Carbon sequestration dynamics and climate change in Subarctic and Low Arctic Organic Cryosols in Canada

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Abstract

Organic Cryosols began to develop in the Low Arctic and Subarctic of the Mackenzie Valley in northwestern Canada between approximately 5480 and 9460 yr BP. In the Low Arctic the long-term rate of organic carbon sequestration in these soils ranged from 1.0–55.0 gC/m^2/yr with approximately 1.0–2.1 gC/m^2/yr being sequestered in the surface soil layer (0–50 cm). In the Subarctic the long-term average rate of organic carbon sequestration in these soils ranged from 4.7–53.7 gC/m^2/yr with approximately 9.6–23.6 gC/m^2/yr being sequestered in the surface soil layer. High rates of organic carbon sequestration occurred in Low Arctic Organic Cryosols at approximately 7000–9000 yr BP and in Subarctic Organic Cryosols at 3000–6000 yr BP and 8000–9000 yr BP. It has been suggested that Subarctic Organic Cryosols could be severely affected by climate change, leading to severe thawing, increased decomposition and, ultimately, cessation of the carbon sequestration process. These soils would thus become a carbon source and could trigger very strong feedback mechanisms that might further increase climate warming.

Key Words

Organic soils, peatlands, radiocarbon dates, sampling, peat, climate warming

Introduction

Organic Cryosols (permafrost-affected organic soils) are common soils in Subarctic and Arctic Canada. These soils cover approximately 284 x10^3 km^2, which is about 23% of the entire area of organic soils in Canada, and contain approximately 35 Gt of organic carbon (Tarnocai 2000; 2006). They are associated with perennially frozen peatlands such as peat plateaus, polygonal peat plateaus and low-centre and high-centre lowland polygons (National Wetlands Working Group 1988). In this paper carbon dynamics are given for Organic Cryosols associated with high-centre lowland polygons in the Low Arctic and polygonal peat plateaus in the Subarctic of the Mackenzie Valley in the Northwest Territories of Canada.

Methods

Organic Cryosols were sampled in two ecological regions, the Low Arctic (site T5: 68^o 57.387 N, 133^o 50.123 W and site MD-1: 69^o 09' N, 134^o 17' W) and the Subarctic (Inuvik area – sites IN-BG-1 and IN-BG-3: 68^o 19' 01"N, 133^o 25' 57"W; Norman Wells area – sites NW-BG-8 and NW-BG-10: 65^o 12' 48" N, 127^o 00' 58" W). The locations of these sites are shown on Figure 1. Although a number of cores were collected from these areas, only the sites listed above were used for analysis in this paper. Sampling was carried out using a SIPRE corer that produced continuous peat cores (3.8 cm in diameter) (Figure 2) for the entire depth of the soil through the basal peat to the underlying mineral layer. These peat cores were used to describe the soil horizons on the basis of the botanical composition of the peat and samples were taken for chemical analysis, bulk density determination and radiocarbon dating.

Organic carbon concentrations were determined using a LECO CHN analyzer (Sheldrick 1984). Frozen weights of bulk density samples were measured in the field, samples were oven-dried at 50^o C in the laboratory and moisture (ice) content and bulk densities were calculated (Sheldrick 1984). Radiocarbon dating was carried out by Beta Analytical Incorporated's radiocarbon laboratory using standard AMS dating analysis.

Carbon accumulation was calculated on the basis of intermittent radiocarbon dates, usually four to six dated depths between the soil surface and the basal peat. The soil organic content (SOCC kg/m^2) of each layer was calculated using the formula:

$$SOCC = C \times BD \times T \times (1 - CF) \quad (1)$$

where C is organic carbon (% weight), BD is bulk density (g/cm^3), T is soil layer thickness (cm), and CF is coarse fragments and/or ice content (% weight). The SOCC calculated for each layer was divided by the age of the layer to determine the average amount of carbon deposited annually.

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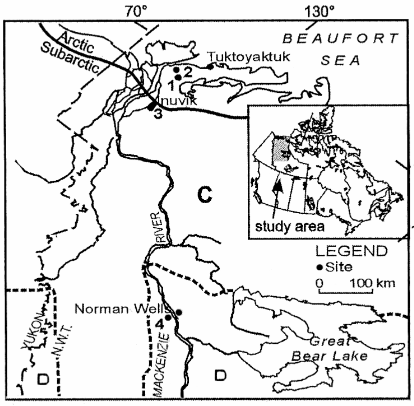

Figure 1. Map showing the sampling sites, the ecological provinces (Subarctic and Arctic) and the discontinuous (D) and continuous (C) permafrost zones.

Figure 2. Frozen soil core samples from the Norman Wells site. The right end of the upper core is the surface and the left end of the lower core is the mineral layer below the basal peat.

Results

Soil characteristics

The organic materials associated with these Organic Cryosols are dominantly moss peat with Sphagnum moss underlain by sedge or woody sedge peat in the peat profile. The active layer of soils (the surface layer that freezes and thaws annually) is between 30 and 50 cm deep. The underlying perennially-frozen layer has an ice content of 75–92%. These soils are very extremely acid to strongly acid (pH 3.7–5.5) and have organic carbon concentrations of 40–55%.

Age

The age of the basal peat represents the beginning of the development (peat deposition) of the Organic Cryosol. Radiocarbon dates for the basal peat of the six soils used in this study range from 5480 ± 50 yr BP to 9460 ± 50 yr BP (Table 1). These dates suggest that, for most of these soils, carbon deposition began shortly after the deglaciation of the Mackenzie Valley.

Table 1. Age of Organic Cryosols based on radiocarbon dates of the basal peat.

Site No.[a]	Peat core sites	Depth (cm)	Age of basal peat (yr BP)	Radiocarbon laboratory number	Sampling date
1	T5	95	7960 ± 80	Beta-240093	November 2007
2	MD-1	735	8850 ± 90	Beta-11565	July 1973
3	IN-BG-1	375	8130 ± 40	Beta-240911	September 2007
3	IN-BG-3	200	5480 ± 50	Beta-240095	September 2007
4	NW-BG-8	208	9460 ± 50	Beta-251736	May 2008
4	NW-BG-10	150	9310 ± 50	Beta-251737	May 2008

[a] Locations of these sites are shown in Figure 1 and the coordinates are given in the Methods section

Carbon accumulation

The means and ranges for carbon accumulations in these soils are given in Table 2. The average rates long-term carbon accumulation were 29.8 gC/m^2/yr for Low Arctic soils and 21.8 gC/m^2/yr for Subarctic soils (Table 2). It should be noted that the higher rates of carbon accumulation in Low Arctic peatlands are due, to some extent, to partial erosion of the surface peat, especially at site T5. As a result, the rates of carbon accumulation in these peatlands were based on the lower depths of the soils, where carbon sequestration had been higher. For example, the date for the 40 cm depth at site T5 was 7380 yr BP. The mean rates of carbon accumulation in the surface layers were 1.5 gC/m^2/yr for Low Arctic Organic Cryosols and 17.8 gC/m^2/yr for Subarctic Organic Cryosols (Table 2). For comparison, Britta et al. (2008) reported long-term carbon sequestration (accumulation) rates of 12.5–12.7 gC/m^2/yr for Subarctic peat plateaus in west-central Canada and 3.7–5.2 gC/m^2/yr for the surface layer.

Table 2. Carbon sequestration rates in various types of peatlands.

Site	Soil	Peatland type	No. of dated layers	Long-term carbon sequestration rates[a] ($gC/m^2/yr$)		Carbon sequestration rates in the surface layer[b] ($gC/m^2/yr$)	
				Mean	Range	Mean	Range
Low Arctic	OC[c]	HCLP[d]	7	29.8	1.0–55.0	1.5	1.0–2.1
Subarctic–Inuvik	OC[c]	PPP[e]	10	24.8	4.7–53.7	18.9	14.8–23.0
Subarctic–Norman Wells	OC[c]	PP[f]	11	18.9	6.1–50.0	16.6	9.6–23.6

[a]based on intermittent dates

[b]0–50 cm depth

[c]OC: Organic Cryosols (Canadian System of Soil Classification) and Histels (US Soil Taxonomy)

[d]HCLP: High-centre lowland polygon

[e]PPP : Polygonal peat plateau

[f]PP : Peat plateau

The rates of carbon accumulation were not uniform during the life of these soils (Table 2). The rate of carbon accumulation in Low Arctic Organic Cryosols was highest between 7000 and 9000 yr BP during the Hypsithermal Maximum (Figure 3). The rate of carbon sequestration in Subarctic Organic Cryosols (in both Inuvik and Norman Wells) also showed increased rates of carbon accumulation between 8000 and 9000 yr BP with a second maximum between 3000 and 6000 yr BP (Figure 3). This suggests that, on Low Arctic sites, carbon sequestration rates reached a maximum between 7000 and 9000 yr BP and then slowed down after this period, becoming very slow during the last several hundred years. The Subarctic sites, on the other hand, had two periods with higher rates of carbon sequestration (8000–9000 and 3000–6000 yr BP) and an intermediate period with a lower rate of sequestration (6000 to 8000 yr BP). These Subarctic sites, however, have still been sequestering carbon at a moderate rate (17.8 $gC/m^2/yr$) during the past several hundred years (Figure 3).

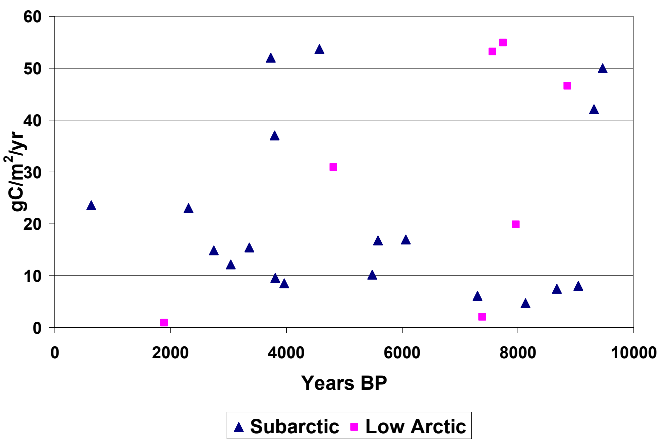

Figure 3. Rates of carbon accumulation in Low Arctic and Subarctic Organic Cryosols during the last 9500 years. Note that the highest rates of carbon accumulation occurred at 7000–9000 yr BP in the Low Arctic and at 8000–9000 and 3000–6000 yr BP in the Subarctic.

Conclusion

Organic Cryosols in the Subarctic and Low Arctic regions of the Mackenzie Valley have been accumulating carbon for the past 9000 years. During this period the rate of carbon sequestration varied widely because of changes in climate, hydrology, composition of peat materials and frequency of wildfires (indicated by the presence of ash layers and charcoal).

Although mean long-term carbon sequestration rates for Organic Cryosols in the two ecological regions are similar (Low Arctic: 29.8 $gC/m^2/yr$; Subarctic: 21.8 $gC/m^2/yr$), these values do not correspond to the current rate of carbon sequestration. The rapid rate of carbon sequestration in Low Arctic Organic Cryosols between 7000 and 9000 yr BP skewed the long-term average rate, giving the impression that these soils still sequester carbon at a high rate. However, the rate of carbon sequestration in the surface layer of these soils is very low (1.5 $gC/m^2/yr$) because drying of the peat surface lead to erosion of the soil surface and wildfires. The current rate of carbon sequestration in Subarctic Organic Cryosols is also lower than the long-term average rate, but these soils are still sequestering carbon at a moderate rate (17.8 $gC/m^2/yr$). Therefore, in order to obtain information on recent carbon accumulation in these areas, carbon sequestration rates for the surface layer should be used.

Global circulation models predict that the greatest increases in temperature will occur in the Arctic and Subarctic regions. Tarnocai (2006) indicated that 18% of the Organic Cryosols in the Arctic and 77% in the Subarctic could be severely to extremely-severely affected by climate change. Since climate warming has already begun to trigger severe thawing of ice-rich permafrost and increased decomposition of peat materials, these soils are in the process of becoming a carbon source and will eventually no longer sequester carbon. This double effect could trigger very strong feedback mechanisms that might further increase climate warming (Oechel *et al*. 1993).

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