Difference of carbon dynamics of soil carbonate under vegetation sequence, Mongolia

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Introduction

The accumulation of carbonate in soils is one of the most prominent soil forming processes in arid and semiarid regions. This carbonate is termed pedogenic or secondary carbonate to distinguish it from lithogenic calcite. It is estimated that soil organic carbon is about 1550 Gt to 1 m depth, while inorganic carbon accounts for 950 Gt to the same depth (Lal, 2004). So, the existence of pedogenic carbonate not only reveals the nature of the soil forming processes of the soil in a particular area but also serves as an important reservoir of carbon in the terrestrial ecosystem. However, there is very little study about dynamics of pedogenic carbonate.

Dissolution of carbonate and its subsequent accumulation in a Bk horizon are governed by two factors: the CO_2 pressure of the soil air and the concentration of dissolved ions in the soil water (Driessen et al., 2001). Therefore, it is important to study the Dynamics of pedogenic carbonate in different vegetations and climates from the viewpoint of its role in the carbon cycle in terrestrial ecosystems.

Mongolia is located in a transition zone between the Siberian taiga and the Central Asian desert region. The soils of the semi arid grasslands that occupy most of the plains have carbonate accumulation horizons. The morphology and characteristics of the soils distributed over the plains area correspond with the vegetation coverage (Dordschgotov, 2003). Therefore, this region was suitable for studying the vegetation-soil sequence.

The objective of this study is to provide information on the dynamics of pedogenic carbonate by using carbon isotope analyses.

Study site

Soil samples were taken from five study sites in a forest steppe, steppe, and govi steppe in Mongolia; Baganuur (BGN) on the forest steppe, Jargalthaan (JGH), Kherlen Bayan-Ulaan (KBU) and Underhaan (UDH) on the steppe, respectively where AWS sites of RAISE project (Sugita et al., 2006), and Bulgan (BG) on the desert steppe. Each study site was located on a flatland. Vegetation at forest steppe and steppe site were described in Asano et al. (2006), and desert steppe site was studied Sasaki et al. (2005). The in KBU, JGH, BGN, and UDH as Calcic Kastanozems (Asano et al., 2006) and that in BG as Haplic Calcisol (FAO/ ISRIC/ ISSS, 1998).

The lacustrine record of Lake Baikal during the past 23,000 years shows the last deglacial was at 18,000 yr BP and that the taiga was developed at 12,000yr BP; after that there was an increase of thick vegetation with extensive development of soil layers (Horiuchi et al., 2000). We can define the soil age as the time when soil genesis started. Carbonate accumulation would start when the climate and vegetation had become amenable to pedogenesis. Thus, it is presumed that the soil ages in the study sites are almost same period at least older than 12,000 yr BP.

Materials and methods

The soil samples taken from each horizon were air dried and passed through a 2-mm mesh sieved.

Stable carbon isotope ratio ($\delta^{13}C$) of soil organic matter and pedogenic carbonate were measured by using mass spectrometer (Finigan, MAT 252). Radiocarbon isotope ratio ($\Delta^{14}C$) was determined by the Tandem-Accelerator Mass Spectrometry (MALT-AMS) system at The University of Tokyo (Matsuzaki et al., 2004). Inorganic carbon content was determined by the wet combustion methods described by Kosaka et al. (1959). The soil organic carbon and total nitrogen contents in the A horizons were determined by the dry combustion method using a NC analyzer.

Results and discussions

$\delta^{13}C$ value of soil organic matter

The $\delta^{13}C$ values of soil organic matter vary from -23.2 ‰ to -20.2 ‰. Bulk C_3 and C_4 plants tissue distinctive $\delta^{13}C$ ranges of -25.0 ‰ to -27.3 ‰ (with a average of -26.2 ‰) and -12.5 ‰ to -14.3 ‰ (with a average of -13.4 ‰), respectively (Li 2006, personal communication). The range of $\delta^{13}C$ values of soil organic matter falls between reported C_3 and C_4 plants. These result suggested the soil organic matter of study sites were derived from mixture grassland of C_3 and C_4 grass in agreement with vegetation survey.

$\delta^{13}C$ value of pedogenic carbonate

The $\delta^{13}C$ values of pedogenic carbonate vary from -1.3 ‰ to - 10.4‰. Two types of vertical distributions were observed : (1) The $\delta\ ^{13}C$ values of pedogenic carbonate increase with soil depth at BGN, JGH, KBU, and UDH site; and (2) no relation was observed with soil depth at BG site. The resulting fractionation $\alpha = 1.004$, which means that the average ^{13}C content of the soil CO_2 between root zone and soil surface is 4.4 ‰ higher than the produced CO_2 in theory (Salomons and Mook, 1986). The $\delta\ ^{13}C$ value of soil carbonate is in equilibrium with atmospheric CO_2 of -8.0 ‰ near the soil surface and decrease with depth due to an increasing proportion of plant-respired CO_2 depleted in ^{13}C (Cerling, 1984; Cerling et al., 1989). So, the vertical distributions of $\delta\ ^{13}C$ value at BGN, JGH, KBU and UDH sites trend suggested that the soil carbonate was equilibrium with soil CO_2. While, pedogenic carbonate in BG has affected or record CO_2 other than modern vegetation.

$\Delta^{14}C$ value of pedogenic carbonate

$\Delta^{14}C$ values for pedogenic carbonate at all sites were from -392 to -776 ‰. Figure 2 shows that the vertical distribution of the inorganic carbon content and the $\Delta^{14}C$ values in the forest steppe soils significantly differed from those in the desrt steppe soils. The ^{14}C contents slightly decreased with depth, presumably due to the decrease in wetting events in the lower part of the profile (Pendal et al., 1994), and this suggested that contamination by more recent ^{14}C derived from plant root respiration, organic mater decomposition, and atmospheric CO_2 was rare.

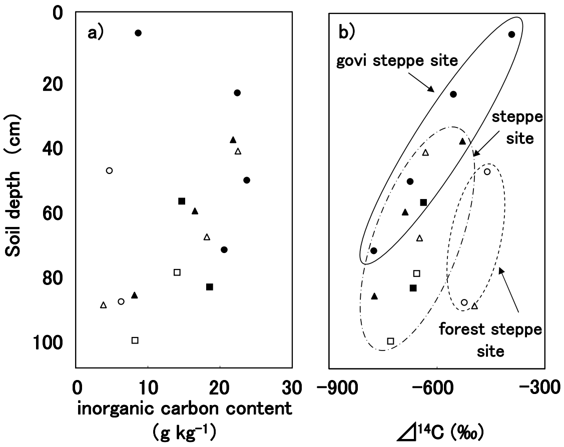

Figure 2 a)Vertical distribution of inorganic carbon content (g kg-1) and b) $\Delta^{14}C$ value of the pedogenic carbonate. (○, BGN; ■, JGH; □, KBU; ▲, UDH; ●, BG)

Exchange of carbonate carbon under vegetation sequence

The results from carbon isotopic analyses showed that exchange of carbonate carbon difference among the study site under vegetation sequence.

Forest steppe: It became clear that exchange of carbonate carbon with soil CO_2 occurs more frequently than steppe and desert steppe site. The abundance ratio of carbon from soil organic matter in pedogenic carbonate reached to 91 %.

Steppe: Exchange of carbonate carbon was not frequent than that in forest steppe, and the record of past plant composition was still remained.

Desrt steppe: The abundance ratio of carbon from soil organic matter in pedogenic carbonate was the lowest among all study sites. It was clarified that the exchange of carbonate carbon was relatively rare.

Reference

Asano, M., K. Tamura, K. Kawada, and T. Higashi, Morphological and physico-chemical characteristics of soils in a steppe region of the Kherlen River basin, Mongolia, *J. Hydrol*., 2006. (In press)

Cerling, T.E., The stable isotopic composition of modern soil carbonate and its relationship to climate, *Earth Planet. Sci. Lett*., **71**, 229-240, 1984.

Cerling, T.E., J. Quade, Y. Wang, and J. R. Bowman, Carbon isotopic in soils and palaeosols as ecology and palaeoecology indicators, *Nature,* **341**, 138-139, 1989.

Driessen P., J. Deckers, and O. Spaargaren, *Lecture notes on the major soils of the world. World Soil Reports* 94, FAO, Rome, 334 pp, 2001.

FAO, ISRIC and ISSS, *World reference base for soil resources*. *World Soil References Reports* 84, FAO, Rome, 88 pp, 1998.

Horiuchi, K., K. Minoura, K. Hoshino, T. Oda, T. Nakamura, and T. Kawai, Paleoenvironmental history of Lake Baikal during the last 23,000 years: evidence from sedimentary and mineralogical analyses, *Palaeogeography*, *Palaeoclimatology*, *Palaeoecolory*, **157**, 95-108, 2000.

Kosaka, J., C. Honda, and A. Iseki, Anew rapid and accurete method for the determination of carbon in soils, *Soil and Plant food*, **5**, 77-83, 1959.

Lal, R., Soil carbon sequestration impacts on global climate change and food security, *Science*, **304**, 1623-1627, 2004.

Matsuzaki, H., C. Nakano, H. Yamashita, Y. Maejima, Y. Miyairi, S. Wakasa, and K. Horiuchi, Current status and future direction of MALT, The University of Tokyo, *Nucl. Instr. Meth. B,* **223-224**, 92-99, 2004.

Pendal, E. G., J. W. Harden, and S. E. Trumbore, Isotopic approach to soil carbon ate dynamics and implications for paleoclimatic interpretations, *Quat. Res*., **42**, 60-71, 1994.

Salomons, W., and W. G. Mook, Isotope geochemistry of carbonate in the weathering zone, In ed. Fritz, P., and J. C. Fontes, *Handbook of Environmental Isotope Geochemistry*, Elsevier, Amsterdam, pp.239-269, 1986.

Sasaki T., T. Okayasu, K. Takeuchi, J. Undarmaa, and J. Sanjid, Patterns of floristic composition under different grazing intensities in Blugan, South Govi, Mongolia, *Jap. J. Glassl. Sci*., **51**, 235-242, 2005.

Sugita, M., J. Asanuma, M. Tsujimura, S. Mariko, M. Lu, F. Kimura, D. Azzaya, and Ts. Adyasuren, An overview of the rangelands atmosphere-hydrosphere interaction study experiment in Northeastern Asia

(RAISE), *J. Hydrol*., 2006. (In press)