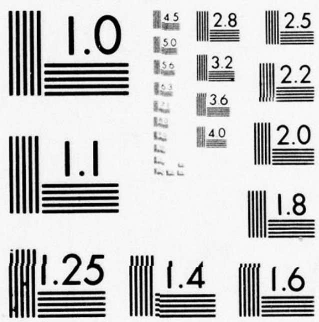
AD-A048 985   COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER N H   F/G 8/12
1977 CRREL-USGS SUBSEA PERMAFROST PROGRAM BEAUFORT SEA, ALASKA.(U)
DEC 77 P V SELLMANN, E CHAMBERLAIN, H T UEDA

UNCLASSIFIED   CRREL-SR-77-41   NL

1 OF 1
ADA048985

END
DATE
FILMED
2-78
DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(14)
CRREL-SR-77-41

CRREL

(12) Special Report 77-41

(6)

1977 CRREL-USGS SUBSEA PERMAFROST PROGRAM BEAUFORT SEA, ALASKA.

(9) Operational Report.

(10) P.V. Sellmann, E. Chamberlain, H.T. Ueda,
S.E. Blouin D. Garfield, R.I. Lewellen

(11) Dec[redacted]77

(12) 23p.

Prepared for
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
and
BUREAU OF LAND MANAGEMENT
By
CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

037 100

mt

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Special Report 77-41

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (*and Subtitle*)
1977 CRREL-USGS SUBSEA PERMAFROST PROGRAM
BEAUFORT SEA, ALASKA
Operational Report

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
P.V. Sellmann, E. Chamberlain, H.T. Ueda,
S.E. Blouin, D. Garfield and R.I. Lewellen

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U.S. Army Cold Regions Research and
Engineering Laboratory
Hanover, New Hampshire 03755

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Bureau of Land Management

12. REPORT DATE
December 1977

13. NUMBER OF PAGES
22

14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)
National Oceanic and Atmospheric Administration
Boulder, Colorado

15. SECURITY CLASS. (*of this report*)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Beaufort Sea
Continental shelves
Core sampling
Drilling
Offshore drilling
Permafrost
Prudhoe Bay
Samplers

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

During the spring of 1977 soil samples were obtained in the Prudhoe Bay area from one hole drilled on land and five holes drilled offshore. The study was a continuation of the program started the previous season to examine the engineering characteristics and properties of permafrost under the Beaufort Sea. Emphasis was placed on establishing the range of thermal and physical properties found in this geological setting, which is thought to be common to much of the eastern Alaska coastal zone. A probe study was also undertaken to increase our understanding of the engineering and thermal properties of this locality.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

20. Abstract (cont'd)

Twenty-seven probe sites were selected to determine local engineering properties and temperature conditions, and to aid in interpreting the lithology between the drill holes. Core drilling information from some of the probe sites was used as control for interpreting the probe records. Deep thermal and geological information was obtained from the drill sites by the USGS personnel participating in the study. Maximum drill hole depth was 68.5 m (225 ft) and maximum penetration depth was 15 m (50 ft). The probe temperature data indicated the presence of permafrost in all holes. Probe penetration resistance measurements helped to delineate shallow, ice-bonded zones, some of which may have been only seasonal. In the core study, frozen sediments were found in only one hole, at approximately the 29.6-m (97-ft) depth. Sediment distribution patterns were much the same as those found in last year's observations, with fine-grained sediments common over the coarse-grained material, and a general increase in fine-grained sediment thickness with increasing distance from shore. The only departure from the previous year's field drilling techniques was the use of larger diameter, thick-walled casing and an air-operated casing driver. The probe equipment and techniques employed, however, represented a significant improvement over the prototype equipment used in 1976.

PREFACE

The authors express their appreciation and thanks to the USGS personnel that participated in this project for their efforts, and to Mr. Allan Delaney of CRREL for his technical assistance and help with preparations for the field activities. They also thank the Outer Continental Shelf Projects Office in Fairbanks, Alaska, for making some field arrangements and providing project support in the field.

The National Oceanic and Atmospheric Administration and Bureau of Land Management support of this program is also appreciated.

Personnel in the CRREL Alaskan Projects Office in Fairbanks, who were involved in shipping equipment to Prudhoe Bay, also deserve special thanks.

INTRODUCTION

This report provides a record of some of the operational aspects and accomplishments of the 1977 Outer Continental Shelf Environmental Assessment Program (OCSEAP) subsea permafrost field program. The spring 1977 study undertaken in the Prudhoe Bay area was an extension of a study initiated during the spring of 1976 (Sellmann et al. 1976, 1977, Iskandar et al., in press) and previous investigations undertaken by Osterkamp and Harrison (1976). The objective of the effort was to examine the engineering characteristics and distribution of permafrost beneath the Beaufort Sea, including supporting geological and thermal studies. This program was based on drilling, sampling, and engineering probe studies using the sea ice as a drilling platform. The project was sponsored by the Bureau of Land Management and directed by the National Oceanic and Atmospheric Administration as part of the OCSEAP program.

The field program was undertaken jointly by the U.S. Army Cold Regions Research and Engineering Laboratory and the United States Geological Survey (Menlo Park) in cooperation with Lewellen's investigations supported by the Office of Naval Research. The thermal logging of the drilled holes and geological interpretation was done by the USGS. The equipment organized and used for this project was mostly provided by CRREL and ONR. The ONR equipment was available from the Naval Arctic Research Laboratory, Barrow, Alaska, under a subsea permafrost project sponsored through the Arctic Institute of North America, contract N00014-75-C-0635, subcontract ONR-457 to Dr. Robert I. Lewellen (Lewellen 1973, 1976a).

Our study in Prudhoe Bay brought to a close one phase of the NOAA program which included an examination of one of the geological settings common to the arctic coastal region through the use of drilling and sampling techniques. This study area was selected for logistics reasons, and for relevance in terms of active development and geological significance. Other OCSEAP projects related to subsea permafrost conducted by the University of Alaska were coordinated with this study. They dealt with permafrost properties and distribution based on drilling and geophysical studies, with emphasis on measuring and predicting the depth of ice-bonded permafrost boundaries (Osterkamp and Harrison 1976, Osterkamp 1975, Rogers 1976).

LOCATIONS OF SITES

Drilling Program

Five sites were selected for drilling and sampling in the Prudhoe Bay area during the 1977 season. They were situated in areas where obvious gaps existed in data from previous drilling activities. The locations of these holes as well as those drilled during the 1976 field season are shown in Figure 1; additional site details are provided in Table I. The sites were positioned using a transit and standard triangulation procedures. Ice thickness and water depth were determined

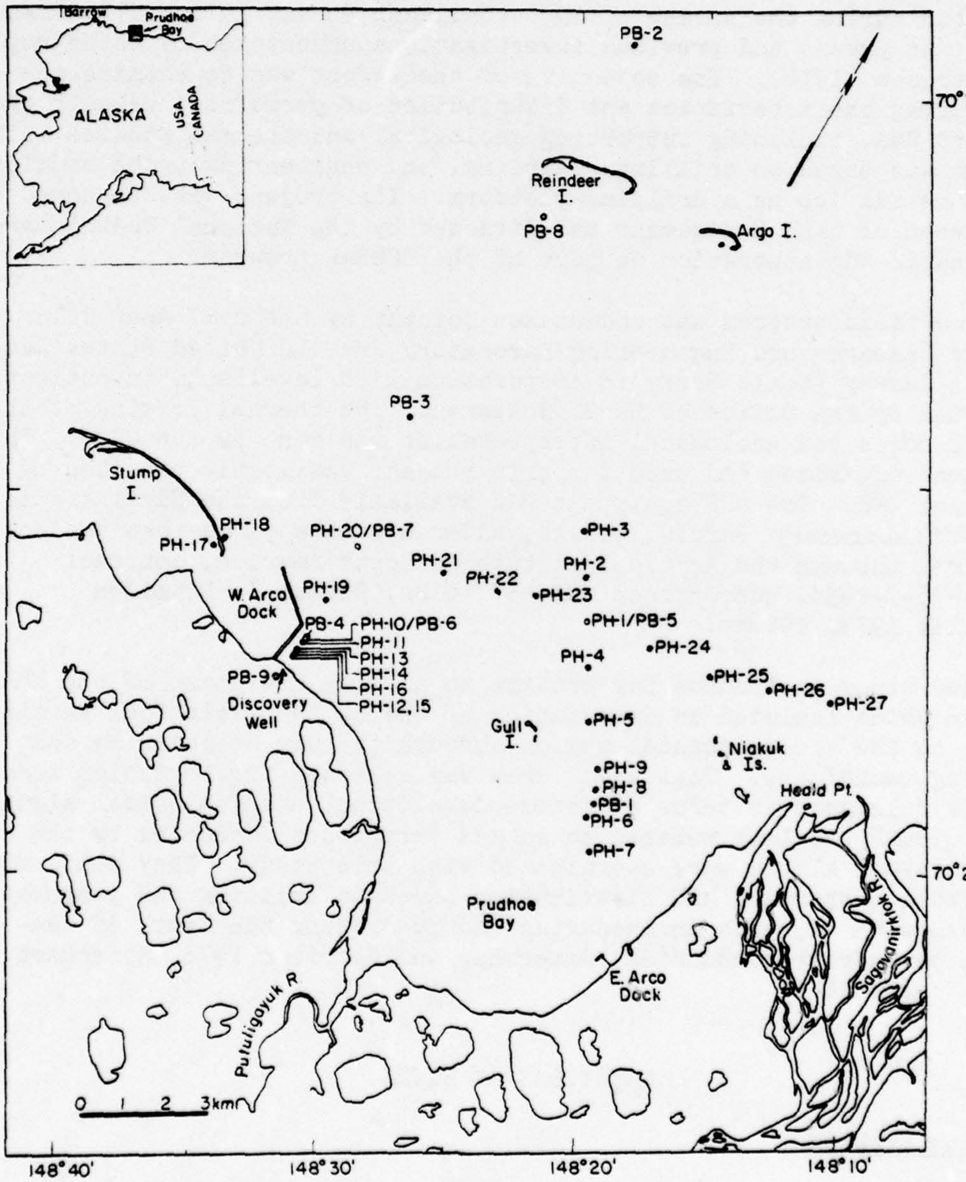


Figure 1. Site locations in Prudhoe Bay, Alaska. PB indicates drill holes; open circles indicate holes drilled during the 1977 season (PB 5-9) and closed circles indicate holes drilled during the 1976 season (PB 1-4). PH indicates probe holes.

TABLE I

DATA FOR 1977 PRUDHOE BAY CRREL-USGS DRILL LOCATIONS

Hole	General Location	Latitude	Longitude	Ice Thickness (m)	Water Depth (m)	Hole Depth (from ice surface) (m)
PB-5	2.8 km NE of Gull Island	70°23.3'	148°19.7'	1.50	1.75	11.8
PB-6	1.0 km NE of Discovery Well	70°23.05'	148°30.6'	1.80	1.85	8.2
PB-6A	1.0 km NE of Discovery Well	70°23.05'	148°30.6'	1.80	1.85	30.6
PB-7	3.5 km NE of Discovery Well	70°24.25'	148°28.5'	1.81	2.86	68.0
PB-8	1.3 km SW of Reindeer Island	70°28.5'	148°21.6'	2.18	6.98	32.4
PB-9*	0.3 km SW of Discovery Well	70°22.55'	148°31.6'	land	land	19.1

* PB-9 was drilled and sampled by R&M Engineering and is located on land.

when each site was first occupied. Tidal fluctuations were observed but they only amounted to very small cycles, on the order of 20 cm.

Even though the ice thicknesses observed were near normal at all sites, thin ice zones associated with the pressure ridges in the area were common.

Probe Study

The probe sites are shown in Figure 1. Their locations were selected based on an attempt to obtain data from most of the (depositional) environments in the Prudhoe area. Data were collected from three lines normal to the coast. The shortest and westernmost line was off Stump Island in an offshore bar environment. The middle line was the one previously established by Osterkamp and Harrison, along which some of last year's drilling efforts were undertaken. It extended true north offshore from the ARCO discovery well near the West ARCO dock. The third line extended offshore east of Gull Island through the first hole drilled in 1976 (PB-1). Normal to these lines a survey was extended from Stump Island to the Sagavanirktok River Delta. This line followed the 2-meter bathymetric contour. The locations of the probe sites and general information concerning them are given in Table II. These sites were also located by standard triangulation techniques.

FIELD OPERATIONS

The field program was initiated on 22 March with mobilization for the drilling effort at Prudhoe Bay. The project individuals that participated in the field program and their various activities are indicated in Table 3. The first hole was started on 30 March after eight days of equipment modification and preparation. Equipment preparation for the 1977 season included installation of an air-driven casing driver and repairs to the drilling unit's hydraulic system. During this mobilization period the drill and shop sled were moved by truck from a storage area at NARCON to the VE Construction Co. camp; from there the equipment could be moved by tractor onto the sea ice. All other equipment was also tranported from NARCON to the VE camp with the exception of some drill rod. Other tasks completed during the mobilization period included 1) modification of the casing hammer compressor for cold weather use, 2) reassembly of all drilling equipment, since many major components had been stored disassembled in preservative to prevent rust, and 3) surveying of ice thickness and marking of routes to proposed drilling sites.

Equipment

Essentially the same equipment was used this season as last (Sellmann et al. 1976, Lewellen 1976b, 1977). An alternate camp was provided by

TABLE II.

DATA FOR 1977 PRUDHOE BAY CRREL PROBE LOCATIONS

Hole	General Location	Latitude	Longitude	Ice thickness (m)	Water depth (m)	Maximum penetration (m)
PH-1	2.8 km NE of Gull Island	70°23.3'	148°19.7'	1.83	1.98	11.8
PH-2	3.7 km NE of Gull Island	70°23.85'	148°19.8'	1.83	3.15	12.3
PH-3	4.7 km NNE of Gull Island	70°24.4'	148°19.85'	1.52	3.23	12.9
PH-4	1.9 km NE of Gull Island	70°22.7'	148°19.7'	1.52	1.52	13.3
PH-5	1.4 km E of Gull Island	70°21.9'	148°19.6'	0.90	0.90	7.5
PH-6	3.3 km SSE of Gull Island	70°20.7'	148°19.7'	1.75	2.93	14.1
PH-7	2.6 km SSE of Gull Island	70°20.3'	148°19.5'	1.60	2.43	15.1
PH-8	2.6 km SE of Gull Island	70°21.2'	148°19.3'	1.50	1.69	10.3
PH-9	2.2 km SE of Gull Island	70°22.55'	148°31.9'	1.28	1.28	15.4
PH-10	1.0 km NE of Discovery Well	70°23.05'	148°30.6'	1.68	2.12	11.3
PH-11	0.8 km NE of Discovery Well	70°22.95'	148°30.8'	1.68	1.73	12.3
PH-12	0.5 km NE of Discovery Well	70°22.85'	148°31'	0.91	0.91	1.3
PH-13	.63 km NE of Discovery Well	70°22.95'	148°30.9'	1.56	1.56	8.4
PH-14	.57 km NE of Discovery Well	70°22.9'	148°30.9'	1.53	1.53	12.2
PH-15	0.5 km NE of Discovery Well	70°22.85'	148°31'	0.69	0.69	1.2
PH-16	0.54 km NE of Discovery Well	70°22.87'	148°31'	1.35	1.35	9.9
PH-17	0.12 km inland from Stump Is.	70°22.25'	148°34.1'	0.91	0.91	4.5
PH-18	0.12 km seaward from Stump Is.	70°24.3'	148°33.7'	1.83	1.94	11.3
PH-19	2.0 km NE of Discovery Well	70°23.5'	148°29.75'	1.80	1.95	10.6
PH-20	3.5 km NE of Discovery Well	70°24.25'	148°28.5'	1.80	2.06	11.1
PH-21	4.2 km NW of Gull Island	70°23.9'	148°25.3'	1.70	1.88	8.3
PH-22	3.3 km NW of Gull Island	70°23.65'	148°23.2'	1.85	2.17	10.9
PH-23	3.2 km N of Gull Island	70°23.6'	148°21.7'	1.60	2.13	11.2
PH-24	3.2 km NW of Niakuk Island	70°22.9'	148°17.3'	1.80	2.03	10.7
PH-25	1.5 km N of Niakuk Island	70°22.6'	148°15'	1.80	2.00	11.6
PH-26	1.9 km NE of Niakuk Island	70°22.4'	148°12.7'	1.80	1.83	10.0
PH-27	2.5 km NE of Heald Point	70°22.2'	148°10.4'	1.65	1.89	14.6

Table III. Project individuals in the field during the 1977 effort.

	Individual	Organization	Time	Activity
1.	Scott Blouin	USACRREL	23 March - 19 April	Probe Study
2.	Edwin Chamberlain	USACRREL	23 March - 5 May	Sample Logging, Processing and Thermal Logging
3.	Allan Delaney	USACRREL	21 March - 1 April	Mobilization
4.	Donald Garfield	USACRREL	23 March - 19 April	Probe Study
5.	Roger Hartz	USGS	15 April - 4 May	USGS Sample Logging and Analysis
6.	Dave Hopkins	USGS	29 March - 16 April	USGS Sample Logging, Analysis, and Interpretation
7.	Robert Lewellen	Contract-USGS	27 March - 5 May	Drilling and Sampling
8.	Vaughn Marshall	USGS	15 April - 6 May	Thermal Observations
9.	Fred Page*	USACRREL	10 April - 10 May	Sample Processing (Fairbanks)
10.	Paul Sellmann	USACRREL	21 March - 5 May	Drilling and Sampling and General Field Operations
11.	Herb Ueda	USACRREL	21 March - 5 May	Drilling and Sampling

* Jerry Brown and Fred Page visited the field activities on 23 April; Page processed samples for chemical analyses in CRREL's Fairbanks lab (Ft. Wainwright).

CATCO which was similar to the unit used during the 1976 field program. Another exception to last year's equipment list was an additional tractor provided by the Navy (ONR-NARL). This large tractor (TD 25) was used to move the probe equipment over the ice and to act as a reaction force for the static probe penetration studies. The only additions to the drilling equipment were the air-operated casing hammer and a 250-cfm compressor for its air supply.

The field and equipment operating procedures were very similar to those of the 1976 program. The new methods and techniques, casing placement and utilization of the new probe equipment, are covered in the following discussion. The field setup of the drilling camp and equipment is shown in Figure 2.

Casing Installation

Failure problems with the NX casing used during the 1976 program, which limited the maximum depth of the holes drilled, led to selection of a new casing string and installation procedure. During the 1976

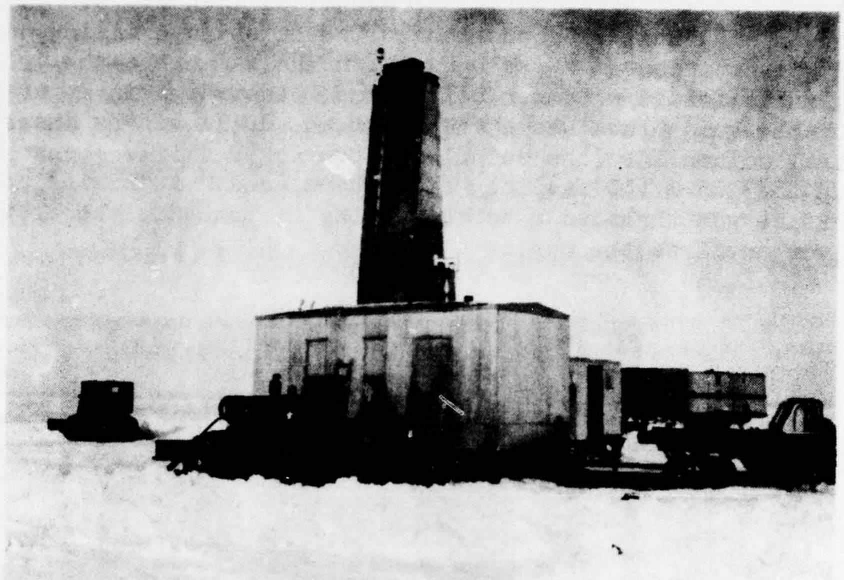


Figure 2. Field setup at drill site PB-7; drill and shop sled in foreground with camp unit in background.

program the NX casing was placed with a manually operated capstan drive and 136-kg (300-lb) drop-hammer. The new casing selected was 11.4 cm (4-1/2 in.) o.d. by 9.5 cm (3-3/4 in.) i.d. flush-joint casing obtained from the Diamond Drill Co. This new casing had approximately a 90% larger cross section and 29% greater surface area than the NX casing previously used. With this larger surface and frontal area, and considering the difficulty in driving experienced the previous year, it was apparent that the drop-hammer would be an inadequate placement method. Furthermore, one of the program objectives was to obtain samples from depths greater than those previously attained.

A McKiernan-Terry No. 5 double acting air-driven pile driver was selected to replace the drop-hammer for driving the large casing. It was selected over hydraulic and other air-operated hammers because of its size, price, compatibility with existing equipment, and the fact that it did not need draw-down reaction force applied to the hammer.* This hammer also had air requirements that could be matched with an available 250-cfm compressor.

The McKiernan-Terry hammer was rated at 1356 N-m (1000 ft-lb) of energy per blow and 300 blows/min. A Davey 7.08 m^3/min (250 ft^3/min), 6.89 x 10^5 Pa (100 lb/$in.^2$) diesel engine driven air compressor was used for the air supply.

*The apparent requirement of some new hydraulic and air hammers for a means of applying a normal load to the hammer eliminated them from consideration because of the difficulty this would have entailed with the existing drilling equipment.

The hammer was installed in a conventional manner with an in-line oiler and deicing unit. Adaptation to the existing drilling equipment required construction of a rack to attach the hammer to the drill and to act as a guide for safe hammer control as illustrated in Figure 3. The removable guide rack was attached to the drill rig by inserting its central column into the spindle of the Acker drill. Lengths of casing up to 3.05 m (10 ft) long could be placed. A driving head with a domed surface was threaded onto the casing to transmit the blow from the pile driver anvil to the casing string.

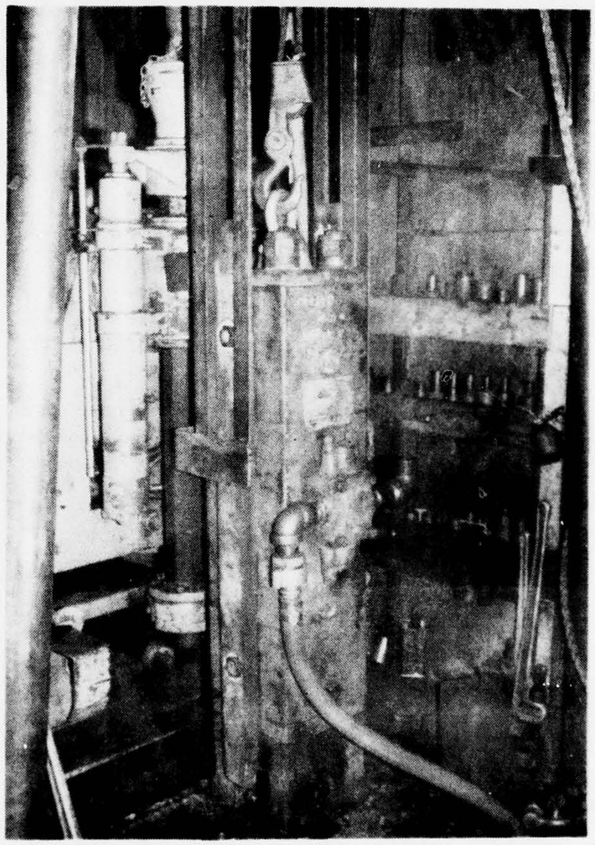


Figure 3. McKiernan-Terry No. 5 air hammer shown mounted in the guide rack constructed to adapt the unit to the Acker drill. Fore-and-aft movement of the rig allowed for hole centering.

In actual operation the rated performance of the driver was never obtained due to system losses and a slightly inadequate output from the compressor. The actual energy output is difficult to measure in the field; however, an estimate can be made. The energy output is determined by the mass of the ram or hammer and its velocity on impact with the anvil. The free-falling hammer, which weighs 91 kg (200 lb) with a 0.18-m (7-in.) stroke, would account for 158 N-m (1400 in.-lb) or about 12% of the rated energy (1356 N-m or 1000 ft-lb). Therefore, the additional force obtained from the air pressure on the piston is critical in determining the impact velocity of the hammer. The blow rate can be used as an approximate measure of the energy output of the hammer, as indicated in the manufacturer's operating manual. An average blow rate of 240 blows/min would suggest an energy of about 1179 N-m (870 ft-lb) per blow. The average pressure at the compressor was 6.2×10^5 Pa (90 lb/in.^{2}) and the highest blow rate obtained was 270 blows/min.

Despite a slightly reduced output the overall performance of the pile driver was very good. It was used to drive casing at PB-6A, PB-7, and PB-8 to depths of 31.4 m (103 ft), 68.6 m (225 ft) and 33.5 m (110 ft) respectively. The penetration rate varied from 0.02 m/min (0.85 in./min) to 0.51 m/min (20 in./min) at an average blow rate of 240 blows/min. These rates naturally varied, depending on depth and material type. The lowest rates were obtained at the bottoms of the holes and were considered refusal. The range indicated above included drives in clay, silt, sand and gravel. Operation of the hammer was steady and trouble-free and its performance was much appreciated by the drilling crew.

It is interesting to note that the energy per blow of the pile driver was about equivalent to that of the 1.3×10^3 N (300-lb) drop-hammer previously mentioned. It is very doubtful that the drop-hammer would have been even half as effective. It must be concluded that other factors such as the 6.7×10^3 N (1500-lb) static weight of the pile driver, the casing weight of 263 N/m (18 lb/ft) and the frequency of impact must have been significant in determining the penetration rate. Blow frequency was probably the most important parameter, since the frequency of the air hammer was at least four times that of the manual drop-hammer.

The new hammer eliminated the need for time-consuming drilling ahead of the casing as was sometimes required last season during attempts to advance the NX casing at depth with the drop-hammer. This greatly increased the casing installation rate, prevented fluid loss into the sediment, and consequently improved the quality of the thermal data.

Even though the new casing was used on only three holes, some belling at the joints was detected. A radial crack over about half the circumference of the casing was found at the base of a set of female threads upon extraction from the 68 m (225 ft) deep hole.

Casing removal was greatly aided by a casing jack that could develop around 1.3×10^5 N (30,000 lb) of force. Even though it made removal much easier it could not start casing extraction without the aid of one of the capstan-operated casing hammers.

Drilling and Sampling

The techniques used for drilling and sampling did not depart significantly from those employed and reported on during last year's program. Detailed observations covering the drilling and sampling are included in Lewellen's formalized field notes (Lewellen 1977). Thermal logs were obtained for the holes, as last year, by the USGS personnel (Lachenbruch and Marshall 1977). The geological and descriptive logging of the holes was done by Hopkins and Hartz, also with the USGS.

Two types of drive samplers were used for all sampling activity. The Washington State sampler was used in fine-grained sediment and a split tube heavy duty drive sampler was used in the coarse, noncohesive material.

The sampling frequency was generally greater than it was last year. The upper parts of all the sections drilled were fine-grained and were for the most part sampled continuously. Core recovery in this part of the section was extremely high, with 90% recovery common. Sampling in the gravel or sands was usually at intervals of 1.5 or 3.0 m (5 or 10 ft) Sample recovery in these sediments was also very good; on only one sample run this season was the recovery zero. Recovery in the coarse-grained sections, however, was not as high as in the fine sediment, although more than 60% recovery was routinely obtained in the sand and gravel.

Wash samples were generally collected from all the sections that were not core-sampled. These samples were collected at the discharge "T" as shown in Figure 4. More than 80 core samples were obtained for subsampling and further laboratory analysis of engineering and chemical properties, and more than 90 wash samples were obtained for USGS geological studies.

Probe Study

The probe equipment used during this year's program was designed for rapid acquisition of engineering data, including thermal profiles. The primary mode of testing with this penetrometer device was planned to be static, although dynamic capability was included.

The testing equipment was completely housed in a 1.52 x 2.59 m (5 x 8-1/2 ft) building mounted on a ski base. The skis also served as a parking pad for the large crawler tractor that acted as the reaction force for testing and eliminated the time-consuming anchor setting procedures employed last season (Fig. 5). The tractor was also used to transport the sled-mounted probe. The heated enclosure contained all the equipment necessary for electrical data acquisition.

Figure 4. Collecting wash samples from discharge "T" at the Mud Pit.

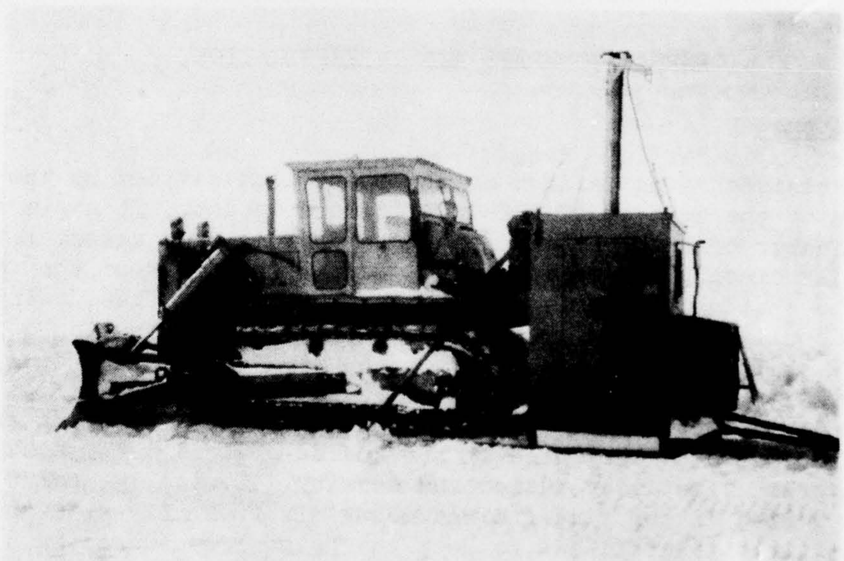


Figure 5. Tractor positioned on probe sled providing reaction force for static testing.

The probe was fitted with a 6.35 cm (2.5 in.) diameter 60° cone. The probe was advanced by using AW size drill rod and casing. The hydraulic system for the static tests had a ram with a 1.83-m (6-ft) stroke, allowing 1.52-m (5-ft) lengths of casing and rod to be used. The system was operated with an electrically powered hydraulic pump capable of driving the probe at a rate of 2 cm/s (0.8 in./s).

Electrical power was provided by a diesel generator mounted in an enclosure on the front of the house. The building was heated with cooling air discharged from the generator.

The total penetration resistance of the casing and the rod were independently plotted as a function of depth on an X-YY recorder. Displacement of the string was monitored with a cable-actuated linear displacement transducer, while load cells were used to measure the two forces. It was not necessary to alternately advance the point and casing as was required the previous season since the individual load cells provided the desired forces simultaneously.

Temperature data were obtained through the probe string after the column, containing a nonfreezing fluid, came to equilibrium. Equilibrium time was determined by sequential measurements. Since thermal disturbances dissipated in 6 to 8 hours, the normal procedure was to allow the probe to remain in place overnight before making temperature measurements.

GENERAL COMMENTS AND INTERPRETATION

Point Resistance

Point resistance is defined as the point load divided by the projected area of the 6.35 cm (2-1/2 in.) diameter point. It appears to be a good indicator of both material strength and, in some cases, material type. As is common practice in Europe, bearing capacity of the various soils can be obtained directly from point resistance. Thus, point resistance could be used to design or evaluate foundations for offshore structures.

Generally, point resistance was low in the fine-grained materials and varied from low to very high in the coarse-grained materials, depending on grain size distribution and density. Typically, point resistance varied in the fine-grained materials from only a few hundred pascals (at times insufficient to keep the point from advancing under the weight of the column) to 13.7×10^5 Pa (200 lb/in.^{2}). Resistance in the coarse-grained materials varied continuously and often dramatically. Resistances as low as 27.5×10^5 Pa (400 lb/in.^{2}) were common, varying upward to 393×10^5 Pa (5700 lb/in.^{2}), the capacity of the equipment, when the standard point was used. A good example of these variations is shown in the data from PH-10 (Fig. 6). This illustration also includes

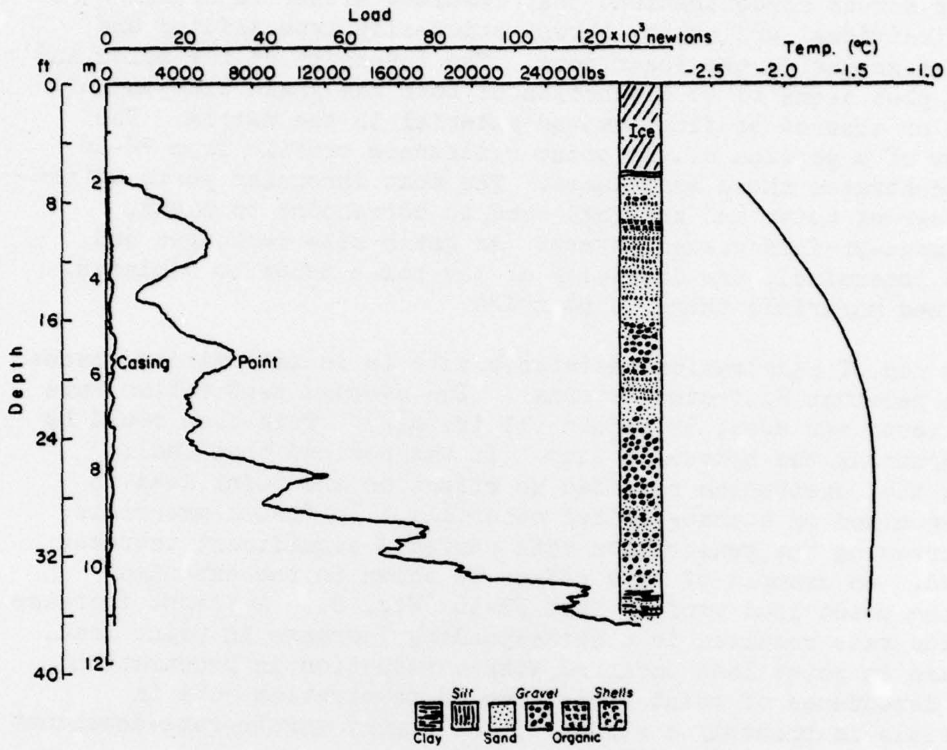


Figure 6. Example of typical probe information, including casing, point load and temperature data, from PH-10 compared to borehole data.

material information from the borehole (PB-6a) at this site as well as temperature data from the probe hole. It is felt that the higher values of point resistance tend to be in layers of coarser material with higher relative densities. Thus a loose, silty sand would tend to have a point resistance toward the lower end of the spectrum while dense, coarse gravel would lie toward the upper end.

Other indications of material type were the sounds and the shape of the plot produced as the point penetrated various materials. When the probe was penetrating granular material, a continuous chain of audible crunches could often be heard that varied in intensity from barely audible to rather loud. These noises were very similar to those heard during high pressure triaxial shear tests on granular soils. The penetration plot varied from a smooth to very irregular (sawtooth) line, with greatest irregularity corresponding to greatest noise. The degree of irregularity and sound intensity was thought to be associated with intergranular stress concentrations that resulted either in crushing or shearing of individual grains, or abrupt stick-slip type sliding and dislocation of grains in the shear zone. The intensity of the noise and peaks on the plot seems to be a function of both the grain size and of the presence or absence of fine-grained material in the matrix. The expanded view of a portion of the point resistance profile from PH-10 (Fig. 7) demonstrates these influences. The most irregular parts of the plot (and severest noise and shaking) tend to correspond to clean, relatively large-grained gravel layers. As grain size decreases and silt becomes intermixed, the intensity of the noise tends to diminish. In fine-grained materials there is no noise.

Another use of penetration resistance data is in determining whether the point is penetrating frozen material. The average penetration rate used in all tests was about 30 cm/min (12 in./min). This rate could be varied by adjusting the hydraulic pump. It was noticed that small variation in the penetration rate had no effect on the point load in either fine-grained or coarse-grained materials. In frozen materials, however, increasing the penetration rate caused a significant increase in point load. An example of this effect is shown in the expanded portion of the point load profile from PH-16 (Fig. 8). A slight increase in penetration rate resulted in a corresponding increase in point load, and a decrease in point load occurred with a reduction in penetration rate. This dependence of point resistance on penetration rate in frozen materials is probably a result of the highly strain-rate-dependent strength characteristics of ice-bonded soils.

In general, it was extremely difficult to penetrate frozen sand and impossible to penetrate frozen gravel. Penetration of a frozen sand was possible using a small (4.6 cm or 1-13/16 in. diameter) point pushed at a very low penetration rate. Point resistance was on the order of 690×10^5 Pa (10,000 lb/in.^{2}). In some cases frozen fine- grained material could be penetrated with the large point driven at the standard rate with a point resistance on the order of 170×10^5 Pa (2500 lb/in.^{2}). However, since no samples of these materials were collected at the probe sites where this occurred, the material characteristics are unknown.

Casing Load

While casing load profiles were obtained from most tests, quantitative analysis of these data is difficult because of the design of the apparatus. Most of the casing load data came from measurements on the casing shown schematically in Figure 9. The 6.35 cm (2-1/2 in.) diam shrouded point is followed by a 15.24 cm (6 in.) long casing shoe of equal diameter welded to the 5.72 cm (2-1/4 in.) diam casing. Thus casing resistance is the sum of the frictional resistance acting on the casing shoe plus any component of resistance resulting from collapse of the hole around the casing above the point and shoe assembly. It is impossible to

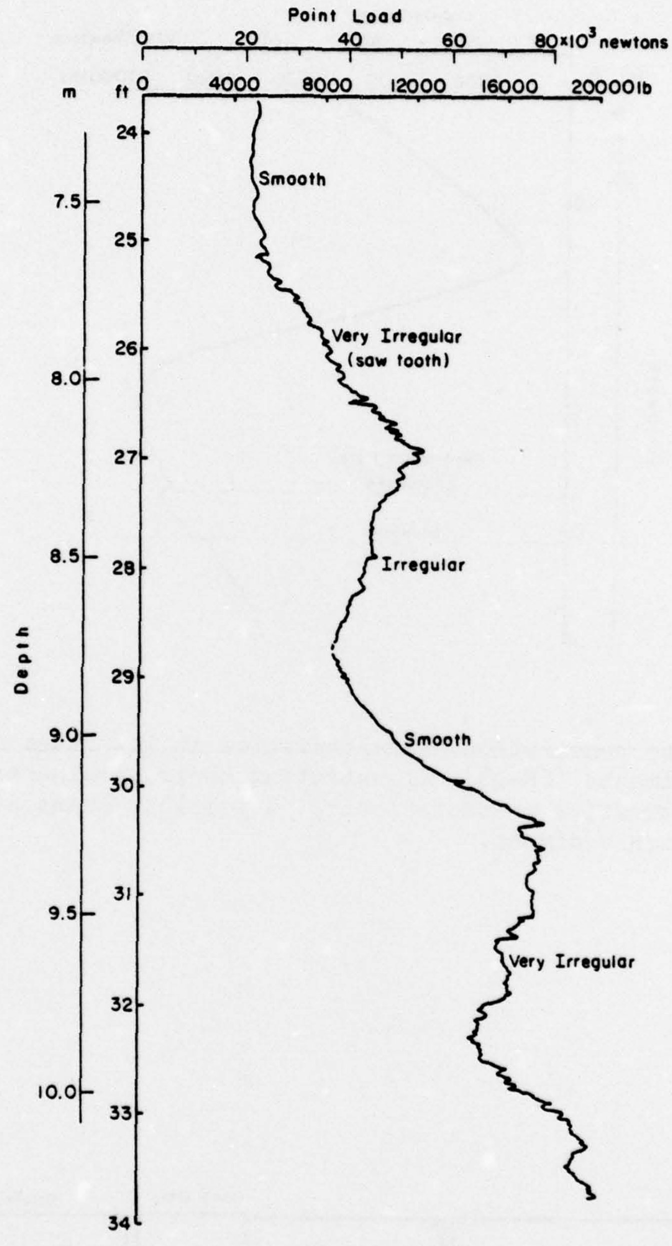


Figure 7. A part of the point resistance profile from PH-10, showing local fluctuations in load thought to correlate with grain size and gradation of the sediment.

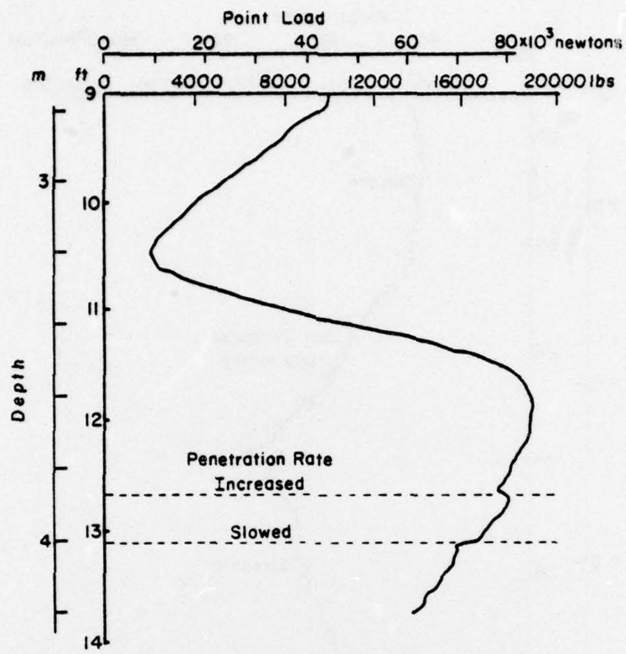


Figure 8. Probe penetration characteristics at low rates in frozen sediments (PH-16), illustrating their strain-rate-dependent deformation characteristics, a possible means of identifying frozen sediment.

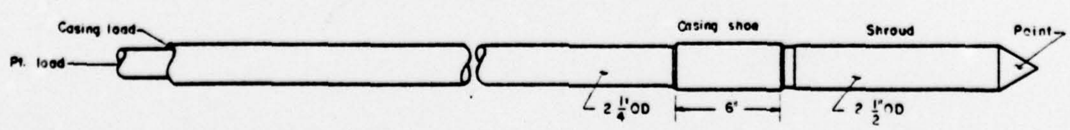


Figure 9. Schematic of casing, and casing shoe.

quantitatively separate these two components. Generally, total casing load was quite low, usually less than 8.9 x 10^3 N (2000 lb). If an 8.9 x 10^3-N (2000-lb) load was borne entirely as shear on the casing shoe, shear stress would average a relatively high 2.9 x 10^5 Pa (42 lb/in.^{2}) over the shoe surface. However, casing load tended to increase with increasing depth of penetration, probably indicating that a portion of the high casing load resulted from collapse around the casing.

In test PH-3, a modified point assembly was tested in which an unshrouded 5.72 cm (2-1/4 in.) diam point was pushed ahead of the 5.72 cm (2¼ in.) diam casing without a casing shoe. Thus the hole made by the point was exactly the diameter of the casing, making this test analogous to a driven foundation pile. As shown in Figure 10, a significant portion of the total load in the string was needed to advance the casing. Even though a majority of the 9.75-m (32-ft) penetration was through fine-grained material having almost no point resistance, the casing resistance built steadily to almost 40 x 10^3 N (9000 lb) before the point reached refusal in a gravel layer. The average shear resistance over the entire casing length was about 23 x 10^3 Pa (3-1/3 lb/in.^{2}). Even though the soil profiles at most of our test sites seem ideally suited for end-bearing piles founded on dense gravels, this test suggests that significant bearing capacity could be generated by the side friction shear component as well.

Detailed results of the engineering probe study as well as core analysis data will be covered in future technical reports.

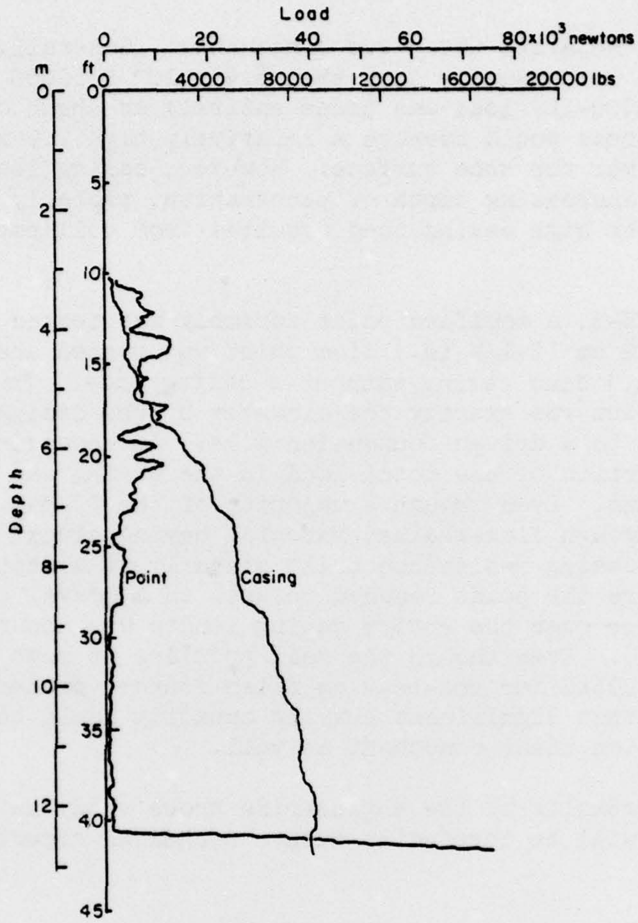


Figure 10. Probe hole 3 illustrates increased casing load with depth when point and casing diameter are the same in material that shows no increase in point resistance with depth.

LITERATURE CITED

Iskandar, I.K., T.E. Osterkamp and W.D. Harrison (In press) Chemistry of interstitial water from subsea permafrost, Prudhoe Bay, Alaska. Prepared for the Third International Permafrost Conference.

Lewellen, R.I. (1973) The occurrence and characteristics of nearshore permafrost, Northern Alaska. North American Contribution to the Second International Permafrost Conference. National Academy of Sciences, p. 131.

Lewellen, R.I. (1976a) Subsea permafrost research techniques. Symposium on Research Techniques in Coastal Environments, Louisiana State University, Baton Rouge, Louisiana.

Lewellen, R.I. (1976b) Drillers field notes -- Subsea Permafrost Program, Prudhoe Bay, Alaska, 1976. On file at U.S. Army Cold Regions Research and Engineering Laboratory.

Lewellen, R.I. (1977) Drillers field notes -- Subsea Permafrost Program, Prudhoe Bay, Alaska, 1977. On file at U.S. Army Cold Regions Research and Engineering Laboratory.

Lachenbruch, A.H. and B. Vaughn Marshall (1977) Subsea temperatures and a simple tentative model for offshore permafrost at Prudhoe Bay, Alaska. U.S. Geological Survey, Menlo Park, California, Open-File Report 77-395, p. 54.

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

Osterkamp, T.E. and W.D. Harrison (1976) Subsea permafrost at Prudhoe Bay, Alaska: Drilling report and data analysis. University of Alaska, Geophysical Institute, Report UAG-R-245.

Rogers, J.C. (1976) Beaufort Sea geophysical permafrost studies. NOAA-BLM OCS Program, Research Unit No. 271, Progress Reports.

Sellmann, P.V., R.I. Lewellen, H.T. Ueda, E. Chamberlain and S.E. Blouin (1976) Operational Report: 1976 USACRREL-USGS Subsea Permafrost Program, Beaufort Sea, Alaska. CRREL Special Report 76-12.

Sellmann, P.V., E. Chamberlain, S.E. Blouin and I.K. Iskandar (1977) Field methods and preliminary results from subsea permafrost studies in the Beaufort Sea, Alaska (abstract). Symposium on Permafrost Field Methods and Permafrost Geophysics, Oct 1977, Saskatoon, Saskatchewan.