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Heavy metals in surface sediments of the continental shelf of the South Yellow Sea and East China Sea: Sources, distribution and contamination

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ABSTRACT

The heavy metals in surface sediments of the continental shelf of the South Yellow Sea (SYS) and the East China Sea (ECS) collected in 2016 were analyzed to assess the heavy metal distributions, contamination status, and likely sources. The metal concentrations generally met the China Marine Sediment Quality criteria. However, the enrichment factor and geoaccumulation index values clearly showed elevated Cd and Pb concentrations in the region. Cd and Pb contamination occurred mostly to the southwest of the Changjiang River mouth and to the east of the Shandong Peninsula because of rapid economic and industrial development. The results are likely to be useful for authorities responsible for sustainable coastal zone management.

1. Introduction

In recent decades, rapid industrial and economic development in China has caused serious environmental problems, including heavy metal contamination (Wang et al., 2007; Wang et al., 2015; Zhuang and Gao, 2015; Chen et al., 2016; Xu et al., 2016; Sun et al., 2017). Heavy metals in sediments can originate from both natural sources and human activities, and they can enter the food web and cause health problems. In China, most previous studies investigating heavy metal contamination in marine sediments have focused on estuaries and semi-closed bays (Wang et al., 2007; Wang et al., 2015; Zhuang and Gao, 2015; Xu et al., 2016; Sun et al., 2017), and few studies have analyzed data collected from the open continental shelf (Cao et al., 2015; Chen et al., 2016; Xiao et al., 2017).

The Yellow Sea (YS) and East China Sea (ECS) together constitute one of the world's most extensive continental shelves. The Huanghe and Changjiang Rivers deliver abundant freshwater, billions of tons of sediment, and heavy metals (Liu et al., 2007a; Yang and Liu, 2007; Cao et al., 2015; Wang et al., 2015). Previous studies have found that the considerable amount of sediments from the Huanghe River (1100 Mt/yr) and Changjiang River (500 Mt/yr) can be dispersed up to hundreds of kilometers across and along the YS and ECS shelf (Liu et al., 2007a; Yang and Liu, 2007). Although heavy metal contamination has been investigated extensively in the YS and the ECS, most studies have focused on estuaries or semi-closed bays (Zhang et al., 2009; Wang et al., 2015; Xu et al., 2016). Fang et al. (2009) found that high metal concentrations occurred along the ECS inner shelf. Jiang et al. (2014) showed that although some areas of the SYS were contaminated by Cd, most were not contaminated or showed low levels of contamination. However, few studies have considered the continental shelf of the SYS and the ECS as a whole. Recently, Chen et al. (2016) conducted comprehensive marine sediment contamination studies for nearly the entire extent of Chinese coastal seas (i.e., the Bohai Sea, YS, ECS, and South China Sea). However, the YS and ECS were not the main focus of their research.

The main aims of this study are to (1) examine the spatial variation in heavy metals; (2) assess the metal contamination using sediment quality guidelines and the enrichment factor (EF) and geoaccumulation index (I_{geo}) methods; and (3) assess the potential sources of these metals in surface sediments of the SYS and ECS continental shelf.

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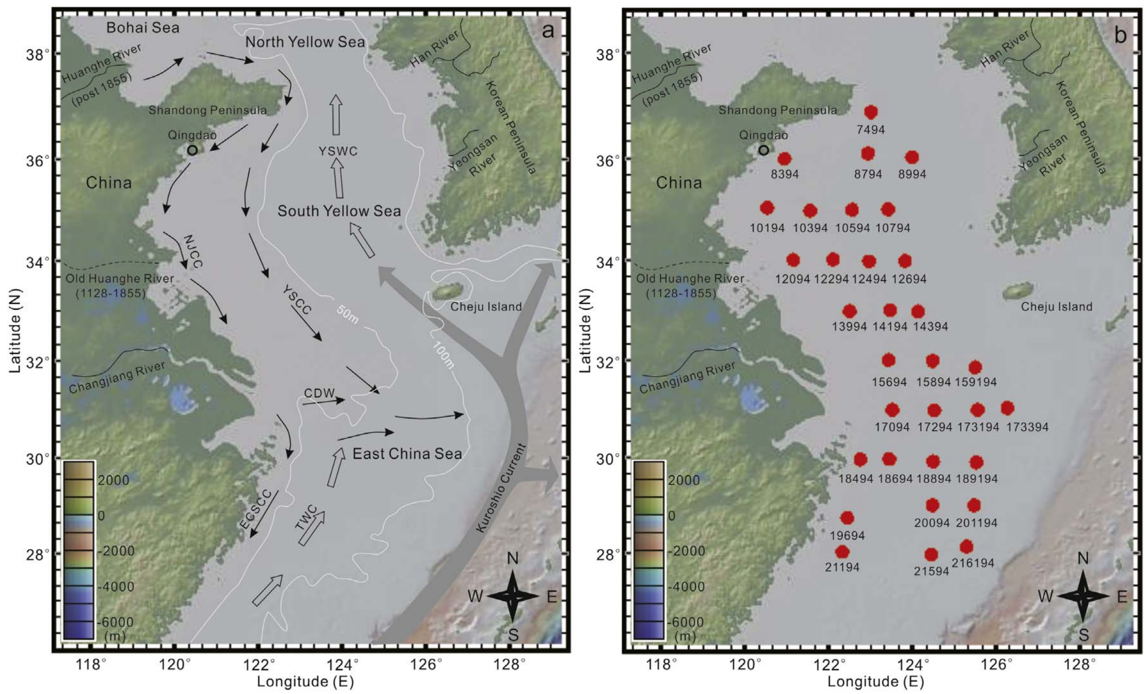

Fig. 1. Surface circulation in the ECS and the SYS (a, after Liu et al., 2007b; Liu et al., 2010), and the sampling sites (b). TWC, YSWC, YSCC, NJCC, CDW, and ECSCC denote Taiwan Warm Current, Yellow Sea Warm Current, Yellow Sea Coastal Current, North Jiangsu Coastal Current, Changjiang Diluted Water, and East China Sea Coastal Current, respectively.

Table 1
Results of standard reference materials analysis (unit: mg kg^{-1}).

Element	GBW07315		GBW07316		BHVO-2		BCR-2	
	Measured values	Certified values	Measured values	Certified values	Measured values	Certified values	Measured values	Certified values
Al	11.6	11.41 ± 0.22	7.55	7.7 ± 0.3	14.2	13.5 ± 0.2	14.4	13.5 ± 0.2
Cu	352	357 ± 20	237.13	231 ± 10	147	127 ± 7	32.8	19 ± 2
Pb	44.9	37 ± 4	21.706	22 ± 5	1.33	NA	12.5	11 ± 2
Zn	143	137 ± 15	145.67	142 ± 22	125	103 ± 6	157	127 ± 9
Cr	65.7	59 ± 6	44.068	38 ± 2	317	NA	17.4	18 ± 2
Cd	0.360	0.25	0.2967	0.3	0.184	NA	0.745	NA
Ni	166	167 ± 12	112.78	108 ± 9	119	119 ± 7	15.2	NA

NA: not available.

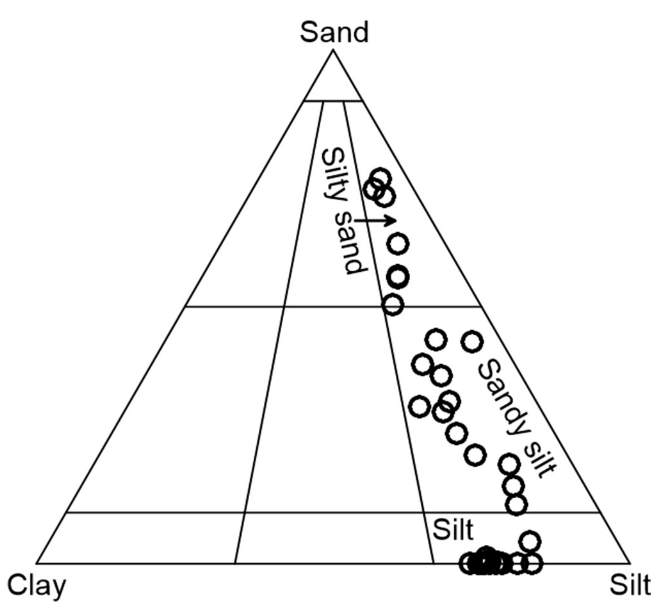

Fig. 2. Classification diagram of sediments in the ECS and the SYS.

2. Regional setting

The YS and ECS are surrounded by Korea and China, which have undergone rapid population and economic growth. The YS is separated from the ECS to the south by a line that connects Cheju Island to the Changjiang River mouth (Yuan et al., 2012), and the YS is divided into the SYS and the North Yellow Sea (NYS) by a line that connects Changsan-got on the Korean Peninsula and Chengshanjiao on the Shandong Peninsula (Jiang et al., 2014).

The Changjiang and Huanghe Rivers are among the world's largest rivers in terms of water discharge and sediment load. The Huanghe and Changjiang river basins cover 75 × 10^4 km^2 and 180 × 10^4 km^2, respectively, and together transport approximately 1600 Mt/yr of sediment to the coastal seas (Milliman and Meade, 1983). A large proportion of this sediment is deposited at their river mouths and adjacent continental shelf (Liu et al., 2007a). The drainage basins and sediment discharge of the Korean rivers (e.g., the Yeongsan and Han rivers) are only 4 × 10^4 km^2 and 3–23.4 Mt/yr, respectively (Lim et al., 2007; Xu et al., 2009). Moreover, Korean river sediments accumulate primarily on the Korean coast (Jung et al., 2016).

Longshore currents, i.e., the Yellow Sea Coastal Current (YSCC) and the North Jiangsu Coastal Current (NJCC), flow southward along the western SYS. The East China Sea Coastal Current (ECSCC) flows