# PERMAFROST PROBLEMS IN OIL AND GAS EXPLORATION AND PRODUCTION

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The nature of permafrost and the problems it creates for oil and gas exploration and exploitation operations have already been discussed widely at this Conference. Indeed, it is difficult to determine what remains to be discussed after reading the abstracts of papers being presented here on the nature of permafrost and natural processes associated with it, the distribution of permafrost in areas where the oil and mining industries are operating, problems with drilling and casing, pipelines, blasting and excavation. To complete the coverage of the subject, the paper by Reed describes the problems associated with permafrost in an oil exploratory venture that has already taken place. These references to apparent duplicate coverage of the subject are not intended as a complaint but an explanation for the attempt of this paper to fill some gaps rather than present an overall picture.

## Characteristics and Influence of Permafrost

Permafrost was first defined in 1945 as "perennially frozen ground" by S.W. Muller of the United States Geological Survey (Muller 1945). Prior to that it was recognized and described in general terms by a number of early explorers, such as Alexander Mackenzie.

In summer the ground thaws from the surface to a depth of several inches or feet whereas the bottom of the permafrost may be at depths varying from a few feet to about 2,000 feet. The surface layer that is subject to repeated freezing and thawing, commonly referred to as the "active layer", causes many of the permafrost problems. It is the active layer that thaws and slowly expels its water during the summer months, causing a morass, or a rough surface consisting mainly of rock fragments. Permafrost has many ground surface expressions, many of them most readily recognizable on air photographs. Some of the more spectacular types have been described by J. R. Mackay (1964):

> "In areas underlain by permafrost, the surface of the ground is frequently broken up into eye-catching geometric patterns of circles, ovals, polygons, and stripes to form what is known as patterned ground. A very distinctive type of patterned ground is the tundra polygon which is widespread in the Arctic and may be easily seen either on the ground or from an airplane. The tundra polygons resemble enormous mud cracks, such as those of a dried-up muddy pool, but with diameters of from fifty to one hundred feet. The tundra polygons may be nearly as

regularly shaped as the squares on a checkerboard, but most are irregular, somewhat like the markings on turtle shells. The boundary between two adjacent polygons is a ditch. Beneath the ditch there is an ice wedge of whitish bubbly ice which tapers downward, like the blade of an axe driven into the ground. Some ice wedges are more than ten feet wide at the top and are tens of feet deep."

There are also many other typical land forms, most of them related to the surface and near-surface geology. Much of the permafrost layer is related to the frozen groundwater in rock or soil interstices, or occurring as beds between layers of shale, silt, etc. Some of these ice layers are apparently so well developed and continuous or so dominant in relation to the interbedded shales and silts that they react under pressure like the plastic layers of salt and gypsum and other evaporites in salt dome areas and, therefore, flow laterally under differential pressure to points of release of pressure where pingos develop at the surface. (This explanation of the formation of pingos does not preclude consideration of other explanations that have been given.) It is well known that pingos are particularly numerous within and near the Mackenzie River delta, where more than 1,500 of them have been reported.

The most useful presentation to date of the general distribution of permafrost is the permafrost map of Canada (Brown, 1967). As the author explains, this map is very generalized and subject to modification as new data becomes available. One feature of such a map that it is hoped may soon be clarified is the extent to which permafrost underlies permanent bodies of water. Most authors avoid the subject and others indicate that the surface of the permafrost is at least lower beneath permanent water bodies. It is reasonably certain that most, if not all, permanent water bodies (i.e. those that have persisted for a long time geologically and do not freeze to the bottom) have no permafrost beneath them. This probably applies even to many small fairly shallow lakes, such as those that provide the water supply for Resolute on Cornwallis Island. They are land-locked and shallow but do not freeze to the bottom. Fish live in them through the winter.

The regional distribution of permafrost is determined by climate but the local variations and characteristics, particularly of the active layer, are controlled mainly by surface geology, which in turn controls the local terrain, soil conditions, vegetation, relief, etc.

With regard to the thickness of permafrost in the Arctic Islands, most of the present knowledge is taken from records of the Dome et al. well, at Winter Harbour, drilled by Peter Bawden in 1961-62, and recorded by G. Jacobsen of the Tower Construction Company (personal communication):

| Date | |
|---|---|
| July 24, 1962 | 1,456,688 feet |
| July 27, 1963 | 1,676,504 feet |
| July 23, 1964 | 1,692,908 feet |
| Probable present maximum | 1,706,032$\pm$ feet |

In reporting these figures, Jacobsen expressed the opinion that the permafrost is probably thicker toward the centre of Melville Island, and the other islands, and that the effect of the sea could explain why permafrost in the Lobitos well, located close to the shoreline on Cornwallis Island, is only about 970 feet thick.

With reference to the excessive thickness of permafrost on the Arctic Islands, it seems unlikely that below 32°F temperatures could penetrate vertically to the depths recorded unless the islands were well above sea level during the Pleistocene. The presence of water passages more than 2,700 feet deep between the present islands also supports the idea that during the Pleistocene they were high flat-topped plateaux, flanked by valley filled glaciers. The relative scarcity of glacial debris on the surface of most of the islands is another pertinent factor. They appear to have been subsequently depressed, possibly as a result of their weight with the intervening ice masses, whereas the relatively recent uplift reported by various observers is probably confined to the last 10,000 years.

## Geological Field Exploration

Walking can be very pleasant or rendered difficult, depending upon the nature of the ground surface. In summer time peat areas can become impossible and thawed bentonitic marine shales may be very difficult to traverse on foot, greatly reducing the efficiency of field parties.

The sealing by permafrost of tension fractures and faults and porous strata in a sedimentary rock sequence is one effect that is generally regarded as unfavourable because it prevents the normal manifestation of evidence of oil or gas, which is commonly used as a guide in selecting areas for close exploration attention. On the other hand, this same sealing effect may have trapped hydrocarbons in reservoirs that would otherwise have escaped over the many thousands of years that have elapsed since the beginning of the Pleistocene. Oil reservoirs in Alaska immediately below the permafrost have already been proven productive.

Transport in the field by motor vehicle can also become very difficult in muskeg or on muddy or other wet terrain as a result of summer thawing of the ground but motor vehicle problems are not regarded as serious, given the financial incentive to overcome the individual problems as they appear.

Air transport is affected by permafrost to varying degrees in winter and summer. The permafrost muskeg areas on the mainland present airstrip landing problems in the summer. During the winter, on the other hand, frozen muskeg and frozen water areas often provide excellent landing strips, even for large aircraft. On the Arctic Islands airstrip problems are less severe due to lack of vegetation cover and more direct dependence upon knowledge of surface geology. The Islands have numerous and widespread areas where airstrips can be built with a minimum of effort. The key to ready recognition of such areas is photogeology and photogrammetry, combined with ground studies of the surface geology. It is, however, not difficult to make mistakes using only photogeology or other studies from the air. Broad flat areas on shale, clay or silt outcrop or in certain areas of stream deltas often turn out to be "booby traps" for the ignorant.

Field party camps are frequently difficult to locate in permafrost areas during the summer, particularly in the Arctic Islands, because of the scarcity of water. Judicious selection of campsites near even small drainage channels fed by continuous seepage can alleviate this problem in many areas.

## Geophysical Exploration

The factors discussed under geological exploration also apply in geophysical exploration, in addition to which the geophysicist has certain problems in evaluating the permafrost layer as a part of the overall geological section. For example, the presence of permafrost in porous rock increases seismic velocities compared with the same porous rock devoid of interstitial filling. This can cause near-surface difficulties in discharging seismic shocks and recording the reflections. Ordinary fresh water freezes in shot-holes drilled in permafrost, besides which, in many areas, as on the Arctic Islands, satisfactory supplies of water for drilling are difficult to find. Nevertheless, seismic and drilling problems due to permafrost are, like transportation problems, being rapidly overcome.

## Exploration and Exploitation Drilling

This activity is also related to the problems of surface transport over the various types of rock and soil affected by permafrost. The importance of effective land vehicles and large airstrips on terrain underlain by permafrost is greatly increased because of the excessive costs involved in drilling operations. Problems of the effect of permafrost on water supply also increase in importance in the drilling of deep holes. The cementation of casing is still another problem. Early in the history of deep drilling in permafrost the freezing effect on the drilling fluid was a problem, but that too has now been largely overcome by the use of appropriate drilling fluids. In fact, all such permafrost problems in relation to deep drilling are being resolved as they appear. Possibly the most awkward problem remaining is that of water supply for drilling fluid in the Arctic Islands, but that also should not be too difficult in most areas. The well exposed geology should permit the operator to find connate water in the synclines by drilling shallow holes, even more easily than he can find oil and gas in the positive areas. Such an approach would only be necessary of course for well sites that are a long distance from sea water or other permanent water bodies.

## Oil Production and Related Pipeline Problems

Some of the problems that will be encountered at such time as there is commercial production in the Far North are:

(a) Waxing of paraffin base oils in production casing, gathering systems and other pipelines. These problems may or may not be severe in the Arctic Islands. All indications to date from oil samples, which have been analyzed, are that most of the oils are likely to be asphaltic base oils, thus reducing the problems of crude oil movement at low temperatures.

(b) Surface pipelining. The problems of trenching for pipelines have been referred to many times in relation to the tendency of the active layer to expel by freezing any lines laid in or close to the active layer. The prevalence of rock outcrops in the Arctic Islands will probably force operators to lay lines above the surface and cover them with soil and rock and/or artificial insulation.

(c) In the building of long-range pipelines between the islands in the Arctic there will be a special problem of connecting surface lines on land with the submarine portions of the lines.

(d) Open air oil storage in the Arctic Islands should not be difficult in most areas, where natural ravines can provide storage by the building of dams. In such cases the impermeable nature of the permafrost will prove to be an ally by sealing the "tanks", thus preventing leakage.

## Other Related Problems, such as Building and Agriculture, etc.

The problems of heavy construction relating to production projects have been discussed and described by other authors at this

Conference. Several statements have been made in published papers with which the author does not entirely agree. One author stated that near Aklavik in the Mackenzie Delta the top 10 feet of perennially frozen silt were found to contain 60 per cent of ice by volume and that, therefore, if this frozen soil thawed there would be a settlement of 6 feet in the top 10 feet. The author overlooked the fact that silt has an interstitial porosity of only 15 to 20 per cent so the settlement would be closer to 4.0 to 4.5 feet. Assuming, however, that the "60 per cent by volume" figure was correct, it would probably mean that the silts were interbedded with ice layers, a situation that is illustrated in Figure 2. Another statement was that permafrost can be neglected when structures are located on sands and gravels. This would be dangerous practice if underlying strata should contain sufficient ice to be plastic and thus capable of lateral flow under pressure. These points are mentioned only as a warning against neglecting some of the commonly known geological factors.

The problem of permafrost in relation to exploration and development in the Far North would be incomplete without mentioning agriculture and colonization. No matter what mining ventures become established, or what oil fields are located, a completely satisfactory development of northern Canada cannot and will not take place until the problem of agricultural development in many of the areas underlain by permafrost have been solved. In this connection, the author quotes from one of his unpublished papers:

> "The subject of the terrain in relation to agriculture is a very big one and I do not intend to go deeply into it, other than to point out that the science of agriculture, like other sciences, is making great progress. It has been found that once the insulation of moss and other vegetation is removed from the permafrost, the latter recedes and growth of crops is encouraged; muskeg areas can be drained and the acid soil treated. These are mere mechanical problems. Culture chemicals can be added to the soil to promote the rate of growth. Photosynthesis by the sun's rays is the principal requirement for plant growth and photosynthesis is by no means confined to the area south of the 60th parallel or any other parallel. Following mechanical treatment of the land surfaces and with the aid of chemicals, garden produce can undoubtedly by produced in significant quantities throughout the Territories and even on the Islands. All these factors and others can and will in future permit the Territories to support a large local population, with some at least of their agricultural food requirements. It does not take much imagination to visualize what increased population and development of other natural resources coulddo to oil and gas development."

Of all the permafrost problems that tend to obstruct oil and other mineral development of the Far North, the relation of permafrost to agriculture could be considered the most important. The others are relatively minor problems that can be solved as they appear, mainly by engineers and scientists. Solutions to many of these problems are already known and are even now in the process of being introduced as corrective measures in the field.

## REFERENCES

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2. Muller, S.W. "Permafrost or Permanently Frozen Ground and Related Engineering Problems", U.S. Geol. Surv. Special Rept., Strategic Engg. Study No. 62, 2nd ed., 231 pp. 1945.

3. Mackay, J.R. "Arctic Landforms" in The Unbelievable Land, ed. I.N. Smith, Queen's Printer, Ottawa, 140 pp., 1964.

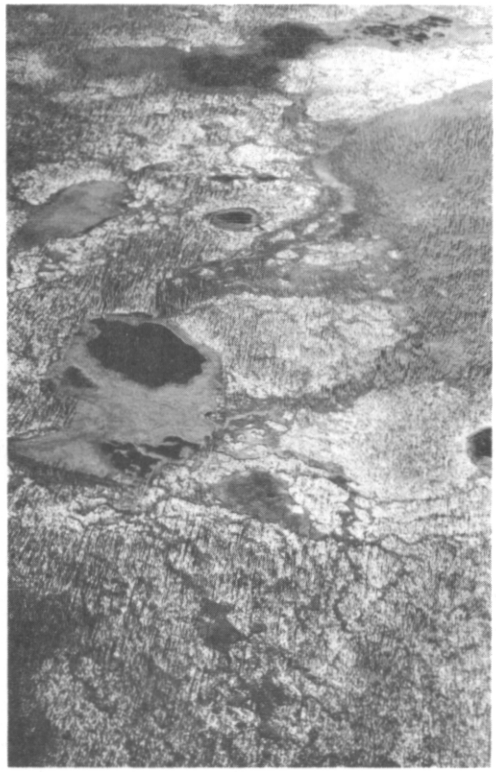

Fig. 1 Typical muskeg - lake permafrost terrain in lower Mackenzie River valley.

Fig. 2 Interbedded silt and ice layers in cutbank on Peel River in lower Mackenzie River basin.

Fig. 3 Earth slide in perennially frozen silt which blocked and deflected the Peel River.

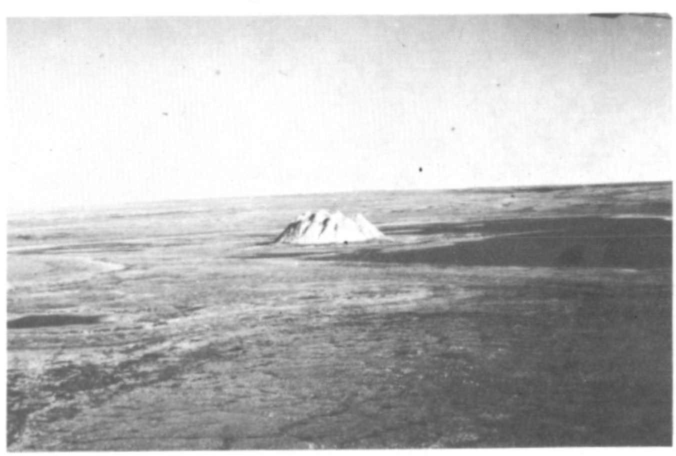

Fig. 4 Pingo in the Mackenzie River delta region. Flanks are composed of Cretaceous strata.

Fig. 5 Cabbages at Fort Good Hope, N.W.T. 14 miles south of Arctic Circle. Vegetables have been grown here for many years in an area from which the permafrost has receded due to removal of surface vegetation. The soil has become "sweetened" by drainage of humic acid which is typical of permafrost areas. Note jacknife for scale.

Fig. 6 Felsenmeer or Palaeozoic rock on the Arctic Islands typical of outcrop areas comprised mainly of carbonates or other competent rock.

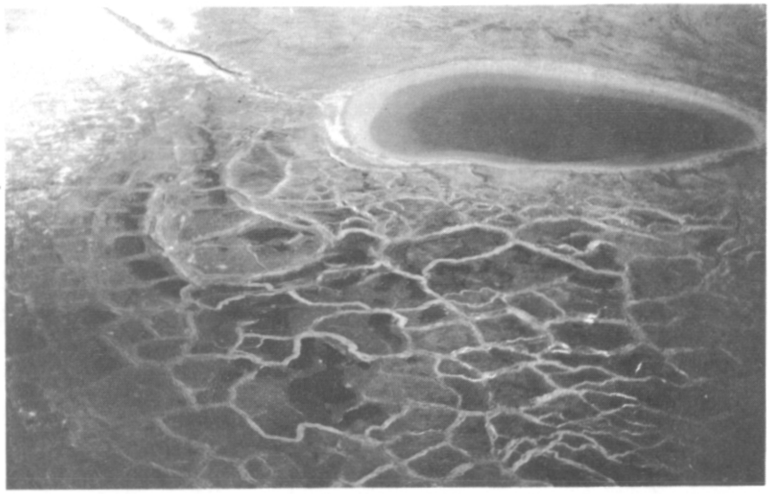

Fig. 7 Depressed centre permafrost polygons containing small lakes on Sabine Peninsula, Melville Island, N. W. T.

Fig. 8 Raised centre permafrost polygons with small lakes in trenches at Eureka, N. W. T. on Ellesmere Island.

Fig. 9 Beaver aircraft mired on landing strip at Bracebridge Inlet on Bathurst Island that appeared from air to be useable. The front wheels on this STOL aircraft are 45 inches in diameter.

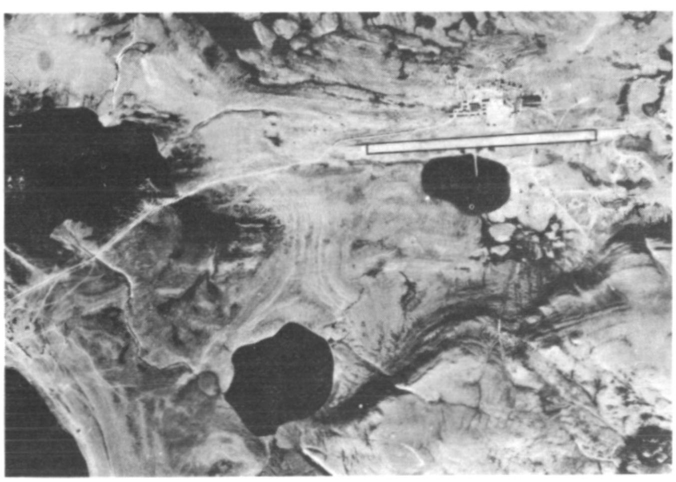

Fig. 10 Good airstrip on well drained felsenmeer developed on dolomite at Allen Bay near Resolute, N. W. T. (RCAF aerial photograph).

Fig. 11 Poor airstrip at Isachsen, N. W. T. on Ellef Ringnes Island on Jurassic-Cretaceous plastic shales in an area where the dendritic stream pattern indicates unfavourable characteristics (RCAF aerial photograph).

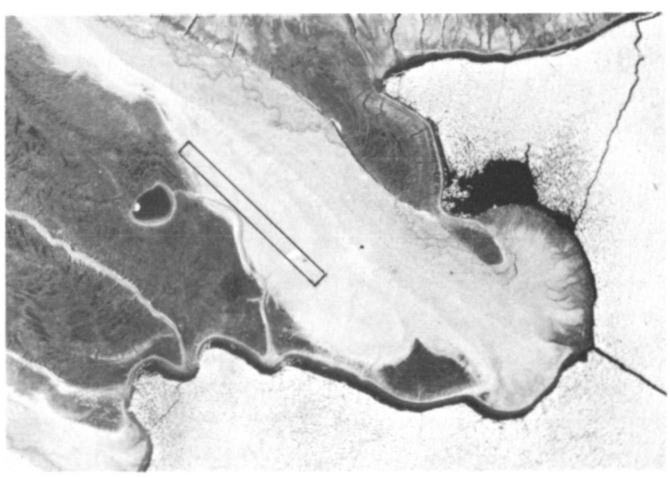

Fig. 12 Airstrip at Sherard Bay, Melville Island, built by Panarctic Oils Limited along a carefully selected long narrow terrace in deltaic area. This strip is sandy and well drained representing a small part of a large deltaic area that appears superficially suitable for airstrip construction (RCAF aerial photograph).