Organic carbon and microbial biomass in a raised beach deposit under terrestrial vegetation in the High Arctic, Ny-Ålesund, Svalbard

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Abstract

Raised beach deposits are widespread on the north-western coast of Spitsbergen, Svalbard. To elucidate the importance of these deposits in an ecosystem carbon cycle, we measured the concentrations of organic carbon and adenosine 5-triphosphate (ATP; an index of living microbial biomass) in a raised beach deposit found under terrestrial vegetation in Ny-Ålesund. A shell in the deposit found at a depth of ca. 20 cm below the ground surface had a (not calibrated) ^{14}C age of 11080 ± 140 yr BP, whereas soil organic carbon in the same deposit showed an older ^{14}C age (22380 ± 90 yr BP). Organic carbon concentration in the layer of 20–40 cm belowground was about 1–2%, which was comparable to those in shallower mineral soil layers. Results of ATP analyses suggested that low but non-negligible amounts of microorganisms existed in the deposit. The proportion of biomass carbon to soil organic carbon tended to decrease with increasing depth, suggesting that organic carbon in the deep layer was less available to microorganisms than that in the shallow layers.

Raised beaches are widely distributed along the north-western coast of Spitsbergen. They are the product of rebound following episodes of isostatic depression under Pleistocene ice sheets in the nearby Barents Sea and in glaciated areas of Svalbard (Forman et al. 1987). Using radiometric and amino-acid dating, geologists have documented Quaternary depositional episodes and the relative sea-level history in detail (Miller 1982; Forman & Miller 1984; Forman et al. 1987).

In contrast, little is known about the ecological importance of raised beach deposits. Several studies have recognized widely varying subsurface microbial communities that use forms of ancient sedimentary organic carbon (MacNaughton et al. 1999; Petsch et al. 2001). More recently, Dutta et al. (2006) and Zimov et al. (2006) reported that ancient organic carbon in Siberian loess deposits (21000–25000 yr BP) began to decompose immediately upon thawing. The contribution of raised beach deposits to the terrestrial carbon cycle might be considerable if the deposits contain a large amount of organic carbon useful to soil organisms.

As part of a study of the carbon cycle in a glacier foreland in Ny-Ålesund, Svalbard (Nakatsubo et al. 2005), we determined the amount and ^{14}C age of organic carbon contained in a raised beach deposit found under terrestrial vegetation. In addition, we measured the adenosine 5-triphosphate (ATP) concentration in the deposit to determine the living microbial biomass.

Materials and methods

Study site and sampling

A raised beach deposit containing seashells was found on the bank of a river flowing through the glacier foreland of Austre Brøggerbreen (East Brøgger Glacier) near Ny-Ålesund in north-western Spitsbergen, Svalbard, Norway (about 20 m a.s.l.; Fig. 1). The site had well

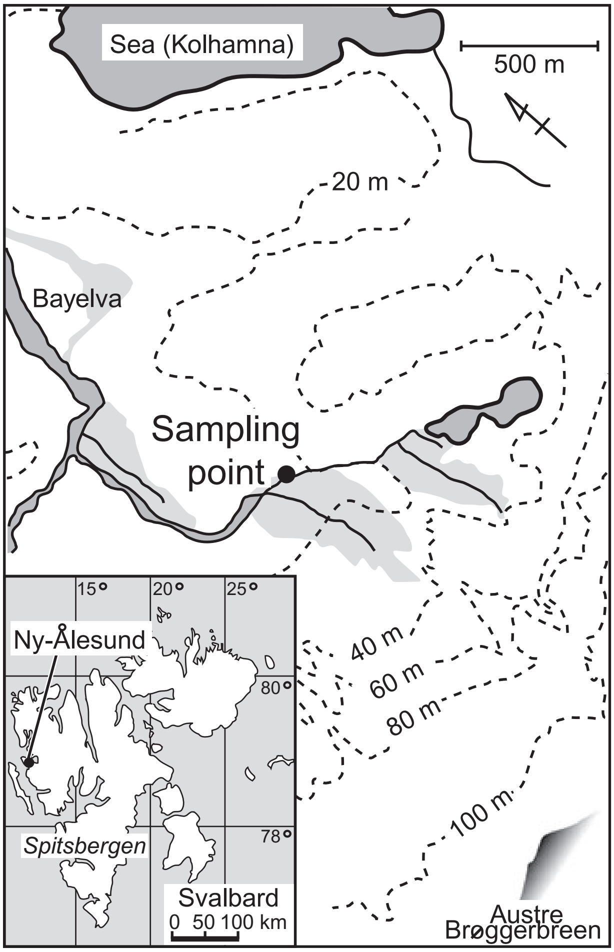

Fig. 1 Map showing the study site.

developed vegetation consisting mainly of *Saxifraga oppositifolia* L. and mosses. The means of annual air temperature and annual amounts of precipitation in this area for 1995–1998 were, respectively, –5.5°C and 362 mm. This site is near the study sites of some previous studies of the carbon cycle in this area (Site 3 in Nakatsubo et al. 1998, 2005). Roth & Boike (2001), who measured the thermal dynamics in soils near the study site, reported that the active layer thawed gradually during summer to depths between 0.9 and 1.1 m.

In August 2005, surface soils covering the bank were carefully removed to expose the soil profile, including layers of the beach deposit. Considerable care was taken to avoid disturbing the soil structure. Soil samples were taken using a steel cylinder (diameter 5 cm, 50 cm^3) from 0–2.5 cm, 10–12.5 cm, 20–22.5 cm, 30–32.5 cm, and 40–42.5 cm of mineral soil layers. To prevent contamination, the steel cylinder was sterilized after each sample was taken. These samples were air-dried (for CN analysis) or freeze-dried (for carbon dating or ATP analysis) in the laboratory at Ny-Ålesund and brought back to Japan. The seashells were observed only in a 5–6-cm-thick reddish silt layer, which was 20–25 cm belowground. They were also collected for carbon dating.

The soil samples for CN analysis were passed through a 2-mm mesh sieve to remove gravel. Root fragments were removed from the samples using a forceps. Total carbon and nitrogen concentrations of the samples were measured using a CN analyser (Perkin-Elmer 2400 II; Perkin-Elmer Inc., Wellesley, MA, USA). Organic carbon contents were determined by removing carbonate from samples according to Sollins et al. (1999). One ml of 5% phosphoric acid was added to the soil (200–1000 mg dry wt.), which was then left at 25°C for 6 h. The procedure was repeated until CO_2 stopped bubbling from the soil. The samples were freeze-dried, with subsequent carbon content analysis using the CN analyser.

^{14}C ages of shell and soil organic carbon

The AMS ^{14}C dates are used to build the chronology of vertical soil profiles. Shell samples were cleaned by soaking them in a 30% hydrogen peroxide solution to remove adherent contaminants derived from soil organic carbon; samples were then reacted with 100% phosphoric acid within evacuated glass vessels at the temperature of 25°C. The graphitization of soil organic carbon was carried out according to a procedure used by Uchida et al. (2004, 2005). The ^{14}C data were acquired at the NIES-TERRA AMS facility at the National Institute for Environmental Studies (Tanaka et al. 2000; Yoneda et al. 2004).

ATP analysis

The concentration of ATP in the deposits was determined using the method of Jenkinson & Oades (1979) with some modification. Freeze-dried soil samples of 1 g (dry wt.) in 15 ml plastic centrifuge tubes were extracted by addition of 5 ml of the TCA reagent (a mixture of 0.5 M trichloroacetic acid and 0.25 M di-sodium hydrogen orthophosphate anhydrous [Na_2HPO_4]) followed by immediate ultrasonic homogenization (Astrason 3000; Misonix Inc., Farmingdale, NY, USA) at 150 W for 2 min. Tubes were kept in ice water during this procedure. After centrifugation of soil suspensions at 5000 rpm for 15 min at 5°C, 50 µl of the clear supernatant was carefully removed using a sterilized pipette to another centrifuge tube. Then, 4.95 ml of 0.025 M HEPES at pH 7.0 solution was added to the tubes and 100 µl was used for ATP analysis.

Sample ATP concentrations were quantified using the luciferin–luciferase enzyme method with light emission

Table 1 Profile of carbon content in the raised beach deposit.

		Concentration (mg C g^{-1})^{b}		Amount (mg cm^{-3})^{c}	
Layer (cm)	Density (g cm^{-3})^{a}	Total C	Organic C	Total C	Organic C
0–2.5	1.3	18.3 (1.5)	17.1 (1.1)	23.8	22.2
10–12.5	1.2	16.5 (0.7)	12.6 (1.4)	19.8	15.1
20–22.5	0.6	14.1 (0.2)	10.5 (0.7)	8.5	6.3
30–32.5	1.1	25.3 (–)	17.1 (–)	27.8	18.8
40–42.5	0.8	20.1 (–)	12.6 (–)	16.1	10.1

[a] Means of 2–3 core samples.

[b] Means of three core samples are shown with SE, except the 30–32.5 and 40–42.5 cm layers (n = 2).

[c] Density × concentration.

Table 2 ^{14}C age (not calibrated) of soil organic carbon (SOC) and seashell in the raised beach deposit.

Layer (cm)		^{14}C age (yr BP)
0–2.5	SOC	5 840 ± 40
10–12.5	SOC	11 440 ± 50
20–22.5	SOC	22 380 ± 90
	Seashell	11 080 ± 140
30–32.5	SOC	35 890 ± 240
40–42.5	SOC	28 490 ± 140

measured using an ATP tester (AF-70; DKK-TOA Corp., Tokyo). Extraction efficiencies were determined by adding known amounts of ATP to soil samples.

Results and discussion

At all depths, organic carbon made up most of the total carbon (Table 1). The difference in the concentration between total and organic C was larger in the deep layers than in the shallow layers, suggesting that deep layers contain large amounts of carbonate. The concentration of organic carbon did not differ significantly among layers (Scheffe's F, $p > 0.05$).

The ^{14}C ages of soil organic carbon (SOC) were dated from the soil surface to 40–42.5 cm. They ranged from 5840 yr BP (0–2.5 cm) to 35890 yr BP (30–32.5 cm) (Table 2). The ^{14}C age profile of SOC was older with increased depth, except for the 30–32.5 cm layer, where the ^{14}C age of SOC was older than that in the 40–42.5 cm layer. However, a large age difference was found between the seashell and SOC in the 20–22.5 cm layer. The seashell was dated on the age of 11080 yr BP, whereas SOC in the same layer showed a much older date (22380 yr BP). The ^{14}C ages of the seashell (11080 yr BP) agree well with those obtained in a study conducted by Forman & Miller (1984), who reported that terraces on the peninsula of Brøggerhalvøya below 44 m had been formed during the last 12000 years. This large difference in the ^{14}C age between the seashell and SOC might be partly explained by contamination with ^{14}C-free fossil carbon such as coal particles, which were widely observed in this area. Another possible factor that might affect the measured ^{14}C age is cryoturbation, which causes vertical movement of unfrozen soil materials. Michaelson et al. (1996) reported that cryoturbation played an important role in the distribution of soil carbon stocks in tundra soils of Arctic Alaska. The reversion of the ^{14}C age that was observed between 30–32.5 cm and the 40–42.5 cm layers might also be explained by cryoturbation.

The results of this study showed that organic carbon in this area has two distinct origins: old organic carbon of beach deposits and more recently deposited organic carbon fixed by terrestrial vegetation. The deep layers contained a large amount of old carbon. The total amount of organic carbon contained in the 10–40 cm layer, as estimated from the average values of density and carbon concentration of the deposits (Table 1), was about 3.8 kgC m^{-2}. This value is larger than the amount of soil carbon contained in the surface soil layer (from O horizon to 10 cm depth of mineral soil) in the latter stage of succession of this area (Nakatsubo et al. 2005). It is therefore concluded that old carbon distributed in the beach deposits represents a large fraction of the soil organic carbon in this area.

The ATP concentration has been used as an indicator of life in soil because exocellular ATP has a half-life of less than 1 h (Contin et al. 2001). The ATP content was highest in the 0–2.5 cm layer (1.1 nmol g^{-1}); it tended to decrease with soil depth (Table 3). However, a low but significant amount of ATP (0.07 nmol g^{-1}) was detected even in the deepest layer (40–42.5 cm), which indicates that living microorganisms are present in the deeper layers (20–42.5 cm) of the raised beach deposit, although the content was significantly smaller than those in the shallow layers (0–12.5 cm) (Mann-Whitney U-test, $p < 0.05$). Contin et al. (2001) reported a strong linear relationship between biomass C and ATP over a wide range of concentrations, giving a mean ATP concentration of 11 μmol ATP (g biomass C)$^{-1}$. Assuming that this

Table 3 ATP concentration and biomass C in the raised beach deposit.

Layer (cm)	ATP concentration[a] (nmol g^{-1})	Biomass C[b] (mg g^{-1})	Biomass/Organic C[c] ×100 (%)
0–2.5	1.10	0.10	0.59
10–12.5	0.74	0.07	0.53
20–22.5	0.10	0.01	0.08
30–32.5	0.07	0.01	0.04
40–42.5	0.07	0.01	0.05

[a] Means of 2–3 core samples.

[b] Conversion factor; 11 μmol ATP (g biomass C)$^{-1}$.

[c] Mean value from Table 1.

ATP-biomass conversion factor is applicable to our site, the microbial biomass C in the deposit can be estimated from the ATP concentration (Table 3). The biomass C in the 0–2.5 cm layer (0.1 mg biomass C g^{-1}) was about half of the value reported for surface soil (0–3 cm including organic soil) under the vegetation near our study site, as determined using the substrate-induced respiration method (Bekku et al. 2004). The value in the deep layers of the deposit was estimated as about 0.01 mg biomass C g^{-1}, which was less than 0.1% that of organic carbon (Table 3). This fact indicates that microbial biomass C represents only a small fraction of soil organic C in the deposit. A small amount of microbial biomass carbon within a large pool of organic carbon indicates a low availability of the carbon source (Insam & Domsch 1988). The decreased fraction of biomass C to soil organic C with increasing depth suggests that organic carbon in the deep layer was less available to microorganisms than that in the shallow layers.

However, the presence of microorganisms does not necessarily mean that they subsisted on old organic carbon in the deposit. It is also possible that they used 'newly-fixed' carbon carried by percolated water and/or cryoturbation. In addition, chemoautotrophic microorganisms and methane-oxidizing bacteria might be included in them. In fact, a recent study showed that considerable methane emission or absorption occurred in this area (Adachi et al. 2006). Further investigation including molecular-level ^{14}C analysis of microorganisms (see Petsch et al. 2001) is necessary to determine whether the microorganisms actually assimilate old organic carbon in the deposits.

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