



動盪的地球

The Dynamic Earth

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面對天災該有謙卑與準備
並保有冷靜與行動力

Magnitude 8.9 NEAR THE EAST COAST OF HONSHU, JAPAN

Friday, March 11, 2011 at 05:46:23 UTC

Japan was struck by a magnitude 8.9 earthquake off its northeastern coast Friday. This is one of the largest earthquakes that Japan has ever experienced.

仙台海嘯高度十公尺 淹溢範圍往內陸一公里

In downtown Tokyo, large buildings shook violently and there is severe flooding due to a tsunami generated by the earthquake.



USGS

Part of houses
swallowed by
tsunami burn in
Sendai, Miyagi
Prefecture (state)
after Japan was
struck by a strong
earthquake off its
northeastern coast
Friday, March 11,
2011.

New York Times



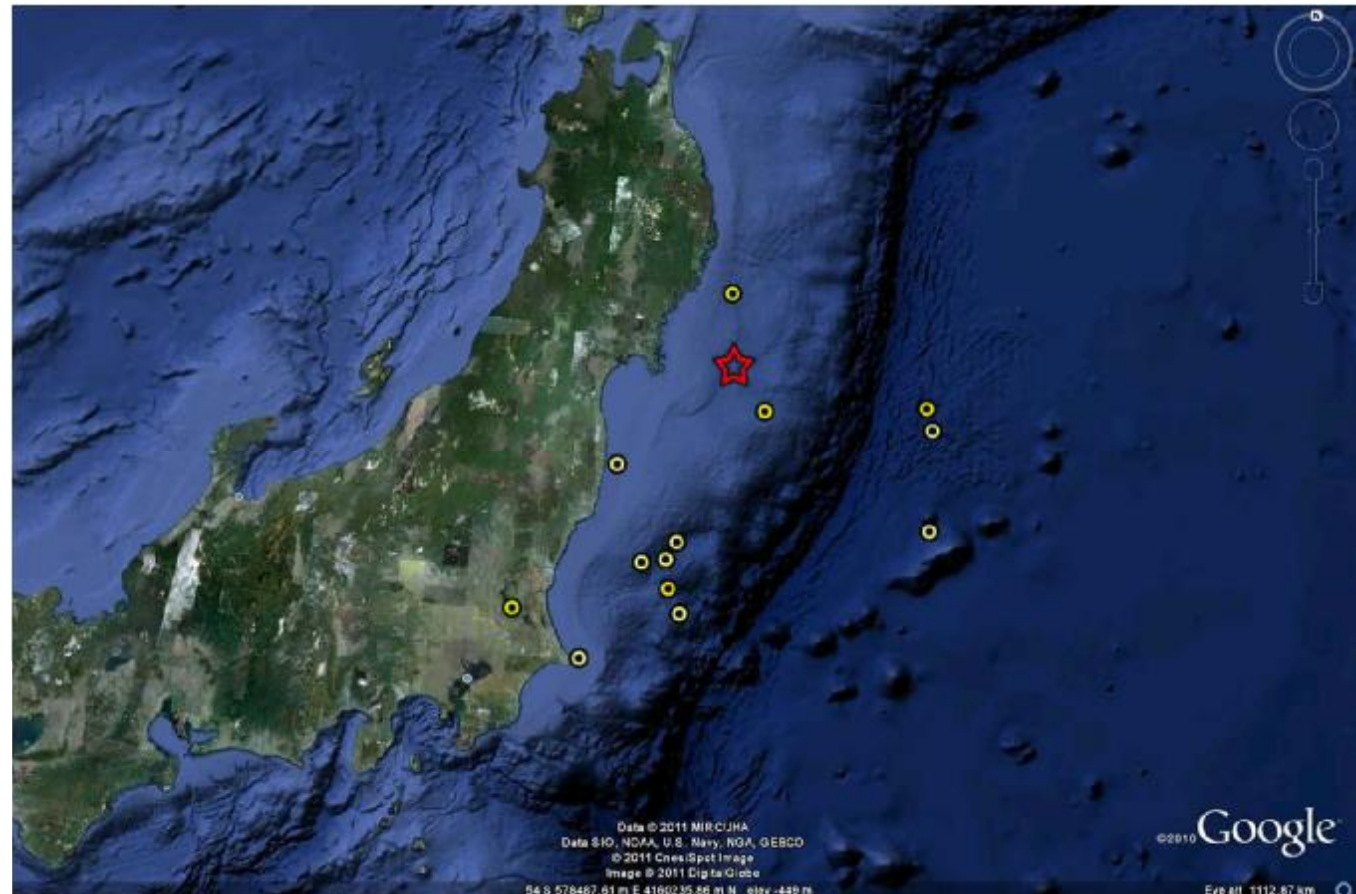
Magnitude 8.9 NEAR THE EAST COAST OF HONSHU, JAPAN

Friday, March 11, 2011 at 05:46:23 UTC

This earthquake was preceded by a series of large foreshocks over the previous two days, beginning on March 9th with an M 7.2 event approximately 40 km from the March 11 earthquake, and continuing with 3 earthquakes greater than M 6 on the same day.

The M8.9 earthquake has been followed by frequent large aftershocks, which can do damage on their own especially to buildings that were compromised in the main shock.”

The M8.9 main shock (red star) is plotted with 14 aftershocks larger than magnitude 6.0. This includes a magnitude 7.1.

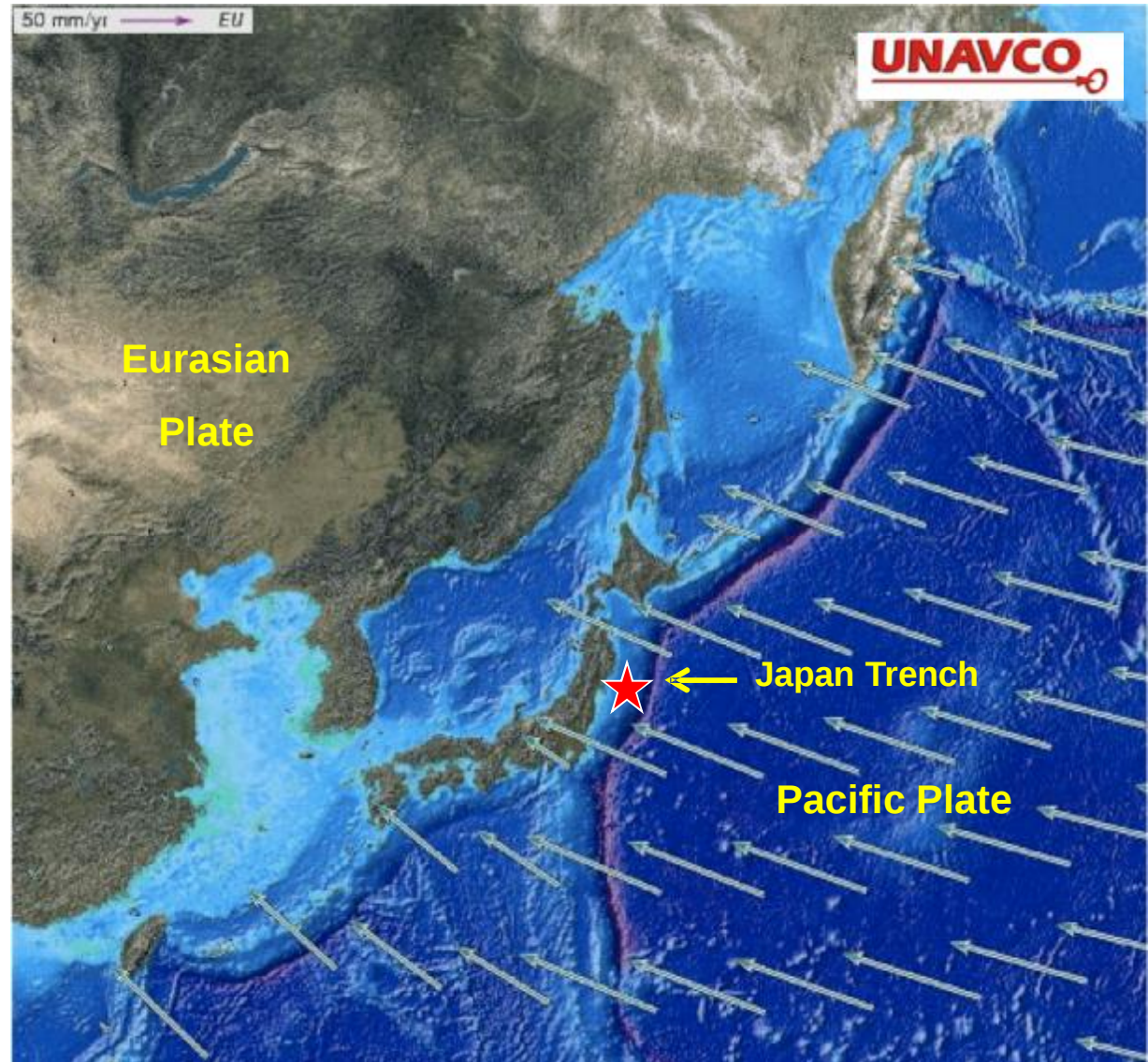


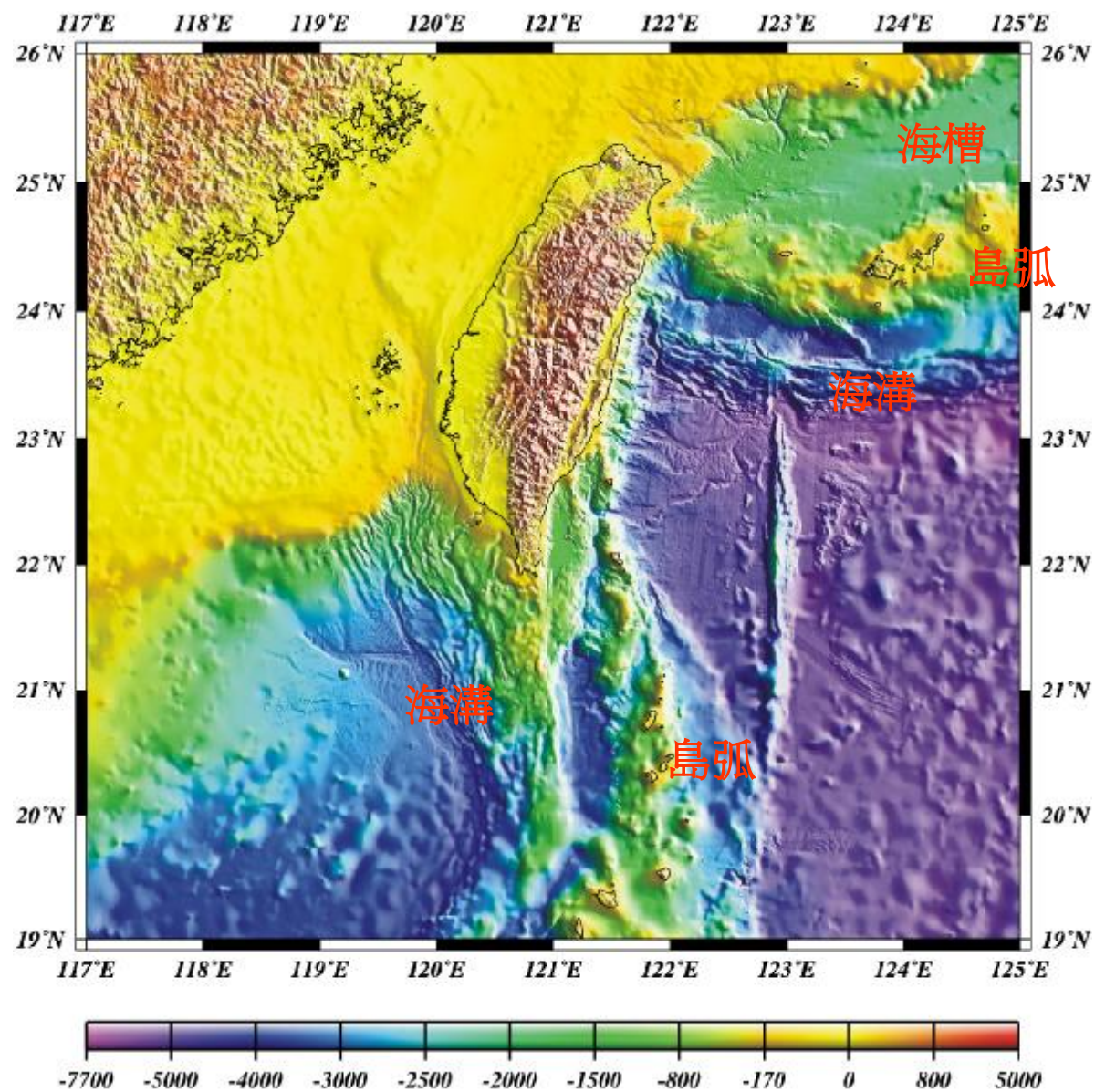
Magnitude 8.9 NEAR THE EAST COAST OF HONSHU, JAPAN

Friday, March 11, 2011 at 05:46:23 UTC

This earthquake was the result of thrust faulting along or near the convergent plate boundary where the Pacific Plate subducts beneath Japan.

This map also shows the rate and direction of motion of the Pacific Plate with respect to the Eurasian Plate near the Japan Trench. The rate of convergence at this plate boundary is about 83 mm/yr (8 cm/year). This is a fairly high convergence rate and this subduction zone is very seismically active.





2011規模6.3 紐西蘭南島 基督城地震

Monday, February 21, 2011 at 23:51:43 UTC



USGS

At least >200 people are reported dead or missing, and there are reports of collapsed buildings, cracked streets and flooding due to ruptured water mains and ground damage.

In this image made from video run by New Zealand's TV3, a rescuer makes a rescue operation for a woman trapped on roof of damaged building in Christchurch, New Zealand after a magnitude 6.3 earthquake rocked the city.

AP Photo/TVNZ





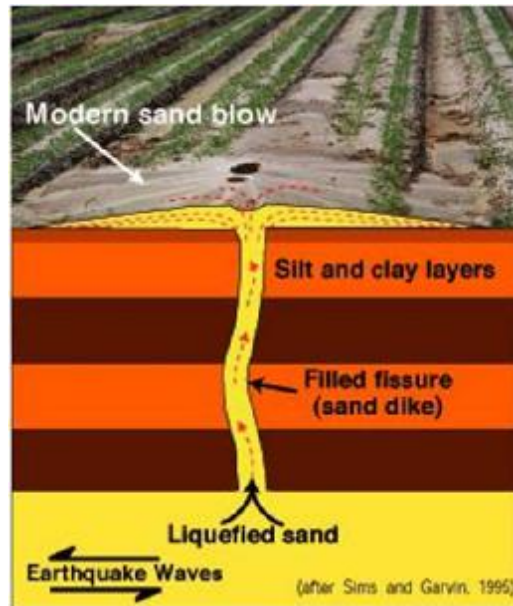




Magnitude 6.3 SOUTH ISLAND OF NEW ZEALAND Monday, February 21, 2011 at 23:51:43 UTC

Liquefaction 液化 (where the solid ground takes on liquid qualities due to increased pressures) causes distortion of buildings and damage to buried cables, water and sewage pipes. Sand blows are characteristic evidence that liquefaction has occurred.

Imagine a cube full of sand and water. If you press it in from both sides (compressing and releasing it, then compressing it again), you build up what's called pore-water pressure," said Martitia Tuttle, geologist and consultant for the U.S. Geological Survey. "It's like shaking a coke can — when the pressure builds up and you release it, the fluid comes shooting to the surface."



Liquefaction occurs (and sand blows are formed) when the soft, sandy soil shakes forcing liquified sand to the surface causing heavy roads or whatever is on the surface to sink

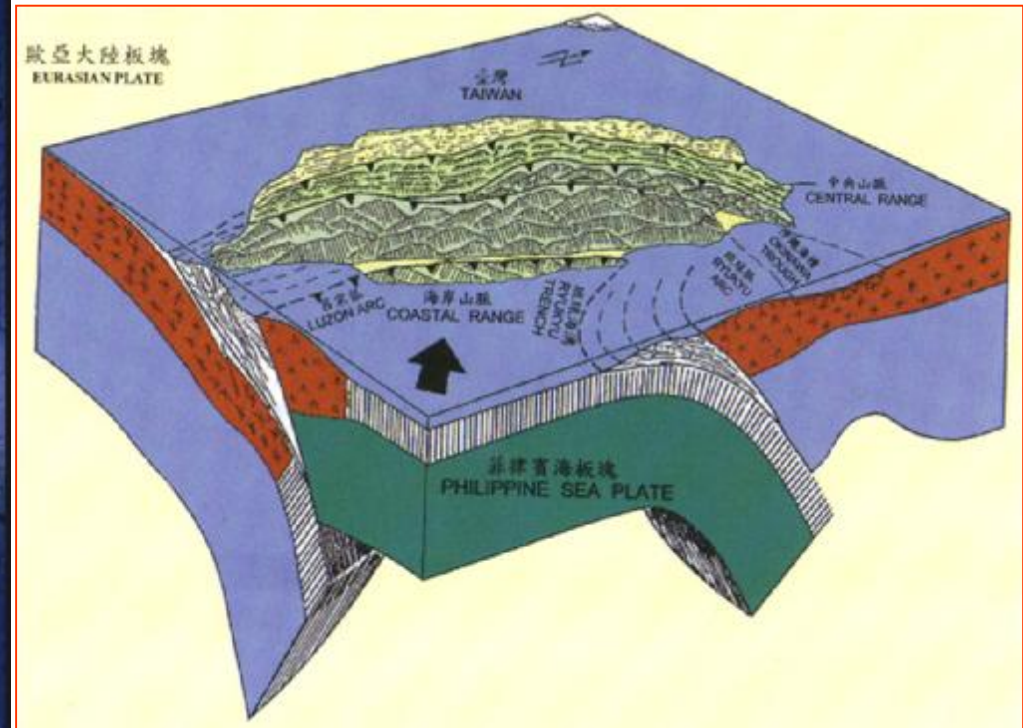
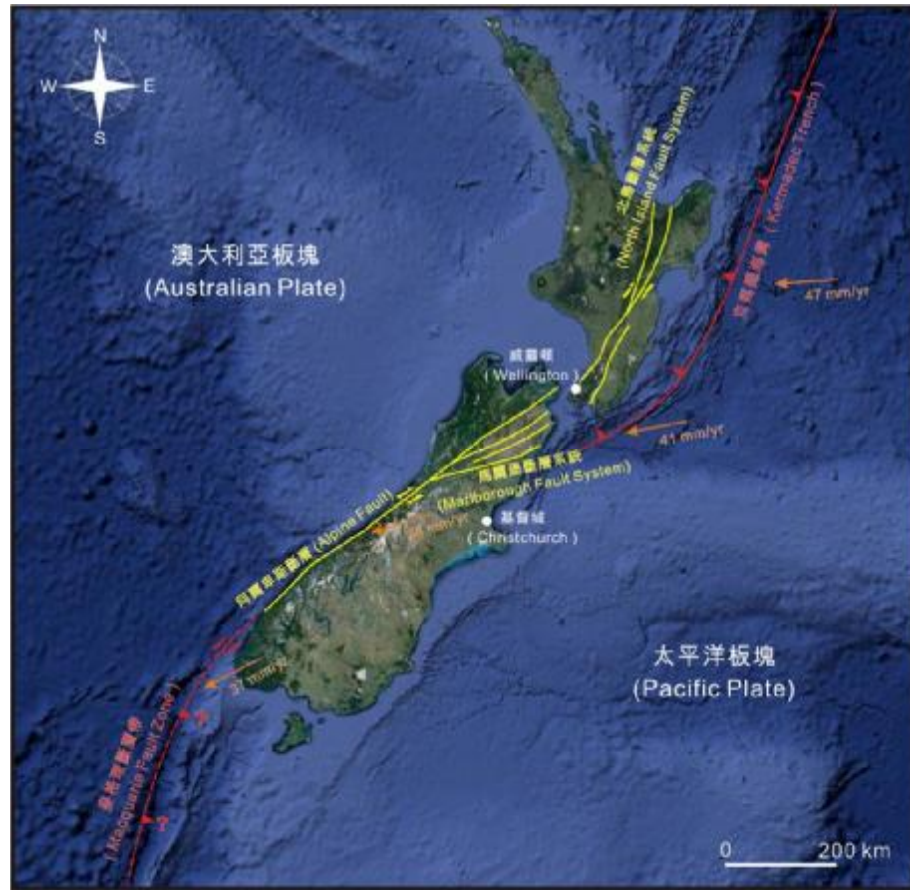
USGS

Sand blow created during the M7.0 New Zealand Earthquake

*New Zealand Herald-
Photo / Georgia Galloway*



紐西蘭與台灣的地體構造



2008 M7.9 Wenchuan, China, Earthquake
汶川地震

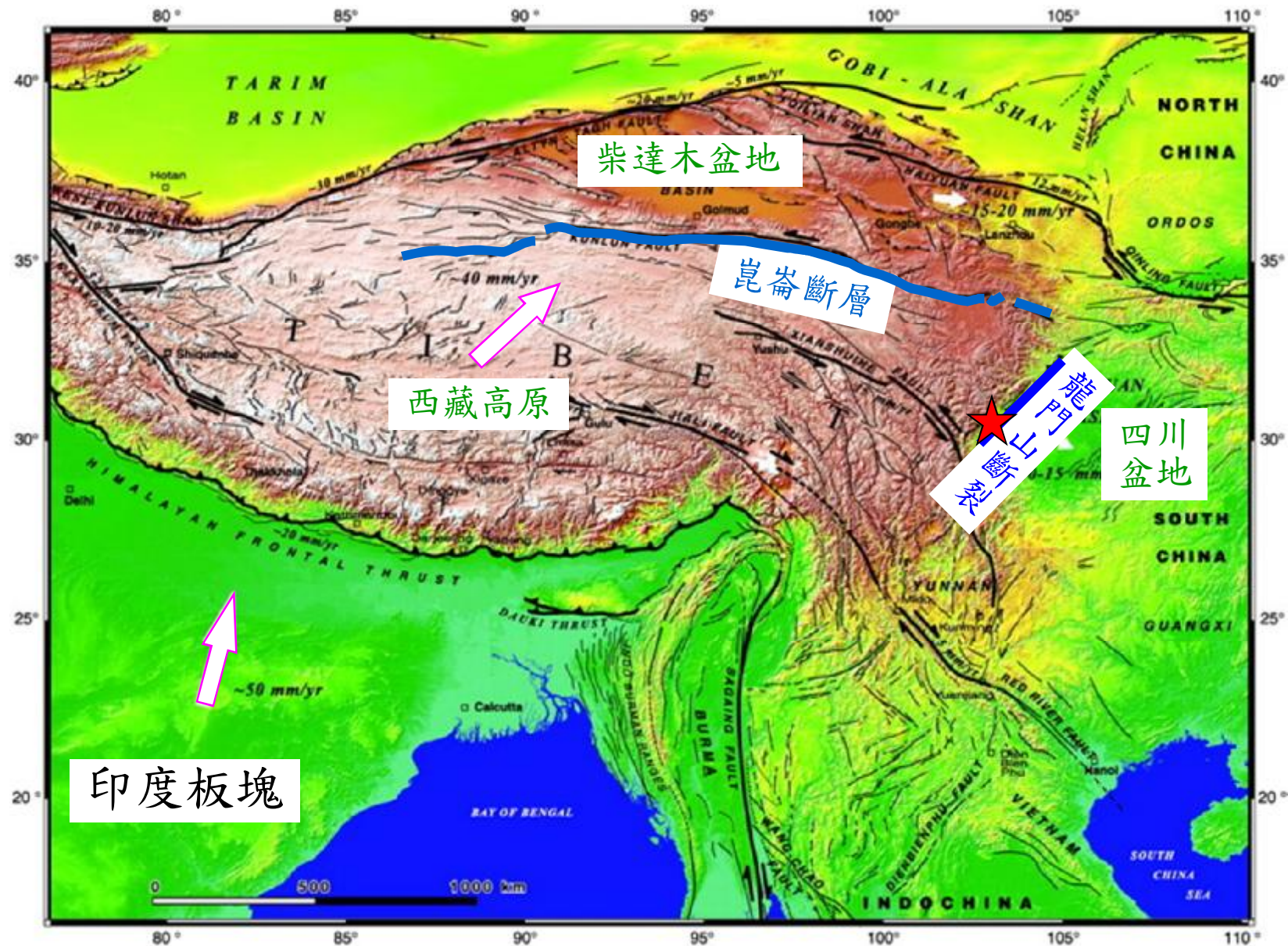




Dead or Missing: > 10萬



2001 Kulun Earthquake, 1997 Manyi Earthquake, 2008 Wenchuan Earthquake

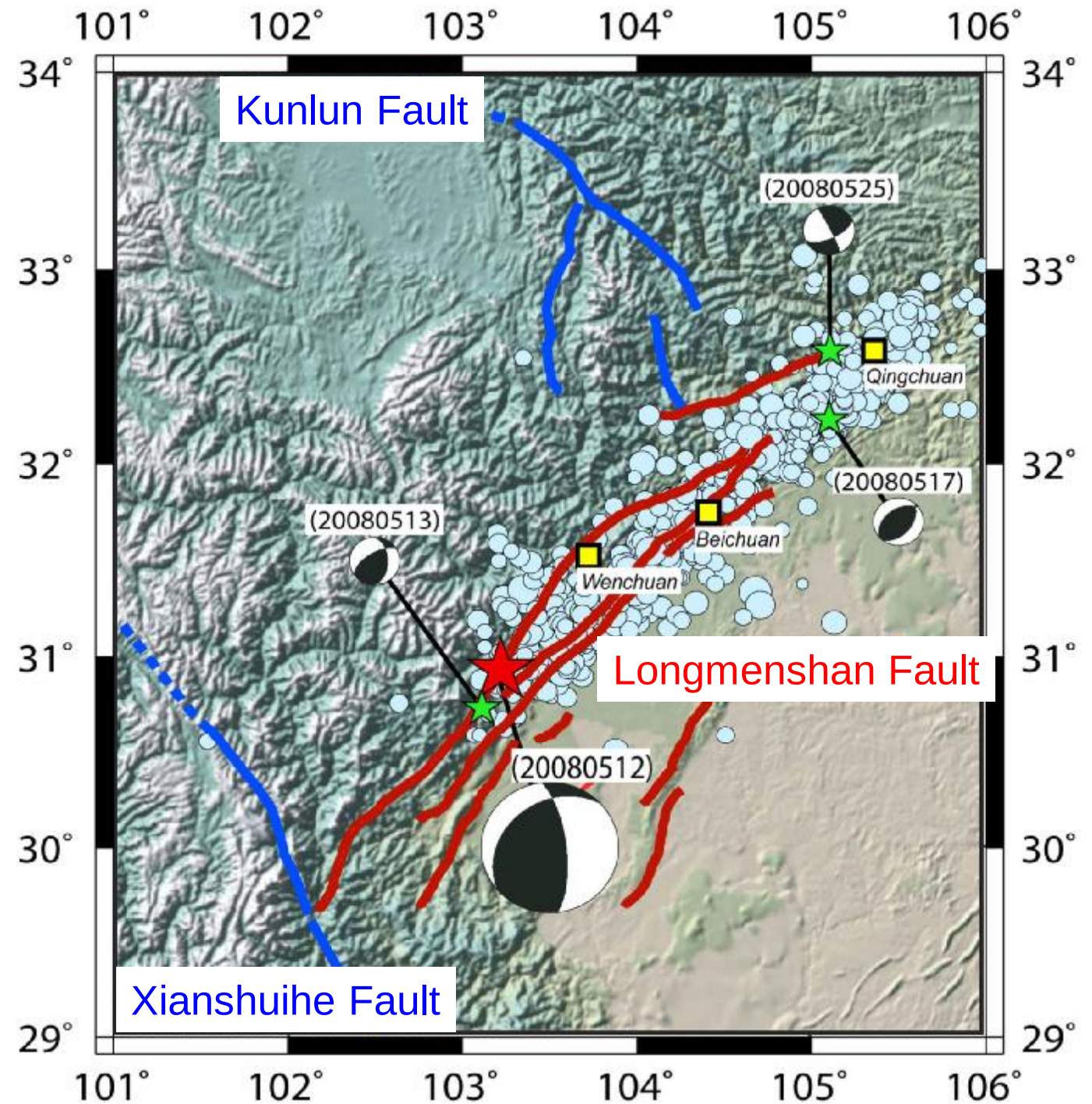


(Tapponnier et al., 2001)

**2008年
Mw=7.9
汶川地震**

★ mainshock

★ aftershock
○





January 12, 2010 Haiti earthquake

M7.0
海地地震

Dead or Missing > 20萬



2004 Sumatra Earthquake Tsunami 印尼地震海嘯 **M9.5**



(c) 2005 issuespotter.com

印尼亞齊



Banda Aceh Shore: Before



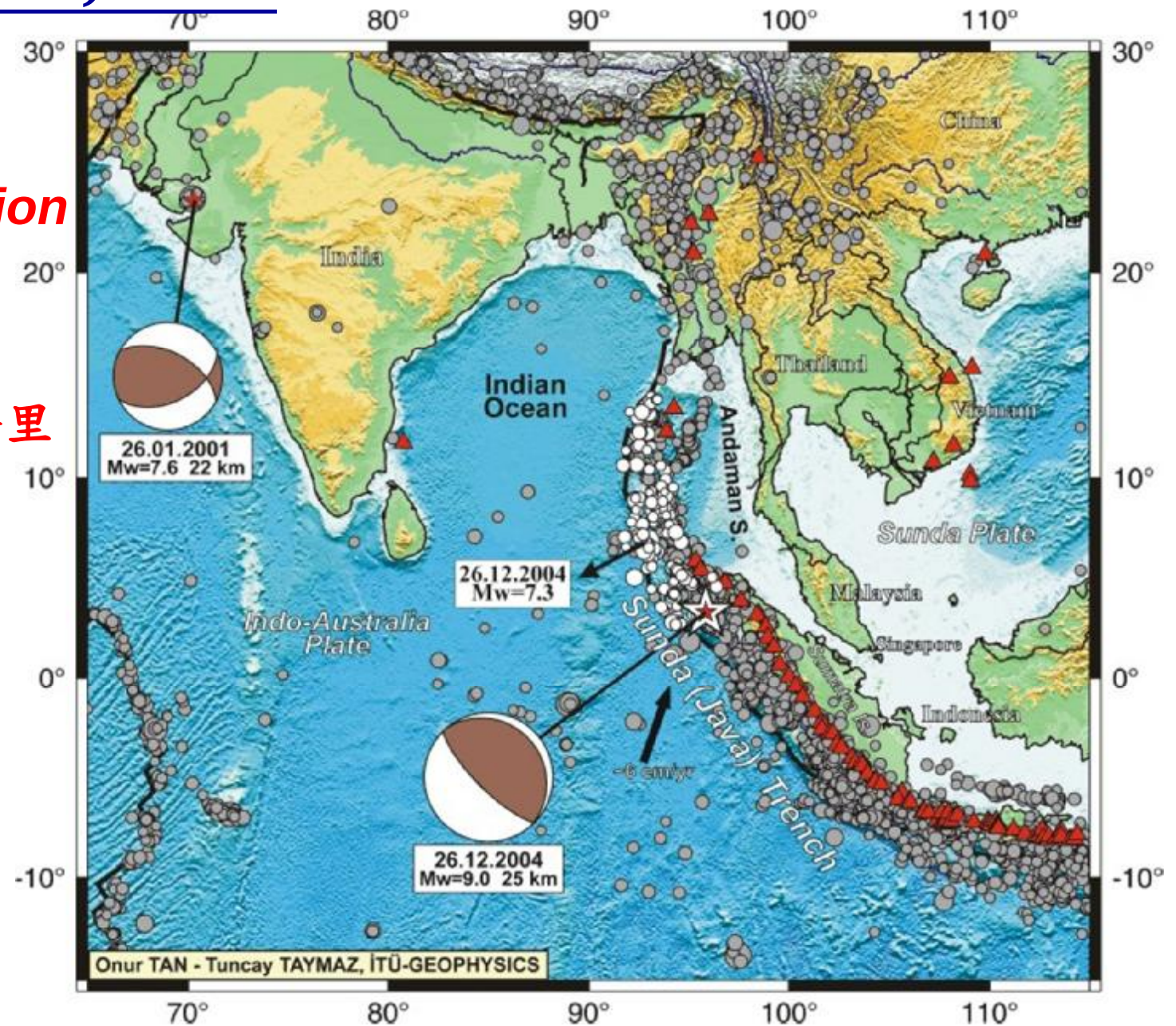
Banda Aceh Shore: After



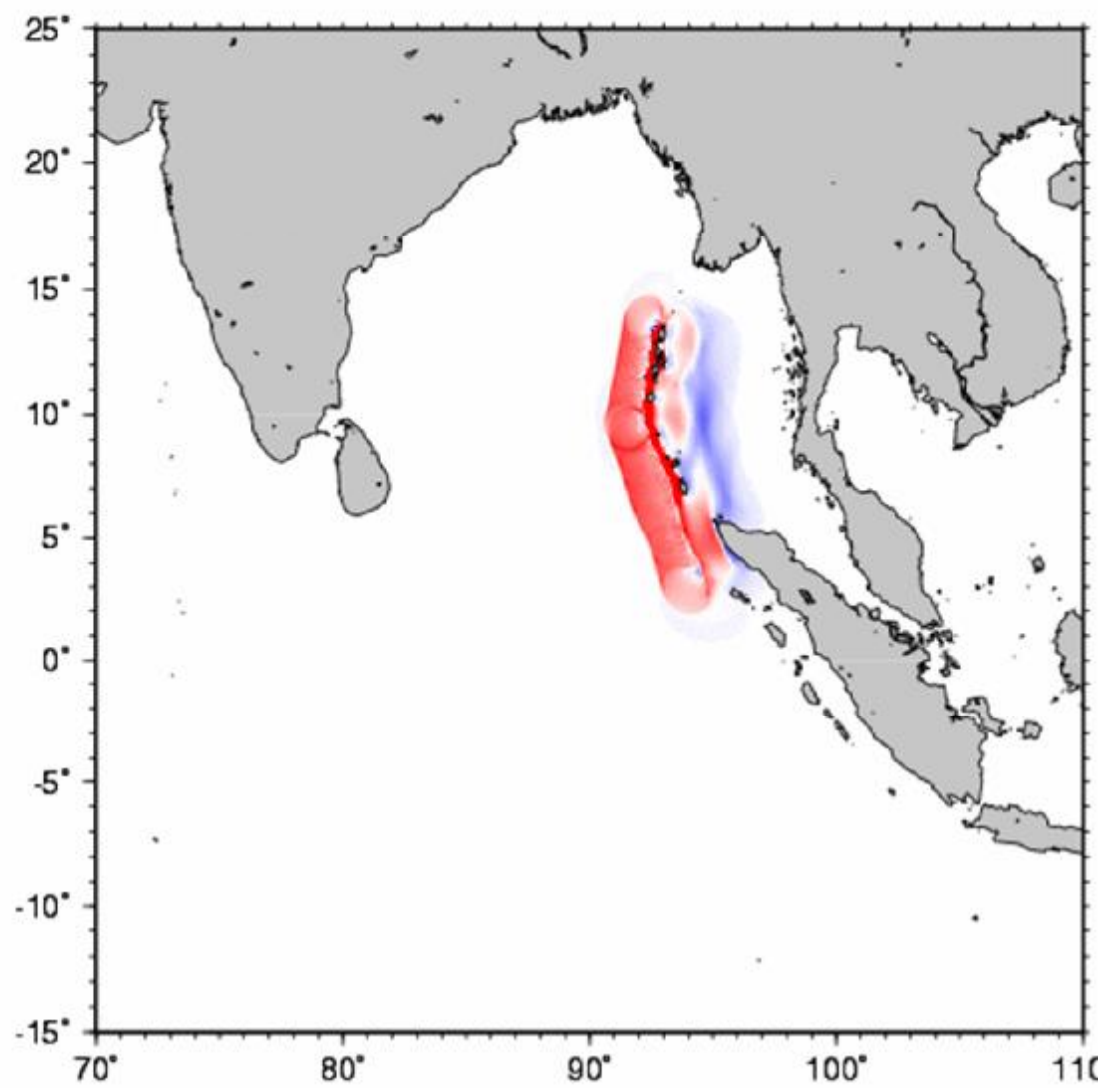
December 26, 2004

**Great subduction
thrust fault
earthquake**

斷層長：1500公里



2004 Sumatra Earthquake 010 min



台灣集集地震 **M7.3**

1999 Chi-Chi, Taiwan, Earthquake







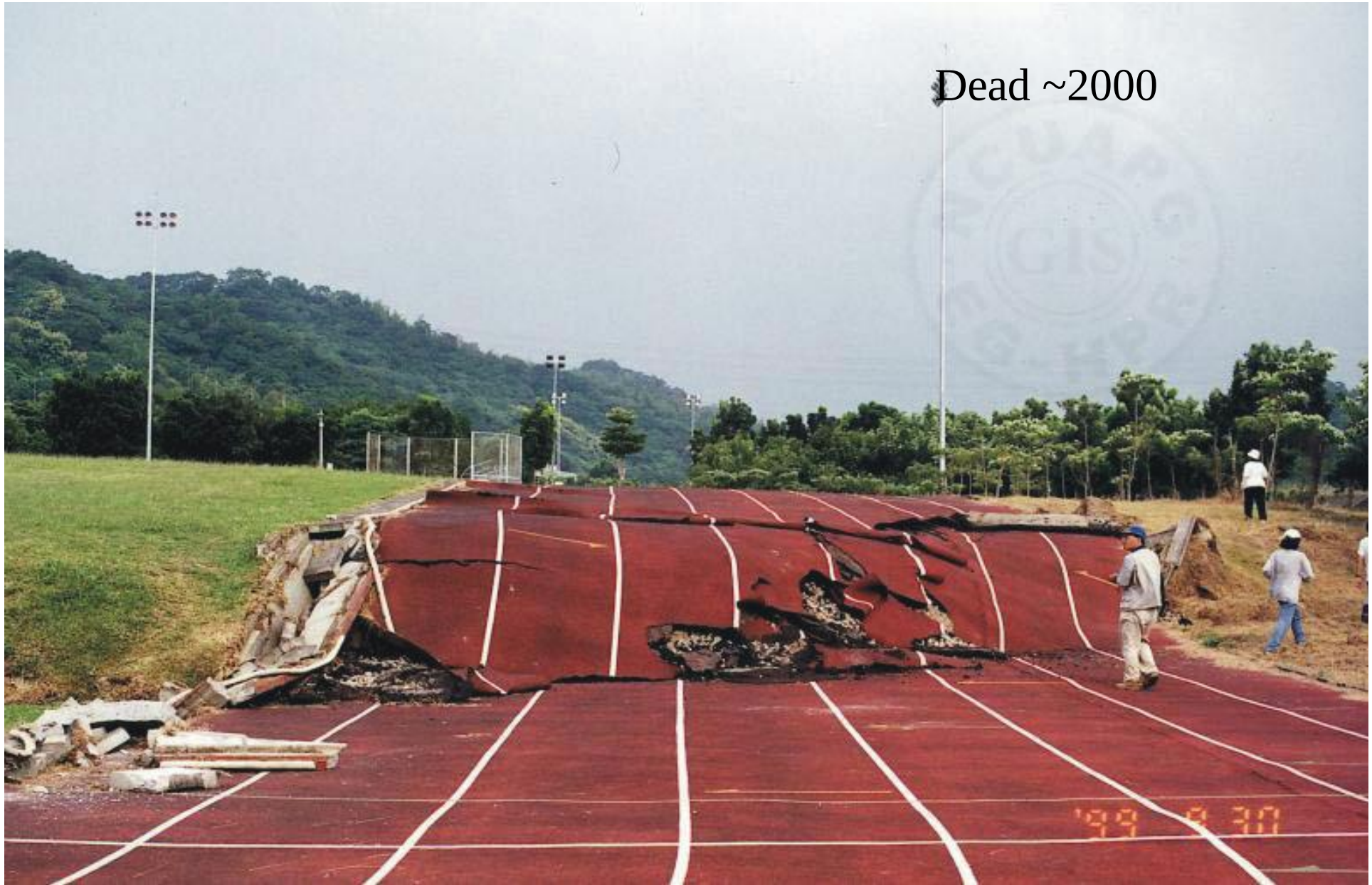
埤豐橋

8 m vertical ground displacement,



霧峰 光復國中

Dead ~2000



北加州地震 1989 Loma Prieta, CA, Earthquake



KGO-TV News ABC-7

日本阪神地震

1995 Kobe, Japan, Earthquake

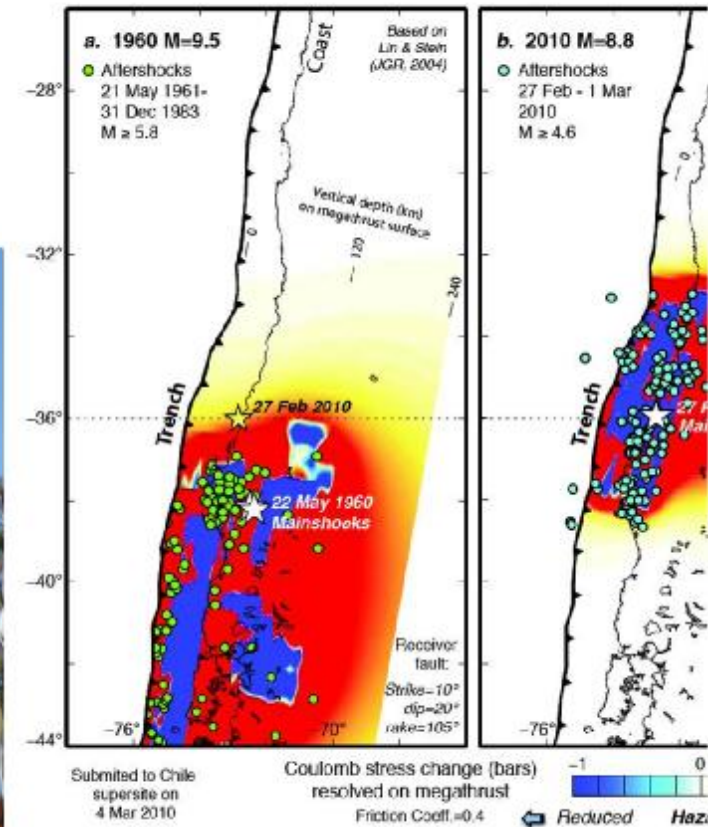


2010 Feb. 27 智利地震

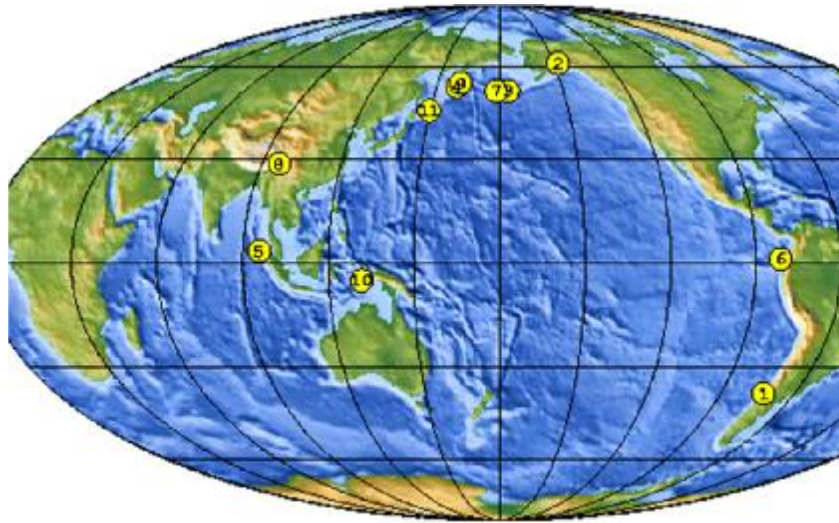
M8.8 Earthquake in Chile



1960 earthquake brings the site of the 2010 rupture 0.5 bar



20世紀 十大地震



USGS National Earthquake Information Center

1999 集集地震: M_w 7.3

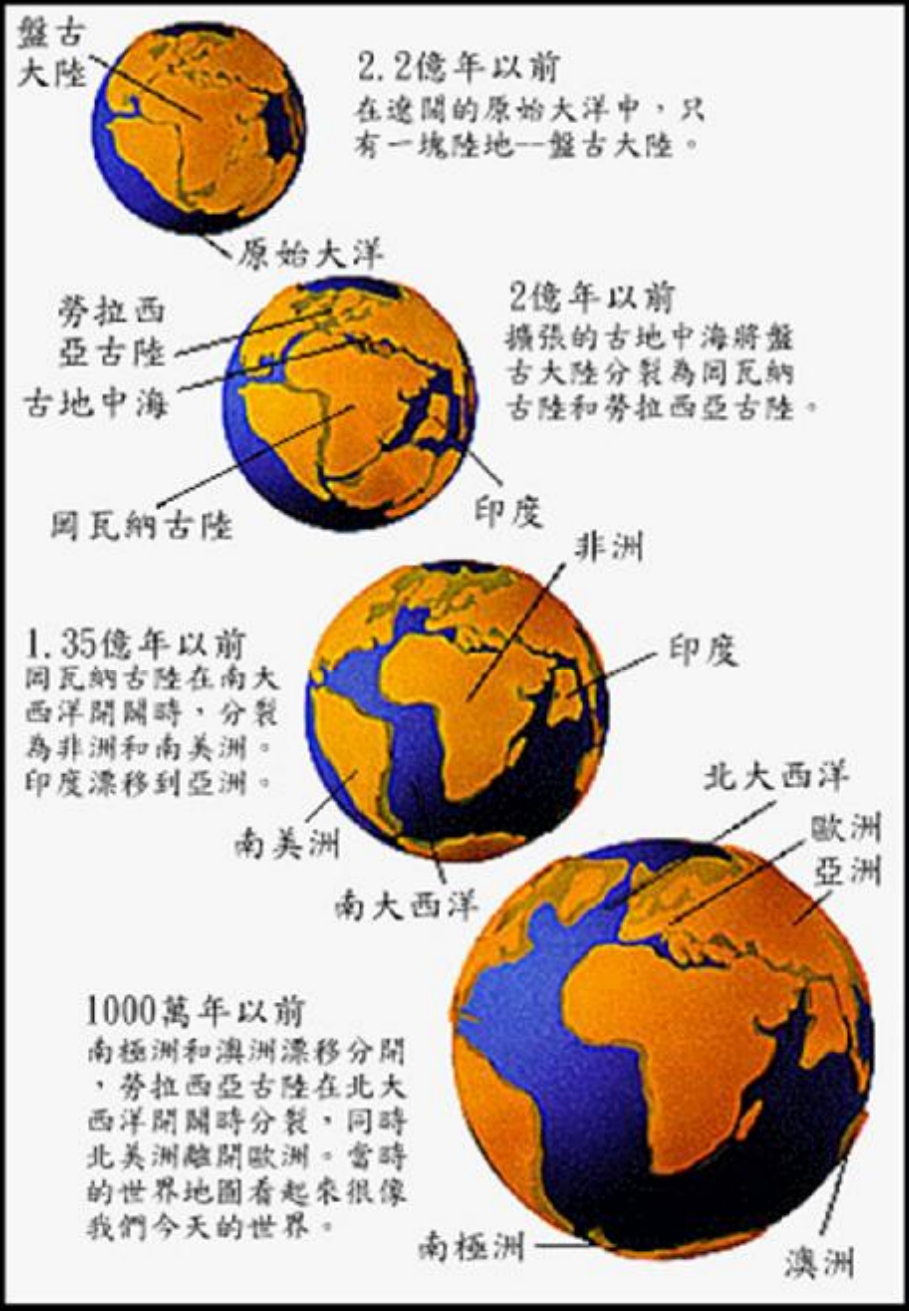
2008 四川地震: M_w 7.9

1976 唐山地震: M_w 7.6

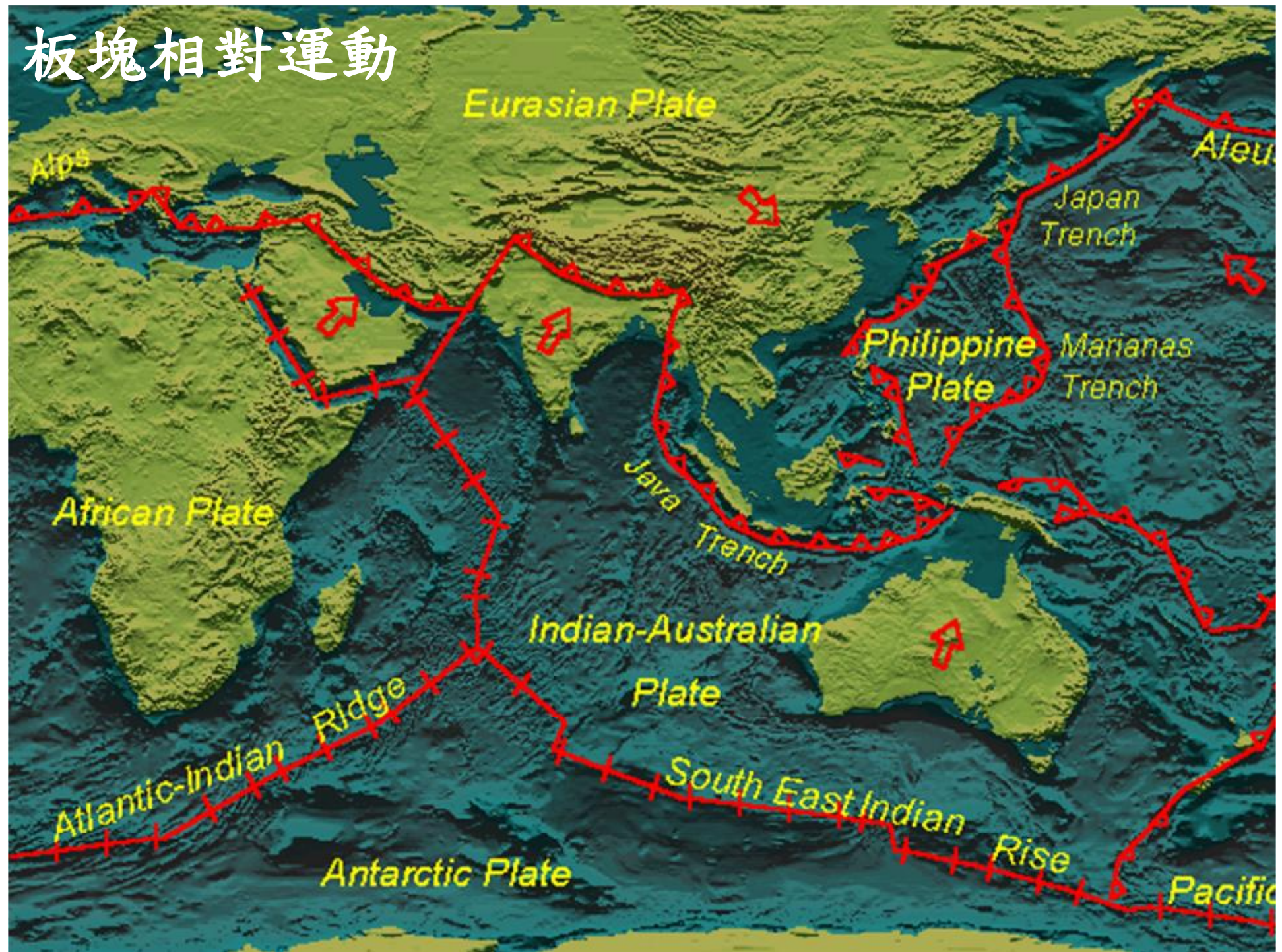
1	Chile	1960/05/22	9.5
2	Prince William Sound, Alaska	1964/03/28	9.2
3	Andreanof Islands, Alaska	1957/03/09	9.1
4	Kamchatka	1952/11/04	9.0
5	Off the West Coast of Northern Sumatra	2004/12/26	9.0
6	Off the Coast of Ecuador	1906/01/31	8.8
7	Rat Islands, Alaska	1965/02/04	8.7
8	Assam - Tibet	1950/08/15	8.6
9	Kamchatka	1923/02/03	8.5
10	Banda Sea, Indonesia	1938/02/01	8.5
11	Kuril Islands	1963/10/13	8.5

歷史災害性大地震

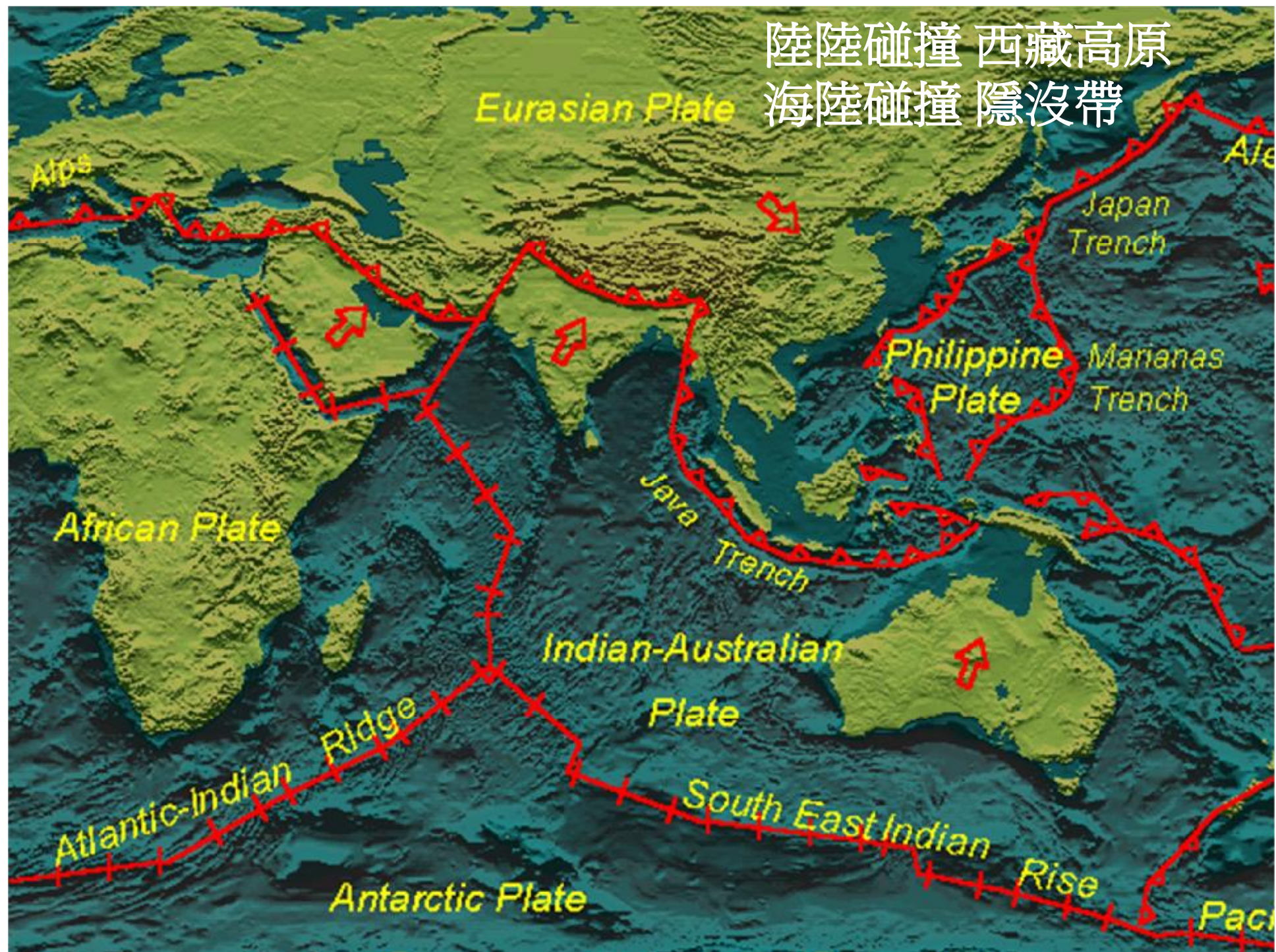
1556 01 23	China, Shensi	830,000	~ 8	
1976 07 27	Tangshan, China	255,000 (official)	7.5	Official casualty figure is 255,000 deaths. Estimated death toll as high as 655,000.
1138 08 09	Syria, Aleppo	230000		
2004 12 26	Sumatra	227,898	9.1	
856 12 22	Iran, Damghan	200,000		
1920 12 16	Haiyuan,China	200,000	7.8	
893 03 23	Iran, Ardabil	150000		
1923 09 01	KantoJapan	142,800	7.9	Extreme destruction in the Tokyo - Yokohama area firestorms burned about 381,000 A tsunami heights as high as 12 m (39 ft)



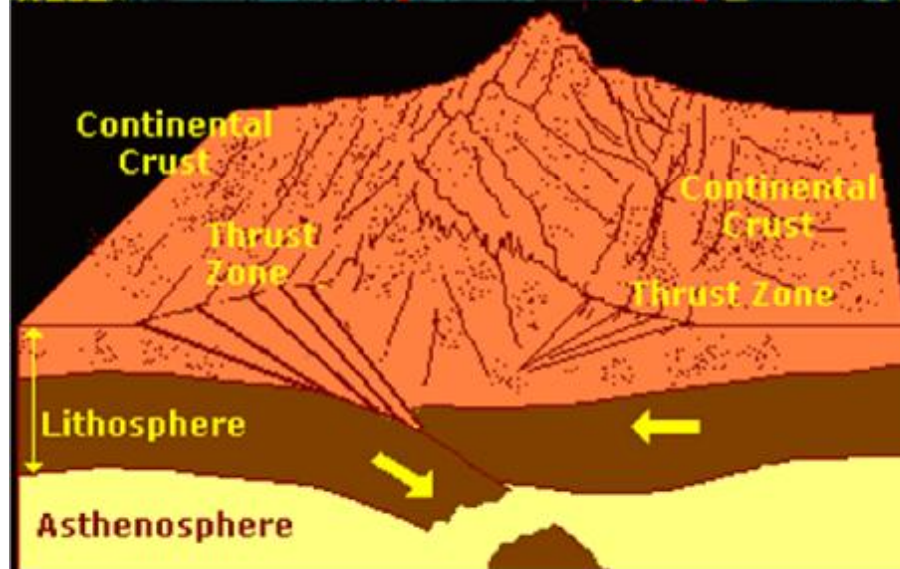
板塊相對運動

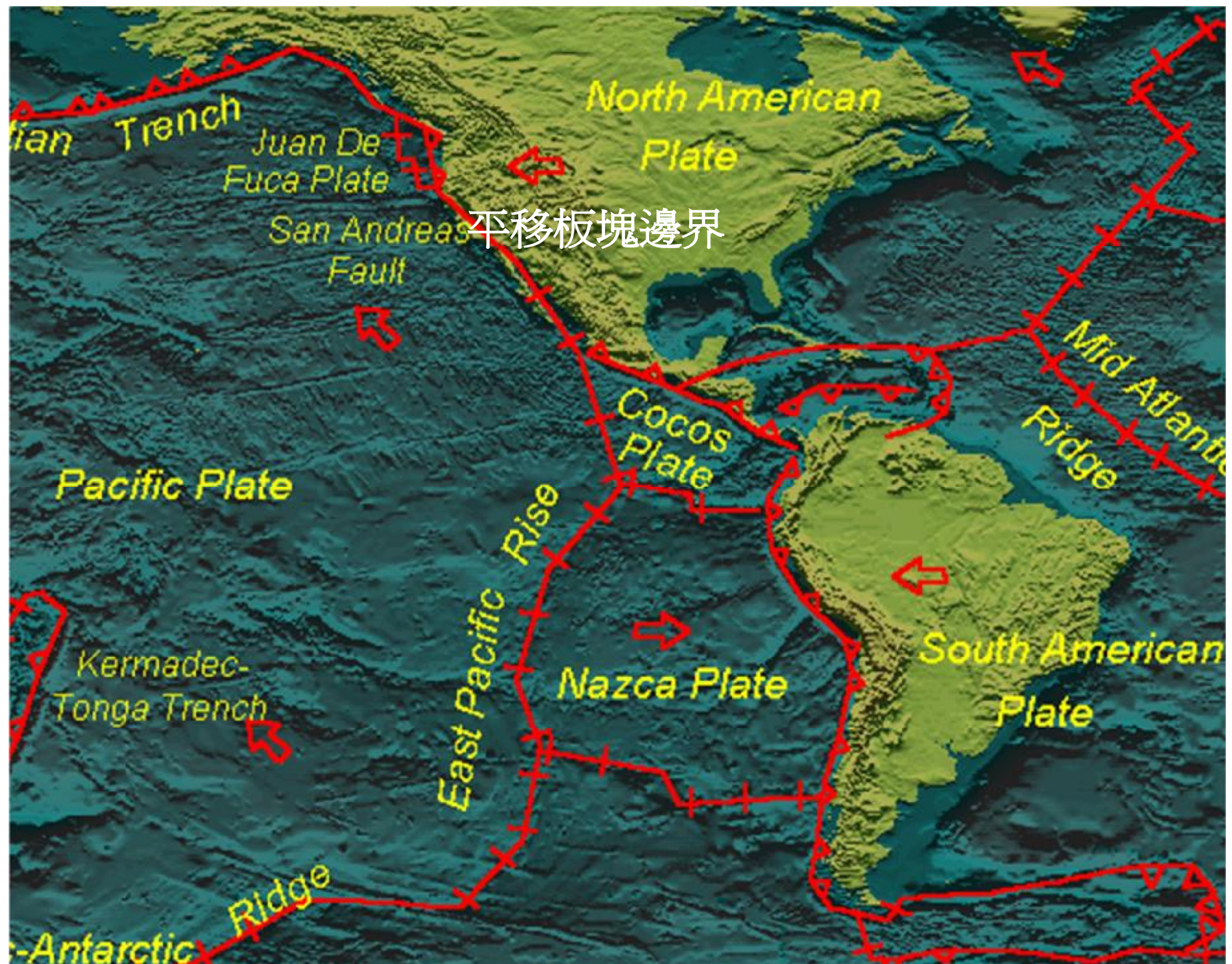


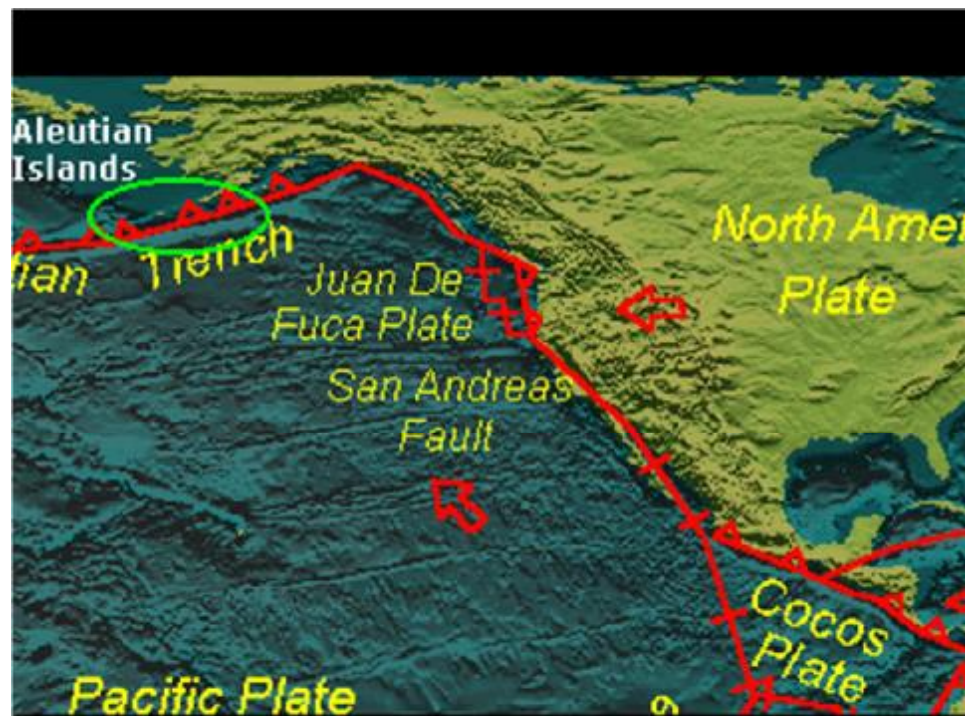
陸陸碰撞 西藏高原
海陸碰撞 隱沒帶



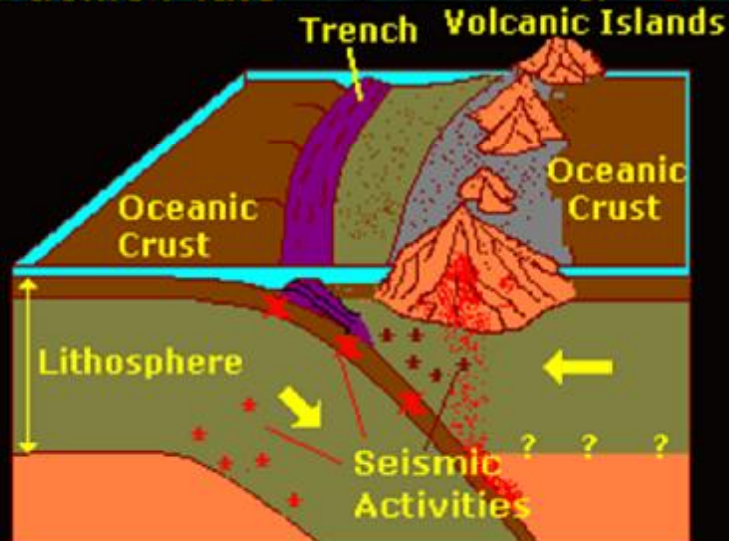
西藏高原

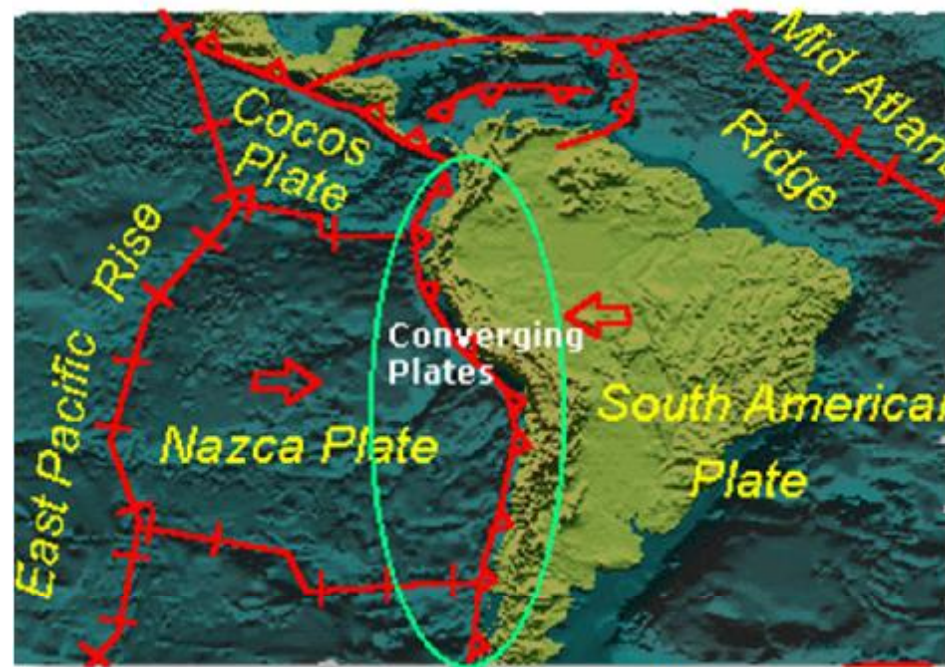






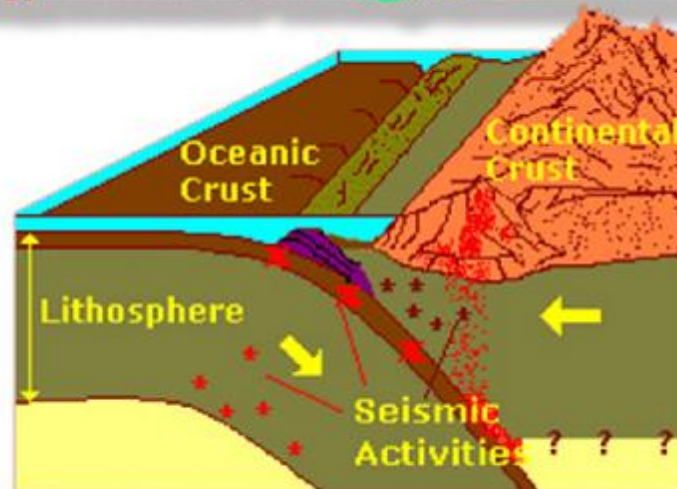
阿拉斯加

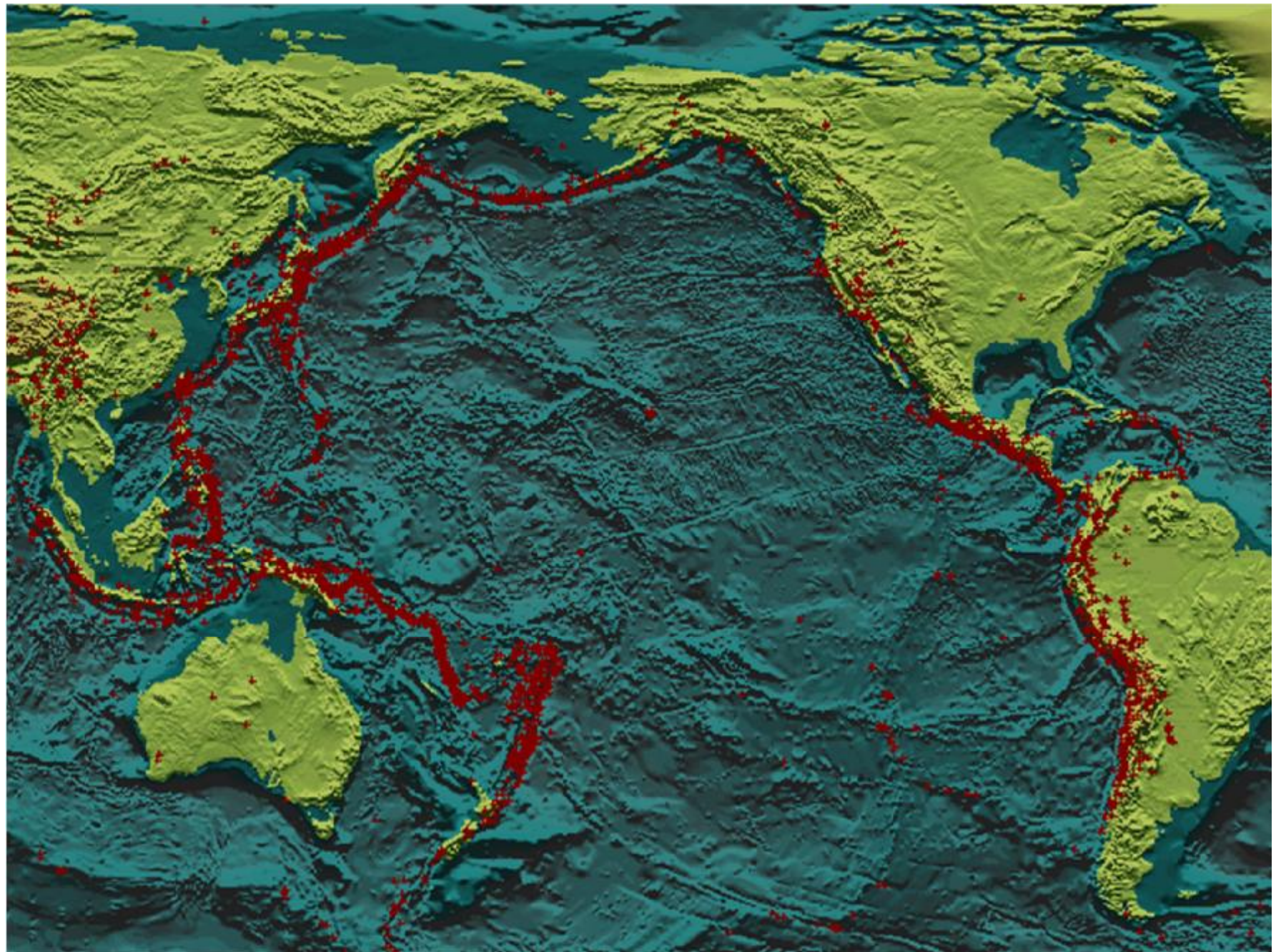




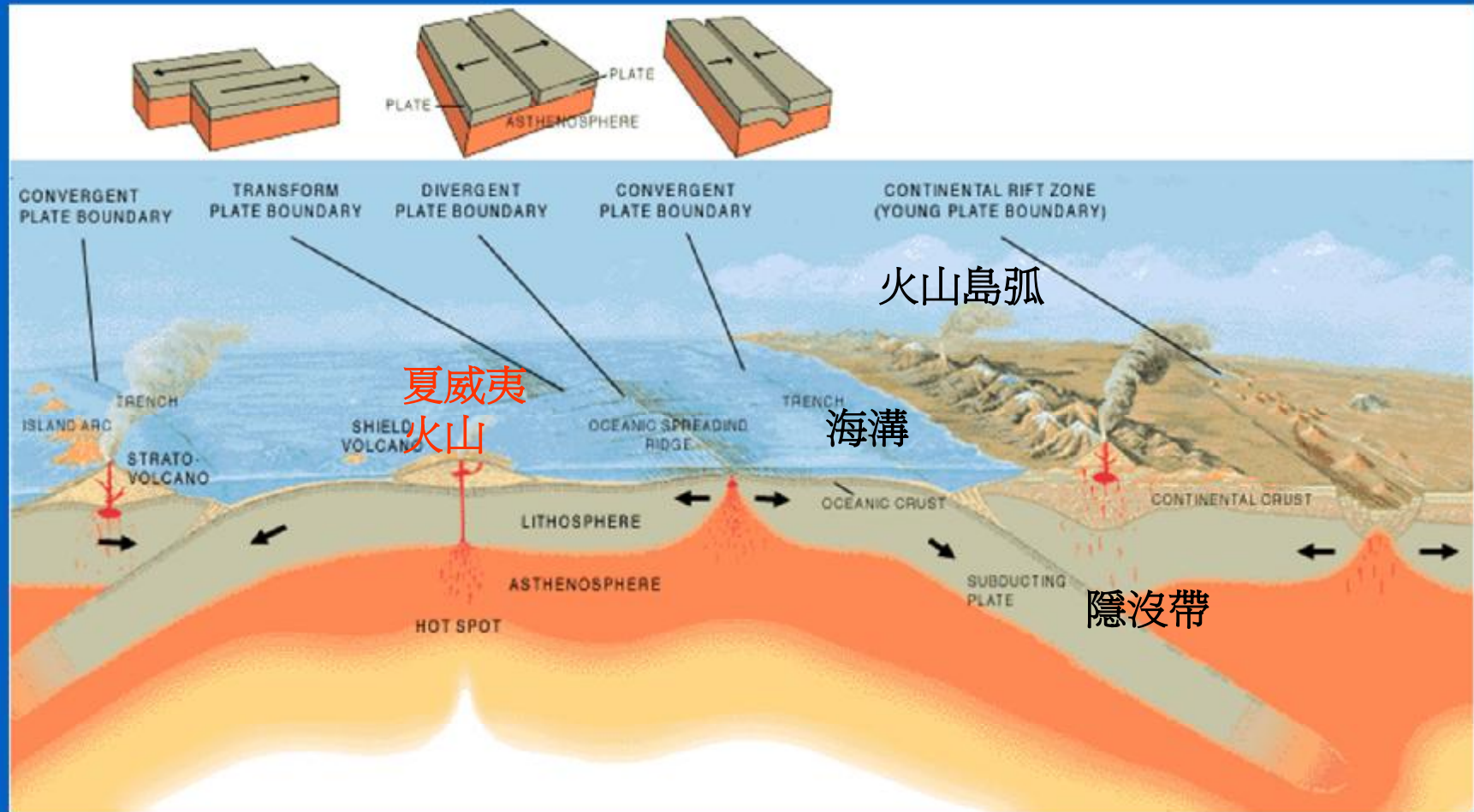
1960 M9.5
2010 M8.8

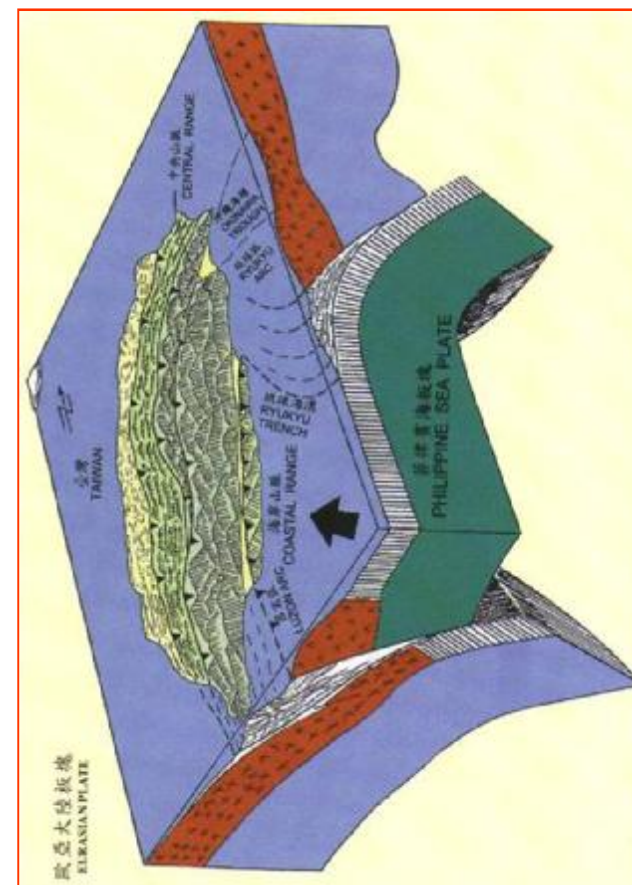
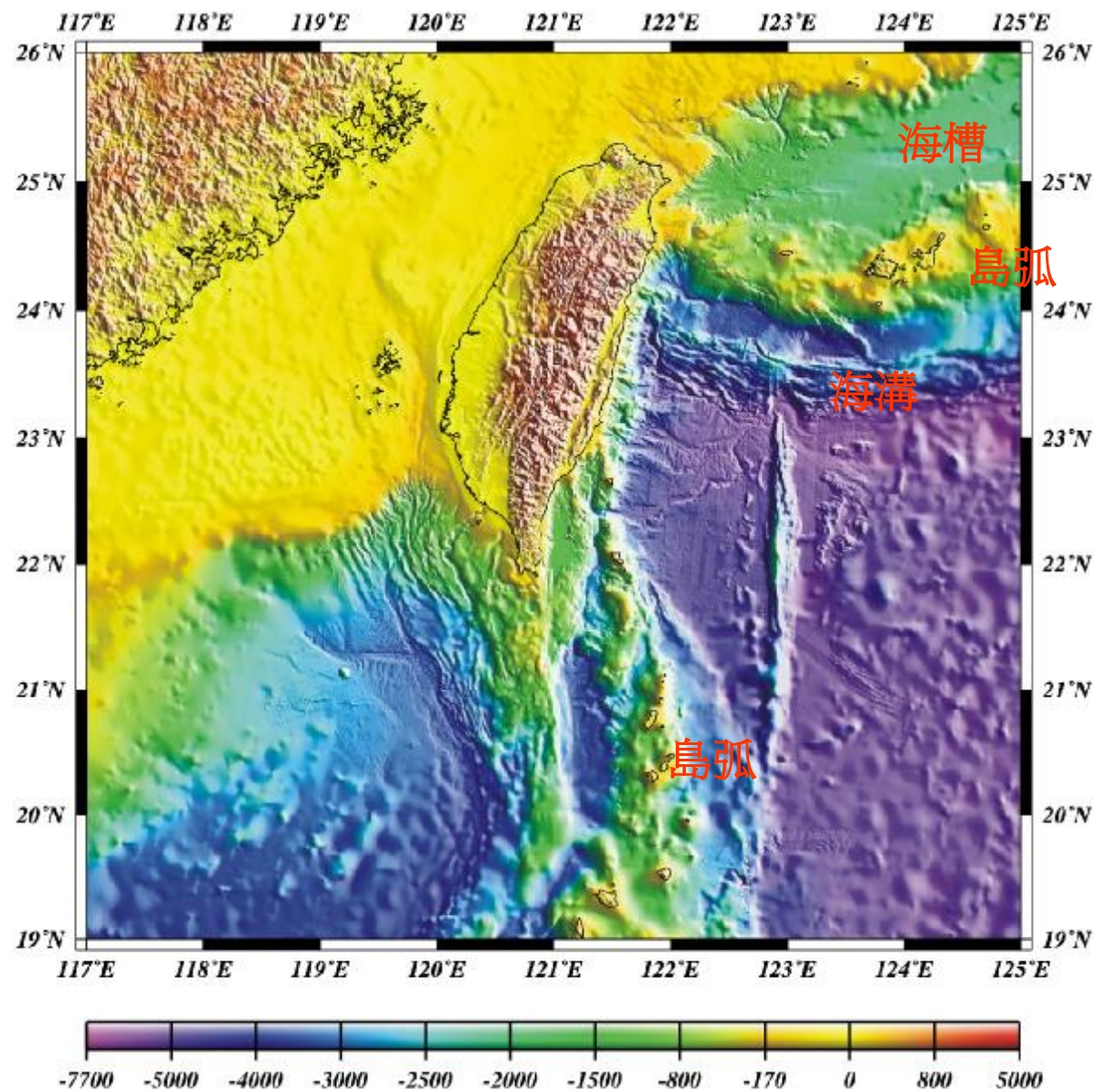
智利

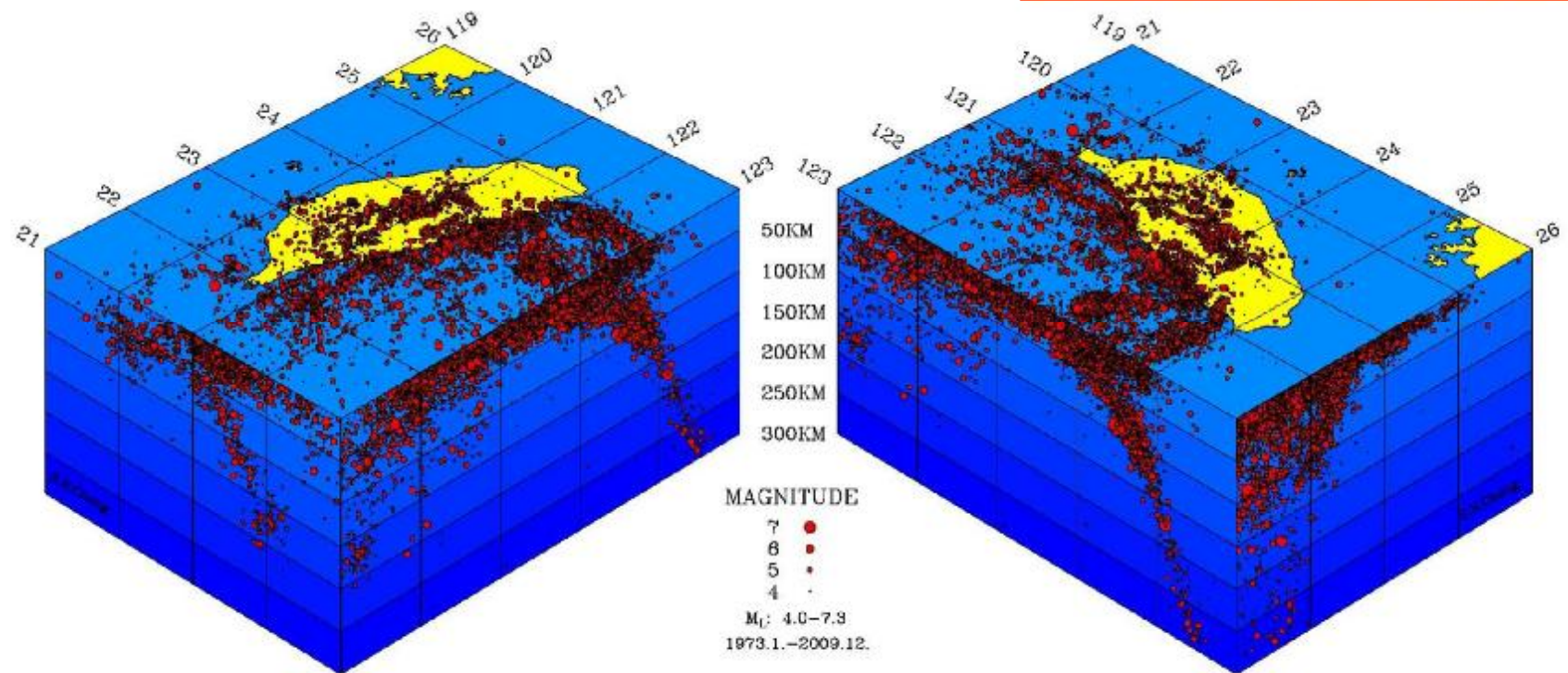
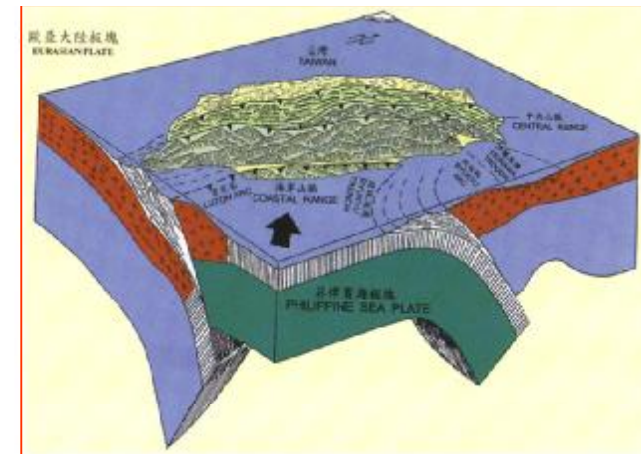


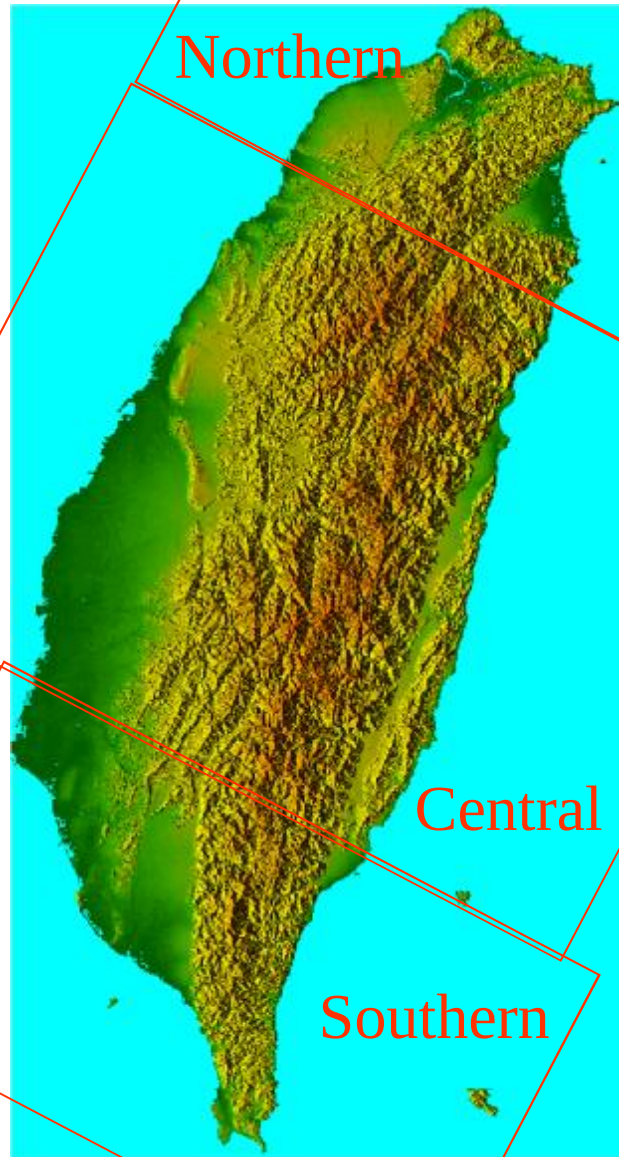


板塊邊界



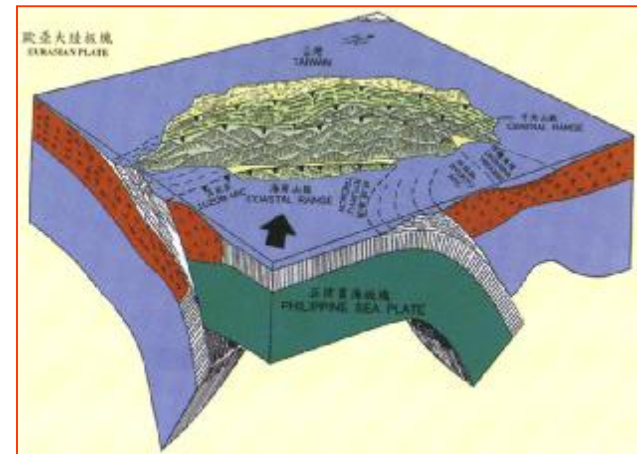






新地體構造

Basic neotectonic provinces of Taiwan

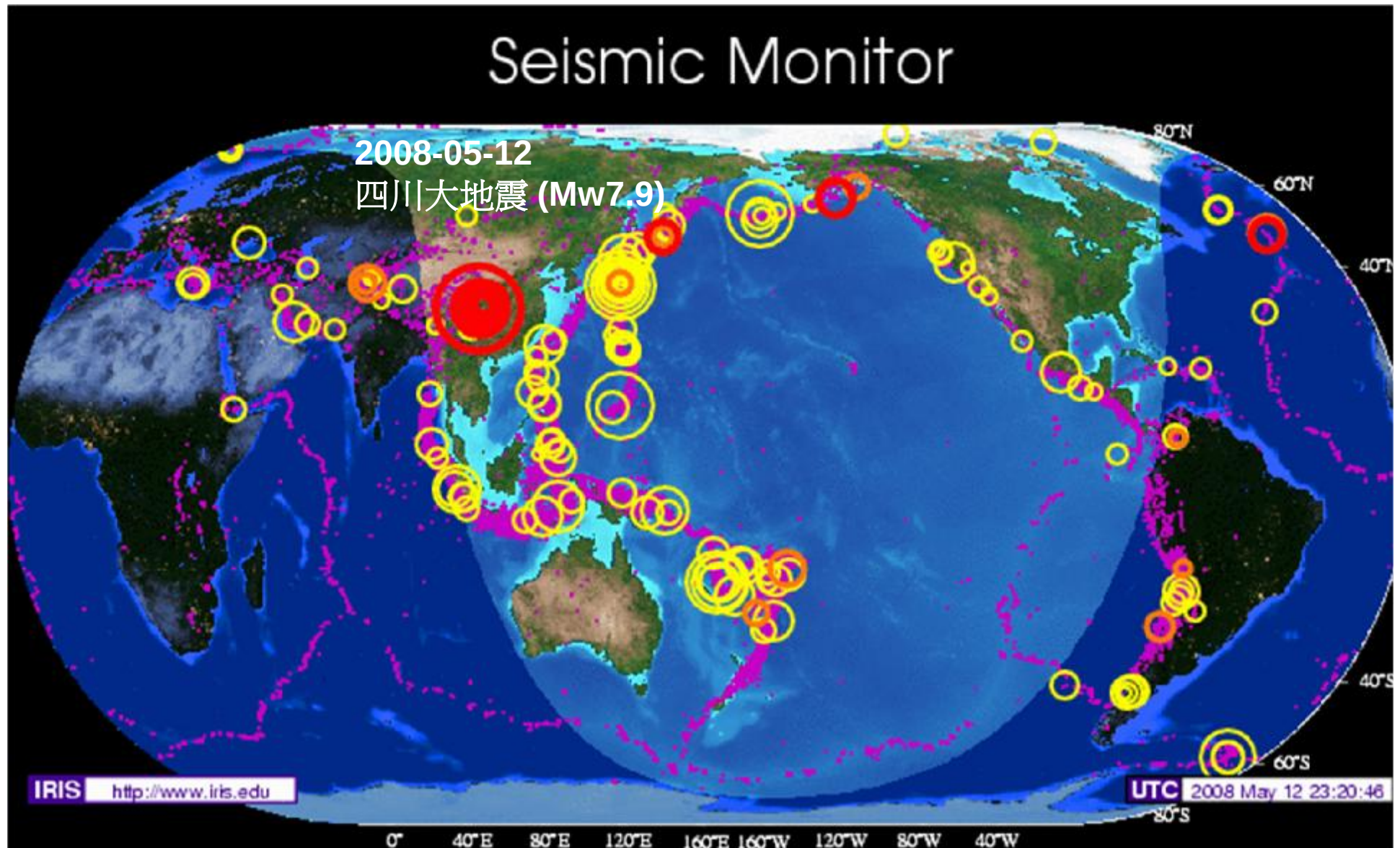


中央大學張中白教授

地震觀測：世界地震觀測網

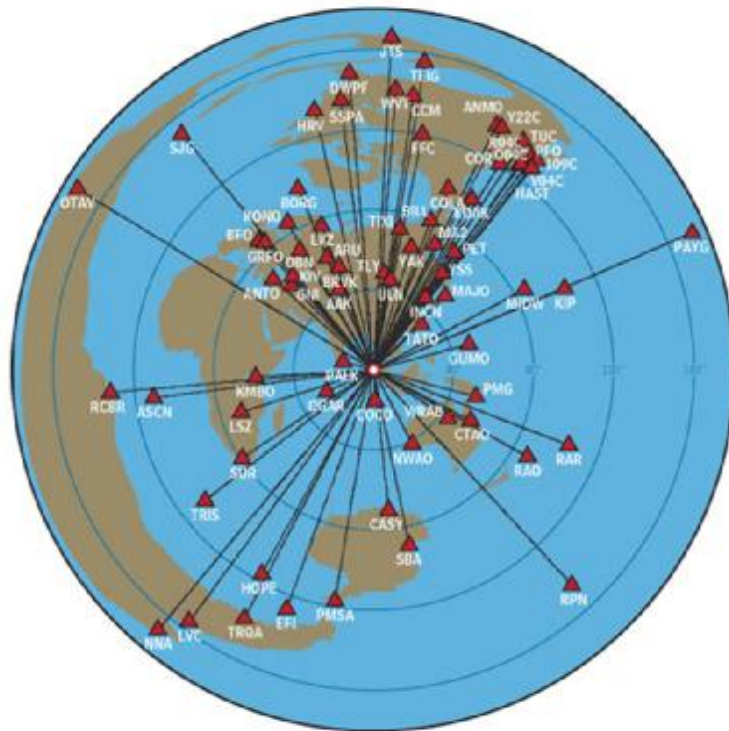
地震記錄=>地震定位 規模 機制 破裂過程

地球內部構造, 地殼 地函 地心 地體構造

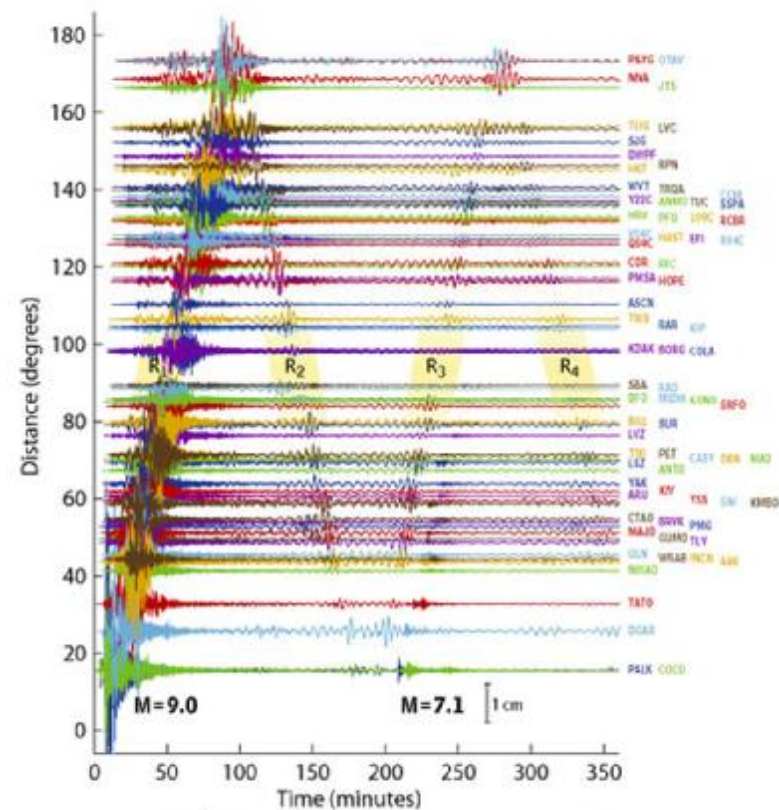


世界地震網 (IRIS)

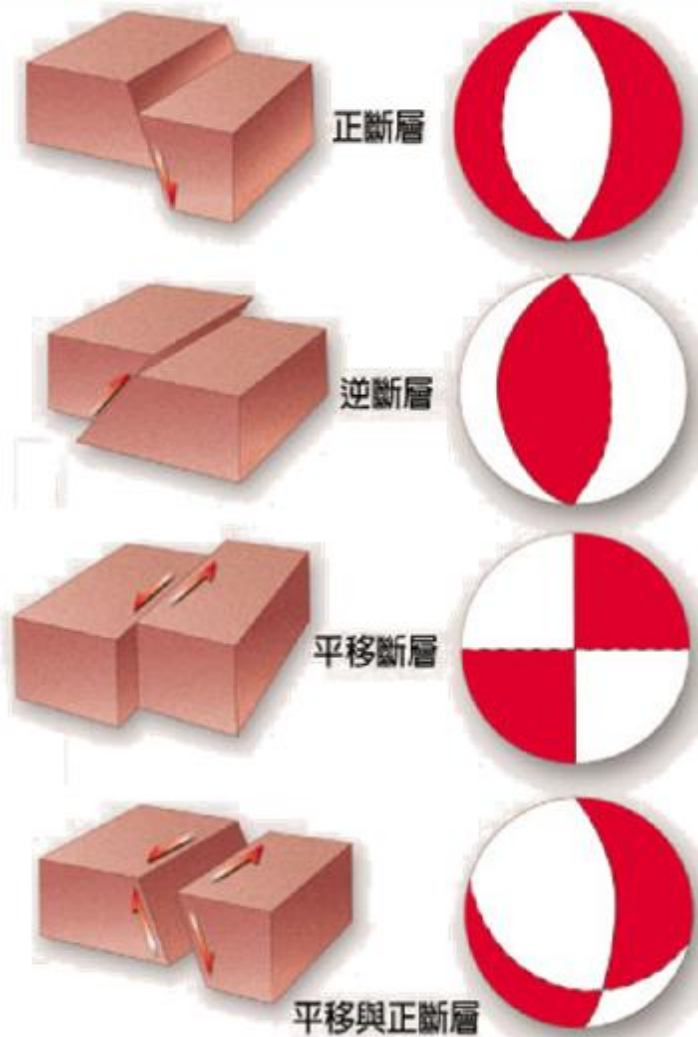
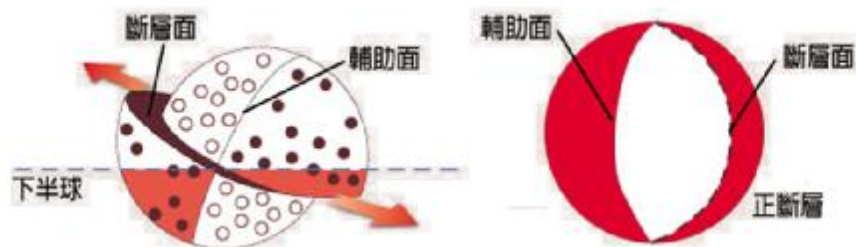
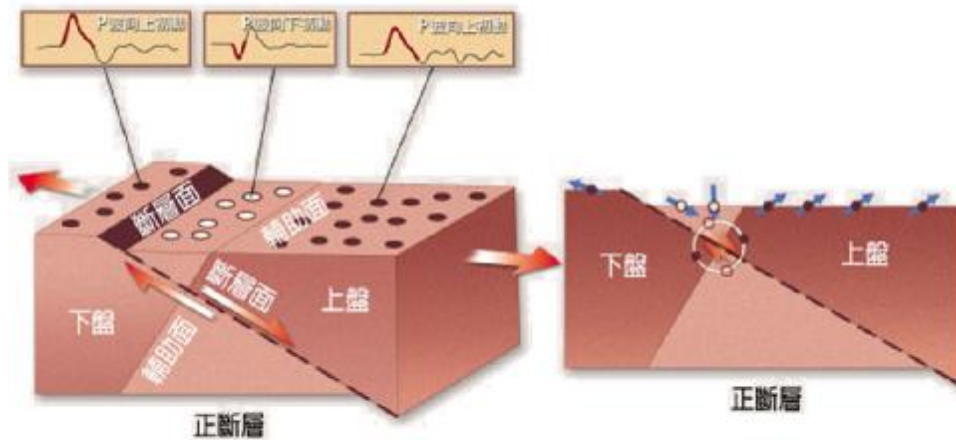
Sumatra - Andaman Islands Earthquake



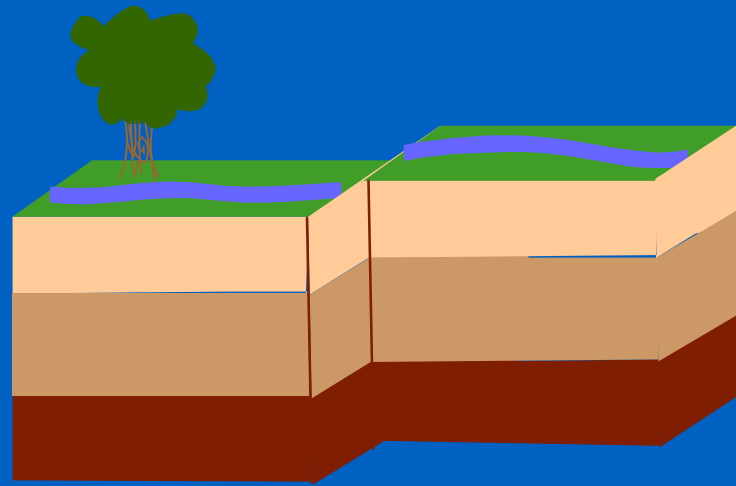
Sumatra - Andaman Islands Earthquake ($M_w=9.0$)
Global Displacement Wavefield from the Global Seismographic Network



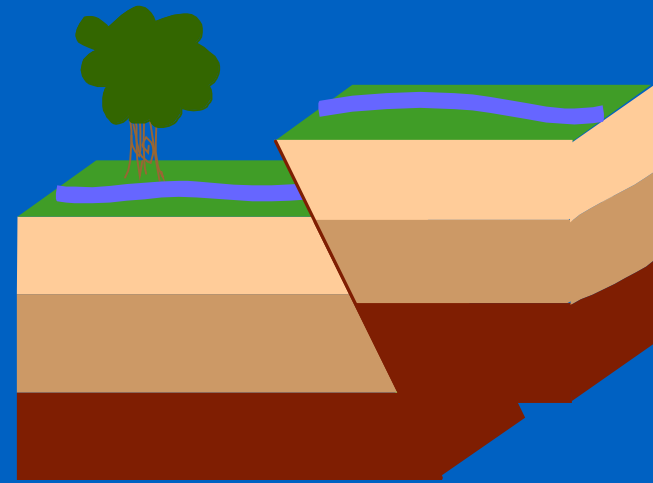
地震震源機制解



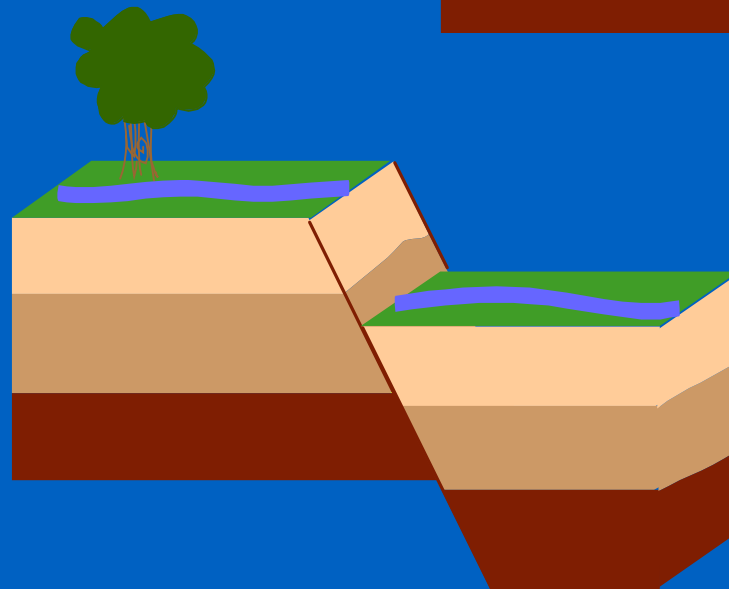
三種斷層型態



走向斷層
Strike-Slip



逆斷層
Thrust



正斷層
Normal



台灣歷史地震觀測站



Taipei Observatory(1897,12)



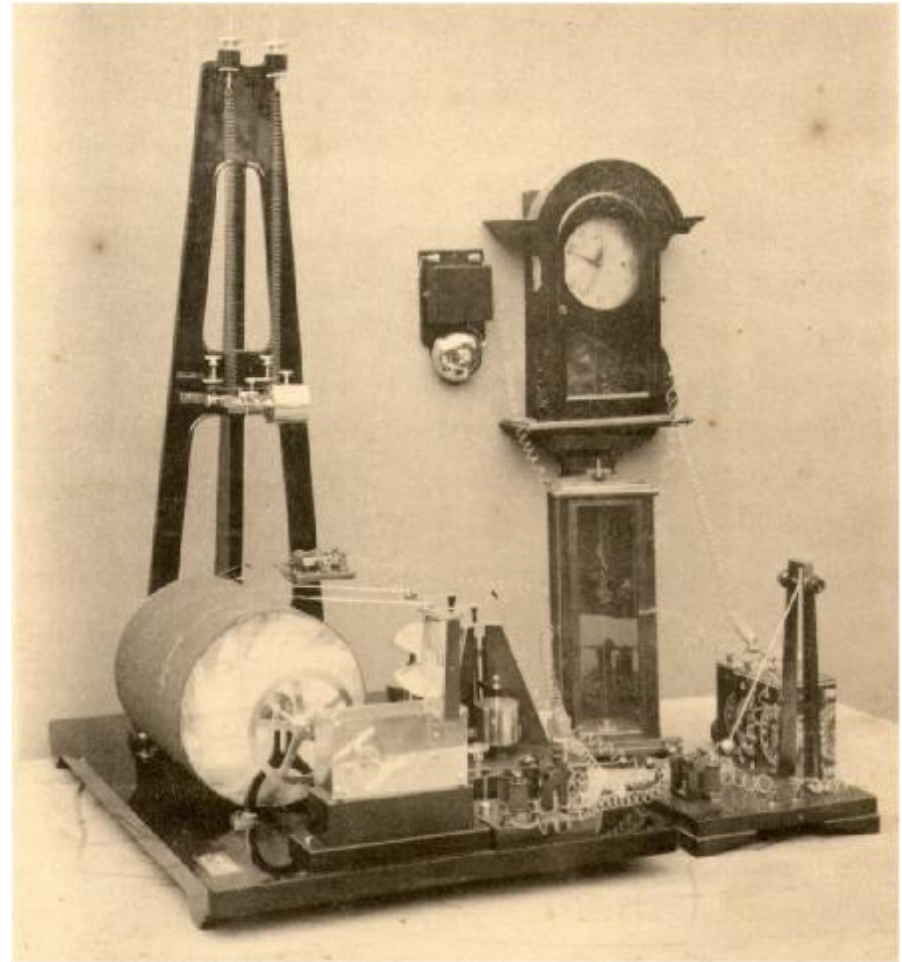
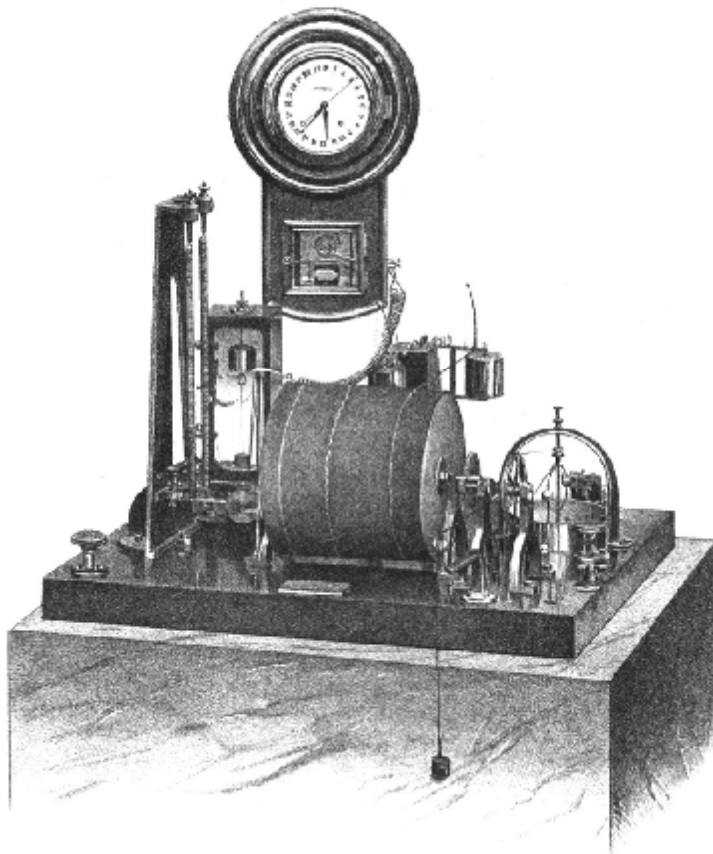
Tainan Observatory(1898,1)



Penhua Observatory(1898,2)

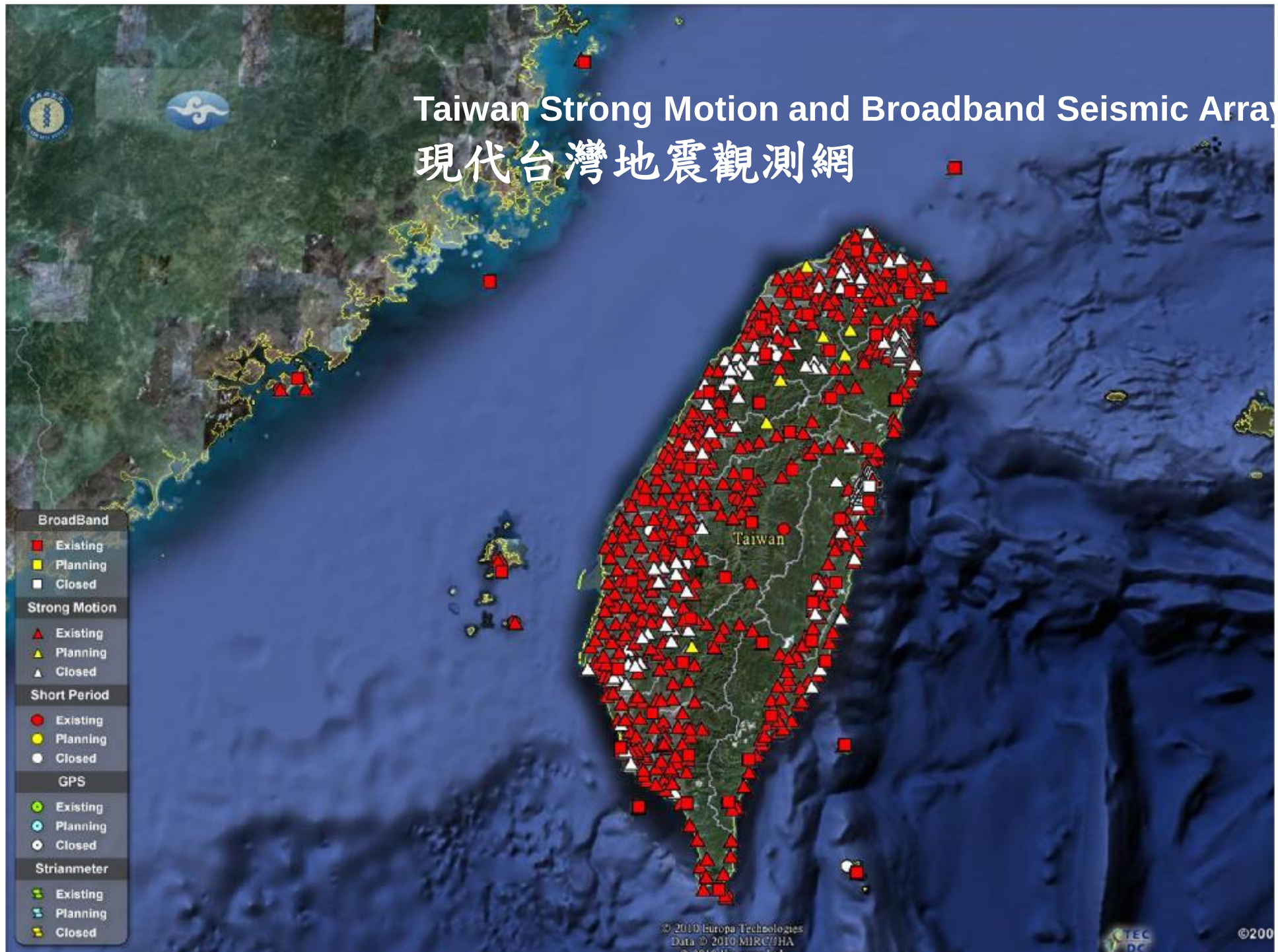
歷史地震觀測儀

GRAY-MILNE SEISMOGRAPH



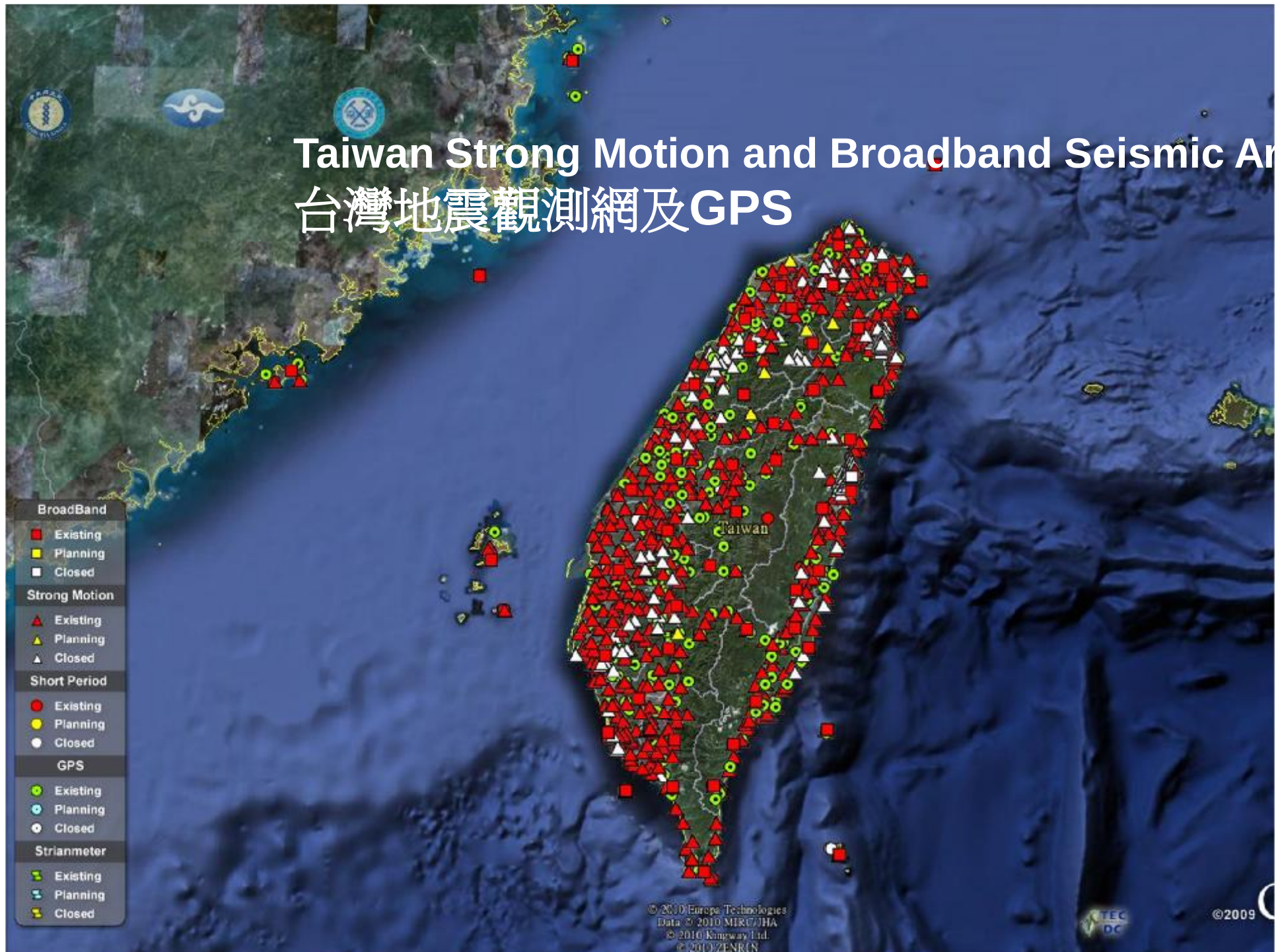
Gray-Milne Seismograph (1897,12,17 Taipei Observatory)

Taiwan Strong Motion and Broadband Seismic Array 現代台灣地震觀測網

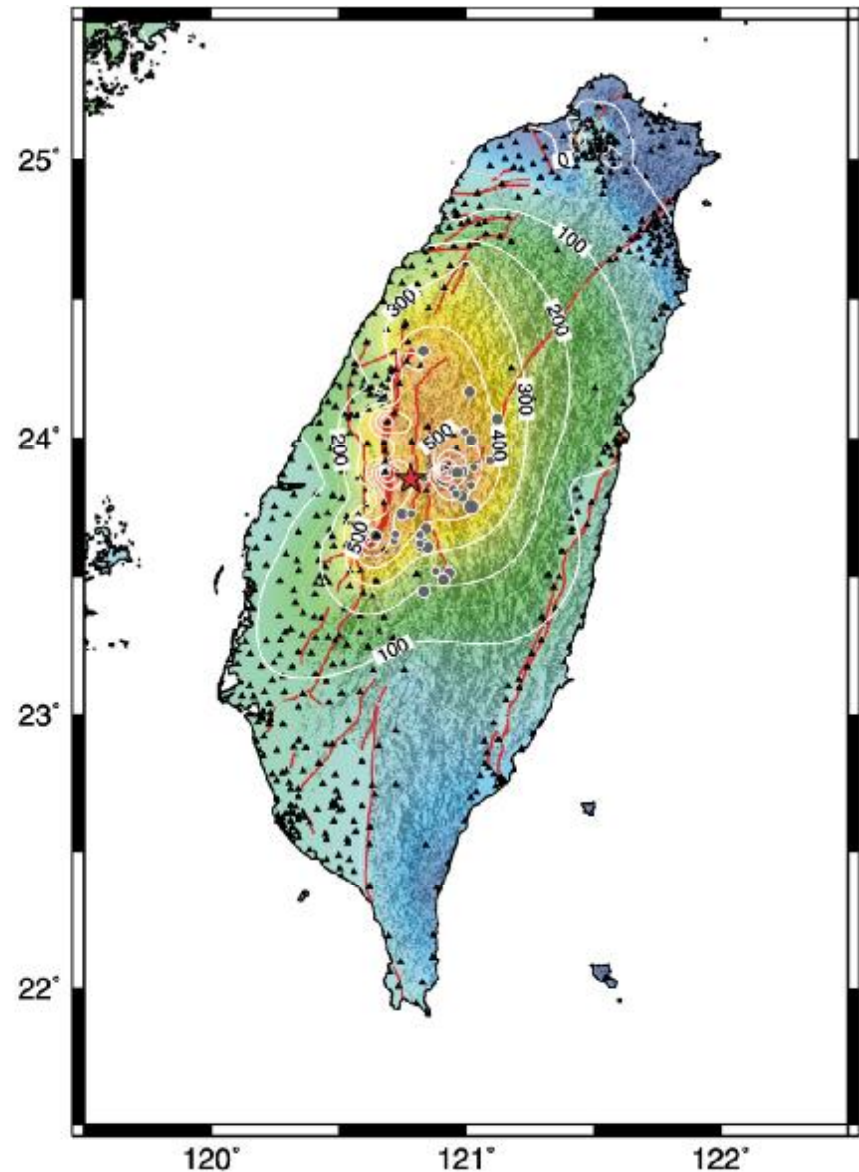
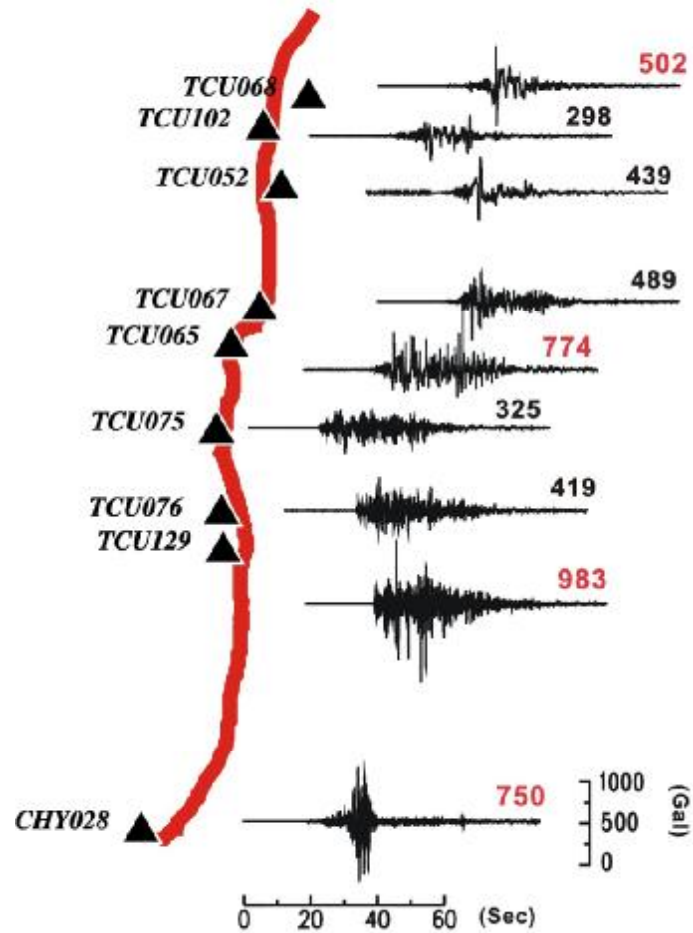


Taiwan Strong Motion and Broadband Seismic Array

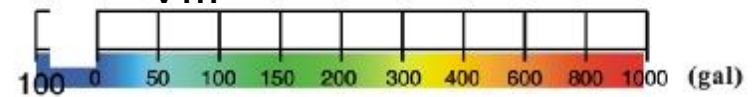
台灣地震觀測網及GPS



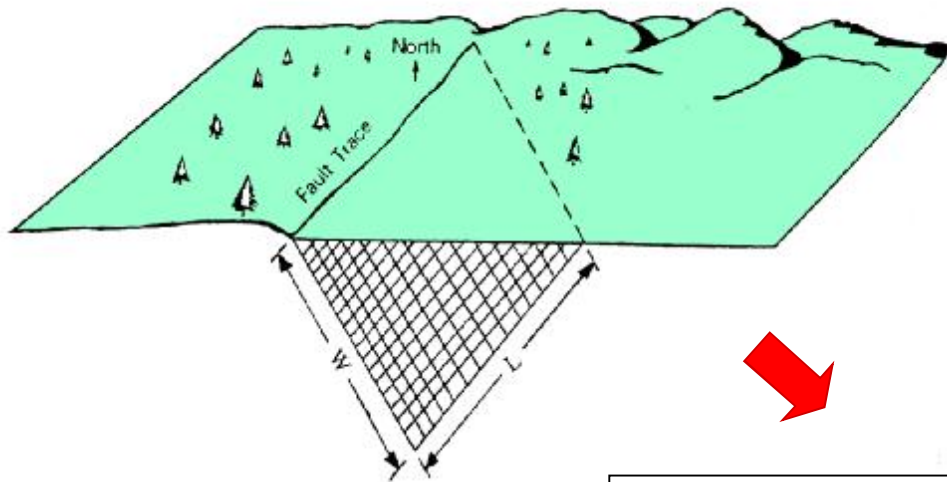
TSMIP



VIII IX

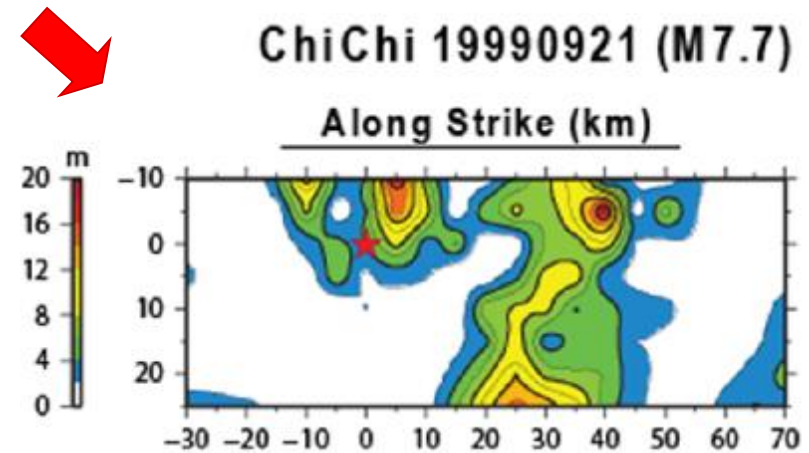


Finite-Fault modeling: Fault Length, Width and Slip



$$A x = B$$

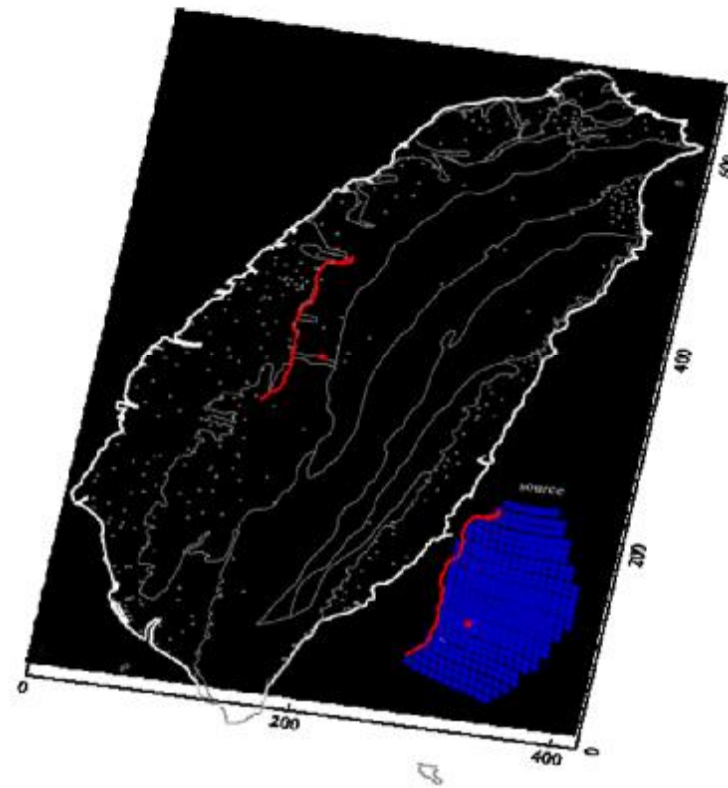
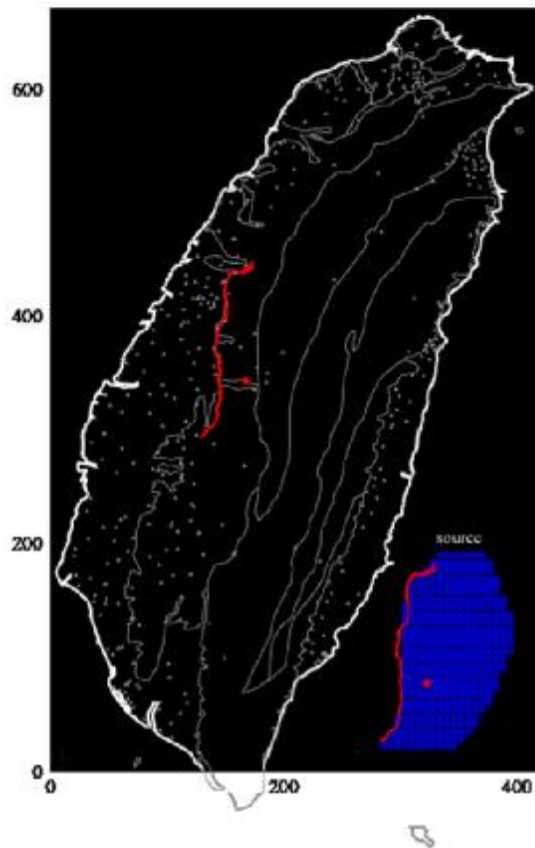
Waveform Inversion



集集地震三維波傳模擬

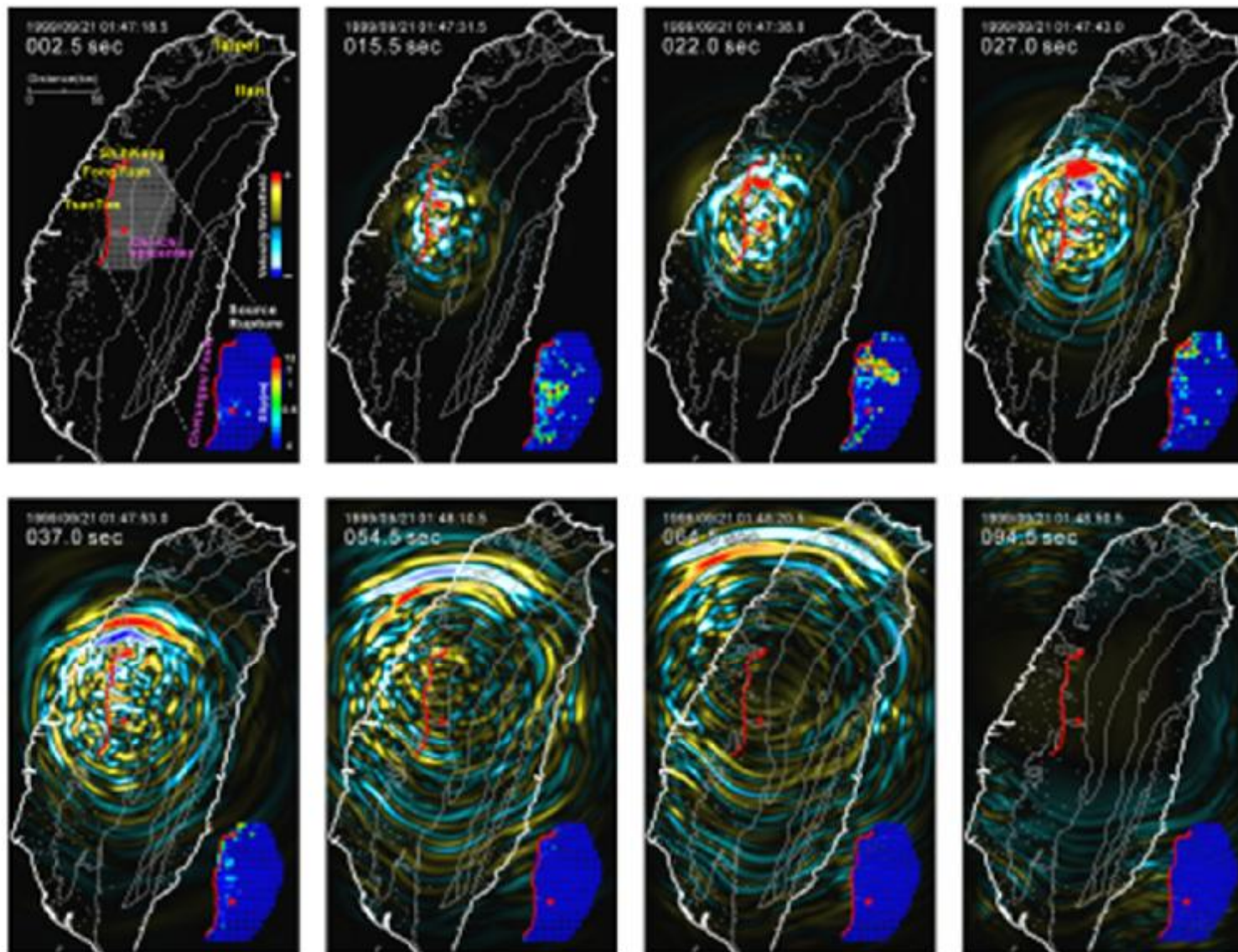
1999/09/21 01:47:16.0

After Initial Time : 000.0sec



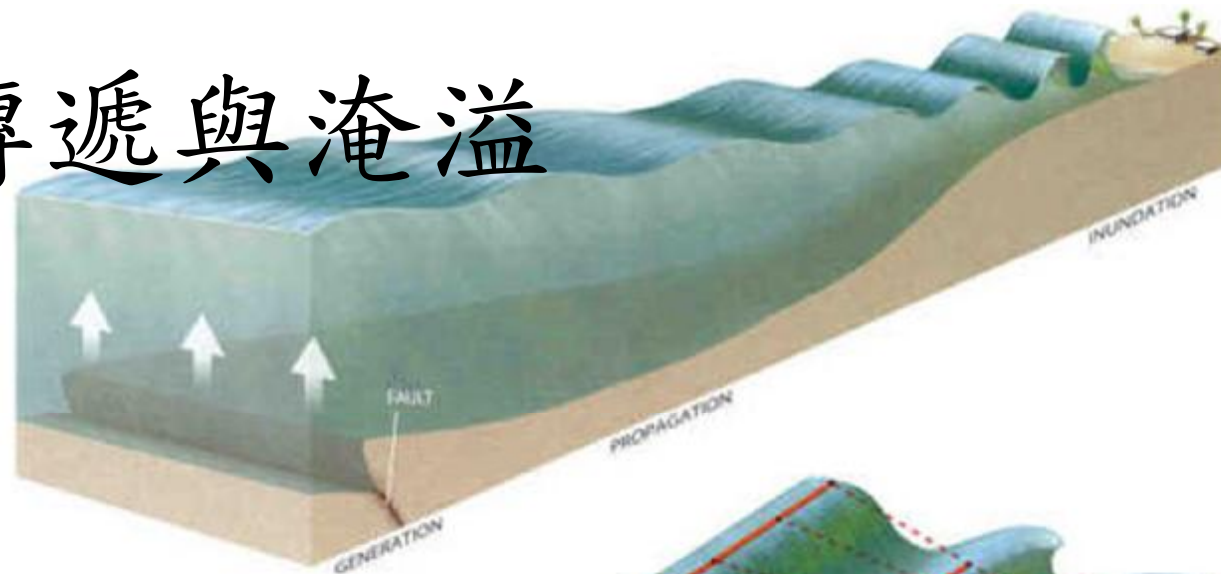
(Lee, Chen, and Ma, JGR, 2007)

Wave Propagation of September 21, 1999 Chi-Chi earthquake

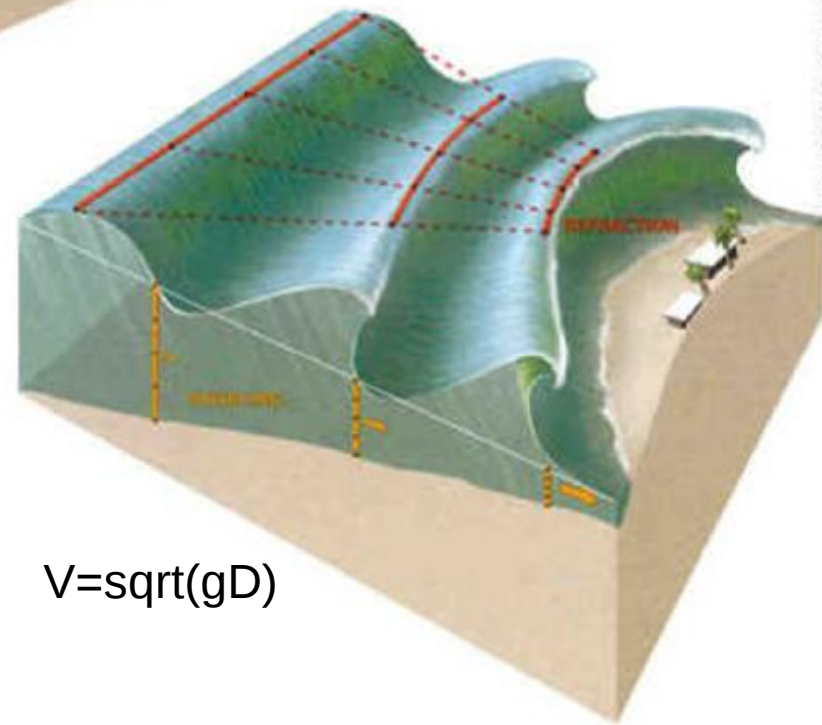


(Lee, Chen, and Ma, JGR, 2007)

海嘯傳遞與淹溢



TSUNAMIS EVOLVE through three stages: generation, propagation and inundation (*above*). A seafloor disturbance, such as motion along a fault, pushes up the overlying water. The wave propagates across the deep ocean at jetliner speeds; however, with a length up to 600 times its height, the wave's slope is often too gentle to notice. The wave slows down to highway speeds as it enters shallow water, and it sometimes runs ashore as a tidelike flood. Other times, refraction and shoaling funnel the wave's energy into a dangerously high wall of water (*right*). Wave energy is squeezed into a smaller volume (*dots*) as it moves into shallower water, slows down and is overtaken by the wave behind, or wraps around a headland. This increased energy density then increases both the wave height and the currents.

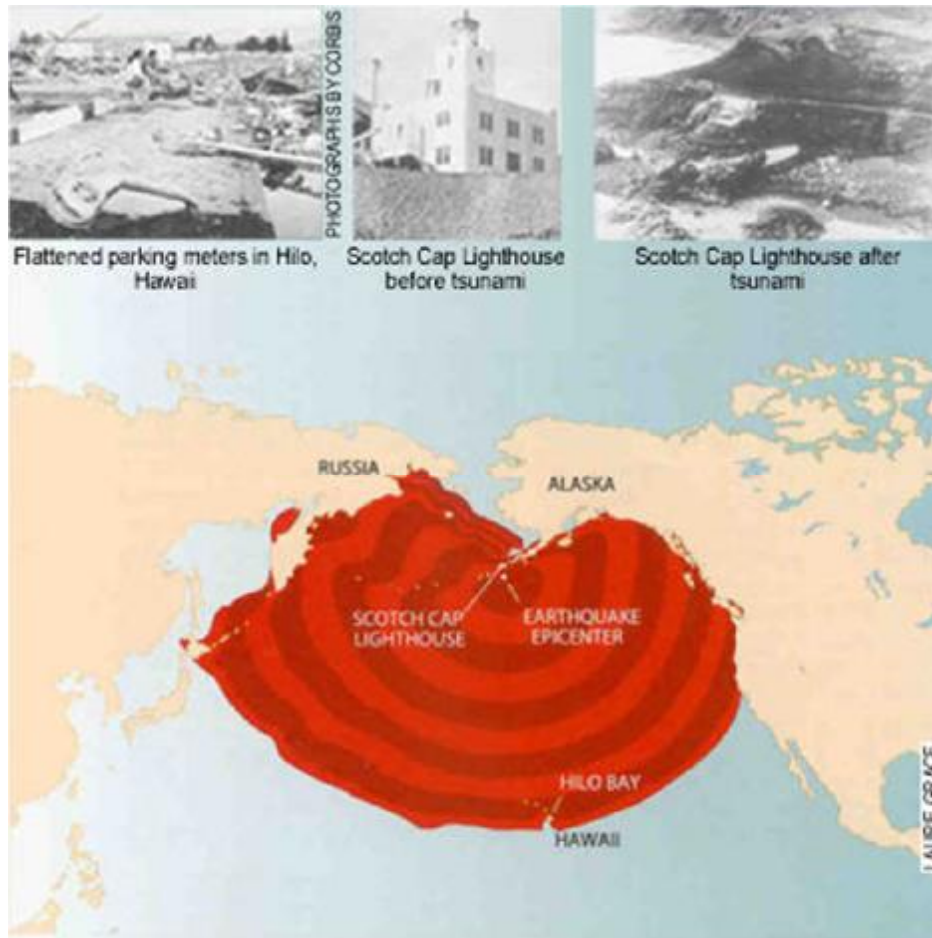


$$V=\sqrt{gD}$$

Not the First, Not the Last
East Aleutian Islands, April 1, 1946
Maximum wave height: 35 meters

海嘯預警

Fatalities: 165



Signs, standardized for all Pacific states, now alert coastal dwellers and visitors to tsunami-prone areas.

歷史海嘯研究

Old Japanese Documents Confirm Warnings of Future North American Earthquakes

- From the tsunami's arrival time in Japan, the Japanese researchers assigned the earthquake to the evening of Tuesday, **January 26, 1700**. In addition, from preliminary estimates of the tsunami's height in Japan, they guessed that the tsunami was too large to explain by a **Cascadia earthquake** less than magnitude 9.
- The researchers begin by showing that the 1700 tsunami crested as much as **15 feet high in Japan**. They then use recent findings about the **Cascadia subduction zone** to relate earthquake size to plausible areas of fault rupture and seafloor displacement.

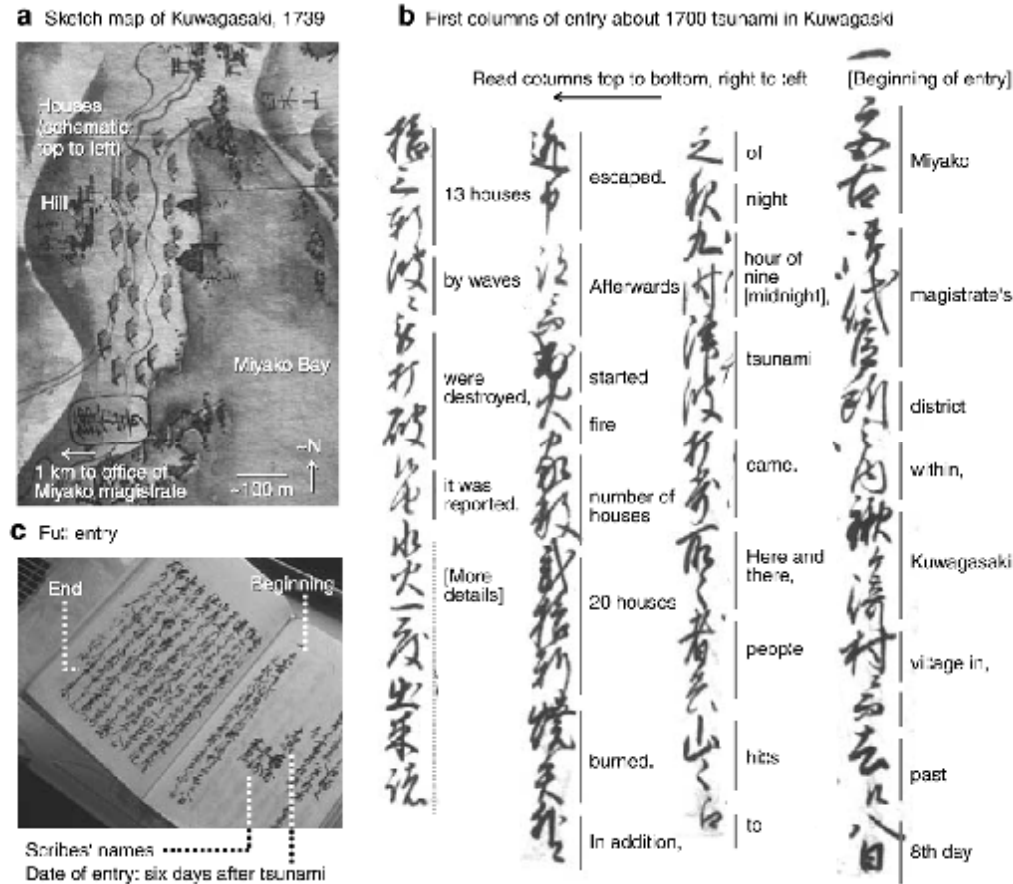
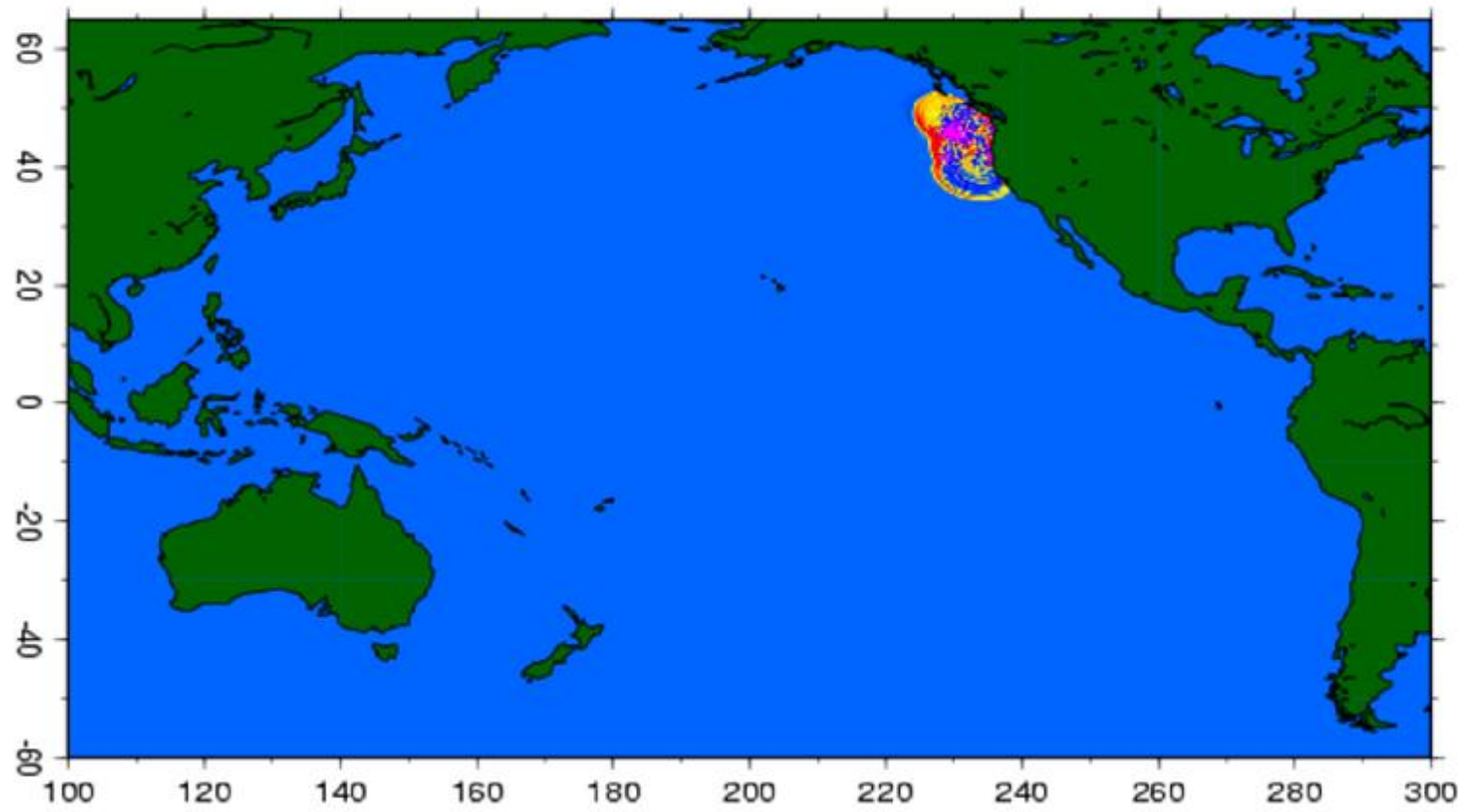
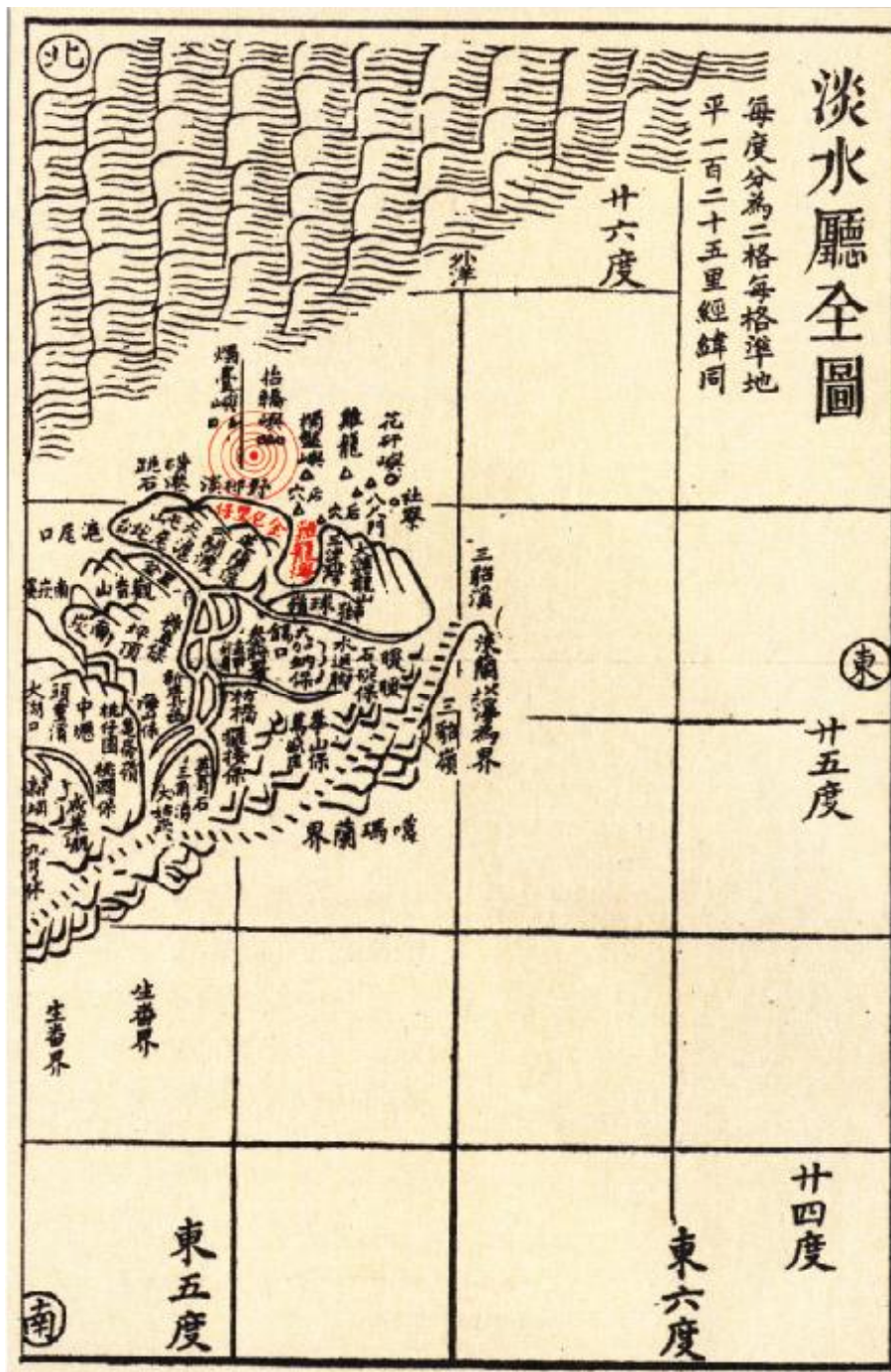


Figure 4. Description of effects of the 1700 tsunami on the village of Kugawasaki. (a) Sketch map of Kugawasaki. (b) First columns of entry about the 1700 tsunami, as recorded in “Morioka-han Zassho,” official records from northern Japan. (c) Pages of “Morioka-han Zassho,” of the volume for the twelfth year of Genroku era, which includes January 1700. Government officials in Morioka based the description on correspondence from magistrates stationed in Miyako, 1 km from Kuwagasaki. The map and the book are courtesy of Morioka City Central Community Center, where they are archived.

01 hour



台灣歷史海嘯： 1867 基隆海嘯



中華民國十九年五月二十五日

居民紛紛遷往高地

太平洋兩岸
遭海嘯襲擊

日本夏威夷百餘人喪生
澳洲菲律賓均蒙受影響

一個鐘頭有一百五十人死亡，較早不確定的報告已指出死亡人數可能更多。災區設施受損，房屋被摧毀，並有房屋倒塌。

A grainy, black and white photograph showing a person standing on a wooden structure, possibly a bridge or walkway, overlooking a body of water. The background features industrial buildings and structures.

[illegible]

時 間 歷史海嘯	海嘯侵襲之地區	出處及文獻所提供之信度、海嘯規模 (M t) 或 浪 高 (H)
1076年(10月31日-11月28日)	海陽、潮陽	宋史五行志 (李善邦, 1981)
1353年8月1日	泉州	元史五行志 (李善邦, 1981)
1604年12月29日	台灣海峽北部	(包澄瀾等, 1991)
1640年 (9月16日—10月14日)	廣東揭陽、澄海、潮陽	Mt = 0, 信度 = 4 (包澄瀾等, 1991)
1641年 (9月16日—11月26日)	廣東澄海、潮陽	(包澄瀾等, 1991)
1661年1月8日	安平	Mt = 1, 信度 = 4 (包澄瀾等, 1991) Mt = 0, 信度 = 4 (游明聖, 1994)
1721年1月5日	台南	Mt = -1, 信度 = 4 (游明聖, 1994)
1721年9月	台南	(包澄瀾等, 1991)
1754年4月	淡水	Mt = 1, 信度 = 3 (包澄瀾等, 1991)
1771年2月24日	日本石垣島	日本石垣島宮良村85.4公尺 (宇佐美龍夫, 1977) 日本石垣島85公尺 (徐明同, 1981)
1781年4-5月	高雄地區	Mt = 1, 信度 = 3 (包澄瀾等, 1991) Mt > 2, 信度 = 4 (游明聖, 1994)
1792年8月9日	彰化地區	(包澄瀾等, 1991) Mt > 2, 信度 = 4 (游明聖, 1994)
1866年6月11日	高雄地區	Mt = 0, 信度 = 4 (游明聖, 1994)
1867年6月11日	基隆地區	Mt = 2, 信度 = 4 (包澄瀾等, 1991) Mt = 2, 信度 = 4 (徐明同, 1981) Mt = 2, 信度 = 4 (游明聖, 1994)

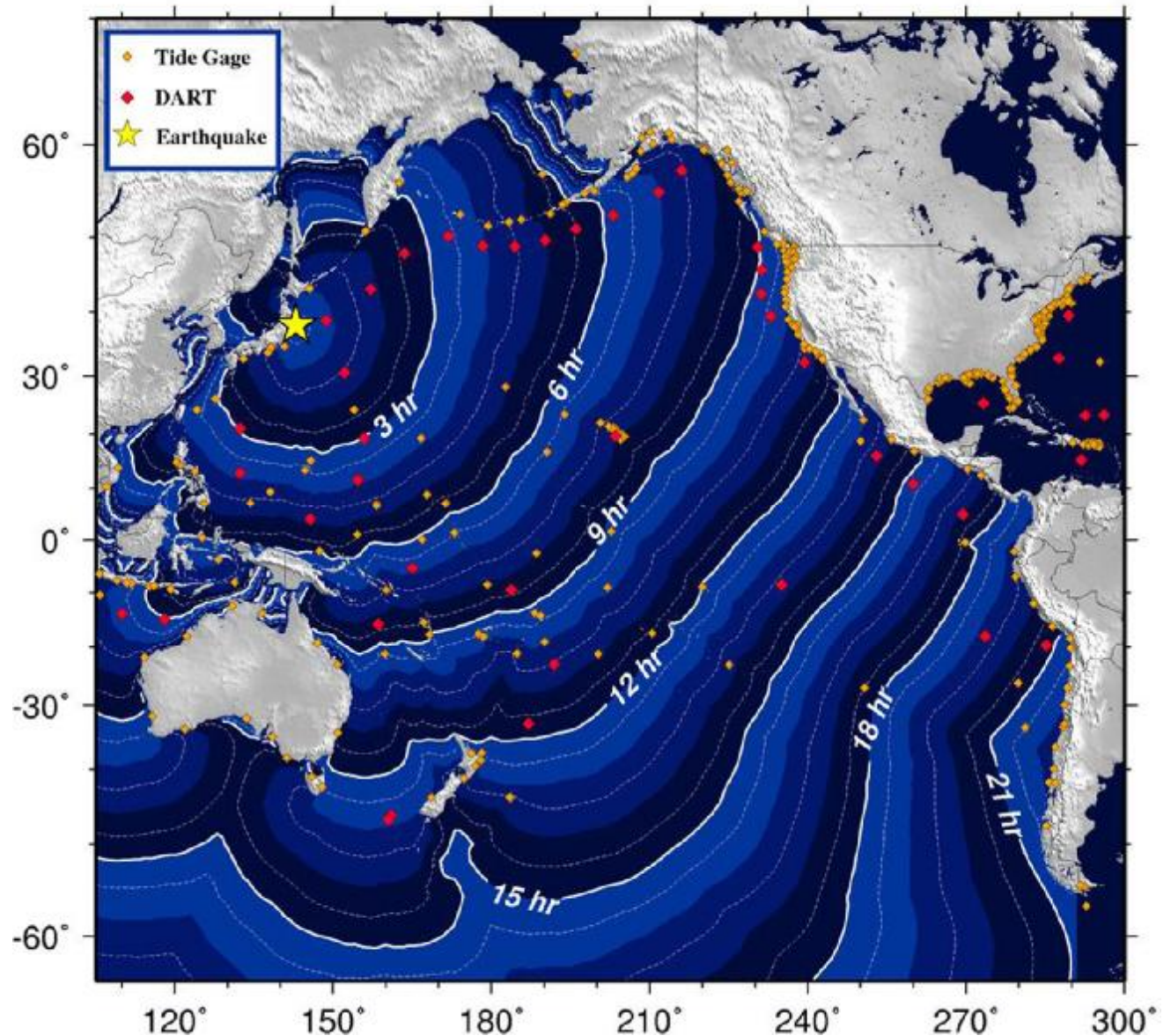
Magnitude 8.9 NEAR THE EAST COAST OF HONSHU, JAPAN

Friday, March 11, 2011 at 05:46:23 UTC

Projected travel times for the arrival of the tsunami waves across the Pacific.

Nearby the earthquake there are only minutes to evacuate. However, in many other regions there is advance warning.

A tsunami map shows projected travel times for the Pacific Ocean. This map indicates forecasted times only, not that a wave traveling those distances has actually been observed.. NOAA

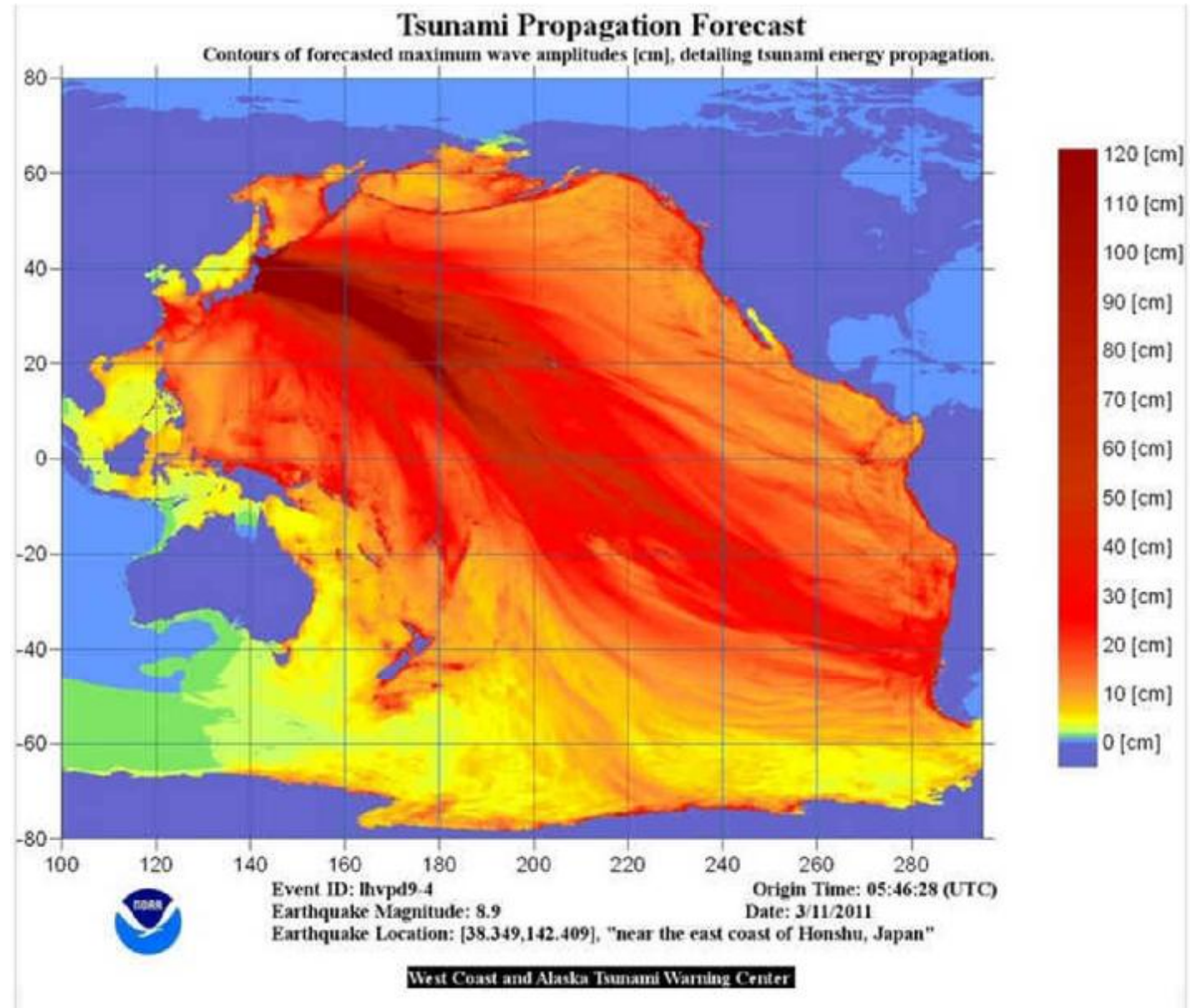


Magnitude 8.9 NEAR THE EAST COAST OF HONSHU, JAPAN

Friday, March 11, 2011 at 05:46:23 UTC

This tsunami propagation forecast model shows the forecast maximum tsunami wave height (in cm). Ocean floor bathymetry affects the wave height because a tsunami moves the seawater all the way to the floor of the ocean.

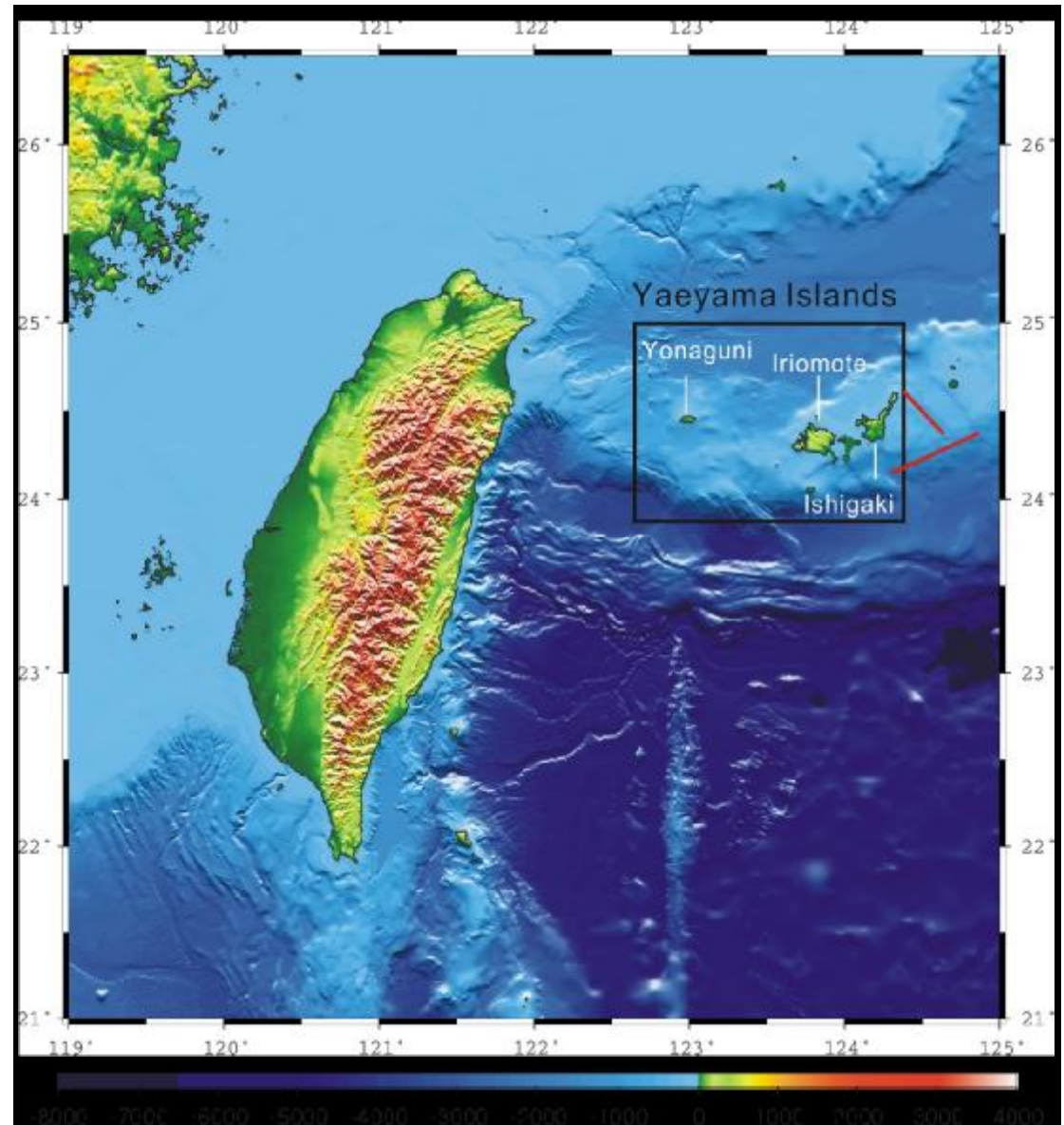
This led to a Pacific wide tsunami warning being issued.

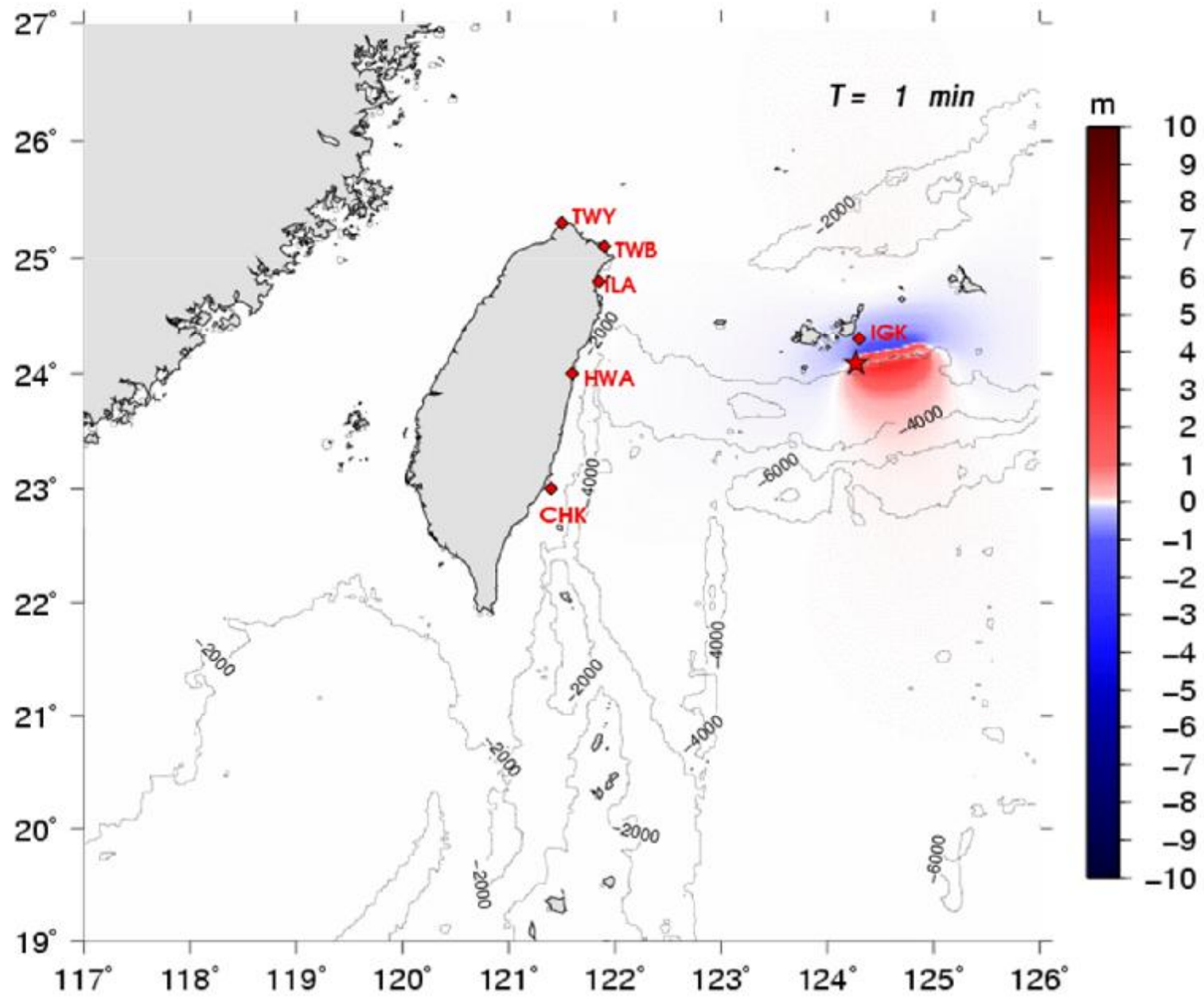


Simulation of the 1771 Ishigaki Tsunami

(Nakamura, 2006)

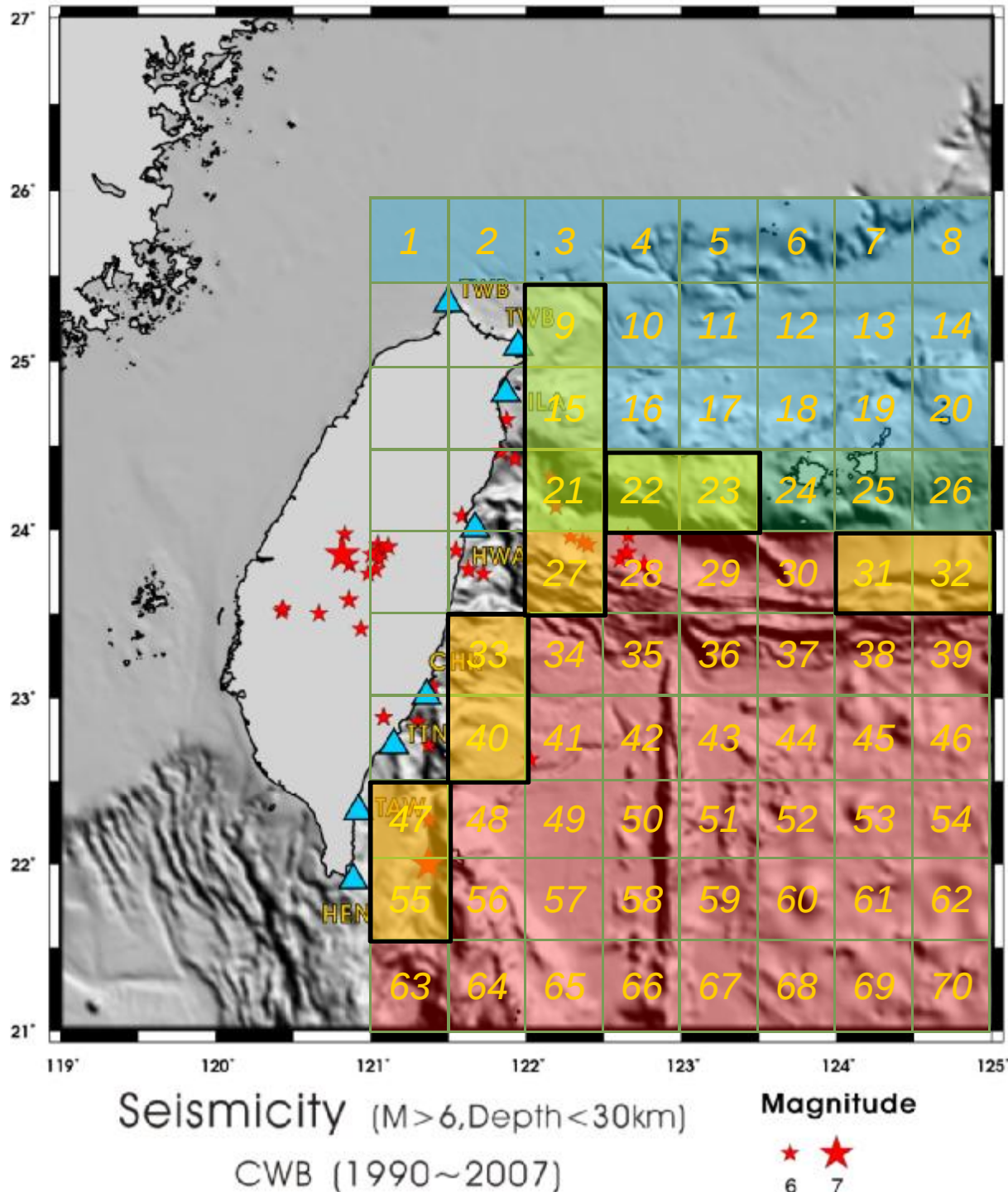
Source parameter	South	East
Mw	7.8	7.6
Φ (strike)	80°	135°
δ (dip)	70 °	70 °
λ (rake)	90 °	270 °
Dip-slip	8m	8m
Strike-slip	0km	0km
Fault depth	0m	0m
L (fault length)	66km	50km
W (fault width)	33km	25km
The top edge of the fault	124.27°E, 24.09°N	124.38°E, 24.63°N



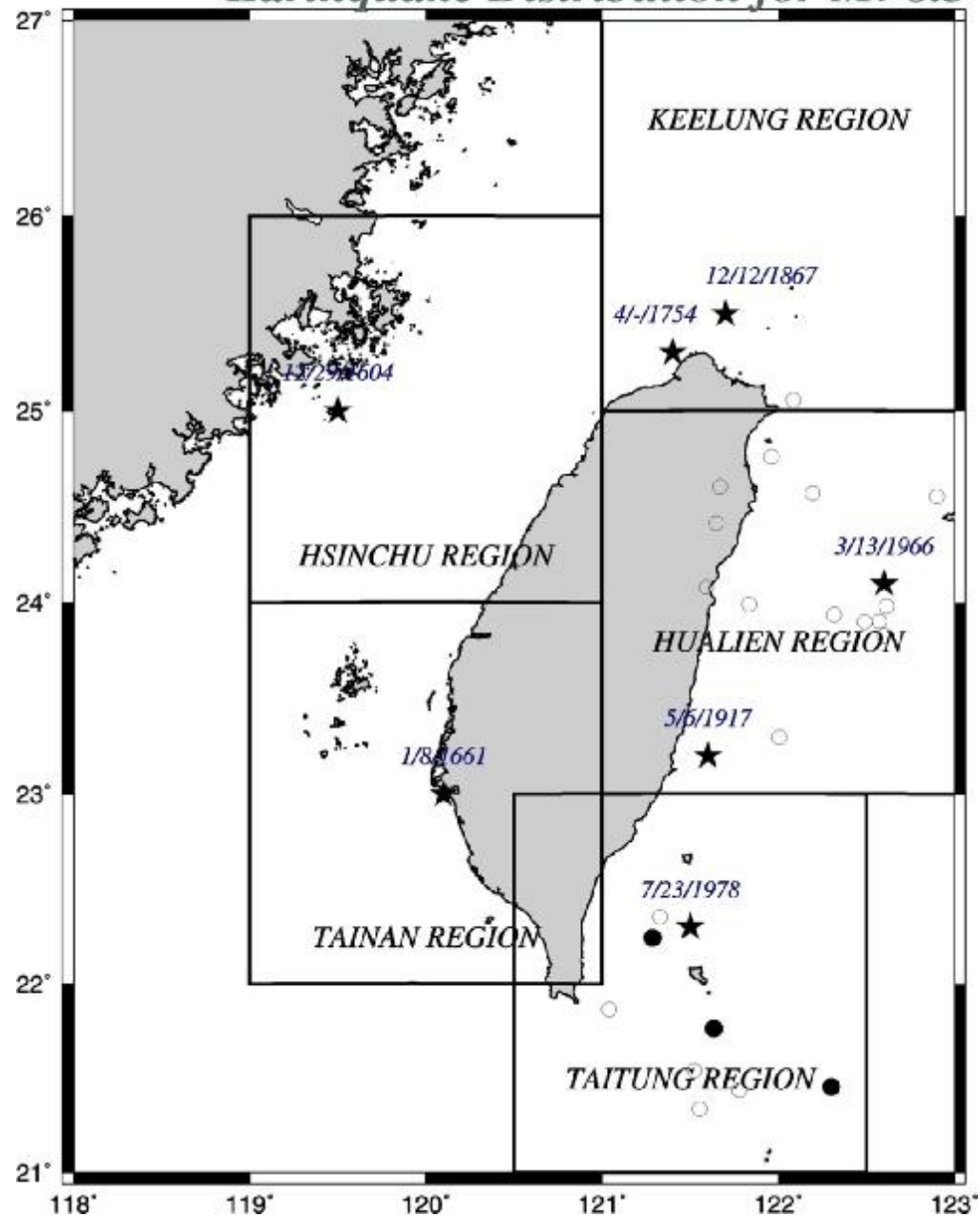


建立海嘯預警系統

- p Tsunami Wave
Propagation Effect: from
Yonaguni, Gagua Ridge,
Ludao, Lanyu, Ryuku Arc
- p Tsunami Potential Area
 - Ryuku Arc
 - Near Coast Events
- p Average velocity
 - Shallow Sea : 8.1 km/min
 - Ryuku Arc : 10.2 km/min
 - Deep water : 13.9 km/min



Earthquake Distribution for $M > 6.5$

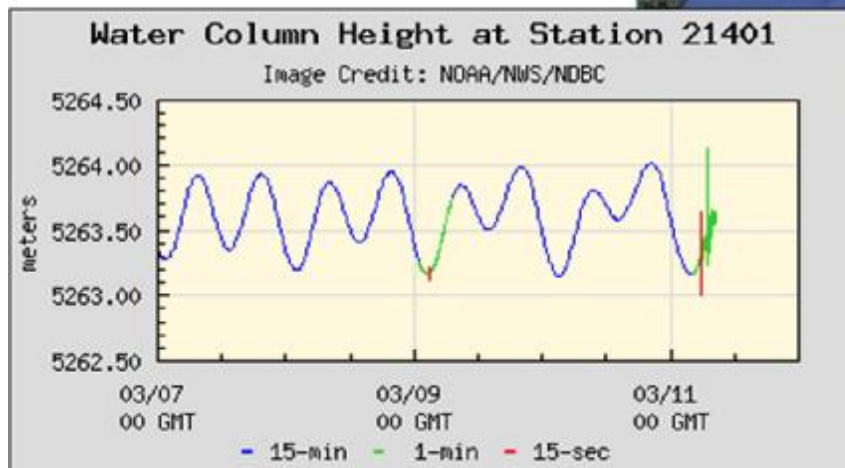
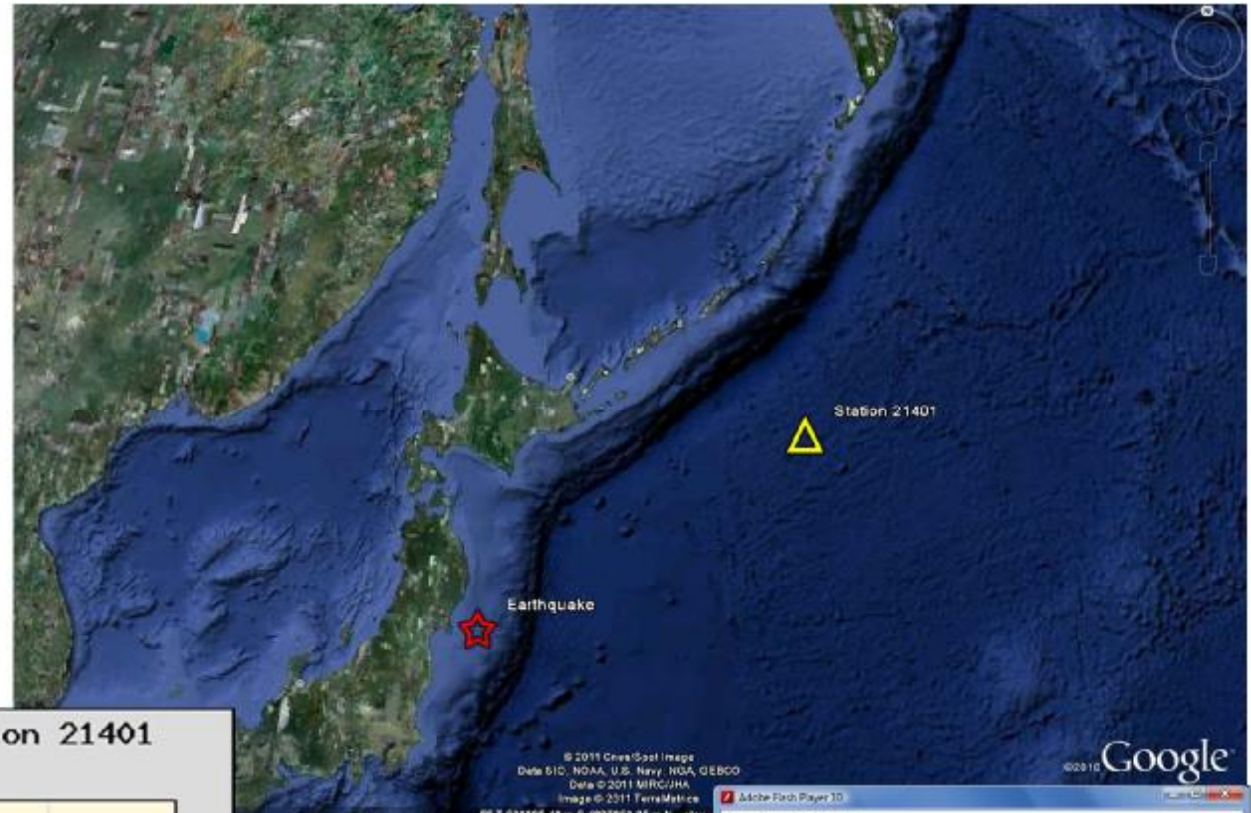


(Ma and Lee, 1995)

Magnitude 8.9 NEAR THE EAST COAST OF HONSHU, JAPAN

Friday, March 11, 2011 at 05:46:23 UTC

Shallow great earthquakes in subduction zones often cause tsunamis when they offset the ocean floor. This offset generates tsunami waves. This earthquake did produce a tsunami, which was measured on a nearby buoy and triggered the warning system.



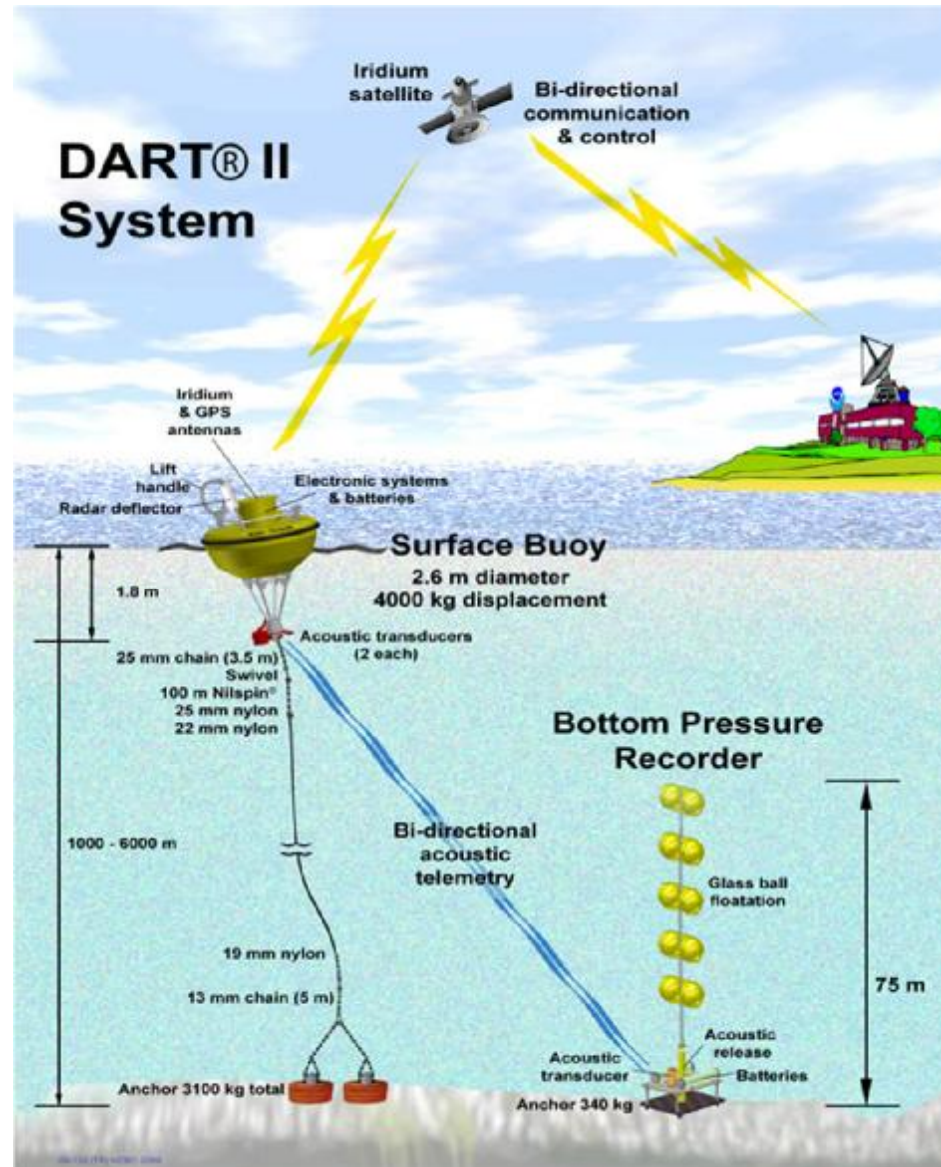
The water column height change that triggered the system.

Flash animation of how the DART system detects ocean waves



Magnitude 8.9 NEAR THE EAST COAST OF HONSHU, JAPAN

Friday, March 11, 2011 at 05:46:23 UTC



The DART II® system consists of a seafloor bottom pressure recording (BPR) system capable of detecting tsunamis as small as 1 cm, and a moored surface buoy for real-time communications.

DART II has two-way communications between the BPR and the Tsunami Warning Center (TWC) using the Iridium commercial satellite communications system. The two-way communications allow the TWCs to set stations in event mode in anticipation of possible tsunamis or retrieve the high-resolution (15-s intervals) data in one-hour blocks for detailed analysis.

DART II systems transmit standard mode data, containing twenty-four estimated sea-level height observations at 15-minute intervals, once every six hours.

台灣代表性歷史地震

時間	地點	備註
1624	台南地區	最早的文獻紀錄
1694	台北地區	形成康熙台北湖
1722	鳳山地區	鯉魚山泥火山爆發
1848	雲嘉彰化	死1030 臺史傷亡最重的
1892	全台	台灣歷史中最大地震

地震歌

有序

林占梅

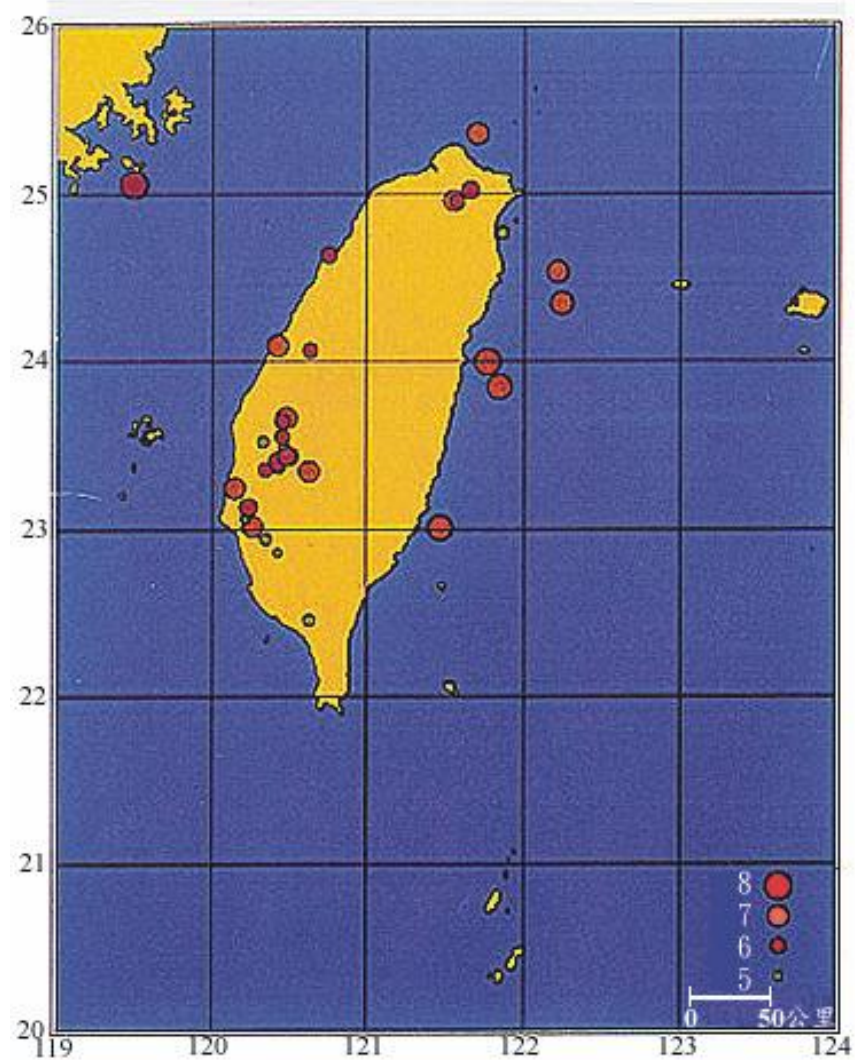
道光戊申仲冬，台地大震；吾淡幸全。而嘉、彰一帶城屋傾圮，人畜喪斃，至折肢破額者又不可勝計矣。傷心慘目，殊難名狀。今歲暮春，復大震二次。驚悼之餘，乃成七古一篇，歌以當哭。時三月初八日未刻也。

天朗氣清日亭午，閒吟散步廊廡
耳根彷彿隱雷鳴，又似波濤風激怒
濤聲乍過心猶疑，忽詫棟樑能動移
頃刻金甌相傾碎，霎時身體若籠篩
廢馬嘶蹶犬狂吠，智者猝然亦愚昧
悲風慘慘日無光，霎爾晴空成晝晦

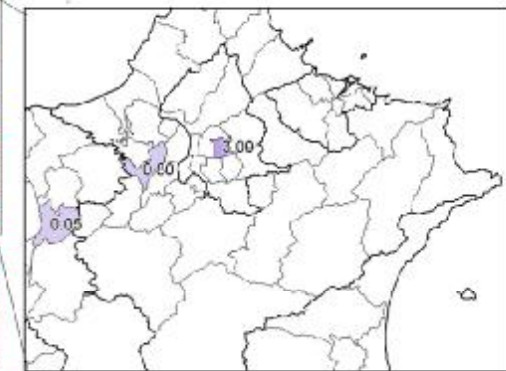
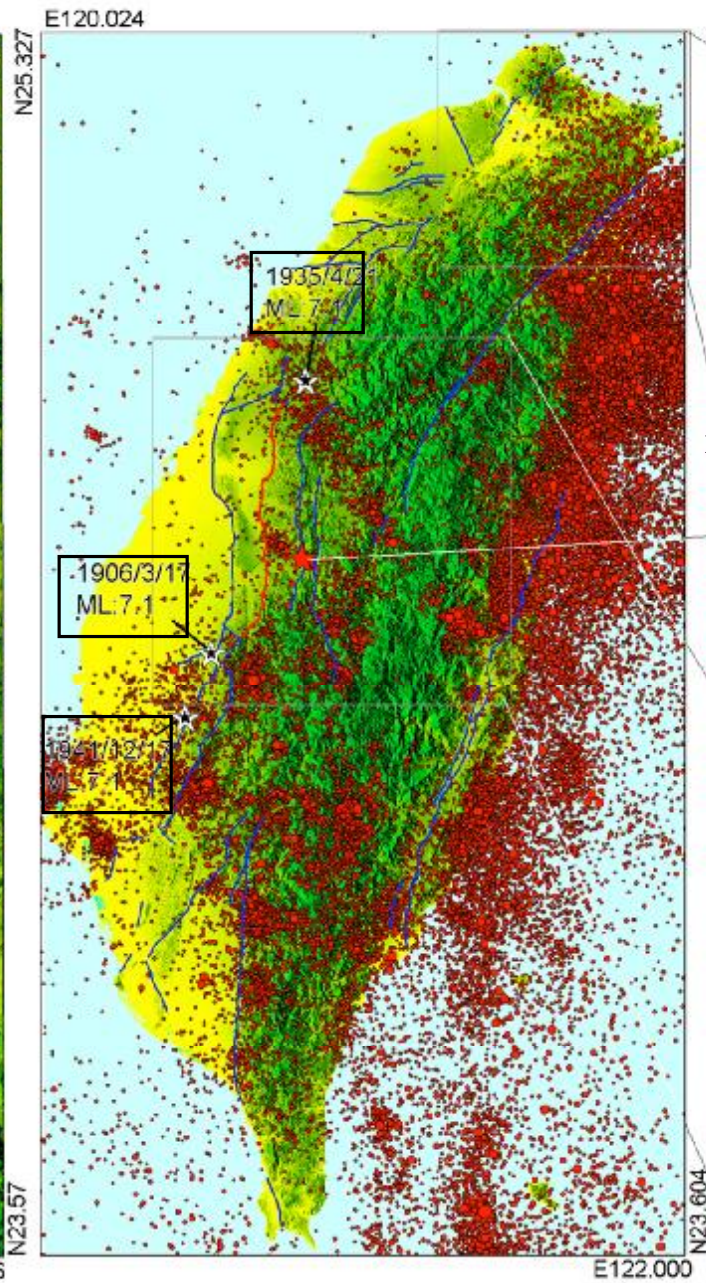
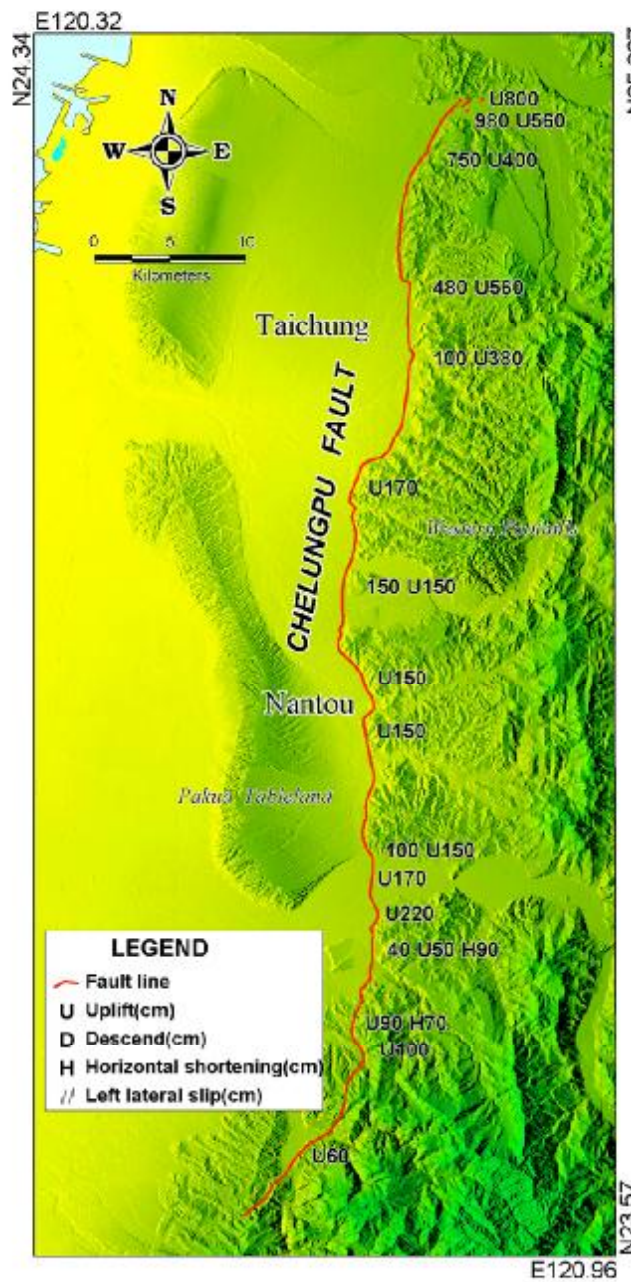
天明明氣清爽，日頭直亭中晝
閒閒踱走廊散步，吟詩食庶饘（ㄊㄩˋㄊㄣˊㄨㄣˊ）
耳腔（ㄎㄨㄣˊ）底，若親像隱約有雷聾（ㄉㄨㄣˊ）
又俗若狂風激怒波濤
濤聲喧仔（ㄉㄨㄣˊ）響過，心肝猶徃懷疑
忽然驚訝，棟樑會震動移徙（ㄇㄨˊㄩˊ）
一目瞞，金屬品仰坭仔坭仔敲倒搥搥破
雄雄身軀像徃籠篩（ㄉㄨㄣˊ），搖動顛簸
馬欄裏馬咩咩亂亂踢，狗青狂吠
聰明人突然也變癡呆
風聲悲鳴悽悽慘慘，日頭暗淡無光
一時天空雖然晴朗，日時卻變成暝暗

795
七言古詩

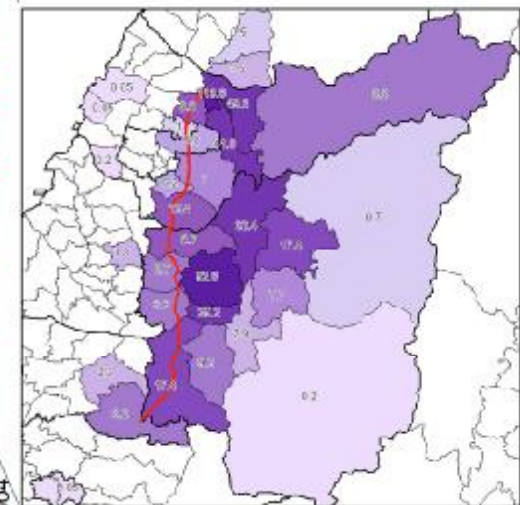
台詩二百首



儀器觀測前（1604-1897年）
定出的33個地震分布圖。



1999/9/21
Mw7.6



■ 1906 梅山地震

The 1906 Meishan Earthquake

06:43 AM on March 17, 1906

1,258 persons were killed

2,385 persons were injured

6,769 houses collapsed

23.550°N, 120.450°E, Dep=15 km,
 $M_L=6.7$, $M_w=6.9$ (Cheng et al., 2010)

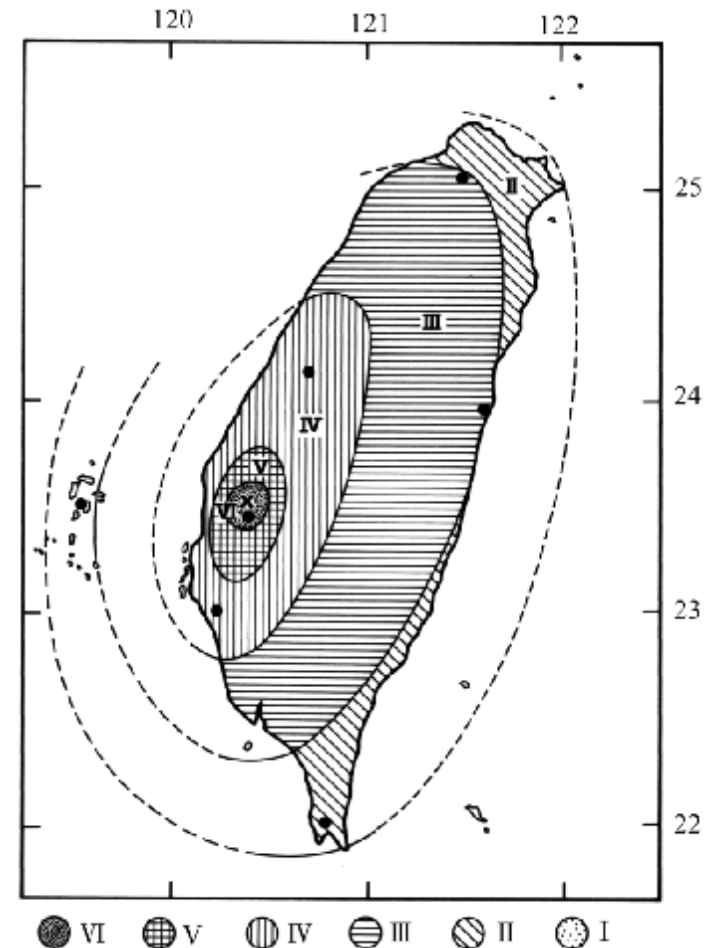
$M_s=6.8$ (Abe, 1981, 1983)

$M_H=7.1$ (Hsu, 1980, 1989)

$M_s=7.0$ (Lee et al., 1976)

$M=7.1$ (Bath & Duda, 1979)

The Meishan Fault (25 km)





The Meishan Fault (25 km)

Release woman foot

551 men and 700 women dead, 1,099 men and 1,334 women injured, the ration of dead and injured men vs. women is 44:56

Raised public concern Foot binding was blamed



■ 1935 新竹台中地震

The 1935 Hsinchu-Taichung Earthquake

06:02 AM on April, 21, 1935

3,279 persons were killed

12,119 persons were injured

17,927 houses collapsed

23.350°N, 120.817°E, Dep=5 km,

$M_L=6.9$, $M_w=7.2$ (Cheng et al., 2010)

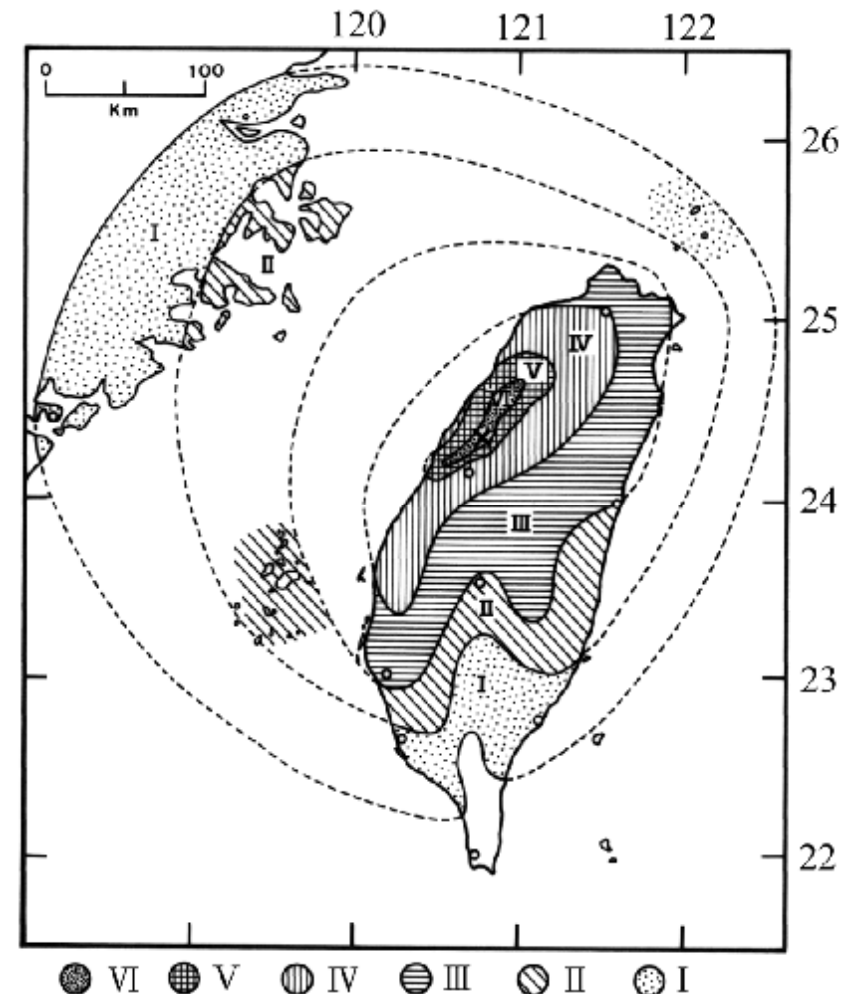
$M_s=7.1$ (Abe, 1981, 1983)

$M_H=7.1$ (Hsu, 1980, 1989)

$M_s=7.1$ (Lee et al., 1976)

$M=7.1$ (Bath & Duda, 1979)

$M=7.1$ (Gutenberg and Richter, 1954)





新竹州峨眉庄峨眉(新竹縣峨眉鄉)在地震後成為一片廢墟，峨眉總戶數為167戶，全倒167戶，全倒率為100%。



台中州豐原郡內埔庄(台中縣后里鄉)屯子腳之慘狀，屯子腳總戶數735戶，全倒509戶，半倒46戶，破損128戶，住家全倒半倒與破損率達93%，總人口數4,578人，死亡440人、重傷210人、輕傷1,081人，死傷率達37.5%。

屯仔腳地震斷層



台中州內埔庄(后里鄉)舊社西方約1公里處的屯仔腳地震斷層露頭，製糖會社的鐵軌(原為直線)扭曲變形，北側地塊下沉45公分並向東移動140公分。



內埔公學校的屯仔腳地震斷層露頭，水平錯動15公分，垂直落差10公分。



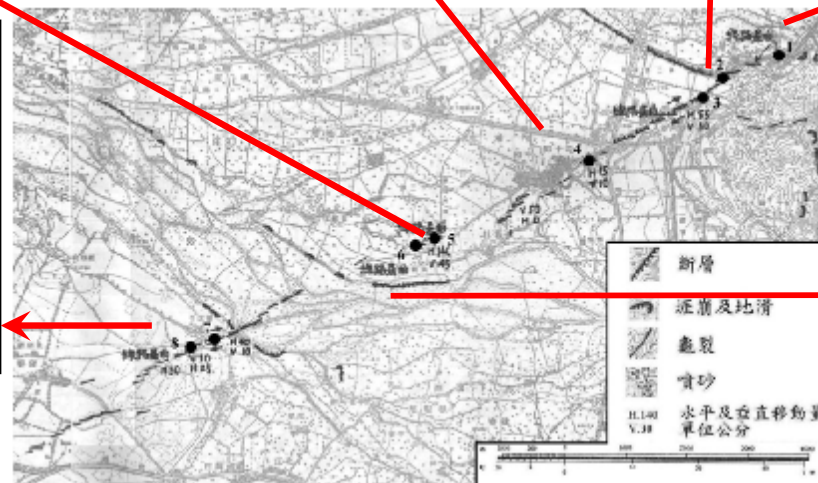
后里埤的破壞，導致3,300甲稻田缺水灌溉，破裂處有明顯的水平錯位。



大安(泰安)火車站月台上之龜裂線

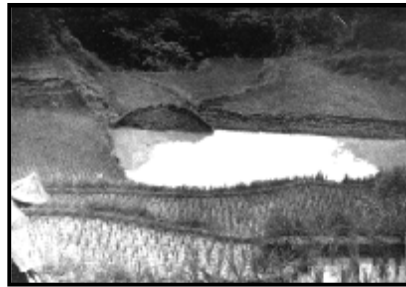


台中州新庄子西方道路之屯仔腳地震斷層露頭，道路被斷層切割成十多段，水平與垂直總錯位量約30公分，斷層二側的民宅全倒



左圖西方約200公尺三角子稻田中的斷層露頭，斷層走向N72oE，圖中符號"X"為地震前同一處的田埂，北側地塊下沉45公分並向東方移動120公分

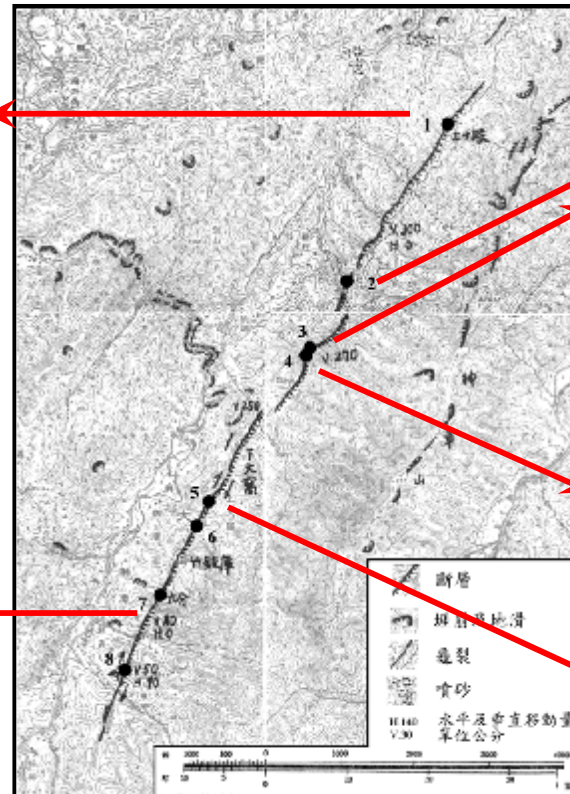
獅潭地震斷層



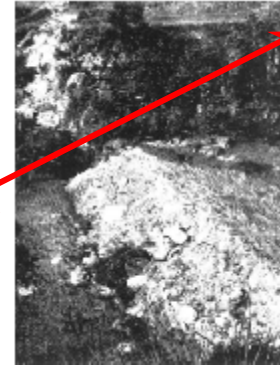
新竹州三灣庄(苗栗縣三灣鄉)上十股獅潭斷層露頭(向西攝)，斷層東側地塊陷落並造成小水池。



獅潭庄永興山地的獅潭地震斷層，斷層上民宅全倒



獅潭地震斷層與神桌山地震斷層分佈圖，底圖為陸地測量部發行之1/50,000地形圖，圖中手寫的阿拉伯數字為野外觀測的錯位量。單位為公分，V與H分別表示垂直向與水平向



紙湖東方1.5公里獅潭地震斷層，垂直落差3公尺



紙湖東方1.5公里之獅潭地震斷層垂直落差3公尺

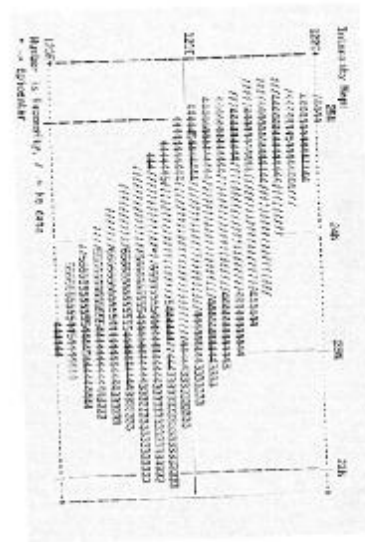
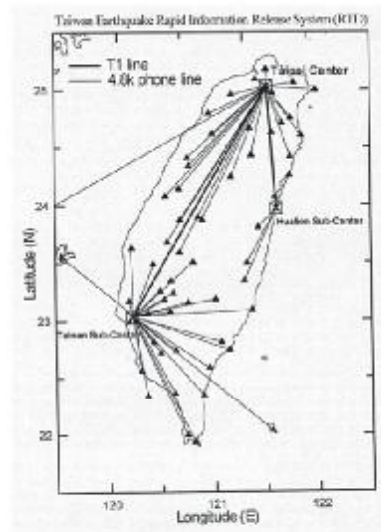


新竹州獅潭庄(苗栗縣獅潭鄉)上大窩之獅潭斷層西側隆起約1公尺，位於斷層上的民宅全倒



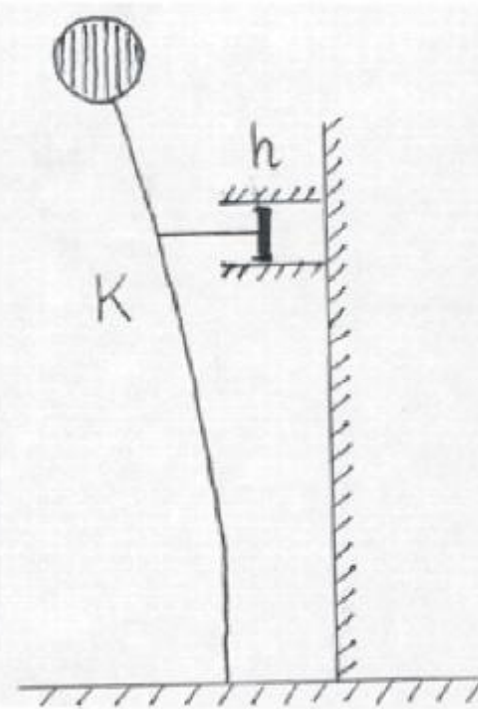
新竹州獅潭庄(苗栗縣獅潭鄉)神卓山溪谷之獅潭地震斷層露頭，東側地塊陷落約1.7公尺(地震前已有3-4公尺的落差)。

Taiwan Real-Time System (RTD) and Chi-Chi Earthquake
(Wu et al. 2000)

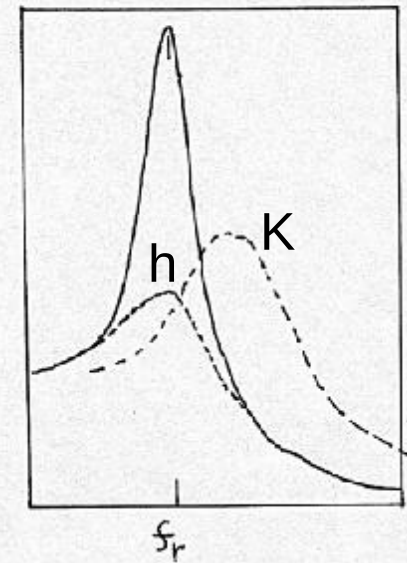


即時地震學、結構控制

Structural Control

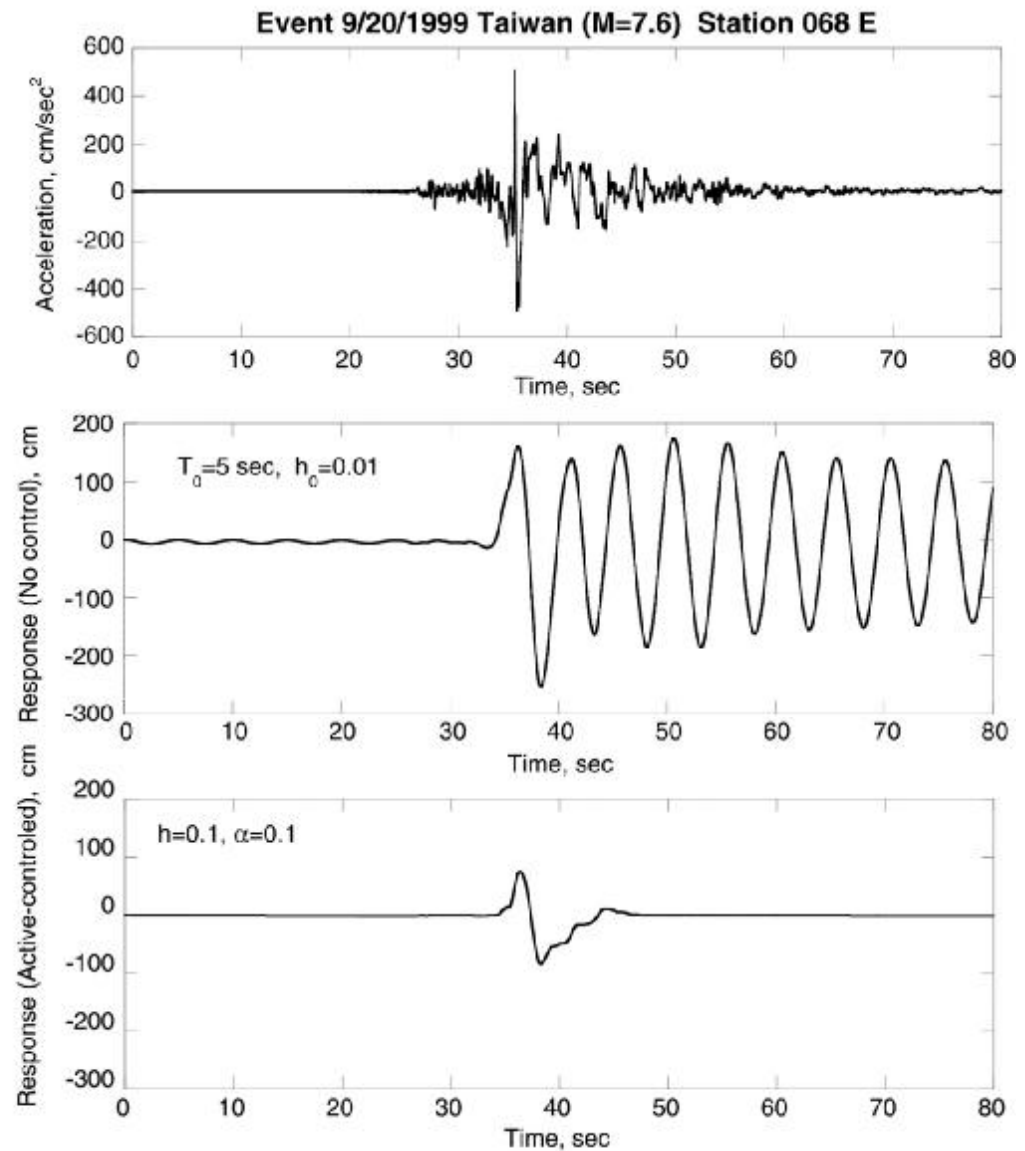


Resonance
—— uncontrolled
..... controlled

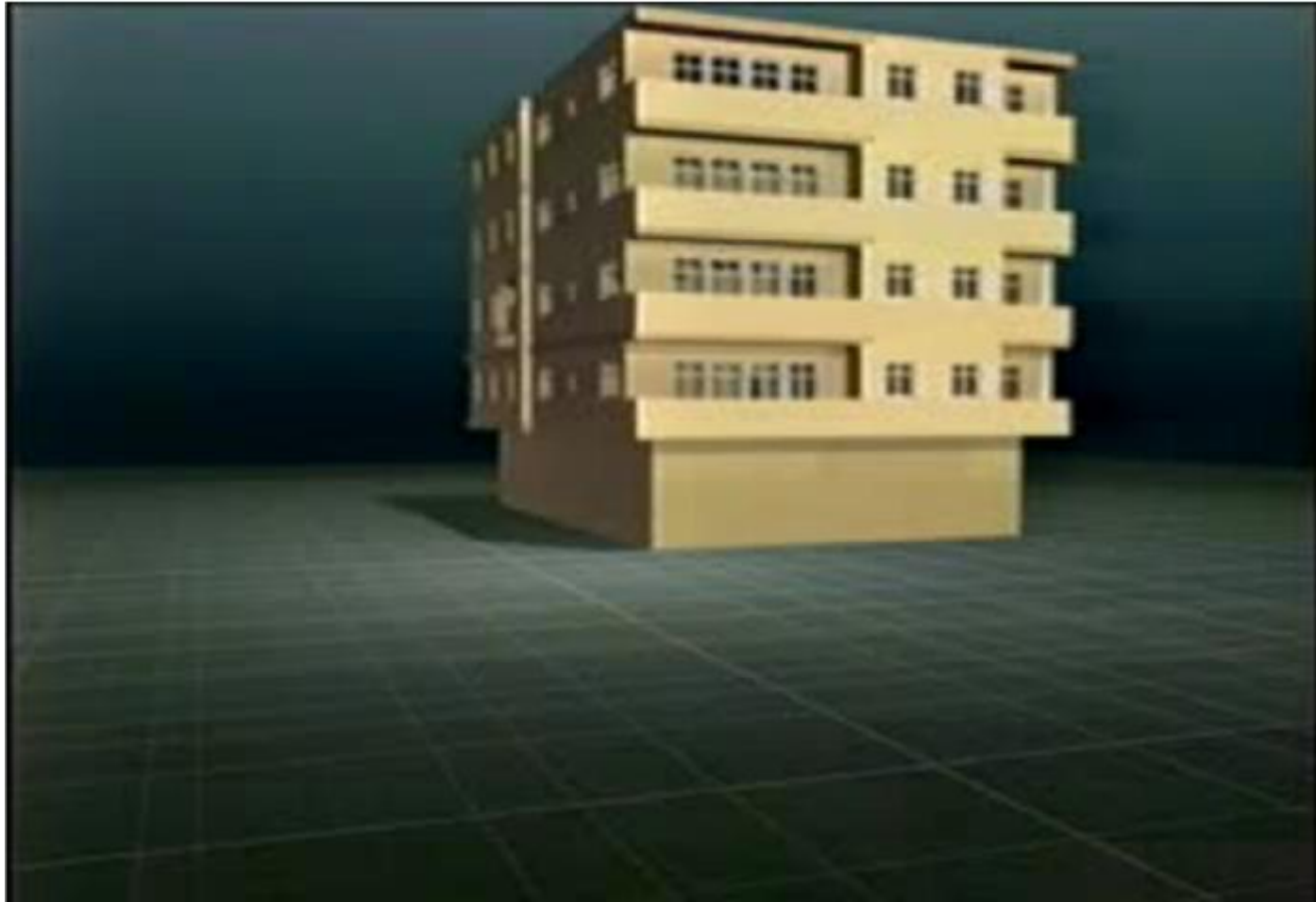


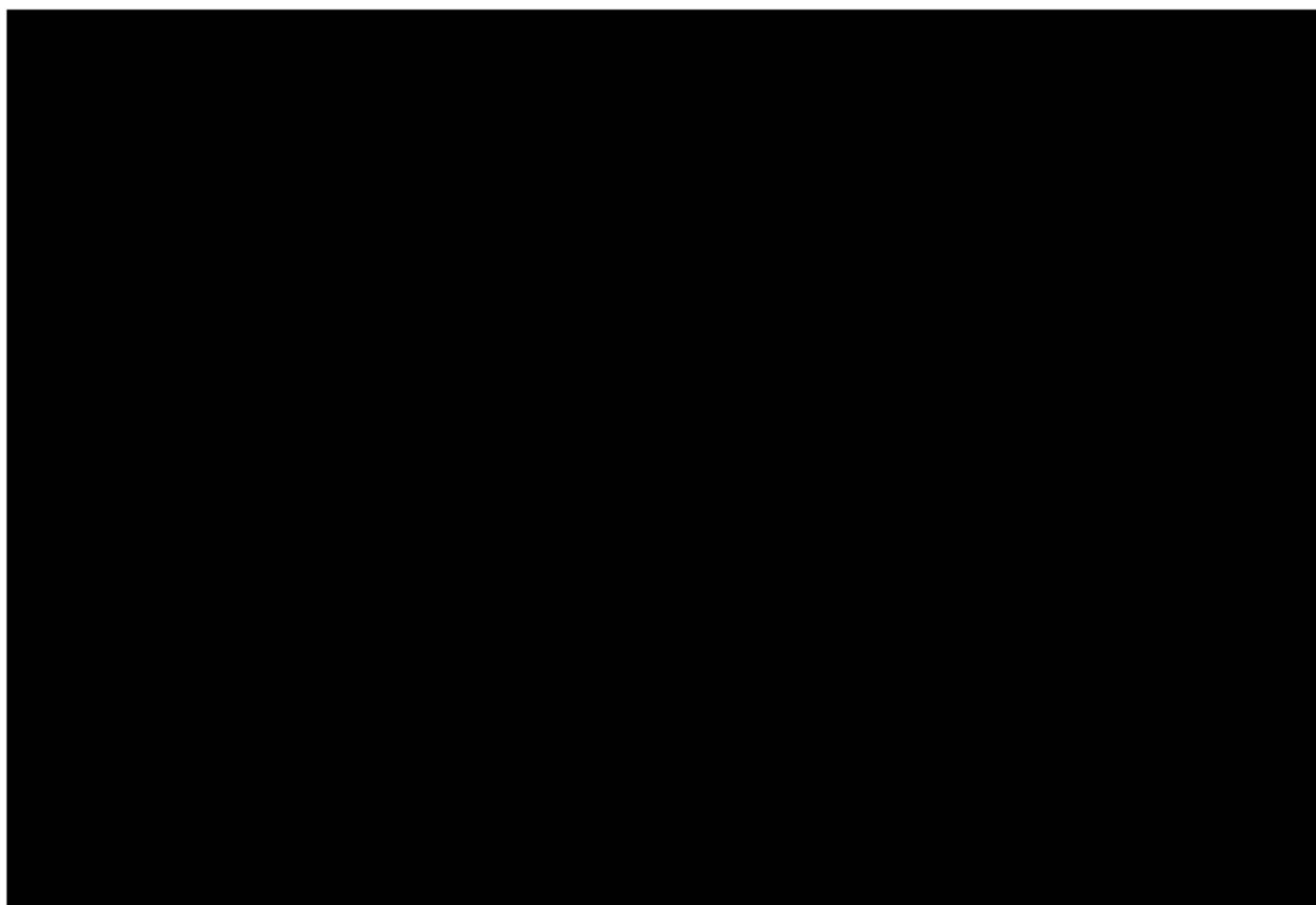
Numerical Simulation of Semi-Active Control

建築阻尼抗震



建築補強







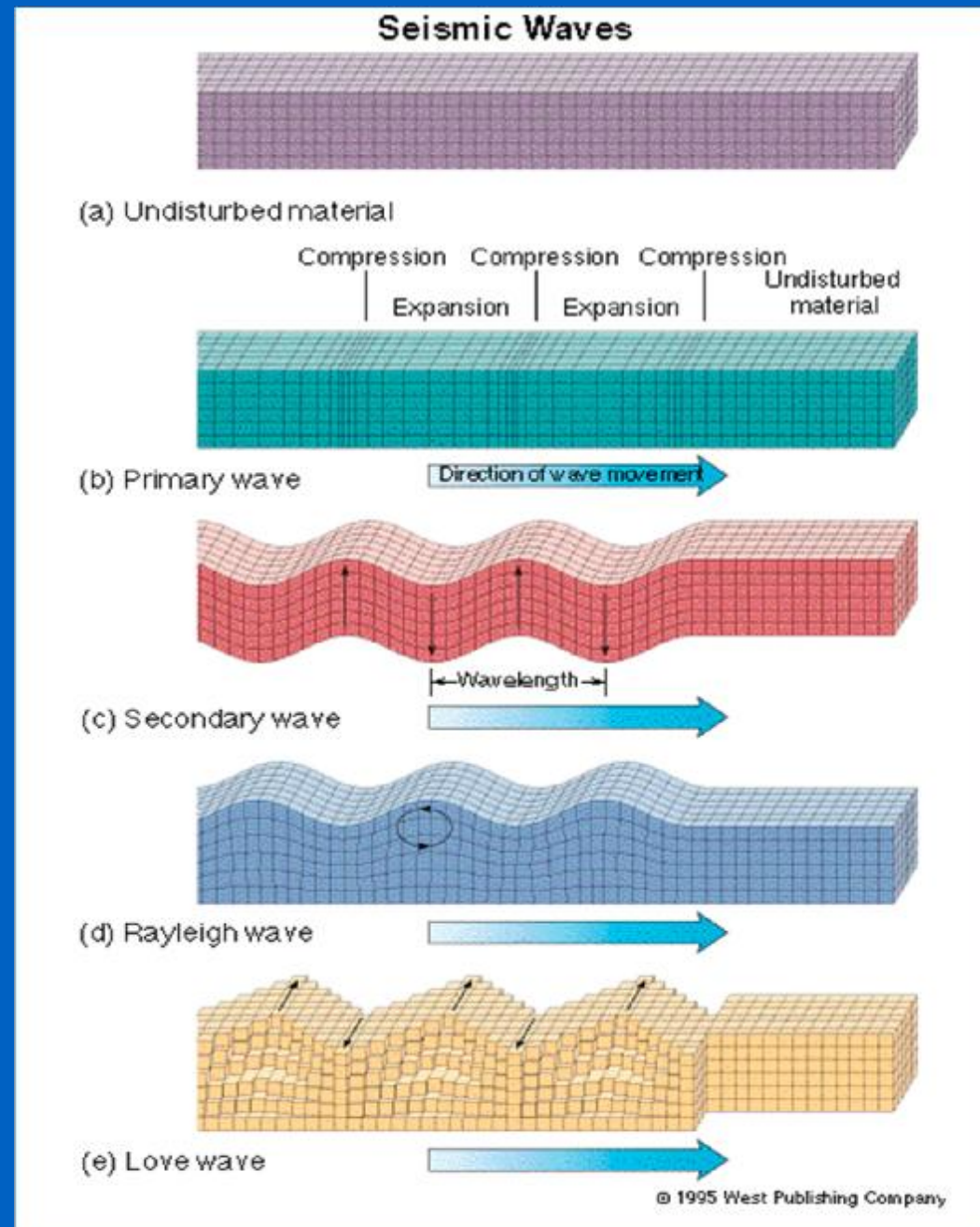
震度 分級	地動加速度 (cm/s^2 , Gal)	簡易圖示	人的感受	屋內情形	屋外情形
0 無感	0.8 以下		人無感覺。		
1 微震	0.8~2.5		人靜止時可感覺微小搖晃。		
2 輕震	2.5~8.0		大多數的人可感到搖晃，睡眠中的人有部分會醒來。	電燈等懸掛物有小搖晃。	靜止的汽車輕輕搖晃，類似卡車經過，但歷時很短。
3 弱震	8~25		幾乎所有的人都感覺搖晃，有的人會有恐懼感。	房屋震動，碗盤門窗發出聲音，懸掛物搖擺。	靜止的汽車明顯搖動，電線略有搖晃。
4 中震	25~80		有相當程度的恐懼感，部分的人會尋求躲避的地方，睡眠中的人幾乎都會驚醒。	房屋搖動甚烈，底座不穩物品傾倒，較重傢俱移動，可能有輕微災害。	汽車駕駛人略微有感，電線明顯搖晃，步行中的人也感到搖晃。
5 強震	80~250		大多數人會感到驚嚇恐慌。	部分牆壁產生裂痕，重傢俱可能翻倒。	汽車駕駛人明顯感覺地震，有些牌坊煙囪傾倒。

6	烈震	250~400		搖晃劇烈以致站立困難。	部分建築物受損，重傢俱翻倒，門窗扭曲變形。	汽車駕駛人開車困難，出現噴沙噴泥現象。
7	劇震	400 以上		搖晃劇烈以致無法依意志行動。	部分建築物受損嚴重或倒塌，幾乎所有傢俱都大幅移位或摔落地面。	山崩地裂，鐵軌彎曲，地下管線破壞。

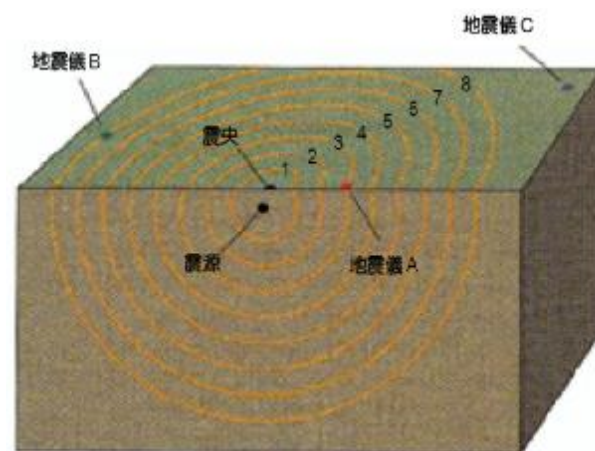
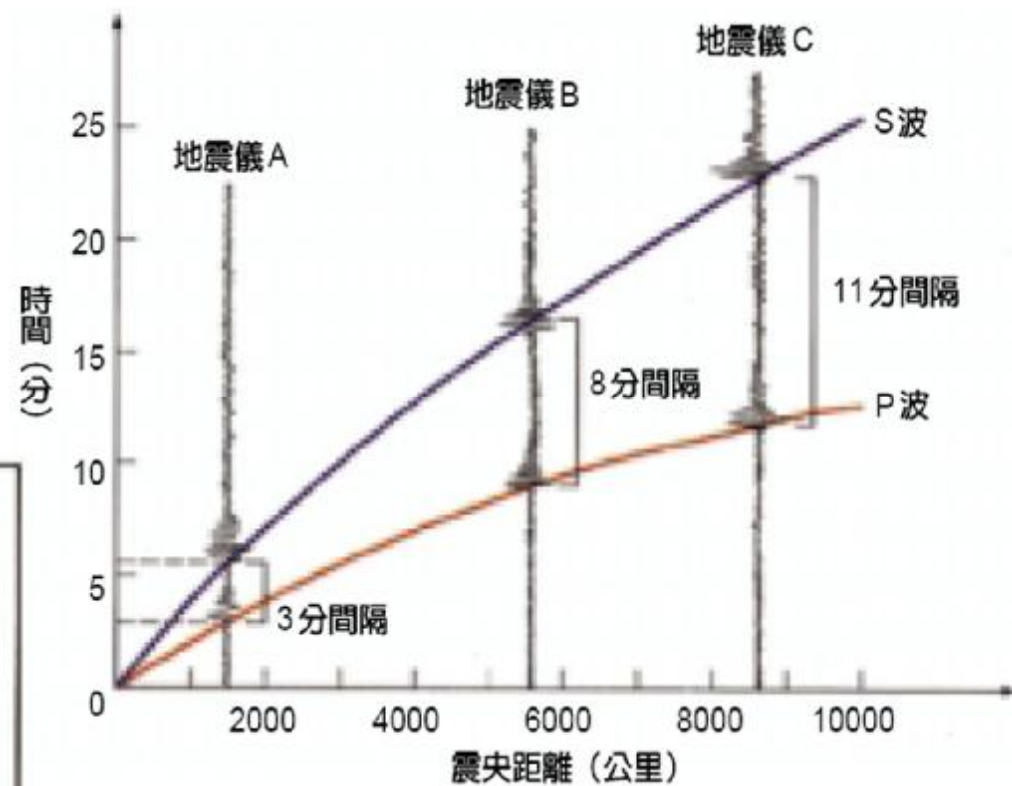
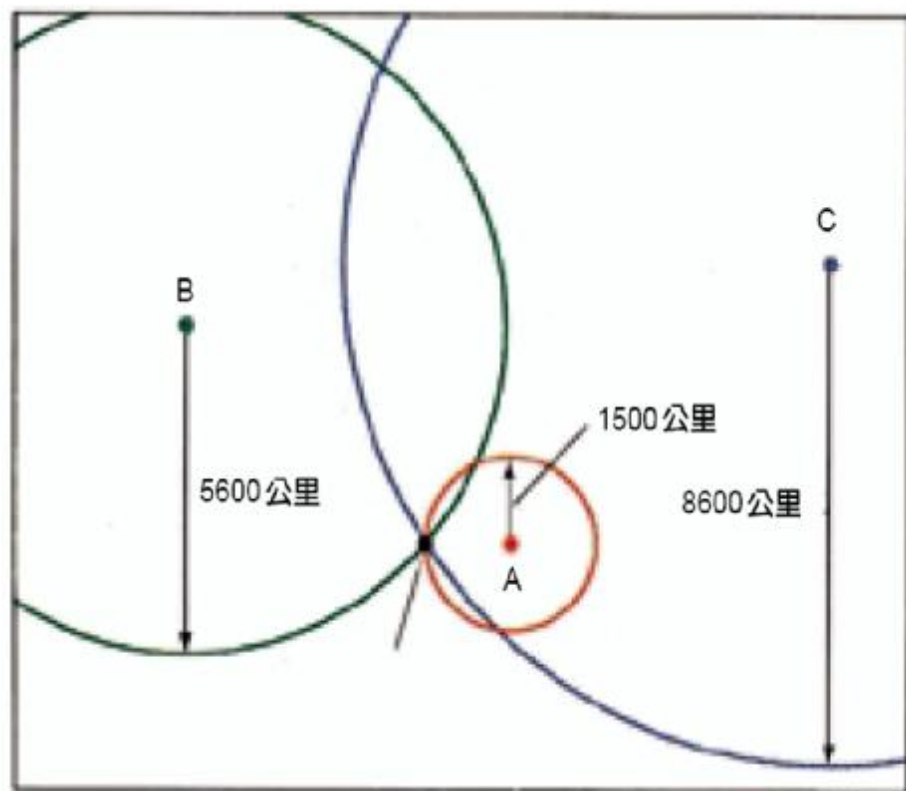
地震波 Seismic Waves

體波 Body Waves
P-wave
S-wave

表面波 Surface Waves
Rayleigh wave
Love Wave

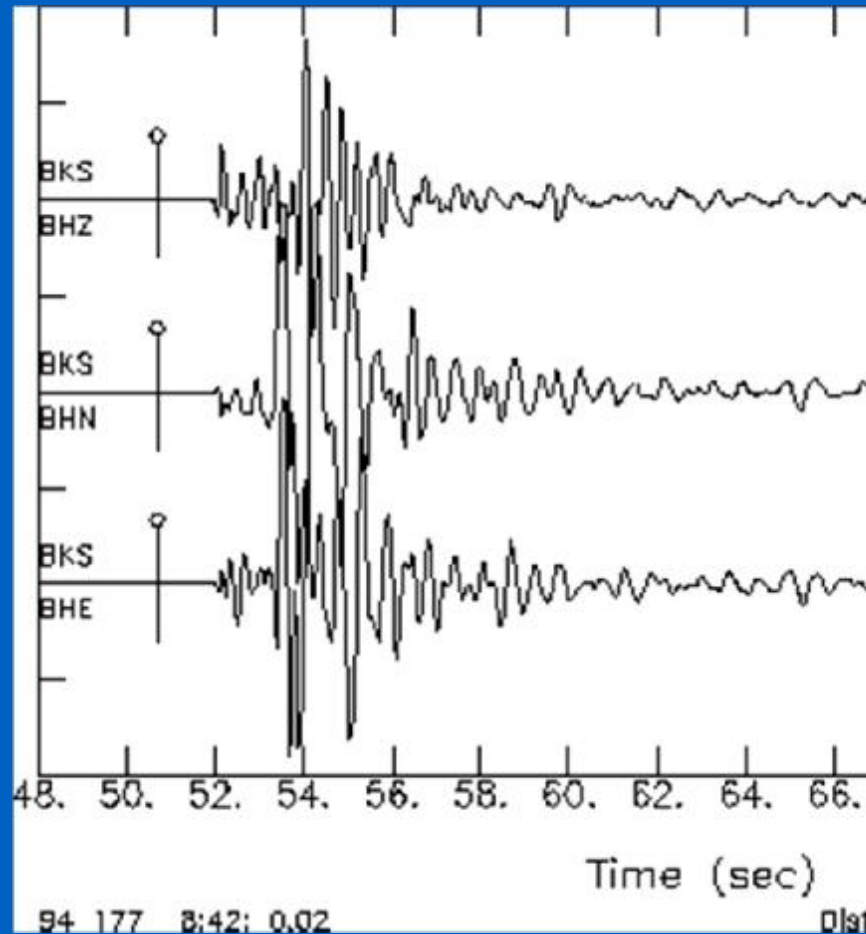


地震定位



Earthquake Magnitude

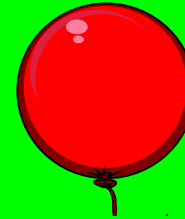
地震規模



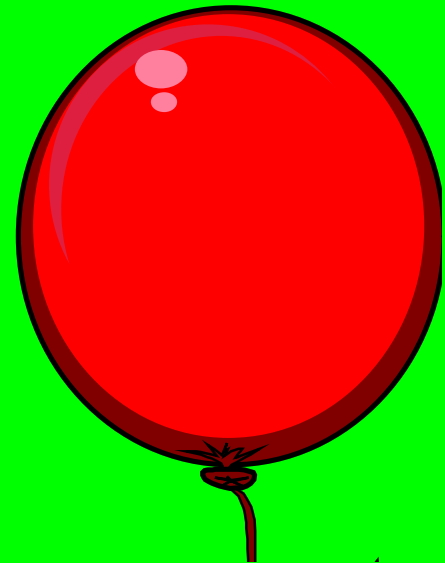
M5



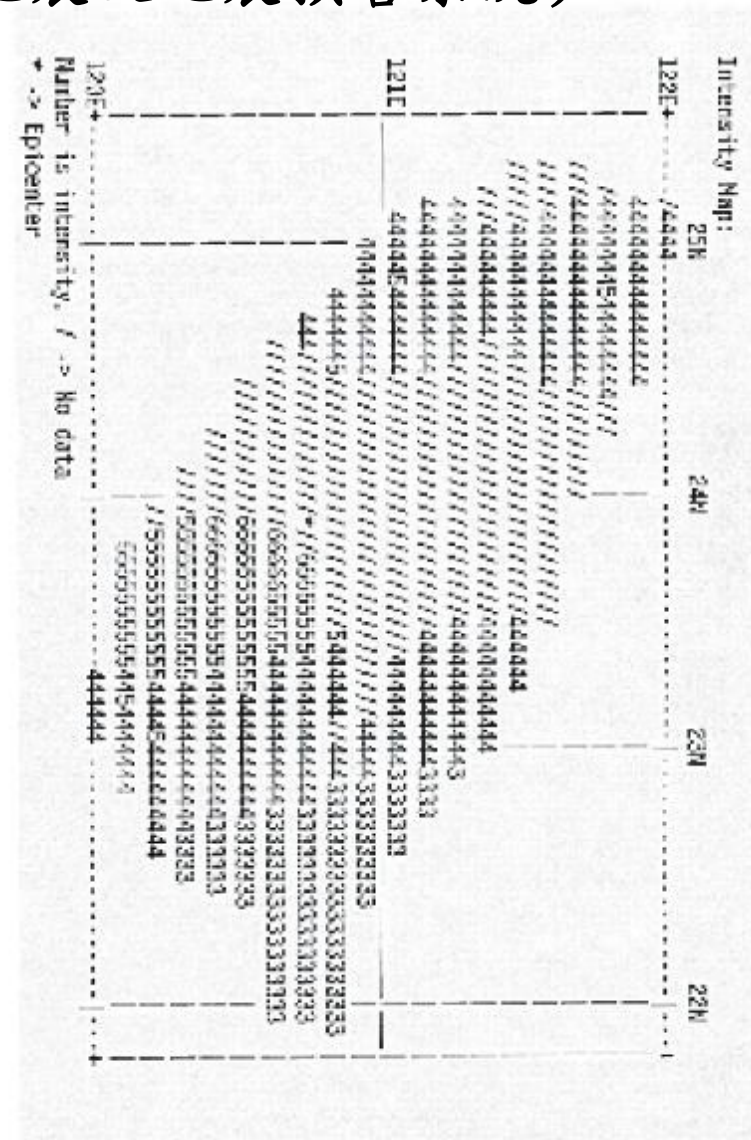
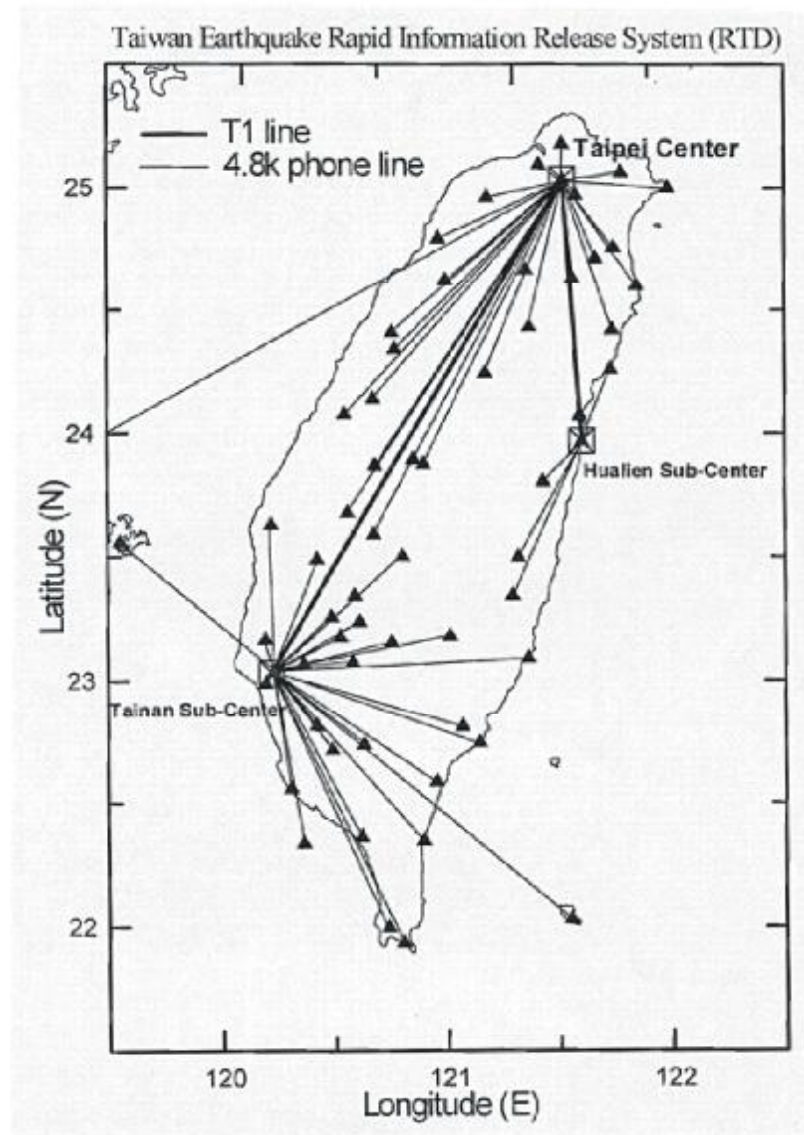
M6



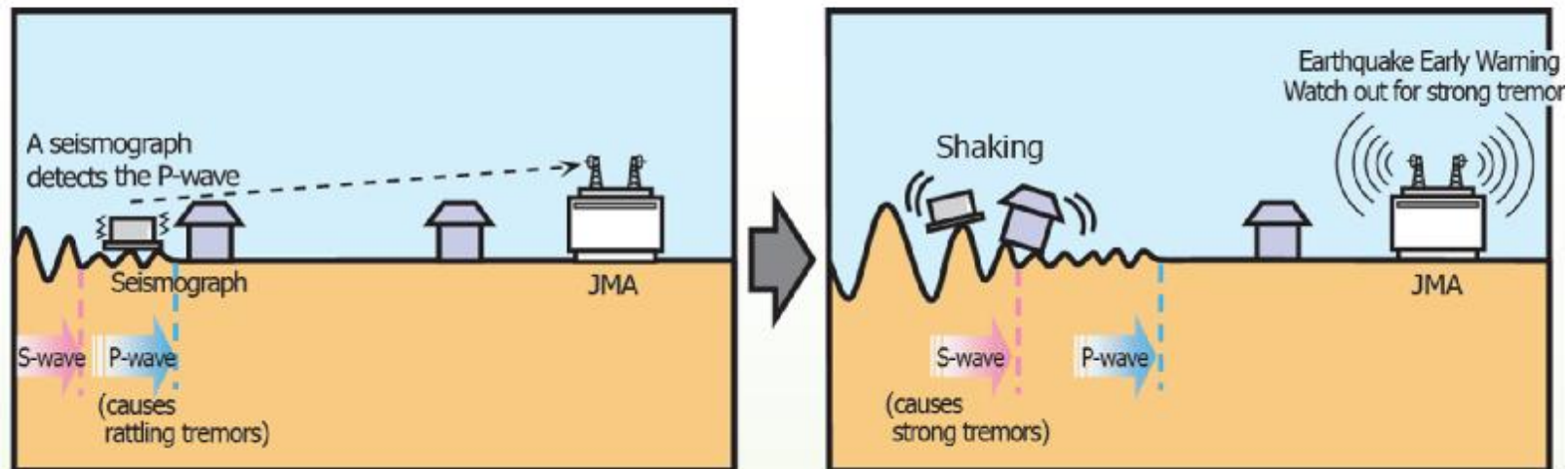
M7



Taiwan Real-Time System (RTD) and Chi-Chi Earthquake (Wu et al. 2000) (台灣及時地震及地震預警系統)

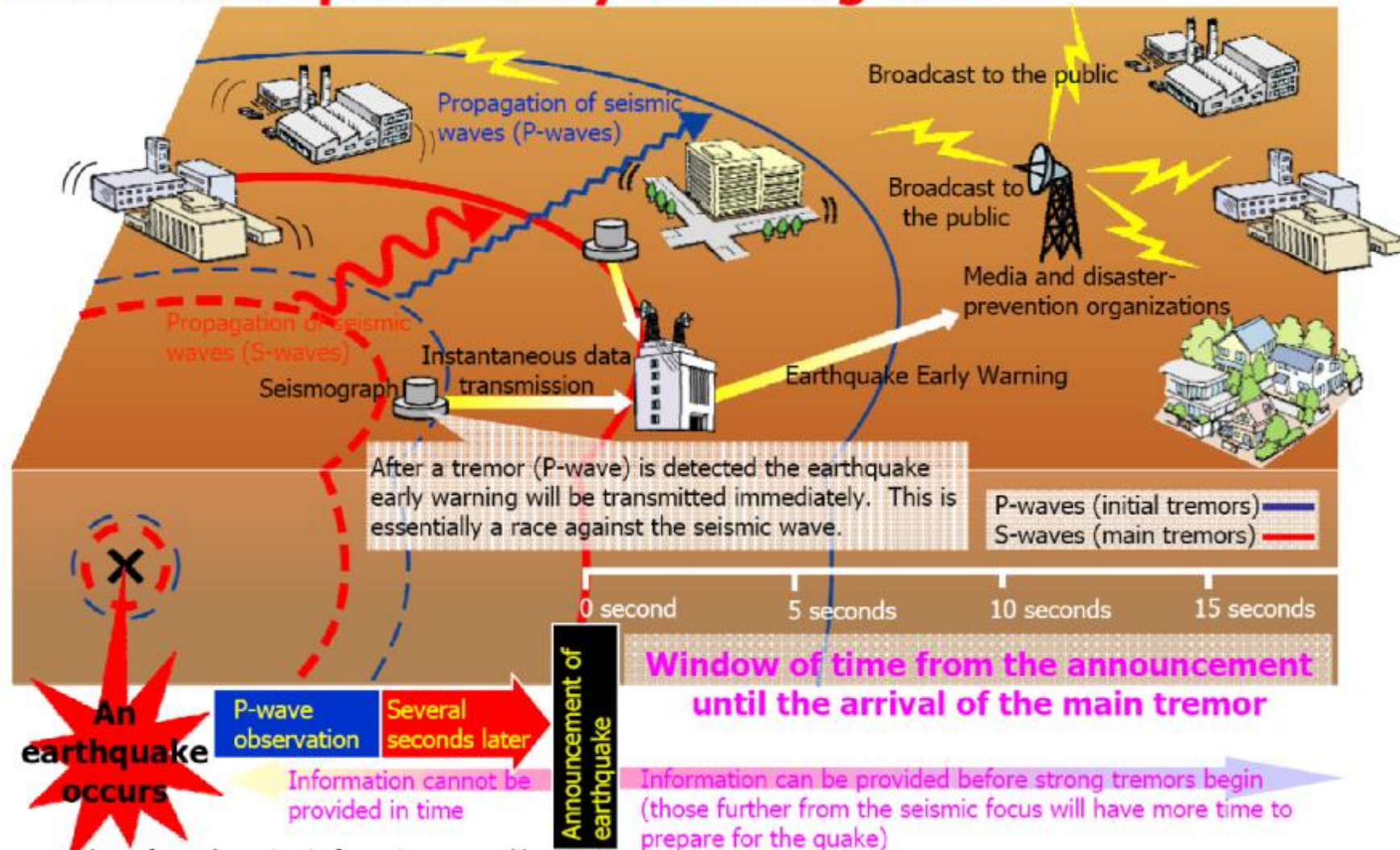


As of 1 October 2007, the Japan Meteorological Agency (JMA) will start the Earthquake Early Warning, a new service that advises of strong tremors before they arrive.



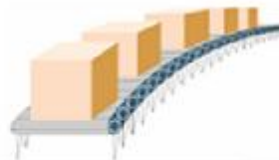
- The Earthquake Early Warning system automatically calculates the focus and magnitude of the earthquake and estimates the seismic intensity for each location by detecting the quake (i.e. the P-wave, or the preliminary tremor) near its focus. An Earthquake Early Warning is then given a matter of seconds (i.e. a few seconds to a few tens of seconds) before the arrival of strong tremors (i.e. the S-wave, or principal motion).
- Earthquake Early Warnings will be provided through various media outlets such as TV and radio.
- Please note that strong tremors may arrive at the same time as the Earthquake Early Warning in areas that are close to the focus of the earthquake.

How the Earthquake Early Warning Works





Controlling trains



Controlling factory lines
--> To mitigate damage



Controlling elevators
--> To prevent people from being trapped



Suspending work in progress
--> To avoid mistakes



Workers performing hazardous tasks
--> To secure safety



To prevent traffic accidents

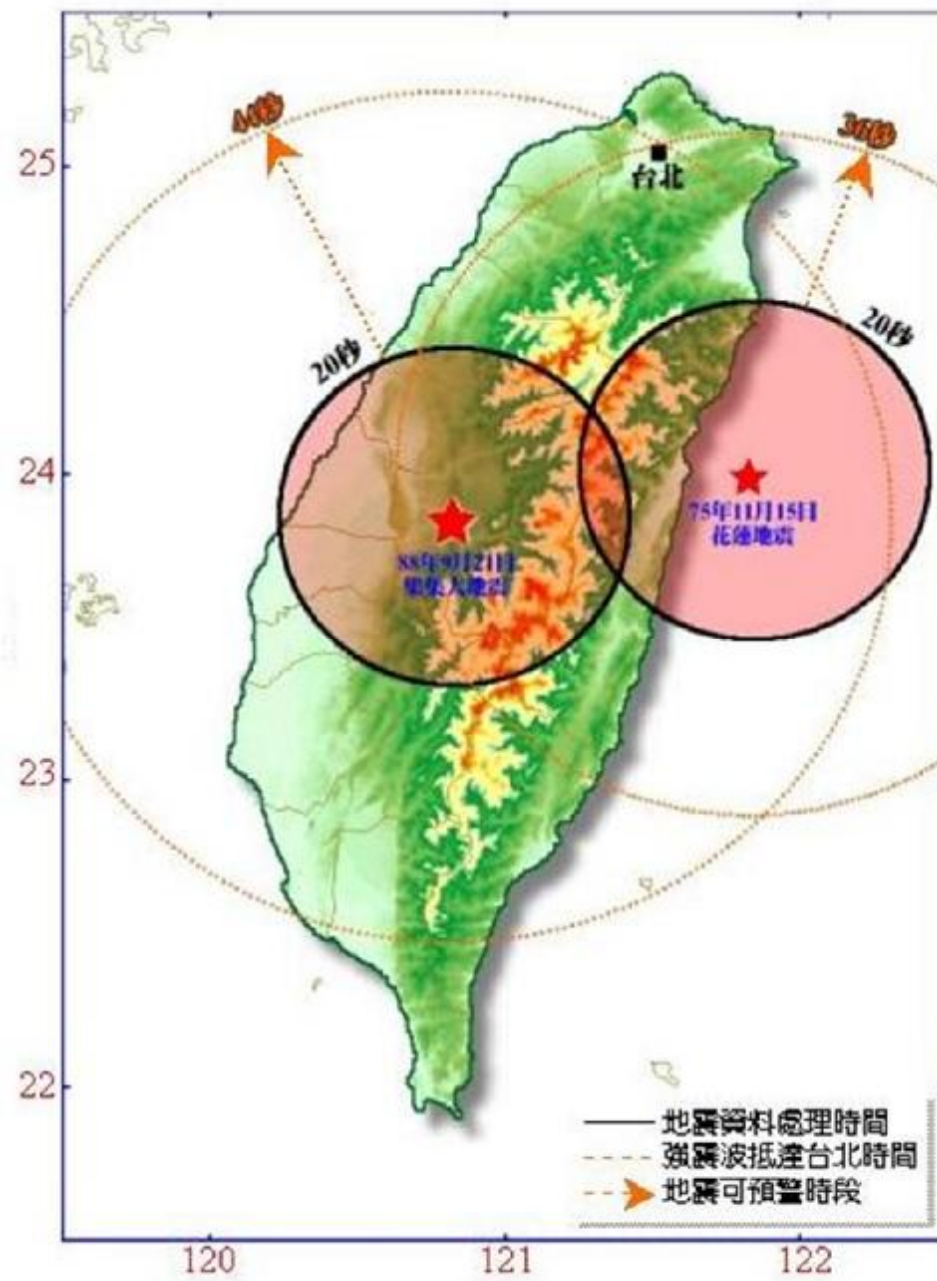


At home
--> To enable personal protection



Alerting schools and assembly halls
--> To guide evacuation



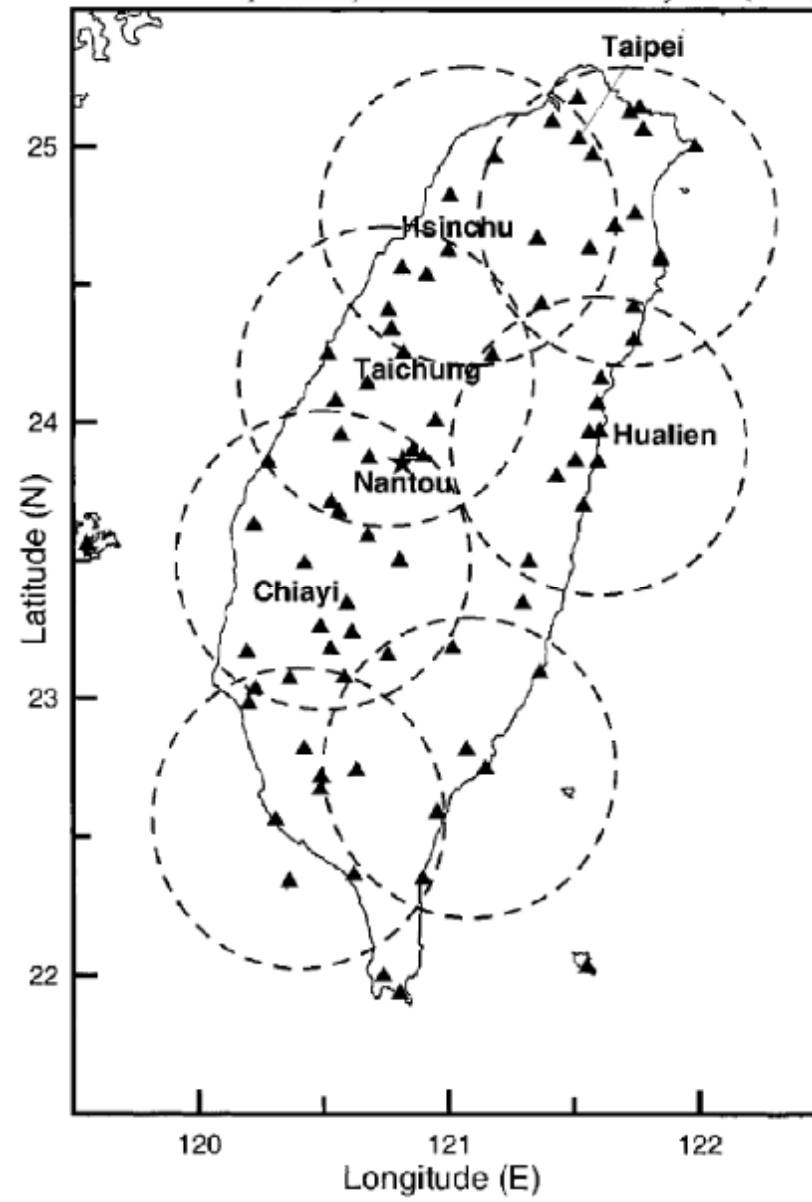


地震研究持續中

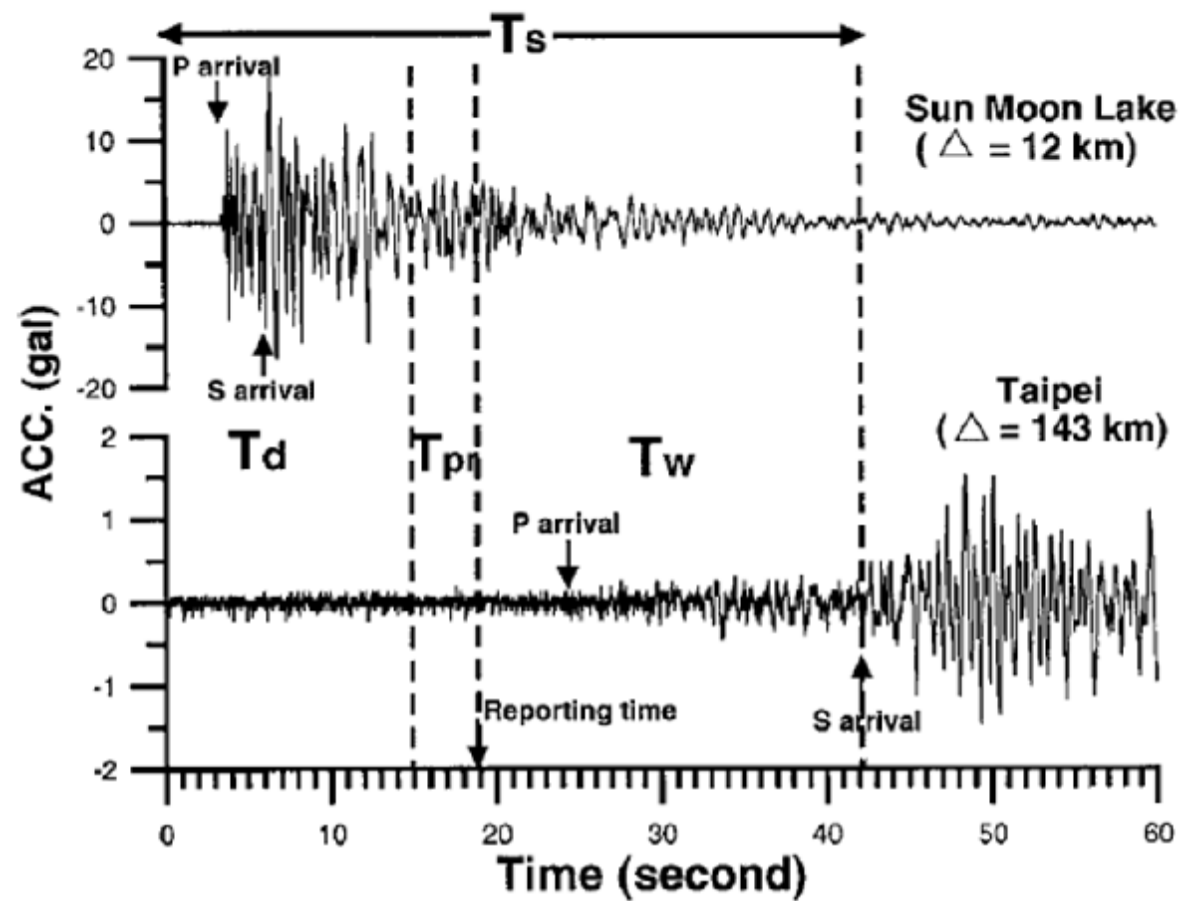
文獻 研究 教育

謝謝!

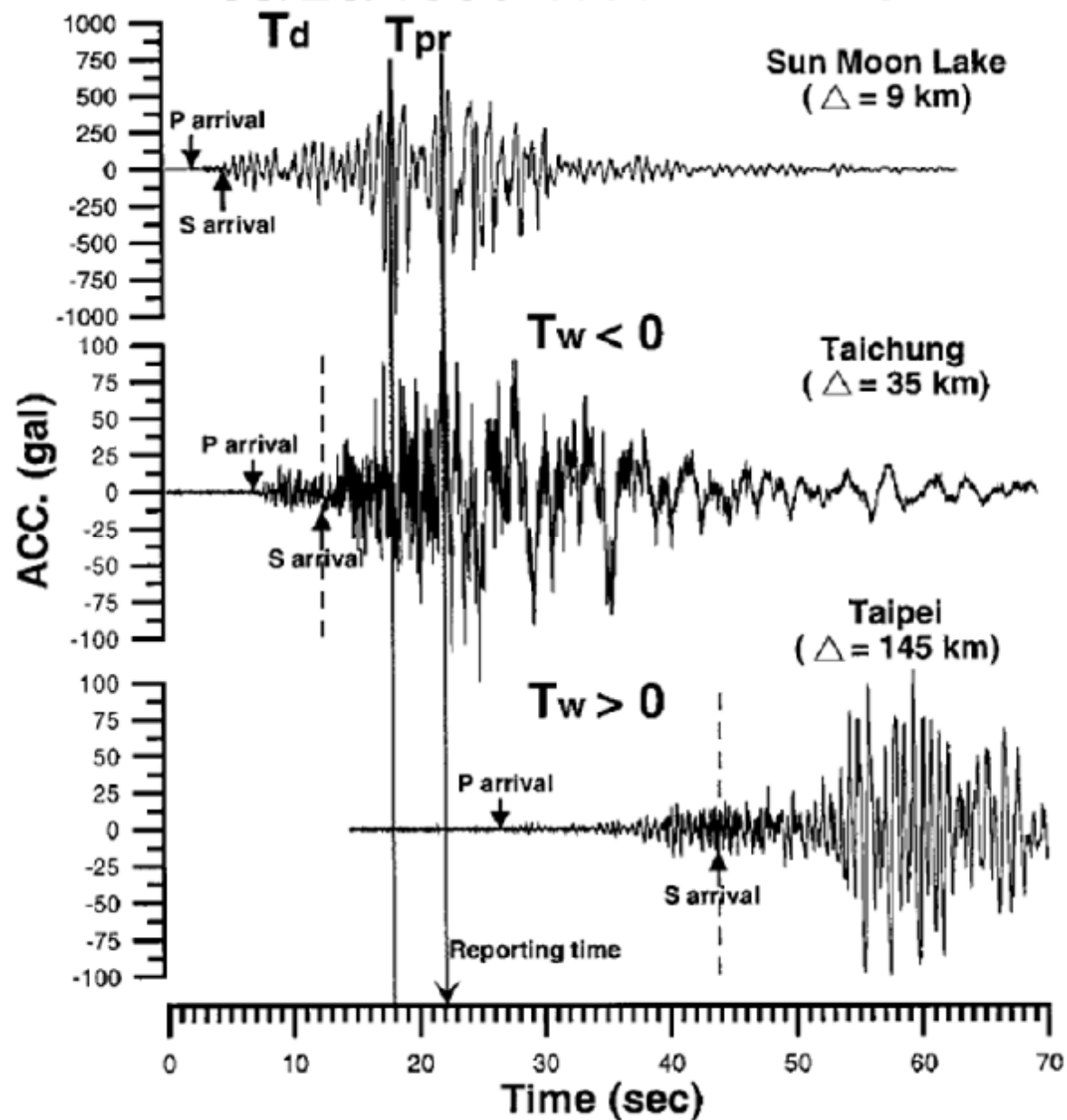
Taiwan Earthquake Rapid Information Release System (RTD)



03/01/2001 16:37:50 M_L 5.5 Depth 17 km



09/20/1999 17:47 Mw 7.6



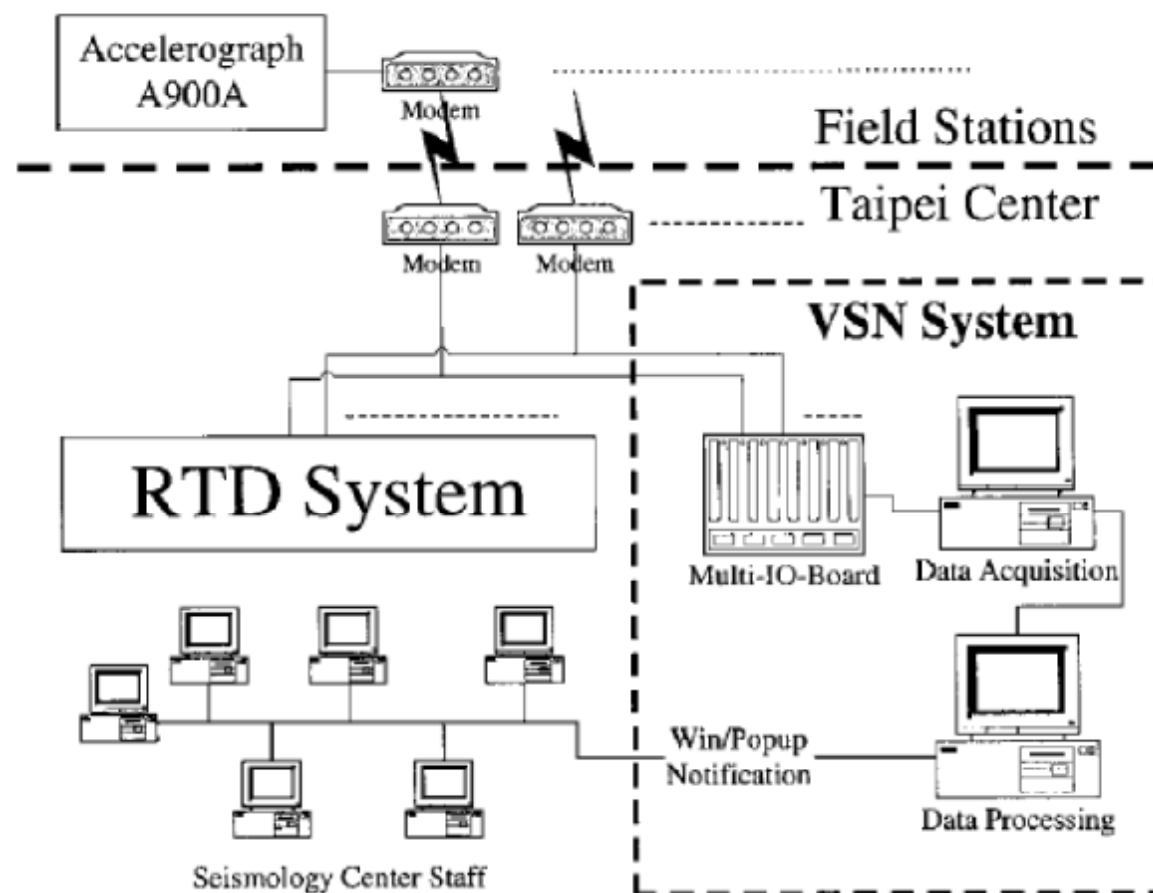
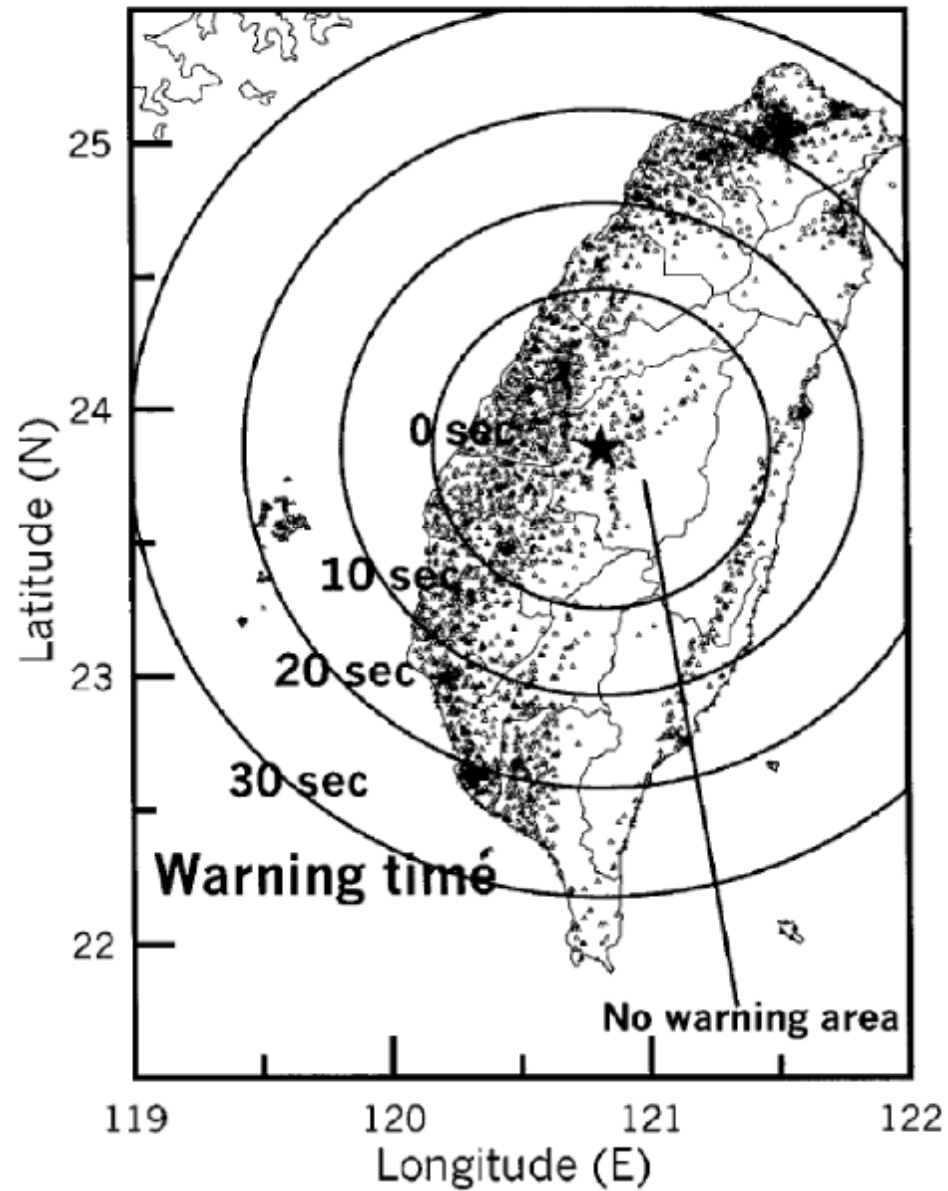
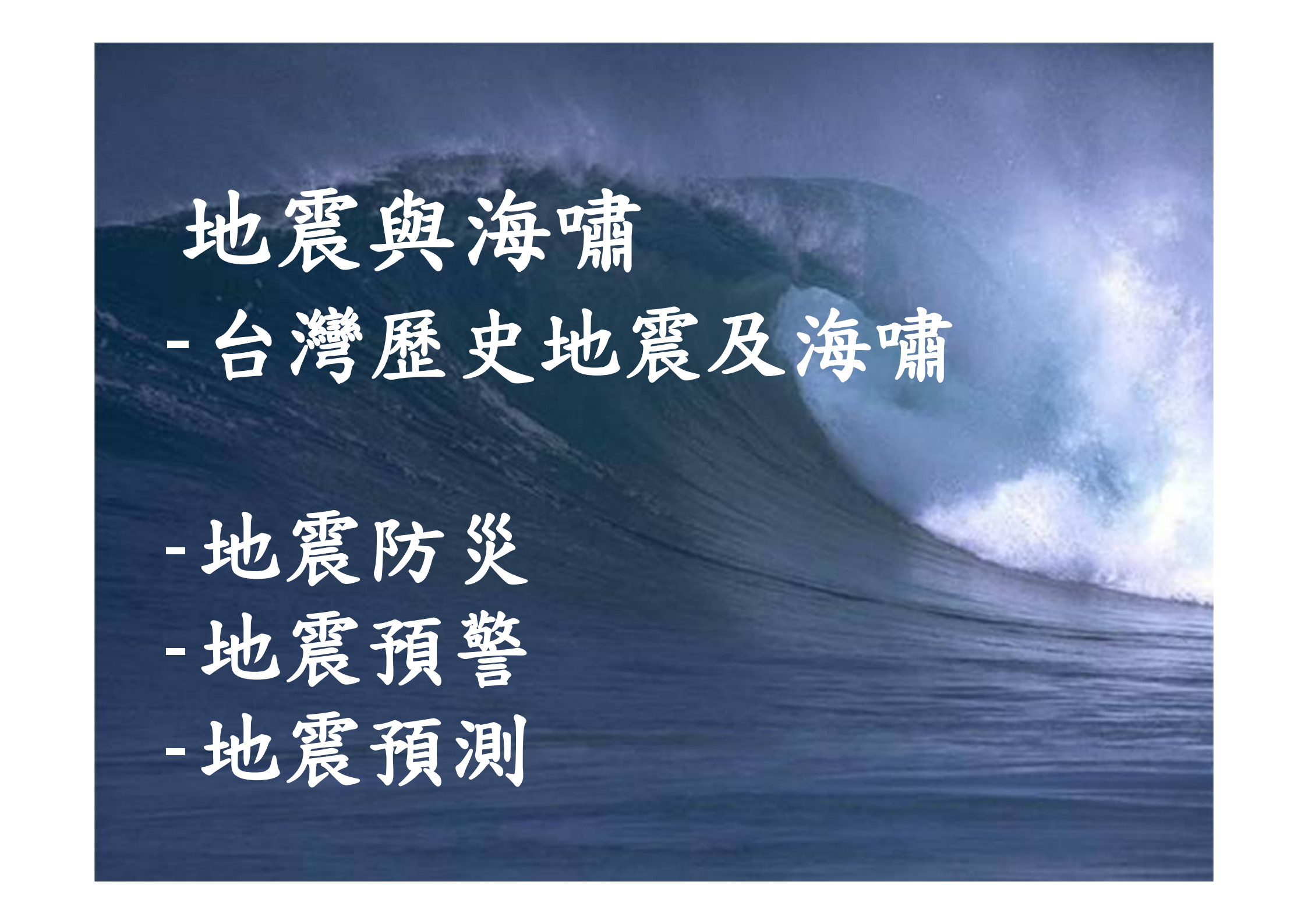


Figure 4. The RTD and VSN system-hardware configuration.

**Early Warning Time of the Earthquake
of Sep. 20, 1999 (Mw7.6)**





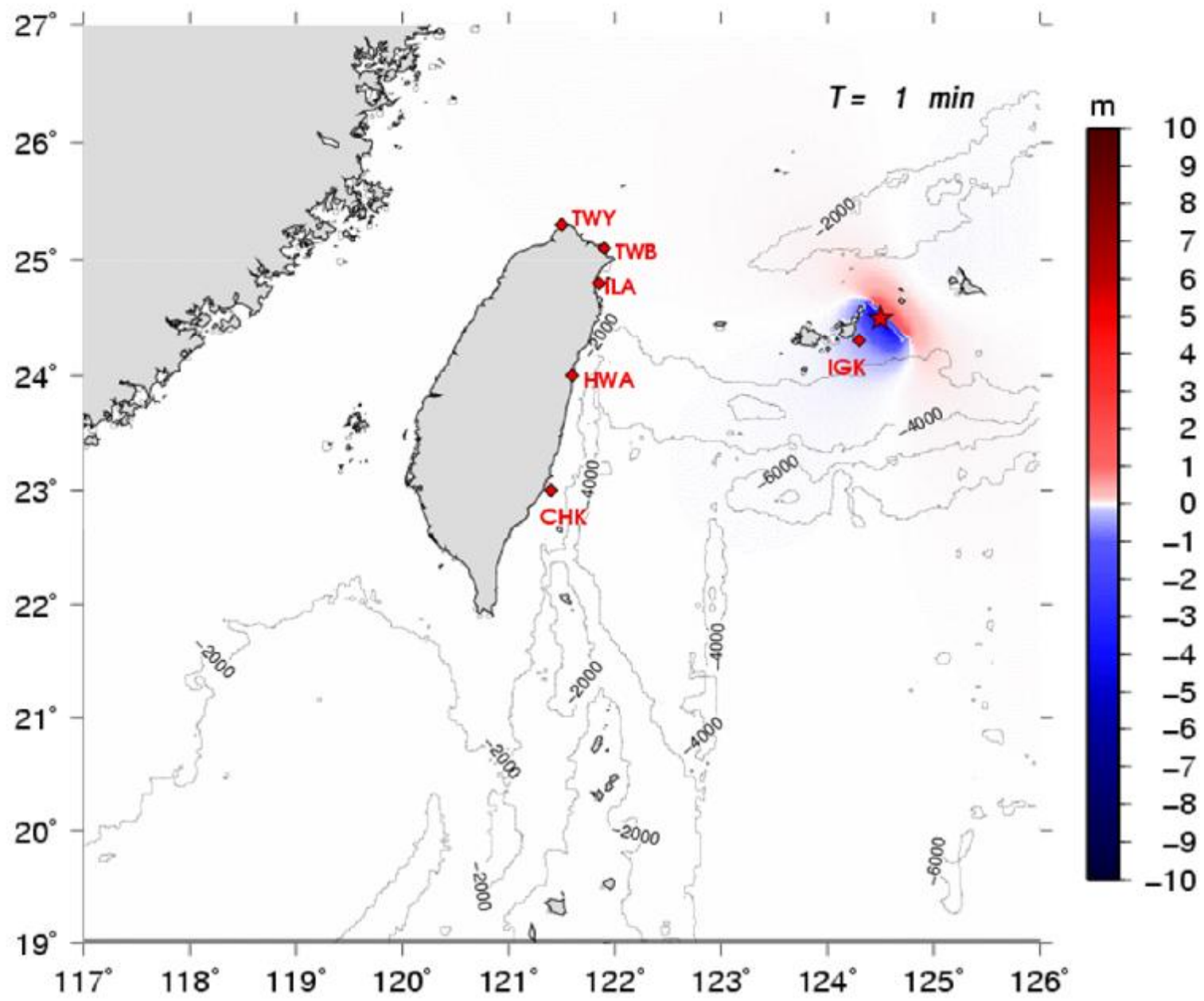
地震與海嘯

- 台灣歷史地震及海嘯

- 地震防災

- 地震預警

- 地震預測



Education Saves Lives
Okushiri, Japan, July 12, 1993
Maximum wave height: 31 meters
Fatalities: 239



Fires and denuded peninsula in wake of the tsunami

**Fires and denuded peninsula in
wake of the tsunami**

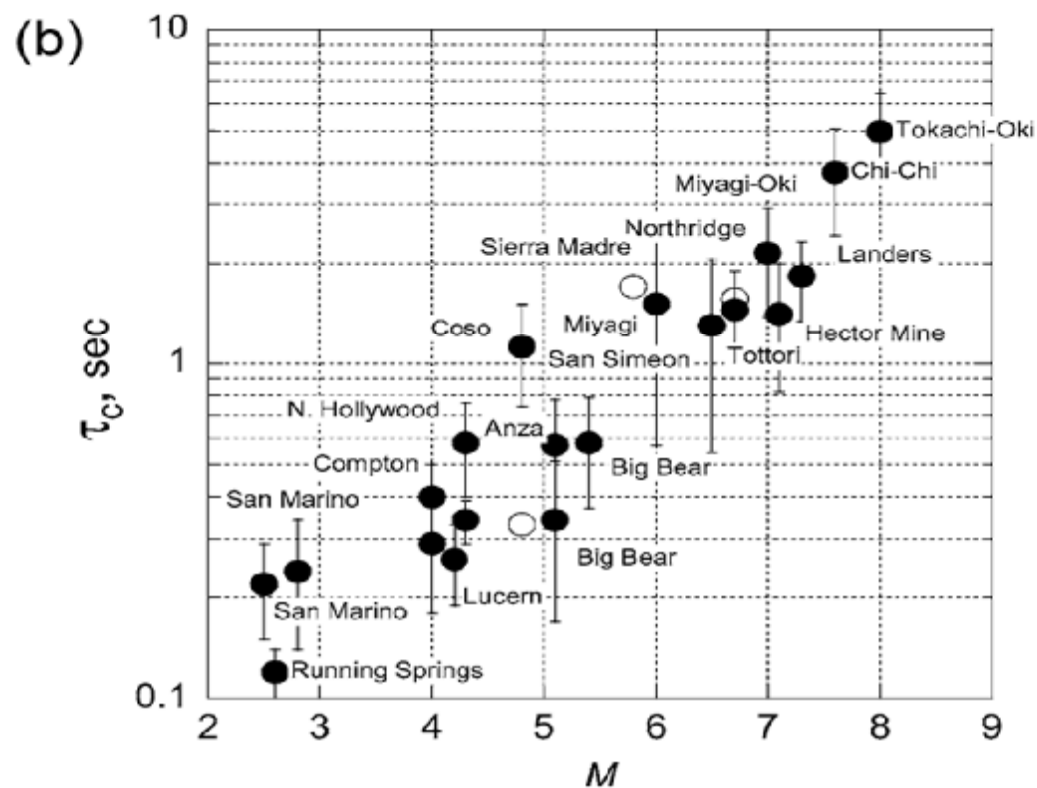
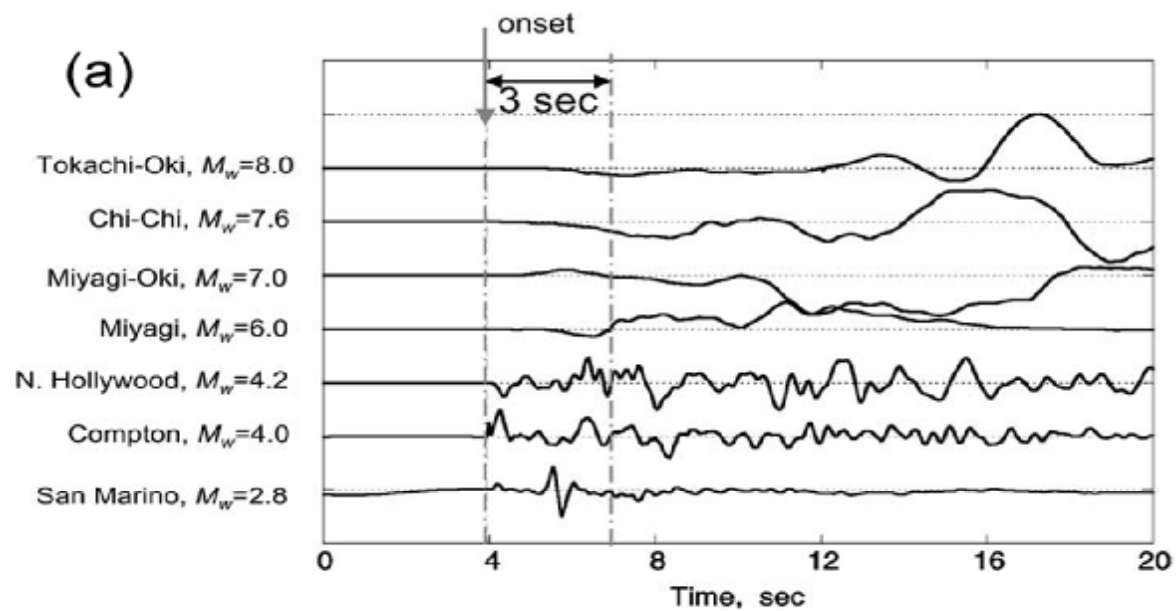


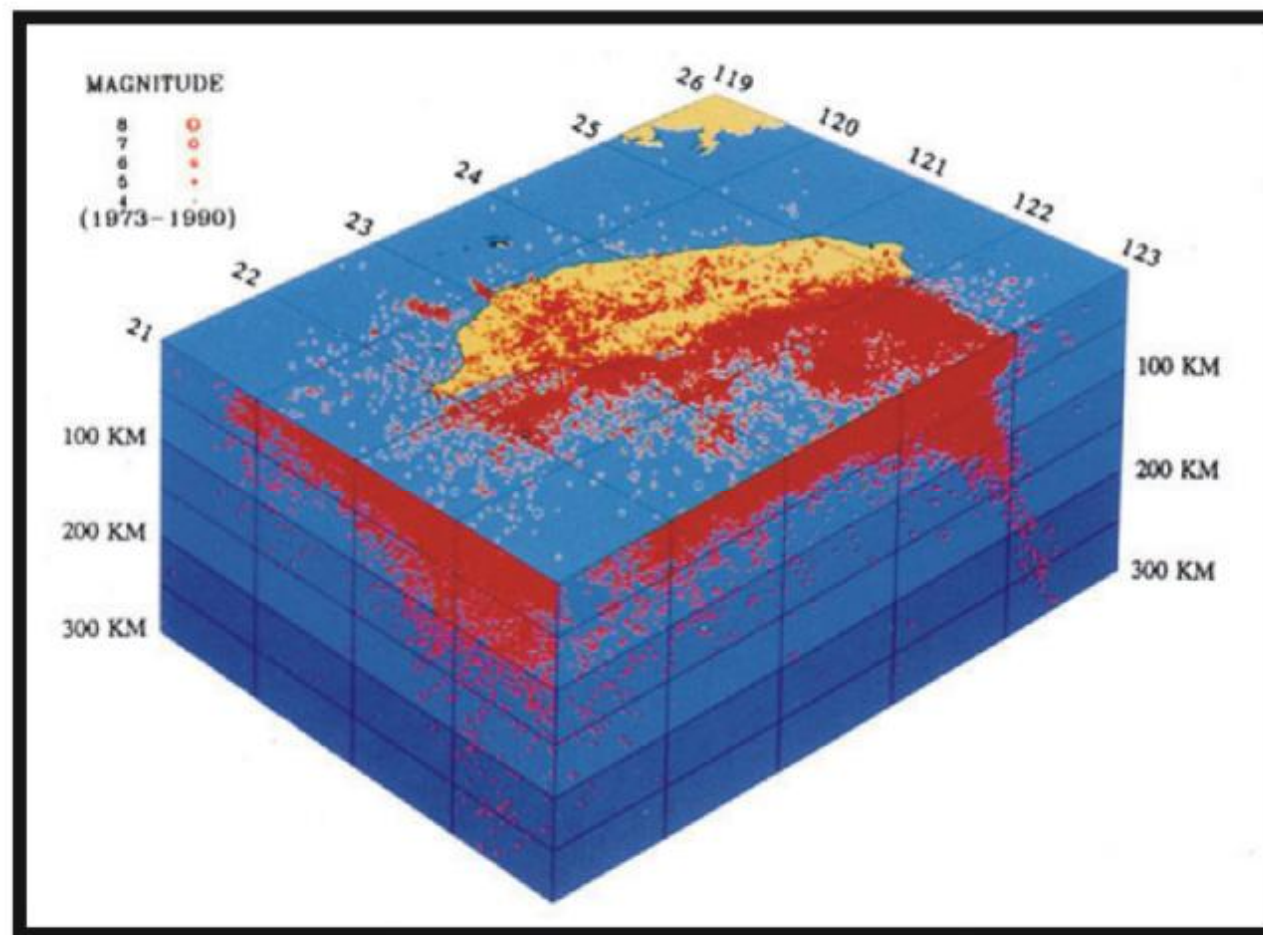
Damaged fire truck amid the debris

**Damaged fire truck amid
the debris**

Strike-slip Fault Example







Normal Fault Example



Dixie Valley-Fairview Peaks, Nevada earthquake
December 16, 1954



Thrust Fault Example





**8 m vertical ground displacement,
Chi-Chi Taiwan earthquake ($M_w 7.6$)**

- 發明動機

根據史書《五行志》記載，東漢時期，中國發生地震的次數是比較多的，從西元92年到西元139年，京城洛陽等地便先後發生過二十次地震，其中六次是破壞性較大的地震，嚴重造成人民生命產的損失。

當時的太使令張衡，目睹地震後的慘狀，痛心不已。由於張衡對天文地理有多年觀察與研究的經驗，因而認為地震是一可以掌握的自然規律。為了掌握各地的震情，救民眾免於災難，也為了破除讖諱（迷信），他認為有必要製作一種儀器來觀測地震。

在張衡孜孜不倦地探索研究下，根據易經八卦為原理，以及六年的艱苦努力之下，終於在西元132年，發明了世界上第一臺測定地震方位的科學儀器——地動儀。



最早地震儀



內部構造及運作

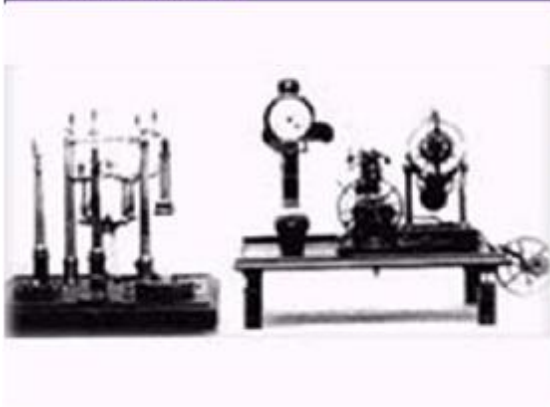
地動儀外觀根據《後漢書》記載其儀體



地震測量工具發展

- 觀測地震的儀器(地震儀):
強震加速度地震儀、寬頻地震儀
- 地震造成地形變動可利用太空觀測技術:
衛星合成干涉影像(InSAR)，GPS衛星觀測之不足。

帕美里地震儀



日據時代的老式地震儀

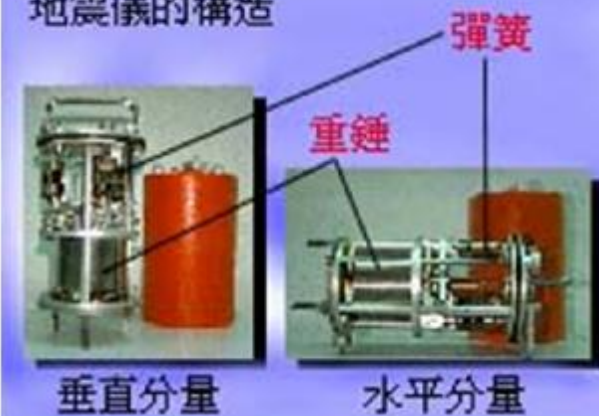


地震儀測量結果



現代地震測量儀器

地震儀的構造



地震規模 vs. 地動位移 及能量

Magnitude Change	Ground Motion Change (Displacement)	Energy Change
1.0	10.0 times	about 32 times
0.5	3.2 times	about 5.5 times
0.3	2.0 times	about 3 times
0.1	1.3 times	about 1.4 times

$$\text{Log}M_o = 1.5M_L + 16.3$$

$$M_o \sim 10^{1.5 \sim 32}$$

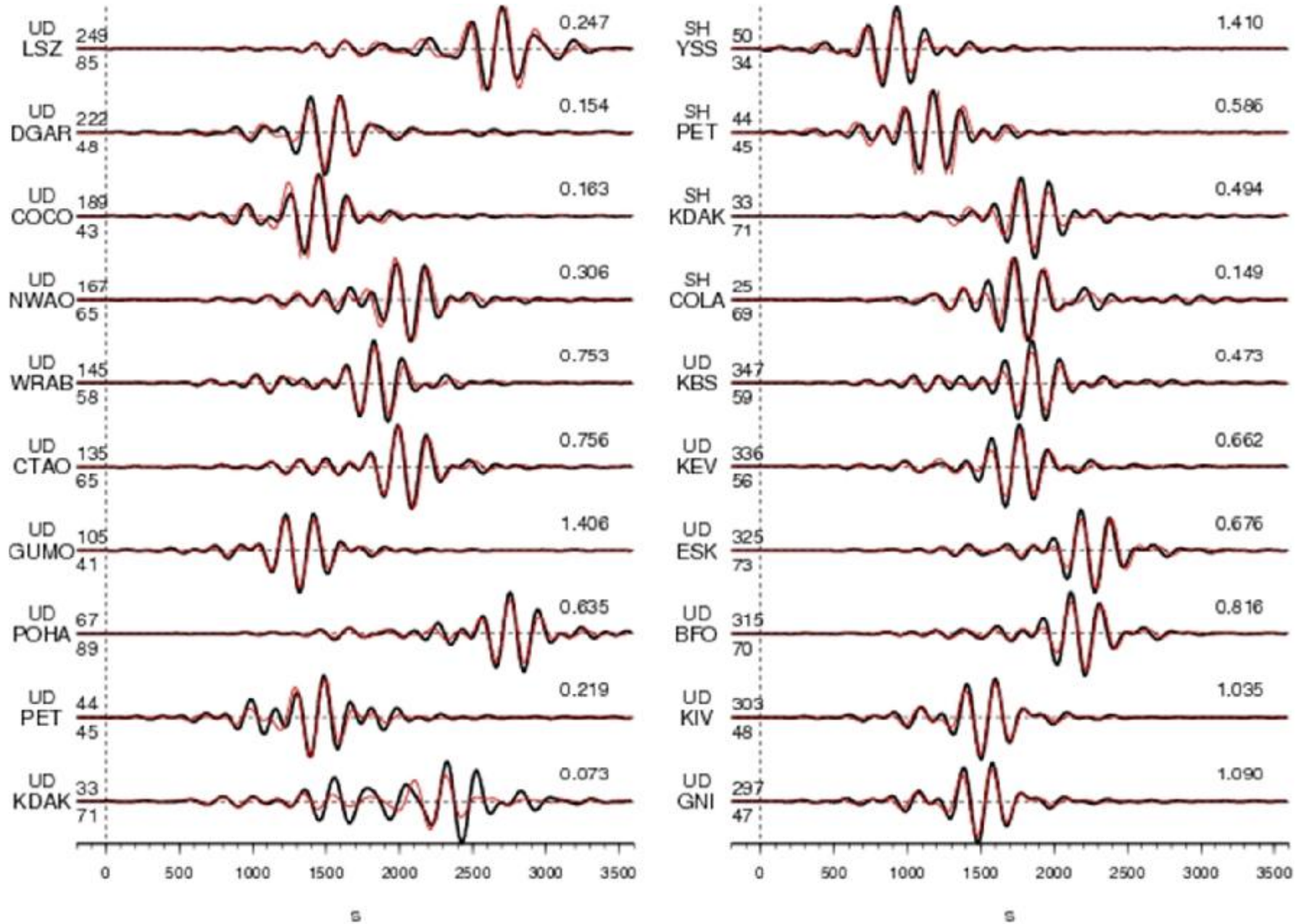
$$M_w = (\text{Log}M_o - 16.3) / 1.5 \quad (\text{地震矩規模})$$

M_o : seismic moment (dyne-cm) (地震波持續震動的能量)

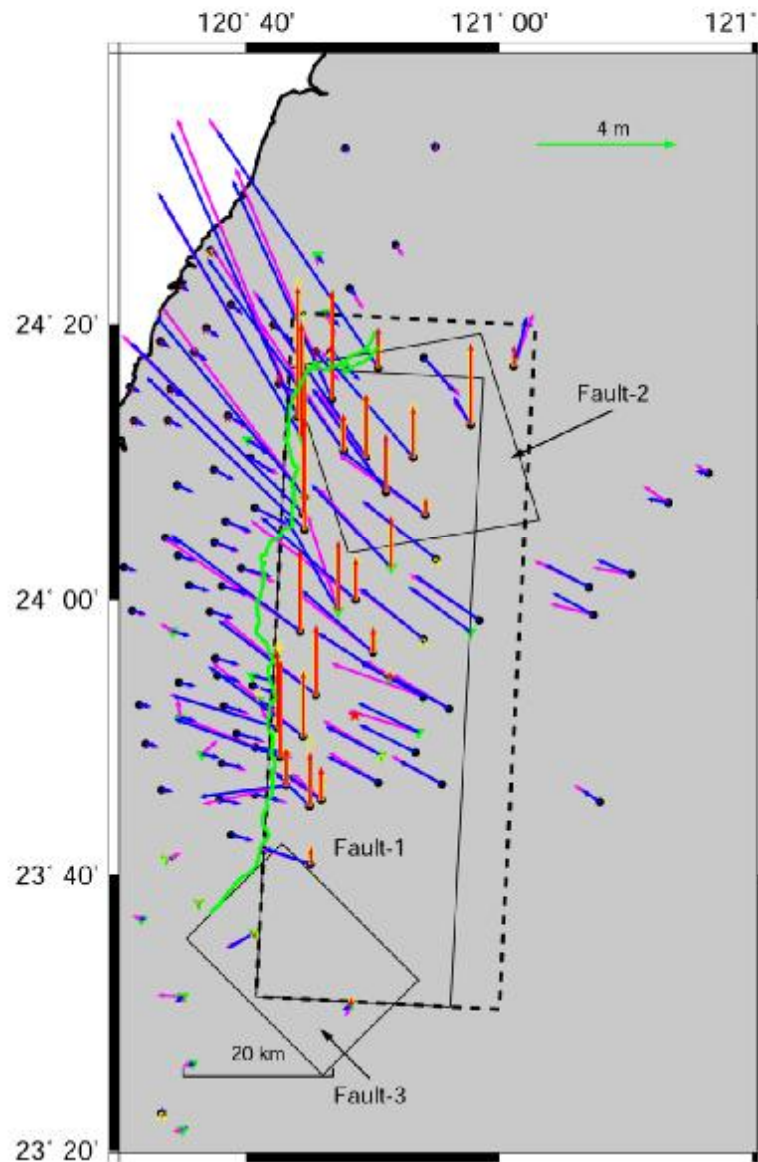
M_L : Richter Magnitude, 芮氏規模

(地動最大震幅)

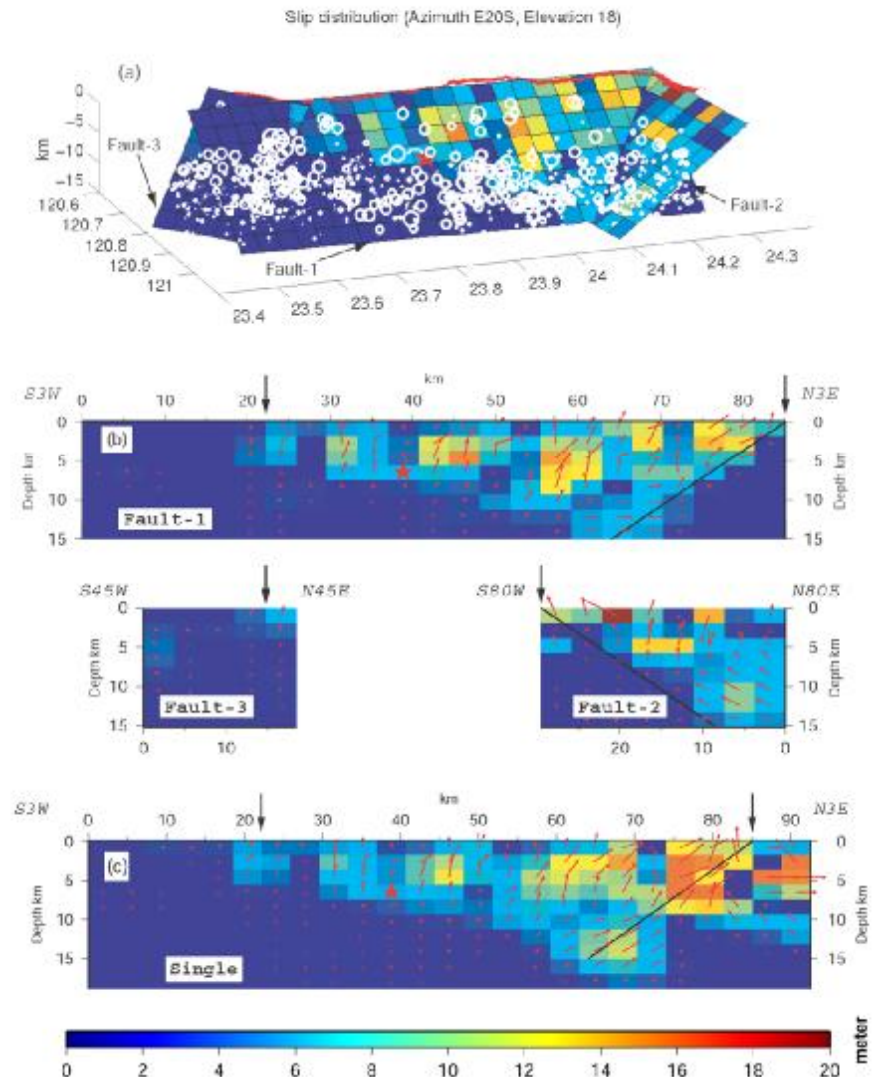
表面波 (Rayleigh wave)



Fault Geometry



1999 集集地震 Mw7.3 [animation](#)
 斷層長100公里
 最大位移於近地表處達12公尺



Fires 火災



Loma Prieta, CA 1989

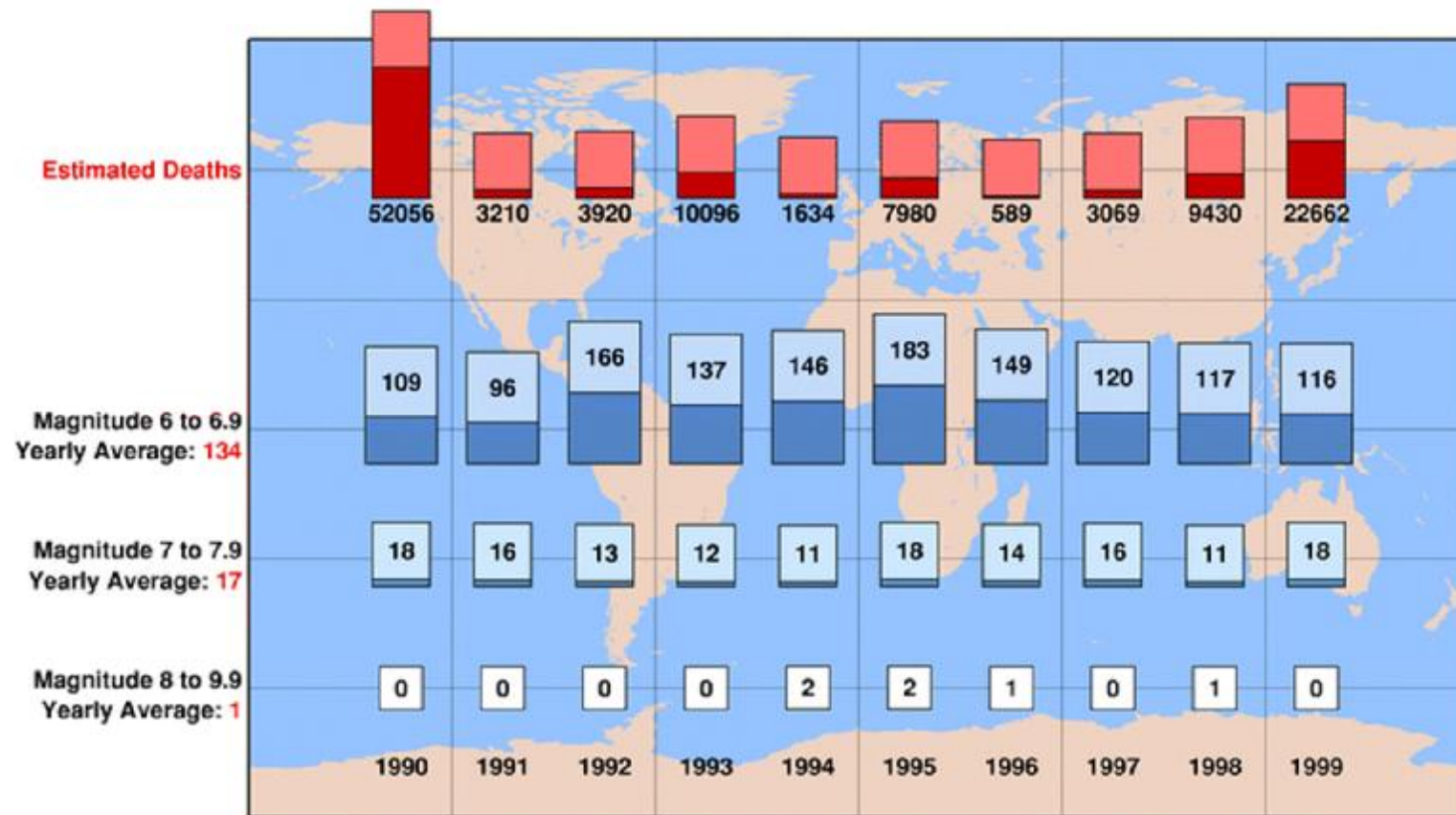
Tsunamis (海嘯)

1957 Aleutian Tsunami



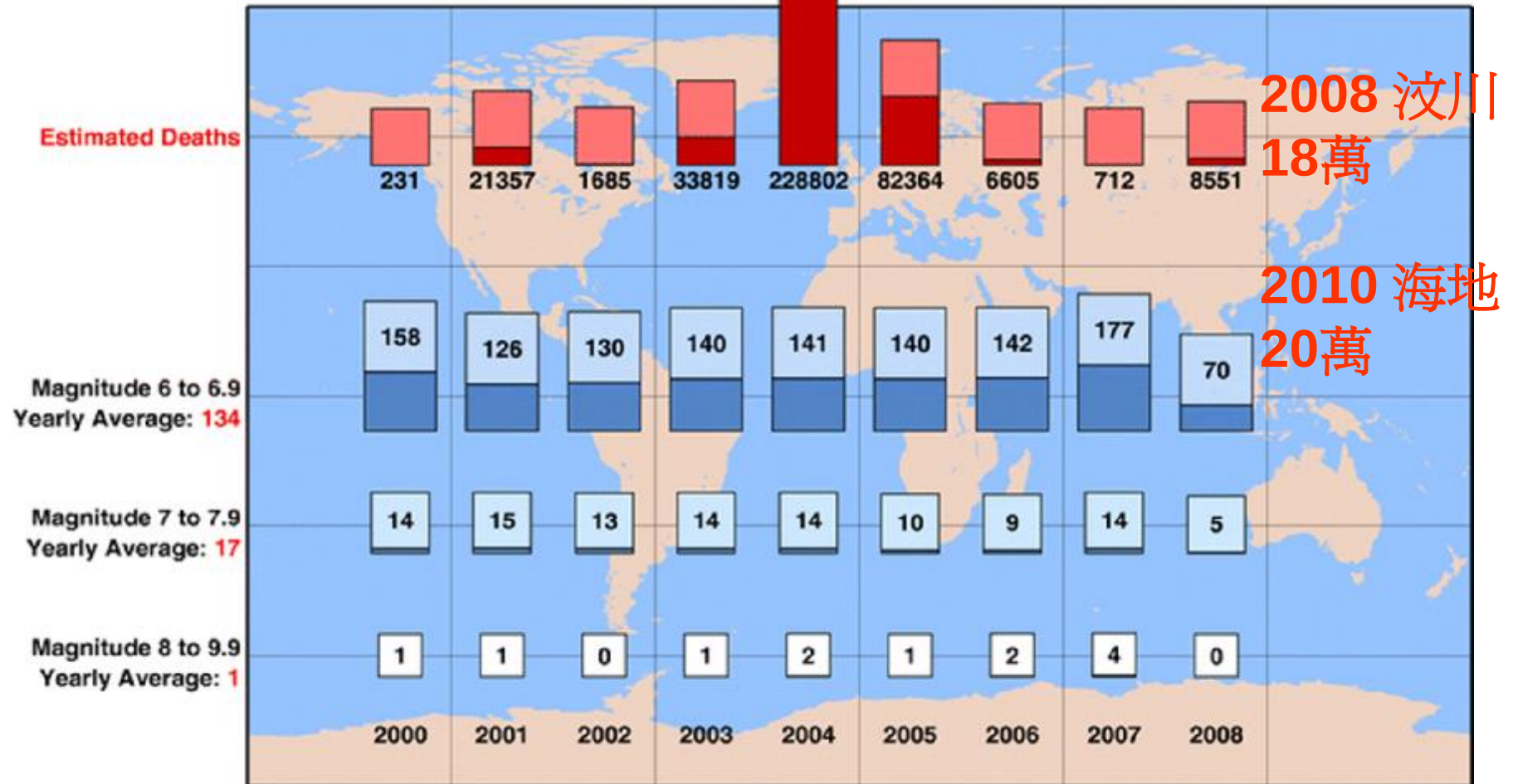
Photograph Credit: Henry Helbush. Source: National Geophysical Data Center

Worldwide Earthquakes: 1990 - 1999 *



* Located by the USGS National Earthquake Information Center

Worldwide Earthquakes: 2000 - 2008 *

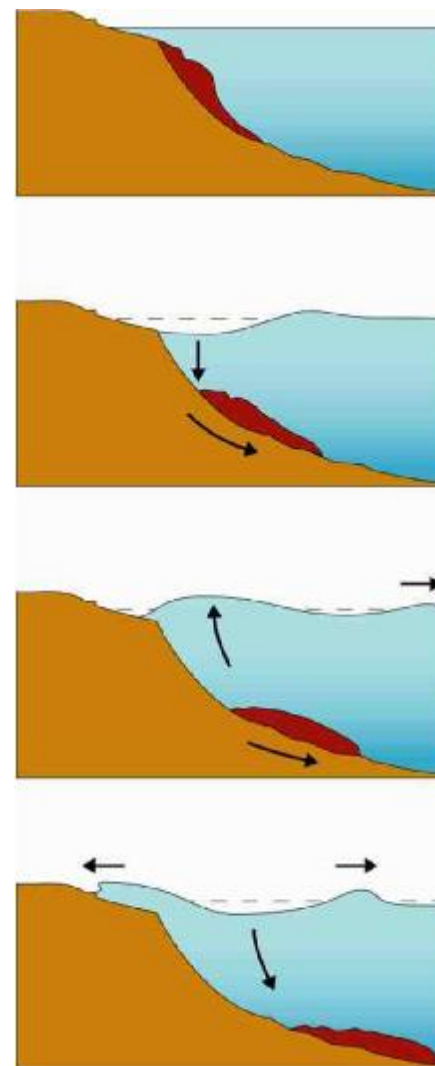


海嘯成因

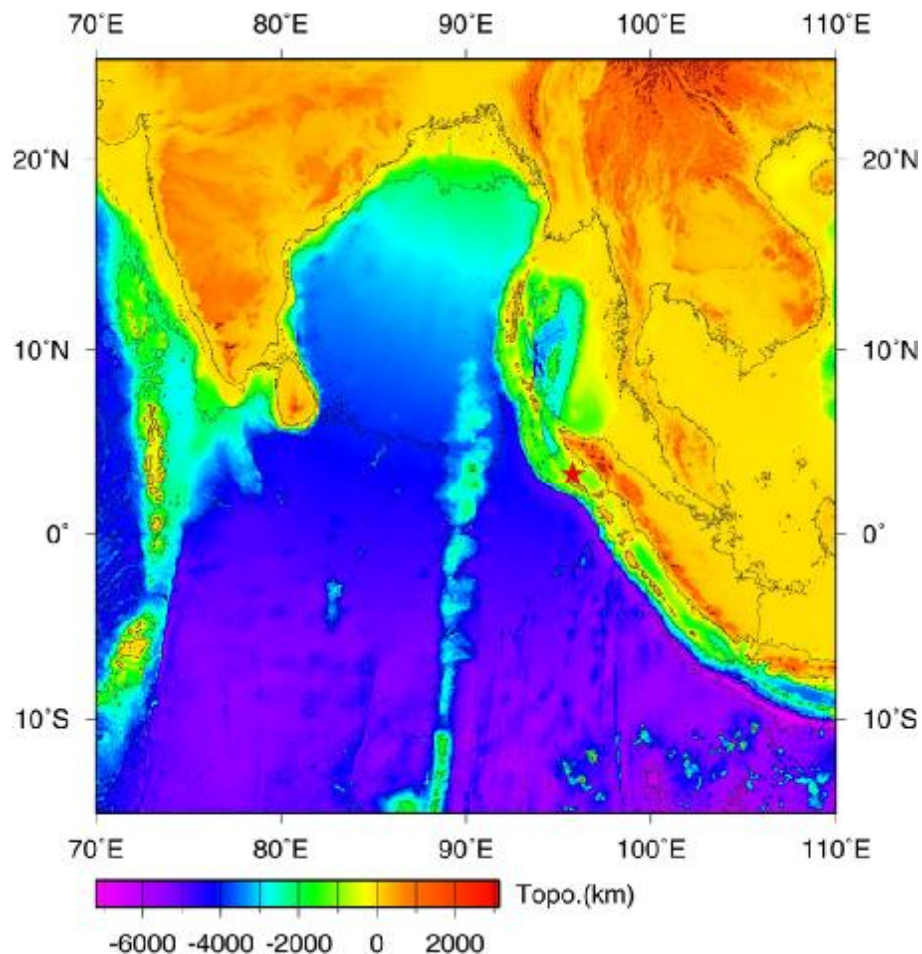
地震



海底山崩



印度洋海底地形

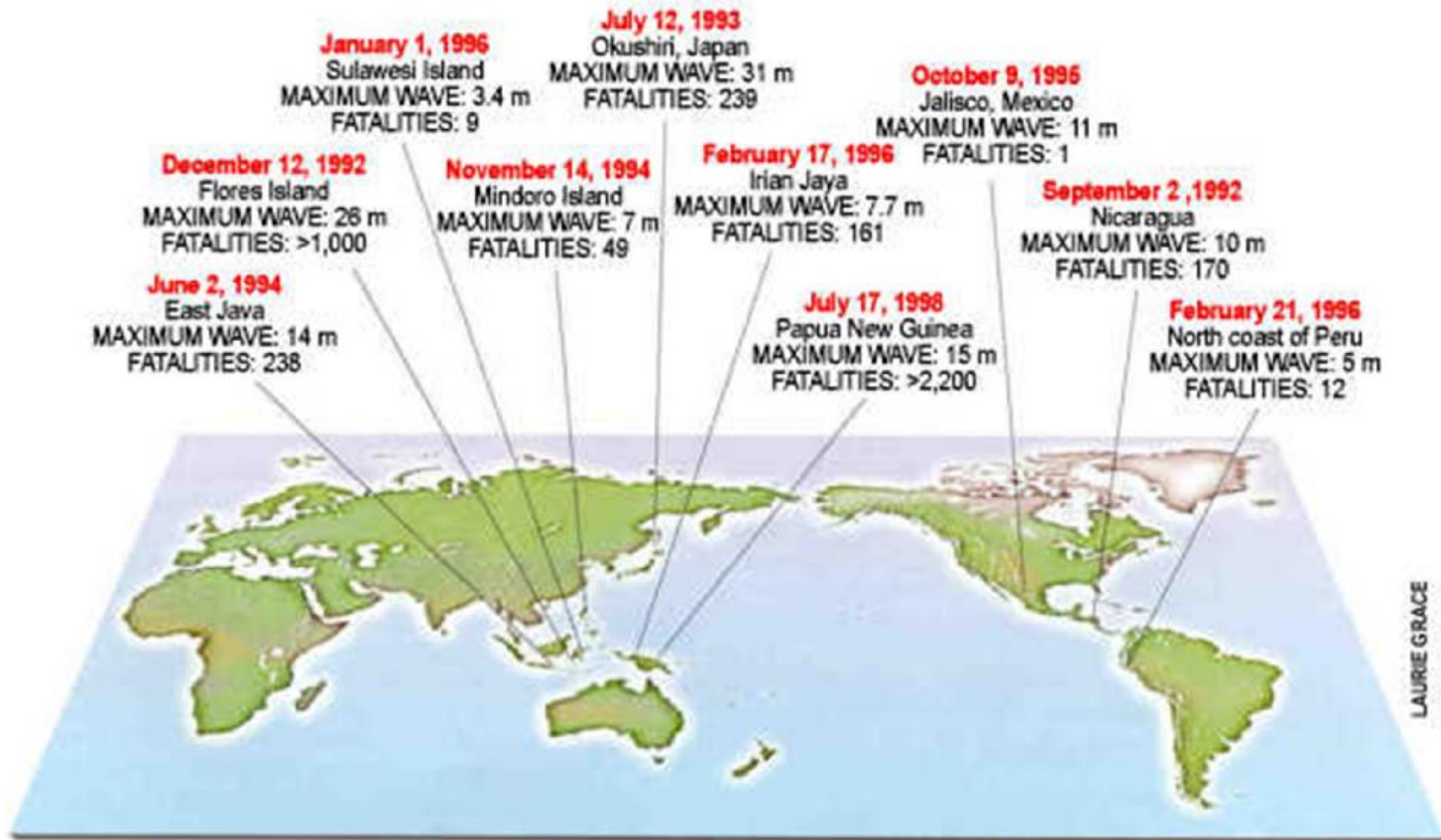


傳播速度

$$V = \sqrt{gD}$$

D: 海底深度

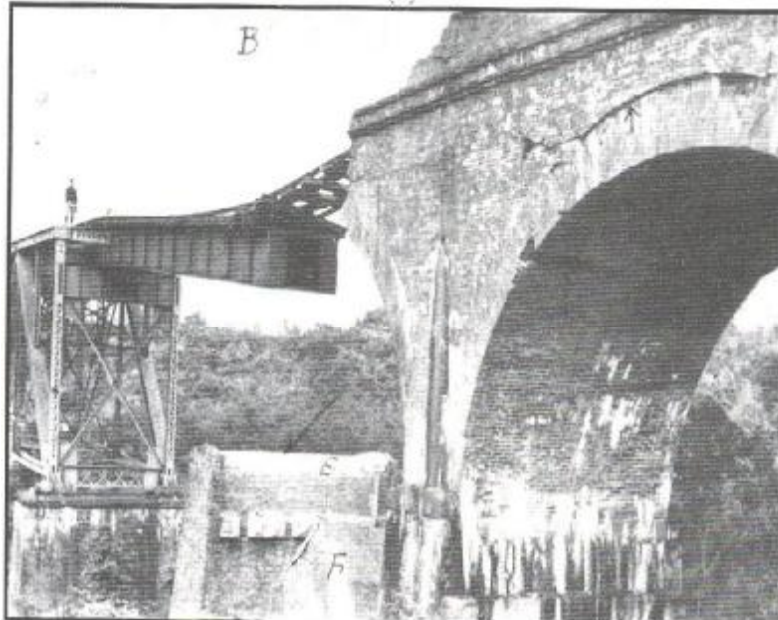
1990~ 海嘯地震



- 世界最大災害地震
1556/1/23 甘肅大地震 死亡83萬人
- 臺灣代表性災害地震(1897~)

時間	地點	規模	災害
1935 0421	台中 新竹	7.1	3297人死亡 12053人受傷 房屋全倒17907間 半倒36871間
1964 0118	白河	6.3	嘉義市大火延燒三小時 被燒面積達240平方公里
1999 0921	集集	7.3	2413人死亡 台灣20世紀最大地震

台中新竹烈震



白河地震



台中新竹烈震



1694 台北大震？「康熙台北湖」

- 清康熙36年郁永河來台於大屯山採硫磺，並將來台遊歷寫成《裨海紀遊》一書。
遊記裡有段描述說過見到的台北為一大湖，其成因是地震所造成。
後人稱此湖為「康熙台北湖」

史集文獻探討

- 郁永河，字滄浪。長年住在閩中地區，康熙三十六年為採硫磺 特地來剛被大清併入版圖的臺灣一趟。

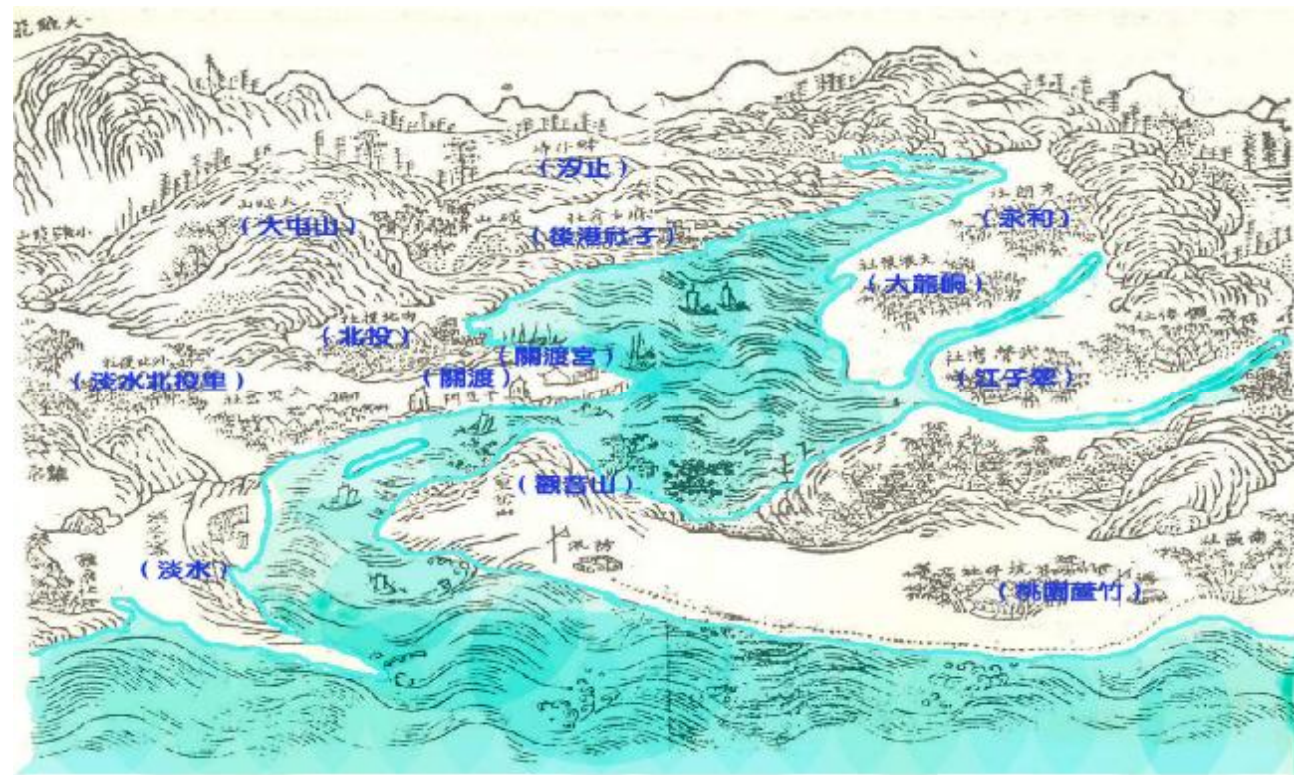
- 五月朔，張大來告屋成。

初二日，余與顧君暨僕役平頭共乘海舶，由淡水港入。前望兩山夾峙處，曰甘答門，水道甚溢，入門，水忽廣，漶為大湖，渺無涯矣……『張大云：『此地高山四繞，周廣百餘里，中為平原，唯一溪流水，麻少翁等三社，緣溪而居。甲戌（康熙33年，西元1694年）四月，地動不休，番人恐怖，相率徙去，俄陷為巨浸，距今不三年耳。』指淺處猶有竹樹梢出水面，三社舊址可識，滄桑之變，信有之乎？既坐定，聞飛湍倒峽聲，有崩崖轉石之勢。

- 1694 台北大震？
康熙台北湖
- 1654年荷蘭人所繪
台北古地圖



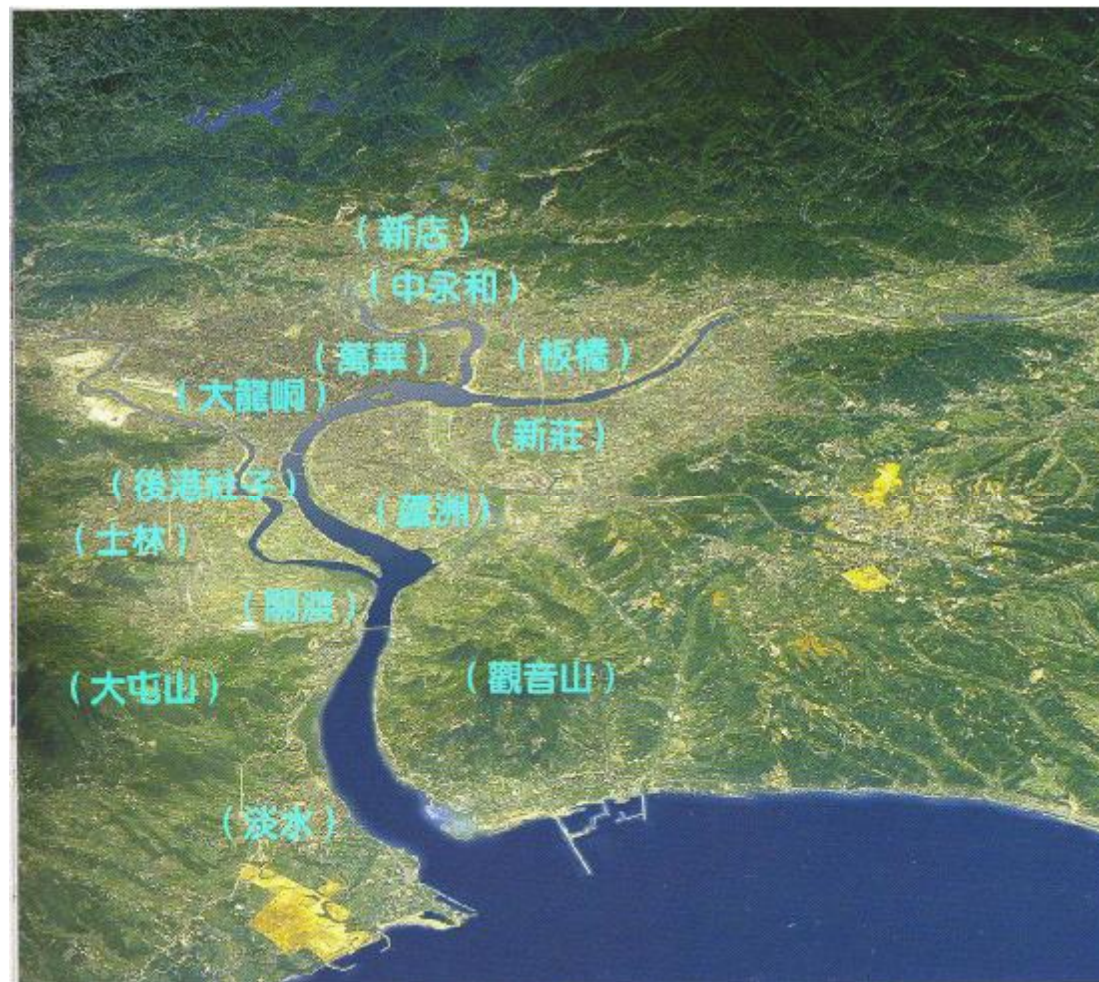
- 康熙56年西元1717年
《諸羅縣志》甘豆門與靈山宮圖



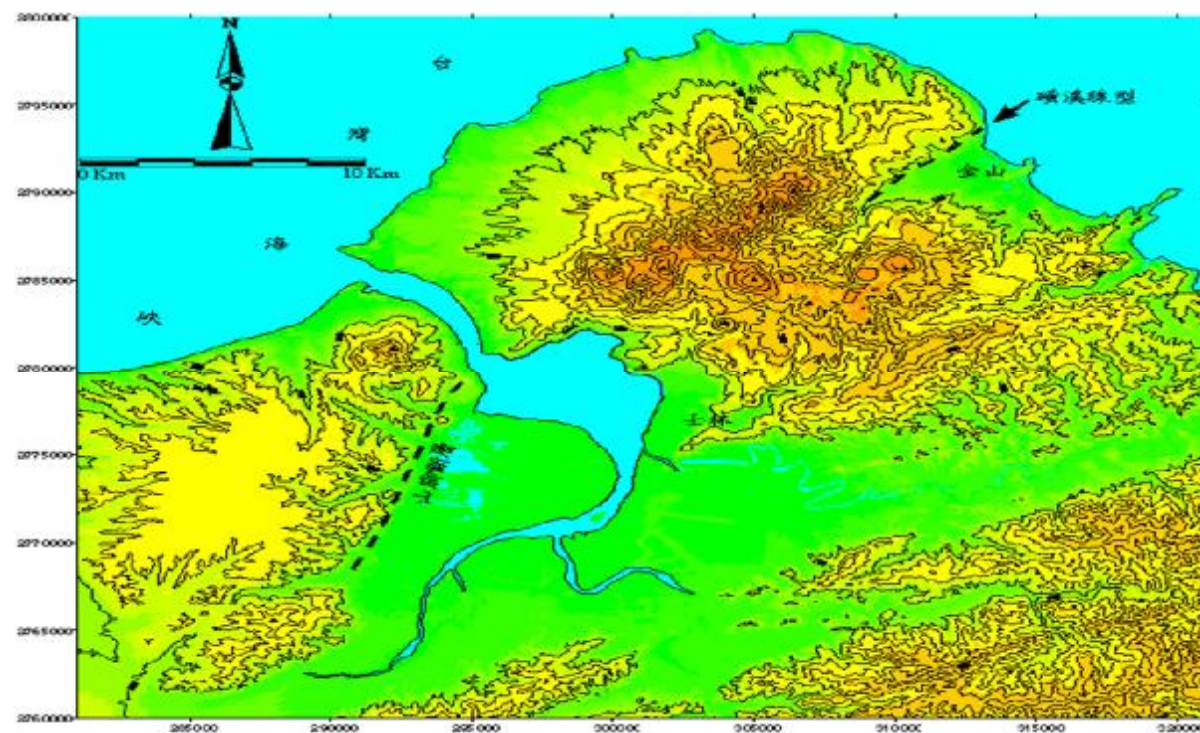
- 乾隆年間彩繪台灣地圖



- 現代台北盆地地圖



- 台北湖模型



本研究模擬的地震規模與文獻紀錄的地震規模的比較

	文獻紀錄之地震規模 (Reference M)	本研究模擬之地震規模 (Simulated M)
基隆地區 (KL) 1867/12/18	7.0[1]	6.9* 7.2**
新竹地區 (HC) 1604/12/29	8.0[2]	8.0* 7.5**
西南沿海地區 (TN) 1661/1/8	6.0[2]	7.4* 7.5**
台東地區 (TT) 1978/7/23	7.0[3]	6.8* 6.6**
花蓮地區 (HL) 1966/3/12	7.8[3]	7.8* 7.9**

註解：

[1] Yi-Ben Tsai,1985

[2] Ye-Lin,1993

[3] Pezzopane and Wesnousky,1989

* : 震源機制之第一解

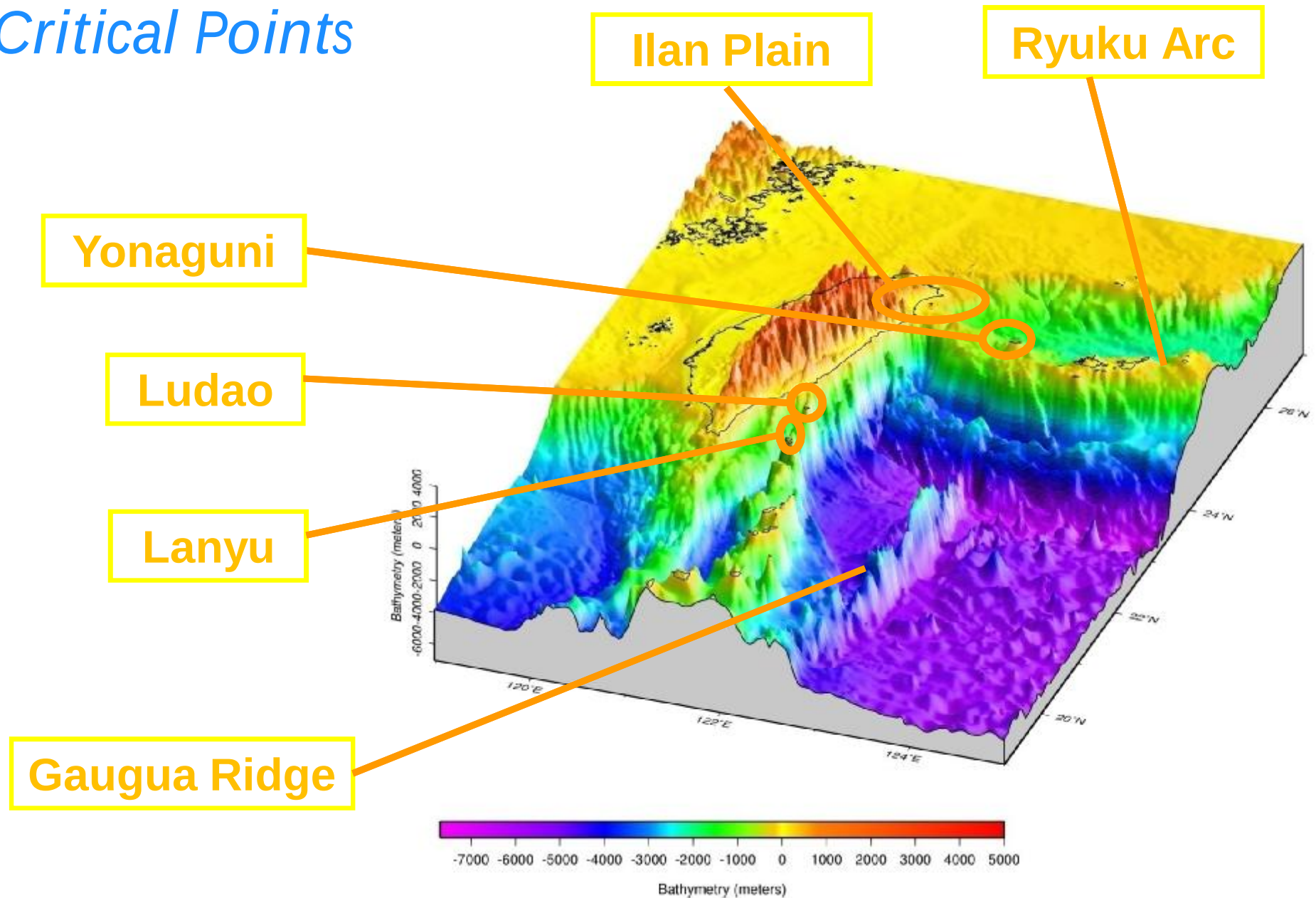
** : 震源機制之第二解

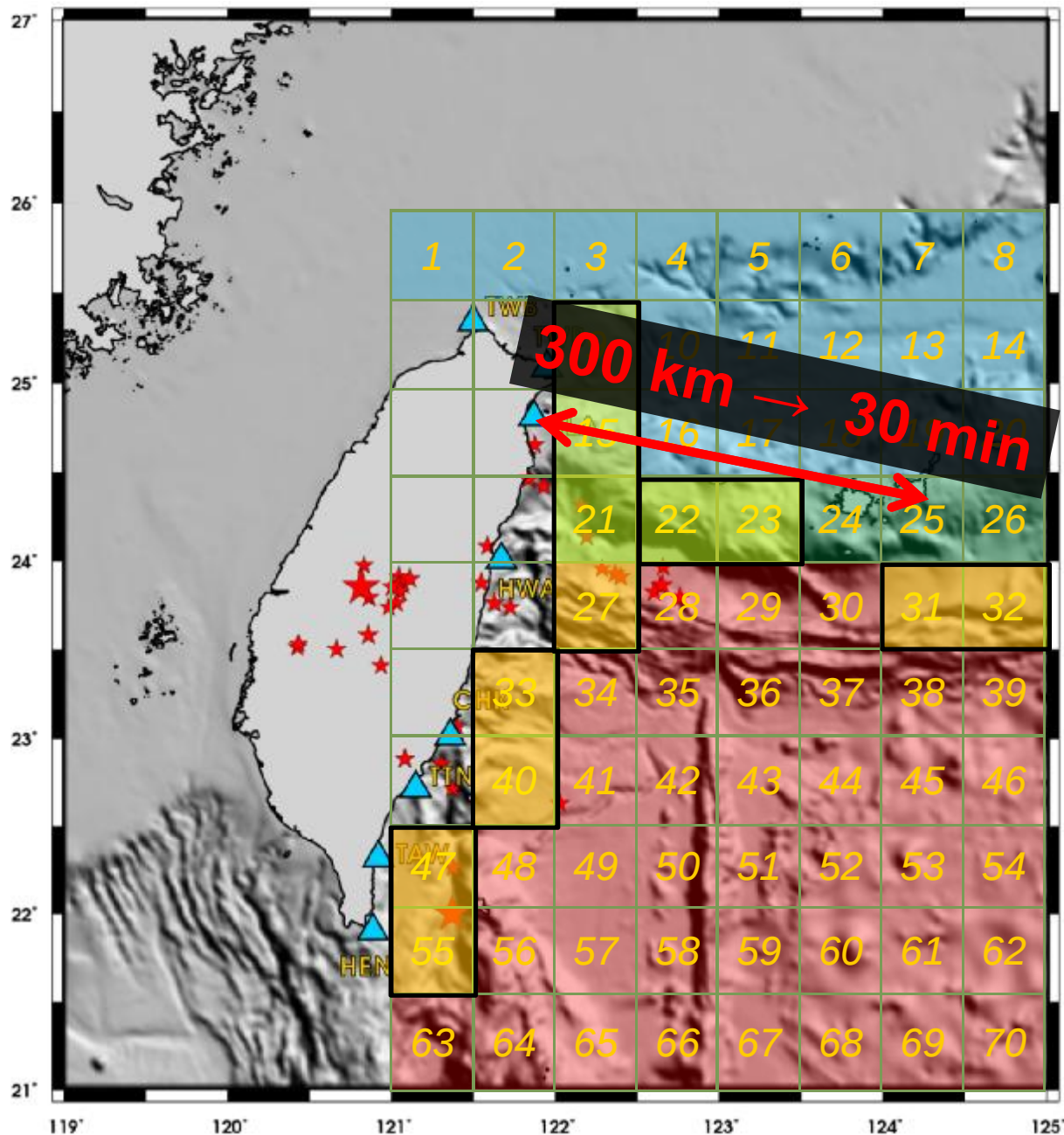
本研究模擬台灣地區的歷史海嘯所得的參數的比較

	站名	傳播距離(km)	初達時間(min)	平均速度(m/sec)	平均週期(min)	平均波長(km)
基隆地區	TWY	37	19	32.3	24	46.56
新竹地區	HSN	130	65	33	85	168.3
西南沿海地區	KAU	13.4	6	37.1	20	44.6
台東地區	TAW	45.6	6	126.67	8	60.8
花蓮地區	ILA	105	9	194.45	13	151.67

Tsunami Wave Propagation Effect:

Critical Points





Seismicity (M>6, Depth<30km)

CWB (1990~2007)

Magnitude



p Tsunami Wave
Propagation Effect: from
Yonaguni, Gagua Ridge,
Ludao, Lanyu, Ryuku Arc

p Tsunami Potential Area
- Ryuku Arc
- Near Coast Events

p Average velocity
Shallow Sea : 8.1 km/min
Ryuku Arc : 10.2 km/min
Deep water : 13.9 km/min

古地震的傳說

- 在過去，由於科學不發達，人們對地震發生的原因，常常借助於神怪的力量來解釋。在我國，民間普遍流傳著這樣一種傳說，他們說地底下住著一條大鼉魚。時間長了，大鼉魚就想翻一下身，只要大鼉魚一翻身，大地便會顫動起來。
- 例如，在古希臘的神話中，海神普舍頓就是地震的神；南美還流傳著支撐世界的巨人身子一動，引起地震的說法；古代日本認為，日本島下面住著大鯰魚，一旦鯰魚不高興了，只要將尾巴一掃，於是日本就要發生一次地震。除此之外，埃及和印度也有關於地下住著動物在作怪的傳說。

竹書本記:

- 災情描述:

上的流星象下雨一般降落下來，這年在河南西部發生了地震，洛河的水都乾了

- 史料可信度:

距離現在都有三千八百年左右了,是我國最早的地震記載，也的地震記載。也有人認為今本《竹書紀年》是後人偽作,不可認為，書雖或為後人偽作，但書中所記的事情也許是世代口見得完全沒有根據。因此，把它當作我國最早的地震記載，。

地震測量工具發展

- **觀測地震的儀器(地震儀):**

現代使用的地震儀，是在本世紀發明的，經過數十年不斷的改進，種類越來越多，性能也越來越精良。

- **設備完善的地震測站有許多種儀器:**

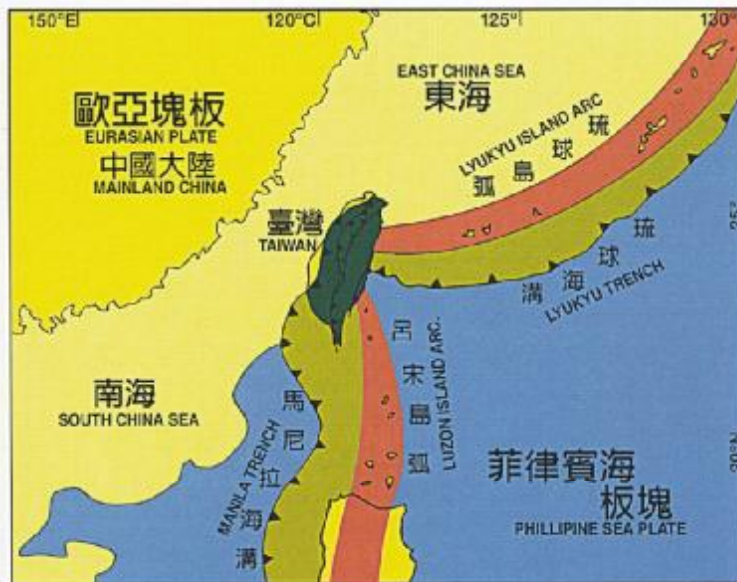
大森式地震儀、強震加速度地震儀、寬頻地震儀、威克式地震儀、簡單式地震儀、長週期地震儀及電磁式地震儀等。

- **地震造成地形變動可利用太空觀測技術:**

衛星合成干涉影像(InSAR)，可以呈現出研究區域全面性的地殼變形型態，彌補點狀GPS衛星觀測之不足。但是InSAR容易受植被影響，精確度亦稍差。

台灣板塊構造

Plate Motion and Tectonic Structure



圖一. 台灣附近之板塊構造分佈
Fig.1 Tectonic Structure Around Taiwan

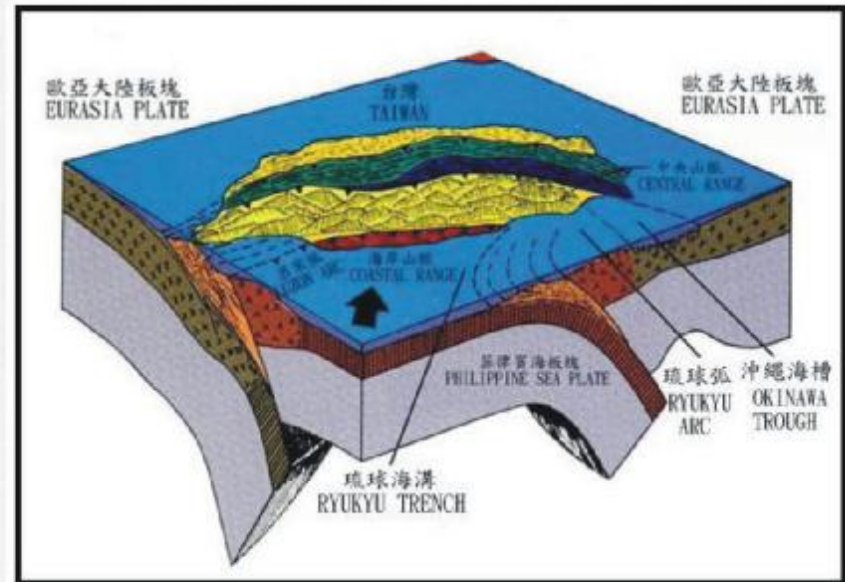
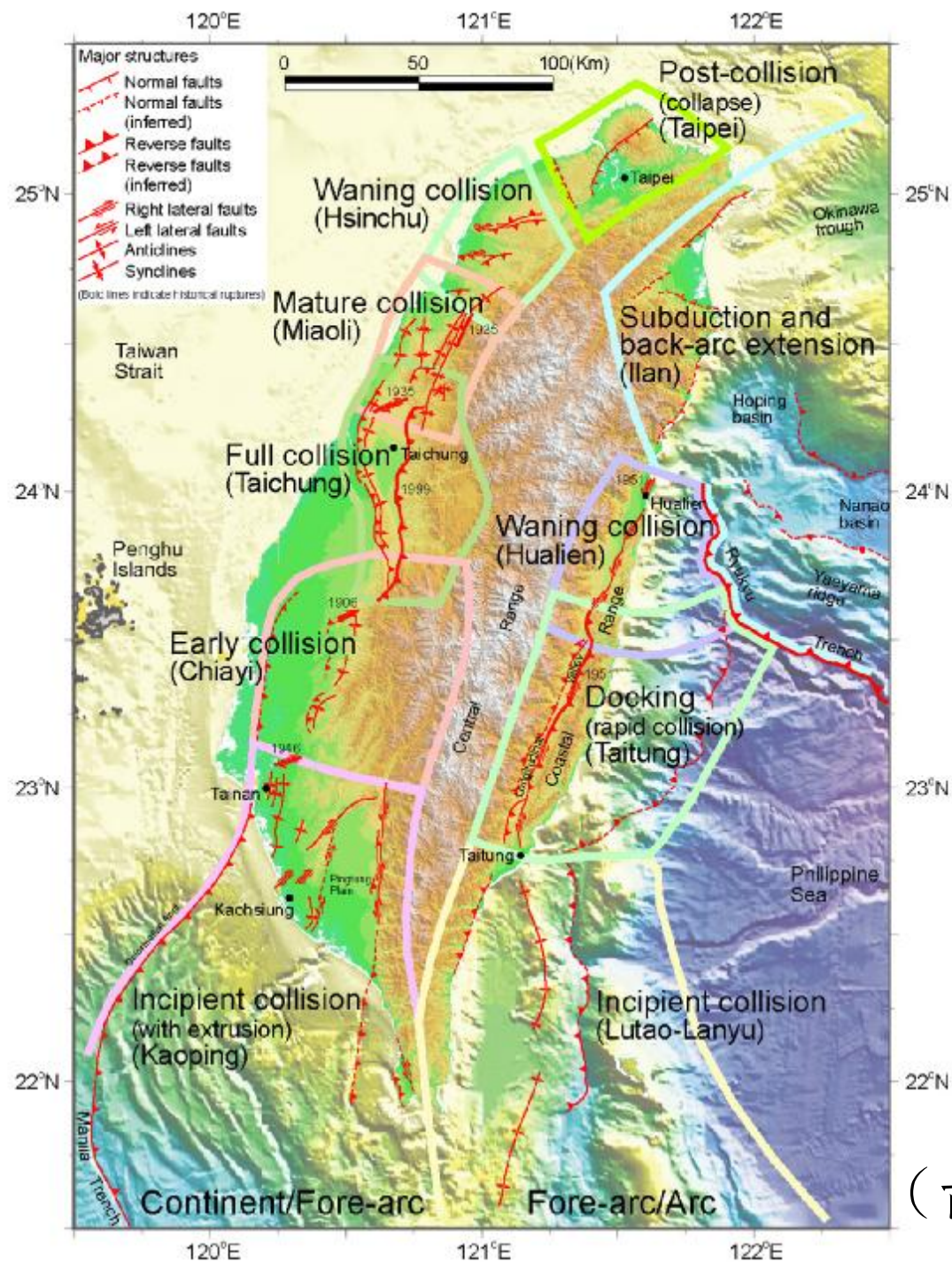
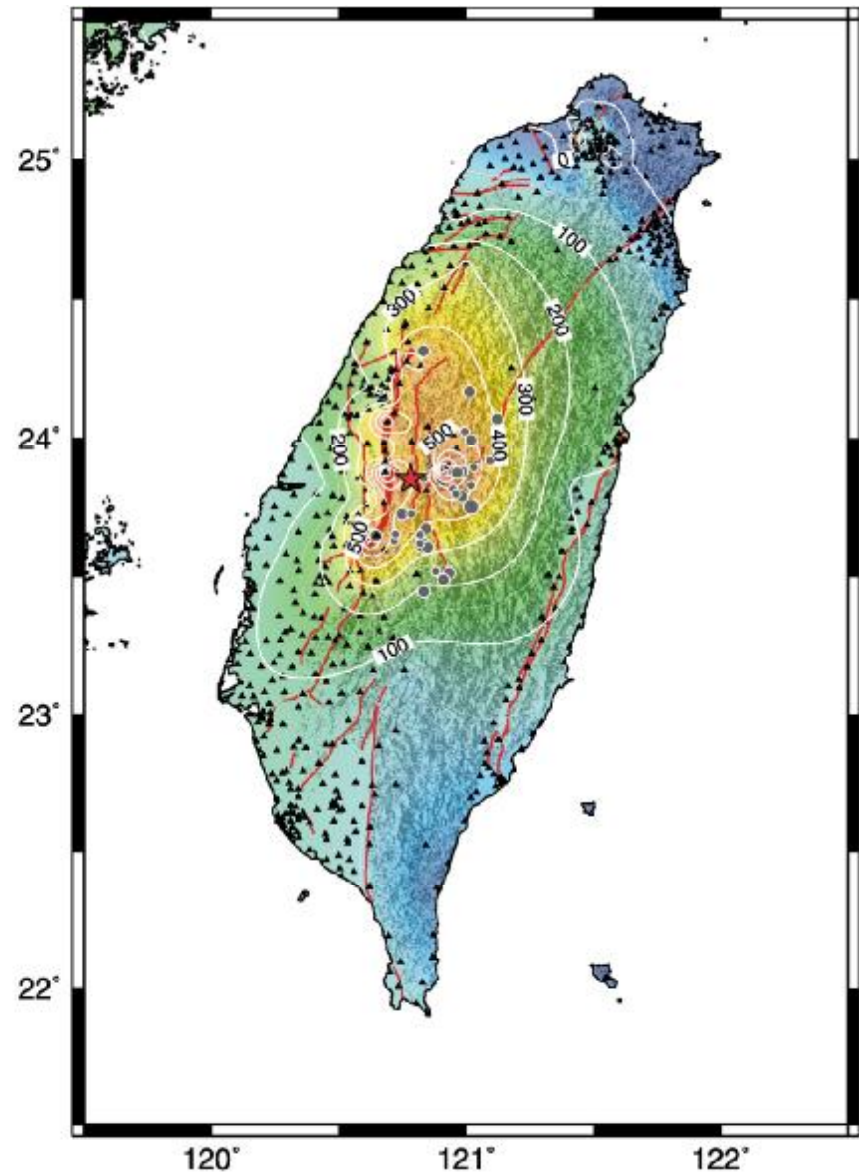
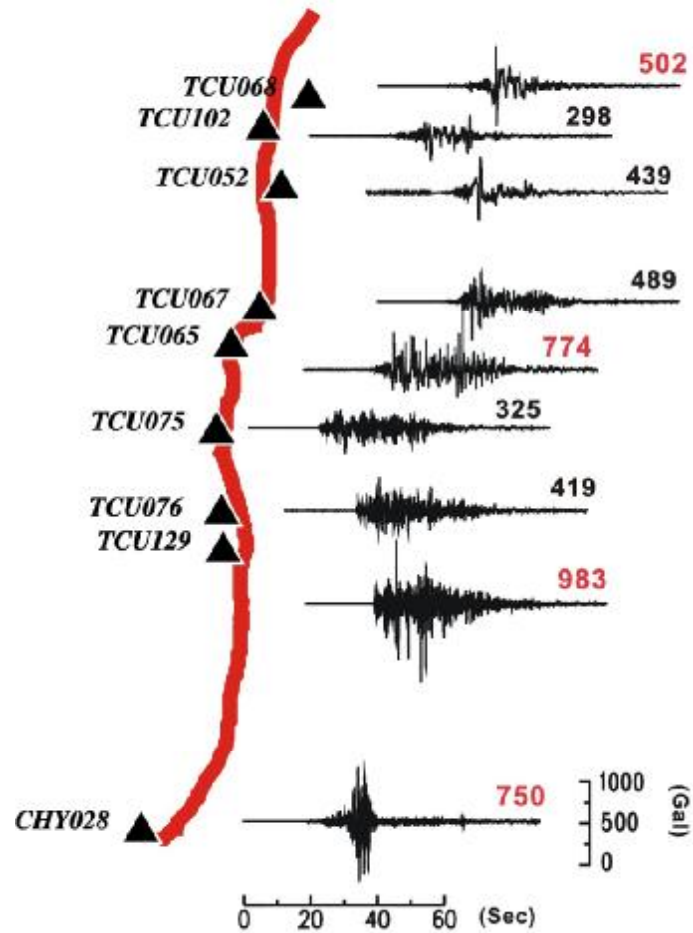


Fig.2 Plate Tectonic of Taiwan

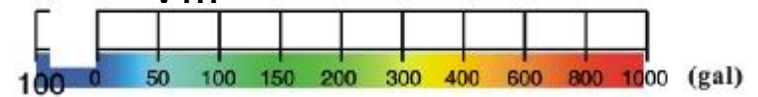


(台灣大學 陳于高教授)

TSMIP



VIII IX

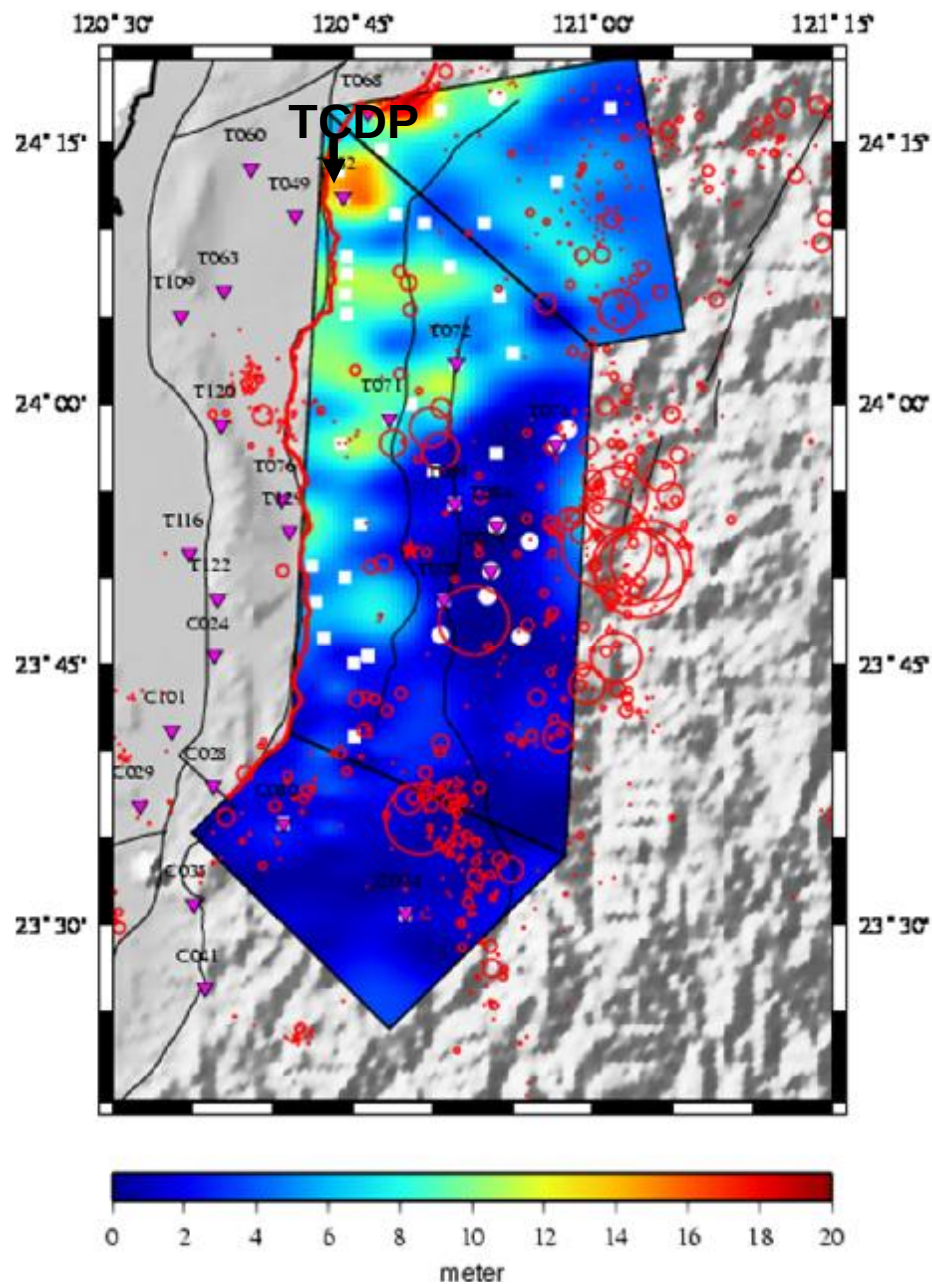


地震以何種型態控制災害的行為？



台灣車籠埔斷層深鑽計劃 (TCDP)

2004~ (NSC)



CLP

Drilling

30

Fault slip
8.3-12m

低角度
淺層大錯動



01/17/2004

Executive Committee

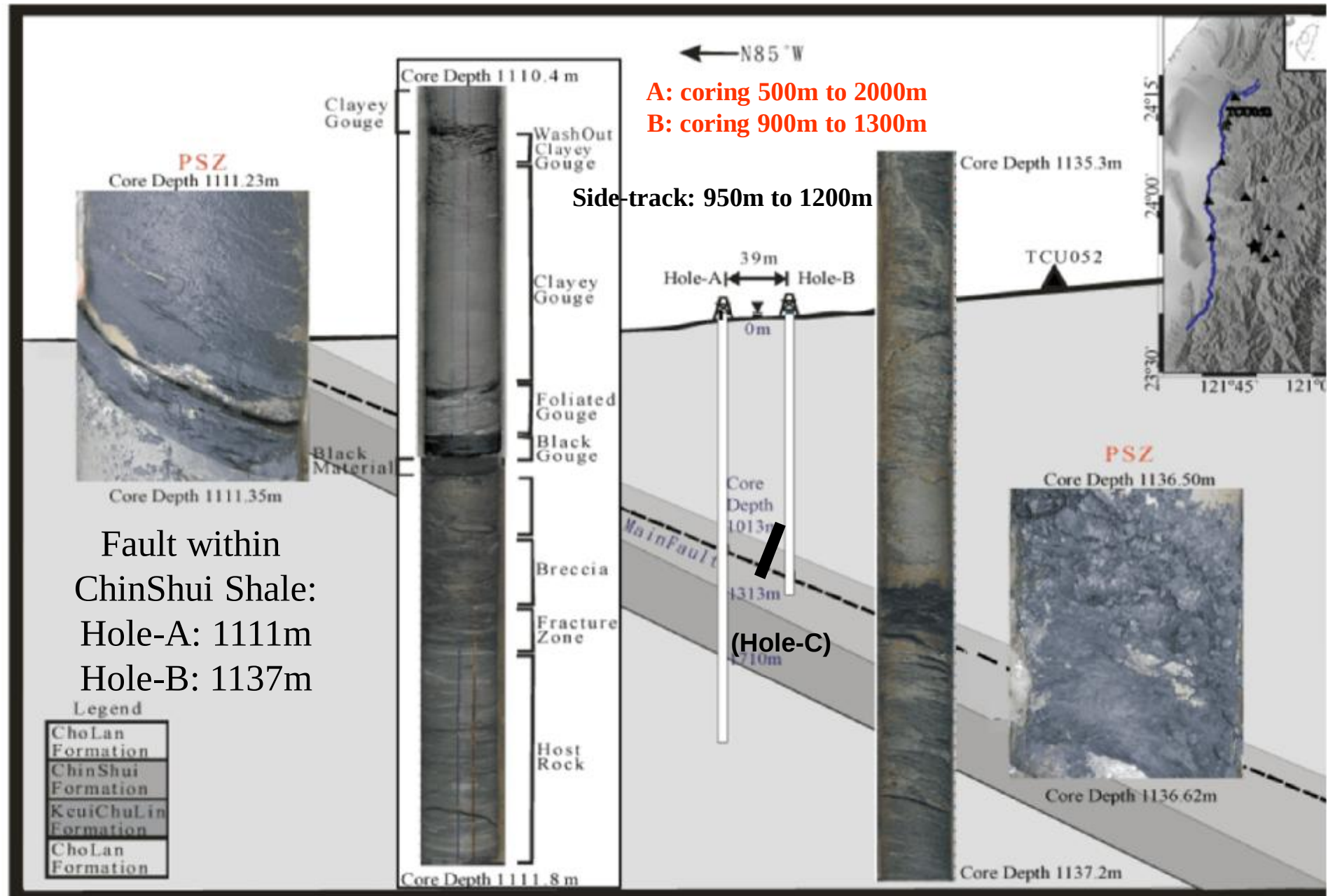
Kuo-Fong Ma	<i>National Central Univ.</i>
Chien-Yin Wang	<i>National Central Univ.</i>
Yi-Ben Tsai	<i>National Central Univ.</i>
Jih-Hao Hung	<i>National Central Univ.</i>
Sheng-Rong Song	<i>National Taiwan Univ.</i>

Hidemi Tanaka	Univ. of Tokyo
James Mori	Kyoto Univ., DPRI
Hisao Ito	AIST
Wonn Soh	JAMSTEC
Mark Zoback	Stanford Univ.
Steve Hickman	USGS
Bill Ellsworth	USGS

***International Continental Drilling Program
(ICDP)***

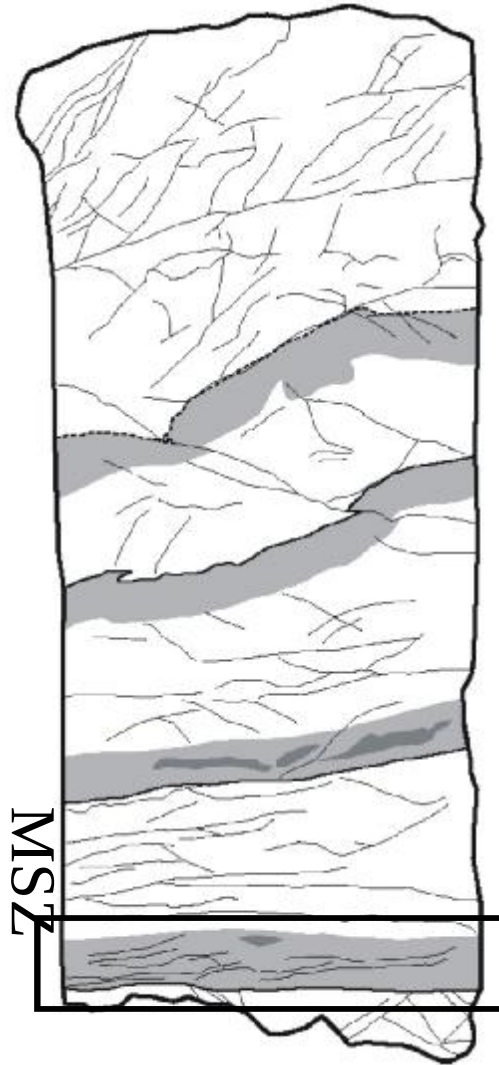
<http://www.icdp-online.de/sites/chelungpu/news/news.html>

TCDP: hole-A, and hole-B Drilling Schedule



Quantification on Earthquake Energy

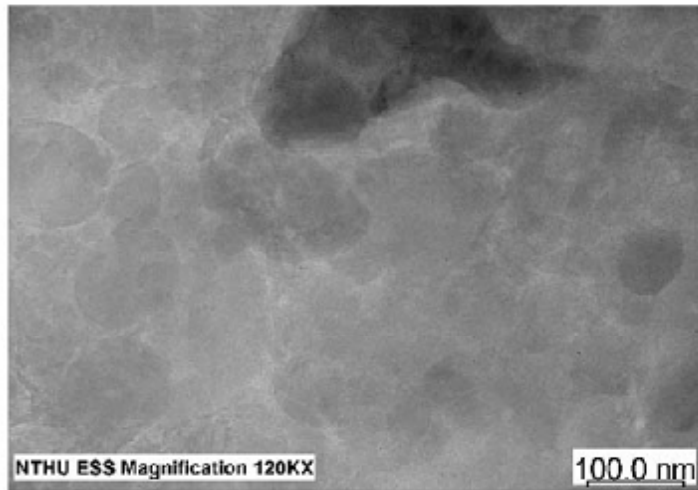
(Ma, Tanaka et al., Nature, 2006)



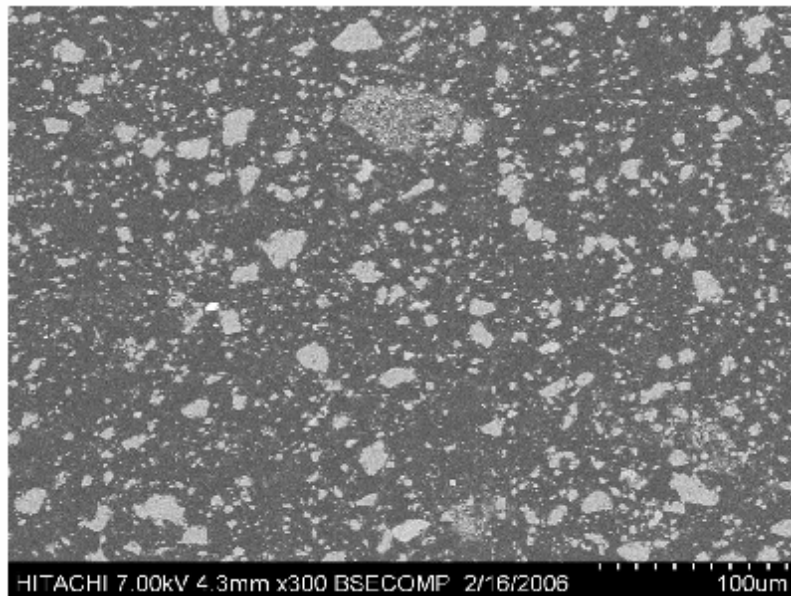
Observation of the grains in MSZ

- TEM, Transmission Electronic Microscope
- SEM, Scanning Electronic Microscope
- OM, Optical Microscope

(b)



SEM images
100 μm



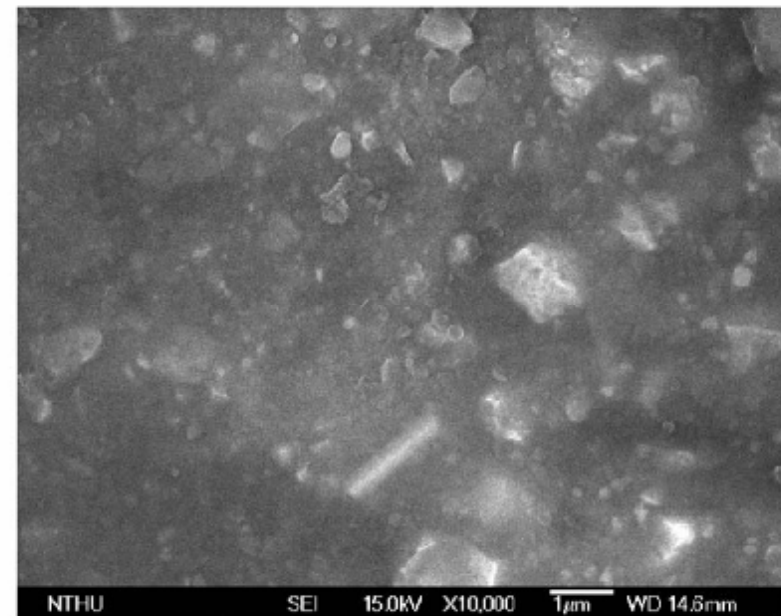
TEM

-Grain Class: 50nm
100 μm

TEM images:
Smaller grains from
non-fracturing

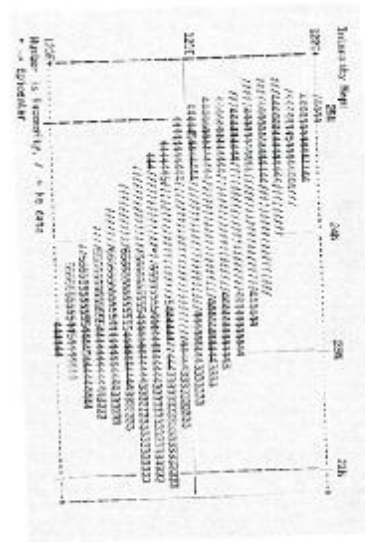
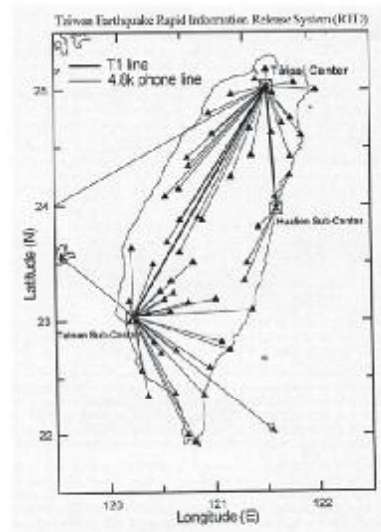
1 μm

(a)



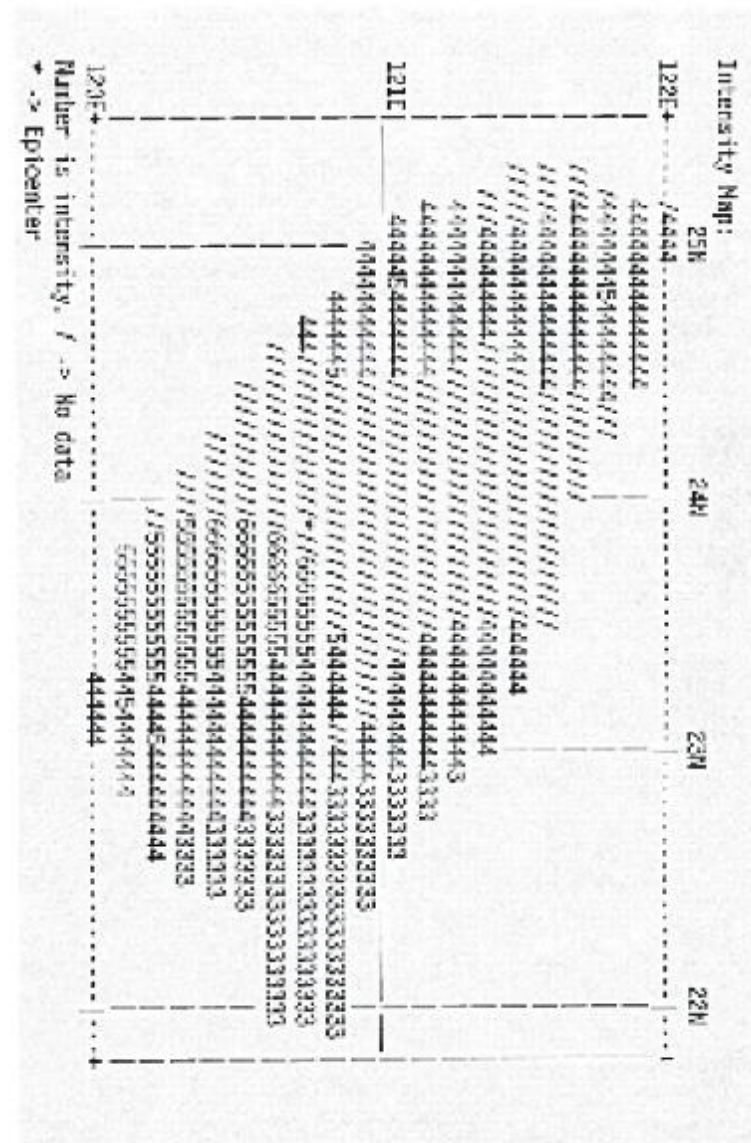
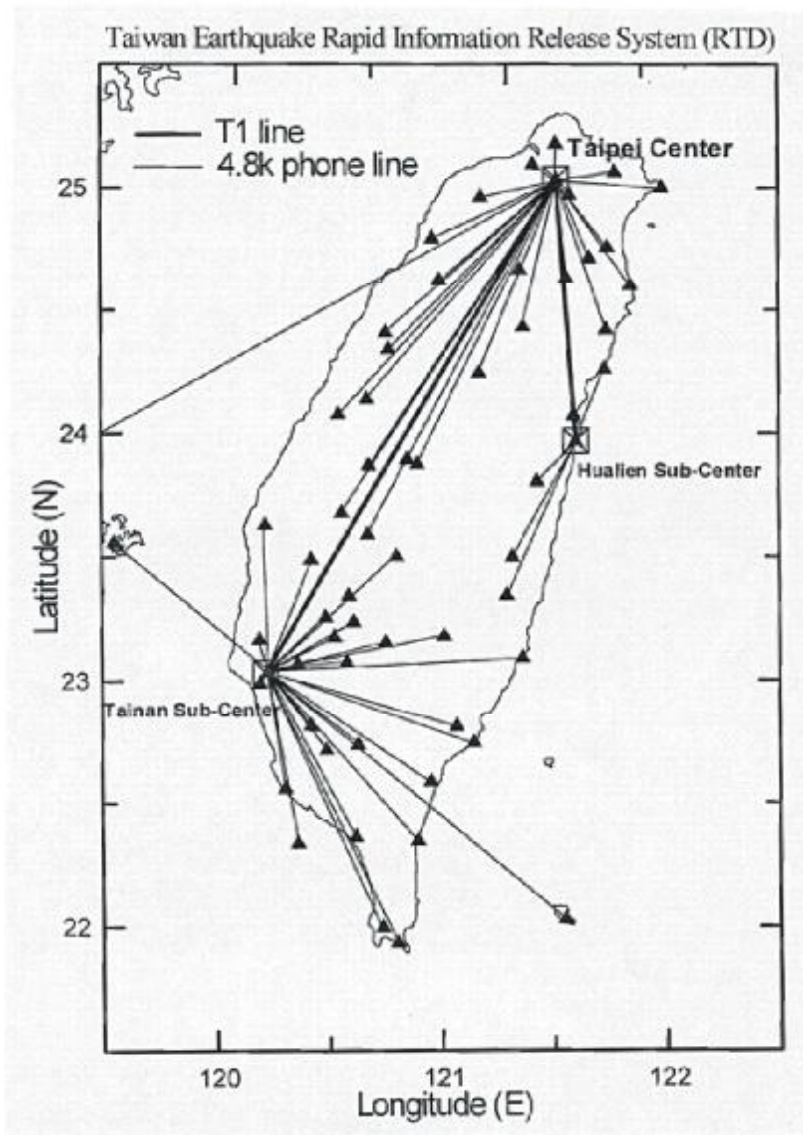
(b)

Taiwan Real-Time System (RTD) and Chi-Chi Earthquake
(Wu et al. 2000)



即時地震學、結構控制

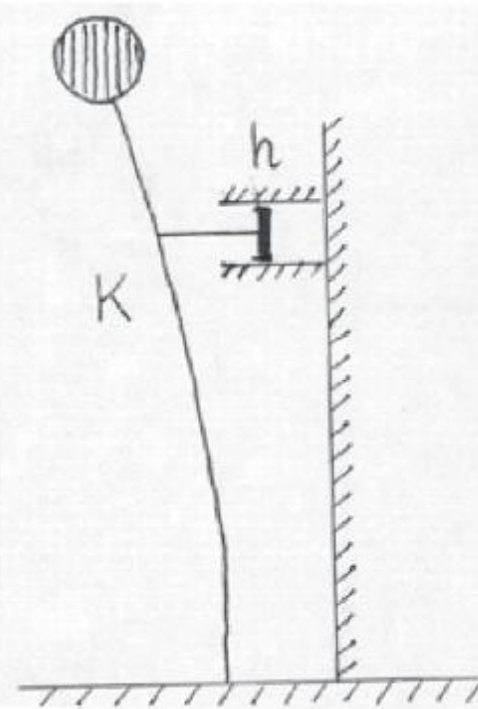
Taiwan Real-Time System (RTD) and Chi-Chi Earthquake (Wu et al. 2000)



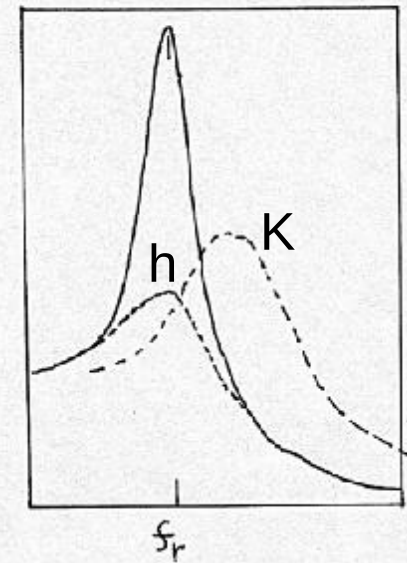
Structural Control



Model Structure

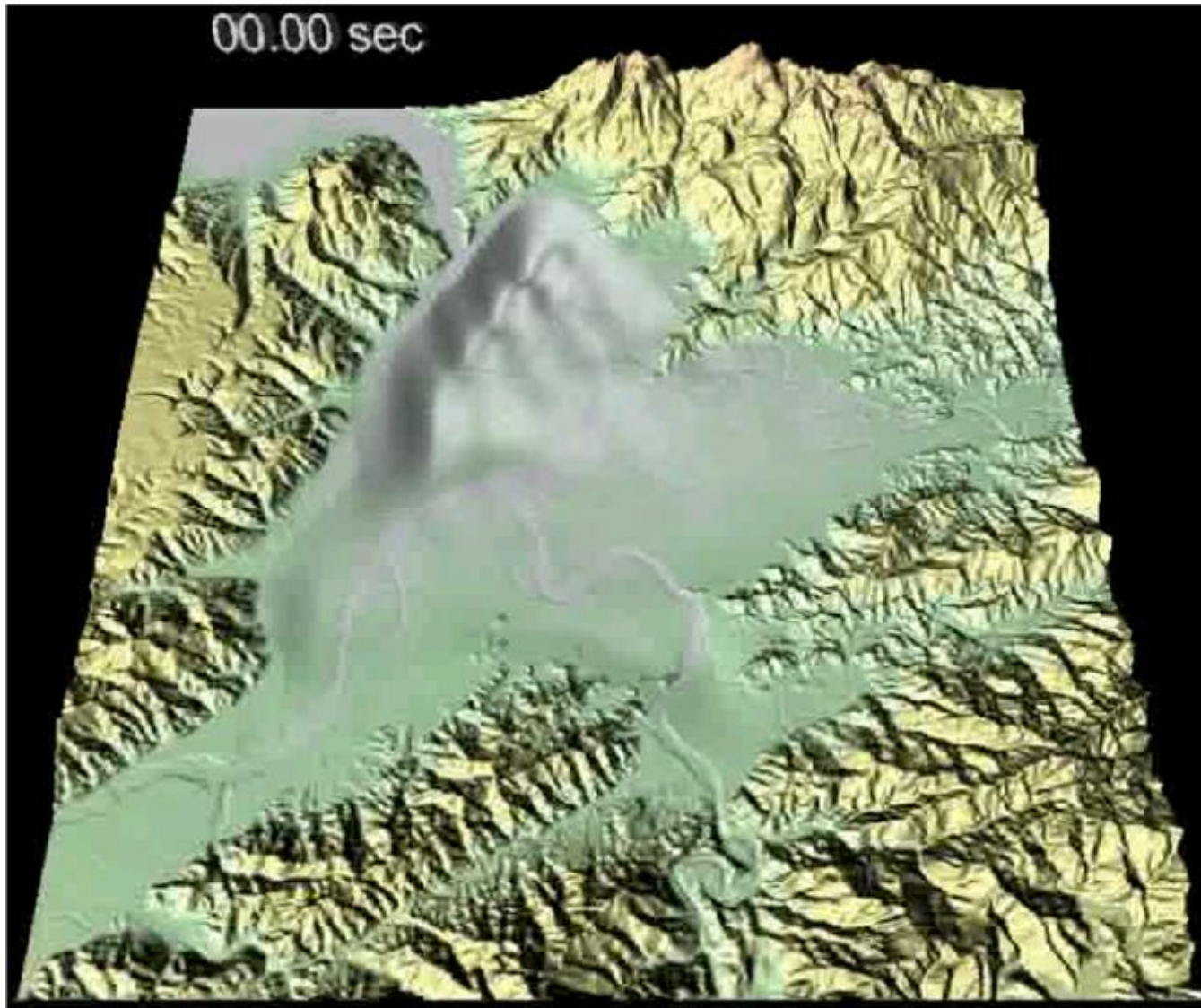


Resonance
—— uncontrolled
..... controlled



虛擬地震：強地動預估

臺北盆地



李憲忠
中研院地球所

康熙年間

陰曆 (康熙年 間)	西元	震災 地區	地震規模			備註
			徐	李	蔡	
21 年 7 月 前	1682/08 前	台南 地區				地鳴
21 年 8 月	1682/09	岡山 地區				地鳴
25 年 4 月 20 日	1686/05/12	嘉 義、 台 南、 高雄		5.5		民房倒塌 甚多
33 年 4 月	1694/4~5	台北 地區	7	5.5		地陷、形成 康熙台北 湖
50 年 9 月 11 日	1711/10/22	台 南、 嘉義	5.5	>= 6.5	7	民房倒塌 甚多
54 年 9 月 15 日	1715/10/11	嘉義 地區	6.5			民房倒塌 甚多
56 年 1 月 21 日	1717/03/03	台灣 南部	6			赤坎城傾 壞
59 年 10 月 1 日	1720/10/31	台 南、 嘉 義、 高雄	6			地裂、噴 砂、死者多 數
59 年 12 月 8 日	1721/01/05	嘉 義、 台 南、 彰化	6.5	6		房屋傾 倒、居民多 壓死
60 年 8 月	1721/09~10	台南 地區				廟宇、房屋 傾、死者多 數
61 年 7 月 11 日	1722/08/22	鳳山 地區				地裂、鯉魚 山泥火山 爆發

Reference:中央氣象局

1999 集集地震



二十世紀傷亡最嚴重的歷史地震

- 1920 年，中國甘肅省發生規模 8.5 地震，20萬人死亡。
- 1923年9月1日，日本關東發生規模8.3 大地震，致使4萬人喪生。東京36萬多戶房屋遭到毀滅，死亡和失蹤者達14萬多。
- 1976年7月28日，中國唐山規模7.8大地震，造成造成本世紀世界地震史上最悲慘的一幕：死亡242769人，重傷164851人

台灣地震觀測史

(1)1897~1944 日據時代

(2)1945~1972 台灣地震觀測低潮期

(3)1971~1990 TTSN時期

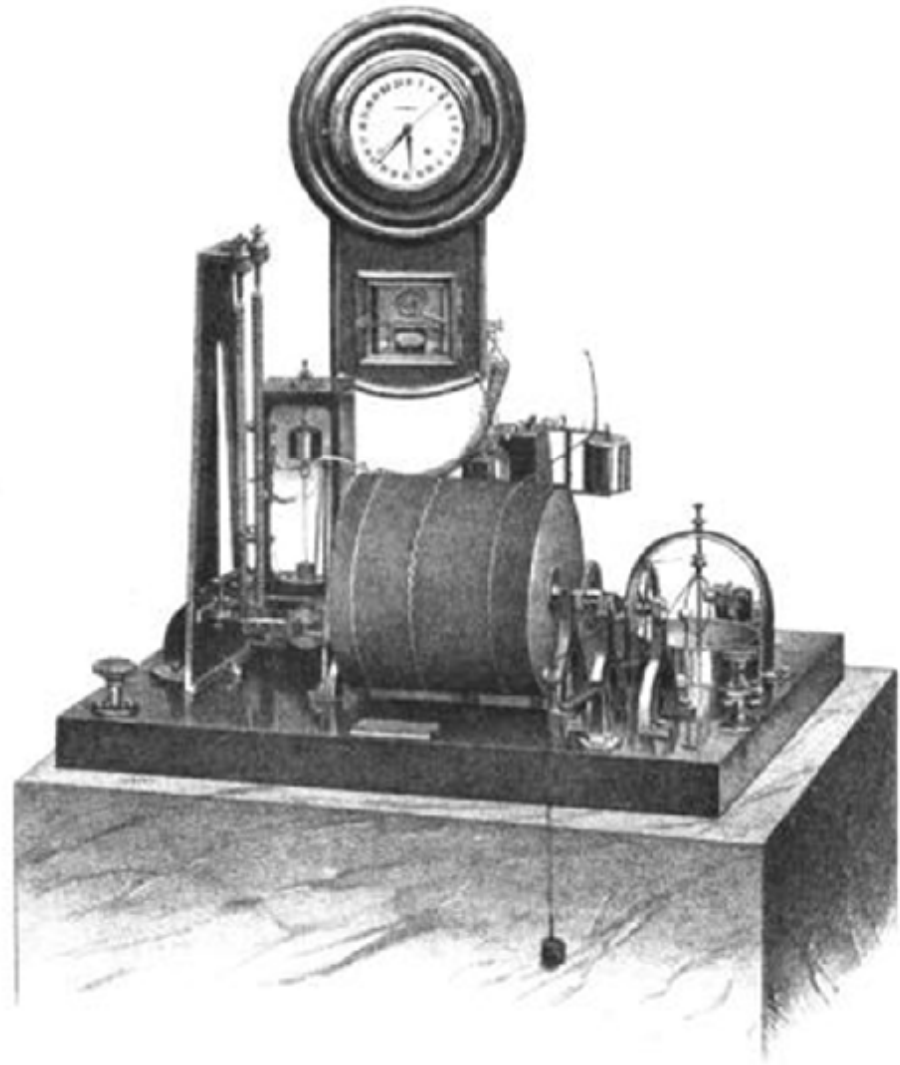
- 蔡義本 鄧大量 吳大銘教授 建立全台地震網

(4)1990~ 現代化觀測時期

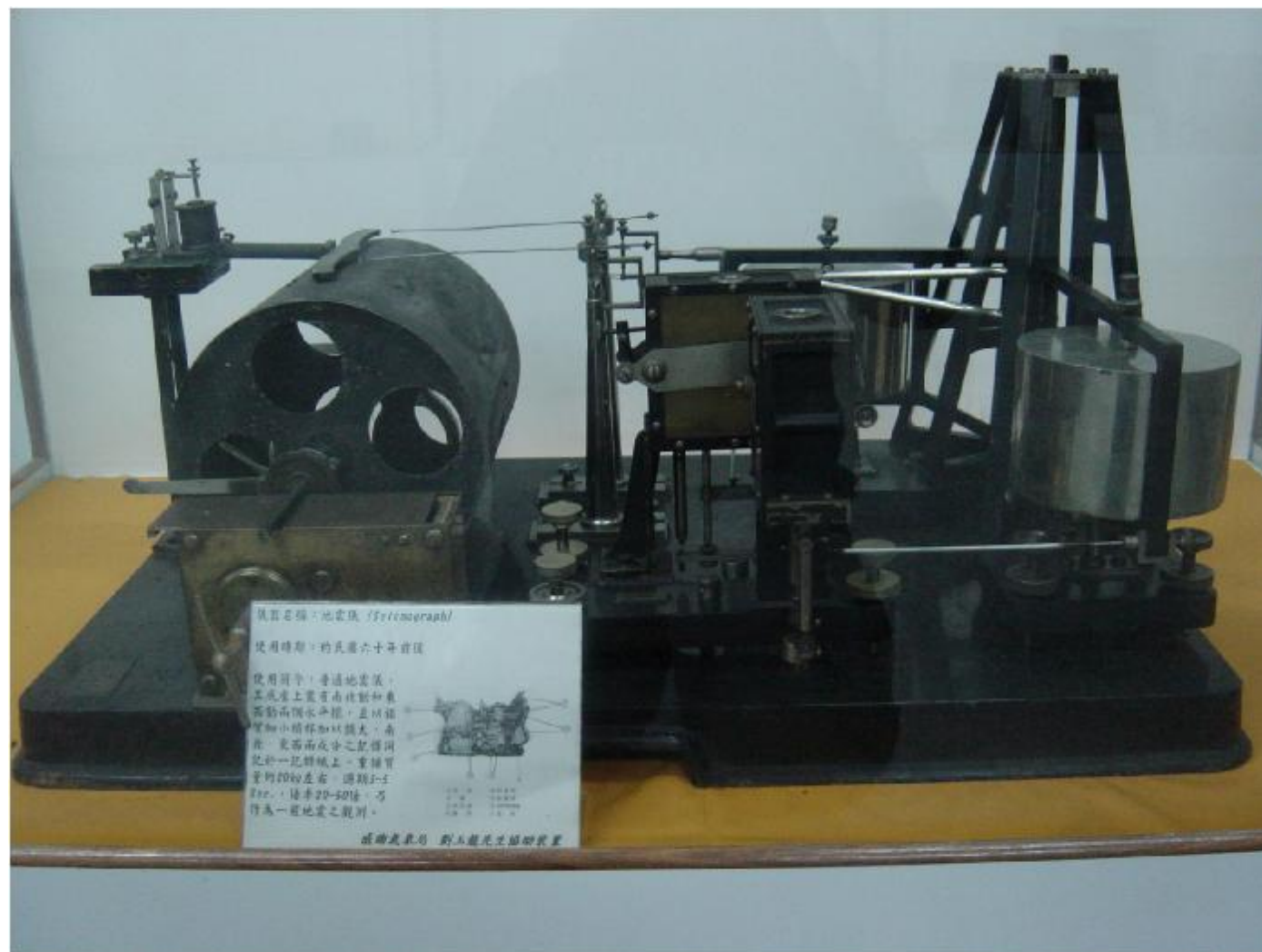
全台強震網及時地震分析

GRAY-MILNE SEISMOGRAPH

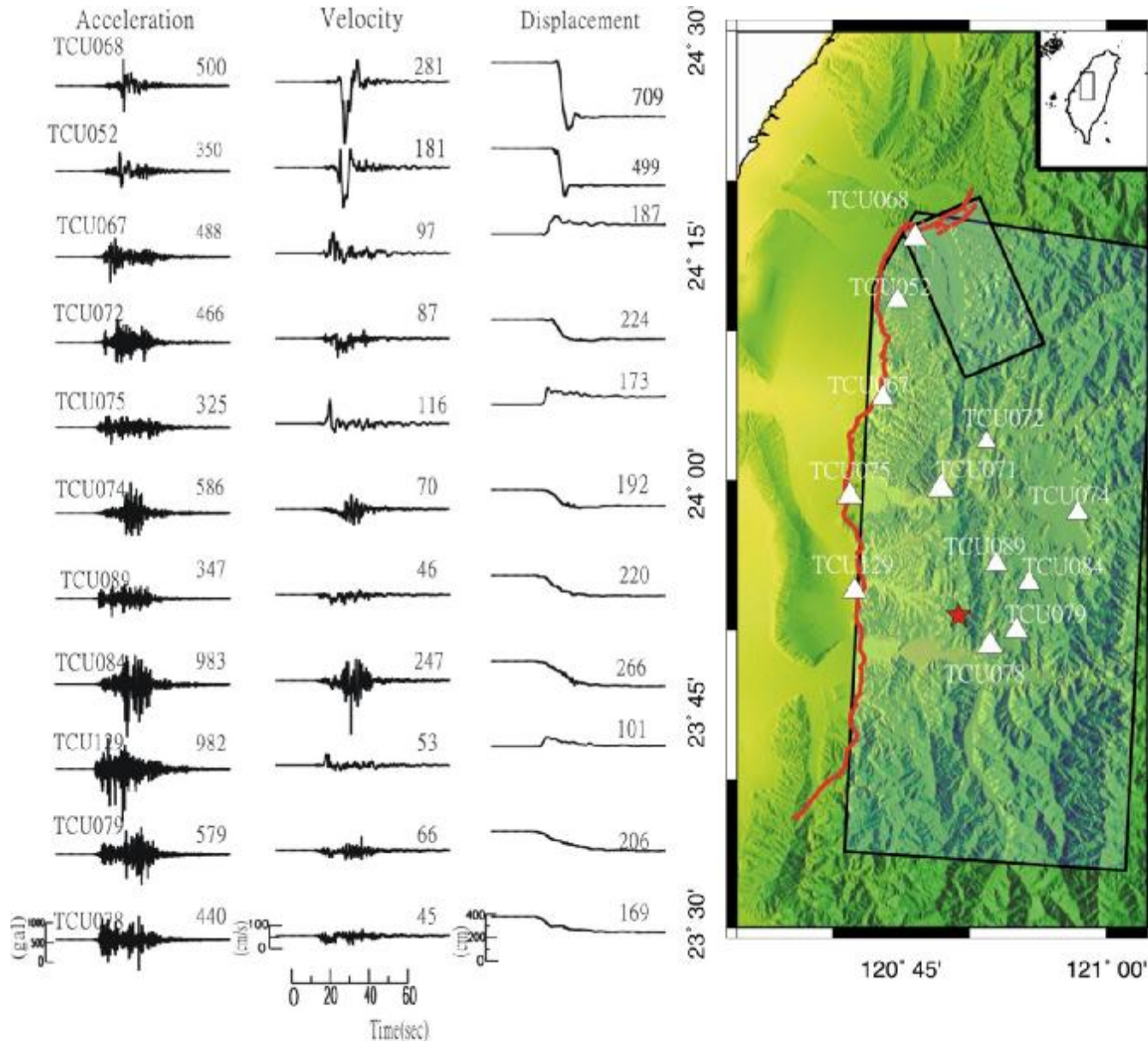
1897年12月設立於
台北測候所之格雷－
米爾恩型地震儀



民國六十年的地震儀



地震動力 (What Controls the Earthquake Dynamics ?)



Dislocation Damage



Shaking Damage

Thrust Fault Example



