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The geochemistry of organic matter in selected Cryosols of Alaska

La géochimie de la matière organique dans des Cryosols en Alaska

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Introduction

Soil organic matter (SOM) consists of 50-58% carbon. Since direct measurement of organic matter is problematic thus soil organic carbon (SOC) is commonly determined and reported. Most research in SOC in the arctic ecosystems have been focused in the storage of total C (Ping et al., 1997a, Michaelson et al., 1996) and very few studies have included the characterization of SOM. Much of the available SOM characterization data is from temperate regions (Stevenson, 1994) and there are very limited data from arctic soils (Beyer et al., 1995). The objectives of this paper is to chemically characterize the SOC in cryogenic soils of Alaska and to relate their composition to soil environment.

Materials and Methods

Study Sites: Soils were sampled from 26 sites representing the major surface coverage of landform/vegetation complexes in arctic Alaska (Michaelson et al., 1996). The sites were representative of the two major geomorphic surfaces/ecosystems (coastal plain and arctic foothills) and were sampled to 1meter depth for this study.

SOM Analysis: Soils were described and sampled according the Soil Survey Manual (Soil Survey Division Staff, 1993). Samples were extracted with 0.1 M NaOH (Michaelson and Ping, 1997), and fractionated using the tandem XAD resin technique of Malcolm and MacCarthy (1992). Total organic carbon (TOC) was determined by LECO 1000 CHN analyzer after the soil sample was treated with dilute acid to remove inorganic C.

Results and Discussion.

Carbon Content: The soil organic carbon content (%SOC) varied according to genetic horizon and ecosystem (Table 1). Coastal plain vegetation is dominantly sedge and the soils are Hemistels (Gelic Histosol) while the arctic foothills soils are dominantly Aquaturbels (Turbic Cryosol). The SOC content of the O and O/A horizons was

consistently lower for the coastal plain pedons compared to those of the foothills an average of 21% SOC versus 25%. The mineral horizons (A, A/B, A/C, Bg, and Cf) however averaged nearly 50% higher SOC content for the coastal plain. These SOC values are much higher than that reported by Kononova (1961) but comparable to the 16-29% of Beyers et al. (1995). The lower C content of the coastal plain O horizons is due to the high mineral content throughout the profiles due to frequent inundation. The %SOC of the upper permafrost layers is low compared with that of the active layer. However, on a volume-weight basis the C stores in the upper permafrost account for 40-50% of the whole pedon C storage. The C stores in the Coastal Plain averaged 62 kg C/m³ whereas the foothills soils averaged 44 kg C/m³ (Michaelson et al., 1996).

SOM Solubility: Solubility of SOM (0.1N NaOH) in the horizons of the coastal plain (CP) were on the average 66% higher than the comparable horizons of the foothills (FH) pedons (Table 1). The differing solubilities reflect contrasting soil conditions with the coastal plain soils having a relatively low degree of humification because of the cold climate condition and the persistent anaerobic condition caused by the perched water table over the permafrost table (Ping et al., 1998). The extractability showed an increasing trend moving from the Oi (L), Oe (F), to the Oa (H) horizons indicating the increased degree of decomposition. Conventionally, the non-extractable fraction is considered as humin. However, in the organic soils, most of this non-extractable fraction proved to be cellulose and hemicellulose. The true humin accounts for 13-26% in the O horizons and 2-10% in the mineral horizons of the TOC (Ping et al., 1997b).

SOM Composition: Contrary to Orlov et al. (1996) and Kononova's (1961) findings, the extractable C of Alaska tundra soils is dominated by humic acids rather than fulvic acids (Table 1). However, such comparison is difficult because the soil type is not specified and the extraction techniques differed. Humic acid (HA) is synthesized through decomposition of SOC and accumulate under relatively static conditions. Cryoturbation and slope processes in arctic soils also contribute to the accumulation and preservation of HA. Comparison of horizons in Table 1 between regions indicates that higher proportions of HA are found throughout the foothills profile but most apparently greater regional differences occur at depth in the mineral horizons. The coastal plain is however higher in the transition horizons (A/B, A/C) because of the higher degree of humification and C accumulation. The A horizon of the foothills averaged 300% higher than for the coastal plain an apparently very active zone for decomposition and preservation due to the formation of Ca-humates. A similar pattern in the occurrence of the lower molecular weight compounds (LMA and HIN) are observed, due the same soil environmental conditions.

Humic Acids to Fulvic acids ratio: The HA/FA ratio has been used as an indicator of SOM humification and soil genesis (Orlov et al, 1996). Their data indicated the HA/FA ratio based on C% averaged 0.6 for tundra soils. However, the data for the tundra soils of Alaska ranged from 0.5 to 2.7 with average values of 1.7 in the coastal plain soils and 1.2 in the foothill tundra soils. Such difference is due to their soil environments: the coastal plain is colder and wetter which favor the preservation of humus, whereas the foothills are warmer and moist which result in higher degree of organic matter degradation.

¹³C NMR Spectral Analysis: Solid state nuclear magnetic resonance (¹³C NMR) spectrometry was used to characterize the chemical composition of all fractions obtained from selected sites in subarctic and arctic Alaskan soils (Malcolm et al, 1995; Candler et al, 1997). All HA and FA spectra indicated aliphatic, ether/alcoholic (carbohydrate), unsaturated (aromatic or olefinic) and carboxyl C components for all horizons from all sites. Aliphatic C appeared to be more important contributors to overall structure increasing with depth in foothill tundra soil. Whereas unsaturated C contribution to overall structure increased with depth in coastal plain soils compared to the foothill tundra soil suggesting disparate biochemical/chemical processes or precursors between sites as well as between horizons. Principal components to structure for the hydrophobic neutral fractions are predominantly aliphatic and carboxyl carbons. The spectra indicated more than one type of aliphatic carbon was present in the tundra soil further supporting distinct chemistries between sites since these features were absent in the coastal marsh samples. Unsaturated carbon contribution to structure is minimal to nonexistent in these fractions. The LMA spectra were indicative of polyhydroxylic/ carbohydrate acids with little or no contribution to structure from unsaturated carbons with one exception. Chemical composition of these arctic soils is similar that observed by Malcolm et al (1995) for subarctic soils although compositions are distinct based on the ¹³C NMR spectra.

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Mots clés : Cryosols, carbone organique, matière organique, sols de la toundra

Table 1. The average soil organic carbon (SOC) character of comparable soil genetic horizons of the coastal plain (*CP*) pedons (8) and the foothills (*FH*) pedons (18). (HA: humic acid, FA: fulvic acid, HON: hydrophobic neutrals, LMA: low mol. wt. acids, HIN: hydrophilic neutrals)

| Horizon | kgC/m ² | | as % of SOC | | | | | | | | | | | | HA/HFF [‡] | | | |
|-------------|--------------------|-----------|-------------|-----------|-------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|---------------------|-----------|------------|------------|
| | 0-100cm | | %SOC | | %ExC [†] | | %HA | | %FA | | %HON | | %LMA | | %HIN | | Ratio | |
| | <i>CP</i> | <i>FH</i> | <i>CP</i> | <i>FH</i> | <i>CP</i> | <i>FH</i> | <i>CP</i> | <i>FH</i> | <i>CP</i> | <i>FH</i> | <i>CP</i> | <i>FH</i> | <i>CP</i> | <i>FH</i> | <i>CP</i> | <i>FH</i> | <i>CP</i> | <i>FH</i> |
| Oi | 5 | 3 | 24 | 42 | 14 | 20 | 8 | 11 | 2 | 4 | 1 | 0 | 1 | 2 | 2 | 4 | 1.7 | 1.1 |
| Oe | 12 | 5 | 26 | 35 | 19 | 28 | 12 | 16 | 2 | 5 | 1 | 0 | 1 | 3 | 3 | 4 | 1.7 | 1.4 |
| Oa | 10 | 7 | 18 | 30 | 23 | 18 | 11 | 9 | 5 | 4 | 1 | 0 | 3 | 2 | 3 | 3 | 0.8 | 1.1 |
| O/A | 2 | 26 | 14 | 29 | 27 | 34 | 17 | 18 | 2 | 3 | 1 | 3 | 2 | 3 | 4 | 6 | 1.8 | 0.5 |
| A | 4 | 6 | 15 | 9 | 14 | 40 | 8 | 25 | 2 | 5 | 0 | 3 | 1 | 3 | 2 | 5 | 1.7 | 1.0 |
| A/B,A/C | 4 | 3 | 20 | 6 | 27 | 38 | 19 | 10 | 2 | 2 | 1 | 0 | 2 | 1 | 2 | 2 | 2.7 | 1.8 |
| Bg | 15 | 7 | 6 | 4 | 12 | 32 | 8 | 18 | 2 | 8 | 1 | 0 | 1 | 4 | 1 | 8 | 1.7 | 1.5 |
| Cf | 20 | 15 | 7 | 6 | 12 | 32 | 7 | 16 | 2 | 7 | 1 | 0 | 1 | 4 | 2 | 4 | 1.5 | 1.2 |
| Ave. | 9 | 9 | 16 | 20 | 18 | 30 | 11 | 15 | 2 | 5 | - | - | 1 | 3 | 2 | 4 | 1.7 | 1.2 |

[†] 0.1N NaOH extractable carbon

[‡] HA: humic acid, FF: fulvic acid fraction including FA, HON, LMA, and HIN.