I.1. THE INFLUENCE OF PERMAFROST ON NORTHERN DEVELOPMENT

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INTRODUCTION

The expansion of settlement from man's early home in the fertile, friendly and protected river valleys of the Middle East has been marked by conquest of one natural obstacle after another. Broad seas, hot, dry deserts, mountain ranges and dense forests each in their turn arrested his progress until new techniques were devised and perfected, and became common knowledge. His invasion of the tropical rainforests was delayed by diseases, and his ventures into the far north – what Stefansson has termed "The Northward Course of Empire" (1) – were handicapped by severe cold and snow, and by the heavy ice which impeded and damaged his ships. In his long and frequently frustrated efforts to make a home in even the remotest parts of the earth, man has encountered, and eventually learned to deal with, an enormous variety of natural hazards.

Perennially frozen ground in the polar regions is one of his most recent natural obstacles. It has become of major importance only in the past few decades, although its existence has long been known. Alexander Mackenzie mentioned it and Jules Verne wrote a novel (2) based in part on it, while the quick-frozen mammoths of Siberia have been a cause of wonder for generations.

How was it that such a widespread phenomenon, covering about one-half of Canada and almost as great a proportion of the Soviet Union, should nevertheless have attracted so little attention that until a few years ago it even lacked a commonly accepted English name and is only now being honoured in Canada by a national symposium?

The world population map demonstrates that man has as yet barely reached in any numbers the southern limit of that one-fifth of the land surface underlain by permafrost.

As a significant factor in northern settlement, permafrost problems arise on a serious scale only when man erects heated buildings and other elaborate structures. In North America at least, this is a comparatively recent event, so there is no long, traditional mastery of the technical skills needed to deal with it. Even today one

* See Appendix "A" for affiliation

hears of contractors and engineers, discomfitted on encountering permafrost for the first time, searching for quick and ready-to-hand means for extricating themselves from its consequences. There must be among arctic folk a diverting repertoire of anecdotes about the calamities of others who did not take seriously the need for handling permafrost gently. One hears tales of undulating airfields, collapsing foundations, detached porches, disappearing furnaces, shattered water lines and sway-backed or rippled roof lines.

There is a popular misconception that in such matters the Russians have been spared our trials. Yet, despite their long experience and remarkable skill in northern operations, Soviet engineers are not proof against similar catastrophes (3, 4). In the early days of northern settlement many mistakes were made and even today criticism is heard of occasional blunders. Older photographs show the effect on small buildings of disregarding the permafrost, and there are more recent illustrations too.

Referring to the early years of the Norilsk mining community at 69°30' N. east of the Yenesei River, one writer states (5):- "A two storey house is to be built. The hardest available spot on the flowering tundra is selected.... Everybody is satisfied that a two storey house on light foundations would be supported. But no sooner did the inhabitants get their stoves going than the frozen mud thawed, cracks appeared in the walls and one corner of the house tilted and collapsed.... In the hut settlement, a kitchen built of bricks disappeared into the ground. It had gone with all its equipment, the potatoes and the cook". The first railway built from Norilsk to the Yenesei River during one winter, disappeared over long stretches in the following summer – taking wagons and locomotive with it. "No wonder people are frightened of the tundra" as one reporter said.

All the difficulties are not in the past. Writing of Yakutia in 1960 one author states -- "Various industries are developing at a rapid pace in the Yakut ASSR. This requires construction projects which must be carried out in severe climatic conditions and on permafrost. Difficulties are encountered because of a lack of building experience in the north". As will be demonstrated later, there have also been notable successes.

THE PROBLEM

To the architect, the contractor, the engineer and the scientist permafrost offers many and complex problems still needing intensive study and discussion. For the geographer who may be concerned with extending settlement into the northland, the problem is less formidable. The question to which he is seeking an answer is, put simply, "To what extent does the presence of permafrost restrict or inhibit development of an area, or so increase the economic cost of doing so as to make it prohibitive?". In answering this he needs to know the extent of permafrost, in general and, whenever possible, in great detail, what its effects may be on selected activities, and the degree to which techniques exist for circumventing it, or at least lessening its consequences when they are unfavourable.

Much remains to be done to determine the extent of permafrost in North America. In this as in so many other cases, Canadians have access to more information about the physical conditions of the Soviet Arctic than they do about their own country. A useful beginning might be preparation of a chart of ignorance indicating those regions of this country where we do not know all we should about permafrost distribution, in area and thickness. Another useful tool would be a permafrost distribution map similar to one recently published in the Soviet Union (6).

It has been stated that about one-fifth of the world's land surface is underlain by permafrost. In seeking to achieve greater precision, one encounters the important differences between areas where it is continuous, discontinuous or sporadic. Furthermore the depth to the upper surface of permafrost varies from place to place as does the total thickness. South of Point Barrow, Alaska, for example, it is more than 1,000 feet thick. At Resolute Bay, N.W.T. on Cornwallis Island somewhat more; east of the Yenesei River in the Taymyr Peninsula of Siberia it is about 1,600 feet; at Sveagruva, a mine in West Spitsbergen, it is a little less than 1,000 feet. While its extent under the seas is rarely known, there is evidence that it extends for some distance off the northeast coast of Siberia.

The limits of permafrost are of course liable to change because of modifications in climate. Human influence is also significant though on a much smaller scale -- as in the clearing of land for cultivation, which usually lowers the permafrost surface, the draining of water-covered areas such as lakes or estuaries, where the level may rise - as it has also in mining dumps in Siberia. Even in temperate climates it may be induced by "leakage of cold" through the bottom of cold storage plants.

INFLUENCE ON MAN'S ACTIVITIES

The more or less direct influence of permafrost on man's activities in the north will now be discussed.

Paramount is transportation, essential to gain access from the south, to explore the area and to carry on economic or military activities. It calls for roads, bridges, airfields (including hangars and other facilities), railroads (and provision of water for steam locomotives), docks and harbours, towers for radio and electrical transmission. Under industrial activities we may include mining and mineral processing, oil drilling, refining and storage, construction of factories, warehouses and office buildings.

Communities call for housing – whether individual or in apartment blocks – streets, water and heat, and the disposal of industrial and commercial wastes, including warm water, and power plants, both thermal and hydro. To all of these may be added miscellaneous public works requiring excavation and earth moving. These and many more may be influenced by the existence of permafrost at the site.

Defence requirements are today in many ways not unlike those of civilian life, except that the sites may be more remote, the projects are planned and executed more urgently, and the cost is usually not a determining factor.

Very considerable experience has been accumulated in railroad and highway building under permafrost conditions. The C.N.R. line to Churchill, Manitoba built a generation ago was a pioneer undertaking in a then unfamiliar environment, and has proved successful (7). The Alaska Railroad from Seward to Fairbanks crosses in one section almost forty miles of permafrost terrain and requires constant attention because of its high ice content (8). It will be interesting to learn whether corresponding problems are encountered in building the Great Slave Lake railway. The Pechora railway in northern European Russia, which extends across the Urals to the Ob River, is probably the longest line yet built on permafrost.

Construction of the Alaska Highway during World War II encountered permafrost and ran into particular difficulty in cuts and on side slopes because of disturbance of the previous heat balance and the drainage system. There is now a network of long distance roads in eastern Siberia linking the seacoast, the Lena River valley, and the Trans-Siberian Railway. Other roads follow the northward flowing rivers. The usual difficulties with permafrost have been reported. In the Thule area of Greenland, there are several miles of highgrade roads on the Air Base itself, and one stretch of about 20 miles which gives access to the ice-cap. The whole system lies on permafrost and has been used by the U.S. Corps of Engineers for research and testing purposes.

Airport construction is in principle not unlike that of a modern highway and employs some similar techniques. Construction of large airfields in the north was rare before World War II when an expanded programme started in Alaska. A few fields were built in northern Canada (originally in the central and eastern parts and later in the Mackenzie River valley), and three large ones in Greenland. The Soviet Union was similarly engaged in part of northeastern Siberia. Since the war there has been widespread construction of civilian airports in Alaska, as well as modernization and expansion of military fields, and in Canada reconditioning of earlier ones and construction in entirely new areas - such as at Resolute Bay, N.W.T. and Inuvik, N.W.T., and in connection with DEW line sites. Thule is the major modern airport in Greenland, but smaller ones have been built at Nord in Pearyland and at Kulusuk in south-east Greenland. The runway at Søndrestrøm has been greatly expanded as have the facilities there, including a large hotel. All this demonstrates that there is now a considerable accumulation of technical experience in airport construction under varied arctic conditions, with permafrost usually an important factor (9). The modern airport in the arctic is now often associated with a townsite, and the inter-relationship of the two may be critical, if only because settlements have much excess heat to dispose of. For example, poor siting may allow warmed water to drain from the town toward the airstrip. In any event utilities are needed, as are fuel storage, housing and barracks, hospitals, operational buildings, repair shops, warehouses, community centres, churches, schools and so on. These each raise their special problems both in relation to the frozen foundation and to one another.

Docks and harbours combine some of the difficulties of on-shore construction with the uncertainties of conditions under tide-water. In each particular project, care is needed to determine the precise extent of permafrost under the foreshore and the sea itself. The port of Churchill, Manitoba, with its large grain elevator, is an example of skilled engineering based on such careful study. However there is still relatively little experience of port construction under permafrost conditions. None of the northern defence undertakings in Alaska, Canada or Greenland has called for anything of this sort. There are understood to be several large river ports and some sea-ports in the permafrost areas of Siberia.

It is in the construction of communities that many of the major problems have arisen and most experience has been gained. Single dwellings of wood in small villages raise no unexpected difficulties. They are subject to displacement from seasonal movement in the active layer and also suffer at times from thawing of the permafrost. Occasionally, there are dramatic bursts of underground water that fill a basement or even a house with ice, but the usual consequences are more prosaic saggings, heavings and crackings. Construction and maintenance of northern cities is another matter. Alaska and the Soviet Union have the greatest experience here since there have as yet been no large towns in northern Canada, with the exception of Inuvik. Greenland settlements have avoided serious problems until recently through being built on rock, following the biblical injunction to stay away from sand! The consequences of the recent widespread erection of schools, hospitals, warehouses, apartments and other large buildings in west Greenland settlements has yet to be seen. There have already been some minor difficulties due, it is understood, to insufficient care in the first few years to take precautions against permafrost. There are many Soviet settlements, some now of considerable size, within the permafrost zone. They include Vorkuta, Igarka, Irkutsk, Bratsk, Chita and Yakutsk and many sites of new power plants, mines and river ports.

Fairbanks, Alaska, though small (15,000), has some of the attributes of a large city - with a university, public and commercial buildings, a central business district, suburbs and three large air bases in the vicinity. Thule, already referred to, though an airbase, is in effect a small town.

What has been the outcome in these and other urban centres of more than thirty years of trial and error, of systematic research and extended practice? A recent Soviet report (10) draws attention to the serious effects of thawing of permafrost following construction:

> "In Chita (on the Trans-Siberian Railroad) for example settlement caused three storey residential buildings to be condemned 4 to 7 years after completion. The outer part of one of the buildings settled more than one meter in relation to the central part and only settlement joints saved it from total destruction. In the Vorkuta mining region about 130 out of 165 buildings inspected from 1948-1950 were found to be more or less deformed and some were totally destroyed as a result of thawing of the permafrost to great depths.... The deformation of buildings is often due to the heat given off and to the discharge of water from sanitary installations."

The same source names five stations on the Amur railroad in eastern Siberia where thawing of the ground beneath dams led to leakage of reservoirs, which quickly become catastrophic, and some installations had to be abandoned.

A comparable statement from Alaska (11), in this case Fairbanks, reads:

> "Heated buildings on the alluvial fans and colluvial slopes are severely distorted unless special engineering techniques are

employed. Buildings with heated basements or buildings that allow heat to enter the ground in other ways have subsided differentially 1 to 2 feet or more, cracking walls and preventing windows and doors from opening. Some buildings are jacked up periodically to maintain a level position."

As a consequence of such conditions, older communities in Russia have been said to have a drunken appearance, and Nome, Alaska has been likened to a scene by a contemporary artist! Yet real success has been achieved both in North America and in the U.S.S.R., usually by strict adherence to now-recognized construction practices. Some of these are:

1. Selection of site. Places with large amounts of buried ice are to be avoided to prevent subsidence when the ground becomes warmed.

2. Preservation whenever possible of the site as it exists, even to the extent of avoiding unnecessary vehicle movement and destruction of the natural cover.

3. Precautions to ensure that the ground will remain frozen e.g., by burying the original surface under a pad of dry, coarse material (as was done with the right-of-way of the Hudson Bay Railroad), and by preventing the escape downward of heat or waste water. Buildings may also be placed on piling with a ventilated space beneath.

4. By allowing in certain cases for the building to settle in a predetermined manner as the ground thaws. This is sometimes unavoidable in the case of buildings with high heat output – e.g., metal refineries.

5. In general guarding against transfer of additional heat to the ground – including transmission of the sun's heat by conduction, and heat from buried water and sewage lines.

NEED FOR EXCHANGE OF INFORMATION

One of the surest ways of improving construction techniques in all such cases is through widespread interchange of experience – even though it may at times have been embarrassingly unsuccessful. As literature concerning North American practices is more readily available, it would seem most useful for me to cite examples from the Soviet Union. I shall refer specifically to the case of Norilsk, certainly the largest community in the zone of continuous permafrost and firmly and successfully established (12). The Soviet Census states that in 1959 it had a population of 108,000. It is an important centre of mineral production and processing. It mines coal, uranium, nickel, copper, cobalt and platinum, in fact fifteen metals are refined there. It is linked by railroad to the port of Dudinka on the east bank of the Yenesei River in latitude $69\frac{1}{2}°$ N. - about the same as Point Hope, Alaska; Cambridge Bay, N.W.T. ; and Disko Island and the Mestersvig mine in Greenland.

The settlement was started in 1935. Now more than 25 years old, it is regarded as a model for the study of large-scale construction in permafrost areas. Although in operation at the outbreak of World War II, the plant was expanded rapidly in the early 1940's because of the urgent need for nickel. The mine site lies in a hilly basin separated from the Yenesei River by eighty miles of swampy tundra. The climate is very severe with high winds and heavy snow in winter, together with a long period of darkness. The coal in the underground mine is of course frozen. The ore is mined by open pit methods.

Initially, it was decided that the only hope of constructing large buildings securely, including the smelters, would be by placing them on rock foundations. This required digging pits as much as 20 metres deep through frozen ground. Traditional wooden houses were built and located wherever it was convenient. Elaborate snow fences were necessary to make it possible to move within the settlement during winter.

There is no doubt that the town as first built, apart from the industrial units themselves, was of a make-shift character and left much to be desired. Apparently there has been a complete reconstruction since the early 1950's and a modern city has replaced the old mining camp. Excavation of large foundation pits has ceased. The earlier practice of placing piles in holes steamed in the ground has been discarded. Reinforced concrete piles are now frozen into holes made with a standard mining percussion drill. The piles are about twenty metres long and produced in a local plant at a rate of 500 a day. Buildings are generally of brick and precast concrete. Photographs (13) suggest that the city is now much like others of the same size in the U.S.S.R. - apartments are of six to eight storeys, there are broad thoroughfares, parks and the usual community enterprises - medical clinics, libraries with 600,000 books, a professional theatre, a very active full-time and part-time educational programme - thirty schools with an enrollment of about 1,300 students and, in addition, a mining and metallurgical technical school with 1,250 day and evening students. The headquarters of the Agricultural Institute of the Far North is there, together with a permafrost research centre. There are also neon signs and a T.V. station. The city claims to be built on two foundations - the mining operations and the permafrost. It is also a centre for study of construction methods by specialists from as far away as Yakutsk and Magadan in eastern Siberia and Salekhard and Vorkuta in the west.

The principles governing construction are said to be these:-

1. Very careful study of the terrain.
2. Foundations are excavated in winter and are laid in winter.

3. Piles are installed in drilled holes.
4. Bricks are laid in summer, but concrete slab construction goes on throughout the year.
5. Utilidors are employed for outdoor piping. They are periodically ventilated by air blown through them.
6. Buildings have a cold, vented basement or lower storey.
7. All buildings and other works are re-examined constantly. For example, the Permafrost Institute has 150 city houses and 20 village houses under observation, along with 100 industrial buildings and other structures, and 75 miles of outside pipelines. The "dynamics of permafrost" are under continuous study; it has been found that temperatures under the townsite are falling.

Research is continuing into such subjects as more efficient and economical types of utilidors (the present ones are double decked - with sewage pipes below, and steam, water and electric lines above); cold floors are complained of so that improved insulation is needed, and radiant heating of floors is being tested; there is need of a flexible seal of some sort to close gaps which may occur between walls and floors or elsewhere. Better pipeline insulation is required. There remain many problems in the efficient disposal of waste water (14).

NATURAL VEGETATION AND CULTIVATION

The distribution of natural vegetation, which is influenced by the presence of permafrost, is of indirect importance to northern settlement. A local supply of timber for construction and fuel is desirable. The comparatively luxuriant vegetation in some areas is in part made possible because the frozen ground does not permit the usual subsurface drainage, so that the modest precipitation becomes more effective. On the other hand, shallowness of the soil restricts the roots and in some cases stunts the growth of trees.

Agriculture is of considerable importance to settlement in some northern areas and is strongly influenced by permafrost (15). As already suggested, vegetative growth may be aided by retention of water near the root system. However, account must also be taken of the disadvantage of a "reserve of cold" retained near the surface where the roots are affected. Fortunately after two or three years of cultivation the permafrost table is lowered until it is usually below the depth reached by most plants. This can be encouraged by retaining snow drifts on the land and by heavy manuring in Spring. These techniques have assisted production of early ripening barley at Igarka in the U.S.S.R. The existence of permafrost may, under some circumstances, be a very considerable handicap to agriculture – notably when the ground contains large quantities of ice. Cultivation leads to thawing and settling – with the resulting hummocky appearance which in extreme cases is termed "thermokarst" from its superficial resemblance to limestone eroded by solution. There may be deep pits, trenches and gullies, as much as five to twenty-five feet across. The only long-term solution is to select areas where the ice content of the ground is low.

Despite the existence of permafrost in addition to a severe climate, small-scale agriculture has become significant in Alaska, northwestern Canada and parts of Siberia and northern Europe, when a local demand exists for the produce.

THE NEED

What should be done so that settlement of the far north, in any case likely to be slow, is not to be further delayed because of inability to operate efficiently and economically in permafrost areas? The following lines of action are suggested:-

1. The exact extent of permafrost distribution by area and depth in Canada is not yet known. Such ignorance should no longer be condoned. There is need for small-scale permafrost mapping of the whole north and of larger-scale mapping of selected areas. This, which is an obligation of the public service, is less a scientific problem than a technical one. In part it requires detailed field work, in part the assembling of existing data.
2. There is need for a freer interchange of information. The first essential is for this to be done within Canada itself, then with the United States. I do not refer here so much to the needs of scientists and other specialists but to the working contractor, engineer and architect, the administrator and the student in training. There is also an urgent need for far greater availability of recent information from the Soviet Union. The literature is now easier to obtain but few can use it in the original Russian. It should be translated on a comprehensive scale. Canada would seem to be a logical place for much of this to be done (16).
3. Literature is useful, the direct exchange of expert personnel is even more so. How many Canadians have been in the famous Obruchev Permafrost Institute in Moscow? Or that at Yakutsk? How many have personally seen and examined modern Soviet projects built on permafrost? Are there any? The barrier to such visits is in part a financial one but is also a political one. Tours should be made by Canadian students of permafrost to such sites as Norilsk, the mining centre of Vorkuta in the Pechora region, Yakutsk now a considerable research centre, and to some of the large new hydro projects scattered throughout Siberia.

4. Finally there is need within Canada for closer contact between the research scientist in university or government and the men who day by day are faced with practical problems. Those of us who have had contacts with Soviet arctic scientists have been impressed by the obviously close ties between them and those concerned with development and production. The practical man seems to turn spontaneously to the scientist for aid, and the scientist is constantly aware of the developments and discoveries made in the field.

Northern Canada will without doubt develop more rapidly in the next few decades than it has since 1930. The tempo of this development will depend upon the enterprise of industry and the attitude of governments. The cost of it, the success of the various undertakings and the comfort and happiness of those who will operate them and live in the new settlements, will depend greatly upon research done well in advance of the immediate need.

The science of geocryology – the study of frozen ground – and its many applications should take a leading place in northern research. It is to be hoped that government agencies, industries, the universities and such organizations as the Arctic Institute will, as a result of this First Canadian Conference on Permafrost, devote greater attention to the subject. The practical returns will more than justify this.

It may not be inappropriate to end by quoting from the distinguished Russian scientist S. P. Suslov, who wrote in his monumental study of Siberia (17):-

> "The geographer, climatologist, hydrologist, soil scientist, geomorphologist, botanist, entomologist, zoologist, agriculturalist, geologist, biochemist, engineer, architect, geophysicist, palaeontologist, archaeologist - all may find much to study and ponder in the regions where permafrost is found. Perhaps the time is not far off when the obstacle that permafrost places in the way of utilization of territories will, dialectically turn into its opposite, and become a powerful productive force that man can control and regulate."

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15. Suslov. op. cit. pp. 138-142.
    Péwé. op. cit. pp. 19-21.
16. An excellent beginning in the translation of polar literature from Russian to English is Problems of the North, published by the National Research Council in Ottawa.
17. Suslov. op. cit. p. 150.

N.B. The following photographs have been contributed by the Division of Building Research, National Research Council to illustrate construction techniques and problems in permafrost areas.

Fig. 1 Slump in gravel pit caused by melting of ground ice after removal of surface vegetation.

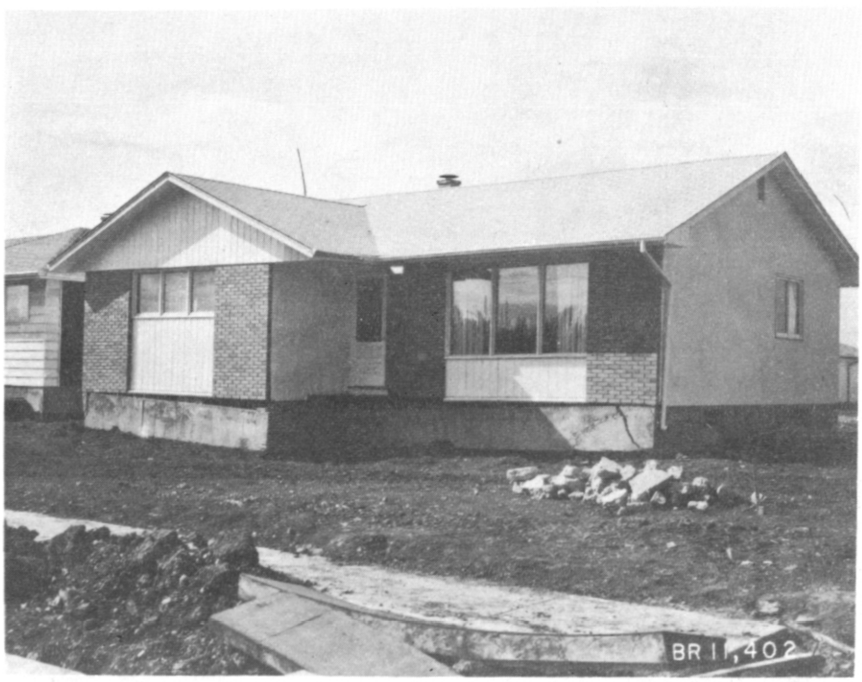

Fig. 2 Thawing of permafrost has caused house foundation to settle unevenly.

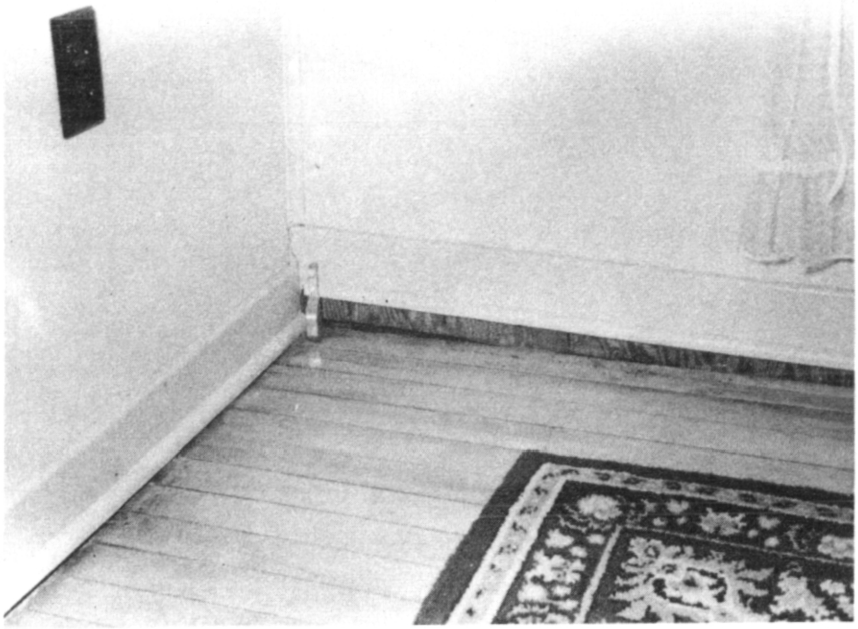

Fig. 3 Settlement of floor in room of house caused by thawing of permafrost.

Fig. 4 Pile steaming and driving on gravel pad for building foundation in continuous permafrost zone.

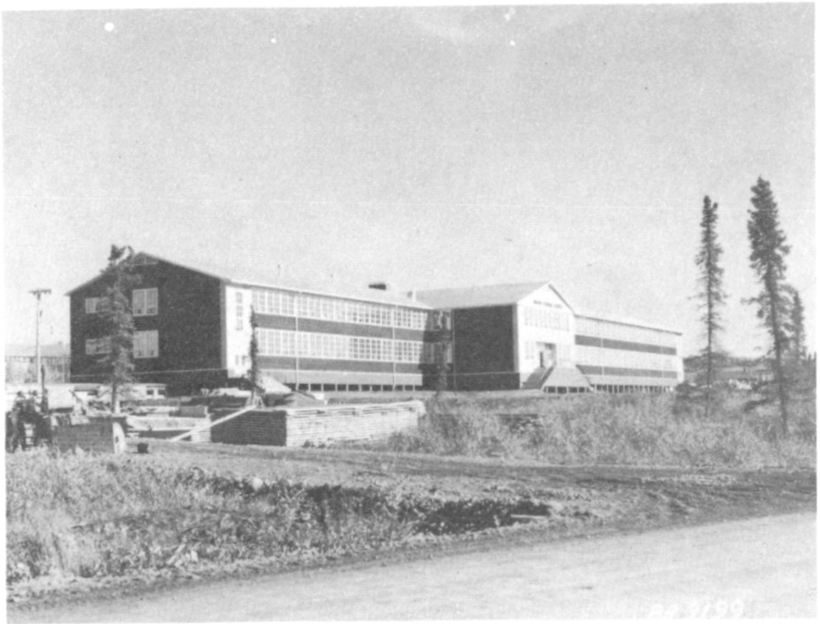

Fig. 5 Two-storey wood frame school on pile foundation in continuous permafrost zone.

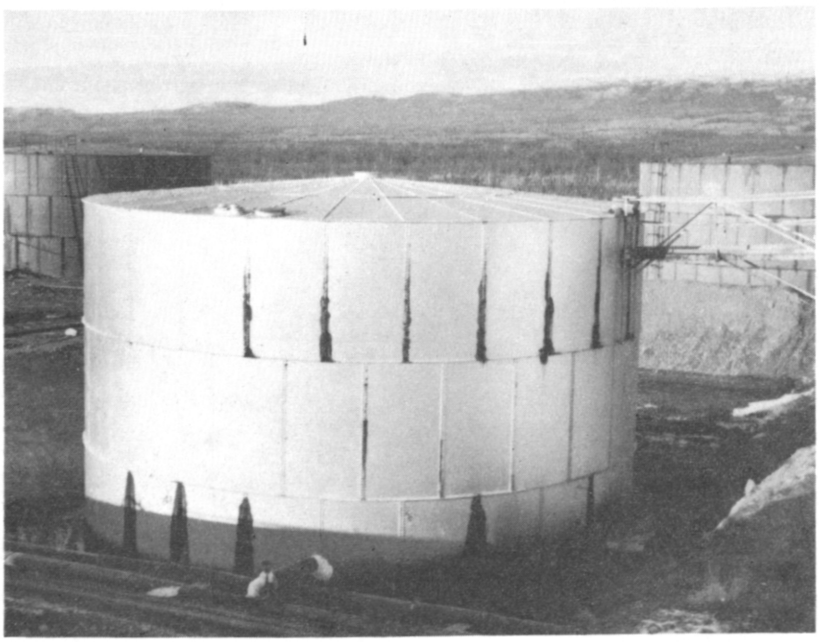

Fig. 6 Thawing of permafrost has caused oil tank to settle unevenly. Oil is leaking between buckled plates.

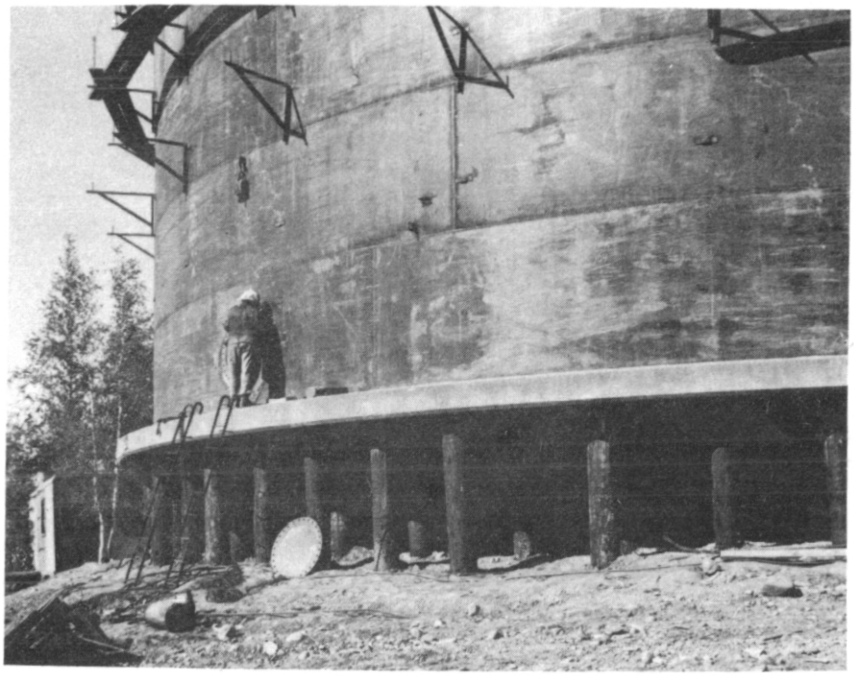

Fig. 7 Pile foundation prevents thawing of permafrost under large oil tank.

Fig. 8 Aluminum sided utilidors on piles in continuous permafrost zone.

Fig. 9 Aerial view of utilidors on piles carrying services to buildings in continuous permafrost zone.

Fig. 10 Construction of road has caused thawing and outflow of underlying perennially frozen silt containing ice near southern limit of permafrost region.