Sources and transportation of suspended matter and sediment in the southern Yellow Sea: Evidence from stable carbon isotopes

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Abstract The concentrations of total suspended matter (TSM) and the compositions of organic stable carbon isotopes of TSM and bottom sediments were analyzed to study the sources of TSM and sediments and the transportation processes. For this study, 284 TSM samples and 64 sediment ones taken from 67 stations along 7 transects and in 5 layers were collected in the southern Yellow Sea on the cruise in May, 1998. The main sediment transportation pattern in the southern Yellow Sea was obtained by analyzing the distribution characteristics of TSM concentration and particulate organic carbon $\delta^{13}C$ values. It was confirmed from the pattern that the bottom layer plays a more important role than the surface one in the transportation processes of terrigenous material to the central deep-water area of the southern Yellow Sea. The Yellow Sea circulation is an important control factor in determining the sediment transportation pattern in the southern Yellow Sea. The carbon isotope signals of sedimentary organic matter confirmed that the main material in sediments with high sedimentation rate in the Shandong subaqueous delta originated from the modern Yellow River. The terrigenous sediments in the deep-water area of the southern Yellow Sea are mainly from the abandoned Yellow River and the modern Yellow River, and a small portion of them are from the modern Yangtze River. The amount of terrigenous material from Korean Peninsula and its influence range are relatively limited. The conclusions derived from TSM and stable carbon isotopes were further confirmed by another independent material source tracer—PAHs.

Keywords: southern Yellow Sea, TSM, material sources, sediment transportation, carbon isotopes.

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Ambient terrigenous materials, especially those from the Yellow River and the Yangtze River, strongly influenced the Yellow Sea sedimentation. Both rivers had flowed into the southern Yellow Sea historically. Several TSM investigations had been done in this region since 1959[1-6]. In these investigations the layered structure of TSM distribution had been discovered and some of its distribution regularities and seasonal changes had been recognized[2]. However, the spatiotemporal distribution and transportation pattern of the terrigenous material in the Yellow Sea was still little known up to now. In the past, the researchers could only use incombustible components in TSM to represent the terrigenous material[2,4], but this concept was very rough because skeletons of marine silicious organisms could mix up in it and the terrigenous material was not all incombustible. The sea surface reflectance images at visible and near infrared channels obtained from satellite remote sensing had been used to explain the front of the high concentration TSM on the shelf[3]. The advantage of this method is its wider spatial coverage and temporal continuity, and the disadvantage is that such observations are only applicable to the surface layer and the higher TSM concentration. Alexander et al.[8] studied the sedimentation in the continental margin and shelf on scales of 0.1 or 1 ka using $^{210}$Pb and $^{14}$C dating, and reasoned out the diffusion system of the Yellow Sea during Holocene and after the Yellow River entered the Bohai Sea in 1855. The southern Yellow Sea can be divided into six areas based on accumulation rates. It was deduced that the Shandong subaqueous delta was the sedimentation center of sediment from the Yellow River. However, it needs evidence from dynamic processes of modern sediments. Here, the concept “subaqueous delta” means a form in physiognomy rather than an estuarine delta.

It is widely interested that the stable organic carbon isotopes have been used as a natural tracer to determine the material source of organic matter in estuaries and coastal environments[9-11]. Many researchers had determined the relative ratios of marine facies to continental facies in organic matter by studying the compositions of its carbon isotopes[12-20]. Even in deep-sea environments this method can also provide information for the particular dynamics study[21]. $\delta^{15}N$ is regarded as a reliable material source tracer in comparison with the other two tracers: $\delta^{15}N$ and C/N ratios[22]. In general, the suspended organic matter will horizontally flow with the movement of water because of its low deposit velocity, so the dynamic behavior of particulate organic matter (POM) in water column can be deduced from carbon isotope data of suspended organic matter.

In this paper, the authors try to explain the material sources and transportation processes by investigating TSM concentrations and stable isotope compositions of POM and sedimentary organic matter in the southern Yellow Sea. The results were compared with those obtained by using another material source tracer—PAHs.
2 Results and discussion

(i) Horizontal distribution characteristics of TSM concentrations. The amount of surface TSM ranges from 0.66 to 13.30 mg/dm$^3$ with a mean value of $3.08 \pm 3.05$ mg/dm$^3$ ($n = 66$) (Fig. 2(a)), revealing the following five obvious characteristics: (1) there is a tongue-like isopleth of 2.0 mg/dm$^3$ extending to the NEE off the Yangtze estuary, and the TSM content decreased from about 4 mg/dm$^3$ to under 1 mg/dm$^3$, which indicates a main diffusion direction of the Yangtze diluted water. But the TSM content near $123^\circ E$ off the Yangtze estuary (Stations F2 and F3) with a value of $2.07 \pm 2.67$ mg/dm$^3$ is lower than that on its both sides, which may be due to the effect of a branch of the Taiwan Warm Current based on the analyses of the Yellow Sea and the East China Sea current system (Fig. 3)[24,25]; (2) there are isopleths parallel to the Subei coastline, the TSM content is high in these areas, and its TSM content rapidly decreases from 13 mg/dm$^3$ to less than 2 mg/dm$^3$ with increasing distance from shore and water depth; (3) there are isopleths of 2.0 and 1.5 mg/dm$^3$ parallel to the shoreline southeast of Shandong Peninsula, which is a manifestation of material coming from the modern Yellow River; (4) the water bloom in spring brings about a cloud-like ununiform TSM distribution in the deep-water area, especially at Station A6 east of Cape Chengshan and at Station C10 with a high TSM content of more than 10 mg/dm$^3$; and (5) there is a lower TSM content tongue-like isopleth of 1.5 mg/dm$^3$ extending to the NNW in the southeast corner of the survey area, which may be related to the influence of the Yellow Sea Warm Current, a branch of Tsushima Warm Current.

The TSM content in the subsurface layer ranges from 0.86 to 43.53 mg/dm$^3$ with a mean value of $5.11 \pm 8.26$ mg/dm$^3$ ($n = 56$) (Fig. 2(b)), and is higher than that in the surface layer. The reason is that spring is the higher reproducing season of phytoplankton in this region, the subsurface layer has richer nutrient and stronger illumination and the phytoplankton concentration in the subsurface layer is higher than that in the surface layer. The distribution characteristics of the subsurface TSM content are similar to those of the surface one. It also shows a high value area south of the abandoned Yellow River estuary in Subei and its maximum is more than 40 mg/dm$^3$, higher than that in the surface layer. Another high value area appears in the area southeast of Shandong Peninsula. Similar to the surface layer, the lower TSM content also appears in the southeast corner of the survey area, and its extent is larger than that in the surface layer.

The TSM content in the intermediate layer ranges from 1.15 to 205.25 mg/dm$^3$ with a mean value of $11.43 \pm 34.02$ mg/dm$^3$ ($n = 56$) (Fig. 2(c)), and is higher