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Seasonal variation of sedimentation in the Changjiang Estuary mud area

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Abstract: Seasonal distributions of suspended matter and their sedimentary effect on the Changjiang Estuary mud area of the East China Sea were discussed, based on three cruise data of total suspended matter, temperature and salinity collected from the Changjiang Estuary and its adjacent area in summer and winter. The results show that the basic pattern of distributions of suspended matter in the study area is almost the same in winter and in summer. Sediments from Changjiang (Yangtze River) to the sea are chiefly trapped to the west of 123°15'E due to a strong obstruction of the Taiwan Warm Current. This suggests that these sediments are mainly transported and deposited in the inner shelf. The sediment supply, Taiwan Warm Current, and Zhejiang Coastal Current show a strong seasonal variation, which results in a strong seasonal variation of the sedimentary effect on this mud area. This mud area is a "sink" of the Changjiang's sediment discharge to the sea and its sedimentation is stronger in summer and weaker in winter.
Key words: suspended matter; sedimentation; seasonal variation; the Changjiang Estuary
CLC number: P512.31; P343.5

1 Introduction

The continental shelf of the East China Sea (ECS) is one of the widest shelves in the world. There are several mud areas distributing like patches on a background of widespread coarser ambient sediments of silt and sand on the continental shelf of the ECS. The coastal mud area can be divided into two parts, namely, the Changjiang Estuary mud area (CEMA) in the north and Zhejiang coastal mud area in the south. Between these two parts there is a silt area (Figure 1). The CEMA's area is about 1.0×10^{10} m^2 and its sediments are mainly clayey silt (Jin, 1992; Qin and Zheng, 1982; Saito and Yang, 1994). The CEMA's depositional rate is the highest on the ECS shelf due to a large sediment supply from Changjiang (Yangtze River) to the sea. Its highest depositional rate is 5.4 cm/a (DeMaster *et al.*, 1985) and its general depositional rates are 1-3 cm/a (Huh and Su, 1999; Jin, 1992). This mud area is an accumulative center of sediment discharge from Changjiang to the sea (DeMaster *et al.*, 1985; Hu *et al.*, 2001; Jin, 1992; Qin and Zheng, 1982) and is a sink of carbon and its relating materials on the ECS shelf (Guo *et al.*, 1999a). The CEMA has been strongly influenced by human activities, and has become one of the key areas on the study of the Chinese Land-Ocean Interaction in the Coastal Zone (LOICZ). Many researchers have studied the sedimentary processes of the CEMA. These studies indicate that the sediments of the CEMA are from Changjiang's sediment discharge (DeMaster *et al.*, 1985; Guo *et al.*, 2000, 2001; Milliman *et al.*, 1985a; Qin and Zheng, 1982; Saito and Yang, 1994; Yang, 1988) and are transported southeastward towards the ECS shelf due to the Coriolis Force. The CEMA is formed in the sub-aqueous deltaic front of Changjiang because of the effects of sedimentary dynamics, geochemistry and biogeochemistry (Cao and Yan, 1995; DeMaster *et al.*, 1985; Gu *et al.*, 1995; Hu, 1984; Jin, 1992; Lin *et al.*, 1995; Milliman *et al.*, 1985b; Shen *et al*, 1983; Tian, 1991; Xie *et al.*, 1983). However, only few studies have been conducted on the seasonal sedimentary effect of the CEMA. The comparison

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of sedimentary processes between the CEMA and distal mud area located to the southwest of Cheju Island has not been studied. Based on three cruise data of total suspended matter (TSM), temperature and salinity collected from the Changjiang Estuary and its adjacent area in summer and winter and data from references, the seasonal distributions of TSM and their sedimentary effect on the CEMA are discussed in this paper.

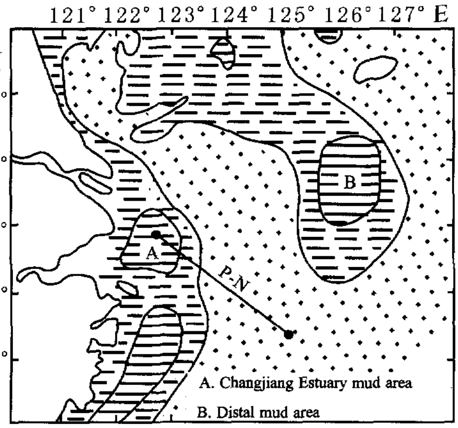


Figure 1 Changjiang Estuary area

2 Method

Total suspended matter (TSM) includes all particles mainly consisting of mineral and rock debris, skeletons and soft parts of organisms, organic and inorganic aggregates in the seawater column. Water samples of TSM at different seawater layers were collected with 2500 ml plastic samplers. Surface seawater was taken by plastic water bucket. Three TSM sampling layers were common for all stations, namely, surface water layer, middle water layer (0.6 total water depth) and bottom water layer (2 m to the seafloor). Usually, 5-8 layer water samples of TSM were collected at one station. Water samples were filtrated by pumping on shipboard through double pre-weighted filters with pores of 0.45 μm in diameter. Filters with suspended matter were washed by distilled water in order to remove salt on the filter, and were dried with low temperature (less than 50°C) in an oven and weighted again to get the weight of TSM. Any reduction of filters due to the above procedure was corrected by the underneath blank one of the double filters. The unit of TSM is mg/L. The data of temperature, salinity and depth was collected from the sensors mounted on the CTD instrument.

3 Results and discussion

3.1 Distributions of TSM, temperature and salinity in summer and winter

3.1.1 Distributions of TSM, temperature and salinity along section P-N in summer and winter

The highest concentration TSM zone is in the mud area located to the west of 122°45'E (Figure 2). This zone corresponds to the coastal water with lower salinity. The Coriolis Force makes a vast of sediments discharging from Changjiang southward transport towards the Changjiang Estuary and Zhejiang coast. Concentrations of TSM decrease sharply from 123°15'E to its easterner shelf. There is obviously a lateral gratitude of TSM at about 123°15'E. The zone fallen in the range from 122°45'E to 123°45'E corresponds to a higher salinity and relative lower temperature seawater. This zone is the Taiwan Warm Current (TWC) water (Su, 1986). The salinity of the bottom layer water in 123°00'E-123°30'E is more than 34.5. There are thermo-cline and halocline in 10-30 m water depth layer. There is a low salinity surface water layer with its depth of 10-20 m along section P-N for the dispersion of the Changjiang Diluted Water (CDW) on the ECS shelf. These results indicate that the CDW can be transported into the east of 123°15'E, but its sediments from the Changjiang discharge almost cannot be dispersed beyond the east of 123°15'E.

The basic distributional pattern of TSM along section P-N in winter is as similar as that in summer (Figure 3). The zone with high concentration TSM (>6 mg/L) is limited to the west of 123°15'E. There obviously exists a lateral gratitude of TSM, temperature and salinity at about 123°15'E. This zone characterized by its lower temperature and salinity is the Zhejiang Coastal Current (ZCC) water. The salinity of the middle and bottom water layers from 123°45'E to 124°30'E is more than 34.5. This zone is the northward Taiwan Warm Current (TWC) water.

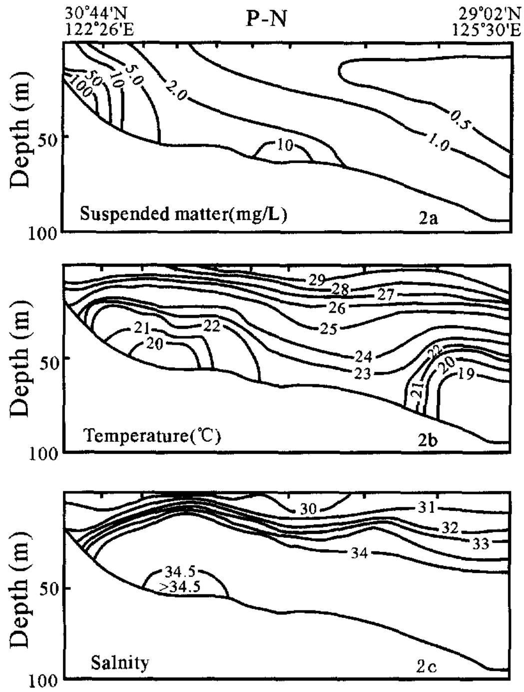


Figure 2 Distributions of concentrations of total suspended matter (mg/L) (a), temperature (°C) (b), salinity (c) along section P-N in the Changjiang Estuary in summer (July, 1998)

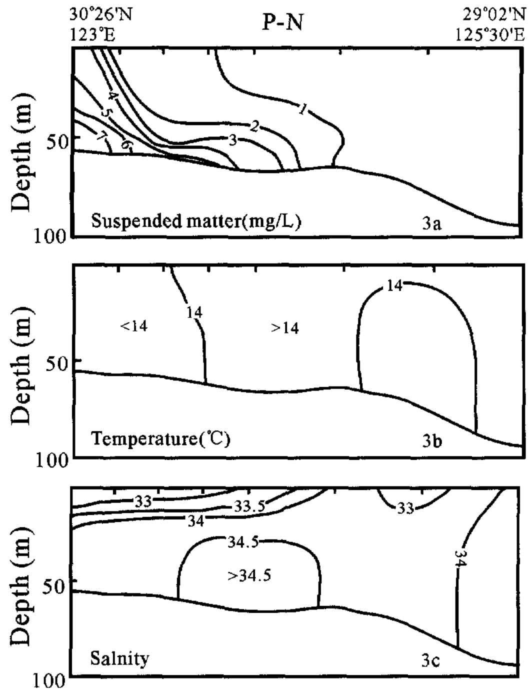


Figure 3 Distributions of concentrations of total suspended matter (mg/L) (a), temperature (°C) (b), salinity (c) along section P-N in the Changjiang Estuary in winter (February, 1997)

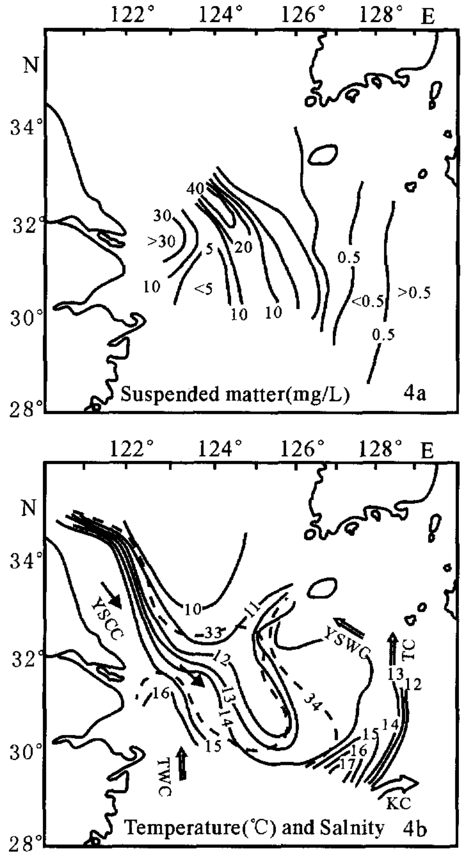
The zone with higher salinity (>34.5) is more westward in summer than that in winter by about one degree latitude, indicating that the intensity of the TWC on the inner shelf in summer is stronger than that in winter, and the influential area of the TWC on the ECS inner shelf is larger than that in winter. This conclusion is in agreement with the references (Su, 2001; Su, 1986).

The distributional pattern of TSM along section P-N indicates that there is a strong obstruction of the TWC to the dispersion of sediments from Changjiang Estuary into the southern and eastern ECS shelf. This effect exists both in winter and in summer, limiting these sediments mainly to the inner shelf.

3.1.2 Horizontal distributions of TSM, temperature and salinity at the bottom water layer in summer and winter Based on the horizontal distributions of TSM at the bottom water layer in the Changjiang Estuary and its adjacent area in summer and winter, the trapping effect of the TWC on the sediments from Changjiang to the sea are further studied.

There are two zones of high TSM concentration to the west of 125°30'E in the northern ECS in early summer, namely, the eastern part and western part (Figure 4). Between these two zones, there is a lower concentration TSM zone (<5 mg/L) at about 124°00'E. The western high concentration TSM zone corresponds to the CDW with lower temperature and salinity. The eastern high concentration TSM zone is in a tongue-shaped distribution southeastward on the northern ECS. This zone corresponds to the Yellow Sea (Huanghai) Coastal Current (YSCC) water with relative lower temperature and salinity. The middle zone with lower concentration TSM corresponds to the TWC water characterized by relative higher temperature and salinity. This pattern is as similar as that at section P-N. This indicates that the dispersion of sediments discharge from Changjiang into the eastern part of the ECS shelf is limited due to the obstruction of the "clean" TWC with its dynamic and temperature-salinity structure (Guo *et al.*, 1999b; Milliman *et al.*, 1985b; Shen *et al.*, 1983; Sun *et al.*, 2000; Xie *et al.*, 1983; Yang *et* *al.*, 1992). The sediment discharge from Changjiang to the sea is trapped in the inner shelf (west of 123°00'E-123°30'E) and sediments are seldom dispersed beyond the east of 124°00'E in summer.

TSM concentrations of the Changjiang Estuary and its adjacent area in winter are obviously higher than that in summer, but TSM concentrations to the west of 122°00'E in summer is higher than that in winter (Figure 5). TSM concentrations (>10 mg/L) in summer are limited to the west of 123°15'E, and TSM concentrations (>50 mg/L) are limited to the west of 122°30'E. There are two zones of high concentration TSM (>50 mg/L) in winter, namely, the western part and eastern part. Between these two zones, there is a zone with lower TSM concentration (<10 mg/L), corresponding to the TWC water. The western high concentration TSM zone is limited to the west of 123°30'E. The eastern high concentration TSM zone is located to the southwest of the Cheju Island, corresponding to the YSCC water. This suggests that the sediments from Changjiang to the sea are mainly distributed to the west of 123°15'E due to the obstruction of the TWC. As showed above, the area of high concentration TSM in winter is higher than that in summer in the Changjiang Estuary and its adjacent area, suggesting that the dispersal area of the sediments from Changjiang to the ECS in winter is larger than that in summer. The limit of dispersal area of suspended sediments from Changjiang in the inner shelf in summer is further westward than that in winter.



YSCC- Yellow Sea Coastal Current
YSWC- Yellow Sea Warm Current
TWC- Taiwan Warm Current
TC- Tsushima Current
KC- Kuroshio Current

Figure 4 Horizontal distributions of concentrations of total suspended matter (mg/L) (a), temperature (℃) and salinity (b) of the bottom water layer in the Changjiang Estuary and its adjacent area in summer (May-June, 1986)

3.2 Seasonal sedimentary effect on the Changjiang Estuary mud area

The above studies indicate that sediments from Changjiang to the sea are almost limited to the inner shelf of the west of 123°15'E because of the obstruction of the TWC, and seldom sediments can be dispersed beyond the east of 124°00'E. The TWC exists yearly (Su, 2001; Su, 1986), and is the controlling factor for the dispersal sedimentary division of the Huanghe-type sediments and Changjiang-type sediments (Guo *et al.*, 2000; Yang, 1988). This means that the transportation and deposition of the main part of sediments from Changjiang to the sea is limited to the inner shelf. The sedimentary process of the CEMA may be influenced by the TWC, ZCC and sediment supply from Changjiang discharge.

The TWC is weaker in winter and stronger in summer (Su, 2001; Su, 1986). The low saline ZCC is mixed by water discharges of Changjiang, Qiantangjiang and their adjacent seawater. The ZCC flows southward due to the prevailing northwest monsoon and the weaker TWC in winter, while the ZCC flows northward due to the stronger TWC and the prevailing southeast monsoon in summer (Su, 2001; Su 1986). This pattern of the ZCC may have a very important effect on the sedimentation in the CEMA. The ZCC can carry a vast amount of sediments from Changjiang Estuary towards the south along the Zhejiang coast when it flows southward. However, the ZCC can obstruct the transportation of sediments from Changjiang

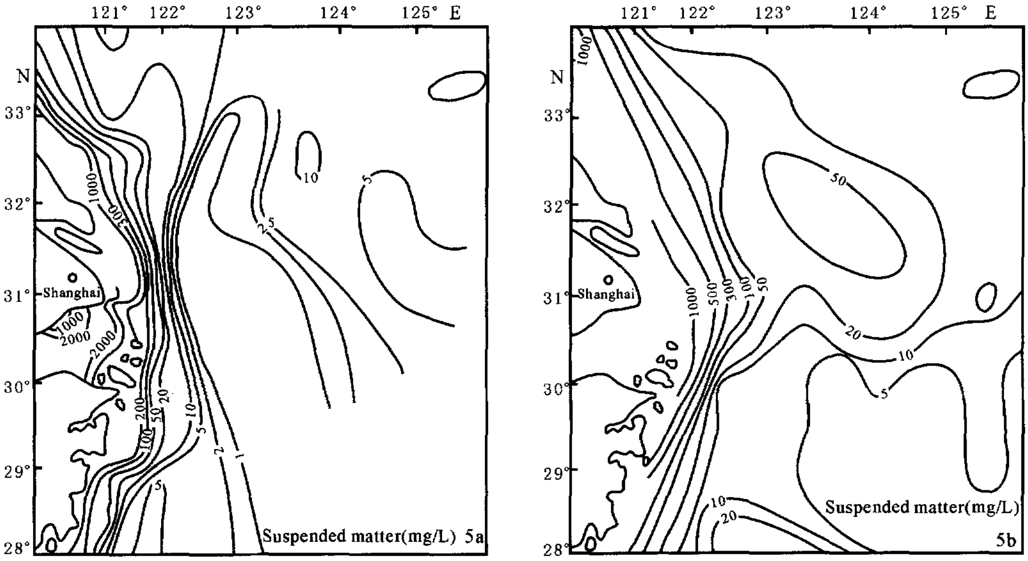


Figure 5 Horizontal distributions of concentrations of total suspended matter (mg/L) of the bottom water layer in the Changjiang Estuary and its adjacent area in summer (August, 1981) (a) and winter (November, 1981) (b) (From Xie *et al.*, 1983)

Estuary into the southern Zhejiang coast when it flows northward. Meanwhile, the discharge of water and sediments from Changjiang to the sea in summer is much more than that in winter because summer is its flood season. The sediment supply of Changjiang to the sea in summer half year (May to October) occupies 78% of the year, being much more than that in winter half year (November to April). The discharge of water and sediments of Changjiang is concentrated on three months, namely, July, August and September. July is in its largest, being 21.9% of one year (Shen *et al.*, 1983). These results suggest that the influential factors on sedimentation in the CEMA including the TWC, ZCC and sediment supply from Changjiang to the sea exhibit a strong seasonal variation.

In summer, the TWC is stronger and the ZCC flows northward. These result in an obstruction of huge suspended sediments from the Changjiang Estuary into the eastern and southern shelf of the ECS. These sediments are trapped and deposited in the CEMA. Therefore, the sediment supply and sedimentary environment in summer are favorable for sedimentation in the CEMA. This makes its sedimentation intensity stronger in summer. Summer is a main season for the accumulation of the CEMA.

In winter, sediments of the CEMA can be resuspended due to the winter storm. This makes the area of high concentration TSM larger than that in summer in the CEMA and its adjacent area. Since the ZCC flows southward and the TWC is weak, sediments in the Changjiang Estuary can be transported into the southeastern part of the ECS, especially some suspended sediments in the CEMA can be moved southward to the Fujian-Zhejiang coast by the ZCC. Consequently, the CEMA becomes a source of the Fujian-Zhejiang coastal mud area. Meanwhile, the sediment supply from Changjiang to the sea decreases sharply in winter. Therefore, the sedimentary environment and sediment supply are unfavorable for sedimentation in the CEMA in winter. Its sedimentation intensity is weaker in winter. The conclusion still cannot be reached whether the CEMA dominates during the period of erosion or during the period of accumulation in winter.

The distal mud area is located to the southwest of Cheju Island (Figure 1). It is indicated that sediments of this mud area are from resuspension of sediments in the sub-aqueous delta of the abandoned Old Huanghe (Yellow River) in northern Jiangsu province during winter storm, and resuspended sediments are moved by the YSCC from the coast in northern Jiangsu into the southwest of Cheju Island (Graber *et al.*, 1989; Guo *et al.*, 1999b; Milliman *et al.*, 1985a; 1989; Qin *et al.*, 1989; Saito and Yang, 1994; Sun *et al.*, 2000; Yang, 1988). Then these sediments are deposited in the distal mud area due to the dynamic of circulation-eddy system and sedimentation of biogenic aggregates (Graber *et al.*, 1989; Hu, 1984; Lei *et al.*, 2001). Guo *et al.* (1999b) indicated that the sedimentation in the distal mud area had a strong seasonal variation, being weaker in summer and stronger in winter. In winter, a large quantity of sediments can be resuspended from the sub-aqueous delta of the Old Huanghe Estuary due to winter storm. The sediments transported by the YSCC into this mud area is large in winter. Since the YSCC is the strongest in winter of a year because of the northwest monsoon, the Yellow Sea Warm Current (YSWC) located in the northeast of the distal mud area becomes the strongest also for compensation of seawater in the semi-enclosed Yellow Sea. The cyclonic eddy closely relating to sedimentation in this mud area is the strongest in winter in a year. Strong eddy in winter may be favorable for its sedimentation (Guo *et al.*, 1999b). Therefore, the sediment supply and dynamic environment is favorable for its sedimentation. However, the frequency of storms is very low in the ECS in summer. The resuspension of sediments in the sub-aqueous delta of the abandoned Old Huanghe Estuary is weaker comparing with that in winter. Sediments brought to the distal mud area from inner shelf by the YSCC are limited. The YSCC recedes to the northwestern part of the shelf, while upwelling water of higher temperature and salinity from the ECS margin intrudes northwestward to the inner shelf due to the prevailing southeast monsoon. Consequently, the center of the eddy moves to the northwestern part of the mud area, and the intensity of the eddy becomes weak. These results suggest that the sediment supply and dynamic environment in summer is unfavorable for its sedimentation. In conclusion, sedimentation processes in the CEMA and distal mud area exhibit a strong seasonal variation, but their patterns are different from each other.

4 Conclusions

It is indicated that sediments from Changjiang to the sea are almost trapped and deposited in the inner shelf of the west of 123°15'E due to a strong obstruction of the TWC. Seldom sediments from Changjiang can be moved eastward beyond the east of 124°00'E. The TWC, ZCC and sediment supply of Changjiang to the sea show a strong seasonal variation. This suggests that sedimentation in the CEMA has a strong seasonal variation. The CEMA is a "sink" of sediments from Changjiang to the sea and its sedimentation is stronger in summer and weaker in winter. Sedimentation processes in the CEMA and distal mud area in the southwest of Cheju Island exhibit a strong seasonal variation, but their processes are different from each other. Sedimentation in the distal mud area is stronger in winter and weaker in summer.

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