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TRANSPORT BEHAVIOR OF PARTICULATE ORGANIC MATTER IN RIVER WATER DURING SNOW MELTING IN THE ISHIKARI, TOKACHI, TESHIO AND KUSHIRO RIVERS, JAPAN

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Abstract

Both $\Delta^{14}C$ and $\delta^{13}C$ were used to study the transport behavior of particulate organic matter (POM) in the Ishikari, Tokachi, Teshio and Kushiro rivers in Japan. Water samples were collected once a month in April and May in 2004 and 2005 during snow melting. Positive correlations were found between $\Delta^{14}C$ and particulate organic carbon (POC) content. Negative correlations were found between $\Delta^{14}C$ and increased water level. These results indicate that the river systems showed similar transportation behavior during snow melting because of the variation of water level and water discharge.

Keywords: Rivers, Carbon Isotopes, POM, Turbidity, AMS, Japan

Introduction

The annual load of riverine particulate organic carbon (POC) from land to ocean corresponds to half the total organic carbon (Meybeck 1982). Transportation of POC in river systems one pathway of the carbon cycle in terrestrial ecosystems is important for the carbon cycle. Geographical, hydrological and land use features control carbon discharge and transport patterns in rivers (Hope *et al.* 1994 and Torn *et al*. 1994). The hydrological situation must be considered in sub-arctic and arctic areas because the watershed environments vary from spring to summer because of snow melt. Snow melt water considerably increases water discharge and transport of inorganic and organic materials from land to ocean (Meyer and Tate 1983 and Telang *et al.* 1991). Particulate organic matter (POM) and its fate in river systems are unknown during snow-melting periods because POM exhibits tremendous temporal and spatial variations in physico-chemical characteristics (Hobbie 2000).

We have to consider the residence time, patterns of transport and discharge of POC for understanding the transport behavior of POC. Both $\Delta^{14}C$ and $\delta^{13}C$ values have proven to be simple and useful parameters to study POM sources and residence times; they are very

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suitable for elucidating POM dynamics (Otowa 1985, Kao *et al.* 2003, Rember and Trefry 2004 and Alam *et al*. 2007). This study applied carbon isotopic ratios ($\Delta^{14}C$ and $\delta^{13}C$) to POM of the Ishikari, Tokachi, Teshio, and Kushiro water to investigate transport behavior in river systems during snow melting in spring.

Materials and Methods

Study area: The Ishikari river runs through the low land in eastern Hokkaido (Fig.1). It has a catchments area of 14330 km^2 and is 268 km long. The main types of land use are forest, agriculture and urban. Rice is the main agricultural product along the river (Wongsa and Shimizu 2004). The monthly average water discharge ranges from 280-500$\times 10^6$ m^3/month, 50% of the precipitation falls as snow. Monthly mean winter precipitation is 46-105 mm and the snow depth is from 38-108 cm from December to late April. Snow melting begins in March and increases water levels and discharges. The highest water discharges at the Iwamizawa-Ohashi in April and is up to 3-4 times greater than that in winter (Ministry of Land, Infrastructure and Transport).

The Tokachi river runs through the south-eastern Hokkaido. It originates from Mt. Tokachi-dake (2077 m) of the Taisetsu mountain range beated in the middle of Hokkaido. It flows through Tokachi plain, which includes old and new alluvial fans and streams terraces. Geological features of the plain are mainly volcanic rocks not consolidated with sediments along. The soils in this area consist mainly of ando and low land soil (Otowa 1985). It has catchments of 9010 km^2 and its length is 156 km long. Monthly mean winter precipitation is 42-60 mm and snow depth is 11-51 cm from December to late April. The monthly average water discharges range from 200-330 $\times 10^6$ m^3/month.

The Teshio river is located in northern Hokkaido. Vegetation is cool-temperate natural mixed forest (Nagasaka and Nakamura 1999). Predominant bed rock is tertiary ande site. Predominant soil is inceptisol (brown forest soil) at the most part of the watershed and histsol (peat soil) at the riparian wetland from middle to lower part of the watershed (Nagasaka and Nakamura 1999). It has catchments of 5590 km^2 and is 256 km in length. Mean monthly precipitation is 30-46 mm. The snow depth is 30-78 cm from January to April. The average monthly water discharges are 60-300 $\times 10^6$ m^3/month.

The Kushiro river flows through west southern Hokkaido. Sampling area was Kushiro Mira which is located on the watershed of the Kushiro river. It has catchments of 2510 km^2 and is 154 km in length. Monthly average precipitation is 29-78 mm and the snow depth is 7-29 cm. Monthly average water discharges vary from 40-65 x 10^6 m^3/month.

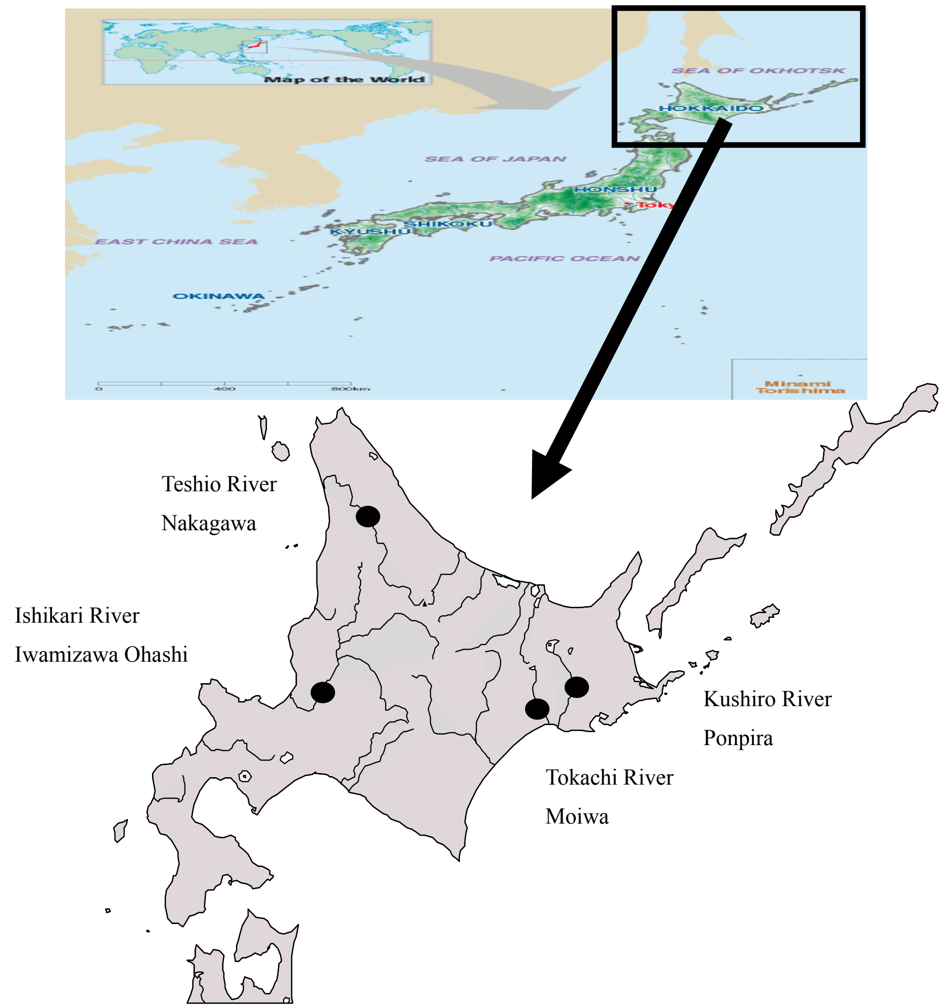

Fig.1. Locations and sampling sites of this study.

Sampling: Water samples were collected once a month at a fixed station in each river system at snow-melting in April in 2004 and 2005, however, water sample for the Teshio was collected in May in 2004 (Table 1 and Fig.1). Fixed station were Iwamizawa for the Ishikari, Moiwa for the Tokachi, Nakagawa for the Teshio, and Ponpira for the Kushiro river. About 70 L of water was collected in polythene containers, which were then transferred to the laboratory.

Table 1. Sampling sites, dates, watershed areas, river lengths, and water levels of this study.

Sampling sites	Sampling dates	Watershed* Area (km^2)	River length* (km)	Water Level* Maximum (m)	Minimum (m)	Increased water level (Maximum-minimum) (m)
Ishikari	2004-4-21	14330	268	5.41	0.76	4.65
	2005-4-8			3.86	0.74	3.12
Tokachi	2004-4-25	9010	156	2.99	1.92	1.07
	2005-4-15			3.02	1.87	1.15
Teshio	2004-5-20	5590	256	10.21	8.52	1.69
Kushiro	2004-4-29	2510	154	2.01	1.28	0.73
	2005-4-13			2.22	1.19	1.03

(*Japan Meteorological Agency, 2004).

Turbidity is the degree of opacity of water resulting from suspended solids measured during sampling using a nephelometer (U-21XD; Horiba Ltd.); it is expressed in TU units. Suspended materials in river water samples were concentrated using a single-flow continuous flowing centrifuge with a flow rate of 15 L / h (Nagano *et al.* 2003). The inside temperature of the centrifuge was maintained at 15-20 °C to avoid transformations of solids (Nagao et al. 2005). These solid samples were dried at 40°C. We calculated suspended solid concentrations in milligram-per-liter units, dividing the dried solid weight by the volume of centrifuged water. The continuous flow method is less efficient for separating low density particulate matter than filtration at low turbidity. The recovery of suspended solids by continuous flow centrifugation was 91-114% at turbidity of 11-248, but was 48-100% (68±20%; nine samples) at turbidity less than 6 NTU. Therefore, in this study, the recovery of suspended particulate materials might be acceptable because of the high turbidity of 6-468 NTU.

Analysis: The POC contents for suspended particles isolated through continuous flowing centrifugation were determined using a total organic carbon analyzer (WR-112; LECO Corp.). Prior to analysis, calcium carbonate was removed by adding 0.1M HCl, rinsing with Milli Q water and subsequent drying. We measured POC and PON content by conflow-MS spectrometer for all of the rivers. The obtained POC contents were expressed as wt. % unit (g C/100 g suspended solid dry basis). We calculated C/N (molar) using data of POC and PON content and used suspended solid weight. The POC concentrations were expressed using the following equation:

$$\text{POC concentration (mg/L)} = \frac{\text{POC (wt. \%) x Mass of suspended solids (mg)}}{\text{Centrifuged water volume (L)}}$$

Radiocarbon (^{14}C) measurements were performed using accelerator mass spectrometry

(AMS) at the National Institute for Environmental Studies, Japan. Dried POM samples were first converted to CO_2 and then purified cryogenically. The purified CO_2 was reduced to graphite with H_2 over Fe. The $^{14}C/^{12}C$ and $^{13}C/^{12}C$ ratios were measured using an AMS system (Model 15 SDH-2; NEC Corp.). The $\Delta^{14}C$ was defined as the deviation from the modern standard in parts per thousand (‰). The $\delta^{13}C$ was defined as the deviation from the PDB standard in parts per thousands (‰). The general mathematical formulae for the expression are as follows (Stuiver and Polach 1977):

$$\Delta^{14}C\ (‰) = [A_{SN}e^{\lambda(y-1950)}/0.7459_{ON}-1]\times1000 \quad (1)$$

$A_{SN}={}^{14}C/{}^{12}C$ of sample normalized to $\delta^{13}C_{PDB}=-25‰$

$A_{ON}={}^{14}C/{}^{12}C$ of standard HOXII normalized to $\delta^{13}C_{PDB}=-25‰$

$\lambda=1/8267\ yr^{-1}$,

y=Measurement year,

$A={}^{13}C/{}^{12}C$

Results and Discussion

Variations in turbidity, POC amount and C/N: POC contents ranged from 1.33 to 8.04% (Table 2). The range was higher than the published range of 2-4% (Rember and Trefry 2004 and Wang *et al.* 1998). The Ishikari river showed the lowest and the Kushiro river the highest in POC contents. C/N ranged from 9-13.

The highest turbidity was found for the Ishikari water sample. POC concentrations ranged from 0.5-6.7 mg/L. The range of POC concentrations was within the range of Thurman (1985). The Ishikari river was highest in POC concentrations and the Tokachi was the lowest. Turbidity and POC content indicate that the POM for the Ishikari was highly loaded with much of inorganic materials with respect to those of others.

Table 2.Turbidity, POC content, concentration, C/N ratio, centrifuged water volume, suspended solids $\Delta^{14}C$ and $\delta^{13}C$ values for the POM in this study.

Sampling sites	Sampling dates	Turbidity (NTU)	Centrifuged water volume (L)	SS (g)	POC content (%)	POC concentrations (mg/L)	$\Delta^{14}C$ (‰)	$\delta^{13}C$ (‰)	C/N
Ishikari	2004-4-21	468	59.8	22.1	1.81	6.67	-364	-30.6	11.7
	2005-4-8	362	32.9	6.4	1.33	2.59	-206	-26.5	12.5
Tokachi	2004-4-25	22	57.9	0.9	2.94	0.46	-242	-29.2	9.9
	2005-4-15	136	44.4	0.5	4.73	0.53	-154	-29.2	9.1
Teshio	2004-5-20	45	75.9	1.8	3.24	0.77	-204	-26.5	10.3
Kushiro	2004-4-29	6	77.5	1.3	4.01	0.67	-39	-29.5	10.1
	2005-4-13		61.6	0.3	8.04	0.39	-17	-30.7	9.4

SS=Suspended solids, POC=Particulate organic carbon

Variations in Carbon isotopic ratios: The $\Delta^{14}C$ and $\delta^{13}C$ values were from -364 to -17‰ and -30.6 to -26.5‰, respectively (Table 2). The Ishikari river showed the lowest and the Kushiro river the highest in $\Delta^{14}C$ values. Carbon isotopic ratios are different by some magnitude in 2004 and 2005 in each sampling site. The variation ranges of $\Delta^{14}C$ and $\delta^{13}C$ values were similar with those within the reported range of riverine POM (Raymond and Bauer 2001). The variations of $\Delta^{14}C$ values were similar with those of (Nagao *et al.* 2005), $\Delta^{14}C$ and $\delta^{13}C$ values ranged from -242 to -215‰ and -26‰ during snow melting at Tokachi Moiwa in 2003, respectively (Nagao *et al.* 2005). In general, the differences in POC contents, $\Delta^{14}C$ and $\delta^{13}C$ values in POC among the sampling sites depend on the residence time, the sources of parent rock, the erosion regime, and the climate of the watershed, the vegetation of the surface, and the decomposition kinetics of the watershed. The values in $\delta^{13}C$ are related to plant biota and physical, chemical, and biological activity of a watershed. It is difficult to understand that what factors are mostly important for the variations in $\Delta^{14}C$ values. Study sites are obviously different from one another in water discharges and in water levels.

Correlations in POC contents, $\Delta^{14}C$ and $\delta^{13}C$ values, and water levels: Riverine organic carbon is a mixture of different organic matter (Hope *et al.* 1994 and Thurman 1985). For better understanding POC characteristics, the correlations in POC content, $\Delta^{14}C$, and $\delta^{13}C$ are plotted in Figs.2a and 2b.

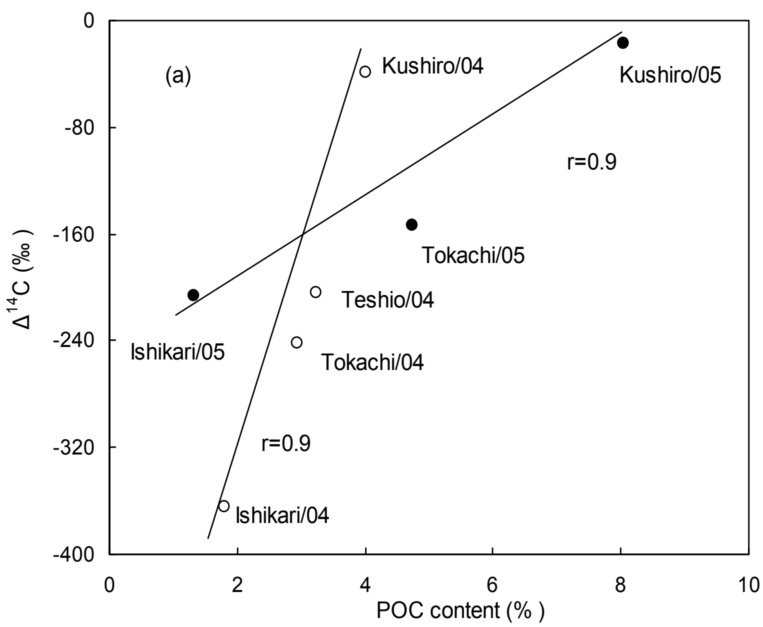

Fig. 2a. Correlations in $\Delta^{14}C$ values and POC content.

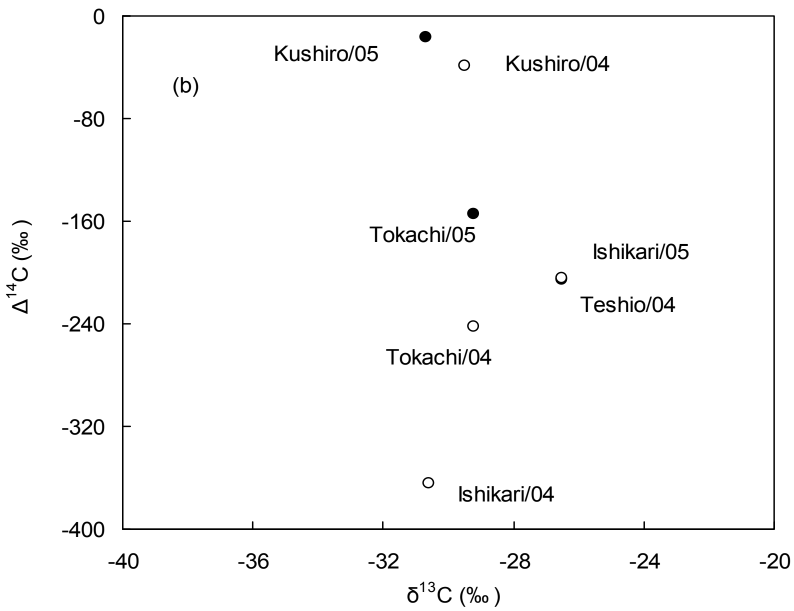

Fig. 2b. Correlations in $\Delta^{14}C$ and $\delta^{13}C$ values.

The $\Delta^{14}C$ values were positively correlated with POC contents (correlation factor of 0.9) (Fig. 2a). These relationships suggest that POM were mixture of older and newly produced organic matter with two end members at each site. However, the older fractions decreased from the Kushiro to the Ishikari. There are no relationships between $\Delta^{14}C$ and $\delta^{13}C$ values (Fig.2b).

This indicates two important meanings. Firstly, the watershed environment and conditions are different from one another. Secondly, POM is a mixture of different residence time and age and transports in river systems from distinct sources during snow melting. ^{14}C variation depends on age of carbon and watershed condition and ^{13}C variation depends on vegetation, soil type, physical, chemical, and biological activities. During spring snow-melt water discharges are higher than other seasons. There are relationships between in POC content, $\Delta^{14}C$, and increased water level with coefficient factor 0.8 and 0.7 in average, respectively (Figs.3a and 3b). These relationships suggest that snow-melting higher water discharge and water levels are one of the factors controlling the transport behavior and characteristics of POC during snow-melting.

Transport behavior of riverine POM: The relationships between POC and $\Delta^{14}C$ indicate that the POC for all rivers show similar transportation behaviors during snow melt in spring through different mechanism; however, POC was a mixture of older and younger organic matter. The C/N ratios follow the shorter ranges which could be an evidence of the positive correlation in POC content and $\Delta^{14}C$ and similar transportation as well. For this reason, distinctive POC content was found during snow-melting in spring than those of summer, winter, and autumn (Alam *et al.* 2007).

Probable sources supplying riverine POC are: 1) direct inputs of litter, 2) soil organic matter through soil erosion, 3) riverine plants and 4) river bottom sediment through re-suspension (Hope *et al*. 1994). The water discharge and water levels during snow-melt appeared as important controlling factor for the similar transport behavior. River bank erosion or re-suspension of bottom sediments is common phenomena during higher water discharges. Through these two phenomena, major fractions of older POC with younger can be mixed by higher water discharge (Telang *et al*. 1985 and Wang *et al*. 1998). Eventually, the positive correlation were found in POC content and $\Delta^{14}C$. So, it could be hypothesized that river soil organic carbon through river bank erosion or re-suspension of

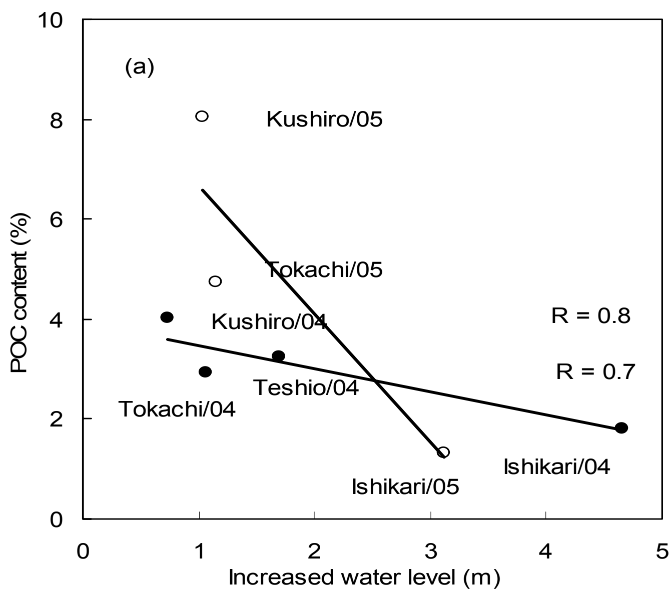

Fig. 3a. Correlations in POC content and increased water levels.

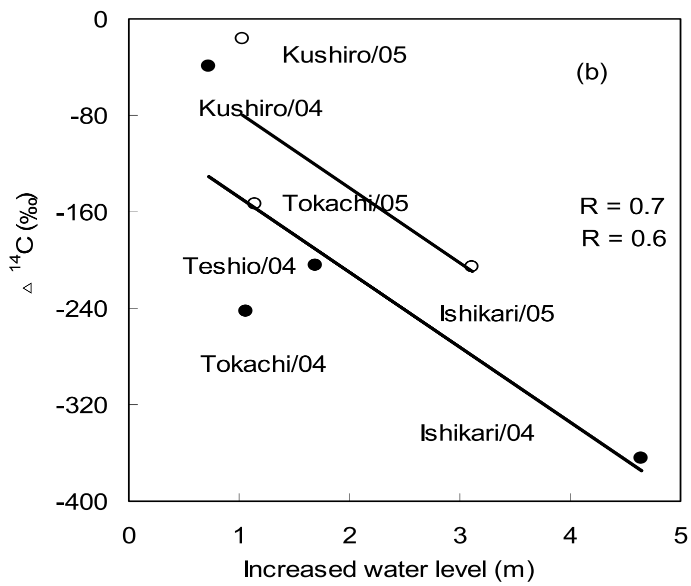

Fig. 3b. Correlations in $\Delta^{14}C$ and increased water levels.

bottom sediment are important sources of riverine POC for all rivers during snow melt. Higher turbidity was found in snow melt than other season (Alam *et al.* 2007) which indicated the higher extent of soil erosion. In general, the $\Delta^{14}C$ values of soil organic matter decrease with increasing depth in soil but $\delta^{13}C$ values should keep constant or vary with depth of soil due to the variability of decomposition of organic materials (Veyssy *et al.* 1996 and Wang *et al.* 1998).

We used $\Delta^{14}C$ and $\delta^{13}C$ values to study the transport behavior of riverine particulate organic matter (POM) for four rivers in Hokkaido during snow melting period. Water samples were collected once a month during snow melting in 2004 and 2005. Suspended solids were collected from the water samples by centrifugation. $\Delta^{14}C$ and $\delta^{13}C$ were analyzed by accelerator mass spectroscopy. The watersheds were different in soil types, plants, and land use. For these reasons, POM was different in $\Delta^{14}C$, $\delta^{13}C$, and POC contents. The similarity among the river systems was due to increased water level. For this hydrological similarity, there was a positive correlation between POC content and $\Delta^{14}C$ values and negative correlation in $\Delta^{14}C$ and increased water level. These results indicate that the river systems showed similar transportation behavior. Higher water discharge and increased water levels are important controlling factors for the similar transport. The possible mechanism is river bank soil erosion or re-suspension of bottom sediment.

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