Continental Shelf Research 130 (2016) 68–78

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Modern muddy deposit along the Zhejiang coast in the East China Sea: Response to large-scale human projects

Gang Xu[a,b,c], Jian Liu[a,b,c,*], Shengfa Liu[b,d], Zhongbo Wang[a,b,c], Gang Hu[a,c], Xianghuai Kong[a,c]

[a] Key Laboratory of Marine Hydrocarbon Resources and Environmental Geology, Ministry of Land and Resources, Qingdao Institute of Marine Geology, Qingdao 266071, China
[b] Laboratory for Marine Geology, Qingdao National Laboratory for Marine Science and Technology, Qingdao 266061, China
[c] Key Laboratory of Coastal Wetland Biogeosciences, China Geological Survey, Qingdao 266071, China
[d] Key Laboratory of Marine Sedimentology and Environmental Geology, First Institute of Oceanography, SOA, Qingdao 266061, China

ARTICLE INFO

Keywords:
Source
Transport
Clay minerals
Grain size
Large-scale human project
Zhejiang coastal muddy deposit

ABSTRACT

Grain size and clay minerals in the surface sediment off Zhejiang Province, China, of the East China Sea were analyzed to study changes in grain size, muddy deposit boundary, and major riverine and other derived matters transport paths in the Zhejiang coastal muddy deposit since the impoundment of the Three Gorges Dam and after other large-scale human projects. The results show that the sediment types are mainly silt and mud in the muddy deposit, divided based on the 10% isoline of the sand-sized component. The sources of sediment in the muddy deposit are mainly the Yangtze River and simultaneously supplies from the Qiantang Jiang, Ou Jiang, relict fine-grain matter, and hydrolyzed volcanic rocks around the Zhoushan Islands. The transport and dispersal of sediments in the study area are largely controlled by the Zhejiang–Fujian coastal current and the Taiwan Warm Current and appear seasonally. The contributions from the Ou Jiang, relict matter, local hydrolyzed matter, and the Qiantang Jiang are enlarged owing to the decline of Yangtze suspended matter and the constructions of major human projects in the Hangzhou Bay, respectively. In addition, the sediment grain size exhibits a fining trend because of the influence of the Three Gorges Dam. The boundary of the muddy deposit is relatively stable after the Three Gorges Dam impoundment north of the city of Zhoushan. In contrast, south of the city of Zhoushan the boundary of the muddy deposit lies toward the east because the sediment supply from the relict fine-grained matters resuspended by the Taiwan Warm Current east of the study area. The changes in the grain size and contributions from smaller rivers and other derived matter as well as the boundary of the muddy deposit there will probably become more pronounced in the future.

1. Introduction and geological background

The East China Sea (ECS), which is located on a wide and flat shelf, is a typical open marginal sea (Miao et al., 2016). Based on sediment grain size together with the overlying water masses, the East China Sea can be divided into three domains: the inner shelf mud area (Fig. 1), the outer shelf sand area, and the slope plus Okinawa Trough mud area (Qin et al., 1987; Su and Huh, 2002).

The East China Sea currents and the East Asian monsoon are the dominant physical drivers of the formation, distribution, and sedimentary processes of the mud belt. The Yangtze-derived sediments are transported onto the shelf mainly by across-shelf dispersion and along-shelf advection (Liu et al., 2006). During summer, the Yangtze River discharges large amounts of water and sediments, with 32% of the riverine sediment load estimated to be deposited at the river mouth sites during this time (Shen, 2001; Xu et al., 2015). During winter, intensified East Asian Monsoon activities and wave action resuspend the deposits of river-derived sediment in the mud area (Liu et al., 2006, 2007; Zheng et al., 2010; Xu et al., 2012). The winter monsoon also drives the Taiwan Warm Current (TWC) to form upwelling circulation offshore, with the Zhejiang–Fujian Coast Current (ZFCC) causing downwelling in the near-shore region. Upwelling and downwelling circulation constrains the distribution of fine-grained sediments within the inner shelf (< 75 m isobath) and formed the “inner shelf mud area of the East China Sea” (Qin, 1987; Gu et al., 1997; Hu and Yang, 2001; Liu et al., 2006, 2007). In addition, the circulation prevents sediments from escaping to deeper waters in the East China Sea (Xu et al., 2013), which means that the fine-grain sediments do not cover the relict sand

* Corresponding author at: Key Laboratory of Marine Hydrocarbon Resources and Environmental Geology, Ministry of Land and Resources, Qingdao Institute of Marine Geology, Qingdao 266071, China.
E-mail address: liujian0550@vip.sina.com (J. Liu).

http://dx.doi.org/10.1016/j.csr.2016.10.007
Received 27 May 2016; Received in revised form 11 October 2016; Accepted 23 October 2016
Available online 25 October 2016

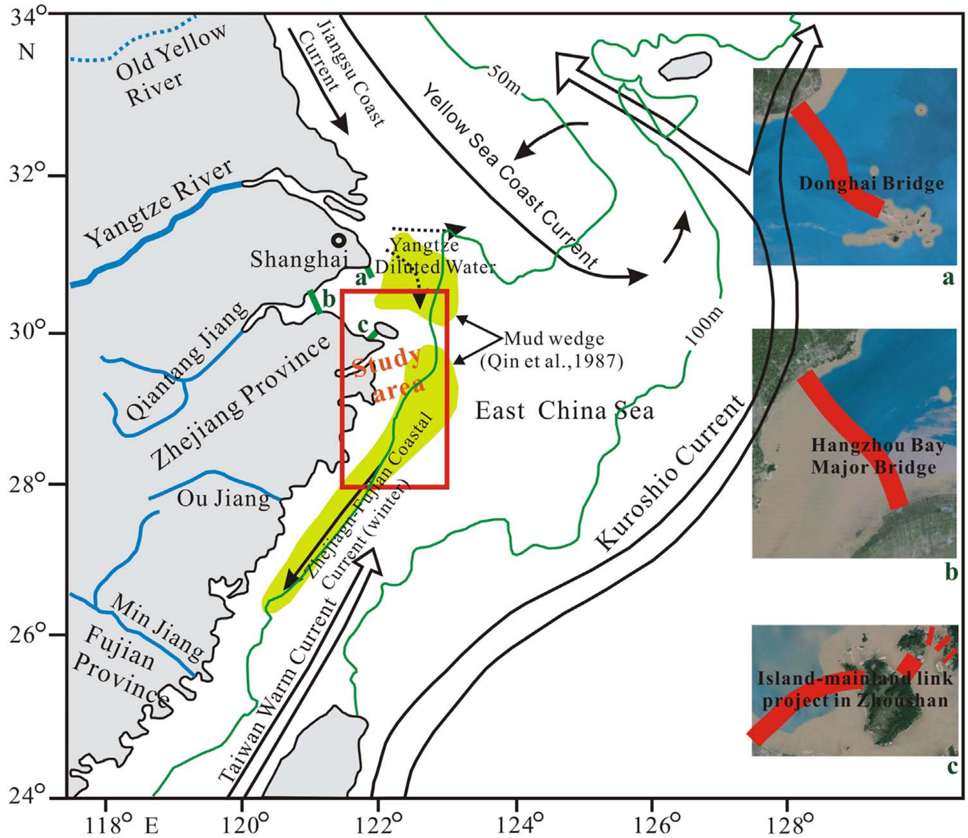

Fig. 1. Location of the study area and mud wedge, regional circulation pattern in the East China Sea, and large-scale human projects around the Zhoushan Islands (modified after Zheng et al., 2010).

located on the middle and outer shelves (Liu et al., 2007; Xu et al., 2009). Radiocarbon dates of shells from the sandy cores located on the outer shelf indicate that the sandy sediments formed after 11 ka BP (Saito et al., 1998). High-resolution seismic profiling has shown that there is a noticeable boundary between the western mud deposit and the eastern relict sand (Liu et al., 2007; Xu et al., 2009). In addition, there are also some reports on the mud boundary of the East China Sea based on sediment mean grain size (Qin et al., 1987; Shi et al., 2010; Luo et al., 2012; Xu et al., 2012). However, because of the scarce number of stations used in the previous studies, it was very difficult to delineate the boundary of the inner shelf mud area of the East China Sea in detail.

The Yangtze River originates from the Qinghai Tibetan Plateau at an elevation of 6600 m and flows eastward for >6300 km. It drains an area of $>1.94\times10^6$ km^2 before finally discharging into the East China Sea. It is the largest river in Asia in terms of water discharge and the third longest river in the world (Milliman and Meade, 1983). Nearly 50,000 dams have been constructed within the Yangtze River basin, of which more than 140 have a reservoir storage capacity of $>10^8$ m^3. Since the construction of the Three Gorges Dam (TGD), the worlds largest hydropower project ever built (Lu and Higgitt, 2001; Nilsson et al., 2005), significant erosion has been observed downstream of the dam in the middle Yangtze River and at the delta front (Yang et al., 2011). In the Yangtze subaqueous delta front, the modern riverine muddy deposits are replaced seaward by older relict sands. The mud margin was found to have retreated landward significantly over the post Three Gorges Dam period owing to erosion driven by the significant decrease in sediment supply from the Yangtze River (Luo et al., 2012). However, relatively little is known about the temporal boundary variation of the Zhejiang coastal mud area after the Three Gorges Dam was constructed. More importantly, it is unclear whether surface sediment coarsening or fining has occurred in the mud area. Knowledge of sediment grain size is of importance in geomorphology, ecology, and engineering, and for the understanding of hydrodynamics, climatic and tectonic changes, and anthropogenic impacts (Luo et al., 2012).

With regard to the source of the mud area, previous reports indicate that nearly all of the sediments on the inner shelf and in particular the mud tongue originate from the upstream regions of the Yangtze River and that small coastal rivers may have local or even regional importance (Qin et al., 1987; Hori et al., 2001; Liu et al., 2007). However, relatively little is known about the source variation of the Zhejiang coastal mud area in response to the many major human engineering projects (e.g., the Three Gorges Dam, the Major Bridge, and some port construction) conducted in the river and along the coast (Fig. 1).

In the present study, we aim to examine the Zhejiang coastal mud area changes in grain size, boundary of the muddy deposit, and the major riverine and other derived matters transport paths in the inner shelf of the East China Sea over the post Three Gorges Dam period and after other large-scale human projects. Our objectives are (1) to investigate whether any changes in grain size and the boundary of the Zhejiang coastal mud area can be observed; (2) to determine whether the source of the Zhejiang coastal muddy deposit has changed; and thus (3) to demonstrate the response of the modern deposits of Zhejiang coastal mud area to the Three Gorges Dam and other human projects.

2. Materials and methods

2.1. Sampling

In this study, 595 surface sediment samples were collected in the summer of 2013 in the East China Sea (Fig. 2). The surface sediment samples here correspond to the top 2 cm of the center of the sampling