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EVOLUTION OF MOUTH BARS IN THE CHANGJIANG ESTUARY, CHINA: A GIS SUPPORTING STUDY

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Abstract: Supported by GIS, 10 pieces of charts of the Changjiang Estuary from 1842 to 1997 are studied. Digital elevation models of Changjiang Estuary is established with Kriging gridding method to research evolution of channel, change of coasts, formation and evolution of islands in mouth bar area with different points of view: transverse sections, longitudinal profiles, plane change, etc. Furthermore, the channel-fill volumes are calculated and calculations of amount of deposition or erosion in different scope between different years are conducted.

Key words: Changjiang Estuary, Mouth bars, GIS, Deposition and erosion of sediment, Calculation

1. INTRODUTION

Mouth bar is a kind of accumulated sediment body due to the changes of dynamic and biochemistrical conditions when rivers converge to big basins, such as Shelf Sea, lakes and reserviors. As an important estuarine geomorphology unit, mouth bar presents upheaval morphology in longitudinal profiles. This geomorphology unit exists in various estuaries that connect with ocean in the world, and especially, it is typical in those estuaries with huge plentiful sediment supply. It causes popular attention because its evolution of siltation and erosion impacts on the hydraulic engineering, navigation, environment, fresh water supply and so on (Wright 1978).

Among the world's rivers, the Changjiang ranks third in length; fifth in average water discharge at its mouth; and fourth in suspended sediment discharge (Schubel and Hirschberg 1982). The Changjiang River traverses Central China in an approximately westerly direction for nearly 6300 km before discharge through the Changjiang Estuary into the East China Sea near Shanghai (Fig.1). The Changjiang Estuary is located on a mesotidal coast and is a partially mixed estuary. The estuary is wide and shallow, and there are four distributaries separated by island and shoals (Fig.1). The Changjiang River discharges approximately 4.86×10^8 tons of suspended sediment into the estuary annually and average suspended sediment concentration is 540 mgl^{-1} (Shen *et al.* 1983). The huge suspended load has created a bar system with depth less than 10 metres extending over 40 km along each waterway (Chen *et al.* 1982). Attempts have been made to understand qualitatively the basic characteristics and the evolution of the mouth bars in Changjiang Estuary since 1950's. Huang (1980) analyses the reasons and places of mouth bars siltation with special reference to the effects on velocity and sediment concentration distributions caused by salt-water intrusion; Chen (1983) studied its morphology and sedimentary structure through comparing mouth bar features of Changjiang Estuary with those of other countries; Shen (1983) and Milliman (1985) researched the sediment transportation and the impact on mouth bar by the maximum turbidity and evaluated the quantity deposition rate; Lin (1990) and Zhang (1995) studied the formation and evolution of mouth bar of Changjiang Estuary through density circulation and sediment flocculation deposition caused by salt and fresh water mixture. Even those result enrich the knowledge about mouth bar in Changjiang Estuary, but the quantitative studies were less than the qualitative studies and high accurate quantity studies are rare because of the complexity and study method limitation.

The appearance of Geographical Information System (GIS) and Digital Elevation Model (DEM) has caused a revolutionary innovation to the theories and methodology of geography and other related subjects (Tang 2000). Through processing plenty of bathymetric data and setting up the DEMs of mouth bar area in Changjiang Estuary with the aid of GIS software, this paper will accurately calculate the amount of deposited or eroded sediment and analyze the evolution process of the bars in Changjiang Estuary based on the achievement in this field, historical data and the newest charts.

2. STUDY AREA

In order to quantitative calculation, mouth bar area in this paper is limited to:121°48' - 122°16'E (Niupi Reef) and 31° 00 - 31°30' N (Fig.1), and the amount of silted or eroded sediment under the depth of -2m (2m above the theoretical depth datum plane) is calculated.

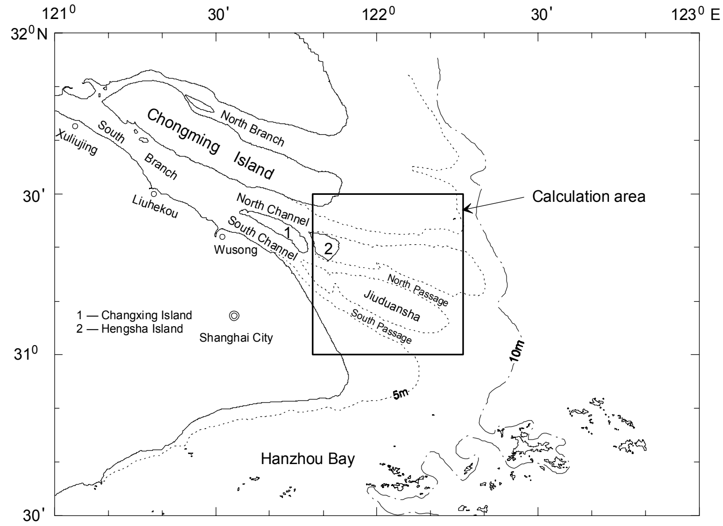

Fig. 1 Location of the study area

Based on the data statistic from 1951 to 1993 at Datong hydrologic station, the average annual runoff discharge and sediment discharge are 8940 $\times 10^8$ m^3 and 4.51$\times 10^8$t separately. On the other hand, the 71.4% of annual runoff and 87.7% of sediment discharge in Changjiang River are mainly center on flood season from May to October, and sediment discharge concentration degree is obvious more than that of runoff. The detail statistical characteristics of runoff and sediment are as follows (Table 1):

Table 1 Hydrologic statistical characteristics of runoff and sediment at Datong station

Content	Statistic year	Average annual	Flood seasons (May - October)	Percentage of flood season	Maximum		Minimum	
					Quantity	Year	Quantity	Year
Runoff ($\times 10^8 m^3$)	1951 - 1993	8940	6358	71.1%	13590	1954	6760	1978
Sediment discharge ($\times 10^8$t)	1953-1993	4.51	3.95	87.7%	6.78	1954	3.09	1992

3. DATA AND METHODS

The 10 pieces of bathymetric charts in Changjiang Estuary, which are chosen from many charts dated from 1842 to 1997, will be analyzed.

Applying GIS product, the ARC/INFO software produced by American Environment System Research Institute (ESRI), and Walking Digital Instrument Calcomp 9100 A0, the depth points and boundary line in bathymetric charts listed on Table 2 are input into computer. After transforming into E00 files, the data will be opened and examined at MAPINFO Platform. Then the basic database is set up with the command " Clean", "Build" and "Addxy" in ARC/INFO. Considering the differences of datum planes, all water depths are corrected into theoretical depth datum plane. The bathymetric contour and 3-dimmension-topography map can be output from Digital Elevation Model Base, which was established with Kriging Gridding Technology. Deposition rate will be received by calculating the volume of the channel shown in Fig.1. Part of digitized results are shown as Fig.2.

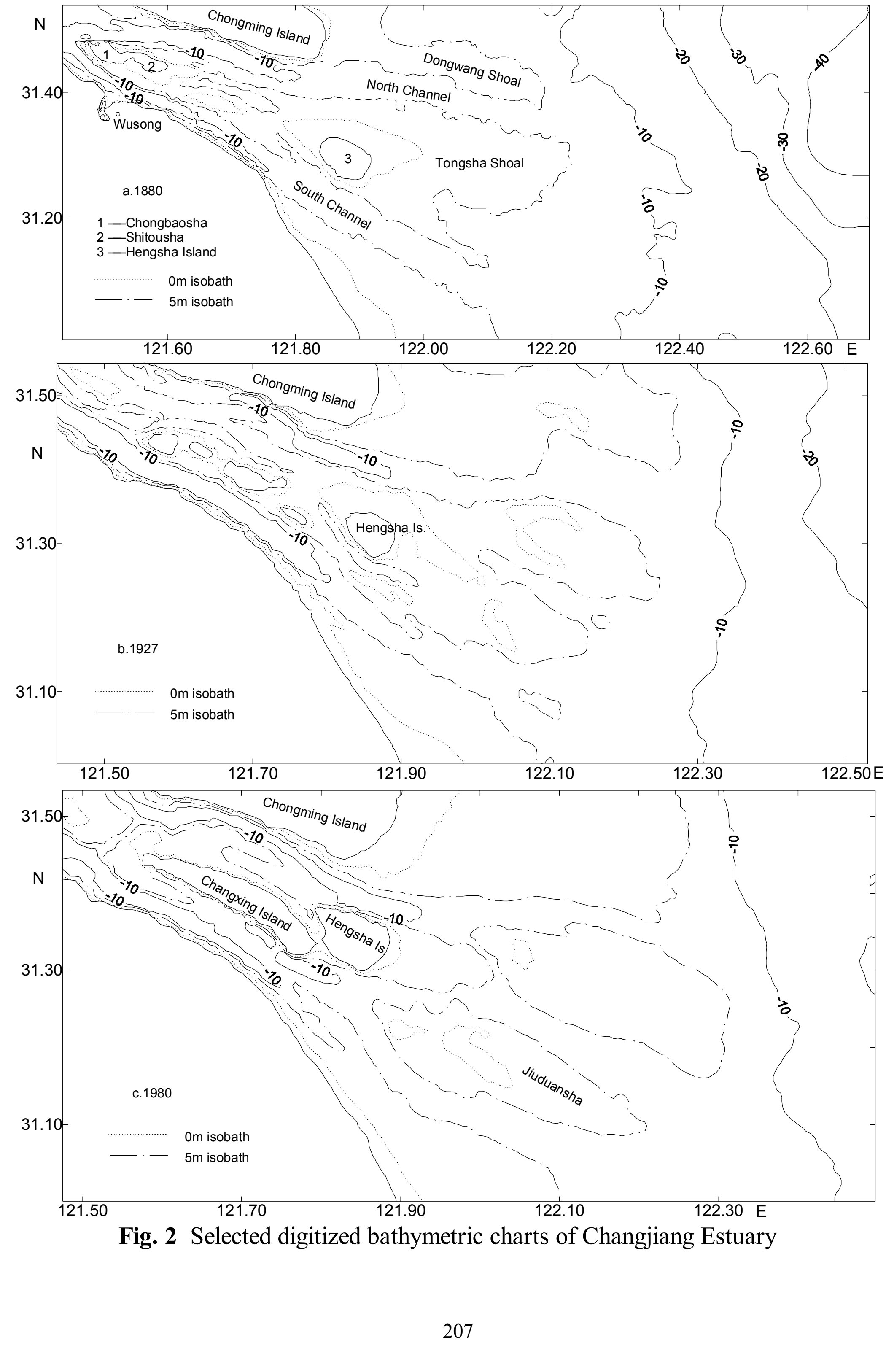

Fig. 2 Selected digitized bathymetric charts of Changjiang Estuary

4. RESULT ANALYSIS

4.1 TRANSVERSE SECTIONS ANALYSIS OF MOUTH BAR

The transverse sections along 122°E in different years is shown as Fig.3. From Fig.3, the results can be obtained: (1) During the early period (1942 - 1927), there are three principal channels —— South Channel, North Channel and North Branch —— in mouth bar area of Changjiang Estuary. The situation of four outlets into the sea (South Passage, North Passage, North Channel and North Branch) was gradually formed later. (2) At the 122°E section, North Channel predominated in water depth with maximum largest depth about 10m in 1842 obviously. (3) From 1842 to 1927, because serious siltation took place in North Channel and the Channel was changed drastically, it appeared that the waterway became shallow and narrow. While South Channel kept relatively stable, and presented balance on charts shown by a little siltation in 1908 and a bit erosion in 1927. Up to 1927 the waterway of South Channel became deeper than North Channel. (4) From 1927 to 1965, the waterway of North Channel was eroded again. The divarication situation of South and North Passages still had not been formed in South Channel in 1927, but the North Passage, whose embryonic form appeared in 1945, had completely formed in 1965. At the same time, the top of Jiuduansha shoal has appeared above the datum plane. (5) 1965 - 1995, the pattern of four outlets into the sea was unchangeable. But during 1965 to 1980, the talweg of North Passage changed from north side to south side. Jiuduansha shoal enlarged and extended rapidly toward south. During 32 years, from 1965 to 1997, the isobaths of 0m and 5m were pushed on about 5.1km and 2.8km towards south with average advancing rates 160my^{-1} and 88my^{-1} respectively. From 1980 to 1997, the advanced distances of isobaths of 0m and 5m were 5.4km and 2.16km with the average advancing rates 200my^{-1} and 170my^{-1}. It was obvious that Jiuduansha has entered the rapid siltation period. (6) Generally, the evolution features are: the sidebeach of south bank eroded towards south; South and North Passage, North Channel moved towards south gradually; Chongming Island extended toward east when its east beach grew high year after year.

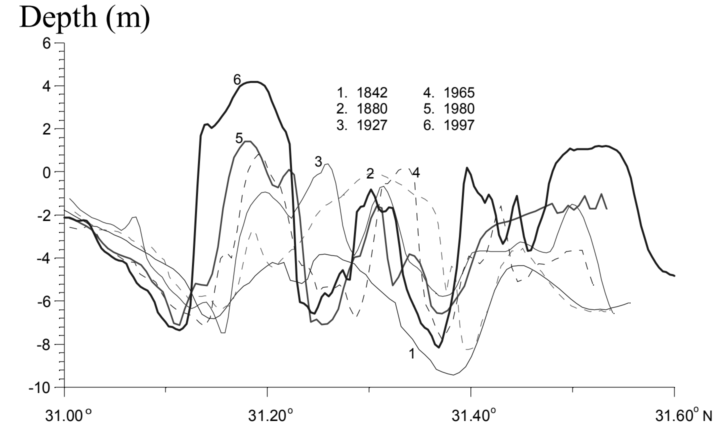

Fig. 3 Transverse sectionss of mouth bars area in Changjiang Estuary (along 122°E)

4.2 LONGITUDINAL PROFILES

Along the talwegs of South Passage, North Passage and North Channel, longitudinal profiles in difference years are compared as follows.

4.2.1 South Passage (Fig.4)

In 1842 the typical waterway mouth bar had been formed in South Passage, whose straight distance of 10m isobath between the mouth and

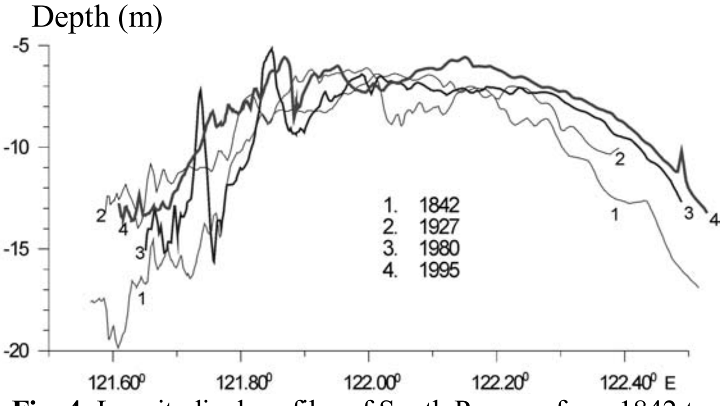

Fig. 4 Longitudinal profiles of South Passage from 1842 to 1995

offshore was 64.25km. Comparing with that in 1842, uphead and downhead of South Passage waterway in 1927 were both flushed in some extent. But the water depth on the top of mouth bar was about 6.2m and changed only a little (Table 2). In 1980 shoal block was formed on upper head of South Passage because a wedge spit so called Jiangya spit was formed and extended toward the inlet of South Passage from south bank (Fig. 2c), which resulted in two steep peaks in longitudinal profile (Fig. 4). From 1927 to 1995, the water depth of top of mouth bar decreased and mouth bar obviously extended toward both west and east.

4.2.2 North Passage (Fig.5)

In view of longitudinal profile of North Passage, the water depth of the top of the bar was only 1m in 1927 because that time North Passage presented a flood channel inserting into Tongsha shoal and hadn't connected with the main channel of upstream (Fig.2b). From 1980 to 1985, the water depth on the top of mouth bar just changed a little, keeping about 5.5m (Table 2), at the same time, mouth bar didn't enlarge its scale obviously and remained steady relatively.

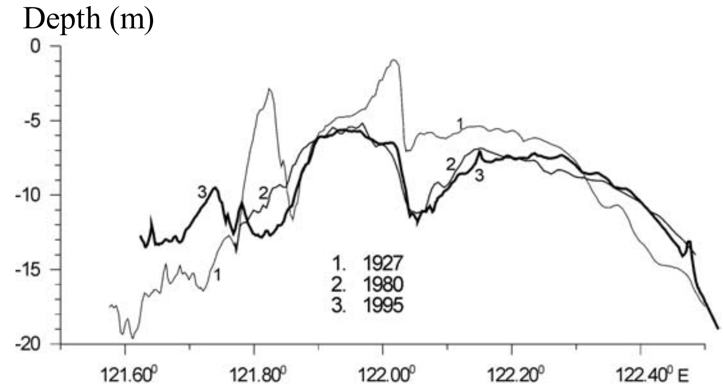

Fig. 5 Longitudinal profiles of North Passage from 1927 to 1995

4.2.3 North Channel (Fig.6)

It was shown by longitudinal profiles of chart in 1842 that the deep pool and shoal alternately appeared along the longitudinal direction of North Channel. Its inlet was shallow owing to existence of many shoals. In 1927 the water depth of the bar top in North Channel was only 5m; from 1980 to 1995, it remained about 5.6m, but there were some extent of erosion in other part of areas.

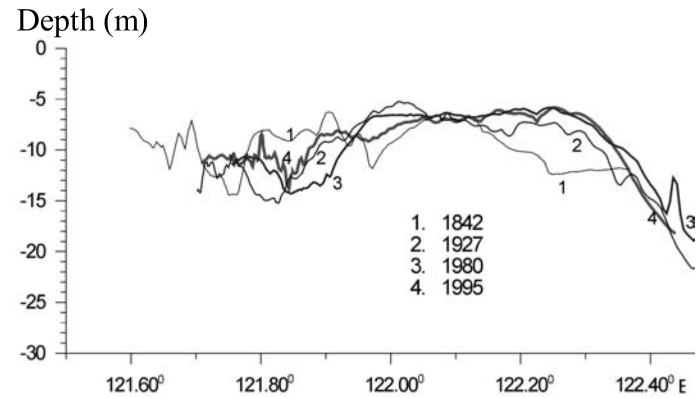

Fig. 6 Longitudinal profiles of South Channel from 1842 to 1995

Table 2 The change of water depth at the top of mouth bar (m)

Year	South Passage	North Passage	North Channel
1842	6.3	/	5.8
1927	6.2	1.0	5.0
1980	5.3	5.2	5.6
1995	5.6	5.8	5.6

4.3 HORIZONTAL VARIATIONS OF MOUTH BAR

By comparing the coastlines and island boundary lines with DEMs in 1880,1927,1980 and 1995, it is shown that in recent 100 years the south bank coastline of Changjiang Estuary (north to 31°N) was stable and changed a little because of historical bank revetments. South coastline of Chongming island was eroded obviously from 1842 to 1927 and regressed toward north, but it remained stable from 1927 to 1995 due to the bank protection engineering. Annual great extension of Chongming eastern coastline toward east reveals that east shoal of Chongming Island is the main dipositional area in Changjiang Estuary. At the same time, the process of formation of Changxing Island and evolution of Hengsha Island has been represented distinctly by Fig.7. Two shoals ——Chongbaosha and Shitousha —— existed as the embryonic form of Changxing Island in 1880 (Fig.2a), which became several shoals dispersedly distributed in 1927 under the actions of river and tidal dynamics day after day (Fig.2b). Up to 1980, these shoals were incorporated and modern Changxing Island had been formed after consecutive sediment deposition and reclamation. From 1980 to 1995, Coastline of Changjiang Island is relatively stable because of bank revetment engineering. Hengsha Island, having existed in 1880 with a small scale, formed earlier than Changxing Island. From then on, Hengsha all the while acted as an independent island with a stable figuration and expanding scale. Because the southeast of Hengsha Island regressed owing to erosion caused by strong actions of flood tidal current and waves and the northwest kept continuous siltation, macroscopically whole Hengsha Island moved towards northeast continuously. Since 1980, because of bank revetment engineering, the position of Hengsha Island is stable, and so is the Hengsha ditch, a flood channel between Hengsha and Changxing.

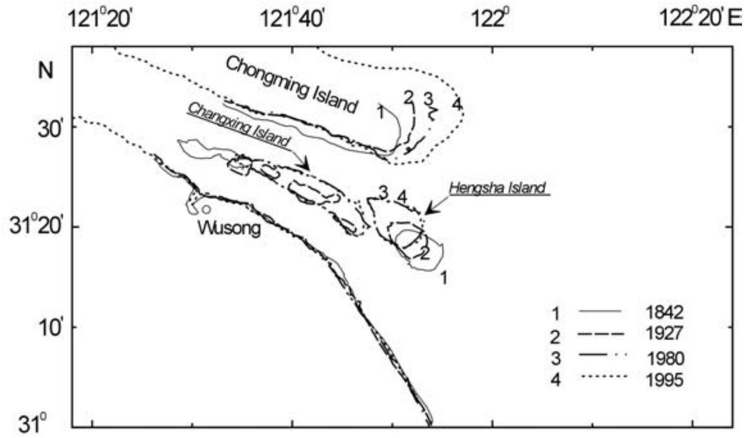

Fig. 7 The evolution of coastline and sandy island boundary from 1880 to 1995

Table 3 The calculated results of siltation or erosion of mouth bar in Changjiang Estuary

Period	Amount of siltation or erosion ($\times 10^8$t)	Annual average ($\times 10^8$t)	Thickness of siltation or erosion (m)	Annual average thickness (cm)
1842-1880	26.198	0.689	0.9308	2.45
1880-1908	1.63302	0.05823	0.058	0.207
1908-1927	1.9560	0.1029	0.069	0.362
1927-1965	-1.8061	-0.0475	-0.063	-0.165
1965-1980	7.9674	0.5321	0.283	1.88
1980-1990	12.983	1.298	0.465	4.65
1990-1995	1.6343	0.3269	0.059	1.18
1995-1997	-3.3474	-1.674	-0.124	-6.19
1842-1997	38.0996	0.246	1.678	1.1

Note: Negative sign express erosion.

4.4 ANALYSIS OF AMOUNTS AND POSITIONS ON SILTATION OR EROSION

In order to present the amounts and positions on siltation and erosion accurately, the calculated area (shown by Fig. 1) is divided into 100×100 nets. Then the amount of siltation and erosion will be obtained by comparing the differences of channel volumes, which is located under -2m water depth (2m above theoretical depth datum plane). The calculated results are as follows:

In general, about 38.1×10^{8}t sediments silted in study area for 155a. from 1842 to 1997 with average deposition rate 0.246×10^{8}ty^{-1}, about 5% of annual sediment flux in Datong Station, and annual average deposited thickness is 1.1cm, which is very near the sedimentary rate (1.14cm/a) of sand bar in Changjiang Estuary estimated by Xu (1985).During this period there are two peak periods of siltation: the first one is from 1842 to 1880, totally 38 years, and the second one is from 1880 to 1990, totally 10 years; their deposition amounts are 26.198×10^{8}t and 12.983×10^{8}t with an average deposition rate 0.688×10^{8}t/a and 1.298×10^{8}t/a separately. Moreover, from 1965 to 1997, about 32 years, its sediment deposition amount, which is 19.237×10^{8}t with average deposition rate 0.601×10^{8}t/a , is also considerable. During the 32 years, short period erosion occurs occasionally, for example, from 1995 to 1997, 3.347×10^{8}t of sediment has been eroded in 2 years, and its average erosion rate is 1.67×10^{8}t/a. In addition, from 1927 to 1965, erosion dominates this area. The amount of erosion is 1.8×10^{8}t with an average erosion rate 0.0547×10^{8}t/a. As a result, from the beginning of 1842, the mouth bar in changjiang estuary is in the status of rapid situation. But after 1880 the siltation rate decreased and erosion started from 1927 to 1965 caused by floods in 1931 1949 1954. Later it began to silt again and during 1980's the deposition rate is up to peak and then is subsiding. From 1995 to 1997,ersion happened again in this area. Therefore mouth bar is developing in spiral style with final tendency of sillation and erosion sometimes takes place owing to the change of dynamic factors.

Shown by the thickness distribution map on silation or erosion from 1842 to 1995(Fig.8), for nearly 150 years, in mouth bar area big scale silation concentrated on Jiuduansha, east beach of Hengsha, east beach of Chongming. The erosive scale is very limited, mainly in the place where now North Passage is in. Moreover, the local area of South Passage is eroded slightly.

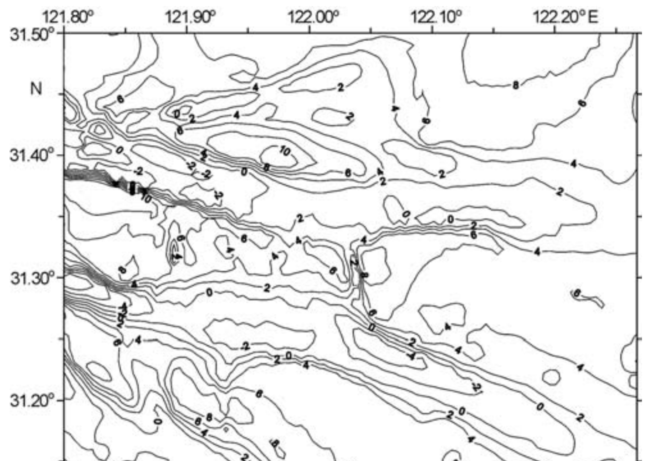

Fig. 8 The sediment thickness of deposition or erosion from 1842 to 1995

5. MAIN CONCLUSION

1.The method of GIS and DEM is worth of deep discussion because of their advantages of high efficiency and accuracy comparing with traditional method in studying of siltation and erosion of estuary.

2.Based on the analysis of bathymetric charts in different periods (1842-1997), some conclusion can be drawn as follows: During the early period (1842-1927), there are three main channels in mouth bar area of Changjiang Estuary and one flood channel developed at Tongsha shoal in 1927. In the second period (1927-1945) an ebb channel formed at South Channel because of the influence of runoff and sediment. In the third period (1945-1965)

North Passage formed after two channels were connected. At the same time Jiuduansha was formed, developed and enlarged after departing from Tongsha shoal. Then situation of four outlets into the sea has been formed. In the forth period (1980-1997)，Jiuduansha deposition rate was fastened and had an obvious tendency of forming an island, so it is obvious that Jiuduansha will become a new Hengsha-Changming island in the future. In a word, the evolution tendency of mouth bar area in Changjiang Estuary is the beach of south coast retreats toward south, South Passage, North Passage and North Channel move gradually toward south and east beach of Changming deposits high and enlarges toward east.

3.The process of coastline change and sand island formation can be presented clearly through digital coastline and island. Changxing Island is developed from those small islands upstream moving toward downstream and being incorporated, and this progress is fasted by bank revetment in the 1960's and 1970's. Hengsha Island is moving gradually toward northwest because of erosion in south side and siltation in north side caused by strong flood tidal current and wave action at the southeast side. At present the position of the two islands is stable and so is the Hengsha ditch.

4.The calculated results of siltation and erosion show that deposition prevails during 155 years (1842-1997), but the process of siltation at mouth bar is relatively complex. In different period the deposition rate is variable and sometimes erosion appears in some areas, which is caused by fluctuating of dynamic conditions. From 1842 to 1997, the amount of silted sediment in study area is 38.10×10^8t with an average siltation rate 0.246×10^8t/a, about 5% of total sediment flux of Changjiang River. And annual average thichness of deposited sediment is 1.1cm. The main siltation places are Jiuduansha, east beach of Chongming, Hengsha and its east beach. North Passage is the main erosion place, and there are slight erosion at upper reaches of North Channel and parts of South Passage. All in word, the area that was eroded is limited, and it only accounts for about 21.4% of total area.

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