Continental Shelf Research 29 (2009) 846–855

Contents lists available at ScienceDirect

Continental Shelf Research

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

Geochemical characteristics of sediment as indicators of post-glacial environmental changes off the Shandong Peninsula in the Yellow Sea

Jian Liu [a,b,*], Yoshiki Saito [c], Xianghuai Kong [b], Hong Wang [b], Ling Zhao [d]

[a] Key Laboratory of Marine Hydrocarbon Resources and Environmental Geology, Ministry of Land and Resources, PR China
[b] Qingdao Institute of Marine Geology, Qingdao 266071, PR China
[c] Geological Survey of Japan, AIST, Central 7, Higashi 1-1-1, Tsukuba, Ibaraki 305-8567, Japan
[d] Nanjing Institute of Geology and Mineral Resources, Nanjing 210016, PR China

A R T I C L E I N F O

Article history:
Received 30 June 2008
Received in revised form
12 December 2008
Accepted 7 January 2009
Available online 21 January 2009

Keywords:
Element geochemistry
Provenance
Oceanic circulation
Shandong Peninsula
Yellow Sea

A B S T R A C T

Core NYS-101, which was recovered at a water depth of 49 m northeast of the Shandong Peninsula in the North Yellow Sea, penetrates the Holocene subaqueous clinoform that wraps around the Shandong Peninsula. The uppermost 18 m of this well-dated core was deposited after about 13 cal kyr BP during the post-glacial transgression. We focused on trace and rare earth element (REE) chemistries of the core sediments in the uppermost 18 m to investigate the sediment provenance and factors controlling the sediment composition. On the basis of down-core distributions of REE fractionation parameters and of ratios among REEs and other immobile elements, we divided the uppermost 18 m into three distinct compositional intervals: Interval 1 (above 6.08 m, from the time tens of years earlier than 6500 cal yr BP up to the present), Interval 2 (13.90–6.08 m, from about 8200 cal yr BP to the boundary between Intervals 1 and 2), and Interval 3 (below 13.90 m, from about 13,000 to 10,400 cal yr BP). The chondrite- and upper continental crust (UCC)-normalized REE fractionation patterns of Intervals 3 and 2 are similar to those of Yellow River sediments, but the patterns in Interval 1 are obviously different.

Results of a geochemical discrimination analysis suggest that the sediments of Interval 2 were transported mainly from the Yellow River by the strong coastal current along the Shandong Peninsula, whereas those of Interval 1 were derived in part from rivers of the Korean Peninsula and the Yangtze River as well as from Yellow River sediments. The sediments of Interval 3 were largely derived from the Yellow River, but local rivers of the Shandong Peninsula contributed minor sediments to the interval, which was deposited in salt-marsh, coastal plain, and subtidal nearshore environments during the early post-glacial transgression. We attribute the change in sediment composition between Intervals 1 and 2 to a dramatic mid-Holocene adjustment of oceanic circulation in the Yellow Sea and adjacent areas, when sediments primarily from the rivers of the Korean Peninsula and the Yangtze River began to be transported to the coasts of the Shandong Peninsula.

1. Introduction

Since the 1980s, a prominent subaqueous clinoform that wraps around the eastern tip of the Shandong Peninsula in the western Yellow Sea (Fig. 1) has attracted great attention concerning its provenance, formation age, and evolution (Milliman et al., 1987, 1989; Alexander et al., 1991; Cheng et al., 2001; Liu et al., 2004). Recent work (Liu et al., 2007) based on high-resolution seismic profiles and borehole data has indicated that the clinoform formed since the beginning of Holocene in response to the stepwise, post-glacial sea-level rise for the asian sea areas (Liu et al., 2004), and the sediment sources have been preliminarily ascertained from the mineral components of the cores (Liu et al., 2007). In addition, surface sediments and short gravity cores in the area have been geochemically tested to determine sedimentation rates (Qi et al., 2004) and heavy-metal contents (Li et al., 1994), and sedimentation rates were also estimated by Alexander et al. (1991) and Liu et al. (2004). Despite these previous studies, no geochemical analyses of cores penetrating the clinoform have been performed to reveal the geochemical fingerprint of the sedimentary processes responsible for the clinoform in relation to environmental changes of the post-glacial transgression.

Geochemical studies of sedimentary sequences have been widely used in paleoenvironmental reconstruction and provenance discrimination (e.g., Thomas and Varekamp, 1991; Yang et al., 2004; Cundy et al., 2006; Turney et al., 2006; Tanaka et al., 2007). Since detrital materials have distinct chemical

* Corresponding author at: Key Laboratory of Marine Hydrocarbon Resources and Environmental Geology, Ministry of Land and Resources, PR China.
Tel.: +86 532 85755832; fax: +86 532 85720553.
E-mail address: liujian0550@vip.sina.com (J. Liu).

0278-4343/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.csr.2009.01.002

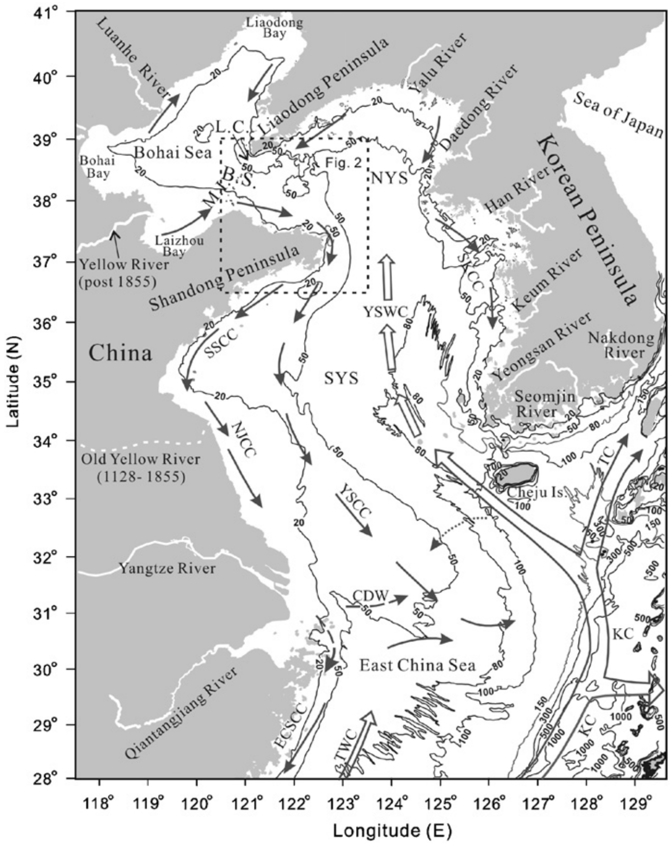

Fig. 1. Bathymetry and water circulation patterns in the Bohai Sea, Yellow Sea, and adjacent areas during winter (modified after Su, 1986; Guan, 1983). The dotted rectangle denotes the area covered by Fig. 2a. Water depths in meters. SYS, South Yellow Sea; NYS, North Yellow Sea; B.S., Bohai Strait; M.I., Miaodao Islands; L.C., Laotieshan Channel. KC, Kuroshio Current; YSWC, Yellow Sea Warm Current; TC, Tsushima Current; TWC, Taiwan Warm Current; YSCC, Yellow Sea Coastal Current; SKCC, South Korean Coastal Current; SSCC, South Shandong Coastal Current; NJCC, North Jiangsu Coastal Current; CDW, Changjiang Diluted Water; and ECSCC, East China Sea Coastal Current.

compositions reflecting their provenance, geochemical responses to paleoenvironmental changes should be registered in the detrital component of sediments, and these responses can be detected by geochemical methods. To gather more information on the environmental changes associated with the deposition of the clinoform, we performed geochemical analyses on one core through the clinoform to elucidate provenance changes caused by environmental changes during deposition. We focused on rare earth elements (REEs) and other immobile elements in the core because of their relatively conservative behavior during sedimentation (McLennan, 1989; Rollinson, 1993), and their wide application in provenance discrimination studies (e.g., Lee et al., 2005; Yang et al., 2004).

2. Geological background

2.1. Regional setting

The Yellow Sea is a typical, semi-enclosed, relatively shallow, western Pacific marginal sea above a flat, broad, tectonically stable shelf between the Chinese mainland and the Korean Peninsula (Fig. 1). It is separated from the Bohai Sea to the west by the Bohai Strait, and from the East China Sea to the south by a line connecting the north edge of the Yangtze River mouth with Cheju Island. The Shandong Peninsula separates the South Yellow Sea (SYS) from the North Yellow Sea (NYS). Water depths in the NYS are generally less than 60 m, and they deepen progressively southward and southeastward in the South Yellow Sea, where a SE–NW-oriented trough (the Yellow Sea Trough) with a maximum water depth of 100 m is defined by the 80 m isobath (Fig. 1, Qin et al., 1989). The water depth in the Bohai Sea is mostly less than 30 m (18 m on average). The Bohai Strait, which connects the Bohai Sea and the NYS, contains more than 20 small islands. There are six major channels between the islands; the largest of these is the Laotieshan Channel in the northern part of the strait, which is about 41 km wide and up to 86 m deep. Most of the other channels are 20–45 m deep (Geng et al., 1983).

Silty and clayey sediments are present mainly in the western and central parts of the NYS and SYS, whereas the sea floor of the eastern part, where there is a large-scale tidal system (Liu et al., 1998) with strong tidal currents, is covered by sandy deposits. Most of the Bohai Sea is floored by muddy sediments, and sandy sediments are distributed mainly in the southern part of Liaodong Bay and in the Bohai Strait (see Fig. 1 for location).

The circulation patterns in the Bohai and Yellow Seas are dominated by the Yellow Sea Warm Current (YSWC) and coastal currents along the western and eastern coasts of the region. The YSWC is a branch of the Tsushima Current that flows northwestward into the SYS and carries warm, salty water into the Yellow Sea, roughly following the Yellow Sea Trough (Fig. 1). In general, coastal currents (which have relatively low salinities because of river inflow) along the Chinese and Korean coasts flow southward in winter and northward in summer, reflecting the prevailing wind direction, but the coastal currents along the southern coast of the Bohai Sea and the western coast of the Yellow Sea (including the Yellow Sea Coastal Current (YSCC), Fig. 1) flow persistently southward, probably owing to the oceanic circulation in the Bohai, Yellow and East China Seas (Wang et al., 2001). In winter, when the shelf water column is nearly homogeneous, the YSWC sometimes intrudes into the NYS (Lan et al., 1986) and even into the Bohai Sea (Hu and Li, 1993; Guan, 1994). In summer, two cold water masses are present in the central NYS and SYS. The YSWC is too weak to reach north of 35°N in summer because the cold water mass in the SYS intrudes southward, hindering the warm current's flow. The seasonal cold water eddy is considered to be responsible for the muddy deposits in the central NYS and SYS (Hu, 1984).

The Yangtze River, or Changjiang, is the fourth and fifth largest river in the world in terms of mean sediment and water discharge, respectively, with annual water discharge of over 928 km^3 (Zhang et al., 1990) and sediment discharge of 4.68×10^8 tons per year (Huang et al., 2001). The river plume (Changjiang Diluted Water) can extend more than hundreds of kilometers away from the river mouth (Beardsley et al., 1985; Lee and Chao, 2003). The suspended particulate mater (SPM) largely from the YSCC and Yangtze River can move to the open sea southeast of the Yangtze River mouth, and most of the SPM can be transported back to the Yellow Sea by YSWC, as evidenced by satellite remote sensing images (Sun et al., 2000).

The Bohai and Yellow Sea shelves are mostly subject to semi-diurnal tides. During the flood tide, tidal currents in the eastern SYS flow northward, circulating counterclockwise south of the Shandong Peninsula and in the NYS (Ding, 1985). The flood current enters the Bohai Sea along the north side of the Laotieshan Channel, owing to the Coriolis force, inducing counterclockwise tidal circulation in Liaodong and Bohai bays. The ebb current flows out of Bohai Sea through the south channels of Bohai Strait (Qin et al., 1990) and then flows into the Yellow Sea (Lee and Chu, 2001). The tidal range is less than 2 m in the central parts of the Bohai and Yellow seas, 4–6 m in Liaodong and Bohai bays, 3–8 m along the western Korean coast, and 2–6 m along the Chinese