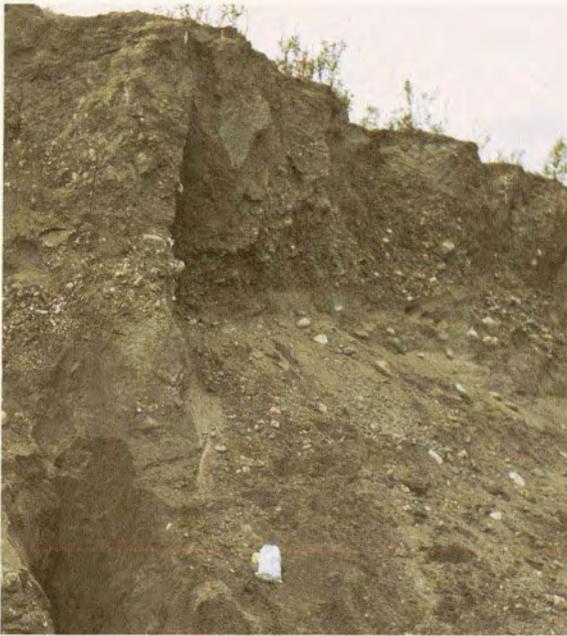


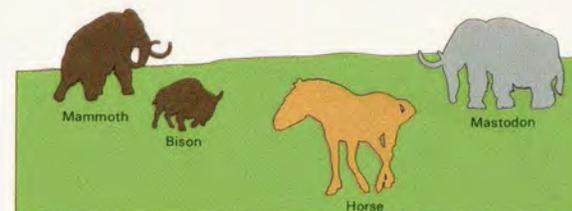
EXHIBIT C

Part 2 of 2



Kiana borrow pit. Gravel, the material required for the construction of roads, drill pads, and airstrips, is very scarce in the NPRA. Photograph by Irvin Tailleux.

Quaternary life on the North Slope once included bison, mammoth, horse, mastodon, lynx, and many other animals and plants now extinct, or gone from the North Slope. It has been suggested that the increasing numbers of early humans living here after the last major ice age led to the demise of many of these species.



Permafrost

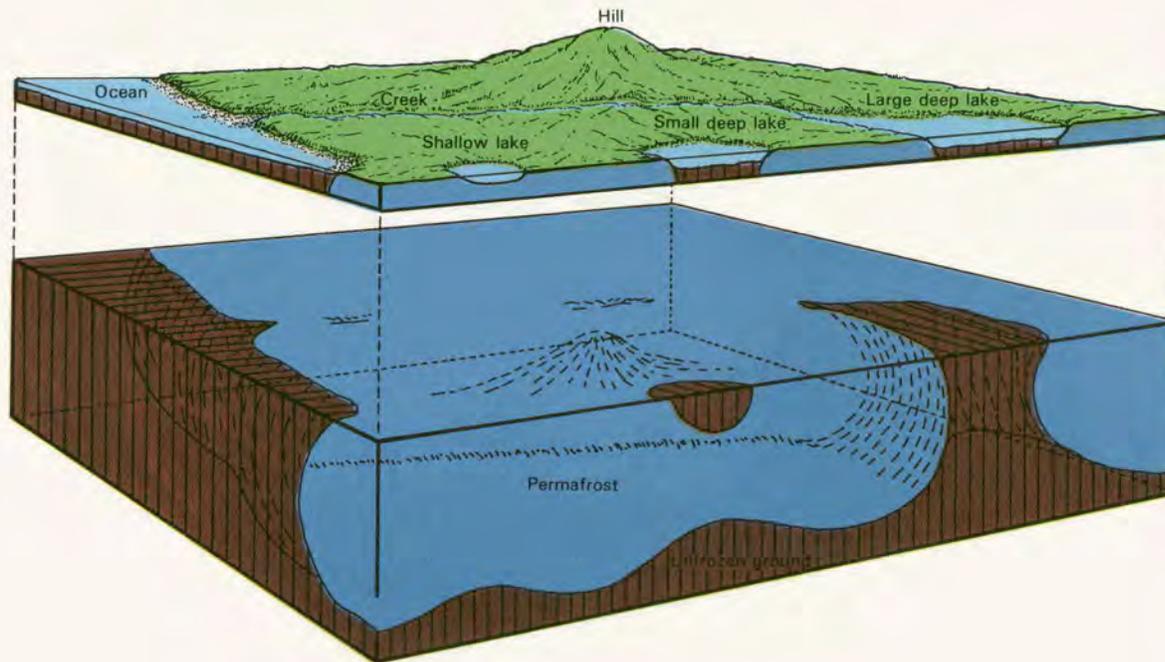
Because the NPRA lies north of the Arctic Circle, the extreme Arctic climate causes the formation of permafrost. Permafrost is present wherever ground temperature remains continuously below 0°C for years. It can cover an entire region, such as the North Slope, or be discontinuous, as in southern Alaska. Nearly all of the NPRA is underlain by permafrost, above which is the “active layer”—all the material that thaws in the summer and refreezes in the winter. The thickness of this active layer varies with local conditions but in the NPRA ranges from 2 to 4 feet. The active layer forms a boggy, swampy surface during the summer thaw. The extreme

Arctic climate of northern Alaska dates back to the pre-Quaternary (3 million to 2.5 million years ago), and so permafrost has been present for a long period.

There is little or no mineral cement or binding in the fine-grained surficial sediment. The individual grains may be surrounded by ice, resulting in ice-rich permafrost. Permafrost is said to be ice rich when it contains more water in the form of ice than the ground could possibly hold if the water were liquid. In general, the Arctic Coastal Plain is underlain by ice-rich permafrost. If the ice melts, settling problems can be extreme and thus present a great engineering challenge.

Permafrost is the dominant factor that influences

the design, engineering, construction, and transportation phases of any operation in the Arctic. Because ice is impermeable, there is no vertical drainage below the thin active layer. The base of the active layer is an irregular surface that ponds water during the thaw, and so in areas of steeper slopes, the water-saturated sediment is ready to start sliding downhill at the least disturbance, and mudslides are common. During the warm months, the wet, soggy tundra is difficult to walk on and impassable for most ground vehicles. In the past, heavy tractors with “caterpillar” belt treads have been used in the summer, sometimes with the bulldozing blade down to remove soft tundra. Some tractor scars are still visible and still eroding after 40 years, and so



All of the NPRA is underlain by a nearly continuous zone of permafrost. This diagram shows the effect of surface features on the distribution of permafrost. Only the area beneath Lake Teshekpuk, the largest lake in the NPRA, lacks a permafrost zone (adapted from Ferrians and others, 1969).

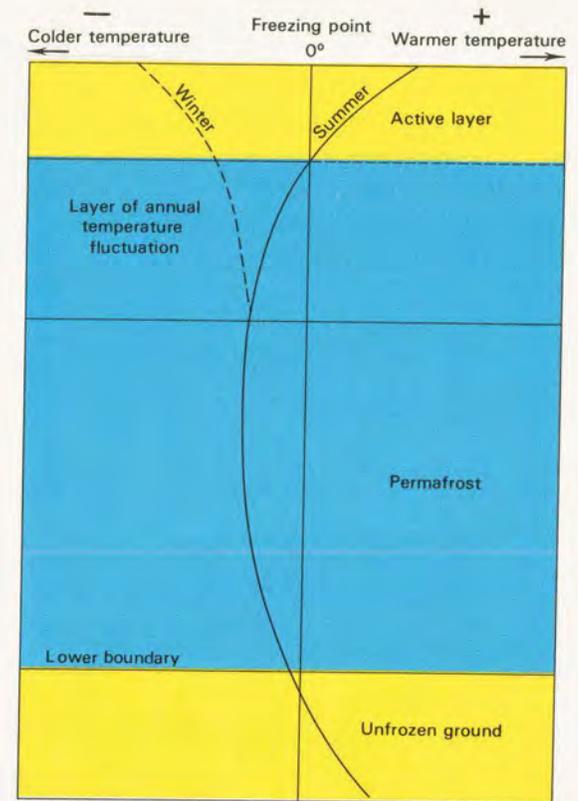
alternative means have been developed for summer ground transport. Large ground vehicles now use wide balloon tires that increase the area of the "footprint" and thus decrease the pressure exerted on the tundra.

Most activity in the NPRA involving heavy equipment takes place after the tundra has frozen and is protected by a snow cover. The surface can then be used for transportation, and little or no damage is caused. Ice roads can be built for the use of surface vehicles. Large or permanent structures are placed

on pilings well above the tundra surface, so that they do not form a "thaw bulb" in the upper surface of the permafrost and create engineering problems or unsightly reminders of human activities. However, drill pads and roads must be carefully located, so that natural drainage is disturbed as little as possible, or else erosion will occur. Aircraft runways are located on frozen lakes wherever feasible. Permafrost affects all facets of Arctic operations, but, as demonstrated by this program, the problems can be solved.



Tracks made by a tracked vehicle in the tundra during the Pet-A program.



Generalized graph of ground temperature versus depth. In the Arctic, annual temperature variations may be detected to a depth of 70 to 100 feet. The lower boundary for permanently frozen ground is about 1,000 feet at Barrow and 2,000 feet at Prudhoe Bay (modified from Haugen and Brown, 1971).

Permafrost contributes to the development of certain ground phenomena that are immediately apparent even to the most casual observer—such as polygonally patterned ground and oriented lakes. Patterned ground is the surface manifestation of vertical ice wedges. The ice wedges are thought to form in contraction cracks in the tundra that fill with water during the summer thaw and refreeze and expand during the next winter. Thus, over time,

the vertical ice body is enlarged until a condition of relative equilibrium is reached. The cracks intersect in irregular patterns, but the most common are five-sided polygons.

Oriented lakes, strikingly evident on maps of the coastal plain, are believed to result from the interaction of prevailing northeasterly winds and ice. The long axes of these lakes are at right angles to the prevailing wind direction. During the spring thaw,

the lake ice melts along the shore first, leaving a moat of water surrounding an ice island. As the wind velocity fluctuates, this ice island moves back and forth in response to the windforce and wind direction. The water is forced around the ends of the ice and erodes the ends of the lake, and thus elongates the lake basin at right angles to the direction of the prevailing wind.



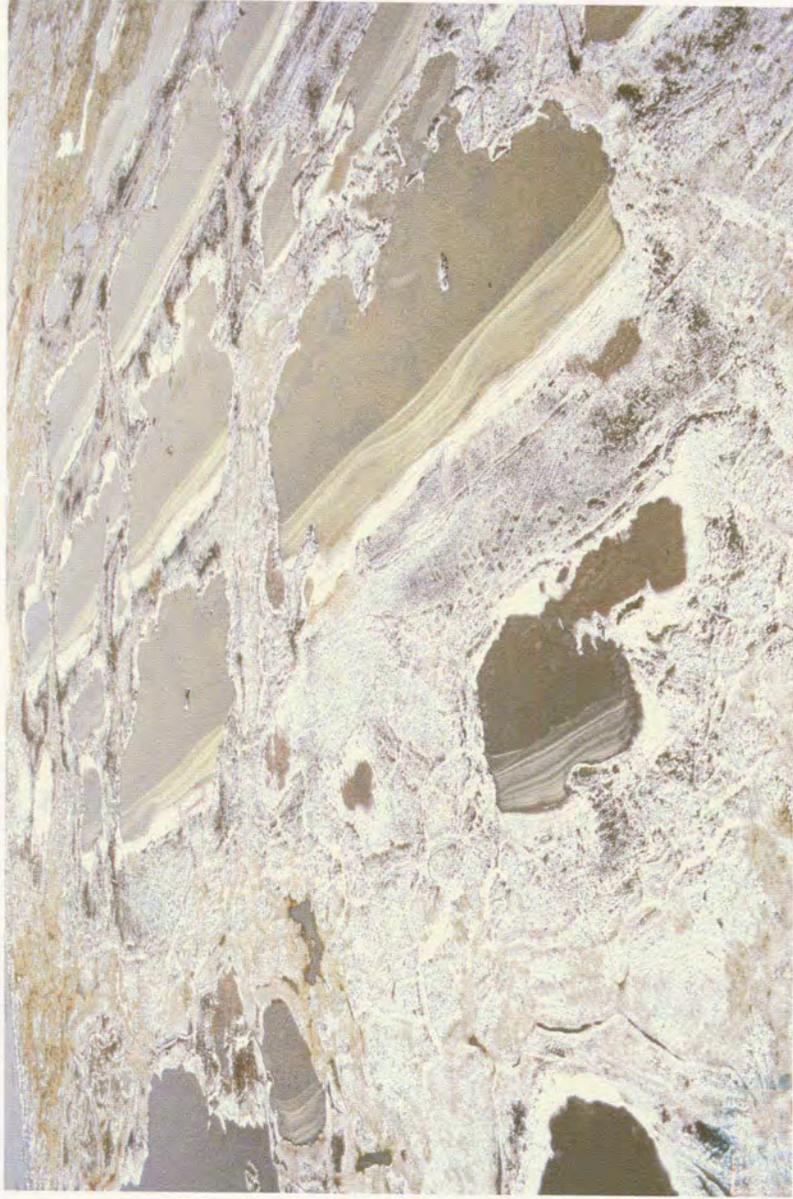
“Resurfacing” an ice road at South Simpson. Using ice roads for transporting heavy equipment during the winter months prevented lasting damage to the tundra. Photograph by John Schindler.



Polygonal or patterned ground results from ground contraction during extremely low winter temperatures. Water and snow that collect in the contraction cracks eventually turn to ice and create intersecting ice wedges that surround each polygon. Photograph by Jeep Johnson.



Rounded hills with ice cores, called pingos, commonly form in the centers of drained lakes as the water-saturated soil freezes inward from the basin sides. When the center finally freezes, the ice can only expand upward and forms a low hill. Photograph by George Gryc.



Oriented lakes result from interaction of the prevailing northeasterly winds with the lake ice. Photograph by George Gryc.



Sampling a small ice wedge beneath the tundra cover. Photograph by Jeep Johnson.

What is the story of the Barrow gas fields?

Gas was discovered at Barrow in April 1949, and the fields hold two records: the South Barrow gas field is the oldest producing field in Alaska, and the South and East Barrow fields are the farthest north in North America. Barrow No. 2, the discovery well for the South Barrow field, was drilled during the U.S. Navy's Pet-4 program.

The base camp for the Pet-4 exploration program was located about 4 miles along the beach from the village of Barrow. This camp evolved into the Naval Arctic Research Laboratory (NARL). It was decommissioned in 1981 and was used only as a base for the gas-field operations, but it is still generally called "the NARL." The discovery well was located about 4 miles southeast of the village and approximately 5 miles south of the base camp. The camp was fueled by oil brought in by barge once a year, until gas was piped from the well into the camp. The camp was completely converted to natural gas by winter 1949-50.

When the Pet-4 exploration program began, there were about 400 inhabitants at Barrow, a community that consisted of a cluster of some 50 houses and buildings. The program provided opportunities for the Eskimos to work for cash wages, many for the first time. Employment opportunities attracted additional inhabitants, and the population of Barrow increased rapidly. Good airport facilities and improved communications, byproducts of the exploration program, made Barrow easily accessible and a rather desirable place to live, so far as amenities were concerned.

The relative conveniences of Barrow, together with its burgeoning Native population, prompted several Federal agencies to establish offices in the village, generally in the form of compounds. These agencies requested the use of natural gas, and so, in 1958, gas was piped into the village and connected to the various compounds, so that they, too, had the use of this superior fuel. The Native inhabitants



The 1977–82 exploration program was designed so that most action took place during the winter months, to minimize environmental disruptions. Because tundra, when frozen and protected with snow cover, makes a good working surface, seismic operations and road and trail construction were largely restricted to the winter season and were rigidly controlled.

A few environmental problems arose, but promptly corrected, at the 28 exploratory wells drilled during the 1977–82 program: minor fuel leaks and spills at the drillsites and from the mobile trains, a few instances of improper waste-water treatment, and insufficient protection for the tundra during the burning off of small amounts of waste oil. Only two problems were significant: one was the difficulty of reestablishing the vegetative cover in the coastal marine environment, and the other the seepage of fluids through the berm surrounding the reservoir pit at the Inigok site. This seepage resulted in some damage to the tundra vegetation, but it is recovering. It was found that planting tundra bluegrass, with plenty of fertilizer added, speeded the recovery.

The environmental impact of the program was minimal to both the land surface and the wildlife. Only about 250 acres was affected by drill pads and reserve pits, and another 168 acres by borrow sites. In addition, about 105 acres was covered over with permanent runways, 15 acres was used as burial sites for old debris, and about 3 acres was occupied by all-season roads. The total acreage disturbed was about 540 acres—only 0.00227 percent of the 23,680,000 acres of the NPRA. About 95 percent of this 540 acres will be difficult to identify within 3 to 5 years. Only the permanent runways and roads will remain in 20 to 25 years as a result of the 1974–82 exploration activities in the NPRA.

Grazing caribou near the Lisburne wellsite. Photograph by Jeep Johnson.





Cushion pink (Silene acaulis) with its long, strong roots anchors itself firmly on rocky mountain summits.



Botanist collects samples of willow growing along a riverbank as part of ecologic-profile studies. Photograph by Jeep Johnson.

Trafficability and movement of supplies and materials

In the NPRA and elsewhere on the North Slope where no permanent roads exist, winter is the best time for overland movement. During the earlier petroleum-exploration program of 1944–53, caterpillar-type tractors were the principle pieces of equipment used to transport large items. Today, they are supplemented by rolligons and other vehicles with rubber tires. Aircraft were used occasionally during the earlier U.S. Navy exploration but became the principle means of transportation during the exploration program described here.

Land traffic was carefully restricted. Overland travel was allowed only after the ground was frozen and snow covered, and before the beginning of the spring thaw. Bulldozing was allowed to level snowdrifts, but the dozer blade was always kept above the tundra surface. Vehicles were selected for their low-ground-pressure qualities. The tundra was further protected by using only selected trails, and repeat runs were required to offset previous tracks, to avoid rutting. Frozen lake surfaces were used as much as possible, and banks were crossed at low angles to minimize damage. The challenge was to transport thousands of tons of machinery, drilling mud, pipe, fuel, and other supplies to remote drill-sites; to construct all the needed facilities; to drill a wildcat well; and then to move off the site, leaving a minimum imprint on the area.



Aerial view of Lonely, the "hub" of the exploration effort. Photograph by John Schindler.



*Incinerator used for burning sludge and solid wastes at Camp Lonely.
Photograph by Jeep Johnson.*



*Some nonburnable wastes that were not removed by barge were buried
in landfill sites similar to this one. Photograph by John Schindler.*

Logistics

The logistic problems attached to an exploration program of this size in the harsh, remote area of the NPRA were great and were complicated by the pervasive presence of permafrost on the environmentally sensitive Arctic Coastal Plain. An idea of the size of the task is illustrated by the volume of material that was moved each year. Every year that the USGS was in charge of the active exploration program (1977 through 1982), more than 50,000 tons of fuel, equipment, and supplies was transported to Camp Lonely, the "hub" of the exploration effort.

The distant-early-warning (DEW)-line site at Pitt Point, known as "Lonely," was chosen as the location for the central camp by the U.S. Navy before transfer of the exploration effort to the USGS. This location was picked because it had a 5,000-foot all-season gravel runway, some fuel tanks already in place, a good beach for unloading barges, and a large unoccupied gravel pad, and it was centrally located for the Navy's exploration plan.

Lonely was a large camp. It was home for about 100 men and women during the busy winter drilling seasons. They lived comfortably, with heat, light, and power supplied by generators. They had hot meals, warm beds, hot showers, flush toilets, and good recreation and exercise facilities. Camp Lonely was equipped with water- and sewage-treatment plants, and an incinerator for burning sludge and solid wastes. The camp was operated with the supervision and approval of the State.

The drilling camps were smaller versions of Camp Lonely. Locating a water source was the first job of the drillsite-construction crews. Then, small-scale waste-treatment systems were set up. Burn baskets were used to burn wood and paper products. Metals and nonburnables were hauled from the drillsite to Camp Lonely or to one of several approved burial sites in the NPRA. Drilling muds was contained in reserve pits.

Construction and seismic camps were mobile facilities, and their utilities differed slightly. Drinking water came from melting snow when lakes were unavailable. Wastes were either incinerated or hauled to Camp Lonely or a drillsite. The State permitted these small mobile camps to dispose of small volumes of oil and other burnables by open burning.

Camp Lonely was also needed to stockpile drilling supplies. Almost all the wells drilled were far from any previous drilling, and little was known about the subsurface conditions. Detailed drilling plans were made before drilling each well—plans based on the best geologic knowledge obtainable. However, subsurface conditions seldom were precisely as predicted, and the amounts of casing, cement, mud, bits, fuel, and myriad other necessities were either overestimated or underestimated, thus, a local stockpiling area was required. Unpredictable drilling conditions, such as overpressured zones and lost-circulation zones, could require extra amounts of drilling mud and additives, or even an unplanned string of casing. This unpredictability of wildcat exploration requires a nearby source of all kinds of drilling supplies.

Most of the annual 50,000 tons of cargo went to Camp Lonely, where it was inventoried and assigned to a well; then, it had to be transported to the well location and, if surplus, transported back to Camp Lonely and put into the inventory again. During the exploration program, more than 250,000 tons of materials was transported by aircraft alone!

The bulk of the material transported from the "Lower 48" to the NPRA came by barge once a year. The ice generally opens and retreats from the beaches long enough in early August to allow barges to land and unload along the Alaska shore of the Arctic Ocean. If barges can get in, they are by far the cheapest method of shipping bulk cargo.

Some rigs drilled as many as three wells during the drilling season—a situation that required close



Welder at Camp Lonely. Photograph by Jeep Johnson.



Landing barges on the coast near Camp Lonely. Shipping by barge is the most inexpensive method of transporting large amounts of material to the Arctic coast but is generally restricted to a short period in August when the ice retreats from the shorelines. Photograph by S. Krogstad.

scheduling and precise planning. Rigs were not moved during the summer, when the tundra was soft. Most rigs were moved with a combination of large C-130 Hercules aircraft with all-terrain vehicle (ATV) support. The primary vehicles used were CATCO Rolligons—a very large tractor-trailer combination mounted on huge, low-pressure, balloonlike tires. These vehicles could carry an 80,000-pound load while exerting only 4 to 5 pounds per square inch on the frozen tundra—less than the average human foot pressure. Each well drilled required that the drill rig, along with the proper amounts of casing, cement, mud, fuel, bits, and so on, be moved to the location. It has been estimated that about 10,000 tons was transported to the average location and that the typical rig move was about 50 miles. These figures translate into approximately half a million ton-miles per location. This huge logistic task was coordinated through Camp Lonely, where the all-season airstrip was expanded, full communication networks were installed, and a large-capacity fuel-storage facility was constructed.

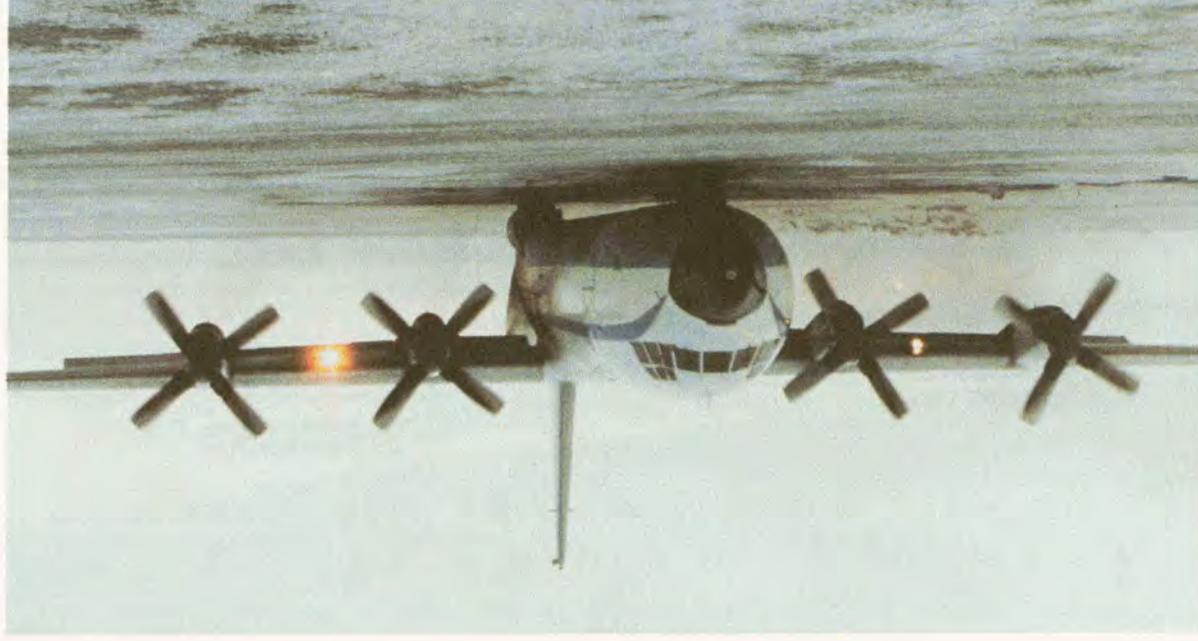
Airstrips

Both ice and gravel airstrips were used in the 1977-82 NPRA program. The advantage of airstrips and roads made of ice is that they are not permanent and thus more acceptable environmentally, and are less expensive. Lakes can also be used to an advantage for airstrips for aircraft up to C-130 Hercules, and Boeing 737 size. For lake or sea-ice airstrips, snow is cleared from the ice surface and then grooved to increase traction. Lake ice must be 4 feet thick for full-load operations (4½ feet for brackish water). In contrast, airstrips on tundra require 1 foot of ice above the frozen ground.

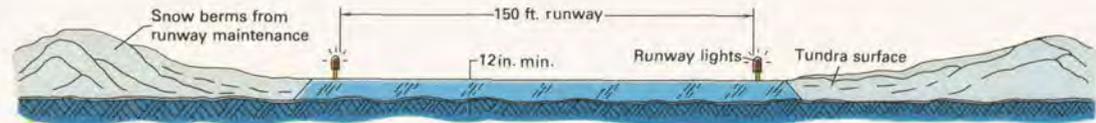
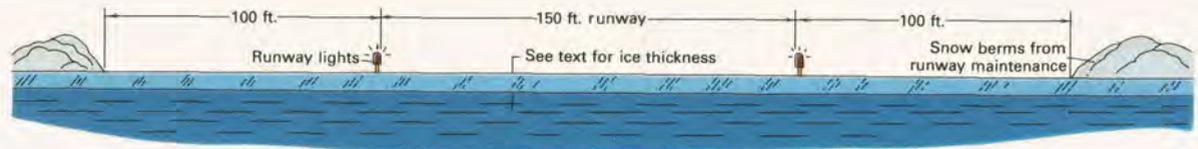
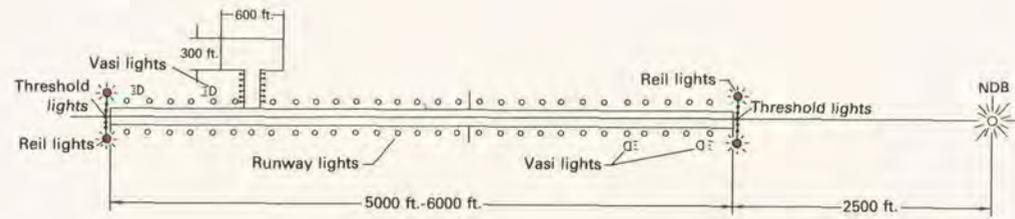
Hercules C-130's (Hercs) provided contractors with the high-volume, high-tonnage capability necessary to transport drilling and construction equipment to the reserve. Photograph by Edmund Grant.



CATCO Rolligon. Huge balloonlike tires exert only 4 to 5 pounds per square inch when carrying as much as 80,000 pounds across the frozen tundra. Photograph by Jeff Johnson.



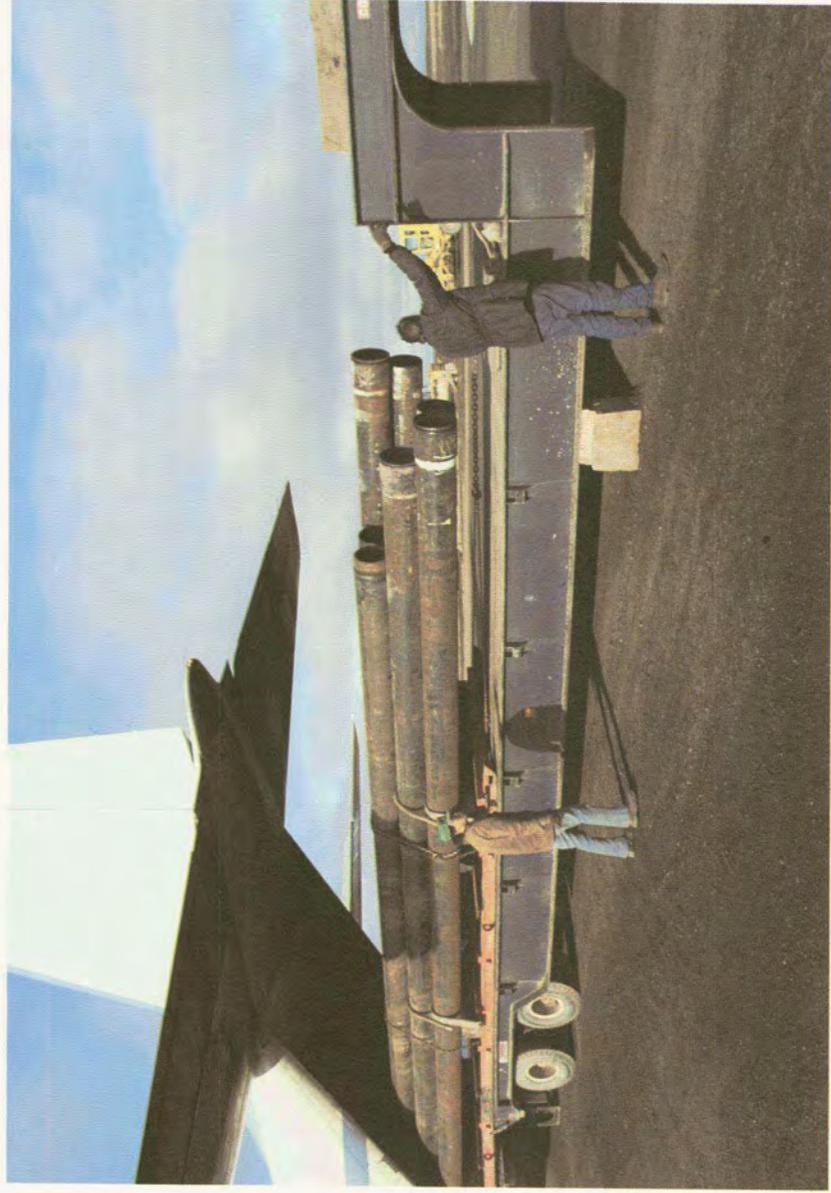
The construction and drilling season normally was limited to the time between winter freeze and spring thaw. Overland travel was not allowed until the surface was frozen to a depth of 12 inches and the average snow cover was 6 inches thick. These regulations restricted the winter working season to about 170 days. Most ontundra ice airstrips could be operational more quickly than lake strips; the time saved might allow a well to be completed in one season instead of two. The necessary requirements for building such an airstrip are a water source nearby and a large flat open area, as much as 6,000 feet long, on which not less than 12 inches of water can be layered and frozen. Vehicles carrying insulated water containers are used to spread the water in thin sheets. The water is spread at a rate that allows complete saturation of the surficial snow and tundra before freezing. Pumping systems using insulated pipes were used to flood some airstrips to hasten thickening of the ice. Using either method, the average ontundra ice airstrip required 7.4 million gallons of water (excluding any required maintenance of the strip) and was built in a few days. An airstrip of this type causes little damage to the tundra but has only a one-season lifespan.



Winter airstrips were constructed on lakes, sea ice, and tundra. Lake ice must be 48 inches thick, and brackish ice 54 inches thick. In addition, to prevent tundra damage, a minimum of 12 inches of ice was required on top of the frozen tundra (modified from Mitchell, 1983).



Workers test the thickness of lake ice. Photograph by Jeep Johnson.



Unloading drill pipe from a Hercules at the Camp Lonely airport. Photograph by Jeep Johnson.

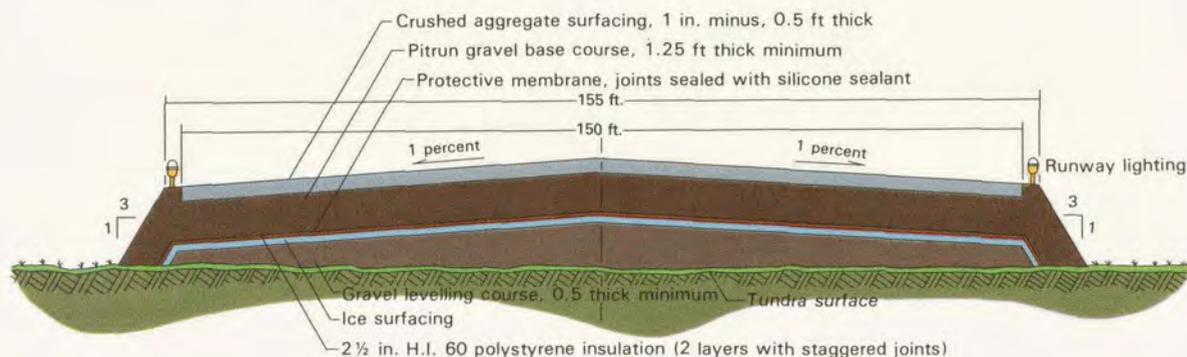
Ice roads

Ice roads were used at most locations for routes between the drillsites and airstrips, borrow pits, and water sources. Snow is compacted over the frozen ground and repeatedly flooded with water to build up ice layers. Roads carrying heavy traffic and heavy loads required thicker ice and more maintenance than those made for less traffic and lighter loads. A 37-mile-long road, the longest in the NPRA, from the Kikiakrorak River delta to the Inigok all-season airstrip, was used to transport 90,000 cubic yards (about 6,000 truckloads) of gravel to build the Inigok drill pad and airstrip. The route took advantage of every lake, pond, and river along the way. A total of 35 million gallons of water was required to form the ice road.

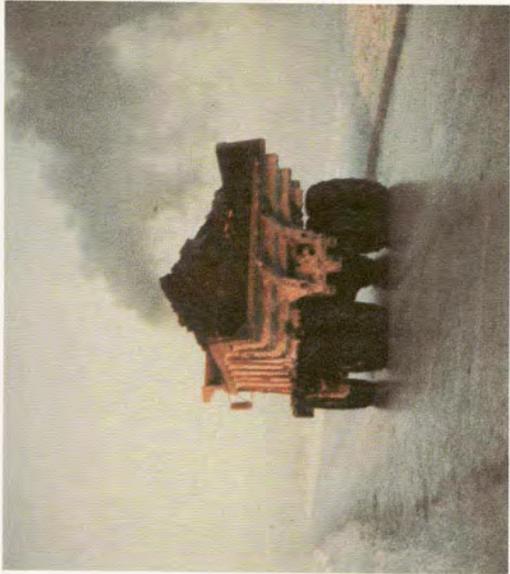
At the Inigok and a few other drillsites, it was essential that the airstrips remain operational throughout the summer, so that the drilling could continue without interruption. The Inigok well needed an estimated 330 drilling days to reach a total depth of 20,000 feet. If drilling had taken place only during the winters, three seasons would have been required—involving twice breaking camp, three times setting up camp, costly idle time for the drill rig between winters, and added risk associated with reentering the drill hole each new drilling season. Despite the environmental and economic drawbacks to gravel-road construction, the lower price and lower risk associated with year-round drilling made it worth the cost.



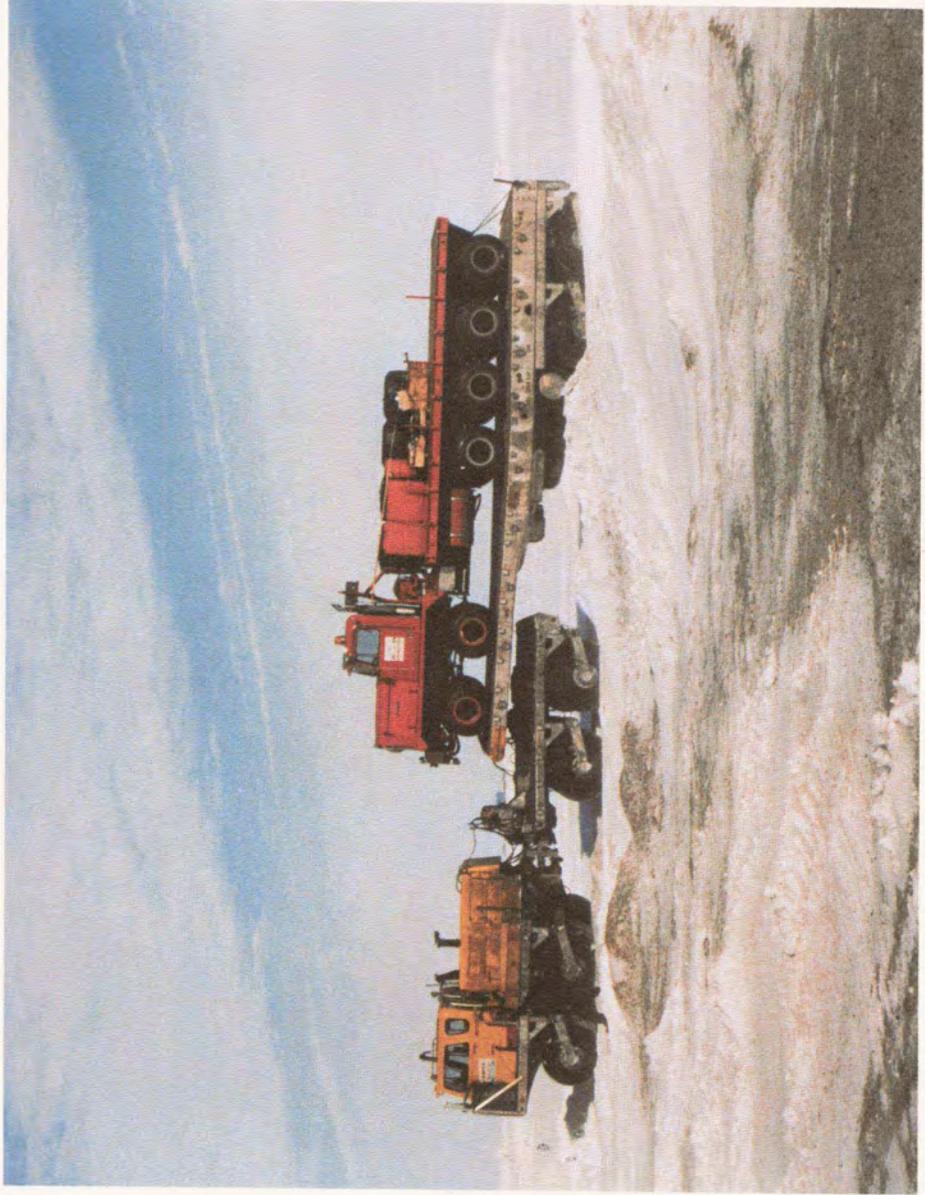
Aerial view of an ice road. Photograph by Jeep Johnson.



Cross section of a typical all-season airstrip. Gravel airstrips were more expensive to construct but could be used year-round (from Brooks, 1983).



Gravel hauled along the ice road at South Simpson. Photograph by John Schindler.



Large trailers used wide balloon tires for transporting heavy equipment across the tundra. Photograph by Jeep Johnson.

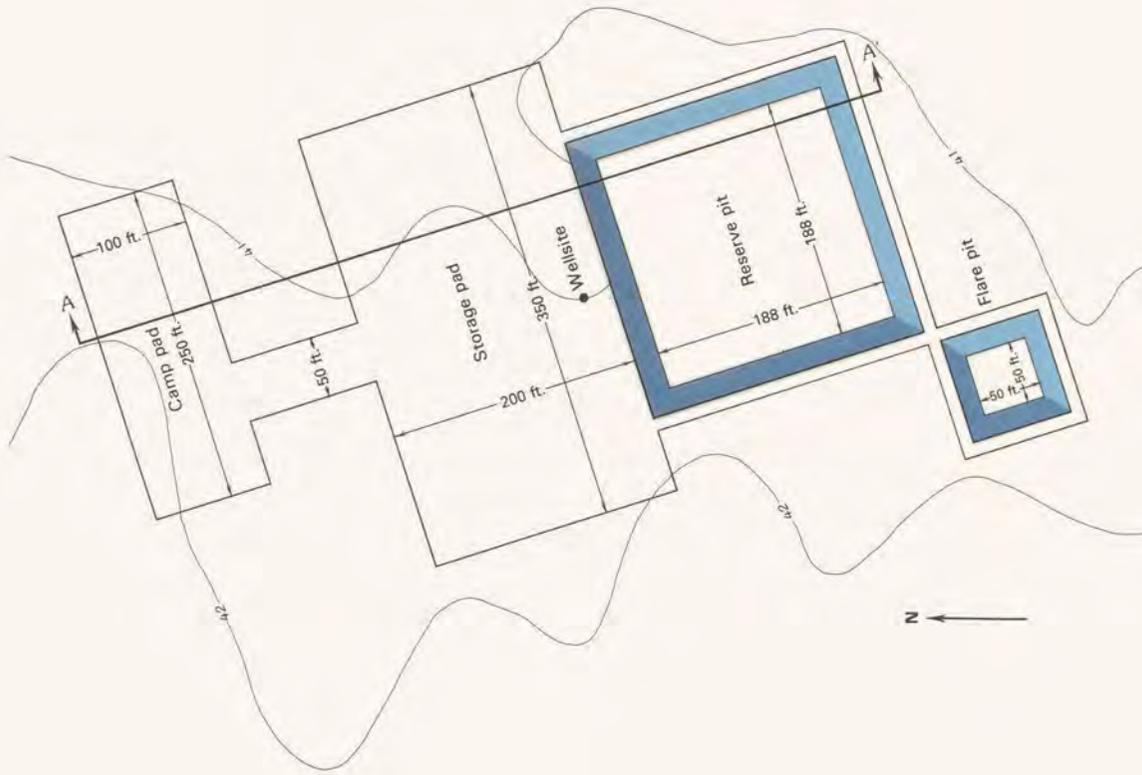


Example of a carefully planned, environmentally sensitive transportation route at the Walakpa No. 2 test well. Instead of a straight road connecting the well to the airstrip, the chosen route avoided the tundra surface as much as possible by taking advantage of every lake, pond, and river along the way.



*Drilling the Seabee No. 1 test well near Umiad on the Colville River.
Photograph by John Haugh.*

Plan view of a one-season, thin-pad design. For safety reasons, the wellbore, the flare pit, the pad used for bulk fuel storage, and the drilling camp on one-season drill pads were separated by at least 300 feet (modified from Mitchell, 1983).



PLAN VIEW



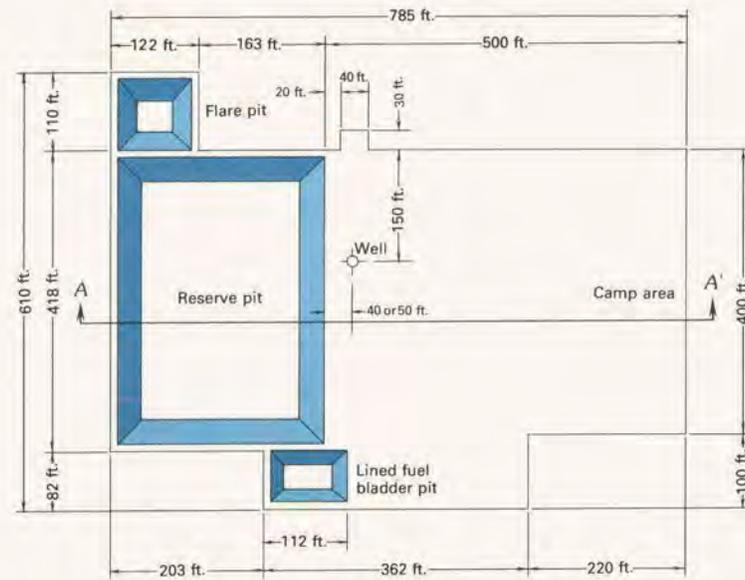
Cross section of the thin-pad design.

SECTION A-A'

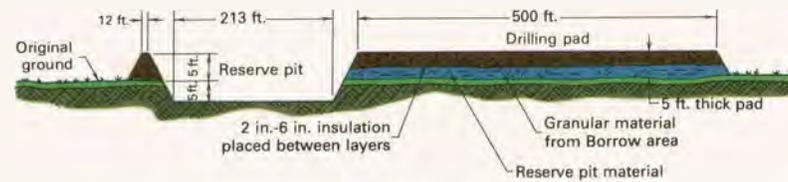
If the thick-pad design was selected, the drill rig was located adjacent to the reserve pit, and the fuel-storage and camp areas were set back from the rig for safety. The pad area around the rig was used for storing drill pipe, chemicals, and mud. The reserve pit was large enough to hold all the spent drilling fluids. A flare pit was used when well fluids recovered during testing needed to be burned off. The pad was elevated about 5 feet above the ground surface and consisted of sufficient fill to prevent the summer thaw from reaching the original tundra. Thus, the subsurface beneath the drilling operation remained frozen.

As the exploration program continued, the thick-pad design was modified to suit the conditions in the NPRA. Because most of the drilling was planned for the winter season, this design was modified to a two-layer pad to conserve the scarce gravel. The lower layer contained ice-rich material excavated from the reserve pit, and the upper layer was of relatively thaw stable material from a borrow site. Settling of the pad was expected when the ice-rich lower layer thawed. Such thawing was caused both by heat resulting from the drilling operation and by the summer melt. The drilling operation generates heat, and warm fluids are circulated in the hole, so that thawing occurs beneath the drill rig even in winter.

To avoid settling of the drill structure, NPRA rigs were supported by pilings extending into the ground well below the expected thaw level. From 50 to 210 pilings were required, depending on the size of the rig. These pilings were set between 14 and 25 feet below the surface, the deeper pilings were placed under the subbase and derrick areas. To set the pile, a 2-foot-diameter hole was augered, the pile put in place, and the hole filled with a slurry of water and soil that froze the piling in place. Thus, the drill rig was supported by pilings and not by the pad.



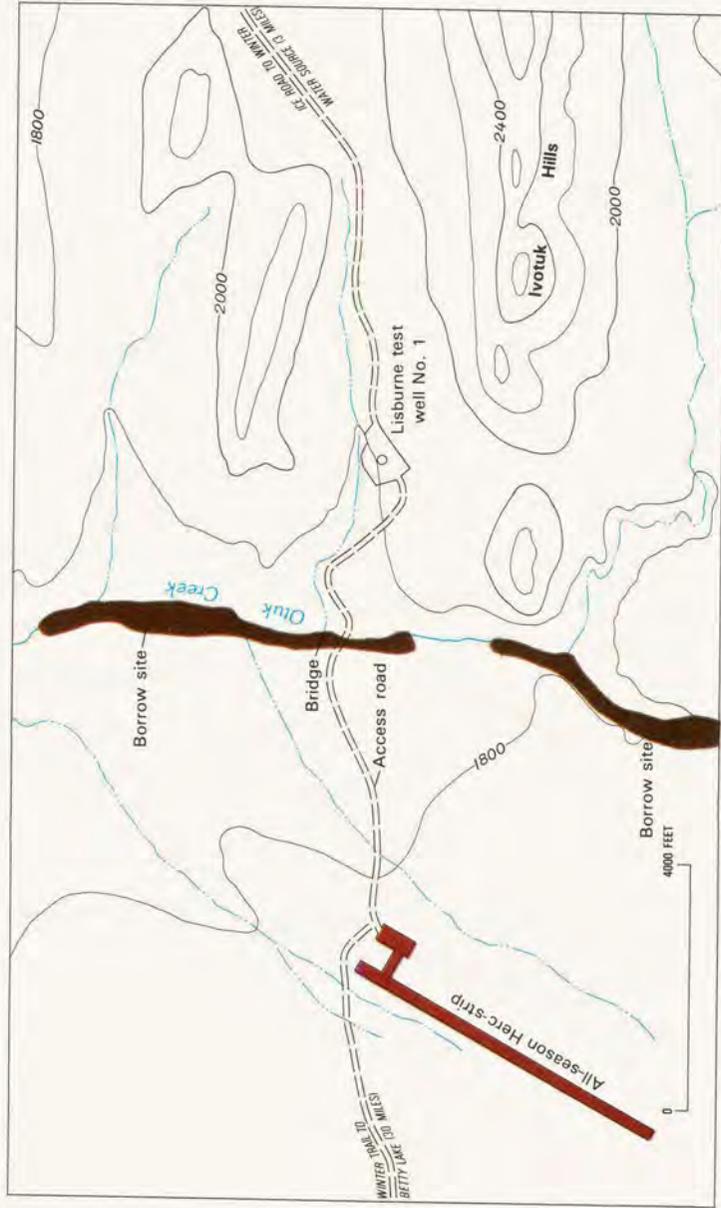
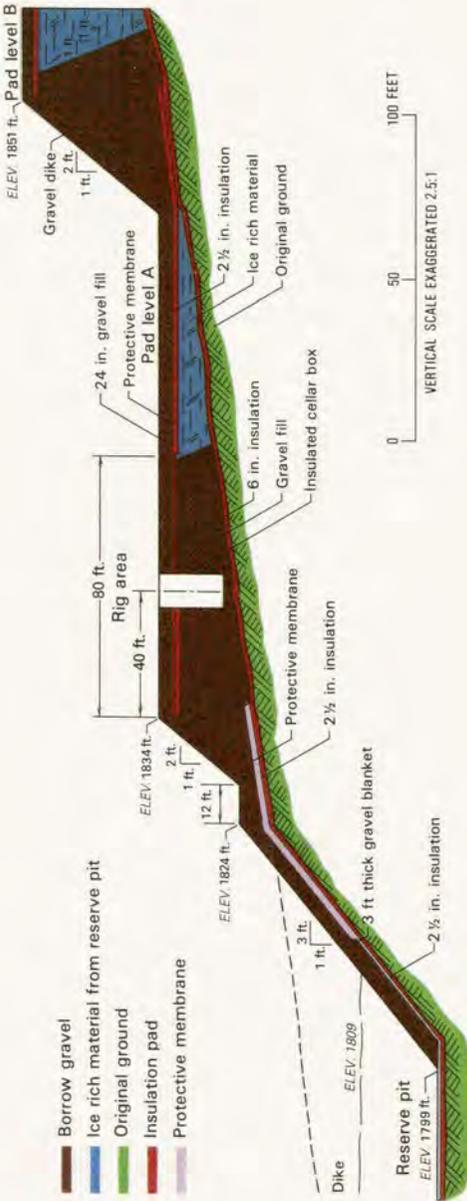
PLAN VIEW



SECTION A-A'

Plan view and cross section of a year-round or all-season drill pad. These pads were modified from the old design by adding a layer of synthetic insulation between the lower, ice-rich layer and the thaw-stable gravel surface (from Mitchell, 1983).

Cross section of the Lisburne drill pad, an all-season thick pad (from Brooks, 1983).



Layout of the Lisburne drillsite (from Brooks, 1983).

Soil conditions varied considerably in the NPRA, but, in general, they were unfavorable for drill-pad construction. Most drill pads were located on ice-rich mud or silt. These materials were excavated from the reserve pit and used as the lower layer of the pad. The upper layer was constructed of fine sand that was found in dune areas or in banks along the rivers or lakes.

The normal time to construct a thick drill pad was about 30 days. Construction usually started in November or December, to allow enough time for the drill rig to be moved to the location, the well to be drilled, and the rig removed before the thaw in mid-May. The drilling camp, fuel, and equipment were usually stacked on timbers and left until the following winter's ice road and ice airstrip were again usable.

The thick-pad design was abandoned after the 1977-78 season because of experience gained at the South Meade site. This test well was located in a

swampy area, and the original design called for a borrow site about half a mile away. To save costs and with the geologist's approval, the drillsite was moved to the borrow site. The reserve-pit excavation produced sufficient material for a thin ice-rich pad, assuming a one-winter operation. This procedure eliminated hauling from a borrow site and building an ice road between the pad and borrow site, and thus reduced costs. It also reduced the environmental impact. The experiment was a success, and the South Meade site was used for a second season with only minor repairs.

The thin-pad design provided a pad thickness of about 2 feet and allowed the pilings to be cut off above the original surface. The elevated pad also kept the drill rig relatively free of snow. The 12 thin pads constructed were totally satisfactory.

The thin-pad concept had several advantages. The pads were less costly to construct than the thick or all-season pads. The need for borrow mate-

rial, its removal, and hauling was not required. Fewer men, less time, and less equipment were needed to complete the preparation of a drillsite. Construction and maintenance of an ice road between the site and borrow pit were also unnecessary. Furthermore, shortened construction time meant that more days were available to drill the well.

The thin pads were also environmentally preferable. Thin pads reduced the area of disturbance by eliminating a borrow site and made rehabilitation and revegetation easier. Use of the thin-pad design eliminated the need to break up and spread the fill, because it was not thaw stable. During the summer after the drilling, the thickness of the pad was reduced about 50 percent or more by ice melt and settling. In addition, the fine-grained soils used in the thin pads were more suitable for revegetation than the gravel surfaces of the thick pads.



Construction of one-season thick pad at the Seabee wellsite. Photograph by Jeep Johnson.



The Lisburne No. 1 test well was completed in summer 1979. Photograph by Jeep Johnson.

Year-round drill pads

The exploration program called for a few 20,000-foot-deep wells, requiring an estimated 350 days of drilling, testing, and plugging. This work would have required three winter-drilling seasons, two pad reconstructions, and about 500 standby days when the drill rig was idle. A total of 900 days was estimated to be required. In contrast, an all-season program could be completed in only 520 days.

Another advantage of all-season drilling is the reduced risk. Risk is always associated with suspending and reentering a well. In permafrost areas, casing can collapse in inactive wells because of ground settling or freezing in the permafrost zone that blocks reentry.

To prevent heat from penetrating the permafrost below an all-season drill pad, a very thick fill or an insulating layer within the pad was required. The NPRA all-season pads used Styrofoam for this insulation because gravel cost more, added to the environmental disturbance, and was scarce. The Inigok well is a good example of an all-season pad. The drill rig was supported by 218 timber piles slurred in place at depths of 25 to 45 feet, depending on the distance from the well. The piles closest to the wellbore needed to be set the deepest to withstand the most force from drilling and the heat generated by the drilling process.

Several other measures were taken to ensure that the drill rig would be adequate for a year-round period. Heavy steel beams spanned the deep-set

center pilings, and 12- by 12-inch timber beams over the outlying pilings were used to distribute the load. A 6-inch-thick layer of insulation was applied to the outside of the conductor pipe to prevent heat flow from the well. Other heat sources were contained by a 6-inch-thick layer of Styrofoam under the drill rig, which was placed at an angle and covered with a plastic liner to direct the flow of liquids into the reserve pit. The upper layer of fill was gravel from a borrow site.

The NPRA exploration pad designs proved to be entirely satisfactory. The thin-pad design was the best choice for wells that could be completed within one winter season, and the all-season design was satisfactory for wells requiring several seasons to complete.



Six-inch-thick insulation protects the permafrost layer beneath the Lisburne drill pad. Photograph by Jeep Johnson.



A gravel access road leads from the well site to the borrow site and all-season Herc airstrip. Photograph by Jeep Johnson.

How were cleanup and rehabilitation accomplished?

Human concern with the deteriorating environment has reached even to the remote areas of Alaska. Pre-1960 construction and engineering activities in Arctic Alaska including the Pet-4 program of 1943-53, the construction of DEW-line stations, and other military and industrial activities, were all conducted without much consideration for possible environmental impacts. The main concern was getting the job done. Although the amount of debris and the extent of damage to the North Slope environment were small and localized, they were starkly visible on the flat and otherwise featureless Arctic plain. Sites along the coast, including Barrow, had large accumulations of abandoned or surplus materials.

Responding to growing criticism, the U.S. Navy, as NPR-4 managers, began a cleanup program in 1971 that was continued by the USGS. The cleanup of old sites and the rehabilitation and revegetation of new drillsites were combined into one large program.

The litter consisted mostly of empty 55-gallon fuel drums. During the Pet-4 program and the ensuing operations, fuel of all kinds was supplied in drums that were abandoned once the contents had been used. Metal deteriorates very slowly in the Arctic. Tens of thousands of these drums were scattered throughout the Reserve, especially in coastal areas, at drillsites, construction sites, and along the trails followed by old tractor trains and geophysical



Fish Creek drillsite, from the 1949 season, as it appeared in 1977 before cleanup. Photograph by John Schindler.

and geologic survey crews. In 1976, the Navy picked up 9,019 barrels, and this was only a beginning.

In 1977, under USGS management, cleanup of old sites was continued, together with rehabilitation and revegetation of the latest drillsites. A barrel crusher was obtained to reduce the bulk, and in 1977, 16,743 barrels were crushed, and 485 tons of debris collected, burned, or stockpiled. In 1978, 1,235 tons of debris was burned or stockpiled. In 1979, the summer cleanup crews worked out of tent camps near the sites, thus cutting the cost of daily commuting from a base camp. During that summer, more than 10,000 tons of debris was handled, burned, or stockpiled for later disposal.

The U.S. Navy hauled much of the debris at Barrow to Seattle for final disposal—a difficult and expensive process—because it was thought that burial in permafrost ground would be difficult and

environmentally unacceptable. However, hauling to the “South 48” was very expensive and simply moved the problem to another region. Thus, in 1980, burial at carefully selected sites was begun. The burial plan included stripping away the organic overburden and stockpiling it to one side, then excavating a pit of sufficient size to hold the debris, placing the debris in the pit, compacting it, and carefully backfilling with the original material so as to cover it at least 2 feet deep. Because the overburden was generally exposed to the winds and cold for less than 2 days and then protected by blown snow after replacement, many plants survived. This meant that the area recovered far more quickly than an area seeded with grass.

The first step at rehabilitation of a drillsite was routine cleanup. All the debris was picked up and burned or returned to a disposal site when the drilling was completed. Pilings were cut off below

ground surface, if possible, and pile caps and sills were burned. Final cleanup took place after the ground had thawed.

After the cleanup stage, the work required depended on the drill-pad design. For thick pads, the pad elevation was lowered, and the excess pad material dumped into the reserve pit. Thinner pads required no rehabilitation, and the five insulated pads required only precautionary rehabilitation. It was important that the Styrofoam remained buried because otherwise it could become a source of litter.

After cleanup, the site was ready for seeding. Active seeding was done before the end of June; dormant seeding was done after the first freezing temperatures of the fall. About 50 pounds per acre of seed mixture was sowed, and 600 pounds per acre of nitrogen-phosphorus-potassium fertilizer was applied. Seed was worked in with tractor tracks



Part of the cleanup operation at old drillsites consisted of cutting off pilings, “below grade” of the drill pad. Photograph by John Schindler.



Barrel crusher. Photograph by John Schindler.



Burning debris at the Oumalik cleanup site. Photograph by John Schindler.



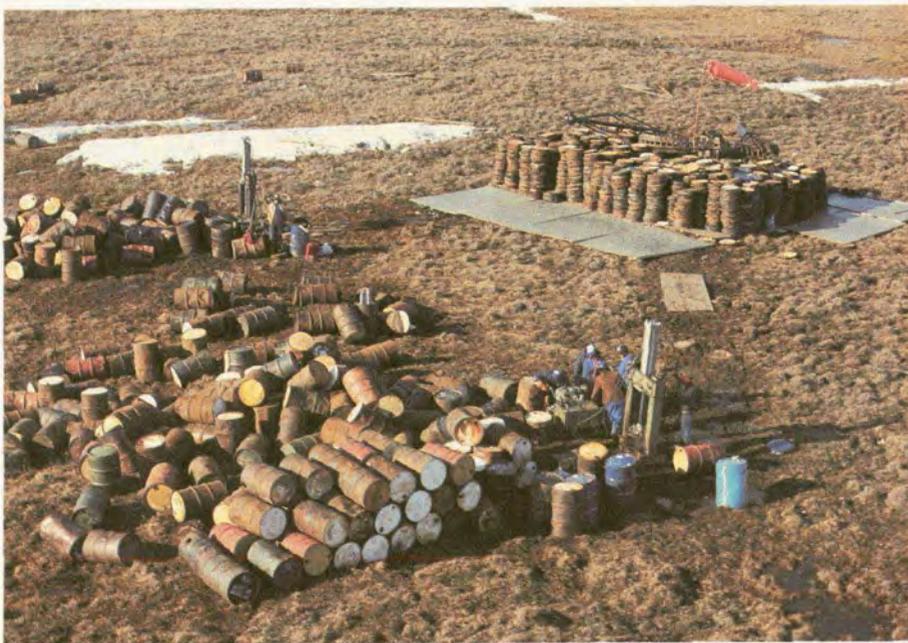
Helicopters were used during the cleanup program for transporting debris to the burial site at Grandstand. Photograph by John Schindler.



Some incombustible material was disposed of in landfills approved by the State of Alaska. Photograph by John Schindler.



A revegetation Rototiller prepares the soil at the Walakpa No. 1 test well. Photograph by John Schindler.



Before and after views of the Oumalik wellsite. View on the right was taken less than a year after the cleanup. Photographs by John Schindler.

to ensure soil/seed contact and prevent wind erosion. This method proved to be moderately successful in the inland locations but failed along the coast. After considerable experimentation, it was determined that tundra bluegrass was best for the coastal locations. This bluegrass is native to the North Slope and allows for other native mosses, lichens, and grasses to reappear. The fertilizer was spread by a helicopter with a special hopper, then worked in to a depth of 4 inches below the surface with a cultivator.

Damage by traffic over winter trails was slight and mostly was confined to the heavily traveled trails near Camp Lonely and Barrow. A "cropduster" airplane was used to distribute fertilizer in these disturbed areas. Both the tundra ice roads and the runways disappeared with the thawing of the active layer in spring, but in some places the tundra would turn brown or dark green. The brown color was caused by freeze-burn of the vegetation through the ice, which did not insulate as well as the snow cover. The green color resulted from a depression in the surface caused by excess weight, creating wetter conditions and more plant growth. Only a small percentage of the 15,000 line-miles of seismic work became green or brown trails. In any case, these colors were short lived and disappeared within 5 years.

Borrow sites were judiciously chosen and carefully mined, and thus required little rehabilitation. Most borrows were in areas flooded by the spring runoff, and so after a year the sites were indistinguishable from the surrounding areas. In selecting a borrow site, a source was chosen where mining would have no effects that could not be corrected by natural processes within a couple of years. The site was excavated only to the normal water level to avoid excess erosion.

The cleanup and rehabilitation program restored the appearance of the NPRA. By the removal or burial of debris, followed by an intensive revegetation program, disturbance to the environment has been minimal.

What is the story of the Barrow gas fields?

Gas was discovered at Barrow in April 1949, and the fields hold two records: the South Barrow gas field is the oldest producing field in Alaska, and the South and East Barrow fields are the farthest north in North America. Barrow No. 2, the discovery well for the South Barrow field, was drilled during the U.S. Navy's Pet-4 program.

The base camp for the Pet-4 exploration program was located about 4 miles along the beach from the village of Barrow. This camp evolved into the Naval Arctic Research Laboratory (NARL). It was decommissioned in 1981 and was used only as a base for the gas-field operations, but it is still generally called "the NARL." The discovery well was located about 4 miles southeast of the village and approximately 5 miles south of the base camp. The camp was fueled by oil brought in by barge once a year, until gas was piped from the well into the camp. The camp was completely converted to natural gas by winter 1949-50.

When the Pet-4 exploration program began, there were about 400 inhabitants at Barrow, a community that consisted of a cluster of some 50 houses and buildings. The program provided opportunities for the Eskimos to work for cash wages, many for the first time. Employment opportunities attracted additional inhabitants, and the population of Barrow increased rapidly. Good airport facilities and improved communications, byproducts of the exploration program, made Barrow easily accessible and a rather desirable place to live, so far as amenities were concerned.

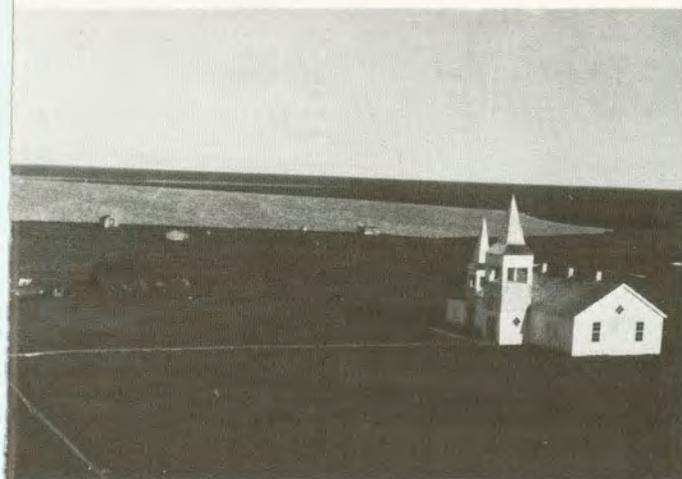
The relative conveniences of Barrow, together with its burgeoning Native population, prompted several Federal agencies to establish offices in the village, generally in the form of compounds. These agencies requested the use of natural gas, and so, in 1958, gas was piped into the village and connected to the various compounds, so that they, too, had the use of this superior fuel. The Native inhabitants



quickly saw the advantages of natural gas and petitioned the Congress for permission to use it. The Congress passed favorably on their petition, and by 1965 Barrow had completely converted to natural gas. The abundant cheap fuel attracted additional people, and the U.S. Navy slowly developed the South Barrow gas field to its present size (six producing wells) in response to the growing demand. The gas produced from the Barrow fields is about 95 percent methane.

In 1974, dwindling reserves of gas in the South Barrow field caused the Navy to drill Barrow No. 12, an exploratory well located about 6 miles east of the original field. The location of this well was based on a seismic survey of the area in 1973. The well penetrated the reservoir sand but did not produce at commercial rates. In early spring 1977, Barrow No. 14 was completed and proved to be a good gas well. It is about half a mile east of Barrow No. 12 in what is now called the East Barrow gas field.

Panoramic view of the Barrow settlement, late summer 1924. Photograph by Phillip S. Smith.

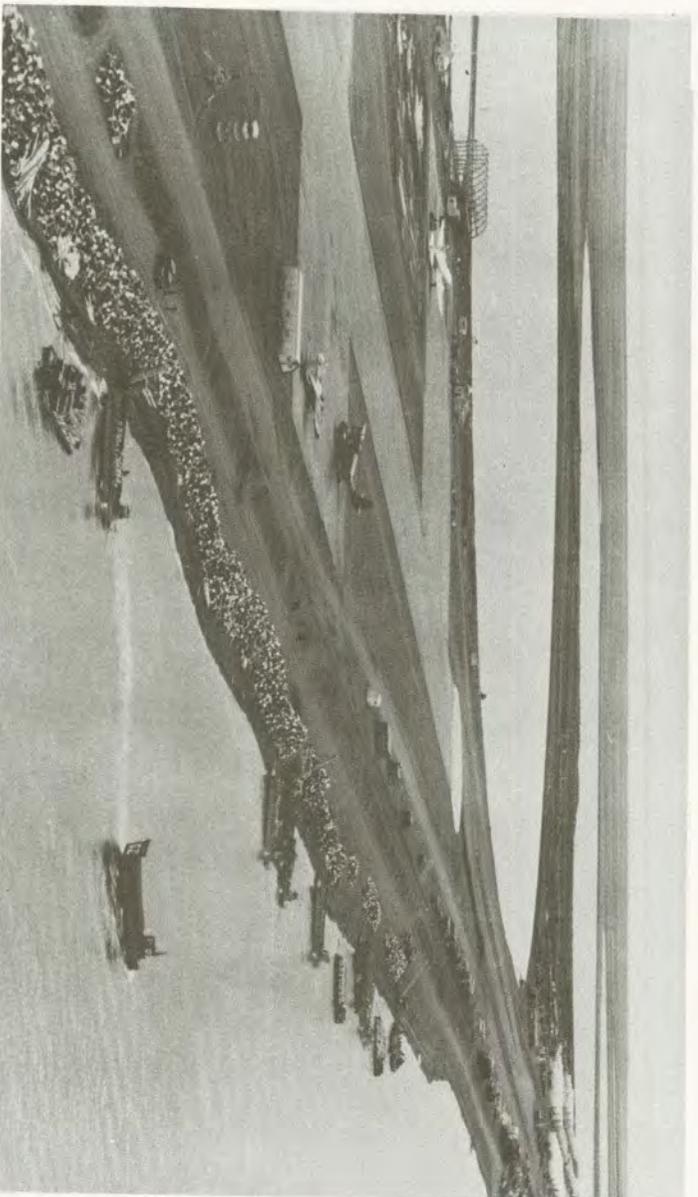




Aerial photograph of Barrow, probably taken in 1963 before completion of the gas-distribution system. Larger buildings are part of Federal compounds: the U.S. Weather Service (right foreground), the Bureau of Indian Affairs (background), and the Public Health Service (background). View northward. Photograph by John Schindler.



Barrow, 1983. The most recent census counted about 3,500 people as year-round residents. Photograph by Robert Lamiz.



Thousands of oil-filled barrels were delivered to Barrow by barge during the Pet-4 program in 1944-53.

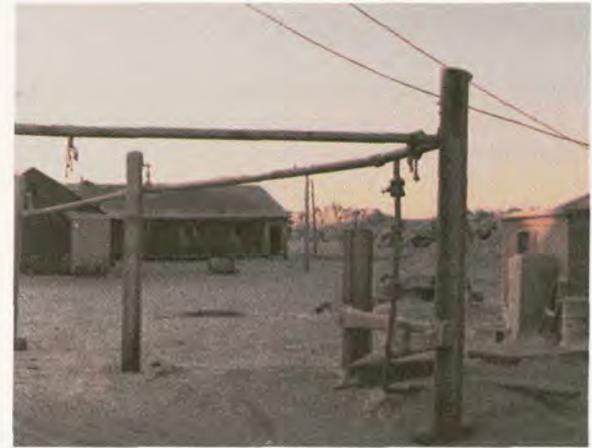
The role of the USGS at Barrow

Gas from the South Barrow field was supplied to the townspeople at a subsidized price, and no limits were imposed on its use. Over the years, the entire Barrow community has become completely dependent on Barrow gas as the source of heat and power—necessities in this cold, harsh climate.

The Naval Petroleum Reserves Production Act of 1976 (Public Law 94-258) transferred jurisdiction of NPR-4 from the Secretary of the Navy to the Secretary of the Interior, effective June 1, 1977. That law directed the Secretary of the Interior to “develop and continue to produce the South Barrow gas field or other such fields as may be neces-

sary to supply gas at reasonable and equitable rates to the Native village of Barrow and other communities and Federal installations at or near Point Barrow, Alaska.” The Secretary of the Interior delegated that responsibility to the USGS. The USGS supplied natural gas to the Barrow community from June 1, 1977, until October 1, 1984.

The Congress passed Public Law 98-366, the Barrow Gas Field Transfer Act of 1984, on July 17, 1984. This law relieved the Secretary of the Interior of his responsibility for supplying Barrow and the nearby Government installations with natural gas. That responsibility was assumed by the North Slope Borough on October 1, 1984, in return for \$30 million and title to the gas fields. The USGS is to furnish technical assistance to the borough on request until October 1, 1989.



Old gas-distribution system suspended from stanchions. Photograph by Robert Lantz.



Old gas-distribution system on barrels. Photograph by Carroll Livingston.



When the Congress approved the sale of gas to the village, a temporary distribution system was built above ground from material left over from the Pet-4 program. Supported on barrel halves or by stanchions, it was prone to leaks and accidental breaks. This photograph of Barrow was taken in 1963 or 1964 during construction of the distribution system. This “temporary” system was replaced in 1982 after some 18 years of service. Photograph by John Schindler.

Gas consumption

All of the gas produced from the Barrow fields was consumed by Federal installations until 1964, when gas was also provided to the village. The volume of gas used by the village that first year (1965) was about 140,000 thousand cubic feet (MCF), or about 36 percent of the 388,846 MCF that was produced; the other 64 percent was used by Federal consumers. The U.S. Navy originally charged Barrow \$0.50 per MCF but reduced that price to \$0.324 per MCF in 1976, which is the current price.

When the responsibility for the gas fields passed to the USGS in 1977, the village was using a little more than half of the gas produced and was just beginning a civic improvement program designed to elevate the standard of living in Barrow to that of a typical small town in the "South 48." The goals—running water, flush toilets, modern houses with

modern conveniences—is near reality, powered by subsidized natural gas. More than 300 new homes have been built in the past 5 years. Floorspace in Barrow is estimated to have increased more than a hundred fold since 1965 to a present 1.5 million square feet. In 1982, the town of Barrow consumed 925,000 MCF of gas, which amounted to 74 percent of the total volume of gas produced during that year. Gas consumption in Barrow increased by 23 percent in 1982 over 1981 and has increased a total of 660 percent since 1965.

Federal gas usage, which has remained relatively stable over the past 5 years, is divided among several installations; the NARL, the DEW-line radar station at Barrow, the Public Health Service Hospital, the Federal Aviation Administration, the National Oceanic and Atmospheric Administration (NOAA) Observatory, the Post Office, and the National Guard Armory. Of these installations, the NARL is by far the largest consumer.



Winter view of Barrow, before the advent of the Pet-4 program. Houses shown are probably typical of the time. If you look closely, you will see 17 dogs hooked to the sled. Dog teams have now been almost completely replaced by snowmobiles. Photograph by Charles Brower.



Present-day whale hunting at Barrow. Much ritual and ceremony are involved. Photograph by John Schindler.



Eskimo house at Barrow in the 1920's. In the old Eskimo culture, fuel in the Barrow area consisted mostly of driftwood, animal oil, and moss, although coal, oil shale, and oil from the seeps were used at times. Fuel was crucial to survival. Homes were small. The sources of heat and light—the cook stove and oil lamp—were the centers of indoor activities and family social life. Photograph by Charles Brower.

Gas production

On October 1, 1984, operation of the gas fields at Barrow was taken over by the North Slope Borough. Before that date, the gas fields were operated and maintained by a contractor under USGS supervision. This contractor was based at the old NARL camp that the U.S. Navy decommissioned in 1981.

The NARL is a large installation and requires considerable maintenance in the harsh climate. The camp is by necessity a standalone operation. There are no public utilities to furnish water supply, sewage treatment, or electricity; all such services must be handled within the camp. The gas-field road network also requires the almost constant use of several pieces of heavy equipment.

When the USGS supervised the operation, the gas fields themselves were constantly watched by gas-field operators aided by a remote monitoring system installed in 1982. Every effort was made to ensure an uninterrupted flow of gas. It was a sizable task, requiring a workforce of about 35 people and costing about \$6 million a year.

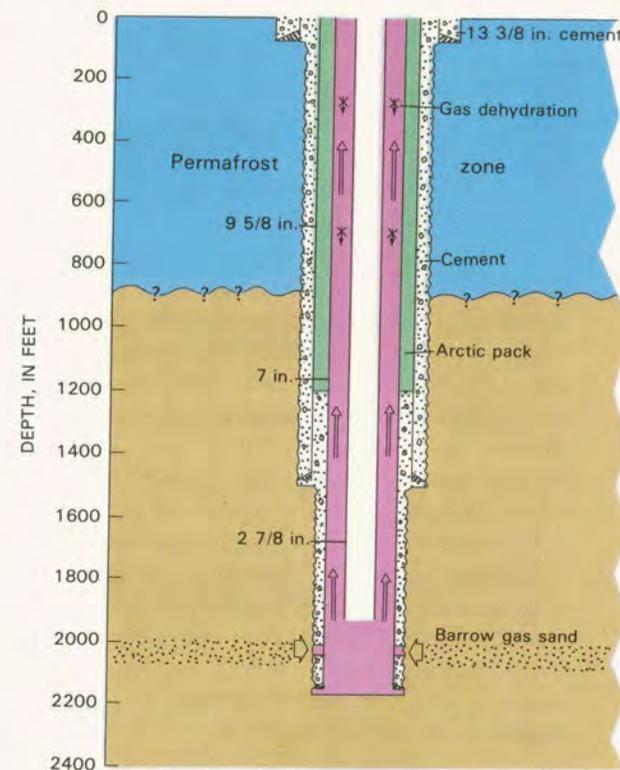


Aerial views of Barrow taken from nearly the same position about 20 years apart (upper, 1963; lower, 1983). Growth in the number and size of houses is readily apparent and explains Barrow's soaring demand for gas. The cluster of buildings in the U.S. Weather Service compound (right foreground) remains about the same. Photographs by Robert Lantz and John Schindler.

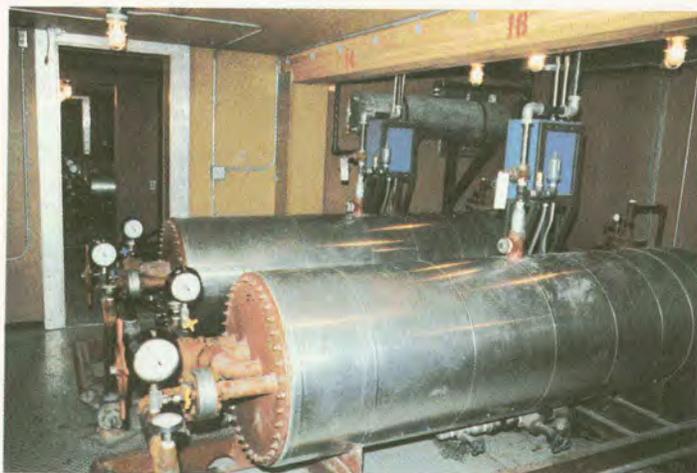
The Barrow gas fields themselves are rather typical except for their location and the pervasiveness of permafrost. Permafrost in the area of the producing fields extends from the surface down to about 1,000 feet. The annual mean temperature at Barrow is about 10°F, and ice is a constant hazard. Water produced with the gas could accumulate in the wells, flowlines, or transmission lines, freeze, and cut off the flow of gas. The wells are not deep; the reservoir sand is above 2,500 feet, and the reservoir temperature is approximately a cool 60°F. The wells are produced in a peculiar manner to utilize the cold permafrost that surrounds the upper part of the wellbore, so as to minimize the amount of water produced with the gas. Barrow gas flows through the annular space between the 7-inch-diameter casing and the 2 7/8-inch-diameter tubing. In most wells, gas flows through the tubing, but because the cross-sectional area of the annulus greatly exceeds that of the tubing, a given volume of gas will travel much slower through the annulus. Thus, as Barrow gas flows slowly up through the freezing temperature of the permafrost, much of the water freezes out of the gas and falls to the bottom of the well. The tubing is only used to clean the accumulated water out of the wells. Alcohol is also injected into the gas stream to reduce still further the chances of ice blocking the flow of gas.



“Blowing” a well. Water vapor produced with the gas freezes out of the slow-moving gas and accumulates in the bottom of the well. To clean out the water, the flow of gas is diverted to the tubing, and the well is opened to the atmosphere. The gas flowing against only atmospheric pressure through the small-diameter tubing attains a high velocity and carries the water to the surface. The water is discharged into the air as vapor, forming a plume. Photograph by Robert Lantz.

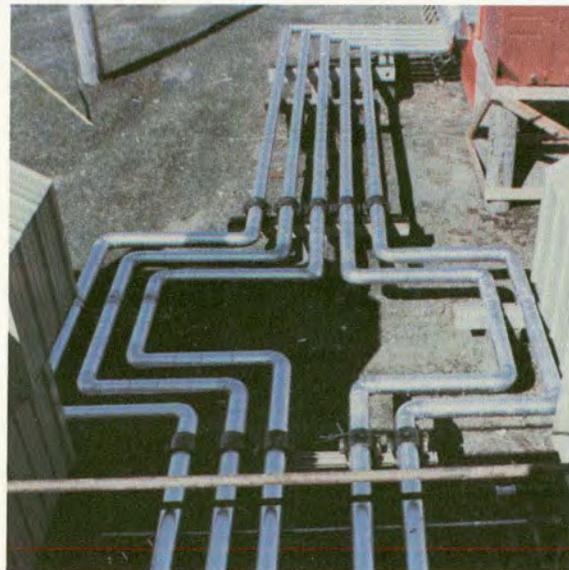


Detailed drilling, cementing, and casing program for a typical Barrow gas well. A 13 3/8-inch-diameter conductor pipe is set at depth of about 80 feet and cemented to the surface. A 12 1/4-inch-diameter hole is drilled to approximately 1,500 feet; 9 7/8-inch-diameter casing is set in the hole and cemented to the surface. An 8 1/2-inch-diameter hole is drilled through the reservoir, in which 7-inch-diameter casing is run and cemented to the top of the cement left at about 1,200-foot depth, which is below the permafrost. Above 1,200 feet, the well is arctic packed (arctic pack is a nonfreezing cement substitute). The 2 7/8-inch-diameter tubing is hung inside the 7-inch-diameter casing, which is perforated into the reservoir rock and thus allows the gas to enter the well. The gas is produced through the annular space between the 7-inch-diameter casing and the 2 7/8-inch-diameter tubing.



Heaters at the East Barrow gas-production facility, where cold gas from the well is heated before the pressure is reduced. Passage of high-pressure gas through a restrictive orifice (“choke” in gas-field language) to reduce the pressure results in a large temperature drop that could freeze water associated with the gas and cause blockage of the line. Heating the gas before choking prevents freezeups. Photograph by Robert Lantz.

Gas from the individual wells goes through flowlines to a central producing facility located in each of the fields, where the gas pressure is reduced and regulated at a transmission pressure of about 225 pounds per square inch. The gas is also metered before entering the transmission lines that carry it to Barrow or the NARL.



Flowlines at the East Barrow gas-production facility. Photograph by David Fears.



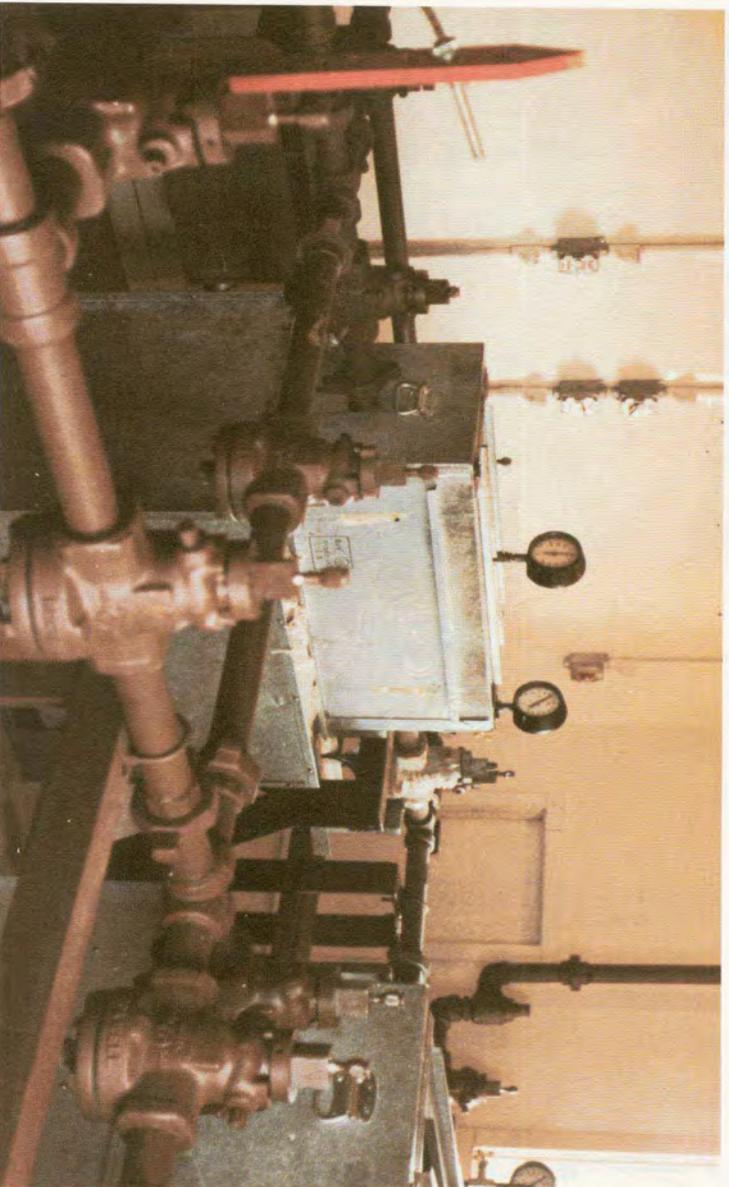
Interior of a wellhouse in the East Barrow gas field, showing a typical wellhead or "Christmas tree" through which the gas is produced. The wellhouses are heated and provide a relatively comfortable environment for the workers. Photograph by Robert Lantz.



Manifold where the flowlines enter the East Barrow metering and regulation (M&R) building. Photograph by Robert Lantz.



Flowlines into the central production facility in the older South Barrow gas field. Note the confusing, interconnected piping, threaded connections, and valving exposed to the weather. The South Barrow production facility and gathering system were largely built on site from surplus materials. As the number of gas wells increased, valves and pipes were added to accommodate them. The operators said "it just grew like Topsy." Photograph by David Fears.



View of the piping inside the M & R building at South Barrow. Photograph by Robert Lantz.

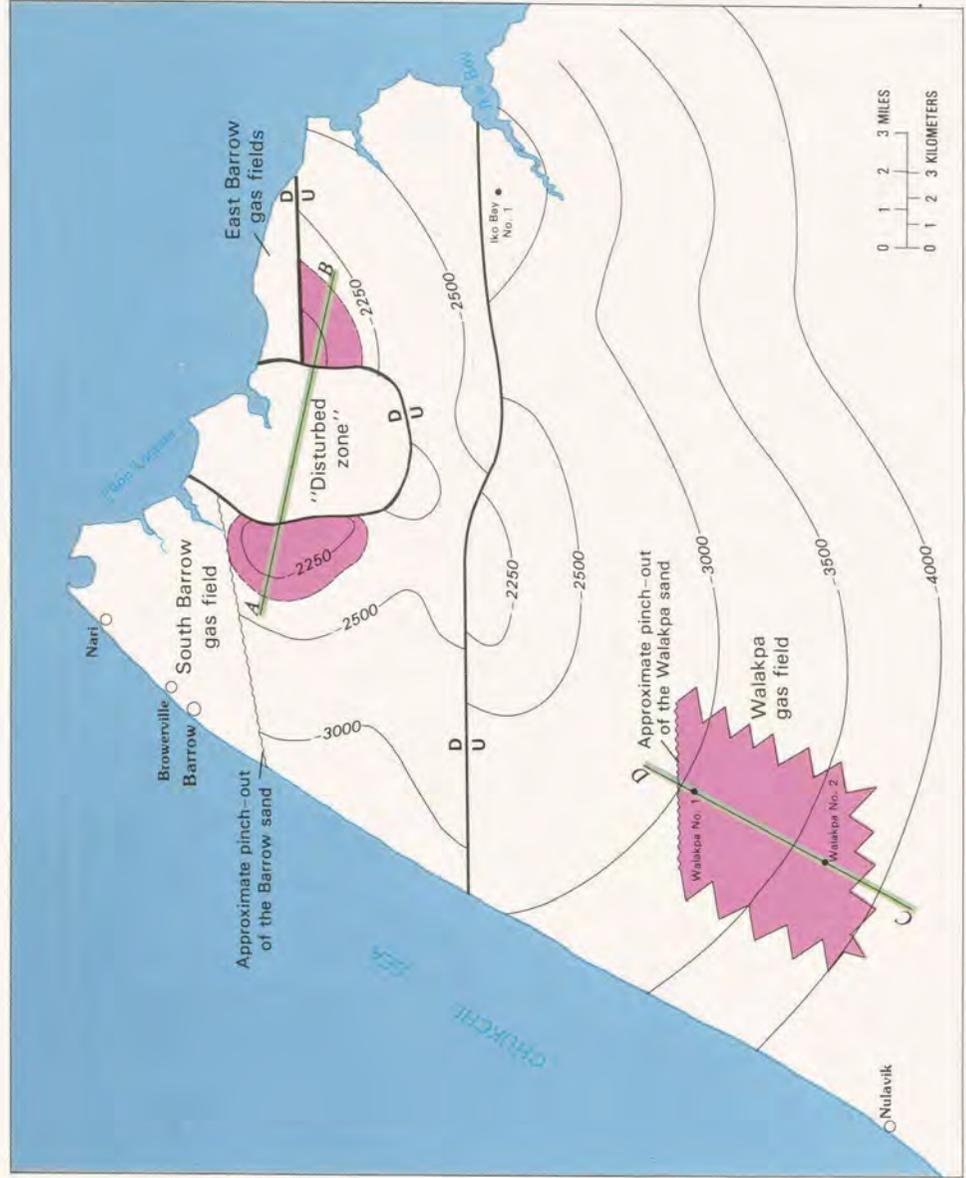
Prospects for supplying future demands

The South Barrow gas field originally contained about 27 billion cubic feet (BCF) of recoverable reserves, and the East Barrow field about 8 BCF. The gas accumulations in the South and East Barrow fields are on the rim of an approximately circular area containing chaotic structures, which the U.S. Navy called the "disturbed zone." Seismic surveys in the area of the disturbed zone indicate the presence of an additional untested rim structure, about the same size as the one at East Barrow, which, if filled with gas, might contain as much as 10 BCF of gas. Another structure is about 7 miles south of the South Barrow field, near old Barrow No. 3—a dry hole completed by the Navy in late August 1949. This small structure, if filled with gas, might also contain as much as 10 BCF.

About 15 miles south of Barrow, a gas accumulation of unknown dimensions was discovered by the Walakpa No. 1 well, drilled by the USGS in February 1980. A confirmation well, Walakpa No. 2, about 5 miles southwest of No. 1, was completed in February 1981. Both wells were tested extensively. The

gas is contained in a stratigraphic trap formed by updip pinchout of the reservoir sand to the north, but additional drilling will be necessary to establish the lateral (east-west) boundaries of the field. The downdip (south) producing limit is also unknown; although the Walakpa No. 2 well is more than 500 feet deeper than the discovery well, it did not reach the lower limit of the gas field. The Walakpa gas field could contain a significant volume of gas if the trap is of large dimensions, as is presently believed.

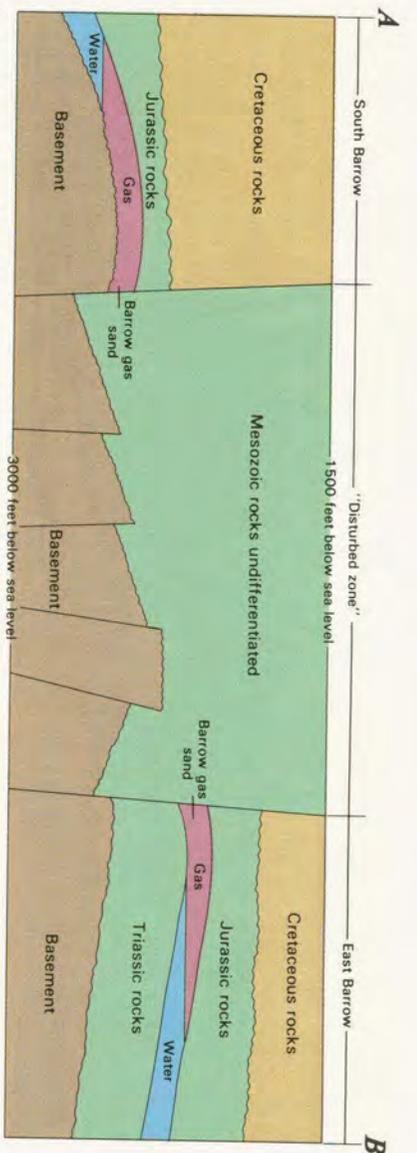
As can be gathered from this discussion, the total volume of producible gas in the sparsely drilled Barrow district is not known with any accuracy. Basement rocks are closer to the surface at Barrow than anywhere else on the North Slope, and the rocks slope away from the Barrow high in all directions. All the wells drilled in the area to date have had some shows of gas, but reservoir rocks are scarce, and without an adequate reservoir, commercial production is impossible.



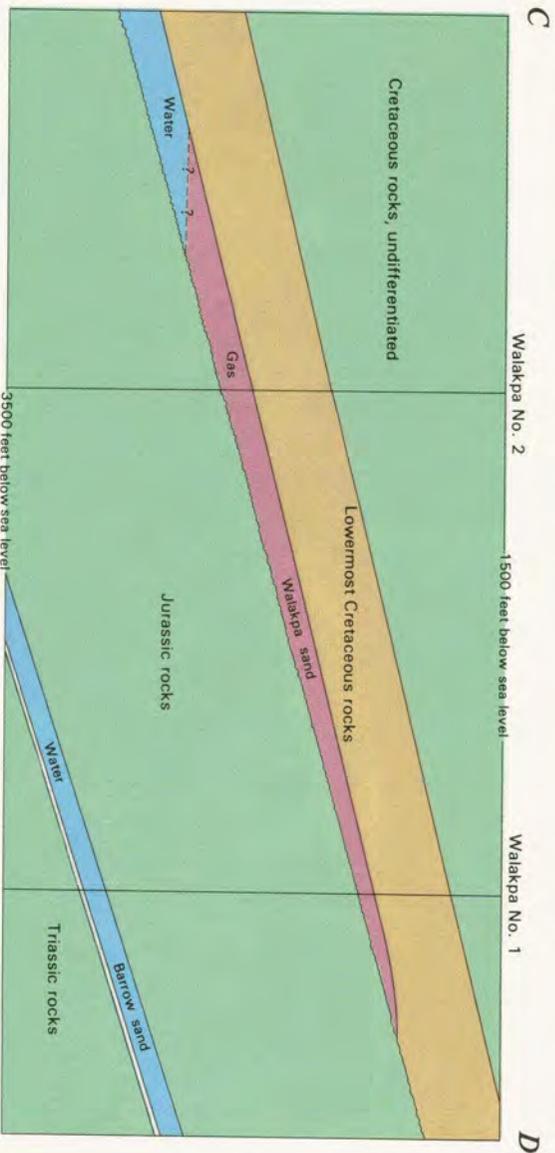
Known gas fields in the Barrow area (shown in red). The areal extent of the Walakpa field is unknown. Contours show configuration of the Barrow gas sand in reference to a level plane (sea level). Heavy lines denote faults; D (down) and U (up) show relative positions of rocks on each side of the faults. Schematic cross sections through the gas fields are drawn along green lines A-B (Barrow fields) and C-D (Walakpa field).

The three known gas accumulations are all less than 3,000 feet deep. The South and East Barrow fields, though not connected, produce from the same stratigraphic horizon—the Barrow sand. The Walakpa field produces from the Walakpa sand, slightly younger and a little above the Barrow sand in the stratigraphic section. Both sands have limited distribution, are of Mesozoic age, and have similar reservoir properties.

Possibly because it occupies the highest structural position in the area, the Barrow district appears to be gas prone. Oil in commercial quantities has not been found, although some was recovered from thin sand of Cretaceous age in the Barrow No. 20 well.



Schematic cross section through the South and East Barrow gas fields along line A-B. This cross section illustrates what petroleum geologists call a "trap." Oil and gas are lighter than water and thus will migrate upward until they are "trapped" in a place from which they cannot escape. The South and East Barrow fields are structural traps—the rocks slope away in all directions, and the hydrocarbons are trapped in the highest part of the arch, or structure. In contrast, the Walakpa field, shown in cross section below, is an example of a stratigraphic trap. Disappearance of the Walakpa sand (reservoir) updip traps the hydrocarbons when they have migrated as far up the reservoir as possible.



Schematic cross section through the Walakpa gas field along line C-D. The Barrow sand, reservoir rock of the Barrow gas fields, is present in the Walakpa area but does not form a trap and contains only water. The Walakpa gas field has not been developed and has produced no gas except for a small amount during testing of the two wells.

The USGS' accomplishments at Barrow

When the USGS was assigned the responsibility of providing gas to the Barrow community, only the South Barrow field was equipped with the facilities necessary to produce gas and with the pipeline connections required to transport the gas to consumers. The East Barrow field consisted of one well but was without producing facilities or pipeline connections. There were no roads to the fields, and the environmental degradation resulting from 28 years of operating the South Barrow field without roads was deplorable. The ratio of remaining producible gas to gas consumption was below normal standards, and gas consumption was increasing rapidly.

The first priority was to find out whether the East Barrow field contained sufficient gas to justify construction of a pipeline and production facilities. Two wells were drilled during the first winter of operation (1977-78), Barrow No. 17 was drilled more than a mile west of the existing well (Barrow No. 14); it penetrated the gas-water contact and established the field-producing limit. Barrow No. 19 was drilled northeast near the crest of the structure, to determine the reservoir characteristics. The wells were extensively cored and tested to obtain the maximum data. Calculations based on this new information indicated that sufficient gas was present to justify construction of production facilities and pipelines, because operation of the new field would nearly double existing reserves.

Construction of the road between the Barrow gas fields. What appear to be large boulders along the shoulder are frozen blocks of gravel. The equipment is operating on an ice road alongside the gravel road. This ice road was built to speed construction; it disappeared with the spring thaw. To conserve gravel the road is one lane wide, with wider spots every quarter-mile to allow vehicles to pass; even so, about half a million cubic yards of gravel was required for the gas-field roads. Photograph by Robert Lantz.



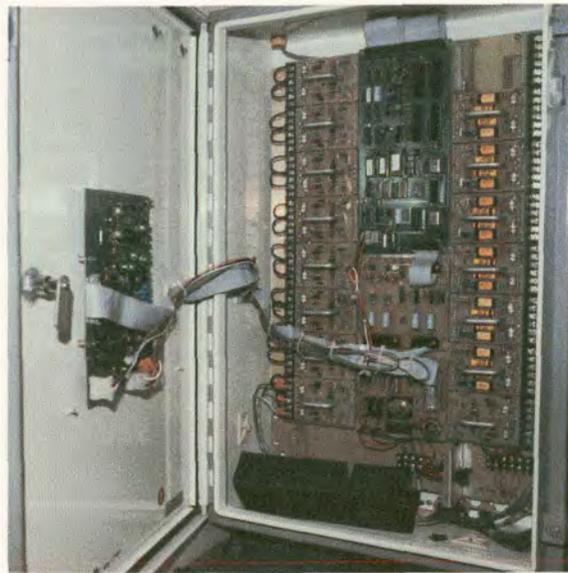
Part of the 6-inch-diameter pipeline from the East Barrow gas field. Expansion loop (center) allows the steel pipe to expand and contract without breaking. The pipe is anchored midway between the expansion loops, which are spaced at regular intervals to avoid any large accumulated movement. The pipeline is supported above ground on wood piling. The taller supports now carry electricity to the East Barrow field. Photograph by Robert Lantz.



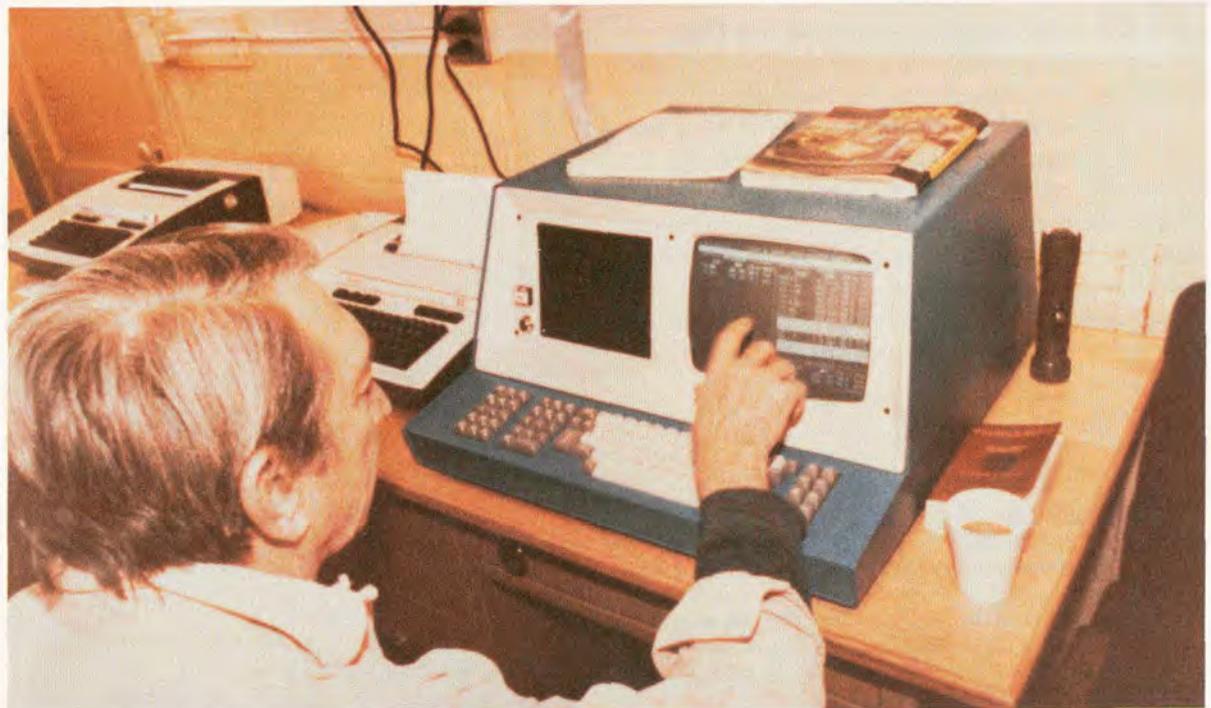
With this positive information in hand, work began at once. Three additional wells were drilled, although one (Barrow No. 20) was damaged during cementing operations and could not be completed as a gas well. An all-weather gravel road was constructed to the gas fields to end the environmental damage associated with gas-field operations. A pipeline was built to carry the gas from the East field to the South field. The old South Barrow producing facility was inspected, and some needed safety features were added. A remote monitoring system was installed. Larger well houses and flowlines were installed at East Barrow than had been used at the South Barrow field, for added safety and reliability. Emergency electrical generating equipment was installed in the gas field as an additional safeguard against interruption of the flow of gas. The East Barrow gas field was brought into production in 1981.

While the gas fields were assigned to the USGS, the producible reserves of gas were increased several times over. A road network was built to minimize environmental damage. Automatic valving and electrical generating equipment, as well as a state-of-the-art producing facility at the East field, were installed. Installation of a system that permits remote monitoring of all key points in the entire producing system and all well houses resulted in a much safer operation and a more reliable supply of gas. The Walakpa gas field was discovered—a field that could contain sufficient gas to supply the energy needs of the Barrow community well into the 21st century.

The current status of all important functions at each well and at each M & R station is checked several times each minute by electronic devices (left) and displayed on a computer terminal located in the office (right). The system automatically sounds an alarm, accompanied by a flashing light that indicates what is wrong, as soon as it senses faltering well or production-system performance. The monitoring system normally operates over telephone lines, but it has a radio backup should the telephone lines fail. Automatic shutoff valves have been installed on the transmission lines, and on wells where possible, to make operating the gas fields much safer. Photograph by David Fears.



A remote monitoring system was recently installed to assure an uninterrupted flow of gas.



What is happening with the leasing of NPRA lands?

Leasing of lands in the NPRA commenced shortly after the Congress authorized private oil and gas exploration and development of the Reserve in the Supplemental Appropriations Act (Public Law 96-514) ending fiscal year 1981. The provisions of that act have shaped the BLM's leasing policy. Five of these provisions are:

- (1) activities in the NPRA will be environmentally sound;
- (2) bidding is to be based on the bidding systems used for large offshore tracts;
- (3) the size of a tract may not exceed 60,000 acres;
- (4) primary leasing term will be 10 years and will be extended so long as paying quantities of oil and gas are produced, and
- (5) half of the leasing receipts are to go back to the State of Alaska.

Some of these provisions were unusual in comparison with the regular leasing procedures set for other onland areas of the United States. Because of the vast size of the Reserve (the second lease sale of 3.5 million acres was the largest Federal offering in history), the BLM was required to use the same leasing technique that is used for large offshore

tracts. For offshore lease sales, private companies submit sealed bids; for onland sales, the BLM determines a fixed price for each tract, and the names of private companies are drawn from a lottery. Also, owing to the large tract size, the Congress determined that the environmental-impact statement completed in 1977 for the entire NPRA satisfied the Environmental Protection Agency's requirements for the first two sales of as much as 2 million acres. In most cases, the private company is to provide the environmental-impact statement for each leased tract.

The NPRA is an ecologically sensitive area, and the subsistence of many Native people is intimately tied to its ecology. In addition to developing regulations protecting the NPRA, the BLM staff gathered new information by visiting North Slope villages. Through public meetings and questionnaires, the BLM hoped to identify additional criteria of concern to the Native people. A list of possible leasing strategies, covering a broad range of environmental ideas, was presented for public comment. The BLM hoped that by working with the public, a management strategy could be devised that would "best mitigate impacts on the values of the reserve."

What is the leasing program?

Generally, the leadup to an NPRA lease sale is a four-part process. First, there is a period of exploration and information gathering; then, private companies are asked to submit nominations and comments about interest areas. The BLM then selects the location and size of the tracts, and identi-

fies any special environmental regulations for each area. Finally, on a certain scheduled day, the actual lease sale is held.

Four lease sales have been offered to date: December 1981, May 1982, July 1983, and July 1984. A fifth sale is scheduled for July 1985.

Summary of the USGS' accomplishments in the NPR-4/NPRA program

NPR-4 was set aside in 1923 by Presidential order as a potential source of oil for the U.S. Navy. The petroleum potential of northern Alaska and the outline of the Reserve were based largely on early explorations by the U.S. Navy and the USGS, and on information collected by other explorers (primarily E. de K. Leffingwell) but published by the USGS.

Between 1923 and 1976, the USGS worked cooperatively with the U.S. Navy to further define the geologic framework, assess the petroleum and other mineral resources, and provide base maps of the Reserve. In 1976, the U.S. Congress transferred responsibility, renamed the Reserve, and redefined the role of the Federal Government. The USGS was assigned the responsibility of continuing the exploration program begun by the Navy, maintaining and operating the Barrow gas fields, and completing the cleanup and rehabilitation of the Reserve and adjoining areas. The Federal exploration program has now been terminated, and a leasing program has begun. Transfer of the Barrow gas fields to the North Slope Borough took place October 1, 1984. The last stage of the cleanup program was completed in summer 1984.

Throughout the history of NPR-4/NPRA, the USGS has carefully documented and made available to the public, largely through its own publications, all the geotechnical information gained through Federal programs. In addition, it has integrated this information with private-exploration results outside the NPRA and periodically reassessed the petroleum potential and the geologic framework of the entire northern Alaska petroleum province and the adjacent Continental Shelf. These are the only Arctic regions within the sovereign domain of the United States, and they are among the last frontier regions for mineral-resource exploration and development. Because of the Arctic climatic and geographic setting, the wilderness aspects, and the indigenous population, these studies present many problems that are unique. The mineral-resource and geotechnical-engineering information has been utilized by Federal agencies in the management of

these public lands and by industry to explore and develop the resources.

A vast amount of geotechnical information on which to base further exploration has been collected and is available in publications and in contractor reports released by the USGS. A few examples are listed in the bibliography that follows to illustrate some results of the program and the kind of information that is available.

Exploration program and hydrocarbon assessment

- The USGS completed the systematic exploration program as mandated by the Naval Petroleum Reserves Production Act of 1976 (Public Law 94-258). A total of 28 test wells were drilled, 7 under U.S. Navy and 21 under USGS supervision; 6 test and development wells were drilled in the Barrow gas fields. Nearly 15,000 line-miles of seismic surveys were completed and interpreted, in addition to the more than 3,000 line-miles completed in the Pet-4 program from 1943 to 1953, which were reinterpreted and integrated into the new surveys.

- Subsurface samples, cores, and cuttings were collected systematically in both the 1943-53 and 1974-82 programs. Because of the frontier nature of the region and the emphasis on a regional evaluation, a larger than usual number of samples were collected, curated, and made available for study in Anchorage, Alaska.

- These subsurface samples were studied by specialists in geochemistry, paleontology, petrology, and core analysis. The basic data and interpretations resulting from these studies are all available.

- An original program for an interactive computer-based data and graphics system was designed with the aid of contractors and is available to the public. This system includes files for base maps, daily drilling reports, digitized subsurface logs, seismic shotpoints, outcrop data, geochemical data and interpretation, and paleontologic information.

- Models of the depositional paleoenvironment have been developed for sandstones of Jurassic and Cretaceous age that are the main prospective reservoirs in the NPRA.

- The first test well in the Foothills thrust belt of the NPRA, the Lisburne No. 1 test well, was drilled to a depth of 17,000 feet. It penetrated five distinct thrust plates, confirming the structural interpretations of the prospect, but no hydrocarbon deposit was discovered.

- Two deep exploratory wells (at the time of drilling, the deepest anywhere in Alaska) were drilled at Tunalik and Inigok. The Tunalik well reached a depth of 20,335 feet and penetrated strong blows of gas in a thick section of Cretaceous-Jurassic rocks. The Inigok well, which was drilled to 20,102 feet to test a deep basement structure, penetrated an unusual and unexpected flow of sulfur and hydrogen sulfide.

- About 15 miles southwest of the Barrow gas fields and downslope from the Barrow structural high, the Walakpa test well penetrated a new gas deposit. A second well extended this discovery, but no additional wells were drilled. Thus, the size of this field has yet to be determined, although it is probably larger than the Barrow fields by a factor of 10 or more. It could provide gas to the local communities well into the 21st century.

- Inasmuch as the exploration program was aimed at an assessment of the oil and gas potential of the entire NPRA, a new approach was developed. A total of 17 petroleum plays—areas of geologically similar prospects—were delimited, and a program to test each was planned and largely completed.

- For all of these plays, the amount of undiscovered crude oil in place is estimated at 0.82 billion barrels at a 95-percent probability and 15.4 billion barrels at a 5-percent probability, for an average of 5.97 billion barrels.

- The total amount of undiscovered natural gas in place is estimated at 2.4 trillion cubic feet (TCF) at a 95-percent probability and 27.2 TCF at a 5-percent probability, for an average of 11.3 TCF.

- The exploration program has extended and refined our knowledge of the geologic framework of Arctic Alaska and the adjoining Continental Shelf. The geologic structural framework is described as consisting of three distinct structural provinces—the Arctic platform, the Foothills fold belt, and the Brooks Range thrust belt. The stratigraphic section is described as consisting of three sequences—the Franklinian rocks of pre-Mississippian age, the Ellesmerian rocks of Mississippian to early Early Cretaceous age, and the Brookian rocks of late Early Cretaceous to Holocene age.

- Interpretations based on plate tectonics suggest that the Canada Basin of the Arctic Ocean formed by rotational rifting of the Arctic platform away from the Canadian Arctic Islands during Jurassic to Early Cretaceous time, and that the southwestward drift of this platform created the Foothills fold belt and the Brooks Range thrust belt by underthrusting.

Cleanup, rehabilitation, and environmental considerations

- Cleanup of debris left by earlier workers in the NPRA and adjoining areas was begun by the U.S. Navy in 1971 mainly in and near the Barrow and Umiat base facilities. The USGS extended this program, reaching out to the remote corners of the NPRA, and completed the cleanup in 1984. Although no precise records exist of the amount of debris collected, it totals tens of thousands of tons

of noncombustible materials and hundreds of thousands of 55-gallon drums—the ubiquitous containers for fuel throughout the remote areas of Alaska.

- For efficiency of operation, cleanup and rehabilitation of the earlier sites were combined with work on the sites of the 1974-82 exploration program. This program involved about 540 of the 23,680,000 acres of the Reserve, and seismic surveys traversed nearly 15,000 line-miles. Except for permanent runways, these areas will return to a near-natural state within a few years.

- To maintain minimum environmental impact, the USGS agreed with the land managers—the BLM—on a system for advance planning, stipulations, and monitoring that set a standard for such cooperation on Federal lands in northern Alaska.

- Environmental stipulations mutually agreed upon by the BLM and the USGS have been carefully monitored by both agencies and by their contractor personnel, and impacts were maintained at an acceptable level.

- A thin-pad design for one-season winter drilling proved to be environmentally preferable and more cost effective than a thick-pad design. Thin pads are more quickly assimilated into the natural surroundings than are thick pads.

- Ice roads, properly constructed, proved to be practical and cost effective, and had little or no visible effect on the tundra.

- Ice airstrips on lakes or constructed by flooding on shallow ponds or marshes proved to be practical and cost effective, and had no adverse environmental impacts.

- Preclearance for environmental, cultural, and archeologic reasons was required and was carried out for all active sites. These surveys and studies contributed much valuable information on archeologic sites.

Operation and maintenance of the Barrow gas fields

- The USGS operated and maintained the Barrow gas fields for the benefit of the Barrow communities and Federal Government installations until October 1, 1984.

- The East Barrow gas field was discovered by the U.S. Navy in 1974, but it remained for the USGS to prove the development potential, complete the facilities, and bring the field into production. Both reserves and delivery are expected to meet anticipated demand at least through 1989.

- The USGS discovery of a new gas field at Walakpa provides the possibility for extended use of gas as the main energy source for the Barrow communities beyond the year 2000.

- The USGS completed a thorough testing program—the first in the history of the fields—to establish reserve limits, individual well capabilities and characteristics, and maximum safe-delivery rates.

- A modernization program was begun to help reduce costs and to increase safety and efficiency. All-season gravel roads were constructed to vital facilities, not only to increase effective operation and safety, but also to reduce environmental impacts caused by repeated vehicular traffic over the surrounding tundra.

- Public Law 98-366, the Barrow Gas Field Transfer Act of 1984, relieved the Secretary of the Interior (and, thus, the USGS) of the responsibility for supplying natural gas to the Barrow community, effective October 1, 1984. The entire gas system is now operated by the North Slope Borough. The USGS is to furnish technical assistance to the borough until October 1, 1989.

Termination of the NPRA program

- In 1982, the NPRA program of the USGS was terminated. The BLM now has the overall responsibility for management and protection of the land within the Reserve. In accordance with the MOU, the USGS has completed its responsibilities, and the area has been returned to the BLM. The project has exemplified how a good working relationship between Government and industry, as well as cooperation of two larger government agencies—the BLM and the USGS—can serve to safeguard the best interests of all concerned.

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Dusk over East Barrow. Photograph by Robert Lantz.



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