



GIFT - 2007
Geosciences in the city

The Dragon Head's story: Water/Land Conflict in Shanghai

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Nine Dragon Wall



Dragon dance

*Dragon culture
in China*



In China, the Yangtze (Changjiang) River is often likened to a “Dragon” because of its length and importance.....

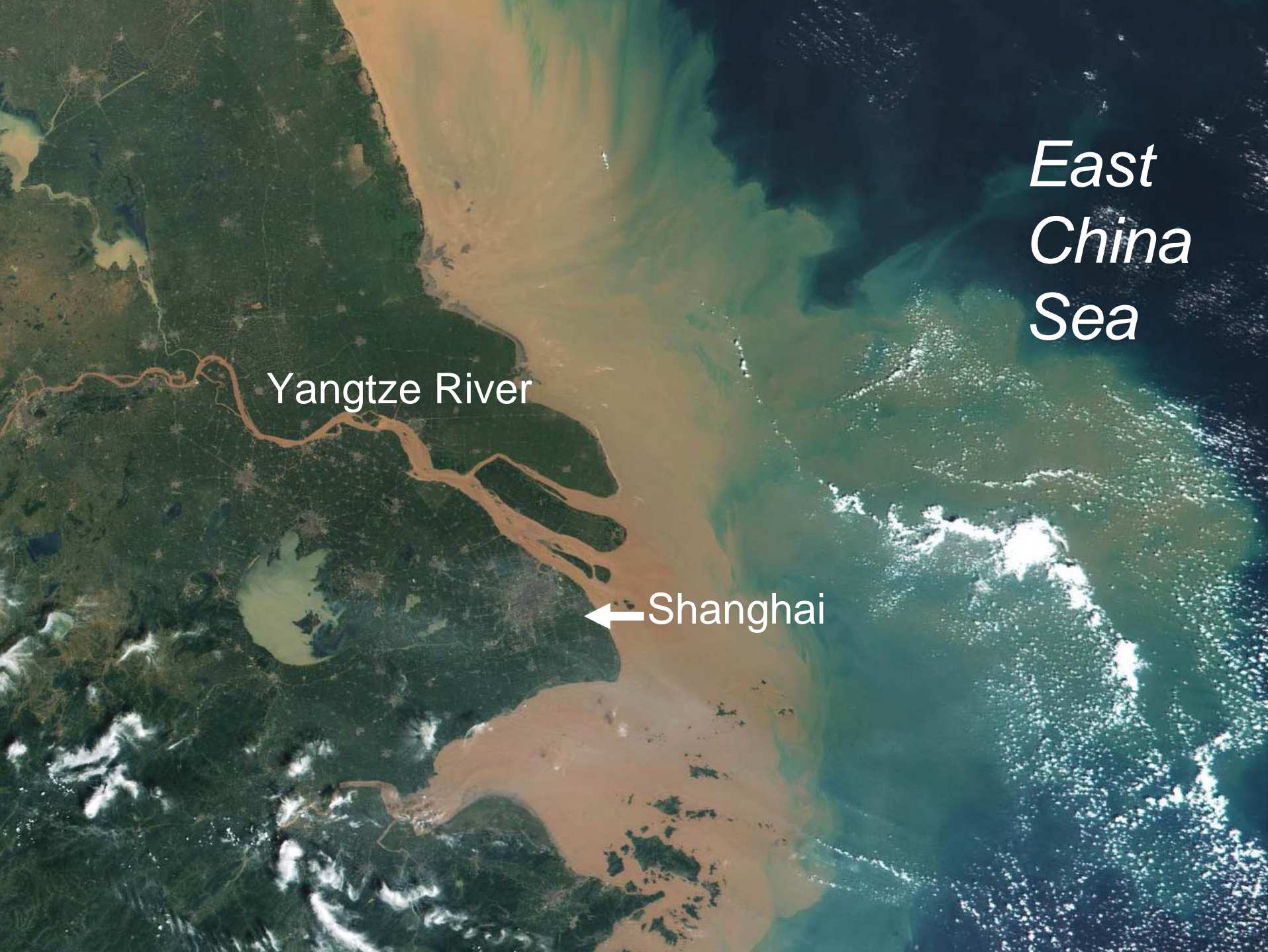


长 “Chang” – long
江 “Jiang” – river



...and Shanghai to the Dragon's Head because of its position and leading role in economy.





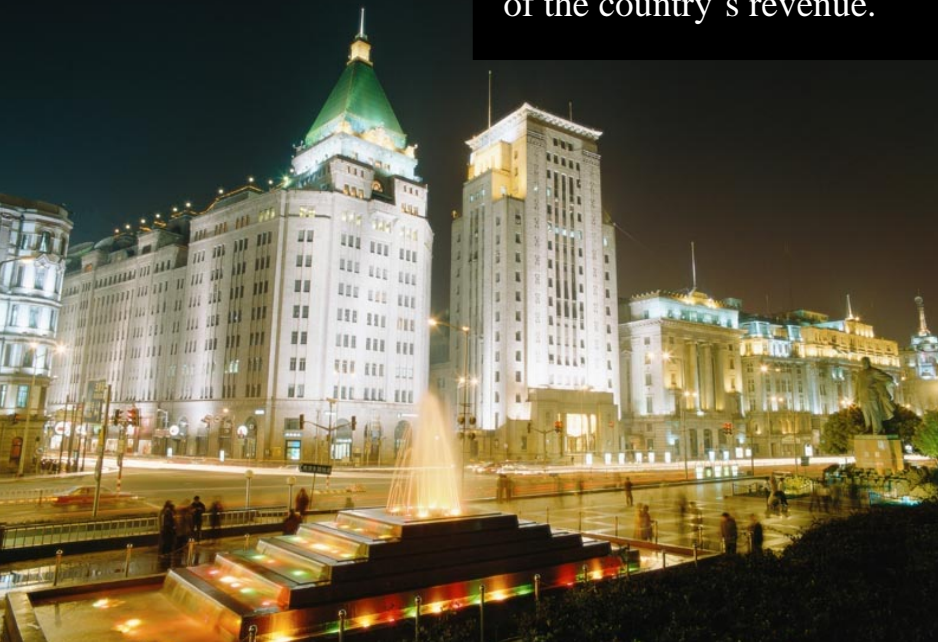
*East
China
Sea*

Yangtze River

← Shanghai



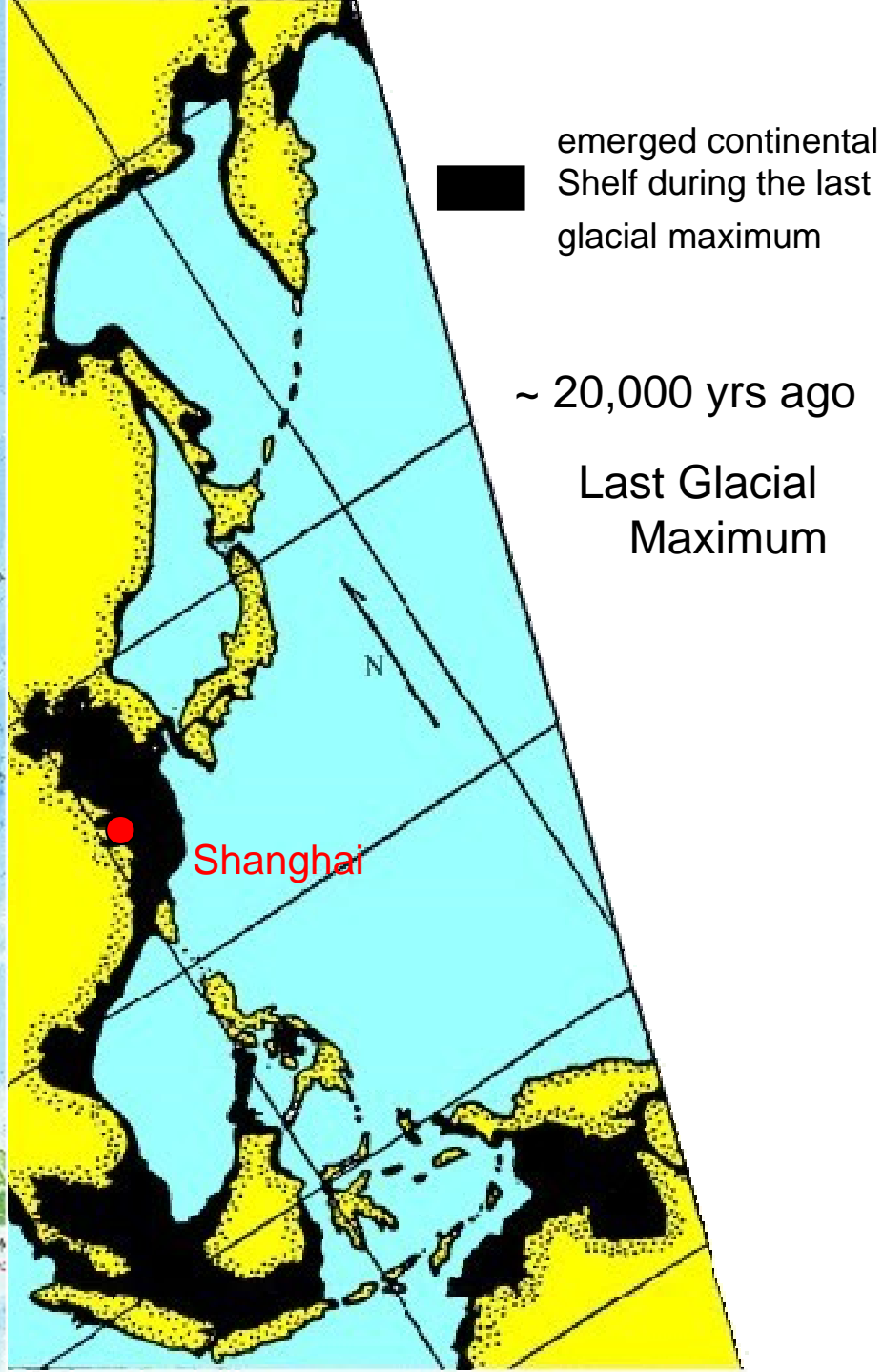
Making up only one thousandth of total area or one hundredth of total population in China, Shanghai contributes more than one tenth of the country's revenue.



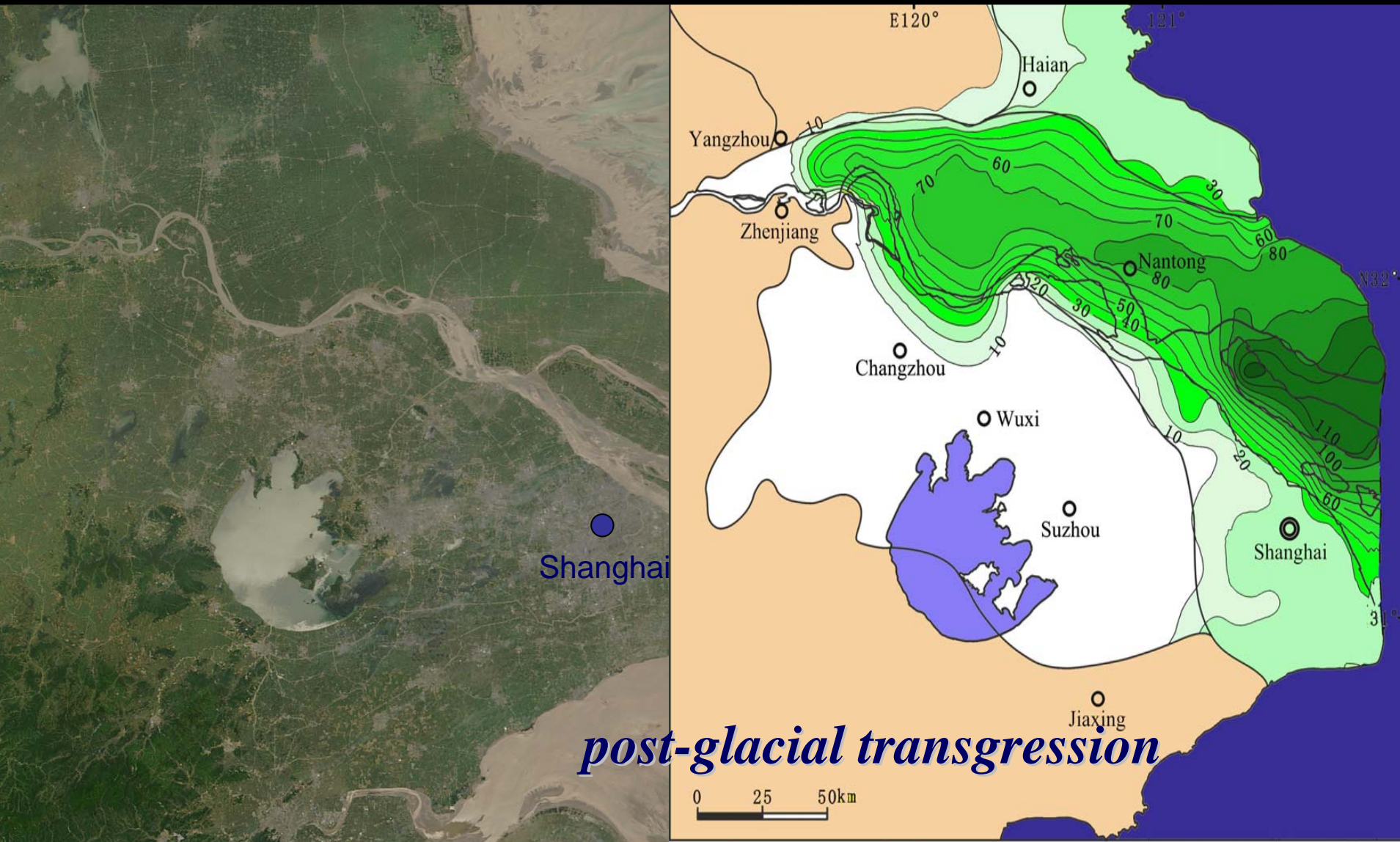
The Dragon Head's story: Water/Land Conflict in Shanghai

- Land emergence
- Land subsidence
- Land acclimation

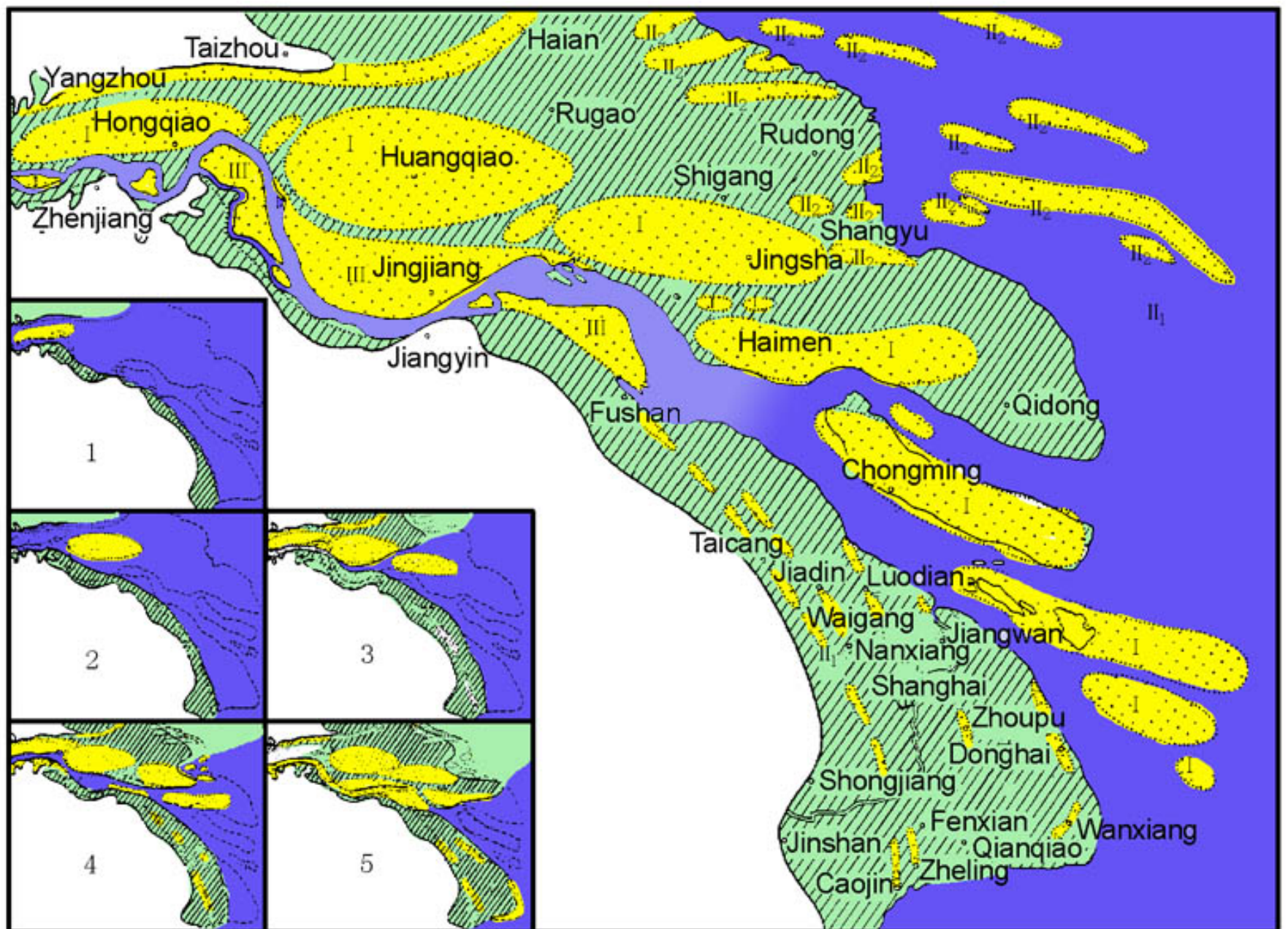


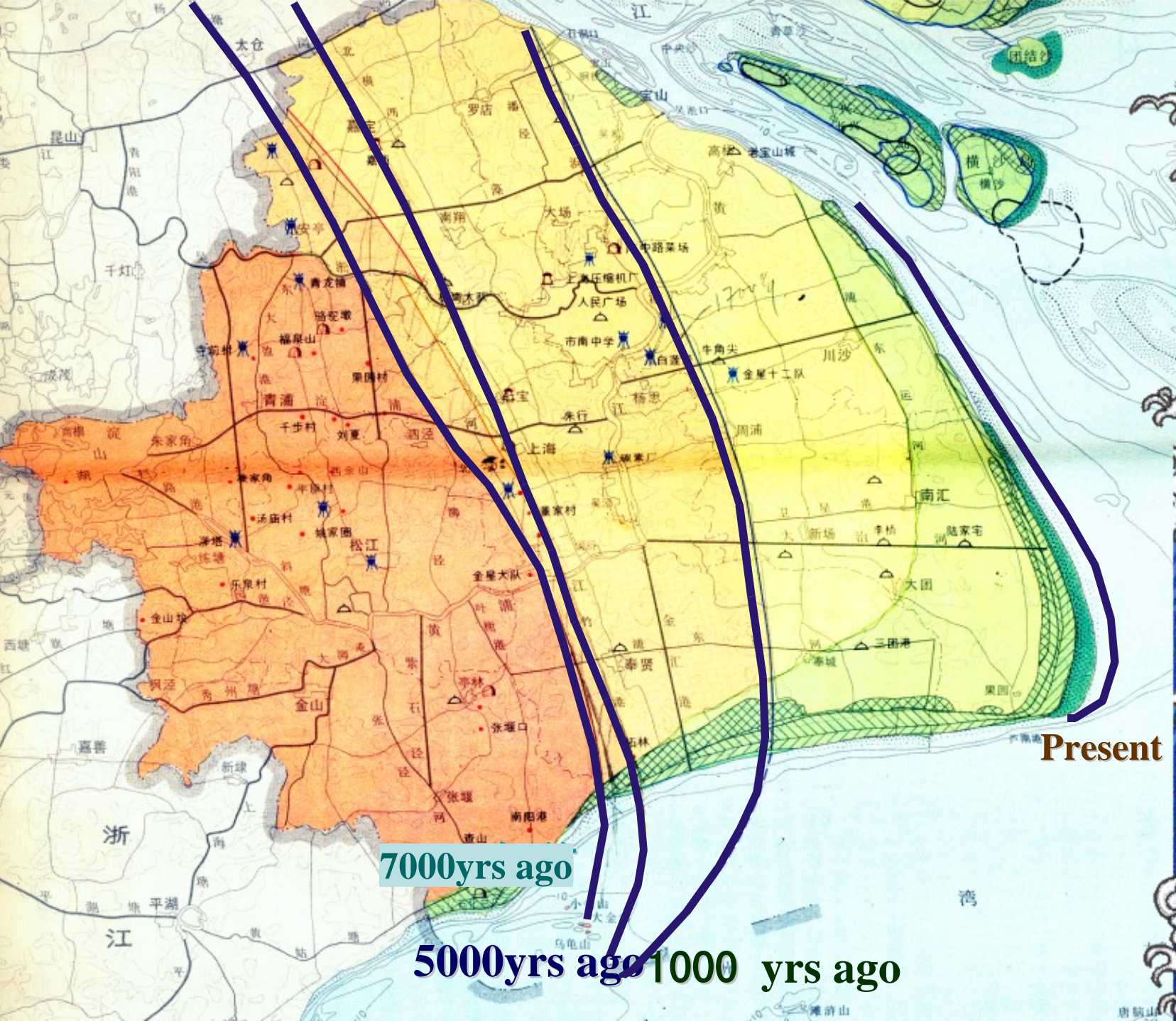


In result of the post-glacial sea transgression, the Yangtze delta at ~7,000 years ago was a part of the East China Sea, and the eastern part of Shanghai was covered by sea water.



Progradation of the Yangtze River delta





7000 yrs ago

5000 yrs ago 1000 yrs ago

Present

An aerial photograph of the Yangtze River delta, showing the river's complex branching pattern as it meets the sea. The water is a mix of brown and blue, with white foam from waves visible. The surrounding land is green and brown, showing some urban and agricultural patterns.

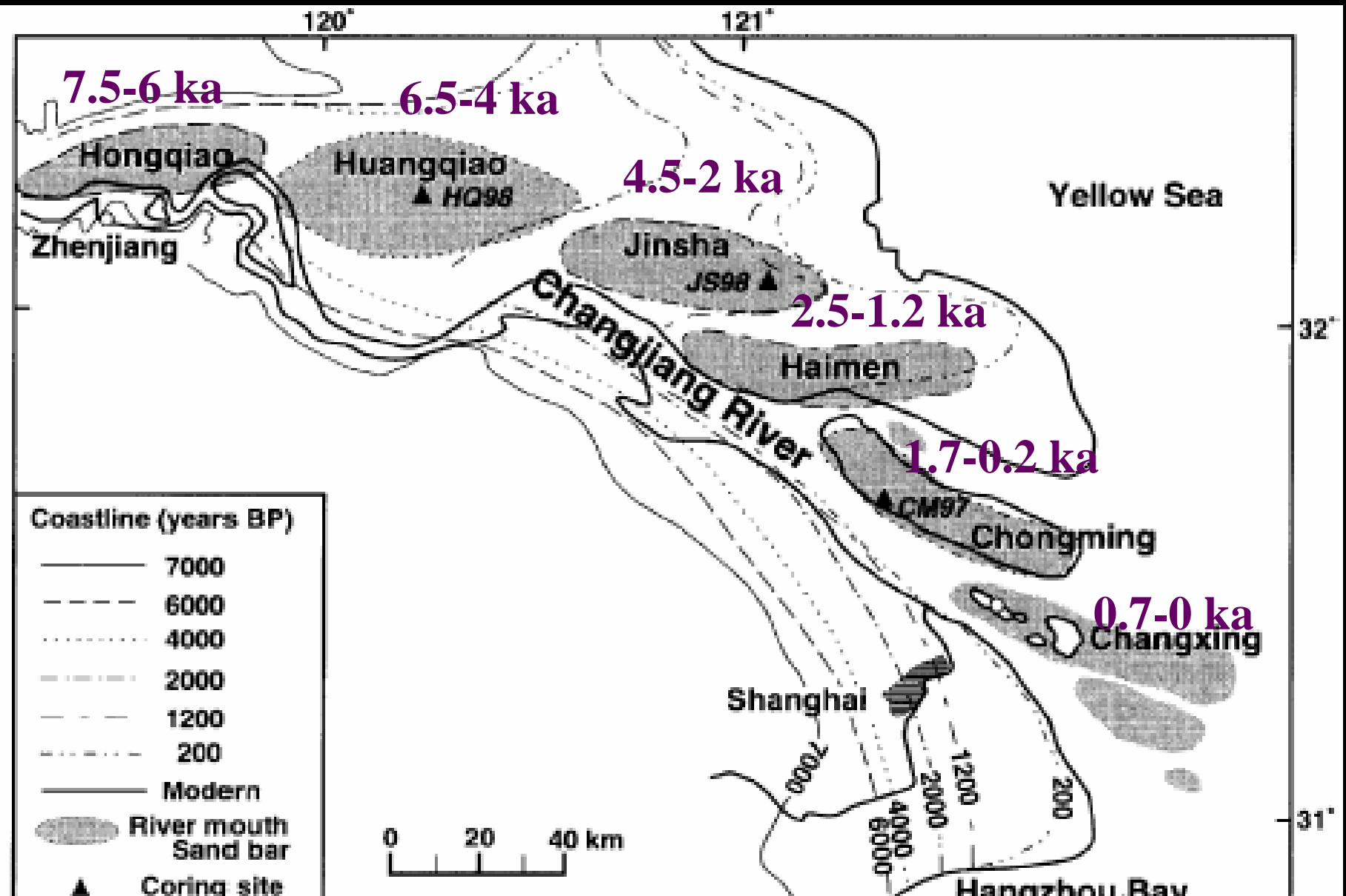
Water/Land Conflict in Shanghai

Since ~ 7,000 years ago:

Progradation of the Yangtze Delta

Growth of land at the cost of sea

Shoreline changes and river-mouth sand-bar evolution since 7000 yr B.P.



秦 - 唐时期的上海地区

~200 BC - 900 AD



海洋
上海
未来

From Qing to Tang Dynasty
~200 BC - 900 AD

宋 - 元时期的上海地区

~ 1000 AD - 1400 AD



From Song to Yuan Dynasty
~1000 AD - 1400 AD

明代时期的上海地区

1400 -1600 AD



Ming Dynasty
1400 AD – 1600 AD

崇明县
万历十一年 (1583)

嘉定县

吴淞所

老宝山

黄浦口

新江乡

海隅乡 青龙镇

青浦县

万历元年 (1573)

北亭乡

集贤乡

松江府

华亭县

修竹乡

枫泾乡

高昌乡

长人乡

白沙乡

胥浦乡

云间乡

Modern Shanghai and the delta



Changjiang Delta

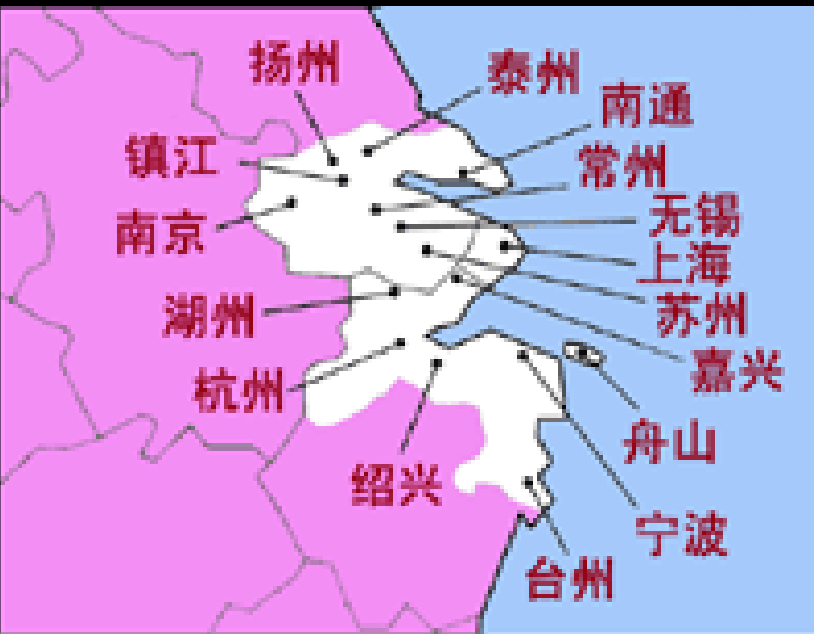


- ※ ~ 50,000 km² in area
- ※ Administratively, it covers entire Shanghai and partly Jiangsu and Zhejiang



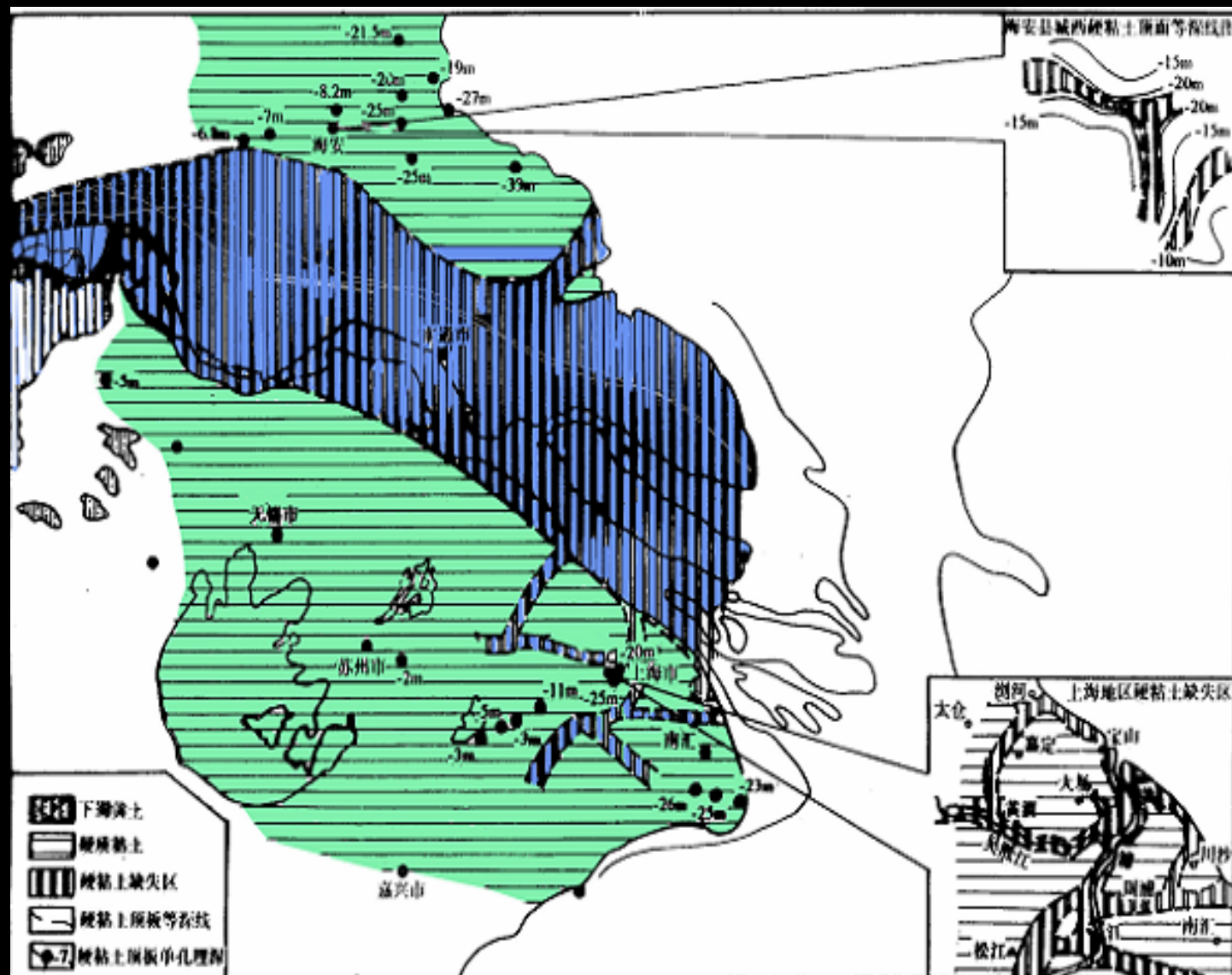
Changjiang Delta Economic Zone

- ~100,000 km² in area, ~75,000,000 population, 16 cities
- Shanghai + Jiangsu + Zhejiang:



2% area
10% population
26% GPT
37% export
53% international investment

incised valley formed during the lowered sealevel stand at MIS 2

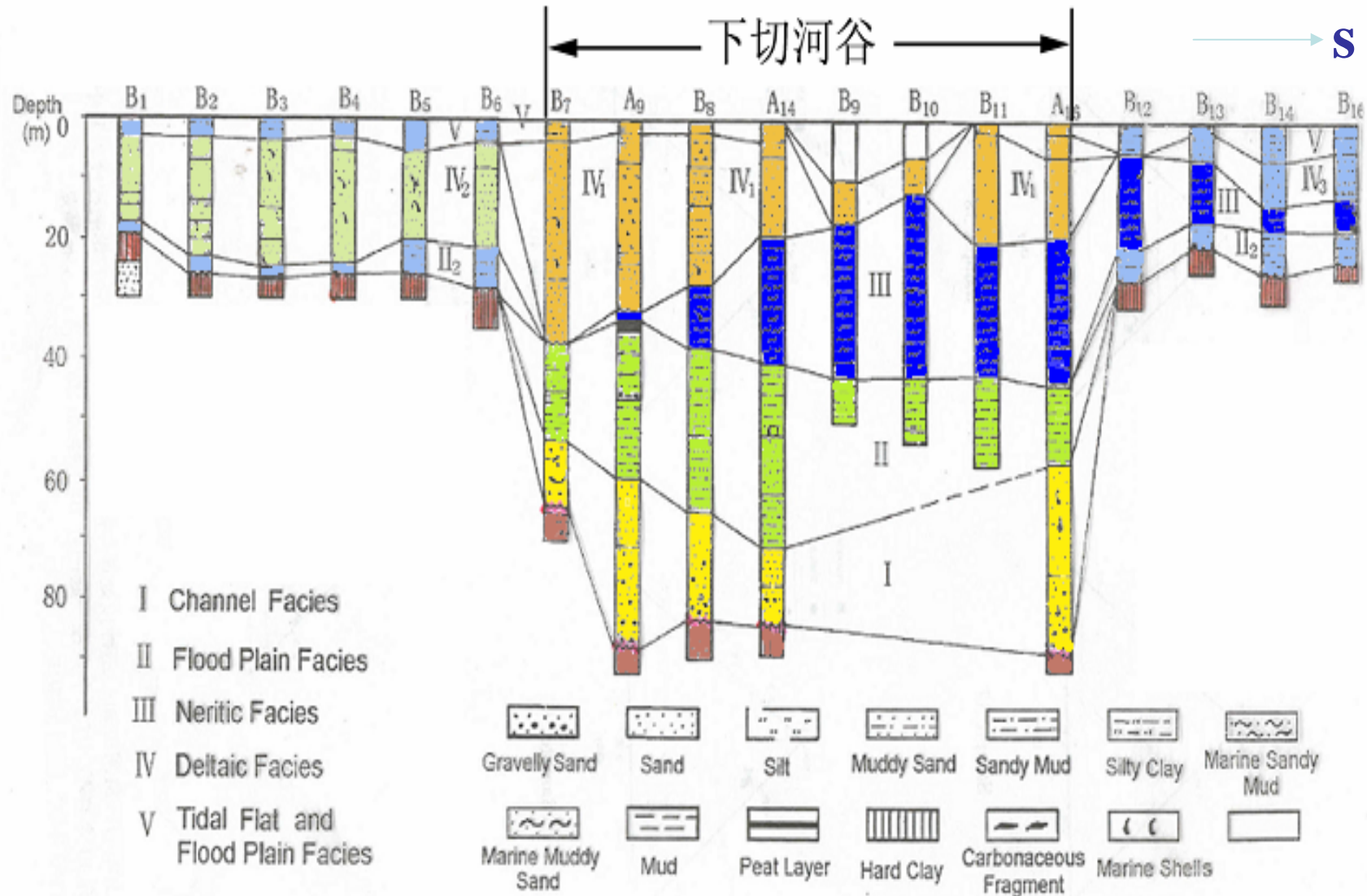


wide
20-60 km
deep
60-80 m

Li et al., 2000

Cross-section across the river channel

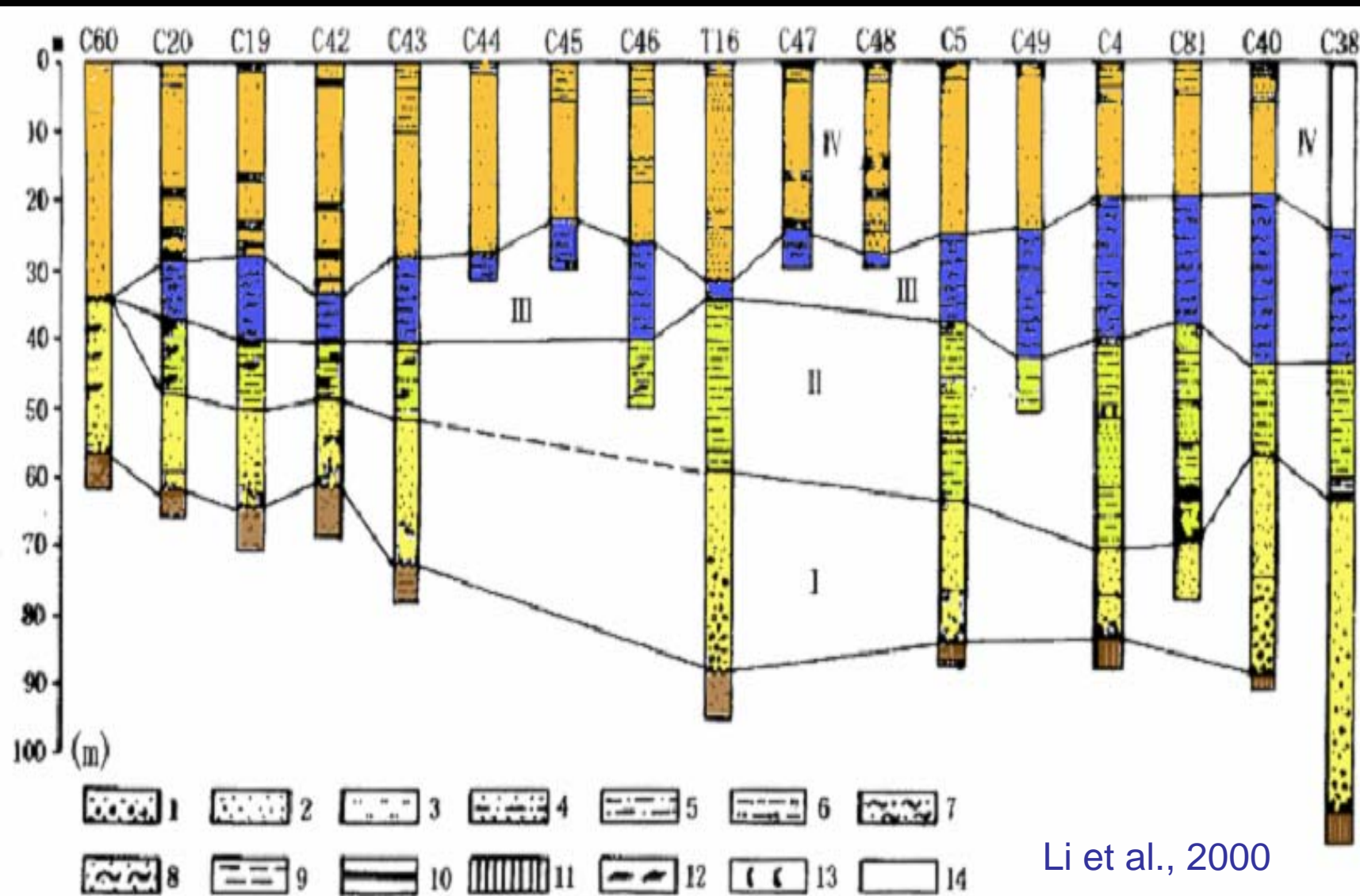
Li et al., 2000



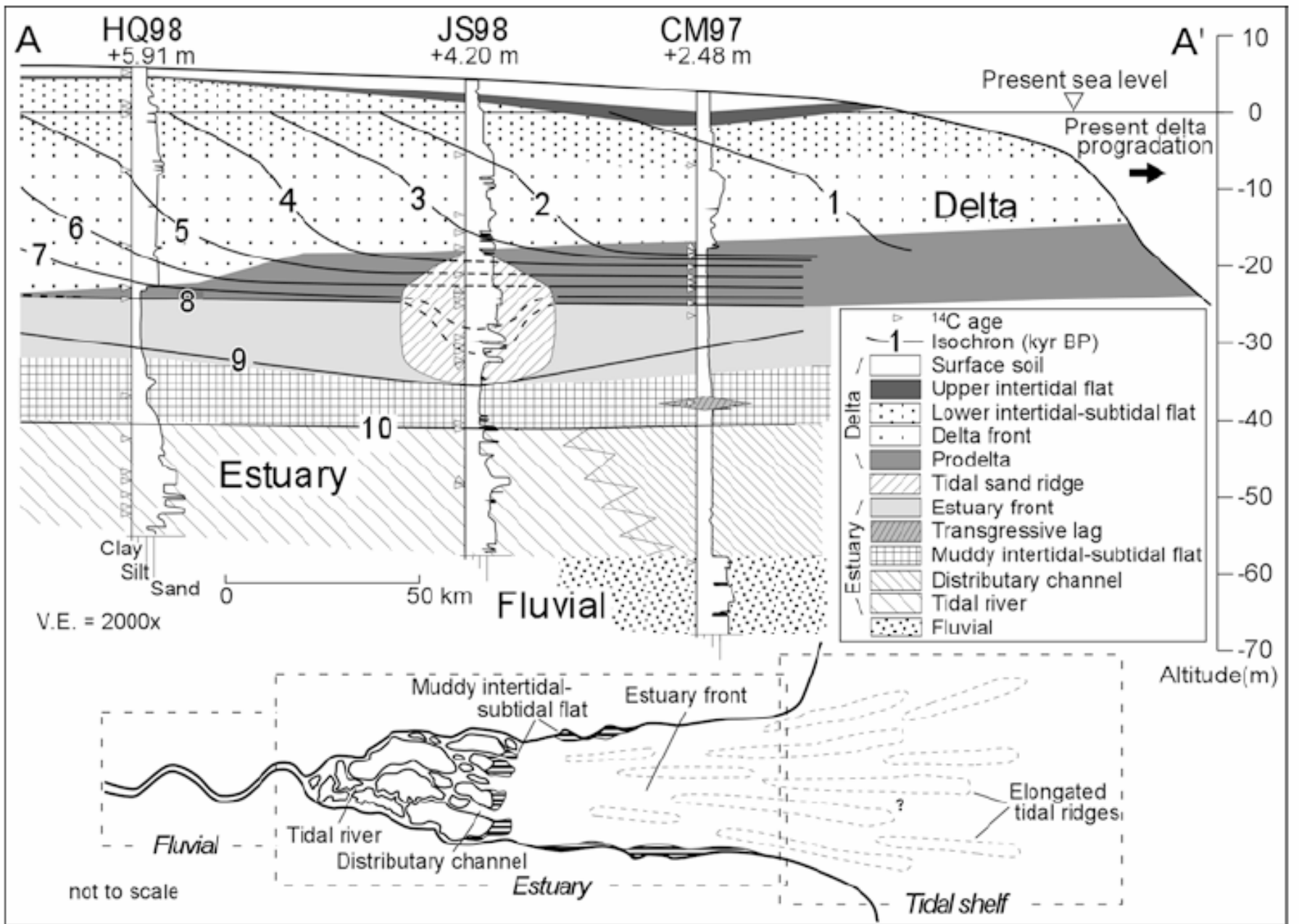
Cross-section along the river channel

MFS

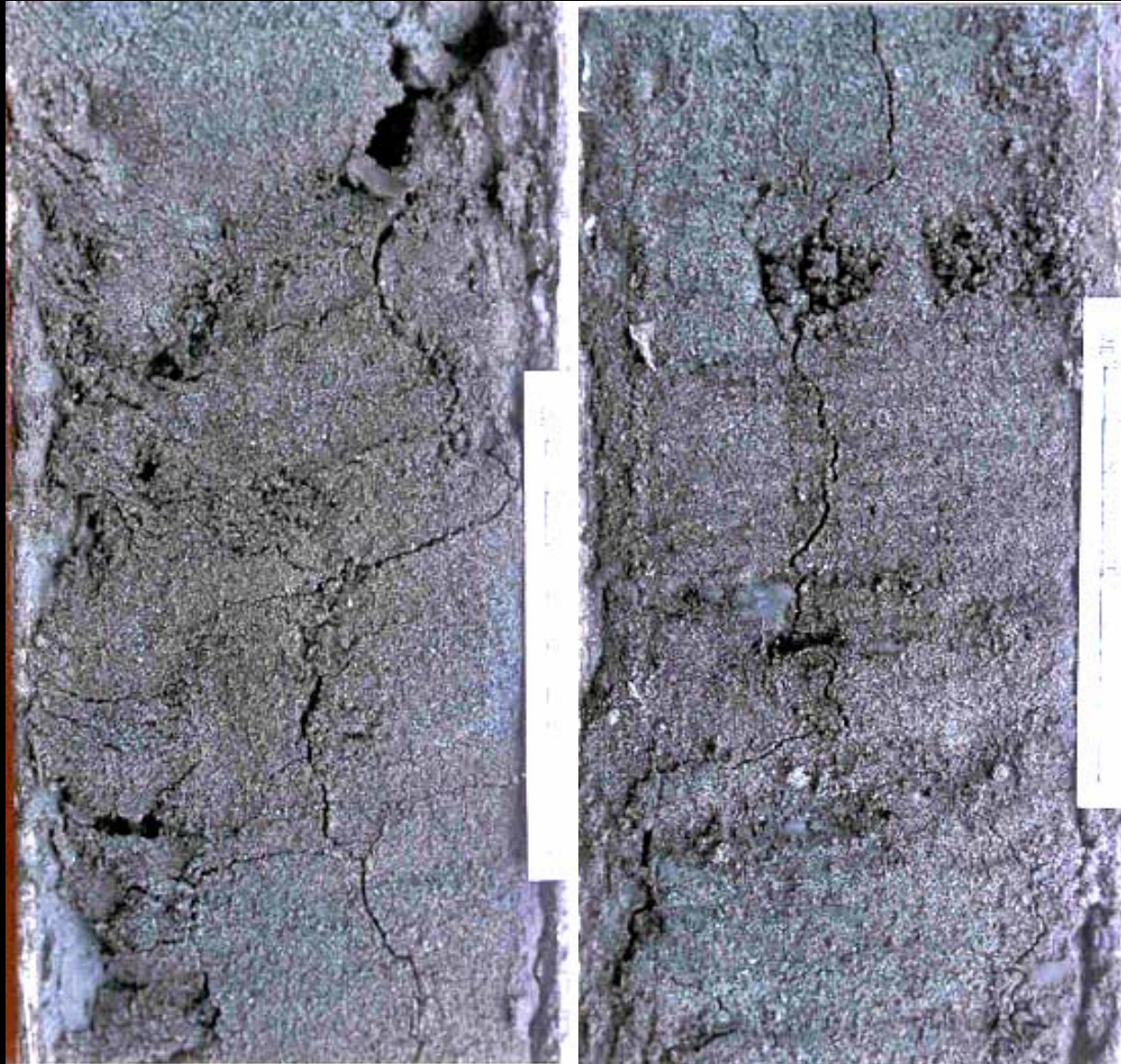
seaward



Li et al., 2000



The river-channel facies



From bottom
to top

The floodplain-estuary facies



The estuary-prodelta facies

Maximum
flooding
surface



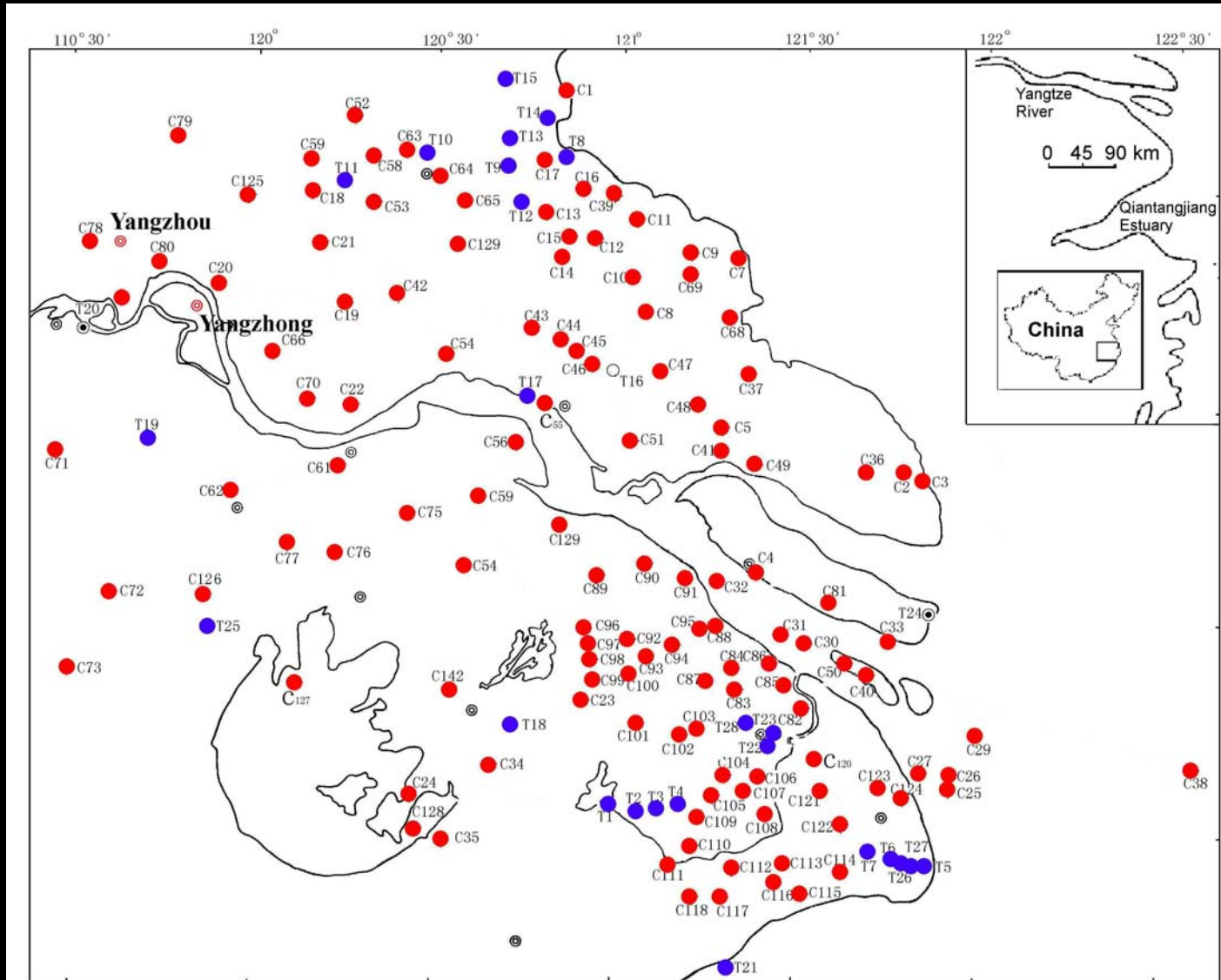
Delta-front facies



Subtidal-intertidal facies

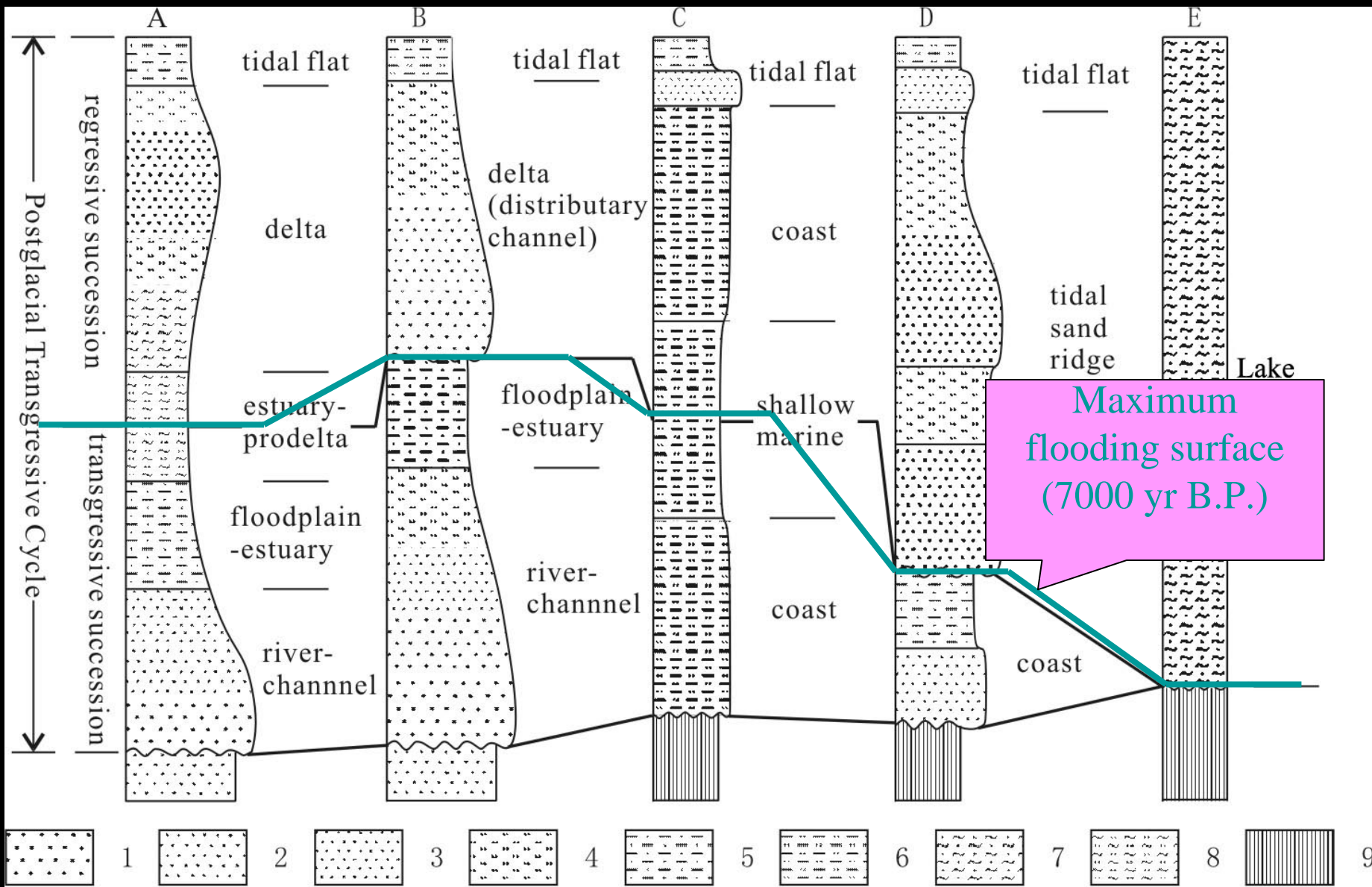


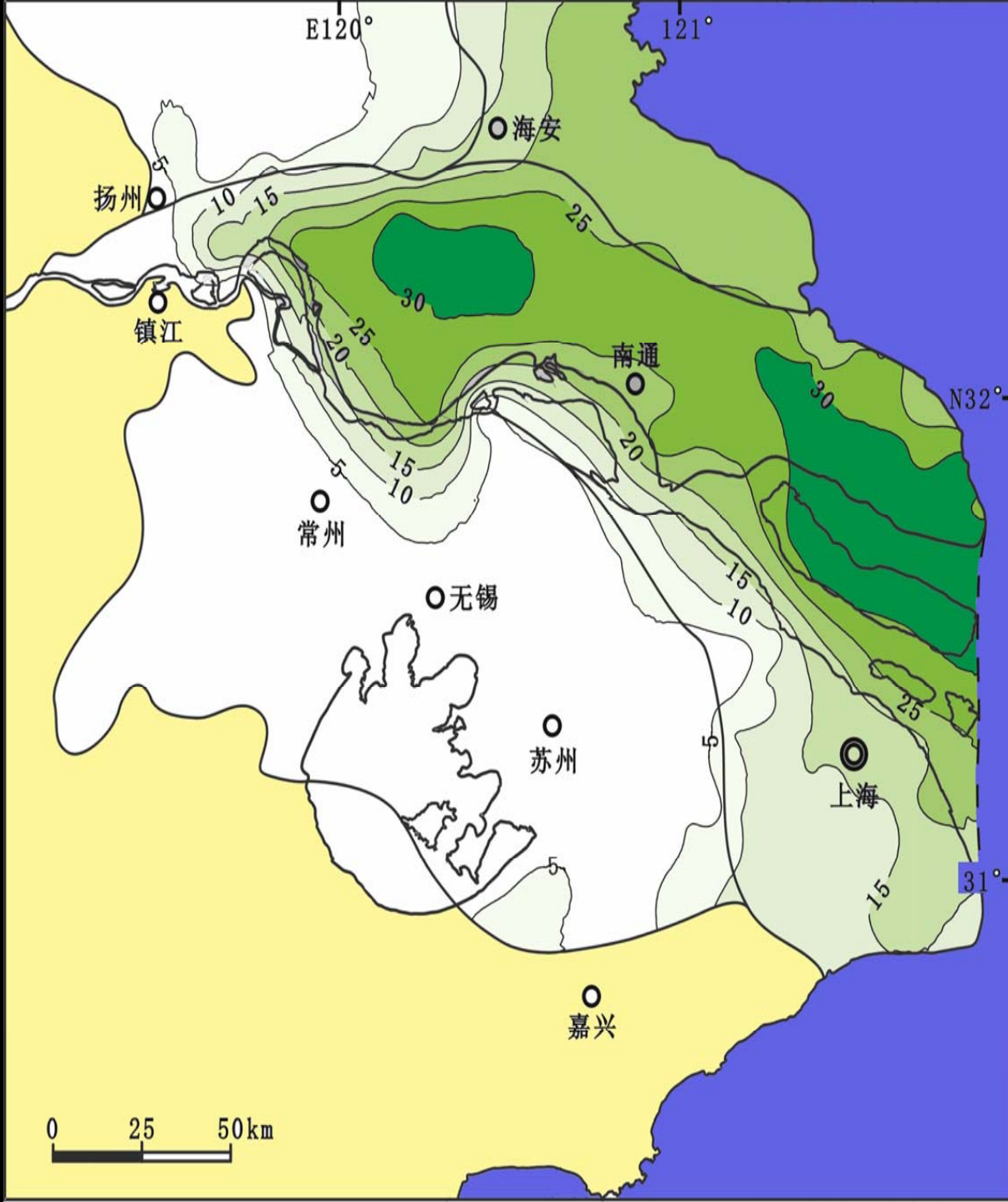
Sediment flux



265
drilling
core

Thickness of postglacial deposits and deltaic deposit since 7000 yr B.P.





Thickness contours:
deltaic deposits since
7000 yr B.P.

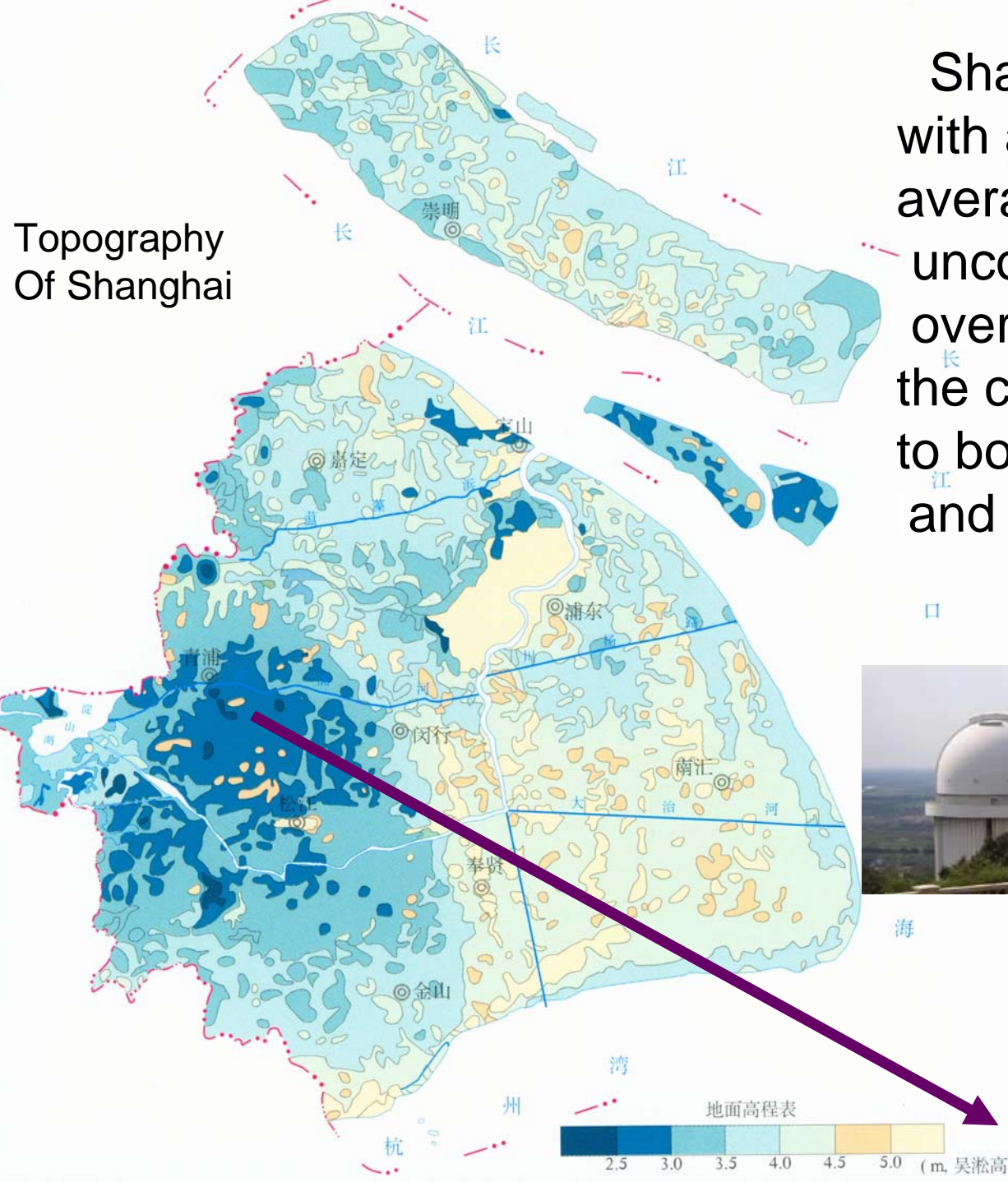
Volume of deltaic
deposits:
 $500 \times 10^9 \text{ m}^3$

The Dragon Head's story: Water/Land Conflict in Shanghai

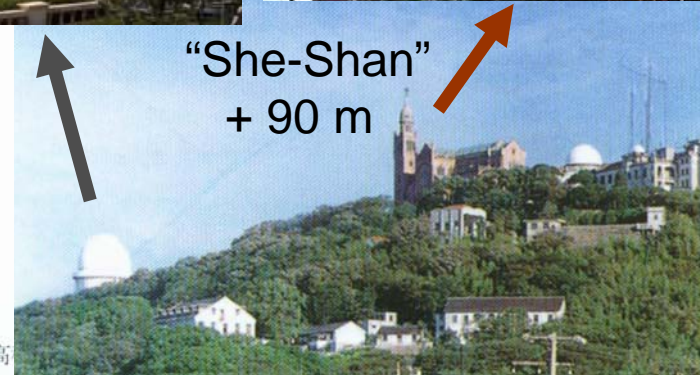
- Land emergence
- Land subsidence
- Land acclimation



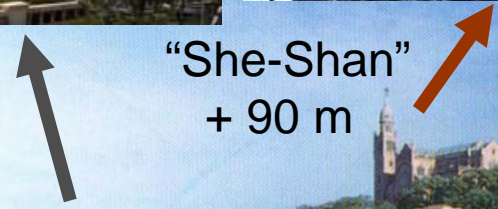
Topography Of Shanghai



Shanghai is a delta plain with an altitude of 3-5 m in average. Underlain by unconsolidated deposits over 300m in thickness, the city is highly susceptible to both sea level rising and and compression.



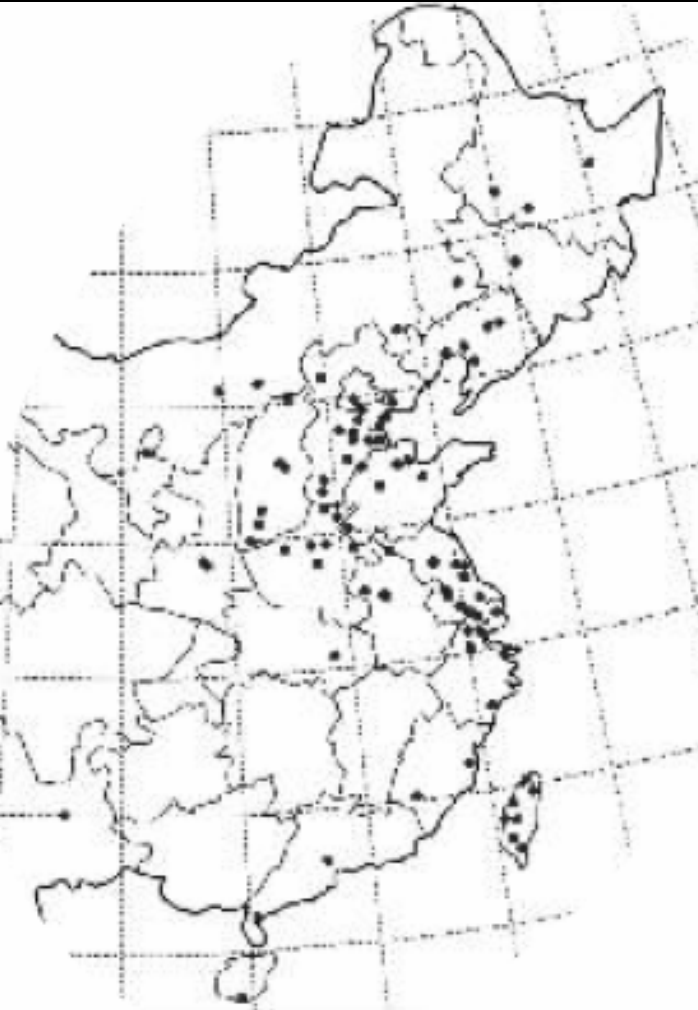
“She-Shan” + 90 m



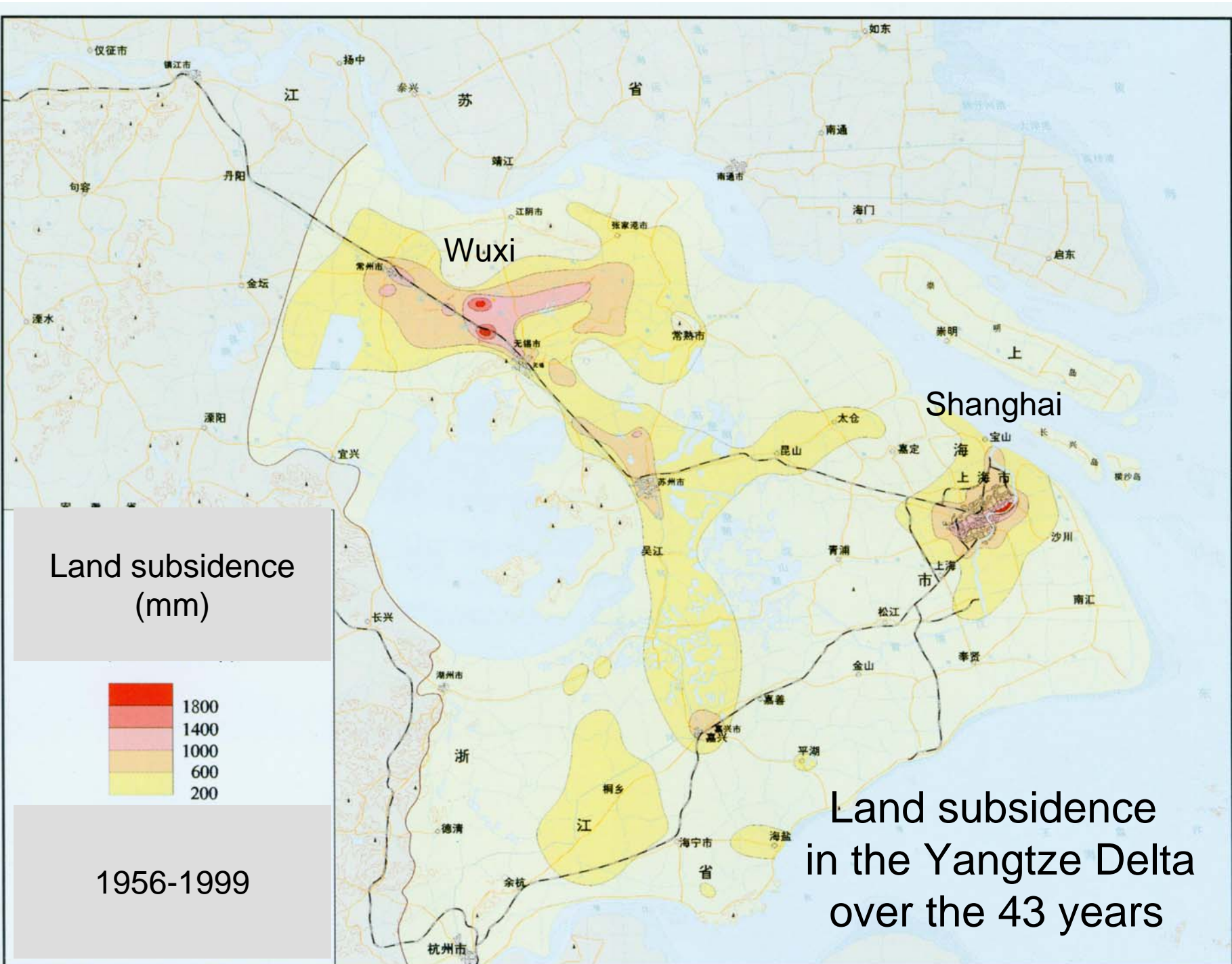
Sea level change and land subsidence

- Sea-level rise: 2 mm/year
- Land subsidence in Shanghai: since 1921,
2.63 m over the ~ 80 years
- Mainly due to the ground water use
- Strict control in Shanghai, but no control
for the delta-wise reservoir

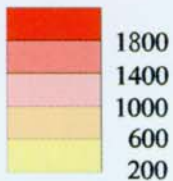
Land subsidence in China



- Over 90 medium to large size cities in China suffer from the land subsidence problem
- In Shanghai and Tianjin land subsidence was initially found in the early 1920s, but greatly deteriorated in the 1960s.



Land subsidence
(mm)



1956-1999

Wuxi

Shanghai

Land subsidence
in the Yangtze Delta
over the 43 years

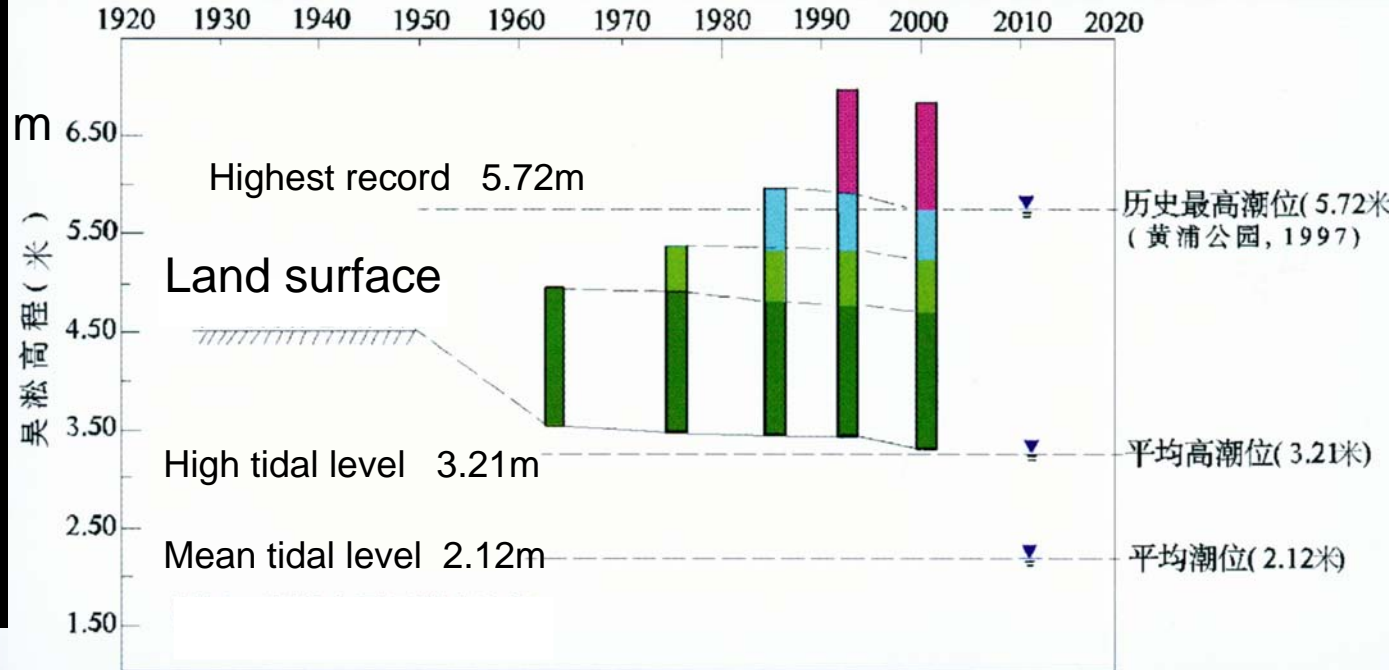


The Bund —
representative place
of subsidence record

Shanghai
Downtown



The bund



In result of land subsidence, the land surface became lower than the higher tidal level, and the Bund has been most sensitive to the high tides and river floods.



1920s – no dyke

1962 dyke -- 4.94m



1974 dyke – 5.8m

Evolution of
flood-preventing
dyke at the Bund,
Shanghai



1992 dyke – 6.9m



Step-wise increase of the dyke height, responding to the progressively subsiding land.



With the land subsidence, the bridge opening becomes much too low for boats to go through.





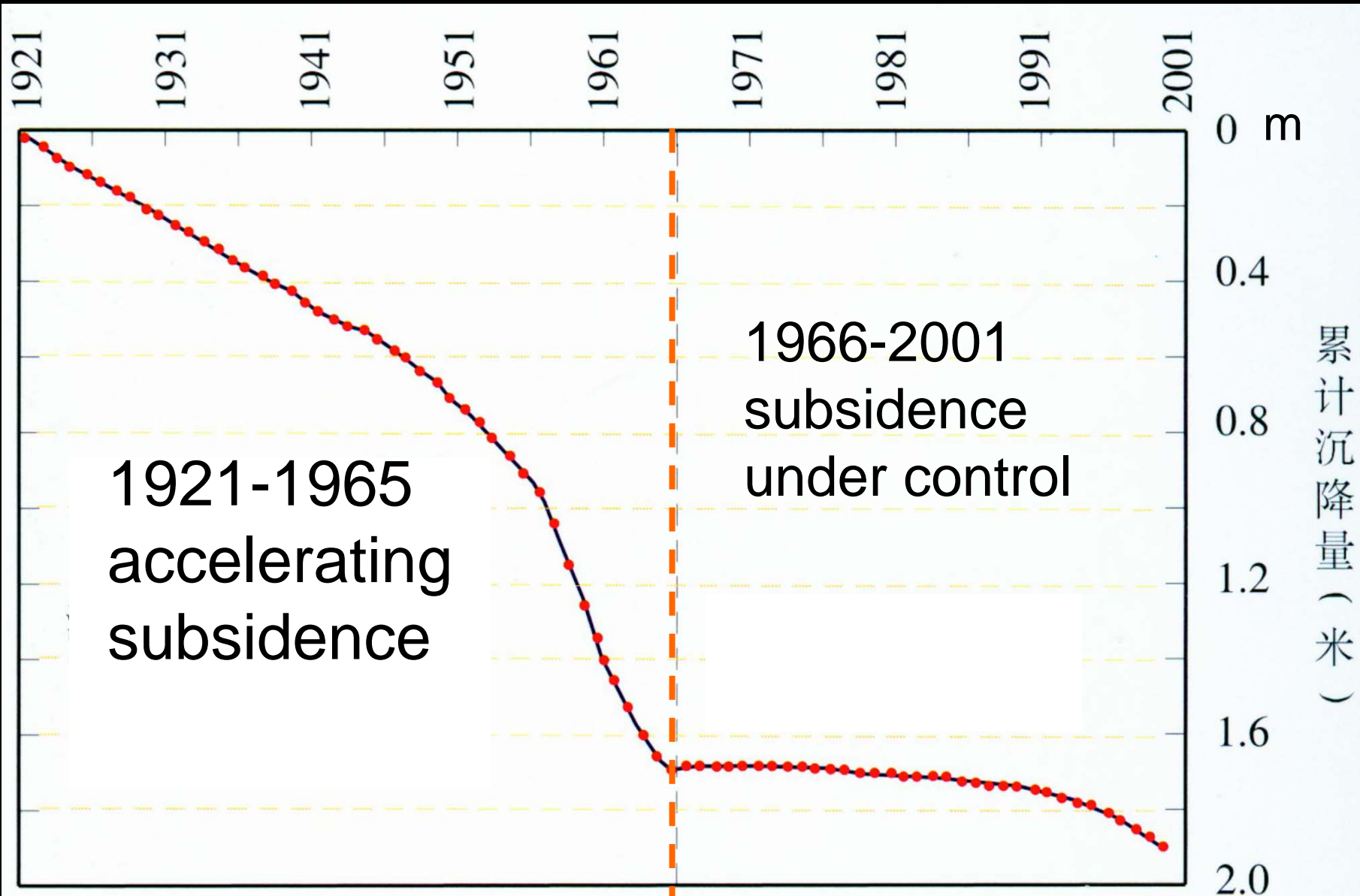
Even buildings and bridges could collapse due to land subsidence



August 2, 1962
Shanghai downtown
was badly flooded

Shanghai was suffering from frequent floods,
as the river water level became higher than the
land surface

Accumulative land subsidence in Shanghai over 80 years





- Why the accelerating land subsidence?
- The main root lies in the intensive use of subsurface water.

The Use of Ground Water in Shanghai



The first “deep” hole was drilled in 1860 near the Bund. The 76.8 m deep well was used for drinking water in the Company

Messers Russell & Co.

1860

Ground water exploration in Shanghai

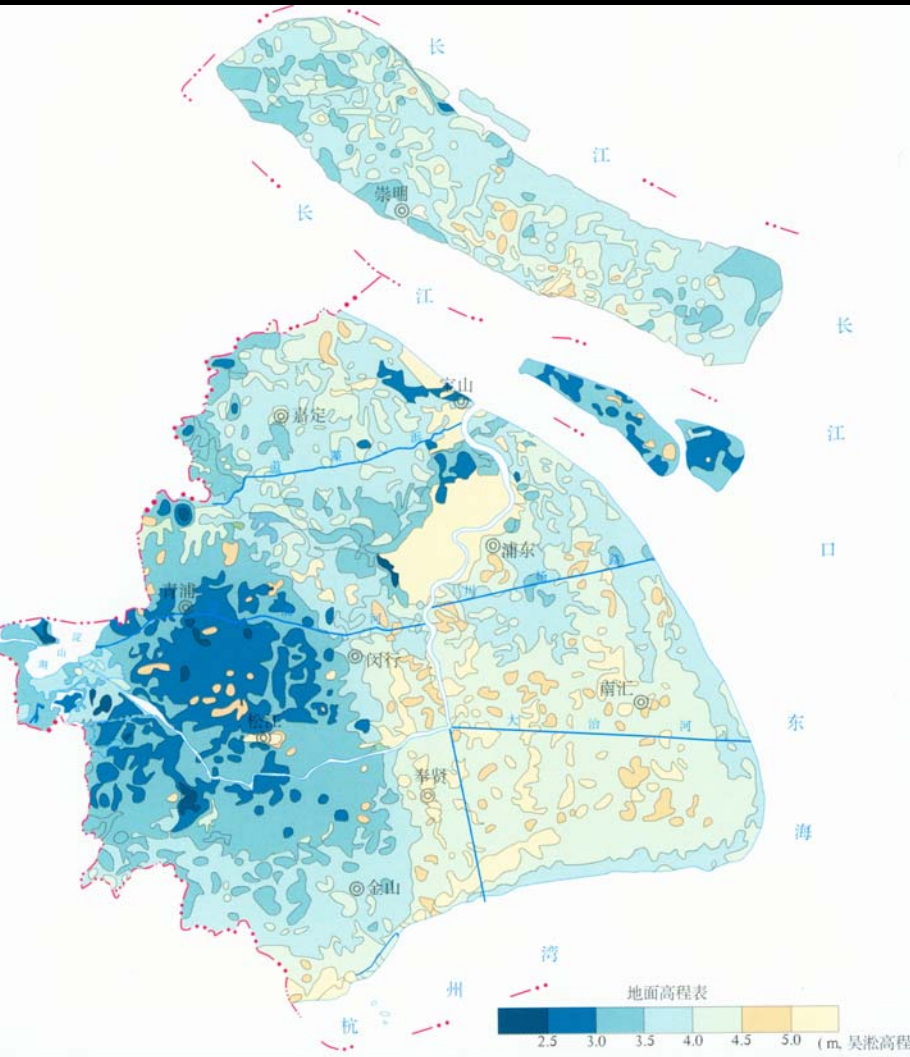


Messers Russell & Co.



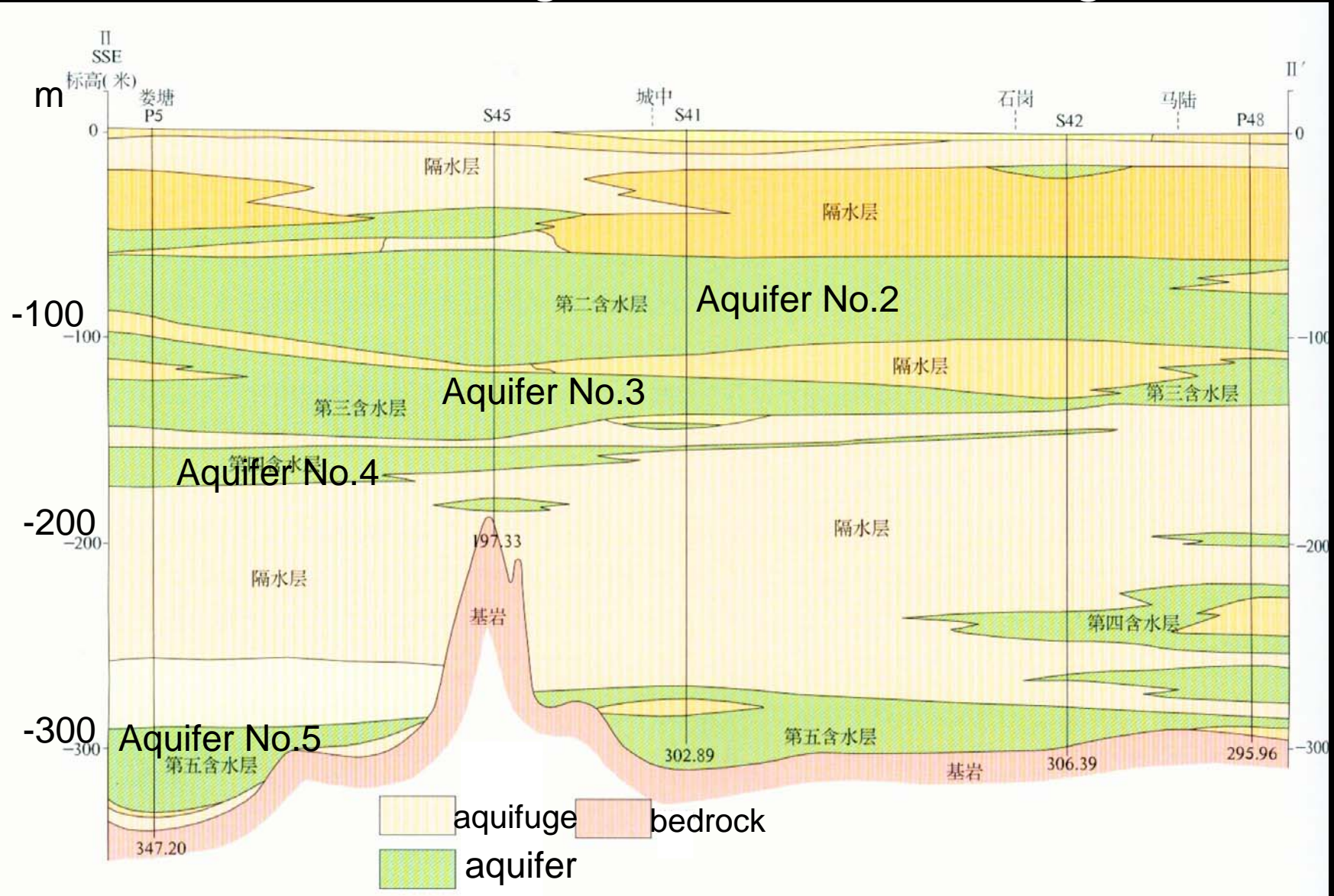
Ground waters up to 200m deep were used as drinking water in many western companies in the early 20th century

Ground water exploration in Shanghai



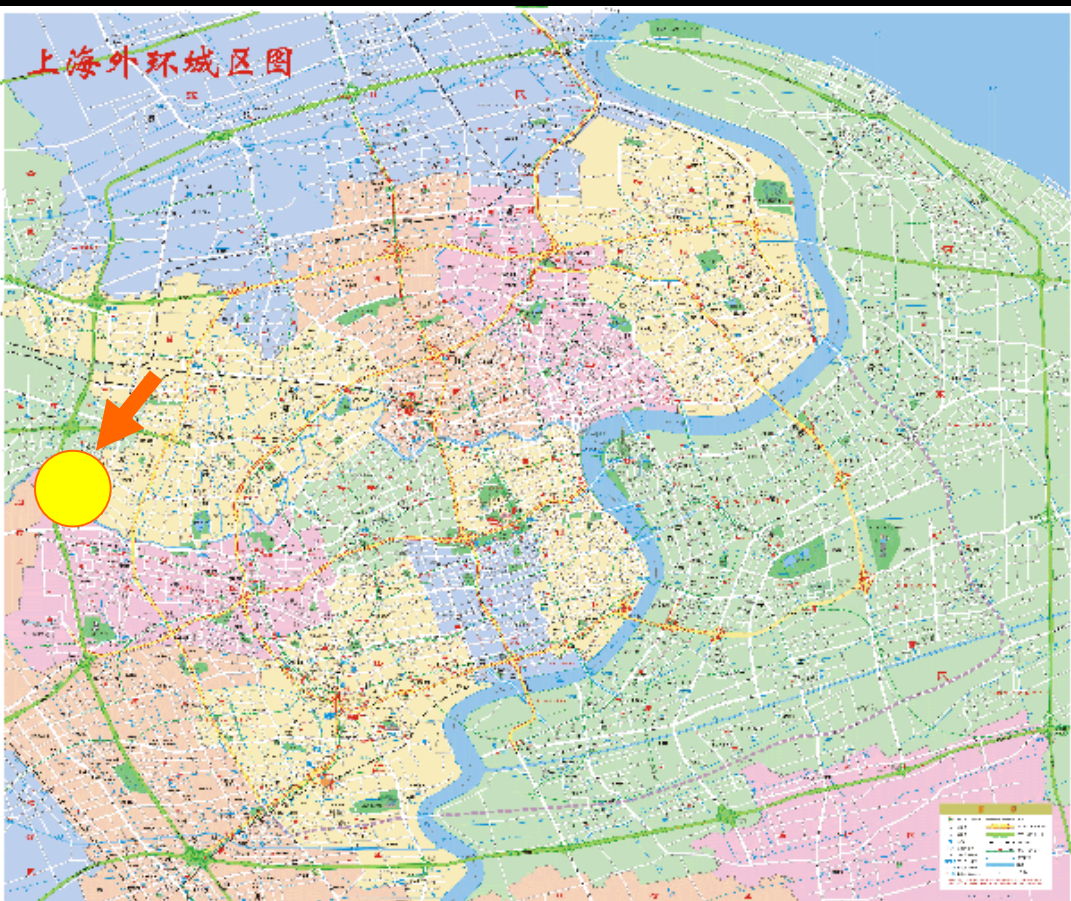
By 1949, there were 708 wells pumping drinking waters from the 4th (~ 200m deep) and 5th (250-280 m) aquifers in Shanghai.

Distribution of ground water in Shanghai



All the Aquifers No.2-5 have been mined for industrial and resident's use

Mineral waters from the deep aquifers in Shanghai



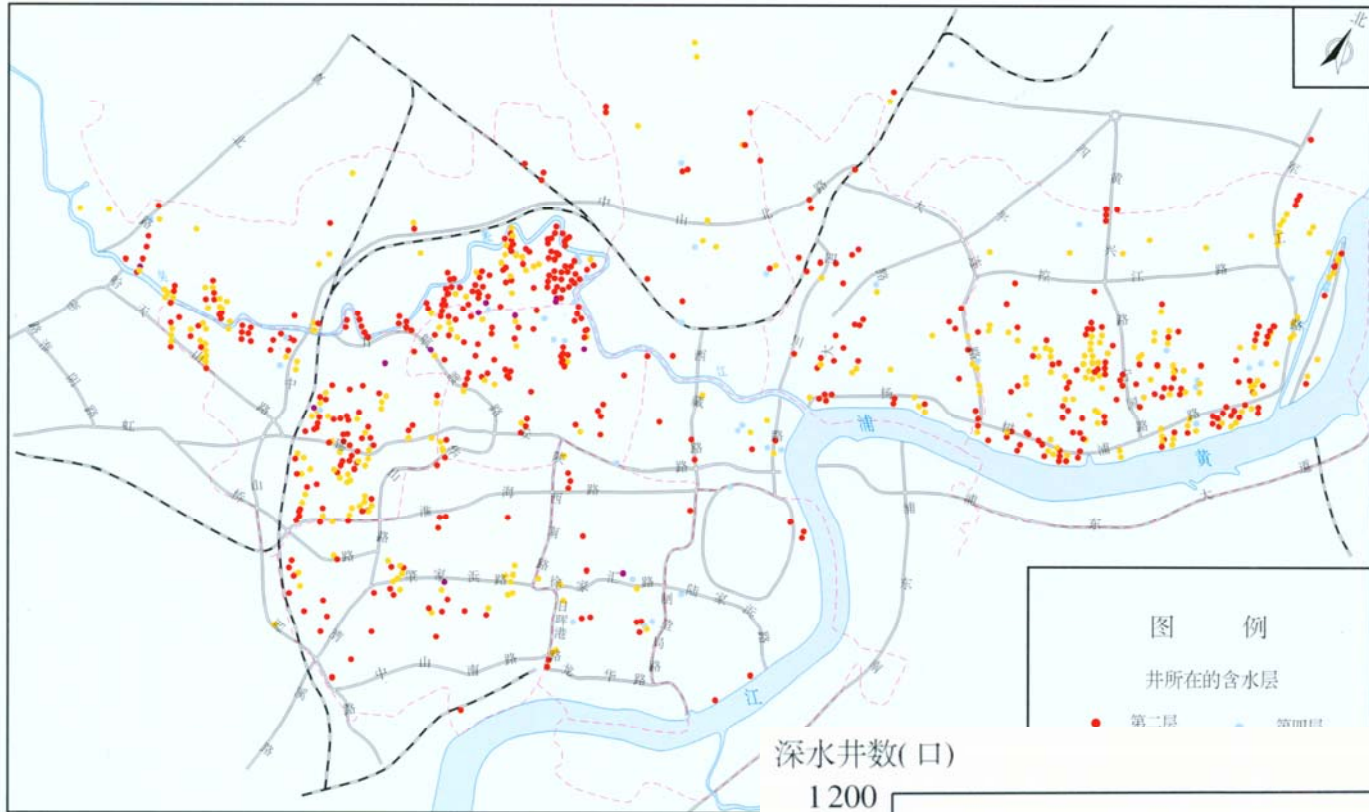
In the 1970s, high-quality mineral waters were discovered in dolomite layers in the western part of the city, Bei-Xin-Jing.

The deepest hole drilled for this mineral water reached 1001 m in depth.

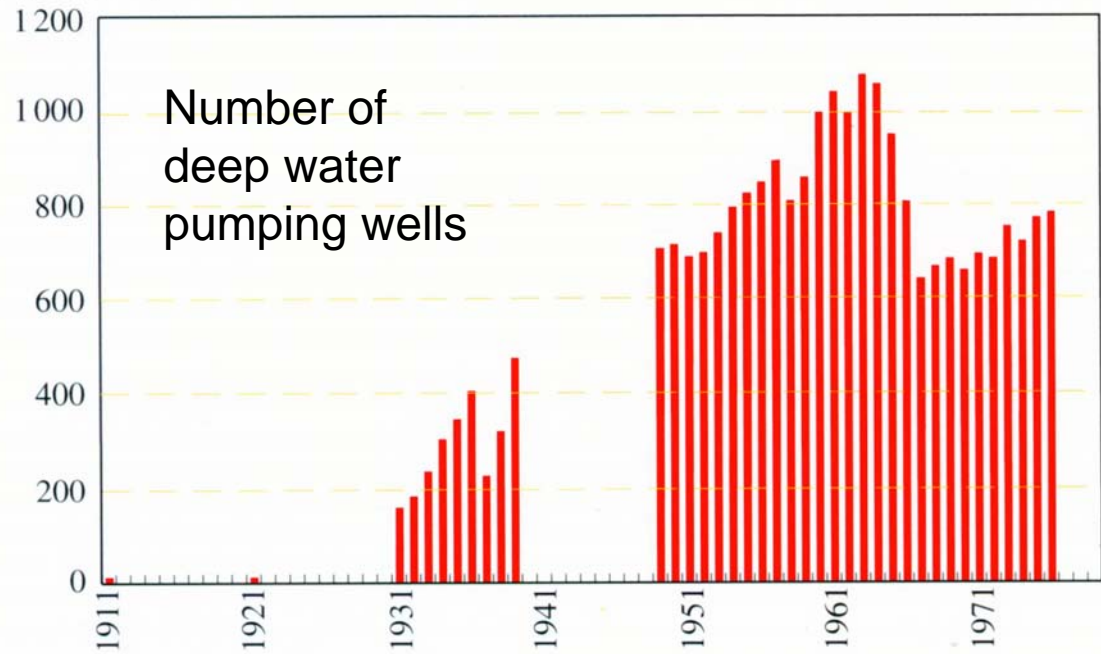


After the 1949 revolution,
the use of aquifers in Shanghai
Significantly intensifies because
of the industrial exploitation

- Land subsidence in Shanghai was initially found in the early 1920s, but became a real hazard in the 1950s when the ground water was extensively exploited for cooling in summer by the newly developed industry.
- In 1963, for example, a total of 200 million cubic meter of ground water was mined in Shanghai.
- Land subsidence reached 38 mm per year in the late 1950s and early 1960s, with the maximal value of 110 mm/year for 1957-1961.
- The total amount of subsidence measured 1.75 m from 1921 to 1965 and locally reached 2.63 m, bringing about serious consequences ranging from land cracking, building slanting to tidal flooding of the city.



深水井数(口)



Water-pumping deep wells in Shanghai for 1949-1963 before the subsidence control

- Starting from 1965, the local government has introduced a series of measures to slow down if not prevent land subsidence in Shanghai.
- **Firstly**, it restricted the ground water pumping, in particularly downtown. The amount of water pumping was reduced from $2 \times 10^8 \text{ m}^3$ in 1965 to $\sim 0.8 \times 10^8 \text{ m}^3$ now.

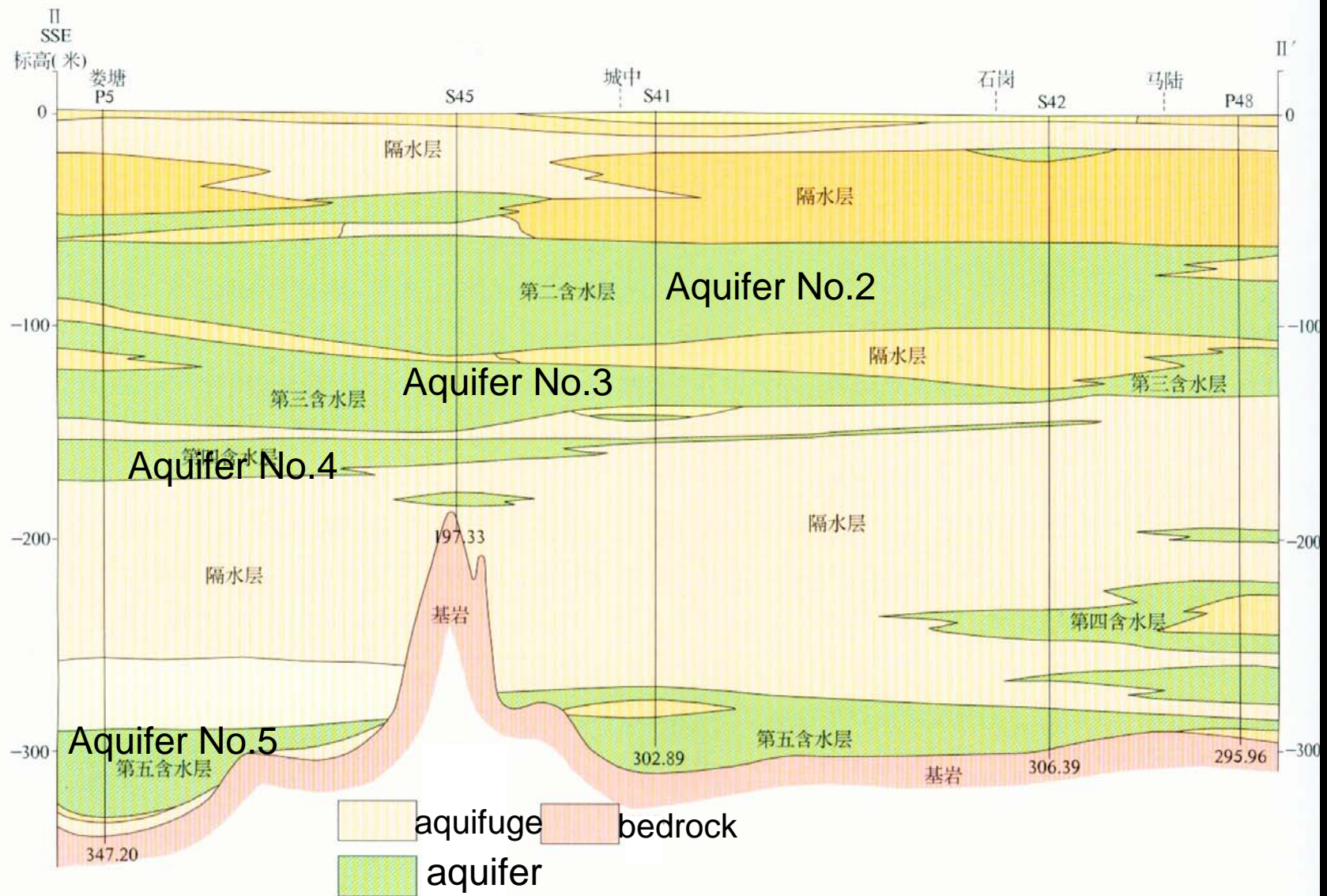
- The **second** measure adopted was artificial recharge of ground water.
- The ground water users are requested to inject the same quantity of water into aquifers in winter as they pumped out in summer.
- This was proved to be a very effective engineering measure.



The summer users of groundwater are requested to inject the same quantity of water into the aquifer



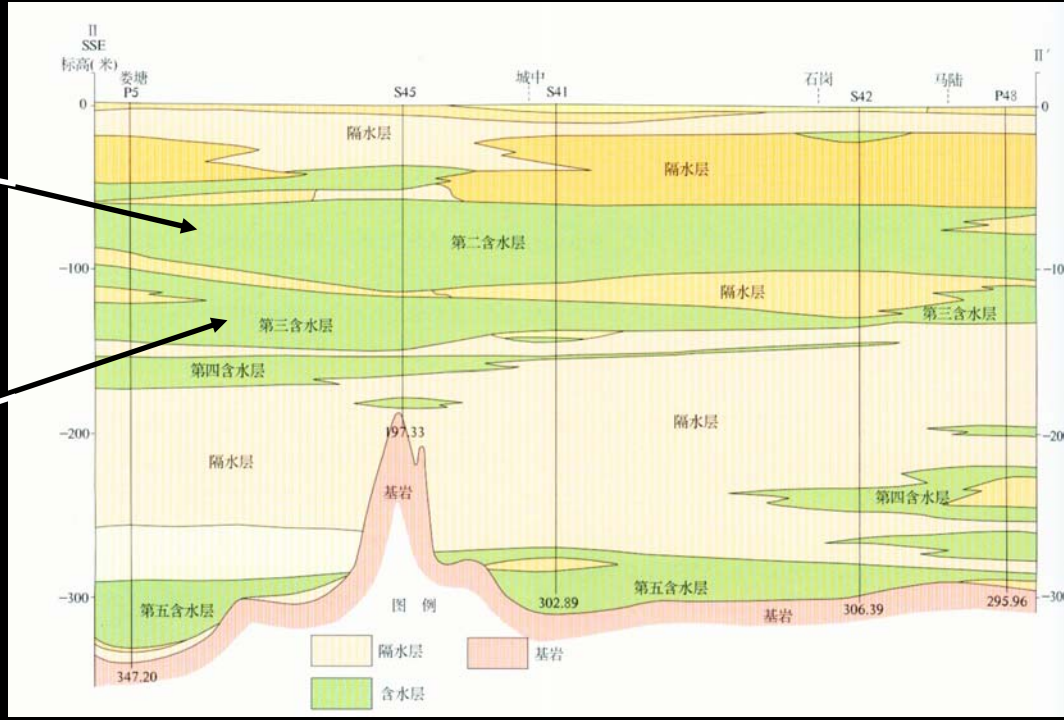
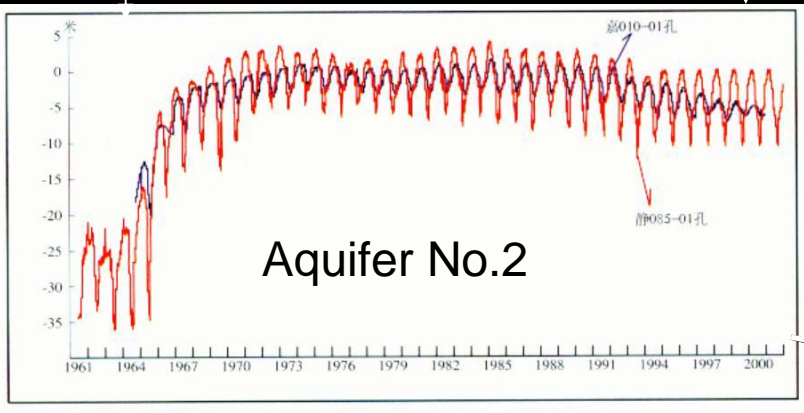
Distribution of ground water in Shanghai



All the Aquifers No.2-5 have been mined for industrial and resident's use

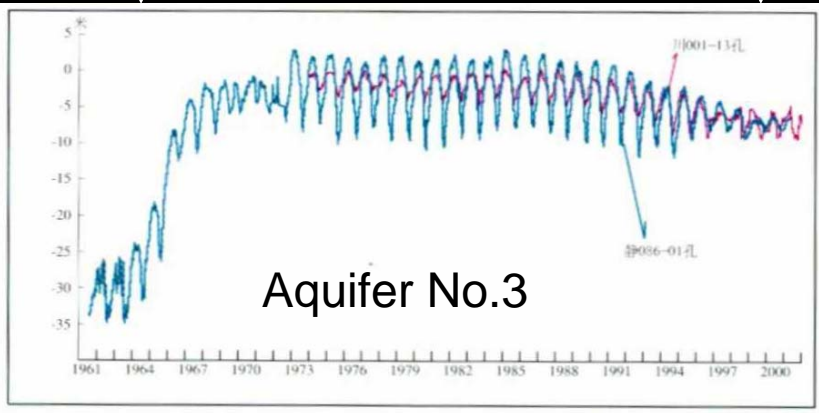
1964

2000



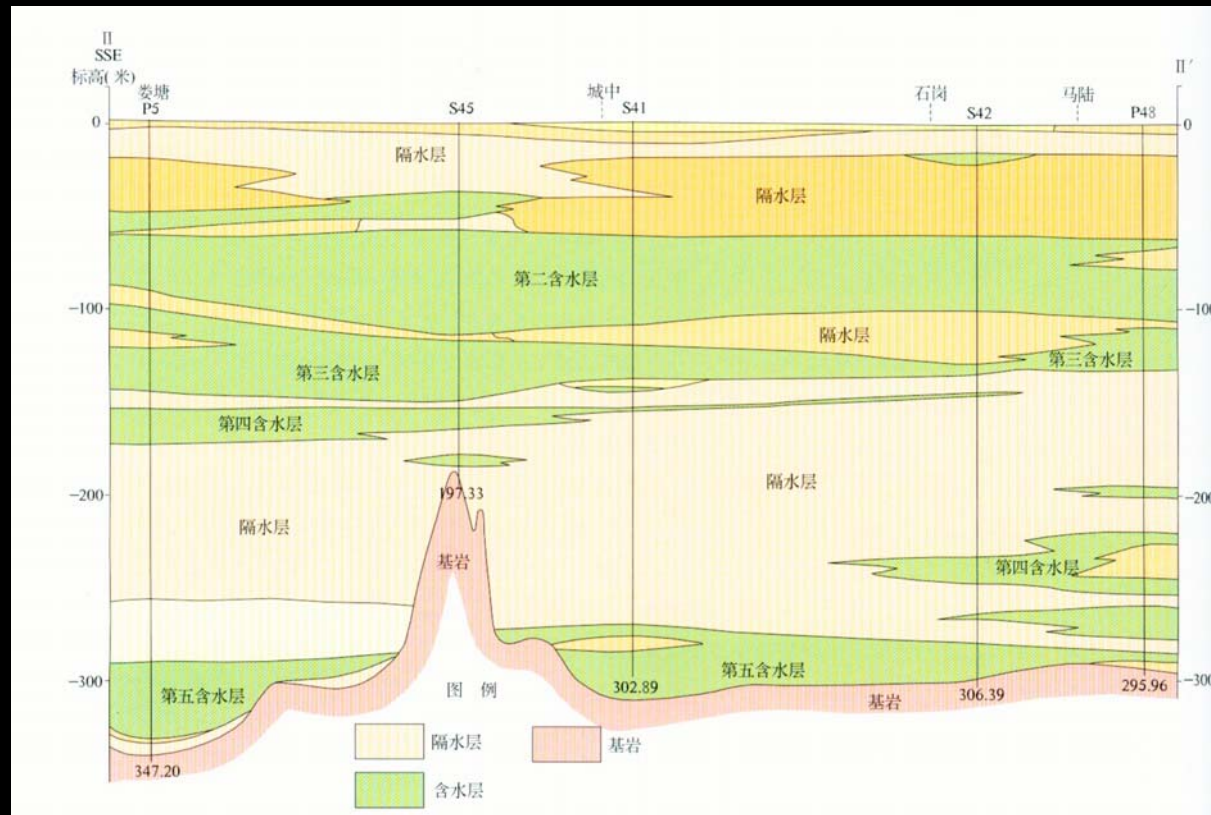
1964

2000



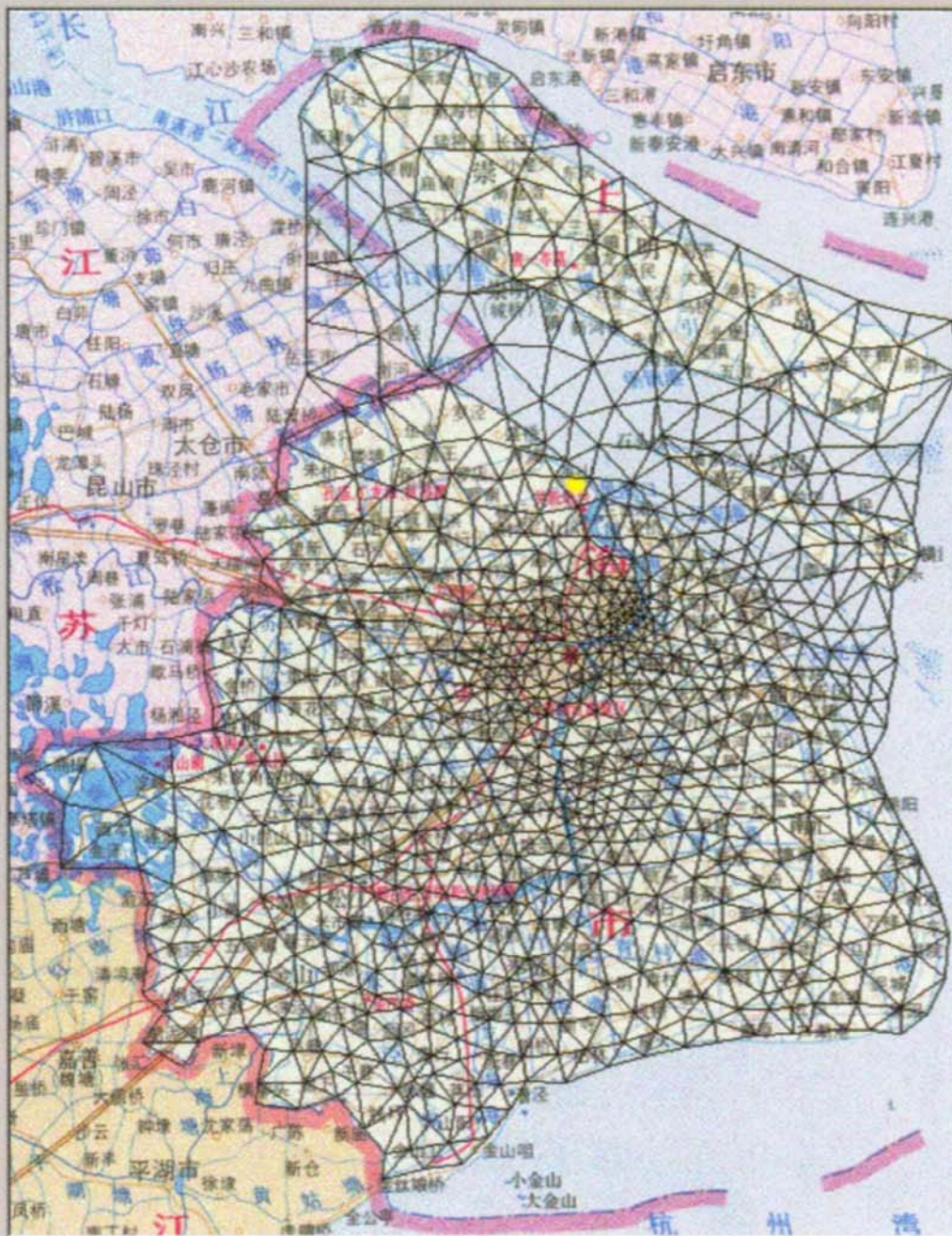
Recovery of ground water levels after injection of water

- **Thirdly**, the industrial use of ground water was moved out from downtown to suburbs, the water mining aquifers moved from shallower to deeper ones.



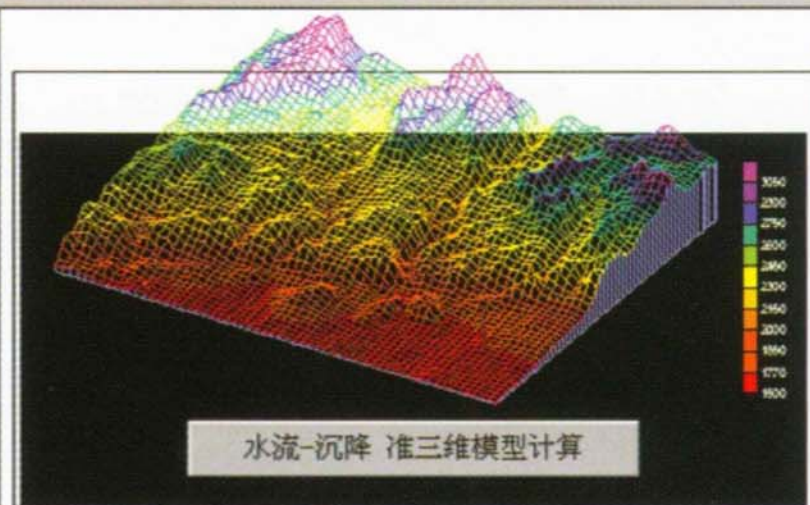
- **Fourthly**, a monitoring network of land subsidence and ground water levels was established, and a research centre was set up.





上海市地面沉降信息系统

监测点位置示意图绘制及准三维模型计算



起止年份选择 预测年份 井孔点半径 色号和图例

1981 2001 2020 1.0 0

地区选择

含水层次选择

采灌选择

全市

全部含水层

采水井

绘制监测点位置

井孔点选择

绘单点位置

水量井

宝001-03

水量井

水位观测孔

宝001-03S

水位孔

孔隙水观测孔

11-1-02

孔隙水

分层标

F 1 # DM

分层标

水准点

4-156A

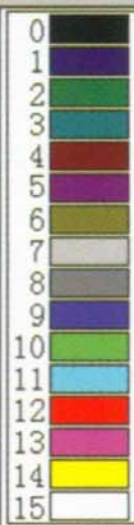
水准点

图形编辑

返回

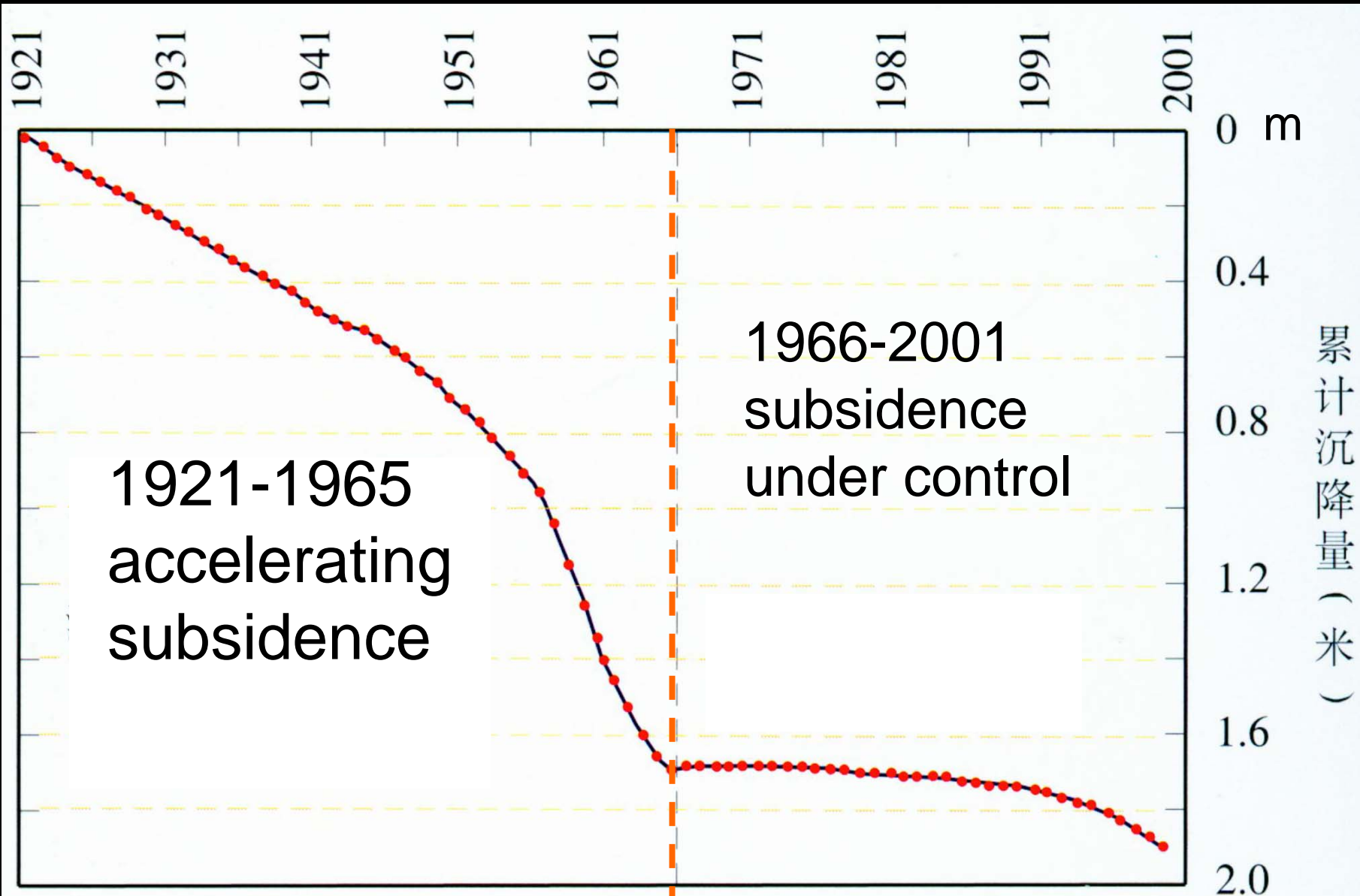
画区框

关闭



请选择年份、地区、含水层次、采灌井、点半径、色号

Accumulative land subsidence in Shanghai over 80 years



Land subsidence in Shanghai

- 1921-1965: 1.76 m subsidence, or 39 mm / yr
- 1999: 12.29 mm / yr
- 2000: < 10 mm / yr
- 2004: 8 mm / yr
- 2010: < 5 mm / yr

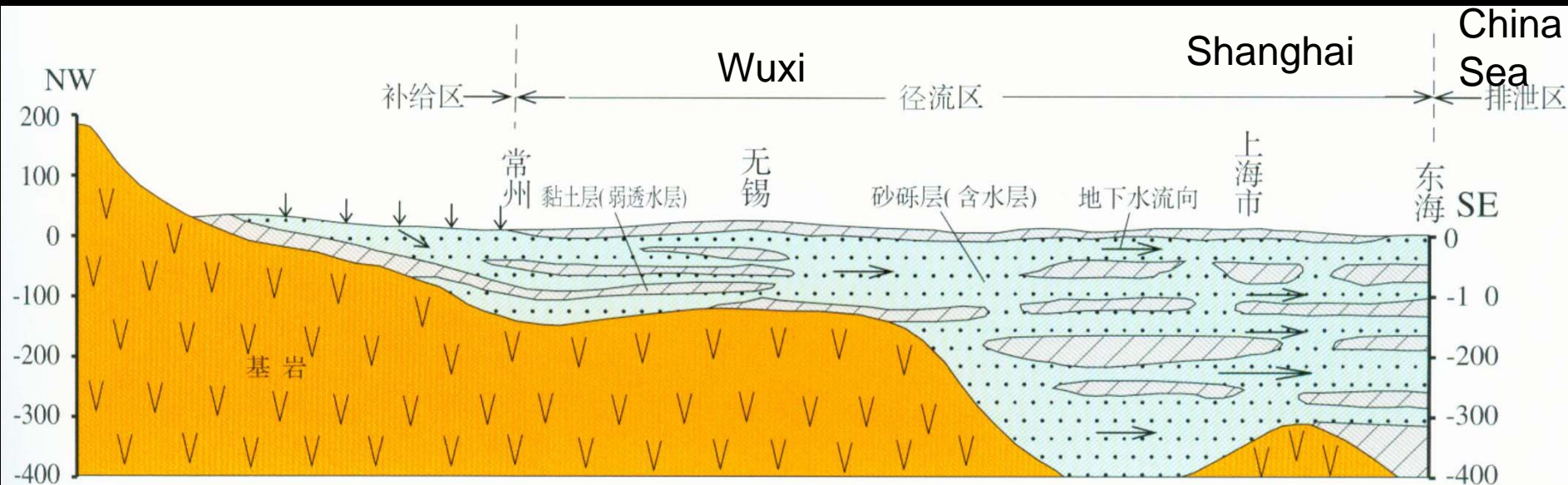
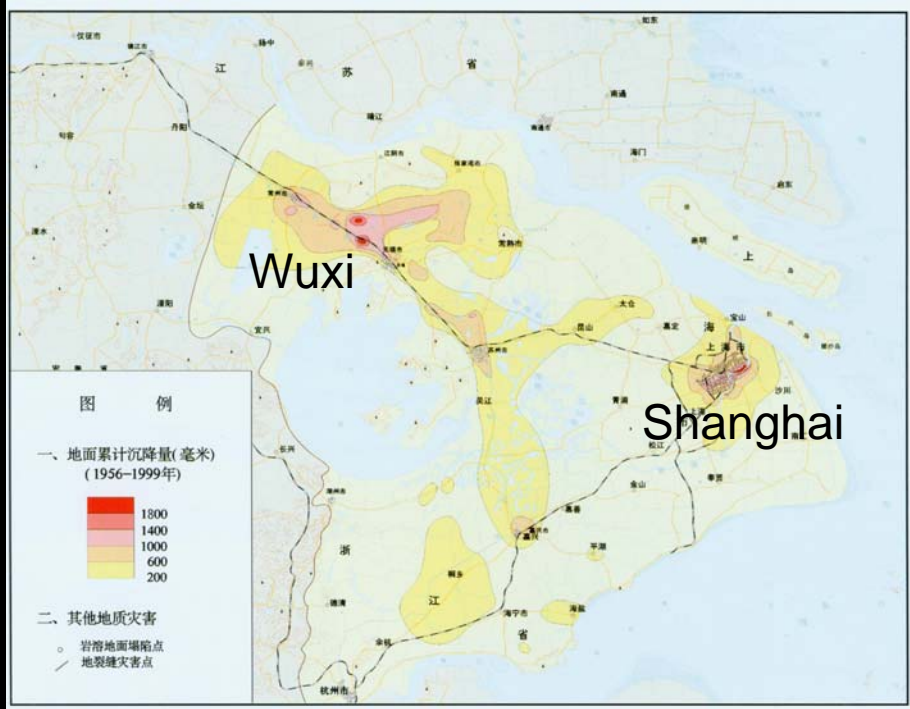
- The integrative measurements were successful, and the subsidence rate declined already in 1966.
- Since the 1990s the annual amount of subsidence has been controlled within the range of 10 mm/year.
- Given the rate of subsidence before the 1965, most of Shanghai would submerge under sea water in the year 1999 without the above efforts.

- Nevertheless, land subsidence remains a major issue for Shanghai.
- On the one hand, the massive construction of **high building** has become a new challenge for land stability.

>4000 buildings over 16 floors in Shanghai



- Second, the economic development of the **entire Yangtze Delta** caused land subsidence outside Shanghai which is beyond its control.



- As **each millimeter** of land subsidence costs Shanghai as much as **20 million** US Dollar, it is too expensive for the city to ignore the challenge.



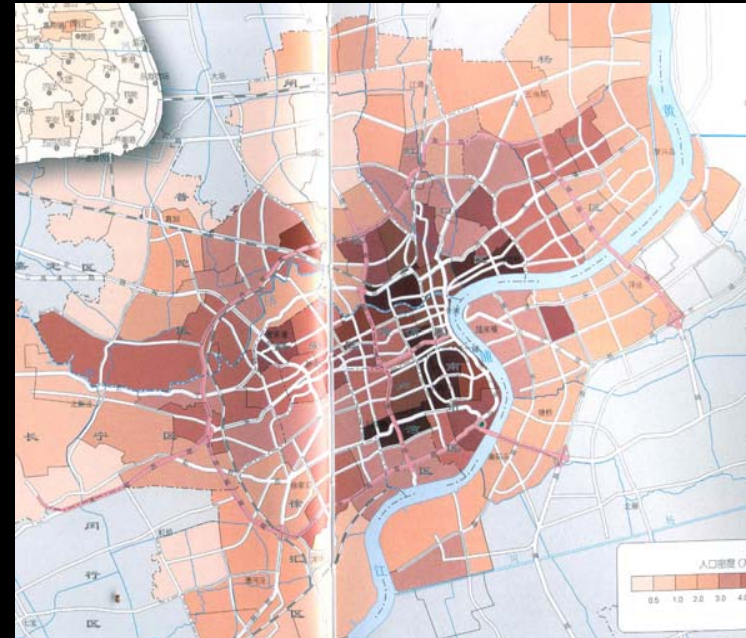
Shanghai Land Subsidence Monitoring Show

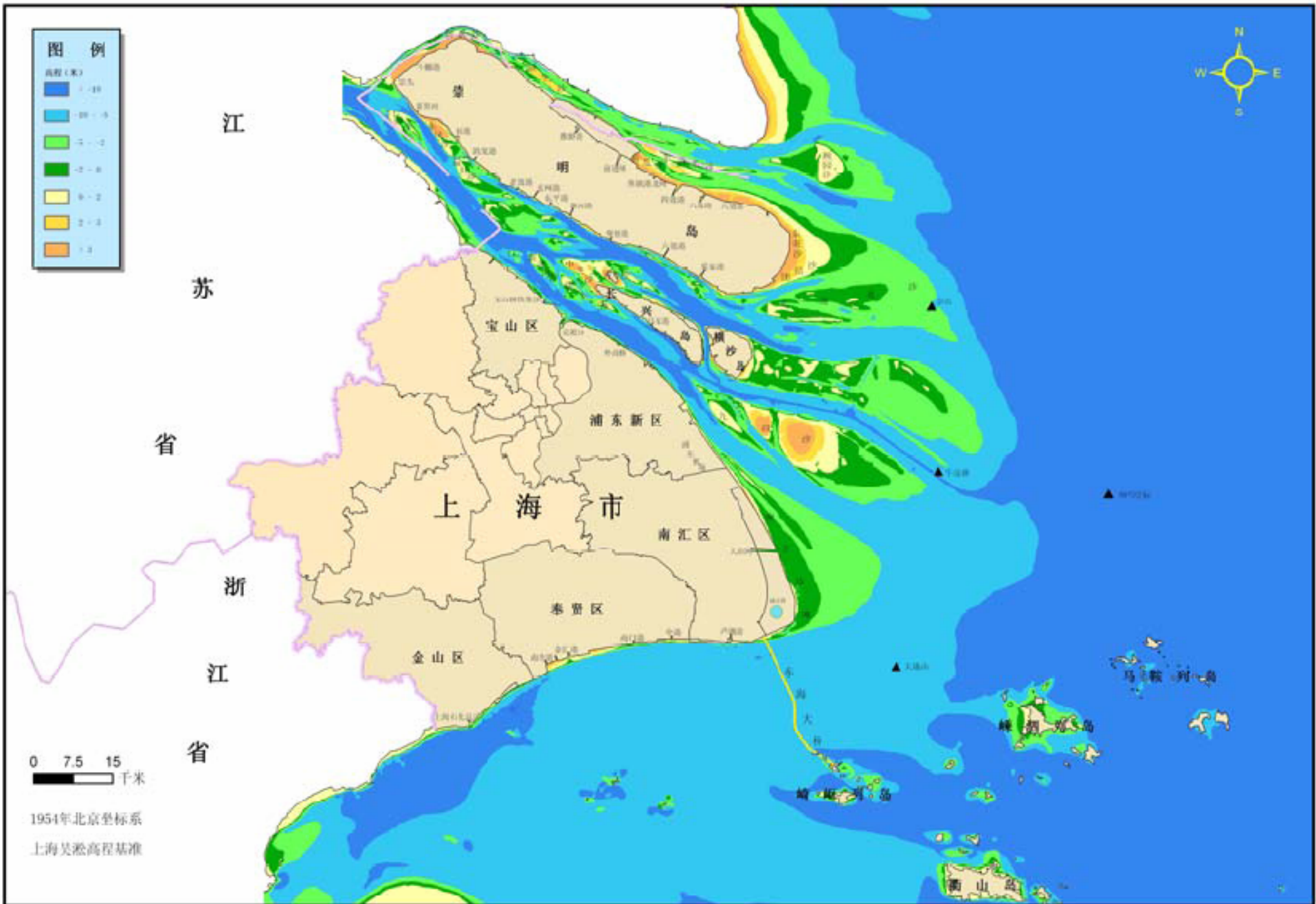




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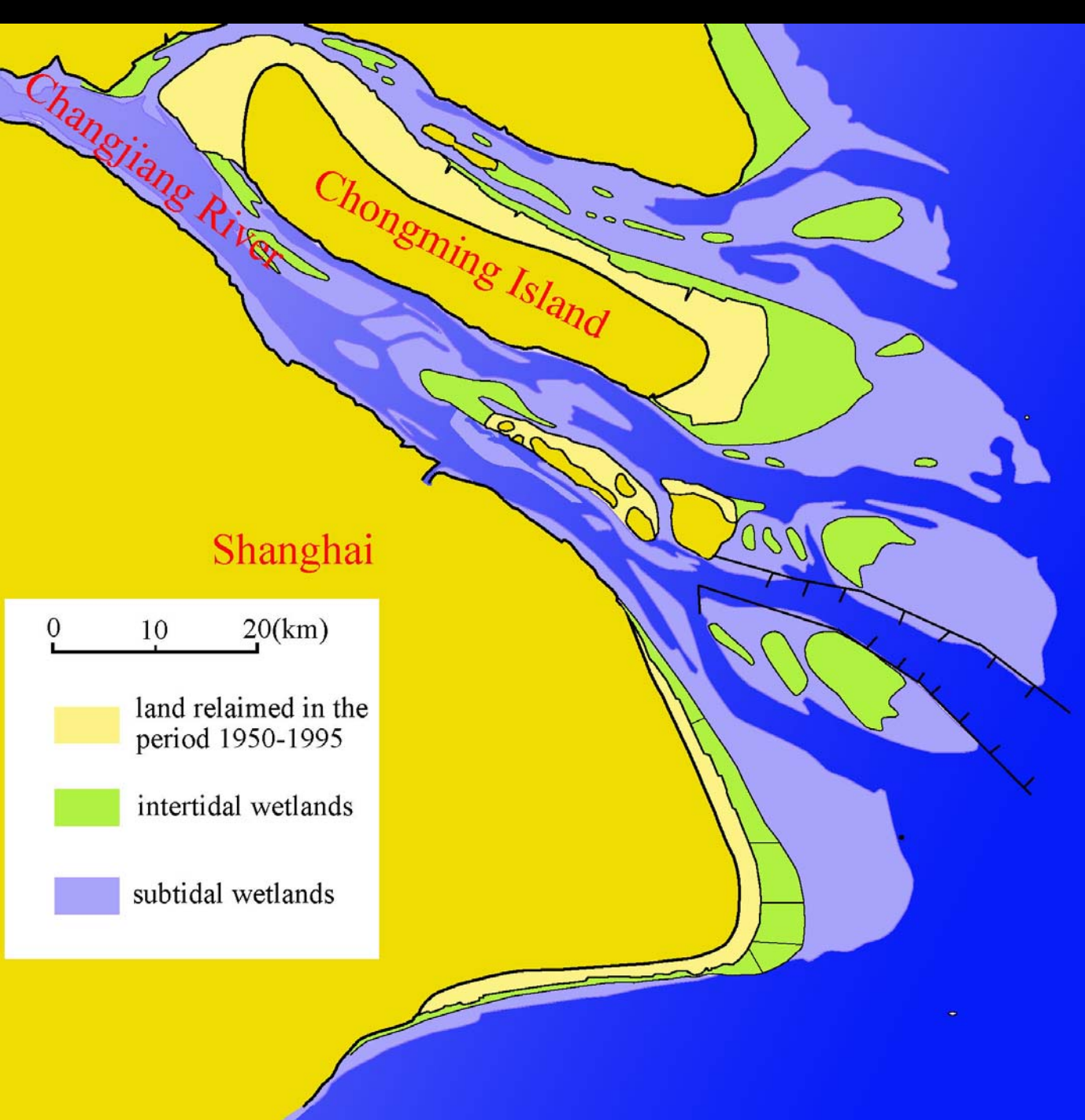




Shanghai foreshore resources

Shanghai wetland



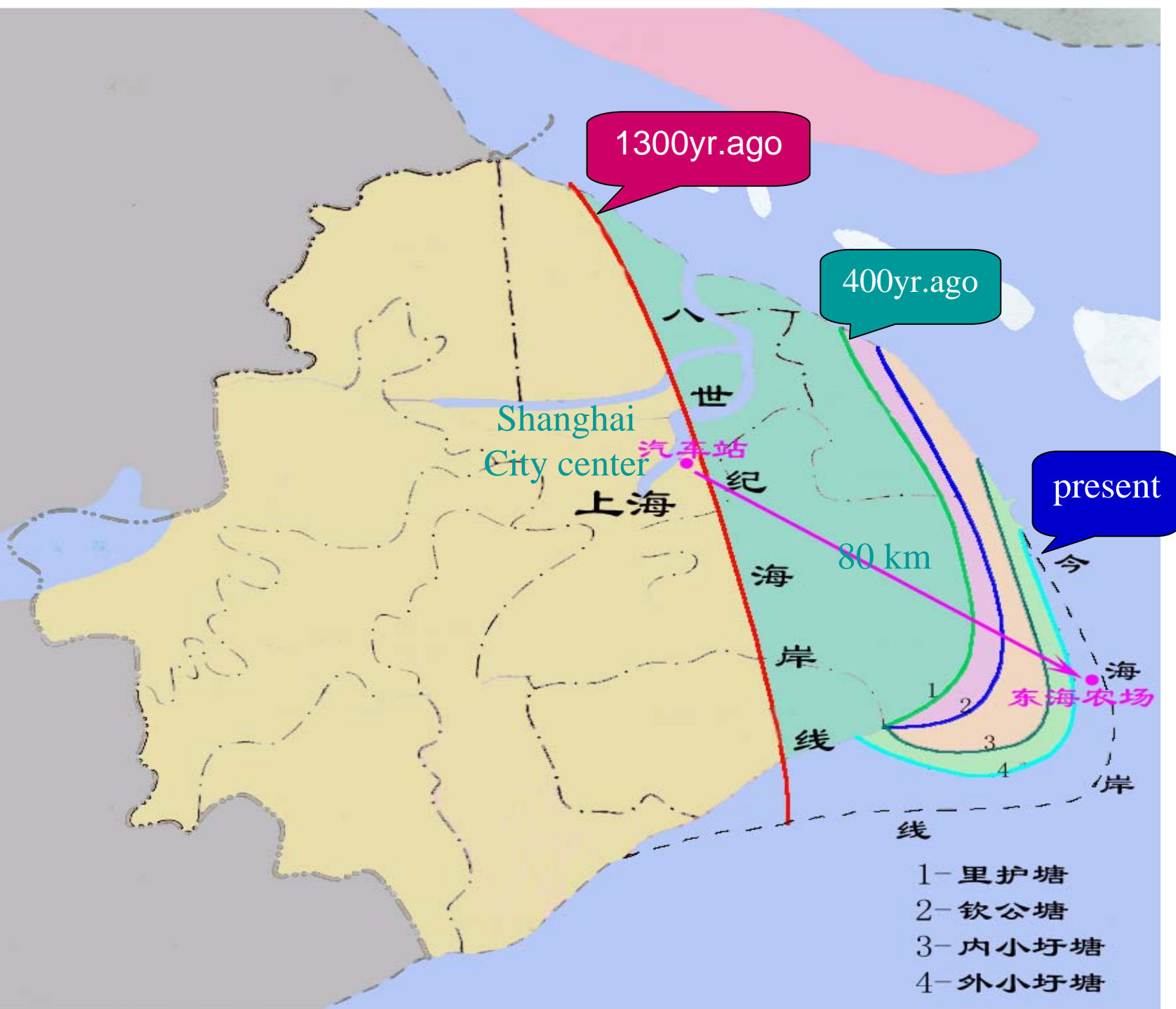


Coastal wetland

Shanghai total area: 6,340 km²

1950-1997:
785.4 km²
16.3 km²/a

2000-2040:
1,213 km²
30.3 km²/a



1300yr.ago

400yr.ago

present

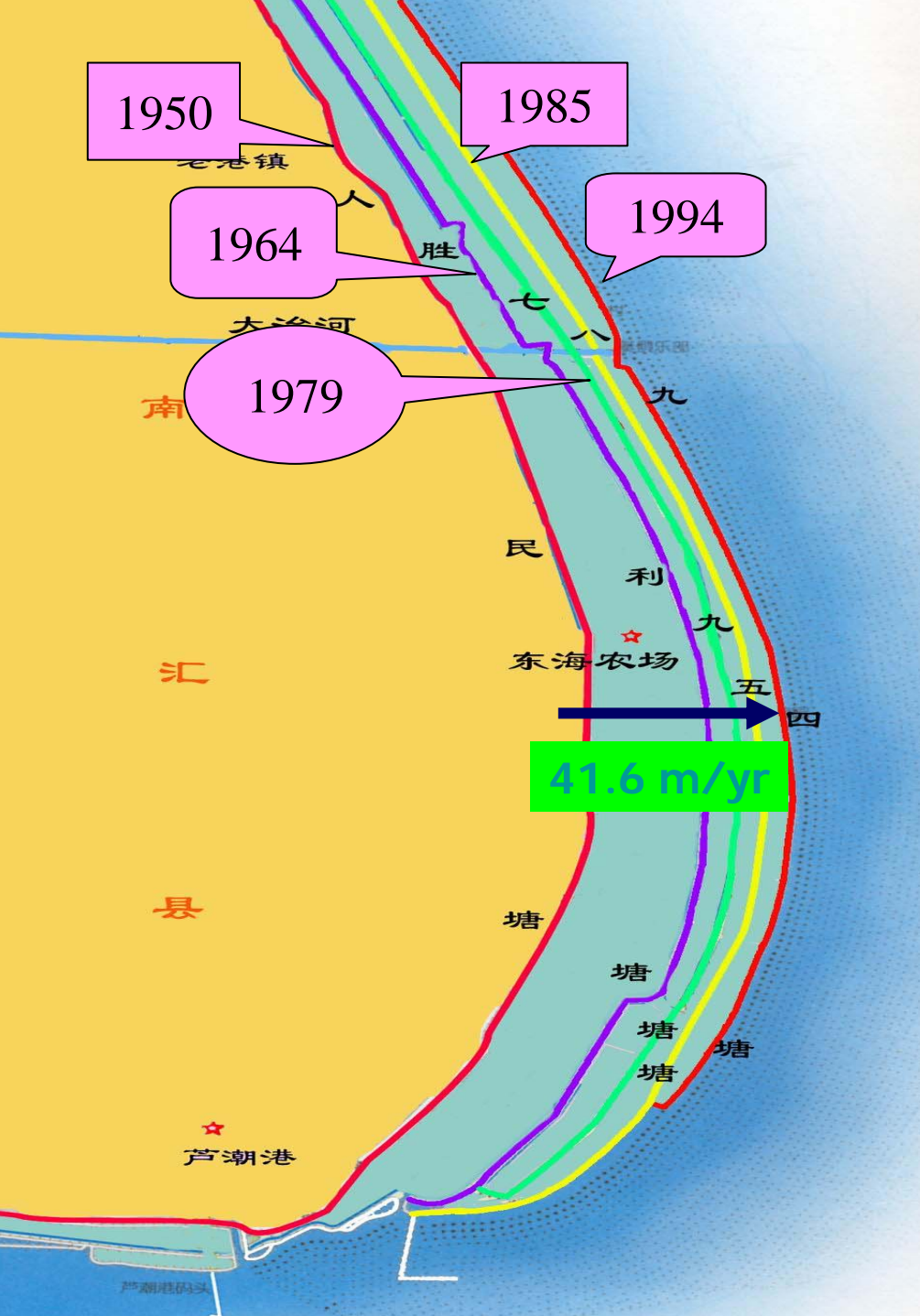
Shanghai
City center

汽车站
上海

80 km

东海农场

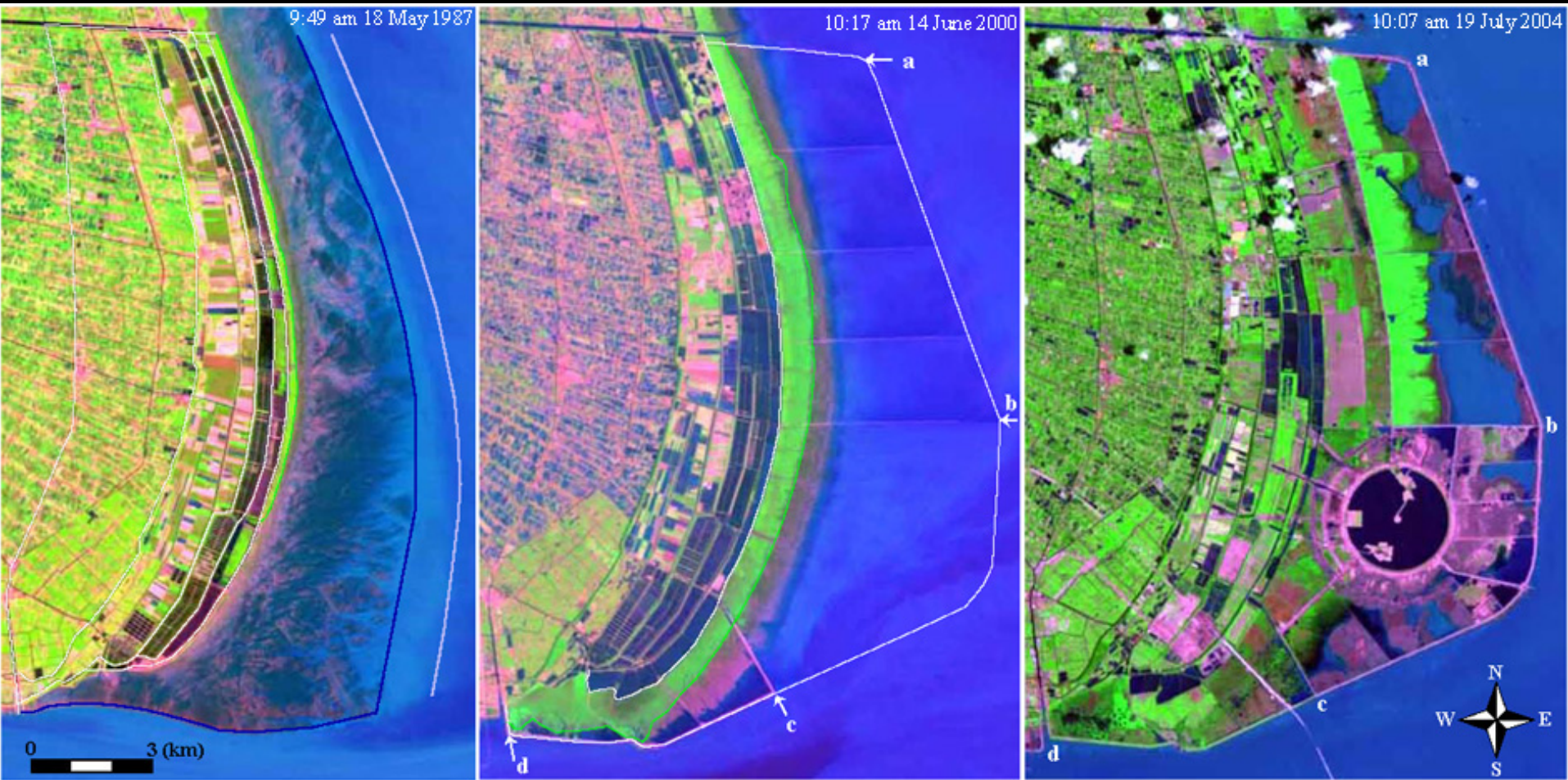
- 1-里护塘
- 2-钦公塘
- 3-内小圩塘
- 4-外小圩塘



reclamation

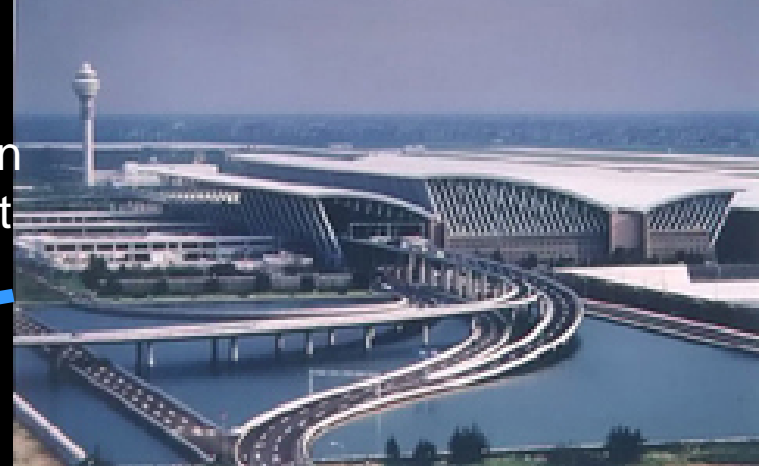
in the last half
of the 20th century

Present Land reclamation project





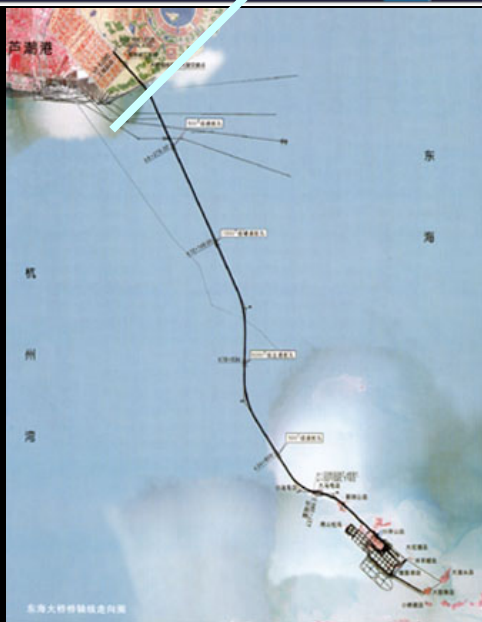
Recent reclamation
--- Pudong airport



--- Lin-Jiang port town



Dong-Hai
Bridge to
Deep-water port
at Yang-Shan





Dong-Hai
Bridge
to
Deep-water port
at Yang-Shan

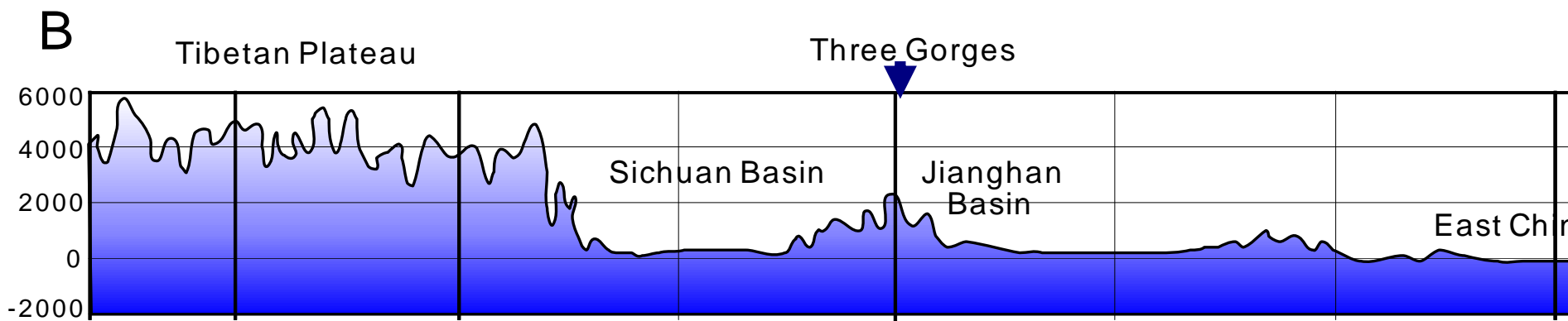
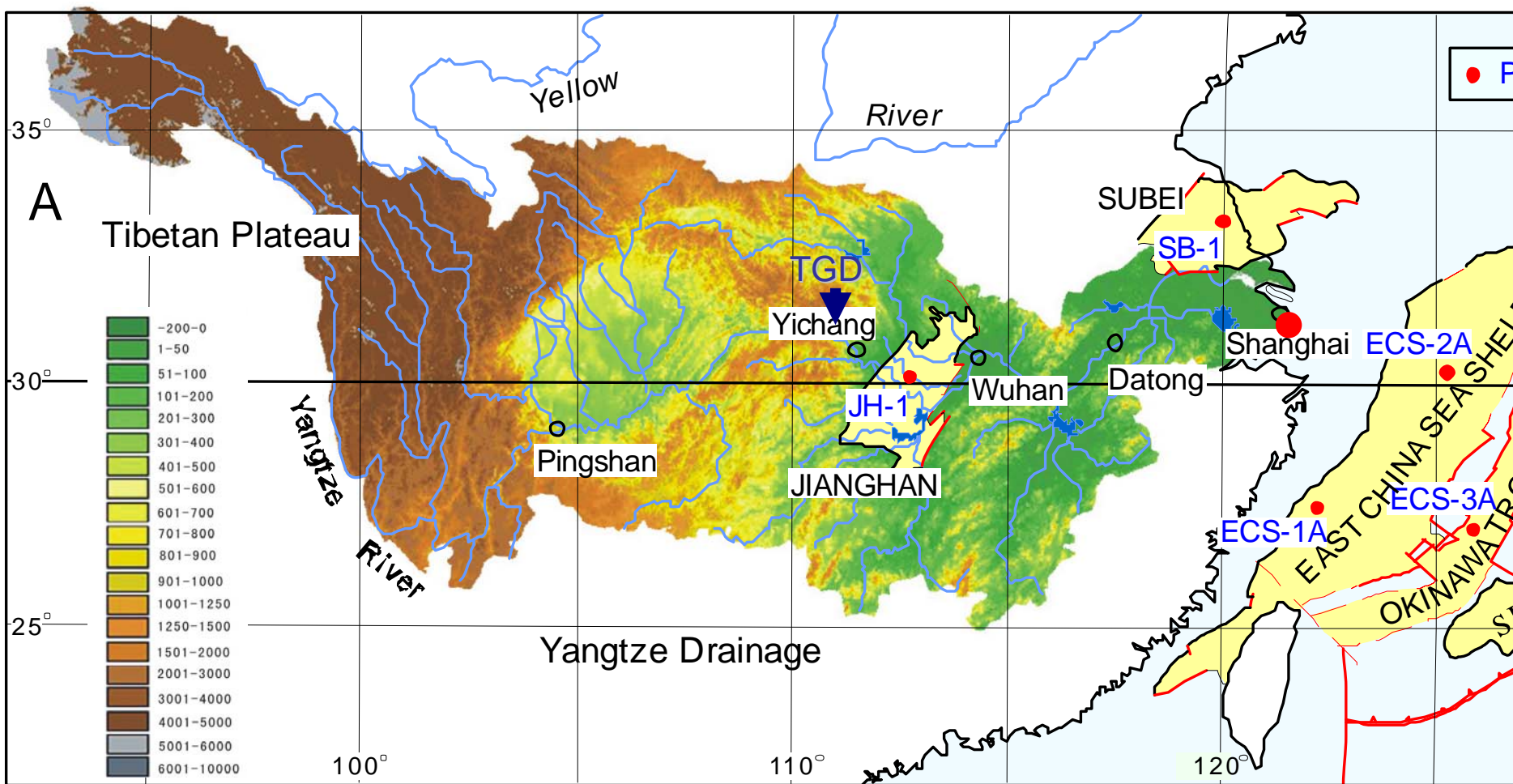




A long-term average showed that the Changjiang River's annually discharges:

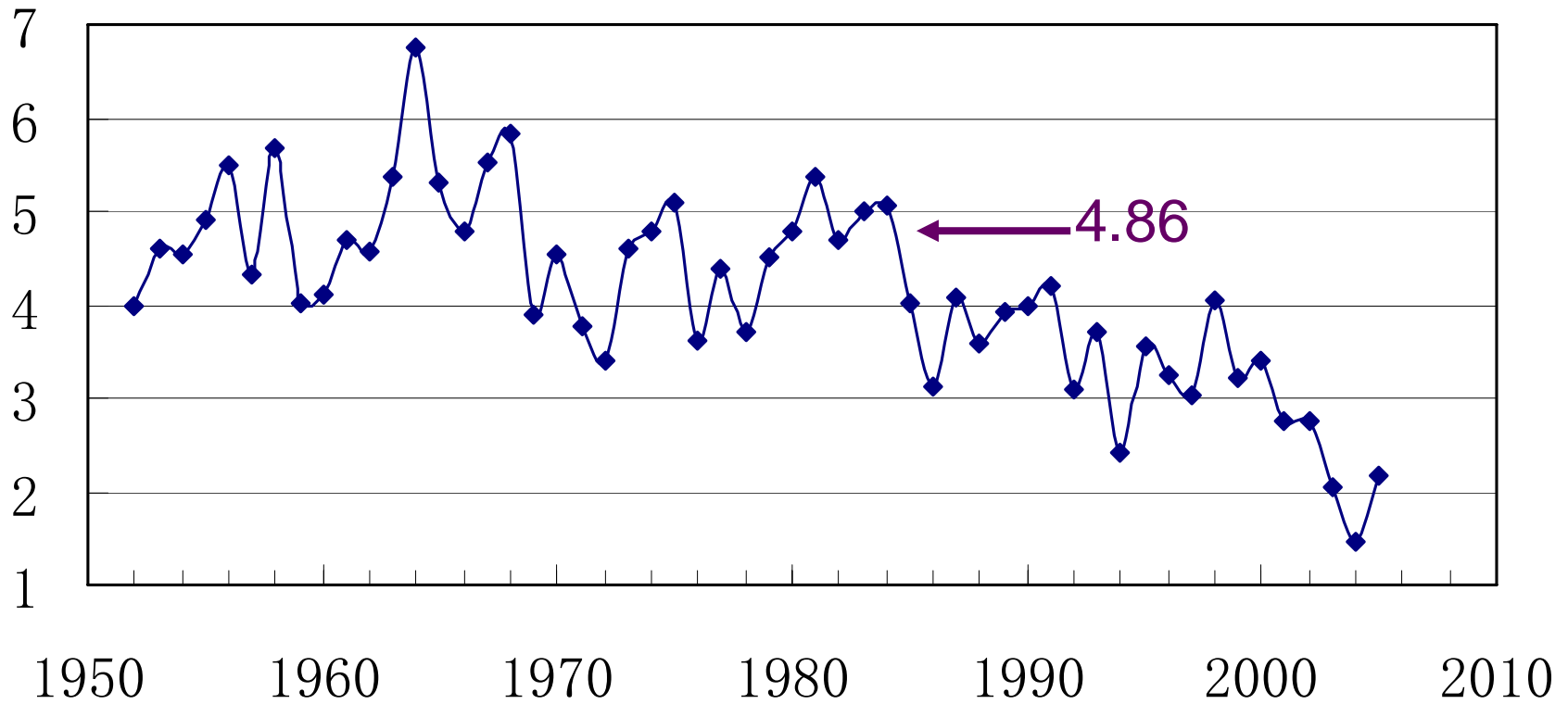
- $9250 \times 10^8 \text{ m}^3$ of water
- $4.86 \times 10^8 \text{ m}^3$ of silt to the sea

Xue , 1995

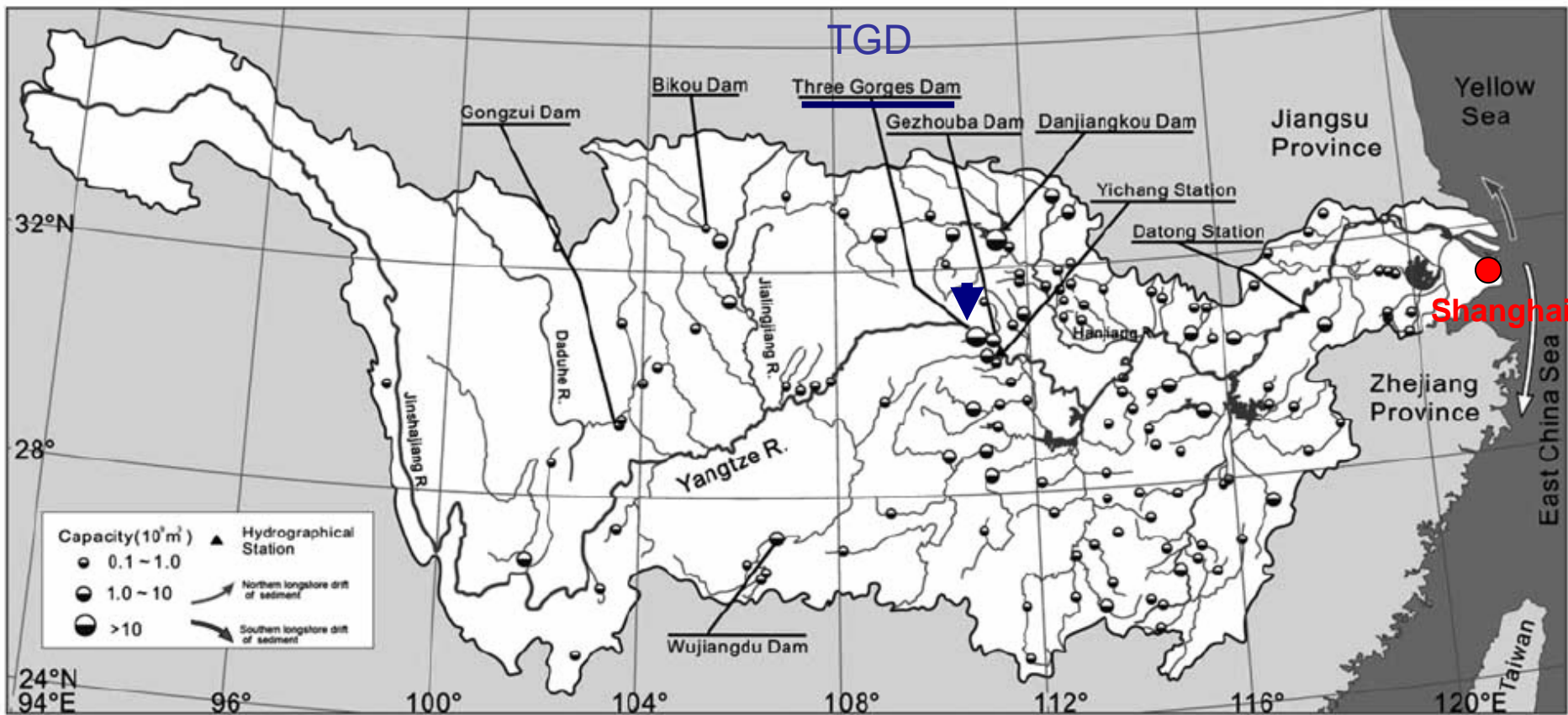


Sediment discharge (10^8 ton)

10^8 t

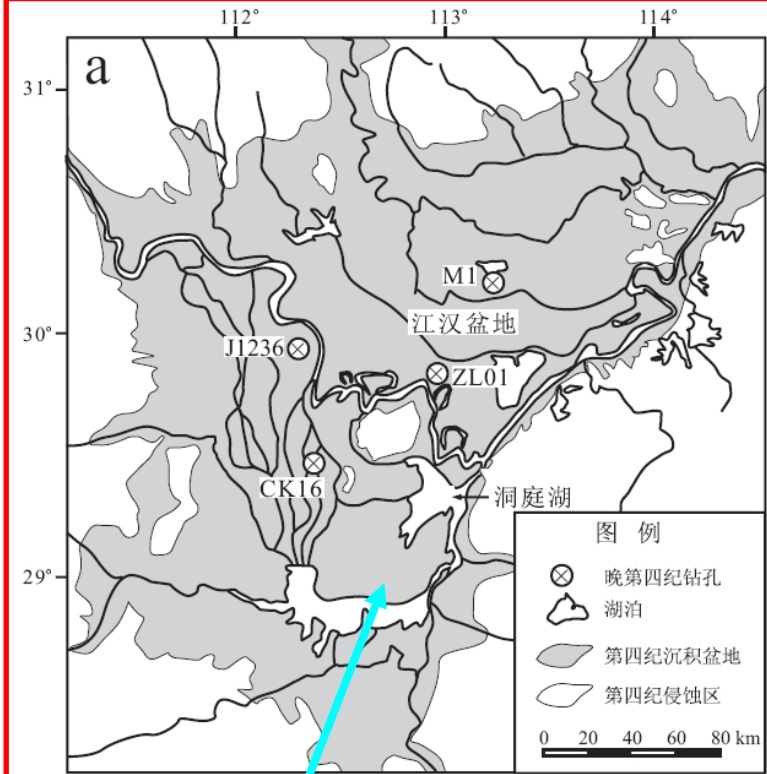
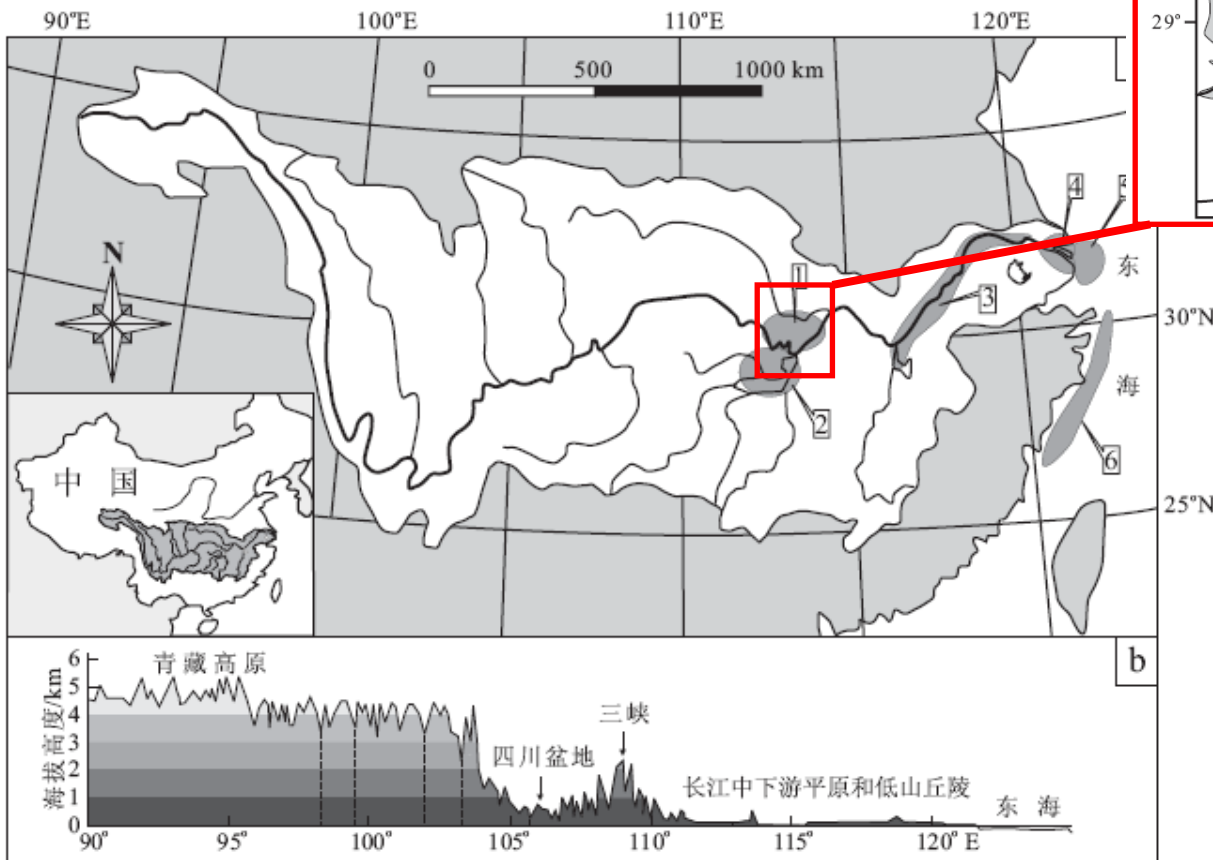


Over the last half century sediment discharge of Yantze R. decreased significantly mainly due to dam construction



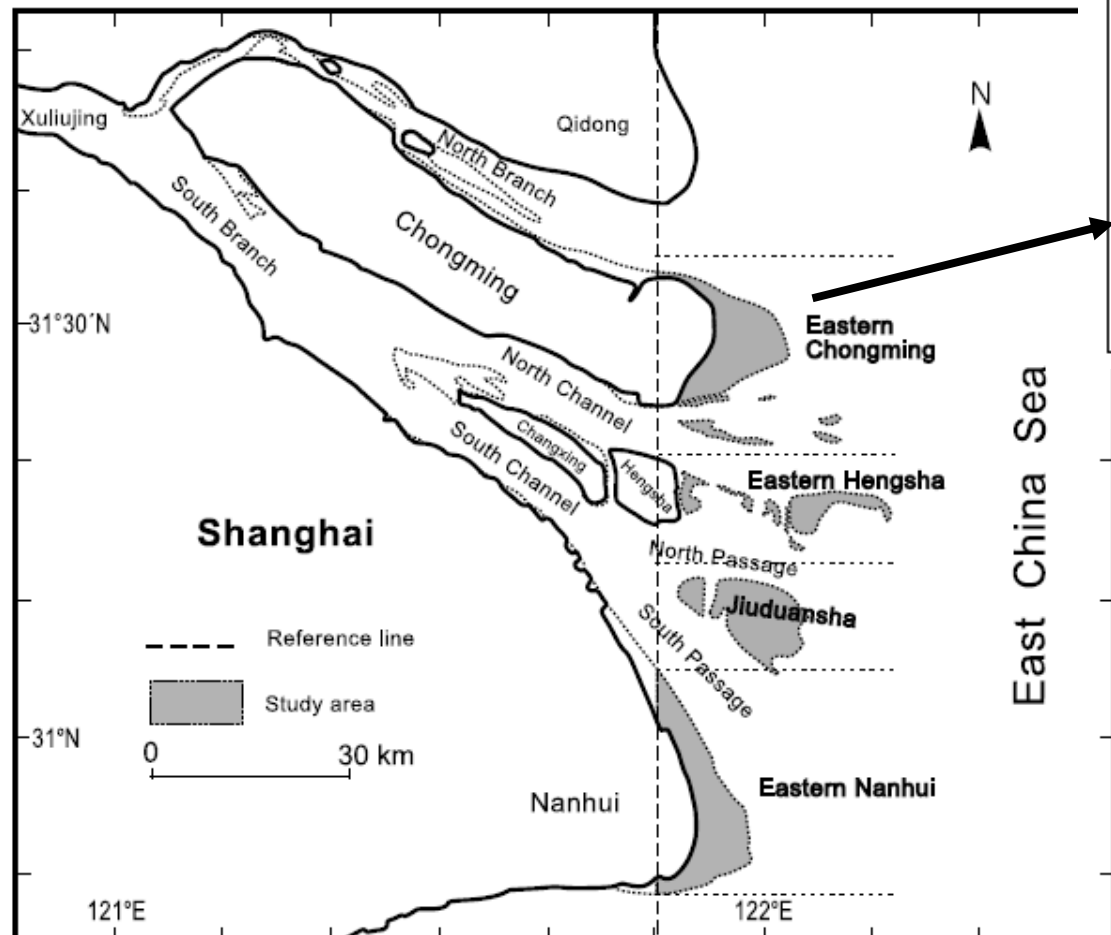
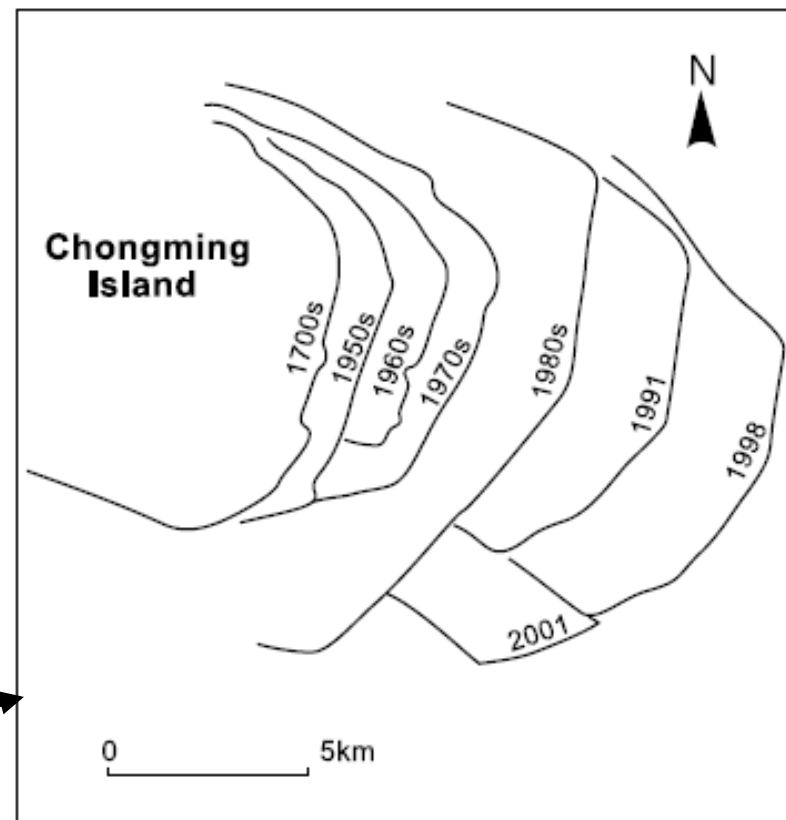
- $\sim 50,000$ dams since 1950
- total storage capacity of reservoirs $\sim 200 \times 10^9 \text{ m}^3$,
or 22% of Yangtze annual runoff
- sediment accumulation in reservoir: $> 850 \times 10^6 \text{ t/yr}$ in 2003

Lake basins in the middle and lower reached have been deposition centres of Yangtze. During the past 7,000 years, a total of 13×10^{11} tonne sediments have accumulated in the middle and lower reaches, compared to 9.5×10^{11} tonne in submarine delta and continental shelf.



Dongting Lake area of the Jiangnan Basin is the largest receives deposition center and receives 1×10^8 tonne sediment per year.

The delta coastline has progradated at 10-20m/yr, and intertidal **wetland** has grown at **~5 km².yr.**



The progradation rate has accelerated in recent centuries. Probably because of deforestation in the catchment area.

Yang et al., 2005

- Many deltas worldwide are retreating due to decreases in sediment supply from **dammed rivers**. Almost no net annual sediment load is delivered to the Nile delta due to the Aswan High Dam and others.
- Shanghai is sitting on a progradating delta. **~2/3** of the Shanghai land area was formed in this way during the past **2000** years, with **1/5** of it obtained in the last **50** years. Shanghai plans to further reclaim **767 km²** of intertidal wetlands.
- Because of construction of 50,000 dams, the sediment accumulation rate in reservoirs along Yangtze has increased from **~0** in 1950 to **>850 x 10⁶ t/yr** in 2003. The **Three Gorges Dam** and other new dams will cause further decrease of sediment discharge rate of Yangtze.

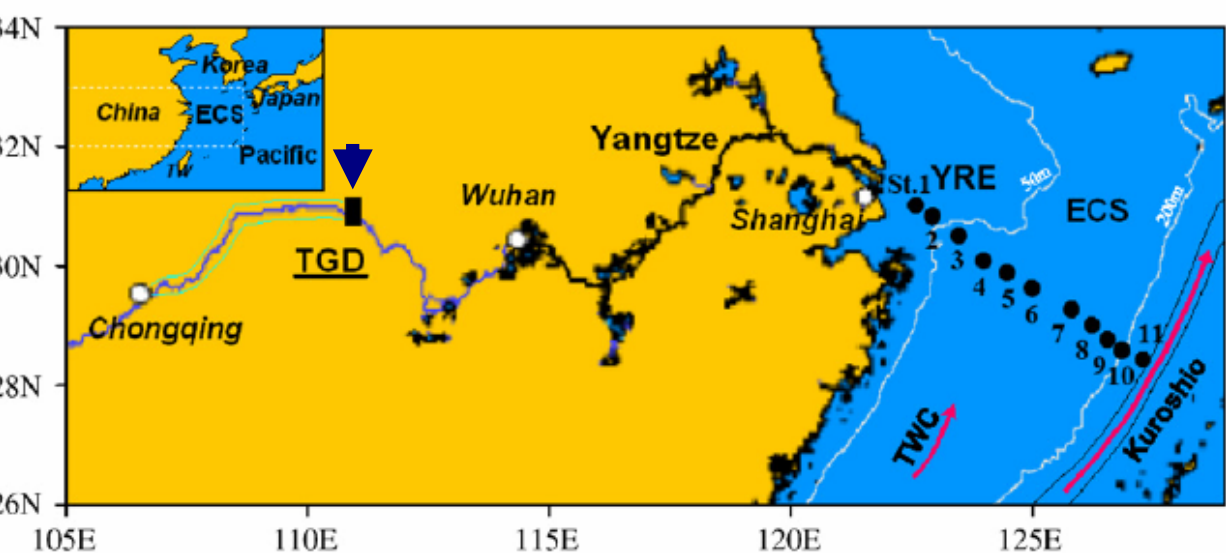


Three Gorge Dam construction:
How much will be the impact
on sediment supply to the delta?



Three Gorge Dam





Jiao et al., 2007

Sediment flux into the sea

Present:

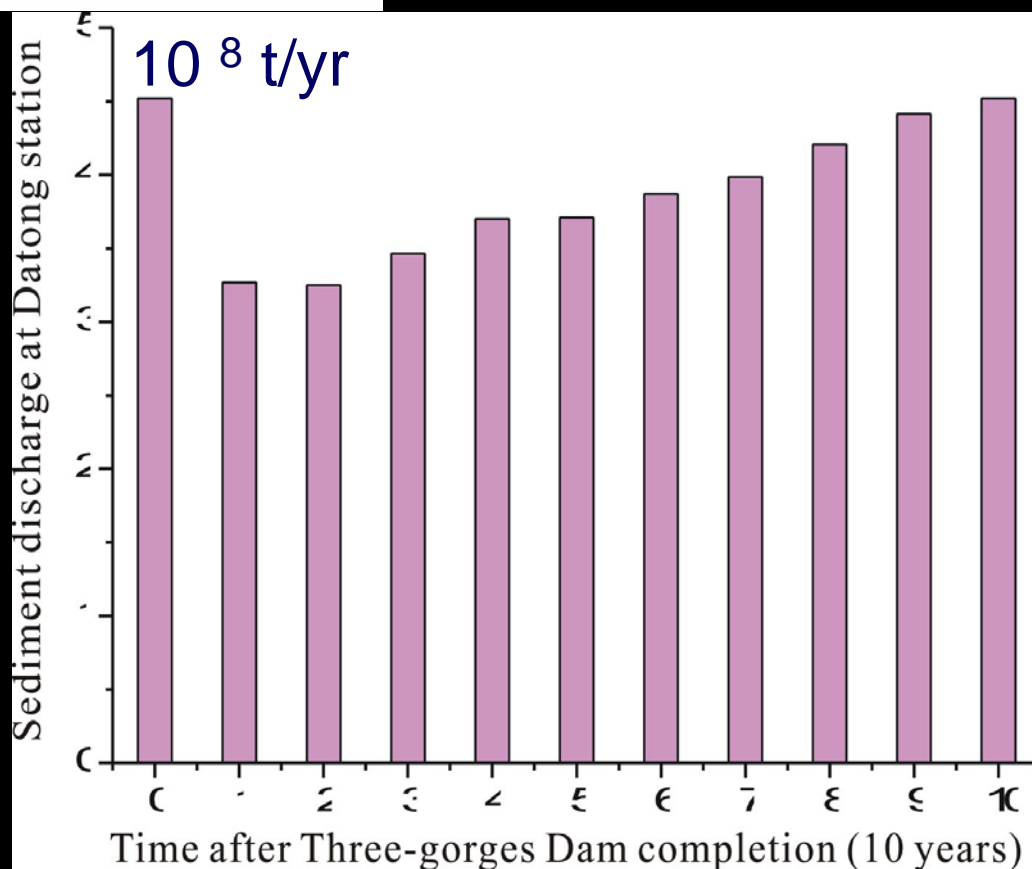
460×10^6 tons

Post-glacial:

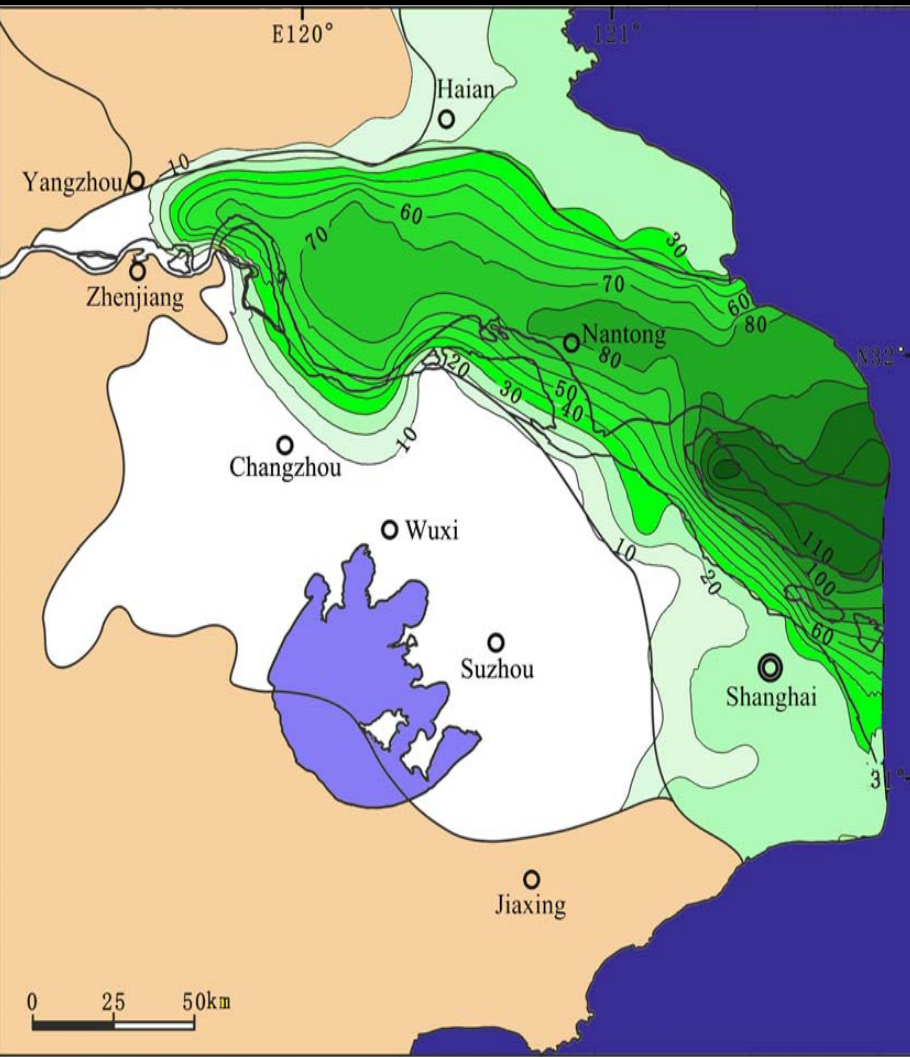
236×10^6 tons

Since 7000 yr B.P.

228×10^6 tons



The **critical sediment discharge (CSD)**
-- turning the delta from construction into
destruction



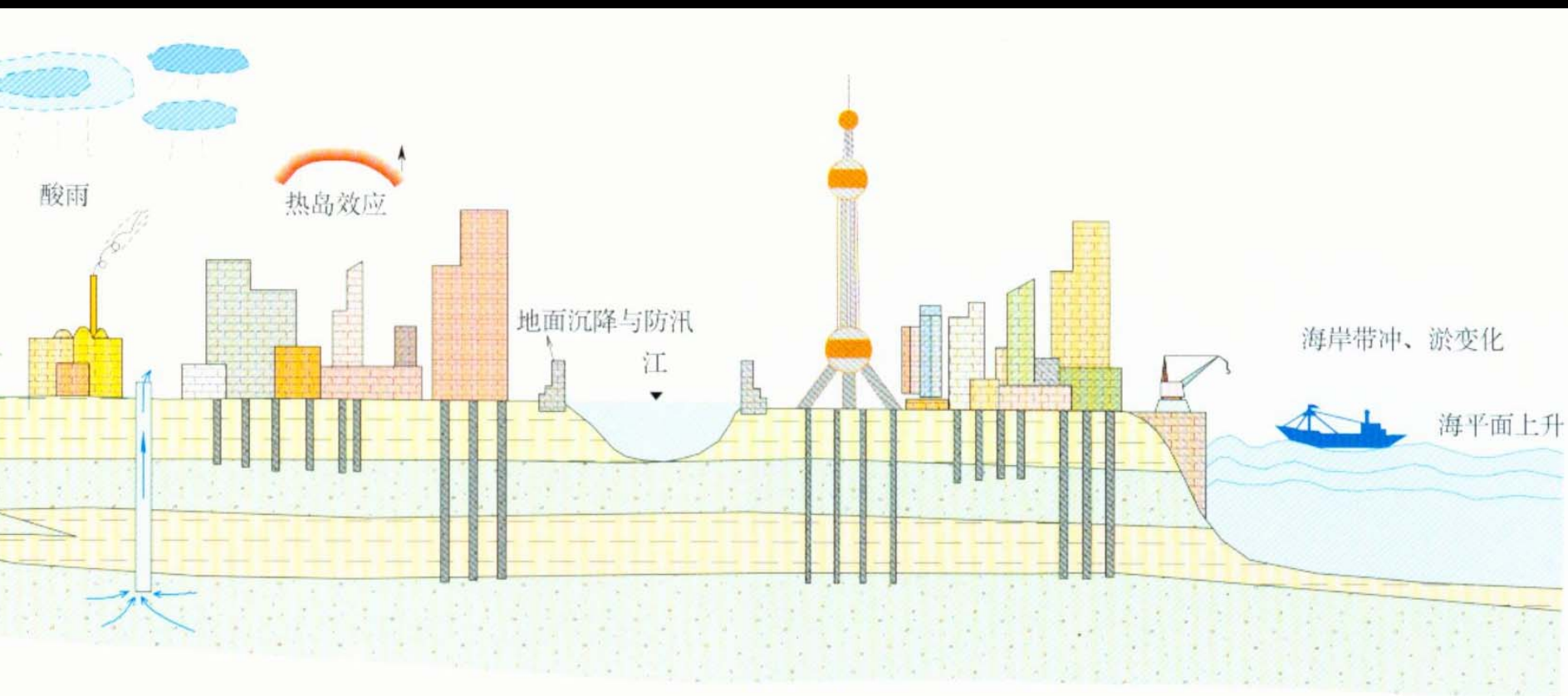
Li et al. (2003)
thought that CSD
should be lower but
very close to the
Holocene mean
sediment discharge of
 $228-244 \times 10^6 \text{ t/a}$

Water/Land Conflict in Shanghai

After construction of dams:

- * The Yangtze Delta remains in its constructive mode unless the sea level rises fast
- * The Yangtze Delta will enter into a destruction phase

Water / land conflict remains one of the major concerns of Shanghai for its sustainable development



Urban geology in Shanghai

地震



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Better City, Better Life







As a Dragon Head, Shanghai has been “drifting along” on the water surface.

Within the last 10^4 of years, the Shanghai area has experienced repeated emergence / submergence cycles, and since the last decades it has still been confronted with the conflict between water and land.



Shanghai reclaims land from the sea, but takes a risk of losing land by using ground water, aside from the enhanced coastal erosion caused by the upstream damming.

Therefore, the story of Dragon Head is continuing...