THERMAL EROSION PROBLEMS IN PIPELINING

T. G. Watmore

The recent increase in oil exploration activity, resulting from the Prudhoe Bay discovery on the arctic coast of Alaska, has moved industry into the permafrost region. Exploration and production methods in the continuous and discontinuous permafrost zones cannot be undertaken as they are in non-permafrost areas in the south. For example, removal of the thin insulating surface by a bulldozer blade during seismic operations has resulted in some thermal erosion. Buildings, roads, airstrips, domestic services, and communication systems, all demand special construction techniques suited to a permafrost environment.

Discovery of commercial oil will result in flowlines and pipelines in the Arctic. Their route location, supply roads, construction and laying techniques and maintenance in permafrost present the subject matter for a great deal of research.

This report documents observations made in the Mackenzie Delta area in early August and in mid-September 1968 with regard to surface damage caused through bulldozing seismograph cutlines. Lines bulldozed prior to freeze-up in October 1964 on the Peel Plateau west of Fort McPherson and others bulldozed in October 1965 near Tuktoyaktuk were inspected.

A short test pipeline at Inuvik was also examined one year after construction. The right-of-way had been stripped to permafrost and used by men and machinery for construction.

During the August 1968 visit, a ground fire occurred at Inuvik which burned over a large area and for a few days threatened the town. The destruction of the surface cover will have marked effects on the topography of the area.

The effects of thermal erosion on the ground surface in the Arctic by seismograph exploration and well drilling is presently minimal. An intensive exploration and development programme which could be triggered by a successful Canadian oil discovery would put industry into the North on a large scale. Collectively the operation could be very damaging to the arctic environment unless care is exercised and the delicate balance of the environment is allowed for in field operations.

The systems for operating in non-permafrost areas will not all suit the Arctic with its continuous and discontinuous permafrost. Industry should evaluate this challenge before intensive activity begins.

June to September are the four months in which Inuvik and Aklavik record mean daily temperatures above freezing. Fort McPherson adds the month of May while Tuktoyaktuk deletes the month of September. Temperatures below freezing may occur at these locations on individual days in any month.

At Inuvik the annual mean total precipitation is just under 11 inches. This is composed of 68 inches of snowfall and the remainder is rainfall. Fort McPherson records 11.6 inches, Aklavik 8.8 inches, and Tuktoyaktuk 6.2 inches as mean annual precipitation. Total precipitation in the delta must, therefore, be considered light.

Windswept tundra surfaces are blown virtually bare of winter snow which accumulates in protected gulleys and depressions. Thus when viewing surface damage in cutlines and other disturbed areas, it may be decided whether the major cause is from melt water runoff or thawing and subsidence of exposed permafrost. Photographs taken at the locations visited for this report indicate that subsidence through thawing of permafrost (thermokarst) accounts for more surface disfigurement than that through erosion from rain runoff and snow melt.

EXPERIMENTAL PIPELINE AT INUVIK

The experimental pipeline is located adjacent to the main access road between the townsite and airport. The site is in the subarctic boreal forest of the Mackenzie Delta. Right-of-way clearing in August of 1967 began with hand brushing of the trees followed by stripping of the surface by bulldozer down to the permafrost table. The trees were piled and many were later put through a chipper for use as surface insulating material. Working conditions were muddy during line laying due to thawing of the permafrost. Surface strippings were pushed back over the line in irregular piles by bulldozers following installation. The investigation of surface conditions one year later was made without the advantage of depth measurements to the permafrost table prior to clearing of the right-of-way.

Plate 1

The map shows the general Mackenzie Delta area with the Mackenzie River system flowing northward to the Arctic Ocean. To the west of the Delta the Richardson Mountains are shown extending into the Brooks Range of Alaska. The three sites visited for this report are shown in relationship to their positions in the Delta.

The bottom photographs show the subarctic vegetation of the Mackenzie Delta in which the pipeline is located. The black spruce is 10 to 15 feet high growing on hummocky ground of clay frost mounds covered by a mat of moss and lichen. Birch, willow and alder are also present. The clay frost mounds are 2 to 4 feet in diameter, 12 to 18 inches high and surrounded by a trench containing Sphagnum moss, grasses and sedges which cover a shallow depth of water over ice. The 4-inch return pipeline can be seen and the irregular pile of strippings cover the main line as a partial insulation. A row of ribboned profile stations cross the right-of-way in the foreground.

Plate 2

The right side of the pipeline right-of-way and a ribboned row of profile stations is shown in the upper photographs. The left side of the right-of-way was shown in Plate 1. In both photographs considerable water has collected in the cleared working areas along the line. Because only 1/4 inch of rain was recorded from June 1 to August 15, 1968, it is obvious that meltwater from the permafrost and greatest settlement in the ground with the highest ice content have accounted for the presence of the water.

Measurements recorded at the stations are shown on the profile plan below the photograph. The surface elevation line traverses between undisturbed ground on either side of the right-of-way. Depths to the permafrost table in the undisturbed areas on either side have been joined by dotted lines to indicate the assumed active layer originally present in the right-of-way. Shaded wedges between the undisturbed surface and permafrost line indicate troughs where Sphagnum moss is the only cover between the ground surface and the subsurface ice.

The disturbed working surface on either side of the line has settled approximately 1 foot in the year since construction. Permafrost has degraded 2 to 3 feet below the original position. The effect of piling surface strippings over the line shows no drop in the shallow trench in which the pipe was laid and the permafrost rises appreciably under this cover. Elevations on the line indicate there is no variation from the original values observed during construction.

Plate 3

South of the main road a second profile was taken along a length of wood chips which were piled, in random fashion, diagonally across a section of the right-of-way.

The photograph indicates, in an arc on the right, the humpy bared work area which had been scraped to the permafrost table. This was relatively flat during construction. Subsidence is now visible in the ground and water present is from thawing of the permafrost for previously mentioned reasons. Wood chip piles are seen along the line and the diagonal cross-sectioned portion crosses the line at the instrument stand.

The profile indicates, by dotted line, the original estimated permafrost table which joins undisturbed sections on opposite edges of the right-of-way. Ground settlement up to 1 1/2 feet is shown in the disturbed ground on either side of the line and permafrost recession approaching 3 feet can be noted. The most notable feature of this profile is the protection given to the permafrost by the wood chips. Unfortunately, the thickness varied from 4 inches to 3 feet which prevented an estimate of the depth of material required to give minimal effective cover.

BULLDOZED CUTLINES AT TUKTOYAKTUK

Ground Features

Some very interesting ground features exist in the far North in which soil types and intense frost action play major roles. Pingos, ground ice and ice wedge polygons comprise three of these features. In each case, the force exerted by ice in a suitable environment is the governing factor.

Pingos and ice wedge polygons are identifiable according to their shapes and presence in low lying poorly drained areas. Ground ice is more difficult to predict. The exposure of ground ice through wave and storm action along coastlines is quite obvious but inland many features are only obvious following a surface disturbance. The bulldozer when ploughing a trail across the landscape may tear the surface insulation off many areas of ground ice, thus initiating thawing.

The preservation of the insulating surface over these features holds the key to the stability of the subsurface. A pipeline laid across a surface containing these features might well be left suspended if proper insulating methods were not used.

Plate 4

Along the coastline of the Beaufort Sea approximately 4 1/2 miles southwest of Tuktoyaktuk massive ground ice is shown exposed beneath a thick layer of soil. Vertical air photographs indicate the presence of considerable erosion and slumping over a large area. Knee-deep mud and water prevented precise measurements of ice thickness, etc. but the boat paddle in the foreground gives some indication of relative sizes. Two ice wedges are also visible in the upper soil layer and extend to the ice sheet. Ice wedges may carry their shapes into and through the planes of ground ice.

The lower photograph shows a pingo in its poorly drained surroundings out of which it had been formed through freezing and ice accumulation. Ice wedge polygons can also be seen in the area surrounding the pingo.

Bulldozed Cutlines

In October 1965, prior to freeze-up, seismograph lines were bulldozed across the tundra surface of the Tuktoyaktuk peninsula. The cutlines peeled back long lines of surface vegetation and soils approximately 14 feet wide and 10 inches deep exposing a relatively smooth, firm surface near the permafrost table on which geophones could be placed. Surface strippings were left in irregular piles on the edge of the line.

These lines were now void of vegetation and surface soils which formed all or part of the material insulating the permafrost. Depending on the soil texture and ice contents in these lines, erosion and subsidence were ready to begin in varying degrees with the spring thaw.

Plate 5

The upper photograph shows an east-west cutline three years later in which limited vegetation has returned and water is pooled in the depressions. To the left, the ground rises in an 8° slope. At the position of the level rod, lying on the surface, one of three recessions into the hillside exist. The line had removed sufficient cover to initiate thawing into either three closely associated ice wedges or what may be a mound of virtually clear ice underlying the hill.

The lower photograph shows the present end of the recession which contains ice overlain by peat and clay with a thick surface vegetation mat. This recession, on the north side of the hill, has moved back approximately 27 feet from the cutline and grown to a depth of 5 feet in three years. Gradual stabilization may occur if sufficient surface cover topples and blankets the ice to provide an insulation barrier. The southern exposure has probably contributed to an increase in the thermal erosion.

Plate 6

The upper photograph shows damage originated by a bulldozer blade which scraped aside no more than 1 foot of peaty surface soil and vegetation for a seismograph line in October 1965. Thawing and settlement has produced a lengthy depression in the cutline which is greater in depth than 6 feet in places. Clear ice is visible under the overhanging surface mat beneath the helicopter. This feature occurs on a relatively flat plane. Ground conditions such as this would prove a problem for stabilization of backfill in pipeline ditching. Special insulation materials or hauling of fill would be necessary to prevent ice melt and the uncovering of a buried line.

The lower photograph shows clear ice under a layer of peat and surface vegetation about 4 feet thick. A bulldozer has ploughed a line through a system of ice wedge polygons and caused considerable subsidence and pooling of meltwater throughout the line. Stabilization has occurred in the surface at a lower elevation and regrowth of vegetation is very slow in the peat.

Plate 7

Previous photographs have indicated the more massive disturbances caused in permafrost through damage to the protective surface layers. The upper photograph of this plate shows a three-year old cutline on a moderately steep clay hillside covered by arctic vegetation. Winter gales virtually denude this higher surface of snow and, therefore, runoff water is insufficient for appreciable erosion. Rainfall is comparable in amount to that of a desert although heavy showers occur occasionally.

The lower photograph, in the same general area, shows a cutline in a broad flat expanse of arctic vegetation underlain by clay. Vegetation has made good recovery in three years, and only minor surface settlement is visible. A closer inspection of this vegetation showed that plants in the cutline are generally the progeny of those on the immediate edges of the line. Pipeline laying and surface restoration would not be a problem in these areas. Roads, however, might still have to be constructed by haul and fill because of permafrost conditions.

BULLDOZED CUTLINES ON PEEL PLATEAU

Surface vegetation on the Peel Plateau is very similar to the Tuktoyaktuk area except that deeply incised drainage courses crossing the plateau from the Richardson Mountains sustain a protected growth of spruce, birch, and other trees in their valleys. Scattered small clumps of stunted spruce also grow in suitable environments on the open plateau.

Shales and sandstones underlie a generally well drained surface which is quite the opposite of the lower altitudes of the Tuktoyaktuk area. A limited inspection revealed the presence of ice features, such as mounds, slumps, and polygons although probably more infrequent than in the Tuktoyaktuk area.

Plate 8

Thawing of an ice mound is in progress in the upper photograph. A saturated layer of slowly descending clay covers the ice face. The exposed ice is 10 feet thick at the apex and 2 feet of silty soil and vegetation comprise the surface cover. Clumps of vegetation hang over the face ready to fall when the ice recedes sufficiently. A bulldozed cutline goes around both sides of this feature but has not been the originating cause of the disturbance. Any construction across or through a feature such as this would require extreme caution in the preservation of the insulating mantle.

The bottom photograph shows a cutline used as the main access line from the Peel River in the distance onto the plateau beginning ascent in the foreground. The line followed a gulley up to the plateau which caused some minor localized increase in erosion. The several miles of flat bulldozed line have stabilized quickly with only a few eroded pockets amidst an excellent return of native grasses. Seeding of grasses and fertilizing for rapid regrowth would be sufficient for surface stabilization in these soils. The adjacent woody vegetation was not noted to have encroached on the line in the first four years.

Plate 9

Deep erosion originating from a bulldozed line stripping off the surface vegetation mat is shown in the photograph. The view is from east to west with the Richardson Mountains in the background. The bulldozed line permitted drainage to travel down an overall 3 per cent slope for a distance of 1 1/2 miles. In four years, a gulley 23 feet across and 8 feet deep has developed at this point. Further uphill depths of gulleying range from 5 to 3 feet and gradually decrease. The slope, distance and accumulation of snow on one steep mountainside, no doubt add an appreciable amount of runoff to the new drainage course. The gulley also now acts as an excellent trap for drifting snow. If blocks had been placed originally to divert drainage into several shallow vegetated gulleys adjacent to the line, this severe erosion may have been avoided.

The profile reproduction gives the relative location of the feature and its cross-section. A small steady flow of water 4 to 5 inches wide and approximately 1/2 inch deep was observed. Because virtually no rainfall occurred from June 1 to August 15, it is concluded that this water supply along the new drainage course originated from melting ground ice in the permafrost.

SURFACE FIRE DAMAGE AT INUVIK

Some observations were made of surface conditions approximately one month after a severe forest fire which began about August 11, and for several days threatened the town and surrounding structures. A small fire spread into several large fronts and moved over the forest and tundra with a wall of fire reported by bulldozer operators to be as much as 15 feet high with very intense heat. Bulldozers ringed the valley bottom around Inuvik with fire guard cutlines as the flames spread over the flat areas and up the hillsides.

Plate 10

The upper photograph shows the "skeleton" of clay frost mounds whose rugged shapes are noticeable throughout the Delta area. Grasses, sedges and Sphagnum mosses filled the trenches and ground birch, Labrador tea, lichens, cranberry, and other plants grew on the tops. The photograph in Plate 1 shows similar ground with a full cover of vegetation. A road built by haul and fill method is shown in the upper portion of the photograph. A 12 foot level rod lies across the mounds in the centre. The removal of the surface vegetation cover will now permit deeper thawing of the permafrost, and it remains to be seen what new surface conditions develop.

The lower photograph shows a bulldozed fireguard line on a clay surface. In thirty days or less a water course 2 feet wide was created 18 inches below the surface originally bulldozed to the permafrost table.

Plate 11

A layer of what appeared to be clear ice when chipped supports, temporarily, a layer of clay in the upper photograph.

The lower aerial view shows the release of permafrost waters along the slopes of the fire-bared hillsides northeast of Inuvik. The amount of erosion in the upper photograph and the volume of released permafrost waters in the lower photograph have developed between August 15 and September 15, a period of one month. Prior to the fire, streams carried only small trickles of water due to the absence of rainfall for 2 1/2 months. Erosion will now increase and the total effect of the fire damage remains to be assessed in the seasons to come.

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Discussion

Dr. R.J.E. Brown commented on fire as a terrain factor affecting permafrost. Less attention has been paid to this than other factors but it is obviously important as evidenced by the author's observations at Inuvik. Although it is a temporary factor of short duration, it can be very significant. Its effects are governed, however, by such factors as the speed with which a fire moves through an area, the heat of the fire, and the moisture content of the surface vegetation. Many forested palsas in the Hudson Bay Lowland in the permafrost region of Northern Ontario show evidence of recent burning. One palsa was visited in 1965 which had been burned earlier the same summer. The trees were charred, the continuous moss cover was blackened and the patches of lichen were burned to white ash. The charred layer extended only one inch below the ground surface beneath which the moss and peat were untouched by the fire. The depth of the active layer did not appear to be significantly different from the active layer in the surrounding unburned areas. The short-termed heat of the fire and the greatly increased albedo of the blackened surface did not appear to affect the underlying permafrost. This is quite the opposite extreme from the situation described by the author at Inuvik where the fire removed the insulating vegetative cover exposing the underlying permafrost to intensive thawing.

Mr. J.G. Dennis submitted the following discussion to the papers by Messrs. J.C. Sproule and T.G. Watmore:

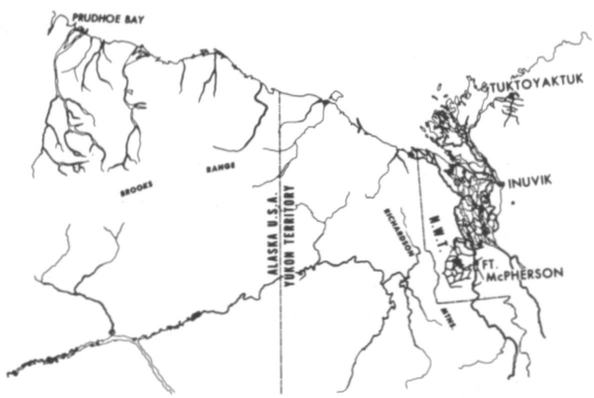
Dr. Sproule oversimplified the relationship between photosynthesis and the environment. Plant growth in the Arctic is primarily limited by temperature, and the 24-hour day cannot compensate entirely for the low summer temperatures which prevail. His pictures of agriculture in the permafrost region were taken probably from locations in the more southerly, forested areas. Such locations generally have warmer summer temperatures than more northerly parts of the permafrost region. The sparseness of the vegetation in Dr. Sproule's photographs of the Arctic Islands suggests that plant growth rates in the Far North are much reduced, compared to growth rates in the agricultural area of the permafrost region. Reduction of growth in the Far North is due to poorly developed soil, moisture deficit and low growing season temperatures.

The lush areas of tundra in the continuous permafrost region provide a false notion of vigorous plant growth. Even in such apparently lush areas, growth is slow. For example, annual growth, expressed in terms of above ground dry weight increase, is probably no more than 20 to 40 per cent of that in unburned Missouri prairie, 10 to 20 per cent of that in planted deciduous forest in England, or 5 to 10 per cent of that in planted pine forest in England. Elongation of rhizomes in the continuous permafrost zone may proceed at rates of no more than 10 to 30 cm per year. Likewise, seed production in these tundra areas may be sporadic and of low yield.

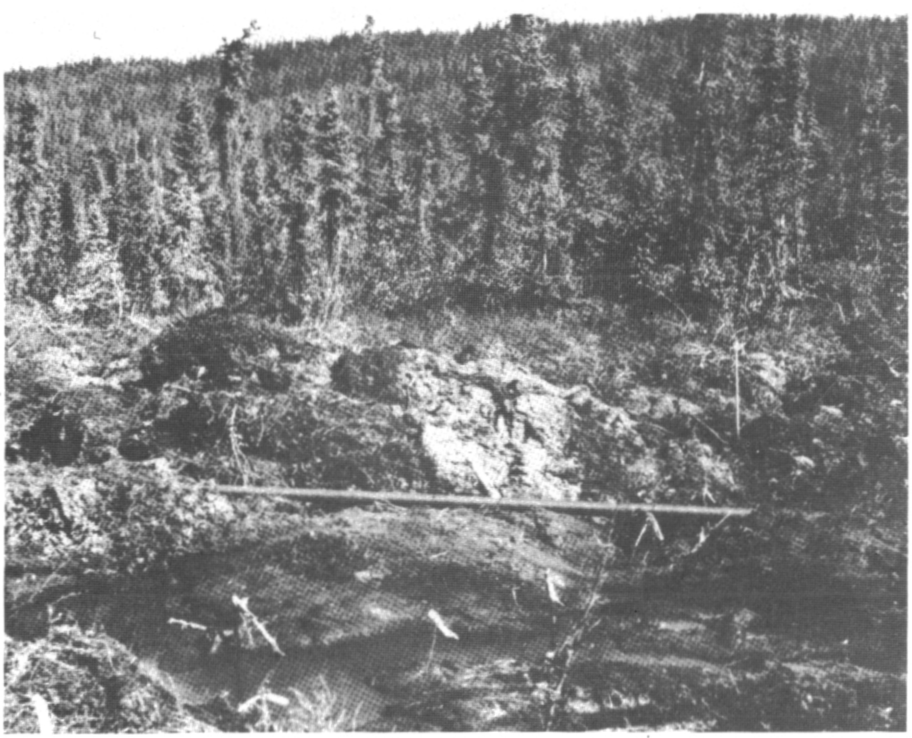
Natural revegetation of disturbed areas in the continuous permafrost zone occurs very sluggishly, compared to rates of revegetation in temperate regions. Natural reseeding cannot be expected to provide rapid revegetation, due to problems of seed production and establishment of seedlings. Vegetative growth into disturbed sites from adjacent, undisturbed plant cover, provides revegetation only slowly. For example, vegetatively produced recovery of plant cover on a 4 metre wide abandoned road could take more than 20 years, even under optimal conditions for growth. Such optimal conditions are unlikely to exist, however, after thawing of permafrost in organic or mineral soils with high content. Hence, mud holes and ponds, created by the destruction of vegetation and the associated deeper thawing that are caused by poorly designed construction activities, may be seasonally present throughout the time span of the construction effort, and for many years thereafter.

Companies engaged in construction in the continuous permafrost zone, and especially on tundra areas having low relief and poor drainage, would benefit from careful preliminary planning based on thawing season field studies. Such thawing season examination of build ing areas would permit site evaluations and subsequent camp designs that are based on microtopographic and vegetational indicators, as well as on other, more standard, considerations. Well designed camp layouts could accelerate rates of construction during subsequent winters. Such layouts could also reduce the magnitude of seasonally recurring problems of mud holes, and of destruction of structures due to settlement, frost heaving, and other factors.

MAP OF MACKENZIE DELTA AREA N.W.T.



EXPERIMENTAL PIPELINE - INUVIK N.W.T.



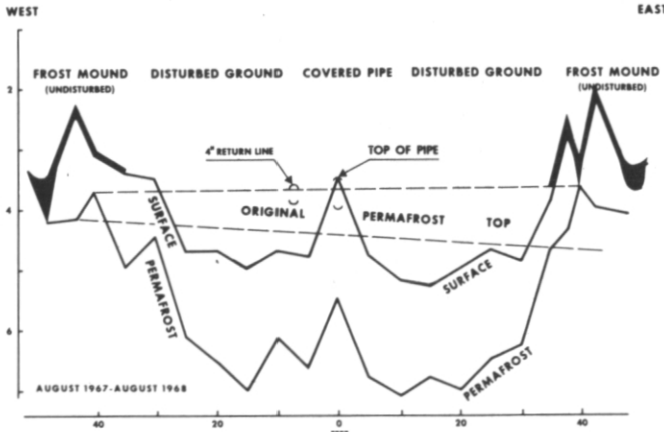
LEFT SIDE OF PROFILE - MAIN LINE
UNDER SOD PILE

EXPERIMENTAL PIPELINE - INUVIK

RIGHT SIDE OF PROFILE

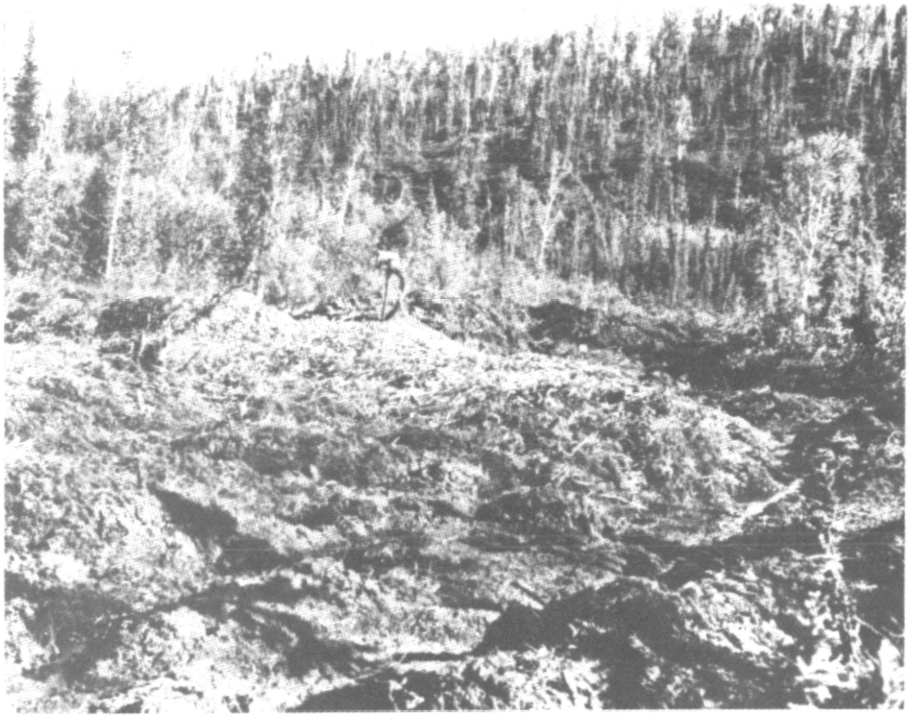
INUVIK

TEST PIPELINE NORTH OF AIRPORT ROAD

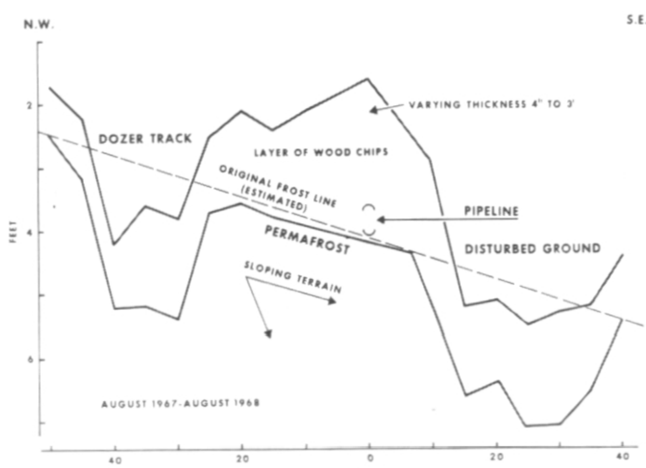


PROFILE ACROSS RIGHT-OF-WAY

EXPERIMENTAL PIPELINE - INUVIK



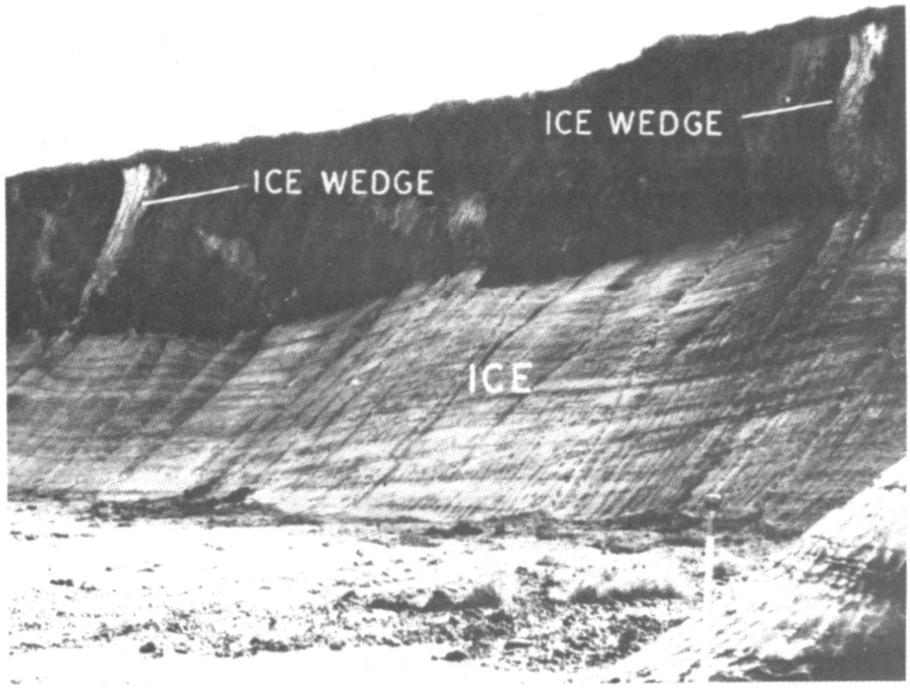
WOOD CHIPS ACROSS PART OF RIGHT OF WAY



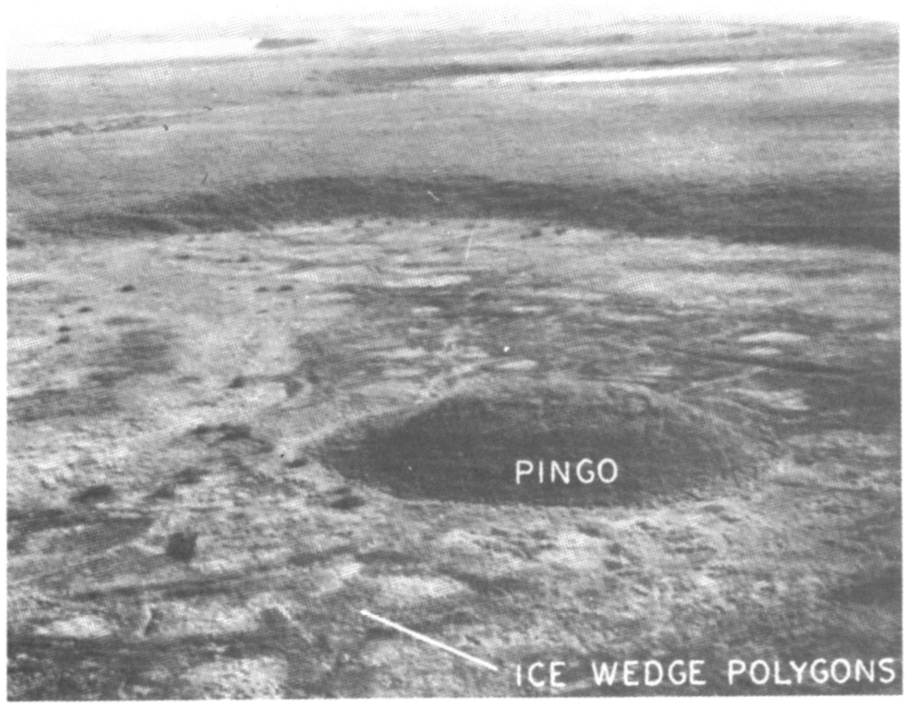
RIGHT-OF-WAY PROFILE ACROSS WOOD CHIPS

PLATE 3

TUKTOYAKTUK PENINSULA - GROUND FEATURES



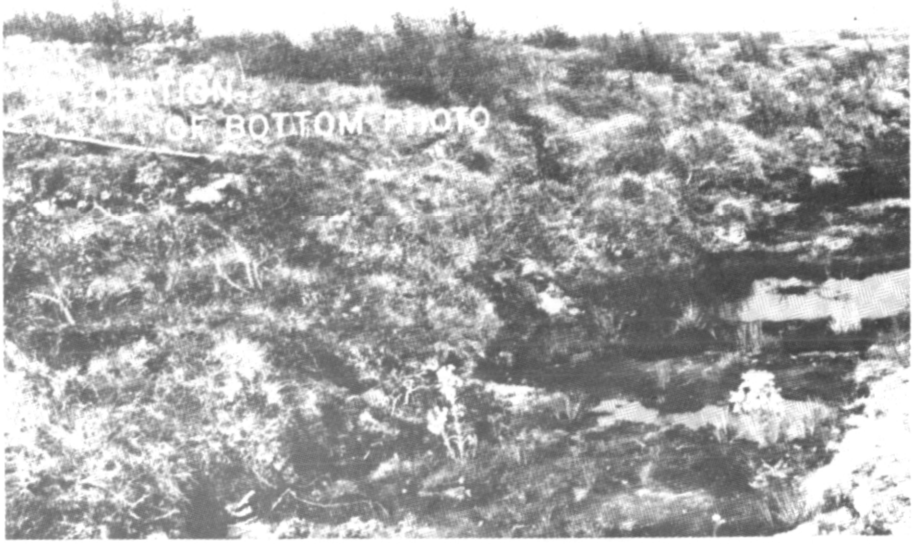
MASSIVE GROUND ICE
ALONG THE ARCTIC COASTLINE



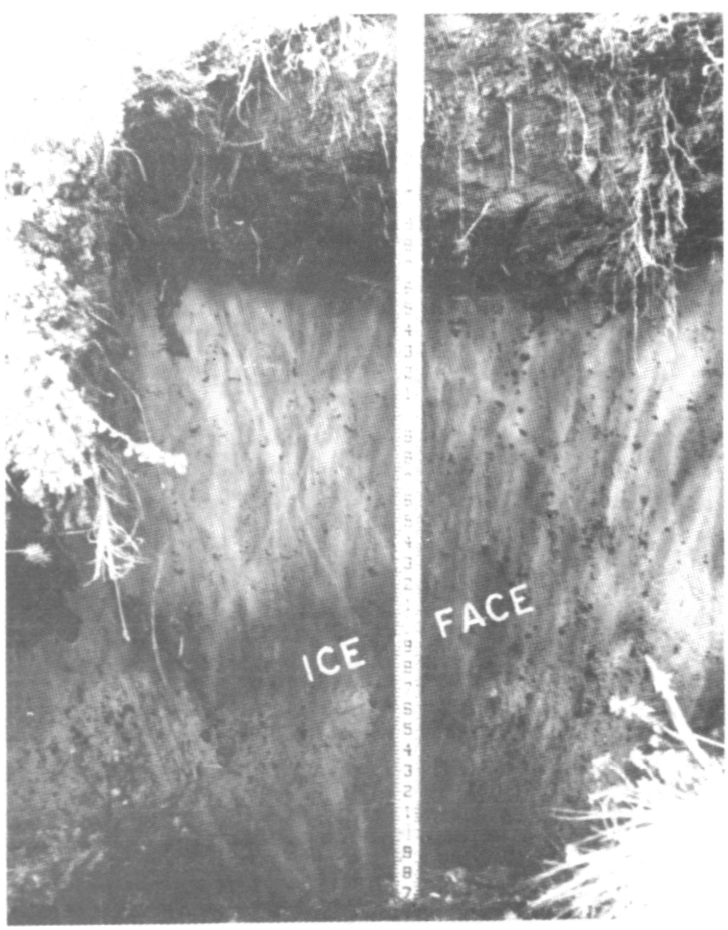
PINGO AND POLYGONS

PLATE 4

TUKTOYAKTUK PENINSULA - BULLDOZED CUTLINES



3 YEAR OLD CUTLINE AT BASE OF HILL

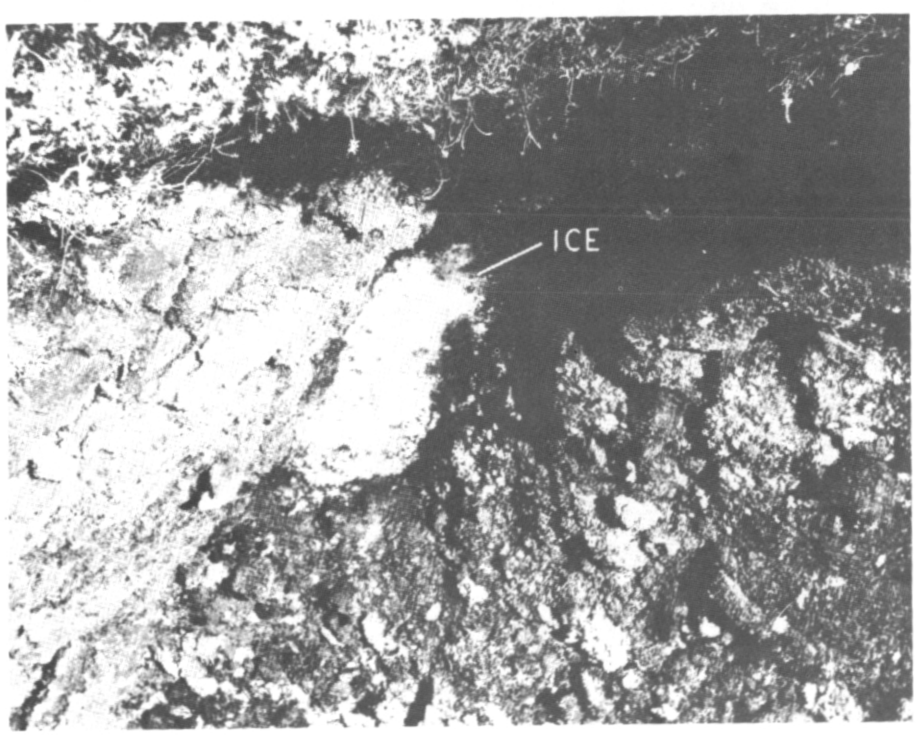


RECESSION INTO HILLSIDE CAUSED BY CUTLINE
IN TOP PHOTO

PLATE 5

TUKTOYAKTUK PENINSULA - BULLDOZED CUTLINES

DEEP THAW RESULTING FROM BULLDOZED CUTLINE

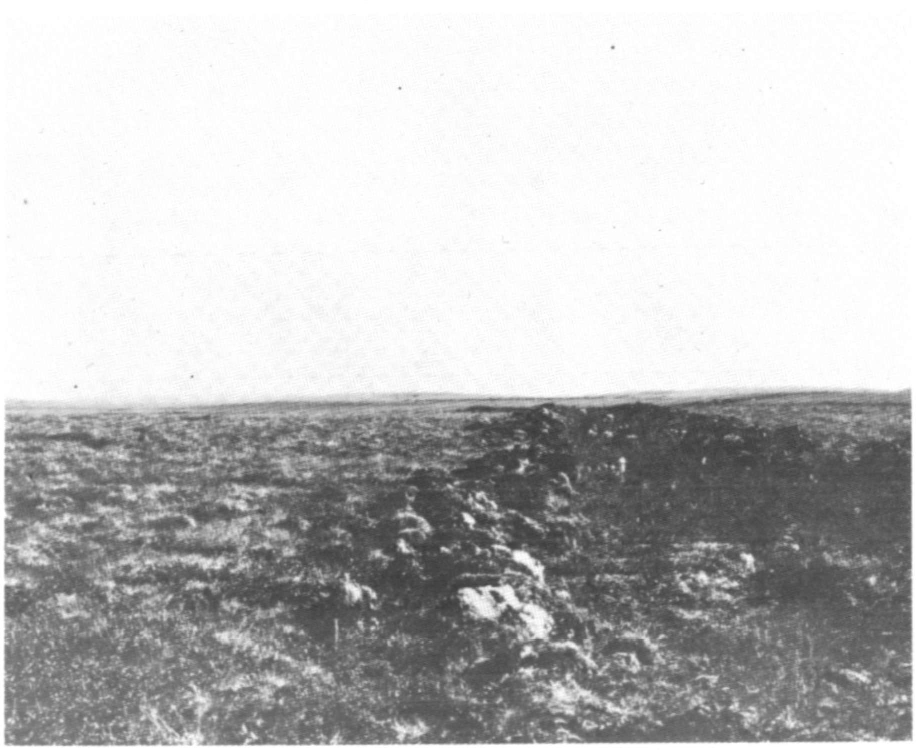


ICE INSULATED BY PEAT IN BOTTOM OF A SETTLED CUTLINE THROUGH PEAT POLYGONS

PLATE 6

TUKTOYAKTUK PENINSULA

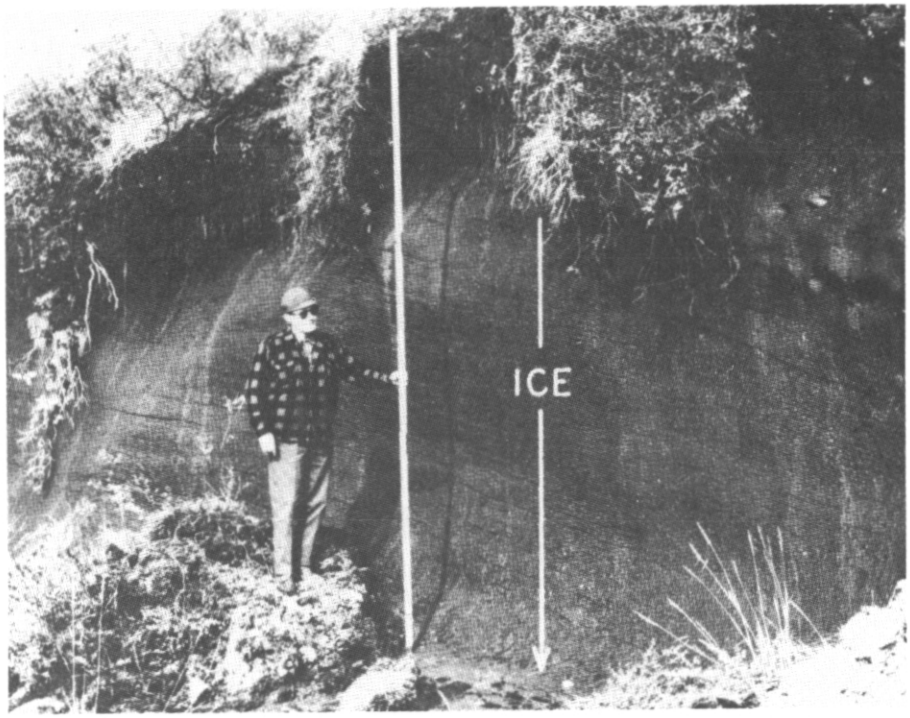
BULLDOZED CUTLINE ON HILLSIDE SHOWING
MINIMUM DISTURBANCE



BULLDOZED CUTLINE WITH RETURN OF VEGETATION

PLATE 7

FORT McPHERSON - PEEL PLATEAU



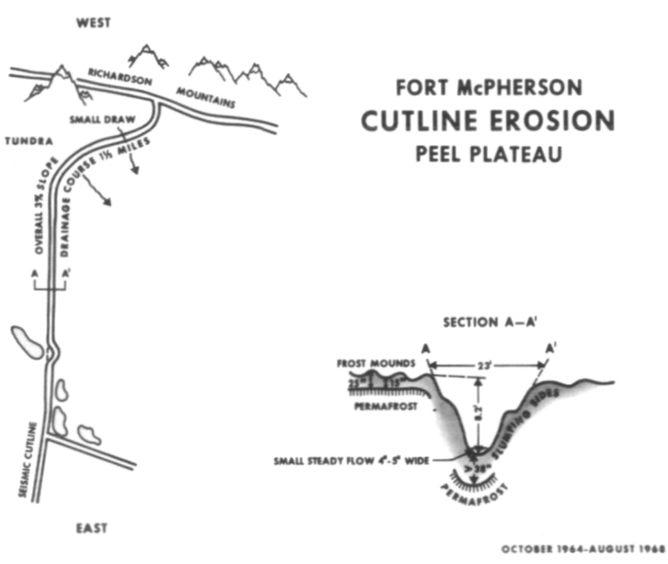
SEGREGATED ICE MOUND - MASKED BY
WET CLAY FACE

NATURAL REVEGETATION OF A CUTLINE

PLATE 8

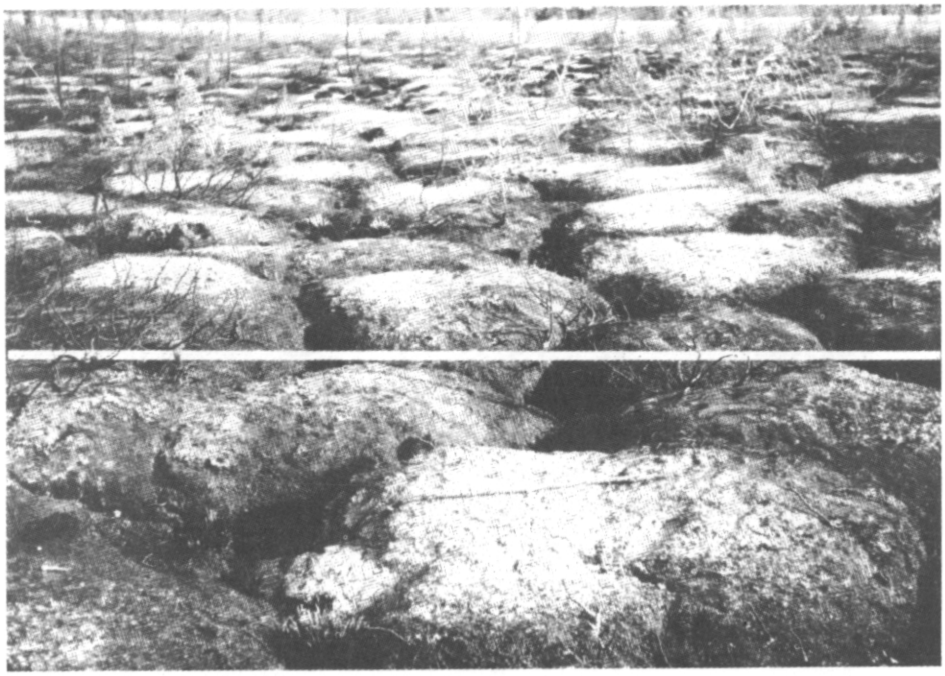
FORT McPHERSON - PEEL PLATEAU

EROSION IN SEISMOGRAPH CUTLINE

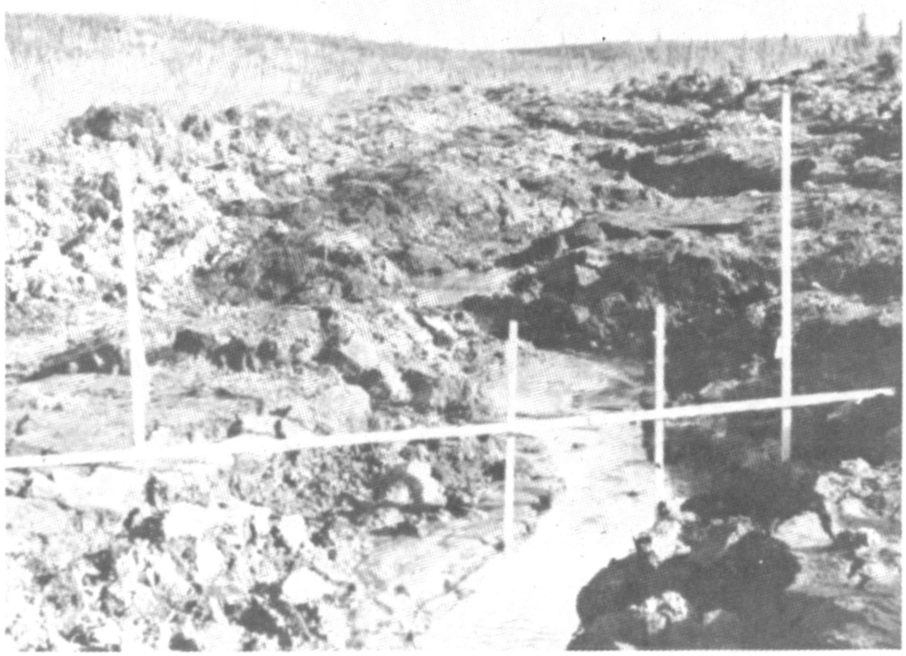


PLAN VIEW AND CROSS SECTION
FOR PHOTOGRAPH

INUVIK - SURFACE DAMAGE BY FIRE



FROST MOUNDS WITH VEGETATION BURNED OFF



EROSION IN FIREGUARD - 30 DAYS AFTER FIRE

PLATE 10

INUVIK - SURFACE DAMAGE BY FIRE

EROSION SHOWING ICE LENS SUPPORTING
SOIL BEHIND LEVEL ROD

RELEASE OF PERMAFROST WATERS
ON BURNED OFF HILLSIDE

PLATE II