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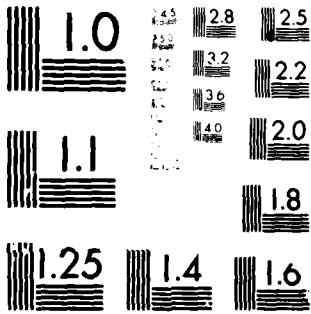
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DRILLING AND CORING OF FROZEN GROUND IN NORTHERN ALASKA, SPRING 1979



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Prepared for
OFFICE OF NATIONAL PETROLEUM RESERVE IN ALASKA
U.S. GEOLOGICAL SURVEY



UNITED STATES ARMY
CORPS OF ENGINEERS
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE, U.S.A.



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**Cover: Drill rig on pingo at Oumalik in National
Petroleum Reserve-Alaska, May 1979.**

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Frozen samples of perennially frozen ground were obtained from 33 holes drilled at six locations in the National Petroleum Reserve - Alaska in the spring of 1979. Total depth of drilling was 510 m (1670 ft), of which 178 m (584 ft) was cored.

The objectives of the program were to define the location and extent of segregated and massive ice at each location and to determine the origins and ages of the ground ice through studies of the hole stratigraphy and future laboratory analyses of core samples.

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20. Abstract (cont'd).

A Mayhew 200 rotary drill rig and a piston-type air compressor were contracted by Husky Oil Co. Air was naturally refrigerated by circulation through cooling units of coiled aluminum pipe and was used as the drilling medium. During coring we used Shelby tubes modified with four tungsten carbide teeth or a standard NXHW double-walled core barrel (Diamond Drill Co.) with three different tungsten carbide bit styles.

In general, the three bits with the double-walled core barrel did not satisfactorily core the frozen sediment or massive ice. The modified Shelby tube generally cut cores with few breaks in ice-rich sediments. At the lowest penetration rates, with normal thrust provided only by the weight of the drill stem, the modified Shelby tube often obtained cores of massive ice with few fractures and unbroken cores of ice-rich sediments. If ice occurred as bands extending through the core diameter, the cores were sometimes fractured along the ice bands. Coring with the Shelby tube often fractured or crushed massive ice if the thrust and rpms of the drill were too high.

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PREFACE

This report was prepared by Dr. Daniel E. Lawson, Research Physical Scientist, and Bruce Brockett, Physical Science Technician, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). The project was funded by the Office of National Petroleum Reserve in Alaska, U.S. Geological Survey, Order Number 72557, Amendment 0002.

CRREL personnel directly involved in the field program described in this report included Dr. Jerry Brown, Chief, Earth Sciences Branch, and field assistants William Davies and Richard Mead. The authors acknowledge the support of CRREL personnel in Hanover, and thank John Ireton and Tom Brooke of Husky Oil Co., Dr. Max C. Brewer and Dr. John Haugh, U.S. Geological Survey, Anchorage, Alaska, and Dr. George Gryc, U.S. Geological Survey, Menlo Park, California, who provided encouragement and assistance throughout the planning and execution of the study. Paul V. Sellmann provided valuable advice throughout the planning of the field work. Dr. Brown's assistance in organizing the field studies is gratefully acknowledged. The authors also thank driller Ernest Dennis of Exploration Supply and Equipment Co., whose experience and willingness to work under extreme conditions contributed significantly to the success of this program. The report was reviewed by Paul Sellmann and Lawrence Gatto of CRREL.

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DRILLING AND CORING FROZEN GROUND IN NORTHERN ALASKA SPRING 1979

Daniel E. Lawson and Bruce Brockett

INTRODUCTION

This report describes the techniques used to drill and core perennially frozen ground at six sites in the National Petroleum Reserve-Alaska (NPRA) from 12 May to 5 June 1979. Prior to this study, CRREL had undertaken similar drilling programs at Barrow, Alaska, and offshore at Prudhoe Bay, Alaska (Sellmann and Brown 1965, Sellmann et al. 1976).

The principal sites investigated in this study were Fish Creek, East Oumalik, Oumalik, and Umiat (Fig. 1). We also drilled on the edge of a bluff on the Titaluk River and in two pingos near the Ikpikpuk River. Fish Creek, East Oumalik, and Oumalik are old petroleum exploration sites, last occupied during the late 1940's and early 1950's. At these sites, the U.S. Navy drilled test wells to determine the oil potential of the NPRA region, then referred to as Naval Petroleum Reserve No. 4 (PET 4) (Reed 1958). Our drill holes at Umiat were located at Seabee, which is the site of a new exploratory test well in the NPRA, and along an old trail just west of Seabee.

The Navy's exploration activities at the PET 4 drill site caused various environmental disturbances. CRREL and associated university investigators are studying the effects of these activities on the vegetation, soils, and permafrost (Lawson et al. 1978, Lawson and Brown 1979, Lawson 1979). The near-surface coring and drilling program described in this report was initiated as part of that research.

The objectives of the drilling and coring program at each site were:

1. Determine the extent and volume of segregated and massive ice.
2. Determine the origin of the ground ice.
3. Define the late Pleistocene stratigraphy.

We logged the geology of each hole, including the depth and thickness of ground ice and the type and location of the sediment, and cored the frozen sediment and ice for future chemical and physical analyses. These analyses will include studies of the ice for chemistry, hydrogen and oxygen isotope content, air content, and crystal size and orientation, and studies of the sediments for grain size, water content, organic content, paleontology, and chemistry. Organics will be dated using radiocarbon techniques. The drill holes were located on geomorphic features representative of each site, generally in the centers of polygons to avoid near-surface ice wedges.

EQUIPMENT

All drilling equipment and tools were provided by Exploration Supply and Equipment Company, Anchorage, Alaska, except as noted. They were subcontracted for this work by Bell, Herring and Associates, Anchorage, Alaska, through Husky Oil Co., for the U.S. Geological Survey.

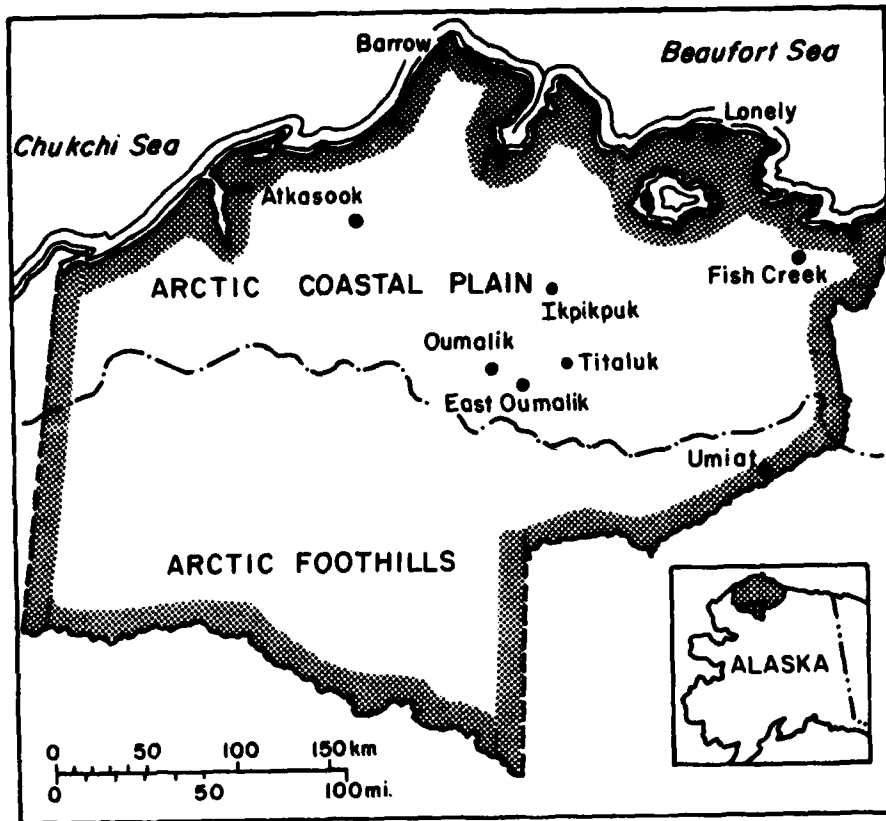


Figure 1. Map showing the locations of the Fish Creek, Oumalik, East Oumalik, Titaluk, Ikpikpuk, and Umiat (Seabee) sites. At each location, several holes were drilled and cored. The shading marks the boundary line of NPRA.

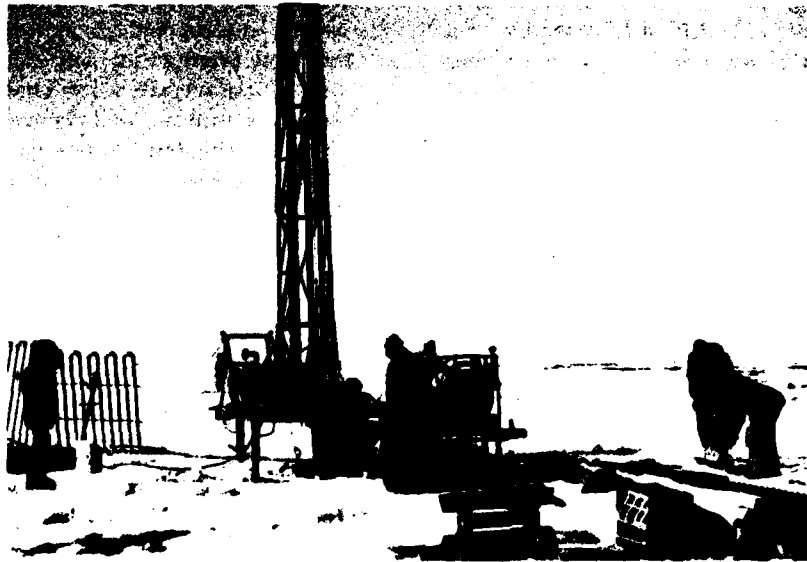


Figure 2. The Mayhew 200 drill (center), compressor, cooling tubes (left), and sampling equipment on drill hole at Fish Creek.



Figure 3. Bell 205 helicopter placing Mayhew 200 drill rig into position at Fish Creek.

The following major pieces of equipment were used:

1. Mayhew 200 rotary drill rig.
2. Gardner-Denver Model ACL 1002, 30-psi, 200-cfm compressor.
3. Two air coolers of coiled aluminum pipe.
4. Bell 205 helicopter.

Figure 2 shows the drilling equipment at Fish Creek.

Drill

The rotary drill was mounted on three pneumatically adjustable legs. A 30-hp, 4-cylinder Wisconsin engine powered the drill unit. The rig's mast can be lowered to a horizontal position if the unit is to be carried in a helicopter sling between drill holes (Fig. 3). The drill, with miscellaneous tools, weighed about 1270 kg. Mechanical failure only caused about 8 hours down-time in 190 hours of operation over 24 days.

Air compressor

The two-cylinder, piston-type compressor was mounted on a frame supported by skids. A 30-hp, 4-cylinder Wisconsin engine powered the compressor. Supports attached to the side of this unit can carry 12 3-m lengths of drill pipe. All bits, core barrels, and miscellaneous supplies were carried in a basket beneath the compressor. This unit weighed about 1134 kg. The compressor operated without failure during the drilling program.

Cooling tubes

The drilling contractor fabricated two air cooling units using aluminum pipes of 3.18 cm (1.25 in.) inside diameter (Fig. 2). About 18 m of pipe was used in each unit. Insulated hose 2.5 cm in diameter connected the compressor to the two cooling units and to the air swivel on the drill.

Each cooling unit stood upright, allowing normal air circulation to cool the pipes. The total surface area for heat exchange was about 4.2 m². During drilling with ambient air temperatures below 0°C and a stiff to gentle breeze, the temperature of the air at the drill end of the cooling units was typically 15°C colder than at the compression end. At these temperatures, the temperature of the air entering the drill hole generally ranged from -3° to -6°C. Compressed air entering the drill hole was usually 2° to 8°C colder than the ambient air temperature. Warm air temperatures (5° to 10°C) and low wind velocities on the last few days of drilling warmed the air entering the drill hole above 0°C, but colder subsurface temperatures kept the temperatures of the air exiting the drill hole below freezing.

Bell 205 helicopter

The helicopter ferried all equipment and supplies from one drill site to another, as well as transporting the work crew (4-6 persons) to and from the base camp at Lonely (Fig. 3). Each change in drilling location required three or four sling loads. The helicopter made separate trips with the drill, the compressor, and a net holding barrels of jet fuel and gas, sampling supplies, equipment, and miscellaneous drilling accessories. The helicopter had a total working weight of about 4536 kg and transported a total of 114,895 kg during the field program. Weather conditions, although often adverse, only caused about 5 hours down-time.

METHODS

Site set-up

A typical set-up for drilling and core sampling and analysis is shown in Figure 2. Tear-down and set-up typically took less than 30 minutes. Helicopter transport between drill holes took from 10 to 20 minutes. Moving between the six study sites required more time. At each drill hole, the drill and the compressor were placed adjacent to one another. Sampling materials, photographic equipment, a wooden miter-box fabricated by CRREL for cutting frozen cores, and a steel core extractor fabricated by the drilling company were placed about 5 m behind the drill (Fig. 2). This layout allowed ample room for removing and adding drill stems and bits and for observing the cuttings and processing cores.

Drilling and coring techniques

We used standard shallow drilling techniques to drill through the perennially frozen ground. A three-wing step bit was used to drill to a prescribed depth prior to coring and to ream the hole after coring when necessary. Drilling rates varied, according to rpm and thrust, with good penetration in most types of material. Penetration rates typically ranged from 0.3-1.5 m/min. Organic zones and partly or fully unfrozen zones often clogged the bit and slowed drilling, sometimes requiring pulling the bit for cleaning. Naturally cooled compressed air was used to prevent melting and to clear chips from the hole during open hole drilling and part of the coring operations. Using air as drilling fluid reduced chemical contamination of the samples.

Cores were cut with two different types of core barrels. Most cores were taken with a contractor-fabricated Shelby tube which consisted of a 6.4-cm (2.5-in.) I.D. steel pipe, about 64 cm long, with either two or four tungsten carbide teeth (Fig. 4). The modified Shelby tube was used as a rotary core barrel. Air was circulated through the hole only during the cutting of about the first two-thirds of the core. The gauge on the teeth undercut the core by about 1-2 mm and overcut the hole by about 5 mm. The carbide teeth were set vertically on the edge of the Shelby tube, with a rake angle of 0° and a relief angle of 30°. We cut cores 0.3, 0.5, and 0.6 m long. After coring several meters of ice-rich sediment in the first few holes, we determined that the two-bit Shelby tube generally cut an unsatisfactory core with many breaks, particularly in ice-rich sediments or massive ice, and we stopped using it.

The modified four-bit Shelby tube retrieved cores successfully in both frozen ice-rich sediments and massive ice, but the quality of the core varied, depending on drilling parameters such as rpm and thrust on the bit. Core recovery required a brief shut-down of the drill and compressor (about 2 minutes) until the core froze to the tube. Rotating the core barrel then broke off the core at the bottom of the hole. Cores of silt-rich sediments containing ice in thin, irregular veins and pores were generally intact with few breaks (Fig. 5). These included fine-grained sediments containing 50-80% ice by volume. Frozen sediments that contained bands of ice extending through the diameter of the core often broke along the ice bands (Fig. 6). Ice-poor cores also usually broke along horizontal ice lenses. If

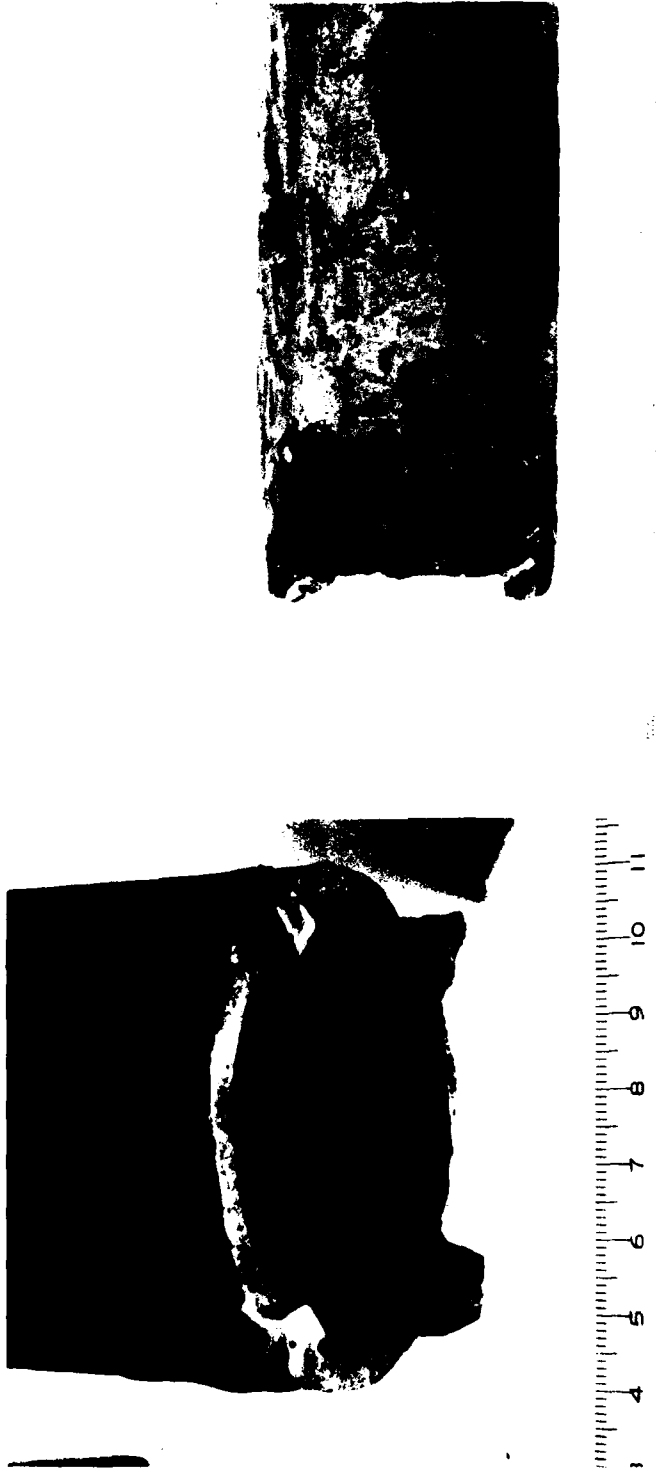
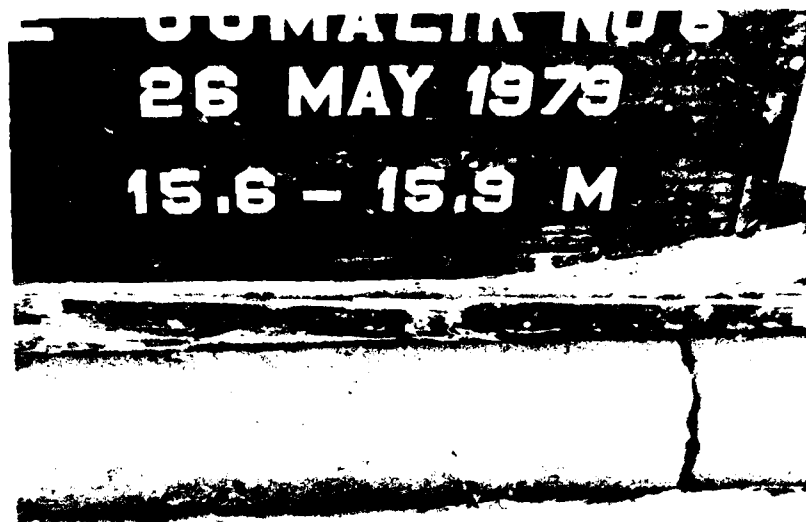
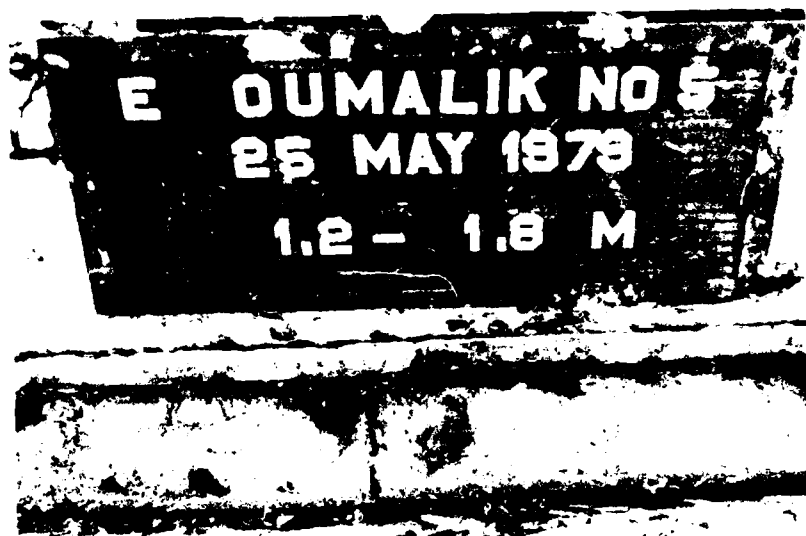


Figure 4. The modified Shelby tube with four tungsten carbide teeth.



a. Core of frozen silt containing about 60% ice by volume in thin (<0.5 mm) veins and pores. The core was broken in two places



b. Core containing silt and ice. The ice is in discontinuous and irregular lenses up to 1.5 cm thick and in irregular, mostly horizontal or vertical veins up to 0.5 cm thick. A sample of the core located from 22 to 25 cm on the scale contained about 75% ice by volume. The 60-cm core was broken at only one location.

Figure 5. Ice-rich sediments cored with the modified Shelby tube.



Figure 6. Ice-rich core with coring-caused breaks along thin horizontal bands of ice that are continuous through the core. Massive ice drilled at high rpms and maximum thrust was badly broken like this core.

the driller knew the frozen sediments contained lense ice, he could improve sample quality by reducing the penetration rate to the minimum. Reducing the penetration rate required limiting normal thrust to only the weight of the drill stem. Unbroken cores up to 50 cm long were taken with the tube. In frozen sediments containing silt or clay, refrozen fines coated 2 mm or less of the core's outer annulus.

In massive ice, we obtained unbroken cores with low rpms and penetration rates controlled only by the weight of the drill stem (Fig. 7). When the driller unknowingly cut into zones of massive ice the cores were fractured throughout. Usually the driller quickly realized the drill was in massive ice and altered the coring rate. Thus, cores of massive ice were often fractured in the upper 10-15 cm and mostly unbroken in the lower 30-40 cm. An annulus of crushed ice about 5 mm thick generally coated ice cores drilled at too high a penetration rate. Occasionally, these high rates also shattered the ice, producing a brecciated core of ice pieces surrounded by crushed ice. The best ice cores obtained were about 50 cm long.

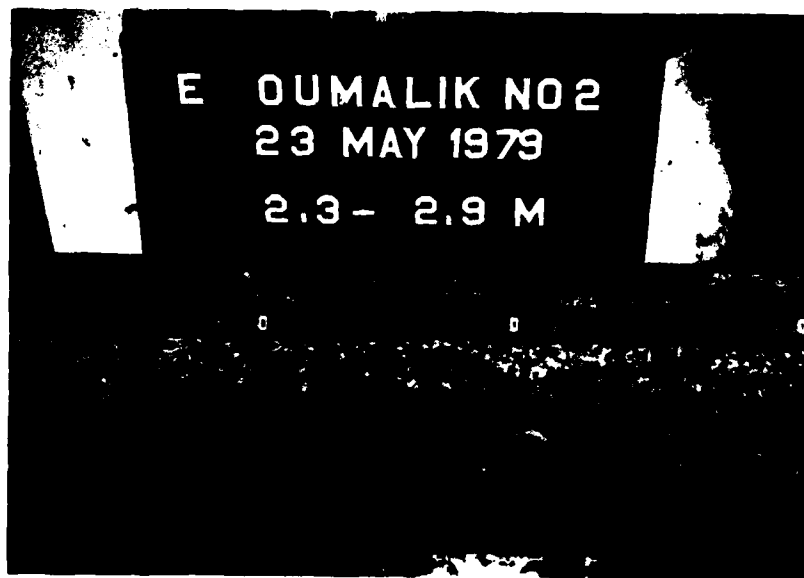
The time necessary to drill and core a hole varied, in part because hole geology determined the intervals at which cores were taken and in part because rates at which different materials can be successfully drilled vary. As extreme examples, at Fish Creek, in ice-rich sand containing no massive ice, we drilled 14 m and took 6.6 m of core in 10 hours. In contrast, at East Oumalik, in ice-rich silt containing large amounts of massive ice, we drilled 41 m and took 15 m of core in 11 hours.

A standard 12.7-cm (5-in.) NXHW double-walled core barrel with an internal core catcher was also used. Three different unmodified bits with tungsten carbide tips, manufactured by Diamond Drill Co., were used with this core barrel: an internal discharge bit (eight cutters), a clay bit (four cutters), and a face discharge bit (four cutters).

None of these bits obtained a core of frozen ice-rich sediments and only one, the internal discharge bit (Fig. 8), cut a core in massive ice. These bits were apparently ineffective in ice-rich sediments because the cutting surfaces and air holes became clogged with chips that were not



a. Ice-rich silt and intact massive ice sampled with the Shelby tube. Ice begins at 10-cm mark on scale. The core barrel broke this 60-cm core in two places.



b. Sixty-centimeter core of silt-rich, massive ice. Core broke while being extracted from the core barrel.

Figure 7. Massive ice cored at lowest rpm and minimum thrust.



Figure 8. Internal discharge bit for double-walled core barrel.

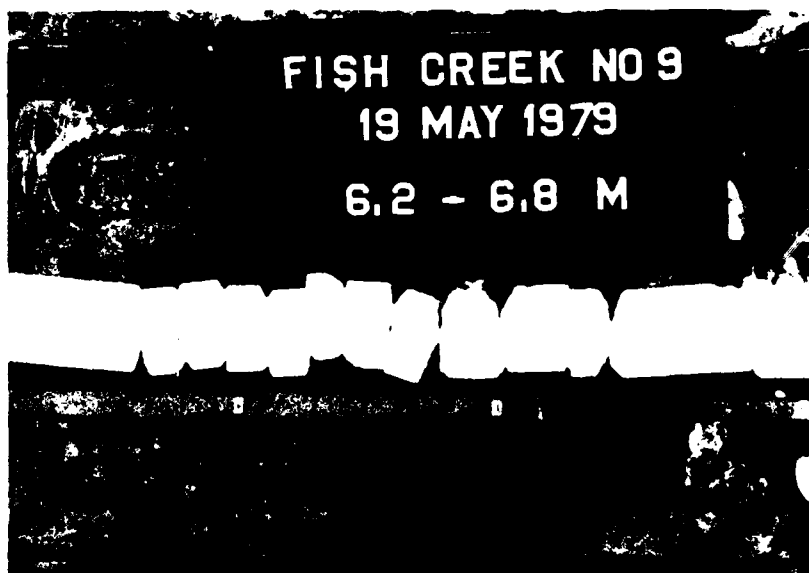


Figure 9. Massive ice sampled with internal discharge bit. Little melting of the core occurred, but breaks were common when thrust and rpms were too high.

removed by the compressed air. Chip removal appeared to be inhibited by incorrectly placed air holes and by an insufficiently overcut hole which did not allow room for cuttings to be removed from the bit.

Although the internal discharge bit could cut cores of massive ice with little melting of the core's surface (Fig. 9), the penetration rates were very slow, 1 cm/min or less. Continuous compressed air flow, the lowest possible rpm, and minimum thrust were necessary to obtain these cores. Cores 0.3-1.4 m long were cut; the longest unbroken core was 0.5 m long. Because of the low cutting rates, we only cut 10 cores with this system.

The cooled air circulation system effectively removed frozen cuttings of ice and sediment from the drill hole at ambient air temperatures of 4°C or less. At air temperatures greater than 4°C, cuttings began to stick to the hole walls. On sunny days with little wind and mid-day temperatures of 8 to 10°C, build-up of cuttings on the hole wall required reaming the hole with the three-wing step bit before coring. At these temperatures and at depths of less than about 18 m, the core's outer annulus of melted material often reached 10 mm. Below about 18 m, the lower subsurface temperatures apparently resulted in effective coring temperatures since the amount of core melt reduced with increasing

depth. On warm days, freezing the core to the core barrel required 5 to 10 minutes shut-down time rather than the normal 2 minutes. However, only two cores were not retrieved during the drilling program.

None of the holes required casing at any depth, although occasional thin zones of unfrozen or partly frozen materials had to be reamed to remove slumped or collapsed material.

Sampling techniques

We took cores whenever the cuttings showed changes in the sediments being drilled and whenever massive ice was encountered. Extracting the core entailed warming the core barrel on the air compressor manifold (Fig. 10), then using the core extractor to remove the core from the barrel (Fig. 11). After extracting core from the core barrel, we immediately placed it on the wooden miter box for logging (Fig. 12). The miter box was lined with plastic food wrap during warm periods to prevent melted core material that adhered to the box from cross-contaminating cores. After the core was scraped clean of any refrozen material, its physical characteristics were recorded. These characteristics included the particle size and shape, structural features, and properties of the ice. We then photographed selected cores. Cores selected for frozen storage were placed in flat polyethylene



Figure 10. Warming the core barrel on the air compressor manifold.



Figure 11. Extracting the core



Figure 12. Cutting the core with a buck saw in the miter box.

Table 1. Drill hole descriptions with moisture content range and total massive ice thickness.

Hole location and number	Total depth (m)	Total length cored (m)	Maximum moisture content (% dry wt)	Minimum moisture content (% dry wt)	Total thickness of massive ice (m)
FISH CREEK					
No 1	15.6	4.4	26.5	16.2	0
No 2	16.0	4.4	186.	17.5	0
No 3	13.0	2.1	35.8	16.7	0
No 4	14.4	5.7	166.	17.8	0
No 5	14.1	4.35	110.	17.5	0
No 6	13.8	6.6	69.8	17.3	0.4
No 7	13.2	5.0	81.5	17.8	0
No 8	12.0	5.7	34.7	16.8	0
No 9 (pingo)	9.0	7.5	27.5	19.9	3.6
No 10	9.3	4.7	224.	18.9	0.4
EAST OUMALIK					
No 1	27.2	13.8	205	23.4	12.2
No 2	24.3	9.1	179.	18.4	12.6
No 3	24.3	8.2	121	29.3	19.5
No 4	20.6	7.0	137.	28.5	2.1
No 5	29.6	8.1	190	47.3	14.5
No 6	39.4	6.9	140.	35.6	11.3
No 7	2.6	1.8	44.2	39.8	0
OUMALIK					
No. 1 (pingo)	25.0	5.4	174.	33.9	12.7
No. 2	18.0	4.7	145.	24.9	0
No. 3	9.0	3.3	105.	24.3	0
No. 4	9.0	3.3	192.	25.1	1.2
TITALUK					
No. 1	39.3	8.1	173.	22.9	4.6
No. 2	3.0	1.8			0
No. 2A	6.3	1.05			0
IKPIKPUK					
No. 1 (pingo)	24.3	7.5	99.3	21.6	10.2
No. 2 (pingo)	16.8	6.0	26.8	26.8	9.2
UMIAT (SEABEE)					
No. 1	4.2	4.2	56.6	43.4	0
No. 2	8.2	3.8	113.	22.6	0
No. 3	9.0	4.8	165.	142.	0
No. 4	13.2	5.5	129.	25.8	0
UMIAT TRAIL					
No 1	13.3	3.9	114.	69.2	1.0
No 2	5.0	4.5	122.	77.1	0.5
No 3	8.0	5.1	110.	52.6	0.8
<hr/>					
Total number of holes: 33	Total depth: 510 meters	Total length cored: 178.3 meters			

tubing and stored on site in Styrofoam coolers filled with snow. Eventually, they were transported by helicopter for cold storage at Lonely. After the drilling program was completed, frozen cores were packed in dry ice and transported as airline baggage to CRREL, Hanover, N.H.

Cores that were allowed to thaw were sampled in the field for a variety of analyses. The type of sample taken was determined by the properties of the core, but the sampling procedure was the same in each case. All cores were cut to length in the miter box using a 61-cm buck saw (Fig. 12). A 5-cm section of core was cut and placed in a tin can sealed with electrical tape for moisture content determinations. We weighed each sample in the field with a triple-beam balance. After returning to Hanover, we reweighed the samples, heated them in an oven at 110°C for 24 to 48 hours, and reweighed them again to determine their moisture content. We are now analyzing the oven-dried samples for grain size.

Isotopic and chemical analyses required placing samples of undisturbed ice in containers that would prevent evaporation. Each sample was cut from the core and placed in a Nalgene plastic screw-top bottle sealed with parafilm, or in a Nalgene autoclavable wide-mouth jar. We followed similar procedures to sample unfrozen sediments for chemical analyses and ice for sediment contents.

We sampled organic-rich zones of the core for radiocarbon dating. We took other samples for textural and other physical analyses, placing each sample in a plastic bag.

All samples that were allowed to thaw were returned by air freight or carried as personal baggage to CRREL, Hanover, N.H.

FIELD STUDY COSTS

The cost for field logistics and the drilling contract amounted to approximately \$165,000. Thus for the 510 m drilled (Table 1), the cost per meter was about \$324. These figures include the cost of the drill crew (driller and assistant), equipment rental from 1 May to 5 June (\$24,000), helicopter crew and rental (110.8 hours operating time between 11 May and 5 June for a total of \$81,000), salaries and overhead for CRREL field

personnel (1532 hours for a total of \$31,000), and room and board at Camp Lonely for all field personnel (6 man-months). They do not include the costs of CRREL administration, logistics, and supply, of pre-fieldwork preparations, such as purchasing and crating field supplies and sampling equipment, of CRREL-owned field gear and sampling supplies and equipment, of the transportation for CRREL personnel, or of shipment of equipment and samples.

RECOMMENDATIONS

The drill, compressor, and cooling tubes operated satisfactorily except when the ambient air temperature was warmer than about 4°C. In part, the reason the cooling tubes were effective below 4°C was the almost continuous wind that is typical of the region. At temperatures in excess of 4°C, not only did cuttings stick to the hole wall and an outer annulus of the cores melt, but sampling the cores before they thawed required rapid processing. Thawed parts of cores cannot be used for most physical or chemical analyses. Also the time necessary to freeze the core to the core barrel increased excessively; in two cases, freeze-on could not be accomplished and the cores could not be retrieved. An air refrigeration unit should be used when the air temperature is above 4°C to ensure that good core and rapid drilling rates are obtained.

The modified Shelby tube cored satisfactorily in sediments with pore and thin vein ice, but generally broke cores of ice-rich sediment along horizontal bands of ice and fractured cores of massive ice.

If the Mayhew system is used in the future, the design of the modified Shelby tube should be improved or bits for the double-walled core barrel with proper air discharge and cutter design should be obtained. The modified Shelby tube is an inexpensive way to obtain cores in frozen ice-poor materials and is a good solution for coring during the time of year when adequate refrigeration need not be maintained.

Also, a canvas shelter for the drill rig and sampling area is needed to break the wind and provide shelter during inclement weather. This shelter would also shade the cores from the sun during processing.

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