Case Study I : Taiwan

Type example of very rapid erosion in an active mountain belt — very well studied — much work by Princeton group led by Professor Suppe.

The rate of erosion can be measured or inferred in six independent ways. The good agreement between these determinations is a confirmation of our high degree of understanding of the active processes:

- stream gauging — gives a direct measurement over past 50–100 years

total sediment load $= 380 \cdot 10^6 \dfrac{\text{tons}}{\text{yr}}$

(This is equal to the sediment load of the conterminous USA!)

erosion rate:

$$\frac{380 \cdot 10^6 \text{ tons/yr} \times 10^6 \text{ yr/Myr}}{\underbrace{2500 \cdot 10^6 \text{ tons/km}^3}_{\text{density of sediments}} \times \underbrace{90 \times 300 \text{ km}^2}_{\text{elevated area}}}$$

$$\boxed{\dot{e}_{\text{Taiwan}} = 5.6 \frac{\text{km}}{\text{Myr}} \quad (56 \times \text{world average})}$$

- ^{14}C dating of uplifted stream terraces and coastal corals gives the same rate — in this case it is an average over the past 5,000 – 10,000 years

- fission – track and $^{40}Ar – ^{39}Ar$ dating of deeply exhumed metasedimentary rocks gives the same rate

  e.g., the apatite crystals at Chipan dropped in temperature by 115° while being uplifted along a 50°C/km geotherm in 0.4 Myr:

  $$\frac{115°C}{50°C/km \times 0.4\ Myr} = 5.5\ km/Myr$$

- steady – state mountain building

  $$\dot{e} = \frac{hV}{W} = \frac{7\ km \times 70\ km/Myr}{90\ km}$$

  $$= 5.5\ km/Myr$$

- comparison of nanofossil age and ~~the~~ proto – metamorphic grade of the shed sediments gives same rate of "unroofing".
- direct bedrock incision measurements – same

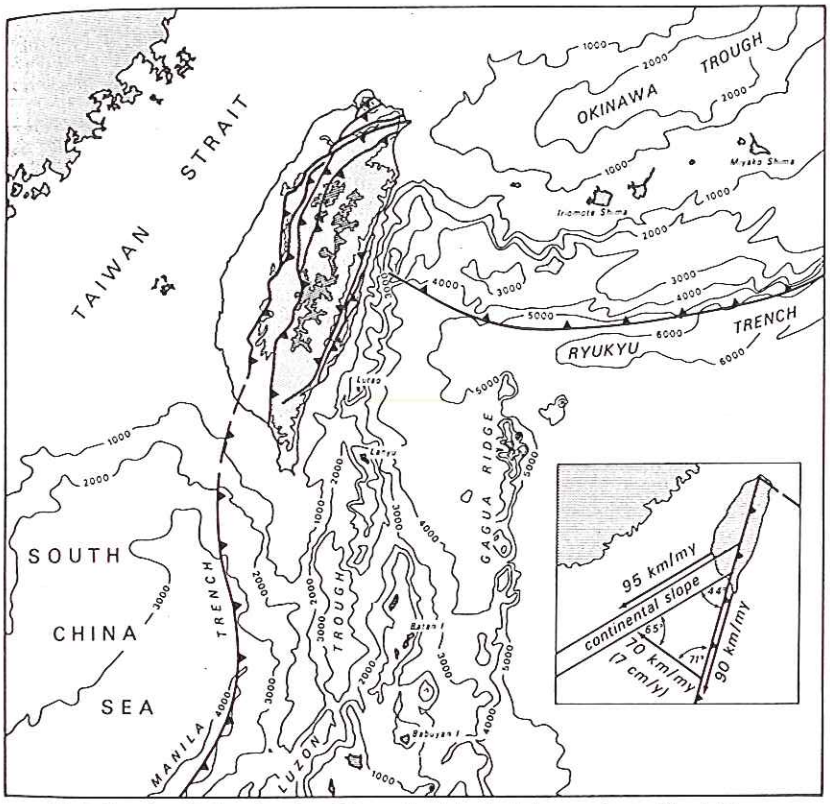
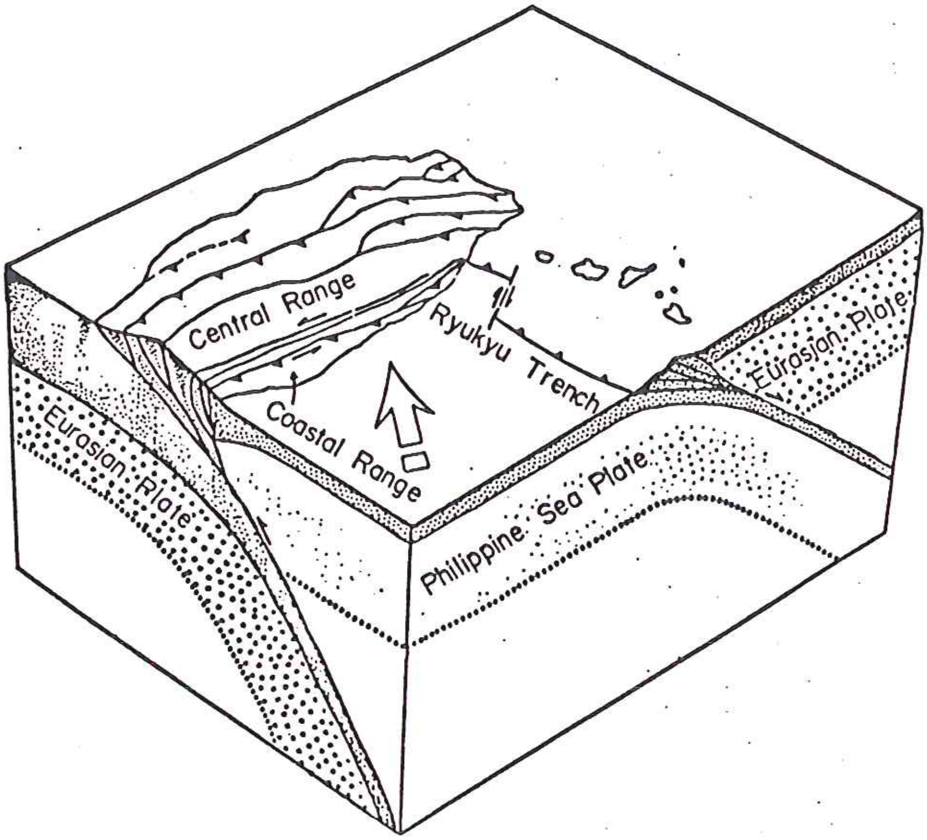
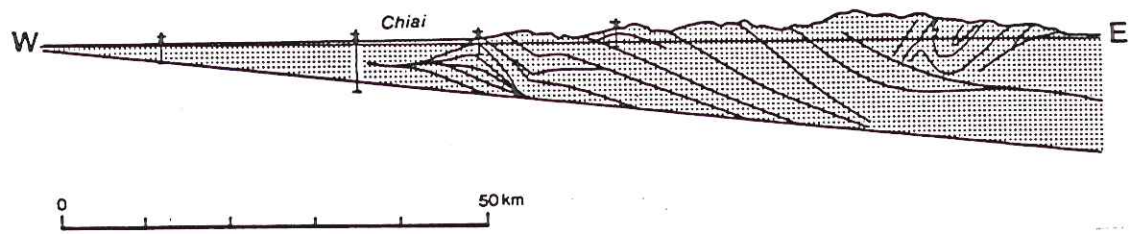
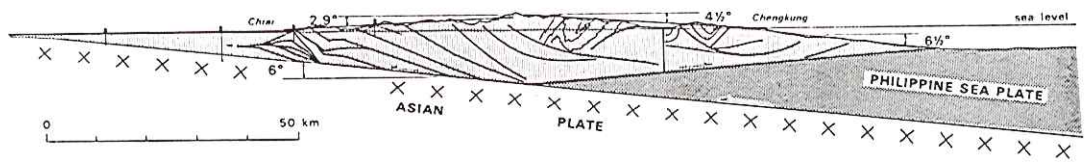


Fig. 9. Tectonic and bathymetric setting of Taiwan with velocity triangle for arc-continent collision in Taiwan assuming plate motions of *Seno* [1977].







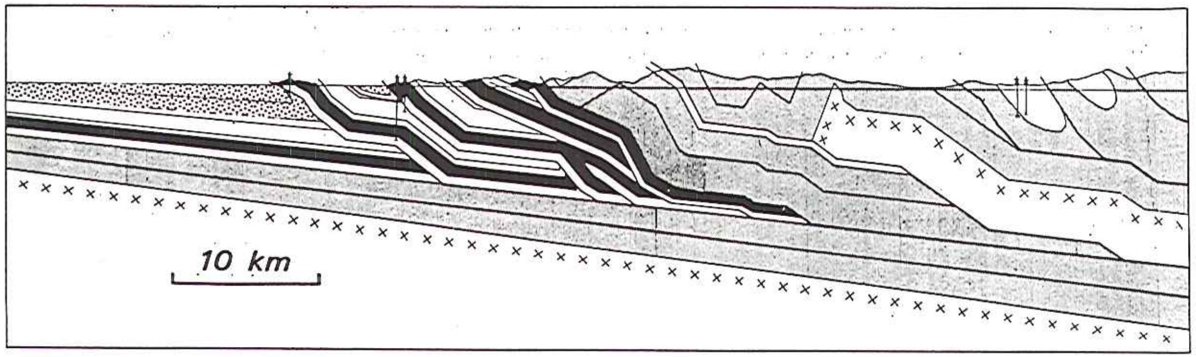


Fig. 7. Simplified structural cross section of northern Taiwan (after Suppe, 1980a). Location of cross section shown in Fig. 2.

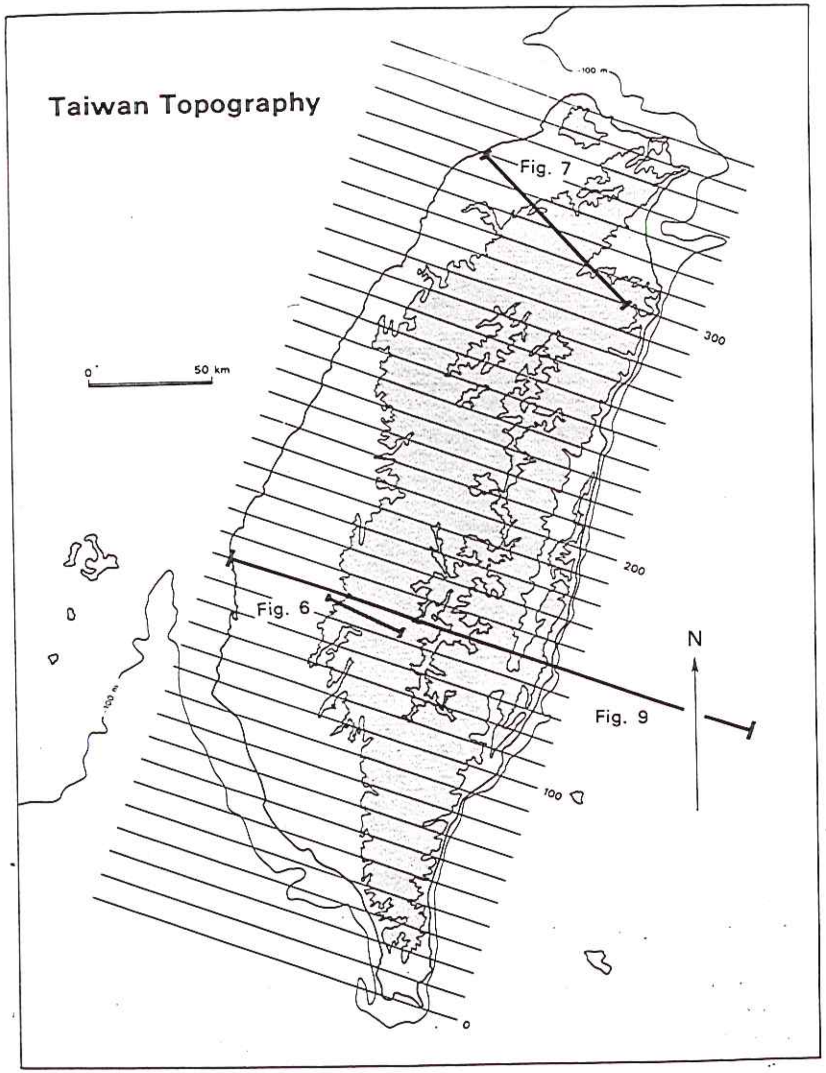


Fig. 2. Simplified topography of Central Mountains of Taiwan. Area above 200 m in screened pattern; higher contour is 2000 m. Family of straight lines show locations of topographic profiles in Fig. 4. Profiles are labeled in distance in kilometers N 20°E of southern tip of Taiwan.

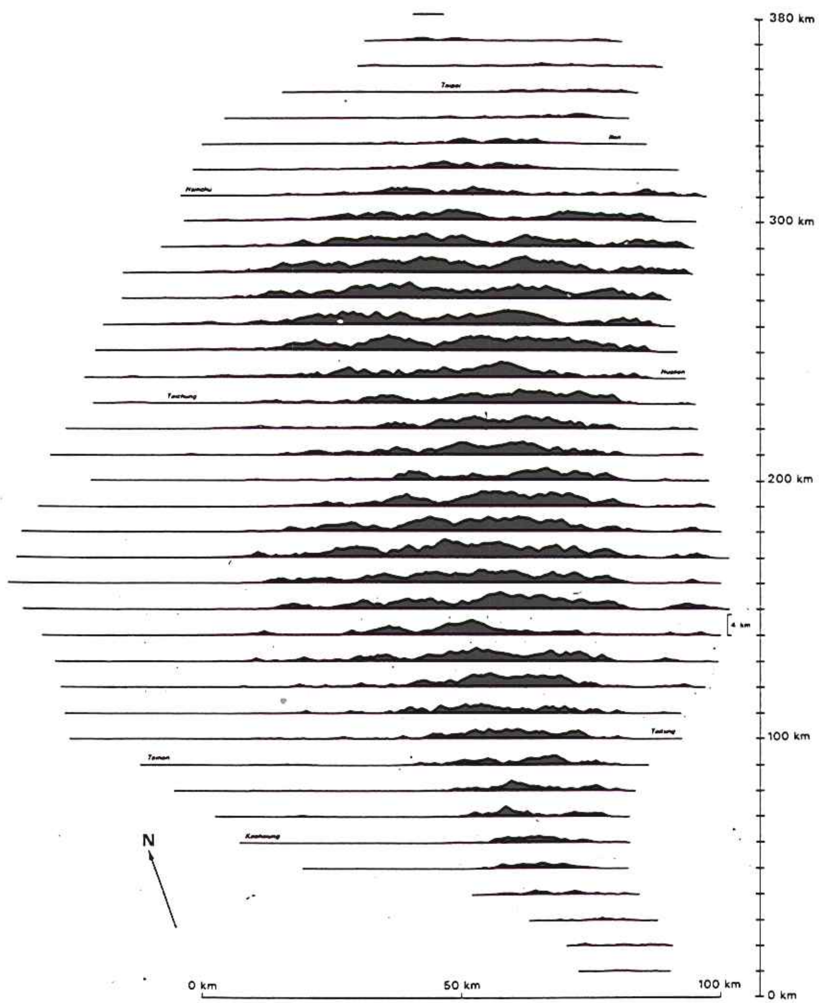
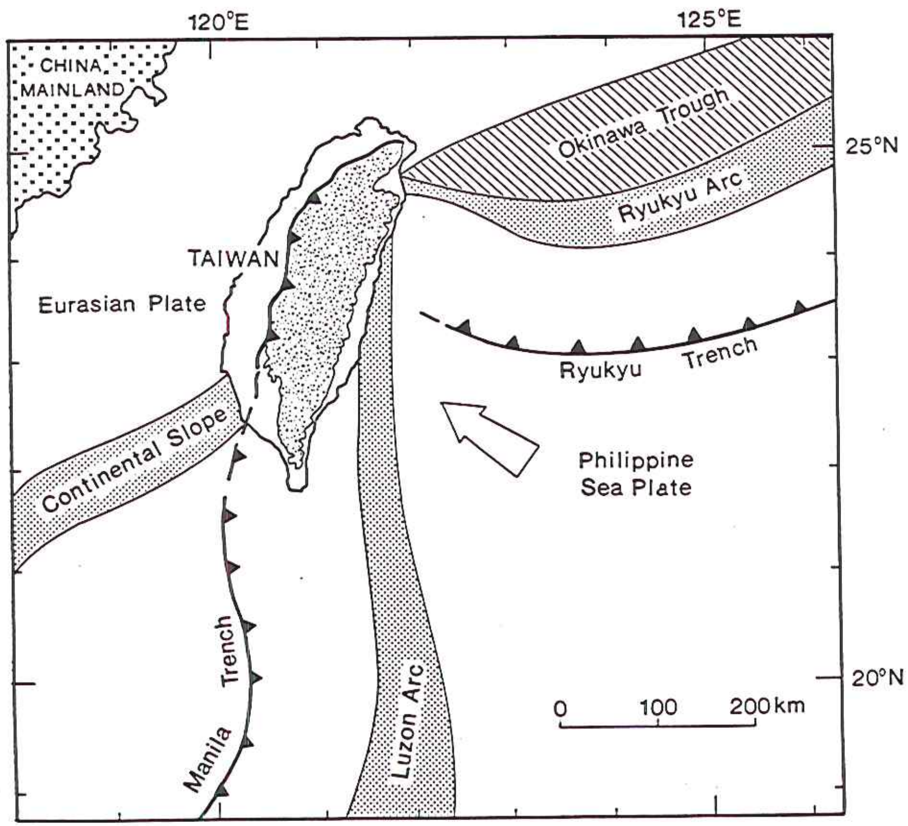


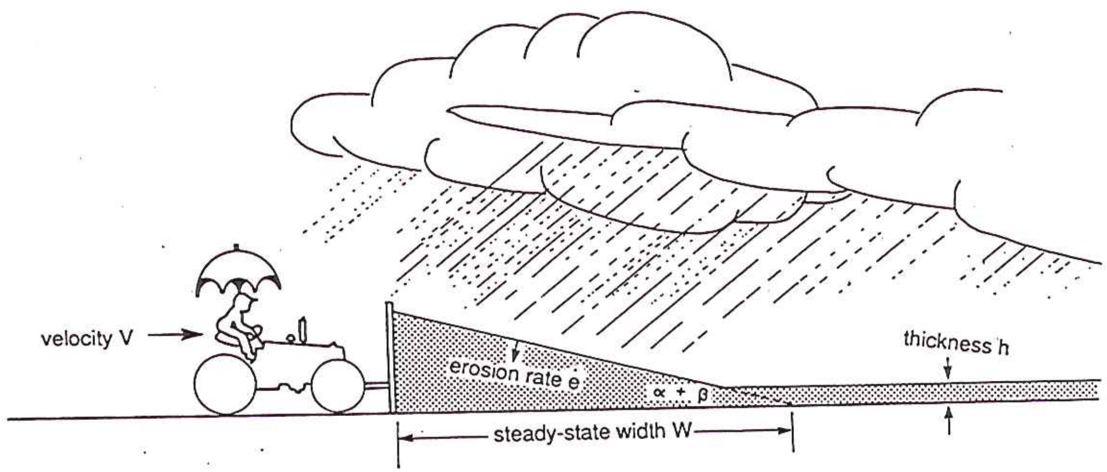
Fig. 4. Topographic profiles of Taiwan along the lines shown in Fig. 2 horizontal scale—vertical scale. Area above sea level shown in black.

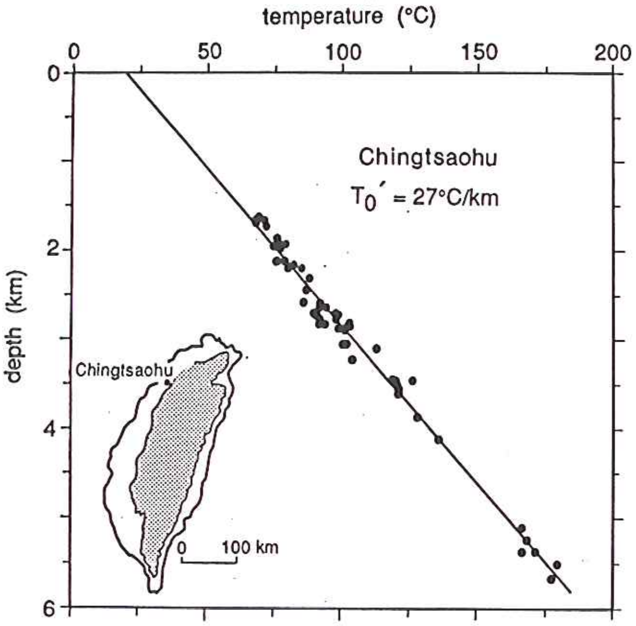
A 200-km-long segment of the **Taiwan fold-and-thrust belt** between 23° N and 25° N is in steady-state.

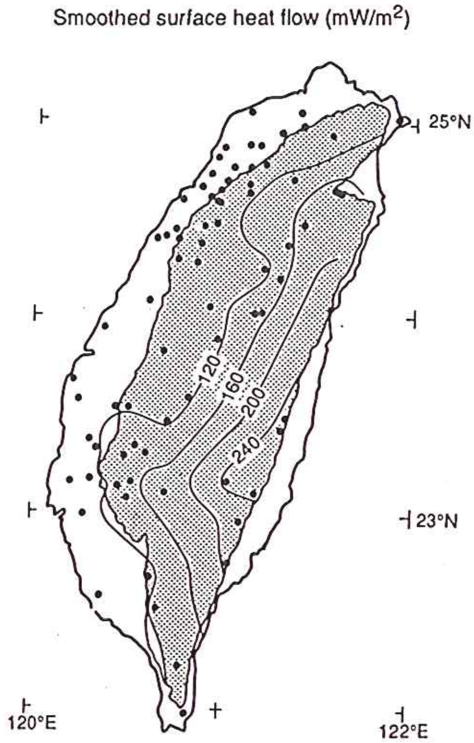
- V = 70 km/Ma: local plate convergence rate
- h = 7 km: deep drilling and seismic profiling
- $\dot{e}$ = 5.5 km/Ma: streamload data, radiocarbon and fission-track dating
- W = 90 km: width of the steady-state region

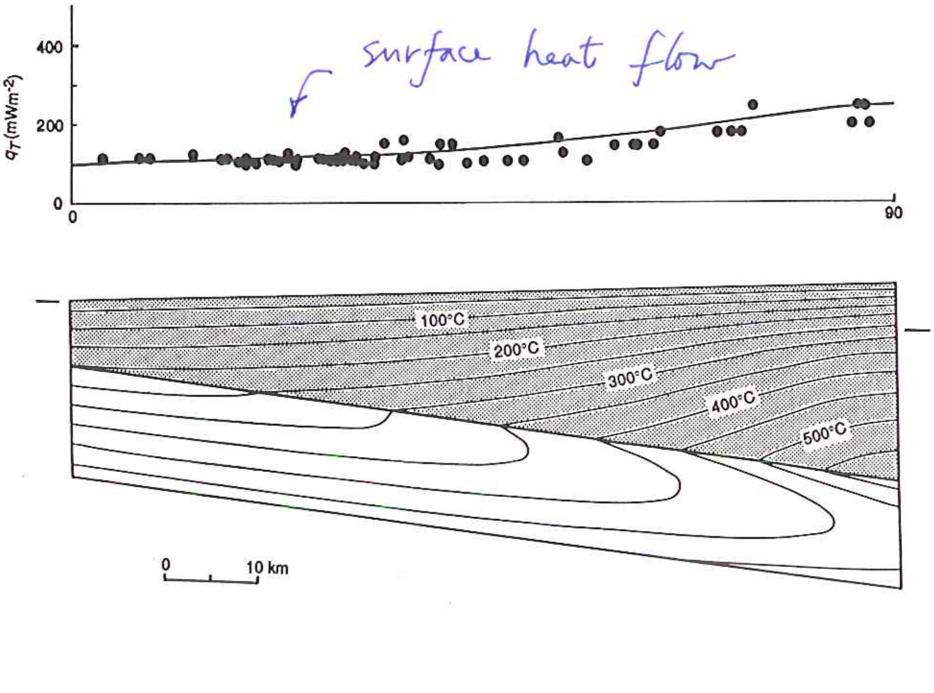


- accretionary influx: hV = thickness of entering section × plate convergence velocity
- erosive efflux: $\dot{e}W$ = erosion rate × width of fold-and-thrust belt

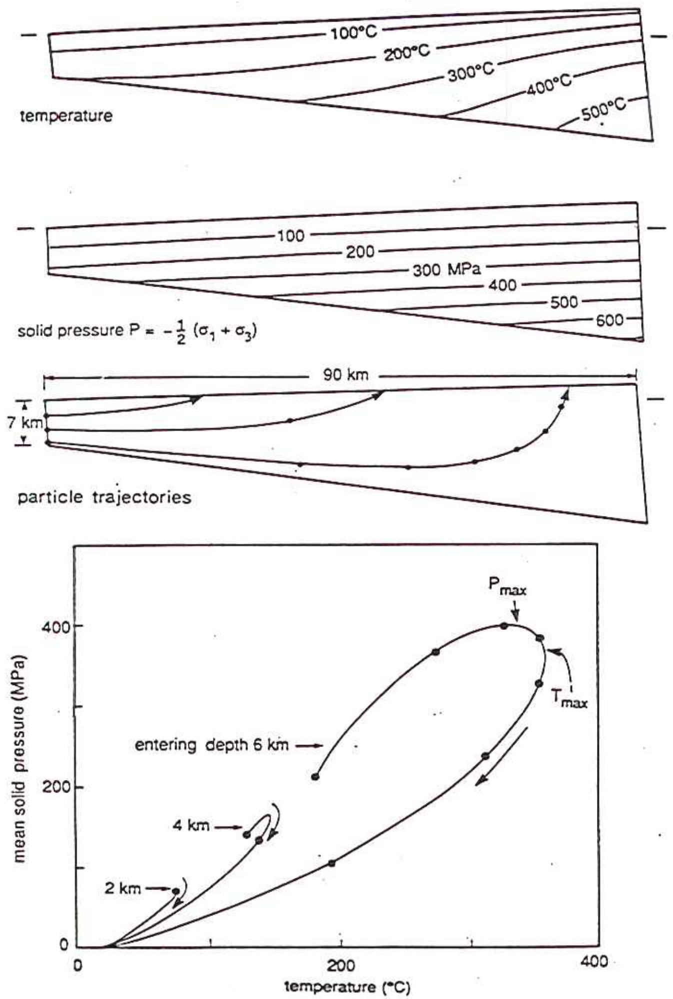


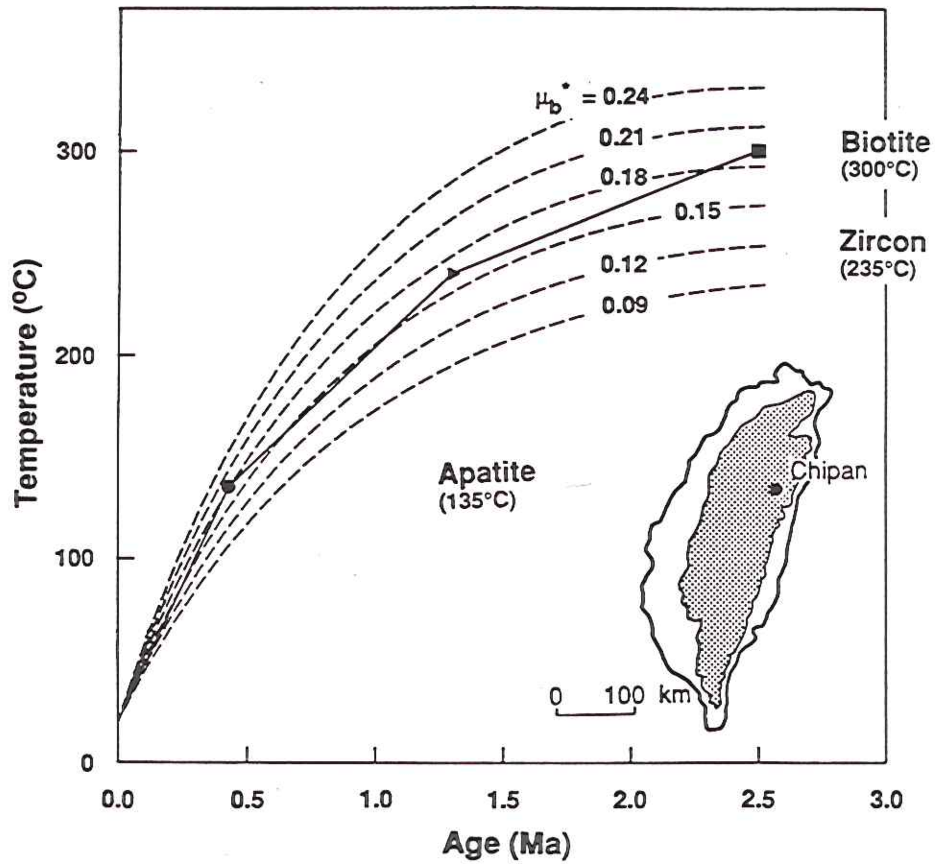

temperature (°C)
0
50
100
150
200
depth (km)
0
2
4
6
Chingtsaohu
$T_0' = 27°C/km$
Chingtsaohu
0 100 km


Smoothed surface heat flow (mW/m^2)
25°N
23°N
120°E
122°E
120
160
200
240


q_T (mWm^{-2})
400
200
0
0
90
surface heat flow
100°C
200°C
300°C
400°C
500°C
0 10 km

The thermal model also predicts the theoretical pressure-temperature-time or **P-T-t trajectories** of rocks that outcrop at the surface. Any information about the P-T-t paths that is preserved in the rocks provides an alternate source of data.





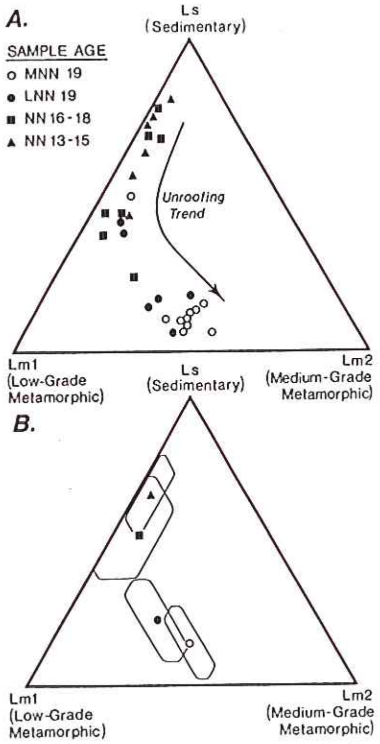


FIG. 6.—Ternary diagram of lithic fragments defined in this paper: sedimentary (Ls); low-grade metamorphic (Lm1); and medium-grade metamorphic (Lm2). A) Distribution of sandstones within a well-defined compositional field. Note that the oldest samples plot near the Ls corner, and younger samples become progressively enriched first in Lm1 and later in Lm2. B) Same diagram plotting means and standard deviations of each age group. Note the strong age dependence of the compositional trend; this reflects unroofing of the (meta)sedimentary complex through time and erosion into progressively deeper (higher-grade) levels in the collision belt.

TABLE 3.—*Calculation of uplift rate*

TIMING of collision-related metamorphism, based on plate kinematic and stratigraphic studies (Suppe 1981; Chi et al. 1981; Buchovecky 1986), about 4.5 Ma.

CONDITIONS of metamorphism, based on petrology and geochemistry of metamorphic rocks in the Central Range (Ernst 1983),

Lm1: T = 325° ± 75°C	P = 3 kbar (chlorite grade)
Lm2: T = 425° ± 75°C	P = 4 kbar (biotite grade).

DEPTH of metamorphism: Modern geothermal gradient in western Taiwan (Suppe and Witke 1977) = 30°C/km. Assuming lithostatic gradient of about 3 km/kbar, depth of Lm2 metamorphism = 12–15 km.

TIMING of surface erosion of biotite-grade (Lm2) metamorphic rocks based on ternary Ls-Lm1-Lm2 diagram (this paper), about 1.4 Ma (= midpoint of lower NN19).

RATE of uplift: Biotite-grade metamorphic rocks uplifted from 12–15 km depth to the surface between about 4.5 and 1.4 m.y. (= 3.1 m.y.): Uplift rate = 3.9 to 4.8 km/m.y.

Case Study II – Huanghe (Yellow) River in China

Second largest sediment load in the world – after the Amazon

- $1100 \cdot 10^6$ tons of sediment / yr
- 98% suspended load

Provides an interesting example of the effects of man on modern erosion rates

- agriculture – soil erosion of plowed fields
- dams – trap sediments
- groundwater "mining" – decreases streamflow
- deforestation – conversion to cropland
- channelization & other flood control measures
- overgrazing
- effect of forest fires

Present-day erosion rate in Huanghe basin:

$$\frac{1.1 \cdot 10^9 \text{ tons/yr} \times 10^6 \text{ yr/Myr}}{2500 \text{ tons/km}^3 \times 0.8 \cdot 10^6 \text{ km}^2} = 0.6 \frac{\text{km}}{\text{Myr}} \quad \left(\frac{1}{10} \text{ Taiwan}\right)$$

Long-term rate determined by seismic measurement of Holocene sediment thicknesses in the Bohai Gulf & Yellow Sea depositional centers is a factor of 10 lower than this.

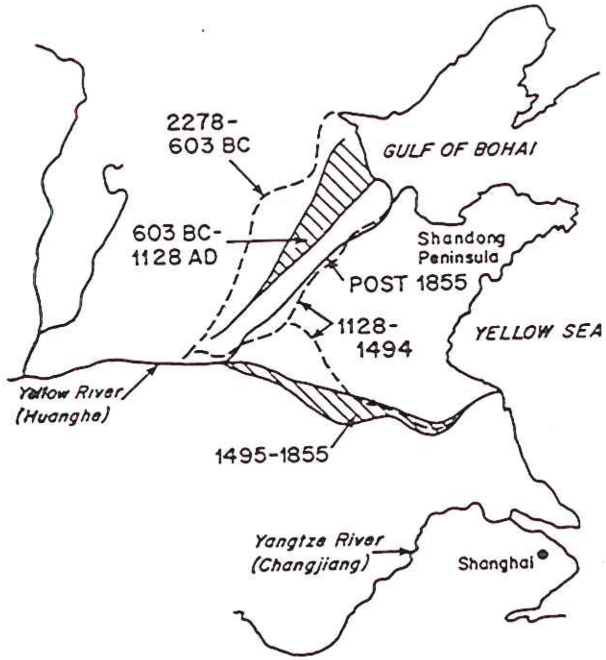
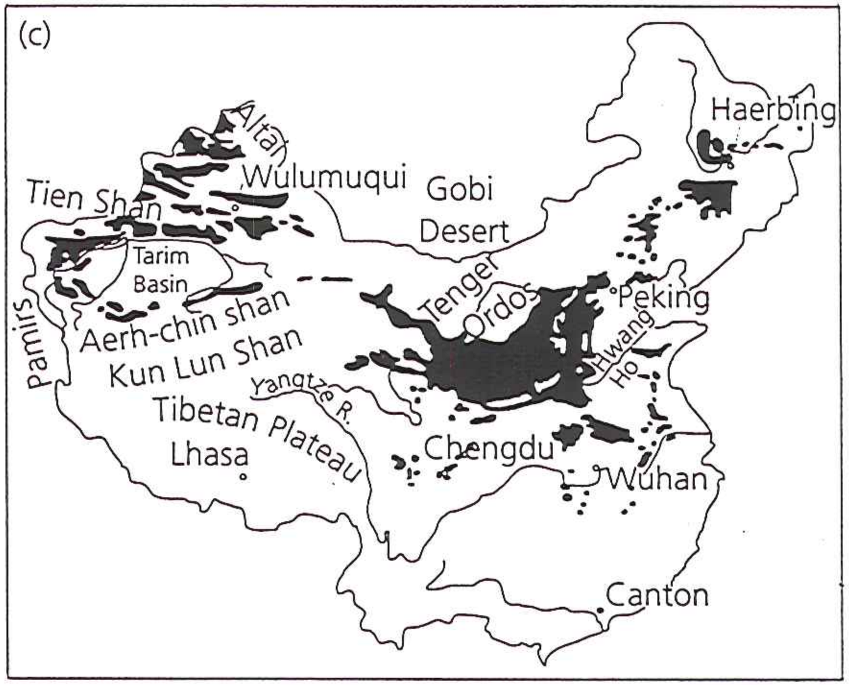


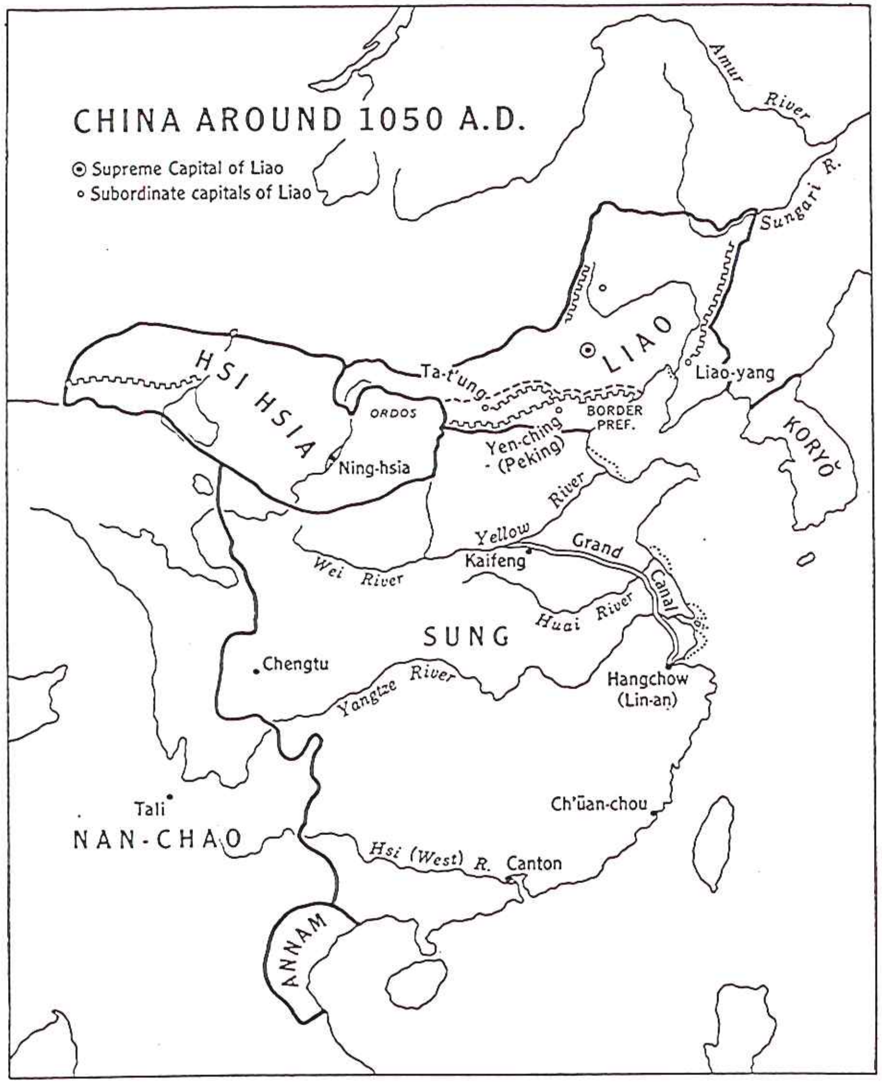
FIG. 2.—Paths of the Yellow River, 2278 BC to present. Years are in AD except where noted. Shaded areas refer to meandering river paths. Modified from Shen (1979).

TABLE 1

MAJOR EVENTS IN THE YELLOW RIVER DRAINAGE BASIN DURING THE PAST 2300 YEARS AND THEIR EFFECTS ON SEDIMENT DISCHARGE

Years	Event	Estimated %age of modern load	Estimated annual load ($\times 10^9$t)	Land over time interval ($\times 10^9$t)
600AD–present	Heavy agricultural usage; extensive erosion of loess plateau	100	1.2	1656
50AD–600AD	Mongol invasion; steppes return to grazing pastures	50	.6	324
200BC–60AD	Agricultural use, with many river channels diverting silt to the ocean	80	1.0	250
340BC–200BC	River channeled; loess plateau mostly forested; relatively little sediment lost by channel overflow	35	.4	59
			Total	2290





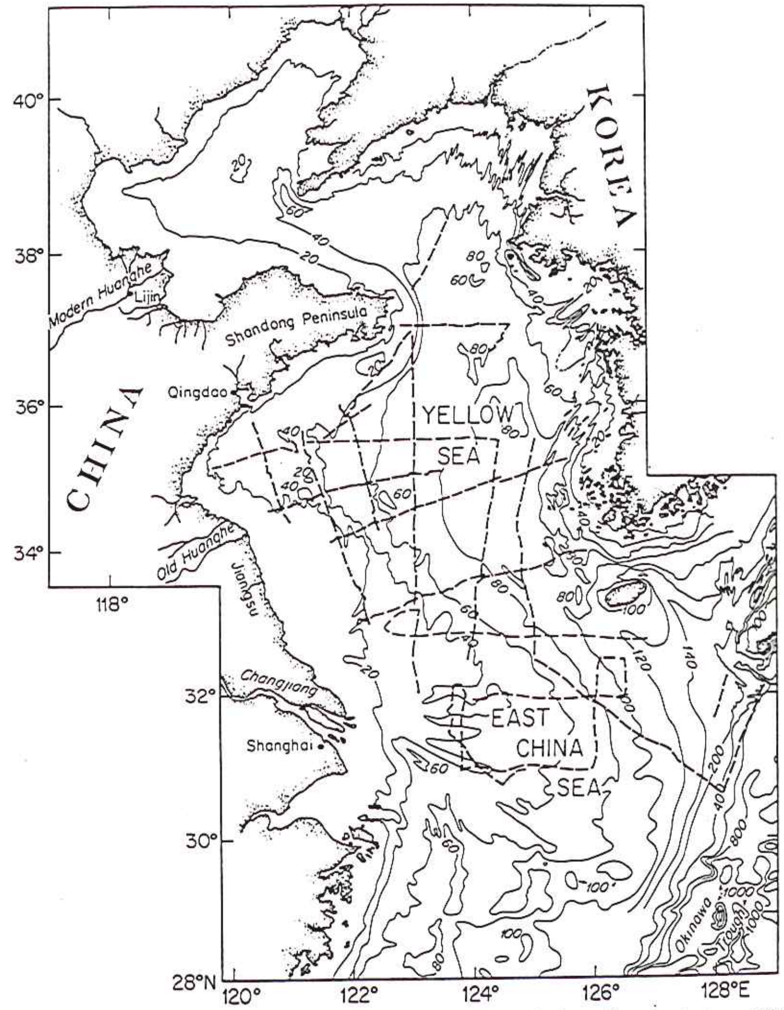


FIG. 1.—Bathymetric map of the Yellow Sea, showing location of seismic profiles taken between 1980 and 1986 which form the basis for the marine isopachs shown in figure 4. Arrows off Jiangsu coast show location of profile shown in figure 5. Depths in meters.

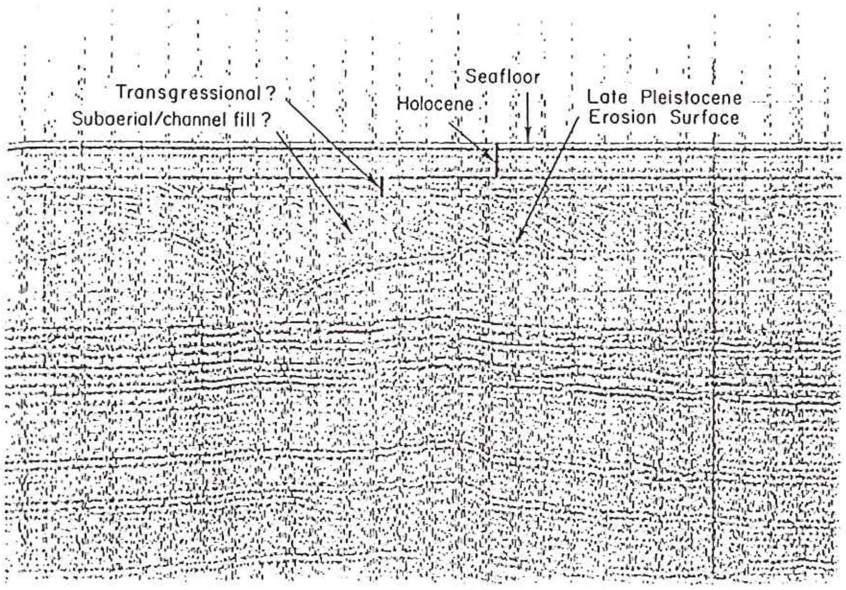


FIG. 3.—Typical high-resolution seismic profile from the central Yellow Sea, southeast of the Shandong Peninsula showing late Pleistocene erosion surface (and possible channel), infilled sediment (channel sands?), a transgressional layer (presumably sand and peat), and an acoustically transparent surface sequence (Holocene neretic muds). Length of record is 40 minutes, or about 4.5 km. Distance between vertical (scale) lines is 25 ms.

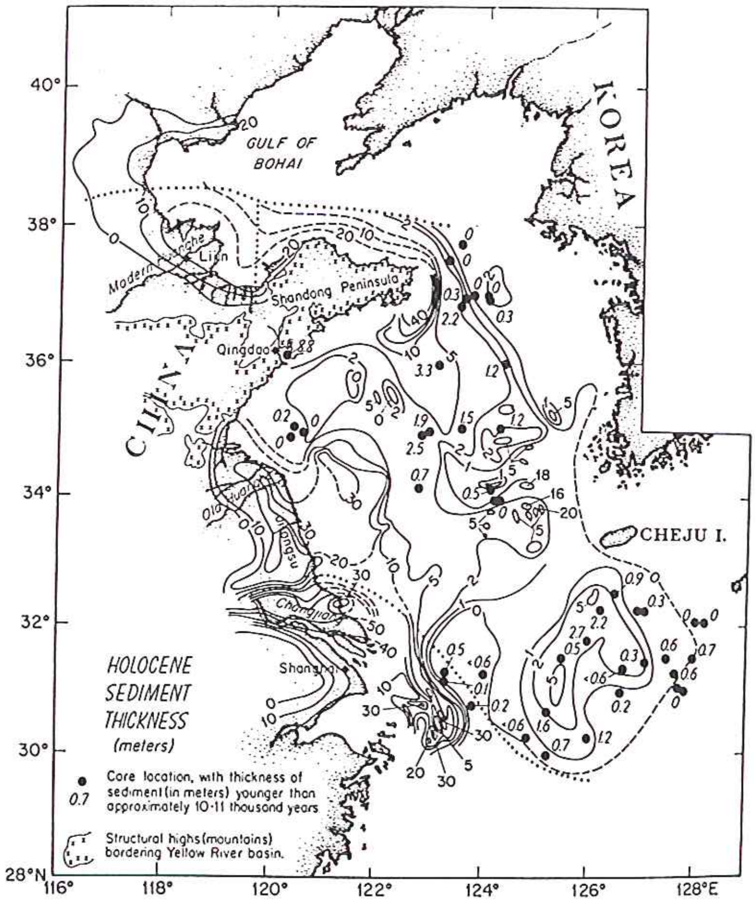


FIG. 4.—Thicknesses of Holocene marine sediment interpreted from land-based and marine-seismic data. Thicknesses are in meters. Sediment isopachs off the Yangtze River are from Gao et al. (1982). Dots with numbers designate Holocene sediment thicknesses (in meters) penetrated by cores; data from Yanagida and Kaizuka (1982), Wang and Wang (1982), Liu et al. (1983), Peng et al. (1984), and Chen et al. (1985). Dotted lines show the approximate north and south boundaries of Yellow-River sediment. Sediment volumes were computed within these boundaries. The N-S dotted line east of Lijin represents the assumed boundary between the northern delta and the Shandong mud wedge; in reality these two features are continuous, and the mud wedge in fact at least partly may represent an older delta.

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TABLE 2

VOLUME OF SEDIMENT IN VARIOUS AREAS AND FACIES

	Volume (km^3)	% of Total Holocene Shelf Sediment
Distal Mud Lens	360	13
Cheju Mud Patch	110	4
South Delta	1290	46
North Delta	540	19
Shandong Mud Wedge	510	18
SUBTOTALS	2810	100
Escaping Shelf	200	
TOTAL SEDIMENT		3000

NOTE.—The distal mud lens is defined as those sediments between 0 and 5 m in thickness, excluding the Cheju mud patch. The Cheju mud patch refers to the local thickening of sediments thicker than 5 m. The Shandong mud wedge is presumed to be the distal portion of the north delta; it is defined as those sediments north and south of the Shandong Peninsula and east of approximately 120°E that are thicker than 5 m (see fig. 4).