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SEDIMENT DISCHARGE OF THE HUANGHE RIVER AND ITS EFFECT ON SEDIMENTATION OF THE BOHAI SEA AND THE YELLOW SEA

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ABSTRACT: The Huanghe (Yellow) River, with annual sediment discharge about 11 $\times 10^8$tons, contributes about 17% of the fluvial sediment discharge of world's 21 major rivers to the ocean because its middle reaches flow across the great Loess Plateau of China. Sediment discharge of the Huanghe River has a widespread and profound effect on sedimentation of the sea. The remarkable shift of its outlet in 1128—1855 A.D. to the South Yellow Sea formed a large subaqueous delta and provided the substrate for an extensive submarine ridge field.The shift of its outlet in the modern delta every 10 years is the main reason why with an extremely heavy sediment input and a micro-tidal environment, the Huanghe River has not succeeded in building a birdfoot delta like the Mississippi. The Huanghe River has consistently brought heavy sediment input to sea at least since 0.7 myr.B.P. Paleochannels, paleosols, cheniers and fossils on the sea bottom indicate that the Yellow Sea was exposed during the late Quaternary glacial low-sea level and the Huanghe River had crossed the continental shelf, discharging its sediment to the Okinawa Trough in about 25,000—15,000 yr.B.P.

KEY WORDS: Huanghe River, sediment discharge, Yellow Sea, Bohai Sea, sedimentation

I. ESSENTIAL HYDROLOGIC CHARACTERISTICS OF THE HUANGHE RIVER

1. Very Small Water Discharge but Extremely Heavy Sediment Load

As the Huanghe River mainly flows through a semi-arid region, with a mean annual precipitation of only 400mm, its water discharge is very small. In its lower reaches, the river bed stands 3—5m(max.10m) higher than the alluvial plain and practically no tributary joins the main stream. Therefore,its water discharge gradually decreases down-stream owing to seepage. Thus, the discharge at Huayuankou is 1,470 m^3/s, while that is only 1,330 m^3 / s at Lijin, less than a tributary (such as the Wujiang River) of the Changjiang (Yangtze) River.

About 90% of sediment load of the Huanghe River comes from the Loess Plateau. At Toudaoguai Station, before the river enters the Loess Plateau, the river water is comparatively clean,with mean sediment concentration of6.11 kg / m^3. But at Longmen Station,after the river flows through a major part of the Loess Plateau,mean sediment concentration rapidly increases to 32.4kg / m^3 or about 5 times that of Toudaoguai. Therefore, although a greater part of water discharge of the Huanghe River comes from its upper reaches, 90% of its sediment load originates from the Loess Plateau (Fig.1).

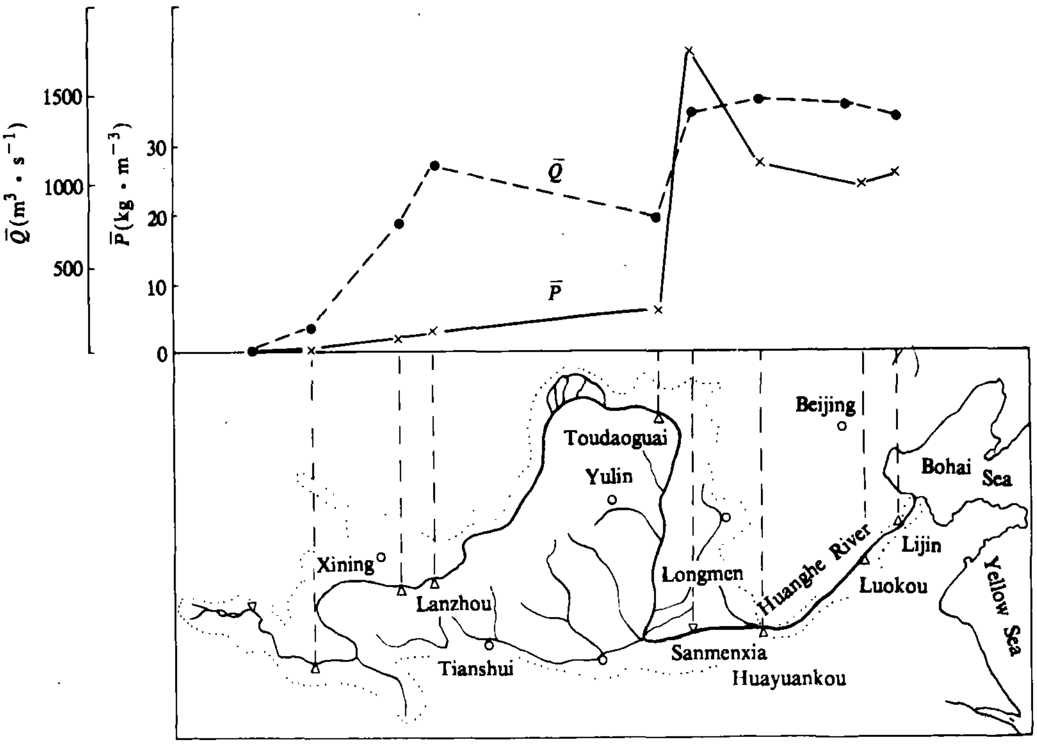

Fig.1 The Huanghe River Basin,showing 30–year average(1950—1979) of water discharge and sediment concentration data for nine stations along the river. Note the abrupt increase of sediment concentration after the river flows through the Loess Plateau. $\bar{Q}$ = water discharge and $\bar{P}$ = sediment concentration

2. High Sediment Concentration in a Very Short Period

Owing to the strong monsoon character of rainfall, about 70% of the annual sediment load appear in July to September. Rainfall on the Loess Plateau occurs mainly as very heavy storms (Table 1), which accounts for 70% of total rainfall from June to August.

Table 1 Maximum rainfall in 24 hours

Station	Yulin	Suide	Wugong	Taiyuan
Rainfall(mm)	136.3	133.0	138.7	183.5

In a few extremely heavy storms,100mm of rainfall may fall in 1 hour,and 59.1 mm of rainfall in 5 minutes has been recorded, which is one of the highest rainfall record in the world. At Shiwan Station,northwestern shaanxi,212.6 mm of rain fell in 6 hours and 25 minutes on July 23, 1971, which is 43% of total precipitation of the locality.At Toudaoguan Station,on August 12, 1978, 93 mm rainfall in 45 minutes were recorded. There are usually 6—12 heavy storms in a year, forming floods with a very high sediment concentration.1 / 4 to 1 / 3 of the annual sediment load can be produced in one single such flood (Table 2). In the lower reaches of the Huanghe River,two floods of exceptionally high sediment concentration in July and August 1977 produced sediment discharge of 20.8×10^8tons,more than annual mean sediment load at Sanmenxia. In Yanan area,Shaanxi, 225 mm of rainfall occurred between the evening on 4 July and the morning on July 6, 1977, and daily sediment discharge at Gangouyi Station on the Yanhe River reached 90.7×10^6tons or 6 times that of annual sediment discharge of Gangouyi in 1976.

Table 2 Maximum sediment concentration and total sediment load during high–concentration floods at Longmen

Time	Duration (h)	Maximum sediment concentration (km / m^3)	Total sediment load in the flood	
			10^8tons	% of the year
July 18(09.00)— July 20(19.00), 1966	58	933	4.53	26.5
August 2(00.00)— August 4(24.00),1970	72	826	4.97	35.3

3. Large Variability in Annual Water Discharge and Sediment Load

On account of the great variability of the rainfall of the drainage basin,the variability of the discharge and sediment load of the Huanghe River is unusually great. At Lijin,according to 1949—1973 data,the annual discharge in the highest water year is 4.38 times that of the lowest water year,while the difference in the annual sediment load amounts to 5.25 times(Table 3).

Table 3 Variability of the annual discharge and sediment load at Lijin, 1949—1973

Year	Annual discharge (10^8m^3)	Annual sediment load (10^8tons)
1958	596.7	21.00
1964	973.1	20.30
1972	222.8	4.08

At Shaanxian Station where the hydrological record is longer,the variability of the annual sediment discharge is even more remarkable. Here,the largest annual sediment discharge is 39.1×10^8 tons (1933), in contrast to the smallest annual sediment discharge of 4.88×10^8 tons (1928).

In 1987, due to unusually dry climate and man-induced factors, annual sediment discharge at Lijin recorded an all-time low of 0.96×10^8 tons, less than 1 / 10 of the mean value.

4. Water–Sediment Correlation Curves

Using 1950–1979 data,correlation curves of mean monthly water discharge and

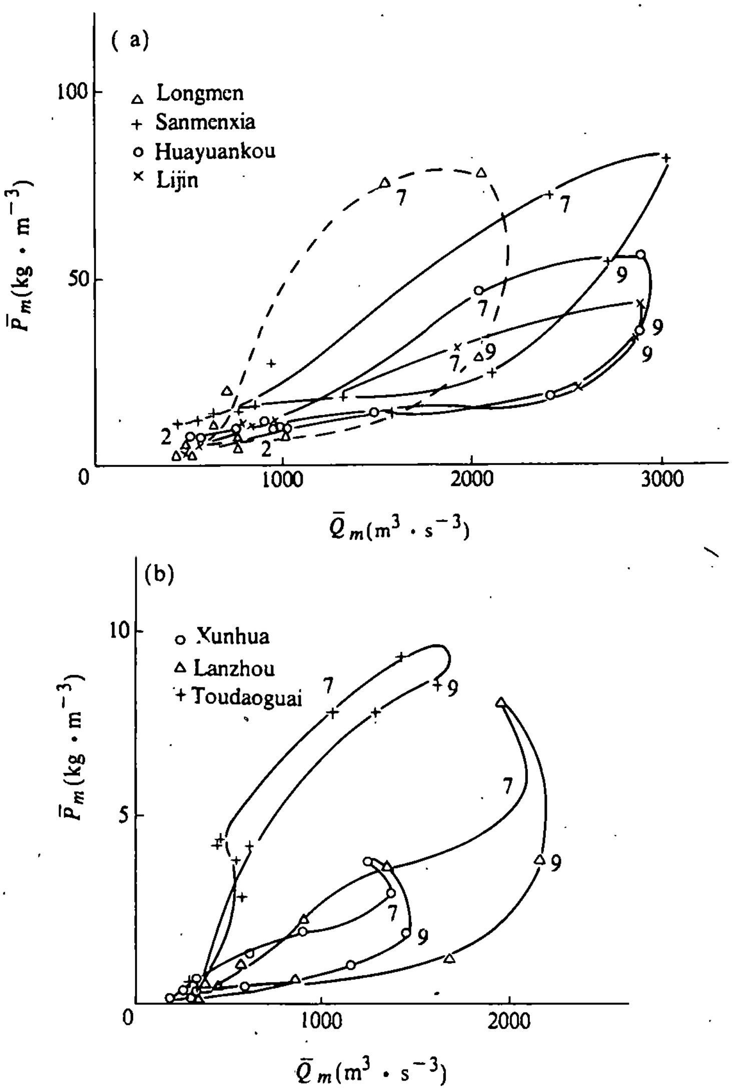

Fig.2 (a) Correlation curves of mean monthly water discharge ($\overline{Q}m$) and mean monthly sediment concentration ($\overline{P}m$) for Lijin, Huayuankou, Sanmenxia and Longmen(i.e.below the Loess Plateau).(b) Correlation curves of Qm and Pm for Toudaoguai, Lanzhou and Xunhua(i.e. above the Loess Plateau)

mean monthly sediment concentration have been drawn for representative stations. The curves are all clockwise (Fig.2), showing that the peak discharge and peak sediment load occur almost synchronously,which is different from the lower reaches of the Changjiang River where a different climatic regime and the presence of large lakes have resulted in curves of a counter–clockwise pattern (Fig.3) [1-2].

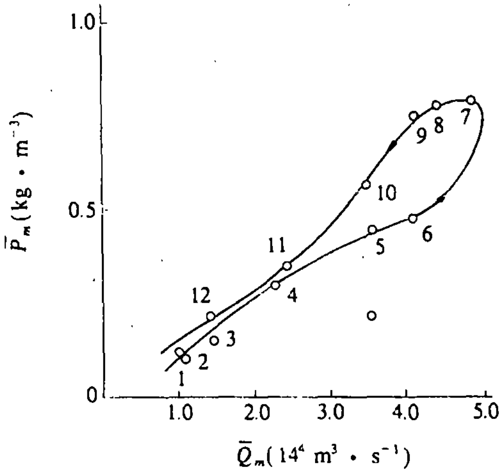

Fig.3 Correlation curve of Datong on the Changjiang River, note its counter clockwise pattern

5. Effect of Man's Activity

Effect of man's activity on fluvial sediment discharge is especially striking in the Huanghe River. Soil conservation and vegetation on the Loess Plateau have a distinct influence on sediment concentration of the Huanghe River and determine the frequency of floods in its lower reaches. After exhaustive study of historical literature,Professor Tan Qixiang pointed out that between 69 A.D. and 1069 A.D., there were only a few floods in the lower reaches of the Huanghe River,but between 168 B.C. and 11 A.D., there were 10 floods in the lower reaches of the Huanghe River, inflicting heavy damages. This is largely due to the fact that the Han population of the Loess Plateau decreased from 2,410,000 in 2 A.D. to 256,000 in 140 A.D. It was not increased until 600 A.D. Therefore,soil erosion was not so serious during 69 A.D.to 600 A.D. [3].

The construction of the Sanmenxia Reservoir had a distinct influence on the sediment discharge of the Huanghe River. The reservoir, with a capacity of 96 $\times 10^8 m^3$, was completed in September 1960. From September 1960 to October 1964, 45.91 $\times 10^8$tons of sediment accumulated in the reservoir. Compared to the years before the construction of the reservoir,only 32% of the total sediment load was carried to the lower reaches.

II. SEDIMENT DISCHARGE TO THE SEA

The annual suspended–solid discharge of the Huanghe River is given as 20.8 $\times 10^8$

short tons by Holeman (1968) or 17.5×10^8 metric tons(average 1933—1958, Shaanxian Station). This represents the suspended–solid discharge of the river when it just leaves the Loess Plateau. Although this is the actual largest sediment discharge value in the river,it is not the amount of sediment delivered to the sea. Below Sanmenxia,about one–quarter of the total suspended load is deposited on the river bed and does not reach Lijin; this is especially true for its coarse population (> 0.050mm) (which constitutes 60%—80% of the total bed sediment in the main channel). For example, during July 1950— June 1960,a little over 17×10^8metric tons of sediment was carried to the lower reaches per year,of which only 13.20×10^9tons reached Lijin and more than 3.5×10^9tons of sediment was deposited on the river bed between Shaanxian and Lijin,so that the stream bed rises about 10 cm per year. Therefore, for the sediment discharge of the Huanghe River to the sea,the data of Lijin which is only 100 km from the mouth should be taken instead of that of Shaanxian about 700 km upstream from Lijin.

The annual suspended sediment load at Lijin is closely related to water discharge and number of storms in the Loess Plateau. For example,1980 was a dry year; the annual water discharge at Lijin was 189×10^8 m^3, or 43.8% of the mean value and the annual sediment load also decreased to 3.08×10^8tons, or 28.8% of the mean value . On the contrary, in 1983, the sediment load was 5.42×10^8tons,or 50.6% of the mean value, but the water discharge was quite considerable, $297\times10^8m^3$, or 69% of the mean value. This is mainly due to the fact that there were not many storms on the Loess Plateau in 1983.

The sediment discharge of the Huanghe River is mainly concentrated in a few large floods in July and August. The sediment discharge in winter (Dec.to Feb.) is only 1.8% of the annual total and that in spring (March to May) is only 7.2% of the annual total. At Lijin,the river channel is often dry for about 10 days during April to June. Great seasonal variation of sediment discharge of the Huanghe River must have considerable effect on sediment dynamics of the coastal zone of the delta.

From Table 4, it can be seen that owing to the construction of Sanmenxia Reservoir, the sediment discharge at Lijin reduced by about one third between 1960 and 1964. It were because the measures for improving the reservoir have been adopted that the sediment discharge has gradually returned to the normal (average about 11×10^8tons), but it is still considerably smaller than before the building of the reservoir (Table 4).

Table 4 Fluctuations of annual sediment discharge at Lijin during different periods

	1950—1959	1960—1964	1964—1973
Annual sediment discharge (10^8tons)	14.63	9.81	11.63

III. EFFECT ON SEDIMENTATION OF THE BOHAI SEA AND THE YELLOW SEA

It is well–known that the Huanghe River frequently shifted its outlet to the sea during historical time. The most remarkable shift was between 1128 and 1855 when its outlet shifted to North Jiangsu and it flowed directly into the South Yellow Sea.

In the late Quaternary,the Yellow Sea was exposed as the land through which the Huanghe River flowed into the Okinawa Trough [4,5] . Therefore, the Huanghe River also has marked effect on sedimentation of the Yellow Sea.

For most of the time, the Huanghe River enters the Bohai Sea. In the modern delta (formed after 1855),the river changes its outlet to the sea almost every 10 years. Two major recent changes of the outlet are: a shift to near Diaokou in 1964 and to Qingshuigou in 1976. Every time a new outlet enters the sea, coarse silts are rapidly deposited near the river mouth, forming spits which extend into the sea as birdfoot–like elongated sand bodies,at a rate of about 7—8 km / yr. For example,from February 1964 to April 1965, the river mouth spit near Diaokou extended nearly 10 km into the sea. Between 1964 and 1976, with the river mouth spits as the framework,a small bird–foot delta was formed. however, since 1976, with the shift of the river outlet to Qingshuigou, the spits and coast near Diaokou were rapidly eroded and retreated. A study of LANDSAT images shows that,from 1976 to 1981,the coast near Diaokou retreated about 6 km and the old spits were cut and almost disappeared. A field survey in July 1984 showed that miniature cheniers, in the form of shell beds,began to accumulate along this part of the coast, whereas, at the present river mouth at Qingshuigou,the coast has been rapidly prograding since 1976. In some localities it has extended as much as 12 km seaward between May 1976 and May 1977 (Fig.4). As the tidal range and wave energy in the coastal zone of the Huanghe River Delta are small and the sediment supplied by the river great,it may be asked why a bird–foot delta like the Mississippi has not been formed. Evidently,the answer mainly lies in the great frequency of movement of the river mouth.

The suspended sediment of the Huanghe River at Lijin is rather fine, with an mean diameter(Md) of only 7μm (Table 5).

Table 5 Grain size of the suspended sediment at Lijin

Grain size(mm)	0.063—0.032	0.032—0.016	0.016—0.008	0.008—0.004	< 0.004	Md
Percent of total	7.10	12.10	25.10	23.70	32.30	0.007

It is estimated that of the total suspended sediment at Linjin,24% goes into the construction of a subaerial delta,40% is deposited in the nearshore zone(which includes the shallow sea 20 km offshore from the tidal flat) and the remainder(36%) is transported and diffused to the sea beyond [6] .

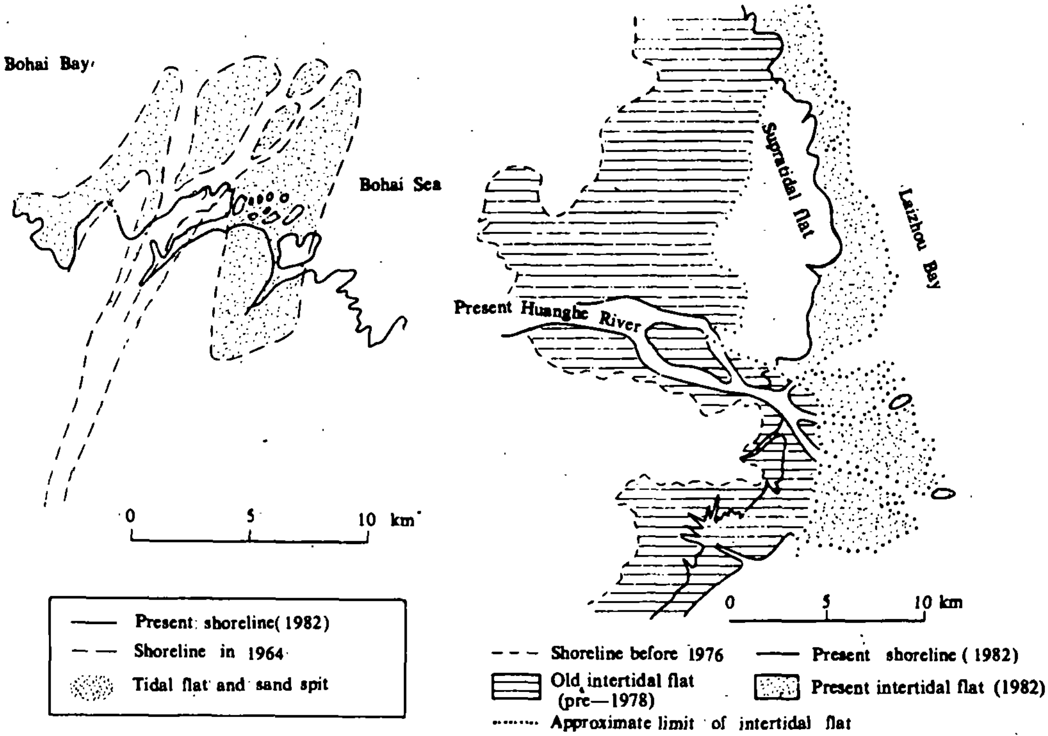

Fig.4 (a) Changes of the coastal zone near Diaokou in the modern Huanghe River Delta due to shift of outlet of the Huanghe River, 1964—1982 (modified after LANDSAT imagery). (b) Changes of coastal zone near Qingshuigou in the modern Huanghe River Delta due to shift of outlet of the Huanghe River, 1964–1982 (modified after LANDSAT imagery)

In the coastal zone,the copious supply of suspended sediment from the Huanghe River is transported by currents to build wide mud–flats along the Bohai Sea and North Jiangsu which,with a width of 10 km,are the widest and most rapidly prograding mud flats in China [7] .

The changes of the outlet of the Huanghe River have had a profound influence on the evolution of tidal mud–flats. Before 1976,mud from the Huanghe River drifted mainly towards the northwest, and consequently,a greater part of the mud–flat along Bohai Bay was prograding. Since 1976,with the shift of the river mouth to Qingshuigou, a major part of the fluvial mud has drifted to the south instead of the northwest.

As can be vividly seen on the LANDSAT image of October 5, 1978, a distinct littoral mud stream is now flowing southward,reaching the head of Laizhou Bay (Plate I: 1). Moreover, both oceanographical data(1983—1984) and NOAA–7 satellite images (July 14, August 15, September 14 and September 24,1983) prove that there exists a turbidity front north of the turbid water plume from the present Huanghe River mouth. These satellite images were taken under N, E, NW and SW wind and quiet conditions respectively (Plate I: 2). The turbidity front is located at 37° 50′N, south of which the suspended sediment concentration is 300 mg / L and salinity is 10%,whereas north of the front it is 50 mg / L and > 20%. The boundary between yellowish fresh water and clean,saline seawater can be clearly seen from a ship sailing along the front,the surface of the former being slightly higher than that of the latter. Computer analysis of LANDSAT tapes (CCTs) reveals that there are a series of clockwise eddies moving southward from the present Huanghe River mouth, bringing sediment with them. Therefore,since 1976,the mud–flat south of the Qingshuigou has been prograding and a wide mid–flat is formed, reaching more than 10 km in width near the Guangli River mouth. However,north of the Qingshuigou,a greater part of the mud–flat,together with the coast,is now suffering from erosion and recession. Such rapid and marked changesinthe coast within a man′s lifetime is perhaps unique in deltas of major rivers of the world.

The wide mud–flat along the coast of North Jiangsu has been formed by sediments of the abandoned Huanghe River which flowed into the South Yellow Sea for more than 700 yr. (1128—1855). Since the shift of the river into the Bohai Sea,the coast of the delta of the abandoned Huanghe River has experienced a rapid retreat and a line of low cheniers has been formed. Outside the mouth of the abandoned Huanghe River, a large subaqueous delta has formed in the South Yellow Sea. The outer edge of the subaqueous delta lies at about −25 m where it slopes with a steeper gradient to the −50 m isobath. The sediment of the subaqueous delta is distinguished by its high $CaCO_3$ content. The 10% isopleth of $CaCO_3$ makes a large lobe outside the mouth of the abandoned Huanghe River (Fig. 5).

In the offshore zone of modern Huanghe River Delta, some areas of sea bottom are covered with fluid mud. In the Sino–Japan joint exploration area (water depth > 15 m), the fluid mud is 40—50 cm thick, with a water content of 64% .The fluid mud banks in the offshore zone form shelter area for small fishing boats during storms. These mud banks are also common in the offshore zone of the Mississippi Delta [8] .

The suspended sediment of the Huanghe River,derived mainly from loess,has a characteristic mineral assemblage and chemical composition. The surficial sediment of Laizhou Bay and the southern part of Bohai Bay is distinguished by a high content of muscovite,carbonate minerals,plagioclase and hornblende,and by a low content of magnetite. These properties are essentially similar to the mineral assemblage of the lower reaches of the Huanghe River. However, the surficial sediment of those parts of the Bohai Sea influenced by sediment from the Liaohe and Luanhe rivers has a very low content of muscovite,carbonate and hornblende [9] . This shows that suspended sediment of the Huanghe River mainly diffuses to Laizhou Bay and the southern part of the Bohai Sea.

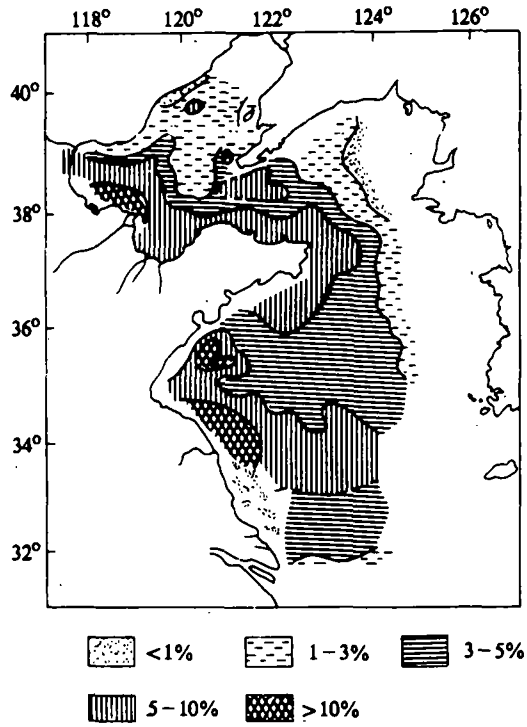

Fig.5 $CaCO_3$content in sea bottom sediments (after QIN 1983)

The distribution of the suspended–sediment concentration in the surficial water of the Bohai Sea also clearly marks the area of diffusion of the Huanghe River sediment. The suspended solid concentration of the surficial seawater was very high off the old Huanghe River mouth,in Bohai Bay and Laizhou Bay in July 1958 and 1962,reaching 100—150 mg / L off the old Huanghe River mouth [10] .A survey in the summer of 1984 by the staff of Shandong College of Oceanography showed that, since the shift of the outlet of the Huanghe River to Qingshuigou in 1976, the distribution of the concentration of suspended solids in the nearshore zone has changed markedly. The suspended–sediment concentration in the surficial seawater off the present river mouth is greater than 100 mg / L, whereas off the former river mouth near Shunxianguo it is less than 50 mg / L.

Finer particulates of the Huanghe River are carried by the Bohai Current through the south Bohai Strait into the Yellow Sea, where they are transported by the Yellow Sea Longshore Current southward to near the Changjiang River mouth. During the summer, especially in the flood years of the Changjiang River, they may join with the water plume of the Changjiang River and reach the sea south of Cheju Island. From a study of clay mineralogy,it has been shown that the South Yellow Sea (about 34° N ,123° E) has received clay minerals supplied by the Huanghe River as well as by the Changjiang River [11] . During strong monsoon surges from mid–October to February,the wind velocity may reach 40 knots / hr over the Central Yellow Sea when large waves with heights reaching 3—4 m are generated and fine sediments on the sea floor are resuspended. Highly turbid water is carried southward by the Liaodong Longshore Current in the coastal zone of the Liaodong Peninsula and by the West Korean Longshore Current in the coastal zone off the west coast of Korea; in the latter area,the volume of suspended sediment transported south has been estimated to be 25—250 $\times 10^6 m^3$ / yr., which is several orders of magnitude greater than the input from Korean rivers alone [12]. It seems that a wide mud–flat along the west coast of Korea and the east coast of the Liaodong Peninsula is incompatible with a small sediment discharge from the Korean and Chinese rivers that flow into this part of the Yellow Sea. The average annual sediment discharge of the Yalu River is only 1.10 $\times 10^6$tons (average 1958—1980) and the suspended–sediment discharge of the Kum River, Korea, is 5.6 $\times 10^6$tons / yr. This suggests that muds may be also derived from the resuspension of old sediments from the bed of the Yellow Sea or from muds carried by the Yellow Sea Warm Current (a branch of the Kuroshio). It appears that the suspended solids in the coastal zone of Korea and the Liaodong Peninsula probably come from various sources and are highly mixed. Therefore, intertidal mud–flats in this area bear no clear indication of having been derived from the Huanghe River.

It is well–known that the suspended sediments of the Huanghe River, derived from loess,have a high carbonate and CaO content,and a distinct montmorillonite peak by which they may be distinguished from suspended sediments of the Changjiang, Yalu and other rivers (Table 6).

Table 6 $CaCO_3$, CaO and clay–mineral content in loess and bottom sediment of the Huanghe River mouth*

	$CaCO_3$ (%)	CaO (%)	Clay minerals (%)			
			I	M	C	K
Loess(generally)	11.6					
Malan loess		7—8	68	9	12	11
Lishi loess		7—9	63—67	12—16	11	10—11
Wucheng loess		7—20	60	19	11	10
Bottom sediment of the present Huanghe River mouth		9.63	67	13	12	8
Bottom sediment in the Changjiang River mouth		3.5—4.2	75—79	2—4	C+K = 19—21	
Mashitai 50 km from the Yalu River mouth	Trace		59	1	30	10

* Data from Liu,Zheng and Zhang. Ages of loess(kyr.B.P.) Malan 1200—30; Wucheng 2400—1200. I = illite, M = montmorillonite, C = chlorite and K = Kaolinite.

X–ray spectra(X–ray analyses were carried out on a Philips diffractometer by the Nanjing Institute of Pedology, Academia Sinica) of separates(< 2μm) of intertidal flat

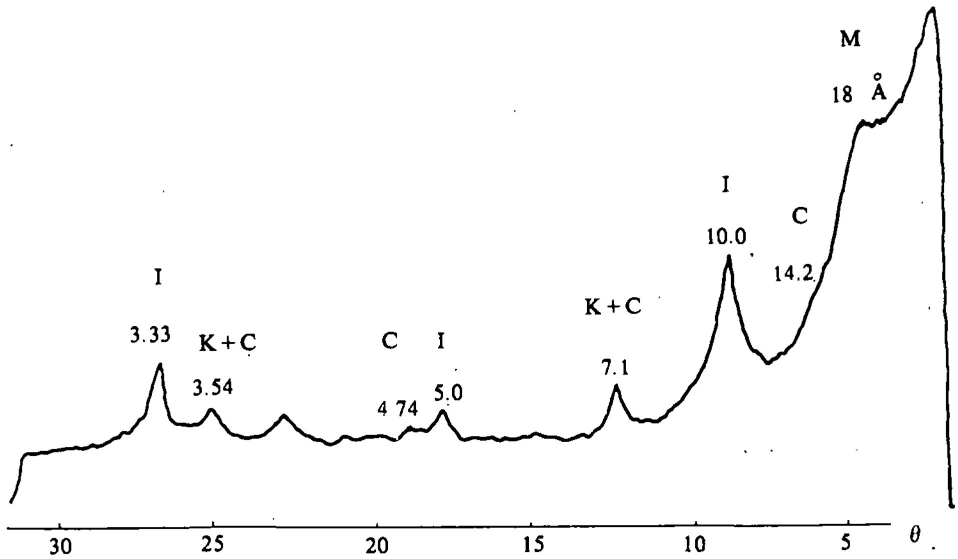

Fig.6 X−ray diffraction spectra of< 2μ sediments from the mouth of the abandoned Huanghe River

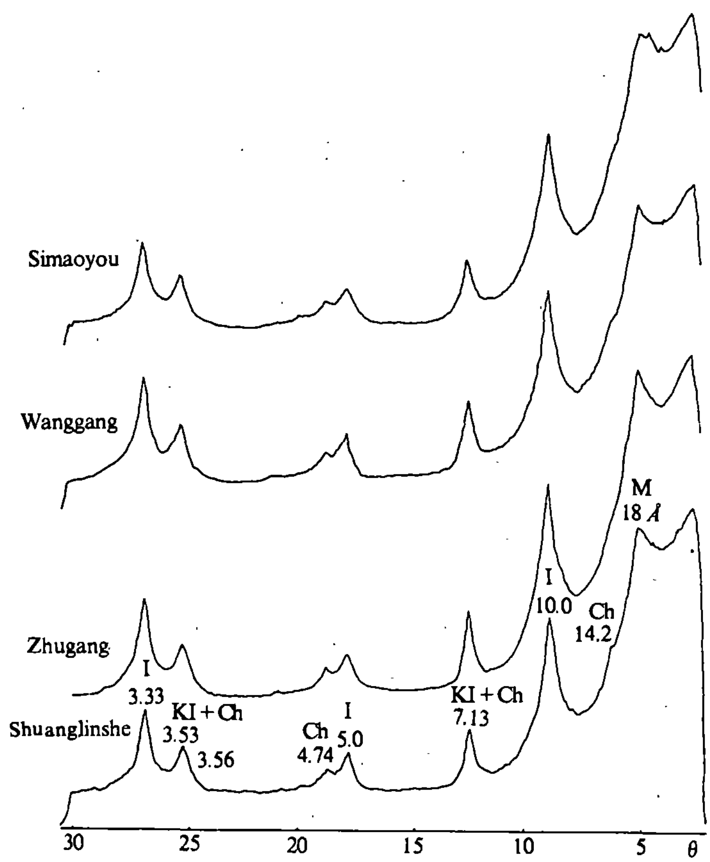

Fig.7 X−ray diffraction spectra of< 2μ sediment from tidal flat of Wanggang,North Jiangsu

sediments of Jiangsu Province show a distinct montmorillonite peak in sediments northof Jianggang (32° 40′N), which is lacking in the sediments from further south (Fig.6,7,8). This fact clearly proves that north of Jianggang,intertidal flat sediments are mainly derived from the abandoned Huanghe River, whereas south of Jianggang it is greatly influenced by sediments from the Changjiang River. Using montimorillonite / Chlorite+Kaolinite as an indicator of source material,the value is> 1.0 north of Jianggang and< 1.0 south of Jianggang (Fig.9).

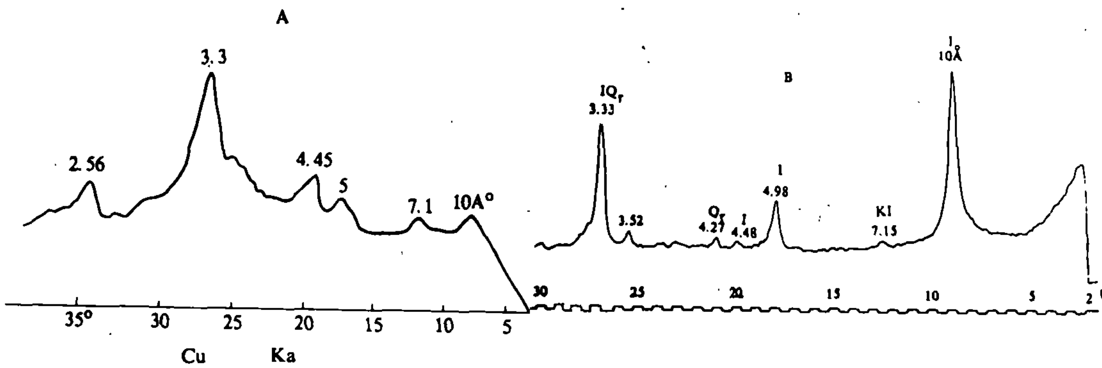

Fig.8 X−ray diffraction spectra of< 2μ sediments from bottom sediments of the Changjiang River mouth (A) and point bar of the Changjiang River at Nantong, Jiangsu Province

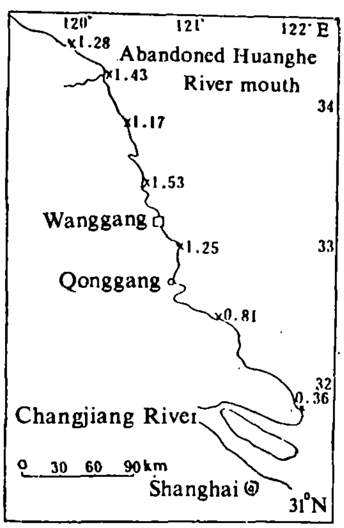

Fig.9 M / C+K ratio of< 2μ sediments from tidal flat of Jiangsu Province(after Zhen, P.B. et al., 1983)

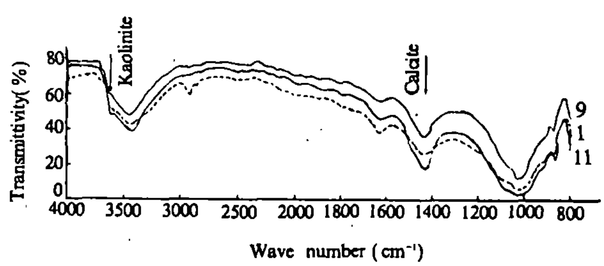

Fig.10 Infra−red spectra of< 2μ sediments from tidal flat of Wanggang,North Jiangsu
Legend: 1 =Zhugang; 9 =Wangang; 11 =Simaoyou

The infrared spectra of sediments north of Jianggang are characterized by a distinct calcite Peak, but near the Changjiang River mouth they are characterized by marked kaolinite peaks and an insignificant calcite peak(Fig.10,11). These results correspond well with data derived from drift bottle test and oceanographic survey in the coastal water of Jiangsu. Preliminary data from the sediments of the intertidal flat at Kulongshan, west of the Yalu River estuary,show that the Ca(0.58—0.65%) and $CaCO_3$ (trace) contents are very low,and the X–Ray spectra show no montmorillonite peak. These are very similar to sediments of the lower reaches of the Yalu River but are entirely different from sediments of the Huanghe River mouth (Fig.12). The clay–mineral assemblage of intertidal muds of the West Coast of Korea is illite (3):chlorite (1):kaolinite (1). Clay minerals from suspended particulate matter in water samples of the Yellow Sea off southwest Korea show a predominance of illite (70%),with lesser amounts of kaolinite (10%)and chlorite (13%);but montmorillonite is virtually absent [12] . This evidently indicates that the influence of the present Huanghe River sediment on this part of the Yellow Sea and Korean coast is insignificant.

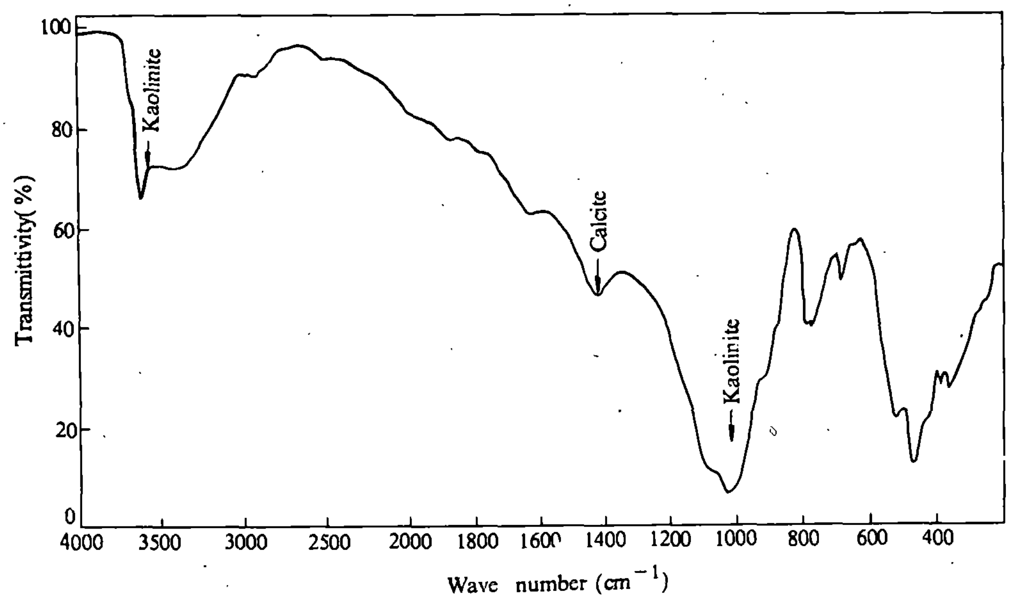

Fig.11 Infrared spectra of< 2μ sediments from point bar of the Changjiang River at Nantong, Jiangsu

IV. PALAEOCEANOGRAPHY

As more than 90% of the sediment of the Huanghe River comes from the Loess Plateau,it is interesting to note that recent paleomagnetic studies show that loess in China began to develop at about the Matayama–Gauss boundary about 2.40 myr. ago. However, the thickest loess layer(Lishi loess), which constitutes about 80% of the whole loess profile,began to accumulate about 1.20 myr. ago. Therefore,it can be assumed that since about 1.20 myr. the Huanghe River has consistently carried its heavy sediment load across the North China Plain to the Bohai Sea and the Yellow Sea.

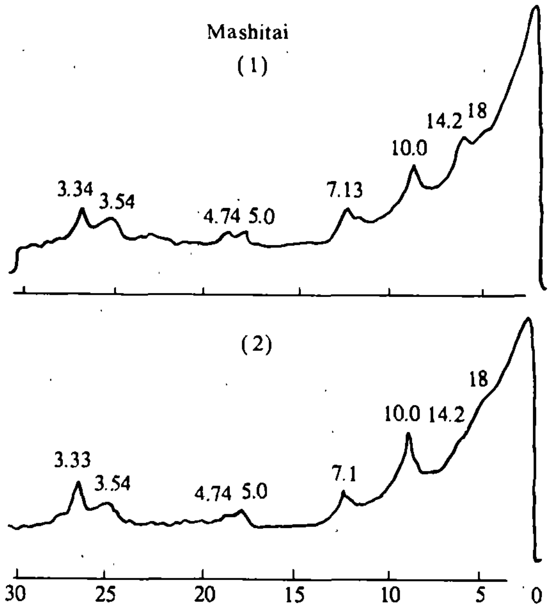

Fig.12 X−ray diffraction spectra of< 2μ sediments from the lower Yalu River (1) and tidal flat, west of Donggou (2)

However, during periods of regression or glacial low sea level, when a large part of the continental shelf of East China was exposed, the Huanghe River extended its course across the newly exposed plain, entering the sea further east from the present coast. The coastline was located at −80m in 72,000 yr.B.P. Between 25,000—15,000 yr.B.P. at the climax of the last glaciation, coastline of the East China Sea was once at −150m [4,13,14] i.e. at the present shelf break. Recent high− resolution seismic profiling has identified a series of buried channels on the middle and outer shelf, and, in or near these channels, fluvial deposits together with fresh water and estuarine fossils have been found [15,16]. In the Yellow Sea, between −50 and−70 m, coring has discovered four layers of paleosols dated 60,000—70,000 yr.B.P., 42,000—55,000 yr.B.P., 20,000—25,000 yr.B.P. and 11,000 yr. B.P. respectively (Fig.13). In some paleosol layers, the paleosol profile can still be clearly distinguished, its upper part rich in plant roots and detritus and its lower part containing carbonate concretions. These characteristics and chemical composition of paleosols on the shelf are similar to paleosols in the loess of North China. The ages of the four paleosol layers are approximately 60,000— 70,000, 42,000— 55,000, 20,000— 25,000 and 11,000— 15,000 yr.B.P., respectively (^{14}C and palaeomagnetic dating), indicating four periods of regression in the last 70,000 yr. when the shelf of the Yellow Sea was largely exposed. Near the present shelf break of the East China Sea, near the −150m isobath, a series of cheniers, dated about 15,000 yr.B.P. was discovered, showing unmistakably the approximate position of the coastline in 15,000 yr.B.P. when the Yellow Sea was entirely exposed. For example,on the outer shelf of the East China Sea,at 31° 45′N, 127° 15′E,a core reveals a shell layer at 230—250 cm below sea bottom. Shells are all estuarine and nearshore species, quite similar to those forming the present cheniers on the coast of the abandoned Huanghe River Delta. Therefore, a detailed investigation of long cores from the Okinawa Trough would be helpful in elucidating the effect of sediment discharge of the Huanghe River on oceans during recent geological time.

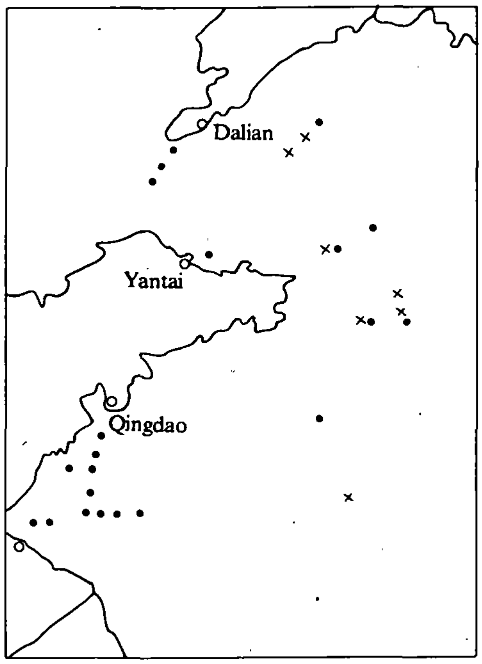

Fig.13 Late Quaternary paleosol and peat layers on the shelf of the Yellow Sea(data from the First Institute of Oceanography,National Bureau of Oceanography)

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Plate 1 LANDSAT imagery, October 5, 197ξ showing a distinct coastal mud stream from the present mouth , of the Huanghe River drifting southward to the Laizhou Bay. Wind E 2m / s.

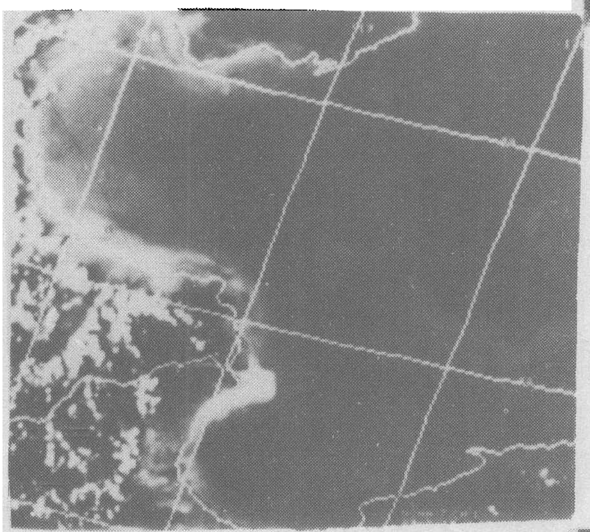

Plate 2 NOAA−7 imagery, August 15 , 1983, showing turbidity front north the present Yellow River mouth. Note also a distinct mud stream flowing southward from the present river mouth.Turbid water on the southern coast of the Bohai Bay is due to stronger wave action (the coast facing N E, the prevailing and strongest wind direction of this region) Wind, quiet.

Plate 3 NOAA−7 imagery, July 14, 1983 showing the fresh water plume drifting toward NE. A distinct turbidity front Can be seen North of the fresh water plume. Wind Nw, 4 m / s.