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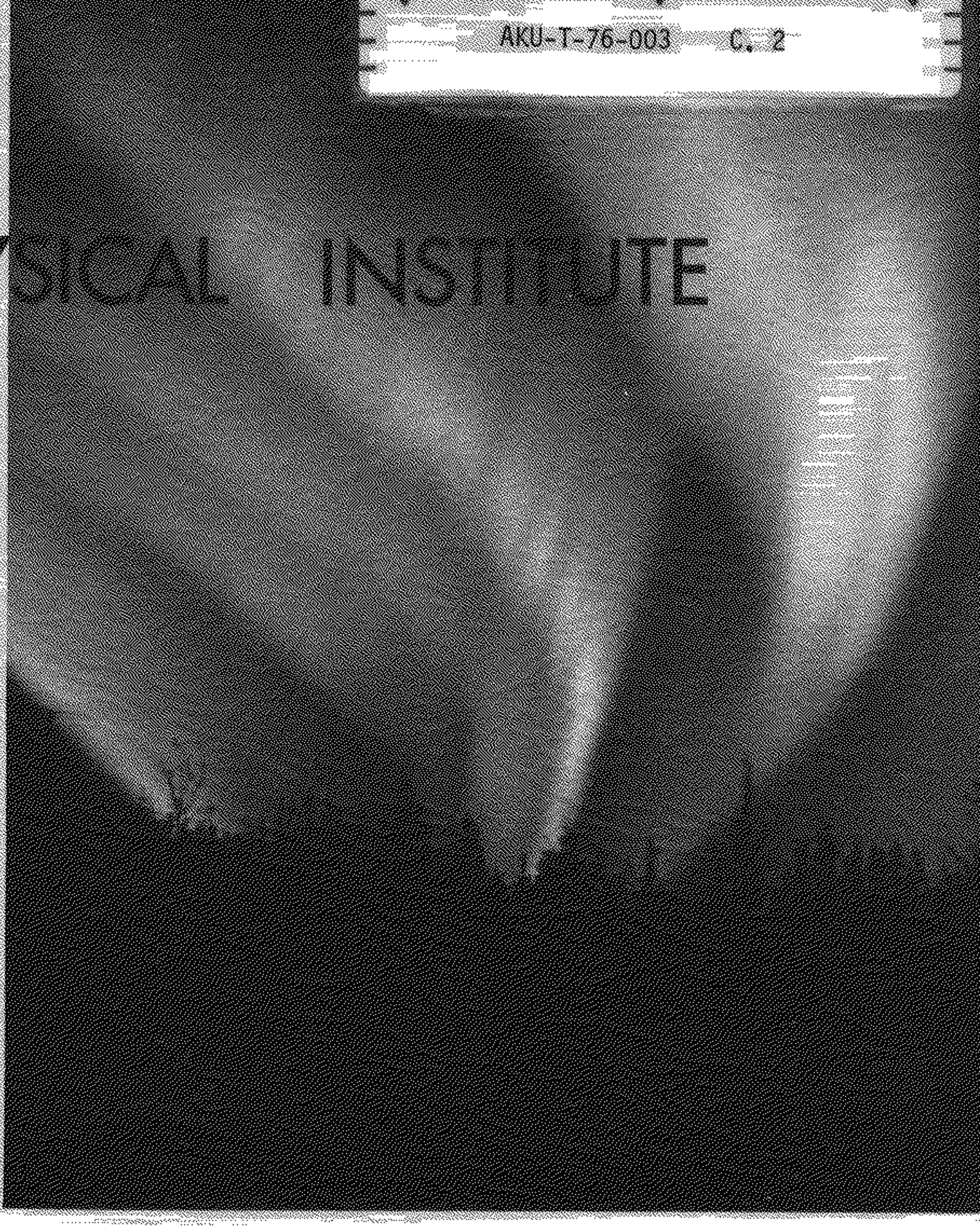

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SUBSEA PERMAFROST AT PRUDHOE BAY, ALASKA: DRILLING REPORT

by

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and

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SCIENTIFIC REPORT

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SUBSEA PERMAFROST AT PRUDHOE BAY, ALASKA: DRILLING REPORT AND DATA ANALYSIS

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SUMMARY

A subsea permafrost drilling program conducted near Prudhoe Bay, Alaska, is described. The drilling and sampling procedures, the techniques, analysis and results of the soil studies, temperature measurements, salt concentration measurements, permeability measurements, penetration tests and the implication of the results for offshore resource development are also given. The conclusions of this research are enumerated below:

(1) Along the line of our drilled holes at Prudhoe Bay, ice-bonded permafrost exists almost up to the sea bed within 200 m from shore. At 481 m from shore, there is an unbonded layer 19 m thick beneath the sea bed. At 3,370 m the unbonded layer is probably between 46 and 71 m thick. This unbonded layer exists in the presence of negative sea bed temperatures.

(2) A sharp, well-defined interface was found between the unbonded layer and the underlying ice-bonded subsea permafrost at all positions within 481 m from land.

(3) The subsea soils are sandy gravel with some silt overlain by a thin layer of silty sand. This layer increases in thickness from a few meters nearshore to about 14 m at 3,370 m offshore.

(4) The mean annual temperature at the sea bed increases from -3.4°C at 203 m offshore where ice freezes to the sea bed to roughly -1.1°C at 481 m offshore to -0.7°C at 3,370 m offshore.

(5) Where ice freezes to the sea bed the mean annual sea bed temperature is several degrees lower (see (4) above) and the thickess of the unbonded layer is only a few meters. A few hundred meters farther offshore (481 m from the beach) where

the ice does not freeze to the sea bed, the thickness of the layer increases rapidly to about 19 m.

(6) The permeability of the subterranean permafrost is zero.

(7) Preliminary experiments indicate that the saturated hydraulic conductivity of the unbonded subsea permafrost is about 10^{-6} to 10^{-7} m s^{-1}.

(8) Salt concentrations where ice freezes to the sea bed range up to 3-4 times that of normal sea water. Where there was 0.1-0.2 m of water under the ice cover, the salt concentration was about twice that of normal sea water. Normal sea water was found under the ice cover 3,370 m offshore where there was about 1 m of water under the ice cover.

(9) A few small ice lenses were found in a hole 195 m from shore. No massive ice was found in any of the offshore holes.

(10) The average thermal conductivity of the unbonded silty soil samples were estimated to be about 1.6 W(m deg)$^{-1}$. For comparison, a value of 2.6 W(m deg)$^{-1}$ was calculated using a weighted geometric mean formula.

(11) The thermal diffusivity of the unbonded silty soil samples, calculated from the average thermal conductivity, was 17 m^2 a^{-1}. This is to be compared with a value of about 21 m^2 a^{-1} for unbonded sandy gravel with silt, obtained from an analysis of the temperature data in hole 481.

(12) The age of some wood, twigs and organic matter found in hole 3,370 at a depth of 13.7 m was 22,300 years with a standard deviation of 1,200 years using a carbon 14 dating technique.

I. INTRODUCTION

Rational development of the offshore oil and gas reserves along the northern coast of Alaska requires a thorough understanding of the subsea soils. Exploration, discovery and production of these oil and gas deposits involve drilling, trenching and the use of these soils as foundations for structures. Therefore, the variations in subsea soil types, their distribution, engineering properties and state of ice-bondedness must be known.

Past sea level history (Müller-Beck, 1966) indicates that the continental shelf along the northern coast of Alaska was exposed to cold air temperatures which caused permafrost to form. Subsequent increases in sea level have resulted in a state of ocean transgression on land until 3,000-4,000 years ago. The sea level has been nearly static since then, but coastal erosion still continues along the flat northern coast of Alaska by thermal and mechanical processes. The average rate of coastal erosion is 1-2 m a^{-1} (Alexander and others, 1975). As a result, the permafrost that has been covered by the ocean during the coastal erosion process has not had sufficient time to respond to the new thermal and salt boundary conditions at the sea bed. In addition, the sea bed temperature appears to be negative (Lewellen, 1973). Therefore, it is probable that substantial areas of subsea permafrost exist on the continental shelf, particularly nearshore. A positive way of delineating areas of subsea permafrost and determining soil properties and state of bondedness is by drilling and soil sampling.

This report describes a subsea permafrost drilling and sampling program which was carried out between April 30 and May 18, 1975, at a site near the northwest corner of Prudhoe Bay, Alaska. Two-meter thick fast ice was used as a drilling platform to drill into the sea bed. The drilling was contracted to the Road Materials Laboratory, Alaska Department of Highways, which is located on the University of Alaska campus. The drilling crew consisted of a geologist, driller and helper who had extensive experience in drilling and sampling permafrost; the principal investigators were also present. The site location was a line extending from the North Prudhoe Bay State #1 well seaward toward Reindeer Island. All holes were drilled within 3.4 km of land and the location of the line of drilled holes is shown in Figure 1. The new Atlantic Richfield Company (ARCO) causeway is ≈ 0.5 km to the west of our drilling line.

The drilling and sampling procedures used, the techniques and results of the soil analysis, temperature measurements, salt concentration measurements, preliminary permeability measurements, penetration tests and the implications of the results for offshore resource development are given. Field drilling logs and sample nomenclature are included in Appendix A.

II. DRILLING AND SAMPLING PROCEDURES

The drill rig was a Mobile B-61 rotary drill mounted on a RN-110 Nodwell tracked vehicle. Logistics support was provided with a RN-75 Nodwell tracked vehicle and two snowmobiles with sleds. Drilling methods included rotary wash boring and the use of hollow stem and standard augers. Rotary wash boring using NX casing, BW rod and sea water mixed with the drilling mud as a drilling fluid was the most satisfactory method for the deeper holes. The mud was used in an effort to reduce the sample contamination by infiltration with drilling fluid.

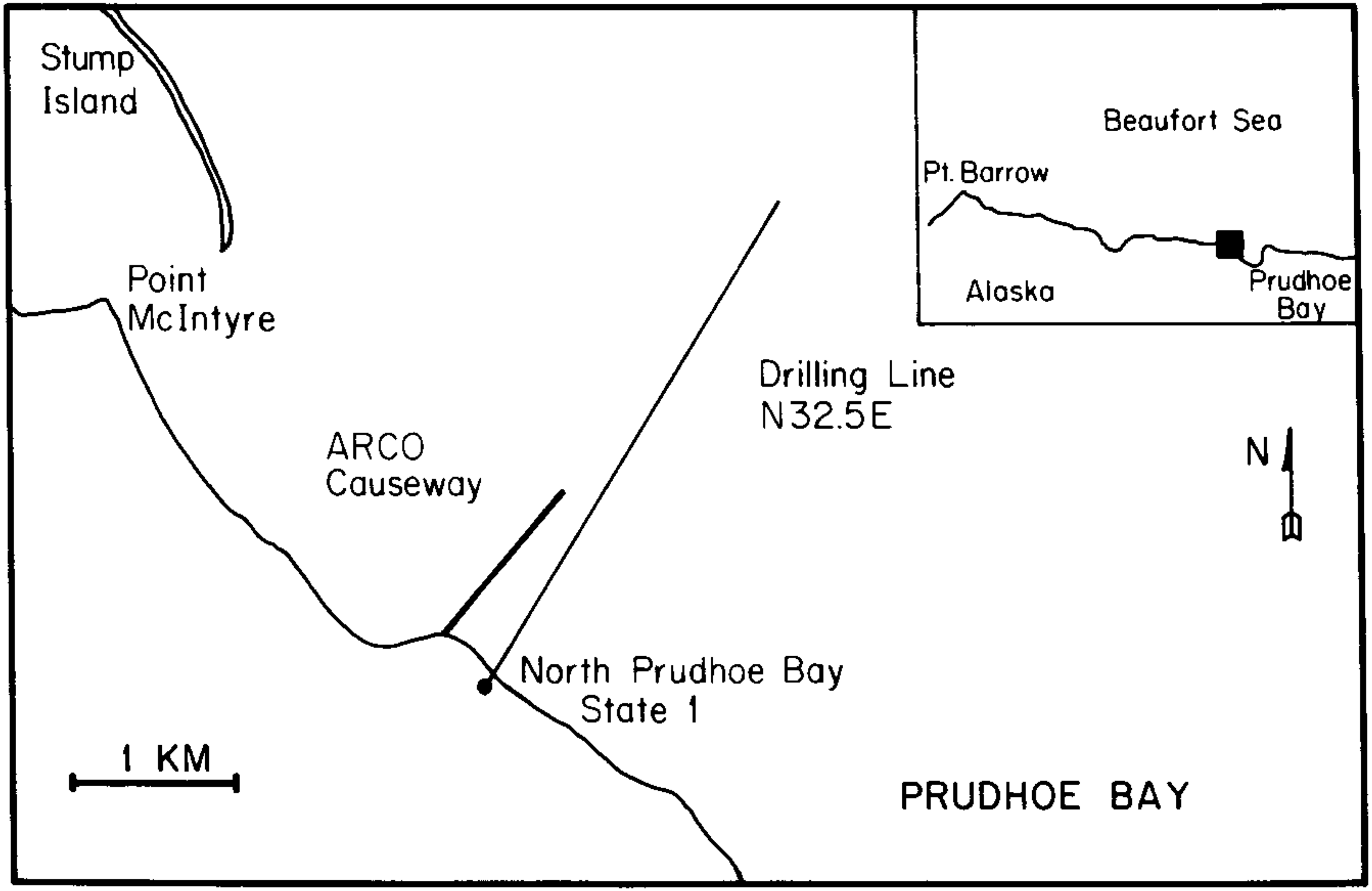

Figure 1. Map showing the location of the drilling line on the northwest corner of Prudhoe Bay.

A hollow stem auger with a 0.075 m I.D. was suitable for shallow holes (< 23 m), except those in the frozen silty soil on land. It was observed that fine sand tended to cause the pilot bit to stick in the auger, and that available power limited the depth. A standard auger with an outside diameter of 0.15 m was used for two holes in the permafrost on land drilled to 12.2 m. Drilling with this auger was very fast and no problems were encountered using it.

Soil samples were obtained with Shelby tubes and by drive sampling. The Shelby tubes, 0.06 m I.D. and 0.76 m long, could only be used in the fine-grained sea bed sediments. These tubes were pushed into the sediments below the bottom of the casing and removed with the sample. The casing was then driven to the next sampling position, cleaned out and another tube pushed into the sediments below the casing. In one hole, nearly continuous Shelby tube samples were obtained to a depth of 5.4 m below the seabed in silty sand sediments. All other soil samples were obtained with a 0.05 m I.D. split-tube drive sampler. Generally, the drive sampler was driven ahead of the casing and the sampler containing the sample removed from the hole. The casing was then driven to the next depth, cleaned out and the next sample taken. One effort to rotate this sampler, fitted with a cutting shoe, into frozen subsea permafrost in hole 195 (195 m from the beach) caused failure of the sampler which remained in the hole and forced its abandonment. The drive sampler was also used to sample ahead of the bit in the hollow stem auger.

Shelby tube samples were sealed in the tubes by driving tight-fitting rubber corks into both ends of the sample tubes, which were then shipped in the thawed state by truck to our laboratory at Fairbanks.

Drive samples were removed from the sampler immediately, carefully scraped clean when there was evidence of drilling mud on their surfaces, and then placed in glass jars. No attempt was made to control the sample temperature during shipment to Fairbanks by truck. A few samples of the frozen permafrost were placed in plastic tubing and shipped by air to Fairbanks in an insulated box cooled with containers of ice-alcohol mixture. These samples were stored in a freezer at the Geophysical Institute, University of Alaska.

A summary of drilling and sampling methods and additional information is given in Table I. The holes are located along a line bearing N32.5°E from the North Prudhoe Bay State #1 well (Figure 1). The hole number is the distance from the beach in meters; negative values apply to holes on land and positive values to holes offshore. A field designation number was assigned to the holes according to the order in which they were drilled. All hole depths and sample depths were measured from the sea ice surface. The drilling time was estimated from the field notes and logs. It is the amount of time spent drilling and does not include down time.

Holes were located by standard surveying methods from a benchmark, a spike driven into a large beam, located about 3.79 m N47.5°E from the axis of the North Prudhoe Bay State #1 well. The well coordinates are 70°22'36"N, 148°31'28"W. The distance to each hole from the benchmark was measured with a Hewlett-Packard 3800-A Distance Ranger. The angle between each hole and the edge of the sheet piling comprising the NE corner of the ARCO causeway was measured with a Wild T-2 theodolite. Positions of most holes are known to within 0.1 m, but in this report,

TABLE I: SUMMARY OF DRILLING AND SAMPLING INFORMATION

HOLE NUMBER	FIELD DESIGNATION	DRILLING METHOD	SAMPLING METHOD	HOLE DEPTH (m)	DRILLING TIME (h)	ICE THICKNESS (m)	NOTES
-226	5	Standard auger	Drive	12.2	5	-	
-225	1	Hollow stem auger	Drive	2.9	3	-	
- 69	14	Standard auger	-	12.2	3	-	
0	2	Hollow stem auger	Drive	3.5	2	-	
190	4	Rotary wash boring	Drive	55.8	20	1.1	Ice frozen to bottom
195	3	Hollow stem auger	Drive	9.9	6	1.1	Ice frozen to bottom
196	9	Penetration test	-	3.4	0.5	1.1	Ice frozen to bottom
203	3A	Hollow stem auger	Drive	22.4	10	1.1	Ice frozen to bottom
334	10	Penetration test	-	3.0	1	1.6	Ice frozen to bottom
403	11	Penetration test	-	4.7	1	1.6	Ice frozen to bottom

TABLE I (Cont'd)

HOLE NUMBER	FIELD DESIGNATION	DRILLING METHOD	SAMPLING METHOD	HOLE DEPTH (m)	DRILLING TIME (h)	ICE THICKNESS (m)	NOTES
481	13	Rotary wash boring	Shelby tube and drive	28.4	18	1.8	<0.1m water under ice
486	12	Penetration test	-	21.4	1.5	1.8	<0.1m water under ice
493	8	Penetration test	-	16.8	1	1.8	<0.1m water under ice
964	7	Penetration test	-	16.8	1	1.8	0.2m water under ice
3,370	6	Rotary wash boring	Shelby tube and drive	45.7	30	2.0	0.8m water under ice

distance, measured relative to the beach, is given to the nearest meter.

The last data were obtained June 14, 1975. All of the offshore holes were destroyed in the course of breakup.

III. PENETRATION TESTS

Some definitions need to be discussed before these data are interpreted. Our entire study area, except possibly for a thin active layer which is warmed in summer, qualifies as permafrost by the usual definition: ground material continuously below 0°C (Muller, 1947). This definition is not so useful in a salty environment, and we have used the terms ice "bonded" and "unbonded" permafrost to indicate whether or not the soil particles are bonded by ice (in a subzero environment). This usage is consistent with a driller's observation as to whether material is "frozen" or "thawed". However, although most subsea permafrost was formed on land, and subsequently thawed downward from the sea bed after ocean transgression, the usage of the terms "frozen" and "thawed" is somewhat loose in that a briny soil may exist in an intermediate state in which comparable amounts of ice and brine are present. Also, it may be possible for such a soil to be unbonded even if some ice is present. Nevertheless, a fairly well defined boundary between bonded and unbonded conditions seemed to exist in the study area, although this is probably not always the case. It also seems likely that an unbonded layer beneath the sea bed at hole 481 and seaward is completely thawed, except possibly very near the unbonded-bonded boundary which underlies it.

A series of penetration tests was performed in an attempt to locate the unbonded-bonded permafrost boundary. While these tests were not the usual standard penetration tests, they were relatively fast and simple to perform. Additionally, the data provide an indication of the subsea soil properties in an area where very few soil data exist. The tests were performed by driving BW drill rod (54 mm diameter), which did not have a driving point, into the sea bottom with a 155 kg hammer dropped 0.75 m. The blow count data are given in the borehole logs in Appendix A. Note that zero depth was taken at the sea ice surface. The position of the unbonded-bonded permafrost boundary was taken as the depth where the blow count increased substantially. It was also based on discussions with the driller and geologist at the time the tests were performed. The blow count profiles are shown in Figures 2-7.

The blow count per 0.3 m intervals in hole 196 (Figure 2) gradually increased with depth under the ice cover to the 3.1 m depth where it doubled. This depth is close to the position (3.7 m) where the lithology changed from silty sand to sandy gravel in nearby drilled holes (190, 195 and 203). However, it was the opinion of the driller and geologist that the sea bed was "frozen" at all depths in these drilled holes. Therefore, the position of the bonded-unbonded subsea permafrost boundary was taken to be the sea bed or 1.1 m. In hole 334, where 1.6 m of ice was frozen to the sea bed, the blow count was nearly constant under the ice cover but increased rapidly at the 2.7 m depth which was taken to be the position of the boundary. It should be noted that assignment of the position of the boundary from the penetration data in holes 196 and 334 is somewhat arbitrary. In addition, it is impossible to distinguish seasonal effects, which are likely to exist in shallow water areas, from these data alone.

The bonded-unbonded subsea permafrost boundary appears to be sharp and well-defined in holes 403, 481 and 486. In hole 403 the boundary

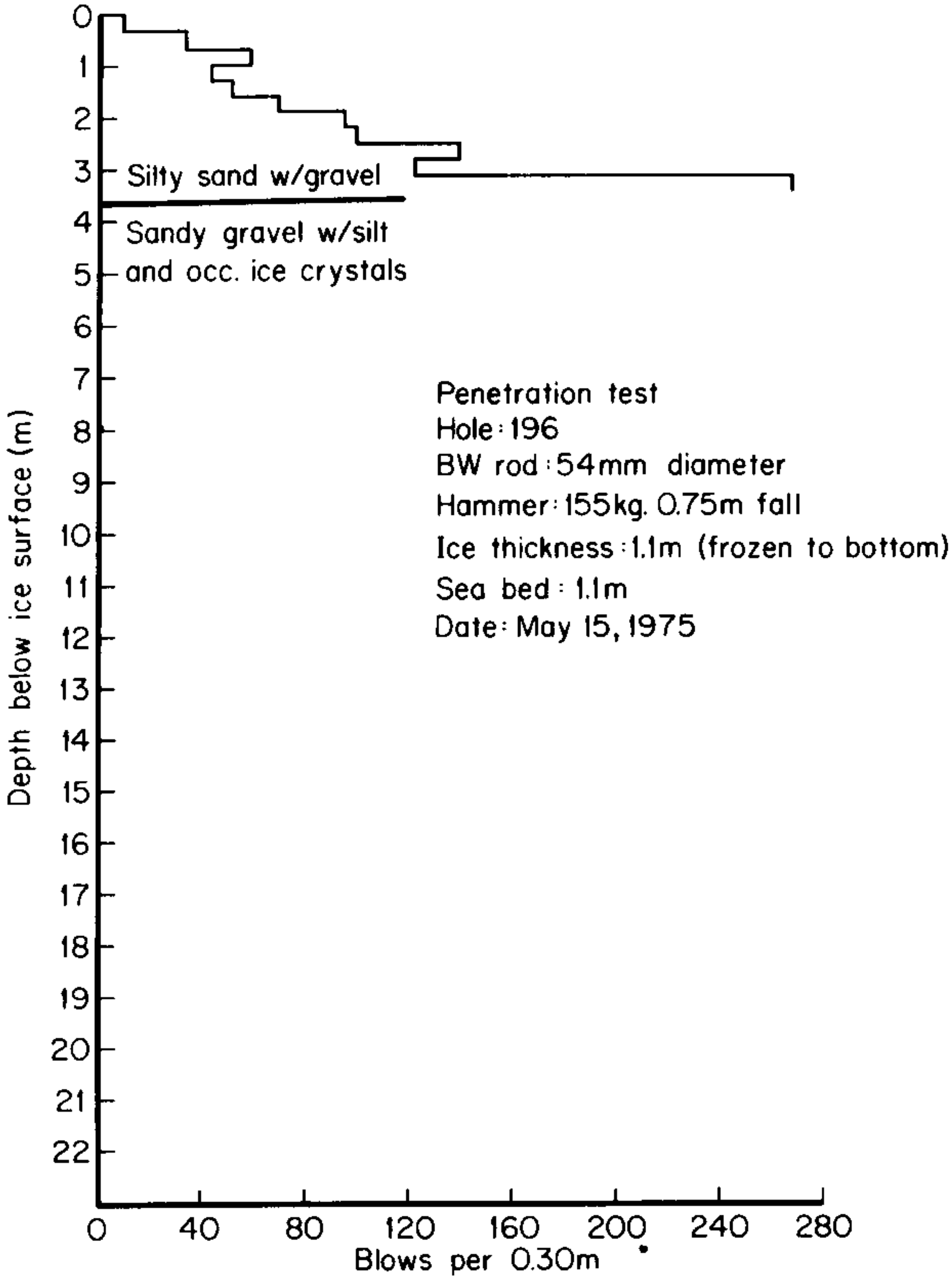

Figure 2. Blow count profiles for the penetration tests performed on holes 196, 334, 403, 493 and 964. The test conditions are given on each figure.

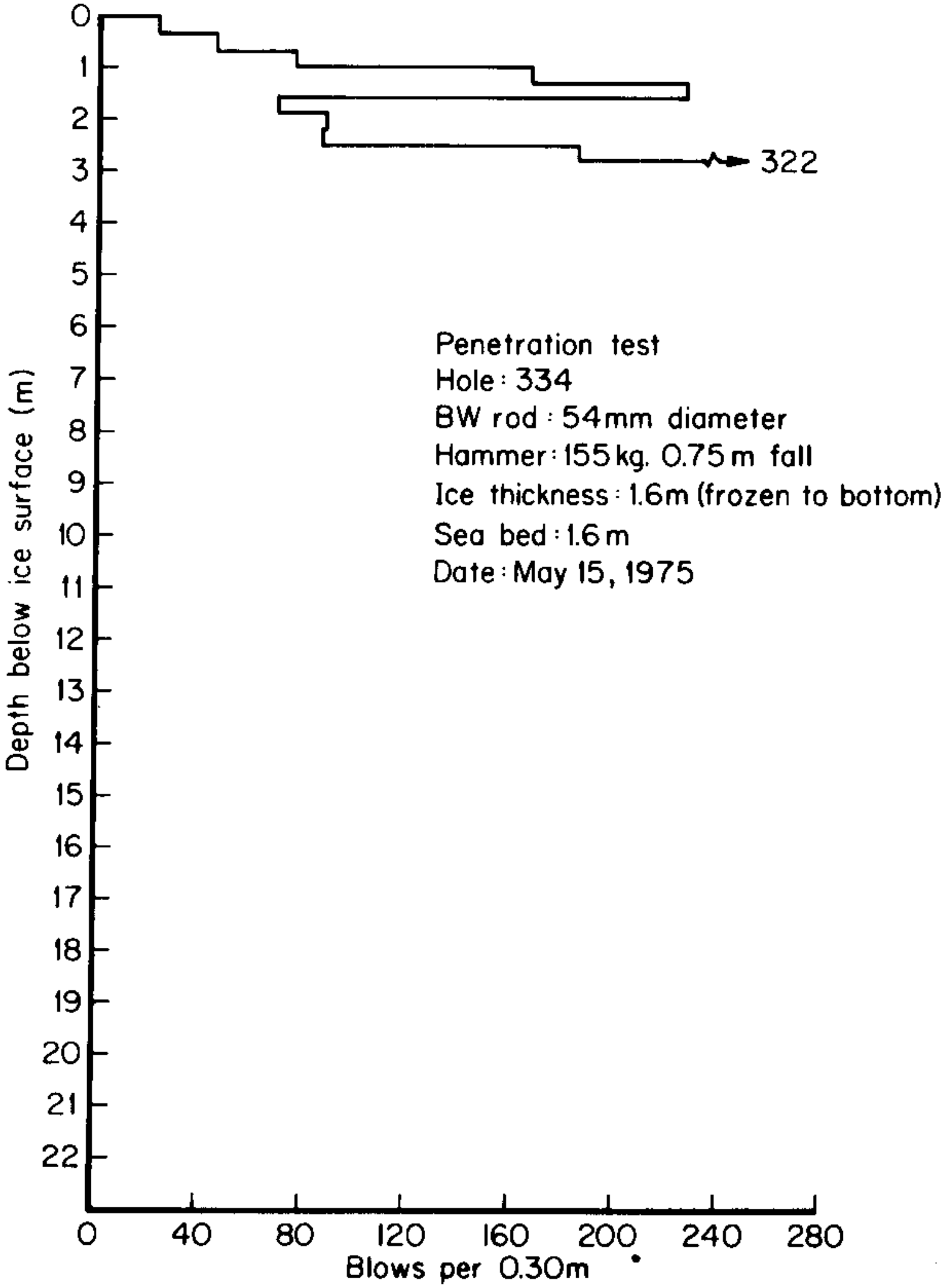

Figure 3. Blow count profiles for the penetration tests performed on holes 196, 334, 403, 493 and 964. The test conditions are given on each figure.

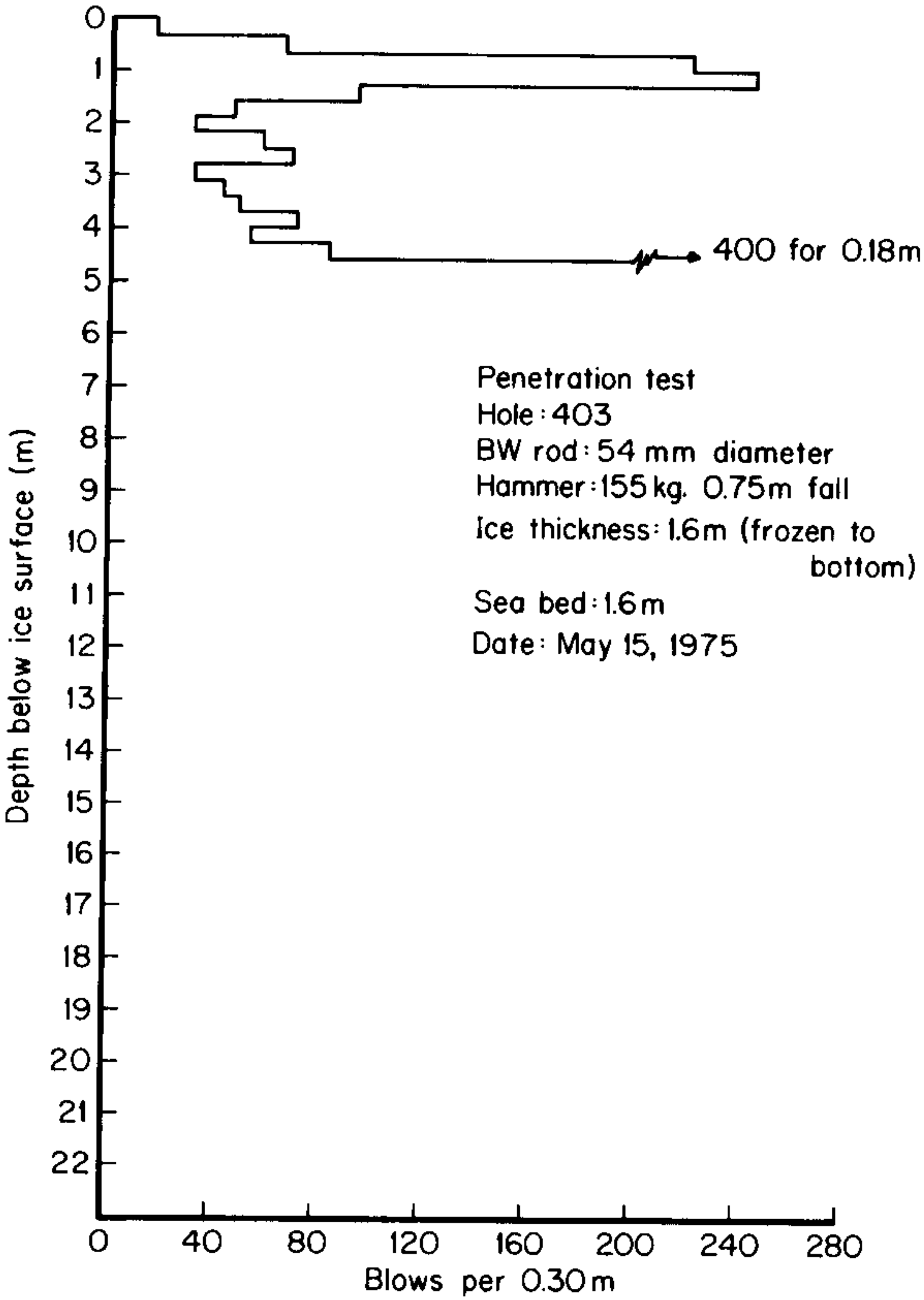

Figure 4. Blow count profiles for the penetration tests performed on holes 196, 334, 403, 493 and 964. The test conditions are given on each figure.

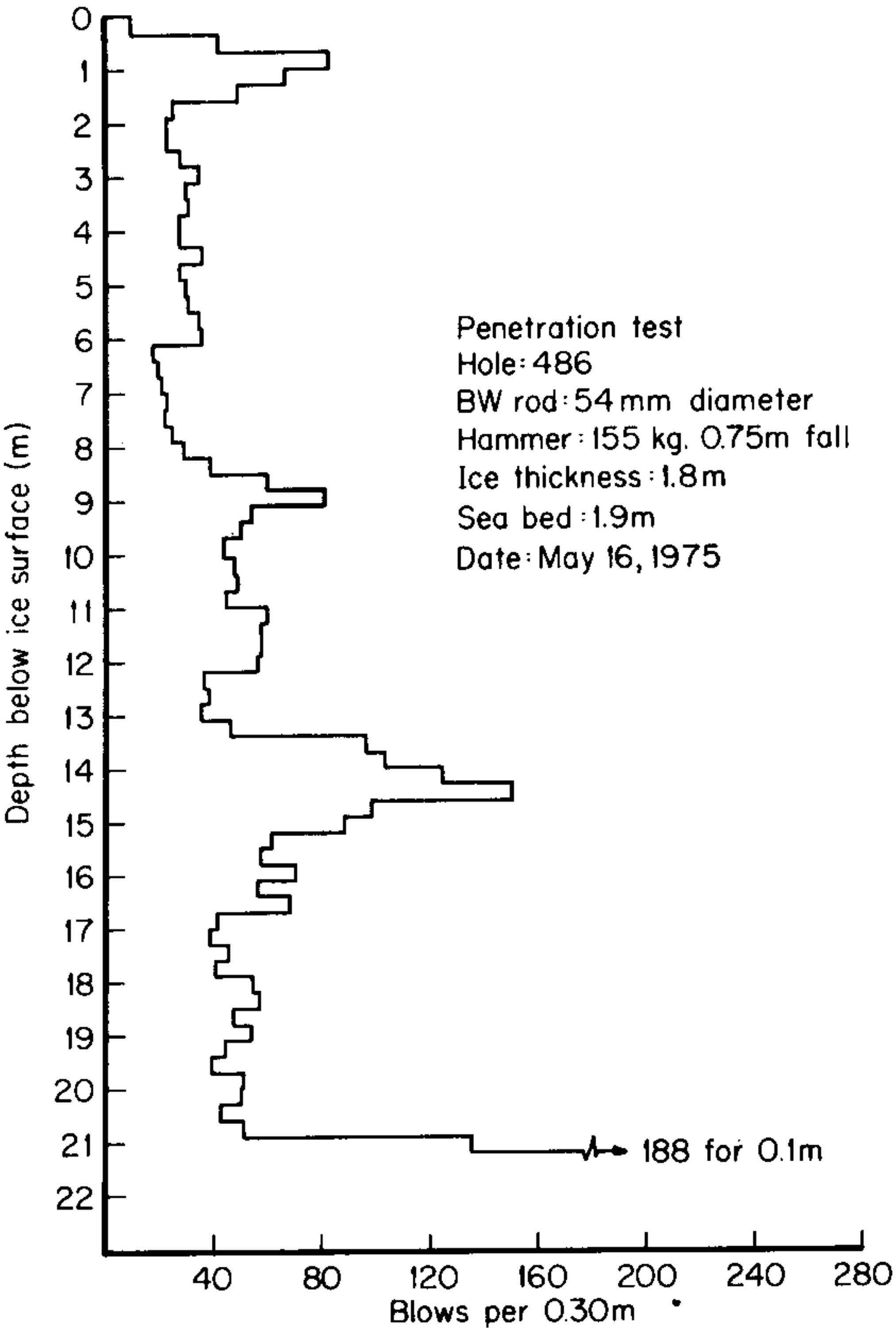

Figure 5. Blow count profiles for the penetration tests performed on holes 196, 334, 403, 493 and 964. The test conditions are given on each figure.

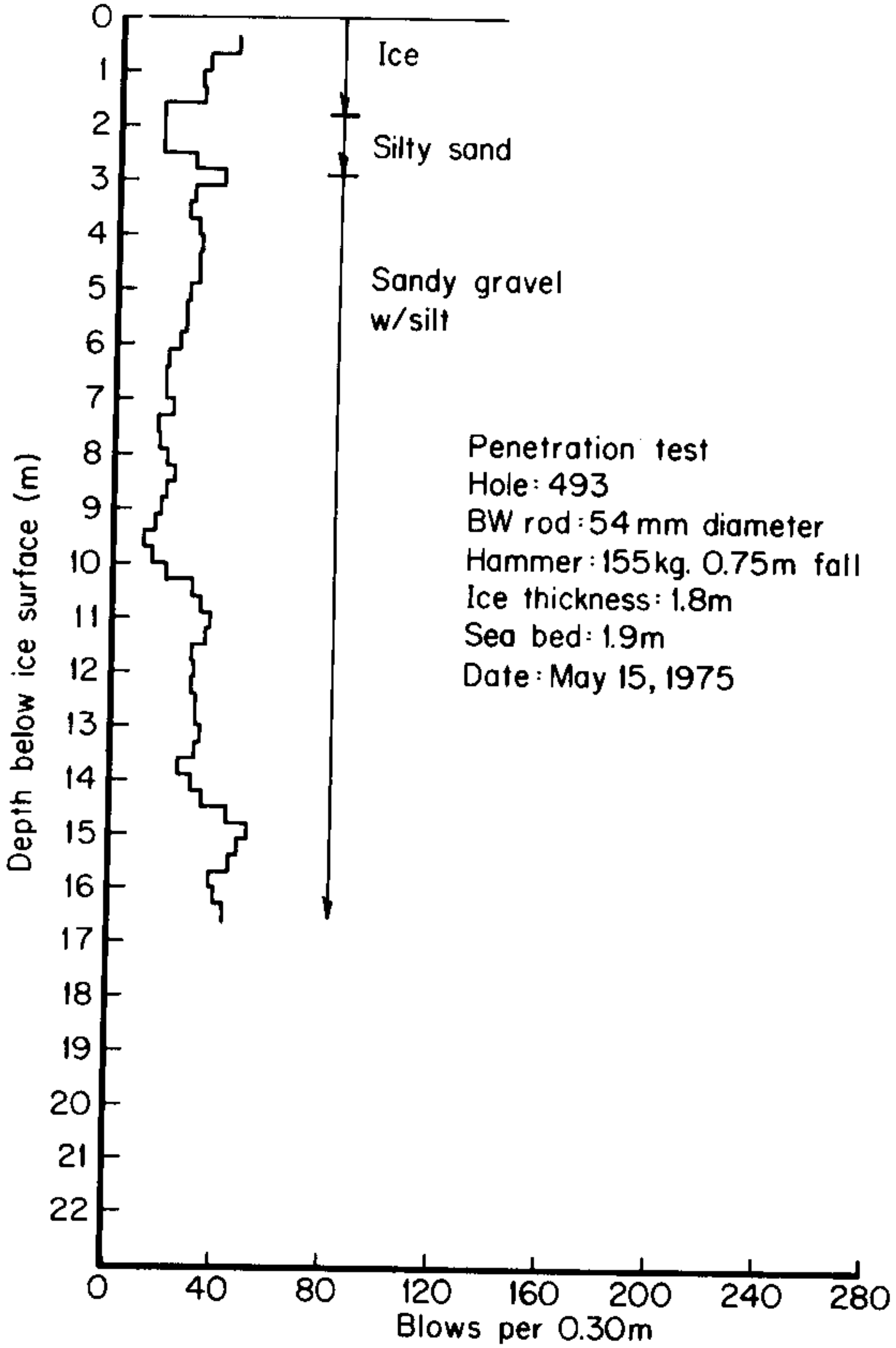

Figure 6. Blow count profiles for the penetration tests performed on holes 196, 334, 403, 493 and 964. The test conditions are given on each figure.

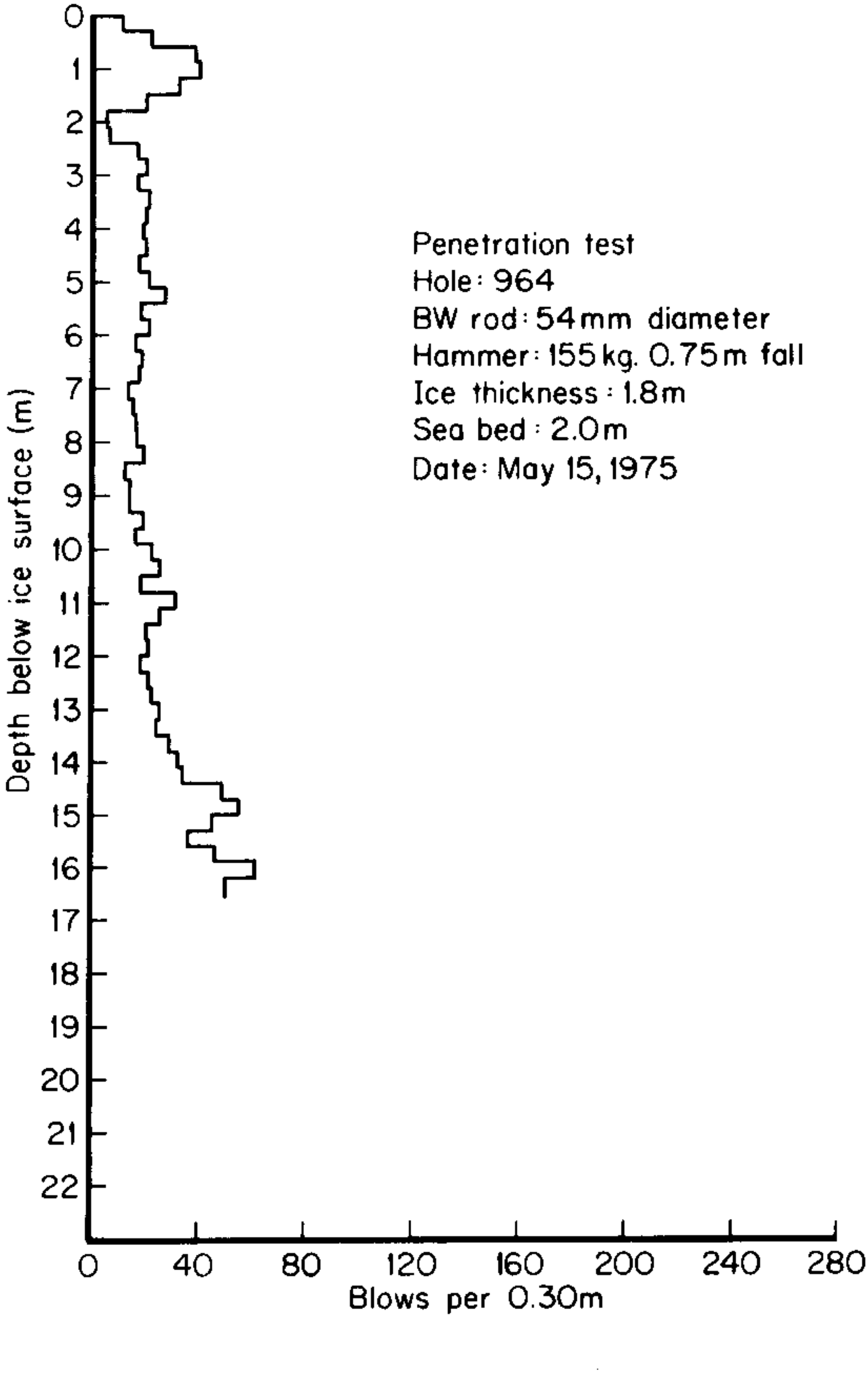

Figure 7. Blow count profiles for the penetration tests performed on holes 196, 334, 403, 493 and 964. The test conditions are given on each figure.

was found at 4.5 m (Figure 4) and in hole 486 at 21.3 m (Figure 5). The boundary in hole 481, a drilled hole, was at 21.1 m according to the opinion of the driller and geologist. This boundary in hole 481 may also be seen as a sharp break in the temperature gradient (see Figure 17) at the 21.1 m depth.

No bonded subsea permafrost was encountered in hole 3,370 to the depth of 46 m (from the ice surface) that was reached. However, it may be possible to deduce the depth to bonded subsea permafrost by the following argument. If the salt concentration in the pore liquid is constant with depth, and the same as that of normal sea water, the bonded subsea permafrost boundary should be found at a depth at which the temperature is the freezing point of sea water, -1.84°C. Extrapolation of our data indicate that this depth is about 49 m from the ice surface (46 m from the sea bed). This argument is consistent with the salinity profiles of Section VI, given the uncertainties. If the bonded-unbonded boundary temperature was the same as at hole 481 (-2.40°C), the boundary would be at about 74 m depth. One would expect the boundary to be between 49 and 74 m, but probably closer to 49 m.

Figure 8 shows that a bench exists in the sea bed out to about 280 m offshore over which the water depth is nearly constant at about 1 m. This bench appears to be an erosional feature similar to that observed by Lewellen (1973) in Elson Lagoon. Figure 8 also shows that the depth to the bonded subsea permafrost increases rapidly between 400-500 m offshore. This suggests that, given the sea ice thickness (2 m at Prudhoe Bay), the bathymetry may be a controlling factor which determines whether or not bonded subsea permafrost will be found near the sea

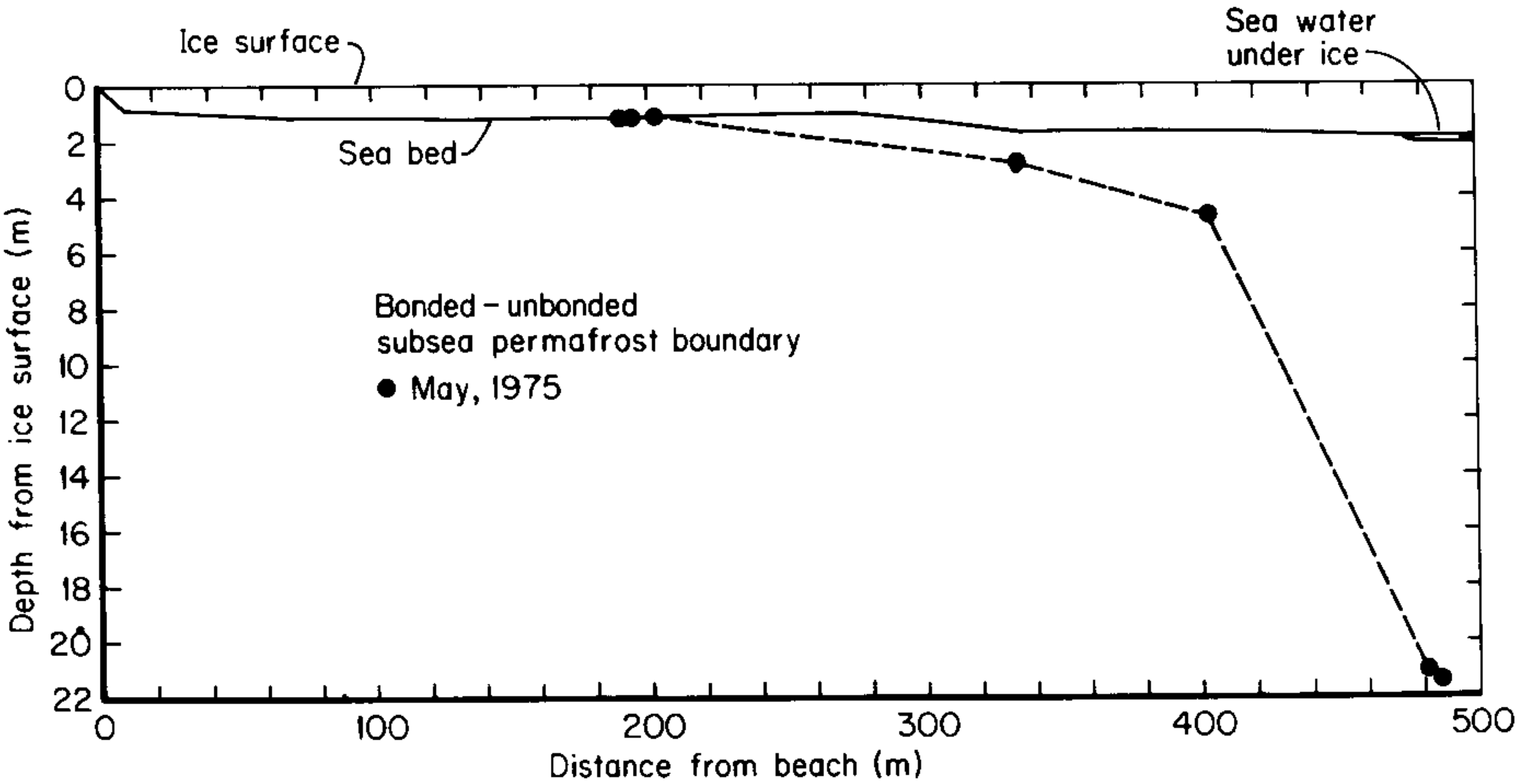

Figure 8. Profile of the nearshore subsea permafrost regime. Subsea soils to the right and above the dashed line are unbonded and soils to the left of it are ice-bonded.

bed. In water depths greater than 2 m, where the ice does not normally freeze to the sea bed, the bonded subsea permafrost might be expected to be well below the sea bed. Thus, the bathymetry, and particularly the position of the 2 m depth contour, may determine the areal distribution of bonded subsea permafrost at the sea bed, at least where conditions are similar to those at Prudhoe Bay.

IV. SOIL ANALYSIS

The soil analysis was done by the Road Materials Laboratory, Alaska Department of Highways, on the University of Alaska campus. The following test procedures were used: Gradation - AASHTO T-11 and T-27, Hydrometer - AASHTO T-88, Atterberg Limits - AASHTO T-89 and T-90, Specific gravity - Alaska T-2, Density - AASHTO T-233, Consolidation AASHTO T-216, and Triaxial compression - AASHTO T-234. Moisture content was obtained by oven-drying at 105°C with the results based on the dry weight of the soil. Data from the soil analysis are included in Appendix B.

Generally, the sea bed was sandy gravel or gravelly sand with some silt overlain by a thin layer of silt or sandy silt which increased in thickness seaward from a few meters near shore to about 14 m at hole 3,370.

Identification of the mineral constituents of some of the soil samples was done by the Division of Mines and Geology, Alaska Department of Natural Resources, located on the University of Alaska campus. The mineral constituents were identified by X-ray diffraction analysis and these results are given in Appendix C. Quartz was the major mineral present in all samples analyzed with calcite, feldspar, dolomite and chlorite occurring in minor (< 10%) or trace quantities.

The bulk density of some of the Shelby tube soil samples from holes 481 and 3,370 was measured, and the measured values used to calculate the moisture content on a volume basis and the relative saturation; the results are shown in Table II. Most of these Shelby tube soil samples and most of the drive samples were saturated as shown by visual observations of supernatant water in the sample jars. It seems quite possible that some water may have been lost during the sampling.

Thermal conductivities of the unbonded silty soil samples in Table II were estimated using the results of Kersten (1949) for fine-grained soils at +4.4°C. An average value for the thermal conductivity of these soil samples is about 1.6 $W(m\ deg)^{-1}$. For comparison, the thermal conductivity of the sandy soils was estimated using a weighted geometric mean formula (Gold and Lachenbruch, 1973). Randomly oriented quartz with a thermal conductivity of 7.5 $W(m\ deg)^{-1}$ was assumed to be the only mineral constituent. The calculation was based on a water content of 40% by volume and gave a value of 2.6 $W(m\ deg)^{-1}$.

The thermal diffusivity is

$$\kappa = \frac{K}{\rho c} \tag{1}$$

where K is the thermal conductivity and ρc is the volumetric heat capacity. For the unbonded fine grained silty soils $\kappa \approx 5.5 \times 10^{-7}\ m^2 s^{-1} = 17\ m^2 a^{-1}$, assuming $K = 1.6\ W(m\ deg)^{-1}$ and using an estimated $\rho c = 2.9\ J(m^3\ deg)^{-1}$. This is to be compared with $\kappa = 28\ m^2 a^{-1}$ obtained from the weighted geometric mean formula using the value of $K = 2.6\ W(m\ deg)^{-1}$, and with $\kappa = 21\ m^2 a^{-1}$ for unbonded sandy gravel with silt, obtained from an analysis of temperature data in hole 481 (Section VII).

TABLE II: MOISTURE CONTENTS, RELATIVE SATURATIONS AND THERMAL CONDUCTIVITIES FOR SOME SHELBY TUBE SAMPLES

Hole Number	Sample Number	Depth (m)	Moisture Content (% by volume)	Relative Saturation (%)	Thermal Conductivity $[W(m\ deg)^{-1}]$
481	13S005.8	1.77	38.0	111	1.8
"	13S008	2.44	36.7	90.8	1.5
3,370	6S009.3	2.83	36.8	91.2	1.5
"	6S012	3.66	42.8	103	1.4
"	6S017	5.18	35.9	101	1.6
"	6S027	8.23	21.7	75.6	1.6

Some wood, twigs and other organic matter were found in hole 3,370 at a depth of 13.7 m. This wood was dated at the Carbon Dating Laboratory, Institute of Marine Science, University of Alaska, using carbon 14. The age was found to be 22,300 years with a standard deviation of 1,200 years.

V. PRELIMINARY EXPERIMENTS ON SATURATED HYDRAULIC CONDUCTIVITY

The saturated hydraulic conductivity of a Shelby tube sample from hole 3,370 was measured by the Road Materials Laboratory. The sample was obtained from the 6.7 m depth by pushing a Shelby tube into the bottom of the cased hole. Rubber stoppers were used to seal the sample in the tube, which was transported in a thawed state to the laboratory. The tests were performed with the Shelby tube placed in a cold box with the temperature varying between -2 and 0°C. Sea water was passed through the sample in the Shelby tube mounted in a vertical position under a constant head and Darcy's law was used to calculate the saturated hydraulic conductivity. The value for the first run was 1.8×10^{-7} $m\ s^{-1}$, and for the second run 6.9×10^{-7} $m\ s^{-1}$, which gives an average value of 4×10^{-7} $m\ s^{-1}$. A soils analysis performed after these measurements showed that this soil sample consisted of 22% gravel, 20% sand, 49% silt and a minor amount (< 10%) clay.

Hole 69 was a 0.17 m diameter hole drilled on land to a depth of 12.2 m for the purpose of measuring the <u>in situ</u> permeability of the ice-bonded subterranean permafrost to a non-freezing fluid. After the hole was filled with fluid, the fluid level remained constant for at least 9 days after an initial transient change in level which we believe was due to seepage of the fluid into the cuttings at the bottom of the hole. It was concluded that the permeability of the bonded subterranean permafrost at this site was essentially zero.

Hole 195 had to be abandoned at the 9.9 m depth when a drive sampler broke off in the bottom of the hole. This hole was drilled with the hollow stem auger and remained open when it was abandoned. At that time it was noticed that the hole was filling with a highly concentrated brine which contained a small amount of ice slush at a temperature of -9.5°C. The position of the brine relative to the ice surface was measured several times for a 15-hour period (see Table III) and was used to calculate the saturated hydraulic conductivity k:

$$k = 6.05 \frac{a^2}{\Delta t} \log \frac{y_0}{y_1} \qquad (2)$$

where a is the radius of the hole in meters, Δt is the time in seconds for the brine to move from position y_0 to position y_1, and k is in m s^{-1}. It should be noted that Equation (2) is semi-empirical in nature (see Luthin, 1966, for a review of Equation (2) and other methods used to estimate k). The brine positions were measured from the brine table which was taken to be 1.0 m below the ice surface since this appeared to be the equilibrium position of the brine after several days had elapsed. Equation (2) gave an average value of $k \approx 2 \times 10^{-6}$ m s^{-1} for the bonded subsea permafrost which is nearly an order of magnitude larger than the value obtained from the laboratory measurement of the unbonded subsea permafrost in the Shelby tube sample.

Large differences between laboratory and field measurements may be expected, given the problems of obtaining an undisturbed soil sample and the coarser soils at hole 195. Additional complications include caving in hole 195 during the experiment and the possibility that the brine came from a highly permeable layer just under the ice or within the

TABLE III: AUGER HOLE MEASUREMENTS AND VALUES FOR k CALCULATED WITH EQUATION (2). THE HOLE RADIUS a = 0.10 m AND THE WATER TABLE WAS 1.0 m FROM THE ICE SURFACE.

TIME	Δt(s)	y_0(m)	y_1(m)	k(m s^{-1})
15:25-15:45	1.20×10^3	6.32	5.40	3.44×10^{-6}
15:45-16:15	1.80×10^3	5.40	4.70	2.04×10^{-6}
16:15-16:50	2.10×10^3	4.70	4.39	8.69×10^{-7}
16:50-17:45	3.30×10^3	4.39	3.33	2.21×10^{-6}
17:45-09:00	5.49×10^4	3.33	0.05 (estimated)	2×10^{-6}

soil. These possibilities, if true, would invalidate the use of Equation (2) to determine k. The above problems in this preliminary work point out the need for more refined experiments to determine hydraulic conductivity for bonded and unbonded subsea permafrost. Perhaps the most significant result is one of engineering interest: A hole or trench made in bonded subsea permafrost may fill rapidly with very concentrated brine.

VI. SALT CONCENTRATION PROFILES

The salt concentration of the pore water was studied by three methods. The first type of measurement, which was performed on most of the samples, was the determination of the electrical conductivity of the supernatant water that all but a few drive samples contained. The second measurement was the determination of the Cl content of the samples with insufficient supernatant water for conductivity measurement, and of several other selected samples. In the third measurement the major ions in three soil samples were analyzed. The first measurements were performed at the Geophysical Institute, the second by the Road Materials Laboratory, Alaska Department of Highways, and the third by the Division of Mines and Geology, Alaska Department of Natural Resources.

The electrical conductivity of the supernatant water was measured by drawing 3 ml of water into a small-volume conductivity cell and then measuring the conductivity at room temperature and a frequency of 1000 Hz. The results are given in Appendix D. All conductivity values were normalized to 25°C using a correction factor of 2% $\deg^{-1}$. Precision of these measurements is about 5%. The conductivity profiles are shown in Figures 9-14. In a few cases the conductivity of water samples obtained

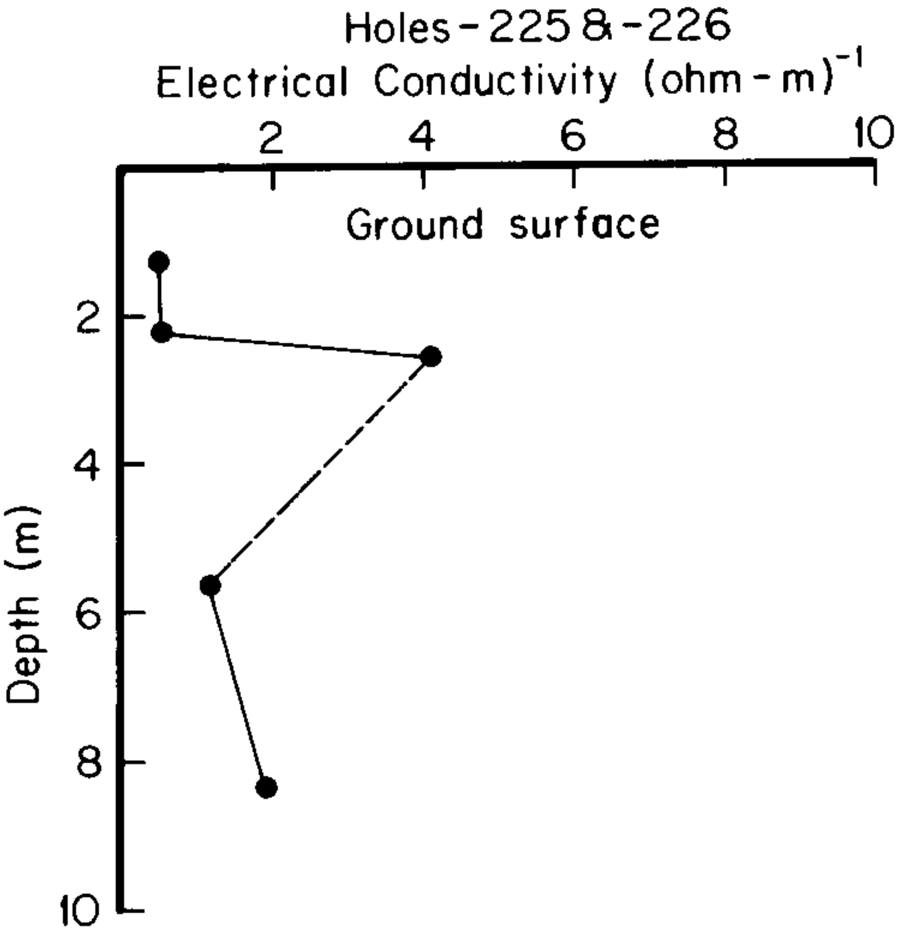

Figure 9. Electrical conductivity profiles for holes -225 and -226, 0, 190, 195 and 203, 481 and 3,370. Note that the depth of the offshore holes was measured from the ice surface.

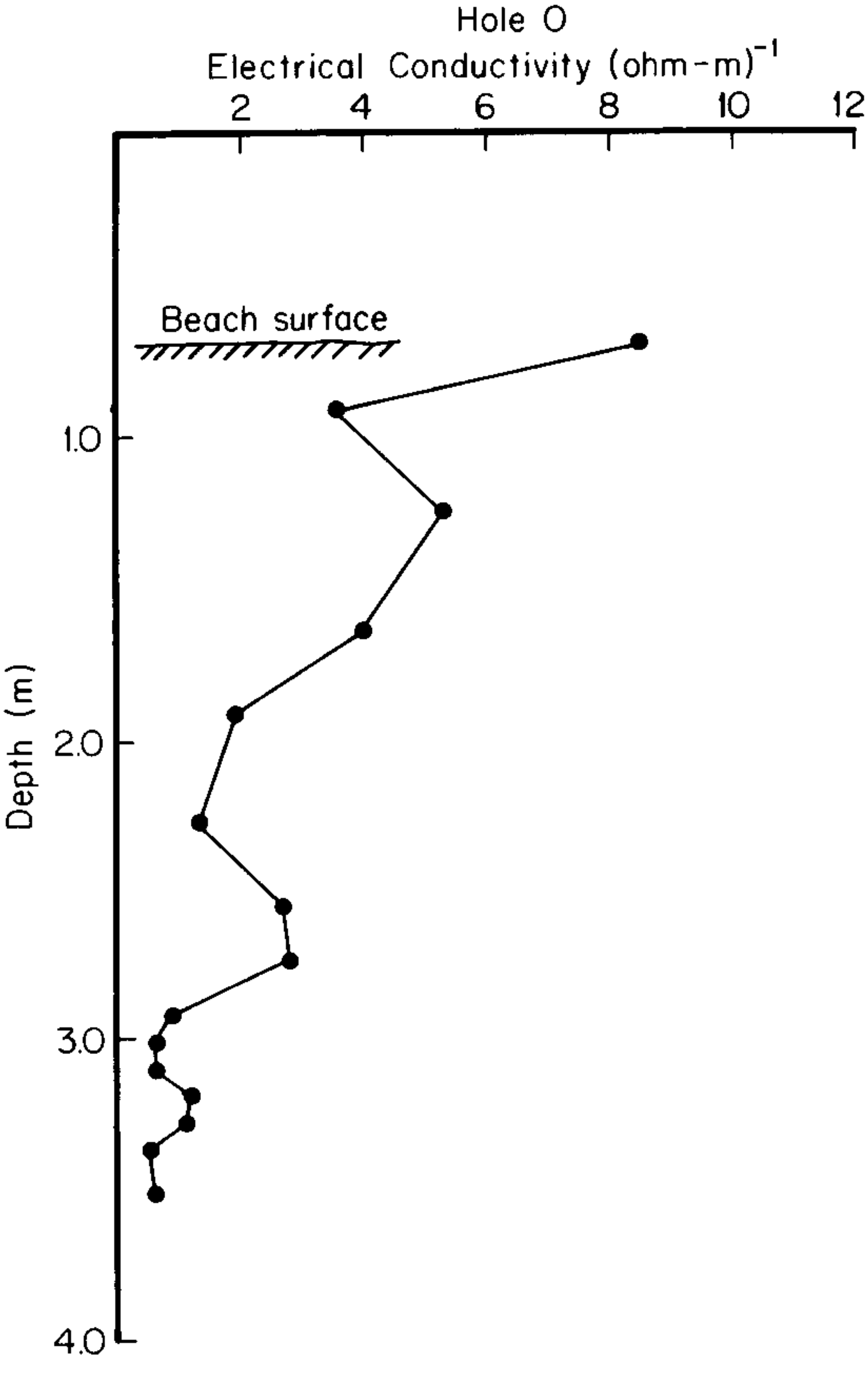

Figure 10. Electrical conductivity profiles for holes -225 and -226, 0, 190, 195 and 203, 481 and 3,370. Note that the depth of the offshore holes was measured from the ice surface.

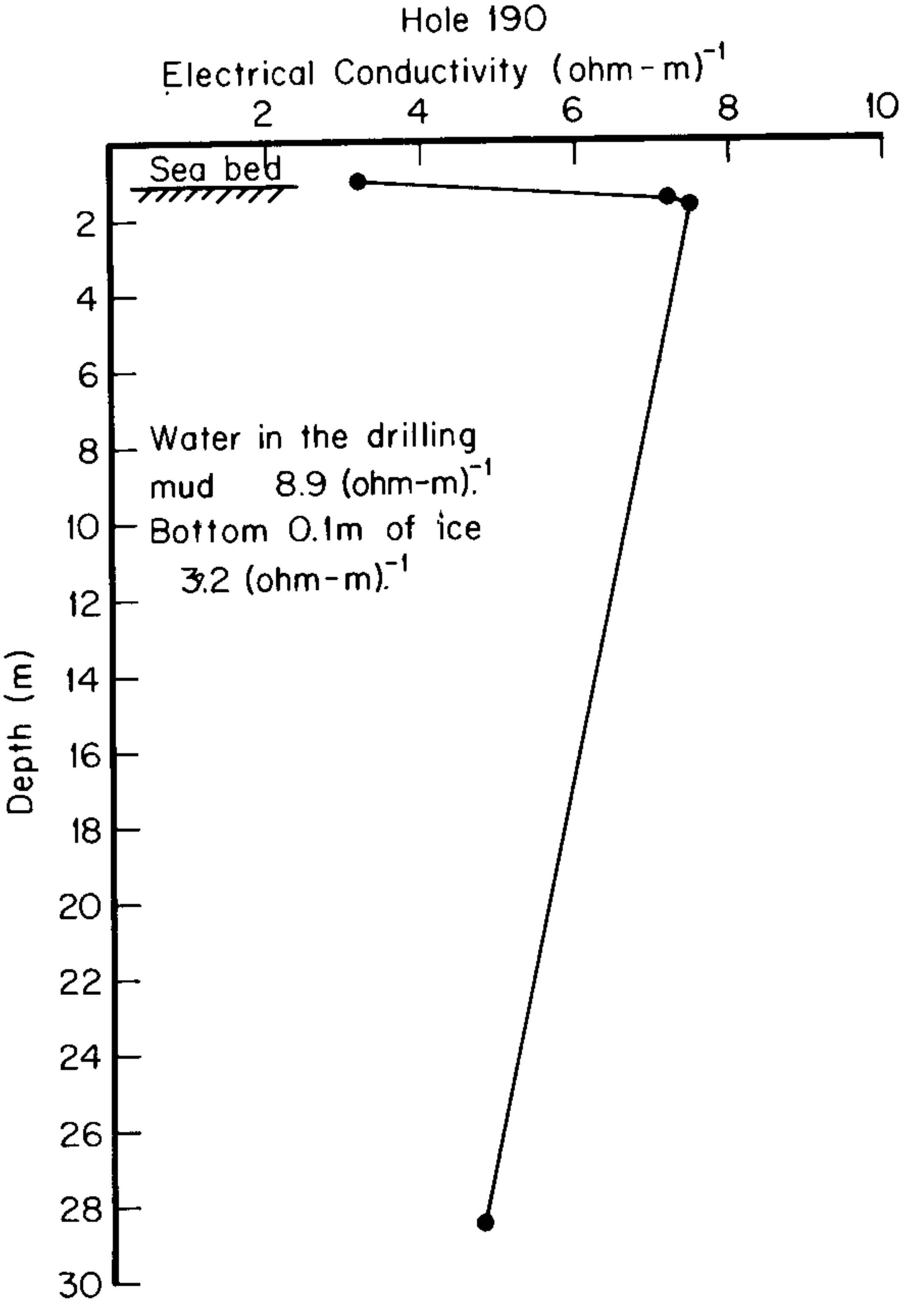

Figure 11. Electrical conductivity profiles for holes -225 and -226, 0, 190, 195 and 203, 481 and 3,370. Note that the depth of the offshore holes was measured from the ice surface.

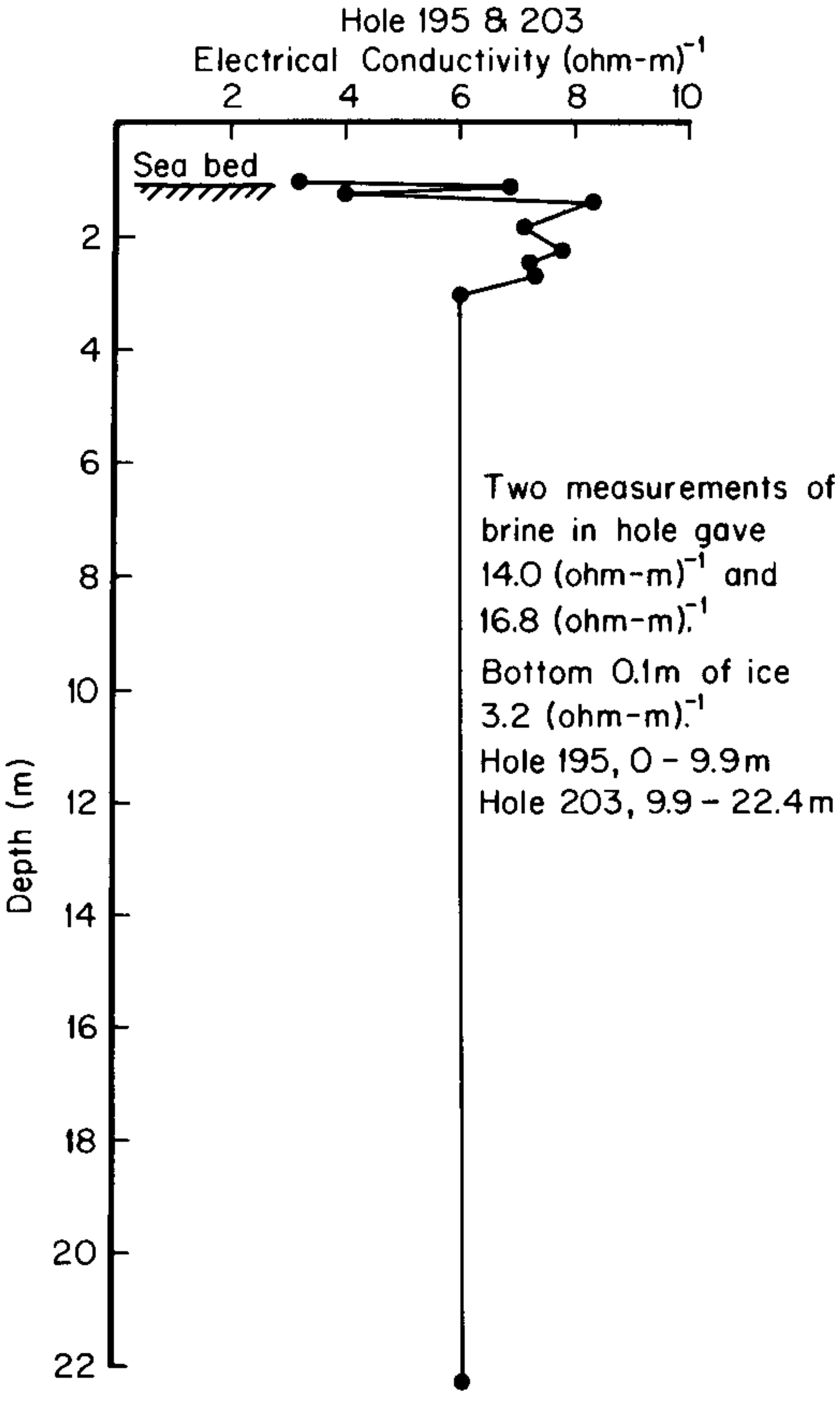

Figure 12. Electrical conductivity profiles for holes -225 and -226, 0, 190, 195 and 203, 481 and 3,370. Note that the depth of the offshore holes was measured from the ice surface.

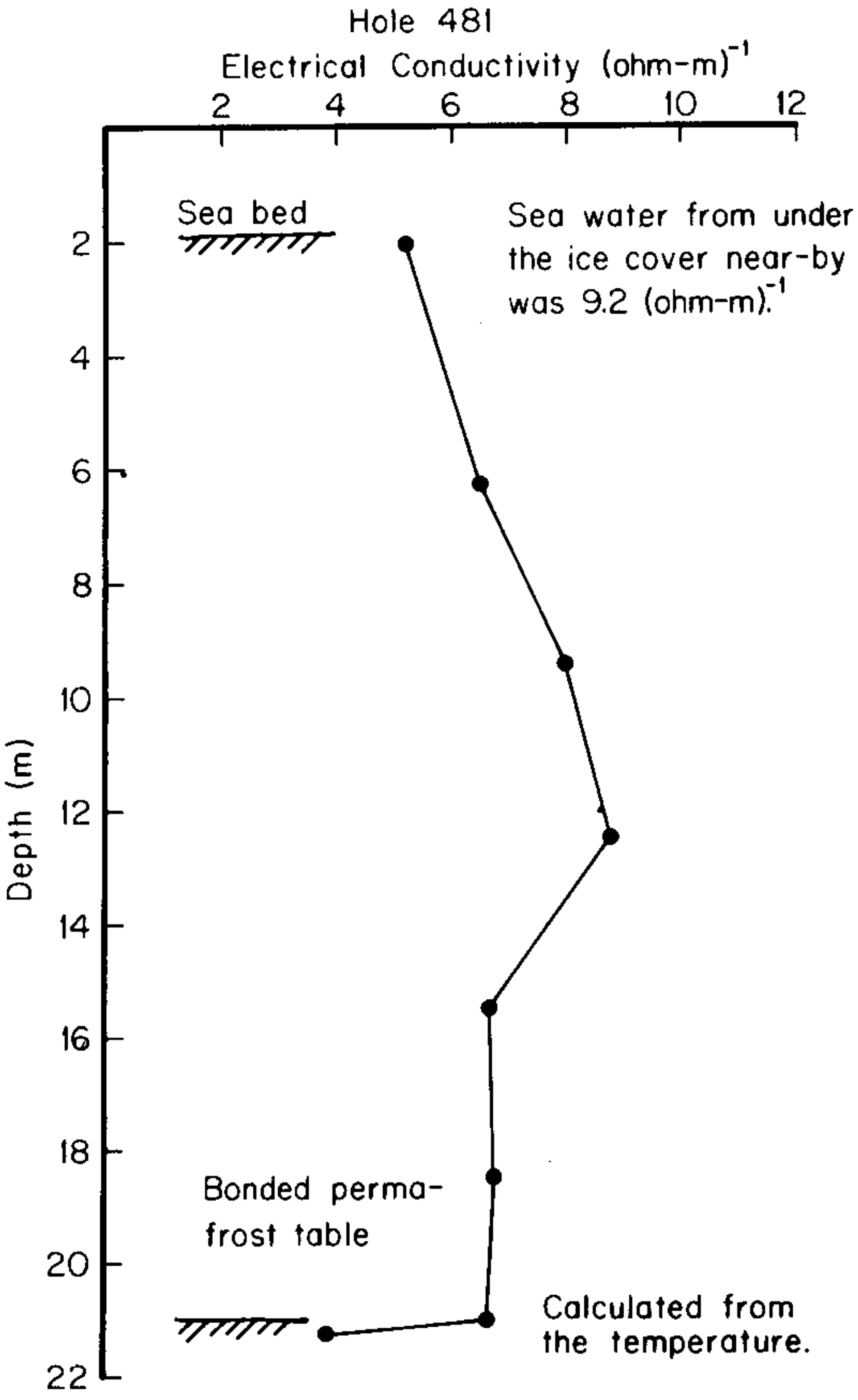

Figure 13. Electrical conductivity profiles for holes -225 and -226, 0, 190, 195 and 203, 481 and 3,370. Note that the depth of the offshore holes was measured from the ice surface.

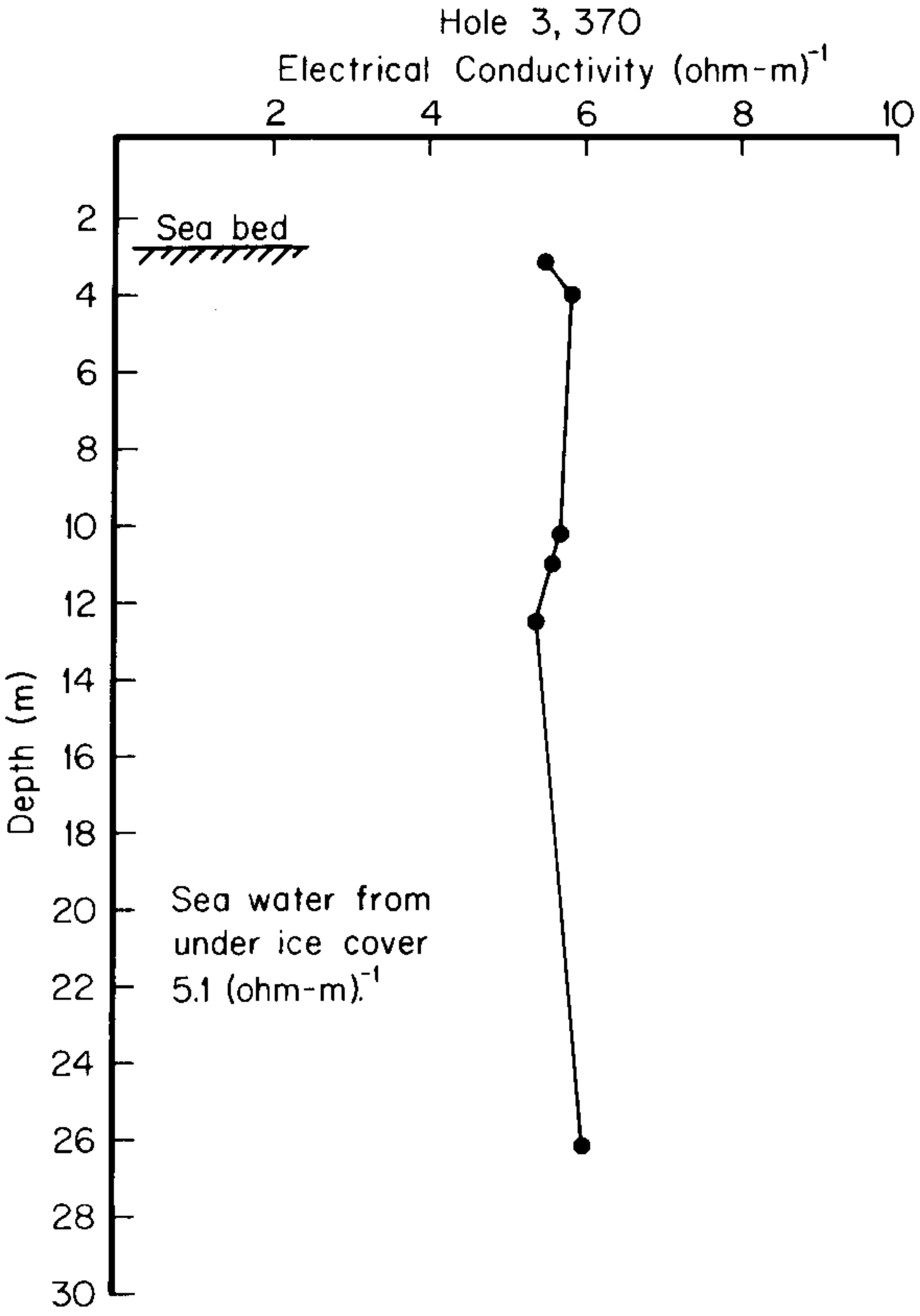

Figure 14. Electrical conductivity profiles for holes -225 and -226, 0, 190, 195 and 203, 481 and 3,370. Note that the depth of the offshore holes was measured from the ice surface.

from under the ice or from the drilling mud were measured and these values are noted on the figures.

The chloride contents of the soil samples were measured using a titration method designed for determining the chloride content of concrete. A variation from the usual technique was that the soil grains were left intact and not powdered as in the concrete test. These chloride contents are given with the soil analysis in Appendix B, and the values listed are based on percent of the weight of the dry soil sample.

Major ions in three samples were determined by quantitative atomic absorption except for Cl which was determined by titration. The results are given in Appendix E.

All of the above measurements made on the soil samples obtained by drive sampling are questionable because of the possibilities of sample contamination and an evaporative loss of water from some of the sample jars. After shipment by truck over the gravel road from Prudhoe Bay to Fairbanks it was found that most of the soil sample jars had slightly loose lids which may have led to a small evaporative loss of water from some of them. A more serious problem involves the possibility of sample contamination during the soil sampling procedures. All of the unbonded and some of the bonded drive samples were taken when the holes were filled with sea water brine or with drilling mud made from sea water brine. Since a split-tube drive sampler was used it was possible for the brine or mud to enter the sampling tube and contaminate the sample. This problem was partially alleviated by using cylindrical sample liners, and by carefully scraping the drilling mud from the soil sample when the sampler was opened. However, the possibility of some contamination still exists. The soil samples taken in Shelby tubes were probably not seriously contaminated nor affected by evaporative loss, although it is possible that some pore fluid was lost during sampling.

In the following paragraphs a description of conditions in the individual holes is given in order that possible contamination effects may be better assessed.

Holes -225 and -226 were drilled on land without the use of drilling mud. The soil samples were taken in the bonded state and kept frozen during transport to the laboratory. Those samples used to determine the electrical conductivity were allowed to melt in closed containers overnight and the conductivity of the supernatant water was measured the following day.

Hole 0 was drilled on the beach without the use of a drilling mud and it remained dry throughout the course of sampling and drilling. The soil samples were taken in the bonded state, placed in sample jars and allowed to melt during transportation to the laboratory where the conductivity of the supernatant water was measured. Chlorinity was measured on two samples by the Road Materials Laboratory and the values obtained agree with the results of the conductivity measurement.

Hole 190 was a cased hole drilled in bonded soils using a drilling mud made from sea water taken from beneath the ice about 500 m or more offshore. These samples were bonded initially and the drilling mud on their surfaces was easy to remove. The samples melted during transportation by truck to the laboratory. Water extracted from the drilling mud had a conductivity of 8.9 $(\text{ohm-m})^{-1}$. The conductivities of all pore water samples in this hole were less than this value.

Holes 195 and 203 were open holes drilled in bonded soils with a hollow stem auger. These holes filled with a brine of very high conductivity [14.0-16.8 $(\text{ohm-m})^{-1}$] and the drive samples were taken in this concentrated brine environment. No mud was used in drilling and the samples appeared to be bonded but in some cases were broken by the sampling process. The samples were allowed to melt during transportation by truck to the laboratory.

Hole 481 was a cased hole drilled through unbonded soil and into the bonded permafrost. The drilling mud was made with sea water from under the ice cover. Brine from under the nearby ice cover had a conductivity of 9.2 $(\text{ohm-m})^{-1}$. Samples obtained in this hole were placed in jars and allowed to warm during transport by truck to the laboratory.

Hole 3,370 was a cased hole drilled in unbonded soils using a drilling mud made with sea water from under the ice cover. The soil samples were placed in jars and allowed to warm during transport by truck to the laboratory. Sea water from under the ice had a conductivity of 5.1 $(\text{ohm-m})^{-1}$ which was less than the conductivity of the pore water of any of the samples. Thus, the sea water in the brine could only have diluted the pore water of the soil samples. This situation is the reverse of that in the other holes where the conductivity of the brine in the drilling mud or hole was always greater than that of the pore water in the soil samples.

Table IV shows the results of calculations based on the analysis of the major ions in three subsea permafrost samples. Additional useful information is also given in the table. The depth was measured from the ice surface. Time from the beach was calculated under the assumption

TABLE IV: RESULTS FROM THE ANALYSIS OF MAJOR IONS IN THREE SUBSEA PERMAFROST SAMPLES WITH RELATED INFORMATION.

	Ratios to Cl^-			
	Sample 4093	Sample 13069.9	Sample 6040	Normal Sea Water
Na^+	0.3075	0.3025	0.3002	0.5557
K^+	0.0167	0.0122	0.0200	0.0206
Ca^{2+}	0.0568	0.0416	0.0414	0.0212
Mg^{2+}	0.0423	0.0210	0.0245	0.0668
SO_4^{2-}	0.119	0.145	0.184	0.140
$\sigma_2 (ohm\text{-}m)^{-1}$	4.8	3.9	5.4	5.3
$\sigma_2 (ohm\text{-}m)^{-1}$	4.8	3.7	2.9	5.3
Fraction of water in the liquid state	0.37	0.56	1.00	1.00
Freezing point (°C)	-1.7	-1.3	-1.9	-1.8
Depth (m)	28.4	21.3	12.2	
Distance from beach (m)	190	481	3,370	
Time from beach (a)	136	344	2,410	
State of sample *in situ*	Bonded	Bonded	Unbonded	

that the average coastal retreat was 1.4 m a^{-1} (Alexander, 1975). The state of the soil sample refers to the <u>in situ</u> condition of the sample. The electrical conductivity σ_1 was the measured conductivity of the supernatant water and the conductivity σ_2 was calculated from

$$\sigma_2 = \sum_i C_i \Lambda_i \tag{3}$$

where σ_2 is the electrical conductivity in (ohm m)$^{-1}$, C_i is the concentration of the i'th ion in equivalent m^{-3} and Λ_i is the partial equivalent conductance of the i'th ion in ohm^{-1} m^2 equivalent^{-1} (Park, 1964). Values of σ_2 obtained from Equation (3) were based on the Λ_i at sea water concentrations corrected to 25°C (Park, 1964) and on the measured C_i for the samples in Appendix E.

Agreement between measured and calculated values of electrical conductivity is excellent for samples 4093 and 13069.9, but poor for sample 6040. The reason for this disagreement in the case of sample 6040 is unknown. In some cases (e.g., samples 6S09.3, 6S012, 4093, 13069.9 and 6040) it was possible to compare σ_1, σ_2 and electrical conductivity values derived from the chlorinity measurements of the Road Materials Laboratory (Appendix B). The difference between these conductivity values was less than 20% except for sample 6040.

The freezing point depression of the relatively coarse-grained soils encountered in this study can be approximated by the freezing point depression of the pore water due to the presence of dissolved ionic impurities. Since electrical conductivity values are related to the ionic concentrations (Equation (3)), then these conductivity values can be converted to salinity (Sverdrup et al., 1942) under the assumption that the ionic ratios are those of sea water. The resulting salinities can be used to calculate the freezing point of the pore water (Doherty and Kester, 1974):

$$T_f = -1.37 \times 10^{-2} - 5.199 \times 10^{-2}\ S - 7.225 \times 10^{-5}\ S^2 \qquad (4)$$

where T_f is in °C and S is the salinity in °/₀₀. The error in this procedure is estimated to be less than 20% for the soil samples obtained. The method can also be inverted to find the electrical conductivity of the pore water from its freezing point. This was done in hole 481. Extrapolation of the temperature data in hole 481 gave a value of $T_f \approx -2.40$°C at the bonded-unbonded subsea permafrost boundary which corresponds to $S \approx 43$ °/₀₀ and a conductivity of 6.3 $(\text{ohm-m})^{-1}$. This conductivity value is plotted in Figure 13 and appears to be consistent with the other electrical conductivities above it in this profile.

Since the ice-bonded samples contained salt, they must also have contained some liquid phase _in situ_. If surface effects are neglected, the _in situ_ fraction of H_2O in the liquid phase is given approximately by the ratio of freezing temperature to _in situ_ temperature (Harrison, 1972, for example). Using _in situ_ temperatures from Section VII, one finds that these fractions are about 0.37 for sample 4093, and 0.56 for sample 13069.9. These samples, although ice-bonded, therefore contained comparable amounts of solid and liquid phase _in situ_. This important conclusion depends on the assumption that no significant contamination occurred during sampling, which, as already noted, is not certain.

VII. BOREHOLE TEMPERATURES

A. Experimental Methods and Results

All borehole temperatures were measured with thermistor sensors. The readout device was a portable, battery-powered Wheatstone bridge (Leeds and Northrup #4289) modified to limit the measuring current to about 20 μA. Sensitivity of this bridge is about 0.001 deg and the manufacturer's stated limits of error of the resistance measurements amounts to ± 0.01 deg. The bridge was checked in the field by measuring a precision resistor with a low temperature coefficient of resistance. Values of this resistance measured in the laboratory at 20 to 22°C averaged 6,000.5 ohm while field measurements averaged 6,004.6 ohm or about 4 ohm high for ambient temperatures ranging from +5°C to -15°C. This increased resistance in the field is primarily due to the temperature sensitivity of the bridge.

A 50 m cable containing 11 thermistors (Fenwal GB32JM19) was installed in hole 190. More details are given in Rogers and others (1975).* The installation procedure consisted of putting the cable into the cased, mud-filled hole and supporting it at the top while the casing was pulled around it. The cable was then supported above the ice with the cable head about 1.6 m out of the ice. All measurements were made with the cable in this position.

The temperatures in holes -225, 203, 481, 493 and 3,370 were obtained by logging pipes installed in the holes with a thermistor on the end of a cable. These Schedule 40 steel pipes of 0.019 m I.D. were installed in the holes after drilling. The casing was pulled around the

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*In this reference, note a typographical error on page A-27. Resistance for thermistor #4 should be 5.6951 x 10^3 ohm.

pipes and the holes were allowed to cave. The pipes were filled with fluid and logged periodically until the fast ice became impractical to walk on about the middle of June. A plastic pipe of 0.019 m I.D. was used in hole -225. This hole was not cased but was backfilled with snow and cuttings from the drilling after the pipe was placed in the hole. The pipe in hole 493 was forced into the hole made by the drill rod during the penetration test.

Rubber jacketed, 2 conductor, #24 AWG, shielded cables (Belden 8413) with a thermistor (YSI #44005) on the end were used to log the pipes. Initially the thermistors were mounted inside stainless steel tubes. However, the time constants of these units were too long and they were modified by removing the stainless steel tubes, remounting the thermistors on the ends of the cables and encapsulating them in epoxy.

The initial calibration of the thermistors in their stainless steel tubes was done by comparison with a Hewlett-Packard 2801-A quartz crystal thermometer in a constant temperature bath. These calibrations were checked periodically by measuring the resistance of the thermistors in an ice bath prepared with deionized water and ground up ice made from deionized water. Calibration temperatures were nominal -20°C, -10°C, 0°C and +10°C. The measured thermistor resistances at -10°C, 0°C and +10°C were used to determine the constants A, B, C in

$$\frac{1}{T} = A + B \log R + C (\log R)^3 \qquad (5)$$

where T is the temperature in °K and R is the thermistor resistance in ohms. Equation (5) was then used to calculate temperatures from measured resistances.

The properties of the thermistors, the mounts and the borehole itself were such that 30 minutes or more was sometimes required for the thermistors to reach equilibrium at a given depth in the pipes; the time also depended upon the temperature differences between readings. As a result, the total logging time for a single pipe was several hours. However, we found by trial and error that a graph of thermistor resistance vs. time^{-1} was linear and could be extrapolated to infinite time after typically 5 to 15 minutes. (This is the time dependence expected for an axial line source pulsed at time zero.) To be consistent in reduction of the data, the measured resistances at each depth were plotted as a function of time^{-1} and the resulting straight lines extrapolated to obtain resistance at infinite time. This procedure removes the thermal disturbance associated with temperature logging. The disturbance due to the drilling process is a separate problem, discussed in the next section.

Two additional effects should be noted. At shallow depths, sharp increases of temperature with depth were evidently causing convection of the fluid in the pipes. This clearly decreased the precision of the measurements by an order of magnitude, judging by the temperature variations observed over short times, but no detailed analysis was done. The other effect is the possibility of an error due to thermal conduction down the pipe. This was analyzed by a method discussed by Bullard (1954), and found to be negligible.

The borehole temperatures are given in Appendix F and illustrated in Figures 17, 20 and 21.

B. Approach of Borehole Temperatures to Equilibrium

The analysis of borehole temperature evolution is necessary because of the information it gives, not only about equilibrium temperatures, but also about the thermal diffusivity of the soil, the presence or absence of ice, possible instrumental problems, and phenomena which occurred during drilling that are related to soil permeability. Most of the necessary theoretical background is described by Lachenbruch (1959); however, some further discussion is useful for the analysis of our data.

1. Theory

The temperature disturbance $T - T_\infty$ due to an instantaneous line heat source of strength Q at time $t = s/2$, is given by

$$T - T_\infty = \frac{Q}{4\pi K} \frac{1}{t-s/2} \tag{6}$$

where K is the thermal conductivity. Time zero is the time at which the drill bit reaches the depth of interest. If heat is generated at a constant rate over the interval $0 < t < s$, the time dependence of $T - T_\infty$ is $\ell n \frac{t}{t-s}$ rather than $\frac{1}{t-s/2}$, but these functions are not significantly different in our applications. Therefore, in the following analysis, the disturbance $T - T_\infty$ can be considered to die off as $\frac{1}{t}$, with the appropriate time origin slightly uncertain, but lying sometime between the start and completion of the drilling. For times much larger than the drilling interval, the uncertainty is not serious.

Boreholes were logged with a thermistor several times in May, and once in June (a different thermistor was used in June). Although repeated laboratory ice point calibrations showed that the thermistors were probably stable at the 0.001 deg level, the field data indicate that much larger systematic errors were probably occurring there. We do not fully understand the source of these errors; however, field conditions were often difficult with low ambient temperatures sometimes accompanied by wind and blowing snow. The data on June 13 and 14 were obtained in the rain, and brackish water covered most of the ice, in some places deep enough to sustain waves. Inevitably, some salt water made its way into the unprotected equipment. These adverse field conditions appear to have caused systematic errors which must be taken into account before the behavior of the borehole temperatures can be understood. In the case of hole 190, in which thermistors were permanently installed, these systematic errors appear to be small.

We must therefore formulate the theory to allow for possible systematic errors on different dates of hole logging. It is convenient to introduce the notation $\xi = \frac{1}{t}$ and to consider three logging dates (t_1, t_2, t_3), or (ξ_1, ξ_2, ξ_3), with corresponding temperatures (T_1, T_2, T_3); a generalization to include more logging dates is straightforward. In the notation used, $\xi_3 > \xi_2 > \xi_1$, so $t_3 < t_2 < t_1$. The true temperature T_n on the nth logging date, the corresponding systematic error ΔT_n, and the measured temperature $\bar{T}_n$ are related by

$$T_n = \bar{T}_n + \Delta T_n \tag{7}$$

We can calculate how the systematic errors affect the predicted equilibrium temperatures T_∞. Since T varies linearly with ξ,

$$\frac{T_3 - T_2}{\xi_3 - \xi_2} = \frac{T_3 - T_\infty}{\xi_3} \tag{8}$$

Using Equations (7) and (8) and solving for T_∞, we find that

$$T_\infty = \frac{\xi_3 \overline{T}_2 - \xi_2 \overline{T}_3}{\xi_3 - \xi_2} + \frac{\xi_3 \Delta T_2 - \xi_2 \Delta T_3}{\xi_3 - \xi_2} \qquad (9)$$

This also hold for any cyclic permutation of the subscripts. The significant interpretation of Equation (9) is that the systematic error in the equilibrium temperature represented by the second term is independent of depth and therefore will not distort the shape of the calculated T_∞ vs. depth curve.

Another problem which we need to consider is the effect of a secular temperature change during the approach to equilibrium. Because T varies linearly with ξ,

$$T_1'(\xi_3 - \xi_2) + T_2'(\xi_1 - \xi_3) + T_3'(\xi_2 - \xi_1) = 0$$

or $$A\, T_1' + B\, T_2' + C\, T_3' = 0 \qquad (10)$$

where $(A,B,C) = (\xi_3 - \xi_2,\ \xi_1 - \xi_3,\ \xi_2 - \xi_1)$. The primes indicate that the temperatures have been corrected for secular change. Because of secular change, we must specify the date of the equilibrium temperature T_∞; i.e., $T_\infty = T_\infty(t)$. It is convenient to use the date t_2 as reference, in which case $T_2' = T_2$. Also, if the secular change is small,

$$T_1' = T_1 - \left.\frac{\partial T_\infty}{\partial t}\right|_{1,2} (t_1 - t_2) \qquad (11)$$

$$T_3' = T_3 + \left.\frac{\partial T_\infty}{\partial t}\right|_{2,3} (t_2 - t_3) \qquad (12)$$

where the subscript 1,2 implies an average over the interval t_1 to t_2, and similarly for the subscript 2,3. The notation $\frac{\partial T_\infty}{\partial t}$ refers to the secular part of the temperature change, and not that due to drilling. Substitution of Equations (11) and (12) into Equation (10) and allowance for systematic errors through Equation (7) gives

$$A \frac{\partial T_\infty}{\partial t}\bigg|_{1,2} (t_1-t_2) - C \frac{\partial T_\infty}{\partial t}\bigg|_{2,3} (t_2-t_3) = A\overline{T}_1 + B\overline{T}_2 + C\overline{T}_3 + \varepsilon \qquad (13)$$

where ε is a systematic error parameter defined by

$$\varepsilon \equiv A\Delta T_1 + B\Delta T_2 + C\Delta T_3. \qquad (14)$$

If there is no fluid motion, the secular change is one-dimensional, and the soil has constant thermal diffusivity κ, then

$$\frac{\partial T_\infty}{\partial t} = \kappa \frac{\partial^2 T_\infty}{\partial z^2} , \qquad (15)$$

where z is the depth coordinate. Solution of Equations (13) and (15) for κ gives

$$\kappa = \frac{A\overline{T}_1 + B\overline{T}_2 + C\overline{T}_3 + \varepsilon}{A \frac{\partial^2 T_\infty}{\partial z^2}\bigg|_{1,2} (t_1-t_2) - C \frac{\partial^2 T_\infty}{\partial z^2}\bigg|_{2,3} (t_2-t_3)}. \qquad (16)$$

Some discussion of Equation (16) is in order. It is often the case that temperature data are available deep enough in the hole so that secular change there can be neglected: $\frac{\partial T_\infty}{\partial t} \cong 0$. For these depths, Equation (13) gives

$$\varepsilon = -(A\overline{T}_1 + B\overline{T}_2 + C\overline{T}_3). \qquad (17)$$

ε is independent of depth, and a reliable estimate of it can be made by averaging the values found for several of these depths. A more difficult problem is the determination of $\frac{\partial^2 T_\infty}{\partial z^2}$. In principle, it is necessary to simultaneously determine κ and T_∞ at all depths where there is secular change. This is possible, but complicated. If the approximation

$$\frac{\partial^2 T_\infty}{\partial z^2} \cong \frac{\partial^2 \overline{T}}{\partial z^2} \tag{18}$$

is valid, solution for κ is easy. This should hold when the drilling disturbance is either small, or independent of depth.

One might therefore proceed as follows:

(a) Compute ε from the deep data using Equation (17).

(b) At each depth where secular change is significant, use the approximation given by Equation (18), together with data from adjacent depths, to compute $\frac{\partial^2 T_\infty}{\partial z^2}$. (The evaluation of this derivative is discussed in more detail in Section VII-B-2).

(c) Compute κ, using Equation (16), preferably at several depths to see how constant it is.

(d) Evaluate the secular change corrections to the approach to equilibrium conditions with Equations (11), (12) and (15).

(e) Find T_∞ with Equation (9) using assumed values for ΔT_2 and ΔT_3 which are consistent with Equation (14).

(f) In some cases it may be worthwhile to iterate, using the better approximation for $\frac{\partial^2 T_\infty}{\partial z^2}$ obtained from these T_∞ values.

One other approximation is of interest. If

$$\left.\frac{\partial T_\infty}{\partial t}\right|_{1,2} \cong \left.\frac{\partial T_\infty}{\partial t}\right|_{2,3} \equiv \frac{\partial T_\infty}{\partial t}, \tag{19}$$

then Equation (13) can be solved for $\frac{\partial T_\infty}{\partial t}$, the corrections for secular change made with Equations (11) and (12), and the equilibrium temperature T_∞ found from Equation (9); κ can then be found using Equation (15).

2. Hole 481

Hole 481 was begun May 16, 1975, and completed early May 18. Most of the drilling was done on May 17. The time origin was taken to be May 17.5. Logging dates were May 20, 21, 28, and June 13. Depths 10.55 m and greater were below the level of significant secular change. Data from 10.55 m to 16.55 m were used to calculate a value of 0.0078 deg d^{-1} for the error parameter ε (Equation (17)). If this error were primarily due to the June 13 data, which seems possible, the systematic error then would be 0.034 deg. The June 13 data were corrected by this amount, and T_∞ at depths 10.55 to 16.55 m calculated by passing a straight line through the data, as illustrated by Figure 15.

Below 16.55 m the situation seems to be more complex. The points at 19.55 and 20.55 m do not seem to follow a $\frac{1}{t}$ behavior (Figure 16). The borehole log indicates that fluid was lost when drilling into the upper part of the ice-bonded layer, which begins at 21.1m. This fluid evidently escaped outside the casing and up into the unbonded layer, which it apparently cooled. The lack of $\frac{1}{t}$ behavior is probably due to the fact that the fluid motion was not localized near the hole axis, which indicates that the unbonded soil is permeable. Although the temperature data from 18.55 m suggests that $\frac{1}{t}$ behavior may have been followed there, it probably was not, since the temperature curve extrapolated from shallower depths (Figure 17) does not pass through the estimated T_∞.

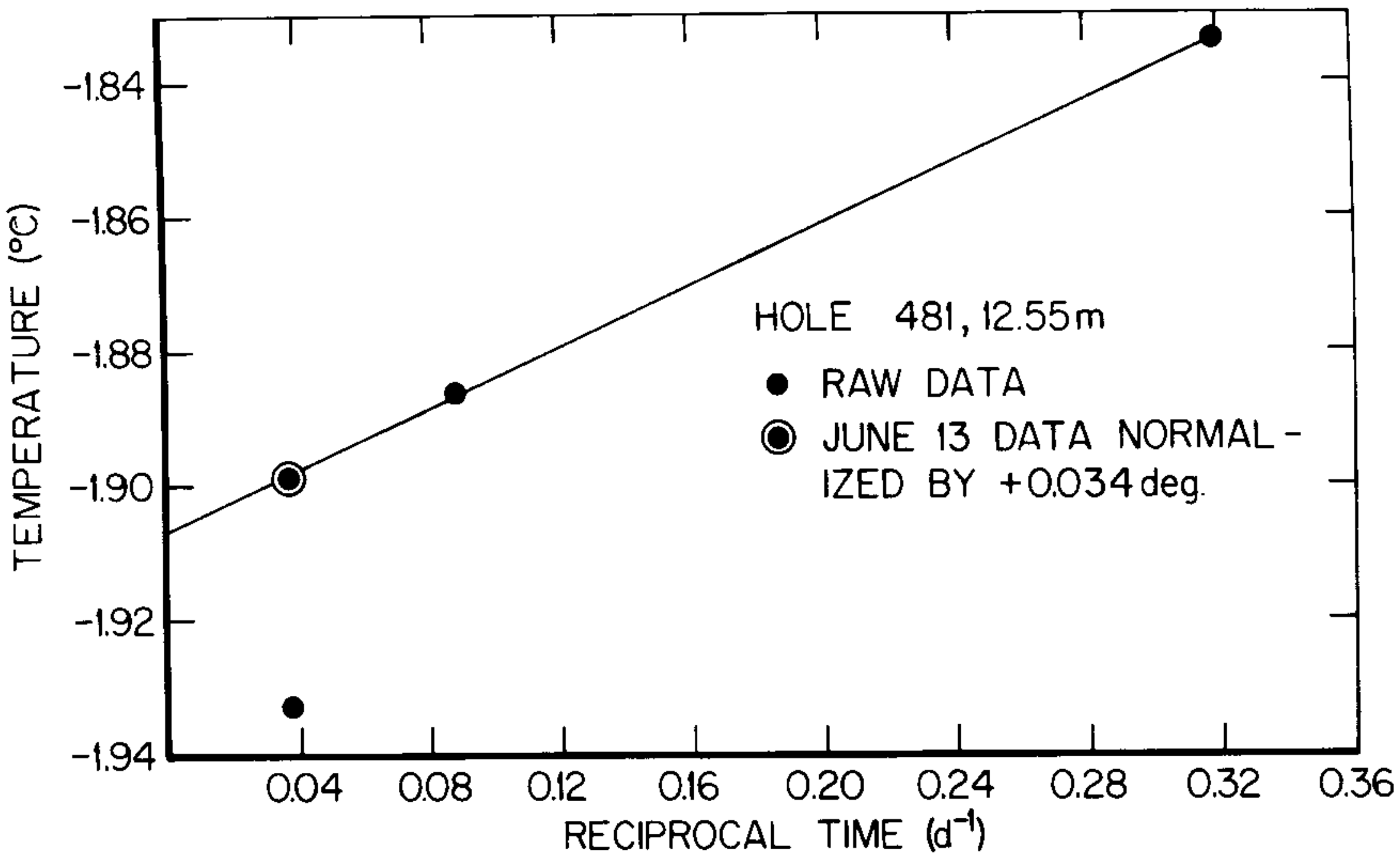

Figure 15. Temperature vs. reciprocal time for hole 481 at the 12.55 m depth.

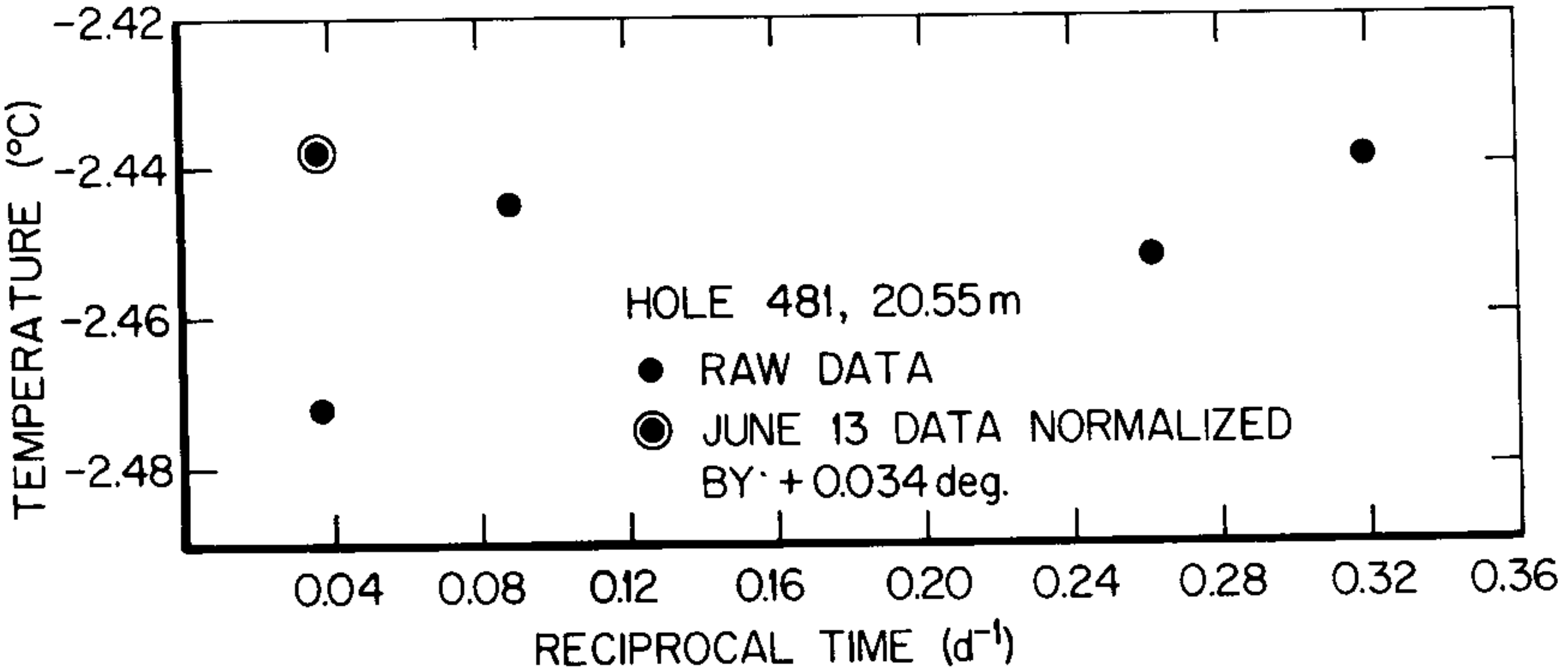

Figure 16. Temperature vs. reciprocal time for hole 481 at the 20.55 m depth. The datum point for May 21 (0.26 d^{-1}) probably does not have the correct normalization relative to the others.

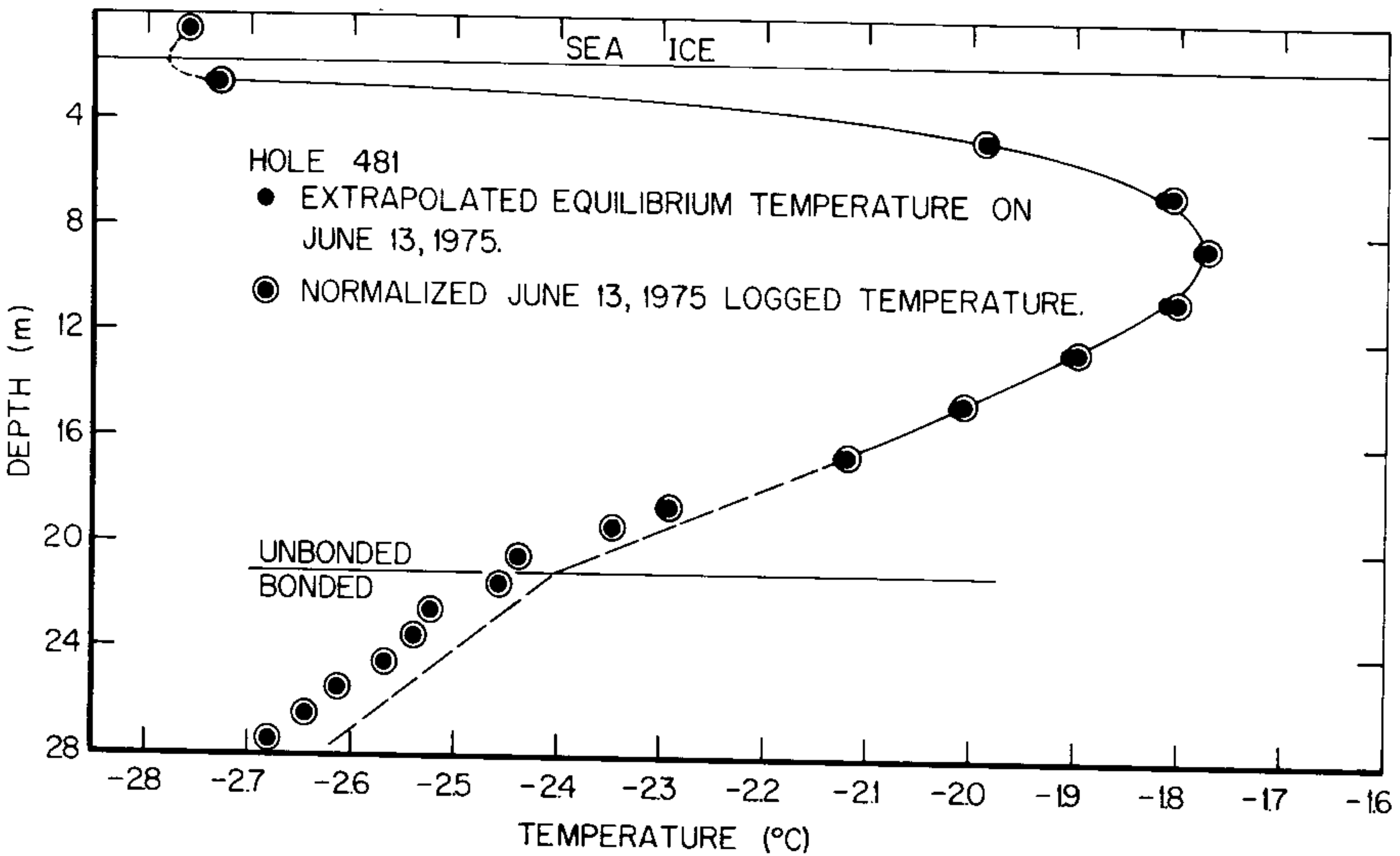

Figure 17. Extrapolated equilibrium temperatures and normalized logged temperatures for hole 481 on June 13, 1975.

Evidently, the effect of the escaping fluid was felt to a distance of several meters. The temperature curve has therefore been extrapolated downward to the unbonded-bonded boundary, ignoring the data from 18.55, 19.55 and 20.55 m (Figure 17).

Below the boundary the situation is also different. $\frac{1}{t}$ behavior is not followed and the temperature changes are large (Figure 18) and positive. This is a chemical effect, due to the fact that the freezing point (about -3.4°C) of the brine used as drilling fluid was lower than the in situ temperature (-2.5°C). The initial temperature, after the brine contacted the ice in the bonded layer, must have been the brine freezing point. Then the brine must have slowly become diluted as it melted ice near the borehole. The temperature should have slowly risen with the decreasing concentration of the brine and the released latent heat. An estimate of the equilibrium temperature was made by extrapolating the temperature down from the unbonded-bonded boundary, in such a way that the resulting curve was more or less parallel with the June 13 data (Figure 17). This procedure is probably valid as long as the rate of approach to equilibrium does not vary systematically with depth below the boundary. Since the difference between the freezing point and the in situ temperature seems to have been roughly constant, this seems reasonable.

Although this description of the behavior of the temperature in the vicinity of the unbonded-bonded boundary seems to be the most reasonable one, it should be borne in mind that it may not be quite right in some of its aspects, basically because of the limited time spanned by the data, and the complications due to the escaping fluid. For example, the

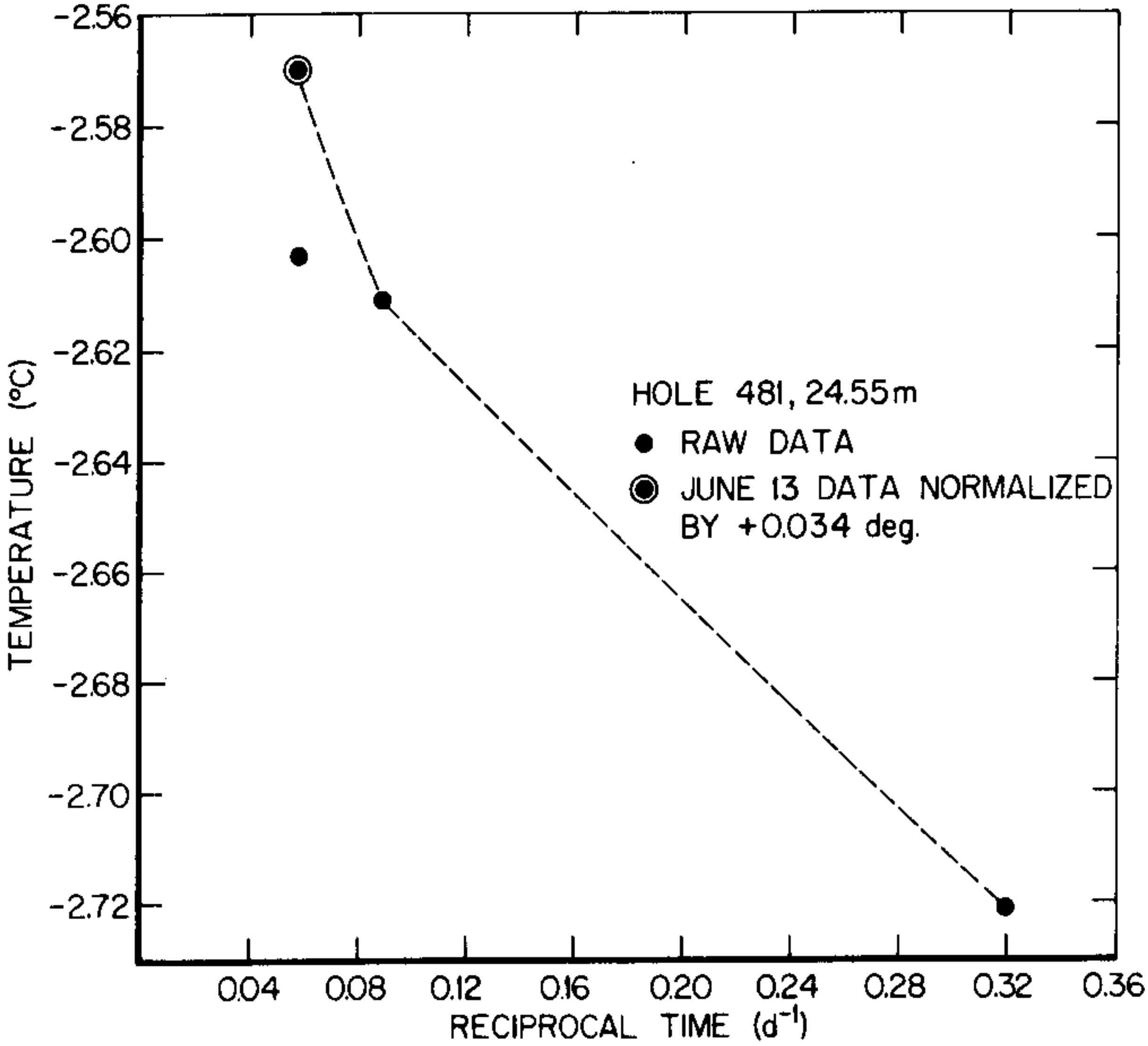

Figure 18. Temperature vs. reciprocal time for hole 481 at the 24.55 m depth.

possibility that the soil contains some ice a short distance above the unbonded-bonded boundary does not seem to be ruled out, even though the boundary was extremely well-defined mechanically.

Above 10.55 m depth secular change, due to the seasonally changing sea bed temperature, seems to be important. The thermal diffusivity was estimated from Equation (16) with the approximation given by Equation (18). At 6.55 m $\frac{\partial^2 T}{\partial z^2}$ was evaluated from the expression

$$\frac{\partial^2 T_j}{\partial z^2} = \frac{T_{j-1} - 2T_j + T_{j+1}}{\Delta z^2} - \frac{1}{12} \frac{\partial^4 T_j}{\partial z^4} (\Delta z^2) \tag{20}$$

where

$$\frac{\partial^4 T_j}{\partial z^4} \approx \frac{1}{\Delta z^4} [T_{j-2} - 4T_{j-1} + 6T_j - 4T_{j+1} + T_{j+2}], \tag{21}$$

and the index j indicates depth. These expressions are straightforward to show starting from the definition of a derivative, and using Taylor's series. The resulting κ is 18 m^2 a^{-1}. For 4.55 m there is insufficient data to estimate the second term on the right side of Equation (20), except on May 21. On this date the second term seems comparable to the first. A similar addition to the first term was assumed to apply on the other dates, although this approximation is probably poor. The resulting κ is 25 m^2 a^{-1}. When the secular corrections are made at both 4.55 and 6.55 m, the temperature approach to equilibrium has about the same slope as the depths below secular change (Figure 19).

Some of the errors in these estimates of κ were investigated theoretically. The uncertainty in the time origin and that due to the

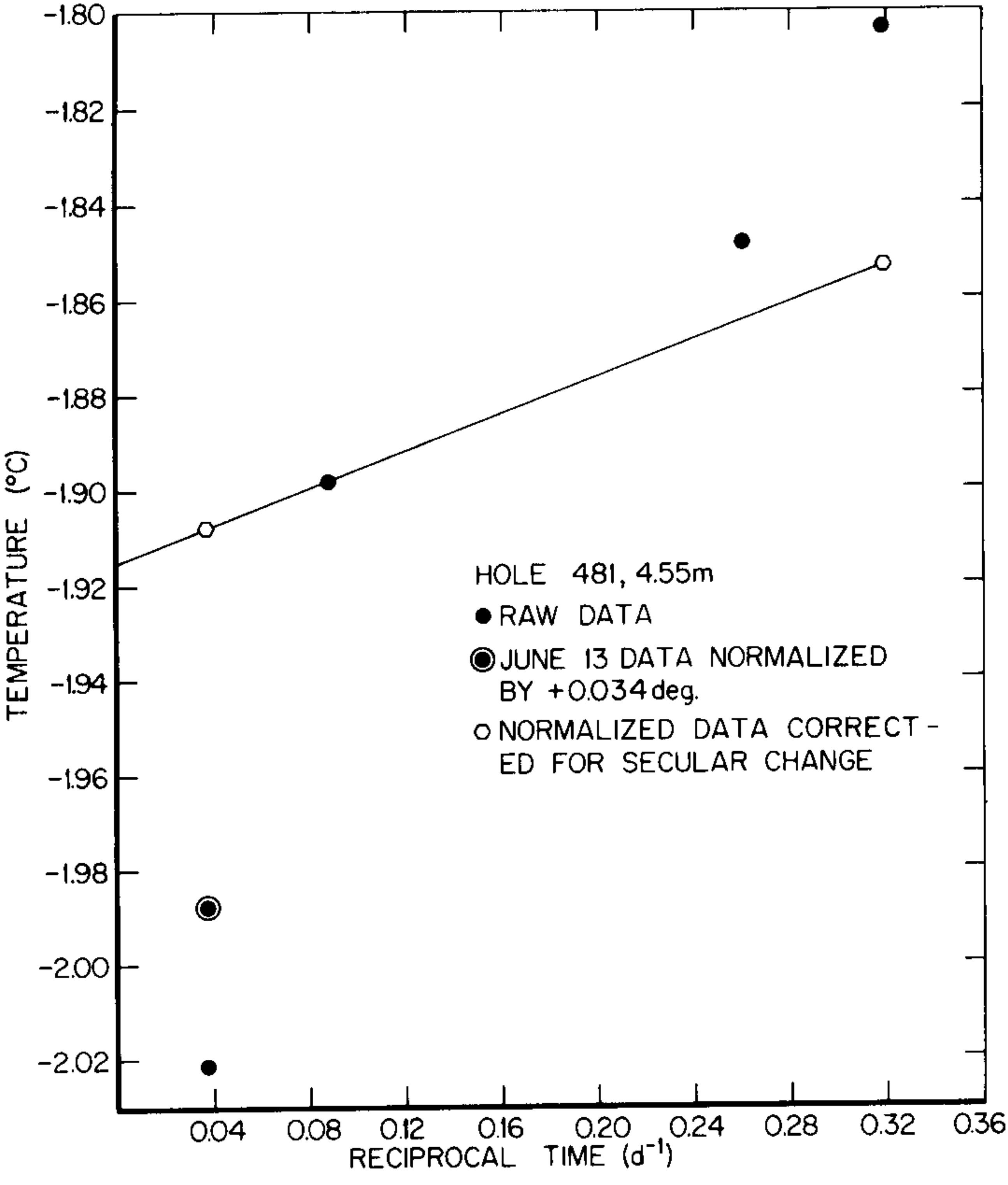

Figure 19. Temperature vs. reciprocal time for hole 481 at the 4.55 m depth. The datum point for May 21 (0.26 d^{-1}) was not used since it probably does not have the correct normalization relative to the other points.

finite radius of the hole seem negligible. At 6.55 m the secular change is small, and temperature measurement errors are important. At 4.55 m the change is large enough so that measurement errors are not important, but as noted above, $\frac{\partial^2 T}{\partial z^2}$ is poorly known. It seems reasonable to average the values at the two depths, giving as a best estimate $\kappa = 21\ m^2\ a^{-1}$ (compare with the estimate of $17\ m^2\ a^{-1}$ in Section IV). This could easily be in error by 30%. It applies to the sandy gravel with silt, rather than to the finer-grained shallow sediments. Although the error is large, the idea of determining κ *in situ* this way seems promising, once it is understood how many data are required. The departure from $\frac{1}{t}$ behavior due to the variation of the source strength and thermal properties with depth should be considered also.

The equilibrium temperature, estimated by methods already described, is slightly dependent upon the time origin, but the effect is dominated by the systematic error discussed above with the result that the systematic error in the estimated equilibrium temperatures is on the order of 0.05 deg. Except near the surface, the random error is about ten times smaller. Equilibrium temperatures are given in Appendix F and Figure 17. The measured temperatures are also given in Appendix F; no systematic correction has been applied to them.

3. Hole 3,370

The analysis of the temperature data from this hole will not be described in detail, since it is in many ways similar to that of hole 481. The error parameter ϵ (Equation (17)) is 0.00203 deg d, which if primarily due to the June 14 data, would imply a systematic error of

0.044 deg on that date. This is 0.010 deg larger than for hole 481, but is not unreasonable given field instrument performance.

Depths 10.48 to 28.48 m and 38.48 to 42.48 m seem to have a reasonable $\frac{1}{t}$ behavior, and the random error of extrapolation to equilibrium temperature T_∞ is probably about 0.005 deg. Depths 30.48 to 36.48 m and 44.98 m do not appear to give a reasonable T_∞ when a $\frac{1}{t}$ extrapolation is performed (Figure 20). Also, the slopes of the $\frac{1}{t}$ plots seem smaller than at the other depths. As in hole 481, the lack of $\frac{1}{t}$ dependence seems to be due to infiltration of drilling fluid, which, according to the borehole log, occurred frequently below about 28 m. At these anomalous depths the true equilibrium temperature is probably more like that indicated by the broken line in Figure 20.

Although much smaller than in hole 481, the secular change should have been observable at 8.48 m, and large enough to interpret in terms of a diffusivity at 6.48 m, although an accurate result would not be expected. The approach to equilibrium at these depths is not understood, since neither of these expectations was borne out. There are many possible reasons, but no obvious way of choosing among them. At 8.48 m and above, the error in the extrapolation to T_∞ is probably of the order of 0.02 deg.

The estimated equilibrium temperatures are given in Appendix F and Figure 20. In addition to the more or less random extrapolation errors, there is an overall systematic error of order 0.05 deg, as discussed in connection with hole 481.

4. Hole 203

Hole 203 was drilled on May 1 and 2. Data are given in Appendix F

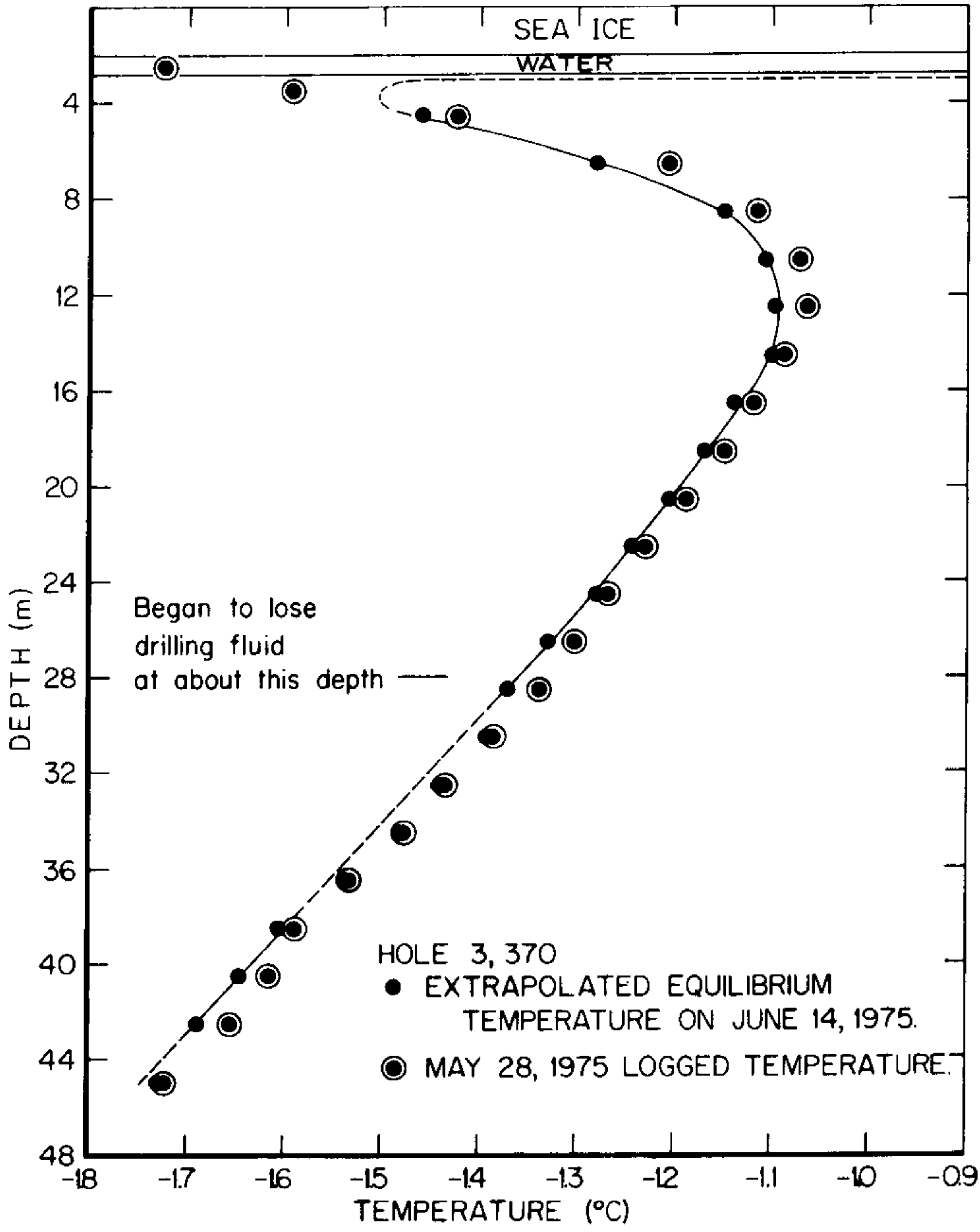

Figure 20. Extrapolated equilibrium temperatures on June 14, 1975 and logged temperatures on May 28, 1975 for hole 3,370.

and in Figure 21. The temperatures on May 29 are probably within 0.03 deg of equilibrium. In addition, there is a systematic error of roughly 0.05 deg.

5. Hole 493

Hole 493 was driven on May 15, 1975. Data are given in Appendix F. Since this hole was logged only once, it is uncertain how close the temperatures are to equilibrium. The systematic error is roughly 0.05 deg.

6. Hole -226

Hole -226 was drilled on land May 6, 1975. The data, given in Appendix F, have not yet been analyzed.

7. Hole 190

As described previously, a thermistor cable was permanently installed in this hole. The systematic errors present in the logged holes seem largely absent; in other words, the error parameter ε (Equation (17)) is approximately zero.

The temperatures at depths of 18.7 m and greater, with the exception of 33.7 m, have a $\frac{1}{t}$ approach to equilibrium (Figure 22), from which the equilibrium temperature T_∞ can be inferred to about 0.005 deg. The thermistor at 33.7 m does not show a reasonable approach to equilibrium (Figure 23). From the lack of such behavior at other depths, we infer that this thermistor was probably defective.

At shallower depths secular change is significant. At 13.7 m the thermal diffusivity κ was estimated by the same method as already described in connection with the 6.55 m depth in hole 481. The result is κ

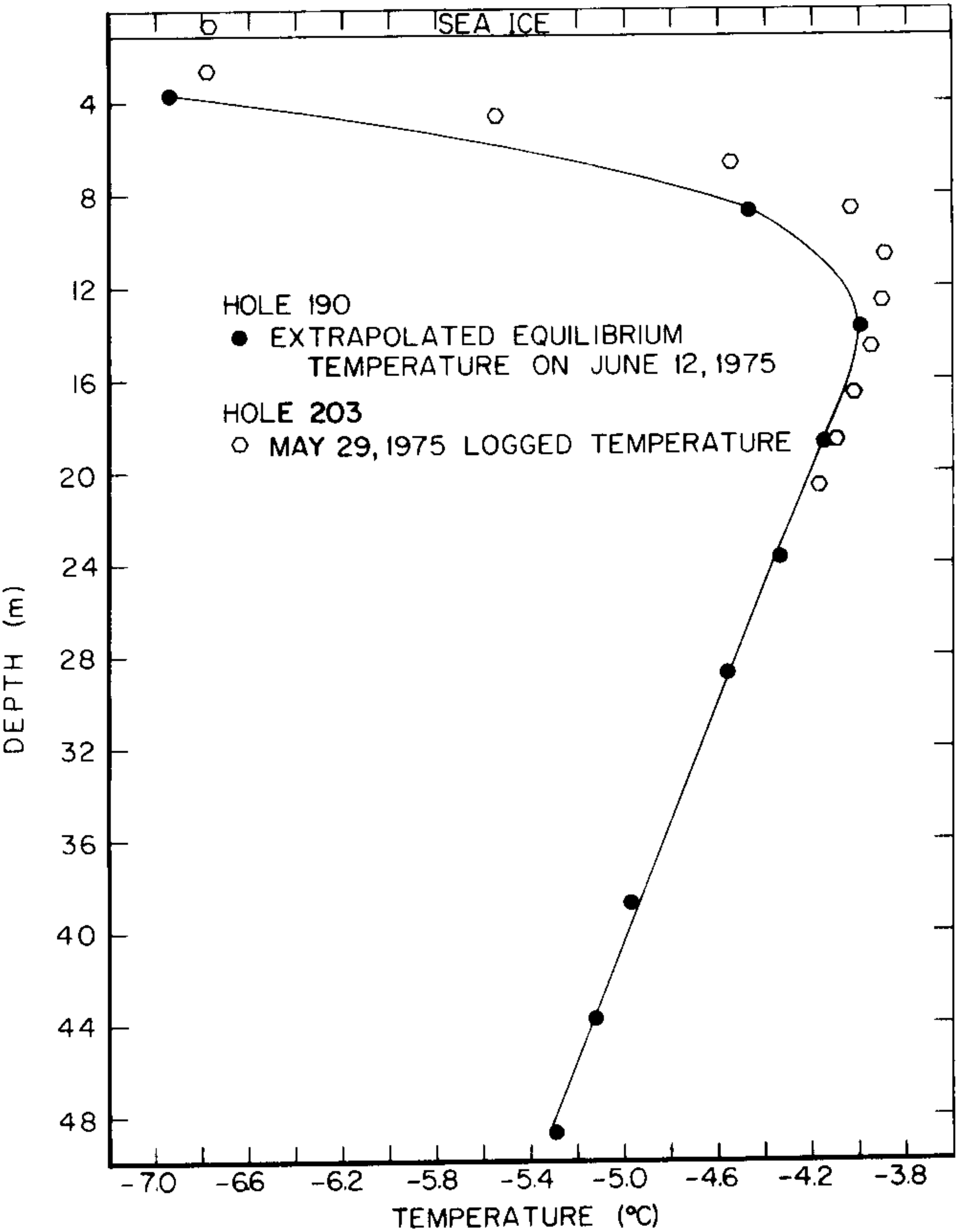

Figure 21. Extrapolated equilibrium temperatures on June 12, 1975 for hole 190 and logged temperatures on May 29, 1975 for hole 203. These data were put on the same figure because the holes were separated by only 13 m in an area of nearly constant water depth.

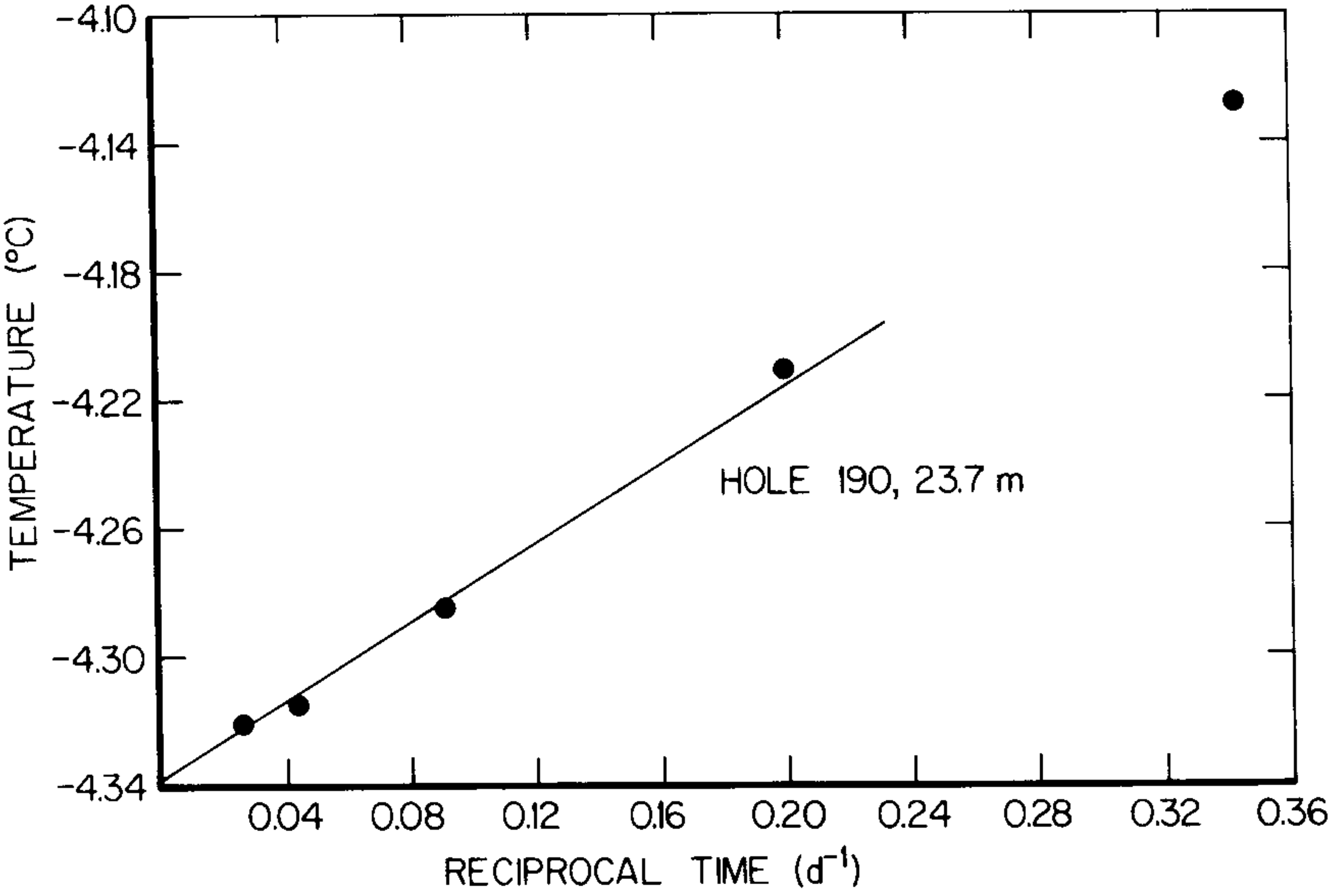

Figure 22. Temperature vs. reciprocal time for hole 190 at the 23.7 m depth. The time origin was May 4, 1975.

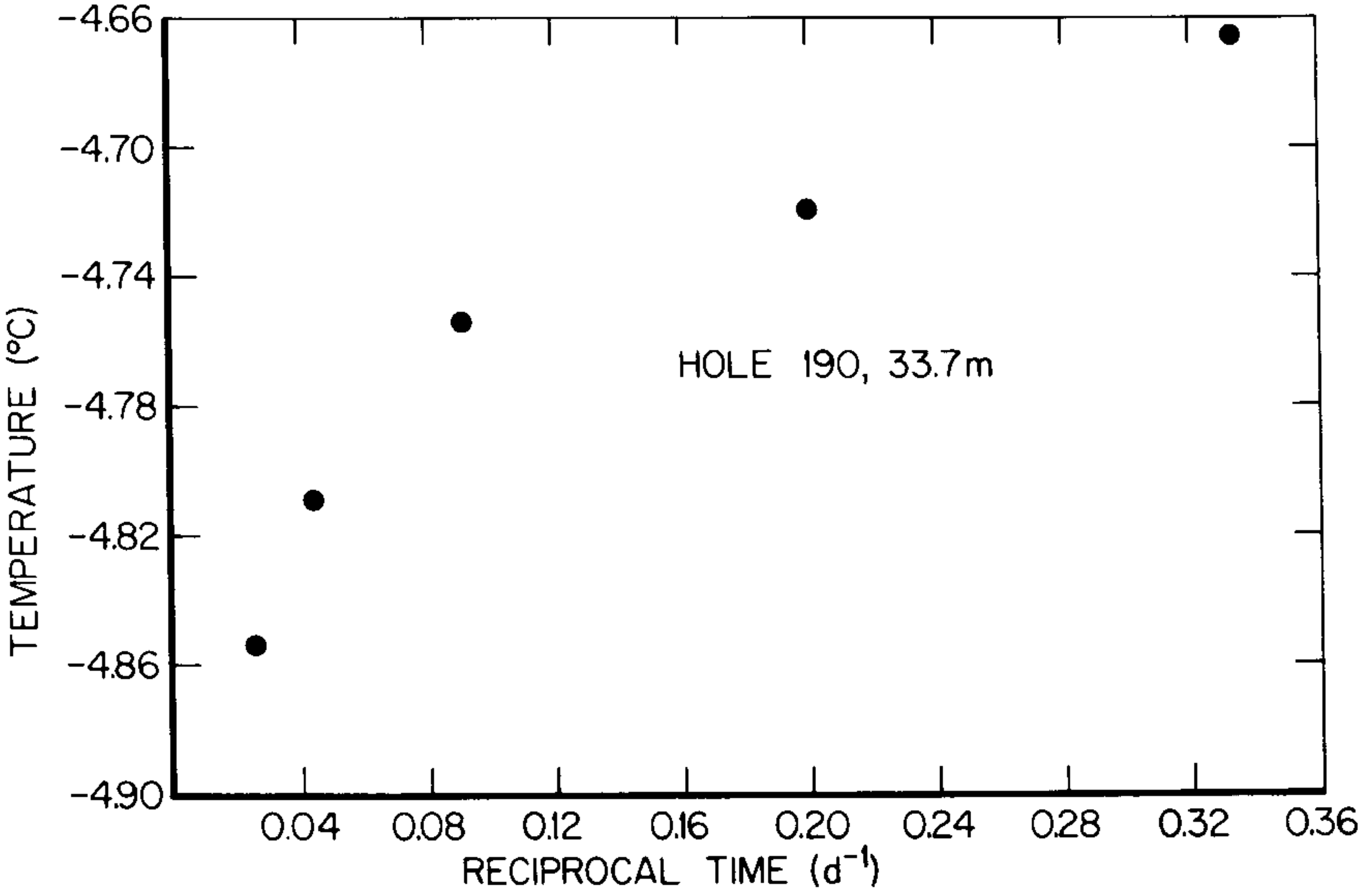

Figure 23. Temperature vs. reciprocal time for hole 190 at the 33.7 m depth. These data, together with those for adjacent thermistors, suggest that this thermistor may have failed after May 15 (reciprocal time 0.091 d^{-1}).

$= 27\ m^2\ a^{-1}$, but due to measurement errors and uncertainty in $\frac{\partial^2 T}{\partial z^2}$, the result could easily be in error by 50%. It may also be worthwhile to note a possible interpretation problem. Since the ground contains ice here, unlike the depths in hole 481 where the thermal diffusivity was estimated, the presence of even a very small amount of salt can lead to very high apparent heat capacity (see Harrison, 1972, for example), and therefore to a low thermal diffusivity. Also, the presence of salt layers could easily make the diffusivity inhomogeneous.

The behavior of the temperature at the 8.7 m depth is complicated, as it shows an initial increase in temperature between May 7 and 9, followed by a rather large decrease thereafter. The initial increase may be a chemical effect analogous to that encountered in the ice-bonded layer in hole 481. Possibly some of the concentrated brine from under the sea ice or from a briny layer in the soil penetrated to this depth, perhaps when the casing was pulled. The decrease in temperature sometime after May 9 is a secular effect. The behavior of the temperature at 3.7 m, which is also not monotonic, is probably dominated by secular change. The processes operating at these two depths are not understood well enough for a reliable correction for the drilling disturbance to be made. The June 12 measured temperatures are given as the safest estimate of the June 12 equilibrium temperatures at these two depths, with an unknown but possibly fairly large (of the order of 0.1 deg) uncertainty.

At depths of 13.7 m and below, the error in the extrapolation to the equilibrium temperatures seems to be of the order of 0.005 deg. This error should be combined with a relative thermistor calibration error of about the same magnitude, giving a random standard error of the order of

0.007 deg. The systematic (depth-independent) error is probably of the order of 0.01 deg or less.

The performance of these thermistors is of interest. Although the manufacturer only claims these units to be interchangeable to 0.1 deg, they seem to be an order of magnitude better. An ice point calibration run in 1973 shows that on the average the temperature at 0°C given by these units is only 0.002 deg low, with a standard deviation of 0.018 deg. The thermistor that later failed at 33.7 m was deleted from these calculations. It showed a larger error of about four standard deviations. The ice point data were used to improve the manufacturer's stated calibration. As noted, the systematic error in the field was estimated to be about 0.01 deg or less.

The data are given in Appendix F and in Figure 22.

C. Discussion

The mean annual sea bed temperature as a function of distance from shore and time since ocean transgression is shown in Figure 24. These temperatures were obtained by extrapolating the deep, approximately linearly varying temperatures in holes 190, 481, and 3,370 to the sea bed; time was obtained from an estimated transgression rate of the order of 1.4 m a^{-1} (Alexander and others, 1975).

These data illustrate the rapid increase in temperature with increasing distance from land. On land the mean annual surface temperature is about -9°C (although a century ago it was roughly 2 deg cooler (Gold and Lachenbruch, 1973)). At a distance of only 190 m from shore, where the ice thickness is 1.1 m and the ice is frozen to the bottom for about five months of the year, the mean annual sea bed temperature is

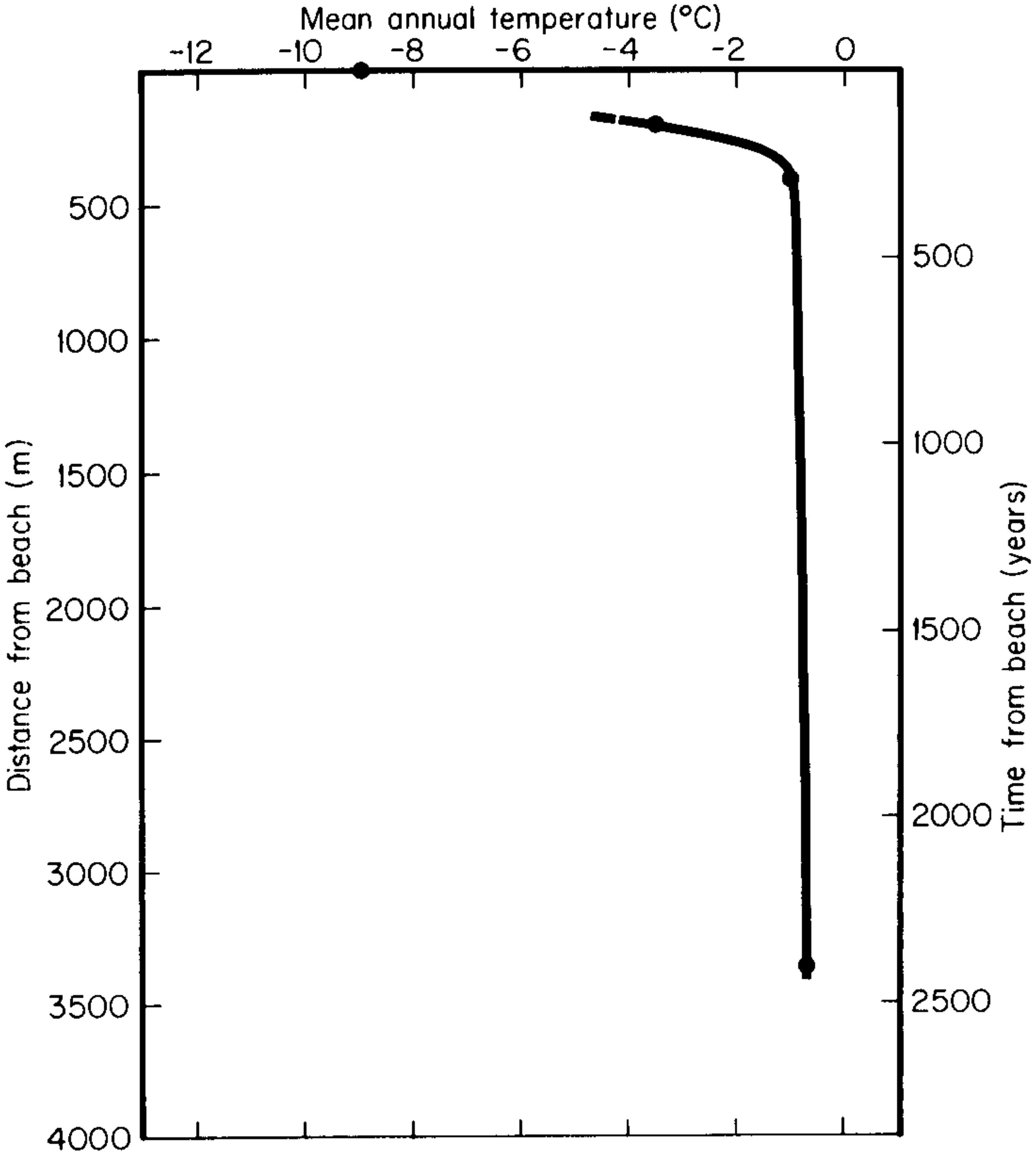

Figure 24. Mean annual sea bed temperature vs. distance and time from the beach. These temperatures were obtained by extrapolating the deep, nearly linear temperatures, up to the sea-bed. Time from the beach was obtained from an estimated transgression rate of 1.4 m a^{-1} (Alexander and others, 1975).

-3.4°C. At a distance of 481 m, where the ice thickness is 1.8 m and the ice does not freeze to the bottom, the mean annual sea bed temperature is about -1.1°C. At 3,370 m, where there is probably about 1m of water under the ice at its maximum thickness, the mean annual sea bed temperature is -0.7°C.

Osterkamp (1975) has suggested that the offshore areas where the sea ice freezes to the sea bed should be treated as a special case in the development of the subsea permafrost regime. From the discussion given here, and from Figures 15 and 16, it is evident that the major changes in the mean annual sea bed temperature, and in fact in the whole permafrost regime near the sea bed, occur within about 500 m of shore. The changes seem to be largely associated with the freezing of the sea ice to the sea bed. Therefore, the water depth is an important controlling factor of the mean annual sea bed temperature, which is the thermal boundary condition of the subsea permafrost regime. It was also noted in Section III that depth has a similarly large effect on the position of the bonded permafrost boundary.

VIII. IMPLICATIONS FOR RESOURCE DEVELOPMENT

(1) Massive ice that exists in the top 25 m of soil on land is probably absent offshore near Prudhoe Bay at water depths greater than 2 m. This conclusion may not hold where shoreline history and/or soil conditions are substantially different from those at our drilling site.

(2) The presence of the unbonded layer offshore indicates that it may be possible to use standard construction techniques for

foundations in this layer. The sandy gravel is an excellent foundation material, and since the material contains little or no ice, there will not be any settlement due to ice melting. A somewhat different situation will prevail if the foundation penetrates into the ice-bonded subsea permafrost.

(3) The presence of a sharp, moving boundary between the ice-unbonded layer and the ice-bonded subsea permafrost may create problems for structural features that transect this interface (e.g., pipelines, tunnels).

(4) The presence of the unbonded layer and other physical considerations imply that it may be difficult to freeze structures like ice islands, gravel islands, gravel causeways, etc., into the sea bed where the water depths exceed a few meters. This would substantially reduce the shearing forces that these structures could withstand.

(5) Trenches or holes made in bonded subsea permafrost near shore are likely to fill with concentrated brine.

(6) The presence of bonded subsea permafrost, probably of considerable thickness and at large distances from shore, implies the existence of problems for the production of hot oil analogous to those on land at Prudhoe Bay.

These statements should be regarded as somewhat tentative since they are based on limited data from one area. Although this is the first offshore drilling experiment at Prudhoe Bay specifically directed at the problem of subsea permafrost, important information from industry projects already exists, although much of it is proprietary and we have not had access to it. The most interesting that we have seen is the data from the sub-surface exploration for the old ARCO dock and its approaches. Relevant data to the west of our study area, from Gull and Reindeer islands, and from wells onshore near the beach also exist.

IX. ACKNOWLEDGMENTS

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X. REFERENCES

Alexander, V. and others (1975), Environmental studies of an arctic estuarine system - final report. Grant R081124-03, ROAP/Task 21

ARY/002, Program element 1BA022. U. S. Environmental Protection Agency, Corvallis, Oregon 97330.

Bullard, E. (1954), The flow of heat through the floor of the Atlantic Ocean. Proceedings of the Royal Society, Series A, Vol. 222, p. 408-429.

Doherty, B. T. and Kester, D. R. (1974), Freezing point of sea water. J. Marine Research, 32(2), 285-300.

Gold, L. W. and Lachenbruch, A. H. (1973), Thermal conditions in permafrost - A reivew of North American literature. Permafrost: North American Contribution to the Second International Conference, Printing and Publishing Office, National Academy of Sciences, Washington, D. C.

Harrison, W. D. (1972), Temperature of a temperate glacier, J. Glaciology, 11(61), 15-29.

Kersten, M. S. (1949), Laboratory research for the determination of the thermal properties of soils. Final report; Engineering Experiment Station, University of Minnesota, Minneapolis, Minnesota.

Lachenbruch, A. H. and Brewer, M. C. (1959), Dissipation of the temperature effect of drilling a well in Arctic Alaska. U. S. Geological Survey Bulletin 1083-C, U. S. Government Printing Office, Washington, D. C.

Lewellen, R. I. (1973), The occurrence and characteristics of nearshore permafrost, northern Alaska. Permafrost: North American Contribution to the Second International Conference, Printing and Publishing Office, National Academy of Sciences, Washington, D. C.

Luthin, J. N. (1966), Drainage engineering. John Wiley and Sons, Inc., New York, New York.

Muller, S. W. (1947), Permafrost or permanently frozen ground. Edwards Brothers, Ann Arbor, Michigan.

Müller-Beck, H. (1966), Paleohunters in America: Origins and diffusion. Science, 152(3726), 1191.

Osterkamp, T. E. (1975), A conceptual model of offshore permafrost. UAG R-234, Geophysical Institute, University of Alaska, Fairbanks, Alaska.

Park, K. (1964), Partial equivalent conductance of electrolytes in sea water. Deep Sea Research, 11, 729-736.

Rogers, J. C., Harrison, W. D., Shapiro, L. H., Osterkamp, T. E., Gedney, L. D. and VanWorner, J. D. (1975), Nearshore permafrost studies in the vicinity of Point Barrow, Alaska. Report UAG R-237, Sea Grant Report 75-6, Geophysical Institute, University of Alaska, Fairbanks, Alaska.

APPENDICES

APPENDIX A

FIELD DRILLING LOGS

These drilling logs were prepared by Mr. M. Grahek of the Road Materials Laboratory, Alaska Department of Highways, and in the field at the time of drilling. The soils were classified according to a visual classification system based on the Unified Soil Classification System as used by the Alaska Department of Highways. The graphical borehole logs were prepared from these drilling logs. Samples were numbered using the field-designated hole number and the depth in feet to the top of the sample. For example, 6040 refers to the drive sample taken from field-designated hole number 6 at a depth of 40 feet. The letter S in the sample number (e.g., 6S017) refers to those samples taken in Shelby tubes. Corresponding hole numbers, as used in the report, for the field-designated hole numbers can be obtained from Table I in the report.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska

LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin: 30Apr75
End:
Weather: +20 O.C. Lt. Snow
Hole No.: 1
Sheet 1 of 1
Total Depth:
Hole Dia.: 3¼
Hole Log By: Geohek
Type of Structure:
Hole Station:
Rt. Ft. Lt. Ft. of ℄
Collar Elevation:
Reference:
Field Party: Goaler, Walden, Manley, Andersen, Harmon
Rig: 05431
Notes: Near No. Prudhoe Bay State No. 1

Ground Water Data		
Depth in ft		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size	Blows/Ft. Depth	Method	Sample No	Blow Count	Loc Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Hollow Stem Auger	0			2"(1.4)	1000	20 68					1" Moss 1" Sand Organic Silt w/ Sand	Auger to 18"
	1					135 13					V. Ice Rich Silt Tr. F. Sand	
	2			3"(3¼)	1001.5	17 17						
	3					25 158						sample @ 1.5'
	4					200+ 10					200/2"	Sampler Full Auger to 4.5'
	5			2"(3¼)	1004.5	17 25						
	6					34 84						Sample
	7					100+ 27					100/3"	Sampler Full drove sampler down same hole
	8				1007.3	53 51					Occ. More Sand	
	9					84 100					100/3"	End hole @ 9.5' 30Apr75 due to ext. slow progress w/H.S.
	10											
	11											
	12											
	13											
	14											
	15											
	16											
	17											
	18											
	19											
	20											

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W 140 lb hammer W 30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begin: 30Apr75
End: 30Apr75
Weather: +20 OC. Lt. Snow

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No: 2
Sheet 1 of 1
Total Depth: 11.5
Hole Dia.: 3 1/4
Hole Log By: Geslok
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: [illegible], Walker, [illegible], Osterkamp, [illegible] Rig: 05431

Notes: ON Beach

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size / Blows/Ft. Depth	Sample Data: Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL			DRILLING NOTES
Hollow Stem Auger	0		2" (3/2)	2000	1 5				x x	ICE			≥2' SNOW ON SURFACE
	1				9 25				x x				Sample
	2				32 34					ORG. SILT ~~W/ICE, SAND~~	2.3-2.8		IN JAR discard Rest
	3			2003	38 34					Silty Sand	3.0-3.4		Auger to 3'
	4				34 60					gravelly	4.1-4.5	"	
	5				68 100+					100/3"	5.4-5.8	"	Sample
	6			2006	18 48					TR gravel	6.3-6.7	"	Auger to 6' Sample
	7				53 58						7.5-7.9	"	
	8				86 95+					95/3"	8.4-8.8	"	Auger to 9'
	9			2009	59 27						sample divided into 9 parts Numbered 2009 (1-9)		Sample
	10				29 57								
	11				225								
	12									T.D.= 11.5'			
	13												
	14												
	15												
	16												
	17												
	18												
	19												
	20												

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/ 140 lb hammer W/30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College Alaska

LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No.
Date Begun: 1 MAY 75 End: 2 MAY 75
Weather: +10 O.C. Lt SNOW
Hole No.: 3-3A Sheet 1 of 4
Total Depth: 73.5 Hole Dia.: 3¼
Hole Log By: Gealhek
Type of Structure:
Hole Station: Rt Ft Lt Ft of ℄
Collar Elevation: Reference:
Field Party: Gealhek, Walden, Mantha, Osterkamp, Hanson Rig: 05431

Notes:
10 ft
3A
O
225'

Ground Water Data		
Depth in ft		
Time		
Date		

Drilling Method	Depth in Feet	Method	Sample No	Blow Count	Subsurface Material	Drilling Notes
4¼" Hlow Stem Auger	0				ICE	16" snow on surface Auger to 30"
	1					
	2					
	2.5	2"(SPT)	3002,5	8		Sample
	3			8 26		3.8 - 4.6 in jars (1-2)
	4		3004,5	56 26	silty sand	sample in same hole 4.6 - 5.0 "
	5			23 33	org. silty F. sand	5.4 - 5.8 "
	6		300[illegible] 5	35 24	silty sand w/gravel	6.1 - 6.5 " Auger to 6.5'
	7			27 22		7.4 - 7.8 "
	8		300[illegible]5	19 15	TR. org. wet	8.1 - 8.5 " sample in same hole
	9			15 33		9.0 - 9.4
	10			38		10.1 - 10.5 AUGER to 17½'
	11					
	12					
	13				sandy gravel w/silt	
	14					
	15					
	16					
	17					
	17.5		3017,5	80		Sample
	18			295		AUGER to 20'
	19					
	20					

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

Project Name: CORE
Project No.:
Bridge No.:
Date Begin:
End:

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No.: 3-3A
Sheet 2 of 4
Total Depth: 23.5
Hole Dia.:
Hole Log By: Gealek
Type of Structure:

Weather:
Hole Station: Rt Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Notes:

Ground Water Data

Depth in ft		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: Blows/ft. Depth	Sample Data: Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Hollow Stem Auger	20							■		Sandy gravel w/silt	Auger to 32½'
	21							■			
	22							■		occ. sm xtals ice	
	23							■			
	24							■			
	25							■			
	26							■			
	27							■			
	28							■			
	29							■			
	30							■			
	31							■			
	32		2' Rotate	30925				■		No Sample	Rotated sampler w/carbide teeth broke off sampler move over ±23' (hole 3A)
	33					X		■			Auger to 40'
	34							■			
	35							■			
	36							■			
	37							■			
	38							■			
	39							■			
	40							■			

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:
Weather:

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No: 3-3A
Sheet 3 of 4
Total Depth: 73.5
Hole Dia:
Hole Log By: Ceslak
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party:
Rig:
Notes:

Ground Water Data	
Depth in ft.	39'
Time	0900
Date	2 May 75

Drilling Method	Depth in Feet	Casing Size	Blows/Ft. Depth	Sample Data Method	Sample No	Blow Count	Loc Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Hollow Stem Auger	40										Sand, gravel w/silt	Auger to 52½
	41											
	42											
	43											
	44											
	45											
	46											
	47											
	48											
	49											
	50											
	51											
	52											2 May 75 Auger to 60'
	53											
	54											
	55											
	56											
	57											
	58											
	59											
	60											

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE
Project No.:
Bridge No.:
Date Begin:
End:
Weather: +18 O.C. Lt. Snow, BR

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No.: 3-3A
Sheet 4 of 4
Total Depth: 73.5
Hole Dia.:
Hole Log By: Geaker
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in feet	Casing Size: Blows/Ft. Depth	Sample Data: Method	Sample No.	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Hollow Stem Auger	60									SAndy gRAvel w/silt	Auger to 72½
	61										
	62										
	63										
	64									becoming More sAndy	
	65										
	66									Appears to be sAnd w/occ. gravel	
	67										
	68										
	69										
	70										Sample @ 72.5 (14" Fill in) drove thru fill
	71										pilot bit stuck in Auger - pull Auger
	72		2" (342)	3A0725	18	X				SAndy gravel	
	73				240					T.D. 73.5'	
	74										
	75										
	76										
	77										
	78										
	79										
	80										

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begun: 3 May 75
End. 5 May 75
Weather: +14 Lt Sn, Lt Br.

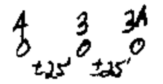
STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No: 4
Sheet 1 of 9
Total Depth: 183
Hole Dia: 3"
Hole Log By: Grahek
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Grahek, Walden, Mather, Hanson Rig: 05431

Notes:

sketch



Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: NX / Blows/Ft. Depth	Sample Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary TRI CONE 1 ⅞ Auger	0										
	1									ICE	Auger to 2½'
	2										NX to 4.8'
	3										drill to 5'
	4									Silty sand	sample drill to 8'
	5		2"(SPT)	A005	28 38	X				sandy gravel 5-5.5 / 5.5-6 in jar	
	6										
	7										sample
	8			A008	25 25	X				silty sand tr. gravel 8.5-9 "	drill ahead to 13
	9										
	10										
	11										
	12									sand gravel w/silt	
	13			A013	125 128	X				13.6 in jar lenses sandy silt & silty sand	sample drill ahead to 20
	14										
	15										NX to 25'
	16										
	17										
	18										
	19										
	20										

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No: 4
Sheet 2 of 9
Total Depth: 183
Hole Dia.:
Hole Log By: Gerlek
Type of Structure:

Weather:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:
Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size NX	Blows/Ft. Depth	Sample Data Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary for core	20										Sand, gravel w/silt	drill ahead to 53'
	21											
	22											
	23											
	24										occ. thin lenses	
	25										silty sand, sandy silt	NX to 50'
	26											
	27											
	28											
	29											
	30											
	31											
	32											
	33											
	34											
	35											
	36											
	37											
	38											
	39											
	40											

Note: Unless otherwise noted all samples are taken w/ 1.4" ID Standard Penetration Sampler driven w/ 140 lb hammer w/ 30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:

STATE OF ALASKA
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Engineering Geology Section
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LOG OF TEST BORING

Hole No: 4
Sheet 3 of 9
Total Depth: 183
Hole Dia:
Hole Log By: Geslok
Type of Structure:

Weather:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Notes

Ground Water Data		
Depth in ft		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size NX	Blows/Ft. Depth	Sample Data: Method	Sample No	Blow Count	Tot. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES	
Rotary Tri-Cone	40										SAND, GRAVEL w/ Silt		0
	41												1
	42										OCC. LENSES SAND, SILT, SILTY SAND		2
	43												3
	44												4
	45												5
	46												6
	47												7
	48												8
	49											drill ahead to 73'	9
	50											NX to 65'	0
	51												1
	52												2
	53												3
	54												4
	55												5
	56												6
	57												7
	58												8
	59												9
	60												0

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begun:
End:

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F College, Alaska
LOG OF TEST BORING

Hole No: 4
Sheet 4 of 9
Total Depth: 183
Hole Dia:
Hole Log By: GRAKEK
Type of Structure:

Weather:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: NX Blows/Ft. Depth	Sample Data Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
ROTARY TRI-CONE	60									SAND, gravel w/silt	
	61										
	62										
	63										
	64									OCC. lenses Sand, silt, — silty sand	drill ahead to 82'
	65										
	66										NX to 80'
	67										
	68										
	69										
	70										
	71										
	72										
	73										
	74										
	75										
	76										
	77										
	78										
	79										
	80										

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:
Weather:
Hole No: 4
Sheet 5 of 9
Total Depth: 183
Hole Dia.:
Hole Log By: Gealex
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:
Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size NX	Blows/Ft. Depth	Method	Sample No	Blow Count	Subsurface Material	Drilling Notes
ROTARY TRI-CONE	80						SAndy gravel w/silt	drill ahead to 92'
	81							
	82						occ. lenses sandy silt, silty sand	
	83							
	84							
	85							
	86							NX to 90' 4 May 75 +24° 15-20mph, o.c.
	87							
	88							drill out & ahead to 93'
	89							
	90							
	91							
	92							
	93			2"(3½")	D93	226 285		SAmple
	94							drill Ahead to 118'
	95							NX to 110'
	96							
	97							
	98							
	99							
	100							

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

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LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:
Weather:
Hole No: 4
Sheet 6 of 9
Total Depth: 183
Hole Dia.:
Hole Log By: Geahek
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:
Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size NX	Blows/Ft. Depth	Sample Data Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES	
Rotary Tri-cone	100	NX									Sandy gravel w/20 H	—	0
	101										—	—	1
	102										Occ. lenses sandy silt, silty sand	—	2
	103										—	—	3
	104										—	—	4
	105										—	—	5
	106										—	—	6
	107										—	—	7
	108										—	—	8
	109										—	— drill ahead to 133'	9
	110										—	—	0
	111										—	— NX to 128'	1
	112										—	—	2
	113										—	—	3
	114										—	—	4
	115										—	—	5
	116										—	—	6
	117										—	—	7
	118										—	—	8
	119										—	—	9
	120												0

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begun:
End:
Weather:

STATE OF ALASKA
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Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No: 4
Sheet 7 of 9
Total Depth: 183
Hole Dia:
Hole Log By: GEALEK
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size NX Blows/Ft., Depth	Sample Data Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
ROTARY TRI-CONE	120									SANDy gravel w/silt	
	121										
	122									OCC. LAYERS SAND, silt, silty SAND	
	123										
	124										
	125										
	126										
	127										drill ahead to 158'
	128										
	129										
	130										NX to 150'
	131										
	132										
	133										
	134										
	135										
	136										
	137										
	138										
	139										
	140										

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begun:
End:
Weather:

STATE OF ALASKA
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Box F, College, Alaska
LOG OF TEST BORING

Hole No: 4
Sheet 8 of 9
Total Depth: 183
Hole Dia:
Hole Log By: Gerlek
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size 4½	Blows/Ft. Depth	Sample Data: Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary Tri-cone	140	↓									Sandy gravel w/silt	
	141											
	142										occ. lenses Band, silt, silty sand	
	143											
	144											
	145											
	146											
	147											
	148											
	149											
	150	↓										5 May 75 +26 deg. clr and fog drill ahead to 120'
	151											
	152											
	153											
	154											
	155	↓										
	156											
	157											
	158											
	159											
↓	160										↓	

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

STATE OF ALASKA
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Engineering Geology Section
Box F, College, Alaska

LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begun:
End:
Weather:
Hole Station: Rt Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Hole No: 4
Sheet 9 of 9
Total Depth: 183
Hole Dia:
Hole Log By: Gralek
Type of Structure:

Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size	Blows/Ft. Depth	Sample Method	Sample No.	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary - Tri-Cone	160										Sandy gravel w/silt	
	161											
	162										occ. layers Sand, silt & silty sand	
	163											
	164											
	165											
	166											
	167											
	168											
	169											tried to install the caistor cable - hole caved to ±160
	170											pulled cable - NX to 155'
	171											drill out & ahead to 183'
	172											put in cable - hole caved @ ±162' again
	173											
	174											
	175											
	176											
	177											
	178											
	179										same to 183'	T.D.=183'
	180											

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
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LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begun: 6 May 75
End: 7 May 75
Weather: +30 FOG
Hole No.: 5
Sheet 1 of 2
Total Depth: 40'
Hole Dia.: 6"
Hole Log By: Geohek
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference.
Field Party: Geohek, Walden, Mathe, Harrison
Rig: 03431
Notes: ±5' from Boring 1

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method: 6" Cont. Fl. Solid Auger

Depth in Feet	Casing Size	Blows/Ft. Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
0										1" MOSS 1" SAND ORG. SILT w/SAND V. ICE Rich Silt	Samples to 9.5' IN Boring 1
2										TR. F. SAnd	
8										Decr. w ICE	Auger to 9.5'
9			2" SS	5009.5						INCR. F.SAND	Sample
10					87 90 200+	X				200/3"	Auger to 11'
11				5011	152 200	X					Sample Auger to 12½'
12				5012.5	150 63	X				V. Little seg. ICE	Sample
13					230 300+	X				300/4"	Auger to 15½'
15				5015.5	140 300+	X				tr. F. GRAVEL 300/3"	Auger to 18½
17										becoming	
18			2"	5018.5	SPW	X				Silty sand Sample melted put in jar	SPW 'U Sampler
19											Auger to 21½
20											

Note: Unless otherwise noted all samples are taken W 1.4" ID Standard Penetration Sampler driven W 140 lb hammer W 30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begin: 6 May 75
End:
Weather: +30 FOG

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No: 5
Sheet 2 of 2
Total Depth: 40'
Hole Dia.:
Hole Log By: GRAHEK
Type of Structure:

Hole Station. Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference.
Field Party: Rig:

Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size / Blows/Ft. Depth	Sample Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
6" Cont Flt Solid Auger	20									Silty sand	—
	21		2"(3½)							TR. F GRAVEL	— SAmple
	22			50215	350	X				—	— 7 May 75
	23									becoming more gravelly	— Auger to 24½
	24		↓	50225	250	X				SANDY GRAVEL	— Sample 18" Fill-in - drove thru
	25									w/silt tr. org	—
	26									—	— Auger to 27½
	27		↓	50235	250	X				— sample in jar	— SAmple
	28									—	— 40" Fill-in - drove thru
	29									—	— Auger to 40'
	30									—	—
	31									—	—
	32									—	—
	33									—	—
	34									—	—
	35									—	—
	36									—	—
	37									—	—
	38									—	—
	39									— T.D.=40'	—
	40										

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

STATE OF ALASKA
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Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begun: 7 MAY 75
End: 14 MAY 75
Weather: +32 Fog
Hole No.: 6
Sheet 1 of 8
Total Depth: 150
Hole Dia.: 3"
Hole Log By: GRANER
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Graner, Walden, White, Harrison Rig: CS431

Notes: ±2 mi. out from end of dock

Ground Water Data	
Depth in ft.	2.0
Time	0900
Date	8 May 75

Drilling Method: Rotary Tri-Cone → | 6" Cont Flt Solid Auger

Casing Size: NX

Depth in Feet	Casing Size / Blows/Ft.	Sample Method	Sample No	Subsurface Material	Drilling Notes
0				—	—
1				—	—
2				ICE —	— Auger through ICE
3				—	—
4				—	—
5				—	—
6				—	—
7				WATER —	—
8				—	—
9	2⅞" Shelby	Push	6S0093	silty sand black w/ org.	— Push shelby into bottom
10					— NX to 12' (push)
11				—	— drill to 12'
12		Push	6S012	—	— pushed shelby
13				—	— NX to 14.5
14				—	— drill to 14.5
15		Push	6S014.5	becoming coarser	— Push Shelby
16				—	— NX to 17"
17		Push	6S017	—	— drill to 17' push shelby
18				—	— NX to 19.5' 8 May 75 +29° Fog
19				TR. F. Gravel	— drill out to 19.5 push Shelby
20					

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

Project Name: CORE
Project No: Bridge No:
Date Begin: End:
Weather:

STATE OF ALASKA
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Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No.: 6 Sheet 2 of 8
Total Depth: Hole Dia.:
Hole Log By: GRALEK
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Notes:

Ground Water Data		
Depth in ft		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: DX / Blows/Ft. Depth	Sample Data: Method	Sample No.	Blow Count	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary Tri-cone	20		2½" Shelby	6SO20.5	Push	Silty SAND (black) TR. F. gravel	NX to 22'
	21					TR. ORG.	drill out to 22'
	22			6SO22	Push		Push Shelby NX to 24½'
	23						drill out to 24½'
	24			6SO24.5	Push		Push Shelby
	25					INCR. Amt. gravel	NX to ~~[illegible]~~ 27 drill to 27'
	26						Push Shelby
	27			6SO27	Push		NX to 29½'
	28						drill to 29½'
	29		2"(3o2)	6O29.5	3 5 7	sample washed	SAmple - 7" Fill in
	30						NX to 32½'
	31	30					Sample - 12" Fill in
	32	17		6O32.5	10 9 8	most of sample washed	NX went down 9" w/sample
	33						NX to 35'
	34	22					drill out to 35'
	35			6O35	10 7 5		SAmple 5' Fill in - v. soft - [illegible]
	36						
	37	25					NX to 40
	38	27					drill out to 40'
	39	37					
	40						

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
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LOG OF TEST BORING

Project Name: CORE
Project No.:
Bridge No.:
Date Begun:
End:
Weather:
Hole No.: 6
Sheet 3 of 8
Total Depth:
Hole Dia.:
Hole Log By: GRAHEK
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party:
Rig:
Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size: NX Blows/Ft. Depth	Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	Subsurface Material	Drilling Notes
Rotary TRI-CONE	40		2(3x2)	6040	6 6 5	X				Silty sand w/tr. gravel occ. tr. org. No Recovery	Sample 12" Fill-in - drove thru
	41										NX to 45'
	42	50									drill to 45'
	43	58									
	44	65									
	45		↓	6045	8 7 6	X				samples in 2 jars	Sample 1" Fill in
	46										NX to 55'
	47	75									drill out to 55'
	48	59									
	49	58									
	50	49									
	51	38									
	52	37									
	53	39									
	54	53								Sandy gravel w/silt	
	55		↓	6055	10 10 10	X					Sample - 2" Fill in
	56										NX to 65'
	57	78									drill out to 65'
	58	98									
	59	98									
	60										

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE

Project No:

Bridge No:

Date Begun:

End:

Weather:

STATE OF ALASKA
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Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No.: 6 Sheet 4 of 8

Total Depth:

Hole Dia.:

Hole Log By: Geolek

Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄

Collar Elevation: Reference:

Field Party: Rig:

Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method: ROTARY/TRI-CONE

Depth in Feet	Casing Size: Blows/Ft, Depth	Sample Data Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	SUBSURFACE MATERIAL	DRILLING NOTES
60	83							Sandy gravel w/silt	—
61	105							—	—
62	85							—	—
63	70							—	—
64	75							—	— SAMPLE placed temp. probe in hole cased 5'-left there
65		3"	6085	9 8 6	☒			— IN JAR +2" ROCKS STUCK IN shoe	— 9 MAY 75 +28° Lt. Br. O.C.
66								—	— NX to 75'
67	60							—	— drill out to 75'
68	68							—	—
69	60							—	—
70	57							—	—
71	59							—	—
72	47							—	—
73	47							—	—
74	50							—	—
75								—	INserted temp probe to 76.5'
76		Temp			☒			—	—
77	72							—	— NX to 85'
78	75							—	— drill out to 85'
79	92							—	—
80									

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No.: 6
Sheet 5 of 8
Total Depth:
Hole Dia.:
Hole Log By: Geaker
Type of Structure:
Weather:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:
Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size NX Blows/Ft. Depth	Sample Data Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Subsurface Material	Drilling Notes
ROTARY - TRI-CONE	80	158							SANDy GRAVel w/silt	
	81	265								
	82	265								
	83	210								
	84	196								
	85		2"(3½)	6085	19 17 17	X	■		2 JARS	SAmple
	86									NX to 90'
	87	165								drill out & Ahead to 93'
	88	140								
	89	133								
	90									Losing mud below NX
	91									NX to 100'
	92									
	93	125								dRill out to 100'
	94	135								
	95	118								Lose WATER @ bottom of NX
	96	138								
	97	146								
	98	176								
	99	193								
	100									

Note: Unless otherwise noted all samples are taken w/ 1.4" ID Standard Penetration Sampler driven w/ 140 lb hammer w/ 30" drop.

Project Name: CORE
Project No.: Bridge No.:
Date Begin: End:
Weather:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No.: 6 Sheet 6 of 8
Total Depth: Hole Dia.:
Hole Log By: GEALEK
Type of Structure:
Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size NX / Blows/Ft. Depth	Method	Sample No.	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
ROTARY TRI-CONE	100	120								sandy gravel w/silt	NX to 105'
	101	148									drill out to 105'
	102	115									
	103	119									
	104	212									10' Fill-in after pulling bit
	105	120									NX to 110'
	106	130									
	107	157									
	108	158									drill out to 110'
	109	188									10 MA 75 +25 clr.
	110	135									NX to 115
	111	218									drill out & ahead to 125
	112	270									Losing water below NX
	113	325									
	114	342									NX to 130'
	115										
	116										
	117										
	118										
	119										
	120										

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

Project Name: CORE
Project No:
Bridge No.
Date Begun:
End:
Weather:

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No.: 6
Sheet 7 of 8
Total Depth:
Hole Dia.:
Hole Log By: Gellek
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size / Blows/Ft. Depth	Sample Data: Method	Sample No	Blow Count	Loc Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary - tri-cone	120									SAND, GRAVEL w/silt	drill out to 130'
	121	156									
	122	174									
	123	178									
	124	150									
	125	136									
	126	143									
	127	205									
	128	296									
	129	248									drill ahead to 133'
	130										NX to 135'
	131										drill out & ahead to 143'
	132										
	133	280									Lose water below NX
	134	325									
	135										
	136										NX to 145
	137										
	138										
	139										
	140										

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE

Project No:
Bridge No:

Date Begin:
End:

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS

Engineering Geology Section
Box F, College, Alaska

LOG OF TEST BORING

Hole No: 6
Sheet 8 of 8

Total Depth:
Hole Dia:

Hole Log By: GeAkek

Type of Structure:

Weather:

Hole Station: Rt. Ft. Lt. Ft. of ℄

Collar Elevation: Reference:

Field Party: Rig:

Notes:

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size NX Blows/Ft. Depth	Sample Data Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary Tri-cone	140									SANDy gravel w/ silt	
	141										drill out & Ahead to 148'
	142										Lose WATER below NX
	143	319									
	144	307									NX to 147½'
	145										drill out & Ahead to 150'
	146										UX to 150'
	147										14 MAY 75 +25 de 20-25mph
	148										drill out to 150'
	149										
	150									T.D. = 150'	installed pipe to ±147'
	151										
	152										After pulling NX, DISTANCE top of ICE to Mudline = 8.5'
	153										
	154										
	155										
	156										
	157										
	158										
	159										
	160										

Note: Unless otherwise noted all samples are taken w/ 1.4" ID Standard Penetration Sampler driven w/ 140-lb hammer w/ 30" drop.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin: 15 Mar 75
End: 15 Mar 75
Weather: +20 Clr. Lt. Br.
Hole No.: P7
Sheet 1 of 1
Total Depth: 55'
Hole Dia.: 2 1/8
Hole Log By: Gealek
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Gealek, Wilder, Matthews, Harrison, Dreckamp Rig: 05421

Notes: @ "E"

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method: BW Rod driven w/ 340# hammer 30" drop

SUBSURFACE MATERIAL

0 1	11	20 21	16	40 41	18
2	22	22	18	42	21
3	38	23	17	43	22
4	40	24	13	44	25
5	32	25	15	45	29
6	20	26	16	46	29
7	5	27	16	47	32
8	6	28	19	48	36
9	17	29	12	49	49
10	20	30	14	50	55
11	17	31	14	51	45
12	21	32	19	52	36
13	20	33	16	53	46
14	19	34	22	54	61
15	20	35	25	55	50
16	17	36	18	56	
17	21	37	31	57	
18	27	38	25	58	
19	18	39	20	59	
20	21	40	21	60	

DRILLING NOTES

T.D. = 55'

Note: Unless otherwise noted all samples are taken W/ 1.4" ID Standard Penetration Sampler driven W/ 140 lb hammer W/ 30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begun: 15May75 End: 15May75
Weather: +25° CLR Lt.BR.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No: P8 Sheet 1 of 1
Total Depth: 55 Hole Dia: 2⅞
Hole Log By: Gealek
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Gesher, [illegible], [illegible], [illegible], Osterkamp Rig: 05431

Notes:
300-400 yds So. of 'E'

Ground Water Data
Depth in ft
Time
Date

Drilling Method: BW Rod [illegible] w/342# hammer 30" drop

SUBSURFACE MATERIAL / DRILLING NOTES

0 1	—	20 21	19	40 41	29	
2	42	22	18	42	31	
3	36	23	18	43	31	
4	29	24	21	44	33	
5	30	25	15	45	31	
6	15	26	16	46	25	
7	15	27	19	47	30	
8	15	28	22	48	34	
9	27	29	19	49	43	
10	38	30	17	50	51	
11	27	31	15	51	47	
12	25	32	11	52	44	
13	29	33	14	53	37	
14	30	34	19	54	39	
15	29	35	29	55	42	
16	29	36	32	56		T.D.=55'
17	26	37	36	57		installed ¾" pipe to ±41'
18	25	38	34	58		
19	25	39	29	59		
20	23	40	30	60		

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begin: 15 May 75
End: 15 May 75
Weather: +28 Clr. Lt. Br.

STATE OF ALASKA
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Engineering Geology Section
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LOG OF TEST BORING

Hole No: P9
Sheet 1 of 1
Total Depth: 11
Hole Dia: 2 7/8
Hole Log By: Geaker
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation:
Reference:
Field Party: Geaker, Walden, [illegible], [illegible] File: 05431

Notes:
NEAR 3, 3A, 4

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method: BW Drill Rod driven w/ 342# hammer, 30" drop

Depth in Feet | Casing Size | Blows/Ft. Depth | Sample Data: Method | Sample No | Blow Count | Loc. Sampled | Recovery | Frozen | Soil Graph

SUBSURFACE MATERIAL — DRILLING NOTES

0 1	8	20 21		—
2	32	22		—
3	57	23		—
4	42	24		—
5	50	25		—
6	68	26		—
7	93	27		—
8	98	28		—
9	*137	29		—
10	*120	30		—
11	*266	31		—T.D.= 11'
12		32		—
13		33		—
14		34		—
15		35		—
16		36		—
17		37		—
18		38		—
19		39		* Marty
20		40		—

Note: Unless otherwise noted all samples are taken w/ 1.4" ID Standard Penetration Sampler driven w/ 140 lb hammer w/ 30" drop.

Project Name: CORE

Project No:

Bridge No:

Date Begin: 15 May 75 End: 15 May 75

Weather: +27' Clr. ct. Be.

STATE OF ALASKA
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Engineering Geology Section
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LOG OF TEST BORING

Hole No: P10 Sheet 1 of 1

Total Depth: 10' Hole Dia: 2 1/2

Hole Log By: Geaher

Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄

Collar Elevation: Reference:

Field Party: Geaher, [illegible] Rig 05431

Notes: Between P8 & P9

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method: BW Drill Rod drives w/340# hammer, 30" drop

Depth in Feet | Casing Size | Blows/Ft. Depth | Sample Data: Method | Sample No | Blow Count | Loc. Sampled | Recovery | Frozen | Soil Graph

SUBSURFACE MATERIAL | DRILLING NOTES

0 1	22	20 21	40 41	—	
2	44	22	42	—	
3	75	23	43	—	
4	165	24	44	—	
5	225	25	45	—	
6	68	26	46	—	
7	86	27	47	—	
8	85	28	48	—	
9	183	29	49	—	
10	322	30	50	—	T.D.=10'
11		31	51	—	
12		32	52	—	
13		33	53	—	
14		34	54	—	
15		35	55	—	
16		36	56	—	
17		37	57	—	
18		38	58	—	
19		39	59	—	
20		40	60	—	

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

STATE OF ALASKA
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Engineering Geology Section
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LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin: 15 May 75 End: 15 May 75
Weather: +28° CLR Lt. Br.

Hole No.: P11 Sheet 1 of 1
Total Depth: 15' 7" Hole Dia.: 2 1/2
Hole Log By: Gealek
Type of Structure:

Hole Station. Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: [illegible], Overcamp Rig: 05 431

Notes: Between P8 & P10

Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method | Depth in Feet | Casing Size | Blows/Ft, Depth | Sample Data: Method | Sample No | Blow Count | Loc. Sampled | Recovery | Frozen | Soil Graph | SUBSURFACE MATERIAL | DRILLING NOTES

Drilling Method: BW Rod driven w/342" hammer 30" drop

0 1	16	20 21	40 41
2	65	22	42
3	220	23	43
4	244	24	44
5	93	25	45
6	46	26	46
7	31	27	47
8	57	28	48
9	68	29	49
10	31	30	50
11	42	31	51
12	48	32	52
13	70	33	53
14	52	34	54
15	82	35	55
16	100/7"	36	56
17		37	57
18		38	58
19		39	59
20		40	60

T.D. = 15' 7"

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begin:
End:
Weather:

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Hole No: 13
Sheet 2 of 5
Total Depth:
Hole Dia:
Hole Log By: Graher
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:
Notes:

Ground Water Data		
Depth in ft		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size NX / Blows/Ft. Depth	Sample Method	Sample No	Blow Count	Lot. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
Rotary Tri-cone	20		3"(342)	13020	5 4 3	X				Sandy gravel w/silt — 20.5 in jar —	NX to 30'
	21									— —	
	22	10								— —	drill out to 30'
	23	22								— —	
	24	32								— —	
	25	34								— —	
	26	52								— —	
	27	52								— —	
	28	56								— —	
	29	54								— —	Sample
	30			13030	9 9 9	X				— 31 in jar —	
	31									— —	
	32	54								— —	NX to 40'
	33	49								— —	
	34	56								— —	drill out to 40'
	35	57								— —	
	36	65								— —	
	37	57								— —	
	38	59								— —	
	39	64								— —	
	40										

Note: Unless otherwise noted all samples are taken ☐1.4" ID Standard Penetration Sampler driven ☐140 lb hammer ☐30" drop.

STATE OF ALASKA
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Engineering Geology Section
Box F, College, Alaska
LOG OF TEST BORING

Project Name: CORE
Project No.:
Bridge No.:
Date Begin:
End:
Weather:
Hole No.: 13
Sheet 3 of 5
Total Depth:
Hole Dia.:
Hole Log By: GRAhek
Type of Structure:
Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation:
Reference:
Field Party:
Rig:
Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size NX / Blows/Ft. Depth	Sample Data: Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
ROTARY / TRI. CONE	40		Y(3X2)	13040	9 8 6	X	■			SANDy gRAVel (gravelly SAND) w/silt 41' in jar	
	41										UX to 50'
	42	68									
	43	70									drill out to 50'
	44	120									
	45	100									
	46	90									
	47	90									
	48	72									
	49	92									sample
	50			13050	10 11 10	X	■				
	51									51' in jar	
	52	90									NX to 60'
	53	106									
	54	107									DRill out to 60'
	55	72									
	56	68									
	57	75									
	58	80									
	59	103									
	60										

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE
Project No.:
Bridge No.:
Date Begin: 15 May 75
End: 16 May 75
Weather: +28° Clr. Lt. Br.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS
Engineering Geology Section
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LOG OF TEST BORING

Hole No.: P12
Sheet 1 of 1
Total Depth: 70'4"
Hole Dia.: 2 7/8
Hole Log By: Geahek
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation:
Reference:
Field Party: Geahek, Walker, Manke, Hanson, Osterkamp
Rig: 05431

Notes:
Just So. of P8

Ground Water Data

Depth in ft		
Time		
Date		

Drilling Method | Depth in Feet | Casing Size | Blows/Ft. Depth | Sample Data: Method | Sample No | Blow Count | Loc Sampled | Recovery | Frozen | Soil Graph

Drilling Method: BW Rod driven w/ 392# hammer, 30 drop

SUBSURFACE MATERIAL

DRILLING NOTES

0 1	9	20 21	17	40 41	36	60 61	57	
2	41	22	19	42	38	62	47	
3	82	23	20	43	35	63	54	
4	66	24	22	44	46	64	44	
5	48	25	21	45	96	65	39	
6	24	26	24	46	103	66	51	
7	22	27	28	47	124	67	50	
8	22	28	38	48	150	68	42	
9	27	29	59	49	98	69	51	
10	34	30	80	50	88	70	135	
11	29	31	53	51	61	71	188/4"	T.D.=70'4"
12	30	32	49	52	57	72		21.4m
13	27	33	43	53	70	73		
14	27	34	47	54	56	74		
15	35	35	48	55	68	75		
16	27	36	44	56	41	76		
17	29	37	59	57	38	77		
18	30	38	57	58	45	78		
19	34	39	57	59	40	79		
20	35	40	56	60	54	80		

Note: Unless otherwise noted all samples are taken w/ 1.4 ID Standard Penetration Sampler driven w/ 140 lb hammer w/ 30" drop.

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Engineering Geology Section
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LOG OF TEST BORING

Project Name: CORE
Project No:
Bridge No:
Date Begin: 16 May 75
End: 18 May 75
Weather: +22 O.C. Lt. Br.

Hole No: 13
Sheet 1 of 5
Total Depth: 93
Hole Dia: 3"
Hole Log By: Geslak
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Geslak, Walker, Moore, [illegible] 05421

Notes: ±20' So. P12

Ground Water Data
Depth in ft.: 16"
Time: 0900
Date: 17 May 75

Drilling Method: 6" C.F.S. 1/Auger ← 6" → Rotary Thr. CORE

Casing Size: NX

Depth in Feet	Blows/Ft. Depth	Sample Method	Sample No	Blow Count	Subsurface Material	Drilling Notes
0					ICE	
1						Auger to 68"
2						
3						
4						
5					Some WATER seeping in @ CONTACT	
6		2½" Shelby	[illegible]	Push	Silty SAND	Push Shelby
7						NX to 8'
8			130008	Push		drill out to 8' push Shelby
9					sand, gravel w/silt not frozen below 10'	NX to 10½'
10						drill out to 10½' NX not clean-NX fell to 11.8 drill out to 11.8
11						
12			1350118	Push		
13						NX to 14'
14			135014	Push	No Recovery	drill out to 14 push Shelby 17 MAY 75 +23 Lt. Snow
15						
16						NX to 20'
17	15					drill out to 20'
18	26					
19	29					
20						

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE
Project No: Bridge No:
Date Begin: End:
Weather:

STATE OF ALASKA
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LOG OF TEST BORING

Hole No.: 13 Sheet 4 of 5
Total Depth: Hole Dia.:
Hole Log By: GRAHEK
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:
Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size NX Blows/Ft. Depth	Sample Data: Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Subsurface Material	Drilling Notes
ROTARY TRI CONE	60		2"(OD)	13068	7 10 11	X	■		SANDY GRAVEL w/ silt 60½ IN JAR	SAmple
	61									
	62	88								NX to 69'5"
	63	77								
	64	88								drill out to 69.4'
	65	85								
	66	104								
	67	125								
	68	148							FROZEN	
	69	200/3"		13069	133 77 88	X	■	■	69.9 IN JAR	SAmple
	70							■		drill ahead to 80' Lose ± 75% water below NX Prob. bad seal in frost
	71							■		
	72							■		NX to 80'
	73							■		
	74							■		
	75							■		drill out to 80'
	76							■		
	77							■		
	78							■		
	79							■		
	80							■		

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE
Project No.:
Bridge No.:
Date Begin:
End:
Weather:

STATE OF ALASKA
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LOG OF TEST BORING

Hole No.: 13
Sheet 5 of 5
Total Depth: 93
Hole Dia.:
Hole Log By: Graker
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation: Reference:
Field Party: Rig:

Notes:

Ground Water Data		
Depth in ft.	5.5	
Time	0945	
Date	12MA75	

Drilling Method	Depth in Feet	Casing Size NX Blows/Ft. Depth	Sample Data: Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES
↑ Rotary Tri-Cone ↓	80		1 (340)	13-80	53 107 280					Sand, gravel w/silt	Sample 12MA75 +22° PC LT Br.
	81										drill ahead to 93'
	82										
	83										
	84										
	85										
	86										
	87										
	88										
	89										
	90										
	91										
	92										
	93									T.D. = 93'	
	94										Install 3/4 pipe to 89' w/±5' stick up
	95										also left 15' NX in hole w/1' stick up
	96										
	97										
	98										
	99										
	100										

Note: Unless otherwise noted all samples are taken w/1.4" ID Standard Penetration Sampler driven w/140 lb hammer w/30" drop.

Project Name: CORE
Project No:
Bridge No:
Date Begun: 18 May 76
End: 18 May 75
Weather: +24 P.C. Lt. Bz.

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS

Engineering Geology Section
Box F, College, Alaska

LOG OF TEST BORING

Hole No: 14
Sheet 1 of 2
Total Depth: 40'
Hole Dia: 6"
Hole Log By: Geaker
Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄
Collar Elevation:
Reference:
Field Party: Geaker, Waldenmuth, Hallsen, Osterkamp
Rig: 05431

Notes:

Ground Water Data

Depth in ft.		
Time		
Date		

Drilling Method: 6" flight auger

Depth in Feet	Casing Size: Blows/Ft. Depth	Sample Data: Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES	
0									1" sod silt w/sand		0
1										Auger to 40'	1
2											2
3									V. ice rich		3
4											4
5											5
6											6
7											7
8											8
9											9
10											0
1											1
2									silty sand		2
13											3
14											4
15											5
16									Sand & gravel w/silt		6
17											7
18											8
19											9
20											0

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

Project Name: CORE

Project No:

Bridge No:

Date Begun:

End:

Weather:

STATE OF ALASKA
DEPARTMENT OF HIGHWAYS

Engineering Geology Section
Box F, College, Alaska

LOG OF TEST BORING

Hole No: 14

Sheet 2 of 2

Total Depth:

Hole Dia.:

Hole Log By: Gesiwk

Type of Structure:

Hole Station: Rt. Ft. Lt. Ft. of ℄

Collar Elevation: Reference:

Field Party: Rig:

Notes:

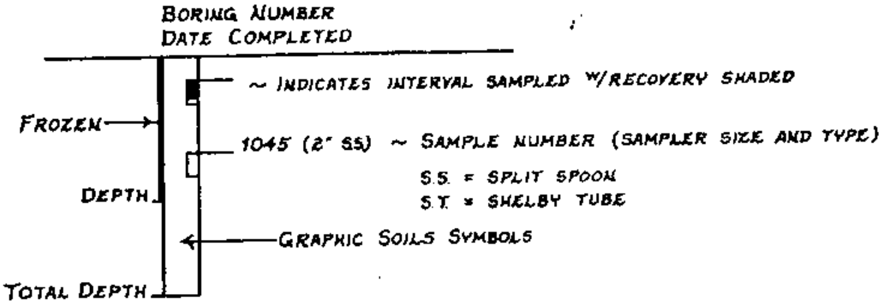
Ground Water Data		
Depth in ft.		
Time		
Date		

Drilling Method	Depth in Feet	Casing Size	Blows/Ft. Depth	Sample Data: Method	Sample No	Blow Count	Loc. Sampled	Recovery	Frozen	Soil Graph	SUBSURFACE MATERIAL	DRILLING NOTES	
6 [illegible]	20										sandy gravel w/silt		0
	21												1
	22												2
	23												3
	24												4
	25												5
	26												6
	27												7
	28												8
	29												9
	30												0
	31												1
	32												2
	33												3
	34												4
	35												5
	36												6
	37												7
	38												8
	39												9
	40												0

Note: Unless otherwise noted all samples are taken W/1.4" ID Standard Penetration Sampler driven W/140 lb hammer W/30" drop.

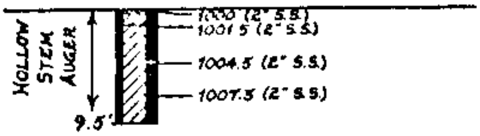
PRUDHOE BAY

KEY



PRUDHOE BAY

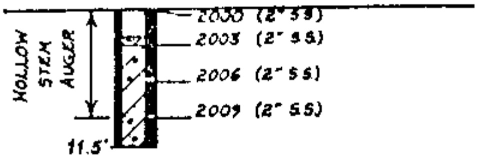
BORING 1
APRIL 30, 1975



0.0'-1.3'	MOSS OVER ORGANIC SILT AND SAND
1.3'-9.5'	VERY ICE RICH SILT, TRACE SAND

PRUDHOE BAY

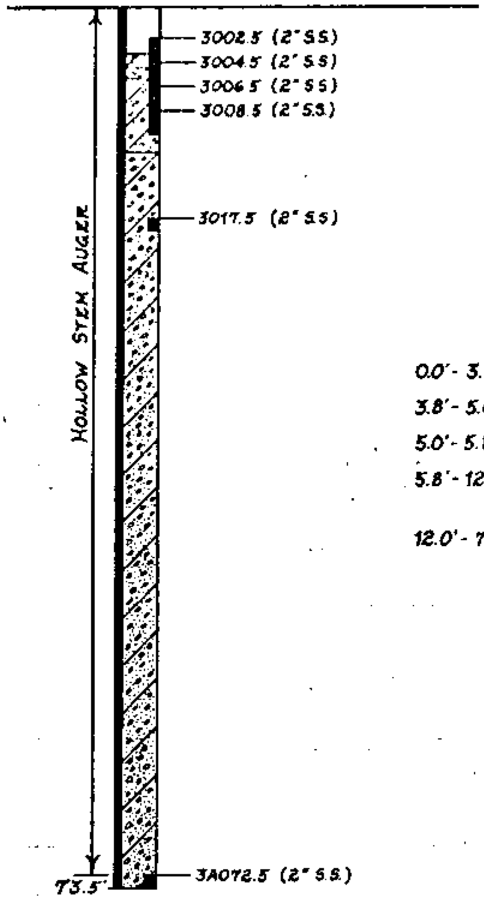
BORING 2
APRIL 30, 1975



0.0'-2.3'	ICE
2.3'-3.0'	ORGANIC SILT W/SAND AND ICE
3.0'-11.5'	SILTY SAND, TRACE GRAVEL

PRUDHOE BAY

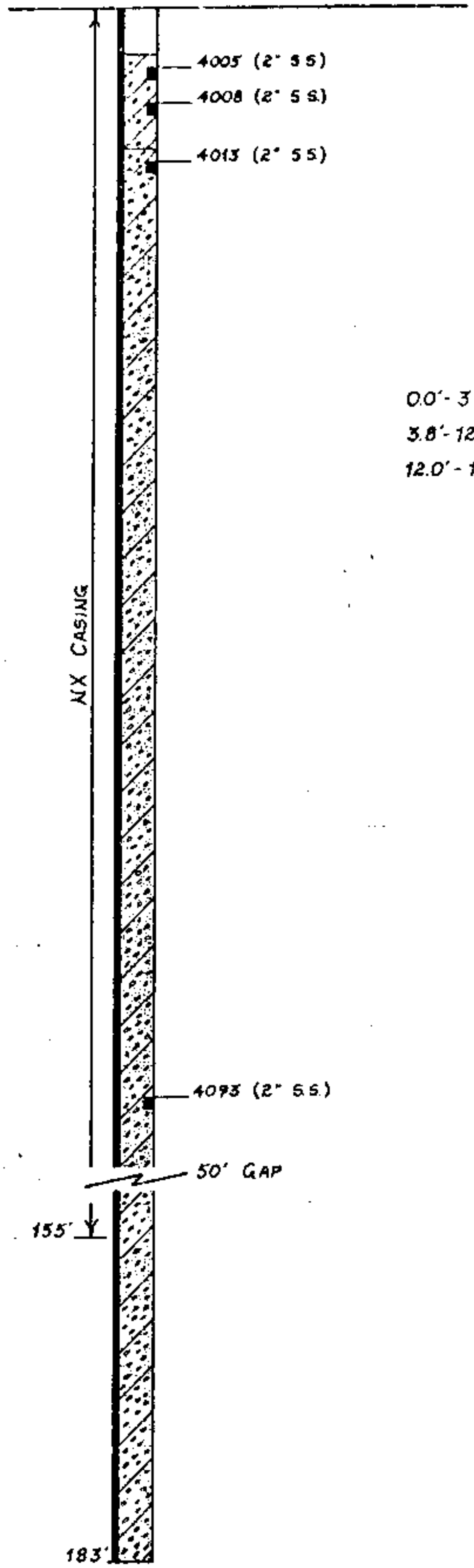
BORING 3 & 3A
MAY 2, 1975



0.0'- 3.8'	ICE
3.8'- 5.0'	SILTY SAND
5.0'- 5.8'	ORGANIC SILTY SAND
5.8'- 12.0'	SILTY SAND W/GRAVEL; TRACE ORGANIC
12.0'- 73.5'	SANDY GRAVEL W/SILT AND OCC. ICE CRYSTALS

PRUDHOE BAY

BORING 4
MAY 5, 1975

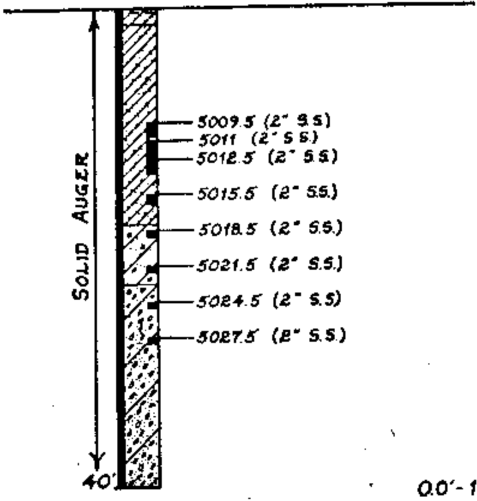


0.0'- 3.8'	ICE
3.8'- 12.0'	SILTY SAND W/GRAVEL
12.0' - 183.0'	SANDY GRAVEL W/SILT; OCC LAYERS SANDY SILT AND SILTY SAND

BY .... DATE .... SUBJECT .... SHEET NO. ...... OF ......
CHKD. BY ...... DATE .... JOB NO. ....

PRUDHOE BAY

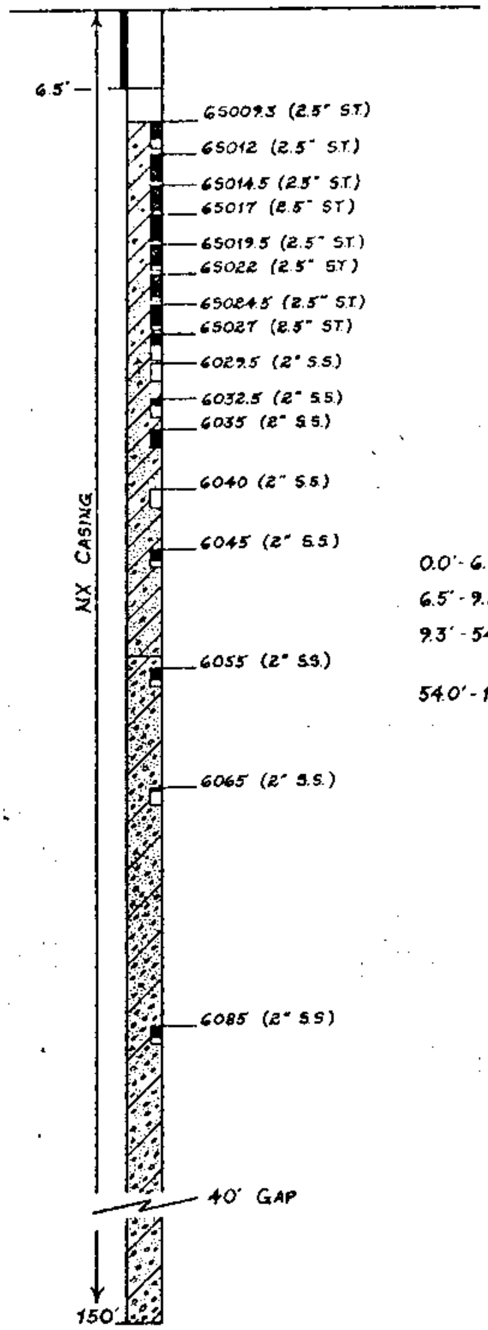
BORING 5
MAY 7, 1975



0.0'-1.3'	MOSS OVER ORGANIC SILT AND SAND
1.3'-18.0'	VERY ICE RICH SILT W/SAND; DECREASING ICE W/DEPTH
18.0'-40.0'	SANDY GRAVEL W/SILT; TRACE ORGANICS

PRUDHOE BAY

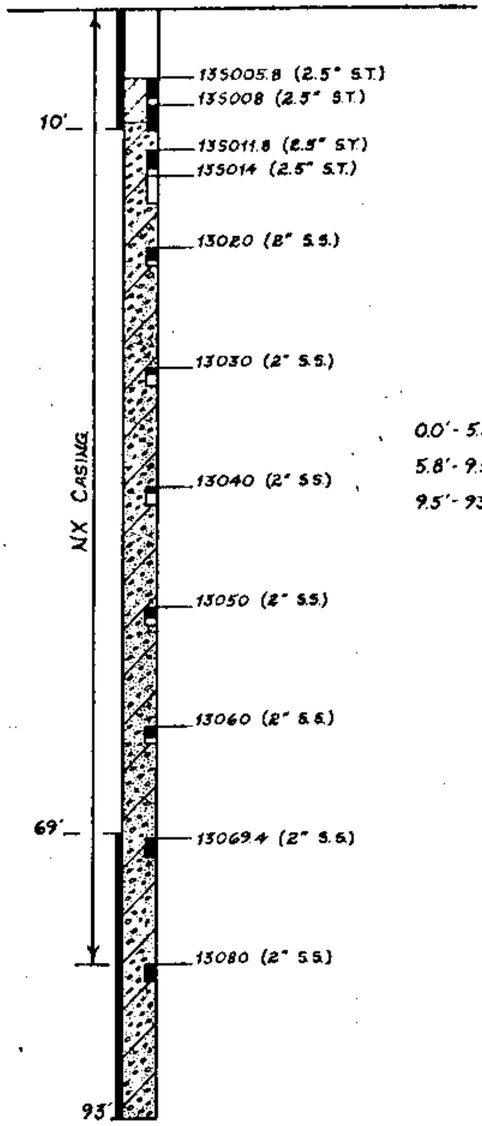
BORING 6
MAY 14, 1975



0.0'-6.5'	ICE
6.5'-9.3'	WATER
9.3'-54.0'	SILTY SAND, TRACE GRAVEL, TRACE ORGANICS
54.0'-150.0'	SANDY GRAVEL W/ SILT

PRUDHOE BAY

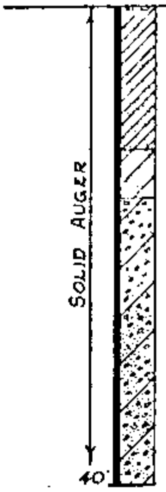
BORING 13
MAY 18, 1975



0.0'- 5.8'	ICE
5.8'- 9.5'	SILTY SAND
9.5'- 93.0'	SANDY GRAVEL W/ SILT

PRUDHOE BAY

BORING 14
MAY 18, 1975



0.0'-12.0'	VERY ICE RICH SILT W/ SAND, THIN LAYER MOSS AT TOP
12.0'-16.0'	SILTY SAND
16.0'-40.0'	SANDY GRAVEL W/ SILT

APPENDIX B

SOIL ANALYSIS

This soil analysis was prepared by the Road Materials Laboratory, Alaska Department of Highways, under the supervision of Mr. D. Esch according to standard AASHTO test procedures as listed in Section IV of this report. Samples were numbered using the field-designated hole number and the depth in feet to the top of the sample. For example, 6040 refers to the drive sample taken from field-designated hole number 6 at a depth of 40 feet. The letter S in the sample number (e.g., 6S017) refers to those samples taken in Shelby tubes. Corresponding hole numbers, as used in the report, for the field-designated hole numbers can be obtained from Table I in the report.

ALASKA DEPARTMENT OF HIGHWAYS
ENGINEERING GEOLOGY SECTION
SUMMARY OF TEST DATA — FOUNDATION SOILS

Project No. R13002 Project Name Geophysical Institute U of A sheet 1 of 1 sheets

Boring & Sample No.	Depth ft.	Laboratory Number	Grading Analysis — % Passing								Atterberg Limits		Nat. Dry Density P.C.F.	Nat. Moist %	Spec. Gravity	F.S.V. (Corps of Eng.)	AASHO Group Classif.	% Organic	% Chlorides & CL-ion	Triax (staged)	PERM
			Gravel			Sand		Silt		Clay											
			1"	3/8"	#4	#10	#40	#200	.02	.002	Liquid Limit	Plastic Index									
135	5.8	75F-549				100	99	15	10.3	5.7	NV	NP	109.8	21.6	2.67			6.2	.36		
135	8	550					100	13	10.5	6.2	NV	NP	99.5	23.0	2.67			9.1	0.51		
65	9.3	551					100	34	7.8	3.5	NV	NP	100.0	23.0	2.68			16.1	.54	XX	
65	12	552					100	80	40.3	9.0	26	NP	96.0	27.8	2.63			15.8	.52	XX	
65	17	553	100	99	98	97	95	9	5.5	3.6	NV	NP	106.4	21.1	2.64			6.1	.37		
65	22	554	100	93	78	67	58	17	8.7	4.9	14	NP		9.2	2.68			9.2			XX
65	27	555	100	85	72	66	51	7	5.4	3.1	NV	NP	118.1	11.5	2.65			4.5	.25		

Remarks:

ALASKA DEPARTMENT OF HIGHWAYS
ENGINEERING GEOLOGY SECTION
SUMMARY OF TEST DATA — FOUNDATION SOILS

Project no. R13002 Project Name Geophysical Institute U of A sheet 1 of 3 sheets

Boring & Sample No.	Depth ft.	Laboratory Number	Grading Analysis —— % Passing								Atterberg Limits		Nat. Dry Density P.C.F.	Nat. Moist %	Spec. Gravity	F.S.V. (Corps of Eng.)	AASHO Group Classif.	% Organic	% Chloride	
			Gravel			Sand		Silt		Clay										
			1"	3/8"	#4	#10	#40	#200	.02	.005	Liquid Limit	Plastic Index								
4	5(5)	75F-867		100	92	84	59	10						20.0				5.5		
4	5(5.5)	868	100	99	93	86	70	26						17.5				7.6		
4	8	869				100	93	16						18.5				7.6	0.501	
4	13	870	100	93	84	74	54	13						12.0				5.9	0.185	
4	93	871	100	56	41	32	22	9						9.1				2.1		
5	18.5	872	100	99	98	93	76	17						16.7				4.5		
5	27.5	873	100	84	54	41	29	10						11.9				3.3		
6	32.5	874	100	77	63	52	40	12						9.1				5.3		
6	35	875		100	99	94	90	14						15.5				6.6		
6	40	876	100	84	72	62	59	10						17.8				2.2	0.30	
6	55	877	*92	74	55	40	26	7						8.3				2.4	0.16	
6	65	878	*34	26	19	13	8	3						3.4						
6	85.5	879	100	79	51	31	19	5						8.9				2.0	0.25	
6	86	880	100	87	71	49	27	8						9.5				1.9	0.27	
13	20	881	100	82	66	56	45	6						13.2				3.5	0.39	

Remarks: * 100% pass 1½"

All samples are nonplastic

ALASKA DEPARTMENT OF HIGHWAYS

ENGINEERING GEOLOGY SECTION

SUMMARY OF TEST DATA — FOUNDATION SOILS

Project No. R13002 Project Name Geophysical Institute U of A sheet 2 of 3 sheets

Boring & Sample No.	Depth ft.	Laboratory Number	Grading Analysis — % Passing								Atterberg Limits		Nat. Dry Density P.C.F.	Nat. Moist %	Spec. Gravity	F.S.V. (Corps of Eng.)	AASHO Group Classif.	% Organic	% Chloride	
			Gravel			Sand		Silt		Clay										
			1"	3/8"	#4	#10	#40	#200	.02	.002	Liquid Limit	Plastic Index								
13	30	75F-882	100	68	52	35	22	6						10.2				2.4		
13	40	883	*88	73	64	56	37	5						16.3				3.9		
2	2.3	884		100	97	92	87	31						23.9				11.7	0.724	
2	4.1	885			100	99	94	24						18.1				9.7		
2	6.3	886	100	99	96	90	82	23						45.8				8.6		
2	8.4	887		100	99	97	92	27						22.5				10.1		
2	9(2)	888			100	99	94	26	16.9	9.4				13.9				8.0	0.108	
2	9(9)	889		100	97	95	89	56						166.5				18.5		
3	2.5(1)	890				100	98	11						26.0				9.5		
3	4.5(4.6)	891	100	99	96	93	83	16						29.1				8.0		
3	4.5(5.4)	892		100	98	96	85	25						30.4				9.1	.809	
3	4.5(6.1)	893		100	97	94	85	15						23.0				13.4		
3	6.5(7.4)	894		100	96	93	87	23						21.1				9.4		
3	6.5(8.1)	895			100	99	92	23						17.3				8.4		
3	8.5(9.0)	896				100	97	49						22.7				7.5		

Remarks: * 100% Pass 1½"

All samples are nonplastic

ALASKA DEPARTMENT OF HIGHWAYS
ENGINEERING GEOLOGY SECTION
SUMMARY OF TEST DATA — FOUNDATION SOILS

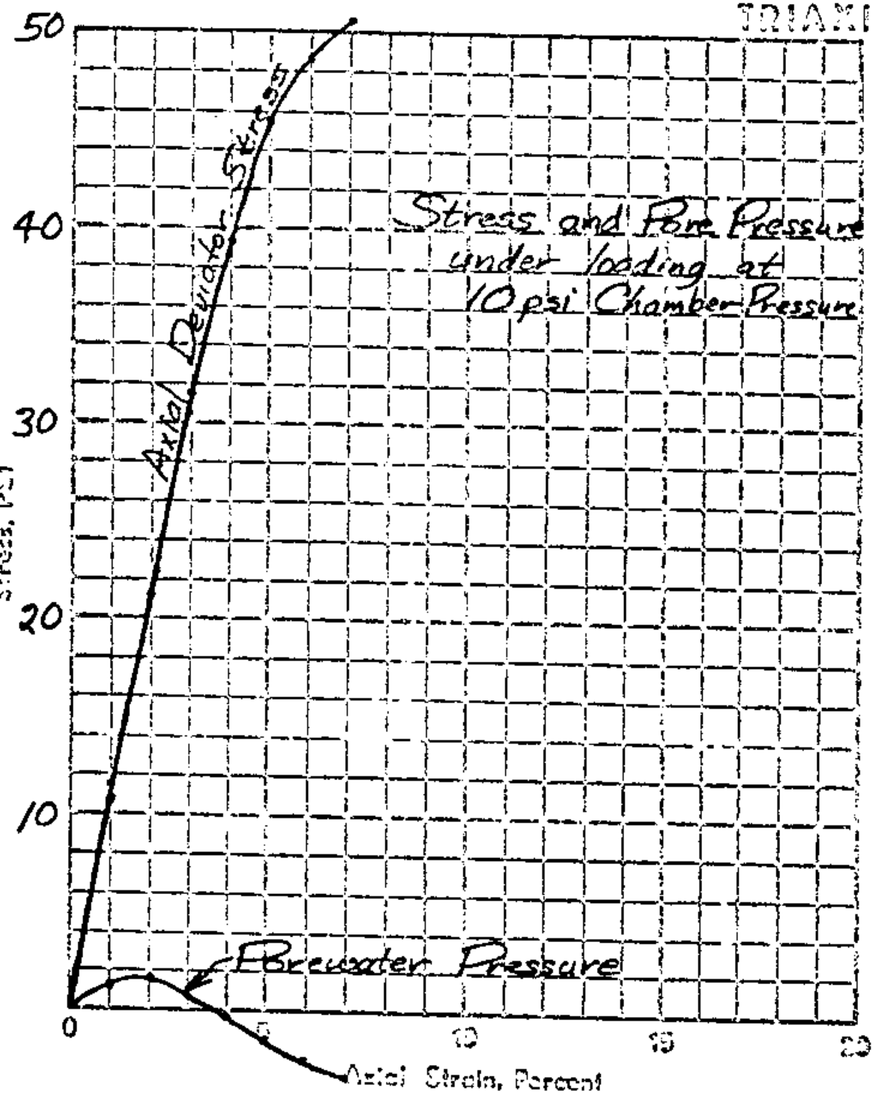
Project No. R13002 Project Name Geophysical Institute U of A sheet 3 of 3 sheets

Boring & Sample No.	Depth ft.	Laboratory Number	Grading Analysis — % Passing								Atterberg Limits		Nat. Dry Density P.C.F.	Nat. Moist %	Spec. Gravity	F.S.V. (Corps of Eng.)	AASHO Group Classif.	% Organic	% Chloride	
			Gravel			Sand		Silt		Clay										
			1"	3/8"	#4	#10	#40	#200	.02	.005	Liquid Limit	Plastic Index								
3	8.5(10.1)	75F-897				100	99	11						23.9				7.3		
3	17.5	898	100	75	53	38	29	8						8.8				4.0	0.084	
3A	72.5	899	100	89	75	56	38	12						13.0				2.1		
13	50	900	*95	75	56	39	23	7						7.7				3.5		
13	69.9	901	100	65	46	29	15	6						9.7				2.1	0.21	
13	60	902	*90	77	63	46	25	2						14.2				3.6		
13	80	903	*97	81	53	34	27	6						8.9				3.6	0.24	

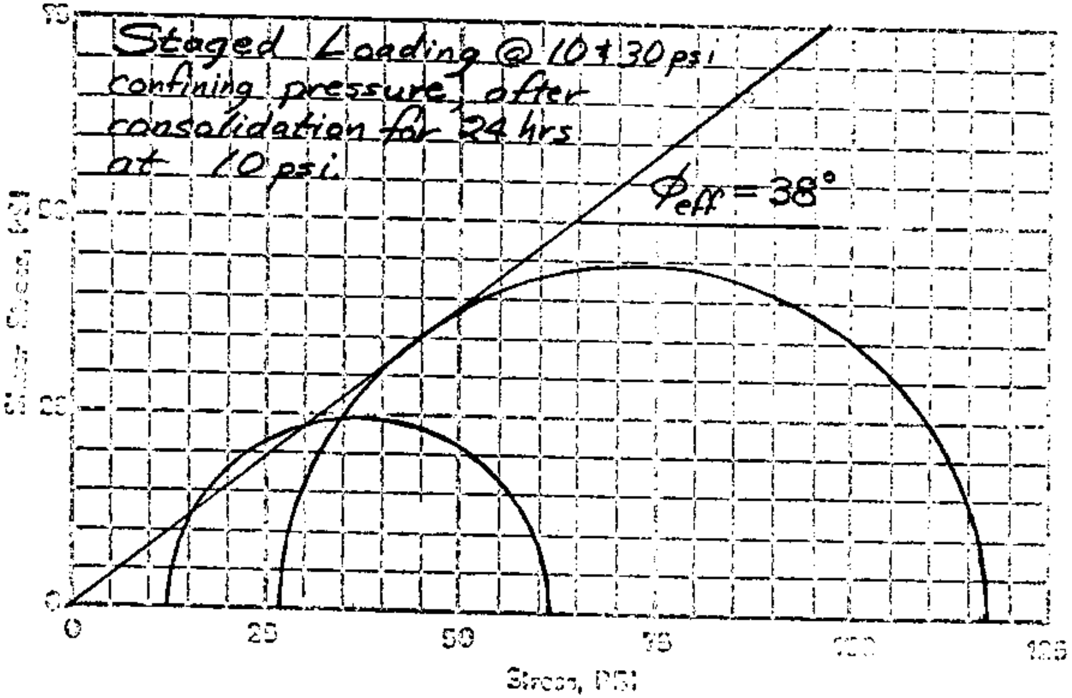
Remarks: *100% Pass 1½"

All samples are nonplastic

TRIAXIAL COMPRESSION TEST



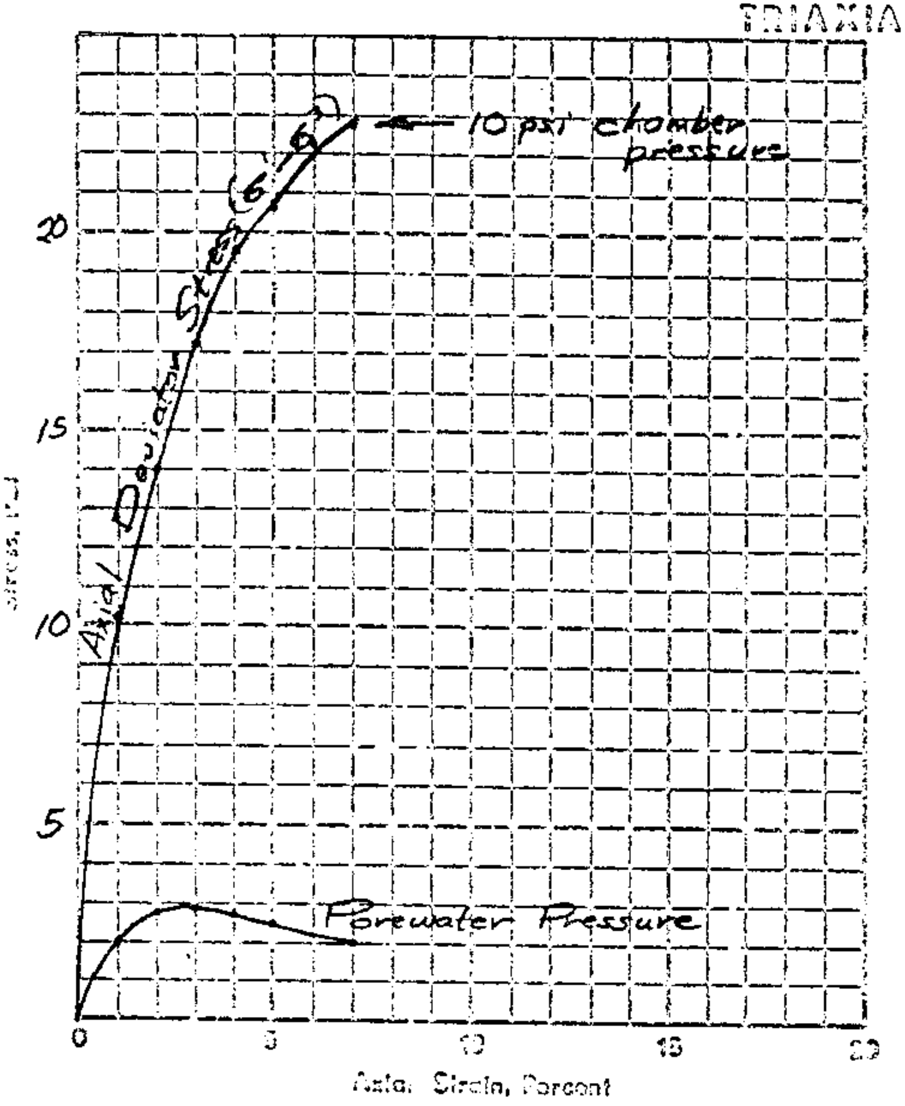
SPECIMEN NO.	INITIAL MOISTURE CONTENT(%)	INITIAL DRY DENSITY (PCF)	CONFINING PRESSURE (PSI)	DEVIATOR STRESS AT FAILURE (PSI)	SOIL TYPE
75F-551	23.0	100.0	10	48.7	Organic, Silty Sand
	"	"	30	90.1	



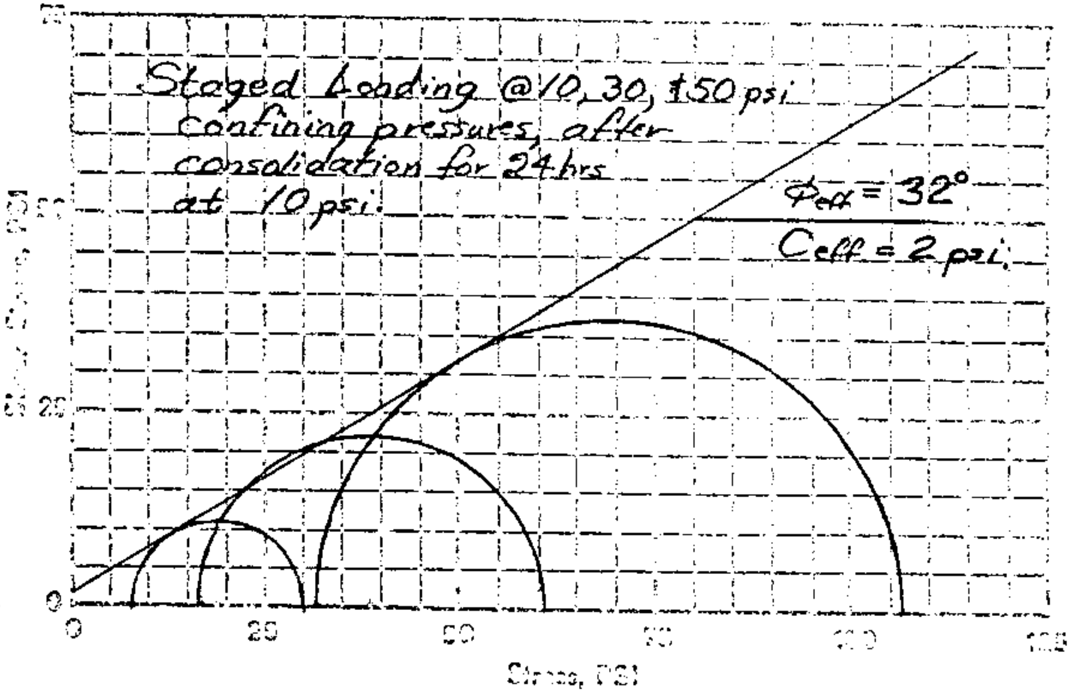
Remarks: Effective Stress Plots
Consolidated - Undrained Triaxial Shear
with Pore Pressure Measurements
Strain Rate ≈ 2% per hour

State of Alaska
DEPARTMENT OF HIGHWAYS
ROAD MATERIALS LAB
PROJECT TITLE: Offshore Permafr

TRIAXIAL COMPRESSION TEST



SPECIMEN NO.	INITIAL MOISTURE CONTENT(%)	INITIAL DRY DENSITY (PCF)	CONFINING PRESSURE (PSI)	DEVIATOR STRESS AT FAILURE (PSI)	SOIL TYPE
75F-552	27.8	96.0	10	22.3	Sandy,
	"	"	30	44.1	Organic
	"	"	50	76.3	Silt


Staged Loading @10, 30, & 50 psi confining pressures, after consolidation for 24 hrs at 10 psi.

$\phi_{eff} = 32°$

$C_{eff} = 2$ psi.

Remarks: Effective Stress Plots
Consolidated - Undrained Triaxial Shear
with Pore Pressure Measurements.
Strain rate ≈ 2.5% per hour

State of Alaska
DEPARTMENT OF HIGHWAYS
ROAD MATERIALS LAB
PROJECT TITLE: Offshore Permafrost
PROJECT NO.: Study @ Prudhoe

APPENDIX C

MINERAL ANALYSIS

This mineral analysis was prepared by Ms. N. C. Veach of the Division of Mines and Geology, Alaska Department of Natural Resources. X-ray diffraction analysis was used to identify the mineral constituents of the soil samples. Samples were numbered using the field-designated hole number and the depth in feet to the top of the sample. For example, 6040 refers to the drive sample taken from field-designated hole number 6 at a depth of 40 feet. The letter S in the sample number (e.g., 6S017) refers to those samples taken in Shelby tubes. Corresponding hole numbers, as used in the report, for the field-designated hole numbers can be obtained from Table I in the report.

Thomas Osterkamp
Geophysical Institute

Received 11-6-75
Report 11-25-75

Sample No.	Marked	Meshes Number	Weight (gram)	Weight (per cent)	Major	Minor + Trace
To-1	3AO	+2.5	27.5	29.70	quartz	calcite
	72.5	-2.5, +4	24.9	26.89	quartz	calcite
		-4, +9	36.3	39.20	quartz	calcite
		-9, +40	2.1	2.27	quartz	feldspar
		-40	1.8	1.94	quartz	feldspar, calcite
To-2	4013	+2.5	36.5	20.81	quartz	calcite
		-2.5, +4	17.7	10.09	quartz	
		-4, +8	20.5	11.69	quartz	
		-8, +9	28.1	16.02	quartz	
		-9, +20	8.4	4.79	quartz	
		-20, +40	4.7	2.68	quartz	feldspar
		-40, +60	26.2	14.94	quartz	
		-60, +100	18.4	10.49	quartz, calcite	feldspar
		-100	14.9	8.49	calcite, quartz	dolomite, feldspar
To-3	4093	+2.5	166.8	55.54	quartz	
		-2.5, +4	55.9	18.61	quartz	
		-4, +10	52.3	17.42	quartz	feldspar
		-10	25.3	8.43	quartz	feldspar
To-4	5027.5	+2.5	93.4	39.64	quartz	calcite
		-2.5, +4	88.5	37.56	quartz	calcite
		-4, +10	51.2	21.73	quartz	calcite, feldspar
		-10, +20	0.3	0.13	quartz	calcite, feldspar
		-20, +40	0.3	0.13	quartz	calcite
		-40, +100	1.2	0.51	quartz	calcite, feldspar
		-100	0.7	0.30	quartz	calcite, feldspar
To-5	6040	+2.5	30.0	46.30	quartz	calcite
		-2.5, +4	16.7	25.77	quartz	
		-4, +10	15.0	23.15	quartz	
		-10, +100	2.5	3.86	quartz	feldspar
		-100	0.6	0.92	quartz	calcite, feldspar
To-6	6085	+2.5	94.6	28.15	quartz	
		-2.5, +4	74.4	22.14	quartz	feldspar
		-4, +10	128.0	38.08	quartz	
		-10, +20	15.4	4.58	quartz	
		-20, +40	9.8	2.92	quartz	
		-40, +100	11.0	3.27	quartz	
		-100	2.9	0.86	quartz	feldspar, chlorite
To-7	13020	+2.5	148.8	42.61	quartz	feldspar
		-2.5, +4	75.5	21.62	quartz	calcite
		-4, +10	64.5	18.47	quartz	calcite
		-10, +20	3.2	0.92	quartz	
		-20, +40	3.3	0.95	quartz	
		-40, +100	48.8	13.97	quartz	
		-100	5.1	1.46	quartz, calcite	feldspar, dolomite chlorite

Sample No.	Marked	Meshes Number	Weight (gram)	Weight (per cent)	Major	Minor + Trace
To-8	13050	+2.5	202.2	44.85	quartz	calcite, feldspar, chlorite
		-2.5, +4	93.0	20.63	quartz	calcite
		-4, +10	120.1	26.64	quartz	calcite, feldspar
		-10, +20	11.2	2.48	quartz	
		-20, +40	14.7	3.26	quartz	
		-40, +100	8.5	1.89	quartz	calcite
		-100	1.1	0.24	quartz	calcite, feldspar
To-9	13080	+2.5	187.3	48.54	quartz	
		-2.5, +4	40.5	10.49	quartz	
		-4, +10	93.1	24.13	quartz	
		-10, +20	11.0	2.85	quartz	
		-20, +40	10.9	2.82	quartz	
		-40, +100	35.3	9.15	quartz	
		-100	7.8	2.02	quartz	feldspar, chlorite, dolomite

Major; more than 10%
Minor + Trace; less than 10%
Determined by X-ray diffraction analysis

Namok C. Veach

Namok C. Veach
Analyst & work done

APPENDIX D

ELECTRICAL CONDUCTIVITY OF THE SOIL WATER

The electrical conductivity of the soil water in the soil samples is given below. The first column of values (σ_1) was determined by measuring the electrical conductivity of the supernatant water in the soil samples. The second column of values (σ_2) were obtained by converting the chloride contents (Appendix B) to values of electrical conductivity by assuming that the ionic ratios of the soil water solution were the same as for normal sea water. The estimated error for this procedure is probably less than 20%. All electrical conductivity values are normalized to 25°C. Samples were numbered using the field-designated hole number and the depth in feet to the top of the sample. For example, 6040 refers to the drive sample taken from field-designated hole number 6 at a depth of 40 feet. The letter S in the sample number (e.g., 6S017) refers to those samples taken in Shelby tubes. Corresponding hole numbers, as used in the report, for the field-designated hole numbers can be obtained from Table I in the report.

Sample Number	Depth (m)	σ_1 (ohm m)$^{-1}$	σ_2 (ohm m)$^{-1}$
Hole - 226			
5018.5	5.64	1.2	
5027.5	8.38	1.9	
Hole - 225			
100-1.30	1.3	0.44	
1007.3	2.2	0.50	
1008.5	2.6	4.1	
Hole 0			
2002.3	0.70	8.5	7.8
2003	0.91	3.6	
2004.1	1.25	5.3	
2005.4	1.65	4.0	
2006.3	1.92	1.9	
2007.5	2.28	1.3	
2008.4	2.56	2.7	
2009(1)	2.74	2.8	
2009(2)	2.83		2.4
2009(3)	2.92	0.87	
2009(4)	3.01	0.64	
2009(5)	3.10	0.62	
2009(6)	3.19	1.2	
2009(7)	3.28	1.1	
2009(8)	3.37	0.53	
2009(9)	3.51	0.59	
Hole 190			
4005.0	1.52	7.2	
4005.5	1.68	7.5	
4008	2.44		7.1
40013	3.96		4.2
4093	28.5	4.8	
Brine in drilling mud		8.9	
Hole 195			
3002.5(1)	1.16	6.9	
3002.5(2)	1.28	4.0	
3004.5	1.40	8.3	
3006.1	1.86	7.1	
3006.5(7.4)	2.26	7.8	
3006.5(8.1)	2.47	7.2	
3008.5(9.0)	2.74	7.3	
3008.5(10.1)	3.08	6.0	
3017.5	5.52		3.3
Brine in hole		14.0	
Brine in hole		16.8	
Hole 203			
3A072.5	22.3	6.2	

Sample Number	Depth (m)	σ_1 (ohm m)$^{-1}$	σ_2 (ohm m)$^{-1}$
Hole 481			
13S005.8	2.1	5.2	4.7
13S008	2.44		5.9
13S017.5	5.34		3.0
13020	6.25	6.5	7.8
13030	9.45	8.0	
13040	12.5	8.8	
13050	15.5	6.7	
13060	18.5	6.8	
13069.9	21.3	3.9	5.9
13080	24.7		7.1
Brine from under nearby ice cover		9.2	
Hole 3,370			
6S09.3	3.14	5.5	
6S012	4.0	5.8	
6S017	5.48		5.0
6S027	8.23		6.0
6032.5	10.2	5.7	
6035	11.0	5.6	
6040	12.5	5.4	4.7
6055	16.8		5.2
6085.5	26.1		7.4
6086	26.2	6.0	7.4

APPENDIX E

CHEMICAL ANALYSIS OF SOIL WATER

The major ions in three soil water samples were determined by Mr. H. Potworowski of the Division of Mines and Geology, Alaska Department of Natural Resources. Atomic absorption was used for all ions except Cl which was determined by titration. Samples were numbered using the field-designated hole number and the depth in feet to the top of the sample. For example, 6040 refers to the drive sample taken from field-designated hole number 6 at a depth of 40 feet. The letter S in the sample number (e.g., 6S017) refers to those samples taken in Shelby tubes. Corresponding hole numbers, as used in the report, for the field-designated hole numbers can be obtained from Table I in the report.

DM-11
Rev. 10/67

Report No. ____

STATE OF ALASKA
Department of Natural Resources
DIVISION OF MINES AND GEOLOGY
Box C, College, Alaska 99701

Date of Report February 20, 1976

LABORATORY ANALYSIS REPORT

For Tom Osterkamp

Address Geophysical Institute, U. of A.

Number of Samples ____

Date Sample Received ____

Work Done: (for Analyst see below)

A. X-ray flourescence quant. ☐ semi-quant. ☐
B. X-ray diffraction ☐
C. Spectrographic quant. ☐ semi-quant. ☐
D. Spectroscopic ☐
E. Atomic absorption quant. ☒ semi-quant. ☐
F. Fire assay ☐
G. Microscopic examination ☐
H. Other (Specify) ☐ ____
I. Ultraviolet light ☐

LABORATORY NUMBER | SAMPLE MARKED | ANALYSIS OR IDENTIFICATION

Core Sample Analysis

	K g/kg	Na g/kg	Mg g/kg	Ca g/kg	Cl^- g/kg	$So_4^=$ g/kg
Core 4093 (43,5)	0.339	6.228	0.857	1.152	20.269	2.41
Core 604c (41)	0.250	3.752	0.306	0.517	12.49	2.30
Core 13 569.9 (69.9)	0.199	4.920	0.341	0.676	16.27	2.36

ANALYST & WORK DONE

ANALYST & WORK DONE

ANALYST & WORK DONE

APPROVED: LABORATORY SUPERVISOR

NOTE: Samples discarded after 60 days and pulps after 6 months unless instructed otherwise.

MOORE BUSINESS FORMS, INC. M

APPENDIX F

BOREHOLE TEMPERATURES

The depths in the first column were measured from the ice surface. Resistances were obtained by graphing resistance vs. time^{-1} for each depth and extrapolating resistance linearly to infinite time. The temperatures were then calculated from these extrapolated resistances using Equation (5). Hole numbers can be related to the field-designated hole numbers using Table I. No corrections have been made for the decrease in cable resistance due to colder ambient temperatures nor for the temperature sensitivity of the Wheatstone bridge.

Hole - 226: May 29, 1975 - First Reading 01:55 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
1.40	18,571	-12.119	
3.40	20,016	-13.465	
5.40	19,547	-13.041	
7.40	18,563	-12.111	
9.40	17,750	-11.301	

Hole 190: May 7, 1975 - First Reading 09:00 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
3.7	7,676.3	-6.506	
8.7	6,829.0	-3.968	
13.7	6,774.1	-3.791	
18.7	6,839.5	-3.948	
23.7	6,881.5	-4.128	
28.7	6,986.5	-4.428	
33.7	7,082.5	-4.665	
38.7	7,062.1	-4.676	
43.7	7,126.2	-4.866	
48.7	7,238.9	-5.191	

Hole 190: May 9, 1975 - First Reading 13:27 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
3.7	7,794.5	-6.838	
8.7	6,811.4	-3.913	
13.7	6,787.0	-3.832	
18.7	6,867.0	-4.034	
23.7	6,908.1	-4.211	
28.7	6,993.5	-4.449	
33.7	7,100.2	-4.719	
38.7	7,103.0	-4.801	
43.7	7,176.0	-4.018	
48.7	7,254.0	-5.236	

Hole 190: May 15, 1975 - First Reading 10:09 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
3.7	7,876.6	-7.065	
8.7	6,822.6	-3.948	
13.7	6,810.8	-3.908	
18.7	6,888.9	-4.103	
23.7	6,931.7	-4.285	
28.7	7,014.6	-4.515	
33.7	7,111.6	-4.754	
38.7	7,135.5	-4.090	
43.7	7,196.5	-5.078	
48.7	7,266.6	-5.274	

Hole 190: May 28, 1975 - First Reading 23:00 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
3.7	7,884.5	-7.086	
8.7	6,917.0	-4.245	
13.7	6,826.4	-3.957	
18.7	6,896.9	-4.128	
23.7	6,941.4	-4.315	
28.7	7,022.2	-4.538	
33.7	7,129.5	-4.809	
38.7	7,147.5	-4.936	
43.7	7,200.0	-5.089	
48.7	7,268.6	-5.280	

Hole 190: June 12, 1975 - First Reading 18:35 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
3.7	7,826.0	-6.925	
8.7	6,986.4	-4.460	
13.7	6,834.0	-3.981	
18.7	6,898.6	-4.133	
23.7	6,943.3	-4.321	
28.7	7,023.7	-4.543	
33.7	7,144.5	-4.854	
38.7	7,152.2	-4.950	
43.7	7,302.2	-5.098	
48.7	7,271.3	-5.288	

Hole 190: Equilibrium Temperature (Referred to June 12, 1975)

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
3.7		-6.94	
8.7		-4.47	
13.7		-3.997	
18.7		-4.147	
23.7		-4.338	
28.7		-4.556	
33.7		?	
38.7		-4.971	
43.7		-5.108	
48.7		-5.293	

Hole 203: May 17, 1975 - First Reading 09:10 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
1.63	14,463	-7.542	
2.63	14,391	-7.450	
4.63	12,911	-5.420	
7.63	12,031	-4.085	
11.63	11,901	-3.879	
15.63	11,973	-3.994	
20.63	12,097	-4.189	

Hole 203: May 29, 1975 - First Reading 00:07 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
0.63	13,864	-6.755	
2.63	13,881	-6.778	
4.63	12,999	-5.548	
6.63	12,329	-4.549	
8.63	12,001	-4.038	
10.63	11,908	-3.890	
12.63	11,917	-3.905	
14.63	11,947	-3.952	
16.63	11,990	-4.021	
18.63	12,038	-4.096	
20.63	12,086	-4.172	

Hole 481: May 20, 1975 - First Reading 15:25 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
0.55	12,384	-4.633	
2.55	11,216	-2.748	
4.55	10,677	-1.803	
6.55	10,616	-1.693	
8.55	10,612	-1.685	
10.55	10,643	-1.742	
12.55	10,694	-1.834	
14.55	10,759	-1.950	
16.55	10,831	-2.079	
18.55	10,925	-2.245	
20.55	11,036	-2.439	
22.55	11,155	-2.644	
24.55	11,200	-2.721	
27.55	11,225	-2.764	

Hole 481: May 21, 1975 - First Reading 07:58 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
0.55	12,446	-4.728	
2.55	11,251	-2.808	
3.55	10,816	-2.052	
4.55	10,702	-1.848	
5.55	10,659	-1.771	
7.55	10,622	-1.704	
17.55	10,885	-2.174	
18.55	10,940	-2.271	
19.55	10,993	-2.364	
20.05	11,013	-2.399	
20.55	11,044	-2.452	
21.55	11,132	-2.605	
26.55	11,176	-2.680	
27.55	11,204	-2.728	

Hole 481: May 28, 1975 - First Reading 19:33 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
0.55	12,179	-4.317	
2.55	11,196	-2.714	
4.55	10,730	-1.898	
6.55	10,660	-1.772	
8.55	10,648	-1.751	
10.55	10,674	-1.798	
12.55	10,723	-1.886	
14.55	10,784	-1.995	
16.55	10,849	-2.110	
18.55	10,948	-2.285	
19.55	10,991	-2.360	
20.55	11,040	-2.445	
21.55	11,084	-2.522	
22.55	11,125	-2.592	
23.55	11,118	-2.580	
24.55	11,136	-2.611	
25.55	11,168	-2.666	
26.55	11,165	-2.661	
27.55	11,190	-2.704	

Hole 481: June 13, 1975 - First Reading 15:17 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
0.55	11,242	-2.791	
2.55	11,227	-2.765	
4.55	10,799	-2.022	
6.55	10,697	-1.840	
8.55	10,678	-1.806	
10.55	10,695	-1.836	
12.55	10,749	-1.933	
14.55	10,810	-2.041	
16.55	10,875	-2.156	
18.55	10,971	-2.325	
19.55	11,003	-2.380	
20.55	11,056	-2.472	
21.55	11,067	-2.491	
22.55	11,105	-2.557	
23.55	11,115	-2.574	
24.55	11,132	-2.603	
25.55	11,158	-2.648	
26.55	11,176	-2.678	
27.55	11,196	-2.713	

Hole 481 Equilibrium Temperatures Referenced to June 12, 1975

Depth (m)	Temperature (°C)
0.55	-2.76
2.55	-2.737
4.55	-1.985
6.55	-1.817
8.55	-1.778
10.55	-1.813
12.55	-1.907
14.55	-2.013
16.55	-2.124

Hole 493: May 17, 1975 - First Reading 15:40 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
1.61	12,068	-4.144	
3.61	10,713	-1.868	
5.61	10,670	-1.790	
7.61	10,629	-1.716	
9.61	10,651	-1.756	
11.61	10,677	-1.803	
12.51	10,707	-1.857	

Hole 3,370: May 16, 1975 - First Reading 13:00 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
0.48	11,144	-2.625	
3.48	10,559	-1.589	
4.48	10,455	-1.398	
6.48	10,339	-1.183	
8.48	10,284	-1.079	
13.48	10,271	-1.055	
18.48	10,321	-1.149	
23.48	10,377	-1.253	
28.48	10,406	-1.307	
33.48	10,491	-1.464	
38.48	10,563	-1.596	
44.98	10,634	-1.725	

Hole 3,370: May 18, 1975 - First Reading 13:58 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
0.48	11,541	-3.294	
3.48	10,566	-1.602	
9.48	10,277	-1.066	
13.48	10,277	-1.066	
18.48	10,322	-1.151	
23.48	10,378	-1.255	
28.48	10,412	-1.318	
33.48	10,492	-1.466	
38.48	10,563	-1.596	
44.98	10,633	-1.724	

Hole 3,370: May 20, 1975 - First Reading 11:38 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
0.48	11,853	-3.802	
2.48	10,623	-1.705	
4.48	10,453	-1.394	
6.48	10,340	-1.184	
8.48	10,286	-1.083	
10.48	10,264	-1.042	
12.48	10,262	-1.038	
14.48	10,284	-1.079	
16.48	10,299	-1.108	
18.48	10,313	-1.134	
20.48	10,334	-1.173	
22.48	10,357	-1.216	
24.48	10,379	-1.257	
26.48	10,392	-1.281	
28.48	10,408	-1.311	
30.48	10,444	-1.378	
32.48	10,471	-1.428	
34.48	10,496	-1.474	
36.48	10,526	-1.529	
38.48	10,553	-1.578	
40.48	10,561	-1.593	
42.48	10.581	-1.629	
44.98	10,629	-1.716	

Hole 3,370: May 28, 1975 - First Reading 14:15 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
0.48	11,959	-3.971	
1.48	11,325	-2.933	
2.48	10,633	-1.724	
3.48	10,561	-1.593	
4.48	10,469	-1.424	
6.48	10,352	-1.207	
8.48	10,303	-1.115	
10.48	10,280	-1.072	
12.48	10,275	-1.063	
14.48	10,288	-1.087	
16.48	10,305	-1.119	
18.48	10,321	-1.149	
20.48	10,342	-1.188	
22.48	10,364	-1.229	
24.48	10,385	-1.268	
26.48	10,403	-1.302	
28.48	10,422	-1.337	
30.48	10,448	-1.385	
32.48	10,474	-1.433	
34.48	10,498	-1.477	
36.48	10,528	-1.532	
38.48	10,559	-1.589	
40.48	10,574	-1.616	
42.48	10,596	-1.656	
44.98	10,632	-1.722	

Hole 3,370: June 14, 1975 - First Reading 00:01 ADT

DEPTH (m)	RESISTANCE (ohm)	TEMPERATURE (°C)	NOTES
0.48	10,194	-0.912	
2.48	9,994.2	-0.530	
4.48	10,508	-1.497	
6.48	10,405	-1.308	
8.48	10,336	-1.179	
10.48	10,314	-1.138	
12.48	10,307	-1.125	
14.48	10,314	-1.138	
16.48	10,333	-1.174	
18.48	10,350	-1.205	
20.48	10,370	-1.243	
22.48	10,389	-1.278	
24.48	10,409	-1.315	
26.48	10,434	-1.361	

Hole 3,370 Equilibrium Temperatures Referenced to June 12, 1975

Depth (m)	Temperature (°C)
0.48	-0.87
2.48	-0.49
4.48	-1.46
6.48	-1.28
8.48	-1.15
10.48	-1.107
12.48	-1.098
14.48	-1.100
16.48	-1.138
18.48	-1.171
20.48	-1.206
22.48	-1.243
24.48	-1.280
26.48	-1.330
28.48	-1.370
30.48	?
32.48	?
34.48	?
36.48	?
38.48	-1.604
40.48	-1.646
42.48	-1.689
44.98	?