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Tidal current-dominated depositional environments in the central-northern Yellow Sea as revealed by heavy-mineral and grain-size dispersals

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ABSTRACT

This study confirms that the fine sand-sized detritus in the central-northern Yellow Sea is chiefly derived by the Yellow River and explains the Holocene Yellow River dispersal system and the preservation of transgressive deposits by heavy-mineral and grain-size analyses. Micas, which are sensitive to hydraulic sorting, offer an effective key for identifying the dispersal of Holocene Yellow River-derived fine-grained sediments. The heavy-mineral compositional changes are attributed to hydraulic sorting by different marine dynamics and various mixing with additional local transgressive deposits of miscellaneous provenance. The effects of hydraulic sorting are dominated by Holocene tidal currents and by foreshore waves during the rapid transgression, respectively. The former results in obvious enrichments of garnet and common stable species such as Ti oxides, tourmaline, and titanite, whereas the latter seems more remarkable for the compositional changes, with further depletion of epidote, actinolite/tremolite and zoisite/clinozoisite. The central Yellow Sea mud deposit and the alongshore muddy zone off the southern Liaodong Peninsula are opposite to each other as a pair of structurally symmetric coalesced terminal lobes far away from the high-energy strait between Cape Chengshan and Changsan-got. The Haiyang subaqueous clinoform as another terminal lobe is revealed by a heavy-mineral index, which represents an extremity of deposits accumulated by the modern Yellow River-derived sediments off the southwestern Shandong coast. A small mud patch is revealed, roughly corresponding to the central regime of the amphidromic system of principal M_2 constituent. The tidal current-dominated depositional pattern proposed here emphasizes the importance of time–velocity asymmetry of tidal currents. Such a dynamic mechanism is primarily responsible for the dispersal of the modern Yellow River-derived sediments when they are entrained from the Bohai Sea to the South Yellow Sea through the Bohai Strait and the strait between Cape Chengshan and Changsan-got.

1. Introduction

Heavy-mineral analysis is one of the most sensitive and widely-used techniques in the discrimination of sediment provenance, reconstruction of sediment-dispersal patterns, and to assist in understanding sedimentary processes (Dinis and Soares, 2007; Sawakuchi et al., 2009; Sevastjanova et al., 2012; Garzanti et al., 2012, 2013a, 2013b, 2014; Pan et al., 2016). Generally, the compositional information of heavy minerals is imprinted by a series of complex processes from source to sink, mainly including weathering at the source area, abrasion during transport, hydraulic sorting, and post-depositional diagenesis (Morton and Hallsworth, 1999). In most cases, the effects of weathering at source area and during transport are minor, but hydraulic controls at the time of deposition and subsequent diagenesis (intrastratal solution) can cause major modifications (Morton, 1985). Therefore, the information carried by heavy minerals is derived from a composite genesis. Its interpretation is constrained by the understanding of specific geological processes and by assessing the relative role of each factor and potential feedbacks with other factors (Garzanti et al., 2013b).

The eastern China continental shelf is characterized by its high-energy hydrodynamic environments, where wave energy dissipation reaches very high values by bottom friction (Lefèvre et al., 2000). Since the Quaternary it has experienced multiple transgressive–regressive cycles due to shallow water depths. At the present day, both Holocene and transgressive deposits with various reworking by marine dynamics are widely present on the seafloor. Dispersal of terrigenous detritus is driven by tidal currents, coastal currents, alongshore flows, waves fuelled by East Asian monsoon, and winter storms, as well as ocean

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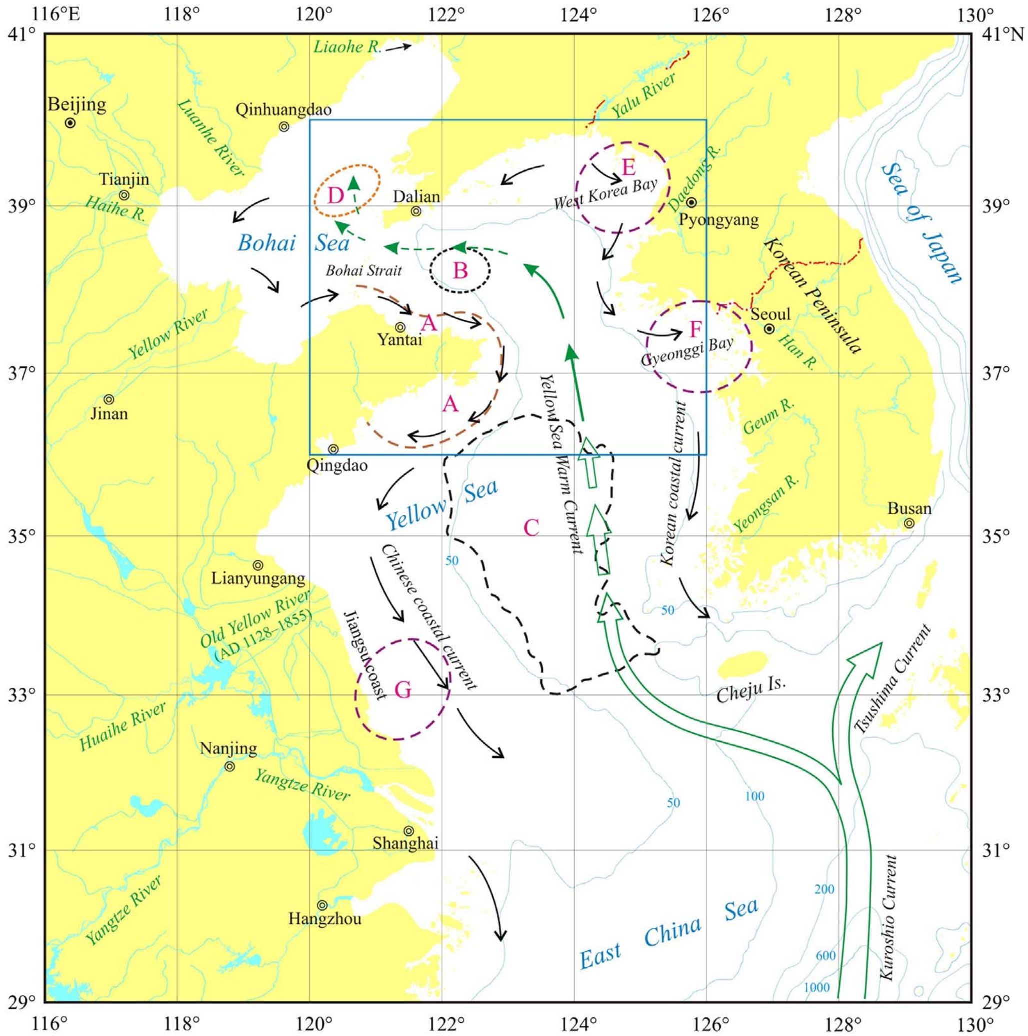

Fig. 1. Schematic map of bathymetry and the regional circulation pattern in the Yellow and Bohai Seas during wintertime, modified after Zheng and Klemas (1982), Beardsley et al. (1985), and Guan (1994). Isobaths are in meters. The study area is outlined by blue lines (for details please see Fig. 2). (A) the Shandong subaqueous clinoform (SSC); (B) the North Yellow Sea mud deposit (NYSM); (C) the central Yellow Sea mud deposit (CYSM) circled by the 25% clay isoline (unpublished data); (D) the eastern Bohai flood-tidal delta; (E) the tidal sand ridges in the West Korea Bay; (F) the tidal sand ridges in the Gyeonggi Bay; (G) the radial tidal sand ridges off the Jiangsu coast. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

currents such as the Kuroshio Current and its branches (the Tsushima Current and the Yellow Sea Warm Current) (Naimie et al., 2001) (Fig. 1).

Hydraulic sorting is of prime importance in marine hydrodynamic regimes, which commonly results in considerable compositional changes not only in heavy-mineral assemblages of the sand-size fraction but also in whole grain-size spectra. The latter involves fine-grained fractions and thus is more sensitive under weak hydraulic conditions. In addition, some of bottom sediments had ever suffered from weathering when they were exposed on the subaerial shelf during late Pleistocene lowstands. Nevertheless, chemical processes were likely to be weak in climates of glacial periods. Former study also demonstrated that mechanical breakdown is unable to markedly affect provenance signatures even during long-distance and prolonged multistep transport in high-energy settings (Garzanti et al., 2012). Therefore, when hydraulic sorting and mechanical weathering are predominant, it is possible and effective using heavy-mineral indices to indicate the relative strength of these effects in terms of the relative stability of heavy minerals.

The principal aims of this article are: a) to illustrate detailed distribution patterns of heavy minerals and their assemblages in the central-northern Yellow Sea; b) to confirm that the Yellow River is the ultimate provenance for all the fine sand-sized detritus by comparison to the heavy-mineral assemblages in the upper-middle reaches of the Yellow River; c) to single out the hydraulic-sorting effects by different marine dynamics based on compositional variations, and to recognize to what extent the mineralogical composition of fine sand-sized sediments is modified in the modern tide-dominated shelf settings; d) to establish a tidal current-dominated dispersal pattern for the Holocene Yellow River-derived sediments when they are entrained through straits by marine dynamics, with specific emphasis on the substantial predominance of time–velocity asymmetry of tidal currents on sediment dispersal. The trends of grain-size distribution and the introduction of heavy-mineral parameters are instructive to distinguish sediment dispersal pathways, and thus to better understand how sediments transport, accumulate, re-disperse, and resuspend in response to marine hydrodynamic environments.

2. Geological and oceanographic settings

The Yellow Sea is an epicontinental shelf semi-enclosed by mainland China and the Korean Peninsula (Fig. 1). It is connected with the Bohai Sea by the Bohai Strait in the northwest and opens to the East China Sea in the south. The North Yellow Sea (NYS) is separated from the South Yellow Sea (SYS) by a line connecting Cape Chengshan (eastern tip of the Shandong Peninsula) and Changsan-got (western tip of the Korean Peninsula). The seafloor is relatively flat with an average water depth of 44 m. It gradually deepens southward. A SE–NW-oriented trough defined by the 60-m isobath lies in the central-eastern SYS (Qin et al., 1989), reaching > 100 m deep in the vicinity of Cheju Island (Chough et al., 2000).

Although dozens of rivers debouch into the Yellow and Bohai Seas, most of them are small to medium except the Yellow River. The Yellow River is notable for its highest suspended sediment load about 1100×10^6 t/yr among large rivers in the world (Milliman and Meade,