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Peatland development at the arctic tree line (Québec, Canada) influenced by flooding and permafrost

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Abstract

In this study, we documented the Holocene history of a peat plateau at the arctic tree line in northern Québec using stratigraphic and macrofossil analyses to highlight the effects of geomorphic setting in peatland development. Paludification of the site began about 6800 cal yr BP. From 6390 to 4120 cal yr BP, the peatland experienced a series of flooding events. The location of the peatland in a depression bounded by two small lakes likely explains its sensitivity to runoff. The proximity of a large hill bordering the peatland to the south possibly favored the inflow of mineral-laden water. The onset of permafrost aggradation in several parts of the peatland occurred after 3670 cal yr BP. Uplifting of the peatland surface caused by permafrost stopped the flooding. According to radiocarbon dating of the uppermost peat layers, permafrost distribution progressed from the east to the west of the peatland, indicating differential timing for the initiation of permafrost throughout the peatland. Most of the peatland was affected by permafrost growth during the Little Ice Age. *Picea mariana* macroremains at 6450 cal yr BP indicate that the species was present during the early stages of peatland development, which occurred soon after the sea regression.

Keywords: Palsa; Peat plateau; Peatland; Little Ice Age; Flooding; Subarctic Québec; *Picea mariana*; Minerotrophic conditions; Geomorphology; Permafrost; Tree line

Introduction

Subarctic permafrost peatlands generally undergo several developmental stages, from shallow open water to fen and occasionally to bog, before reaching the permafrost stage (Heim, 1976; Couillard and Payette, 1985; Allard and Seguin, 1987a; Lavoie and Payette, 1995; Vardy et al., 1998; Arlen-Pouliot and Bhiry, 2005; Bhiry and Robert, 2006). The length of each stage of this classical hydroseral succession depends on regional climatic conditions and local factors associated with substrate, slope, and hydrology. The permafrost stage coincides with the inception of palsas (permanently frozen peat mounds, generally <100 m in diameter) and peat plateaus (permanently frozen peat mounds, generally >100 m in diameter) (Zoltai, 1972; Payette, 2001).

Peatland inception in subarctic Québec occurred soon after the regression of the Tyrrell Sea (6000–7000 cal yr BP). Palsas and peat plateaus in this area formed after 3200 cal yr BP, in particular during the last 1500 yr (Payette, 2001), with the period before 1000 cal yr BP and the Little Ice Age (500–100 cal yr BP) being the most favorable for permafrost expansion. The uplifting of the peat surface caused by the establishment of permafrost greatly reduces or interrupts peat accumulation and completely modifies the plant cover. Permafrost decay since the end of the Little Ice Age has been attributed to recent climate change (Laberge and Payette, 1995; Halsey et al., 1995; Matthews et al., 1997; Zuidhoff and Kolstrup, 2000; Vitt et al., 2000; Beilman, 2001). Palsa decay induces thermokarst ponds where mineral and organic sediments from the surrounding area accumulate before the pools fill in with vegetation (Arlen-Pouliot and Bhiry, 2005).

Several studies have shown that subarctic peatlands are influenced by allogenic factors such as climate and autogenic processes such as peat accumulation (or *Sphagnum* acidification). However, few studies have examined the role of local geomorphic factors on peatland succession. Local factors could mitigate or exacerbate the impact of changing climatic con-

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ditions on peatland development. For example, two nearby peatlands subjected to the same climatic conditions would develop differently if one was located in a depression bordered by relatively steep slopes and the other in level topography.

In this study, we reconstructed the long-term development of a permafrost peatland based on peat stratigraphy and macrofossil analysis. The main objectives were to distinguish between allogenic and autogenic processes involved in its development and to assess whether local geomorphic conditions may influence peatland succession and the succession of the classical hydrosere. Because the peatland was at the arctic tree line and in a confined depression, we postulated that its development was closely associated with changing climatic conditions, local geomorphic setting, and permafrost dynamics since deglaciation. In addition, we were interested to collect further information on the initial arrival and establishment of tree species in this tree line area using plant macroremains from thick peat sections.

Study site

The study site is located near the Hudson Bay coast in subarctic Québec, in an area that emerged from the Tyrell Sea about 6500 cal yr BP (Allard and Rousseau, 1999). The studied permafrost peatland is in the rivière Boniface watershed (57°44′N, 76°05′W), about 40 km east of Hudson Bay and 10 km south of the arctic tree line (Payette, 1983) (Fig. 1). The area is in the zone of discontinuous but widespread permafrost (Allard and Seguin, 1987a). Climatic data from the Inukjuak weather station, 130 km northwest of the study area, indicate a mean annual temperature of −7.5 °C, mean monthly temperature in the coldest month (February) of −26 °C and in the warmest month (July) of 9 °C. Mean annual precipitation is about 550 mm, with approximately 40% falling as snow.

The study site is on the Precambrian shield with granito-gneissic outcrops arranged in a low elevated plateau with small hills (200 m a.s.l.) and large depressions (110–130 m a.s.l.).

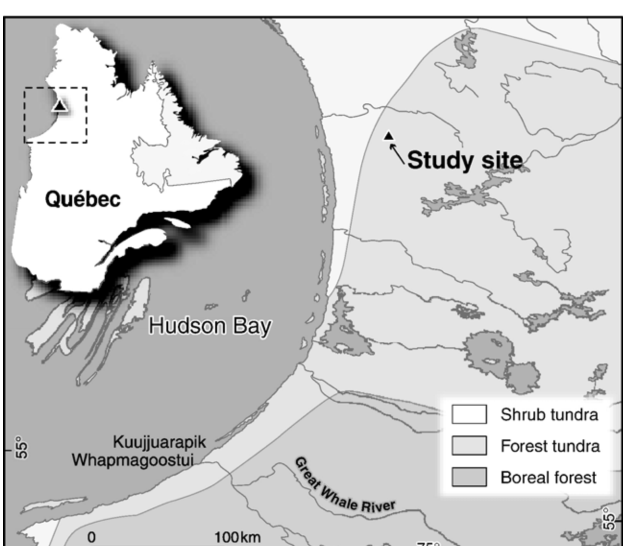

Figure 1. Location of the study site along the eastern coast of Hudson Bay, with dominant vegetation zones indicated.

Deglaciation of the study area was followed by the marine invasion of the Tyrrell Sea, which reached an altitude of 175 m a.s.l. Marine shells at 135 m a.s.l. and 140 m a.s.l. near the study site were dated to 6280 cal yr BP (5730 ± 140 ^{14}C yr BP) (Payette and Filion, 1993) and 6320 cal yr BP (5810 ± 120 ^{14}C yr BP) (Allard and Rousseau, 1999).

The regional vegetation is dominated by forest-tundra communities with black spruce (*Picea mariana* [Mill.] B.S.P.) as the dominant tree species. Spruce-moss stands are the most important forest type in depressions, whereas scattered lichen-spruce woodlands and krummholz (pigmy forests) are distributed on hillsides and exposed summits along with stands of lichen-heath-dwarf birch (*Betula glandulosa* Michx.).

The studied permafrost peatland is in a forested valley bounded by the Lac des Pluviers (unofficial name, Payette and Filion, 1993) to the east, Lac des Bécassines (unofficial name) to the west, a forested hill to the north, and an exposed hill to the south (Fig. 2). The distance between the two lakes is about 550 m. The peatland is adjacent to Lac des Bécassines and about 290 m from Lac des Pluviers. Lac des Pluviers stands about 4.5 m above Lac des Bécassines. The peatland is east–west oriented and approximately 260 m long and 150 m wide. It belongs to the category of peat plateau composed of elongated permafrost mounds (palsas) separated by linear, wet depressions (Payette, 2001). A 30-m-long pond in the northwest corner of the peatland (Fig. 2), likely associated with permafrost decay, is surrounded by willow (*Salix* sp.) and black spruce. The highest permafrost mound is about 9.5 m above the present level of Lac des Bécassines. The height of most permafrost mounds is about 6.5 m. A small stream runs along the south side of the peatland and discharges into Lac des Bécassines. The peat accumulated over fluvio-marine sediments.

Three main peatland habitats were identified based on topography and vegetation cover. The ponds are colonized by herbaceous plants (*Carex aquatilis*, *Carex rariflora*, *Eriophorum angustifolium*), brown mosses (*Scorpidium scorpioides*, *Drepanocladus exannulatus*), and *Sphagnum recurvum*. On the drier palsa tops and slopes, *B. glandulosa*, *Rubus chamaemorus*, *Polytrichum strictum*, and lichens are the dominant species. Because of contrasting drainage conditions in the linear depressions, the vegetation cover is more diversified and includes several species adapted to varying soil moisture such as *B. glandulosa*, *R. chamaemorus*, *Vaccinium uliginosum*, *Empetrum nigrum*, *Vaccinium vitis-idaea*, *C. aquatilis*, *Sphagnum fuscum*, *Sphagnum capillifollium*, *Sphagnum subfulvum*, *Mylia anomala*, and *Cladina stellaris*.

Methods

The Holocene development of the peatland was reconstructed from peat sections using peat stratigraphy, plant macrofossil assemblages, and radiocarbon dating of peat layers. Three sections were dug to study the peatland: Section 1 (200 cm thick) was located in the northern part of the peatland at the edge of the northwest pond (Fig. 2), whereas Section 2 (200 cm thick) and Section 3 (120 cm thick) were in the southeastern part and the southwestern part of the peatland, respectively (Fig. 2).