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Organic carbon cycling in sediments of the Changjiang Estuary and adjacent shelf: Implication for the influence of Three Gorges Dam

Dong Li [a,b], Peng Yao [a,c,d,*], Thomas S. Bianchi [e], Tingting Zhang [a,b], Bin Zhao [a,b], Huihui Pan [a,b], Jinpeng Wang [a,b], Zhigang Yu [a,d]

[a] Key Laboratory of Marine Chemistry Theory and Technology, Ministry of Education, Qingdao 266100, China
[b] College of Chemistry and Chemical Engineering, Ocean University of China, Qingdao 266100, China
[c] Qingdao Collaborative Innovation Center of Marine Science and Technology, Qingdao 266100, China
[d] Institute of Marine Organic Geochemistry, Ocean University of China, Qingdao 266100, China
[e] Department of Geological Sciences, University of Florida, Gainesville, FL 32611-2120, USA

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ABSTRACT

Surface sediments collected from the Changjiang Estuary and adjacent shelf were analyzed for elemental and stable carbon isotopic composition, and lignin–phenols to investigate spatial variability of the sources, transport and decay of sedimentary organic carbon (OC). Bulk and molecular proxy data indicated a mixed marine/terrestrial OC sources in the study area. A three end-member mixing model using Monte-Carlo simulation showed that marine OC was the predominant OC source, accounting for an increasing fraction along the coast and seaward, while soil-derived OC and C_3 vascular plant detrital OC decreased seaward and southward. Large fragments of lignin-rich C_3 vascular plant OC were deposited mainly near the river mouth, whereas fine-grained lignin-poor soil-derived OC was delivered further south alongshore. Higher values of lignin decay indices, seaward and southward, were attributed to selective transport of terrestrial OC on fine-grained particles and efficient remineralization in mobile muds. Λ_8 of OC in Changjiang Estuary sediments has slightly decreased in recent years, which could in part be due to the trapping of terrestrial coarse particles by the Three Gorges Dam (TGD). Also, we propose that there has been an increasing input of phytodetritus derived from freshwater phytoplankton to coastal sediments after the construction of the TGD.

1. Introduction

Large-river delta-front estuaries (LDEs) and their adjacent ocean margins are the major repositories for over 95% of river sediments and ~90% of the organic carbon (OC) buried in marine sediments (Bianchi and Allison, 2009; Hedges and Keil, 1995; McKee et al., 2004; Milliman and Farnsworth, 2011; Syvitski et al., 2005). The spatial dynamics of terrestrial OC derived from plants, soils and riverine organisms (both autotrophic and heterotrophic), widely dispersed along estuarine and shelf/slope gradients, are largely controlled by hydrodynamic conditions (such as river discharge and coastal currents) and geomorphological settings (Prahl et al., 1994; Goñi et al., 1998; Gordon and Goñi, 2004; Bianchi et al., 2002, 2007a, and references therein). While high phytoplankton productivity is commonly found in most coastal systems, terrestrial OC can represent a considerable fraction of the total OC pool in LDE sediments — due to its relative stability over marine OC (Burdige, 2005; Hedges et al., 1997). In addition to differences in OC source stability, physical reworking and highly dynamic microbial activities in LDE sediments have also been shown to have a significant influence on the preservation of sedimentary OC for both terrestrial and marine sources (e.g. Aller and Blair, 2006; Aller et al., 2008; Bianchi, 2011; Blair and Aller, 2012; Zhu et al., 2013). Despite such efforts, carbon cycling in LDEs, including the sources, composition and dispersal process, especially the effects of OC composition on the preservation of OC in highly mobile sediment regions, is still poorly understood (Bianchi, 2011; Li et al., 2012; Sánchez-García et al., 2009; Zhu et al., 2011a, 2013).

The dispersal of Changjiang-derived sediments is largely affected by the seasonal hydrodynamics and believed to be largely responsible for the formation of the mobile-mud belt along the ECS inner shelf (Fig. 1; Liu et al., 2006, 2007). Previous studies have shown that terrestrial OC is a critical component of sedimentary OC in these reworked mud regions of the Changjiang LDE and adjacent ECS shelf (e.g. Deng et al., 2006; Hu et al., 2012; Li et al., 2012, 2013; Xing et al., 2011; Zhang et al., 2007; Zhu et al., 2008, 2011a, 2013). Furthermore, these studies also provide valuable insights regarding the spatial variation, abundance, age as well as burial of sedimentary OC in this dynamic environment. However, the sources, distribution and fate of OC, especially those

* Corresponding author. Tel./fax: +86 532 66781659.
E-mail address: yaopeng@ouc.edu.cn (P. Yao).

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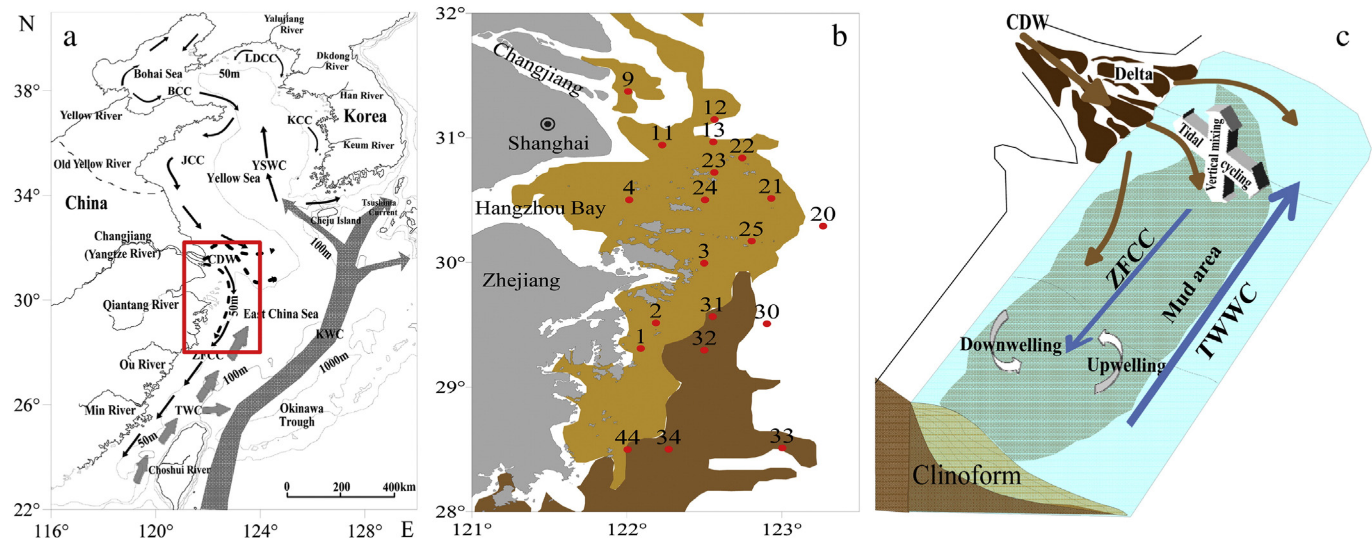

Fig. 1. Maps of the study area. (a) Map of the Eastern China Marginal Seas including the ocean currents. KWC, Kuroshio Warm Current; TWWC, Taiwan Warm Current; YSWC, Yellow Sea Warm Current; JCC, Jiangsu Coastal Current; CDW, Changjiang Diluted Water; ZFCC, Zhejiang-Fujian Coastal Current; BCC, Bohai Coastal Current; LDCC, Liaodong Coastal Current; KCC, Korea Coastal Current. Red box area indicates the research area in this study. (b) Sampling locations at the Changjiang Estuary and East China Sea (ECS) inner shelf. The mud deposits (yellow and brown area) are displayed according to Qin et al. (1996). (c) Simple tridimensional conceptual model of study area and oceanographic processes affecting the sediment dispersal. Upwelling and coastal clinoform mud was redrawn from Liu et al. (2006).

terrestrial sources, in sediments of the Changjiang LDE and adjacent ECS shelf remain poorly explored. Moreover, the construction of the Three Gorges Dam (TGD) in the Changjiang River has significantly reduced the annual sediment discharge to estuarine regions from ~4.2×10^8 t/year to ~1.5×10^8 t/year since its first filling stage in June 2003 (Dai and Liu, 2013; Xu and Milliman, 2009; Yang et al., 2011 and references therein), and the change of water discharge, which has been more influenced by other factors (e.g. precipitation, agricultural water and domestic water) rather than from construction of TGD (L. Zhang et al., 2014). Furthermore, the growing consumption of chemical fertilizers and discharge of domestic wastewater in the Changjiang watershed has also changed the nutrient structure, causing nuisance algal blooms in the Changjiang drainage basin and coastal region (Jiang et al., 2014; Li et al., 2014 and references therein).

In this study, we measured stable carbon isotope ($\delta^{13}C$) and lignin biomarkers of OC in surface sediments collected from the Changjiang LDE and adjacent ECS shelf (Tables 1 and 2), in order to further investigate the sources and decay of sedimentary OC, with particular reference to terrestrial OC in the mud area of this highly dynamic system. This study builds on previous publications in this region by providing further spatial resolution of sediment carbon cycling in the mud belt of this highly dynamic LDE (Deng et al., 2006; Hu et al., 2012; Li et al., 2012, 2013; Xing et al., 2011; Zhang et al., 2007; Zhu et al., 2008, 2011a, 2013). Here, we combine our data with results from previous work (data sources are shown in Table A.3) in this region, to provide a more integrated temporal and spatial perspective of changes in OC carbon sources. We used $\delta^{13}C$ and lignin contents (Λ_8) of OC in suspended particulate matter (SPM) and surface sediments of the

Table 1
Bulk properties of surface sediments in the Changjiang Estuary and ECS inner shelf.

Site	Longitude (°E)	Latitude (°N)	Water depth (m)	TOC (%)	TN (%)	Molar C/N ratio	$\delta^{13}C$ (‰)	Median grain size (um)	Sediment compositions		
									%Sand (>63um)	%Silt (4–63um)	%Clay (<4um)
1	122.09	29.31	10	0.42	0.07	7.1	-22.2	12	1.0	76.8	22.2
2	122.19	29.51	11	0.42	0.07	7.2	−23.5	12	1.3	77.5	21.2
3	122.50	29.99	21	0.34	0.05	7.4	−22.8	16	12.2	70.1	17.7
4	122.02	30.50	11	0.43	0.06	7.9	−23.3	9	4.0	66.6	29.4
9	122.01	31.37	11	0.12	0.02	6.9	−23.6	99	52.6	28.6	18.8
11	122.23	30.94	11	0.43	0.07	7.3	−23.1	11	1.4	76.3	22.3
12	122.57	31.15	21	0.55	0.09	7.2	−23.0	8	1.1	69.9	29.0
13	122.56	30.97	16	0.48	0.08	6.8	−23.5	11	1.3	75.5	23.2
20	123.27	30.29	57	0.24	0.04	6.4	−20.4	101	58.6	25.7	15.7
21	122.93	30.51	48	0.51	0.08	7.1	−21.9	11	13.8	60.5	25.7
22	122.74	30.84	27	0.47	0.07	7.5	−22.9	11	2.4	73.0	24.6
23	122.56	30.72	17	0.41	0.06	7.3	−23.4	15	7.1	72.4	20.5
24	122.50	30.50	27	0.45	0.07	7.6	−22.8	10	1.6	73.1	25.3
25	122.81	30.17	33	0.57	0.10	6.7	−23.0	8	0.4	69.0	30.6
30	122.90	29.51	57	0.45	0.08	6.8	−20.8	14	32.8	45.6	21.6
31	122.55	29.56	33	0.63	0.10	7.4	−22.8	7	3.6	67.3	29.1
32	122.50	29.30	41	0.62	0.10	7.4	−22.0	7	0.4	71.6	28.0
33	123.00	28.51	72	0.56	0.10	6.6	−22.1	6	0.2	64.4	35.4
34	122.27	28.50	57	0.68	0.11	7.1	−21.6	6	0.4	65.6	34.0
44	122.01	28.50	22	0.57	0.09	7.1	−22.4	7	0.1	68.2	31.7