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CHARACTERISTICS OF PERMAFROST IN THE TANANA FLATS, INTERIOR ALASKA

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Abstract

The Tanana Flats is a wetland region located on the distal slopes of an extensive alluvial fan complex built out of the Alaska Range. Vegetation in the Flats consists of a mosaic of fen, birch forest, black spruce forest, shrub, and bog. Permafrost is not present in the fen and bog areas, but it exists on the bordering forested or shrub areas 0.5 to 2 m above water level. Our studies show that permafrost in the Flats is relatively warm at -0.2 to -0.7°C, and that the distribution and characteristics of permafrost are related to the geobotanical conditions at a specific site. In general, permafrost is more ice rich and shows higher secondary porosity where finer-grained sediments (silts) are abundant. These are environments characterized by birch forest vegetation. Permafrost in areas of birch forest appears more susceptible to thaw and is currently showing signs of extensive degradation.

Introduction

Recent investigations in the Tanana Flats of Interior Alaska (Figure 1), have identified large areas of unfrozen fen peatlands maintained by the discharge of groundwater through unfrozen gravels and silts (Racine and Walters, 1994). Where these unfrozen fens border slightly higher birch forest, underlain by permafrost, there is widespread evidence of bank collapse, forest drowning, and moat formation, suggesting the degradation of the permafrost underlying these forests (Figure 2). In contrast, where the fens border black spruce forest and shrub bog, there is little evidence of thermokarst. This study is a documentation of the evidence of preferential thawing of permafrost associated with birch forests and possible causes in relation to permafrost characteristics.

Because of the long and complex history of the Tanana Flats in terms of both the surface and subsurface movement of glacial meltwater from the Alaska Range and the present mean annual temperature of about -3.3°C in this area, we believe that permafrost conditions here are extremely dynamic. This is especially important in light of projected climatic warming scenarios. The present study is part of a larger project to investigate permafrost dynamics in the Tanana Flats. Our approach includes an attempt to understand, classify, and map the landscape-scale pattern of permafrost distribution in relation to vegetation and near-surface sediment type.

Study area

The Tanana Flats is situated on the distal slopes of a large alluvial fan complex built out of the Alaska Range on the south (Figure 1). Climatic fluctuations during the Quaternary caused glacial expansion and recession in the Alaska Range, which in turn built a broad slope of coalesced alluvial fans, pushing the Tanana River northward against the Yukon-Tanana Upland. The thick unconsolidated deposits of the fan complex document a long and complicated record of alternating cycles of silt and gravel deposition and erosion along with the formation and destruction of permafrost (Péwé and Reger, 1983).

The northwest portion of the Tanana Flats, where we conducted our studies, is dominated by thick (3 to 4 m) abandoned floodplain cover deposits and organic floating-mat fens over gravel (Jorgenson *et al.*, 1996). Common vegetation includes birch (*Betula papyrifera*) forests, alder (*Alnus tenuifolia*) shrub swamps, floating-mat fens dominated by buckbean (*Menyanthes trifoliata*),

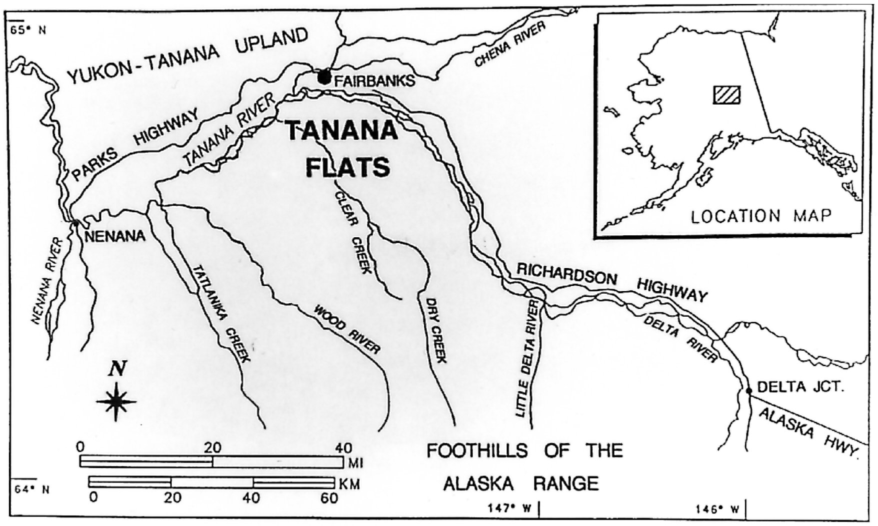

Figure 1. Map showing location of the Tanana Flats area, Interior Alaska.

Figure 2. Oblique aerial view of a floating mat fen with drowning birch forest in the foreground and midground. Airboat trails approximately 2 m wide can be seen in the middle of the fen.

collapse-scar bogs dominated by *Sphagnum* mosses, with occasional patches of black spruce (*Picea mariana*) forests, and shrub birch-ericaceous low shrub (Jorgenson *et al..*, 1996).

The area is a groundwater-discharge wetland, with the fens fed by springs that upwell through taliks or unfrozen zones in the permafrost (Racine and Walters, 1994). Surface water moves slowly through poorly defined drainage ways which run from southeast to northwest across the Flats. Topographic relief in the study area is less than 2 m and consists of relatively flat permafrost peatlands rising about 0.5 to 2 m above the water level in the floating-mat fens.

In contrast with the relatively well known distribution of permafrost north of the Tanana River along its floodplain (Péwé and Reger, 1983) and in the Yukon-Tanana Upland (Jorgenson and Kreig, 1988; Haugen *et al..*,1982), little is known about permafrost conditions south of the Tanana River in the Tanana Flats. Interior Alaska lies entirely within the discontinuous permafrost zone and the Tanana Flats is generally considered to be underlain by frozen ground (Péwé, 1975). Permafrost features such as ice-wedge polygons and palsas are uncommon, but thermokarst depressions are relatively abundant.

Methods

Two 1000 m long transects were established across fens into the adjacent terrain-vegetation units of birch forests, spruce forests, and bogs (Figure 3). Both transects were run in a southwest-northeast orientation, perpendicular to the northwestward flow of water and the linear trend of the terrain-vegetation units in the Flats. In each terrain-vegetation type, information on soils, vegetation, topographic relief, and hydrology was obtained at a centrally located site. Several 100 m transects were established through the birch forest portion of the longer transects beginning at the fen border and running through the birch forest. Here more detailed profiles of soils, thaw depths, vegetation, and topographic microrelief were obtained. An autolevel was used to measure relative ground surface and water surface elevation changes.On both long and short transects, a steel rod was used to determine the presence of permafrost and the thickness of the active layer in early September. Soil temperatures were measured hourly at depths of 0.1, 0.5, 1, and 3 m with a Campbell Scientific CR-10 datalogger and thermistors over a 1 year period. A SIPRE ice corer was used to obtain 2 to 3 m long cores of permafrost, and ice content and structure (cryostructure) was determined using the classification of Murton and French (1994). Cores in nonpermafrost areas (fens and bogs) were obtained with a 4 inch (10 cm) diameter PVC pipe equipped with a hacksaw blade at the cutting edge. Samples (both frozen and nonfrozen) were collected for laboratory analyses which included grain size distribution, moisture content by weight, moisture content by volume, organic content by loss-on-ignition, and bulk density following standard procedures(Lawson, 1983, 1986).

Results

PROFILES

A range of terrain types with associated soil, topographic, and vegetation conditions was encountered along the 1000 m transects (Figure 3). Typically, the 300-400 m wide fen is bordered on both sides by birch forests. Behind the birch forests are moss and low shrub bogs as well as black spruce forest. Although permafrost is absent in the fens and moss bogs, the black spruce forest, shrub birch-ericaceous shrub bog, and birch forests are all underlain by permafrost (Figure 3).

Where the birch forest borders the fen, there typically exists a zone at least 50 m wide of live, dying, or dead birch occupying a moat area (Figure 3). The moat occasionally contains signs of beaver activity such as dams, lodges, or felled trees from the edge of the birch forest. Commonly, the moat contains a pit and mound topography consisting of a complex pattern of slightly higher mounds supporting live birch interspersed with subsided depressions with both deep and shallow water containing dead and/or dying submerged birch. Permafrost was detected under some of the higher remnant blocks of birch forests.

Pit and mound topography is also found in the interior of the birch forests, confirming degradation of permafrost in these stands. While most pits appear to be separate, some closer to the fen actually have connections to the fen border and moat. The water-filled depressions in the birch forest are narrow and elongate or circular, varying in width from only 2-3 m up to 8-20 m, respectively. Commonly, two to four such water-filled depressions occur over a distance of about 50-

Table 1. Summary comparison of permafrost characteristics in spruce, birch, and shrub bog environments

Vegetation type:	Spruce	Birch	Shrub Bog
Active layer thickness (cm)	52 - 66	62 - 90	63 - 130
Sediment type	fine sand and silt	silt and silty clay loam	silt
Cryostructure	lenticular to structureless	lenticular and suspended	lenticular
Volumetric ice content (% total core)	19 - 29	27 - 51	22 - 30

75 m through the birch forest (Figure 3). The sides of the pits rise 0.3-1 m from a water or floating vegetation mat surface to the birch forest floor. In these pits, the wet organic layer consisting of both birch forest peat and accumulated floating mat vegetation is up to 1.5 m thick above silts. In the larger water-filled pits, no permafrost could be found to a depth of 2.5 m in late August, whereas permafrost was encountered at a depth of 0.8-1 m in the adjacent birch forest (Figure 3). The thaw depth profile through the birch forest tends to match the surface mesotopography.

NEAR-SURFACE SEDIMENT AND PERMAFROST CRYOSTRUCTURE

Subsurface profiles in the terrain types along the transects show an organic horizon underlain by silt or silty clay loam above sand with a gravel layer at a depth of 3 to 4 m (Figure 3). Organic horizons 0.75 to 1.5 m thick occur in the fen and in the moss bog type environments. In the case of the fens, the organic mat consists predominantly of buckbean whose intertwined roots and rhizomes form a dense network which floats and is usually capable of supporting a person's weight. Moss bogs are found in collapse scar environments and are dominated by Sphagnum. Organic horizons in birch forests and spruce forests range from 30 to 50 cm thick.Soils in these forested areas are histic pergelic cryaquepts. In late August, the frost table is usually located in the organic horizon or just below this in the silt layer.

Permafrost cores provide information on ice contents and structures in the near-surface frozen sediments (Figure 3 and Table 1). Fine-grained sediments, mostly silts, sands, and silty clay loams, make up the mineral soils in all of the cores, but the textural type varies somewhat in relation to the terrain-vegetation unit (Table 1).Sediment underlying areas of black spruce forest has a greater amount of fine- to medium-grained sand along with silt. In areas of shrub bog, the sediment is mostly silt. In areas of birch forest, the underlying sediment has a greater percent of silty clay loam and clay loam along with silt. This difference in sediment textures, in turn, corresponds to the amount of ice and type of ice structures in the frozen sediments. Lenticular cryostructures are the most common type of ice structure in all of the cores (Figure 4A). Structureless cryostructures, in which ice is contained in pore spaces and is not visible (Murton and French (1994), are associated with sand-size sediments (Figure 4B). Such cryostructures are found in permafrost underlying black spruce forest. Suspended cryostructures are common in the finest-grained sediments, the silty clay

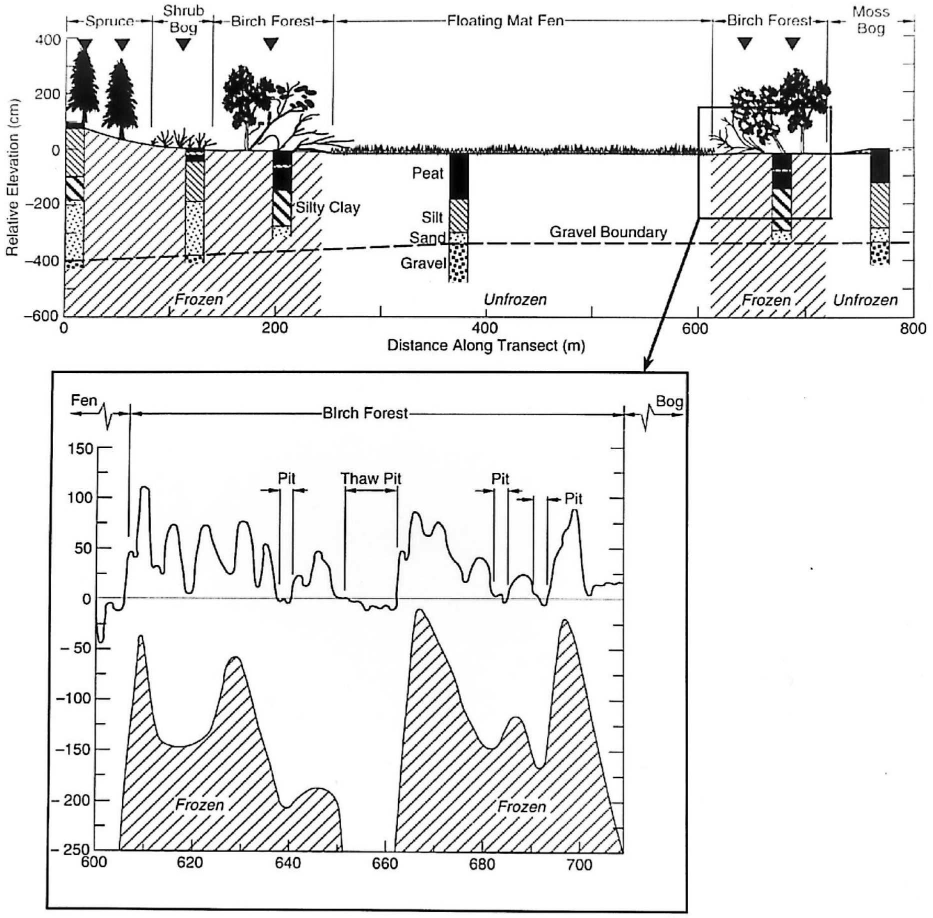

Figure 3. Cross-sectional profile of a portion of a long transect across different terrain-vegetation units. Black triangles indicate locations of permafrost cores. Larger-scale profile presents a more detailed section through the birch forest showing surface topography and frost table profile (September 1995).

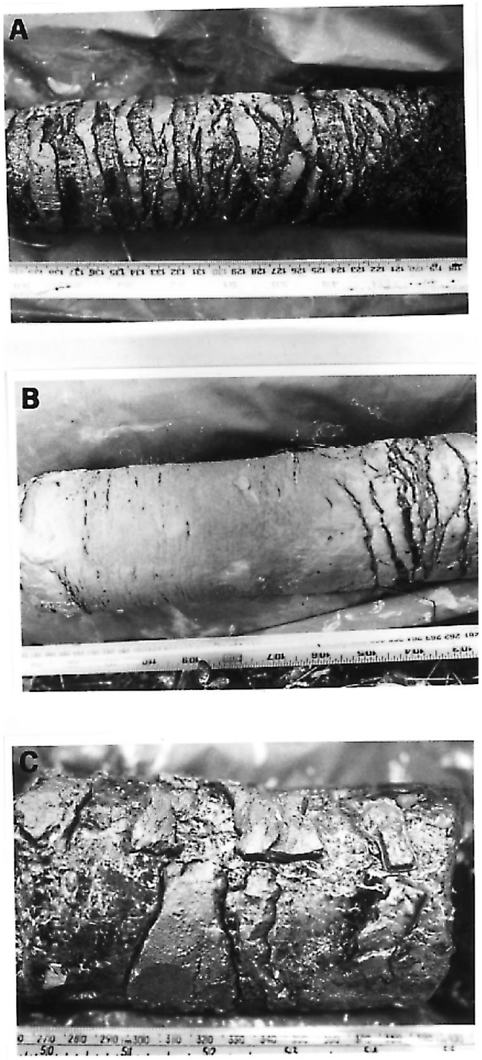

Figure 4. Permafrost cores showing typical cryostructures: (A) lenticular cryostructure in silt;(B) structureless cryostructure in fine-grained sand, grading to lenticular away from center of core where sediment becomes more silty; and (C) suspended cryostructure consisting of angular blocks of silty clay in ice. All cores are approximately 7 cm wide and have been allowed to thaw slightly in order to emphasize the features.

loams and clay loams underlying areas of birch forest (Figure 4C). The volume of ice in the permafrost is greatest where the sediment is the finest. Thus, ice makes up less than about 20% by volume of the near-surface frozen sediments in areas of black spruce forest to more than 50% of the frozen sediments in areas of birch forest (Table 1).

Monitoring of permafrost temperatures with dataloggers indicates that temperatures at 3 m depths in birch forests with degrading permafrost were maintained at a near constant temperature of -0.2°C throughout the year. In contrast, in the black spruce forest with stable permafrost, temperatures at the 3 m depth varied from -0.2 to -0.7°C annually.

Permafrost Degradation

The extent of permafrost degradation was determined by relating permafrost characteristics (cryostructures and temperatures) to vegetation and terrain types along the transects and by mapping the distribution of ecosystems. Applying this procedure to the portion of the Tanana Flats managed by the U. S. Army at Ft. Wainwright (263,759 ha), Jorgenson *et al.*. (1996) determined that 16% is unfrozen with no previous permafrost, 44% has stable permafrost, 9% is partially degraded, 25% is mostly degraded, and 6% has totally degraded. They estimated that, when considering only that portion that currently has or has recently had permafrost, approximately 48% of the permafrost-dominated land has been affected by thermokarst development.

Some indication of rates of permafrost degradation can be determined by comparing aerial photographs. Recent short term (less than 10 years) observations at some locations in the Flats have revealed dramatic changes. At one site of about 1.5 ha observed since 1989, there has been an almost total thawing of permafrost. At another site where we have constructed a 1 km transect, comparison of air photos from 1949 and 1989 shows a decrease of approximately 24% in the area underlain by permafrost. Based on air photo interpretation and our field observations over the last several years, we estimate that frozen ground along the margins of these “birch islands” has been degrading laterally at approximately 0.5 to 1 m per year.

Discussion and conclusions

Thawing of permafrost beneath birch forests is occurring in the Tanana Flats of Interior Alaska. Degradation is greatest along the edges of birch forests where they border extensive fens. In the frozen silty sediments underlying the birch forests, suspended and lenticular cryostructures are common, and the amount of thaw settlement after melting indicates there is as much as 1.5 m of ice in the sediments. These cryostructures are typical of aggradational ice formed at the top of the permafrost boundary but lack the vertical ice veins typically found in cold permafrost.

Drowned forest and collapse features along wetland-upland borders are well known and have been described by Drury (1956) and Luken and Billings (1983) in Interior Alaska and by Zoltai and Tarnocai (1975) in Canada. The thawing of permafrost banks bordering wetlands and other water bodies has been documented by Drury (1956) as including the “phenomenon of the advance of bog margins by thawing and undermining the forest.”Although the occurrence of thaw has been well documented in the Subarctic, the causes and ecological effects of this thaw subsidence in terms of successional processes involving wetland formation, colonization, and infilling are poorly known (Seppälä, 1986).

The process of permafrost thaw and bank collapse occurring along wetland margins in the Tanana Flats is probably due to a number of factors. The relatively warm temperature of the permafrost (-0.2 to -0.7°C) makes it very susceptible to thaw. These temperatures are probably maintained by heat flow from groundwater movement at depth. Another important factor is the heat transfer from the relatively warm surface waters of the fens (12 to 16°C by August) to the adjacent permafrost underlying the forests.The influence of beavers is also important, since they cut birch trees which may open up the forests, and they create dams in moat areas which raise water levels and increase flow rates along the banks. The finding that the permafrost underlying the birch forests consists of clayey, ice-rich sediments which are particularly susceptible to thaw subsidence is very significant and explains why areas of birch forest are experiencing the greatest degree of degradation.

Higher temperatures in Interior Alaska over the last several years (Osterkamp, 1983) may also be responsible for accelerated degradation of permafrost and expansion of wetlands in this area. Since the mid 1970s, there has been an increase of approximately 1 to 2°C in mean annual air temperature in Alaska (Osterkamp, 1983). Although long-term monitoring of permafrost temperatures in the Tanana Flats has not been done, studies by Osterkamp (1994) at a site in the Chena River floodplain near Fairbanks indicate that permafrost temperatures there have increased by about 1.5°C from just 1990 to 1993. We continue to map the landscape-scale pattern of permafrost distribution in the Tanana Flats in relation to vegetation, near-surface sediments, and ice volume and have begun to monitor thermal conditions in a variety of terrain-vegetation types. The lowland birch forests in the Tanana Flats may represent one of the most sensitive ecosystems in Interior Alaska in terms of response to climatic change.

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