



Fate of Carbon in Alaskan Landscapes Project – Database for Soils from Eddy Covariance Tower Sites, Delta Junction, AK

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1.00 INTRODUCTION

1.10 Background

Soils in Alaska, and in high latitude terrestrial ecosystems in general, contain significant amounts of organic carbon, most of which is believed to have accumulated since the start of the Holocene about 10 ky before present. High latitude soils are estimated to contain 30-40% of terrestrial soil carbon (Melillo et al., 1995; McGuire and Hobbie, 1997), or ~ 300-400 Gt C (Gt = 10^{15} g), which equals about half of the current atmospheric burden of carbon. Boreal forests in particular are estimated to have more soil carbon than any other terrestrial biome (Post et al., 1982; Chapin and Matthews, 1993). The relations among net primary production, soil carbon storage, recurrent fire disturbance, nutrients, the hydrologic cycle, permafrost and geomorphology are poorly understood in boreal forest. Fire disturbance has been suggested to play a key role in the interactions among the complex biogeochemical processes influencing carbon storage in boreal forest soils (Harden et al., 2000; Zhuang et al., 2002).

There has been an observed increase in fire disturbance in North American boreal black spruce (*Picea mariana*) forests in recent decades (Murphy et al., 1999; Kasichke et al., 2000), concurrent with increases in Alaskan boreal and arctic surface temperatures and warming of permafrost (Osterkamp and Romanofsky, 1999). Understanding the role of fire in long term carbon storage and how recent changes in fire frequency and severity may influence future high latitude soil carbon pools is necessary for those working to understand or mitigate the effects of global climate change.

1.20 Objectives

The overarching objective of this work is to quantify, over several time scales, the rate of carbon accumulation in Alaskan ecosystems, and the likely fate of that carbon in response to climate change. Since fire disturbance is suggested to be one of the most important modulators of soil carbon accumulation in black spruce forests, the focus has been to identify fire-disturbed study sites and to document their recovery over time. A post-fire chronosequence of burned sites with suitable controls is used to substitute space for time (i.e., burns of different ages). The overall study has identified a black spruce

post-fire chronosequence that is the subject of significant collaborative research efforts into the role of fire in ecosystem function (O'Neill et al., in review).

Initial site selection focused on two locations in black spruce forest where eddy covariance towers for measuring CO₂ and moisture fluxes are in place. The towers are maintained by J. Randerson (see Sec. 1.40), and are located in typical boreal black spruce forest within an area of discontinuous permafrost (O'Neill et al., in review) near Delta Junction, AK (Fig. 1). The first tower site is a control site of mature black spruce forest estimated to be at least 100 yr since the last burn. The second tower site is a burn site of black spruce forest contiguous with the control site that burned in 1999 leaving only dead trees and approximately the lower half (by vertical extent) of the highly organic surface soil layers. A primary goal of the data set presented here is to characterize soils within the footprint of the eddy covariance towers. The emphasis is on characterization of organic soil layers. This data report represents the first of several to describe soils in boreal black spruce forest following fire. The two sites described in this data report represent a control and recent burn that were not discussed in O'Neill et al. (in review) but in the same study area near Delta Junction, AK. Subsequent reports will describe soils from older burns and corresponding controls using some of the same sites discussed in O'Neill et al.

1.30 Approach

Soils were described along linear transects extending to the south and east of the eddy covariance towers. The south transect was emphasized due to prevailing southerly winds during the growing season. Soils were described approximately every 10 to 20 m along transects. Soil descriptions (see Sec. 2.10) were by horizon, including moss, litter, organic and upper mineral soil horizons. Soils samples were taken in about half of the pits and analyzed for physical data including bulk density and particle size analyses, and chemical data including carbon and nitrogen elemental compositions, and carbon isotopic composition.

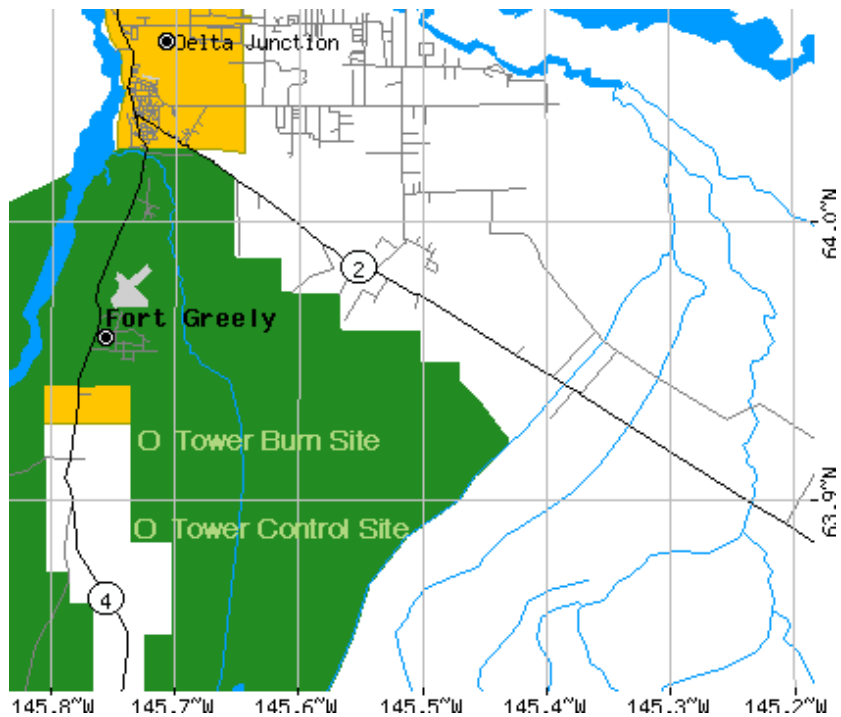
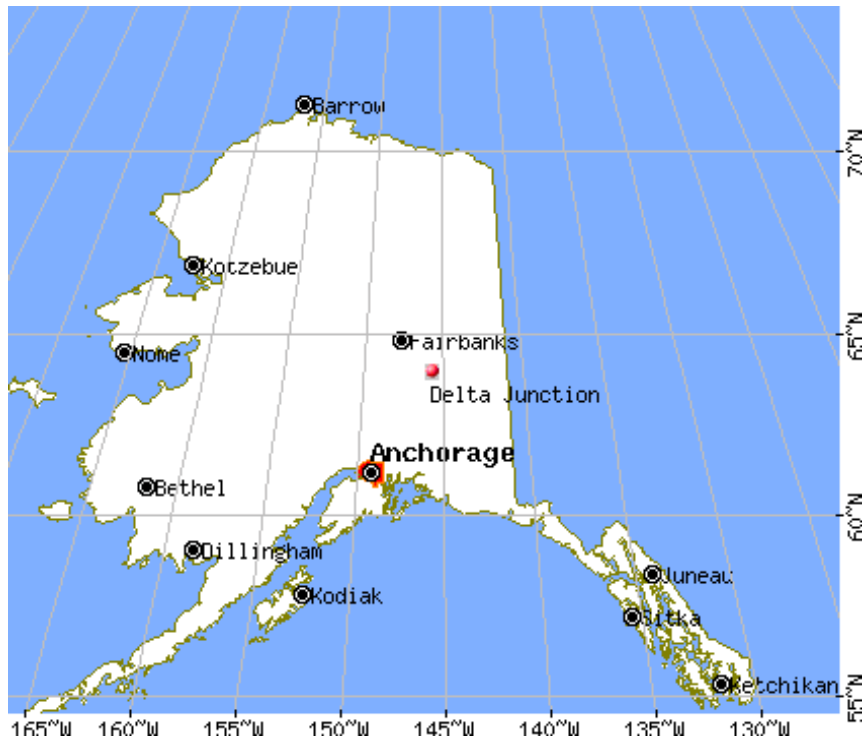


Figure 1. Map indicating location of study area. The tower sites are located on the Fort Greely military reservation (green), approximate 9 miles south of Delta Junction, AK.

1.40 Collaborations and Ancillary Data

The sampling sites described here are the focus of several ongoing investigations. Studies include the following: i) ecosystem recovery following fire; ii) static-chamber CO₂ flux and CO₂ isotopes; iii) soil moisture, temperature and soil lysimeters; iv) surface moisture and CO₂ fluxes using eddy covariance towers; v) remote sensing; and vi) nitrogen mass and isotope balances in relation to C storage and net primary production.

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2.00 METHODS

2.10 Field Methods

Soils were excavated by shovel and auger to 1–2 m depths, and described according to USDA-NRCS (Soil Survey Staff, 1998) and Canadian (Canadian Agricultural Services Coordinating Committee, 1998) methodologies from the pit face or auger borings. A variety of field properties were recorded for soil horizons at different depths. Horizon layers, represented by a one- or two-letter code, are as follows:

- L Live moss layers, which are green and generally contain some leaf and needle litter.
 - D Dead moss layers comprised of non-decomposed or slightly decomposed dead moss. The dead moss layer is characterized by fibric organic horizons that contain more moss than roots.
 - F Fibric (according to Canadian soil system) or fibrous organic layers, which vary in degree of decomposition but in which roots are more abundant than recognizable moss parts. In most cases these layers would be considered Oi layers (US soil system) or upper duff (USFS system).
 - M Mesic (according to Canadian soil system) organic layers, which are moderately decomposed with few if any recognizable plant parts other than roots. M layers are generally Oe horizons (US) or lower duff layers (USFS).
 - H Humic (Canadian soil system) or sapric organic layers, which are highly decomposed. This layer generally smears upon squeezing and has no recognizable plant parts, both of which indicated a high degree of decomposition. H layers are generally Oa horizons (US soil system) or lower duff (USFS soil system) layers.
- A, B and C horizons (US and Canadian soil system) indicating mineral soils or soils with less than 50% organic matter as judged in the field.
- bL burned or charred live moss layer plus any ash.
 - bD burned or charred dead moss layer plus any ash.
 - bF burned or charred fibric layer plus any ash.
 - bM burned or charred mesic layer plus any ash.

Generally, sampling did not cross a layer/horizon boundary, nor did sampling cross a 5 cm increment boundary within the upper highly organic soil layers (e.g., a horizon from 3 to 7 cm was split into two samples, one from 3 to 5 cm and another from 5 to 7 cm). Samples collected for bulk density were usually also used for chemical analyses. Samples collected for moisture content measurements were used only for that purpose (see also Sec. 3.23).

Bulk density samples were collected with a variety of tools, including cores of known diameter (mineral soil) and rectangles of known area (litter and organic horizons).

The most consistent and accurate bulk density estimates for mineral soils were made from cores obtained with a Model 0200 coring device from Soilmoisture Equipment Corporation (Goleta, CA) in which internal rings can be disassembled to obtain intact samples. Less consistent and less accurate measurements were obtained from cores taken with a hand-driven soil AMS corer (“shelby”) or with a 5 cm bevel-ended cylinder (“H-ring”). After collection samples were weighed within 24 hours and air-dried.

2.20 Sample Preparation and Drying

Field notes were used to inventory all samples entering the laboratory. Samples were visually inspected and weighed when received. Any discrepancy between field descriptions or weights and laboratory observations was resolved before sample preparation began or the sample was discarded. Samples were processed immediately or stored in the dark at 4° C until processing commenced.

All soil samples were placed on open shelves in an isolated room and allowed to air dry to a constant weight. Temperature during air-drying ranged from 20 to 30°C. After air-drying, moisture samples/splits were oven dried for 48 hours in a forced-draft oven. Moisture samples that appeared to contain greater than 20% organic matter (e.g., moss, litter) were oven dried at 65°C to avoid loss or alteration of organic matter by oxidation or decomposition. The remaining moisture samples were oven dried at 105°C.

Air-dry mineral soil samples for were gently crushed using a ceramic mallet and plate, being careful to break only aggregates. The crushed sample was mixed and split into subsamples for analysis and archiving. The chemical fraction was weighed and sieved using a 2 mm screen. Soil particles not passing the 2 mm screen were removed, weighed and saved separately. Soil passing the 2 mm screen was ground by hand using a mortar and pestle or the ceramic mallet and plate to pass through a 60 mesh (0.246 mm) screen. The ground material was mixed and placed in a labeled, glass sample bottle for subsequent analyses.

Air-dry organic soil samples were thoroughly mixed then split into subsamples for analysis and archiving. The subsample for chemical analysis was weighed and roots greater than 1 cm in diameter were removed, weighed and saved separately. The remaining large roots or clumps in the analytical fraction were manually chopped or

crushed and mixed thoroughly with the finer sample material. The sample was then milled in a cyclone sample mill (Udy Corp., Ft. Collins, CO, USA) to pass a 0.5 mm screen. The milled sample was thoroughly mixed and a representative sample placed in a labeled, glass sample bottle for analytical chemistry.

Archive fractions of most of the samples described here are available by contacting J. Harden at the address given above. All excess sample and waste were oven-dried at 120°C for 72 hours prior to disposal according to U.S. Dept. of Agriculture guidelines for sterilization and soil disposal.

2.30 Total Carbon, Total Nitrogen, ^{13}C , ^{15}N

A Carlo Erba NA1500 elemental analyzer (EA) coupled to a Micromass Optima isotope ratio mass spectrometer (IRMS) in continuous flow mode was used to determine total carbon, total nitrogen, ^{13}C and ^{15}N . Samples were combusted in the presence of excess oxygen. In a continuous stream of helium, the resulting sample gasses were swept through an oxidation furnace followed by a reduction furnace to yield CO_2 , N_2 and water vapor. Water was removed by a chemical trap, and CO_2 and N_2 were chromatographically separated before entering the Micromass Optima IRMS for quantification of C, N, ^{13}C and ^{15}N . C and N were determined by integrating the major ion peaks (mass 44 for CO_2 , and mass 28 for N_2) and comparison with ethylene diamine tetra-acetic acid (EDTA) standards which were also used as isotopic standards for ^{13}C and ^{15}N . Sample mass ranged from ~ 2 to 30 mg depending on the estimated carbon content. For reliable quantification of ^{15}N , at least 15 to 30 μg N are generally needed and few samples met this criterion. Thus the ^{15}N data are not reported here; the ^{15}N data are available from the authors by special request. The ^{13}C data are reported in the usual delta notation ($\delta^{13}\text{C}$) as deviations in parts per thousand (‰) relative to a standard

$$\delta^{13}\text{C} \text{ ‰} = \left\{ \left[\frac{(^{13}\text{C}/^{12}\text{C})_{\text{sample}}}{(^{13}\text{C}/^{12}\text{C})_{\text{standard}}} \right] - 1 \right\} * 1000$$

where the standard is Pee Dee Belemnite (PDB).

Working standards were used in EA-IRMS runs for checking consistency and overall precision, but were not quantified independently for all constituents (%C, %N, $\delta^{13}\text{C}$, $\delta^{15}\text{N}$). Two working standards were included in all EA-IRMS sample runs. The first

was a marine sediment (MESS-1) issued by the Chemistry Division of the Canadian National Research Council with carbon certified to be 2.99% by weight. The second working standard was a river sediment (NBS 1645) issued by the National Bureau of Standards, now the National Institute of Standards and Technology (NIST), with nitrogen certified to be 0.0797% (797 ppm) by weight. Certified values were obtained from Govindaraju (1989) in which certified values were reported without standard error. The sediment working standards MESS-1 and NBS 1645 are most representative of mineral soil samples. Additionally, about half the sample runs included NIST 1547, a peach leaf standard with nitrogen certified to be $2.94 \pm 0.12\%$ by weight. NIST 1547 peach leaves are more similar to the highly organic surface soils, but had significantly higher N content (C:N ~16:1) than the bulk of organic layer soil samples (C:N ~ 30 to 70:1). It is worth noting that professionally prepared standards are generally ground more finely and more uniformly than the samples prepared for this study. For example, NIST 1547 was milled to a uniform particle size of $\sim 75 \mu\text{m}$ whereas the organic soil samples were milled to pass a 0.5 mm screen (Sec. 2.20). To estimate precision for the organic soil samples, a number of working standards were prepared in the same manner as samples had been and incorporated into the last several sample runs. Three of these standards are included in the comparison of working standards below: LMOSS, live moss (L horizon in Sec. 2.10); DMOSS, dead moss (D horizon in Sec. 2.10); and BDUFF, representative of a combination of the bF, F and M horizons in Sec. 2.10.

Working standard	MESS-1	NBS 1645	NIST 1547	LMOSS	DMOSS	BDUFF
%C	3.03	5.37	46.8	39.1	37.8	39.1
%C Std.Dev. (n)	0.19 (50)	0.38 (46)	0.7 (96)	0.57 (9)	0.52 (11)	0.4 (12)
%N	0.19	0.088	2.84	0.65	0.72	0.88
%N Std.Dev. (n)	0.014 (45)	0.008 (45)	0.13 (104)	0.03 (10)	0.03 (11)	0.03 (12)
$\delta^{13}\text{C}$	-25.6	-22.4	-26.1	-28.4	-27.9	-27.4
$\delta^{13}\text{C}$ Std.Dev. (n)	0.23 (54)	0.47 (55)	0.33 (104)	0.17 (11)	0.14 (11)	0.14 (12)
$\delta^{15}\text{N}$	2.2	3.7	1.5	-3.2	-2.1	-0.5
$\delta^{15}\text{N}$ Std.Dev. (n)	1.9 (52)	0.62 (51)	0.28 (97)	1.4 (11)	0.69 (11)	0.48 (11)
n, total	54	55	107	11	11	12

Table 1. Working standards for EA-IRMS analyses. "n, total" is the total number of analyses; the number in parentheses following the standard deviation is the number of data used to compute the mean and standard deviation after eliminating data outside of two (2) standard deviations from the mean. Certified values as follows: MESS-1, %C = 2.99; NBS 1645, %N = 0.0797; NIST 1547, %N = 2.94 \pm 0.12 (see text).

2.40 ^{14}C Analyses

A few ^{14}C data are available at the time of publication. The ^{14}C content of ground, untreated soil was measured by vacuum sealing an homogenized sample containing ~1 mg C with cupric oxide and elemental silver in a quartz tube and combusting at 850°C. The CO_2 produced was purified cryogenically and reduced to graphite using a modified reduction method with titanium hydride, zinc, and cobalt catalyst (Vogel, 1992). The graphite target is measured directly for ^{14}C at Lawrence Livermore National Laboratory, Center for Accelerator Mass Spectrometry.

The ^{14}C data are expressed in Delta notation ($\Delta^{14}\text{C}$) similar to $\delta^{13}\text{C}$ above, i.e., the deviation in the $^{14}\text{C}/\text{C}$ in parts per thousand (‰) from a standard [$(^{14}\text{C}/\text{C})_{\text{standard}} = 1.176 \times 10^{-12}$], with additional correction for possible fractionation effects based on ^{13}C (see

Stuiver and Polach, 1977; Stuiver, 1980). To convert $\Delta^{14}\text{C}$ values to percent Modern (*pM*) values, simply divide by 10 and add 100. $\Delta^{14}\text{C} = 0 \text{ ‰}$ (i.e., 100 *pM* or $^{14}\text{C}/\text{C} = 1.176 \times 10^{-12}$) approximately represents the $^{14}\text{C}/\text{C}$ of atmospheric CO_2 in the year 1890.

2.50 Particle Size Analyses

A limited number of mineral soil samples were selected for particle size analyses by conventional pipette analyses (Gee and Bauder, 1986). In some samples, the 30% hydrogen peroxide treatment was insufficient to remove organic carbon completely and results may have been skewed toward overestimation of sand and/or coarse silt fractions. The samples for which organic carbon may have been problematic in particle size analyses are indicated in the “Notes” column of Table 4 (Delta_Tower_Physical file).

3.00 DATA-SET IDENTIFICATION

3.10 Sample Labels

The first two letters in the sample labels represent Donnelly Flats, DF. The second two letters represent either Tower Control, TC, or Tower Burn, TB. Following the letters, DFTC or DFTB, the first number represents the profile number, from 1 to 23, depending on the transect. A decimal point separates the profile number from the basal depth of the sample in cm. For example, DFTC1.20 denotes a sample from Donnelly Flats Tower Control, profile 1 with a basal depth of 20 cm.

3.20 Data-set descriptions

The following subsections briefly describe the contents of five separate downloadable files containing the soil data collected from Tower Control and Tower Burn sites near Delta Junction, AK. The first is a text file containing brief descriptions of the study area and individual sites where soil samples were obtained. The next three files are data files with identical listings of the samples and associated data. The final file is also a data file with the field descriptions of all sites along the transects.

3.21 Delta_Tower_Sites file (Table 2)

This text file contains site locations and descriptions of sites where soils were sampled. General information such as sampling date, investigators and vegetative cover is noted.

3.22 Delta_Tower_Field file (Table 3)

This file contains the field descriptions of the sampled soils and includes the following columns:

PROFILE SITE ID—keyed to the Delta_Tower_Sites file for location and site information; see also Sec. 3.10.

DEPTH—indicates the basal depth in cm of sampling increment.

HORIZON CODE—general description of the sampled horizon (see Soil Survey Staff, 1998 and also Sec 2.10 above).

SAMPLE DESCRIPTION—brief description of the sample.

ROOTS—root abundance and size using conventions of Soil Survey Staff (1998).

FIELD pH—the pH of the sample as determined in the field.

MOIST COLOR MUNSELL—color of moist soil based on the Munsell soil color chart.

STRUCTURE—grade, size, strength and type of soil structure following conventions of Soil Survey Staff (1998).

TEXTURE CLASS—soil texture class following conventions of Soil Survey Staff (1998).

PLASTICITY—plasticity following conventions of Soil Survey Staff (1998).

STICKINESS —stickiness following conventions of Soil Survey Staff (1998).

FIRMNESS—moist consistence following conventions of Soil Survey Staff (1998).

Within the data, “n/a” indicates not applicable and a blank cell indicates no analyses.

3.23 Delta_Tower_Physical file (Table 4)

This file contains the physical data on the samples including bulk densities, volumetric moisture contents and particle size analyses. The bulk density sample was usually identical with the analytical sample and was thus air-dried to preserve chemical

integrity. Therefore, air-dry bulk density is reported for the less than 2 mm fraction of the sample for the purposes of calculating carbon (or nitrogen) inventories since the %C and %N were determined only for the less than 2 mm fraction. Thus %C and %N were also determined on air-dry samples (see below). Note that using air-dry bulk density and air-dry %C provides a robust and internally consistent way to calculate carbon inventories. However, all data are also reported on a moisture-free or oven-dried basis by applying a correction to account for the moisture remaining in the air-dry samples. The correction was obtained from the moisture samples that were both air-dried to constant weight and oven-dried. The moisture content of air-dried samples used for the correction is also provided for completeness. Any errors in the moisture corrections are likely small relative to analytical uncertainties. The following columns are included in the Delta_Tower_Physical file:

PROFILE SITE ID—keyed to the Delta_Tower_Sites file for location and site information; see also Sec. 3.10.

DEPTH—indicates the basal depth in cm of sampling increment.

HORIZON CODE—a general description of the sampled horizon (see Soil Survey Staff, 1998 and also Sec 2.10 above).

SAMPLE DESCRIPTION—brief description of the sample.

FRACTION >2 mm IN SAMPLE—dry weight percent of soil particles not passing through a 2 mm sieve after gentle crushing.

ROOTS >1 cm IN SAMPLE—dry weight percent of roots larger than 1 cm in diameter in the sample.

AIR-DRY BULK DENSITY (<2 mm)— grams of air-dry soil per cubic centimeter with soil particles greater than 2 mm and roots greater than 1cm diameter removed.

DRY BULK DENSITY (<2mm)—grams of moisture-free soil per cubic centimeter with soil particles greater than 2 mm and roots greater than 1cm diameter removed; calculated from the air-dry bulk density by multiplying by (1 – fraction moisture in air-dry sample); no volume adjustment has been made for the fractions removed.

TOTAL DRY BULK DENSITY—grams of moisture-free soil per cubic centimeter for the entire soil sample with no fractions excluded; calculated similar to **DRY BULK DENSITY (< 2 mm)** except the particles greater than 2 mm and roots greater than 1 cm diameter have been added back.

VOLUMETRIC MOISTURE—the volume percent water in the sample assuming similar moisture and bulk density samples.

MOISTURE IN AIR-DRY SAMPLE— percent by weight of moisture remaining in sample after air-drying to constant weight determined by subsequently oven-drying the sample. Note that these data were obtained from a separate moisture sample and were used to calculate the Dry Bulk Density (<2 mm), Total Dry Bulk Density, %C and %N on a dry weight basis (see Table 5, Delta_Tower_Chemistry file) and are provided only for reference.

SAND (< 2 mm)—percent by weight of soil particles greater than 0.05 mm in the sample remaining after removal of particles greater than 2 mm and roots greater than 1 cm diameter.

COARSE SILT (< 2 mm)— percent by weight of soil particles in the size range from 0.02 to 0.05 mm in the sample remaining after removal of particles greater than 2 mm and roots greater than 1 cm diameter.

FINE SILT (< 2 mm)— percent by weight of soil particles in the size range from 0.002 to 0.020 mm in the sample remaining after removal of particles greater than 2 mm and roots greater than 1 cm diameter.

CLAY (< 2 mm)— percent by weight of soil particles less than 0.002 mm in the sample remaining after removal of particles greater than 2 mm and roots greater than 1 cm diameter.

NOTES—OM++ indicates residual organic matter in sample may have skewed particle size results toward increased sand and/or coarse silt; OM± indicates residual organic matter in sample, but likely not enough to skew particle size results.

Within the data, a “-” indicates not present in sample, “n.d.” indicates no data for any of a number of reasons, and a blank cell indicates no analyses.

3.24 Delta_Tower_Chemistry (Table 5)

This file contains the data from the EA-IRMS analyses (see also Sec. 2.30) and includes the following columns:

PROFILE SITE ID—keyed to the Delta_Tower_Site file for location and site information; see also Sec. 3.10.

DEPTH—indicates the basal depth in cm of sampling increment.

HORIZON CODE—a general description of the sampled horizon (see Soil Survey Staff, 1998 and also Sec 2.10).

SAMPLE DESCRIPTION—brief description of the sample.

AIR-DRY %C—percent by weight of carbon in air-dry soil sample with soil particles greater than 2 mm and roots greater than 1 cm removed, used for calculating soil carbon inventories in conjunction with air-dry bulk density.

AIR-DRY %N—percent by weight of nitrogen in air-dry soil sample with soil particles greater than 2 mm and roots greater than 1 cm removed, used for calculating soil nitrogen inventories in conjunction with air-dry bulk density.

%C—percent by weight of carbon in moisture-free soil sample calculated by multiplying air-dry determinations of %C by the reciprocal of (1– fraction moisture in air-dry sample) using moisture content in air-dry sample as reported in Delta_Tower_Physical file (see above).

%N— percent by weight of nitrogen in moisture-free soil sample with soil particles greater than 2 mm and roots greater than 1 cm removed; calculated by multiplying air-dry determinations of %N by the reciprocal of (1– fraction moisture in air-dry sample) using moisture content in air-dry sample as reported in Delta_Tower_Physical file (see above).

$\delta^{13}\text{C}$ —per mil (‰) value of $\delta^{13}\text{C}$ relative to Pee Dee Belemnite (see Sec. 2.30).

$\Delta^{14}\text{C}$ — per mil (‰) value of $\Delta^{14}\text{C}$ (Stuiver and Polach, 1977).

3.25 Delta.Tower.Transects (Table 6)

This data file contains the field descriptions of soils at sites along the transects that were only described and not sampled, and includes the following columns:

PROFILE SITE ID— general identifier where only soil descriptions obtained (see also Sec. 3.10).

DEPTH—indicates the basal depth in cm of sampling increment.

HORIZON CODE—a general description of the sampled horizon (see Soil Survey Staff, 1998 and also Sec 2.10).

SITE INFORMATION—general site information such as location, sampling or description date, investigators and vegetative cover.

SAMPLE DESCRIPTION—brief description of the sample.

ROOTS— includes root abundance and size classes following conventions of Soil Survey Staff (1998).

FIELD pH—the pH of the sample as determined in the field.

MOIST COLOR MUNSELL—includes moist soil color using the Munsell soil color chart.

STRUCTURE—grade, size, strength and type of soil structure following conventions of Soil Survey Staff (1998).

TEXTURE OR VON POST—soil texture following conventions of Soil Survey Staff (1998).

Within the data, “n/a” indicates not applicable and a blank cell indicates no analyses.

4.00 References

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