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^{14}C as a tool for evaluating riverine POC sources and erosion of the Zhujiang (Pearl River) drainage basin, South China

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ABSTRACT

Radiocarbon can serve as a powerful tool for identifying sources of organic carbon and evaluating the erosion intensity in river drainage basins. In this paper we present ^{14}C-AMS measurements of particulate organic carbon (POC) collected from the three major tributaries of the Zhujiang (Pearl River) system: the Xijiang (Western River), Beijiang (Northern River) and Dongjiang (Eastern River) rivers. Furthermore, we discuss the distribution of POC ^{14}C apparent ages and the related watersheds erosion of these rivers. Results yield $\Delta^{14}C$ values of −425‰ to −65‰ which indicate that the ^{14}C apparent ages of suspended POC in the entire area are in the range of 540–4445 years. The POC apparent ages from Xijiang are mostly between 2000 and 4000 years, while in Dongjiang they mostly range from 540 to 1010 years. These ^{14}C apparent ages indicate that the watershed erosion of the Xijiang is more severe than that of the Dongjiang. This is in agreement with other data showing deeper erosion in Xijiang due to human activities.

1. Introduction

1.1. General introduction

Rivers are important components in both the long-term geologic and short term carbon cycles. They expose and erode ancient carbon buried in sedimentary rocks, and are the primary export path for all terrestrial carbon sources to the ocean [1]. Radiocarbon provides useful information about the main sources of carbon transported in rivers and streams [2,3] and has been employed as a tracer in various systems, including soils. It has been widely applied in studying processes of mass transfer and in geochronological research [4]. Representative rivers of different annual discharge, basin area, land-use pattern and geological conditions are the Amazon River [5,6], the York River [7], the Lanyang Hsi River [2] and small mountainous rivers of Papua New Guinea [8], whose values of $\Delta^{14}C$ and $\delta^{13}C$ have distinctive temporal-spatial variations.

The goal of the present research is to investigate the values of $\Delta^{14}C$, $\delta^{13}C$ of riverine organic matter in order to understand the relationship between the origin of riverine organic matter and the rate of soil erosion of the Zhujiang drainage basin.

1.2. Site description

The Zhujiang drainage basin is situated between 21.31–26.49°N and 102.14–115.53°E with a drainage area of 0.45×10^6 km^2, in a region of subtropical monsoon climate in South China (Fig. 1). This area is strongly affected by East Asian monsoon and South Asian monsoon, with 80% of annual precipitation occurring between April and October. Vegetation types of the drainage basin are evergreen monsoon rainforest, broadleaf forest and grassland. The Xijiang drainage basin is highly populated, cultivated and industrialized, and has been drastically affected by anthropogenic activities, such as road construction and deforestation. As a result, in recent years the forests have been replaced by grasslands and farmlands.

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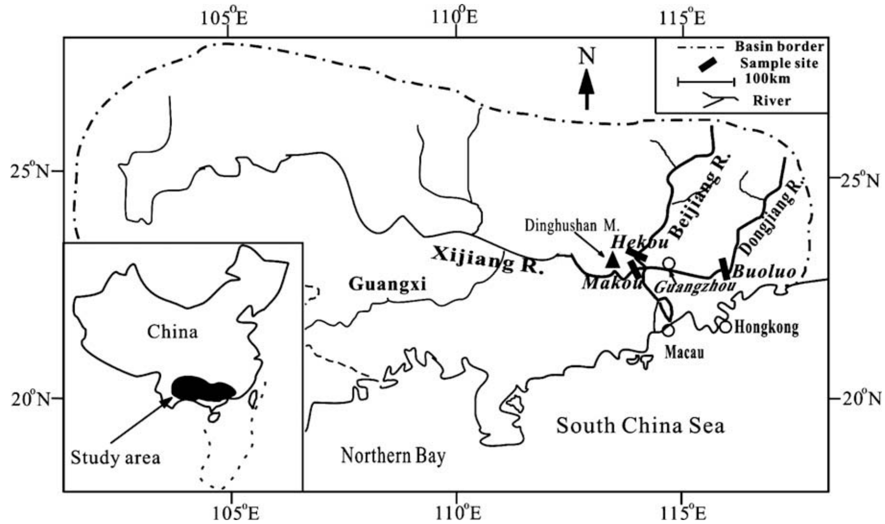

Fig. 1. Map of the Zhujiang drainage basin and sampling sites.

2. Methods

2.1. Sample collection

Samples were collected in hydrological stations at Boluo (along the Dongjiang), Makou (along the Xijiang) and Hekou (along the Beijiang) in the years 1998, 2000, 2004, 2005. The water was filtered through preheated (550 °C, 6 h) Whatman 47 mm GF/F (0.7 μm pore size) glass fiber filters. The filters with the suspended sediment were quickly frozen with dry ice (−78 °C) during transport and stored in −20 °C refrigerator upon return to the laboratory for $\delta^{13}C$ and ^{14}C analysis.

2.2. Analyses

GF/F filters were freeze-dried and analyzed for POC with a CHNOS analyzer (Vario EL III) after removing the inorganic carbon by reaction with HCl at laboratory. Pretreatment methods of samples for $\delta^{13}C$ were conducted as described by Wu et al. [9] and then analyzed by a Finnigan Delta-plus XP analyzer.

Processing procedure of ^{14}C sample preparation was as follows: (1) the carbonatic material was removed from the sample by addition of 10% HCl solution; (2) the non-dissolvable material was separated from the solution, then 2% NaOH was added to the cleaned remains and stirred and left to rest for 24 h; (3) the 10% HCl was poured into the cleaned remains, boiled slowly, rinsed and dried. The dried material was used to produce graphite targets for ^{14}C analysis which were completed by the Sample Synthesizing System at the Guangzhou Institute of Geochemistry, Chinese Academy of Science. The $^{14}C/^{12}C$ ratios were determined by the 2 × 6 MV EN Tandem AMS facility at the Institute of Heavy Ion Physics, Peking University. The POC values are given as ppm with analytical error of 2%. The ^{14}C values are reported as $\Delta^{14}C$‰ values with an average error of ± 5‰ and the ^{13}C values are given as $\delta^{13}C$‰ with an error of ±0.2‰ (Table 1).

3. Results and discussions

3.1. The ^{14}C value and apparent ages in POC

To understand the origin of the POC in the Zhujiang, we analyzed the $\Delta^{14}C$ values of suspended sediments and calculated their apparent ages in its main tributaries, Dongjiang, Xijiang and Beijiang. The results were reported in terms of apparent age relative to 1950 following the convention of Stuiver and Polach [10]. The results are listed in Table 1.

The $\Delta^{14}C$ values were different in the three tributaries. In the Dongjiang, the values were constant and exceeded −193‰, which indicated that the major contribution is of modern carbon source. In the Xijiang, however, the $\Delta^{14}C$ values mostly ranged from −368‰ to −201‰, some even as low as −425‰, implying that a large part of the POC is derived from a deep soil profile which explain the high content of "old carbon" suspended in the river. The $\Delta^{14}C$ values in the Beijiang was from −254‰ to −175‰, implying older ages than Dongjiang.

The POC content in our study is between 0.8 and 2.95 ppm. The negative correlation between the POC concentrations and $\Delta^{14}C$ values (Fig. 2) implies that at times of higher content of POC in the suspended sediment, the ages of POC are older due to deep erosion as will be discussed below.

3.2. The relationship between apparent ages of POC and soil erosion

The isotopic signature of riverine POC reflects its sources which are mostly eroded soil. When the riverine organic matter contains significant deep eroded soil, the $\Delta^{14}C$ values are expected to be more negative, with older apparent ages. As mentioned before, the Dongjiang has much higher $\Delta^{14}C$ values, consistent with an undisturbed area. This suggests that in the Dongjing basin there is little contribution of older carbon of deeper parts of the soil profile. It can be concluded, therefore, that the POC of Dongjing is derived mainly from the surface soil. In the Xijiang, the lower $\Delta^{14}C$ values of POC suggest the influence of erosion of deeper parts of the soil profile, which was the origin of "old carbon" and older apparent ages.

The ^{14}C of suspended sediment at different sampling cruises in 1998, 2000, 2004 and 2005 in the different locations (Fig. 1), yield apparent ages in the range of 540–4445 years, which correspond with the soil ages of 0.3–1.5 m depth profile in this watershed [11–13]. The apparent ages of most suspended POC in the Xijiang were older than 2000 years, which was consistent with the soil ages of 1.2–1.5 m depth profile [11–13]. On the other hand, the apparent young ages of suspended POC in the Dongjiang, ranging from 540 to 1010 years, are consistent with the surface soil ages. These results showed that in the Xijiang basin the effect of erosion is more severe, eroding deeper into the soil profile. This erosion is

Table 1
^{14}C analysis of suspended sediment samples.

Sample No.	Sample date	Sample site	POC (ppm)	$\delta^{13}C$ (‰)	Apparent age (BP, year)	$\Delta^{14}C$ (‰)	pMC (%)
XLLQ1097	Aug., 1998	Boluo	0.90	−22.57	1010 ± 80	−118 ± 10	89.25
XLLQ1098	May, 2000	Boluo	1.20	−23.34	750 ± 60	−89 ± 7	92.04
XLLQ1100	Aug., 2000	Boluo	0.80	−21.99	540 ± 60	−65 ± 7	94.74
XLLQ1101	May, 2000	Boluo	1.30	−23.33	1720 ± 80	−193 ± 10	81.58
GZ2484	Jun., 2005	Boluo	0.98	−23.83	617 ± 26	−74 ± 3	92.83
XLLQ1102	Jun., 2000	Makou	1.42	−22.89	1540 ± 80	−174 ± 10	83.49
XLLQ1103	Aug., 2000	Makou	2.04	−23.24	2050 ± 60	−225 ± 7	78.31
GZ2473	Mar., 2004	Makou	2.82	−25.20	3690 ± 28	−368 ± 3	63.15
GZ2474	Apr., 2004	Makou	2.95	−25.88	4445 ± 34	−425 ± 4	57.40
GZ2475	May, 2004	Makou	1.23	−23.67	1134 ± 32	−132 ± 4	87.07
GZ2476	Jun., 2004	Makou	2.29	−23.68	2738 ± 34	−289 ± 4	71.31
GZ2477	Jul., 2004	Makou	1.64	−23.27	1798 ± 32	−201 ± 4	80.23
GZ2478	Aug., 2004	Makou	1.75	−23.59	2304 ± 29	−249 ± 4	75.28
GZ2479	Sept., 2004	Makou	2.78	−23.84	3632 ± 28	−364 ± 3	63.78
GZ2480	Oct., 2004	Makou	2.05	−24.72	2658 ± 36	−282 ± 4	71.87
GZ2481	Dec., 2004	Makou	2.57	−26.07	3374 ± 34	−343 ± 4	65.56
GZ2482	Jun., 2005	Makou	1.86	−23.10	1983 ± 29	−219 ± 4	78.43
XLLQ1104	Aug., 2000	Hekou	1.60	−24.12	1550 ± 100	−175 ± 12	83.18
GZ2483	Jun., 2005	Hekou	2.07	−23.83	2349 ± 31	−254 ± 4	74.82
GZ2485	Aug., 2004	Hekou	1.20	−21.87	2254 ± 27	−245 ± 3	76.02

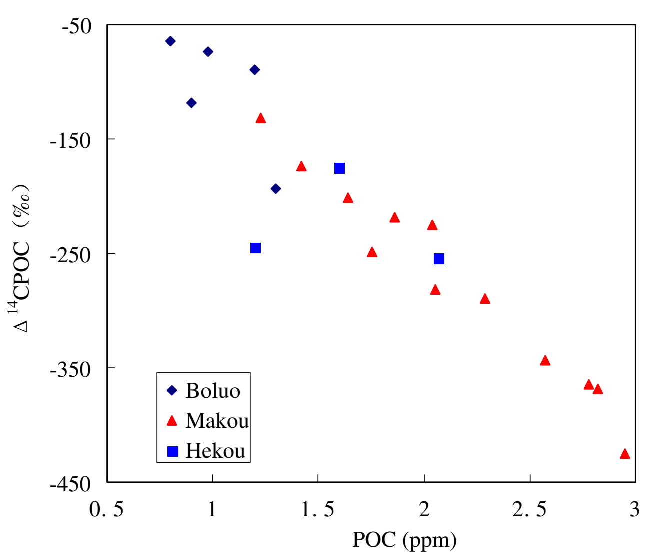

Fig. 2. Relationship between POC concentration and POC$\Delta^{14}C$ in suspended sediment of the Zhujiang.

mainly induced by human activities, resulting in a more violent process than that of Dongjiang basin.

3.3. Implications of $\Delta^{14}C$ and $\delta^{13}C$ values of the POC

The values of suspended POC$\Delta^{14}C$ varied from −65‰ to −425‰ in the Zhujiang. Compared with the Amazon River (−145‰) [6], these values were mostly more negative (corresponding ages were older). Compared to small rivers, on the other hand, these values were less negative than that of Lanyang Hsi (−875‰) [2].

Located in a subtropical climate zone, the organic matter near the surface is expected to be decomposed relatively quickly and only at deeper parts of the soil the organic matter will be preserved. This creates a situation in which deep erosion of soil will yield older apparent ages than actually exist in the field. According to several studies, some POC$\Delta^{14}C$ values of different types of forest soil were positive (post-bomb) in the Zhujiang drainage basin [11–13]. Leung [14] also detected the influence of post-bomb carbon in soil and vegetation in the natural environment of the Hong Kong Special Administrative Region and the Guangxi Zhuang Autonomous Region. Furthermore, the POC$\Delta^{14}C$ values of vegetation were similar in these two regions. These results show that surface soil in the studied watershed also has some post-bomb carbon. However, no sample contained detectable amounts of bomb carbon, which implies that the weak signal of post-bomb ^{14}C has been lowered by the above erosion processes.

Fig. 3 shows that the relationship between POC$\Delta^{14}C$ values and the $\delta^{13}C$ can imply the sources of POC. The samples with less negative $\delta^{13}C$ value mainly originate from C_4 grasslands, while the samples with more negative $\delta^{13}C$ value mainly derive from C_3 forest area [15]. The samples with more negative values of POC$\Delta^{14}C$ originate from the deeper soil of erosion area which represent older soils of more natural periods when grasslands were less abundant. In contrast, less negative values of POC$\Delta^{14}C$ derive from surface or shallow layer soil.

Fig. 3 also indicates the correlation between POC$\Delta^{14}C$ and $\delta^{13}C$ of the suspended sediment in the Zhujiang, which differ from the results of Santa Clara River [3]. The reasons for these differences are not clear and probably derive from differences in the condition of these basins such as hydrological dynamics, anthropogenic

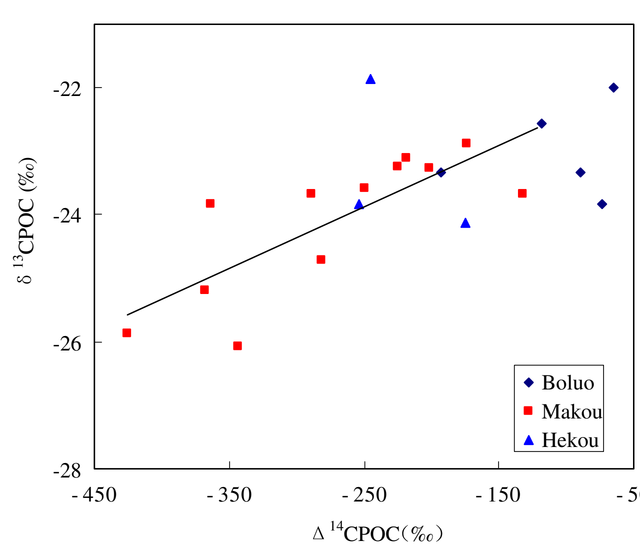

Fig. 3. POC$\Delta^{14}C$ and POC$\delta^{13}C$ of suspended sediment in the Zhujiang.

activity, soil erosion, vegetation coverage rate, surface geology and agricultural run-off.

4. Conclusions

The significant spatial variations in the $\Delta^{14}C$ values of riverine suspended sediment from the three tributaries of the hydrographic basin of the Zhujiang reflect the main organic sources and the erosive degree of their drainage basin. Clearly, the apparent ages of most suspended POC in the Xijiang were older than 2000 years, which was consistent with the soil ages of 1.2–1.5 m depth profile. This implies that the soil erosion of the Xijiang basin is more severe than that of the Dongjiang and the Beijiang basins. We hope this research will be helpful to the local decision-makers of water and soil conservation policy. This work also enriches the ^{14}C database for the carbon cycle research.

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