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Article abstract

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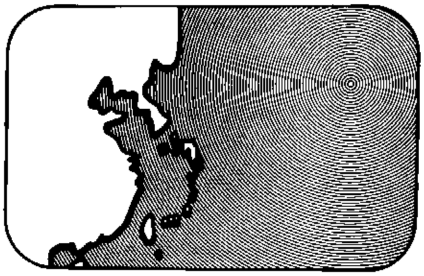

The Coast of China

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Summary

The 32,000 km coastline of China can be classified into two major types: the bedrock embayed coast and the plains coast. The distribution of these types is controlled by geological and tectonic setting, particularly zones of uplift and subsidence. The sedimentary processes along the coast of China are greatly affected by the large rivers which deliver enormous amounts of sediment. The sediment supplied is redistributed by monsoon waves and tidal currents. Within tropical and subtropical climate zones, the growth of mangrove and corals is also an important factor in coastline formation.

The coastal research in China is combined with various coastal engineering projects, which require information on coastal processes for the installation of port facilities. Thus practical requirements advances the understanding of coastal dynamic geomorphology.

Introduction

The coast of China extends in a 18,400 kilometre long arc from the mouth of the Yalu River on the China-Korea border in the north to the mouth of the Beilun River on the China-Viet Nam border in the south (Fig. 1). The total length of the coastline, including the more than 6000 islands, is approximately 32,000 km. The general outline of the coast is controlled mainly by geological structure and deposition from a number of large rivers. The coast is acted upon by monsoon wind waves and tidal currents.

Geological Structure

The Continental Shelf and adjacent Mainland of China is composed of a series of NE or NNE trending uplifted and depressed belts that intersect obliquely with the coastline. From west to east, these are the Bohai Basin (Fig. 2) the Shangdong-Liaodong uplift, the southern Yellow Sea depressed belt, the Zhejiang-Fujien uplift, the East China Sea depressed belt and Tiawan fold belt. A bedrock-embayed coast with rock islands is formed along the uplift belts, while a plains coast, usually with a large river, is always formed along the depressed belts. In the South China Sea, NE trending block faults define the main trend of the bedrock embayed coast, with inlets developed along NW trending faults.

Rivers

Three major rivers and many minor rivers carry large volumes of fresh water and sediment to the coast of China (Table I). River influence on the coast is not limited to the vicinity of the mouth; river sediment is redistributed along the plains coastline, where it is a major factor in coastal development.

Coastal Processes

The coastal tides of China are formed as a result of the tides of the Pacific Ocean interacting with the coastline and submarine topography of the continental shelf. They therefore have great regional

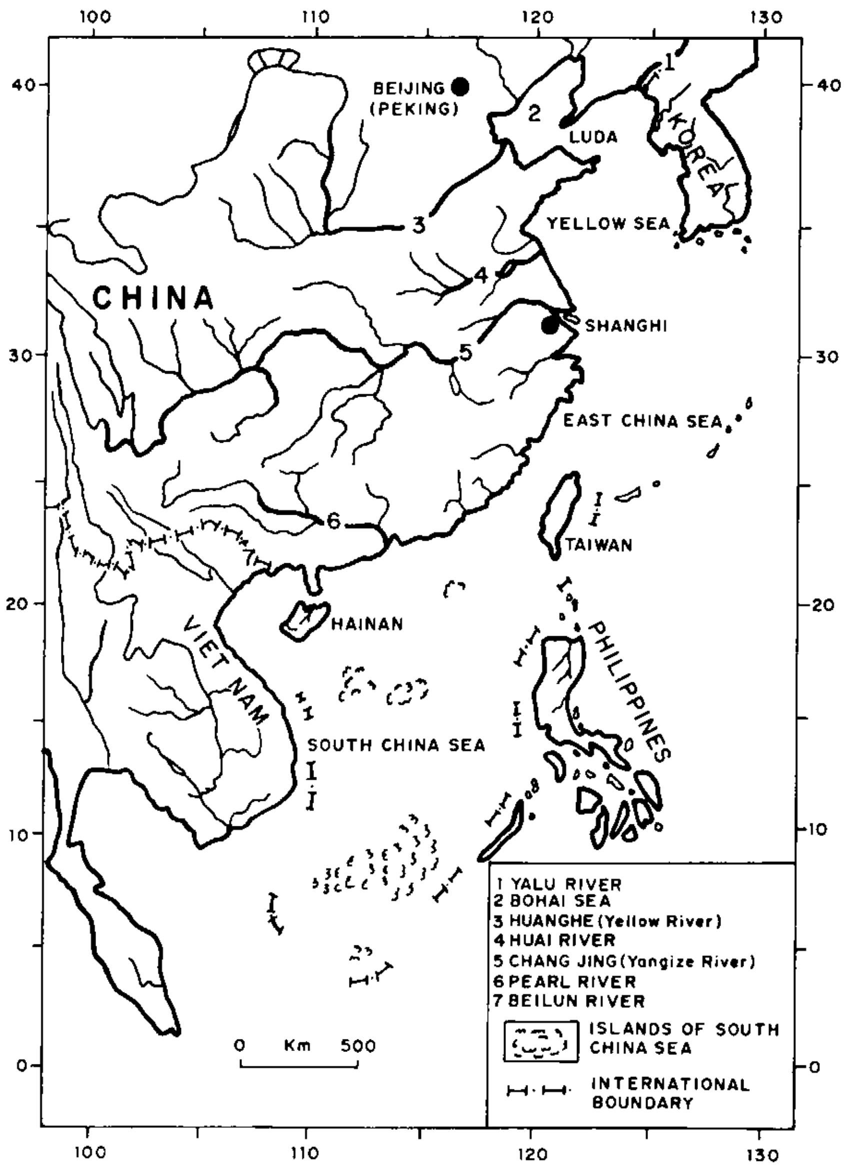
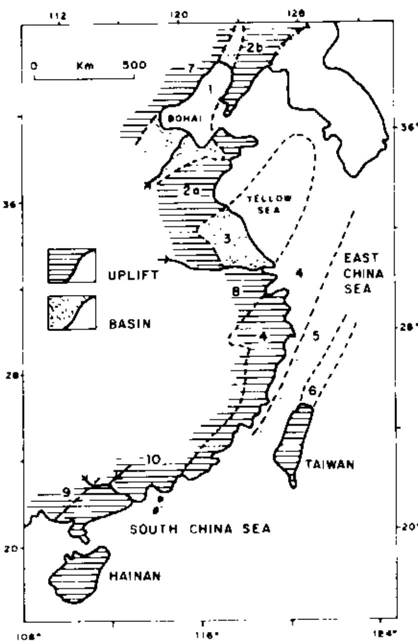


Figure 1
The Coastline of China.



1. BOHAI BASIN
2a. SHANGDONG UPLIFT
2b LIAODONG UPLIFT
3. SOUTHERN YELLOW SEA DEPRESSED BELT
4. ZHEJING-FUJIEN UPLIFT
5. EAST CHINA SEA DEPRESSED BELT
6. TAIWAN FOLD BELT
7. YIN SHAN UPLIFT
8. YANGTZE FOLD BELT
9. GUASI-HUNAN FOLD BELT
10. GUA DONG-FUKIEN FOLD BELT

Figure 2
Basic tectonic map of the mainland coast of China

Table I *Annual water and sediment discharge of the three major rivers of China.*

River	Annual Water Discharge $10^8 m^3$	Annual Sediment Discharge 10^8 Tonne
Huanghe (Yellow River)	485.65	12.0
Chang-Jiang (Yangtze River)	9793.5	4.0≈5.0
Pearl River	3700 00	0.85≈1.0

variations. The tides of south China Sea are predominantly diurnal, with a small range (1 or 2 m). The Bohai, Yellow and east China Seas have a dominant semi-diurnal tide with a large range (3 m or more), producing strong tidal currents. Tidal bores occur in many estuaries. Over one-third of the coastline of northern China is made up of tidal flats.

The action of surface waves, principally wind waves, is the main mechanism in shaping most of the coast. Wave patterns are dominated by the monsoon. Northerly waves prevail in the winter, moving southwards to reach the north of Taiwan Province in September, 10° N in October, and covering the entire seaboard in November. During January the wave directions change clockwise along the edge of the Mongolian high pressure system. This change is related to the monsoon, with northwesterly wave direction in Bohai Sea gradually swinging toward northerly to northeasterly in the southern East China Sea and South China Sea.

Southerly waves prevail in the summer, moving northward from the South China Sea. They appear first in February, and by May they dominate a wide area to the south of 5° N. In July southerly waves prevail along the entire seaboard. The wave directions change anti-clockwise along the edge of the Indian Ocean low pressure system, being southwesterly in the South China Sea to the south of 15° N. These change northwards through southerly to southeasterly waves in the East China, the northern Yellow and Bohai Seas.

There is a transitional period between the summer and the winter, during which the wind directions fluctuate, and there are no prevailing waves.

The Major Coastal Types and Their Characteristics

The sea coast of China can be classified in two major types: the bedrock embayed coast and the plains coast. Both may contain river mouth coasts, which are important because of the large populations that they support. In the south, under the tropical and subtropical climate, the coastline is also modified by the growth of coral reefs and mangrove swamps.

Bedrock-Embayed Coast. The coast develops where the mountains meet the sea, and is characterized by irregular headlands, small bays and islands. The submarine coastal slopes are very steep, and as a result, wave energy is high, influencing both erosion and deposition. Coastal sediment is coarse sand and cobbles. Detailed coastal morphology is related to wave action and is dependent on coastline exposure, submarine slopes, the type of bedrock and sediment supply. This type of coast is found along the Liaodong Peninsula, Shangdong Peninsula, the Zheziang, Fujiang, Guangdong and Guangsi province.

The bedrock embayed coast can be subdivided in four subtypes according to the stage of development.

1) Marine - erosional embayed coast; This is developed on hard crystalline rock where the rate of erosion is slow, and there has been little coastal modification since the post glacial rise of sea level. Little sediment is supplied by either rivers or coastal erosion, so sediment along this type of coast is deposited only in a few areas in the form of small bay head beaches and sand spits. The main coastal features are thus erosional, rather than depositional. This type of coast is favourable for the building of sea ports, such as the Luta ports on the Liaodong Peninsula.

2) The Marine erosional-depositional type: This is most commonly developed where there are Miocene granites covered with a thick layer of weathered deposits, such as those on the Shangdong Peninsula. This material is readily eroded by wave action and by the many small rivers that transport large amounts of sandy material to the sea. Therefore, erosional features such as rock benches and terraces and depositional features, bay-bars, sand spits and tombolos are developed. The sediments locally contain valuable placer deposits, including zircon, rutile, monazite and gold.

3) Marine depositional type: The bedrock of this type of coast is relatively soft. Marine erosion has supplied large amounts of sediment, that forms a straight prograding barrier shoreline normal to the prevailing wave direction. A narrow coastal plain is built in front of an irregular line that represents the original bedrock coastline. Thus the embayed coast matures to the plains-coast. This type of coast is very common in south China.

4) The tidal inlet-embayed coast: This type of coast is also common in south China. Here the major NE-SW trend of the coastline is cut by long, narrow bays following NW trending faults. Small islands or sand spits protect the mouths of the bays, forming tidal inlets, which are swept clean by the powerful ebb tidal currents. Sediment is deposited in the form of ebb deltas outside the tidal inlets. This type of inlet is suitable for harbours.

Plains Coast. On the basis of genesis, the plains coast can be subdivided into two types.

1) The alluvial plains coast: Most of this type of coast is located seaward of mountain ranges. The plains are built by fluvial sediments from the mountain rivers. The plains continue seaward and the submarine coastal slopes are low with gradients of 1:100 to 1:1000. As a result, there is a very wide breaker zone, with active sediment movement both longshore and onshore. Barrier bars, sand spits, submarine bars and extensive sandy beaches are the typical features of this coast. Many beaches are prograding, with several beach ridges, and lagoons behind the bars.

2) The marine depositional plains coast: This type of coast is flat and very extensive, and is located on the lower parts of large rivers in areas of subsiding basement, such as the north Jiangsu plain, North China plain and the Liaohe plain. The coastal slopes are very gentle, with gradients in the order of 1:1000 to 1:5000. As a result, effective wave action is well offshore; thus tidal currents play a major role in shaping the coast. The sediment consists mainly of suspended silt and mud transported by rivers. This fine sediment cannot be deposited in the shallow nearshore zone, but accumulates either offshore in deeper water or on the upper part of tidal flats.

A typical coast profile passes from salt flats through intertidal mudflats to the submarine coastal slope. The salt flat extends inland from a shell ridge (Chenier) above the intertidal zone. The shell ridges are preserved for a considerable time and are useful indicators of the location of ancient coastlines. Occasionally relict lagoons are found behind the shell ridges. The intertidal mud flats can be extensive as a result of the three metre tidal ranges. For example, along the west coast of Bohai Bay, tidal flats are 4 to 6 kilometres wide (see Fig. 3), with slopes of 1:1000 to 1:3000. In the southern part of the North Jiangsu Plain the intertidal mud flats are wider still. On the basis of several years of research it was discovered that the intertidal flat can be divided in four geomorphological and sedimentary zones which are the result of tidal currents acting on the flat (Table II). The submarine coastal slope is below the intertidal zone. The seaward slope from the intertidal flat is very gentle, in the order of 1:500 to 1:1500, with a concave profile. Over 10 kilometres offshore, the water is only 3 to 5 metres deep. Occasionally there are 2 or 3 metre high shell banks and depressions of similar dimensions. The sediment becomes finer offshore, from sandy silt at the low tide level to very fine mud in depths of more than 10 metres.

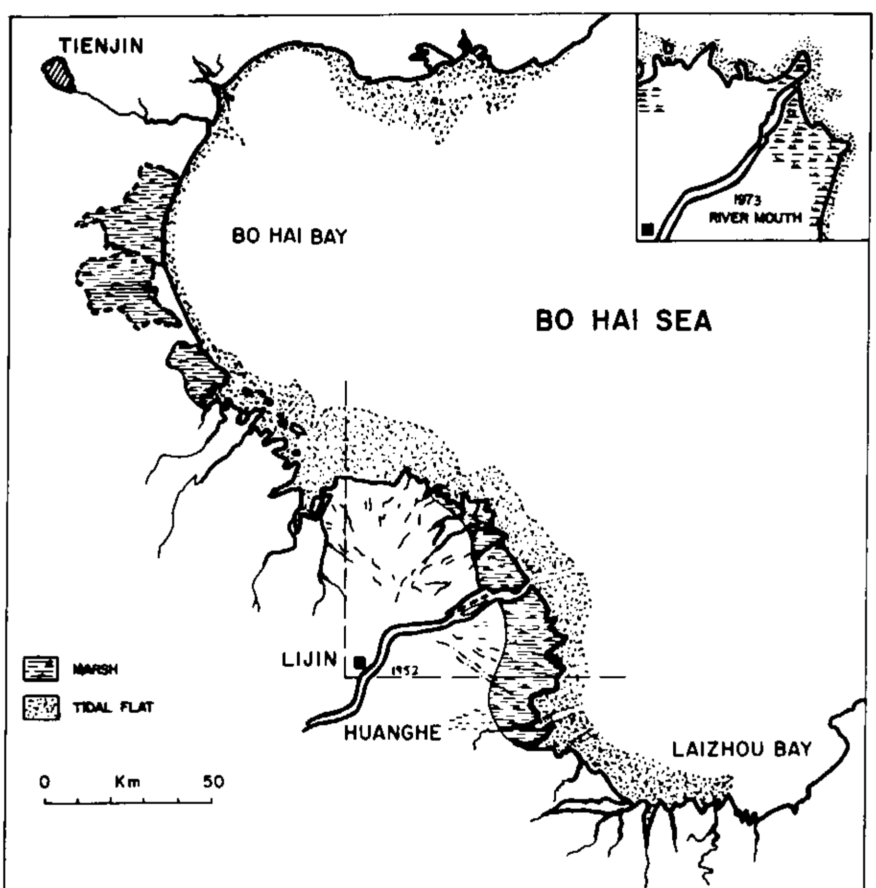


Figure 3
Huanghe Delta.

The plains coast represents a balance between wave erosion and deposition of unconsolidated sediment that is dependent on sediment supply, principally from rivers. If the amount of the sediment supplied is larger than the amount eroded, the coastline progrades; if the sediment supply is reduced or stopped, wave erosion causes the coastline to retreat. Relative changes in sea level do not effect to any great extent the development of the plains coastline. For example, the west coast of Bohai Bay, which receives the sediments of the Huanghe (Yellow River), is prograding despite a steady regional subsidence since the late Miocene. During the time when the Huanghe changed its course to the south and entered the Yellow Sea, the coastline retreated, due to the lack of sediment.

The River Mouth Coast. The Huanghe (Yellow River) has the highest rate of sediment discharge of any Chinese river, and carries the sediments into Bohai Bay (Fig. 3). The bay is shallow with a maximum depth of 40 metres; the tidal range is only about one metre at the river mouth; and wave action is also minimal. The sediment of the Huanghe is deposited along both sides of the river mouth in the form of 'finger bars'. The growth of the finger bars is rapid: we measured 10 km progradation in a single year. To either side, the bars protect bays in which fine sediment collects, forming mud flats. Beyond the mud-bays the older delta shoreline is being eroded, because the modern river sediment does not reach these areas. The lower Huanghe changes its course every 6 to 8 years, forming a new set of finger bars. The abandoned channel finger bars are slowly eroded by waves and the sediment is redeposited along the shoreline, so that with time a large and symmetrical fan delta is formed around the distributaries. Within a period of 120 years a fan-shaped delta prograded seawards from Lijin with a distal margin in 15 metres of water.

The Chang Jiang (Yangtze) River mouth faces the open East China Sea (Fig. 4). Wave action at the mouth is stronger than at the Huanghe. Most of

Table II *The intertidal zones.*

Zone	1. Outer Depositional Zone	2. Erosional Zone	3. Inner Depositional Zone	4. Polygon Zone
Location	immediately shoreward of the low tide level	around mid tide level	immediately below the lower high tide level	between lower high and maximum tide level
Morphology	wave or current ripples	overlapping 'fish scale' structure or tidal channels	mud flat or mud pools	polygon fields or marsh (near river mouth)
Sediment	very fine sand or coarse silt	alternating laminae of fine silt and mud	mud	clay or clayey-mud
Dynamics	tidal currents and microwaves	tidal currents, mainly ebb currents	tidal currents, mainly flood currents	tidal currents and evaporation due to solar heating
Processes	deposition of thin layers over large area	deposition during flood, erosion during ebb current	extensive deposition	stable (during maximum tide deposition, erosion during storm

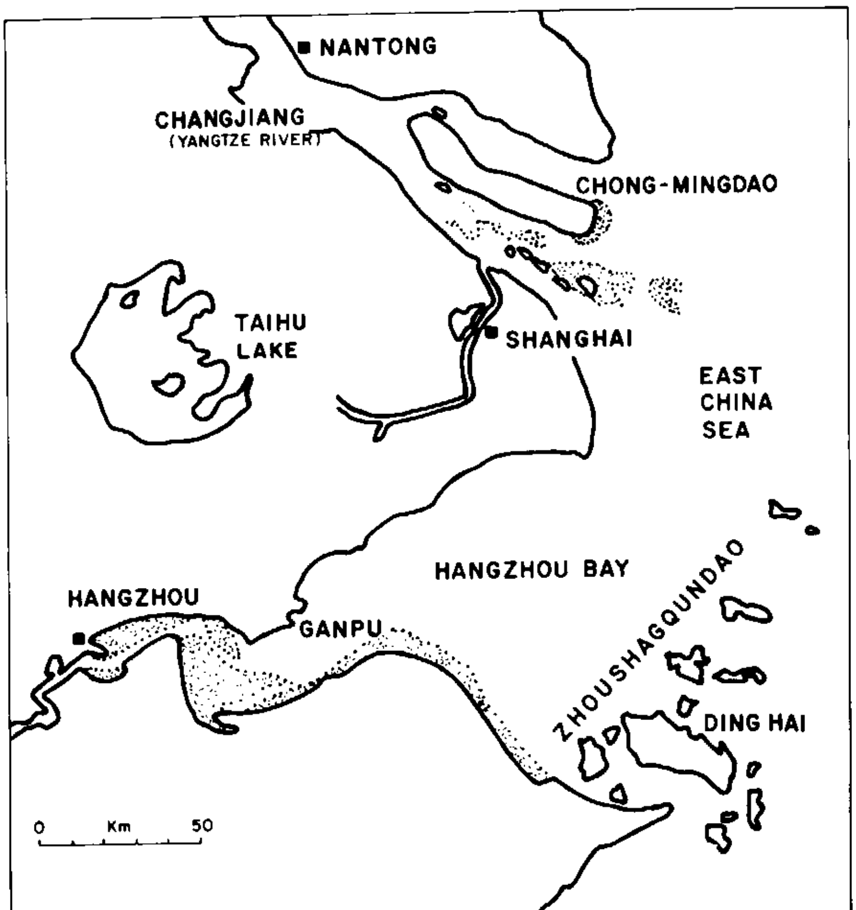


Figure 4
Changsiang Delta and Hangzhou Estuary.

the sediment accumulates in the inner part of the river mouth, and as a result, a series of sand islands and river-mouth banks are formed. Depending on the wave direction, some sediments are transported to the north or south by the longshore currents forming extensive mudflats, some just seaward of the cliffs of the bedrock coast to the south. There is a submerged ancient Chang Jiang river channel crossing the continental shelf. It starts at some distance from the modern river mouth and extends to the Okinawa Trough. At the present time tidal currents in this channel reach 50 cm/s and thus may transport sediment to the Continental Shelf, and possibly to the trough. Thus the modern Chang Jiang river delta is relatively small, and is growing towards the southeast in the shape of the bird beak-like protrusions.

The Pearl River delta is transitional between the estuarine type and the delta type of coastline, with sediment accumulating in a bedrock bay sheltered by islands (Fig. 5).

The estuaries, such as Hangzhou Bay (just south of Shanghai, Fig. 4), carry very little sediment. The tidal range is high, up to 9 metres, depending on the shape of the coastline, and there is a distinct tidal bore. During the historical period, the Hangzhou estuary has tended to shoal and as a result, the tidal ranges have decreased.

Coral Reef and Mangrove Coast (Biogenic Coast). Most of the south China sea islands are atolls which are still growing. The basement of the atolls consists of Tertiary fold ridges. Block faulting and subsidence have resulted in reefs over 1000 metres thick (Fig. 6). Fringing reefs are found surrounding Hainan Island, Taiwan and many other small islands. At present, the coral growth is poor.

In China, the mangrove can grow south of latitude 27° N. Along the mainland coast the mangrove swamps grow intermittently at river mouths, bays or lagoons, but the growth is stunted with only small bushes (mainly *Avicennia*). Mangrove jungles grow along the northeast coast of Hainan Island.

Coastal Research in China

Systematic study of coastal geomorphology in China started in the nineteen fifties. The term 'sea coast' in China has a wide meaning. It includes the land along the coast, the beaches and the submarine coastal slope, i.e., the entire coastal zone. As a result, we investigate the whole coast from backbeach to shore and offshore, out to depths where waves start to move sediment. The work

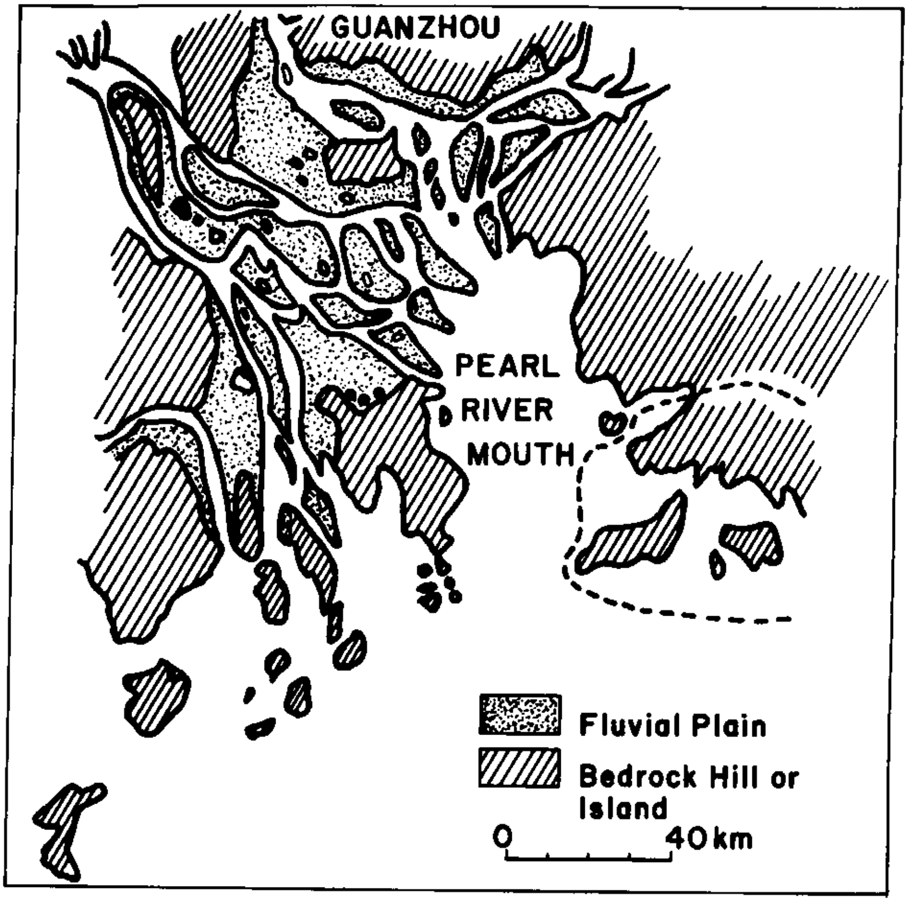


Figure 5
Pearl River Delta.

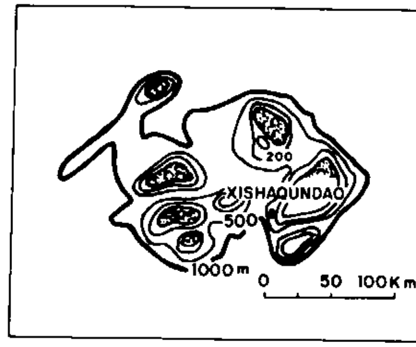


Figure 6
The atolls of Xishaqudao.

is therefore carried out on land over the intertidal zone and at sea. We analyze the sea coast from the point of view of morphology, dynamics and sedimentology. This comprises the 'coastal dynamic geomorphology'. The aim of this research is to define the source and movement of the sediments and predict the developmental trends. On the basis of these analyses, we determine the character and genesis of the coast. Through such research, we choose the ideal sites for new harbours, new docks or navigation routes in order to avoid the problem of siltation. For example, Tianjin New Harbour was built on mud flats of Bohai Bay. Shortly after its completion, the harbour had to be deepened due to extensive siltation, and a total of six million m^3 of silt was removed annually. This example triggered extensive coastal research programs and subsequently, many harbour sites were chosen on the basis of thorough studies of coastal geomorphology. Unfortunately, some harbours still have been built without proper study, and have serious siltation problems. To avoid these, extensive coastal dynamic geomorphologic studies are now required before building any harbours. Thus practical requirements have advanced coastal science.

For this type of research, there is a team of coastal geomorphologists, physical oceanographers and engineers working together on the same project. Depending on the research aims, each participant contributes with plans for the project. The work of the coastal geomorphologists, who normally come from universities and institutes, is the basis of most of these studies. The Department of Transport supports this work with technicians, money, ships, vehicles and drilling equipment. When the project is finished a report is submitted to them. The data are also used for scientific research. For example, in the Tianjin New Harbour project, we studied the mud flat coast and the Huanghe delta; with the Chinhuangtau oil port project, we investigated the barrier bar coast; with the South China port projects we investigated tidal inlets and coral reefs, and with the Chang Jiang River mouth project, we studied the estuary. This research accelerated the advancement of the knowledge about the coast of China. For example, we were able to establish the mudflat zonation, the proper significance of the shell ridges, and the dynamics of estuarine channels, among others.

We suffer from a lack of contacts between ourselves and scientists outside China. We would like to establish and maintain close cooperation with scientists of other countries and participate in international meetings and publish in international journals.

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