Continental Shelf Research 140 (2017) 84–95

Contents lists available at ScienceDirect

Continental Shelf Research

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

Magnetic properties indicate sediment provenance and distribution patterns in the Bohai and Yellow Seas, China

Yonghong Wang[a,*], Shuang Wang[b], Meng Liu[a]

[a] Key Lab of Submarine Geosciences and Prospecting Techniques, MOE and College of Marine Geosciences, Ocean University of China, Qingdao 266100, PR China

[b] Key Laboratory of Marine Hydrocarbon Resources and Environment Geology, Qingdao Institute of Marine Geology, Ministry of Land and Resources, Qingdao 266071, PR China

ARTICLE INFO

Keywords:
Sediment sources
Distribution pattern
Transport
Controlling factors
Magnetic properties
The Bohai and Yellow Seas

ABSTRACT

The sources, transport pathways and main distribution limitations of surface sediments were clearly identified in the Bohai Sea (BS) and Yellow Sea (YS) by combining the particle size and magnetic property distribution characteristics. The sediment distribution pattern on shelves is mainly controlled by the sediment sources, which include Huanghe-derived sediments, coastally eroded sediments, old Huanghe and old Changjiang subaqueous delta sediments, and mixed sediments transported by the Yellow Sea Warm Current (YSWC). The distribution pattern of silt reflects the transport pathway and limitation of the Huanghe- and old Huanghe-derived sediments, and the sand distribution reflects the final distribution of the coastally eroded sediments, including the eroded old Changjiang subaqueous delta sediments. In addition to the sediment sources, the complex hydrodynamic pattern on the shelves has an important influence on sediment distribution and transport. The sediment particle size and topography of shelves exert limited control over the sediment distribution. Surface sediment sources in the central South YS (SYS) were identified, with the most important contribution being from mixed sediment sources and a convergence area of finer sediment located at approximately 123°E, 36°N.

1. Introduction

Sediment sources and transport on shelves always play important roles in global change and land-sea interaction research because they contain rich information on the terrestrial sediment supply, coastal morphodynamics, and marine hydrodynamics. In addition, these processes bring a large amount of nutrients and pollutants to the coasts and influence the circulation and transport of substances and the ecological environment (Lesueur and Tastet, 1994; Lesueur et al., 1996). Sedimentation on the shelves of the Bohai Sea (BS) and Yellow Sea (YS) in China provides a typical example for studying sediment sources and transport because two large rivers, the Huanghe (Yellow River) and the Changjiang (Yangtze River), bring approximately 10% of the global fluvial suspended sediment discharge into the broad shelves (Milliman and Meade, 1983). These two large rivers are thought to be the main sediment sources that contribute to the shelf deposits. The fine sediments from these two rivers and other sources are dispersed and mixed on the shelves through complex hydrodynamic processes (Dong et al., 2011). These sediments form patches of mud deposits in this area and are becoming important components in sedimentation models (Milliman et al., 1985; Gao et al., 2000). The sources of mud deposits in the central South Yellow Sea (SYS) are debated despite several studies that have been conducted in this area (Ren and Shi, 1986; Milliman et al., 1985; Qin et al., 1989; Alexander et al., 1991; Park et al., 2000; Yang et al., 2003; Yang and Liu, 2007; Wang et al., 2009). Therefore, the provenance areas and the sedimentary processes of terrigenous sediments on shelves surrounding China have been a major focus of marine geological studies in Asia (Liu et al., 2003; Yang et al., 2003; Lim et al., 2007; Xu et al., 2012; Kim et al., 2013; Um et al., 2013). In recent decades, advancements have been made in our understanding of geological historical evolution; sea level changes from the Holocene to the Pleistocene, based on core sampling (Lee and Chough, 1989; Kim and Kennett, 1998; Jin and Chough, 1998; Park et al., 2000; Li et al., 2000, 2014a, 2014b; Liu et al., 2002, 2004, 2009a, 2009b; Yang et al., 2003; Lim et al., 2006; Wang et al., 2007, 2014; Yang and Liu, 2007; Yang and Youn, 2007; Jiang et al., 2009; Dong et al., 2011; Lu et al., 2011); and hydrodynamics and sedimentation, based on mathematical modeling (Zhu and Chang, 2000; Yuan et al., 2008; Zhou et al., 2015; Lim et al., 2015; Zeng et al., 2015; Pang et al., 2016) and field observation (Li et al., 2016a, 2016b).

* Corresponding author.
E-mail address: yonghongw@ouc.edu.cn (Y. Wang).

http://dx.doi.org/10.1016/j.csr.2017.04.012
Received 15 April 2016; Received in revised form 28 April 2017; Accepted 29 April 2017
Available online 02 May 2017

However, (1) how the finer sediments from these two large rivers distribute after they are transported to the shelves and (2) what the sediment transport pathways and sediment contribution patterns from different sources are in the BS and YS remain unclear. (3) Multiple sources have been recognized for the mud deposits of the central SYS (Wang et al., 2009), but the distribution of the different sources is unclear.

These lingering issues have caused confusion in the understanding of the sedimentary environment and substance exchanges. For example, researchers have calculated the inputs from the Huanghe and Changjiang to balance the sediment supply on the shelves of the BS and the YS (Lee and Chough, 1989; Yang and Liu, 2007; Wang et al., 2014), but still found a gap in the balance between the two inputs and supply. Although the sediments of the mud deposit in the SYS are considered to originate from multiple sources based on mineralogy and geochemistry (Ren and Shi, 1986; Milliman et al., 1985; Qin et al., 1989; Alexander et al., 1991; Park et al., 2000; Yang et al., 2003; Yang and Liu, 2007; Yang and Youn, 2007; Wang et al., 2009), the contributions of different sources are unclear.

In recent years, ample surface sediments have been collected due to an increase of geological surveys in this area. Thus, work has focused on sediment sources and transport based on the sedimentary features of these surface samples, providing valuable indexes of the contributions from different sediment sources (Liu et al., 2003; Ge et al., 2003; Hu et al., 2009, 2016; Wang et al., 2009; Kim et al., 2013; Lin et al., 2014). However, these studies were limited to relatively small patches of the BS and YS, for example, around Cheju Island (Kim et al., 2013), near the East China Sea (Liu et al., 2003), and in the BS (Wang et al., 2015), and they are unable to provide a comprehensive view of the complex sediment distribution pattern and transport for the whole study area.

This study will address the above three questions through analysis of the particle sizes and magnetic properties of surface sediments in large areas of the BS and YS. Analysis of the magnetic properties, especially magnetic susceptibility, of surface sediments has been widely applied to trace the sediment source distribution in various depositional environments (Watkins and Maher, 2003; Liu et al., 2003; Ge et al., 2003; Kim et al., 2013). These analyses will provide a valuable method and an important opportunity to identify and understand the sediment distribution patterns, sources and transport in the BS and YS.

2. Geographical setting

The study area includes the BS, the North YS (NYS) and the SYS. The BS is a nearly closed inner sea with an area of 7.7×10^4 km^2 and an average depth of 18 m. Mud deposit I, which is located in the southwestern BS (Fig. 1, area I), has a sedimentation rate of 1.5–7.1 mm a^{-1} (Li and Shi, 1995). The NYS is separated from the BS to the west by the Bohai Strait and from the SYS to the south by the eastern tip of the Shandong Peninsula and the western tip of the Korean Peninsula, with a water depth of generally less than 70 m. The deposition rates in mud deposit II off the Shandong Peninsula in the NYS are 1–2 mm a^{-1} (Jiang et al., 2003). This mud deposit formed 8.2–8.4 cal kyr BP (Liu et al., 2007), is > 40 m thick near the Shandong Peninsula and thins offshore (Liu et al., 2002). The southwestern Cheju Island Mud (CIM) is the only Holocene depocenter far from the coast or a sediment source, and its accumulation rate is up to 5 mm a^{-1} (Lim et al., 2007).

The SYS covers an area of approximately 400,000 km^2 with a maximum water depth of 100 m and an average water depth of 55 m (Qin et al., 1989). The seafloor deepens progressively southeastward with asymmetrical isobaths and forms a SE-NW shallow trough (called the Yellow Sea Trough) in its southern direction (Qin et al., 1989). The western parts of the SYS are surrounded by a rock-embayed coast in the north and an extensive mudflat coast in the southwest (Qin et al., 1989). Most shelves in the YS were exposed as land during the last glacial period and then covered by seawater during the post-glacial period. Mud deposit III (Fig. 1) in the central SYS, where water depths locally exceed 70 m, is approximately 6.1×10^5 km^2 in area (Li et al., 2005) and has a sedimentation rate < 1 mm a^{-1} (Lim et al., 2007).

The BS and YS are characterized by complex hydrodynamic conditions (Fig. 1B). In the BS, the tide regime is complex and dominated by irregular semidiurnal tides with a tidal range of < 1.5 m. The isobath-parallel tidal current, with a velocity of < 1.0 m s^{-1}, flows southward during flood tides and northward during ebb tides and plays a critical role in transporting suspended sediments along the coast (Zang, 1996). Waves are closely associated with prevailing winds in the study area. In summer, southward winds prevail, but northward winds are dominant in winter. Winds with a maximum velocity of > 11 m s^{-1} come primarily from the northwest and northeast in the winter season (Zang, 1996).

Tides are typically semi-diurnal (M_2) in the YS, ranging from 1.5 to 8 m (Chough et al., 2000), and the rates of tidal currents vary from slower than 40 cm s^{-1} in the central parts of the NYS and SYS to faster than 100 cm s^{-1} in the southwestern and northeastern YS (Dong et al., 1989; Qin et al., 1989). Apart from tidal effects, there is a northward inflow of the YSWC along the eastern margin and a southward inflow of the Jiangsu Coastal Current (JSCC) or the YS Coastal Current (YSCC) along the west coast (Fig. 2, Beardsley et al., 1985; Hu and Li, 1993). In the eastern region, there is a southward inflow of the Korean Coastal Current (KCC). The other main hydrodynamic factors include the South Shandong Coastal Current (SSCC), the Kuroshio Current (KC) and the Taiwan Warm Current (TWC) (Fig. 1). The warm and salty KC flows northward along the shelf break of the East China Sea and notably influences the distribution of water masses and sedimentation.

YS Cold Water (YSCW) is observed in the deeper locations during summer (Hu and Li, 1993; Naimie et al., 2001). It has been suggested that downwelling exists in the upper layer and upwelling in the lower layer of the YSCW (Hu and Li, 1993). The Changjiang discharge predominantly flows southeastward along the Chinese coast during winter, whereas, during summer, the Changjiang Diluted Freshwater (CDFW) extends as a low salinity plume to the northeast in the direction of Cheju Island (Fig. 1, Beardsley et al., 1985).

3. Materials and methods

3.1. Sample collection and particle size analysis

One hundred and thirty surface sediment samples were collected from the uppermost 0–10 cm from the study area using a box core deployed from the R/V Dong Fang Hong 2 of the Ocean University of China in 2012 (Fig. 1A, black dots). Samples were obtained from the cores using a stainless steel spoon and then stored at 4 °C in vessels in the laboratory until particle size and magnetic analyses.

The particle sizes of the 130 bulk samples were measured using a laser particle-size analyzer (Coulter LS-100Q) at the Institute of Marine Geology, Ministry of Land and Mineral Resource, China. Samples of 2–3 g were transferred into 50 ml beakers, to which distilled water and 5 ml of H_2O_2 (30%) were then added. The beakers were left for one night to remove organic matter. After ultrasonic dispersion, the samples were placed into the analyzer in turn to measure the particle size of each sample. Particle size analyzers categorize grains in the 0.1–2000 μm range. The contour figures of magnetic susceptibility and grain size were created with Surfer software.

3.2. Magnetic measurements

The magnetic properties of 160 surface sediment samples, including the 130 bulk samples from the fieldwork and 30 from published references, were measured and collected. The samples were measured at the Institute of Marine Geology, Ministry of Land and Mineral Resource, China. These bulk samples were dried at 40 °C and then dispersed gently with an agate mortar. The samples were packed into