台灣弧陸碰撞造山運動機制及麓山帶地 質構造

Li-Wei Kuo
郭力維

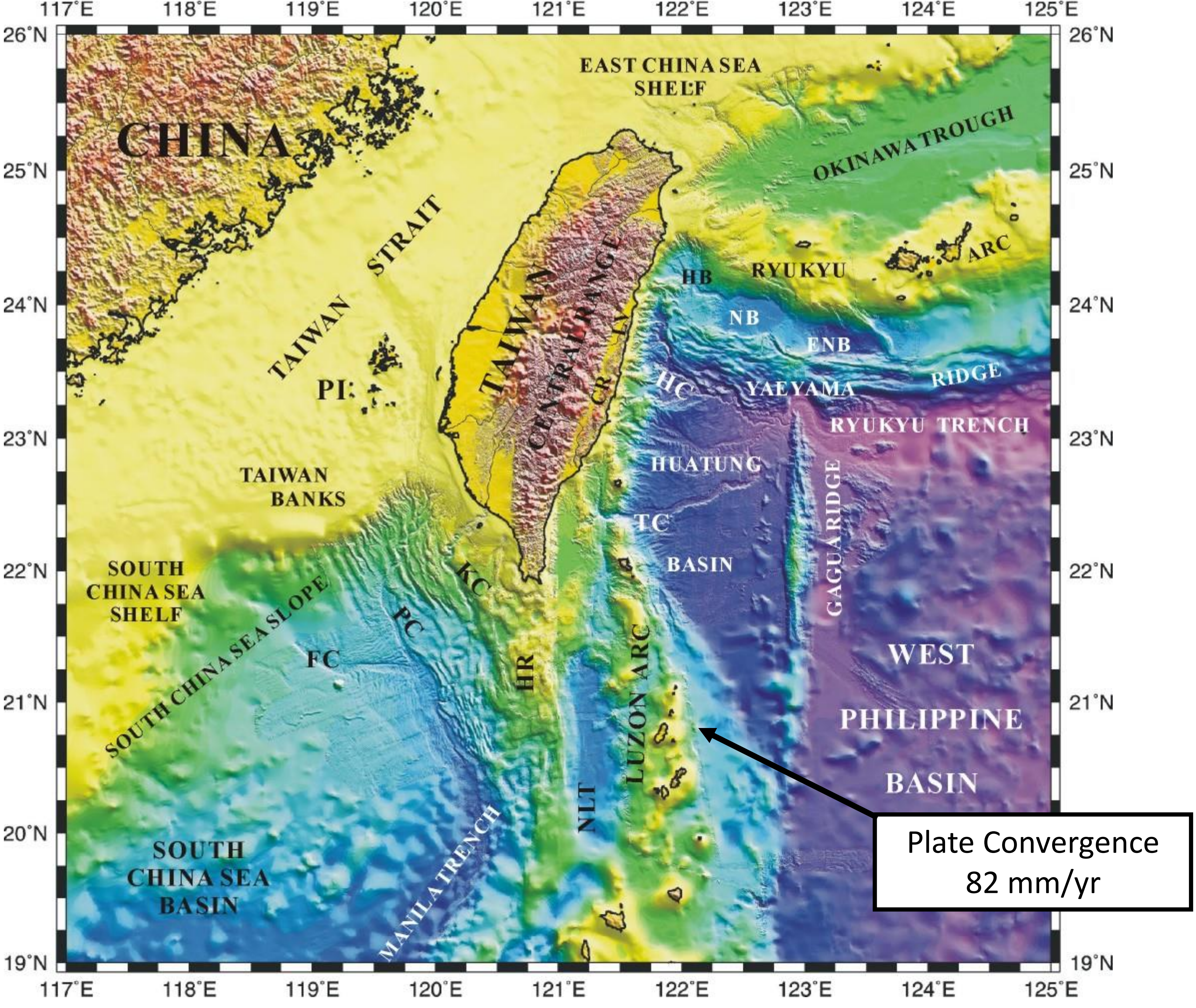
台灣造山運動的機制

- 台灣的造山模式
  - 薄皮與厚皮的構造形式及證據
  - 基底滑脫面的存在,深度與形貌
  - 各種模式相對應的野外及地球物理資料觀察
- 淺層(西部麓山帶)之構造形式
- 正斷層重新活動的模式與力學機制
- 新期構造運動
  - 地殼形變監測方法
  - 熱定年學與地殼抬升

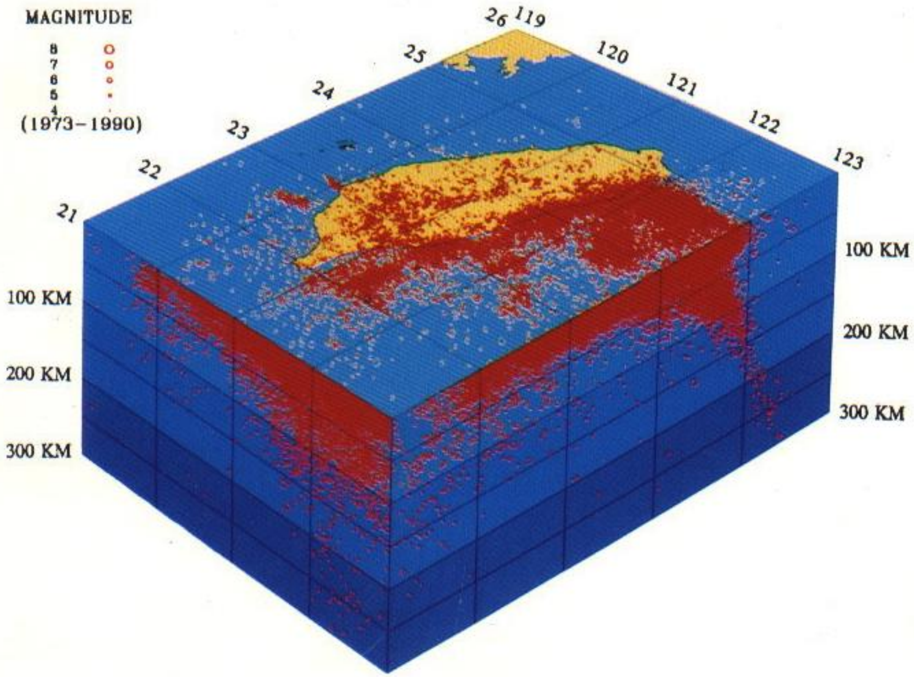
key scientific questions need to be addressed

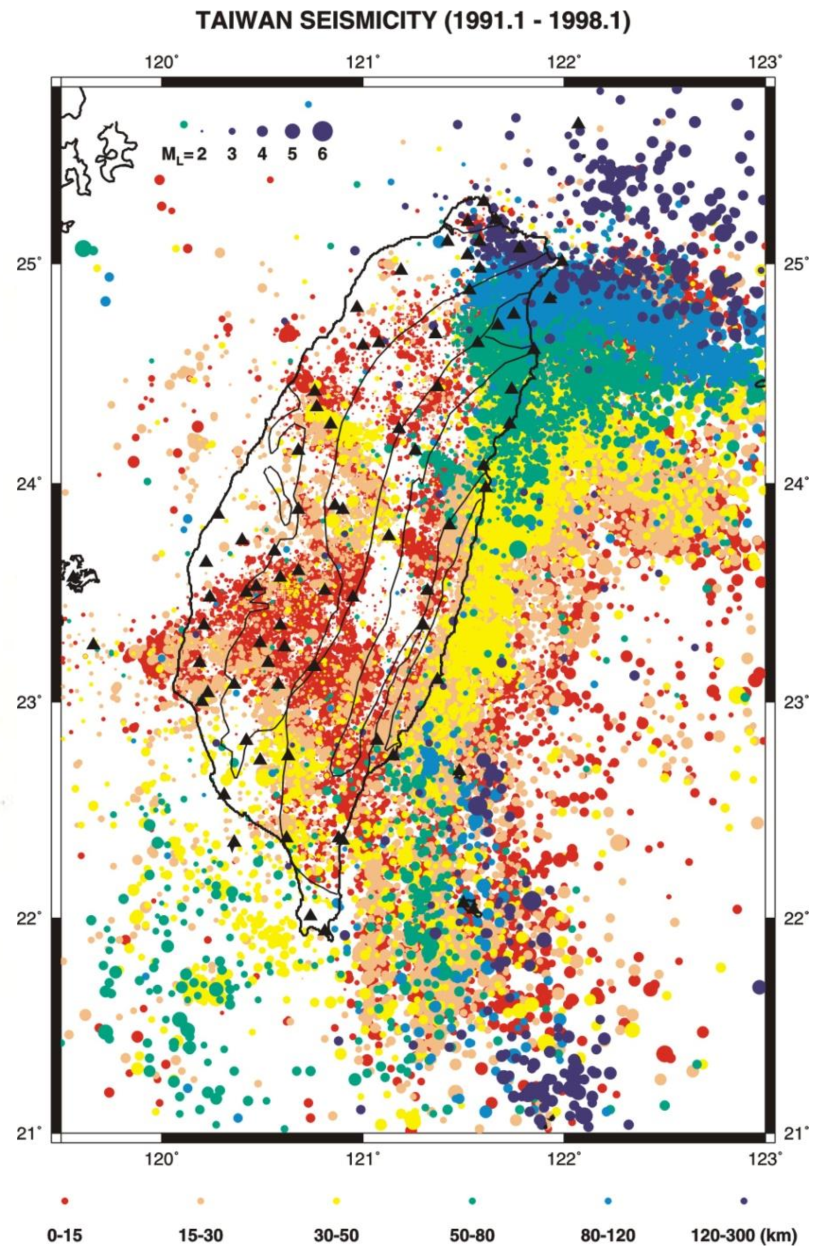
- How is the 80 cm/yr convergence rate across Taiwan accommodated by crustal and lithospheric deformation? (in other terms, what is the partitioning of deformation from the western foothills of the central range to the Longitudinal valley?) and what are the physical factors controlling this partitioning?
- What proportion of the deformation is absorbed by large recurring earthquakes or aseismic deformation (ductile flow or possibly slow events)? and what are the physical factors controlling?
- Is the interseismic deformation stationary or does it vary with time? (lateral variations may actually reveal temporal changes during the seismic cycle) ?
- Does the critical brittle taper model really apply to explain the mechanics of mountain building in Taiwan?
- What is the role played by deep seated upper mantle processes?

http://www.tectonics.caltech.edu/taiwan/index.html

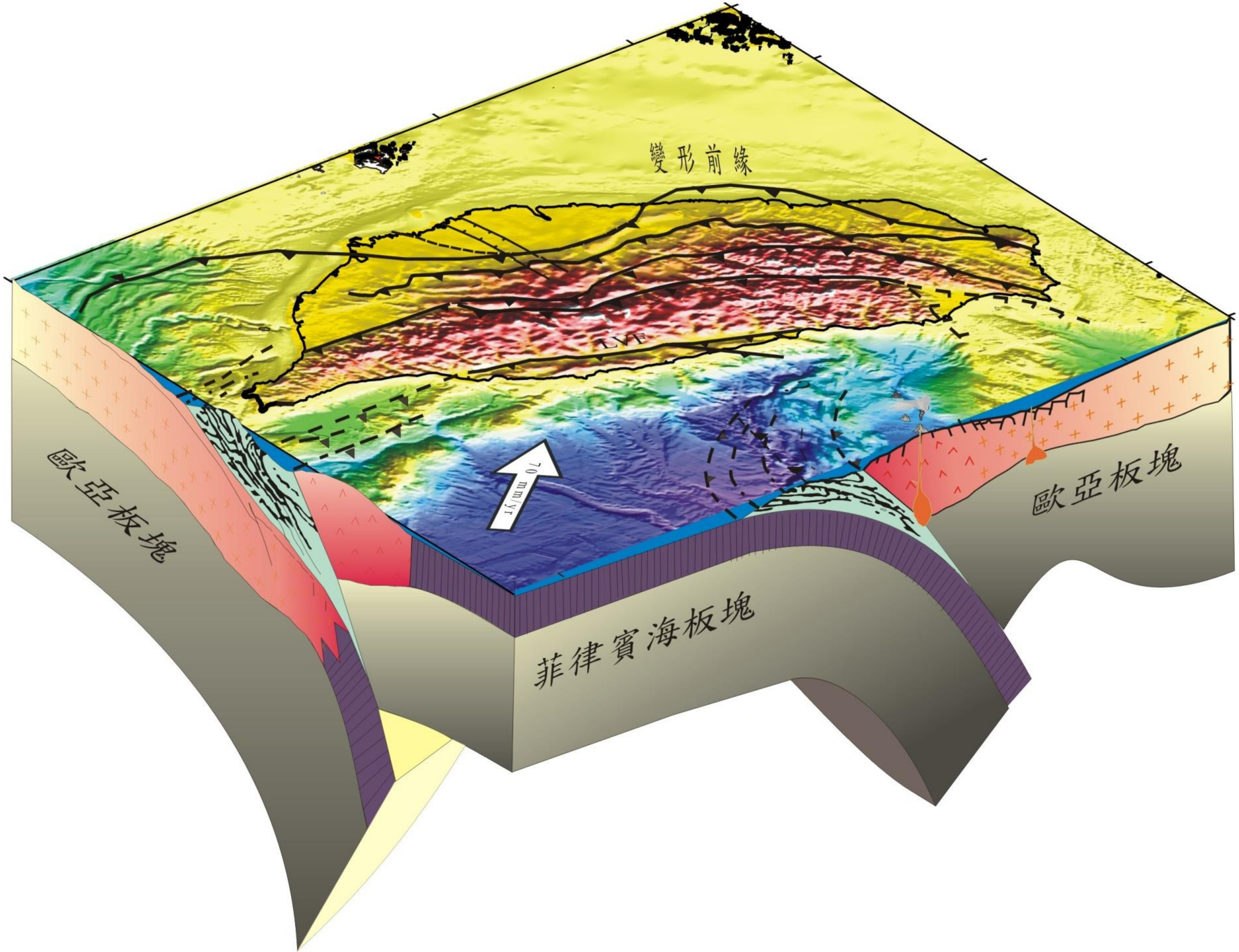

117°E
118°E
119°E
120°E
121°E
122°E
123°E
124°E
125°E
26°N
25°N
24°N
23°N
22°N
21°N
20°N
19°N
CHINA
EAST CHINA SEA SHELF
OKINAWA TROUGH
TAIWAN STRAIT
TAIWAN
CENTRAL RANGE
CR
LV
HB
RYUKYU
ARC
NB
ENB
RIDGE
HC
YAEYAMA
RYUKYU TRENCH
PI
TAIWAN BANKS
HUATUNG
TC
BASIN
GAGUA RIDGE
SOUTH CHINA SEA SHELF
SOUTH CHINA SEA SLOPE
KC
PC
FC
HR
LUZON ARC
WEST PHILIPPINE BASIN
NLT
MANILA TRENCH
SOUTH CHINA SEA BASIN
Plate Convergence
82 mm/yr

台灣地體構造-古典觀點


MAGNITUDE
8
7
6
5
4
(1973–1990)
100 KM
200 KM
300 KM


TAIWAN SEISMICITY (1991.1 - 1998.1)
120°
121°
122°
123°
25°
24°
23°
22°
21°
M_L = 2 3 4 5 6
0-15
15-30
30-50
50-80
80-120
120-300 (km)

台灣地體構造-古典觀點



Tectonic map of Taiwan

Five geological units:

A. Coastal Plain

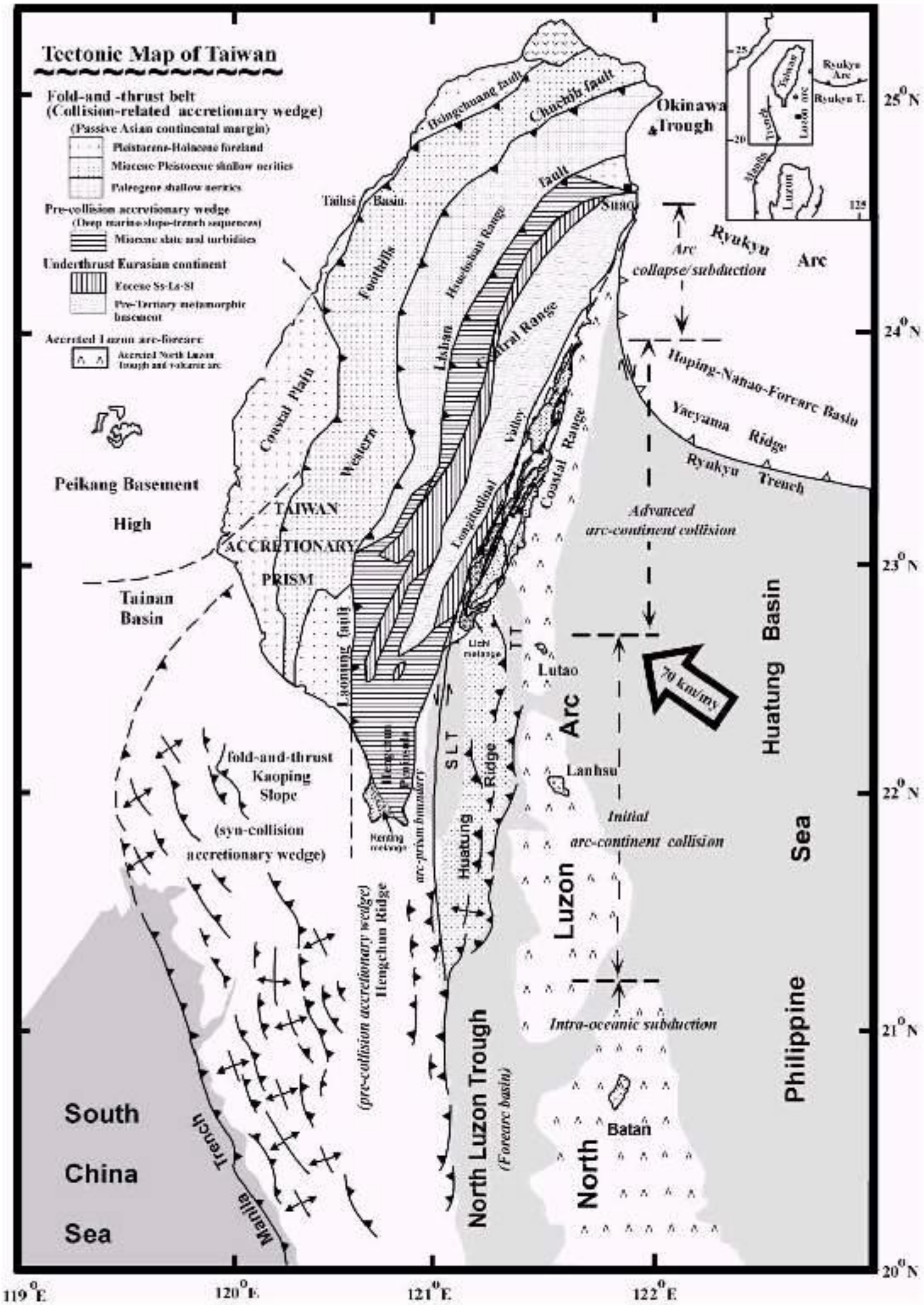
B. Western Foothills

C. Hsuehshan Range

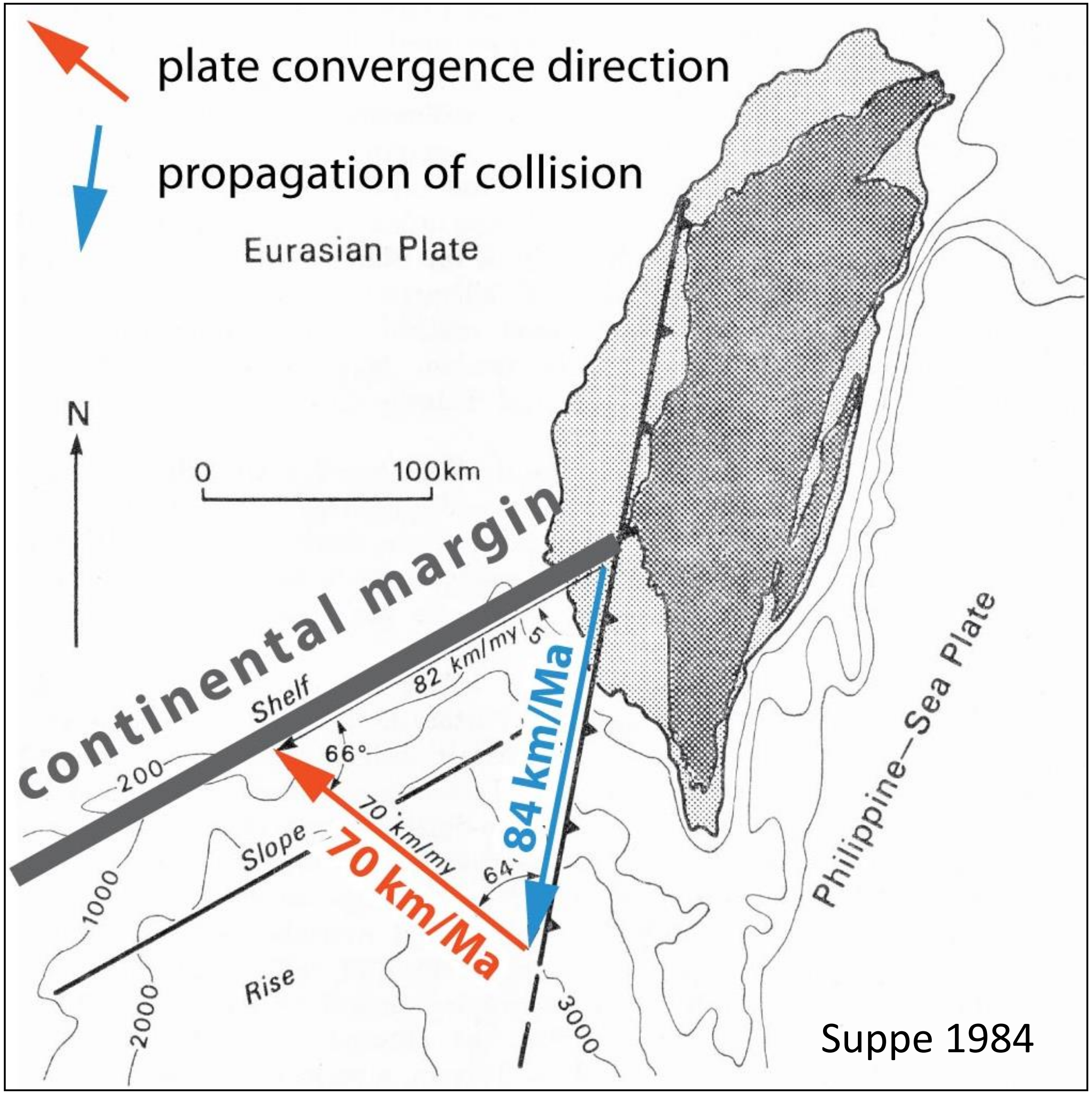
D. Central Range

E. Coastal Range

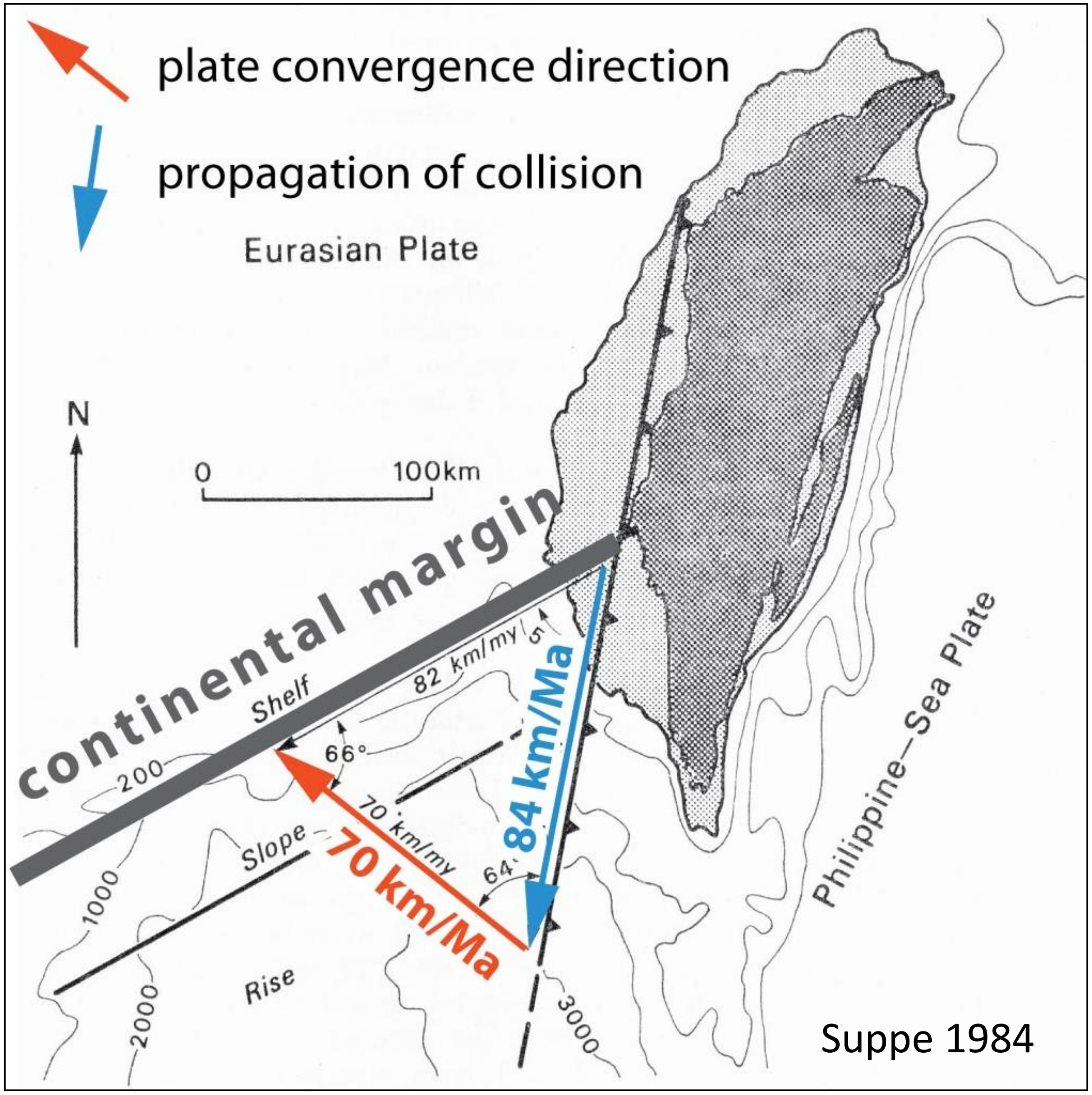
(Huang et al., 2000)



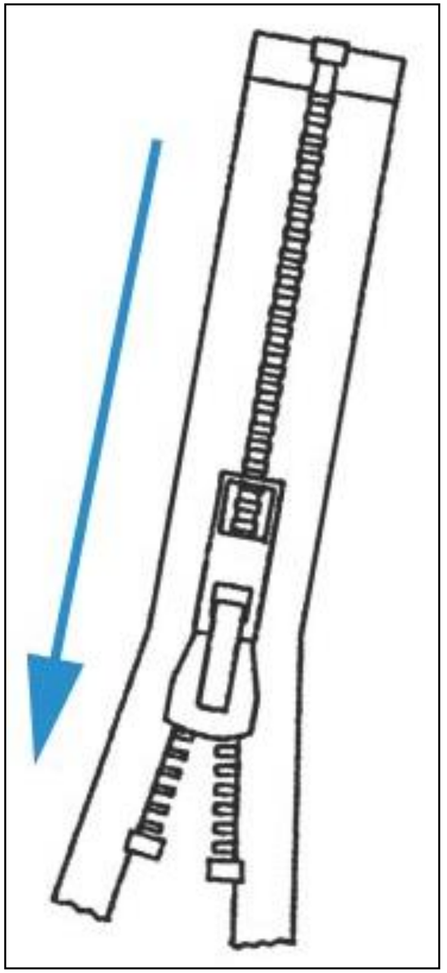
Diachroneity of continent-island arc collision



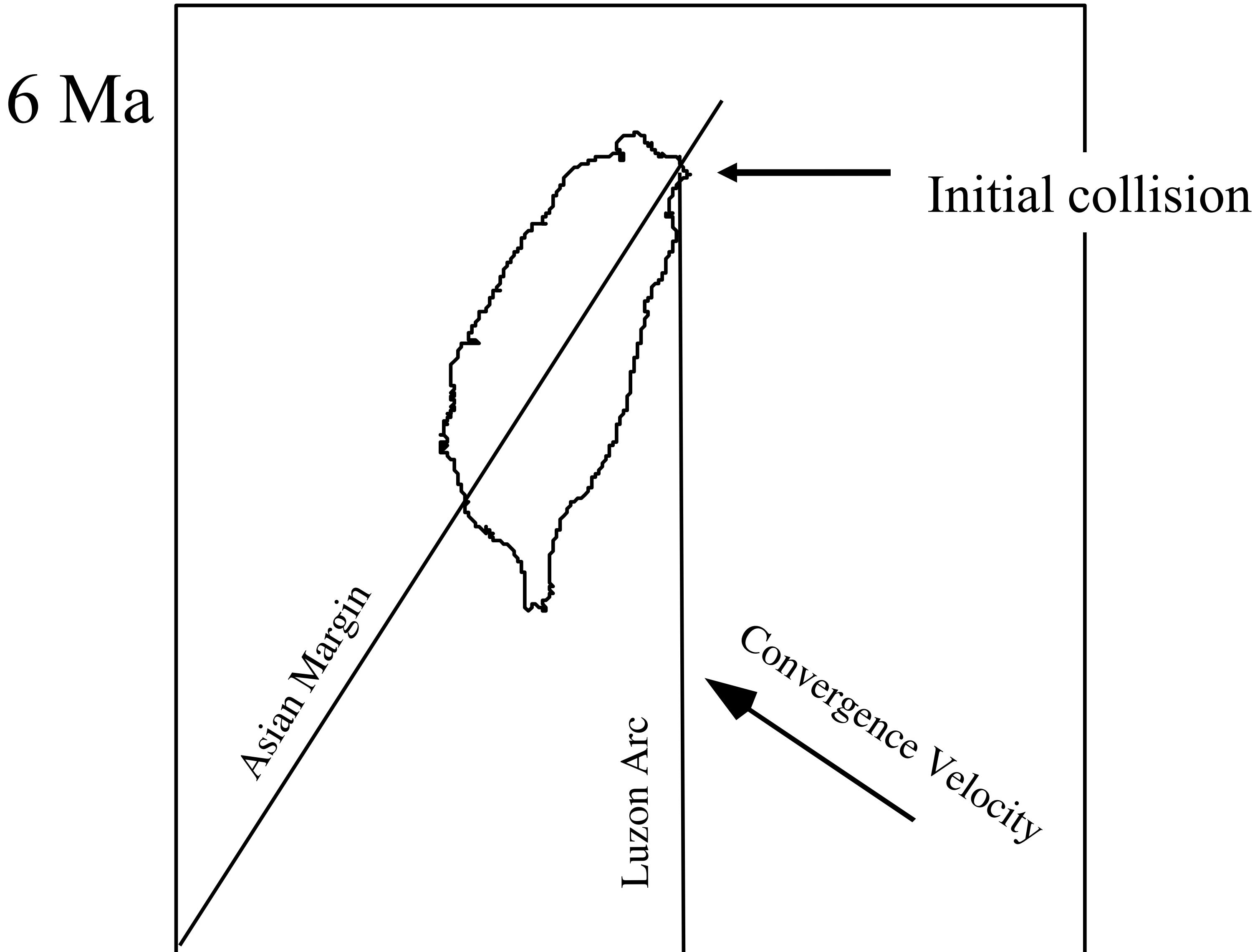
Diachroneity of continent-island arc collision



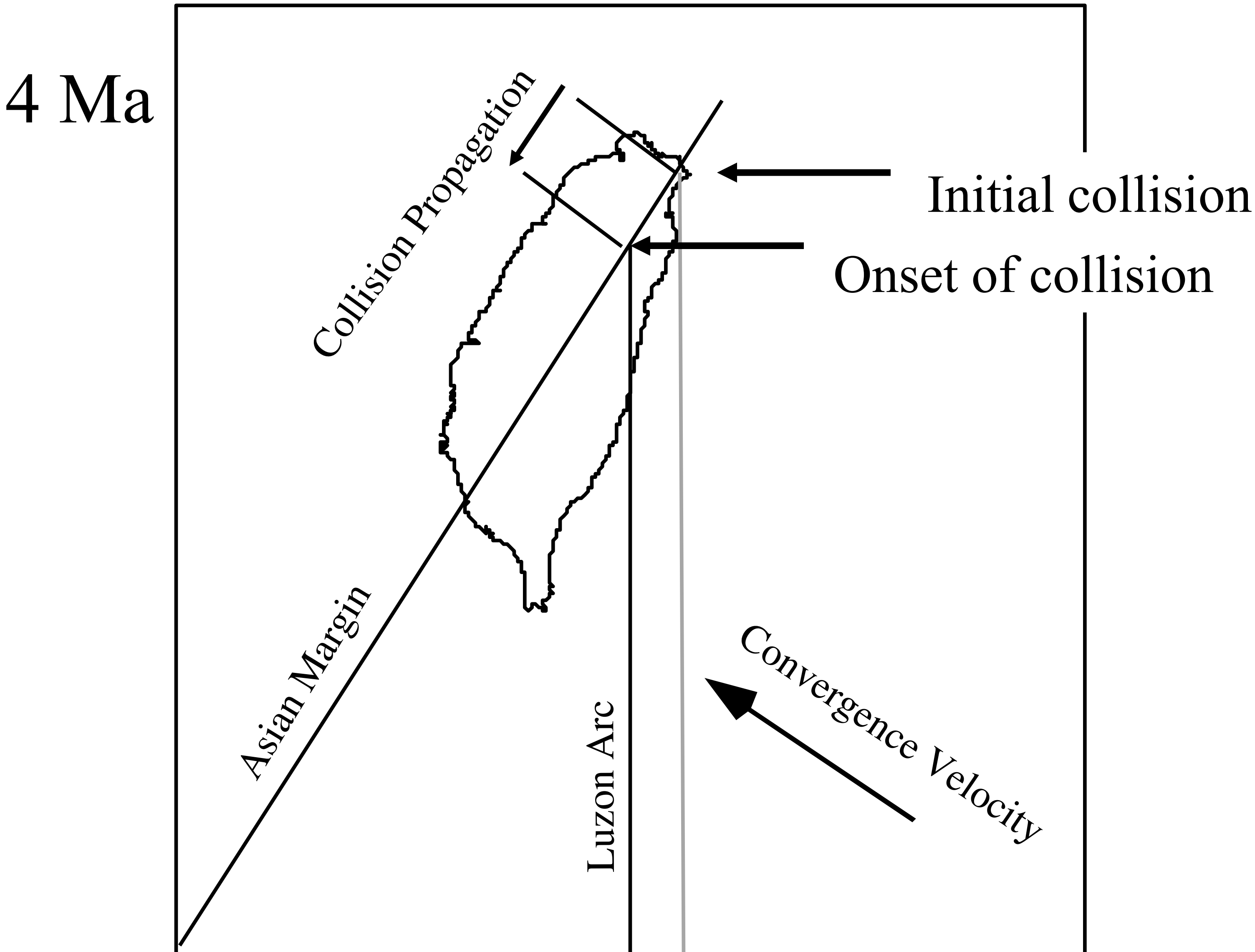
Time-space Equivalence



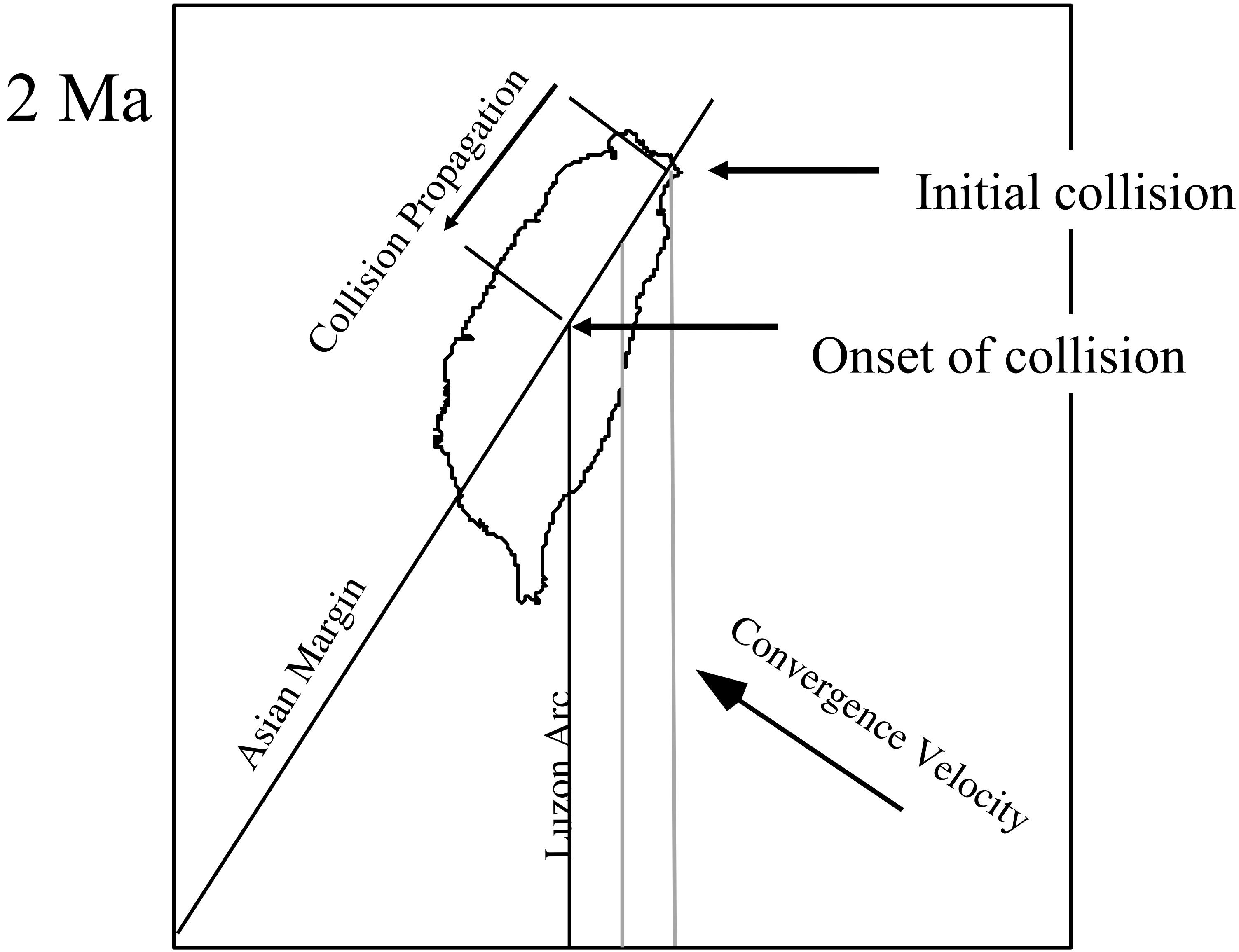
Space - Time Equivalence



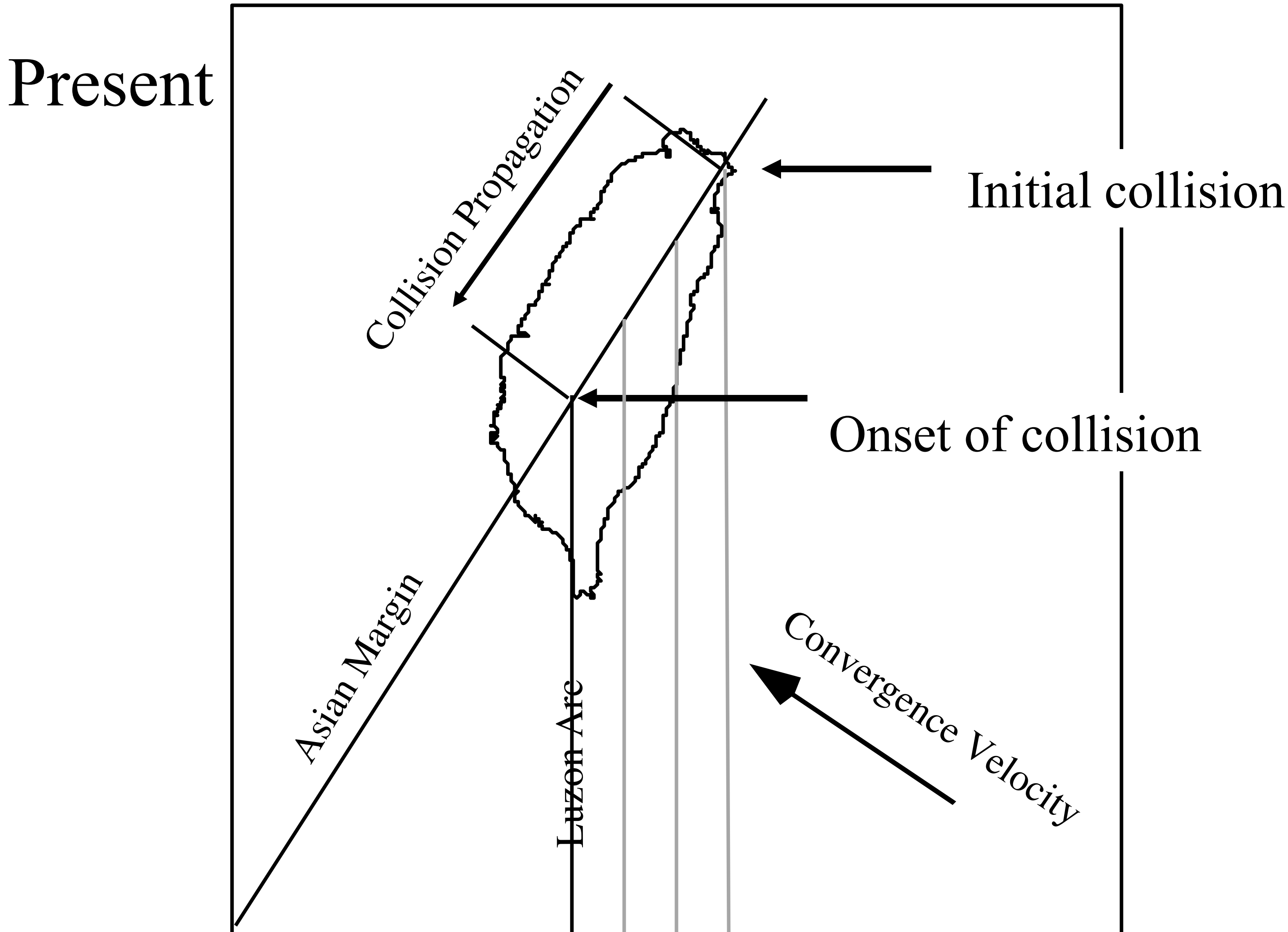
Space - Time Equivalence



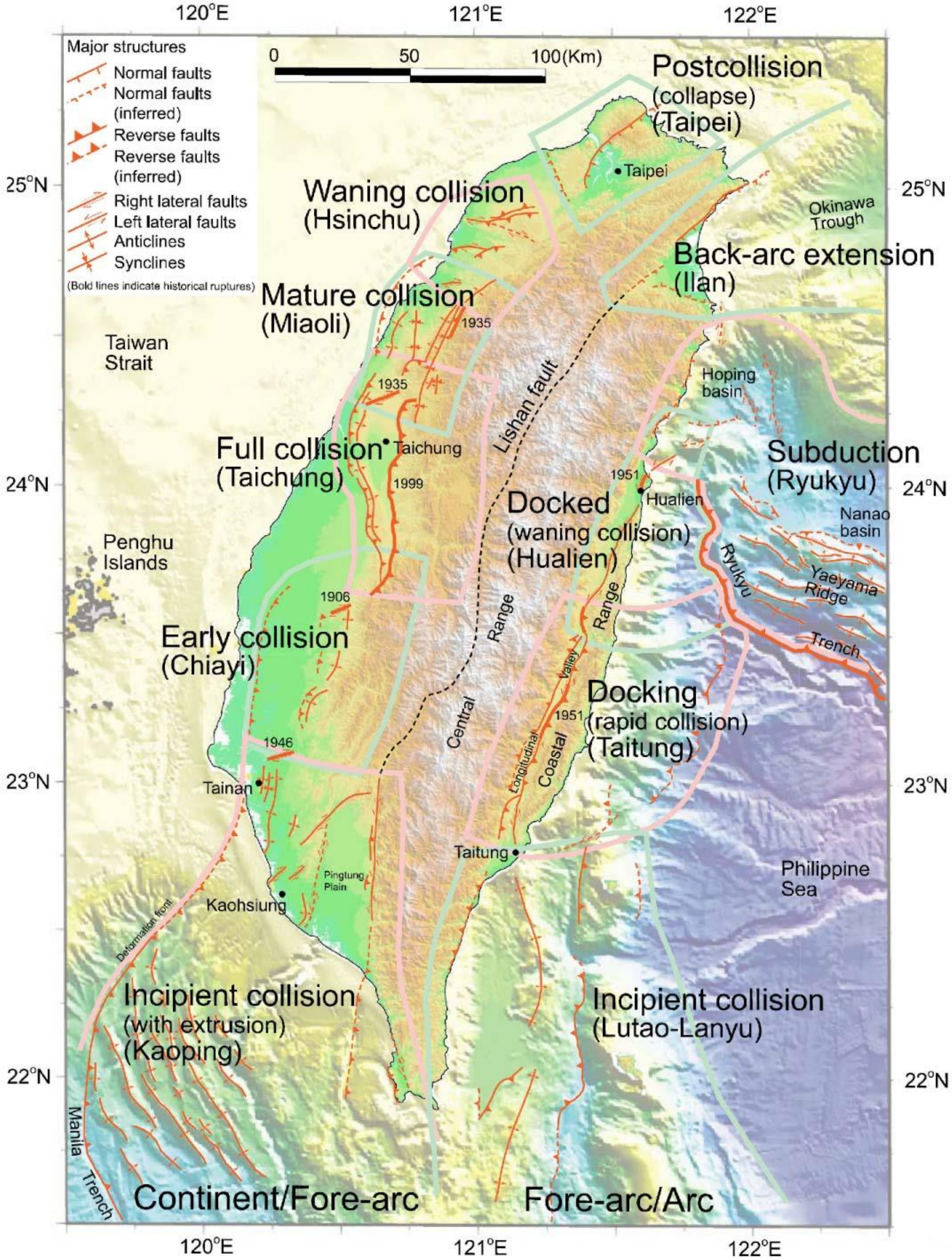
Space - Time Equivalence

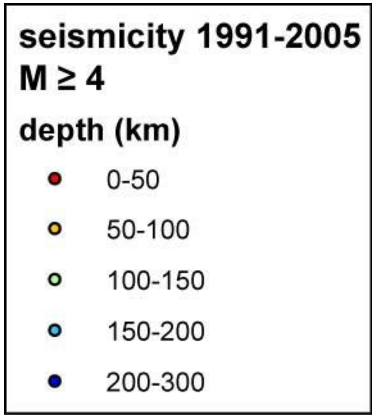


Space - Time Equivalence



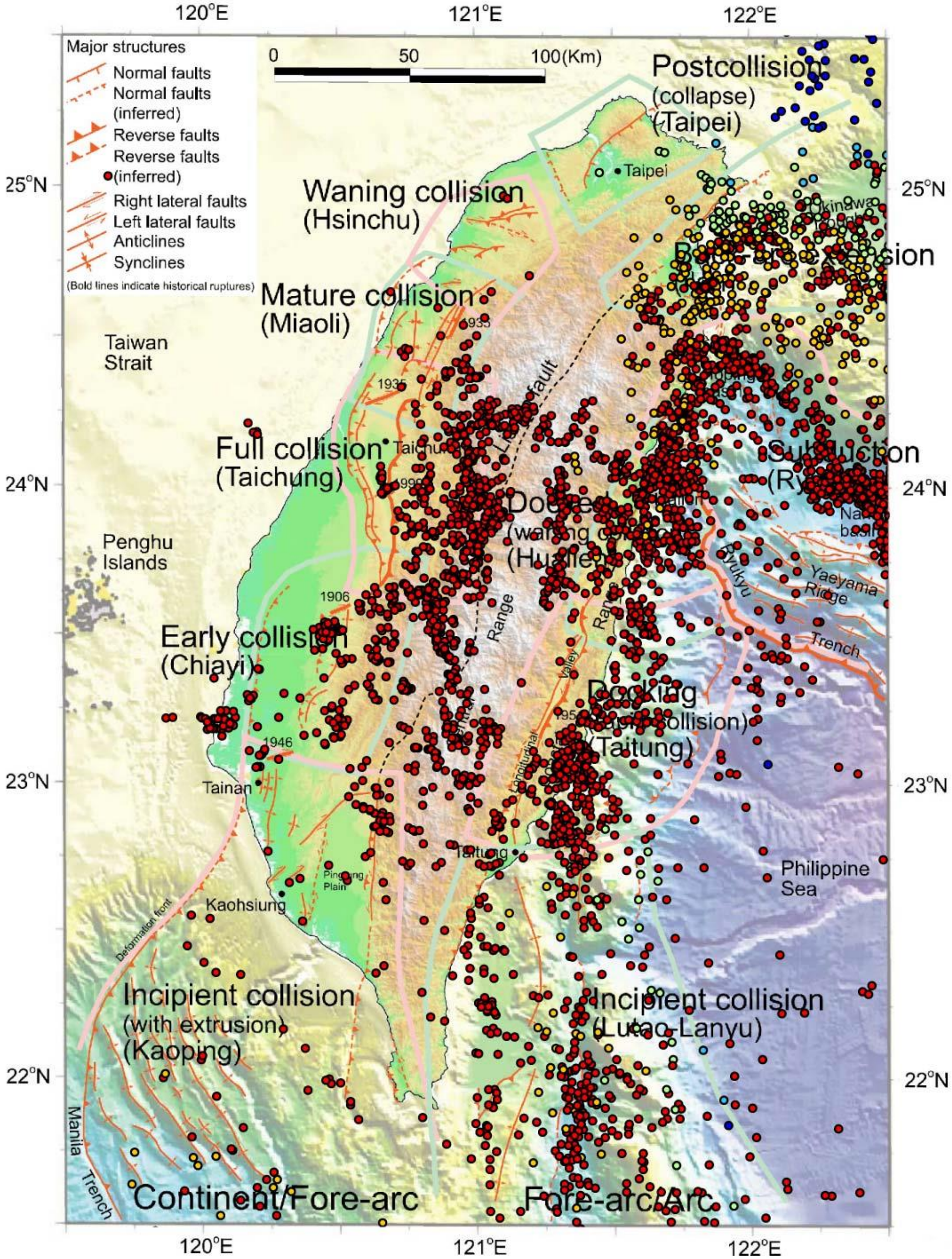
Major active structures in Taiwan

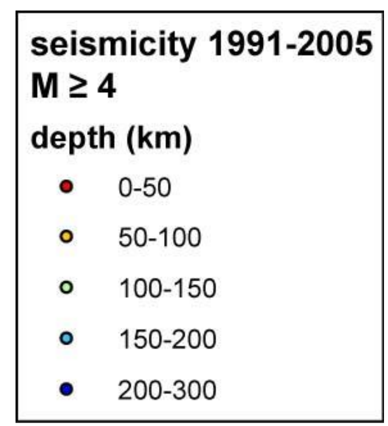




Shyu et al. 2005

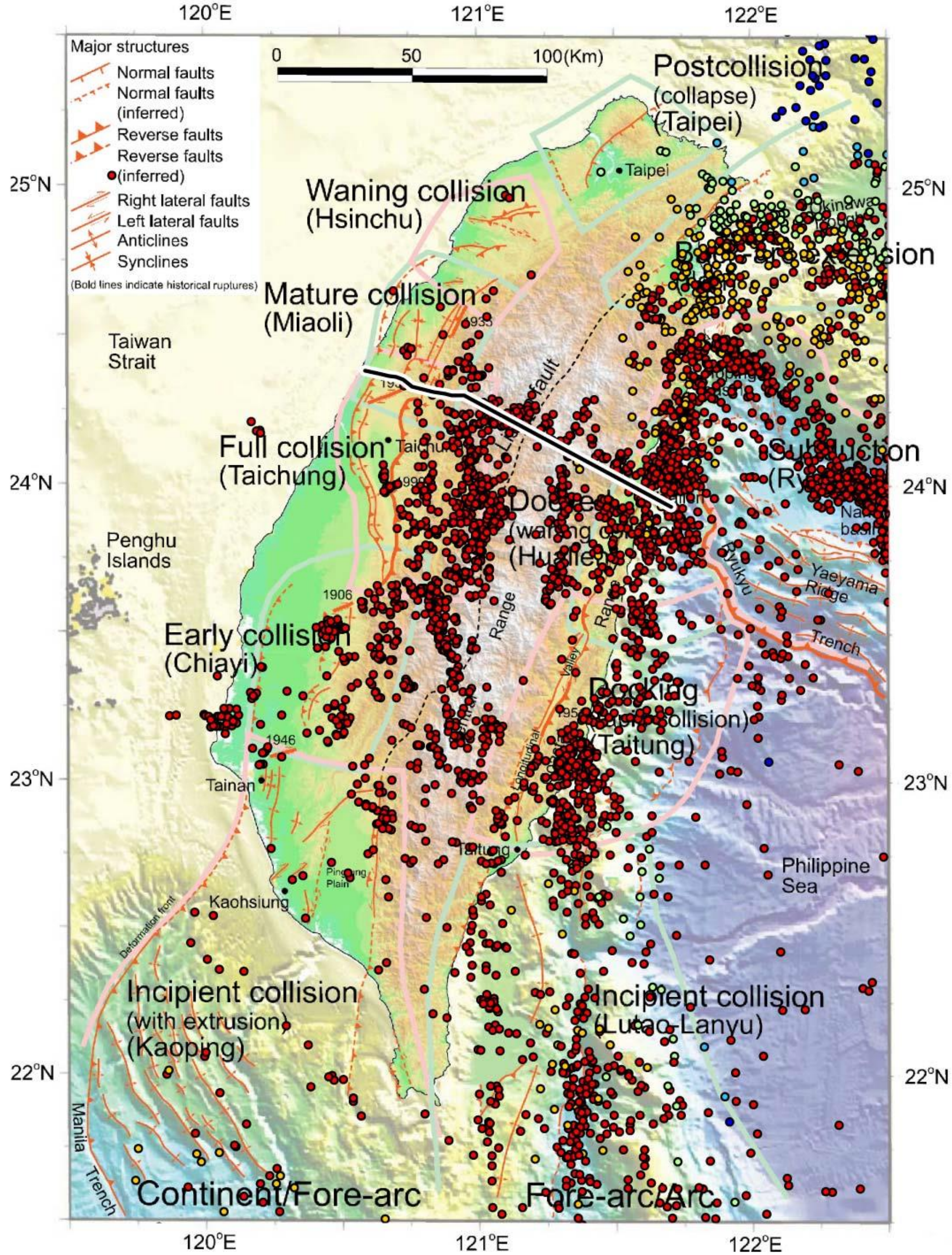
Major active structures in Taiwan

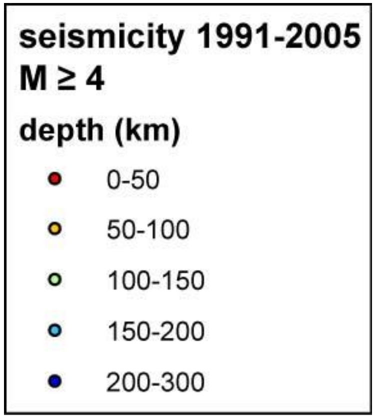




Shyu et al. 2005

Major active structures in Taiwan



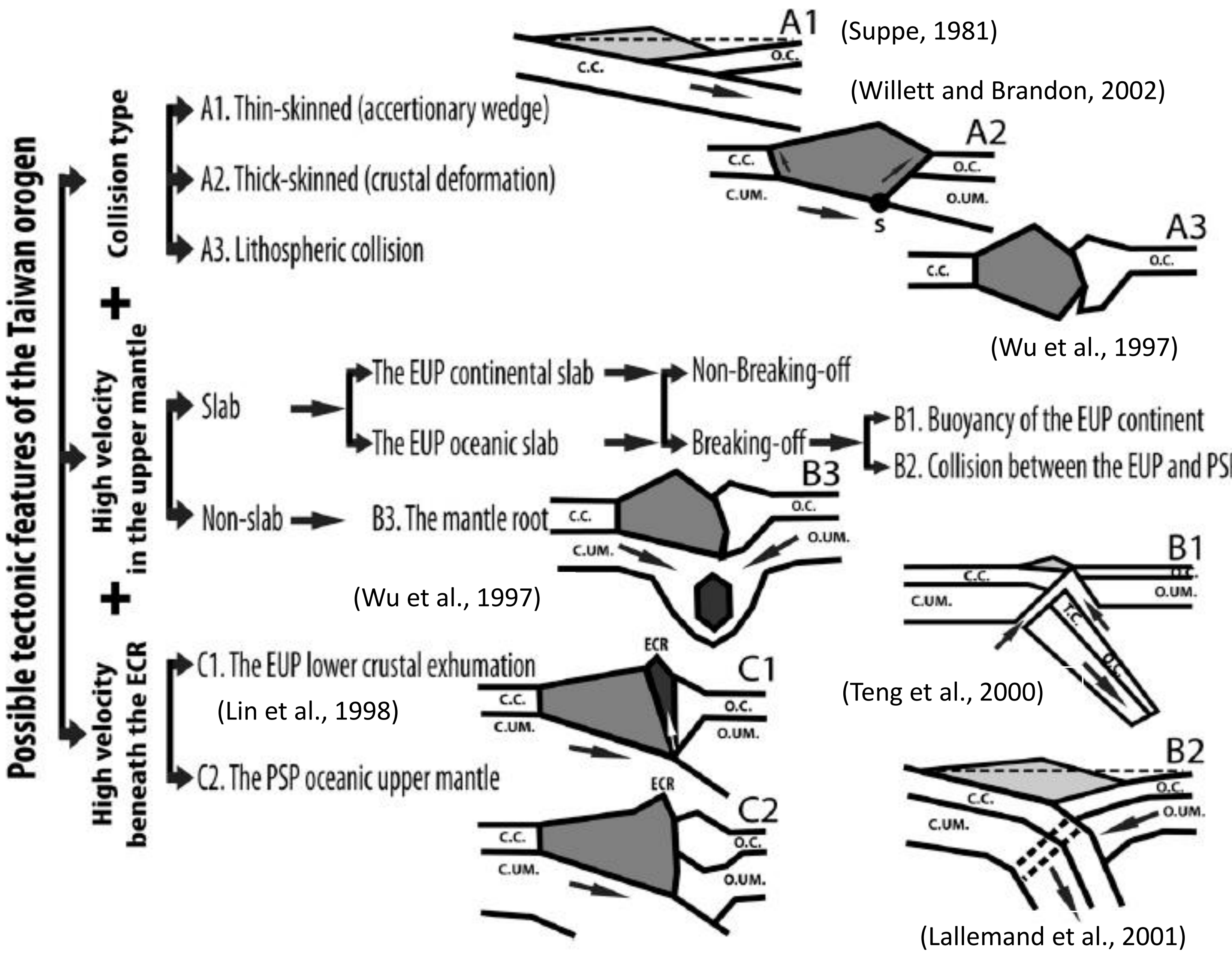


Shyu et al. 2005

Current tectonic models of Taiwan

- Accretionary wedge (Thin skin model) : J. Suppe
- Lithospheric collision (Thick skin model): F. Wu
- Continental Subduction: A. Chemeda
- Arc-continent collision: C.Y. Huang
- Slab break-off: L.S. Teng
- Crustal exhumation: C.H. Lin
- many others…

Current tectonic models of Taiwan



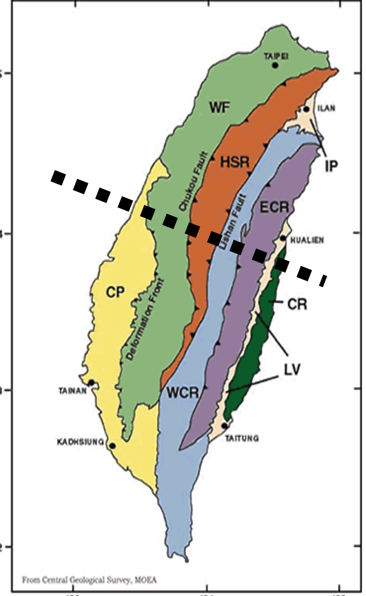
Kinematic Models of Taiwan

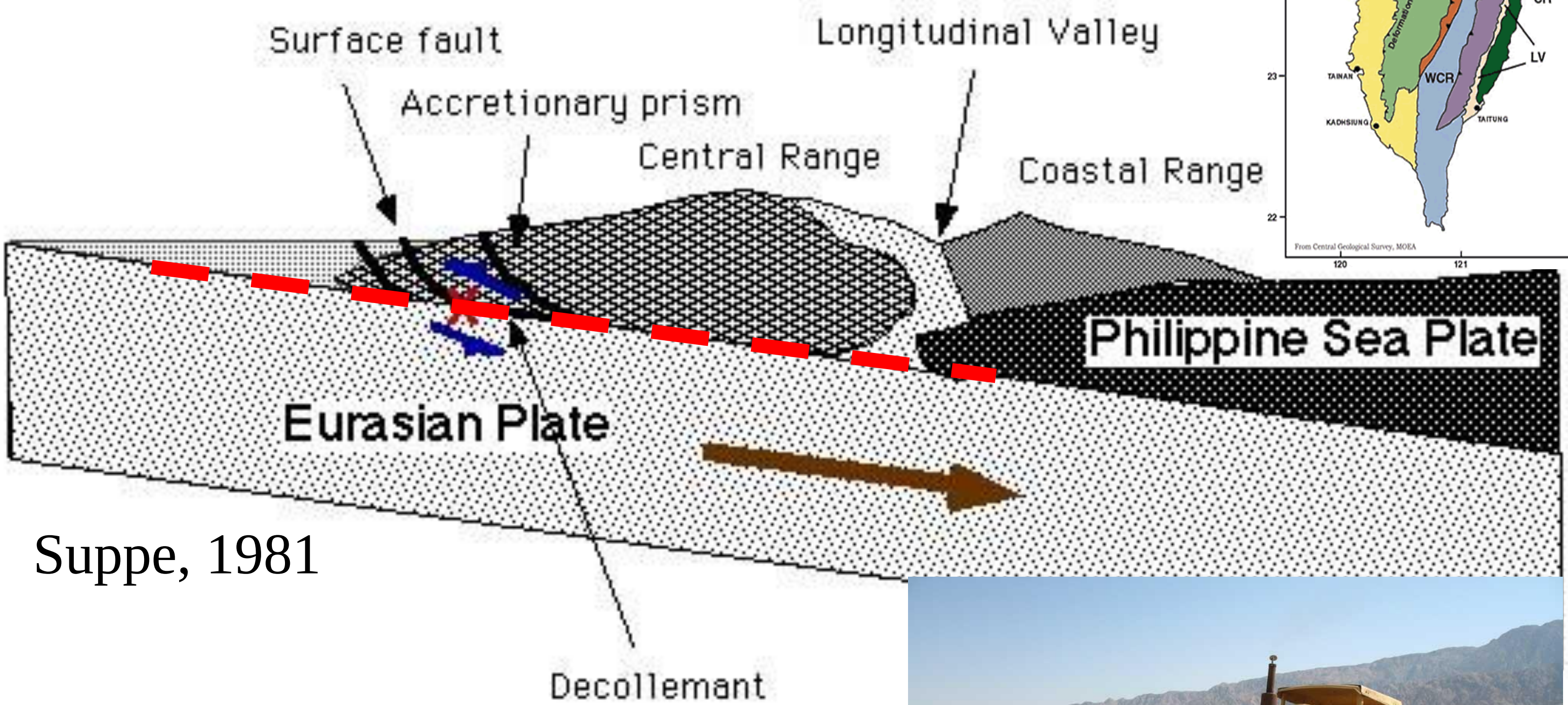
1. Collision with Subduction - Thin-skinned Model : Double-wedge model (Suppe)
2. Collision without Subduction - Thick-skinned (Lithospheric) Model (Wu)
3. Flake Tectonics - Both thin- (Foothills) and thick- (Central Range) skinned tectonics + mountain collapse (Huang, Teng)
4. Other Models: a) Obduction then collision; b) Double collision; c) Arc-arc collision; d) modified thin-skinned model

1. Characteristics of Thin-skinned Model

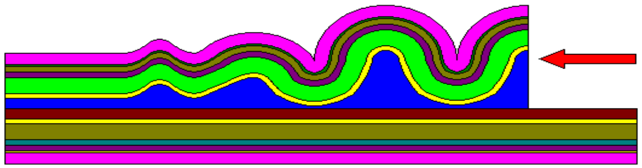
- Accretional Wedge Model – Very Weak
- No basement involved – exists a decollement separate sedimentary cover and basement, i.e., the boundary is decoupled
- Thrust faults- horizontal displacement is predominant, and vertical uplift is minor Philippine Sea (PH) Plate as a backstop
- Eurasian (EU) Plate subducted underneath PH
- Particle path

Thin-skinned model

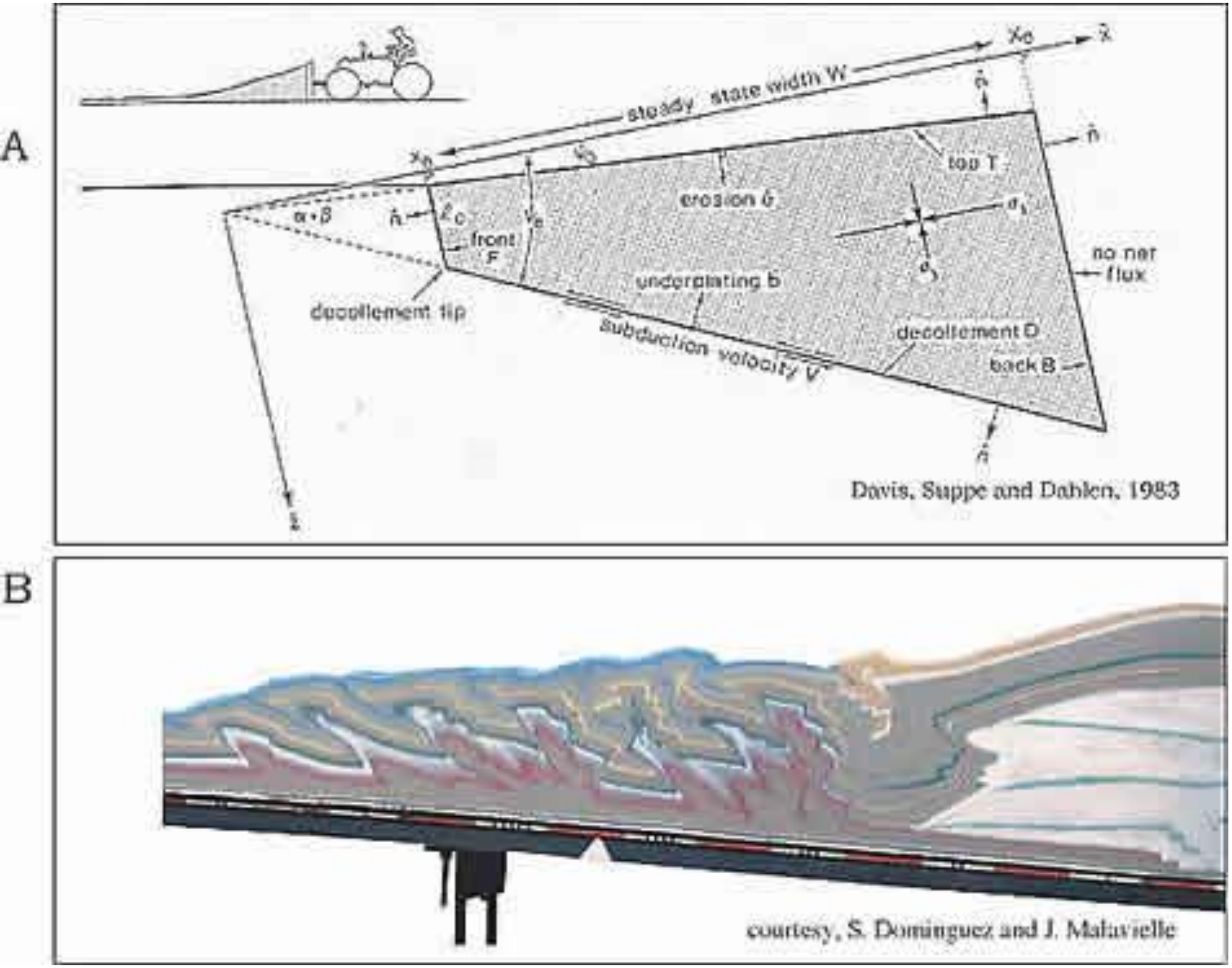


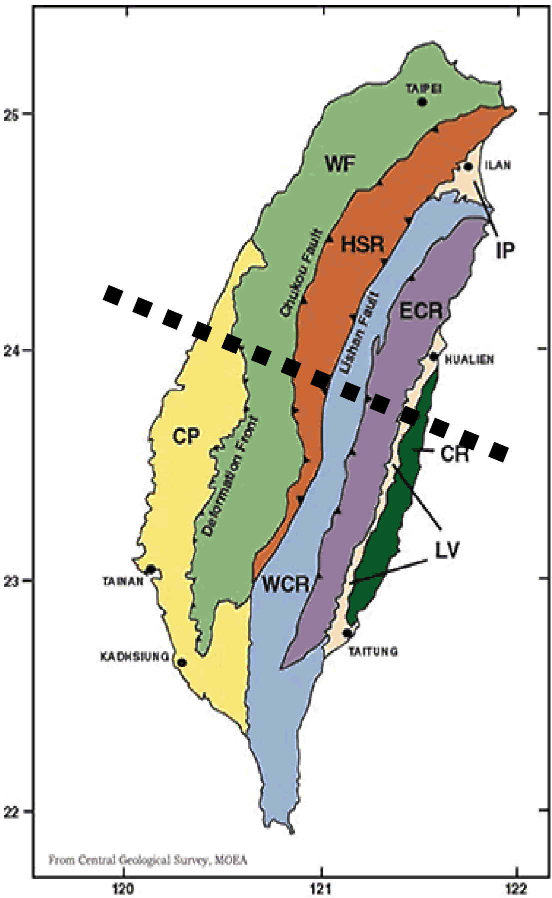


Suppe, 1981



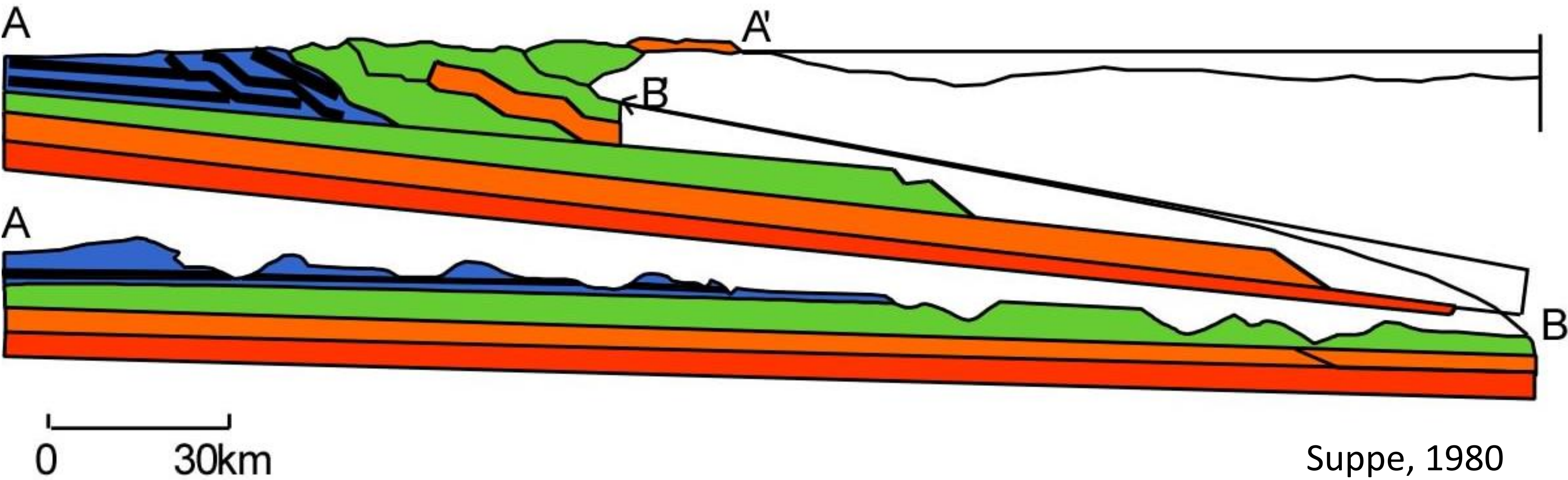
Critical-wedge (thin-skinned) model





Davis et al., 1983
Dahlen et al., 1984
Barr and Dahlen, 1989

Retrodeformable cross-section



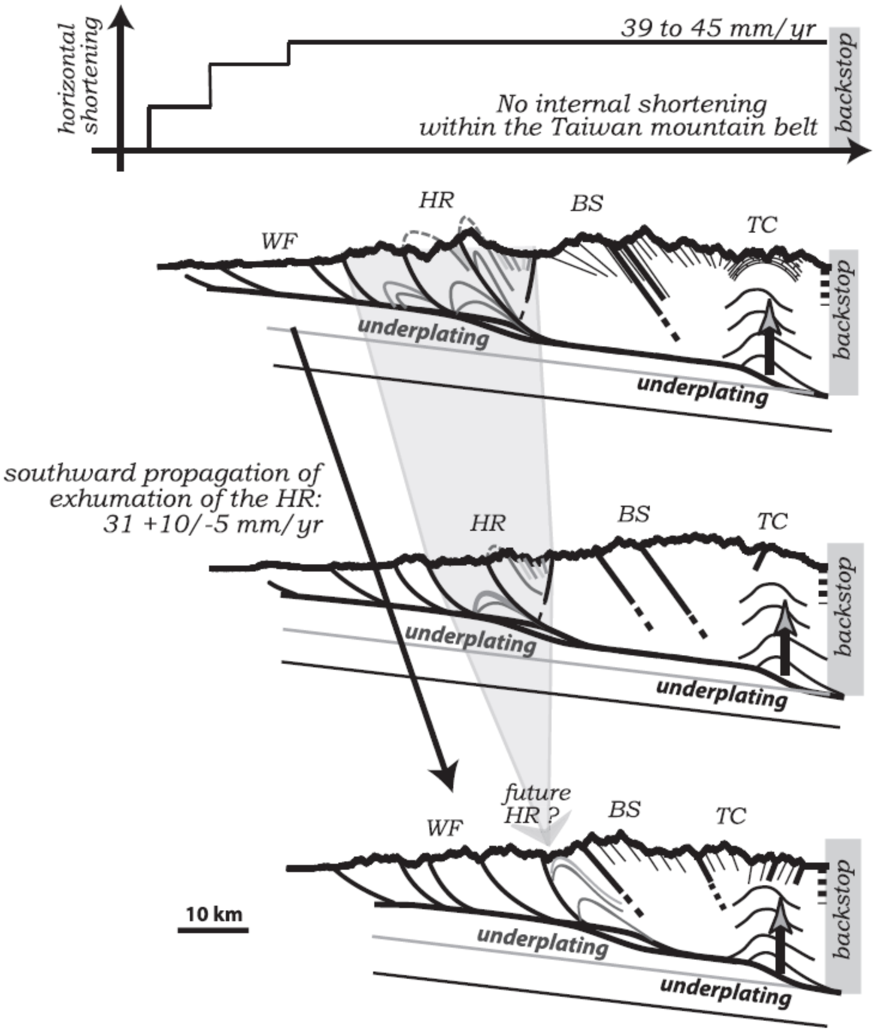
Suppe, 1980

Western Foothills: Sedimentary Sequences
(Late Oligocene to Early Pleistocene)

Western Central Range: Argillite-Slate Series
(Eocene to Middle Miocene)

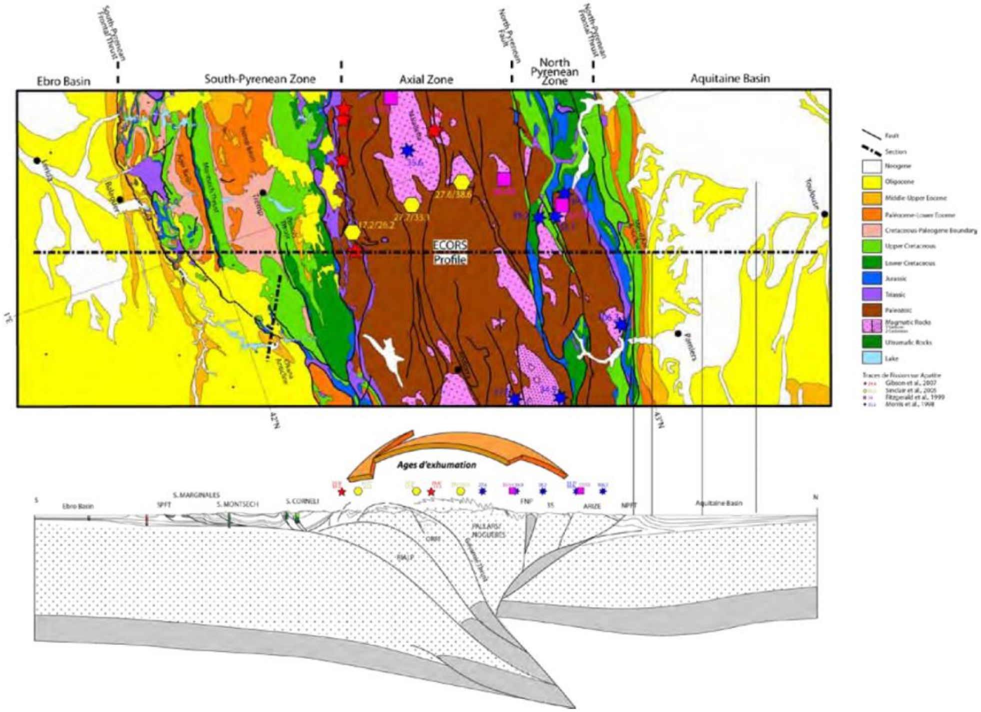
Eastern Central Range: Tananao Schists
(Permo-Triassic to Early Tertiary)

Underplating underneath the HR and CR



Simoes et al., 2007

Underplating in the Axial zone of the Central Pyrenees



Sequence of exhumation from North to South (2009 Taiwan-France joint excursion field guidebook)

Geological Evidence of Thin-skinned Tectonics

Pros:

- Southwestern Offshore Taiwan
- Onshore Field evidences
- P-wave velocity
- Earthquake data (1999 Chi-Chi EQ)

Cons:

- Gravity modeling
- Earthquake data

Tectonic map of Taiwan

Five geological units:

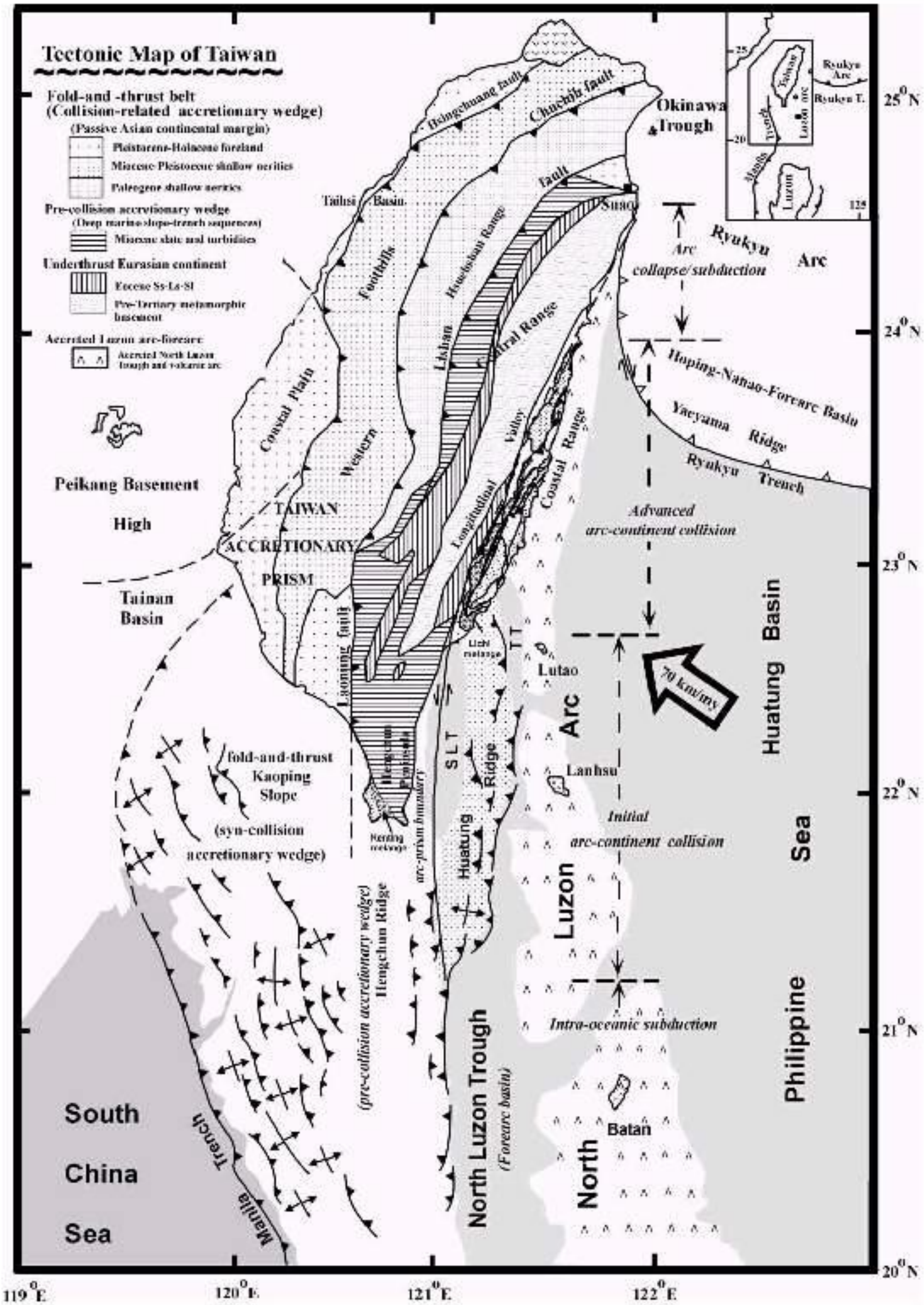
A. Coastal Plain

B. Western Foothills

C. Hsuehshan Range

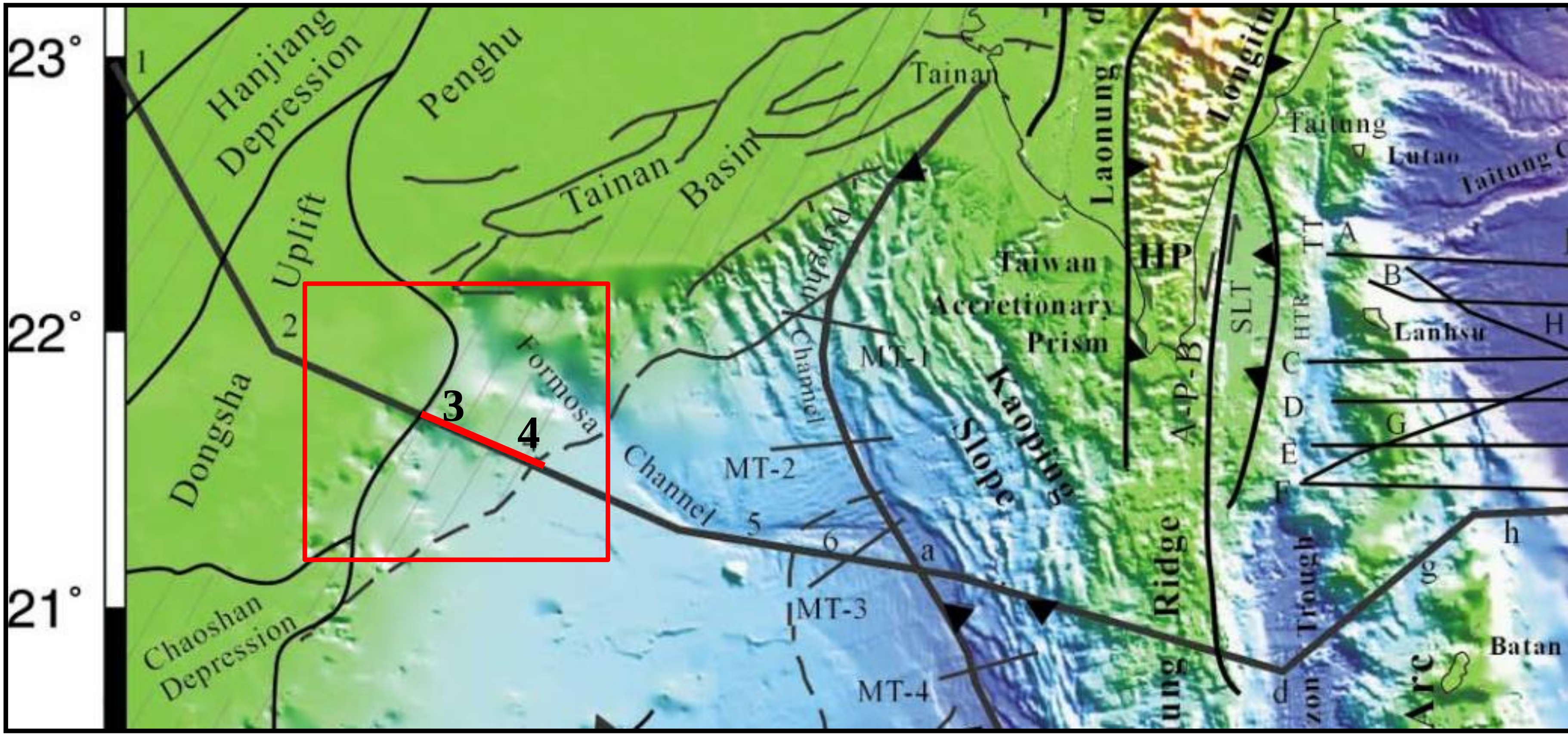
D. Central Range

E. Coastal Range



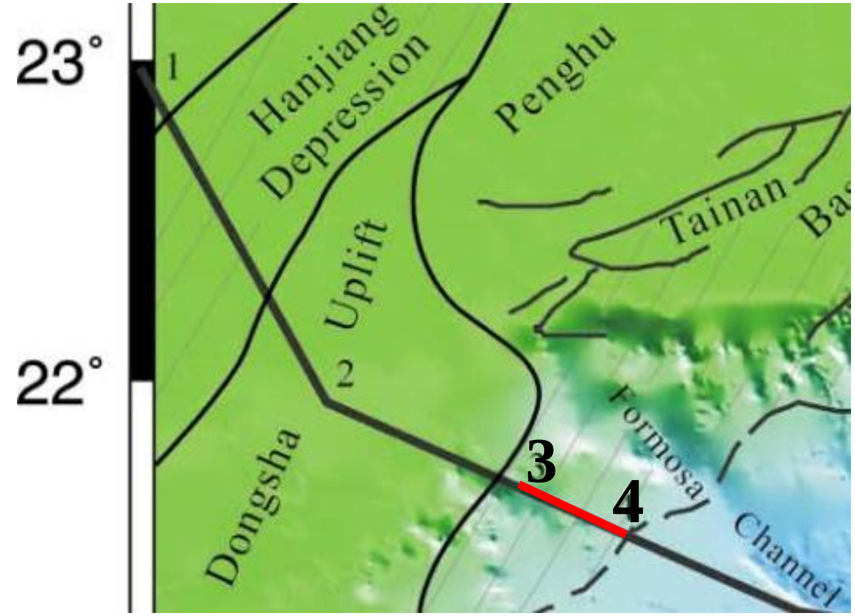
(Huang et al., 2000)

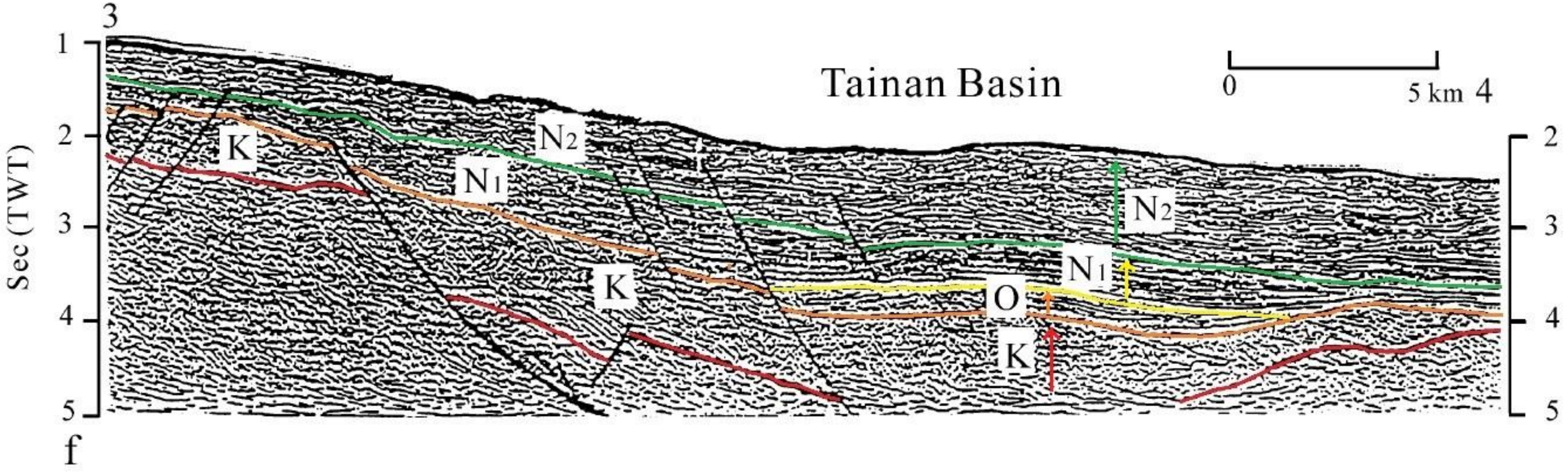
Tainan Basin



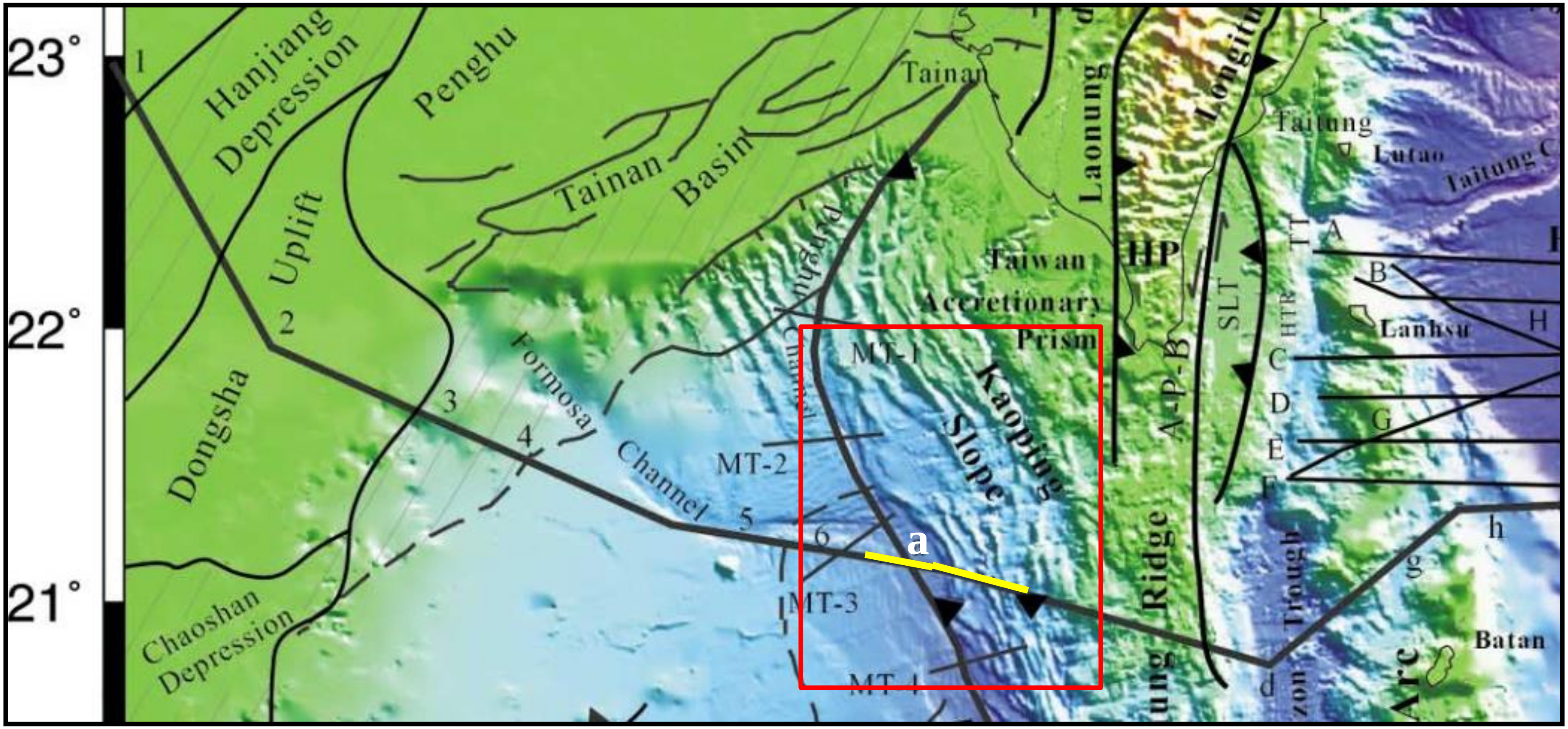
Tainan Basin

- N_1:early Neogene
- N_2:late Neogene
- O:Oligocene
- K:Cretaceous

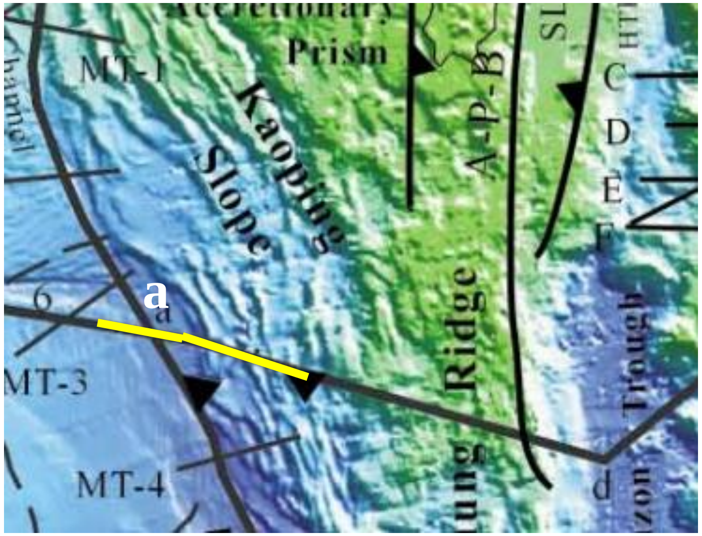


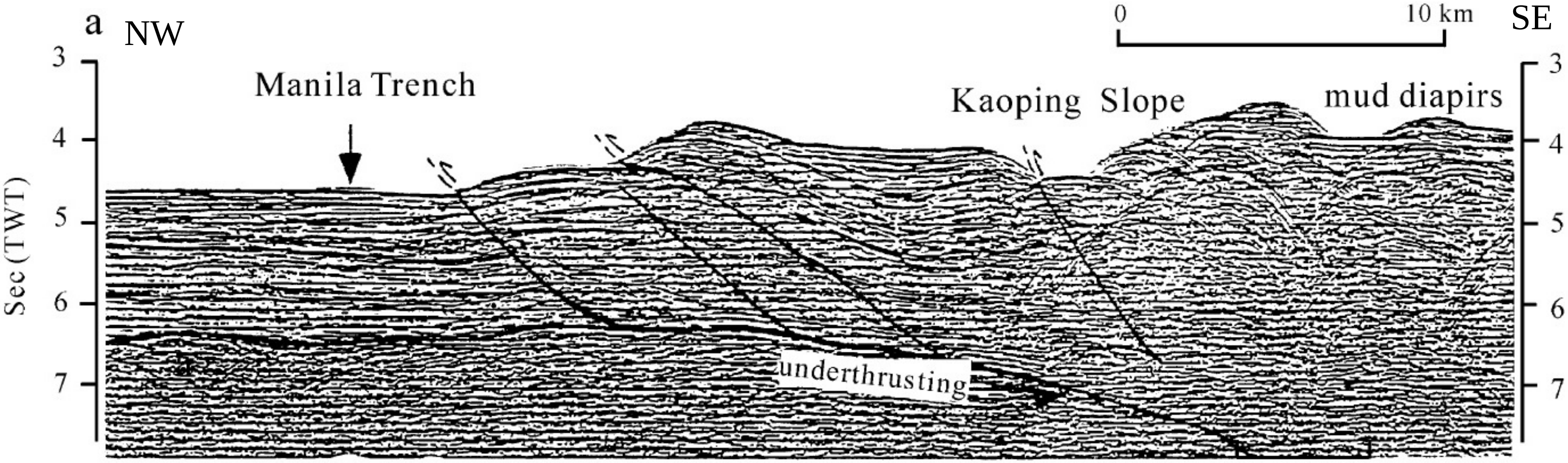


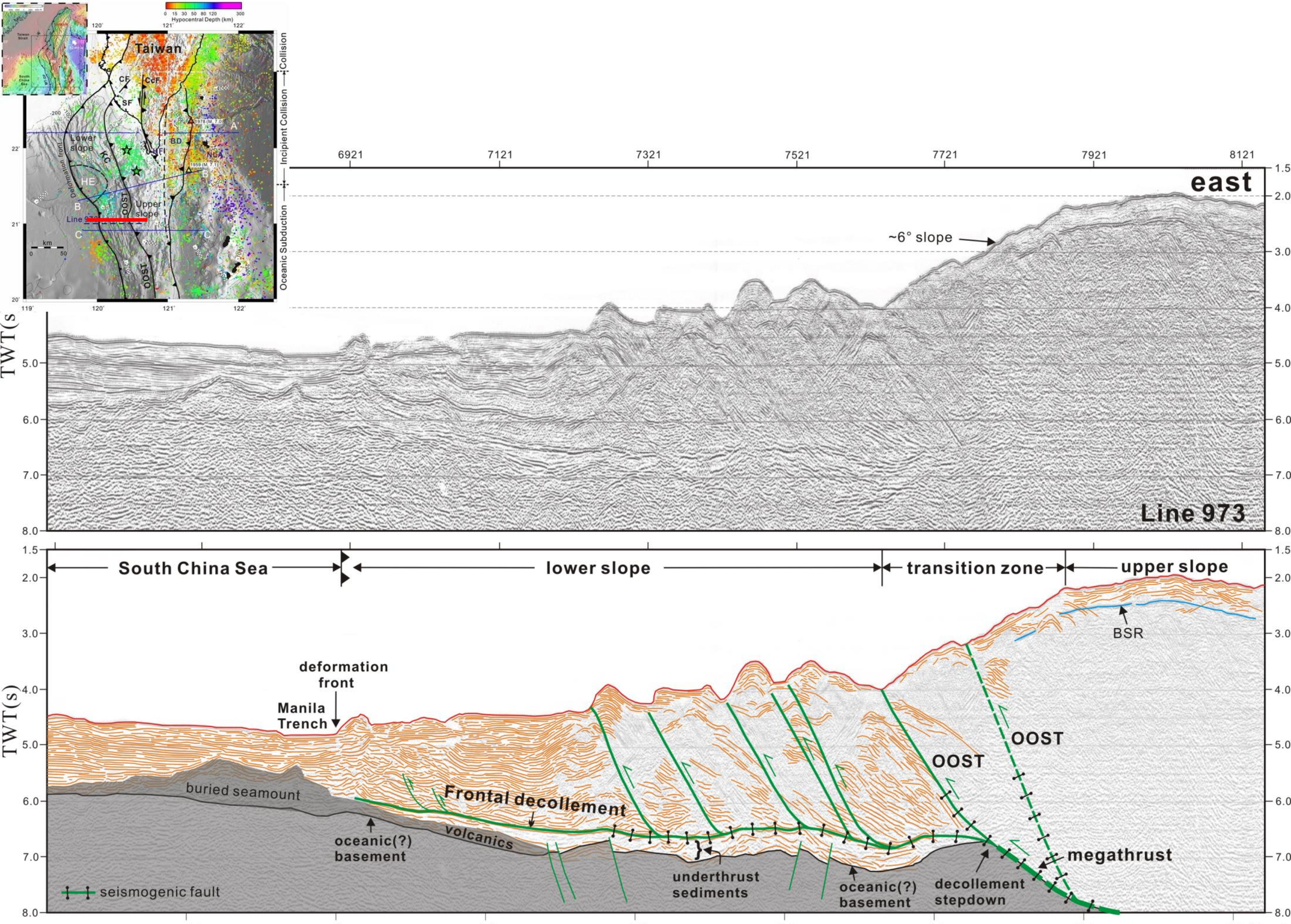
Kaoping Slope



Kaoping Slope

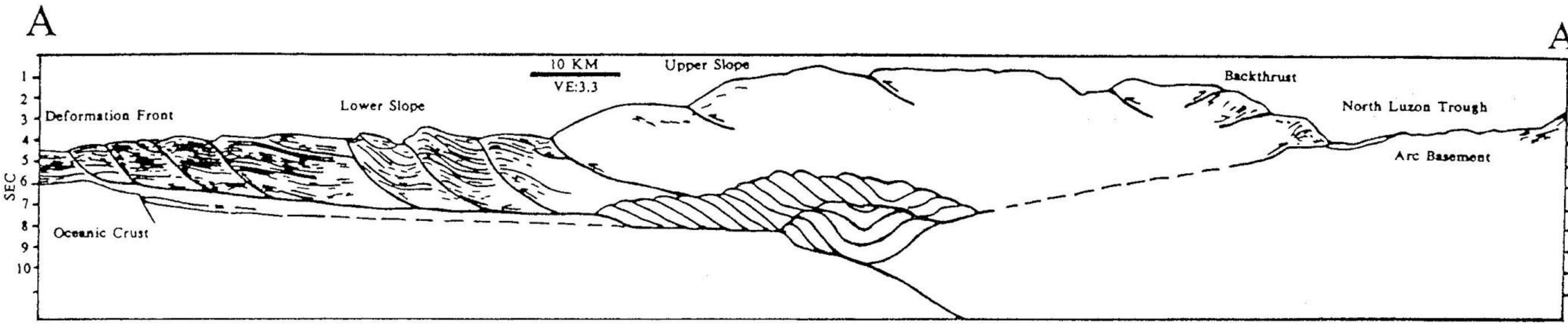


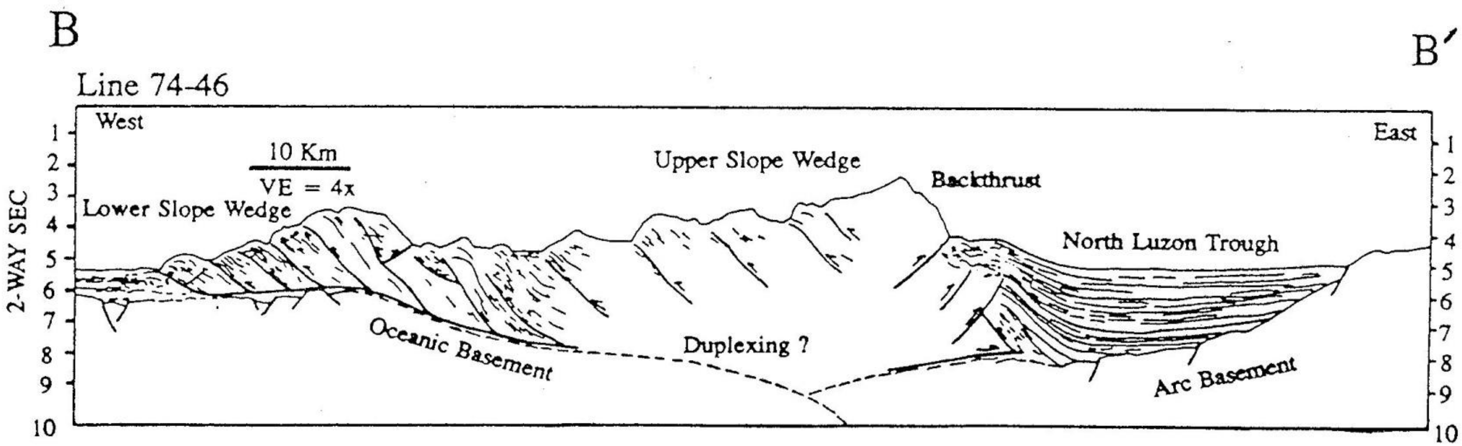




Lin et al., 2008

Structures in southern offshore Taiwan

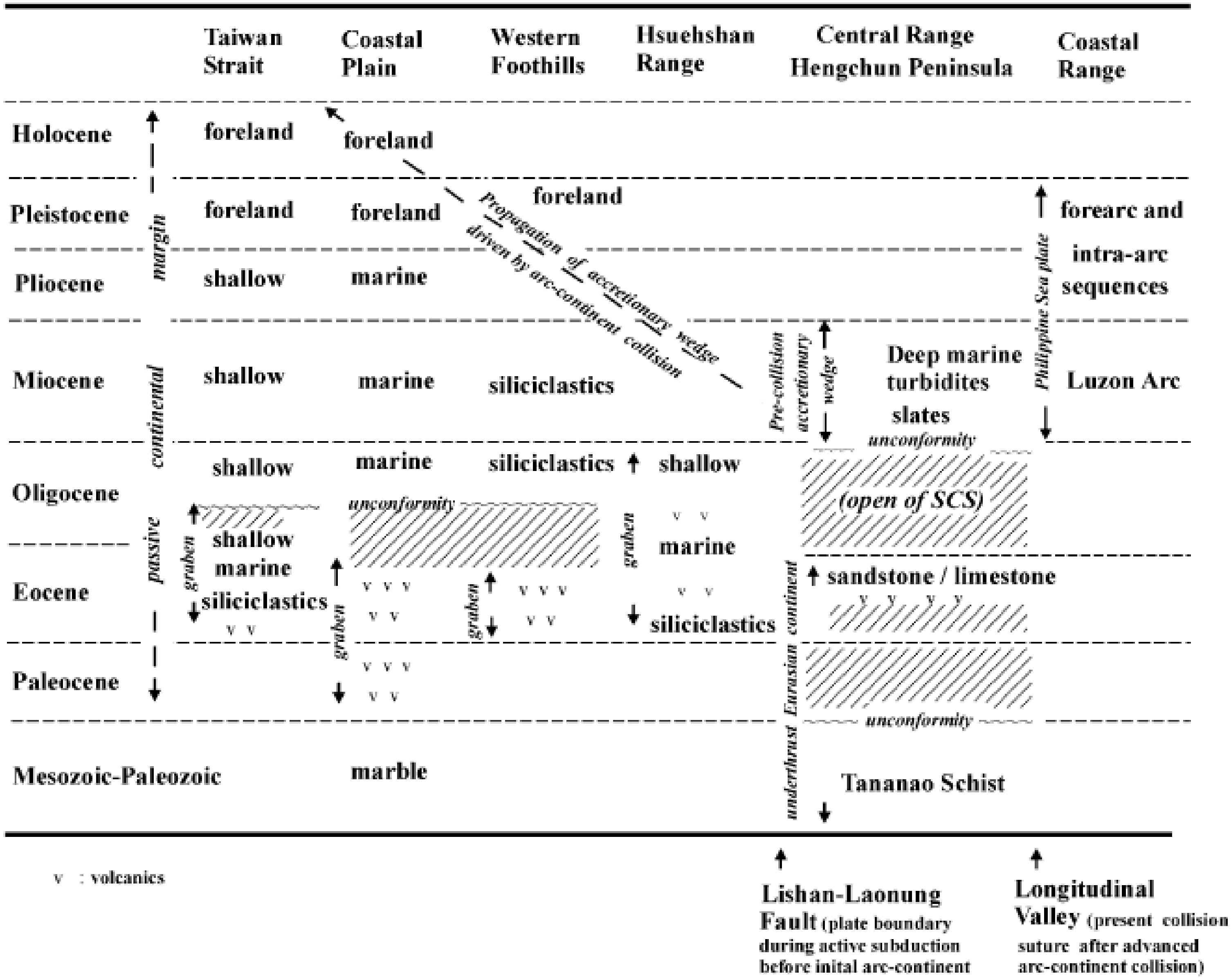




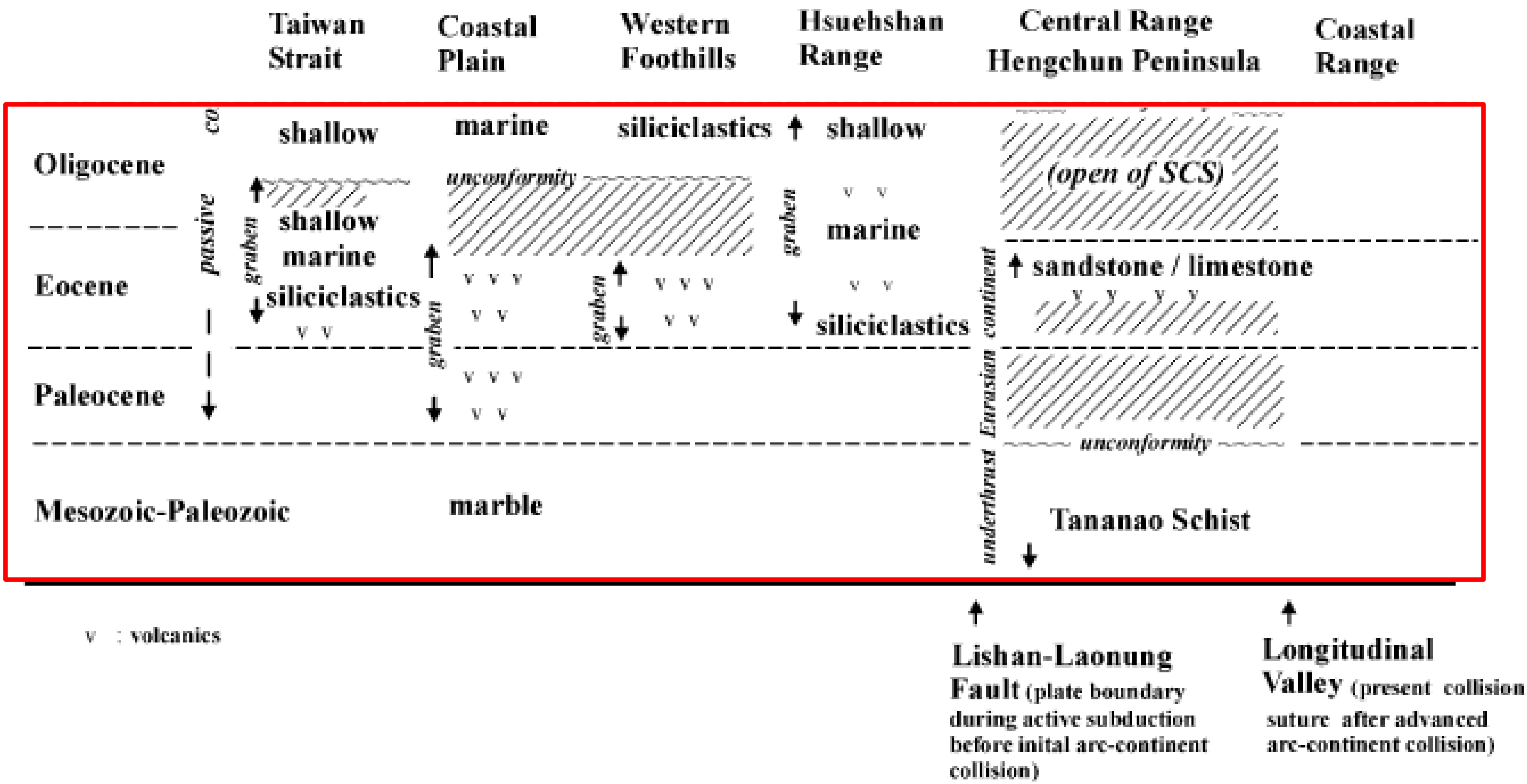
圖九、台灣西南海城代表性的震測剖面解釋顯示剛開始的弧陸碰撞(上圖)及隱沒作用(圖 B)。由於構造複雜導致震測品質不佳,所以上部斜坡(upper slope)祇有少數斷層。脫序的逆衝斷層及重複堆疊的逆斷層係推測的構造(Reed et al.,1992)。

Tectonostratigraphy of Taiwan

C.-Y. Huang, et al. / Journal of Asian Earth Sciences 19 (2001) 619–639

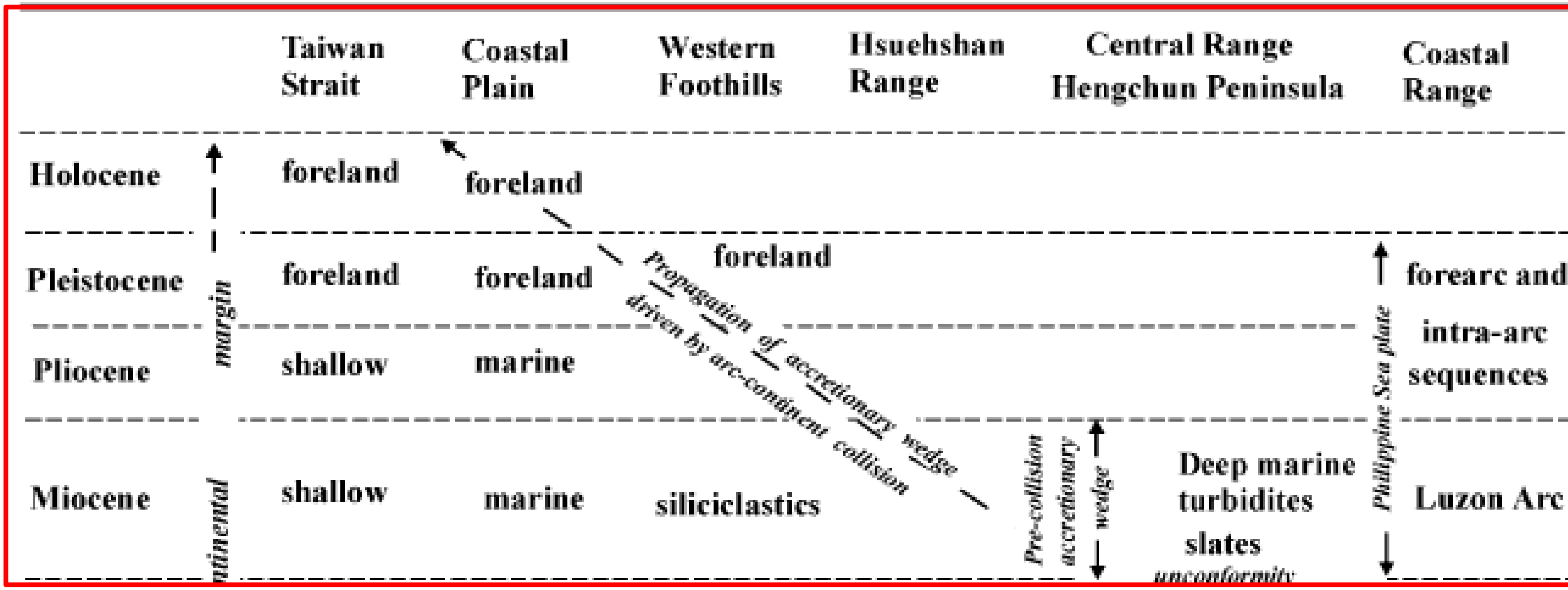


Mesozoic-Paleozoic to Oligocene



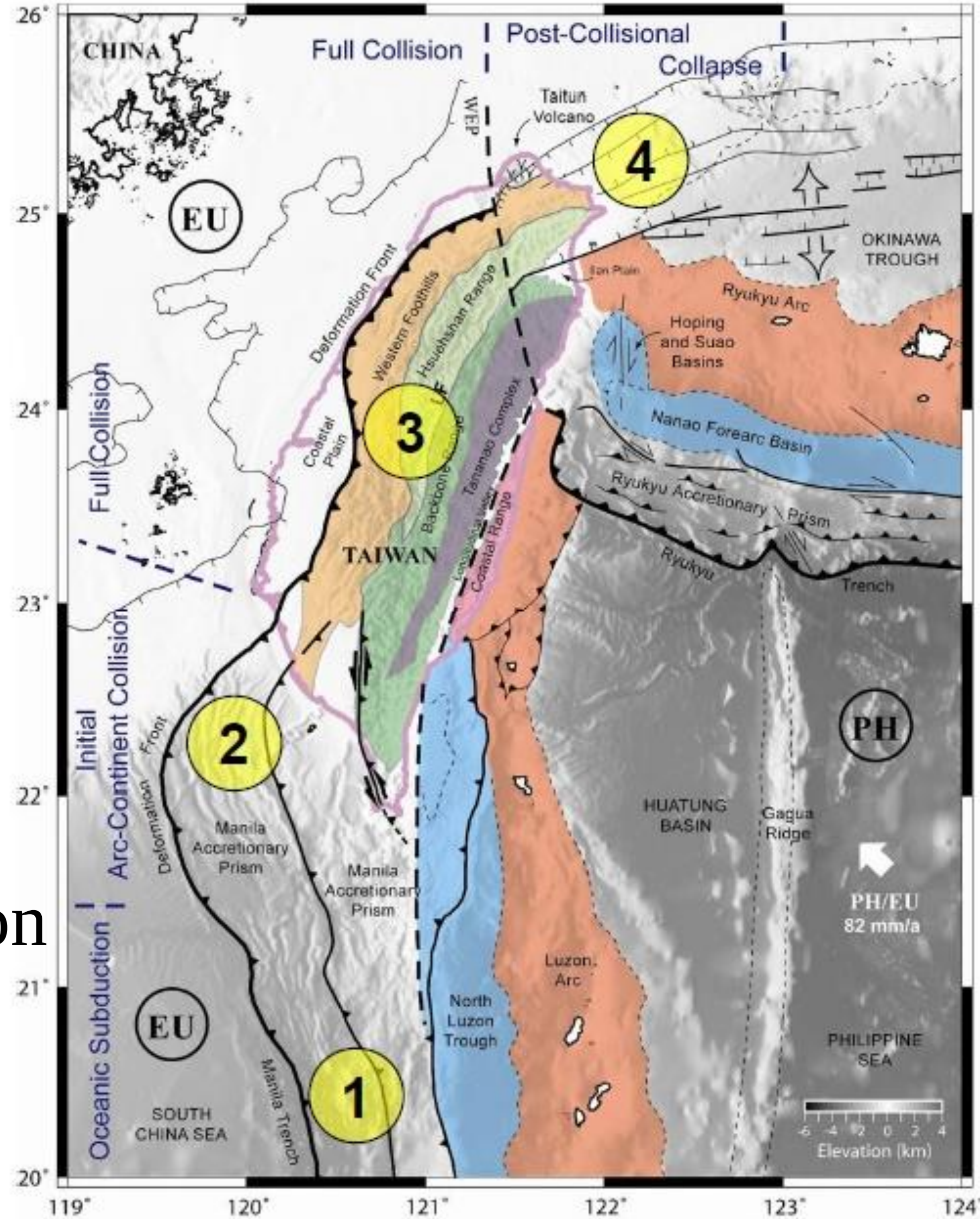
Miocene to Holocene

C.-Y. Huang, et al. / Journal of Asian Earth Sciences 19 (2001) 619–639



Four tectonic settings

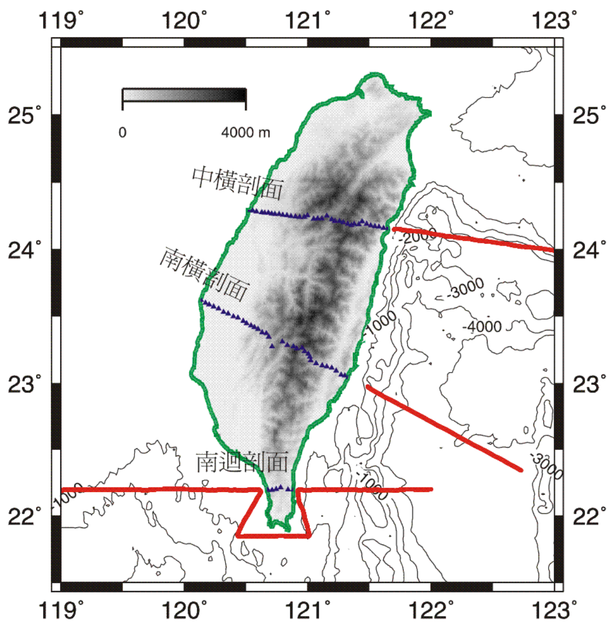
- Structural comparisons between onshore and offshore southern Taiwan
- Five structural units developed in four tectonic settings.
- oceanic subduction → initial arc-continent collision →advanced arc-continent collision → final arc subduction



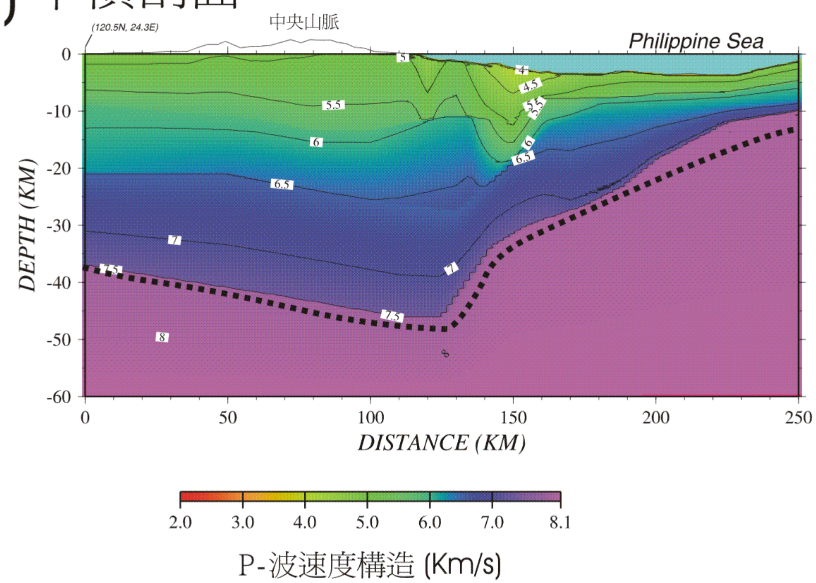
(Courtesy of A.T. Lin)

Wide-angle Seismic Profiles

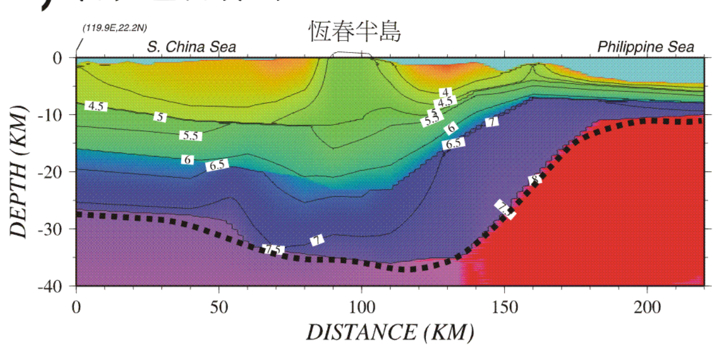
(a.)



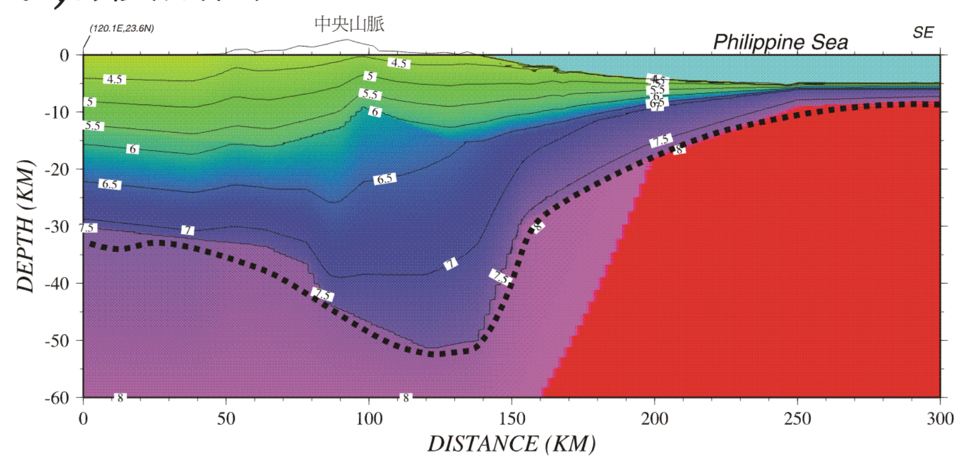
(b.) 中横剖面



(c.) 南迴剖面

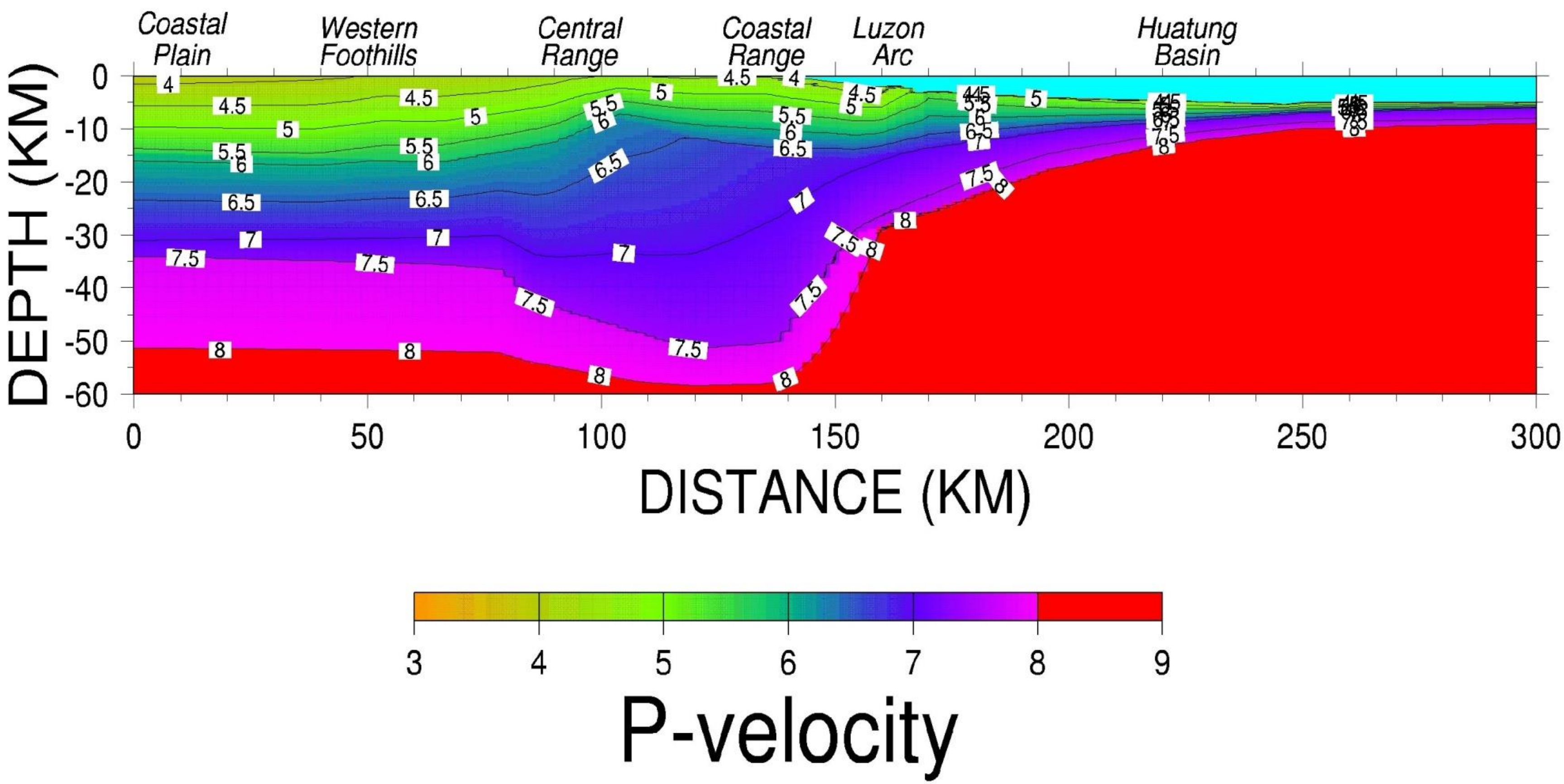


(d.)南横剖面

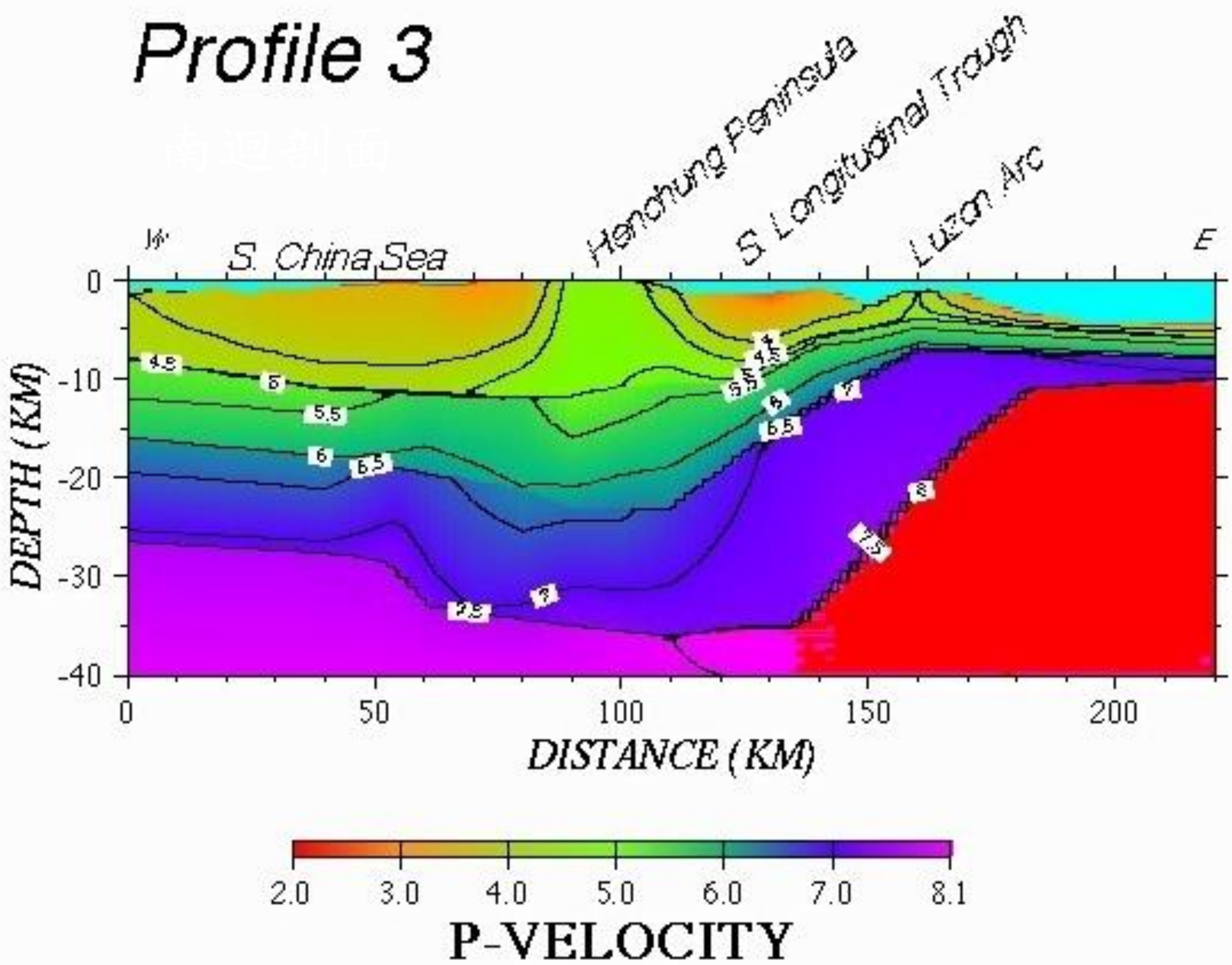


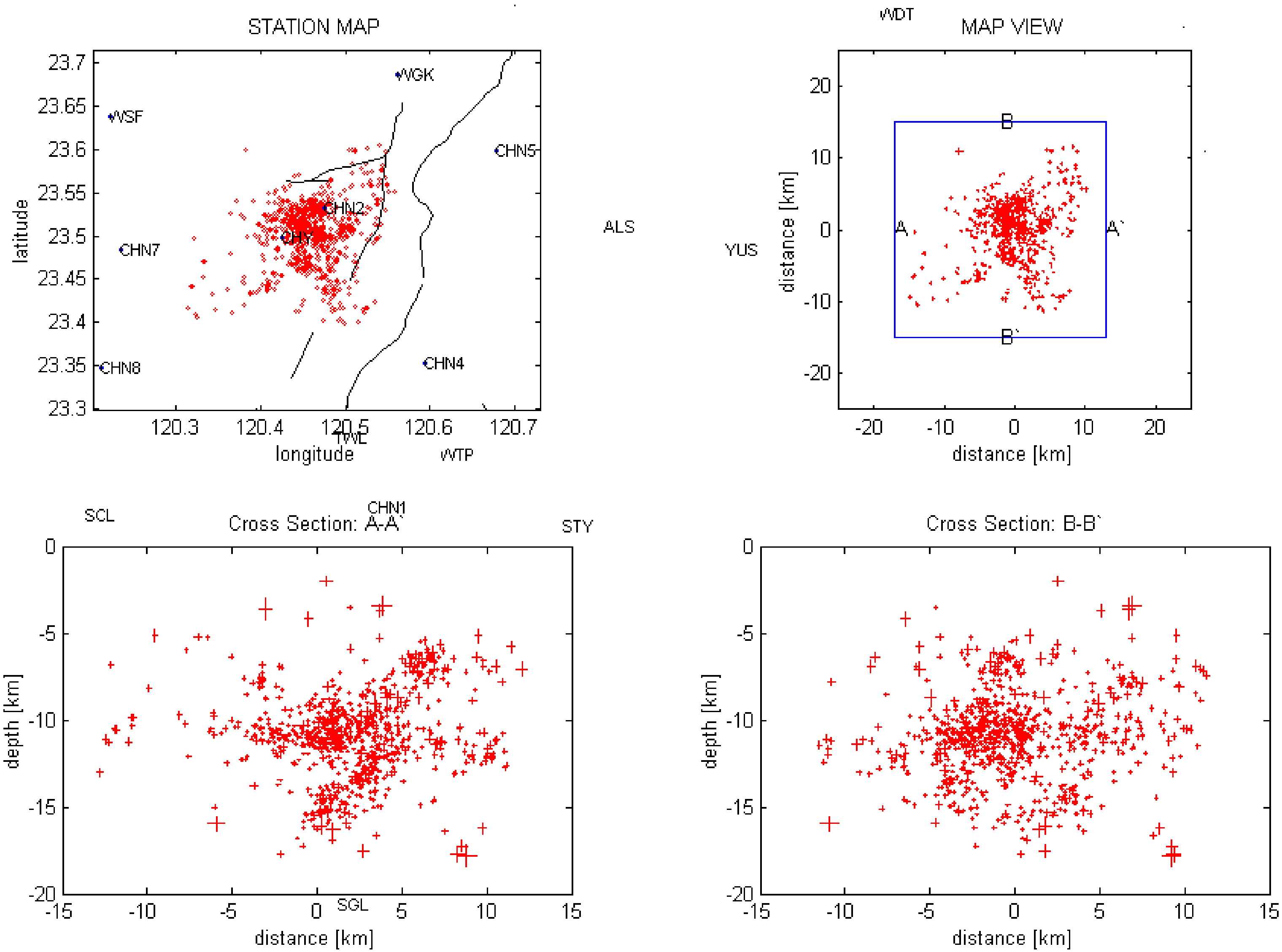
(Yeh et al., 1989; Shih et al., 1989)

Southern Profile （南橫剖面）



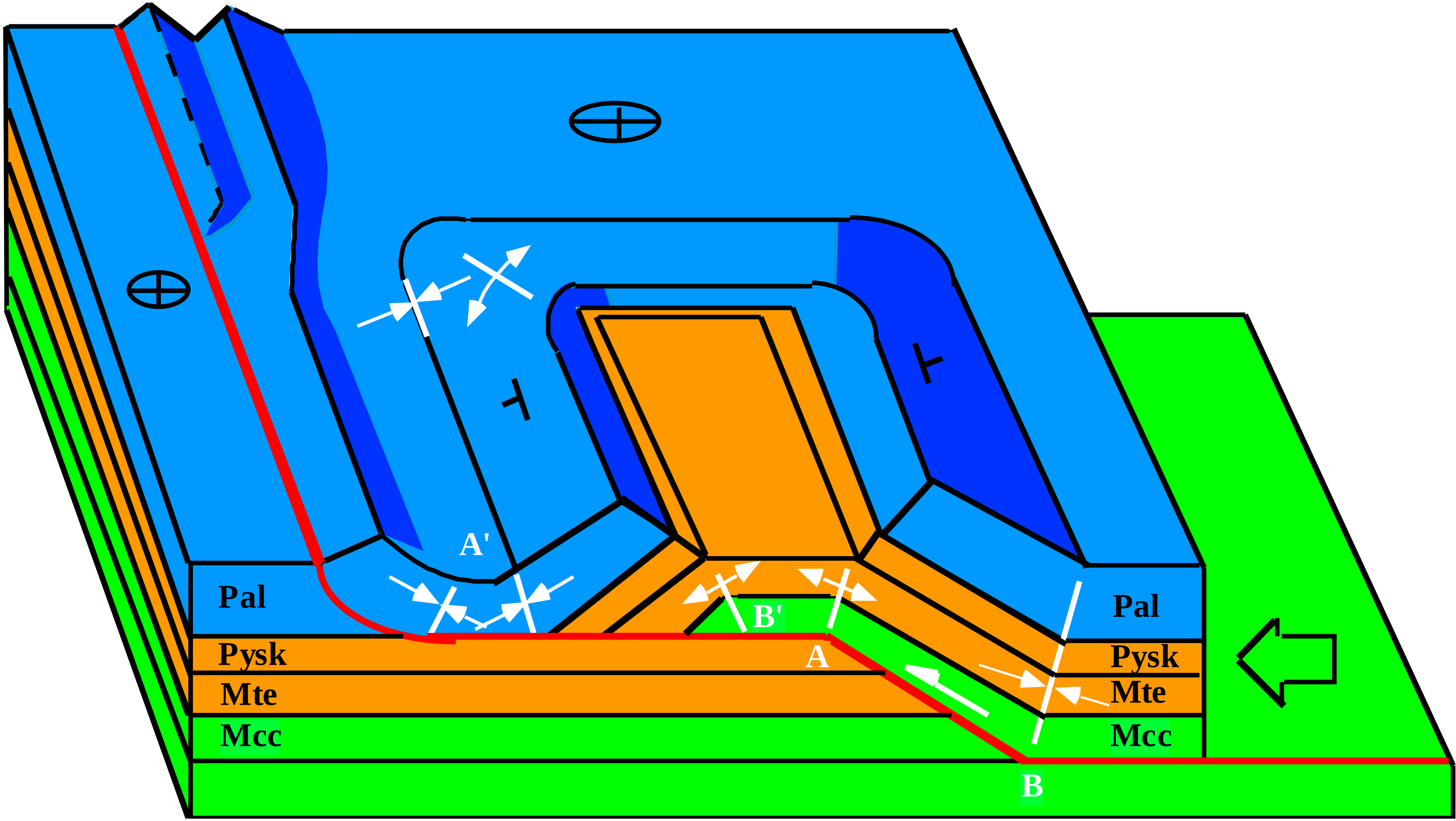
P-wave velocity of 5.5 km is the boundary between sedimentary rocks and basement


Profile 3
Hengchung Peninsula
S. Longitudinal Trough
Luzon Arc
W
E
S. China Sea
DEPTH (KM)
0
-10
-20
-30
-40
0
50
100
150
200
DISTANCE (KM)
2.0
3.0
4.0
5.0
6.0
7.0
8.1
P-VELOCITY

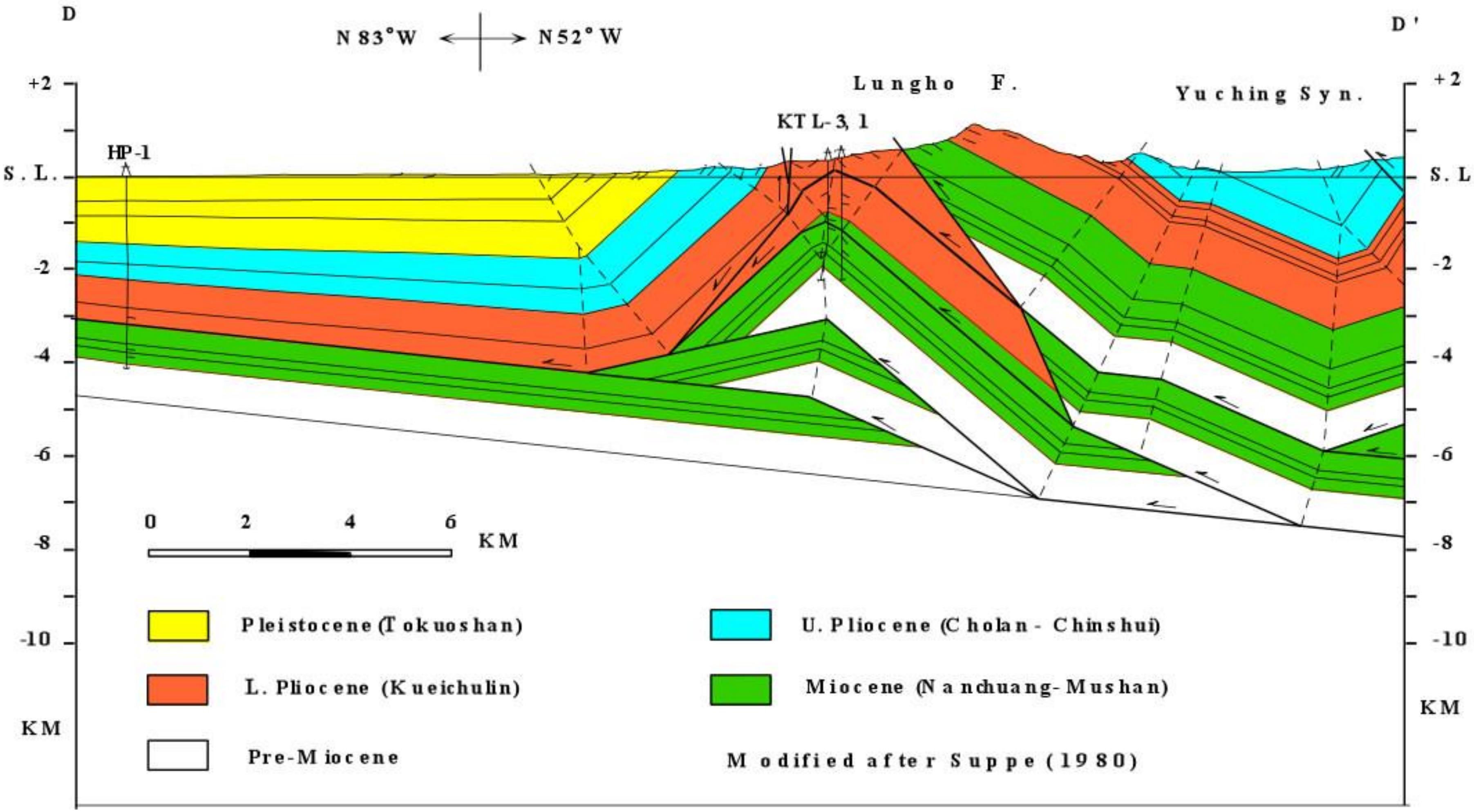


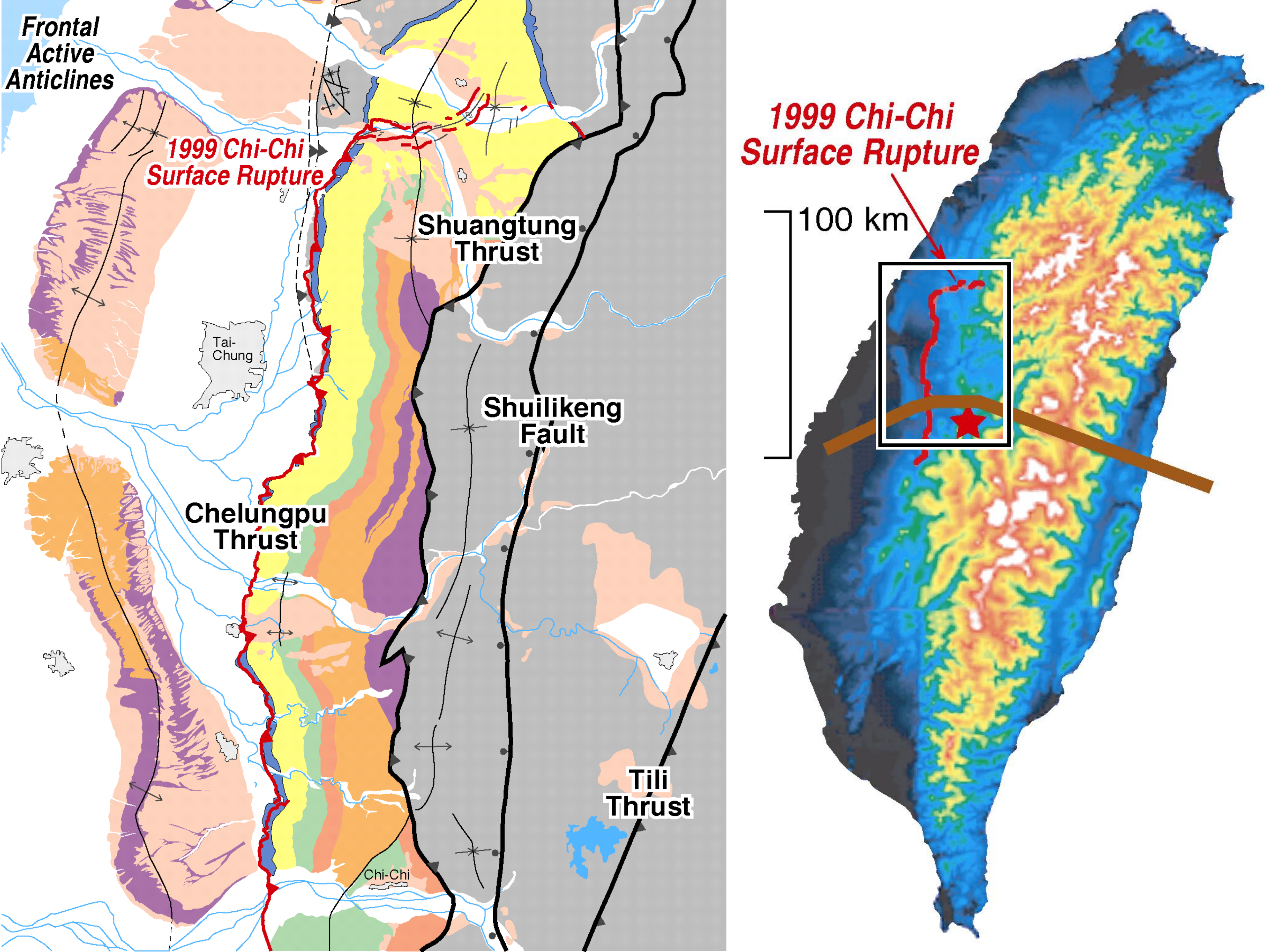
嘉義地區震源分佈圖(1022地震後), A linear belt of earthquake foci located between 10-12 km deep is seen in lower left figure (饒瑞君等, 2002)

Fault-Fold geometry of a Decollement fault

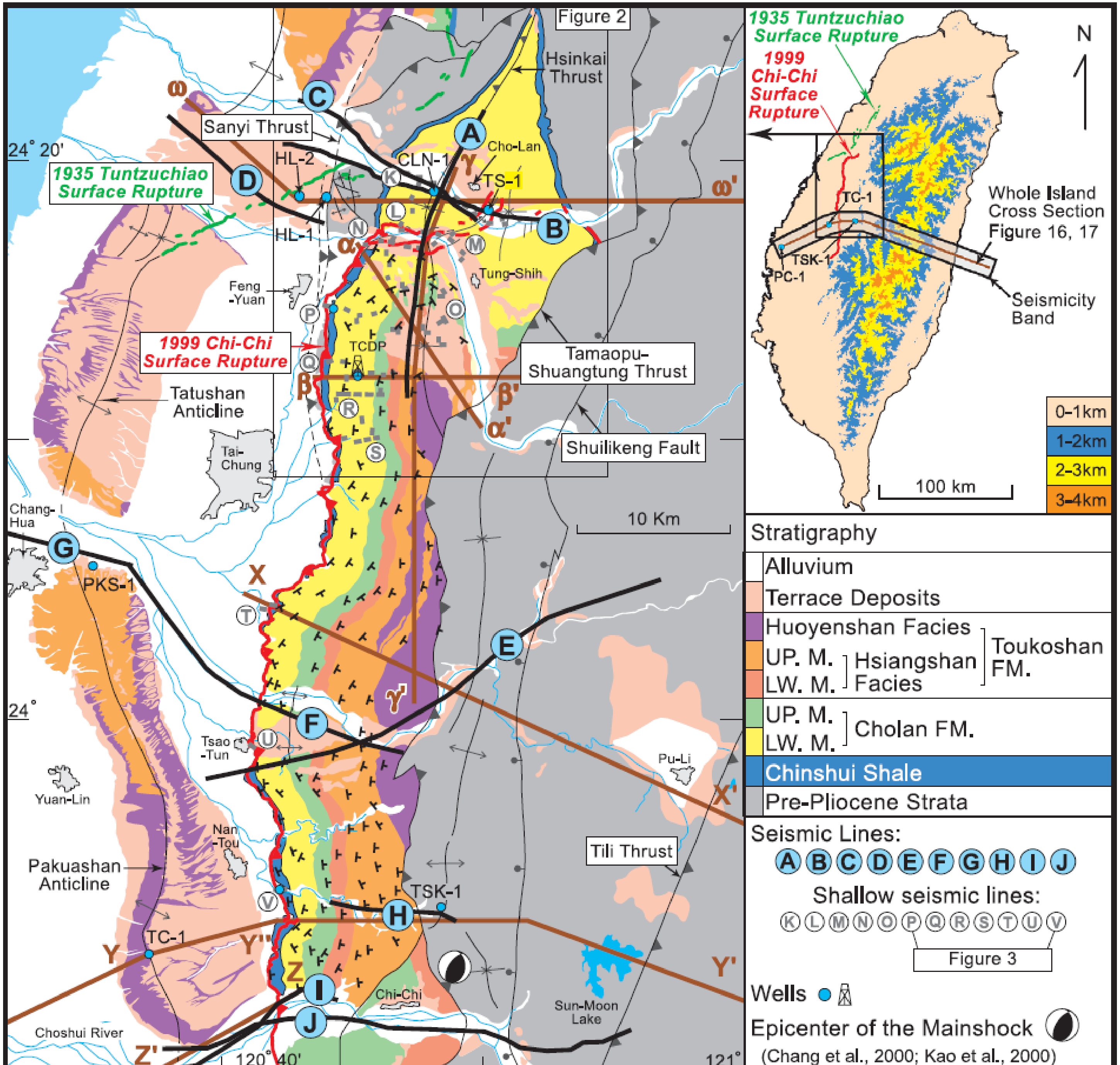


Fault-Fold geometry of a Decollement fault





Frontal Active Anticlines
1999 Chi-Chi Surface Rupture
Tai-Chung
Shuangtung Thrust
Shuilikeng Fault
Chelungpu Thrust
Tili Thrust
Chi-Chi
1999 Chi-Chi Surface Rupture
100 km



(Yue et al., 2005)

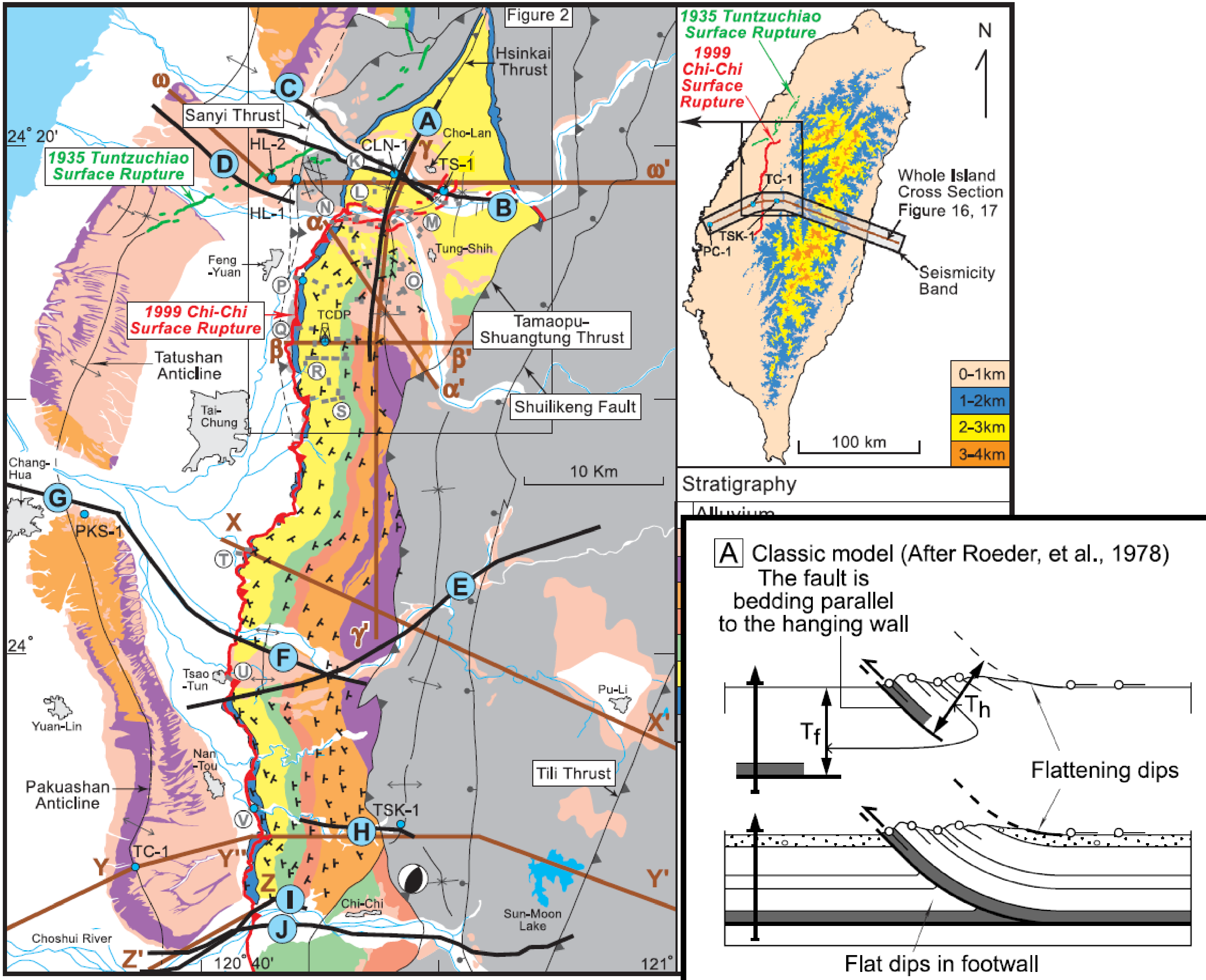
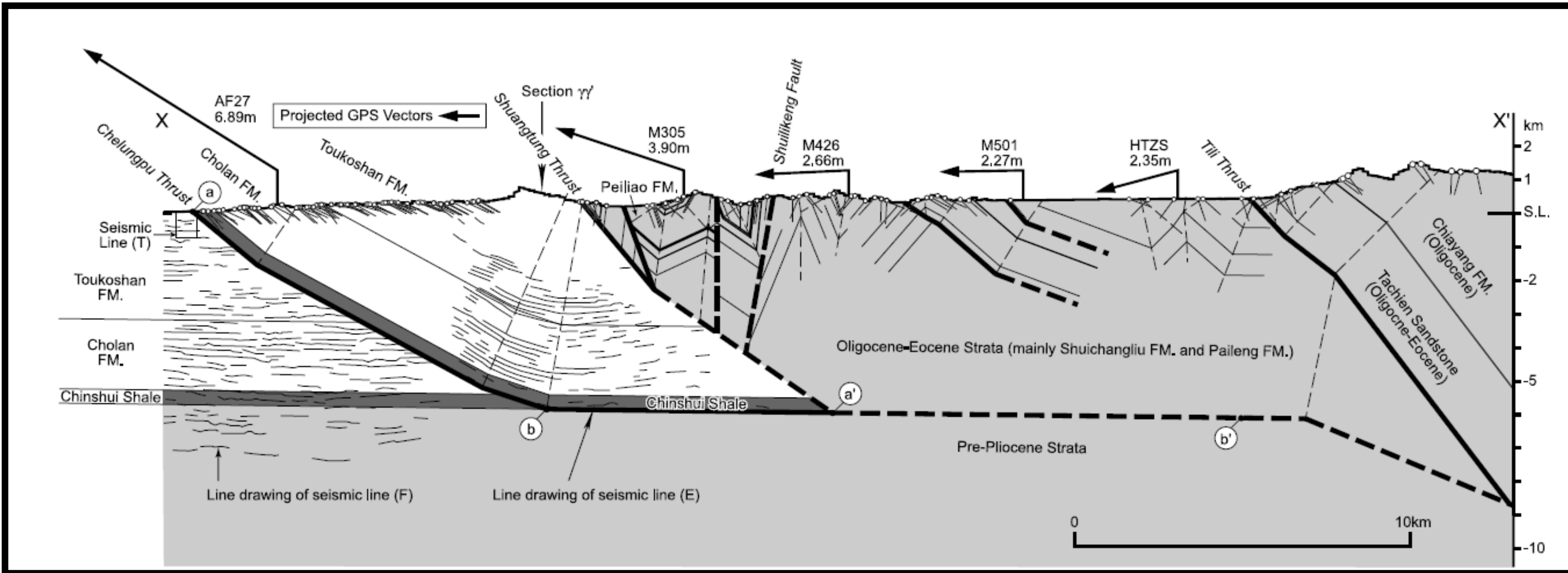
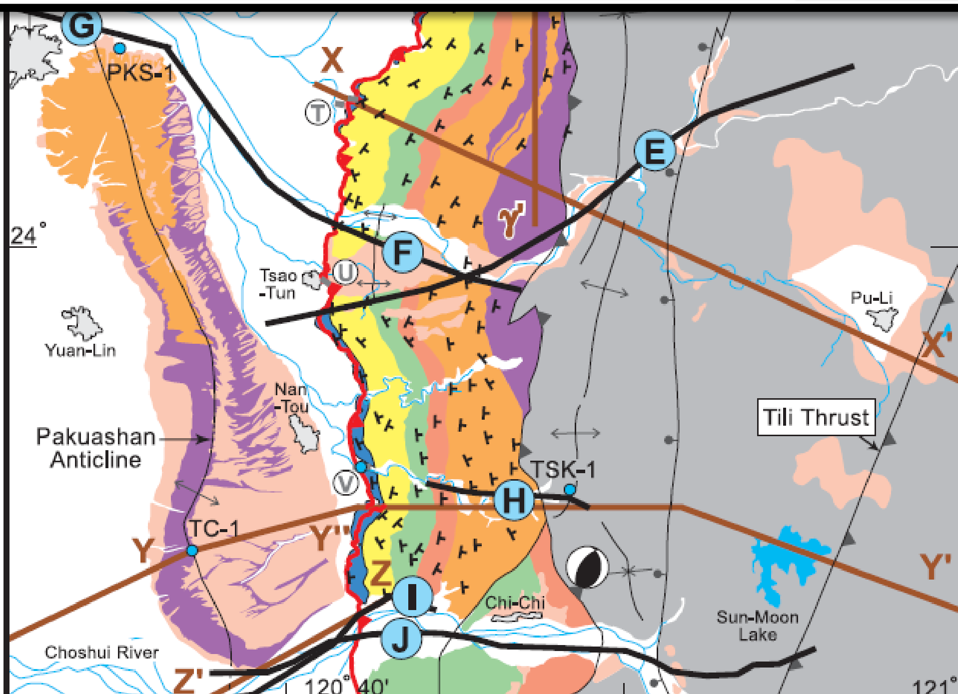


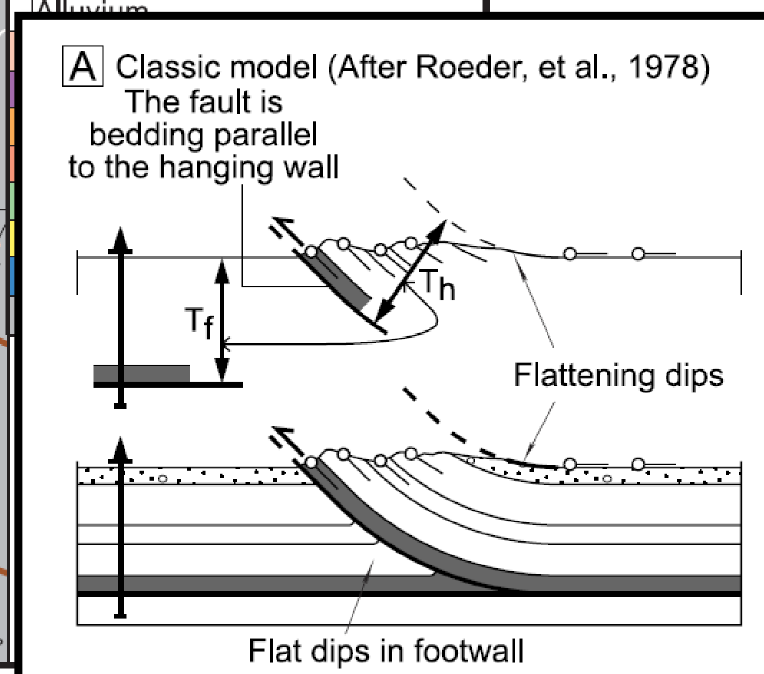
Figure 2
Hsinkai Thrust
Sanyi Thrust
24° 20'
1935 Tuntzuchiao Surface Rupture
HL-2
HL-1
CLN-1
Cho-Lan
TS-1
Tung-Shih
Feng -Yuan
TCDP
1999 Chi-Chi Surface Rupture
Tamaopu-Shuangtung Thrust
Tatushan Anticline
Shuilikeng Fault
Tai-Chung
Chang-Hua
PKS-1
10 Km
24°
Tsao -Tun
Pu-Li
Yuan-Lin
Nan -Tou
Pakuashan Anticline
Tili Thrust
TSK-1
TC-1
Chi-Chi
Sun-Moon Lake
Choshui River
120° 40'
121°
1935 Tuntzuchiao Surface Rupture
1999 Chi-Chi Surface Rupture
N
TC-1
TSK-1
PC-1
Whole Island Cross Section Figure 16, 17
Seismicity Band
100 km
0-1km
1-2km
2-3km
3-4km
Stratigraphy
A Classic model (After Roeder, et al., 1978)
The fault is bedding parallel to the hanging wall
T_h
T_f
Flattening dips
Flat dips in footwall



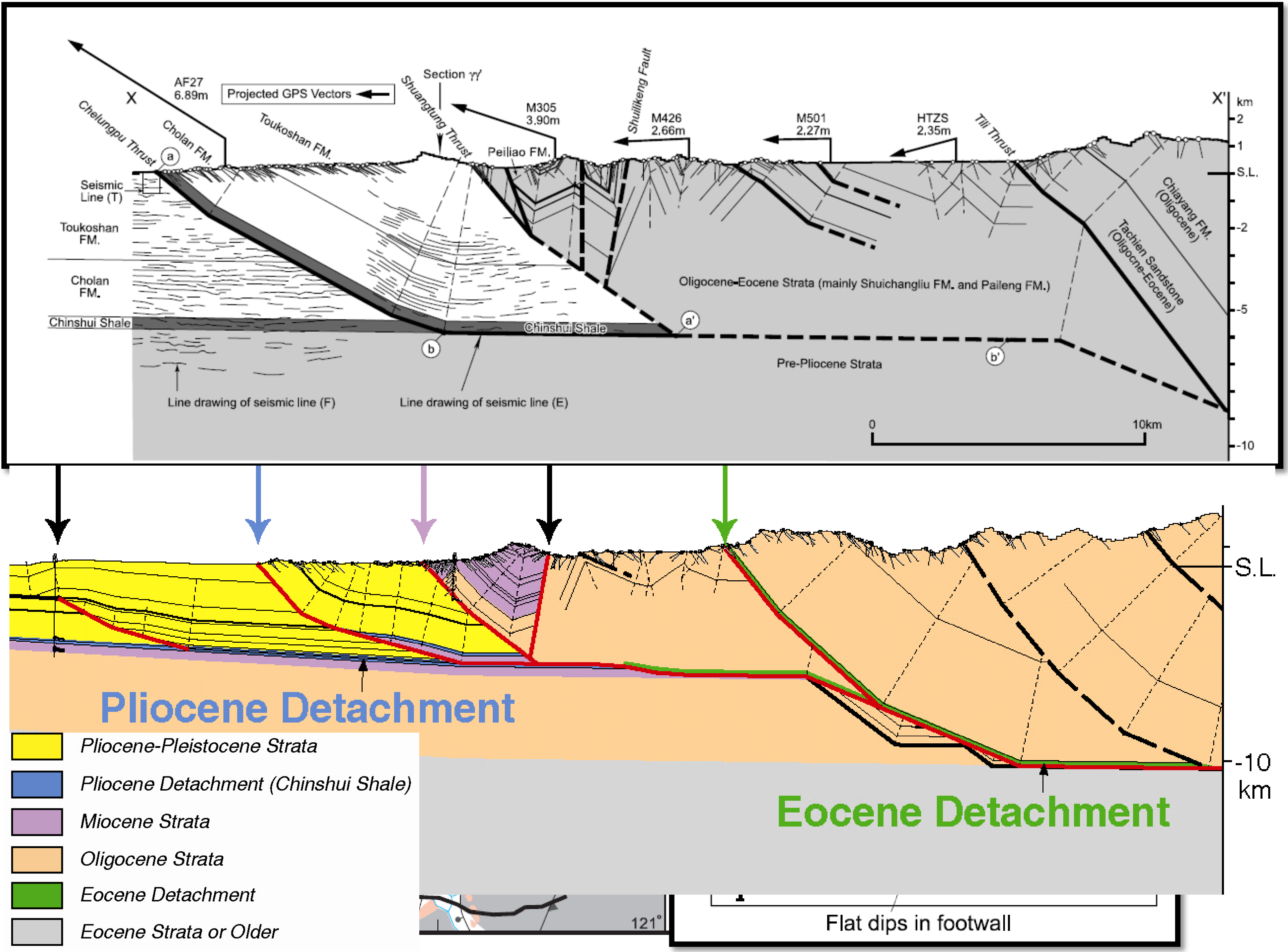
X
X'
km
2
1
S.L.
-2
-5
-10
AF27
6.89m
Projected GPS Vectors
Section γγ'
M305
3.90m
M426
2.66m
M501
2.27m
HTZS
2.35m
Chelungpu Thrust
Cholan FM.
Toukoshan FM.
Shuangtung Thrust
Shuilikeng Fault
Peiliao FM.
Tili Thrust
Seismic Line (T)
Toukoshan FM.
Cholan FM.
Chinshui Shale
Chinshui Shale
Chiayang FM. (Oligocene)
Tachien Sandstone (Oligocene-Eocene)
Oligocene-Eocene Strata (mainly Shuichangliu FM. and Paileng FM.)
Pre-Pliocene Strata
a
a'
b
b'
Line drawing of seismic line (F)
Line drawing of seismic line (E)
0
10km



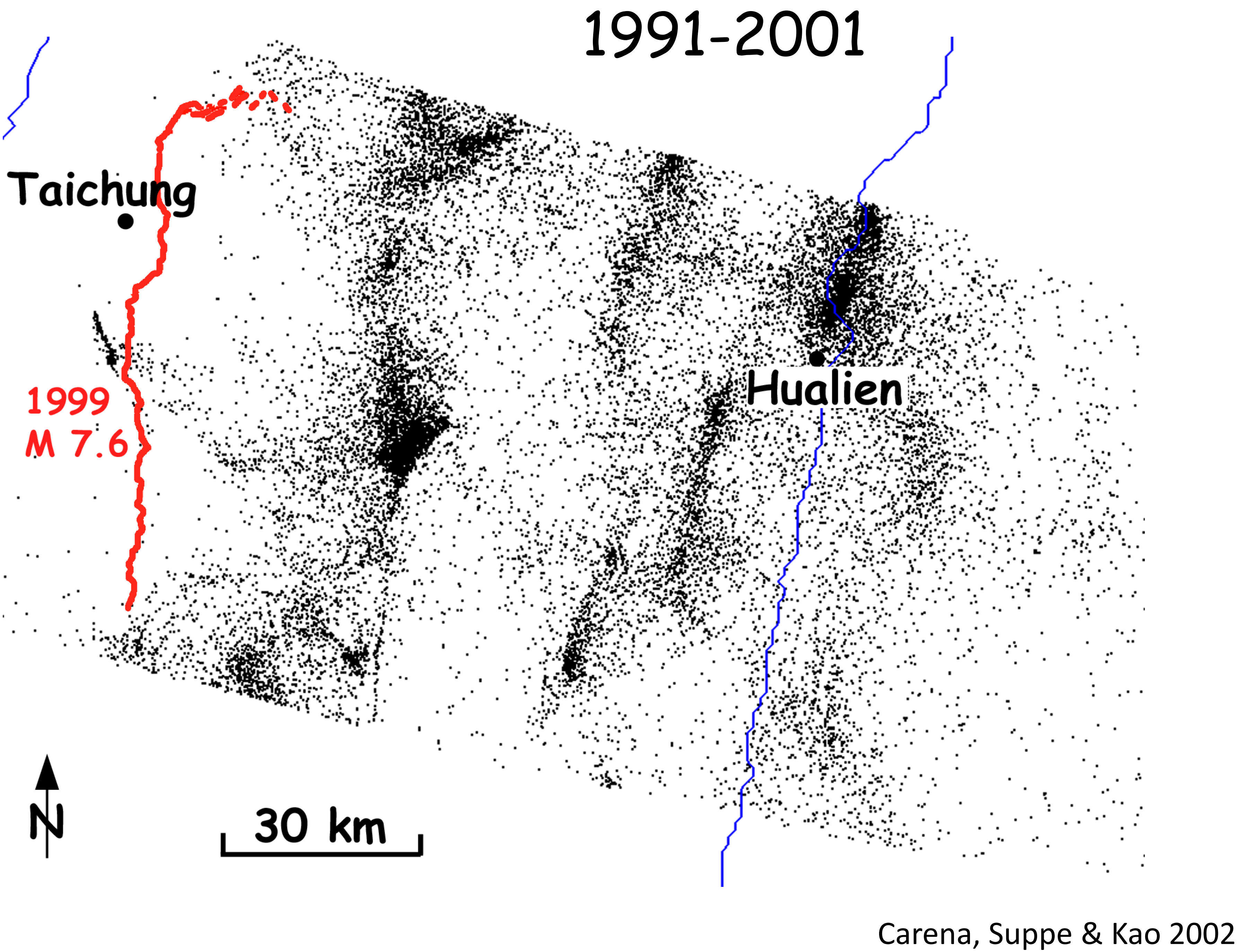
G
PKS-1
X
T
E
F
U
γ'
24°
Tsao -Tun
Yuan-Lin
Pu-Li
X'
Nan -Tou
Tili Thrust
Pakuashan Anticline
V
TSK-1
H
TC-1
Y
Y''
Y'
Z
I
J
Chi-Chi
Sun-Moon Lake
Choshui River
Z'
120° 40'
121°
Alluvium

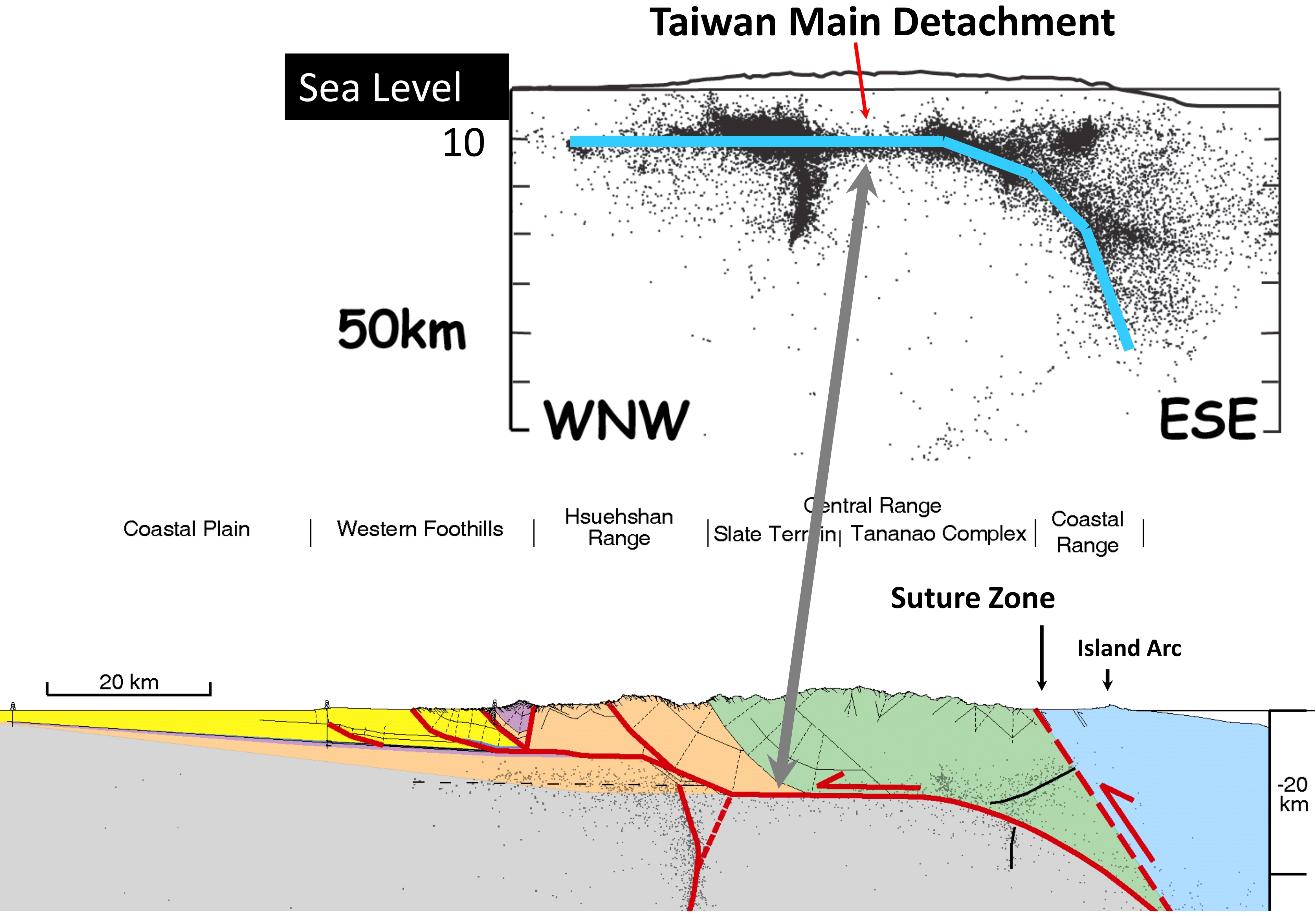


A Classic model (After Roeder, et al., 1978)
The fault is bedding parallel to the hanging wall
T_h
T_f
Flattening dips
Flat dips in footwall

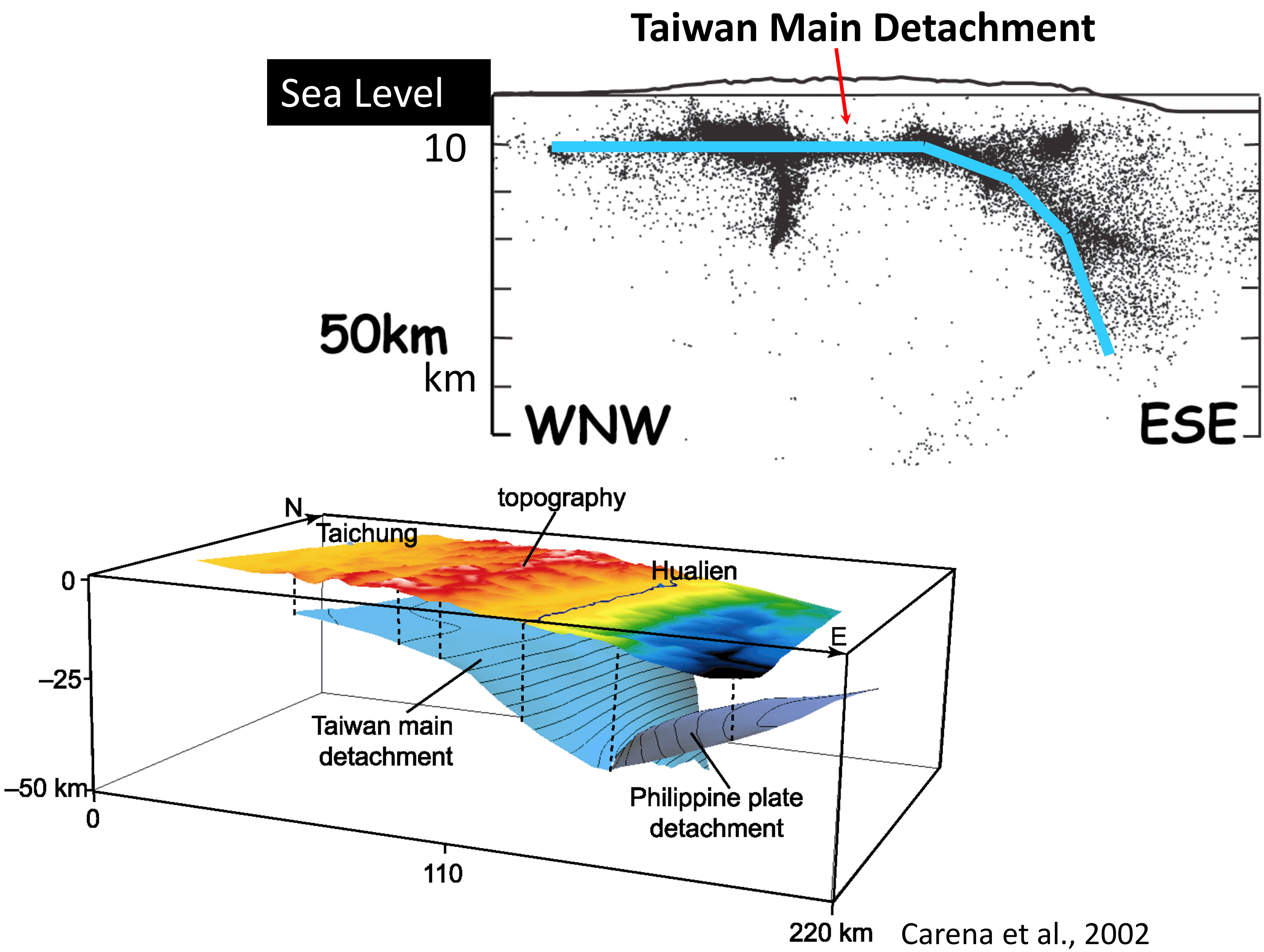


X
AF27
6.89m
Projected GPS Vectors
Section γγ'
M305
3.90m
Shuilikeng Fault
M426
2.66m
M501
2.27m
HTZS
2.35m
Tili Thrust
X'
km
2
1
S.L.
-2
-5
-10
Chelungpu Thrust
Cholan FM.
Toukoshan FM.
Shuangtung Thrust
Peiliao FM.
Seismic Line (T)
Toukoshan FM.
Cholan FM.
Chinshui Shale
Chinshui Shale
Oligocene-Eocene Strata (mainly Shuichangliu FM. and Paileng FM.)
Chiayang FM. (Oligocene)
Tachien Sandstone (Oligocne-Eocene)
Pre-Pliocene Strata
Line drawing of seismic line (F)
Line drawing of seismic line (E)
0
10km
Pliocene Detachment
S.L.
-10
km
Eocene Detachment
Pliocene-Pleistocene Strata
Pliocene Detachment (Chinshui Shale)
Miocene Strata
Oligocene Strata
Eocene Detachment
Eocene Strata or Older
121°
Flat dips in footwall

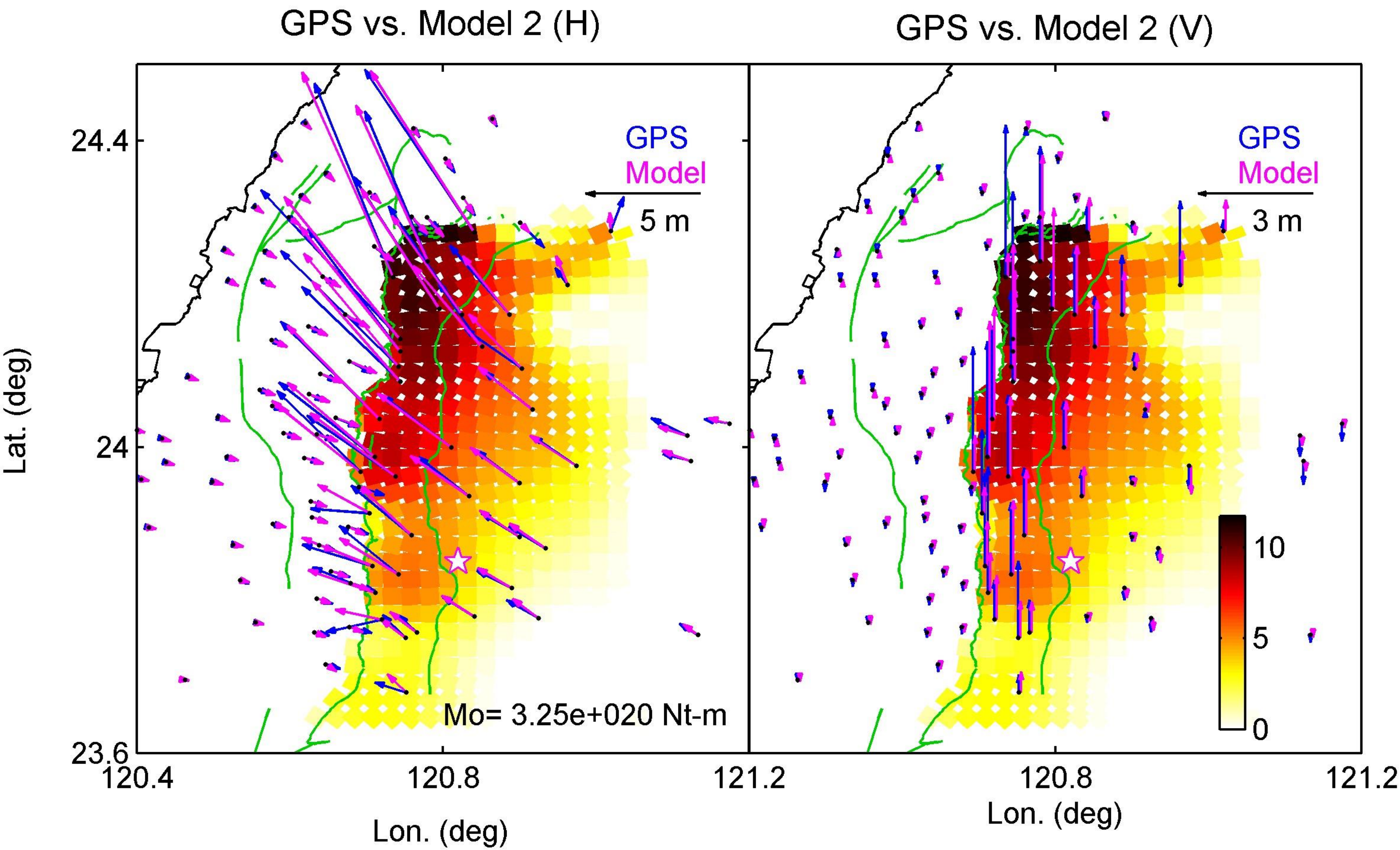

1991-2001
Taichung
1999
M 7.6
Hualien
N
30 km
Carena, Suppe & Kao 2002



Carena et al., 2002

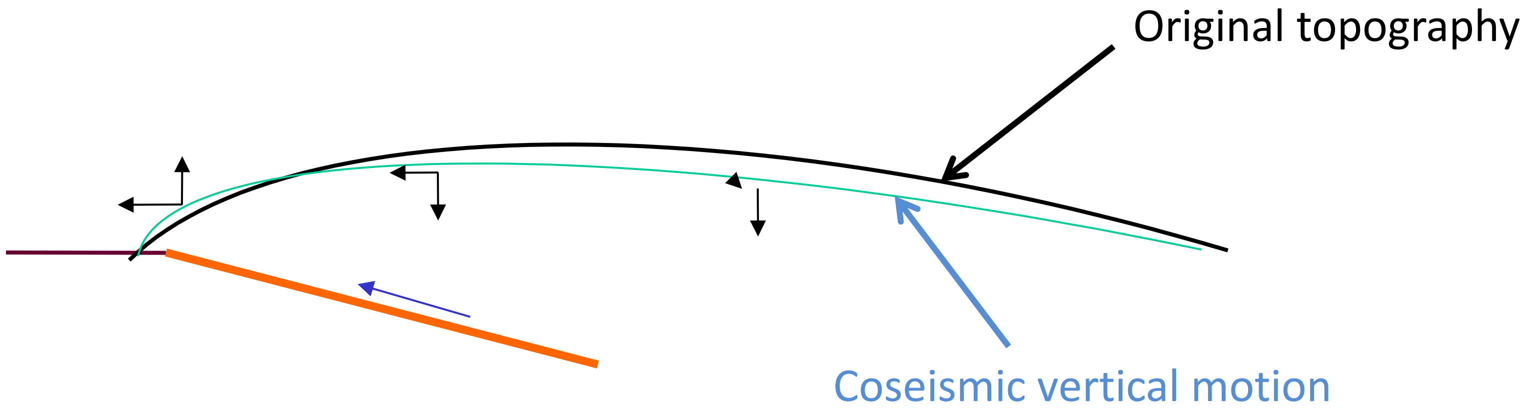


Carena et al., 2002

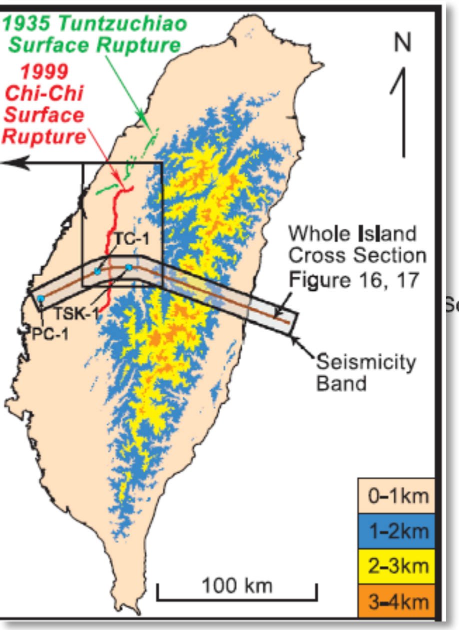


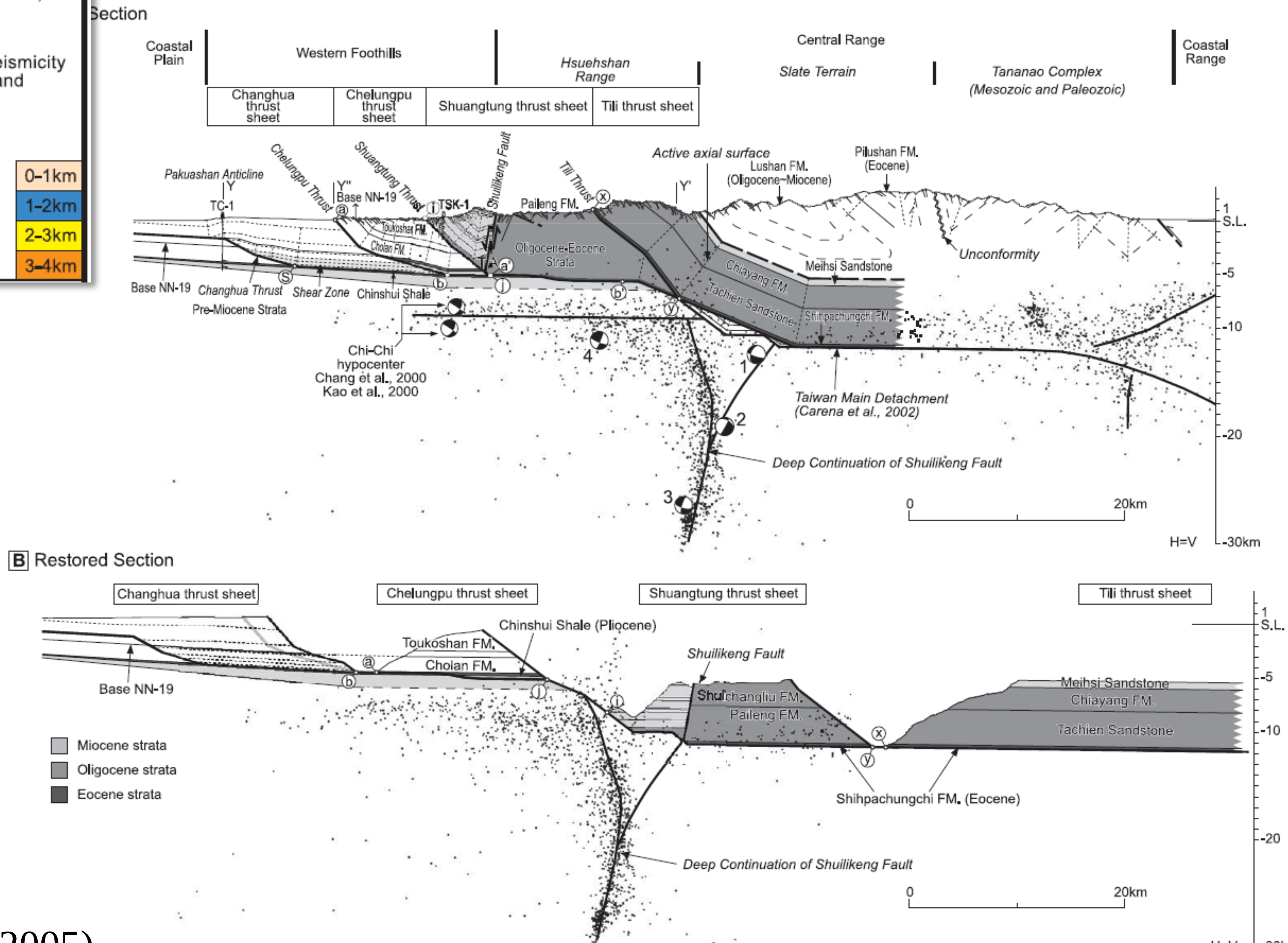
Hsu et al. (2003)

Mechanism of Rebound Thrust



During the Chi-Chi earthquake the Central Range subsided about 60 cm. But average uplift rate of the Central Range is ~1 cm/yr. If recurrence interval is about 1000 years, then the mountain is uplifting with a net of 9.4 (10-0.6) m during last 1kyr!



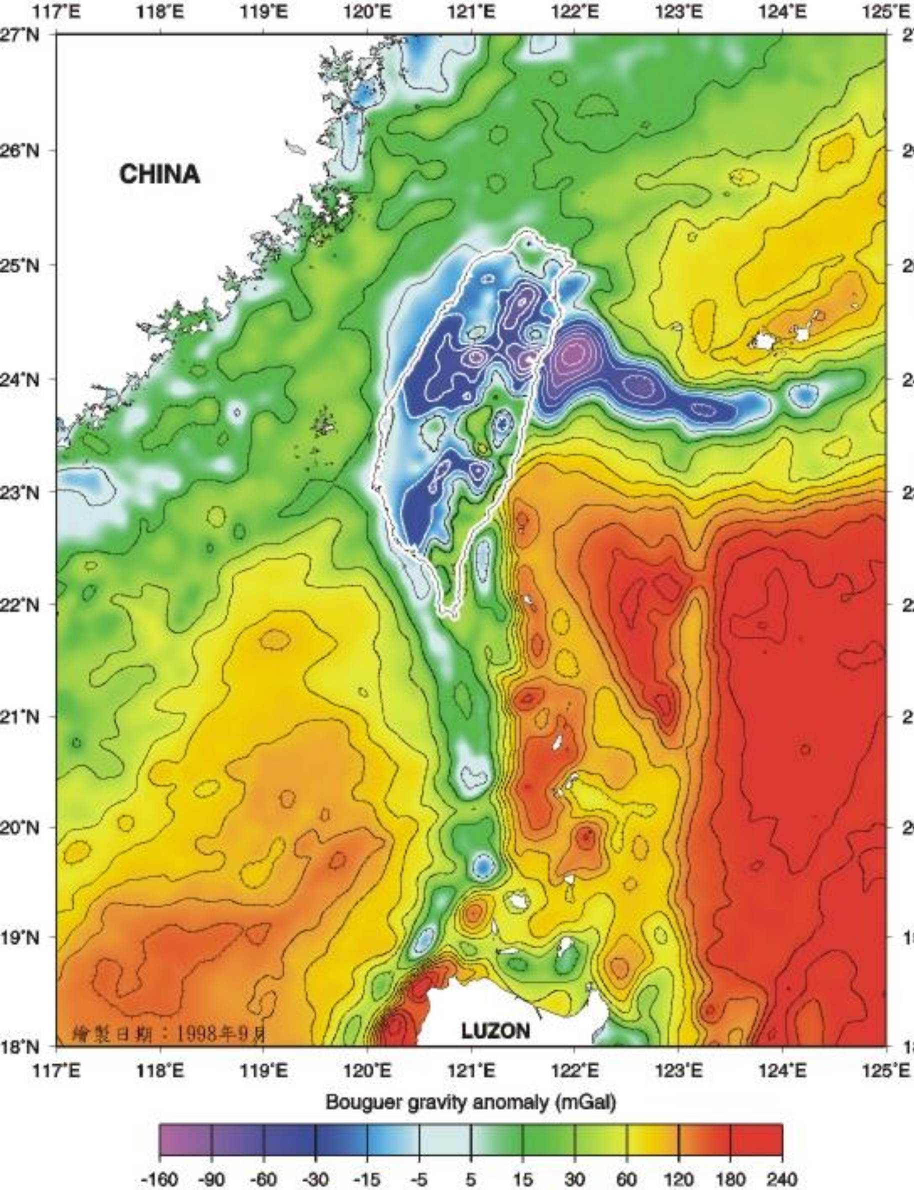


(Yue et al., 2005)

Decollement faults in western Taiwan Fold and Thrust Belt

- Field Evidences
- Locations of detachments in Taiwan
  - Pre-Miocene : bottom of Wuchihshan Fm
  - Miocene: Nanchuang Fm.
  - Pliocene: Chinshui Fm.
- Depth of basal Detachment ~10 km depth

台灣周圍布蓋重力異常圖
Bouguer Gravity Anomaly around Taiwan



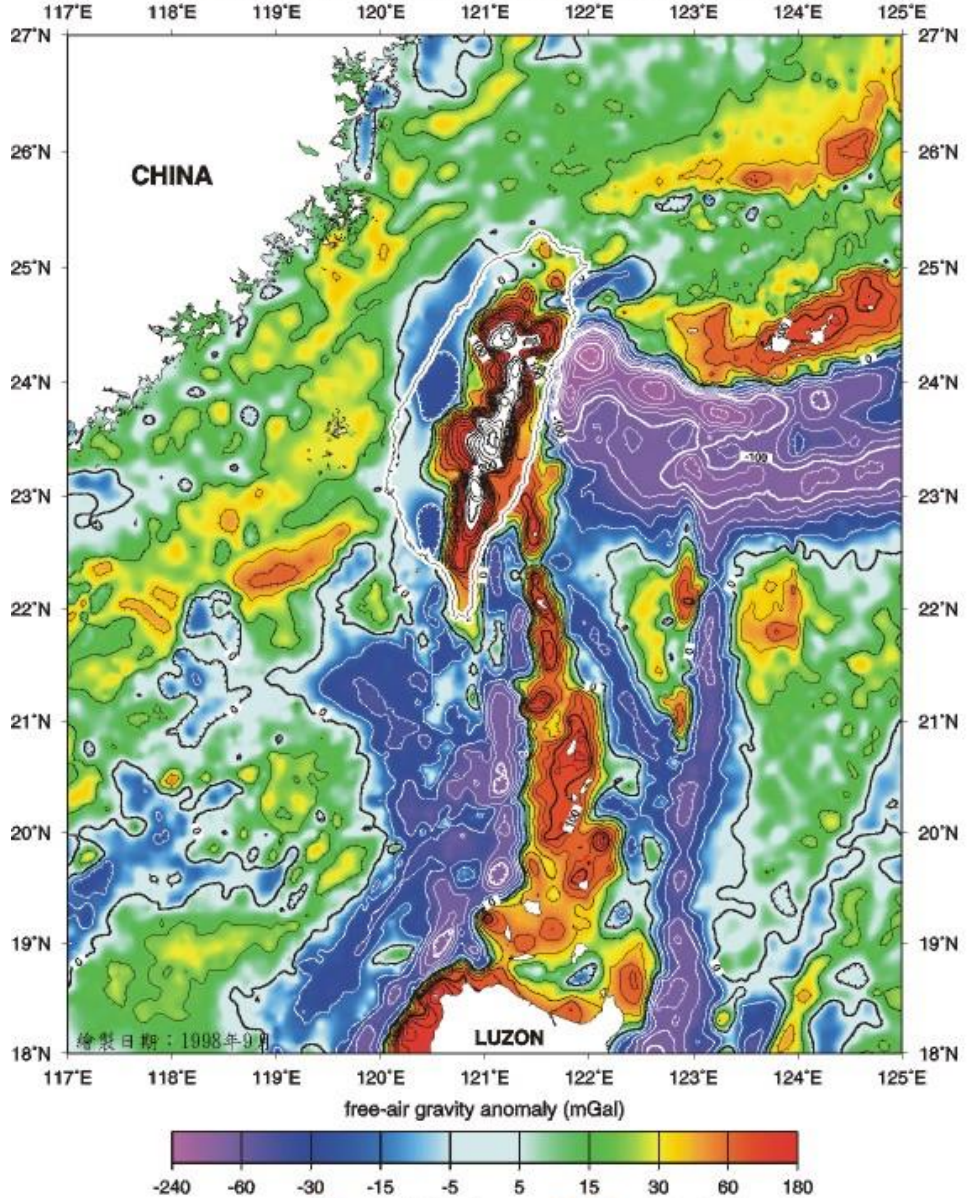
編製單位：國立台灣大學 海洋研究所　國家海洋科學研究中心 海洋資料庫

資料來源及整編請參考：

Hsu, S. K., C. S. Liu, C. T. Shyu, S. Y. Liu, J. C. Sibuet, S. Lallemand, C. Wang, and D. Reed, 1998: New gravity and magnetic anomaly maps in the Taiwan-Luzon region and their preliminary interpretation., TAO, Vol. 9, No. 3, 509-532.

ODB_CD003: gravity/hsu_bg_1am.grd

台灣周圍自由空間重力異常圖
Free-Air Gravity Anomaly around Taiwan



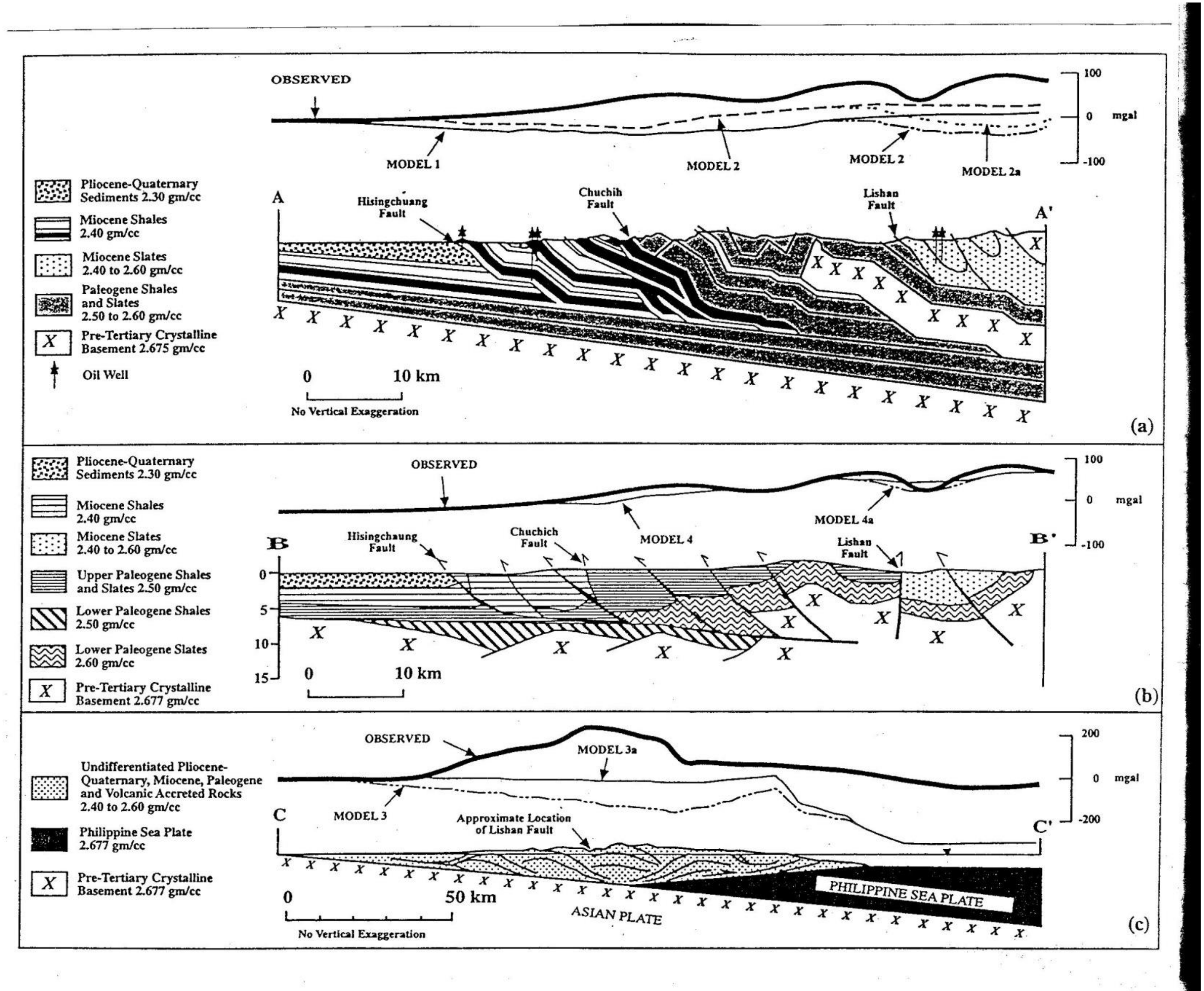
編製單位：國立台灣大學 海洋研究所　國家海洋科學研究中心 海洋資料庫

資料來源及整編請參考：

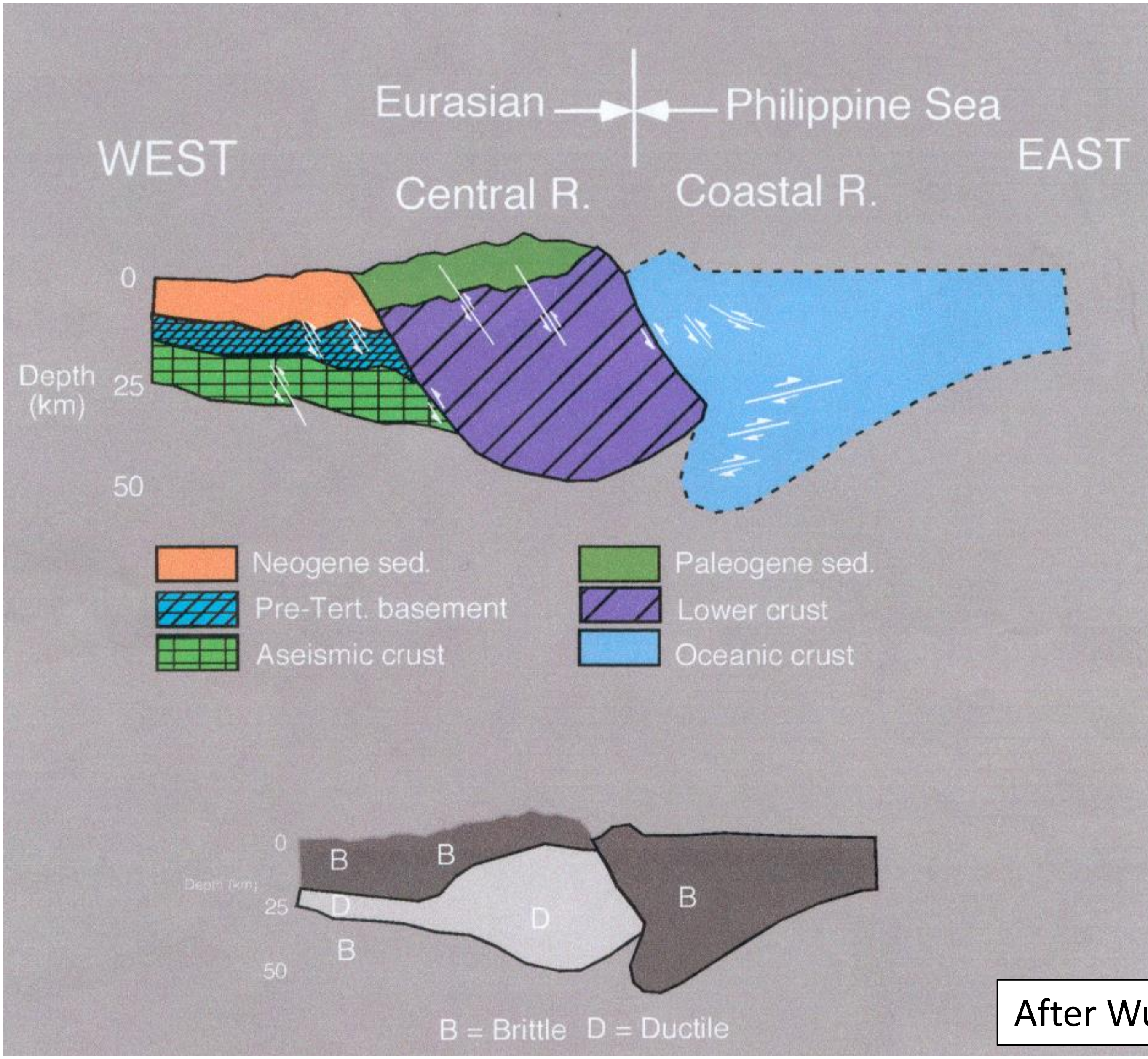
Hsu, S. K., C. S. Liu, C. T. Shyu, S. Y. Liu, J. C. Sibuet, S. Lallemand, C. Wang, and D. Reed, 1998: New gravity and magnetic anomaly maps in the Taiwan-Luzon region and their preliminary interpretation., TAO, Vol. 9, No. 3, 509-532.

ODB_CD003: gravity/hsu_grav_1am.grd

Gravity model shows that the material undernearth Central Range is not compensated by thin-skinned tectonics



2. Characteristics of Thick-skinned Model

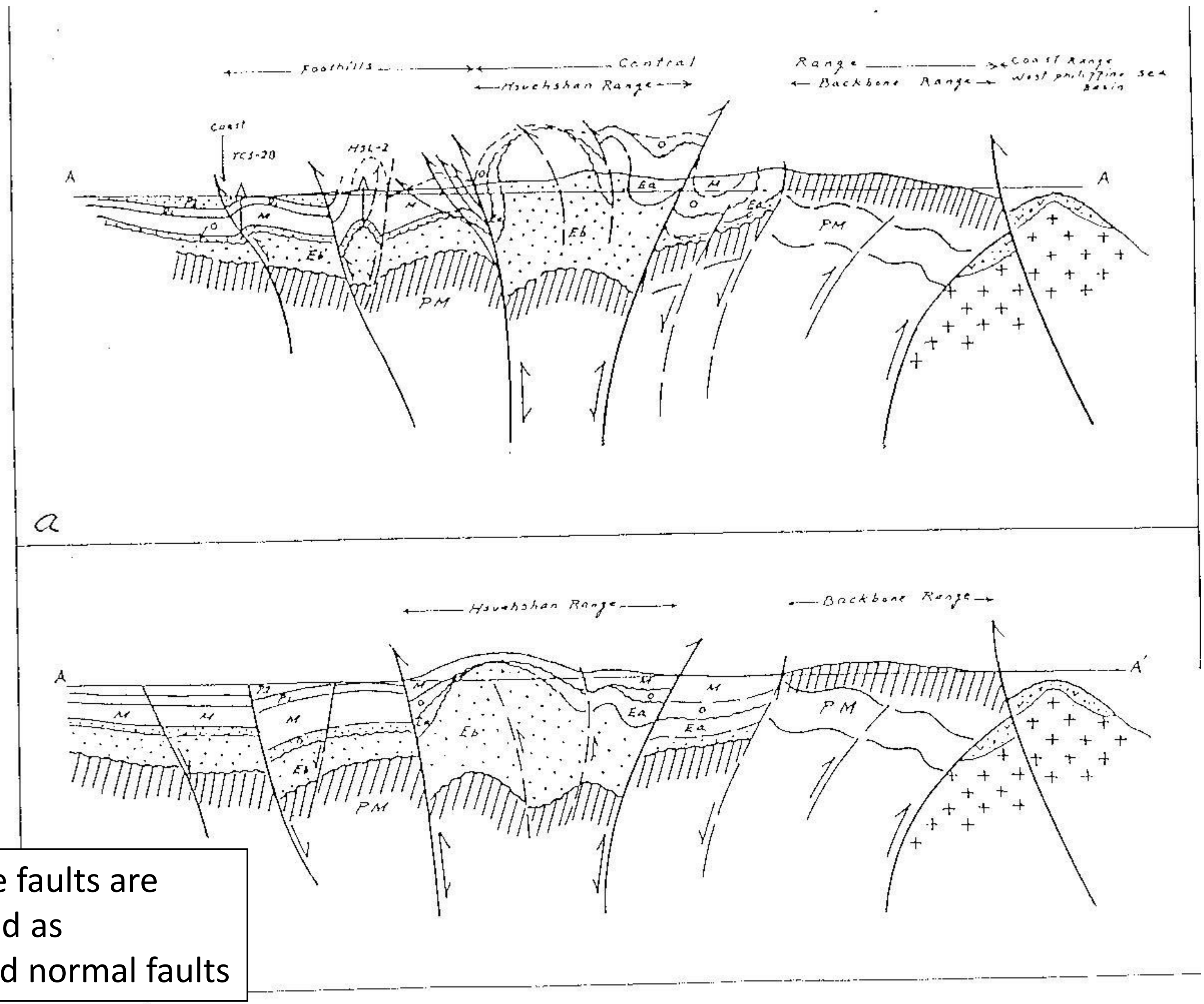


After Wu et al., 1997

2. Characteristics of Thick-skinned Model

- Vertical Uplift dominant – vertical tectonics, uniform uplift
- Geological boundary (i.e., Foothills/ Slate Belt) would be a major displacement boundary
- High-angle reverse faults and also reactivated normal faults
- Low T, high P and high density material beneath CR (Lithospheric thickening)-Roots beneath CR (isostacy or dynamic)
- Thickening of PH into Luzon island
- Sedimentary/basement is coupled, Out-of-Plane movement

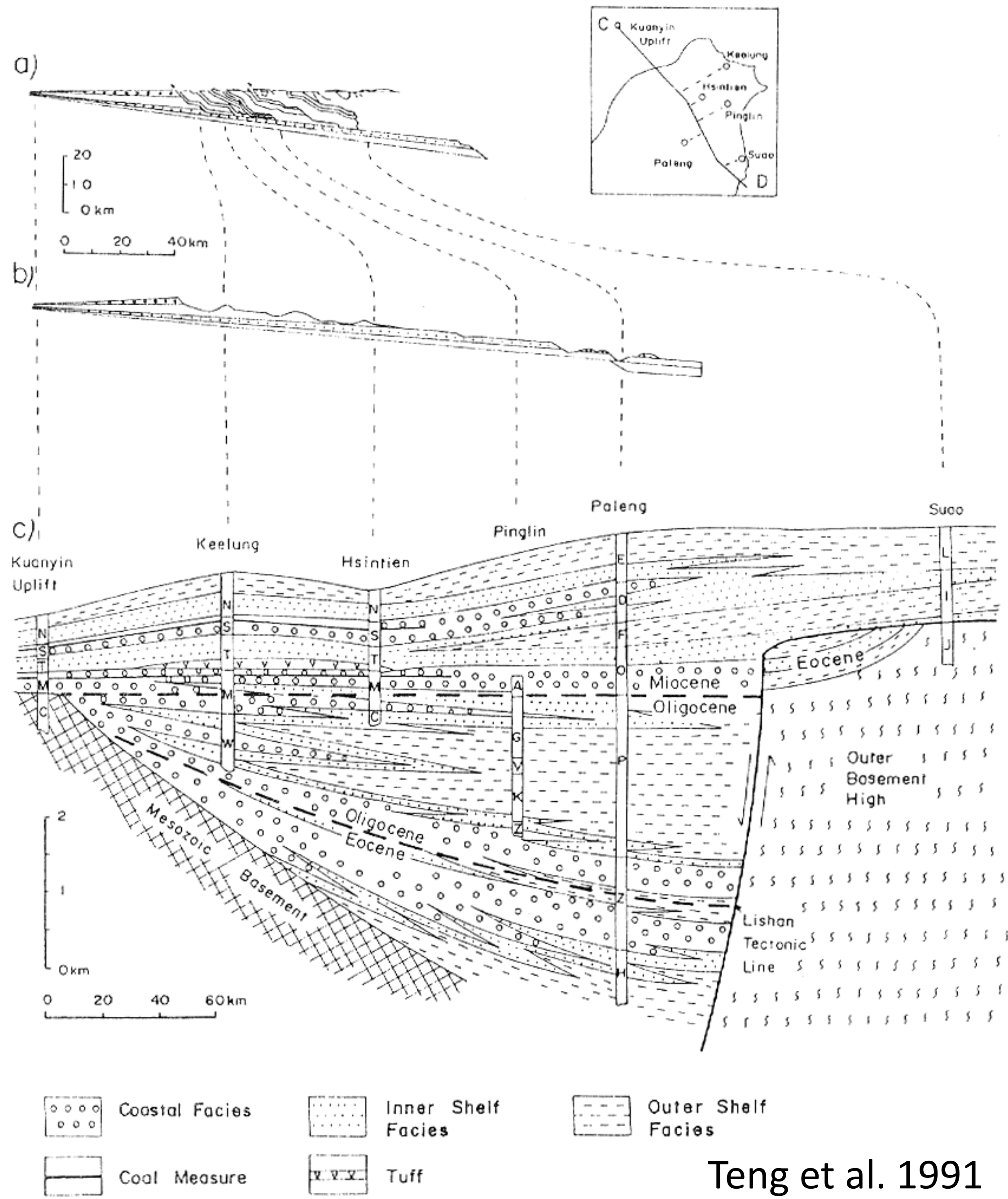
Thick-skinned interpretation of structures in Central and north Taiwan



All reverse faults are interpreted as reactivated normal faults

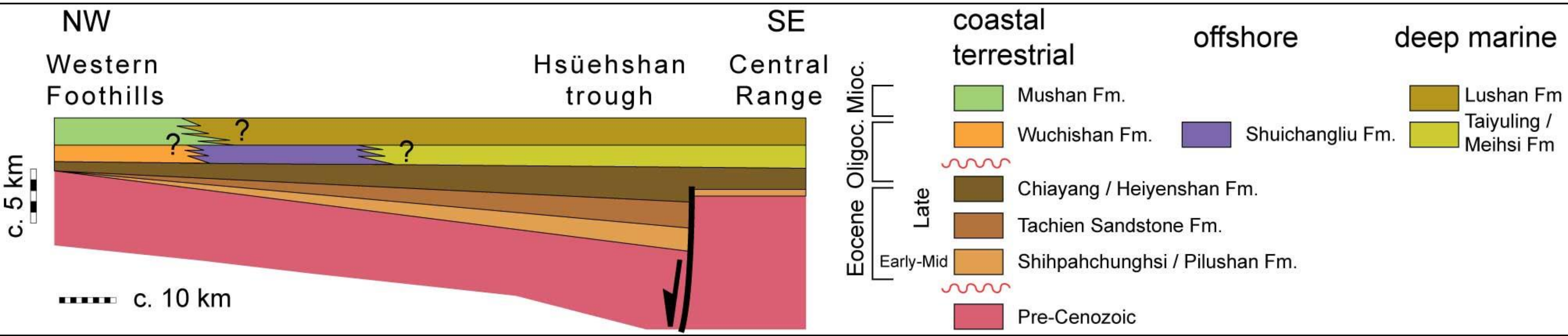
Stratigraphic observations

The Hsüehshan Range: a Paleogene Graben

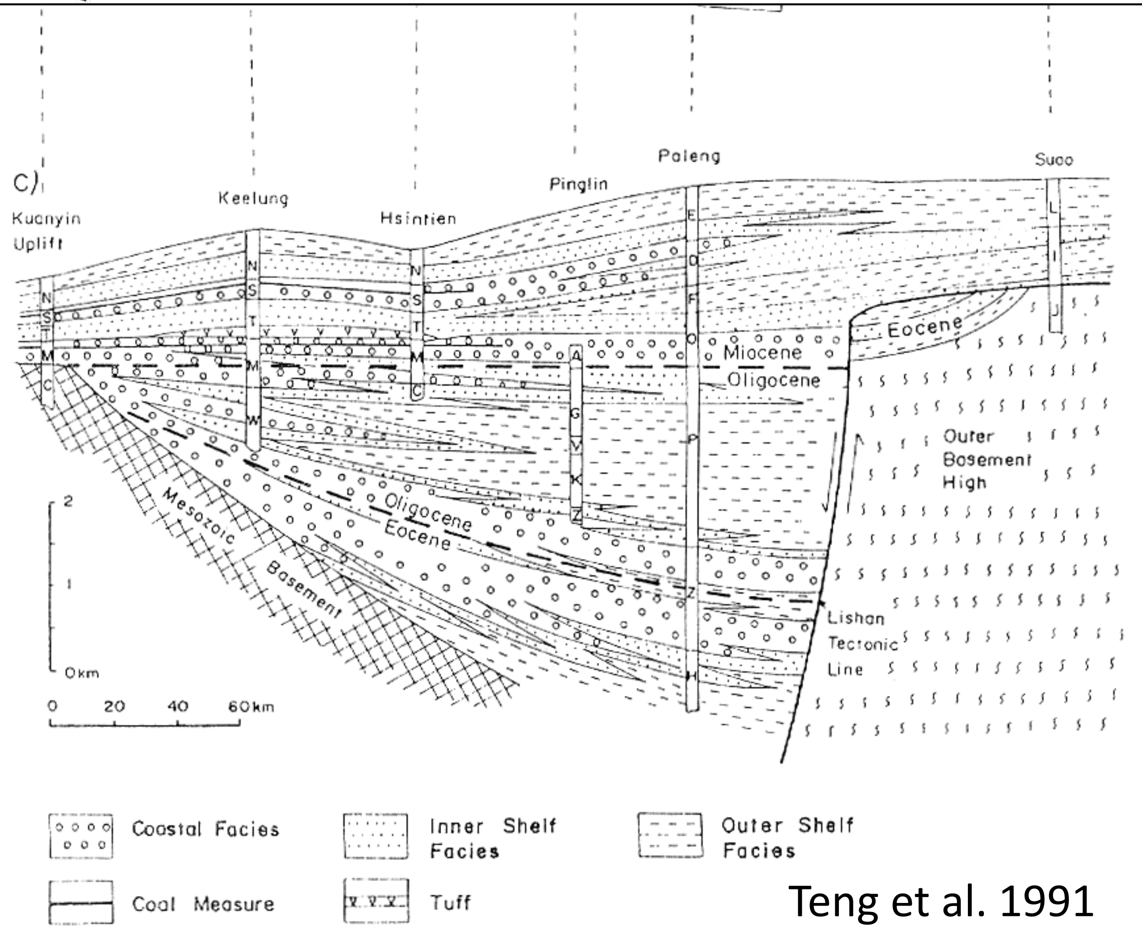


Teng et al. 1991

Stratigraphic observations



The Hsüehshan Range: a Paleogene Graben



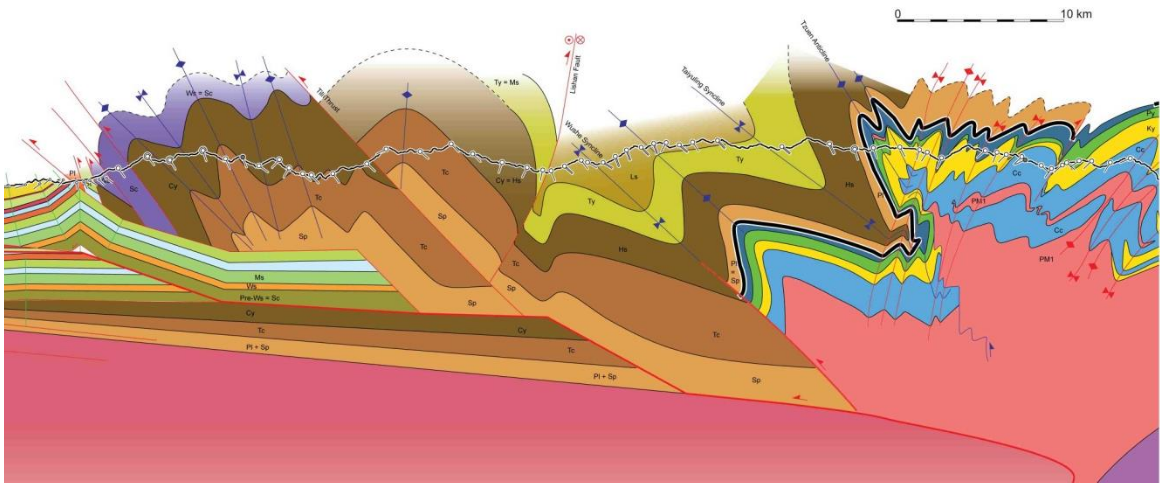
Teng et al. 1991

Stratigraphic observations

Thick-skinned Tectonics:

Hsüehshan Range

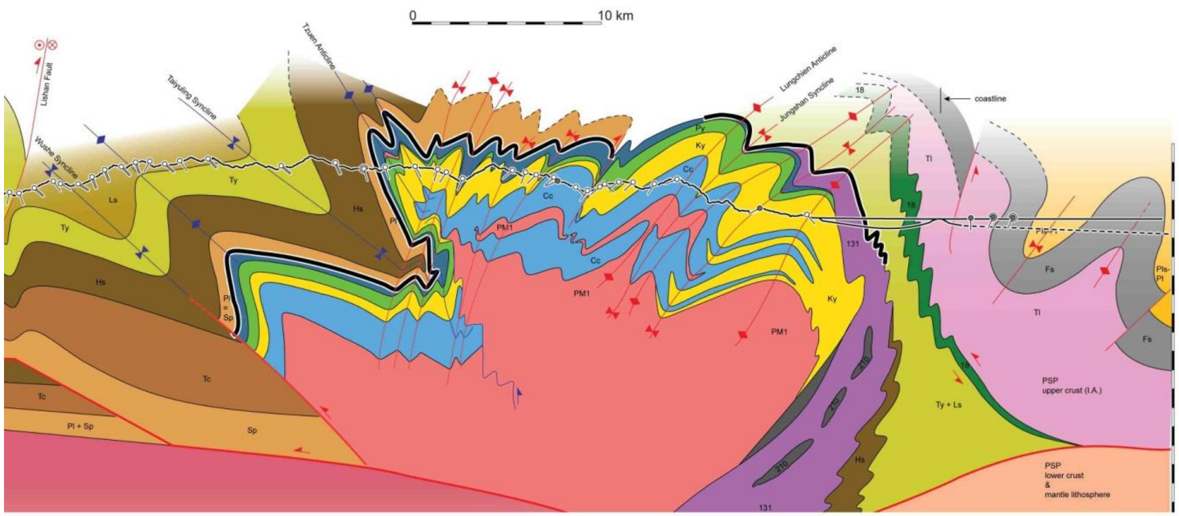
• an inverted Paleogene graben



Central Range

• the easterly adjacent basement high

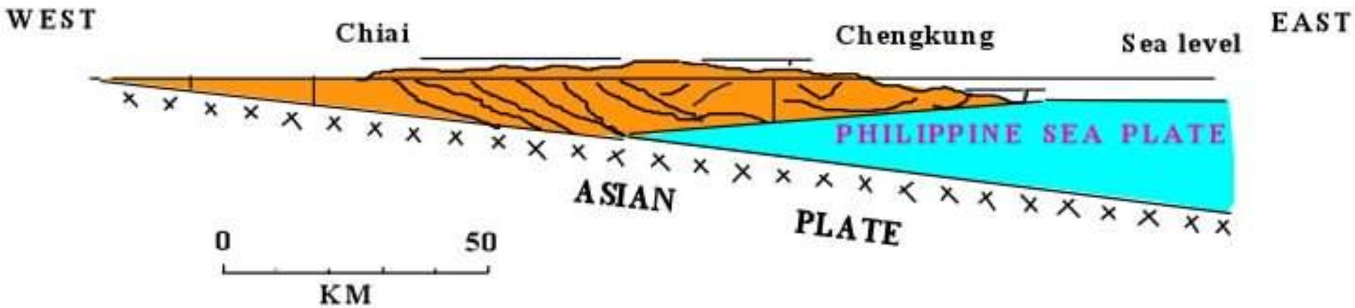
• exposed in a crustal-scale backfold that overprints earlier W-facing structures



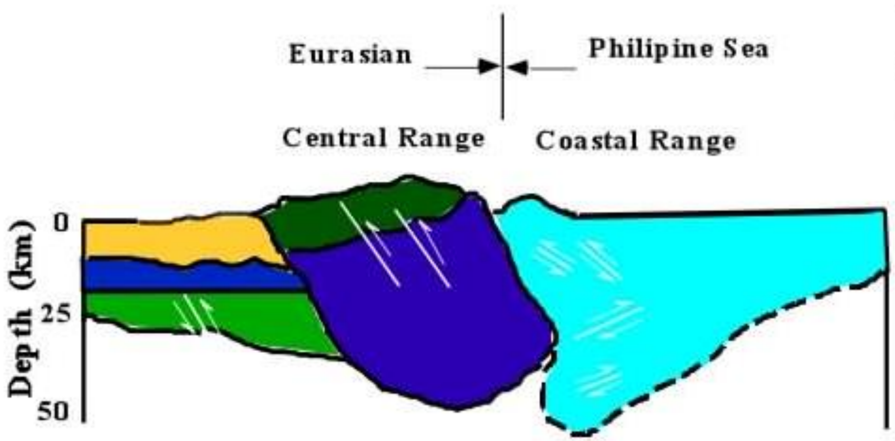
3.Modified Thin-skinned Tectonics

- Mountain Collapse in the Central Range (east rim) and Coastal Range– Crespi and Byrne
- Crustal Peeled-off Model (黃奇瑜)
- Subducted Oceanic crust – Remnant arc (Chemenda, Malavieille)
- Slab break-off（板塊拆離）of EU plate (Teng, Lallemand, Wang)
- Crustal exhumation: (Lin)
- Many others

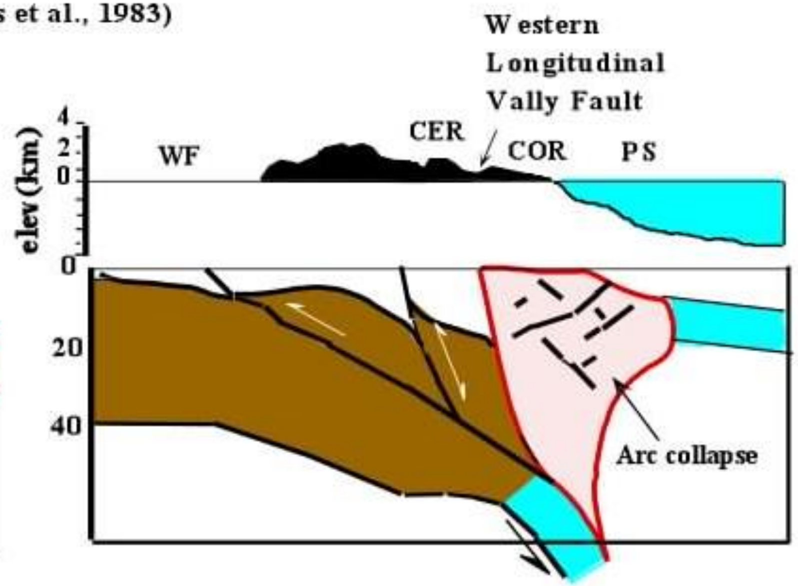
Geodynamic Models of Taiwan Mountain Belt



A Thin-skinned (Suppe, 1980; Davies et al., 1983)



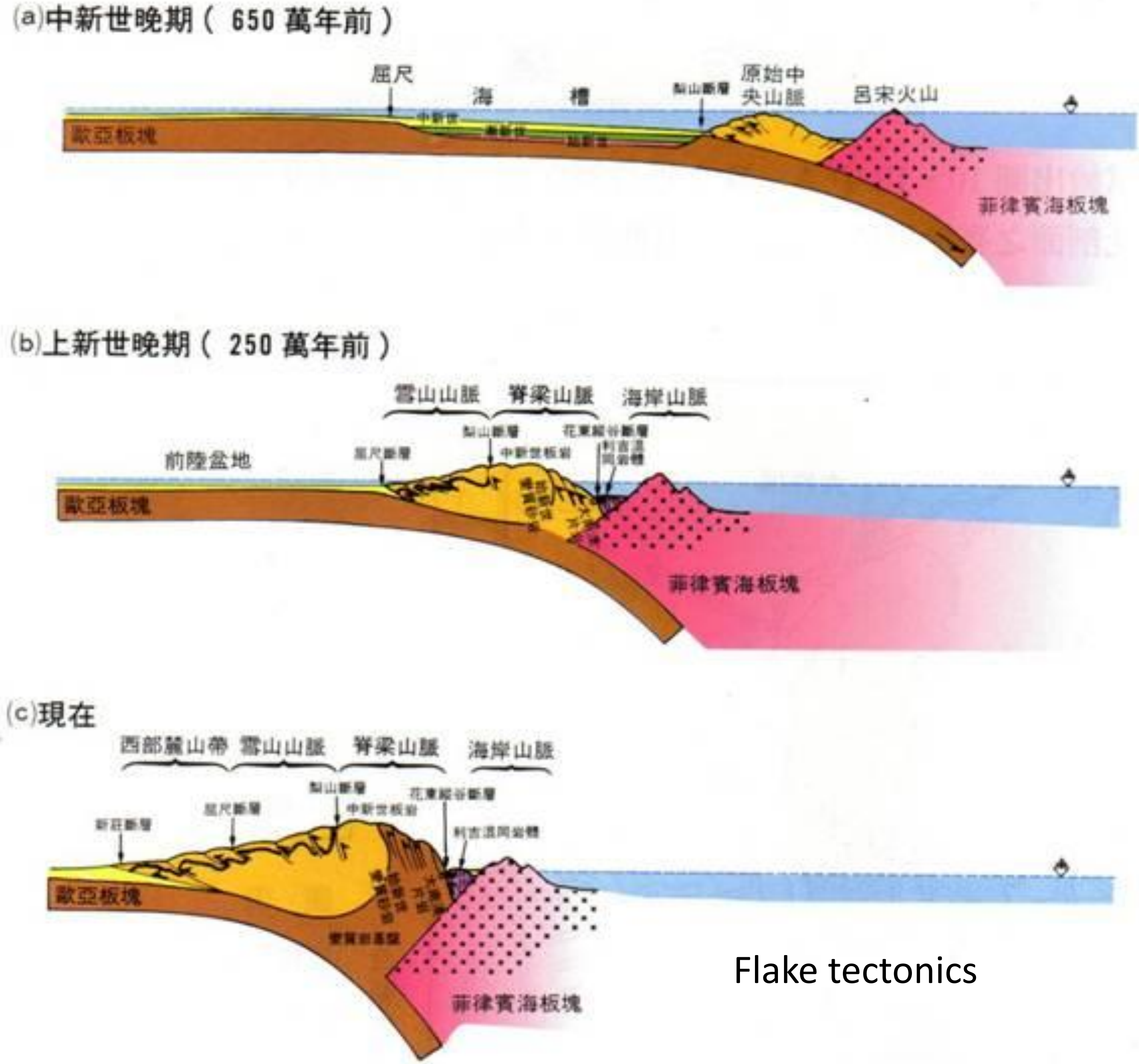
B Lithospheric thickening (Wu, et al., 1997)



C Crustal extension in the Backbone Range (Byrne, 1995)

台灣式碰撞

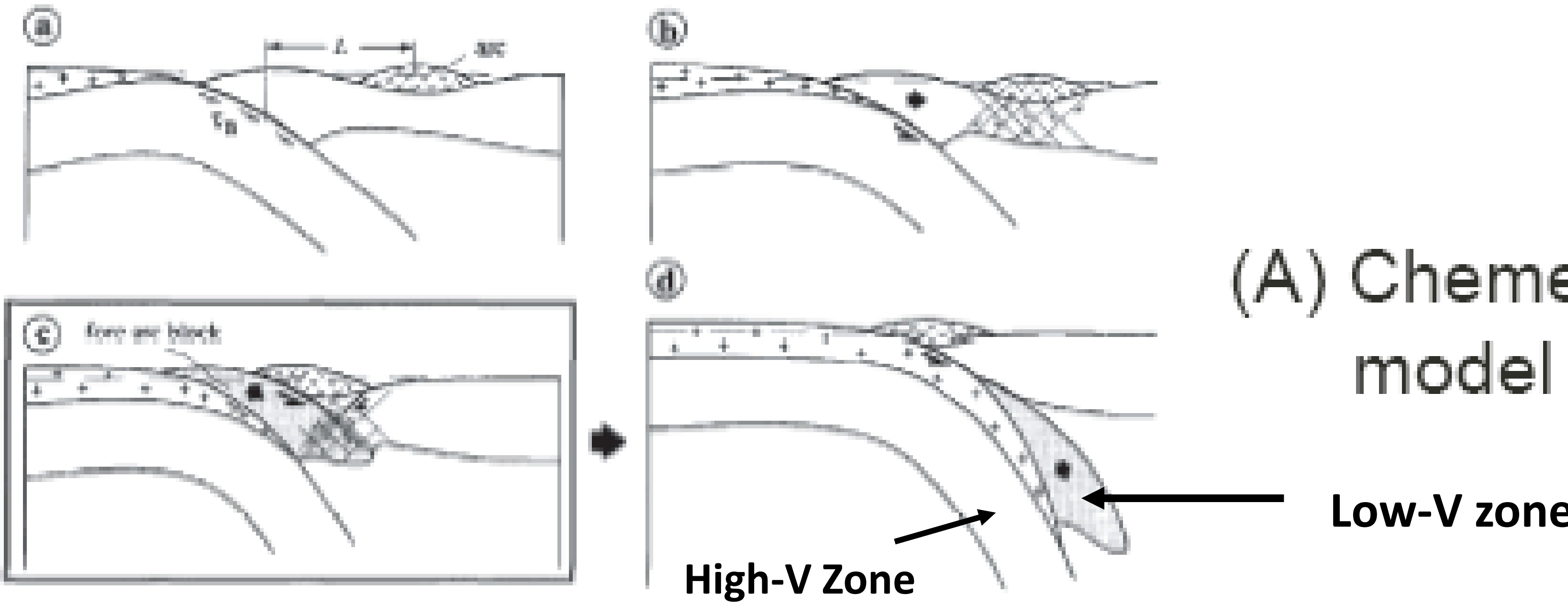
(黃奇瑜)



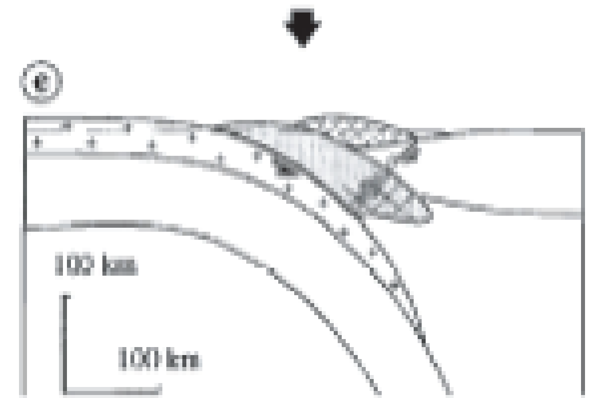
Flake tectonics

Eurasian Continent was peeled off at upper part whereas subducted in the lower part

Subducted Oceanic crust – Remnant arc (Chemenda, Malavieille)

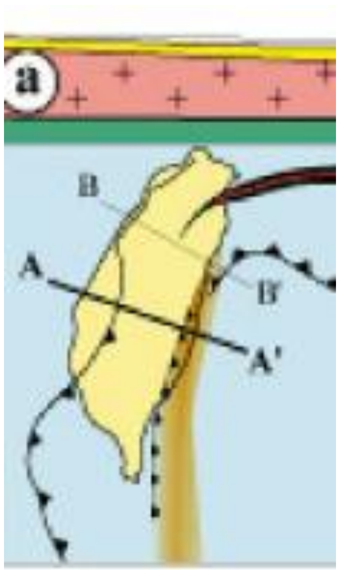


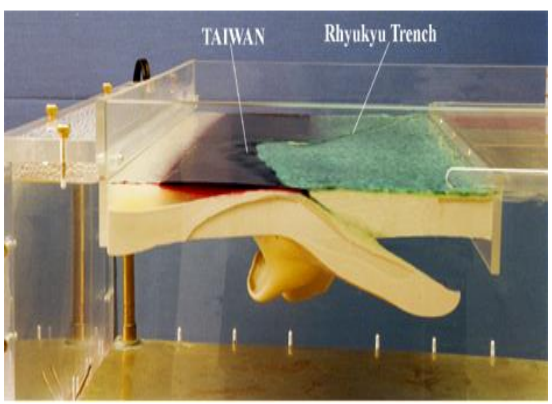
(A) Chemenda model

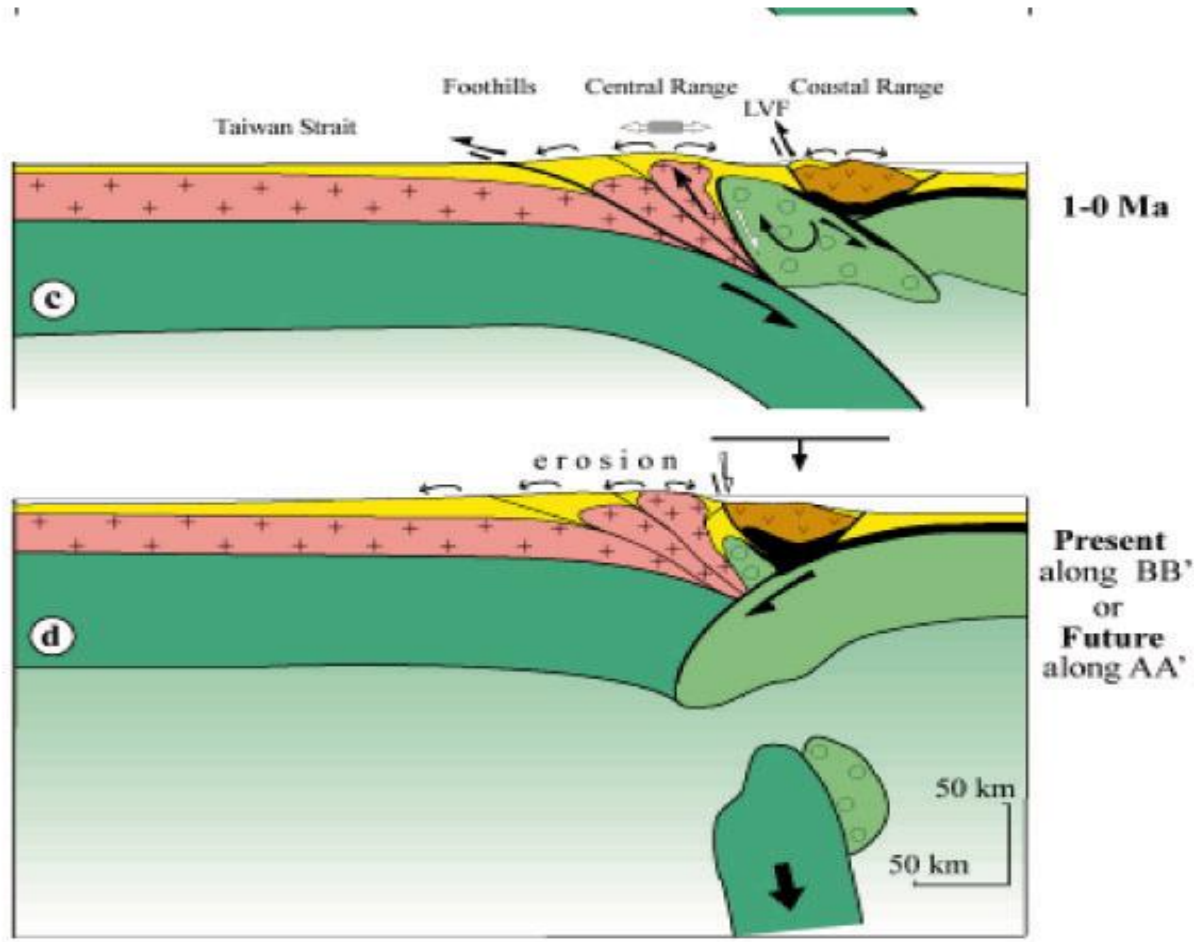


(A) Model of arc-continent collision from Chemenda et al., 1997b. The critical point of this lithospheric-scale model is that the arc is a zone of weakness, so that when thickened crust of the continental margin enters the subduction zone the forearc block becomes entrained with it and detaches from the upper plate at the arc. This model predicts that both the forearc block and continental margin crust may be found beneath the remnant arc terrane and the oceanic plate

Continental Subduction and Slab Break-off

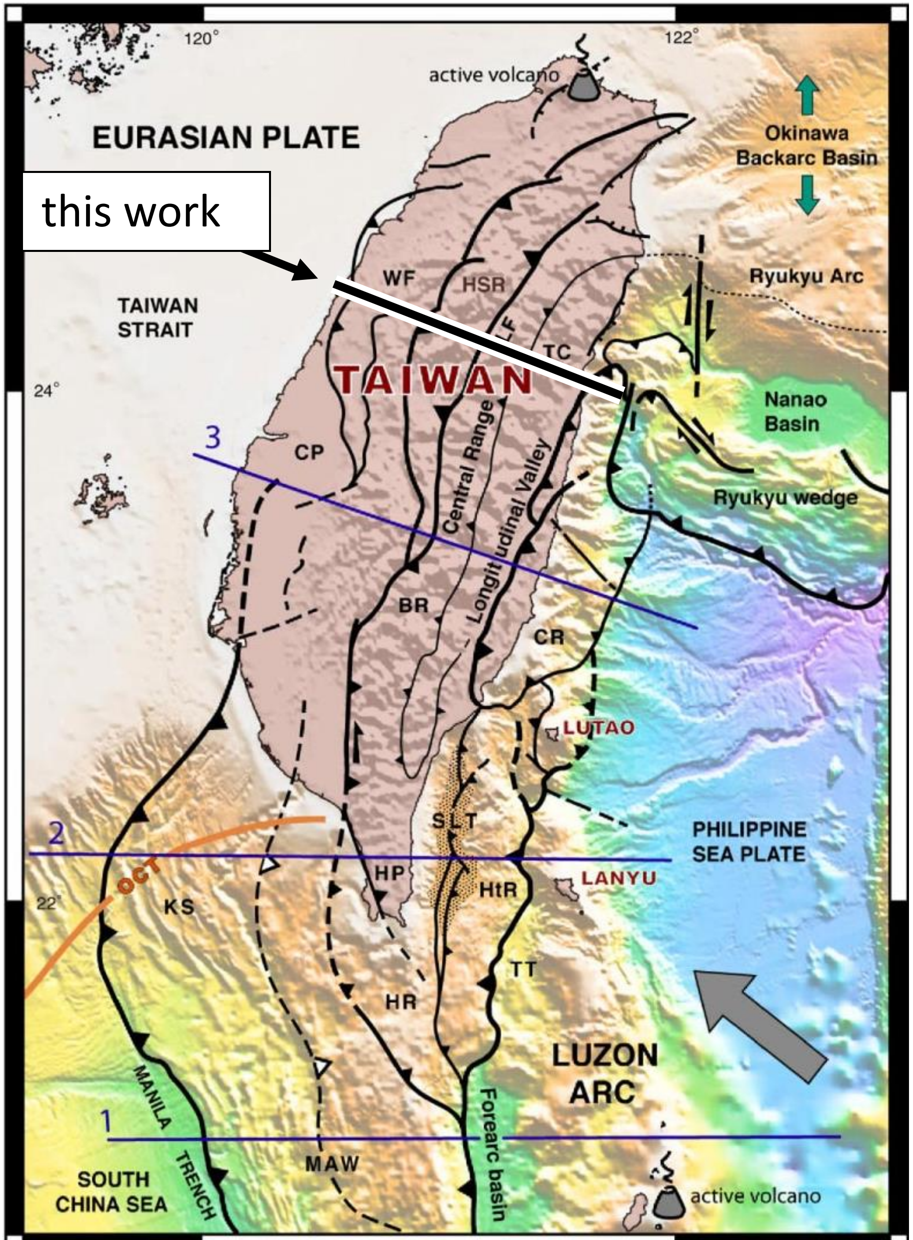


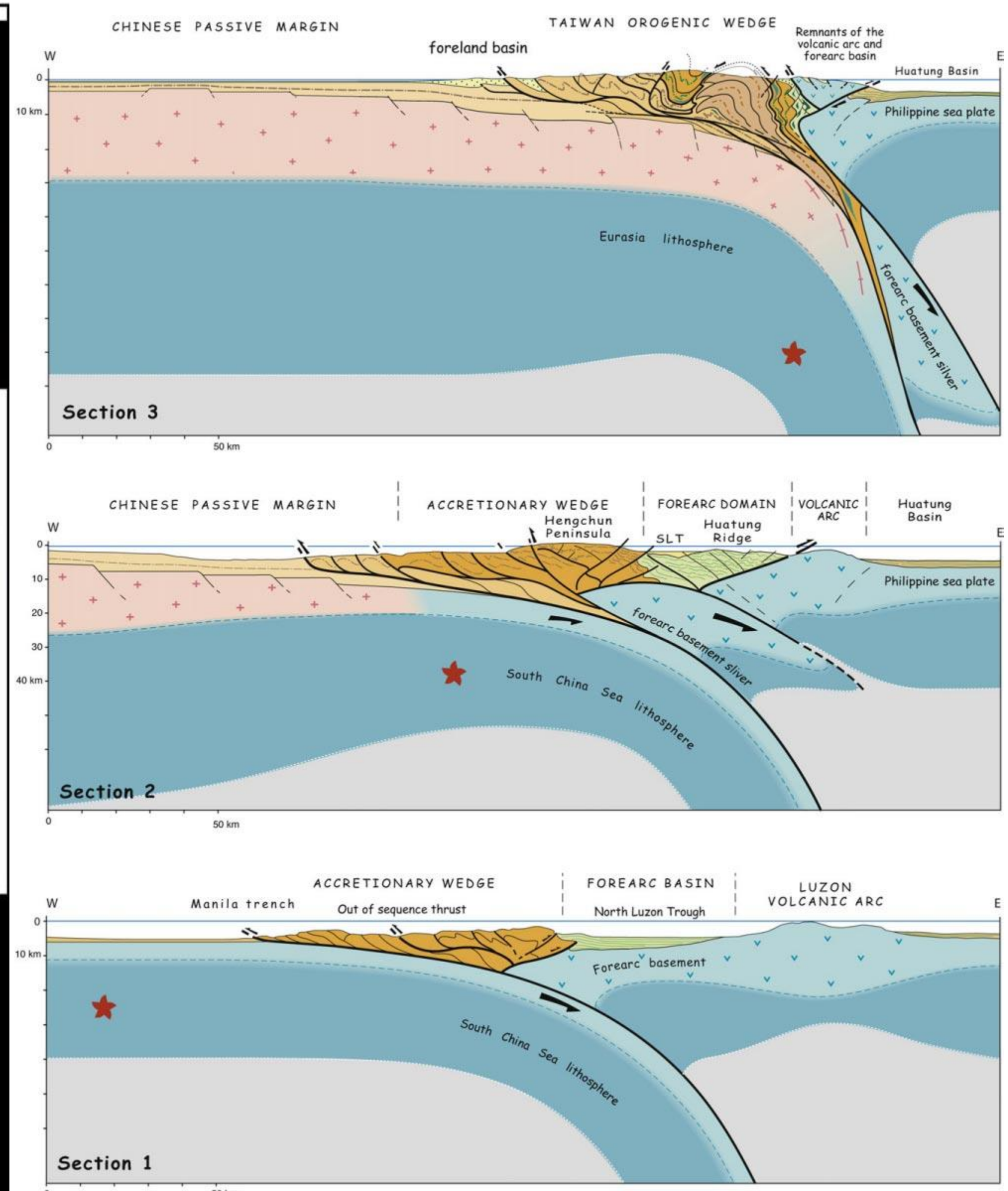




Chemenda et al., 2001

Diachroneity of continent-island arc collision

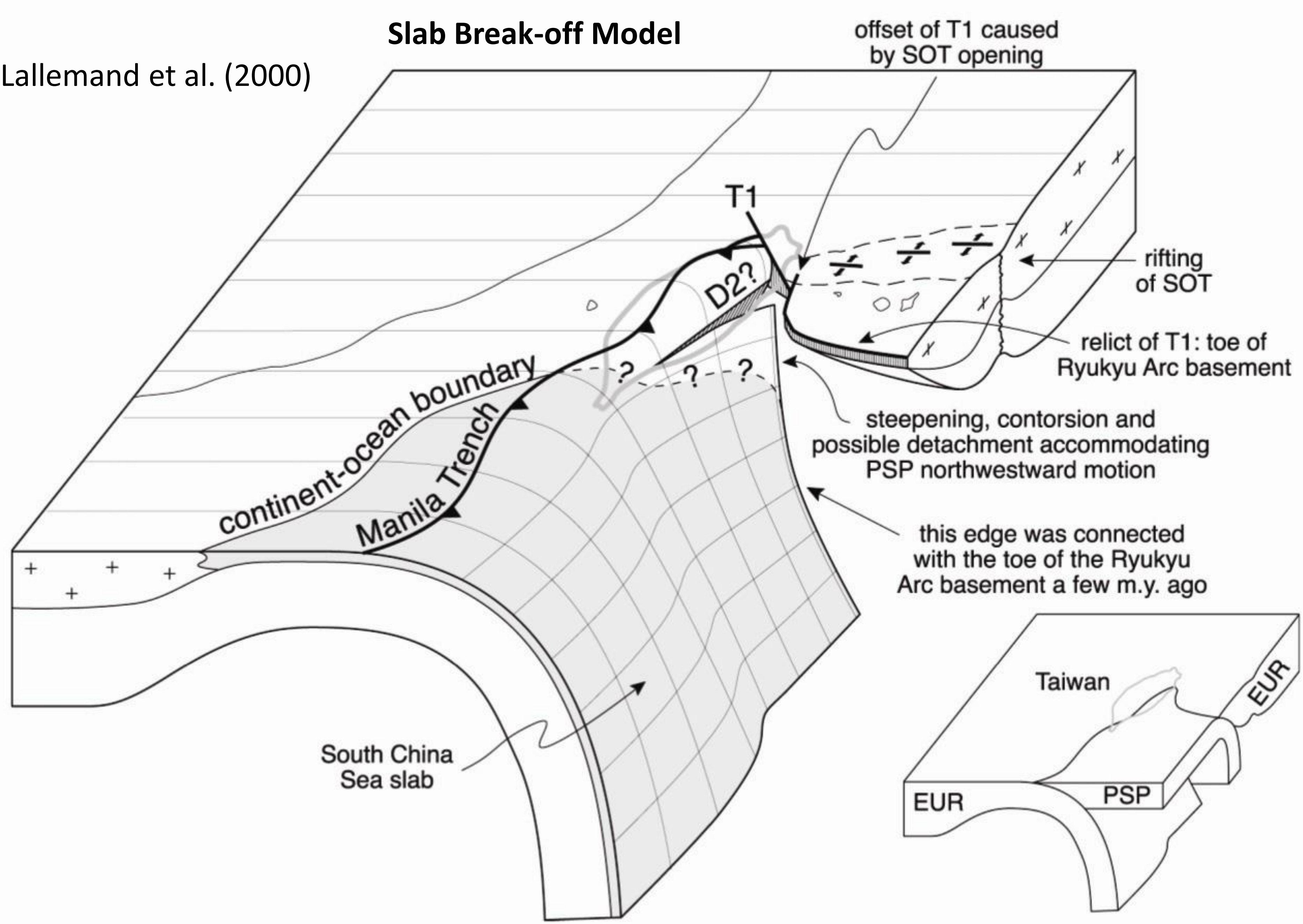


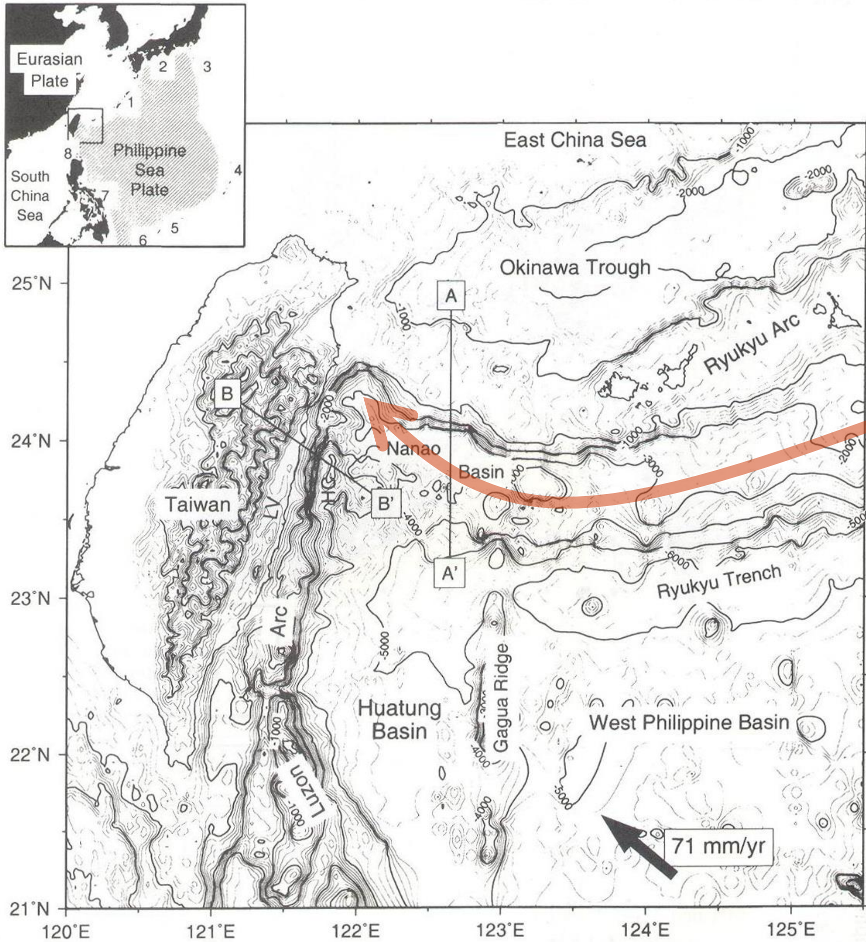


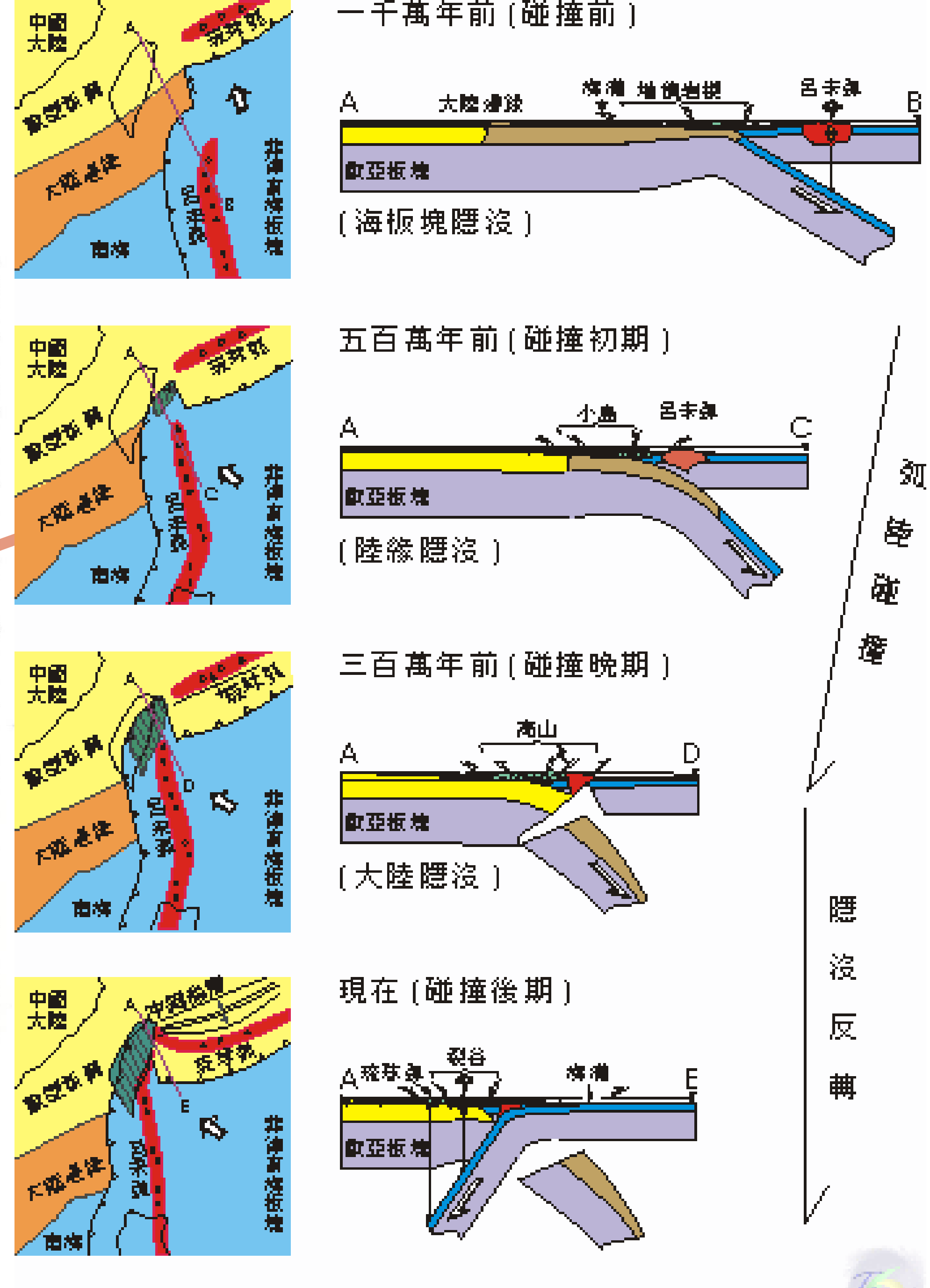
Malavielle & Trullenque 2008

Slab Break-off Model

Lallemand et al. (2000)



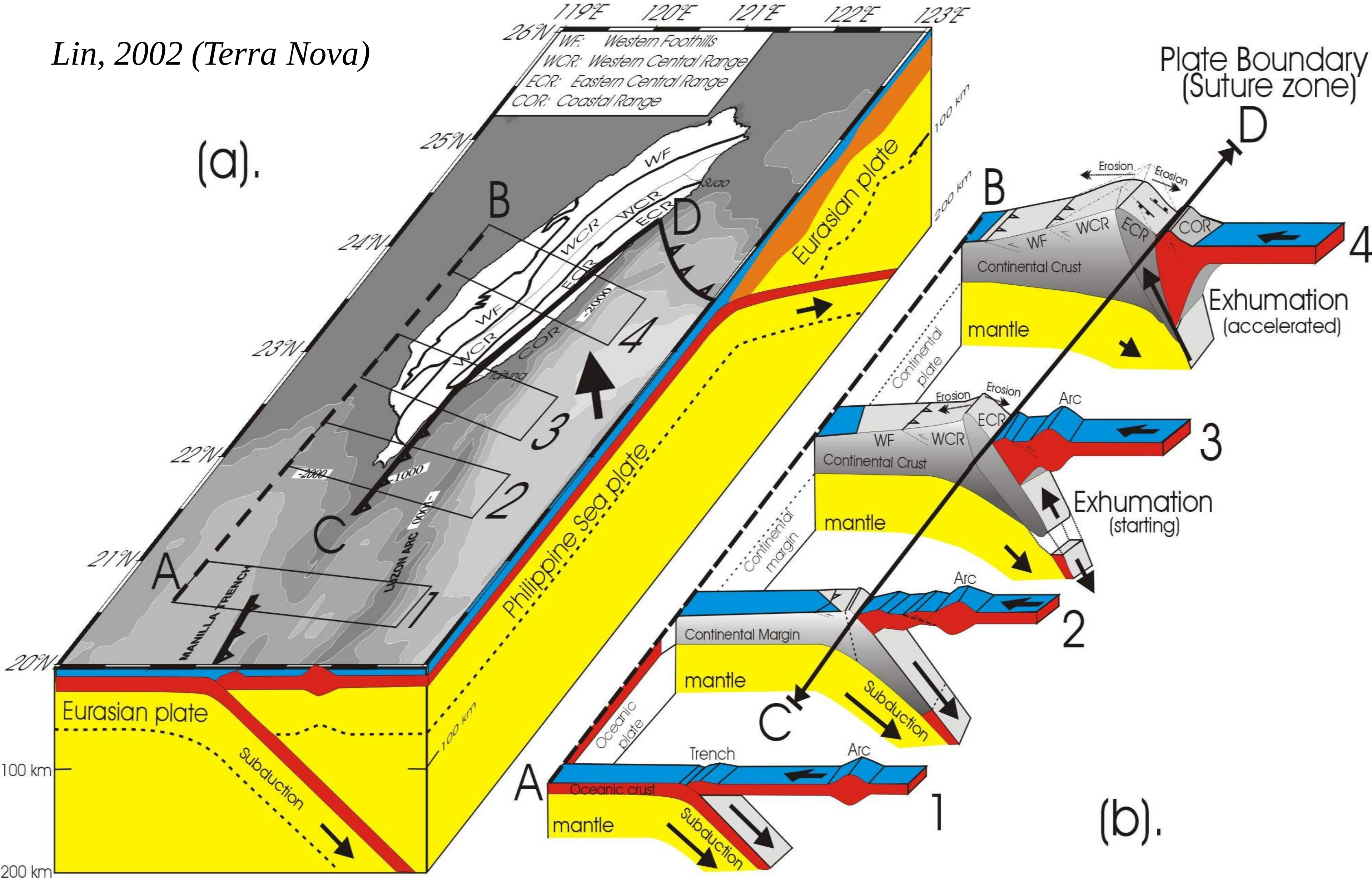

Eurasian Plate
Philippine Sea Plate
South China Sea
East China Sea
Okinawa Trough
Ryukyu Arc
Nanao Basin
Taiwan
Ryukyu Trench
Huatung Basin
Gagua Ridge
West Philippine Basin
Luzon Arc
71 mm/yr
A
A'
B
B'
25°N
24°N
23°N
22°N
21°N
120°E
121°E
122°E
123°E
124°E
125°E


一千萬年前（碰撞前）
A
B
大陸邊緣
海溝
增積岩楔
呂宋弧
歐亞板塊
（海板塊隱沒）
五百萬年前（碰撞初期）
小島
C
（陸緣隱沒）
三百萬年前（碰撞晚期）
高山
D
（大陸隱沒）
現在（碰撞後期）
琉球弧
裂谷
E
弧陸碰撞
隱沒反轉
中國大陸
南海
菲律賓海板塊

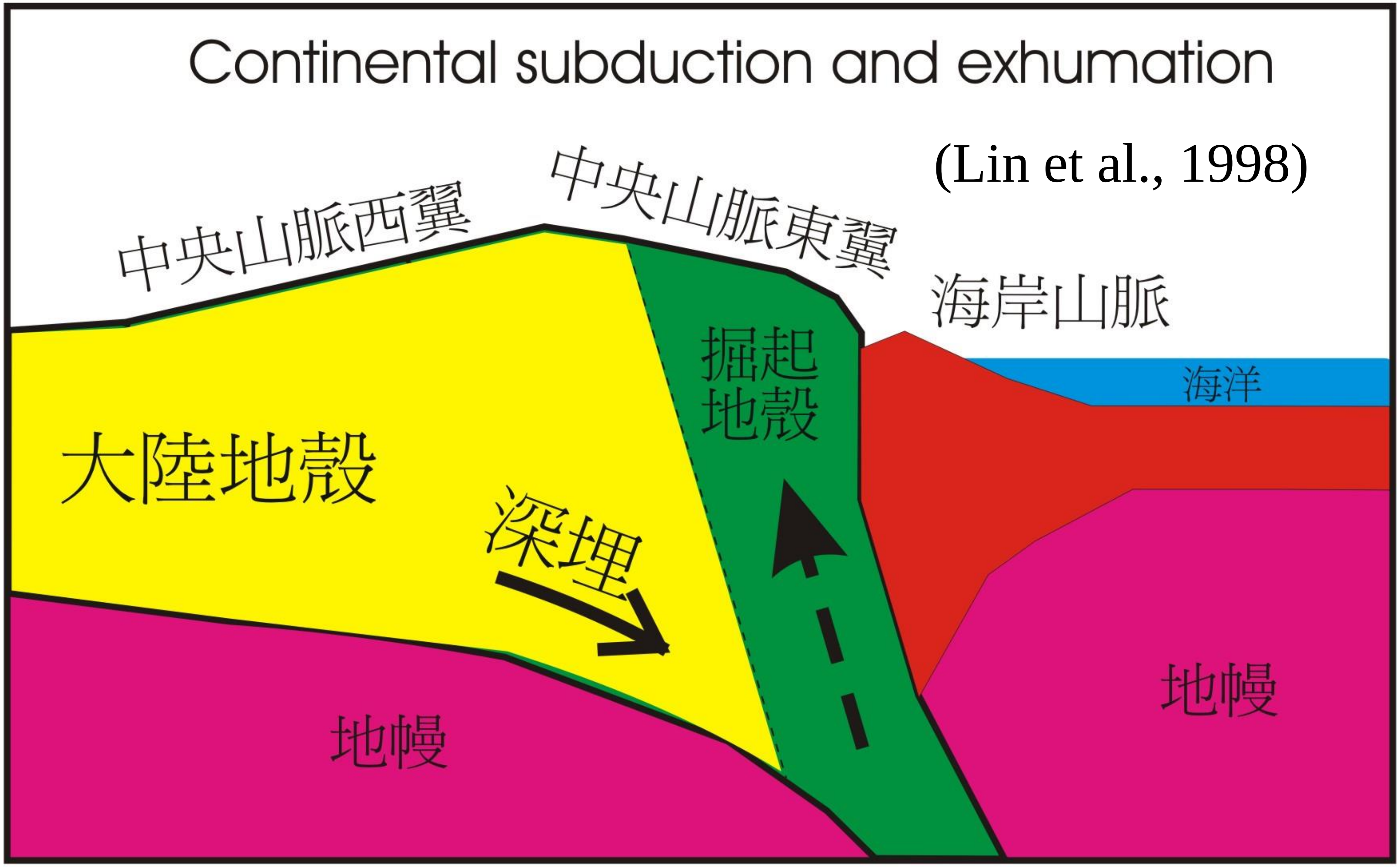
弧陸碰撞演化圖

Continental Subduction and Crustal Exhumation

Lin, 2002 (Terra Nova)



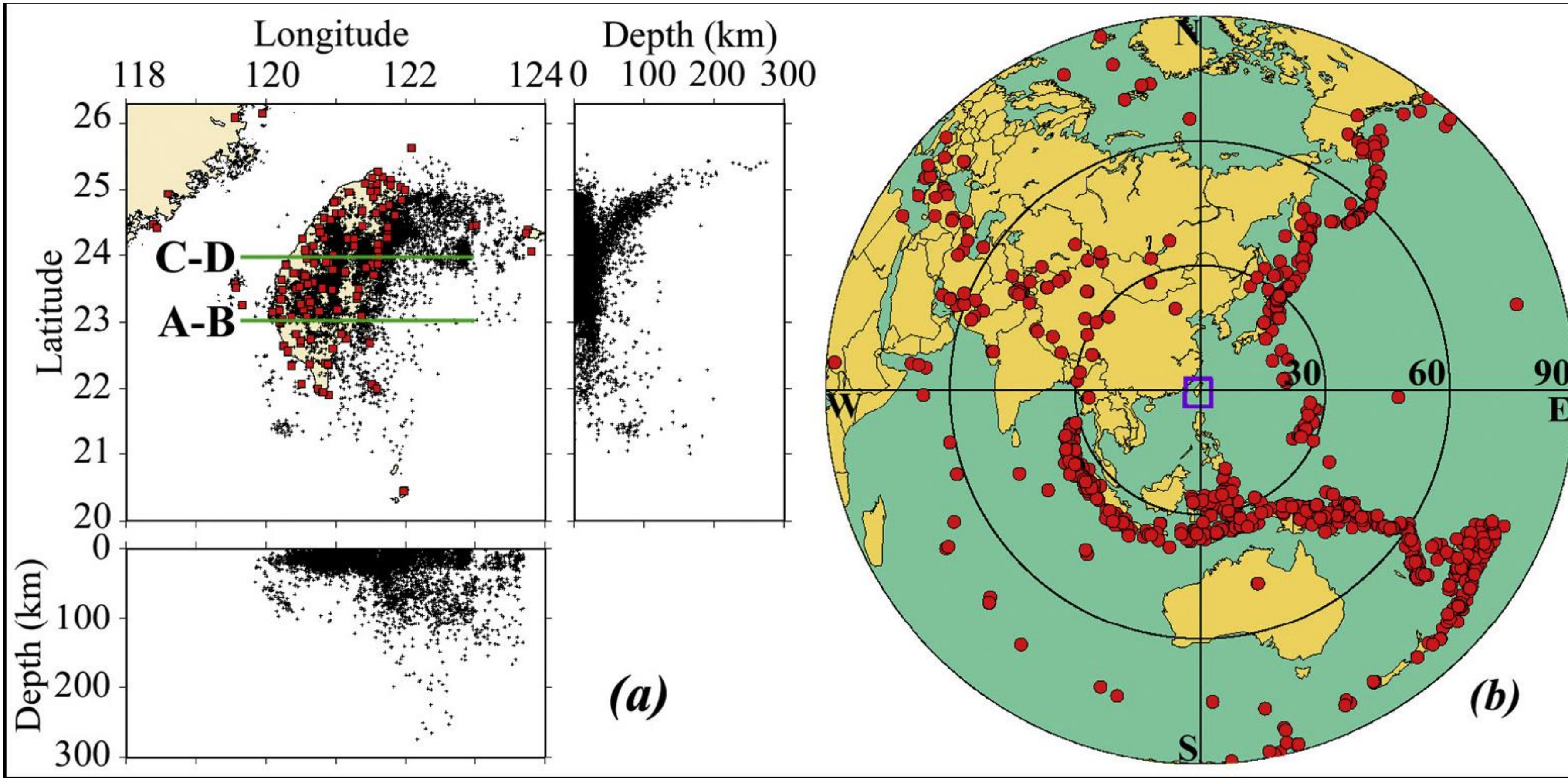
台灣造山運動模式



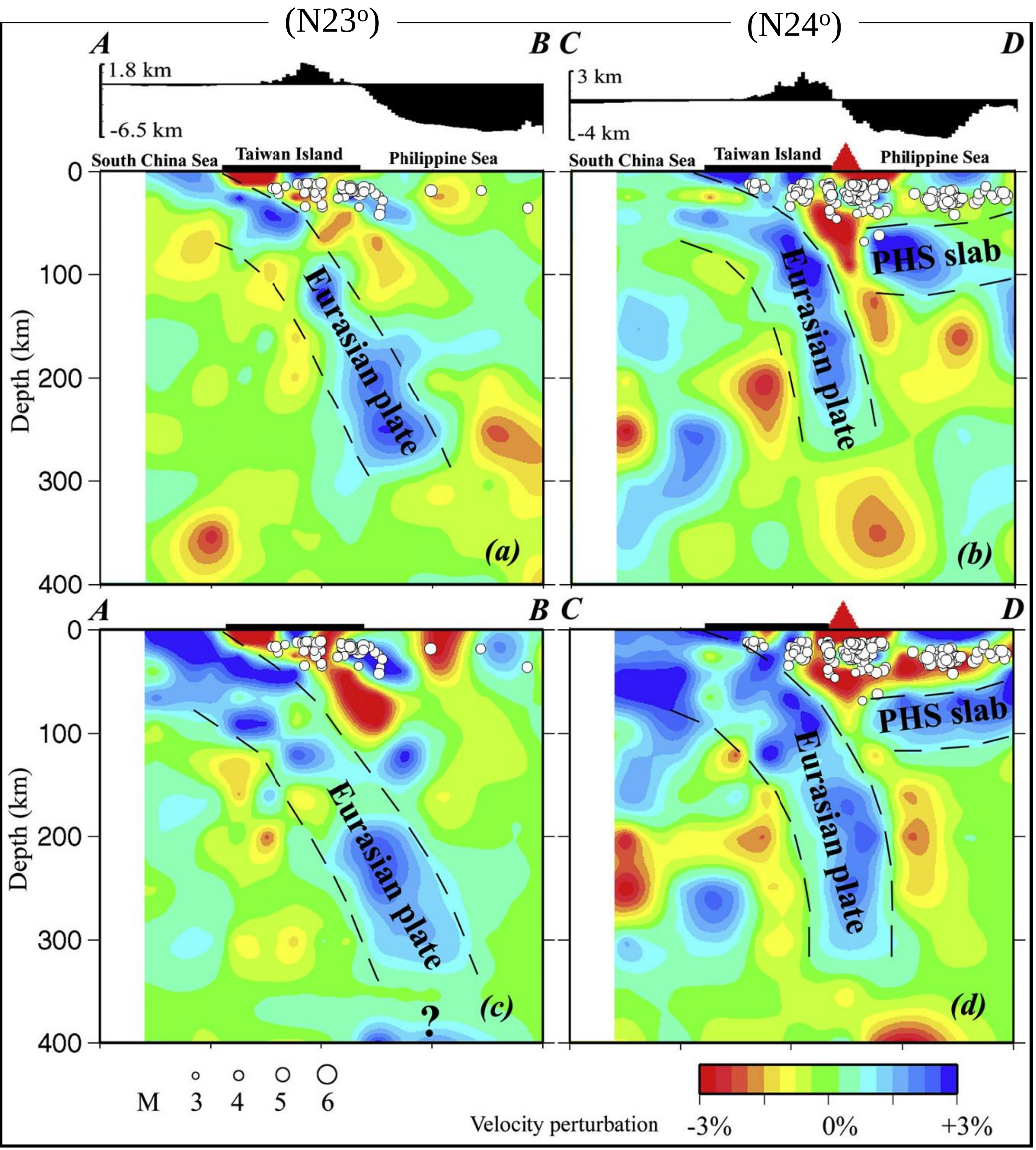
地殼深埋後再掘起之造山運動模式。紫色部份代表地幔(Mantle)。
黃色部份代表台灣西部地區下方，較厚的大陸性地殼。
綠色部份爲中央山脈東翼下方，經深埋且變質後再掘起之大陸性地殼。
紅色部份爲海岸山脈及太平洋下方，較薄之海洋性地殼。

Tomographic evidence for the Eurasian lithosphere subducting beneath south Taiwan

(Wang et al, 2006, GRL, VOL. 33)



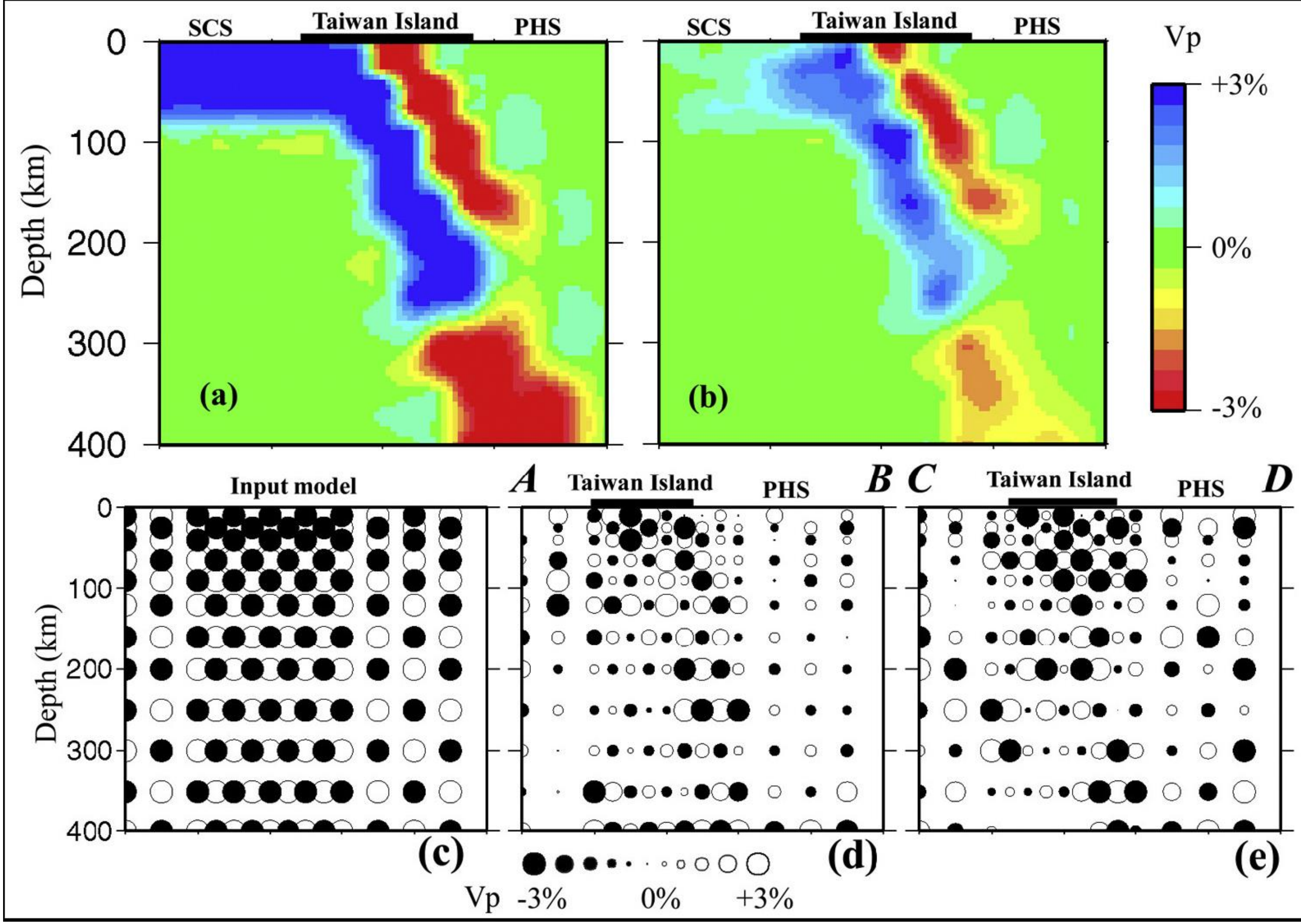
(a) 3-D hypocentral distribution of the 6,782 local earthquakes with magnitudes larger than 3.5. Red squares denote the 98 stations that recorded P-wave arrival times from the local and teleseismic events from March 1995 to October2005. (b) Red circles show the epicentral locations of the 1,108 teleseismic events used in this study.



(a–b) Tomographic images determined without considering the subducted Eurasian and Philippine Sea plates in the velocity model. (c–d) considering the subducted Eurasian slab (down to 600 km).

Results

- **A high-velocity zone (65–80 km thick) is imaged clearly from the surface down to a depth of 300 km**
- **Dipping angle of the subducted plate in section A-B is smaller than that in section C-D (Figure 3), reflecting the decrease of the convergence rate of the Eurasian plate from the south to north**
- **No background earthquakes deeper than 120 km are observed, implying Taiwan is not dominated by the subduction of Eurasian plate beneath Philippine Sea plate at present but in the past.**
- **A good correlation between the active volcano and the low-velocity (low-V) anomaly, which also exists at upper boundary of the subducted Eurasian plate**



Results of synthetic recovery-test and checkerboard resolution test (CRT): (a) input model and (b) inversion results determined by using local and teleseismic data simultaneously. Red color represents low velocity while blue color indicates high velocity. The velocity-perturbation scale is shown on the right. (c–e) Input and inverted CRT results along the sections A–B and C–D.

Implication and Conclusion

- Tomographic images indicate that the upper part of the continental Eurasia plate is peeled off to build the mountains while its lower part subducts beneath the oceanic Philippine Sea plate.
- Assuming that the plate convergence rate is constant at 7 cm/yr [Seno et al., 1993], it takes about 4–5 Ma for the subducted Eurasian plate to reach a depth of 300 km. This is remarkably consistent with geological inferences that the orogeny of Taiwan was initiated in the early Pliocene (5 Ma) [e.g., Teng, 1990].
- This velocity model, in general, agrees with the models such as arc-continent collision and thin-skinned collision proposed by previous studies. The mountain building, active seismicity and crustal deformation in the central region of Taiwan are mainly caused by the Eurasian continental plate subducted beneath south Taiwan and colliding with the subducting Philippine Sea slab.

造山模式比較

- **黃奇瑜: Flake tectonics**
- **林正洪: Mantle subduction (crustal exhumation)**
- **鄧屬予: Lithosphere break-off and subduction**
- **Lallemand: 3-D break-off + T1 plate boundary**
- **Wang: Subduction + remnant arc (oceanic plate)+ crustal peeled-off + break-off (?)**

黃、林模式

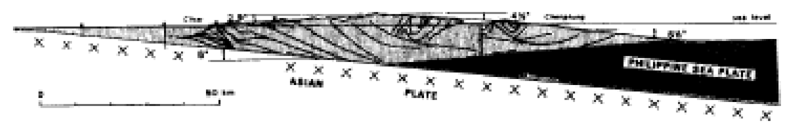
同: EU plate, 地殼部分崛起形成中央山脈; 地函部分隱沒

異: 有無板塊折離及地函上湧

鄧模式:整個岩石圈隱沒及地函上湧

Summary-1

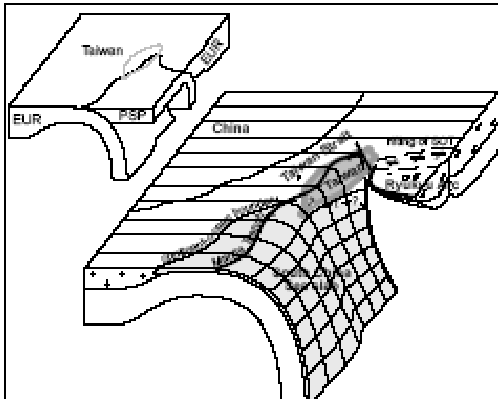
Current Conceptual Models



(A) Thin Skinned Detachment
Suppe (1987)

Characteristics:

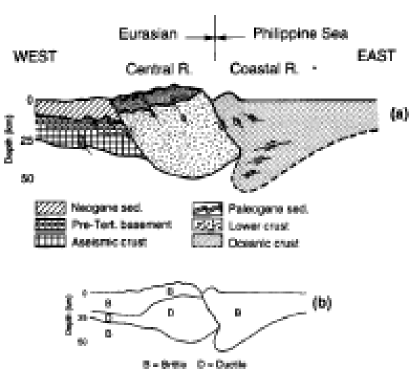
1. Accretionary wedge.
2. Critically tapered wedge - very weak.
3. Continental (light) subduction.
4. Philippine Sea plate (oceanic) backstop.



(B) Thin Skinned
(Lallemand et al., 2000)

Characteristics:

1. Continuation of Suppe model oceanward.
2. A steep subduction with tear at the ocean-continent boundary (based on high velocity zone under island).
3. 3-dimensional.
4. Continuation of Luzon slab.
5. "Subducted" continental root.



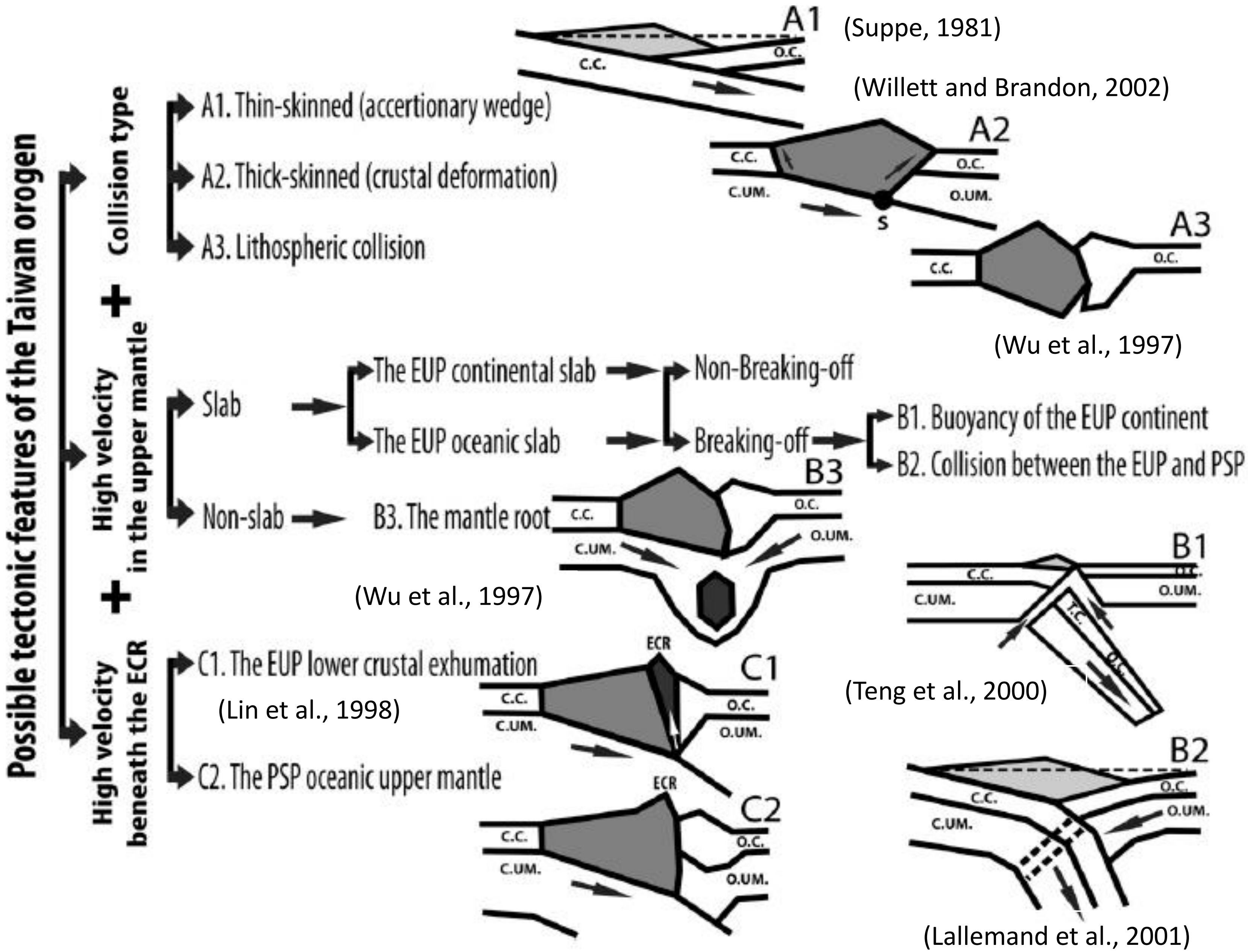
(C) Lithospheric model
(just south of 24^{o}N)
(Wu et al., 1997)

Characteristics:

1. Lithospheric depths.
2. Rheological sandwich and lateral changes.
3. Major blocks of Central Ranges, Foothills, and Coastal Ranges.
4. Central Ranges has root (isostatic or dynamic?).
5. Oceanic lithosphere thickens into island.
6. Out-of-plane escape is allowed.

Figure 15

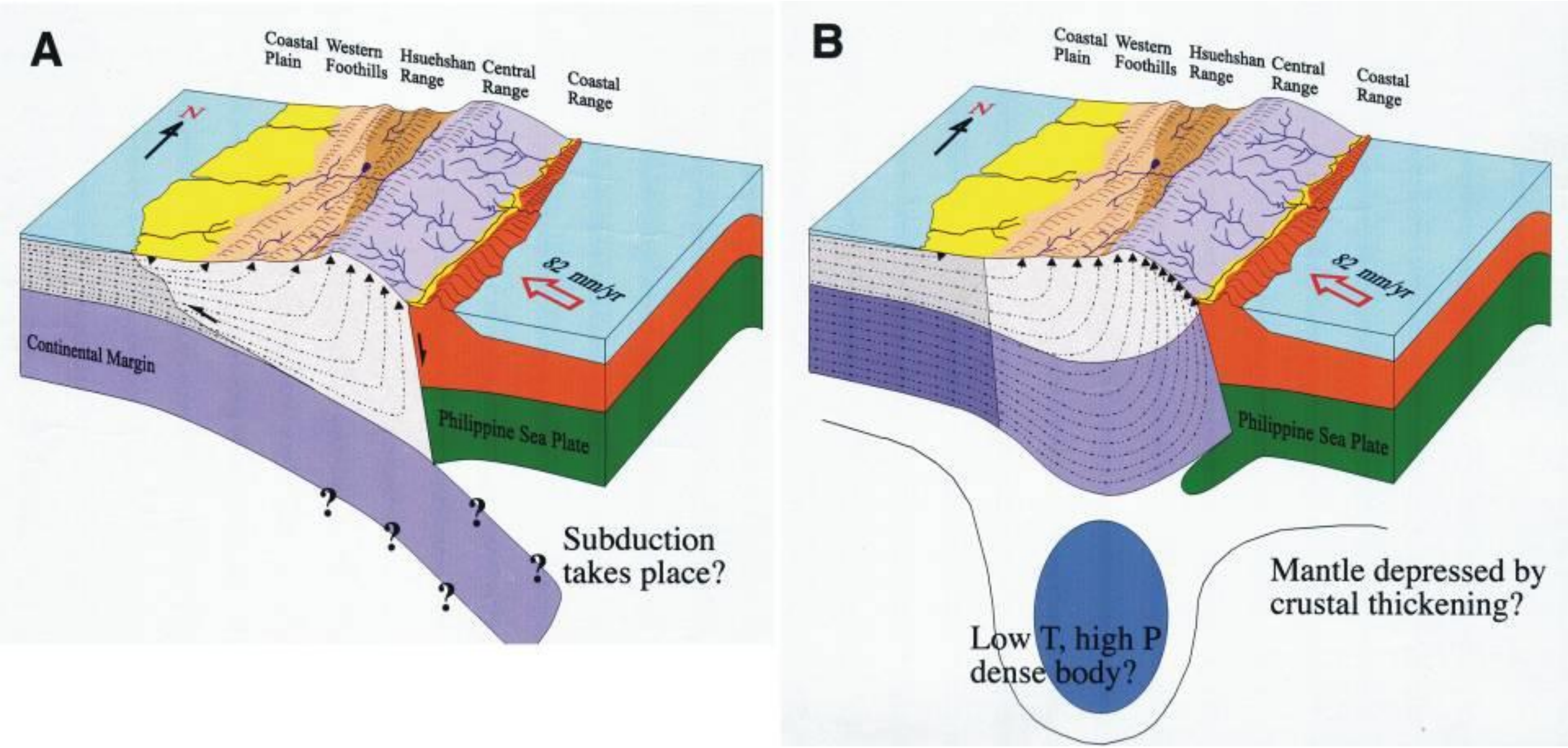
Summary-2

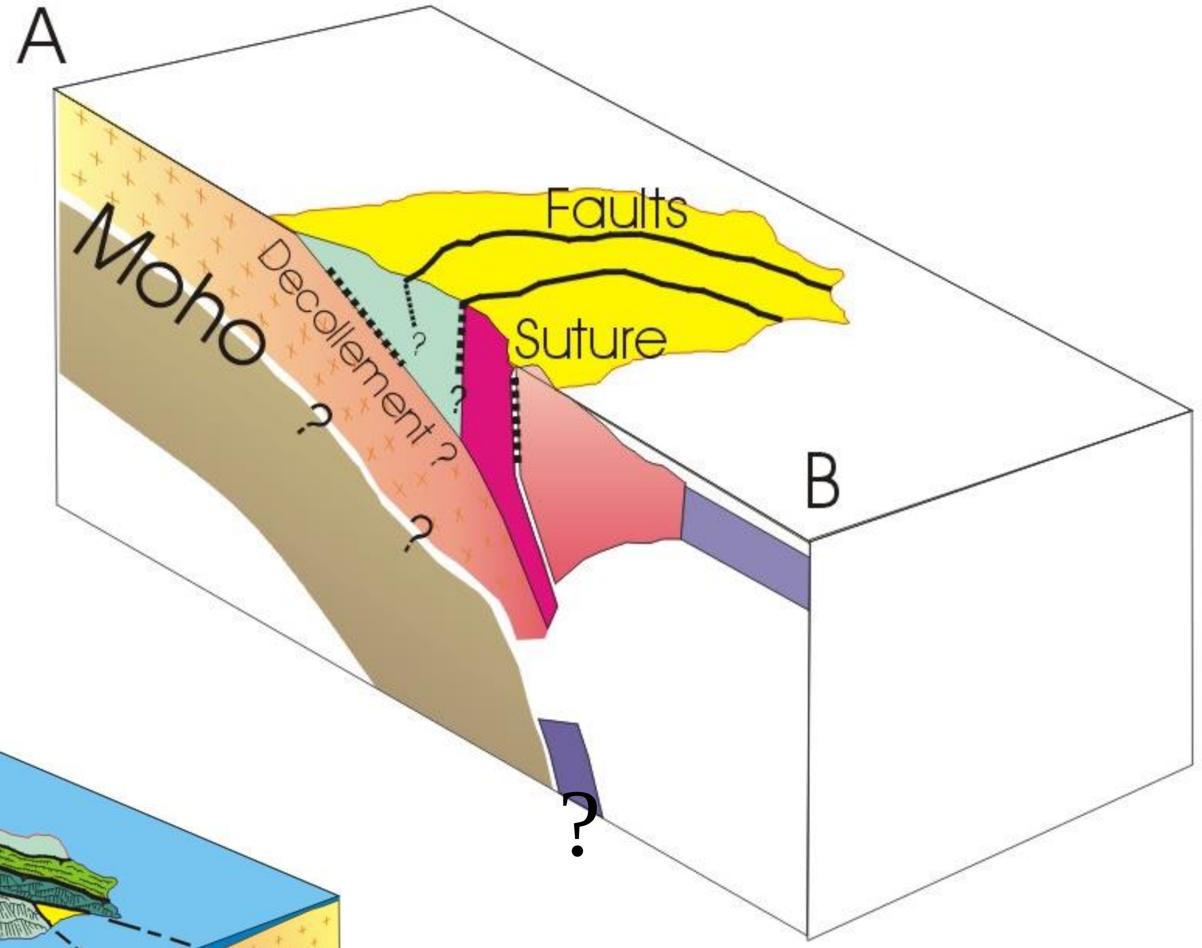


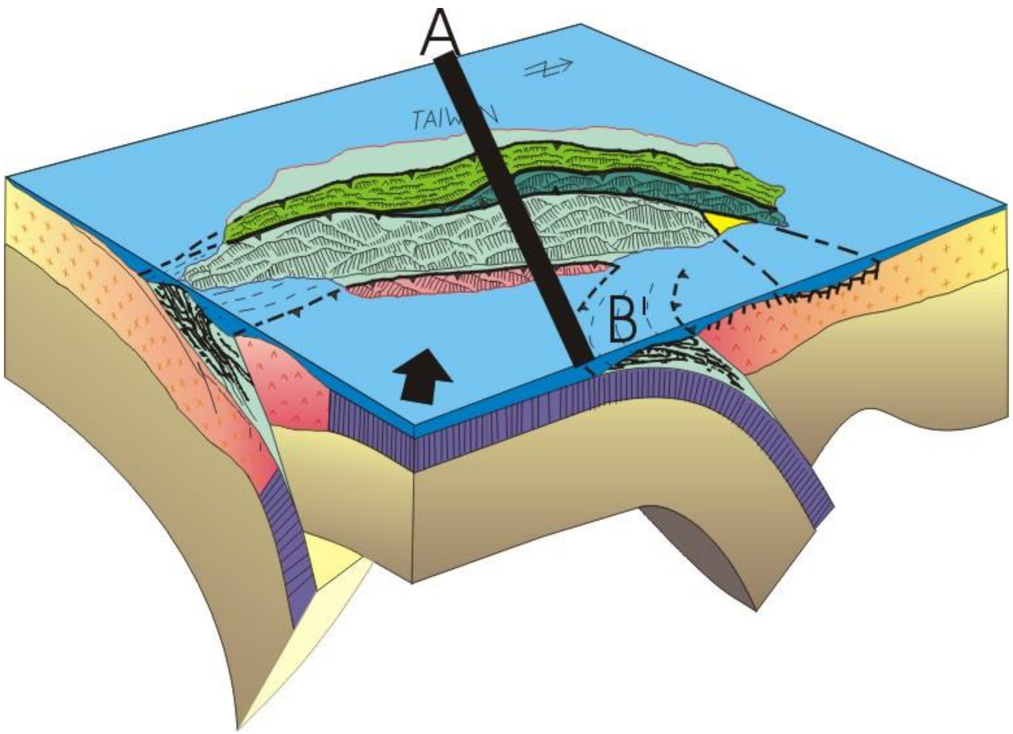
Possible tectonic features of the Taiwan orogen
Collision type
A1. Thin-skinned (accertionary wedge)
A2. Thick-skinned (crustal deformation)
A3. Lithospheric collision
+
High velocity in the upper mantle
Slab
The EUP continental slab
Non-Breaking-off
The EUP oceanic slab
Breaking-off
B1. Buoyancy of the EUP continent
B2. Collision between the EUP and PSP
Non-slab
B3. The mantle root
+
High velocity beneath the ECR
C1. The EUP lower crustal exhumation
C2. The PSP oceanic upper mantle
A1
(Suppe, 1981)
C.C.
O.C.
(Willett and Brandon, 2002)
A2
C.C.
O.C.
C.UM.
O.UM.
S
A3
C.C.
O.C.
(Wu et al., 1997)
B3
C.C.
O.C.
C.UM.
O.UM.
(Wu et al., 1997)
B1
C.C.
O.C.
C.UM.
O.UM.
T.C.
O.C.
(Teng et al., 2000)
ECR
C1
C.C.
C.UM.
O.C.
O.UM.
(Lin et al., 1998)
ECR
C2
C.C.
C.UM.
O.C.
O.UM.
B2
C.C.
O.C.
C.UM.
O.UM.
(Lallemand et al., 2001)

Why are those models so different?

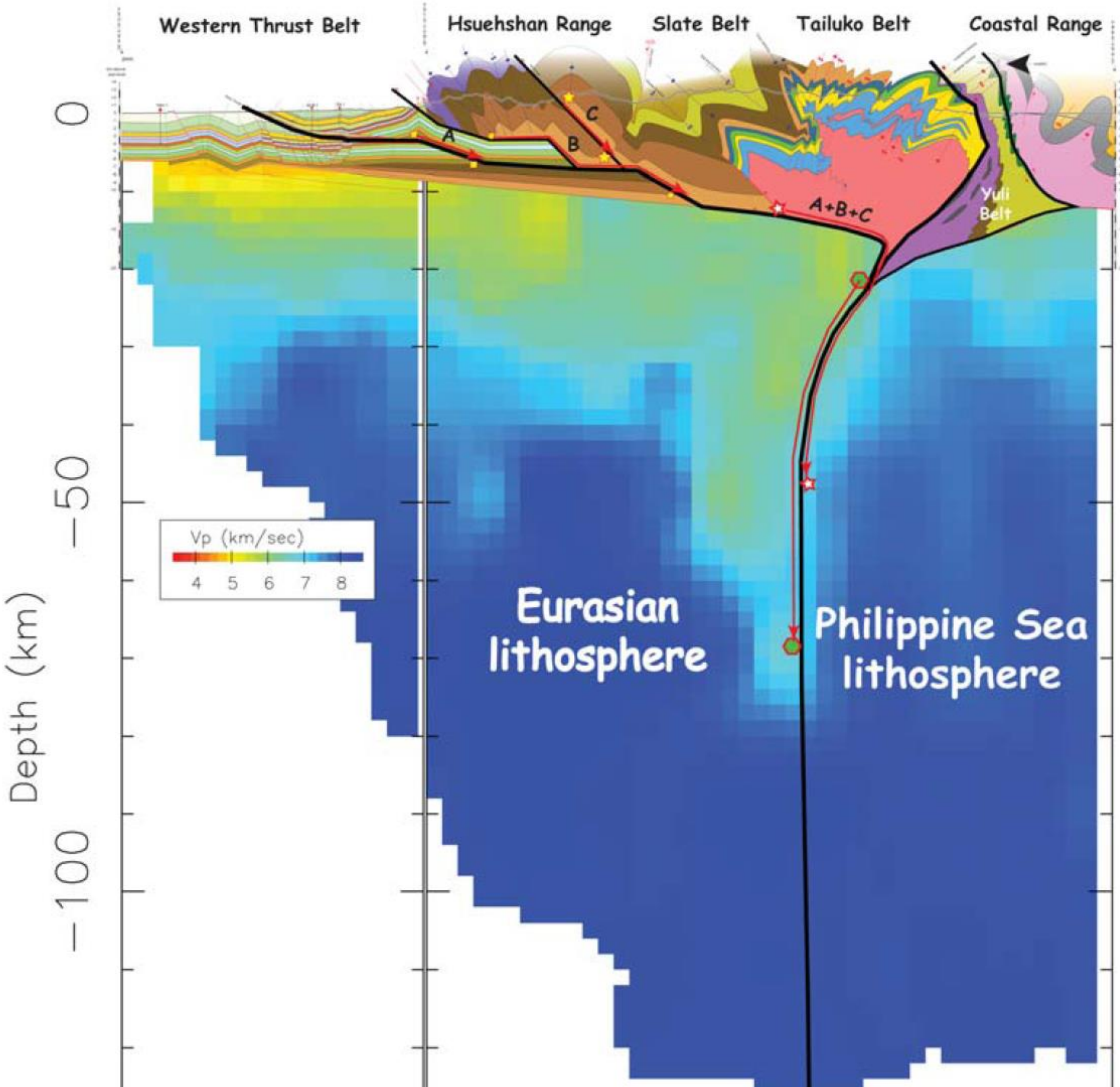
Arc-continental collision? Continental subduction? Lithospheric collision? Slab break-off?



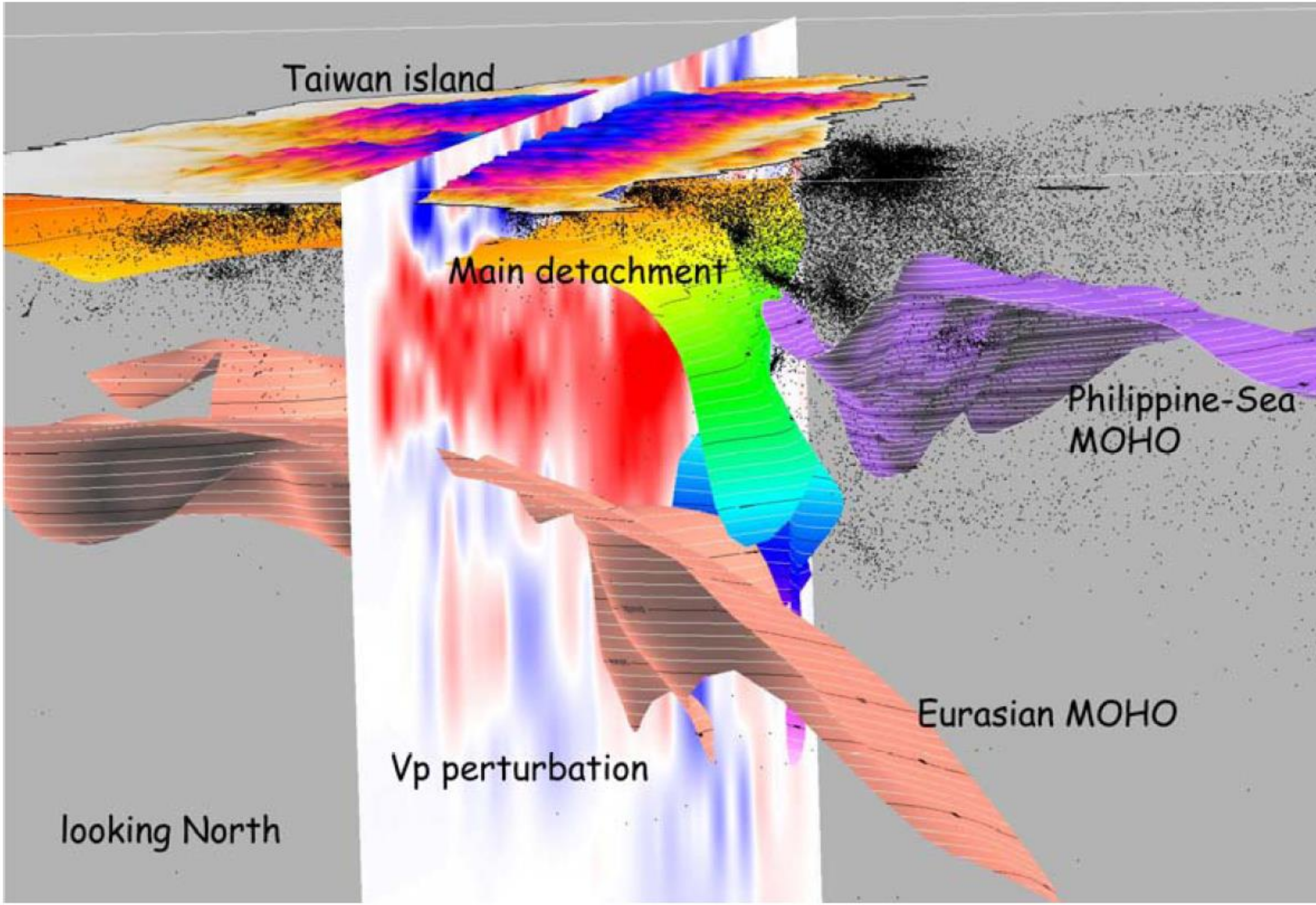




Deep Structure?



Western Thrust Belt
Hsuehshan Range
Slate Belt
Tailuko Belt
Coastal Range
A
B
C
A+B+C
Yuli Belt
Vp (km/sec)
4 5 6 7 8
Eurasian lithosphere
Philippine Sea lithosphere
0
−50
−100
Depth (km)



Taiwan island
Main detachment
Philippine-Sea
MOHO
Eurasian MOHO
Vp perturbation
looking North

TAIGER (TAiwan Integrated GEodynamics Research) Project for Testing Models of Taiwan Orogeny

台灣大地動力學國際合作研究計畫

總主持人：吳大銘 教授

台灣計畫主持人：王乾盈 教授

Why Study Taiwan?

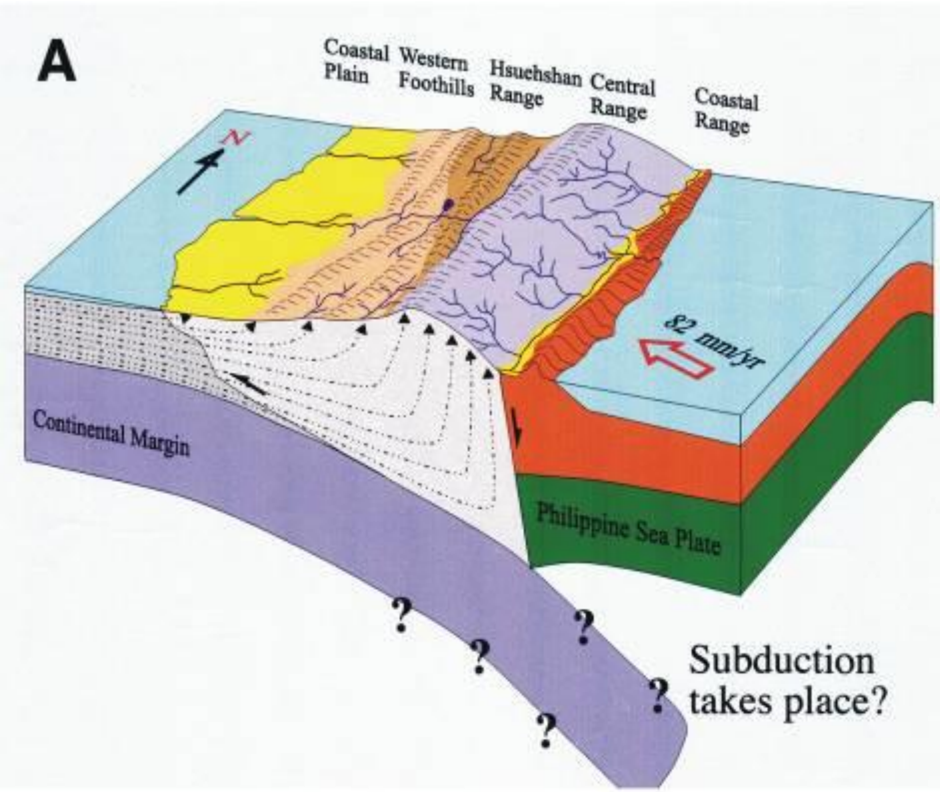
- 台灣年輕造山帶：Taiwan is young, geologically speaking (~4 m.y. since the beginning; vs ~10 my for New Zealand, ~35 my for Himalaya, ~ 120 my for Alps…)

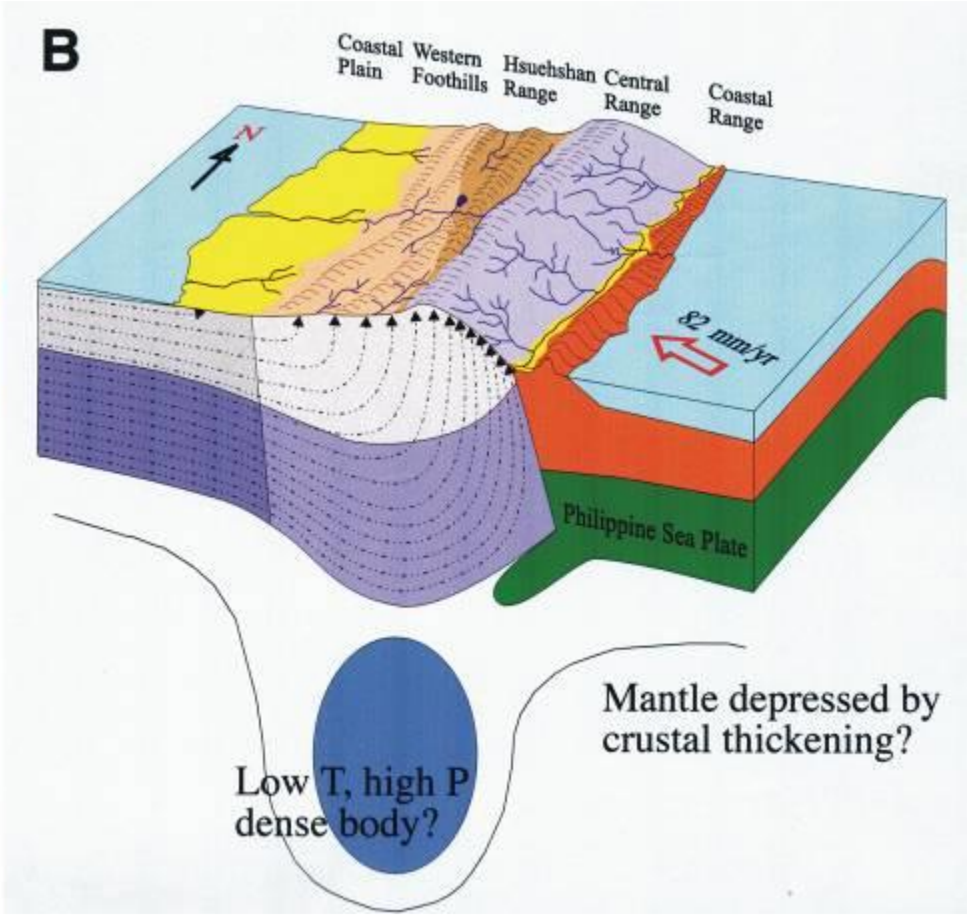
- 台灣快速造山：Taiwan is *active (the most active?); rising at >1.5 cm/yr (or 15 km in the last million year?) with earthquakes telling us where and how deformation are taking place*

- 現生材料：For old mountain ranges many assumptions are needed in reconstructing its history or understand the mechanisms.　For Taiwan such a problem is lessened.

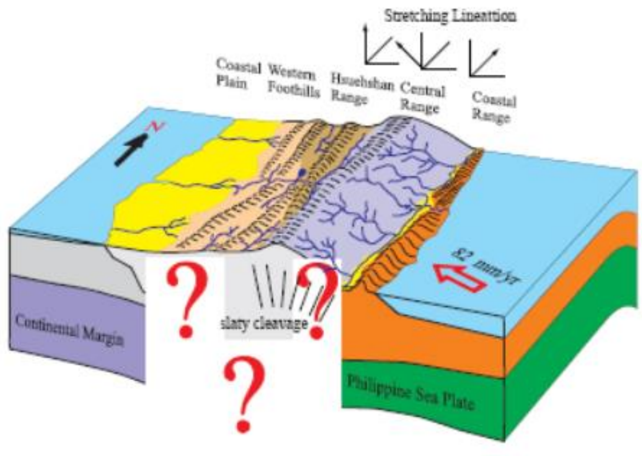
Why are those models so different?

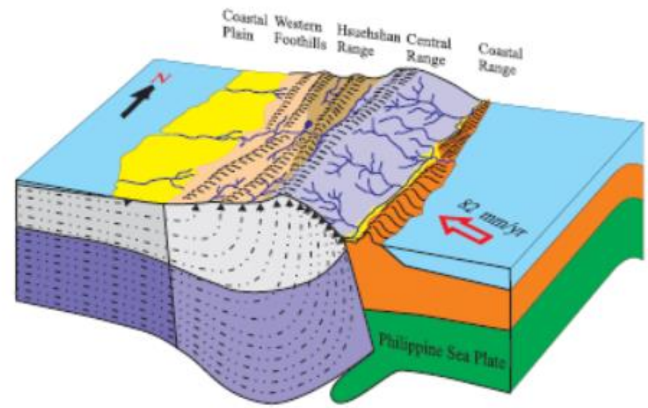
Arc-continental collision? Continental subduction? Lithospheric collision? Slab break-off?



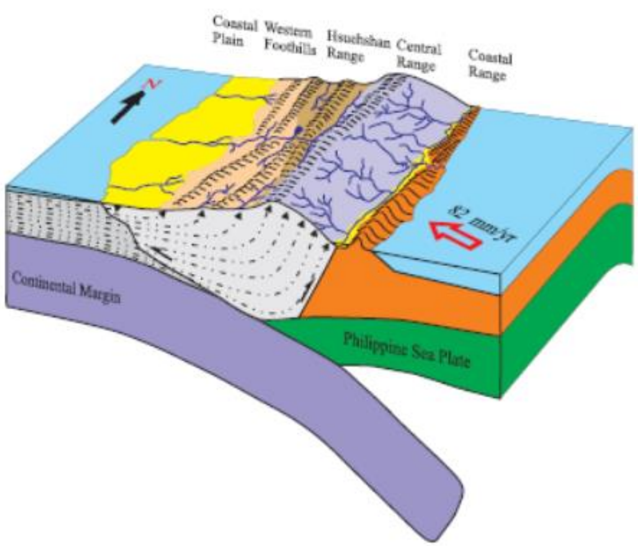


(a)Pure shear without subduction (Wu, 1997)

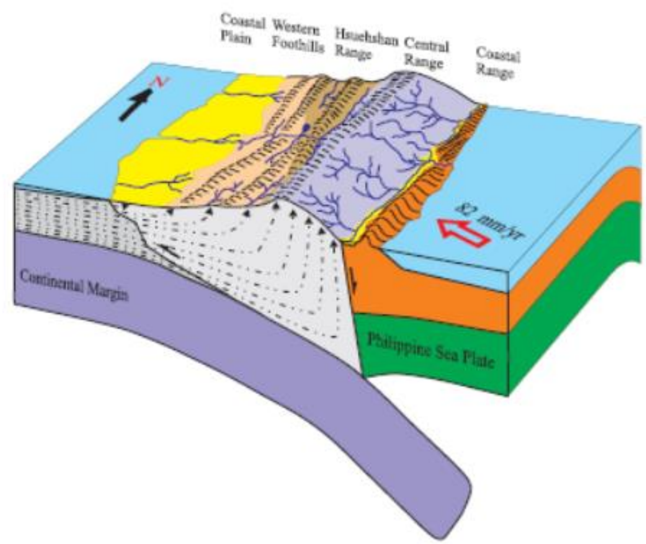




(b) thin-skinned doubly vergent wedge model (Willett et al., 1994)



(c) Thin-skinned corner flow model (Lin, 2000)



Models of Lithospheric Collision for Taiwan with resulting different kinematics within the mountain belt.

What is TAIGER?
（五項工作）

- 天然地震：陸地寬頻網 Land broadband instruments to enhance the existing broadband networks for recording both local earthquakes and teleseisms (Ongoing)
- 天然地震：海底寬頻網 Marine broadband deployment around the island to increase the aperture of the available broadband networks (2007/10)
- 人工震源：Land explosions for low-fold wide angle and CMP profile reflections across the island along three transects (2008/02)

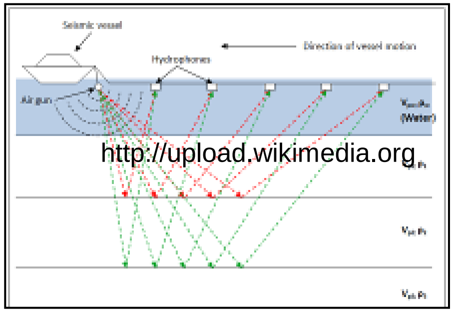
How TAIGER (Ct’d)

- 海陸聯炸：Marine MCS and reversed sea-land wide-angle profiling using airgun signals along six transects (2008/4)
- 大地電磁：Magnetotellurics along several transects (O)

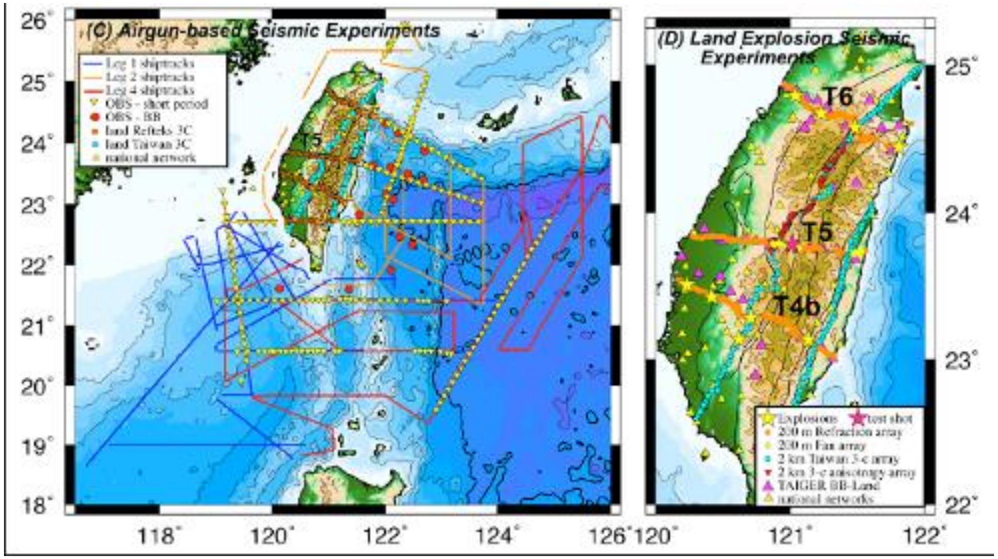
TAIGER2008~2009 (陸地爆炸、海陸聯測)

higher resolution, shallower velocity structures

海上震測 MCS



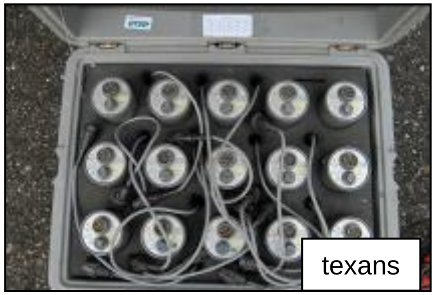
2009 海陸聯測　　2008 陸地炸測



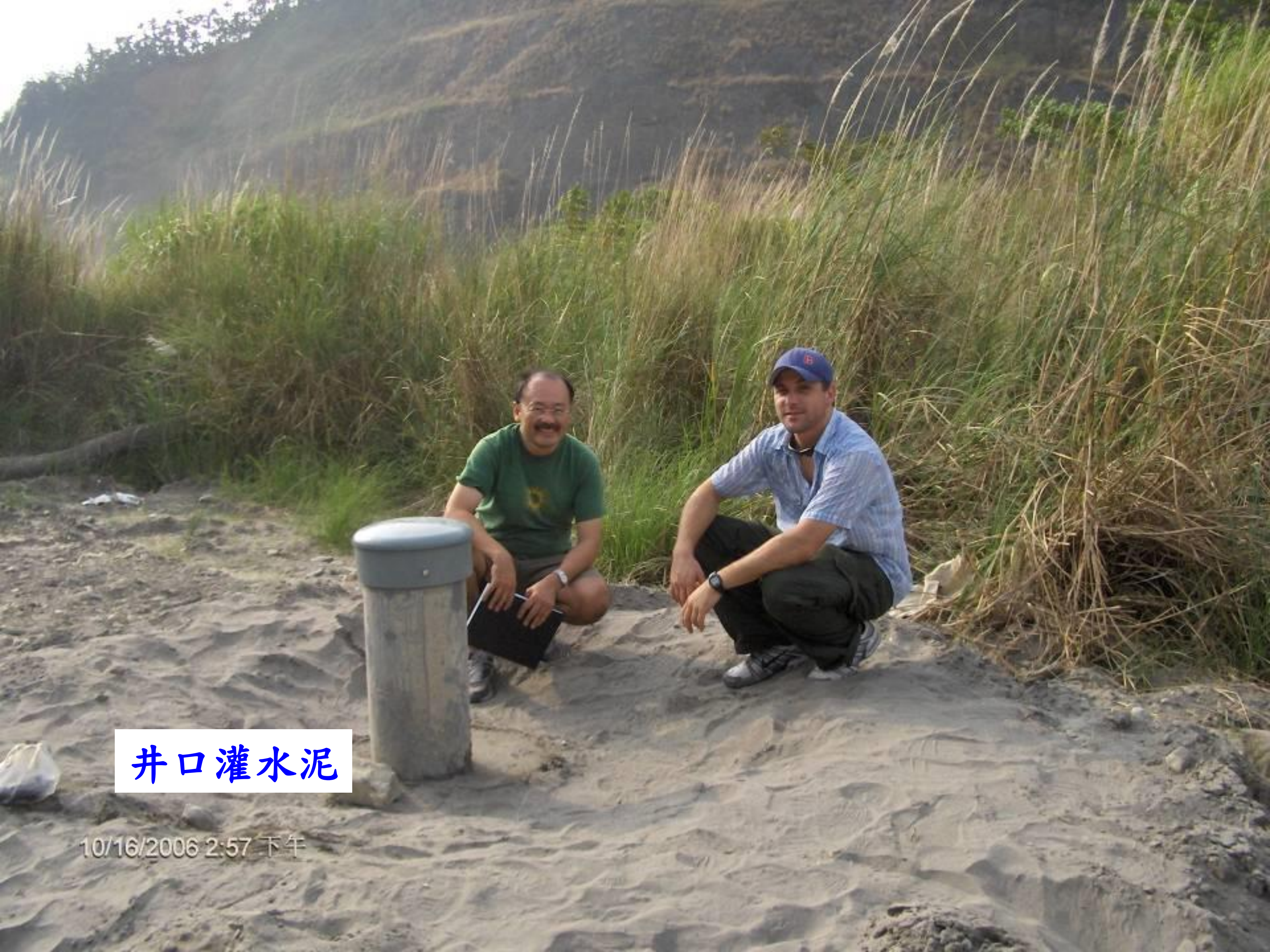

炸點


空氣槍


RV Marcus Langseth

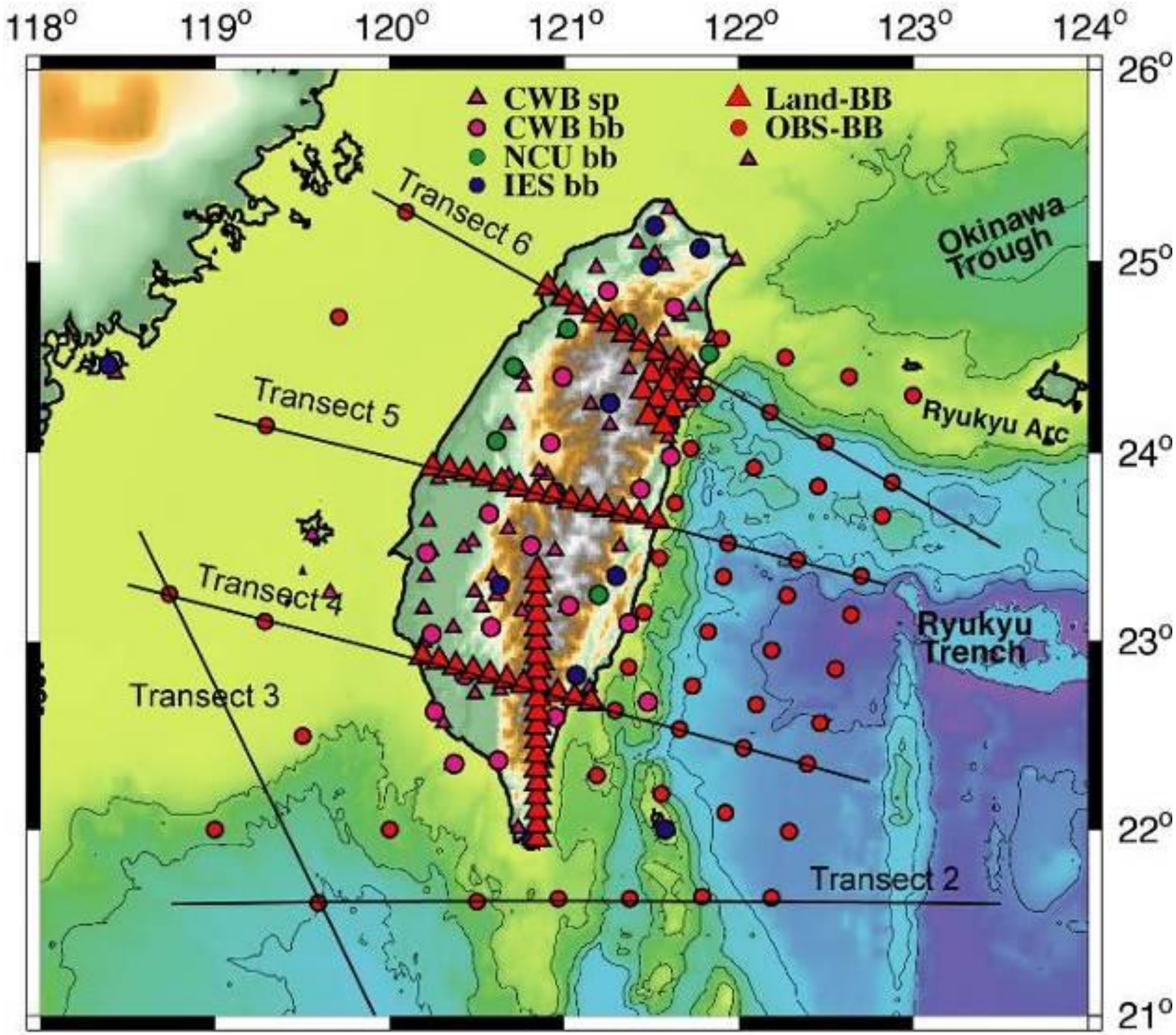

texans

井深60m，井徑12英吋


井口灌水泥
10/16/2006 2:57 下午

警車監送炸藥

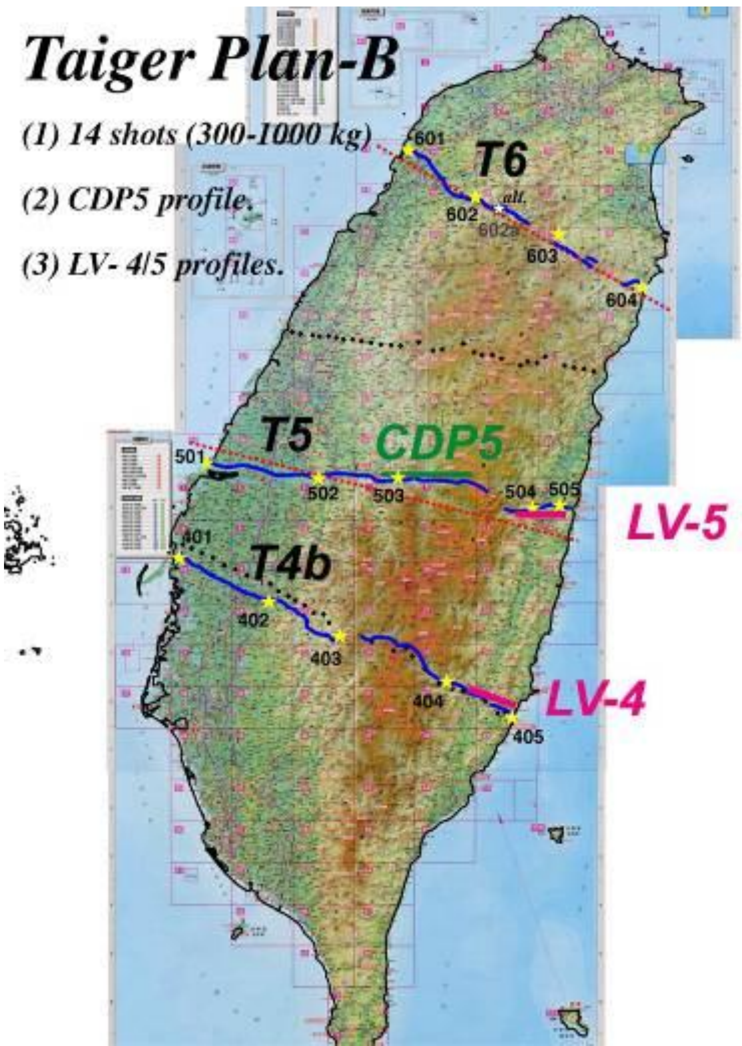
Passive Seismology
（天然地震）



陸地地震儀：
60＋100

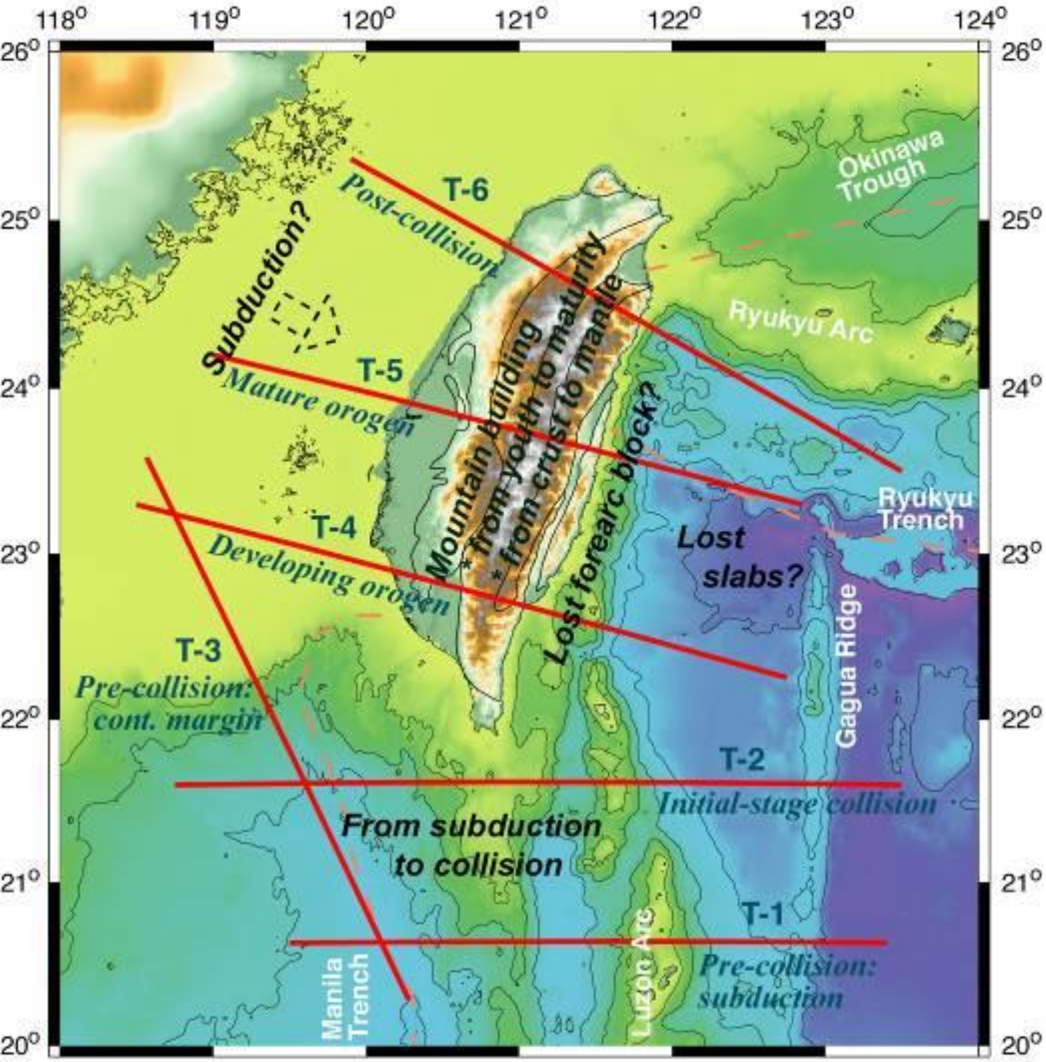
海底地震儀：
60

Active Seismology
（人工震源）



- 北中南三線：1000 kg shots along T4b, T5, T6
- CDP線：30 Km (30 shots) CMP line across Lishan fault

Sea-Land Profiles （海陸聯炸）



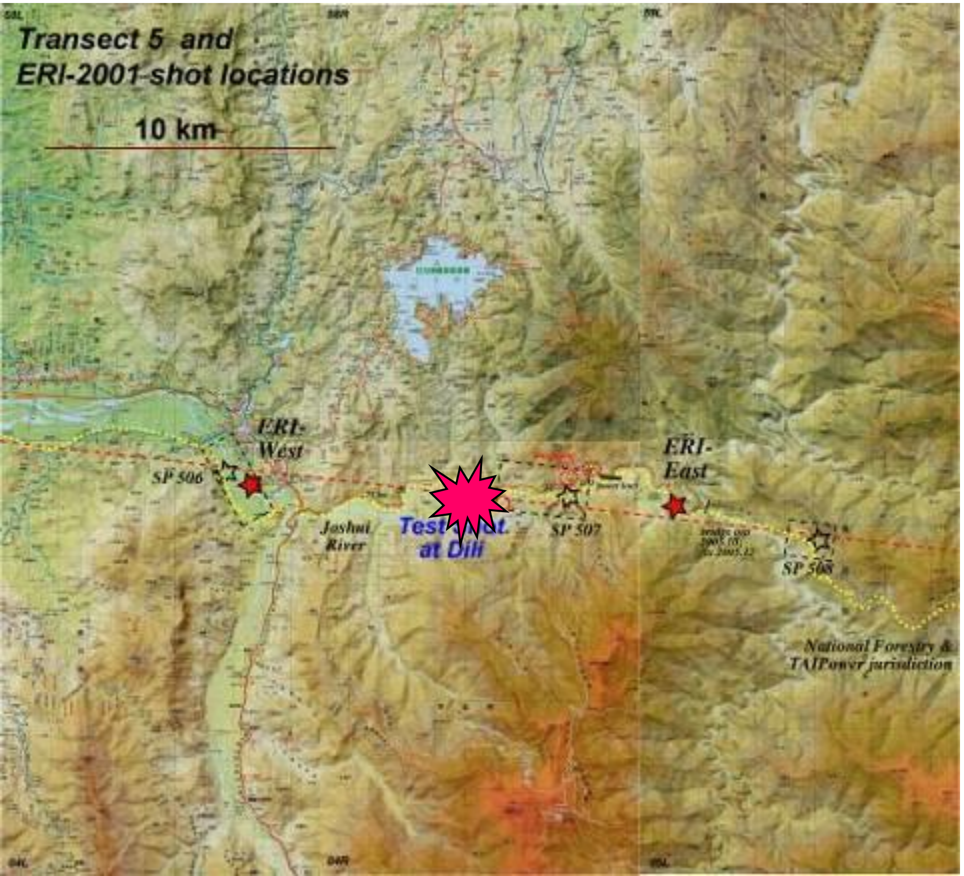
Transects 1, 2, 3,4,5,6:

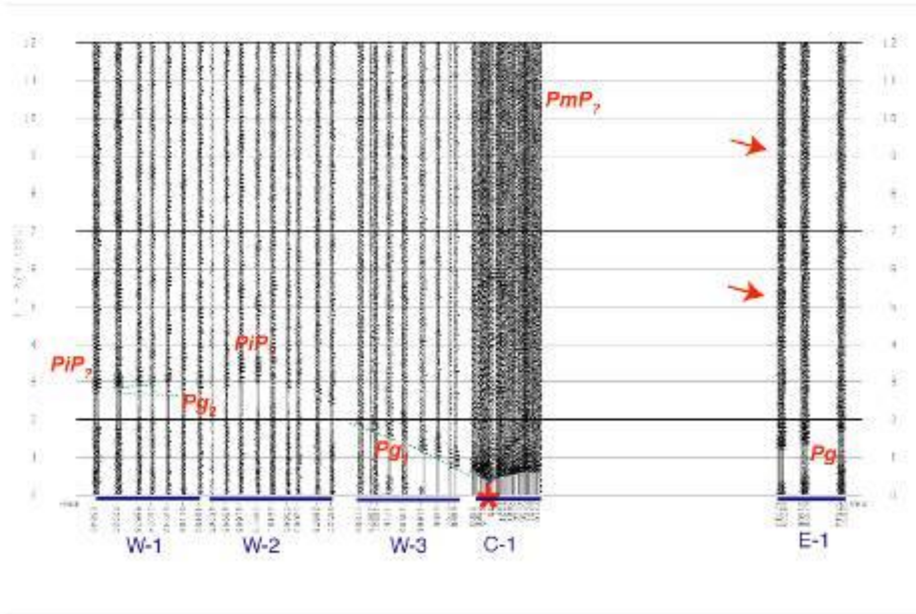
MCS/OBS/airgun transects.

150 IRIS

人工震源：地利500kg 爆炸測試

500 Kg Dili Test Shot
- 60 m deep hole
- 150 Texans





2004~2013 Geophysical Experiments

2008. 02

新竹地震？乳膠炸藥炸的

〔記者王錦義、沈繼昌、洪友芳、游太郎／連線報導〕咦，有地震嗎？不，是學術單位半夜在引爆炸藥！

750公斤炸藥 震度達3級

為了偵測地殼構造，由中央大學主導的Taiger炸測計畫利用炸藥探測地質，七日凌晨一點，中央大學地球科學系在新竹縣竹東鎮二重地區的頭前溪畔，引爆一個重達七百五十公斤的乳膠炸藥，巨大爆炸引起芮氏規模二點六的地震，竹市及竹北震度達三級，連遠在十公里外的住戶都感受到人為地震威力；七百五十公斤的乳膠炸藥，威力可摧毀一棟三十層的大樓建築。

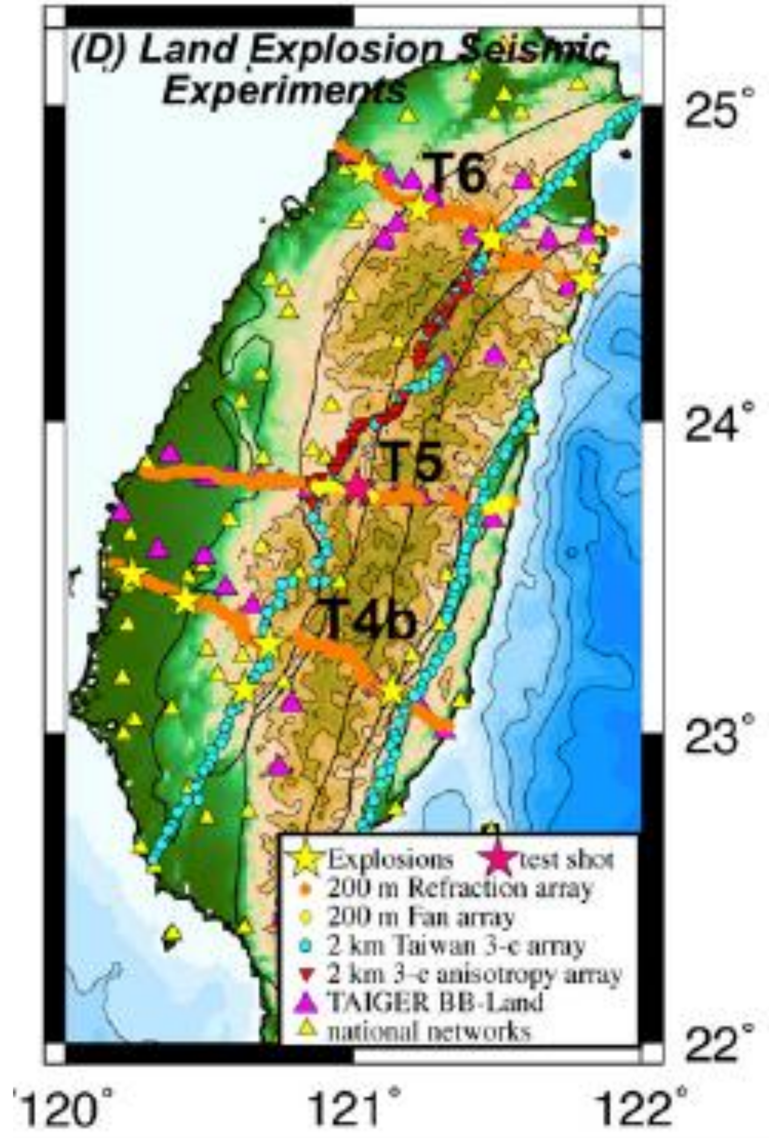
新竹縣消防局長林祥欽得知此事後相當震怒，他說，依消防法第十四條規定，使用炸藥爆破要向縣消防機關申請許可，但消防局並未接獲申請，明天將發函實驗單位說明，如有違規將依法開罰。新竹縣警局竹東警分局長林志鈞說，警方曾接獲中大委託的地景實業公司申請，要求戒護運送炸藥到頭前溪畔，但對於試爆是否合法，非警方權責。

近高鐵維修廠 還好沒事

由於爆炸點附近就是高鐵頭前溪橋及高鐵維修機廠，高鐵新竹站公共事務處指出，位於桃園的行車控制中心在第一時間就收到地震訊息，立即派人檢查相關結構及設施，確認完全沒有任何問題，一切正常。

圖為二○○六年十月十九日，中央大學在南投縣地利村進行的炸測實驗，孔徑十二吋塑膠套管，放入五百公斤乳膠炸藥，炸測前後狀況，可見到炸藥引爆後，塑膠套管被炸得浮出地面。（翻攝自Taiger計畫網頁炸測實驗，附錄A）

中央大學主導的Taiger炸測計畫在新竹縣頭前溪畔埋設七百五十公斤乳膠炸藥引爆，引起芮氏規模二點六地震，竹市及竹北震度達三級，李姓農民說附近田地被弄得亂七八糟。（記者王錦義攝）



2004~2013 Geophysical Experiments

2009年4月30日星期四

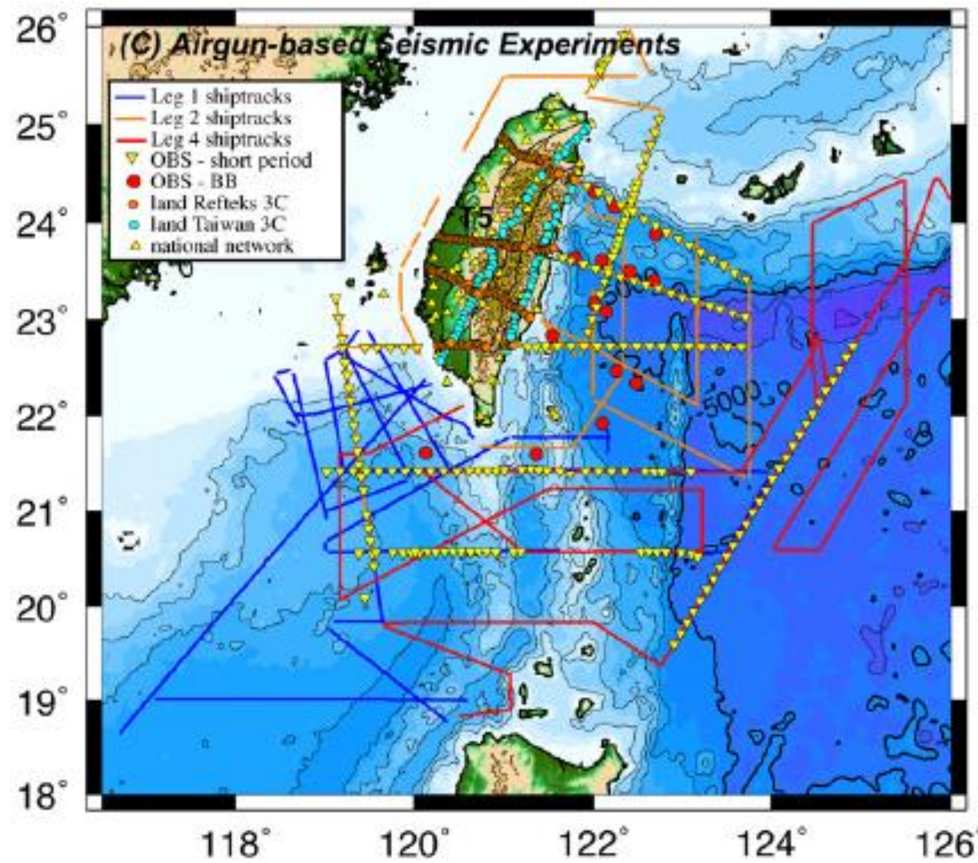
避開白海豚活動範圍 TAIGER研究續做 2009. 04

避開白海豚活動範圍 TAIGER研究續做
【聯合報／記者楊正敏／即時報導】
http://udn.com/NEWS/NATIONAL/BREAKINGNEWS1/4879307.shtml
2009.04.30 10:12 pm

針對環保團體「台灣大地動力學國際合作計畫（ＴＡＩＧＥＲ）」會傷害中華白海豚等保育類海洋生物的疑慮，由於科學證據顯示，實驗已避開白海豚的活動範圍，只要遵循美國「意外騷擾許可」（ＩＨＡ）的規範，計畫仍可進行。

由於環保團體日前質疑ＴＡＩＧＥＲ計畫中美國藍賽斯研究船使用的研究用空氣槍，可能對依賴聲納系統的中華白海豚等在台灣海峽活動的鯨豚有極大的殺傷力，國科會今天舉行跨部會審查會，並聽取環保團體及國外學者專家的意見。

國科會副主委陳正宏說，這項研究有助於了解地下地質，無論是對地震研究、尋找替代能源都相當重要。



2004~2013 Geophysical Experiments

首度精準確認：中央山脈地殼 厚達45公里

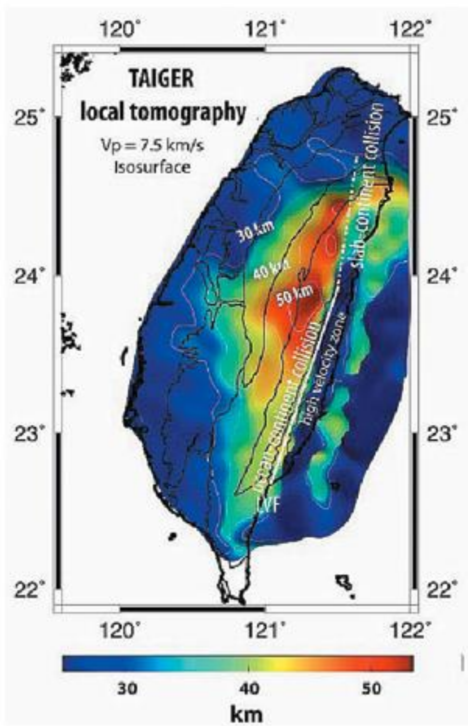
2013. 05

【聯合晚報／記者嚴文廷/台北報導】 2013.05.01 03:02 pm

由國科會補助中央大學經過8年研究，首度精準確認中央山脈底下的地殼厚度達45公里，比全球的平均值35公里高出許多，顯示中央山脈造山運動還在持續進行中，發生大地震的可能性比較高，其餘平地區域如有地震以小型地震為主。

中央大學地球物理所教授王乾盈指出，一座山能夠有多高，取決於地殼下方的厚度多深。例如喜馬拉雅山地殼深度厚達80公里，才能支撐超過8000公尺以上的高度，因此稱山的地底厚度為「山根」，就像是冰山浮出水面只有一點點，但地底下有很大塊的冰支撐著。

過去測量工具不足，始終無法確認台灣的山根到底有多厚，這次經由國科會經費支持、台美合作偵測，終於確認台灣地底的山根厚度。



中央研究院歷經8年台美跨國合作，發現中央山脈的「山根」厚達45公里，顯示台灣的造山運動還有很多的成長空間。
王乾盈/提供

時間	標題	剪報來源
2013-05-03	大學影展起跑　兩岸三地青年創意大PK ...	中央廣播電台
2013-05-03	大學影展　集結兩岸青年導演創作...	中國時報
2013-05-03	9至12月巡迴播映　大學影展　首邀中港台...	聯合報
2013-05-02	高齡就業　學者：提升專業技能 ...	台灣醒報
2013-05-02	4月消費者信心指數連四個月走揚 ...	聯合影音網
2013-05-02	＜在台南＞雨弦積極面對生命　■李瑞騰...	中華日報
2013-05-02	台灣地殼解密　北部地殼相對穩定...	台灣立報
2013-05-02	研究：北台灣大地震頻率較低...	中央社
2013-05-02	研究精測　中央山脈地殼厚達45公里 ...	中央廣播電台
2013-05-02	中央山脈仍造山　桃園以北地殼穩定 ...	中廣
2013-05-02	中央山脈底45公里　台灣持續造山! ...	華視新聞網
2013-05-02	首度確認！中央山脈地殼厚45公里　發生大...	ETtoday
2013-05-02	台北.北海岸造山完成　地殼相對穩 ...	公視新聞網
2013-05-02	首度確認！中央山脈地殼厚45公里 ...	台視新聞
2013-05-02	學者首確認　中央山脈「厚」45公里...	蘋果日報

時間	標題	剪報來源
2013-05-02	北台灣地殼較薄地震較少也較弱...	Upaper
2013-05-02	中央山脈地殼厚45公里　地震機率高 ...	人間福報
2013-05-02	台灣北部地殼最穩　學者：不等同核電廠安全...	大紀元時報
2013-05-02	北部造山運動南移　可供地震模擬 ...	台灣醒報
2013-05-02	研究發現：中央山脈地殼厚達45公里 ...	聯合新聞網
2013-05-02	中央山脈地殼厚45公里...	聯合新聞網
2013-05-02	北部三核電廠地殼變動　全臺最低...	國語日報
2013-05-02	中央山脈底45公里　台灣持續造山...	聯合影音網
2013-05-02	台灣研究：中央山脈地殼厚達45公里　大地...	國際線上
2013-05-02	台灣中央山脈地殼厚達45公里：大地震幾率...	北京新浪網
2013-05-02	學者首度精準確認：中央山脈地殼　厚達45...	聯合晚報
2013-05-02	北台三核電廠　大地震機率低 ...	中國時報
2013-05-02	中大研究：北台灣大地震機率小 ...	聯合報
2013-05-02	中央山脈地殼厚45公里　大地震機率高...	自由電子報
2013-05-01	馬總統褒揚蕭樂同少將 ...	青年日報

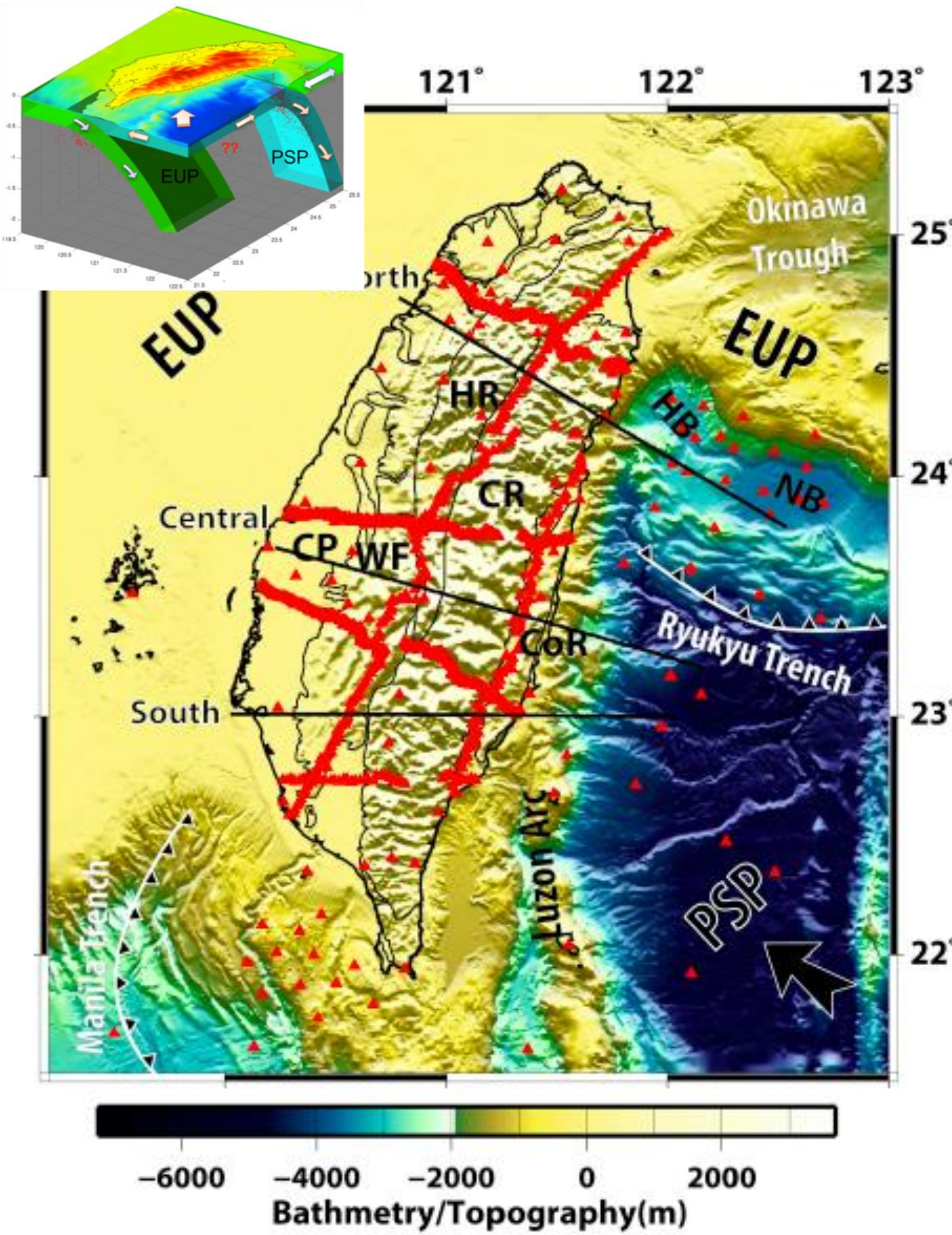
Thoughts behind TAIGER Experimental Design

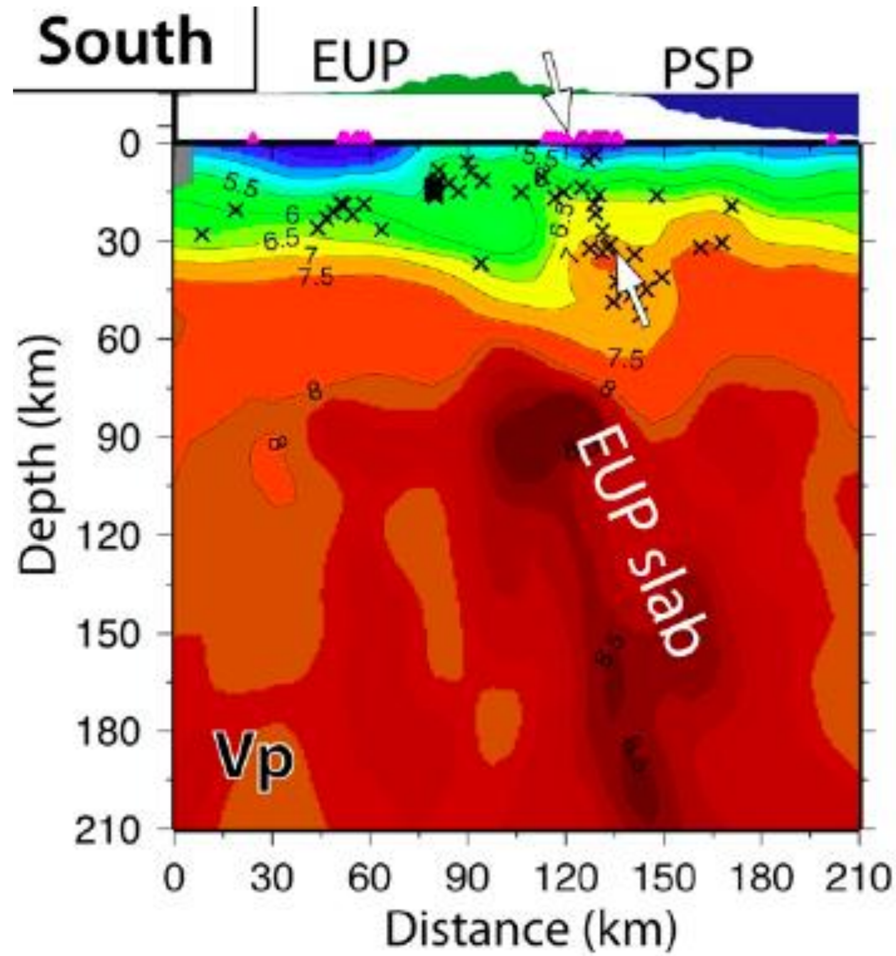
- 中部造山：General models of mountain building in Central Taiwan
- 東部隱沒帶：Problems of the northeastern/eastern Taiwan plate boundary
- 南部向東隱沒：Problems related to the subduction of Eurasian plate under Southern Taiwan
- 台灣海峽：Tectonics of Taiwan Strait
- 掉落的板塊：Lost slabs east of Taiwan?

What can TAIGER do?

- Improved image of the upper mantle under Taiwan **(上部地函）**
- Locating earthquakes and determine focal mechanisms of offshore earthquakes（**外海地震**）
- Mapping S-splitting in the crust and upper mantle to determine foliation（**地殼及上部地函的方向變形**）
- Hunt for detachment fault（**滑脫面**）

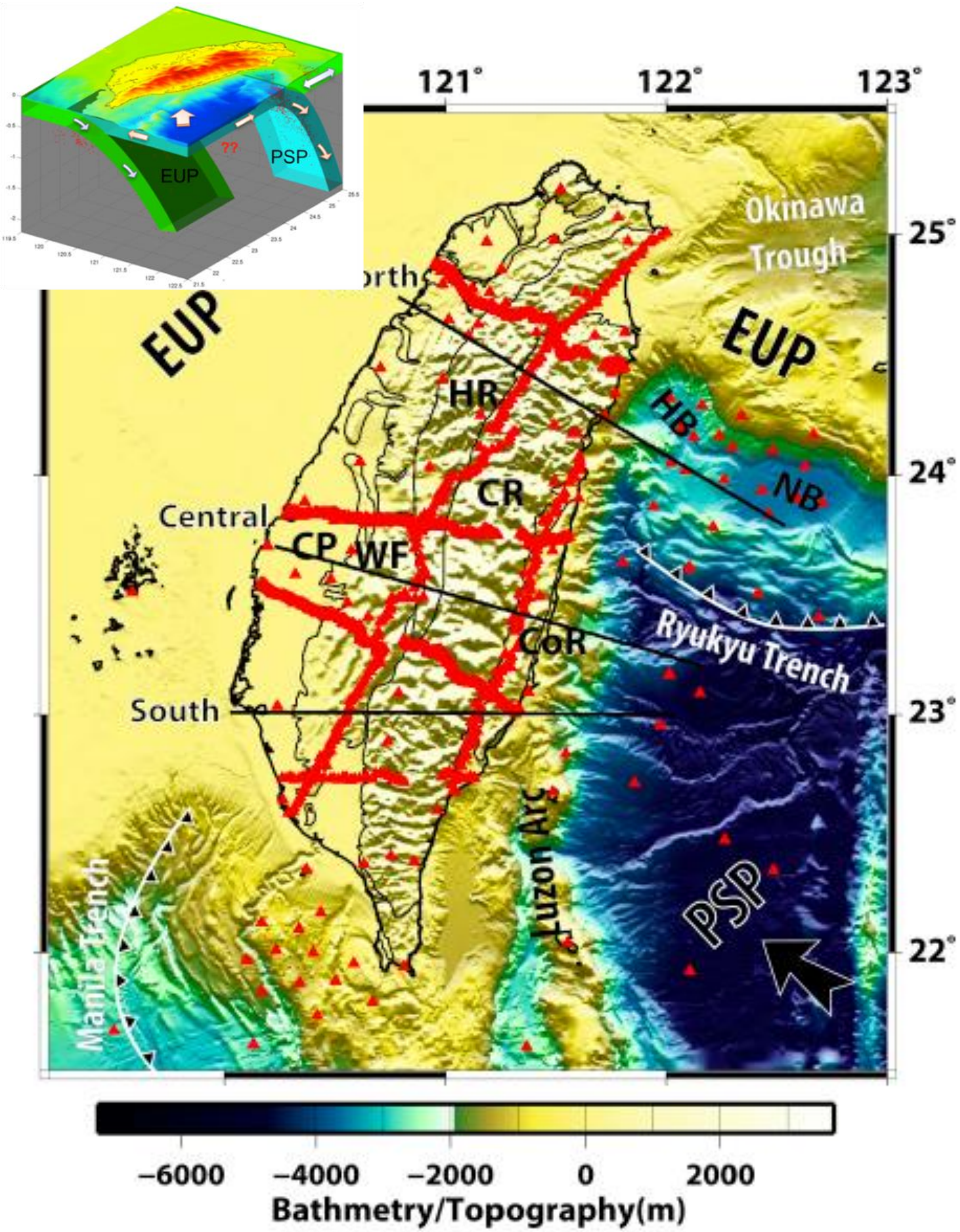
TECTONIC SETTING

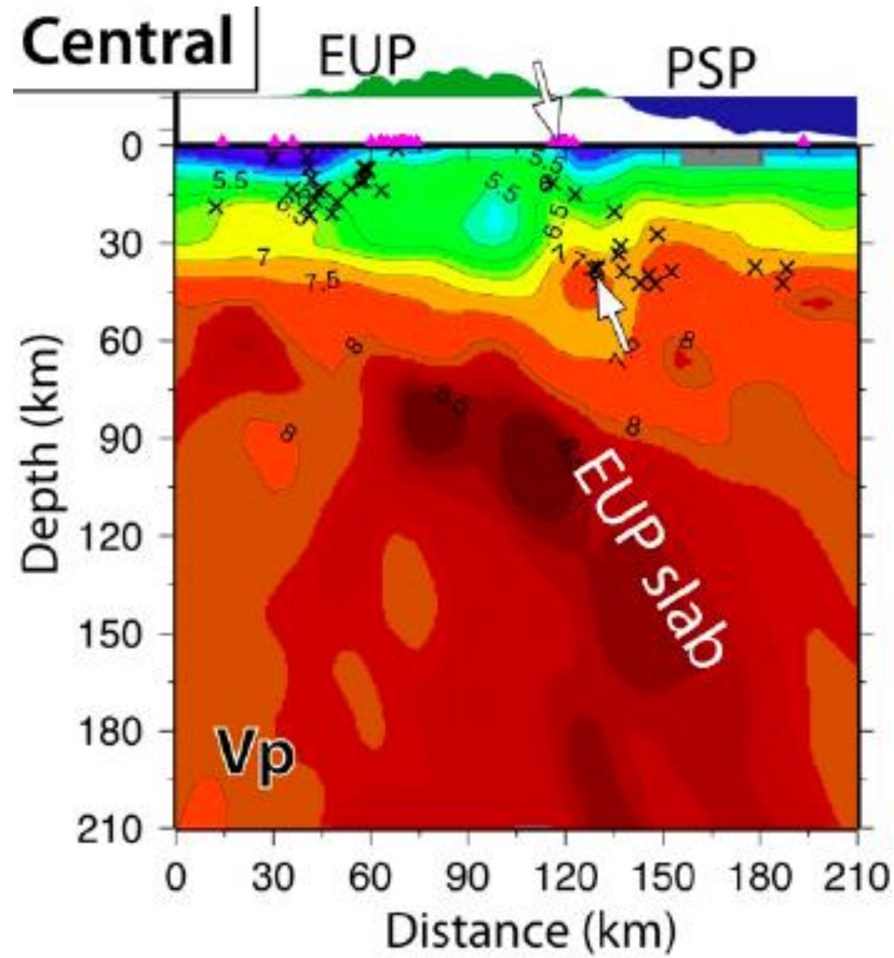




(Kuo-Chen et al., 2012, JGR)

TECTONIC SETTING





(Kuo-Chen et al., 2012, JGR)

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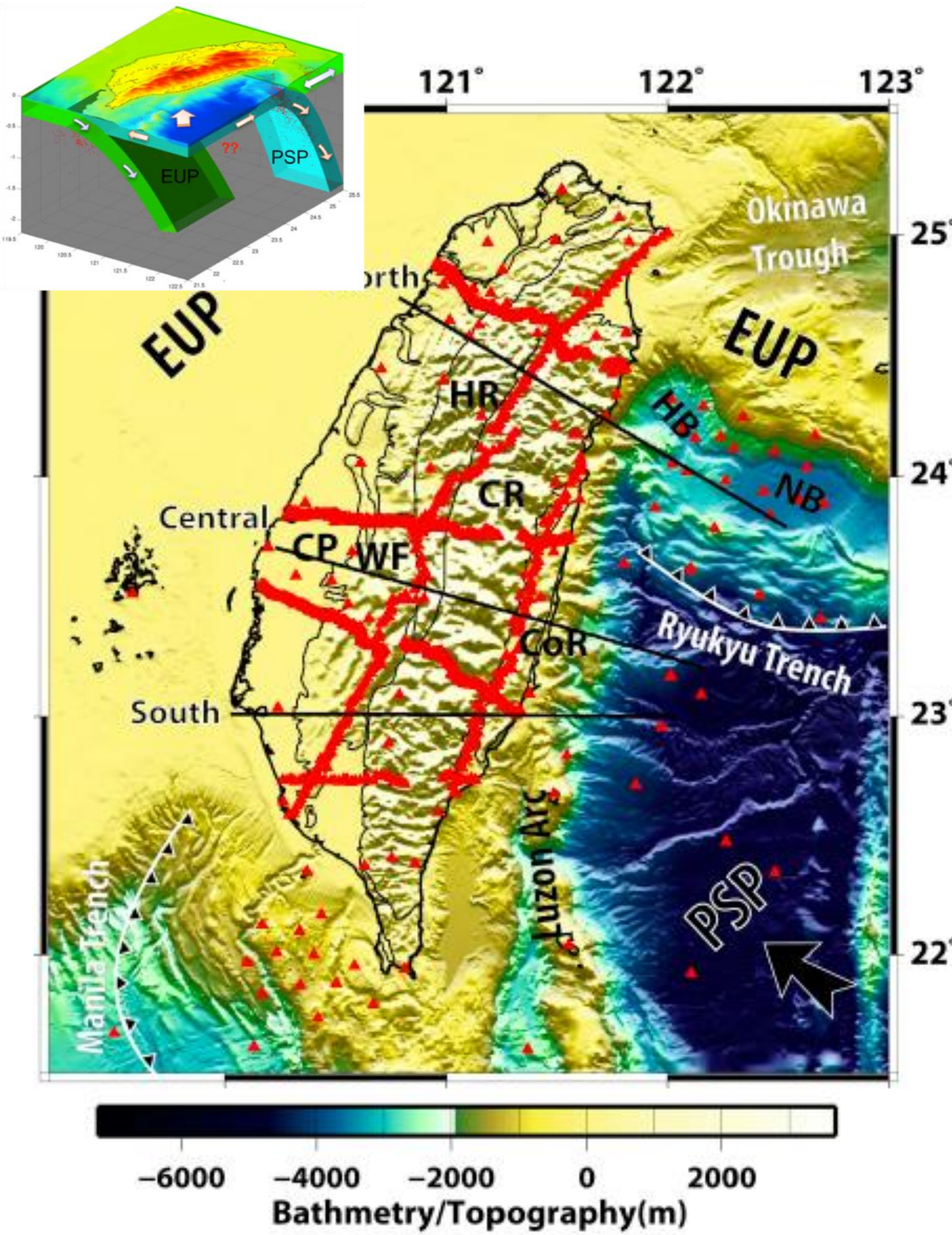
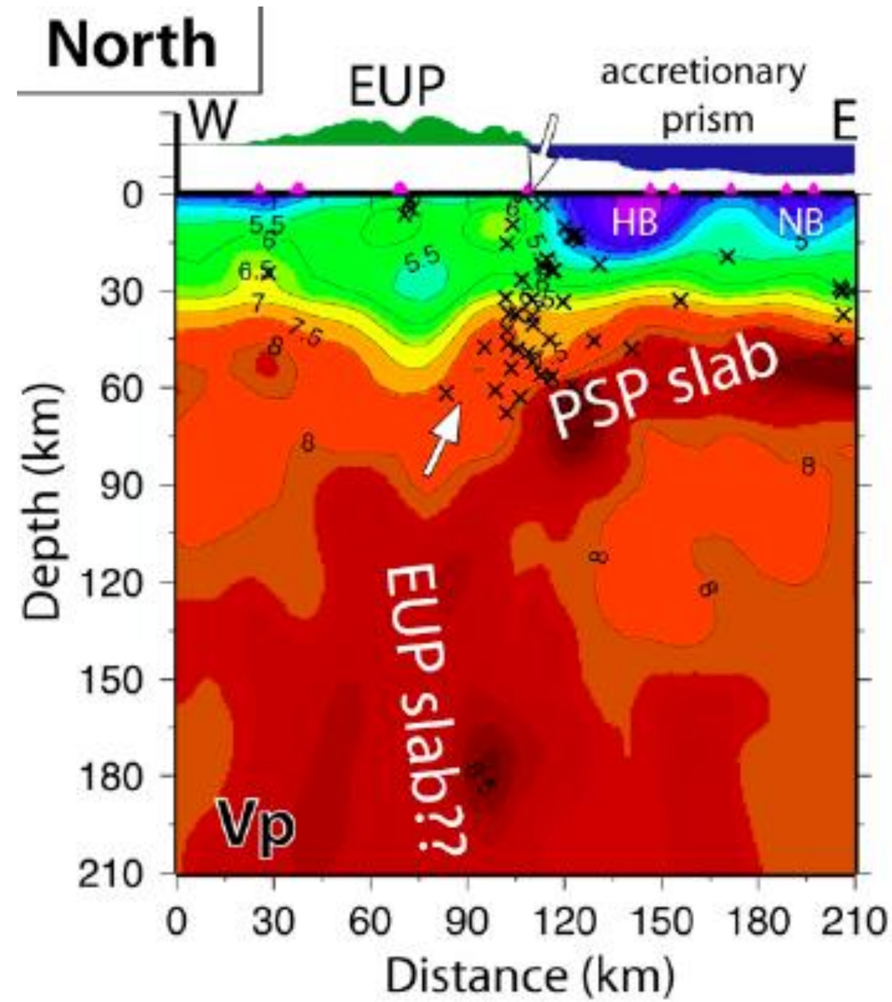
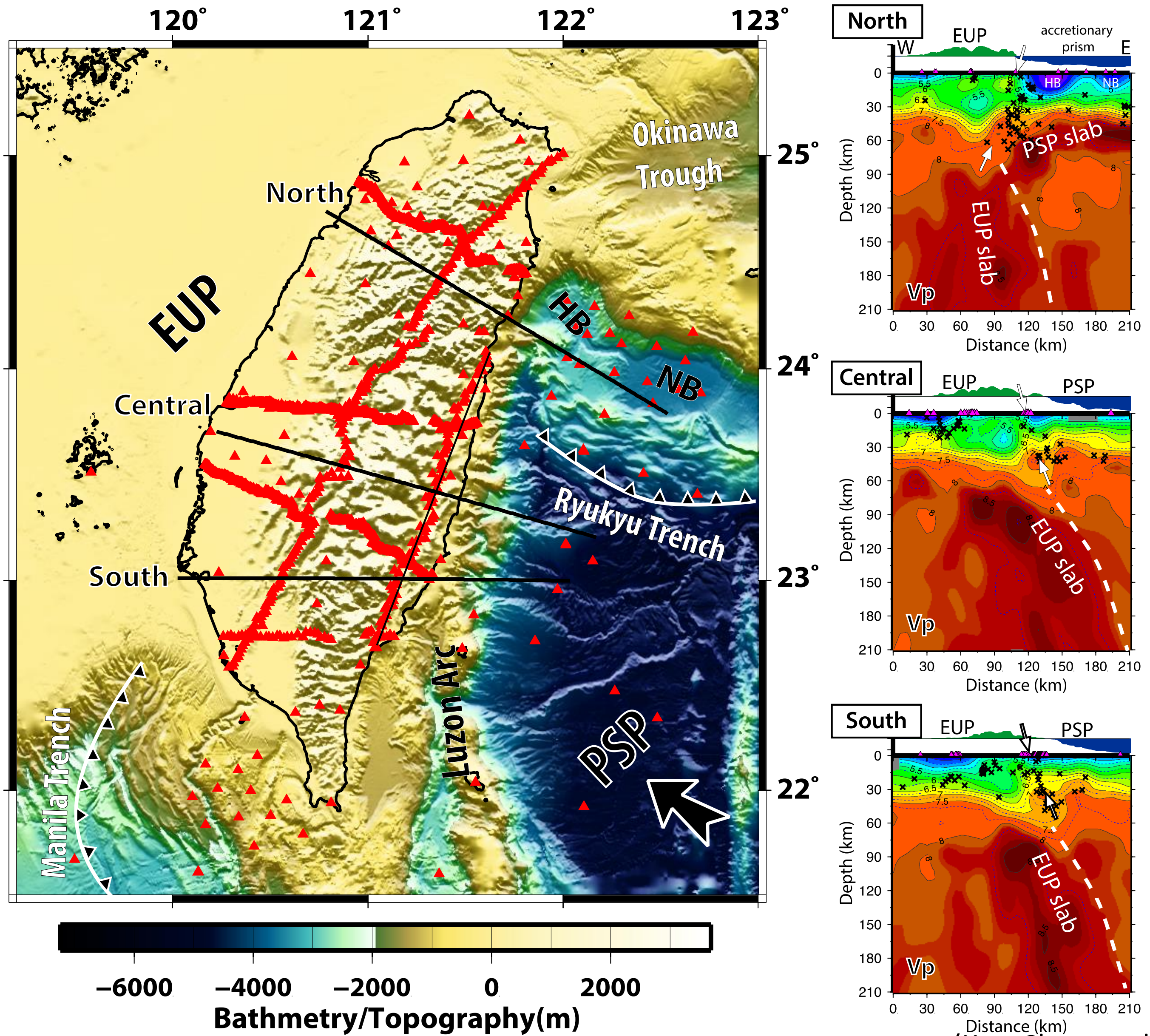




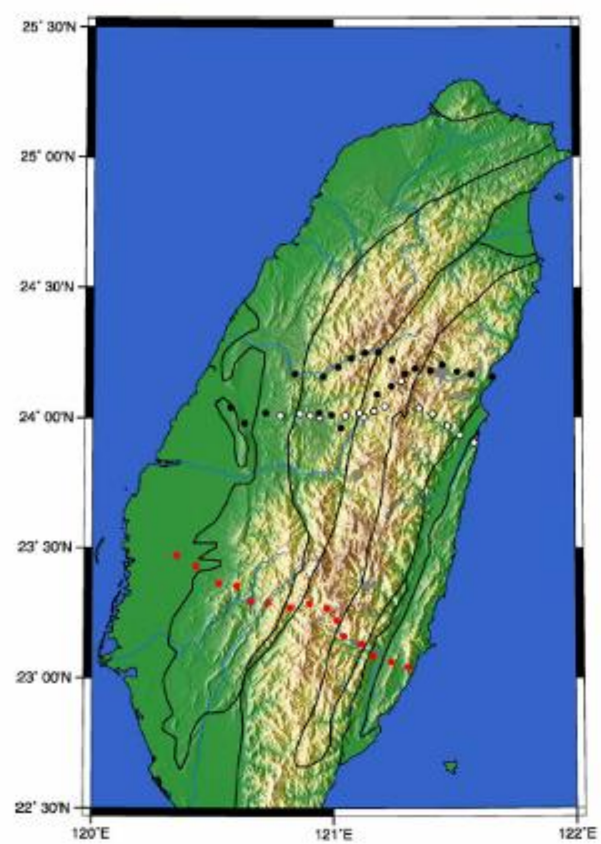
(Kuo-Chen et al., 2012, JGR)

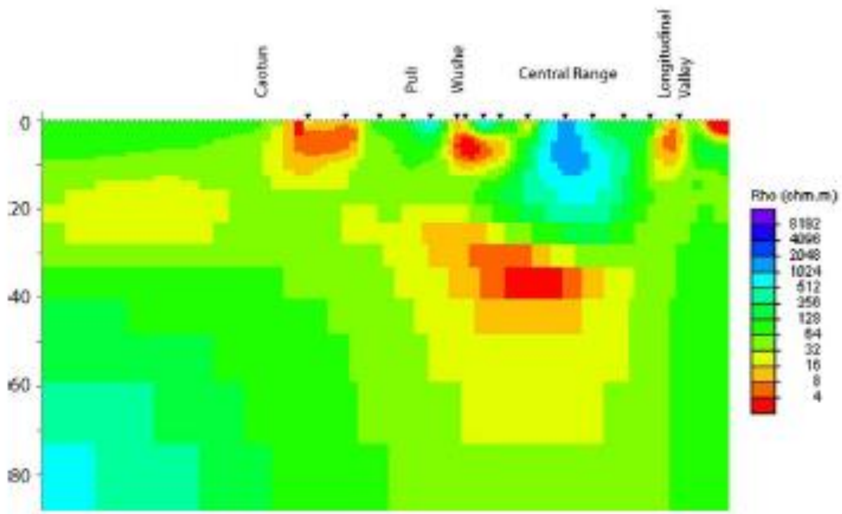
TECTONIC SETTING



(Kuo-Chen et al., 2012, JGR)

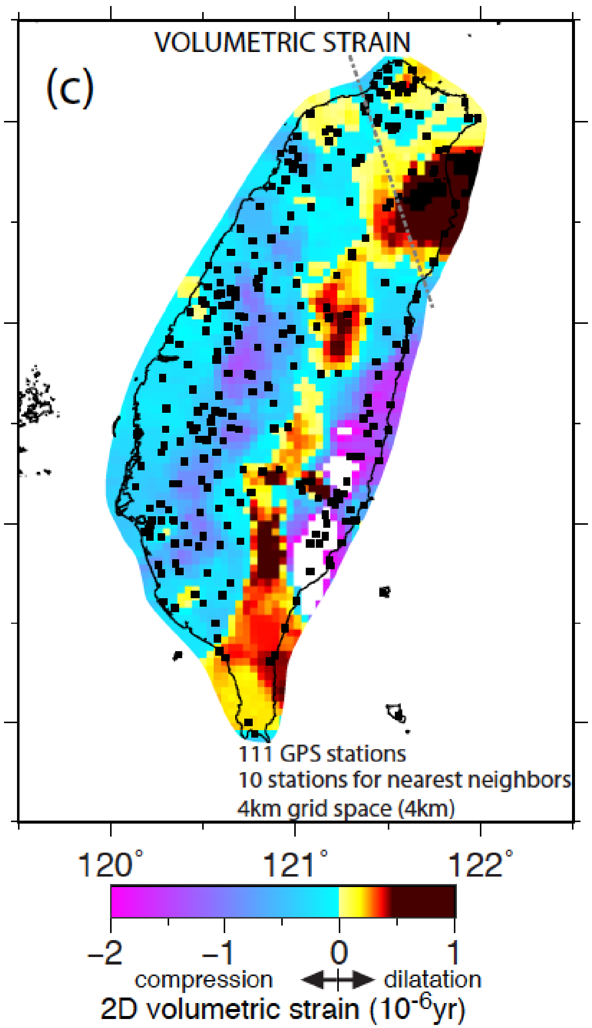
Preliminary MT profile across Taiwan

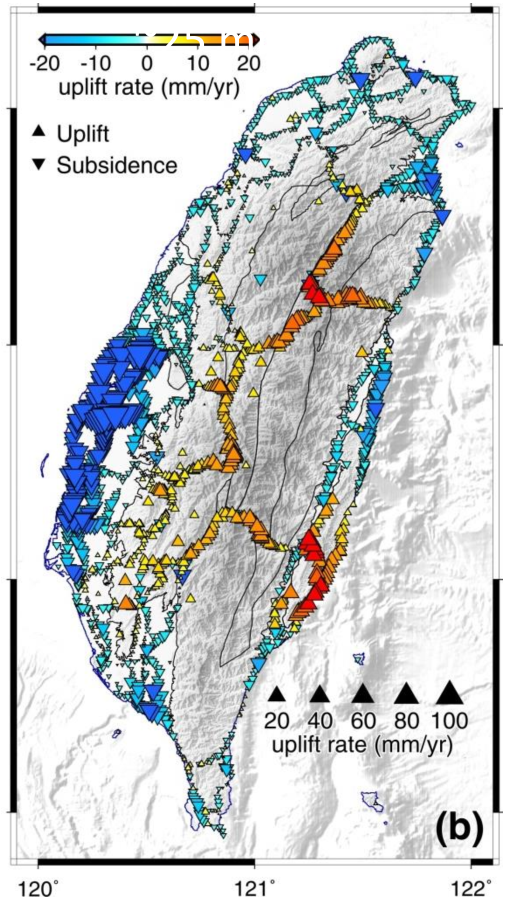


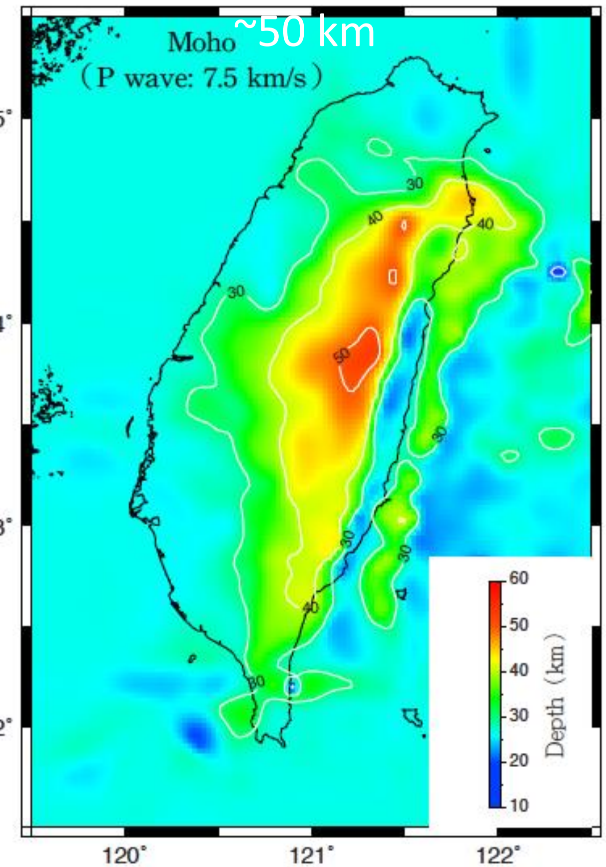


Resistive Central Range
Lower crustal conductive zone

TECTONIC SETTING





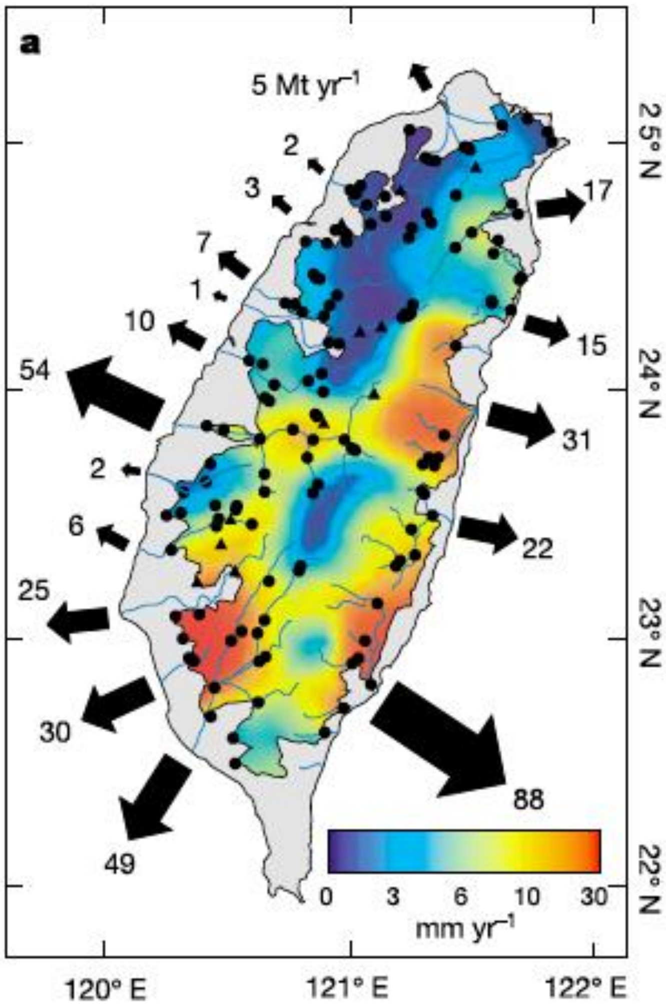


(Ching et al., 2011, JGR)

TECTONIC SETTING

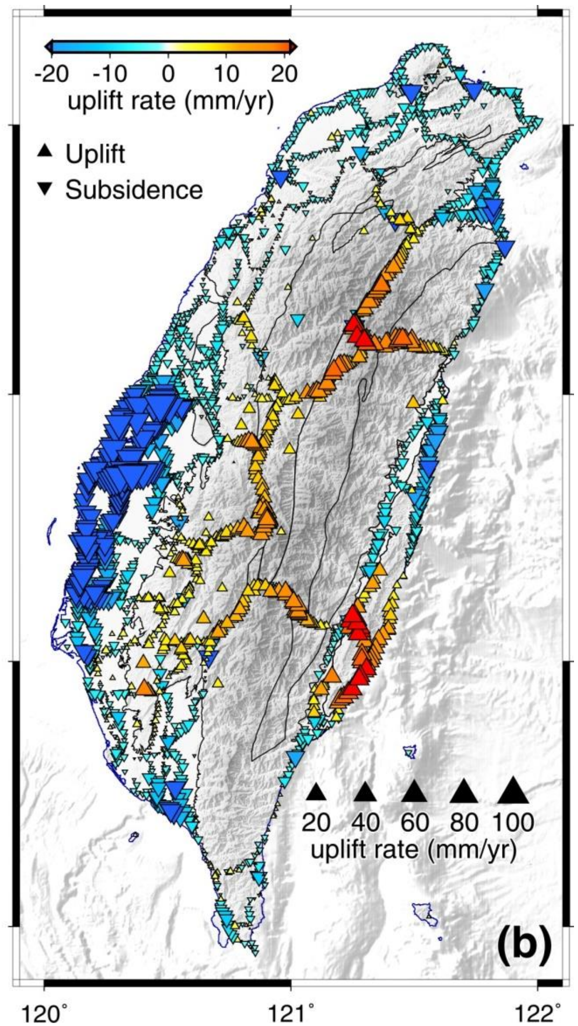
6.5 Ma young mountain: a "snapshot" for an initial orogeny

Erosion rate:
~ 30 mm/yr

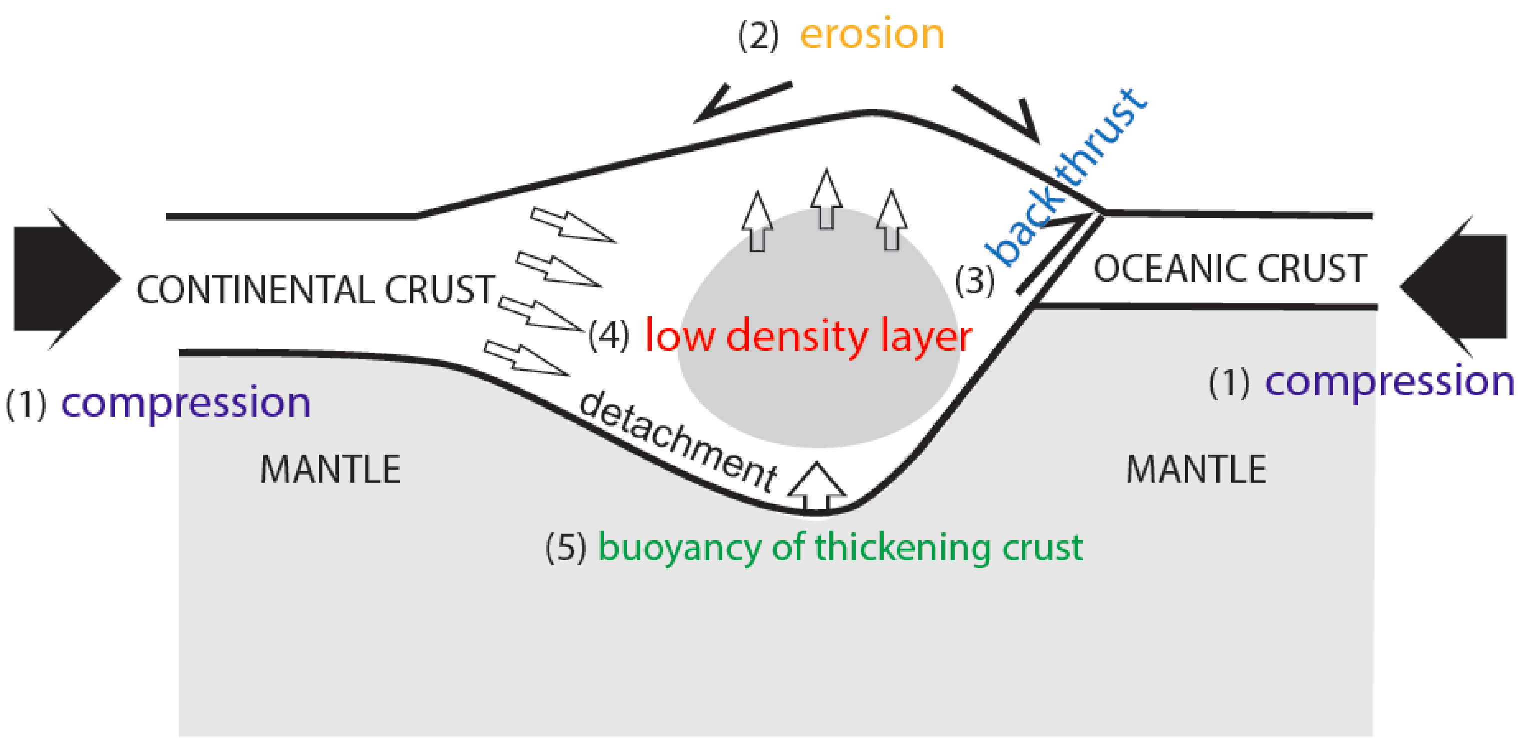


(Dadson et al., 2003, Nature)

Uplift rate:
~25 mm/yr



(Ching et al., 2011, JGR)



- From Vp/Vs tomography, the ***α-β quartz transition*** may occur at ~24±3 km beneath the Central Range.
- This phase transition (low density layer) might play an important role for the mountain building process.

Evidence of Reactivation on pre-existing Normal Faults

- Abrupt change of facies and stratigraphic thickness across major thrust (reverse) faults
- High-angle dipping reverse faults at depth (>10km)
- Change of strtigraphic separation from pre-extensional units to syn-extensional units
- The presence of high pore pressure zones between the Miocene Nanchuang and Pliocene Niaotsui Formation.