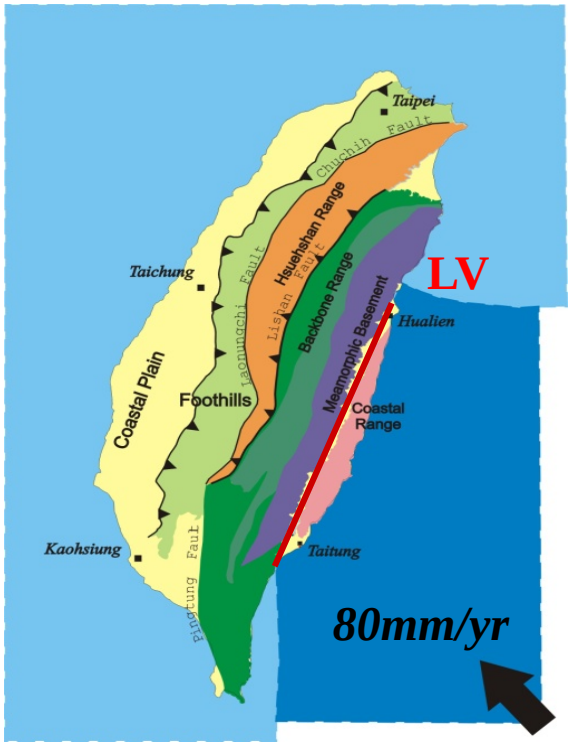
Recent Research Progress on the Chihshang Active Fault Observatory



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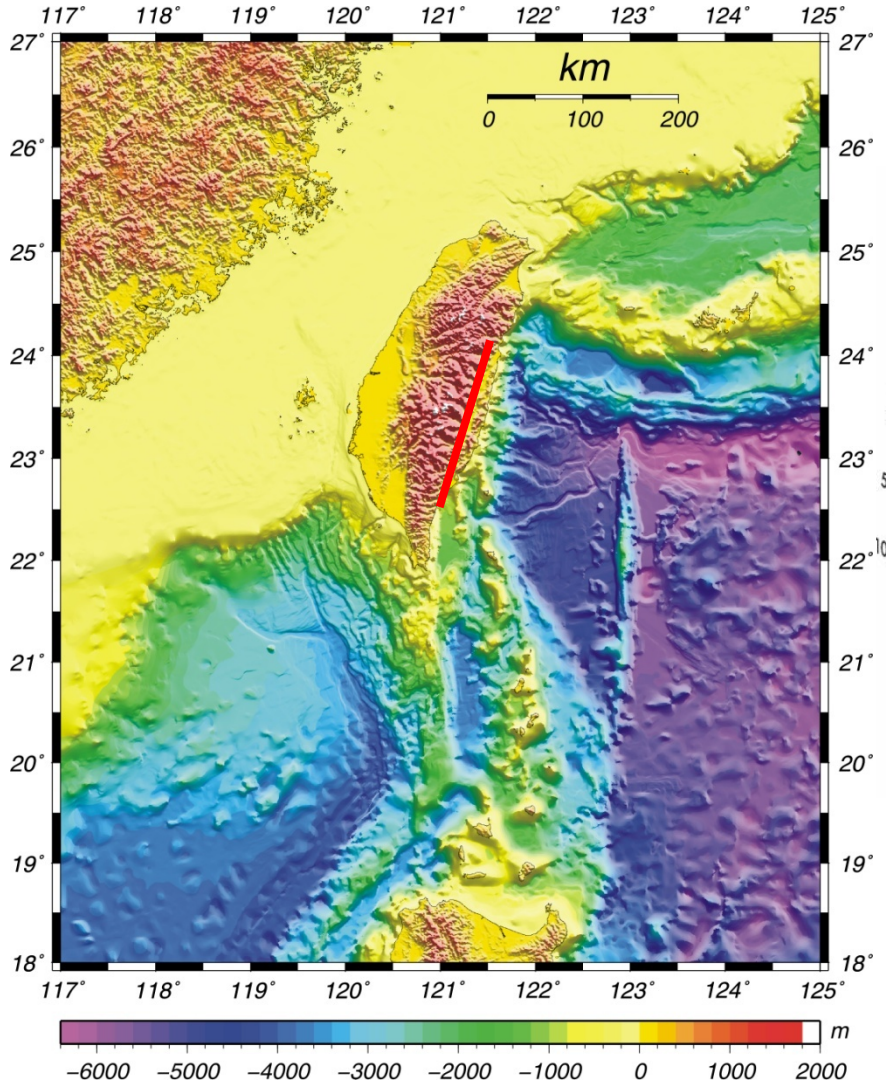
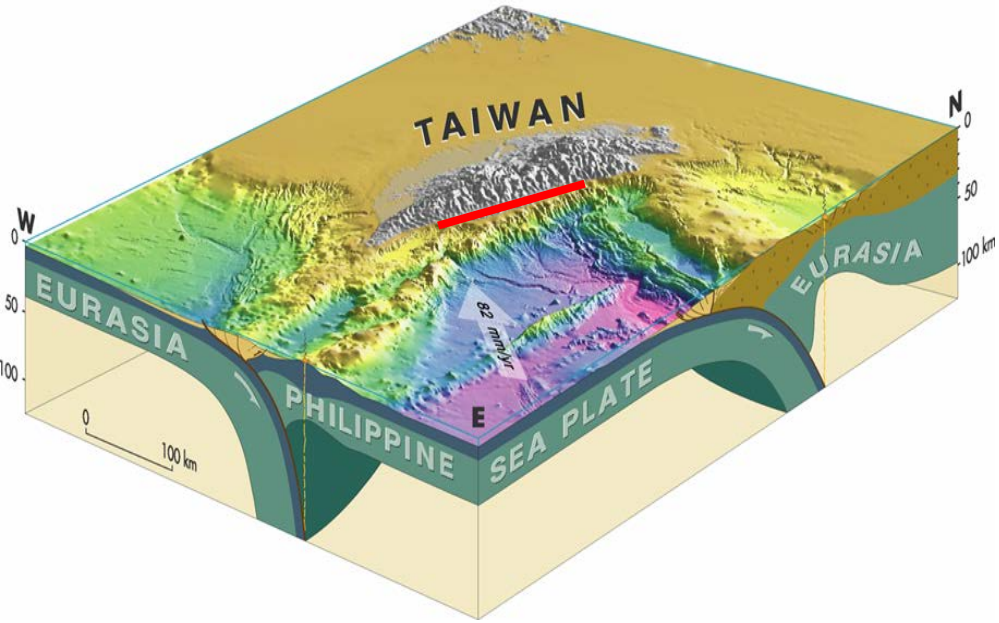
中央研究院 ACADEMIA SINICA

Opposing Subduction:

between Philippine Sea, Eurasia, and South China Sea





(Angelier, 1986, 1990; Chang et al., 2001; Malavielle et al., 2002)

Taiwan arc-continent collision

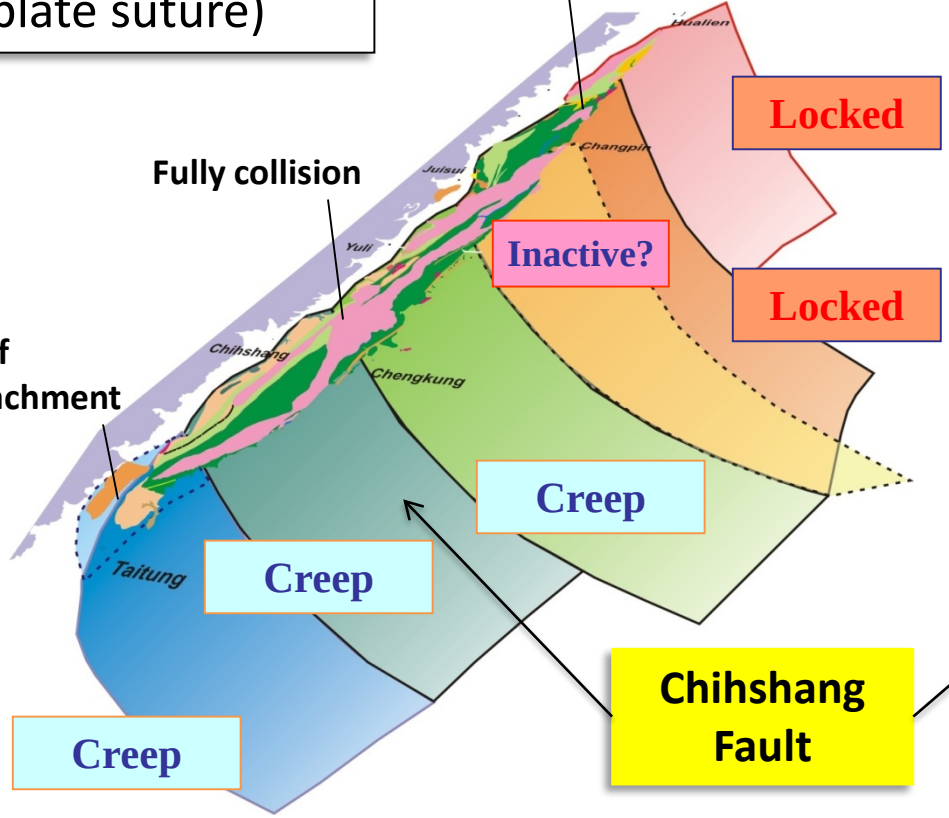
between Philippine Sea, Eurasia, and South China Sea

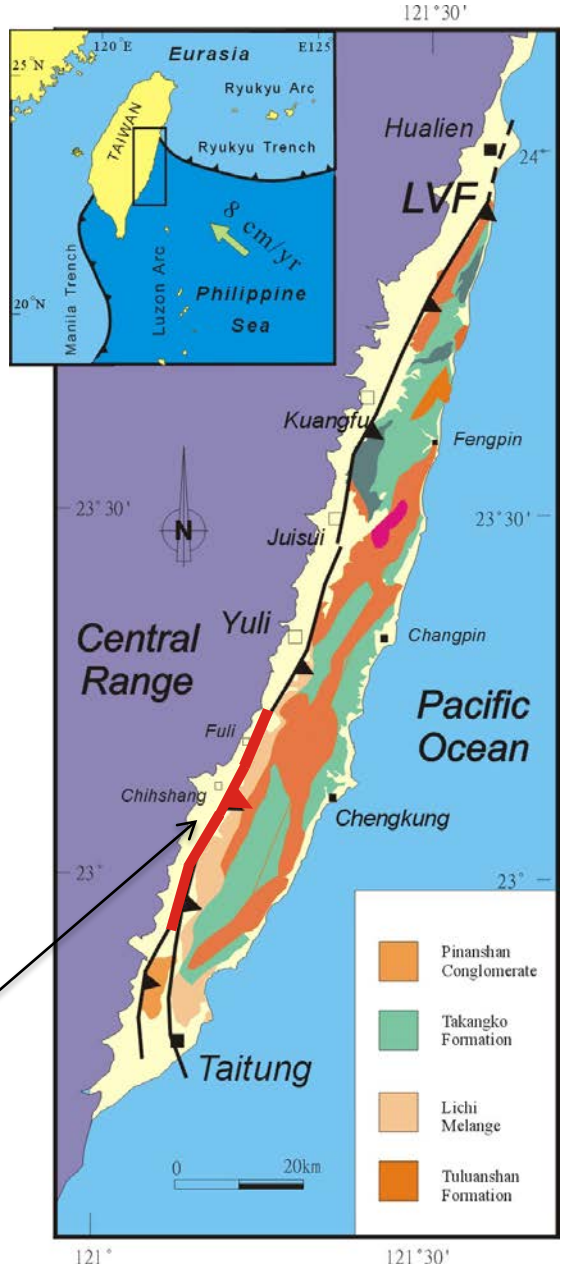
Longitudinal Valley Fault (LVF)
(plate suture)

Waning collision
Begin of subduction

Fully collision

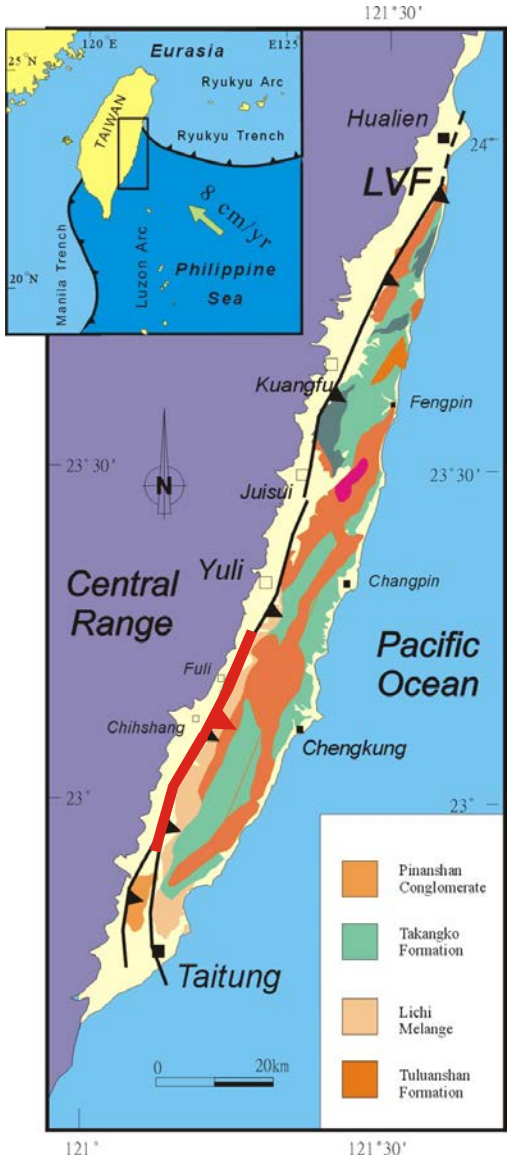
Begin of Arc attachment

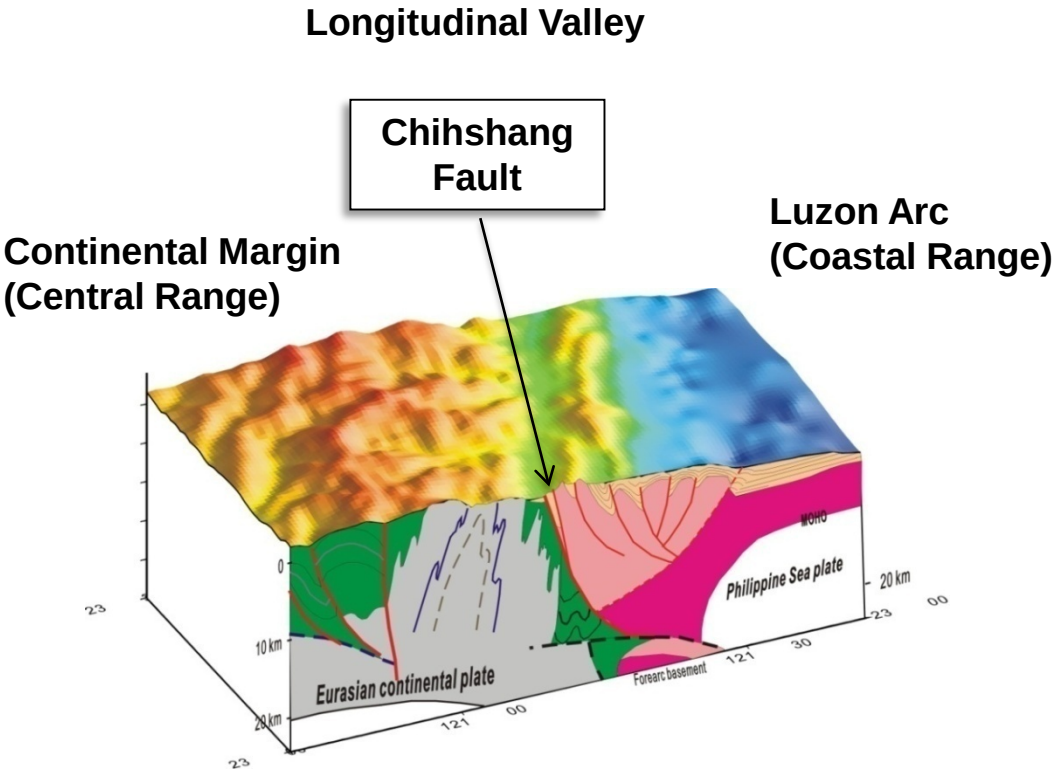




Chihshang Fault

a rapid creeping reverse fault with occasional moderate earthquakes

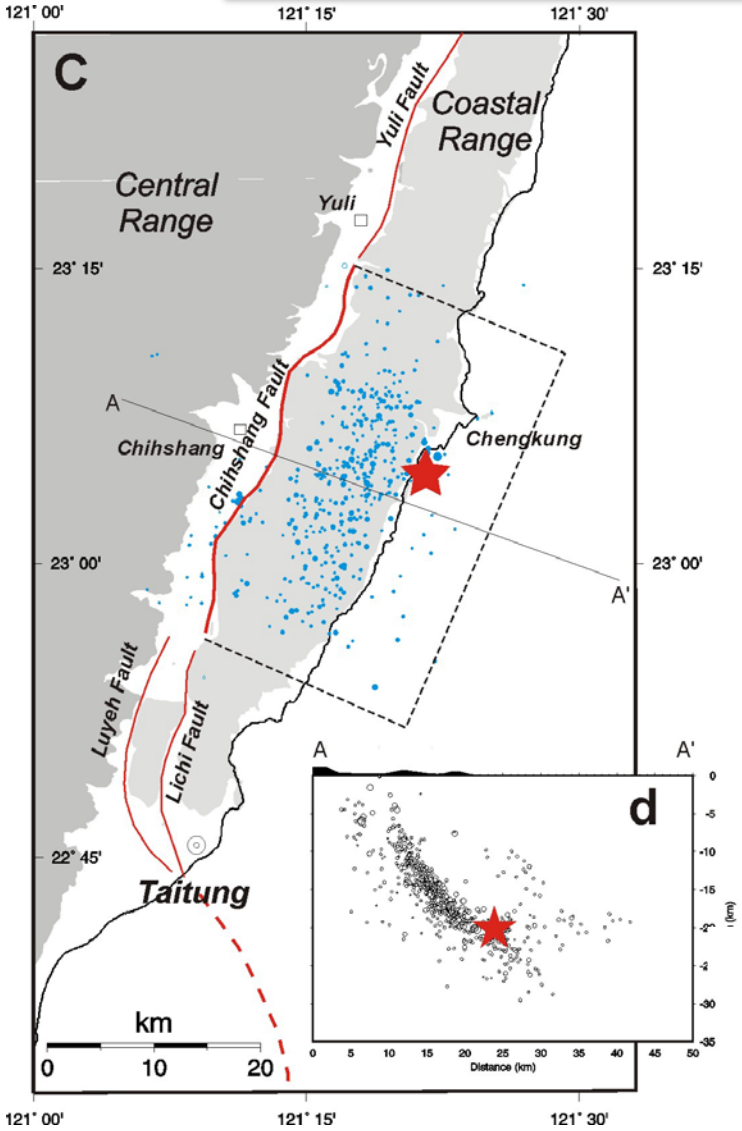




(Modified after Malavieille et al., GSA, 2004)

2003 Mw 6.8 Chengkung Earthquake

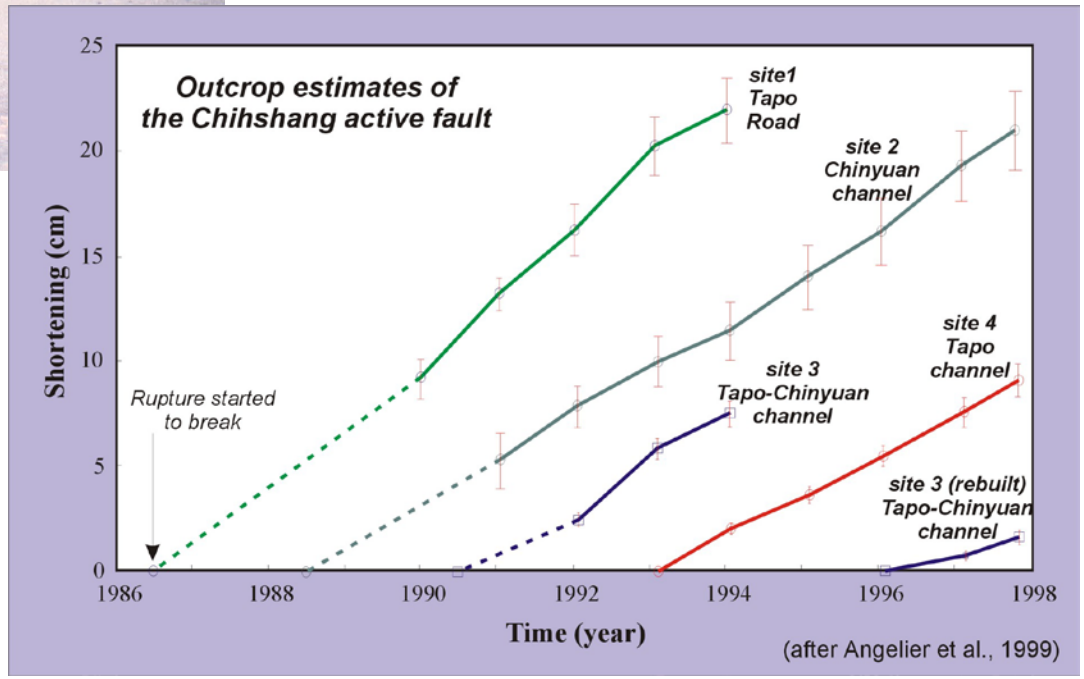
Ruptured from the Chihshang Fault



(Lee et al., 2006)

Rapid Surface Creep

Of the Chihshang Fault



Chihshang Active Fault Observatory

Chihshang Active Fault Observatory

1. Observation and Instrument

   Continuous : creep meter, GPS, seismometer, tiltmeter, groundwater level

   Campaigned: GPS, EDM laser, leveling, Nail network, slug test

2. Surface creep

   Short-term and long-term creep rates

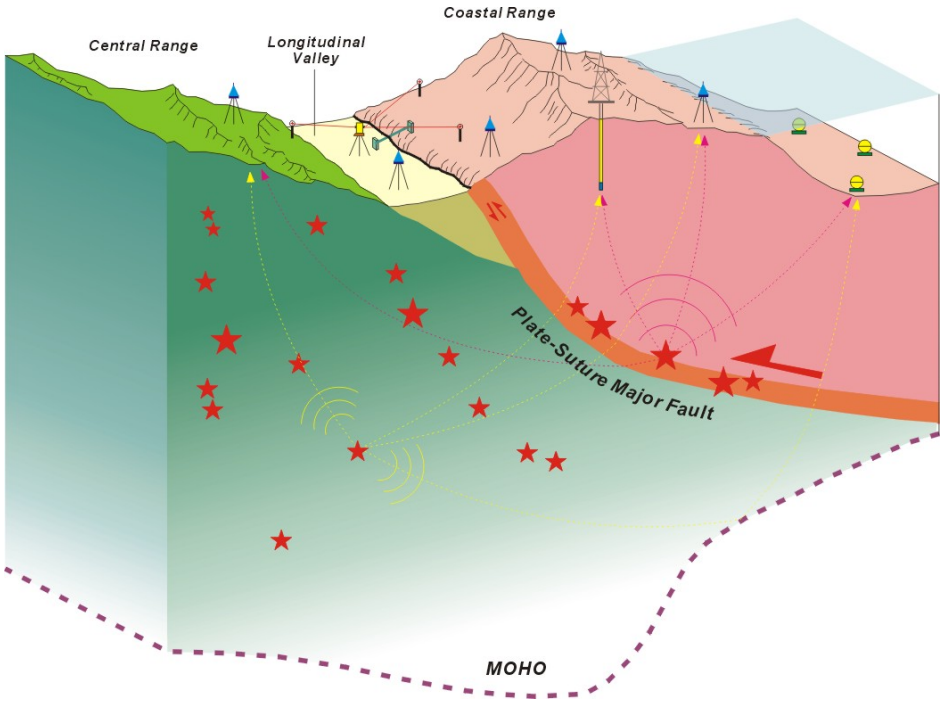
   Pre-, co- and post-seismic creep

   Seasonal locked

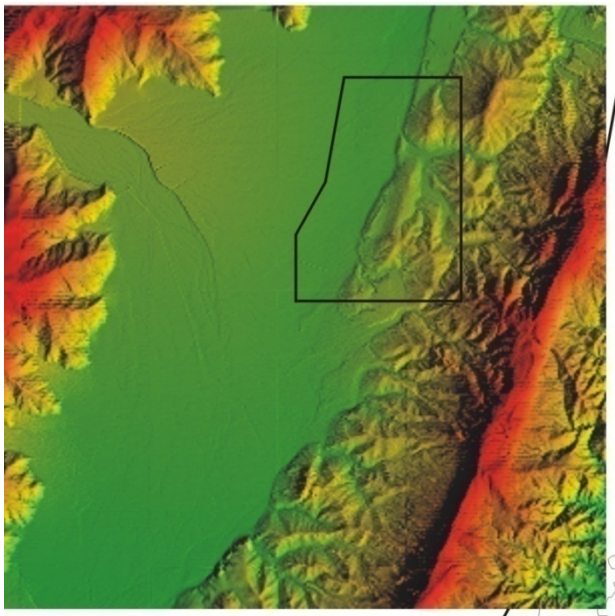
3. Slip kinematics and behaviors

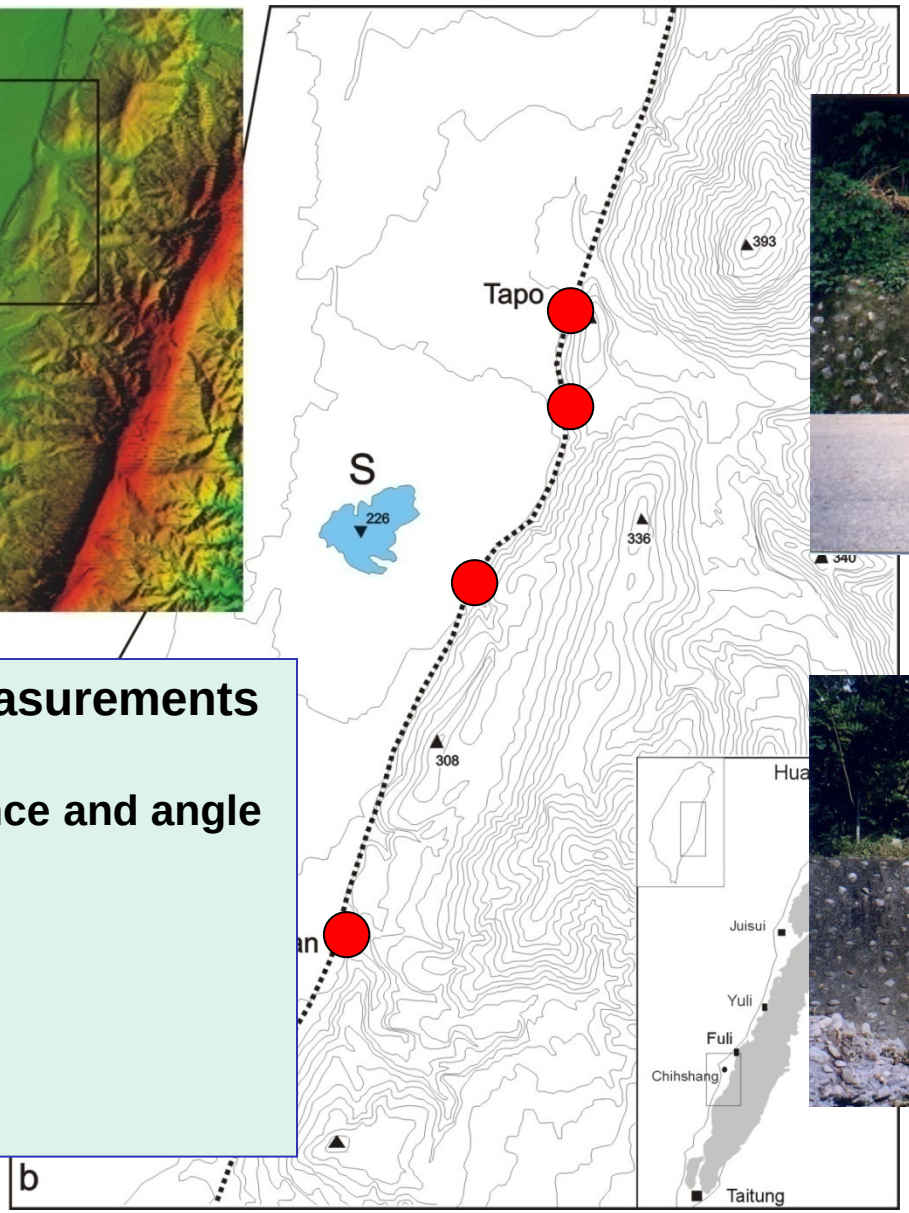
4. Frictional property modeling

5. Hydraulic property and system



Near Fault Measurements: geodetic networks and creep meters





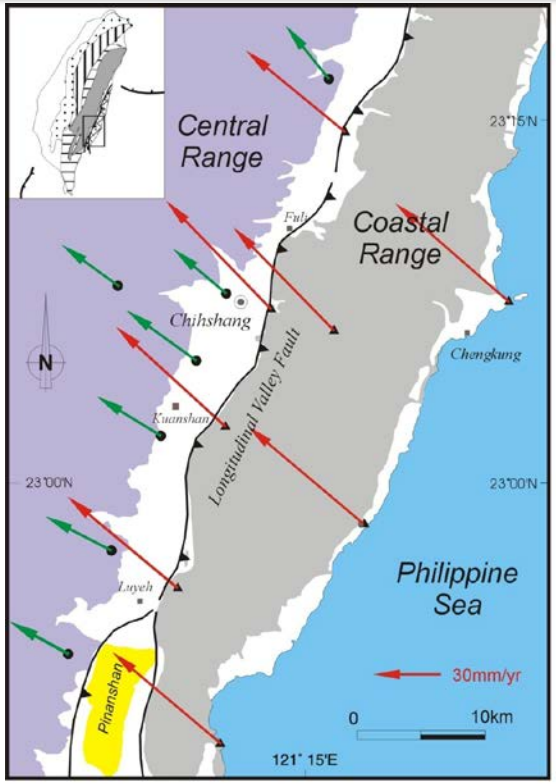
Near Fault Measurements

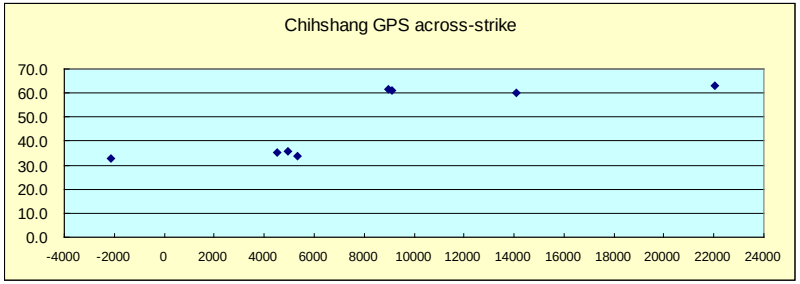
- **Triangle distance and angle**
- **Leveling**
- **GPS**
- **Creep meters**

Result I: Surface Creep

Geodetic Data: GPS and Leveling (Intersiemic)

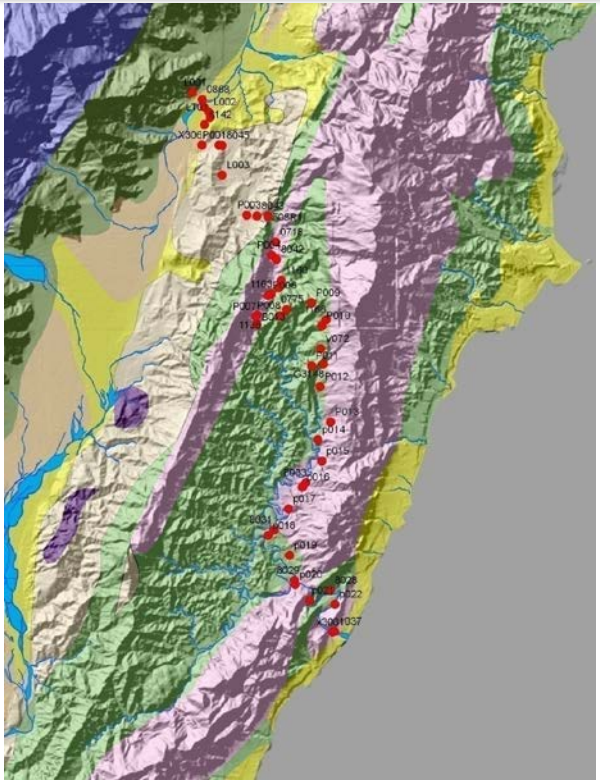
Interseismic GPS rate: 30 mm/yr

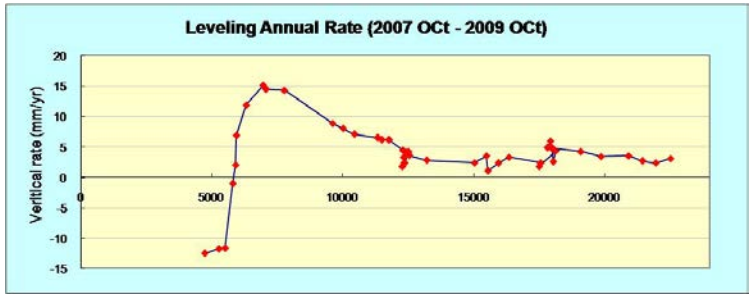




(after Yu et al., 1997; Yu and Kuo, 2001)

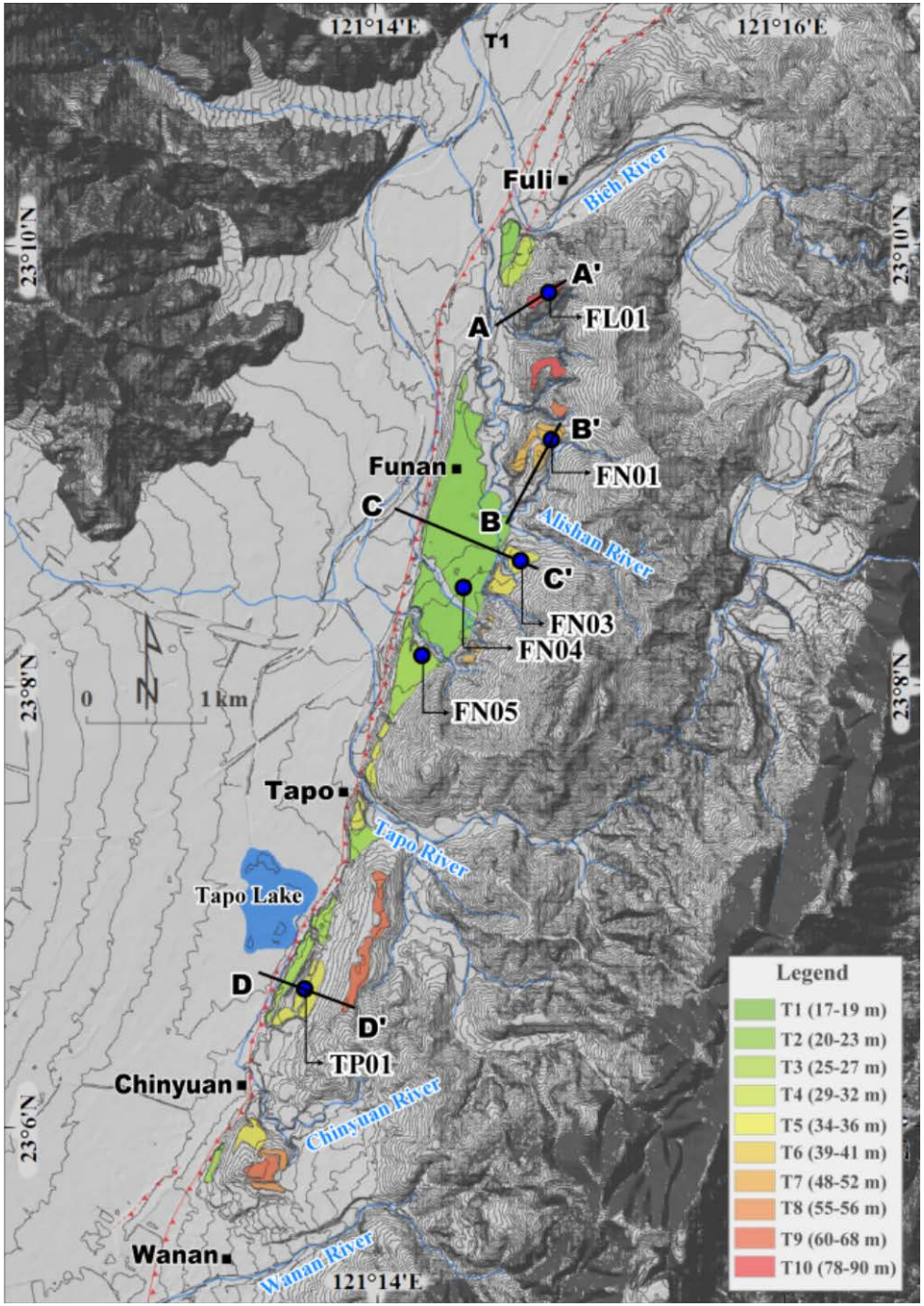
Leveling vertical rate: 27-29 mm/yr



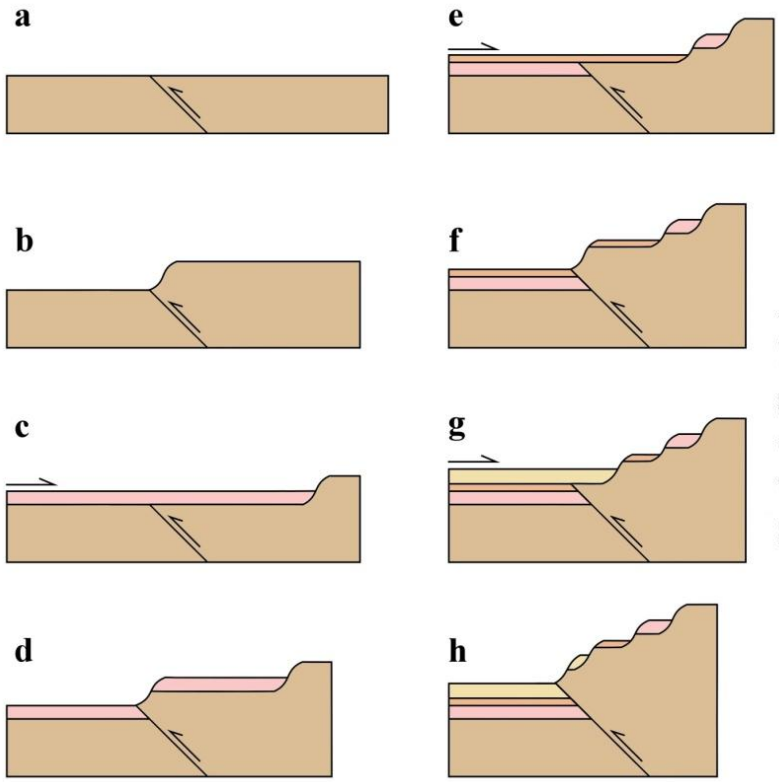


Alluvial deposits and long-term fault slip rate…

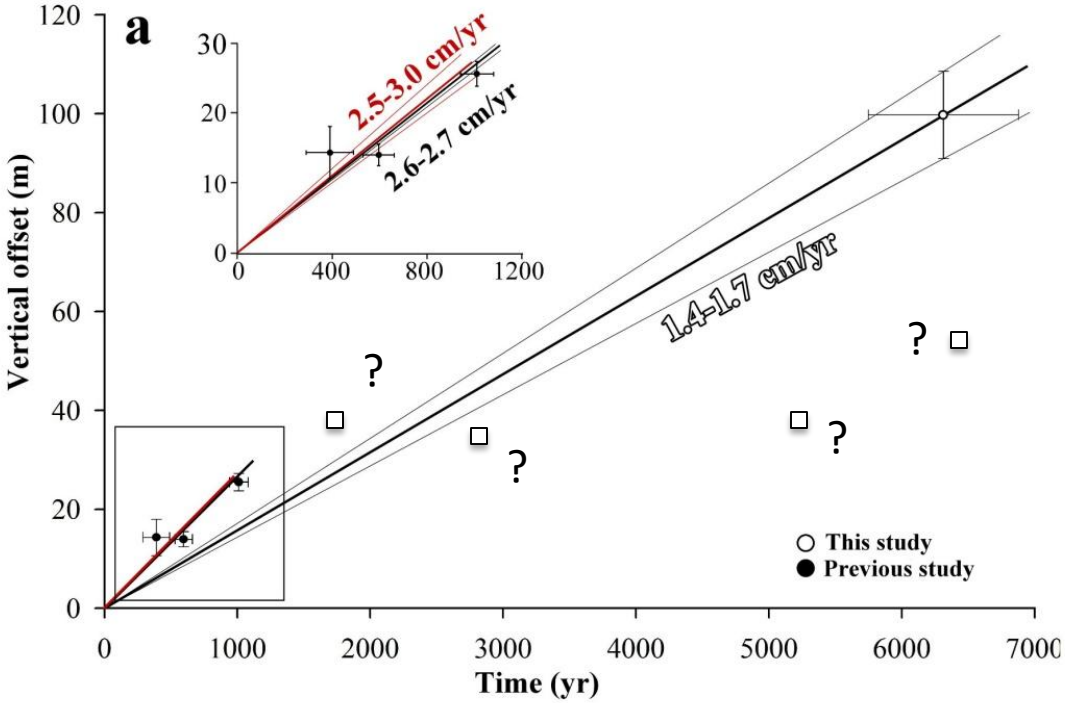
8-10 levels of terraces along the Chihshang Fault



Long-term (Holocene) fault slip rate…



Dating of terrace deposits



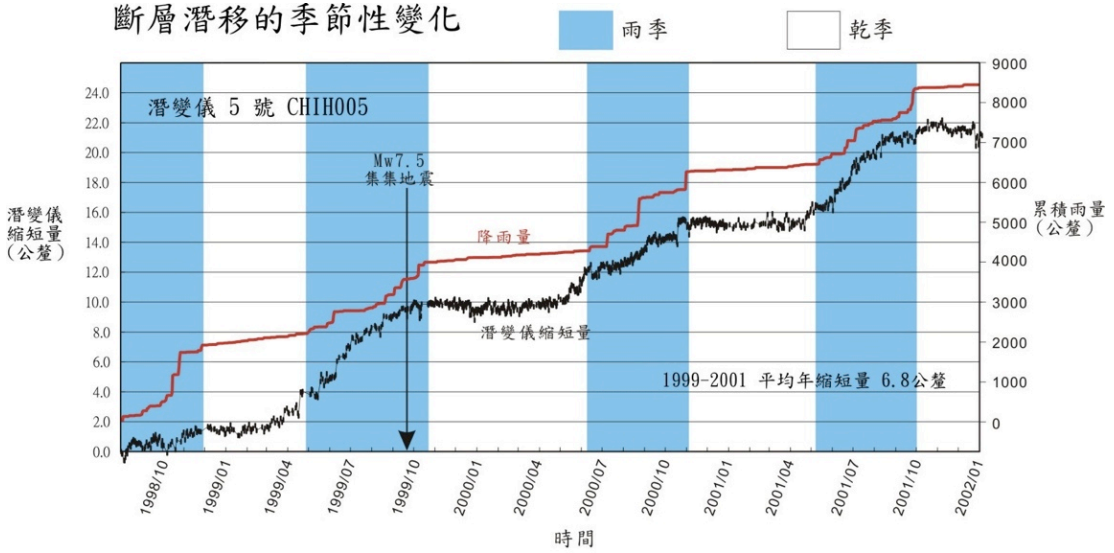
25-30 mm/yr or 14-17 mm/yr

(Chu and Chen, 2009; Chang et al., 2014)

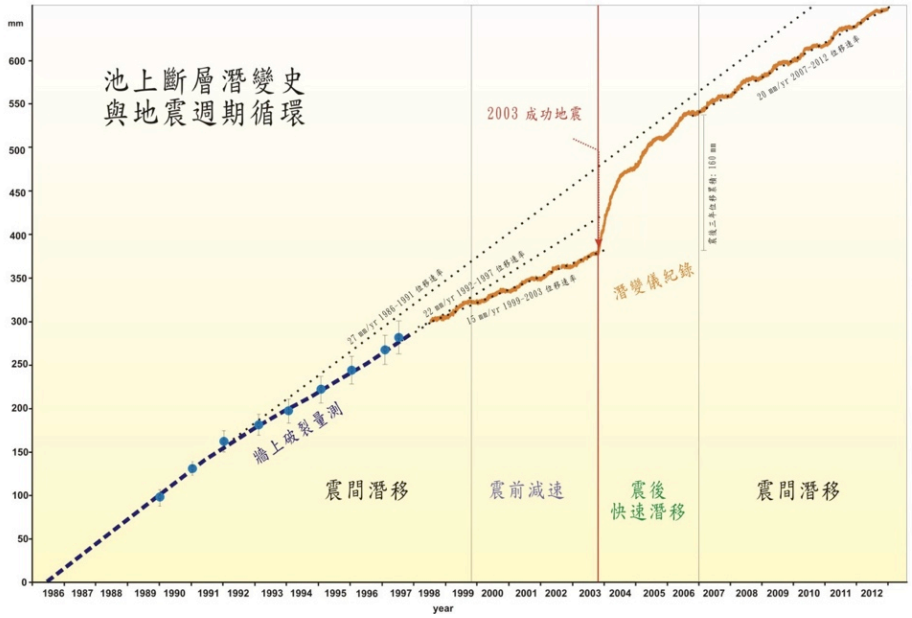
Near-fault Surface Creep Measurements

1. Seasonal creep (dry season locked)

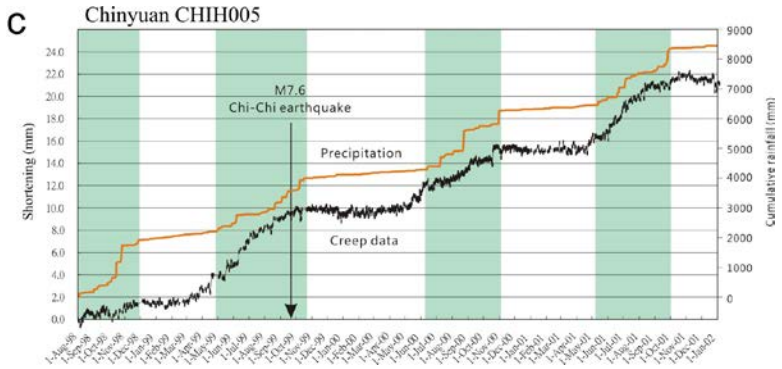
2. Post-seismic creep (co-seismic locked)

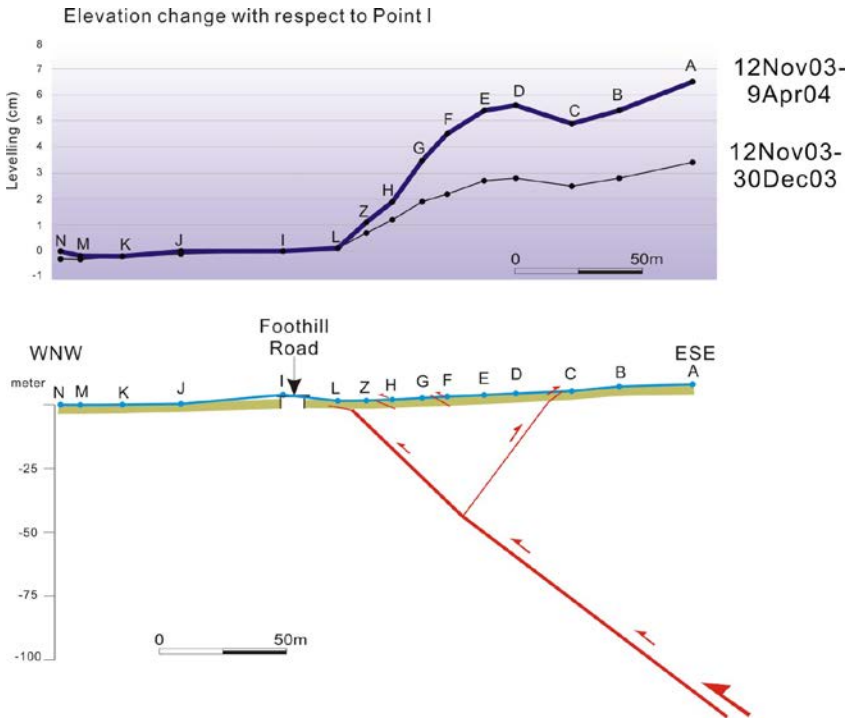


Surface Creep History since 1986

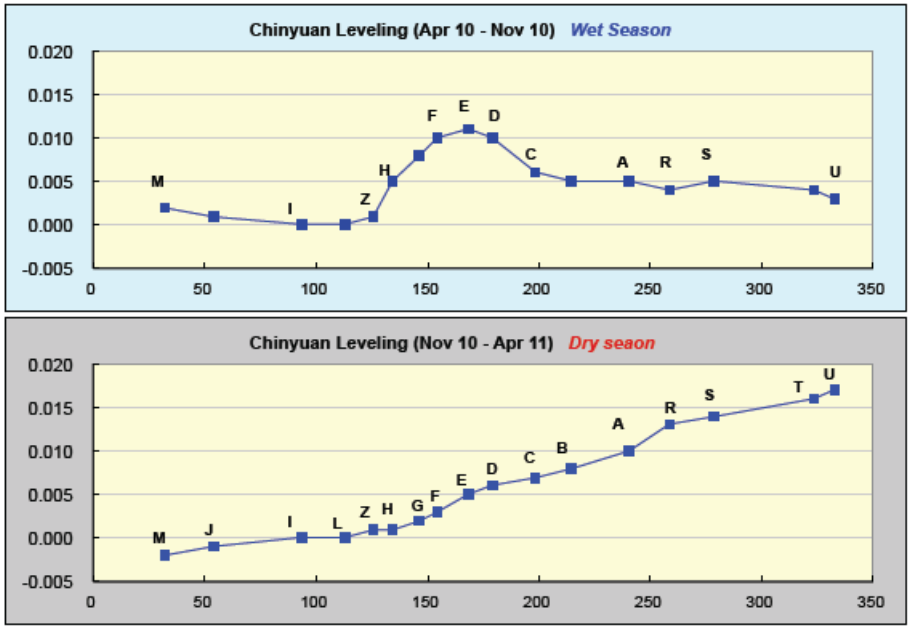


Near-fault seasonal locked at the shallow level





Typical seasonal style of Leveling results

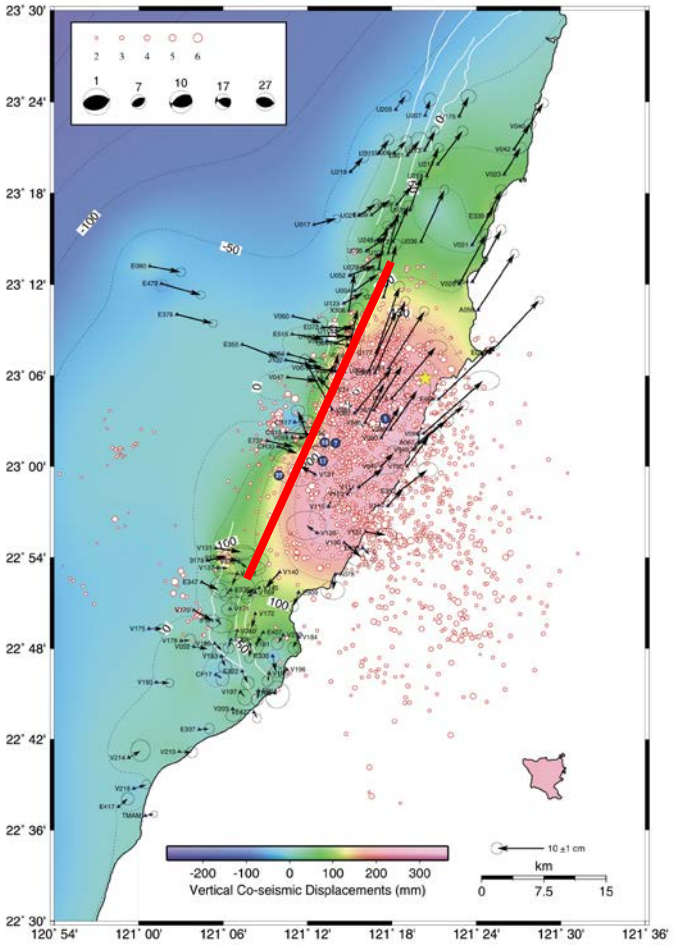


Surface locked when the fault is dry (in dry season)!

Result II:
M6.8 Chengkung Earthquake

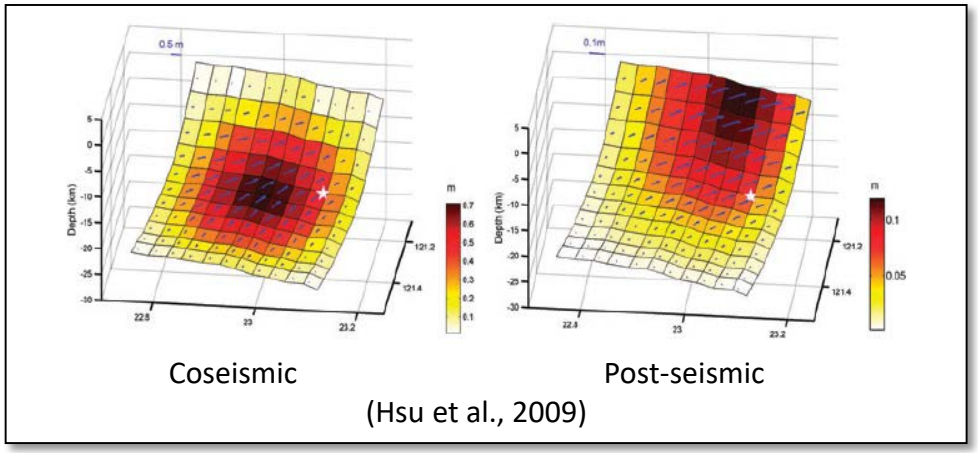
Co- and post-seismic kinematics: Elastic Dislocation Model

2003 M6.8 Chengkung Co-seismic GPS



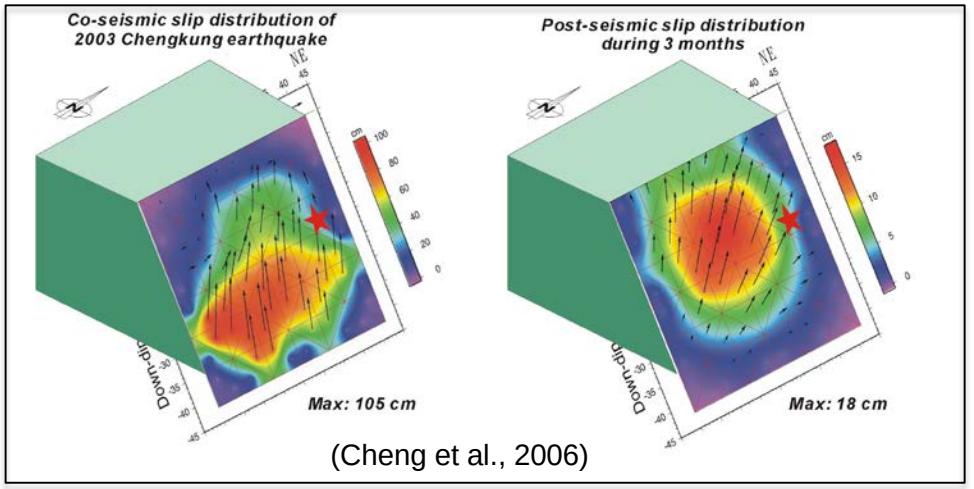
(Ching et al., 2004)

Slip Distribution on the Fault



Coseismic Post-seismic

(Hsu et al., 2009)



(Cheng et al., 2006)

Shallow level velocity strengthening friction modeling

1) 1-D diffusion Model

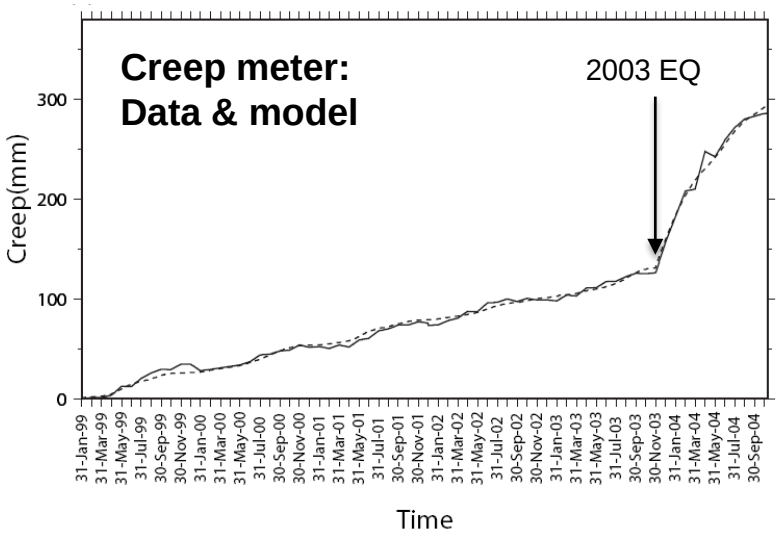
2) Coulomb Failure Criteria

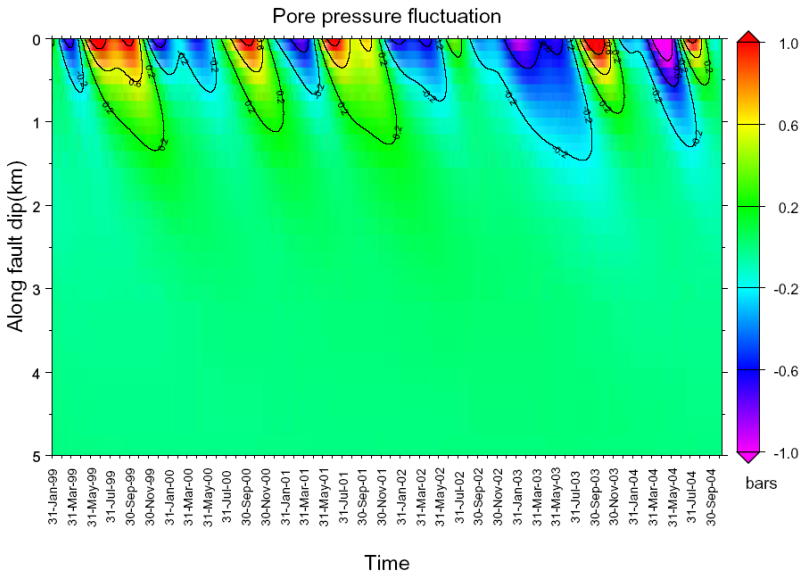
3) Velocity-dependent Friction law

$$\tau = \sigma\mu_* + a\sigma \ln\left(\frac{V}{V_*}\right), \quad a > 0$$

(Ruina , 1983; Perferttini and Avouac, 2007)

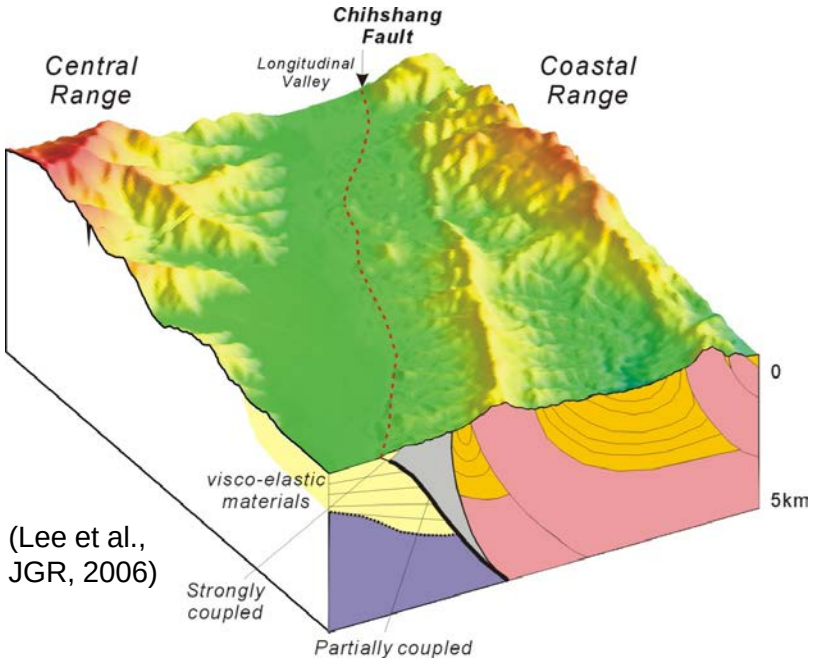
Co-seismic and seasonal locked zone
- depth: **0 - 500 m**
- friction properties (a-b): 0.003-0.005
- hydraulic diffusivity (k): 0.05-0.8 m/s



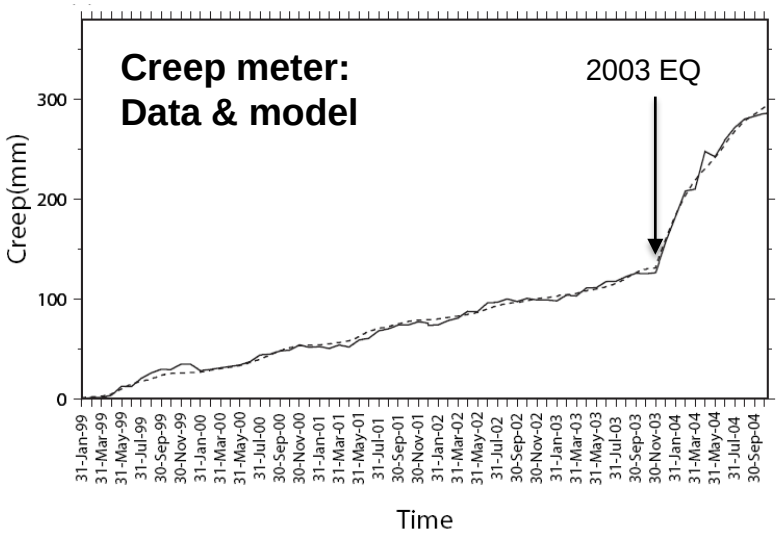


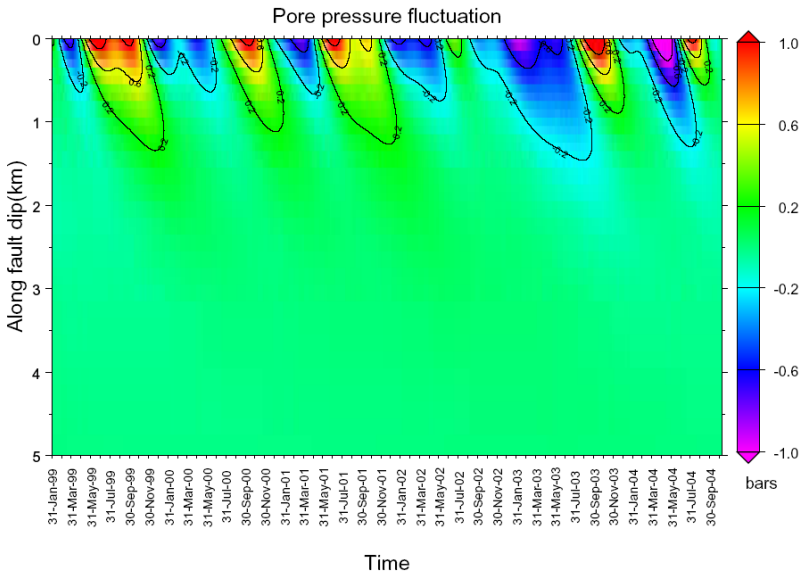
(Chang, Wang and Lee., GJI, 2009)

Shallow level velocity strengthening friction modeling



(Lee et al., JGR, 2006)





(Chang, Wang and Lee., GJI, 2009)

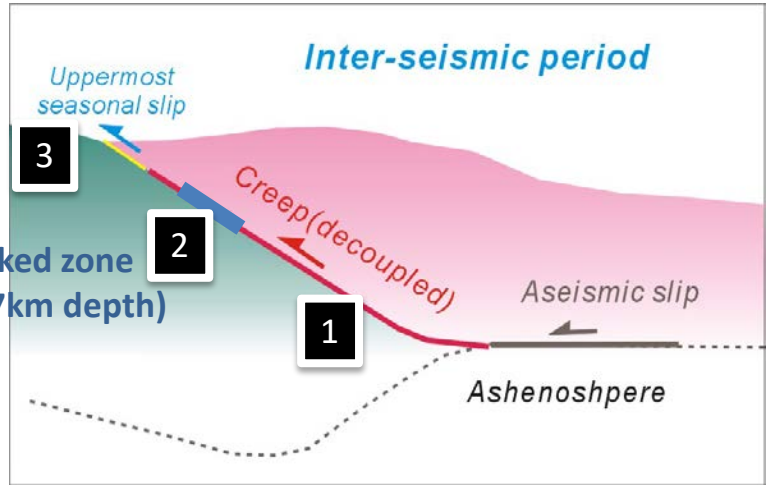
Co-seismic and seasonal locked zone

- depth: **0 - 500 m**
- friction properties (a-b): 0.003-0.005
- hydraulic diffusivity (k): 0.05-0.8 m/s

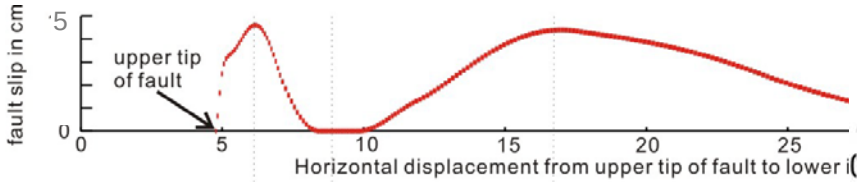
Result III
Kinematics and slip behavior during earthquake cycle

Variation of Slip distribution during earthquake cycle

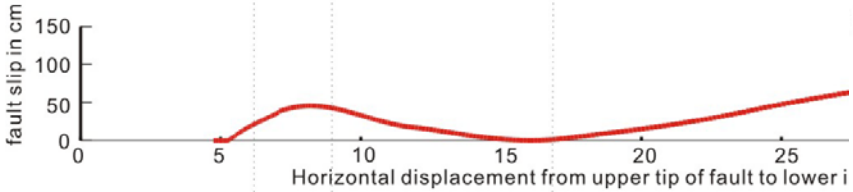
Elastic dislocation inversion from leveling and GPS data



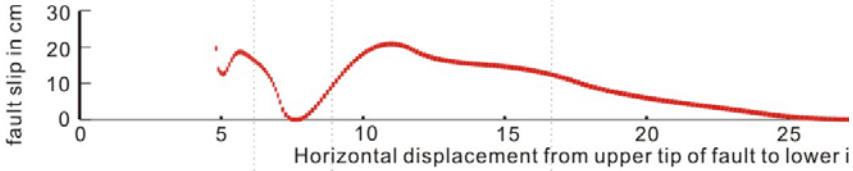
A. Inter-seismic



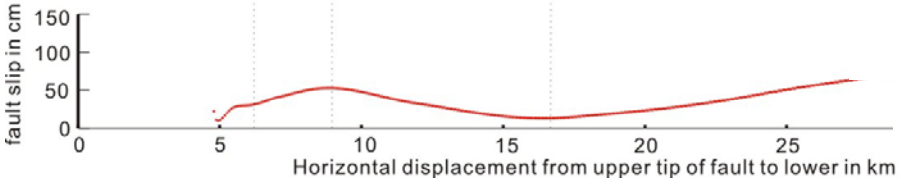
B. Co-seismic

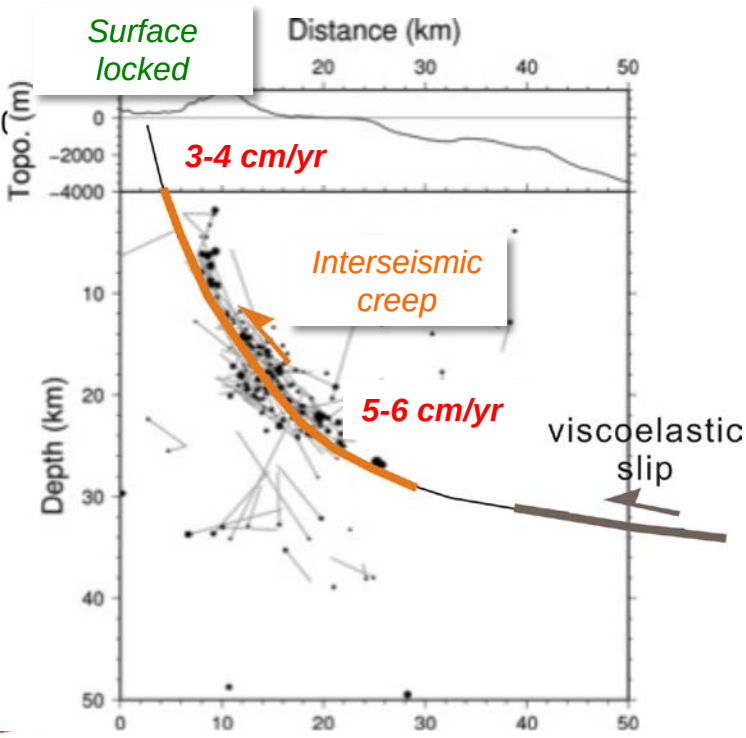


C. post-seismic



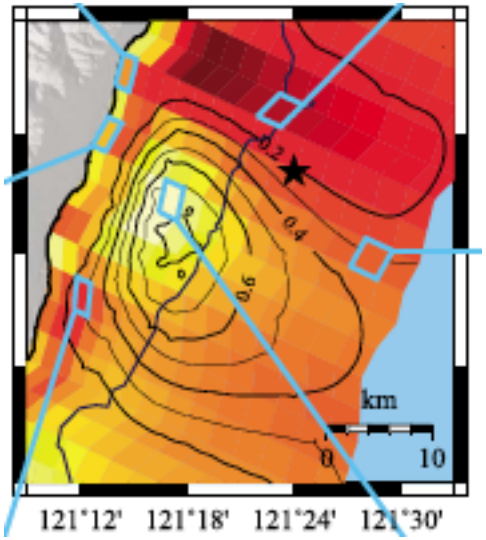
D. Combined co- and post-seismic



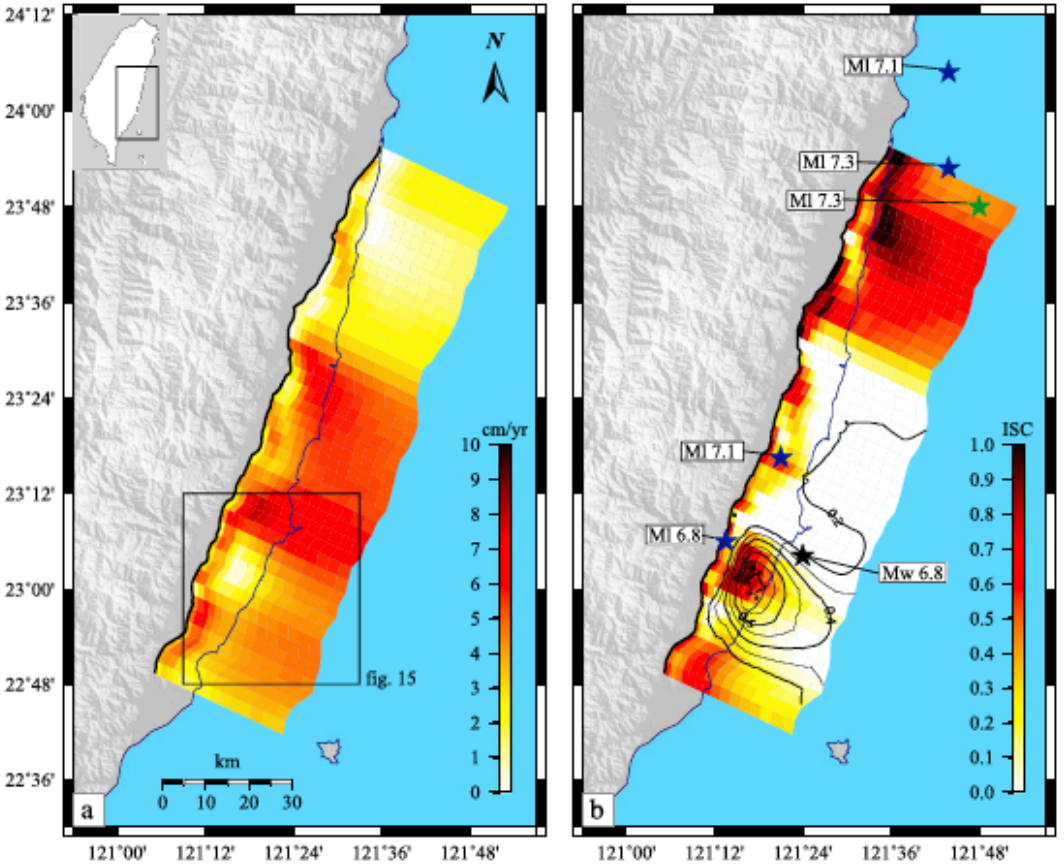


(Huang and Lee, in preparation)

3-D Variation of Interseismic slip distribution along LVF



Interseismc slip and coupling
(inversion from GPS and PS-InSAR)



(Thomas et al., JGR, 2014)

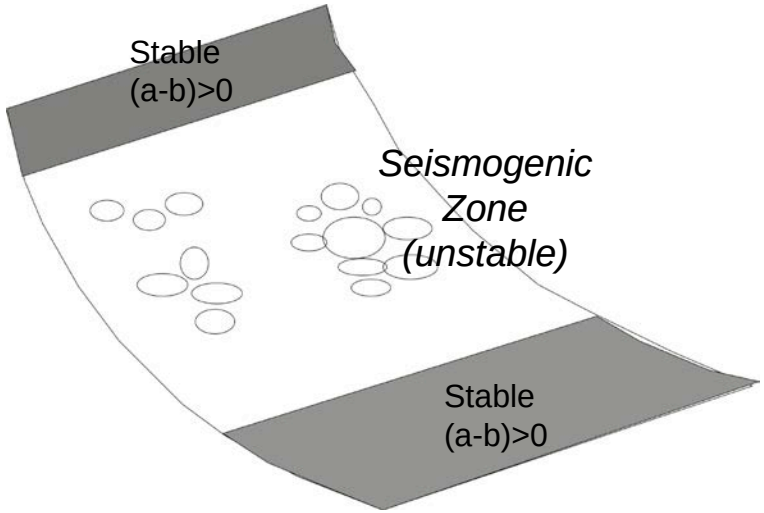
Result IV
Slip Behaviors and
fault's **Frictional Property**

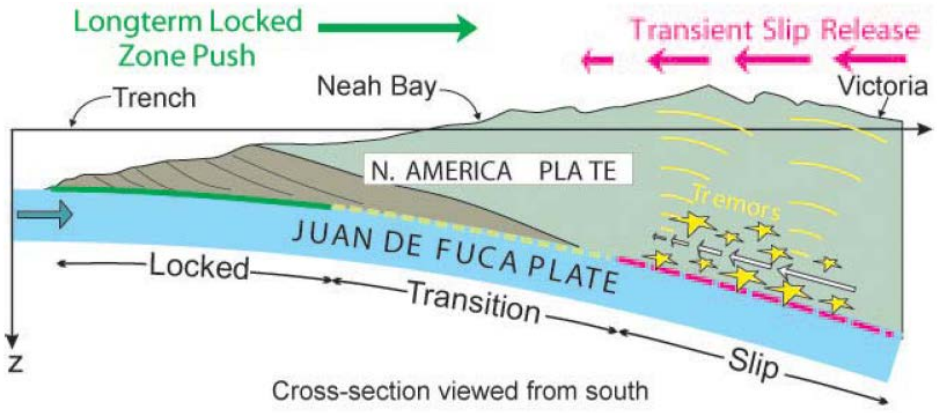
Frictional Property
Velocity-dependent frictional law

$$\tau = \left[\mu_0 + a \ln\left(\frac{V}{V_0}\right) + b \ln\left(\frac{V_0\theta}{\mathcal{L}}\right)\right]\bar{\sigma}$$

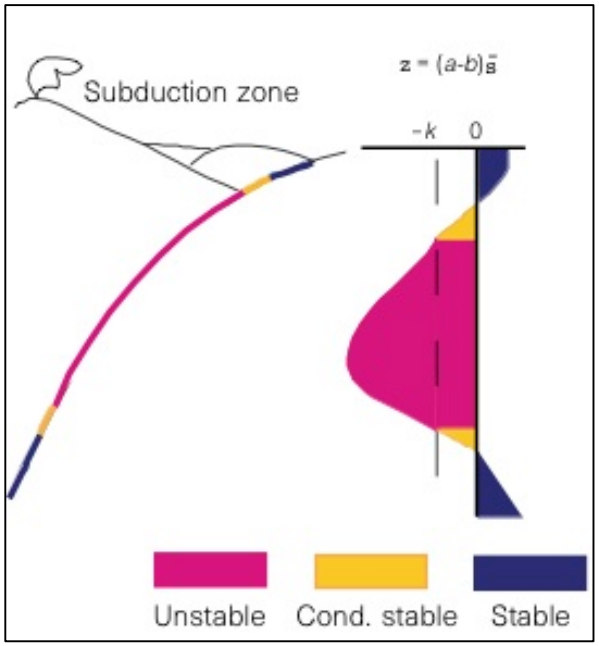
(Dieterich, 1979; Ruina, 1983)

Friction Property (a-b)





(Flueck et al., JGR, 1997)

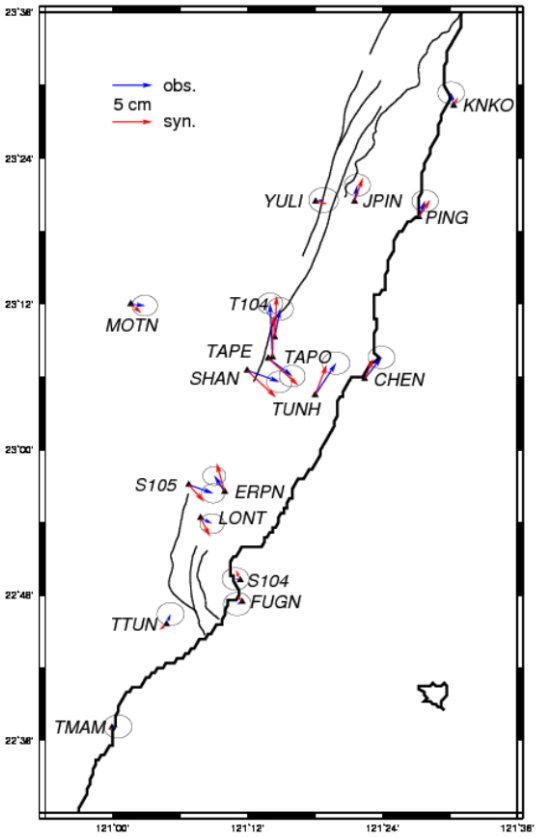


(Scholz, Nature, 1998)

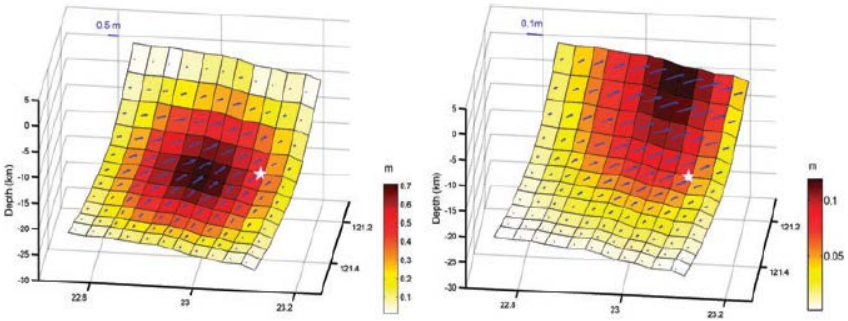
Frictional Property in 3-D Fault Patch：

A case study of 2003 Chengkung earthquake

$$\begin{cases} V(i,t) = V_0(i)\exp\left[(\Delta CFF(i,t)+CFF_0)/a(i)\sigma(i,t)\right], \\ \tau = \sigma\mu_* + a\sigma\ln\left(\dfrac{V}{V_*}\right), \quad a > 0 \end{cases}$$



150 days of post-seismic creep

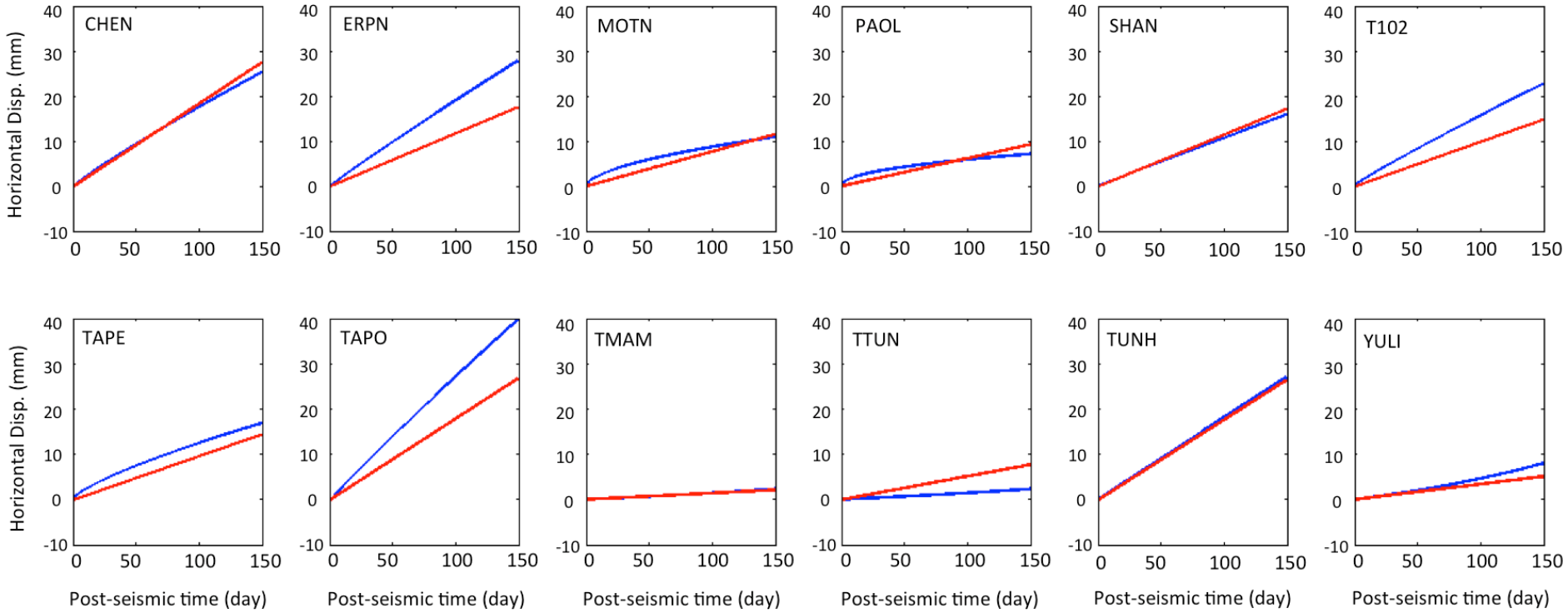


Coseismic Post-seismic

(Hsu et al., 2009)

Frictional Property and GA modeling

Post-seismic slip of the 2003 Chengkung earthquake



Case of best-fit:

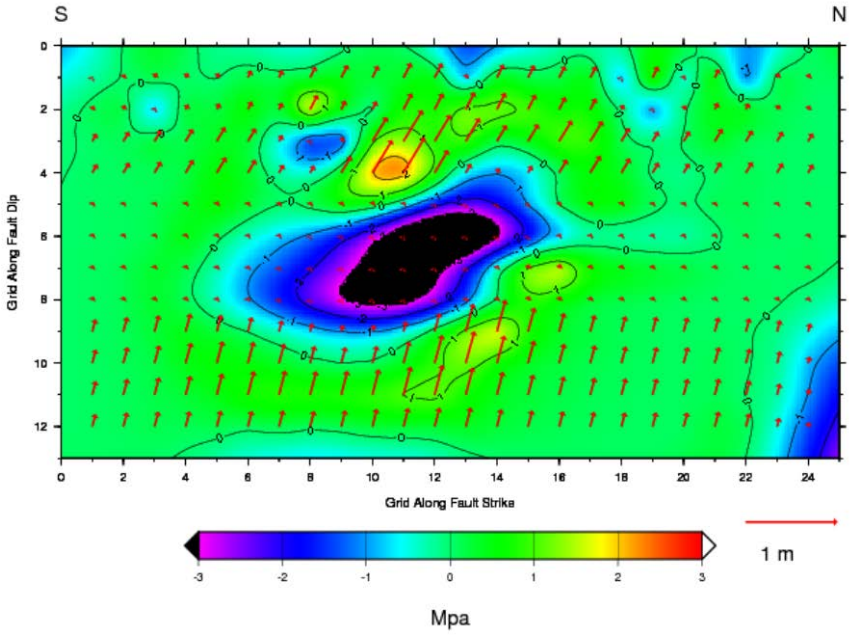
Coseismic model: **Hsu et al. (2009)**

(a-b)= 6 layers, uniform $\mu^* = 0.41$, $d(\sigma_1-\sigma_3)/dz = 98$ MPa/km

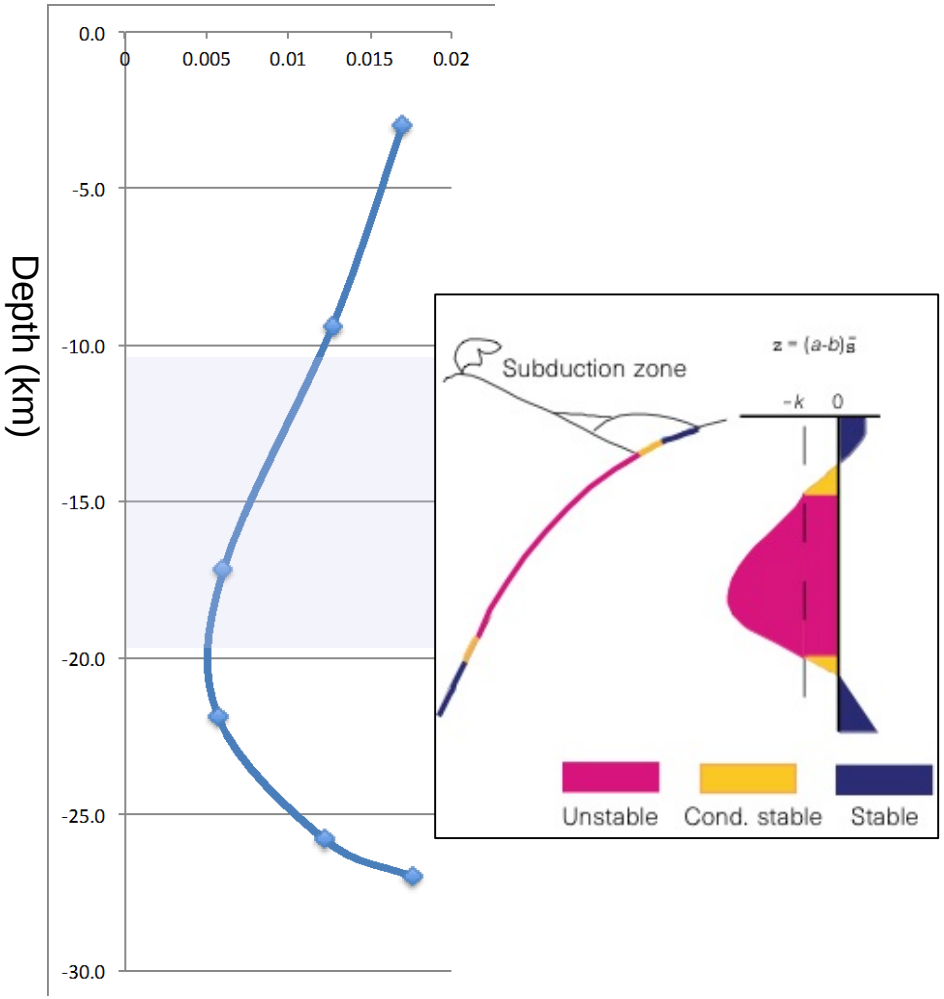
Frictional Property and GA fitting：

A case study of 2003 Chengkung earthquake

150 days of post-seismic creep



(a-b)



Case of best-fit:

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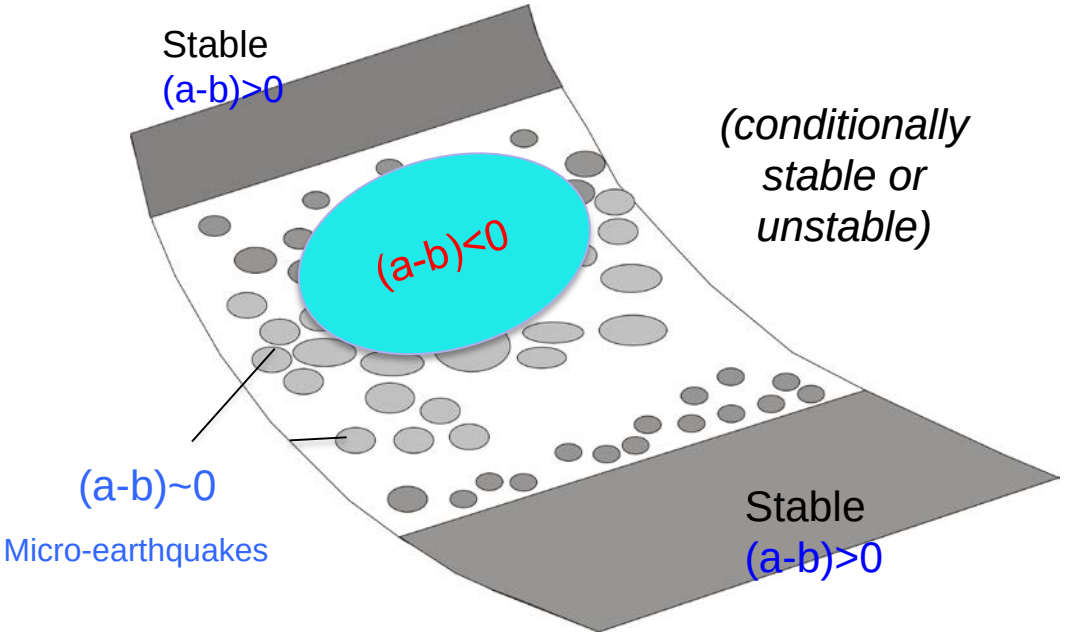
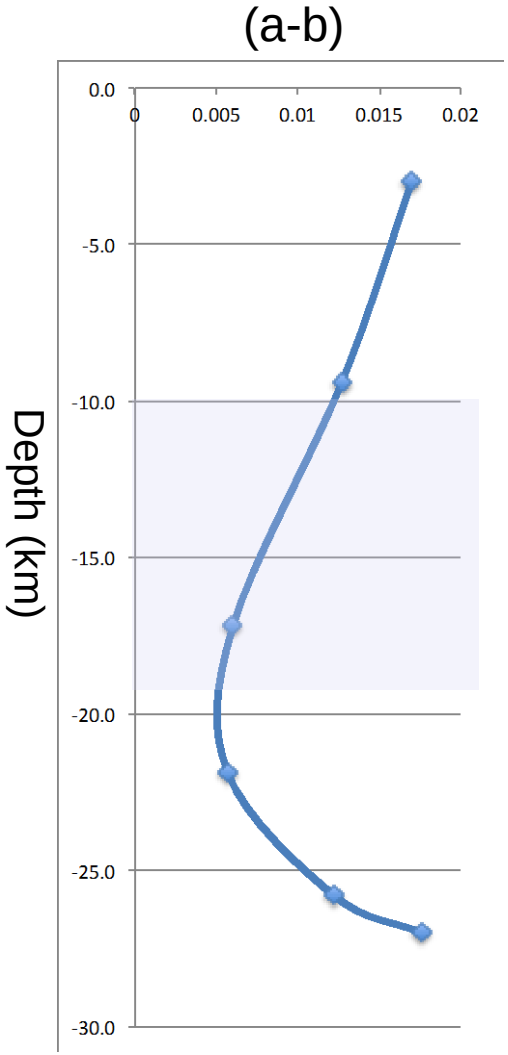
$d(\sigma_1-\sigma_3)/dz = 98$ MPa/km

Frictional Property and GA fitting：

A case study of 2003 Chengkung earthquake

Frictional property on Chihshang Fault





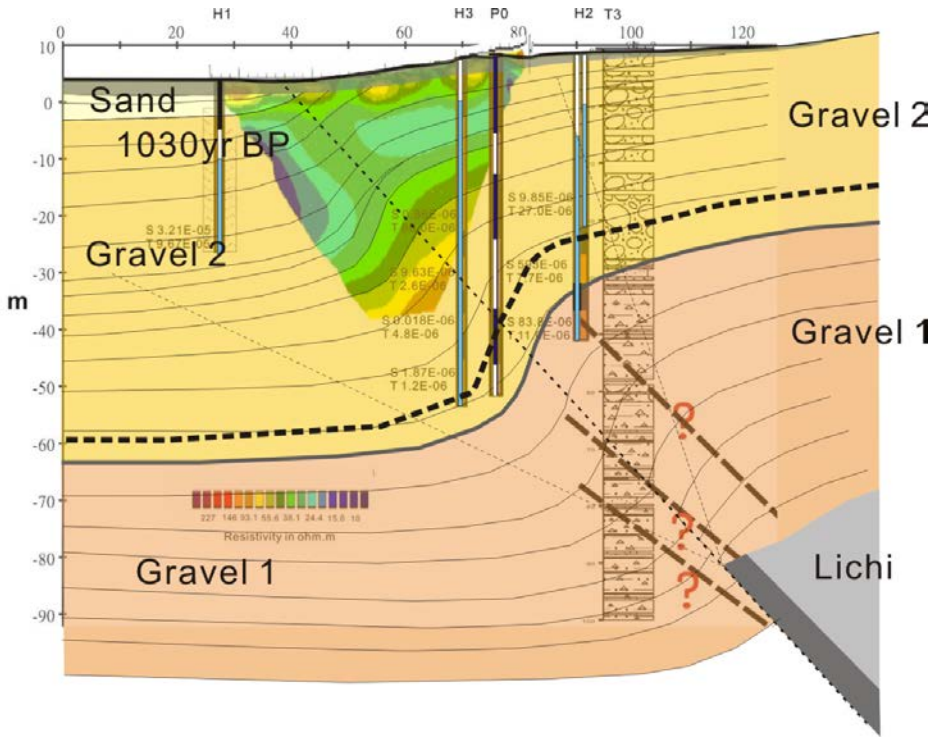
Result V:

Hydraulic Property on the surface fault zone

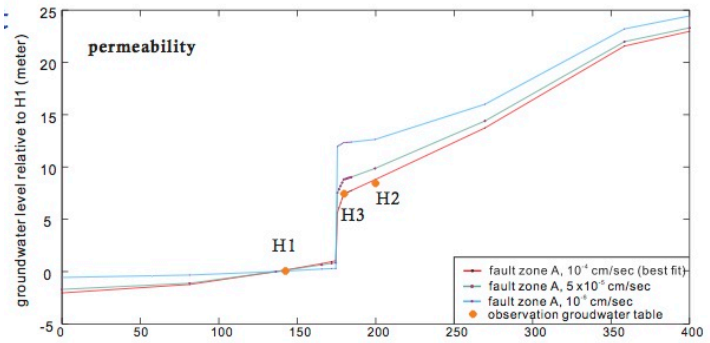
Hydraulic measurements and on-site tests

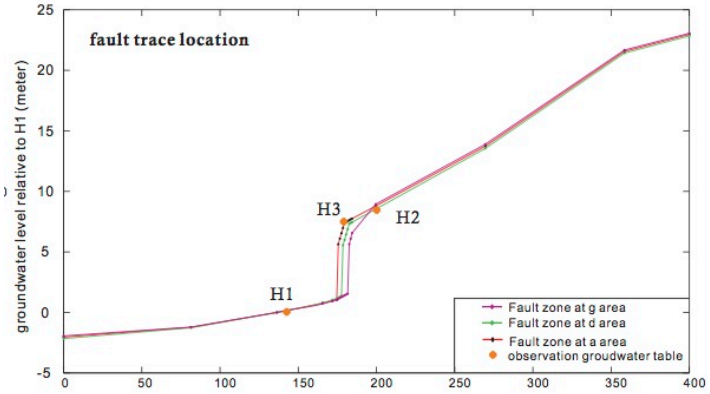
Injection/pumping experiment

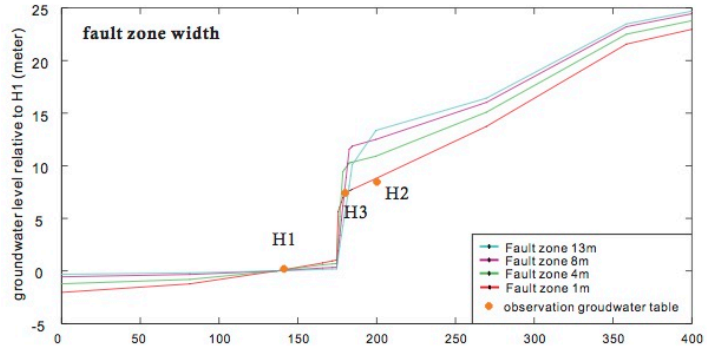
Repeated (monthly) slug tests



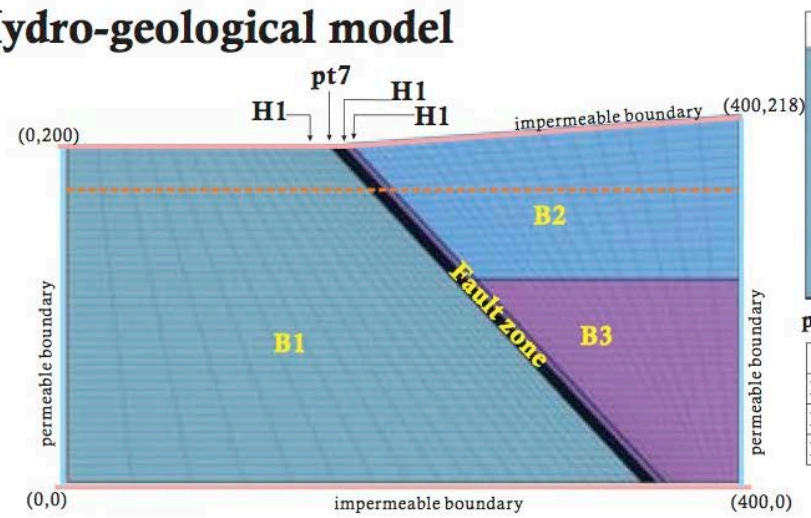
Hydraulic modeling

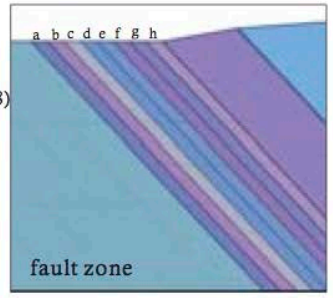






(Mu et al., AGU, 2014)





parameters:

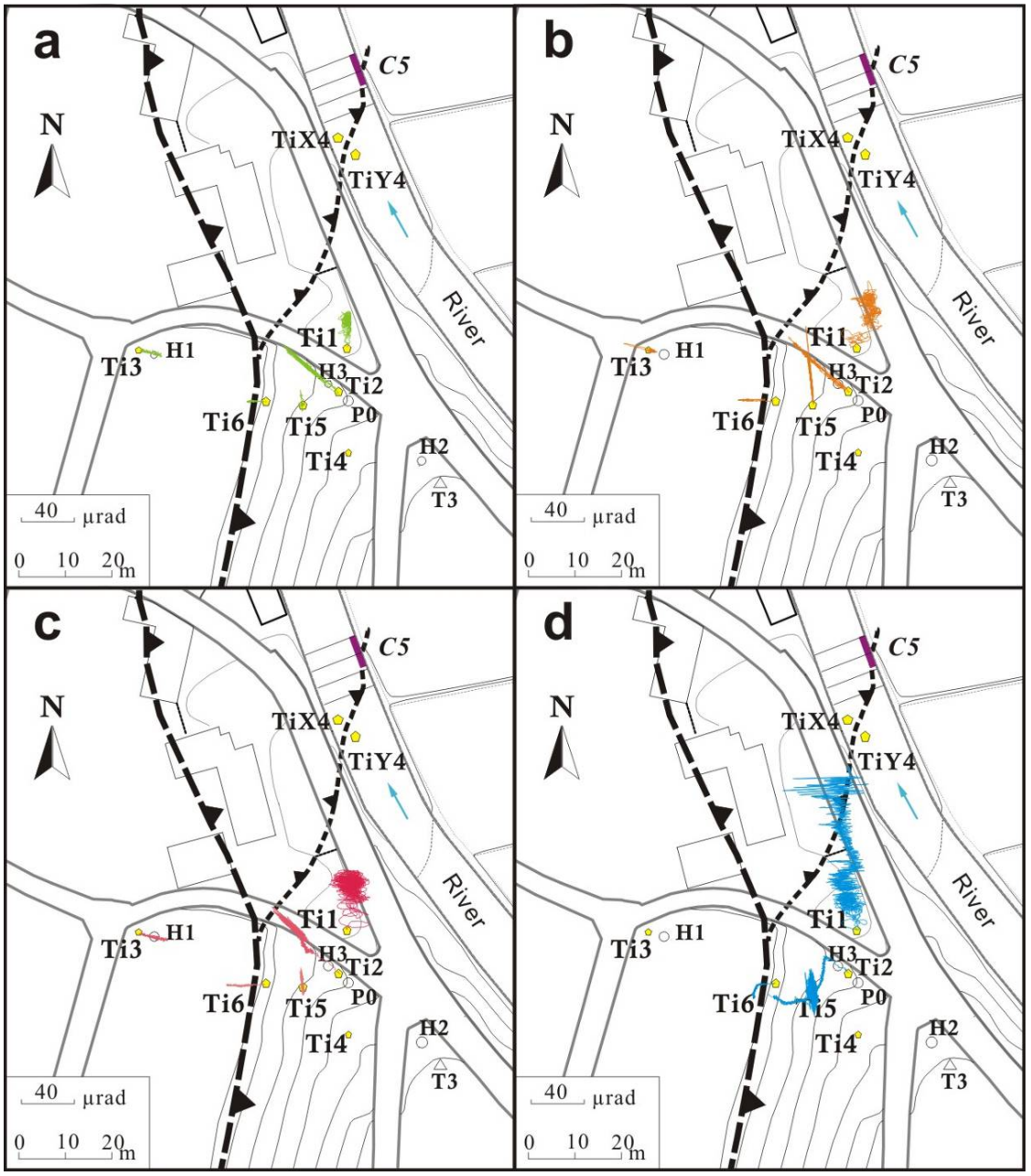
	materiel	porosity	permeability
B1	alluvial deposit	0.25	10^{-2} cm/s
B2		0.25	10^{-2} cm/s
B3	Lichi Melange	0.1	10^{-12} cm/s

1. 3 layers of permeability + fault zone
   B1, B2: 10^{-2} cm/s (gravels)
   Fault zone : 10^{-5} ~10^{-4} cm/s
   B3: 10^{-12} cm/s (Lichi melange)

2. Fault zone influence width: **4-5 m**

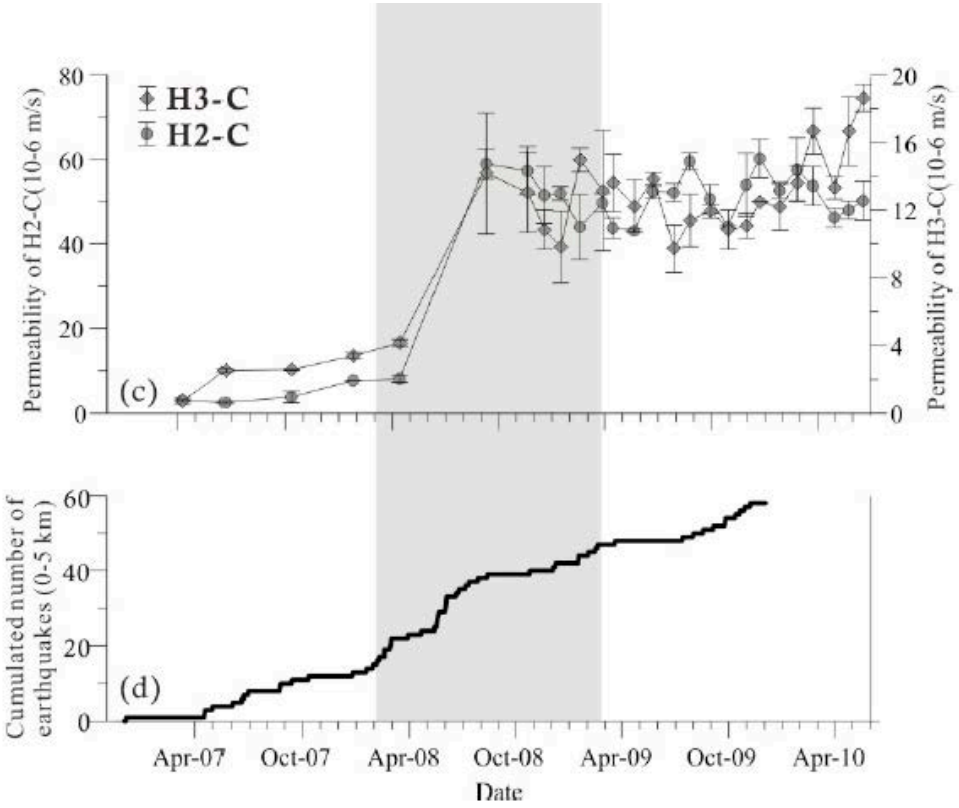
Injection Tests

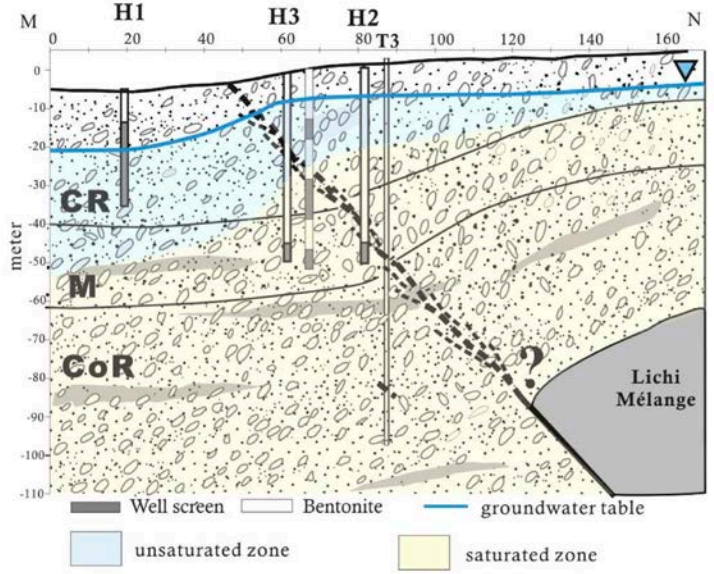
Fault zone acted as a **hydraulic barrier** to impede groundwater flow !



(Mu et al., in preperation)

Permeability Increase
by earthquake swarm (seismic wave?)

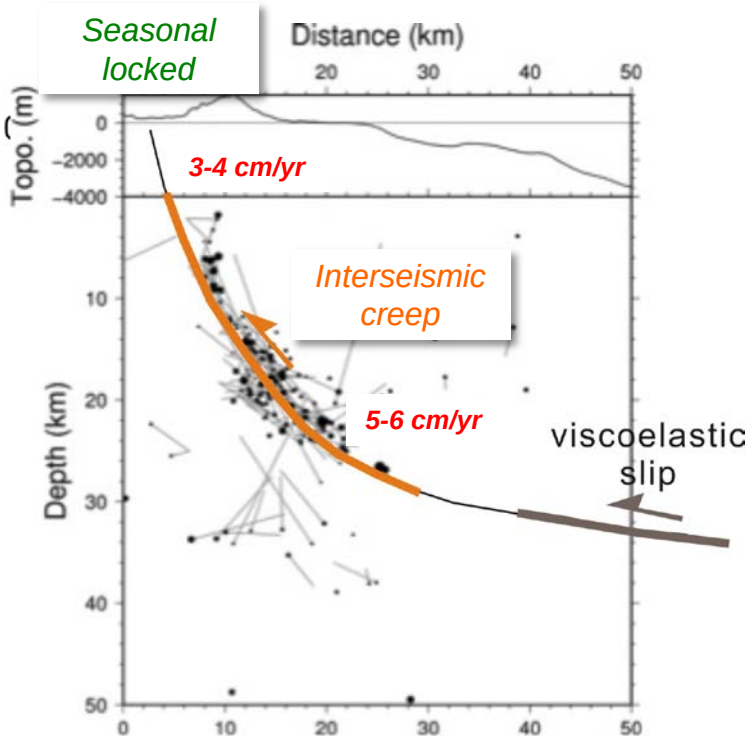




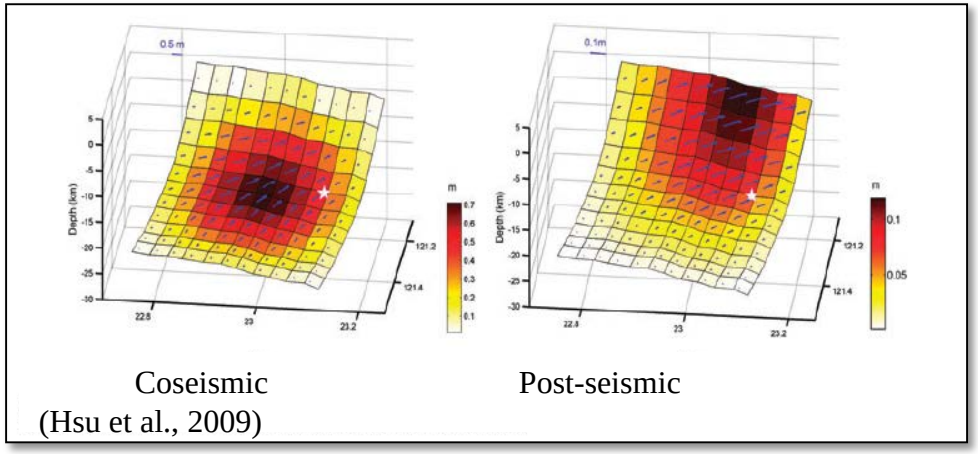
(Mu et al., AGU, 2016)

Conclusions: what we learned from….

Interseismic Fault Slip

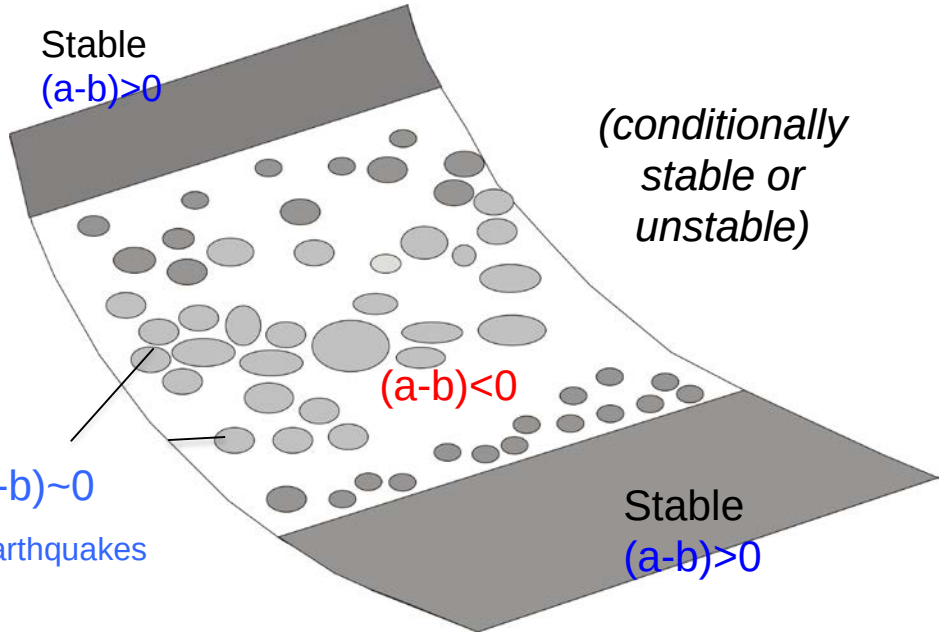


Co-and post-seismic Slip

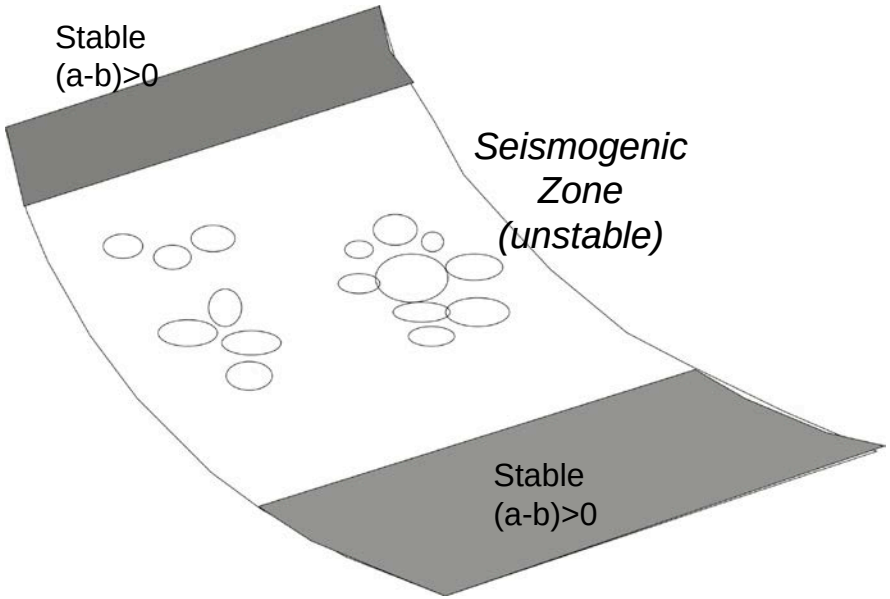


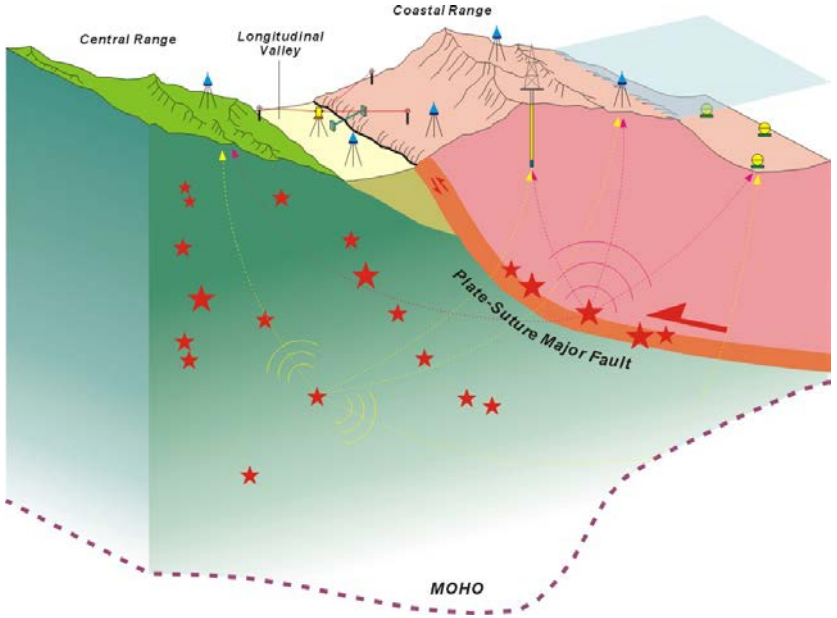
Coseismic (Hsu et al., 2009)

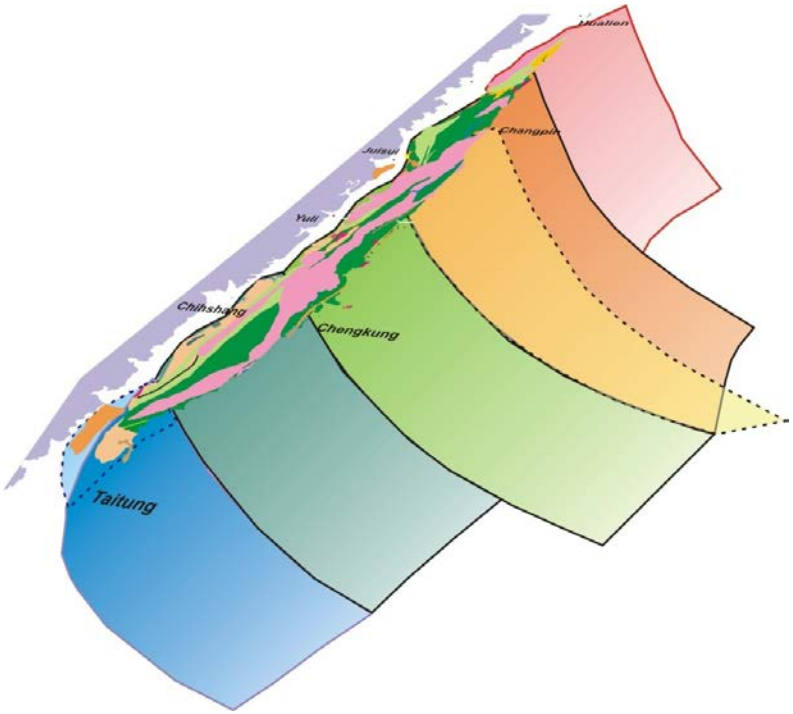
Post-seismic



Perspectives







Thank you for your attention