Journal of Coastal Research	6	3	559–572	Fort Lauderdale, Florida	Summer 1990

Geomorphological Development and Sedimentation in Qiantang Estuary and Hangzhou Bay

Chen Jiyu,[†] Liu Cangzi,[†] Zhang Chongle[†] and H. Jesse Walker[‡]

[†]Institute of Estuarine and Coastal Research
East China Normal University
Shanghai, P. R. C.

[‡]Department of Geography
Louisiana State University
Baton Rouge, LA 70803, U.S.A.

ABSTRACT

CHEN JIYU; LIU CANGZI; ZANG CHONGLE, and WALKER, H.J., 1990. Geomorphological development and sedimentation in Qiantang Estuary and Hangzhou Bay. *Journal of Coastal Research*, 6(3), 559–572. Fort Lauderdale (Florida). ISSN 0749-0208.

The Qiantang Estuary which fronts on Hangzhou Bay is a typical funnel-shaped estuary. It formed under specific geomorphological and hydrological conditions. This article discusses the development processes of the estuary and the large bar that occurs in it. The funnel-shape is a prerequisite for the formation of the bar which conditions the existence of the Hangzhou bore. There is a temporal sequence that extends from the time of the formation of the funnel-shaped estuary through that of the bar to the bore.

ADDITIONAL INDEX WORDS: *China, delta, deposition, estuary, bar, sediment flux, texture, tidal bore, tide, Yangtze.*

INTRODUCTION

The Qiantang River empties into Hangzhou Bay in the vicinity of Ganpu (Figure 1). The area of its drainage basin is 49,900 km^2, its mean annual discharge is 2.905 $\times 10^{10}$ m^3, and the quantity of mean annual sediment transport is 6.68 $\times$ 10^6 tons. The length of the estuarine region, from the tide-influenced limit at Luccibu (A in Figure 1) to the mouth of Hangzhou Bay (D), is 270 km. This zone can be divided into three sections: (1) the upper section (A-B), which is 83 km long. In it there are many islets and the river bed is relatively stable; (2) the middle section, known as the Qiantang River, extends from Wenjiayan (B) to Ganpu (C) and has a length of 101 km. It contains a large bar, is wide, shallow, and anastomosing, and has the famous Qiantang bore; (3) the offshore section, i.e. Hangzhou Bay (C-D), extends downstream from Ganpu for 90 km, is funnel shaped, and has a stable bottom.

The Qiantang Estuary is a typical funnel-shaped bay in contrast to the Changjiang (Yangtze River) which has formed a large deltaic system. The difference in the development of these 2 river mouth areas is related to sediment discharge. For example, the Changjiang transports 4.7 $\times$ 10^9 tons of sediment per year whereas the Qiantang transports only 5–6 $\times$ 10^6 tons or less than 2 percent as much.

The funnel-shape of the Bay gives rise to strong deformation ofthe tidal wave and strengthens the tidal current. The strong tidal current significantly influences the geomorphological processes and sedimentation in the Qiantang River and Hangzhou Bay. The study of the geomorphological and sedimentary processes in Qiantang River and Hangzhou Bay is of value to the theory of estuarine research and provides a scientific basis for land reclamation, channel control, and coastal protection. The upper section (A-B) was the subject of a paper by YU *et al.*, (1964).

89022 received 14 April 1989; accepted in revision 16 January 1990.

THE FORMATION OF THE FUNNEL-SHAPED HANGZHOU BAY

In plan view, Hangzhou Bay has a funnel shape with its width decreasing from mouth to apex. The width of the Lucaogang cross-section located in the bay mouth is 100 km, at Ganpu 20 km, and in the vicinity of Hangzhou, only 1

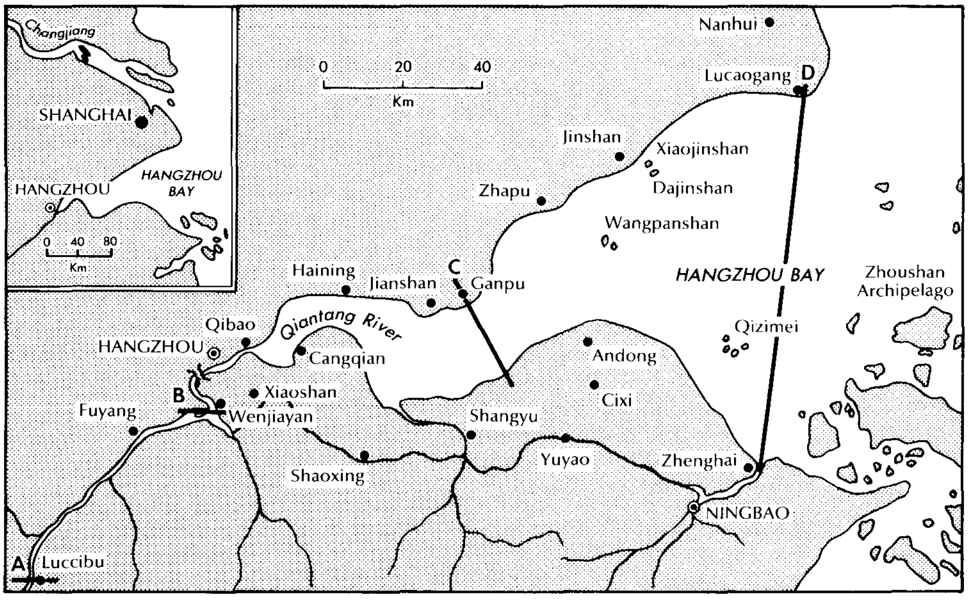

Figure 1. Location of the Qiantang Estuary.

km (Figure 1). The development of the funnel shape is related to the depositional history of the shorelines of Hangzhou Bay. This development has occurred in conjunction with the formation of the Changjiang Delta (Figure 2).

About 7,000 BP, during the period of postglacial transgression, sea water reached the river section upstream of Fuyang (CHEN, 1964). During that period, West Lake (situated in Hangzhou) was a lagoon (WANG PINXIAN and YE GUOLIANG, 1979). By 5,000 to 6,000 BP, the coastline of the Changjiang Delta was about 5 km to the west of the 3,000 BP line (Figure 2). At that time, Hangzhou Bay was a drowned valley. For 2–3,000 years, the coastline was relatively stable because of the small quantity of silt carried by the Changjiang (LIU *et al.*, 1985 and LIU and WALKER, 1989). During this period, Hangzhou Bay was not funnel-shaped.

After about 3,000 BP, human modification of the Changjiang drainage area resulted in a large increase in the quantity of sediment in the river and the delta advanced rapidly. By 400 AD, the coastline had moved eastward 15 to 20 km and reached the Ganpu-Wangpanshan-Zhoupu line (Figure 2). The southern coastline extended along the Xiaoshan-Cixi-Longcheng line. With continuous progradation of the Changjiang Delta, Nanhui Cape (a nodal point between the Changjiang Estuary and Hangzhou Bay) migrated north-eastward. In this way, the width of the Bay increased, resulting in deformation of the tidal wave and strengthening of the flood tidal current. The flood tidal current from Zhoushan Archipelago flowed toward the northern coastline of the Bay, and the coastline along the Wangpanshan region was eroded. In the 12th Century, the coastline retreated to the Ganpu-Dajinshan-Nanhui line. By 1250 AD, the Dajinshan and Xiaojinshan hills had become islands. In 1472 AD, a seawall of stones was built replacing an earthen dike in order to control erosion. While the western section of the northern coastline was being eroded, the front of the Changjiang Delta was prograding rapidly (CHEN, 1988). As a result, the northern coastline of Hangzhou Bay advanced 40 km eastward leading to the

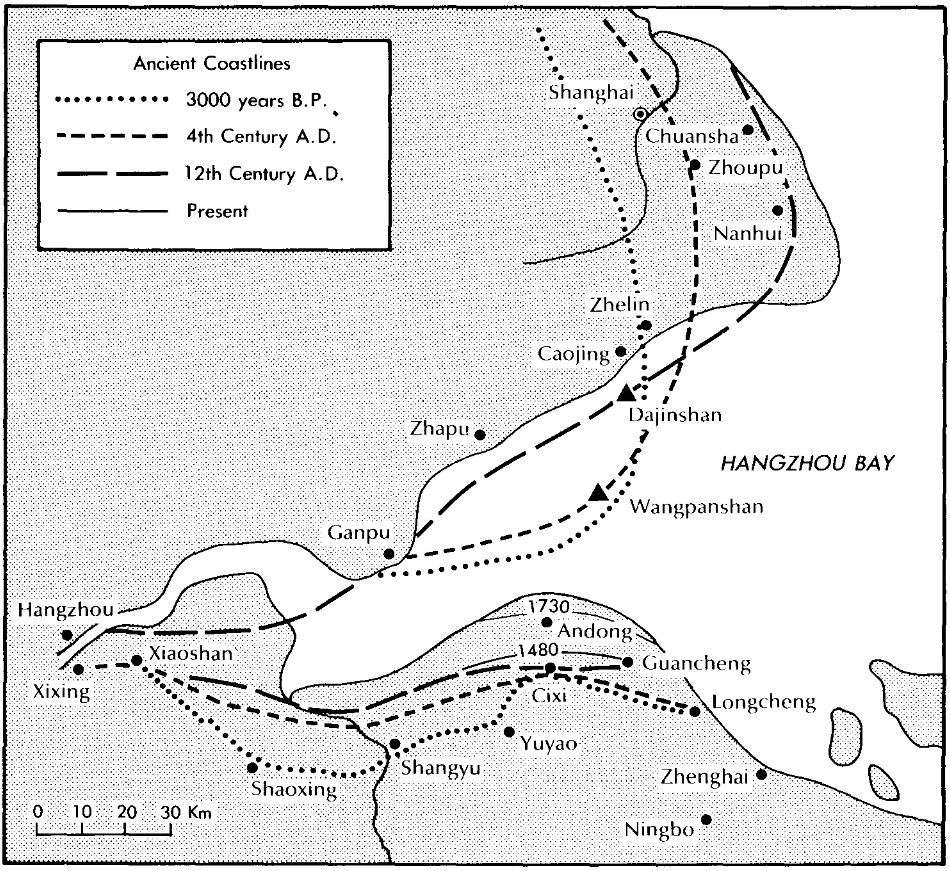

Figure 2. Coastline change in Hangzhou Bay through time.

modern configuration of the northern coastline of Hangzhou Bay (Figure 2).

The southern coastline of Hangzhou Bay aggraded slowly before the 14th Century. In the 13th Century, historical records show that there was a retreat of 8 km (CHEN, 1947). Since the 14th Century, the rate of siltation has been rapid; the maximum rate occurred in the vicinity of Andong. Its beach prograded 15 km in 600 years at a rate of 1 km/40 yrs and the southern coastline became arc-shaped projecting northward.

Historical records show that around 3,000 BP, Hangzhou Bay was a wide, drowned valley, and that the funnel shape had already begun to develop. In this period, because the bay mouth was relatively narrow, the quantity of tidal water entering the bay was less than today and the deformation of the tidal wave was not as extreme as it is today.

FORMATION OF THE LARGE BAR IN THE QIANTANG ESTUARY

Shape and Sequence of Bar Formation

On the longitudinal profile between Zhapu and Wenjiayan, there is a major bar (Figure 3). Its highest point, located betweenCangqian and Qibao, is 13 m higher than the bay bottom near Zhapu. The bottom gradient declines at the rate of 0.1 to 0.2 ppt downstream and 0.06 ppt upstream. The bar is 130 km long, 27 km wide, and has a maximum thickness of 20 m. The total volume is about 4.25×10^{10} m^3 (CHEN *et*

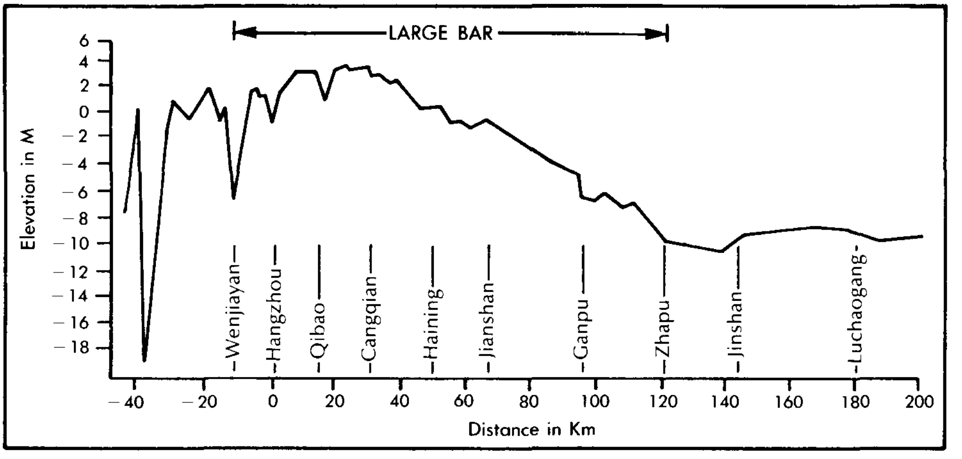

Figure 3. Longitudinal Profile of the Qiantang Estuary.

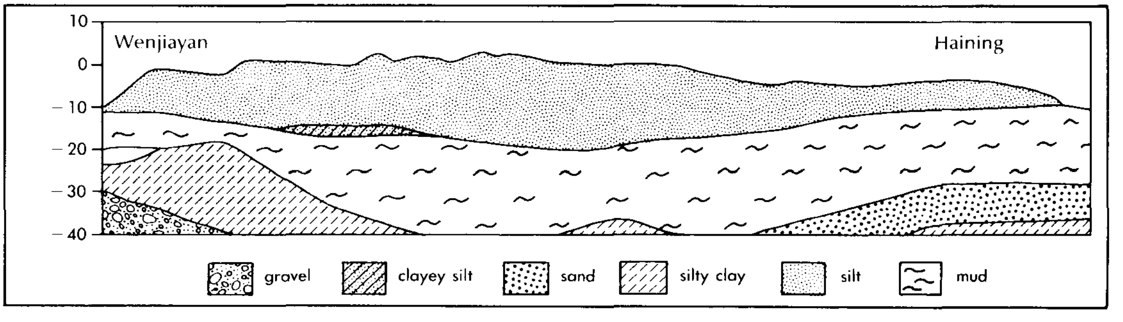

Figure 4. The longitudinal geologic profile of the large bar in Qiantang Estuary.

al., 1964). Its longitudinal and cross-sectional profiles are all convex.

The bar is mainly composed of silt.[1] The medium diameter of the grains is between 0.026 and 0.090 mm with those with diameters of 0.02 to 0.04 mm predominating. The deviation coefficient is about 1.2. It shows horizontal and oblique bedding. There are some lenses composed of silty clay, which are intercalated in the silt of the bar. The entire bar overlies mud layers of a marine facies that formed in the middle of the Holocene giving a coarsening upward Holocene sedimentary sequence. The bottom of the shallow-sea facies mud is uneven. Under it are late Pleistocene fluvial deposits (Figure 4). The sedimentary facies mentioned above, from bottom to top, have a vertical sequence—fluvial facies /shallow sea facies/ estuarine facies—which demonstrates the development of the sedimentary environment since the late Pleistocene in the bar region of the Qiantang Estuary.

1. Historically this bar has been referred to as a sand bar (Chen *et al.*, 1964).

Formation of the Bar

Sand bodies are built under specific geomorphological and hydrodynamical conditions. The formation of the bar is related to the funnel shape of the estuary which affects the nature of the tidal wave and the characteristics of freshwater runoff and sediment conditions.

Deformation of the Tidal Wave The constricting nature of the shorelines in the estuary results in increases in tidal range and tidal wave deformation as a tidal wave progresses riverward. As a result the velocity and therefore carrying capacity of the flood current is much larger than that of the ebb current. For example, in the Lucaogang section near the Hangzhou Bay mouth, the maximum vertical-mean flood and ebb current velocities are almost equal: 130 cm/sec and 131 cm/sec respectively. In the Wangpanshan section near middle of the Bay, the maximum vertical-mean velocities of the flood and ebb current are 206 cm/sec and 171 cm/sec respectively (LI and HU, 1987). Upstream of Haining, the flood current velocity is twice that of ebb current velocity (DAI, 1980) (Figure 5). The predominance of the flood current results in deposition within the Estuary.

Freshwater Discharge In the Estuary, there are two opposing currents, river flow and flood tidal current. The relative strength of these two currents determines the position of sediment deposition. According to data collected from 22 estuaries, QIAN *et al.* (1964) pointed out that the position of sand bar formation in estuaries is related to the ratio Q1/Q2 (Q1—bed-forming discharge, Q2—mean tidal discharge). When $Q1/Q2 < 0.02$, sediment is deposited inside an estuary and when $Q1/Q2 > 0.10$, sediment is deposited outside an estuary. The bed-forming discharge in the Qiantang Estuary is 1,980 m^3/sec, and the mean tidal discharge near Ganpu (near the dividing point between the Qiantang River and Hangzhou Bay) is about 1.9×10^5 m^3/sec. So Q1/Q2 is 0.01. Therefore, the depositional zone is located in the Qiantang River and a bar is built.

Nature of Sediment Transport In the Qiantang River, water is clear and the quantity of suspended sediment is small. The mean suspended sediment in the water column is 0.2–0.4 g/l. The total annual mean sediment transport is only 6.68×10^6 tons. Therefore, the Qiantang River is not the main material source of the bar. However, the mean suspended sediment capacity near Ganpu is as high as 3–4 g/l and the total quantity of sediment moved is as high as $1 \times 10E + 07$ tons per tidal period. So it can be concluded that most of the material building the bar comes from Hangzhou Bay.

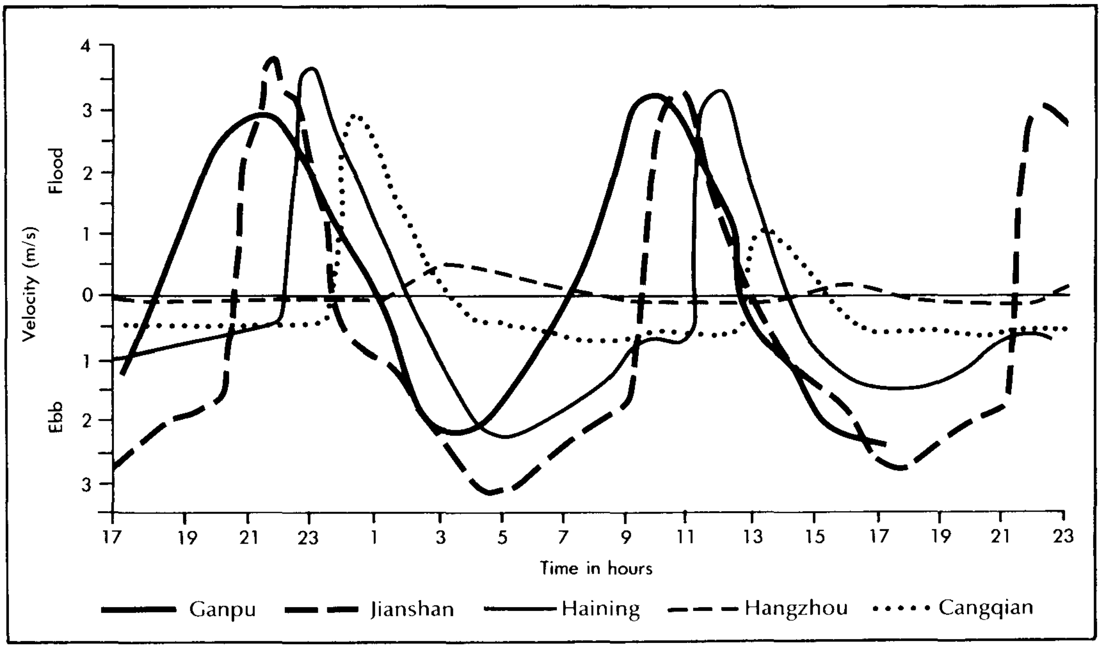

Figure 5. Flood and ebb velocity curves at selected stations.

The Bore

When the tidal wave propagates into the Bay, the narrowing geometry causes an increase in the tidal range. For example, the mean tidal range of Lucaogang near the bay mouth is 3.21 m, at Jinsha, 3.91 m, and at Ganpu, 5.54 m. At Ganpu the maximum range is 8.93 m.

Between Ganpu and Jianshan, when the wave is highly asymmetric, it begins to be affected by the bar (Figure 3) and soon breaks, forming the famous Qiantang bore (Figures 6 and 7) (CHEN *et al.*, 1964). The bore is at a maximum near Haining, where the height of the tidal wave averages 1–2 m, with a maximum height of over 3 m.

RIVER BED CHANGE

The bar between Wenjiayan and Ganpu changes character more frequently than elsewhere for several reasons, including:

(1) The bed in the bar section is wide and shallow. The mean depth is only 1–1.5 m. At low water, the ratio of width and depth ($\sqrt{B}/H$) is large. For example, the ratios in Cangqian, Haining, and Jianshan are 29.6, 37.3, and 44.6, respectively. They are almost equal to that of the Huanghe (Yellow River) bed which is famous for its shifting characteristics.

(2) The material in shoals and channels is mainly fine silt (D 50 = 0.02–0.04 mm) with small deviation, and its resistance to erosion is poor. A current with a velocity of 0.3–0.4 m/sec is enough to resuspend the particles.

(3) Tidal currents are strong. The maximum vertical-mean current velocity is 4 to 5 m/sec. Bed-building forces are very strong and the sediment-load concentration of the current is large. The maximum concentration is 51 g/l.

(4) The growth and decline of the relative strength of discharge and tidal current and the divergence of the dynamic axis of flood and ebb currents cause the main current to shift between the northern and southern banks.

Because of the shifting position of the main

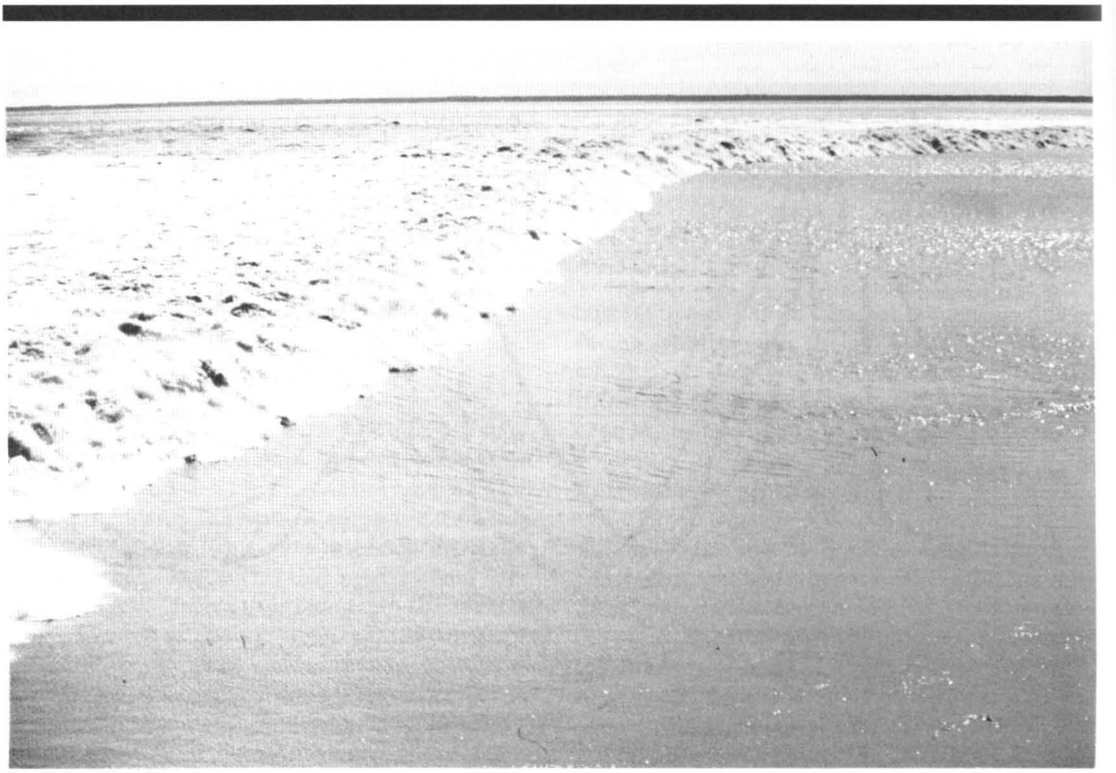

Figure 6. Front edge of the Qiantang bore on 17 October 1989. (Photo: H. J. Walker).

current the banks are formed and eroded irregularly. In order to protect the bank, sea-walls were built more than 1,000 years ago (CHEN, 1988). The rock sea-walls built in the Ming and Qing dynasties were major coastal engineering structures and rank with the Great Wall and the Grand Canal as the greatest engineering projects in ancient China.

In the historical period, the channel between Hangzhou and Jianshan changed course several times (Figure 8). Before 1695 AD, the channel passed through the South Passage between Zheshan and Kanshan. After 1695 AD, the South Passage silted up and the channel passed through the North Passage, north of Zheshan. In the short periods from 1680 to 1695 and from 1747 to 1759, the channel ran into Hangzhou Bay via the Middle Passage. Since 1759, the currents have passed through the North Passage.

In the past 200 years, the shorelines have been relatively stable but the thalweg has moved. During the period 1954–1969, the thalweg varied its position within a band 20 km wide (Figure 9). The movement of the thalweg is characterized by both multi-year changes and seasonal changes. In dry years, the ebb current weakens and the main current moves southward; in flood years, the ebb current strengthens and the main current moves northward. Some variation also occurs seasonally. With the shifting of the main current the shore is often eroded. The maximum recorded erosion was 245 m in one day.

With suspended sediment moving upstream and downstream, the height of the river bed often changes. The mean variation, upstream of Haining, is more than 4 m with a maximum of 9 m. The variation of river bed height is also related to the contrasting strengths of runoff and tide. Generally speaking, during a flood year or flood season, the river bed erodes, the height of the bar summit decreases, and the location of the summit moves downstream; during dry years or the dry season, the river bed silts up, the bar summit increases, and the posi-

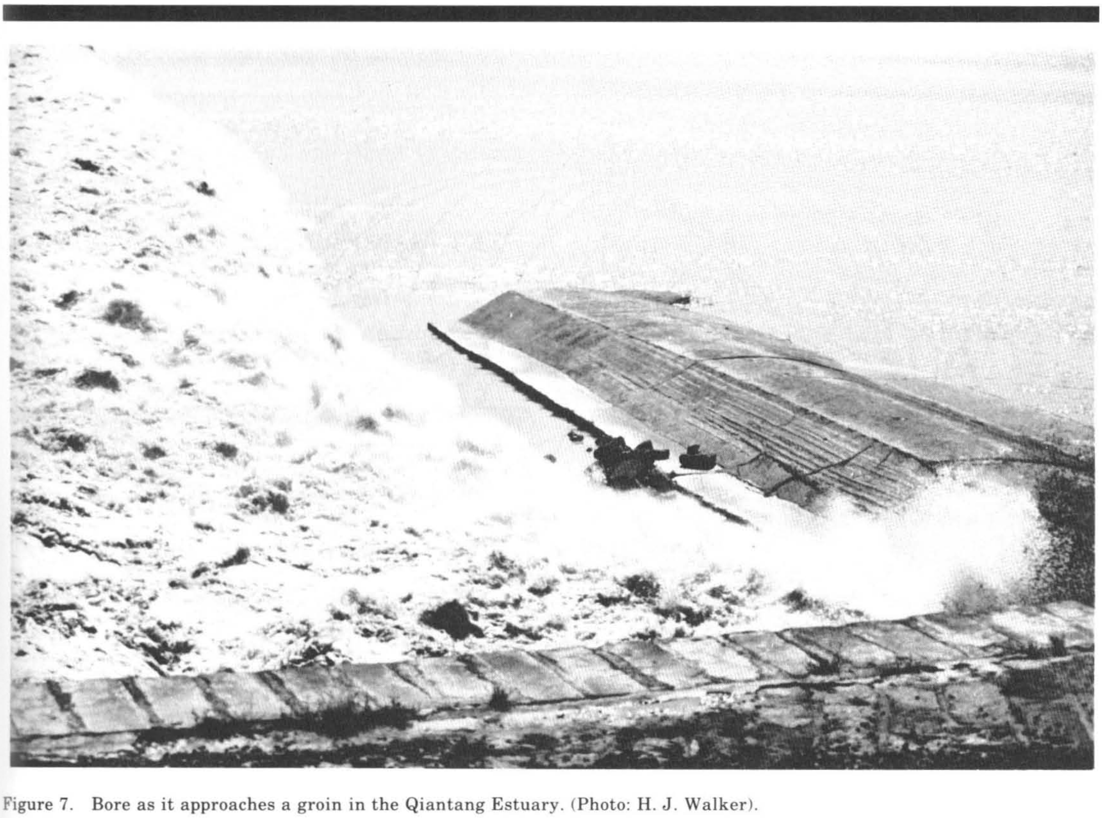

Figure 7. Bore as it approaches a groin in the Qiantang Estuary. (Photo: H. J. Walker).

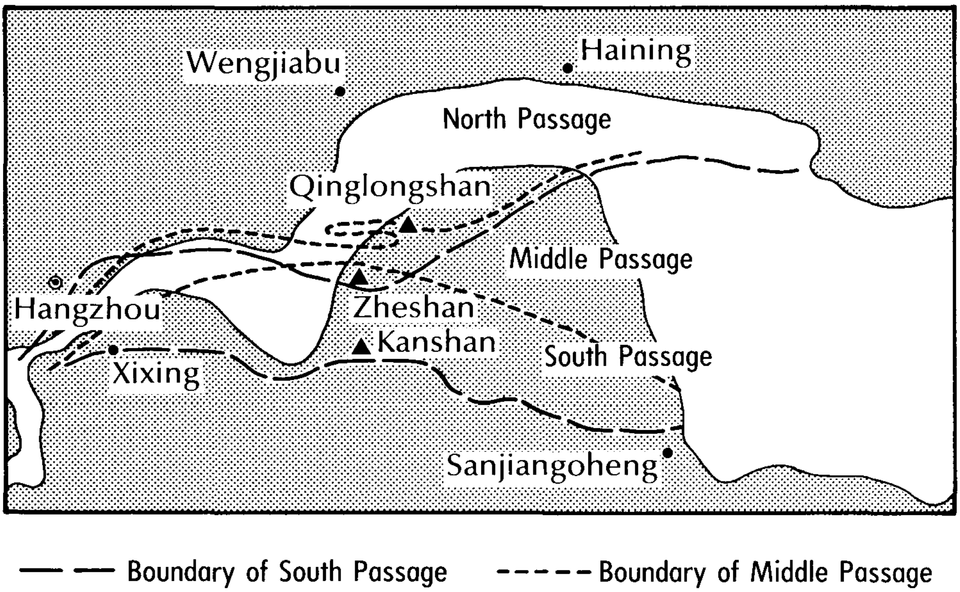

Figure 8. Passage changes in the Qiantang Estuary.

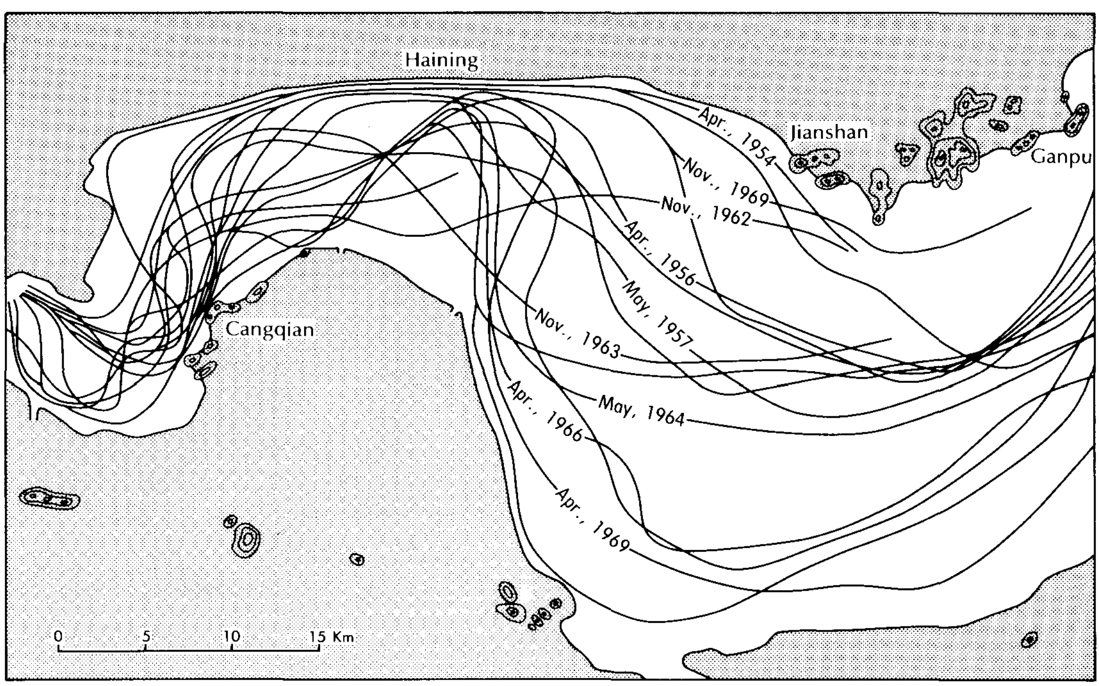

Figure 9. Shifting of the thalweg in the Qiantang Estuary (from Dai and Li, 1980).

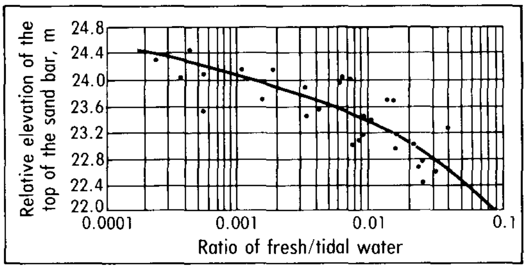

Figure 10. Changes in elevation of the bar relative to the ratio of the fresh/tidal water (from Qian *et al.*, 1964).

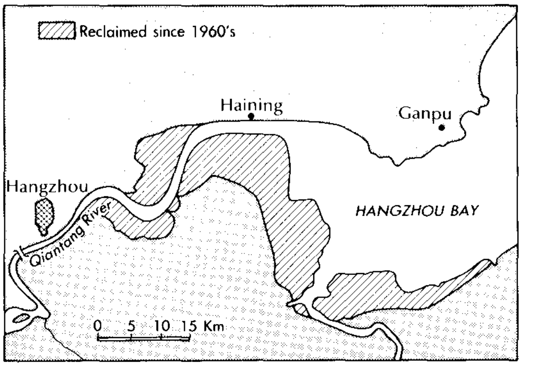

Figure 12. The location of polder areas upstream of Ganpu.

tion of the summit moves upstream (Figures 10 and 11). In other words, the periodic variation of the ratio Q1/Q2 results in both crosswise movement of the streamline and strong longitudinal deformation of the bed.

Continuous deposition in the bed results in enlargement of the beach area and in raising beach heights. Since 1968, 800,000 mu (1,500 mu = 1 km^2) of this deposited area have been reclaimed (Figure 12). On the southern bank, the coastline of Toupeng has advanced northwards 7 km, and has resulted in a narrowing of river width from 11 km to 2.5 km along the Yanguan-Toupeng section and from 26 km to 15 km along the Jianshan-Sanjiangzha section. This narrowing has been beneficial to the stability of shoreline.

EROSION AND DEPOSITION IN THE HANGZHOU BAY

East of Ganpu, the depth of Hangzhou Bay is 8 to 10 m. In the northern part of the Bay, there is an erosional area with a depth of more than 10 m. However, in Jinshan channel, the mean depth is 20 m and the maximum depth is 50 m. The channel was formed by the action of flood tides and eddy currents. In the southern part of Hangzhou Bay an arc-shaped shoal with a width of more than 10 km has developed (Figure 13). In the vicinity of the Qizimei Island there is a tidal current ridge with a length of 20 km and a width of 2 to 3 km. Its longitudinal direction is NW-SE in correspondence with the direction of tidal currents. In addition, in the near bank zone between Ganpu and Jinshan, there are several erosional channels and tidal current ridges of different sizes.

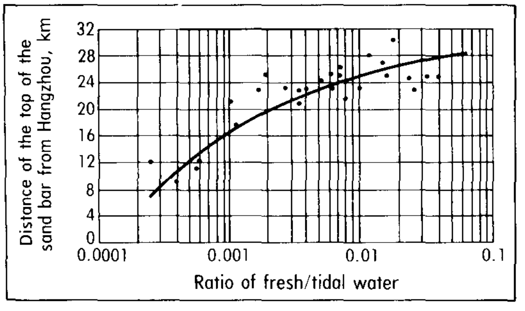

Figure 11. Changes in location of the bar in relation to the ratio of the fresh/tidal water (from Qian *et al.*, 1964).

Hangzhou Bay can be divided at Jinshan into 2 parts: east and west. In the eastern part, bottom topography is more or less uniform and the difference between erosion and deposition is small (Figure 14).

In the western part of the bay, the bottom topographic change is relatively large, and the extent of erosion and siltation is also large. Because the Andong shoal has silted up rapidly in past decades, the channel has narrowed. This narrowing has caused heavy bottom erosion in the northern part of the Bay. In the nearshore area between Jinshan and Ganpu the mean annual rate of vertical erosion is more than 5 cm with a maximum of more than 20 cm/yr. In the southern part, deposition predominates. The rate of deposition exceeds 5 cm/yr, with a maximum rate (20 cm/yr) occurring in the vicinity of Andong shoal. The only exception is to the west of Andong shoal, where partial ero-

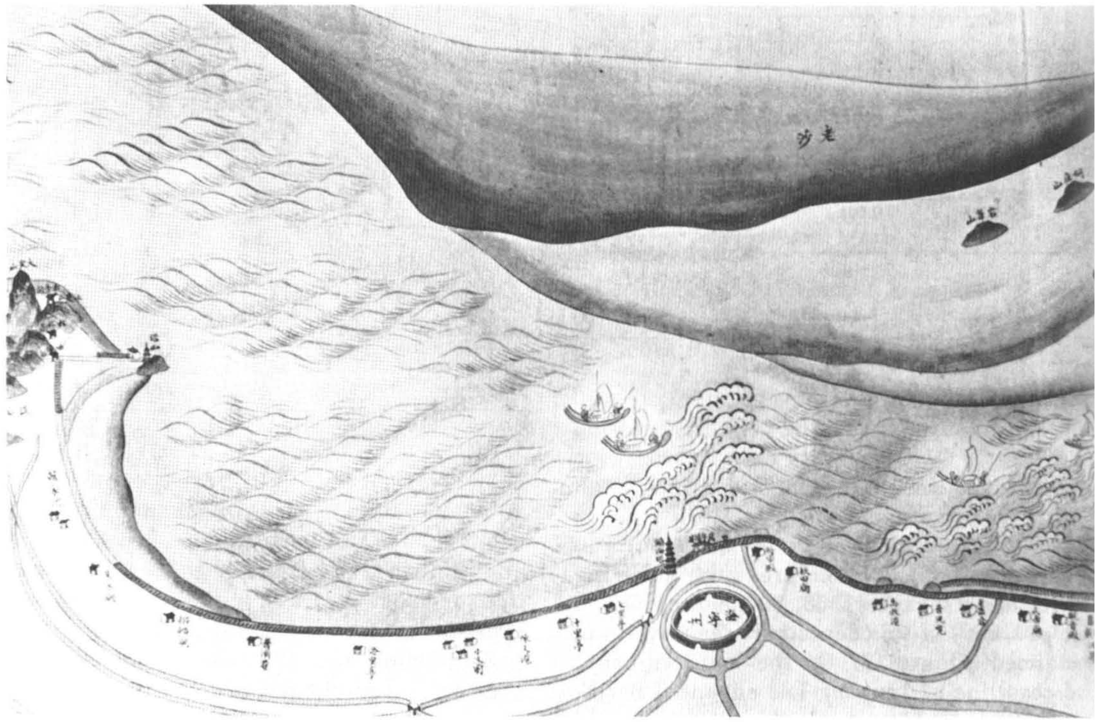

Figure 13. 18th Century map showing growth of bar (South is up on the map). The pagoda in the center of the photo is at Haining. Original in the Library of Congress listed as Hummel 1930, No. 4.

sion occurs due to a southward shift of the main current.

HANGZHOU BAY AND SEDIMENT EXCHANGE

In Hangzhou Bay the variables of topography, runoff, and sediment conditions complicate sediment exchange. Variations occur between the areas inside and outside of the Bay, between Hangzhou Bay and the Changjiang Estuary, and between Hangzhou Bay and the Qiangtang River. They also occur between bottom sediment and suspended sediment in the Bay and crosswise in the Bay.

Sediment Exchange Inside and Outside Hangzhou Bay

The Hangzhou Bay mouth, with a width of about 100 km, has the highest tidal range in China. Under the action of strong flood and ebb tidal currents, sediment moves upstream and downstream periodically. According to surveying data, the quantity of tidal water entering and exiting Hangzhou Bay during a tidal period is 2.10 to 3.67 $\times$ 10^{10} m^3; the quantity of sediment is 2.70 to 8.22 $\times$ 10^7 tons. But the net flux ranges from 4 to 11 $\times$ 10^6 tons, which accounts for 5 to 10 percent of total quantity of sediment transported. Because the grain size of the suspended sediment entering and exiting Hangzhou Bay is small with a medium diameter of 9 to 11 μ, and the velocity of the current in the Bay is large, most sediment remains in suspension and moves back and forth with the tidal currents.

This exchange has an obvious seasonal variation. Usually, the net sediment flux is outward in summer and inward in winter. In summer, the branch of the Kuroshio-Taiwan warm current causes the main axis of Changjiang dis-

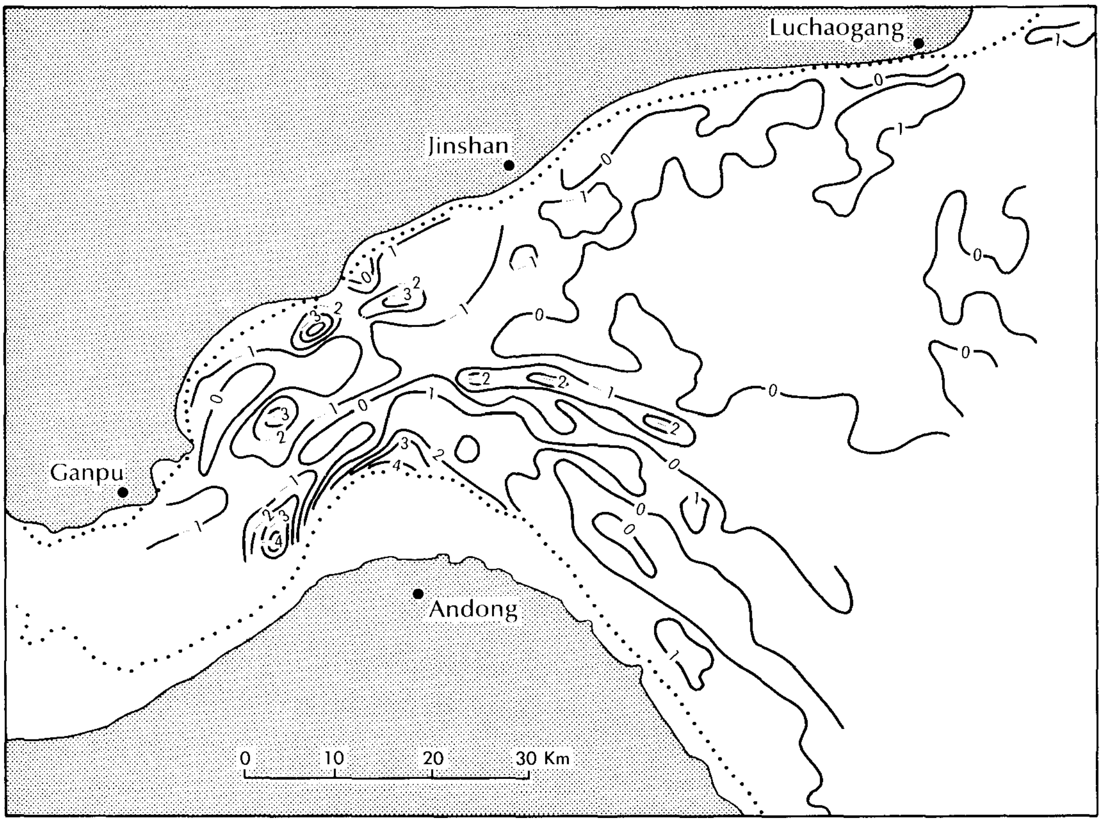

Figure 14. The rate of erosion and deposition during 1959–1979(m).

charge to move NE, and causes the offshore hyper-saline and low-sediment water body to approach Hangzhou Bay. During flood periods, low-sediment-laden water runs into the Bay. With the increase in velocity, sediment-carrying capacity increases, bottom erosion strengthens, and large quantities of bottom sediment are resuspended. During ebb periods, high sediment-laden water runs outside the Bay. So in summer, the sediment flux is outward.

The opposite condition occurs in winter. Because the main tongue of the Changjiang discharge moves south, the hyper-saline and low-sediment-laden water outside Hangzhou Bay retreats. Thus, low-saline and high-sediment-laden water moves out of the Bay. In flood period, the high-sediment-laden water runs into the Bay. The sediment flux is inward.

SEDIMENT EXCHANGE BETWEEN HANGZHOU BAY AND THE CHANGJIANG

The annual runoff of the Changjiang is 9.25×10^{11} m^3, and the annual sediment runoff is 4.86×10^8 tons. The majority of sediment is deposited in the estuarine region. A small part of the sediment diffuses outward, and moves south along with the Jiangsu-Zhejiang coastal current. Hangzhou Bay, adjacent to the Changjiang Estuary, is influenced by the current. The direct sediment exchange between the Changjiang Estuary and Hangzhou Bay is confirmed by the following facts:

(1) In sediment distribution diagrams, both winter and summer, there is a high sediment-laden region which extends from the Changjiang Estuary to Hangzhou Bay (Figure 15).

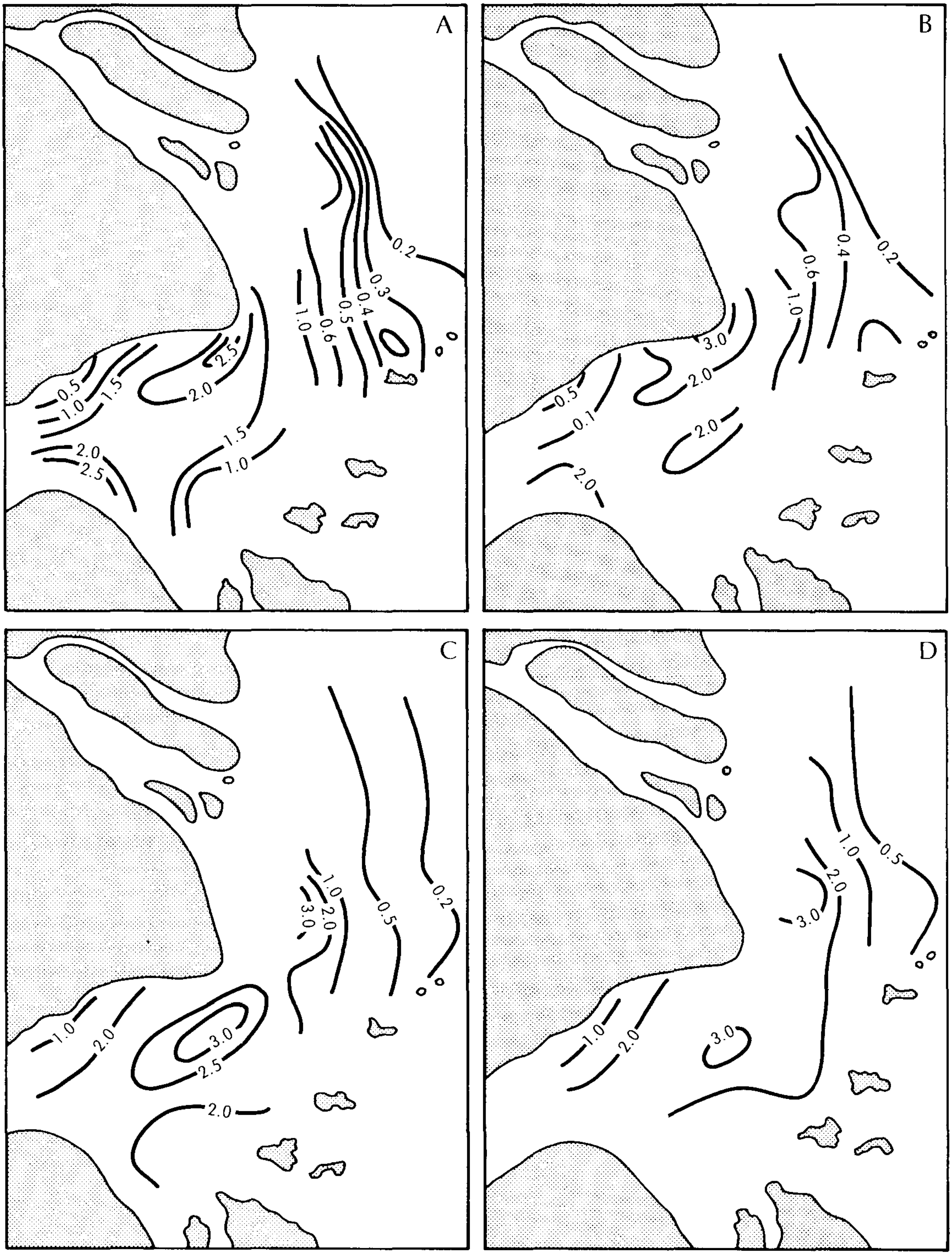

Figure 15. Distribution of suspended sediment in Hangzhou Bay and Changjiang Estuary (g/l): (A) July 21, 1982, spring flood tide; (B) July 21, 1982, spring ebb tide; (C) December 16, 1982, spring flood tide; (D) December 16, 1982, spring ebb tide.

(2) The salinity distribution diagram shows the direct influence of Changjiang's slightly saline water on Hangzhou Bay. The nearshore area of the northern part of the Bay has lower salinity and the salinity of the Bay is higher than that of the Bay mouth (Figure 16).

(3) Field data from the front of Nanhui shoal demonstrate that there is a residual current pointing SW-S. Thus, there is a current from the Changjiang passing through Nanhui and entering Hangzhou Bay.

(4) The bottom grain-size distribution diagram shows that there is a sedimentary region with silt-clay extending from Changjiang Estuary to Hangzhou Bay.

Sediment Exchange between Hangzhou Bay and the Qiantang River

As mentioned above, there is a large bar in the Qiantang River. The bar is still being formed. Its material is mainly provided by Hangzhou Bay downstream of Ganpu. Topographic diagram comparisons between 1972 and 1982 show that total deposition in the section of Qibao-Ganpu was about 1.02×10^9 m^3, while in the same period, the total quantity of erosion in the section of Ganpu-Jingshan was 8.9×10^5 m^3. During flood tide periods, large quantities of sediment from Hangzhou Bay enter the Qiantang River and are deposited. During flood years and flood seasons, the river bed in the river section is strongly eroded and the summit of the bar moves downstream. In this way, a small part of the sediment moves outward, and joins the sediment movement in Hangzhou Bay.

CONCLUSIONS

According to the analysis of sediment exchange forms in Hangzhou Bay, it can be concluded that the material of the Qiantang River bar comes mainly from the bottom erosion of Hangzhou Bay and only partly from Changjiang Estuary and the adjacent region outside the Bay. The source material coming from the Qiantang River basin is almost negligible in so far as the bar is concerned. Although the sediment coming from the Changjiang has some influence on Hangzhou Bay, the adjustment of erosion and siltation in the Bay is no doubt the most significant factor in sediment exchange.

ACKNOWLEDGMENT

We thank Wu Chaoyu and an anonymous JCR reviewer for numerous suggestions. Further we thank Mary Lee Eggart and Clifford Duplechin, of the cartographic laboratory of the Department of Geography and Anthropology, Louisiana State University, for drafting all line drawings.

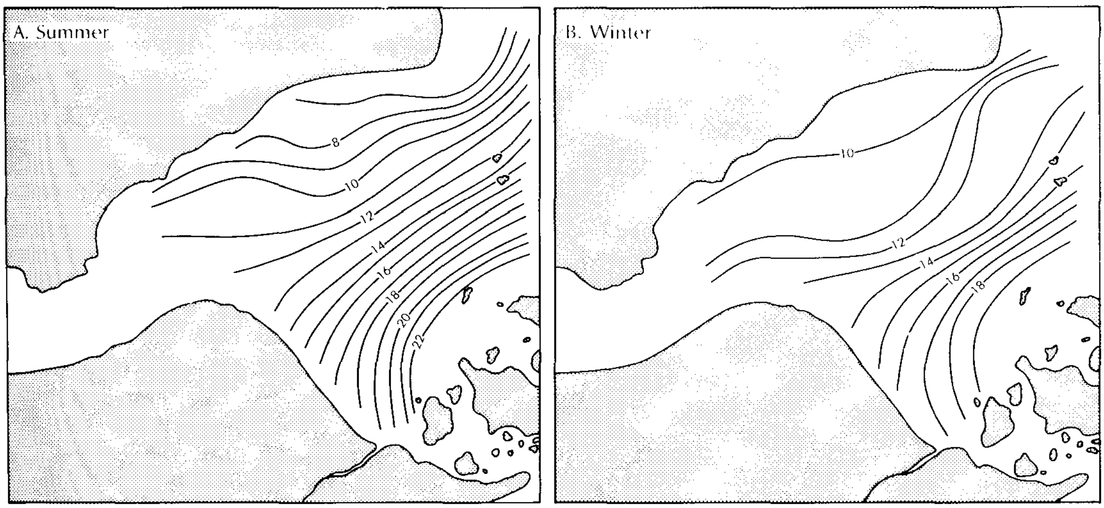

Figure 16. (A) Salinity in ‰ of the 5 m layer in summer, (B) salinity in ‰ of the 5 m-layer in winter.

LITERATURE CITED

CHEN JIYU, 1947. A preliminary study of the physiography of the Hangzhou Bay. *The Zhejiang Journal*, 1(2), 85–92 (in Chinese).

CHEN JIYU and LIU CANGZI, 1988. The People's Republic of China—Central. *In:* WALKER, H. J., (ed.). *Artificial Structures*. Boston: Kluwer Academic Publishers, pp. 339–354.

CHEN JIHU; LUO ZUDE; CHEN DECHANG; XU HAIGEN, and QIAN PENGNIAN, 1964. Formation of the river mouth bar and its historical evolution in the Qiantang Estuary. *Acta Geographica Sinica*, 30(2), 109–123 (in Chinese).

DAI ZEHENG and LI GUANGBING, 1980. The fluvial process of the Qiantang River Estuary and its regulation. The international symposium on river sedimentation, Vol. 1, pp. 457–466. *Water Resources and Electric Power Press*, China.

LI SHENDUO and HU HUI, 1987. A study on the current field of the Hangzhou Bay. *Oceanologia et Limnologia Sinica*, 18(1), 28–38.

LIU CANGZI; WU LICHENG, and CAO MIN, 1985. Sedimentary characteristics of cheniers in southern Changjiang Delta and their origin and age determination. *Acta Oceanologica Sinica*, 7(1), 55–66 (in Chinese).

LIU CANGZI and WALKER, H. J., 1989. Sedimentary characteristics of cheniers and the formation of the chenier plains of East China. *Journal of Coastal Research*, 5(2), 353–368.

QIAN NING; XIE HANXIANG; ZHOU ZHIDE, and LI GUANGBING, 1964. The fluvial processes of the big sand bar inside the Qiantang Estuary. *Acta Geographica Sinica*, 30(2), 124–141 (in Chinese).

WANG PINXIAN and YE GUOLIANG, 1979. Micropaleontological evidence for the history of the West Lake, Hangzhou. *Oceanologia et Limnologia Sinica*, 10(4), 374–382.

YU ZHIYING; LIU CANGZI; LUO ZUDE, and SUN JIANYING, 1964. Some important problems of the geomorphic development of the Qiantang Estuary. *Journal of East China Normal University*, Natural Science Edition, (1), 97–111 (in Chinese).

□ RÉSUMÉ □

L'estuaire du Qiantang, faisant face à la Baie de Hangzhou, est une estuaire en entonnoir. Il s'est formé dans des conditions géomorphologiques et hydrodynamiques particulières. On expose les modalités du processus du développement de l'estuaire et de son importante barre. La forme en entonnoir est une condition préalable à la formation de la barre, laquelle conditionne l'existence du mascaret de Hangzhou. La séquence se déroule ainsi dans le temps: formation d'un estuaire en entonnoir, d'une barre, d'un mascaret.—*Catherine Bressolier (Géomorphologie EPHE, Montrouge, France).*

□ RESUMEN □

El estuario de Quiantang frente a la bahía de Hangzhou es el típico estuario con forma de embudo. Se formó bajo unas condiciones geomorfológicas e hidrológicas específicas. Este artículo discute los procesos de desarrollo del estuario y la gran barra que se forma en él. La forma del embudo es un requisito previo para la fomación de la barra en la entrada de Hangzhou. Hay una secuencia temporal que se extiende desde la formación del estuario, en forma de embudo, hasta la de la barra en la entrada.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*

□ ZUSAMMENFASSUNG □

Der Qiantangästuar, der der Hangzhoubucht gegenüberliegt, ist ein typischer trichterförmiger Ästuar. Er bildete sich unter speziellen geomorphologischen und hydrologischen Bedingungen. Dieser Artikel diskutiert die Entwicklungsprozesse des Ästuars und der langgestreckten Sandbank, die in ihm auftritt. Die Trichterform ist eine Voraussetzung für die Entstehung der Sandbank, welche die Hangzhou-Gezeitenwelle bedingt. Es existiert eine zeitliche Abfolge, die sich von der Bildung des trichterförmigen Ästuars über diejenige der Sandbank bis zur Ausbildung der Gezeitenwelle erstreckt.—*Helmut Brückner, Geographisches Institut, Universität Düsseldorf, F.R.G.*