SOILS OF NORTHERN CANADIAN PEATLANDS:

THEIR CHARACTERISTICS AND STABILITY

C. TARNOCAI and S.C. ZOLTAI

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SOILS OF NORTHERN CANADIAN PEATLANDS: THEIR CHARACTERISTICS AND STABILITY

C. Tarnocai and S.C. Zoltai[1]

INTRODUCTION

Organic soils associated with peatlands comprise approximately 12% of the land area of Canada. On approximately 927 113 km^2, according to the Soil Map of Canada (Clayton et al. 1977), they are the dominant soils and, on an additional 152 751 km^2, they occur in association with other soils. Approximately 60% of these soils are perennially frozen, while the remaining 40% are unfrozen. Thus, the perennially frozen peatlands are by far the most common types in northern Canada, with unfrozen peatlands, although present in the north, occurring mainly in the south.

As the pace and scope of human activity in northern Canada has accelerated and expanded during the last two decades, peatlands and organic soils have been affected by increasing development and land use practices. Research has shown that perennially frozen peatlands are especially sensitive to damage (Kurfurst 1973, Strang 1973, Sims 1976, Reid 1977). These soils can be called fragile, as even a relatively slight disturbance can cause a long-lasting detrimental effect that is out of proportion to the initial action. Recent experience, however, has taught us that when extreme caution is exercised and proper management practices are applied, it is possible to avoid serious and lasting environmental damage.

This paper deals with the most common peatland types of northern Canada and with their associated soils. The stability of these soils under natural conditions and under different land use practices is discussed.

[1]Respectively, Land Resource Research Institute, K.W. Neatby Bldg., Ottawa, Ontario K1A 0C6, Canada; Northern Forest Research Centre, Edmonton, Alberta T6H 3S5, Canada.

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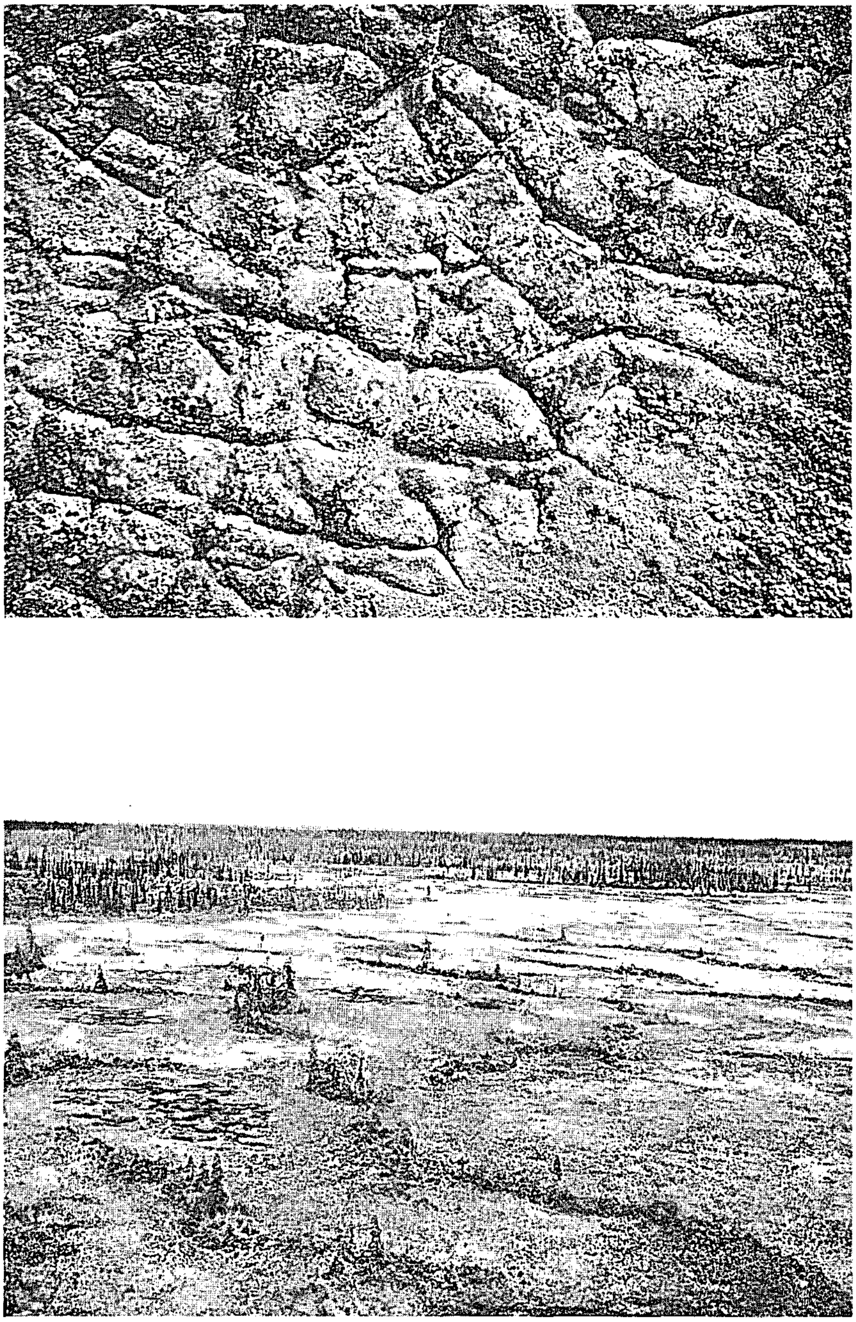

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Figure 1. Common peatland types in northern Canada.

A. High-centre lowland polygons near Tuktoyaktuk, N.W.T.

B. Patterned fen near Fort Simpson, N.W.T.

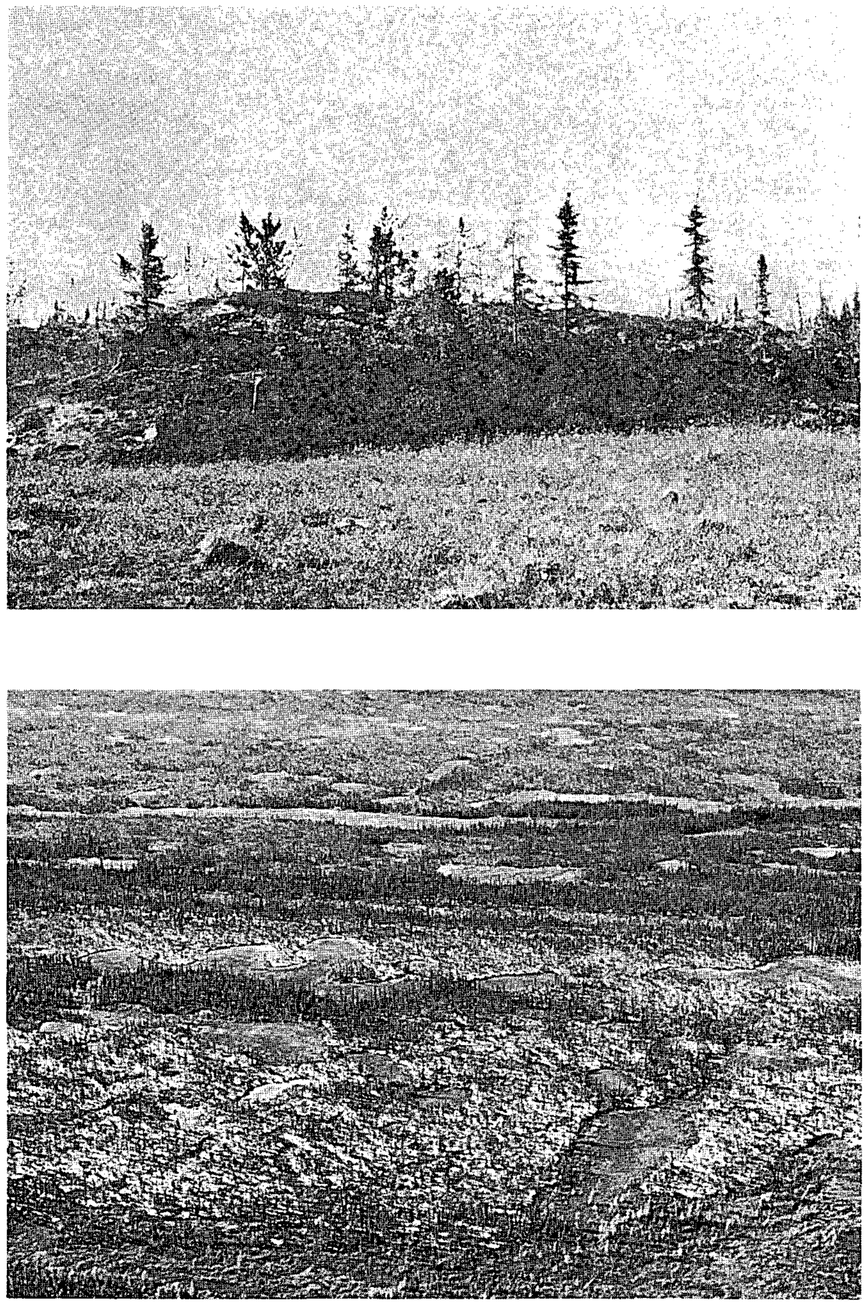

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Figure 2. Common peatland types in northern Canada.

A. Wooded palsa, approximately 5 m high, near the Nahanni Range in the Sibbeston Lake area, N.W.T.

B. Open black spruce-lichen covered peat plateaus west of Norman Wells, N.W.T.

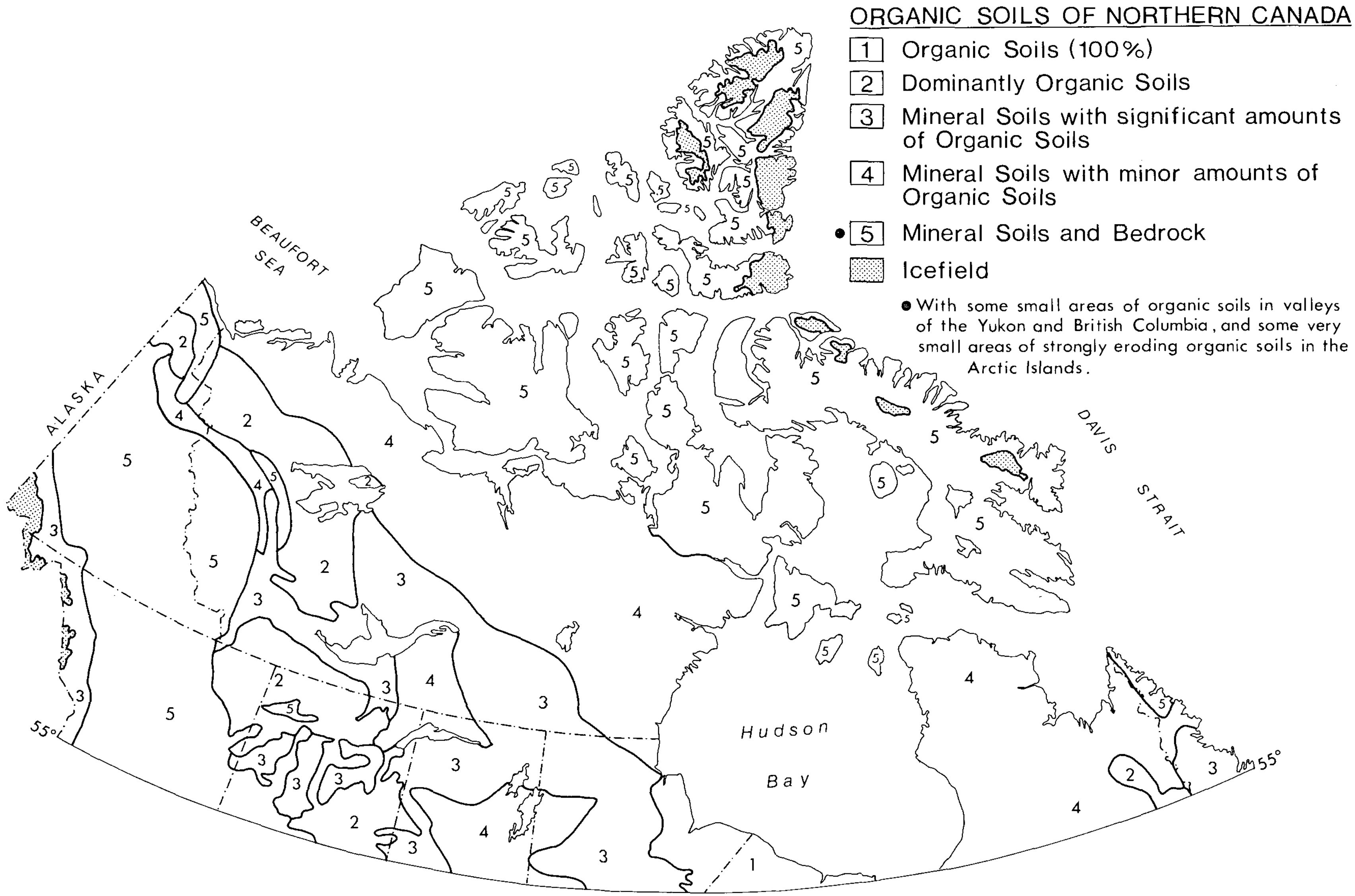

Figure 3. Organic soils of northern Canada. (The northern part of the provinces are mainly after Clayton et al. 1977).

TABLE 1. SOME OF THE PHYSICAL AND CHEMICAL PROPERTIES OF ORGANIC SOIL

Horizon	Depth cm	Material	Fiber Content % Undist.	Rubbed	Pyro-phos. %	Ash %	pH	Org. C %	N %	CEC meq.	Exchangeable Cations meq/100g Ca	Mg	K	Na	H
			Fibric Organic Cryosol (Tarnocai 1973)												
Of	0- 25	Sphagnum peat	88	-	0.12	2.61	2.5	60.3	1.57	99	8.08	3.03	0.89	0.61	85.95
Ofz1	25-119	Sphagnum peat	80	-	0.18	2.90	3.1	61.6	0.91	109	20.70	2.52	0.16	0.63	85.00
Ofz2	119-212	Sphagnum peat	78	-	0.20	4.41	4.1	64.8	0.81	105	40.90	4.79	0.20	0.65	58.00
Ofz3	212-260	Brown-moss fen peat	72	-	0.64	12.28	4.7	58.5	1.11	131	73.73	11.86	0.20	0.80	44.50
11Cgz	260-290	Clay loam	-	-	-	-	6.0	-	-	28	21.79	4.25	0.37	0.50	0.58
			Mesic Organic Cryosol (Tarnocai 1972a)												
Of	0- 84	Woody forest peat	83	-	-	4.9	4.3	48	1.01	126	33.50	27.00	0.02	0.05	59.9
Omz1	84-188	Moss and woody forest peat	60	-	-	7.3	5.4	49	2.02	139	86.00	20.80	0.02	0.07	26.9
Omz2	188-226	Moss forest peat	33	-	-	20.5	6.0	53	-	110	71.48	20.60	0.60	0.80	13.9
11Cgz	226-319	Clay	-	-	-	-	7.3	2	0.01	23	-	-	-	-	-
			Terric Mesisol (Mills et al. 1977)												
Om1	0- 30	Fen peat	58	22	20.5	15.0	6.7	56.7	2.4	156	116.7	26.3	0.8	0.6	12.0
Om2	30- 60	Fen peat	54	6	20.6	12.9	5.9	55.5	2.4	172	124.7	25.5	0.2	0.4	21.5
Om3	60- 90	Fen peat	42	2	35.0	12.5	6.2	59.0	2.7	186	140.6	27.8	0.1	0.4	17.5
Oh	90-110	Fen peat	38	-	28.7	10.9	6.2	58.1	2.9	184	144.4	26.3	0.1	0.3	13.0
11Ckg	110+	Very fine sand	-	-	-	-	7.2	-	-	-					

ORGANIC SOILS

Associated Peat Landforms

The predominant peat landforms occurring in the Arctic (north of the arctic tree line) are the lowland polygons (Figure 1A) of both the high- and low-centre types (Zoltai and Tarnocai 1975). In the vicinity of the arctic tree line, polygonal peat plateaus become the dominant landform type (Zoltai and Tarnocai 1975). Still further south, the vast areas of the northern coniferous forest are associated with peat plateaus and palsas (Figure 2, A and B), with increasing amounts of fen (Figure 1B) and unfrozen bog peat landforms (Tarnocai 1970, 1974; Zoltai et al. 1975; Zoltai and Tarnocai 1975) being found in the southern portion.

Distribution and Composition

The term "organic soils" refers to all soils which have more than 40 cm of organic material or, if the soil is underlain by bedrock, more than 10 cm of organic material. They are classified as Organic Cryosols in Canada (Canada Soil Survey Committee 1978) or as Pergelic Histosols and Pergelic Histic subgroups of other orders in the United States (Soil Survey Staff 1975) if perennially frozen conditions exist within 1 m of the surface. On the other hand, if no perennially frozen conditions exist, they are classified in the Organic Order in Canada (Canada Soil Survey Committee 1978) or as Histosols in the United States (Soil Survey Staff 1975).

Organic soils developed from peat materials represent one of the major soils across a wide belt in northern Canada (Figure 3). These soils are dominantly Organic Cryosols (Pergelic Histosols) with only small amounts of Mesisols and Fibrisols (Histosols) occurring in the south. In the Cordillerran region (northern British Columbia and the Yukon Territory) organic soils occur mainly in small areas in the valleys. On the arctic islands only very small areas of strongly eroding organic soils are found.

The Organic Cryosols, which are associated with perennially frozen peat landforms, have developed mainly from moderately decomposed forest peat or forest peat underlain by fen peat (Mesic Organic Cryosol) and from undecomposed sphagnum peat (Fibric Organic Cryosol). The chemical properties of these soils depend mainly on the peat materials from which they have developed. In general, soils developed from forest peat are medium to strongly acid while those developed from sphagnum peat are very strongly to extremely acid (Table 1).

Unfrozen organic soils, which belong to the Organic Order, occur dominantly in the more southerly peatlands of northern Canada. Mesisols, which have developed from fen peat are medium acid (Table 1) and are associated mainly with horizontal and patterned fens (Figure 1B) (Tarnocai 1970, 1974; Zoltai et al. 1973). Fibrisols have developed from forest and sphagnum peat and are associated with blanket bogs, flat bogs and bog plateaus (Tarnocai 1970, 1974; Zoltai et al. 1973). Most of these soils, especially those associated with fen peatlands, are very poorly drained and are saturated with water to the surface for most of the year.

PROPERTIES AFFECTING SOIL STABILITY

One of the main reasons for the sensitivity of perennially frozen organic soils, particularly of those occurring in the discontinuous permafrost zone, is their very delicate thermal balance with their environment. Soil temperature data concerning Organic Cryosols in central Manitoba (Table 2) indicate that the mean annual soil temperature of the perennially frozen layer is at, or slightly below, 0°C. During the summer months both the active layer and the vegetation cover provide the insulation that maintains the negative thermal balance of the frozen core. Any disturbance in the vegetation and, especially, drastic disturbance and removal of the active layer will upset this balance and trigger thermal degradation (Thie 1974, Reid 1977). Thus, the surface peat cover plays a very important role in maintaining a negative thermal balance in the perennially frozen subsoil.

TABLE 2. MEAN ANNUAL SOIL TEMPERATURES (1971-1977) OF PERENNIALLY FROZEN ORGANIC SOILS IN NORTH CENTRAL MANITOBA (MEASURED AT VARIOUS DEPTHS)

	Location		Mean Annual Soil Temperature °C			
Site No.	Lat.	Long.	20 cm	50 cm	100 cm	150 cm
63K1	54°26' N	100°52' W	1.3	0.2	-0.1	-0.1
63K2	54°38' N	101°05' W	1.5	0.1	-0.2	-0.2
63K6	54°35' N	100°52' W	0.6	0.0	-0.2	-0.2
6301	55°28' N	98°09' W	1.5	0.2	-0.1	-0.1

Another reason for this sensitivity, particularly of the Organic Cryosols, is the high ice content. Organic Cryosols associated with palsas and peat plateaus have an ice content that ranges between 60% and 90% on a volume basis (Tarnocai 1972a, 1973; Zoltai and Tarnocai 1971, 1975). Ice occurs mainly in the form of ice crystals in these soils, but ice layers and lenses are common at the peat-mineral soil interface. The elevation of palsas 1-5 m above the peatland is caused by a corresponding accumulation of ice, mainly in the top layers of the mineral subsoil. In addition to these ice forms, Organic Cryosols associated with polygonal peat plateaus and lowland polygons contain large amounts of wedge ice (Figure 4) (Tarnocai 1973; Zoltai and Tarnocai 1975). Although the moisture content of perennially frozen peat is generally comparable to that of peat in unfrozen peatlands (80-95%), the presence of ice in layers or wedges increases the total moisture content of the frozen peatland.

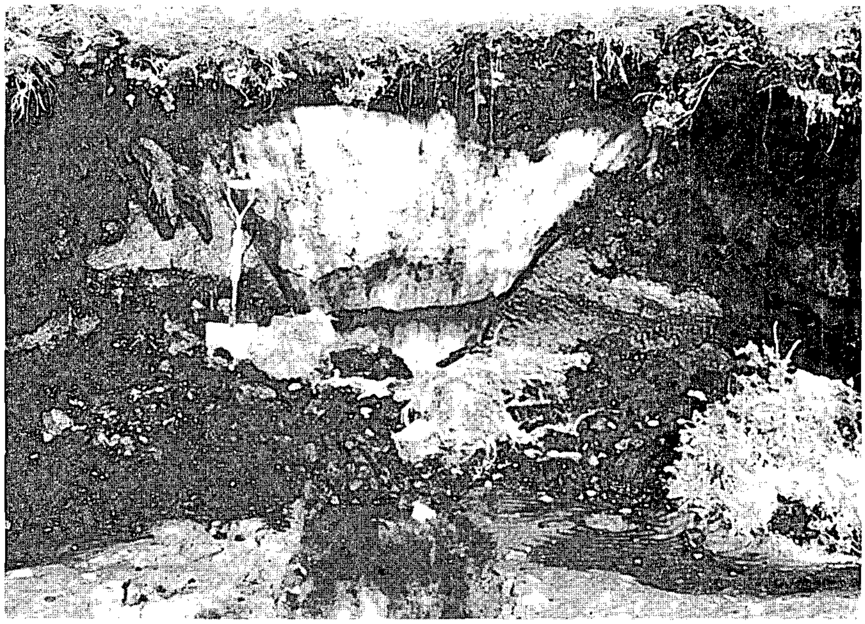

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Figure 4. Ground ice in peat deposits.

A. Exposed ice wedge in high-centre lowland polygon, near Tuktoyaktuk, N.W.T.

B. Ground ice in Mesic Cryosol on Bathurst Island, N.W.T. The cylindrical holes indicate where the ice content samples were taken.

NATURAL STABILITY

Peat deposits began forming about 4000-6000 years ago, several thousand years after the retreat of glacial ice from the continental portion of northern Canada. On the arctic islands, however, deposition began 8500-9000 years ago, shortly after the glacial ice melted (Tarnocai 1978). These time differences occurred because the climate was too dry and warm for peat deposition on the continent, while the cooler and moister climate of the arctic islands was much more favorable for peat deposition. The climate, however, became cooler about 5000 years ago and, since this time, peat development has ceased in the arctic islands, while the boreal and subarctic regions have become established as the areas of optimum peat development.

As the climate deteriorated further, permafrost formed in the existing peat deposits and, due to ice lens formation, morphological changes took place which created perennially frozen peat landforms such as palsas, peat plateaus, and polygonal peat plateaus. Some of these peat landforms existed well to the south of the present discontinuous permafrost zone (Zoltai 1971) but, due to an intermediate warming of climate, they melted and collapsed. The area they covered is still visible, however, since the vegetation has not yet had enough time to heal these collapsed areas. This collapsing is still taking place at a rate of approximately 1% per year on an areal basis (Tarnocai 1972b), or approximately 0 to 1 m per year horizontally (Thie 1974) in south-central Manitoba. The rate of collapse decreases as one proceeds to the north.

Perennially frozen peatlands, when considered independently of changing climate, have a cyclic nature with developing, mature, overmature, and collapsing stages. Although this degrading or collapsing stage (Figure 5) is very common throughout northern Canada, it is probably most striking on the arctic islands where most of the peatlands are very old and are strongly eroding despite the cold climate.

Wildfires can initiate the thawing and eventual collapse of perennially frozen peatlands in the southern fringe of the discontinuous permafrost zone (Thie 1974, Reid 1977). Further north, however, where the temperature of the peat is lower, the effect can be minimal (Strang 1973). Brown (1968) found little difference in the thickness of the active layer under burned and unburned palsas in the Hudson Bay Lowland.

Unfrozen peatlands do not have this cyclic nature which is so typical of the perennially frozen types. Their rate of growth (deposition) fluctuates but they maintain continuous growth until an outside factor such as changes in the hydrologic regime or fire alters the environment.

STABILITY AND LAND USE PRACTICES

Increased human activity in northern Canada during the past two decades has resulted in a greater use of our organic soils. The initial lack of knowledge of these soils and associated peatlands resulted in activities that caused considerable damage. Consequently, studies were carried out during the last decade (Kurfurst 1973, Strang 1973) and, as a result of the experience gained, land use practices and regulations as well as some of the

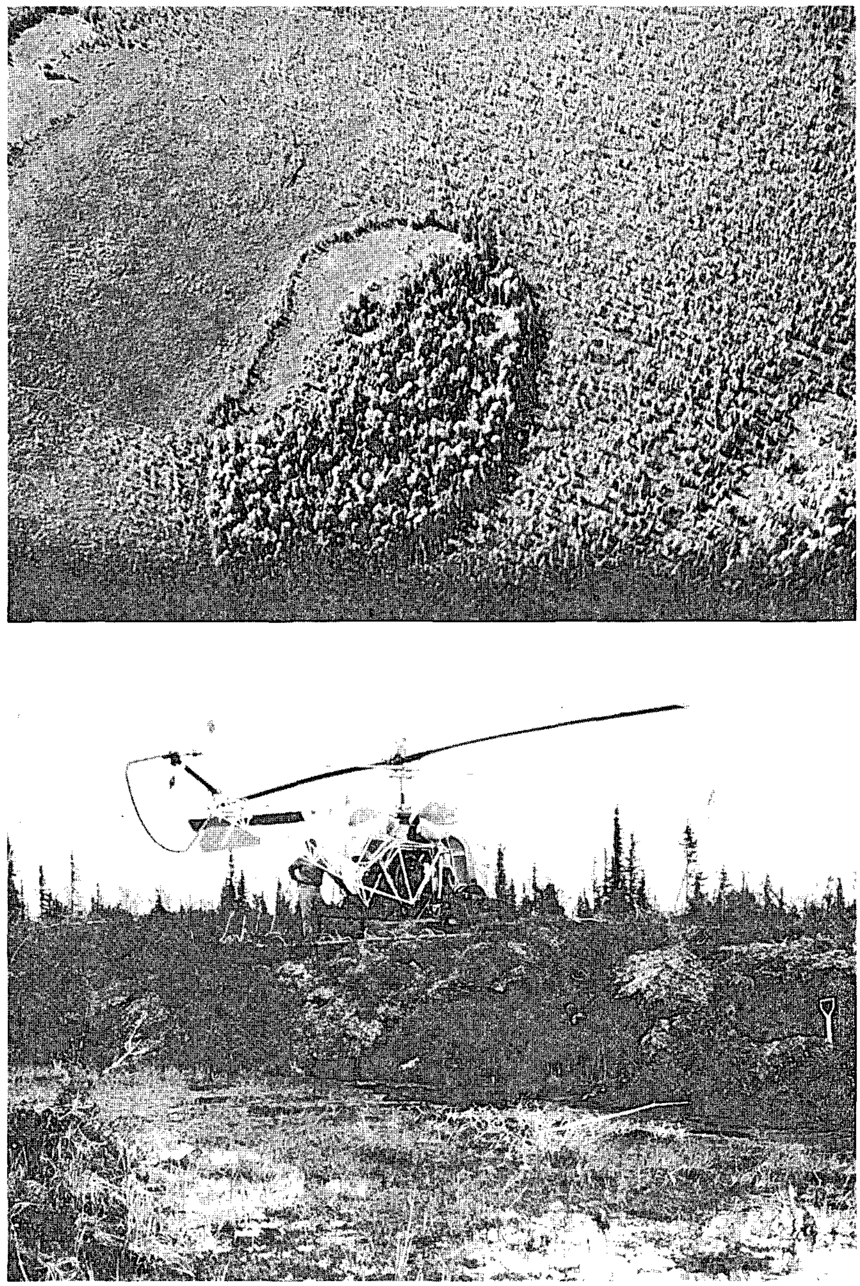

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Figure 5. Some of the natural collapsing processes in peatlands.

A. Collapsing peat plateaus in the Wabowden area, central Manitoba. Note the former size of the peat plateau as outlined by a line of trees (centre) and the collapsing process, indicated by dead trees (lower right corner).

B. Strongly collapsing peat plateau in the Sibbeston Lake area, N.W.T. Note the large amount of water (foreground) resulting from melting of ground ice.

engineering practices were modified to eliminate or at least minimize the damage. Some of the problems relating to the use of peatlands and organic soils are still unsolved and further research is required. In the following sections, some examples are given for land use practices and engineering methods implemented to date and their effect on the peatland environment is discussed.

During 1968-70 power transmission line towers were installed on a peatland-dominated region of north central Manitoba. On peatland areas, the construction of the tower foundations was carried out by excavating a 6.6 x 6.6 m area to a depth of 2.3 m and back-filling it with gravel. This formed the base for the tower, which was further secured by four guy cables. The severe disturbance of the peatland surface during excavation, especially in perennially frozen peatlands, caused the area around the tower base to become water-saturated, often with open pools of water being formed, as a result of runoff and the melting of ice in the frozen soil (Figure 6A). This water froze during the winter, resulting in drastic shifts of the towers due to frost heave. Additionally, the transmission line right-of-way, which had been badly scraped by bulldozers and other tracked vehicles, subsided and became water-saturated. Recently, Manitoba Hydro has tried to correct the situation with peat capping around the base of the towers and with revegetation but has had very little success (Sims 1976).

Roads, railroads and seismic lines crossing peatlands, especially peatlands of the perennially frozen type, cause numerous problems. According to the usual practice, the peat material is removed and the excavation is back-filled with granular materials or the roadbed is placed on partially excavated peat. In both cases, drainage ditches are dug on both sides of the roadbed. All of these activities cause massive surface disturbance which results in further melting and subsidence of the surface, even in those cases where the peat has been removed completely (Figure 7, A and B). Winter construction methods cause little surface disturbance and, when the roadbed (1-2 m thick) is placed on this undisturbed surface, the problems relating to subsidence are largely overcome (MacFarlane 1969, Charles 1959). Using the natural drainage paths instead of preparing ditches can eliminate ponding and erosion.

Seismic operations carried out during the summer months created a great deal of surface disturbance with subsequent melting and subsidence (Figure 7B). Seismic operations carried out during the winter months greatly minimize the surface disturbance and thus cause little or no permafrost degradation (Strang 1973).

All peatlands are very sensitive to hydrological changes. Any increase or decrease of water level or change in water chemistry has a drastic effect on peatland vegetation and on the soil. Very often roads and railroads partially or completely block the natural drainage, considerably raising the water level. This water level change will affect the peatland vegetation (Jeglum 1975) and cause degradation of the perennially frozen soil. Excess drainage, on the other hand, could lower the water table to such an extent that the peat deposit becomes dry and susceptible to fire.

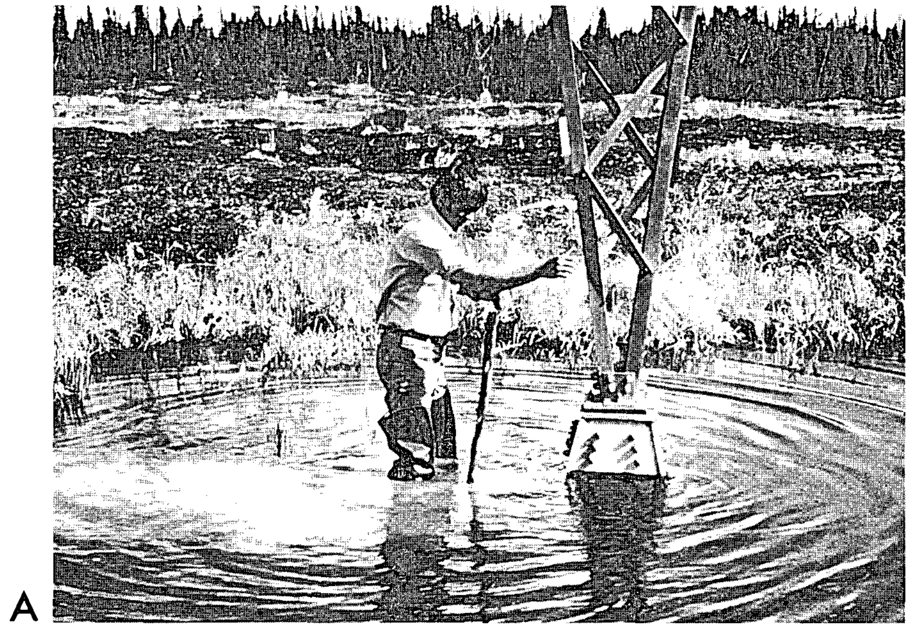

Figure 6. Some of the collapsing and degradation on peatlands resulting from human activities.

A. Transmission line tower base in a pool of water caused by collapsing and melting of ground ice, northern Manitoba (Sims 1976).

B. Melting of frozen peat materials and floating peat resulting from a drastic increase of water level caused by a hydroelectric dam. Southern Indian Lake reservoir, northern Manitoba.

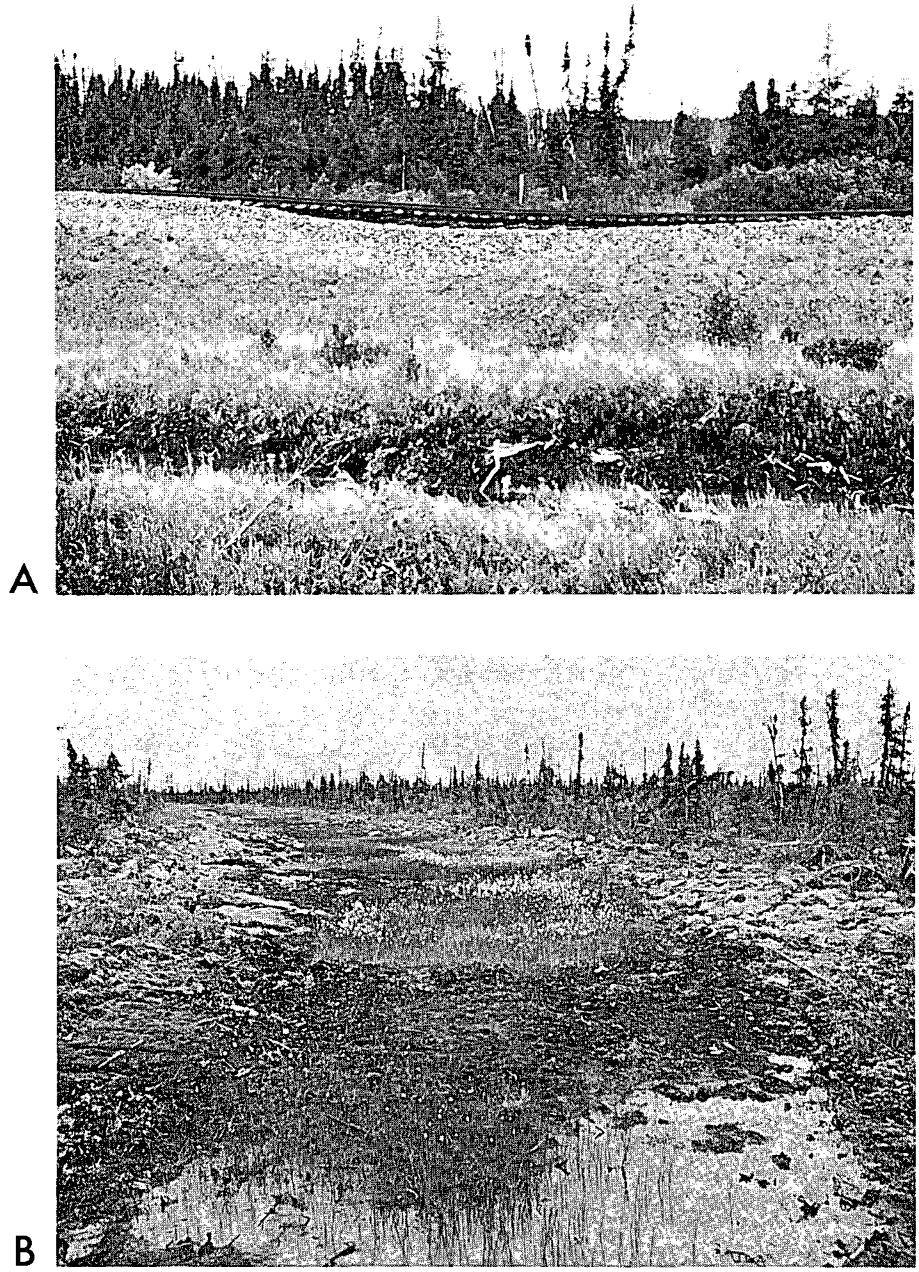

Figure 7. Further collapsing and degradation on peatlands resulting from human activities.

A. Subsidence of ice-rich peat and mineral materials underlying a railroad bed. Thompson, Manitoba.

B. Subsidence and erosion along seismic lines in the Mackenzie Valley, N.W.T.

Flooding due to hydroelectric dams causes irreversible destruction of peatlands. As a result of increased water levels, large bodies of peat begin floating (Figure 6B) and peat shorelines, especially the frozen ones, undergo rapid erosion as a result of both thermal and mechanical processes (Newbury et al. 1978). These processes cause a deeply incised niche to form at and immediately below the water's edge. As this niche enlarges, slumping occurs and frozen materials are exposed directly to warm lake water and wave action. Since slumped materials are continuously washed away by wave action and carried away by currents, further melting and erosion takes place.

SUMMARY AND CONCLUSIONS

The unfrozen peatland ecosystem, under natural conditions, is fairly stable. Perennially frozen peatland ecosystems, on the other hand, are subject to natural, long-term cyclic changes, especially in southern areas. They are in a very sensitive balance with the environment and, therefore, represent a fragile system.

Some human activities have drastically altered the peatland ecosystem, thus causing irreversible damage. Proper land use practices and correct engineering methodology can minimize these problems by maintaining the proper balance between the factors controlling the ecosystem stability and the environment. Further research concerning peatland development and dynamics is required to provide a fuller understanding of this balance in the peatland ecosystem so that terrain sensitivity ratings for organic soils and peatlands can be improved. These ratings can aid land use managers and engineers when selecting the proper land use and the least expensive, but safest, construction methods for the particular peatland environment.

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