AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2017GL075543

Key Points:
- Deposition of soil material in the river channel appeared to be more derived from deep old permafrost than surface soils
- Deposition of permafrost soils at the coast was affected by hydrodynamic sorting, coastal currents, and drifting ice
- Degradation and organo-mineral interactions likely played important roles in the depth-dependent thermal stability of Arctic soils

Supporting Information:
- Supporting Information S1

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Citation:
Zhang, X., Bianchi, T. S., Cui, X., Rosenheim, B. E., Ping, C.-L., Hanna, A. J. M., … Allison, M. A. (2017). Permafrost organic carbon mobilization from the watershed to the Colville River delta: Evidence from ^{14}C ramped pyrolysis and lignin biomarkers. *Geophysical Research Letters*, *44*. https://doi.org/10.1002/2017GL075543

Received 2 SEP 2017
Accepted 10 NOV 2017
Accepted article online 13 NOV 2017

Permafrost Organic Carbon Mobilization From the Watershed to the Colville River Delta: Evidence From ^{14}C Ramped Pyrolysis and Lignin Biomarkers

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Abstract The deposition of terrestrial-derived permafrost particulate organic carbon (POC) has been recorded in major Arctic river deltas. However, associated transport pathways of permafrost POC from the watershed to the coast have not been well constrained. Here we utilized a combination of ramped pyrolysis-oxidation radiocarbon analysis (RPO ^{14}C) along with lignin biomarkers, to track the linkages between soils and river and delta sediments. Surface and deep soils showed distinct RPO thermographs which may be related to degradation and organo-mineral interaction. Soil material in the bed load of the river channel was mostly derived from deep old permafrost. Both surface and deep soils were transported and deposited to the coast. Hydrodynamic sorting and barrier island protection played important roles in terrestrial-derived permafrost POC deposition near the coast. On a large scale, ice processes (e.g., ice gauging and strudel scour) and ocean currents controlled the transport and distribution of permafrost POC on the Beaufort Shelf.

1. Introduction

The permafrost-dominated Arctic region of the Earth is experiencing temperature rise that is twice as fast as the global average (Intergovernmental Panel on Climate Change, 2013). The organic carbon (OC) pool stored in these regions, estimated to be around 1,300 pg (Hugelius et al., 2014), has become vulnerable to extensive thawing. Substantial amounts of carbon are preserved in ice-rich yedoma deposits, a special type of permafrost that accumulated during Pleistocene (Strauss et al., 2013; Zimov et al., 2006). Under the current warming trajectory, it is estimated that 5% to 15% of the terrestrial permafrost OC pool will be released in the form of greenhouse gases during this century (Schuur et al., 2015), resulting in a positive feedback that will increase the rate of global warming (Schuur et al., 2008).

Numerous studies have focused on the dynamics of permafrost degradation in Arctic soils (Payette et al., 2004; Schädel et al., 2016; Schuur et al., 2009; Zimov et al., 2006). As for the transport of permafrost-derived OC by river systems, most research has focused on the dissolved organic carbon (DOC) pool (Frey & McClelland, 2009; Spencer et al., 2015; Striegl et al., 2007; Zhang et al., 2017). Because of the high lability of permafrost-derived DOC, much of the DOC in river headwaters that is derived from watershed soils is consumed by microbes and photodegradation before reaching the coast (Cory et al., 2014; Mann et al., 2015; Vonk et al., 2013). In contrast, permafrost-derived particulate OC (POC) in Arctic rivers seems to be stable enough to survive transport to the coast (Feng et al., 2013; Schreiner et al., 2014; Tesi et al., 2016). The sources of permafrost-derived POC, however, its pathway of delivery to the coast, and its distribution once reaching the coastline are largely understudied.

The Colville River (Figure 1) is the largest river catchment on the North Slope of Alaska underlain by continuous permafrost and terminates on the inner shelf of the Beaufort Sea (Walker, 1998; Walker & Hudson, 2003). Peak water discharge reaches ~6,000 $m^3\ s^{-1}$ for a few weeks each year as snowmelt accumulates and ice breaks up in spring (Arnborg et al., 1967; Walker & Hudson, 2003). Bank erosion in Arctic rivers is

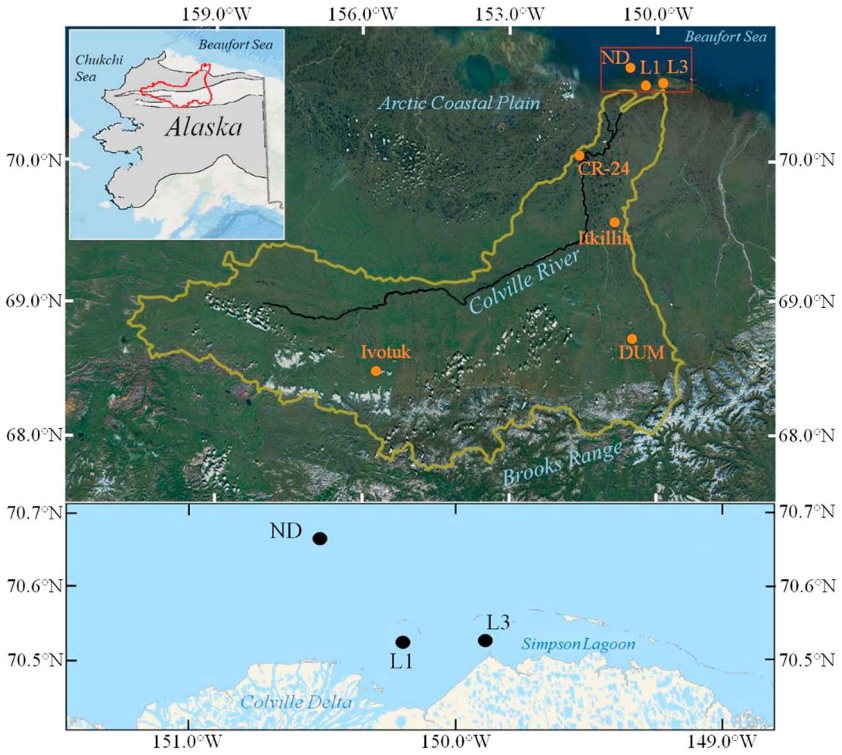

Figure 1. Map of study area and sample locations. Inset on the left shows the Colville River watershed within red line, underlain by yedoma deposits in gray from Kanevskiy et al. (2011). Bottom map shows sample locations at the Colville Delta.

suggested to be an important mechanism for carbon export to the Arctic shelf (Drenzek et al., 2007; Goñi et al., 2005). For example, the Itkillik River (the largest tributary of the Colville River) is a major source of watershed soils to the Colville and likely its delta, a consequence of extensive riverbank erosion (Kanevskiy et al., 2016). The Colville River Delta and the adjacent Simpson Lagoon are largely protected from intense ice grounding (Barnes et al., 1984) and have been shown to contain well-laminated undisturbed sediments (Hanna et al., 2014; Schreiner et al., 2013). Thus, certain regions of the Colville Delta are repositories of inputs of permafrost-derived OC mobilized from the watershed over centennial and millennial timescales.

Previous studies in the Colville River Delta, using bulk elemental, isotopic, and biomarker analyses, have shown the dominant terrestrial riverine inputs in sediments near the river mouth (Schreiner et al., 2013; Zhang et al., 2015). Here we used a relatively new technique, ramped pyrolysis-oxidation (RPO) radiocarbon (^{14}C) analysis to investigate the sources of the terrestrial inputs. This technique has enabled the determination of thermochemical stabilities as well as the full spectrum of radiocarbon ages of OC (Rosenheim et al., 2008; Rosenheim & Galy, 2012; Williams et al., 2014). It has been used successfully to study soil properties (Plante et al., 2013; Vetter et al., 2017) and the transport of POC in major rivers (Rosenheim & Galy, 2012; Rosenheim et al., 2013). Complementarily, we employed lignin biomarkers as indices of soil degradation and vascular plant sources (e.g., Ertel et al., 1986; Goñi et al., 2000; Tesi et al., 2014). Previous work has combined the use of lignin biomarkers and RPO ^{14}C analysis to examine linkages between watershed inputs and coastal-deltaic storage using delta sediments (Schreiner et al., 2014). Our study builds on this previous work using a more comprehensive suite samples from soils, river, and deltaic sediments, collected from the Colville River basin, to more fully investigate the fate and transport of thawing permafrost-derived POC from the upper watershed, to river channels, and eventually the delta. This work constrains permafrost inputs to inner coastal regions (Feng et al., 2015, 2013; Gustafsson et al., 2011; Tesi et al., 2014), as well as deeper waters in the Arctic Ocean (Bröder et al., 2016; Tesi et al., 2016) and adds to our understanding of permafrost carbon cycling and transport along the aquatic continuum in the Arctic.

2. Material and Methods

2.1. Sample Collection and Preparation

Sample locations of watershed soils, river, and deltaic sediments, shown in Figure 1, cover a broad expanse of the Colville River watershed. Samples were obtained from an expansive sampling effort and from researchers who had samples from past and ongoing research projects in the Colville River watershed. Thus, not all samples were collected at the same time and processed in exactly same manner. Ivotuk and DUM soil samples were collected in 1999 (Michaelson & Ping, 2003) and 2009, respectively, in the upper watershed. Sampling depths went down to the active layer and upper boundary of permafrost, using methods described by Michaelson et al. (1996). Samples were air dried at room temperature for several days. Itkillik yedoma samples were collected using SIPRE corer at the Itkillik yedoma exposure site in 2011 (Kanevskiy et al., 2016) and oven dried at 90°C. The CR-24 river sediment (upper ~5 cm) was collected from a slough connected to the Colville River main channel in August 2012 (Hanna et al., 2016). Sediment cores L1 and L3 were collected in the delta using a Rossfelder P-3 submersible vibracorer in August 2010 (Schreiner et al., 2013) and subsampled at 2 cm intervals. River and delta sediment samples were freeze dried. Although samples gathered together were dried at different temperatures, such differences did not have a large effect on certain lignin proxies ($[Ad/Al]_v$, $[Ad/Al]_s$, C/V, and S/V), based on a simple laboratory experiment we conducted to examine drying artifacts (see details in supporting information Text S1). Most published thermographs (Rosenheim et al., 2008; Schreiner et al., 2014; Vetter et al., 2017) showed negligible amount of CO_2 production under 90°C, indicating minimal effects of drying temperatures on bulk thermal stability. All soil and sediment samples were homogenized prior to analyses.

2.2. Lignin Biomarkers

Lignin phenols were extracted based on the alkaline CuO oxidation method of Goñi and Hedges (1992). Eight individual lignin phenols are commonly used as terrestrial biomarkers, including syringaldehyde, acetosyringone, syringic acid, vanillin, acetovanillone, vanillic acid, *p*-coumaric acid, and ferulic acid. The ratios of vanillic acid to vanillin ($[Ad/Al]_v$) and syringic acid to syringaldehyde ($[Ad/Al]_s$) were used as indices of lignin degradation in soils and sediments (Goñi et al., 2000; Opsahl & Benner, 1995; Tesi et al., 2014). The ratio of syringyl (S, sum of syringaldehyde, acetosyringone, and syringic acid)/vanillyl (V, sum of vanillin, acetovanillone, and vanillic acid), and cinnamyl (C, sum of *p*-coumaric acid and ferulic acid)/vanillyl (V) is also useful indicators of plant origin (Goñi et al., 2000; Hedges & Ertel, 1982). Λ_8, the sum of the eight lignin phenols, is not discussed in this paper because different drying processes have a significant effect on this proxy (see details in supporting information Text S1).

2.3. Ramped Pyrolysis Analysis

RPO was performed on soil and sediment samples, using the procedure described in Rosenheim et al. (2008). In brief, around 3 mg of OC of each decarbonated sample was added to the pyrolysis reactor and heated under ultrahigh purity (UHP) helium (He; 35 mL min^{-1}) flow to 1000°C at a constant temperature ramp rate of 5°C min^{-1}. As the sample decomposed in the He gas, UHP O_2 was continuously injected (4 mL min^{-1}) immediately downstream of the pyrolysis furnace, rapidly oxidizing the pyrolysis products to CO_2 in the 800°C combustion chamber—catalyzed by oxidized copper wire intertwined with Pt and Ni wires. CO_2 subsamples were collected based on the thermograph curve of CO_2 and real-time temperatures. Subsampled CO_2 gas was then purified cryogenically and sealed into borosilicate glass tubes with copper oxide and silver wire and baked at 550°C prior to graphitization. Surface soil samples were not measured for RPO ^{14}C analysis as they have modern bulk ^{14}C values (data not shown here).

2.4. Graphitization and Radiocarbon Analysis

CO_2 gas samples were sealed in glass tubes and extracted cryogenically on a vacuum line and sealed in Pyrex reactor tubes packed with zinc, titanium hydride, and catalyst iron (Xu et al., 2007). CO_2 gas was converted to graphite after sequential combustion at 500°C for 3 h and 550°C for 4 h. Graphite samples were analyzed at the National Ocean Sciences Accelerator Mass Spectrometry facility at Woods Hole Oceanographic Institution. Radiocarbon results were corrected for blank contamination from RPO and graphitization, following the methods of Fernandez et al. (2014) and Cui et al. (2017), respectively. Modern and dead-carbon contamination in the pyrolysis system has been decreasing and becoming more consistent since the system was

first installed at the University of South Florida and over the time period of sample analysis in this study (Figures S1 and S2).

3. Results and Discussion

3.1. Soil OC Decomposition and Aging

One of the general principles of the RPO technique is that CO_2 produced at low temperature is derived from less thermally stable (labile) molecules, whereas CO_2 produced at high temperature originates from more thermally stable (refractory) molecules (Plante et al., 2013; Rosenheim et al., 2008). The thermographs from surface (<10 cm) and deep soils (>40 cm) in the Colville River watershed showed a wide bimodal distribution (Figures 2a and 2c) and a more homogenous narrow range (Figures 2b, 2d, and 2f), respectively. This possibly reflected decreases in molecular diversity in the deeper more degraded soil OC (SOC). This may be explained by the fact that fresh surface soils have a greater diversity of compounds with both biodegradable compounds (e.g., fatty acids, amino acids, and sugars) and stable macromolecular compounds (e.g., lignin), compared to the more degraded deep soils (Guggenberger et al., 1999; Hatcher et al., 1981; Lichtfouse et al., 1998). As biomolecules decompose, polycondense, and geopolymerize over time (i.e., soil depth) (Gleixner, 2013; Maillard, 1917; Schmidt et al., 2011), the thermal stability of the deep SOC converges into one pool. The decomposition of OC in deeper horizons was accompanied by higher lignin degradation indices ($[Ad/Al]_v$ = 0.81 ± 0.04, $[Ad/Al]_S$ = 0.71 ± 0.13) than surface soils ($[Ad/Al]_v$ = 0.54 ± 0.06, $[Ad/Al]_S$ = 0.52 ± 0.02) (Table S3). Similar S/V and C/V ratios in surface and deep soils suggested that angiosperm grasses were dominant during the entire accumulation period (Figure S3). Even though source plots of lignin-based ratios need to be carefully interpreted (Hedges & Prahl, 1993; Hernes et al., 2007), the fact that angiosperm grasses (e.g., tussock and sedge) represented one of the major types of vascular vegetation currently (Walker et al., 2005) and previously (at least in Holocene) in this region (Anderson & Brubaker, 1993) adds to our confidence in these results.

Thermal stability of SOC is also likely to be affected by the presence of minerals. In this study, even though the Itkillik subsample was only slightly below surface (12–17 cm) and shared similar degradation indices ($[Ad/Al]_v$ = 0.56, $[Ad/Al]_s$ = 0.48) to surface soils ($[Ad/Al]_v$ = 0.54 ± 0.06, $[Ad/Al]_s$ = 0.52 ± 0.02) (Table S3), the thermograph was more analogous to the deep soils (Figures 2b, 2d, and 2f) than surface soils. Based on OC analyses, surface soils had negligible mineral content (TOC > 40%), while the subsurface soil (TOC = 21%) and deep soils (TOC = 2.0 ± 1.6%) had variable and significantly higher mineral content (Table S3). In this case, a shift of labile pool to higher temperature from surface to subsurface soils may in part be attributed to the presence of organo-mineral interaction which has been shown to protect and stabilize labile compounds, via ligand exchange with mineral hydroxyls and adsorption (Kleber et al., 2007). Meanwhile, thermal stability of the stable pool was possibly transformed by organo-mineral interactions which needs further exploration. In general, organo-mineral interactions likely play an important role in thermal stability (Plante et al., 2009) and long-term stabilization of SOC (Lalonde et al., 2012; Marschner et al., 2008; Shields et al., 2016).

Similar thermal stability of deep soils, apart from stabilization by organo-mineral associations, can also result from low microbial activities in frozen deep soils. Deep soils at the three locations showed similar RPO thermographs and an increasing trend of ^{14}C age with pyrolysis temperature, possibly indicating similar SOC composition. Microbial activity was likely limited in frozen deep soils (Brooks et al., 1998; Michaelson & Ping, 2003), with decreases of microbial enzyme kinetics expected at lower temperature. Meanwhile, deep soils had similar $[Ad/Al]_v$ ratios with only a slight increase in $[Ad/Al]_s$ ratios with soil depth (Table S3), possibly indicating no extensive degradation in deep soils with soil depth. Thus, we posit that once SOC in soils has been degraded to a certain degree and stabilized with minerals and frozen condition, there appears to be little preferential decomposition of certain groups of compounds, at least with respect to our detection techniques.

3.2. Transport of Deep Soil to the River

Similarities in the thermographs, age distributions, bulk radiocarbon ages, and lignin indices of deep soils and river sediments suggest greater accumulation of deep soil inputs to the Colville River main channel than surface soils (Figure 3). As shown in Figure 2, the thermographs of Ivotuk-d and DUM-d peaked at ~400°C, fairly

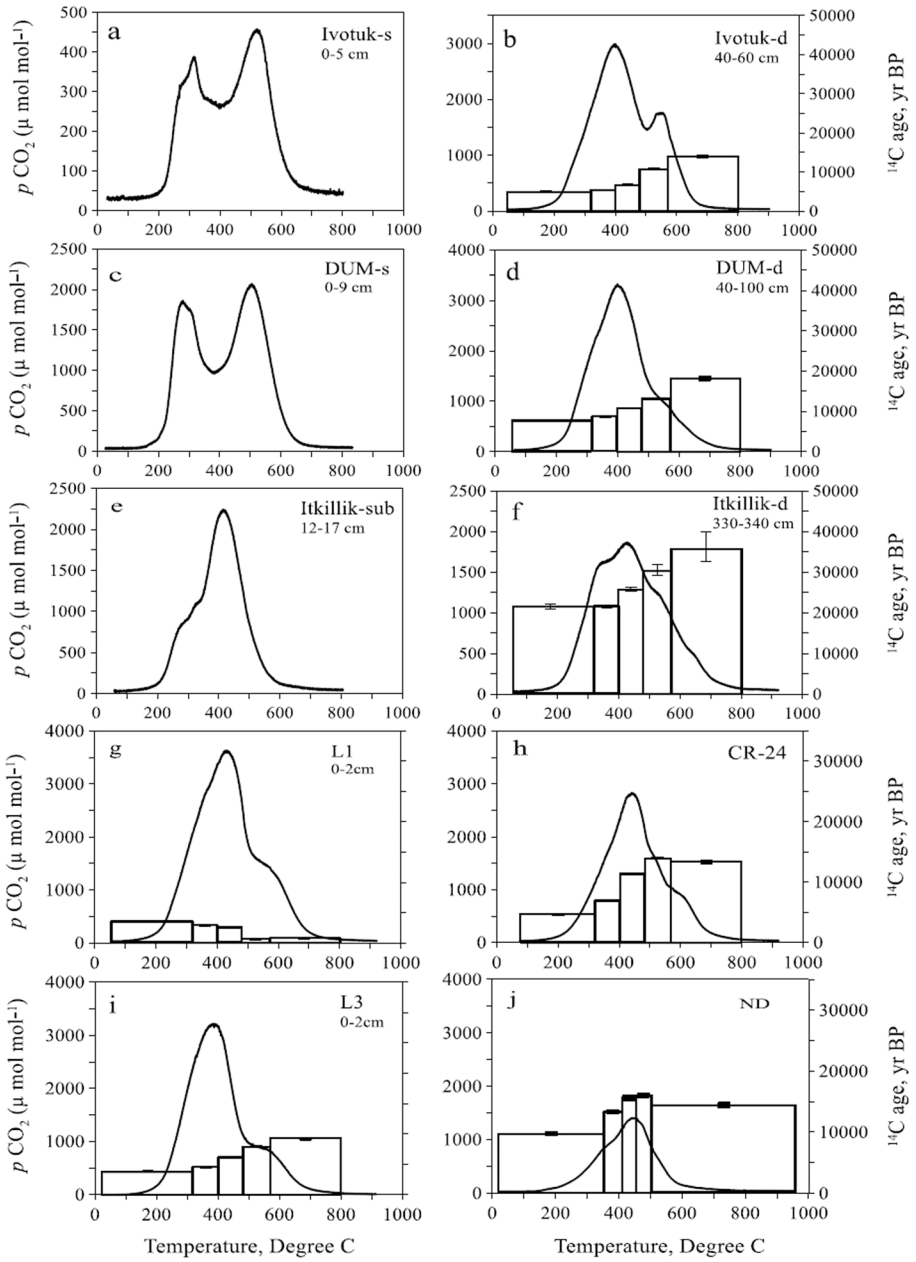

Figure 2. Thermographs (black lines, left *y* axis) and ^{14}C age distribution of CO_2 splits (bars, right *y* axis). Soil samples: (a) Ivotuk-s, (b) Ivotuk-d, (c) DUM-s, (d) DUM-d, (e) Itkillik-sub, and (f) Itkillik-d. River sediments: (h) CR-24. Deltaic sediments: (g) L1, (i) L3, and (j) data for ND site, from Schreiner et al. (2014).

similar to river sediment CR-24 which peaked at ~430°C. The ^{14}C age distribution of river sediment CR-24 followed the same trend of increasing ^{14}C age from lower to higher temperature splits during RPO, with the exception of the last split. Considering that fresh surface soils had a stable pool peaking at ~500°C (Figures 3a–3c), the relatively younger radiocarbon ages of the last split in river sediments may reflect small inputs of OC from surface soils which has been noted in compounds indicative of such sources (Williams et al., 2014). Charring of a small fraction of less thermally stable compounds which decomposes at higher temperature (Williams et al., 2014) cannot be ruled out; however, the fresh surface material high-temperature peaks are a more likely source of younger material to high-temperature fractions. The suggestion that deep soils are the dominant inputs is also supported by the old bulk radiocarbon age (10,000 yr B.P.) of CR-24 (Table S3). Not just CR-24, other surface sediment samples that were taken

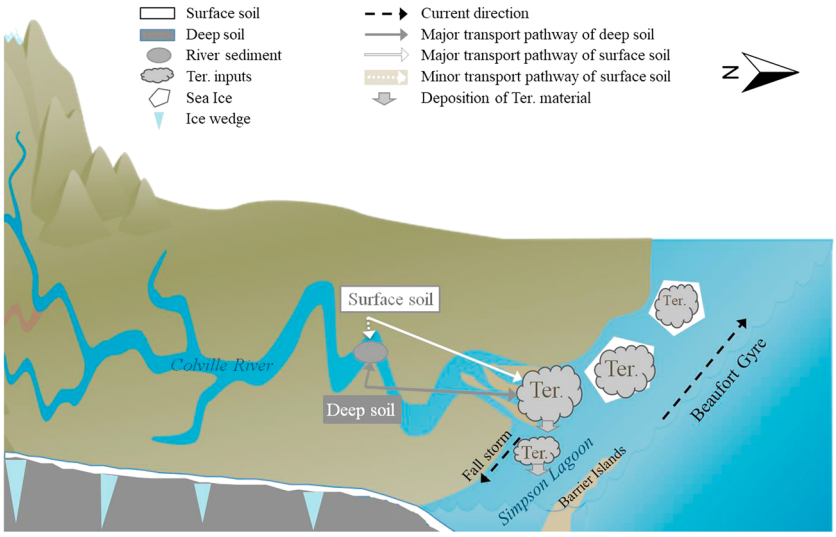

Figure 3. Proposed pathways of terrestrial POC (from surface and deep soils) transport and deposition in the Colville Delta and the inner shelf of the Beaufort Sea. Deep soil is the dominant source for river sediments. As temperature increases and sea ice breaks up, fluvial-derived terrestrial material (Ter., a combination of surface and deep soils) is likely transported to the west side of the delta by Beaufort gyre except the delta locations protected by barrier islands. Deposition of Ter. OC along the pathway in the inner shelf is unlikely because of ice processes (e.g., ice gouging and strudel scour) and Ter. OC on sea ice will be transported further offshore. In the fall, when storm fronts shift the current direction near the Colville Delta to the east, Ter. OC can also be deposited in the Simpson lagoon, with protection from barrier islands.

along the main river channel during the same field study also showed old bulk radiocarbon ages (4,000–10,000 yr B.P.) except the two samples that were taken from a vegetated sand bar (1,000–2,000 yr B.P.) (Figure S4). Higher decay indices in the deeper soils ($[Ad/Al]_v = 0.81 \pm 0.04$, $[Ad/Al]_s = 0.70 \pm 0.15$) and river sediments ($[Ad/Al]_v = 0.81$, $[Ad/Al]_s = 0.64$) than surface soils ($[Ad/Al]_v = 0.53 \pm 0.07$, $[Ad/Al]_s = 0.51 \pm 0.02$) (Table S3) also supported the dominance of deep soil inputs to sediments in river channels, assuming that significant increases in the [Ad/Al] ratios were unlikely during fluvial transport.

The possible dominance of deep soil over surface soil deposition in river channels is likely a result of the peak ice breakup and flooding period in spring. During the peak ice breakup and flooding events (only 4% of a year), 62% of the annual sediment load is mobilized in the Colville River, which likely coincides with extensive erosion, transport, and deposition of soil material (Walker & Hudson, 2003). In this case, any low-density easily suspended surface soils, rich in plant debris with a modern ^{14}C signal, would most likely be transported downstream to the lower river channel and/or delta, with a greater fraction of the higher-density (more mineralogical) deep soil residing in the river channel (Figure 3). During summer, as temperatures continue to rise, frozen ground gradually begins to thaw, and thaw slumps and other thermal erosion mechanisms (e.g., gully erosion) would also be expected to deposit some soil material at the river bars and channels (Costard et al., 2003; Lantz & Kokelj, 2008). These particular pathways of soil transport, however, would only work for short distances because of the low water discharge at this time of the year (Holmes et al., 2008).

3.3. Deposition of Soil Material at the Coast

RPO thermographs and radiocarbon results of surface sediments from Colville River deltaic stations L1 and L3 indicated the deposition of permafrost-derived SOC at the delta. Similar RPO thermographs of the delta samples, river sediment (CR-24), and deep soils (Ivotuk-d and DUM-d) all showed peak values around 400°C with and a secondary shoulder at 600°C, reflective of thermochemically similar OC composition. This suggests that deep permafrost soils are being transported along the aquatic continuum to the Colville River Delta. Bulk radiocarbon ages of 2150 and 5410 yr B.P. in L1 and L3 surface sediments, respectively, also supported the deposition of permafrost-derived deep soil because the surface sediments there appear to be deposited around 2007 based on ^{137}Cs dating (Hanna et al., 2014). Meanwhile, compared to river sediments, the deltaic sediments showed younger radiocarbon signals, indicating inputs of OC from other sources, such as modern marine and/or surface soil OC. Although previous work showed that marine inputs are a minor contributor to

the total OC at these two delta sites, reflected in part by low $\delta^{13}C$ values (Schreiner et al., 2013; Zhang et al., 2015), they contribute disproportionally to the bulk radiocarbon age because of their relatively greater fraction of modern radiocarbon.

Fluvial-derived plant debris inputs from surface soils in the watershed may also contribute to the younger radiocarbon ages of deltaic sediments than river sediments, especially at Station L1 (Figure 3). In fact, the RPO ^{14}C pattern of younger radiocarbon ages at higher temperatures in Station L1 (0–2 cm) was unusual. After excluding any possible effects of oil contamination on the radiocarbon pattern at this site (supporting information Text S2), we further analyzed a sample from station L1 just below the ^{137}Cs peak (at a depth of 28–30 cm) to investigate whether the relatively young signature pattern was related to thermonuclear bomb tests or attributable to deposition of modern OC. Results from this deeper sample were similar to those in the surface sediment (Figure S5), suggesting that sediments with the same OC sources have been deposited here for at least the last few decades. As mentioned earlier, deposition of soil material in the upstream river channels was mostly from deep soil horizons, suggesting that much of surface soil OC was transported downstream, eventually reaching the coast. Particularly, the abundance of lignin in surface soils (Feng et al., 2013) may explain the association of younger ages with high temperature in the RPO at Station L1, because lignin needs a higher temperature to decompose (Williams et al., 2014; Yang et al., 2007). Also, lignin decay proxies were relatively low ($[Ad/Al]_v = 0.47$ and $[Ad/Al]_s = 0.52$) (Table S3), indicating inputs of fresh material from surface soils at L1.

The older radiocarbon age of OC at the high-temperature splits in L3 than L1 suggested additional source inputs of radiocarbon old OC, aside from riverine inputs. The coastline of Simpson Lagoon is composed mostly of peat-rich bluffs about 1 m in height with sandy beaches below (Schreiner et al., 2013), and the age of peat could be a few thousand to 10,000 years old (Carter, 1981; Eisner et al., 2005; Kanevskiy et al., 2013). Previous studies in this region have demonstrated the importance of coastal erosion (Ping et al., 2011; Reimnitz et al., 1988), especially near the eastern region of the Simpson Lagoon (Schreiner et al., 2013; Zhang et al., 2015). In addition, peat here possibly has been through extensive humification which can transform OC into more recalcitrant humic substances—resulting in increases in thermal stability (Stevenson, 1994). Thus, we speculate that the age distribution difference between sites L3 and L1 in the high-temperature range may also result from peat inputs at L3.

Different from stations L1 and L3, the surface sample from the other coastal station, ND (Figure 1), showed a much older radiocarbon age (Figure 2). High-resolution acoustic reflection data revealed potential disruption of sediments at this site, and along with no measurable ^{137}Cs activity, it appears that there has been negligible modern (last ~50 years) sediment accumulation—likely due to ice effects on sediment accumulation/transport (A. J. M. Hanna, personal communication, 2017). The inner shelf of the Alaska Beaufort Sea is highly erosional in nature, with extensive reworking and removal of sediments via ice gouging and strudel scour (Héquette et al., 1995; Reimnitz & Kempema, 1983; Wolf et al., 1987). Much of the Beaufort Sea inner shelf, with the exception of restricted bays and lagoons, is characterized by an erosional unconformity with negligible Holocene sediment overlying the Pleistocene transgressive surface (Reimnitz et al., 1988; Wolf et al., 1987). Thus, the old radiocarbon age of Station ND may also be reflective of the relict Pleistocene material (yedoma) that was in place before this area was transgressed. This site also primarily consists of overconsolidated mud, which is the sum of silt and clay (0.7% sand and 99.3% mud content). This is in agreement with the high mud content in aeolian yedoma deposits (Table S5).

3.4. Effects of Coastal Conditions on the Distribution of Terrestrial Inputs

Hydrodynamic sorting and coastal erosion may play important roles in OC deposition in Arctic coastal regions. As mentioned before, the young radiocarbon ages and low degradation indices at station L1 were indicative of preferential deposition of surface soil material that was generally lower in bulk density (e.g., plant debris). Grain size analyses (Table S5) showed possibly less winnowing of fine particles at L1 because of relatively greater protection from ocean storms and waves (than L3) due to barrier islands (Figure 1). We see more laterally transported coastal material deposited at L3, as reflected by the coarser grain size of sediment there, compared to generally finer sediments delivered by the river (Hanna, 2015). Thus, it appears that L1, because it is closer to river mouth and more protected by barrier islands with minimal coastal erosion, was likely more of a depocenter for riverine inputs (Figure 3) (Hanna et al., 2014; Schreiner et al., 2013).

The ND site, as mentioned previously, is in an area that is likely experiencing significant erosion and/or sediment reworking from ice processes. Thus, the inner shelf beyond the protection of barrier islands may be an area of bypass for the large sediment load exported from the river to the deeper Beaufort Shelf (Reimnitz et al., 1988). In addition, as the Beaufort shelf is mostly covered by sea ice during spring (Reimnitz et al., 1978; Schulze & Pickart, 2012), when the majority of the sediment load is transported to the coast, it is likely that a fraction of the river POC is deposited on the surface of the sea ice and then transported to the west of the delta when the ice breaks. This western transport would be driven by the current of the Beaufort Gyre (Figure 3). In the fall, riverine POC can be transported to the east side of the delta by storms, with a small portion of annual riverine POC likely deposited in Simpson Lagoon (Figure 3). Transport and deposition of terrestrial-derived permafrost OC has been reported in other Arctic regions (e.g., Laptev Sea) (Tesi et al., 2016), despite the difference of the river inputs and sea ice regimes in these two systems (Reimnitz et al., 1994).

4. Conclusions

We demonstrated the mobilization, transport, and deposition of OC from deep permafrost soils to river channels and then coasts in an Arctic region. Surface and deep soils showed distinct RPO thermographs (two regimes versus one regime) and lignin parameters, indicating effective usage of RPO and lignin biomarker techniques to differentiate source pools of terrestrial material in the watershed, as previously shown in this study area (Schreiner et al., 2014). Degradation of OC in soils played an important role in compositional difference between surface and deep soils. Organo-mineral interactions and frozen state are important factors for long-term SOC storage. Thermographs, radiocarbon signals, and lignin biomarkers of deep soils, river, and deltaic sediments indicated the transport of old permafrost soil OC into river channels and eventually to the coast. Additionally, peat deposition to the east of the Colville delta from coastal erosion was likely based on the relatively older radiocarbon age at higher temperatures. Hydrodynamic sorting and barrier island protection play important roles in terrestrial POC deposition near the coast. In addition, ice process (e.g., ice gouging and strudel scour) and ocean currents also likely controlled the deposition, transport, and distribution of terrestrial POC on the Beaufort Shelf.

Acknowledgments
This research was partially supported by funding from the National Science Foundation (NSF EAGER Grant ARC-0935336 and NSF Grants OPP-80937700 and ARC-1023623). The Jon and Beverly Thompson Endowed Chair of Geological Sciences to T. S. Bianchi also provided funding for this project. Special thanks to Destiny Reese for assistance in ramped pyrolysis analysis. All data used in this manuscript are presented in tables and supporting information file. Finally, we thank the two anonymous reviewers for their insightful comments to make this manuscript much improved.

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