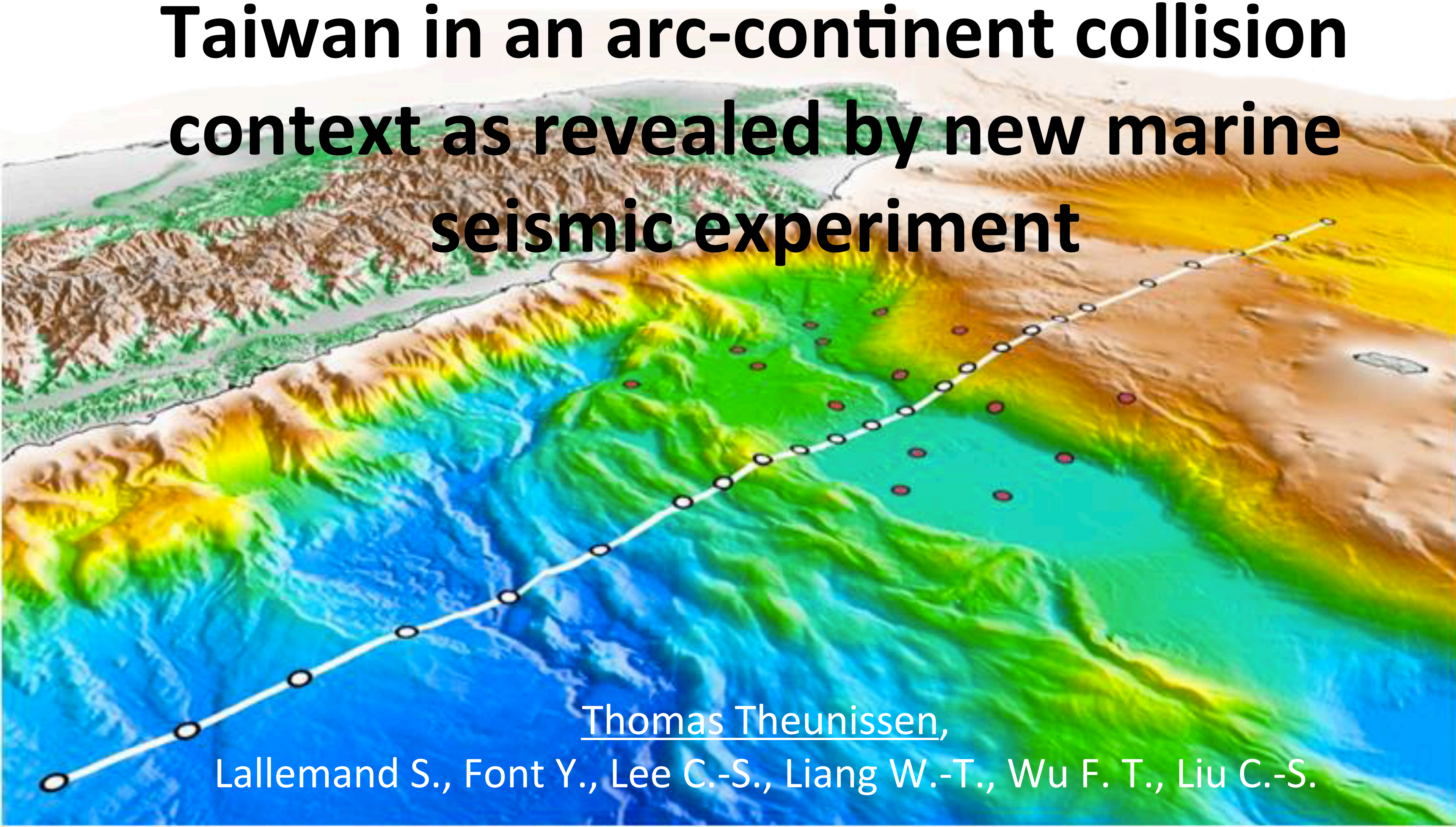
Crustal deformation offshore East Taiwan in an arc-continent collision context as revealed by new marine seismic experiment



Thomas Theunissen,
Lallemand S., Font Y., Lee C.-S., Liang W.-T., Wu F. T., Liu C.-S.

Taiwan and the Southernmost part of the Ryukyu subduction

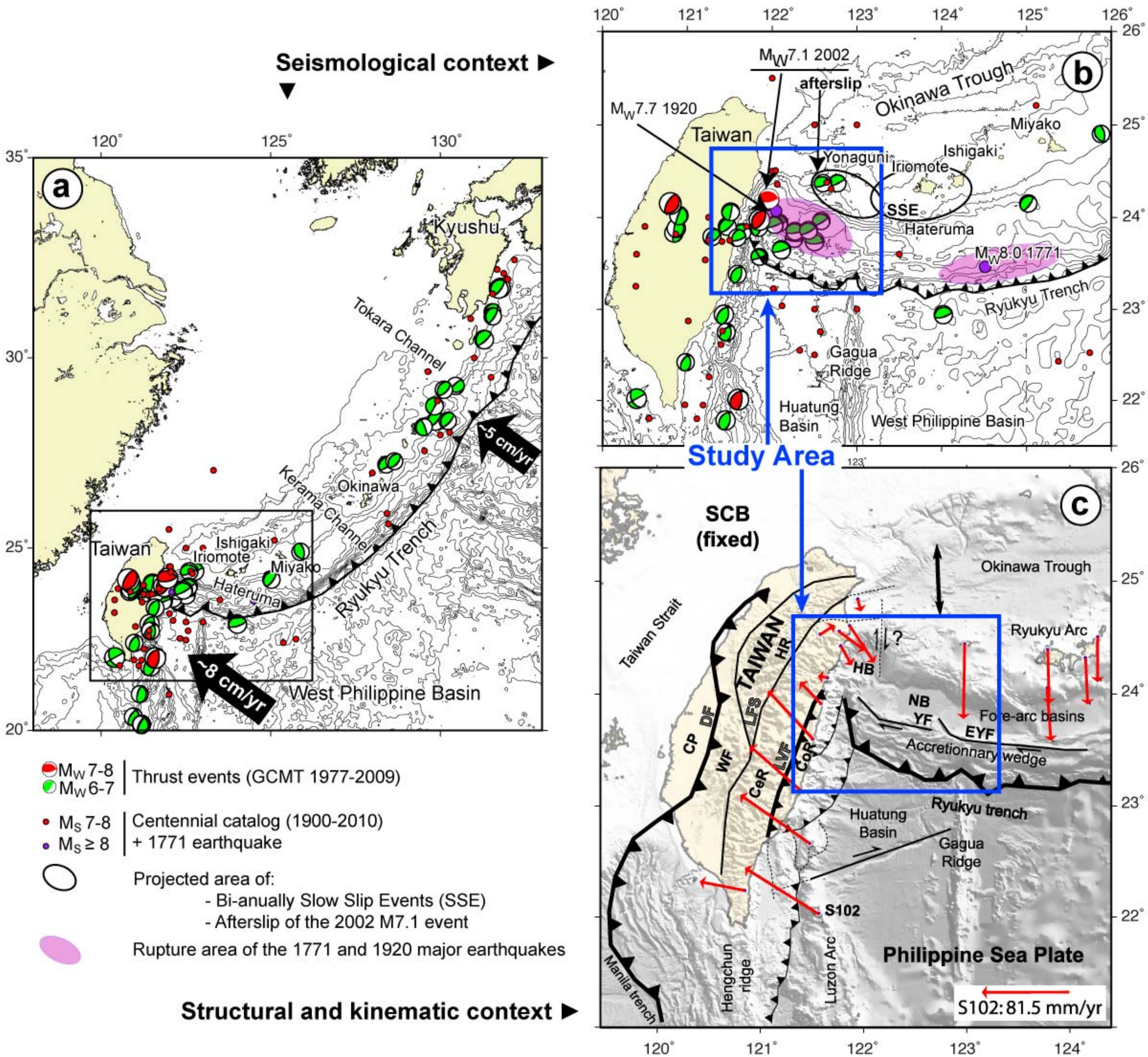
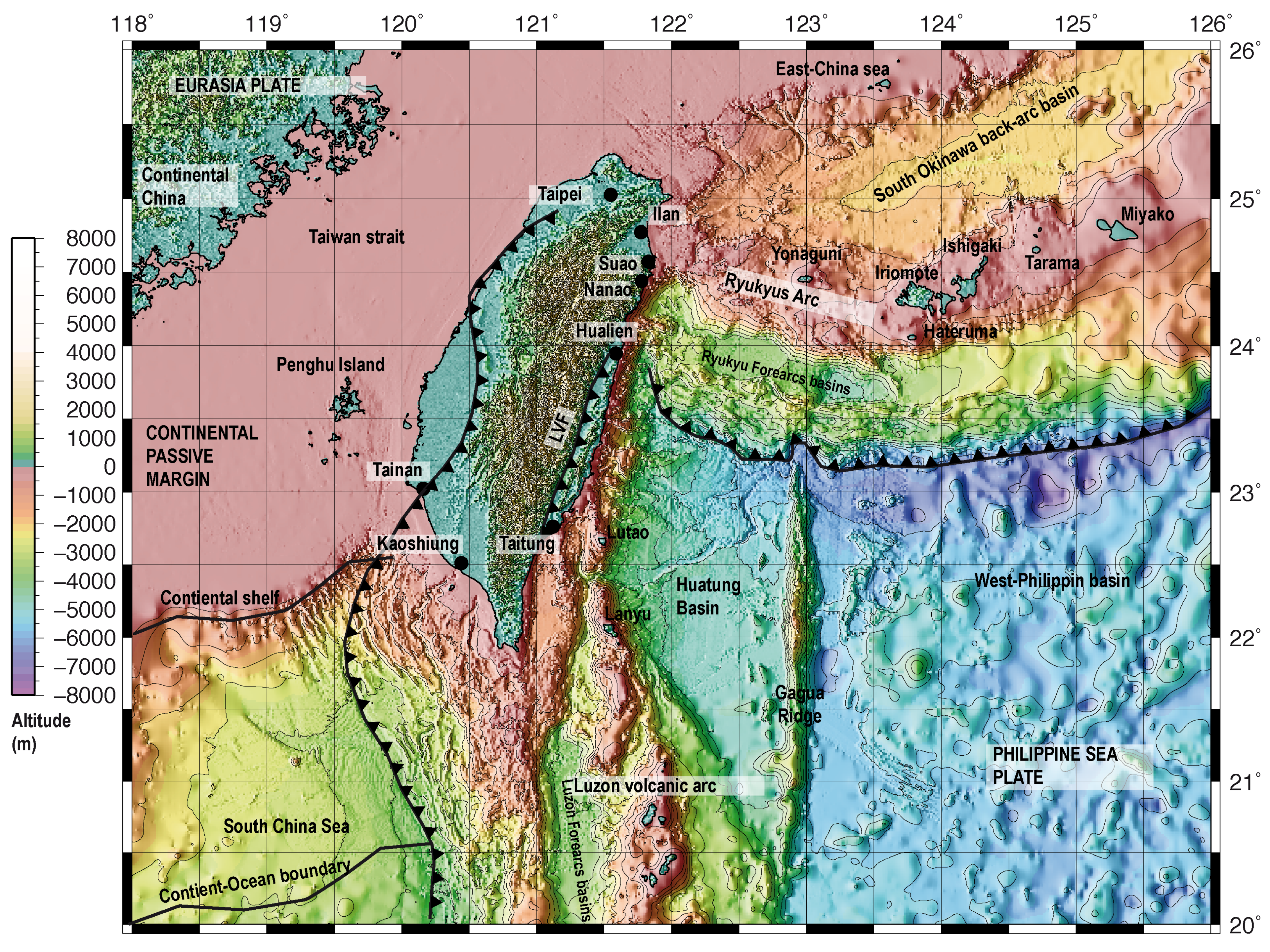


Fig1

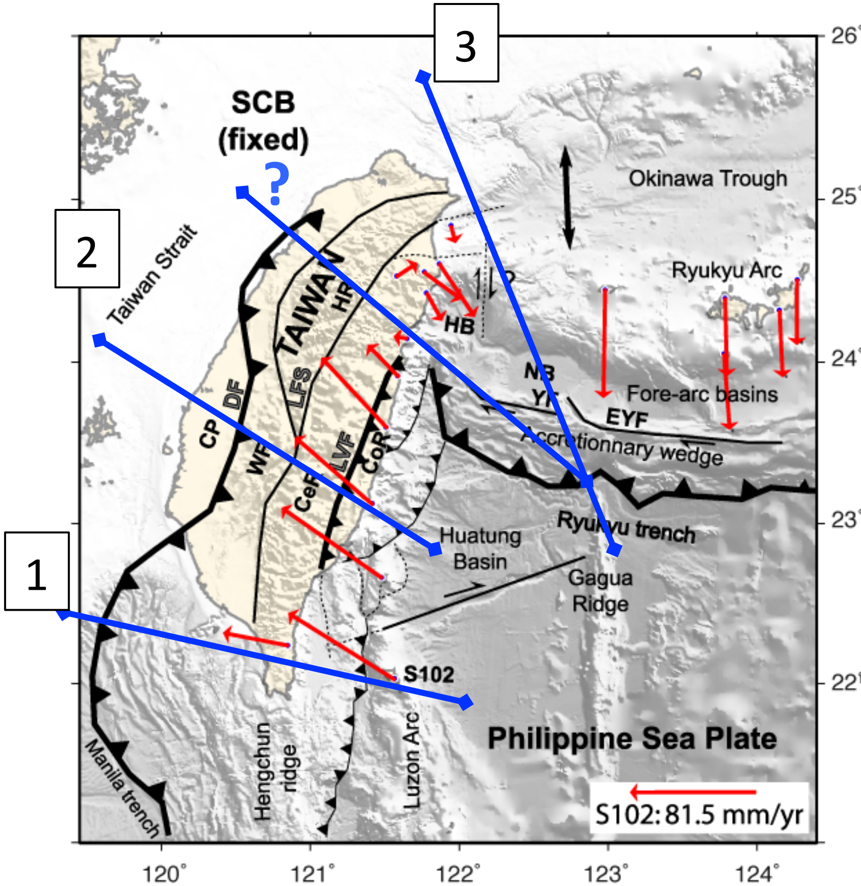
Theunissen et al. (2012)

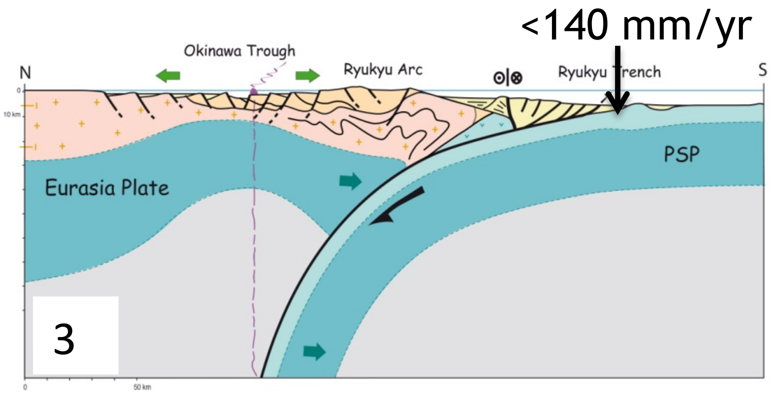


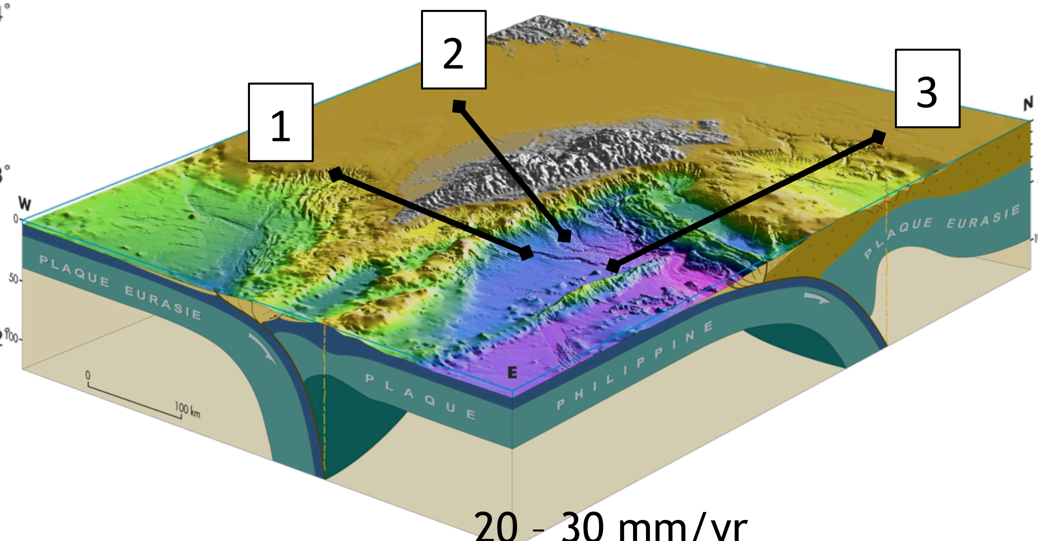
118°
119°
120°
121°
122°
123°
124°
125°
126°
26°
25°
24°
23°
22°
21°
20°
EURASIA PLATE
Continental China
Taiwan strait
East-China sea
South Okinawa back-arc basin
Taipei
Ilan
Suao
Nanao
Hualien
Yonaguni
Ishigaki
Iriomote
Tarama
Miyako
Hateruma
Ryukyus Arc
Ryukyu Forearcs basins
Penghu Island
CONTINENTAL PASSIVE MARGIN
LVF
Tainan
Kaoshiung
Taitung
Lutao
Lanyu
Huatung Basin
West-Philippin basin
Contiental shelf
Gagua Ridge
PHILIPPINE SEA PLATE
Luzon volcanic arc
Luzon Forearcs basins
South China Sea
Contient-Ocean boundary
8000
7000
6000
5000
4000
3000
2000
1000
0
−1000
−2000
−3000
−4000
−5000
−6000
−7000
−8000
Altitude (m)

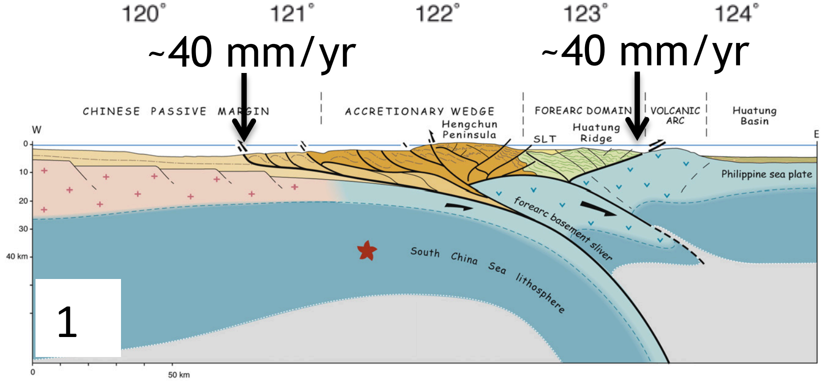
How the plates accommodate the convergence in the collision area ?

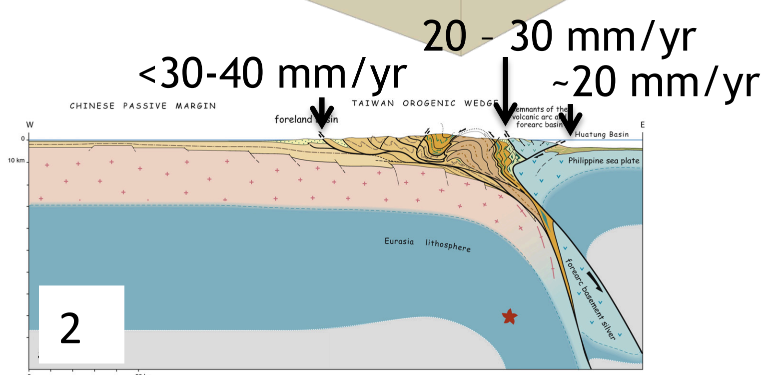
From South to North







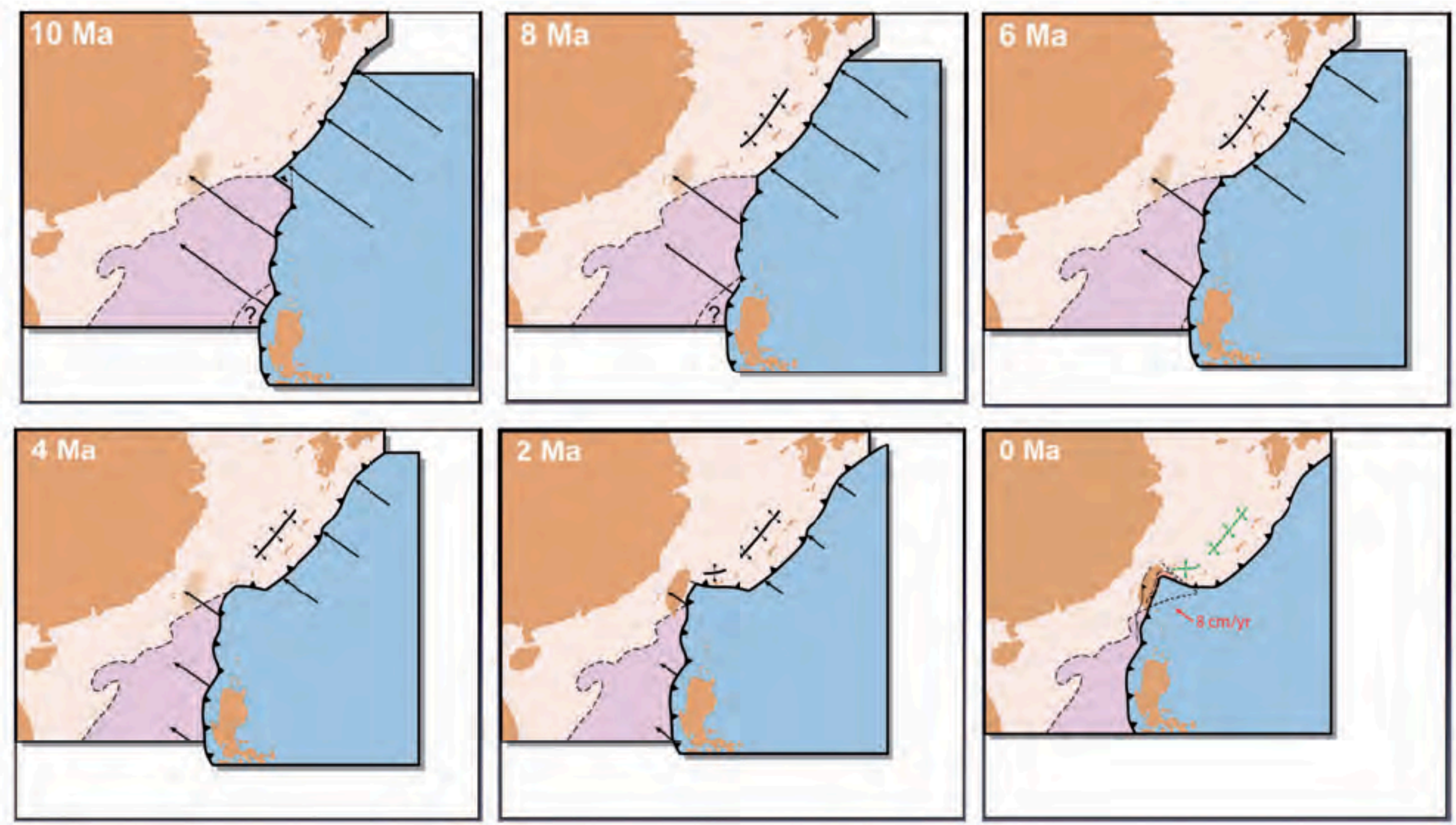




Yu et al., 1997; Malavieille et al, 2002; Simoes et Avouac, 2006; Malavieille, 2009; Huang et al., 2010

How the plates accommodate the convergence in the collision area ?

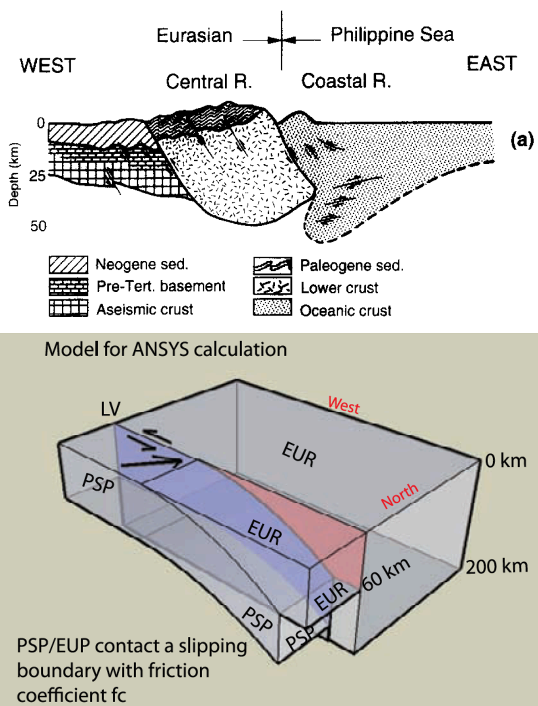
A plate reconstruction model …



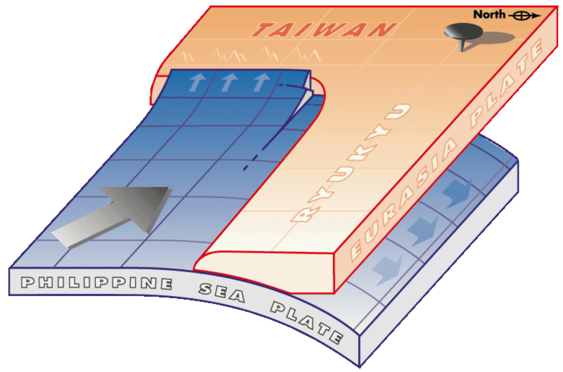
Lallemand et al., 2001

How the plates accommodate the convergence in the collision area ?

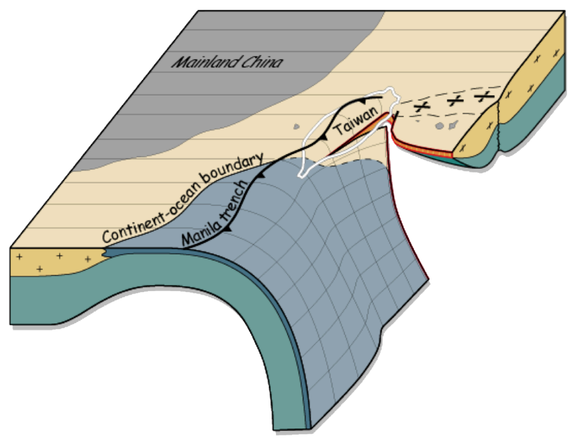
Some conceptual models…

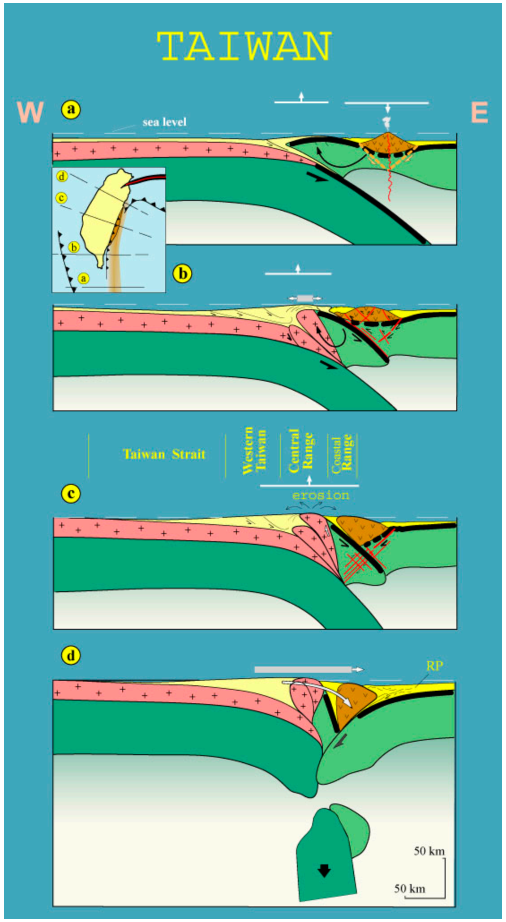


Wu et al. (1997, 2009)



Lallemand et al. (1997, 2001)

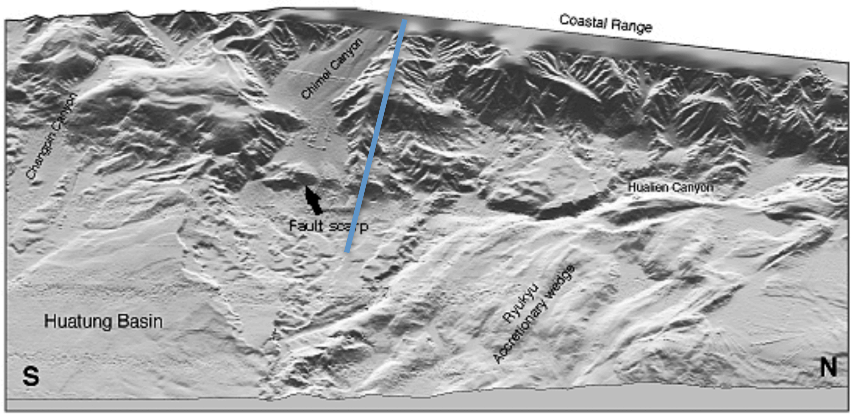


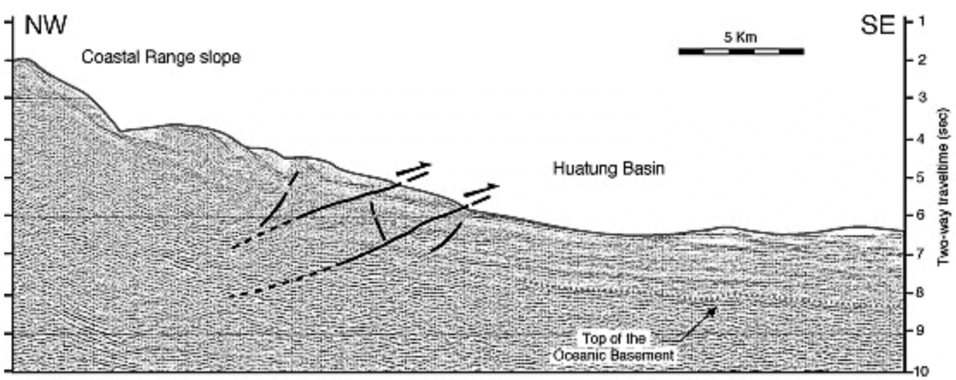


Chemenda et al. (1997, 2001)

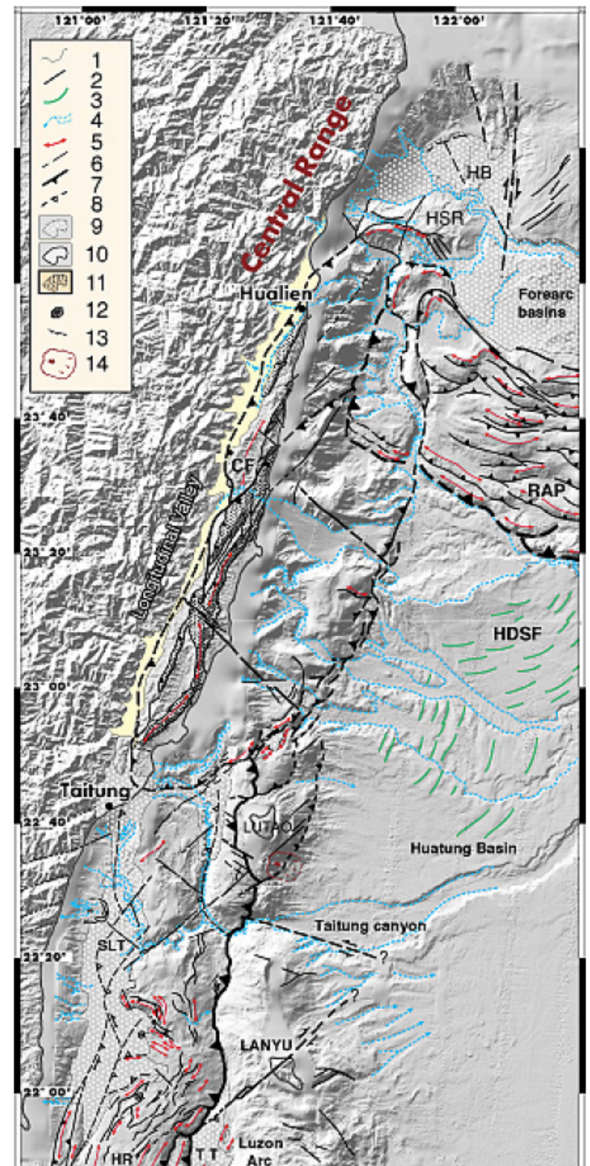
How the plates accommodate the convergence in the collision area ?

Some observational models …
(more or less)





EW-160



Malavieille et al. 2002

How the plates accommodate the convergence in the collision area ?

Some observational models …
(more or less)

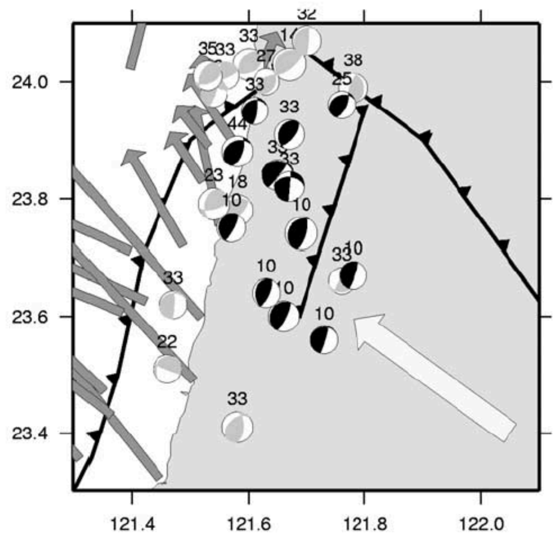
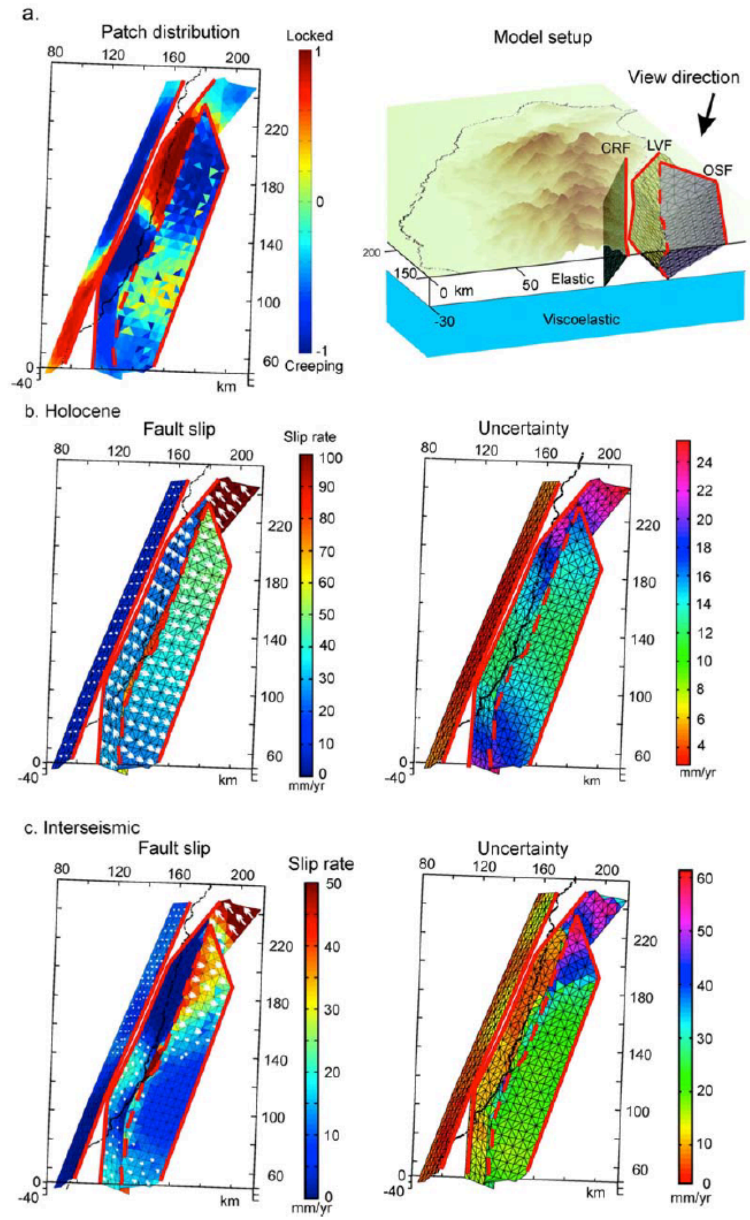


Figure 14. Focal mechanisms from the Harvard CMT catalog ($M > 4$, depth < 50 km). Solid mechanisms all denote a fault with a strike of 23°N and dip of 73° with the horizontal. The grey vectors denote the GPS velocity vectors of *Yu et al.* [1997]. The open vector represents the PSP motion. Barbed lines represent the Ryukyu trench where the central segment denotes our proposed southward continuation.

Bos et al. 2003

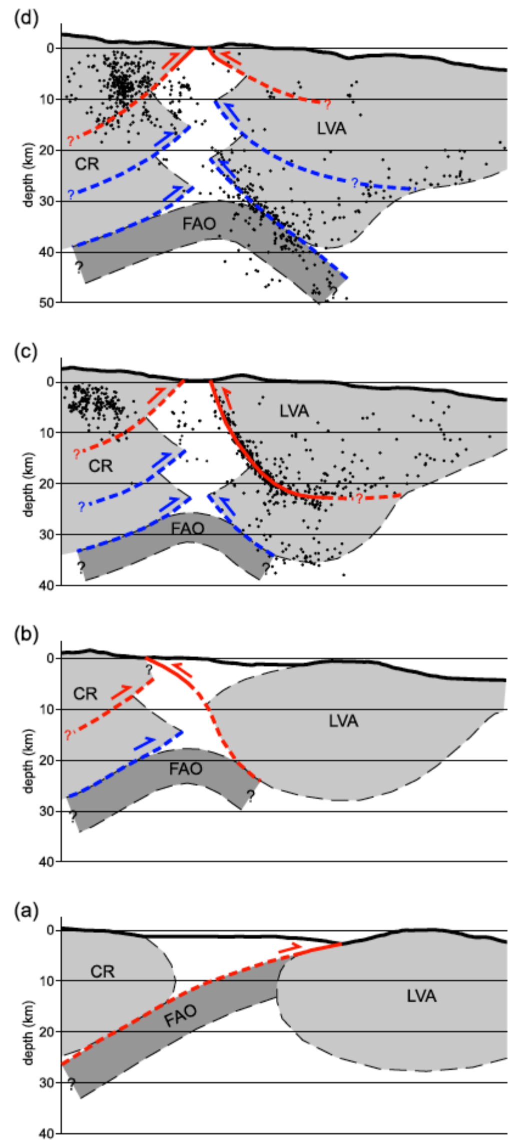


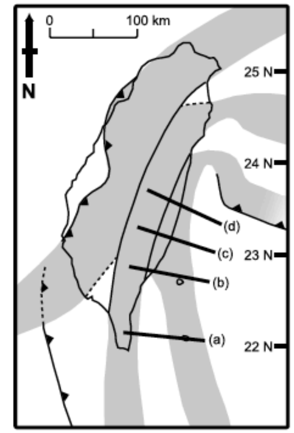
GPS (H+V), InSAR-inferred vertical motion, creepmeters LVF, Holocene marine terraces uplift rates

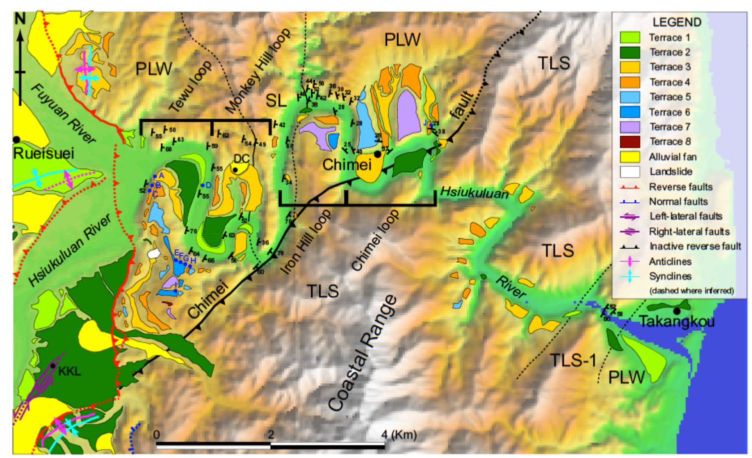
Huang et al. 2010

How the plates accommodate the convergence in the collision area ?

Some observational models …
(more or less)



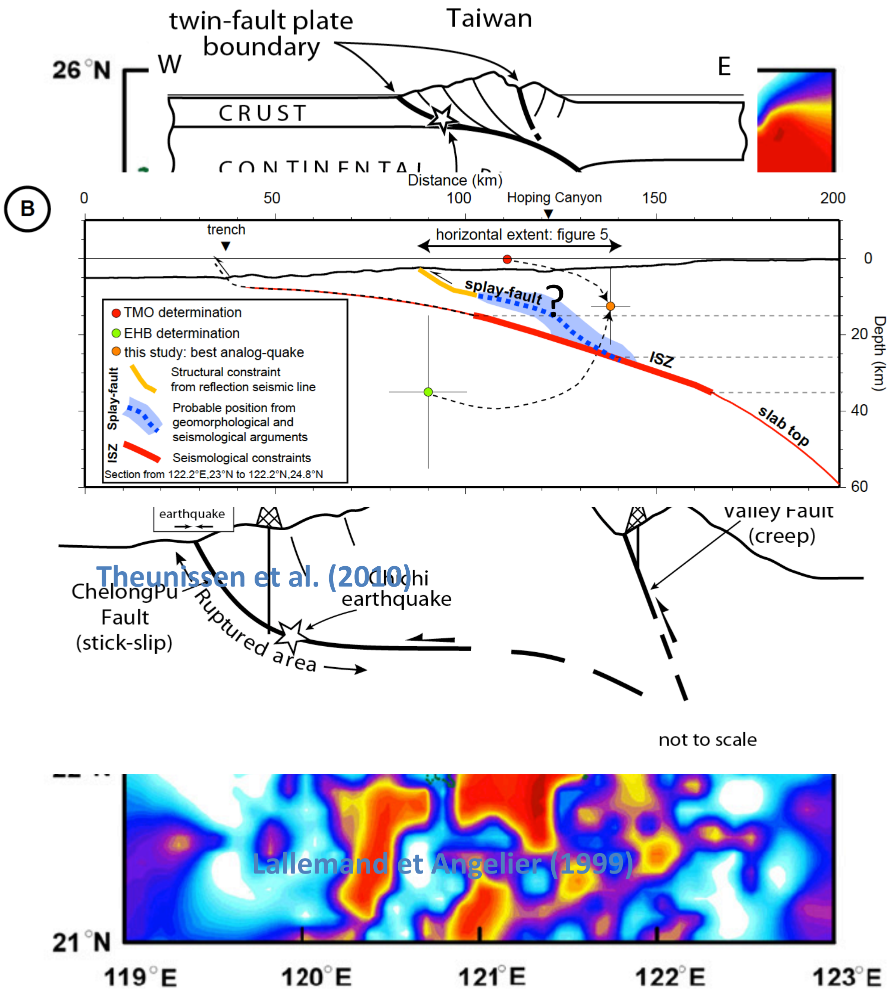


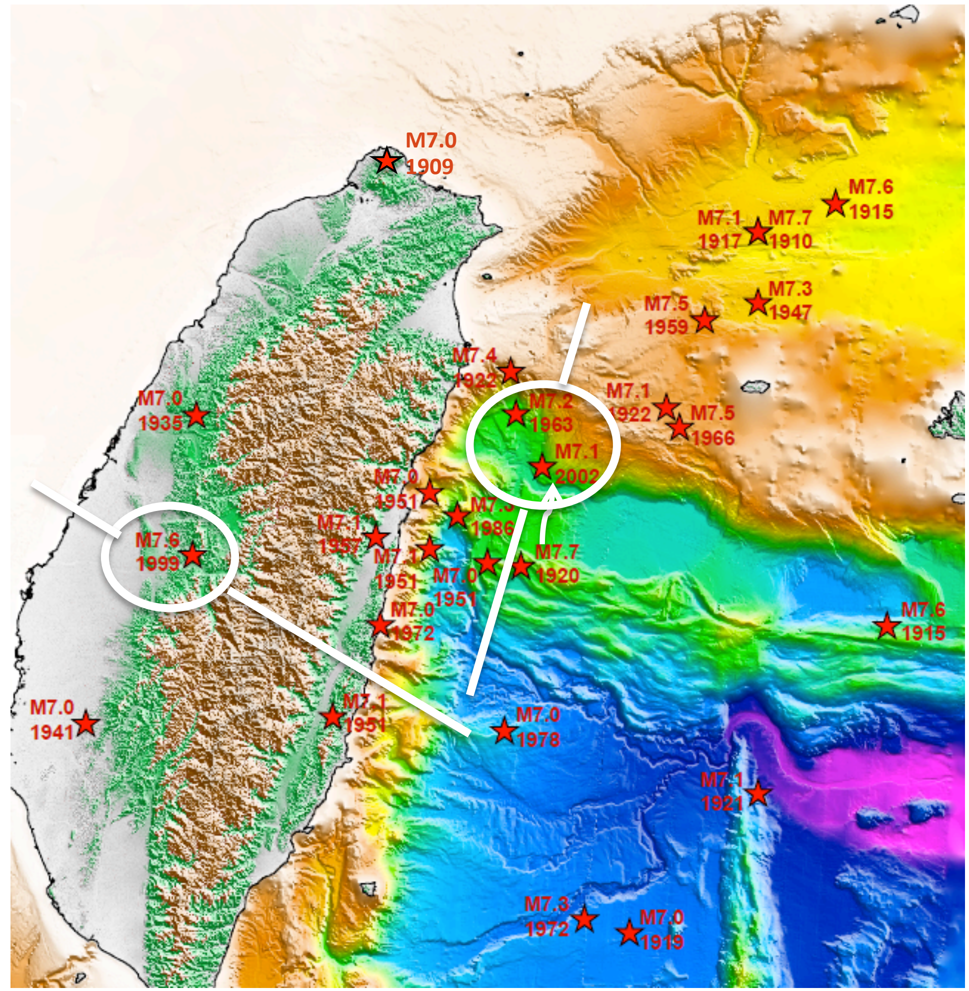


Hsiukuluan River across the Coastal Range.

Shyu et al. 2006

Major earthquakes occured offshore since 1900





Seismic moment distribution since 1900

27 earthquakes with moment magnitude >7

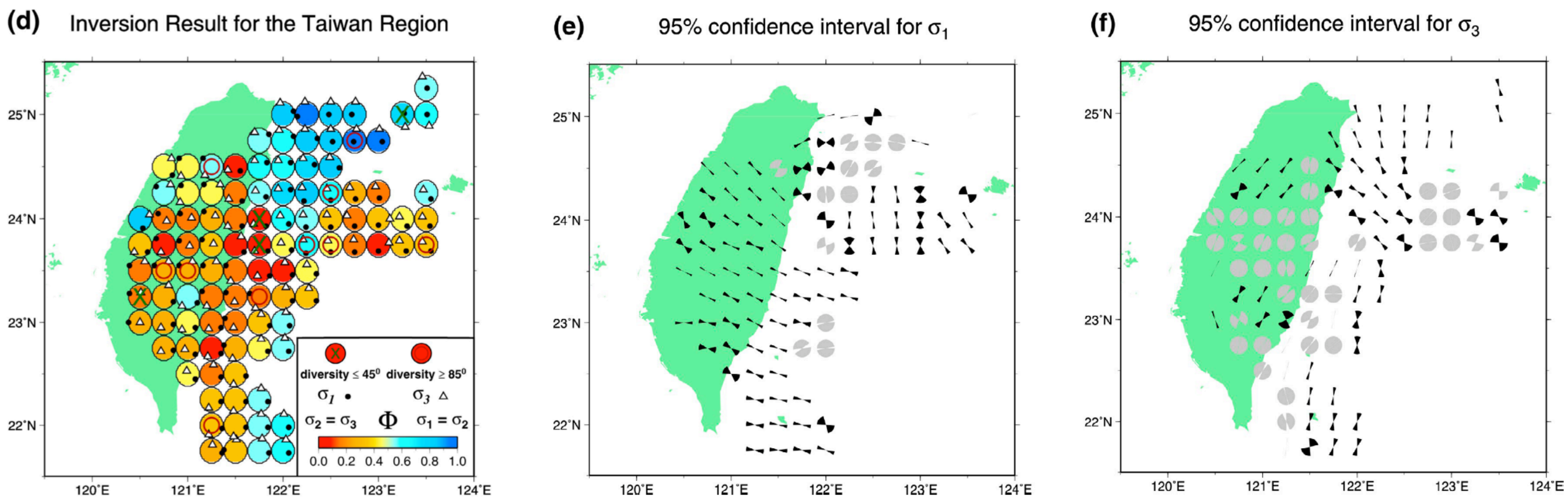
Chen et al. (2009)

Theunissen et al. (2010)

How to explain stress field and seismicity distribution?

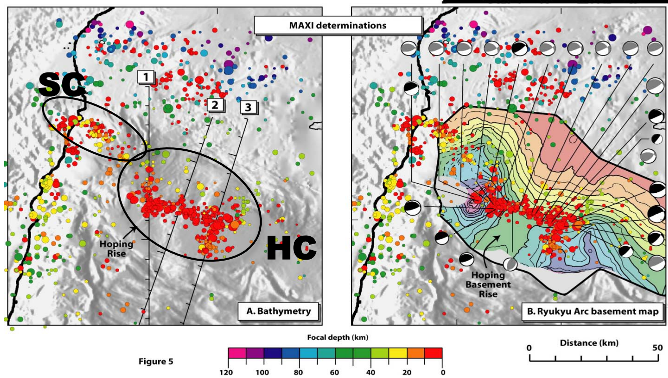
Complex stress field

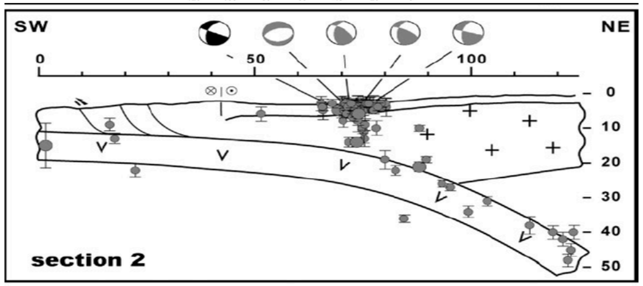
Crustal stress field from focal mechanisms inversion (2300 earthquakes; depth < 35 km)



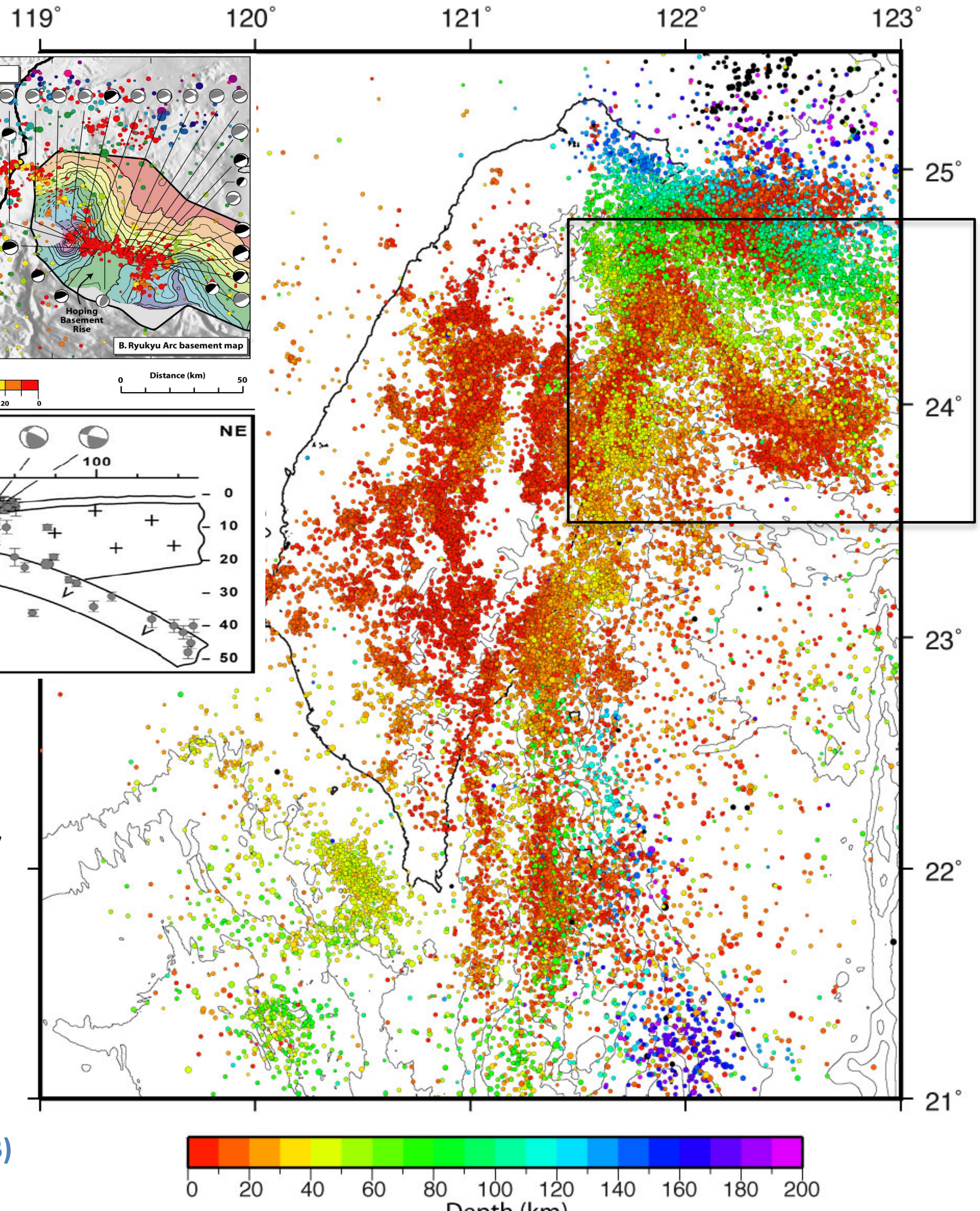
Wu et al. (2010)

How to explain stress field and seismicity distribution?





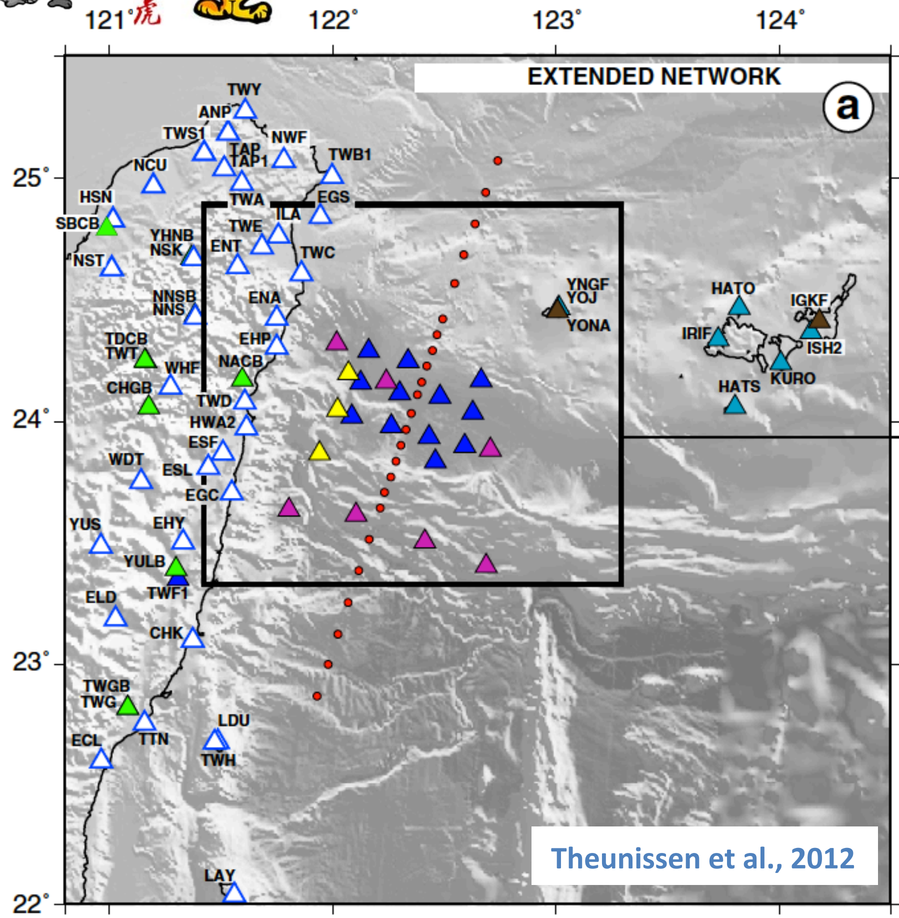
Font et Lallemand (2009)

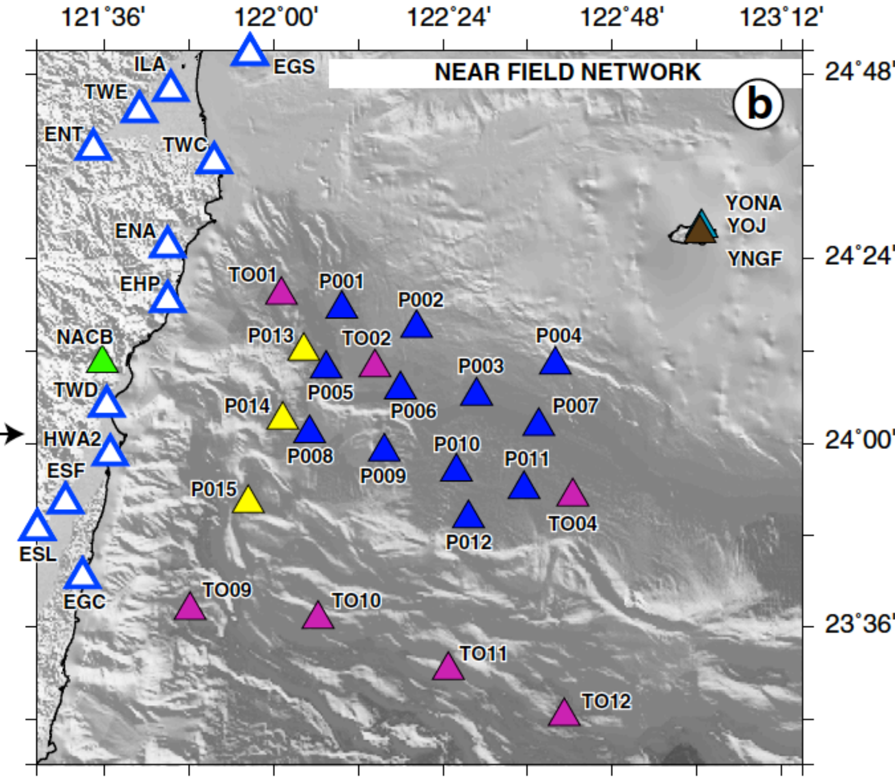


Clustered seismicity

M>3: 1991-2008
40524 earthquakes
Central Weather Bureau (CWB)

Better image the structure and better locate earthquakes





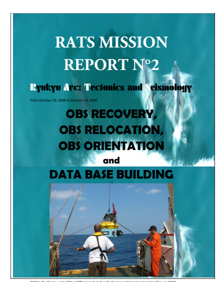
Stations used in this study 07/19/2008 - 10/22/2008 **3 months**

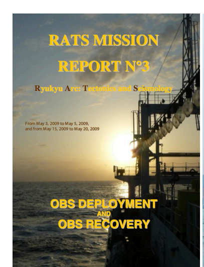
- OBS INSU/CNRS
- OBS NTOU
- OBS TAIGER

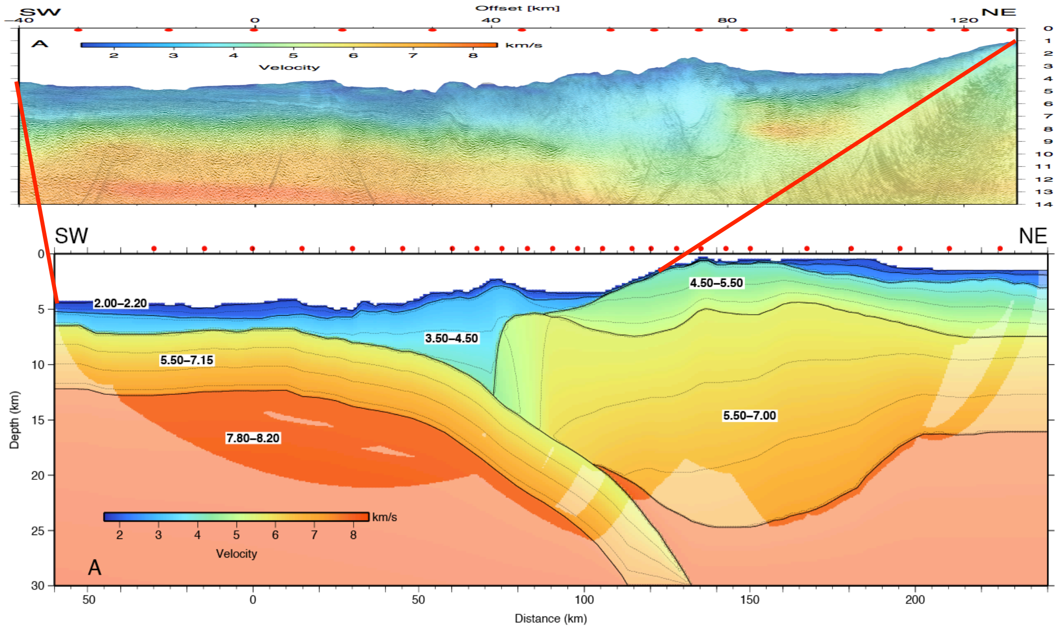
RATS1

- BATS
- F-NET
- CWB
- JMA

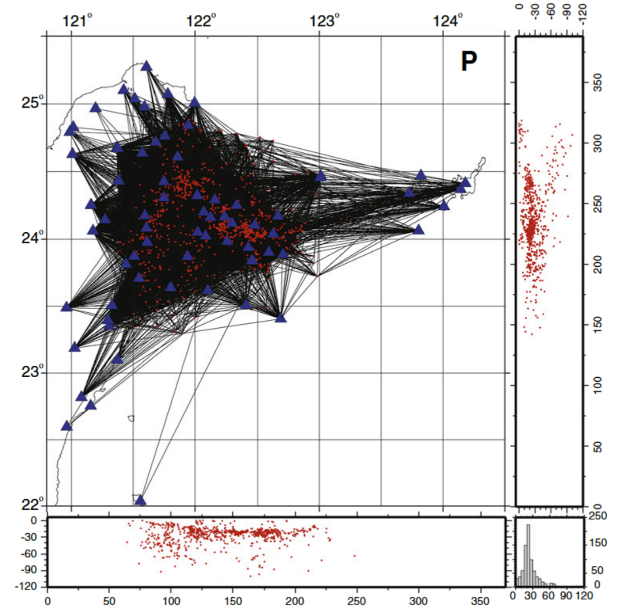
● **OBS of the RATS2 active seismic experiment**
05/03/2009 - 05/20/2009







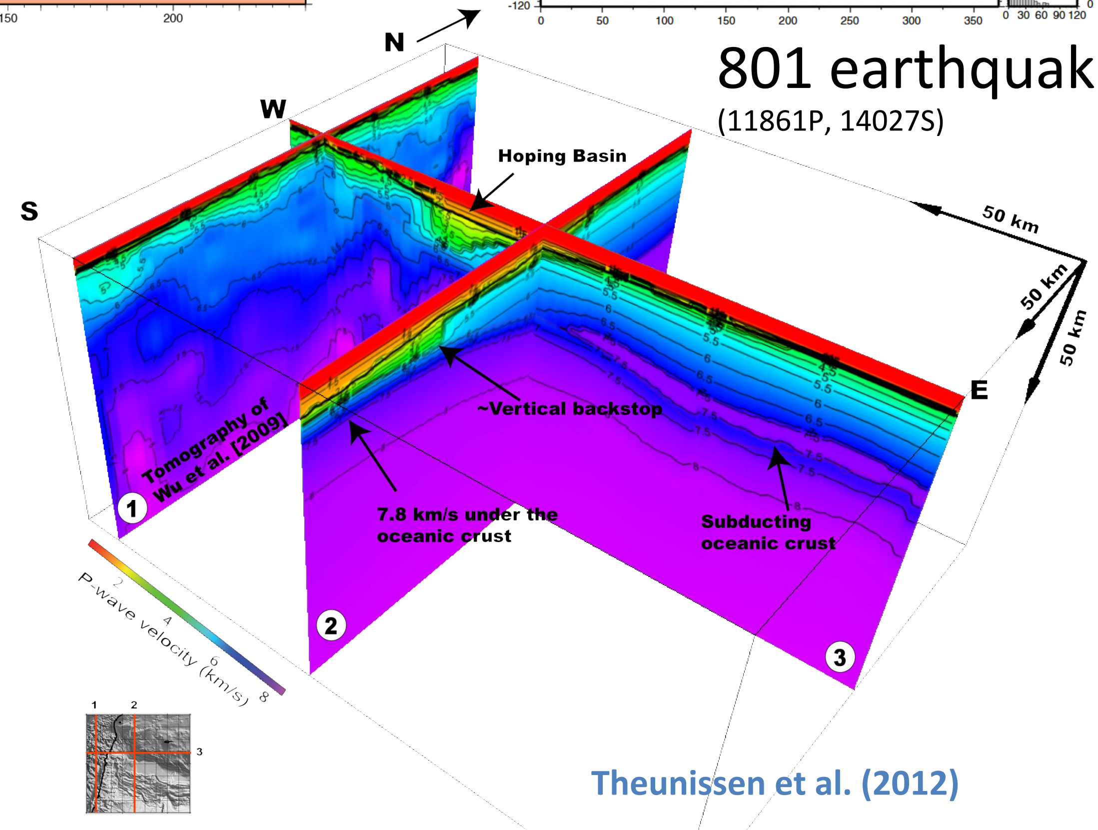
Klingelhoefer et al. (2011)



801 earthquakes

(11861P, 14027S)

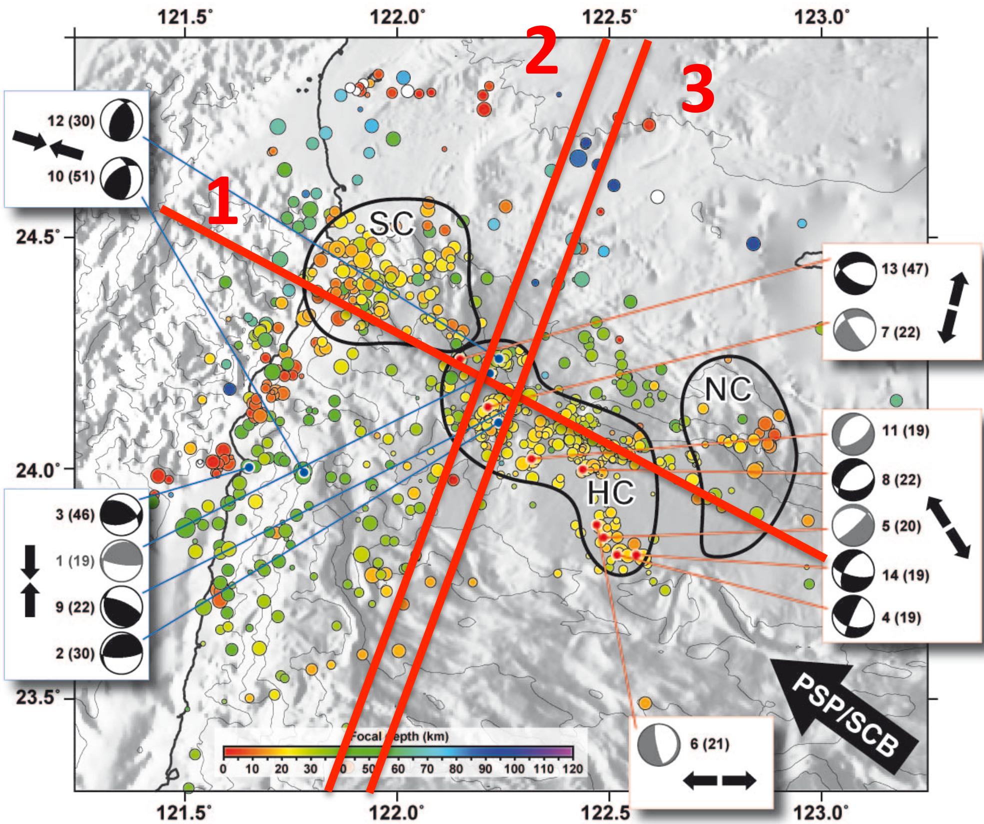
Data processing

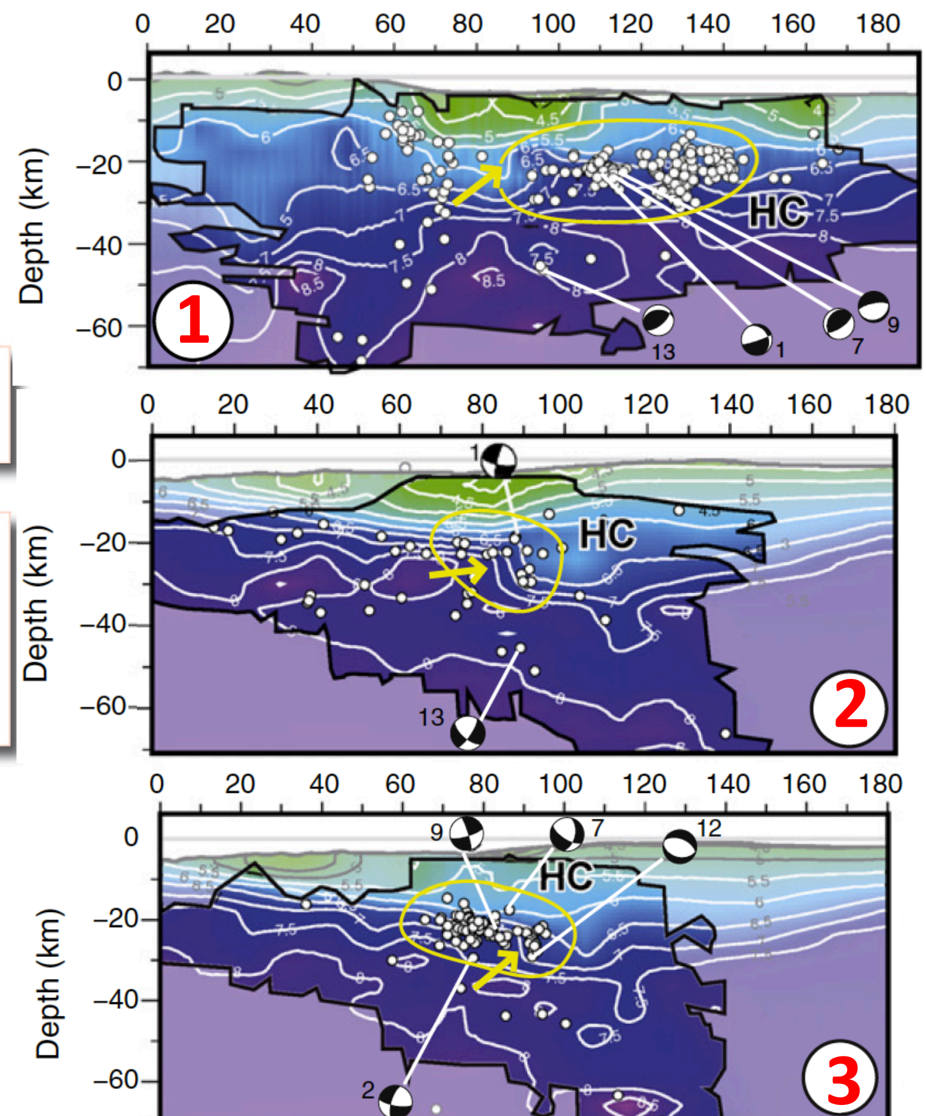


Theunissen et al. (2012)

Better image the structure and better locate earthquakes

Temporary passive experiment



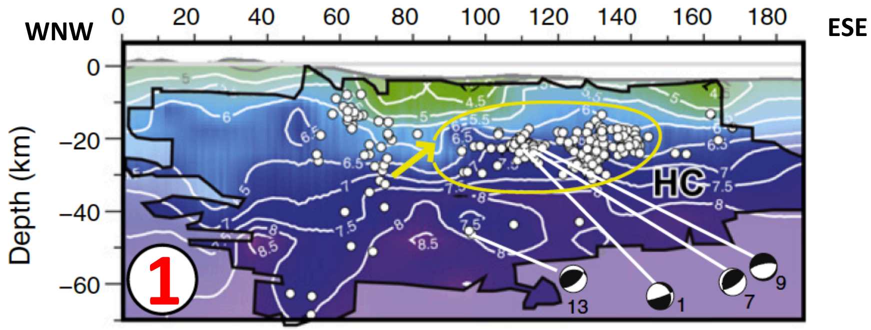


3 months of micro-seismicity
(M_L between 1 and 4.9)

Theunissen et al., 2012

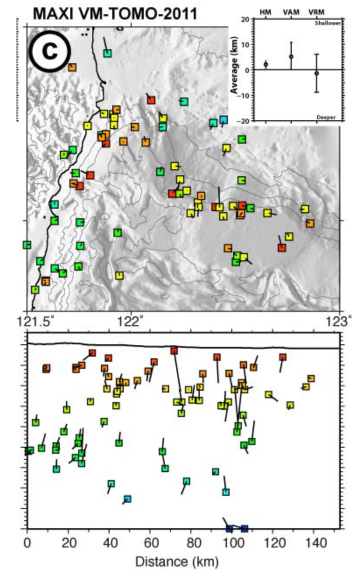
Better image the structure and better locate earthquakes

Temporary experiments



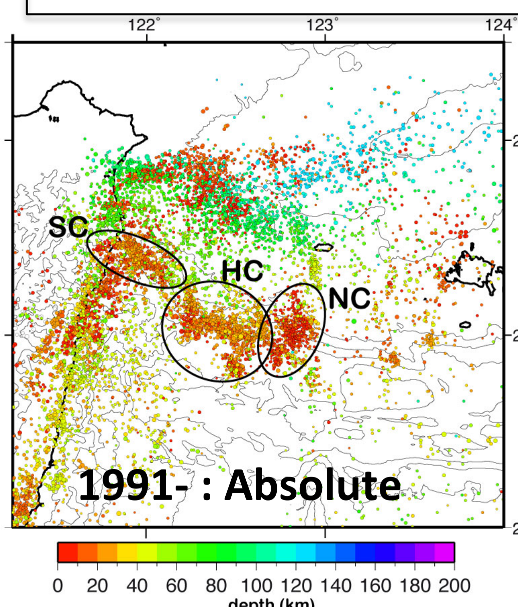
3D tomographic P- and S-waves velocity models

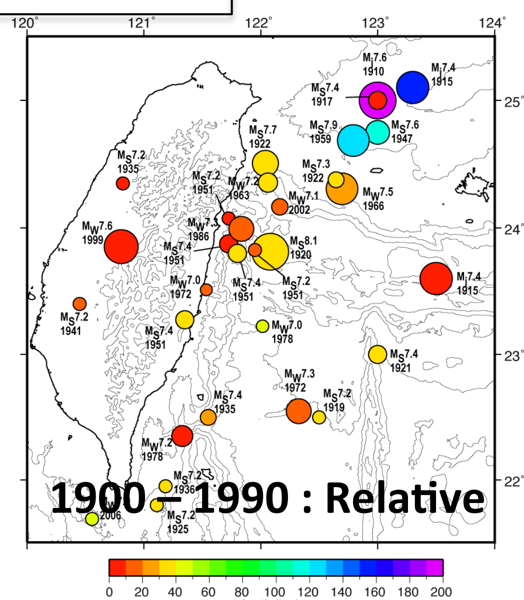
Δdepth = -1 ± 6 km in average



73 events among 801 are used as reference (= also recorded both by CWB and JMA seismic networks) **to validate 3D absolute earthquake location <u>without using OBS</u> <u>using the new 3D tomographic velocity model</u>**

Re-localization of the entire catalog

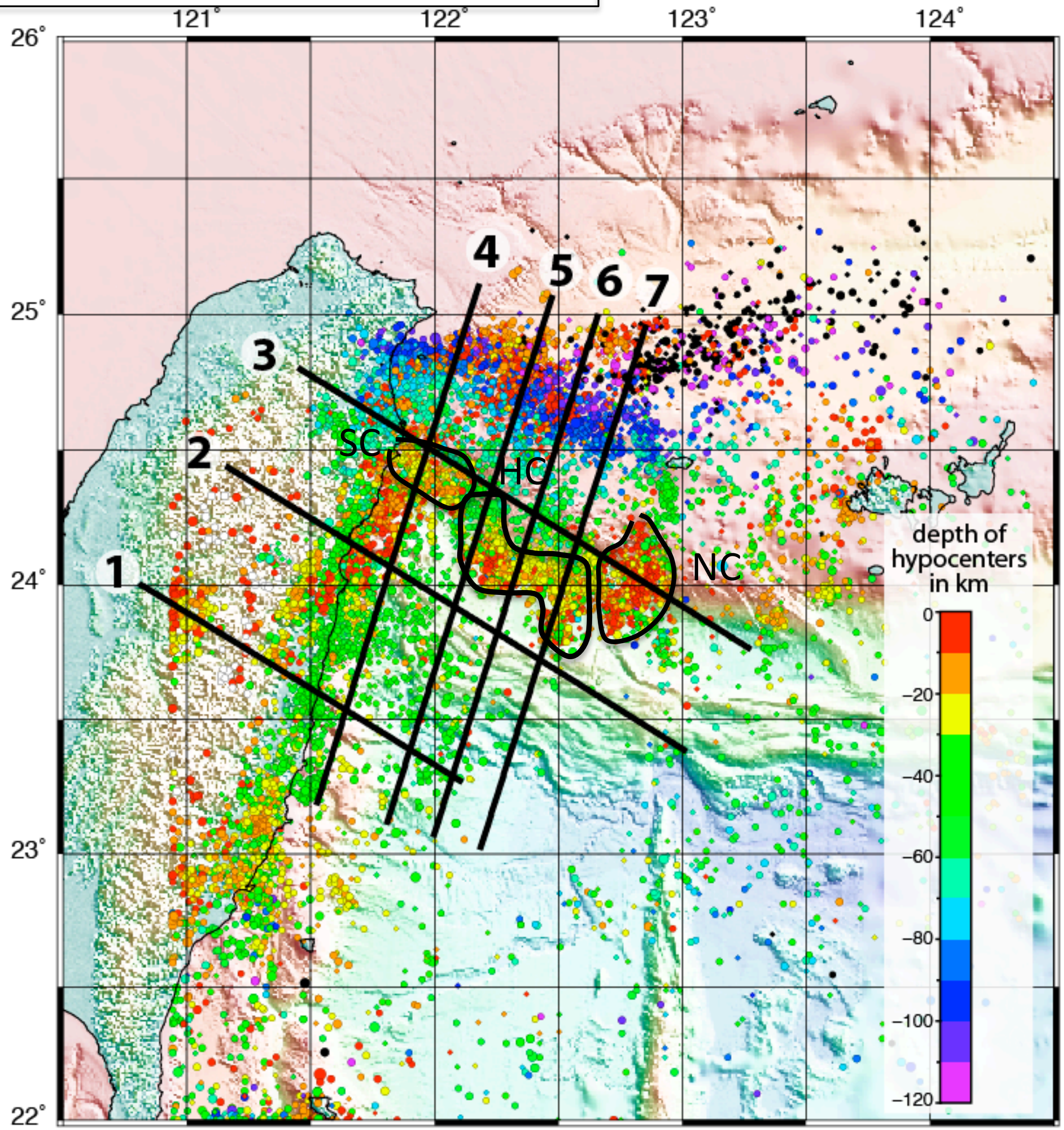




Theunissen et al., 2010
Lallemand et al., 2013

Re-localization of the entire catalog

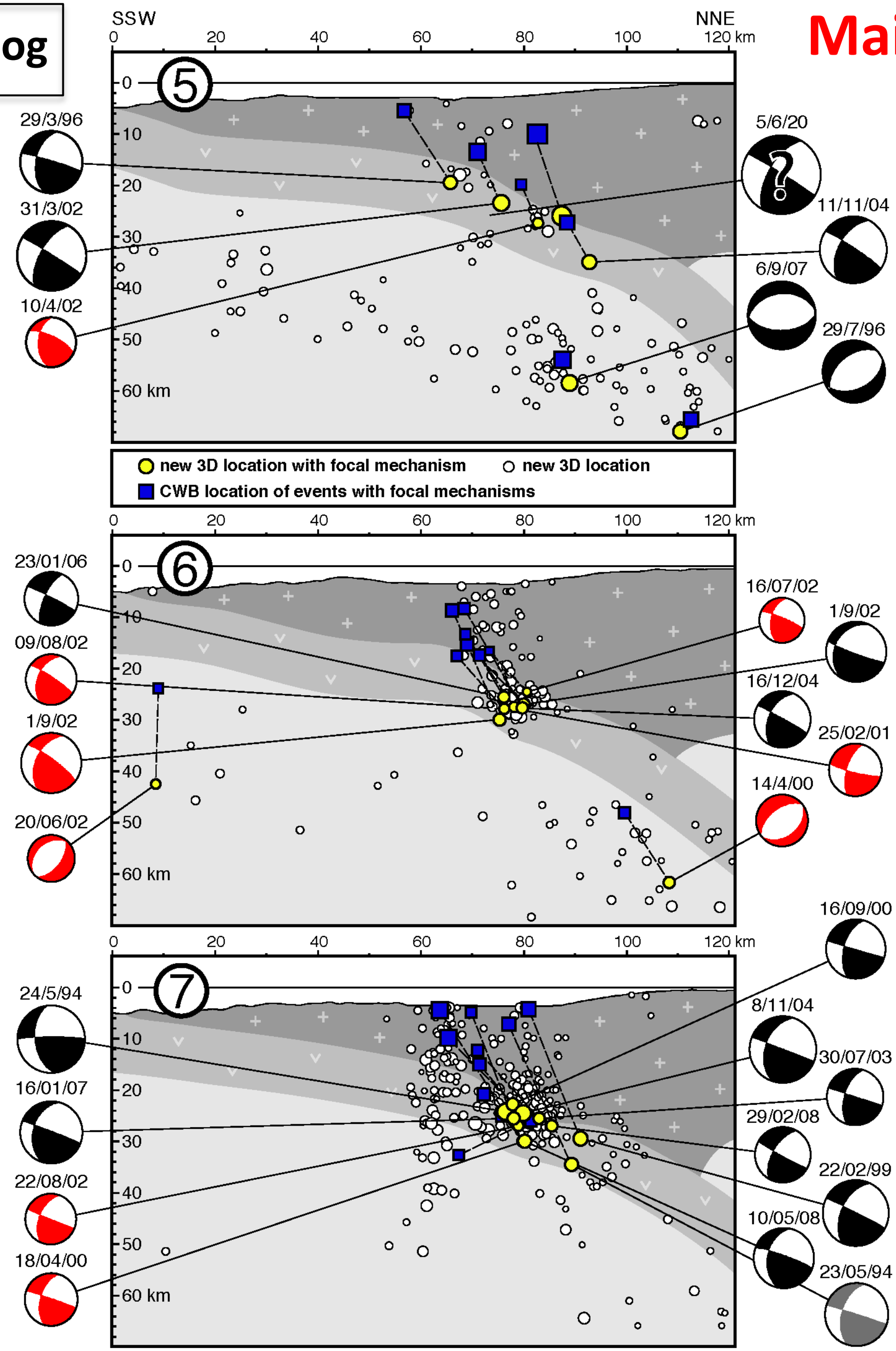
Main results



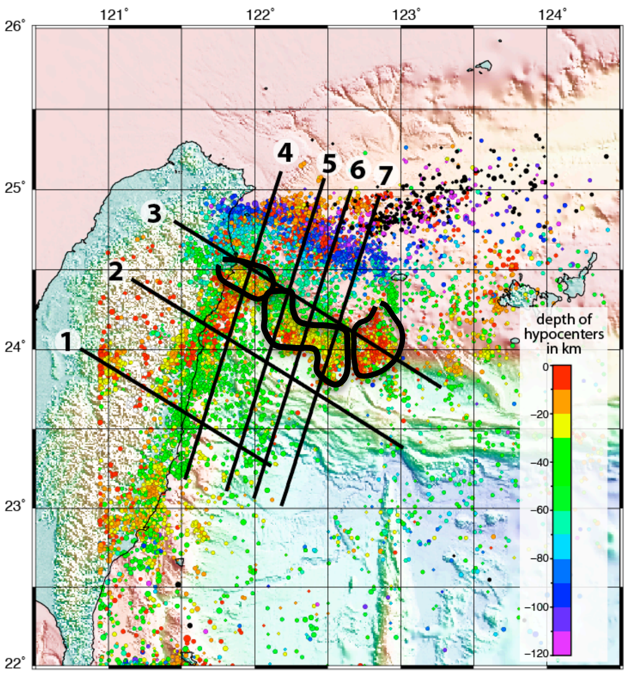
Lallemand et al., 2013

Re-localization of the entire catalog

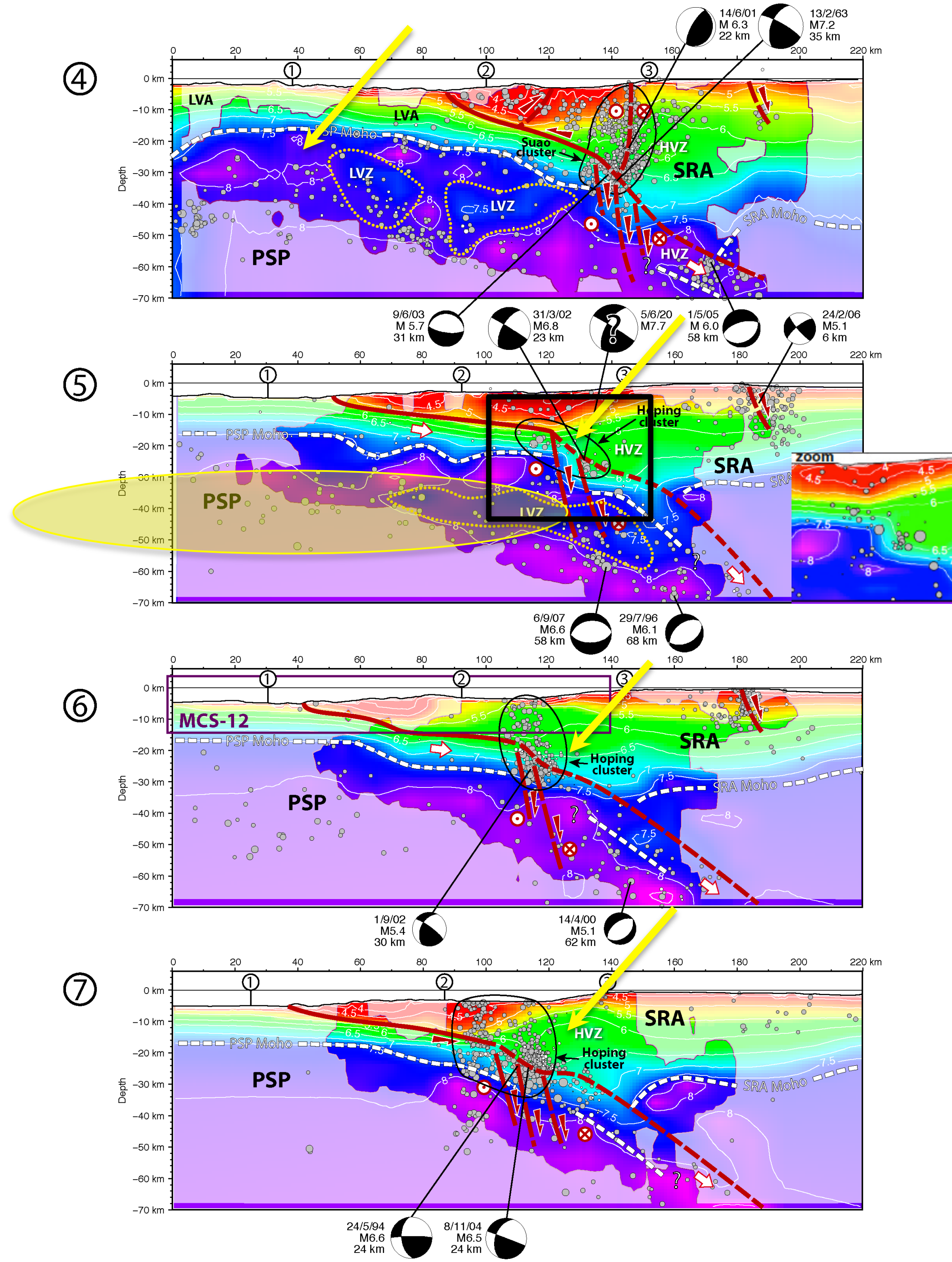
Main results



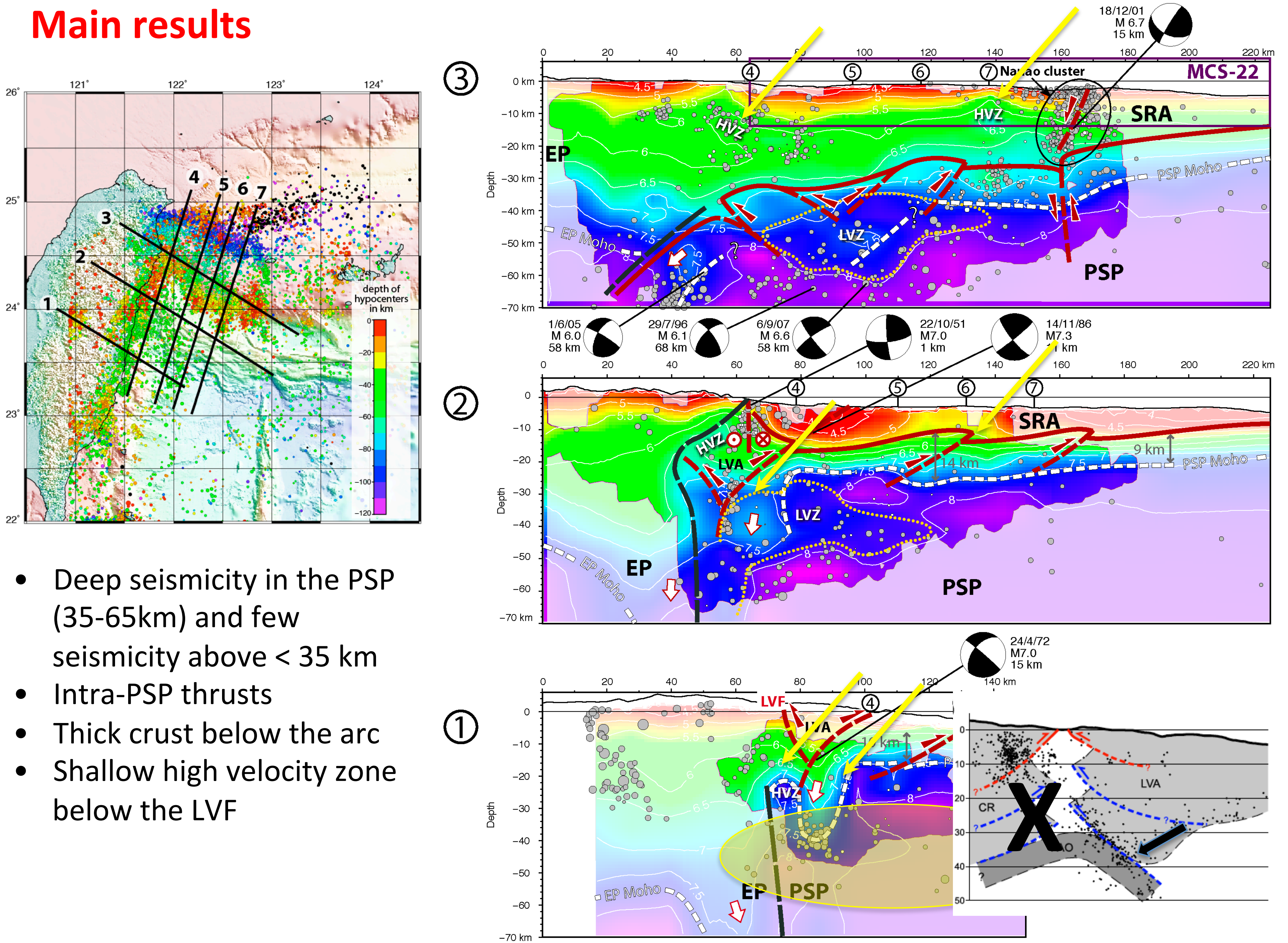
Main results



- Deep seismicity in the PSP (35-65km)
- Low velocities V_P below the PSP
- Step in the PSP
- Interplate seismicity (HC) and intraplate seismicity



Main results

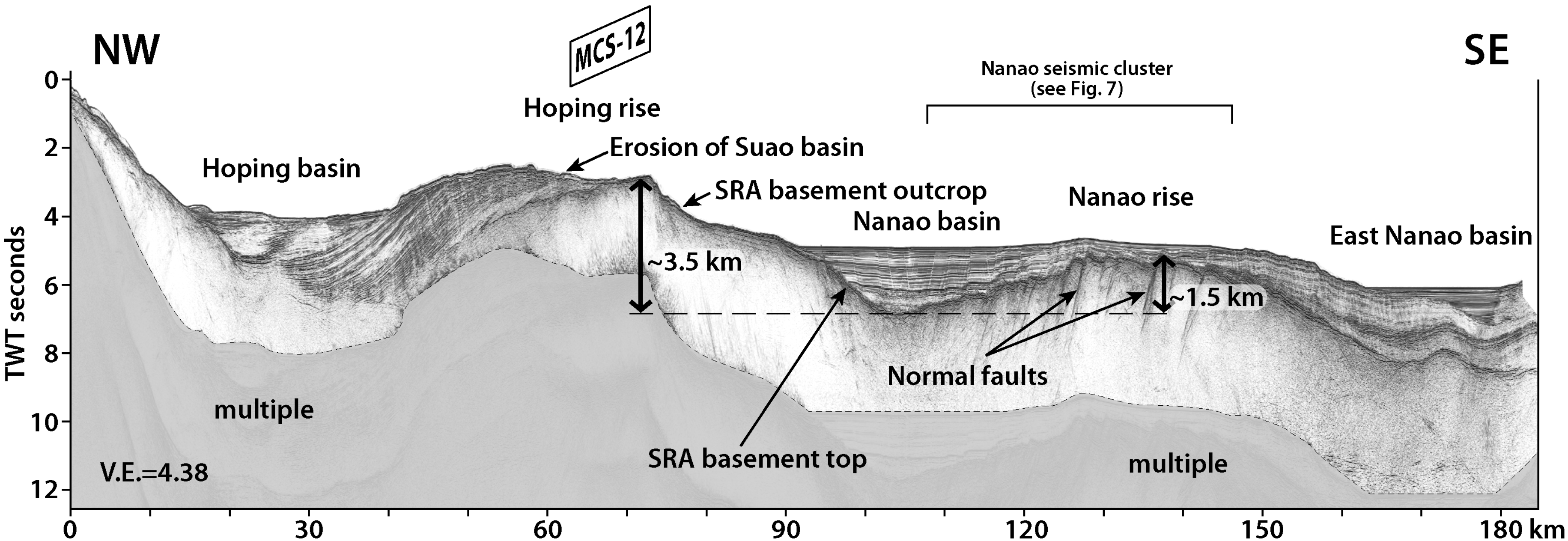


- Deep seismicity in the PSP (35-65km) and few seismicity above < 35 km
- Intra-PSP thrusts
- Thick crust below the arc
- Shallow high velocity zone below the LVF

Shallow crustal structure along the forearc :

→consequence of the PSP deformation (subduction interplate geometry)

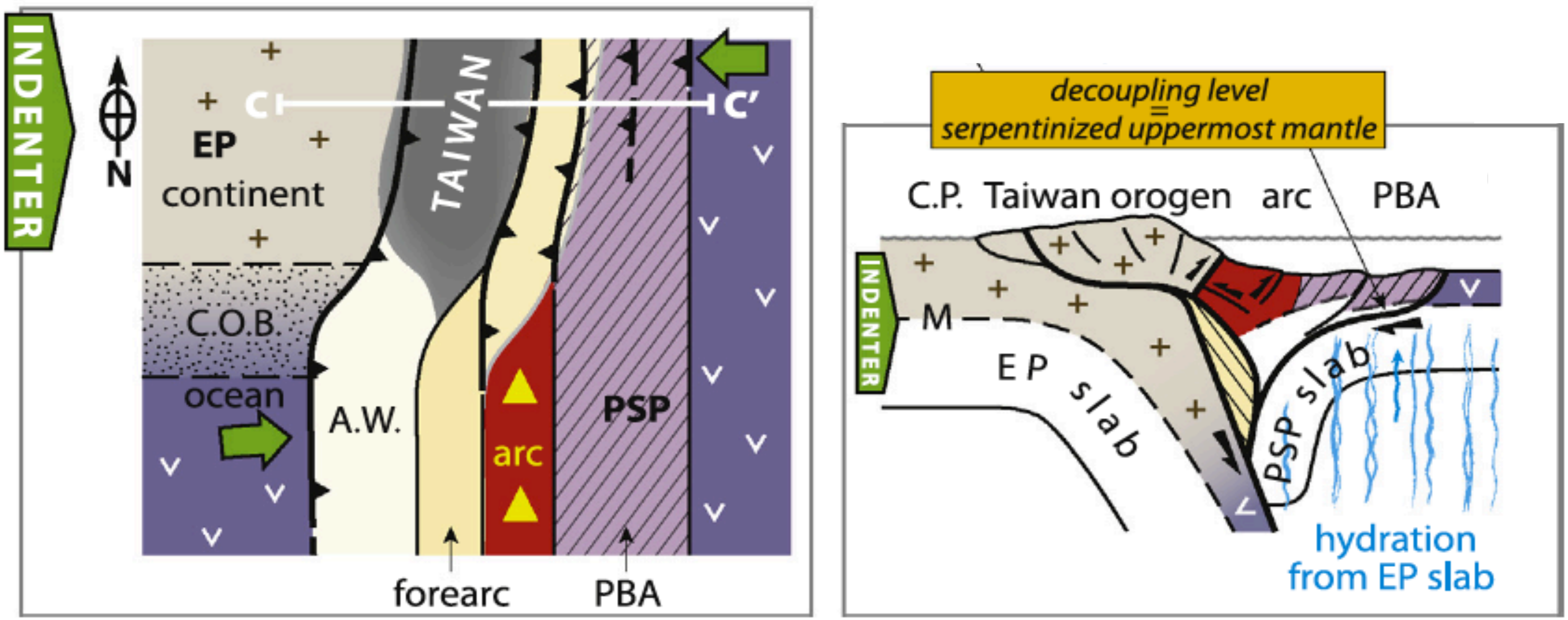
MCS-22



Main results

Upper-mantle decoupling level

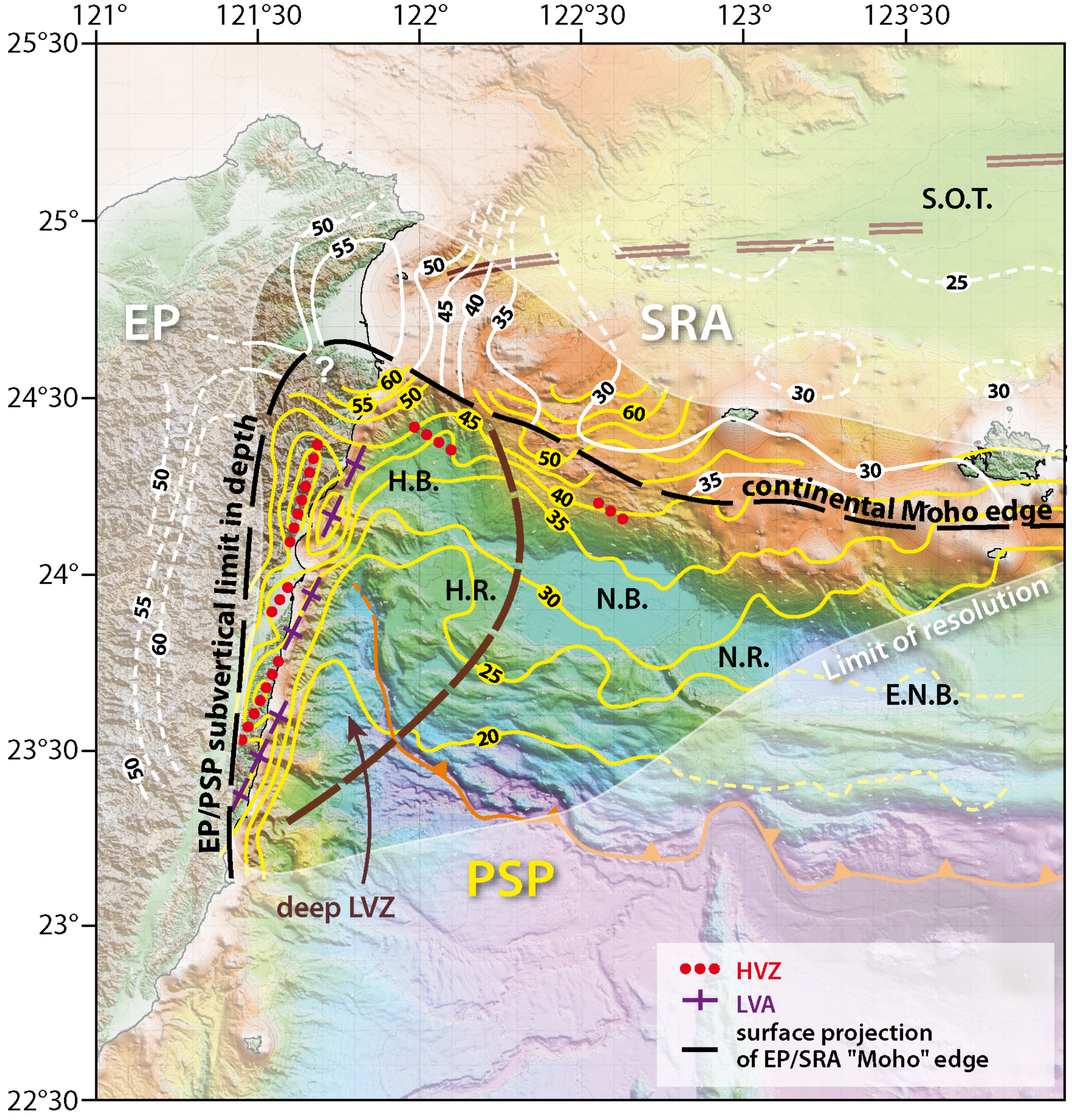
→ mechanism in favor of intra-oceanic crust N-S thrusts



Lallemand, 2013

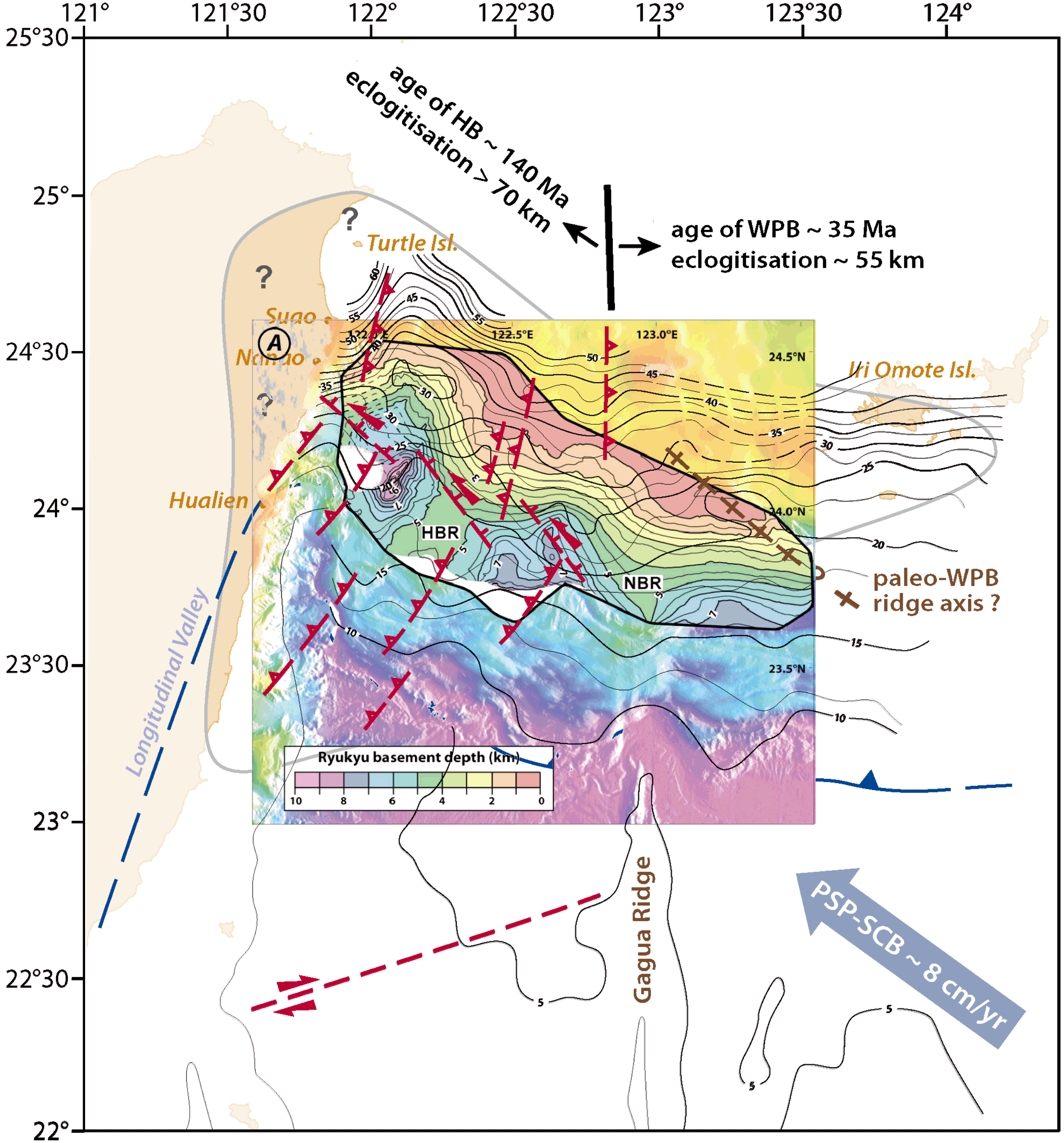
Geometry of main crustal features

→ mohos of the PSP, SRA and EP ; positions of the main velocities anomalies



Main results

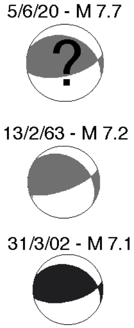
Geometry of interplate

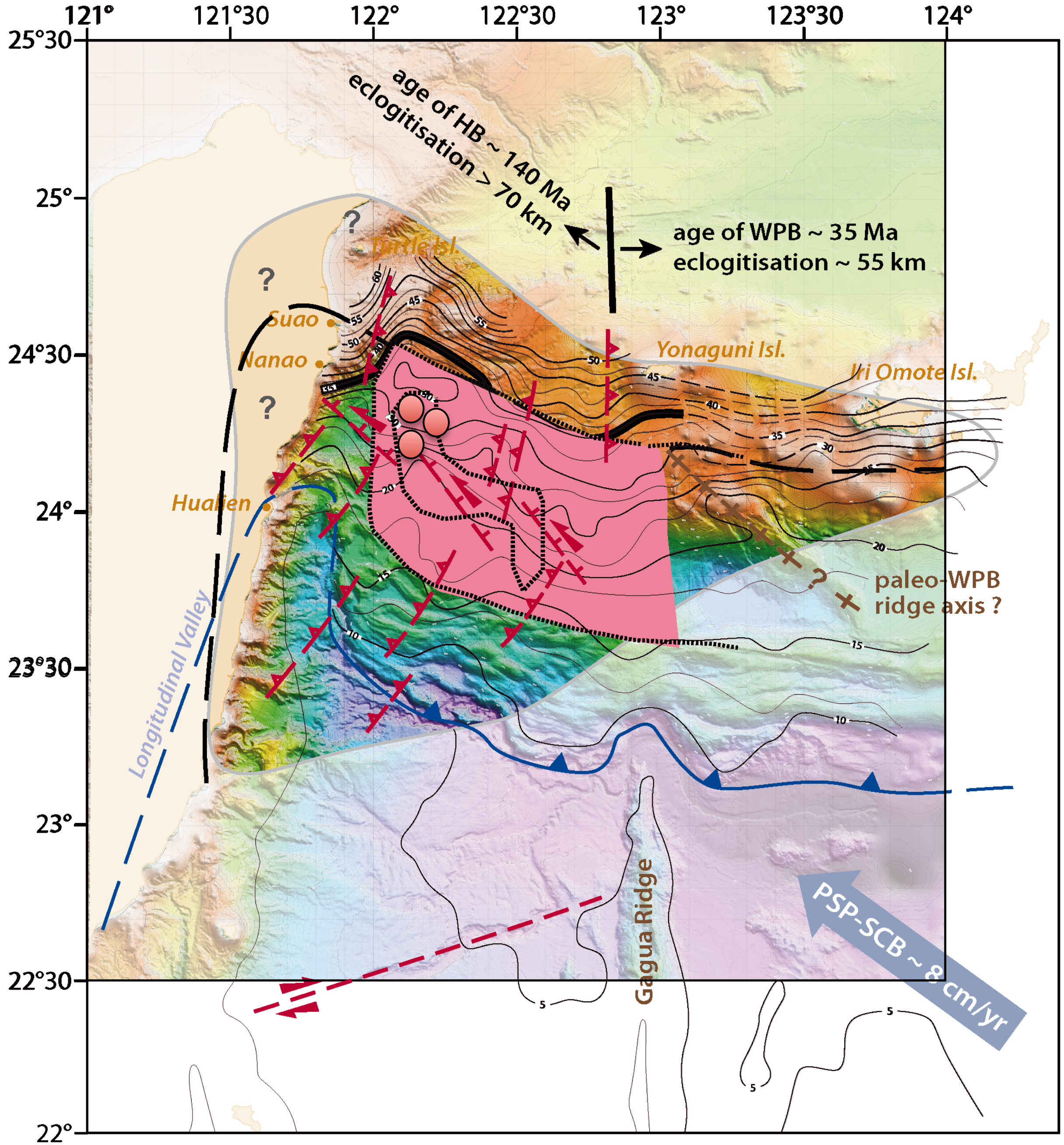


Link between interplate geometry and basement topography of forearc basins

Main results

Geometry of interplate

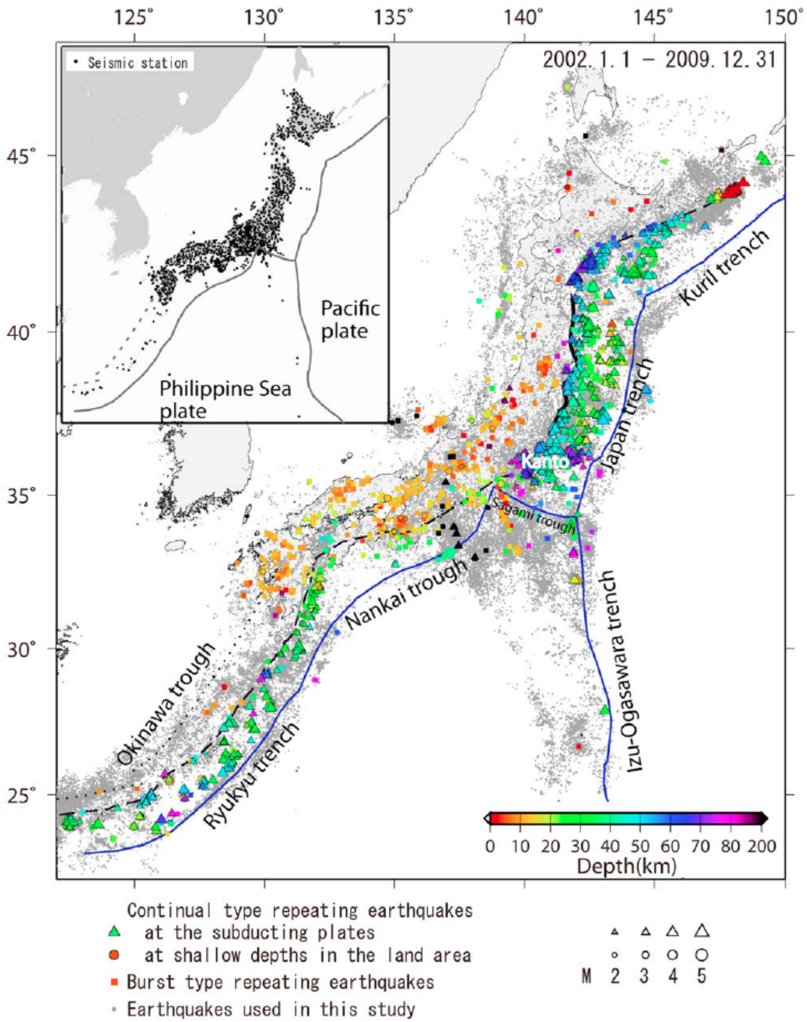


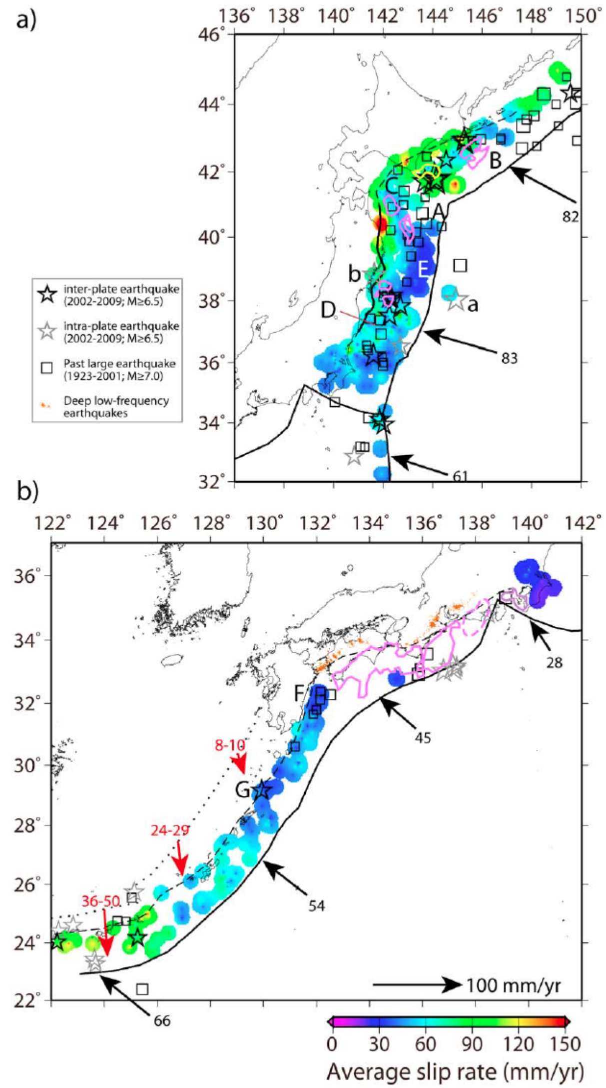


Link between interplate geometry and seismicity

What about the coupling of the interplate?

Seismic coupling < 0.4 based on 1900-2008 catalog of seismicity Theunissen et al. (2010)
M_W 8.1 (7m slip with our geometry) is improbable. This slip-deficit is rather compensated by stable aseismic slip or/and by the intra-PSP deformation along the ~N-S thrusts

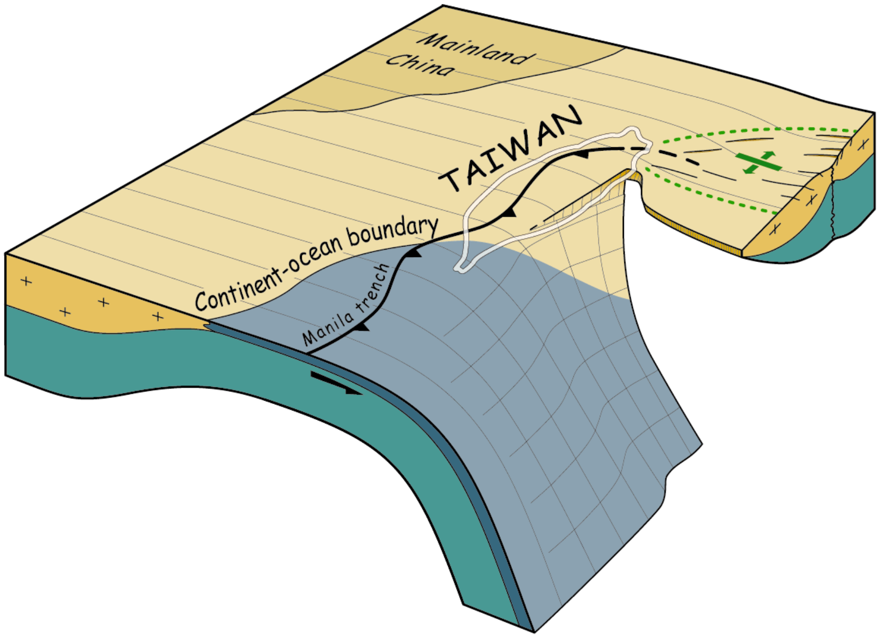


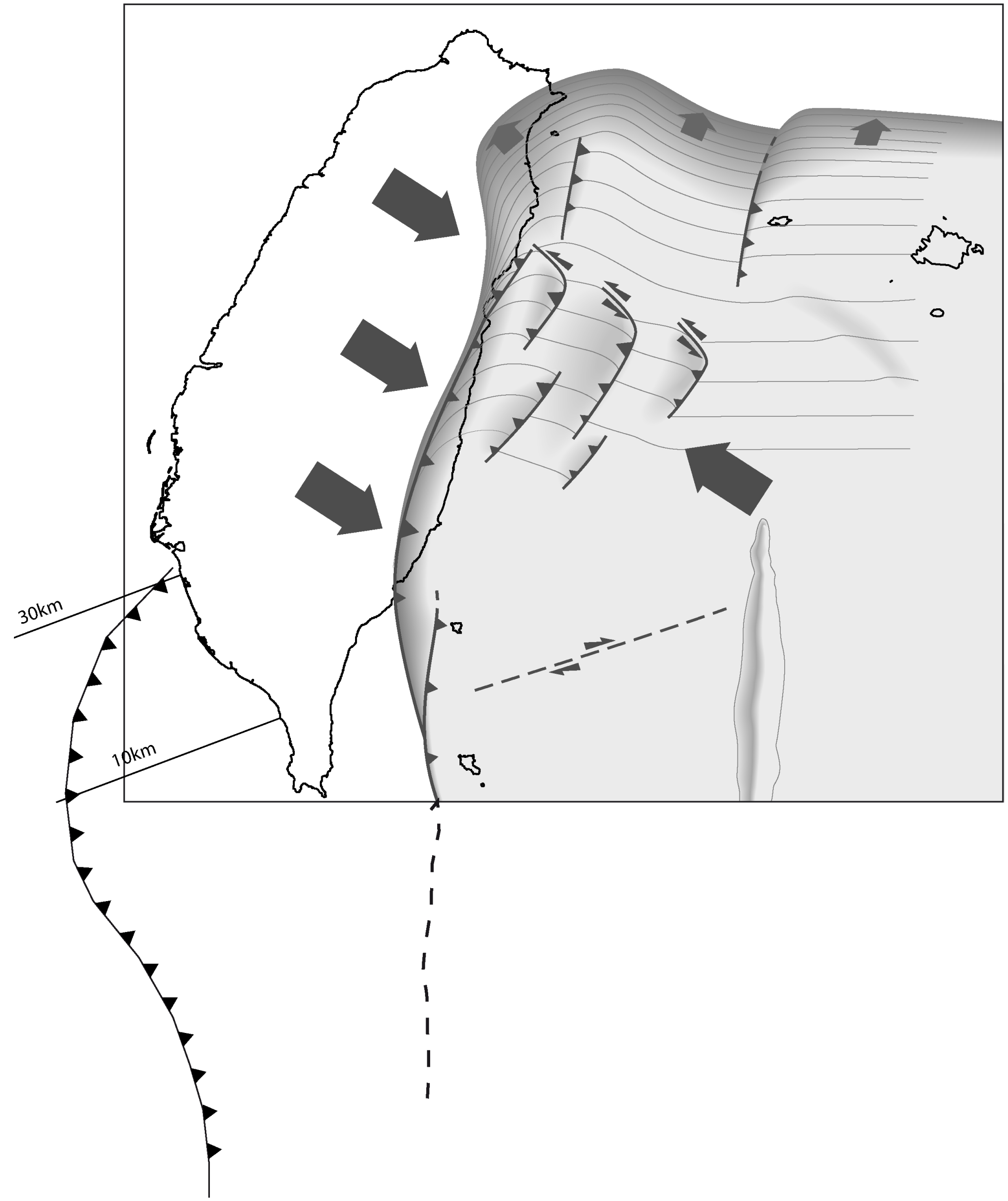


Igarashi (2010)

Model of deformation of the PSP

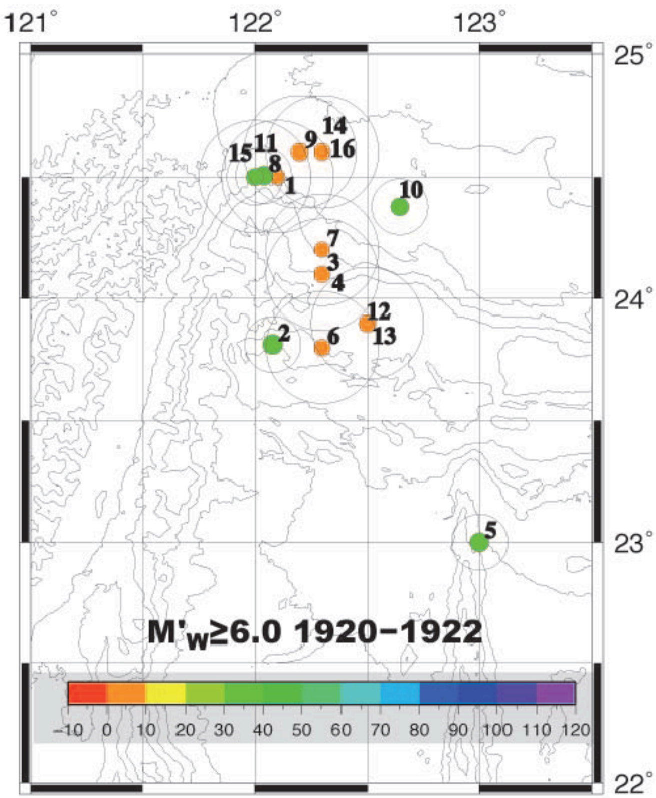
Convergence accommodation

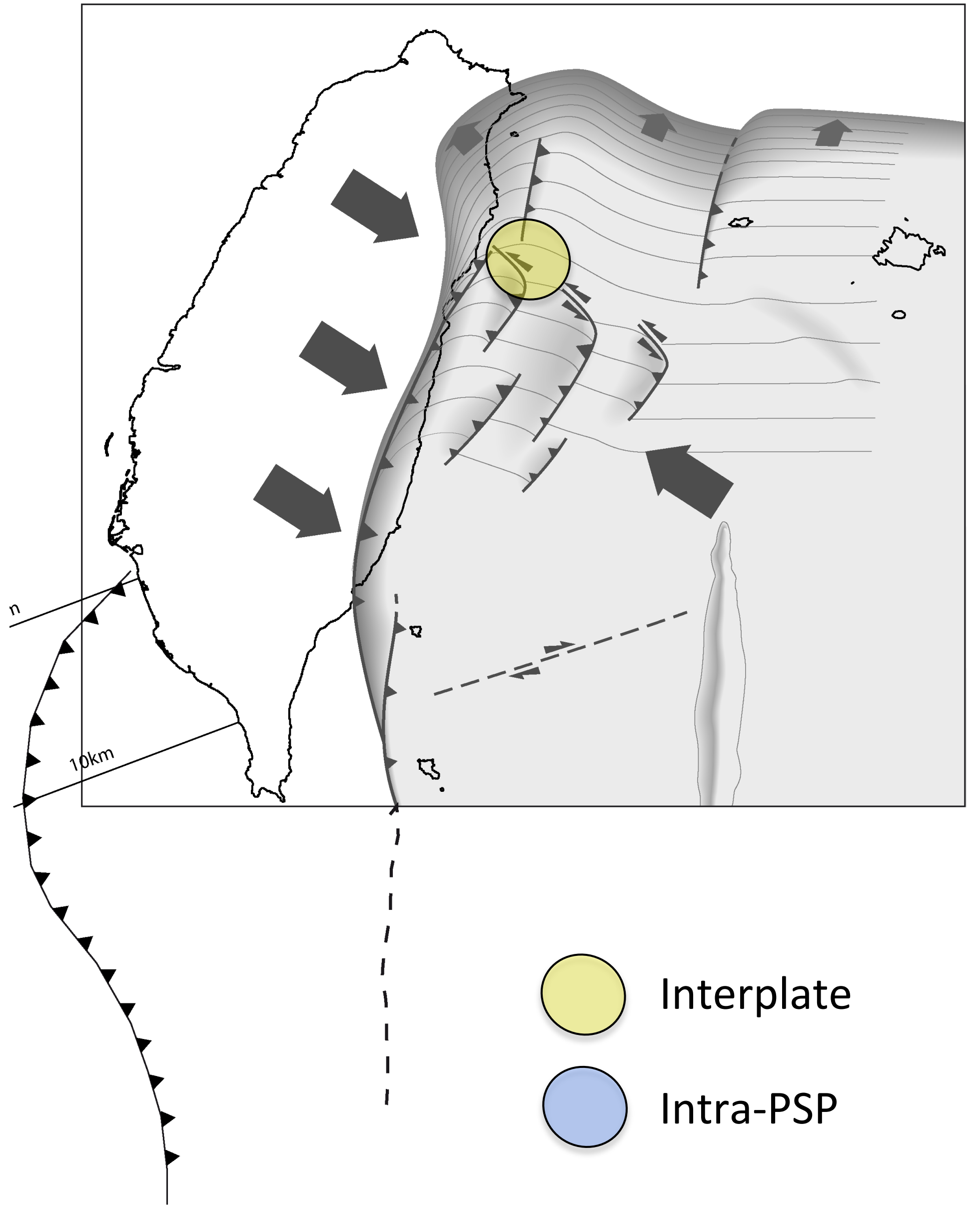




Model of deformation of the PSP

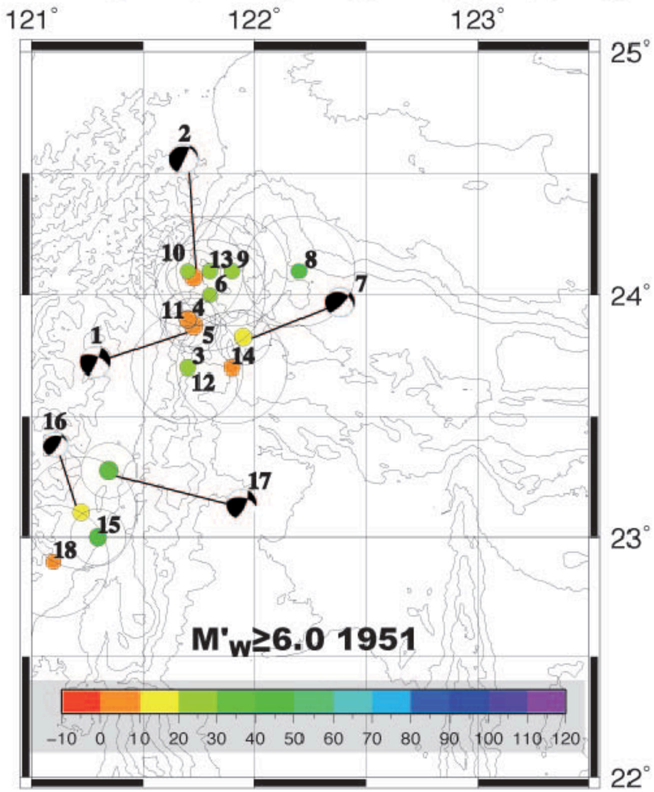
1 1920	1	22	21	44	30.0	122.10	24.50	0.0	6.0
2 1920	6	5	4	21	35.4	122.08	23.81	35.0	7.7
3 1920	10	20	10	2	16.0	122.30	24.10	0.0	6.0
4 1920	10	20	19	16	0.0	122.30	24.10	0.0	6.2
5 1921	4	2	9	36	0.0	123.00	23.00	35.0	7.1
6 1922	7	2	13	30	0.0	122.30	23.80	0.0	6.1
7 1922	7	19	12	54	50.0	122.30	24.20	0.0	6.0
8 1922	9	1	19	16	9.2	122.04	24.51	35.0	7.4
9 1922	9	4	17	53	35.0	122.20	24.60	0.0	6.5
10 1922	9	14	19	31	42.5	122.64	24.38	35.0	7.1
11 1922	9	15	7	45	0.0	122.00	24.50	0.0	6.2
12 1922	9	17	7	53	0.0	122.50	23.90	0.0	6.0
13 1922	9	17	9	59	18.0	122.50	23.90	0.0	6.6
14 1922	10	14	3	56	25.0	122.30	24.60	0.0	6.1
15 1922	10	14	23	45	0.0	122.00	24.50	35.0	6.7
16 1922	10	27	14	22	40.0	122.30	24.60	0.0	6.2

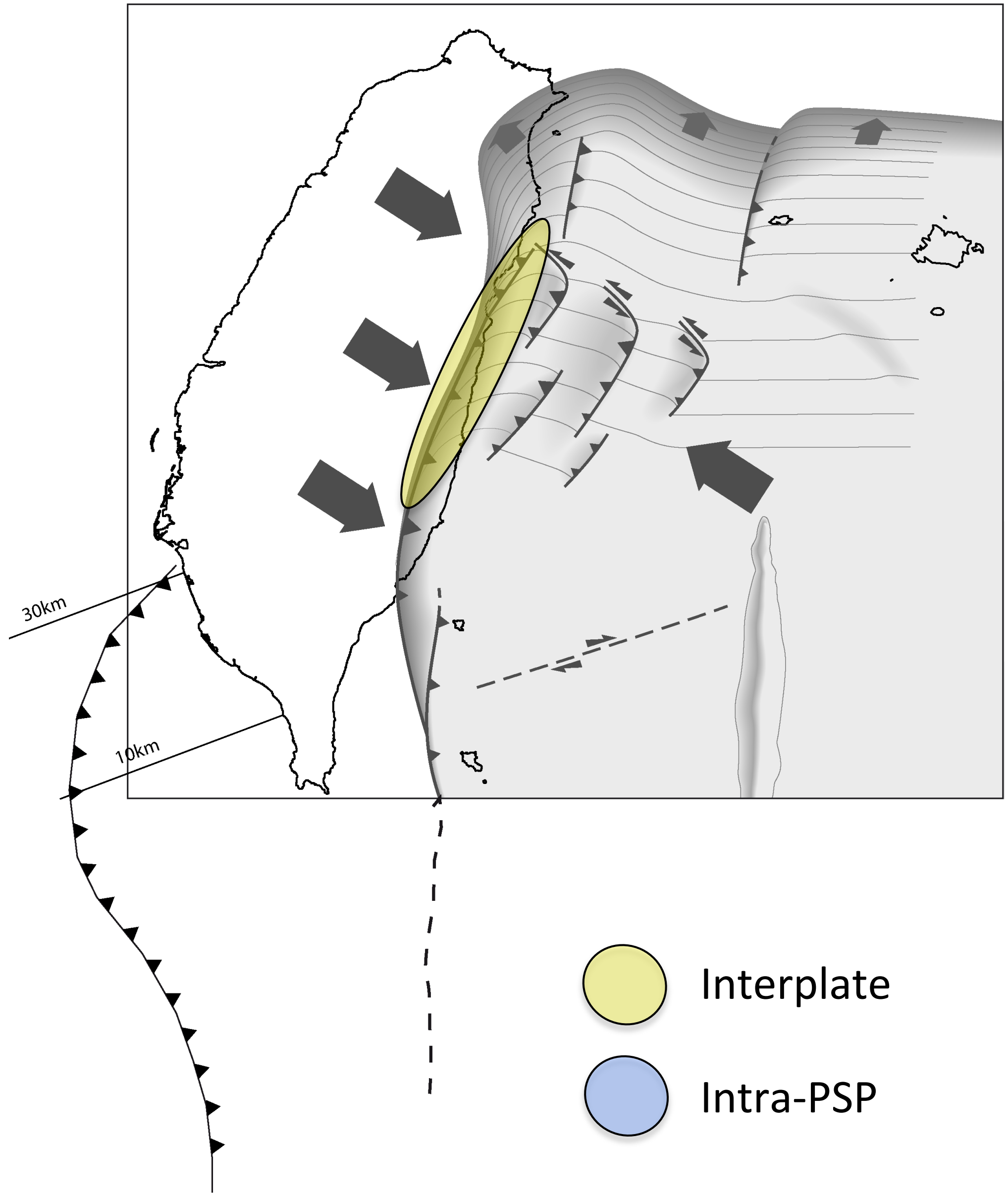




Model of deformation of the PSP

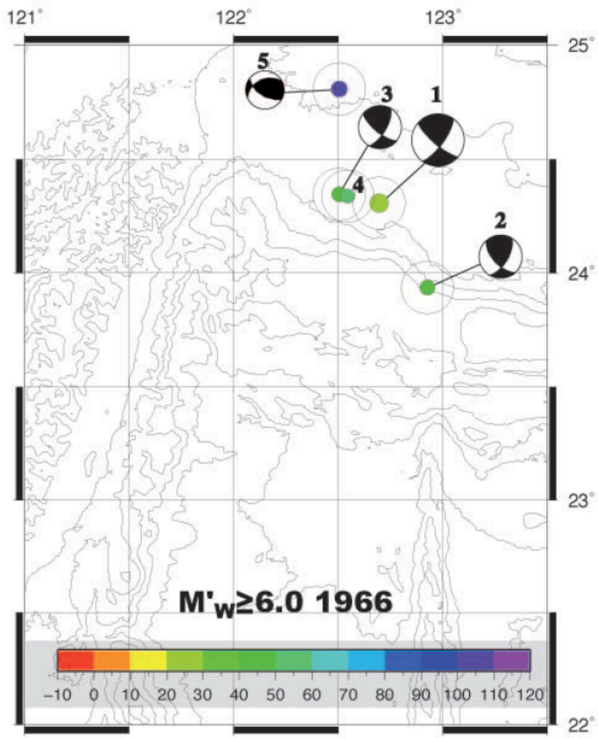
1	1951	10	21	21	34	14.0	121.72	23.88	4.0	7.1
2	1951	10	22	3	29	27.0	121.72	24.07	1.0	7.0
3	1951	10	22	3	52	0.0	121.70	23.70	0.0	6.0
4	1951	10	22	4	28	0.0	121.70	23.90	0.0	6.8
5	1951	10	22	5	18	0.0	121.70	23.90	0.0	6.5
6	1951	10	22	5	24	0.0	121.80	24.00	20.0	6.0
7	1951	10	22	5	43	1.0	121.95	23.82	18.0	7.0
8	1951	10	22	11	11	0.0	122.20	24.10	40.0	6.0
9	1951	10	22	12	48	0.0	121.90	24.10	20.0	6.1
10	1951	10	22	14	47	0.0	121.70	24.10	20.0	6.0
11	1951	10	22	15	30	0.0	121.70	23.90	0.0	6.4
12	1951	10	22	20	52	0.0	121.70	23.70	20.0	6.1
13	1951	10	23	1	19	0.0	121.80	24.10	20.0	6.1
14	1951	10	23	8	55	0.0	121.90	23.70	0.0	6.1
15	1951	10	25	12	19	0.0	121.30	23.00	40.0	6.4
16	1951	11	24	18	47	0.0	121.22	23.10	16.0	6.6
17	1951	11	24	18	50	18.0	121.35	23.27	36.0	7.1
18	1951	11	26	6	38	0.0	121.10	22.90	0.0	6.0

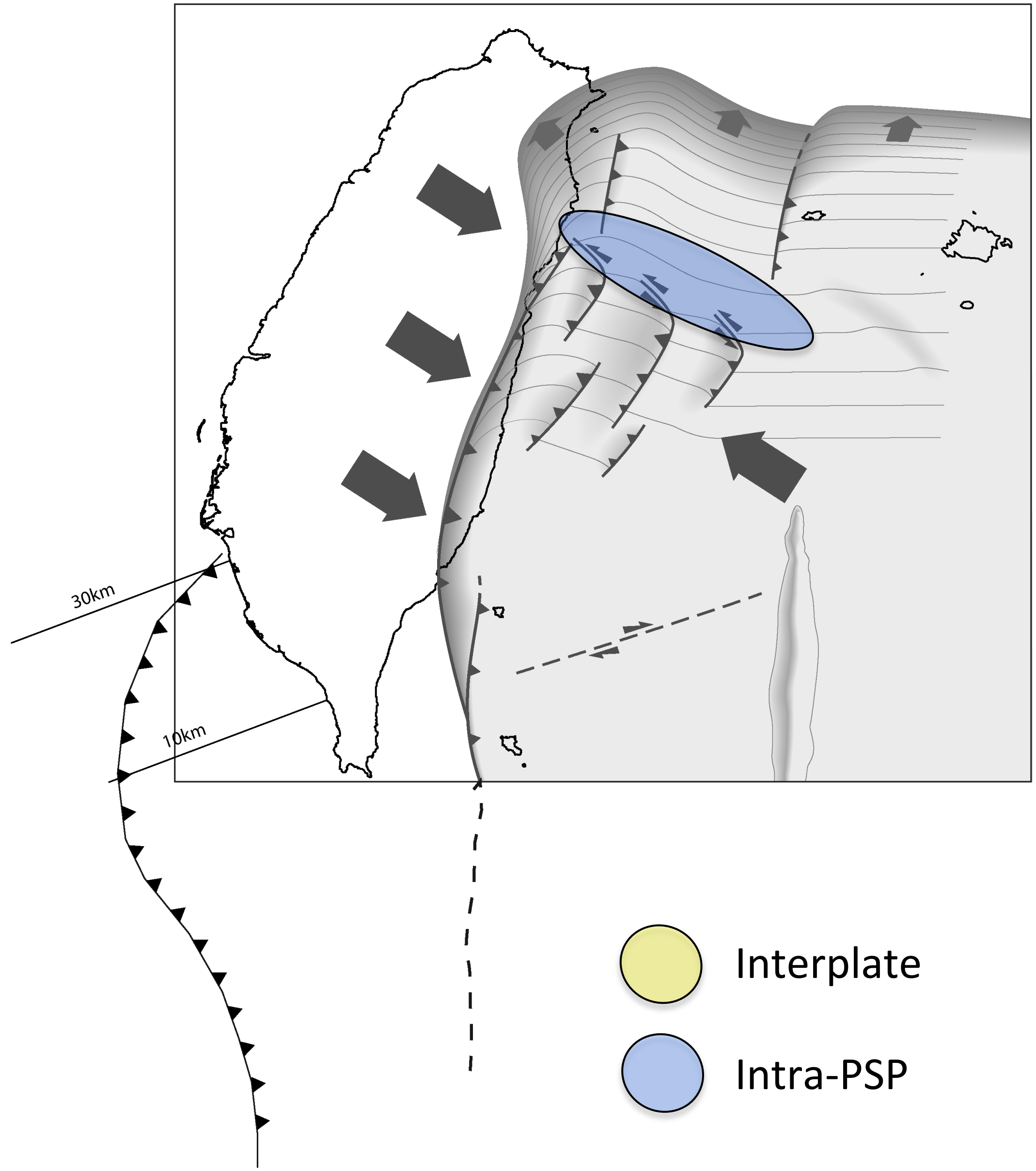




Model of deformation of the PSP

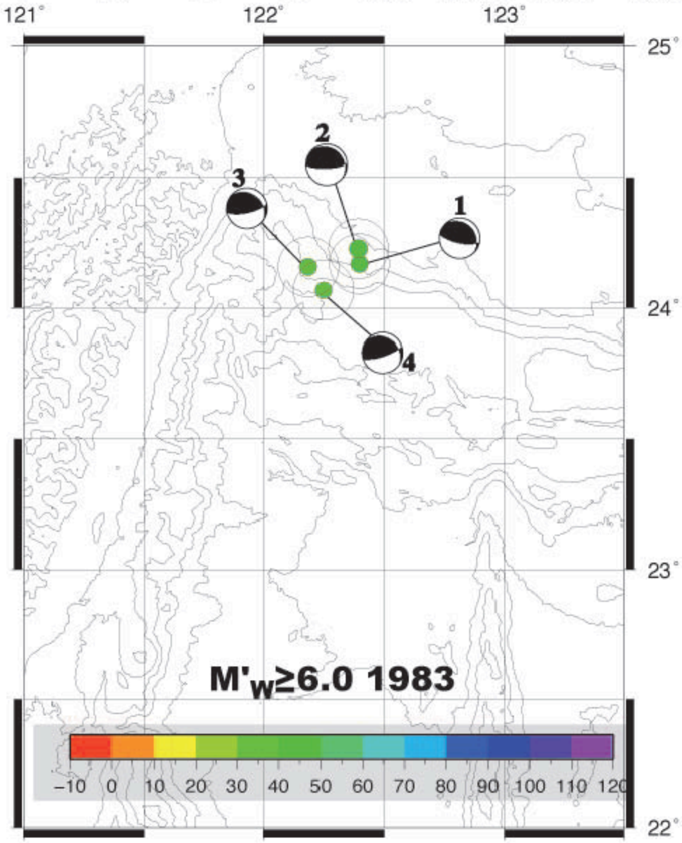
1	1966	3	12	16	31	19.8	122.69	24.31	28.9	7.5
2	1966	3	23	0	4	34.6	122.93	23.94	47.3	6.2
3	1966	5	5	14	21	19.9	122.51	24.35	49.8	6.2
4	1966	5	28	0	3	57.5	122.55	24.34	55.2	6.0
5	1966	7	1	5	50	38.8	122.51	24.81	109.9	6.7

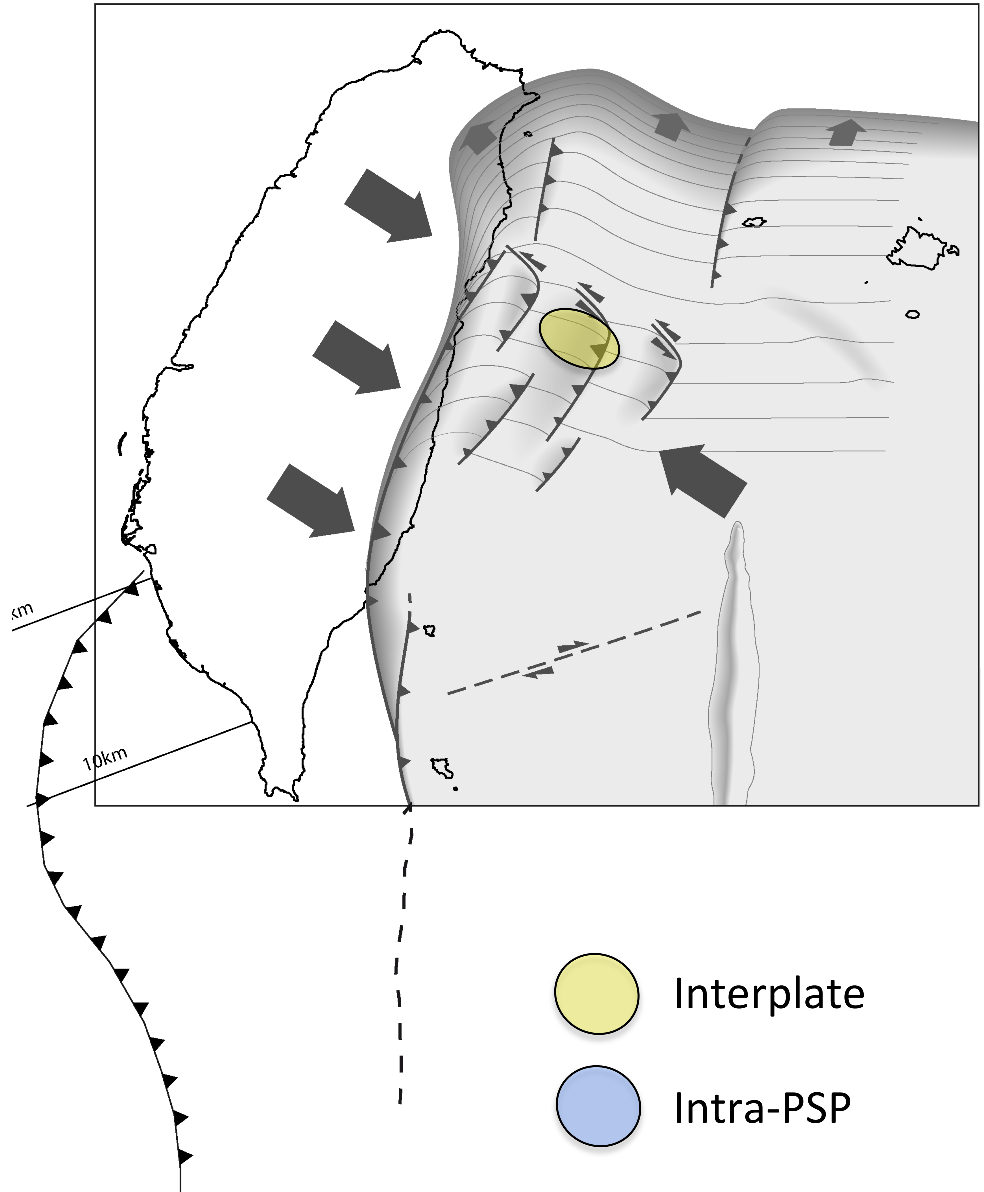




Model of deformation of the PSP

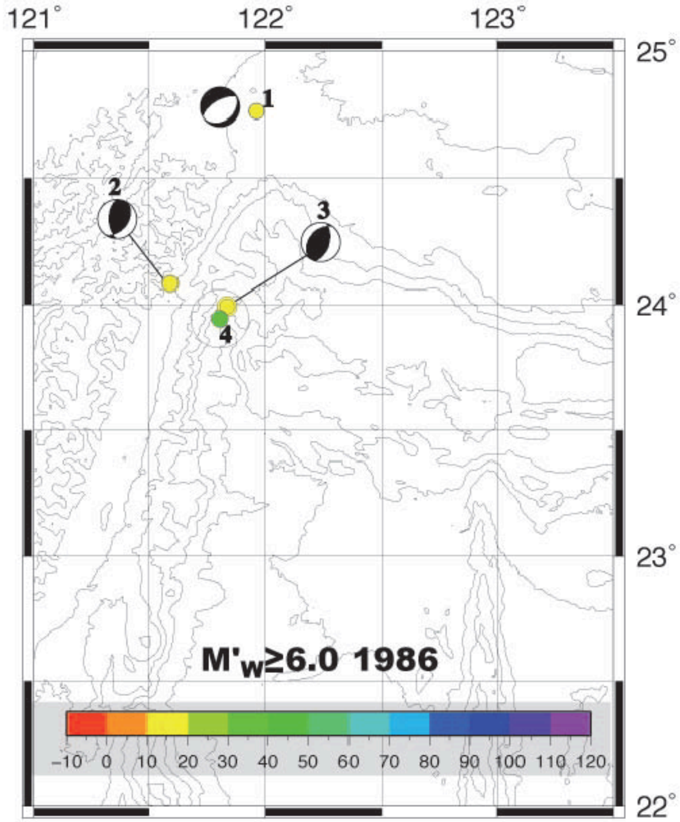
1	1983	6	21	14	48	3.5	122.40	24.17	43.8	6.2
2	1983	6	24	9	6	43.0	122.39	24.23	48.7	6.6
3	1983	9	21	19	20	40.7	122.19	24.16	39.5	6.4
4	1983	9	23	12	29	21.3	122.25	24.07	37.0	6.0

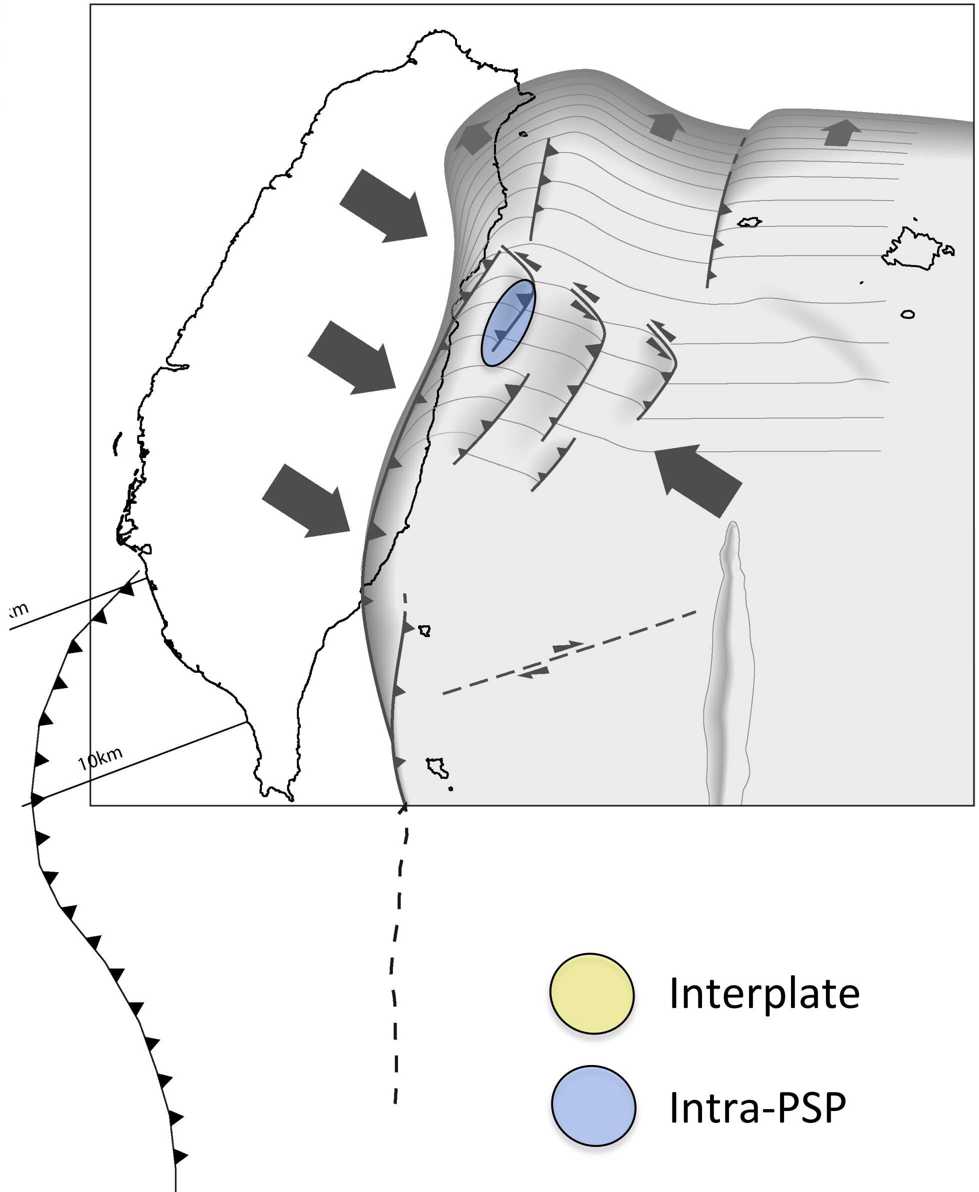




Model of deformation of the PSP

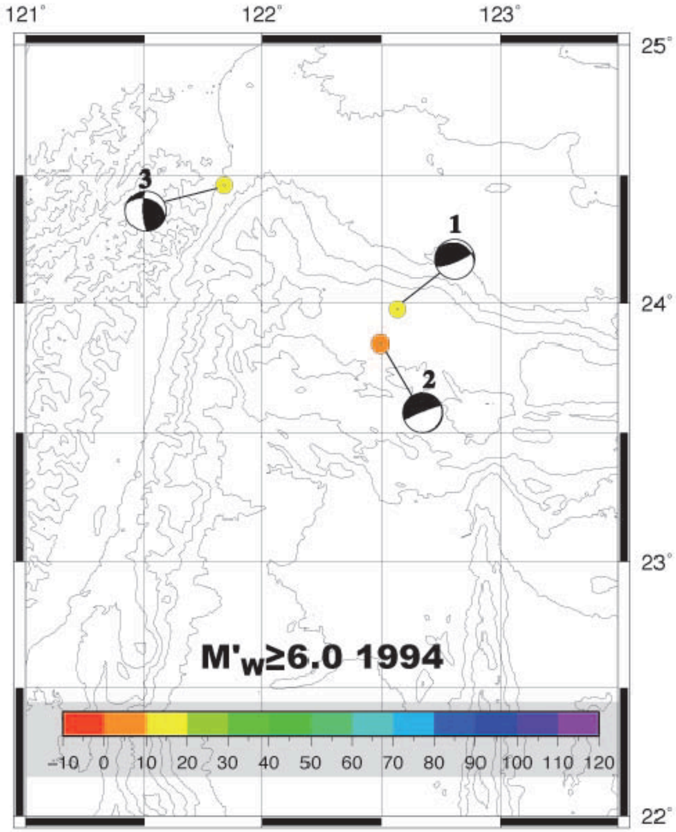
1 1986	1	16	13	4	32.0	121.96	24.76	10.2	6.0
2 1986	5	20	5	25	49.6	121.59	24.08	15.8	6.2
3 1986	11	14	21	20	4.5	121.83	23.99	15.0	7.3
4 1986	11	14	23	4	37.1	121.80	23.94	32.1	6.3

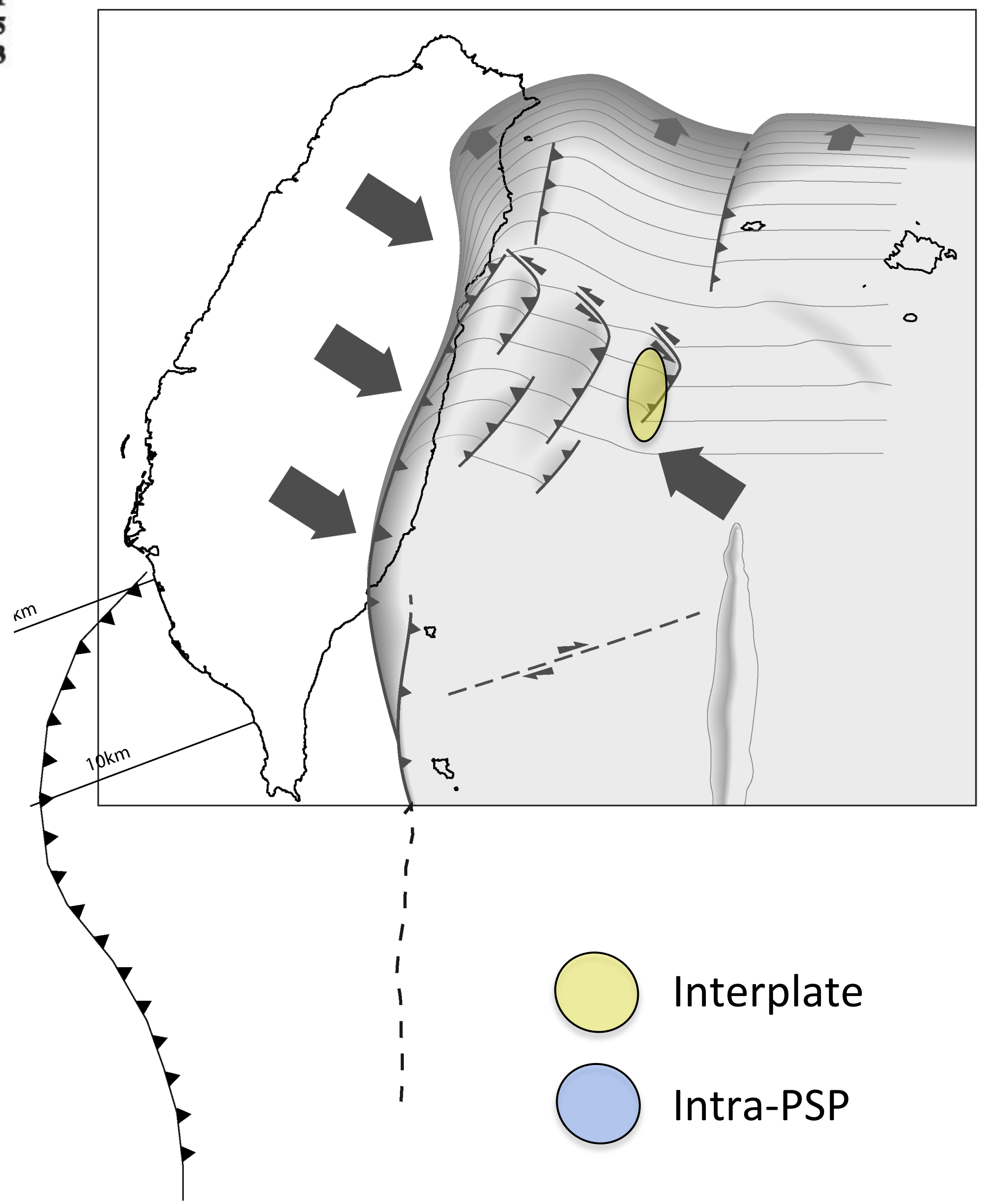




Model of deformation of the PSP

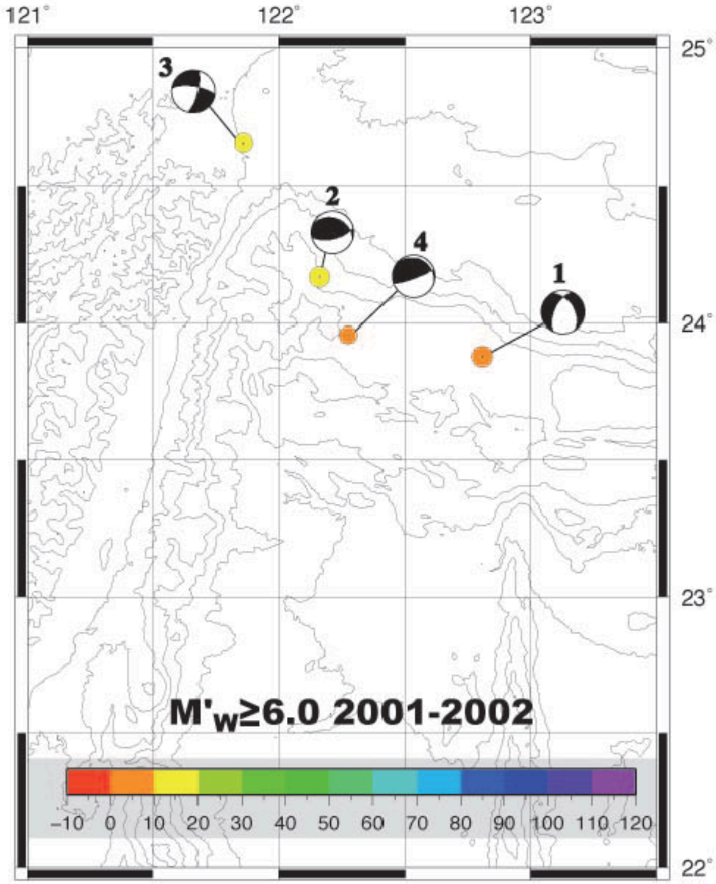
1 1994	5	23	5	36	1.9	122.57	23.98	12.7	6.1
2 1994	5	24	4	0	40.5	122.50	23.84	4.9	6.5
3 1994	6	5	1	9	30.1	121.84	24.46	10.8	6.3

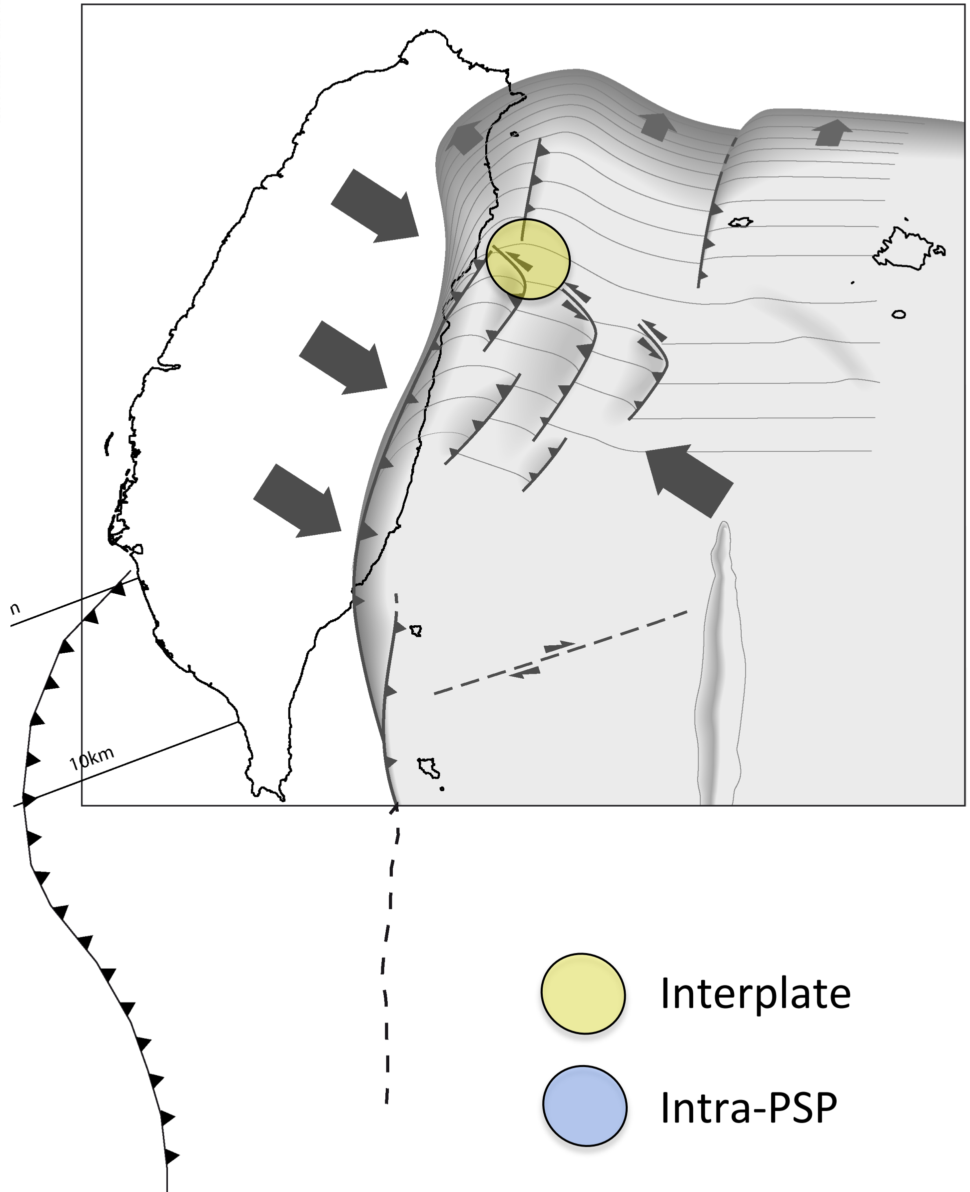




Model of deformation of the PSP

1 2001	12	18	4	3	0.8	122.81	23.88	4.1	6.8
2 2002	3	31	6	52	50.0	122.16	24.17	16.5	7.1
3 2002	5	15	3	46	5.9	121.86	24.66	12.2	6.1
4 2002	5	28	16	45	15.0	122.28	23.96	7.7	6.0





Thank you !!