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High-resolution reconstruction of late Pleistocene climate based on TOC content in a 54 m sediment core drilled from Takano Formation, central Japan

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The Takano Formation of late Pleistocene lacustrine sediment is distributed at the southern Nagano City. The TKN-2004 core, 53.88 m long, was taken at the central part of the basin, and is composed mostly of homogenous clayey silt. Age of the sediment was estimated from the relationship between radiometric ages and calibrated depths of DKP, Aso-4, K-Tz, Ata and Aso-2 tephras, postulating that the sedimentation rate is constant.

Paleoclimate from 169 ka to 37 ka was reconstructed on the basis of TOC content variation. The long-term TOC fluctuations are concordant with the SPECMAP curve. This result is supported by pollen composition. The short-term variations are similar to stadial-interstadial cycles in the Greenland ice cores, and most of warm peaks can be correlated with IS 9 to 25.

Key words : late Pleistocene, paleoclimate change, SPECMAP, stadial-interstadial, Takano Formation, TOC

Introduction

Recently, the rapid climate changes clarified by $\delta^{18}O$ fluctuation of the Greenland ice core becomes one of the important concerns to people because it may cause serious damages to the human society. So, the detailed paleoclimate studies are required not only in the polar regions but also in the mid-latitude regions where many people live.

In this study, we have tried to reconstruct the late Pleistocene paleoclimate of Japan in high time-resolution based on the TOC content of lake sediment with comparison of pollen analysis. A part of this study has been recently published in Tawara et al. (2006 b).

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Study Area

The Takano basin locates at the southern margin of Nagano City, central Japan. The location can refer to Fig. 1 of Tawara et al. (2006 b). The altitude of the basin is about 730 m. The basin is about 1 km long (ENE-WSW direction) and 700 m wide (NNW-SSE direction). The Takano Formation is partly dissected by small streams and several outcrops can be observed at the base of cliffs. Kimura (1987 ; 1996) found several widespread marker tephras such as AT, DKP, K-Tz and Aso-4 etc., and revealed its stratigraphic outline. The top horizon of the formation partly remains flat plain which may correspond to ancient lake bottom. Kimura (1987) proposed that the basin was formed by tectonic activities of the Takanogawa Fault and Karuizawa flexure in the early Late Pleistocene. Modern climate conditions of Shinshu-shinmachi meteorological observatory of altitude 509 m and around 3 km west to the basin are as follow ; mean annual temperature 11℃, mean annual precipitation 1100 mm and climate zone closer part of under Cfb/Dfa boundary.

TKN-2004 Core

An undisturbed core of 53.88 m length (TKN-2004 core) was taken by double tube core barrel system at the former Takano Elementary School (N36°32′55″, E138°2′7″) in June 2004 (recovery rate=99%). The drilling site was selected at the central part of the basin. The sediment is mainly composed of homogenous black-gray clayey silt intercalated with more than 80 layers of tephra some of which are well-known widespread marker tephras. In this cored sediment, we have recognized the following marker tephras based on mineral composition, morphology and chemical composition of volcanic glasses and mafic mineral composition (Nagahashi et al., 2005 ; Kimura, 1996) ; DKP, Tt-E, Aso-4, K-Tz, On-Pm1, Ata, Tt-D, SK, and Aso-2.

As the cored sediment is almost homogenous, it is reasonable to postulate that sedimentation was continuous and constant in rate. Therefore, age model of the sediment can be constructed from the relationship between the radiometric ages of some marker tephras and their depths. In this study, five widespread marker tephras namely DKP (52 ka, ^{14}C, Nakamura et al., 1992 ; 1067 cm in depth), Aso-4 (89±7 ka, K-Ar, Matsumoto et al., 1991 ; 1949.4 cm in depth), K-Tz (98±26 ka, FT, Danhara, 1995 ; 2228 cm in depth), Ata (108±3 ka, K-Ar, Matsumoto and Ui, 1997 ; 2366.9 cm in depth) and Aso-2 (141±5 ka, K-Ar, Matsumoto et al., 1991 ; 4357.9 cm in depth) were used for a age model. The depth was calibrated by removing the thickness of every tephra layer of which sedimentation time is almost 0. Based on the age model, the average sedimentation rate is 0.36 mm/yr (36 cm/kyr). This means that one sample of 1 cm thickness covers 28 years on average. From this age model, the age of top of unweathered cored sediment (230 cm deep) is 37 ka and bottom of the cored sediment is 169 ka.

Method and Results of TOC and TN analysis

The sediment of the TKN-2004 core was cut in every 1 cm interval except for tephra layers and its surface horizon above 230 cm in depth which is deeply weathered. A part of the dried sample (a few hundred mg) was pulverized in an agate mortar and was added 3%-HCl to eliminate carbonates. About 4900 samples were analyzed for total organic carbon (TOC), total nitrogen (TN) and total sulfur (TS) contents using Thermo Finnigan Flash EA 1112. In this study, we describe only about TOC and TN contents and C/N ratio because the TS content was very low, and could not be detected in many cases. The stratigraphic variation of TOC content, TN content and C/N ratio were described in Fig. 3 of Tawara et al. (2006 b).

The TOC content varies from 1 to 8% in the TKN-2004 core with some exceptions. Four-times repetitions of relatively high and low horizons can be recognized in the cored sediment. The values are 3-8% in the high horizons and 1-5% in the low ones. The high TOC horizons correspond to at the depths of 230-920 cm, 1590-1920 cm, 2070-2670 cm and 2930-3700 cm, and the low ones are 920-1590 cm, 1920-2070 cm, 2670-2930 cm and 3700-5387 cm.

The TOC value varies also in a short interval such as within a few meters. The amplitude of variations are from 2 to 3% and the variation patterns look like saw-teeth in most cases. Those fluctuations are distinct in the major part above 3700 cm in depth.

The TN content varies from 0.1 to 0.6% in this cored sediment. The values are 0.3-0.6% in the high TOC horizons and 0.1-0.4% in the low ones. The TN content varies with the TOC variation.

The C/N ratio generally ranges from 6 to 15 and its average is around 11. This suggests that the TOC in the sediment is mainly derived from aquatic organisms. The values of C/N ratio are 11-16 in the high TOC horizons and 6-11 in the low ones.

Implication of TOC fluctuations

The pollen analysis of the TKN-2004 has been completed recently. Based on the ratio of the temperate tree pollen content to the sub-arctic one, 4 warm horizons and 5 cold ones can be identified in the cored sediment (Tawara et al., 2006a). The warm horizons are at the depths of 617-771 cm, 1569-1953 cm, 2087-2830 cm and 3080-3830 cm, and the cold ones are 230-617 cm, 771-1569 cm, 1953-2087 cm, 2830-3080 cm and 3830-5387 cm. Generally, the warm ones correspond to the high TOC horizons, the cold ones correspond to the low ones. The relationship between the TOC content and the ratio of temperate trees pollen content to sub-arctic conifer trees has a positive correlation ($R^2=0.33$, $p<0.001$). Same relationship was reported in the cored sediment of Lake Nojiri (Kumon et al., 2003). Additionally, Kumon et al. (2005) proposed that TOC was controlled by winter temperature through biological productivity in lake water. Therefore, it is considered that the TOC variation can be regarded as a useful paleoclimate proxy which shows warm-cold climate change.

Paleoclimate reconstruction based on TOC content

To simplify the discussion, the TOC fluctuation is focused here. The stratigraphic variation of TOC content can be translated into a time-series fluctuation based on the age model mentioned before. The fluctuation shows changes in long term of several thousands to a few ten thousands years and in short ones of several hundreds to a few thousands years as shown in Fig. 1. As high TOC period is warm and vice versa, the long warm-cold cycles are identified as climate-phase C1 (169–129 ka), W1 (129–108 ka), C2 (108–101 ka), W2 (101–87 ka), C3 (87–83 ka), W3 (83–74 ka), C4 (74–58 ka) and W4 (58–37 ka) (Tawara et al., 2006 b). The C1 to C4 correspond to cold periods and the W1 to W4 is warm periods. The long term fluctuation of paleoclimate is concordant with the SPECMAP curve (Martinson et al., 1987) during MIS 6 to 3 in the fluctuation pattern, duration time and boundary ages (Tawara et al., 2006 b).

The short term fluctuation of the TOC content shows jagged variation of which amplitude is 2–3% and endures for several hundreds to a few thousands years. In most part, the short-term fluctuation has similar periodicity with stadial-interstadial cycles of $\delta^{18}O$ recorded in the Greenland ice cores but the peak form and relative amplitude are not completely same. The discrepancy might be caused by difference of regional atmospheric circulation system between East Asia and North Atlantic regions, and the difference of proxy property. Although there are some differences, it can consider that the jagged variation correspond to stadial-interstadial cycles recorded in GISP 2 (Stuiver and Grootes, 2000) and/or NGRIP (North Greenland Ice Core Project Members, 2004) etc. based

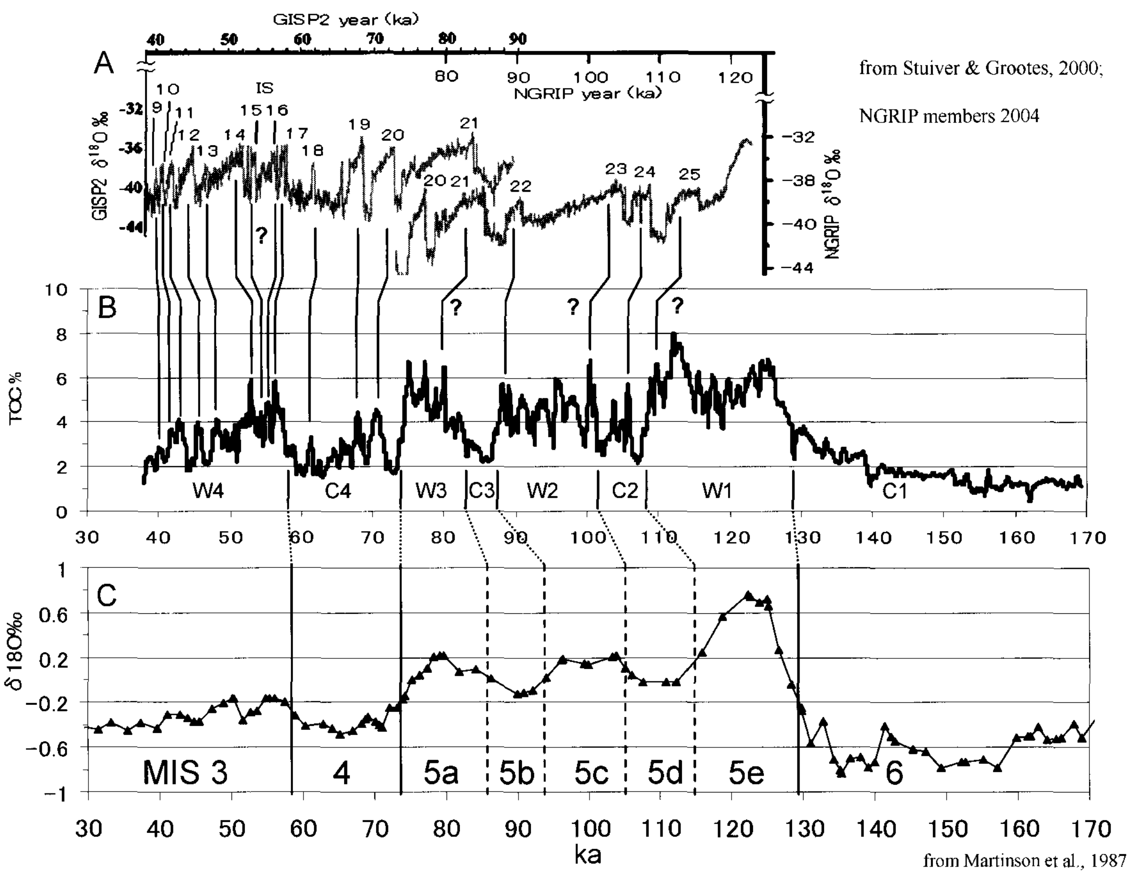

Fig. 1 Comparison of TOC content of Takano Formation with the $\delta^{18}O$ of Greenland ice core and marine isotope stages. A : $\delta^{18}O$ records of Greenland Ice core (GISP2 and NGRIP) (Stuiver and Grootes, 2000 ; NGRIP members, 2004), B : TOC profile in TKN-2004 core, C : Marine oxygen isotope curve of SPECMAP (Martinson et al., 1987).

on relative position with long term climate change and those ages. Most of the warm periods can be correlated to IS 9 to 25.

Conclusion

In this study, the late Pleistocene climate from 169 ka to 37 ka was reconstructed with the data of 28 years interval on average. The TOC profile in the TKN-2004 core shows long term and short term changes of paleoclimate. The long term ones are concordant with the SPECMAP curve, showing paleoclimate of land area from MIS 6 to 3. The short ones seem to be stadial-interstadial cycles and most of warm periods can be correlated to IS 9 to 25. This is the first detailed and continuous climate reconstruction in Japan for the late Pleistocene. This result can be a standard climate information of Japanese lands area and can be correlated with the other climate data through the marker tephras.

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中部日本，高野層ボーリングコアの全有機炭素含有率変動に基づく更新世後期の古気候変動の高解像度復元

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長野市南部に分布する更新世後期の湖成層である高野層において，全層ボーリングを行い 53.88 m の連続したコア試料を得た．コア試料は，黒灰色でほぼ均質な粘土質シルト～シルトの層相を示し，多数のテフラ層を挟んでいる．これらのうち 5 つの広域指標テフラ（DKP, Aso-4, K-Tz, Ata, Aso-2）の放射年代値と補正深度を用いて年代モデルを作成した．高野層の TOC 含有率の経年変動は，本コア試料中の花粉組成変化と同調しており，およそ 169 ka～37 ka における数万年周期の長期の気候変動を示している．この変動は MIS 6～3 前半における海洋酸素同位体比変動と同調しており，各ステージに対比される長期の温暖期・寒冷期が認識できた．また，数百～数千年周期の短期の寒暖変動も存在しており，これらは亜氷期-亜間氷期サイクルに相当すると考えられる．また，それらの温暖期の多くは IS 9～25 に対比される可能性がある．