Man Against the Sea: Natural and Anthropogenic Factors in the Changing Morphology of Harngzhou Bay, circa 1000 - 1800

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...aestus ab undis
aequoris exesor moerorum litora propter.
[... commotion from the waves of the sea,
that devourer of the walls beside the shore.]
Lucretius, *De rerum natura*, vi.925-6

SUMMARY

Inner Harngzhou Bay 杭州灣, on the east coast of China at approximately 30° N, is an unstable macrotidal estuarine system whose geographical configuration has altered dramatically over the last thousand years. In particular, the mouth of the Qiarntarng River 錢塘江 has shifted twice: (1) in 1620 from a southern debouchment just to the north of Mount Kan 龕山 to a central or mid-bay debouchment south of Mount Herzhuang 河莊山, and (2) in 1692-5 from this central debouchment to approximately its present northern exit. A general impression of these changes may be had from Figure 1, a recent remote-sensing image of the area, and Figure 2, which provides a key to the main natural features shown in Figure 1.

A thousand years ago there was an approximate balance between the deposition of sediments, mostly brought in by the tides from the mouth of the Yarngzii immediately to the north, and their removal by river flow, especially at periods of peak discharge, in conjunction with ebb tides. Human intervention made a major contribution to disrupting this equilibrium by the building of sea-walls, the diversion of rivers, and the reduction of peak discharge, in part by storing water in irrigation systems. The shift of the Yellow River to a predominantly southern course after 1194, and especially the increased discharge of sediment at its sea-mouth as the result of hydraulic engineering in 1578-9, also played a part, by increasing the quantity of of fine-grain sediment transported southwards down the coast.

A general idea of the changes is given by Figure 3, which sketches the early mid-Qing-dynasty inner bay (early 18th century), and Figure 4, which shows it in Sohng times (12th century).

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The commitment of both local society and imperial government to complex and costly hydraulic systems in this area created forms of what may be termed 'technological lock-in', in other words a foreclosing of other options on the future use of labour, resources, and administrative inputs, though release from 'lock-in' could also sometimes occur as the result of shifts in the patterns of sediment deposition and erosion that were favourable to human economic interests. The present paper summarizes and interprets previous work on the hydrology and hydraulics of this area, presents a preliminary reconstruction of the geographical pattern of change based on historical maps and documents, and outlines some of the analytical problems that will need to be addressed in the future. It also shows that, under certain circumstances, geomorphological change, partly anthropogenic in origin, can affect human social and economic life over relatively short periods (typically tens to hundreds of years). The conclusion is that long-term economic history without environmental history is, at best, lopsided and, at worst, misleading.[2]

1. THE GEOGRAPHICAL CONTEXT

Figure 1 is a false-colour image of inner Harngzhou Bay 杭州灣. The area shown is approximately 69 kilometers east to west, and the date is 3 March, 1986. The original image is composed of frequency bands 3 (red), 7 (middle infra-red), and 5 (near middle infra-red) of the Thematic Mapper system operated by EOSAT.[3] The elongated depositional shoals aligned parallel to the direction of tidal flow that are characteristic of most macrotidal estuaries (tidal range > 4m) can be seen in the lower part of the channel. As will be shown later, parts of the earlier coastlines appear as discontinuities in the intensity of reflectance, in colour, and in texture, on both the northern and southern shores.

The important geographical features are as follows: (1) the Qiarntarng River 錢塘江, which flows from west to east into inner Harngzhou Bay); (2) the cities of Harngzhou 杭州 (on the left bank of the river, about mid-way up the left side of the map), Shaohxing 紹興 (near the bottom of the map, slightly right of centre, at the junction of the long flattened V formed by the ancient transport canal), and Yarn'guan 鹽官 (Haainirng 海寧 in most of late-imperial times) on the central northern coast near the middle of the shallow arc facing the thumb-shaped peninsula of the Narnsha 南沙 ('southern sands') that sticks up into the centre of the inner bay; and (3) the hills in and around the Bay that have been the only constant features in historical times. The most evident of these is Kanshan 龕山 (also known as Harngwuushan 杭塢山), which is almost dead-centre in the satellite image. To its north, located from south to north respectively, are two groups of smaller hills rising out of the alluvial land-surface, the first centred on Zheeshan 赭山 and the second on Herzhuangshan 河莊山, and, lastly, to the northeast of the latter,

FIGURE 1
Remote-Sensing Image of Harngzhou Bay on 3 March, 1986

The cover picture shows the modern sea-wall at Wudong Lock on the eastern shore of the Yuyao salient, southern coast of Harngzhou Bay, China. Reclaimed farmland lies to the right of the sea-wall (west) and tidal flats to the left (east). The fishing-boats are moored in the channel leading to the lock (just out of the photograph to the right). This development is part of a process of dyking, desalinisation and land-reclamation that has been going on in this area for at least a millennium and a half. Tidal inlets used to run into the hills in the far distance.

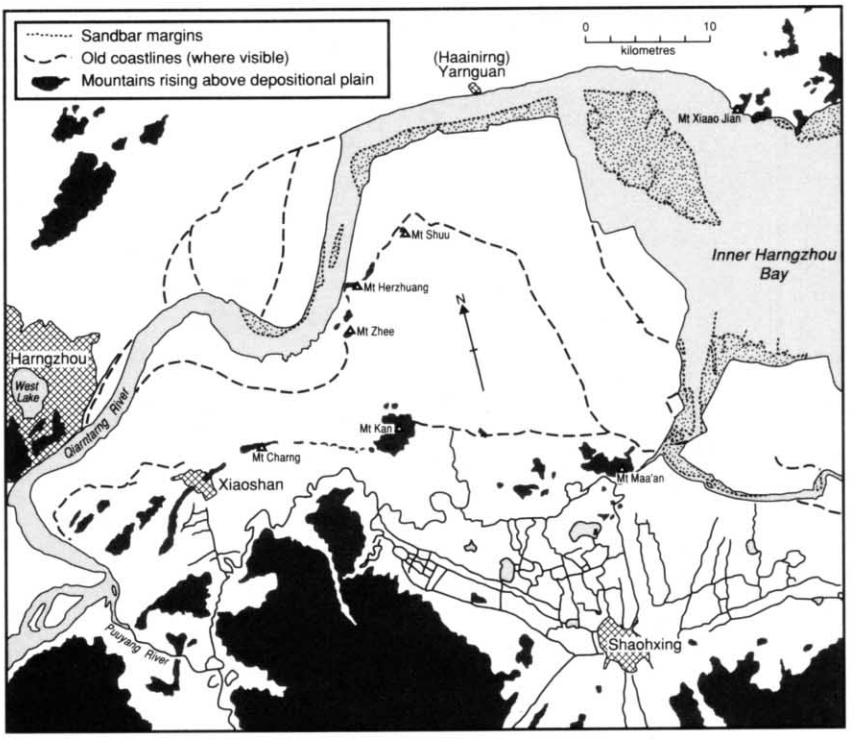

FIGURE 2
Key to the principal natural features shown in Figure 1

there rises the low and isolated Shuushan 蜀山. On the northern shore, east of Yarn'guan/Haainirng are two hills, from west to east, the Xiaao (or Lesser) Jianshan 小尖山 and the Dah (or Greater) Jianshan 大尖山. The south-pointing promontory to the east of these two hills culminates in the Taashan 塔山 ('Tower Mount'), between which and the coast a sea-wall was built (or possibly re-built) in the 18th century.

Rainfall in the area ranges from 1300 to 1500mm a year. Most of it (≈ 40%) is concentrated in the period mid-June to mid-July, the season of the so-called 'Plum Rains' (*meiryuu* 梅雨)[4] in the Yarngzii valley, when the summer monsoon airflows meet the polar cold air mass.[5]

The dominant pattern of run-off is from the hills on the south side of the Bay, which feeds not only the Qiarntarng River but also lesser but still important rivers such as the Puuyarng 浦陽江 (which today flows in a northwesterly direction into the Qiarntarng a little distance upstream from Harngzhou city, but which before the mid-15th century took a northerly course directly into the Bay), and the Caor'er 曹娥江 (which enters the Bay east of the Narnsha from the southeast corner of the

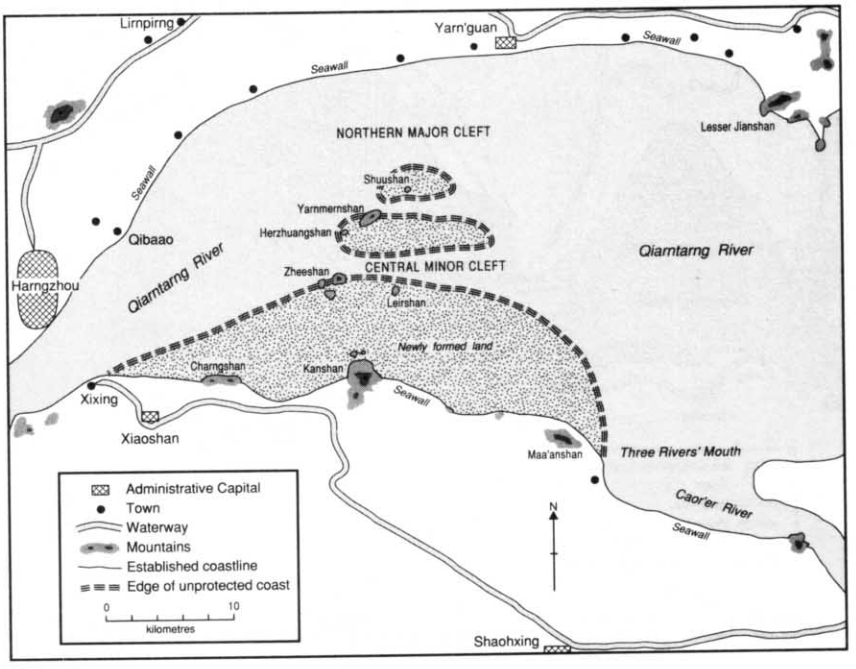

FIGURE 3
Sketched reconstruction of the inner part of Harngzhou Bay in early mid-Qing times (early18th Century)

satellite image). In the past, smaller streams off the hills also fed the elongated man-made Mirror Lake (Jihnghur 鏡湖or Jiahnhur 鑑湖) that lay for a millennium to the east and west sides of Shaohxing (then called Yuehzhou 越州) just south of the transport canal, until it largely disappeared through siltation about a thousand years ago early in the Northern Sohng dynasty. Its traces may still be seen in the image, especially on the western side, having a shape resembling a dragonfly's wings. Five hundred years ago, all three of the major rivers entered the Bay just west of the debouchment of the Caor'er, and the point of confluence was and still is known as Three Rivers' Mouth 三江口, a name that only makes sense in the light of its history.

The present coastline is to all intents completely enclosed within seawalls, and has been for more than a thousand years. The remnants or traces of some parts of earlier seawalls may be seen lying inland. Others have long since vanished under the waves and tides. Figures 3 and 4 show the main features of the seawalls in the mid-17th and the 11th century respectively.

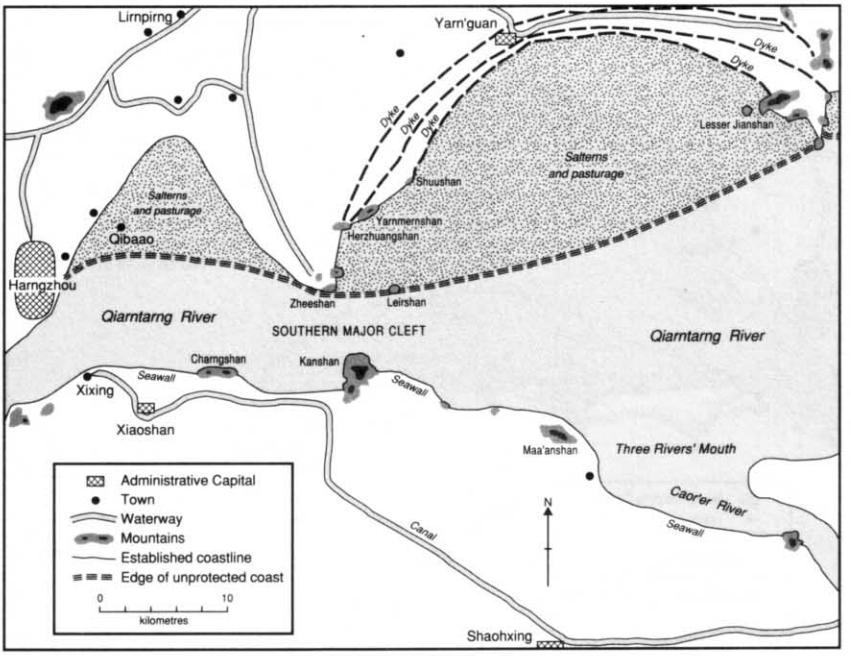

FIGURE 4
Sketched reconstruction of the inner part of Harngzhou Bay in Sohng times (12th Century)

The main cereal crop of the area is rice, and in some places there are extensive plantings of mulberry trees. In the past it was a major area for salt-production, but the percentage of salt in the brine seems to have declined over the centuries, and saltern areas have been developed into farmland. Morita Akira's 森田明 study of the organization for sea-walls in Jiangsu and Zherjiang provinces shows that the reason for the building of the sea-walls that run down the coast of southern Jiangsu and northern Zherjiang provinces was, in the first place, to exclude saline water from coastal lands formerly used for fishing, salt-extraction, reed-growing, and some limited farming, so that they could be reclaimed for more productive agriculture, and only in the second to protect the inhabitants of these coasts from the incursions of high tides.[6]

The outer bay, as may be seen from British Admiralty chart #1199 for 1984[7] (not reproduced here), has a funnel shape that is the cause of a tidal bore which can exceed 3 m in height and 13 knots in speed.[8] The Pacific tides, which are twice daily here and of approximately equal strength, approach from the southeast and enter the Bay through the

channels separating the islands in the Zhoushan archipelago 舟山群島 (to the east of, and outside, the area shown in the satellite image).

Lastly, it is useful to place the historical picture in the longer-term perspective of geomorphology. Yarn Qirnshahng 严钦尚 and Huarng Shan 黄山 have shown[9] that at the time of the maximal oceanic withdrawal, about 15000 BP, a drop of from 150 m to 160 m below the present shoreline, there was a depressed trough running south from Lake Taih 太湖, and lying from 15 m to 25 m below the modern sea-level. This trough carried a major tributary into the palaeo-Qiarntarng River just north of the site of the future Harngzhou city. As the climate warmed up in the post-glacial era, the ocean rose to a maximum slightly above the present level between 7000 BP and 6500 BP. This created a northern estuary emptying into the bay, up the line of the former tributary channel. The lowest-lying parts of the platform between Harngzhou Bay and Lake Taih were covered with a shallow sea. The remainder became tidal flats with interspersed zones of low-salinity marshland on the higher ground. Deposition of sediment helped to raise the plain to its present-day height of from 2 m to 4 m above mean sea-level. By 2500 BP the northern estuary, having first contracted, became filled in to the point at which direct contact with Lake Taih was broken, and this allowed the lake to begin to move towards a fresh-water regime. We may speculate that this process, whereby tidal deposition blocked off the northern estuary, was made possible by the fact that the flow of water south from the lake, and from the Tianmuh hills 天目山 on the estuary's southern flank, was insufficient to provide a counterbalancing scour. As the sea-level fell further, these deposits would have blocked a northern exit by the Qiarntarng River. For the moment, this is speculation.

Likewise, Chern Qiaoryih 陈桥驿 and two colleagues have argued that the lakes of the coastal plain along the southern shore of the bay were vestigial depressions left behind by the retreat of the sea from the foot of the coastal mountains about 4000 years BP, and point put that they have the shallow profiles, with gently sloping sides, that are characteristic of such lakes. There were more than 200 of them initially in the Nirngbo-Shaohxing plain. They were mostly saline at first, but were converted to fresh-water lakes by the installation of locks and sea-walls. Towards the end of the + 1st millennium they had either begun to silt up or be encroached upon by farmers wanting extra land, or both. Today there are only about 28 of them left. Modern reservoirs, in contrast, are mostly up in the hills and hold only about 40% of the water in total that is estimated to have been held in the lakes of the plain at their maximum extent.

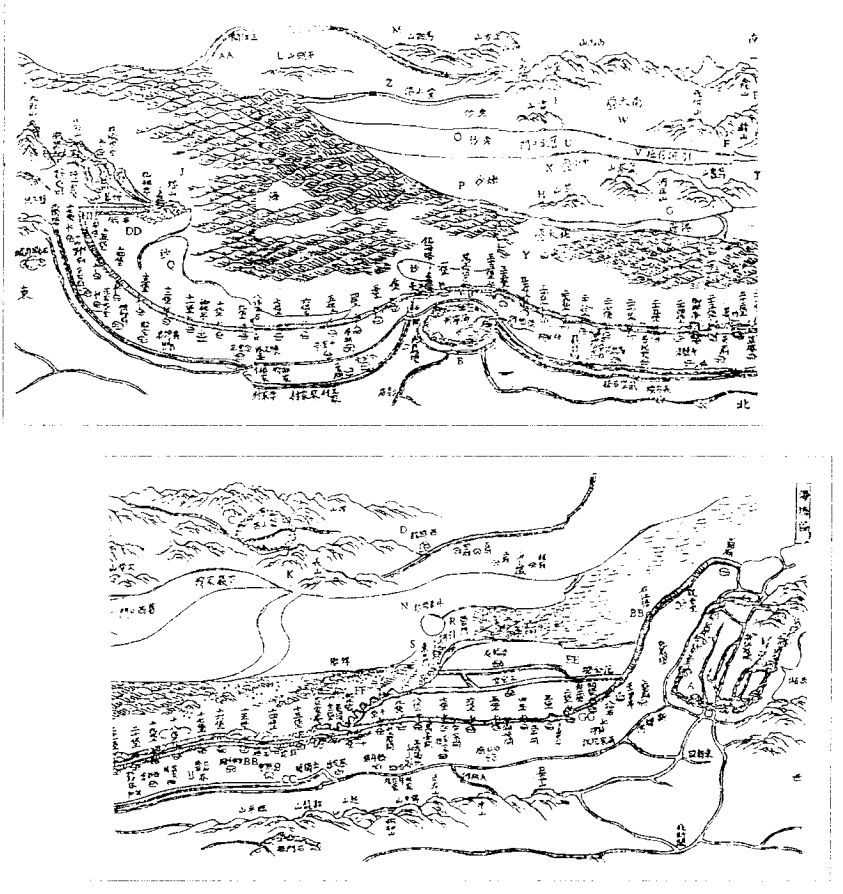

FIGURE 5
The Mouths of the Qiarntarng River at the End of the 18th century

Cities and towns A Harngzhou 杭州 B Haainirng 海寧 C Xiaoshan 蕭山 D Xixing customs station 西興關 *Hills* E Mt Kan 龕山 F Mt Zhee 赭山 G Mt Herzhuang 河莊山 H Mt Shuu 蜀山 I Mt Leir 雷山 J Mt Taa 塔山 K Mt Charng 長山 L Mt Pirngtour平頭山 M Mt Maa'an 馬鞍山 *Sandbanks* N Ox-tongue Sands 牛舌頭沙 O 'Old Sands' 老沙 P 'Soft Sands' 嫩沙 Q 'Sands' 沙 *Mouths and channels* R West mouth 西口門 S East mouth 東口門 T Old West mouth 舊西口門 U Old east mouth 舊東口門 V Old site of induction channel 引河舊址 W Southern major cleft 南大嶝 X Central minor cleft 中小嶝 Y Northern major cleft 北大嶝 Z Daangshan inlet 黨山港 AA Three rivers' lock 三江閘 *Seawalls and dykes* BB Stone riverbank dyke 石江塘 CC Earthen reserve dyke 土備塘 DD Stone sea crossdyke 石壩 EE Fahngong dyke 范公壩 FF Tiaoshuui dyke挑水壩 GG Old earth dyke 老土塘 HH Brushwood dyke 柴塘

2. THE SHIFTING LANDSCAPE: THE CARTOGRAPHIC RECORD

The only constant features in an altering landscape of alluvial plains, tidal flats and shallow sea were the mountains. Figure 2, based on the satellite image reproduced in Figure 1, shows the main mountains in the bay and along its coasts, and these should be used as points of reference when following the topographies reconstructed in this section.

We begin with a survey of historical maps, moving backwards in time from the more to the less certain. The general pattern once established, we shall consider the details provided by the documentary record.

Figure 5 reproduces a combination of oblique aerial view and map, orientated towards the south, from the 'Haaitarng tur' 海塘圖 (Maps of the Seawall) in the Harngzhou Prefectural Gazetteer, showing the mouth of the Qiarntarng around the end of the +18th century. The key identifies the more important features.

This late-eighteenth-century topography may have related to the modern topography approximately as follows: the twentieth-century acute-angled bend in the Qiarntarng upstream of Harngzhou is not in evidence. Level with this city, the river turns towards the north and is constricted in a short reach with a north-north-east orientation just downstream of a line drawn between the city and Xixing. A recently reclaimed area projects into the river at this point from the left bank, protected by the Fahngong Dyke (inside of which runs the Old Earth Dyke) and the Tiaoshuui Dyke, the latter apparently further safeguarded by groins. Downstream of this point of constriction, the river turns somewhat eastwards again in an almost straight line to a point just north of Mount Shuu, broadening as it does so. There are extensive undyked foreshores along the right bank, while the northern shoreline to Haainirng is guarded by a stone dyke (crosshatched double line) and, for most of its length, an inner earthen dyke. The stone dyke from Harngzhou to Haainirng is lined with 33 watch-stations (*baao* 堡). From Haainirng to the foot of the Mount Xiaaojian (the Lesser Jianshan) the north shore is protected partly by a stone dyke (perhaps as far as the eighth watch-station) and partly by the Brushwood Dyke (*chairtarng* 柴塘), with a further 17 watch-stations, and the inner earthen dyke. There is a stone cross-dyke running from the mainland to Mount Taa, and also a sandy foreshore, now so reduced as to hardly exist, running from between the fourth and fifth Haainirng watch-station along the northern coast and out to this headland. Within the Narnsha peninsula, the earlier river mouths through the Southern Major Cleft and the Central Minor Cleft have silted up. On the eastern shore there are what appear to be two successive layers of "old sands" and one of "soft sands" that together reach as far as Mount Pirngtour. This last-mentioned, apparently well north of Mount Maa'an and the old south-shore seawall, cannot at present be identified either on available maps or the satellite image.

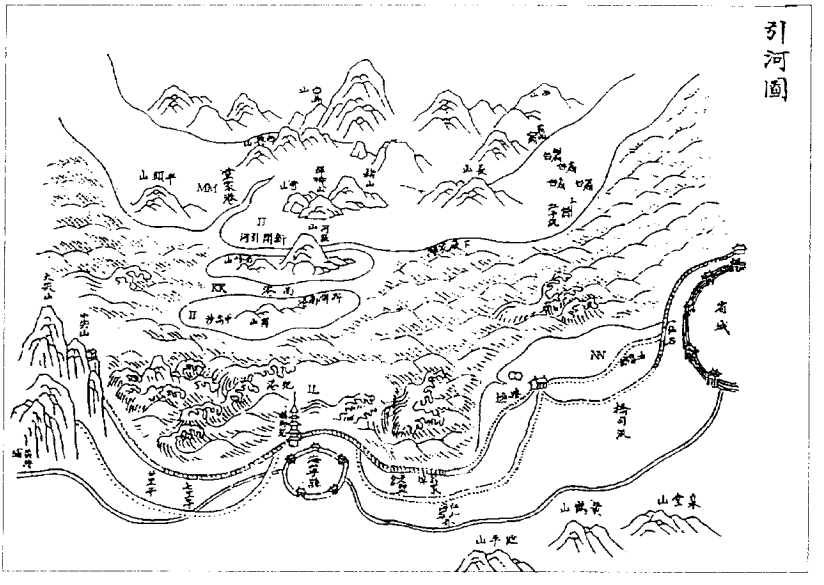

FIGURE 6
The Mouths of the Qiarntarng River *circa* 1733

Sandbanks
II Central high sands 中高沙
Mouths and channels
JJ Newly opened induction channel 新開引河
KK Newly opened Southern Channel 新開南港
LL Qii channel 屺 MM Daangjjia Inlet 黨家港
Seawalls and dykes
NN Earthen reserve dyke 土備塘 OO Brushwood dyke 柴塘

Figure 6 shows the mouths of the Qiarntarng River as they were perhaps around 1733, when the first attempt at reopening the central minor cleft by means of an 'induction channel' was undertaken, but before the third and more long-lived effort in 1747, since it is evident from the map itself that the situation represented dates from before the greater part of the Brushwood Dyke had been converted to stone (a process that began in 1732[10]), and likewise from before the final stage of building of the cross-dyke to Mount Taa in 1740. Only the earthen dykes and the Brushwood Dyke are shown. The Key lists only those features that are different from those in Figure 5.

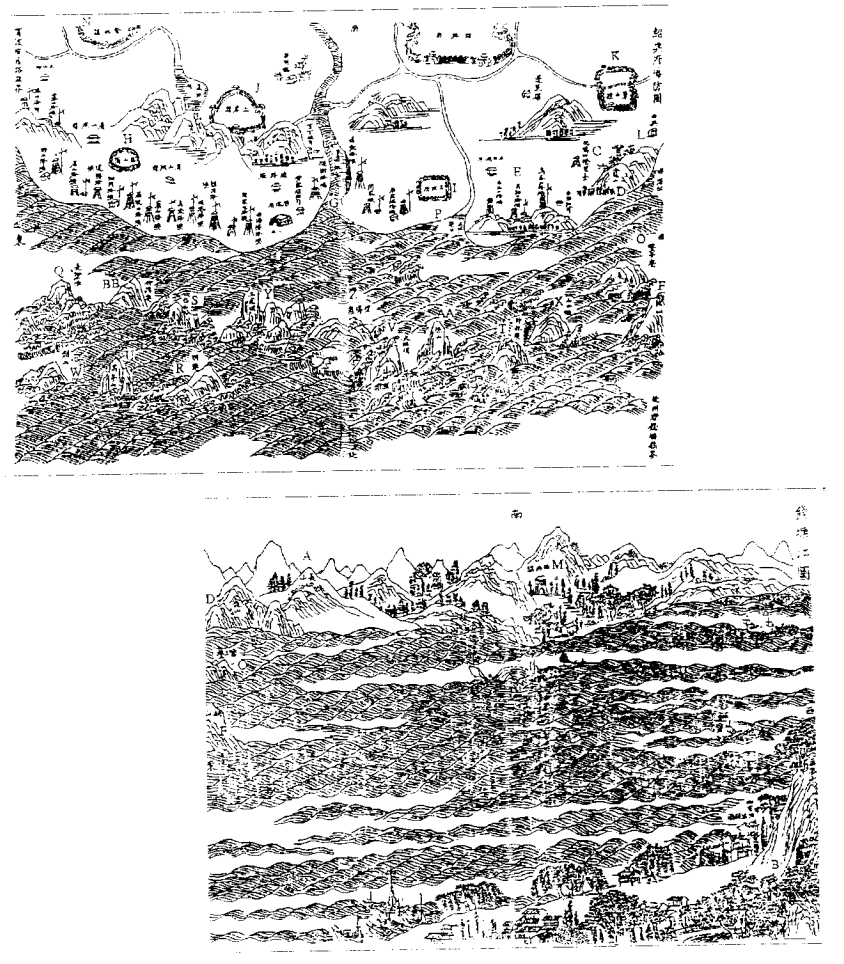

FIGURE 7
The Three Mouths of the Qirntarng River in the Early 17th Century (A cartographic/pictographic composite)

Mountains: A Mt Charng 長山 B Mt Fehnghuarng 騍臚s C Mt Kengwuu watch-tower 坑塢山瞭望臺 D Mt Kan 龕山 *Watch-towers and beacons:* E Mt Maa'an beacon 馬鞍山烽堆 F Mt Zhee 赭山 *River:* G Caor'er 曹娥江 *Cities and military stations:* H Lirnshan guard 臨山衛 I Sanjiang suoo 三江所 J Shahng-yur W 虞縣 K Xiaoshan 蕭山縣 L Xixing 西興 M Xixing customs station 西興關 N Yuryaor 餘姚縣 *Channel:* O Biczii mern 鱉子門 *Lock:* P San-jiang zharkoou 三江閘口 *Islands and reefs:* Q Charng-tur inlet 長塗港 R Chour inlet 稠港 S Daih shan 岱山 T Duihzhentour 對針頭 U Gaotirng shan 高亭山 V Huooyahntour 火焰頭 W Jiahn shan 劍山 X Shahngxiah banks 上下墝 Y Wuuhuu reefs 五虎礁 Z Yarnchaang bank 鹽場器AA Yur shan 漁山 BB Zhur-xing inlet 竹興港

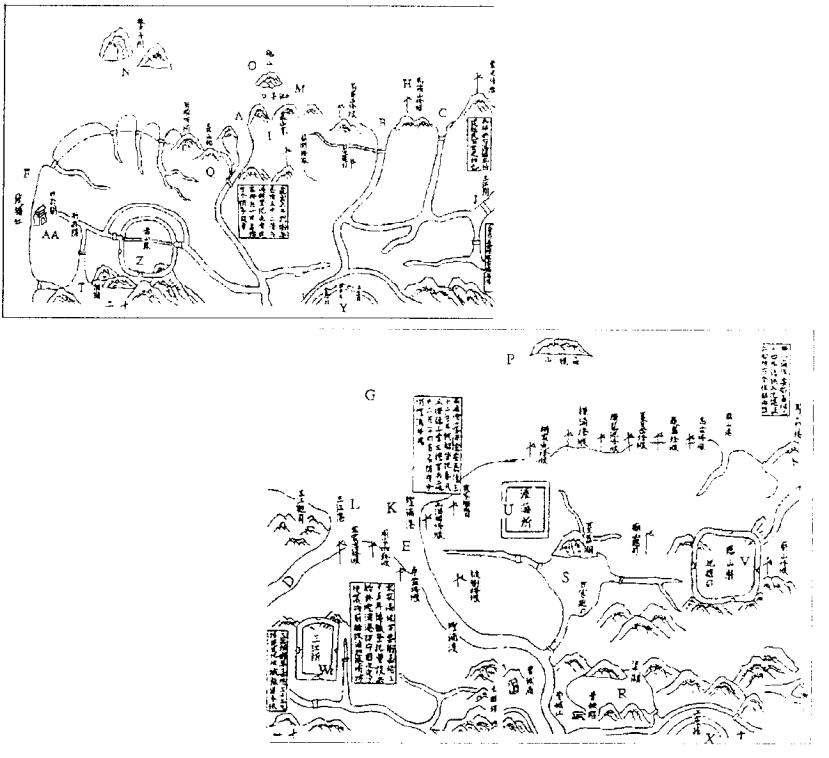

FIGURE 8
The South Shore of Harngzhou Bay in the Later 16th century

Rivers: A Unnamed (a mouth of the Puuyarng?) 浦陽江 B Unnamed (a mouth of the Qiarnqing ?) 錢清江 C Unnamed (a mouth of the Qiarnqing ?) D Probably the Xixiaao jiang 西小江 E Caor'er 曹娥江 F Qiarntarng 錢塘江 G Harngzhou Bay (or Houh Sea 後海) *Mountain military camps and beacons:* H Mt Maa'an beacon 馬鞍山烽堆 I Mt Kan camp 龕山寨 (Founded in 1553 to defend against 'Japanese' pirates, 'now' discontinued.) *Lock:* J Three Rivers' lock 三江閘 *Inlets and harbours:* K Chengpuu gang [Clam inlet harbour] 蛏浦港 (Warships stationed here in the 1550s.) L Sanjiang gang [Three Rivers' harbour] 三江港 M Shizii koou [Lion's mouth] 獅子口 N Biezii koou [Turtle hatchlings' gate] 鱉子門 *Islands:* O Qiur shan 毬山 P Biaanjiao shan 扁礁山 *Mountain:* Q End of Mt Charng 長山頭 *Lakes:* R L. Liarng 梁湖 S L. Xiahgaih 夏蓋湖 T L. Xiang 湘湖 *Prefectures, counties, guards, and military stations:* U Lihhaai military station 瀝海所 V Lirnshan guard 臨山衛 W Sanjiang station 三江所 X Shahngyur county 上虞縣 Y Shaohxing prefecture 紹興府 Z Xiaoshan county 蕭山縣 AA Xixing customs station 西興關

Figure 7 is a composite cartographical/topographical scene, looking southwards from Mount Fehnghuarng 鳳凰山 (just south of Harngzhou) across the Qiarntarng River. We have assembled it from two separate pages of the Zherjiang provincial gazetteer that seem, in spite of important differences in conceptualization (such as the mapping of the background in the left half as against the pictorial treatment in the right half), minor stylistic differences (like the visual conventions used to show the waves), and different subject matter (the inclusion of coastal defence stations in the two left-hand panels, and of ships in the right-hand ones), to illuminate each other when taken together.[11] The date of the scene is best taken as some time in early 17th century, since the Mirng system of Guards (*weih* 衛) and military stations (*suoo* 所) is shown, but it is probably unwise to try to be more precise. Its value is that it shows all three mouths of the river functioning, including the old south exit between Mount Kan and Mount Zhee, which is labelled the Turtle Hatchlings' Cleft (*biezii mern* 鱉子瞥) after the midstream group of low hills that divides it into two channels. Three Rivers' Mouth Lock (P) is visible in the second panel from the left. The most surprising features are the numerous reefs and small islands east of Mount Zhee and north of the mouth of the Caor'er River, none of which can be found on modern maps and which may therefore have been transients. The midbay peninsula is almost entirely missing.

Figure 8 has a northern orientation and shows the southern shore of the bay in the later 16th century, with the focus on coastal defences.[12] The key is given below. There are some obvious errors, such as the westward deplacement of the Turtle Hatchlings' Gate 鱉子門 (N, which should be approximately level north/south with Mount Kan), that indicate caution is required in accepting its other features at face value. These features are, however, striking. The Narnsha 南沙 peninsula does not exist, and three rivers, whose mouths are marked 'A', 'B', and 'C', empty into the Qiarntarng River where the peninsula now is: 'A' is to the east of Mount Charng 長山 and west of Mount Kan 龕山; and 'B' and 'C' are to the west and east respectively of one of the groups of small hills (either the Taihher shan 太和山 which lies on a line between Mount Kan and the northern extremity of Mount Maa'an 馬鞍山, or the Shahngfang shan 上方山 and the Nanpirngshan 南屏山) that are located west of Mount Maa'an. The topography shows that the 'Mount Maa'an Beacon' (labelled 'H') is not placed on the summit of Mount Maa'an but on one of these small hills. These rivers, like the Small West River that enters the bay east of Mount Maa'an and is closed by the Three Rivers' Lock (labelled 'J'), all appear to be isolated from the sea by locks (double lines). The only seawall specifically indicated is that around the eastward bend of the Qiarntarng northwest of Xiaoshan (single line), which continues down to the lock on river 'A' east of Mount Charng. It would appear that the mouth of the Caor'er River is more open than it has been in the 20th century, widening markedly at Clam Inlet Harbour (Chengpuu gang 蟶浦港, labelled 'K') facing Three Rivers' Harbour 三江港, that

the coastal sandbars so evident there in modern times have not yet built up, and that the lower section of the Caor'er river has not yet formed the meanders so evident in Figure 1. This pattern also fits better with that of the 'new' map reproduced in the *Three Rivers Lock*, rather than the 'old' one.[13]

Figure 9 shows the northern coast at about the same period as Figure 8 (the cartouche on the upper left referring to 'Japanese' pirates in 1549 as 'first' attacking).[14] It is orientated towards the south, and shows the peninsula (markedly foreshortened) now stretching south from Shirdun 石墩, with its military encampment and headquarters, and Haainirng, to hills now on the southeastern edge of the present Narnsha, such as Mount Yarn 岩 (also 巖 or 垵) 山 and Mount Zhee 赭山, with their military beacons. The straight-line distance from Shirdun to the south end of Mount Zhee is approximately 36 kilometers, and the line runs directly across the present mouth of the Qiarntarng. Haainirng is separated from the sea by a substantial expanse of sands solid enought to support 8 military beacons (*fengdui* 烽堆), each indicated by a Ω symbol. The isolated drainage pattern of the eastern half of these sands (left-hand panels) suggests the régime typical of a free-standing bank (such as the depositional island in the modern channel shown in Figure 1). The absence of any visible southern shore in the right-hand panel should probably be taken as a cartographic convention rather than an indication of the great width of the river. The mountains on the coastline west (that is, to the right) of Mount Zhee are unidentified. Figure 10 takes us as far as the detailed map record goes.[15] It shows Haainirng in Yuarn times (as may be seen from its designation as a *zhou* 州 'department' rather than a 'county'), in a northward-facing orientation. The key indicates the most important features. The most striking aspect of the topography is the wide, gently concave, arc of continuous shoreline running west-to-east from north of Mount Shuu to Mount Shirdun and Mount Dahjian, separating the department capital from the sea by perhaps 6 kilometers (seeing that the distance from Mount Shuu to Haainirng (Yarn'guan) today is about 12 kilometers). The whole coast is protected by two dykes (shown by vertically scored lines, which should not be confused with the almost identical lines for the department boundaries), (*Xiarntarng* 鹹塘), which incorporates the Ox Barrage (*Niurbei* 牛陂), and the inner (*Niurbei* 牛陂), and the inner Fresh-Water Dyke (*Dahntarng* 淡塘). The eastern half of the coast is also guarded by a third dyke, still further inland, the New Daohrern Dyke 道[16]人新塘 . There is evidence of settlement in the area later covered by the Major North Cleft, such as Chuu Village 楮村, and various postal relay stations (*pu* 舖), and 'landing places' (*buh* 步 = *buh* 埠). In Sohng times there were also two salterns in this area, one at Mount Shuu and one at Mount Yarn.[17] There is an array of closely aligned irrigation canals (*jiaan* 筧, more properly 'bamboo flumes', but this seems an unlikely sense in context), and cross-dykes (*yahn* 堰), to the northwest of the Haainirng, but this feature seems to have left no discernible trace today.

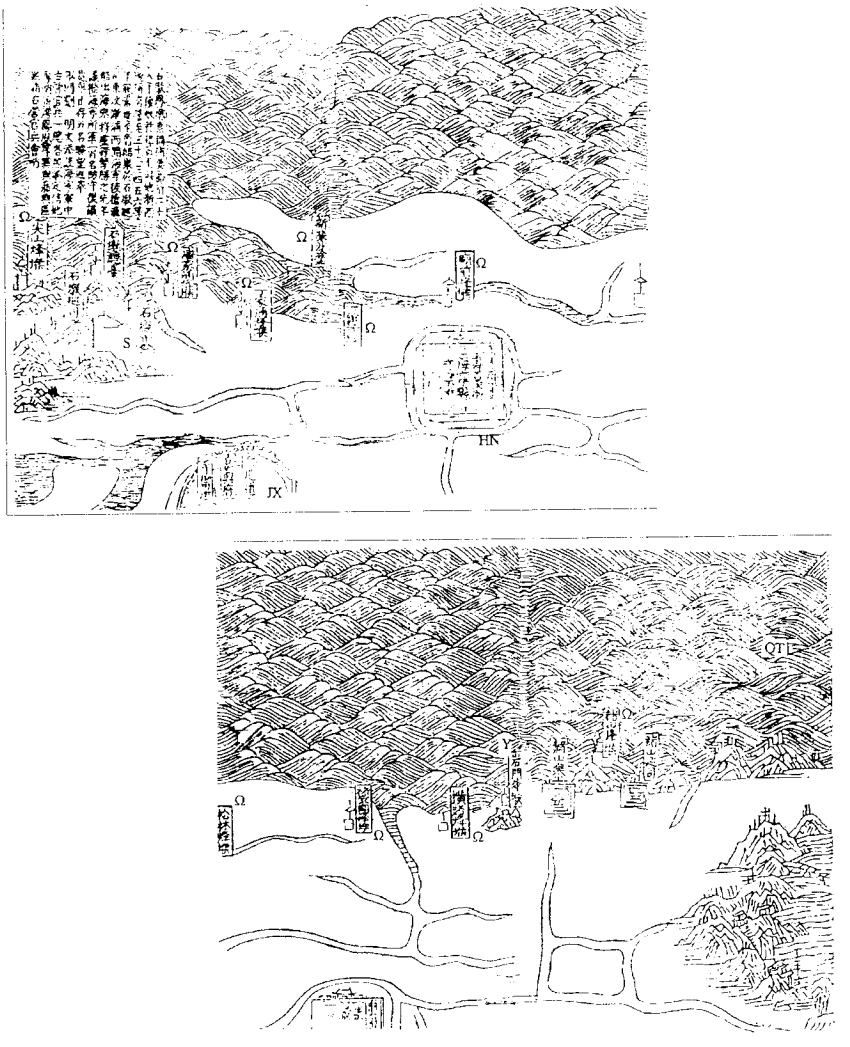

FIGURE 9
The Northern Shore of Harngzhou Bay in the later 16th Century

Military beacons are all marked with a Ω
S Shirdun 石墩 military complex Y Mt Yarn beacon 岩山烽堆 Mt Zhee 赭山 military complex JX Independent battalion 守禦所 under the Military Intendant 兵巡道 of Jiaxing prefecture 嘉興府 HN Haainirng county 海寧縣 QT Qiarn-tarng river 錢塘江

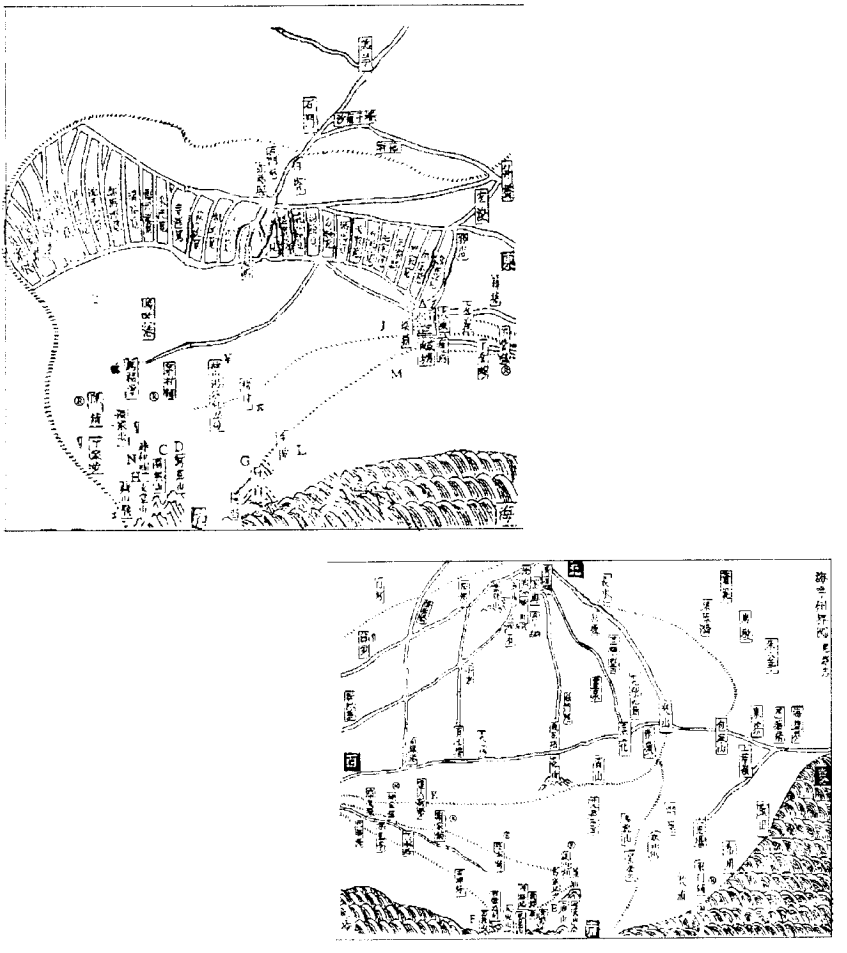

FIGURE 10
The Northern Shore of Inner Harngzhou Bay in Yuarn Times

Mountains A Mount Dahjian 大尖山 B Mount Fehnghuarng 鳳凰山 (not to be confused with its more famous namesake in Harngzhou) C Mount Ger'aoh 葛墺山 D Mount Herzhuang 河莊山 E Mount Miaoh 庙山 F Mount Shirdun 石墩山 G Mount Shuu 蜀山 H Mount Werntarng 文堂山 I Mount Zhee beacon 赭山烽 *Dykes* J Dahn dyke 淡塘 K Daohrern new dyke 道人新塘 L Ox barrage 牛陂 M Xiarn dyke 鹹塘 *Settlements* Landing places 步 : ¶ Postal relay stations 鋪 : ® Village 村 : π Department capital 州治 : Δ Customs station 稅課局 : ¥ Temple 寺 : N Shirher rural district 時和鄉

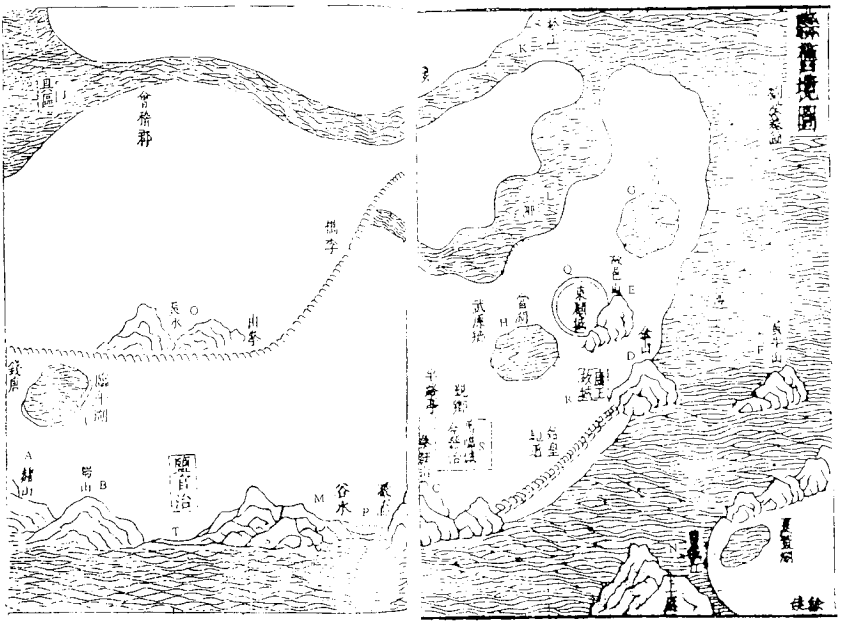

FIGURE 11
The North Coast of Inner Harngzhou Bay in Qirn/Hahn times

Mountains

A Zhee shan 赭山
B Shuu shan 蜀山
C Qirnzhuh shan 秦駐山
D Jin shan 金山
E Guhyih shan 故邑山
F Huarngniur shan 黃牛山

Lakes

G Zheh hur 柘湖 (supplied from the Haaiyarn map, shown here as Tuoh hur 鼉湖)
H Dang hur 當湖
I Lirnpuu hur 臨浦湖
J Juhqu 具區 (= Taih hur)

Rivers, etc

K Song jiang 松江
L San Maor 三
M Guu shuui 谷水
N Caor'er jiang 曹娥江
O Charng shuui 長水
P Gaanpuu 澉浦

Settlements

Q Dong Guh cherng 東顧城
R Kang Warng guh cherng 康王故城
S Maahaor cherng 馬嗥城 (now site of Haaiyarn 海鹽)
T Haaiguan 海官

Figure 11 is a sketchy outline of the entrance to the bay from Qirn/Hahn times, about 2000 years BP, included in the gazetteers for Haaiyarn county and Haainirng department.[18] Mount Zhee and Mount Shuu are shown on the northern coast. Lake Taih appears under its pre-imperial name of Juhqu 具區, and is drained by a Song River 松江 much wider than it is today. There are probably two dykes, though this is speculative: one is what seems to be a seawall south of Mount Jin 金山, but labelled "Imperial Way of the First Emperor" (*Shiihuarng chirdaoh* 始皇馳道), and the other a long inland barrier that runs from Qiarntarng (錢唐[only altered to 塘 in Tarng times to avoid the use of the dynasty's name]) to cut off the San Maor 三 泖 inlet. Early in the +1st century the capital city of Haaiyarn was drowned by the Dang Lake 當湖(some sources say the Zher Lake 柘湖) and had to be re-established nearby. The Guu River 谷水 appears only as a name, west of Gaanpuu 澉浦, but on a map for Haaiyarn for a slightly earlier date[19] the course is shown flowing down from a lake into the bay at the same point. The general impression of the north coast is thus of a lowlying area full of lakes, open to the tides and hence somewhat saline. We turn now from the cartographic record to the documentary record.

3. THE SHIFTING LANDSCAPE: THE DOCUMENTARY RECORD

The basic pattern of change discussed here is summarized in the *Sanjiang-zhar wuh quarnshu* 三江閘務全書 [Complete documents relating to the affairs of the lock at Three Rivers' Mouth] compiled around 1702 by Cherng Mirngjiuu 程鳴久 (style Herzhu 鶴翥):[20]

> The overall pattern is that the water from the upper reaches of the Zher River 浙江 [i.e., the Qiarntarng] flows out through [one of] three clefts (*mern* 門, literally 'gorge']. There is a large cleft to the south and to the north, and a small central cleft in the middle between them. When the water makes its exit through one of these clefts, the other two are both silted up. They have opened in sequence, changing around among themselves. The time during which water is passing out through one of them may be several hundreds of years or less than a hundred, but is not to be reckoned in years and months. If we speak with respect to the Sohng dynasty, then in 1094 the water went out through the large southern cleft [implying, but not explicitly stating, that it had taken a different route previously]. More than five hundred years later, in 1620, it went out via the small central cleft, but in less than a century this was silted up, and the cottages, graves, fields, and gardens of the large northern cleft were all given over to the flow of the river. During 1692 and 1693 the current was still slight, but on 2 August 1695 it broke through in tumultuous fashion and became a large river. The sands in such places as Gualih 瓜瀝 and Jiuudun 久墩 on the border between the counties of Xiaoshan and Shanyin forthwith lay exposed to the air. In the autumn of 1693, for no reason, they collapsed totally without trace. Fortunately the sands in such places as Dongtang Bay 東湯灣 [seawards of the Lock] were actually extended, and the people could

> not contain their delight. I have heard, however, from those living along the sea-coast that they did not consider this to be a cause for rejoicing, but as something deserving profound anxiety....

The inner bay was extraordinarily unstable.

The changes in the shape of Harngzhou Bay in historical times have been extensive, and it therefore seems likely that the patterns of tidal flow have also changed. Different coastline geometries imply different patterns of reflection, refraction, and interference by incident waves, and hence different patterns of sediment transport, deposition, and removal.[21] A tantalizing but somewhat obscure passage that refers to such effects of is quoted in the Haainirng county gazetteer as a note to an entry dated 1500:

> For many long years there have been counter-currents and unmoving accumulations of water (*suhhuir tirngxuh* 泝洄渟滀). The streams[22] have thrown out sand-bars like obstructing walls. Thus the river-mouth has become constricted and the tides constrained so that they strike when reflected (*faanji* 反擊) against the concave shore (*wei'an* 隈岸) of Yarn'guan [Haainirng].[23]

A problem for future research on the bay will to be see if the sequence of geometries reconstructed by the historian can be shown to have shaped their own evolution.

There is also a useful entry in the historical section of the *Zhongguor zihrarn dihlii* 中国自然地理 [Natural geography of China][24] , which points out that the Warngparn mountains 王盤山 [25], a group of rocky islands now about 20 km out to sea off Zhahpuu 乍浦 on the north shore (northeast of the northeast corner of the satellite image in Figure 1), were joined to the mainland in Jihn 晉 times. According to the Sohng-dynasty writer Charng Tarng 常棠:

> The Huarngparn Mountains are far out in the sea, but the pillars of the bridge are still standing. In 1241 one could still find such things as old wells, small stone bridges, and the stumps of large trees along the shoreline in the tide. If one looked at the characters inscribed on the bricks of these wells, one could learn that a military colony had been stationed here in Eastern Jihn times.

The shape of the bay 1500 years ago was markedly different from that which it has today. In Eastern Hahn times for example, the philosopher Warng Choong 王充 reported that not only the Qiarntarng but also "the rivers of Shanyin [i.e. Shaohxing] and of Shahngyur," on the south coast of the bay, "both had great waves (*tao* 濤," or in other words tidal bores.[26]

A thousand years ago the Qiarntarng opposite Harngzhou city was a less stable system than it has since become. For example, the poet Su Shih 蘇軾 (Dongpo 東坡), who served for a time in the 11th century as the sub-prefect of Harngzhou, wrote:[27]

> In the course of twenty years I have personally seen countless drownings. Those who come and go from [the coastal prefectures of] Wen, Tair, Mirng, and Yueh all cross [the Qiarntanrng River] at Xixing 瀝. They do not venture into the defile where the shifting hills (*furshan* 浮山)[28] are. Though their boats do from time to time capsize, this is not frequent. Those who come and go from [the inland prefectures of] Quh, Muh, Chuh, Wuh, Sheh, Xuan, Raor and Xihn ... and who all make their way, in both directions through the Lorngshan [stream] 龍山河 [which gave access to the city from the south via a lock], go along the river. The river being full of banks and shallows, they are obliged to ride on the tide if they are to proceed. The tide comes in from the east of the sea-gate (*haaimern* 海門) with the force of a thunderstorm, but there are shifting hills rising up in the midst of the river and facing the hills of Fisherman's Inlet (Yurpuu 漁浦-- south of Xiaoshan and approximately opposite Harngzhou), and interlocking like dog's teeth. So it is that one sees the waters of the tide swirling in eddies there, and striking against them with redoubled fury. The silt shoals shift around, assuming the forms of demons and spirits, often surging forth from the deep pools to form mounds that run for more than 100 *lii* and then vanish again between sunrise and sunset. Even the captains of boats and fishermen are unable to be certain where the deeps and the shallows are.

In similar fashion, Qiarn Weirshan 錢惟山, who was a native of Harngzhou, wrote in the middle of the 14th century that[29]

> A hilly eyot[30] (*shanyuu* 山嶼) shifts about (*fur* 浮) in the river, appearing to be a stable rock. When the incoming tide leaves the sea-gate behind,[31] it divides in the middle into two branch-streams, the eastern one of which goes along the shores of Yueh [that is, Shaohxing] towards the Furchurn 富春 [that is, the Qiarntarng River above Harngzhou], and the western one of which strikes straight against this eyot with furious onslaught, and then withdraws. It is called the "tide that turns its head around" (*huirtour-chaor* 回頭潮).

This feature is not mentioned at later dates. It seems, too, that there may have been pressure at this time against the northern bank of the river, which then ran from Harngzhou city along the southern boundary of Rernher county to Mount Zhee, but across which the river now flows on its way to the bay.

Some time before the 11th century the trend of sedimentary deposition on the north shore of the bay was reversed, and the low-lying coastal land (which was then many kilometers south of the present north shore, as will be shown later) began to be washed away. There is a general description of this, from a late-Mirng-dynasty perspective, in Guh Yarnwuu's *Commanderies and Principates*:[32]

> The [northern] sea-wall is 100 *lii* distant from the prefectural city [of Jiaxing]. It runs all the way through the territories of Pirnghur 平湖 and Haaiyarn, a length of 170 *lii*. To the south it looks across [the bay] to Guihji [Shaohxing] and to Sihmirng 四明 [Nirngbo]. The old gazetteer records that when the First Emperor of Qirn was here, he wished to build a bridge across the sea.[33] There are still stones sticking up out of the sea even now, which people point to as being the columns of this bridge.

The Sohng-dynasty gazetteer notes that 50 *lii* to the south-east of Haaiyarn there used to be the Water-Storage Barrage (*zhuhshuui bei* 貯水陂), and 3 *lii* south of this the Indigo Field Inlet (*larntiarn puu* 藍田浦), and 3 *lii* further east the Transverse Inlet (*herng puu* 橫浦), linking in an easterly direction with Guhyih [顧邑 – unidentified]. When one went southward towards the sea there were also the Thirty-Six Sands, the Nine Mudflats, and the Eighteen Mounds, as well as the Seven Peaks of Huarngparn 黃盤, spread out across the seaside waste-land.

Today the county capital [of Haaiyarn] is only half a *lii* away from the sea, which has entirely drowned the last traces of the former barrage and reservoir. The tides flow back in a rotating fashion (*huirliur* 洄流) from the sandbar (*dan* 潬) [that has accumulated] on Mount Zhee and Mount Kan,[34] and strike against the borders of Haainirng and Huarngwan. When they reach the White Tower Rocks (*bairtaa* 白塔)[35], where the Qirn once had a guard-station, they are in a condition of redoubled agitation in which rogue waves (*yourtaor* 游濤) are carried along by the wind, destroying people's houses and damaging their crops.

There have been constant proposals for dykes. In the Kaiyuarn reign-period [713 - 741] the Taihpirng Sea-wall was built. In the Shaohxing reign-period [1131 - 1162] the county magistrate constructed twenty *lii* of dykes, while in the Xianpirng reign-period [993 - 1004] Transport Commissioner Charng Maoh 常楙 built a new dyke that was 36250 feet in length. In the *jiaachern* year of the Zhihzhehng reign-period [1364] the county magistrate ... built 48000 feet of sea-defence dyke, but once it had grown old, being an earth dyke, it was easily destroyed. After this the land gradually turned into sea.

With the rise of the Mirng, ever more detailed proposals were made for improvements in the control of the sea, but the sea-wall repeatedly collapsed.

This litany of effort underpins our later argument that there was a serious degree of technological 'lock-in' once local society had become committed to its hydraulic system. The question remains, though, as to why first the outer northern coast (around Haaiyarn), and then the inner norhern coast (around Haainirng), were now being attacked.

In the + 1st millennium, and probably for some considerable period of time before this, the Qiarntarng River debouched through the sea-gate between Mount Kan and Mount Zhee . This was known in Qing times as the Major Southern Cleft (*narn dah mern* 南大門). In the course of the first half of the + 2nd millennium, it became silted up and after 1620 the river debouched through the Minor Central Cleft (*zhong xiaao mern* 中小門). The history of the Narngaang 南港 (a minor central channel) is unclear, but it was said, in 1734, to have "long ago been intermittently used by ships carrying firewood or salt."[36] Between the early 1690s and the middle of the 18th century the river shifted again, this time to the Major Northern Cleft (*beei dah mern* 北大門). It seems that in the later 18th century this channel ran immediately west and north of Mount Herzhuang 河莊山 as now,[37] rather than some way away from it as in the earlier part of this century.

A summary of this history was given in a report made to the emperor in 1733 by Haaiwahng 海望 and his colleagues:[38]

> The surplus vital energy (*qih* 氣) in the roots of the mountains would seem to resemble the drawn-out fibres of silk floss, so that when the tides pass the sediment accumulates. It may happen at times that there is a passage through, but it will subsequently become blocked again.
>
> Thus, if the water does not go south, it goes north. If it goes south there are, however, Mount Kan and Mount Charng (常山, presumably for 長山) to defend against it. If it goes north, there is only the line of sea-walls, and it is easy in the extreme for the water to break in and flood.
>
> At the present time, *the Major Southern Cleft has already silted up* [emphasis added] and become level land. Some tens of years ago [that is, *circa* 1700], some water was still passing in and out of the Minor Central Cleft. The water has gradually shifted to the north since then. The mulberry fields and cottages of the Major Northern Cleft have already become an expanse of open sea. We fear that should it be desired to block off the wild waves of the open ocean, to cause it to return to the central channel, it is beyond human power to do so.

With this as an introduction we now turn to descriptions of specific periods. Guh Zuuyuh's 顧祖禹 geographical handbook, compiled in the seventeenth century but for readers of the histories, and evidently referring to an earlier period, says of Mount Kan:

> It looks down on the Qiarntarng River, and rises up to face Mount Zhee in Haainirng on the other side. There are small hills along its flank, called the Turtle Hatchlings' Hills (*biehzii shan* 鱉子山). The river flows out between them. Therefore this is known as the Turtle Hatchlings' Gate, or the Seagate. It is the lock and key of the Qiarntarng.[39]

Elsewhere he notes of the river near Xiaoshan that

> In times past it was 30 *lii* broad [that is, about 17.3 kilometers]. In recent years tide-borne sediment has gradually accumulated, and it is less than 20 *lii* across. The broadest part of the mouth on the seaward side is almost 70 *lii*.[40]

In Guh Yarnwuu's anthology of documents, assembled about the same time, he cites an earlier source that has the elders of Haainirng saying:

> Mount Zhee is in the south of the county, and is the gateway actually used by the river. To the east lies Huarng Bay (Huarng wan 黃灣), a harbour with access to the sea. These two endpoints are 140 *lii* apart, but there is no intermediary city wall that can be defended. When the 'Japanese' made raids in earlier years, they would first speed to Mounts Kan and Zhee, then take possession of Mount Shirdun 石墩山.[41]

This suggests that, at the time to which this refers, the coastline ran unbroken from Mount Zhee (now halfway down the west shore of the Narnsha peninsula on the *southern* side of the bay) to Mount Shirdun, part of the Jianshan group on what is today the *northern* shore.

The documentary record is thus in agreement with the maps considered above. It also amplifies it. Thus, with respect to Figure 12, the Saltwater Dyke (*xiarntarng* 鹹塘), set back slightly from the coast, and its western sector running from just south of Haainirng city to the western

slopes of Mount Shuu, then south to the east of Mount Herzhuang, is said to have collapsed some time before 1299 but to have been rebuilt in 1327,[42] or 1329/30.[43] The *Geographical Digest* states that this dyke, and the adjacent Freshwater Dyke (*dahntarng* 淡塘) replaced the Tarng-dynasty dyke that had been mostly destroyed in the tidal disasters of the early 11th century. When the Saltwater Dyke was rebuilt "the sea sands once again rose up rapidly [outside it], so any collapse could be avoided. For this reason the name of the department was changed to 'Sea Peace' [Haainirng]."[44]

The northern bank of the Qiarntarng River immediately inside the Major Southern Cleft is inadequately covered by the maps available, and reconstructing it from documentary sources has to be provisional. The section on land routes in the 1529 gazetteer for Rernher county 仁和縣(one of the two prefectural counties of Harngzhou) says that "to the southeast [of Harngzhou city] one goes to Stone Bridge at Mount Zhee, reaching the border of Yarn'guan [Haainirng] after 66 *lii*."[45] (There was also a water-route – along the Tangcun Dyke 湯村塘.) This suggests a continuous shoreline from Harngzhou city to Mount Zhee. The same source also indicates that Rernher county contained cantons (*lii* 里) called 'Mount Zhee' (in Charngleh rural district 長樂鄉) and 'Seagate' (in Lirnjiang rural district 臨江鄉).[46]

This bank was under attack from at least the early 12th century. According to an official writing in 1116, "in recent years the hydrological circumstances have changed somewhat. From passing out to the sea by Mount Zhee, the water has turned and gathered at Yarnmern 巖/垵/岩門 and Bairshir 白石 in the area along the northern bank. The damage done to the commoners' farmland and to the salterns extends 30 *lii* from east to west and more than 20 *lii* from south to north." In 1117 the prefect of Harngzhou observed that "the town of Tangcun, and Yarnmern , and Bairshir lie alongside the Qiarntarng River as it makes its way out to the great sea. Day and night the two tides have little by little gnawed them away and encroached inland."[47] This situation worsened after the end of the 14th century:

> Charngleh district is close to the Qiarntarng River on its southern side, and from the closing years of the Horngwuu reign-period [about 1390] until 1409 in the Yoongleh reign-period it was smitten by the river and the tides. The dyked banks were broken down.... In the fifth lunar month of 1414 Heaven-Nature unloosed torrential rains and merciless winds. The lightning-swift river and the tides overwhelmed the level land, the deep water reaching more than 10 *lii* from south to north and over 50 *lii* from east to west.... Many of the inhabitants were drowned. There were countless deaths, and the survivors fled. Dwellings were swept away without trace, and the farmland was totally submerged.[48]

Thus the Minor Central Cleft and the approach to the Major Northern Cleft were being opened from the *landward* side at this time.

On the seaward side the low-lying flats along the north coast of the outer bay were the first to be stripped away. Thus a Sohng-dynasty gazetteer records an extensive loss of land southeast of Haaiyarn, including irrigation systems, "now all submerged in the sea."[49] This may have removed one of the outer defences of the northern coast of the inner bay. A benchmark for the inner bay is provided by the record that when the sea-wall for Yarn'guan (Haainirng) was rebuilt in 721 it was at that time 30 *lii* south of the city (which is today on the sea-coast), and the sea was a further 10 *lii* south of the wall.[50] Some erosion was noticed in 1122,[51] but the real assault began early in the 13th century:

> In 1219 the sea at Yarn'guan forsook its ancient course, and the tides rushed in across more than 20 *lii* of level land, reaching in their incursions as far in as the county capital. The creek at Lurzhougaang 蘆洲港, and a number of salterns ... were all destroyed. Mount Shuu was engulfed in [surrounded by"?] the sea. Almost half of the dwellings and farmlands were lost. The salt water reached four prefectures. The prefects of that time reported that, "... Last year the waters of the sea rose suddenly, and rushed in across the sandy shores, each breakthrough carrying it in a few tens of feet further, for day after day.... The might of the tides presses in on the inhabitants. If the spring tides should irrupt with angrily bubbling waves, and a typhoon to back them, inspiring a convulsion of nature, it is all but inevitable that for 100 *lii* the common folk will be buried in the guts of the fishes."[52]

In 1222, when the tides broke in again, Liur Houh 劉垕, the intendant of Zherxi , told the emperor that the threat was to the whole area to the east and south of Lake Taih, which might be rendered uncultivable by salination if nothing were done.[53]

The overall pattern during the Mirng and the Yuarn can be summarized by quoting Chern Shahn's 陳善 *Discussion of Sea-Walls*, written early in the 17th century:

> The county capital of Haainirng borders the sea on its southern side.... The sea-wall is only a hundred paces away from the city wall. Eastwards it goes as far as Haaiyarn, and westwards to the Qiarntarng River, stretching north to south for 100 *lii*. To the southwest of this sea-wall is Mount Zhee, which faces Mount Kan to the south. These mountains enclose the sea-gate between them, where the tides enter the river's mouth.
>
> Theorists aver that the sea is clear out in the vastness of the ocean,[54] but that when it arrives here it is constricted so that it cannot do as it will. It forthwith turns back eastwards in anger, reversing its direction of circulation. There is also Mount Shirdun to obstruct it, so that it becomes still more enraged and thereupon strikes in unstable fashion both east and west. The damage that this does is concentrated on Haainirng.
>
> I would observe that, according to the old gazetteer, there were more than 20 *lii* of sand-fields outside the sea-wall, and that on the landward side of these sand-fields there were more than 160 or 170 *qing* 頃[55] of farmland, pastures, and orchards of mulberries, silk-thorns and jujubes. {So long as there was this external protection for the sea-wall, the tides could not impact on it and wash it away, and there was every assurance that what was on the landward side of the stone sea-wall could endure.

> Today, the sand-fields and pastures have been entirely swept away by the sea. The protecting sands have totally disappeared. Life depends solely upon this girdle of newly constructed sea-wall.
>
> I shall not record the constructions and destructions of the sea-wall since Sohng and Yuarn times,}[56] but from the Horngwuu reign-period [1368-99] to the Wahnlih reign-period [1573 - 1619], the sea has changed on five occasions, and the wall has been rebuilt *five times*. [emphasis added][57]

One source suggests that the mouths of the Qiarntarng were becoming blocked as early as the beginning of the 15th century. In 1420 an official from the Memorials Office reported that, "in the past there were seaways at Mount Zhee and Mount Yarnmern, but today both are closed by sediment, and so the behaviour of the tides has become still fiercer."[58] In spite of this, it does not seem likely that the Northern Major Cleft was already being used by this time. Evidence that it was *not* is provided by a letter written some time in the 17th century by Zhang Cihzhong 張次仲, who was a native of Haainirng:

> The sea at our county of Haainirng is no more than an arm of the great ocean, but, when the tides strike and the sands are gnawed away, one at once sees people's fields and their houses being submerged.... To the west, Mounts Kan and Zhee face each other south and north, enclosing the sea-gate between them, the mouth where the sea enters the river. To the east are Mount Shirdun and Mounts Dahjian and Xiaaojian rising up unexpectedly in a corner of the sea, and forming the entranceway through which the sea comes into Haainirng. The tide rises in the east and passes Zhahpuu and Gaanpuu, being confined within the 'Eight Mountains of the Nearby Sea' (*jihnyarng ba shan* 近洋八山 [probably the *xiah ba shan* 下八山 off Zhahpuu]).
>
> The Qiarntarng River drains out to the west of [its confluence with] the Puuyarng River.[59] It passes the Yarn Foreshores (*yarntan* 嚴灘)[60] and so exits [into the sea]. The Yarn Cleft (*yarn mern* 嚴門) is constricted between the space of the sea-gate between Mount Kan and Mount Zhee. The entrance is exceedingly narrow, and of such a nature as to compel [the waves] to strike against each other. Since [the waves] have come from far away, they inevitably grow tumultuous and angry. For this reason they strike about in swirling fashion, with a dashing noise, and there is the menace of their bursting through [the sea-wall]....
>
> The county capital is bounded by a sea-wall a hundred paces to its south.... The section of several tens of *lii* near the city is locked by the [two] Mounts Jian at the east, and secured by Mount Zhee at the west, making an embracing arc [whose ends] protrude out [into the sea]. The county capital is to the north of these two mountains, the three of them constituting a three-sided *diing* 鼎 vessel that is struck at an oblique angle by the water. The area outside the city wall has become a headland-enclosed bay (*aoh'wei* 隩隈) for the sea.
>
> When the tide rushes into the Yarn Cleft it is held fast by the outflow of the river, which it strikes against and then returns north. These several tens of *lii* are attacked from three sides, and so it is that we constantly see the sea-wall being broken down here.[61]

The *Three Rivers' Lock* puts the date of the change at 1692-5. Presumably the northern channel after this time ran well south of the

northern coast, since there was also a period of about 50 years in the middle of the 17th century during which the pressure on the northern sea-wall is reported as having been eased. According to the county gazetteer for Haainirng:

> After the sea-wall of Haainirng county was rebuilt in 1664, the area outside it was covered with protective sands that piled up for several tens of *lii*. The local people built shacks on it, to the extent of several hundreds of families. This settlement was called 'The Village without a Name'. Near to the dyke the sand gradually became less saline and cotton was cultivated. On the new sands along the sea-shore they reduced brine by evaporation and boiled it to make salt. People garnered these profits without any longer being aware of the menace presented by the sea. In this year [1715] the wind-driven tides suddenly irrupted, and the sea-wall was smashed through.

There followed a period of instability:

> From 1720 to 1721 the protective sands were demolished each day by a hundred feet or more, even by several hundreds.... After [1724] the tides struck northwards every day. The protective sands were swept away without a remnant left. The dyke was repeatedly rebuilt and repeatedly broken.[62]

In 1720 the governor of Zherjiang, Zhu Shih 朱軾, reported to the emperor that, "recently, on account of the blockage caused by the deposition of silt, the river water and the tides have been made to move entirely to the northern bank."[63] This sounds like a decisive shift, but in fact there followed two decades of strenuous efforts to redirect both river and tides back to the Minor Central Cleft, especially by dredging In 1733, for example, some time after an earlier effort at clearing the central channel started by Zhu Shih had been abandoned, the Yongzhehng emperor observed that:

> If we dredge an induction channel (*yiinher* 引河) in the Minor Central Cleft in addition to [other measures proposed] and thus divide the flow of the Qiarntarng River into the sea, so as to reduce the force of the water, it would seem that this would also offer advantages.[64]

His successor, the Qianlorng emperor, wrote in 1762 that "in recent years the pattern imposed by the tides has been gradually pressing into the Major Northern Cleft,"[65] and it is clear during the middle of the century there was a period during which the flows moved about considerably. Later in the same year the emperor wrote a summary history of these changes, much of it based on his own personal observations:

> After 1745, and prior to 1757, the sea went through the Central Cleft. The people of Zherjiang remarked that this was most fortunate and something exceedingly hard to obtain. I made visits on two occasions in 1757 to observe it, and to offer my congratulations on this good fortune [to the God of the Sea]. I did not dare to be certain, however, that this situation would last. Not long afterwards, in the autumn of 1758, there were scars in the sediment[66] piled up on the northern headland of Mount Leir 雷山[67]; and in the spring of 1759 [the tides] pressed exclusively through the Northern Major Cleft. The

> protective sands along the northern shore were little by little scoured away. These had been the defence for the sea-wall of wooden billets and the stone sea-wall. At this moment it was no longer possible to delay the conversion of the section of the wall that was made of wooden billets to stone.[68]

The main channel seems to have oscillated between north and south up to 1765, but by 1780 or thereabouts it had settled into essentially the modern pattern.[69]

The present-day course of the lower Qiarntarng River is thus only a little more than 200 years old.

4. THE MECHANISMS OF SEDIMENT TRANSPORT

Before examining the local details, it is useful to make some general observations. Estuarine hydrology is complex, depending on the oscillatory motion of the tidal flow and the discharge of water from one or more rivers. The pattern of the tide in turn depends on, and shapes, the geometry of the coastline, which creates effects of reflection and refraction. In some cases the Coriolis pseudo-force may have some effect.[70] In the case of Harngzhou Bay, the tides come in from the Pacific along a southeast-to-northwest alignment between the southern end of Kyûshû and the northern end of Tairwan, entering through the multiple straits of the Zhoushan archipelago.[71] The Coriolis force, in so far as it affects them, would thus tend to inflect their path towards the northern shore of the bay. The Coriolis force would likewise cause the current of the Yarngzii to be deflected towards the south, then southwest, after entering the sea, and this combination explains why some of its load of sediment is carried in the direction of Harngzhou Bay.[72]

In this context it should be borne in mind that the period from approximately 1194 to 1853/5 was unusual in that the Yellow River exited only 400 kilometers north of the Yarngzi during this time.[73] In the 16th century this southern mouth was blocked with silt to the extent that extensive flooding was caused inland and the idea of trying to dredge clear its path to the sea was officially discussed, only to be rejected as impracticable.[74] It seems possible that the silt load in the Yellow Sea being carried southward, and likewise in the general direction of Harngzhou Bay, was over 60% denser than it is today.[75]

Sediment is also usually being cycled from one part of an estuary to another. As Dyer notes, "in many circumstances it is difficult to tell whether there are any long term trends because the large variations mask them, and it may take only a small variation of sea-level to destroy a local equilibrium." Since most sediment discharge occurs at occasional extreme events, and erosive power rises more than linearly with discharge, "this intermittency causes considerable problems for sampling as well as in estimating the effect of riverine sediments on estuarine and coastal sediment budgets."[76] The composition of the bed can also

determine how particles move. Thus surface ionic charges on clays increase the adhesion between particles, but these are absent from sands. So can biological activities. Some bacteria, for example, secrete mucus that can stabilize beds. Finally, human intervention on upstream river systems may have downstream hydrological consequences. L.B. Leopold has noted that "the reduction of floods by storage decreases ... the competence [carrying power] of the transporting stream," and hence "the reduction of the floods reduces the ability of the stream to rework the tributary débris."[77]

Qiarn Nirng 钱宁 and his colleagues Xieh Hahnxiarng 谢汉祥, Zhou Zhihder 周志德, and Lii Guangbiing 李光炳,[78] have described the hydrodynamics of inner Harngzhou Bay (about 30 years ago) in terms of the rapidly varying structure of the huge and mostly subsurface bar of finely sorted particles, with diameters predominantly within the range 0.005 mm to 0.1 mm, that lies between Gaanpuu 澉浦 and Wernjiayahn 閻家堰(on the eastern bank of the river some distance upstream from Harngzhou city). They state that it runs for 130 km, and this is approximately the length of a line measured at an equal distance from both banks on a map of the appropriate date. The fine-grained particles are free of marine vegetation and so are easily entrained by the motion of the water. Chern Jiryur and his colleagues[79] have estimated the mean thickness of the bar as 20 m, and its volume as about 4.3×10^{10} m^3.

The thalweg, or central line of flow, over the bar shifts seasonally with variations in river discharge, and also from year to year. In extreme cases, these movements have covered 200 m in 24 hours, and they have shown a range of about 10 km south of Haainirng.[80] The depth of the bar also varies with time. As Qiarn *et al.* note, "sometimes large quantities of sediment enter the river-mouth sector from Harngzhou Bay and are deposited there. At other times, large quantities of sediment are scoured from the river-mouth sector and transported outside. The range of the change in the mean height of the riverbed occasioned by the inward and outward movements of sediment can be in excess of 4 m upstream of Haainirng, and has reached 9 m. The range for the thalweg is over 6 m, with a maximum of over 15 m having been reached."

Compared with that of a river like the Yarngzii, the load of sediment carried by the Qiarntarng is light. The annual mean load is about 5.4×10^6 tonnes, and except at times of peak discharge amounts to less than 0.1 kg/m^3. This is two orders of magnitude less than that often found in incoming tides at Gaanpuu. Most of the sediment in the bar thus probably derives from the Yarngzii, which empties into the sea rather more than 100 km to the north.

Approximate overall equilibrium requires that the discharge from the river should scour away any residual quantity representing the difference between what is brought in by the rising tide and what is taken out by the predominantly slightly less rapidly moving ebb. (Otherwise the estuary would fill up and vanish, or the bar would be displaced offshore.) Evidence collected since 1915 indicates that when the riverine flow is

below 2000 m^3/sec tide-driven deposition dominates, and that when it is greater than 8000 m^3/sec river-driven scouring of the channel prevails, with an unstable equilibrium at intermediate values. The reason that the flow of the river is crucial, even with its lower volume, is because, under appropriate conditions, it can reverse the difference between the normally greater competence of the incoming tide as compared to that of the more slowly moving ebb.

Since the period of heaviest rainfall is between May and August (with a peak in June-July), discharge reaches its maximum in July and August, and falls to its minimum in November and December.[81] At Haainirng characteristic values for sediment brought in and sediment removed in one semi-diurnal cycle of the tide (season not specified) have been measured as, respectively, 1.8 x 10^6 tonnes and 0.85 x 10^6 tonnes. The sensitivity of the balance of forces between the river and the tide is apparent from Table 1, which shows the values for Qibaao Station 七堡站, which is about 39 km further upriver from Haainirng (measured along the centre of the line of flow). The width of the river here in the 1980s was just under 2 km but may have been greater in the late 1950s,

River discharge (water) m^3 / sec *	Direction of tide	Velocity of tide m/sec	Volume of tide 10^6 m^3	Volume of sediment trans-ported 10^3 tonnes	Density kg/m^3
Low 232	In	+0.80	106	+582	5.49
	Out	-0.63	105	-203	1.93
High 6030	In	+0.49	24.7	+47.1	1.95
	Out	-1.11	259	-719	2.78

* Annual mean: 988 m^3/sec.

TABLE 1
Riverine and tidal flows, with related sediment transport, in the Qiarntarng River measured at Qibaao Station

Source: Qiarn Nirng, et al., "Processes in recent times affecting the sandbar" (1964), p. 139. Last column calculated by present authors.

to judge from the map in the article. The data for sediment transport appear to be measurements, not estimates, but the method used is not stated, and they should be understood as illustrative, and not as presenting a comprehensive picture.

In years of low rainfall the bar builds up, while it decreases in height during years of heavy precipitation. Thus, after increasing during the dry period through 1951 and 1952, and the only moderate rains of 1952, it had reached a maximum at Zharkoou 閘口 in 1953 of 26 m. The scouring due to the heavy rains of 1954 reduced its maximum height in the year by almost 2 m.

It seems reasonable to hypothesize from these findings that anthropogenic alteration of the river flow around the bay in historic times is likely to have had some significant effect on the pattern of sediment deposition. The second article, that by Chern Jiryur and his colleagues, in fact provides an example: the alteration of the course of the Puuyarng River between 1457 and 1464, so that most of it emptied into the Qiarntarng upstream of Harngzhou, is said to have increased the scour below Wernjiayahn, and thus made the upper end of the bar retreat seawards.

The most important forms of human intervention probably affecting the evolution of the bay were (1) the stabilization of parts of the coastline with sea-walls, and (2) the reduction of the peak discharge of some of the rivers emptying into it. This statement is based on the hypothesis that the relative strengths of the forces tending to make for the deposition or removal of sediment in the various parts of the inner bay were often close enough to equilibrium for the relatively small effects of man-made structures to be sufficient in some cases to alter a trend or arrest it. This hypothesis seems reasonable as regards (1), though a number of seawalls succumbed to the attacks of the sea. As regards (2) it should be treated as speculative, though there is historical evidence to support it.

An example of the causal mechanism that we are suggesting was important is given in the Kangxi reign-period gazetteer for Shaohxing prefecture:

> In 1457 the prefect Perng Yih 彭誼 had the White Horse Mountain Lock (*bairmaa-shan zhar* 白馬山閘) built in order to block off the tides at Three Rivers' Mouth.[82] Eastwards of the lock [the seaward side] it all silted up and became farmland. After this the river's water was no longer in direct contact with the sea.[83]

White Horse Mountain Lock did not last long, however, being derelict by the + 16th century.[84]

Other factors were certainly at work in increasing the deposition of sea-borne sediments, among them perhaps the shape of the rivers, though the question was controversial. As an illustration we may cite of the comments of the grain-transport commissioner Jia Daan 郟亶 (who

flourished in the middle of the 11th century) on sediment in river-mouths:[85]

> I have also heard that in ancient times the inlets (*puu* 浦) that entered the sea from the town of Qinglorng 青龍鎮 in Xiuhzhou 秀州 [south of present-day Shahnghaai] had 72 loops (*huih* 會 = *huih* 匯), and were serpentine and meandering. There was a profound significance in this, which we may take as being that the water tended in an easterly direction by following the lie of the land. Even though [the streams] were serpentine and meandering, no harm was done thereby to their eastwards flow. If a southeasterly wind blew up, whipping the ocean tides so they poured in in torrential turbulence, the intervals between [the river-bends] provided something for them to rebound from, and the sediment (*nirsha* 泥沙) did not penetrate far inland. People of these later times have not understood the intentions of the men of old, and are of one mind that [these rivers] should be straightened. Thus, if it should happen that there is an east wind, and the ocean tides pour in in torrential turbulence, the sediment now travels with their flow straight upstream, there no longer being any obstacle in its way. All creeks and inlets entering rivers, lakes, and the sea are in a similar situation. When one talks, therefore, of "clearing them one day and finding them closed up the next," this is what is being referred to.

The meander zone may, just possibly, have helped to keep the rivers scoured by concentrating the ebb flow in a smaller channel than that of the flood, because of channel cross-sectional asymmetry,[86] but the observation of the effects of reflection as reducing deposition is interesting. With respect to the area surveyed in the present paper, the effects of straightening the course of the Qiarnqing River 錢清江 on the seawards side of the lock built at Three Rivers' Mouth in 1537 are recorded in the commentary on the maps in *The Three Rivers' Lock*:

> If the old map is not included, people will not be aware how excellent things were in past times [the collection of documents dates from about 1702], when the mouth of the lock was always clear. If the new map is not included, people will not be aware of recent changes, and of how easily the lock's mouth [now] silts up.... The Nine Bends Sands (*jiuuqu sha* 久曲沙) are connected with the topographic disposition (*fengshuui* 風水 = geomantic character) of the entire prefecture, but most especially with that of the lock. Now, when there were bends in the sands then the tide did not come straight in, and the sediment was brought to a halt because it followed these curves. Therefore the lock was always clear. The two large bends were subsequently cleared away, and it is certainly the case that the water [now] exits more easily, but the tide likewise comes in more easily, and the mouth of the lock is more easily liable to become silted up. As to the West Bend Spit (*xi huih zuui* 西匯嘴) and the East Charn Spit (*dong charn zuui* 東嘽嘴), these two [extended bars of] sands [at the mouth of the river] appear in the old map as intertwining, and the shape of the sands is long and broad. They constituted the outer defences of the lock. Today the ends of the two sand-bars lie open and exposed, and their shapes are constricted to half of what they were before. The force of the tides strikes powerfully against the lock and harms it.[87]

It seems that human intervention was capable of having significant effects, though sometimes not of the kind intended.

5. ENGINEERING THE SEA

a. Mirror Lake

The south-shore sea-wall was only the final control mechanism in the irrigation system created for the Shaohxing plain, which had advanced slowly northwards from the alluvial fans at the foot of the mountains for more than a millennium as the tidal wetlands were reclaimed for farming. A historical overview of this process is given by Maa Yaohxiang 馬堯相, writing at an unknown date but before the middle of the 17th century:

> The water sources of Guihji [Shaohxing] flow from the southwest to the northeast. *In ancient times they were in direct communication with the sea.* [emphasis added] The inrush and the drainage were not regulated, which harmed the common folk. After [Later] Hahn times, when Maa Zhehn 馬臻 had built Mirror Lake to receive the water off the mountains, sluice-gates were installed along the dykes, being opened and shut at the appropriate seasons. When water was in short supply they drained the lake to irrigate the fields. When water was plentiful they closed the lake and drained water from the fields into the sea....
>
> Later they also built the sea-wall and opened Yuhshan Sluice [the principal control-point for water from the south entering the Qiarnqing River, about 33 *lii* north of Shaohxing city and Mirror Lake]. After this the embankments of the lake slowly fell into disrepair. Though there were proposals in the Sohng dynasty to restore the lake, it had by this time become unnecessary. The reason for this was that the waters flowing into Guihji by diverse channels were several tens in number....
>
> ... One may say that those fields that lie along the feet of the mountains are watered by their springs, while those that border the sea are supplied by the streams that branch from the former. These latter, having obtained what the former has accumulated for them, are also spared the disasters [i.e., spate flooding] that afflict the former, both of these benefits depending on the sea-wall along the Inner Sea (*houhhaai* 後海 [i.e., Harngzhou Bay]), which both stores the water and discharges it.
>
> For this reason, when previously, under the Hahn, there was no sea-wall, it was essential to build Mirror Lake [as a reservoir for fresh water]. In these later times when, since the Sohng, there has been no Mirror Lake, keeping the sea-wall in good repair has been essential.[88]

The basis for the study of the southern shore of Harngzhou Bay was laid by Chern Qiaoryih 陈桥驿 in five articles:[89] The first of these studies describes how hydraulic engineering transformed the Shaohxing plain. The south-to-north flow of approximately twenty small rivers coming off the hills into the bay below was intercepted by the construction of a long and narrow retention basin, the Mirror Lake referred to above (and shown in part as the 'dragonfly-wing' pattern at the bottom of Figure 1). This

covered about 206 km^2. Not long afterwards a canal with an approximately parallel orientation was built from Xixing 西興 (which faces Harngzhou across the Qiarntarng river) to the bank of the Caor'er River, and later on to Nirngbo 寧波. The purpose of the basin was to retain water from the peak discharge in May to August, and release it to the fields below as needed. To prevent salinization by the incursions of the tide, locks and sluices were installed at the outlets of the drainage channels. These were gradually brought under the control of a single sluice at Yuhshan 玉山 (sometimes also called the Zhuchur Sluice 朱儲斗門), located at the present-day town of Dooumern-zhehn 陡 亹鎮.

By Mirng times, after having had an earlier course through Lirnpuu and the other broads southwest of Xiaoshan (and by now dried up), the lower Puuyarng River (here also known as the West Small River or the Qiarnqing 錢清江) ran out west-to-east roughly parallel with Mirror Lake and the canal, but to the north of it, emptying into the sea at Three Rivers' Mouth.[90] The Puuyarng was apt to flood the plain and the effects were made more serious by the sea-wall, which blocked easy drainage . In 1457-64 the Qixiahn Hill 七賢山, also known as the Qiryahn Hill 磧堰山, south of Lake Xiang 相湖, was therefore cut through and the greater part of the river's water was diverted westwards into the Qiarntarng river just upstream from the city of Harngzhou. Figure 1 shows this cut in the hill clearly (near the southwest corner of the image), to the west of where the present Puuyarng bends west at the town of Lirnpuu 臨浦鎮, and also the remnants of the former northerly main course, with the residual isolated or semi-isolated oxbow meanders characteristic of shifts of this nature.

After Mirror Lake had silted up in the 11th century it was apparently too costly to dredge it clear again. One estimate, made at the time, was that it would have needed 5000 men 15 years to dredge it to a depth of 5 feet. (Using the estimated area given above and the approximation of 0.3 meters per Chinese foot, it seems that this implies that one man could remove over 11 cubic meters of sediment a day, which seems high, though perhaps conceivable if it was soft.) Nor was there general agreement among members of the community that dredging was desirable.[91] Those who had reclaimed parts of the lake had no desire to lose their fields; there were more northerly reservoirs that were in some respects more conveniently placed (though Chern does not note that they lacked the height above the fields, and hence the head of water, that Mirror Lake had possessed); and the sea-wall offered a barrier against the sea-water.

Chern originally suggested[92] that one of the reasons for the accelerating deposition of alluvium in Mirror Lake was the cutting of the upstream forests, which were of the tropical mixed type, with a substantial proportion of conifers, a trend that had begun to become noticeable after the Jihn 晉 government had moved south in the 4th

century. The theme of deforestation is examined more systematically in the second and third articles. There were three main phases:

1. The first source of pressure on them was the rise of the kingdom of Yueh 越 in the middle of the - 1st millennium. Timber was needed for buildings and boats, and to fuel the metallurgical, ceramics, and salt industries. The consequences were not severe. Even in Hahn times coffins were being made here out of whole logs, rather than planks.

2. After the + 4th century the use of timber probably began to exceed the capacity of the forests for self-renewal. Chern notes the appearance of merchants who cut and sold wood and bamboos. From the last part of the Tarng dynasty onwards some of the forested hills were partly cleared for tea-gardens, but tea only grows well on sheltered sunny slopes, and it was still essentially a luxury at this time. The effect is unlikely to have been great.

By the Sohng dynasty, however, Zhuang Jihyuh 莊季裕 could observe of the area around Yuehzhou 越州 (Shaohxing) that "there are hills but no trees." Peasants began to move up into the mountains in Southern Sohng times where they grew a cereal called *jih* 穄 of which it was said that "its sprouts resemble millet but its awns those of rice," as well as other dry-land crops like ordinary millet, buckwheat, and beans. This process presumably led to a permanent stripping of much of the forest.

Disaster struck in the 18th century when maize (which probably arrived in the area around the middle of the 16th century) and sweet potatoes (which came in perhaps half a century later) were grown on an ever-expanding scale in the hill country. Chern quotes the "Jixiarng-zhih" 機祥志 [Monograph on auspicious events] from the *Mirngshu* 明書 [History of the Mirng] to the effect that "for the first time people burnt land clear in the mountains of Zherjiang, and the grasses and trees on both sides were swept away." By the later part of the Qing dynasty Guihji was without significant forest cover. The extraction of salt from brine had to move from a process of boiling to solar evaporation because of the shortage of fuel.[93]

Although river sediment was a relatively minor component in the infilling of the inner bay, this account provides an provisional chronological framework within which to consider the possibility of increased run-off caused by the loss of vegetation cover

b. Early Seawalls

The most recent work in Japanese on the sea-walls has been that by Honda Osamu 本田治. His article "Sô-Gen jidai Settô no kaitô" 宋元時代浙東の海塘 [The sea-walls of Zherdong in the Sohng and Yuarn Periods] establishes a preliminary chronology for the sea-walls of this period along the southern coast of the bay. The first reliable record is of a *re*building in the Tarng dynasty, though there are indications that some sea-walls may have been in existence here much earlier.

The entire south shore of the bay was enclosed by a sea-wall about 500 *lii* (i.e., 289 kilometers) long, running from its western terminus at Mount Charng to Dihnghaai 定海 (modern Zhehnhaai) at its eastern end. For the period that concerns us, the section of some 61600 feet protecting

the area that is now Shaohxing prefecture, and sometimes called the Inner-Sea Sea-Wall (*houhhaai-tarng* 後海塘), was built 40 *lii* north of the prefectural capital in the early 13th century (replacing the earlier Tarng wall). It was said that, being "on the shore of the great sea," "if it is not repaired in good time, the fields and cottages will be drowned." By Mirng times about one third of it was faced with stone.[94] The purpose of the wall was mainly "to keep the [fresh] water in and to irrigate the fields."[95]

c. The Puuyarng River

In his fifth article, Chern suggests that the earliest lower course of the Puuyarng River was to the west into the Qiarntarng River, but in an indirect fashion through two broads[96] that have by now long since silted up, namely the Lirn Broad 臨浦 and the Yur (or Fisherman's) Broad 漁浦. This may well have been the case for at least part of the river's water, and that there was an old 'curvilinear' western course, *before* the shift to a northern and northeastern exit, or for a time co-existing with it,[97] is supported by the passage from Maa Yaohxiang quoted earlier. There is also probably a geological fault in the line of the hills here, and an overflow channel for waters may well have existed here before the Mirng The shift of the main channel to this cutting through the hill, so strikingly visible as anthropogenic on the satellite image of Figure 1, may have been a complex process. In our view, however, he overemphasizes the unsatisfactory nature of the documentary evidence[98] for the establishment of the main channel through the Qiryahnshan 磧堰山 (or Qixiahnshan 七賢山) in the Mirng period, and some of the material he cites can as well be taken as supporting the view that the main course immediately prior to the 15th century was indeed to the north. For example, the "Monograph on Rivers and Channels" in the *Mirng History* 明史 states that:

> In 1435, the Ministry Bureau Secretary Sheen Zhong 沈中 said that the Small West River in Shanyin 山陰 communicated upstream with Quhzhou 衢州 and Jinhuar 金華, and *downstream with the sea-mouth of the Three Rivers* 三江海口... It had recently silted up, and it was necessary *to build* (*zhur* 築) the Qih Dam 戚堰 at Lirnpuu, to block the water from *the lakes*, so that they flowed *as before* out the Small River (p. 70).

The italicized words indicate that the Puuyarng and the Small West River were, at this time, the same watercourse, that the Qir Dam was not yet in existence, and that up to this time the water from "the lakes," which probably refers to the famous 72 lakes of the middle Puuyarng, had flowed out along a northerly course. At the same time it suggests that there was at least an overflow through the Qiryahnshan, once a blockage had occurred. Similarly, in 1482, the Prefect of Shaohxing, Daih Huu 戴琥, wrote that

> The Zhujih River 諸暨江 [i.e., the Puuyarng] used to have the Qir Dam 磧堰, *so that it joined together with the Small West River* to enter the sea. Only since the dam has disappeared has it *for the first time* divided into two (p. 70)[italics added].

Professor Chern notes that the name "Qir Dam" goes back to at least the 12th century,[99] and we agree with him that the issue is a complex one that will benefit from re-examination.

The changes in the pattern of flow of the lower Puuyarng River while on its *northwards* lower course ebded by causing trouble. At first it came north, emptying out of Bairmaa Lock. When this lock became silted up, it turned northeast, flowed across the lower plain at this time in an approximately west-to-east alignmen in the bed of the Qiarnqing 錢清. Maa Yaohxiang describes what happened :

> There was a further cause for anxiety. All the water of the lakes of the counties of Puuyarng 浦陽[present-day Puujiang] and Jihyarng 暨陽 [present-day Zhujih] *used to* flow into the Jihyarng River 暨陽江 [presumably the Puuyarng], then turn north*west* [emphasis added] and enter the Zher River 浙江 [the Qiarntarng]. Its configuration was curvilinear and it could not go straight to its destination.[100] *Later* it passed through Fisherman's Inlet and entered the Qiarnqing River [i.e. going north and then *east*]. To the north it went out of Bairmaa [shan] and other locks, and so entered the sea [directly].
>
> Today, however, *these locks have also silted up.* The water has no through passage. Once there are floods, it has to flow eastwards and make Guiji [Shaohxing] its sinkhole. Although there is the Yuhshan Sluice, it is not adequate to discharge [so much] water moving west-to-east with such force. Every time this happens, people break open the dykes. Though some limited relief is thereby obtained from the emergency, they are obliged at once to repair the [dykes of these] inlets (*puu* 浦) so that they are ready to store water again. This, too, is work that is hard to accomplish.[101]

Here, too, is an example of 'technological lock-in,' though in this case the problem was eventually solved. Once a community is committed to a system of this sort, it has no easy option – barring some technological escape – but to allocate labour and resources to maintaining it, even if the costs start to rise.

The county gazetteer for Shanyin (the western part of Shaohxing) emphasized this problem, while indirectly indicating the extent to to which the flow of the rivers had by now been separated from the sea:

> After Mirror Lake had been done away with, and made into farmland, whenever the springs [in the hills above it] overflowed, there was nowhere for the water to be stored. It was joined by the water of the Waan River 浣江 [Puuyarng], which poured into the West [Small] River.... Shanyin thus became a vast flood. Whenever there were heavy rains, the water was so placed that it spread far and wide. With only the single lock at Yuhshan, it was impossible to drain it all off.[102]

The terrain was said to have had "the configuration of a water-jar" (*wehngxirng* 甕形).

Between 1448 and 1511 at least 13 new locks were built to drain off the water of the West Small River both to the north and the south, and to drain two "new rivers", one near Mount Kan and one simply attributed to Shanyin county, both presumably north into the Sea Gate area.[103] These measures were not adequate, and the temporary breaching of the dykes was still required in emergencies. According to one source:[104] "The mouths of the two locks [at Biaantuo 扁〔匾〕拖, near Yuhshan] are narrow in the extreme. When the water arrives here it overflows several hundred [square] *lii*. When it reaches the sea-wall it has become a ferocious and turbulent commotion that is a great disaster for the farmland." The Shanyin county gazetteer commented that, "once the dykes had been broken and the wild torrents had foamed swiftly away, it was inevitable the channels would rapidly run dry. The weary people were then burdened by having to plug the breaches, yet before this work had been completed they would be suffering from a shortage of water."[105]

The solution lay partly in the re-routing of the Puuyarng River already referred to, the use of locks at and near the Mar Stream (Marqi 麻溪)[106] to stop too much water coming north, and the building of the Yihngxiuh Lock (*yihngxiuh zhar* 應宿閘), or Three Rivers' Lock (*sanjiang zhar* 三江閘), whose 28 sluices (*dohng* 洞) were each named for one of the 28 stellar mansions (*xiuh* 宿), across the mouth of the Puuyarng at Three Rivers' Mouth. It was constructed between a large hill and a very small one that were joined by a natural stone pavement into which the huge stones of the lock's foundation were 'mated' and caulked with a sort of paste made out of boiled millet stalks and lime or mortar (*hui* 灰).[107] It was flanked to the north by an earth wall that was 4000 feet long and 400 feet (*sic*) broad, reinforced by iron and later bamboo in a fashion that the sources do not specify except to note that it was needed because the 'mud' (*naoh* 淖) of which this barrier had been made proved 'unpredictable at first.' The flow of water was regulated by means of a double layer of wooden planking in each sluice. The construction is said to have been hurried: the 'threshold' on which the lock stood was not perfectly 'level and tight;' the wooden boards leaked and had to be repaired, and some of them replaced, every dry season. The initial outlay required in money was 6000 ounces of silver for the lock and that for the earth dyke several times that amount, both raised by a levy on acreage in the three counties affected. The labour was mobilized by conscripting local commoners on a rotating basis. "With this, the water no longer behaved violently, and the sea-wall was no longer [deliberately] breached and repaired."

The massive lock was completed in 1537. The engineered separation of the Shaohxing plain water system from the sea was now total except for the Caor'er River on the extreme eastern edge. The result (at least on the plausible assumption of *post hoc ergo propter hoc*) was the immediate build-up of sediment deposits off-shore:

> The tides were blocked by the lock and the earthen dyke, and could no longer insinuate themselves upstream. This made it possible to farm more than 10,000 *moou* [within the sea-wall]. Outside the dyke, where hills formed flanking wings, the sediment (*yu* 淤) became soil (*raang* 壤) so that little by little [a further] several hundred *qing* of farmland could be obtained.[108] The marshy portions could be used for growing reeds. The brine could be drawn off to make salt. The swampy pools could be used for fishing. Mulberry trees could be grown along the edges of its fields, and merchants could travel on its paths.[109]

Given this evidence of seaward-side land formation following the lock's building in 1537, and the overall chronological sequence of events, there is a case for suspecting that the filling in of the Major Southern Cleft and the ensuing shift in the debouchment of the Qiarntarng River in 1620 to the Minor Central Cleft, may have been in part the consequences of the preceding hydraulic closure of the coastal plain along the southern shore of the bay in which the Three Rivers' Lock was the culminating installation. These processes in the inner bay were of course interconnected with a larger pattern of events in the outer bay – such as the separation of Huarngparnshan from the coast – that were outside, or almost outside, human influence.

It was said in the 17th century that the effect of the work of Tang Shaoh'en, the creator of the Three Rivers' Lock, was that "with regard to the high and low conditions of the water, he regulated them to proportional quantities (*fen shuh* 分數)."[110] In other words, the peak discharge (*jiershuui* 節水 = 'seasonal flood') was replaced by a managed régime. In the words of Cherng Mirngjiuu, in the later 17th century,

> In years past, both the sea and the river-channel were deep. Today the sediment accumulates easily, and makes use of the flowing [river-]water to scour it clear. The water of summer and autumn is, however, closely linked to farming operations. It is necessary to conserve it with a grudging parsiomony. When winter has come, then there is no cause not to take the boards [in the lock-sluices] down and to desist from caulking [the fissures in them] with mud.... Before the peak discharge is finished [in the early summer], the lock-gates are closed, but caulking is not necessary. Once the peak discharge is past, it is essential, once the gates have been shut, to caulk [the cracks].... [But] opening and shutting ought to follow the particular seasonal conditions. It is not right to adhere inflexibly to a set pattern.[111]

The management of the lock had observable effects. As Cherng wrote:

> It is now a hundred and some tens of years since His Honour Tang built the great lock, and renovation has been undertaken twice in the space of this time.... Over these years the tides have caused difficulties, with sediment blocking it up, the problem being that there is no strategy for dredging it clear....
>
> If the lowest boards of the deeper sluices are entirely removed, then the state of the water will be swiftly rushing along, and the ferocity of the current redoubled. *The sediment that comes in with the tide will, in the same fashion, be taken out by the tide.* [Emphasis added.] If it is not seen to that the lowest

boards are removed, then inevitably the current cannot move swiftly right down at the bottom.

It is, however, entirely the responsibility of the lock-workers to remove or retain these lowermost boards at the times when the lock is vented. In the deep sluices, where opening and closing off are difficult, they either go only halfway, or do not remove the boards completely. For this reason the clear water floats over the top and the current does not reach to the bottom. The sediment accumulates here, and there are no means of expeditiously draining it away. This is one reason why the river is silted up....[112]

A lack of rain and a well-repaired lock could also trigger deposition. The 'Summary of Current Concerns' relating to the lock noted that

> Harm caused by silt blockage began in 1671. After this time there were years of hot, dry weather. Although the situation was manageable upstream of the lock, it often happened that downstream the silt piled up as far as the East Charn Spit [at the mouth], and the water inside would often accumulate for a month or more without draining away. After the repairs done to the lock in 1682, there were not many fissures through which the water could leak out, and the current in the river [below the lock] repeatedly flowed in reverse direction (*lüü huir* 履洄), and under these conditions it was easy for the sediment to block it up.[113]

The current was also slowed down by fishing-screens. Cherng noted that

> What is more, curved screens (*qu bor* 曲簿= 箔) are used to trap fish. According to the old system, this would begin at mid-autumn and the screens would then all be withdrawn after the first full moon of the [lunar] new year. Today, the number of fishing-screens has incessantly increased, and there is no season at which they are withdrawn. Furthermore, multi-layer fishing-screens are set up everywhere, cutting off the current and making ... pools in which the water-weeds start to grow after enough time has passed, and this is even more effective in bringing the flow to a stop.[114]

The destruction of vegatation cover on lowlying land could also under certain circumstances accelerate deposition in the riverbed:

> In 1664 the main provincial army forces pastured their horses along the sea-coast [by the mouth of the river], and by so doing destroyed all the reeds. The salt-producing households took advantage of this opportunity to develop it all as being 'unvegetated land' (*bairdih* 白地)[115]. Since the turbid flows were no longer confronted by the reeds, whenever there was a fierce rainstorm, the mud floating on top of the bare land was swept into the river, where it accumulated....
>
> Since the reeds were destroyed by this pasturing of horses, the sand-flats in several places have been eroding away for the last twenty years or so. Both upstream and downstream of the lock [the channel] has been constantly full of sediment. It is because this has been happening for the last twenty years or so that it is possible to be certain that it is because of the destruction of the reeds that the river is filling up, and, perhaps, that the land is eroding....
>
> Although there is no unvarying pattern to ersoion and deposition, it is deposition that dominates, and this is an omen that the land surface is in the

> course of extending. After a few more years the sea-mouth will be locked shut.[116]

We have dealt in our other paper with the contrasting role of salt-tolerant vegetation in facilitating the reclamation of bay-shore land.

d. Later Seawalls

In spite of the immensity of the forces involved, the conception of controlling the bay, at least to some extent, seems to have emerged in the 18th century. Thus in 1723 the Yongzhehng Emperor favoured dredging one of the blocked mouths of the Qiarntarng "so that there is a through-flow, causing the tides not to cause an obstruction by dropping their load of sediment" and thus safeguarding the Haainirng sea-wall.[117] The clearest example of this interventionist approach was the plan put forward in 1732 to build a stone barrier across the neck of the sea separating the Lesser Mount Jian on the mainland east of Haainirng from Mount Taa 塔山 about half a kilometer off the coast:

> It will divide and overcome the force of the water, so that the tides go south, and we may anticipate the renewed deposition of protective sands along the northern bank.[118]

This barrier was to be 1820 Chinese feet in length, and it was estimated that it would have to range from 40 to 130 feet in depth. When the final sector of 810 feet was completed in 1739, however, the greatest depths were reported to be only 18 to 19 feet because of the deposition of "floating sand." The disparity was commented on, but no further explanation given.

Groins of two sorts were also built to neutralize the impact of the waves on the sea-wall, though it is hard to tell what use they may have been without knowing more than we do about the exact nature of the locations where they were placed. One type was the 'chicken's-beak bar' (*jizuui-bah* 雞嘴壩), a narrow, pointed spit whose purpose was said to be to 'deflect the return flow' (*yii tiao huir-liuh* 以挑迴溜) so that the fury of the waves would find it hard to act in mutually reinforcing fashion.[119] The other type was the semi-circular 'grass platter' (*caao parntour* 草盤頭), which was described as 'a barrier-dyke to deflect the water' (*tiaoshuui-bah* 挑水壩) sticking out into the sea, and could be 30 or 40 feet high. The rationale behind it was that, 'in those places where the dyke is fundamentally stable, it may happen that when sands have piled up on the shore opposite, or sand-bars have accumulated out of sight under the sea, the pattern of force in the water will strike directly [against the dyke], which being thus assaulted will no longer be safe but in peril. For this reason grass platters are built to deflect the currents' (*tiao liuh* 挑溜).[120] It may have been of more use as an artificial headland concentrating wave-energy onto itself by refraction, and hence away from the rest of the sea-wall.

A third protective measure was the 'water-leveller' (*taanshuui* 坦水), which was a kind of hydraulic glacis sloping downwards at the foot of the outer side of the sea-wall. It was constructed with rubble, topped with stone slabs secured between double rows of timber pilings. The idea, it may be surmised, though there is no explicit evidence for this suggestion, was to destroy the coherence of waves being reflected from the sea-wall and so lessen their capacity for undermining the wall's foundations by interacting with the incoming waves. The *Record of the Sea-Wall* observed that:

> To the east of Haainirng, however [in contrast to the firm 'iron-board sands' in Haaiyarn discussed immediately before this], in the district around the Jian mountains, there is also water from the river flowing down. The tide and the river strike against each other in conflict, and if the tidal bore (*chaortour* 潮頭) then rises high, feeling out [the shore] at an oblique angle and gnawing at it sideways on, the resulting situation is impossible to resist. Furthermore, when the tide is ebbing, the river water, following the lie of the land, washes and scours [the mud] away (*shahnshua* 汕刷)[121]. If the foot [of the sea-wall] is not solid, it is hard to be without anxieties. For this reason the sea-wall at Haainirng has been repeatedly re-built. After the main body of the sea-wall was doubled [in size] the hydraulic glacis at its base was also doubled, but since on all previous occasions rubble (*kuaihshir* 塊石) has been used, even though numerous slabs have been laid, from three to five layers of them, it has been easily scattered. Thus there have been frequent re-layings, and this is in no way a policy that provides a permanent solution.[122]

When that part of the sea-wall that directly defended Haainirng city, some 5052 Chinese feet, was being rebuilt in stone in the early 1730s, it was equipped with a glacis that, the *Record* implies, it was hoped would be massive enough to resist these processes of destruction. It was estimated that each section of this glacis, some 10 feet long and 12 feet across, contained 100,800 *jin* 觔 (of the general order of 50 tons by modern conversion ratios but probably here a good deal less) of rubble perhaps[123] about 6 feet deep, and had a covering of stone slabs seven inches thick, and 12 feet by 1.2 feet in size. The immense size of the undertaking is evident, even if the weight of the rubble used is almost certainly substantially overestimated (by the use of a modern conversion ratio) at approximately 25 thousand tons.

Another example of the intention to manipulate the way in which the bay changed is the following account, unfortunately not always easy to translate accurately, of the efforts of Grand Secretary Ji Zengyurn 嵇曾筠 to clear a central exit for the river in the mid-1730s:

> Although the disasters to the sea-walls take place on the northern shore in Haainirng county, the causes of the trouble are on the south shore. This is because on the south shore there are always sandy foreshores (*shatan* 沙灘) rising up by deposition, and deflecting the flow (*tiao liuh* 挑溜) so that it goes northward, and the sea-walls are in ever more danger....
>
> Grand Secretary Ji Zengyurn created the method of 'making use of the water to attack the sand' (*jieh-shuui gong-sha zhi faa* 借水攻沙之法). He either used

metal implements to excavate the sandy islands of the southern shore in a way that followed the lie [of the land] (*suir shih* 隨勢), or 'cut off the roots' in accordance with the flow of the current (*shuhn liuh jier gen* 順溜截根)[124], or else dug channels to meet the incoming tide, so causing the water of the river and the tides of the sea to come and go day and night, themselves doing the scouring. The flow of the river moved towards the south shore day by day, while on the north shore the deposited sands grew daily higher. Thus was the great work accomplished.

In 1744, the governor, Charng'an 常安, contrived the means to dredge an induction channel through the Minor Central Cleft; and, in the area around Mount Shuu, he used as before the 'method of cutting the sand' (*qieh-sha zhi faa* 切沙之法). On the inside he dredged and scooped, while on the outside he extracted and cut (*tiaoqieh* 挑切). In the spring and summer of 1747 the tides little by little swung towards the south, and the deposited sands [on the north side ?] appeared wider and wider each day. In 1748 the Minor Central Cleft was flowing through in full, and it is by no means certain that the method of cutting the sands was unconnected with this success.[125]

At the same time as an exit channel was being cut south of Mount Shuu, the Qianlorng Emperor ordered that bamboo panniers (presumably with stones in them) should be placed along the northern shore of the bay 'to deflect the current and suspend the silt (*tiao-liuh guah-yu* 挑溜掛淤).'[126] There was thus a growing sense on the part of the authorities, even if only partly well-founded, that it was possible to some extent to manipulate the coastal sea.

6. TECHNOLOGICAL LOCK-IN

'Technological lock-in' is a concept commonly used in economic theory to describe certain exceptional cases where an established but inferior technology continues to dominate because of secondary advantages that derive from the consequences of its prior establishment.[127] In this paper the idea has been used to describe cases where the commitment of of an economic and social system to a particular technology has proceeded to the point that (1) its abandonment would lead to immediate losses in production, and often of social stability and security, that are unacceptable under any 'normal' conditions, even where there are evident long-term benefits in prospect from a change of strategy, and (2) a substantial proportion of the economy's currently available resources (such as money, labour, materials, skills, and organizational capacity) are *constantly* required for the *maintenance* of the system. The effect is that a sizeable part of the future is, so to speak, 'mortgaged' indefinitely. The true cost of the system has therefore to include the loss of the opportunity to use this proportion of output in a different, and possibly ultimately more productive, fashion.

In the present paper we have considered a largely unstable system of hydraulic coastal defences, and, by implication, the consequently

unstable hydraulic network inland that depended on it. Attention has been drawn at appropriate points to aspects of lock-in. There are difficulties in a meaningful historical cost-benefit analysis, however, that may be briefly mentioned here.

1. The determination of the appropriate spatial and financial unit of account is problematic, though to some extent operationally defined in terms of the areas on which surcharges in labour-services and money were levied to pay for construction and maintenance. Hydrological units (demarcated by watersheds and comparable natural features) tend not to coincide with hydraulic units (since a large proportion of farmland within a given watershed may not benefit from irrigation or flood-control), and interests external to the unit (such as the imperial government's concern to protect the Grand Canal to the north of Haainirng from the invasoion of the tides) may also be important.

2. A non-trivial component of coercion was usually involved, and even where payments were made (which was quite extensively done in Qing times) they did not necessarily reflect the market value of labour or materials.

3. The long periods of time involved (typically hundreds of years) make it hard to find a suitable means of comparing monetary values at widely separated dates. (The use of the – very high – real Chinese rates of interest for time-discounting leads to absurdities over such long spans of time.) This difficulty is compounded by the need for almost continual maintenance, and quite frequent reconstruction, if the flow of income from the original investment, and from many other dependent investments (such as the desalinization of fields, the construction of subsidiary water-systems, settlements, and the like), is not to vanish.

Because of these and other difficulties, we often find ourselves obliged to depend mainly on the perceptions of the officials and members of the gentry responsible for making decisions. Thus, when the government cut in half the funds for the maintenance of the Three Rivers' Lock in 1678, in order to make money available for military expenditures, the harvests in Shaohxing are said to have suffered for year after year in consequence.[128] Likewise, in 1682 it was said on a stele inscribed in memory of His Honour Jiang 姜公 that if the dyke along the West Small River was breached, "the fields of three counties had no harvest for two years."[129] The compilation of the documents relating to the Three Rivers' Lock, and a two-volume supplement in about 1851,[130] was primarily motivated by a concern for continuity in the methods used by those undertaking maintenance and reconstruction. As one of the prefaces observed, "Alas! If there are founders of enterprises in this world, there must be continuators who come after them."[131]

The scale of work needed for a major renovation may be seen from the report on that directed in 1578 by Prefect Xiao Liarnggahn 蕭良幹, which cost about 60% of the original construction forty-one years earlier:

> They first built cross-dykes (*yahn* 堰) upstream and downstream of the lock, in order to provide a barrier against floods and tides [while the work was in progress]. The method used for these was that of heaped earth faced with slabs of stone. They also emplaced small 'shuttle mounds' [*suodun* 梭墩, perhaps raised walkways on which the workmen could walk back and forth to access their work] in front of the lock. They used stones mated in interlocking fashion, built upwards from below. Whenever they encountered fissures in these stones, they would consolidate them with [molten ?] cast iron. On the top of the lock, from head to tail, they ensured that the covering stones were level; and they further added large stones on both sides [of each sluice] to serve as water-guides (*larn* 欄), so that each of the 28 sluices was separately fed by a sluice-way cut in these guides. In places where there were cracks or splits they would pour in [molten] tin to which the ash of glutinous millet (*huishur* 灰秫)[132] had been added. They also attended in comprehensive and scrupulous fashion to the baseboards (*diibaan* 底板), the threshold stones (*kaanshir* 檻石), and the banks on both sides, wherever these needed repairing, replacing, or resetting in correct alignment, and wherever mortar (*hui* 灰) or iron were needed....
>
> This work was managed by Sub-prefect Yarng Zhuang, helped by Assistant County Magistrate Zhehng Rihhui, and Battalion Commander Taor Bang.... They spent several thousand ounces of silver, and employed several thousand workers. The project was completed in three months....
>
> The shape of the lock was stronger and thicker. It was on this account *really a second creation.*[133] (emphasis added)

The nature of more routine maintenance work may be seen from the regulations left by Prefect Xiao, and the other officials who also rebuilt the lock over the following century. The following is a typical example:

> Item: There are 1113 lock-boards [*zharbaan* 閘板 – used to close off the sluices]. Each one is 8.3 inches across and 4.2 inches thick. The labour-cost is 0.3 ounces of silver. One each board is a pair of iron rings, weighing 12 ounces. The labour-cost is 0.06 ounces of silver. The selection and procurement of material for these boards shall be entrusted either to honest and capable officials or to the lock officials themselves. They shall be furnished with the money and go in person into the hills to purchase large pine-trees at standard prices, and hire artisans to split them into sections. The pieces used should have all four corners square, and be sturdy and without imperfections. Those with flimsy edges are to serve as roofing-boards.... Old boards are to be replaced every other year, and the lock-workers are to send them as before to the area in front of the Zuooshehng temple for the quantity to be verified. If there is a shortfall, they are to be punished and obliged to make restitution, and the same will apply if there are cases of boards being carried off by the current when the lock has been being opened, or of having rotted when piled up together, or of having been stolen.[134]

This was only a small part of a complex operation that was habitually seen as imposing a severe burden on local inhabitants.

In a stele dated 1630 and commemorating the dredging of the Qiarnqing River by the Prefect of Shaohxing, Liur Guangdoou, the burdens of water control are likened to the attacks made on China by the northern barbarians:

> The disasters caused by water in the Southeast are like the troubles occasioned by the barbarians under the late Southern Sohng dynasty, who were a poison to our people when they entered.... Yet the affliction of water is worse than they were.... Though the Yaan Brook 剡溪 rushes down vigorously into the southern parts [of Shaohxing], and the Zher River and the sea have fierce tides that shake its north, disasters such as the present blocking up have not been heard of before. Among these are the approximately three thousand *moou* or more of newly emerged sands [stretching out] from Houhguo 後郭[135], which have caused the nature of the water to become unruly, rushing northwards and then following a path southwards. The fertile soil in the places harmed has been engulfed and cannot pay its taxes. The thread-like length of sea-wall, struck at both straight on and at an angle, has had no means to resist it. When [the flood-water] broke in during the spring, there was no wheat harvest; and when it broke through in autumn there was no rice harvest.... Though the county magistrates spent their treasure to buy masonry, and led the people to rebuild the sea-walls, yet time and again the wild waves flooded in, and the stones did not always adhere firmly together. This was indeed bestowing a fortune on the boundless floods, or like repeatedly sending our wealth each year to the barbarians at the time of the Southern Sohng, without being able to satisfy their desires.... [Although Prefect Liur has had the river dredged,] the situation resembles that of the barbarians after 1126 [when the Northern Sohng capital fell], and the exhaustion of our people is like that following the constriction following the migration south at that time. But for Prefect Liur, though, those of our people who live here would now be fish and turtles.[136]

There was a commitment here that could not easily be escaped, unless perhaps by good luck the pattern of natural forces changed; and the cost of doing so would have been perceived to have been high.

Morita has made clear the heavy financial and human costs of maintaining the sea-walls. He quotes, for example, the county gazetteer for Huartirng 華亭 which states that "the repair and construction of the sea-walls is a huge undertaking and highly expensive, requiring the collaboration of the entire county." And, again, that "these days the building of the sea-walls is mostly done in the dog-days [approximately late July to mid-August], the workmen steaming and burning in the blazing summer weather, ... gathered together in the disease-inducing heat (*shashuu* 痧署),[137] with one knows not how many of them dying at the foot of the sea-wall."

Honda Osamu has also traced the slow spread of construction in solid masonry over the centuries following the Sohng. This was at least ten times as expensive in terms of initial costs (though not necessarily more costly when considered in conjunction with maintenance over time) as the older methods using earth, 'dam-timbers' (*jiahnmuh* 楗木),[138] and bamboo baskets or wooden coffers filled with small stones or rubble. His

materials make clear the burden of maintenance on labour, organizational capacity, and material resources, especially wood. He cites, for example, a description in the county gazetteer for Shahngyur 上虞 of the rebuilding of 19940 feet[139] of sea-wall that runs as follows:

> The method is to use, for every 10 feet, 32 pine-trees (*songmuh* 松木 = Pinus spp.) one foot in diameter and 8 feet in length. These are set in 4 rows, unevenly, and sunk deeply into the ground. After this, stones 5 feet long and a half of this in width are laid at right angles to each other in an interlocking pattern on top of the level stones in 5 layers, all set into each other like dog's teeth, so that they cannot be dislocated. In places where there is a depression in the sands on the seaward side they build 8 layers. The height is over 10 feet. The top is covered with flagstones so as to seal it with their pressure. On the landward side there is a fill of stone rubble to a depth of more than a foot, and then earth is banked up next to it. The base is 20 feet wide, and the top diminishes to a quarter of this.

It may be calculated that this relatively small sector would have needed 6×10^4 pine-trunks and over 10^6 cubic feet of stone. Nonetheless there must have been a significant contrast in durability with the Sohng-dynasty earth-and-brushwood sea-wall at Harngzhou that Honda mentions as having to be rebuilt every three years.

In a sense the Chinese 'won' their war with the sea in Harngzhou bay. Land was reclaimed and farmed, as is evident from the most casual glance at Figure 1. The historic price paid for extensive interference with the hydrology of the area, and the ecosystems connected with it, was not, as it sometimes is – overall – disaster, but something much subtler, – conservatism.

NOTES

[1] We have treated this topic in, "Action at a Distance: The influence of the Yellow River on Hangzhou Bay since +1000," to be published in the proceedings of the 1993 Hong Kong conference on the history of the environment in China.

[2] The romanization of Chinese used here is based on Lirn Yuutarng 林語堂 (Lin Yutang), *Chinese-English Dictionary of Modern Usage* (1972. Hong Kong: Chinese University of Hong Kong Press) modified to fit the current *pinyin* system. Thus second and fourth tones (the rising and falling tones) are indicated by unsounded post-vocalic 'r' and 'h' respectively, and the main vowel in third-tone words (the low dipping-rising tone) is doubled. Note that 'c' is pronounced 'ts', 'q' as 'ch', 'x' as 'sh', and 'zh' as 'j' in this transcription.

3 Acknowledgements are due to EOSAT for the data, ACRES (Australian Centre for Remote Sensing) for photo-reproduction, and thanks to Robin Grau and Merv Commons (both of the Research School of Pacific and Asian Studies, Australian National University) and Paul Hutton (Division of Water Resources, CSIRO) for help with the image processing.

[4] Possibly, but not certainly, a euphemism for 'mildewing' or 'rotting' rains (*meir* 霉 or *meir* 黴). See *Cirhaai* 辭海 (1947 edn.) under these characters.

[5] Ding Yihui, *Monsoons over China* (Dordrecht, Boston, London: Kluwer, 1994), pp. 195 et seq.

[6] Morita Akira 森田明, *Shindai suirishi kenkyû* 清代水利史研究 [Studies on water control in the Qing dynasty] (Tokyo: Aki shobô, 1974.), "Kô.Setsu ni okeru kaitô no suiri soshiki," 江浙における海塘の水 利組織 [The hydraulic organization for sea-walls in Jiangsu and Zherjiang provinces].

[7] Hydrographer of the Navy (Taunton, U.K.: 1984): China - East Coast: Ningbo Gang to Changjiang Kou. Scale 1:300000 at latitude 30°.

[8] [U.K.] Naval Intelligence Division, *China Proper*, III (Edinburgh: H.M.S.O., 1945), p. 291.

[9] In their "Harng-Jia-Hur pirngyuarn quarnxinshih chernji huarnjihng de yaanbiahn" 杭嘉湖 平原全新世沈积环境的演变 [The evolution of the holocene sedimentary environment in the Harngzhou-Jiaxing-Hurzhou plain], *Dihlii xuerbaoh* 地理学报42.1 (Mar. 1987).

[10] Dir Junliarn翟均廉, ed., *Haaitarng-luh* 海塘錄 [A Record of the Sea-Wall], in *Qirndihng sihkuh quarnshu* 欽定四庫全書, Shii-buh 史部 11, *ceh* 冊 583 (Compiled after 1764 and before 1781. Reprinted 1986, in Wernyuan-ger edn.: Tairbeei: Tairwan shangwuh yinshu-guaan), p. 369.

[11] *Zherjiang tongzhih* 浙江通志 [Comprehensive gazetteer for Zherjiang province] (Shahnghaai: Shangwuh, 1934), *j.*1, pp. 200-1 and 172-3.

[12] Guh Yarnwuu顧炎武, *Tianxiah juhnguor lihbihng shu* 天下郡國 利病書 [Documents on the Advantageous and Disadvantageous Aspects of the Commanderies and Principates of the Empire] (Compiled 1639-62. Rep. 1936, Sihkuh shahnbeen congshu ed.), *ceh* 32, Zherjiang *shahng*, pp. 11a - 12b.

[13] Cherng Mirngjiuu 程鳴九, *Sanjiangzhar-wuh quarnshu* 三江閘務全書 [Complete documents relating to the affairs of Three Rivers' Lock], 2 vols., (Jiehmeir-tarng cangbeen. Prefaces 1684, 1685, 1687; probably completed in 1702. Probably (re)published with a two-volume continuation in 1854: see n. 98 below), *shahng*, *shahng j.*, 1a - 4b. We are grateful to Professor Shiba Yoshinobu for making available to us a photocopy of this rare work.

[14] Fahn Lair范淶, comp., *Liaang-Zher haaifang leihkaao xuhbian* 兩浙海防類考續編 [Continuation of the investigation by categories of the maritime defences of the Two Zher provinces], #482 in *Zhongguor fangzhih congshu*, Huar-zhong {hereafter *ZGFZCS*}. (1602. Rep. Tairbeei: Cherngwern, 1983), pp. 102-5.

[15] *Haainirng zhou zhih* 海寧州志 [Gazetteer of Haainirng Department] #591 in *ZGFZCS*, Huar-zhong (Yuan. Rep. Tairbeei: Cherngwern, 1983), *j.* 1, pp. 56-7.

[16] The transcription of this character is uncertain.

[17] *Gazetteer of Haainirng Department*, map, p. 15.

[18] *Haaiyarn xiahn turjing* 海鹽縣圖經 [Maps of Haaiyarn County] #589 in *GFZCS*, Huar-zhong (Tairbeei: Chengwern, 1983), pp. 20-1, and *Gazetteer of Haainirng Department*, pp. 50-1.

[19] *Maps of Haaiyarn County*, pp. 24-5.

[20] *Three Rivers' Lock*, *shahng*, *j.*2, p. 2a.

[21] R. Silvester, *Coastal Engineering,* II (Amsterdam, London, New York: Elsevier, 1974), pp. 143-5, illustrates these effects for a partial seawall, but the processes operate equally with natural features.

[22] The text is unclear. *Zhu qi* 諸溪 ("all the streams") may in fact be *Zhee qi* 赭溪 ("Zhee's streams") .

[23] *Haainirng county gazetteer*, p. 469.

[24] Chinese Academy of Sciences, (Beijing: Kerxuer,1982), pp. 238-42

[25] Alternatively, Huarngparn 黃盤.

[26] Warng Choong, *Luhn Herng jiaoh-shih* 論衡校釋 [Discourses Weighed in the Balance, with corrections and explanations], ed. Huarng Hui 黃暉 (Tairbeei: Tairwan shangwuh yinshuguaan, 1964), p. 173. The term *tao* 'great wave' is clearly used by Warng in the sense of 'tidal bore', as on p. 175.

[27] Su Shih, *Su Dongpo jir* 蘇東坡集 [Collected works of Su Dongpo] (Shanghaai: Shangwuh yinshuguaan, 1930), *ceh* 5, *j.* 9, p. 53.

[28] There was a Mount Fur (Furshan 浮山) in the Qiarntarng, but the term seems to be generic here.

[29] Cited in Chern Jiryur 陈吉余, Luor Zuuder 罗祖德, Chern Derchang 陈德昌, Xur Haaigen 徐海根, and Qiaor Perngniarn 乔彭年 , "Qiarntarng-jiang herkoou shakaan de jihndaih guohcherng" 钱塘江河口沙坎的近代过程 [Fluvial processes in recent times of the sandbar at the mouth of the Qiantang River {authors' own translation}], *Dihlii xuerbaoh* 30.2 (June, 1964.), p. 121.

[30] An islet in a river or lake.

[31] At this date between Mount Kan and Mount Zhee, not the present debouchment.

[32] Guh Yarnwuu, *Commanderies and Principates*, *ceh* 22, Zherjiang *xiah*, pp. 3b-4a.

[33] The British Admiralty chart #1199 shows a straight line may be followed across the bay from Huarngwan 黃灣 such that depth at low tide nowhere exceeds 5 m. The project may have therefore seemed attractive at first sight.

[34] *Huir* 洄 has two senses, namely of a movement *against* the current, and of a *rotating* liquid motion. *Dan* 潬 is a deposit merging from water.

[35] Now about 2 kilometers offshore just southwest of 30° 30' N and 121° E. They have a height above mean sea-level of 47 meters. Admiralty chart #1199.

[36] *Haainirng xiahnzhih* 海寧縣志 [County gazetteer for Haainirng] #516 in *ZGFZCS*, Huarzhong (1765. Rep. Tairbeei: Cherngwern, 1983), p. 500.

[37] *A Record of the Sea-Wall*, pp. 361 and 365.

[38] *Haainirng county gazetteer*, p. 491.

[39] Guh Zuuyuh 顧祖禹, *Durshii fangyuh jihyaoh* 讀史方輿紀要 [Geographical Digest for Readers of the Histories] (1667. Rep. Beeijing: Zhonghuar shujur, 1957), p. 3836.

[40] Guh Zuuyuh, *Geographical Digest*, p. 3837. The imperial period *lii* can for general purposes be taken as 0.576 kilometers.

[41] Guh Yarnwuu, *Commanderies and Principates*, Sherjiang *shahng*, p. 2a.

[42] *Haainirng county gazetteer*, p. 464.

[43] Guh Zuuyuh, *Geographical Digest*, p. 3767.

[44] Guh Zuuyuh, *Geographical Digest*, p. 3767.

[45] *Rernher xiahnzhih* 仁和縣志 [Rernher county gazetteer], #179 in *ZGFZCS*, Huar-zhong (Rep. 1975. Tairbeei: Cherngwern.), p. 55.

[46] *Rernher county gazetteer*, p. 53. The crude map of the southern coast of Rernher in *Harngzhou fuuzhih* 杭州府志 [Harngzhou prefectural gazetteer] # 524 in *ZGFZCS*, Huar-zhong (1579. Rep. Tairbeei: Cherngwern, 1983), pp. 72-3, shows a line of eleven landing-places (*buh* 埠) stretching due west from Mount Zhee, and facing Mount Kan, Mount Charng, and Xixing across the river.

[47] Guh Zuuyuh, *Geographical Digest*, p. 3760.

[48] *Rernher county gazetteer*, p. 390.

[49] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*, pp. 3b - 4a.

[50] *Haainirng county gazetteer*, pp. 461, 463.

[51] *Haainirng county gazetteer*, p. 1663.
[52] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*, pp. 42ab. Compare *Haainirng county gazetteer*, p. 463 : "The 40 *lii* south of the county capital have turned entirely into sea."
[53] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*, pp. 42b-43a. Compare *Haainirng county gazetteer*, p. 463.
[54] The discoloration of the coastal water due to its load of sediment is strikingly visible from satellite photographs.
[55] 1 *qing* = 100 *moou* 畝 = approximately 7 (Mirng-dynasty) hectares.
[56] The passage in braces is only in the *Haainirng county gazetteer*, p. 471.
[57] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*, pp. 47ab.
[58] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*, p. 46b.
[59] At this period in the southwest corner of Xiaoshan county.
[60] Probably at the Lower Yarn Family Bay (*xiah Yarnjia wan* 下嚴家灣) on the right bank obliquely opposite Mount Werntarng 文堂山. See *Harngzhou fuuzhih* 杭州府志[Harngzhou prefectural gazetteer] # 199 in *ZGFZCS*, Huar-zhong (Prefaces 1888/94/98. Rep. Tairbeei: Cherngwern, 1974), p. 256.
[61] *A Record of the Sea-Wall*, p. 667.
[62] *Haainirng county gazetteer*, pp. 474-5.
[63] *Haainirng county gazetteer*, p. 477.
[64] *A Record of the Sea-Wall*, pp. 323-4.
[65] *A Record of the Sea-Wall*, p. 331.
[66] Such scars were thought to indicate the imminent removal of the sediment in which they appeared.
[67] Located east of Mount Charnji 禪機山 and on the northeast extremity of the south bank of the Central Cleft. See *Haainirng county gazetteer*, pp. 70-1.
[68] *A Record of the Sea-Wall*, p. 342, and compare p. 351.
[69] *A Record of the Sea-Wall*, p. 353.
[70] Newton's first law of motion makes it appear that bodies constrained to move on the surface of a rotating sphere (except exactly along the equator) turn towards the right in the northern hemisphere in the case of a right-handed rotation (as of the Earth), and to the left in the southern.
[71] See Sun Xiangpirng 孙湘平, *et al.*, *Zhongguor yarn'ahn haaiyarng shuuiwern qihxiahng gaihkuahng* 中国沿岸海洋水文气象概况 [An outline of the hydrological patterns and weather of China's coastal seas] (1981. Beeijing: Kehxuer chubaansheh), pp. 15-6.
[72] Professor John Chappell, personal communication.
[73] C. Blunden and M. Elvin, *Cultural Atlas of China* (Oxford: Phaidon Press, 1983), map on p. 15.
[74] Tani Mitsutaka 谷光隆, *Mindai Kokô-shi kenkyû* 明代河工史研究 [Studies on the history of hydraulic works on the Yellow River in the Ming dynasty] (Kyôto: Dôhôsha, 1991), pp. 64, 71.
[75] Elvin and Su, "Action at a Distance."
[76] K.R. Dyer, *Coastal and Estuarine Sediment Dynamics* (1986. Chichester: Wiley), especially pp. 3-10 and 256-8.
[77] L.B. Leopold, M.G. Wolman, and J.P. Miller, *Fluvial Processes in Geomorphology* (1964. New York: Freeman), pp. 455-6.
[78] "Qiarntarng-jiang herkoou shakaan de xirngcherng jir qir lihshii yaanbiahn" 钱塘江河口沙坎的形成及其历史演变 [The formation of and the historical

changes in the sandbar at the mouth of the Qiarntarng River], *Dihlii xuerbaoh* 30.2 (June, 1964.).

[79] "Chern Jiryur, et al., "Fluvial processes in recent times of the sandbar at the mouth of the Qiantang River." See note 29 above.

[80] At a time when the channel here was wider than the 3 km that it is today.

[81] Sun Xiangpirng, *et al., Coastal Hydrology*, p. 13.

[82] Cherng Mirngjiuu, *Three Rivers' Lock* (*xiah, xiah j.*, p. 34a [in sequence, the given pagination being faulty here]) says that this lock is 45 *lii* northwest of Shanyin county capital at the foot of Bairmaa Mountain.

[83] *Shaohxing fuuzhih* 紹興府志 [Shaohxing prefectural gazetteer], #520 in *ZGFXCS*, Huar-zhong (1587. Rep. Tairbeei: Cherngwern, 1983), p. 591.

[84] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*, p. 48a.

[85] Okazaki Fumio 岡崎文夫 and Ikeda Shizuo 池田靜夫, *Kônan bunka kaihatsu shi* 江南文化開發史 [History of the Development of Jiangnarn] (Tokyo: Kôbundô, 1940).

[86] See, for example, L. D. Wright, J.M. Coleman, and B.G. Thom, "Sediment Transport and Deposition in a Macrotidal River Channel: Ord River, Western Australia," in L. E. Cronin, ed., *Estuarine Research*, vol. 2 (New York: Academic Press, 1975), p. 319.

[87] Cherng Mirngjiuu, *Three Rivers' Lock, shahng, j. shahng*, pp. 1ab.

[88] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*, pp. 43a-44b.

[89] [1] "Guudaih Jiahnhur xingfeih yuu Shan-Guih pirngyuarn norngtiarn shuuilih" 古代鉴湖兴废与山会平原农田水利[The rise and disappearance of Mirror Lake, and agricultural land and water control in the Shanyin-Guihji plain in ancient times] in *Dihlii xuerbaoh* 地理学报 28.3 (Sept. 1962). [2] "Guudaih Shaohxing dihqu tianrarn senlirn-de pohhuaih jir qir duih norngyeh-de yiingxiaang" 古代绍兴地区天然森林的破坏及其对农业的影响 [The destruction in ancient times of the natural forests of Shaohxing and its impact on agriculture], in *Dihlii xuerbaoh* 31.2 (June 1965). [3] "Lihshii-shahng Zherjiang-sheeng de shandih keenzhir yuu shanlirn pohhuaih" 历史上浙江省的山地垦殖与山林破坏 [The historical development of the mountain lands of Zherjiang province and the destruction of the mountain forests], in *Zhongguor shehhuih kehxue* 中国社会科学 4 (1983). [4] "Luhn lihshii shirqi Nirng-Shaoh pirngyuarn de hurpo yaanbiahn" 论历史时期 宁绍平原的湖泊变迁 [On the changing distribution of lakes in the Nirngbo-Shaohxing plain in historical times], in *Dihlii yarnjiuh* 地理研究 3.3 (Sept. 1984). And co-authored with Lüü Yiichun 呂以春 and Yueh Zuumour乐祖谋: [5] "Luhn lihshii shirqi Puuyarng-jiang xiahyour de herdaoh biahnqian" 论历史时期浦阳江下游的河道变迁 [Changes in the lower course of the Puuyarng River in historical times] in *Lihshii dihlii* 历史地理 1 (1981).

[90] That is, the Qiarntarng on its old southern course, the Puuyarng (before it was largely re-routed as described below), and the Caor'er.

[91] Studies of the rise and fall of lake-based irrigation in the Shaohxing region are tangential to our present concerns, but we would particularly mention Nishioka Hiroaki 西岡弘晃, "Sôdai Kanko no suiri mondai" 宋代鑑湖の水利問題 [The question of the hydraulics of Mirror Lake in Sohng times] in *Shigaku kenkyû* 史学研究 117 (1972), a pioneering account of the specifically social forces pressing for the conversion of lakes to arable land.

[92] In a recent conversation with the authors on 27.xii.94, Professor Chern expressed some doubt about this point.

[93] This had already happened in Furjiahn province. See M. Elvin, "Skills and Resources in Late Traditional China," in D.H. Perkins, ed., *China's Modern Economy in Historical Perspective* (1975. Stanford: Stanford U. P.), p. 100.

[94] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*, 50a. "Facing" is *zouh / zhouh* 甃, which means "a well", and "to repair a well".

[95] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*, p. 41b. There are similar comments in the Guh Zuuyuh, *Geographical Digest*, pp. 3833-4.

[96] We use the old Norfolk word for these coastal salt-water lakes called *puu* 浦 (though aware that many of the Norfolk broads were not saline).

[97] As shown in the map of Shaohxing in the Southern Sohng, in Warng Shirperng 王十朋, comp., *Chorngkeh Guihji san fuu* 重刻會稽三賦 [Three prose-poems on Guihji reprinted], #552 in *ZGFZCS*, Huar-zhong (Mirng. Rep. Tairbeei: Cherngwern, 1983), pp. 16-17.

[98] See, for example, Pirng Herng 平衡, *Sanjiangzhar-wuh quarnshu xuhkeh* 三江閘務全書續刻 [Supplement to the *Complete Documents relating to the Affairs of the Lock at The Three Rivers' Mouth*] (prefaces 1835 and 1836; probably printed in 1854), *j.* 1 , p. 14a: "In the Tianshuhn reign of the Mirng [1457-1464] His Honour the Prefect Perng Yih cut through Qiryahn Mountain in order to draw the water from the upper reaches [of the Puuyarng] into the Qiarntarng River via Fisherman's Broad."

[99] Chern, "Lower course of the Puuyarng," p. 73.

[100] In the middle of the + 1st millennium, the Puuyarng River entered a lake, the Lirnpuu 臨浦, north of where Lirnpuu town 臨浦鎮 stands today, but which has long since vanished, and then passed through a narrow channel into Fisherman's Inlet (*yurpuu* 漁浦), also now disappeared, which in turn emptied into the Qiarntarng some way upstream of Harngzhou city. See Chern Qiaoryih's fifth article summarized above and Shiba, *Jiarngnarn*, pp. 554-5, and 564.

[101] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*

[102] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*, 47a.

[103] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*, 47ab.

[104] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*, 48b.

[105] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*, 47b-48a.

[106] Located a short way upstream of the point where the Puuyarng River had been re-routed.

[107] Guh Yarnwuu, *Commanderies and Principates*, *ceh* 50, *fuhzhu* [appended notes], 60a, note 9. The stones of the piers were tapered (*yaan* 剡) where they met the impact of the water, "so that they did not fight with it."

[108] One *qing* = 100 *moou*, hence say another 300 or 400 *qing* in all.

[109] Guh Yarnwuu, *Commanderies and Principates*, Zherjiang *xiah*, 49a.

[110] Cherng Mirngjiuu, *Three Rivers' Lock*, *shahng*, "Tang-shern shirshih luh", 12b.

[111] Cherng Mirngjiuu, *Three Rivers' Lock*, *xiah*, *xiah j.*, p. 3a.

[112] Cherng Mirngjiuu, *Three Rivers' Lock*, *xiah*, *xiah j.*,pp. 36ab.

[113] Cherng Mirngjiuu, *Three Rivers' Lock*, *xiah*, *xiah j.*, p. 38a.

[114] Cherng Mirngjiuu, *Three Rivers' Lock*, *xiah*, *xiah j.*, p. 39a. *Shahng*, *shahng j.*, p. 45b also speaks of removing fishing-screens "so that the current of the river would flow swiftly to the sea."

[115] This term seems originally to have referred in Sohng times to uncultivated official land sold off for farming. See Sutô Yoshiyuki 周藤吉之, *Chûgoku tochi-seido-shi kenkyû* 中國土地制度史研究 [Studies on land-tenure systems in

China] (Tokyo: Tokyo University Press, 1954), p. 194, n. 11. Later it could simply mean 'untaxed land', with an implication of its being heavily saline soil. See Hoshi Ayao 星斌, comp., *Chûgoku shakai keizai shi go-i zokuhen* 中国社会経済史語彙続編 [Supplement to *A Glossary of Chinese Social and Economic Terminology*] (Yamagata: Kôbundô, 1975), p. 132.

[116] Cherng Mirngjiuu, *Three Rivers' Lock*, *'xiah, xiah j.*, pp. 39b-41a.

[117] *A Record of the Sea-Wall*, p. 319.

[118] *A Record of the Sea-Wall*, p. 384.

[119] *A Record of the Sea-Wall*, p. 384.

[120] *A Record of the Sea-Wall*, pp. 381-2.

[121] For the justification of this translation, see *shahnsuun* 汕損 in E-tu Zen Sun, *Ch'ing Administrative Terms. A Translation of the Terminology of the Six Boards with Explanatory Notes* (Cambridge, Mass.: Harvard University Press, 1961), #2428, p. 354.

[122] *A Record of the Sea-Wall*, p. 381.

[123] "Perhaps" because, in the absence in the source of quantified information about the slope of the glacis, it is unclear where the height was taken.

[124] Meaning unclear. Perhaps the 'roots' were obstructions?

[125] *A Record of the Sea-Wall*, p. 383.

[126] *A Record of the Sea-Wall*, p. 365.

[127] For a summary of the idea as used in modern economics, see W. Brian Arthur, "Positive Feedbacks in the Economy," *Scientific American* 262.2 (Feb. 1990), especially pp. 84-5: "Increasing-returns mechanisms ... can ... cause economies ... to become locked into inferior paths of development.... Technological conventions ... tend to become locked-in by positive feedback."

[128] Cherng Mirngjiuu, *Three Rivers' Lock*, *shahng*, Luu preface, p. 2a.

[129] Cherng Mirngjiuu, *Three Rivers' Lock*, *shahng*, *shahng j.*, p. 35b.

[130] Pirng Herng, *Supplement to the 'Complete documents relating to matters concerning the Three Rivers' Lock.'* See n. 97 above.

[131] Cherng Mirngjiuu, *Three Rivers' Lock*, *shahng*, Luoh preface, p. 1b.

[132] *Huishur* on its own was used, presumably as a mortar, to 'stick stones together.' See Cherng Mirngjiuu, *Three Rivers' Lock*, *shahng*, *shahng j.*, 16a.

[133] Cherng Mirngjiuu, *Three Rivers' Lock*, *shahng*, *shahng j.*, pp. 14ab. Compare the account in *id.*, 16ab.

[134] Cherng Mirngjiuu, *Three Rivers' Lock*, *shahng*, *shahng j.*, pp. 20b - 21a.

[135] This is an unidentified place-name, possibly related to the alternative name for Harngzhou Bay, namely Houhhaai 後海, and with a sense perhaps of 'the defensive perimeter of the Houh Sea.'

[136] Pirng Herng, *'Three Rivers' Lock,' Supplement*, *j.*1, pp. 15a - 16a.

[137] *Sha* has a variety of meanings, including colic, a cholera-like disease, and measles.

[138] On the use of 'dam-timbers' (*jiahn* 楗) for blocking breaches in a dyke, the gaps between them being infilled with vegetable material and earth, see the notes in Simaa Qian 司馬遷, *Shiijih* 史記 [Records of the Grand Historian] (Han. Rep. Beeijing: Zhonghuar shujur, 1973), pp. 1413-4.

[139] Ther used to be several hundred kinds of 'foot' (*chii* 尺) in China. The mason's foot was either 11.08 or 10.09 inches, and the Board of Revenue foot 13.18 inches. See [U.K.] Naval Intelligence Division, *China Proper* (1945. Edinburgh: H.M.S.O.), III, 607..