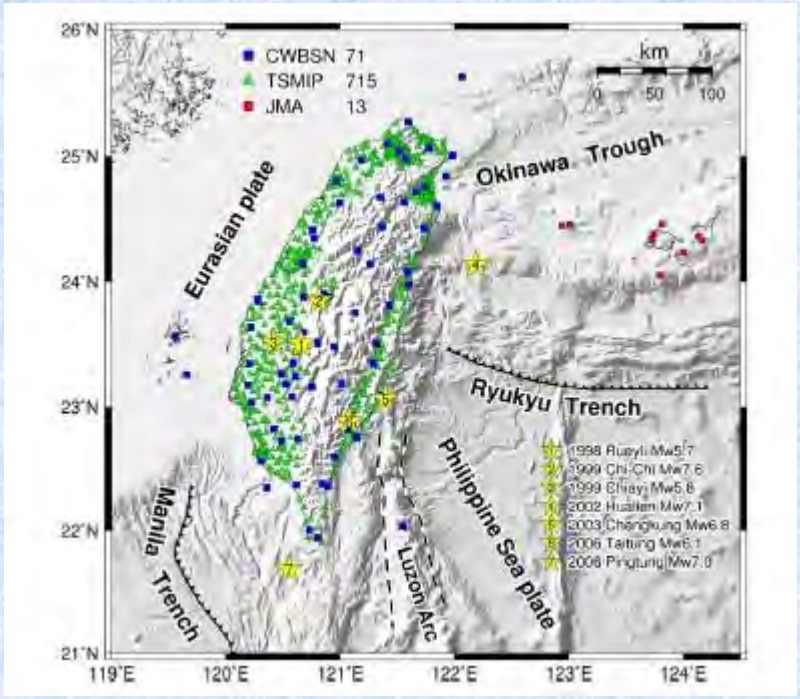
Earthquakes of Taiwan

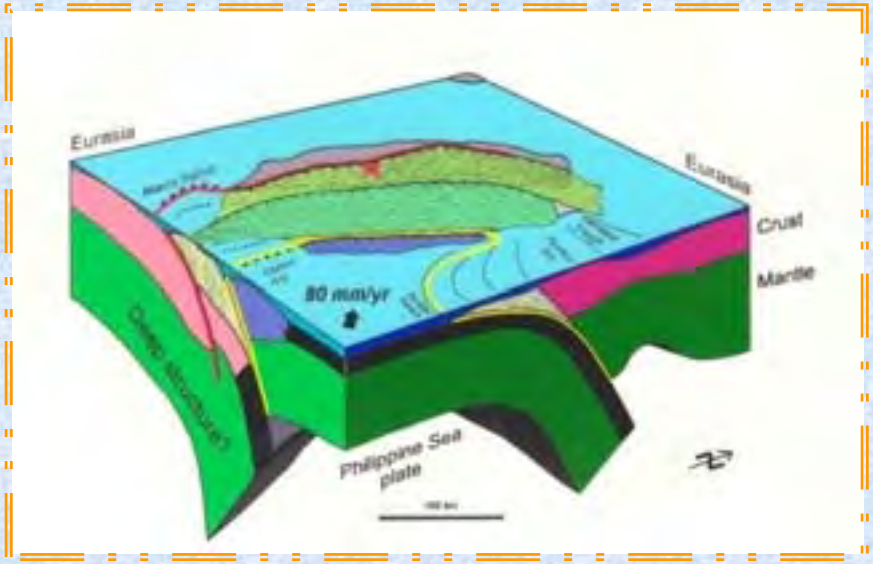
Jeen-Hwa Wang
Institute of Earth Sciences
Academia Sinica

Regional Tectonics

2D View



3D View

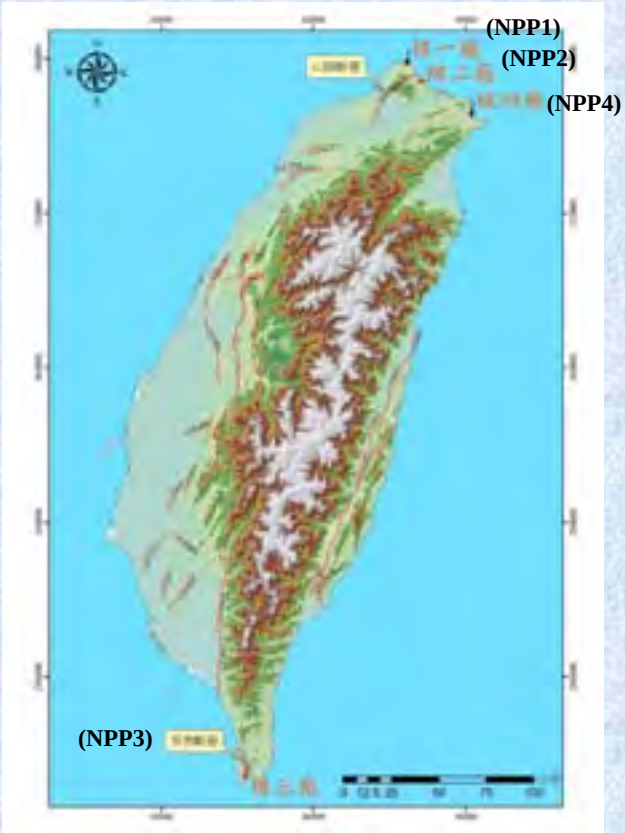


Active Faults

Main Factors to Define an Active Fault by the Central Geological Survey

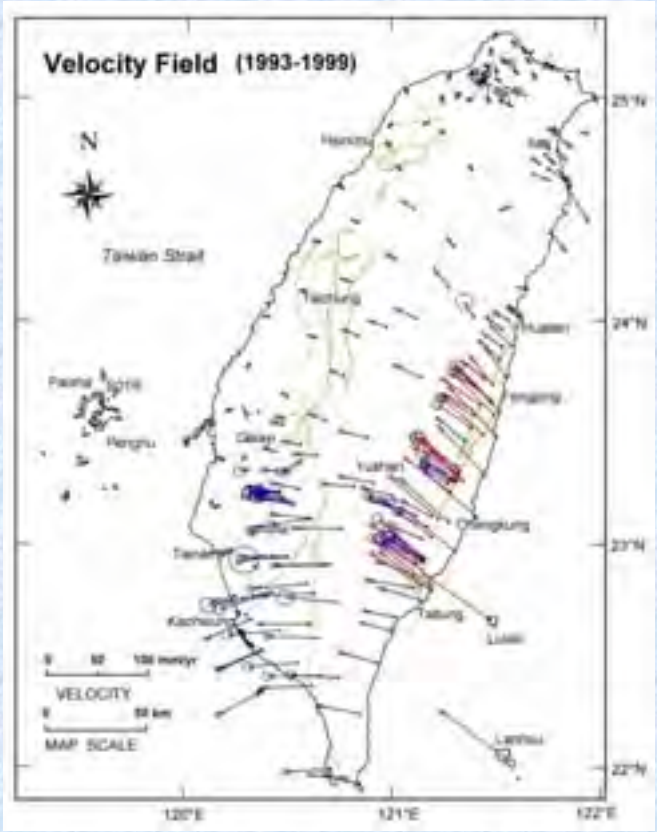
- **Category I active faults: if there has been movement observed or evidence of seismic activity during the last 10,000 years.**
- **Category II active faults: if they have been recognized at the surface and which have evidence of movement in the past 100,000 years.**
- **Uncertain active faults: if they have been recognized at the surface and which have evidence of movement in the Quaternary.**

Distribution of 33 Identified Active Faults: 20 for C-I and 13 for C-II

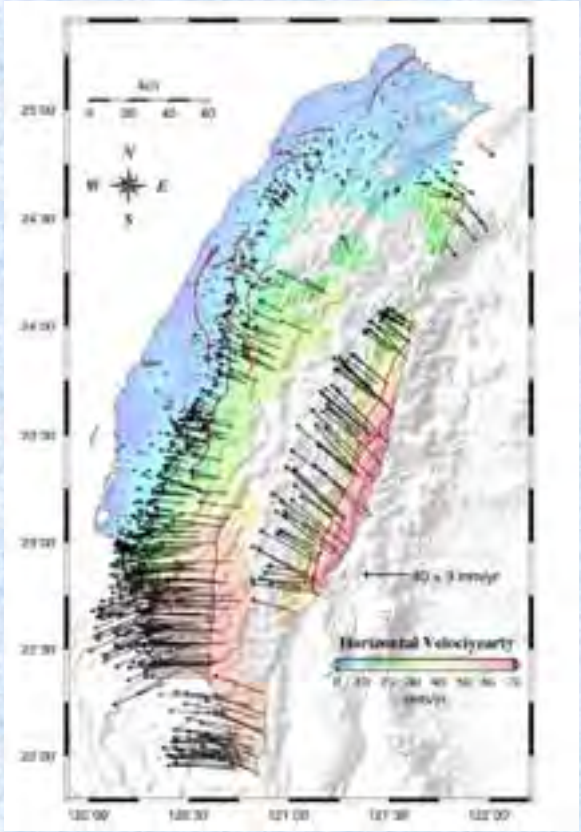


Velocity Fields of Crustal Deformations

From 1993 to 1999 (Yu et al., 1998)



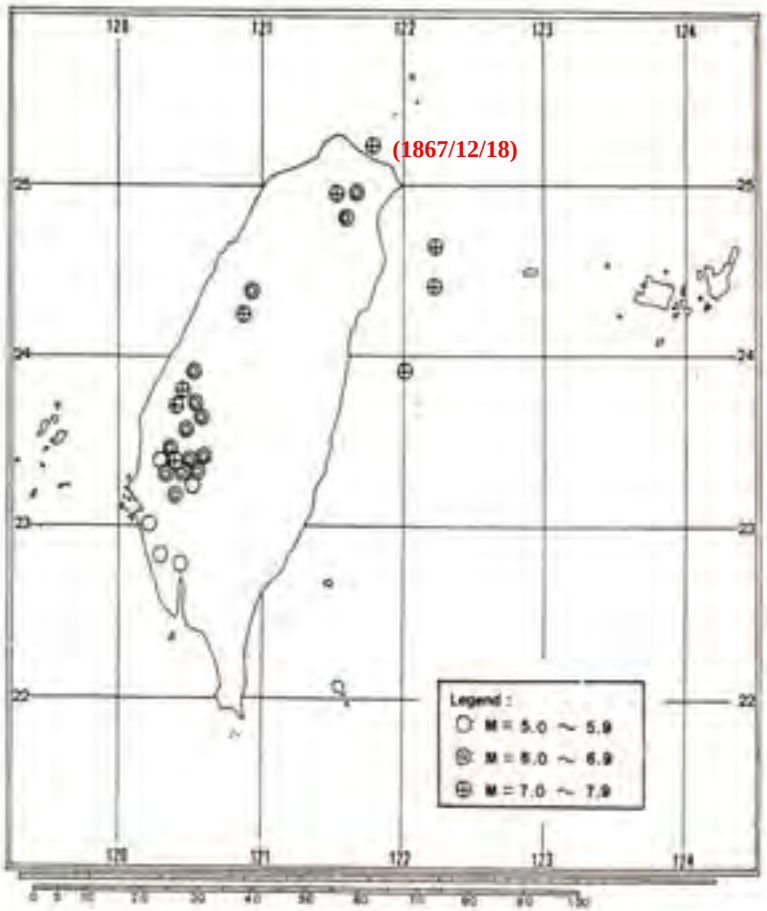
From 2002 to 2012 (CGS, 2013)



Main Historical Events from 1644 to 1899

明清時代破壞性大地震〔參照徐氏（1985）〕

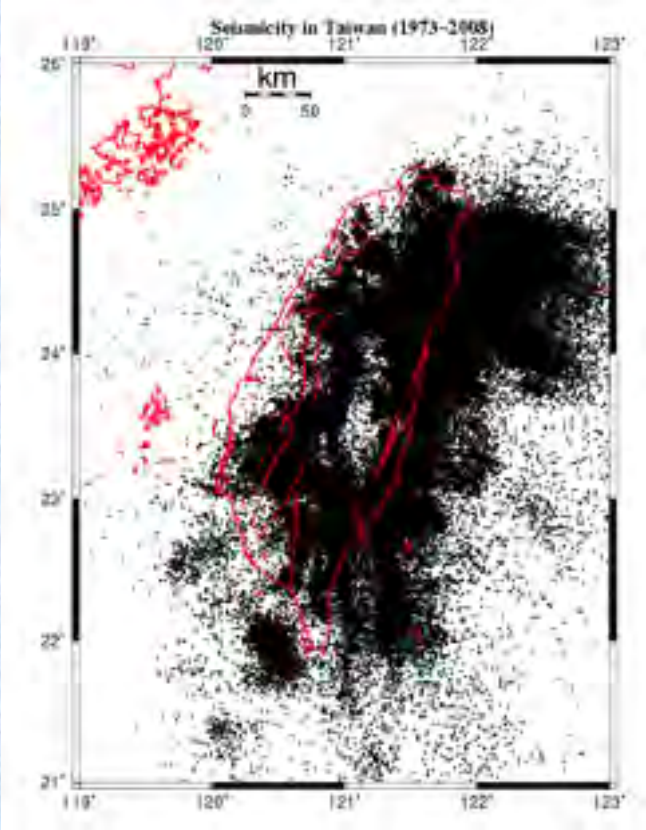
發震時（陰曆）	（陽曆）	震災地區	推定前大震度	推定地震規模
1. 崇禎17年6月30日	1644年7月30日	南部	V	5.0
2. 永歷9年12月14日	1655年1月21日	台南	V	5.5
3. 康熙33年4月1日~4月30日	1694年4月24日~5月23日	台北	VI	7.0
4. 康熙50年9月11日	1711年10月22日	台南	V	5.5
5. 康熙54年9月15日	1715年10月11日	嘉義	VI	6.5
6. 康熙55年9月16日	1716年11月2日	嘉義、台南、高雄	V	6.0
7. 康熙56年1月21日	1717年3月3日	嘉義、台南、高雄	V	6.0
8. 康熙59年10月1日	1720年10月21日	嘉義	V	6.0
9. 康熙59年12月8日	1721年1月5日	台南、嘉義	VI	6.5
10.雍正13年12月18日	1736年1月30日	台南、嘉義	VI	7.0
11.乾隆42年11月1日~11月30日	1777年11月30日~12月29日	嘉義	VI	6.0
12.乾隆57年6月22日	1792年8月9日	嘉義、彰化	VI	7.1
13.嘉慶16年2月24日	1811年3月18日	嘉義、彰化	VI	6.5
14.嘉慶20年6月5日	1815年7月11日	台北、宜蘭	VI	6.5
15.嘉慶20年9月11日	1815年10月13日	嘉義、斗六、彰化、淡水、新竹	VI	7.1
16.嘉慶21年8月1日~30日	1816年9月21日~10月20日	宜蘭	V	7.2
17.道光13年11月3日~22日	1833年12月13日~30日	宜蘭	V	7.0
18.道光19年5月17日	1839年6月27日	嘉義	VI	6.5
19.道光20年10月1日~10月30日	1840年10月25日~11月23日	斗六	VI	6.0
20.道光25年1月26日	1845年3月4日	彰化	VI	6.5
21.道光28年11月8日	1848年12月3日	彰化、鹿港、嘉義	VI	7.0
22.道光33年3月1日~30日	1850年4月12日~5月11日	嘉義	V	5.5
23.同治元年5月11日	1862年6月7日	台南、嘉義	VI	6.5
24.同治4年9月18日	1865年11月6日	台北、基隆	VI	6.0
25.同治6年11月23日	1867年12月18日	台北、基隆	VI	7.0
26.光緒7年1月20日	1881年2月18日	新竹	VI	6.0
27.光緒8年10月29日~11月7日	1882年12月9日~16日	全台	V	7.5
28.光緒18年3月26日	1892年4月22日	台南、安平	V	5.5



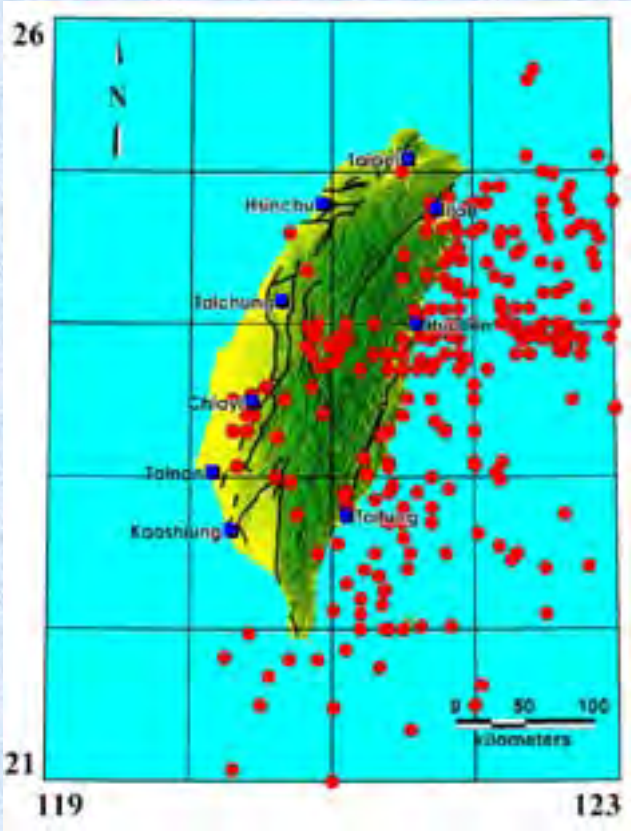
圖一：明清時代破壞性大地震分佈圖

Spatial Distribution of Earthquakes

M≥3 Events (1973-2008)

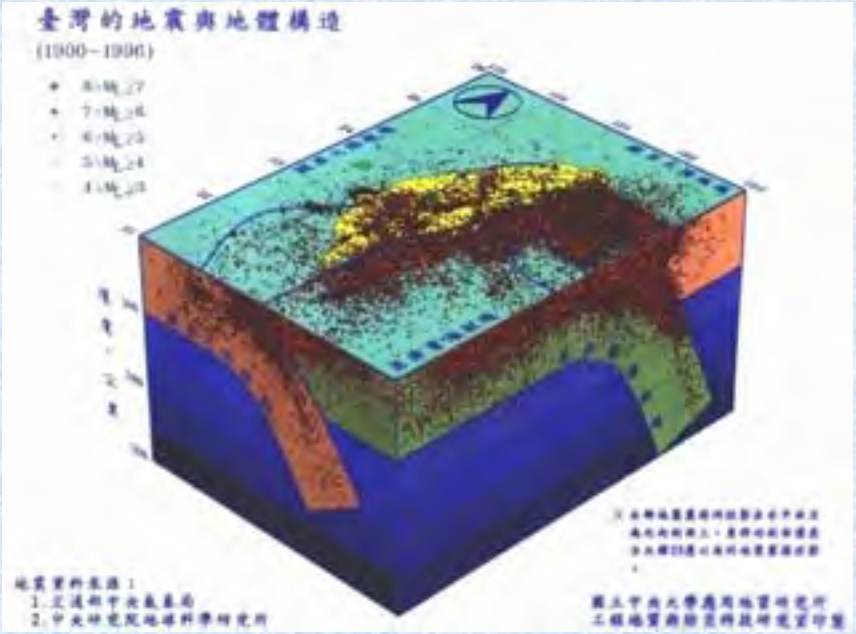


M≥6 Events (1900-2012)

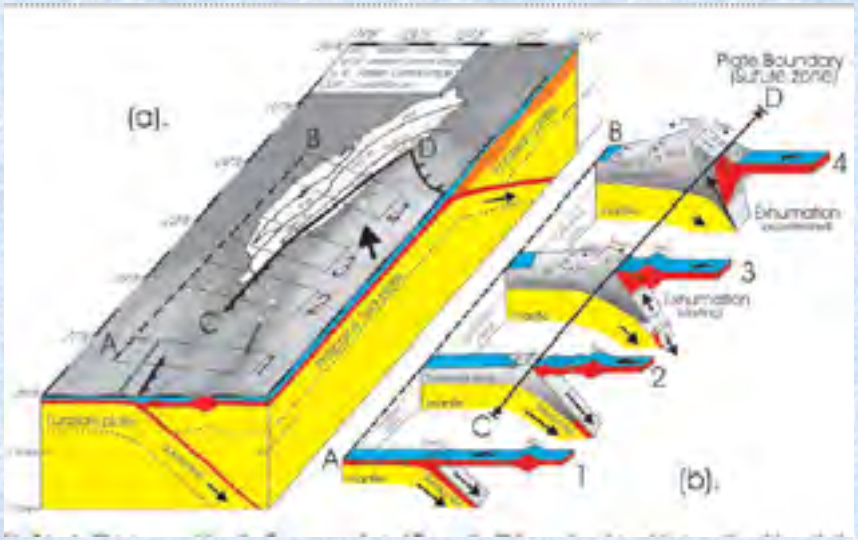


3D View of Seismicity and Regional Tectonics

3D View



Lin (2002)

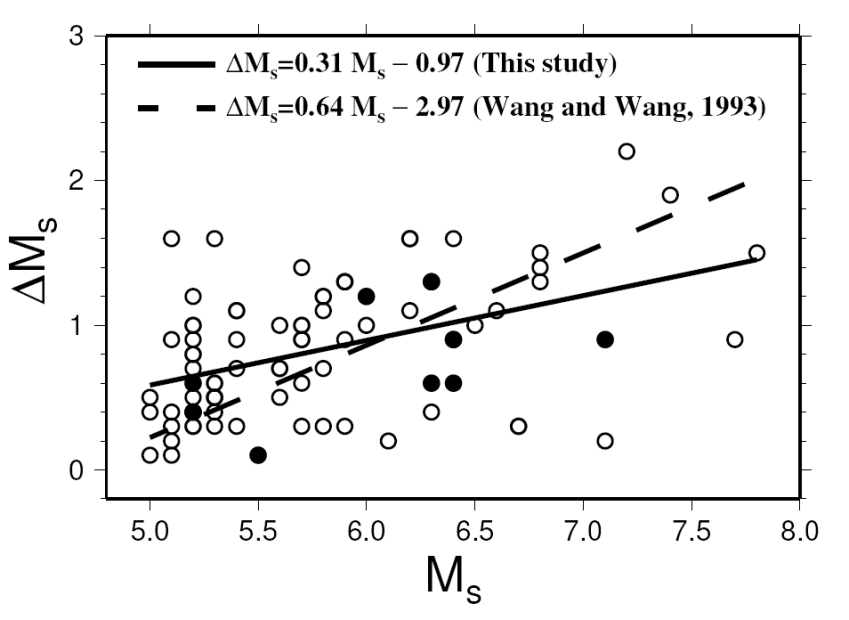


Debate: Thin-skinned model vs. Lithosphere collision model

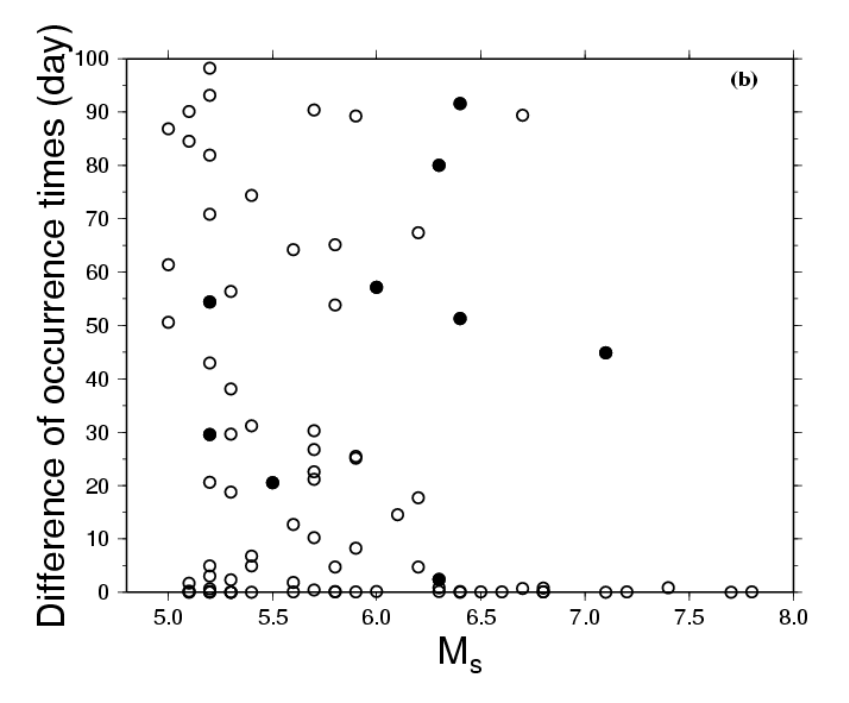
Mainshocks and Largest Aftershocks

(Chen and Wang, PAGEOPH 2012)

$\Delta M_s=(M_s)_{mainshck}-(M_s)_{aftershock}$

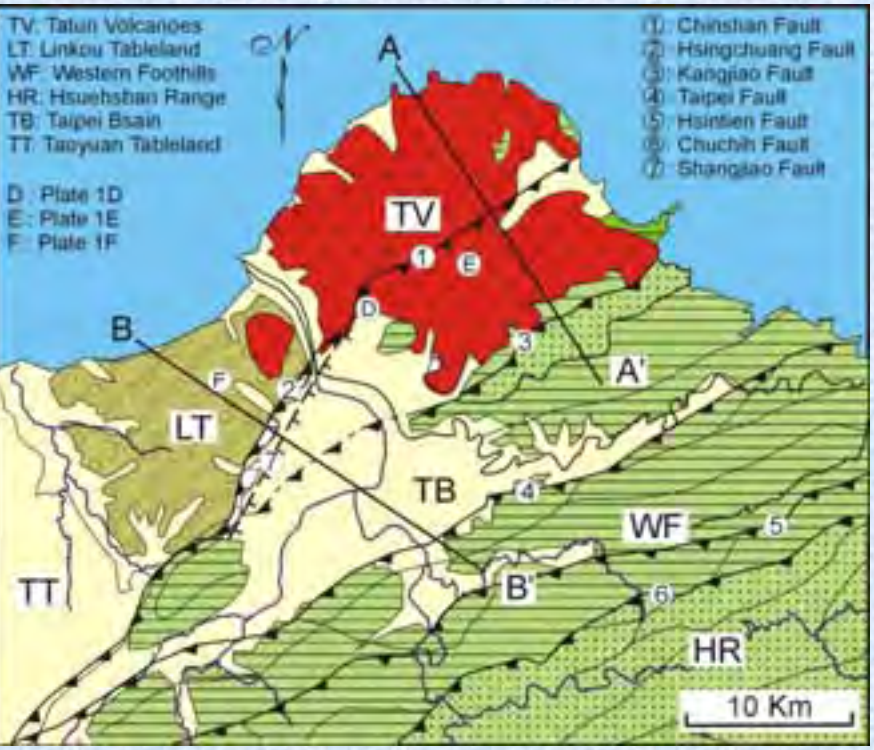


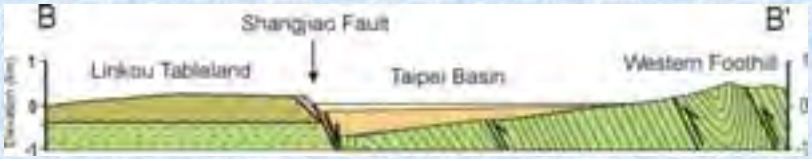
Difference of Occurrence Times



Geology of Northern Taiwan (including the Taipei City and New Taipei City (formally Taipei County), and Keelung City)

Regional tectonics has changed from compression to extension since about 0.8 m.y. ago.

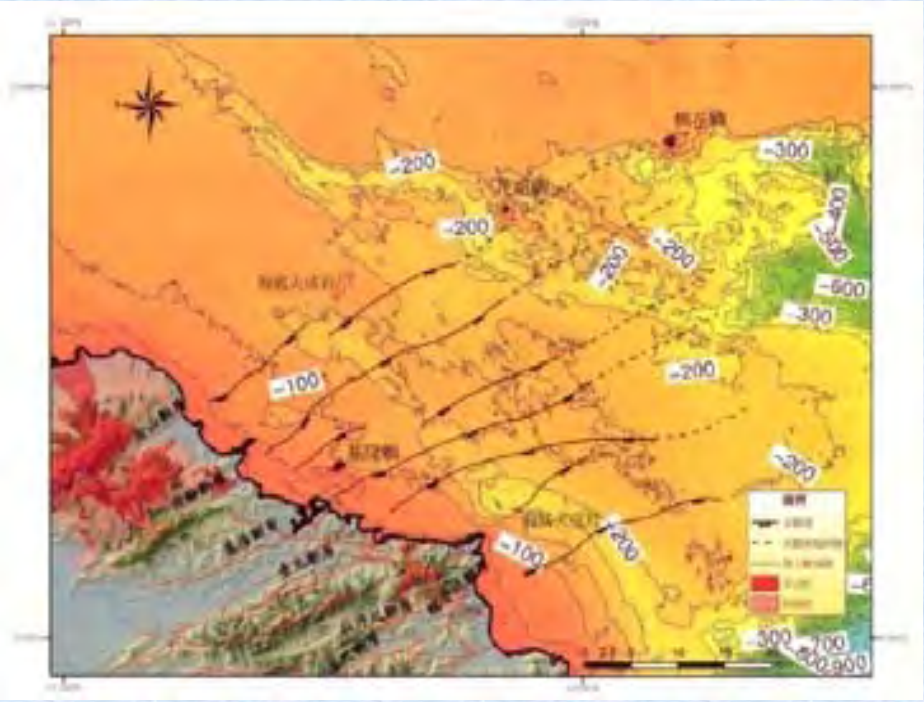




Shih et al. (2006)

Main Faults in Northern Taipei

- 1. Hsingchun fault, including Chinshan fault (Thrust fault)
- **2. Shangjiao fault (Category II active normal fault)**
  southern segment: strike: N30°E; dip: >70°SE
  northern segment: strike: N45°E; dip: >70°SE
- 2. Kangjiao Fault
- 3. Taipei Fault
- 4. Shintein Fault

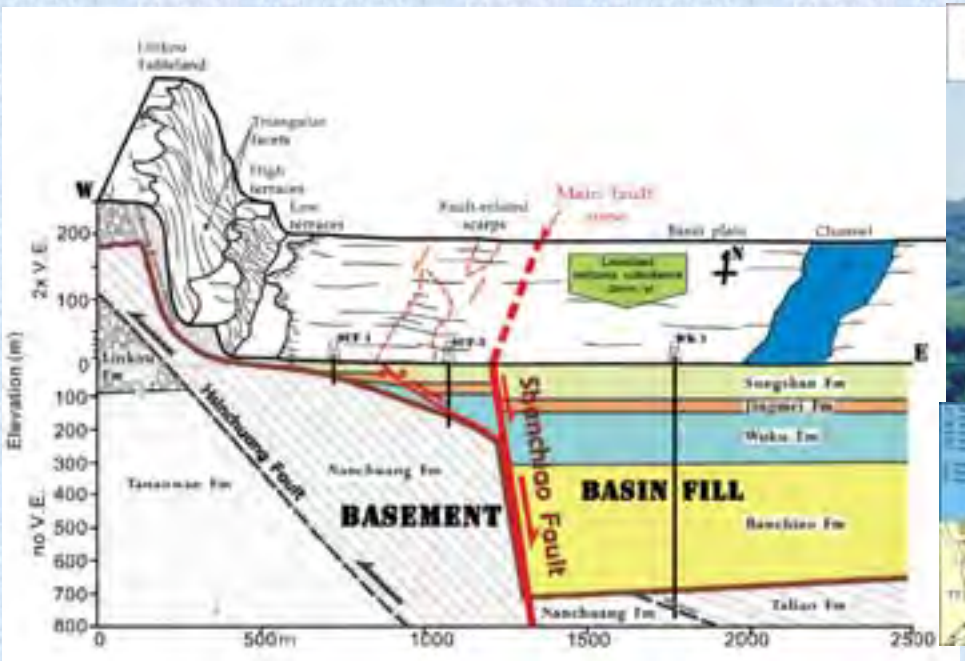


臺北盆地內第三紀地層斷層構造圖（摘自王執明等,1978）

Damaged Earthquakes near the TMA

Time	Location	M	Effects
1659/10-11	Near Taipei		Aftershocks
1694/4-5	Near Taipei	7.0	Kanshi Taipei Lake (康熙台北湖)
1815/7/11	Near Taipei	6.5	Minor damages
1853/5-8	Tatungshan		Earthquake Sound
1860/11-12	Near Taipei		Landslide
1865/11/6	Near Taipei		Landslide, death
1867/12/18	Offshore Keelung(?)	7.0	Tsunami : height>10 m surface rupture Death: several hundreds Injured: many Many houses collapsed or damaged
1881/12/08	Near Taipei		Minor damages
1909/04/15	25°N, 121.5°E h=80 km	7.3	Death: 9 Injured: 51 Collapsed Houses: 122 Damaged houses: 1050
1910/04/12	25°N, 123°E h=200 km	8.1	
1917/07/04	25°N, 123°E	7.4	
1917/07/04	25°N, 123°E	7.0	
1988/07/03	25.16°N; 121.57°E h=5 km	5.3	Injured: 16

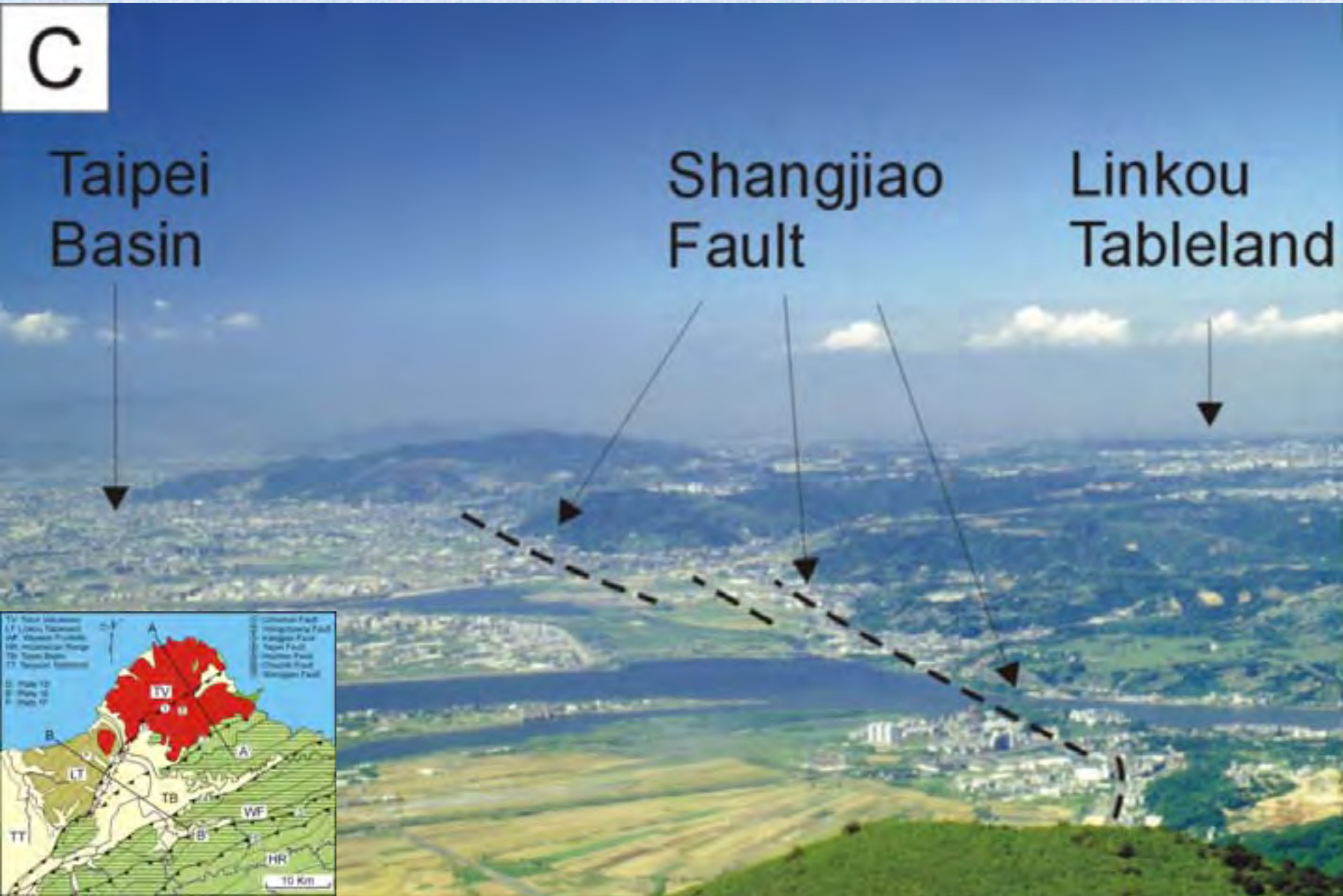
3D Structure of the Shangjio (or Shanchiao) Faults in the Wuku Area and a Fault Scarp of the Chinshan Fault at the Tatun Volcano Group



Chan et al. (TAO, 2010)

From J.F. Lee

Surface Traces of the Shangjiao Fault



Estimates of M, D_{max}, and D_{ave}

The magnitudes (M), maximum displacements (D_{max}), and average displacements (D_{ave}) of potential earthquakes rupturing the Shangjiao fault or its southern and northern segments are estimated from the empirical relationships for normal faults inferred by Wells and Coppersmith (1994):

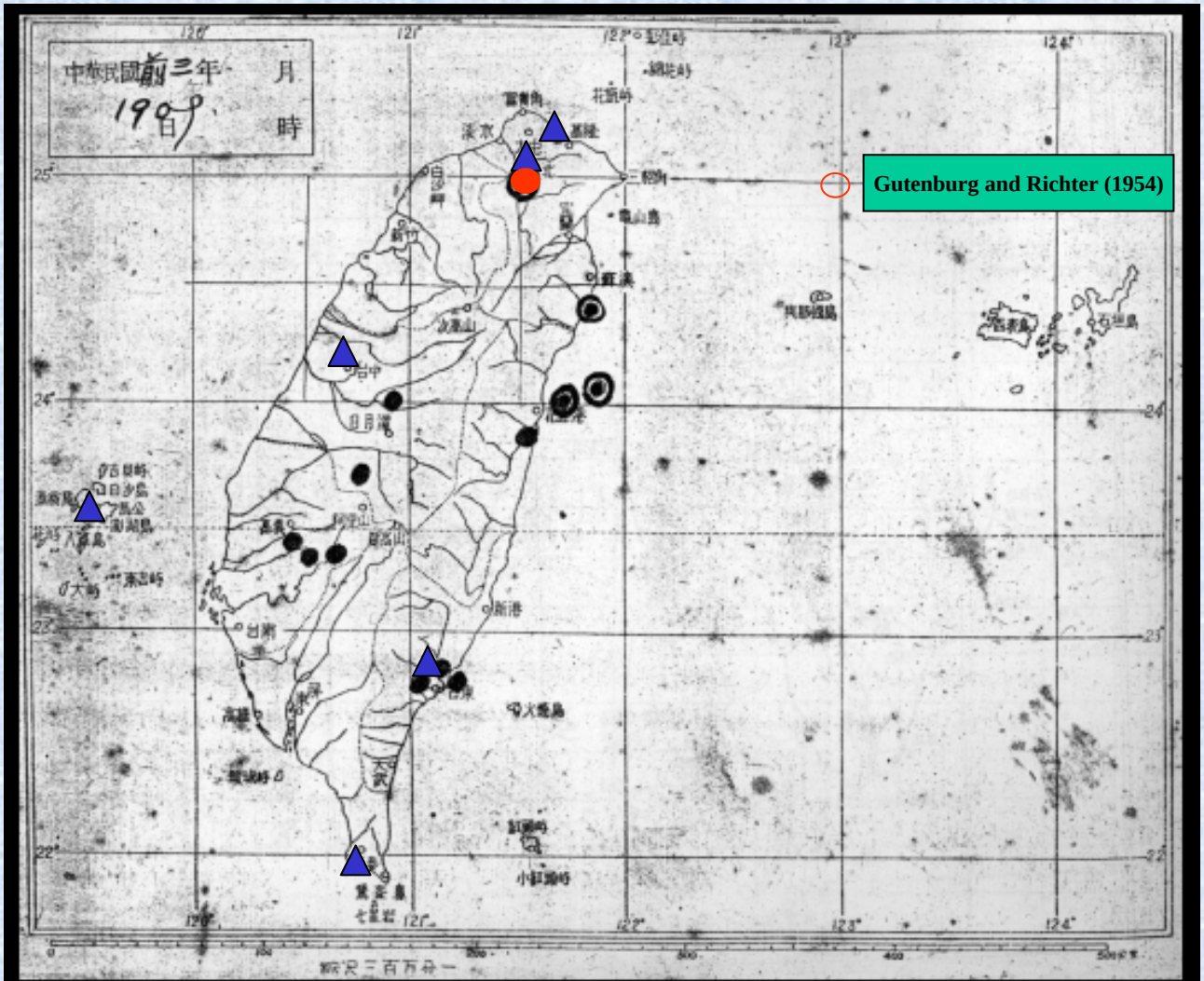
$$M=(4.86\pm0.34)+(1.32\pm0.26)\times\log(L)$$

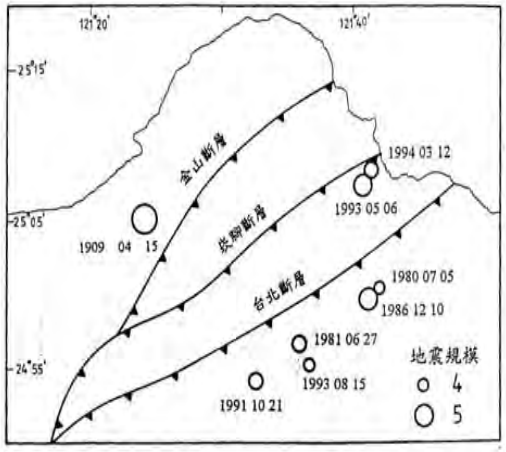
$$\log(D_{max})=(-1.98\pm0.50)+(1.51\pm0.35)\times\log(L)$$

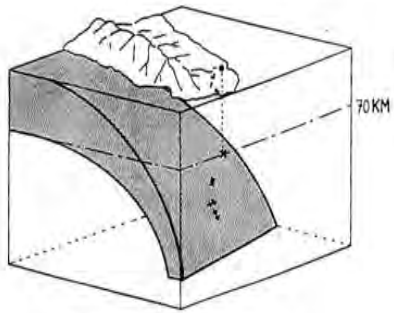
$$\log(D_{ave})=(-1.99\pm0.72)+(1.24\pm0.49)\times\log(L)$$

Fault(s)	M	D_{max}	D_{ave}
Shangjiao Fault			
southern segment: L=20 km	5.9≦6.6≦7.3	0.11 m≦0.97 m≦8.71 m	0.02 m≦0.42 m≦9.57 m
northern segment : L=25 km	6.0≦6.7≦7.4	0.14 m≦1.35 m≦13.19 m	0.02 m≦0.55 m≦13.63 m
L=50 km	6.3≦7.1≦7.9	0.31 m≦3.85 m≦47.87 m	0.04 m≦1.31 m≦46.63 m
Shangjiao Fault:			
L=45 km	6.3≦7.0≦7.8	0.27 m≦3.28 m≦39.35 m	0.03 m≦1.15 m≦38.91 m
L=70 km	6.5≦7.2≦8.1	0.46 m≦6.40 m≦89.51 m	0.05 m≦1.99 m≦83.55 m
L=90 km	6.6≦7.4≦8.3	0.61 m≦9.35 m≦142.85 m	0.06 m≦2.71 m≦129.07 m

Larger Earthquakes and Seismic Stations in 1909





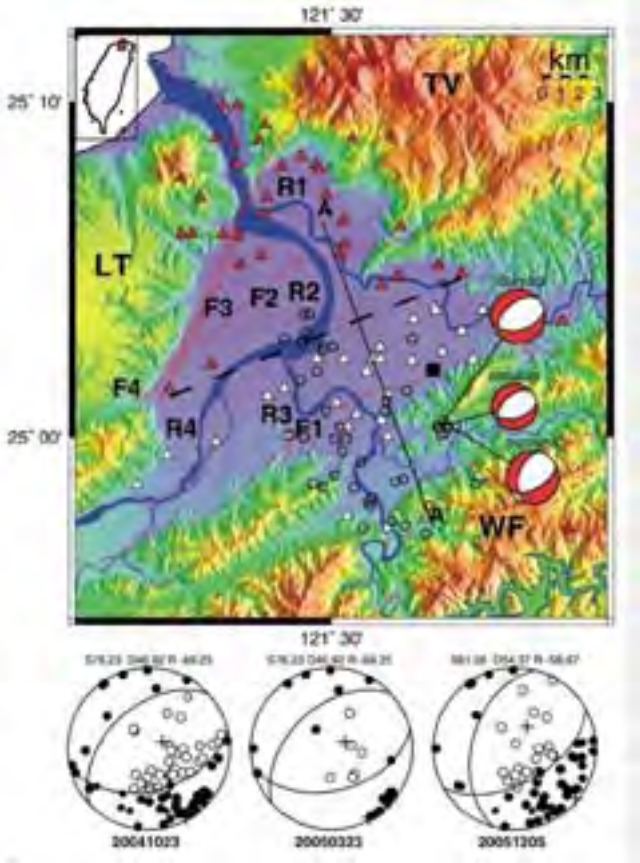


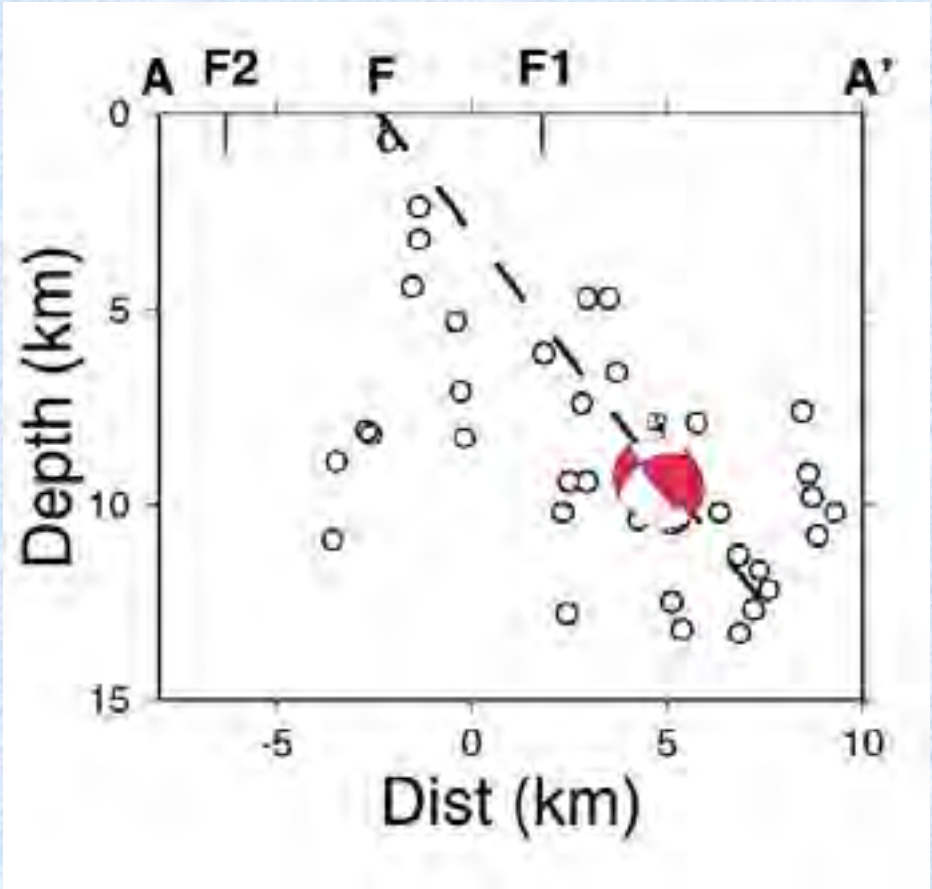
圖四 台北地震與台灣北部隱沒帶關係示意圖（M≥4）
（×：震源，●：震央）

1909 Taipei Earthquake

Time	Location	M
1909/04/15	CMO, Japan: 25°N, 121.5°E Gutenberg and Richter (1954): 25°N, 121.5°E h=80 km Kanamori et al. (2011): 25°N, 121.5°E h=50-100 km	CMO, Japan (1951): M_K=6.9 (with a radius of perceptibility of 900 km) M_J=8.3 Gutenberg and Richter (Seismicity of the Earth and Associated Phenomena, 1954): M_{GR}=7.3 m_B=7.1 (These values were also used by some others.) Wang rt al. (TAO, 2011): M_s=7.1 (conversed from M_{GR}) Kanamori et al. (GJI, 2011): M_w=7±0.3

A Blind Fault below the TMA

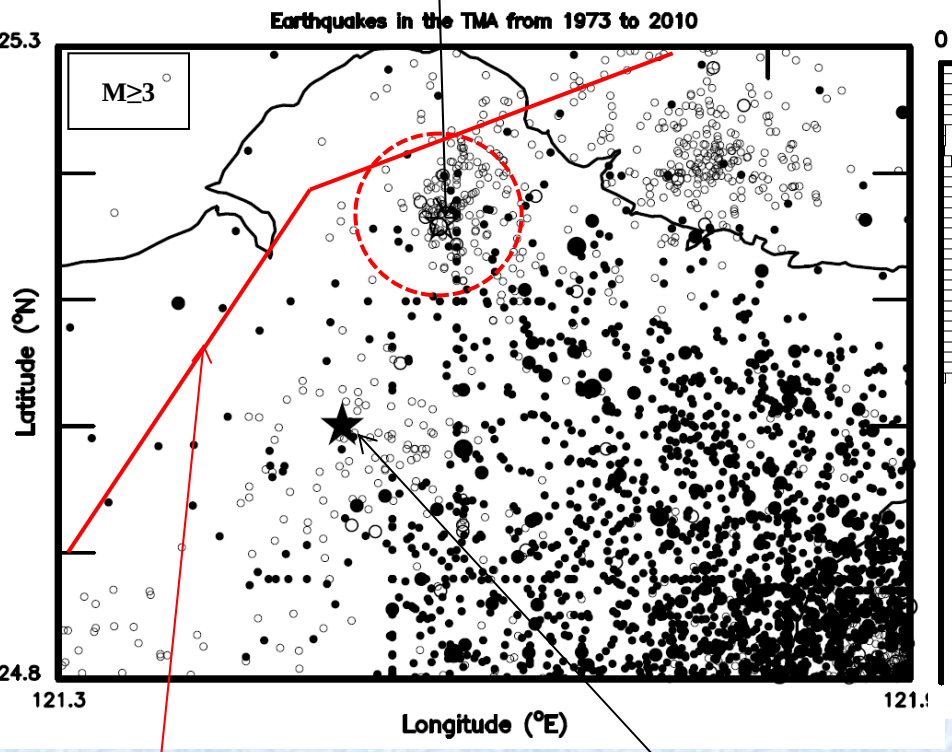


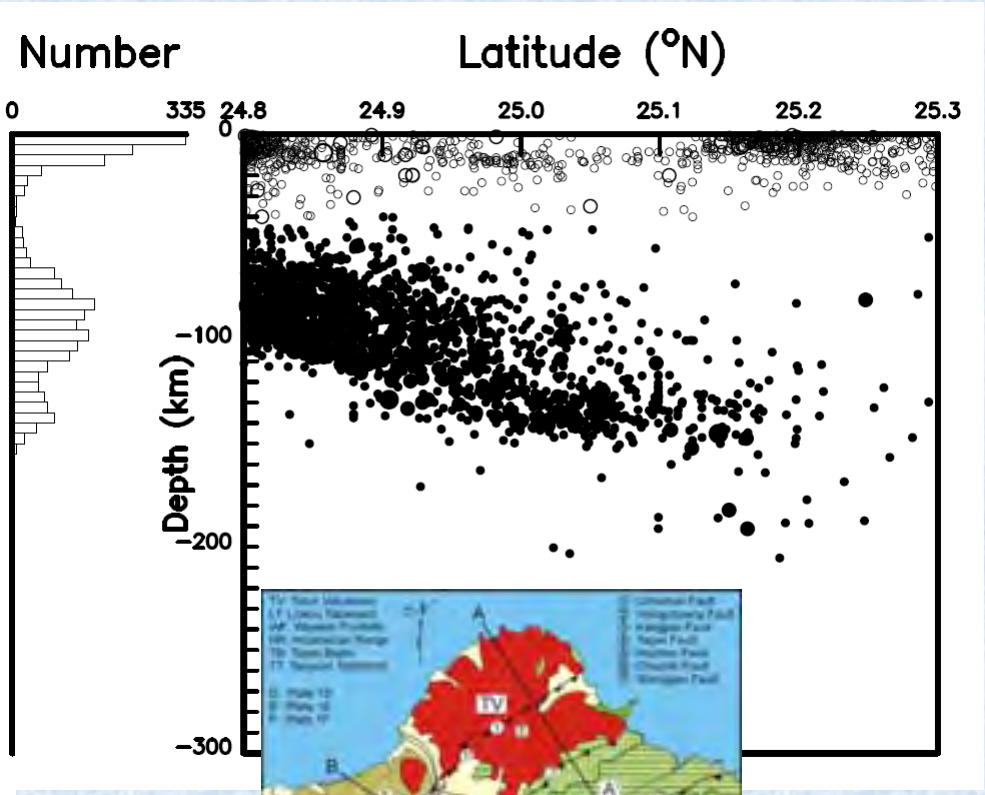


Chen et al. (2010)

Distributions of M≥3 Earthquakes during 1973 to 2010 (Wang et al., 2009)

The July 3, 1988 Earthquake

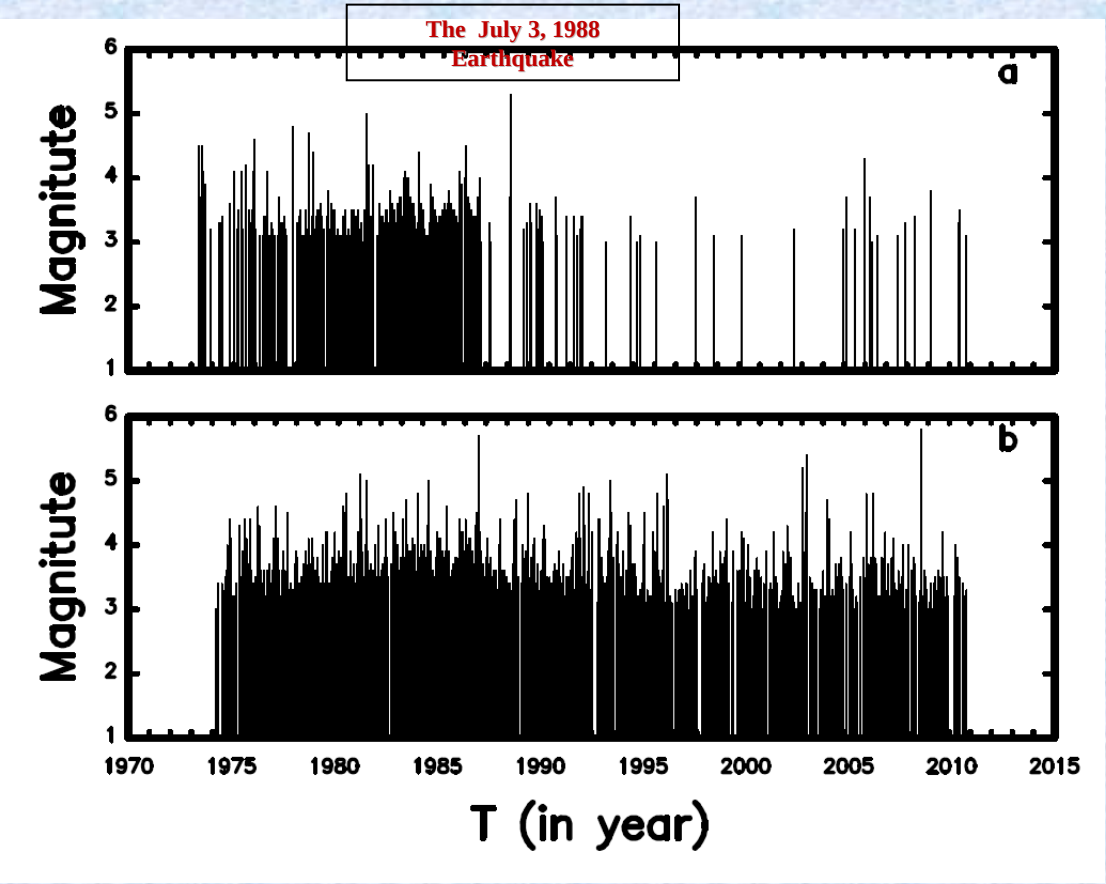




The Shangjiao Fault

The April 15, 1909 Earthquake

Time Series of M≥3 Events



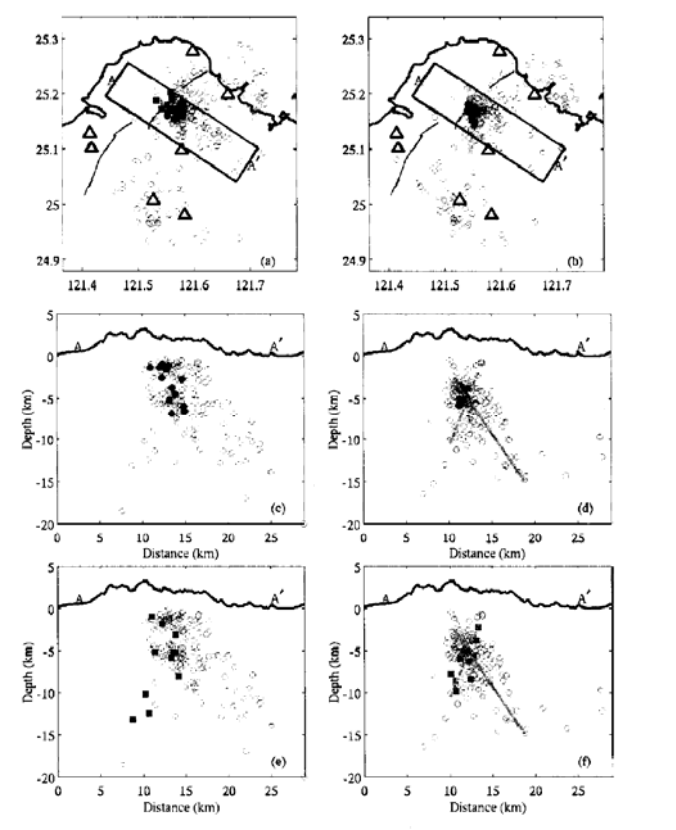
Shallow Earthquakes

Deep Earthquakes

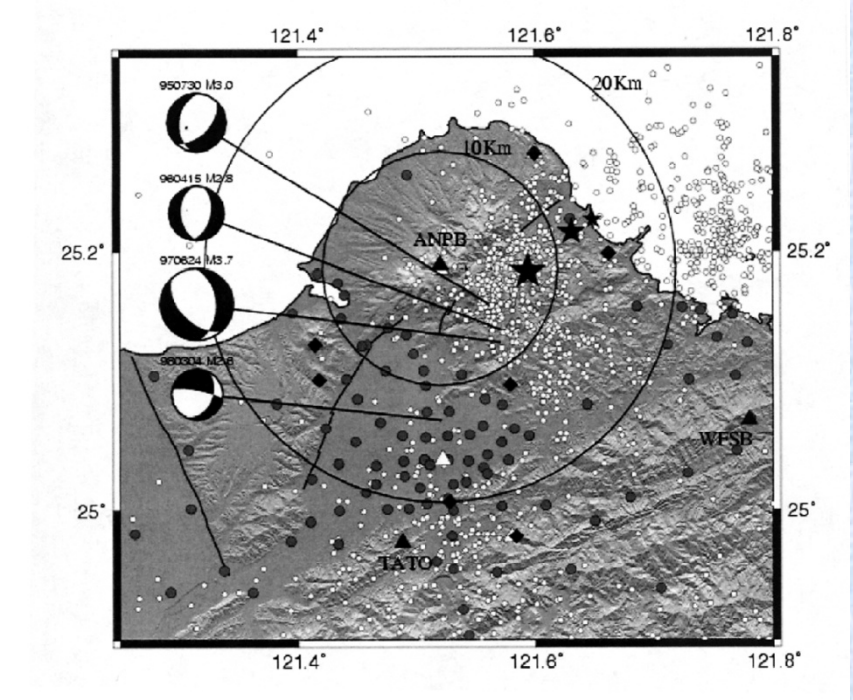
Seismic Profile and Focal Plane Solutions

(Kim et al., TAO, 2005)

Seismic Profiles



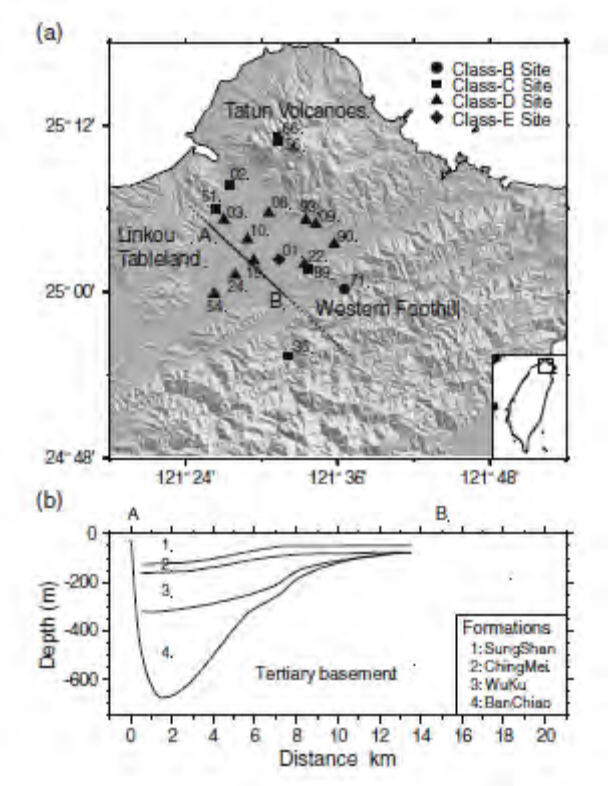
Focal Plane Solutions



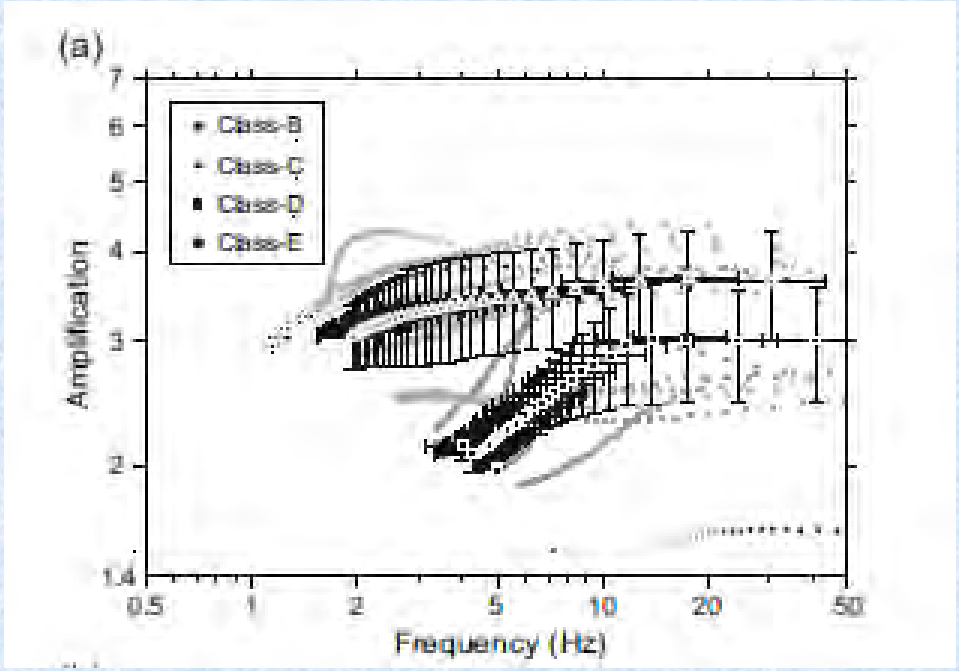
Site Amplifications in Taipei

(Huang et al., JOSE, 2009)

Station Sites and Classification



Site Amplifications



Chaochou Fault and Hengchen Fault

	Chaochou Fault	Hengchen Fault
Type	Reverse	Reverse
strike	N(5°-10°)E	N22°W
dip	75°–80° to east	>70° to east
length	~100 km (Lin and Shih, 2006) ~140 km (Hsu and Chang, 1979)	Inland: 16 km Inland+offshore: 41 km (CGS) 50 km (Chen)
seismicity	Currently low	Currently low

Estimates of M, D_{max}, and D_{ave}

The magnitudes (M), maximum displacements (D_{max}), and average displacements (D_{ave}) of potential earthquakes rupturing the Chaochou fault and Hengchun fault are estimated from the empirical relationships for thrust faults inferred by Wells and Coppersmith (1994):

$$M=(5.00\pm0.22)+(1.22\pm0.16)\times\log(L)$$

$$\log(D_{max})=(-0.44\pm0.34)+(0.42\pm0.23)\times\log(L)$$

$$\log(D_{ave})=(-0.60\pm0.39)+(0.31\pm0.27)\times\log(L)$$

Fault(s)	M	D_{max}	D_{ave}
Chaochou Fault L=100 km	6.9≦7.4≦8.0	0.40 m≦2.51 m≦15.85 m	0.12 m≦1.05 m≦8.91 m
L=140 km	7.1≦7.6≦8.2	0.42 m≦2.89 m≦19.72 m	0.12 m≦1.16 m≦10.83 m
Hengchun Fault L=16 km	6.1≦6.5≦6.9	0.28 m≦1.16 m≦4.82 m	0.11 m≦0.59 m≦3.08 m
L=41 km	6.5≦7.0≦7.5	0.34 m≦1.73 m≦8.88 m	0.12 m≦0.79 m≦5.31 m
L=50 km	6.6≦7.1≦7.6	0.35 m≦1.88 m≦10.10 m	0.12 m≦0.84 m≦5.96 m

Disastrous Earthquakes near Hengchun

(No Damage Report for Chin and Ming Dynasties)

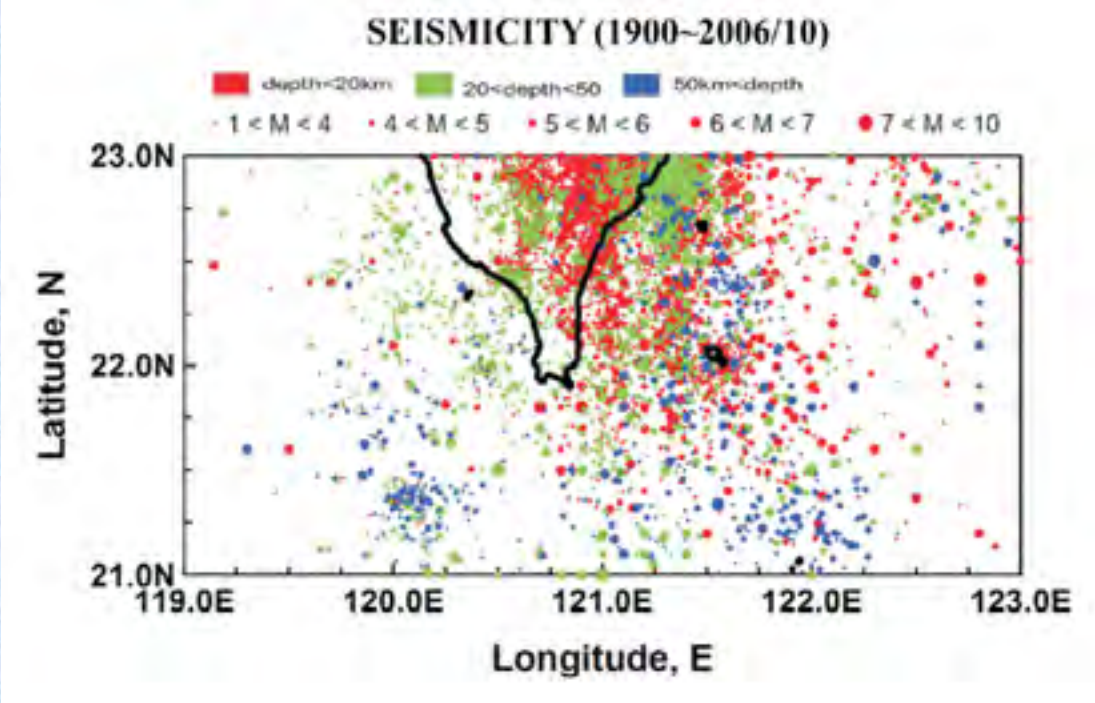
Event	Epicenter	Depth (km)	M_L	Damage	Remarks
1936/08/22	22.0°N, 121.1°E		7.0	Injured: 14 Collapsed buildings: 37 Damaged buildings: 341	Hsu (1980)
1955/04/04	21.8°N, 120.9°E	5	6.7	Injured: 7 Collapsed buildings: 22 Damaged buildings: 171	Hsu (1980)
1959/08/15	21.5°N, 121.2°E	20	6.8	Death: 17 Injured: 68 Collapsed building: 1214 Damaged buildings: 1375	Hsu (1980)
1959/08/18	21.1°N, 121.7°E	15	6.1	Collapsed buildings: 32 Damaged buildings: 5	Hsu (1980)
1959/09/25	22.1°N, 121.2°E	10	6.5	Injuried:3 Collapsed building: 3 damaged buildings: 65	Hsu (1980)
2006/12/26 (Pingtung Earthquakes) 1: normal faulting 2: strike-slip faulting	21.69°N, 120.56°E 21.97°N, 120.42°E	44 50	7.0 7.0	Death: 2 Injured: 42 Collapsed buildings: 3 Damaged buildings: many Shut-down of Unit 2 of NNP3 Fires Failures of submarine cables etc.	CWB Huang et al. (2008) and Wen et al. (2008) 50 km to NPP3

Geology and Seismicty in the Hengchun Peninsula

(Wen et al., TAO, 2008)

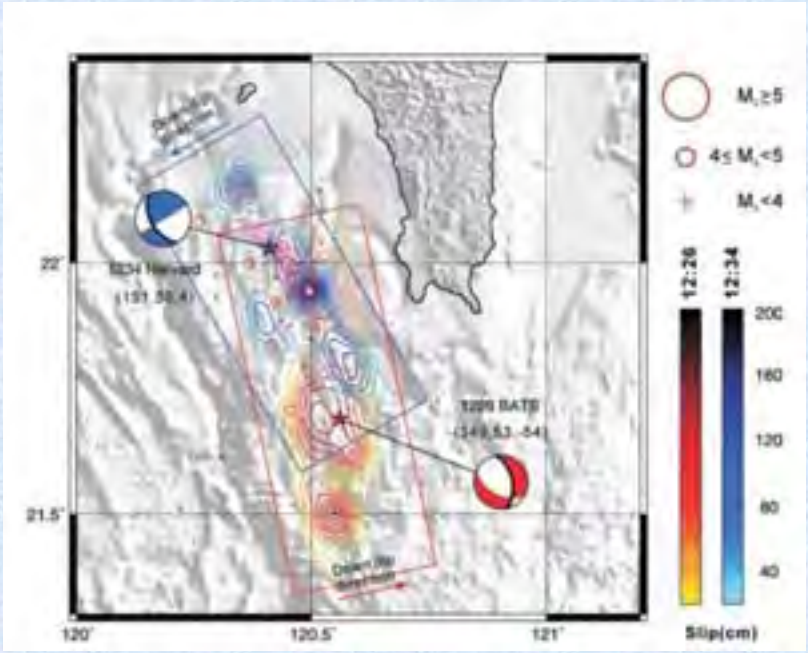
Geology

Background Seismicity (1900-2006)

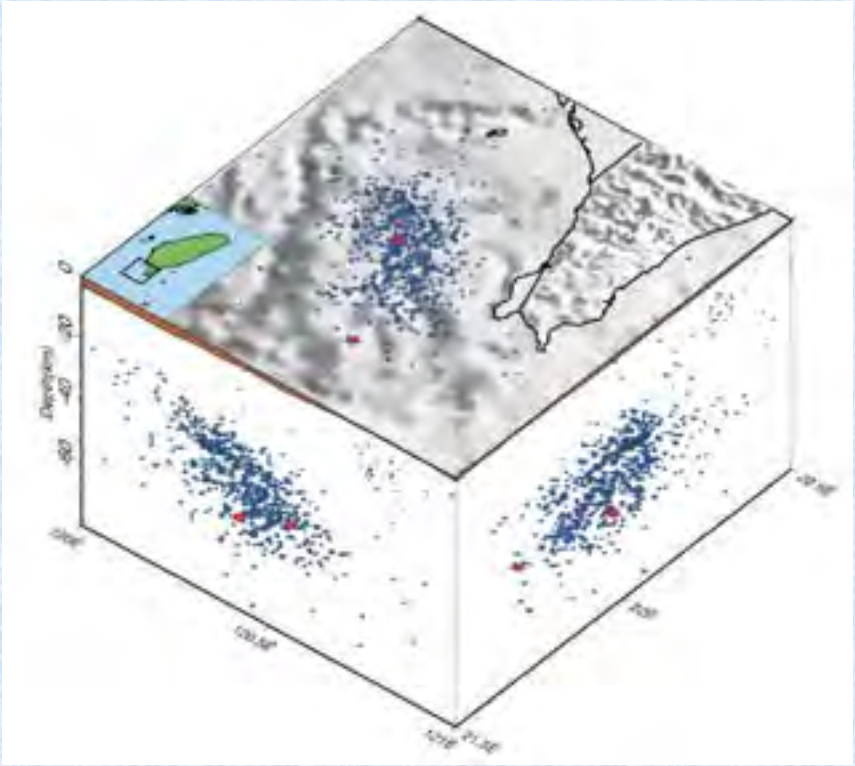


The December 26, Pingtung Earthquakes

Lee et al. (TAO, 2008)

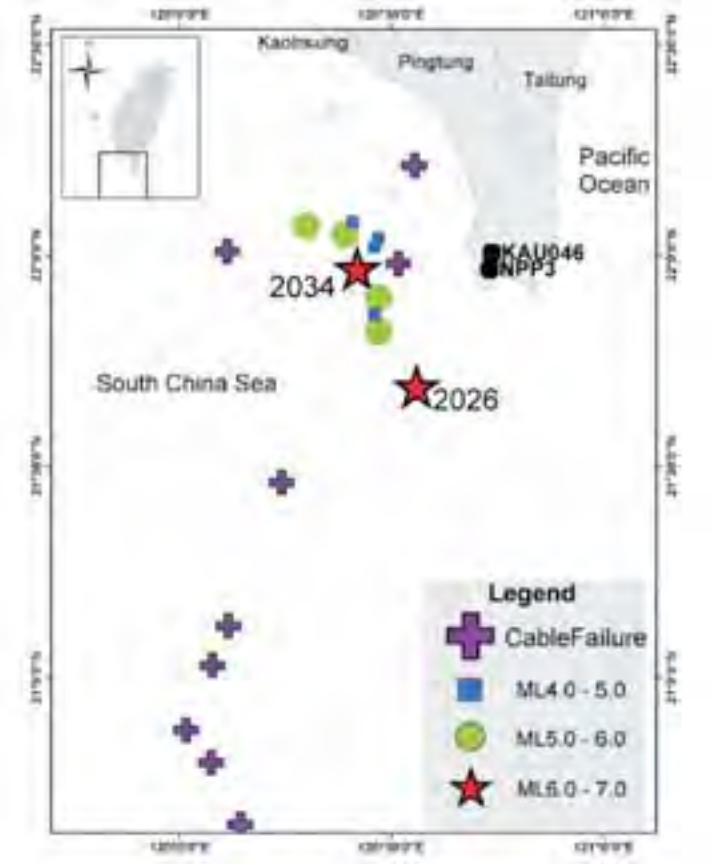


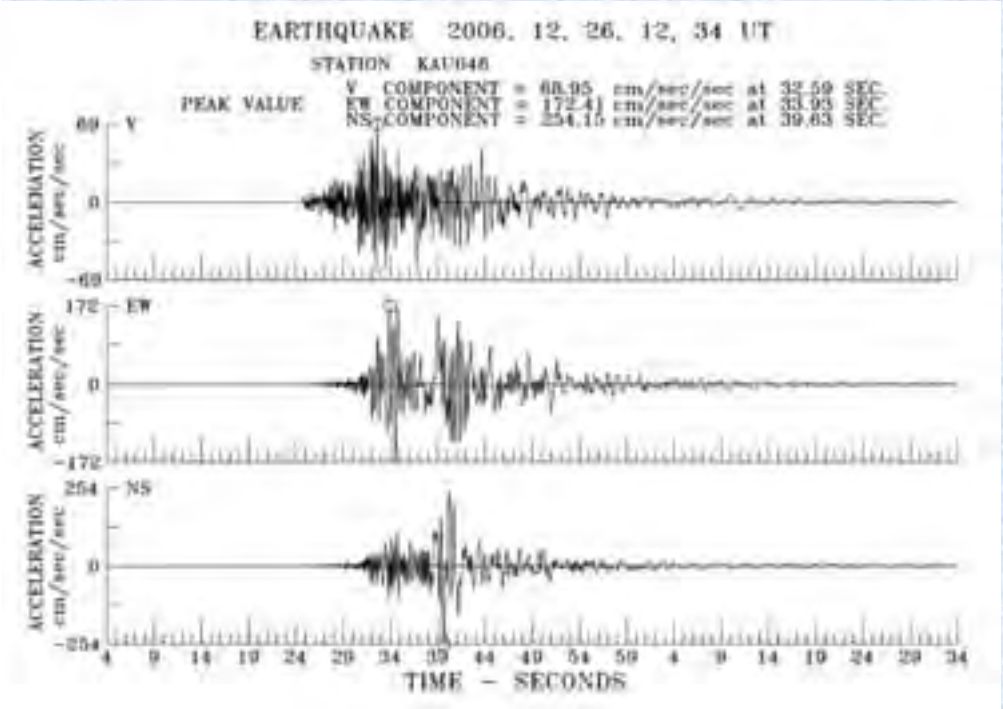
Huang et al. (TAO, 2008)



An Example of Accelerograms Generated from the Pingtung Earthquake

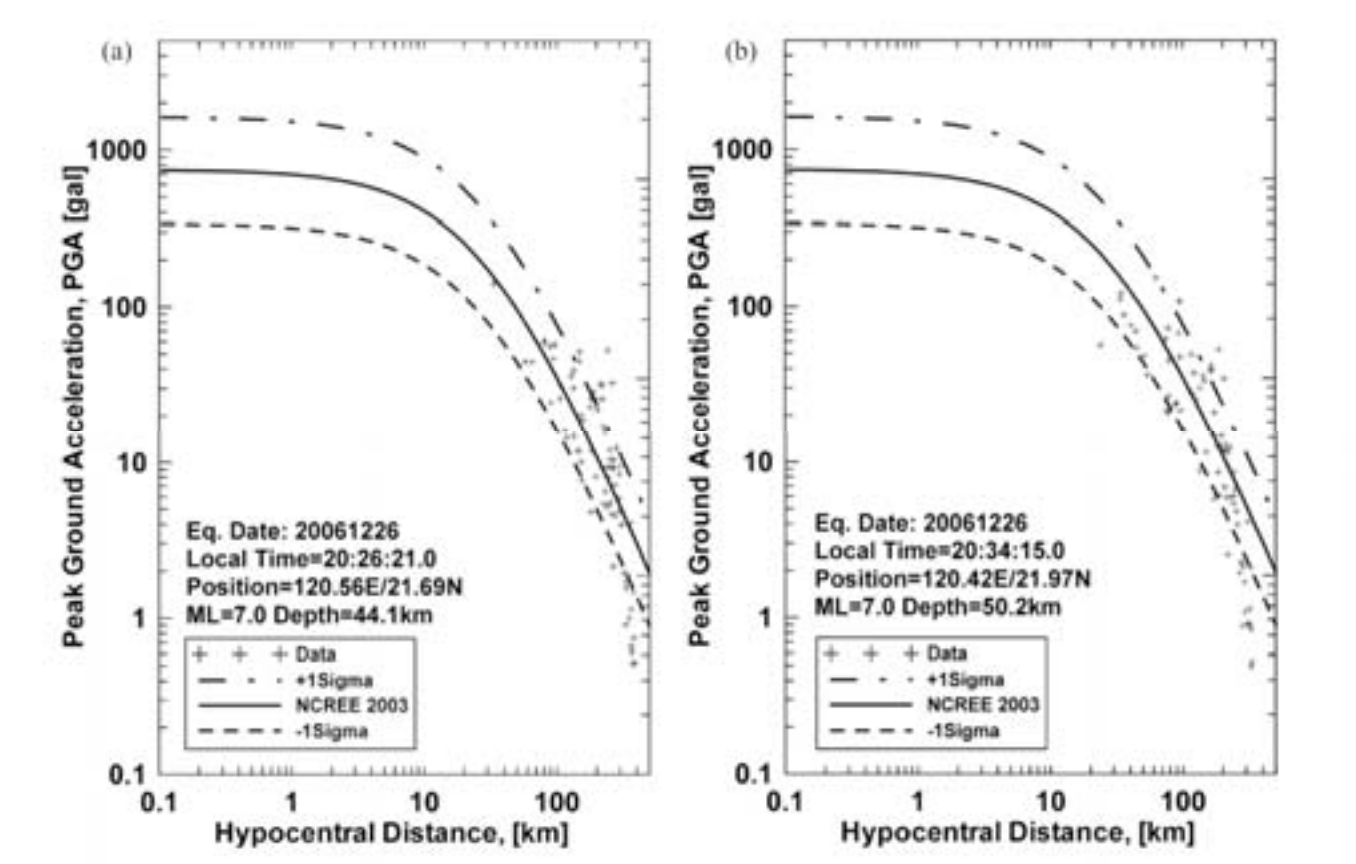
(Wen et al., TAO, 2008)





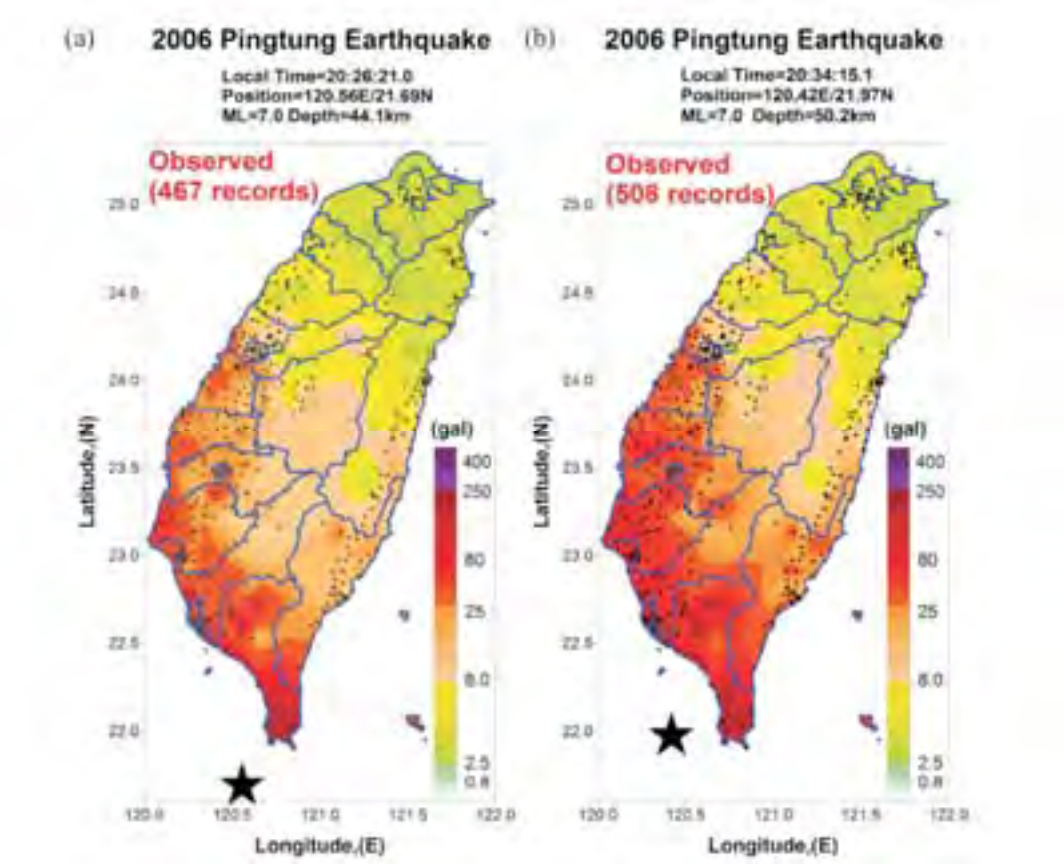
Attenuation Curves

(Wen et al., TAO, 2008)



Shakemaps of PGA Values

(Wen et al., TAO, 2008)

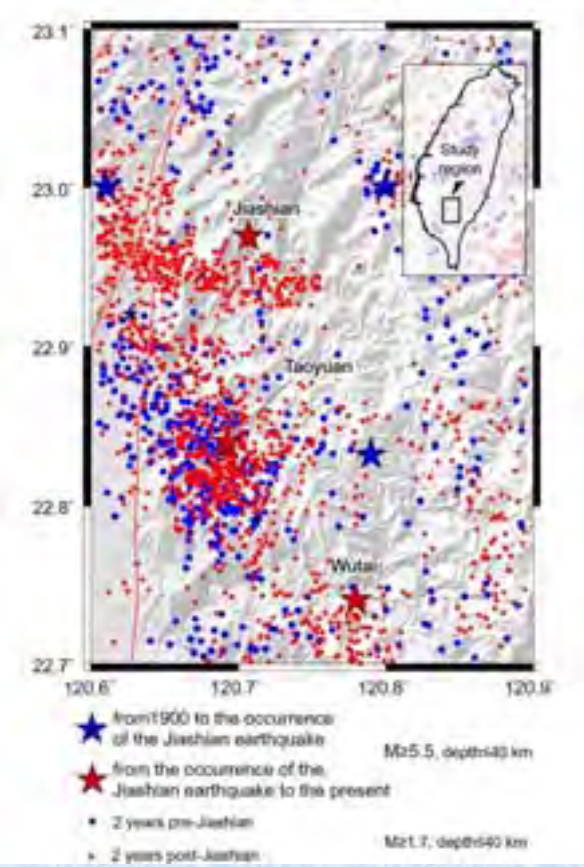


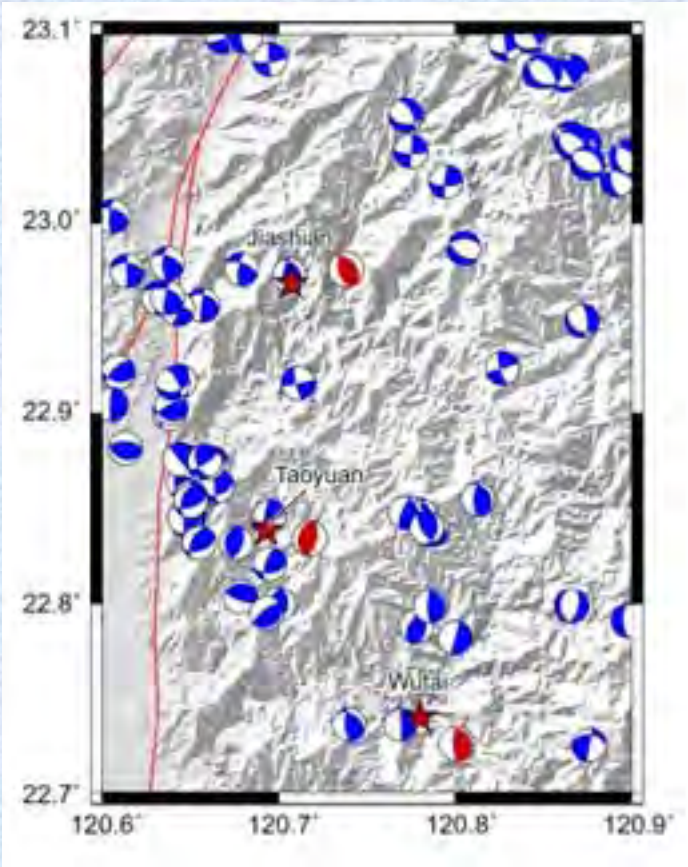
Four M>5.5 Earthquakes near the Chaocho Fault from 2006 to 2012

Event	Epicenter	Depth (km)	M_L	Strike, dip, rake (in degree)
2010/03/04 Jiashian Earthquake (thrust faulting)	22.96°N, 120.70°E	23	6.4	313, 41, 42
2010/07/25 Taoyuan Earthquake (thrust faulting)	22.84°N, 120.74°E	17	5.5	14, 58, 91
2012/02/26 Wutai Earthquake (thrust faulting)	22.74°N, 120.78°E	20	6.1	320, 20, 52

Three Earthquakes near the Chaocho Fault

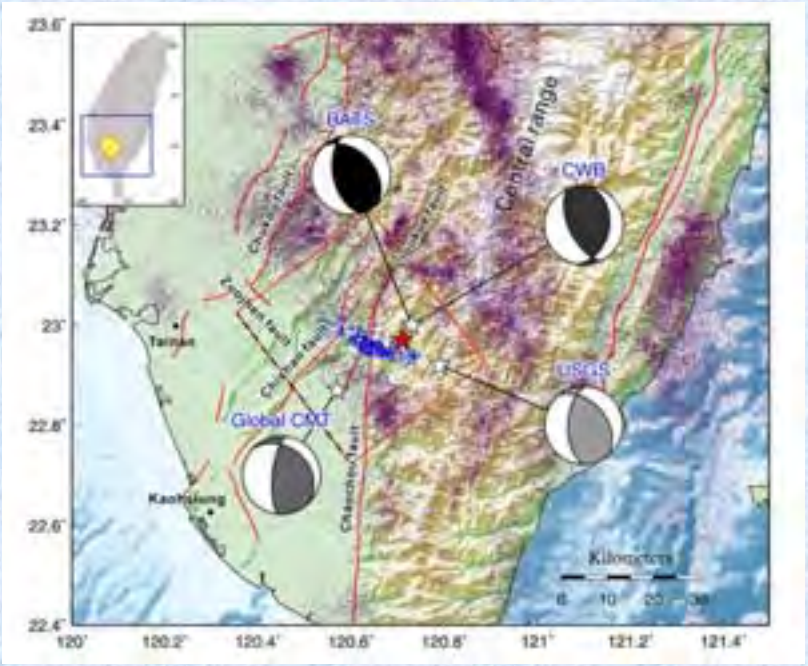
(Chan and Wu, JAES 2012)

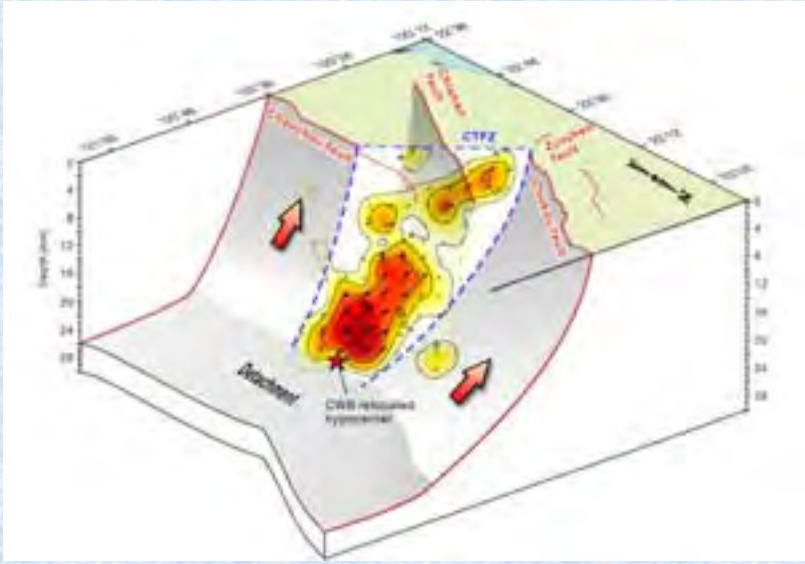




The March 4, 2010 M6.4 Jiashian Earthquake

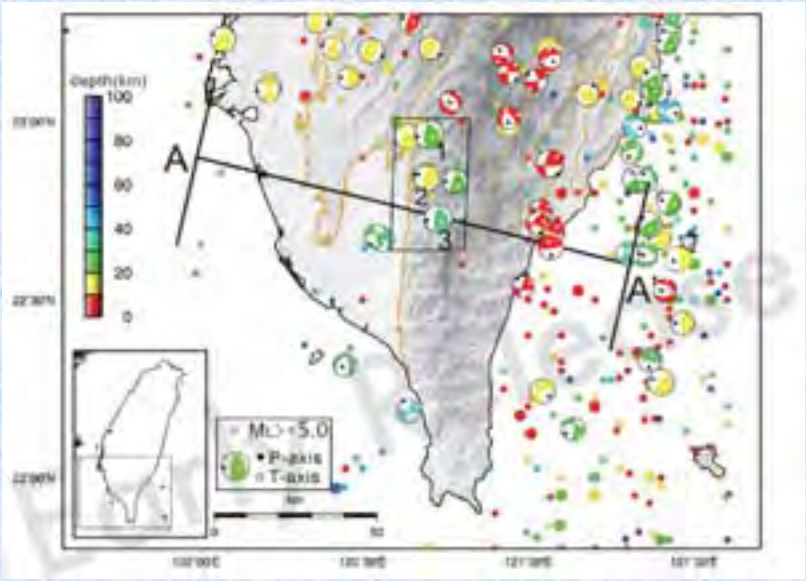
(Lee et al., JAES 2013)

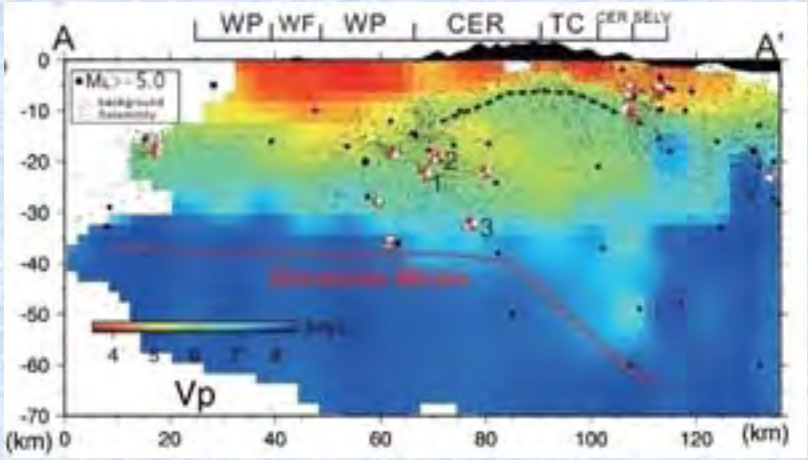




The February 26, 2012 M6.1 Wutai Earthquake

(Chen et al., TAO 2013)





WP: Western Plain
WF: Western Foothills
CER: Central Range
TC: Tananao Complex
SELY: Southern Extension of the Longitudinal Valley

謝　　謝

Thanks for Attention