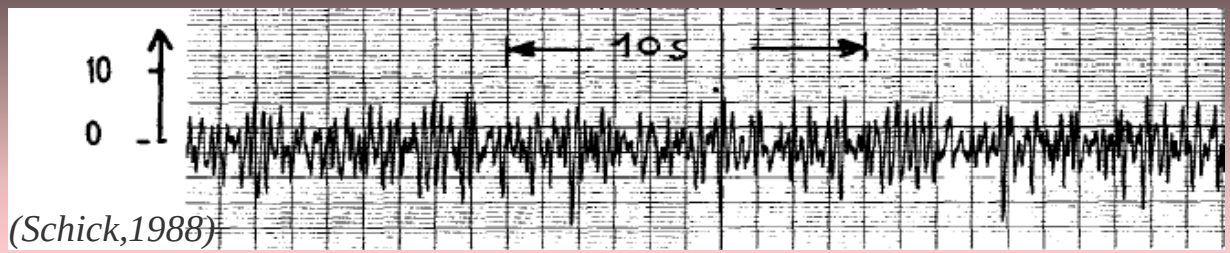
Space and time behavior of non-volcanic tremor in the southwest Japan subduction zone

Obara (2002); Obara et al. (2004) ; Hirose and Obara (2005)



(Schick,1988)

Kate H. Chen, 27 July 2006

Outline

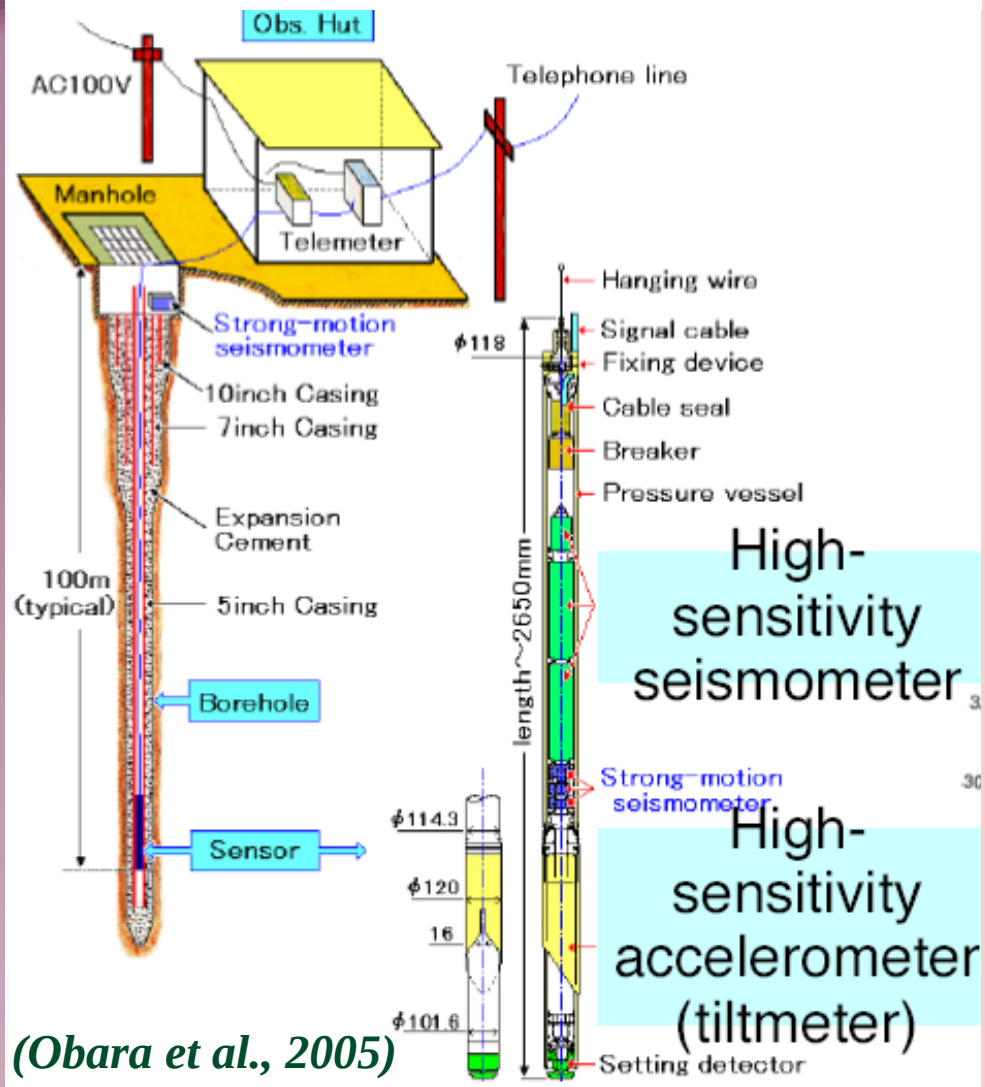
What they found?

- **Spatial distribution of tremor:**
  - **Wide-range, Clustering**
- **Time sequence of tremor :**
  - **Periodicity, Migration, Triggering**
- **Coherency with slow slip events:**
  - **Long-term, short-term**

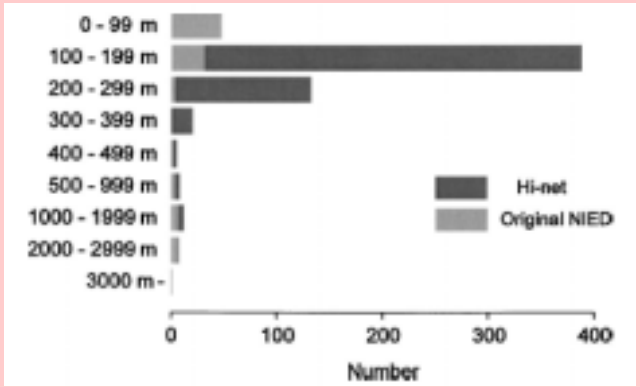
What questions remain open?

High-sensitivity seismograph network(Hi-net)

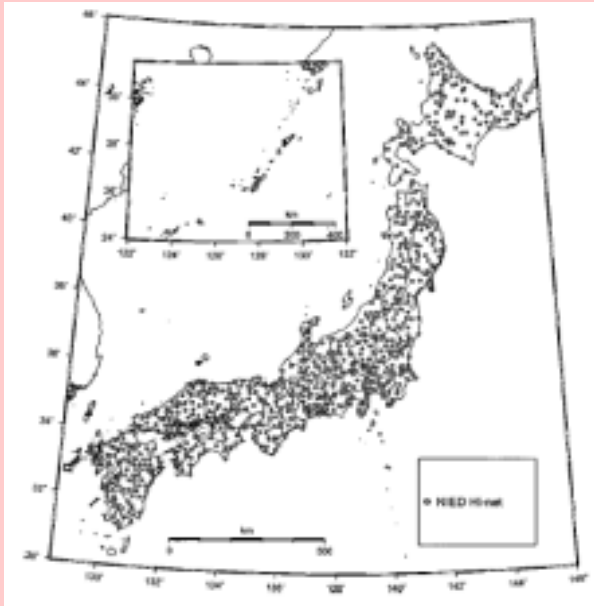
The borehole for the NIED Hi-net seismic observations:



(Obara et al., 2005)



Over 600 stations



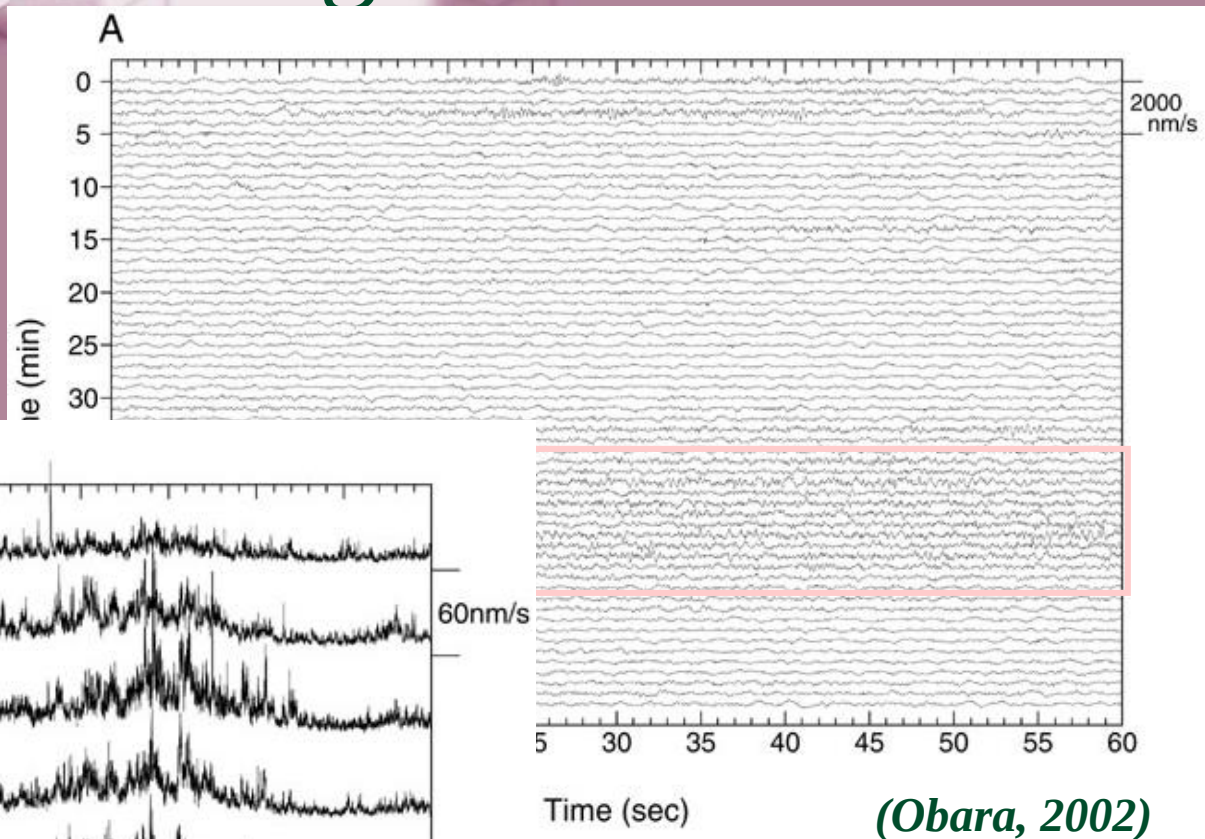
* provide a high-level detection capability for microearthquakes

Noise-like signal?

IKTH station

Vertical component

2001 Aug. 17 4:00 am



(Obara, 2002)

(Obara, 2002)

The coherence between stations

→ common source??

→ distribution of the relative arrival times

Locate them!

- Calculation of cross-correlation coefficient (ccc):

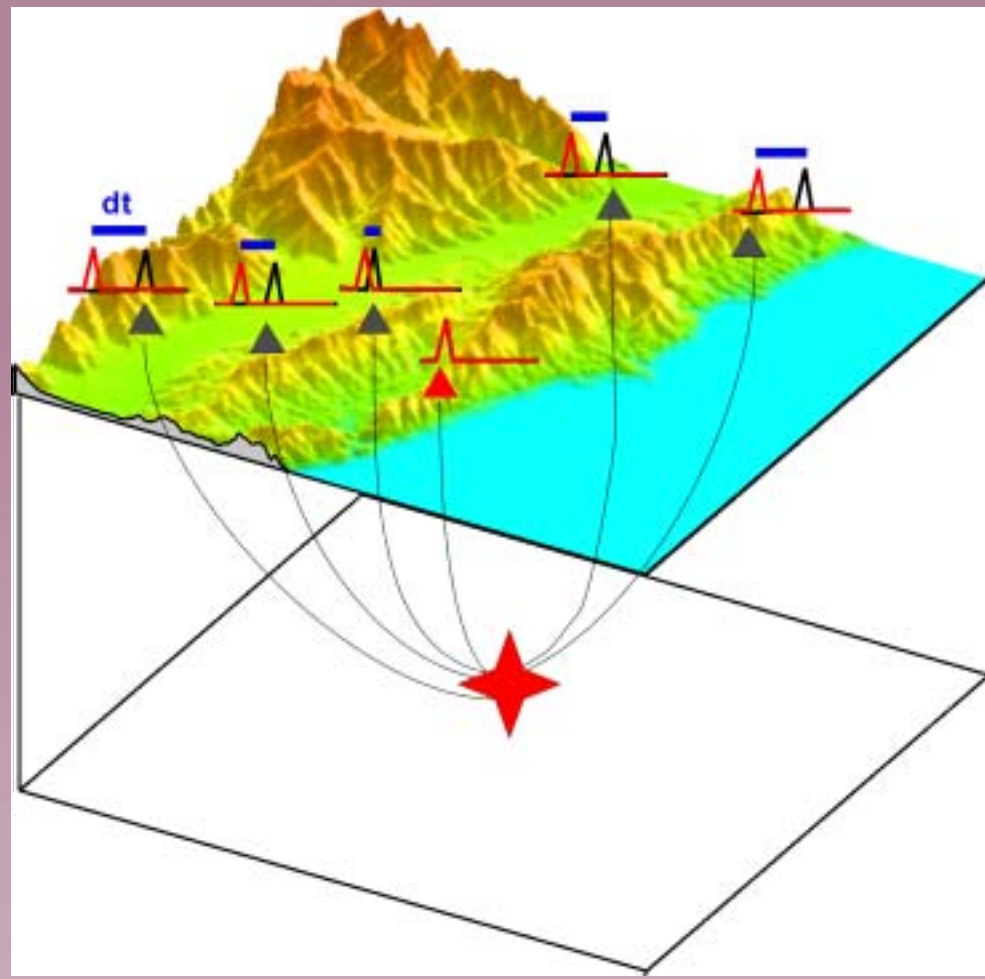
  -Station-pairs

  -2-min length with 1-min moving window

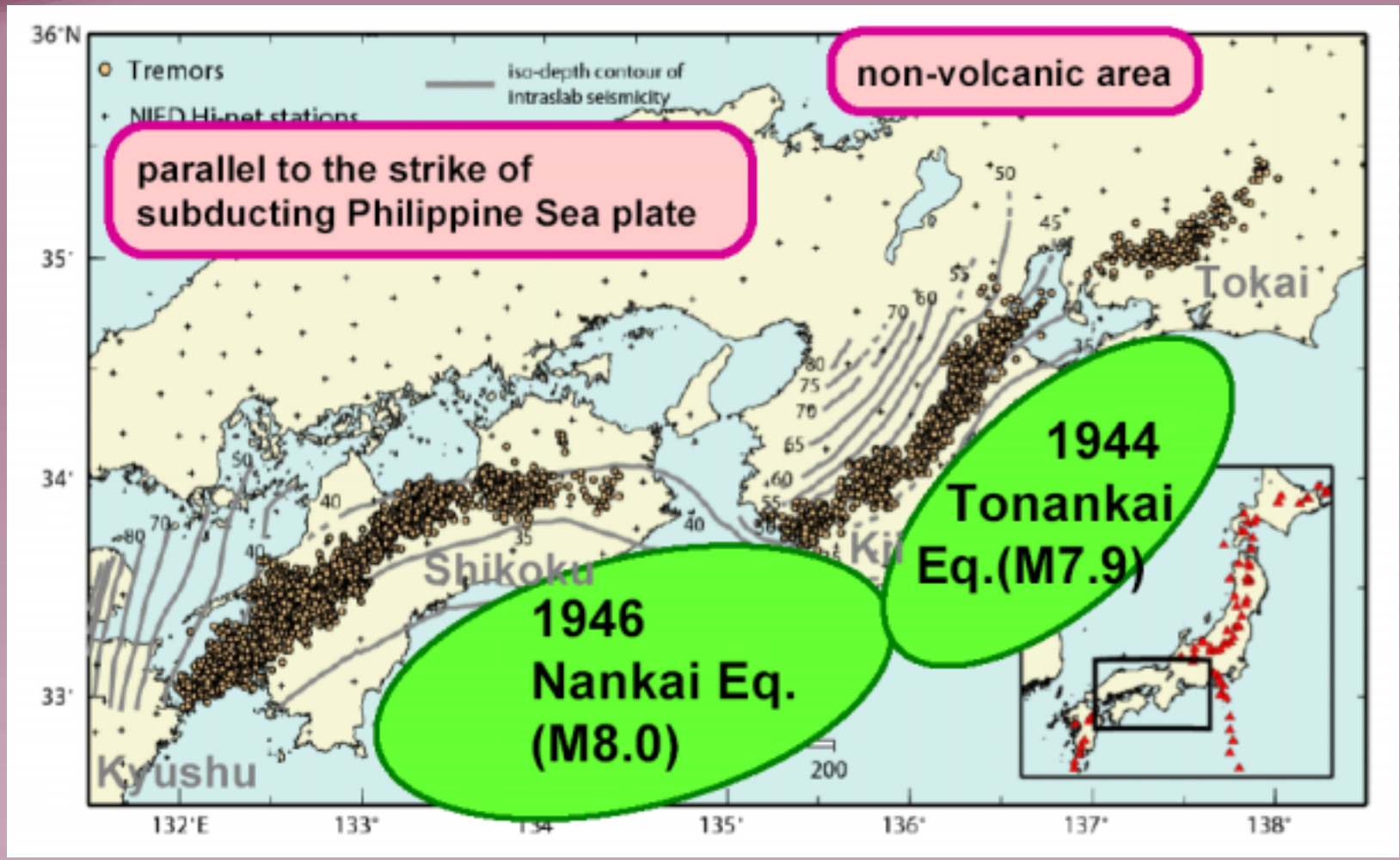
  -When ccc>0.9 →time delay is applied for further process

- **Location of tremor:**

  the center of the distribution of tremors determined for 1 hour.

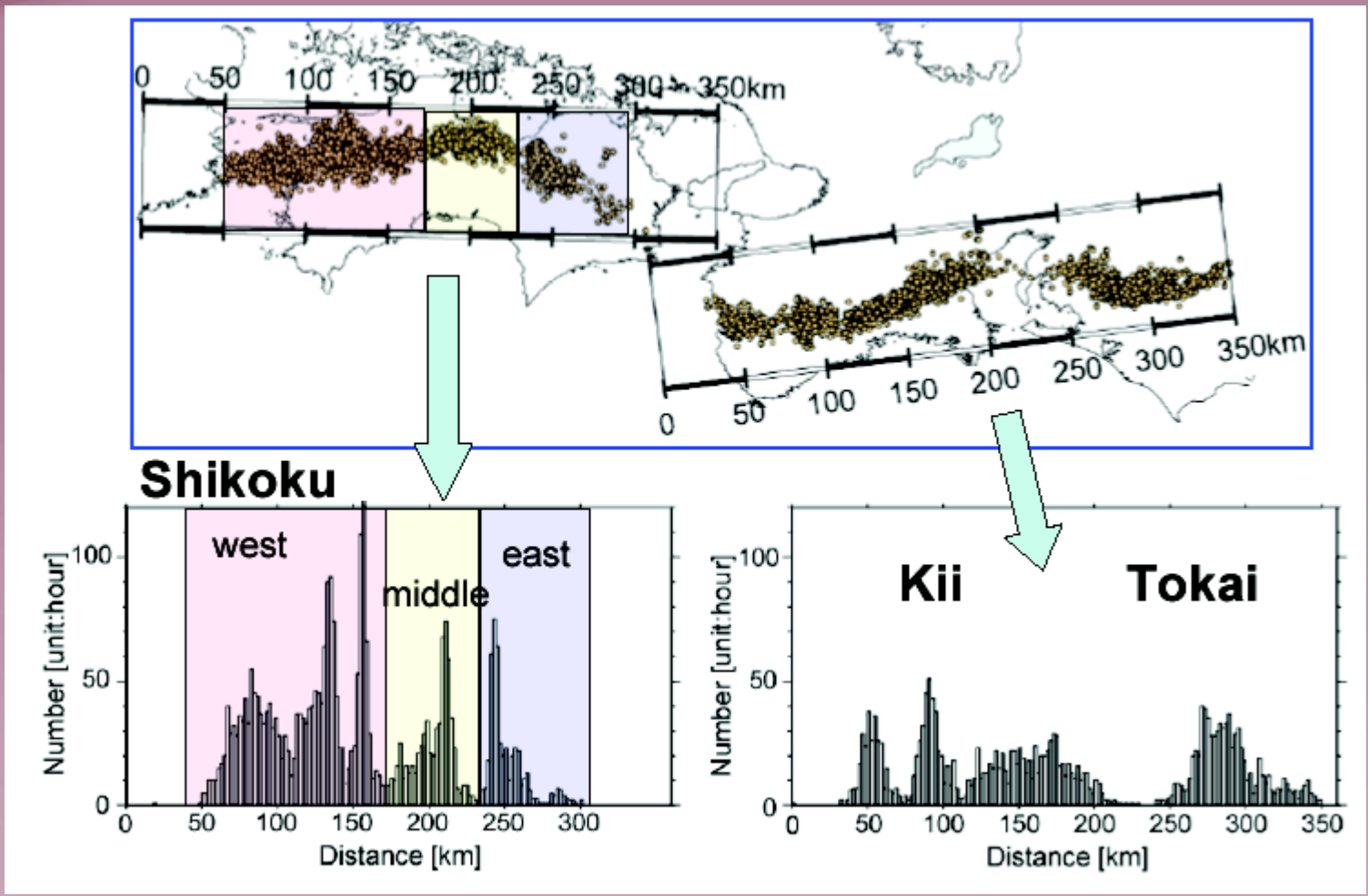


Spatial distribution of tremors



(Obara, 2002) The shape and position agreement → the vibrations are of tectonic origin

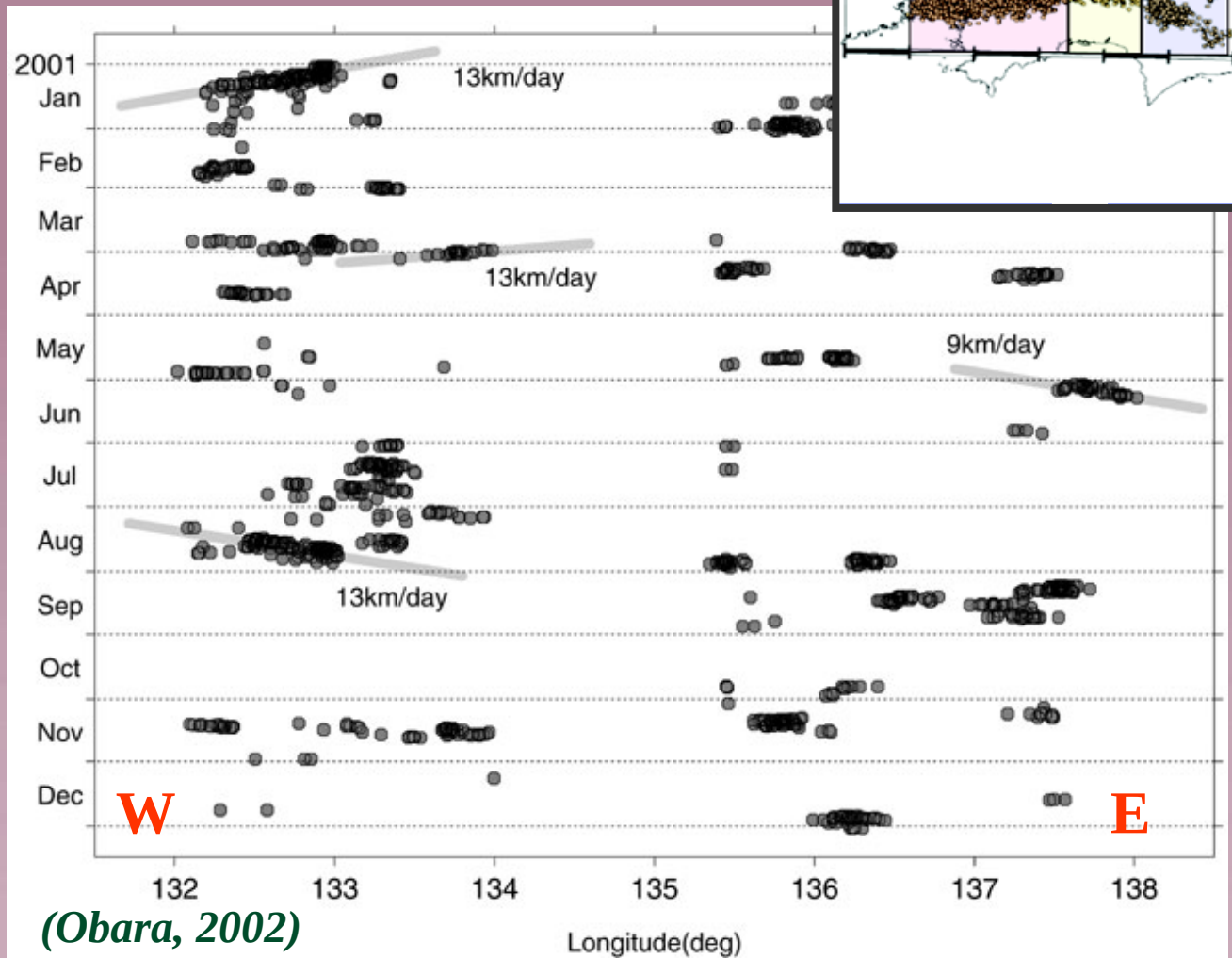
Clustering of tremor activity



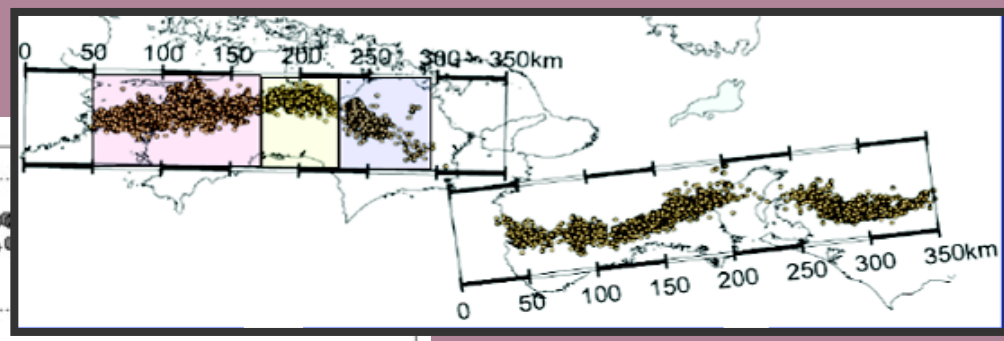
(Obara, 2004)

Migration of tremors

- The tremor did not always remain in one region but sometimes migrated.

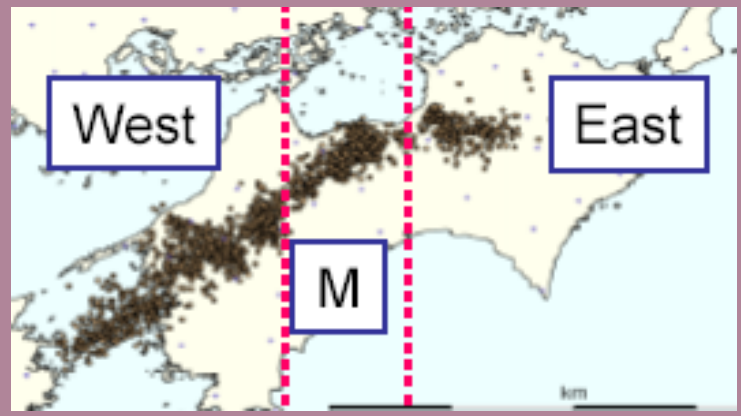


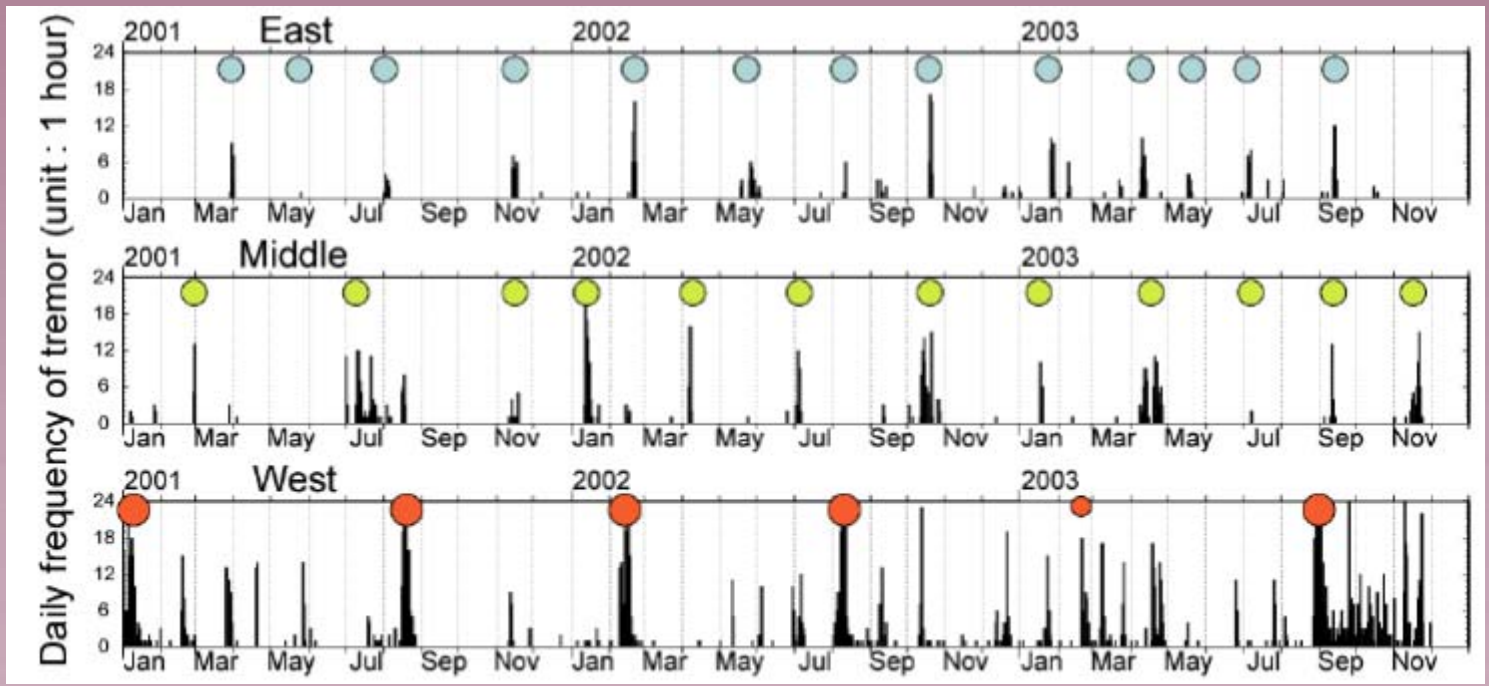
(Obara, 2002)



Occurred periodically?

- Periodic activity if tremors in Shikoku

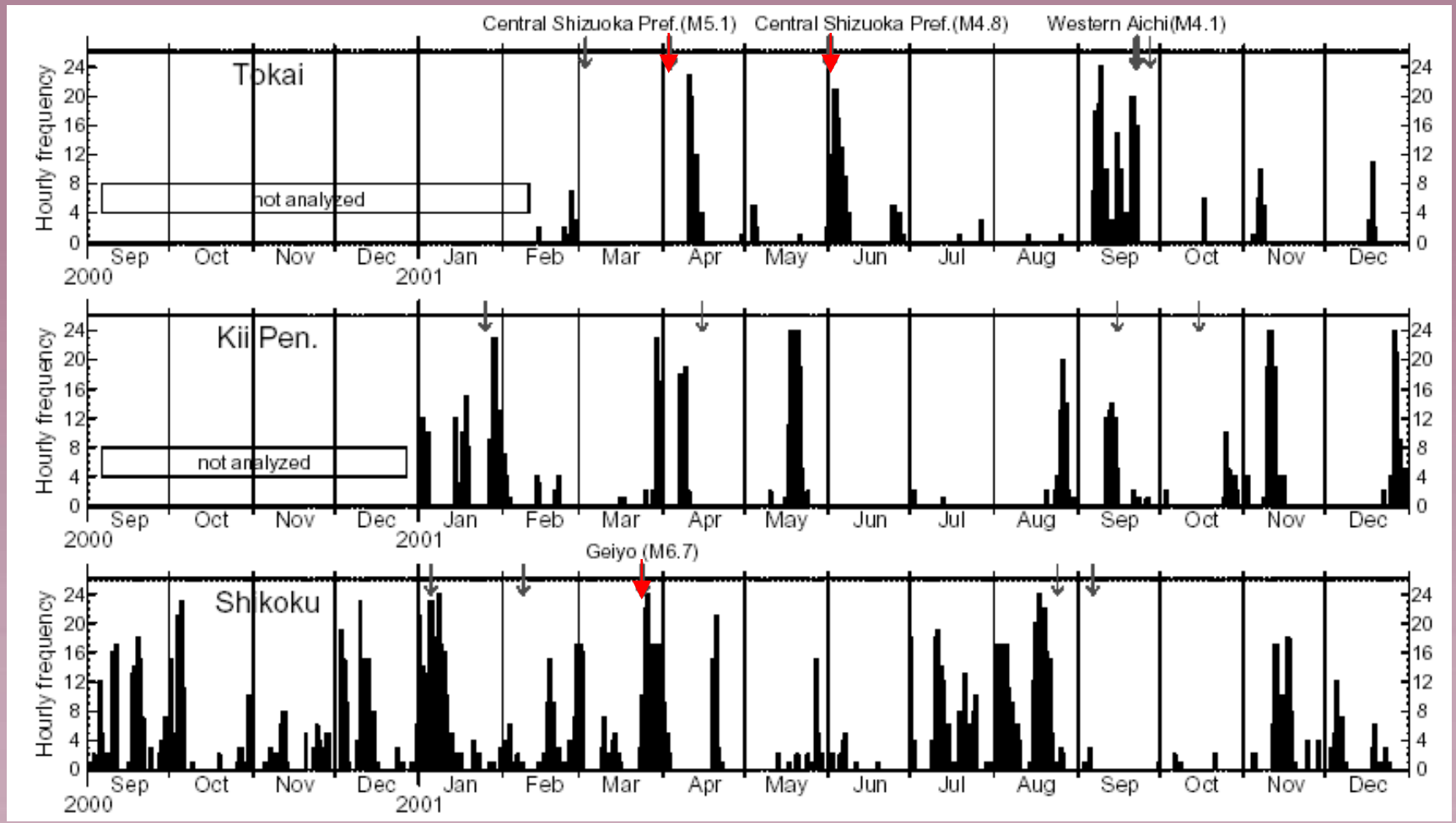




(Obara, 2004)

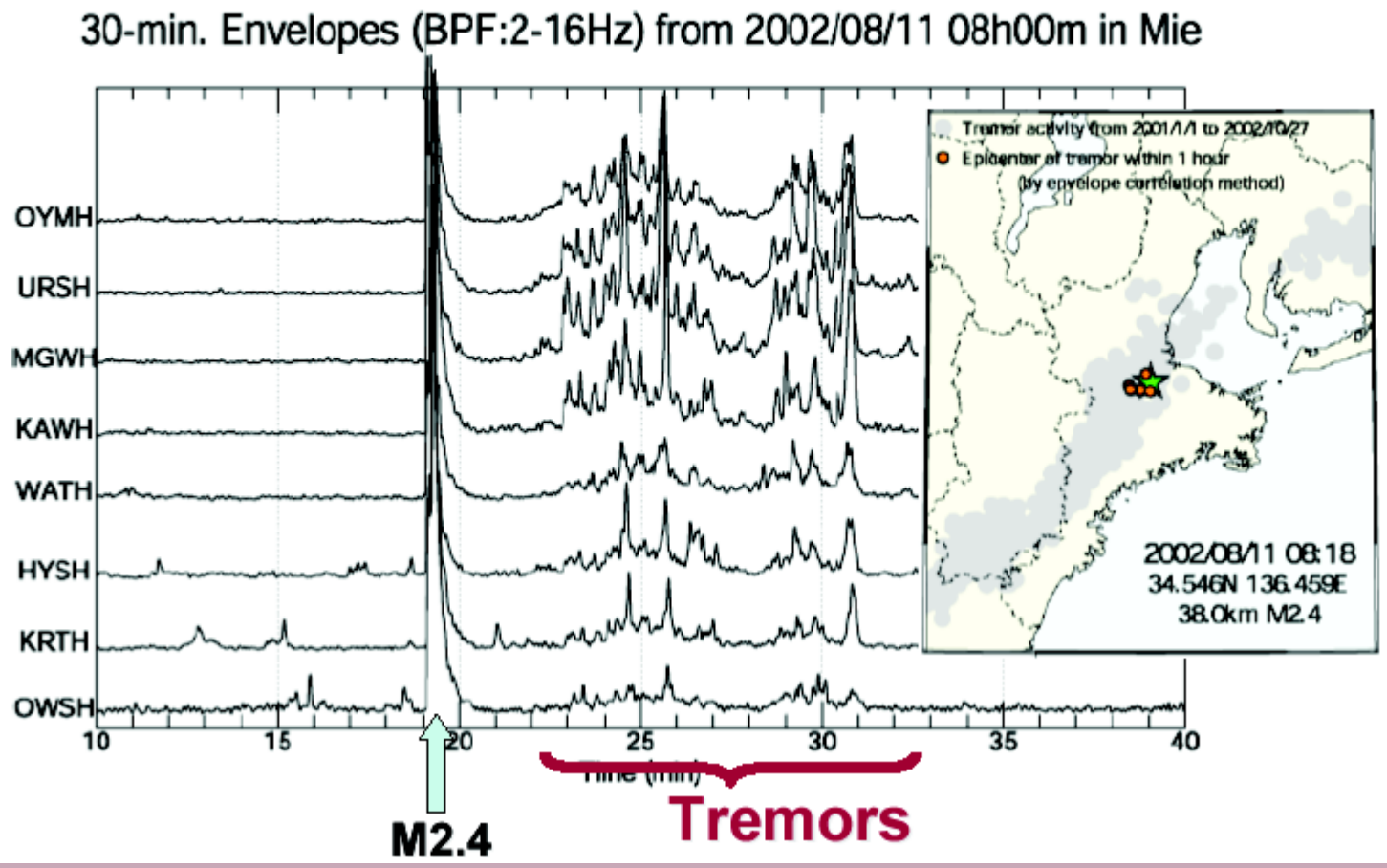
Temporal correlation with earthquakes

- The tremors sometimes triggered by a nearby relatively large earthquakes



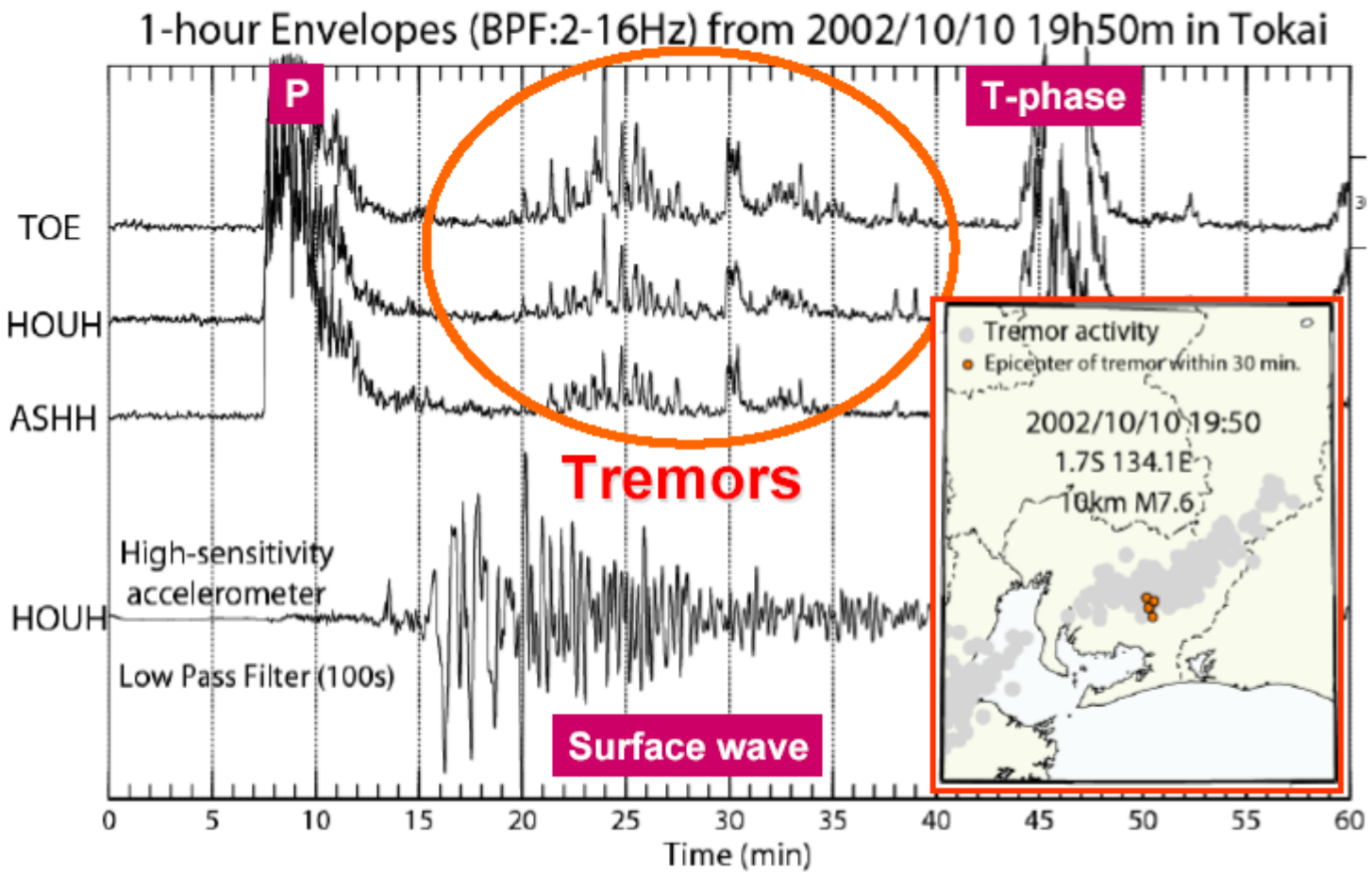
(Obara, 2002)

Tremor triggered by M2.4 microearthquake



(Obara, 2004)

Tremor triggered by M7.6 Indonesia earthquake



(Obara, 2004)

Summary of deep tremor activity

- **Non-volcanic deep tremor:**

- The tremors are extremely large scale phenomenon characterized by a long time duration (hours to weeks) and a very wide source area (over 600 km in length).

- They are not distributed homogeneously on a narrow belt-like zone but clustered in the zone.

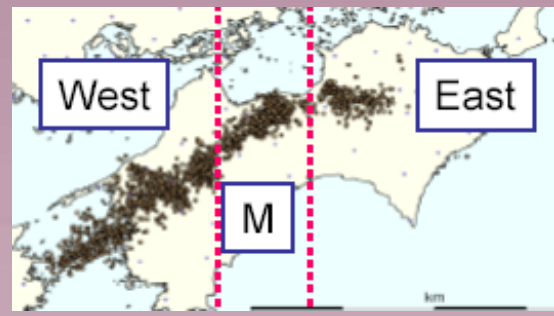
- Sometimes triggered by seismic wave.

- **Major tremor**

- occurs periodically (6 months in W. Shikoku, 3 months in E. Shikoku)

- continues for days ~ weeks

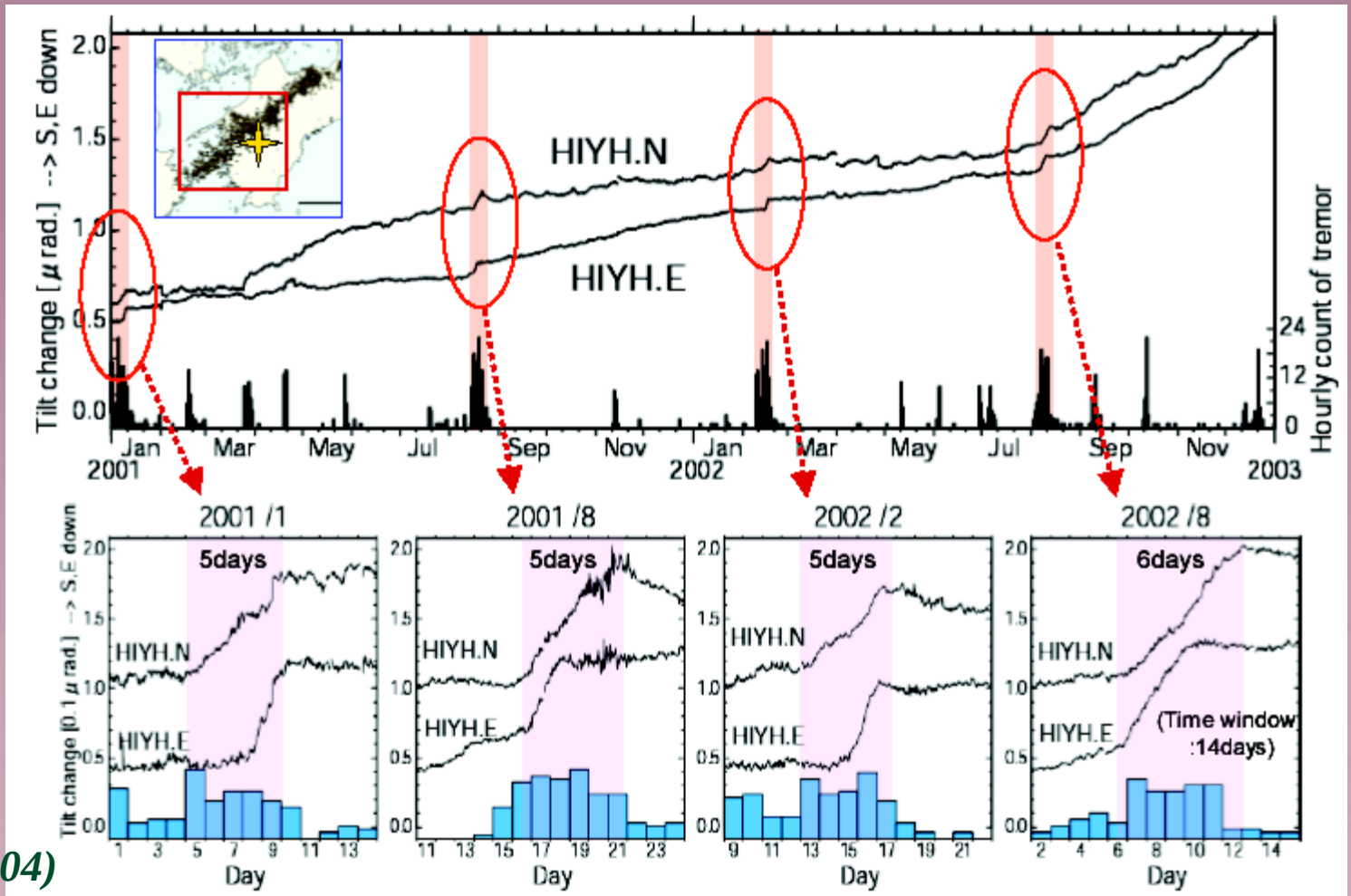
- migrates along the strike of subduction slab



The connection between crustal deformation, slow slip events, and tremor ?

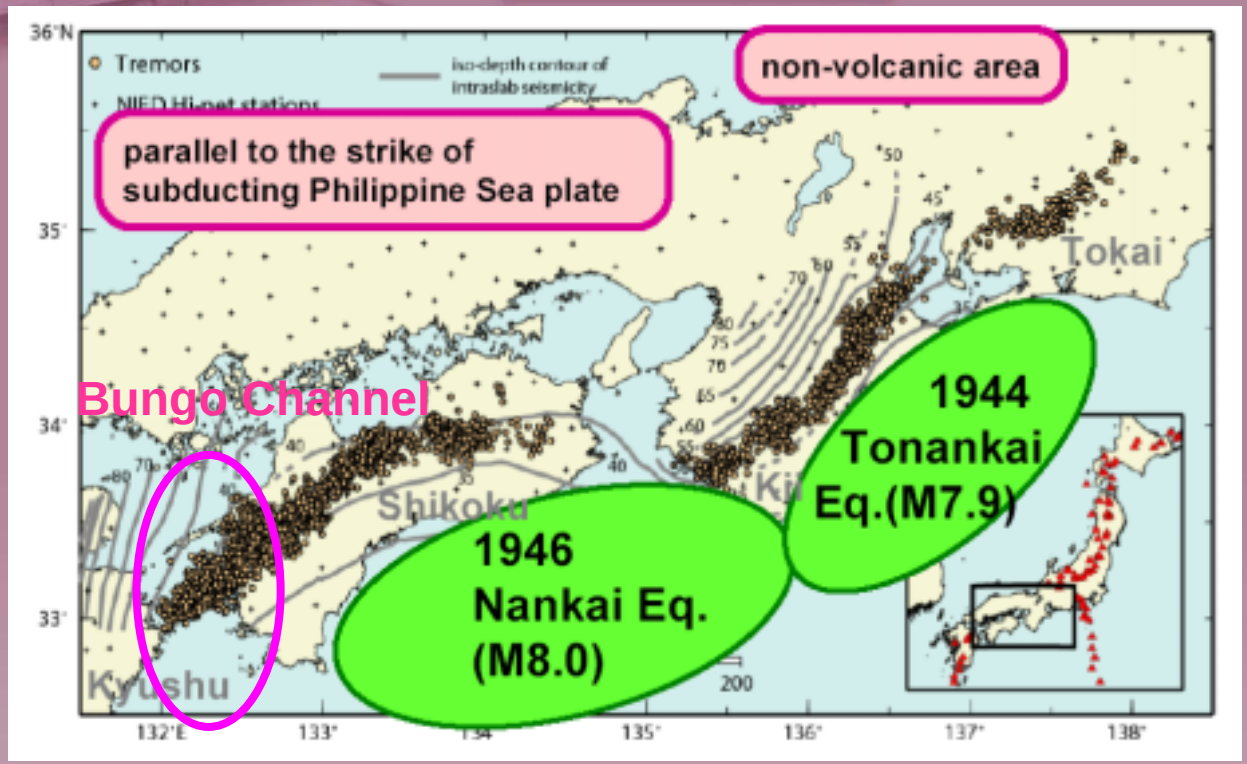
Tremor observation vs. tilt change

- Horizontal component of high-sensitivity accelerometer
- Equipped in all Hi-net stations
- Analyzed as ground tilt



(Obara, 2004)

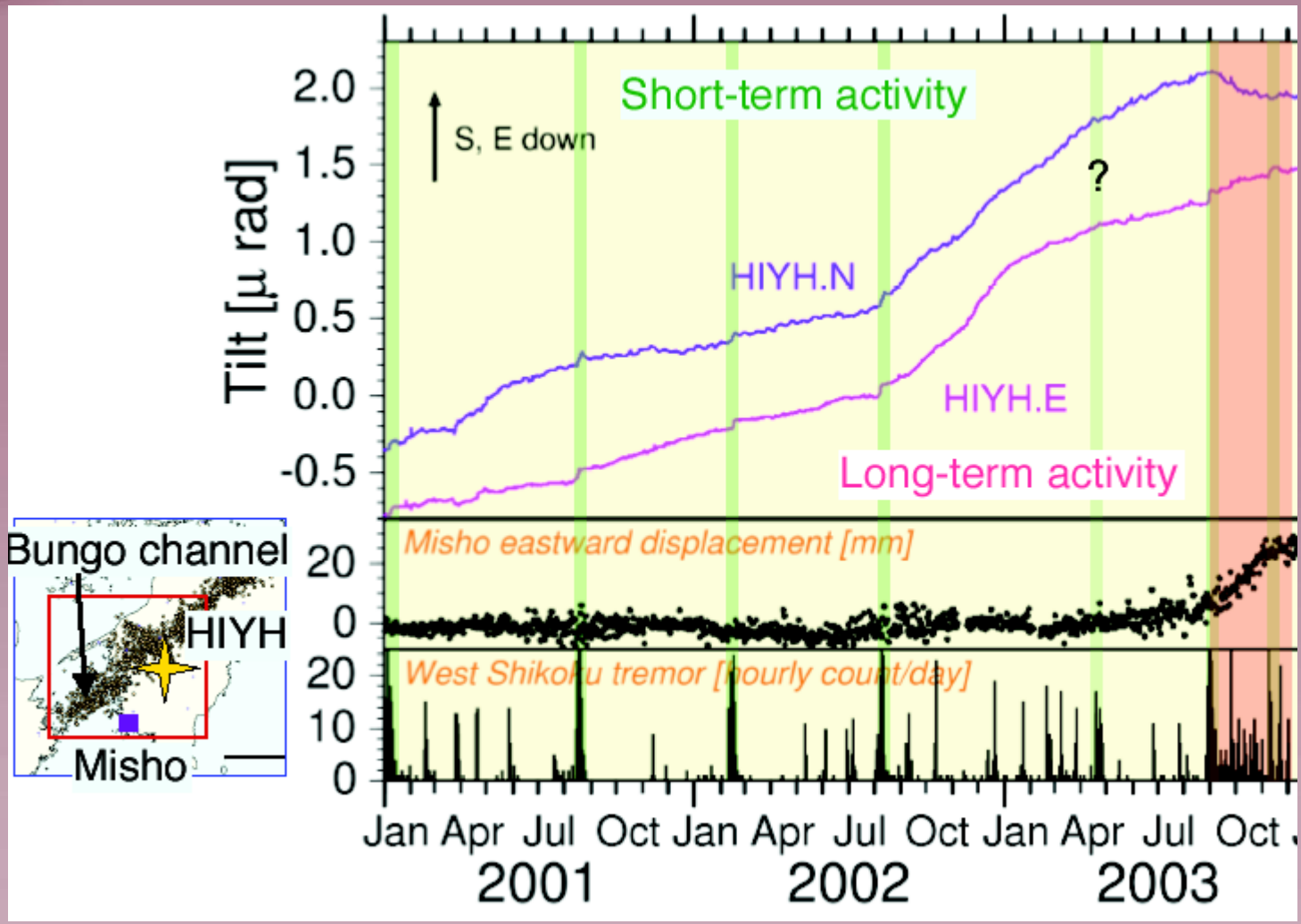
Short-term and long-term slow slip events



- Around the **Bungo channel**, two type of SSEs are observed:
  - Long-term SSEs (~1-yr duration)
  - Short-term SSEs (~ 1 week duration)

Short-term SSEs:

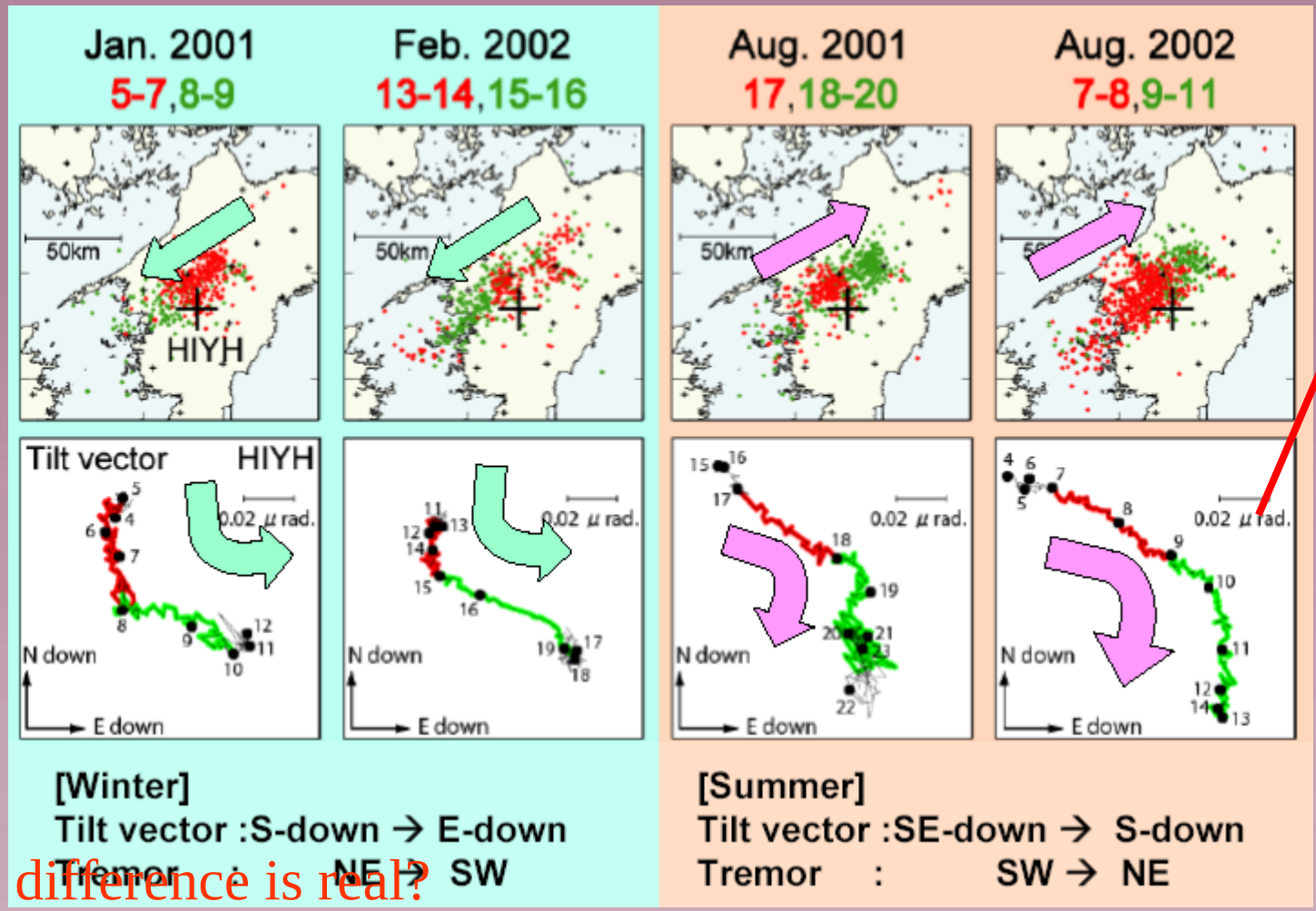
1) Title, GPS, and Tremor



(Hirose and Obara, 2005)

2) Migration of tremor and tilt

- When tremors are mainly located in NE part → tilt vector indicates south-down.
- When tremors are mainly located in SW part → tilt vector indicates SE-down.



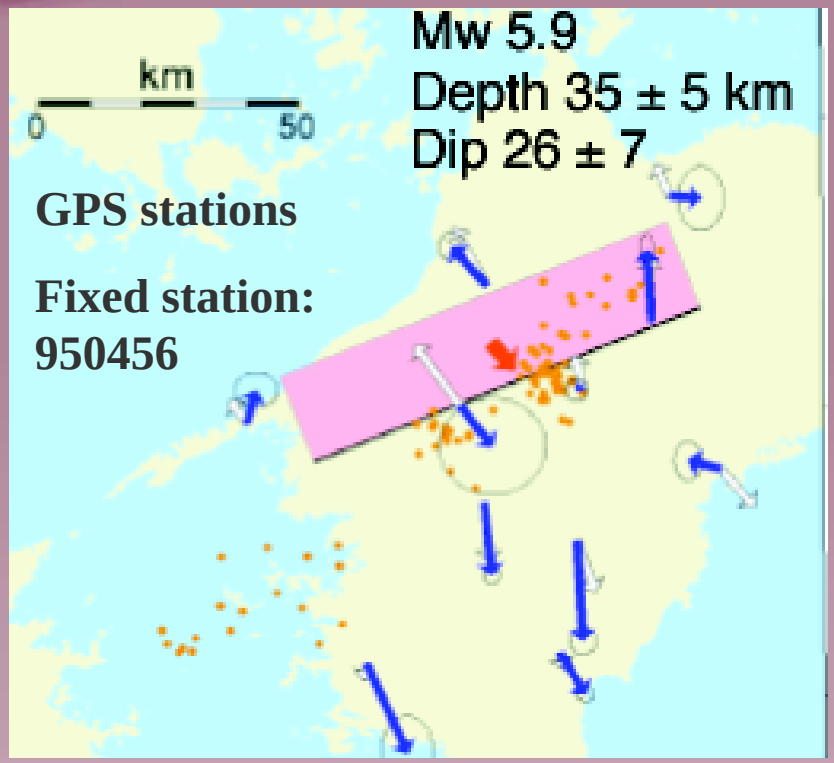
Micro-rad.

Seasonal difference is real?

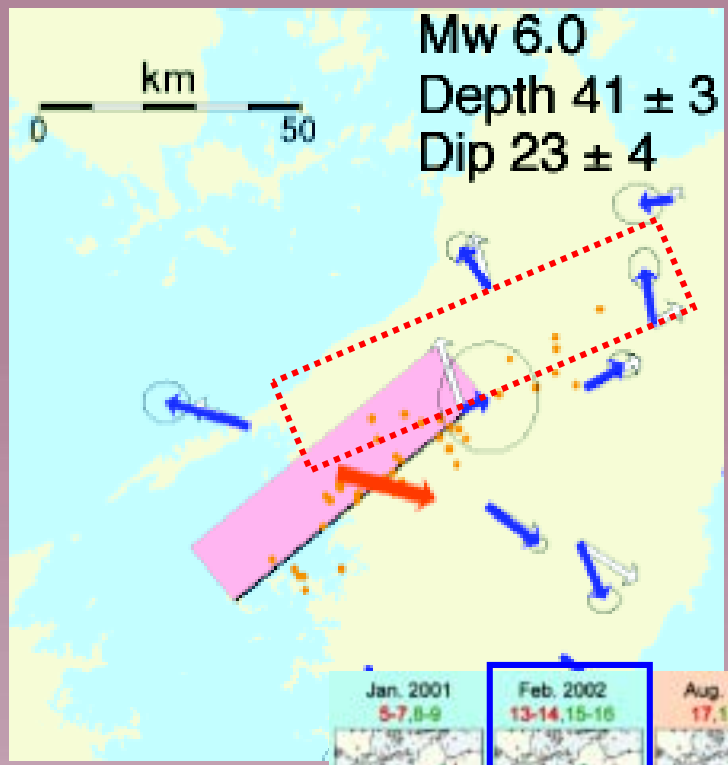
3) Fault model -2002 Feb. episode

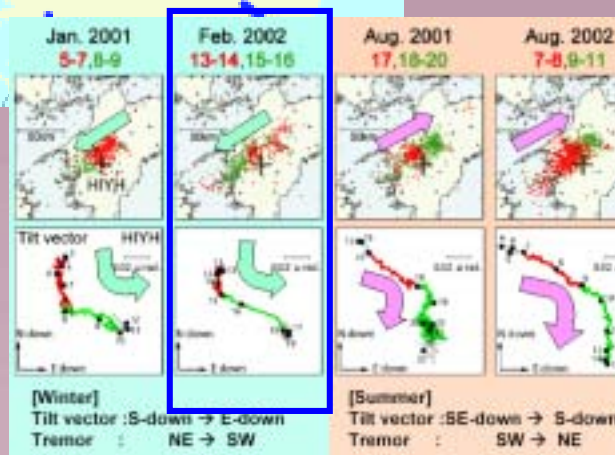
Obs.
Cal.
Estimated slip

Feb. 9 – Feb. 15



Feb. 15 – Feb. 17



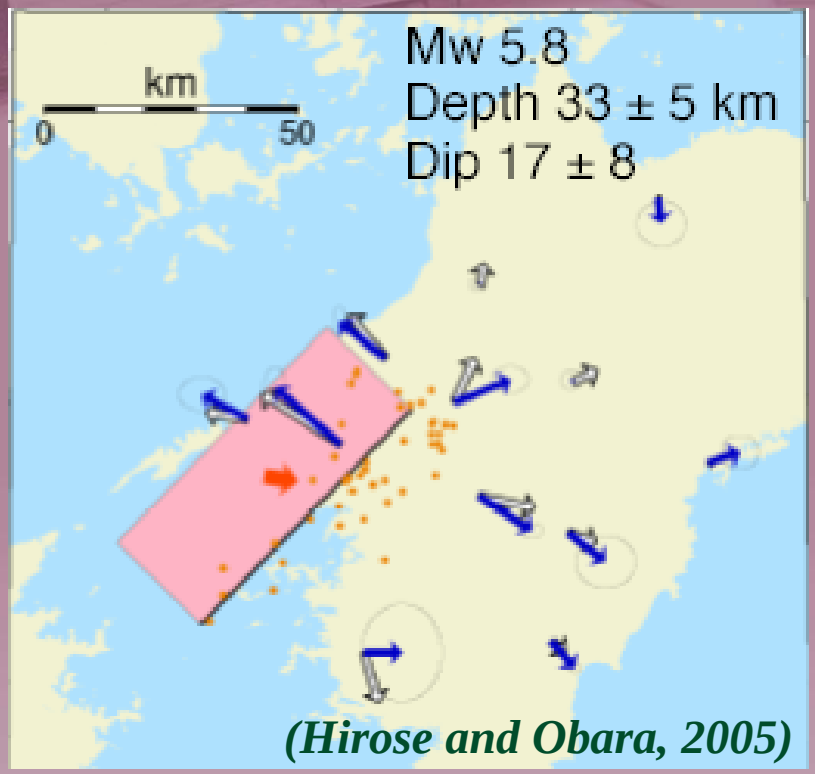


- Location of slow slip fault correlates with tremor sources
- Source area migrates from NE to SW

3) Fault model-2002 Aug. episode

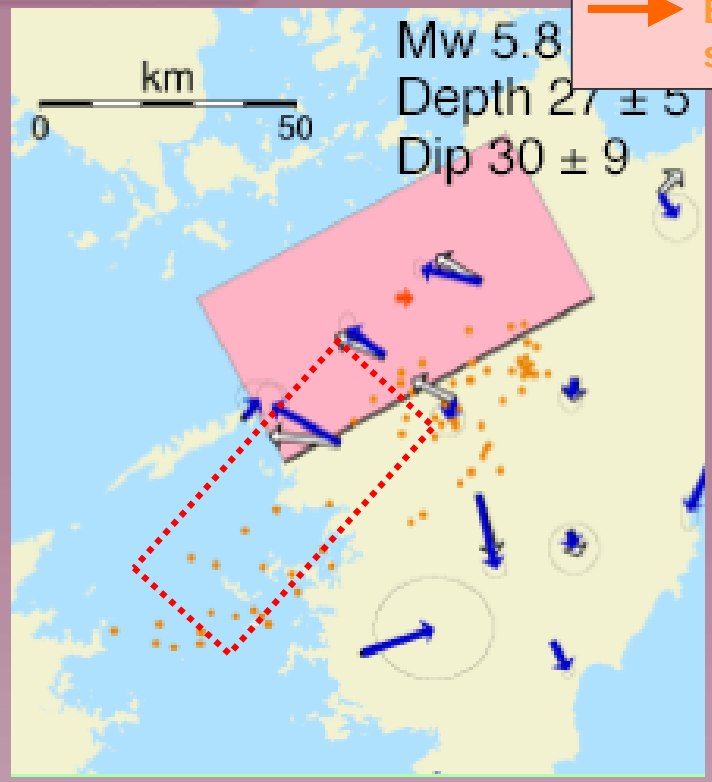
Obs.
Cal.
Estimated slip

Aug. 6 – Aug. 9



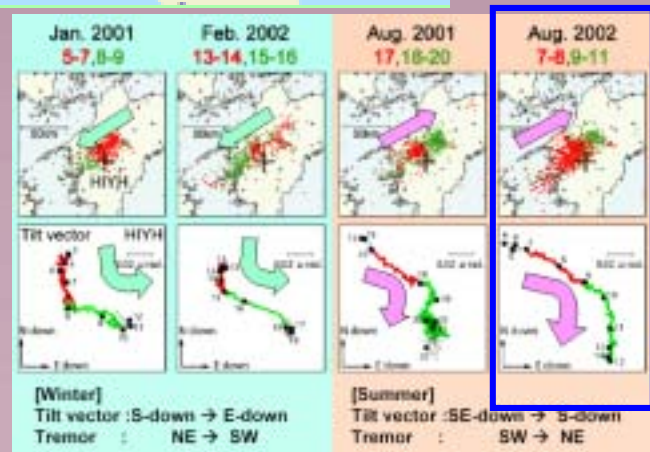
(Hirose and Obara, 2005)

Aug. 9 – Aug. 12



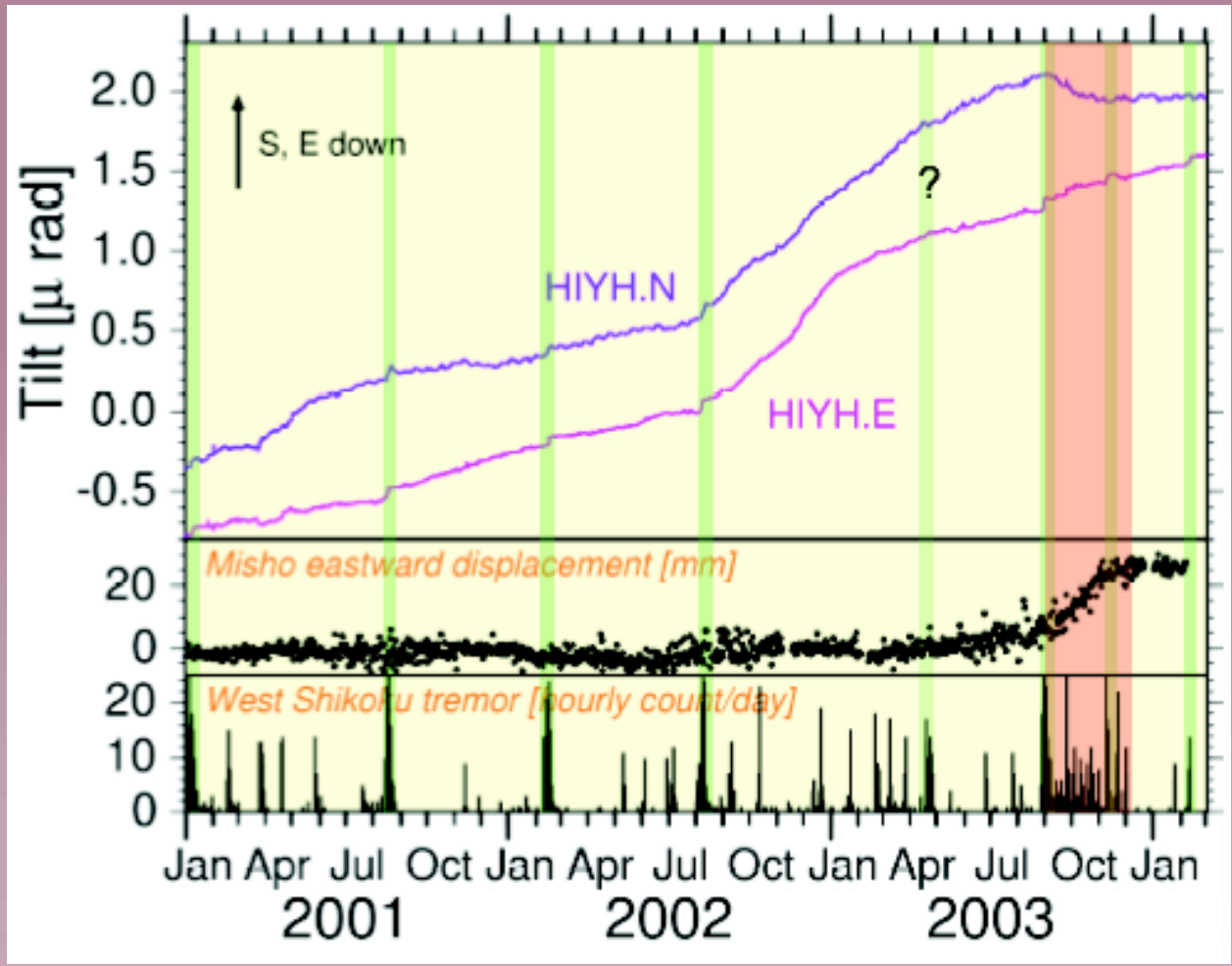
- Location of slow slip fault correlates with tremor sources
- Source area migrates from SW to NE

→ indicates the "real" connection between tremor and surface deformation



Long-term SSEs:

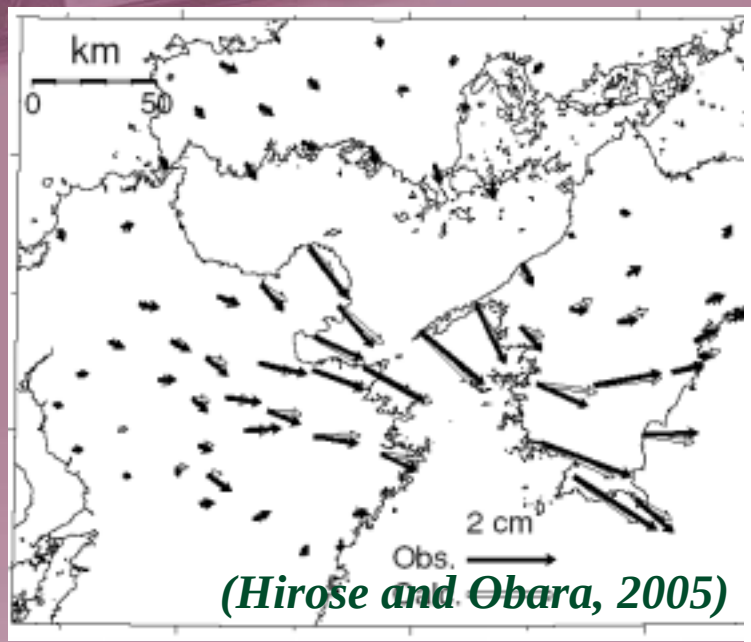
1) Title, GPS, and Tremor



(Hirose and Obara, 2005)

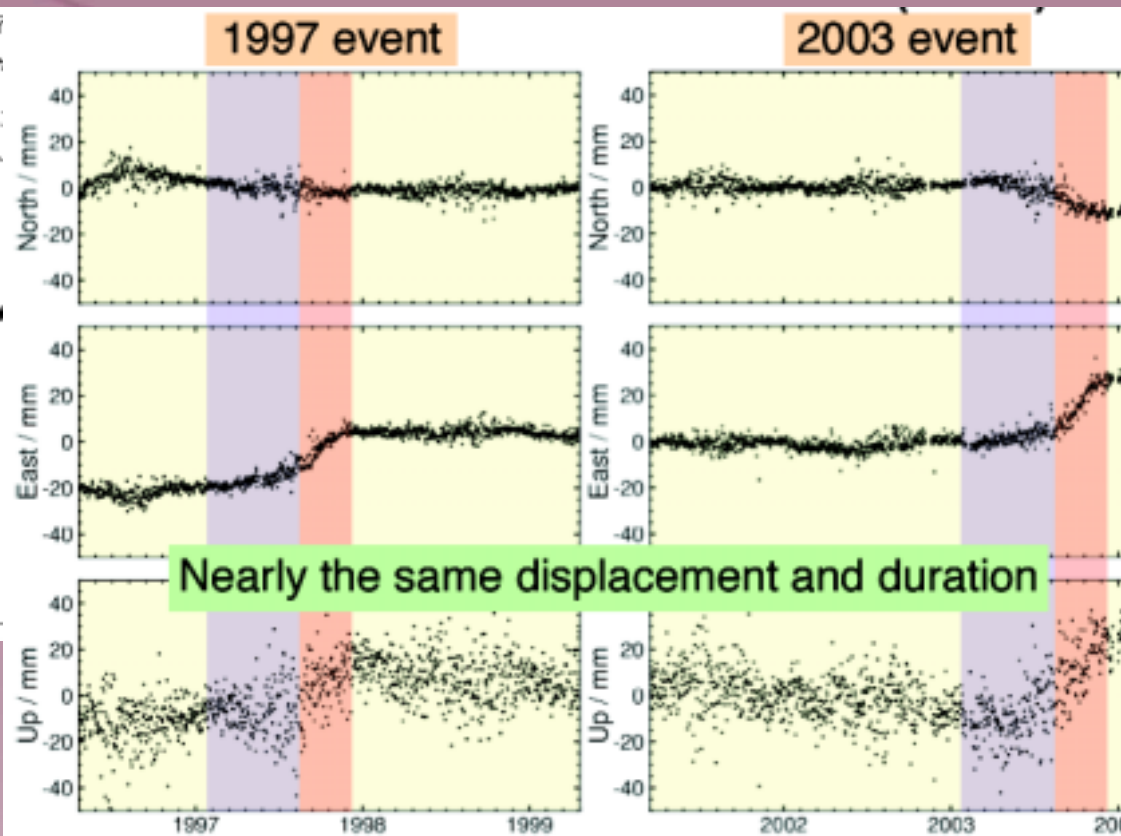
2) Surface deformation field

2003 long-term SSE



(Hirose and Obara, 2005)

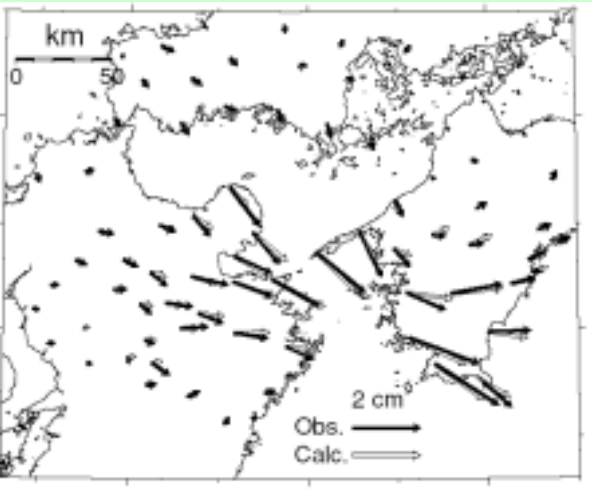
1997 long-term SSE



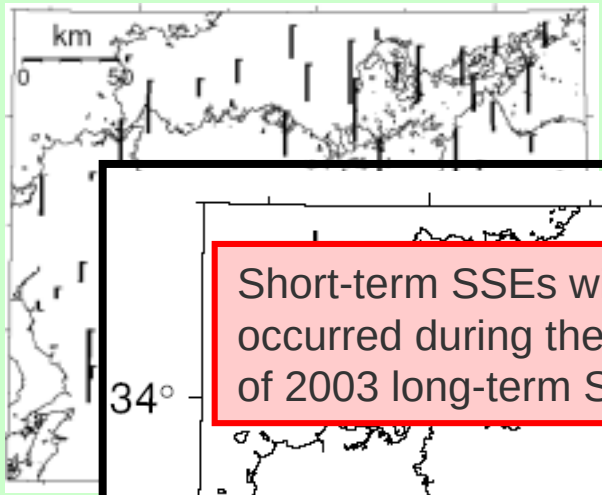
- The spatial pattern of the horizontal displacement vectors appears to be approximately the same as that in the previous 1997 SSE.

2) Surface deformation field & fault model

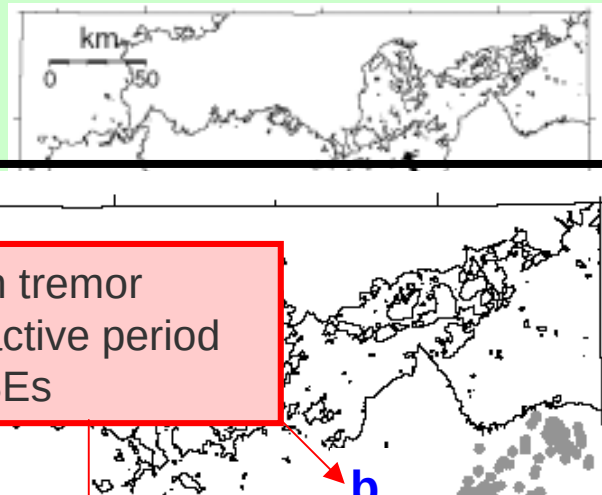
Horizontal displacements



Vertical displacements



Title

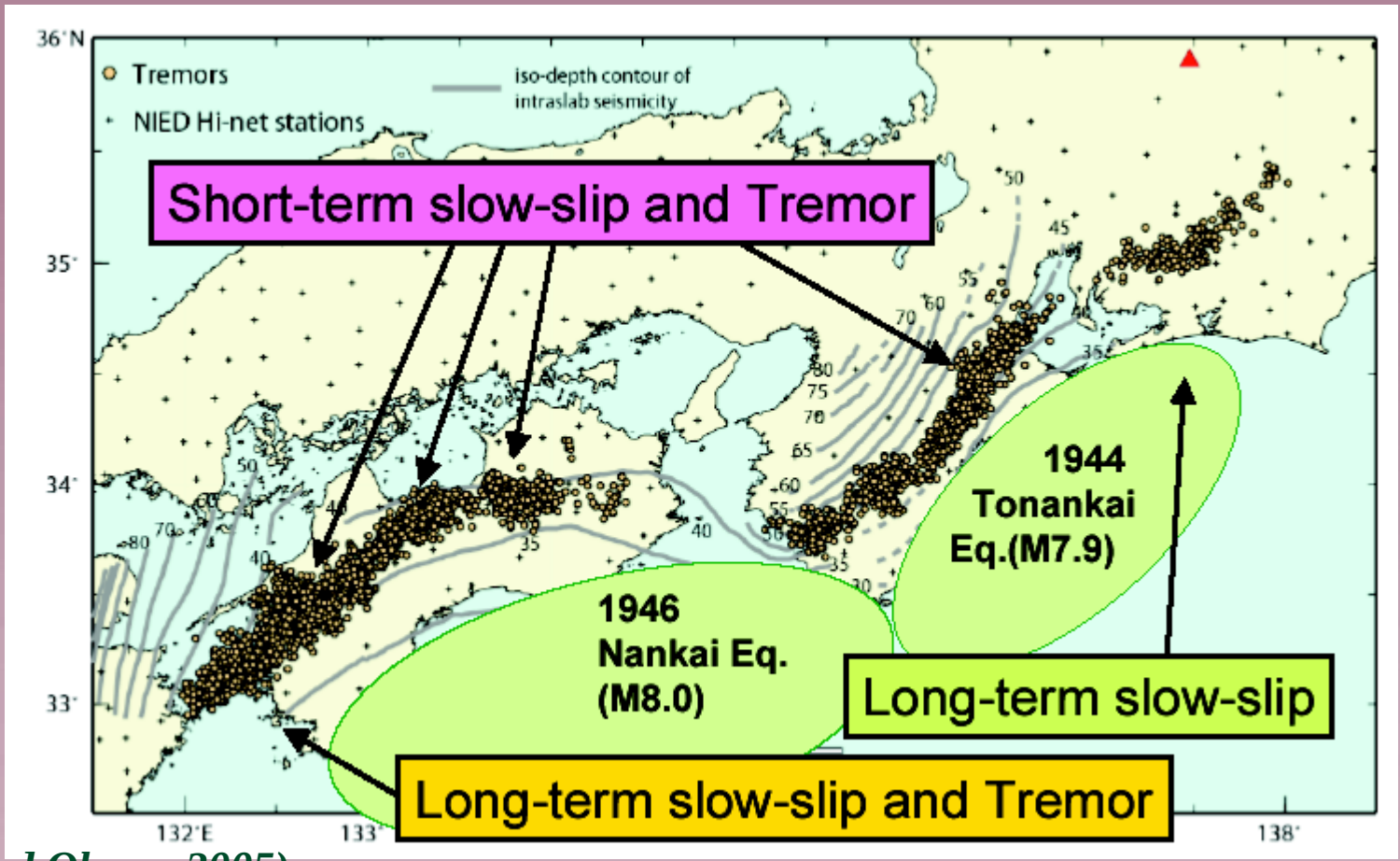


The simple rectangular fault model can explain the observed crustal deformation data.

(Hirose and Obara, 2005)

Distribution of short- and long-term SSEs

Tremor and short-term SSEs:
detected along the strike of subducting slab
Tremor and long-term SSEs:
detected in Bungo Channel but unclear in Tokai



(Hirose and Obara, 2005)

Summary

- Location of tremors?

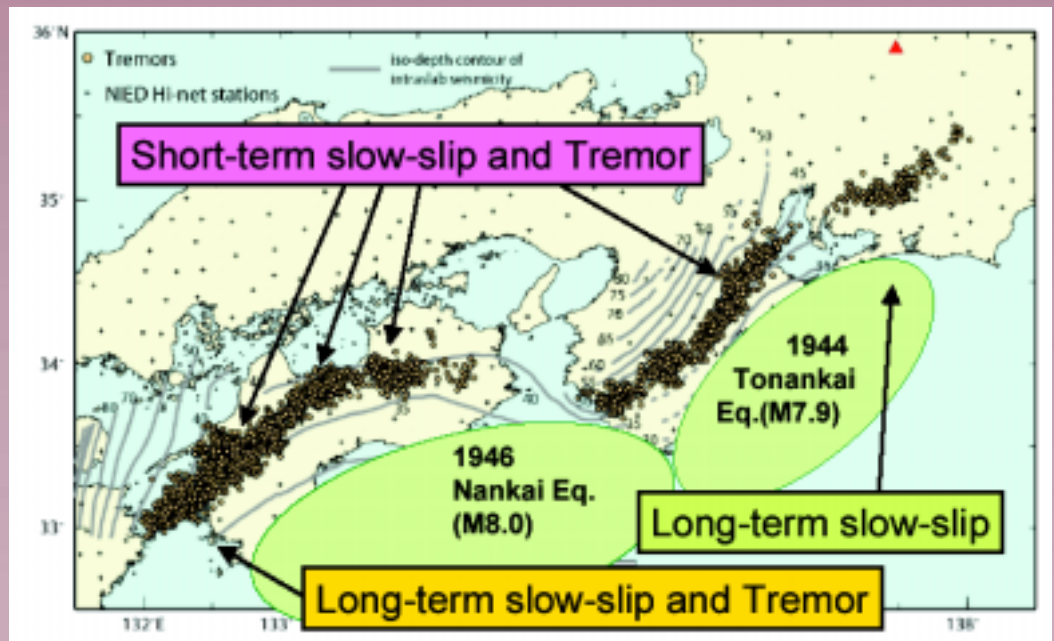
Deep tremor occur in a narrow belt at the down dip of the seismogenic zone.

The agreement of tremor locations with the shape and position of the seismic zone indicates that the vibrations are of tectonic origin.

- Location of SSEs?

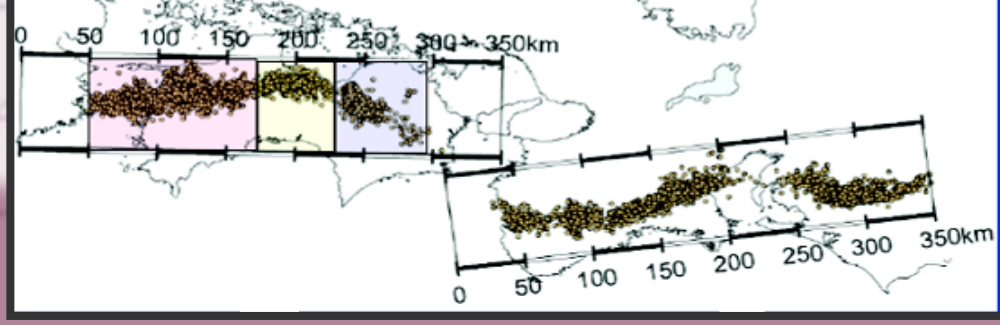
Slow slip events occur in some parts of the tremor zone.

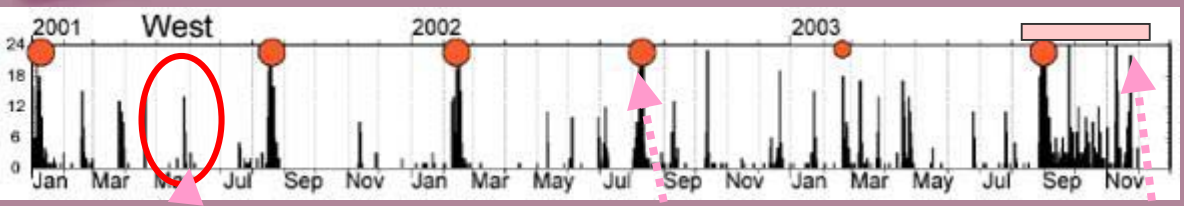
The style of the coupling phenomenon has regional difference.



(Hirose and Obara, 2005)

Summary





Minor tremor

Major tremor

?

Duration : hrs ~ days

Duration :days ~ weeks

Tr : 3 months (E) 6 months (W)

?

Too small to detect?

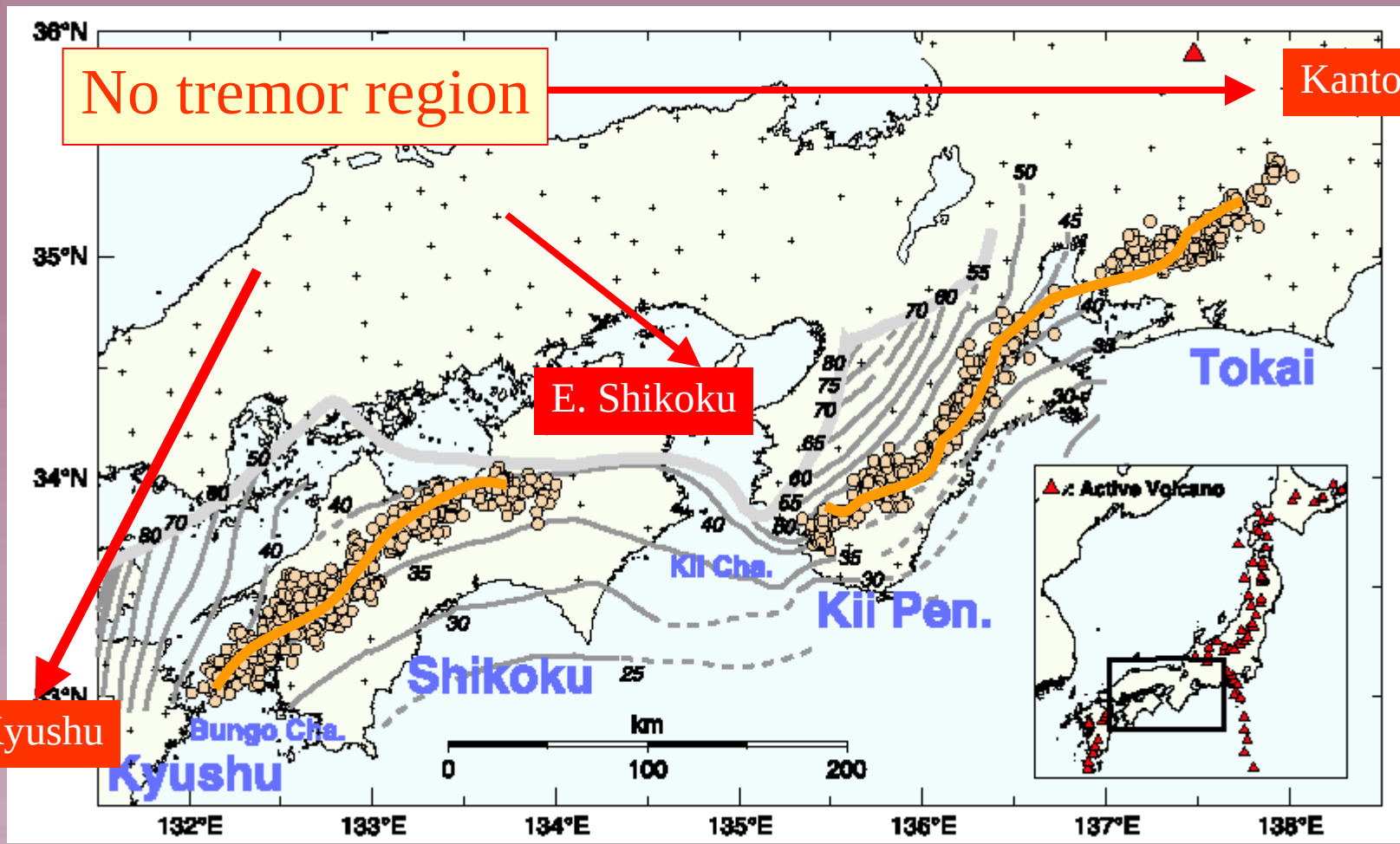
Short-term SSEs

Long-term SSEs

Difference in generation mechanism?

Duration ~ 1 week	**Duration ~ 1 yr**
Tr=2~6 months	**Tr=6 yr**
Deeper portion	**Shallower portion**
Faster slip rate ~ 1 cm/day	**Slower slip rate ~10 cm/yr**

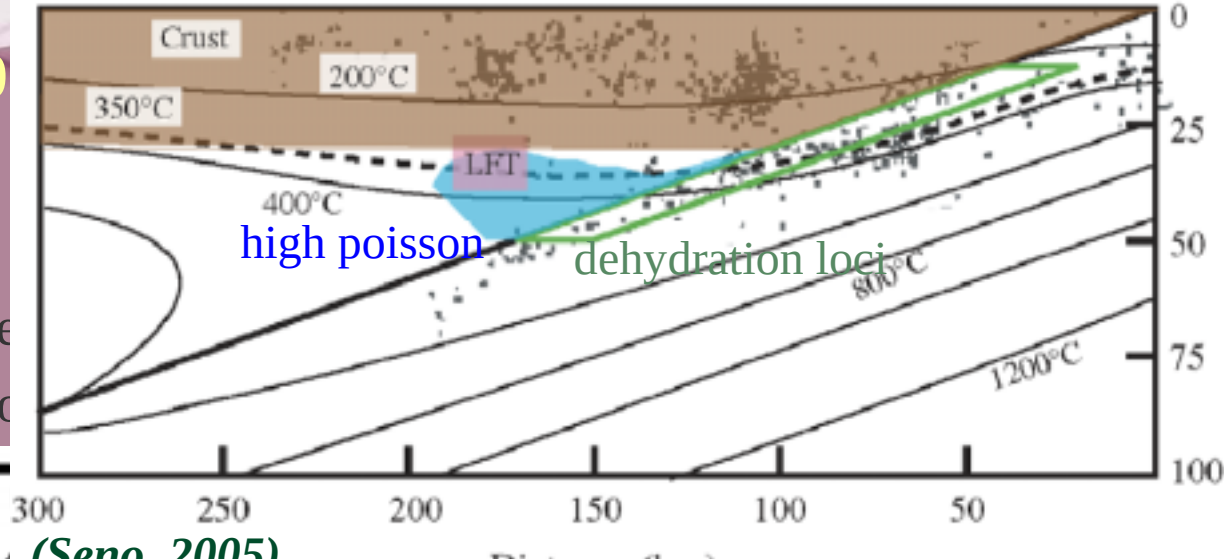
Questions remain open



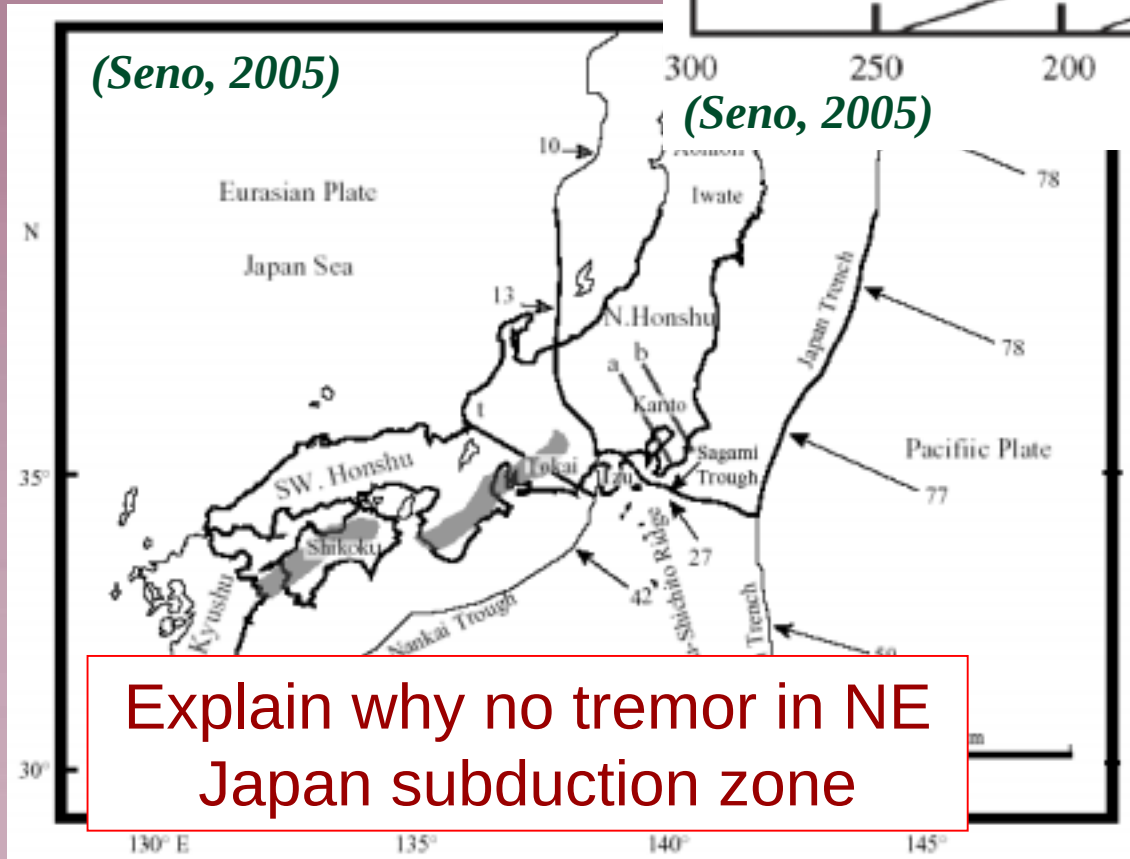
(Seno, 2005) *(Obara, 2002)*

The cause of non-volcanic tremor?

- Hypothesis (Obara, 200
- Flow of water liberated
  PSP.
- NE Japan: PP(130 million ye
- SW Japan: PSP(15~30 millio

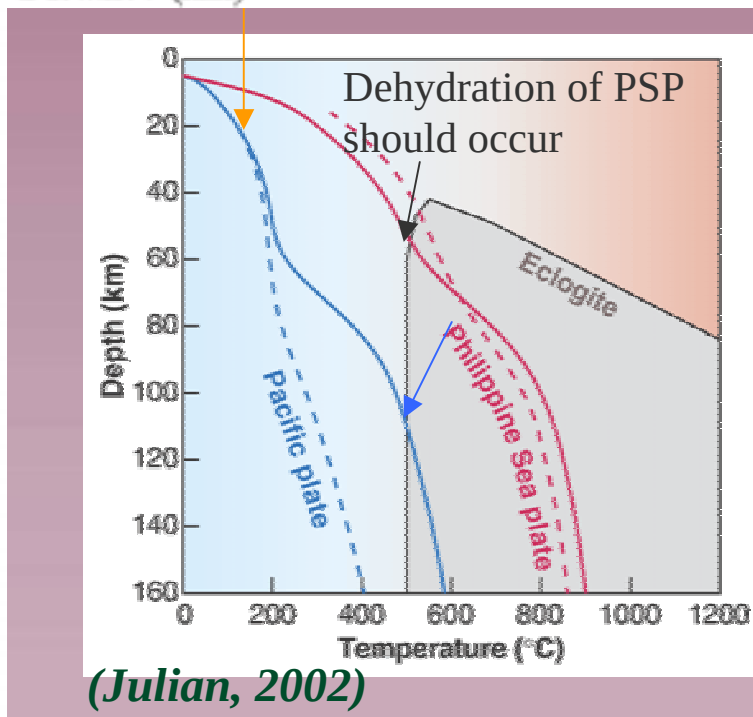


(Seno, 2005)



(Seno, 2005)

Explain why no tremor in NE Japan subduction zone



(Julian, 2002)

Non-volcanic tremor occurs elsewhere?

Places where young, warm lithosphere subduct?

Southern Mexico & western South America

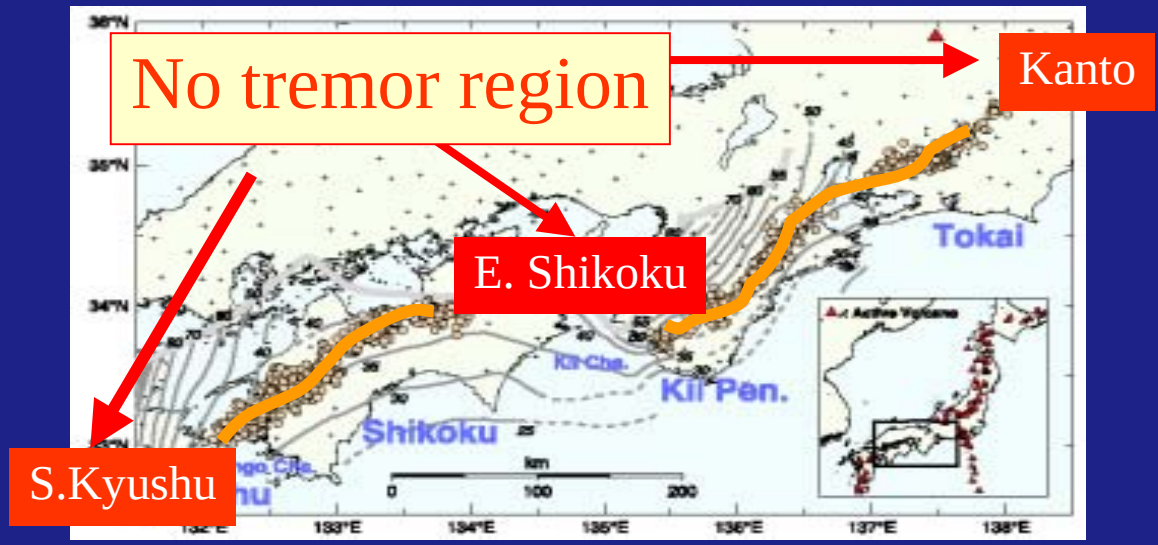
Slow slip events observations (the existence of serpentinite : high poisson ratio or high Vp/Vs ratio)

→ slow slip promote tremor activity?

Fully characterizing the seismic behavior correlated to slow slip ~

Low-frequency earthquakes in Shikoku, Japan, and their relationship to episodic tremor and slip

Areas without earthquakes within the subducted crust



Kanto

E. Shikoku

S. Kyushu（？）

||

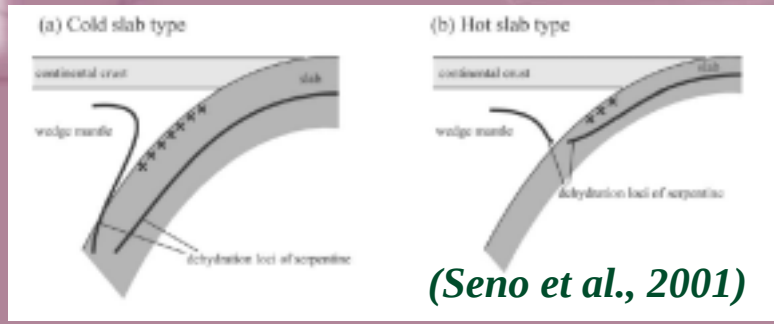
Areas without non-volcanic tremor

(Seno, 2005)

The cause of non-volcanic tremor?

- Hypothesis (Seno and Yamasaki, 2003):
- **Subduction of Normal oceanic crust:**

  Hot slab type- Nankai Trough



(Seno et al., 2001)

- **Subducted continental or island-arc crust:**

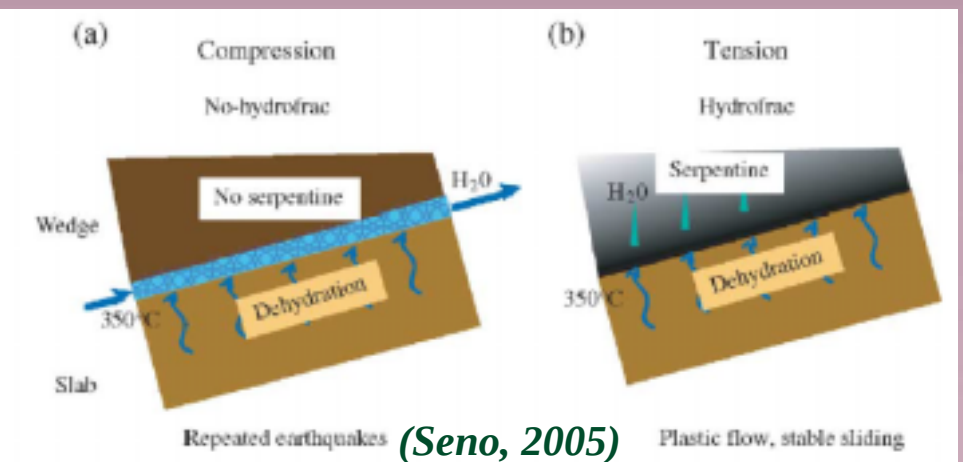
  mainly composed of granite, then does not involve dehydration.

→ NO TREMOR , NO EARTHQUEAKES within the subducted crust!

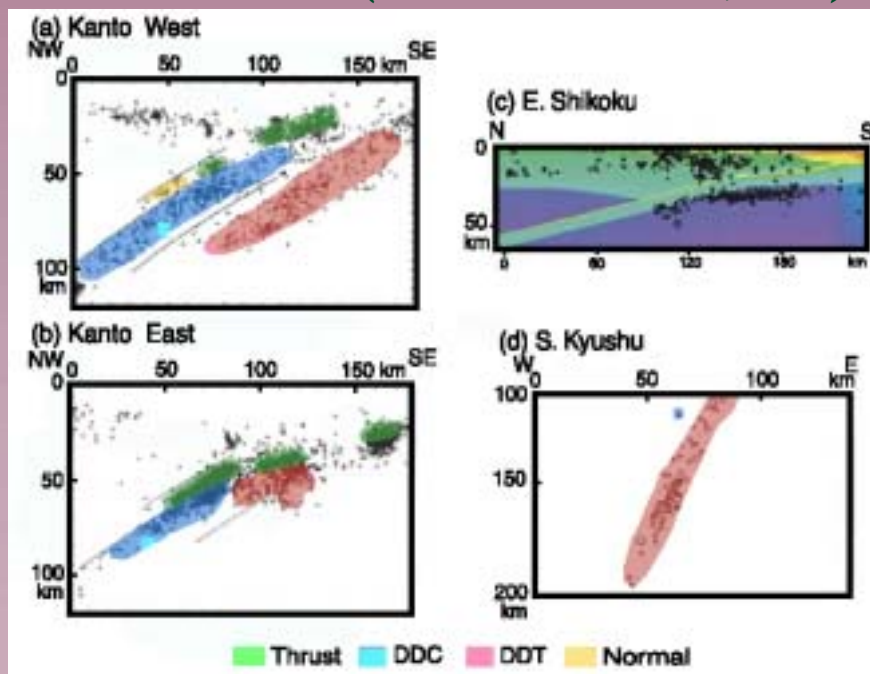
(Seno and Yamasaki, 2002)

Intraslab seismicity exists in the mantle.

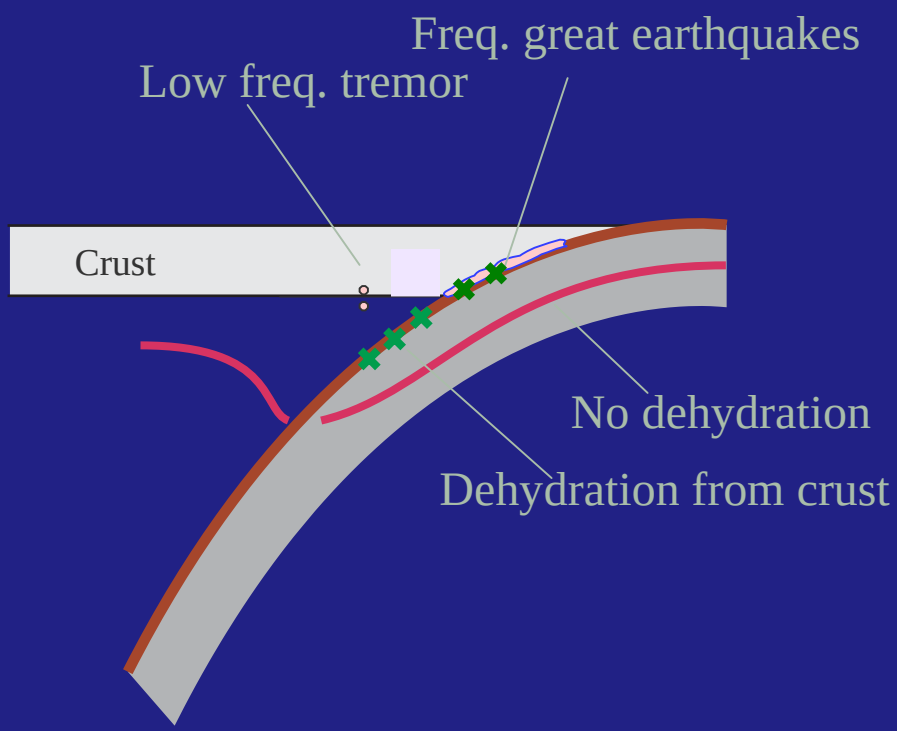
Seismicity within the subducted crust are lacking!



(Seno, 2005)



Normal oceanic crust subduction

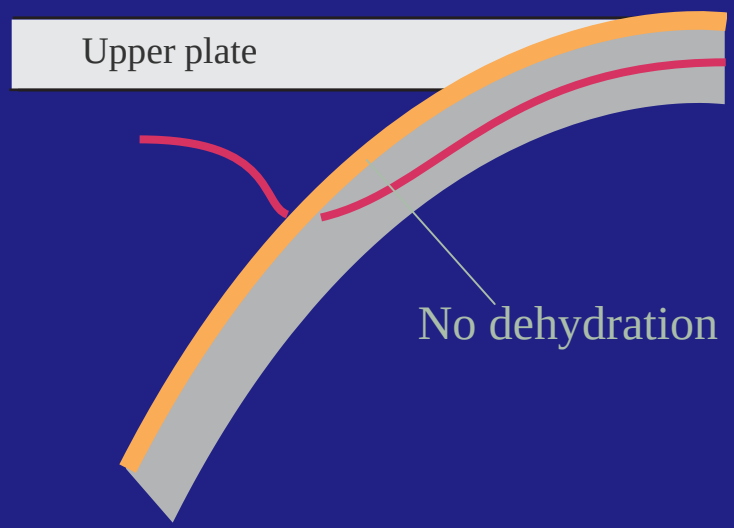


NankaiTrough

Island-arc crust or continental crust subduction

No great earthquakes

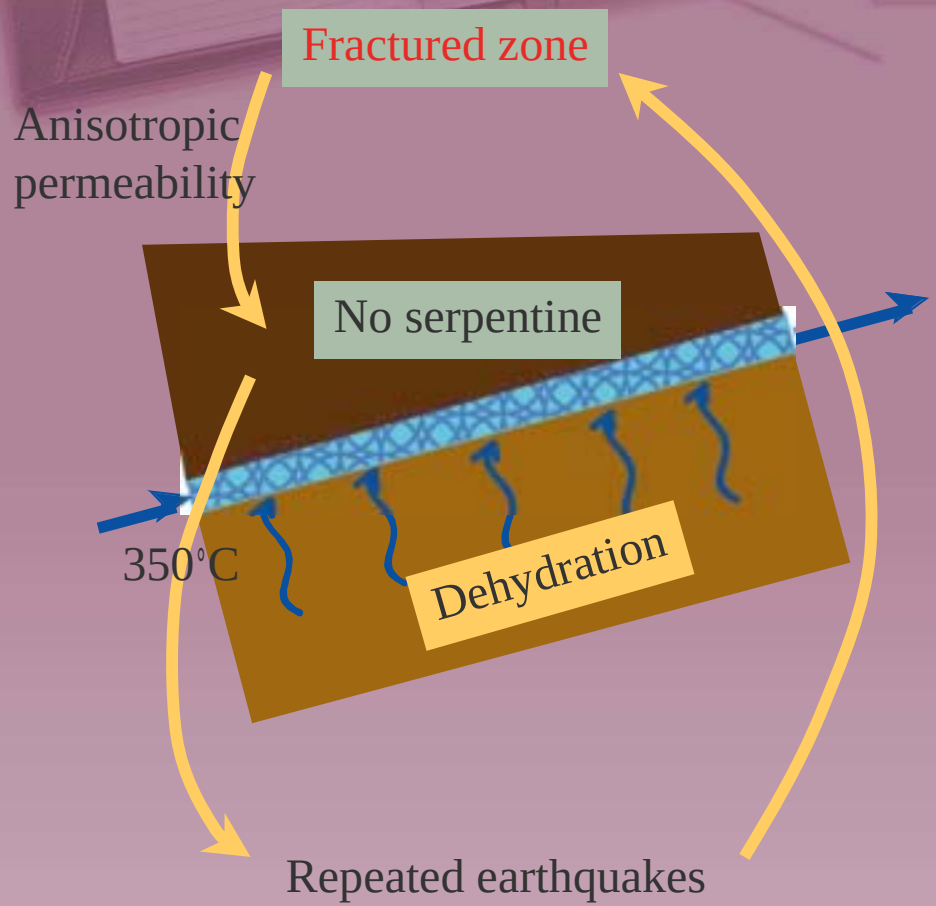
No low freq. tremor

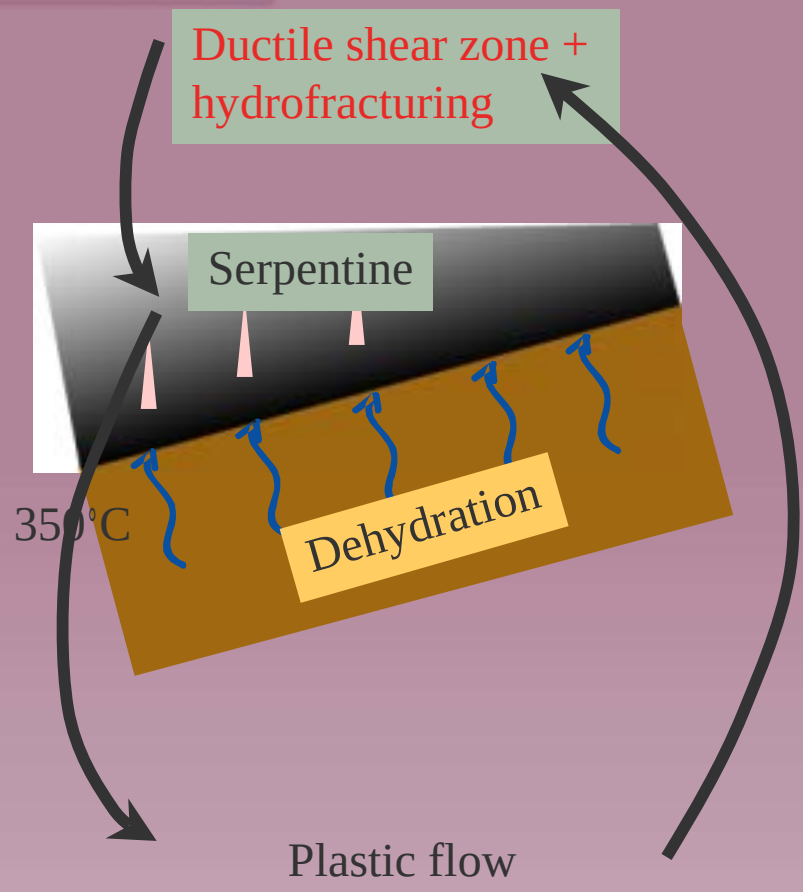


N. of Izu, Zagros, Himalaya

(Seno, 2005)

Cold mantle wedge





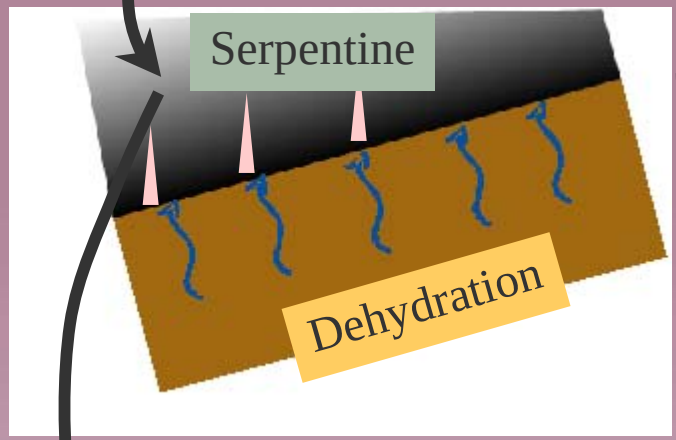
N. Honshu, Kanto, S. Kyushu

Iwate-oki, Bonin, Tonga

(Seno, 2005)

Hot mantle wedge

Ductile shear zone +
hydrofracturing



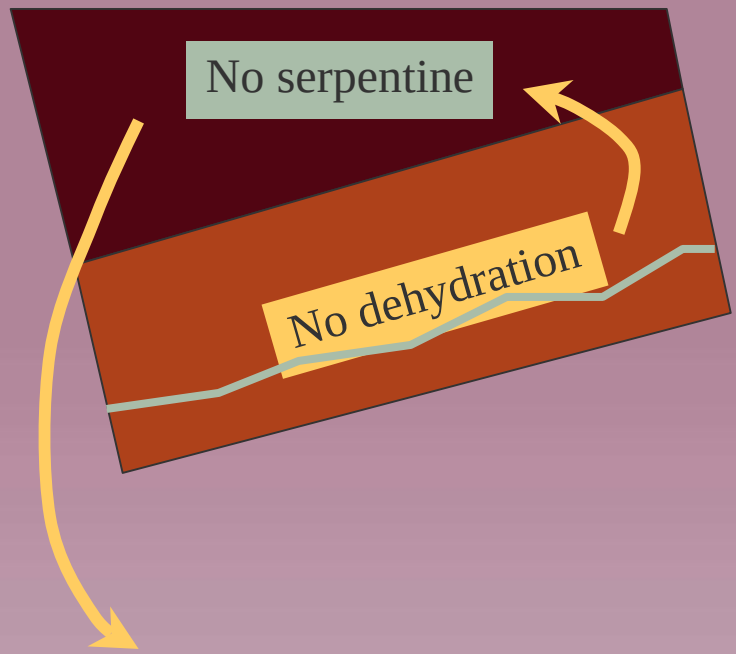
350°C

Plastic flow

Nankai, Ryukyu, Cascadia, Mexico

(Seno, 2005)

Collision zone



Stable sliding with very high shear stress

or delamination

N. Izu, Himalaya, Zagros

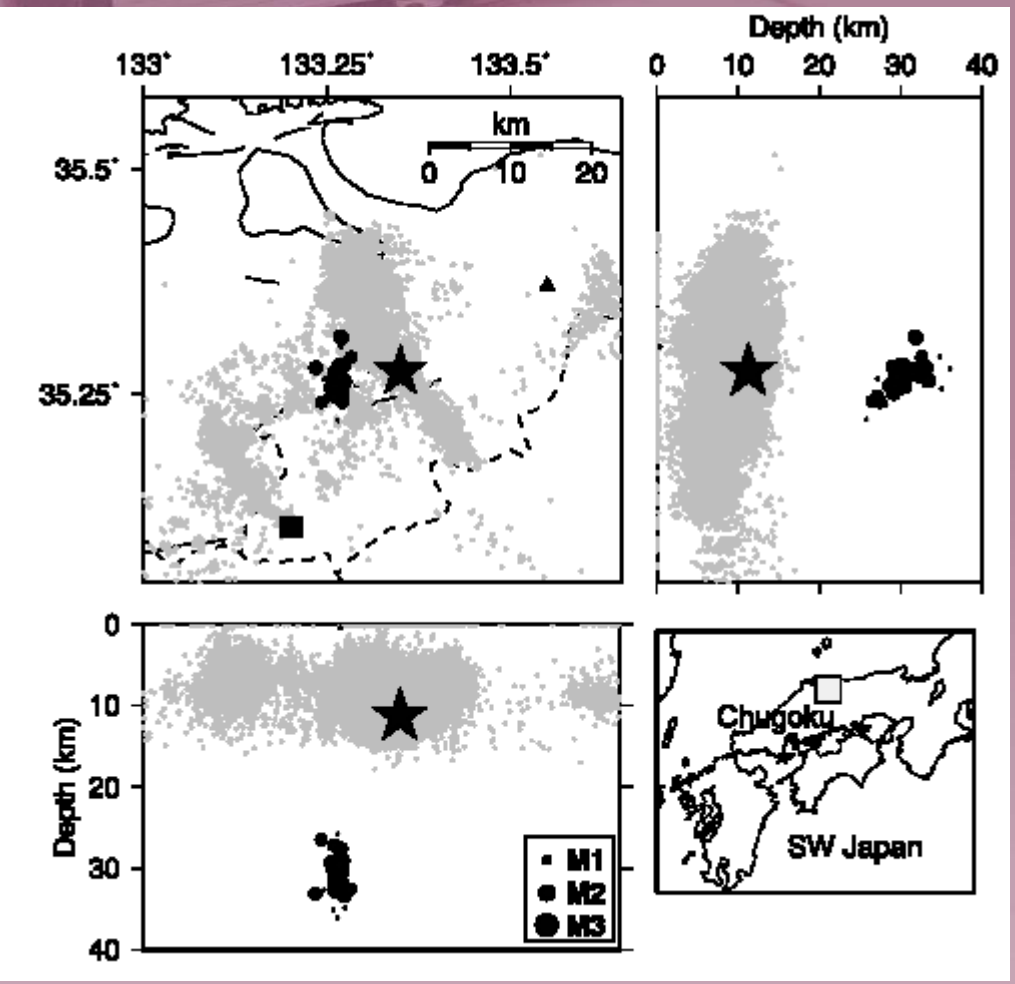
(Seno, 2005)

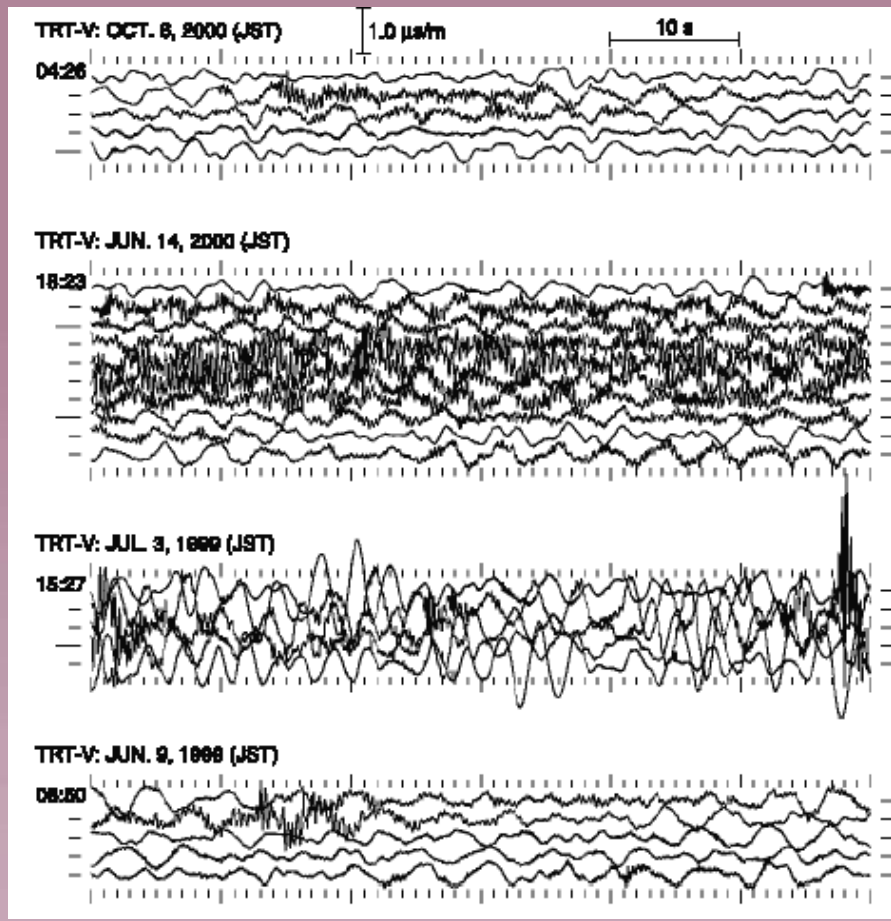
Tremor and slow slip

	W. Shikoku	Cascadia
Recurrence	6 month	13-16 months
Duration	Few weeks	6~20 days
Slow slip events	~0.1 micro radian (tiltmeter)	~ 5mm(GPS)
	Connection between tremor and slip is less robust	

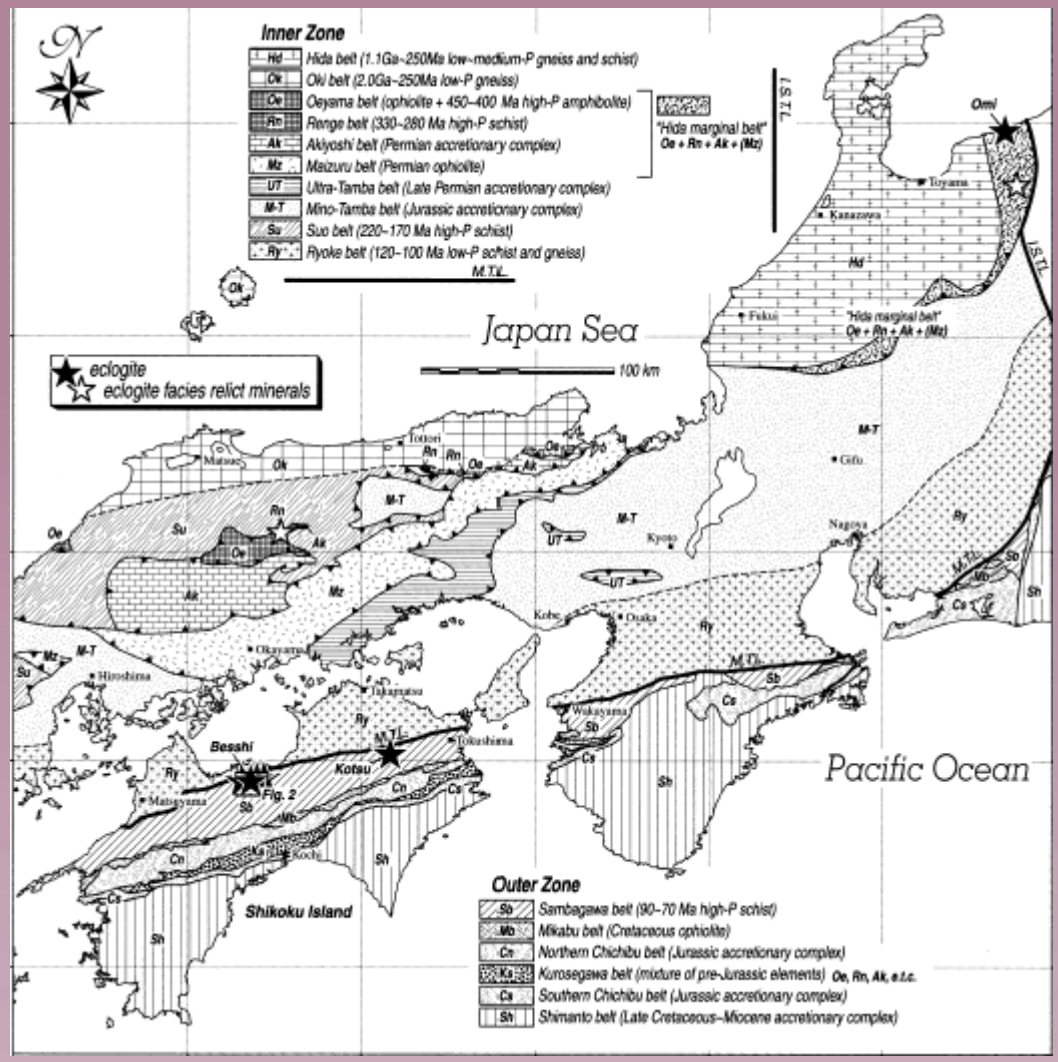
Along-strike migration

Low frequency events

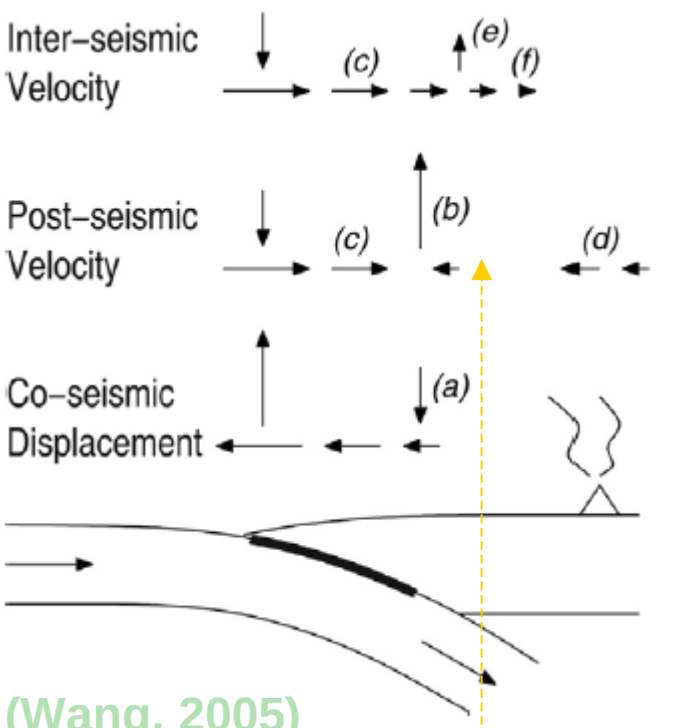




(Ohmi and Obara, 2002)

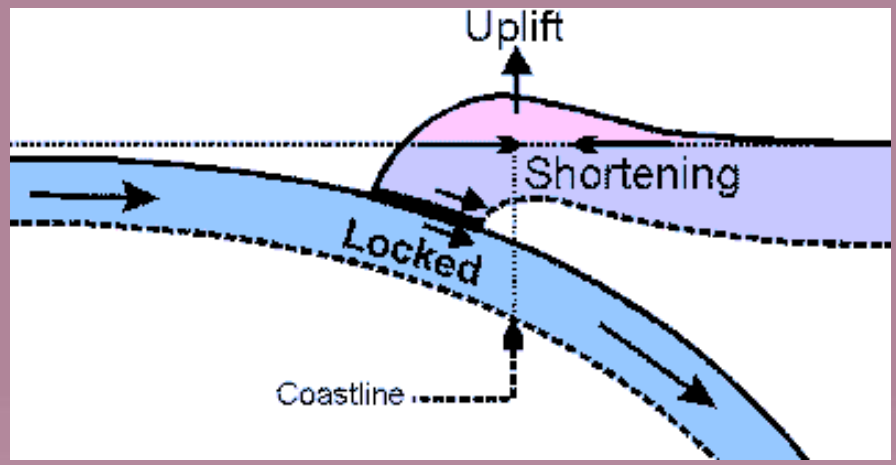

Inner Zone
Hd Hida belt (1.1Ga–250Ma low–medium-P gneiss and schist)
Ok Oki belt (2.0Ga–250Ma low-P gneiss)
Oe Oeyama belt (ophiolite + 450–400 Ma high-P amphibolite)
Rn Renge belt (330–280 Ma high-P schist)
Ak Akiyoshi belt (Permian accretionary complex)
Mz Maizuru belt (Permian ophiolite)
UT Ultra-Tamba belt (Late Permian accretionary complex)
M-T Mino-Tamba belt (Jurassic accretionary complex)
Su Suo belt (220–170 Ma high-P schist)
Ry Ryoke belt (120–100 Ma low-P schist and gneiss)
M.T.L.
"Hida marginal belt" Oe + Rn + Ak + (Mz)
I.S.T.L.
eclogite
eclogite facies relict minerals
Japan Sea
100 km
Pacific Ocean
Omi
Toyama
Kanazawa
Fukui
Gifu
Nagoya
Kyoto
Osaka
Kobe
Wakayama
Tottori
Matsue
Okayama
Hiroshima
Takamatsu
Tokushima
Matsuyama
Kochi
Besshi
Kotsu
Fig. 2
Shikoku Island
Outer Zone
Sb Sambagawa belt (90–70 Ma high-P schist)
Mb Mikabu belt (Cretaceous ophiolite)
Cn Northern Chichibu belt (Jurassic accretionary complex)
Ks Kurosegawa belt (mixture of pre-Jurassic elements) Oe, Rn, Ak, e.t.c.
Cs Southern Chichibu belt (Jurassic accretionary complex)
Sh Shimanto belt (Late Cretaceous–Miocene accretionary complex)

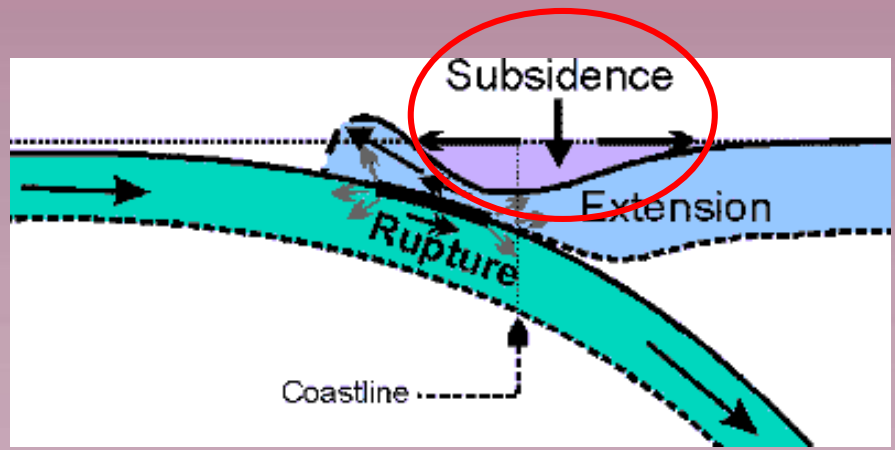
Subduction earthquakes cycle deformation



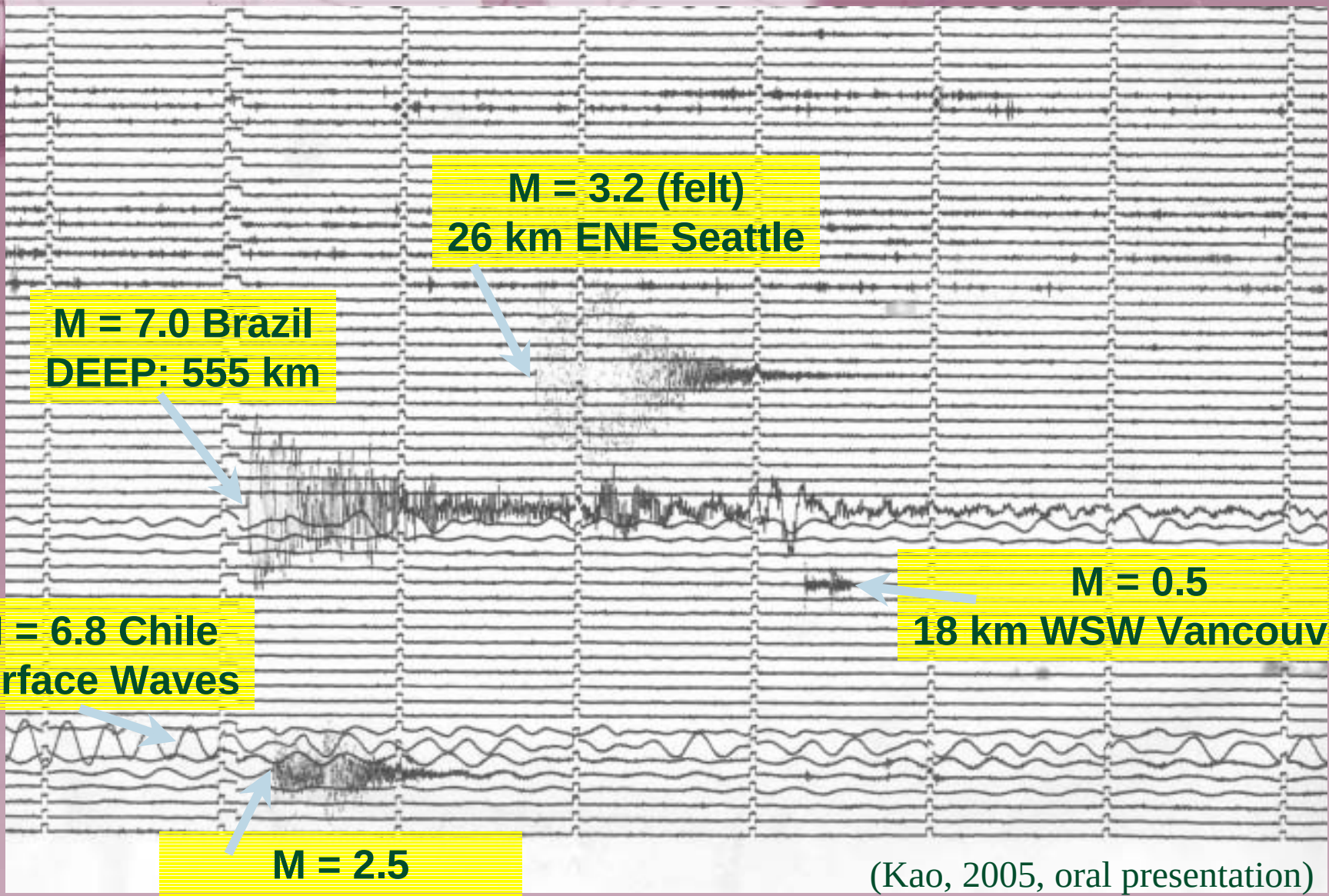
(Wang, 2005)

The max. co-seismic subsidence quickly bounces back to become a region of uplift (b)



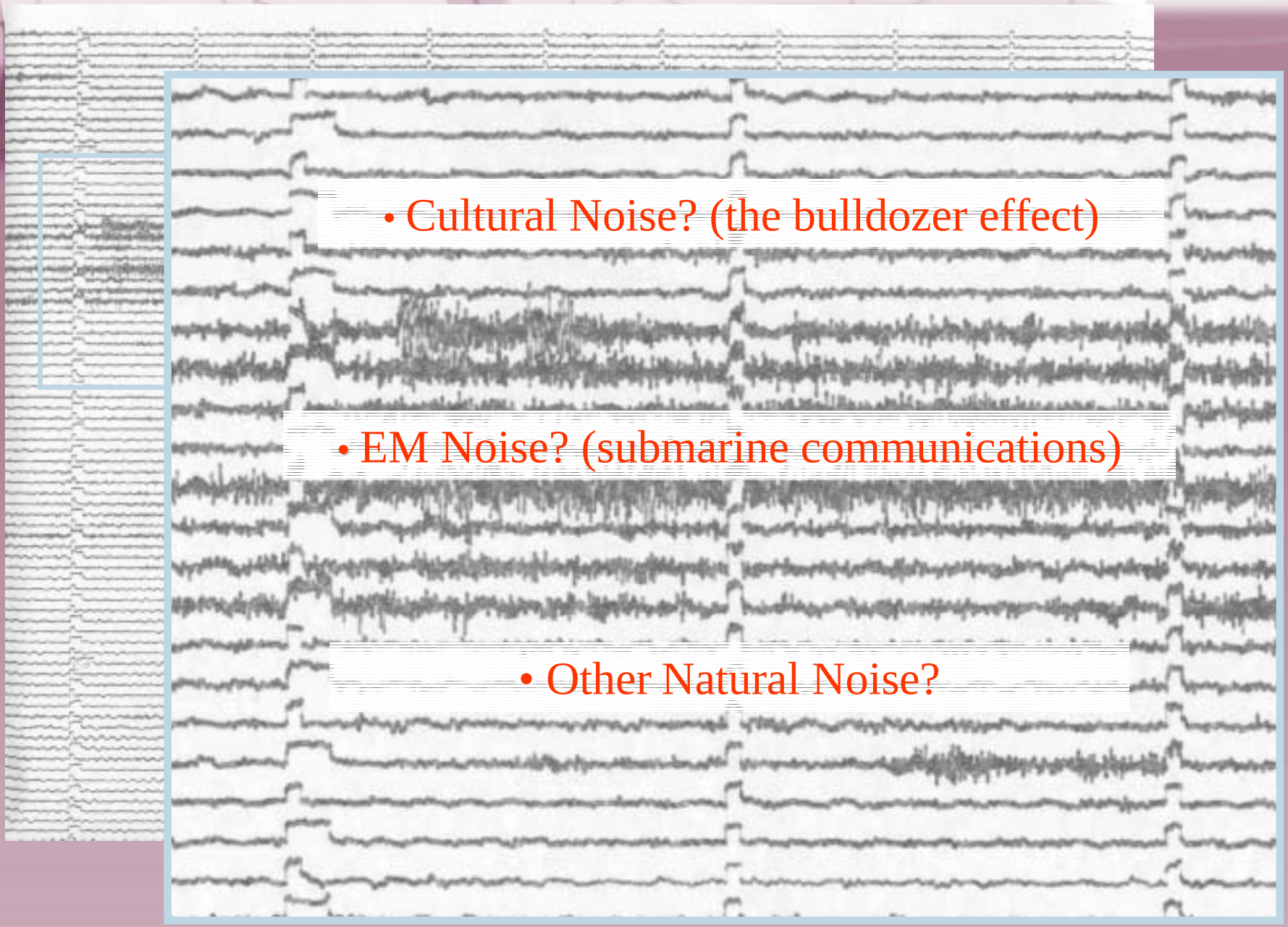


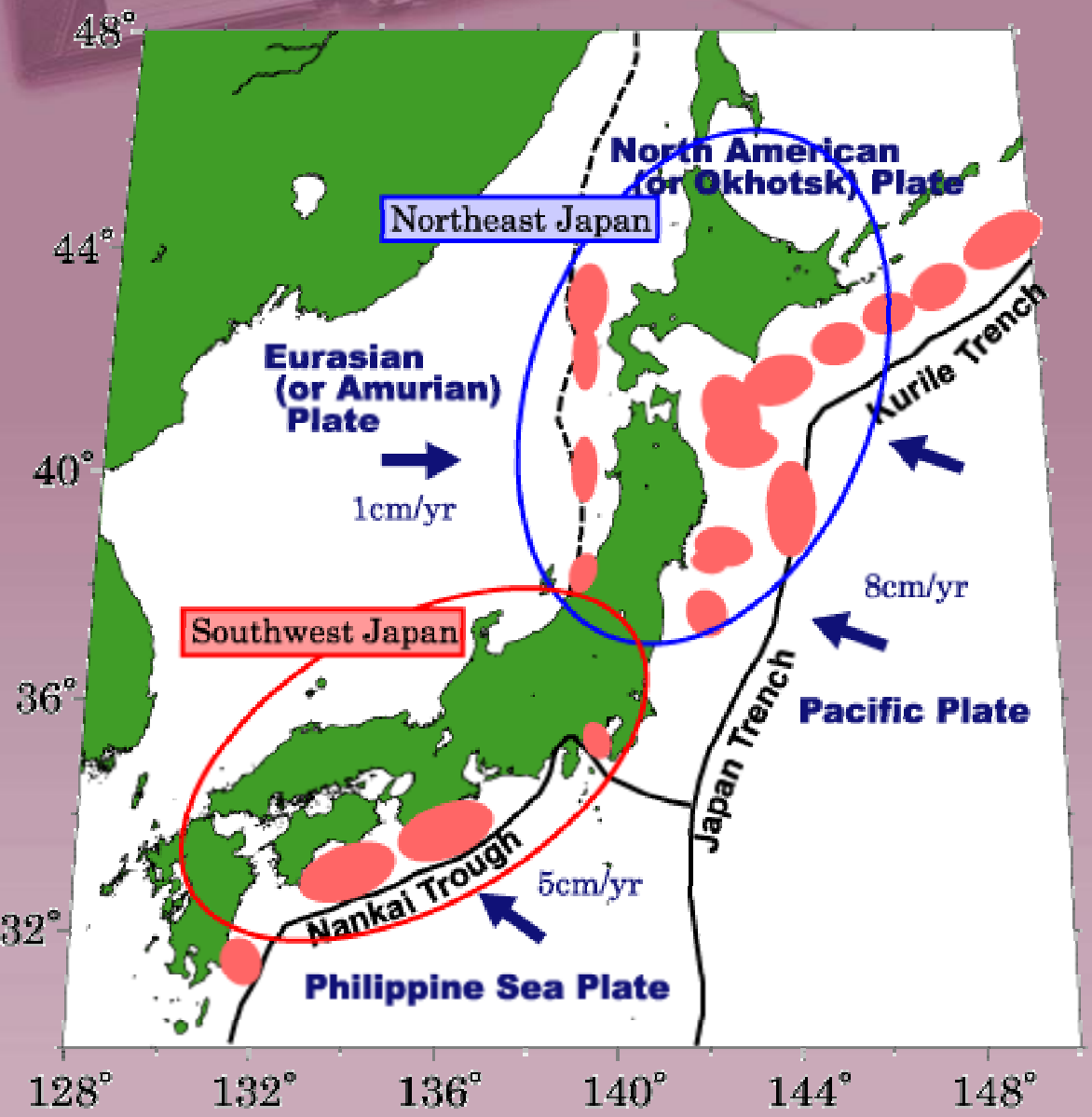
(http://gsc.nrcan.gc.ca/geodyn/eqcycle_e.php)



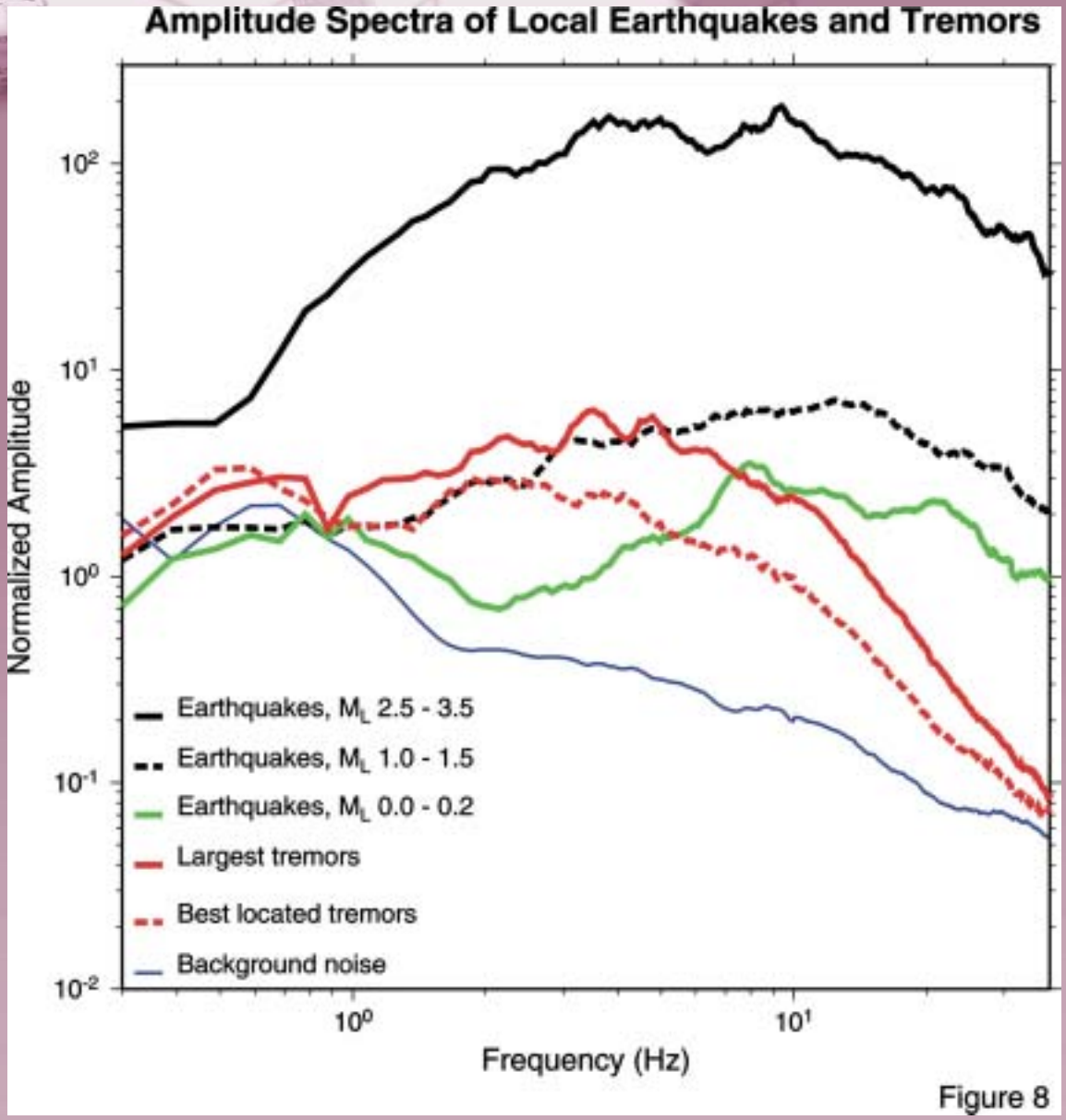
Typical earthquake signals observed at the same seismic station (PGC)

Innovative Explanations for Recurring Seismic “Noise”




48°
44°
40°
36°
32°
128°
132°
136°
140°
144°
148°
North American
(or Okhotsk) Plate
Northeast Japan
Eurasian
(or Amurian)
Plate
1cm/yr
Kurile Trench
8cm/yr
Southwest Japan
Pacific Plate
Japan Trench
Nankai Trough
5cm/yr
Philippine Sea Plate

Comparison of Vertical Velocity Amplitude Spectra



(Kao et al., 2005)