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 propriet.
[... 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 杭州湾, 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 Qiartmarg River 錦塘江
has shifted twice: (1) in 1620 from a southern debouchment just to the
north of Mount Kan 龟山 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 Yarngzi 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).
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 杭州湾. 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 Qiartnang River 钱塘江, 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 绍興 (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 Kangshan 竿山 (also known as Harngwuushan 杭塟山), 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 赵山 and the second on Herzhuangshan 河莊山, and, lastly, to the northeast of the latter,
FIGURE 1
Remote-Sensing Image of Hangzhou 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 Hangzhou 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, desalination 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.
there rises the low and isolated Shuushan 蜀山. On the northern shore, east of Yarn'guan/Haainiring are two hills, from west to east, the Xiaoo (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 seawall 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) in the Yarngzii valley, when the summer monsoon airflows meet the polar cold air mass.

The dominant pattern of run-off is from the hills on the south side of the Bay, which feeds not only the Qiarrantang River but also lesser but still important rivers such as the Puuyarng 浦陽江 (which today flows in a northwesterly direction into the Qiarrantang 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
satellite image). In the past, smaller streams off the hills also fed the elongated man-made Mirror Lake (Jinhghur 鏡湖 or Jiahnhr 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.
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 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.\(^7\)

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
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channels separating the islands in the Zhoushan archipelago (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. Yann Qirnshahng and Huarng Shan have shown 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, and lying from 15 m to 25 m below the modern sea-level. This trough carried a major tributary into the palaeo-Qiarnshang 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 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 Qiarnshang River. For the moment, this is speculation.

Likewise, Chern Qiao-yih 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 out 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 Niringbo-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.
Cities and towns
A Hangzhou 杭州  B Haaining 海宁  C Xiaoshan 萧山
D Xixing customs station 西兴关  E Mt Kan 赵山  F Mt Zhe 趟山
G Mt Herzhuang 河庄山  H Mt Shun 舍山  I Mt Leir 雷山  J Mt Ta 塔山
K Mt Chang 长山  L Mt Pirngtoor 平頭山  M Mt Maa 马鞍山  N Sandbanks 沙嘴
O Ox-tongue Sands 牛舌頭沙  P 'Old Sands' 老沙  Q 'Soft Sands' 软沙
R Mouths and channels
  R West mouth 西口门  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 引河旧址
W Southern major cleft 南大亹  X Central minor cleft 中小亹  Y Northern major cleft 北大亹  Z Daangshan inlet 黄山港
AA Three rivers' lock 三江闸  BB Seawalls and dykes 石塘  CC Earthen reserve dyke 土塘  DD Stone sea crossdyke 石塘  EE Fahngong dyke 柴塘
FF Tiaoshuui dyke 桃水壩  GG Old earth dyke 老土塘  HH Brushwood dyke 柴塘

FIGURE 5
The Mouths of the Qiarntarng River at the End of the 18th century
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 ‘Haaitarung tur’ 海塘圖 (Maps of the Seawall) in the Harngzhou Prefectural Gazetteer, showing the mouth of the Qiirntarung 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 Qiirntarung 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 Tiaooshuui 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 Haaining 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 Haaining is lined with 33 watch-stations (baao 堡). From Haaining 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 (chaitarung 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 Haaining 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 Mt Pirnigtour. 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 新聞引河
KK Newly opened Southern Channel 新聞南港
LL Qi channel 嘉

_Seawalls and dykes_

NN Earthen reserve dyke 土備塘

MM Daangijia Inlet 黨家港

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 173210), 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)

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 ?) 錦清江  C Unnamed (a mouth of the Qiarnqing ?) D Probably the Xixiaoo jiang 西小江 E Caor' er 曹娥江 F Qiarntraang 錦塘江 G Harngzhou Bay (or Houh Sea 後海) Mountain military camps and beacons:  H Mt Maa'an beacon 山山峰堆 I Mt Kan camp 巖山寨 (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] 鎮浦港 (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 Biezzi koou [Turtle hatchlings’ gate] 繁子門 Islands:  O Qiur shan 楊山 P Miaanjiao shan 扁礁山 Mountain:  Q End of Mt Chjng 長山頭 Lakes:  R L Liang 梁湖北 S L Xiahaai 夏蓋湖 T L Xiang 湘湖 Prefectures, counties, guards, and military stations:  U Lihhaai military station 溼所 V Limshan 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 Fehnghuang 鳳凰山 (just south of Harngzhou) across the Qiartarang 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. 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 men 衆子門) 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. The key is given below. There are some obvious errors, such as the westward displacement of the Turtle Hatchlings’ Gate 獅子門 (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 Narsha 南沙 peninsula does not exist, and three rivers, whose mouths are marked ‘A’, ‘B’, and ‘C’, empty into the Qiartarang River where the peninsula now is: ‘A’ is to the east of Mount Charrng 長山 and west of Mount Kan 龍山; 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 Shahnglang 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 Qiartarang northwest of Xiaoshan (single line), which continues down to the lock on river ‘A’ east of Mount Charrng. 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 螃浦港, 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 Haairnymg, to hills now on the southeastern edge of the present Nansha, such as Mount Yarn 岩 (also 崗 or 堡) 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 Qiarrtang. Haainirmg is separated from the sea by a substantial expanse of sands solid enough to support 8 military beacons (fengdwi 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 Haairnirmg 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 Dahbijian, separating the department capital from the sea by perhaps 6 kilometers (seeing that the distance from Mount Shuu to Haainirmg (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), (Xiarrntamg 咸塚), which incorporates the Ox Barrage (Niurbei 牛陂), and the inner (Niurbei 牛陂), and the inner Fresh-Water Dyke (Dahnitang 淡塚). The eastern half of the coast is also guarded by a third dyke, still further inland, the New Daohretn Dyke 道人新塚. There is evidence of settlement in the area later covered by the Major North Clef, such as Chuu Village 楚村, and various postal relay stations (pu 舗), 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 就, more properly ‘bamboo flumes’, but this seems an unlikely sense in context), and cross-dykes (yahn 堑), to the northwest of the Haainirmg, 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 $\Omega$

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 Haaining county 海寧縣  QT Qiantang 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 Fehnghuareng 凤凰山 (not to be confused with its more famous namesake in Harngzhou)  C Mount Geraoh 葛壟山  D Mount Herzhuang 河庄山  E Mount Miaoh 庙山  F Mount Shirdu 石墩山  G Mount Shu 屈山  H Mount Wenntareng 文堂山  I Mount Zhee beacon 紫山烽
Dykes J Dahn dyke 淡塘  K Daohrem new dyke 道人新塘  L Ox barrage 牛陂
M Xiarn dyke 稀塘  Settlements Landing places 步 :  Postal relay stations 舳 :  Village 村 :  Department capital 县治 :  Customs station 官税議局 :  Temple 寺 :  Shirher rural district 時和鄉
FIGURE 11
The North Coast of Inner Harngzhou Bay in Qirn/Hahn times

Mountains
A Zhe shan 赤山
C Qirnzhuh shan 曳駐山
E Guhyih shan 故邑山
B Shuu shan 蜀山
D Jin shan 金山
F Huarrngniur shan 黃牛山

Lakes
G Zehe hur 拓湖 (supplied from the Haaiyarn map, shown here as
Tuoh hur 蒲湖)
H Dang hur 對湖
I Lirmpuu hur 臨浦湖
J Juqu 具區 (= Taih hur)

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

Settlements
Q Dong Guh cherng 東顧城
R Kang Warng guh cherng 康王故城
S Maahaor cherng 馬桀城 (now site of Haaiyarn 海鹽)
T Haiguan 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 Haainirn department. Mount Zhee and Mount Shuu are shown on the northern coast. Lake Taih appears under its pre-imperial name of Juhqu 卜区, 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 chi'irdooh 始皇驰道), and the other a long inland barrier that runs from Qiarnarng (only altered to Targ in Targ 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 拓湖) and had to be re-established nearby. The Guu River 谷水 appears only as a name, west of Gaanpuu 滬浦, but on a map for Haaiyarn for a slightly earlier date 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 low-lying 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 三江閩務全書 [Complete documents relating to the affairs of the lock at Three Rivers’ Mouth] compiled around 1702 by Cheng Mirngjiu 程鳴久 (style Herzhu 鶴鑫). The overall pattern is that the water from the upper reaches of the Zher River 浙江 [i.e., the Qiarnarng] flows out through [one of] three clefts (mersh 壑, 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 slit 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 slit 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 爬瀨 and Jiuddun 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 東塘灣 [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. A tantalizing but somewhat obscure passage that refers to such effects of is quoted in the Haainrng 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 tirmxuh 洗涸涸漥). The streams 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 隘岸) of Yarn’guan [Haainrning].

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 zihrrn dihil 中国自然地理 [Natural geography of China], which points out that the Warngparn mountains 王盤山, 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 Solng-dynasty writer Charng Tarng 常濤:

The Huarnparn 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 漯,” or in other words tidal bores.

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:
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 Qiartanarg River] at Xixing 浸. They do not venture into the defile where the shifting hills (furshan 浮山) 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 Xin ... and who all make their way, in both directions through the Lornghshan [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 (haiamn 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:

A hilly eyot (shaunuu 山嶼) shifts about (fur 浮) in the river, appearing to be a stable rock. When the incoming tide leaves the sea-gate behind, 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 Qiartarang 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” (huairour-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:

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

The Sohng-dynasty gazetteer notes that 50 līi to the south-east of Haaiyarn there used to be the Water-Storage Barrage (zhūshuǐ hui 聚水陂), and 3 līi south of this the Indigo Field Inlet (lāntiān pū 藍田浦), and 3 līi further east the Transverse Inlet (hēng pū 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 Huarngpın 黃盤, spread out across the seaside waste-land.

Today the county capital of Haaiyarn is only half a līi 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 (huìliú 洪流) from the sandbar (dún 潭) [that has accumulated] on Mount Zhee and Mount Kan, and strike against the borders of Haainirng and Huarngwan. When they reach the White Tower Rocks (bái tā 潭岩), where the Qirn once had a guard-station, they are in a condition of redoubled agitation in which rogue waves (yéntaō 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 Kaiyuan reign-period [713 - 741] the Taihpíng Sea-wall was built. In the Shaohsing reign-period [1131 - 1162] the county magistrate constructed twenty līi of dykes, while in the Xianping reign-period [993 - 1004] Transport Commissioner Chāng Māoh 長橋 built a new dyke that was 36250 feet in length. In the jiaochern year of the Zhīzhēng 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 Ming, 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 northern coast (around Haainirng), were now being attacked.

In the + 1st millennium, and probably for some considerable period of time before this, the Qianmarng River debouched through the sea-gate between Mount Kan and Mount Zhee. This was known in Qing times as the Major Southern Cleft (nān dān měn 南大灘). 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 (zhōng xiāo měn 中小灘). 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.” Between the early 1690s and the middle of the 18th century the river shifted again, this time to the Major Northern Cleft (bāi dān měn 北大灘). It seems that in the later 18th century this channel ran immediately west and north of Mount Herzhuang 河莊 as now, 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.
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 Chang (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 sited 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 feel 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 項祖禹 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 Qiarntrang River, and rises up to face Mount Zhee in Haaining on the other side. There are small hills along its flank, called the Turtle Hatchlings' Hills (bielzii shan 鱗子山). 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 Qiarntrang.  

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.  

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

Mount Zhee is in the south of the county, and is the gateway actually used by the river. To the east lies Huarn Bay (Huarn 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.

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 (xiarntrang 鹹塂), set back slightly from the coast, and its western sector running from just south of Haaining 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 (dahnzang 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’ [Haainirg].”44

The northern bank of the Qiarntang 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 Rernheh county 仁和県 (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 [Haainirg] after 66 lli.”45 (There was also a water-route – along the Tangcun Dyke 湃村壩.) This suggests a continuous shoreline from Harngzhou city to Mount Zhee. The same source also indicates that Rernheh county contained cantons (lii 里) called ‘Mount Zhee’ (in Charngleh rural district 長樂鄉) and ‘Seagate’ (in Linnjiang 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 岩門 and Bairshir 白石 in the area along the northern bank. The damage done to the commoners’ farmland and to the salters extends 30 lli from east to west and more than 20 lli from south to north.” In 1117 the prefect of Harngzhou observed that “the town of Tangcun, and Yarnmern, and Bairshir lie alongside the Qiarntang 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 Qiarntang River on its southern side, and from the closing years of the Horngwuu reign-period [about 1390] until 1409 in the Yoonglegh 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 lli from south to north and over 50 lli 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.” 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. Some erosion was noticed in 1122, 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 Lurzhouaang and a number of salters were all destroyed. Mount Shuu was engulfed in 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."

In 1222, when the tides broke in again, Liur Houh, 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.

The overall pattern during the Mirng and the Yuarn can be summarized by quoting Chern Shahn's 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 Qianntarng 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, 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 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.
MAN AGAINST THE SEA

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, but from the Horngwu 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] 17

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 张次仲, who was a native of Haaining:

The sea at our county of Haaining 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 Xiaojian rising up unexpectedly in a corner of the sea, and forming the entranceway through which the sea comes into Haaining. The tide rises in the east and passes Zhaapu and Ganpuu, being confined within the ‘Eight Mountains of the Nearby Sea’ (jihuyan shan ba 咸洋八山) probably the xiah ba shan 下八山 off Zhaapu).

The Qiarntarng River drains out to the west of [its confluence with] the Puuyang River. It passes the Yarn Foreshores (yarnyan 雅滩) and so exits [into the sea]. The Yarn Cleft (yarn mern 雅倉) 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 艙 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 島腕) 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. 51

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 seawall 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 līi. 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 ruptured, 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.\(^\text{62}\)

In 1720 the governor of Zherjiang, Zhu Shih 朱轼, 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."\(^\text{63}\) 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 Yongzheng emperor observed that:

If we dredge an induction channel (yīnhēṛ河) in the Minor Central Cleft in addition to [other measures proposed] and thus divide the flow of the Qiānmārṛg River into the sea, so as to reduce the force of the water, it would seem that this would also offer advantages.\(^\text{64}\)

His successor, the Qianlong emperor, wrote in 1762 that "in recent years the pattern imposed by the tides has been gradually pressing into the Major Northern Cleft,\(^\text{65}\) 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\(^\text{66}\) piled up on the northern headland of Mount Leir 雷山; 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. 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. 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. In the case of Harngzhou Bay, the tides come in from the Pacific along a southeast-to-northwest alignment between the southern end of Kyūshū and the northern end of Tairwan, entering through the multiple straits of the Zhoushan archipelago. The Coriolis force, in so far as it affects them, would thus tend to deflect their path towards the northern shore of the bay. The Coriolis force would likewise cause the current of the Yarngzi 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.

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. 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. 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.

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." 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."  

Qiarn Niren 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 濱浦 and Wernjialahn 閒家壟 (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 x 10¹⁰ m³.

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 Haainiring. 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 Haainiring, 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 Yarrgzii, the load of sediment carried by the Qiarntrang is light. The annual mean load is about 5.4 x 10⁶ tonnes, and except at times of peak discharge amounts to less than 0.1 kg/m³. 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 Yarrgzii, 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. At Haaminrng 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 Qibaoao Station 七堡站, which is about 39 km further upriver from Haaminrng (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,

<table>
<thead>
<tr>
<th>River discharge (water)</th>
<th>Direction of tide</th>
<th>Velocity of tide m/sec</th>
<th>Volume of tide 10$^6$ m$^3$</th>
<th>Volume of sediment transported 10$^3$ tonnes</th>
<th>Density kg/m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low 232</td>
<td>In</td>
<td>+0.80</td>
<td>106</td>
<td>+582</td>
<td>5.49</td>
</tr>
<tr>
<td></td>
<td>Out</td>
<td>-0.63</td>
<td>105</td>
<td>-203</td>
<td>1.93</td>
</tr>
<tr>
<td>High 6030</td>
<td>In</td>
<td>+0.49</td>
<td>24.7</td>
<td>+47.1</td>
<td>1.95</td>
</tr>
<tr>
<td></td>
<td>Out</td>
<td>-1.11</td>
<td>259</td>
<td>-719</td>
<td>2.78</td>
</tr>
</tbody>
</table>

* Annual mean: 988 m$^3$/sec.

**TABLE 1**

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

Source: Qiam 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 閣口 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 PuuyarngRiver 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 彭誥 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. 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.

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

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 稼贊 (who
flourished in the middle of the 11th century) on sediment in rivermouths.\(^{85}\)

I have also heard that in ancient times the inlets (puu 浦) that entered the sea from the town of Qinglong 青龍鎮 in Xiuhzhou 秀州 [south of present-day Shahghai] had 72 loops (huiih 會 = huih 會), 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 錦清江 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 (jiuqu sha 久曲沙) are connected with the topographic disposition (fengshui 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 huiih zooi 西匯嘴) and the East Charn Spit (dong charn zooi 東嘿嘴), 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 Yaoxiang, 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 Qianqing River, about 33 *li* 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 (houthhaai 後海 [i.e., Haining 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 Haining Bay was laid by Chern Qiaoeryth 陳橋驿 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 km². Not long afterwards a canal with an
approximately parallel orientation was built from Xixing 西興 (which
faces Harngzhou across the Qianntarng river) to the bank of the Caor' er
River, and later on to Niringbo 宁波. 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
朱储斗門), located at the present-day town of Doooumern-zhehn 陡潭
鎮.

By Ming 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 錦清江) 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.' 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 Qieryahn Hill
礦堰山, south of Lake Xiang 相湖, was therefore cut through and the
greater part of the river’s water was diverted westwards into the
Qianntarng 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. 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 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 阮 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 bamboo. From the last part of the Tarn 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 Jiyou 趙季裕 could observe of the area around Yuehzhou 越州 (Shaoxing) 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 jiju 楓 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 Ming] 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.95

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 Setô no kaitô” 宋元時代澱東の海塘 [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 rebuilding in the Tarn 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 li 莫 (i.e., 289 kilometers) long, running from its western terminus at Mount Charn to Dihngshai 定海 (modern Zhehnhai) 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 後海壩), was built 40 lì 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 Puyuarng River

In his fifth article, Chern suggests that the earliest lower course of the Puyuarng River was to the west into the Qiarntarng River, but in an indirect fashion through two broads96 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 Yaoxhixiang 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 evidence98 for the establishment of the main channel through the Qiaryhnshan 礫壩山 (or Qiixianhshan 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 山隂 communicated upstream with Qulhzhou 衢州 and Jinhuan 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 (zhue 築) the Qi Dam 戥壩 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 Puyuarng and the Small West River were, at this time, the same watercourse, that the Qi 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 Puyuarng, had flowed out along a northerly course. At the same time it suggests that there was at least an overflow through the Qiaryhnshan, once a blockage had occurred. Similarly, in 1482, the Prefect of Shaohxing, Daith Huu 戴號, wrote that
The Zhujih River [i.e., the Puuyarng] used to have the Qir Dam 濟堰, 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, 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 ebbed 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 alignment in the bed of the Qiarnqing 錢清. Maa Yaoxiang describes what happened:

There was a further cause for anxiety. All the water of the lakes of the counties of Puuyarng 濟陽[present-day Puujiang] and Jihyarng 景陽 [present-day Zhujih] used to flow into the Jihyarng River 景陽江 [presumably the Puuyarng], then turn northwest [emphasis added] and enter the Zher River 浙江 [the Qiarnqings]. Its configuration was curvilinear and it could not go straight to its destination. 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 [Shaoxhing] 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 濟) so that they are ready to store water again. This, too, is work that is hard to accomplish.

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 Shaoxhing) emphasized this problem, while indirectly indicating the extent 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 沃江 [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.

The terrain was said to have had “the configuration of a water-jar” (wehngxirng 筩形).
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. These measures were not adequate, and the temporary breaching of the dykes was still required in emergencies. According to one source: "The mouths of the two locks [at Biaantuo 拖, near Yuhshan] are narrow in the extreme. When the water arrives here it overflows several hundred square lī. 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."

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), to stop too much water coming north, and the building of the Yihngxiuh Lock (yihngxiuh zhār 應宿閘), or Three Rivers' Lock (sanjiang zhār 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). 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 淤) 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 膳) became soil (raung 墩) so that little by little [a further] several hundred qing of farmland could be obtained. 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.

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 Qiarrarng 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 Huarrngparshar 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).” In other words, the peak discharge (jiershuí 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 parsimony. When winter has come, then there is no cause not to take the boards [in the lock-sluiices] 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.

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 sluiices 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...

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 (liū liū 履流), and under these conditions it was easy for the sediment to block it up.

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

What is more, curved screens (qu bor 曲溥 = 箩) 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.

The destruction of vegetation 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’ (bai rén 白地). 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 erosion 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.\textsuperscript{116}

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

\textit{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 Yongzheng Emperor favoured dredging one of the blocked mouths of the Qiannanqin “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 Haaining sea-wall.\textsuperscript{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 Haaining from Mount Taa\textsuperscript{\textsuperscript{}} 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.\textsuperscript{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’\textsuperscript{119} (jizzuui-bah 雞嘴壩), a narrow, pointed spit whose purpose was said to be to ‘deflect the return flow’ (yii tiao huir-liuh 以挑迴流) so that the fury of the waves would find it hard to act in mutually reinforcing fashion.\textsuperscript{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)\textsuperscript{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-leveler’ (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 piling. 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 Haainingr, 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 scourcs [the mud] away (shahsua 洗刷). If the foot [of the sea-wall] is not solid, it is hard to be without anxieties. For this reason the sea-wall at Haainingr 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 (kuatlahir 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.

When that part of the sea-wall that directly defended Haainingr 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 副 (of the general order of 50 tons by modern conversion ratios but probably here a good deal less) of rubble perhaps 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 Zengyunn 稹曾筠 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 Haainingr 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 (tiuo liu 挑溜) so that it goes northward, and the sea-walls are in ever more danger....

Grand Secretary Ji Zengyunn created the method of ‘making use of the water to attack the sand’ (jiieh-shuuui 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 (shuahn liuh jier gen 順溜截根), 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, Chang'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 jia 切沙之法). On the inside he dredged and scooped, while on the outside he extracted and cut (tiaojueh 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 Qianlong 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 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 Haainiring 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 Shaoxing are said to have suffered for year after year in
consequence. 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." The compilation of the documents relating to the Three Rivers’
Lock, and a two-volume supplement in about 1851, 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."
The scale of work needed for a major renovation may be seen from the report on that directed in 1578 by Prefect Xiao Lianggah 廉良幹, which cost about 60% of the original construction forty-one years earlier:

They first built cross-dykes (yahs 堤) 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 槽墩, 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 槎), 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 灰糊) had been added. They also attended in comprehensive and scrupulous fashion to the baseboards (daibaan 底板), the threshold stones (kaashir 檜石), 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 Rihui, 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 Zuoshen 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 Qianqin 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 浙溪 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 moku or more of newly emerged sands [stretching out] from Houguo 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 constricting 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 Huarting 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 (shashhuu 热暑),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 槎木),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\(^1\) of sea-wall that runs as follows:

The method is to use, for every 10 feet, 32 pine-trees (songmu 桐木 = 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 \(6 \times 10^4\) pine-trunks and over \(10^6\) cubic feet of stone. Nonetheless there must have been a significant contrast in durability with the Sohung-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 Lin Yuutang 林玉堂, *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 微*). See Cirkaai 聒海 (1947 edn.) under these characters.
MAN AGAINST THE SEA

9 In their "Harngh-Jia-Hur pirngyuarn quarnxinshih chernji huarnjihng de yaanbiahnh" 江浙平湖新事紀頒演變 [The evolution of the holocene sedimentary environment in the Harnghzou-Jiaxing-Hurzhou plain], *Dihlhi xuervaoh* 地理学报42.1 (Mar. 1987).
13 Cherrng Mirngjiuu 程鳴九, *Sanjiangzhar-wuh quarnshu* 三江開闢全書 [Complete documents relating to the affairs of Three Rivers' Lock], 2 vols., (Jieheir-targ cangbeen. Prefaces 1684, 1685, 1687; probably completed in 1702. Probably (re)published with a two-volume continuation in 1854: see n. 98 below), shahn, shahn j. 1a - 4b. We are grateful to Professor Shiba Yoshinobu for making available to us a photocopy of this rare work.
16 The transcription of this character is uncertain.
17 Gazetteer of Haaining Department, map, p. 15.
19 Maps of Haaiyarn County, pp. 24-5.
22 The text is unclear. *Zhu qi* 諸溪 ("all the streams") may in fact be *Zhee qi* 赤溪 ("Zhee’s streams").
23 Gazetteer of Haaining county gazetteer, p. 469.
24 Chinese Academy of Sciences, (Beijing: Kerxuer,1982), pp. 238-42
Alternatively, Huarngpan 黃盤.


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

Cited in Chern Jiryur 陳吉余, Luor Zuuder 羅祖德, Chern Derchang 陳德昌, Xur Haagiex 徐海根, and Qiao Perngniarn 乔彭年, “Qiannarng-jiang herkouo shakaan de jihndhau guochereng” 錢塘江河口沙坎的近代过程 [Fluvial processes in recent times of the sandbar at the mouth of the Qiandong River {authors’ own translation}], *Dihll xuerbaoh* 30.2 (June, 1964.), p. 121.

An islet in a river or lake.

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

Guh Yarnwu, *Commanderies and Principates, cch 22*, Zherjiang xiah, pp. 3b-4a.

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.

Huir 洞 has two senses, namely of a movement against the current, and of a rotating liquid motion. Dan 澹 is a deposit merging from water.

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.


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

Haaining county gazetteer, p. 491.


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


Haaining county gazetteer, p. 464.


*Rernher county gazetteer*, p. 390.


Haaining 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.”
54 The discoloration of the coastal water due to its load of sediment is strikingly visible from satellite photographs.
55 1 qing = 100 moo = approximately 7 (Ming-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.
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.
72 Professor John Chappell, personal communication.
75 Elvin and Su, “Action at a Distance.”
78 “Qiantrang-jiang herkoou shakaan de xirngcherng jir qir lihshii yaanbianh” 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 Qiantang River], *Dihlil i xuerbaoi* 30.2 (June, 1964).

74 “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 Xiangping, *et al., Coastal Hydrology*, p. 13.

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


87 Cherng Minxjiiu, *Three Rivers’ Lock, shahng, j. shahng*, pp. 1ab.

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


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

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

Guh Yarnwuu, Commanderies and Principates, Zherjiang xiah, 50a. “Facing” is zuoth / zhouth 脈, which means “a well”, and “to repair a well”.

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

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).


See, for example, Pirng Herng 平衡, Sanjiangzhar-wuh quarnshu xukkeh 三江開務全書續刻 [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 Pirng Yih cut through Qiryahn Mountain in order to draw the water from the upper reaches [of the Puuyarng] into the Qiartang River via Fisherman’s Broad.”

Chern, “Lower course of the Puuyarng,” p. 73.

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 (yurppu 漁浦), also now disappeared, which in turn emptied into the Qiartang some way upstream of Harngzhou city. See Chern Qiaoaryih’s fifth article summarized above and Shiba, Jiarngnarn, pp. 554-5, and 564.

Guh Yarnwuu, Commanderies and Principates, Zherjiang xiah

Guh Yarnwuu, Commanderies and Principates, Zherjiang xiah, 47a.

Guh Yarnwuu, Commanderies and Principates, Zherjiang xiah, 47ab.

Guh Yarnwuu, Commanderies and Principates, Zherjiang xiah, 48b.

Guh Yarnwuu, Commanderies and Principates, Zherjiang xiah, 47b-48a.

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

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

One qing = 100 moou, hence say another 300 or 400 qing in all.

Guh Yarnwuu, Commanderies and Principates, Zherjiang xiah, 49a.


Chern Minrgjiu, Three Rivers’ Lock, xiah, xiah j., p. 3a.

Chern Minrgjiu, Three Rivers’ Lock, xiah, xiah j., pp. 36ab.

Chern Minrgjiu, Three Rivers’ Lock, xiah, xiah j., p. 38a.

Chern Minrgjiu, 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.”

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


A Record of the Sea-Wall, p. 319.
A Record of the Sea-Wall, p. 384.
A Record of the Sea-Wall, p. 384.
A Record of the Sea-Wall, pp. 381-2.
For the justification of this translation, see shahsuan 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.

A Record of the Sea-Wall, p. 381.
“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.
Meaning unclear. Perhaps the ‘roots’ were obstructions?
A Record of the Sea-Wall, p. 383.
A Record of the Sea-Wall, p. 365.
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.”

Cherng Mirgjiu, Three Rivers’ Lock, shahng, Luoh preface, p. 2a.
Cherng Mirgjiu, Three Rivers’ Lock, shahng, shahng j., p. 35b.
Pirng Herng, Supplement to the Complete documents relating to matters concerning the Three Rivers’ Lock.’ See n. 97 above.

Cherng Mirgjiu, Three Rivers’ Lock, shahng, Luoh preface, p. 1b.
Huishar on its own was used, presumably as a mortar, to ‘stick stones together.’ See Cherng Mirgjiu, Three Rivers’ Lock, shahng, shahng j., 16a.
Cherng Mirgjiu, Three Rivers’ Lock, shahng, shahng j., pp. 14ab. Compare the account in id., 16ab.
Cherng Mirgjiu, Three Rivers’ Lock, shahng, shahng j., pp. 20b - 21a.
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.’

Sja has a variety of meanings, including colic, a cholera-like disease, and measles.
On the use of ‘dam-timbers’ (xiahm 橋) 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, Shijih 史記 [Records of the Grand Historian] (Han. Rep. Beeijing: Zhonghau shujur, 1973), pp. 1413-4.
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..