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# Remineralization of sedimentary organic carbon in mud deposits of the Changjiang Estuary and adjacent shelf: Implications for carbon preservation and authigenic mineral formation

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

[a] Key Laboratory of Marine Chemistry Theory and Technology, Ministry of Education, Qingdao 266100, China
[b] Qingdao Collaborative Innovation Center of Marine Science and Technology, Qingdao 266100, China
[c] Institute of Marine Organic Geochemistry, Ocean University of China, Qingdao 266100, China
[d] College of Chemistry and Chemical Engineering, Ocean University of China, Qingdao 266100, China
[e] Department of Geological Sciences, University of Florida, Gainesville, FL 32611-2120, USA
[f] Department of Environmental Science and Engineering, Fudan University, Shanghai 200433, China

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ABSTRACT

Knowledge of the fate of sedimentary organic carbon (SOC) in large-river delta-front estuaries (LDEs) is critical for understanding the global carbon cycle. In this study, remineralization of total organic carbon (TOC) in the Changjiang Estuary and adjacent East China Sea (ECS) shelf were investigated by combining sediment and pore water analyses. Distinctively low TOC to sediment surface area (TOC/SSA) loadings ($<0.40$ mg $m^{-2}$) were observed mainly in the mud deposits comparable to tropical deltaic mobile muds or delta topset, indicating an inefficient SOC preservation. Anaerobic incubations showed that the net reaction rate of $\Sigma CO_2$ in pore waters over the whole core (0–24 cm) of sediments in the Changjiang Estuary was 5.1 mmol $m^{-2}$ $d^{-1}$, and over the upper 15 cm was 9.3 mmol $m^{-2}$ $d^{-1}$. $\Sigma CO_2$ in pore waters from incubated sediments decreased with time and the consumption rate in the lower layer of sediments was 4.2 mmol $m^{-2}$ $d^{-1}$, close to the consumption rate of major cations, especially calcium, indicating the precipitation of authigenic carbonates. Overall, remineralization of SOC in mobile-mud belts could play a critical role in the biogeochemical cycling and storage of OC, and other important biogenic elements in this highly dynamic LDE.



## 1. Introduction

Large-river delta-front estuaries (LDEs) are the primary interfaces between terrestrial and oceanic environments where material transport, sediment deposition, and nutrient cycling have important impacts on global ocean biogeochemistry (McKee et al., 2004; Syvitski et al., 2005; Burdige, 2007; Aller et al., 2008a; Bianchi and Allison, 2009; Milliman and Farnsworth, 2011). It has been estimated that more than 90% of sedimentary organic carbon (SOC), both allochthonous and autochthonous, is trapped in LDE and adjacent coastal margins (Hedges and Keil, 1995; Bianchi and Allison, 2009). The efficiency of SOC burial on a shelf largely depends on the type of geological margin it resides on (e.g., active or passive) (Blair and Aller, 2012). For example, in LDEs situated on passive margins, like the Mississippi River and the Amazon, significant amounts of OC inputs are remineralized more efficiently than active margins. This is in part, due to comparatively greater accommodation space, residence time, lower elevation gradient in the floodplain, and a wider shelf (Blair and Aller, 2012). In addition to these differences in physical features, other factors such as chemical composition and age of the SOC, the associated organo-mineral matrix and/or aggregate, and redox conditions, to mention a few, are also important in determining what is ultimately buried in shelf sediments (e.g., Bianchi and Allison, 2009; Bianchi, 2011; Blair and Aller, 2012; Li et al., 2012, 2013).

Much of the pioneering work of Aller and co-workers in tropical LDE environments, i.e., the Amazon River Delta (Brazil) and the Gulf of Papua (Papua New Guinea), has shown the importance of mobile muds in LDEs as suboxic “fluidized-bed reactors” or “incinerators” of SOC (e.g., Aller, 1998; Aller and Blair, 2004; Aller and Blair, 2006; Aller et al., 2008a; Blair and Aller, 2012). For example, mobile muds in the Amazon Delta, have been shown to have high depth-integrated

* Corresponding author at: Key Laboratory of Marine Chemistry Theory and Technology, Ministry of Education, Qingdao 266100, China.
Tel./fax: +86 532 66781659.
*E-mail address:* yaopeng@ouc.edu.cn (P. Yao).

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(0–10 cm) remineralization rates (based on $\Sigma CO_2$ production) of SOC that ranged from 19 to 127 mmol $m^{-2}$ $d^{-1}$—with substantial seasonal variability (Aller and Blair, 2006). Similarly, high $\Sigma CO_2$ production fluxes were also observed in mobile muds (0–20 cm) from the Gulf of Papua (35–42 mmol $m^{-2}$ $d^{-1}$), particularly during monsoon periods due to enhanced resuspension (Aller et al., 2008a). Interestingly, high remineralization rates have resulted in low preservation of OC in the upper surface sediments of these mobile muds, as reflected by the low total OC to sediment surface area (TOC/SSA) loadings found in these sediments ($<0.40$ mg $m^{-2}$). These low values are comparable to deep-sea sediments that receive considerably less organic carbon deposition (Aller, 1998; Blair and Aller, 2012).

To date, most studies on the fate of SOC in LDEs have been conducted in tropical deltaic environments, where the majority of riverine sediment inputs to the global ocean are highest (Syvitski et al., 2005). However, there has recently been an increase in the number of studies on OC cycling in subtropical LDEs, particularly as it relates to anthropogenic effects. For example, the Changjiang (Yangtze River) LDE in the East China Sea (ECS) has received considerable attention, in part, due to the rapid land-use changes occurring in east China (Li and Wang, 2003). Similar to many LDEs, the Changjiang LDE is also characterized by high sedimentation rates, but with distinctively low terrestrial OC preservation efficiency (Blair and Aller, 2012). In fact, the sources, distribution, and burial of OC in sediments of the Changjiang Estuary/ECS shelf have been well studied over the past decade (e.g. Deng et al., 2006; Zhang et al., 2007; Zhu et al., 2008, 2011a, 2011b, 2013; Xing et al., 2011; Hu et al., 2012; Li et al., 2012, 2013, 2014).

Despite such efforts, little remains known about the remineralization of SOC throughout the estuary and ECS inner shelf. The primary objectives of this study were to quantitatively constrain the remineralization and preservation of SOC in the Changjiang Estuary and adjacent shelf, and to examine the role of mobile-mud deposits on biogeochemical cycling of carbon and other important elements in this region. In general, we used grain-size analysis SSA, TOC contents and stable carbon isotope abundance ($\delta^{13}C$) to characterize the basic properties of sediments and organic carbon, TOC/SSA loadings to investigate the preservation of SOC and direct measurements of net reaction rates of $\Sigma CO_2$ and major cations in sediment cores to locate "hotspots" of SOC remineralization and element cycling.

## 2. Study area

The study area was located between 28.5 °N–31.5 °N latitude and 121.5 °E–123.5 °E longitude at the Changjiang Estuary, with the water depth ranging from 10 to 72 m along the inner-shelf of the ECS (Fig. 1, Table 1). The Changjiang has the fourth and fifth largest discharge of sediment ($\sim 4.8 \times 10^8$ t $yr^{-1}$) and water ($\sim 9.0 \times 10^{11}$ $m^3$ $yr^{-1}$), respectively, of all global rivers (Milliman and Farnsworth, 2011). The river drains an area of $1.94 \times 10^6$ $km^2$, and annually transports $1.2 \times 10^7$ t of particulate organic matter (POM) to the estuary and its adjacent coastal areas, making it the dominant sources of terrigenous and riverine matter to the ECS (Milliman et al., 1985; Deng et al., 2006; Bianchi and Allison, 2009).

Hydrographic conditions in the Changjiang Estuary and the coastal area of ECS are governed by two southward currents, the Yellow Sea Coastal Current (YSCC) in the north, and the Zhe-Min Coastal Current (ZMCC) in the south (Liu et al., 2010). These currents, which are most active during winter, carry water and sediments from the Changjiang southward along the inner shelf. In addition, there is a northward flow of warm saline water on the middle shelf named Taiwan Warm Current (TWWC). This current intensifies during summer in response to the prevailing southeast monsoon, and thus largely weakens the southward transport of

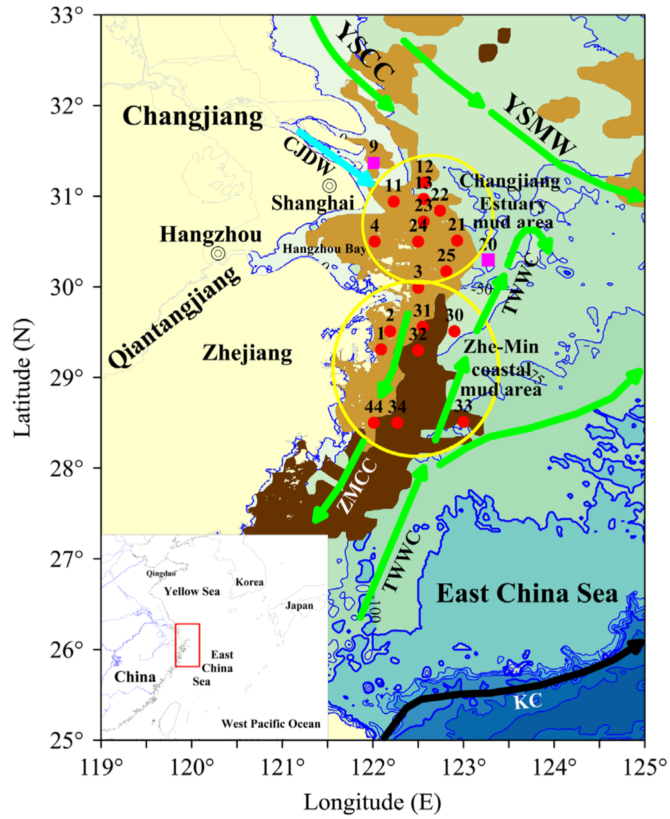


**Fig. 1.** Sampling locations at the Changjiang Estuary and the inner-shelf of East China Sea (ECS) and the local rivers (Changjiang (Yangtze River) and Qiantang River). The mud deposits (yellow and brown area) are displayed according to Qin et al. (1996). Arrows indicate the direction of the currents (from Liu et al., 2007). CJDW: Changjiang Diluted Water; YSCC: Yellow Sea Coastal Current; YSMW: Yellow Sea Mixing Water; ZMCC: Zhe-Min Coastal Current; TWWC: Taiwan Warm Current (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

sediments along Zhe-Min coast during this time (Liu et al., 2006). In fact, the dispersal pattern of fine-grained sediments discharged by the Changjiang is believed to be deposited first in the estuarine region in summer and then re-suspended and remobilized southward in winter along the Zhe-Min coast (Liu et al., 2006; Liu et al., 2007). During this seasonal transport, many of these sediments are trapped along the inner shelf forming a mobile-mud belt in the ECS (Fig. 1) (e.g. Milliman et al., 1985; Liu et al., 2006; Liu et al., 2007; Zhu et al., 2011a; Hu et al., 2012; Xu et al., 2012). These dynamic sedimentary transport processes result in considerable hydrodynamic sorting of river-derived sediments and greatly influence the fate of SOC in this LDE (Hu et al., 2012, Li et al., 2014).

## 3. Materials and methods

### 3.1. Sampling

Sampling was conducted onboard the *Runjiang* 1 (Zhoushan Runhe Co., Ltd., China) during the flood period from July 29 to August 3, 2011 (Fig. 1). Most samples were collected from the mobile-mud belt region. Surface sediments, from 20 sampling sites (Fig. 1; Table 1), from the mouth of Changjiang River to the Zhe-Min coastal area, were collected using a stainless steel box-corer. Sub-cores were collected to a sediment depth of ca. 5 cm, homogenized and used as surface sediment samples. All samples were stored in pre-combusted small alumina boxes at −20 °C before laboratory analyses.