

RIVERINE SEDIMENTS AND CHINESE COASTLINE CHANGES^①

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ABSTRACT: The tectonic uplifting and depression in the coastal zones results in the anormal distribution of riverine sediments. The coastal zones of tectonic depression areas received about 95% of the riverine sediments, whereas the tectonic uplift belts received only 5% of that, which is the main reason for the variety of the coastline types and the changes in the coastline. On the basis of this anormal distribution of riverine sediments in Chinese coastline, this paper discusses the scope and time of the maximum transgression, the trend, rate and period of the coastline changes, and the impact of riverine sediments on the future changes in coastline.

KEY WORDS: coastline, coastal environment, riverine sediments, sea level rise

I. TECTONIC MOVEMENT AND RIVERINE SEDIMENTS

The uplifting of the Qinghai-Xizang (Tibet) Plateau generated large and sediment-laden rivers, thus the northern Indian Ocean and the western Pacific Ocean received large volume of riverine sediments which constitute about half of the total riverine sediments in the world.

Chinese coastline crosses both tectonic uplift belts and tectonic depression belts. Rivers such as the Huanghe (Yellow) River and Changjiang (Yangtze) River, etc. carrying large volume of sediments mainly run into the sea at the tectonic depression belts, and rivers such as the Zhujiang (Pearl) River and Hanjiang River, etc. into the sea at the fault basins in the tectonic uplift belts, thus resulting in the unbalanced distribution of riverine sediments at Chinese coastline. The tectonic depression areas including the depression belts and the fault basins at the uplift belts receive above 95% of the riverine sediments, whereas the uplift areas only receive less than 5%. Meanwhile the length of the coastline at the depression areas is only 21.6% of the total Chinese coastline, and it is 78.4% at the uplift areas. These facts show the difference in received sediments in a unit length(km), i. e., the riverine sediments received at the depression area in one square kilometers is average more than 40 times of that at the uplift area (Li *et*

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al., 1994).

The difference in vertical tectonic movement in Chinese coastal areas and the abnormal distribution of riverine sediments along coastline are the main reasons for the varied changes in coastlines. The coastline advances rapidly at the tectonic depression areas where large volume of riverine sediments are deposited, forming broad delta, coastal plain, muddy beach, etc., e. g., Bohai Bay, Jiangsu coastline, Huanghe River, Changjiang River and Zhujiang River. The advancing rates of the coastline during the Holocene at the tectonic uplift areas were rather smaller because of the limited receipt of riverine sediments, e. g., Shandong Peninsula and Liaodong Peninsula, and coastlines in Fujian, Guangdong and Guangxi provinces.

II. SOURCES OF RIVERINE SEDIMENTS AND THE MAXIMUM TRANSGRESSION LINE

The extents and occurring time of the Holocene maximum transgression, which vary remarkably at coastal areas, are important parameters in analysing the environmental evolution of the studying coastal areas. Generally, the transgression extents are larger (i. e., 100 – 300 km) in the large river deltas and the areas influenced by these deltas; whereas, the maximum transgression lines are only a few kilometers, even several hundred or tens meters, away from the present coastlines.

The distances of the maximum transgression line away from the coastlines vary obviously even in the deltaic areas. Take the Changjiang River Delta as a good example, the maximum transgression line at the main deltaic body is about 300 km landward, whereas it is only 40 – 80 km away from the coastline at Shanghai area and the north flank of the delta. Sedimentary movement usually results in adjustment of sedimentary volume in coastal areas. The maximum transgression line is landward farther in the sedimentary areas, e. g. Zhejiang coastline and northwest Shandong Peninsula. Here, the former case is result of southward movement of the Changjiang riverine sediments, and the latter case is a product of western movement of sediments in the north of Shandong Province.

The occurrence of the maximum transgression varied greatly with locations, which was earlier in tectonic depression areas, about 7500 – 2000 a B. P. in the Changjiang River Delta (Li *et al.*, 1979) and later in tectonic uplift areas, about 6000 – 5000 a B. P. e. g. along coastlines in Fujian and Shandong provinces (Xie *et al.*, 1986; Zhuang *et al.*, 1986). The maximum transgression occurred at different times at different parts even within the same delta. For example, the maximum transgression occurred about 7500 a B. P. at the top of the delta, 7000 – 6000 a B. P. at the south flank, and 7000 – 5000 a B. P. at the north flank (Liu *et al.*, 1985; Jiangsu, 1986).

The occurring time of the maximum transgression is closely related to the sea level changes and sedimentary rates which are influenced by sediment discharges. The process of the Holocene transgression can be roughly separated into two stages, i. e., (1) 8000 – 7500 a B.

P. , the sea level rose rapidly and exceeded the sedimentary rate, resulting in transgression; (2) 7500 a B.P. to present, there is controversy on the process of the sea level rising during this period, but the general trend of the sea level rise is relatively slow. At the large river estuaries where the sedimentary rate was higher, the sea level rise and the sedimentary rate reached their balance earlier, whereas in lower sedimentary rate areas, they reached their balance later, which is the main reason of the variation of the maximum transgression time in the tectonic uplift areas and the tectonic depression areas, and at the tops and flanks of the deltas.

The scope of the maximum transgression is controlled by the river sediment discharge and the original topography. In the tectonic depression areas, especially at the large estuaries, sea water can flood larger area with the same elevation of sea level as the topography is smoother, and the abundant riverine sediments favor the progradation of the coastline there. Otherwise, the maximum transgression line is closer to present coastline in the tectonic uplift areas because of the steep coastline and limited sediment supply.

The areas near the maximum transgression line are rather sensitive to changes in sediment supply, for example, two sedimentary layers absented marine microfossils were found in 3 – 4 m marine faces at the top area of the Changjiang River Delta. Regional comparative analysis shows that these layers are results of abrupt increase of terrigenous clastic sediments, which resulted from the river channel migration. In the North China Plain, alternative occurrence of marine and terrigenous sediments can be found far upstream of the maximum transgression line because of the changes in subdelta progradation and their locations (Li *et al.* , 1995).

Besides, big tides, waves, and storm surges etc. can also bring marine microfossils to areas near the maximum transgression line to form the layers rich in the marine microfossils. These kinds of changes in the amount of the marine microfossils are not necessarily related to the changes in sea level.

III. RIVERINE SEDIMENTS AND TREAD, RATE, AND CYCLITY OF COASTLINE CHARGES

The coastlines tended to migrate landward before the maximum transgression, then tended to retrograde seaward. This cyclicity can be found at any area in coastal plains and deltaic plains, and the period is from several thousand years to tens thousand years. The periods of coastline changes at any two nearby points are unequal on vertical coastline sections.

The process and rates of Chinese coastline changes vary remarkably since the Holocene maximum transgression. First, there are obvious differences between tectonic depression areas and tectonic uplift areas. The prograding rates of the former vary from several meters to tens meters per year and the latter are usually less than one meter per year. The prograding rates of coastlines in the tectonic depression areas change obviously since the maximum transgression. Take the Changjiang River Delta as an example, there are 3 – 5 shelly and sandy ridges at the back of the south flank, and the total width is 4 – 8 km, ^{14}C ages are 7000 to 3000 a B.P from

east to west, so the prograding rates are about 1–2 m/a. However, the coastlines prograded 30–60 km since 3000 a B.P., i.e., the prograding rates are 10–20 m/a, which is ten times that of the former situation. The ^{14}C and ^{210}Pb dating and study of tidal-flat development in the cores on Nanhui Farm at the front of the south flank of the Changjiang River Delta show that the average sedimentary rates are 1.2 mm/a since 6000 a B.P., 3.0 mm/a since 3000 a B.P., about 8–9 mm/a in recent 1000 years, and 22–38 mm/a in recent 100 years (Li *et al.*, 1993). This trend is coincident with the changes in coastline progradation, which demonstrates that the variations of the coastline prograding rates reflect the changes in sediment discharges of the Changjiang River. Three or four levees are also found nearby the maximum transgression line at the north flank of the Changjiang River Delta and at the Jiangsu coastal areas, and their total width is about 10–20 km formed during 7000–3000 a B.P. (Jiangsu, 1986), so it can be concluded that the coastline prograding rates are 2.5–5.0 m/a. However, the coastlines has prograded 40–70 km since the year 1128, i.e., the prograding rates reach 40–70 m/a. Although there are differences in the prograding rates at the south and north flanks of the Changjiang River Delta, the processes of transgression are similar. However, the progresses since the maximum transgression are obviously different at the coastlines of the Bohai Gulf. No remarkable levees are found nearby the maximum transgression line, but four shell banks are found at the broad coastal plain from the maximum transgression time to the present coastline, so there is no obvious trend of variations in coastline prograding rates, which may be connected with that the Huanghe River ran into sea hereby during 8000–7000 a B.P.

The above-mentioned shell banks and sandy banks are mainly located in muddy coastal areas. These levees usually experienced processes of rapid progradation of coastlines, and decreasing or diminishing of riverine sediment supply, erosive retrograding of coastlines, and deposition of coarse sediment. Then the coastlines tend to be stable, and finally the riverine sediment discharges increase again and the coastline prograde rapidly again, forming the broad coastal plain between two levees. Therefore, the changes in riverine sediment discharges result in sub-cycles of the coastline changes with a period of about 100 years, and the main geological records are beach ridges. Within these cycles, the actual amplitudes and rates of coastline changes are different from the above-mentioned average rates of coastline changes of the coastal banks. Take the Huanghe River Delta as an example, the modern delta with an area of about 6000 km² was formed in Shandong Province with about 100 years since the Huanghe River changed its main channel from north Jiangsu Province to Bohai Gulf in 1855, and the coastline prograded 100 km, so the prograding rate is about several hundred meters per year (Cheng, 1987). Meanwhile, the coastlines are strongly eroded at the abandoned Huanghe River mouth area in north Jiangsu Province, and the coastlines have retrograded by 20–30 km. The retrograding rates are about thousand meters per year at first, and decrease gradually with 10–20 m/a at present (Chen, 1990). Therefore, within a cycle of coastline changes, the actual amplitude and rate of coastline change are rather larger than that recorded in geological records.

Coastline changes in deltaic areas resulted from migration of main channel are especially

obvious in the Huanghe River Delta. The prograding rate of coastline at the estuary reached several kilometers annually, but after the migration of the main channel the eroding rate there reached several hundred meters annually. Besides the migration of main channel, the changes in runoff and sediment discharge, the alternation of flooding and dry seasons, and changes in tides and wave can result in the periodic coastline prograding/retrograding, and the cycling duration is less than one or several years.

The general trend of the coastline changes at the sandy-gravel coastal areas in the tectonic uplifting belts is accumulating and prograding, but the suborder cycles are more frequent, smaller and more complicated. There are seasonal cycles as well as eroding/accumulating cycles of several years. Each windy wave cycles, even each tidal cycle can lead to a prograding/retrograding coastline change, and the period of the change is shorter. The periods of coastline changes with various time and scales are observable, but it is rather difficult to distinguish them in geological records.

As the cycles of coastline changes of various time and scales are superimposed together in Chinese coastal areas, it is necessary to distinguish them first so as to utilizing them into environmental analysis. To analyze the tendency of coastal changes, the geological records of reverse trend generated properly by the suborder changes. For example, rapid and strong erosion resulted from ocean factors can be usually found in the prograding coastal areas, so it is necessary to eliminate its impact when analyzing the tendency of coastline changes.

IV. IMPACT OF RIVERINE SEDIMENTARY DISCHARGE ON THE PREDICTION OF FUTURE COASTLINE CHANGES

The future coastline changes are controlled by many environmental factors, including tectonogenic and marine, global and regional etc. . These factors act together, making the predicting work become very complicated. As this problem is importance, many researchers have carried out various studies on the problem, among which the most successful method is using elevation-area method to predict the landward migration of coastline. During the 1980s, the study on global warming and sea level rising showed many predicting scheme of the sea level rising in the next century. By comparing the predicted sea level rise and the elevation of the coastal area, the distance of landward coastline migration under each sea level rise is predicted, then, the area inundated by seawater and the proper economic loss are estimated. This method was used in China to estimate some lowlying land. However it is worthy to point out that this method may be not appropriate to the cases in China. First, Chinese coastal areas are rich in riverine sediments. As discussed above, the coastline changes are controlled not only by sea level changes but also by riverine sediment discharges, and the ratio of these two factors determines the direction of coastline movement. Even if the coastline migrates landward, the impact of sediment discharge must be eliminated. Secondly, coastal banks are rather common in Chinese coastal areas. The construction of banks began in the Tang and the Song dynasties, and

widespread in the Ming and the Qing dynasties. At present, about 13 000 km coastlines are protected by the banks, and the design standards improved gradually with economic development, e. g. , the design standards of many banks in Shanghai area are against tidal impact of one event in one thousand years. Therefore, one predict the future coastline changes, the influence of bank construction must be considered. However, the factors considered in this method are so simple that it is not applicable to the prediction of coastline changes in most Chinese coastal areas.

Sediment discharges play a very important role in the prediction of coastline changes as the riverine sediments are so abundant in Chinese coastal areas, however the variation of the sediment discharges and their impact on coastline changes are rather difficult to predict.

First, forest destruction and over grazing lead to land erosion, and increase river sediment discharge; on the other hand, reservoir construction and freshwater adjusting engineering decrease runoff discharge and sediment discharge. The impacts of these two kinds of human activity may increase with population growth and economic development. Second, even if decreasing of riverine sediments tends to dominate in future, the occurring time varies with different areas. The Huanghe River and the river running into Bohai Gulf show apparently this trend (Han, 1994). The Three Gorges project and Longtan Hydroelectric Engineering (Zhongshan, 1989) will force the Changjiang River and Zhujiang (Pearl) River follow this trend. Further, decreasing in riverine sediment discharge doesn't necessarily mean retrograding of delta and coastline. Even in the Huanghe River Delta where apparent decreasing in sediment discharge has occurred, there are no enough evidences to prove it. In large estuarine areas where the deltas prograde obviously at present, it is necessary to study the condition of stabilizing the deltaic system and the critical value of changes in riverine sediments in order to predict correctly the future coastline changes.

The riverine sediment discharge has decreased remarkably along some sandy gravel coastlines, and the coastlines tend to retrograde, but the decreasing in riverine sediments may not be the main reason of coastline erosion. As pointed out by some researchers (Zhuang *et al.* , 1989; Xia *et al.* , 1993), widespread use of sands and gravels as building materials at beaches and lower river reaches become the main reason of coastline erosion. In the 1950s, over-use of beach sands and gravels at George coastlines results in the coastline changing from depositing to eroding. Italian coastlines become almost wholly eroding in the 1950s because of over-utilization of beach sands and gravels. Therefore, it is worthy to study the proper portion of coastline erosion caused by utilization of beach sands and gravels as building materials in China. Besides, some coastline erosion is the result of river channel migration and normal coastline evolution. For example, the erosion of the abandoned Huanghe River mouth and expansion of its estuarine area are caused by the northward migration of the Huanghe River and running into Bohai Gulf. The coastline erosion began in 1955, prolonged to present with decreasing in eroding intensity, and there are no relationship between changes in riverine sediment discharge and eroding intensity in recent 10 years. The increasing in eroding scope is accompanied by the accumulating and

prograding of Qonggang coastline , which belong to normal evolution of the coastline.

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