# PERMAFROST AND PET 4

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## HISTORICAL BACKGROUND

Pet 4 was the abbreviation for a major oil exploration programme in northern Alaska from 1944 through 1953. The exploration was largely within Naval Petroleum Reserve No. 4 but in part extended beyond the Reserve into adjacent areas that at that time were closed to entry by Public Land Order 82. The Reserve covers about half of Alaska north of the Brooks Range and embraces about 37,000 square miles - or an area as large as the state of Indiana.

The Brooks Range is the northwest extension of the Rocky Mountain system and crosses northern Alaska from east to west. Thus, very generally, the geologic pattern northward across NPR4 from the Brooks Range to the Arctic Ocean is comparable to that eastward from the Rockies in Colorado across the Great Plains to the Mississippi. North of the Brooks Range is a foothills belt in the order of 75 miles to 100 miles wide that narrows eastward, and north of that is a coastal plain that is about 60 miles wide at the Colville River on the east and about 100 miles wide immediately south of Point Barrow. The total east-west distance across northern Alaska at about the north front of the Brooks Range is approximately 600 miles.

Surface rocks over much of the foothills belt and almost all of the coastal plain are Cretaceous, part of the filling of a large east-west trending geosyncline that extends northward far under the Arctic Ocean. The geosyncline is more than 20,000 feet deep to basement rocks near its axis, but the base of the geosyncline is only about 3,000 feet deep near Point Barrow on the north limb. Over much of the coastal plain and a part of the foothills, the bedrock is covered by a blanket of younger sedimentary material, sometimes called the Gubik formation, that would be essentially unconsolidated except that it is frozen. The Gubik formation ranges up to perhaps 1,500 feet thick but generally is much thinner.

Exploration started in 1944. Ten years and about $50,000,000 later in 1953 the exploration was terminated. The knowledge gained of the geology, the oil and gas possibilities, and operating conditions and techniques in that part of Alaska have been invaluable. Certainly the work provided a large part of the substantive basis on which all sorts of activities have gone on in the area since that time including the oil exploration that resulted in the recent discoveries by Atlantic Richfield on state leases near Prudhoe Bay 70 miles east of the eastern boundary of NPR4.

Plenty of permafrost problems were encountered in Pet 4. The experience may be of some use in solving the permafrost problems that are being faced and surely will have to be faced continually as petroleum exploration and development proceed in the North American Arctic.

All of Alaska north of the Brooks Range lies well within the permafrost region. The thickness of permafrost in northern Alaska ranges up to more than 1,300 feet. The coldest depth is about 110 feet below the surface in most places and from there down the temperature is approximately 1 degree Fahrenheit higher for every 45 feet of depth. The temperature at the coldest level is about 14°F. The permafrost, especially in fine-grained material like much of the Gubik formation, generally contains large quantities of ice in the form of grains, films, fracture fillings, sheets, wedges, and irregular bodies. The permafrost does not extend out beneath the Arctic Ocean. Furthermore, there are large unfrozen zones under the lakes that are deeper than approximately 13 feet, the deepest penetration of winter freezing into fresh water. Thus bottom temperatures of such lakes are never below the freezing point.

The permafrost problems that were encountered are divided into three categories: 1) Camp construction and maintenance problems; 2) Oil exploration problems; 3) Oil and gas production problems.

## CAMP CONSTRUCTION AND MAINTENANCE

Early in August 1944 the ships of the first support expedition stood off Cape Simpson, about 50 miles east of Point Barrow, in conditions of fog, rough weather, and floating ice. No good location could be found on that tideless shore and on 10 August the idea was abandoned of making the initial landing near the oil seepages at Cape Simpson. That decision was a most fortunate departure from the original plan. The ships retreated to the vicinity of Point Barrow, and a site was selected about 5 miles northeast of the village of Barrow. There a long and wide beach of coarse sand forms the shore, and on that beach most of the camp was constructed. Some of the buildings, those in the line farthest from the water, were off or partially off the beach on the tundra. The buildings on the tundra had foundation problems throughout Pet 4. Thus the main camp that was to serve for 10 years as the major supply base, was built mainly on the coarse beach sand in which drainage is good so that the upper level of ground ice is approximately 10 to 12 feet below the surface. The buildings therefore were placed on that natural coarse sand pad with ample depth to the ice layers below.

Then another remarkably fortunate decision was made to put the airfield along the same beach at the north end of the camp area. Had it been placed farther from the ocean, on the tundra, as considered initially, all sorts of unsuspected difficulties surely would have been encountered. Now, it is well known that offshore water depths, beaches, ice conditions, and foundation conditions all are much better at Barrow than at Cape Simpson.

Most of the original buildings were set on railroad ties laid on the sand, but the galley had a poured concrete floor. The utility building housed a boiler, generators, water tanks, a water purification unit, laundry, and portable fire fighting unit. Latrines were constructed and the waste hauled away in 56-gallon drums. The camp was enlarged and improved as Pet 4 went on, but the method of construction first used proved generally satisfactory for foundations on the beach sand.

In the second year of Pet 4 a major subsidiary base was established near the southeast corner of NPR4 about 170 miles southeast of Barrow called Umiat. It was necessary to be near the so-called Umiat anticline, which was to be drilled, but the specific location was selected on the flats of the Colville River where good gravel was abundant. A thick gravel fill was required at Umiat to raise the camp above the swampy flat. Tundra vegetation was backfilled around some of the buildings to minimize thawing and settlement.

In most places in NPR4, except on the beach sand, antenna poles and tall poles for transmission lines required the thawing of permafrost with a prospect boiler and steam point. Small poles were set in gravel-filled fuel drums, and the drums were set in the ground to their tops in holes excavated by dynamiting. An interesting development at the Point Barrow camp was the excavation deep in the permafrost behind the beach of a large excavation as a natural refrigerator, largely for frozen-meat storage. It is still there and fully operable as care always has been taken to open the shaft as rarely as possible, to store meats while frozen, and to protect against heat entry in all possible ways.

In 1947, the prime contractor for Pet 4, ARCON, took on an additional responsibility to construct three facilities for a Loran system that was to be established along the north coast. The code name of the project was Beetle. Beetle A was a 625 foot steel tower to be erected at Skull Cliff about 32 miles southwest of Point Barrow. Beetle B was a camp and airstrip at Barter Island about 300 miles east of Barrow. At Skull Cliff the material underground is frozen unconsolidated silt and ice. Great care was taken in handling the permafrost. Massive foundations were required for each of the four legs of the tower because the tower weighed 300,000 pounds and a very small amount of differential settlement would have caused failure. The work in the area was complicated by thawing, and difficulties were aggravated by the continual churning up of the mud with heavy equipment. The later concrete work was further complicated by cold weather necessitating the use of heated water in the aggregate, heating of the mixers, and curing under tarpaulins with heat applied.

At Beetle B ARCON recommended that the camp and airstrip be built on a sand and gravel spit. The airfield was built there and required the removal of 15,000 yards of overburden and backfilling with 40,000 yards of gravel. It was satisfactory. The Army preferred the higher tundra near the base of the spit, however, as the site for the camp. Buildings were placed on gravel pads and concrete slabs were poured on the pads for laundry, galley, powerhouse, and shop buildings. Buildings for radio operations and a remote transmitter were on piles as were masts for antennas. Within a month the concrete slabs began to crack and settle unequally because of melting beneath. When it was thought that equilibrium has been reached, the machinery was raised, and the floors recast to level but to little avail. A few months later the foundations were found to be saturated. Pumps were installed but settlement continued. Eventually the structures had to be replaced on piles.

## OIL EXPLORATION

### Seismic Effects

Pet 4 included many miles of seismic shot hole lines, and on the coastal plain it was found that the best depth for the holes was between 50 and 60 feet. Because the ground was frozen, almost all holes could be shot as many times as desired without damaging the hole and causing any appreciable loss of energy. Permafrost, however, did cause difficulty in interpreting seismic results because of high velocity readings in the permafrost near the surface. It has been mentioned already that the permafrost table is deeper below large deep lakes or even may be absent entirely. On the coastal plain, problems were encountered in interpreting seismic exploration results correctly because the frozen material around the lakes transmits seismic waves differently than the unfrozen material beneath the lakes. In some instances this resulted in data that was interpreted as indicating bedrock structures where none exist. For example, all horizons showed an elongated syncline under Lake Minga, a lake on the coastal plain sufficiently large and deep that it would not freeze to the bottom in winter. After considerable study it was concluded that the apparent syncline was the result of decreased velocities in unfrozen material under the lake and not a structural feature at all. Difficulty was encountered also in interpreting seismic results in the Umiat area. There it was found that, because of the high velocity of the frozen upper layers, only a bed that would transmit seismic waves at a greater velocity would furnish good subsurface information.

## Heavy Overland Freighting

Transportation of supplies and equipment was a major problem in Pet 4. In the summer the wet, soggy tundra was difficult to traverse even on foot. The most important point that had to be kept in mind with regard to overland freighting was the vast difference between summer and winter conditions. From November or December until April or May, the tundra was frozen and solid. It would support heavy loads after freezing had penetrated to the permafrost table.

It soon became apparent in Pet 4 that most of the heavy hauling would have to be done by tractor trains in the winter. The weasel, M29C, a light-tracked vehicle, was a useful personnel carrier and light land vehicle. Careful driving was required because of the vehicle's two weak spots -- the differential and the tracks. LVTs, landing vehicles tracked, were used for specialized transport over the tundra and around and near camps in both summer and winter. The operating and especially the maintenance costs were high, however, and the maximum load that could be carried was about 12,500 pounds. Ton miles moved ranged from 749,000 in 1947 to 2,509,000 in 1953. In 1948, when 841,000 ton miles were hauled, the cost was 35 cents per ton mile. In 1952, when 2,412,000 ton miles were moved, the cost was 29.4 cents per ton mile.

By contrast, in the summer of 1949, some drill collars and a kelly, the latter 44 feet long and weighing 2 tons, were moved by LVT from Oumalik, one of the drill sites, to Point Barrow for repair, and returned to the site at a cost of 94 cents a ton mile.

## Drill Rig Foundations

Supports for heavy drill rigs that had to remain stationary for many months during the drilling of deep holes were a special problem. The warm or hot drilling mud from depth could not be allowed to thaw the foundations beneath the rigs and had to be carried well away from the structures at the surface to prevent thawing of the permafrost and the creation of quagmires around the rigs.

In some instances, as at the Topagoruk site, refrigerated foundations were practicable and reasonably inexpensive. Sills, usually 12 inches by 12 inches, were laid on the ground and underlain with 1 inch steel pipe through which a refrigerant was circulated. At the Oumalik site, where drilling was expected to continue for two years, the conductor pipe was arranged so that it could be refrigerated and the pile foundation was designed so that the piles could be refrigerated when temperatures approached the melting point of ice.

Foundation designs varied with the estimated load, the length of time the hole was expected to be drilling, and the season during which drilling would be taking place. With experience it became possible to provide simpler, cheaper, and better foundations. For rigs to be erected on gravel floodplains, it was found that timber sills were sufficient and no concrete pedestals were needed. Rigs on silt usually were placed on piles frozen into the silt. Sills that could be refrigerated were used in some foundations and were satisfactory but required a larger personnel to operate the refrigerating system during the summer.

## OIL AND GAS PRODUCTION

Pet 4 yielded a relatively small amount of information about the estimation of reserves of oil and gas in structures that are in, or partly in, the permafrost or are covered by permafrost and on production problems in permafrost areas. Enough was learned, however, to indicate the nature and importance of some of the problems.

The extraction of petroleum from zones in the permafrost was not well understood, but it was apparent that production through the permafrost would raise special problems. If water was present, the wells sometimes froze up; casings were difficult to maintain; and the effectiveness of artificial heating was not fully appraised. After considerable study over several years, the Operating Committee for Pet 4 estimated reserves in the Umiat structure ranging from 30,000,000 to more than 100,000,000 barrels. The wide range of the estimates was due largely to different guesses as to the proportion of the oil in the structure that could be produced through the permafrost.

In an attempt to understand the accumulation of oil and some gas in the area of the large seepages near Cape Simpson, it was concluded that the oil had migrated from sands through faults and fractures only to become trapped beneath and in the permafrost.

Experience with the production of gas from or below the permafrost was mainly from the relatively small Point Barrow gas field. The problems were of two types - the collapse of casing in the permafrost because of the refreezing of moisture and the formation of ice and hydrates in flow strings and lines because the fluids originate in formations that are below freezing or must pass through such formations to reach the surface.

At the Point Barrow field some water is present with the gas and care must be taken to prevent freezing of the moisture as it comes up with the gas. A typical solution was used at South Barrow Test Well 4 where the well was produced alternately through the annulus between the 7 inch and the 10 3/4 inch casings and the annulus between the 2 1/2 inch and the 7 inch casings. Ethylene glycol was injected into whichever annulus was not being used for production.

## SUMMARY

### Do's and Don'ts

The experience of Pet 4 resulted in the recognition of a group of correct and incorrect procedures for arctic operations. A substantial number of these were related to permafrost.

#### DO'S

1. For foundations on frozen silt use piles rather than concrete footings.
2. Use slow burning powders for blasting frozen fine-grained soils.
3. Use higher velocity dynamites for shattering frozen gravel with high moisture content.
4. Remove silt from beneath concrete foundations and floors.
5. Provide space for air circulation under buildings whenever possible.

#### DON'TS

1. Do not backfill with frozen material.
2. Do not grade roads or runways without removing sufficient frozen silt.
3. Do not cast concrete against frozen gravel.
4. Do not allow moisture to accumulate under footings.
5. Do not allow runoff water from roofs to accumulate around buildings.

### The Future

This paper mentions briefly only a few of the problems related to permafrost in the Pet 4 project. As oil exploration and development in northern North America proceed, these and other such problems will be encountered. Industry can and will build on the experience of Pet 4 and other earlier northern projects, but much more understanding of the phenomena and development of operating techniques are needed. Many questions will have to be answered.

1. How difficult is it to build airstrips on sea ice?
2. Are airfields best located on the tundra, ocean beaches, old

beach lines inland, glacial outwash, or river bars?

3. What are the shore processes and how do they affect the unloading of supplies and equipment?
4. Can shore deposits be stabilized for foundations and transportation?
5. Can a dock be constructed that will stay in place?
6. What sort of equipment might be developed for better transportation across the tundra, especially during breakup and freezeup?
7. How can water supply and sewage disposal problems be resolved more efficiently?

The questions are endless. The outstanding need, however, is for more and better information about the environment, including permafrost conditions. If enough is known about the environmental phenomena, the means to cope with them can be found and improved.