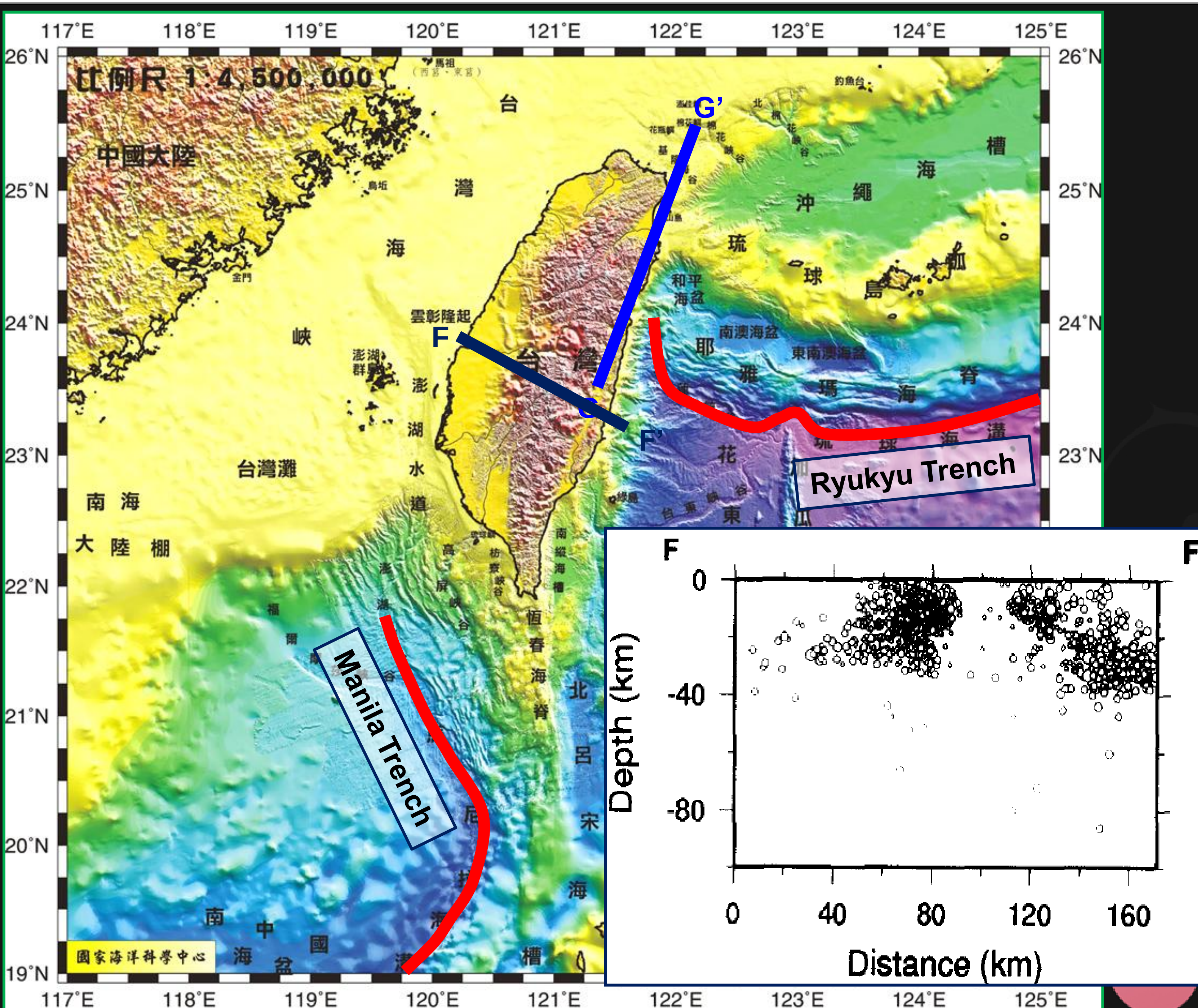
Evidence of a subducted slab beneath central Taiwan

Speaker: Yen-Fu Chen

References

- Lallemand, S., Font, Y., Bijwaard, H., Kao, H., 2001. New insights on 3-D plates interaction near Taiwan from tomography and tectonic implications. Tectonophysics 335, 229-253.

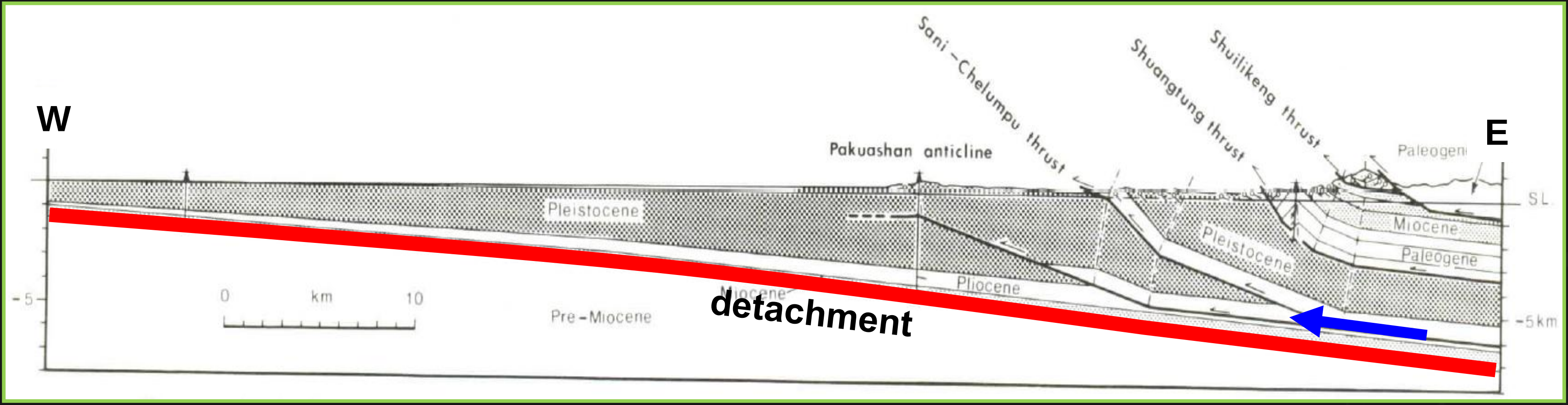
- Chen, P.-F., Huang, B.-S., Liang, W.-T., 2004. Evidence of a slab of subducted lithosphere beneath central Taiwan from seismic waveforms and travel times. Earth and Planetary Science Letters 229, 61-71.



比例尺 1:4,500,000
117°E
118°E
119°E
120°E
121°E
122°E
123°E
124°E
125°E
26°N
25°N
24°N
23°N
22°N
21°N
20°N
19°N
中國大陸
雲彰隆起
澎湖群島
台灣灘
南海大陸棚
和平海盆
南澳海盆
東南澳海盆
G'
F
F'
Ryukyu Trench
Manila Trench
國家海洋科學中心
F
F'
0
-40
-80
Depth (km)
0
40
80
120
160
Distance (km)

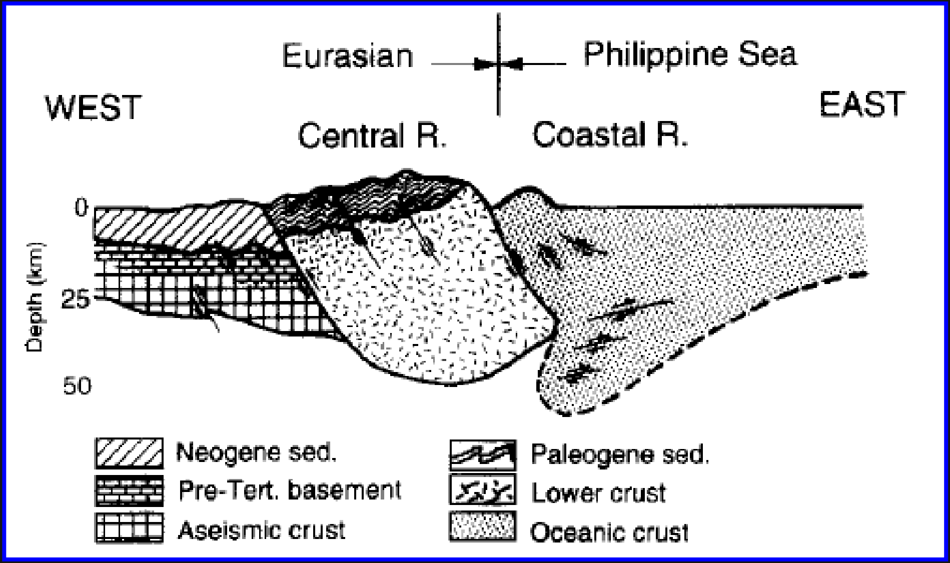
Hypotheses of the Taiwan orogeny

- Thin-skinned model



(Suppe, 1987)

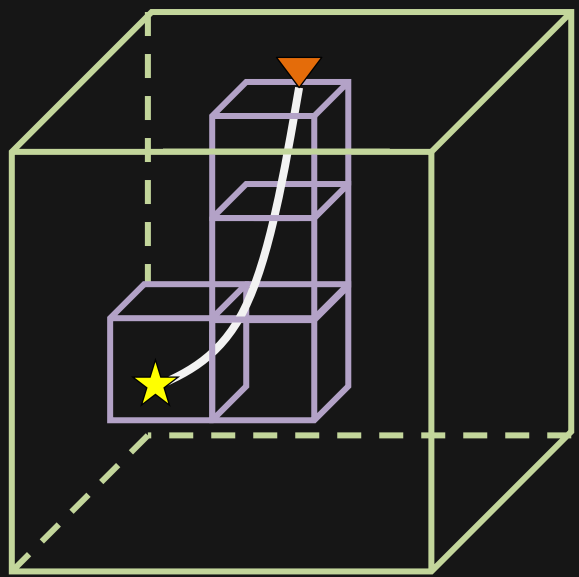
- Thick-skinned model



(Wu et al., 1997)

Seismic tomography

- Construct images from seismic wave.
- In the same layer, the different velocities may be caused by different materials.



$$\text{known}: t, L_1, L_2, L_3, L_4$$

$$\text{find}: V_1, V_2, V_3, V_4$$

$$\frac{L_1}{V_1} + \frac{L_2}{V_2} + \frac{L_3}{V_3} + \frac{L_4}{V_4} = t$$

t : travel time from hypocenter to the station

L_i : length of ray path in each square

V_i : velocity of squares

- If there are many ray paths, then we can resolve the unknowns and obtain velocity structures.

Mathematical formulation

- Known: initial origin time, initial hypocenter, initial velocity model

Cause by difference of origin time

Cause by difference of location

Cause by difference of velocity model

$t^{obs} - t^{cal}$

$$r = \Delta t_e + \frac{\partial t}{\partial x_e}\Delta x_e + \frac{\partial t}{\partial y_e}\Delta y_e + \frac{\partial t}{\partial z_e}\Delta z_e + \sum_{n=1}^{N}\frac{\partial t}{\partial v_n}\Delta v_n$$

r : arrival time residual

$\Delta t_e, \Delta x_e, \Delta y_e, \Delta z_e$: perturbation to hypocentral parameters

Δv_n : perturbation to velocity parameters

$\frac{\partial t}{\partial x_e}, \frac{\partial t}{\partial y_e}, \frac{\partial t}{\partial z_e}, \frac{\partial t}{\partial v_n}$: calculate from initial velocity model

(Thurber, 1983)

Inversion

L, number of ray paths; m, number of events;

N, number of velocity parameters.

$$r = \Delta t_e + \frac{\partial t}{\partial x_e}\Delta x_e + \frac{\partial t}{\partial y_e}\Delta y_e + \frac{\partial t}{\partial z_e}\Delta z_e + \sum_{n=1}^{N}\frac{\partial t}{\partial v_n}\Delta v_n$$

$$\begin{bmatrix} 1 & \frac{\partial t_1}{\partial x_1} & \frac{\partial t_1}{\partial y_1} & \frac{\partial t_1}{\partial z_1} & \cdots & 0 & 0 & 0 & 0 & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & \cdots & 1 & \frac{\partial t_m}{\partial x_m} & \frac{\partial t_m}{\partial y_m} & \frac{\partial t_m}{\partial z_m} & \cdots \end{bmatrix} \begin{bmatrix} \Delta t_1 \\ \Delta x_1 \\ \Delta y_1 \\ \Delta z_1 \\ \vdots \\ \Delta t_m \\ \Delta x_m \\ \Delta y_m \\ \Delta z_m \\ \Delta v_1 \\ \vdots \\ \Delta v_N \end{bmatrix} = d_{L\times 1}$$

- Least squares

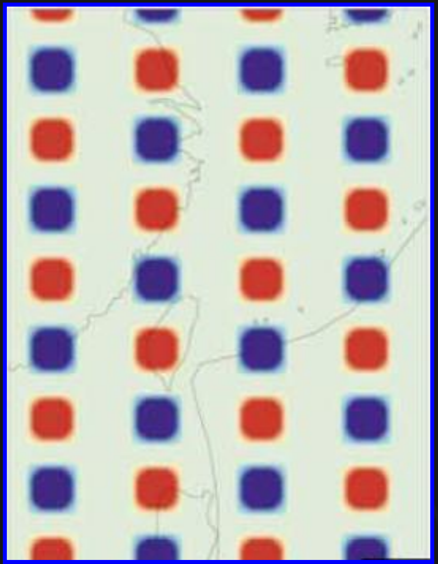
Global tomography

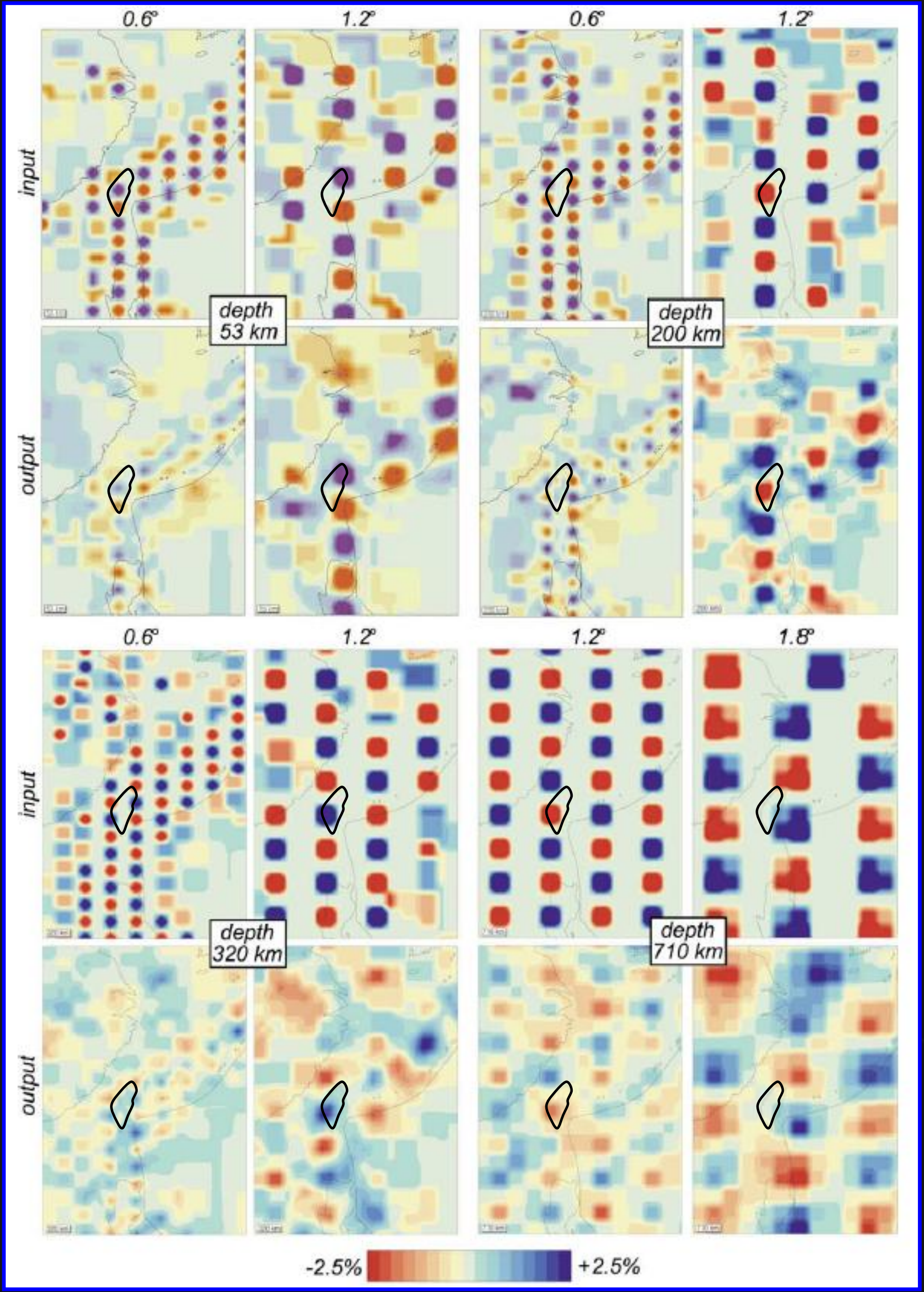
- Bijwaard et al., 1998
- Data (1964-1995)
  - ISC (International Seismological Center)
  - USGS's NEIC (US Geological Survey's National Earthquake Information Center)
  - Temporary seismic stations
- Relocated by Engdahl et al., 1998
- 7.6 million teleseismic P, pP, and pwP data

Resolution analysis

- Spike test (similar to Checkerboard test)
- First, add velocity anomalies to initial velocity model with positive and negative sign alternately.
- Second, calculate synthetic travel times from each hypocenter to stations through spike velocity models.
- Third, synthetic travel times are inverted for the spike velocity models from the initial model.
- If the initial pattern is restored in some areas, then the resolution of those areas is good.

Tomography	Spike test
Observed arrival times	Synthetic travel times
The same stations	
The same hypocenters	
The same initial model	
True velocity structures	Spike velocity models

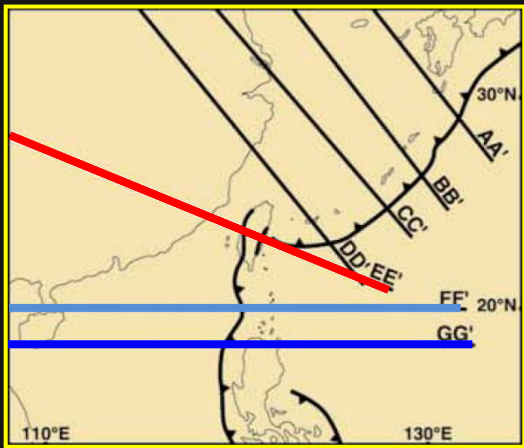


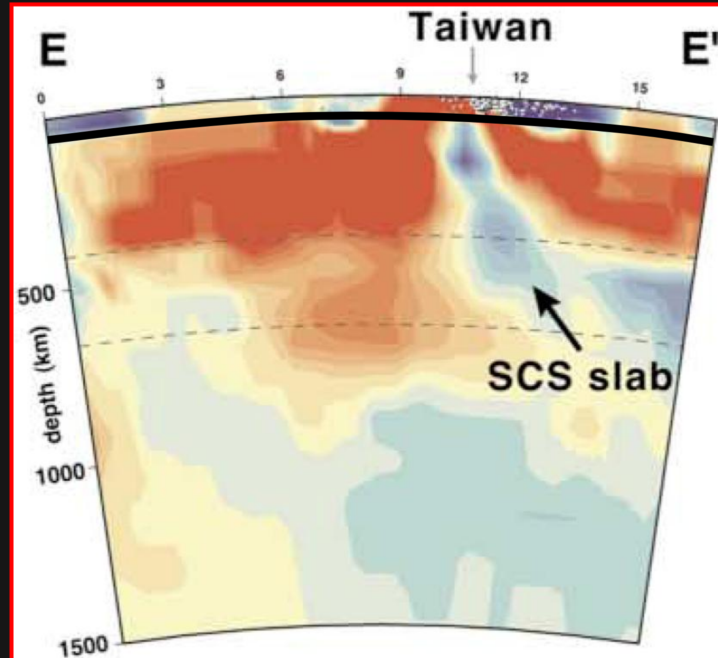


4 sizes of spikes (0.6, 1.2, 1.8 and 2.4 °) and 13 different depths between 18 and 710 km.

Resolution for 1.2 ° is better from 53 to about 320 km.

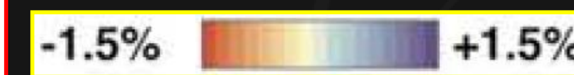
In 710 km, the resolution is worsen to 1.8 °.

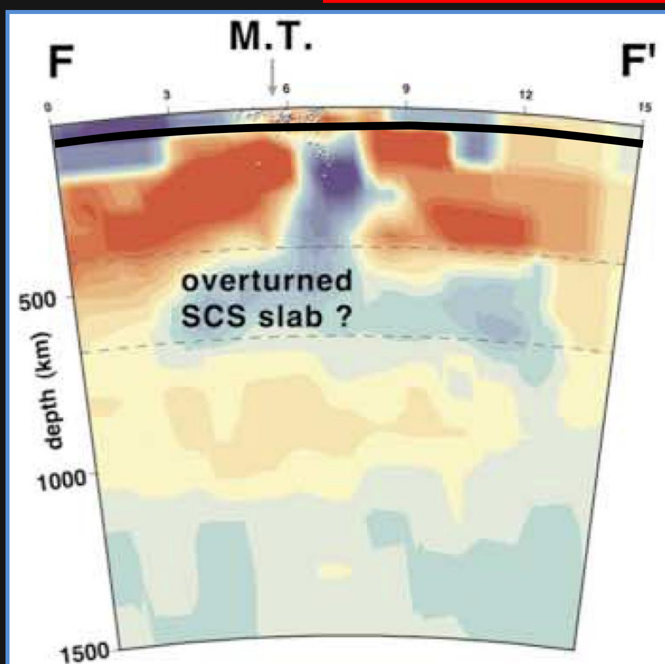


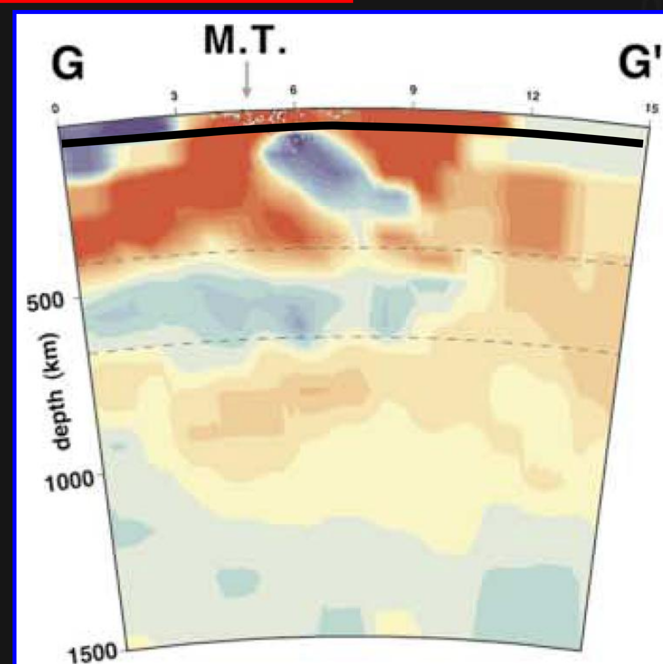


SCS: South China Sea

M.T.: Manila Trench



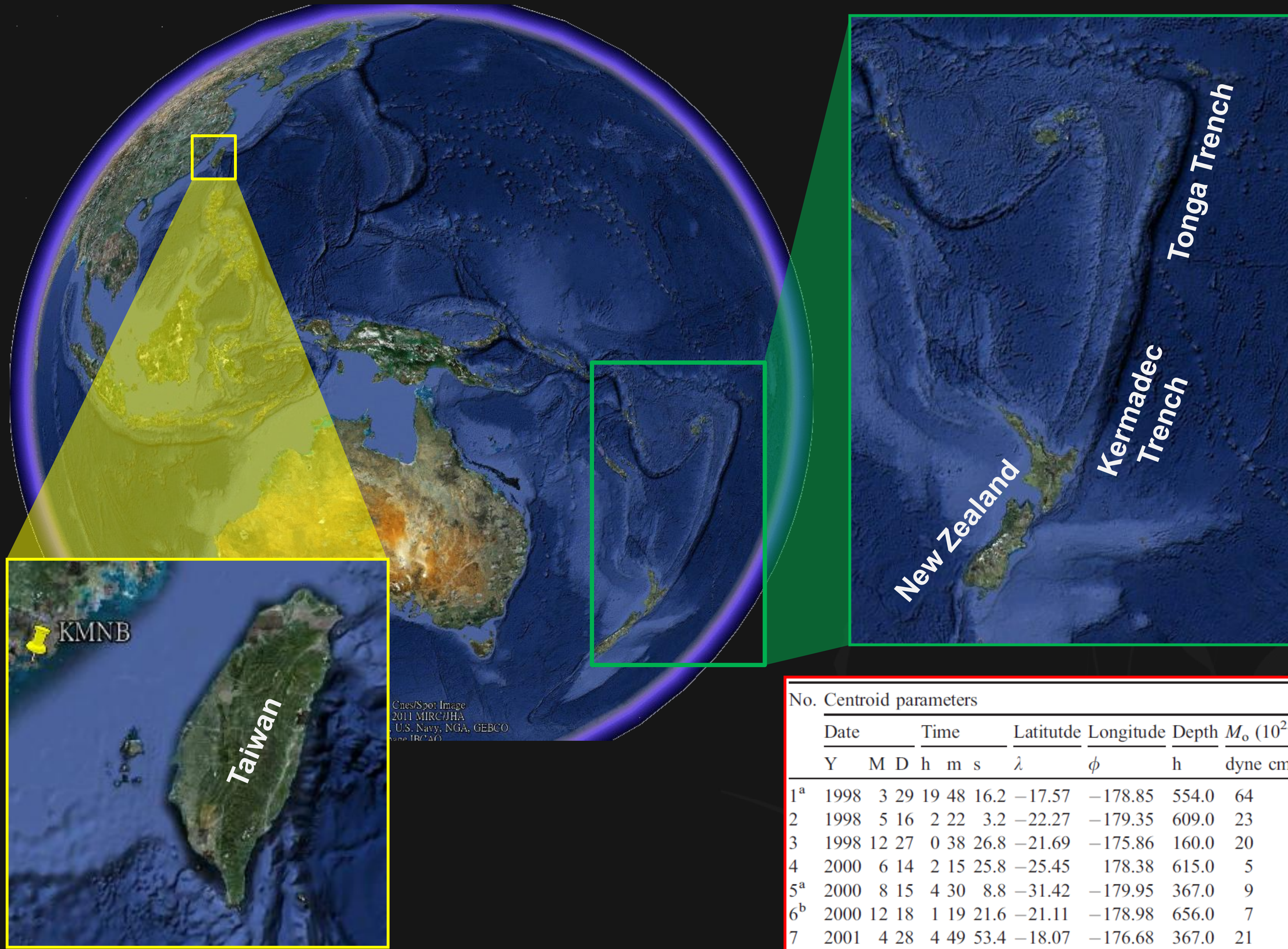




Seismic effects of a subducted slab

- Earlier arrival time
- Reduced amplitude
  - The velocity in the slab is faster than velocity in the surrounding material, so the wavefront in the slab becomes separated from the wavefront in the surrounding material.
  - Furthermore, the energy in the slab is drained out and flowed in the surrounding material.

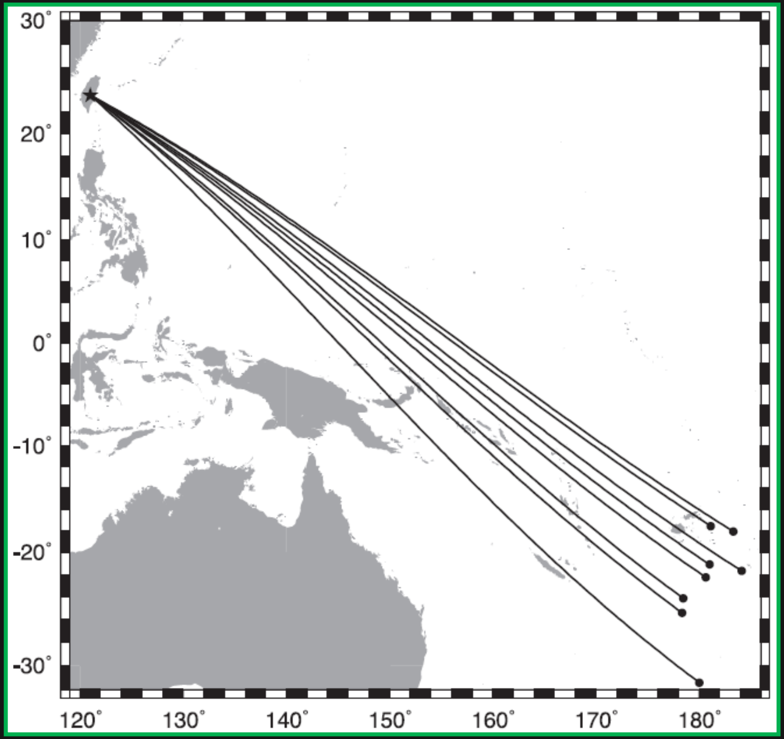
(Vidale, 1987)

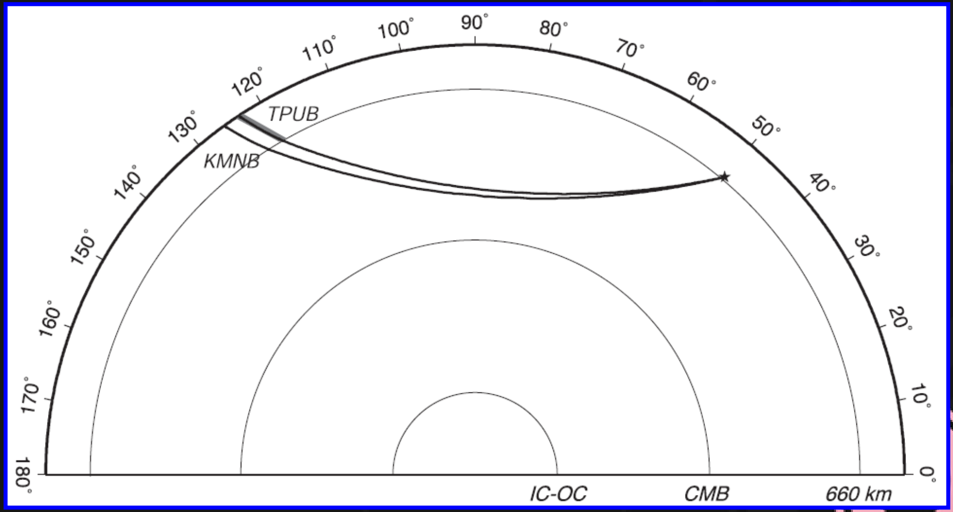


No.	Centroid parameters									
	Date			Time			Latitutde	Longitude	Depth	M_o (10^{25})
	Y	M	D	h	m	s	λ	ϕ	h	dyne cm
1[a]	1998	3	29	19	48	16.2	−17.57	−178.85	554.0	64
2	1998	5	16	2	22	3.2	−22.27	−179.35	609.0	23
3	1998	12	27	0	38	26.8	−21.69	−175.86	160.0	20
4	2000	6	14	2	15	25.8	−25.45	178.38	615.0	5
5[a]	2000	8	15	4	30	8.8	−31.42	−179.95	367.0	9
6[b]	2000	12	18	1	19	21.6	−21.11	−178.98	656.0	7
7	2001	4	28	4	49	53.4	−18.07	−176.68	367.0	21
8	2002	8	19	11	8	24.3	−24.16	178.49	699.0	430

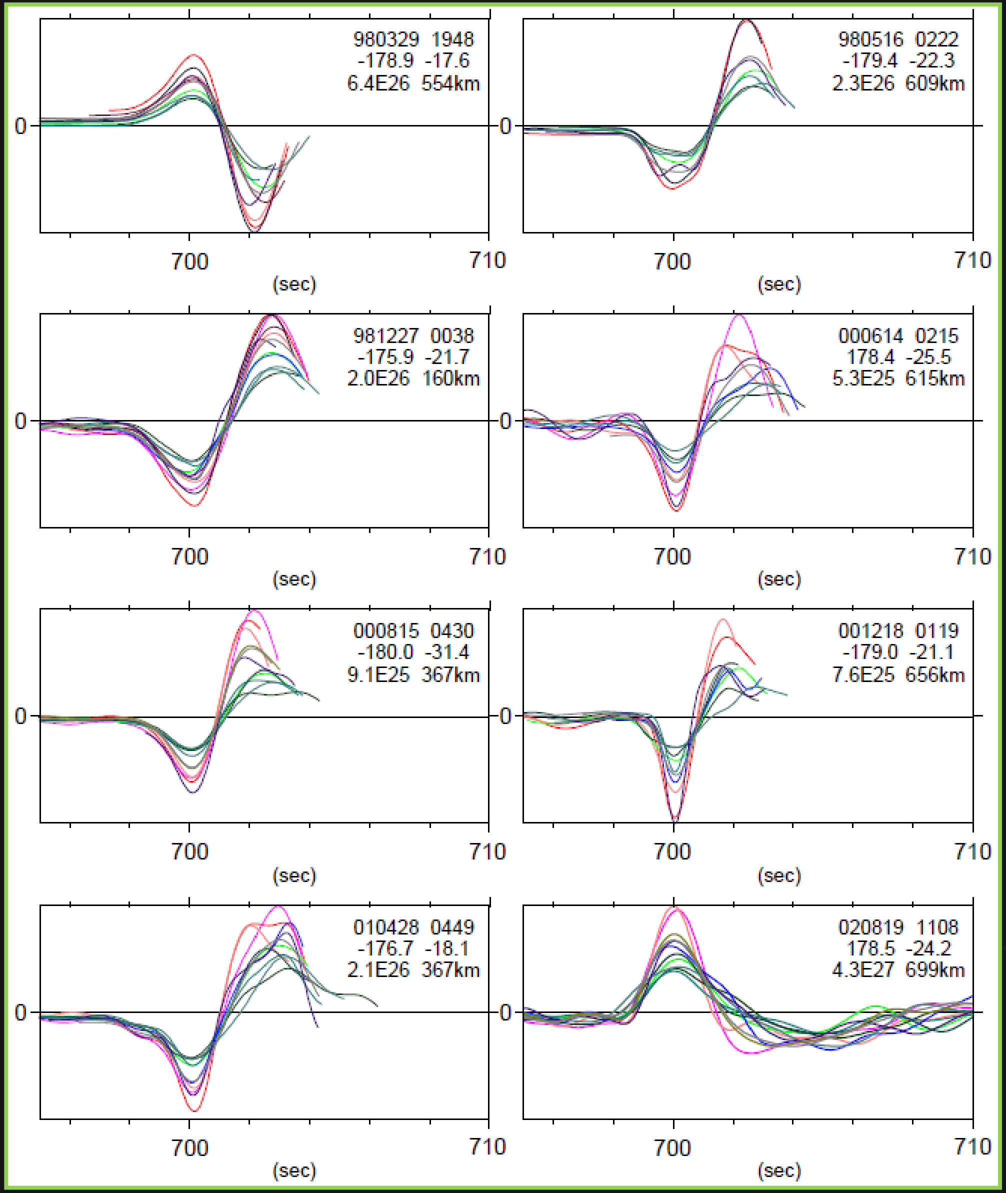
Why choose earthquakes from Tonga-Kermadec?

- Suitable azimuth
- Suitable epicentral distance





Data analysis



Bandpass: 1~4Hz

The different colors stand for different stations.

P wave aligned at 700s.

Those waveforms show similar patterns but different amplitudes.

Data analysis

- Differential residual times relative to KMNB

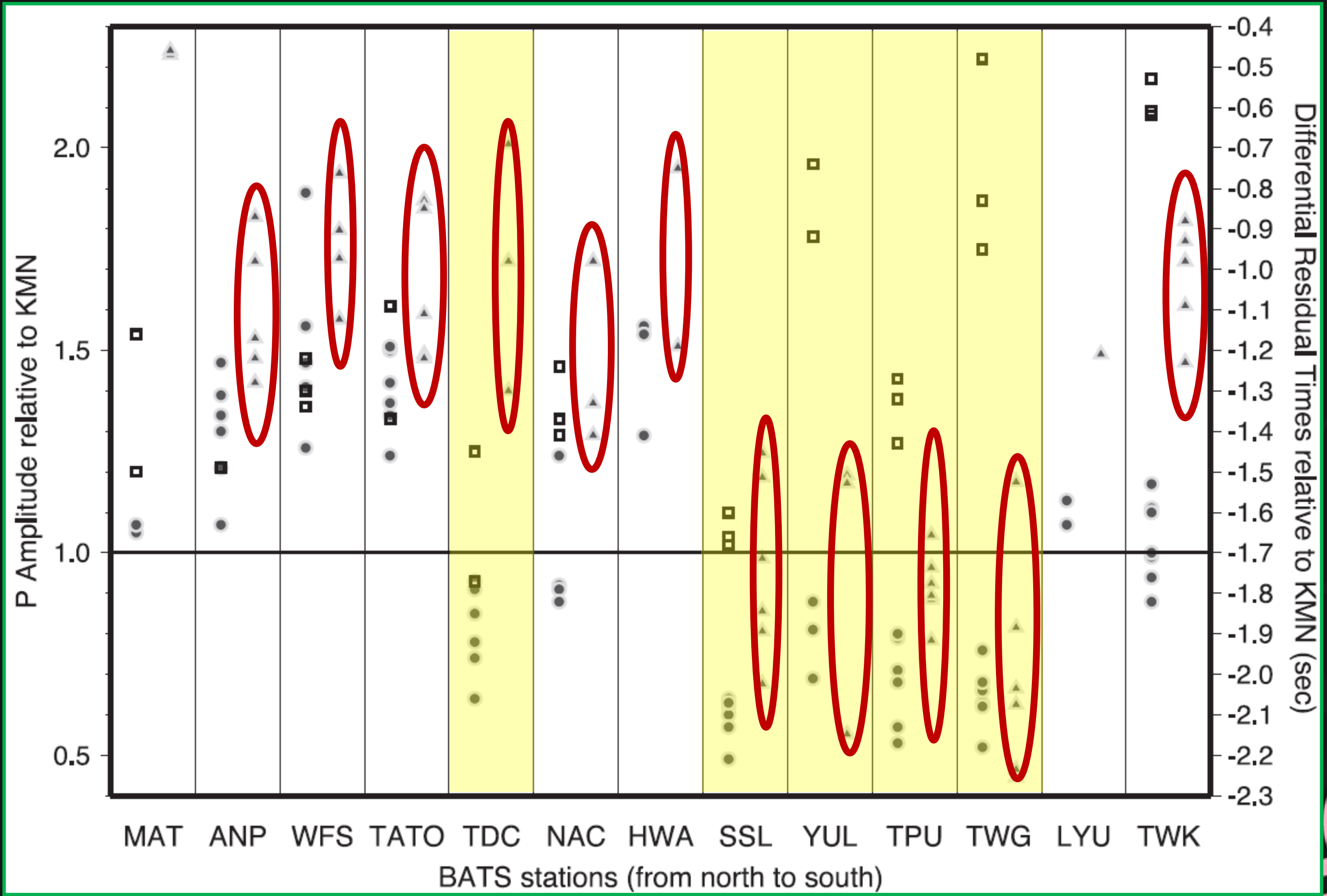
$$\mathrm{DRTS}_{\mathrm{bats}} = \left(T_{\mathrm{bats}}^{\mathrm{obs}} - T_{\mathrm{bats}}^{\mathrm{the}}\right) - \left(T_{\mathrm{kmnb}}^{\mathrm{obs}} - T_{\mathrm{kmnb}}^{\mathrm{the}}\right)$$

bats: any BATS station

kmnb: Kinmen station

obs: observed travel time that is corrected for station elevations

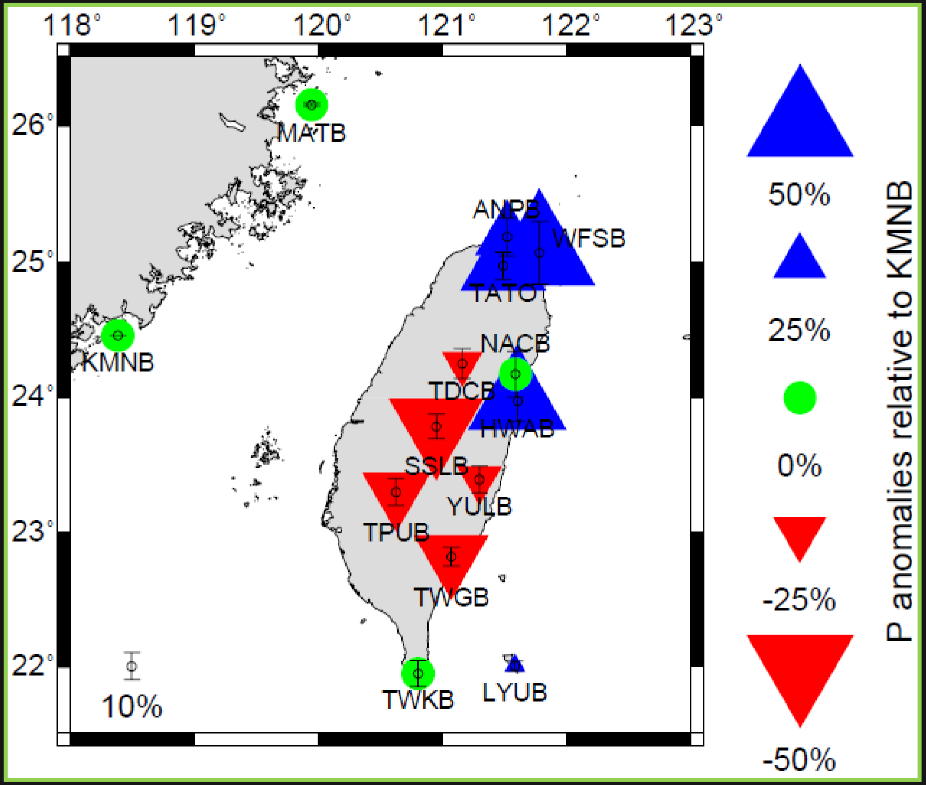
the: theoretically calculated travel time from iasp91

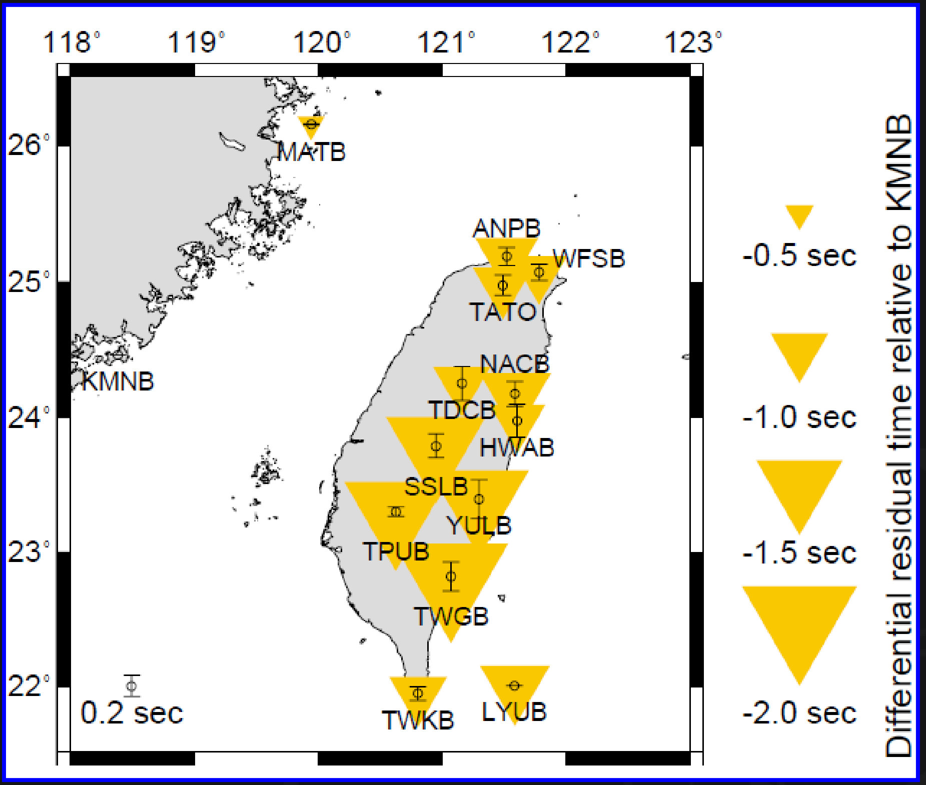


□ P ratios of the Hindu Kush events

▲ DRTS of the Tonga-Kermadec events

● P ratios of the Tonga-Kermadec events

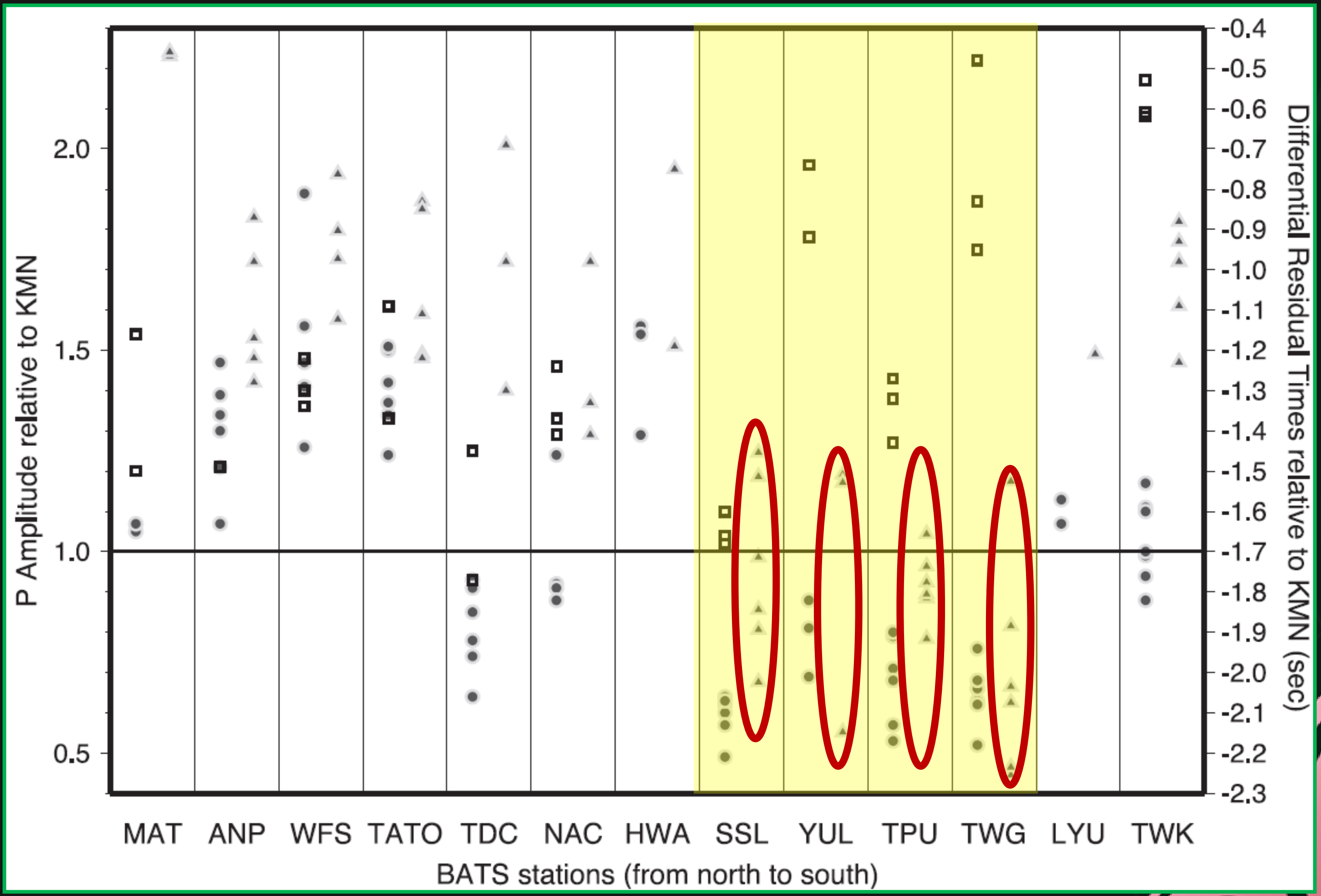




- The reduced amplitudes are concentrated in central Taiwan.
  - High-velocity anomaly in the mantle
  - High seismic attenuation in the crust

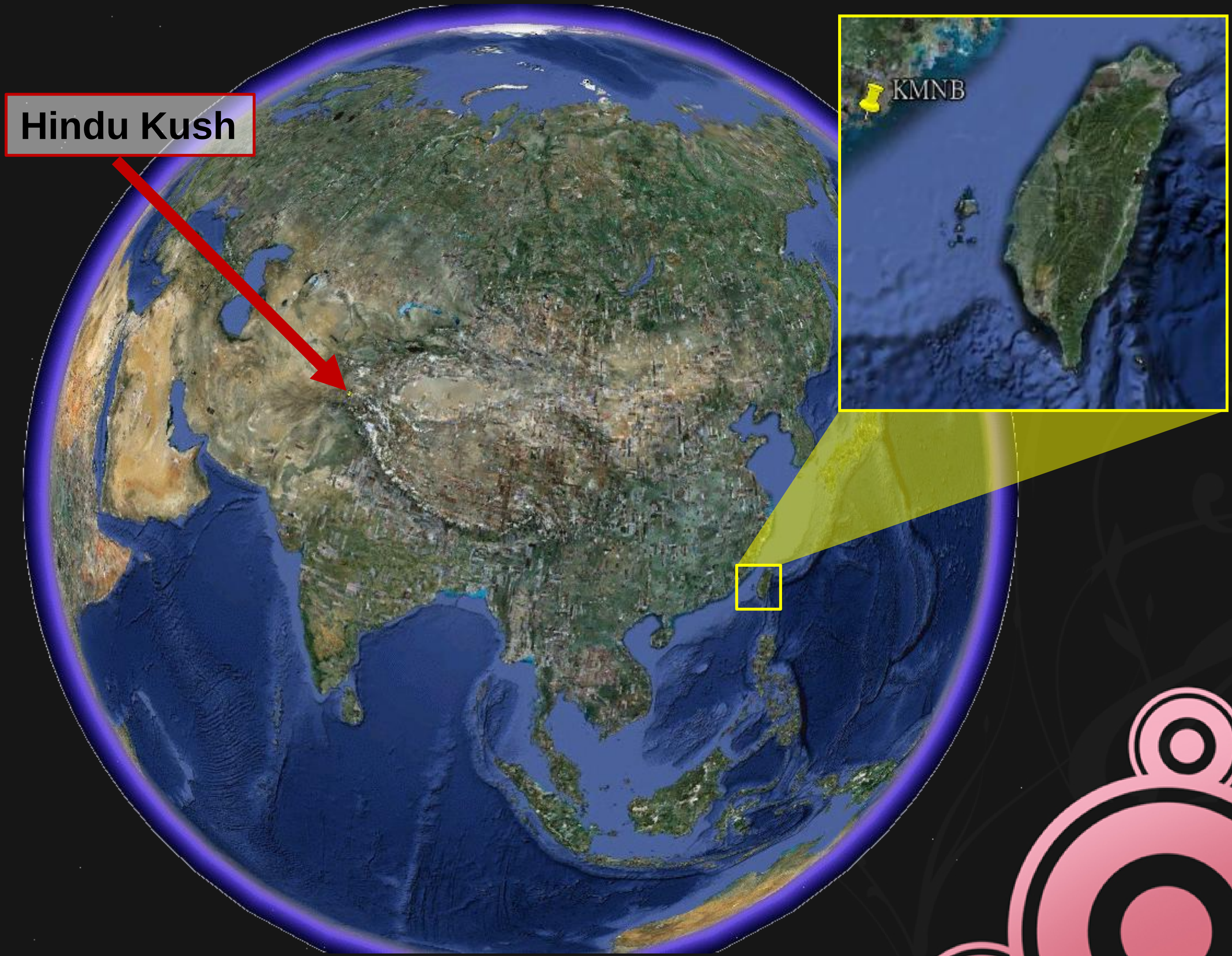
High-velocity anomaly in mantle or high seismic attenuation in the crust?

- If the reduced amplitudes are resulted in low Q crustal materials, then those materials trend to be slow for seismic wave.

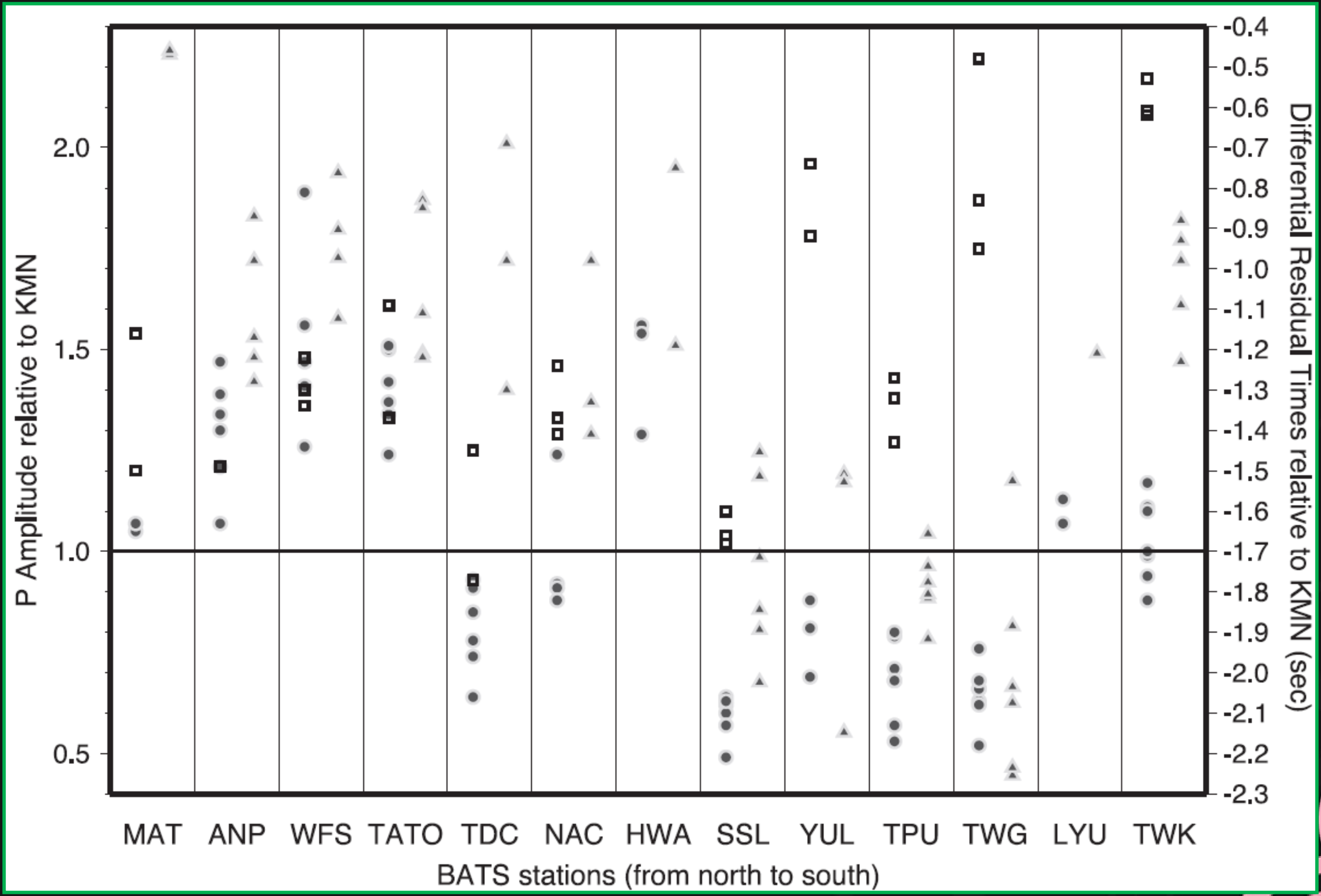


High-velocity anomaly in mantle or high seismic attenuation in the crust?

- If the observed reduced amplitudes are resulted in low Q crustal materials, then those materials trend to be slow for seismic wave.
- If it is result of crust effects, the observed patterns will be independent of earthquake azimuths.



Hindu Kush
KMNB



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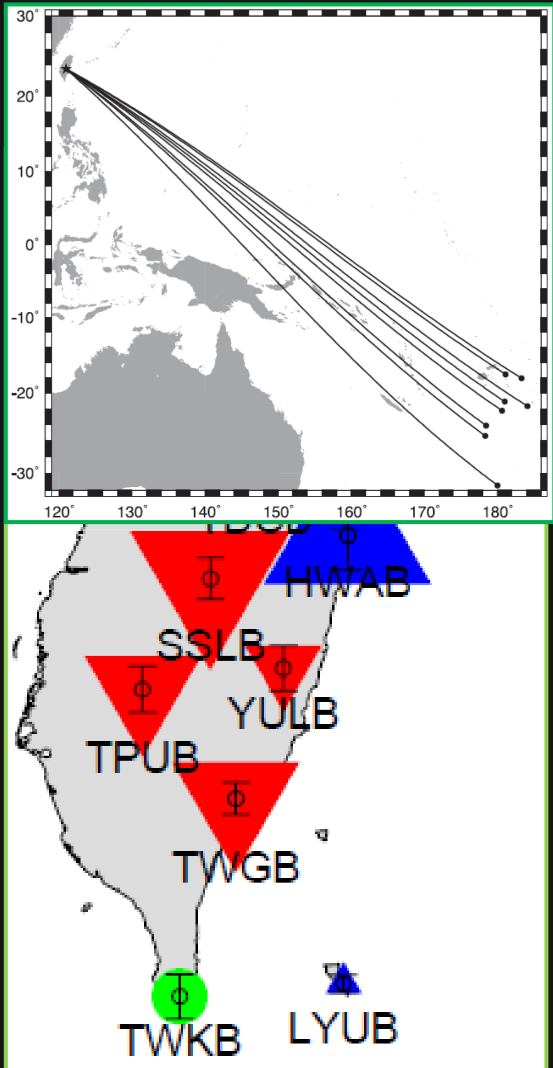
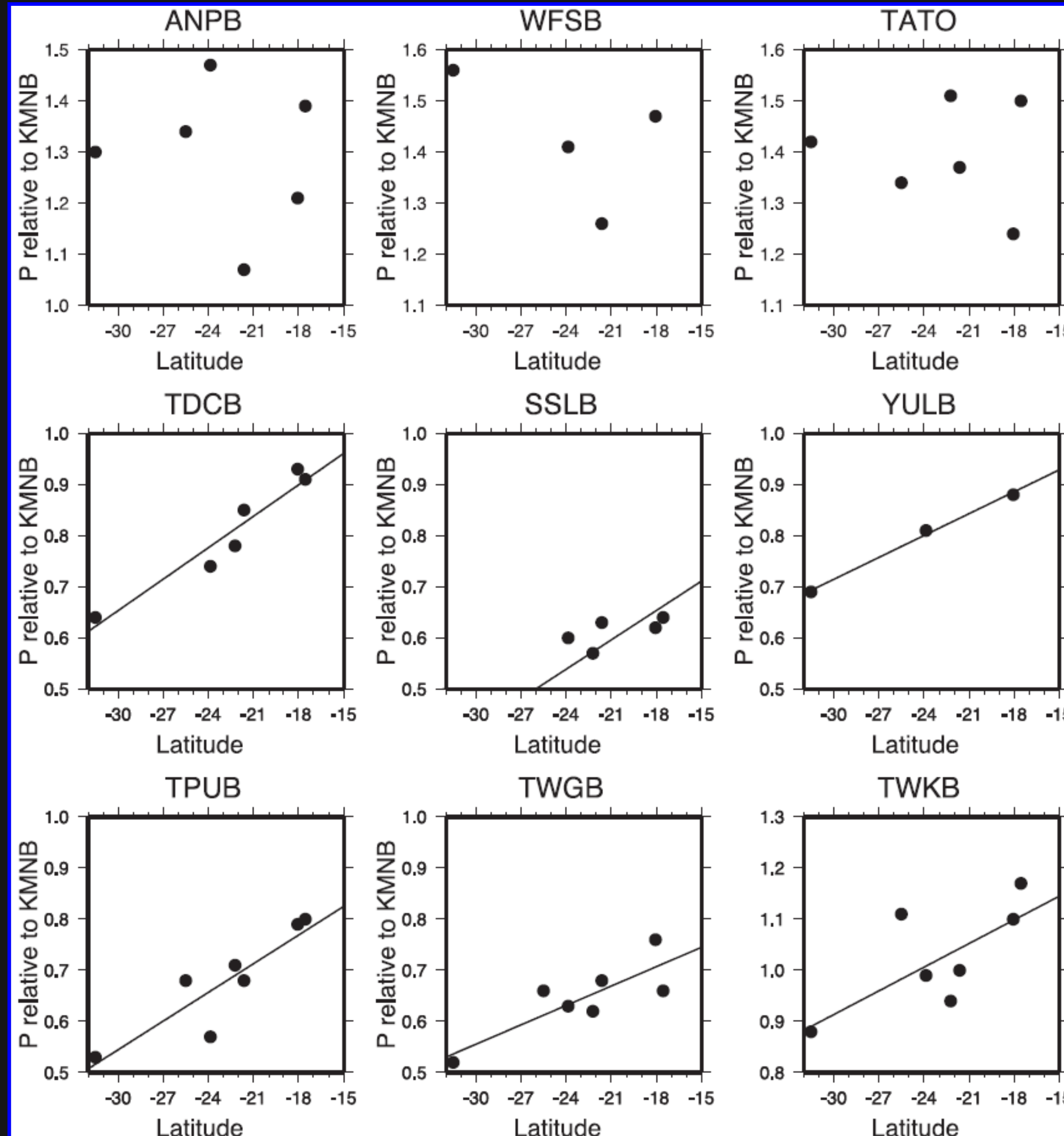
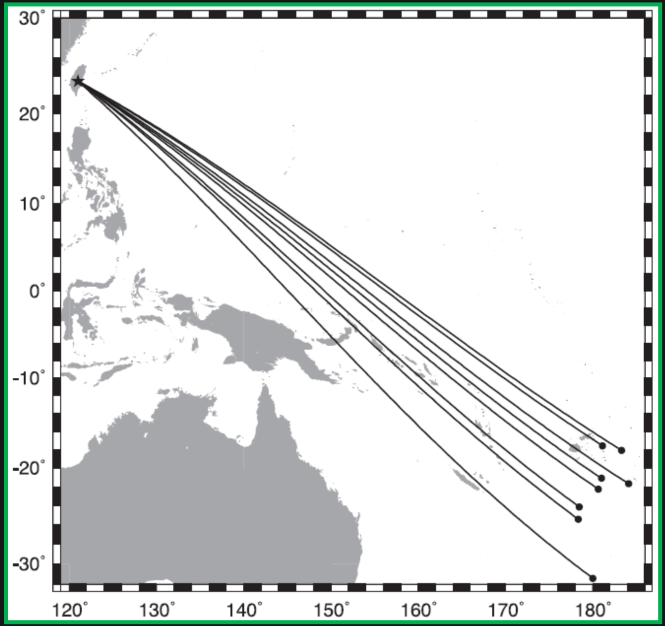
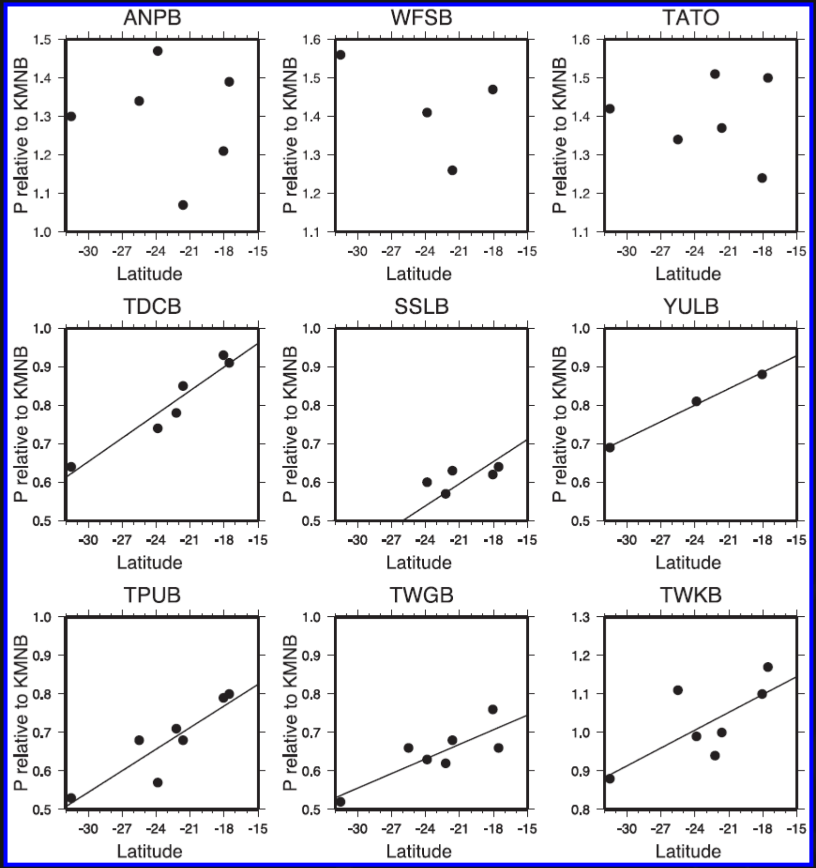

30˚
20˚
10˚
0˚
-10˚
-20˚
-30˚
120˚
130˚
140˚
150˚
160˚
170˚
180˚
HWAB
SSLB
YULB
TPUB
TWGB
TWKB
LYUB


ANPB
WFSB
TATO
TDCB
SSLB
YULB
TPUB
TWGB
TWKB
P relative to KMNB
Latitude
-30
-27
-24
-21
-18
-15

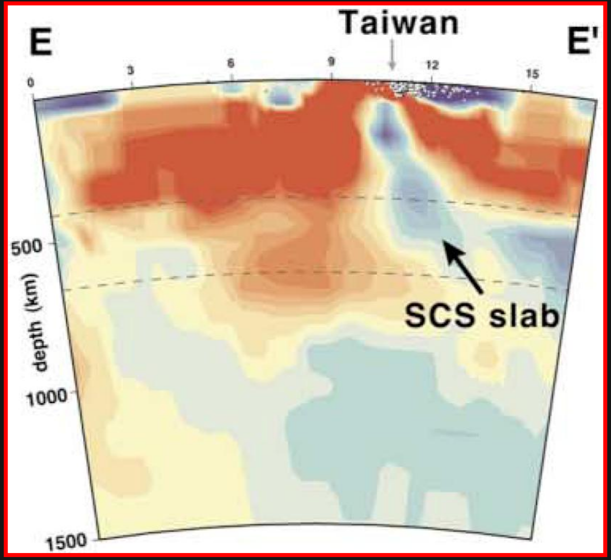




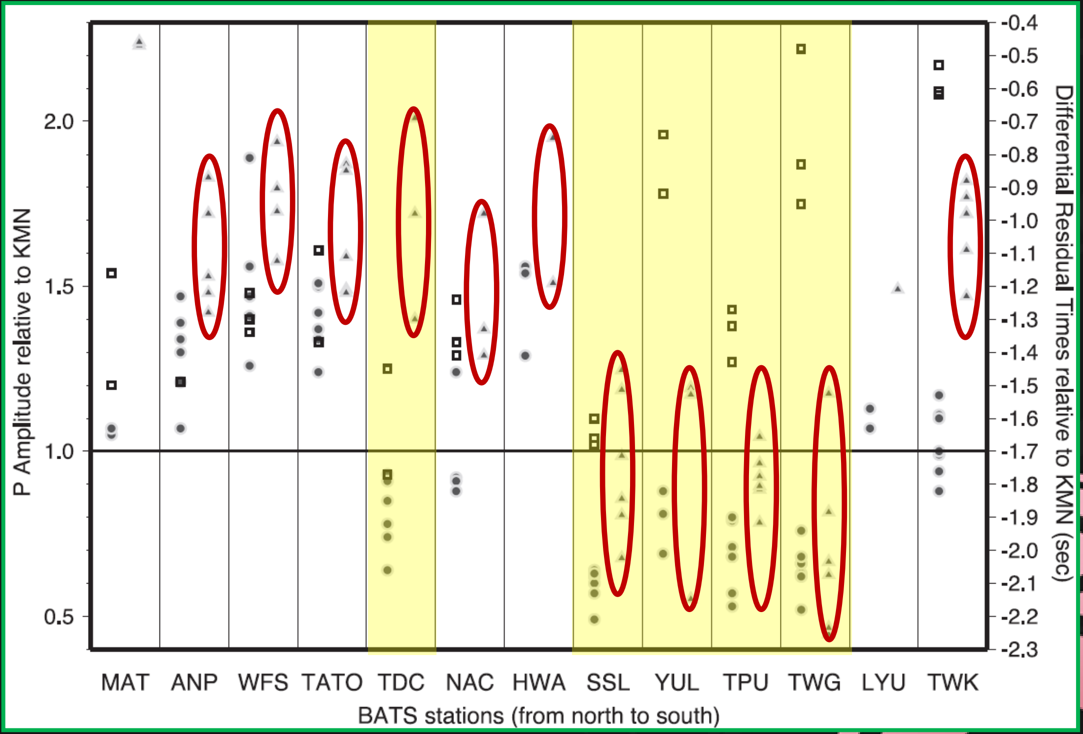
- For crustal effects to produce the linear positive correlation, the lateral heterogeneities would be unreasonably large.
- The positive correlation indicates the subducted slab is hotter to the north. It is consistent with the idea that arc-continent collision is propagating southward.

Conclusion

- According to the global tomography and teleseismic data analysis, I consider the subducted slab exists beneath central Taiwan.



(Lallemand et al., 2001)



(Chen et al., 2004)