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Effect of mineral sediments on carbon mineralization, organic matter composition and microbial community dynamics in a mountain peatland

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ABSTRACT

Carbon (C) dynamics in northern peatlands are an important factor in the global C balance under climate change scenarios. They are microbially driven and influenced by the chemical composition of organic matter. Peatlands in the Rocky Mountains are usually formed on mineral sediments or developed with interbedded mineral lenses, which have been found to affect soil properties such as volumetric water content, pH, TOC and TN. Our objective was to investigate whether the presence and relative depth of mineral horizons (i.e., stratified mineral horizons) affect microbial community structure and C composition, and in turn influence C mineralization. Three organic soil profile types were selected in the Sibbald research wetland of southwestern Alberta: peat over silty mineral over calcareous sediment (PMC), peat over silty mineral over peat (PMP), and sedge peat over moss peat profiles (PP). Peat samples were subjected to C composition and microbial community abundance and structure measurement and then incubated to test potential C mineralization. The main differences were detected in subsurface peat. In subsurface peat above mineral sediments (PMC, PMP) versus at equivalent depth in PP, the presence of a mineral horizon caused different C mineralization (mg C-CO_2 kg^{-1} soil) among soil types (PP > PMC and PMP). In addition, specific C mineralization (mg C-CO_2 kg^{-1} SOC) decreased with depth in subsurface peat in PP, but not in PMP, as greater volumetric water content (θv) above the mineral horizon created anaerobic conditions in PMP. Microbial community structures also differed between PMP and PP due to different θv in peat below mineral sediments. Recalcitrant C: labile C, bacteria: fungi, and microbial physiological stress were greatest in the subsurface peat above mineral sediments. Depth had an even greater effect: both C mineralization and microbial abundance decreased significantly with depth. Moreover, microbial community structure mainly grouped according to relative depth. Overall, our findings indicated that stratified mineral horizons affected C mineralization, microbial community structure, and peat chemistry in subsurface peat.

1. Introduction

Northern peatlands play an important role in global C cycling, as they constitute approximately 30% of global soil carbon (C) and have the greatest organic carbon (SOC) density (1140–1430 Mg C ha^{-1}) with only 3% coverage of the land area (Gorham, 1991; Eglin et al., 2010). High C density and C accumulation in these cold, waterlogged peatlands indicate the potential for substantial CO_2 and CH_4 emission (Frolking et al., 2011). Northern peatlands have been acting as a C sink, but the response of the global net C balance to a changing climate remains uncertain (Wu and Roulet, 2014). Moreover, peatland stratigraphy can be complex with great variety

Abbreviations: PMC, Sedge peat/silty mineral sediments/calcareous sediments; PMP, Sedge peat/silty mineral sediments/moss peat; PP, Sedge peat/moss peat; B:F, Bacteria to Fungi ratio; GP:GN, Gram positive bacteria to gram negative bacteria ratio; RC:LC, Recalcitrant C to labile C ratio; SOC, Soil organic carbon; θv, Volumetric water content; C:N, Carbon to nitrogen ratio.

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in peat thickness, origin, and hydrochemical properties (Charman et al., 1995). In the Rocky Mountains, for example, peatland stratigraphy can be considerably more complex owing to regional geomorphic instability. Peat profiles in mountain environments can include frequent interruptions by mineral or ash lenses (Kubiw et al., 1989; Sewall et al., 2015) or contain underlying mineral sediments (Kubiw et al., 1989; Chadde et al., 1998; Morrison et al., 2015) originating from upslope slides. Little is known about whether and how mineral sediments affect C cycling in peatlands.

Climate factors such as temperature and water content are the dominant controls of C mineralization (Sierra et al., 2015; Preston and Basiliko, 2016). Carbon dynamics are further influenced by organic matter (OM) stability (Six et al., 2002; Davidson and Janssens, 2006). The OM stability depends on whether OM is protected from microbial decomposition by physical (aggregates), chemical (organo-mineral complexes and/or adsorbed by clay or silt) and/or biochemical (OC composition) mechanisms (Han et al., 2016). In peatlands, biochemical protection is key because bulk peat is usually weakly decomposed and unprotected by mineral particles. Biochemical stability is reflected in the relative abundance of labile versus recalcitrant C functional groups (Beer et al., 2008). As peat decomposes, OM composition changes, with increasing recalcitrant C and decreasing labile C (Tfaily et al., 2014). Different residues have different OM compositions: Mosses (such as *Sphagnum* spp.) are more likely to release phenolic compounds whereas vascular plants are more likely to release lignin (Verhoeven and Toth, 1995; Williams et al., 1998). Fourier Transform Infrared (FTIR) spectroscopy has been widely used in peatlands (Artz et al., 2006; Broder et al., 2012; Tfaily et al., 2014) as it provides absorption bands characterizing the relative abundance of C compounds (i.e. polysaccharides, phenolic and aliphatic, aromatic groups, and lignins) via ratios of recalcitrant fractions and labile fractions (Beer et al., 2008). However, it remains unclear how these C fractions affect C mineralization in peatlands, particularly in the presence of complex stratigraphy.

Microbes are important mediators of C mineralization. Microbial community dynamics change with nutrient levels, pH, and especially O_2 availability, which is often associated with increasing depth and/or water content related to hydrologic conductivity (Fierer et al., 2003; Artz et al., 2006; Lin et al., 2014). Microbial community composition and peat chemistry are highly correlated with each other. The chemical composition of organic matter is affected by microbial decomposition (Šnajdr et al., 2011); however, different C fractions also support different microbial communities (Preston et al., 2012). For example, microorganisms can be divided ecologically into copiotrophs and oligotrophs (Fierer et al., 2007). Copiotrophs prefer soils with more labile C, whereas oligotrophs are usually more abundant in soils with higher content of recalcitrant C (Bastian et al., 2009). Phospholipid fatty acid (PLFA) analysis is widely used to monitor broad changes of the viable microbial community structures with C decomposition and sensitivity of the microbial community structure to substrate quality and other abiotic factors (Preston et al., 2012; Peltoniemi et al., 2015). It has been found that the shift of microbial community structures from copiotrophs to oligotrophs as a result of different C composition can be reflected by increasing of gram positive bacteria to gram negative bacteria ratio (GP:GN) in PLFA measurement (Yao et al., 2000). In addition, some GN bacteria with cyclopropyl fatty acids in their membrane respond to stress associated with nutrient depletion, O_2 status, acidic pH, and osmotic stress (Grogan and Cronan, 1997). Therefore, the ratio of cyclopropyl fatty acids to monounsaturated fatty acids is used as an indicator of physiological stress. Moreover, bacteria to fungi ratios (B:F) reflect soil function and vary with environmental conditions such as temperature, O_2, pH, nutrients, and available C (Prosser et al., 2007).

In peatlands with complex stratigraphy, mineral sediments can provide nutrients and electron acceptors, which can increase decomposition of nearby peat (Broder et al., 2012). Our previous work showed that the presence and types of stratified mineral horizons regulated movement of groundwater and diffusion of major and trace nutrient elements with groundwater, which affected spatial distribution of soil properties such as volumetric water content (θv), pH, total organic C (TOC) and total nitrogen (TN) (Wang et al., 2016). Changes in these soil properties should impact peat profile development, microbial communities and biogeochemical processes (Lehmann and Kleber, 2015), but this requires investigation. We conducted this study to: 1) examine whether the stratified mineral horizons affect C mineralization by influencing microbial community structure and C composition; and 2) determine whether the influence of stratified mineral horizons varies by depth.

2. Material and methods

2.1. Site description

Sibbald Research Wetland in the Kananaskis region of southern Alberta, Canada was selected as the research site (Latitude: 51.06N, Longitude: 114.87W) (Fig. 1A). This hummocky peatland is located within a relatively level valley at 1480 m a.s.l. The peat origins in this peatland are sedges (*Carex aquatilis*; 40–50% fiber content) for upper peat (~0–50 cm). Deeper peat (~50–130 cm) was dominated by less decomposed mosses (60% fiber content), mostly *Sphagnum* spp. mosses and a few brown mosses (*Drepanocladus* sp. *and Scorpidium* sp). The site has been described by Janzen and Westbrook (2011) and Westbrook and Bedard-Haughn (2016). We classified the research area into three main soil types according to the presence and types of stratified mineral horizons (Wang et al., 2016). Briefly, in the southwest zone of the basin, with the presence of silty mineral and calcareous sediments at the base, the soil profile is sedge peat/silty mineral sediment/calcareous sediment (PMC). In the central zone, a silty mineral horizon is interbedded in peat, i.e. sedge peat/silty mineral sediment/moss peat (PMP). In the northeast zone, no mineral horizons are present within 2 m, so it is classed as sedge peat/moss peat (PP) (Fig. 1B). Sedges are the most common vegetation in PMC and along the creek in PMP. In PP and the remainder of PMP, both sedges and willows (*Salix* spp.) are dominant. For PMC and PMP profiles, each can be further divided into two sub-types according to depth of mineral lens (Fig. 1C). PMC1 and PMP1 represent profiles where mineral horizons or mineral lenses are present at shallower depth (30–40 cm), whereas PMC2 and PMP2 represent the profiles where mineral horizons or mineral lenses are present at greater depth (>50 cm). In total there are five sub-types: PMC1, PMC2, PMP1, PMP2 and PP.

Eight sampling points were selected from each soil type (including four from each of the PMC and PMP sub-divisions). The distances between any two given sampling points were greater than the minimum distance to obtain independent samples (50 m in PMC, 60 m in PMP and 70 m in PP; Wang et al., 2016). At each sampling point, samples were collected by auger to approximately 1.3 m depth, including equal thicknesses of peat above and below the silty mineral sediments in PMP and including the calcareous sediments at the base of PMC. At each sampling point, the peat profile was divided into five layers according to depth and stratified mineral horizons. The first layer was the top 10 cm; below that, layers were divided according to transition of mineral sediment and peat, changes of fiber content according to von Post test, and thickness (Wang et al., 2016). To simplify the depth of peat relative to mineral sediments, peat materials were grouped into three depth classes: *Surface peat* referred to the top 10 cm, peat layer(s)