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An Integrated Study of Sediment Discharge from the Changjiang River, China, and the Delta Development Since the Mid-Holocene

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ABSTRACT

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The accelerated growth of the Changjiang River delta since 2,000 BP was formerly attributed to the intensified human activity in the drainage basin. An integrated catchment-deltaic study shows that this rapid growth began at the time when the headward aggradation of the Changjiang river-bed since the last deglaciation had come to an end, which allowed the river to carry more sediments into the sea. Although the Changjiang drainage basin has experienced an unprecedented intensity of human activities in the past 40 years, the sediment discharge either from the upper basin or from the river mouth into the sea did not show any significant increase due to its small sediment delivery ratios. It is proposed that the anthropogenic modification has exerted a dual effect on the sediment discharge into the sea. However, it suggests that the ancient human activities were far from producing any significant difference in the sediment discharge between the two periods before and after 2,000 BP.

The development of the Chenier Plain from 6,400 to 3,500 BP was the result of coastal profile adjustment in response to sea-level rise since the postglacial period. Sedimentary evidence suggests that at this time the direct sediment inputs from the river into the shallow-water coast was considerably lower. A preliminary estimate shows that during this period about 46 to 92 million tons of sediments were annually deposited on the middle-lower river-bed and its flood-plains, approximately equivalent to 10% to 20% of the present Changjiang's sediment discharge into the sea.

From 3,500 to 2,000 BP was a period of discontinuity of deltaic land progradation. This discontinuity occurred at the time when the process of coastal profile adjustment had largely been completed, whereas the longitudinal river-bed profile of the middle-lower Changjiang River had not yet adjusted to the sea-level. The sediment deficiency into the sea, as a result of the river-bed aggradation before 2,000 BP, may partly account for the land-forming discontinuity. Meanwhile, most of the sediment from the river mouth was trapped by the relatively deep-water sedimentary basin to build the underwater delta and a new coast profile, which paved the way for the rapid seaward growth of deltaic land after 2,000 BP.

ADDITIONAL INDEX WORDS: *Chenier Plain, shoreline accretion, deltaic basin, post-glacial sea-level rise, deltaic progradation, coastal floodplain.*

INTRODUCTION

As a sub-system of the earth's surface environment, the Changjiang drainage basin constantly undergoes exchanges of mass and energy with atmosphere and ocean, which involves a variety of complicated processes and consequently contributes to changes of the global environmental system. One of the most important materials discharged from the Changjiang River is sediments supplied by the drainage basin. Like other forms of effluents, such as organic matter and chemical constituents, the sediments from the drainage basin are determined in their amount and composition by the interaction of climate with the underlying land surface of the drainage basin. These sediments are ultimately a major source for deltaic development and contain much information on the past change of drainage basin environment. Therefore, an integrated catchment-deltaic study will improve our understanding of the changes of drainage basin environment, the mechanism of deltaic development and the changes of sediment flux into the near-coast seas. It is praiseworthy that the Integrated Catchment-Coastal Zone Study was proposed in 1990 as an important part of the core project "Land-Ocean Interactions in the Coastal Zone" in the framework of "International Geosphere-Biosphere Programme (IGBP Report 12, 1990)". Undoubtedly, the Changjiang River basin and its deltaic coast should occupy an important position in such a study of global scale. It has been clear that this integrated study should comprise a wide range of issues covering

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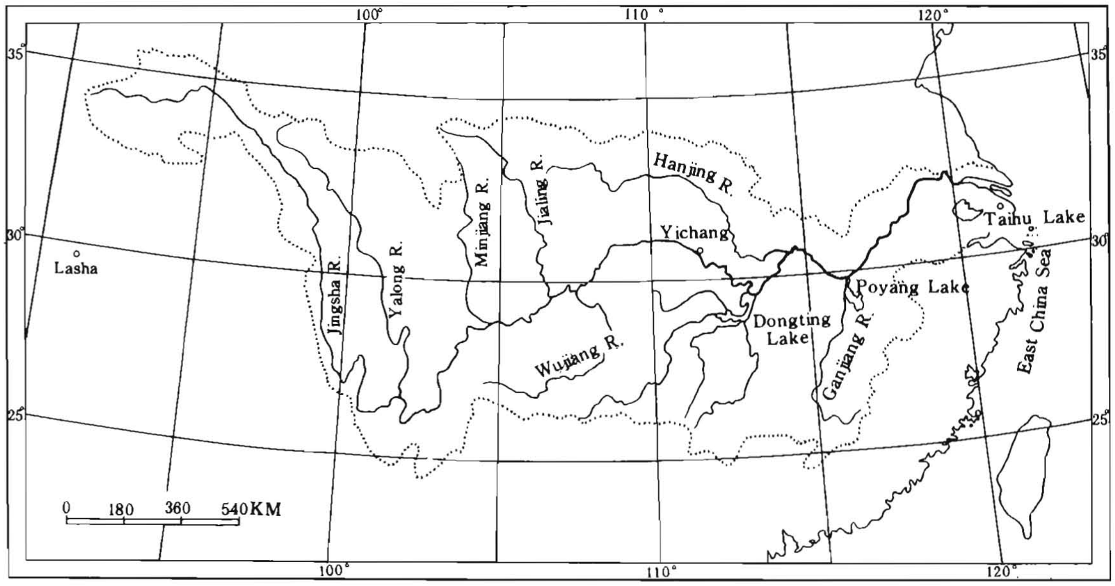

Figure 1. Geographical setting of the Changjiang River and its drainage basin.

geological, biological and chemical processes with different time-scales. The present study only deals with some aspects in the deltaic development, sediment discharge and drainage basin environment of the Changjiang River since the mid-Holocene.

MAJOR CHARACTERISTICS OF THE CATCHMENT-DELTAIC SYSTEM

Being one of the largest rivers in the world, the Changjiang River originates in the Qinghai-Xizang Plateau and extends 6,300 km eastwards, transversing a vast expanse of Chinese mainland, and finally emptying into the East China Sea (Figure 1). The total drop of water from its source to its mouth is as great as 6,500 meters, which provides it with an extraodinarily high potential energy for carrying its sediment loads to the sea. It drains an area of 1,808.5 thousand square kilometers with an annual runoff discharge of about 29,000 cubic meters per second. The annual suspended sediment discharge averages about 4.7 hundred million tons a year since the 1950's. The Changjiang River may be divided into three parts:

(1) The Upper Reach from the Source to Yichang

The upper reach extends 4,529 km in length, with a water drop about 6,450 m. The annual mean precipitation gradually increases from about 400 mm in the west to about 1,200 mm in the east, with remarkable regional variation due to the topographic variation. Important is the temporal distribution: about 72% of the total annual runoff and 87% of the total sediment discharge occur primarily in May to October. The upper Changjiang River drainage basin can be further divided into two parts with respect to the spatial characteristics of sediment yield: (1) the upper part with low sediment yield where the modulus of annual sediment output is lower than 200 T/km^2, and (2) where most parts of the area are geographically characterized by the high-frigid environment with an elevation of more than 4,000 meters. It is here that there is little anthropogenic influence on the land surface processes. As a result, the sediment concentration is relatively lower. For example, it is 0.54 kg/m^3 at Batang, 0.51 kg/m^3 at Shigu and 0.76 kg/m^3 at Dukou (Figure 2); the lower part with high sediment yield, where the modulus of sediment output is mostly higher than 500 T/km^2. The maximum zone with the output modulus varying from 1,000 to 4,000 T/km^2 extends in a southwest to northeast direction (Figure 2). The sediment concentration rapidly increases from 0.76 kg/m^3 to 1.70 kg/m^3 within a short distance from Dukou to Pingshan. Such a phenomenon is unique along the entire branch of

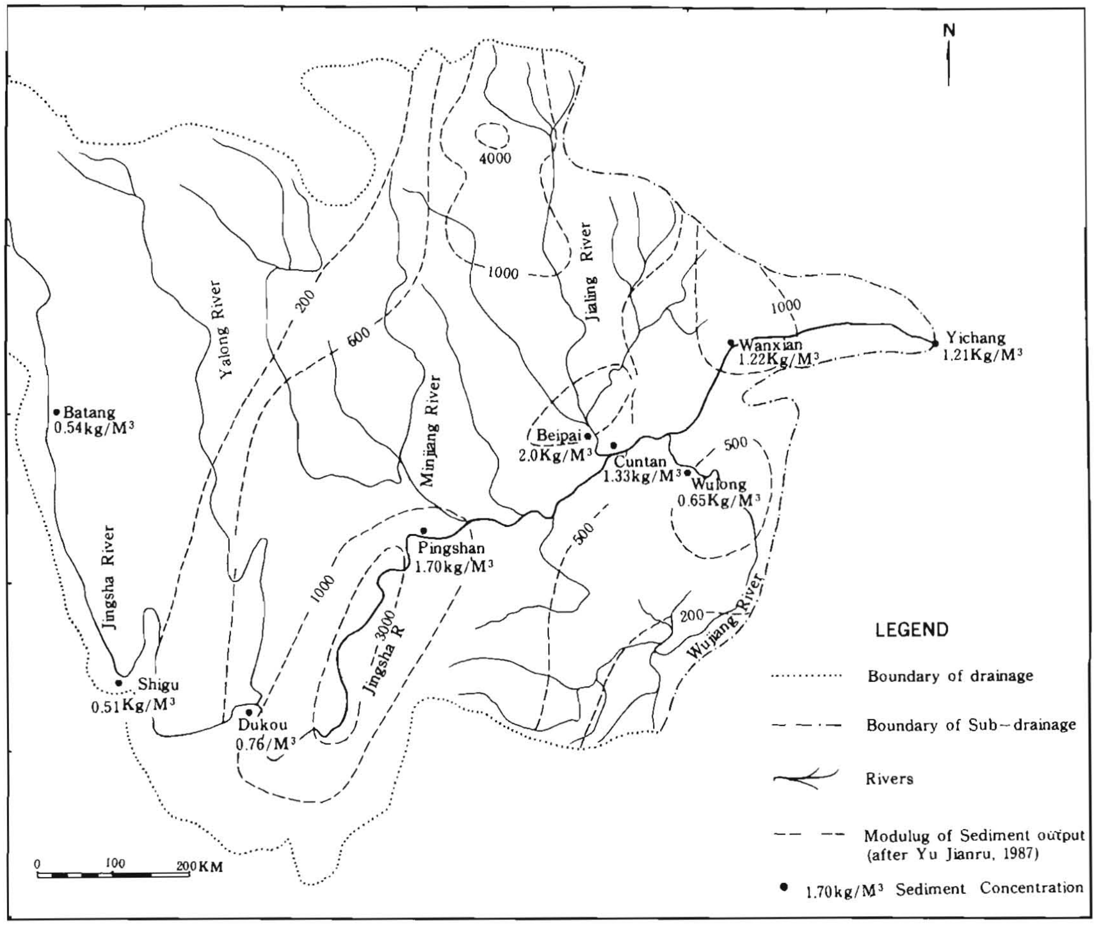

Figure 2. The modulus of sediment output in the upper Changjiang drainage basin and the spatial variation of suspended sediment concentration.

the river. Geographically, the areas with the high output modulus are located around the branch river from Dukou to Pingshan, the lower reach of the so-called "Jinsha River" which means "gold sand river" in Chinese, and around the upper and lower basin of Jialing River, a main distributary which annually provides the branch river with a sediment discharge as high as 1.45×10^8 tons. The relatively high sediment discharge, which is equivalent to about 32% of the total sediment discharged into the sea, and its large yearly variation from 0.731×10^8 to 3.56×10^8 a year, makes the Jialing River the most important distributary for the changes of sediment output from the upper Changjiang River basin. There are several factors that are responsible for these areas of the maximum sediment output. First, the lower reach of the Jinsha River is located in the transitional zone of two major geotectonic and geomorphological units where earthquakes are common, and the bedrock is fractured and has undergone intense weathering. The land surface is deeply incised with a sharp contrast between the high mountains and deep valleys. These conditions together with seasonally occurring heavy precipitation resulted in strong gravitational geomorphological processes, such as landslides, mudflows, *etc.* Second, the high sediment yield in the upper Jialing River basin can be attributed to the Quaternary loess deposits which are a southern extension of the Loess Plateau into the Changjiang River basin. Third, the lower part of the upper Changjiang

River basin is an area under strong anthropogenic stresses; i.e., about one hundred million people live in this area. Deforestation, mining and other changes in land-use over the last 40 years has strongly modified the land surface processes and consequently, has greatly increased the sediment yield.

(2) The Middle Reach from Yichang to Hukou

The middle reach is 927 km in length extending from Yichang to Hukou, the outlet of the Poyang Lake. It is characterized by an extensive development of the flood plains and lakes which have functioned as traps for sediments and as a buffer zone for flood discharge from the upper river basin. The slope of river-bed is gentle with a mean gradient about 0.00003, approximately 22 times smaller than that of the upper reach. Therefore, this area is most vulnerable to the attack of disastrous floods from the upper reach (which had a maximum flow of 110,000 m^3/sec in 1870). Important is the role of the Dongting Lake in modulating the runoff and sediment discharges from the upper reach. Each year about $1{,}180 \times 10^8$ m^3 of water runoff passes through Dongting Lake carrying with it a large quantity of sediments. Statistics show that the total sediments annually deposited in the Dongting Lake is as high as 0.984×10^8 m^3, which mostly comes from the upper river basin (LEADING GROUP, ACADEMIA SINICA, 1988).

(3) The Lower Reach from Hukou to the Mouth

The lower reach of the Changjiang River extends about 844 km in length. Its upper part from Hukou to Nanjing is characterized by the dense distribution of fluvial islands with the river gradient greater than its lower part. From Nanjing downstream, the gradient is considerably lower. In some parts of near-estuary reach, there even occurs a negative gradient. The sediment concentration varies from 0.55 to 0.61 kg/m^3. About 72% of the total runoff is concentrated in the flood season from May to October carrying about 87% of the annual sediment load into the sea.

(4) The Changjiang River Delta

Like many other large deltas, the Changjiang River delta is a product of post-glacial sea level rise. When sea level had attained the present stand around 6,000 BP, the Changjiang Estuary was a funnel-shaped estuary with its apex located between Yangzhou and Zhenjiang, the two cities at Jiangsu Province, located 150 km upwards from the present apex near Xuliujing (Figure 3). Since the mid-Holocene, the development of the Changjiang River delta has undergone three important stages that can be closely related to the adjustment of the Changjiang River's longitudinal profile and the coastal onshore-offshore profile. One outstanding feature is that almost all the deltaic land was formed after about 2,000 BP—4,000 years later than the time when the sea level had already reached its present position. Meanwhile, an underwater delta as great as 10,000 square kilometers or more had developed, with its frontal edge reaching a water depth from −30 m to −50 m (CHEN *et al.*, 1985).

PROBLEM OF DELTAIC LAND-FORMING DISCONTINUITY

Since the 1950's, great progress has been made in the study of geomorphological development of the Changjiang River delta. The early systematic studies were carried out by Chen Jiyu and his co-workers (CHEN *et al.*, 1959). Their study indicates that after the last deglaciation, the apex of the funnel-shaped estuary was located between Zhenjiang and Yangzhou. They also proposed that the development of the Old Ridge which extends from Chaojing through Taicang to Fushan (Figure 3) varies from 5 to 20 km in width and is closely related to the origin of the Taihu Lake. It subsequently was found that the Old Ridge is made up of a series of parallel chenier-like sedimentary bodies. Sedimentological studies indicate that the shell composition in the ridge is generally as high as 50–80% (LIU *et al.*, 1985), and that these parallel chenier-like sedimentary complexes are known collectively as the Chenier Plain (LIU and WALKER, 1989). From the historic record and archaeological studies, TAN (1973) proposed that the southern Changjiang River delta east of the Chenier Plain was formed within the last one or two thousand years. This is confirmed by the radiocarbon ages from the younger cheniers east of the Chenier Plain (LIU and WALKER, 1989).

Since the 1980's with the wide application of ^{14}C techniques in dating, the picture of delta development has become more and more clear (ZHANG *et al.*, 1982; LIU *et al.*, 1985; LIU and WALKER, 1989). A considerable number of data indicate that the parallel chenier groups gradually become younger in age, ranging from 6,400 to 3,500 BP (Figure 3). Studies of bottom sediments from the Taihu Lake indicate that it was a semi-en-

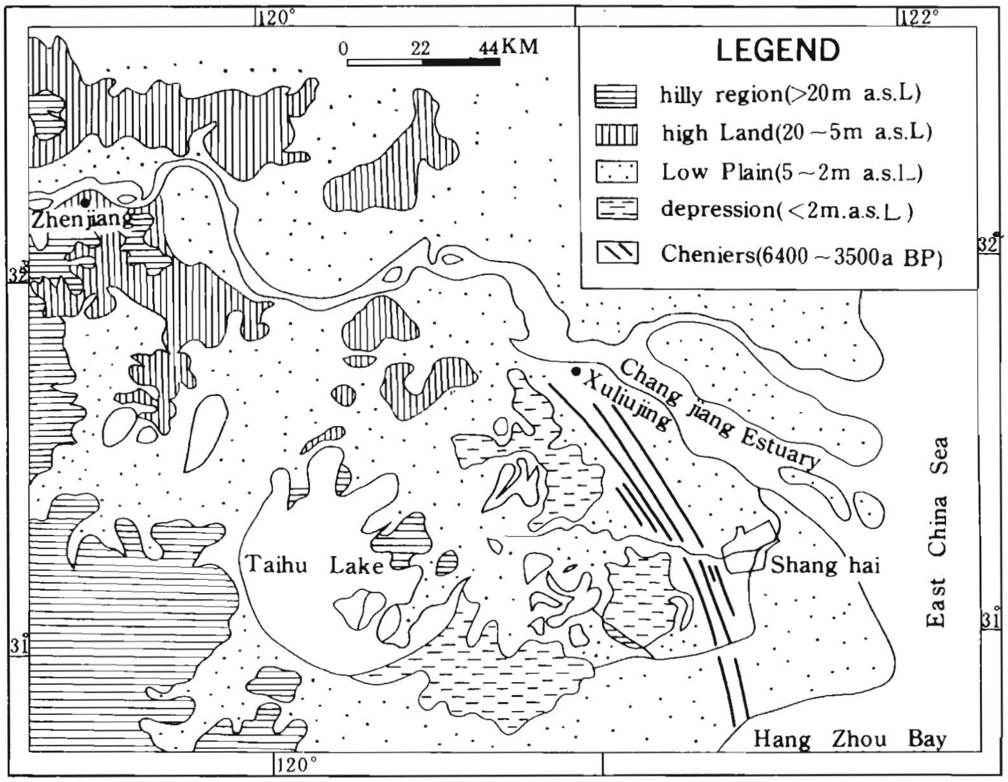

Figure 3. Geomorphological map of the southern Changjiang River delta and its vicinities.

closed lagoon and marsh land at this period on which the coastal water and dynamics still had a considerable effect especially during the period of storm-surges.

The above-stated facts suggest a discontinuity in the delta development and a variation in the velocity of seaward land progradation; *i.e.*, (1) land progradation occurred very slowly from 6,400 to 3,500 BP, when the narrow chenier plain of 5 to 20 km wide was formed and most of the sediment source was not directly from the Changjiang River, (2) from about 3,500 BP to about 2,000 BP, there is no significant land progradation; *i.e.*, the "land-forming discontinuity" and (3) after about 2,000 BP, the land progradation was greatly accelerated and almost all the deltaic land is formed within this period. The rapid growth of the delta since about 2,000 BP was presumably attributed to the increase of sediment discharge caused by the changes of drainage basin environment especially as a result of the anthropogenic activities (YANG and CHEN, 1985; LIU *et al.*, 1985; CHEN *et al.*, 1985).

As the data accumulates, the author finds that this problem deserves further study, and that an integrated study on catchment-deltaic systems may give us a deeper insight into the stages of delta development as well as their relationships to the drainage basin environment, the sediment discharge, and the coastal sedimentary basin since the mid-Holocene.

MORPHOLOGICAL CHARACTERISTICS OF THE DELTAIC SEDIMENTARY BASIN AND ITS EFFECT ON DELTAIC PROGRADATION

There is no direct relationship between the speed of land progradation and riverine sediment discharge since this speed only reflects the areal increase of the delta above the sea level. In fact, most riverine sediment loads are trapped by the sedimentary basin in its effort to build an underwater delta. This is demonstrated by the quantitative estimate that the shoreline accretion during the past 2,000 to 3,000 years is <5% of the total Changjiang load (MILLIMAN *et al.*, 1985). The remainder is mostly deposited onto the submerged delta. Therefore, any conclusion based on the speed of land progradation that includes changes in the Changjiang's sediment discharge since the mid-Holocene should be drawn with great caution. Theoretically, it is difficult to determine vertically and laterally what the deltaic volume is of different periods because of the problems with deltaic boundary determination and chronology.

There is one fundamental difference in the morphology of the sedimentary basin between the two periods before and after about 2,000 BP. In the mid-Holocene when the sea level had approached the present stand, the morphology of the sedimentary basin still basically preserved the characteristics of the latest ice-age when the sea level was about 100 to 130 m lower than the present stand. A number of deep cores (YANG *et al.*, 1988; QIN *et al.*, 1987) indicate that the river channel at the location of the present estuary has been deeply incised downward to the level of −55 to −60 m during the latest ice-age when the terrestrial processes such as the fluvial process and wind-drift process were the major dynamic agents for the landform development in this sedimentary basin. This is because the postglacial sea level rise was so rapid that there was not enough time for the adjustment of the sedimentary basin to the coastal hydrodynamic processes. Previous studies indicate that the postglacial sea level rise in East China was accomplished in three major jumps immediately after 12,000 BP, 10,500 BP and 8,500 BP. Between these jumps, the sea level was relatively stable (YANG and CHEN, 1985). These findings coincide with the oxygen isotopic evidence from Tropical Atlantic cores (MIX *et al.*, 1985) and that there exists three large steps (14,000–12,000 BP, 10,000–9,000 BP and 8,000–6,000 BP) indicating the maximum changes of ice-volume on the earth's continent. These dramatic changes in sea level and continental ice-volume may be compared with the episodes of abrupt climatic changes proposed by FLOHN (1984).

According to the paleo-ground surface of the latest ice age reconstructed from a considerable number of drillings, the ground surface gradient at the latest ice-age is considerably larger than the present surface gradient of the submerged delta. The deep water sedimentary basin and greater coastal gradient therefore had hindered the rapid deltaic land progradation for a period of time before the coastal profile adjustment had been completed.

RIVER-BED PROFILE ADJUSTMENT AND SEDIMENT DISCHARGE INTO THE DELTAIC BASIN

Sedimentary evidence from the East China continental shelf indicates that the sea level in the last glacial maximum (18,000–15,000 BP) was about 100 to 130 m lower than that of the present. As a response, the middle and lower Changjiang River and its distributories developed a deeply-cut channel. On the beds of present Taihu Lake (YANG, 1986), Poyang Lake (ZHU *et al.*, 1983) and Dongting Lake (YANG *et al.*, 1987), the three greatest lakes in the Changjiang River basin (Figure 1), there is still widely preserved the erosional and depositional landforms indicating that the ground surface was incised to the depth of −20 m, −15 m and <10 m downwards from the present lake bed, respectively. Therefore, as a response to the mid-Holocene high sea level, a large scale of aggradational process both in areal coverage and in vertical magnitude has taken place in the branch, the distributaries and their flood-plains. A large number of drillings reveal that the thickness of aggradation in the branch channel is as great as 50 m in the present estuary, and gradually decreases upwards to about 5 m near the outlet of the Dongting Lake (YANG *et al.*, 1987). As a consequence of river-bed aggradation, the Changjiang River's water table gradually became higher. YANG and YAN (1990) find the thickness of flood-plain deposits is abnormal, greatly exceeding the maximum water table variation of the Changjiang River in this century. They attributed this abnormally thick deposit to the gradually raised water table since the mid-Holocene as a result of the river-bed aggradation. The data available indicate that the process of aggradation is characterized by the headward aggradation. The maximum depositional zone gradually shifted upwards from the estuary to the segment near the outlet of the Dongting Lake within the period from 6,500 BP to 2,000 BP. The three largest lakes, the Taihu, the Poyang and the Dongting are to a great extent related to the process of river-bed aggradation and the water table rise in their origin. For example, the flood-plain deposits in a fluvial island off the outlet of the Poyang Lake is

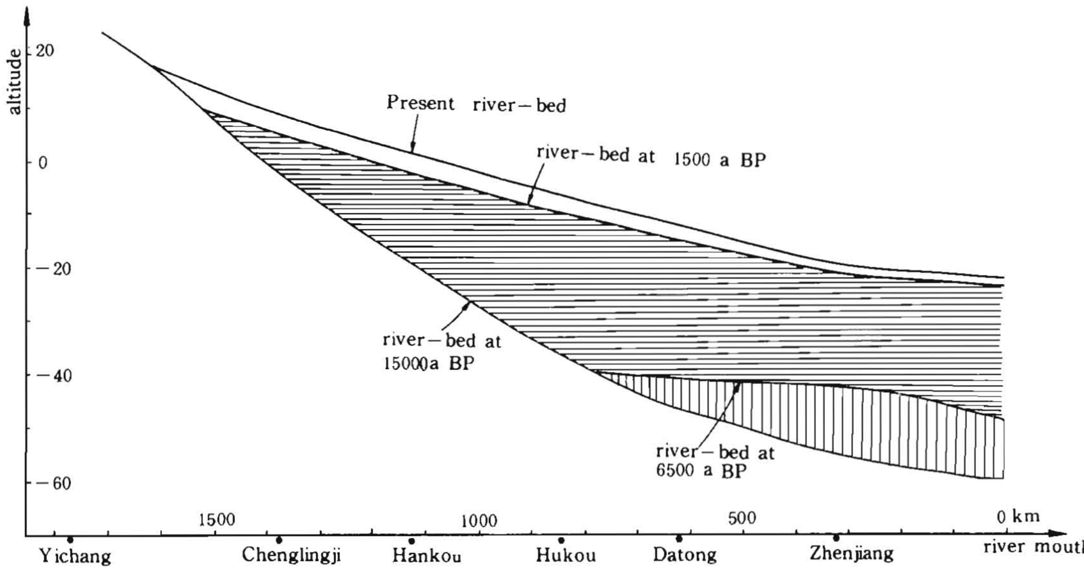

Figure 4. Model of headward river-bed aggradation at the middle and lower reaches of the Changjiang River since 15,000 BP.

as great as 36.05 m, while the maximum range of the water table since this century is only 13.61 m. The ^{14}C datings indicate that these flood-plain deposits began to develop only after 3,800 BP. The sedimentary studies show that it is only after 2,000 BP that the Poyang Lake had come into existence which is much later than the beginning of river-bed aggradation.

According to data on the longitudinal river-bed profile in the latest ice-age (Yang, 1986; Geographical Institute, 1985) and the headward aggradation model since Holocene from the drillings and ^{14}C datings (Yang *et al.*, 1987; Yang and Yan, 1990), the author has made a preliminary quantitative estimate concerning the depositional amount based on the model shown in Figure 4. In this model, the aggradation process is considered only within a narrow zone consisting of the branch river and its flood-plain and varying from 5 km to 10 km in width. Moreover, the flood-plain is thought to be aggradated upwards at the same magnitude as the river-bed. Meanwhile, the headward river-bed aggradation had not reached the outlet of the Poyang Lake before 6,500 BP. By 1,500 BP, the aggradational process had basically come to an end when it reached the segment upward from the outlet of the Dongting Lake. Based on the above mentioned assumption, the sediment amount is calculated to about 23 to 46 $\times$ 10^{10} tons which means that about 46 to 92 million tons of sediment, which is approximately equivalent to about 10%-20% of the total Changjiang's loads, was annually deposited within the middle and lower reach. This, together with the effect of the sedimentary basin geometry stated in the former section, may explain the very slow deltaic land progradation during this period.

SEDIMENT SUPPLY, DISCHARGE AND CHANGES OF RIVER BASIN ENVIRONMENT

Sediment discharge from the Changjiang River to the sea is essentially dependent upon the two kinds of factors; *i.e.,* (1) sediment supply which is connected to the geology, geomorphology, vegetation and human activity, *etc.*, in the basin; and (2) sediment transportation capacity which is dependent on the fluvial dynamics per the amount of runoff and its temporal-spatial distribution. Hence, it is clear that the sediment discharge, as a whole, is a product of the interaction of climate with the underlying drainage basin surface. Therefore, the increase of annual sediment discharge to the sea since 2,000 BP, if any, may be mainly attributable to the changes in vegetation, precipitation and the intensity of human activity. Other factors, such as geology and geomorphology, can be basically considered as a constant with

Table 1. *Decrease of forest coverage in the upper Changjiang River basin since the 1950's.*

Location		Coverage		
County	Province	1950's	1980's	Data Source
Wanxian	Sichuan	18.9%	7.8%	Leading Group, Academia Sinica, 1988
Wushan	Sichuan	23.6%	11.7%	
	Sichuan	24%	13%	
Nayong	Guizhou	33.9%	7.2%	Li Wenhua, 1989
Fangxian	Guizhou	36.5%	7.75%	

regard to their role in affecting the sediment discharge within such a short period of time.

Since the 1970's, a considerable number of studies on the climatic changes of China since the mid-Holocene have been made by Chinese scientists. However, these studies were only concerned with the changes of surface air temperature and the vegetation migration. For example, Zhu Kezhen, the pioneer in studies on the paleoclimatic changes of China, found that during the first month after the Spring Festival (late January to early February), temperatures were about 3° to 5° higher than those of 6,000 BP in the lower Yellow River basin from the historical records (ZHU, 1979). In the past ten years, a large number of spore-pollen analyses and macrofauna-floral fossil assemblages discovered have further enriched our understanding of the mid-Holocene climate and vegetation seasonality. As stated above, there are still few quantitative or even semi-quantitative studies on the changes of precipitation, runoff, and vegetation coverage since the mid-Holocene, since these issues are very complicated in nature and researchers are confronted with many difficulties. There is no evidence yet indicating significant changes in precipitation, vegetation coverage, and river runoff that may account for the assumed sharp increases of sediment discharge over the last 2,000 years. However, it appears that the intensity of human activity in the drainage basin around 2,000 BP was far from producing any significant effect on the land surface processes and sediment discharge. This conclusion is supported by the study of anthropogenic effects on the sediment discharge over the last 40 years, in which human activity has increased on an unprecedented scale. The following data in Tables 1 and 2 may give us a deep impression of what has occurred in the drainage area as a result of human activities. In the upper Changjiang River basin, the reduction of vegetation coverage is estimated to be more than 50% based upon data from the

Table 2. *Increase of soil-loss area from the 1950's to the 1980's in the upper Changjiang River basin.*

Location			
County/ District	Province	Decrease	Data Source
Li Xian	Gansu	53.1%	Chengdu Institute of Mountainous Disaster and Environment Studi (Academia Sinica, 1990)
Shangxian	Shanxi	37.8%	
8 counties	Sichuan	40.4%	
	Jiangxi	14.7%	Jing Ke et al., 1990
Huizhou	Anhui	50%	Comprehensive Scientific Investigation Team, 1986

1950's. During the same period, the total area that has undergone a soil-loss process has increased from 299.5 to 352.2 thousand square kilometers (LEADING GROUP, ACADEMIA SINICA, 1990). The soil erosion process in the mid-lower basin, as a whole, is less intense compared with that in the upper basin because of different geologic and geomorphological backgrounds. However, soil erosion has intensified since the 1950's, especially in mountainous and hilly regions (Tables 1 and 2).

With the background of the above-mentioned strong anthropogenic effect on soil erosion, is there any indication of sediment discharge increase into the sea? Statistics based on the data from the Datong Hydrometric Station show that there has been no significant increase since the early 1950's. It is worth noting that the upper and lower Changjiang basins have functioned differently with respect to their net contribution to the sediment output. The upper basin is a sediment source area which provides 5.26×10^8 tons of sediments a year measured at the Yichang Hydrometric Station from 1950 to 1986, while the middle and lower basins in general act as a sediment sink because the sediment output to the sea measured at the Datong Hydrometric Station averages 4.70×10^8 tons a year. This means that about 0.56×10^8 tons of sediments from the upper basin have been trapped by the mid-lower basin each year. These amounts of sediment are mostly concentrated in the Dongting Lake and the adjacent fluvial plains in Hubei and Hunan provinces.

While there is little controversy about the views of no increase of sediment output to the sea, debate still exists about the change of sediment discharge from the upper river basin which has been and still is one of the major concerns surorunding the construction of the Three-Gorge Hydroelectric Engineering Project. Figure 5 shows the

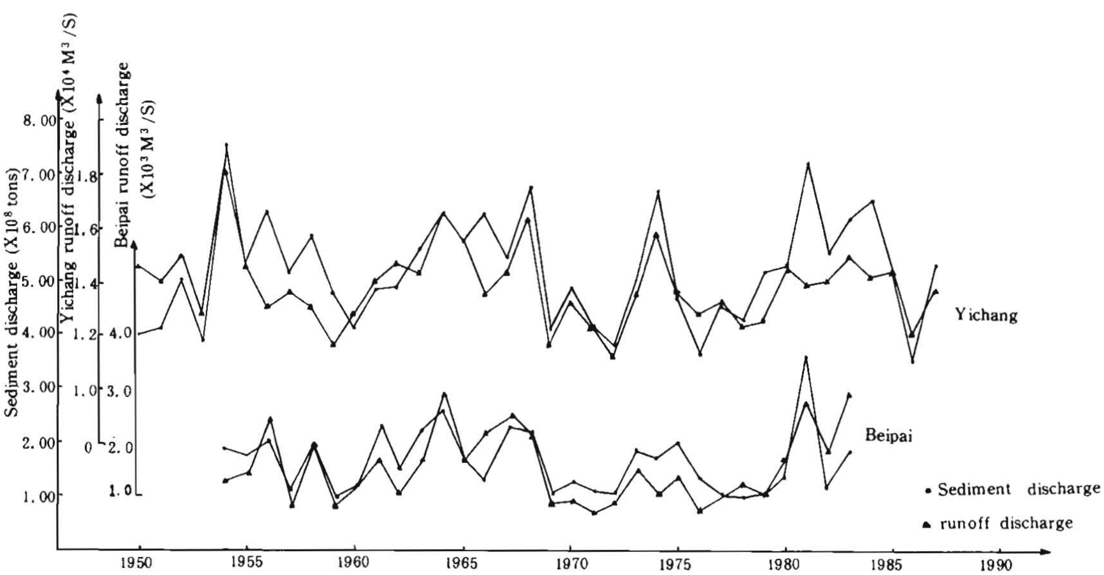

Figure 5. The annual sediment discharge and the yearly mean runoff discharge from the upper Changjiang river basin (Yichang) and the Jialing River (Beipai) since the 1950's.

changes of annual mean water discharge and the yearly suspended sediment output from the Yichang Hydrometric Station since the early 1950's. Statistical studies indicate that the correlation coefficient between the yearly accumulated water discharge and the sediment discharge is as high as 0.9998. This result indicates that the changes in the river discharge from the upper basin is the most important factor in controlling the sediment output. It also implies that the increase of sediment discharge from the period before 2,000 BP to after 2,000 BP, if any, must have been accompanied by an increase of runoff discharge. Meanwhile, the relatively low correlation coefficient ($R = 0.7$) between water discharge and sediment amount on an annual basis suggests that the temporal and spatial distribution of precipitation may cause large fluctuations in the annual mean sediment concentration and the annual sediment discharge.

Some researchers have proposed that the sediment output from the upper basin has shown an increasing trend since 1978 (LEADING GROUP, ACADEMIA SINICA, 1988) on the basis that there is a dramatic increase of sediment discharge in the early 1980's under a moderate annual runoff discharge (Figure 5). The author finds that such a high sediment discharge was often coupled to abnormal runoff and sediment discharges in some tributary drainage basins especially in the Jialing River basin (Figure 2). For example, it can be found that the abnormal runoff and sediment output from the Jialing River in 1981 is responsible for the dramatic increase of sediment discharge from the upper Changjiang River (Figure 5), when the sediment discharge from the Jialing River reached 3.56×10^8 tons—2.11×10^8 tons more than the average value (1.45×10^8 tons a year) since 1954. This increase is equivalent to about 40% of the average annual sediment discharge since 1950 from the upper basin. In the same year, the annual mean runoff discharge from the Jialing River also reached its high value of 3,260 m^3/sec, which is 140 m^3/sec less than the maximum value recorded since 1954. However, this increase in water discharge with respect to its longterm average is only equivalent to 4.0% of the yearly mean discharge from the upper basin or ten times less than the relative increase of sediment discharge (40%) as stated above.

Sediment Delivery Ratios (SDR) are one of the most important parameters in describing the ratio of sediment yield to the total sediment output in a given drainage basin. Studies have indicated that SDR show a general decreasing tendency with the increase of drainage area (WILLIAMS, 1972). Even for such a river basin with an extraodinary high sediment yield, as the middle Yellow River

Table 3. *The total number and capacity of reservoirs by the year 1979 in the provinces at the Middle and Lower Changjiang River basin.*

Province	Total Number	Total Capacity ($\times 10^8$ m^3)	Source
Shanxi	461	42.17	The basic data about the flood control in the middle-lower reaches of the Changjiang River, compiled by the flood control headquarters for the middle-lower reaches of the Changjiang River, 1982
Henan	511	24.08	
Hubei	6,200	486.73	
Hunan	12,665	195.86	
Jiangxi	9,834	225.87	
Anhui	2,353	90.06	
Jiangsu	646	14.17	
Total	32,670	1,079.51	

Table 4. *Decrease of lake areas in the middle-lower Changjiang River basin since 1950 as a result of the accretion and reclamation.*

Lake	Province	Present Area (km^2)	Lake Area Decrease	Source
Dongting Lake	Hunan	2,820	1,620	See Table 1
Changhu Lake	Hubei	122.5	28.0	
Sanhu Lake	Hubei	4.0	90.0	
Honghu Lake	Hubei	402.0	258.0	
Datong Lake	Hubei	9.0	101.0	
Dasha Lake	Hubei	33.3	63.0	
Poyang Lake	Jiangxi	3,050.0	940.0	
Taihu Lake	Jiangsu	2,886.6	299.2	Nanjing Geography Institute, 1985
Total		9,327.4	3,399.2	

basin, SDR also decreases as the area of drainage basin increases (MU and MENG, 1982). Up to now, there has been no systematic study done on SDR in the Changjiang River basin. However, it can be expected that in the Changjiang River basin with an area as large as 180×10^4 square kilometers, the SDR would be small enough to obscure the effect of sediment yield increase on the sediment output from the basin. Meanwhile, the human activities in the past decades have exerted dual effects on the changes of SDR. On the one hand, as stated above, they contributed considerably more sediments by intensifying the erosional processes on land surface. On the other hand, a large number of reservoirs built in the last few decades have functioned as sediment traps which has reduced the sediment inputs into the branch river. In the upper basin, for example, the total volume capacity of reservoirs built in the last 40 years is estimated to be more than 166×10^8 cubic meters, of which about 40% is located in the Jialing River basin, an area of extraordinary high sediment yield. The field measurements suggest that the annual loss of reservoir capacity in the upper basin totals to about 3×10^8 cubic meters (LEADING GROUP, ACADEMIA SINICA, 1988). In the mid-lower basin, the reservior capacity had reached up to $1,079 \times 10^8$ cubic meters from the 1950's to the year 1979 (Table 3). During the same period, sedimentation processes and land reclamation has greatly decreased the areas of the natural lakes. The total areal decrease of the major lakes listed in Table 4 amounts to 3,399 square kilometers. Therefore, the human activities have exerted a dual effect. They create a large number of reservoirs and at the same time rapidly reduce the areas of natural lakes. Both the natural lakes and the man-made reservoirs are major sediment traps which to a large extent determines the changes of SDR. Although it is presently difficult to evaluate its net effect, the author believes that the change of SDR in the river basin as a result of human activities is very small, as is reflected by the changes of sediment discharge from the river mouth since the early 1950's.

CONCLUSION

The rapid deltaic progradation after 2,000 BP is not induced by ancient anthropogenic activity in the Changjiang River drainage basin. There is no evidence that suggests either a systematic increase of the sediment discharge since 2,000 BP, or a significant difference in sediment discharge between the two periods before and after about 2,000 BP. After the post-glacial sea level rise, a headward aggradational process had taken place in the mid-lower river-bed and the adjacent flood-plains. A preliminary estimate indicates that about 10% to 20% of the total annual sediments from the drainage basin was deposited in the middle and lower reaches of the Changjiang River from 6,400 BP to 1,500 BP. This reduction of sediment discharge into the sea may explain the very slow deltaic progradation in this period. Additionally, because the deep-water deltaic sedimentary basin attracted more sediments at this time, the proportion of sediment discharge in shoreline acretion is reduced.

The development of Chenier Plain, aged from 6,400 BP to 3,500 BP, is a product of the coast profile adjustment. The abundant shell composition in the chenier-like deposits indicate that the direct sediment input from the Changjiang

River into the shallow-water coastal areas is considerably lower. From about 3,500 BP to about 1,500 BP a period of the land-forming discontinuity occurred when the above-mentioned adjustment had largely been completed, yet the longitudinal river-bed profile adjustment had not yet come to an end. The rapid deltaic progradation began after about 2,000 BP when the two kinds of adjustment had largely come to an end.

Over the past 40 years, although the Changjiang River drainage basin has experienced an unprecedented intensity of modification by human activities, there is no indication suggesting a significant increase of sediment discharge into the sea. The anthropogenic effects on the sediment output from the upper basin, if any, are reflected only when abnormally intense precipitation occurs in certain tributary basins and a high sediment yield results, as was the case in the early 1980's. This is mainly due to the sediment delivery ratios being very small in such a large drainage basin as the Changjiang River, and because the anthropogenic modification has shown to exert a dual effect on the sediment discharge that flows into the sea. The extensive flood-plains and large lakes in the middle and lower basins have functioned as important sinks for the sediments from the upper basin. These conclusions also indicate that the intensity of ancient human activity in the drainage basin was not responsible for producing any significant increase of sediment input into the sea from the period before 2,000 BP to after 2,000 BP.

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