Revisit of Taiwan Historical Damaging Earthquakes for Seismic Hazard itigation

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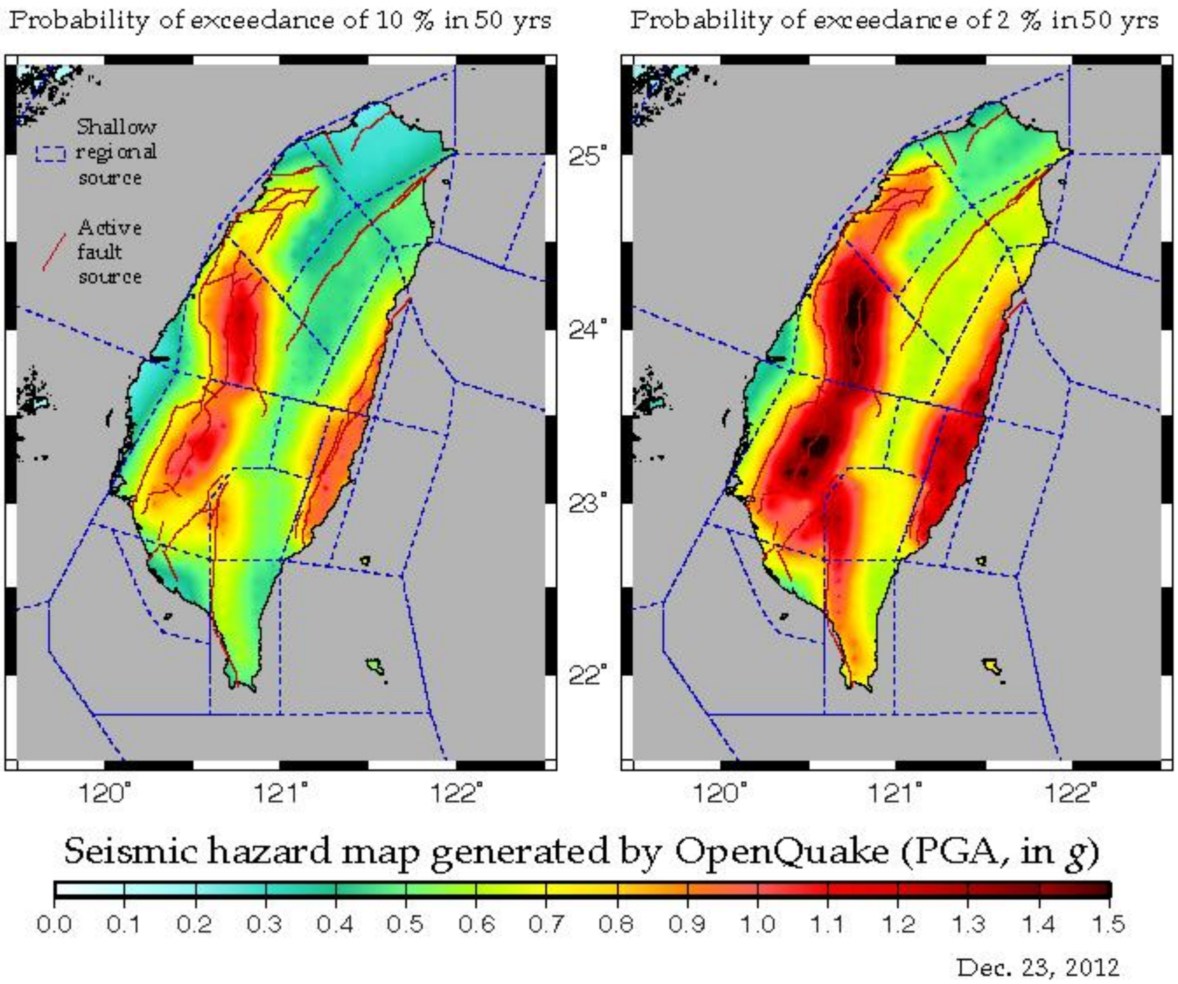
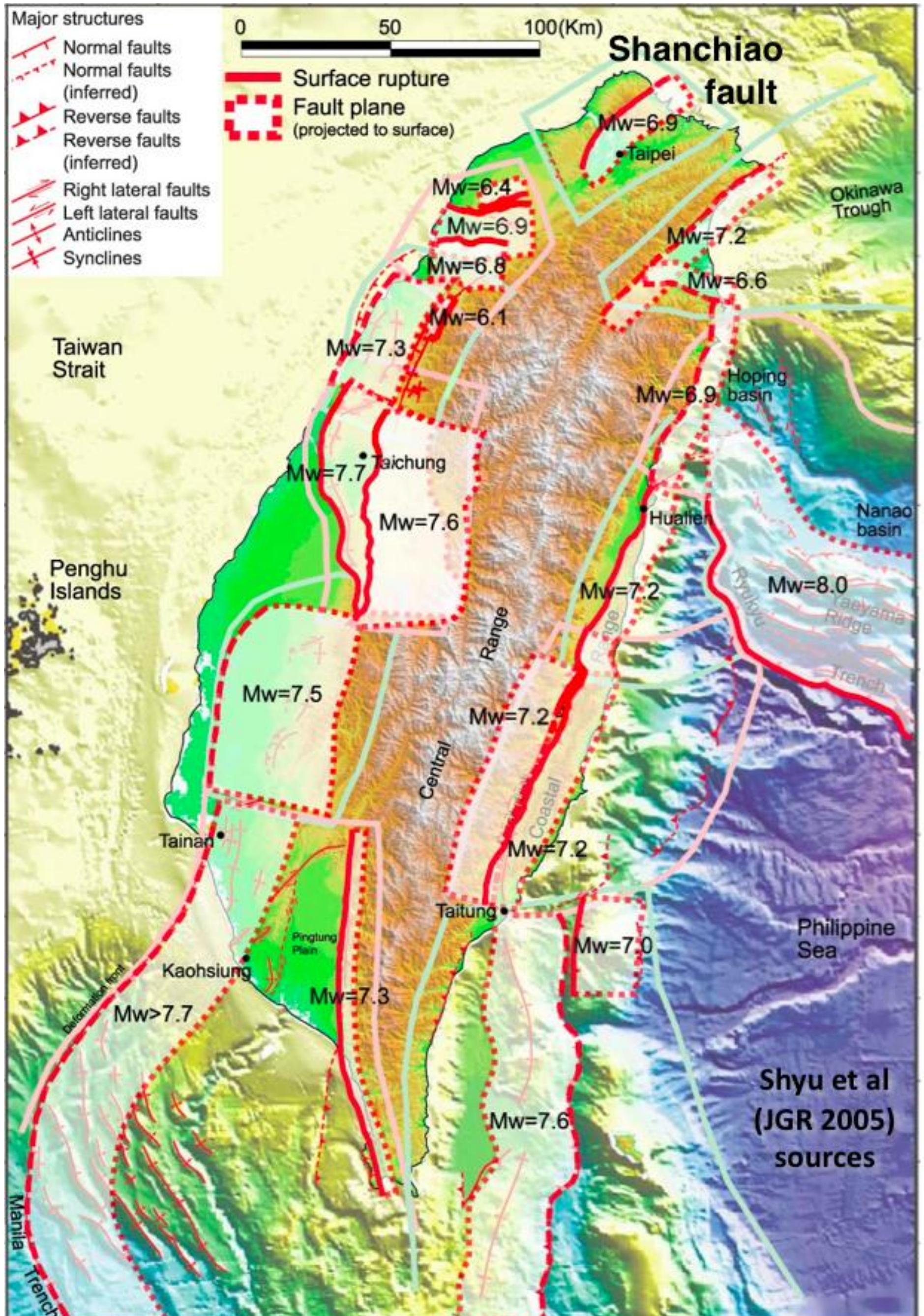
Toward PSHA Taiwan 2014



TAIWAN Earthquake Model

Earthquake Source Model : Bruce Shyu



- **Taiwan Earthquake Model**

PSHA

-Earthquake Source Model

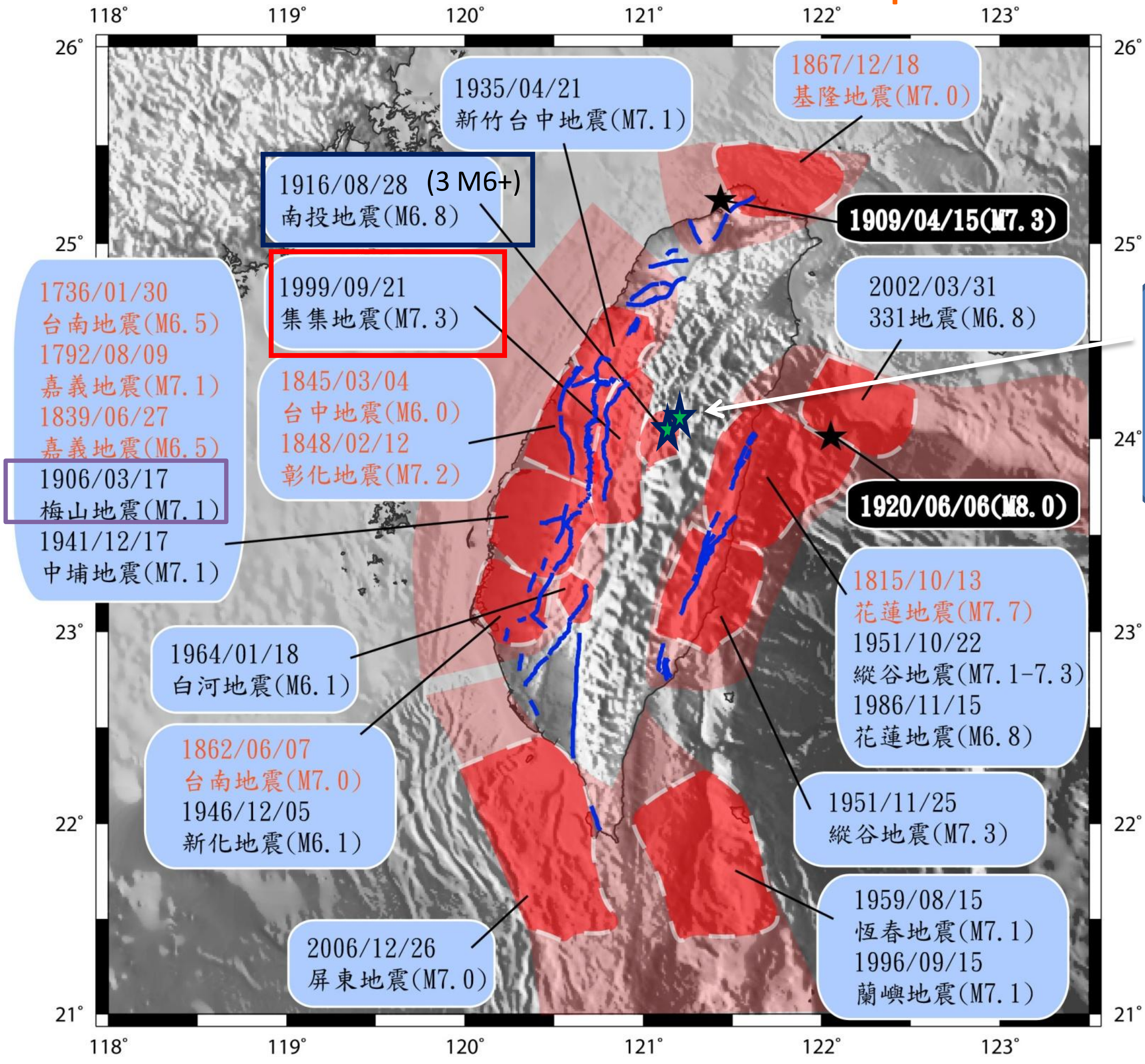
-Area Source

-Historical Earthquake Studies using historical seismograms

-Potential damaging earthquakes ,which not yet known had occurred (Taiwan historical document, ~400 years)

Historical Damaging Earthquakes in Taiwan since 1700s

Relative quiet in seismicity



20130327 M6.1
20130602 M6.3

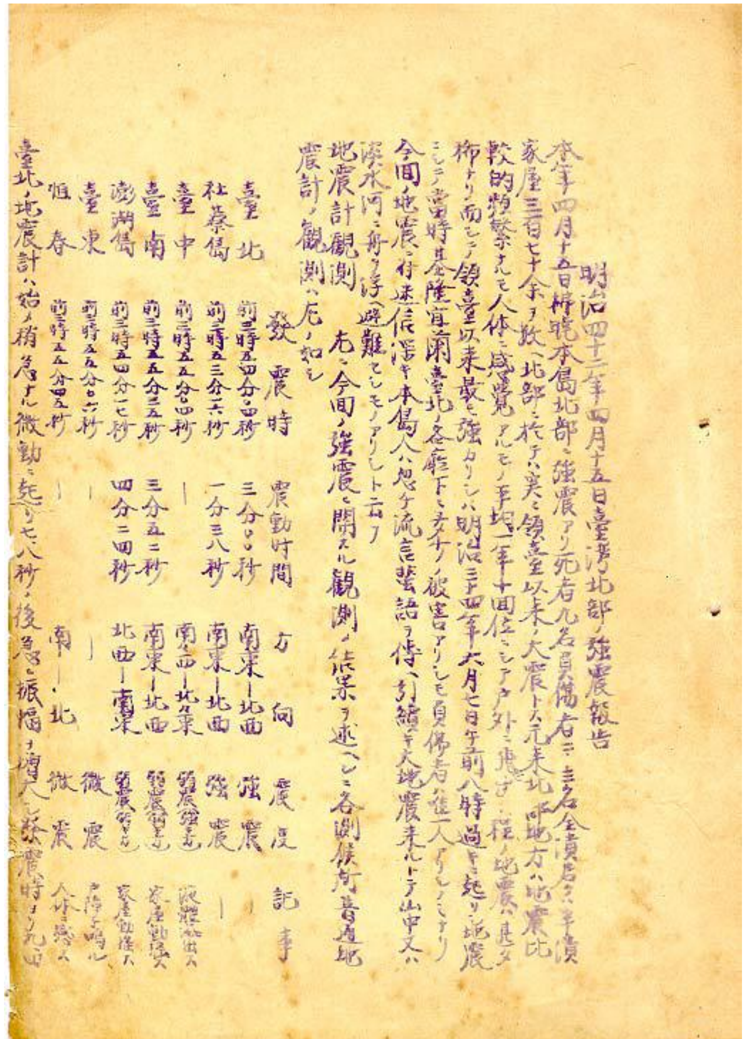
19160828 M6.8
19161115 M6.2
19170105 M6.2

Compilation of Historical Earthquakes

http://tec.earth.sinica.edu.tw/TEM/hisevent/hisdoc.php

by S.-N. Cheng and CWB Colleagues

1909 0414 Taipei Earthquake Taihoku Report



明治四十二年四月十五日臺灣北部ノ強震報告

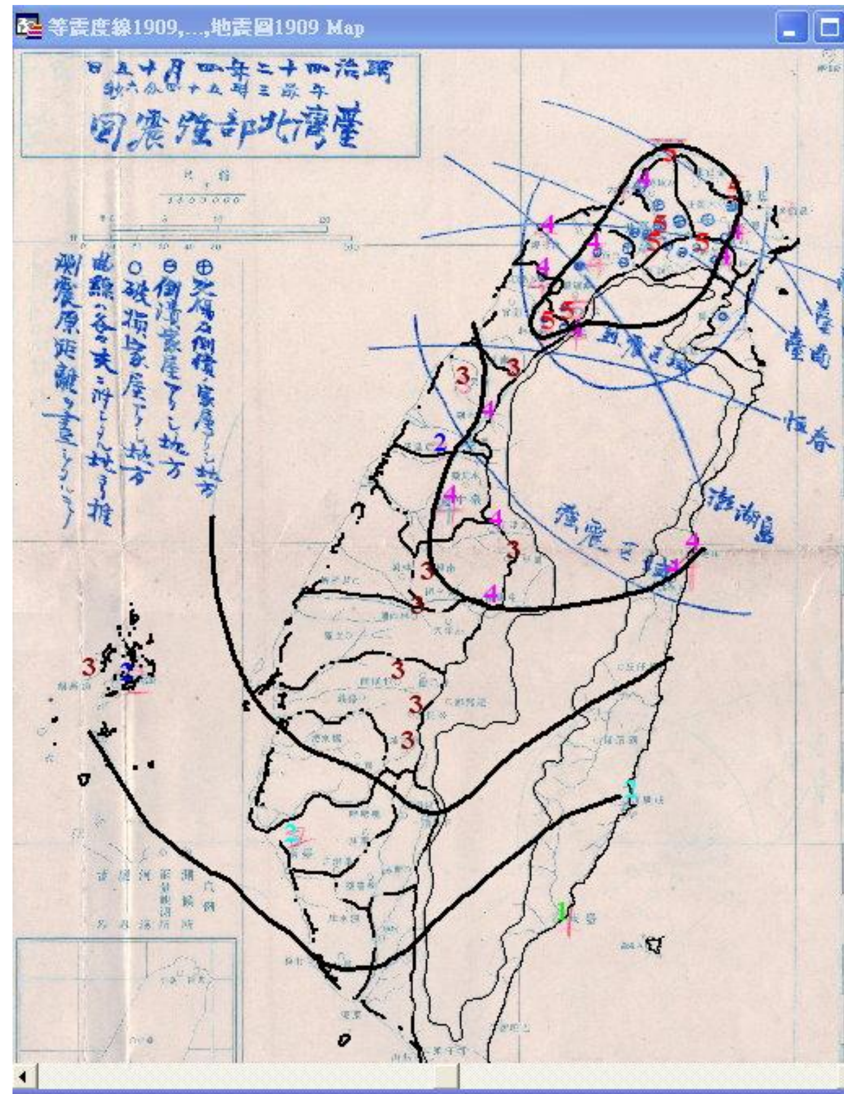
本年四月十五日拂暁本島北部ニ強震アリ死者九名負傷者二十三名全潰家屋三百七十余ヲ数ヘ北部ニ於テハ実ニ領臺以来ノ大震ト云フ元来北部地方ハ地震比較的頻繁ナルモ人体ニ感覚アルモノ平均一年十回位ニシテ戸外ニ飛出ス程ノ地震ハ甚タ稀ナリ而シテ領臺以来最モ強カリシハ明治三十四年六月七日午前八時過キニ起リシ地震ニシテ当時基隆宜蘭臺北ノ各庁下ニ於テ少ノ被害アリシモ負傷者ハ僅ニ一人アリシノミナリ

今回ノ地震ニ付テ迷信深キ本島人ハ恐ヶ流言蜚語ヲ伝ヘ引続キ大地震来ルトテ山中又ハ淡水河ニ舟ヲ浮ヘ避難セシモノアリシト云フ

地震計観測　左ニ今回ノ強震ニ関スル観測ノ結果ヲ述ヘシニ各測候所ニ於ケル地震計ノ観測ハ左ノ如シ

	發震時	震動時間	方向	震度	記事
臺北	前三時五四分四秒	三分〇〇秒	南東—北西	強震	—
社寮島	前三時五三分六秒	一分三八秒	南東—北西	強震	—
臺中	前三時五五分四秒	—	南西—北東	弱震(強キ方)	[illegible]
臺南	前三時五五分三五秒	三分五二秒	南東—北西	弱震(弱キ方)	家屋動揺ス
澎湖島	前三時五四分一七秒	四分二四秒	北西—南東	弱震(弱キ方)	家屋動揺ス
臺東	前三時五五分〇六秒	—	—	微震	戸障子鳴ル
恒春	前三時五五分四五秒	—	南—北	微震	人体ニ感ス

臺北ノ地震計ハ始メ稍急ナル微動ニ起リ七八秒ノ後急ニ振幅ヲ増大シ発震時ヨリ九四[illegible]

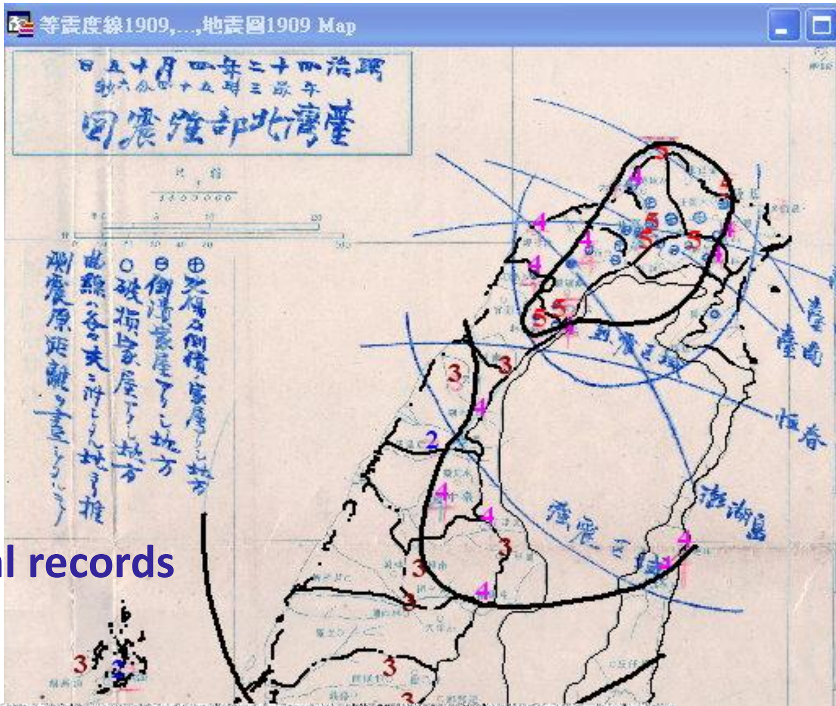


Compilation of Historical Earthquakes

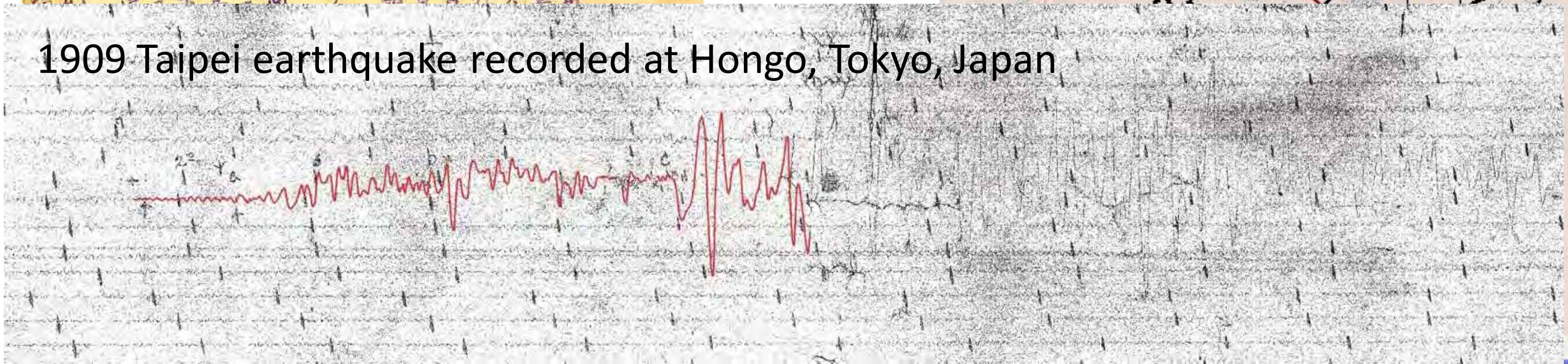
1909 0414 Taipei Earthquake Taihoku Report

明治四十二年四月十五日臺湾北部ノ強震報

	發震時	震動時間	方向
臺北	前三時五四分〇四秒	三分〇〇秒	南東—北
社寮島	前三時五三分六秒	一分三八秒	南東—北
臺中	前三時五五分〇四秒	—	南西—北
臺南	前三時五五分三五秒	三分五二秒	南東—北
澎湖島	前三時五四分一七秒	四分二四秒	北西—南
臺東	前三時五五分〇六秒	—	—
恆春	前三時五五分四五秒	—	南—北

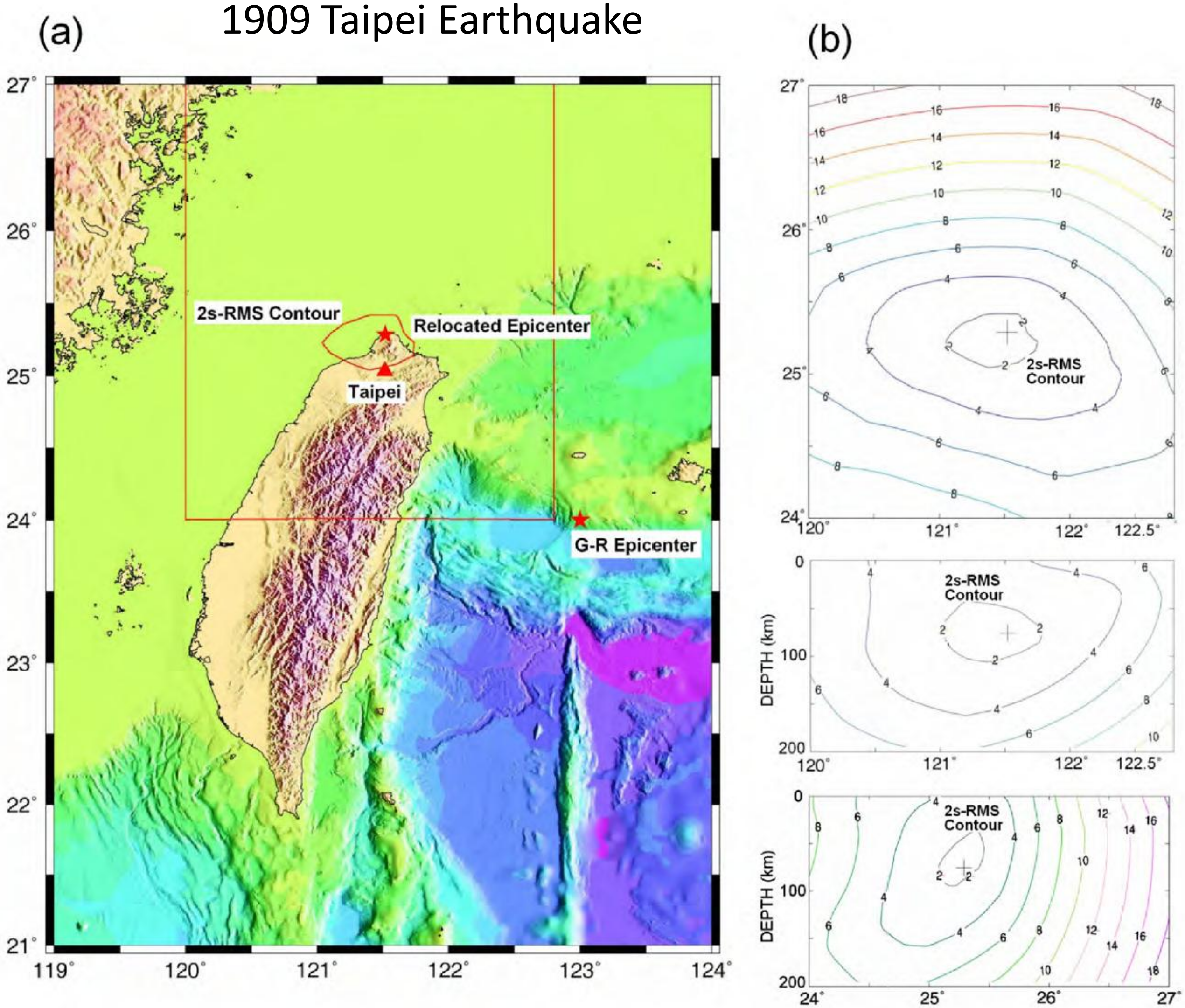


Collecting of historical records



1909 Taipei earthquake recorded at Hongo, Tokyo, Japan

1909 Taipei Earthquake



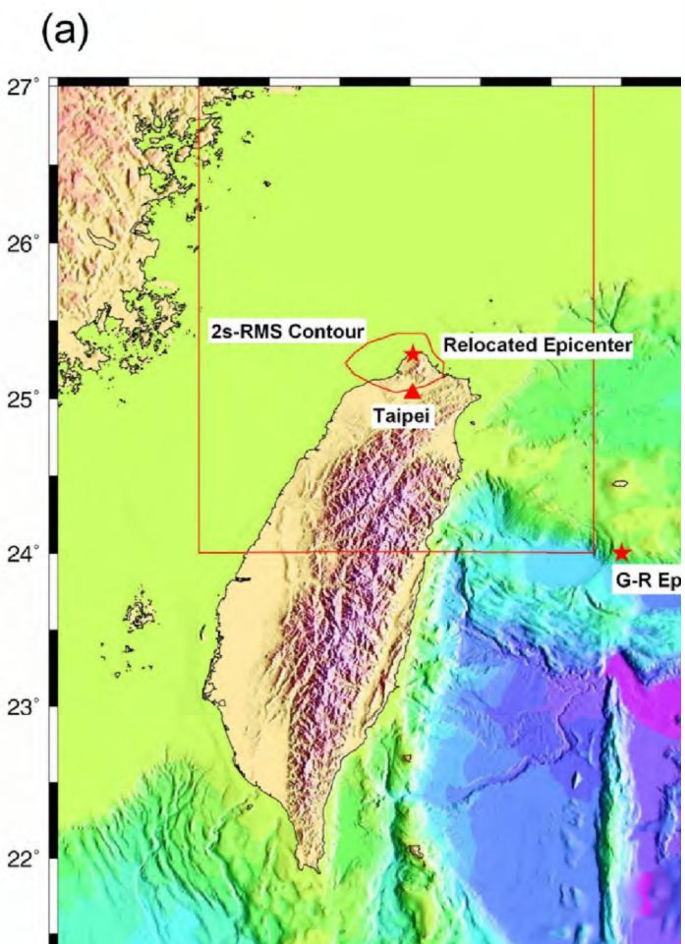
Latitude = 25.28º N,
Longitude = 121.52º E,

Depth=75km
(50-100 km)

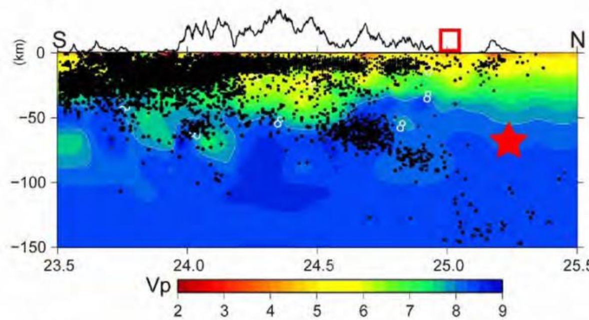
Determine from
Amplitude ratio
M_W of 7±0.3
Intra-plate event

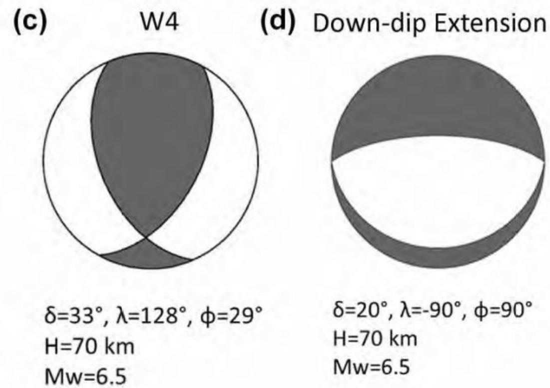
Fig. 1

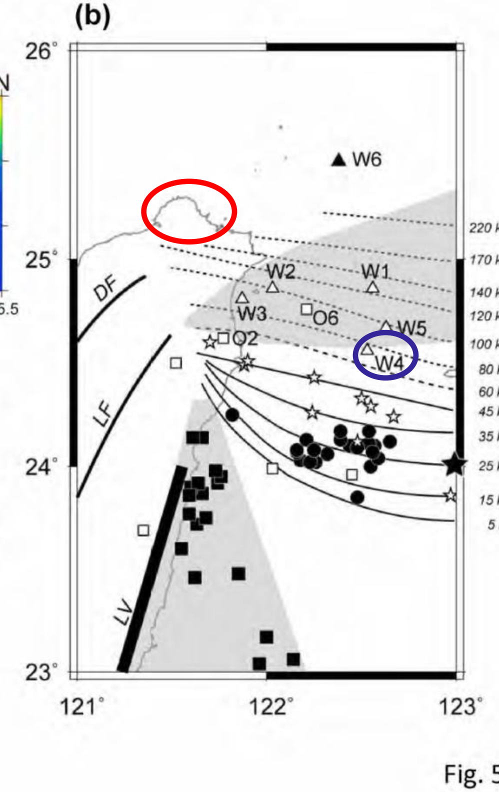
(Kanamori, Lee and Ma, GJI, 2012)



M6.5-7.0
Depth~ 75km





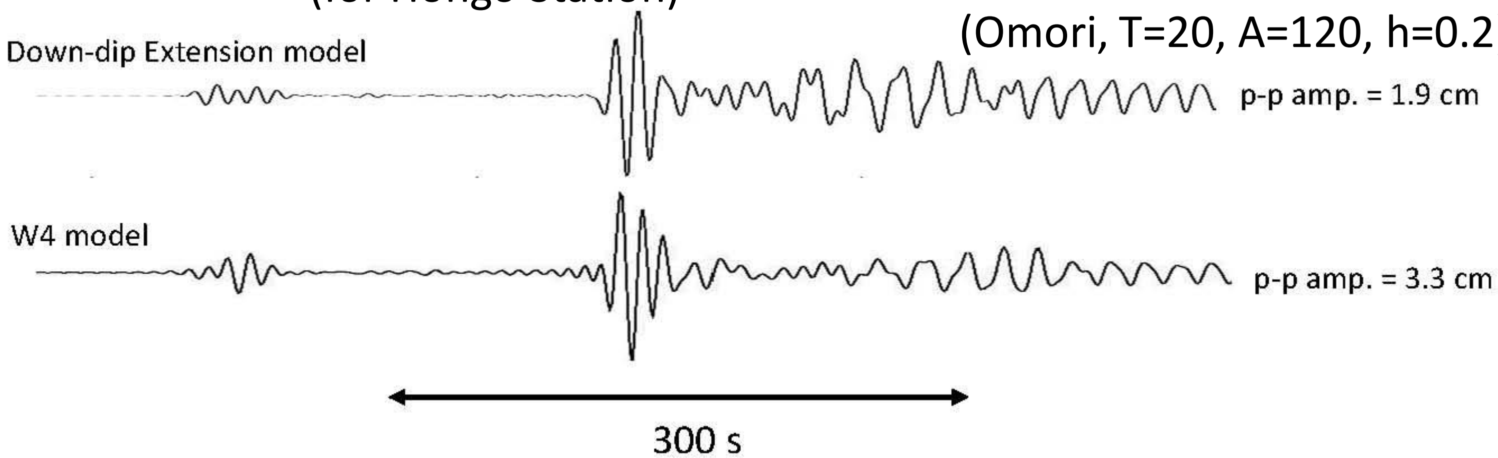


Focal Mechanism ?

(Kao, Shen & Ma, JGR, 1998)

1909 Taipei earthquake recorded at Hongo

(a). Synthetic Omori seismograms for the two down-dip extension mechanisms (Mw=6.5, H=70 km)
station TTO
(for Hongo Station)



(b). Synthetic Wiechert seismograms for the two down-dip extension mechanisms (Mw=6.5, H=70 km)
Station BFO
(for Gottingen Station)

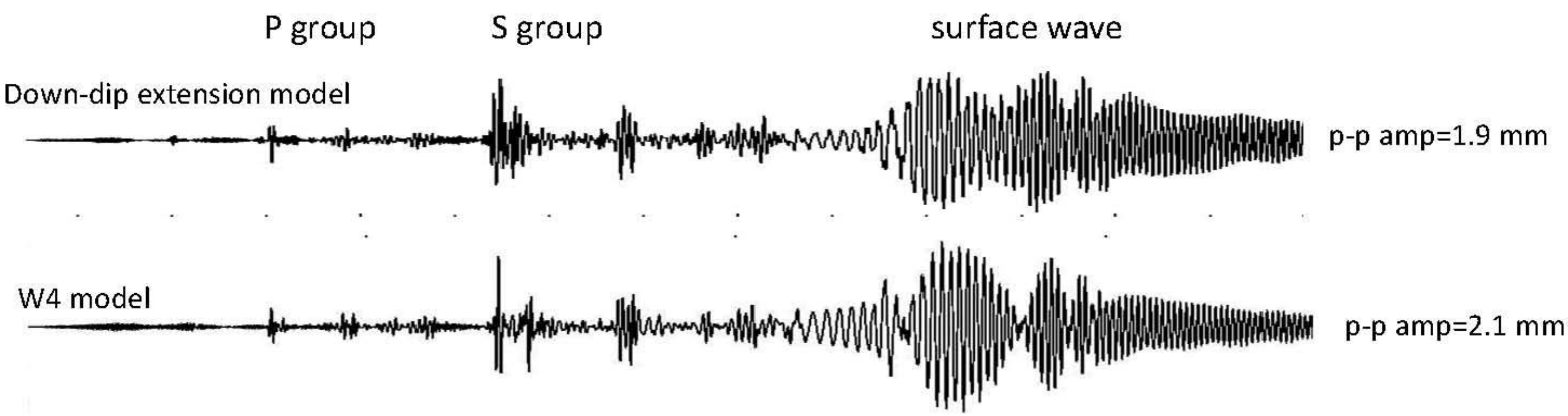


Fig. 7

(a). Synthetic Omori seismograms for the two down-dip extension mechanisms (Mw=6.5, H=70 km) station TTO

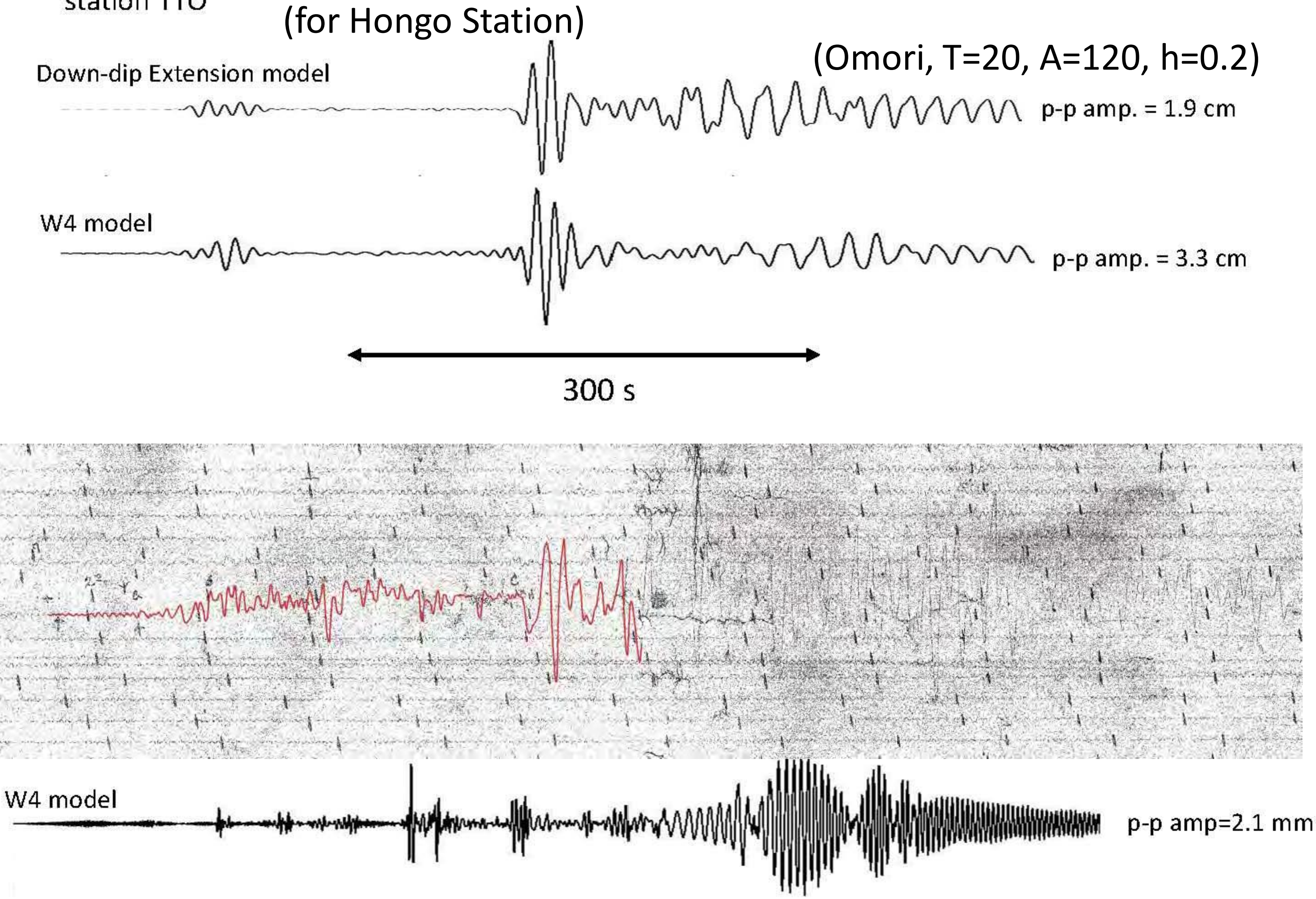


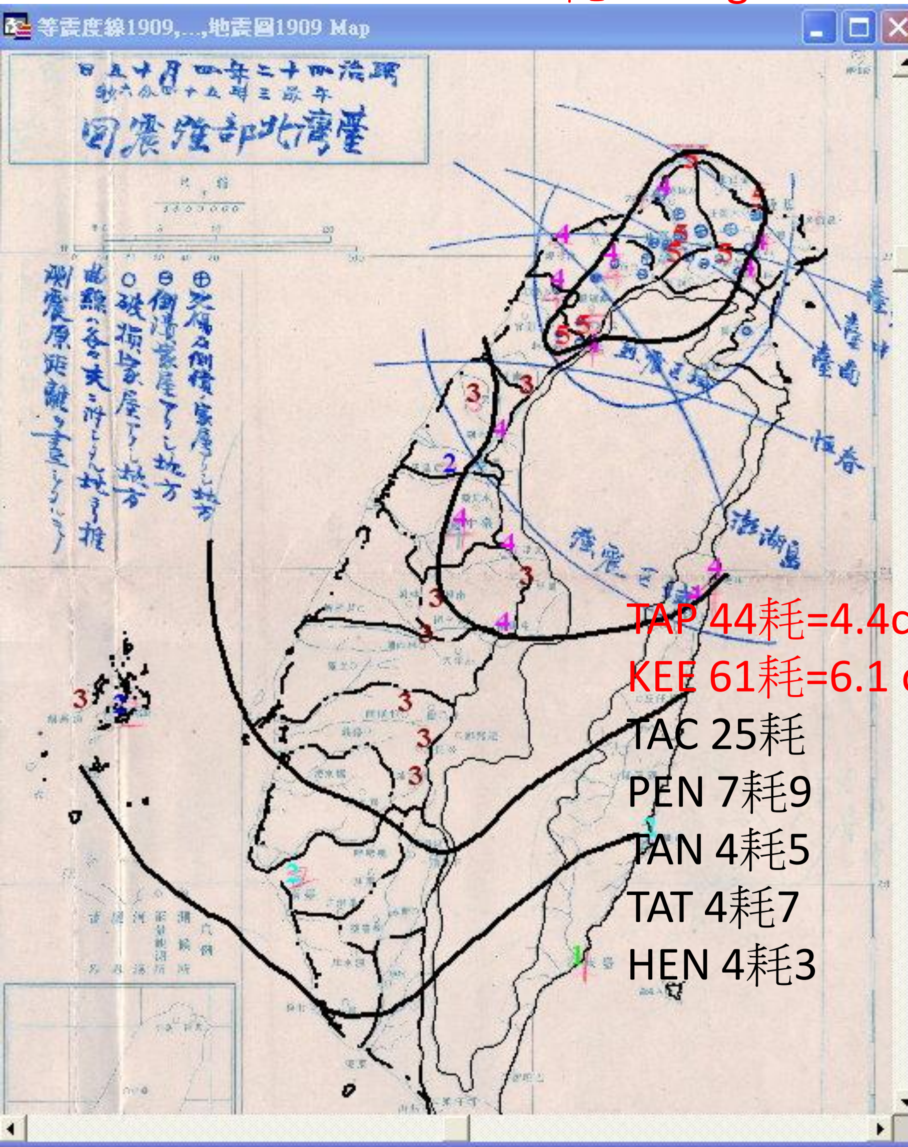
Fig. 7

PGV, acc=(2*pi/T)**2*amplitude=> PGA

TAP= (2*3.14/1.21)2*44/2=592耗=59.2 gal**

TAP T=1.2 sec Acc=592耗=59.2 gal

KEE T=1.3 sec Acc=670耗=67.0 gal



TAP 44耗=4.4cm/sec

KEE 61耗=6.1 cm/sec

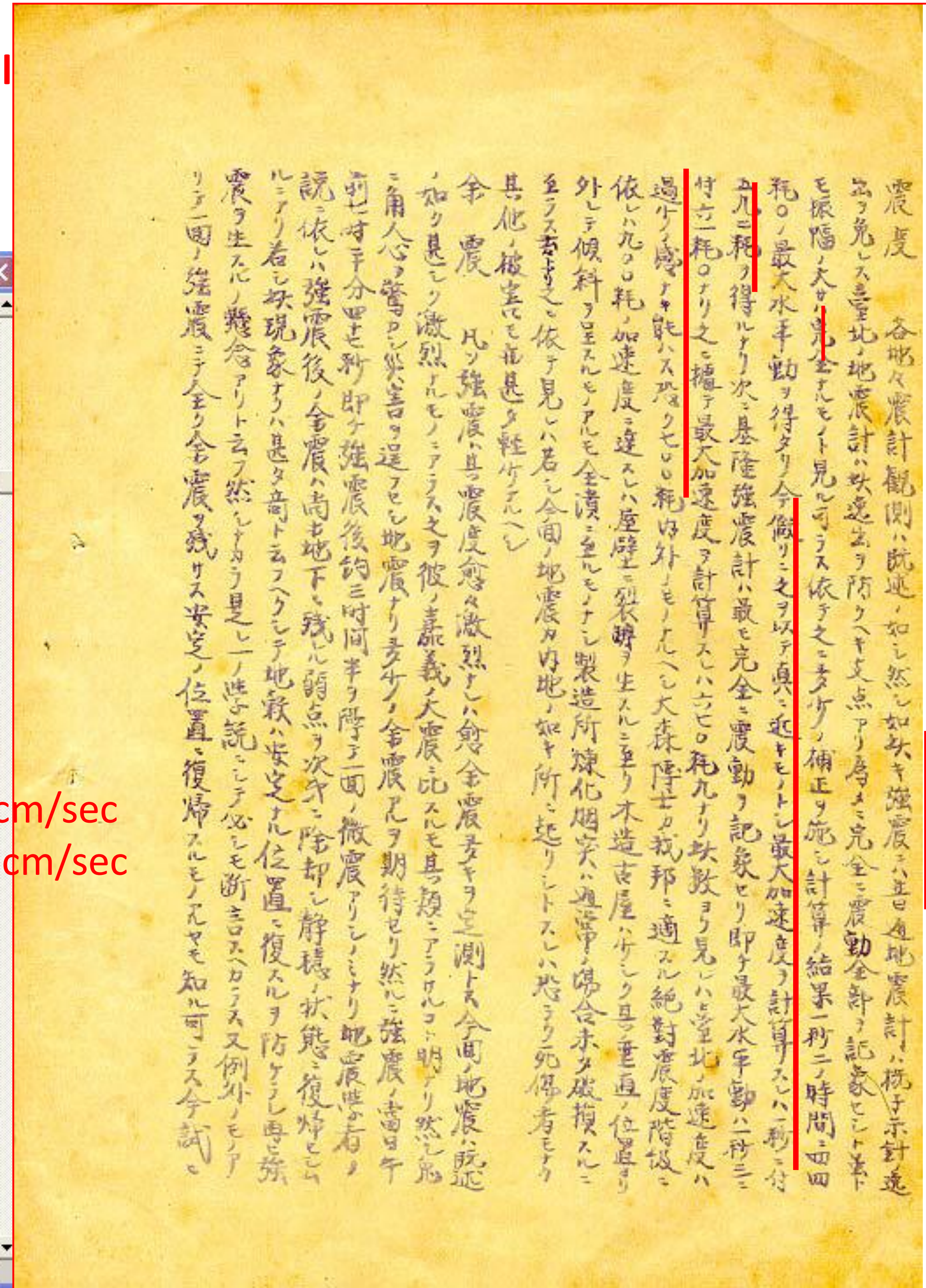
TAC 25耗

PEN 7耗9

TAN 4耗5

TAT 4耗7

HEN 4耗3



震度　各地ノ震計觀測ハ既述ノ如シ然レ共如斯キ強震ニハ普通地震計ハ概子示針逸出ヲ免レズ臺北ノ地震計ハ此逸出ヲ防クヘキ丈点アリ爲メニ完全ニ震動全部ヲ記象セシト雖トモ振幅ノ大サハ過大ナルモノト見ル可ラス依テ之ニ多少ノ補正ヲ施シ計算ノ結果一秒二ノ時間ニ四四粍〇ノ最大水平動ヲ得タリ今假リニ之ヲ以テ眞ニ近キモノトシ最大加速度ヲ計算スレハ一秒ニ付五九二粍ヲ得ルナリ次ニ基隆強震計ハ最モ完全ニ震動ヲ記象セリ即チ最大水平動ハ一秒三ニ付六一粍〇ナリ之ニ據テ最大加速度ヲ計算スレハ六七〇粍九ナリ此數ヨリ見レハ臺北ノ加速度ハ過少ノ感ナキ能ハス凡ソ七〇〇粍内外ノモノナルヘシ大森博士カ我邦ニ適スル絶對震度階級ニ依レハ九〇〇粍ノ加速度ニ達スレハ屋壁ニ裂罅ヲ生スルニ至リ木造古屋ハ少シク其ノ垂直ノ位置ヨリ外レテ傾斜ヲ呈スルモノアルモ全潰ニ至ルモノナシ製造所煉化烟突ハ過半ノ場合未タ破損スルニ至ラス云々之ニ依テ見レハ右ハ今回ノ地震カ内地ノ如キ所ニ起リシトスレハ恐ラク死傷者モナク其他ノ被害モ甚タ軽少ナルヘシ

余震　凡ソ強震ハ其ノ震度愈々激烈ナレハ愈々余震多キヲ豫測ス今回ノ地震ハ既述ノ如ク甚シク激烈ナルモノニアラス之ヲ彼ノ嘉義ノ大震ニ比スルモ其ノ類ニアラサルコト明ナリ然ルニ兎ニ角人心ヲ驚カシ災害ヲ逞フセシ地震ナリ多少ノ余震アルヲ期待セリ然ルニ強震ノ當日午前七時五十分四十七秒即チ強震後約三時間半ヲ隔テ一回ノ微震アリシノミナリ地震學者ノ説ニ依レハ強震後ノ余震ハ尚ホ地下ニ殘ル弱点ヲ次第ニ除却シ靜穩ノ状態ニ復帰セシムルニアリ若シ斯ク現象ナラハ甚タ奇ト云フヘクシテ地殻ハ安定ナル位置ニ復スルヲ防ケラレ再ヒ強震ヲ生スルノ懸念アリト云フ然レトモ是レ一ノ學説ニシテ必シモ断言スヘカラス又例外ノモノアリテ一回ノ強震ニテ全ク余震ヲ殘サス安定ノ位置ニ復帰スルモノナルヤモ知ル可ラス今試ニ

Modeling of the 1909 earthquake (on-going)

PGV, acc=(2*pi/T)**2*amplitude=> PGA

TAP= (2*3.14/1.21)2*44/2=592耗=59.2 gal**

TAP T=1.2 sec Acc=592耗=59.2 gal

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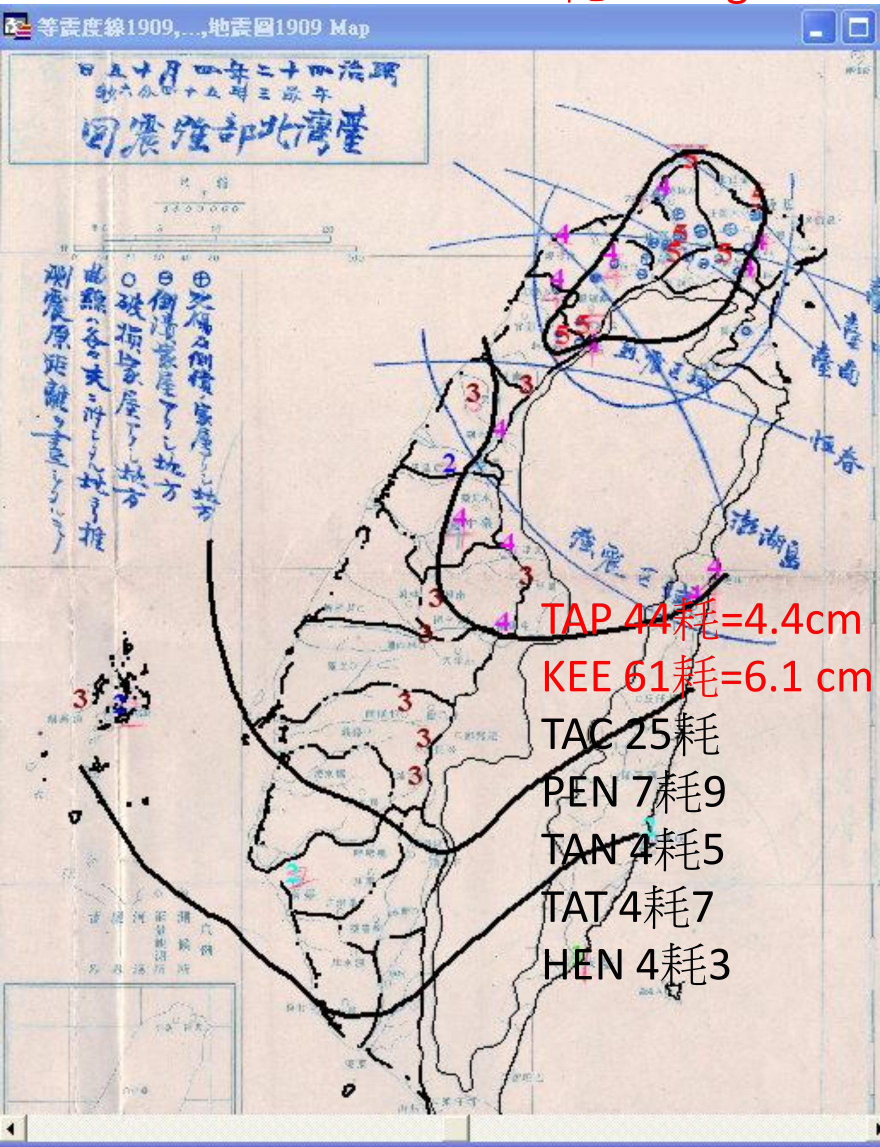
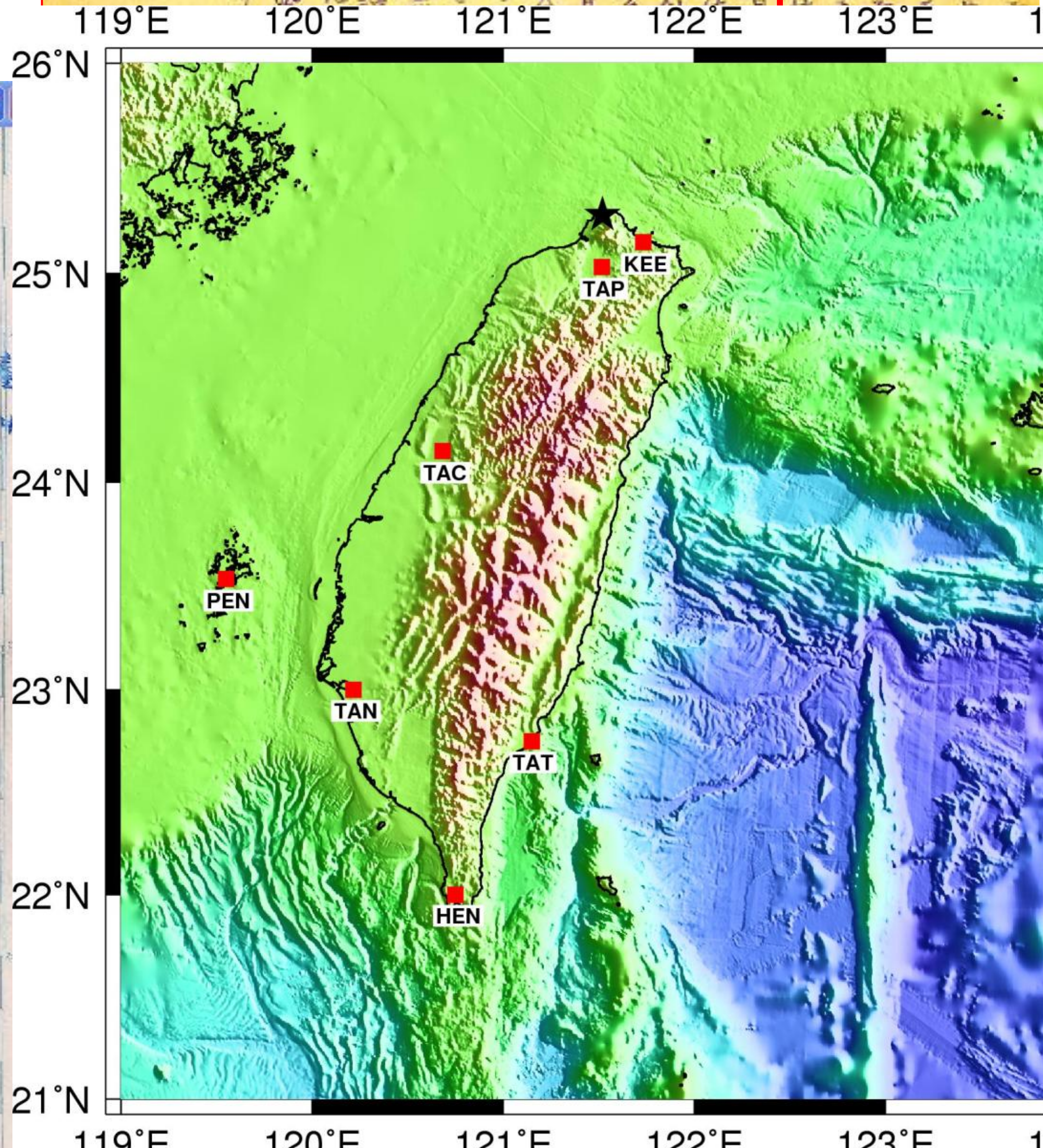
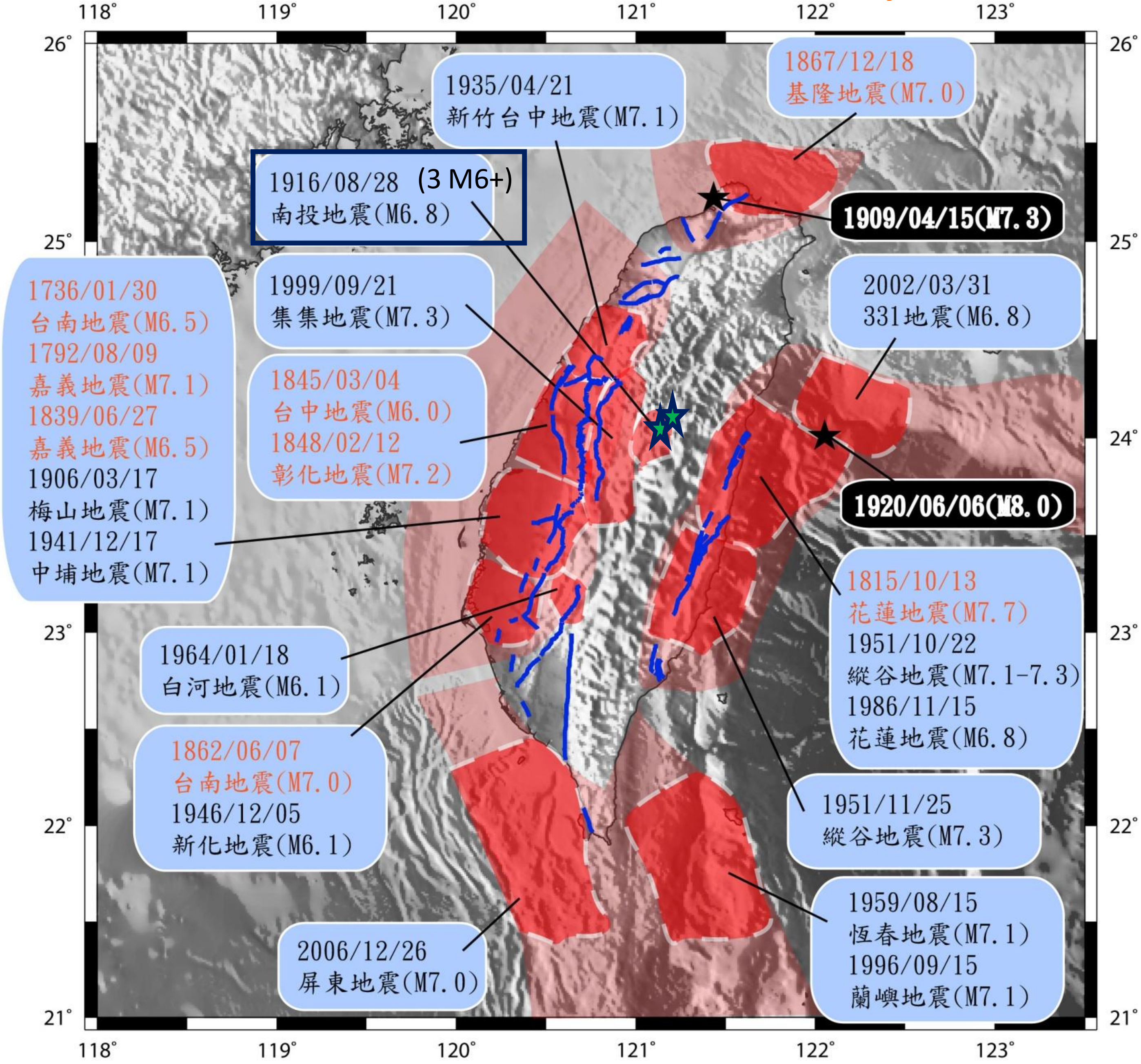


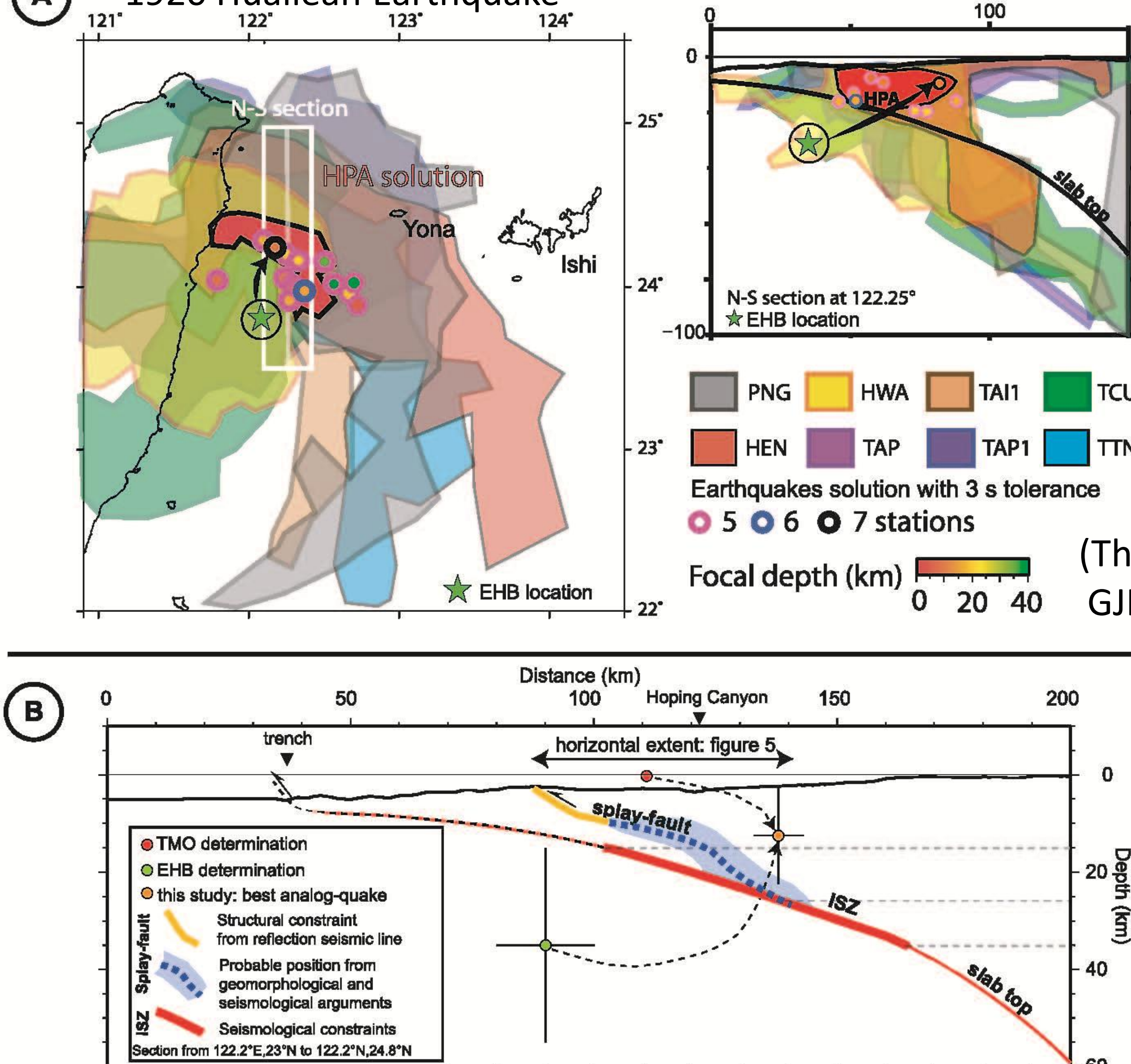


Historical Damaging Earthquakes in Taiwan since 1700s

Relative quiet in seismicity

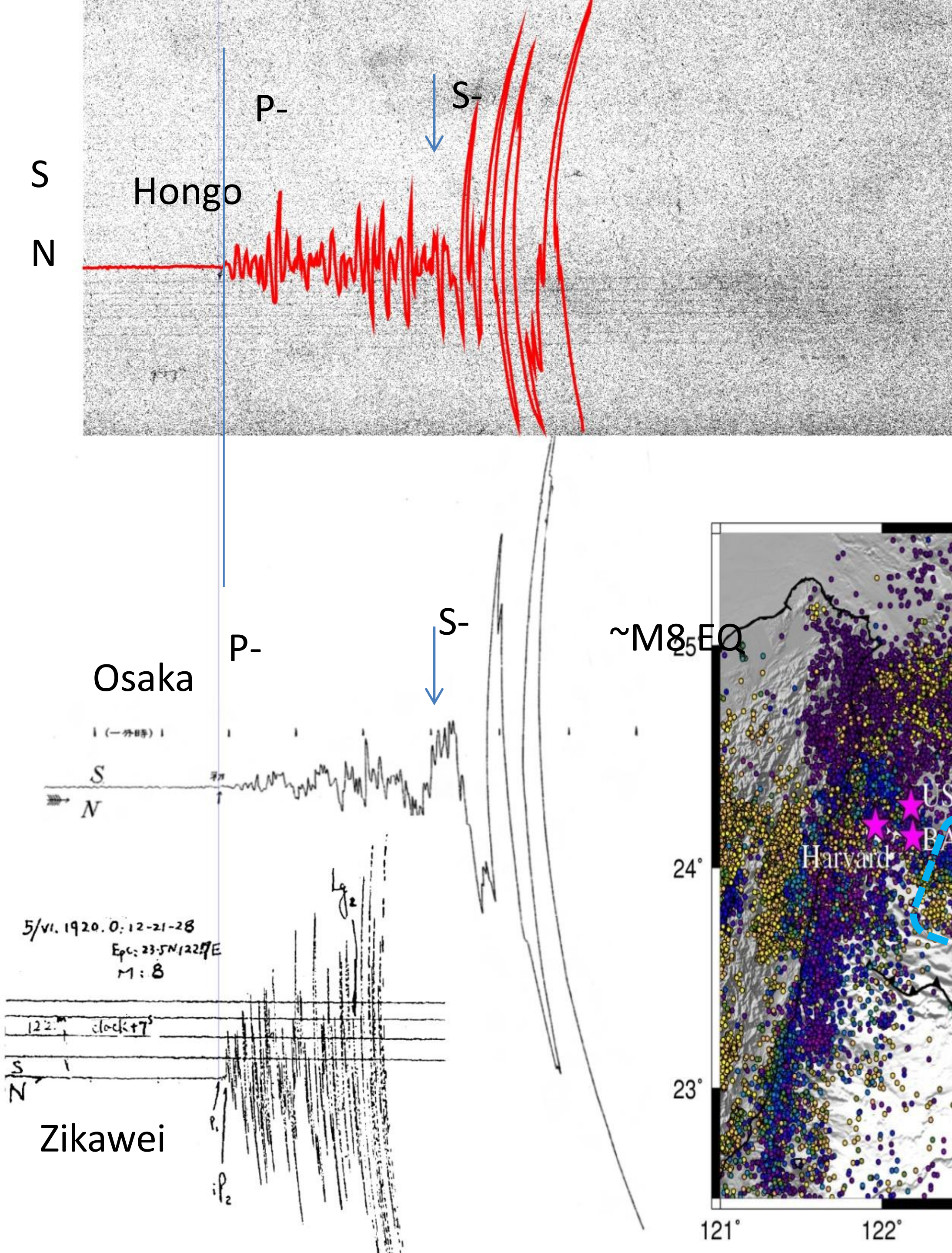


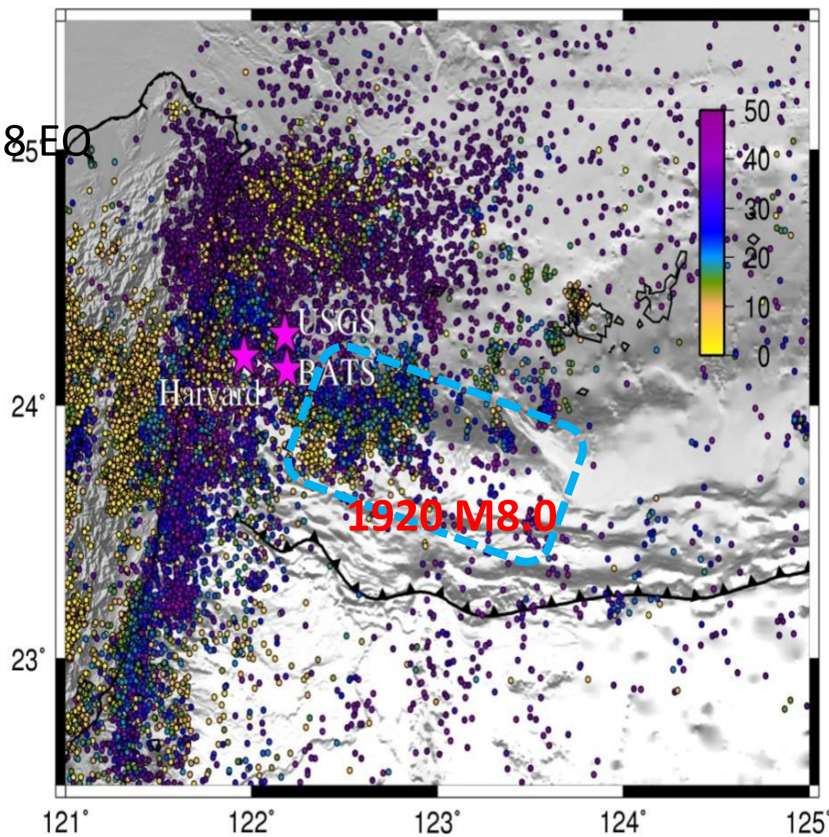
1920 Hualiean Earthquake

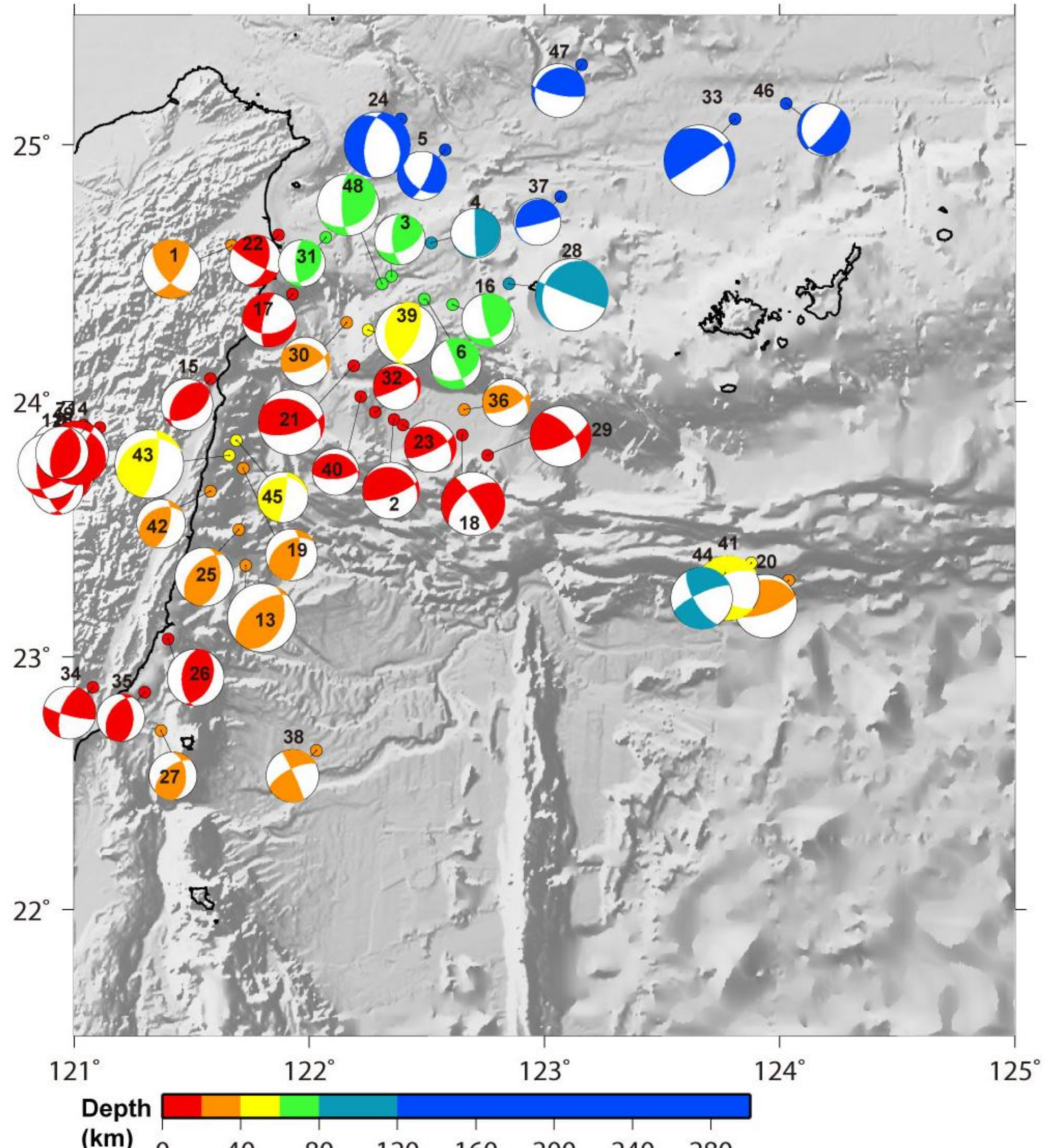


(Theunissen et al., GJI, 2010)

Figure 4. (a) Determination of the high probability area (HPA) where the M'_W 7.7 1920 earthquake occurred and (b) location of the best analogue-quake from Font *et al.* (2004) compared to the position of the ISZ and the possible splay fault. The tolerance for each envelope is ± 3 s (see text for more details). The best '1920 analogue-quake' (1994/10/09) solution is unique. Other earthquakes are selected with the same maximum 3 s tolerance on SP_{RES} but with less correlated stations. The area defined in surface is more extended than in section because all envelopes do not cross in depth to the north. The slab top is built

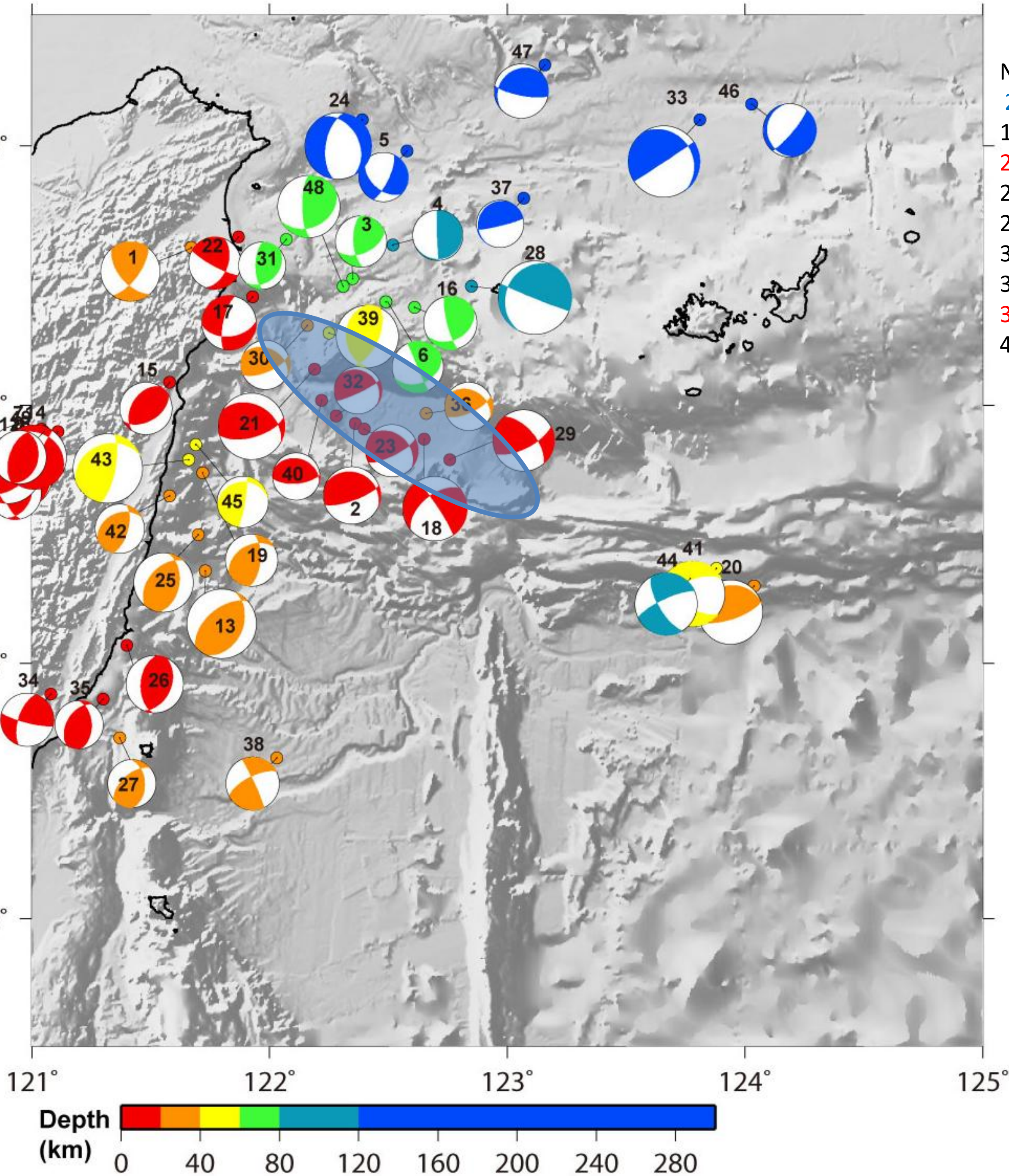

S
N
Hongo
P-
S-
Osaka
P-
S-
S
N
5/VI. 1920. 0: 12-21-28
M: 8
S
N
Zikawei
~M8 EQ


USGS
BATS
Harvard
1920 M8.0
50
40
30
20
10
0
25°
24°
23°
121°
122°
123°
124°
125°



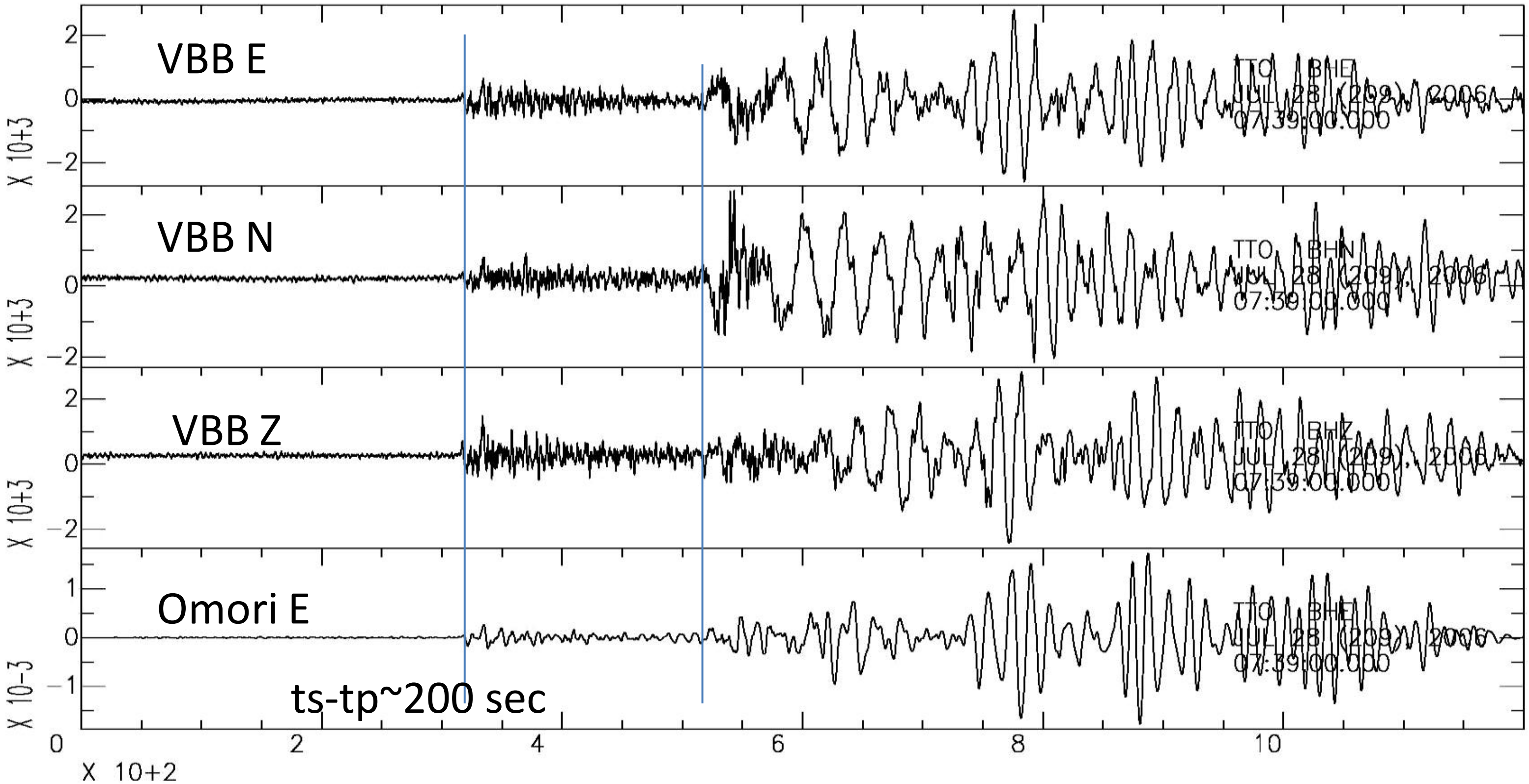
25°
24°
23°
22°
121°
122°
123°
124°
125°
Depth (km)
0
40
80
120
160
200
240
280

1995-2013
M>6



No.	Lon.	Lat.	Dep.	ML	title	Strike	Dip	Rake	F
2	122.36	23.93	6.00	6.40	199603051452	296	21	134	H
18	122.65	23.87	12.00	6.70	200112180403	231	56	-9	BA
21	122.19	24.14	13.81	6.80	200203310652	74	63	65	KH
23	122.40	23.91	15.23	6.20	200205281645	312	37	154	E
29	122.76	23.79	10.00	6.58	200411081554	320	60.2	155	
30	122.16	24.31	27.26	6.09	200411110216	297	34	135	H
32	122.28	23.96	16.76	6.00	200509060116	313	20	157	H
36	122.66	23.97	27.97	6.02	200607280740	299	33	139	H
40	122.22	24.02	18.08	6.00	200907131805	85	65	80	CV

TTO station F-net, Japan, velocity and simulated Omor record for 20060728 event
Omori Instrument, T=12.5 sec, V=120, h=0.2



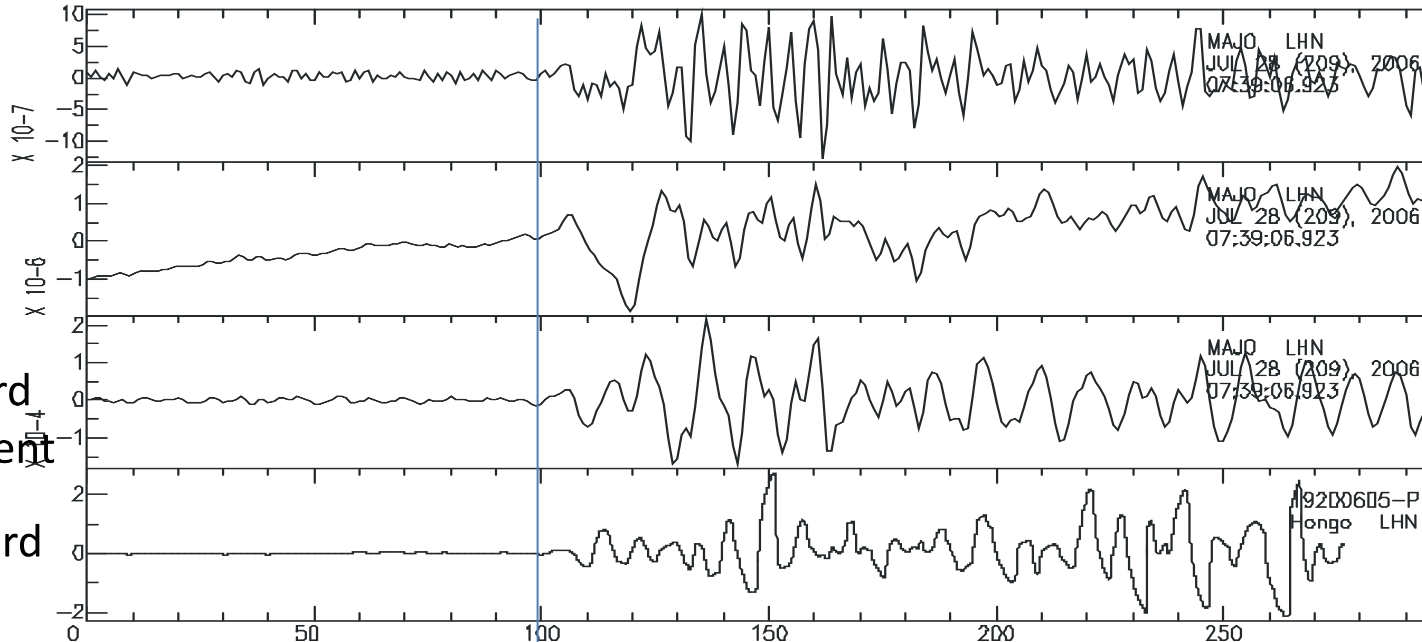
Time (sec)

VBB MAJO station

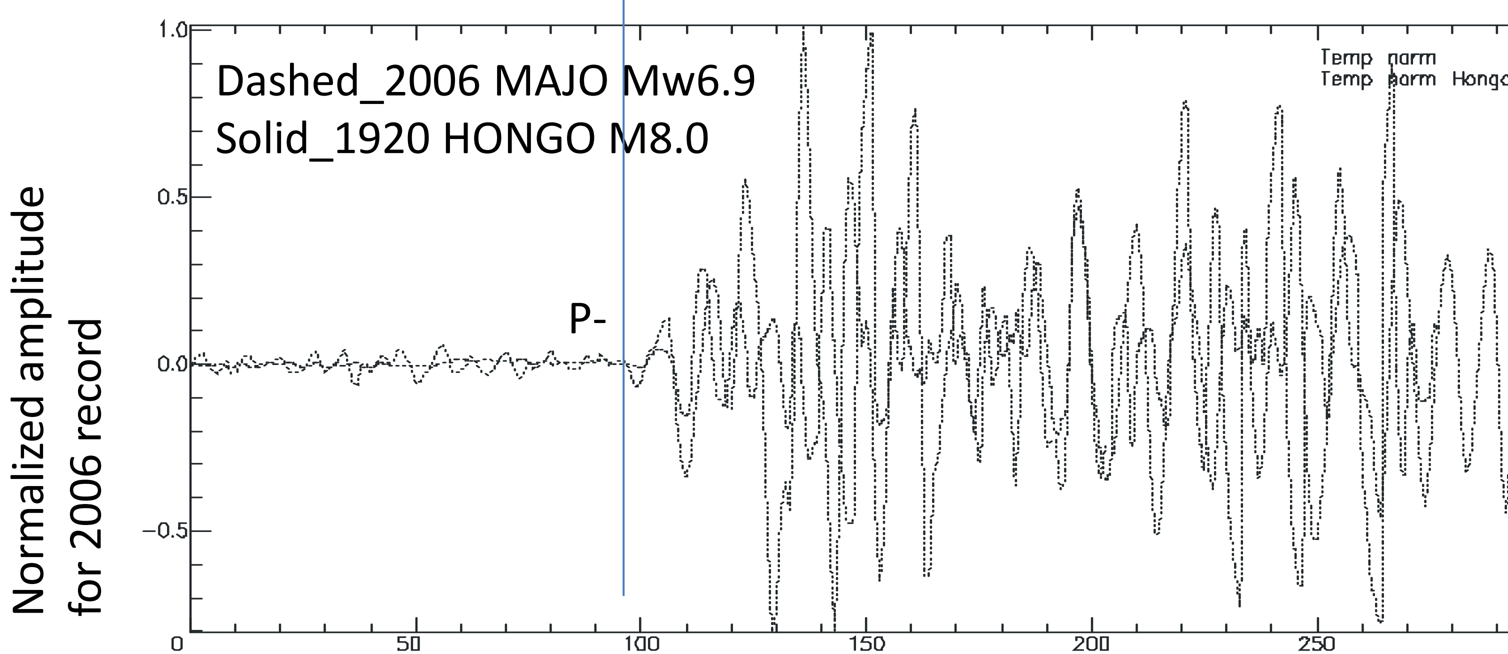
Displacement

Simulted Omori record at ABU from 2006 event

HONGO_Omori record 1920

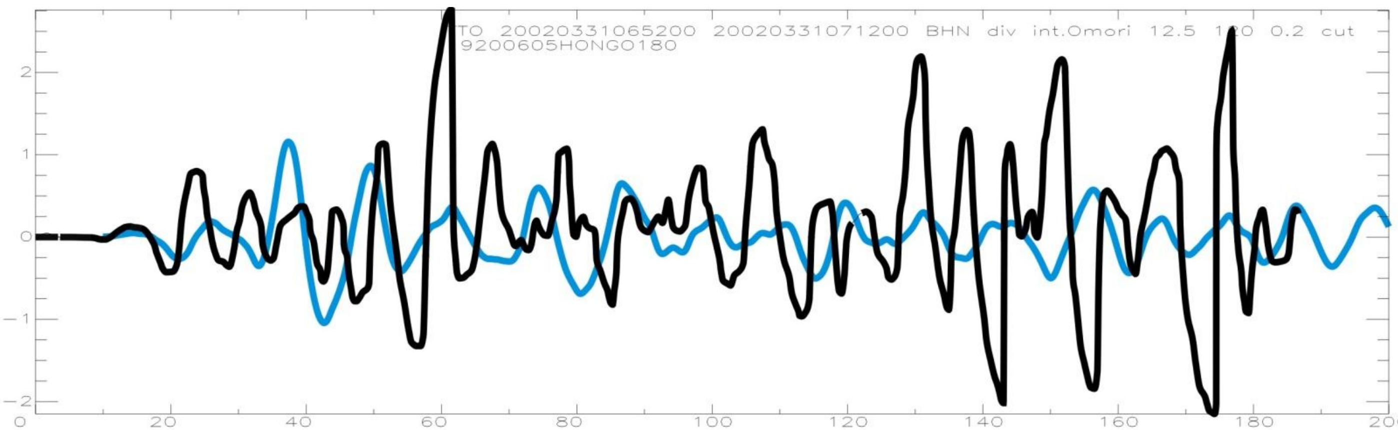


Simulation
Of the 1920
Earthquake
May 17th
TEM session by
Dr. Y.T. Yen

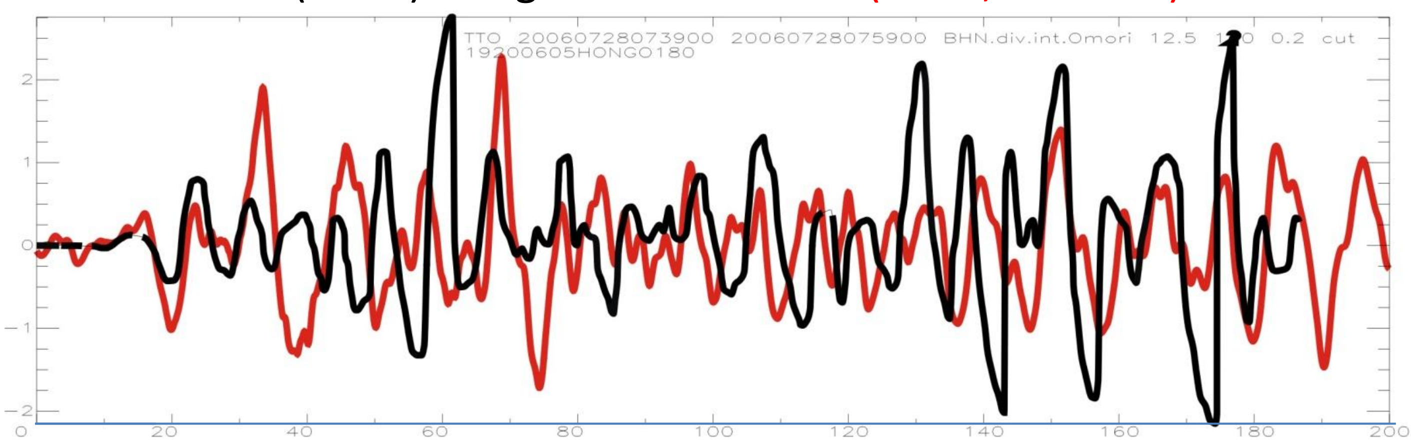


Comparison of the simulated Omori records to Omori Hongo record (T=12.5, V=120, h=0.2)

Black: 1920 Hongo Blue: 20020331(M6.8, D=14km) TTO x 100



Black: 1920(M8.0) Hongo Red: 20060728(M6.0, D=28km) TTO x 10000

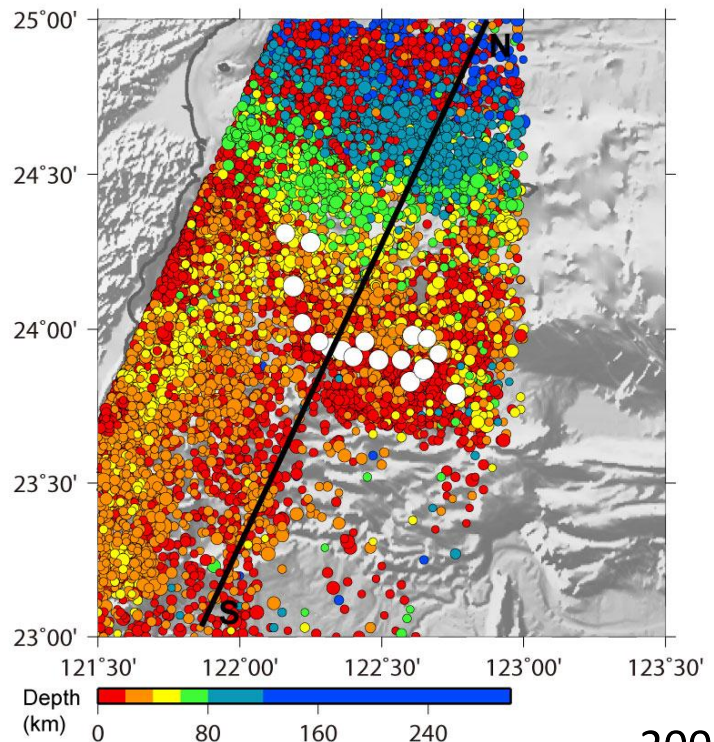


0

200 sec

⇒More similar in waveform from the 20060728 to the 19200605 earthquake

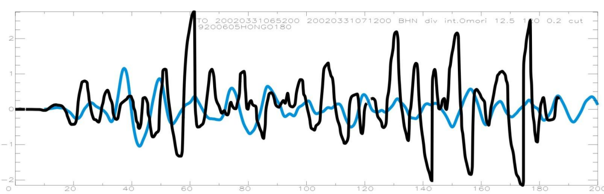
⇒20020331 event tends to have longer period signal than the 20060728 and 19200605 event



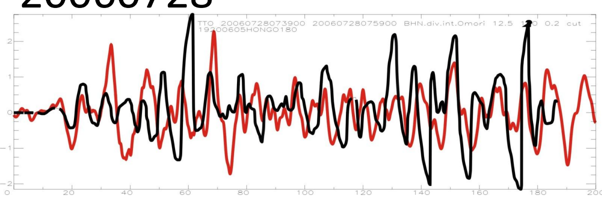
More homogeneous
(longer period)
at shallower slab (~15km

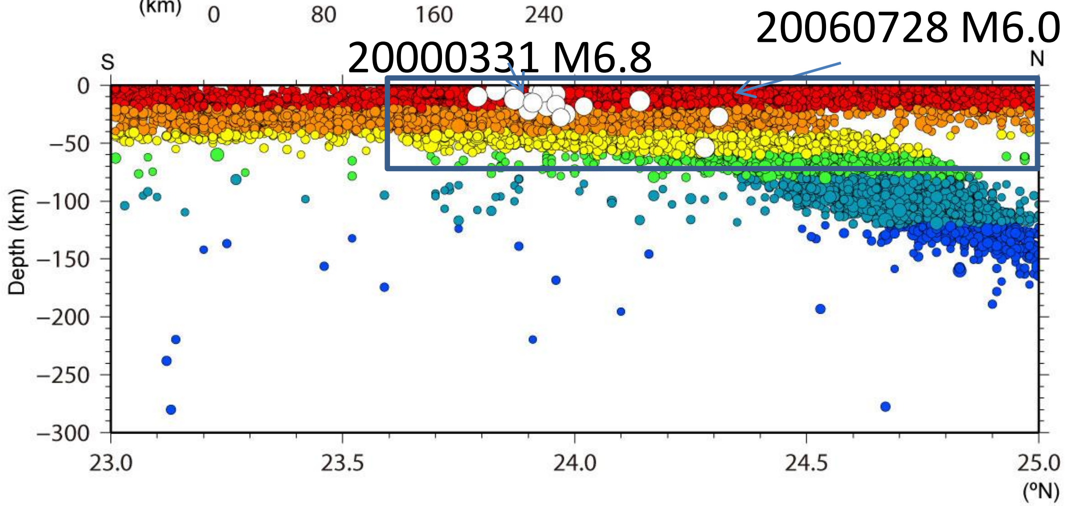
More heterogeneous
(higher frequency)
at deeper slab (~30km)

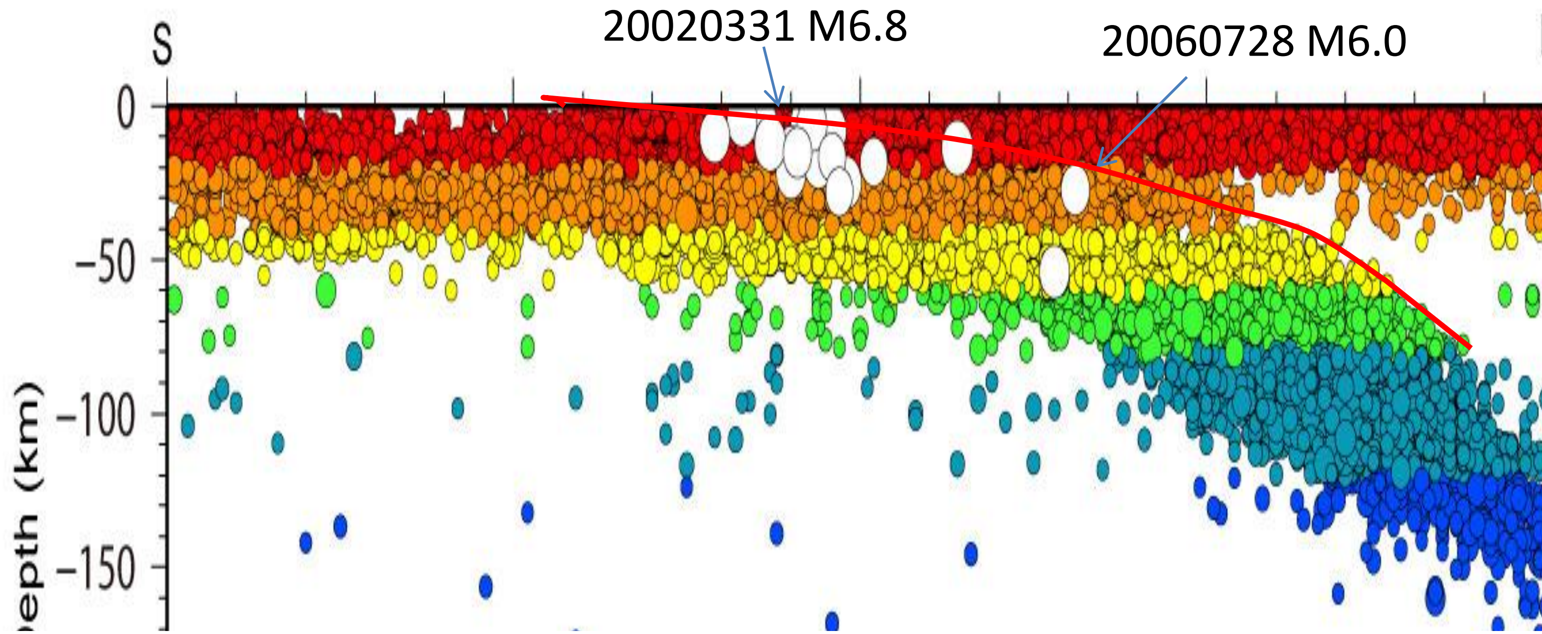
20000331



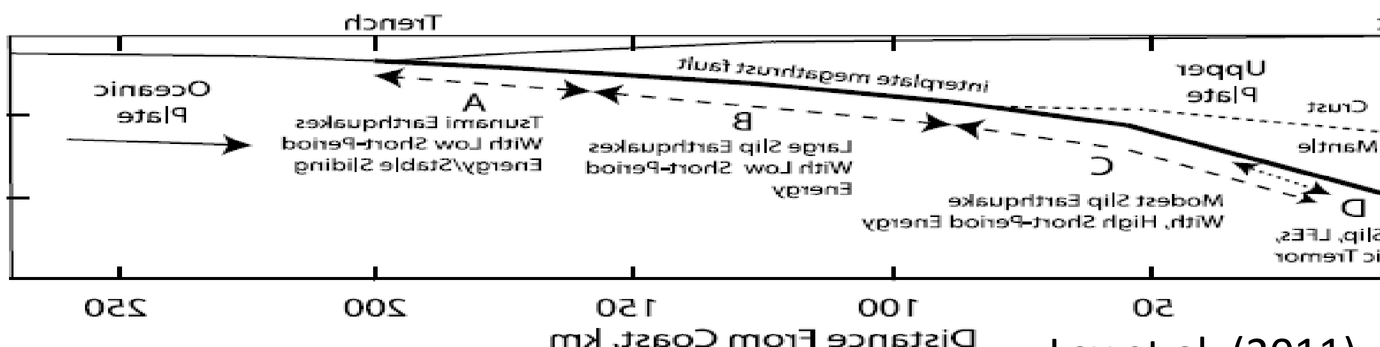
20060728







20020311(M6.8): Zone B
20060728(M6.0): Zone C
19200605(M8.0): Zone C and B



Lay et al. (2011)

Slip toward to Trench type event?

Zone, C, B, A

A: Tsunami Earthquakes with low short-period energy/stable sliding
B: Large slip earthquake with low short-period energy
C: Moderate slip earthquake with high short-period energy
D: Slow Slip, LFEs, seismic tremrors

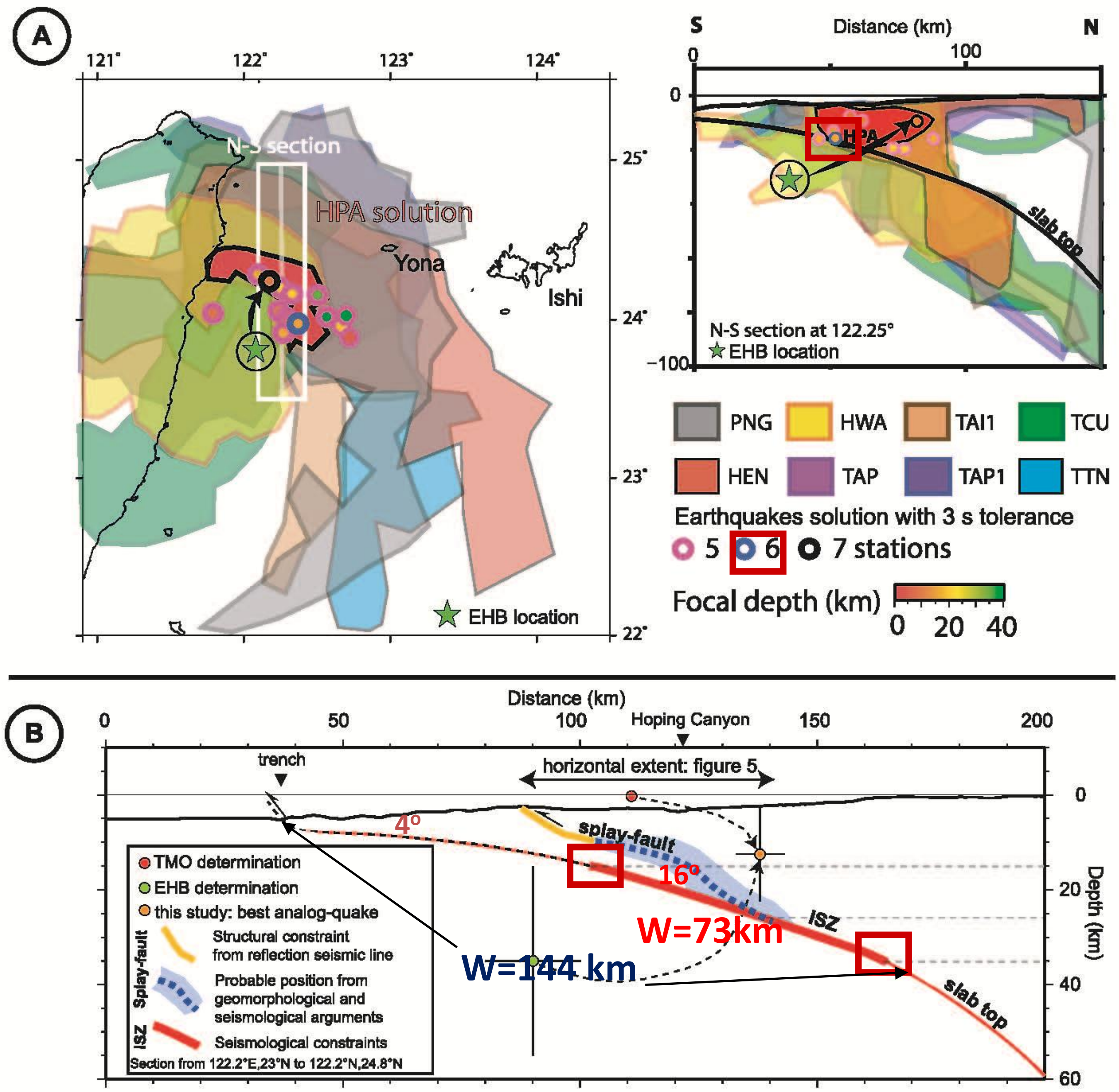


Figure 4. (a) Determination of the high probability area (HPA) where the M'_W 7.7 1920 earthquake occurred and (b) location of the best analogue-quake from Font *et al.* (2004) compared to the position of the ISZ and the possible splay fault. The tolerance for each envelope is ± 3 s (see text for more details). The best '1920 analogue-quake' (1994/10/09) solution is unique. Other earthquakes are selected with the same maximum 3 s tolerance on SP_{RES} but with less correlated stations. The area defined in surface is more extended than in section because all envelopes do not cross in depth to the north. The slab top is built

Scaling using AREA

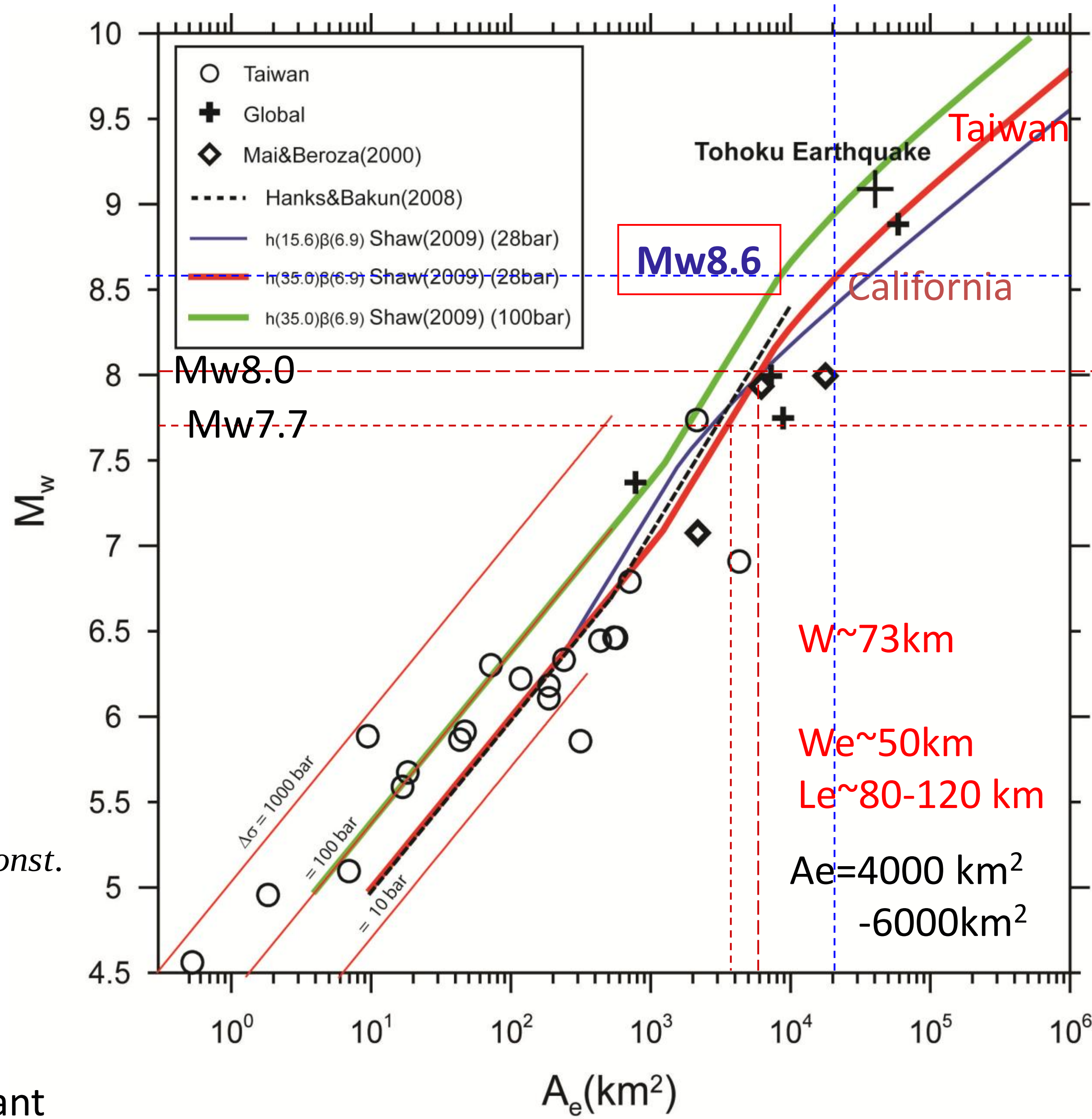
h : seimogenic depth
β: scaling parameter related to the effective fault width

- Small-Moderate earthquakes
  Mw ~ LogA
- Large earthquakes
  Mw ~ 4/3logA
- Extra largest earthquakes
  Mw ~ 2/3logA

$$M = \log A + \frac{2}{3}\log\frac{\max(1,\sqrt{\frac{A}{H^2}})}{[1+\max(1,\frac{A}{H^2\beta})]/2} + const.$$

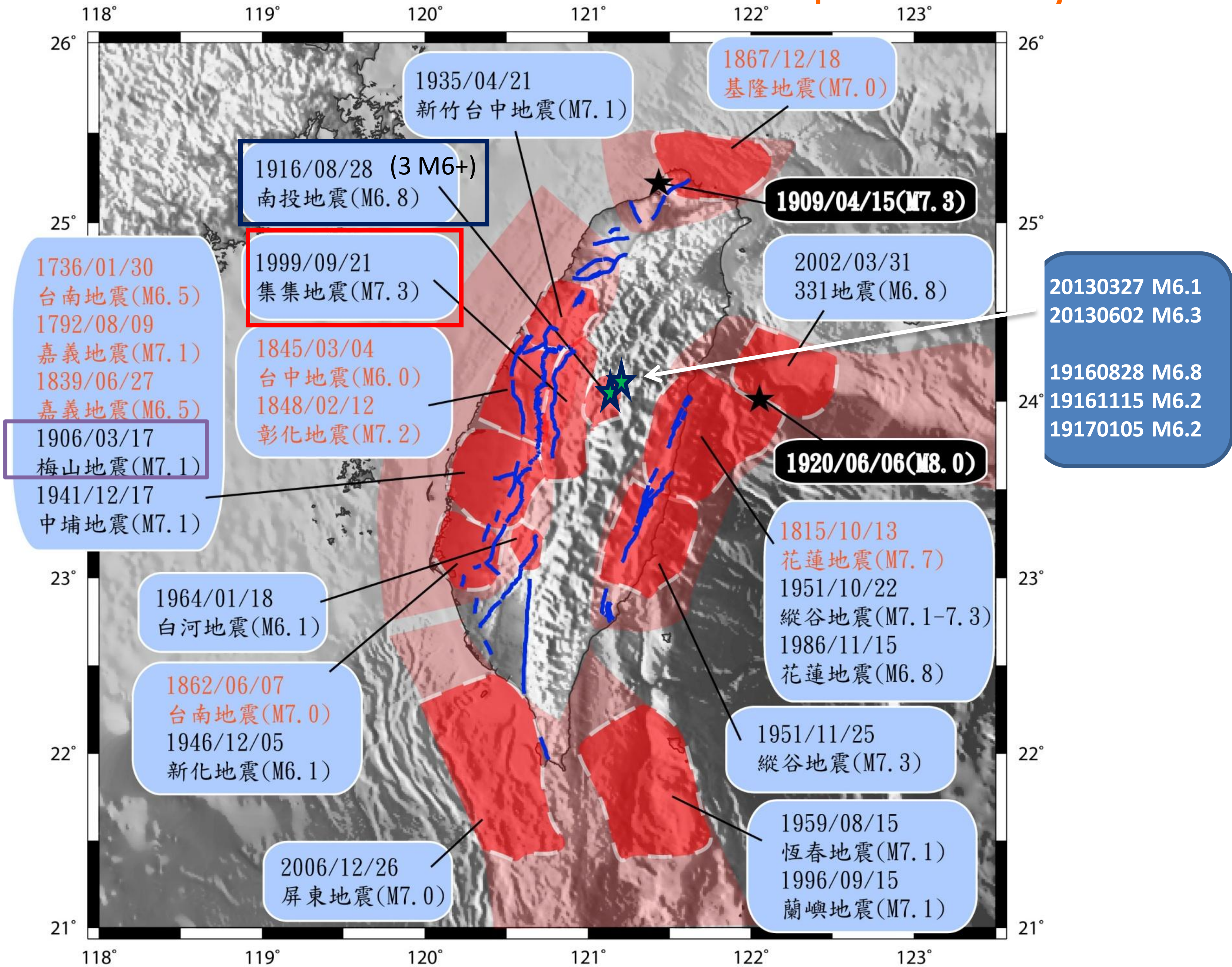
(Shaw, 2009)

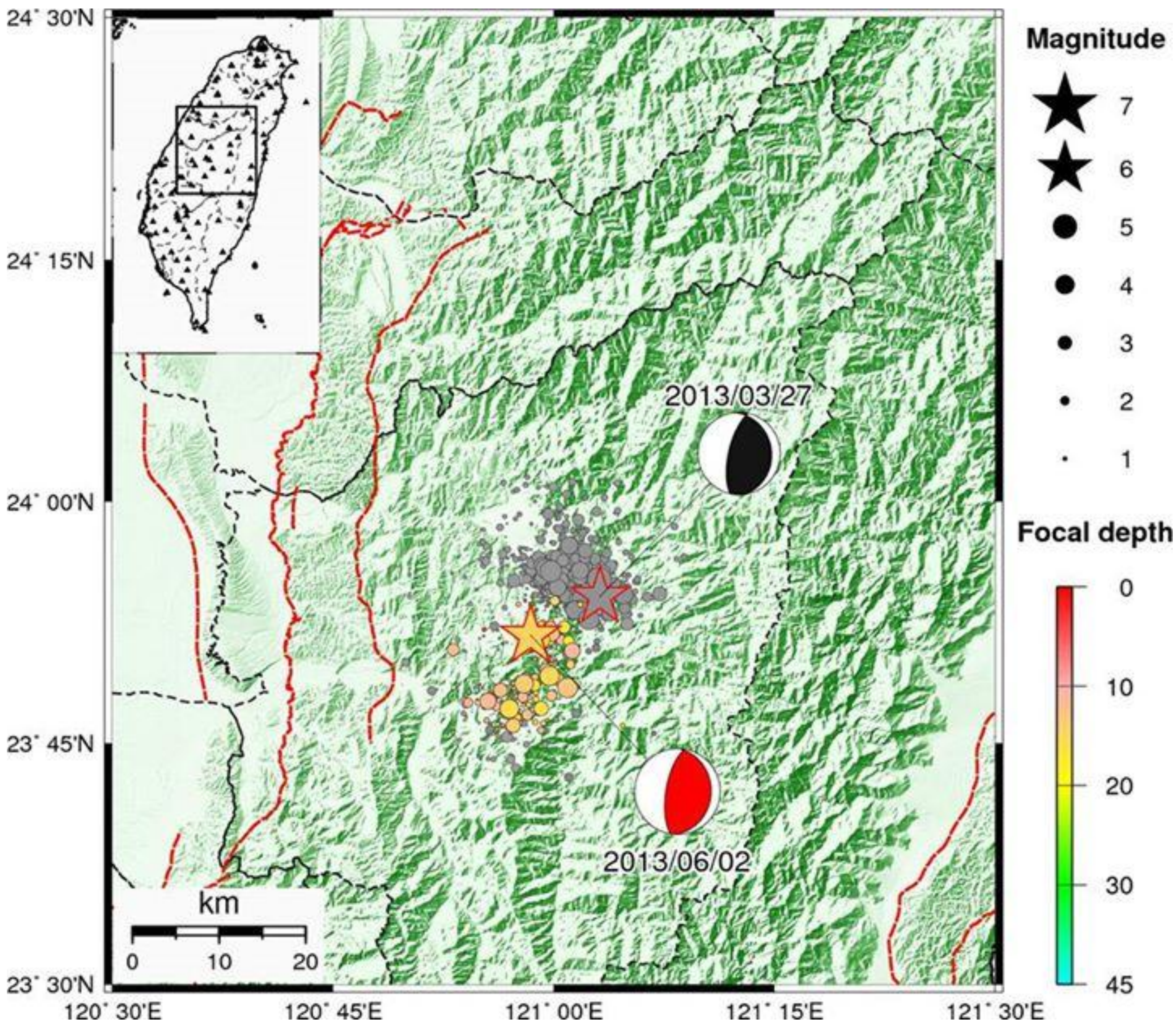
Const.: Stress drop related constant

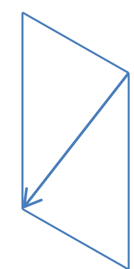


Historical Damaging Earthquakes in Taiwan since 1700s

Relative quiet in seismicity







Rupture pattern?

Historical events 歷史地震 (氣象局地震中心)

時間 緯度 經度 深度(km) 規模 死亡 屋毀

-1916 8 28 15 27 24.0 121.0濁水溪上流45 6.8 16 614 南投地震系列。埋沒14戶。

-1916 11 15 6 31 24.1 120.9臺中東南 3 6.2 1 97 南投地震系列。

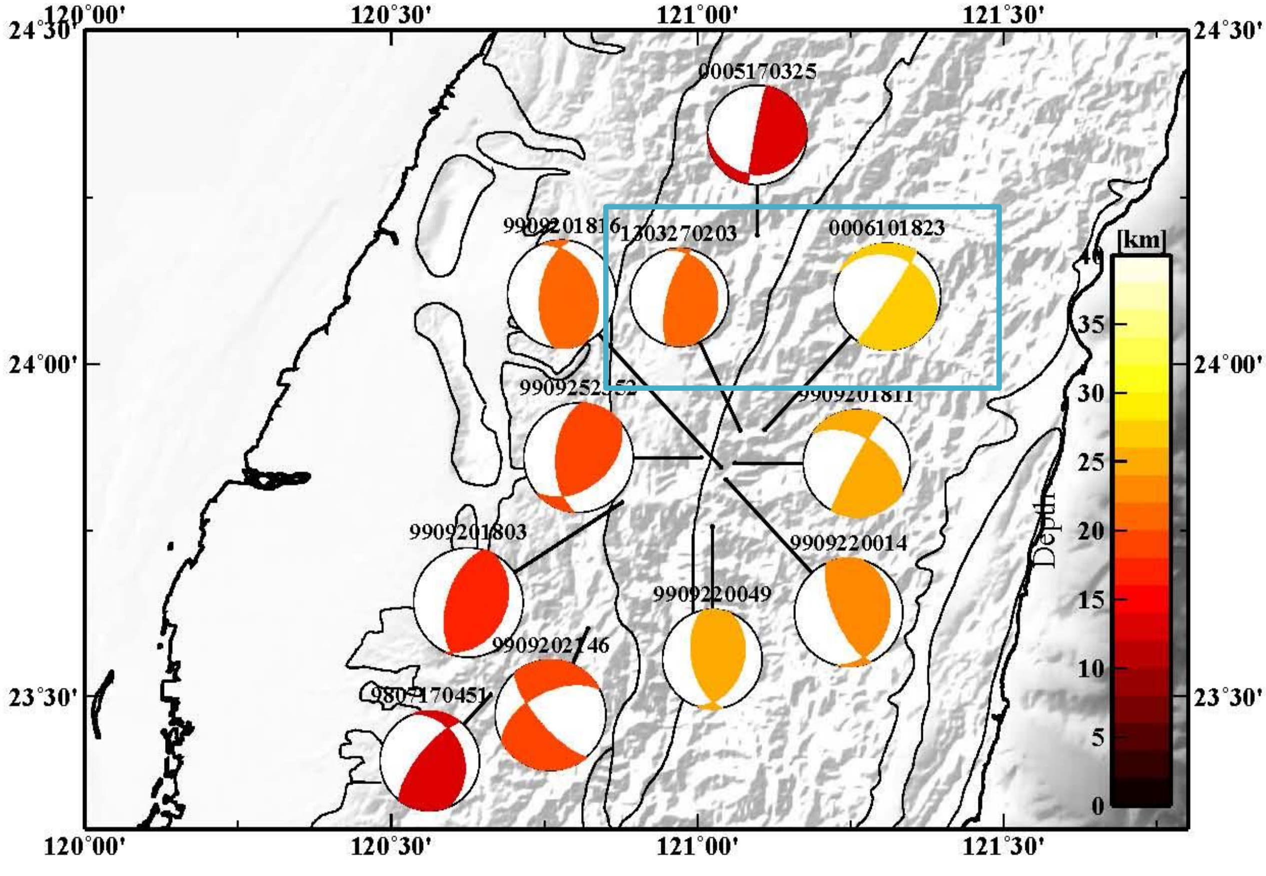
-1917 1 5 0 55 24.0 121.0埔里附近 淺 6.2 54 130 南投地震系列。

-1917 1 7 2 8 23.9 120.9埔里附近 淺 5.5 187 南投地震系列。

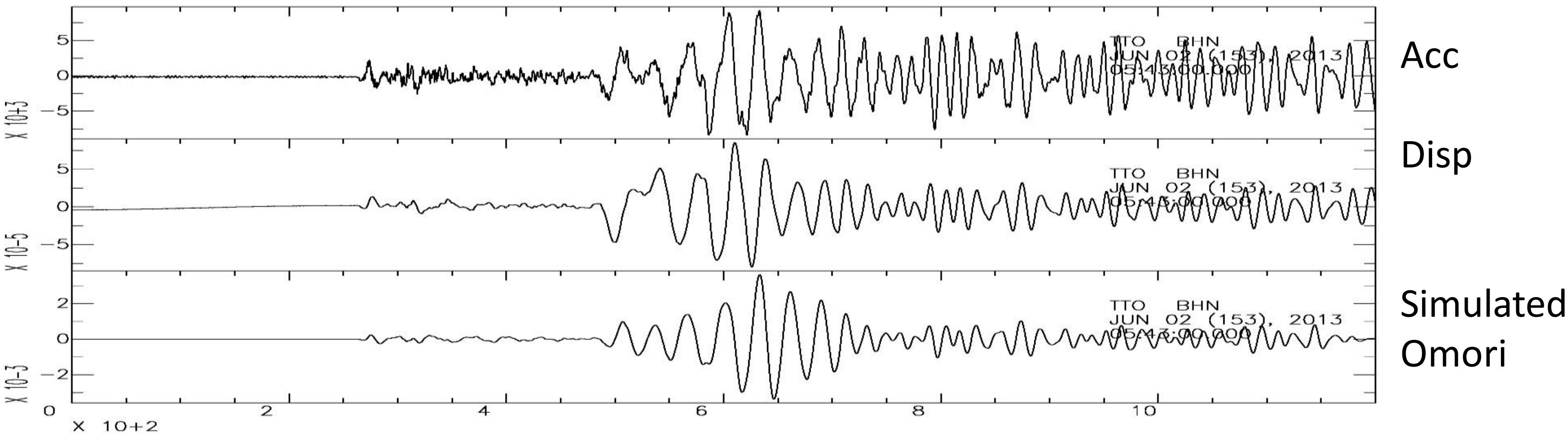
***2013032710 03 23.9 121.07 15.4 6.2**

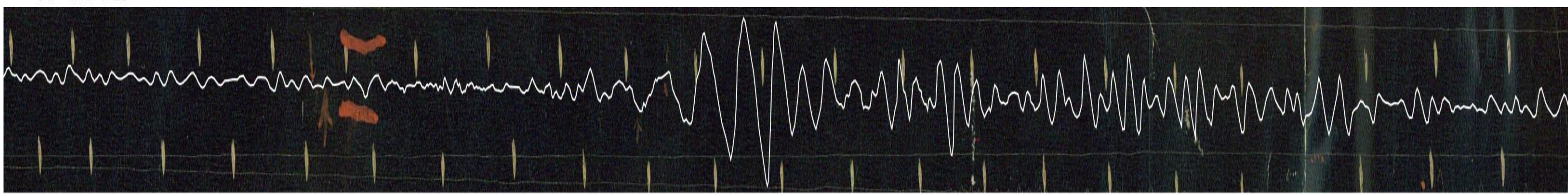
2013060205 43 23.9 121.00 10.0 6.3

Mw>5.5 in Central Taiwan (1995.7−2013.4)



20130602 TTO _acc_disp_Omori SN-component (ML6.3, Mw5.73)

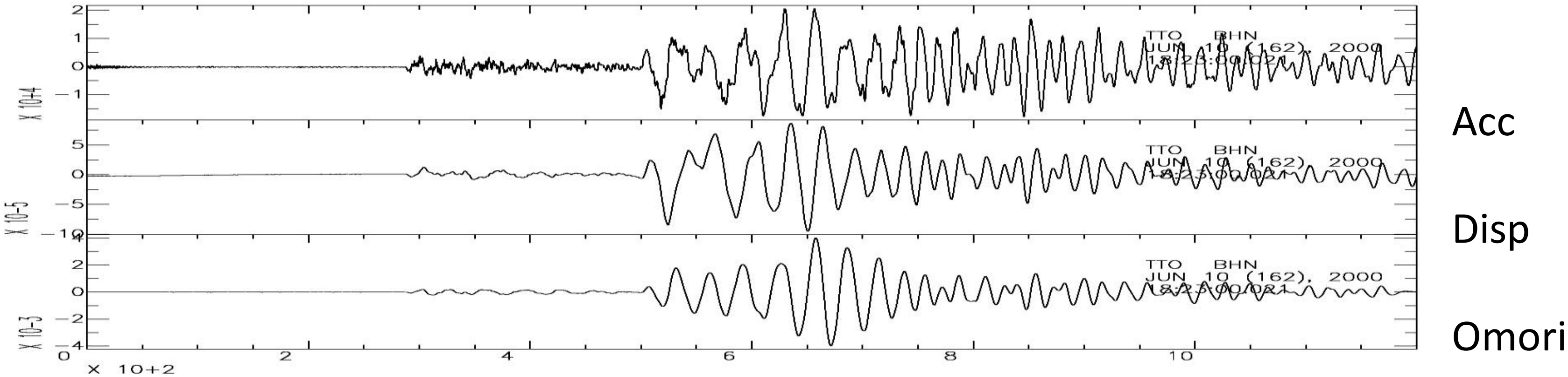




Hongo SN Omori record, T=30 sec, V=20, h=0.2, M6.8

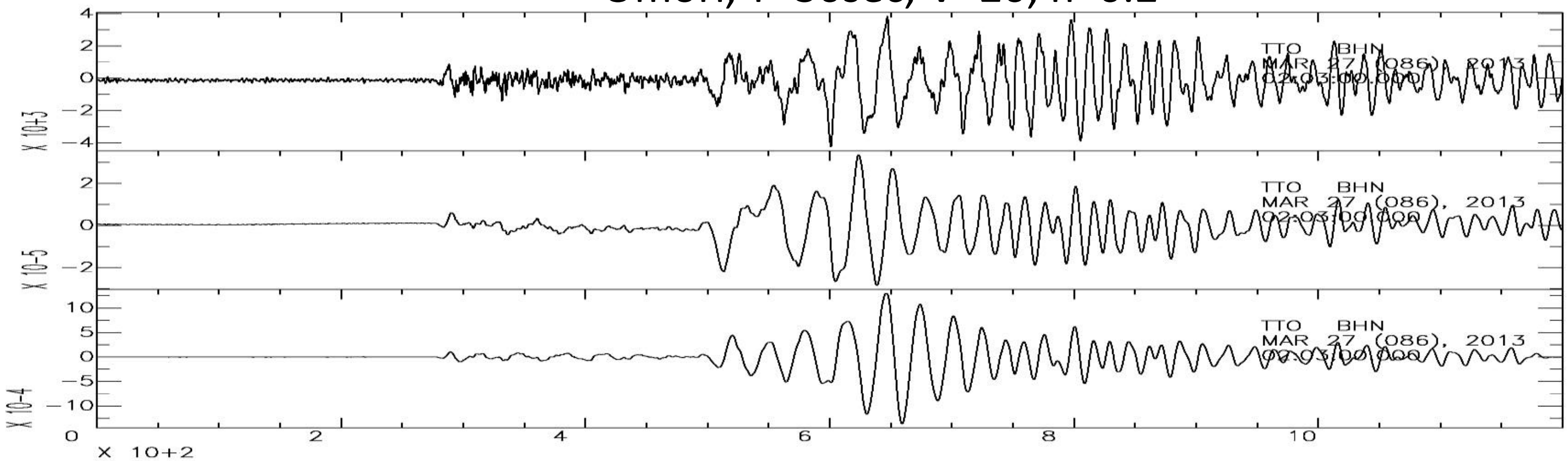
200006101823_TTO_acc_disp_Omori SN component

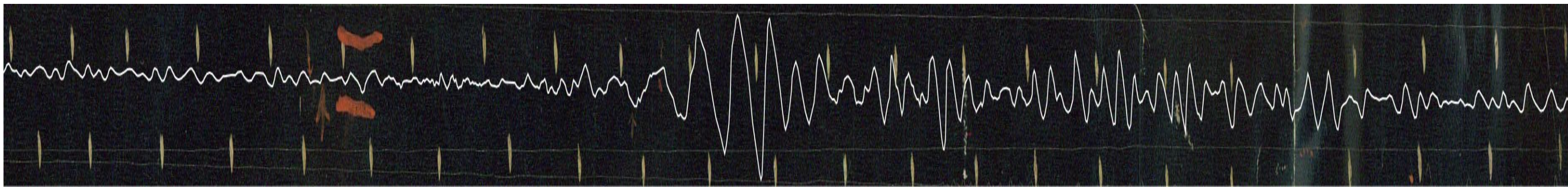
Omori, T=30sec, V=20, h=0.2



201303270203_TTO_acc_disp_Omori SN component

Omori, T=30sec, V=20, h=0.2

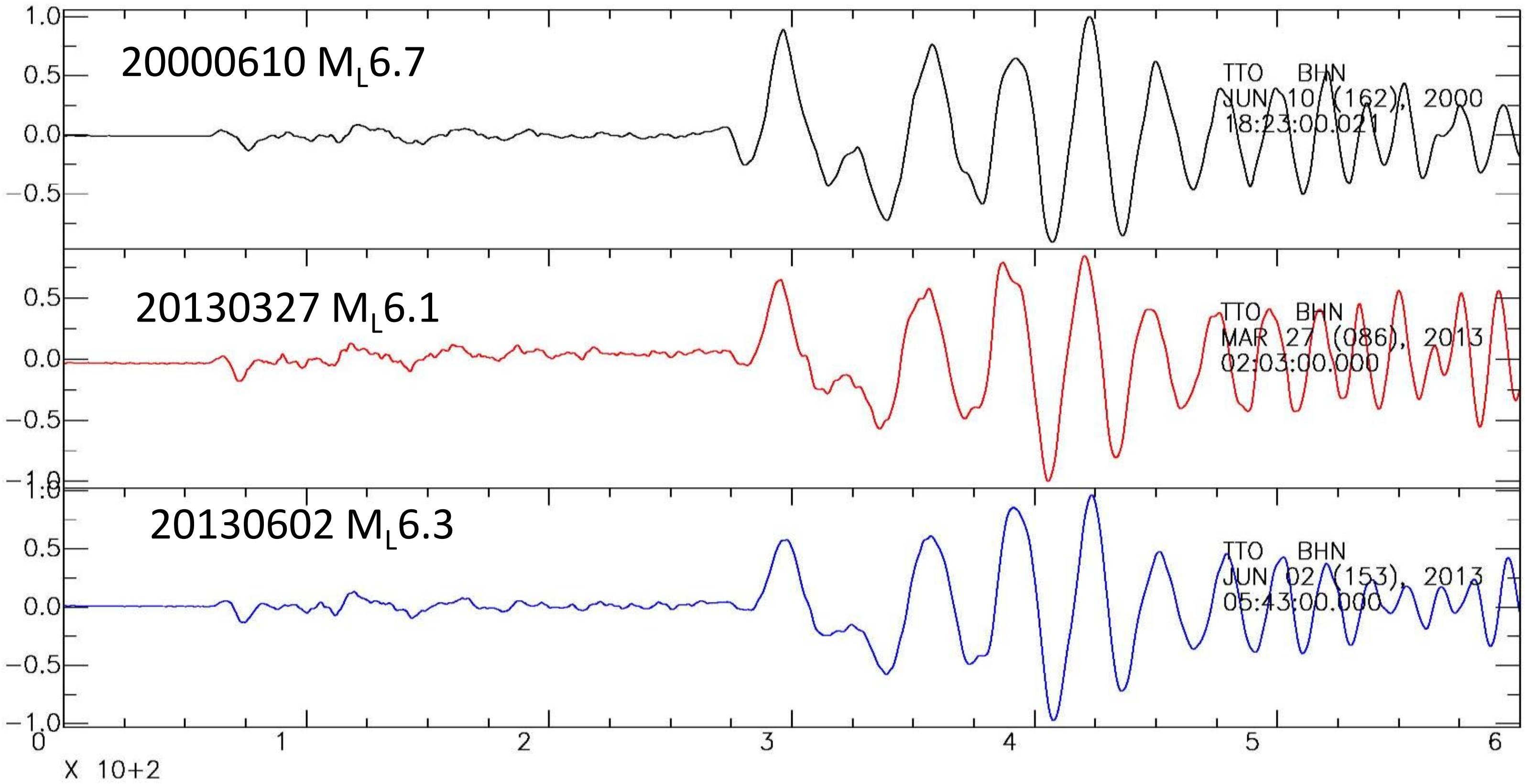




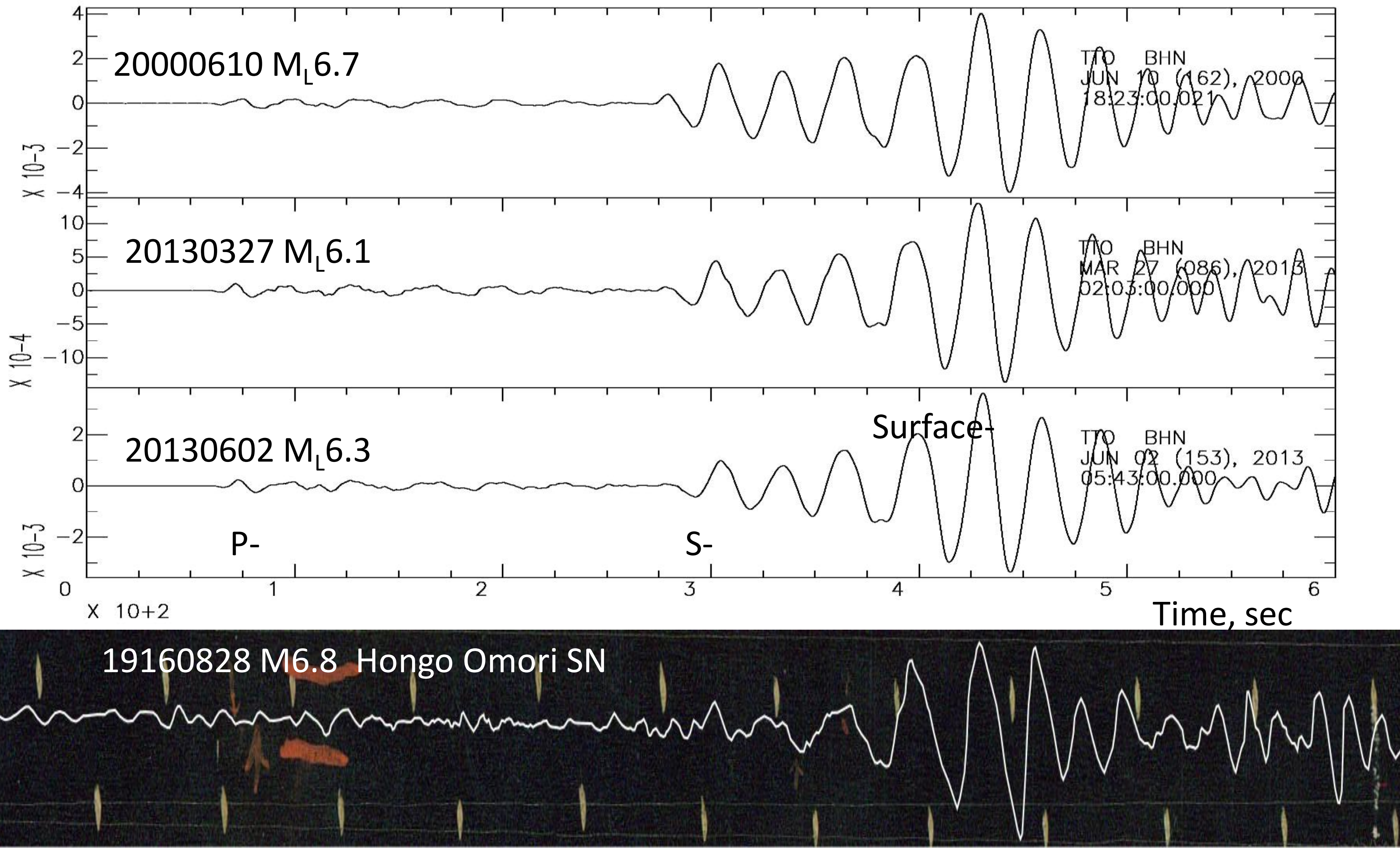
Normalized records at TTO for NS component

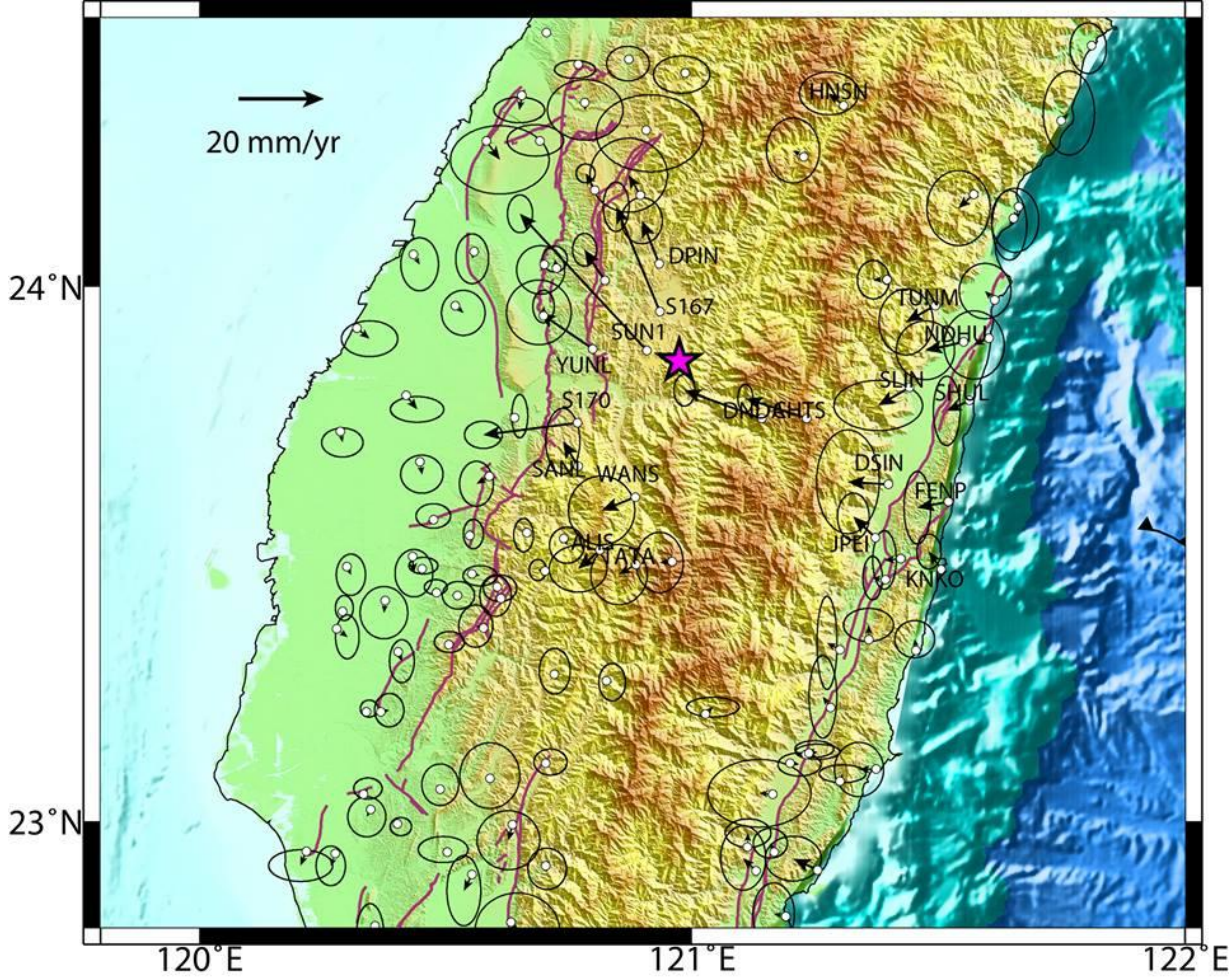
-These three events with similar waveforms, but, in general, 20130327 and 20130602 are more similar

- Similar generation of surface wave



Simulated Omori records of Japan F-net TTO station for SN component
1916 Omori Instrument Reponse T=30sec, V=20 h=0.2

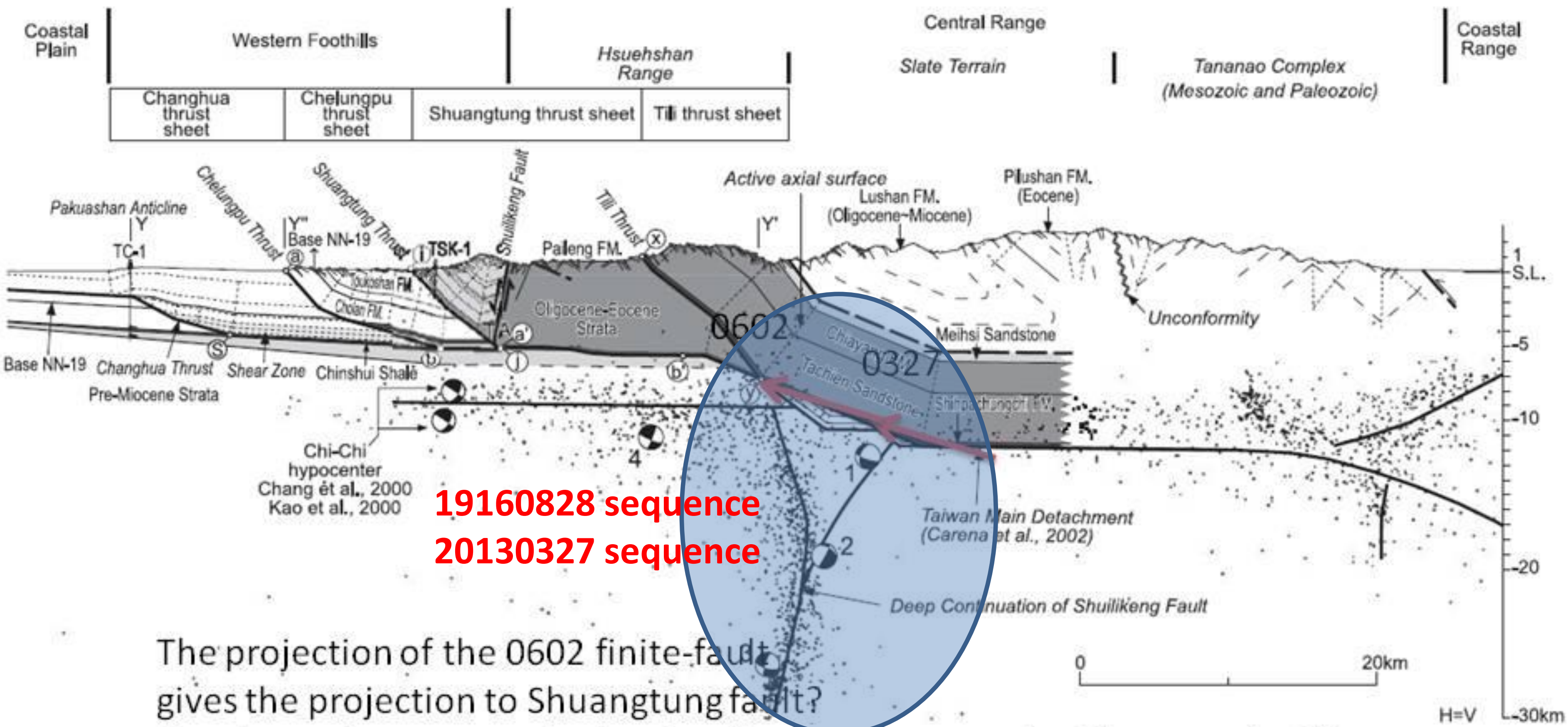




20 mm/yr
HNSN
DPIN
S167
SUN1
YUNL
S170
SANL
WANS
ALIS
TATA
DNDA
CHTS
TUNM
NDHU
SLIN
SHUL
DSIN
FENP
JPEI
KNKO
24°N
23°N
120°E
121°E
122°E

Previous models

- A forward breaking sequence above a basal detachment extends eastward with ramp and flat. -----(*Yue et al., 2005*)



The projection of the 0602 finite-fault gives the projection to Shuangtung fault?
But, the real movement is the decollement connected to Shautung fault?

Conclusions and Challenges

- How to deal with low probability (extreme event which was not yet occurred? e.g. 1920 M8.0 Hualiean earthquake => rupture to the trench? Manila Trench event?

- Considering the tectonic events (not active faults), or, the seismogenic earthquake source in PSHA or SHA?

- Earthquake Scenario for large (extreme) earthquakes.
  (Source Model; Fine 3D velocity structure and subsurface structure of to engineering bedrock and seismic bedrock)

- Continuing the literature search on paleo-earthquakes/tsunamis and modeling of the historical earthquakes. Collaboration with **geologists, and engineers**.

THANK YOU!