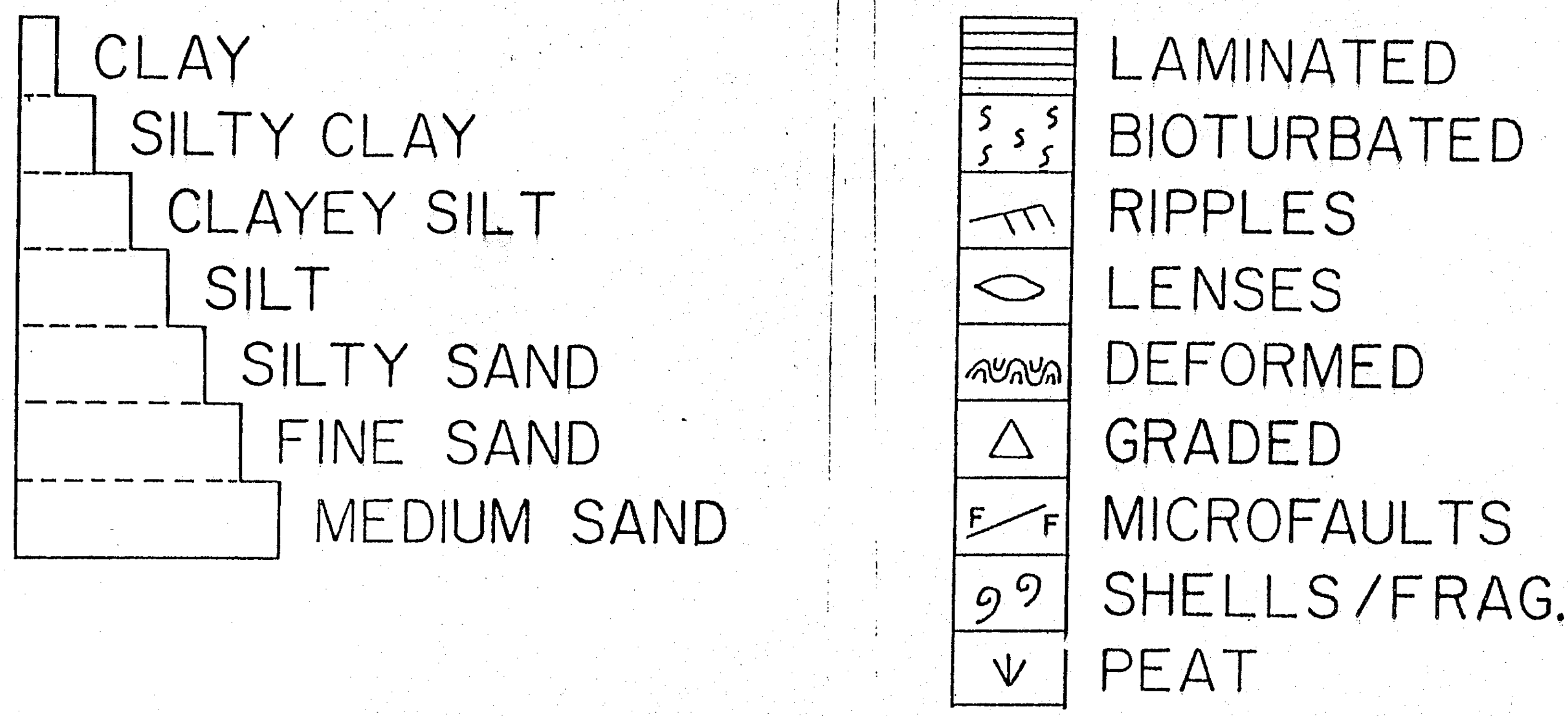


Figure 9d

TABLE 5

Key To Lithologic Description



Of the sandy cores which were split, fine and medium sand were most abundant, although rare coarse sand and gravel were observed. Peels made in the field indicate that the sands are commonly parall--lly laminated, with the laminae often dipping up to 20 degrees. Occasional fine-scale cross-lamination was also observed. A unit of diamicton (predominantly muddy sand with occasional gravel clasts) was present at the bottom of boreholes 36+00 and 38+00.

Shells and shell fragments were present in many cores, associated both with fine and coarse sediments. Large pieces of wood were recovered at several intervals in various boreholes and fibrous peat was found in core from borehole 38+00.

A very preliminary analysis of lithologies and sedimentary structures leads to some tentative interpretations. The silts and clays largely represent marine and deltaic environments. Generally, the preservation of sedimentary structures and thicker beds indicate proximity to the delta mouth. The more bioturbated lithologies probably represent more open marine conditions. The fine and medium sands are most likely subaqueous deltaic deposits, as evidenced by the presence of shell fragments, but subaerial deposition cannot be ruled out at this time. Clay-draped floating ripples may indicate intertidal conditions, although similar lithologies have been observed from sub-tidal deltaic environments. A more detailed analysis of the sediment facies will allow much more detailed interpretations in the future.

Stratigraphy

At this time, the age and correlation of the cored sediments is not known. The area is very important stratigraphically as it lies between shelf sediments of latest mid-Wisconsinan to Holocene age and between sediments on Richards and Pullen Islands, thought to be of early Wisconsinan age. The presence of a diamicton (possibly till) in boreholes 36+00 and 38+00, and of dateable wood and peat in borehole 38+00 will provide very important data on the Wisconsinan glacial history of this area.

13. Shear Vane Tests (K. Moran)

Plots of the undrained shear strength vs. depth for each borehole, based on miniature vane shear tests on the split cores, are presented in Figure 10. The initial trends in the data show that boreholes closest to Richards Island are lower in shear strength. The strength is generally less than 20 kPa with little indications of zones of high strength (Figs. 10a, 10b and 10c).

Further offshore, samples from boreholes 3+00 and 6+00 show slight increase in the shear strength (Figs. 10e,10f and 10g). These samples display typical increases of shear strength with depth, with values of less than 10 kPa at the top of the boreholes to values of 25-30 kPa at 20 metres below seabed. An exception to this trend are samples from borehole 1+50 (Fig. 10d) where the shear strength remains below 20 kPa throughout most of its length. However, a distinct zone of higher shear strength of up to 50 kPa was identified between 12 and 13 metres below seabed.

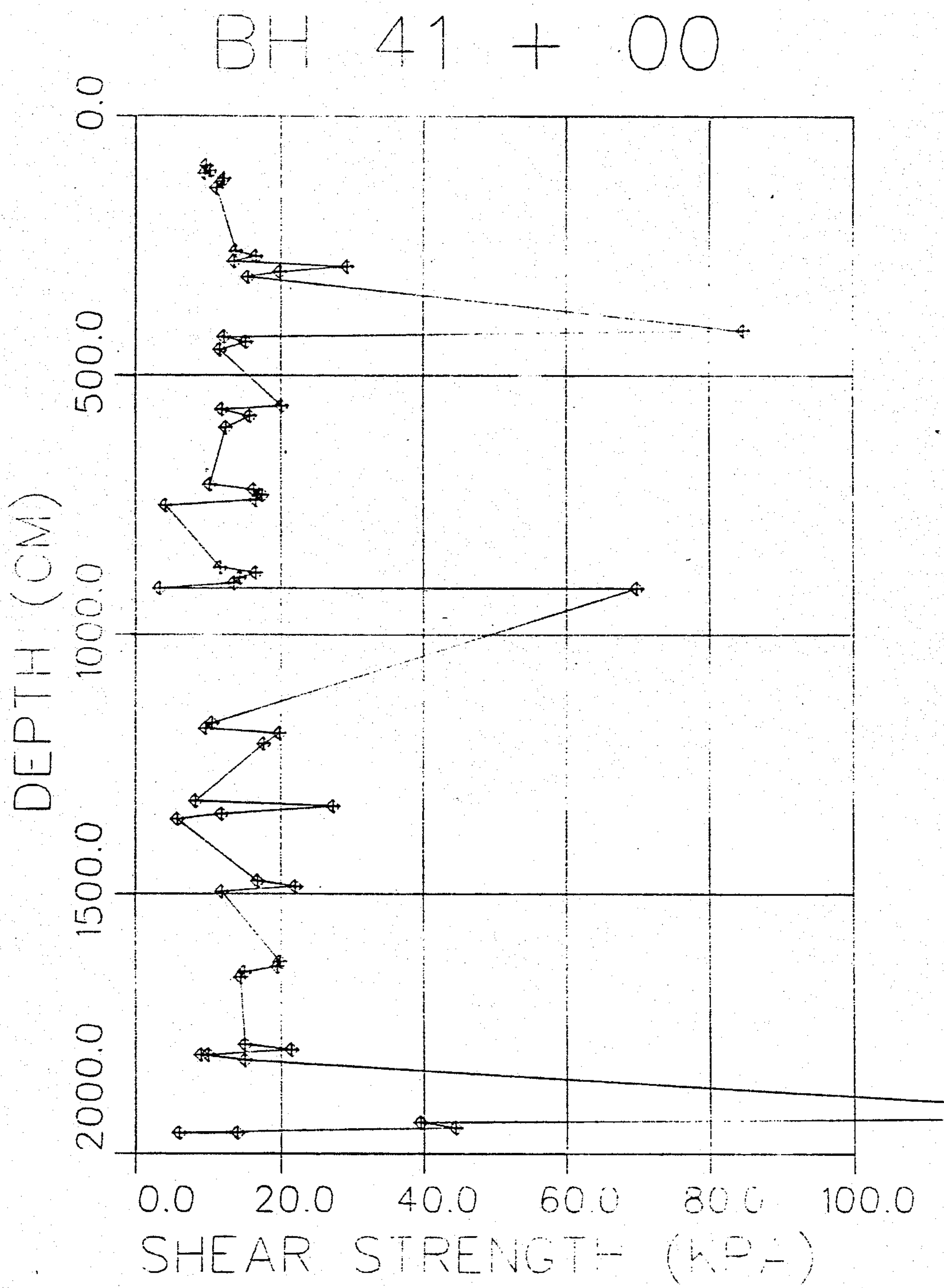


Fig. 10 a

Figure 10 a - s: Undrained shear strength vs depth

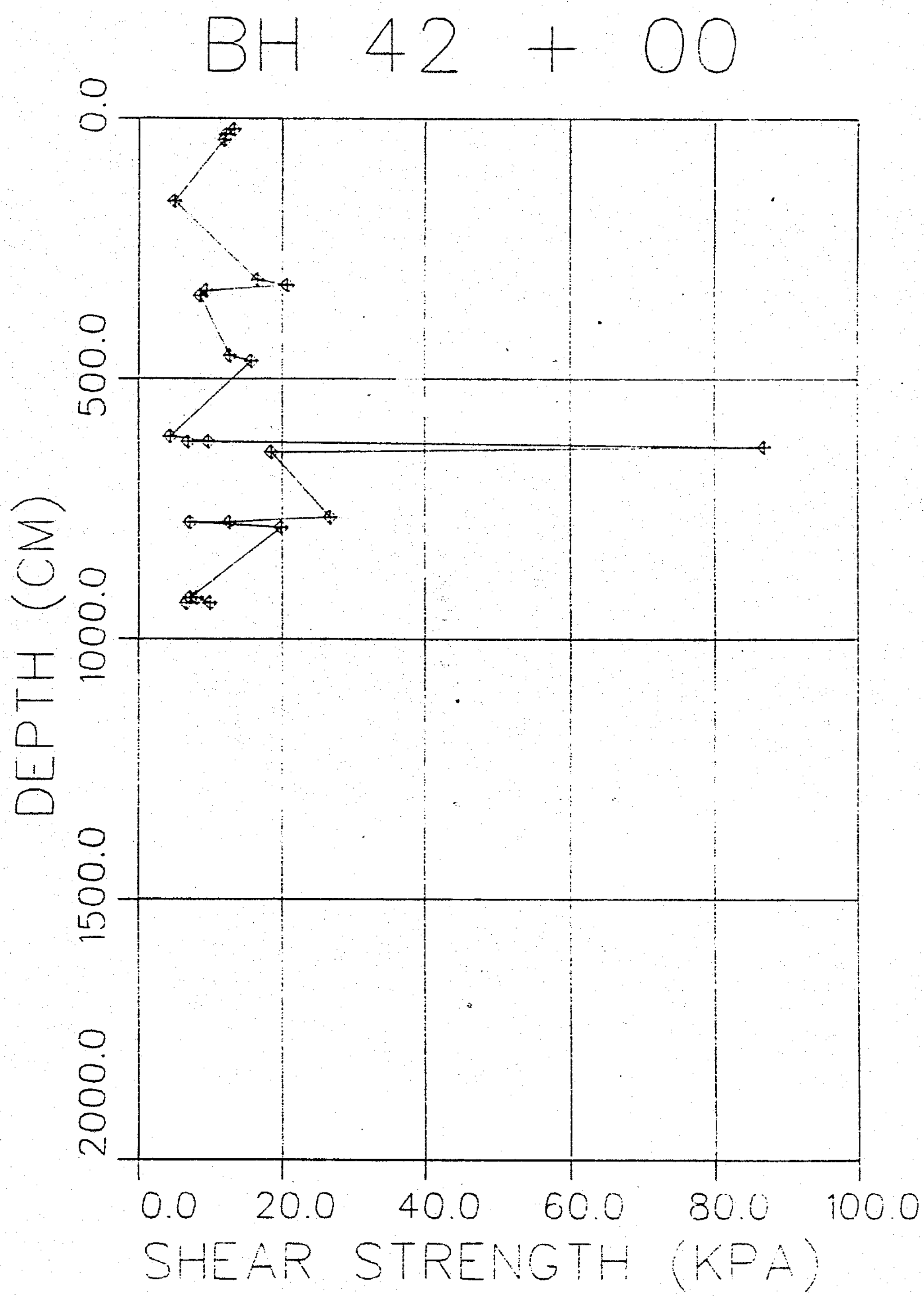

BH 42 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 b

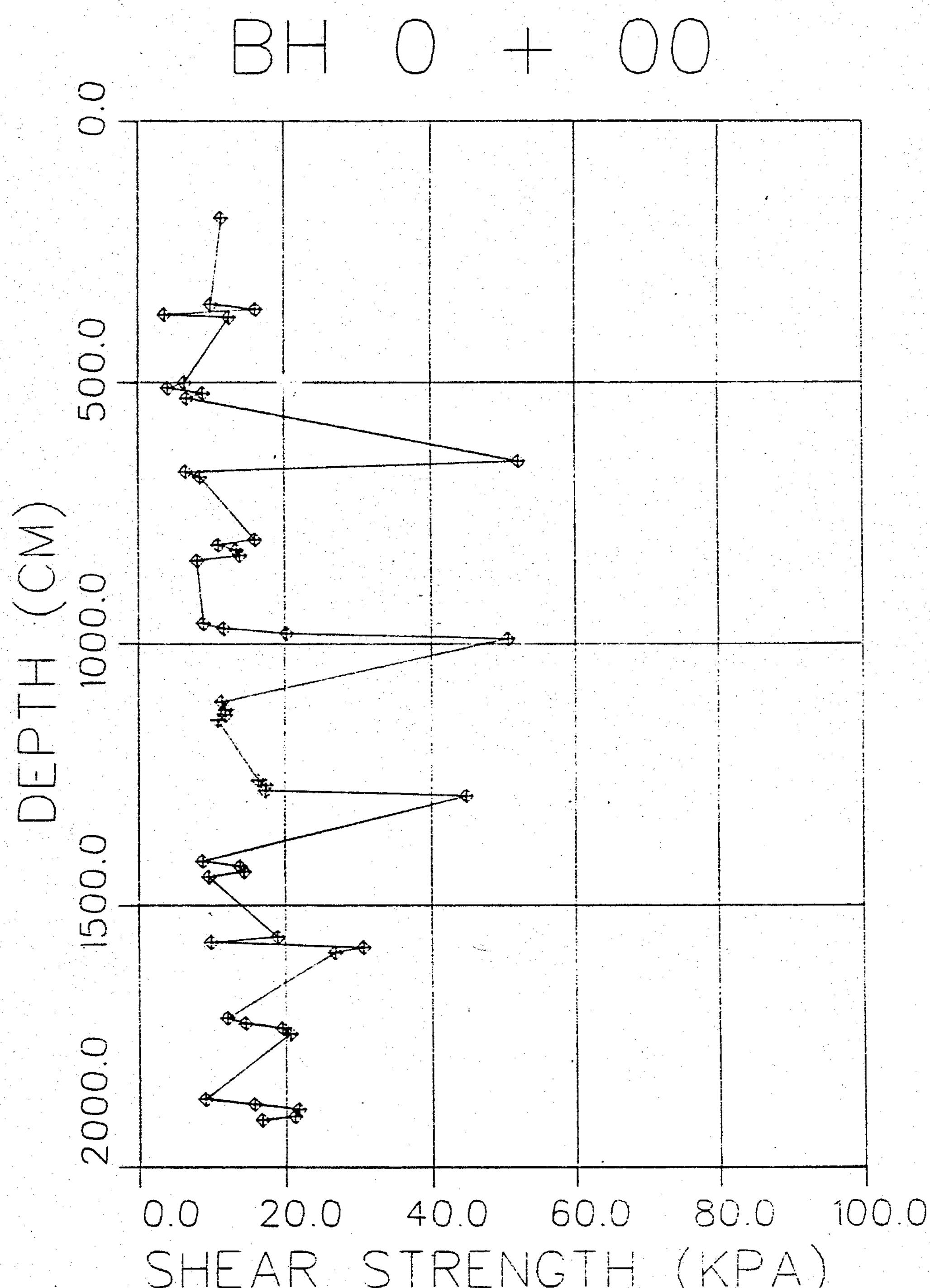

BH 0 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 c

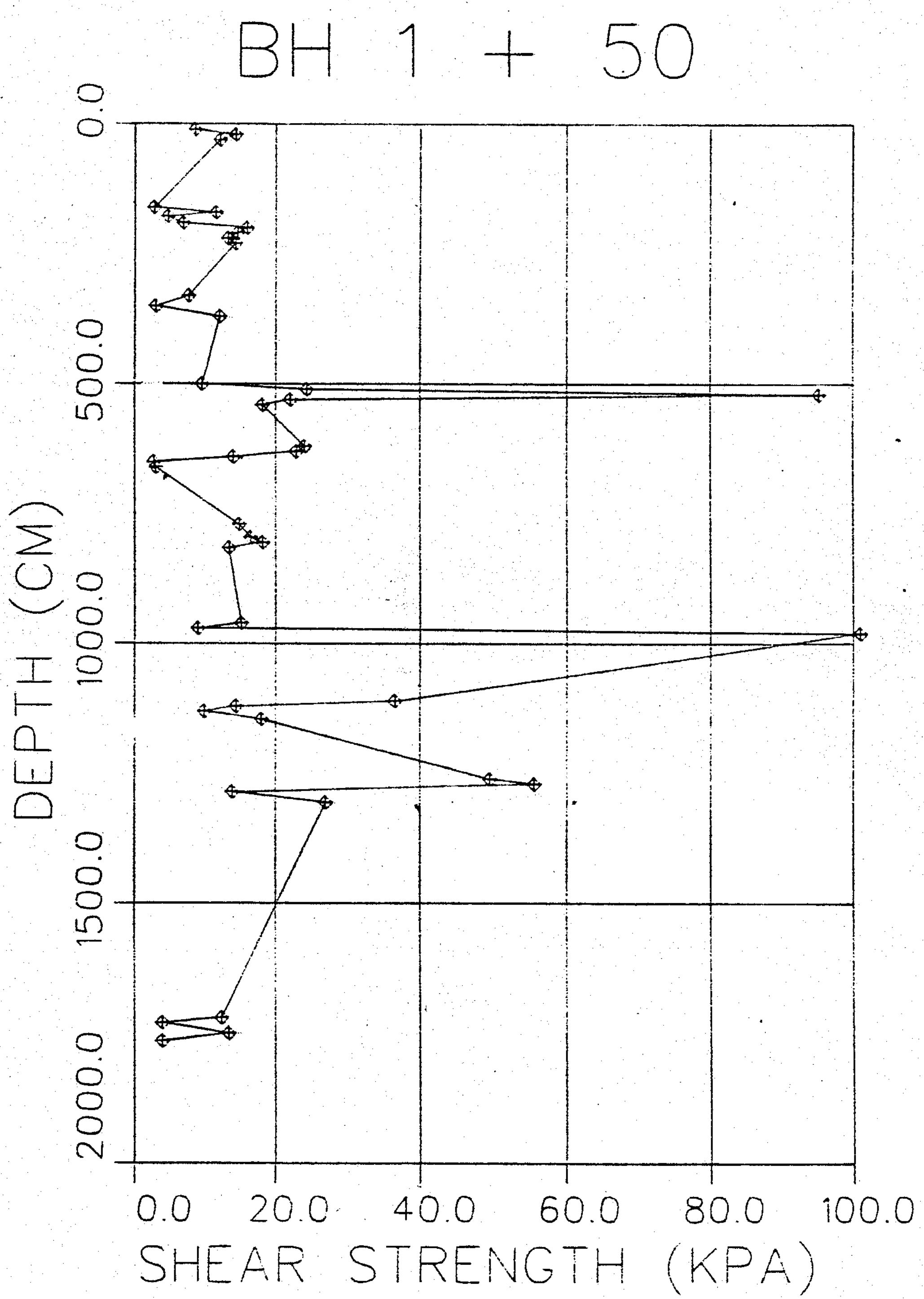

BH 1 + 50
0.0
500.0
1000.0
1500.0
2000.0
DEPTH (CM)
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig.10 d

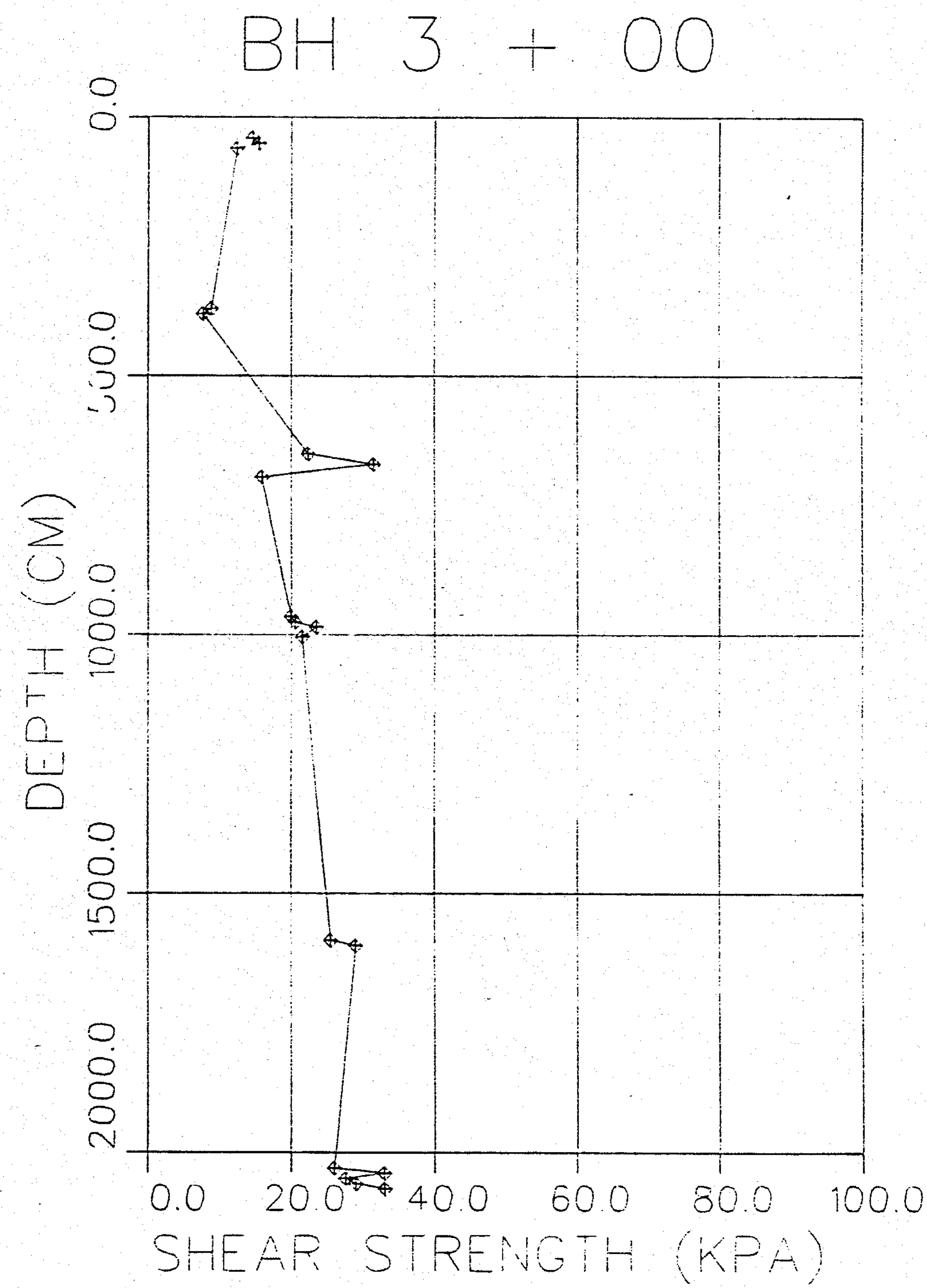

BH 3 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 e

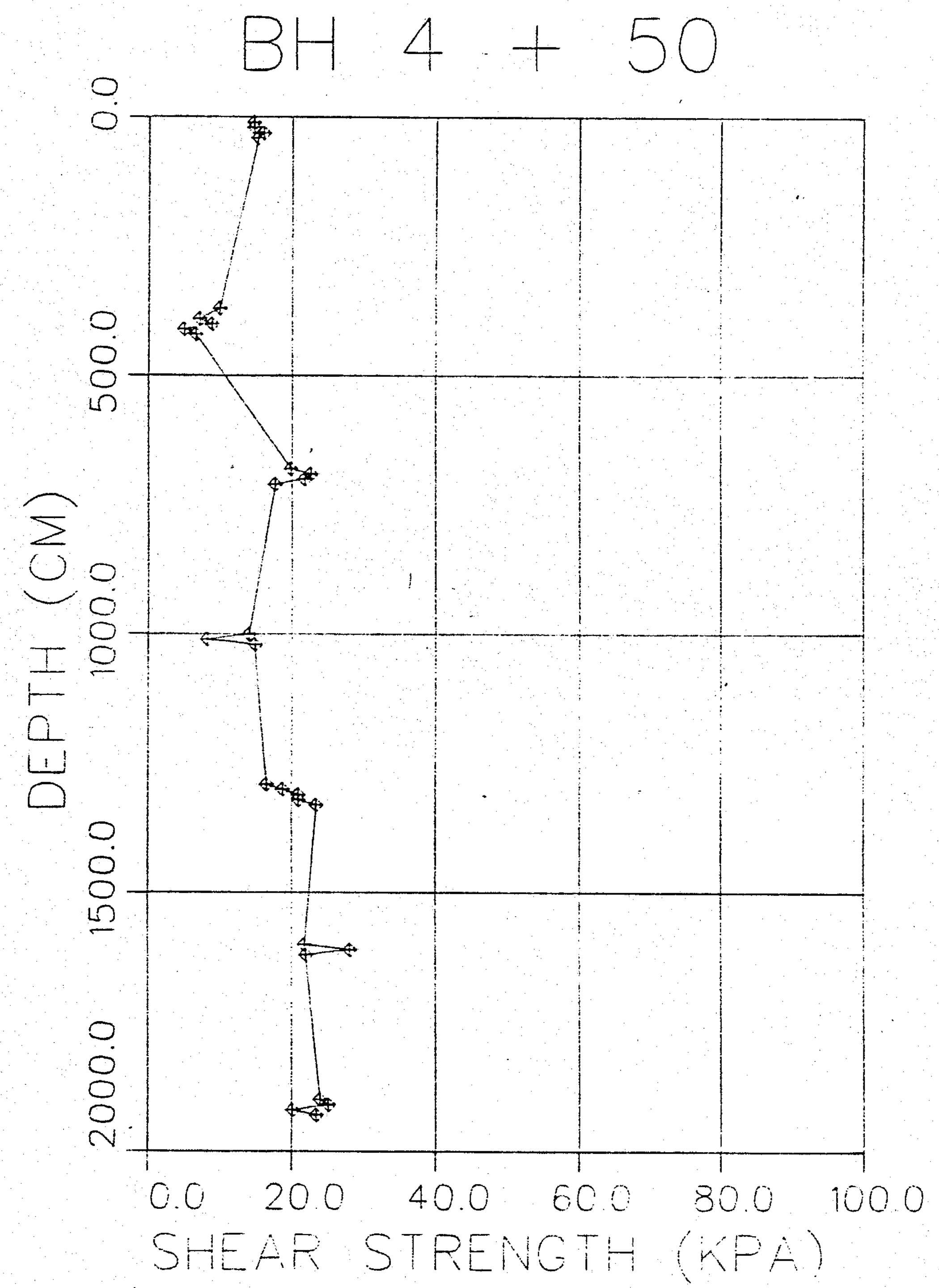

BH 4 + 50
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 f

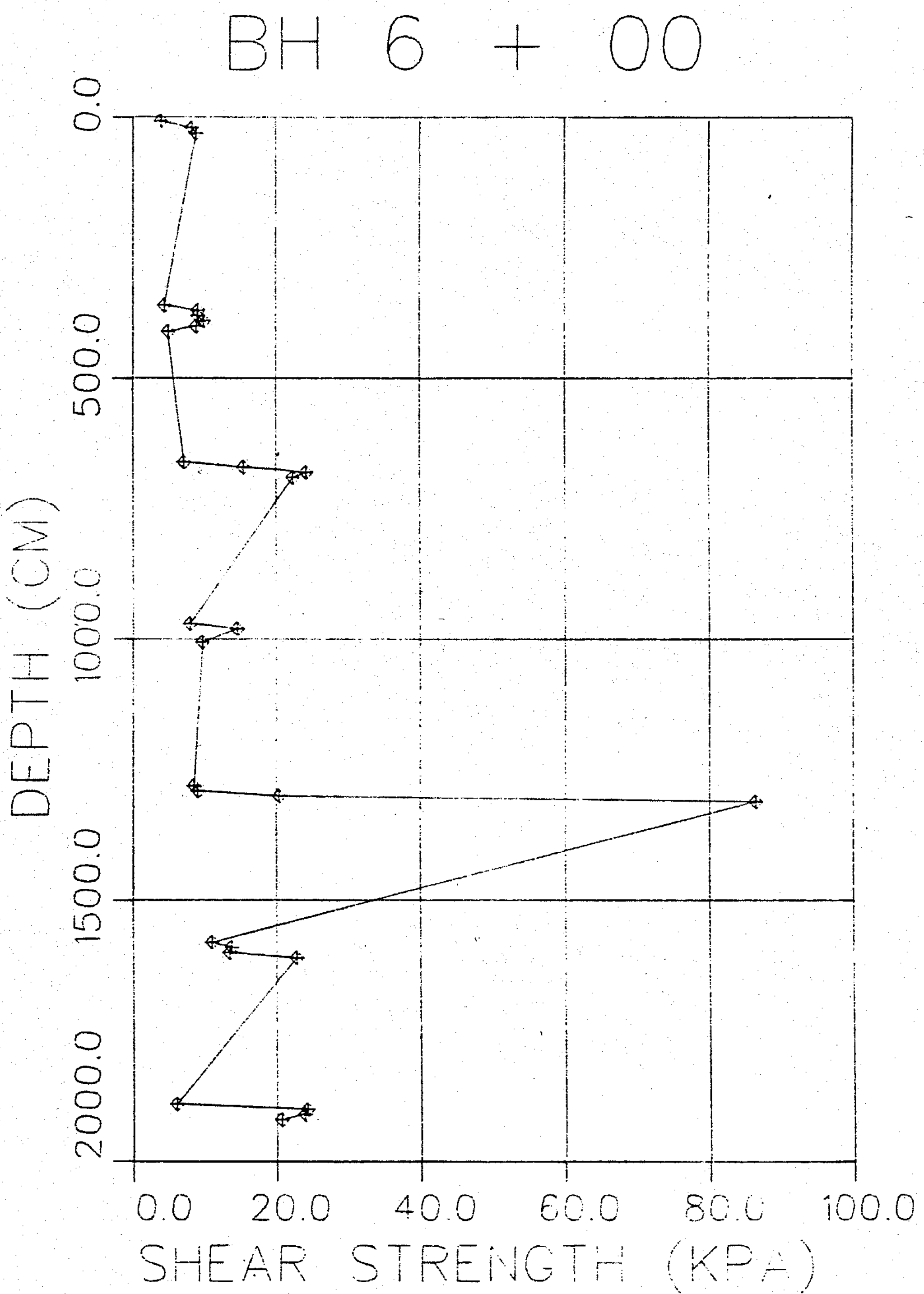
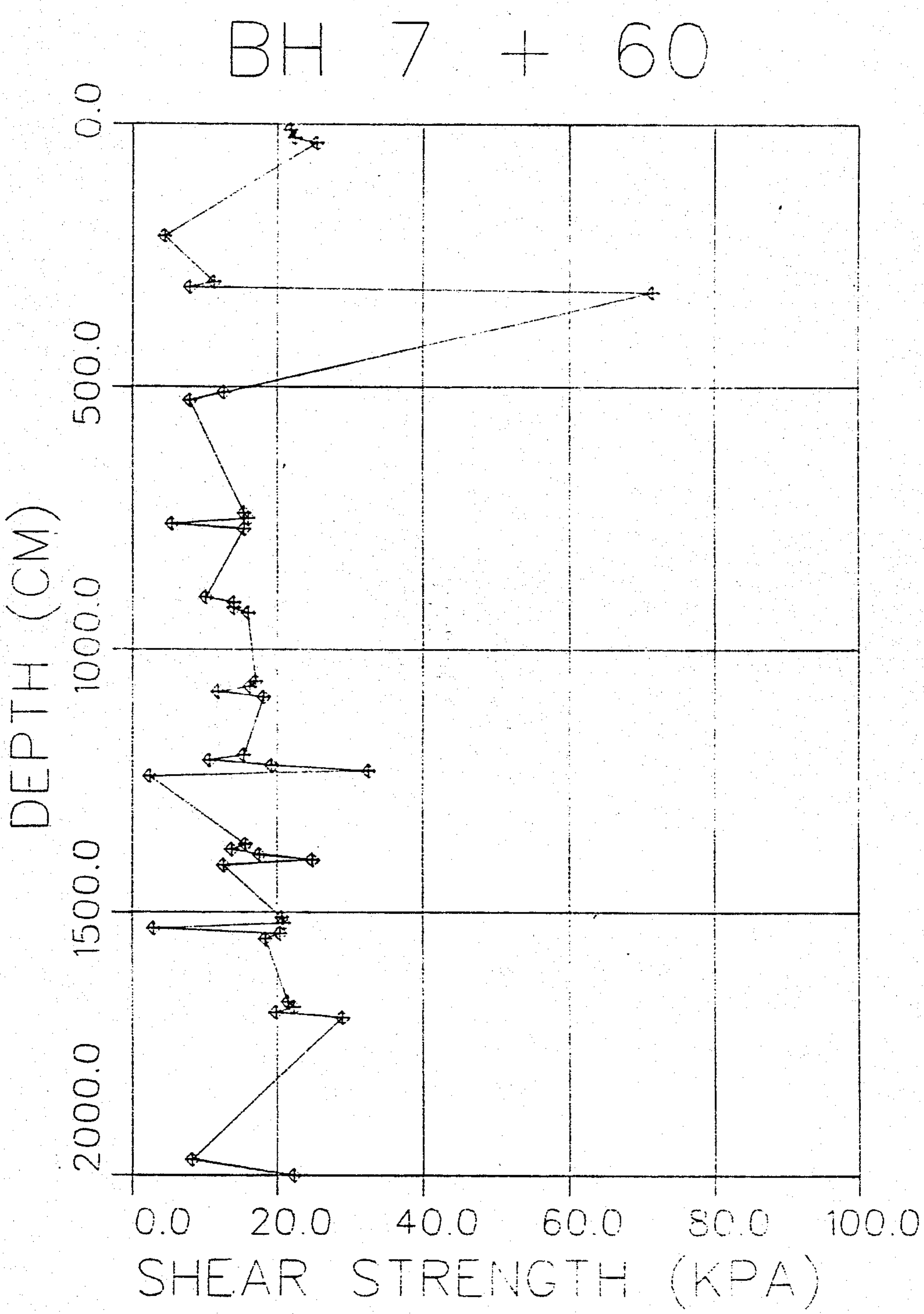

BH 6 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 g



BH 7 + 60
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 h

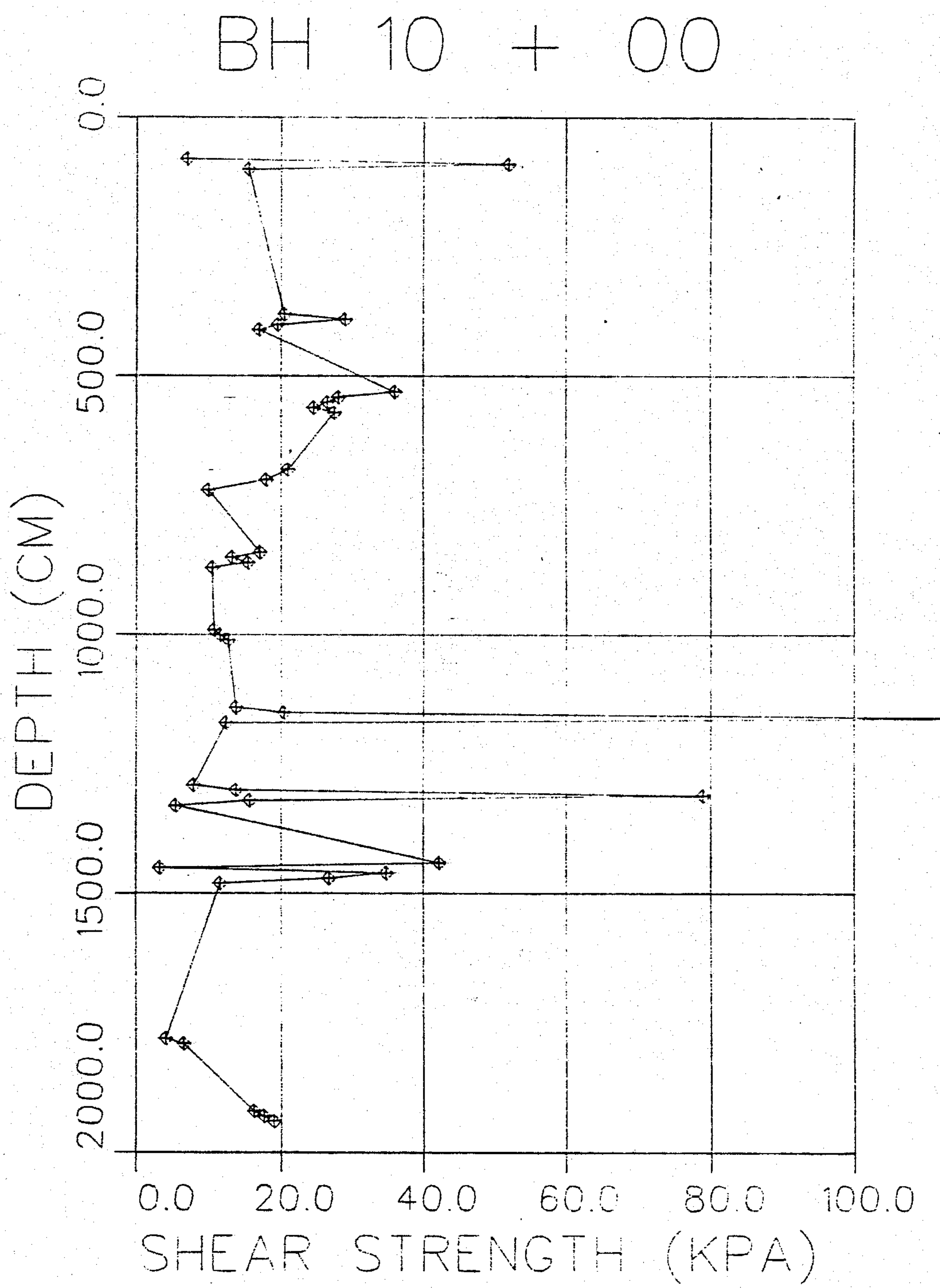

BH 10 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 i

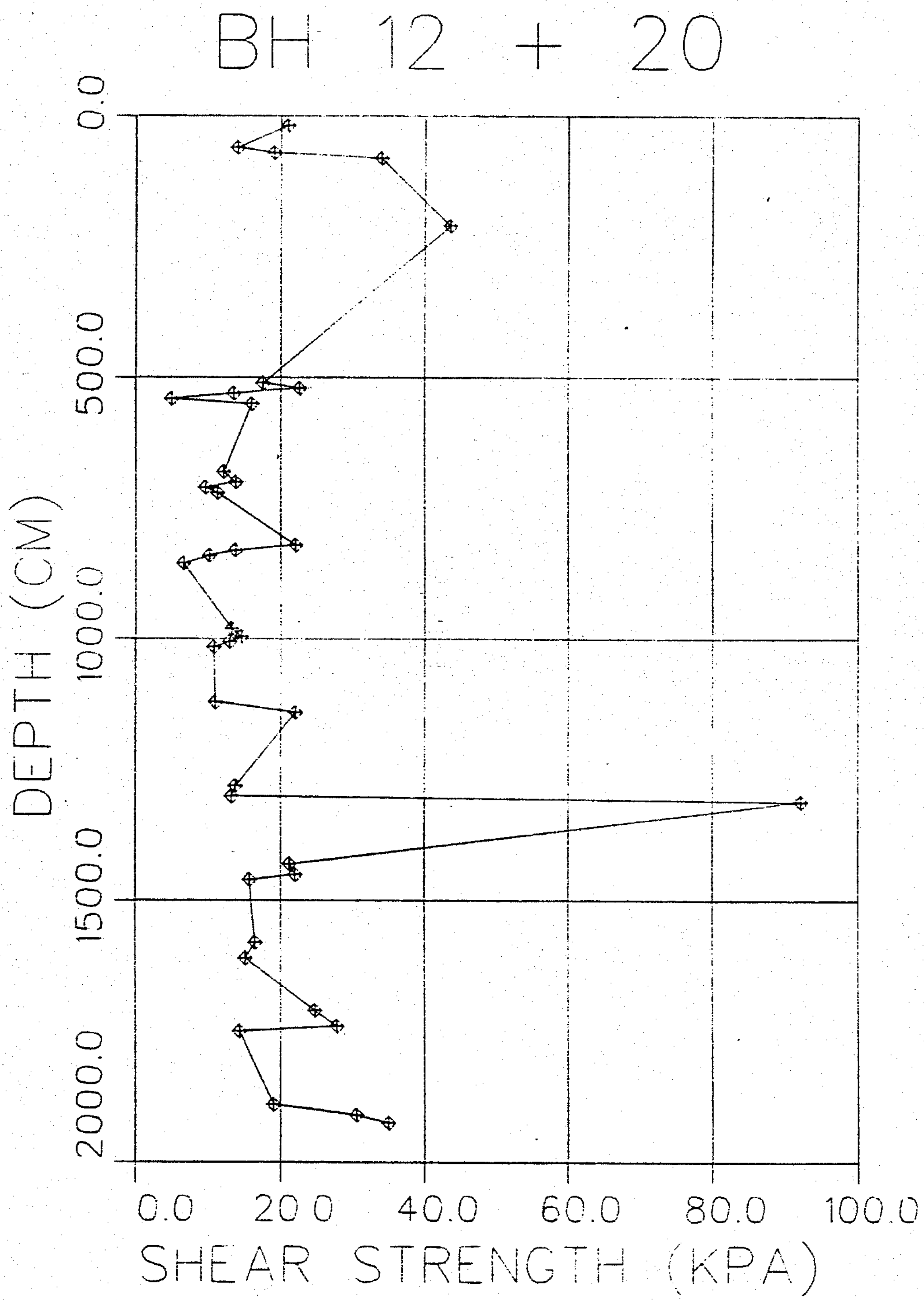
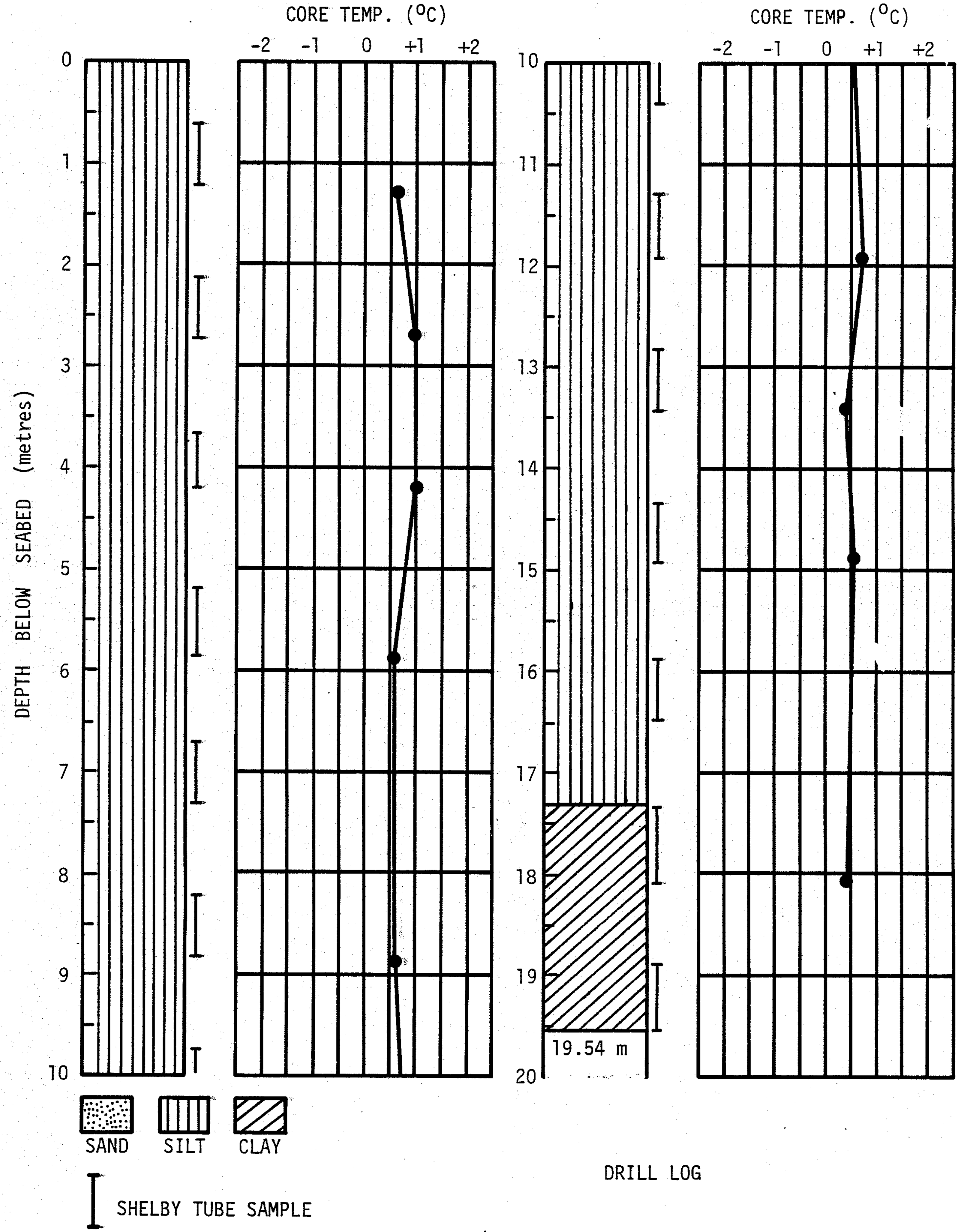

BH 12 + 20
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

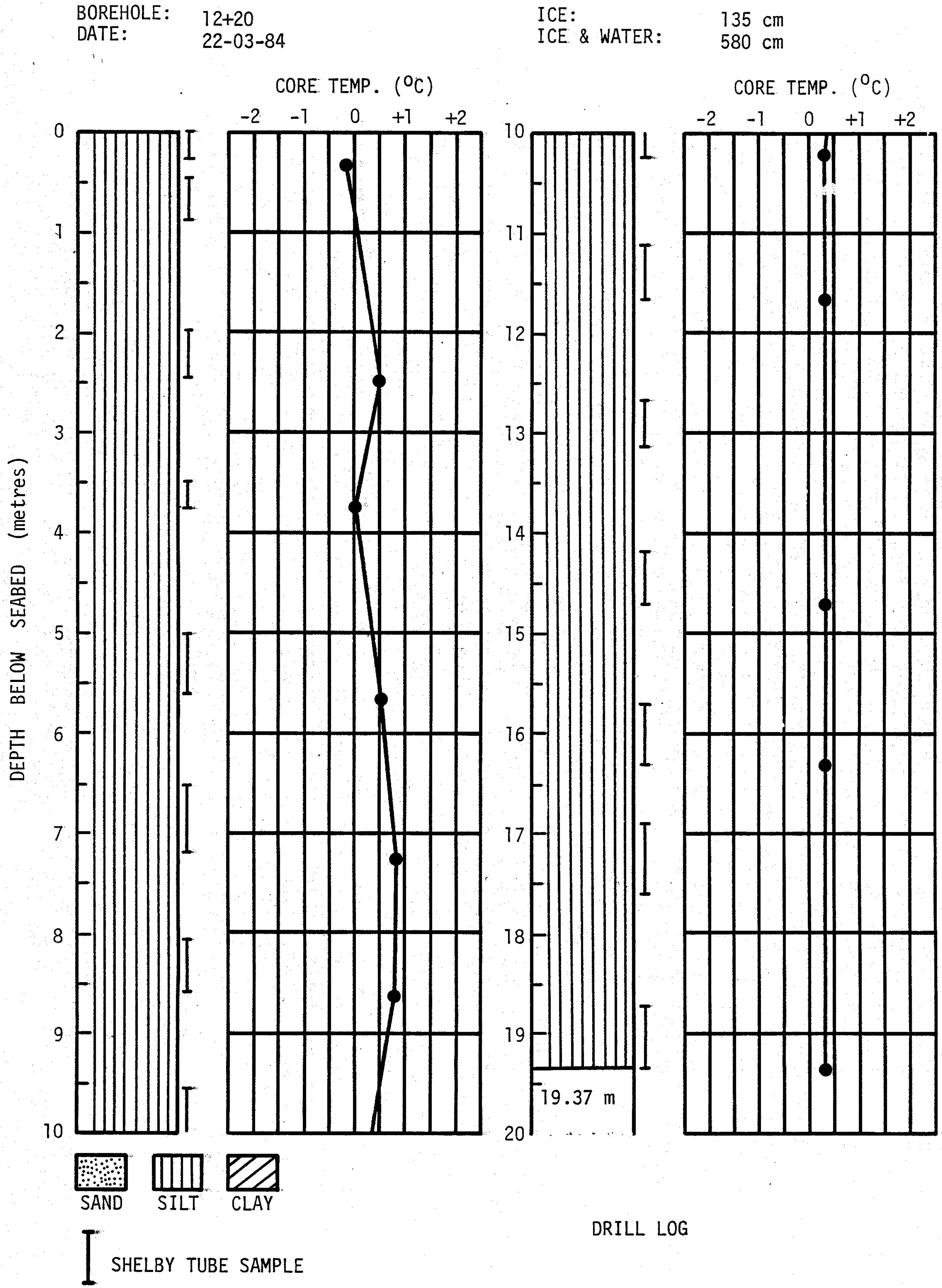
Fig. 10 j

BOREHOLE: 10+00
DATE: 22-03-84

ICE: 190 cm
ICE & WATER: 530 cm



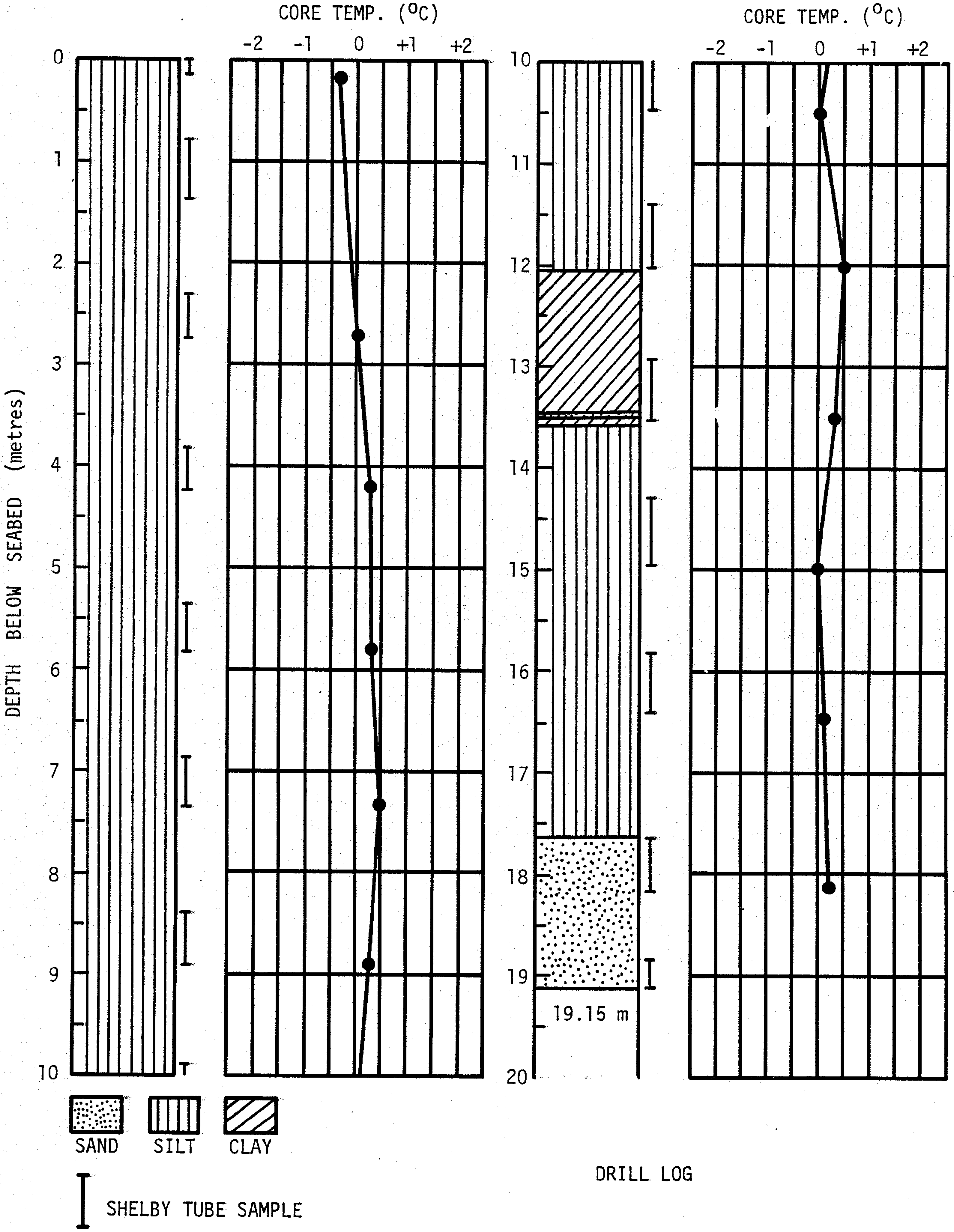
DRILL LOG


BOREHOLE: 12+20
DATE: 22-03-84
ICE: 135 cm
ICE & WATER: 580 cm
CORE TEMP. (°C)
-2 -1 0 +1 +2
DEPTH BELOW SEABED (metres)
0 1 2 3 4 5 6 7 8 9 10
10 11 12 13 14 15 16 17 18 19 20
19.37 m
SAND
SILT
CLAY
SHELBY TUBE SAMPLE

DRILL LOG

BOREHOLE: 15+00
DATE: 22-03-84

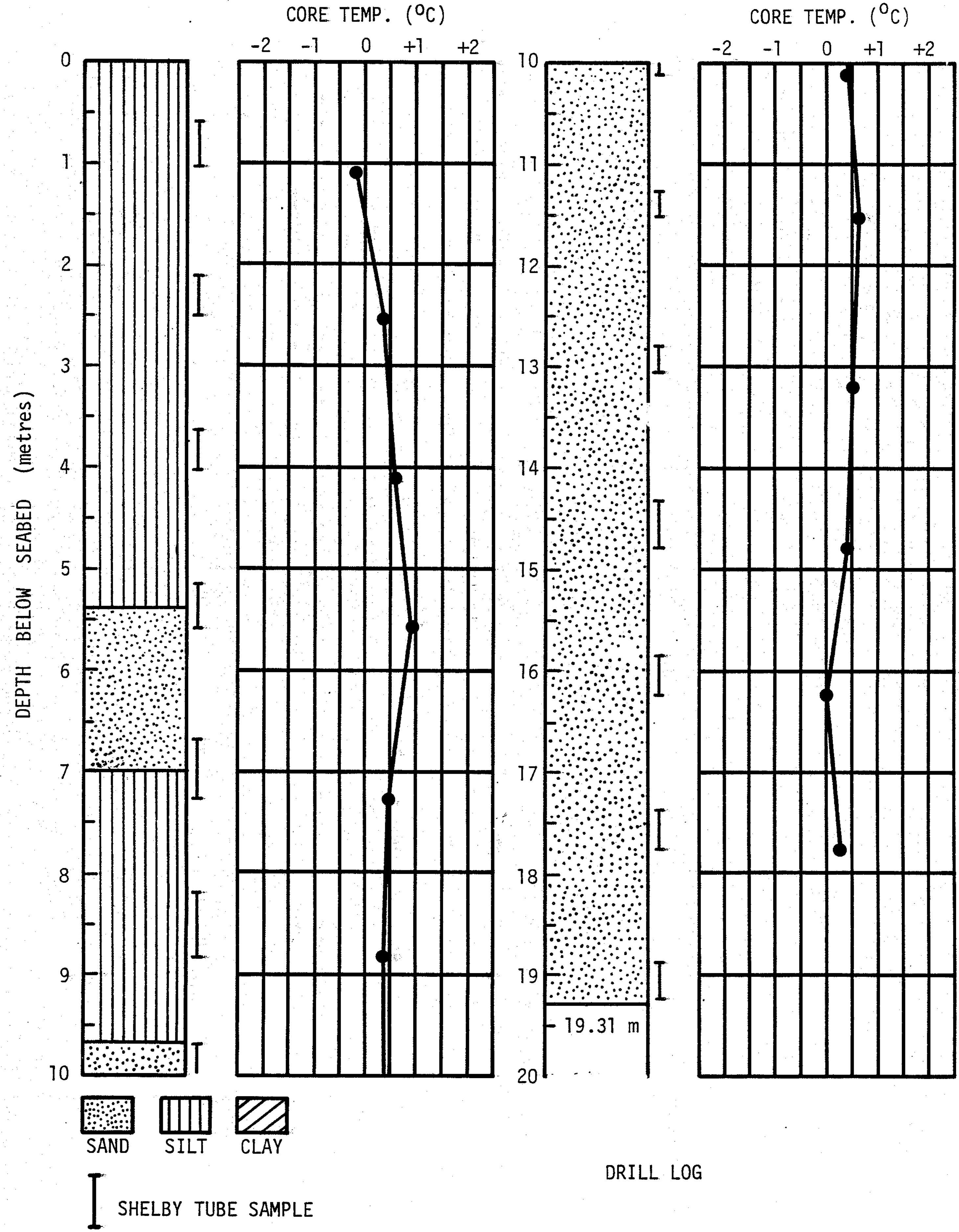
ICE: 160 cm
ICE & WATER: 713 cm



DRILL LOG

BOREHOLE: 17+60
DATE: 22,23-03-84

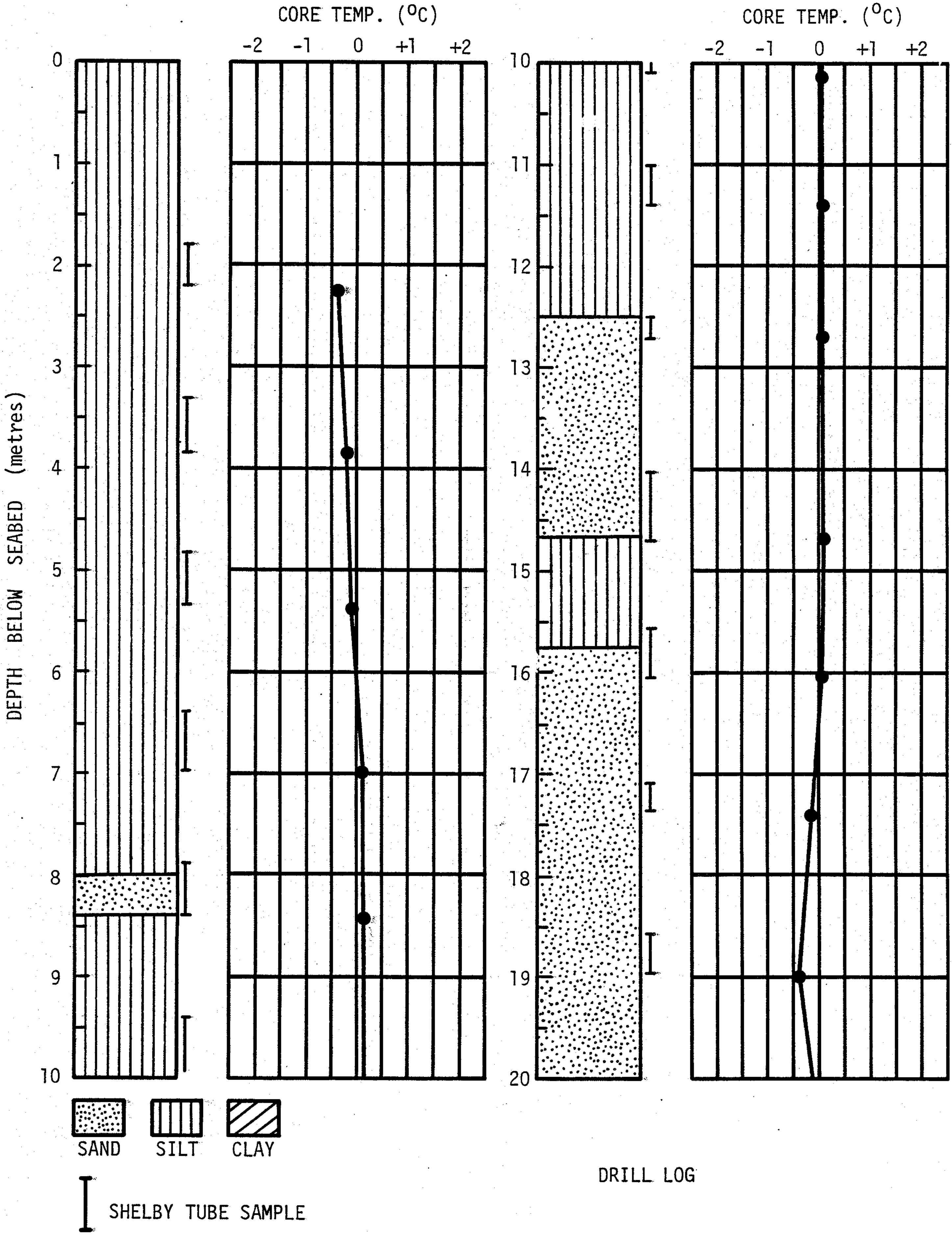
ICE: 170 cm
ICE & WATER: 810 cm



DRILL LOG

BOREHOLE: 17+60A
DATE: 25-03-84

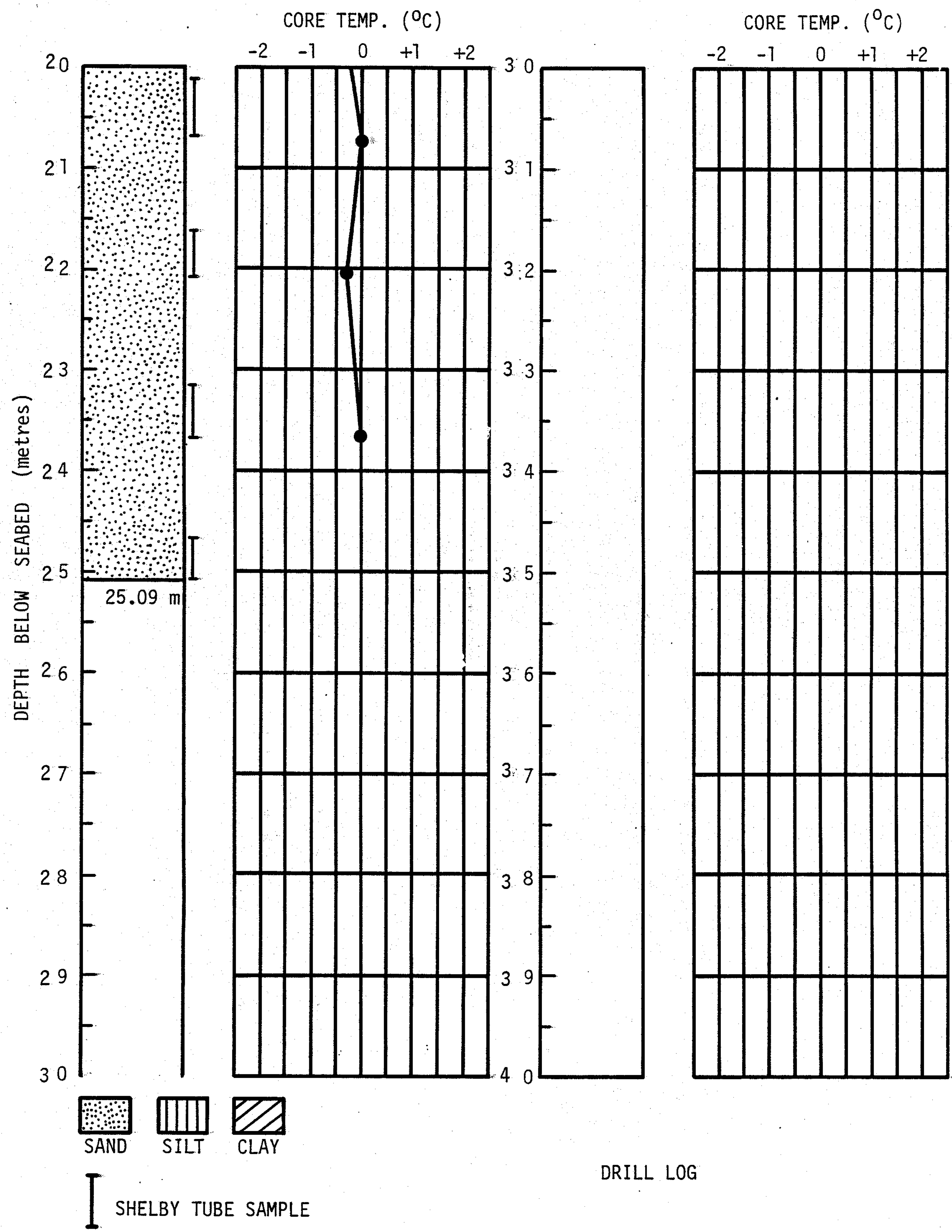
ICE: 170 cm
ICE & WATER: 810 cm

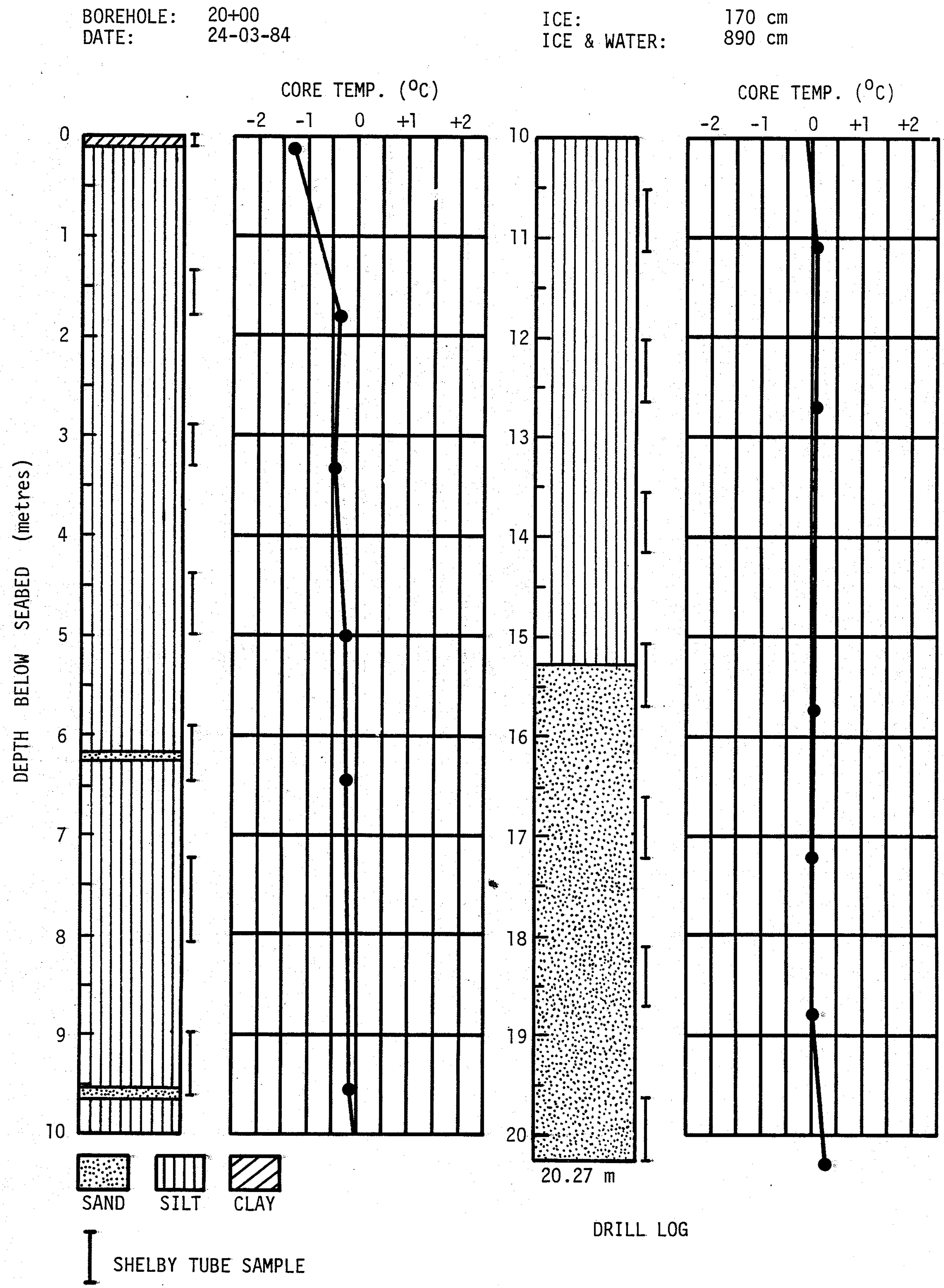


DRILL LOG

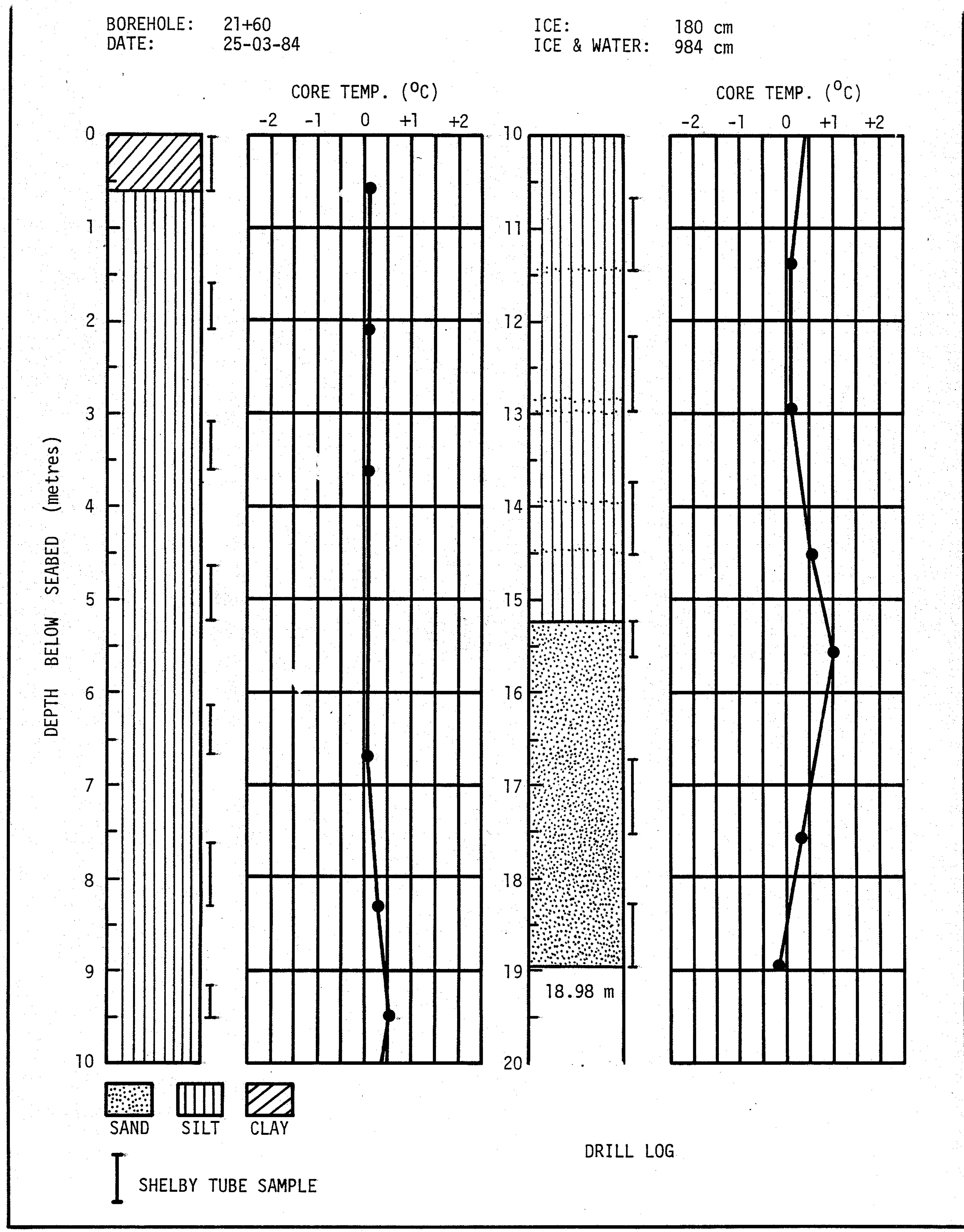
BOREHOLE: 17+60A
DATE: 25-03-84

ICE: 170 cm
ICE & WATER: 810 cm





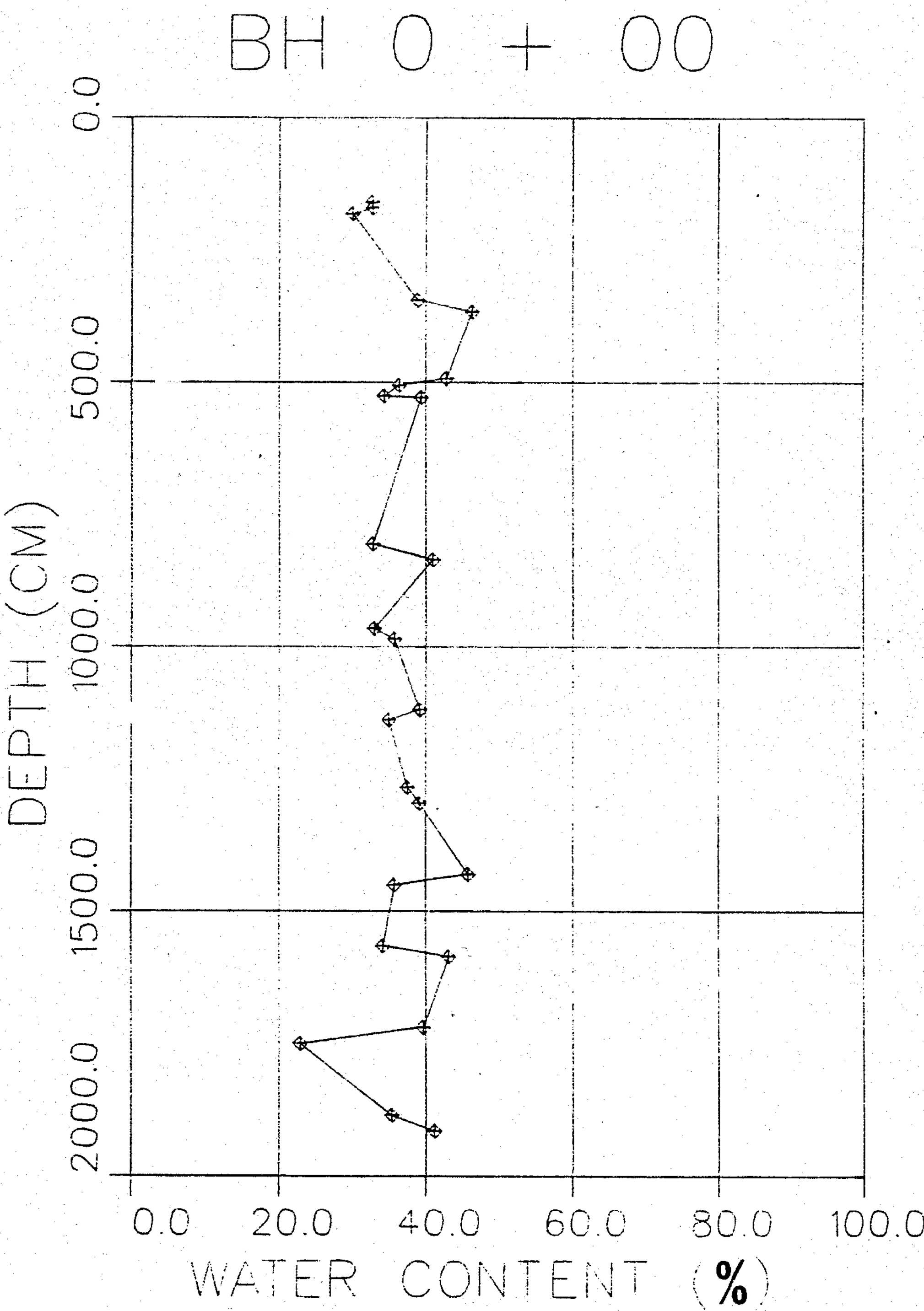
BOREHOLE: 20+00
DATE: 24-03-84
ICE: 170 cm
ICE & WATER: 890 cm
CORE TEMP. (°C)
-2 -1 0 +1 +2
DEPTH BELOW SEABED (metres)
0 1 2 3 4 5 6 7 8 9 10
11 12 13 14 15 16 17 18 19 20
20.27 m
SAND
SILT
CLAY
SHELBY TUBE SAMPLE
DRILL LOG



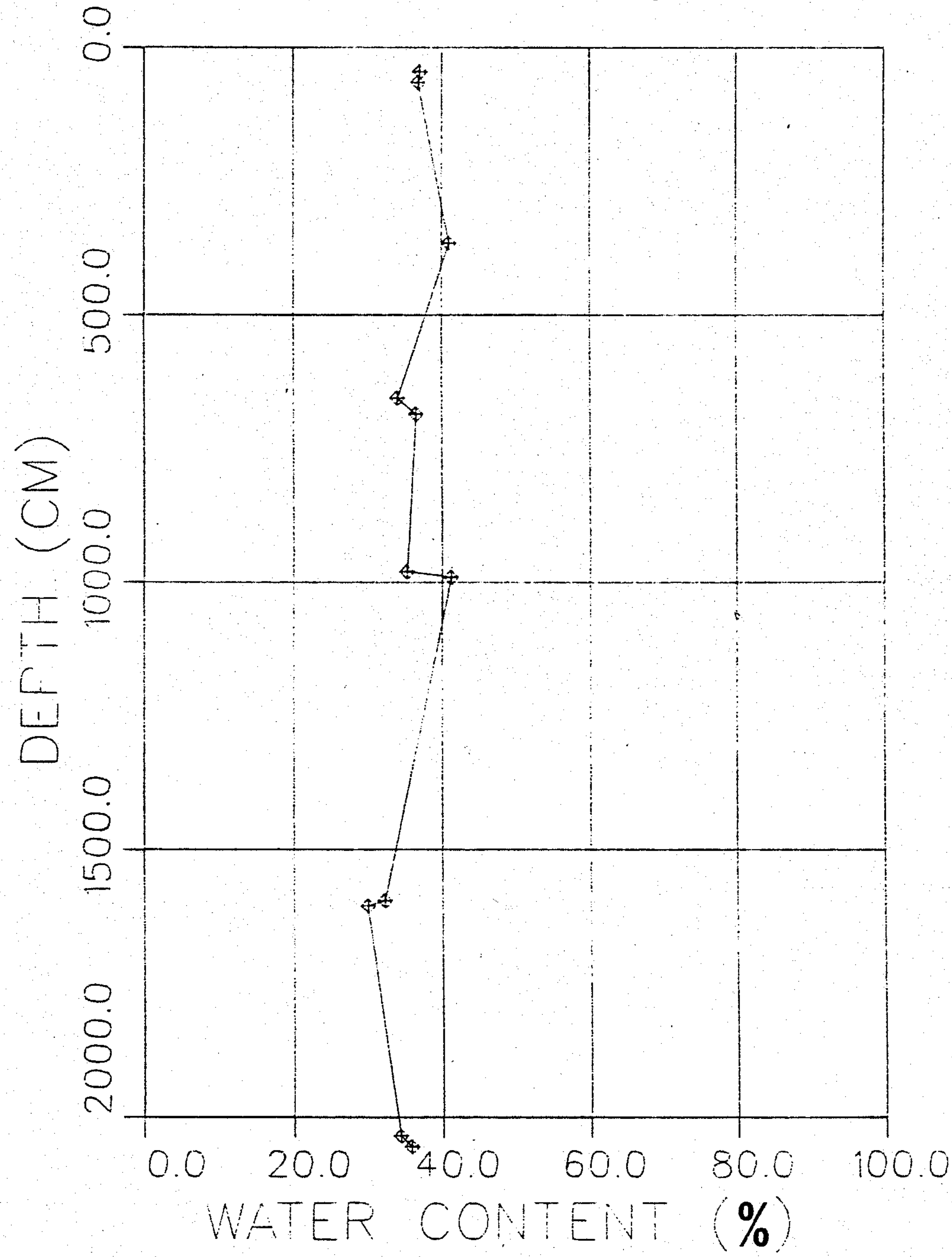
BOREHOLE: 21+60
DATE: 25-03-84
ICE: 180 cm
ICE & WATER: 984 cm
CORE TEMP. (°C)
-2 -1 0 +1 +2
DEPTH BELOW SEABED (metres)
0 1 2 3 4 5 6 7 8 9 10
10 11 12 13 14 15 16 17 18 19 20
18.98 m
SAND
SILT
CLAY
SHELBY TUBE SAMPLE
DRILL LOG

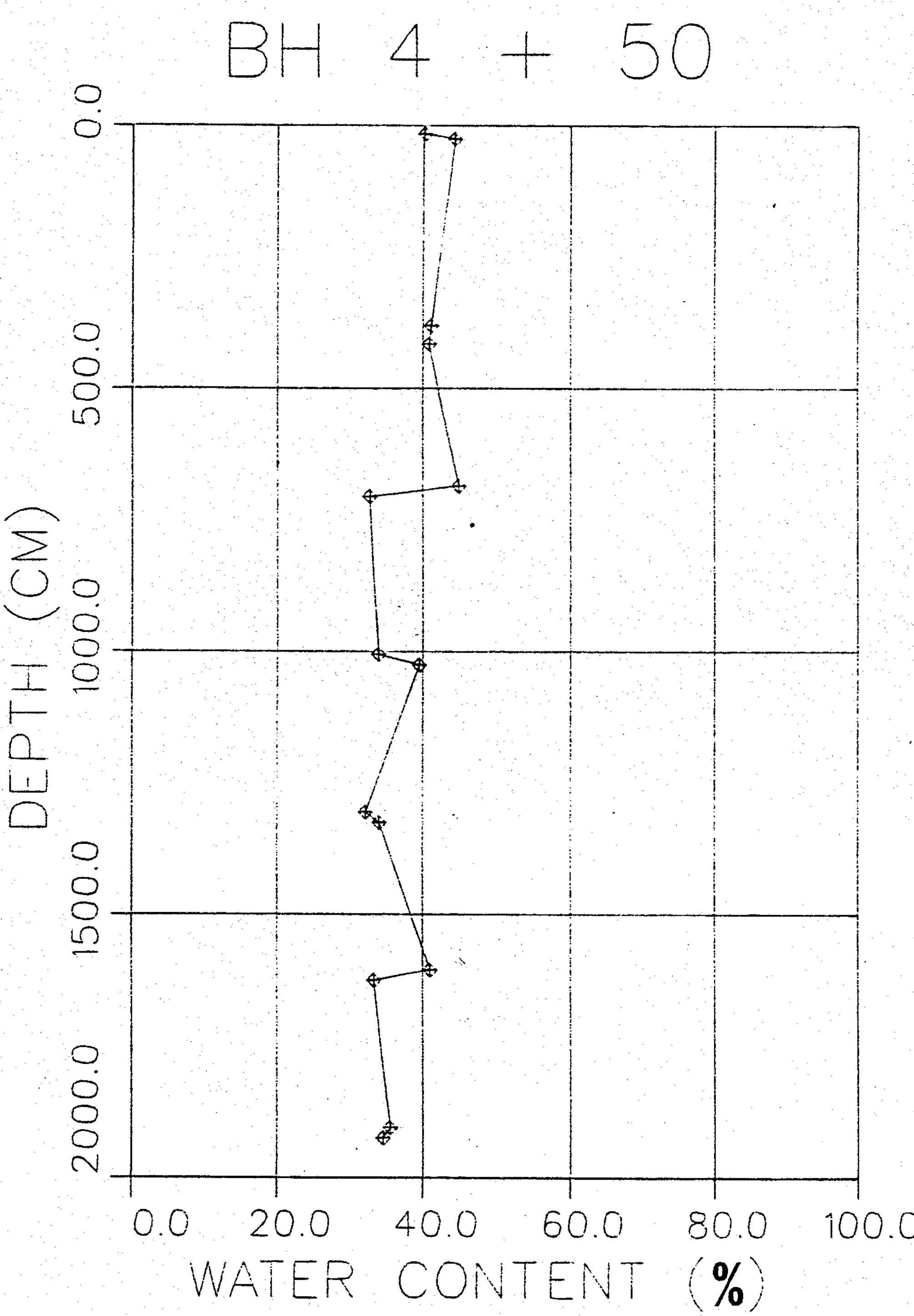
APPENDIX B

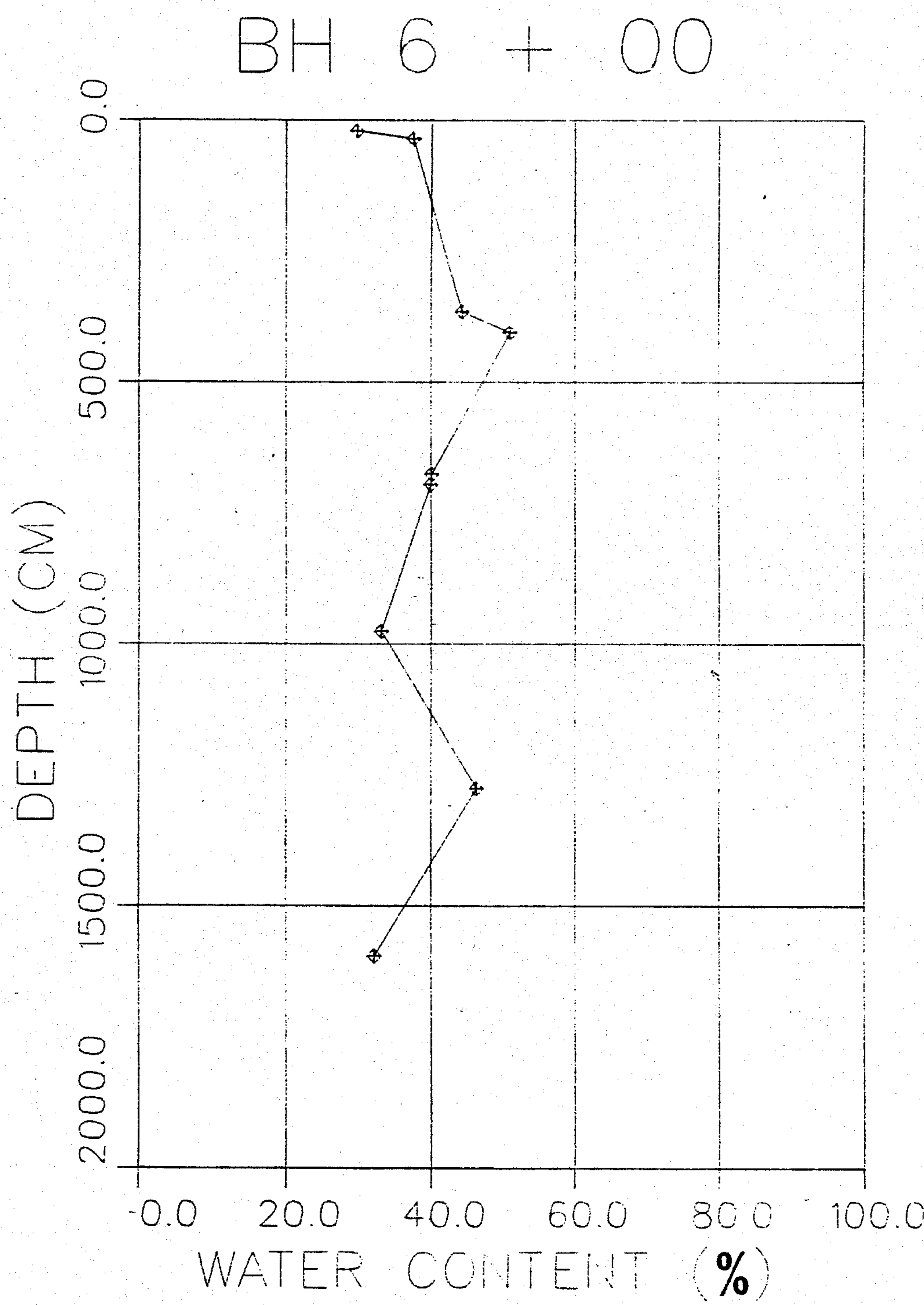
W A T E R   C O N T E N T S

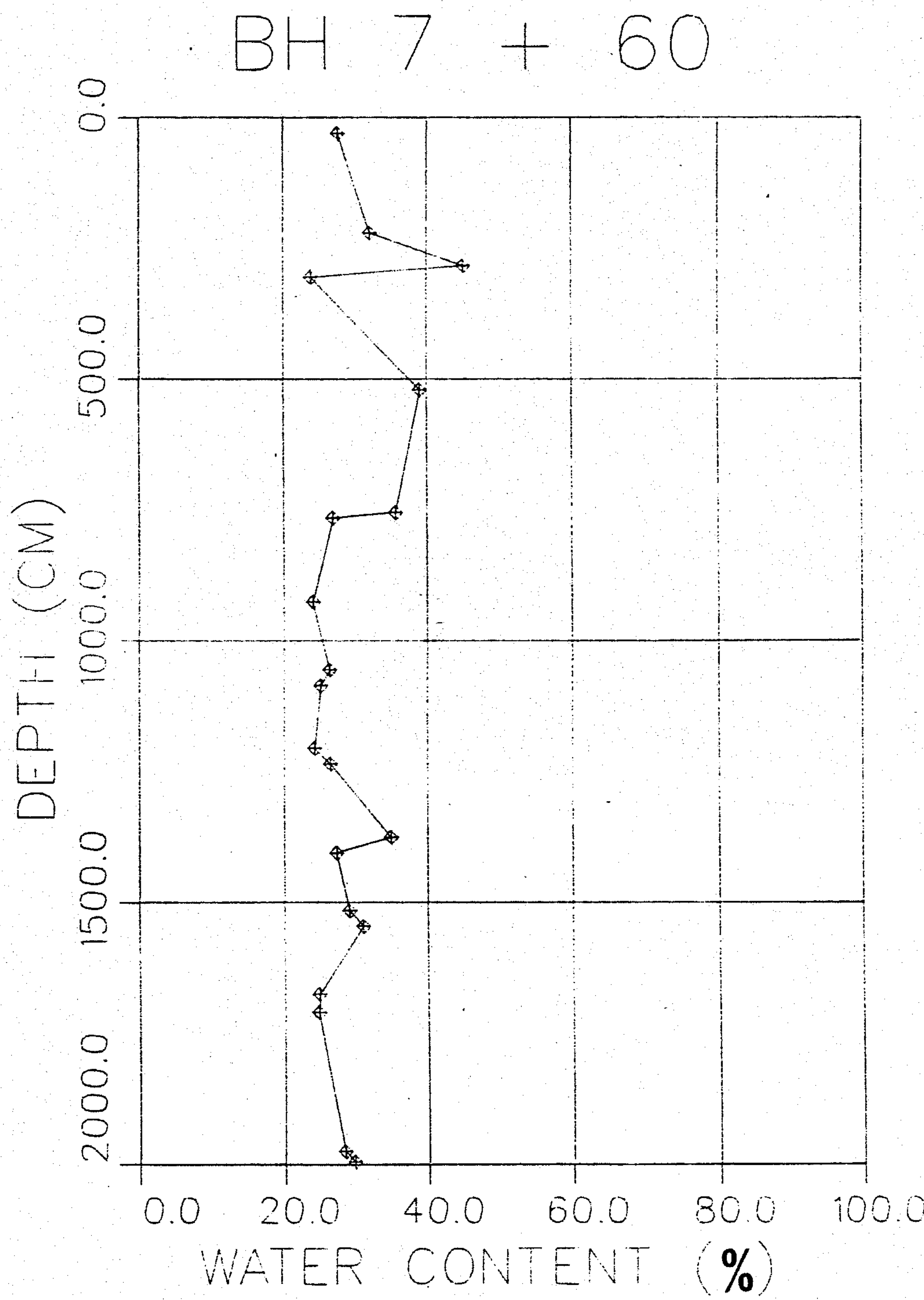

BH 0 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)

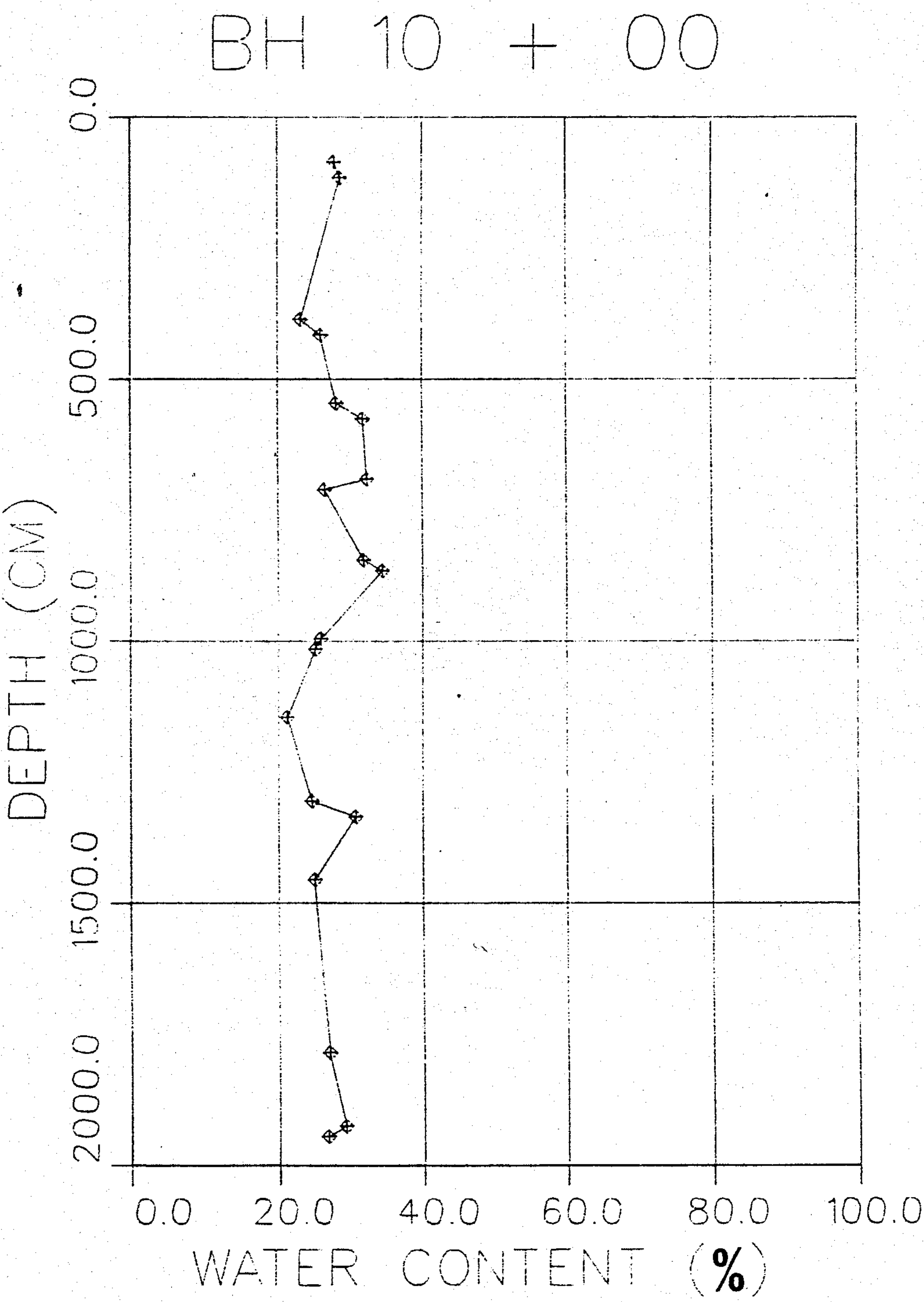
BH 3 + 00


0.0
500.0
1000.0
1500.0
2000.0
DEPTH (CM)
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)


BH 4 + 50
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)

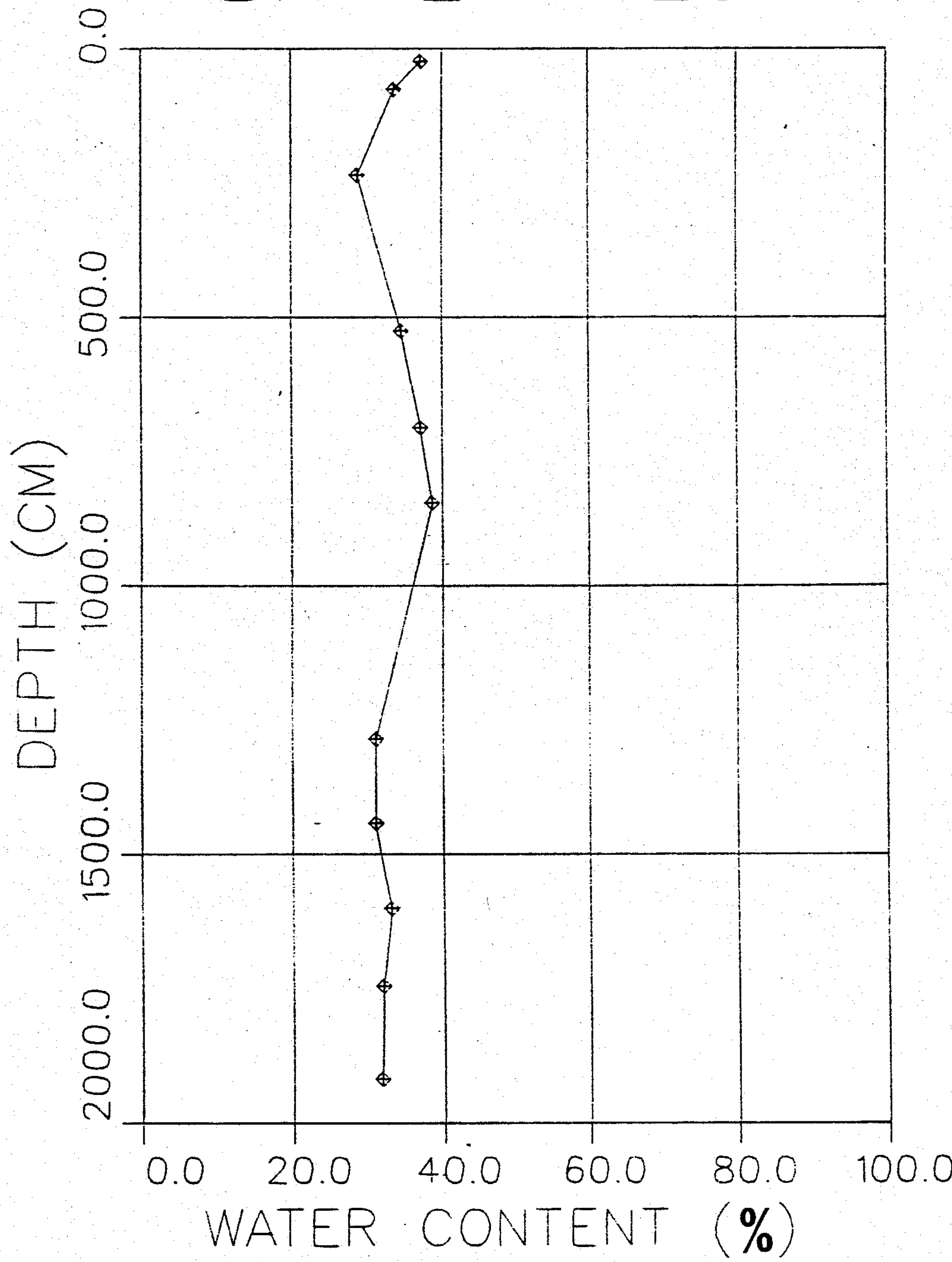

BH 6 + 00
0.0
500.0
1000.0
1500.0
2000.0
DEPTH (CM)
-0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)


BH 7 + 60
0.0
500.0
1000.0
1500.0
2000.0
DEPTH (CM)
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)

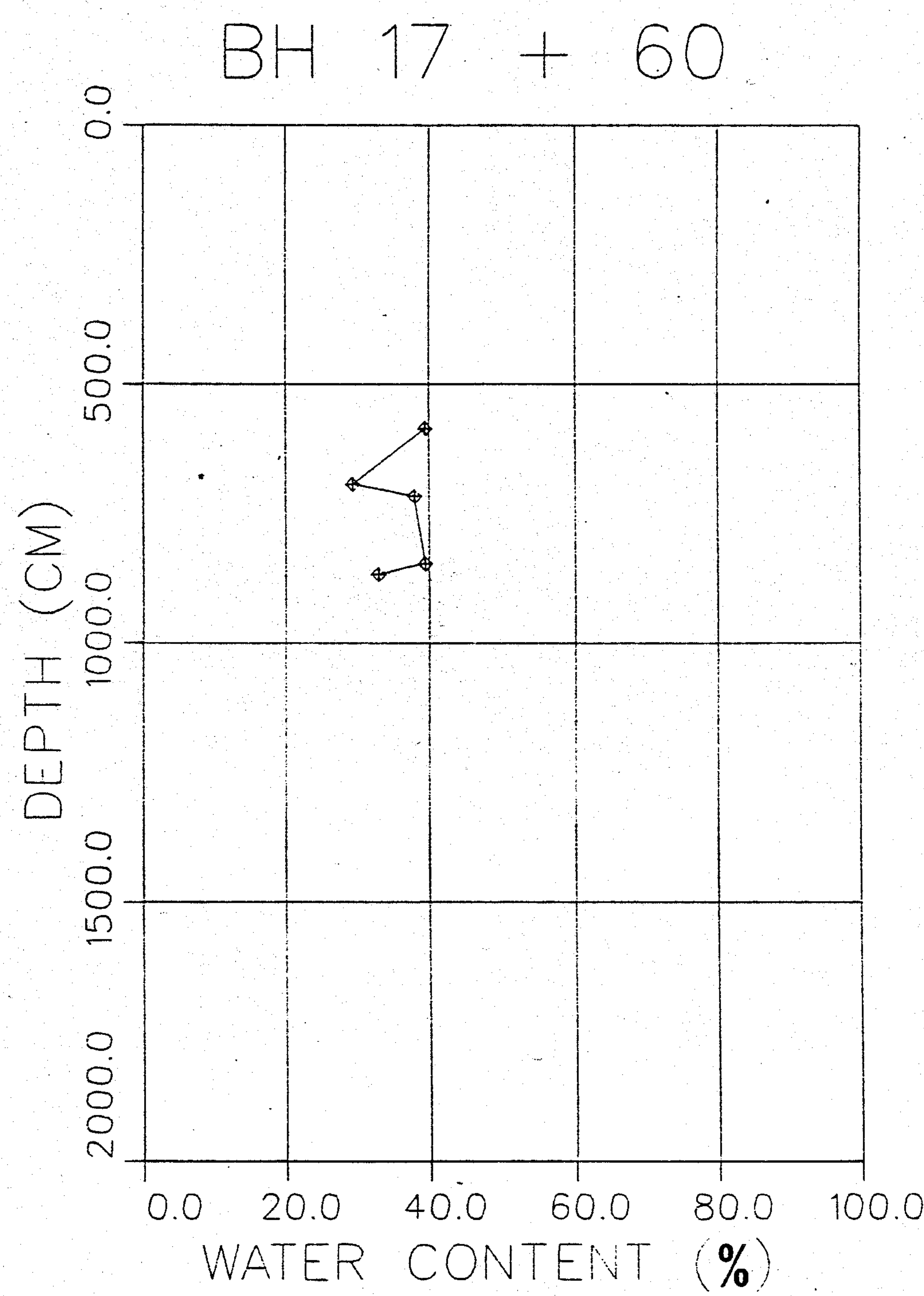


BH 10 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)

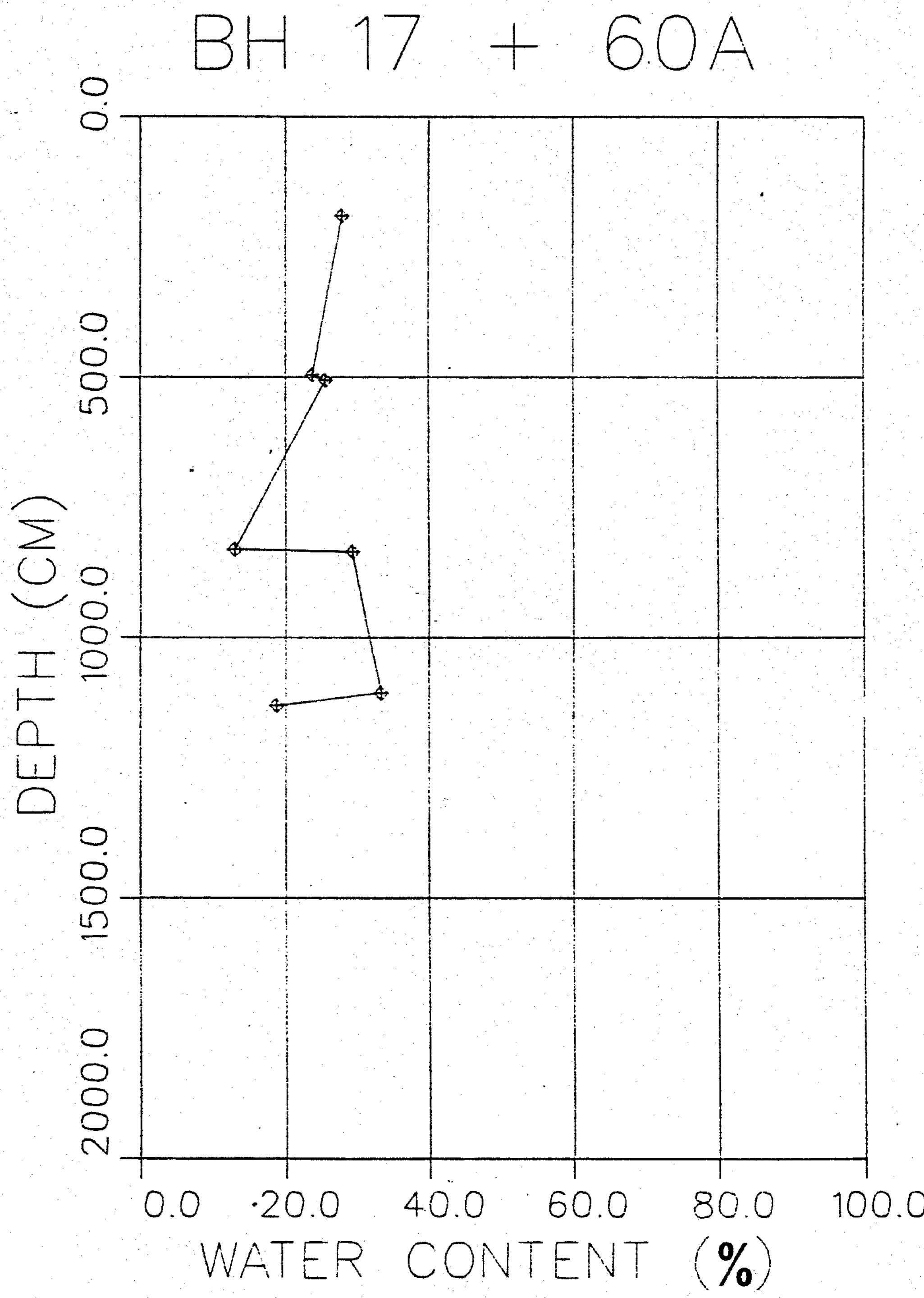
BH 12 + 20



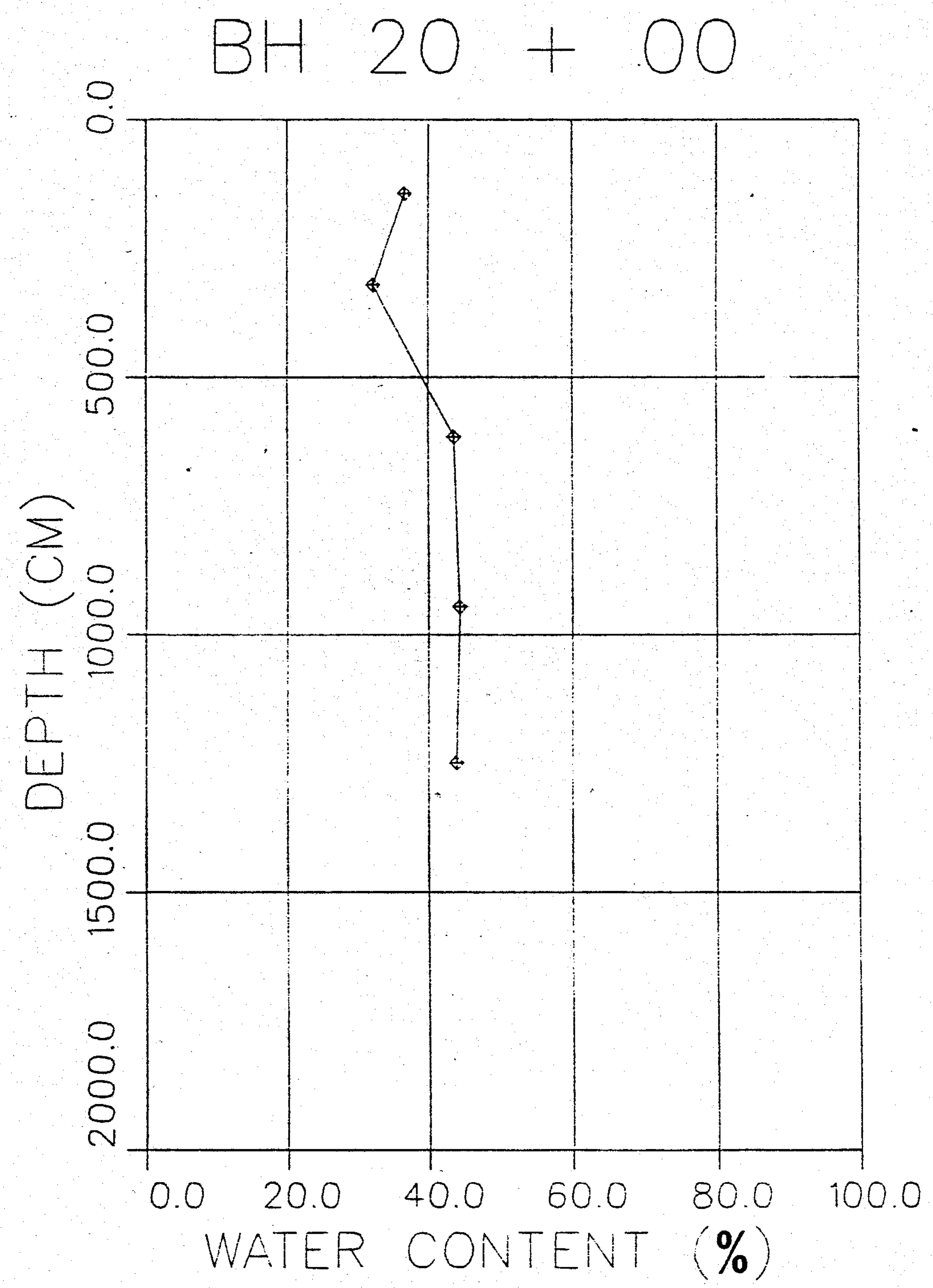
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)



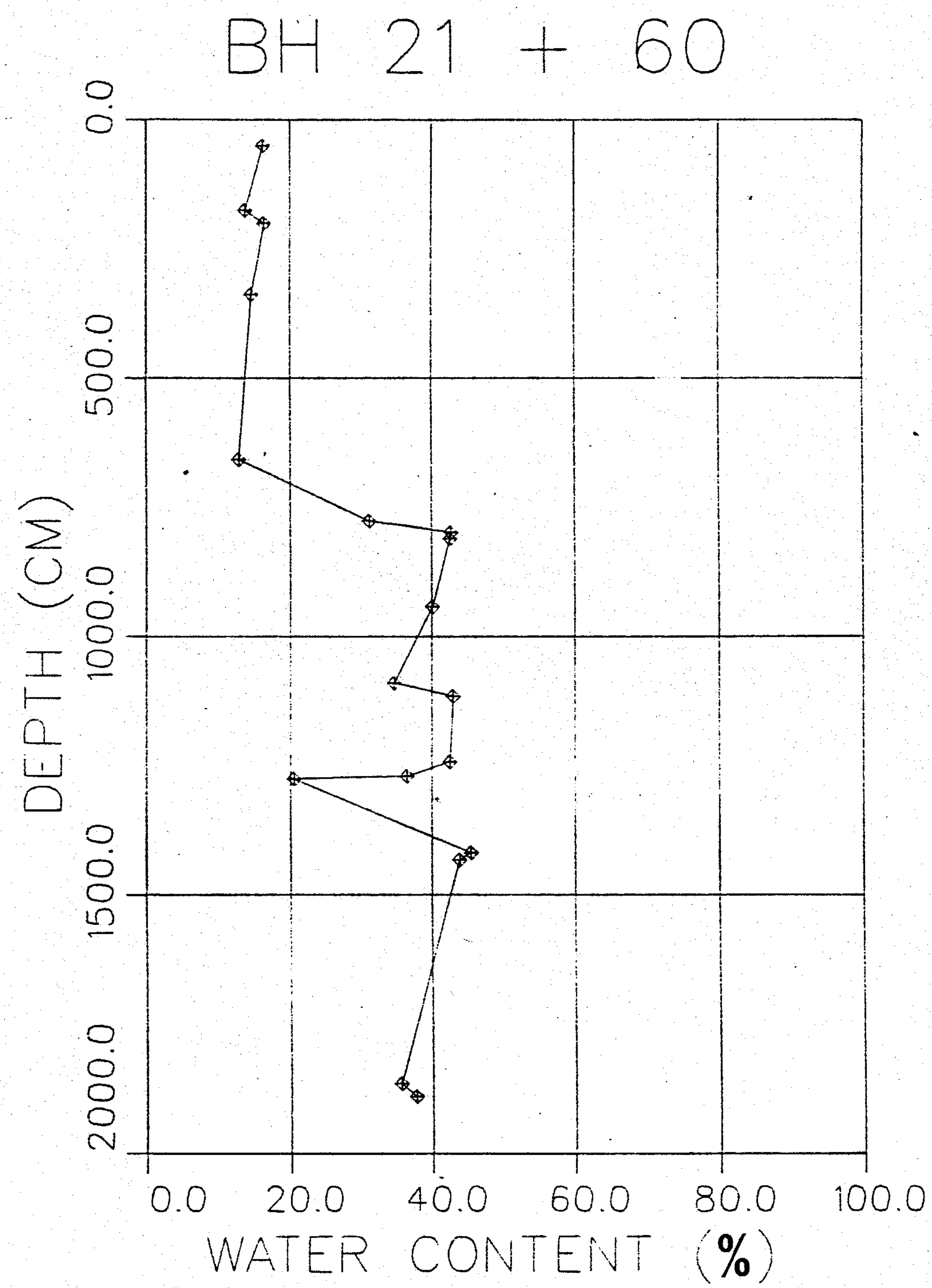
BH 17 + 60
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)



BH 17 + 60A
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)

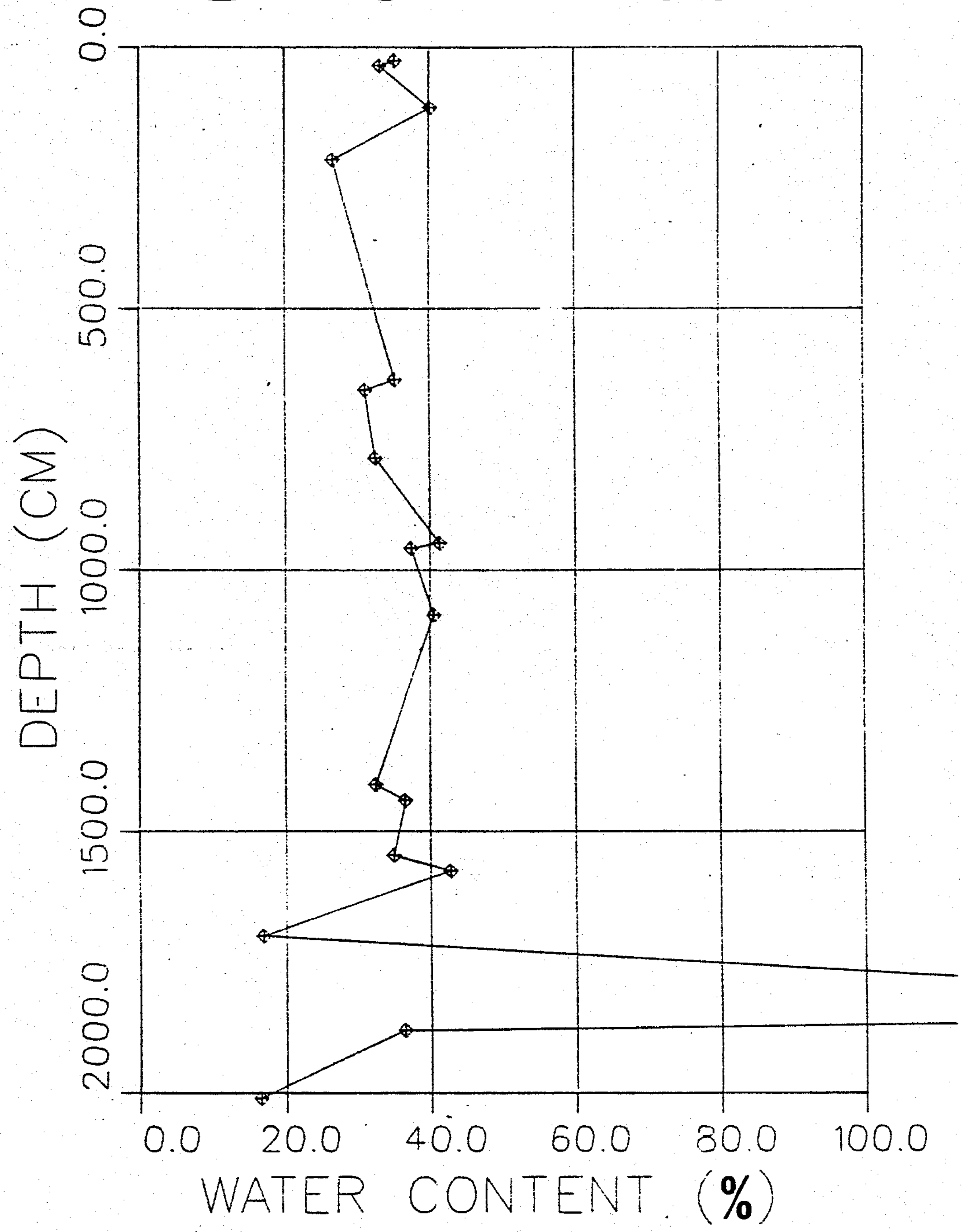


BH 20 + 00
0.0
500.0
1000.0
1500.0
2000.0
DEPTH (CM)
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)



BH 21 + 60
0.0
500.0
1000.0
1500.0
2000.0
DEPTH (CM)
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)

BH 34 + 00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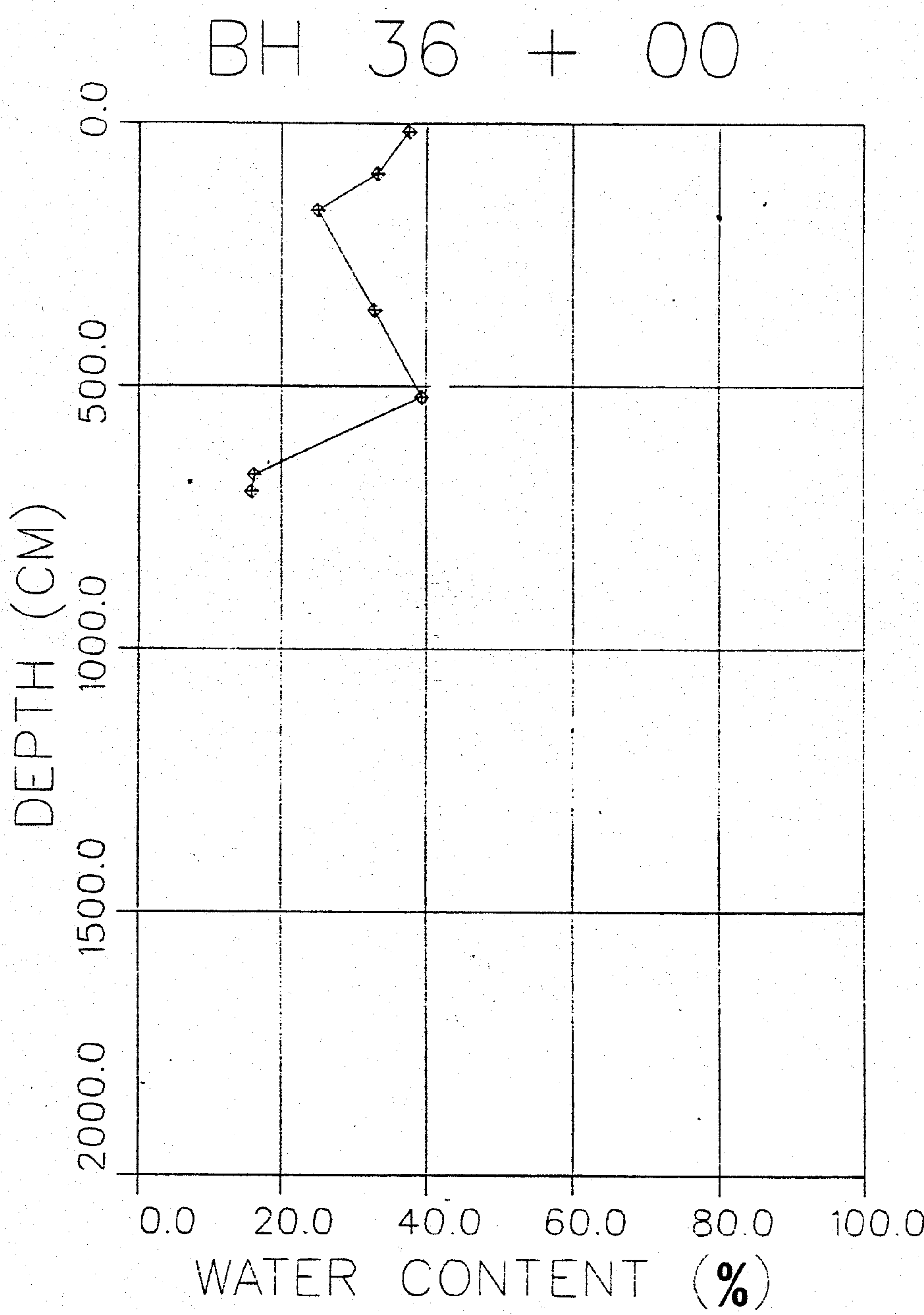
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)


BH 36 + 00
DEPTH (CM)
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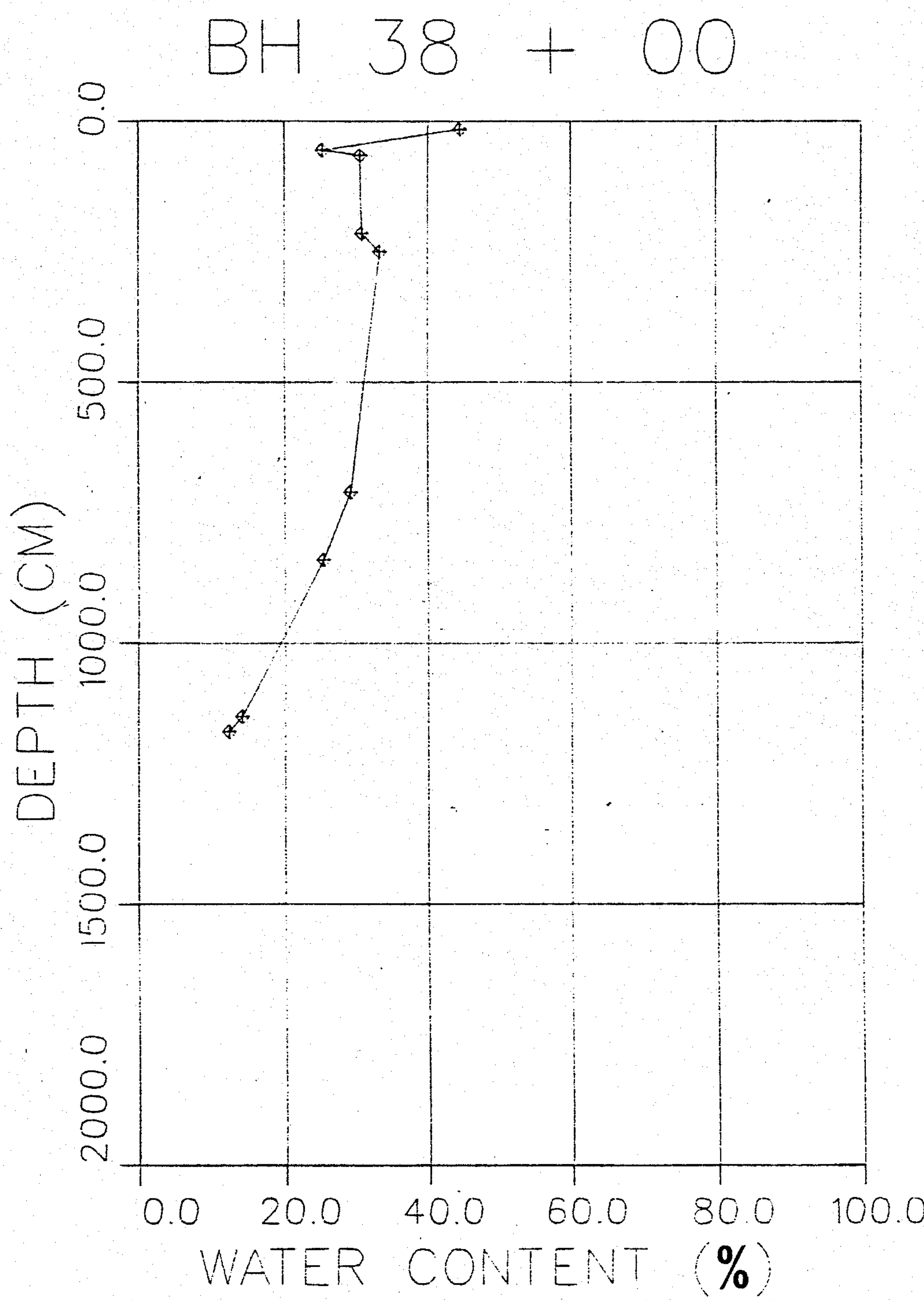
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)


BH 38 + 00
DEPTH (CM)
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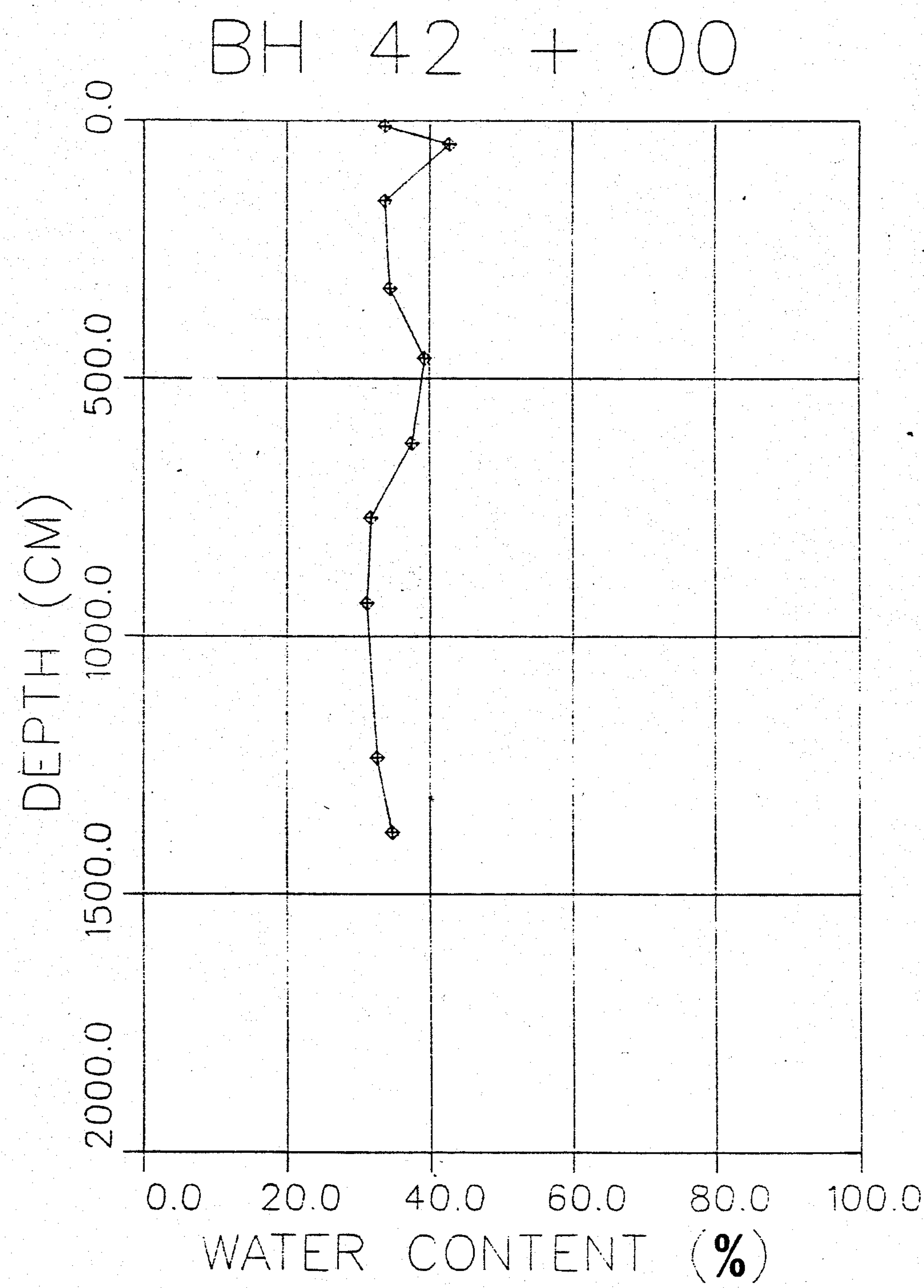
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)


BH 42 + 00
DEPTH (CM)
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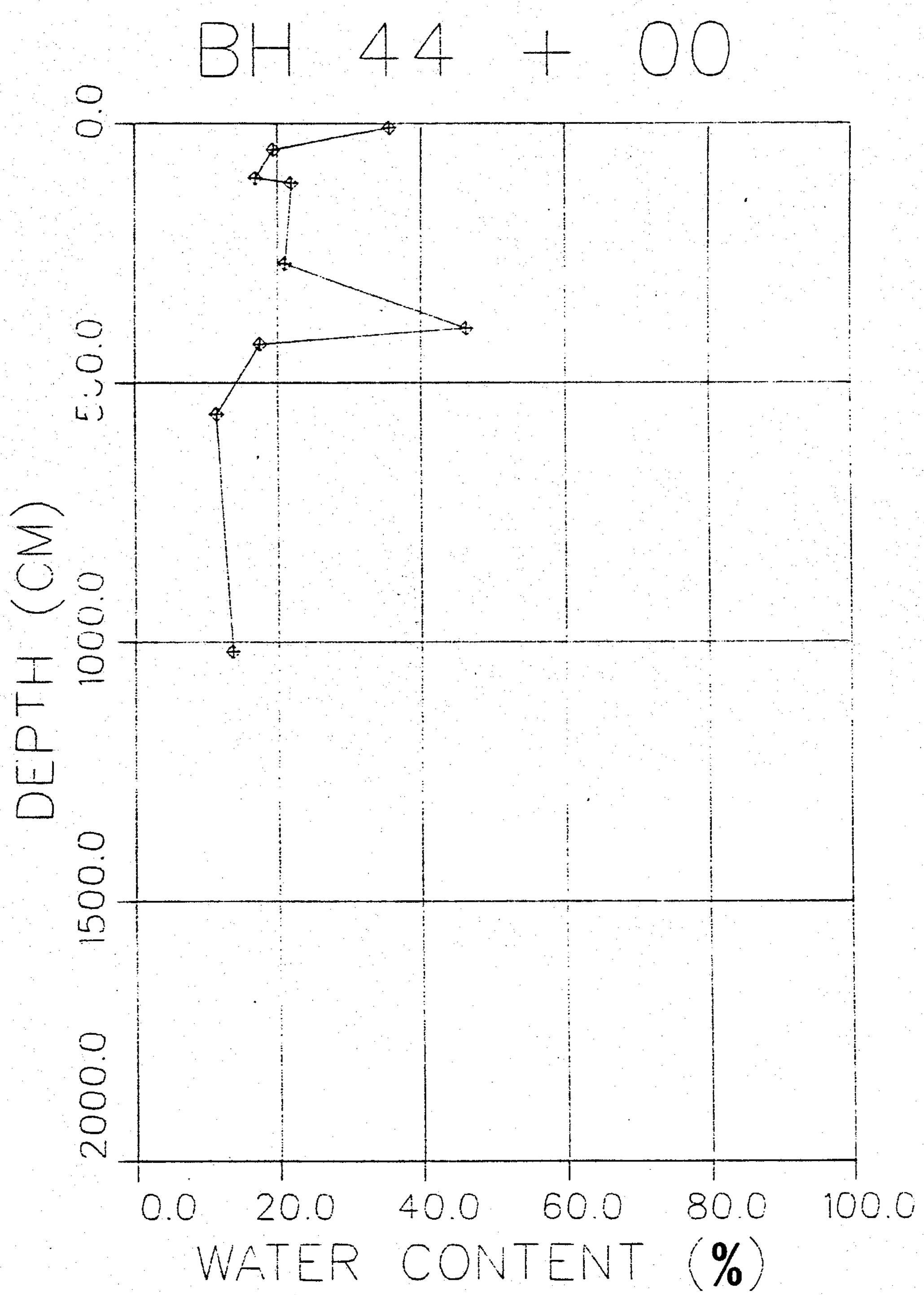
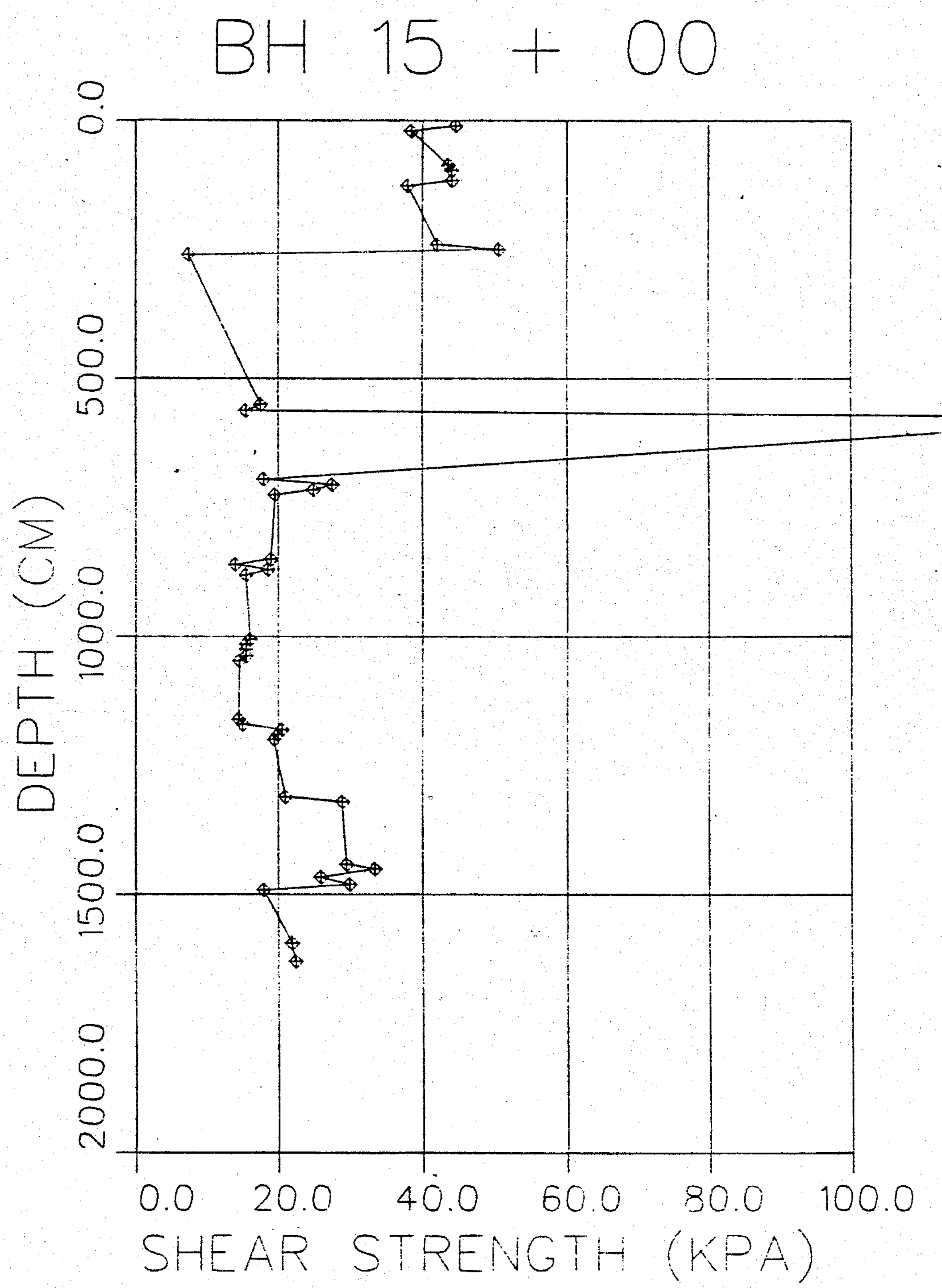
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)


BH 44 + 00
0.0
500.0
1000.0
1500.0
2000.0
DEPTH (CM)
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)



BH 15 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
SHEAR STRENGTH (KPA)
0.0
20.0
40.0
60.0
80.0
100.0

Fig. 10k

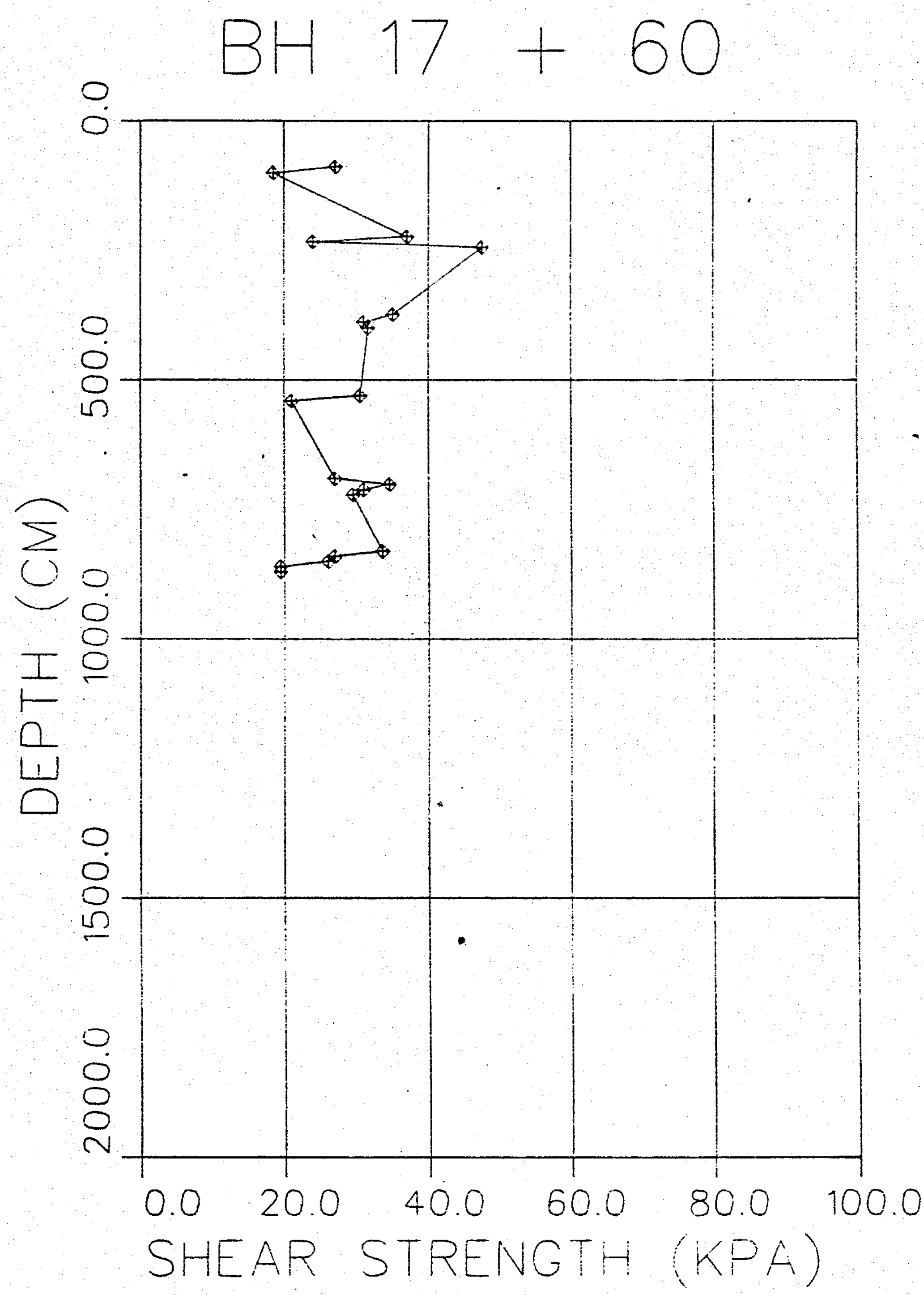

BH 17 + 60
0.0
500.0
1000.0
1500.0
2000.0
DEPTH (CM)
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 1

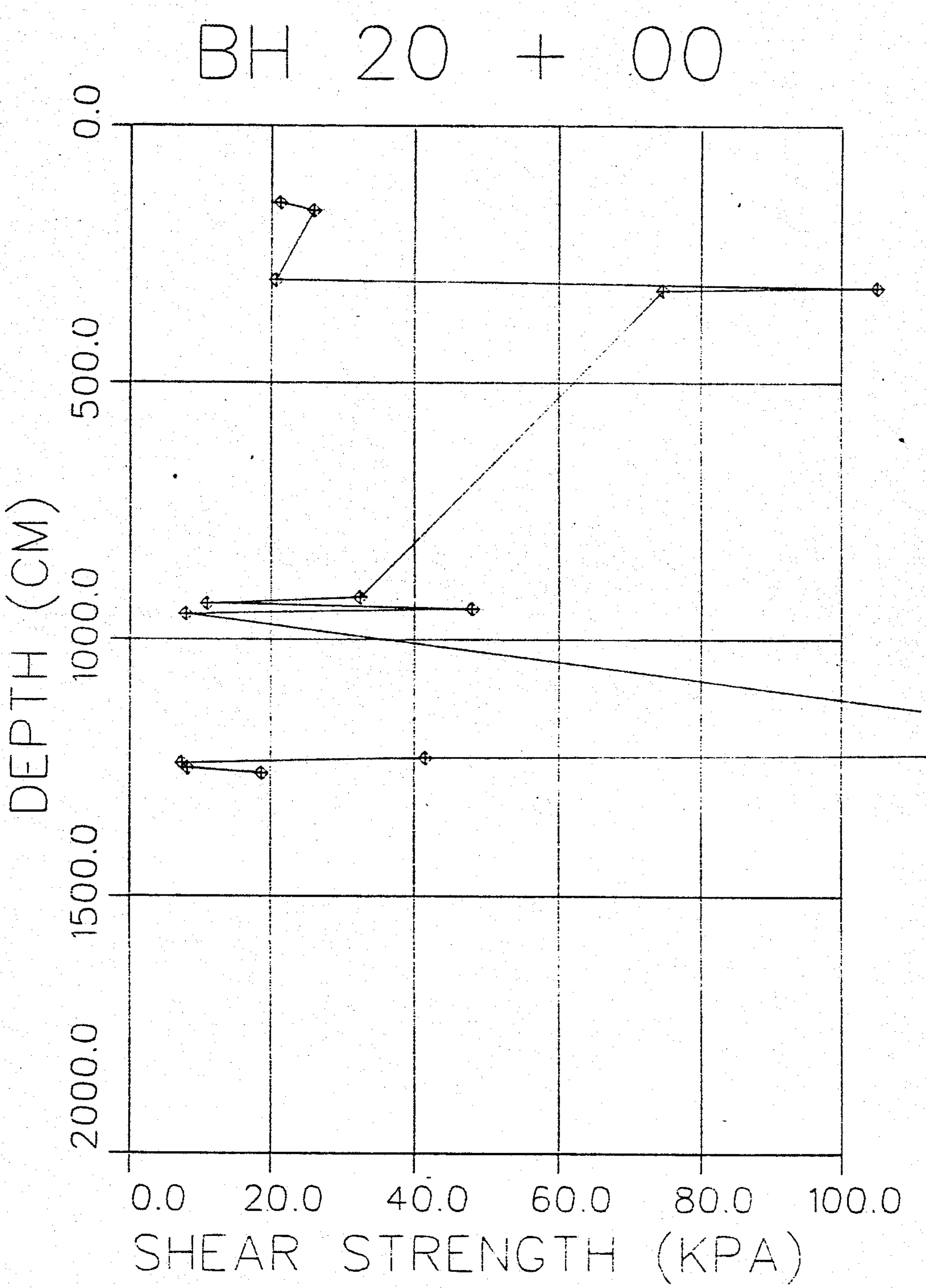

BH 20 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 m

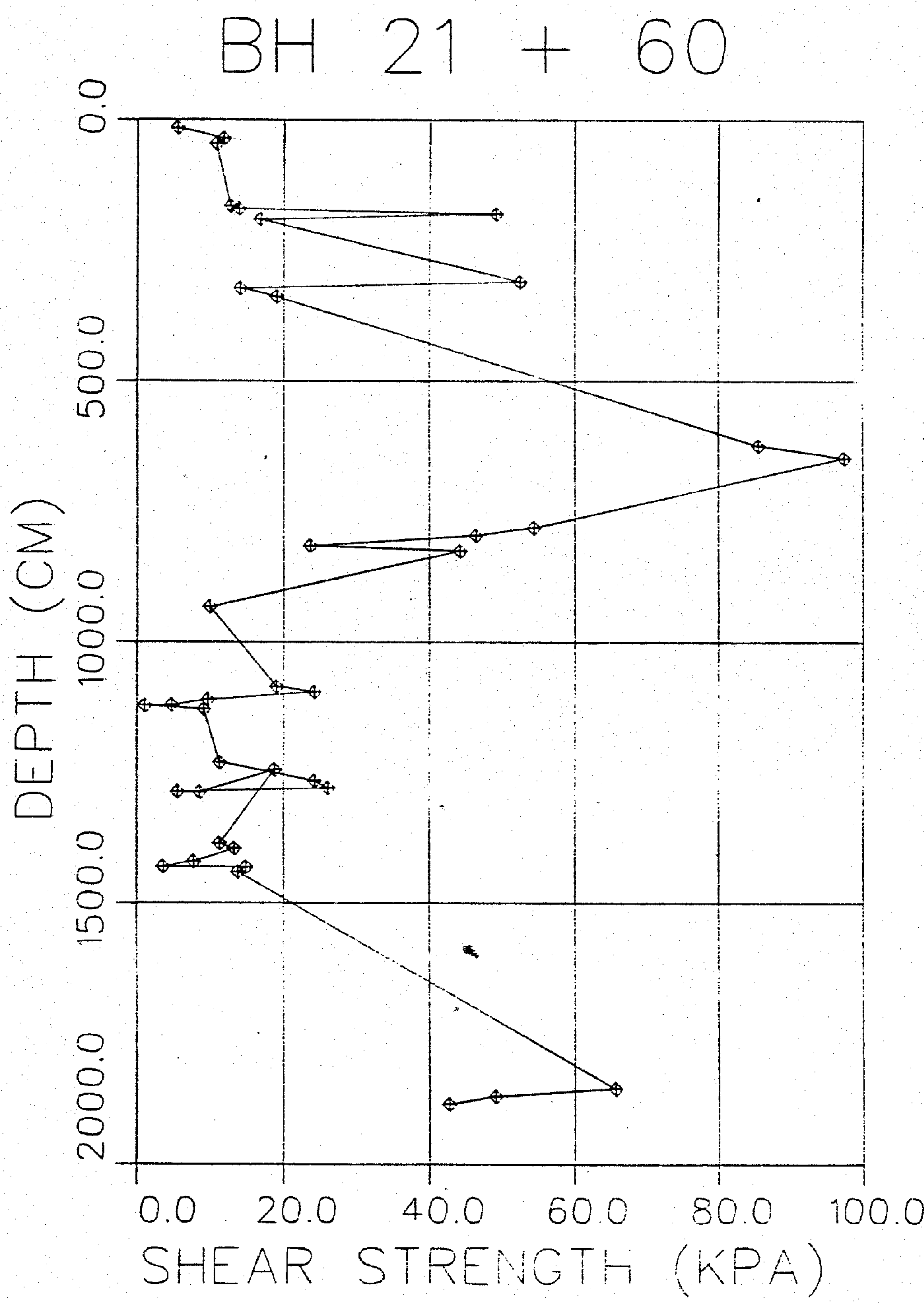

BH 21 + 60
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 n

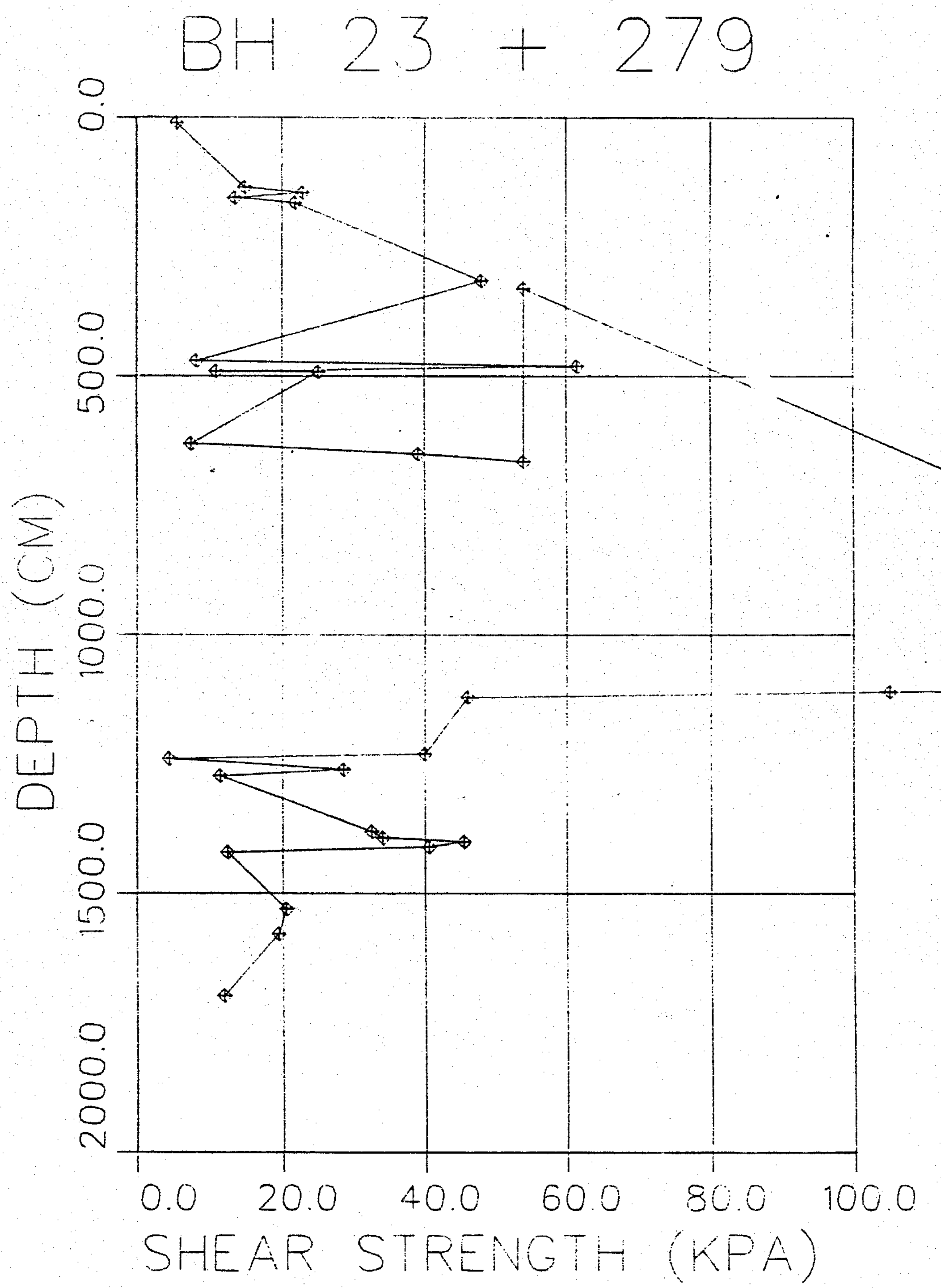

BH 23 + 279
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 o

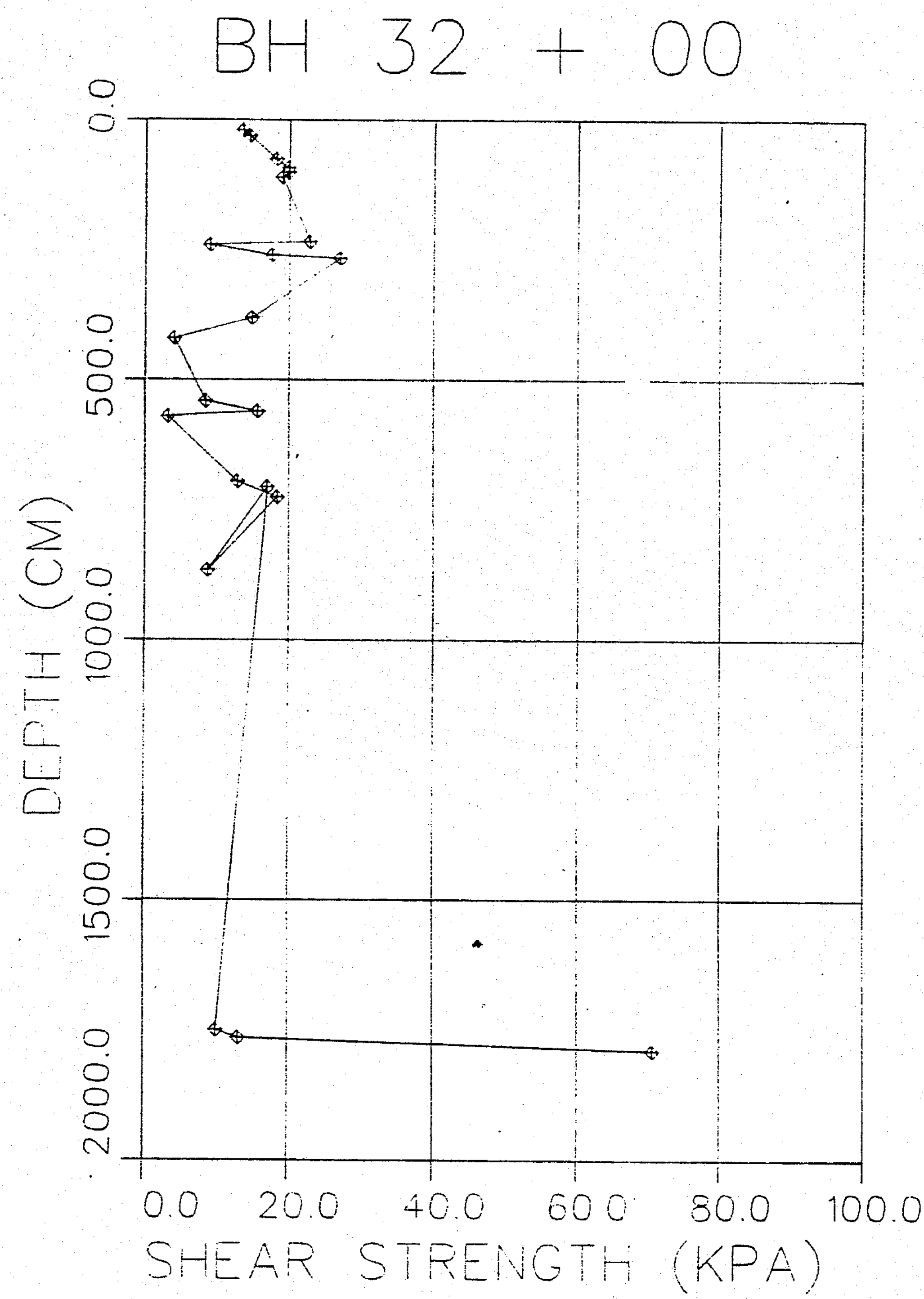

BH 32 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 p

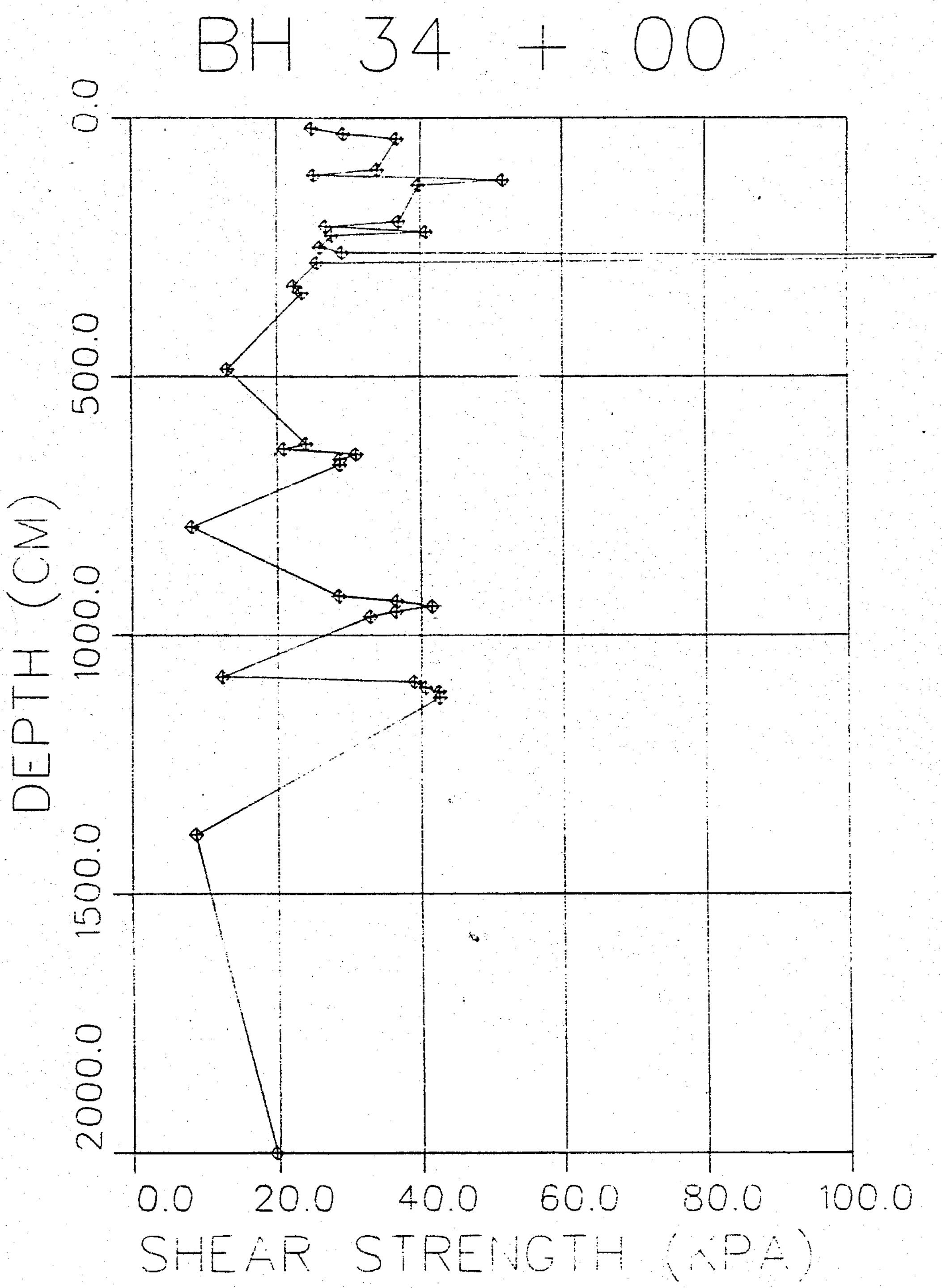

BH 34 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 q

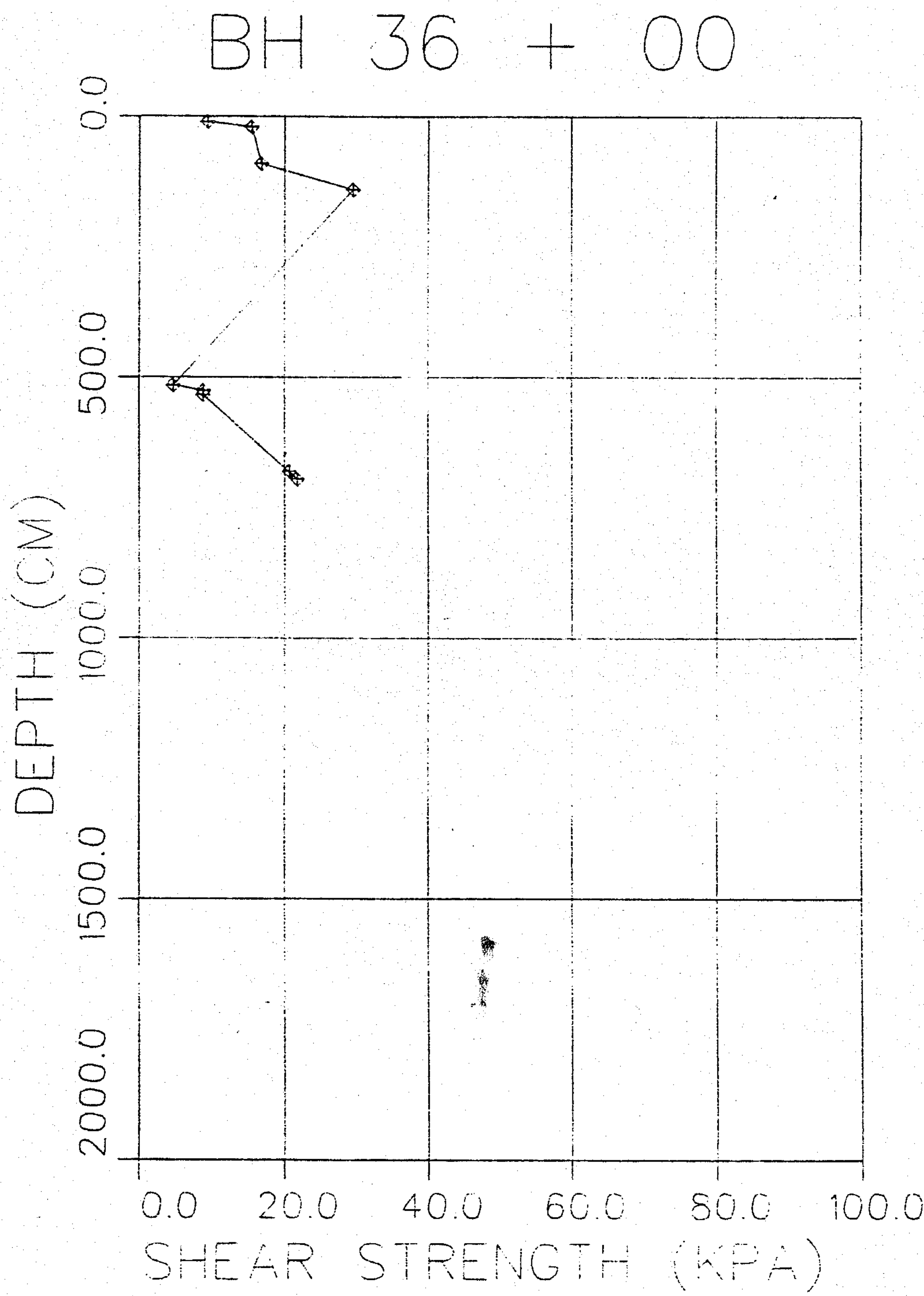

BH 36 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 r

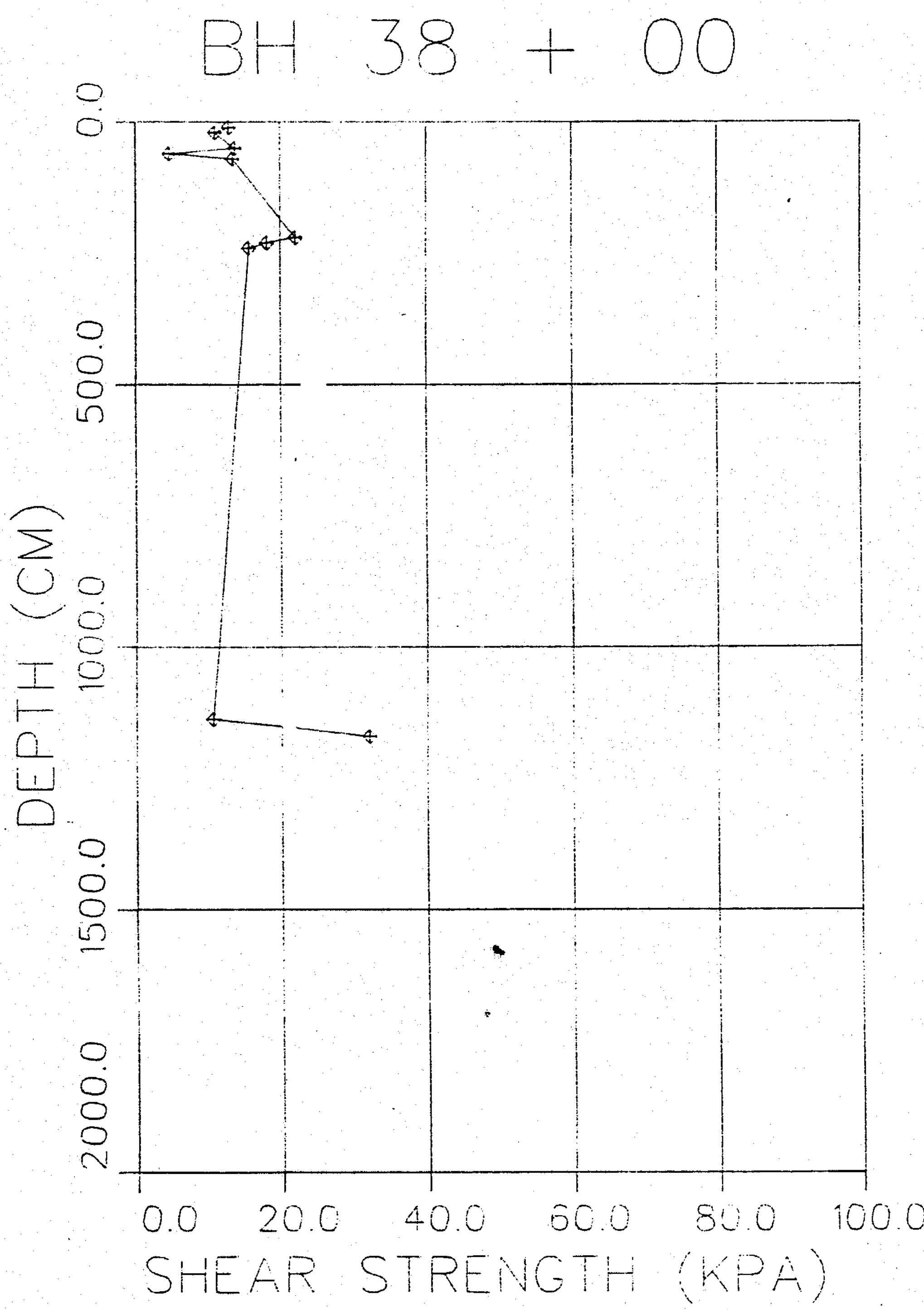

BH 38 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
SHEAR STRENGTH (KPA)

Fig. 10 s

The samples from drill line between boreholes 7+60 and 23+279 displays similar general trends in shear strength. Samples from all of these boreholes, have a zone of higher shear strength up to 70 kPa in the top 6 metres (Figs. 10h to 10o). Below this zone, the strength decreases to near 20 kPa however a few samples show again slight increase at depth.

Boreholes 32+00 and 38+00 are along the drill line near Pullen Island. Although the stratigraphy is much more distinctive in these boreholes, the shear strength does not indicate any trends. Figures 10p to 10s display the plots of the shear strength for these boreholes. Most of the shear strengths are near 20 kPa with the exception of borehole 34+00 (Fig. 10g), where the strengths vary between 20 and 40 kPa.

The future correlation of this data with the plasticity indices, the grain size, and the stratigraphy will greatly enhance the interpretation.

14. Water Content and Bulk Density Measurements (K. Moran)

Figures 11a to 11d are representative plots of water content vs depth below seabed. All show typical trends of decreasing water content with depth, although all water contents in general are very low (25-50%). The highest water content values are encountered furthest offshore (Fig. 11c) and the most uniform or typical decreases are nearshore (Figs. 11a and 11b). Closest to Pullen Island, the water contents do not decrease significantly with depth (Fig. 11d), which correlates well with the variations in shear strength with depth. Appendix B contains the remainder of the water content data, plotted against depth below seabed for each borehole. The bulk density of the sediment varies between 1.3 and 1.9 g/cm^3 with a mean of 1.77 g/cm^3. Future correlations with grain size and lithology is necessary in order to meaningfully interpret this data.

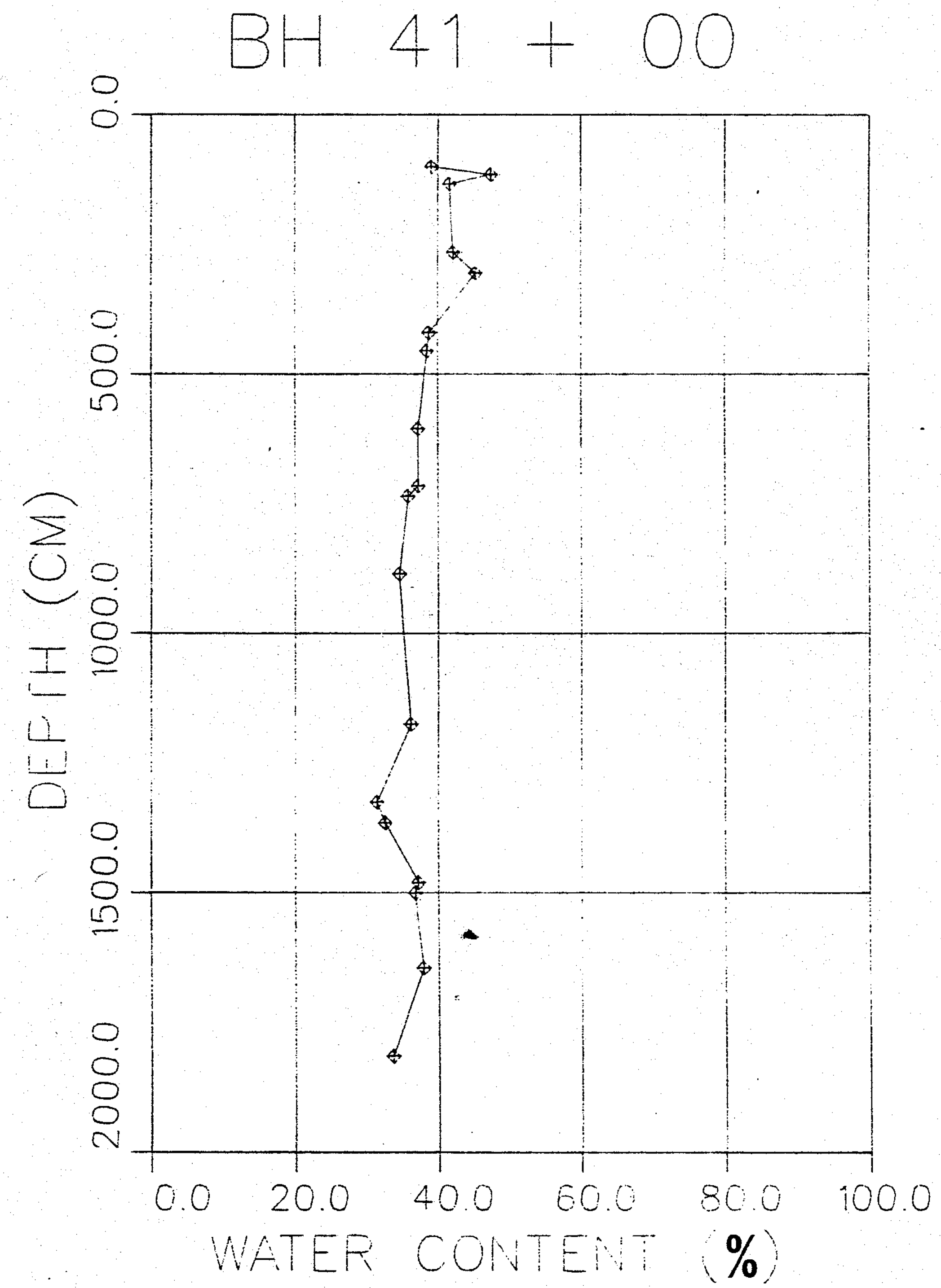

BH 41 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)

Fig. 11 a

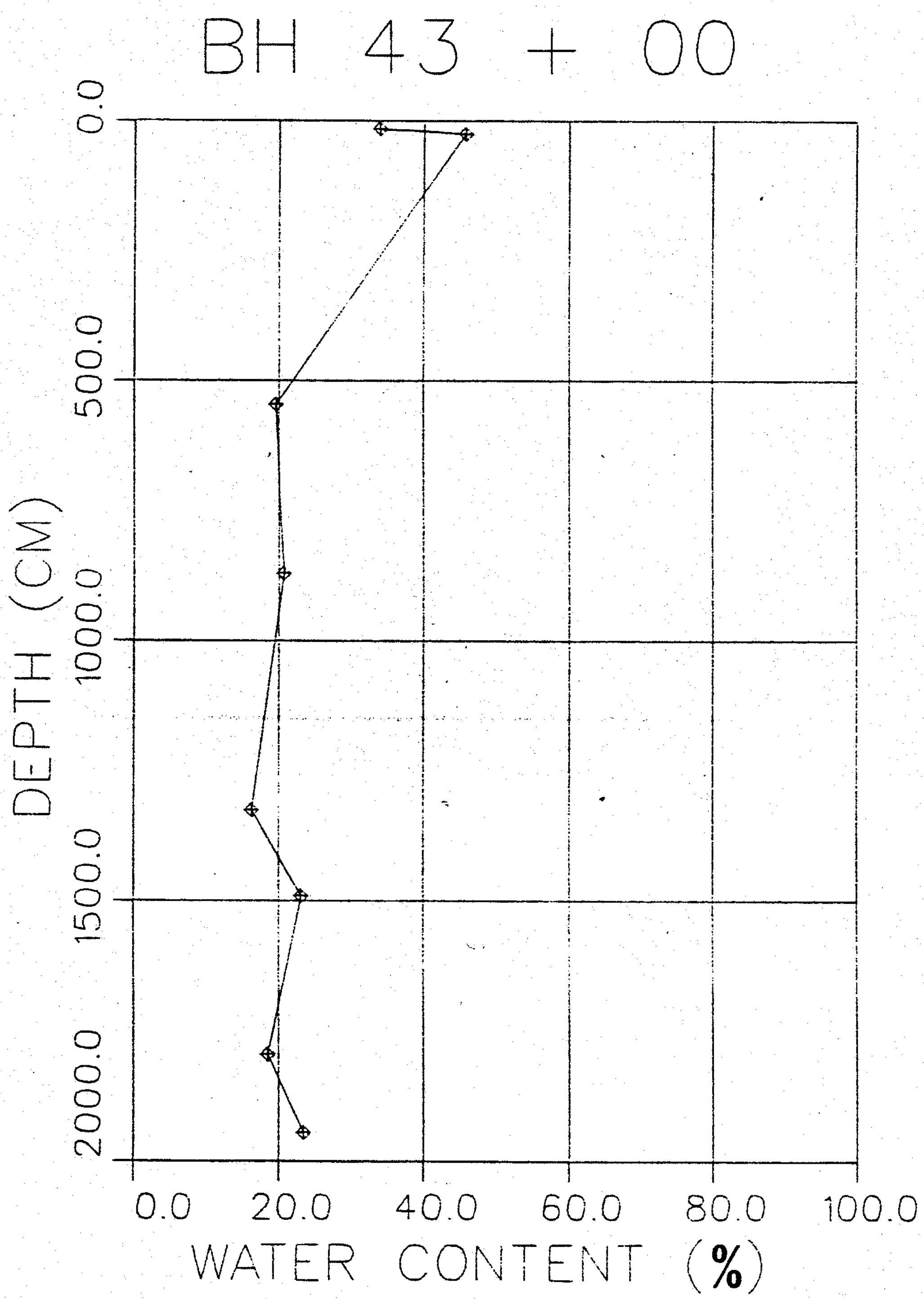

BH 43 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)

Fig. 11 b

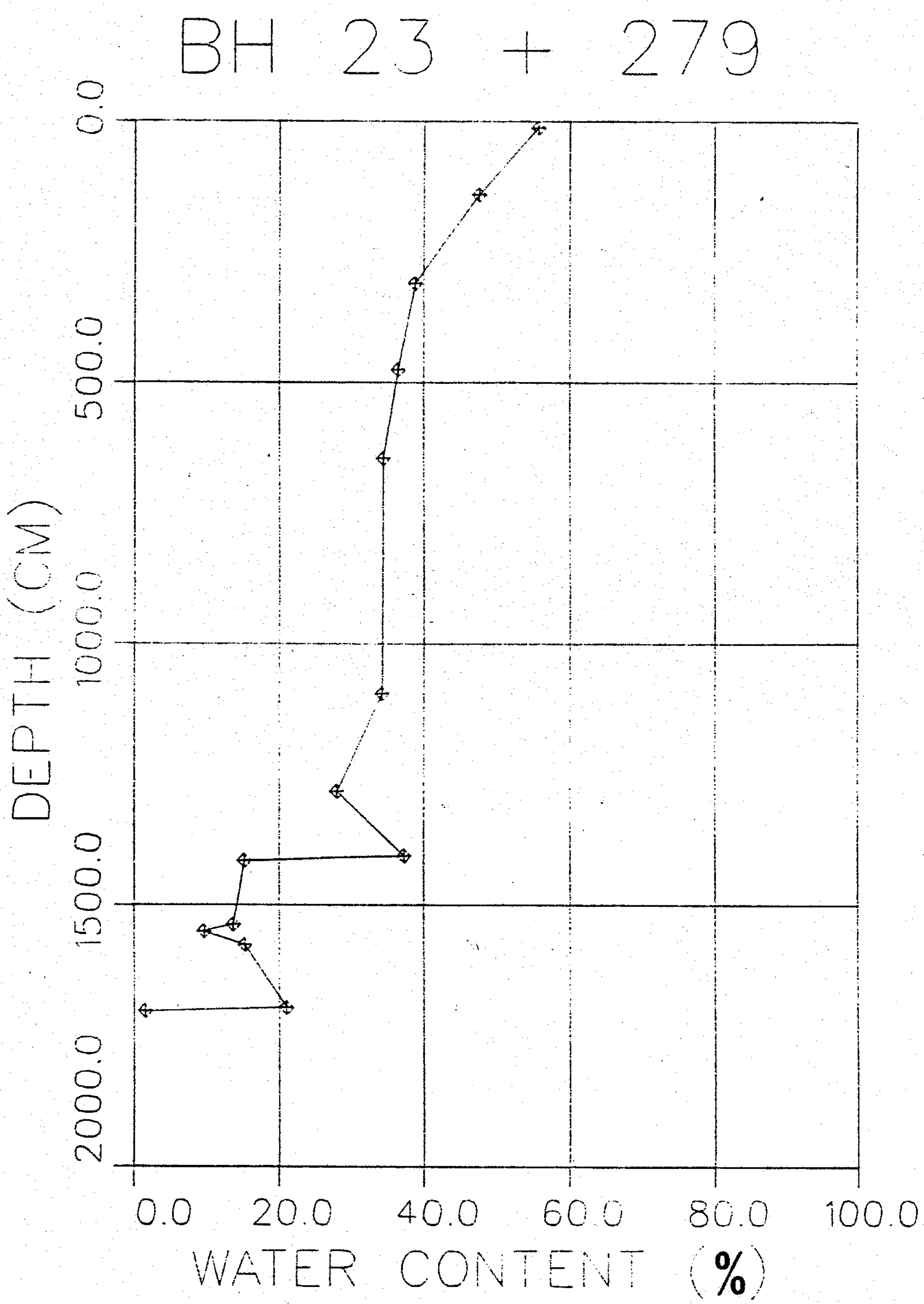
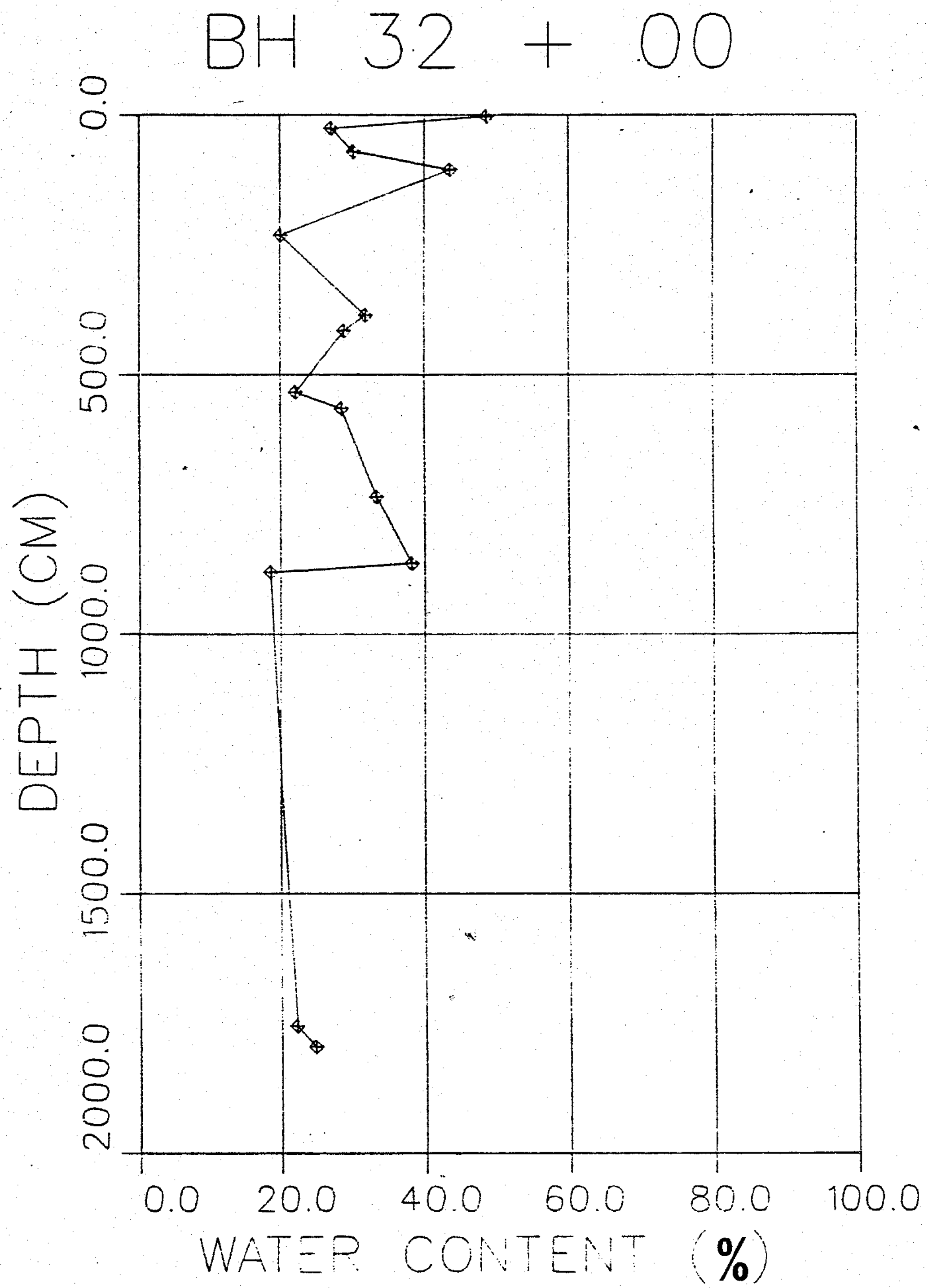

BH 23 + 279
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)

Fig. 11 c



BH 32 + 00
DEPTH (CM)
0.0
500.0
1000.0
1500.0
2000.0
0.0
20.0
40.0
60.0
80.0
100.0
WATER CONTENT (%)

Fig. 11.d

15. CTD (conductivity, temperature and depth) Survey (P. Hill)

Several CTD casts were made during the program. On 17 March, stations 12 00 and 11 60 were occupied and salinity measurements indicated presence of fresh water to a depth of approximately 4 metres; salinities below 4 metres increased to a maximum of 18.55 o/oo. Near bottom, temperatures reached lows of -0.23°C at site 11+60. On March 29, stations 32+00 to 38+00 were occupied and measurements showed a similar profile with a very strong halocline at depth between 5.0 and 5.5 metres. Near bottom temperatures were all above 0°C.

On April 1, site 36+00 was occupied for 12 hours to examine the variability over a tidal cycle. Using bottle casts and refractometer salinity measurements, data was collected almost continuously. At most depths, salinity remained at zero for the duration of the experiment. However, at the bottom (5 metre depth), measurable salinities from 4 to 13 o/oo were observed from 12.09 hr to 19.08 hr. This suggests that the marine water wedge fluctuates in position over a semi-diurnal tidal cycle. Confirmation of these results awaits laboratory analysis of salinity samples and calculation of temperatures from calibration charts.

16. Unconfined Compression Tests (T.H.W. Baker)

Unconfined compression tests were performed in the field laboratory on samples from varying depths from several boreholes. These tests can be used as a strength index and can be compared with the results of the miniature vane tests.

Samples tested in unconfined compression are required to be selfsupporting. For this reason specimens were not taken from Shelby tube samples that consisted of sandy or soft clayey soils. None of the samples tested contained ice. Specimens were typically 150 mm long and 72 mm in diameter. Samples from the following boreholes were tested: 1+50, 17+60A, 21+60, 23+279, 32+00, 41+00 and 44+00.

Tests were undertaken using a 50 kN triaxial load frame (ELE model EL25-284) and a displacement rate of 3 mm/min (2%/min). Tests results are presented in Table 6. The range of strength values varies from about 34 to 147 kPa. The high strengths may be indicative of overconsolidation. Stiff laminations of silt or sand seemed to be present in specimens exhibiting high strengths. A comparison with the stratigraphy and other physical properties (e.g., moisture content, grain size and salinity) will be necessary to more fully understand the significance of these strength index values. The shear strengths from the miniature vane tests will be correlated with this data.

17. Thermal Conductivity Test (T.H.W. Baker)

In support of the heater tests performed by W. Harrison and J. Morack in borehole 36+00, a sample was taken to Ottawa for thermal conductivity analysis.

A Shelby tube sample from borehole 36+00 was sub-sampled by pushing a 10 cm long steel cylinder, 3.5 cm diameter, into the end of the Shelby tube. The Shelby tube sample was partially extruded and the small steel cylinder was cut out. The depth of the sub-sample was from 1.5 to 1.6 m. Plastic caps and wax were used to seal the ends to prevent moisture loss

TABLE 6

Unconfined Compression Tests

Borehole Number	Sample Depth (m)	Shear Strength (kPa)	Failure Strain (%)
1+50	7.69- 7.86	48.1	6.6
	9.90-10.04	89.2	8.1
	11.37-11.55	83.3	7.6
	12.78-12.97	74.5	4.5
	17.42-17.60	85.3	4.1
17+60A	2.03- 2.21	72.6	14.5
	5.17- 5.38	68.6	4.8
	8.05- 8.22	80.4	7.8
	11.10-11.25	89.2	3.8
21+60	3.14- 3.32	147.1	11.0
	7.91- 8.09	78.5	6.0
	11.22-11.37	49.0	9.7
	13.90-14.07	49.0	8.0
23+279	3.26- 3.41	117.7	17.0
	12.33-12.52	107.9	15.0
32+00	0.79- 0.97	44.1	6.5
	2.47- 2.62	61.8	8.4
	5.36- 5.54	34.3	9.2
	7.01- 7.19	43.1	13.8
	17.61-17.79	54.9	4.1
36+00	1.31- 1.49	77.4	5.8
	6.72- 6.90	43.1	34.3
41+00	1.21- 1.36	58.8	5.3
	1.36- 1.52	39.2	4.5
	4.44- 4.61	19.6	8.9
	5.76- 5.93	49.0	13.0
	9.08- 9.25	49.0	9.4
	11.99-12.20	39.2	7.6
	15.06-15.25	58.8	9.1
44+00	3.91- 4.09	39.2	8.0

and the sample was hand-carried on the plane to Ottawa. Laboratory tests classified the sample as a clayey silt with a water content of 30% by dry weight and a pore water salinity of 11 ppt.

The tests were performed at the Earth Physics Branch of EMR under the supervision of A. Taylor. A 6 cm Fenwal needle probe was inserted into the 10 cm specimen retained at room temperature (22°C) for a period of about 18 hours. A current of 99.8 mA was supplied to the probe heater with a power output of 0.52 W. Temperature measurements were taken during the heating phase of 350 sec and during the cooling phase from 350 to 700 sec. Data used to compute the thermal conductivity was taken from the heating phase during the period from 20 to 140 sec. Although the computer program used to analyze the heating phase data was not set up to compute the thermal conductivity using the cooling phase data, the data is available for future analyses of the cooling phase. The average thermal conductivity measured was 1.79 WmC. Figures 12a and 12b show the plots of test runs number 3 and number 5.

18. Future Tests (P.J. Kurfurst)

A series of long-term, specialized or time-consuming tests is being planned in the next few months. Sub-samples from every Shelby tube have been retained for standard tests (moisture content, density, Atterberg limits, sand-silt-clay ratio) to be carried out by GSC independently in the laboratories in Ottawa and Halifax. Seventeen Shelby tube samples were not extruded in the field. After the tubes were sealed, they were shipped to other laboratories for specialized tests. Three Shelby tubes will be tested at the NRCC laboratories under dynamic

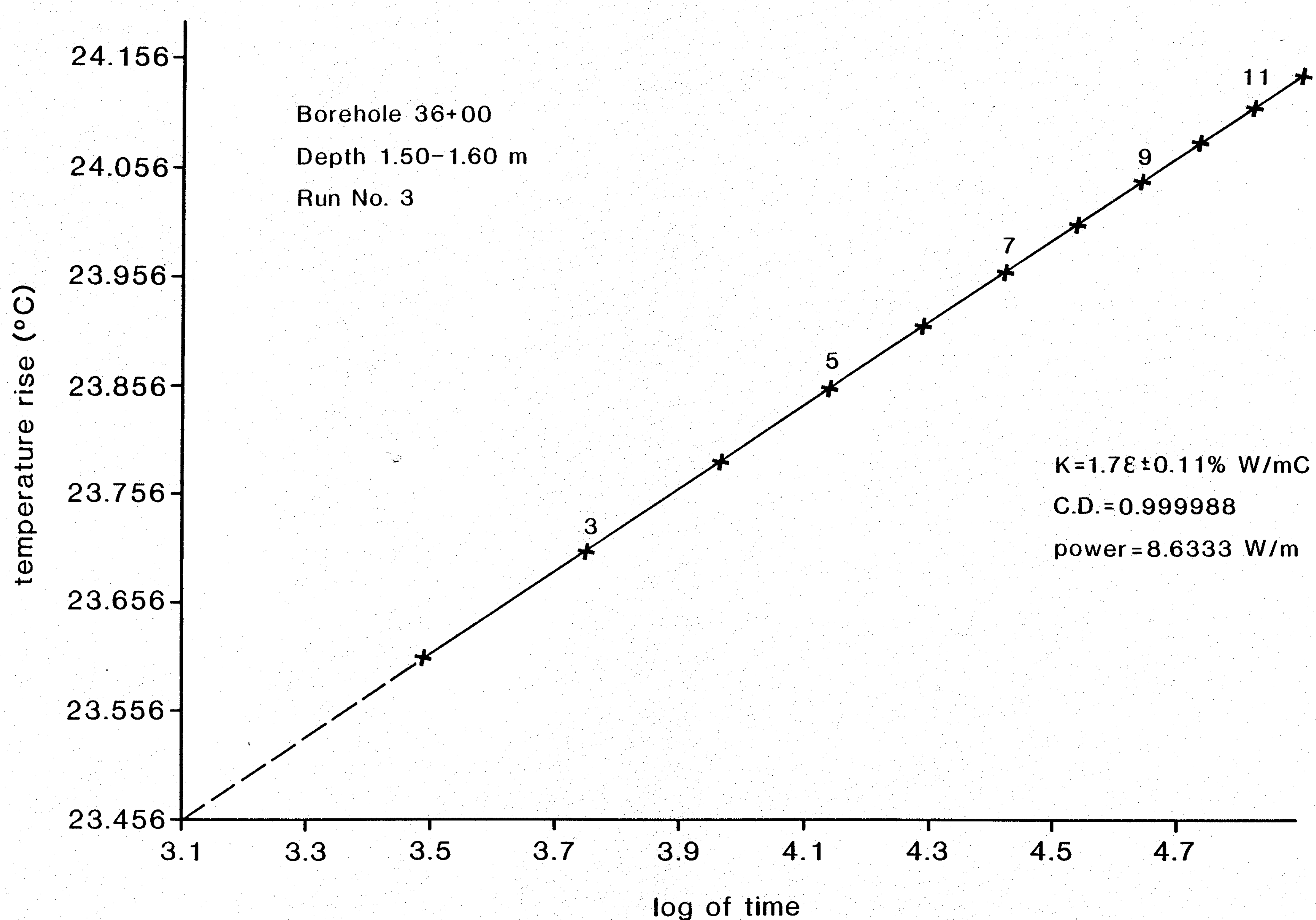
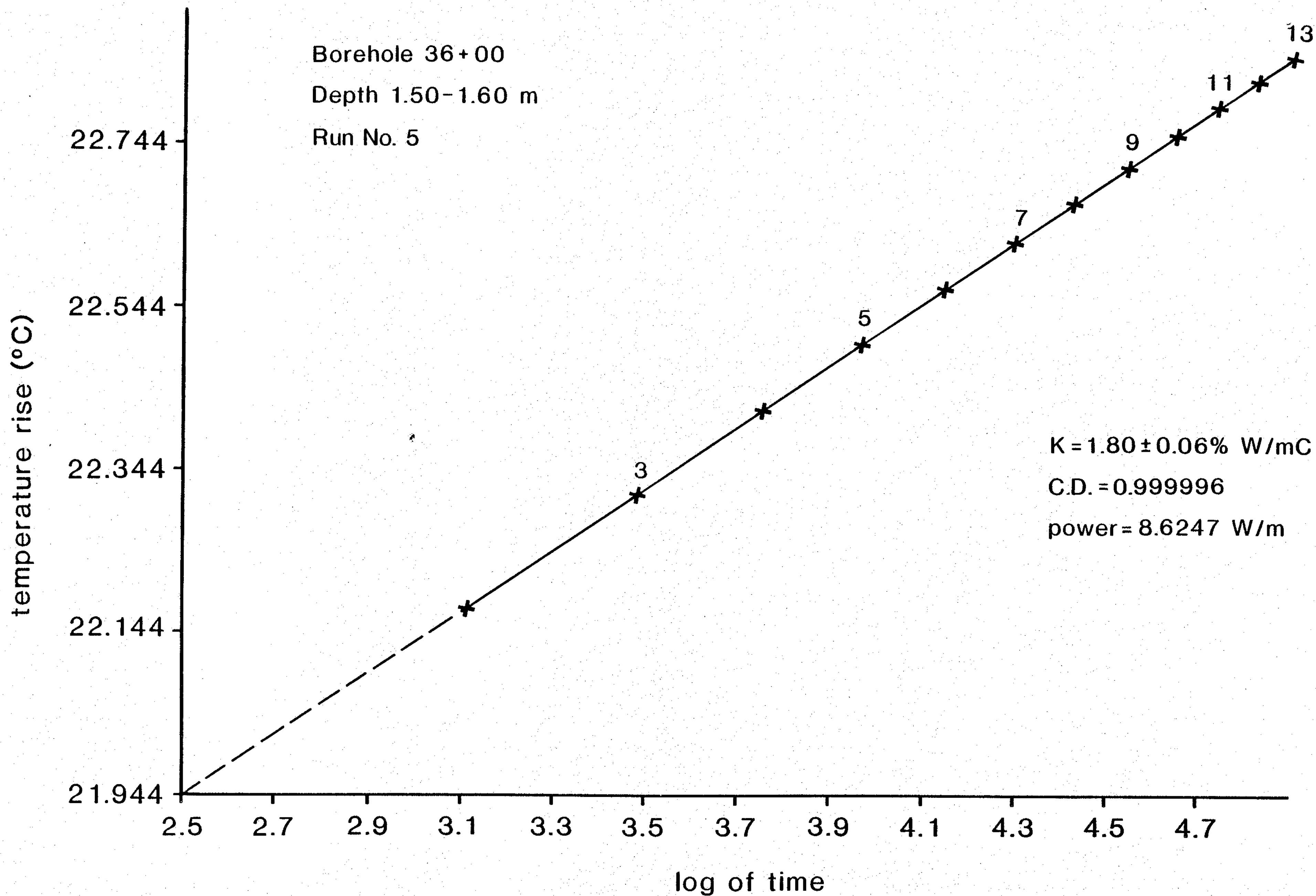


Figure 12 a - b: Thermal conductivity plots

Figure 12 a



Borehole 36+00
Depth 1.50-1.60 m
Run No. 5
K = 1.80 ± 0.06% W/mC
C.D. = 0.999996
power = 8.6247 W/m
temperature rise (°C)
22.744
22.544
22.344
22.144
21.944
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
4.7
log of time
3
5
7
9
11
13

Figure 12 b

triaxial conditions to determine their potential for liquefaction and consolidation tests will be carried out to measure the overconsolidation ratios. Grain size analysis, moisture content and salinity tests will be also performed on these specimens. The remaining fourteen Shelby tube samples will be tested under triaxial conditions to determine their undrained shear strength. After completion of the triaxial tests, grain size analysis, moisture content and salinity tests will be also carried out.

Acoustic velocity measurements (compressional and shear waves) on frozen and unfrozen samples will be carried out at the GSC cold room facilities in Ottawa under conditions approximating the in-situ conditions. The results will be used to determine the dynamic and static moduli, to compare them with the results from the feild seismic surveys, and to evaluate changes and disturbance that the samples undergo during transportation.

Acknowledgments

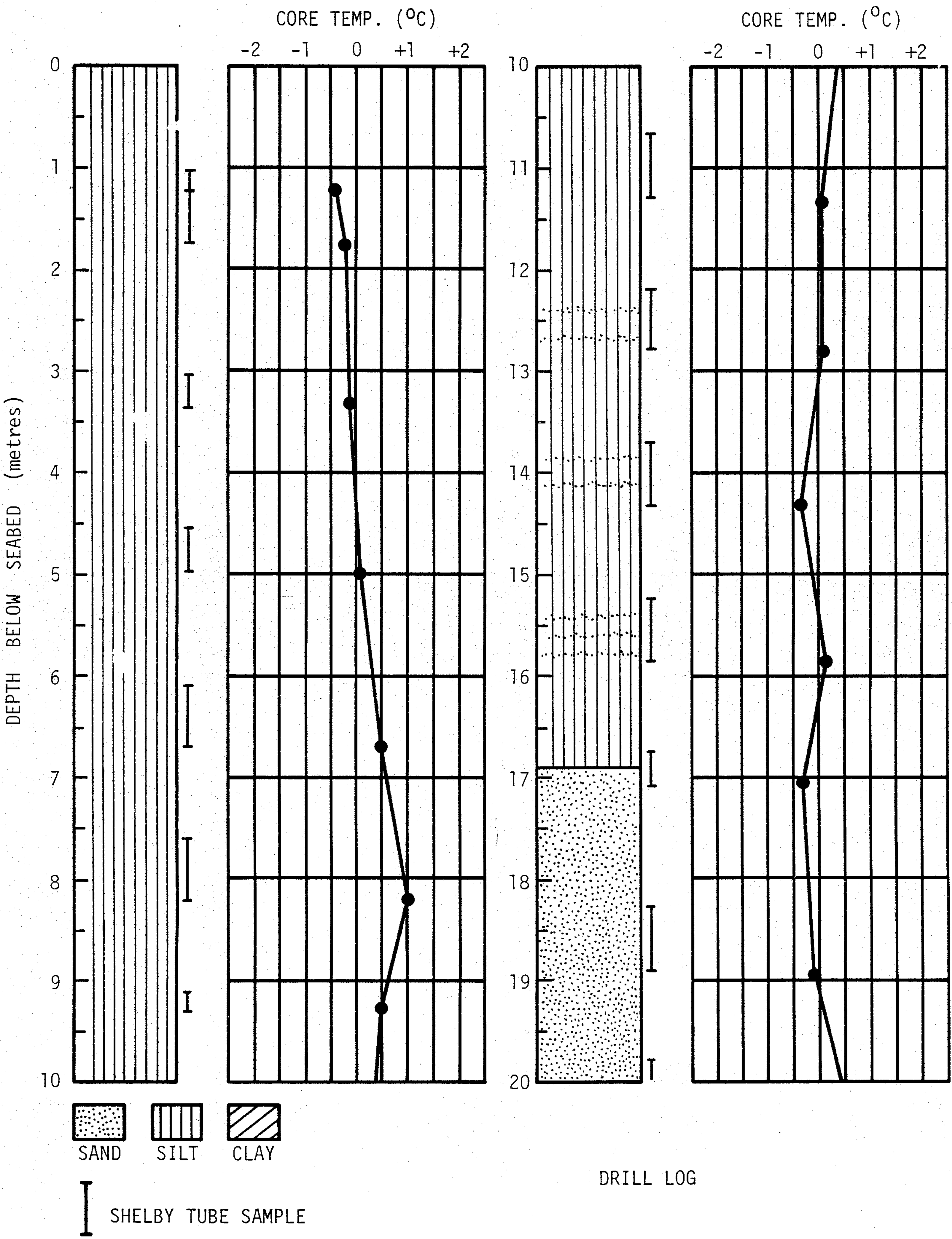
The authors wish to express their sincere appreciation to S. Pullan, M. Nixon, R. Good, R. Burns, and F. Jodrey for their excellent work in the field and for their help in preparation of this Open File. Thanks are also extended to K. Gillespie, Klohn Leonoff Ltd., for his capable handling and supervision of the drilling contract.

APPENDIX A

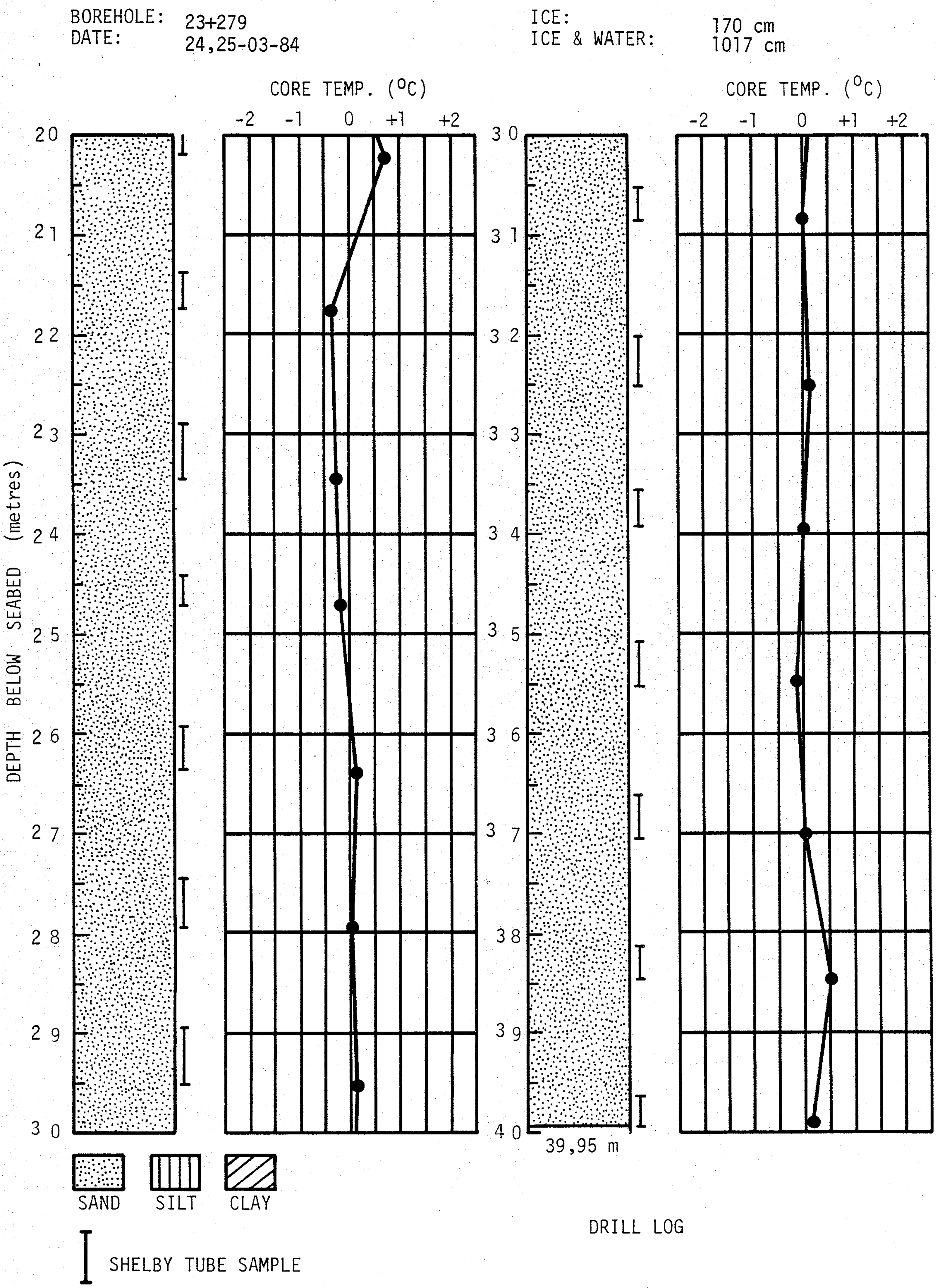
D R I L L   L O G S

BOREHOLE: 23+279
DATE: 24,25-03-04

ICE: 170 cm
ICE & WATER: 1017 cm

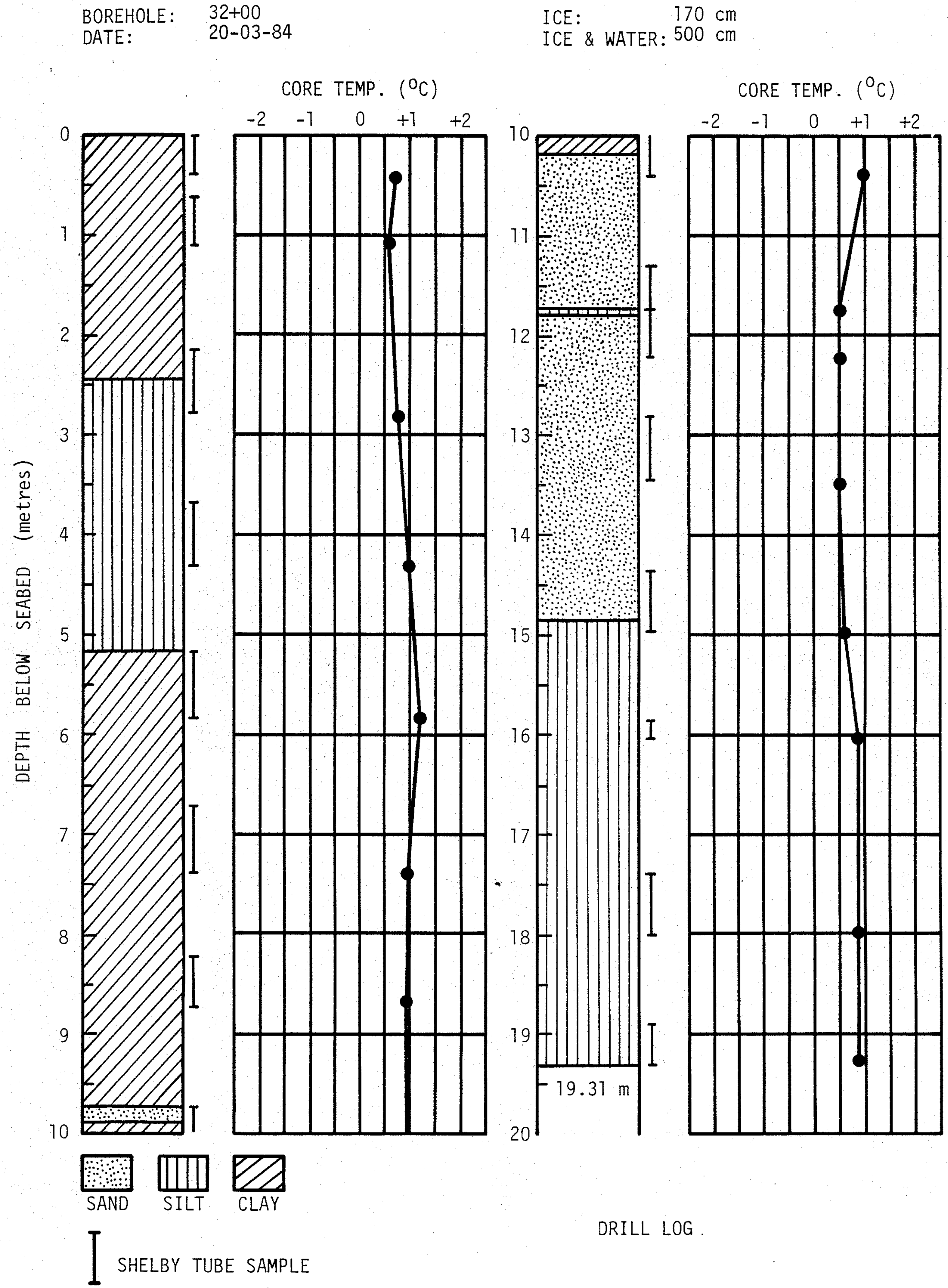


DRILL LOG



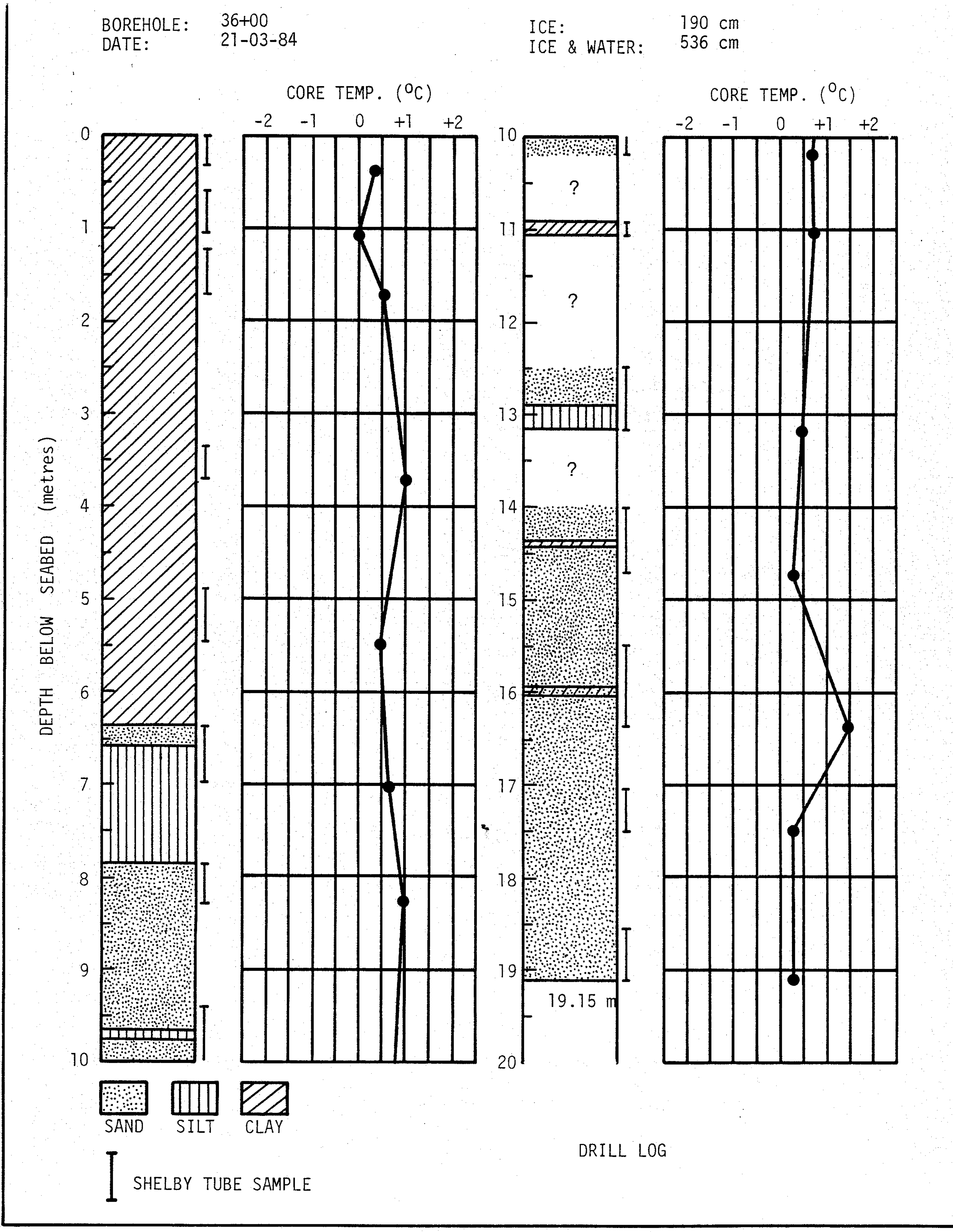
BOREHOLE: 23+279
DATE: 24,25-03-84
ICE: 170 cm
ICE & WATER: 1017 cm
CORE TEMP. (°C)
-2 -1 0 +1 +2
CORE TEMP. (°C)
-2 -1 0 +1 +2
DEPTH BELOW SEABED (metres)
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
39,95 m
SAND
SILT
CLAY
SHELBY TUBE SAMPLE

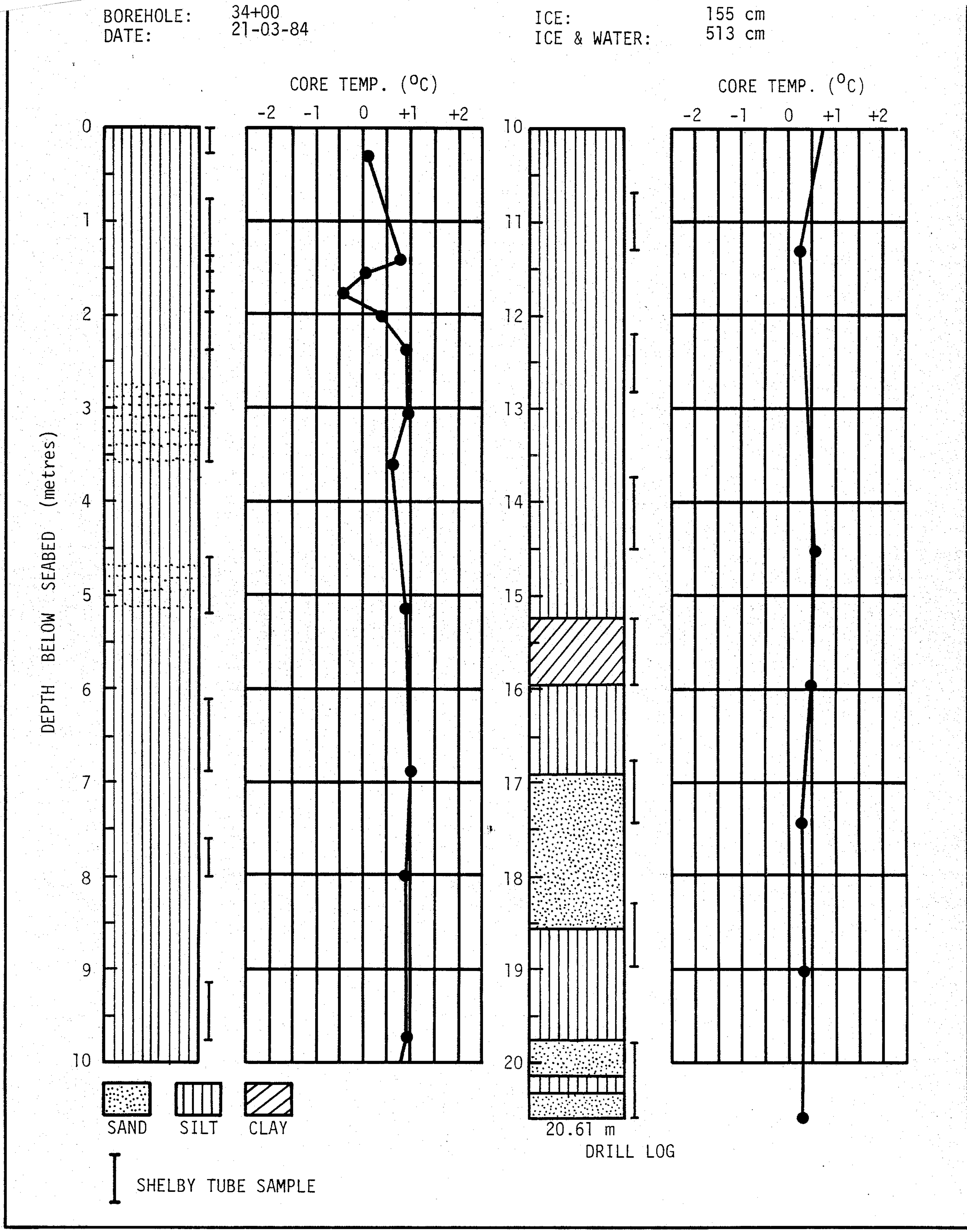
DRILL LOG



BOREHOLE: 32+00
DATE: 20-03-84
ICE: 170 cm
ICE & WATER: 500 cm
CORE TEMP. (°C)
-2 -1 0 +1 +2
DEPTH BELOW SEABED (metres)
0 1 2 3 4 5 6 7 8 9 10
10 11 12 13 14 15 16 17 18 19 20
19.31 m
SAND
SILT
CLAY
SHELBY TUBE SAMPLE

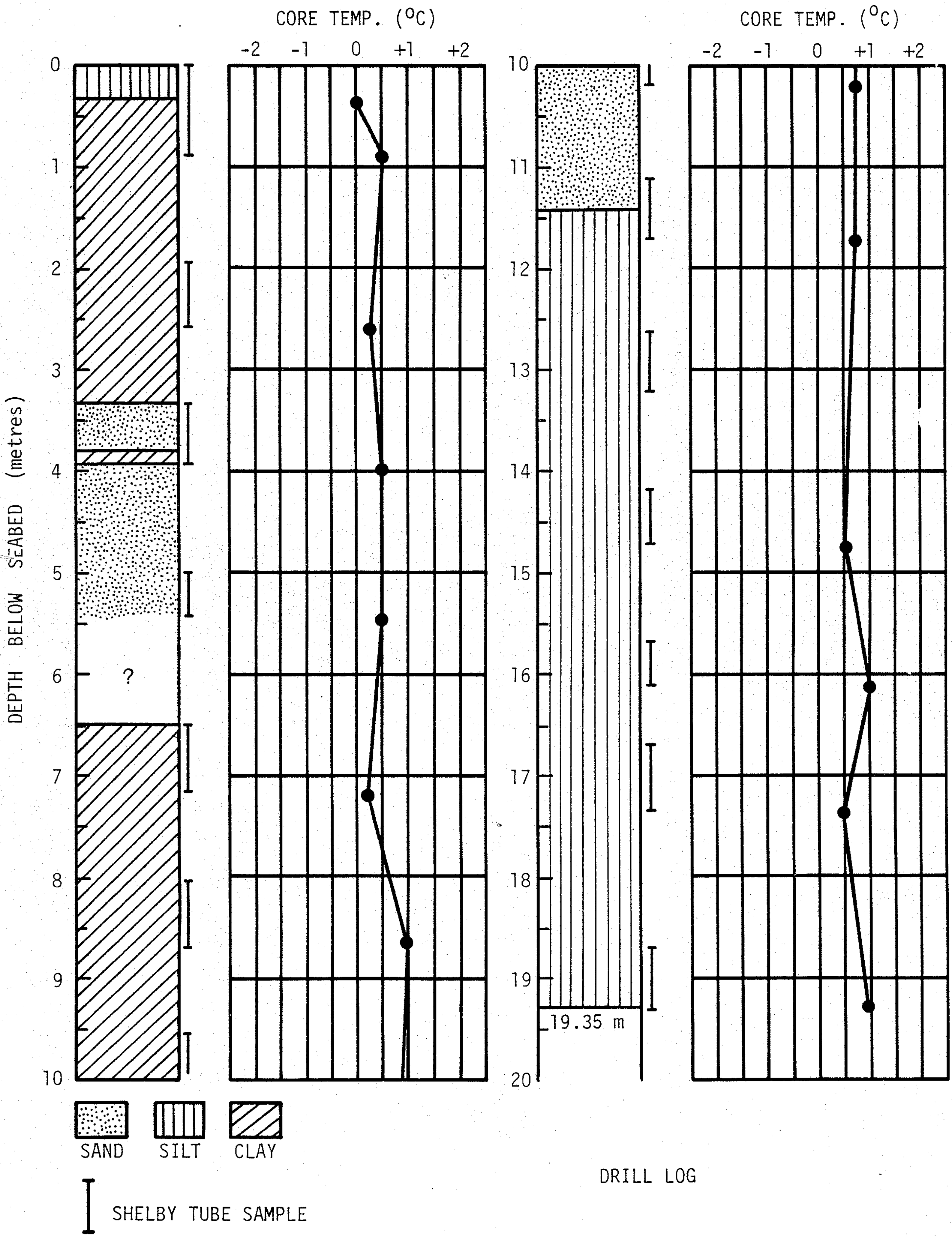
DRILL LOG.


BOREHOLE: 36+00
DATE: 21-03-84
ICE: 190 cm
ICE & WATER: 536 cm
CORE TEMP. (°C)
-2 -1 0 +1 +2
DEPTH BELOW SEABED (metres)
0 1 2 3 4 5 6 7 8 9 10
10 11 12 13 14 15 16 17 18 19 20
?
?
?
19.15 m
CORE TEMP. (°C)
-2 -1 0 +1 +2
SAND
SILT
CLAY
SHELBY TUBE SAMPLE
DRILL LOG


BOREHOLE: 34+00
DATE: 21-03-84
ICE: 155 cm
ICE & WATER: 513 cm
CORE TEMP. (°C)
-2 -1 0 +1 +2
DEPTH BELOW SEABED (metres)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
20.61 m
DRILL LOG
SAND
SILT
CLAY
SHELBY TUBE SAMPLE

BOREHOLE: 38+00
DATE: 21-03-84

ICE: 155 cm
ICE & WATER: 590 cm



DRILL LOG