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A STUDY OF SUB-SEABOTTOM
PERMAFROST IN THE BEAUFORT SEA
MACKENZIE DELTA BY HYDRAULIC
DRILLING METHODS,
Spring 1978

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Abstract

During the spring of 1978, 12 holes were hydraulically jet-drilled from the sea-ice to maximum depths of 61m beneath the Beaufort Sea. The holes, located in a line across the Delta Front north of Richards Island, were instrumented with temperature cables and monitored as the thermal disturbance due to the jetting dissipated. Much of the sea-bottom material encountered was marginally ice-bonded and permafrost occurred at all sites. Temperatures in the sea-bottom were below 0°C averaging around -1.5° to -1.0°C . Temperature gradients were near isothermal and are probably indicative of relict degrading permafrost. The shallow lithology interpreted from the drilling logs revealed definite changes in material type and thickness occurring across the Delta Front from Mackenzie Canyon to Kugmallit Bay. Water temperature and salinity profiles at the drillsites reflected the influence of the warmer and fresher Mackenzie River waters flowing into Mackenzie Bay and Kugmallit Bay.

Résumé

Durant le printemps de 1978, 12 forages hydrauliques à jet continu d'eau furent effectués jusqu'à une profondeur maximum de 61m sous la mer Beaufort. Les forages furent alignés le long de la courbe bathymétrique de 10m au nord de l'île Richards. Un câble contenant des détecteurs de température fut installé dans chaque trou et la température surveillée pendant que la perturbation thermique due à l'effet du jet d'eau se dissipait. Les sédiments étaient en grande partie liés par la glace. Chaque trou fut foré à travers le pergélisol; les températures sous le fond étaient en dessous de 0°C et en moyenne entre -1.5° et -1.0°C . Les gradients géothermiques étaient presque isothermiques et indiquent probablement du pergélisol relict et dégradant. La lithologie peu profonde interprétée selon les carnets de sondage révèlent des changements définitifs dans le type de sédiments et dans leur épaisseur le long du front du delta. Les profils de la température et de la salinité de l'eau reflètent l'influence de l'eau douce et chaude de la rivière Mackenzie qui se déverse dans les baies de Kugmallit et de Mackenzie.

INTRODUCTION

For several years the Department of Energy, Mines and Resources has been investigating the occurrence and distribution of sub-seabottom permafrost in the Beaufort Sea as part of a program of geotechnical research related to engineering construction and hydrocarbon exploration. The widespread occurrence of permafrost on the Beaufort Shelf area is well documented (Judge et al, 1975, Hunter et al, 1976) from regional seismic surveys and temperature measurements. However, such detailed aspects of permafrost distribution as the temperature and temperature gradient variations in response to Mackenzie River water outflow, the degree of ice-bonding and its relation to subsurface lithology and geological history, are poorly understood.

In the spring of 1976, a drilling and temperature logging program was carried out by EMR using a low cost hydraulic water jet-drilling technique (Judge et al, 1976) using the shore-fast ice as a drilling platform. Five holes were drilled and logged for lithology and temperature; the results were encouraging enough to continue the work during the 1977 spring field season. During this season a total of 22 holes were drilled and logged for lithologies and temperatures (MacAulay et al, 1977), many of which were drilled to a depth of 50 metres or more. This report is a summary of the continuation of this drilling program during the 1978 spring field season.

The drilling equipment and procedure as well as temperature cable installation were essentially unchanged from that of the 1977 season and a detailed description is given in MacAulay et al, 1977.

SURVEY AREA

The location of the Delta Front holes from 1976, 1977 and the 1978 drill holes are given in Fig. 1. The 1978 holes were positioned within 2 kilometres of the estimated edge of shore-fast ice; the growth of shorefast

ice was inhibited by the action of strong easterly winds which produced large flow edge leads and did not allow the attachment of pack ice.

The drill sites were positioned by Global Navigation System installed in a Bell 205 helicopter. From repeated fixes using known points on land and the Imperial Oil Limited Isserk E-27 well site, accuracy of all holes is ± 0.25 kilometre. Holes were located approximately 6 to 8 kilometres apart across the front of the eastern delta area.

ITINERARY

Field personnel H.A. MacAulay, and R.M. Gagne left Ottawa March 3, and met J.A. Hunter in Inuvik on March 4. Equipment assembly begun in Inuvik during the week of March 5 - 11. Two ATCO portable buildings (living quarters) were transported to Tuktoyaktuk. The main party consisting of R.A. Burns, M. Burgess, V. Allen, and A.S. Judge arrived in Tuk on March 15 and equipment was assembled and tested. Camps were moved to drill site 78-1 and 78-2 on March 21 by Bell 205 helicopter (Polar Continental Shelf Project) and drilling began. Camp and drill gear were moved by helicopter at approximately 2-day intervals. During camp moves the installed temperature cables along the line were read by A.S. Judge, M. Burgess and V. Allen. By April 3, all 12 holes were completed and the camps were then deployed to drilling locations on land for other drilling programs. Temperature cable installations were monitored periodically by A.S. Judge and M. Burgess through to April 16/78 when shifting ice began to break the cables.

In addition to the temperatures determined from the installed cables, additional observations of temperature and salinity were made in the water column overlying the sediments using incremental logging equipment.

LITHOLOGY RESULTS

The interpreted geological logs are given in Appendix A; descriptive logs and sample depths are given in Appendix B. A generalized lithological section based on logs for 1976, 1977 and 1978 holes is given in Fig. 2.

In contrast to previous years drilling, much of the sub-seabottom material encountered appeared to be marginally ice-bonded although all measured temperatures were below 0°C. The top few metres of clays and silts were non-ice-bonded in all holes. Occasional coarse-grained lenses (1 m thick) in both the ice-bonded and non-ice-bonded state, were encountered within the top 5 metres in many of the holes. The degree of ice-bonding in the fine-grained material appeared to increase with depth in some holes as shown by the drilling rates. Ice lenses of thickness in the order of 10 cm were encountered. All thick layers of sand penetrated were non-ice-bonded and presumed saturated with saline water; because of the disturbance by water-jet drilling it was not possible to measure the salinity in these horizons.

Washed samples were taken wherever possible in both the fine-grained and coarse-grained sections. In the sand sections where the hole was in danger of being plugged by return flow, sampling was often not attempted and the section was drilled as quickly as possible.

In hole 78-6 a thick section of ice was interpreted from 31 metres to 50 metres depth. No samples could be obtained; however, drilling characteristics were identical to drilling with the hydraulic jet drill in massive ice onshore on the Tuktoyaktuk peninsula; ie., fast drilling rate, no return sample flow, no blockage of flow at the drill bit after a drill section was added, chattering of drill rod indicating frozen material, and an open hole (the sides of the hole did not cave). Beneath the ice layer the drill encountered loose sand containing a large quantity of gas. This section

resembles that which would be encountered in segregated ice formations on land; thin layers of fine-grained material overlie the ice layer which has formed within coarse-grained material.

From Fig.2 some broad generalizations of shallow lithology can be made. A definite change in the material type occurs between the Mackenzie canyon sediments and sediment north of the area between Garry and Pullen Islands. The change occurs between holes 77-16 and holes 77-17. South of 77-16 the sediments are predominantly fine grained clay and silts. North, and northeast of 77-17 thick sections of sand and gravel are interlayered with clays and silts with varying degrees of ice bonding. East of hole 78-6 a fine grained clay silt layer increases in thickness and may be correlated with the inshore extension of the Kugmallit trench; this fine grained layer is marginally ice-bonded but the sand beneath shows little drilling evidence of ice-bonding.

Small quantities of gas were encountered in several of the boreholes and appeared to be associated with non-ice-bonded horizons. In hole 78-6 a large gas pocket was encountered; gas collected beneath the sea-ice and was flared through a 20 cm flare stack (flame height of 1 metre) for three days before the rate diminished. Gas was observed bubbling up through cracks in the sea ice in a 30 metre radius about the hole. A sulphur deposit was noted on the end of the flare stack although no odour was observed from the gas.

Temperature Measurements

The 1978 Delta Front holes were drilled to depths ranging from 24 to 61 m below sea level. Multithermistor cables were installed in all twelve holes and total depths instrumented ranged from 20.3 to 55.5 m. All cables were of the following configuration: total length 61 m, the top 0.5 m blank, the bottom 30.5 m consisting of ten evenly spaced sensors (3.05 m). One cable was installed per site, except at 78-2, where two

were strapped together to cover the total depth drilled. A total of 132 individual sensors were emplaced. The cables were monitored for a period of up to 3 weeks as the thermal disturbance due to the jetting dissipated. Total monitoring periods varied from a minimum of 262 hrs. at 78-10 to a maximum of 526 hrs. at 78-2.

Temperature logs are tabulated for each drill site in appendix C. In general, the final log is considered to be that which most closely approximates equilibrium temperatures. However at a few sites, for example, 78-9 and 78-10, the final logs (and perhaps prior logs) indicate erratic temperatures. These are highly suggestive of sensor, and thus, cable, failure due to shifting of the shore-fast ice. Selected temperature logs have been plotted for each site (appendix B). These suspected cable failures should be borne in mind when analyzing the temperature profiles. As well, a few sensors probably indicate that the sediments at those depths are at freezeback, the temperatures being close to the freezing point and having essentially not changed during monitoring. Calculations of the equilibrium temperatures based on the rate of change of temperature after cessation of drilling are being undertaken. These results will be presented in a future report.

Tentative equilibrium temperatures are negative in all drillholes and generally around -1.5° to -1.0°C , although ranging from -2° to -0.5°C . Temperature profiles show no consistent changes or trends across the delta front. In fact little change in temperature occurs across the delta front. Tentative temperature gradients based on the last temperature log or preliminary equilibrium temperature calculations indicate very near isothermal gradients, on average slightly positive (for the depth interval below the penetration of the annual bottom water temperature wave). The following trend from west to east is however suggested; gradients changing from slightly

negative (similar to 1977 holes) to slightly positive. These near isothermal gradients are probably indicative of relict degrading permafrost. The positive gradients, i.e. increasing temperatures with depth, in the eastern drill sites (eg. 78-11, 78-12) suggest thinner permafrost to the east. However, permafrost thicknesses cannot be easily and accurately extrapolated under these near isothermal conditions.

Water salinity and temperature profiles were obtained at 6 of the drill-sites; a YSI SCT meter (model 33) was used for the former measurements, a single thermistor probe for the latter. These data are tabulated in appendix C. Cross profiles, along the Delta Front, of water temperature and salinity are presented in figure 3. The drillholes closely follow the 10 m bathymetric contour; water depths range from 9.3 to 14.3 m and increase to the east. The influence of the warmer and fresh Mackenzie River waters, flowing into Mackenzie Bay in the west and Kugmallit Bay in the east, is observable on both the temperature and salinity profiles. At all sites water temperatures decrease with depth and salinities increase; temperatures range from -0.3° to -1.72°C , salinities from 6.0 to 35.5‰. However the sites closer to the Kugmallit and Mackenzie troughs are warmer and fresher; surface water is less than 15‰ and warmer than -1°C . Those sites furthest from the Mackenzie River influence (78-6 to 78-8) north of Richards Island are coldest and most saline. The influence of the Mackenzie River waters is greater in the west (78-1 to 78-4) bottom water temperatures and salinities are warmer and fresher (17‰, -1.55°C) than at the easternmost sites (30‰, -1.74°C).

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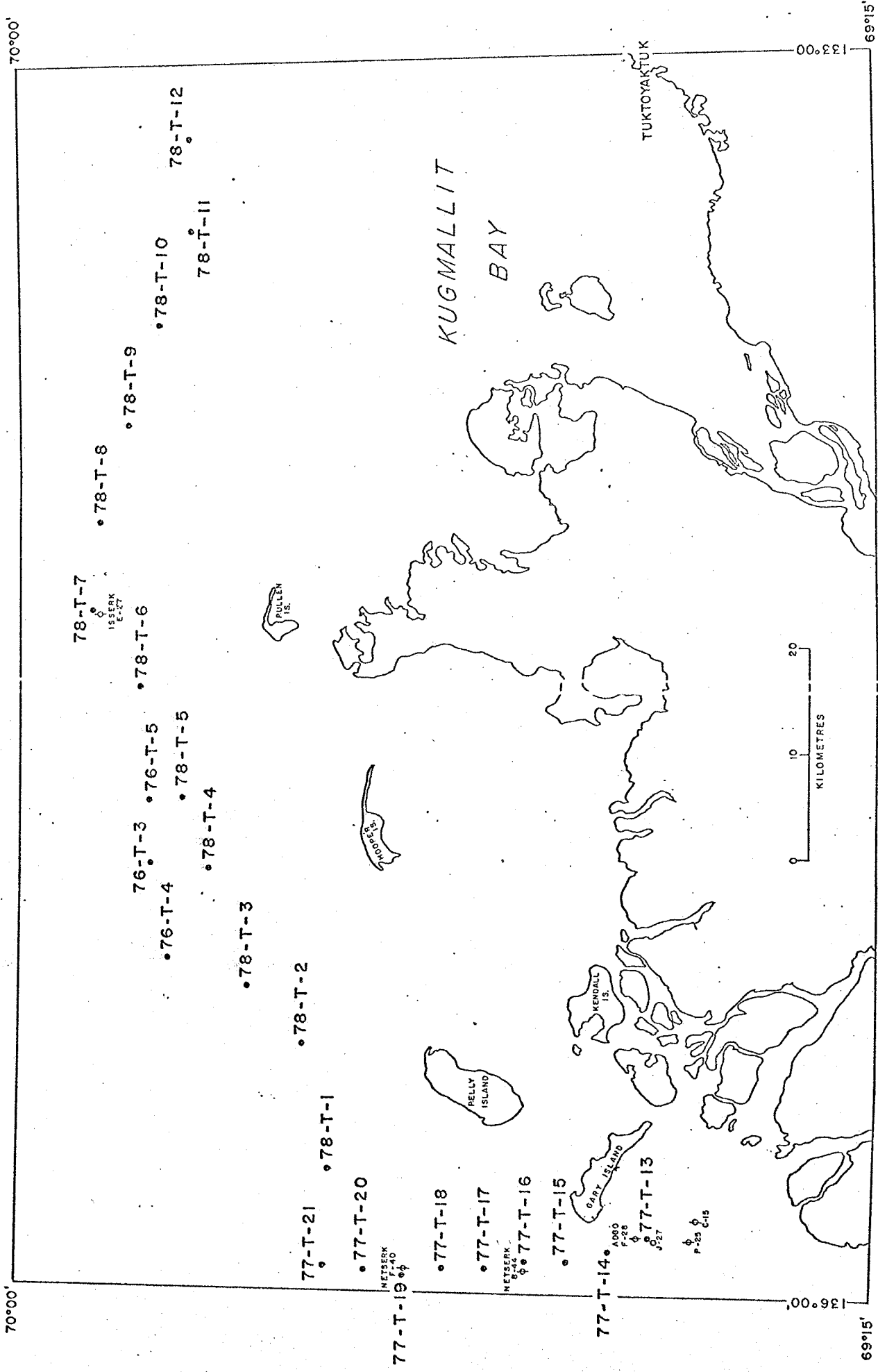
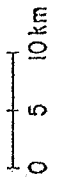


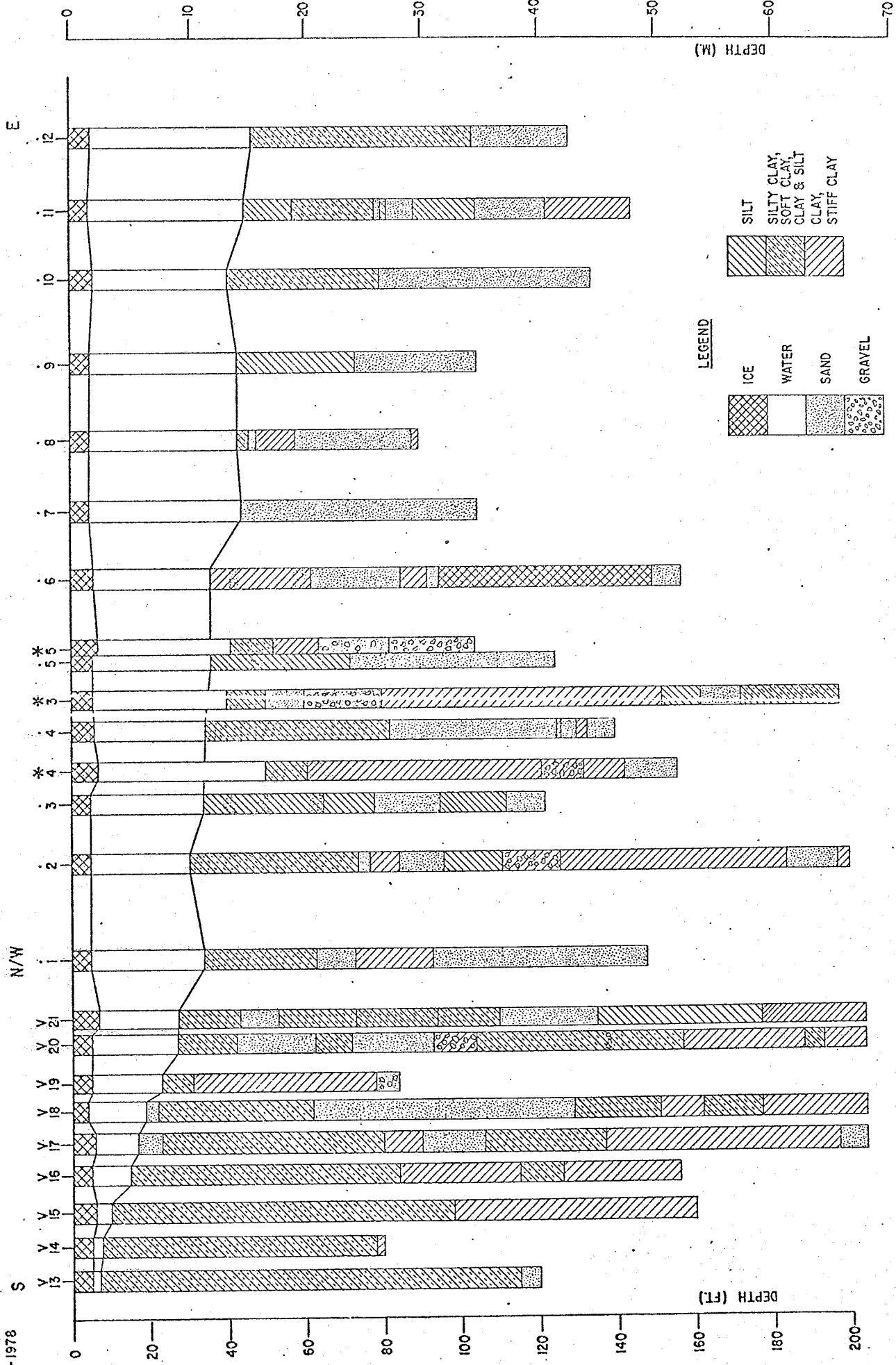
FIGURE 1 LOCATION OF 1977 & 1978 DRILL HOLES

FIG-2 LITHOLOGY OFFSHORE JET DRILL SITES — MACKENZIE DELTA, BEAUFORT SEA

1:500,000



* — 1976
 V — 1977
 . — 1978



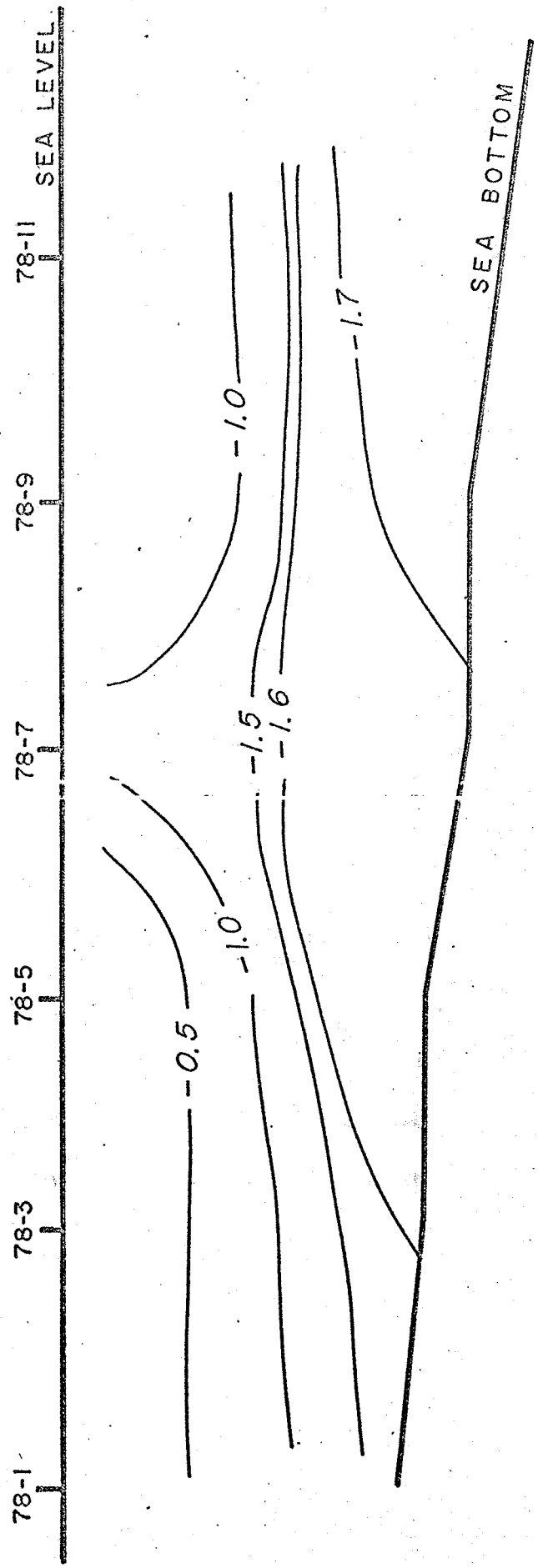
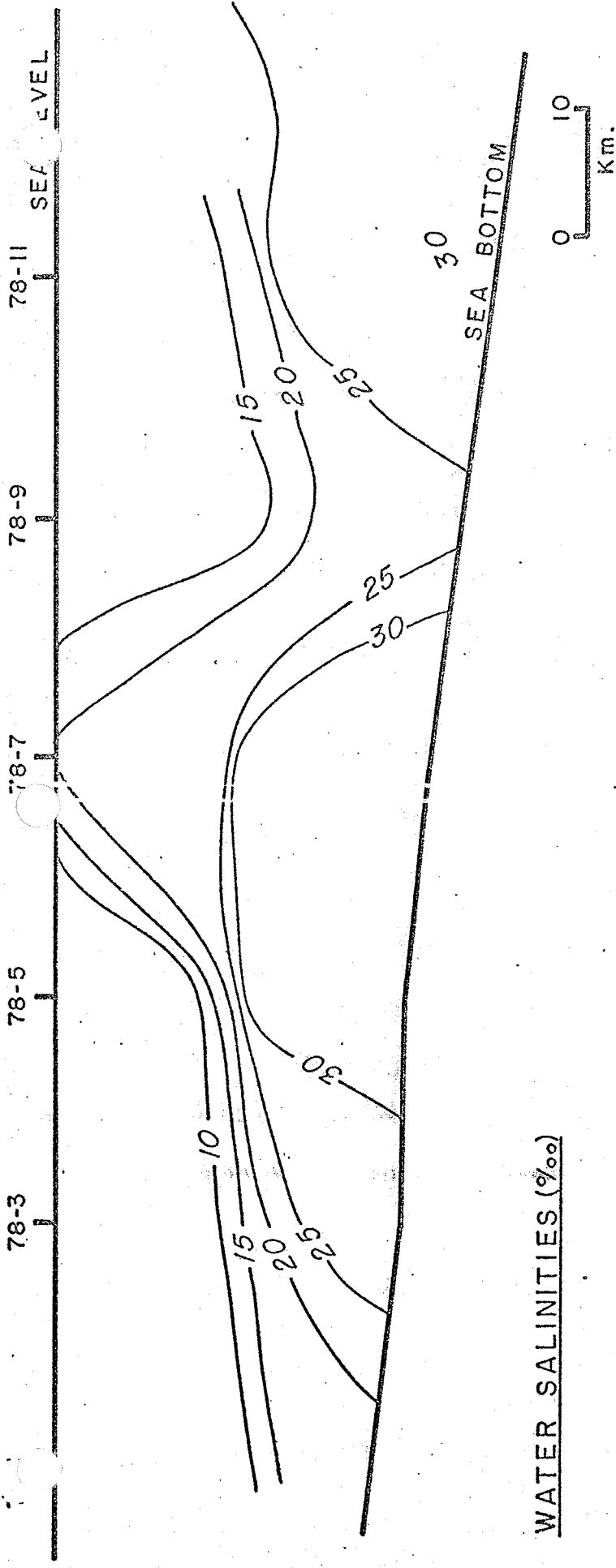


FIGURE 3 MARCH 1978 JET DRILL SITES

APPENDIX A

GEOLOGICAL LOGS, DRILLING RATES, TEMPERATURES

1978 DRILL HOLES

EARTH PHYSICS BRANCH NO. BEAUFORT, DELTA FRONT 7A-1

DIRECTION DE LA PHYSIQUE DU GLOBE NO.

EARTH PHYSICS BRANCH NO. BEAUFORT, DELTA FRONT 7A-2

DIRECTION DE LA PHYSIQUE DU GLOBE NO.

69 DEGREES 43.4 MINUTES NORTH
135 DEGREES 42.6 MINUTES WEST

ELEVATION 0 METRES

69 DEGRES 43.4 MINUTES NORD
135 DEGRES 42.6 MINUTES OUEST

ELEVATION 0 METRES

DIAGRAMMES DONNANT LA TEMPERATURE EN FONCTION DE LA PROFONDEUR

DIAGRAMMES DONNANT LA TEMPERATURE EN FONCTION DE LA PROFONDEUR

DEPTH (M)	TEMP (C)	DATE	TEMP (C)	DATE	TEMP (C)	DATE	TEMP (C)	DATE	TEMP (C)	DATE	TEMP (C)	DATE	TEMP (C)
26	-56	3 7 74	-91	3 4 74	-96	3 7 74	-93	3 4 74	-91	3 7 74	-96	3 4 74	-93
14.5	-61	3 7 74	-91	3 4 74	-96	3 7 74	-93	3 4 74	-91	3 7 74	-96	3 4 74	-93
17.5	-67	3 7 74	-91	3 4 74	-96	3 7 74	-93	3 4 74	-91	3 7 74	-96	3 4 74	-93
20.6	-68	3 7 74	-91	3 4 74	-96	3 7 74	-93	3 4 74	-91	3 7 74	-96	3 4 74	-93
23.6	-68	3 7 74	-91	3 4 74	-96	3 7 74	-93	3 4 74	-91	3 7 74	-96	3 4 74	-93
25.7	-68	3 7 74	-91	3 4 74	-96	3 7 74	-93	3 4 74	-91	3 7 74	-96	3 4 74	-93
29.7	-72	3 7 74	-91	3 4 74	-96	3 7 74	-93	3 4 74	-91	3 7 74	-96	3 4 74	-93
32.4	-72	3 7 74	-91	3 4 74	-96	3 7 74	-93	3 4 74	-91	3 7 74	-96	3 4 74	-93

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE. LOGGING OF THIS HOLE IS COMPLETE.

TEMPERATURES OBTENUES A PARTIR D'UN CABLE A THERMISTORS MULTIPLES. LE SONDAGE DE CE PUITS EST TERMINE.

EPB AND GSC JET DRILL HOLE 7A-1
-WELL STOPPED 25 3 74
-DRILLING FOR 1 DAY
-TOTAL DEPTH 3A METRES
-PROFONDEUR TOTALE 3A METRES
-DRILLING STOPPED 25 3 74

WATER DEPTH 10.4 M. TOTAL DRILL TIME 3 HRS.

EARTH PHYSICS BRANCH NO. BEAUFORT, DELTA FRONT 7A-3

DIRECTION DE LA PHYSIQUE DU GLOBE NO.

EARTH PHYSICS BRANCH NO. BEAUFORT, DELTA FRONT 7A-4

DIRECTION DE LA PHYSIQUE DU GLOBE NO.

69 DEGREES 49.0 MINUTES NORTH
135 DEGREES 14.7 MINUTES WEST

ELEVATION 0 METRES

69 DEGRES 49.0 MINUTES NORD
135 DEGRES 14.7 MINUTES OUEST

ELEVATION 0 METRES

DIAGRAMMES DONNANT LA TEMPERATURE EN FONCTION DE LA PROFONDEUR

DIAGRAMMES DONNANT LA TEMPERATURE EN FONCTION DE LA PROFONDEUR

DEPTH (M)	TEMP (C)	DATE	TEMP (C)	DATE	TEMP (C)	DATE	TEMP (C)	DATE	TEMP (C)	DATE	TEMP (C)	DATE	TEMP (C)
27	-54	3 7 74	-91	3 4 74	-96	3 7 74	-93	3 4 74	-91	3 7 74	-96	3 4 74	-93
11.0	-54	3 7 74	-91	3 4 74	-96	3 7 74	-93	3 4 74	-91	3 7 74	-96	3 4 74	-93
14.3	-55	3 7 74	-91	3 4 74	-96	3 7 74	-93	3 4 74	-91	3 7 74	-96	3 4 74	-93
17.1	-67	3 7 74	-91	3 4 74	-96	3 7 74	-93	3 4 74	-91	3 7 74	-96	3 4 74	-93
20.1	-61	3 7 74	-91	3 4 74	-96	3 7 74	-93	3 4 74	-91	3 7 74	-96	3 4 74	-93
23.2	-61	3 7 74	-91	3 4 74	-96	3 7 74	-93	3 4 74	-91	3 7 74	-96	3 4 74	-93

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE. LOGGING OF THIS HOLE IS COMPLETE.

TEMPERATURES OBTENUES A PARTIR D'UN CABLE A THERMISTORS MULTIPLES. LE SONDAGE DE CE PUITS EST TERMINE.

EPB AND GSC JET DRILL HOLE 7A-3
-WELL STOPPED 27 3 74
-DRILLING FOR 1 DAY
-TOTAL DEPTH 37 METRES
-PROFONDEUR TOTALE 37 METRES
-DRILLING STOPPED 27 3 74

WATER DEPTH 10.7 M. TOTAL DRILL TIME 2.4 HRS.

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE. LOGGING OF THIS HOLE IS COMPLETE.

TEMPERATURES OBTENUES A PARTIR D'UN CABLE A THERMISTORS MULTIPLES. LE SONDAGE DE CE PUITS EST TERMINE.

EPB AND GSC JET DRILL HOLE 7A-2
-WELL STOPPED 24 3 74
-DRILLING FOR 1 DAY
-TOTAL DEPTH 61 METRES
-PROFONDEUR TOTALE 61 METRES
-DRILLING STOPPED 24 3 74

WATER DEPTH 9.3 M. TOTAL DRILL TIME 2.5 HRS.

TEMPERATURES OBTENUES A PARTIR D'UN CABLE A THERMISTORS MULTIPLES. LE SONDAGE DE CE PUITS EST TERMINE.

EPB AND GSC JET DRILL HOLE 7A-2
-WELL STOPPED 24 3 74
-DRILLING FOR 1 DAY
-TOTAL DEPTH 61 METRES
-PROFONDEUR TOTALE 61 METRES
-DRILLING STOPPED 24 3 74

WATER DEPTH 9.3 M. TOTAL DRILL TIME 2.5 HRS.

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE. LOGGING OF THIS HOLE IS COMPLETE.

TEMPERATURES OBTENUES A PARTIR D'UN CABLE A THERMISTORS MULTIPLES. LE SONDAGE DE CE PUITS EST TERMINE.

EPB AND GSC JET DRILL HOLE 7A-4
-WELL STOPPED 26 3 74
-DRILLING FOR 1 DAY
-TOTAL DEPTH 24 METRES
-PROFONDEUR TOTALE 24 METRES
-DRILLING STOPPED 26 3 74

WATER DEPTH 10.4 M. TOTAL DRILL TIME 0.4 HRS.

TEMPERATURES OBTENUES A PARTIR D'UN CABLE A THERMISTORS MULTIPLES. LE SONDAGE DE CE PUITS EST TERMINE.

EPB AND GSC JET DRILL HOLE 7A-4
-WELL STOPPED 26 3 74
-DRILLING FOR 1 JOUR
-PROFONDEUR TOTALE 24 METRES
-FORAGE ARRETE LE 26 3 74

WATER DEPTH 10.4 M. TOTAL DRILL TIME 0.4 HRS.

EARTH PHYSICS BRANCH NO.
BEAUFORT, DELTA FRONT 78-6

DIRECTION DE LA PHYSIQUE DU GLOBE NO.

69 DEGRES 54.0 MINUTES NORTH
134 DEGRES 33.9 MINUTES WEST

ELEVATION 0 METRES

SUMMARY OF DEPTH-TEMPERATURE LOGS

DEPTH (M)	DATE	TEMP (C)	DATE	TEMP (C)
13.7	29 3 78	-1.21	3 4 78	-1.21
16.8		-1.26		-1.26
19.6		-1.23		-1.23
22.9		-1.25		-1.25
25.9		-1.22		-1.22
29.0		-1.18		-1.18
32.0		-1.05		-1.05
35.1		-0.72		-0.72

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE. LOGGING OF THIS HOLE IS COMPLETE.

EP9 AND GSC JET DRILL HOLE 78-6
-WELL SPUNDED 29 3 78
-DRILLING FOR 1 DAY
-TOTAL DEPTH 48 METRES
-DRILLING STOPPED 28 3 78

WATER DEPTH 11 M. TOTAL DRILL TIME 1.5 HRS.

EARTH PHYSICS BRANCH NO.
BEAUFORT, DELTA FRONT 78-7

DIRECTION DE LA PHYSIQUE DU GLOBE NO.

69 DEGRES 56.3 MINUTES NORTH
134 DEGRES 22.5 MINUTES WEST

ELEVATION 0 METRES

SUMMARY OF DEPTH-TEMPERATURE LOGS

DEPTH (M)	DATE	TEMP (C)	DATE	TEMP (C)
15.9	1 4 78	-0.95	3 4 78	-1.09
18.9		-0.97		-1.20
22.0		-0.96		-1.27
25.0		-0.82		-1.31
28.1		-0.74		-1.07

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE. LOGGING OF THIS HOLE IS COMPLETE.

EP9 AND GSC JET DRILL HOLE 78-7
-WELL SPUNDED 31 3 78
-DRILLING FOR 1 DAY
-TOTAL DEPTH 32 METRES
-DRILLING STOPPED 31 3 78

WATER DEPTH 13.4 M. TOTAL DRILL TIME 0.9 HRS.

EARTH PHYSICS BRANCH NO.
BEAUFORT, DELTA FRONT 78-5

DIRECTION DE LA PHYSIQUE DU GLOBE NO.

69 DEGRES 51.6 MINUTES NORTH
134 DEGRES 44.8 MINUTES WEST

ELEVATION 0 METRES

SUMMARY OF DEPTH-TEMPERATURE LOGS

DEPTH (M)	DATE	TEMP (C)	DATE	TEMP (C)
13.7	30 3 78	-0.73	3 4 78	-1.13
16.8		-1.00		-1.26
19.4		-0.81		-1.11
22.9		-0.88		-1.16
25.9		-0.80		-1.19
29.0		-0.81		-1.22
32.0		-0.30		-1.04
35.1		-0.15		-0.72

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE. LOGGING OF THIS HOLE IS COMPLETE.

EP9 AND GSC JET DRILL HOLE 78-5
-WELL SPUNDED 29 3 78
-DRILLING FOR 1 DAY
-TOTAL DEPTH 38 METRES
-DRILLING STOPPED 29 3 78

WATER DEPTH 11 M. TOTAL DRILL TIME 2.1 HRS.

EARTH PHYSICS BRANCH NO.
BEAUFORT, DELTA FRONT 78-4

DIRECTION DE LA PHYSIQUE DU GLOBE NO.

69 DEGRES 56.3 MINUTES NORTH
134 DEGRES 8.5 MINUTES WEST

ELEVATION 0 METRES

SUMMARY OF DEPTH-TEMPERATURE LOGS

DEPTH (M)	DATE	TEMP (C)	DATE	TEMP (C)
13.7	30 3 78	-2.31	1 4 78	-1.39
16.8		-0.61		-1.07
19.5		-1.40		-0.51
22.9		-0.69		-0.55
25.9		-0.13		-0.72

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE. LOGGING OF THIS HOLE IS COMPLETE.

EP9 AND GSC JET DRILL HOLE 78-4
-WELL SPUNDED 30 3 78
-DRILLING FOR 1 DAY
-TOTAL DEPTH 27 METRES
-DRILLING STOPPED 30 3 78

WATER DEPTH 13.1 M. TOTAL DRILL TIME 0.9 HRS.

DIAGRAMMES DONNANT LA TEMPERATURE EN FONCTION DE LA PROFONDEUR

DEPTH (M)	DATE	TEMP (C)	DATE	TEMP (C)
13.7	9 4 78	-1.20	12 4 78	-1.10
16.8		-1.05		-1.06
19.4		-1.25		-1.07
22.9		-1.14		-1.14
25.9		-1.19		-1.19
29.0		-1.20		-1.20
32.0		-1.22		-1.23
35.1		-1.04		-1.06

TEMPERATURES OBTENUES A PARTIR D'UN CABLE A THERMISTORS MULTIPLES. LE SONDAGE DE CE PUITS EST TERMINE.

EP9 AND GSC JET DRILL HOLE 78-5
-WELL SPUNDED 29 3 78
-DRILLING FOR 1 DAY
-TOTAL DEPTH 38 METRES
-DRILLING STOPPED 29 3 78

DIAGRAMMES DONNANT LA TEMPERATURE EN FONCTION DE LA PROFONDEUR

DEPTH (M)	DATE	TEMP (C)	DATE	TEMP (C)
13.7	6 4 78	-1.52	9 4 78	-1.56
16.8		-1.23		-1.33
19.5		-0.78		-1.07
22.9		-0.80		-1.00
25.9		-0.72		-1.04

TEMPERATURES OBTENUES A PARTIR D'UN CABLE A THERMISTORS MULTIPLES. LE SONDAGE DE CE PUITS EST TERMINE.

EP9 AND GSC JET DRILL HOLE 78-6
-WELL SPUNDED 30 3 78
-DRILLING FOR 1 DAY
-TOTAL DEPTH 27 METRES
-DRILLING STOPPED 30 3 78

EARTH PHYSICS BRANCH NO. BEAUFORT, DELTA FRONT 76-9
 DIRECTION DE LA PHYSIQUE DU GLOBE NO. 811
 BEAUFORT, DELTA FRONT 76-9

69 DEGREES 53.9 MINUTES NORTH 69 DEGRES 53.9 MINUTES NORD
 133 DEGREES 54.6 MINUTES WEST 133 DEGRES 54.6 MINUTES OUEST
 ELEVATION 0 METRES

DIAGRAMMES DONNANT LA TEMPERATURE EN FONCTION DE LA PROFONDEUR
 SUMMARY OF DEPTH-TEMPERATURE LOGS

DEPTH (M)	DATE 3 4 78		DATE 6 4 78		DATE 9 4 78		DATE 12 4 78	
	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)
14.0	-1.51	-1.64	-1.27	-1.46	-1.07	-1.13	-1.07	-1.07
17.1	-0.97	-1.15	-1.15	-1.33	-1.11	-1.11	-1.11	-1.11
20.1	-1.12	-1.17	-1.19	-1.18	-1.21	-1.21	-1.05	-1.05
23.2	-1.09	-1.14	-1.13	-1.53	-1.02	-1.02	-1.02	-1.02

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE. LOGGING OF THIS HOLE IS COMPLETE.
 EP8 AND GSC JET DRILL HOLE 76-9
 -WELL SPUNDED 2 4 78
 -DRILLING FOR 1 DAY
 -TOTAL DEPTH 29 METRES
 -DRILLING STOPPED 2 4 78
 WATER DEPTH 13.1 M. TOTAL DRILL TIME 1.2 HRS.

EARTH PHYSICS BRANCH NO. BEAUFORT, DELTA FRONT 76-10
 DIRECTION DE LA PHYSIQUE DU GLOBE NO. 811
 BEAUFORT, DELTA FRONT 76-10

69 DEGREES 52.5 MINUTES NORTH 69 DEGRES 52.5 MINUTES NORD
 133 DEGREES 39.1 MINUTES WEST 133 DEGRES 39.1 MINUTES OUEST
 ELEVATION 0 METRES

DIAGRAMMES DONNANT LA TEMPERATURE EN FONCTION DE LA PROFONDEUR
 SUMMARY OF DEPTH-TEMPERATURE LOGS

DEPTH (M)	DATE 2 4 78		DATE 3 4 78		DATE 4 4 78		DATE 6 4 78		DATE 9 4 78		DATE 12 4 78	
	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)
16.1	-0.29	-0.36	-0.60	-0.97	-1.13	-1.13	-1.07	-1.07	-1.13	-1.13	-1.13	-1.13
19.2	-0.36	-0.49	-0.91	-1.01	-1.11	-1.11	-1.11	-1.11	-1.11	-1.11	-1.11	-1.11
22.3	-0.49	-0.53	-1.01	-1.02	-1.21	-1.21	-1.05	-1.05	-1.05	-1.05	-1.05	-1.05
25.3	-0.53	-0.53	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02
28.4	-0.53	-0.53	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02
31.4	-0.53	-0.53	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02
34.5	-0.53	-0.53	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02
37.5	-0.53	-0.53	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02
40.6	-0.53	-0.53	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE. LOGGING OF THIS HOLE IS COMPLETE.
 EP8 AND GSC JET DRILL HOLE 76-10
 -WELL SPUNDED 1 4 78
 -DRILLING FOR 1 DAY
 -TOTAL DEPTH 41 METRES
 -DRILLING STOPPED 1 4 78
 WATER DEPTH 12.4 M. TOTAL DRILL TIME 1.3 HRS.

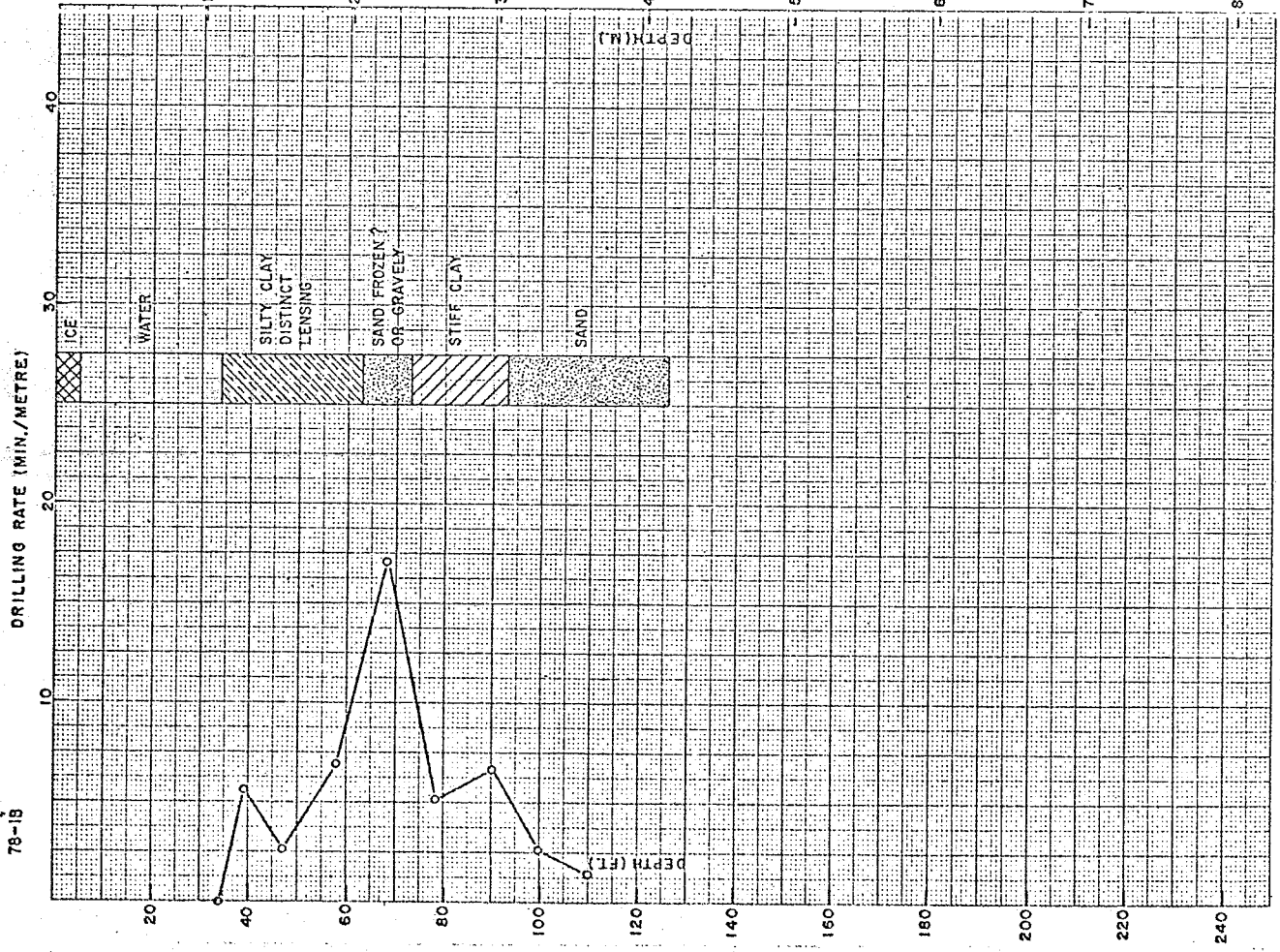
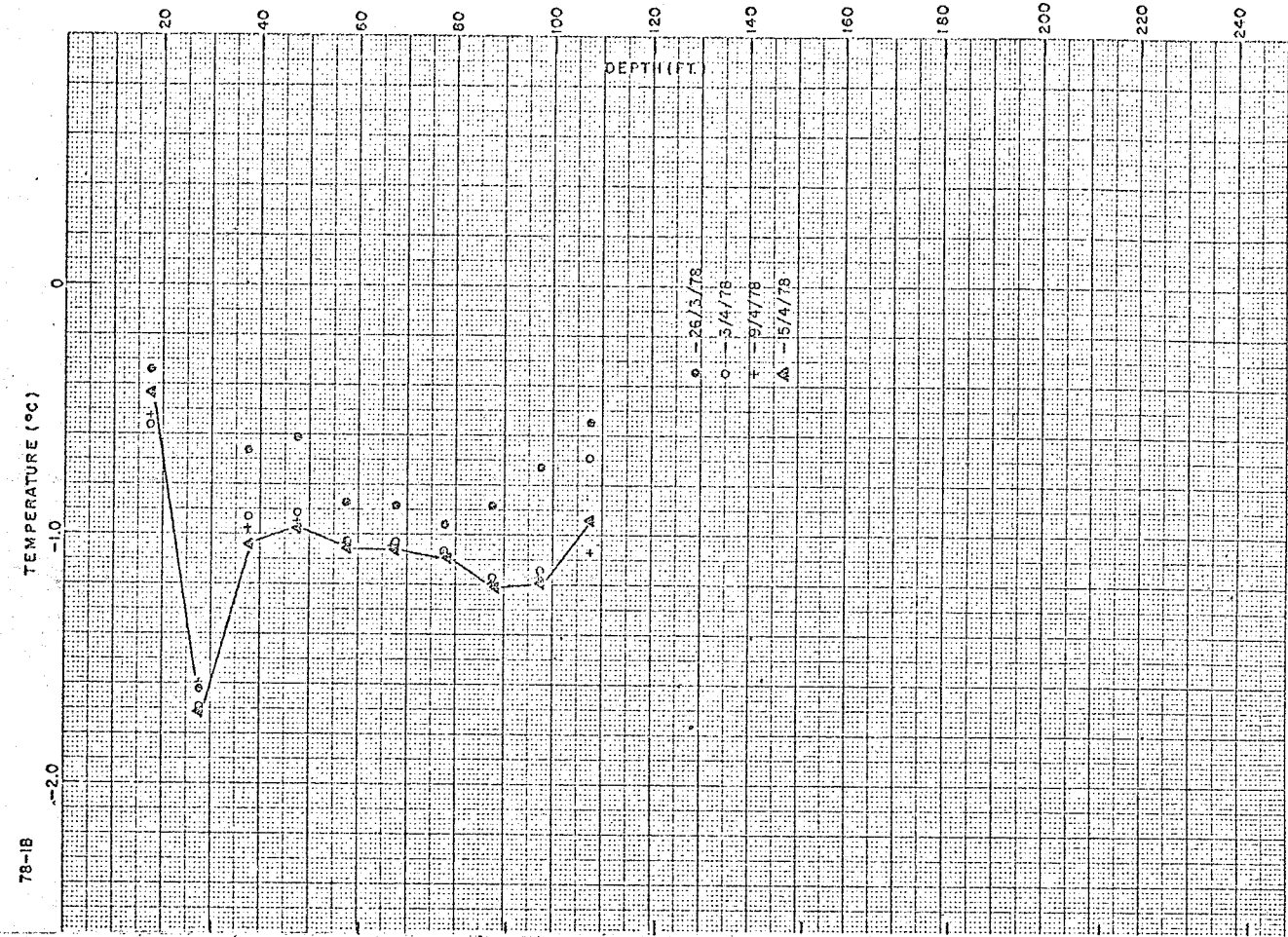
EARTH PHYSICS BRANCH NO. BEAUFORT, DELTA FRONT 76-11
 DIRECTION DE LA PHYSIQUE DU GLOBE NO. 811
 BEAUFORT, DELTA FRONT 76-11

69 DEGREES 51.5 MINUTES NORTH 69 DEGRES 51.5 MINUTES NORD
 133 DEGREES 26.0 MINUTES WEST 133 DEGRES 26.0 MINUTES OUEST
 ELEVATION 0 METRES

DIAGRAMMES DONNANT LA TEMPERATURE EN FONCTION DE LA PROFONDEUR
 SUMMARY OF DEPTH-TEMPERATURE LOGS

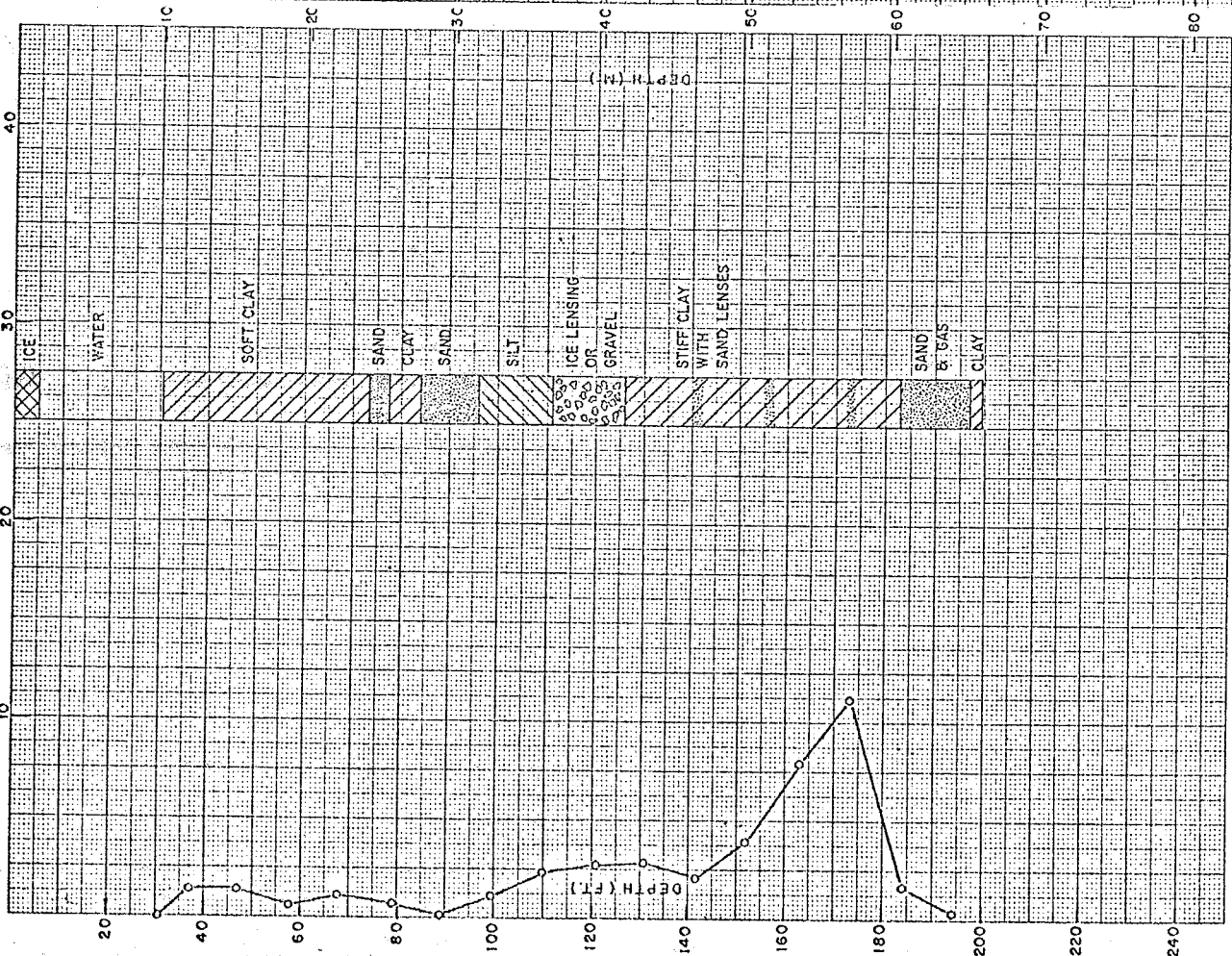
DEPTH (M)	DATE 12 4 78		DATE 12 4 78		DATE 16 4 78		DATE 16 4 78	
	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)	TEMP (C)
14.9	-1.07	-1.07	-1.07	-1.07	-1.23	-1.23	-1.23	-1.23
18.0	-1.07	-1.07	-1.07	-1.07	-1.12	-1.12	-1.12	-1.12
21.0	-1.07	-1.07	-1.07	-1.07	-1.26	-1.26	-1.26	-1.26
24.1	-1.12	-1.12	-1.12	-1.12	-1.26	-1.26	-1.26	-1.26
27.1	-1.18	-1.18	-1.18	-1.18	-1.30	-1.30	-1.30	-1.30
30.2	-1.25	-1.25	-1.25	-1.25	-1.30	-1.30	-1.30	-1.30
33.3	-1.25	-1.25	-1.25	-1.25	-1.30	-1.30	-1.30	-1.30
36.3	-1.25	-1.25	-1.25	-1.25	-1.30	-1.30	-1.30	-1.30
39.3	-1.25	-1.25	-1.25	-1.25	-1.30	-1.30	-1.30	-1.30
42.4	-1.25	-1.25	-1.25	-1.25	-1.30	-1.30	-1.30	-1.30

TEMPERATURE RESULTS ARE OBTAINED FROM A MULTITHERMISTOR CABLE. LOGGING OF THIS HOLE IS COMPLETE.
 EP8 AND GSC JET DRILL HOLE 76-11
 -WELL SPUNDED 4 78
 -DRILLING FOR 1 DAY
 -TOTAL DEPTH 45 METRES
 -DRILLING STOPPED 4 78
 TOTAL DRILL TIME 2.7 HRS. WATER DEPTH 13.7M. ONLY ONE LOG PRIOR TO FAILURE



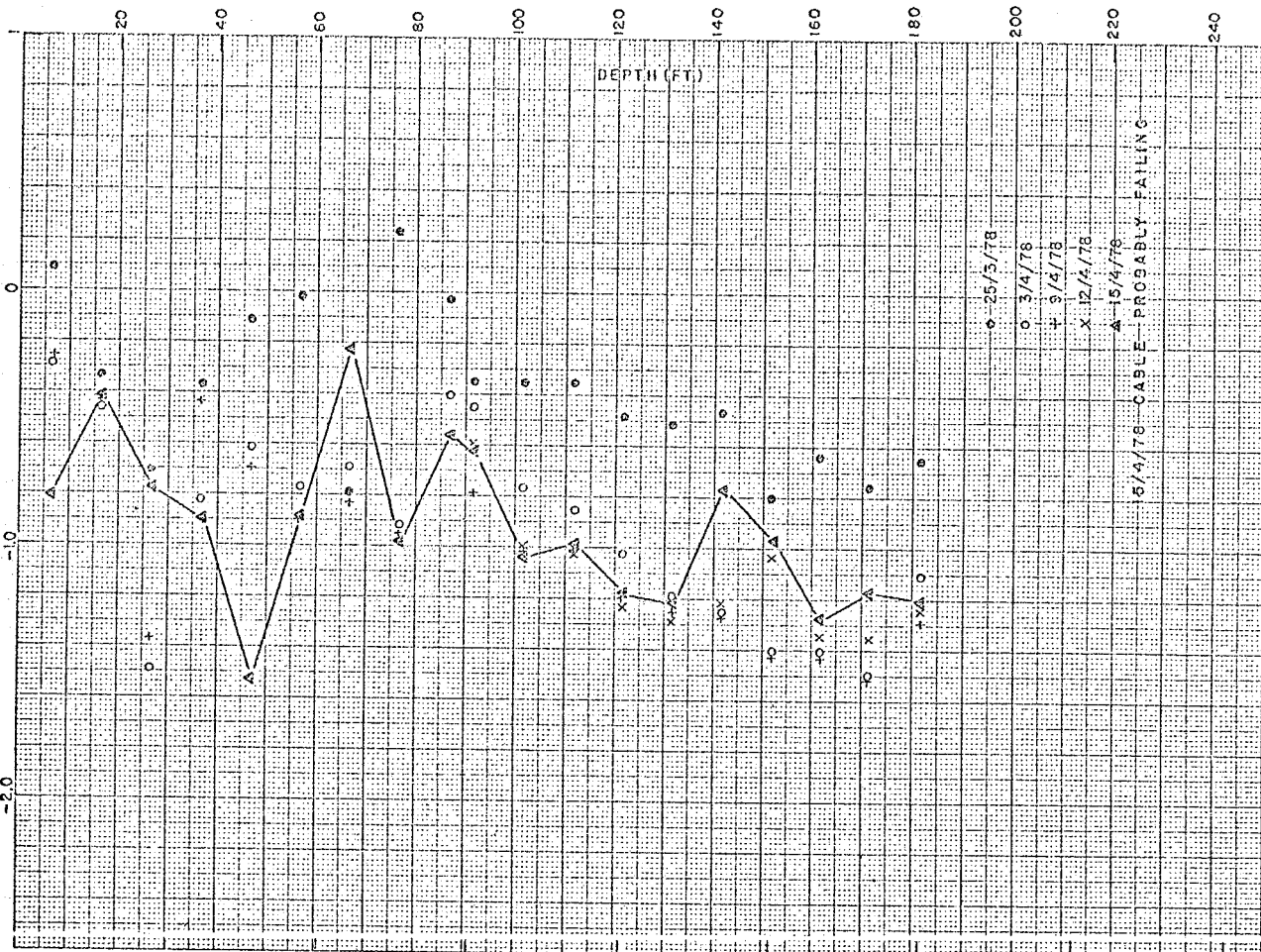
78-2

DRILLING RATE (MIN./METRE)



78-2

TEMPERATURE (°C)



16/4/78 CABLE - PROBABLY FAILING

▲-15/4/78

×-12/4/78

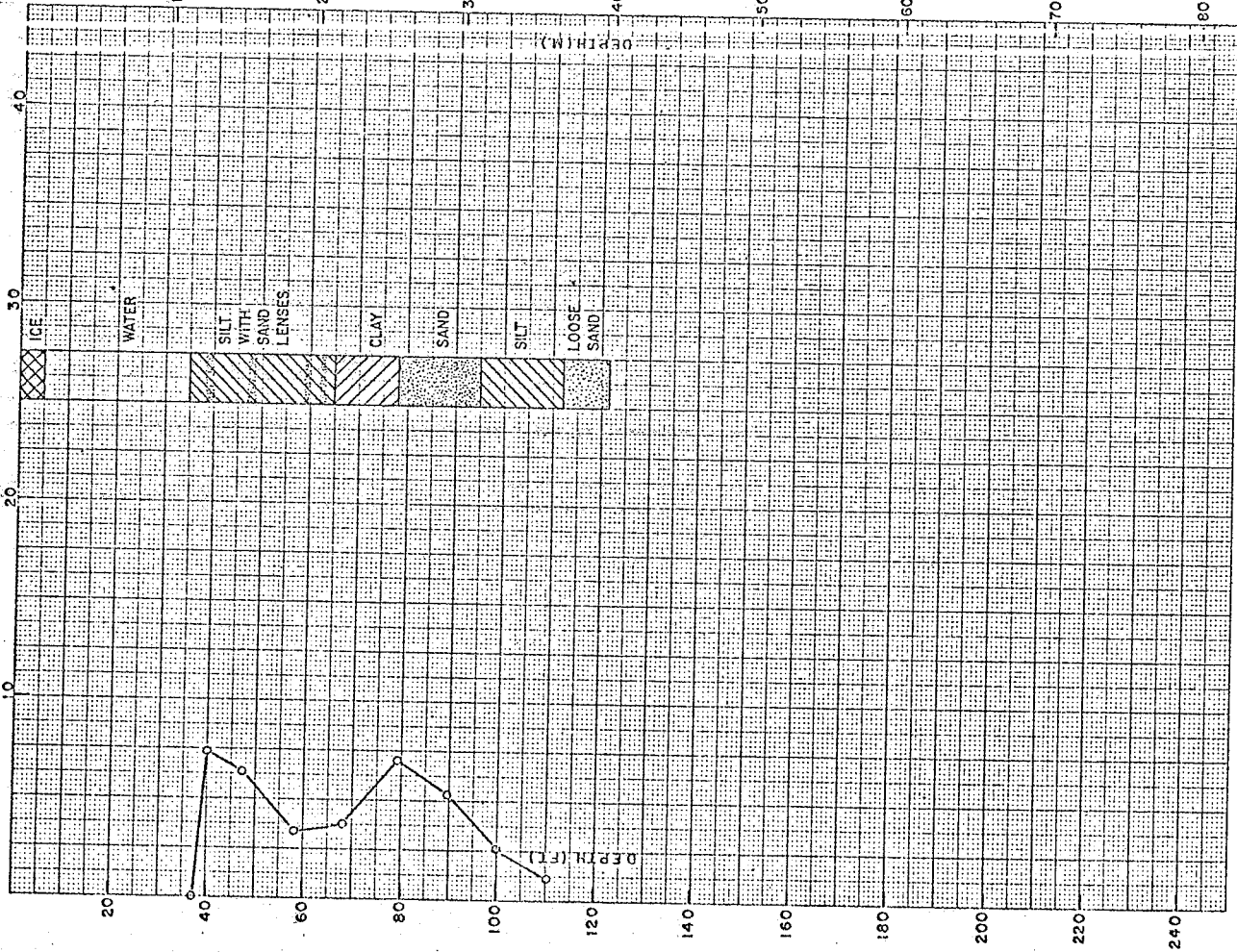
+ 3/4/78

○ 3/4/78

○-25/3/78

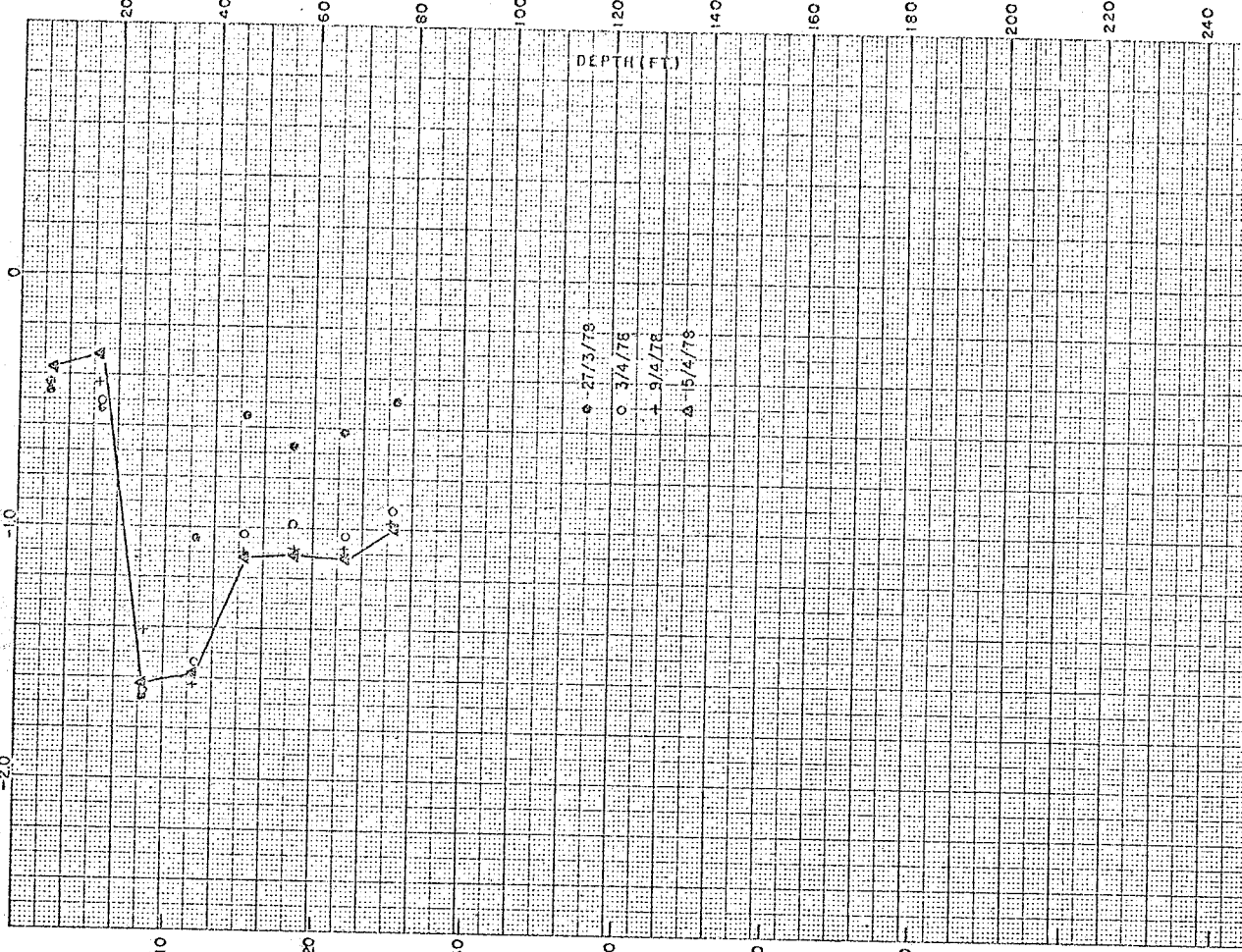
78-3

DRILLING RATE (MIN./METRE)



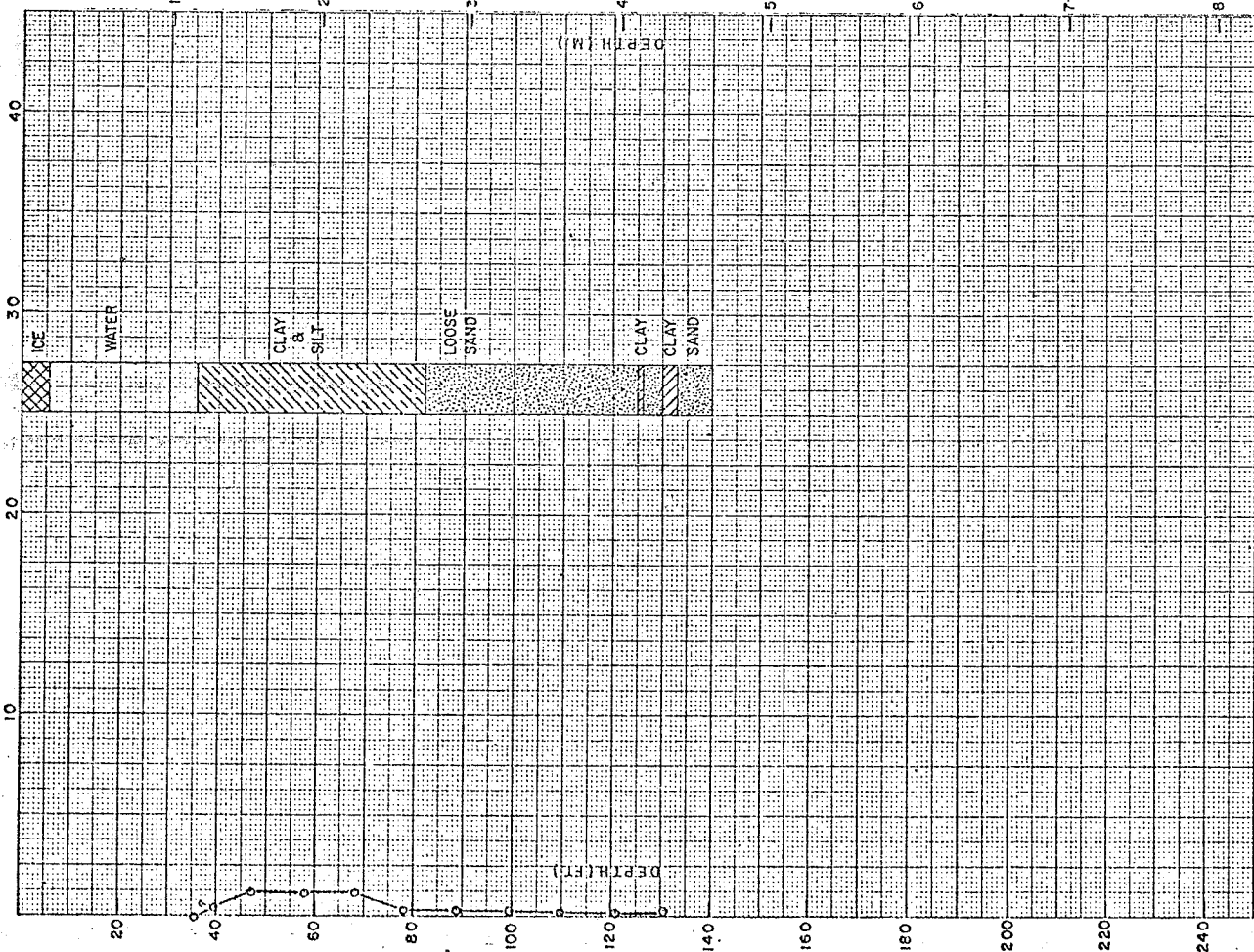
78-3

TEMPERATURE (°C)



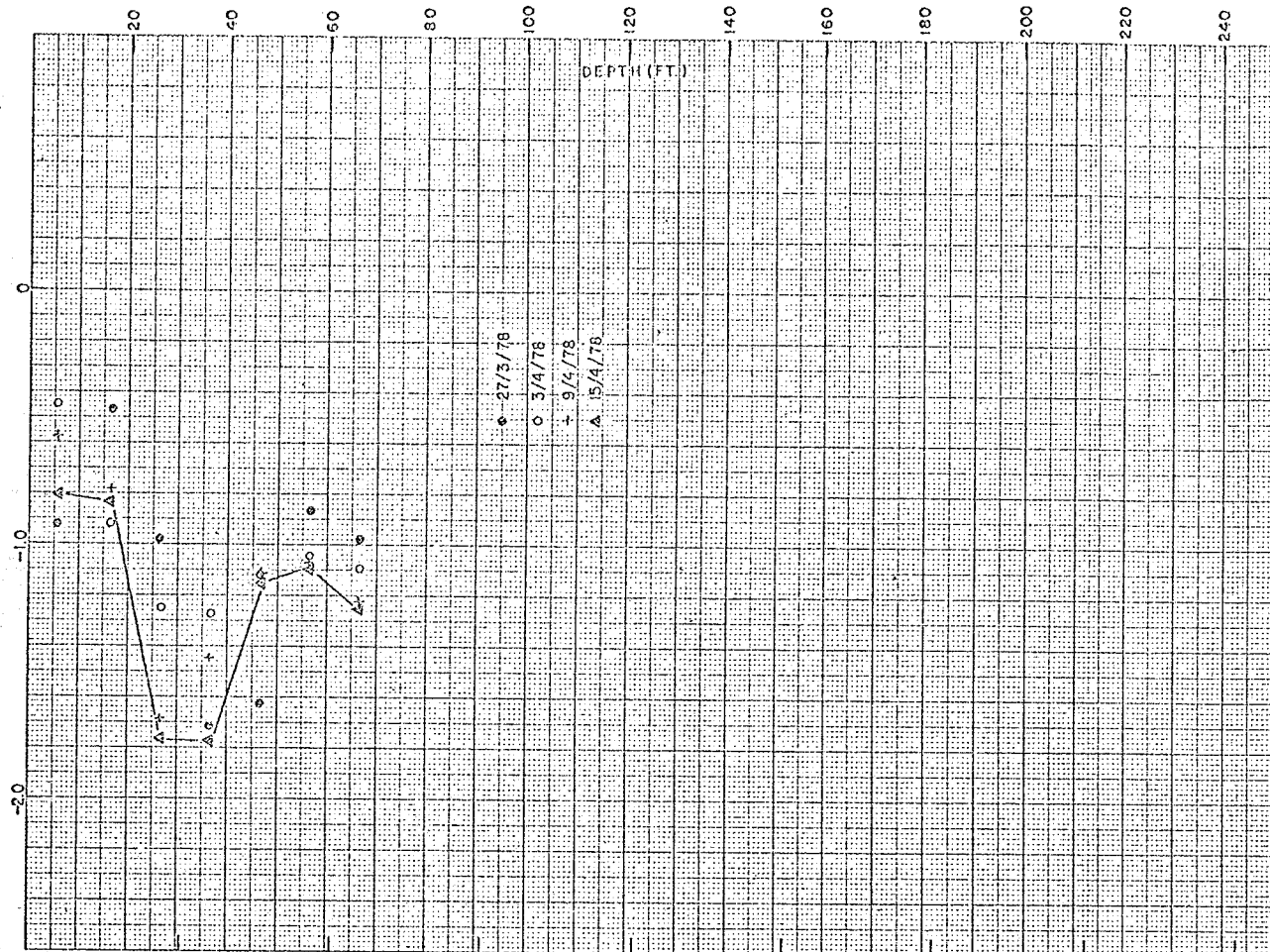
78-4

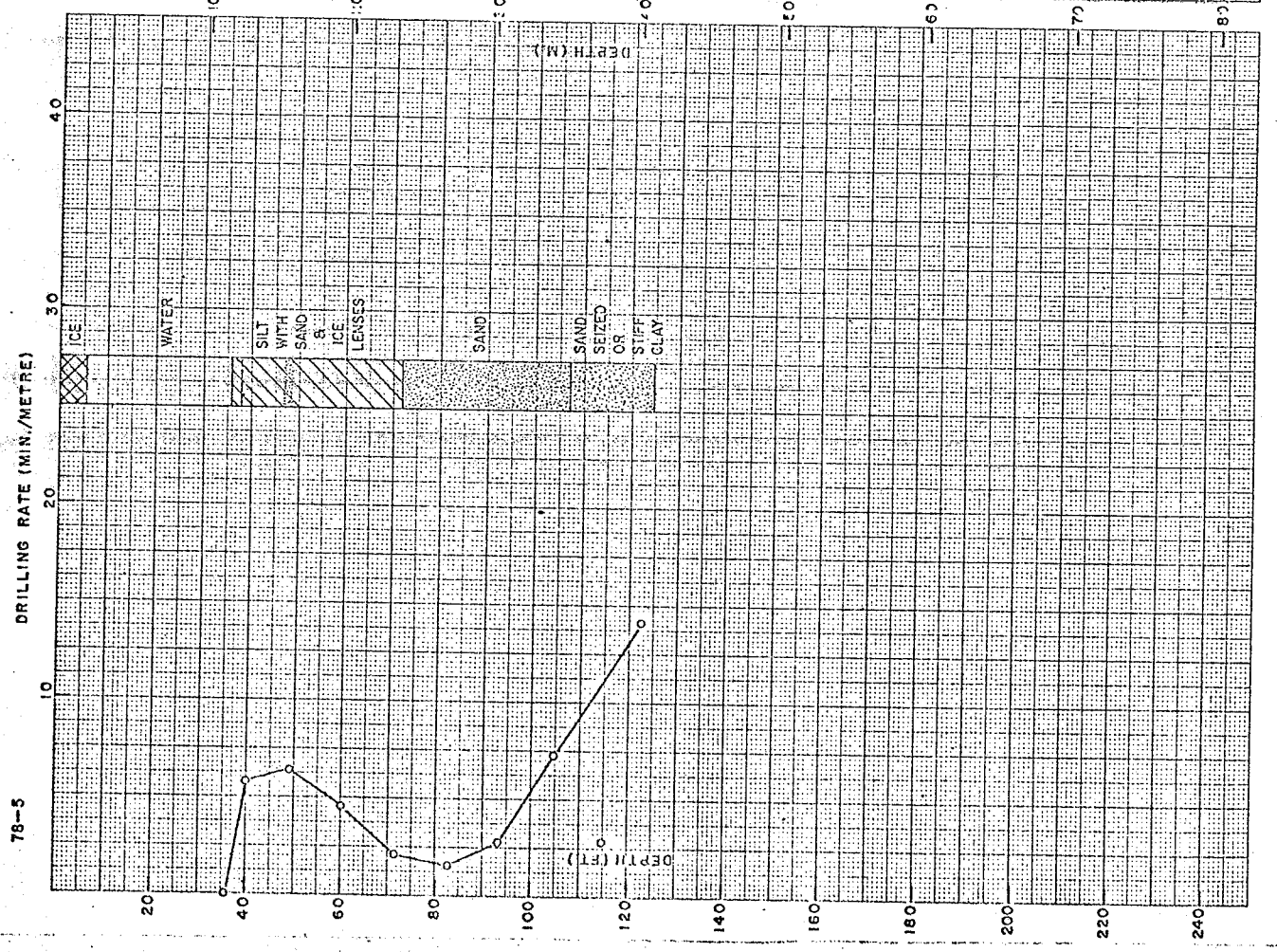
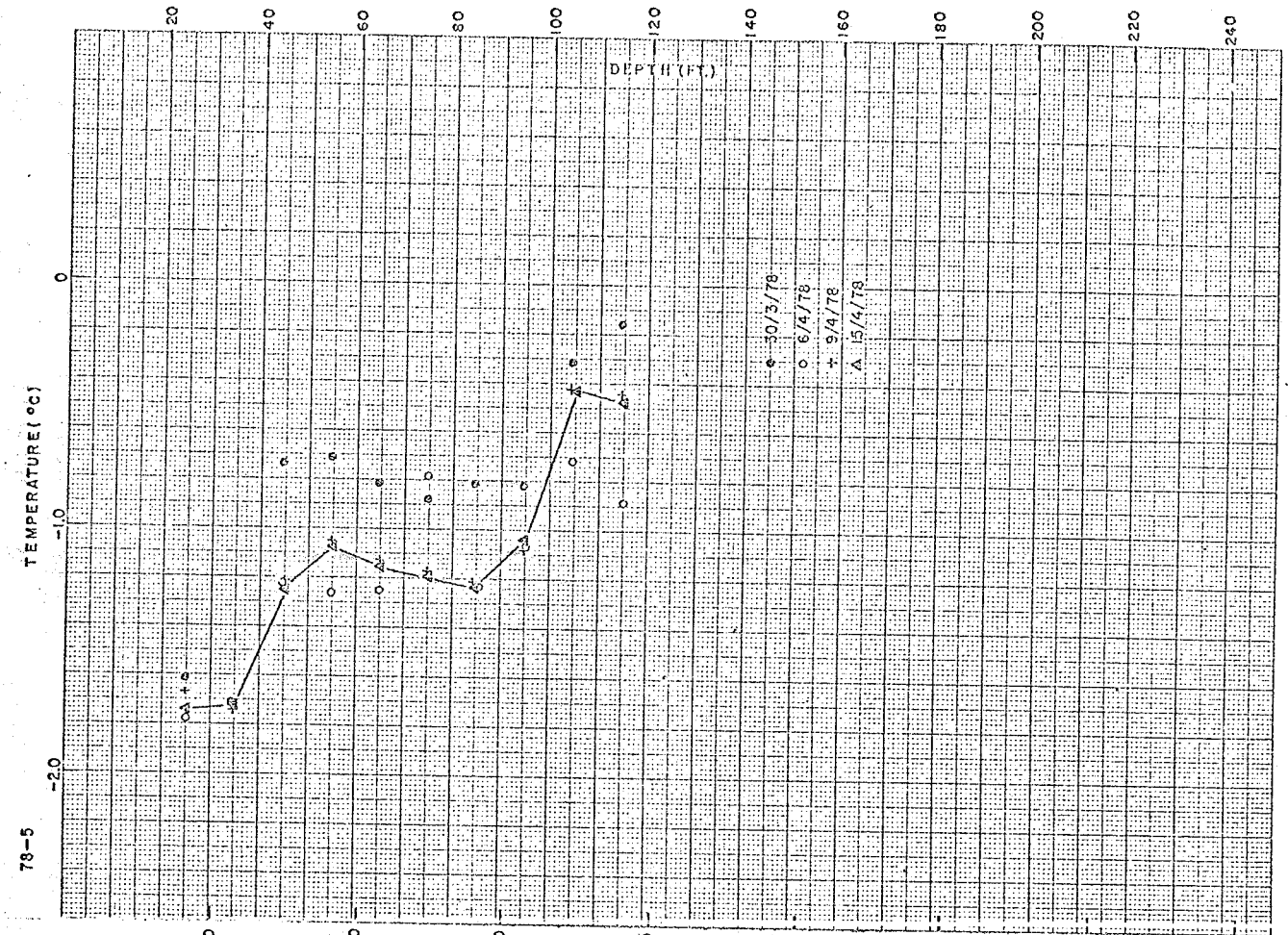
DRILLING RATE (MIN./METRE)

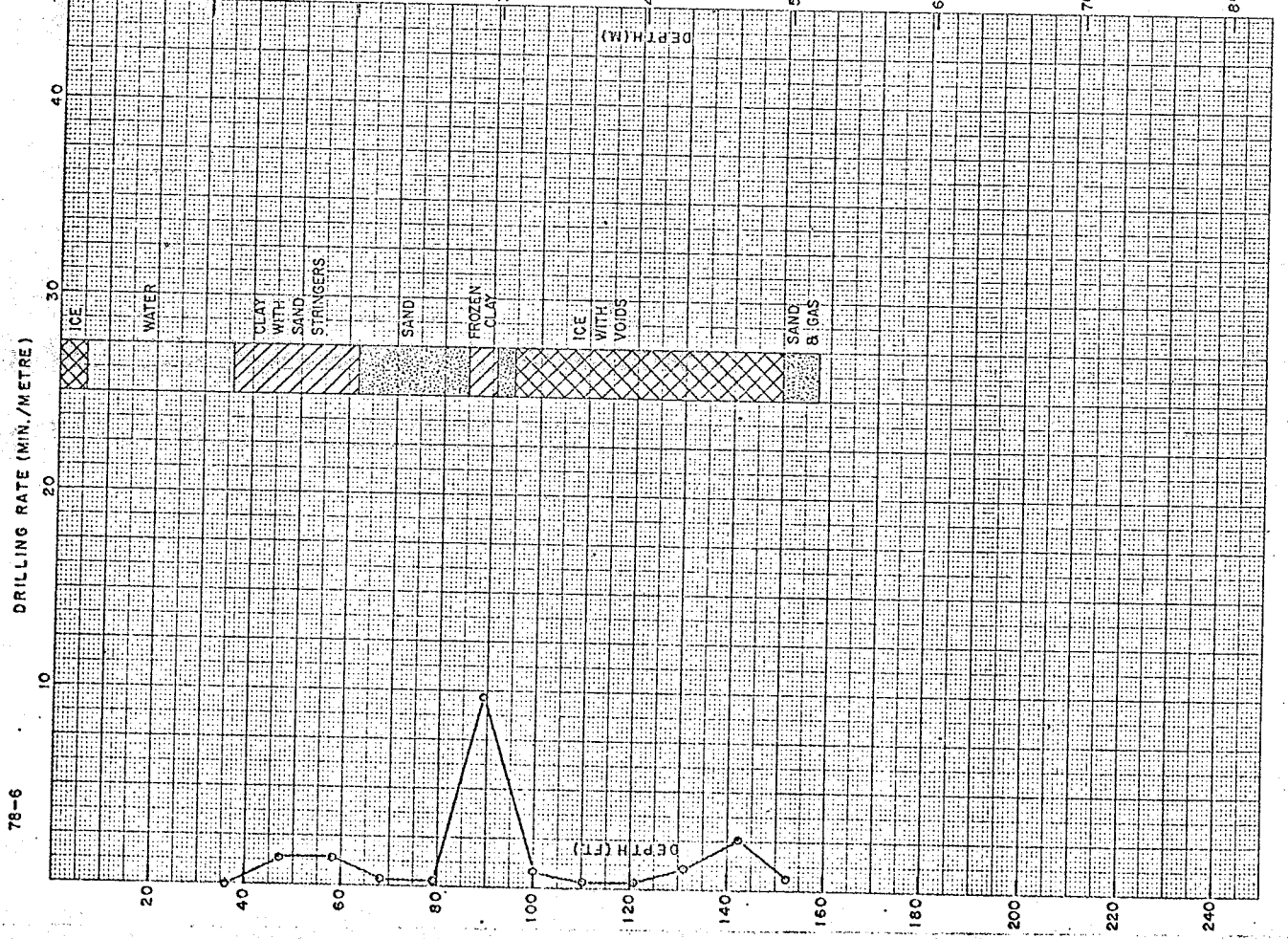
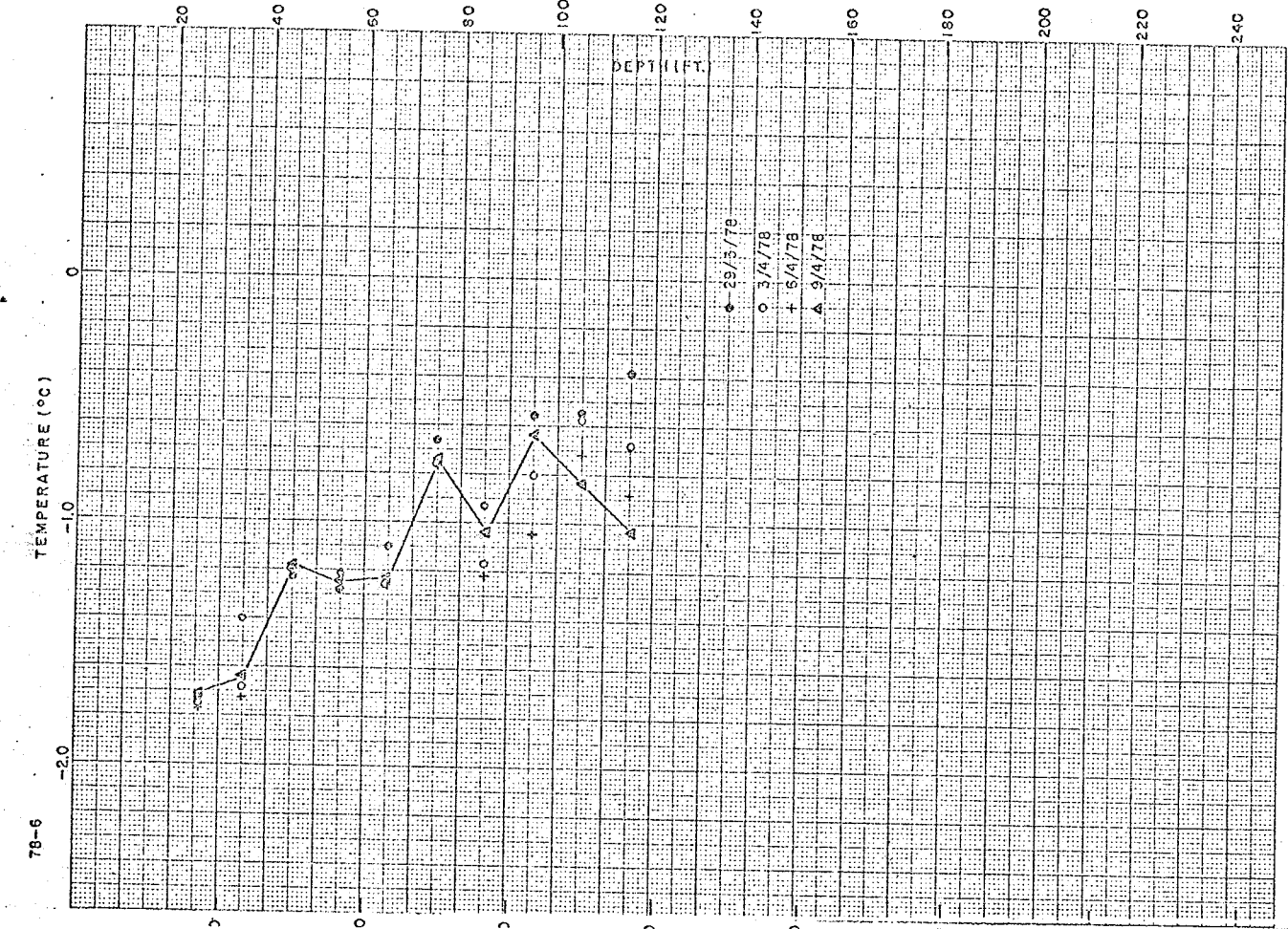


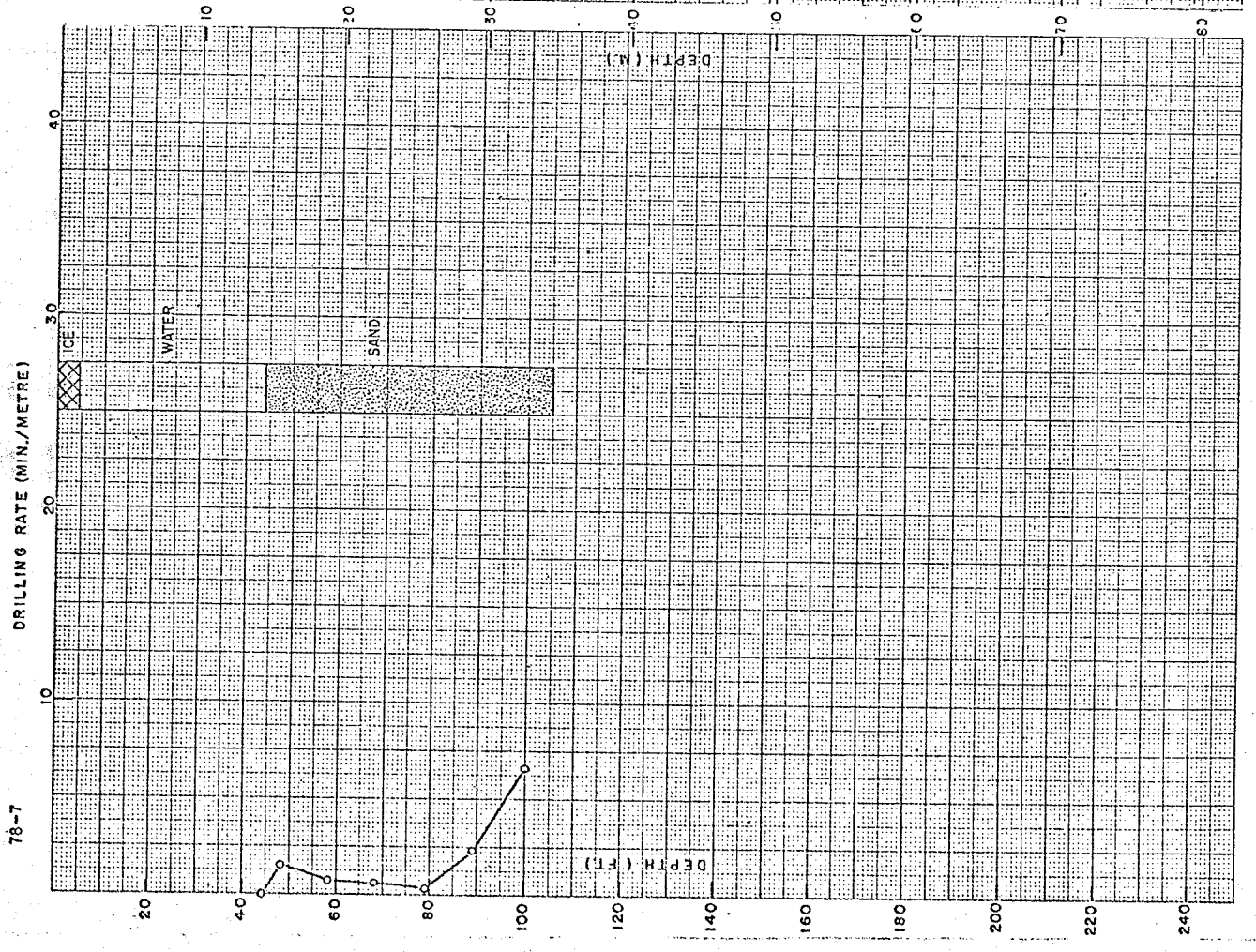
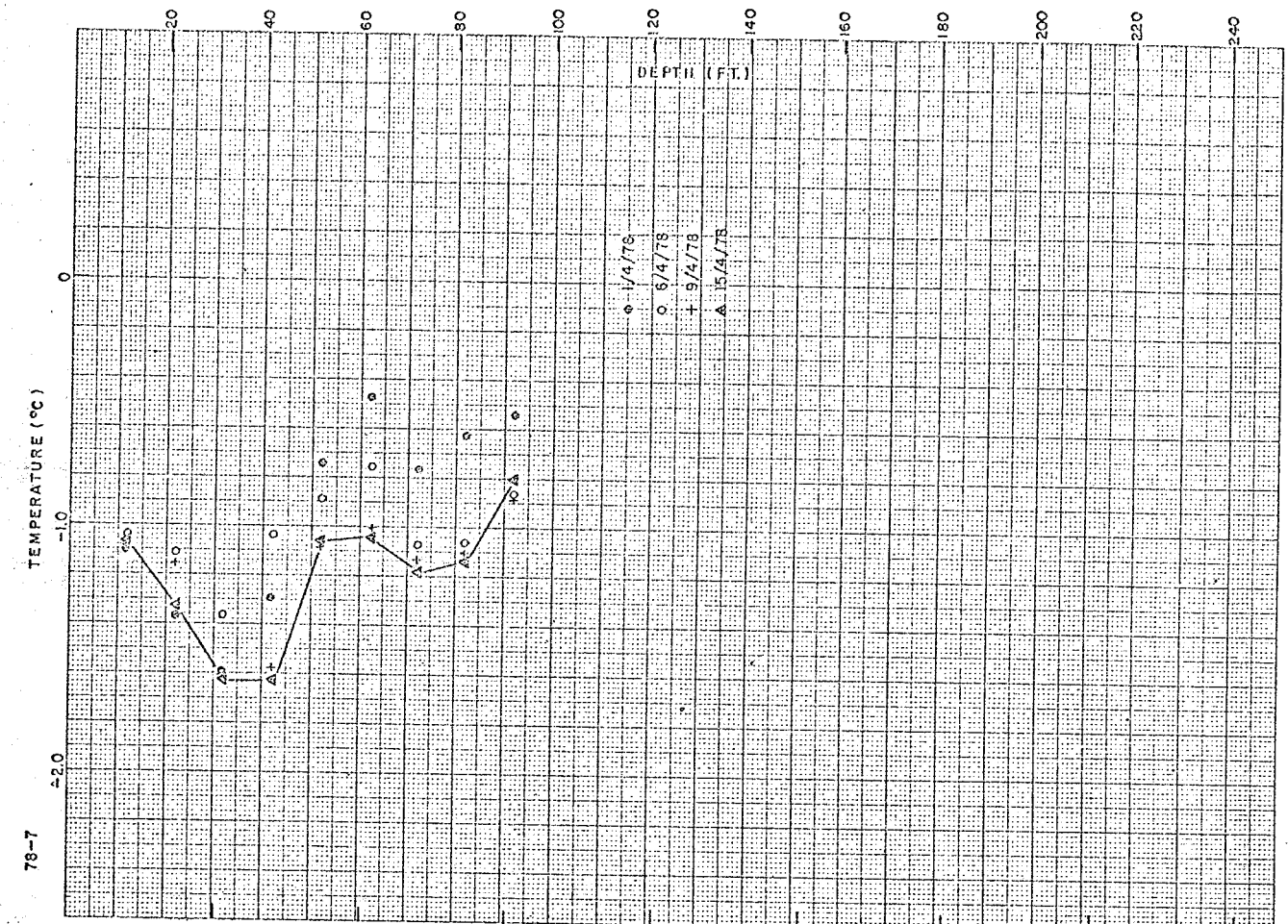
78-4

TEMPERATURE (°C)

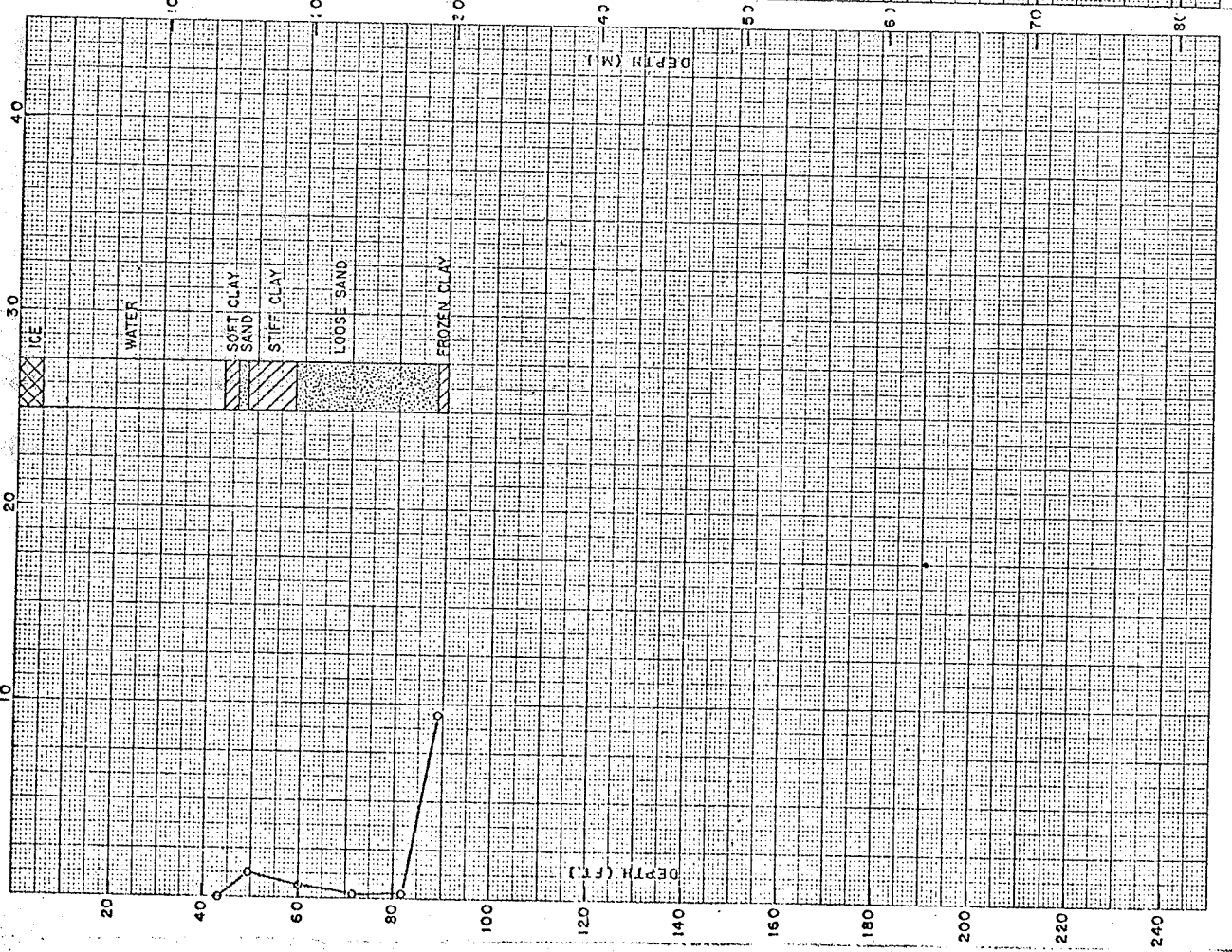




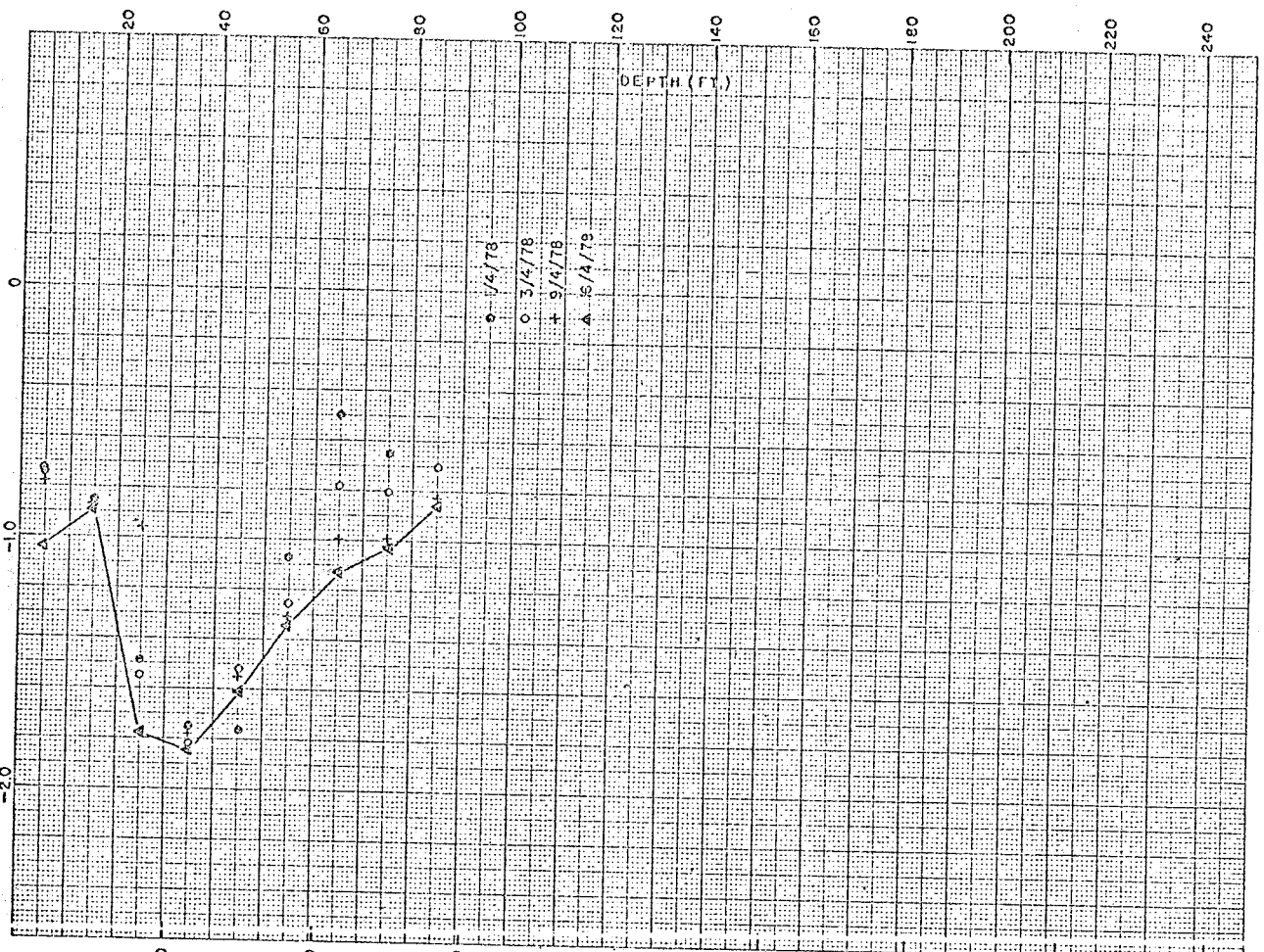




78-8 DRILLING RATE (MIN./METRE)

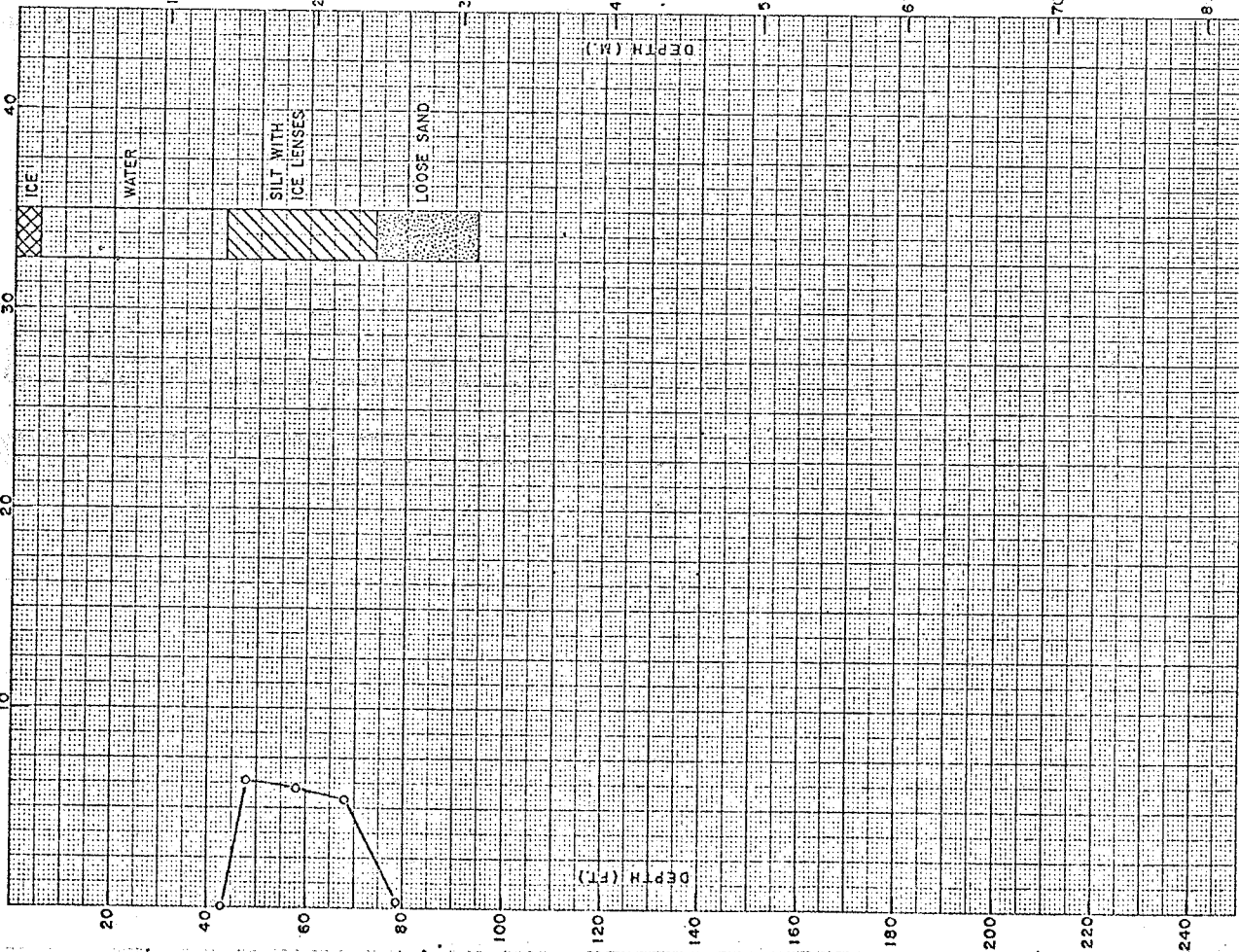


78-8 TEMPERATURE (°C)



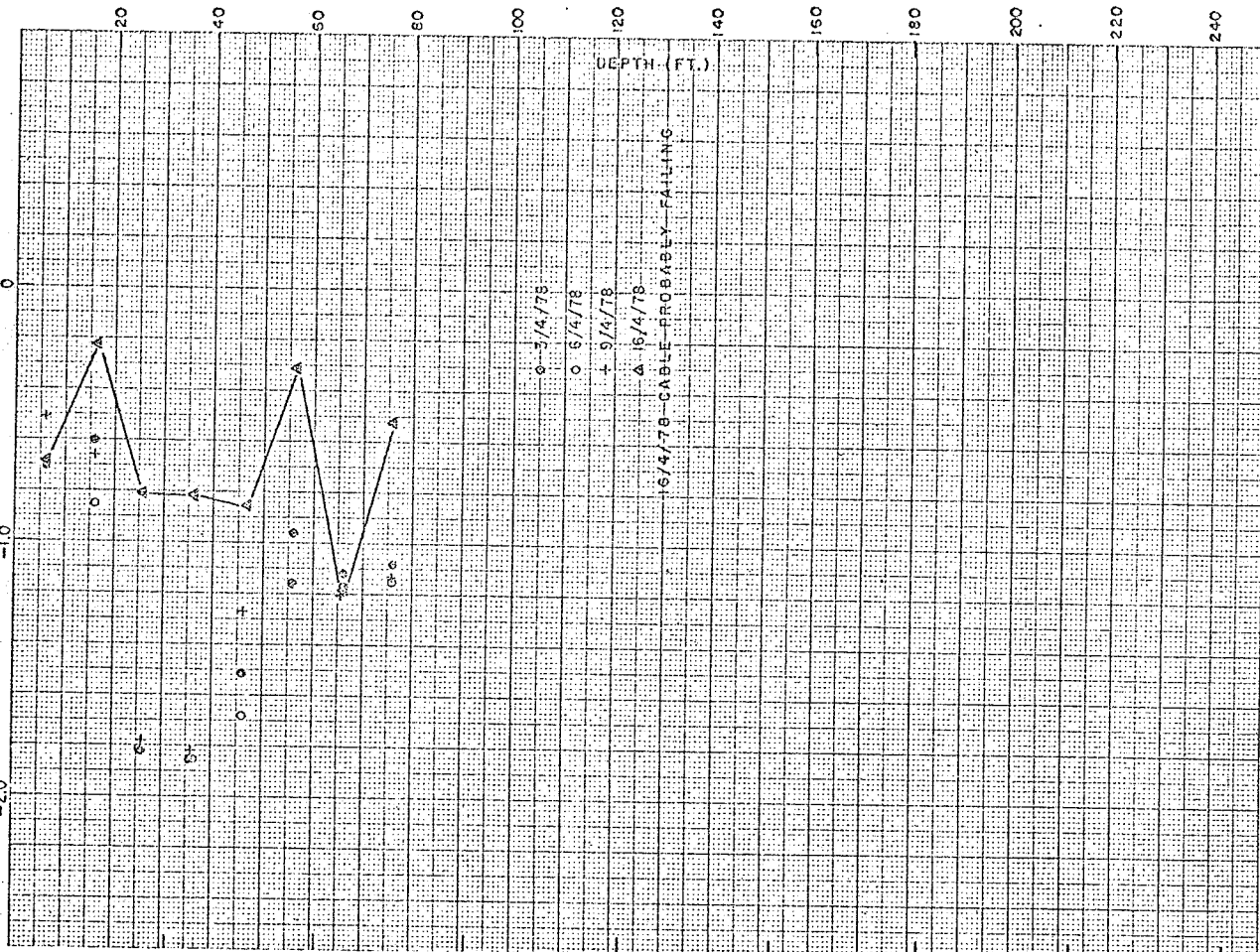
78-9

DRILLING RATE (MIN./METRE)



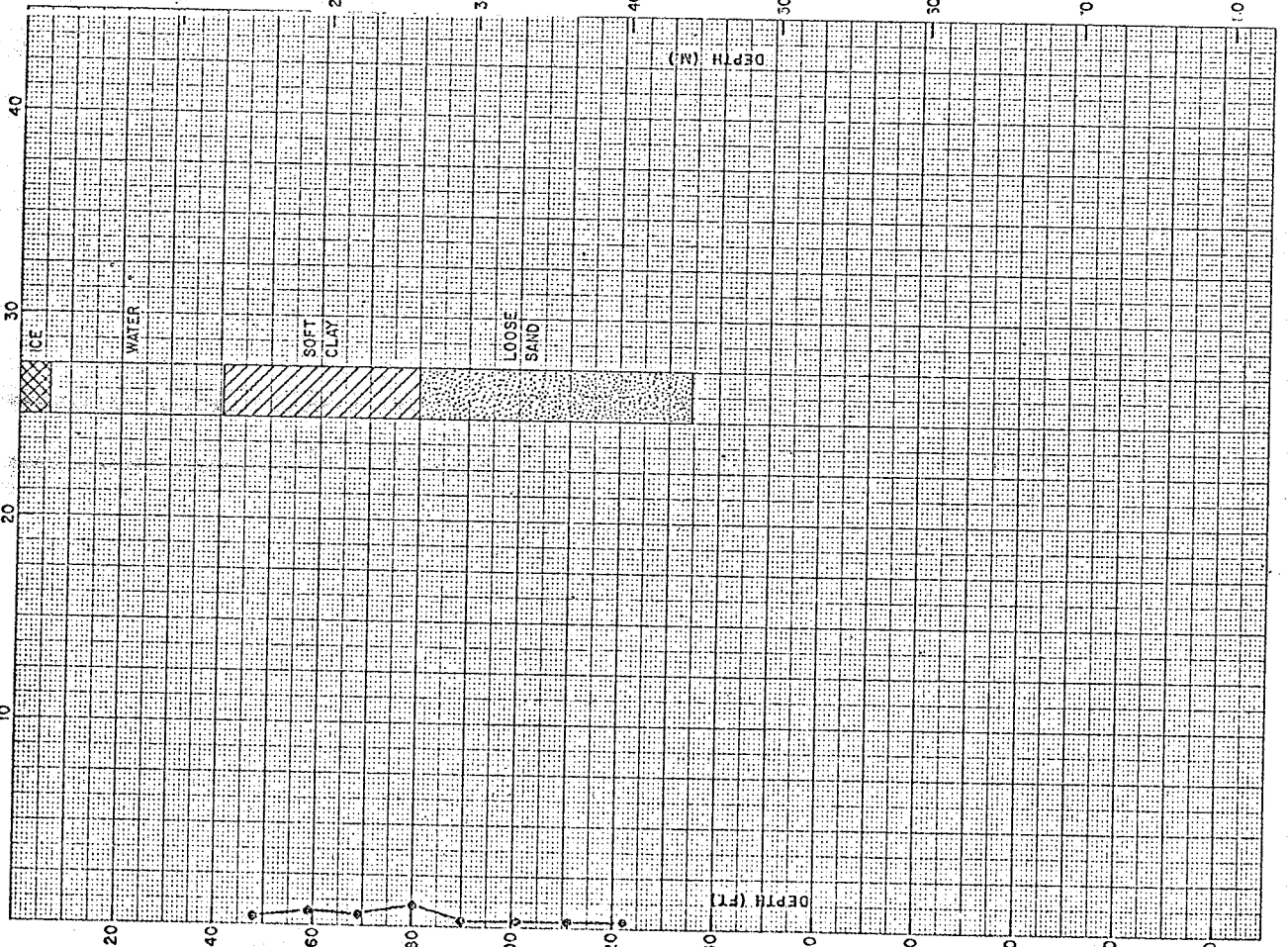
78-9

TEMPERATURE (°C)



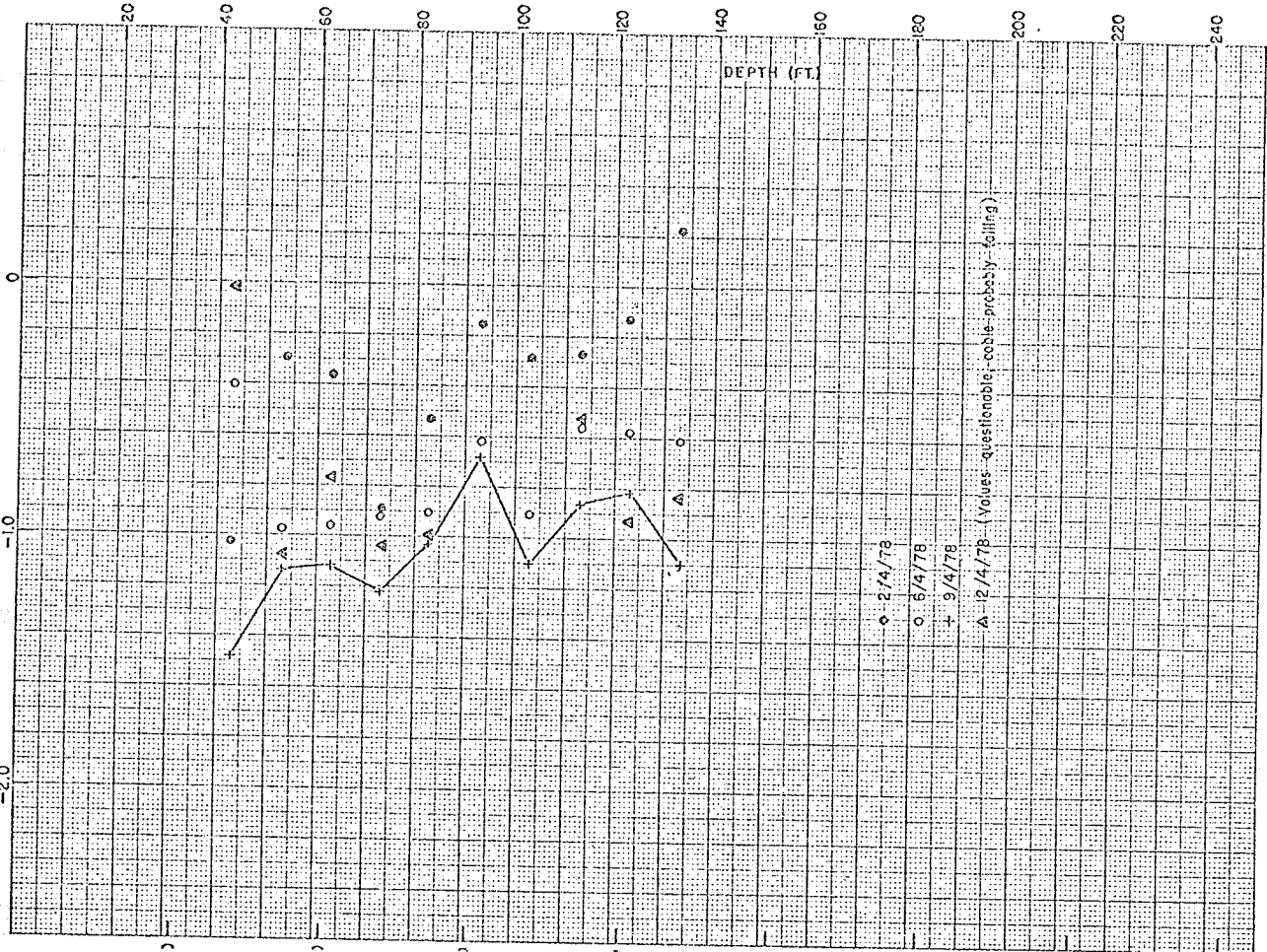
78-10

DRILLING RATE (MIN./METRE)



78-10

TEMPERATURE (°C)

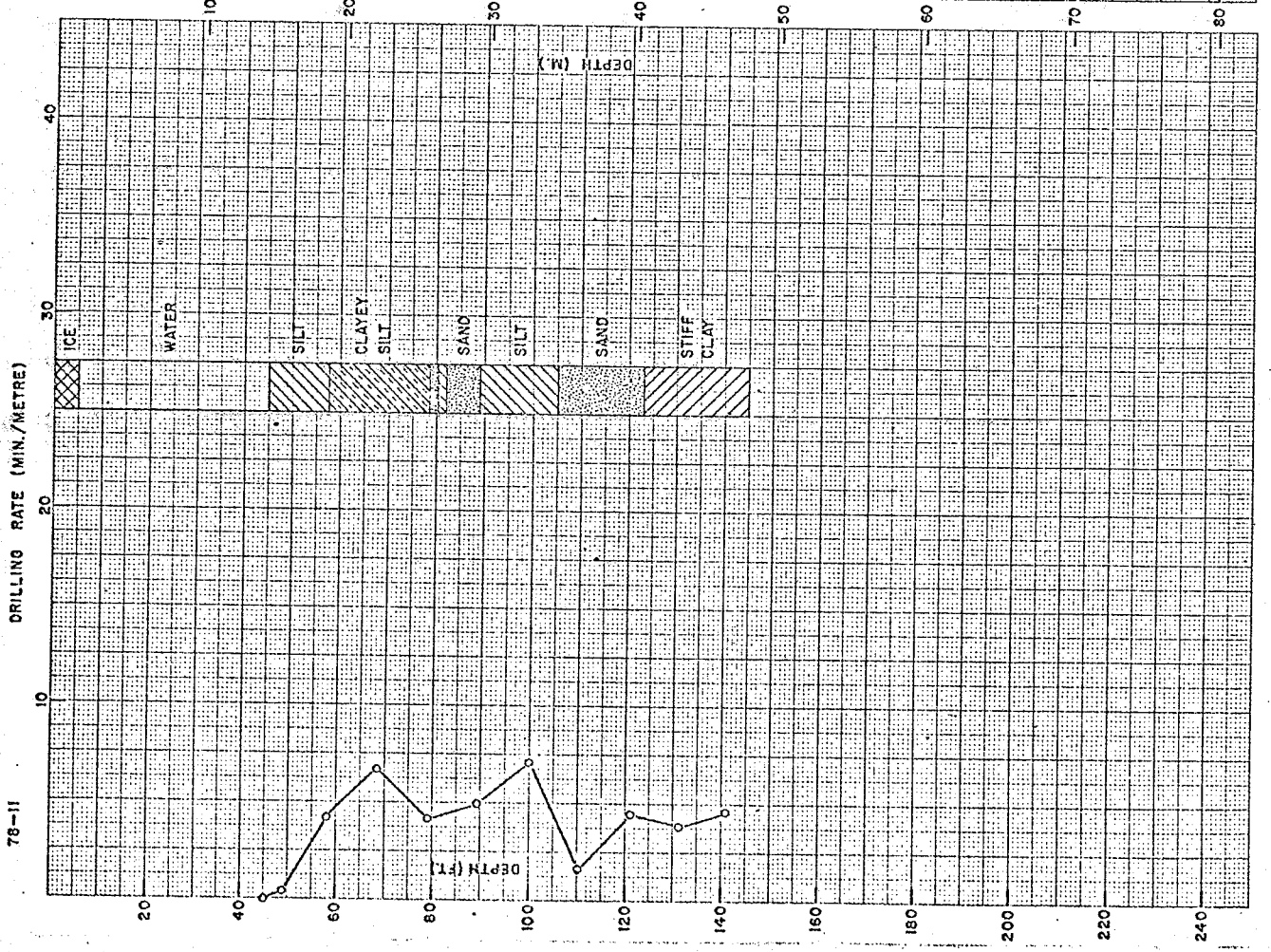
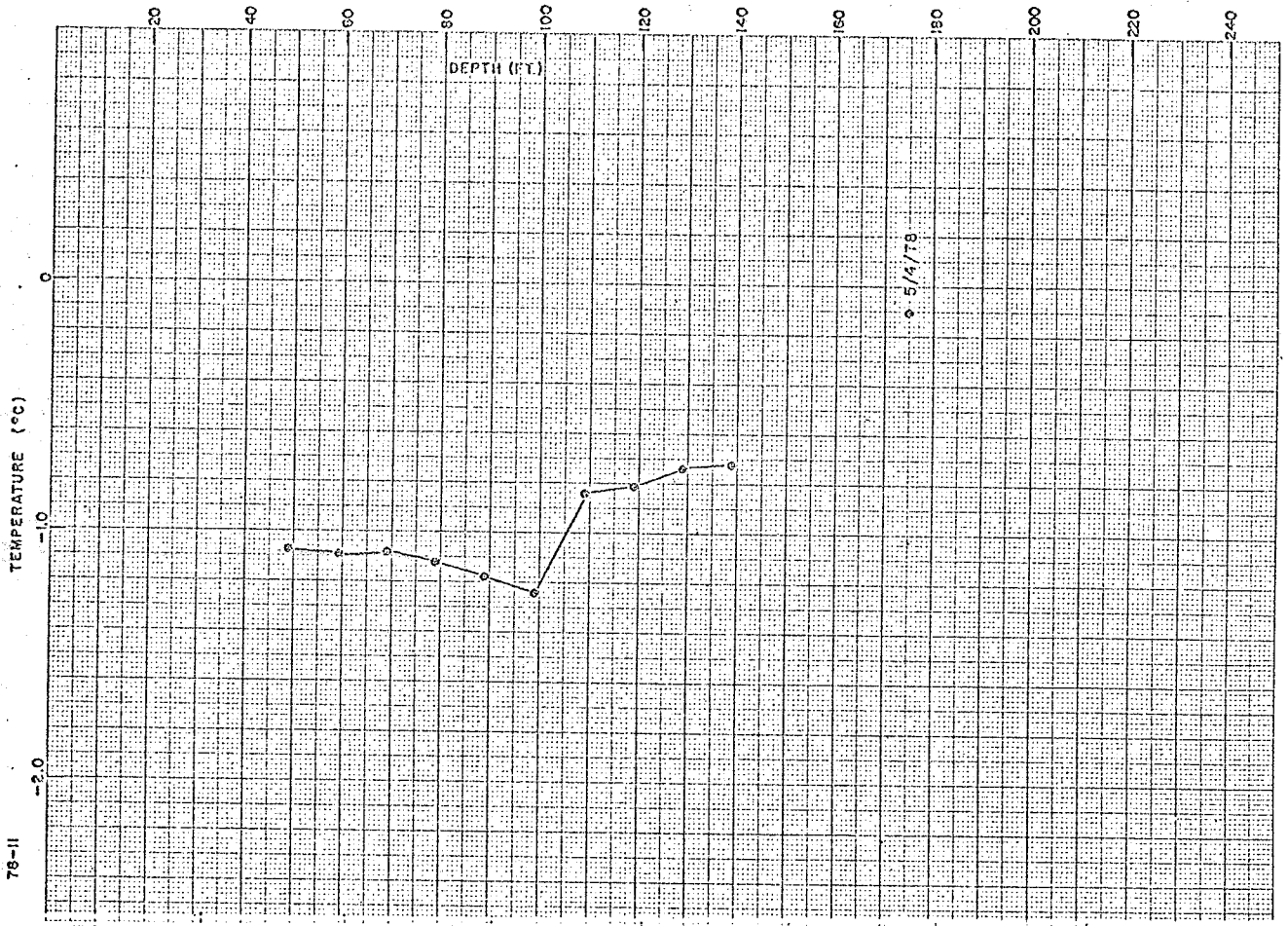


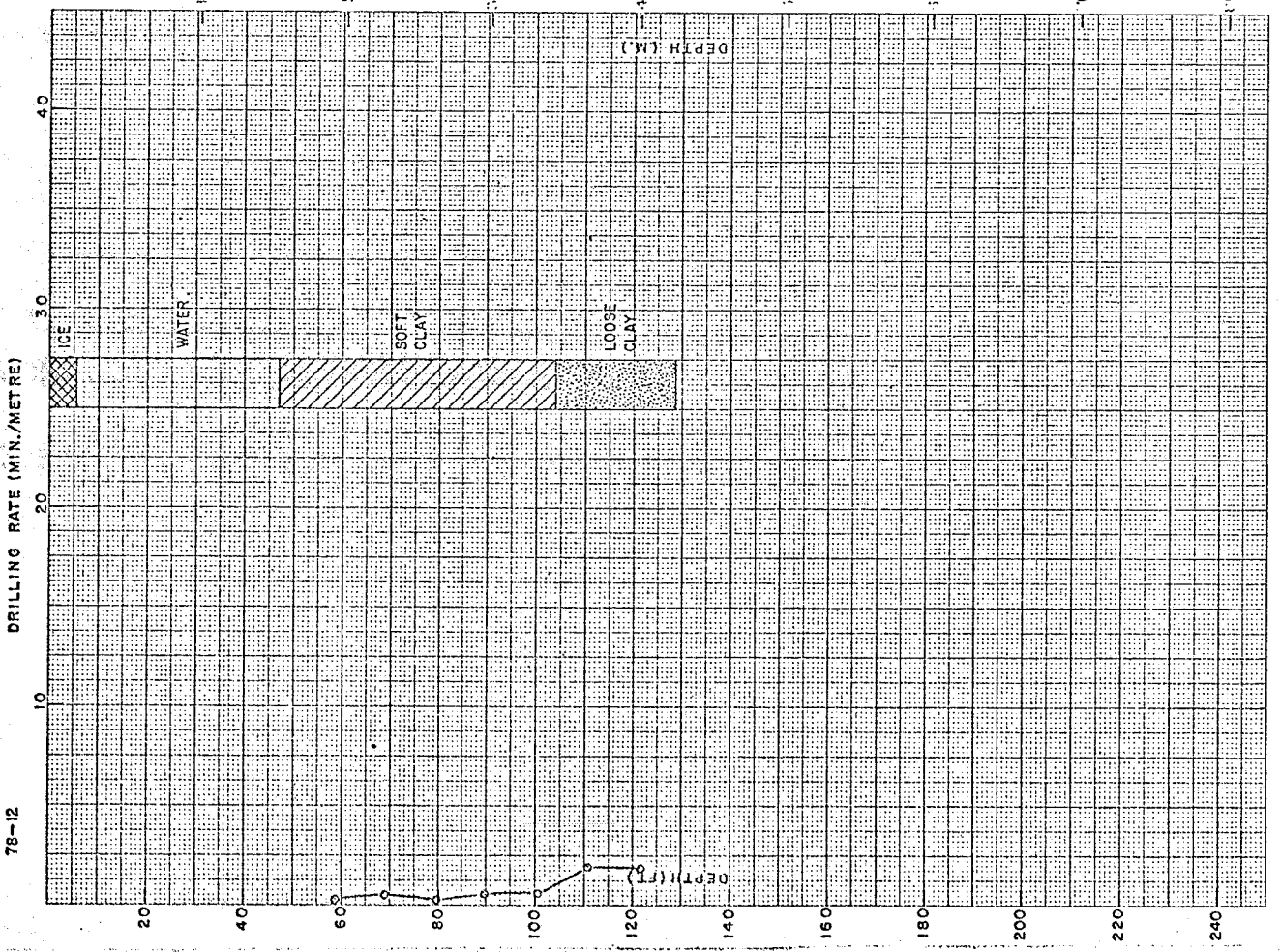
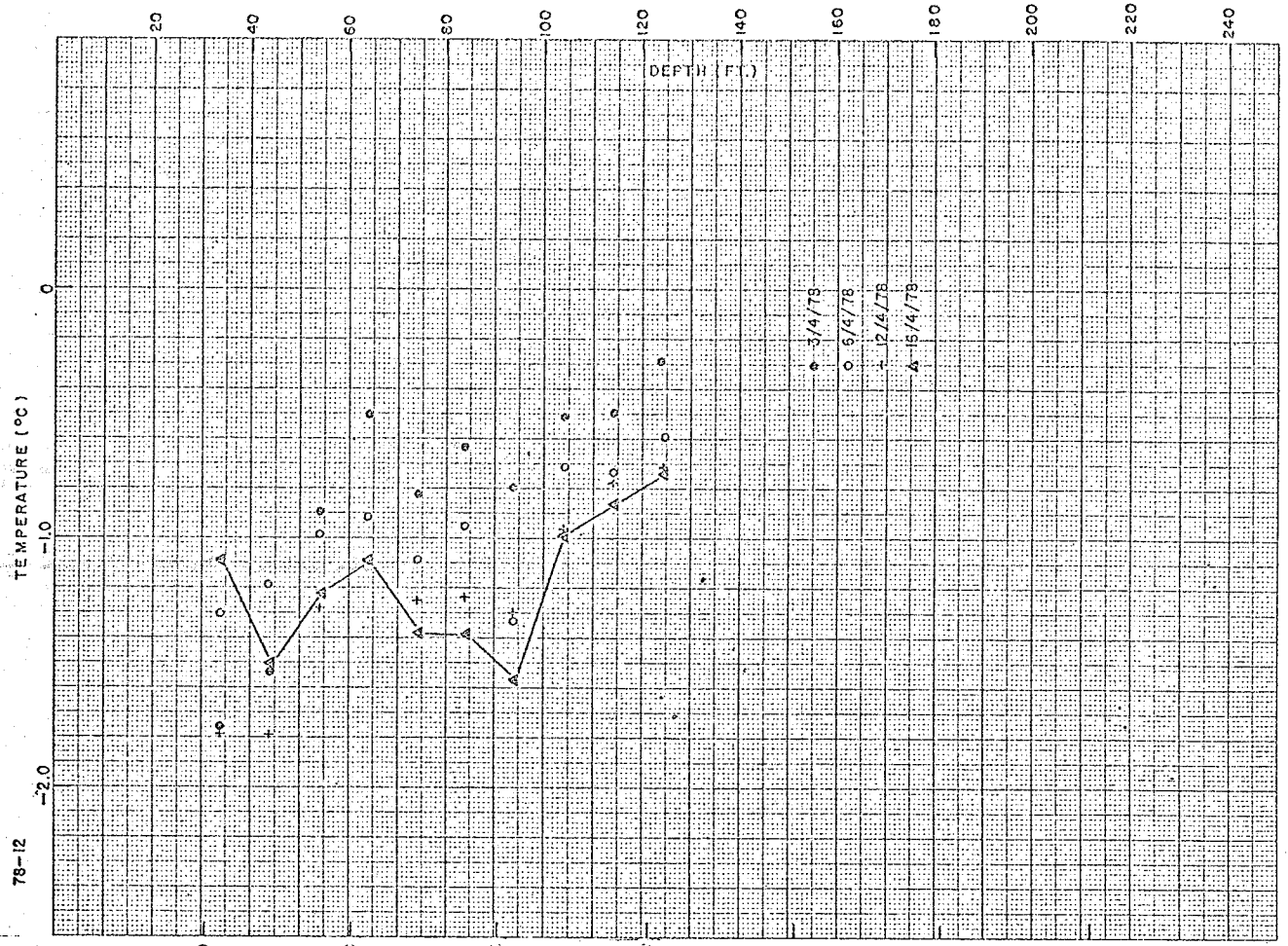
o 2/4/78

△ 6/4/78

+ 9/4/78

A 12/4/78 (Values questionable - cable probably failing)





HOLE NO. 78-1A AREA DELTA FRONT DATE 24/3/78

LAT. 69° 43.8' N. WATER DEPTH + ICE 34 Ft.

LONG. 135° 42.6' W ICE THICKNESS 5 Ft.

PIPE L	DEPTH	TIME	PRESS	REMARKS
1	10.5 ft			
2	21.0			
3	31.5			Sea bottom 34 Ft. below ice-surface
4	42.0	11:45		Frequent ice lensing
5	53.5	12:12		Distinct lensing
6	64.0	12:25		(Problems new swivel coming unscrewed)
7	74.5	12:54		Thick heavy clay (?) - some lensing
8	85.0	14:02		- few lenses, easier at base
9	95.5	14:31		- distinct lensing
10	106.0	14:56		- dropped last 5' in sand
11	116.5	15:10	PRESSURE NOT RECORDED	Fast drilling in sand- water flow on disconn. (few bubbles)
12	127.0	15:15		" "
13	137.5	15:19		" "
14	148.0	15:29	PRESSURE NOT RECORDED	Medium " " " - no flow on disconn.
15		15:37		pipe jammed; unable to recover or advance, tried to circulate. On disconnection water column 7' high in drill tent, initially clear then almost black. Started 16:10 ended 16:35. Water fresh. Thermistor cable could not be run as pipe full of goo at 25'. Too dangerous to attempt recirculation as suspect flow only stopped by silting of pipe. Hole abandoned.

HOLE NO. 78-2AREA DELTA FRONTDATE March 24, 1978LAT. 69° 45.2'WATER DEPTH + ICE 30.5'LONG. 135° 24.1'ICE THICKNESS 5.5'

PIPE L	DEPTH	TIME	PRESS	REMARKS
10.5	31.5 - 42	4 min		31.5 - 34.5 mud, 34.5 - 42 stiff clay & silt silt & clay returns, no sample
10.5	42 - 52.5	13:19 13:23		stiff clay, no sample
10.5	52.5 - 63	13:25 13:27		clay, no sample
10.5	63 - 73.5	13:30 13:33.5		clay with sand lenses (fast drilling)
10.5	73.5 - 84	13:36 13:38		73.5 - 77.6 fast drilling (sand, loose) 77.5-84 clay
10.5	84 - 94.5	13:41 13:41.5		fast drilling - loose sand
10.5	94.5-105	13:43.5 13:45	NOT	94.5-96.5 sand, 96.5-105 silt with sand
10.5	105-115.5	13:48 13:55?		105-111 silt, 111-115.5 coarse gravel stringers
10.5	115.5-126	13:47.5 13:56	PRESSURE	coarse material or ice lenses
10.5	126-136.5	14:00 14:08.5		clay, clay returns, small sample
10.5	136.5-147	14:10.5 14:17		clay with sand lenses
10.5	147-157.5	14:19.5 14:32		stiff clay
10.5	157.5-168	14:33.5 14:57.0		stiff clay
10.5	168-178.5	15:00 15:35		clay with sand stringers (fast drilling) gas bubbles
10.5	178.5-189	15:38 15:43		178.5-183 clay (stiff), 183-189 sand (fast drilling) much gas
10.5	189-199.5	15:45 15:46		189-197 - sand, 197-199.5 clay
				pipe seized
				Installed thermistor cables # 208 and # 209. Bottom therm on # 208 is at 181.5'.
				Top therm at 91.5'. Bottom therm on # 209 is at 86.5', top therm is 3.5' above ice
				Installed 2" plastic casing to 95'.

HOLE NO. 78-3AREA DELTA FRONTDATE March 27, 1978LAT. 69° 48.0' NWATER DEPTH + ICE 35 Ft.LONG. 135° 14.7' WICE THICKNESS 5 Ft.

PIPE L	DEPTH	TIME	PRESS	REMARKS
1	10.5			in water
2	21.0			"
3	31.5			"
4	42.0	10:45		5' in water, 3' silt, 2' sand
5	52.5	11:02		silt with thin sand or ice lens
6	63.0	11:29		slow drilling - clay fine sand (wrench speeded up considerably)
7	73.5	11:52		stiffer drilling in clay
8	84.0	12:06	NOT RECORDED	back pressure on disconnect - sand
9	94.5	12:21		" - sand
10	105.0	12:46		no back pressure = silt
11	115.5	13:06		loose sand last 3 ft
12	121.5	13:17	PRESSURE NOT RECORDED	4' 0" remains above ice. Very fast drilling
		13:19		loose sand. Pipe pushed hard into base but
				strong flow on disconnect (2' head). Held
				until cable prepared. Cable lowered to
				2nd last thermistor at top pipe. Lowest
				thermistor depth. 76.25 ft from ice surface
				therm +3 1/4', -6 1/4, -16 1/4, -26 1/4,
				-36 1/4, -46 1/4, -56 1/4, -66 1/4, -76 1/4'
				from ice surface
				Cable # 217

HOLE NO. 78-6

AREA DELTA FRONT

DATE March 28, 1978

LAT. 69° 54.0'

WATER DEPTH + ICE 36 Ft

LONG. 134° 33.9'

ICE THICKNESS 5.5 Ft

PIPE L	DEPTH	TIME	PRESS	REMARKS
10.5	31.5-42'			soft clay
10.5	42-52.5'	12:04 12:08		stiff clay with sand stringers
10.5	52.5-63'	12:11 12:15		52.5'-62' clay with sand stringers, sand at 62'
10.5	63-73.5	12:17.5 12:18.5		sand with ice lenses
10.5	73.5-84	12:21 12:22		sand (loose)
10.5	84-94.5	12:24 12:55		84-85 loose sand 85-91.5 frozen clay, 91.5-94.5 loose sand or void
10.5	94.5-105	12:58 13:01	RECORDED	ice with voids
10.5	105-115.5	13:03 13:04	RECORDED	ice with voids
10.5	115.5-126	13:07 13:08	RECORDED	ice with voids some gas bubbles
10.5	126-136.5	13:10 13:14	NOT RECORDED	ice
10.5	136.5-147	13:17 13:25	NOT RECORDED	ice
10.5	147-157.5	13:27 13:29	NOT RECORDED	147-150 ice, 150-157.5 loose sand gas blowing out of sump hole E.O.H.
				installed thermistor cable # 211
				top therm at 25' below ice-level, bottom therm at 115'.
				The steel pipe had to be pulled up three sections to install cable since fresh water returns were frozen in the pipe.
				Built 6" dia. flare stack on sump hole, flared gas (3' flame) for 48 hrs, gas escaping up cracks in ice in 100' radius about stack. Gas has slight odour of H ₂ S, sulphur stain on flare stack.

HOLE NO. 78-9 AREA DELTA FRONT DATE April 2, 1978

LAT. 69° 54.2 N WATER DEPTH + ICE 43 Ft

LONG. 133° 53.8 W ICE THICKNESS 5 Ft

PIPE L	DEPTH	TIME	PRESS	REMARKS
1	10 1/2			in water
2	21			"
3	31.5			"
4	42.0			"
5	52.5	9:55		1' in water, silt some ice lens
6	63.0	10:18	RECORDED	silty some ice lens?
7	73.5	10:37		as above, 68-73' faster unfrozen
8	84.0	11:05		loose sand
9	94.5	11:10		"
10	105.0	11:15	NOT PRESSURE	"
				stiff at start of 10 sand cave of
				frozen clay. Broke pipe at sea floor
				attempting to force. Moved over few inches and redrilled
1	10.5			in water.
2	21.0			"
3	31.5			"
4	42.0			"
5	52.5	12:25		1' in water, silt with ice lens
6	63.0	12:46		silt some ice lens
7	73.5	13:08		"
8	84.0	13:28		loose sand
9	94.5	13:30		

APPENDIX C
TABLES OF
WATER SALINITY, WATER TEMPERATURE
AND DRILLHOLE TEMPERATURE LOGS

Well No.	Date	Time	Temperature (°C)	Salinity (ppt)
101	10/10/50	10:00	10.0	1.0
101	10/10/50	11:00	10.5	1.0
101	10/10/50	12:00	11.0	1.0
101	10/10/50	13:00	11.5	1.0
101	10/10/50	14:00	12.0	1.0
101	10/10/50	15:00	12.5	1.0
101	10/10/50	16:00	13.0	1.0
101	10/10/50	17:00	13.5	1.0
101	10/10/50	18:00	14.0	1.0
101	10/10/50	19:00	14.5	1.0
101	10/10/50	20:00	15.0	1.0
101	10/10/50	21:00	15.5	1.0
101	10/10/50	22:00	16.0	1.0
101	10/10/50	23:00	16.5	1.0
101	10/10/50	24:00	17.0	1.0
101	10/10/50	25:00	17.5	1.0
101	10/10/50	26:00	18.0	1.0
101	10/10/50	27:00	18.5	1.0
101	10/10/50	28:00	19.0	1.0
101	10/10/50	29:00	19.5	1.0
101	10/10/50	30:00	20.0	1.0
101	10/10/50	31:00	20.5	1.0
101	10/10/50	32:00	21.0	1.0
101	10/10/50	33:00	21.5	1.0
101	10/10/50	34:00	22.0	1.0
101	10/10/50	35:00	22.5	1.0
101	10/10/50	36:00	23.0	1.0
101	10/10/50	37:00	23.5	1.0
101	10/10/50	38:00	24.0	1.0
101	10/10/50	39:00	24.5	1.0
101	10/10/50	40:00	25.0	1.0
101	10/10/50	41:00	25.5	1.0
101	10/10/50	42:00	26.0	1.0
101	10/10/50	43:00	26.5	1.0
101	10/10/50	44:00	27.0	1.0
101	10/10/50	45:00	27.5	1.0
101	10/10/50	46:00	28.0	1.0
101	10/10/50	47:00	28.5	1.0
101	10/10/50	48:00	29.0	1.0
101	10/10/50	49:00	29.5	1.0
101	10/10/50	50:00	30.0	1.0
101	10/10/50	51:00	30.5	1.0
101	10/10/50	52:00	31.0	1.0
101	10/10/50	53:00	31.5	1.0
101	10/10/50	54:00	32.0	1.0
101	10/10/50	55:00	32.5	1.0
101	10/10/50	56:00	33.0	1.0
101	10/10/50	57:00	33.5	1.0
101	10/10/50	58:00	34.0	1.0
101	10/10/50	59:00	34.5	1.0
101	10/10/50	60:00	35.0	1.0
101	10/10/50	61:00	35.5	1.0
101	10/10/50	62:00	36.0	1.0
101	10/10/50	63:00	36.5	1.0
101	10/10/50	64:00	37.0	1.0
101	10/10/50	65:00	37.5	1.0
101	10/10/50	66:00	38.0	1.0
101	10/10/50	67:00	38.5	1.0
101	10/10/50	68:00	39.0	1.0
101	10/10/50	69:00	39.5	1.0
101	10/10/50	70:00	40.0	1.0
101	10/10/50	71:00	40.5	1.0
101	10/10/50	72:00	41.0	1.0
101	10/10/50	73:00	41.5	1.0
101	10/10/50	74:00	42.0	1.0
101	10/10/50	75:00	42.5	1.0
101	10/10/50	76:00	43.0	1.0
101	10/10/50	77:00	43.5	1.0
101	10/10/50	78:00	44.0	1.0
101	10/10/50	79:00	44.5	1.0
101	10/10/50	80:00	45.0	1.0
101	10/10/50	81:00	45.5	1.0
101	10/10/50	82:00	46.0	1.0
101	10/10/50	83:00	46.5	1.0
101	10/10/50	84:00	47.0	1.0
101	10/10/50	85:00	47.5	1.0
101	10/10/50	86:00	48.0	1.0
101	10/10/50	87:00	48.5	1.0
101	10/10/50	88:00	49.0	1.0
101	10/10/50	89:00	49.5	1.0
101	10/10/50	90:00	50.0	1.0
101	10/10/50	91:00	50.5	1.0
101	10/10/50	92:00	51.0	1.0
101	10/10/50	93:00	51.5	1.0
101	10/10/50	94:00	52.0	1.0
101	10/10/50	95:00	52.5	1.0
101	10/10/50	96:00	53.0	1.0
101	10/10/50	97:00	53.5	1.0
101	10/10/50	98:00	54.0	1.0
101	10/10/50	99:00	54.5	1.0
101	10/10/50	100:00	55.0	1.0

March 1978 Beaufort Sea Jet Drilling Sites

Depth	78-1	78-3	78-5	78-7	78-9	78-11
(m)						
1	6.0	6.5	6.5	20.5	12.2	11.5
2	6.0		6.0	20.5	11.8	11.5
3	6.0	6.5	6.0	21.0	11.8	11.5
4	6.5	7.0		21.0	11.8	11.7
5	7.0	8.0	12.5	24.0	11.8	13.0
6	9.0	12.0	31.0	34.0	12.0	16.5
7	15.5	24.0	31.5	34.2	18.5	27.0
8	16.5	25.0	32.5	35.5	19.5	28.0
9	17.5	25.8	32.7	35.7	21.0	28.7
10	17.5	26.0	33.0	35.5	22.0	29.0
11		26.5	33.0	35.5	22.5	29.5
12				35.5	22.7	29.7
13					23.0	30.0
14						30.0

Water Temperatures

March 1978 Beaufort Sea Jet Drilling Sites

78-1		78-3		78-5		78-7		78-9		78-11	
Depth (m)	Temp. (°C)	Depth (m)	Temp. (°C)	Depth (m)	Temp. (°C)	Depth (m)	Temp. (°C)	Depth (m)	Temp. (°C)	Depth (m)	Temp. (°C)
3.7	- .43	4.0	- .51	3.0	- .28	1.8	-1.14	3.0	- .83	3.0	- .77
0.0	-1.55	11.0	-1.60	4.6	- .44	3.0	-1.05	4.6	- .76	4.6	- .72
				6.4	-1.38	4.6	-1.04	6.1	-1.22	6.1	-1.16
				7.9	-1.65	6.1	-1.58	7.6	-1.64	7.6	-1.66
				9.5	-1.66	7.9	-1.63	9.5	-1.69	9.1	-1.71
				10.7	-1.66	9.1	-1.66	11.0	-1.72	10.7	-1.74
				11.0	-1.65	10.7	-1.69	12.5	-1.72	12.2	-1.74
						12.2	-1.69	13.4	-1.68	13.7	-1.72
						12.5	-1.69				