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Sedimentary processes on an estuarine marsh island within the turbidity maximum zone of the Yangtze River mouth

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Abstract Sedimentary characteristics and processes on an estuarine marsh island in the Yangtze Estuary (East China Sea) show that (1) the mean grain size of the surficial sediments varies between 0.003 and 0.16 mm, the finest sediment being more enriched in the marsh center particularly under calm weather conditions during the flood season, and the coarsest sediment being more enriched on the low seaward tidal flats particularly after storms; (2) the sediment organic carbon content is generally less than 1.4 wt%; (3) the annual vertical marsh accretion is in the range of 20 cm, with a maximum value of 40 cm in the middle of the marsh; and (4) the seasonal cycle in plant growth strongly influences sediment grain size and erosion-accretion events.

Introduction

The question whether it is possible for coastal sedimentation to compensate for global sea-level rise has attracted increasing attention worldwide (e.g., Komar 1976; Meadows et al. 1998). Along some European and North American coasts, net annual accretion is only a few millimeters in some regions, whereas net erosion occurs in others (e.g., Wang et al. 1993; Oost 1995; Williams and Hamilton 1995).

In the Yangtze River mouth (East China Sea), tidal-flat sedimentation has been investigated along the southern bank (Shao and Yan 1982), the eastern shore of Chongming Island (Xu 1985), and around the islands of Changxin and Hengsha (Yang and Xu 1994). In these areas, a supratidal zone is generally absent because of land reclamation. Dams and protective structures have inevitably modified the hydrodynamics and sedimentary processes in much of the region, especially during spring tides. Clearly, it is meaningful to choose sites with essentially no human influence in studies of ‘natural’ coastal sedimentation.

Jiuduansha Island is an excellent site in this respect because it is still unspoiled by human interventions and hence a virgin land for scientific research. In addition, it is influenced by tides and waves, while lying in the turbidity maximum zone of the estuary. As such, it is an environment different from, and therefore complementary to more traditional study sites along the mainland coast.

In addition to presenting results on sediment texture and vertical accretion rate, data on tidal creeks and sediment organic carbon were extracted from Yang (1990, 1994).

Study area

The Yangtze River, considered to be the fourth largest river in the world (Eisma 1998), transports $4.7 \times 10^8$ t/year of fine-grained sediment into the East China Sea. Most of this river-born material is composed of silt and clay (D$_{50}$ = 0.027 mm), half of which settles in the river-mouth area (Chen et al. 1985). The accumulation of this sediment has led to the formation of three islands (Chongming, Changxin, and Hengsha islands) over the last 13 centuries, all of which are inhabited (Fig. 1). In contrast, Jiuduansha Island is a young, uninhabited intertidal island which formed in the last century (Yang 1998).

On Jiuduansha Island, the mean and maximum tidal ranges are 2.67 and 4.62 m, respectively (GSIC 1996). Currents weaken landwards in the intertidal zone, with maximum current speeds of $< 0.5$ m/s in the marshes, and $< 1.0$ m/s on the lower tidal flats (Yang 1994). Frequent storms affect the estuary each year, a maximum
wind velocity of 36 m/s having been recorded just off the river mouth (GSCCI 1988). Jiuduansha Island is situated in the turbidity maximum zone of the river mouth (Shen et al. 1992). The suspended sediment concentration (SSC) in the intertidal area is generally 1–3 g/l, fluid mud (SSC > 30 g/l) occasionally occurring in the river flood season (personal observation). The border between the unvegetated flats and the marsh is situated almost 50 cm above the mean sea level. The marsh vegetation is dominated by the pioneer plants Scirpus maritimus and Scirpus triqueter. Salinity varies from 1 to 6‰ during the season of vegetation growth in summer.

**Methods**

A total of 83 surficial (top 2 mm) sediment samples were collected along cross-shore and longshore transects under fair-weather conditions during the marsh flowering season in order to examine the general pattern in grain-size distribution. Storm deposits were sampled after a severe typhoon event. The positions of the sampling sites were determined by means of a GPS.

A combination of standard sieving and settling procedures (e.g., Carver 1971) was used for sediment grain-size analyses. The following textural classification scheme was used. Sandy: > 80 wt% sand, < 20 wt% silt + clay; muddy: > 80 wt% silt + clay, < 20 wt% sand; sandy mud: 50–80 wt% silt + clay, 20–50 wt% sand; muddy sand: 50–80 wt% sand, 20–50 wt% silt + clay (sand: 0.063–2.0 mm; silt: 0.063–0.004 mm; clay: < 0.004 mm; mud: < 0.063 mm).

Mean grain size (Mz), standard deviation (σ), kurtosis (Kg), and skewness (SK3) were calculated using the formulae of Folk and Ward (1957).

Field measurements of vertical accretion rates were carried out at 16 sites through the combined use of buried plates and rods. In each case, the thickness of the sediment layer above the plate, and the height of the rod above the sediment surface were recorded (if a scour pit was eroded around the base of the rod, its depth was subtracted).

Sediment particles adhering to plant stems were washed down with clear water. The turbid water was filtered through pre-weighed filters (pore size 0.45 μm) which were then oven dried at 60 °C and re-weighed.

**Results and discussion**

**Grain size**

The sand and mud dry weight % contents of the sediments vary in the range 0.2 to 98%, and 2.5 to 94%, respectively. Clay contents never exceed 50 wt%. The median grain size (D50) varies from 0.004 to 0.135 mm, whereas the Mz values fluctuate between 8.5 and 3.0Φ (0.003–0.125 mm). This general feature is similar to findings for other sectors of the river mouth (Shao and Yan 1982; Xu 1985; Yang 1990; Yang and Xu 1994), reflecting the riverine sediment source. For 95% of the samples, the mean diameters (in Φ unit) are larger than the median diameters (in Φ unit) (Mz = 1.022Φ50 + 0.267, r = 0.93). There is also a positive correlation between mean diameter (in Φ unit) and standard deviation (in Φ unit) (σ = 0.468Mz–0.794, r = 0.92). Skewness values lie between −0.15 and +0.64 (+0.44 on average), with 97% of the values being positive. Kurtosis values vary between 0.69 and 2.91 (1.55 on average). Walger (1962; also see Seibold 1963) gives a Φ50 versus QDΦ (QD denoting the quartile deviation) cumulative diagram for a range of Φ50 = 0–4.5. The diagram shows that QDΦ values tend to be lowest for Φ50 = 2.5–3.0, i.e., QDΦ increases for Φ50 values > 3.0 or < 2.5. This means that sediments in this size range (2.5–3.0 Φ) are most easily reworked.

Mud occurs in the center of each of the three marsh areas of the island, these being separated by a subtidal channel and an intertidal creek (Fig. 2). Sediments become progressively coarser with distance from the mud depocenters. This pattern may result from a shoreward reduction of hydrodynamic energy (cf. Yang 1994). Thus, the energy level is greatly attenuated by marsh vegetation, and fine-grained sediments can settle easily (Yang 1998). Coarsest sediments are found on the seaward side of the island where a major sand sheet has developed (Fig. 2). This reflects variations in wave energy around the island. Thus, on the downstream seaward side of the island, mean and maximum wave heights are 1.0 and 6.2 m, respectively, whereas on the upstream side these values decrease to 0.2 and 3.2 m, respectively (GSCCI 1988). In terms of wave energy, where $E = (1/8)gH^2$ (Wang and Huang 1988), the mean and maximum wave energy on the seaward side are 25 and 4 times as large, respectively, as their counterparts.