Active Fault Observation and Research on Earthquake Potential in Taiwan

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CENTRAL GEOLOGICAL SURVEY

Outline

- Plate tectonic setting and historical earthquake disasters of Taiwan
- Geologic investigation of active faults
  - Detail active fault mapping
  - Fault geometry investigation
  - Paleoseismologic study
- Crustal deformation observation
  - GPS ground surface displacement monitoring
  - Precise leveling survey across active faults
- Earthquake precursor research
  - Geochemical monitoring
  - Groundwater pressure, and
  - Borehole strainmeter measurement
- Concluding remarks

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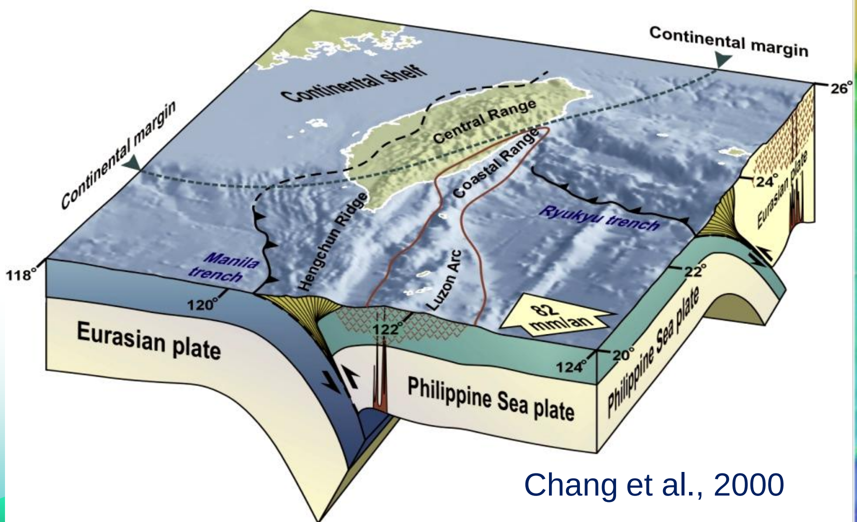
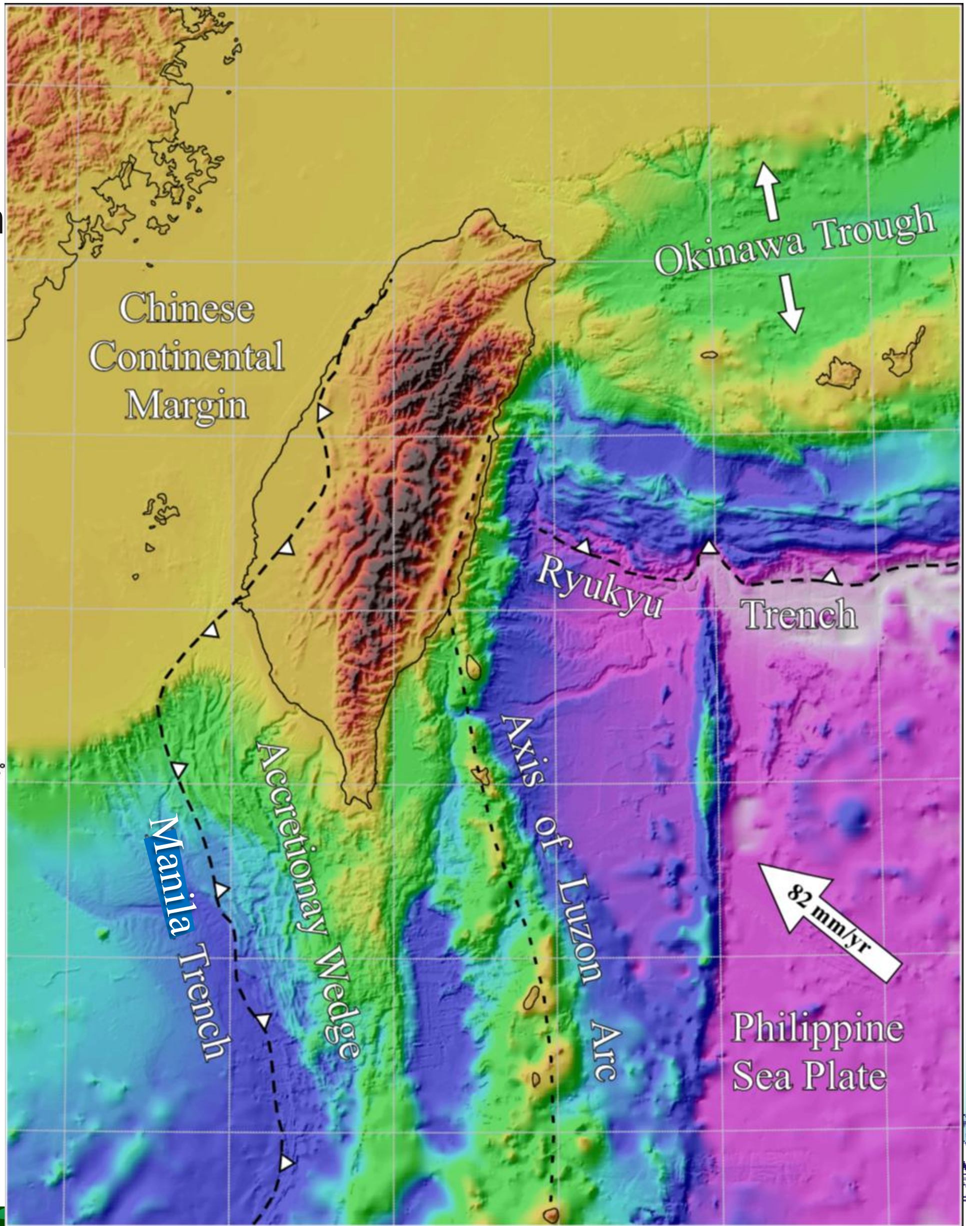
Plate Tectonic Setting

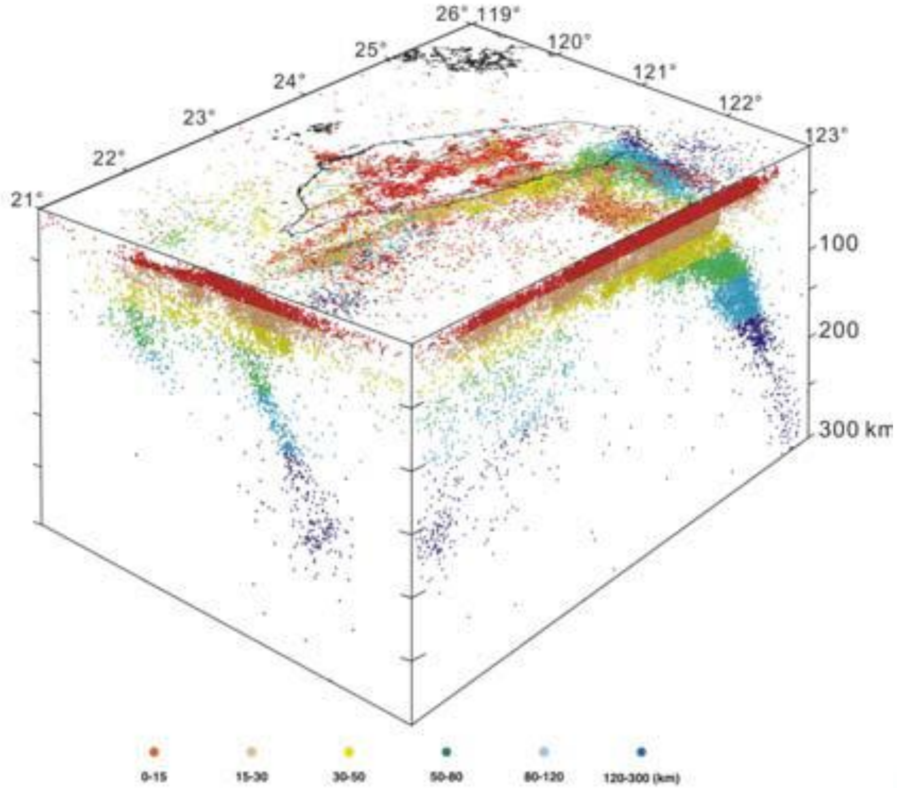
- Offshore northeast of Taiwan, the Philippine Sea plate is subducting northward under the Eurasian plate.
- The southern part of Taiwan, the Eurasian plate is subducting eastward under the Philippine Sea plate.
- In between these two subduction zones, collision is taking place with the contact between the Eurasian and the Philippine Sea plates along the Longitudinal Valley.

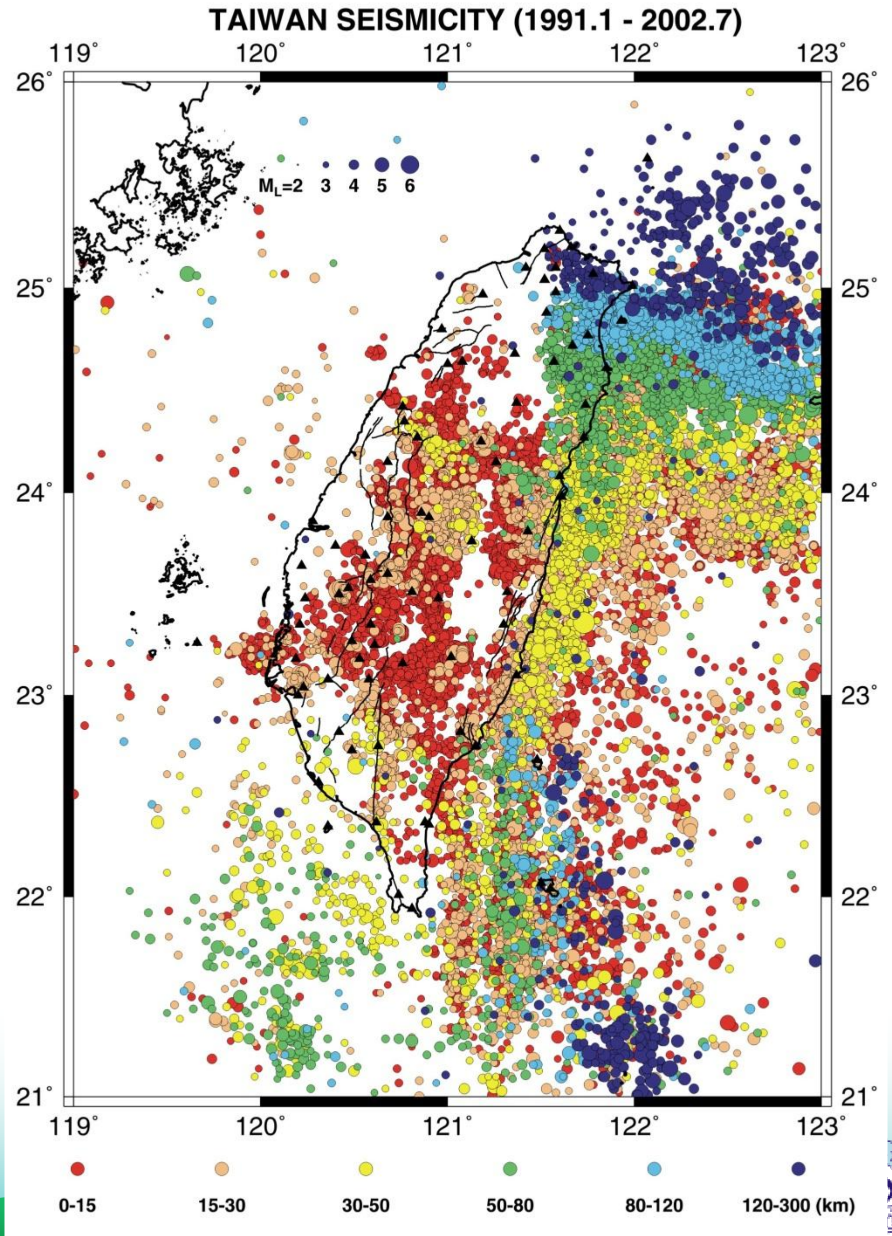


Chang et al., 2000



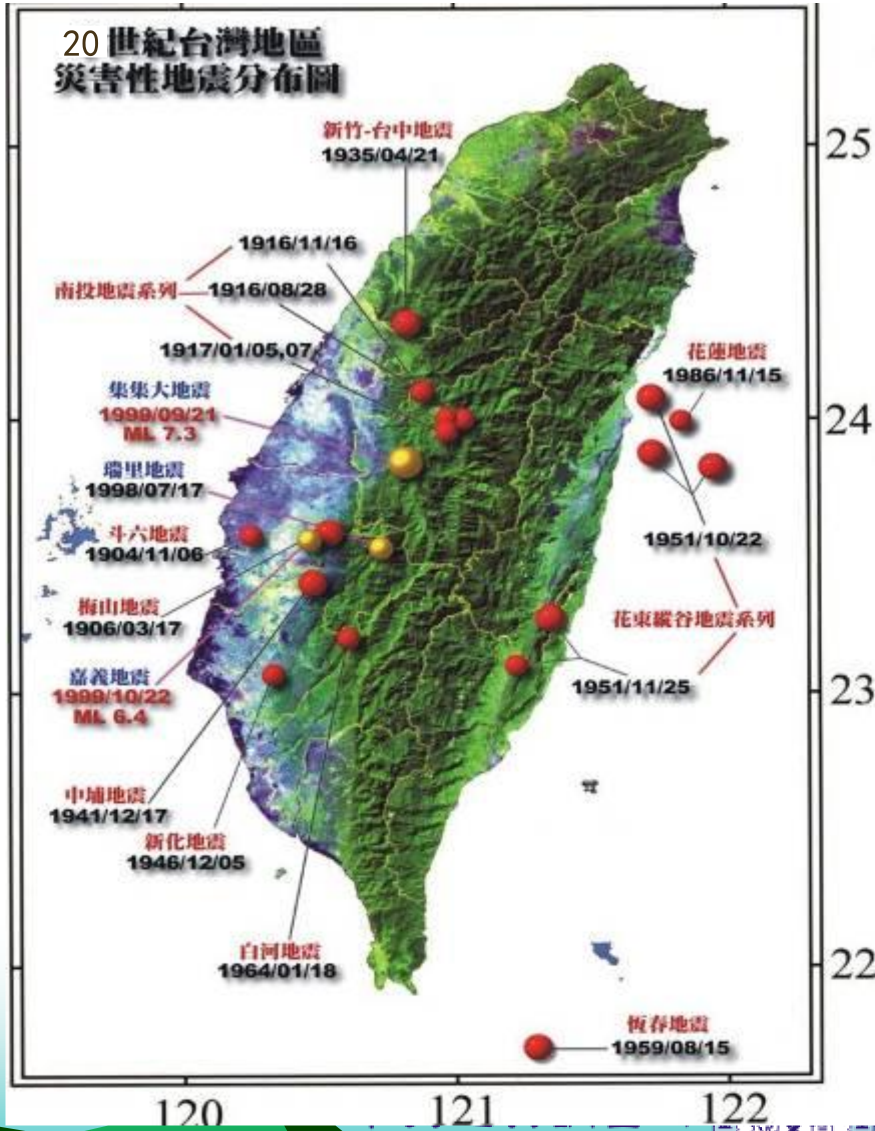
Subduction zones unraveled by seismicity

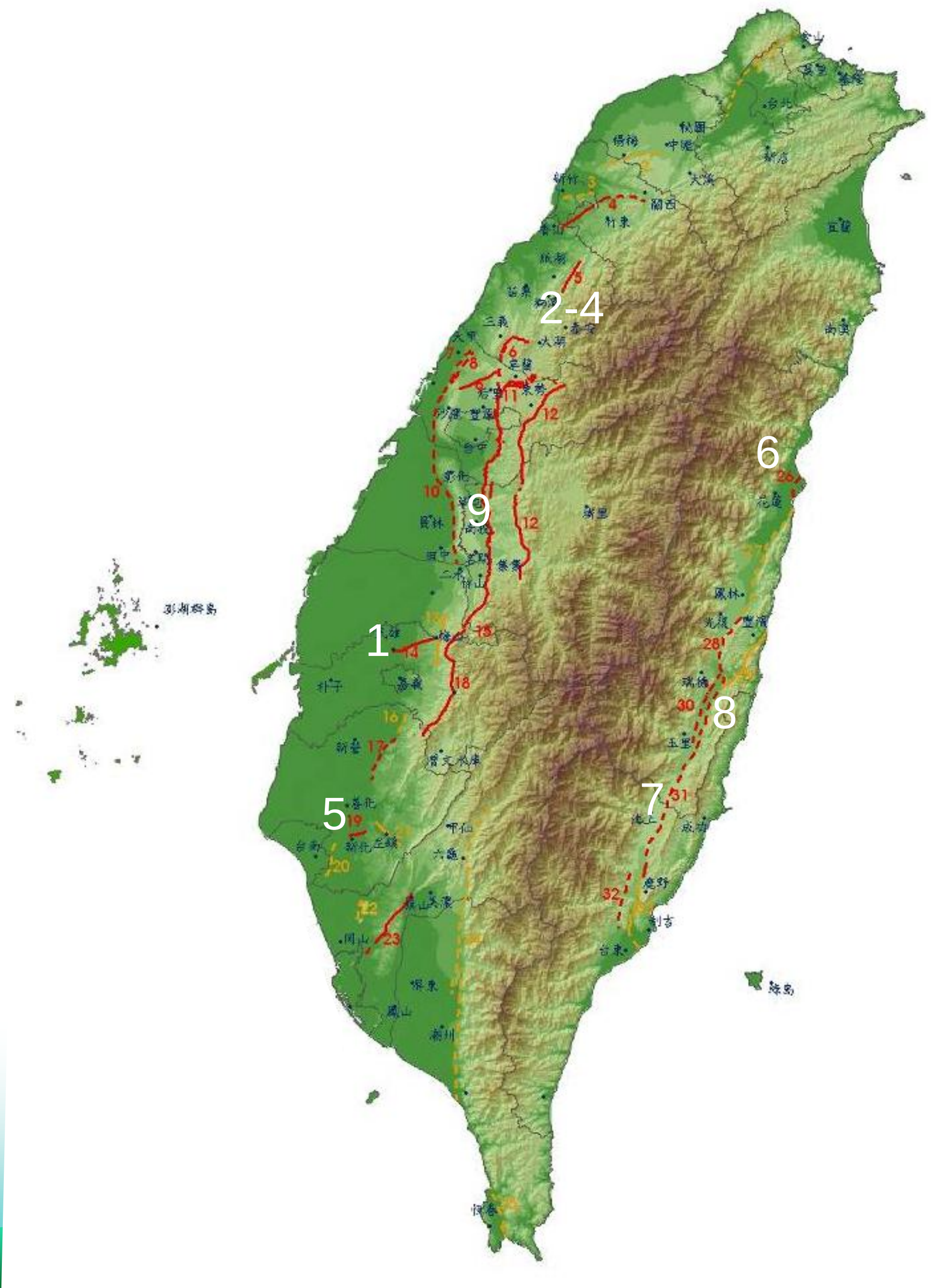




Disastrous Earthquakes for the 20th Century

Name	Occurred Time	Depth of focus (km)	Magnitude (M_L)	Casualties
1. Douliu	1904/11/06	7	6.1	145 dead, 158 injured
2. Meishan	1906/03/17	6	7.1	1258 dead, 2385 injured
3. Nantou	1916/08/28	45	6.8	16 dead, 159 injured
4. Hsinchu-Taichung	1935/ 04/21	5	7.1	3276 dead, 12053 injured
5. Zhongpu	1941/12/17	12	7.1	358 dead, 733 injured
6. Hsinhua	1946/12/05	5	6.1	74 dead, 482 injured
7. A series of East Rift Valley	1951/10 -11	4 36	7.3 7.3	68 dead, 856 injured ; 17 dead, 326 injured
8.Hengchun	1959/ 08/15	20	7.1	17 dead, 68 injured
9. Baihe	1964/01/18	18	6.3	106 dead, 650 injured
10. Haulien	1986/11/15	15	6.8	13 dead, 45 injured
11. Chi-Chi	1999/09/21	8	7.3	2456 dead, 10718 injured





Faults activated in 20th century

No.	Fault Name	Occurred Time	M_L
1	Meishan F.	1906.03.17	7.1
2	Shihtan F.	1935.04.21	7.1
3	Tuntzuchiao F.	1935.04.21	7.1
4	Shenchoshan F.	1935.04.21	7.1
5	Hsinhua F.	1946.12.05	6.1
6	Milun F.	1951.10.22	7.3
7	Yuli F.	1951.11.25	7.3
8	Rueisuei F.	1972.04.24	6.9
9	Chelungpu F.	1999.09.21	7.3

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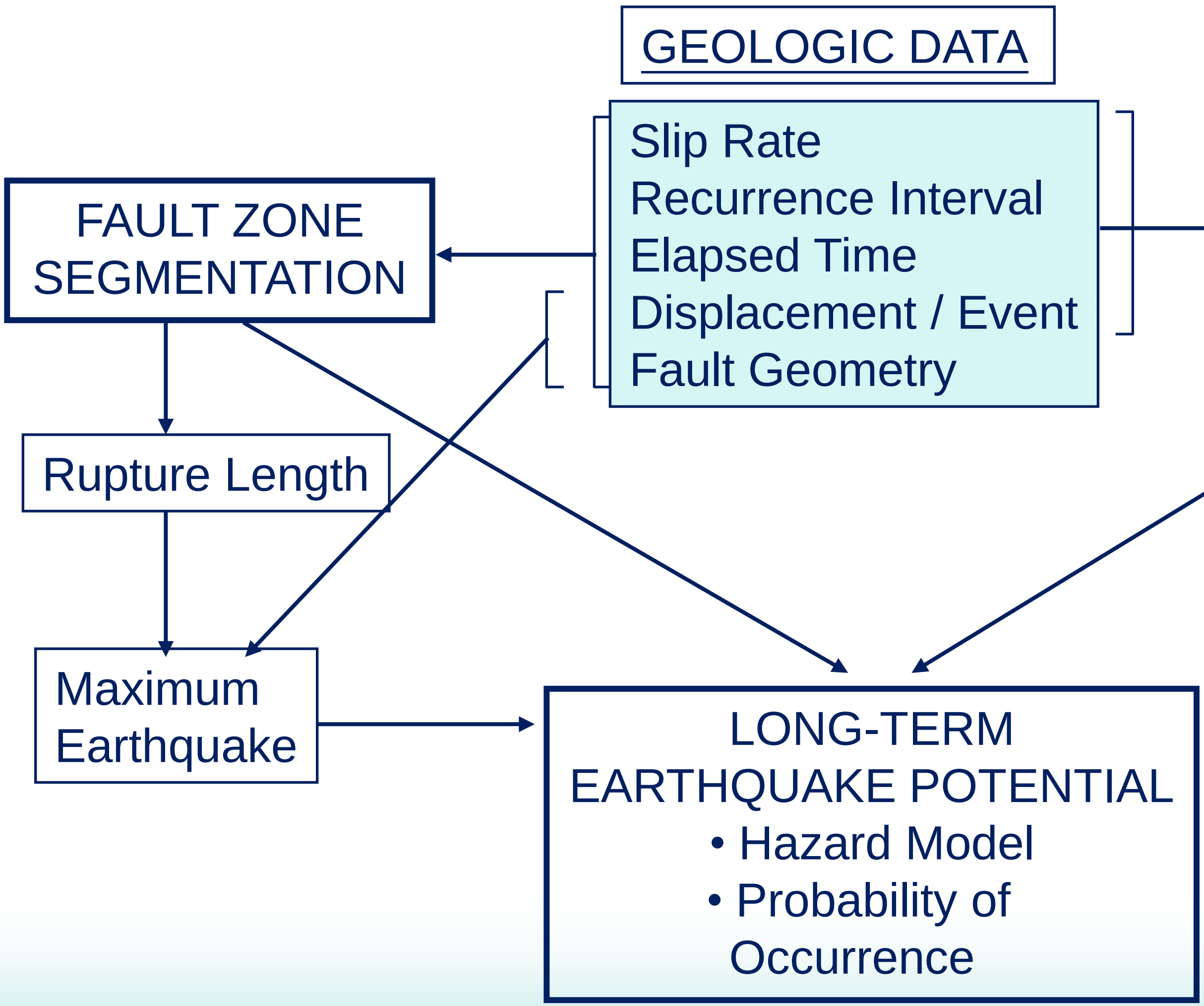
Seismic Hazard Assessments for Active Faults



From Schwartz and Coppersmith (1986)

Methodology for acquiring active fault parameters

- Fault geometry
  - Detail mapping
  - Geophysical exploration (seismic reflection, electric resistivity)
  - Deep borehole drilling
- Slip rate
  - Short term:monitoring horizontal and vertical displacement
  - Long term：paleoseismology
- Recurrence interval & elapsed time
  - Paleoseismology
  - Historical records
- Displacement/event
  - Paleoseismology
  - Historical records

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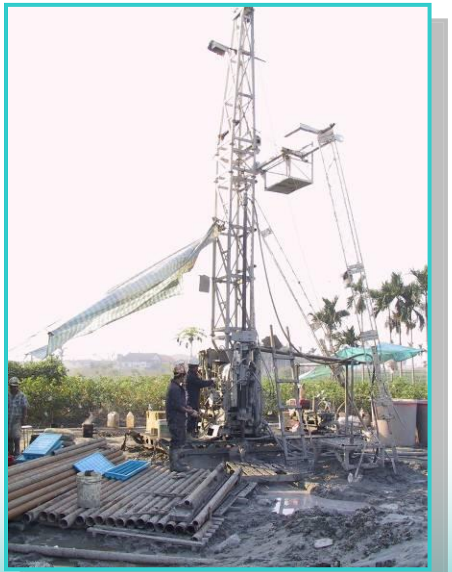
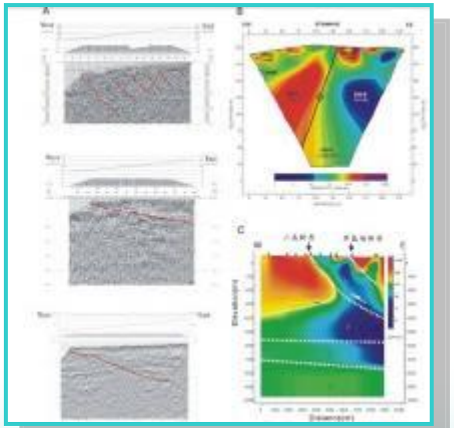
Mapping Active Faults

- Conventional methods and techniques, including interpretation of aerial photos and satellite imageries, field mapping, geophysical exploration, borehole drilling etc. are used for active fault mapping.
- To revise 1:500,000 active fault map.
- To Compile and publish 1:25,000 strip maps of active faults



Borehole drilling

Outcrop investigation



Geophysics prospecting

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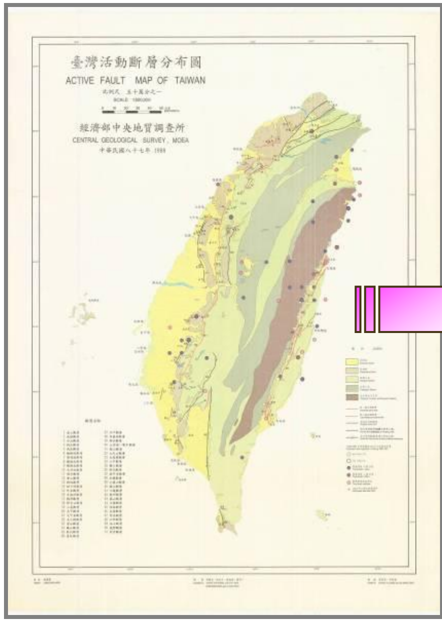
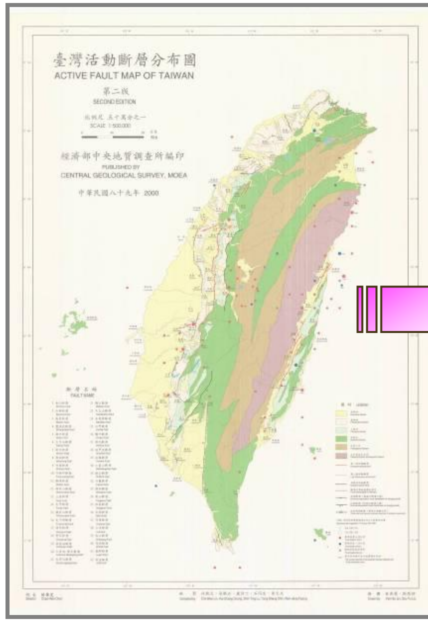
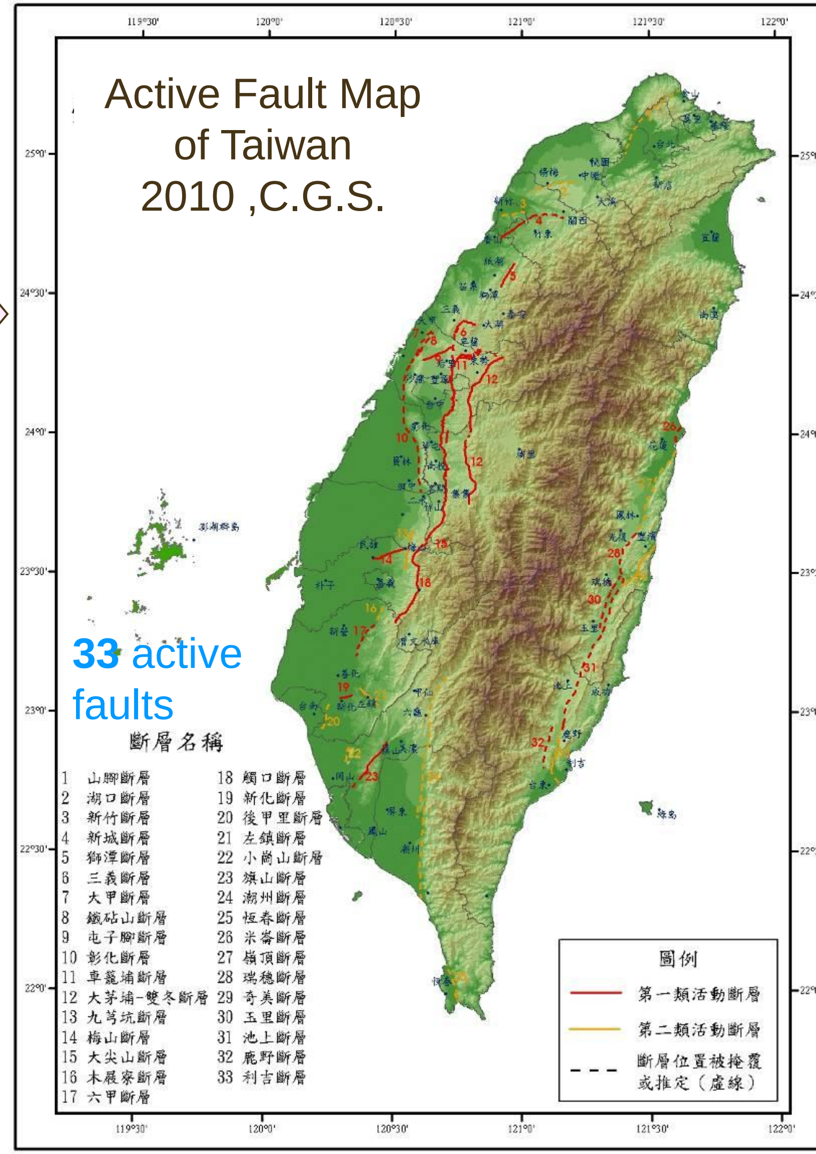
Active Fault Map of Taiwan



1998
(1:500,000)
51 active faults

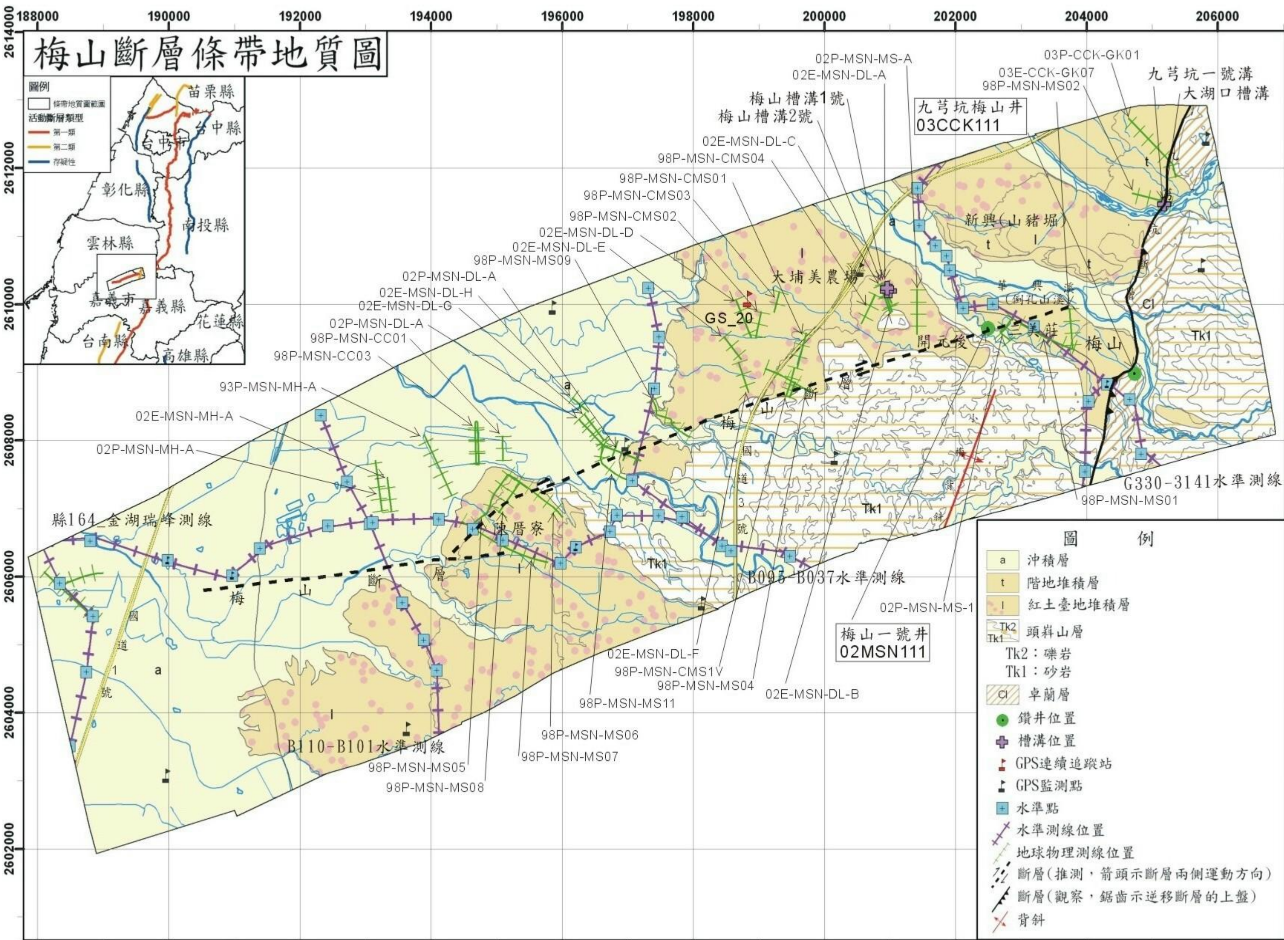


2000
(1:500,000)
42 active faults



- With the increase of data, the numbers, locations and category of the faults also change.

The Strip Map of Active Faults (1/25,000)



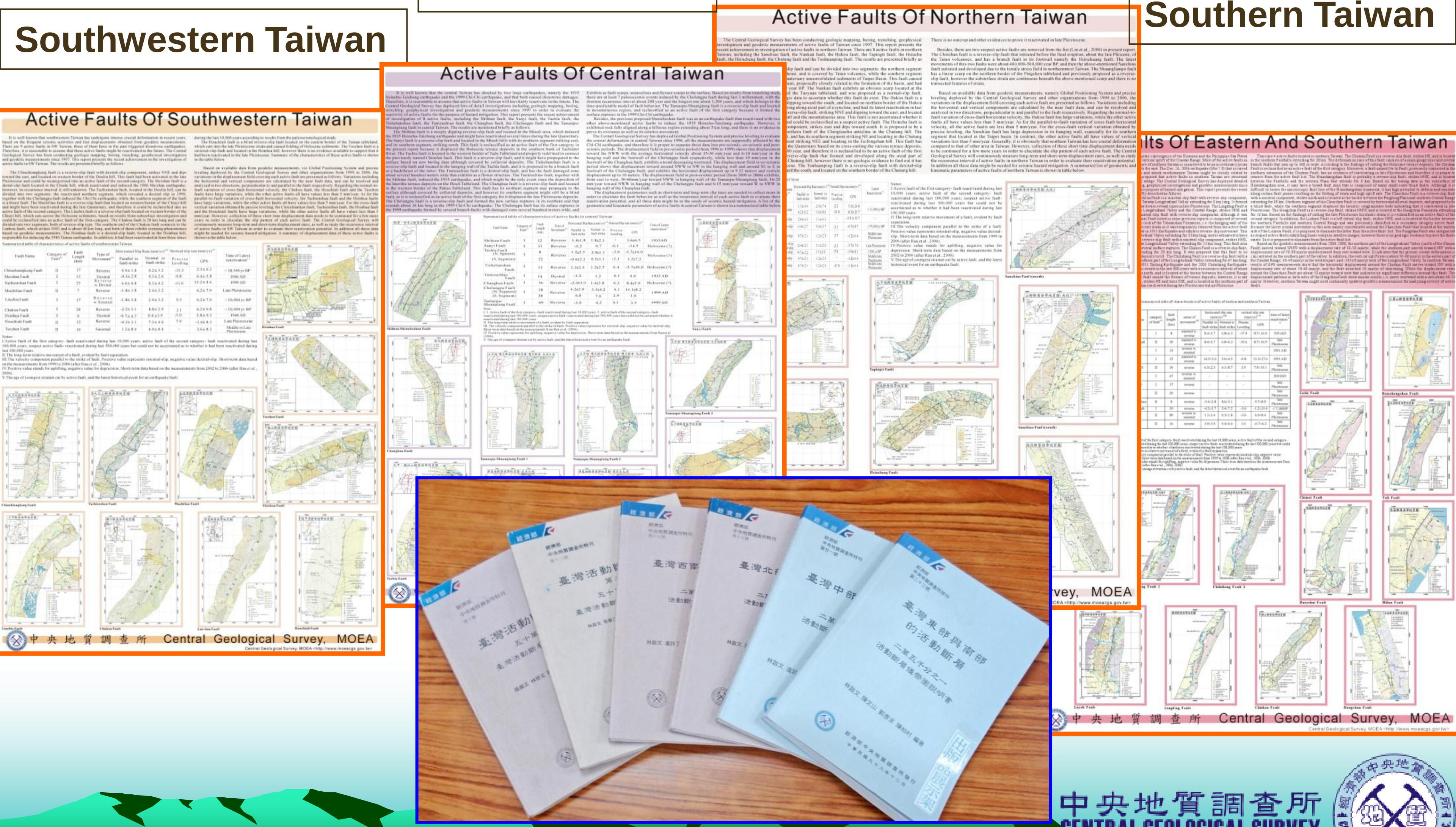
The Strip Map of Active Faults (1/25,000)

Southwestern Taiwan

Central Taiwan

Northern Taiwan

Eastern and Southern Taiwan



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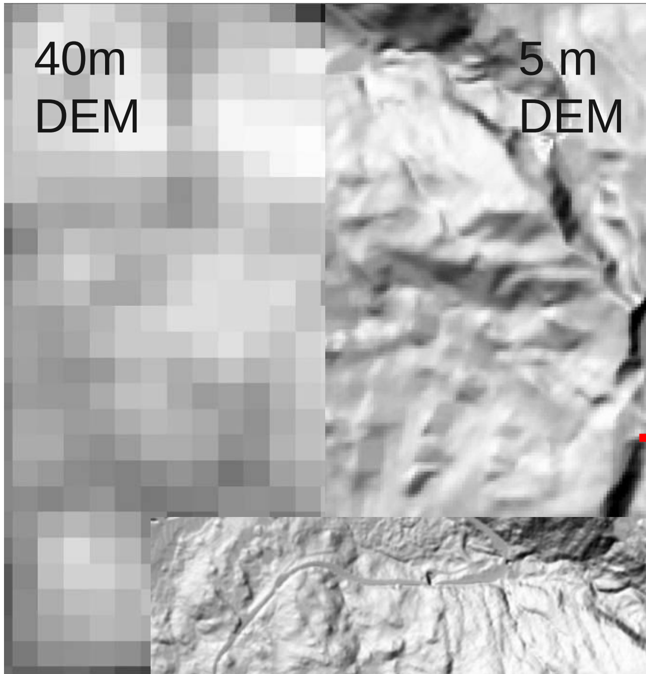
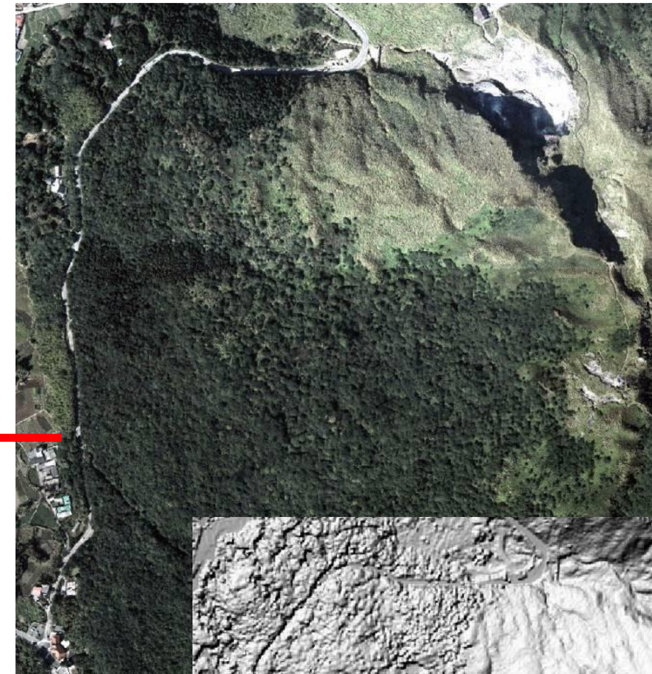
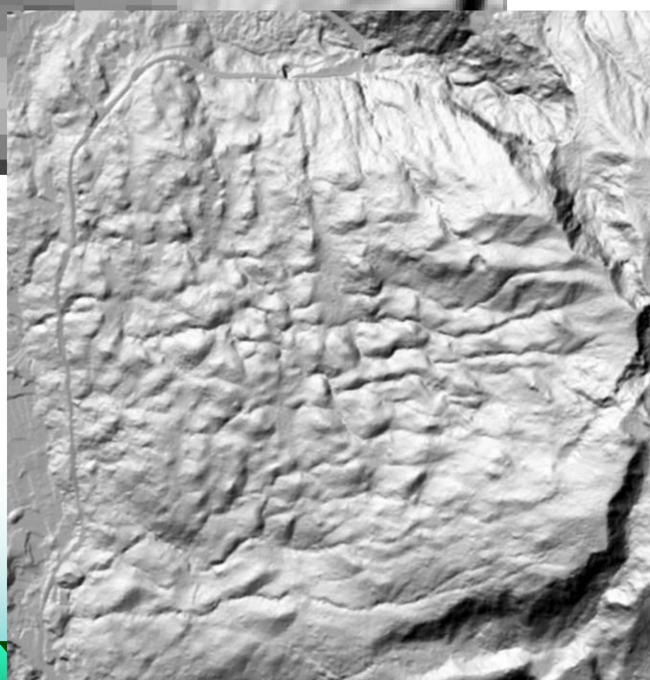
LiDAR-derived Images: Clarity of Bare Ground

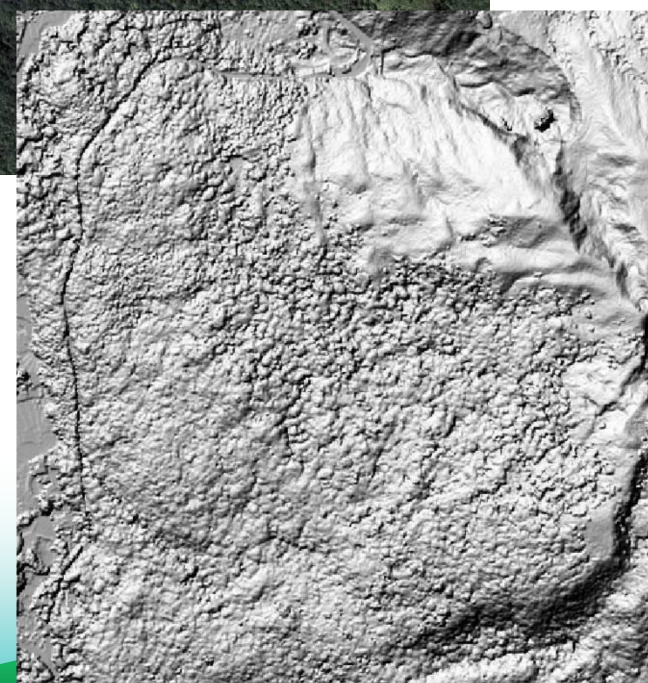




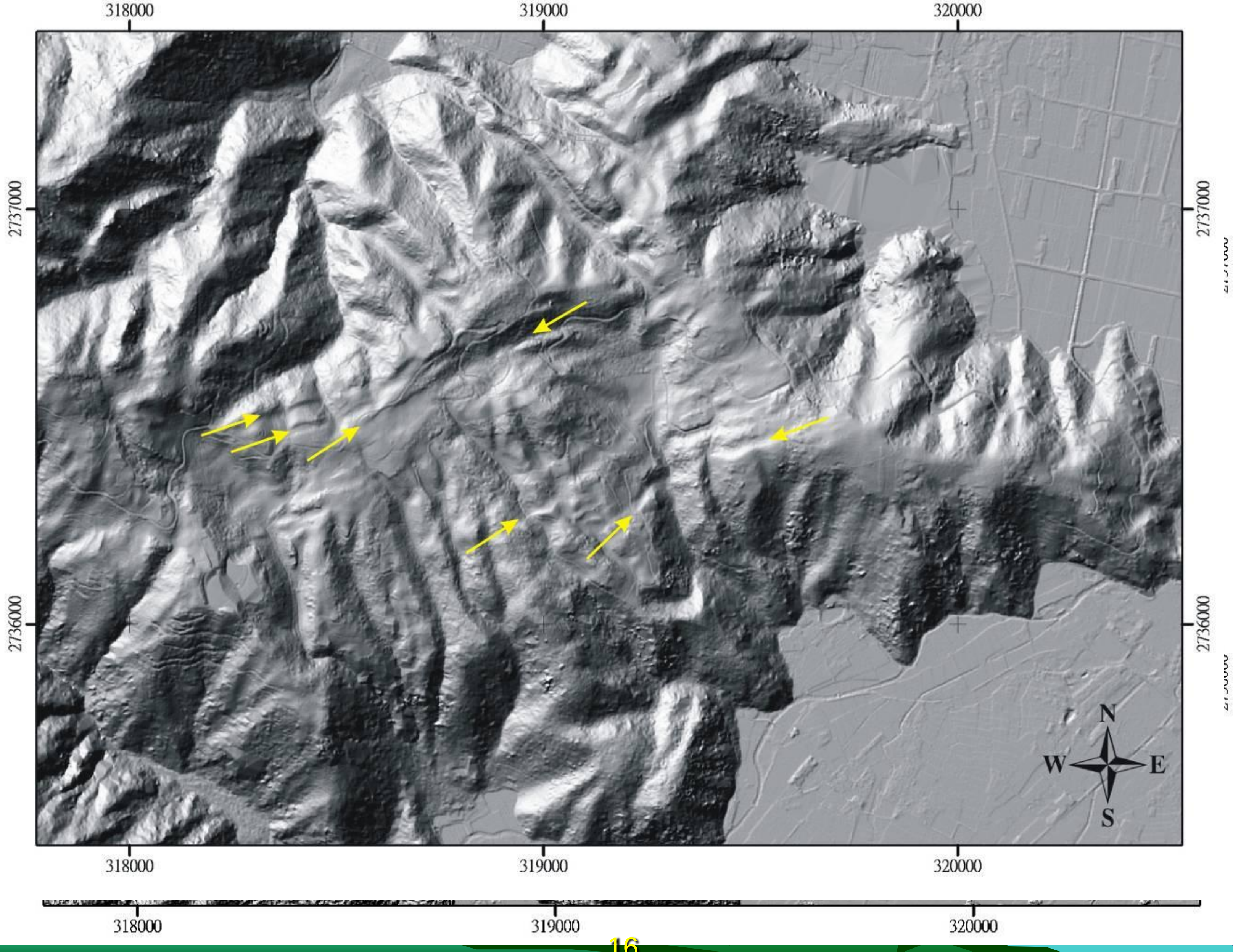
Airphoto

400 m

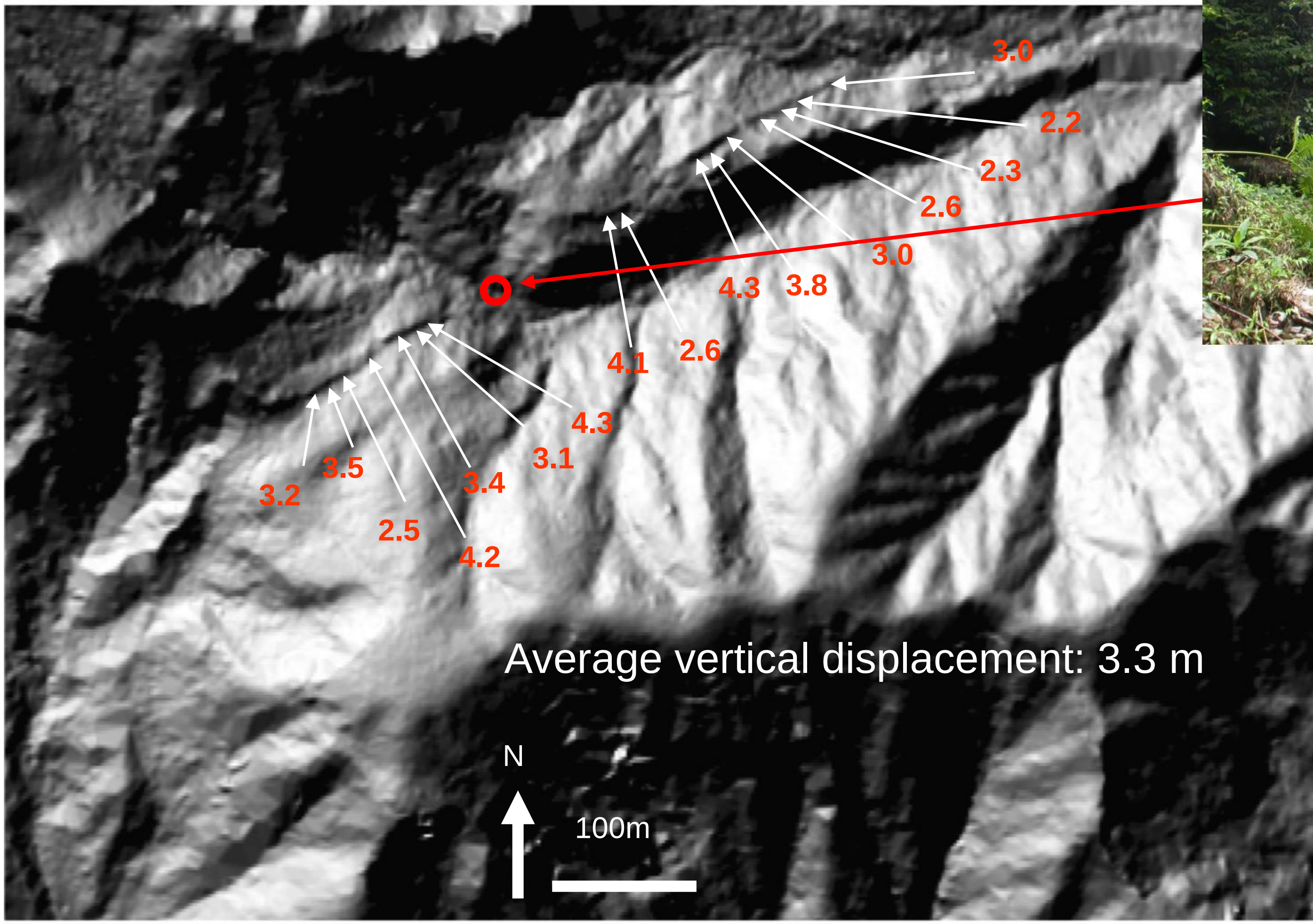


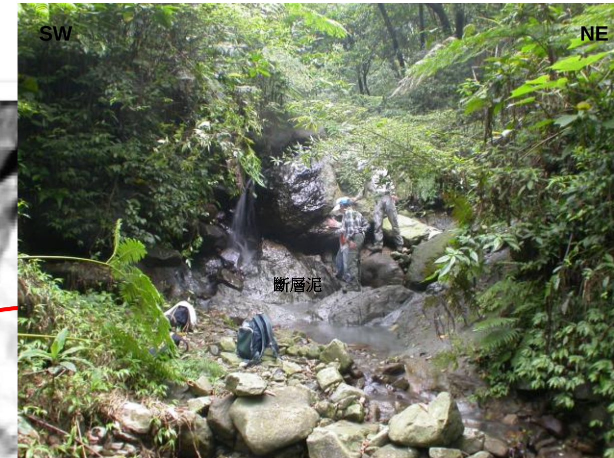


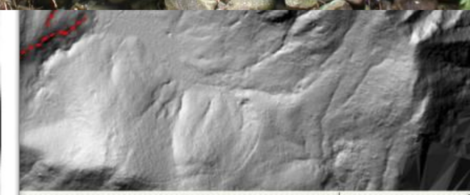
Fault Scarps are greatly enhanced after "striping" the vegetation

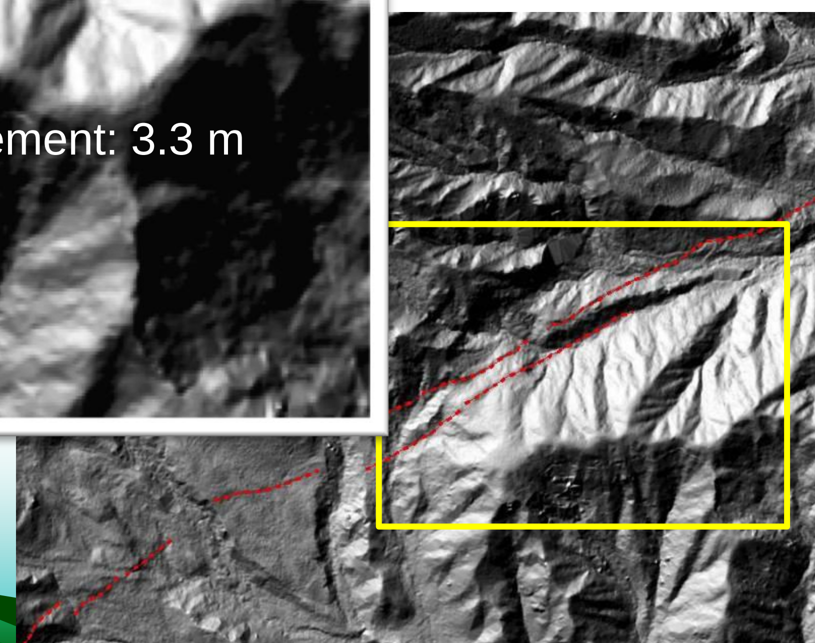


Mapping faults using the shading map derived from LiDAR



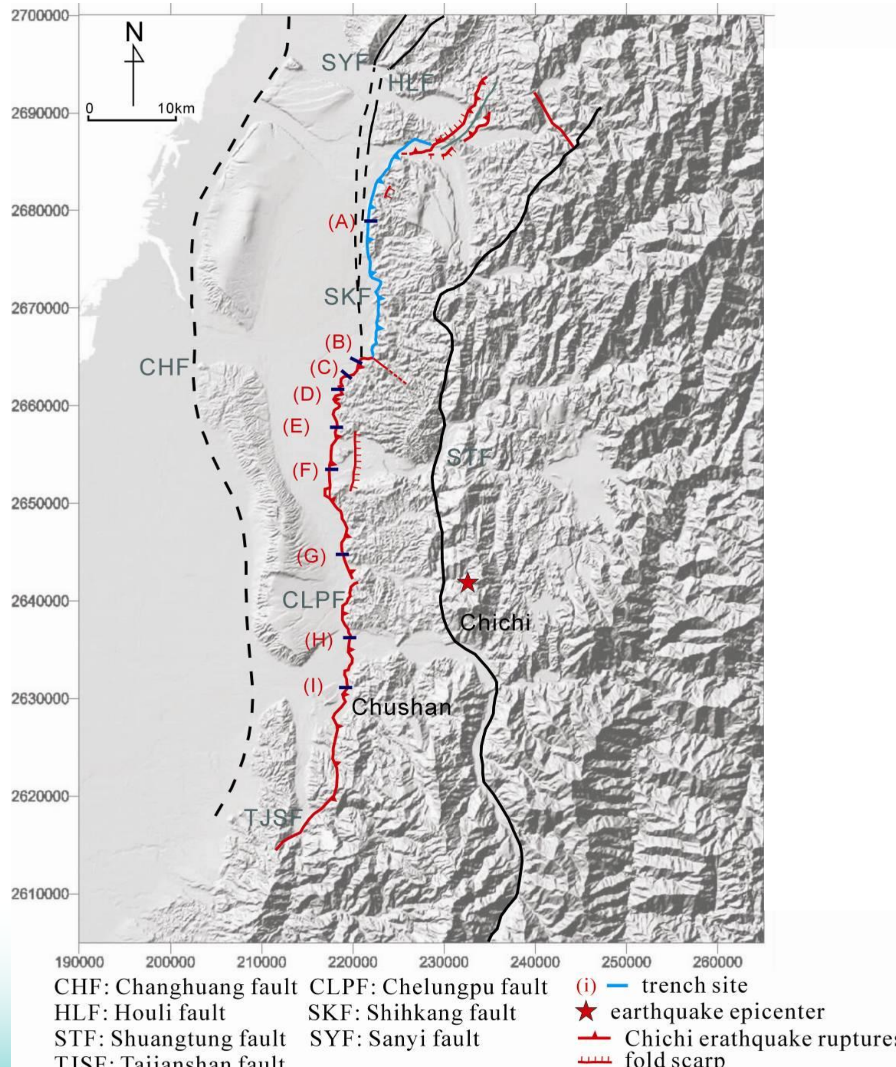


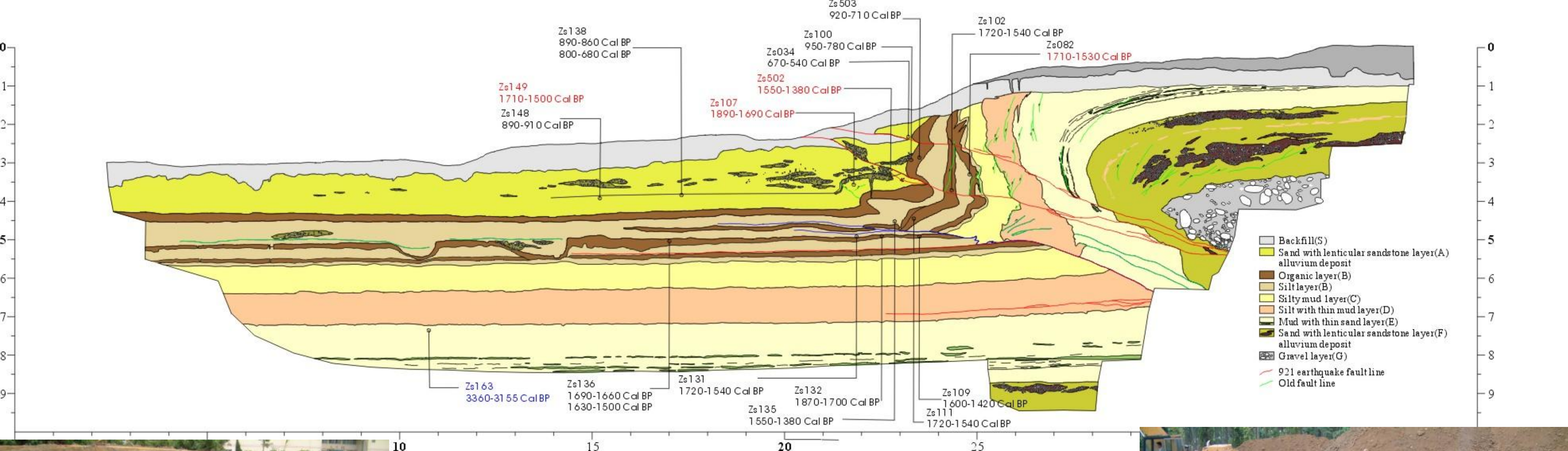




Paleoseismologic study

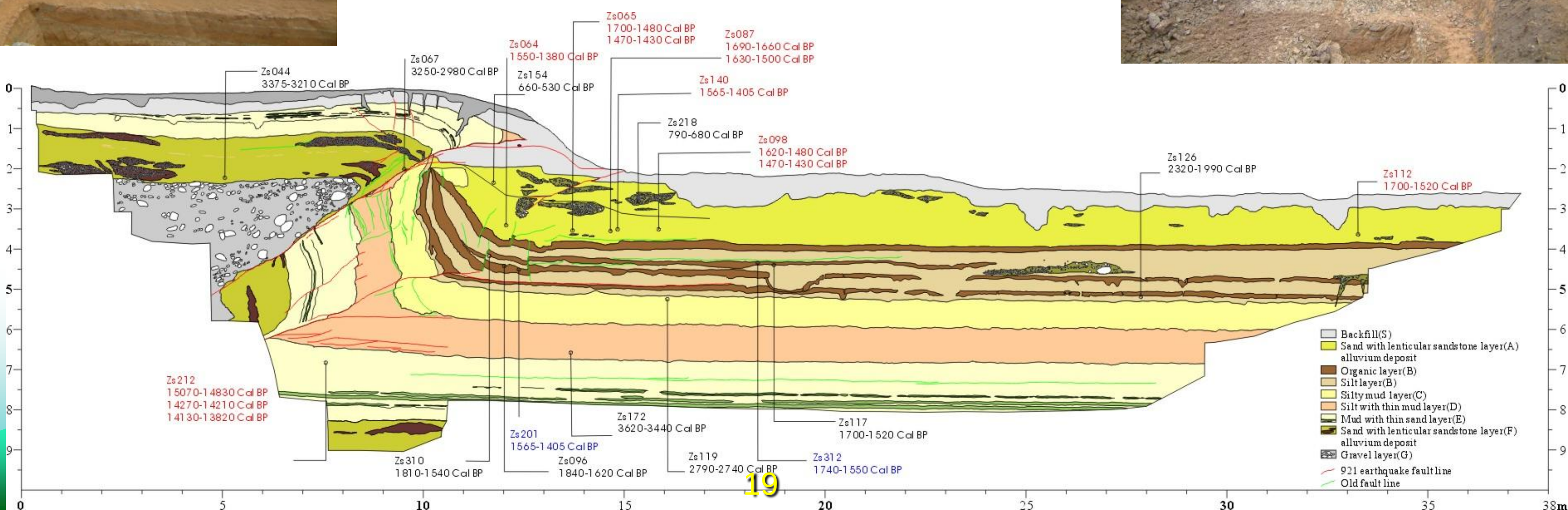
- 9 trenches have been excavated along the Chelungpu fault after the Chi-Chi earthquake.
- 16 active faults have been trenched in the past decade.



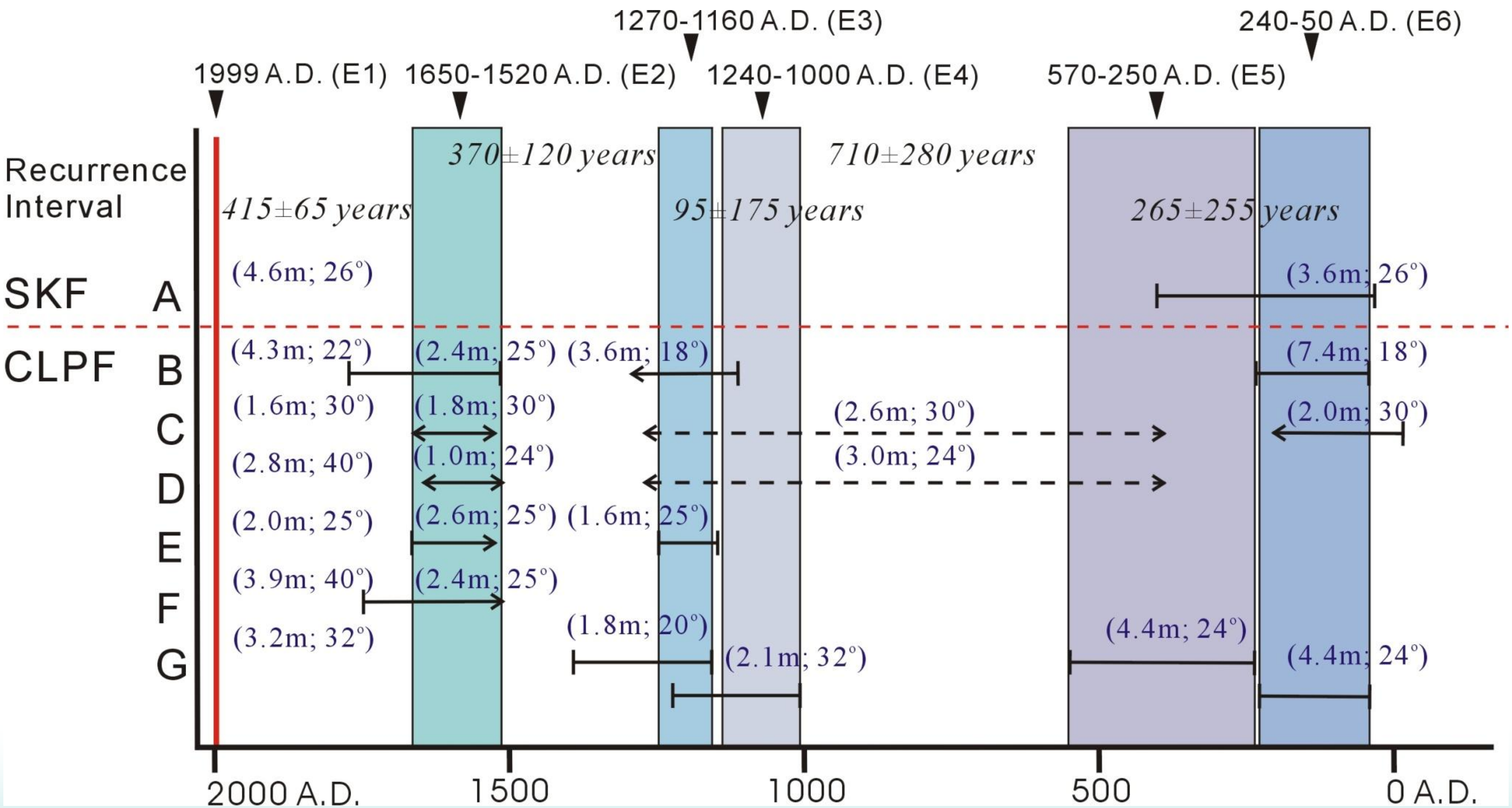


Northern wall

Southern wall



Reconstruction of Paleoseismic Events of the Chelungpu fault



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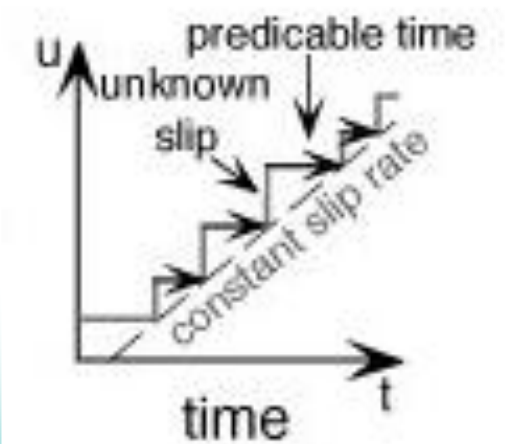
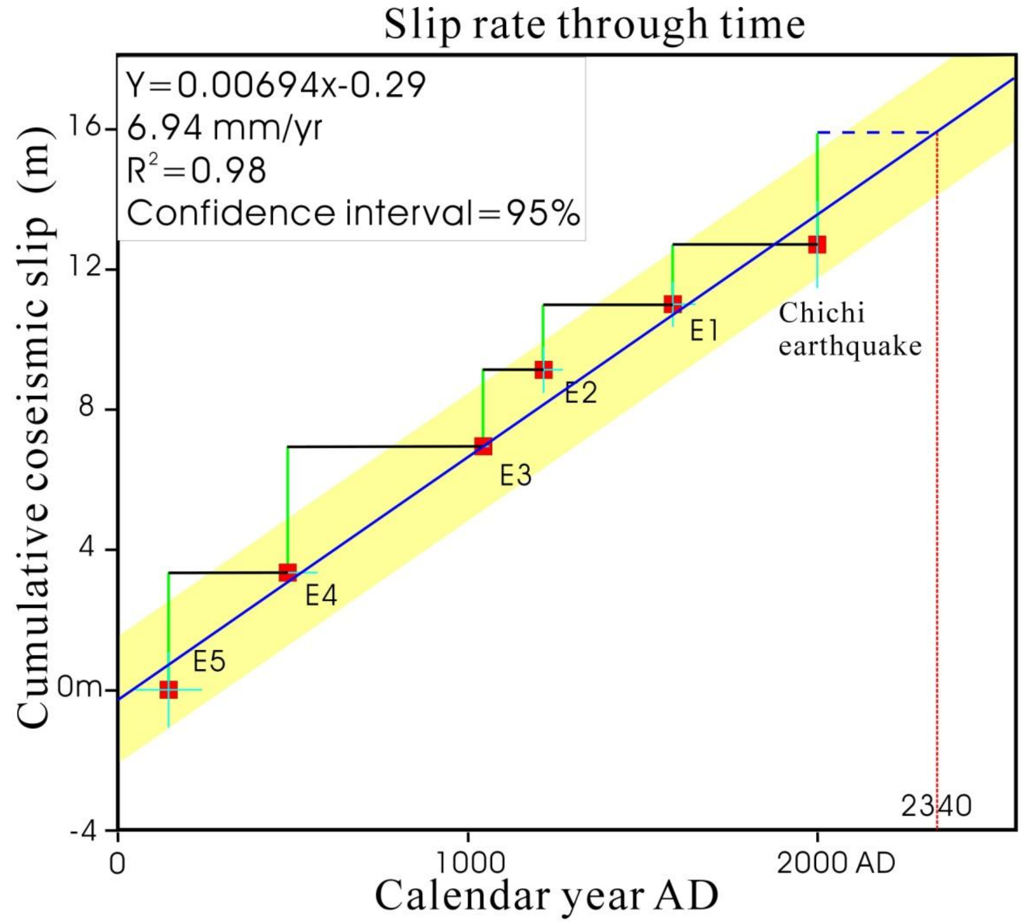
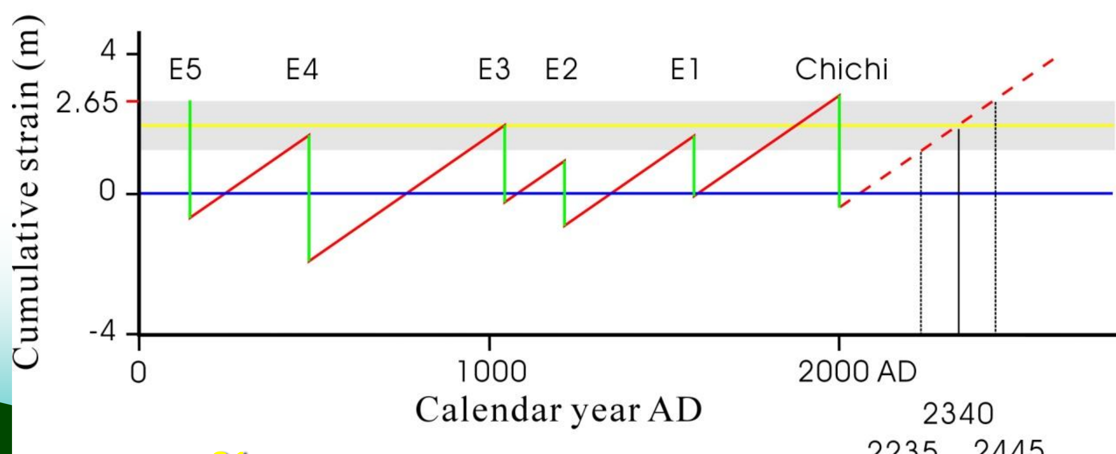
The movement of the Chelungpu fault is time-predicable, but what about the others?







Parameters of active faults in Taiwan

f. name	Sense of movement	dip	Vertical displacement			Long-term slip rate	Recurrence interval	Elapse time	
斷層名稱	特性	(度/方向)	(mm/yr)			移速率 mm/yr)	(yr)	活動時間 (yr)	綜合評估或建議
			階地定年	鑽探對比	槽溝開挖				
山腳斷層(北)	正移	>60/東							斷層應位在金山2號井南側
山腳斷層(南)				-1.2*f					
湖口斷層	逆移	~40/南		1.7±0.8*e					
新竹斷層	逆移兼右移	~50/南	<1.2*d	<1*e					
新城斷層	逆移	~30/南			~1*a				
獅潭斷層	逆移	>60/西							
三義斷層	逆移	40-60/東							
大甲斷層(北)	逆移	40-50/東		1.7-5.5*b					
大甲斷層(南)		/東							
鐵砧山斷層	逆移	/西							
屯子腳斷層	右移	高角度						A.D.1935	
彰化斷層	逆移	/東		4.3-10.3*b					
車籠埔斷層	逆移	~40/東			3.47*a	~6.94*a	200-700*a 平均300-400*a	A.D.1999	
大茅埔-雙冬斷層	逆移	~45/東						A.D.1999	
九芎坑斷層	逆移	20-30/東							可能於近百年內有地震事件*a 斷層應位於古坑2號井東側*b
梅山斷層	右移	>60						A.D.1906	平移斷層，每處槽溝中所見的地震事件，不足以代表全新世以來完整的古地震時序。*a
大尖山斷層	逆移兼右移	>60/東						A.D.1999	

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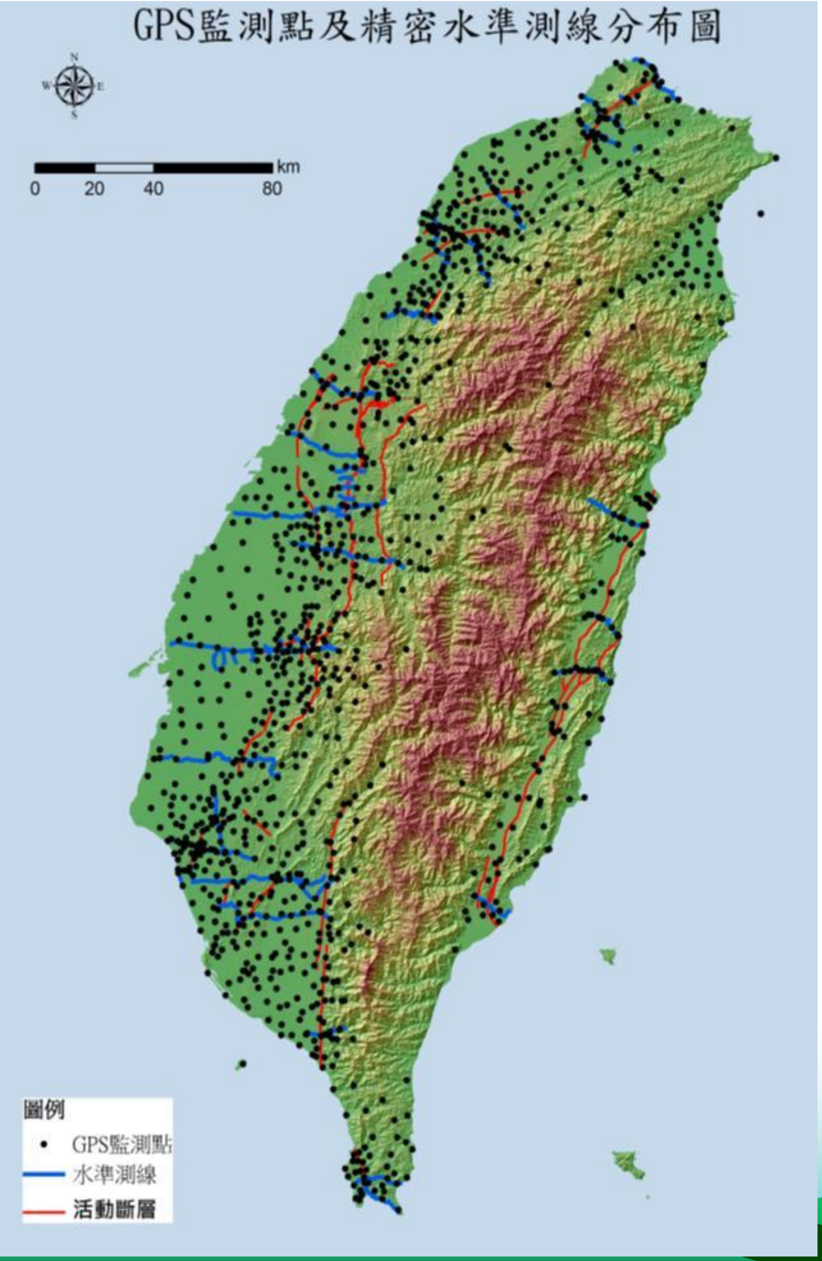
GPS Stations

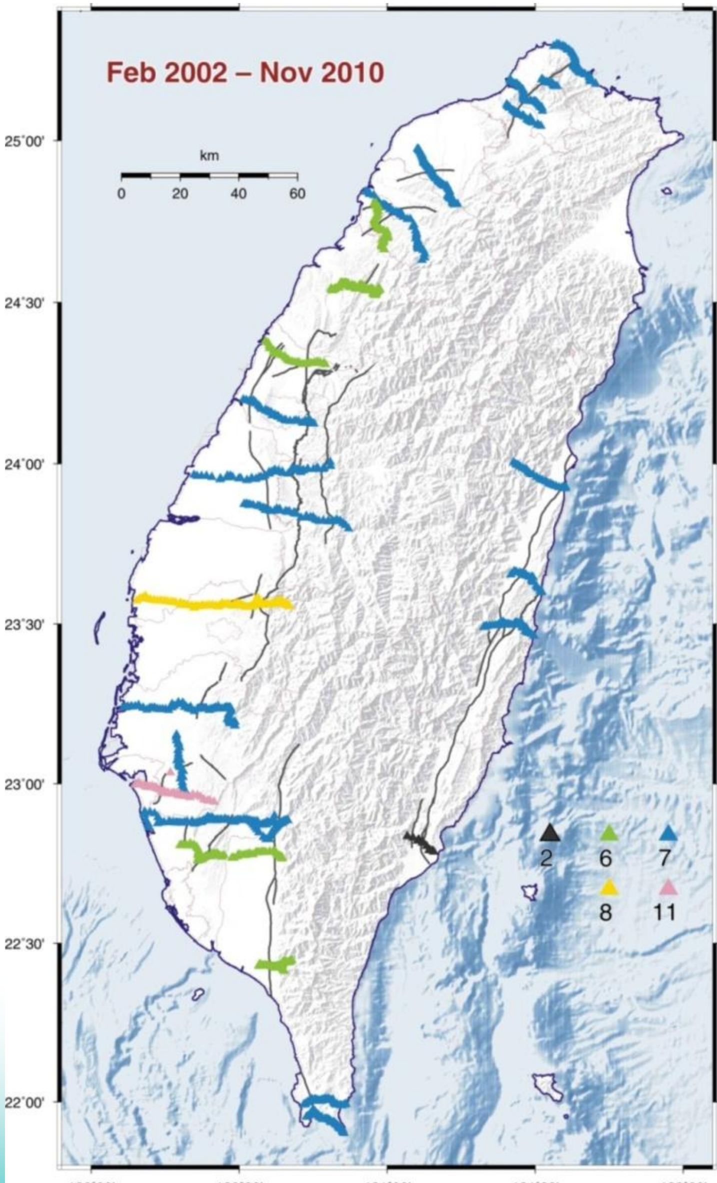


- 70 continuous GPS stations have been installed by CGS since 2002
- 150 continuous GPS stations installed by CWB (not shown on the map)
- 1000 Campaign-mode sites have been established and have been occupied once annually

Continuous GPS station

Campaign GPS station

Precise Leveling across active faults

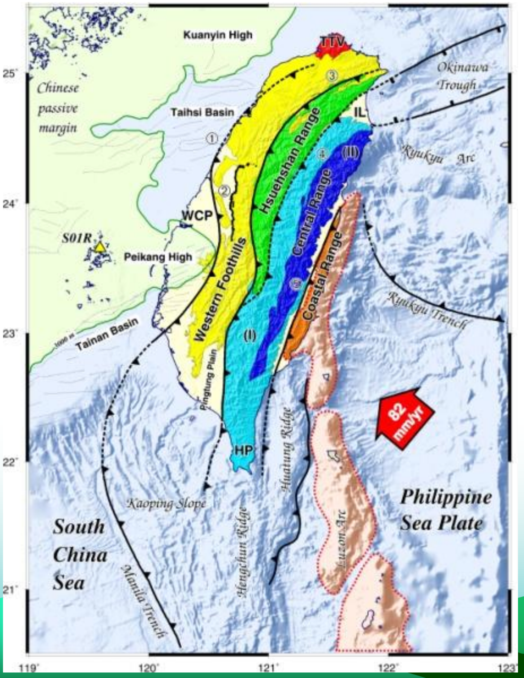


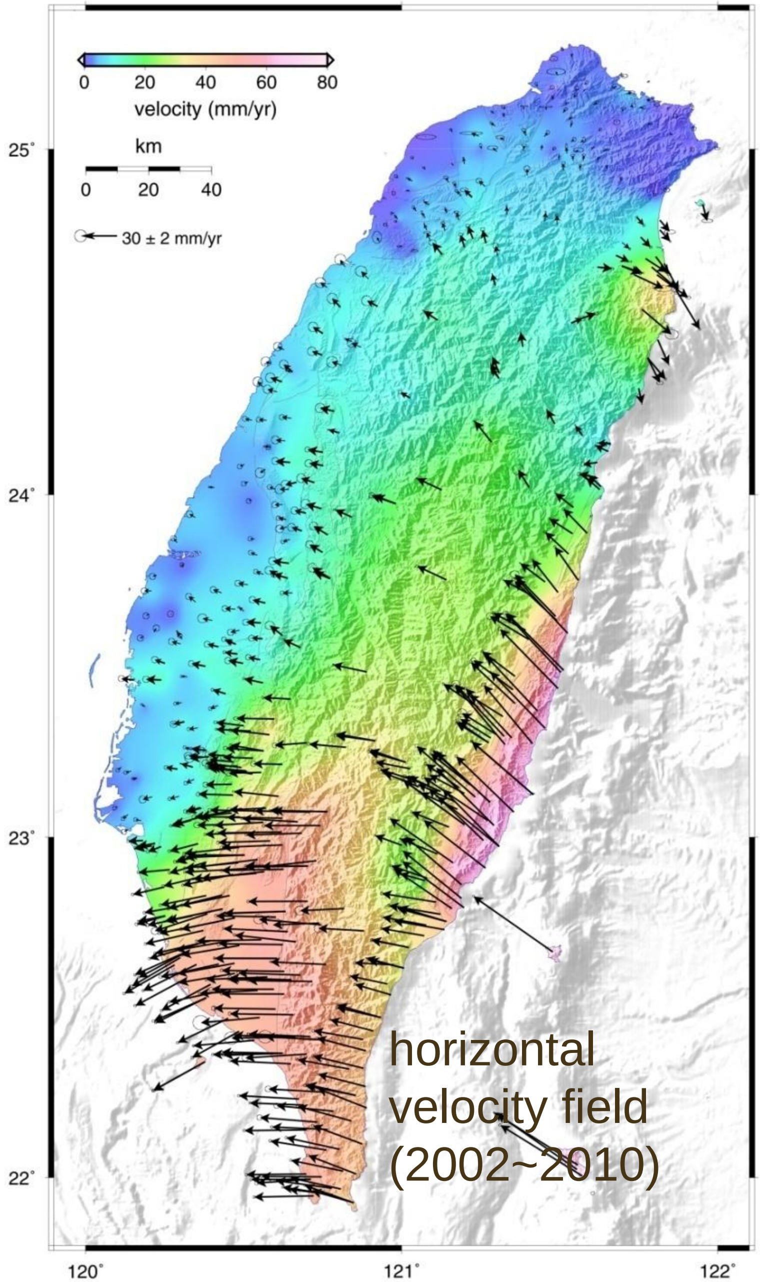
- 41 precise leveling lines, summing up to 1000km length, have been deployed across active faults.
- Occupied once per year
- To monitor the relative displacements across active faults and estimate the short-term slip rate of the faults

Precise Leveling Measurement

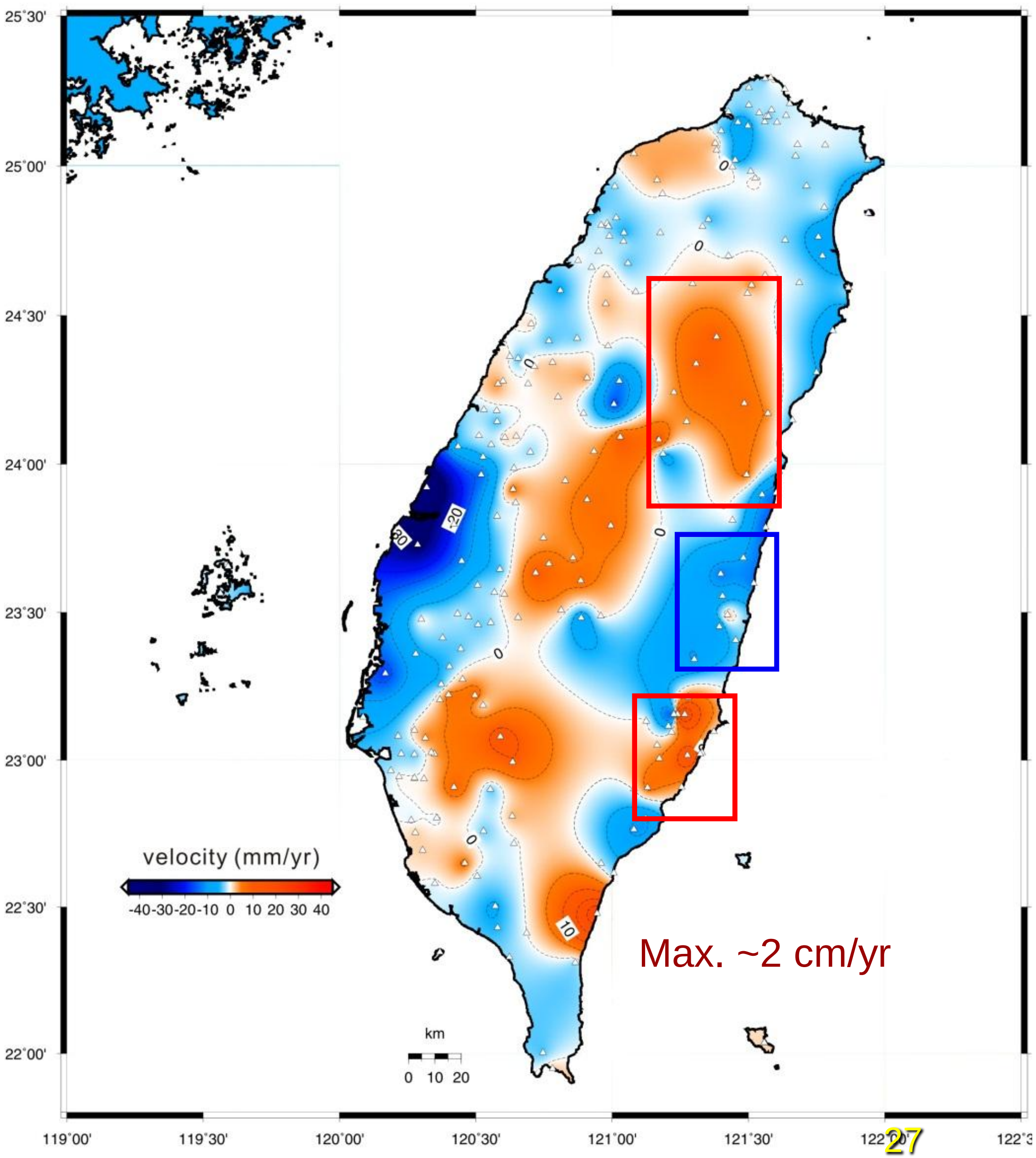
Horizontal velocity field of Taiwan

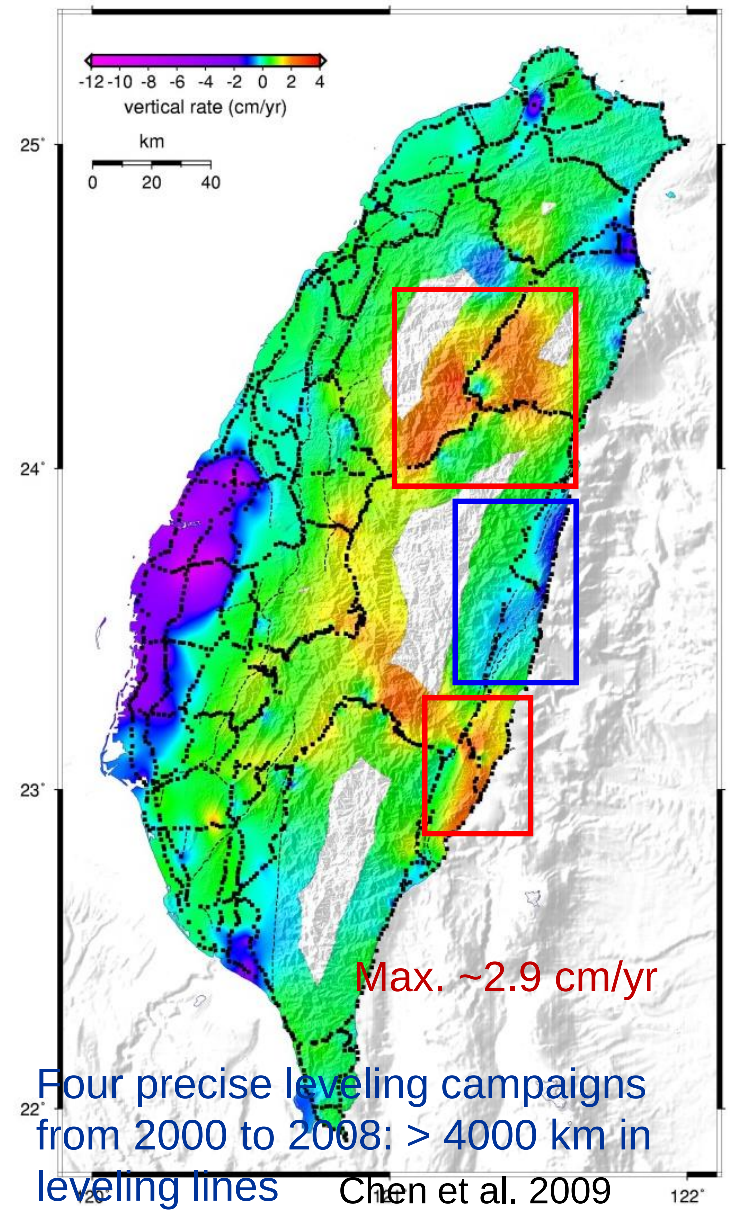
- The Coastal Range and the southwestern Taiwan are highly deformed.
  - ✓ Eastern : 60-80 mm/yr northwestward.
  - ✓ Southern : 50-60 mm/yr westward.
  - ✓ Central & Northern : < 10 mm/yr.
- Sharp contrast between Coastal Range and Central Range
- Sharp contrast across the active fault zone in southwestern Taiwan





Vertical Deformation revealed by CGPS and precise leveling

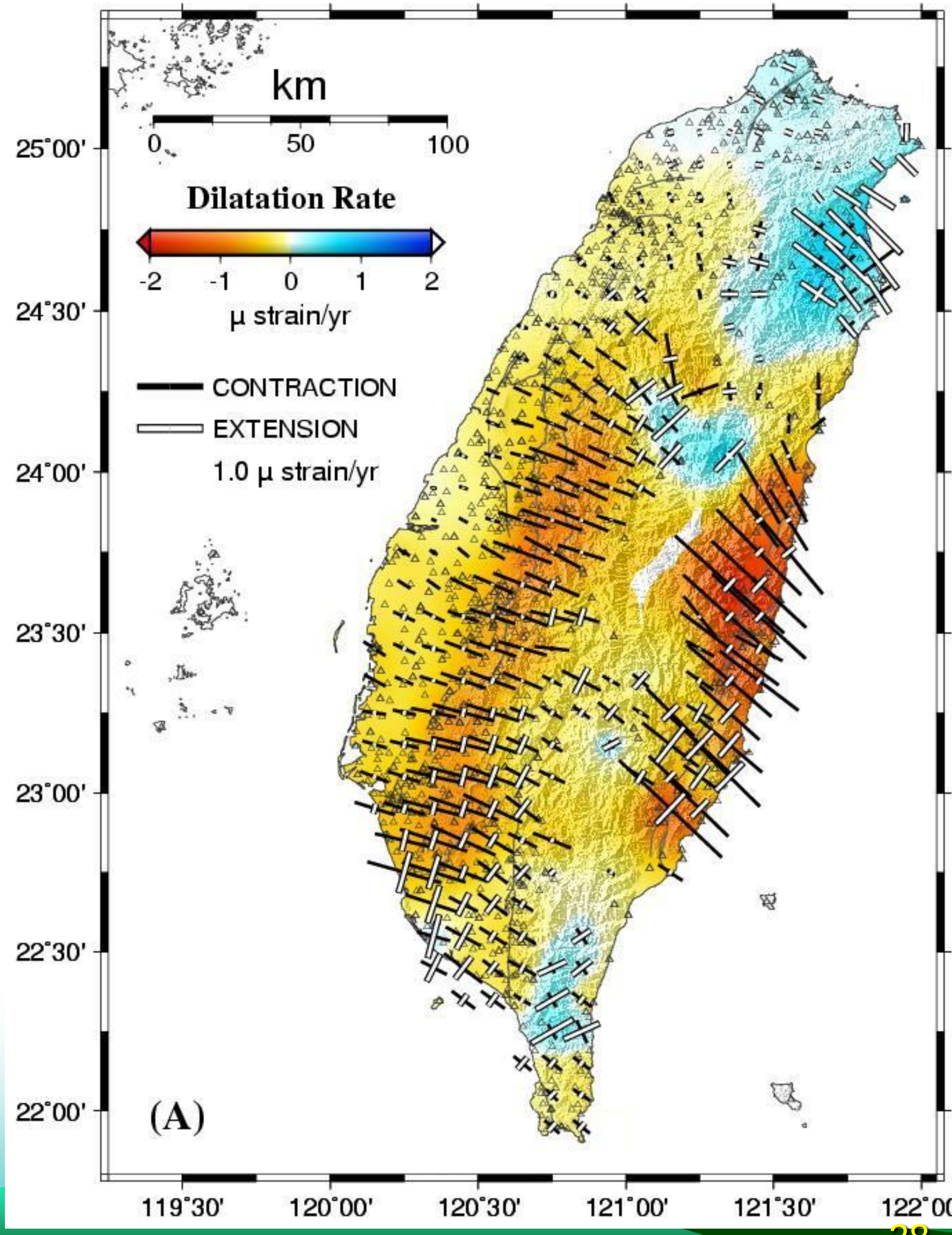


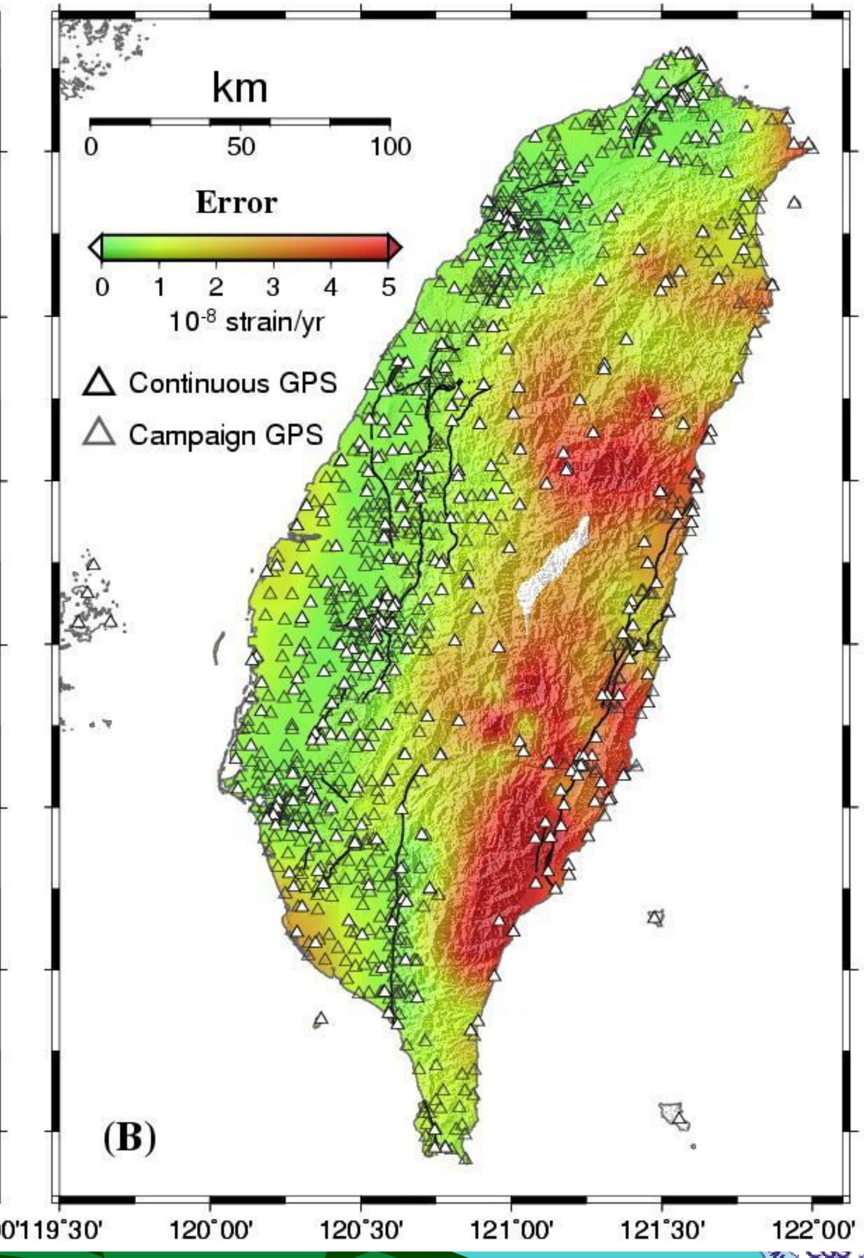


Four precise leveling campaigns from 2000 to 2008: > 4000 km in leveling lines

Chen et al. 2009

Strain Rate Field of Taiwan, 2001-2011





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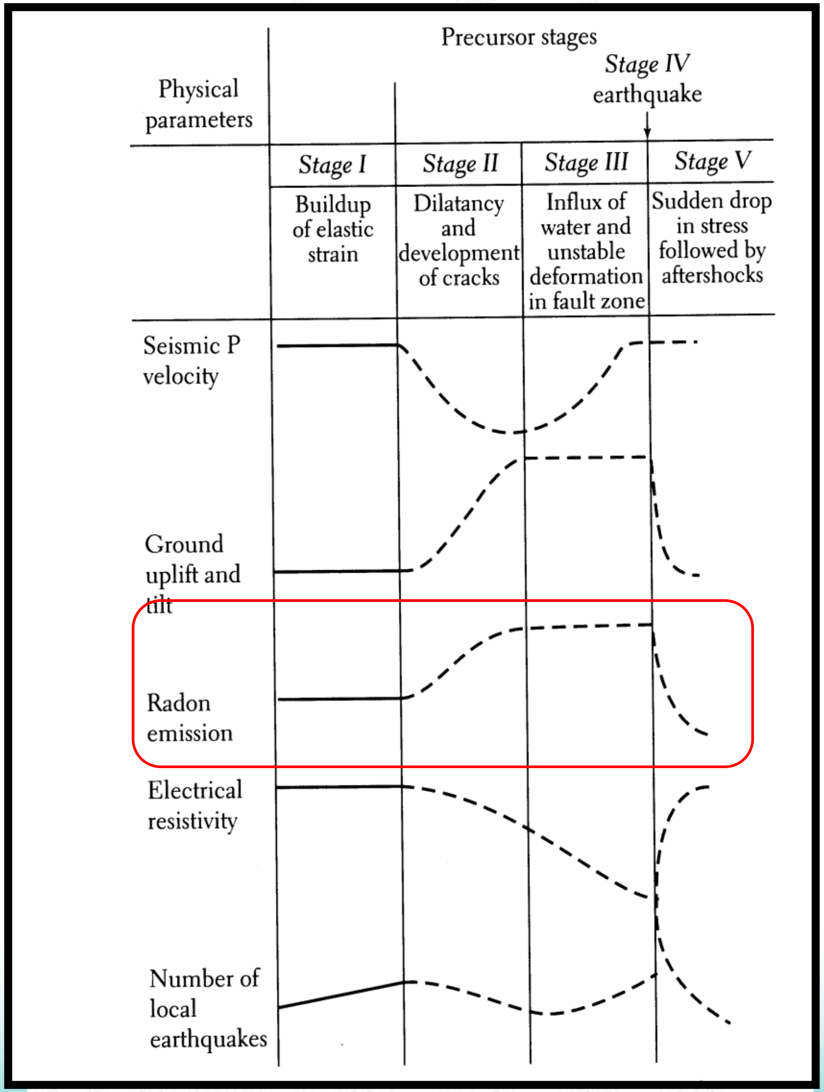
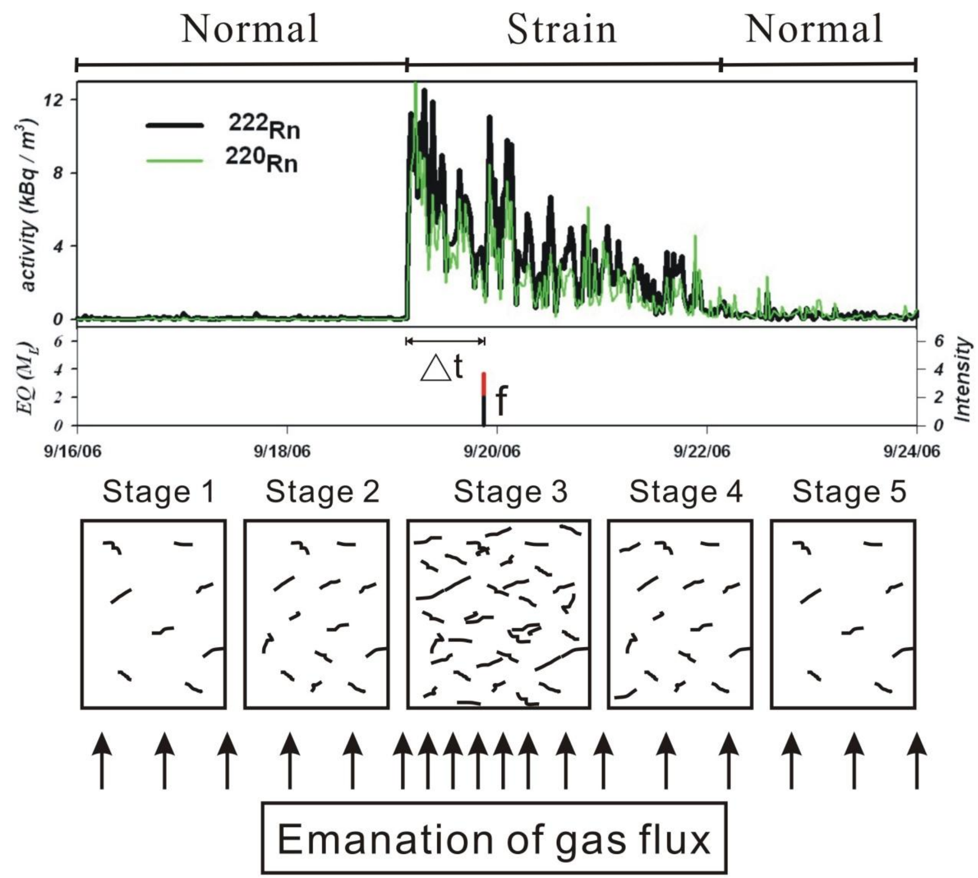
Geochemical Monitoring

SUGGESTED PHYSICAL CLUES FOR EARTHQUAKE PREDICTION



After Predicting Earthquakes, National Academy of Sciences, 1976.



Fu et al. (2009)

Stage 1: Buildup of elastic strain

Stage 2: Dilatancy and development of microcracks

Stage 3: Emanation of gas filled pores and then migrated upward to surface

Stage 4: Elastic strain is dropped after earthquake and then the micro-cracks returns to its original position

Stage 5: Original condition

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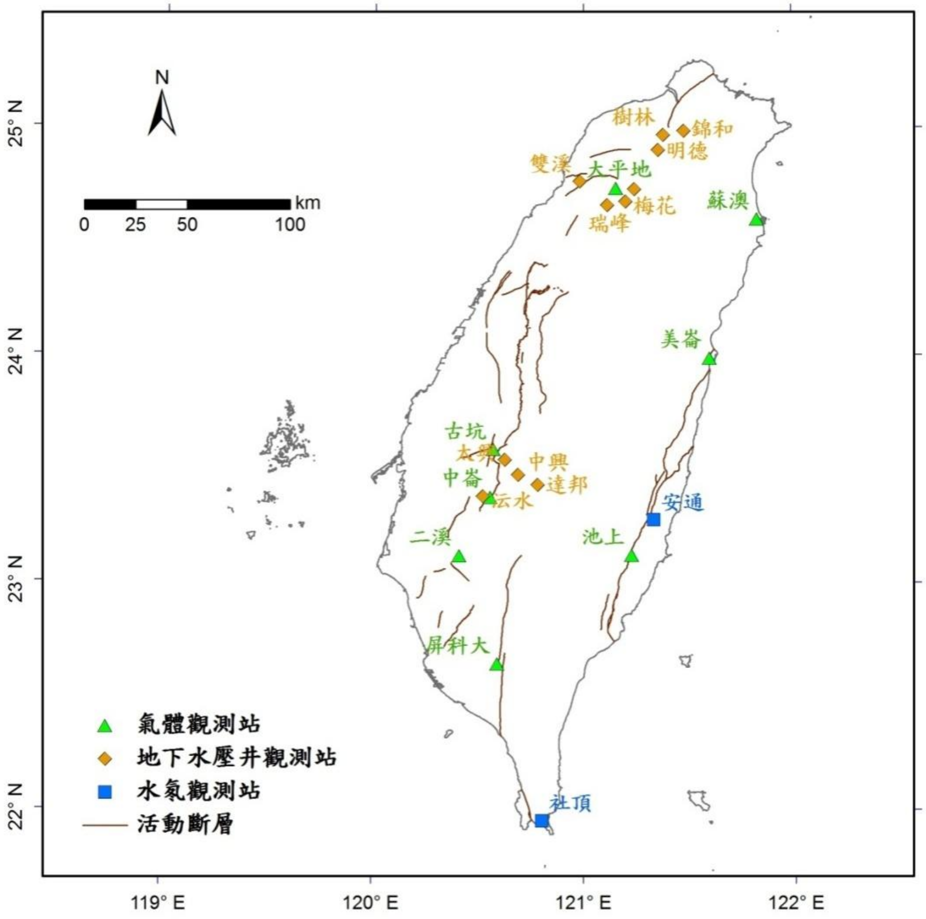
CGS

Geochemical stations of radon



- 10 geochemical stations have been installed in the vicinity of active faults
  - ✓ 8 soil-gas radon stations: 大平地 (TPT) 、 古坑站(GK) 、 中崙站(CL) 、 二溪站(RS) 、 屏科大(PT) 、蘇澳(SA) 、 美崙 (ML) 、池上 (CS)
  - ✓ 2 groundwater radon stations: 安通(AT) 、社頂(SD)

Soil gas geochemical station

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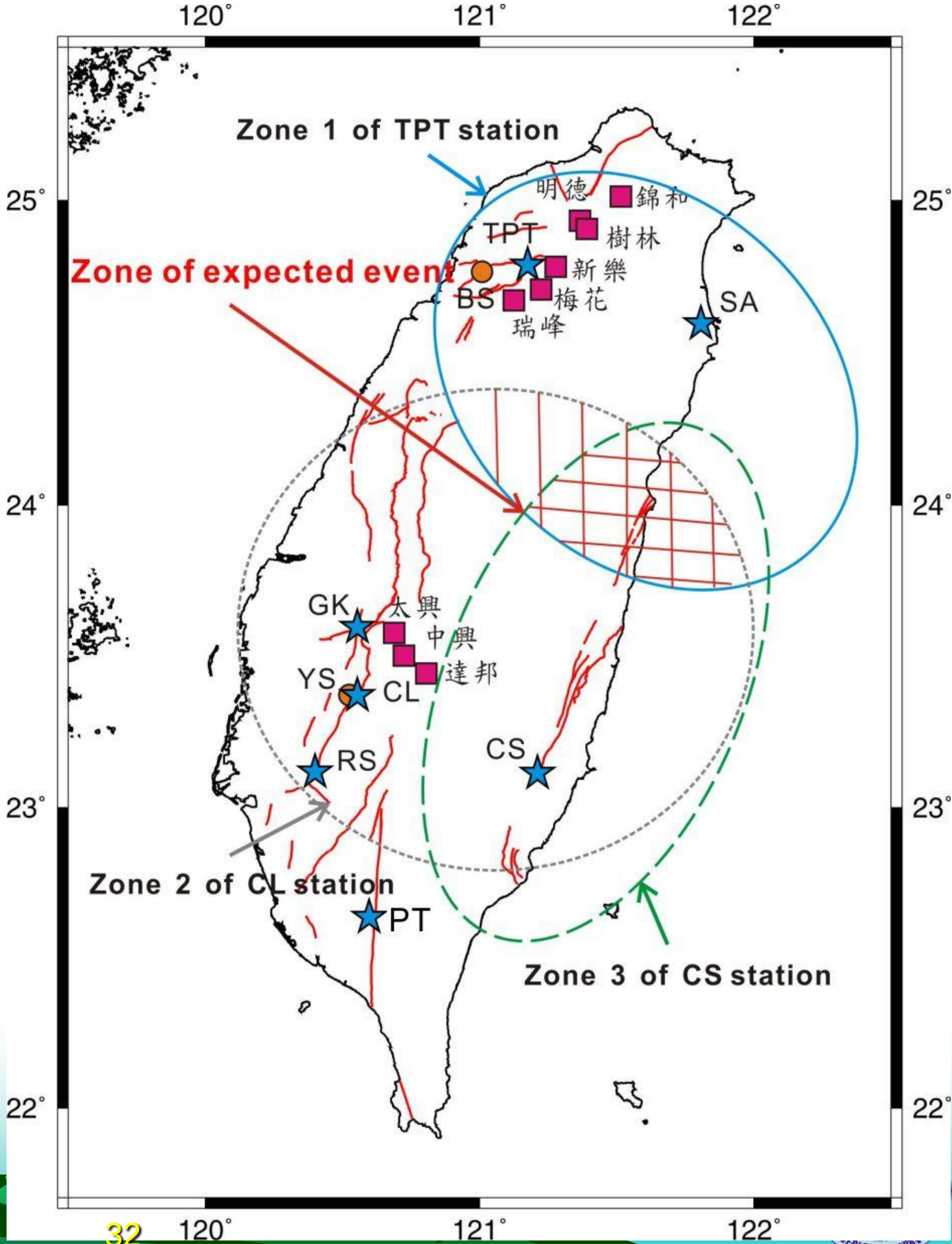
Precursor model of observatory network

- Each station has its own earthquake-sensitive zone
- The intersection of different sensitive zones will be the area where the expected seismic event may occur in the coming 2 weeks.



The correlation between radon observation and seismic events

- After several years observation, earthquake sensitive zone for each station has preliminarily been outlined.
- If anomalies appear in several stations the expected event may occurred in the intersection area of their sensitive zones.
- The radon anomalies for 6 major events of M_L >5 have been recorded in multiple stations since the end of 2009:
  - 11/05/2009, Nantou, M_L = 6.2, stations with radon anomaly: TPT, CL, CS
  - 12/19/2009, Hualien, M_L = 6.9, stations with radon anomaly : TPT, CL, CS
  - 1/19/2010, Hualien, M_L = 5.6, stations with radon anomaly : CL, CS
  - 2/12/2010, Nantou, M_L = 5.2, stations with radon anomaly : TPT, GK, CL, CS
  - 03/04/2010, Kaohsiung, M_L = 6.4, stations with radon anomaly : GK, CL, PT, CS
  - 11/21/2010, Hualien, M_L = 6.1, stations with radon anomaly : TPT, CS

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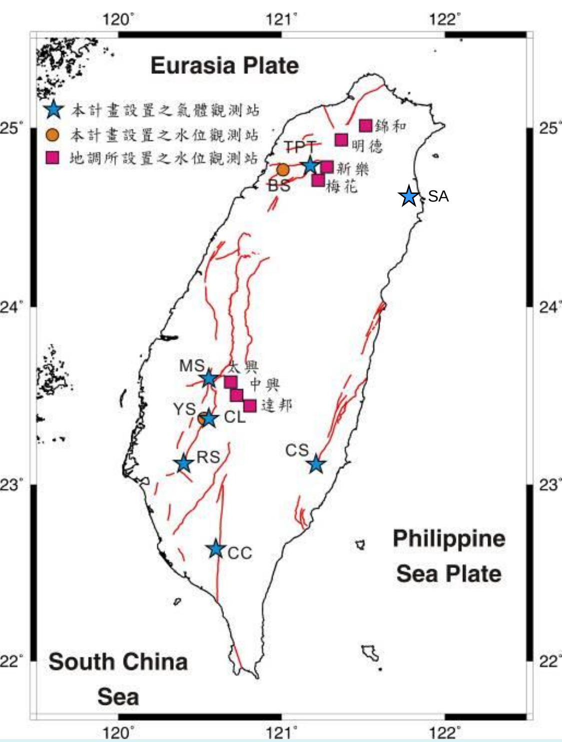
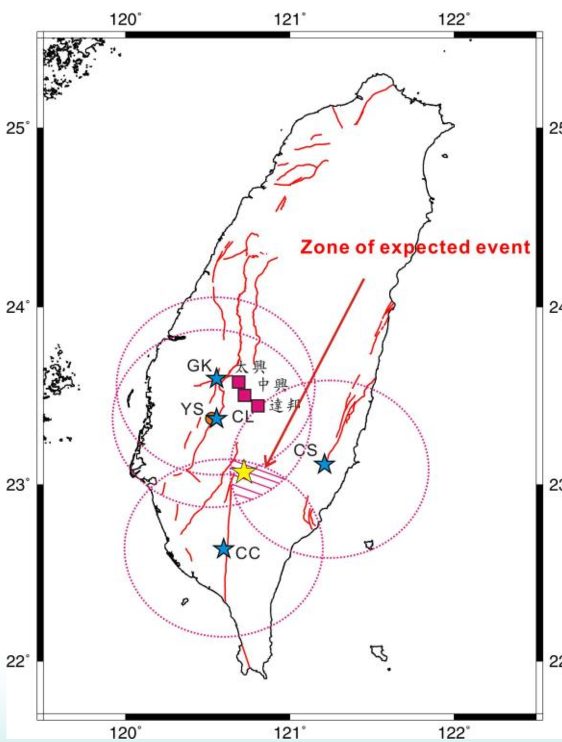
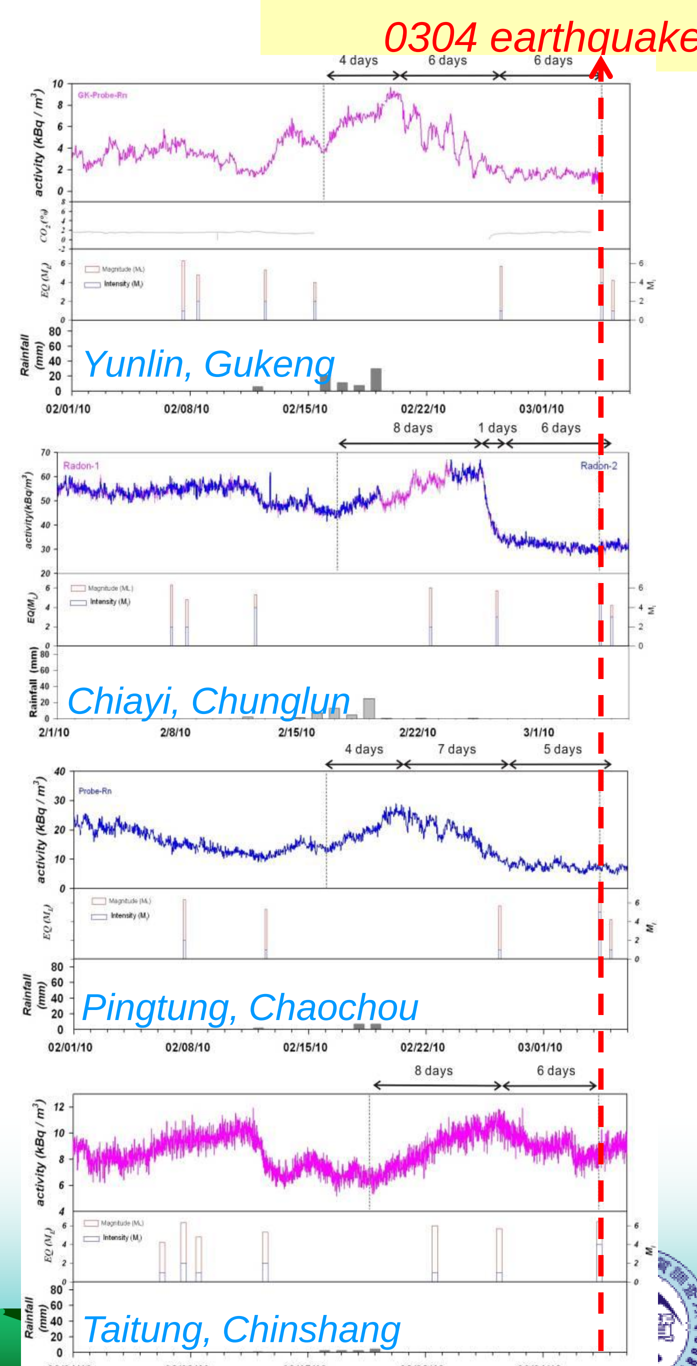
Radon anomalies observed prior to 03/04/2010 earthquake

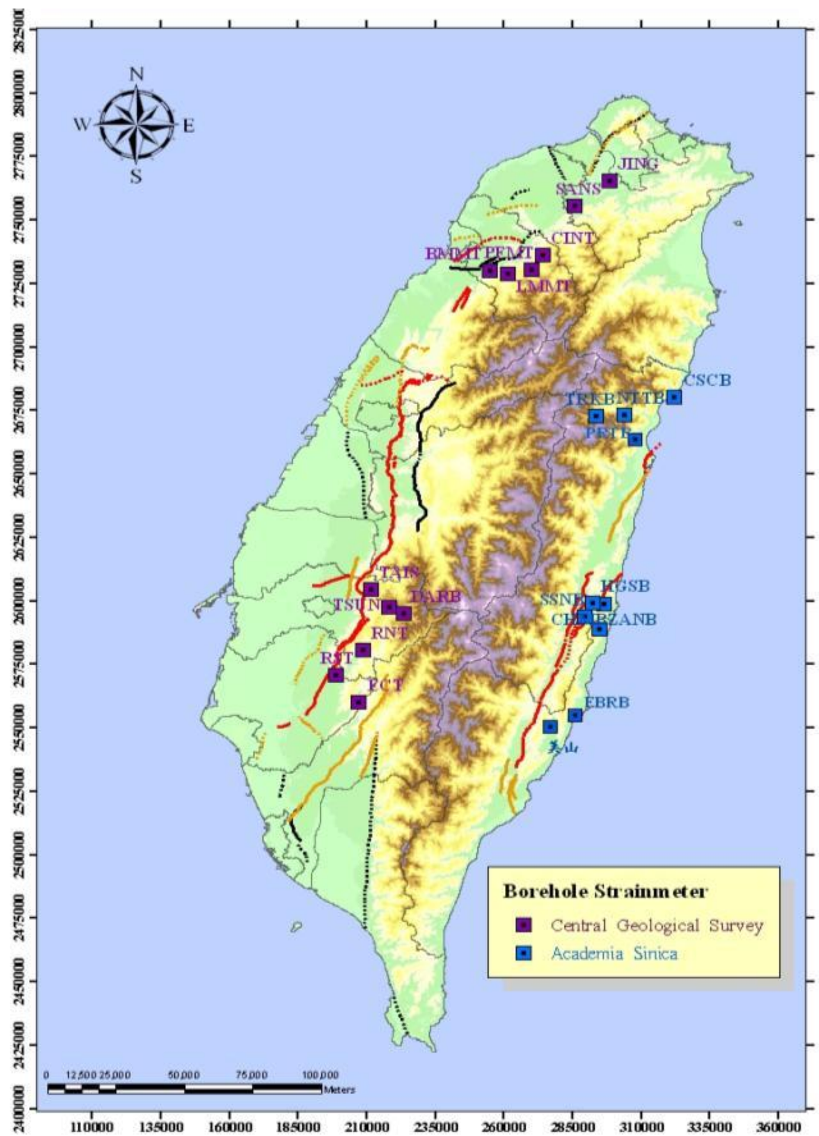
- 2 weeks before 20100304, radon anomalies had been detected in GK, CL, CC, and CS stations.



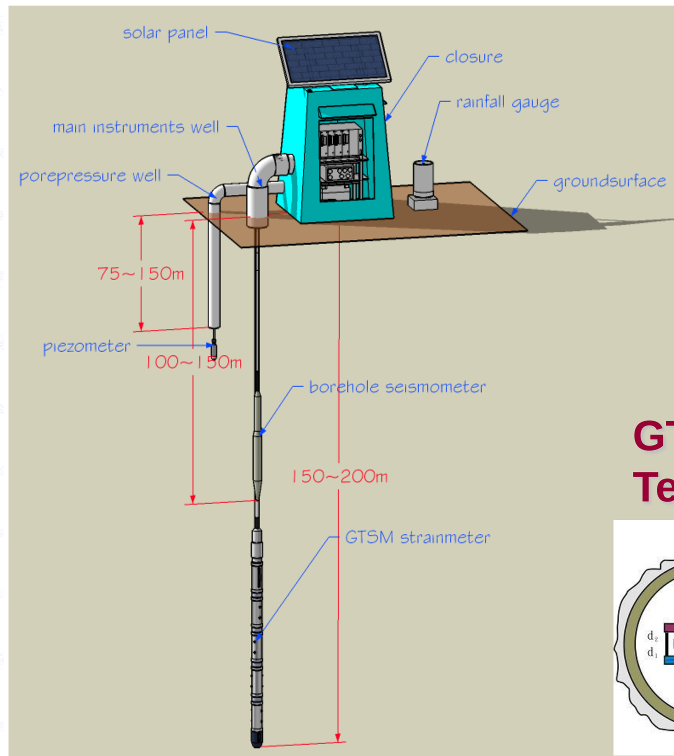




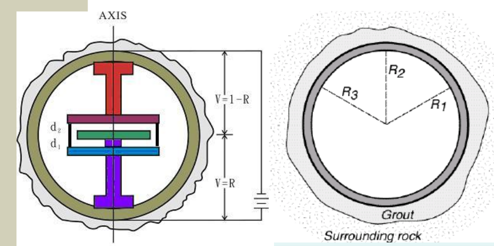
Borehole Strainmeter Stations



- 13 borehole strainmeter observatories have been installed in western Taiwan by CGS since 2002
- 10 installed in eastern Taiwan for PBO by IES, Academia Sinica



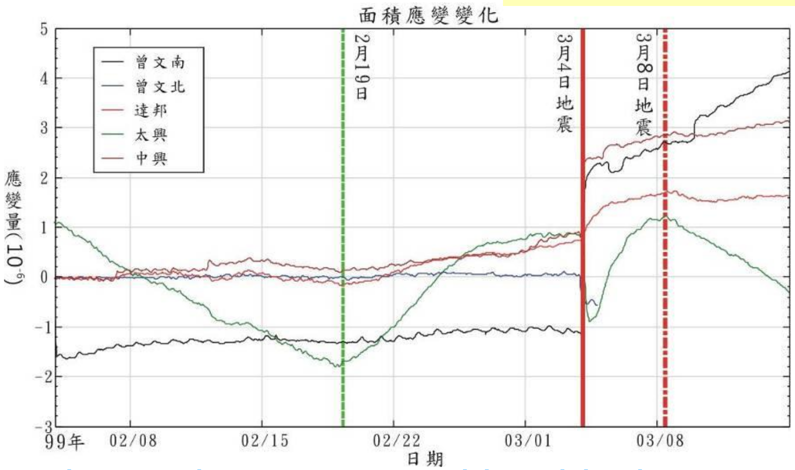
GTSM: Gladwin Tensor Strainmeter



中央地質調查所 CENTRAL GEOLOGICAL SURVEY

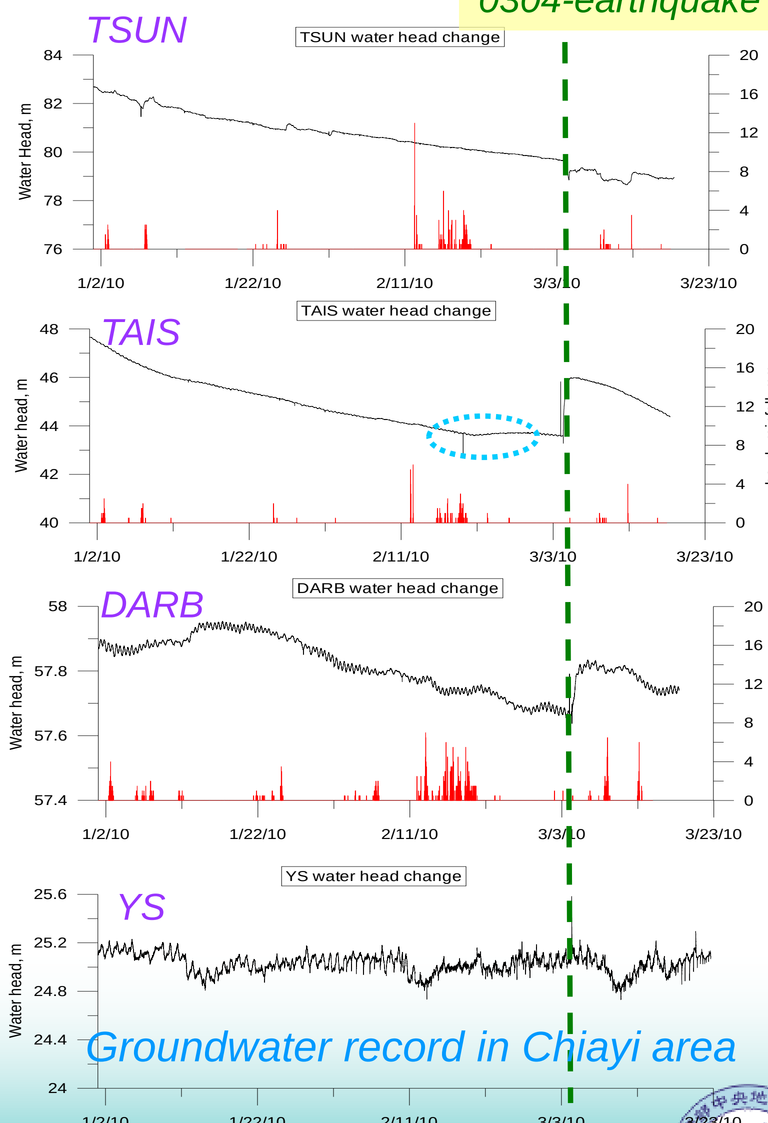
Researches on other earthquake precursors

0304-earthquake



The strainmeter record in Chiayi area

0304-earthquake



Groundwater record in Chiayi area

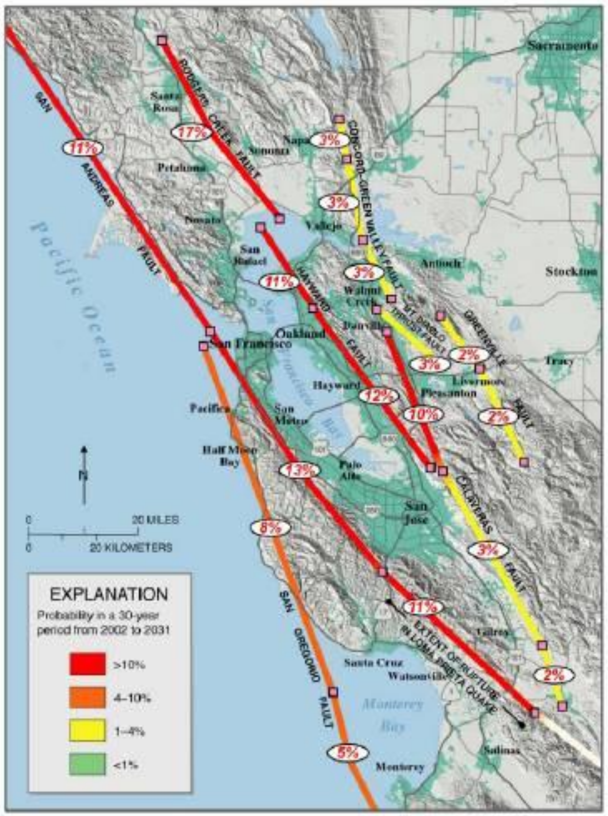
- The pre-seismic and co-seismic strain variations had been recorded in RST, RNT, DARB, TAIS and TSUN
- The groundwater piezometers, co-site with strainmeter, showed only co-seismic water level change, but without apparent anomalies prior to the earthquake.

Concluding remarks

- A precise active fault maps are essential for seismic hazard mitigation and the LiDAR-derived imageries can greatly improve the precision and accuracy of active fault investigation.
- GPS observation and leveling survey should be persisted to monitor the crustal deformation in the vicinity of active faults as well as the whole island.
- The radon anomalies observed in recent years have been correlated with the seismic events of the magnitude greater than 5. It is also possible to determine the precursory time and location of an upcoming earthquake.
- The correlation between magnitude and radon variation has not well established yet.
- Joint observation of different precursors such as variations of foreshocks, radon emission, groundwater level, strain, ground displacement, etc. may provide an opportunity for successful prediction of an earthquake.

Long-term potential evaluation of fault-source earthquakes

Evaluating the probabilities of large-scale earthquakes for each active fault is one of our next major assignments in active fault research.



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~Thanks for Your Attention~

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