Intraslab earthquake

At depths of intraslab EQs, confining pressure becomes huge and materials will not fracture in a brittle manner under differential stresses (Paterson, 1978).

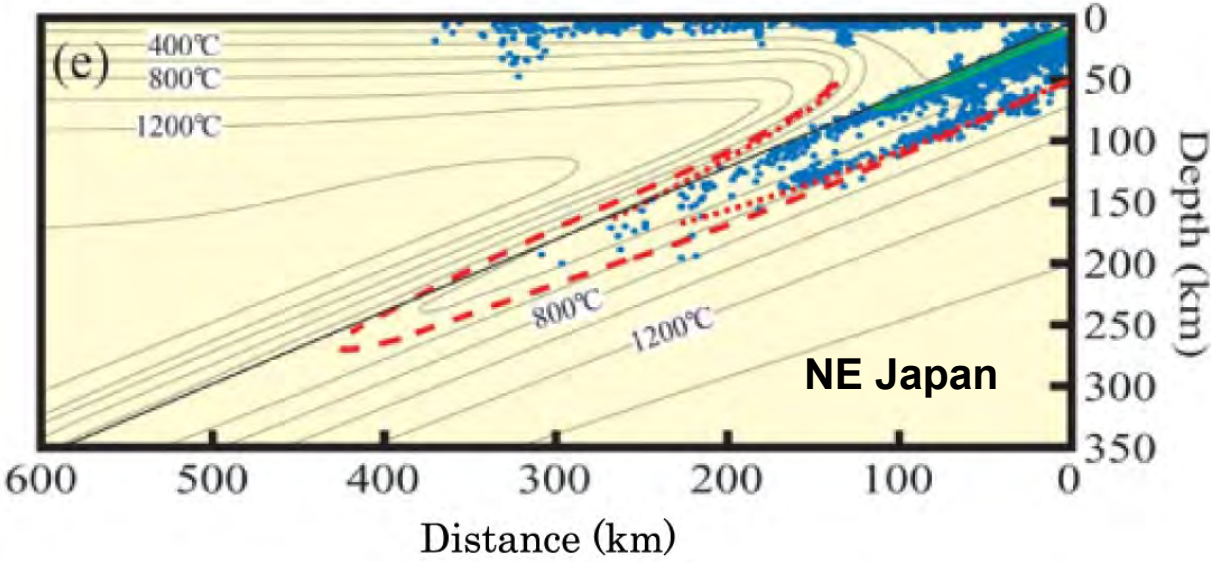
→ Special weakening mechanism is required for generation of intraslab EQs.

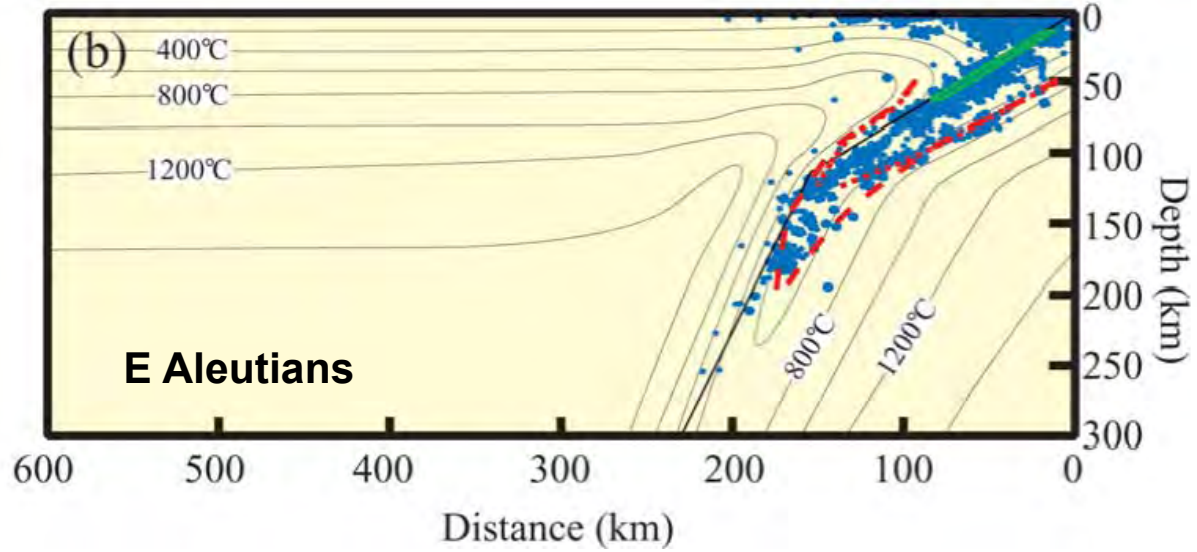
→ One important hypothesis: Dehydration embrittlement

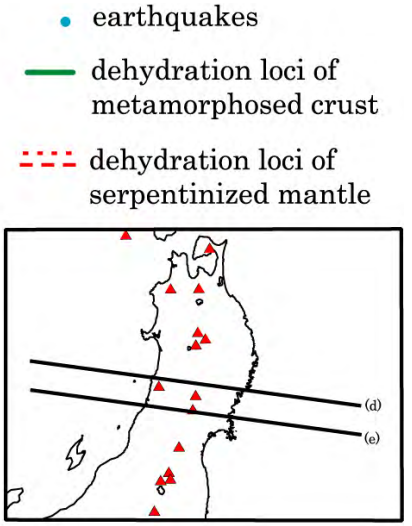
→ 1) Intraslab EQs occur at locations where subducting slab passes through phase boundary accompanied by dehydration reaction (or dehydration loci)

2) Low-V oceanic crust persists down to depth of the phase boundary

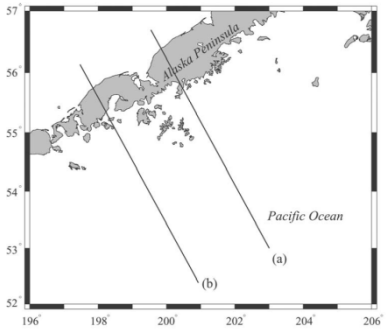
Dehydration loci of crust & mantle







(Yamasaki & Seno, JGR 2003)

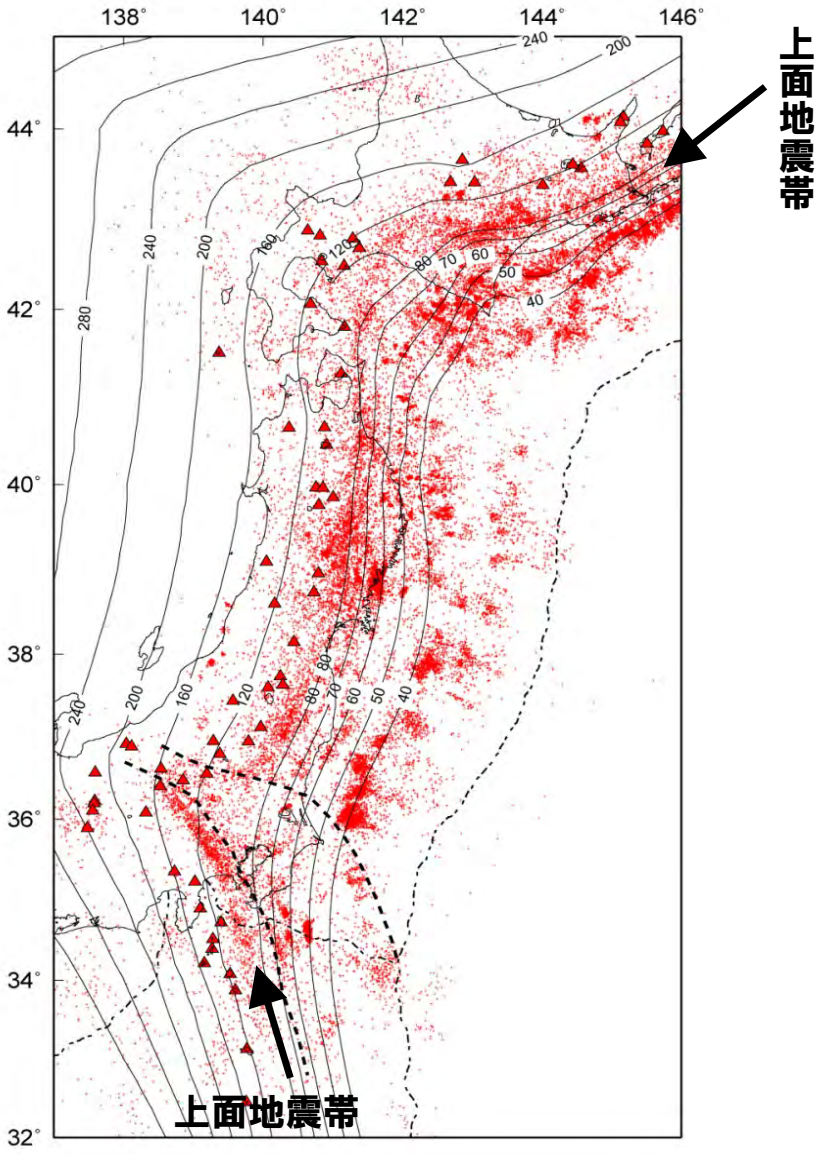


Dehydration loci of metamorphosed crust, shown by green lines, and of serpentinized mantle, shown by red lines estimated by Yamasaki & Seno seem to coincide with locations of intermediate-depth seismicity.

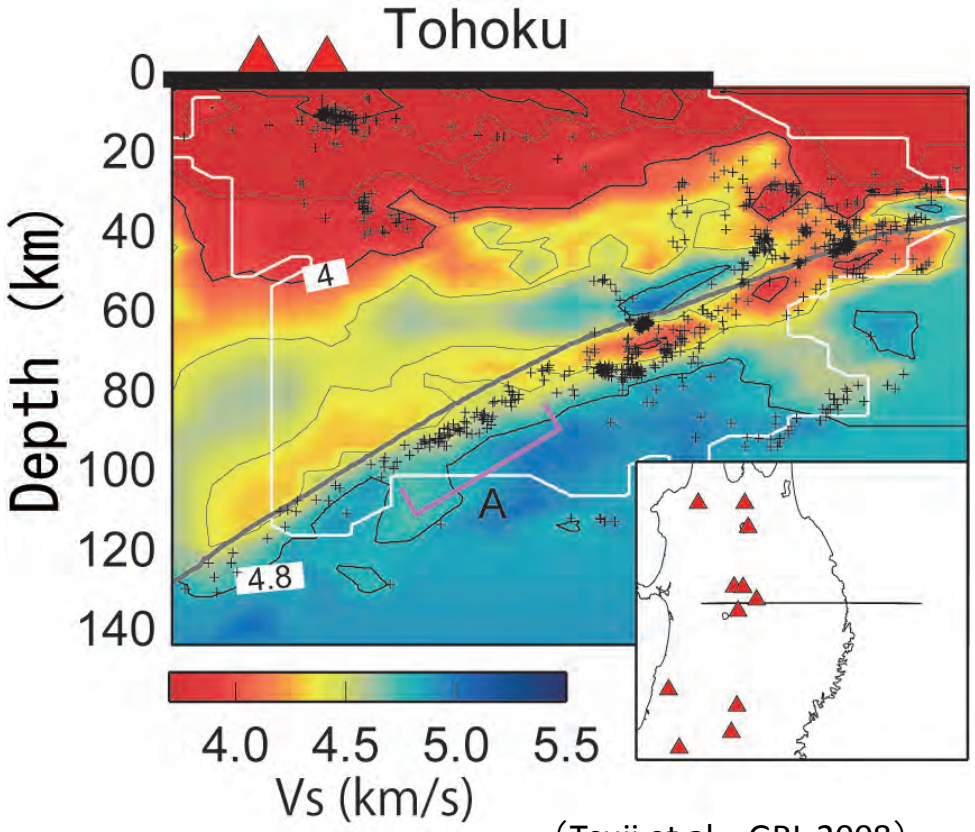
→ support dehydration embrittlement, and explain why double seismic zone is formed

EQs in slab crust – upper-plane seismic belt

EQs in slab crust: Upper-plane seismic belt at a depth of ～80km



Across-arc vertical cross section of Vs



（Tsuji et al.，GRL 2008）

・上面地震帯の深さまで低速度域が及ぶ

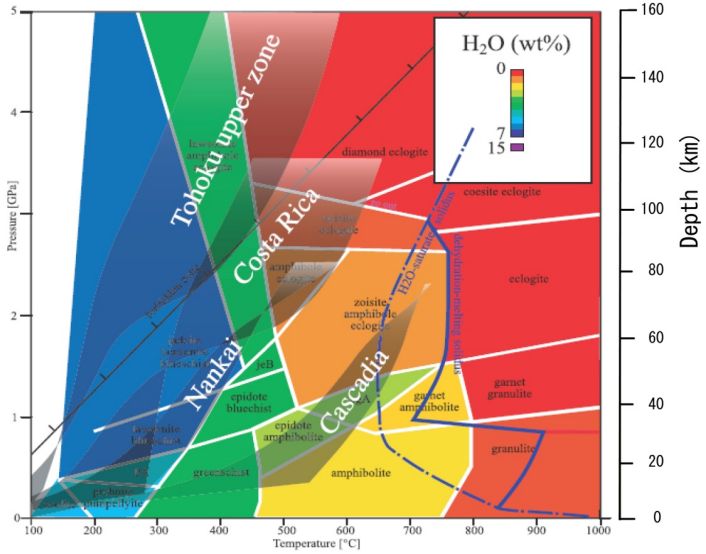
Low-V layer in the slab crust persists to a depth of upper-plane seismic belt

・上面地震帯の位置で相転移が生じていることを示唆

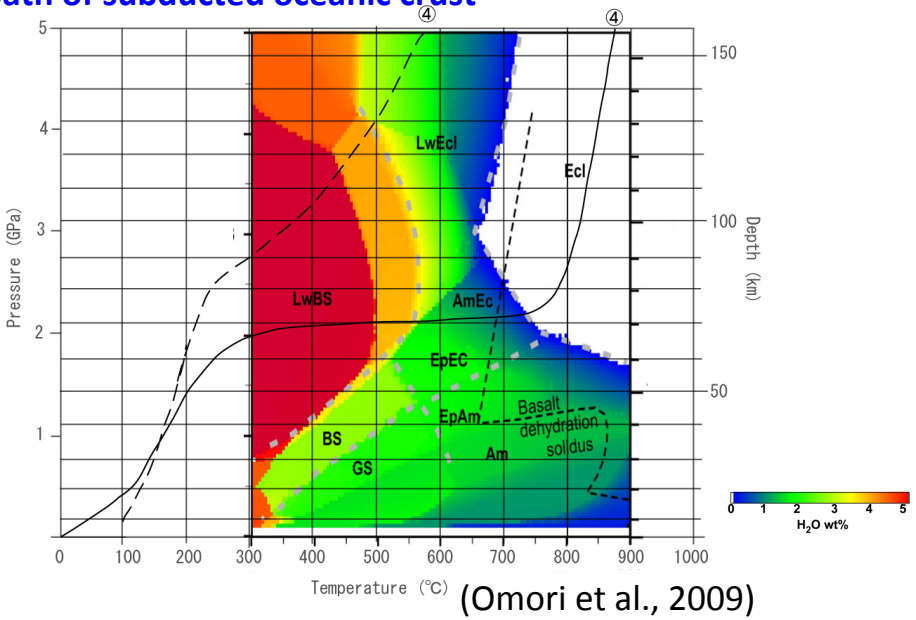
Suggest phase transformation takes place at a depth of the upper-plane seismic belt

Upper-plane seismic belt corresponds to dehydration loci?

●Phase diagram of MORB & P-T path of subducted oceanic crust

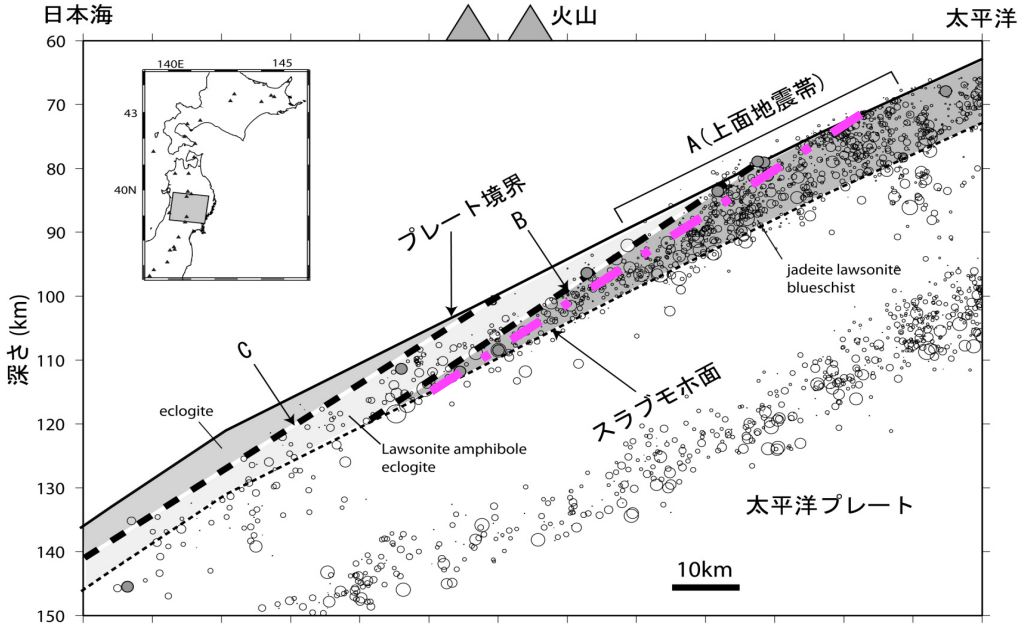


(Hacker et al., 2003)



(Omori et al., 2009)

●Upper-plane seismic belt & facies boundaries on an across-arc vertical section



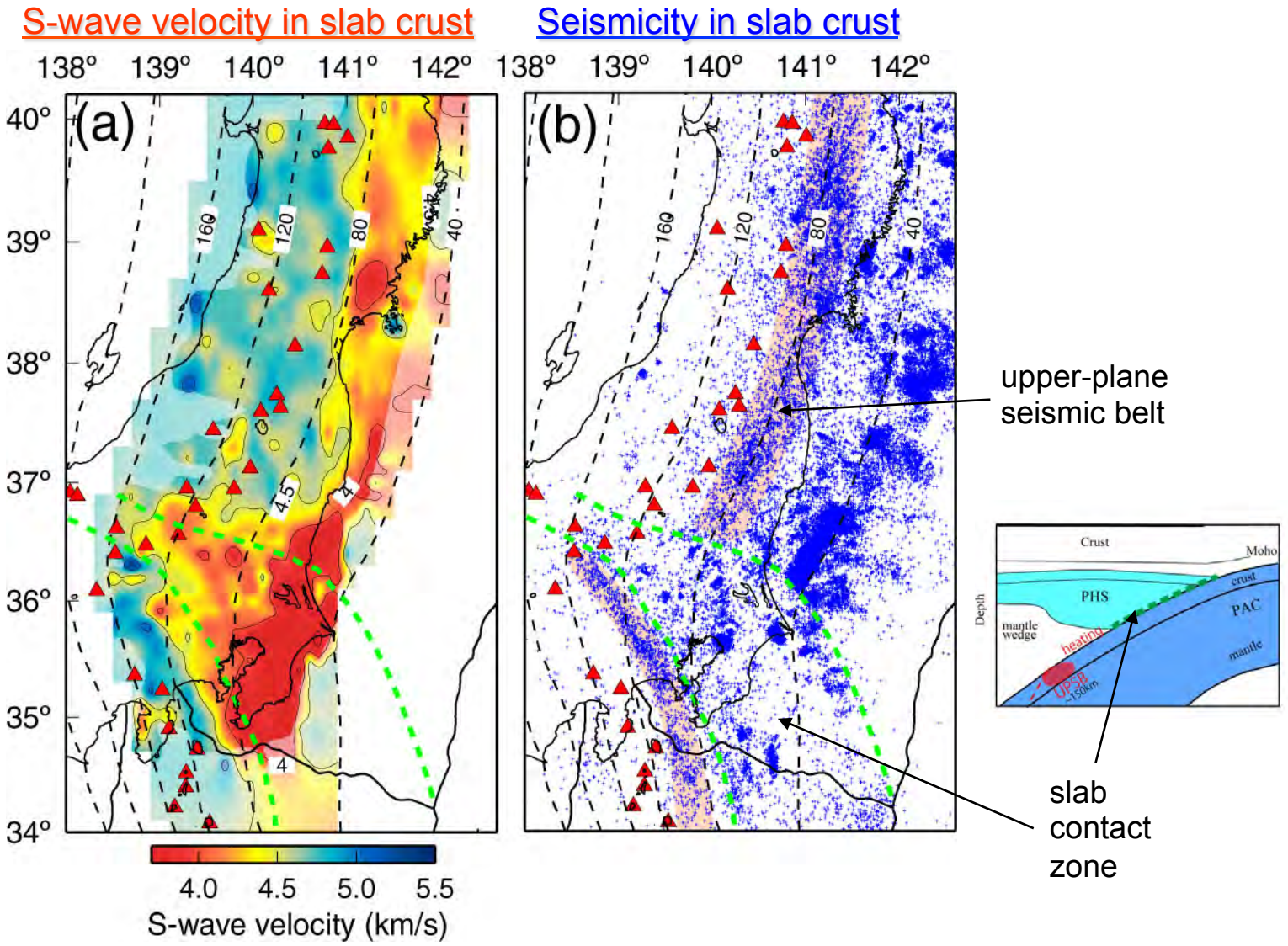
(Kita et al., 2006)

phase diagram	geotherm
Hacker et al. (2003)	Peacock & Wang : iso-viscous (1999)
Omori et al. (2009)	van Keken et al. (2002): stress & temperature-dependent viscosity

スラブ地殻のS波速度分布とスラブ接触域：PHSの遮蔽による相転移の遅れ

(Nakajima et al., GRL 2009)

- Low-Vs persists down to the depth of upper-plane seismic belt(~ 80 km)
- In Kanto, where overlying PHS slab inhibits heating by mantle wedge and suppress temperature rise in PAC slab crust, Vs in PAC slab crust remains low to greater depth, seismic belt being distributed along down-dip limit of this low-V crust.
- Support dehydration embrittlement model



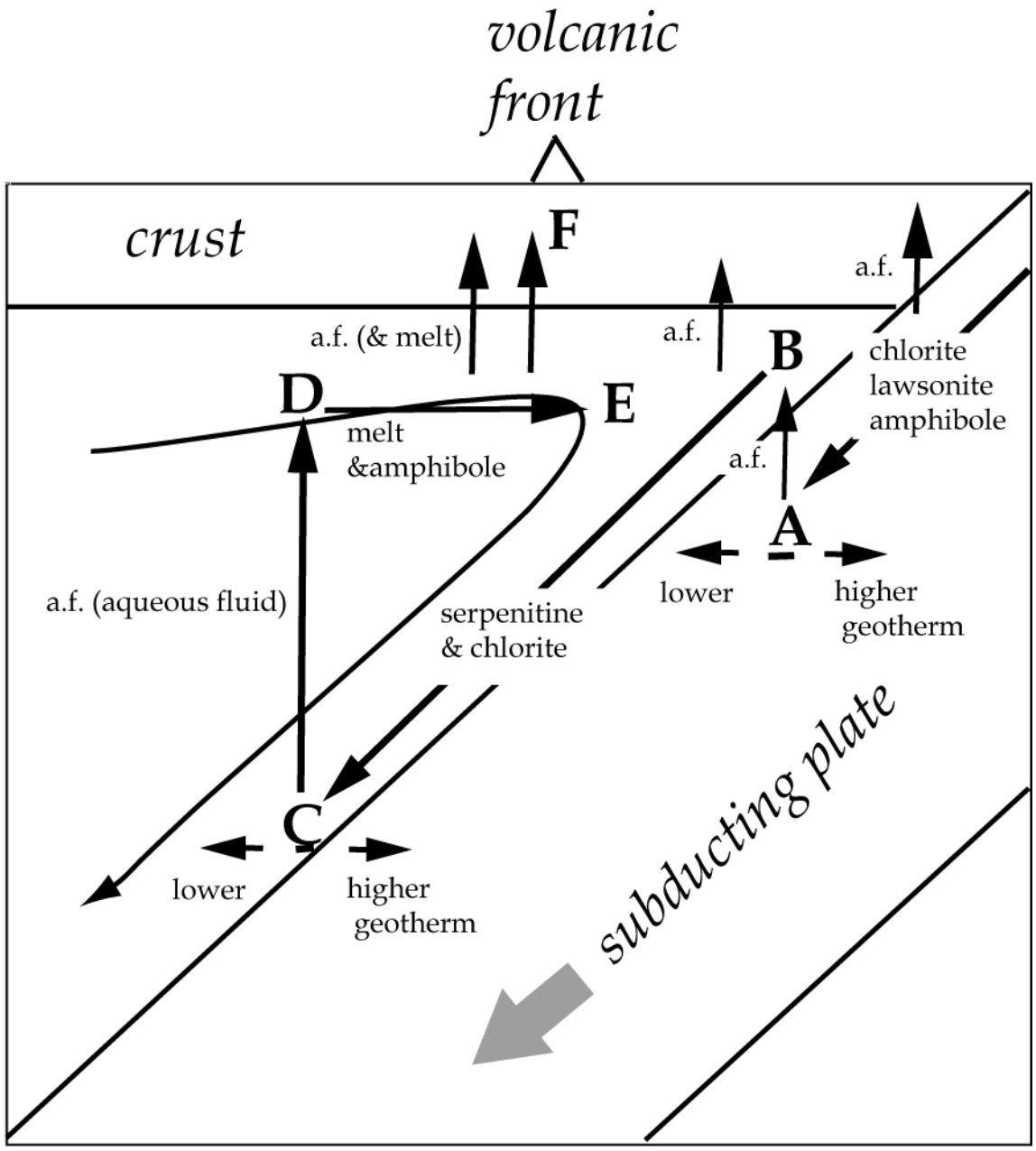
- Overpressurred fluids cause intermediate-depth intraslab EQs

4. スラブから島弧地殻への水の輸送と火山フロントの形成

4. Transportation of aqueous fluids from slab to arc crust and formation of volcanic front

スラブから島弧地殻への水の輸送経路とその担い手となる相

・東北日本のような古いプレートの沈み込み帯

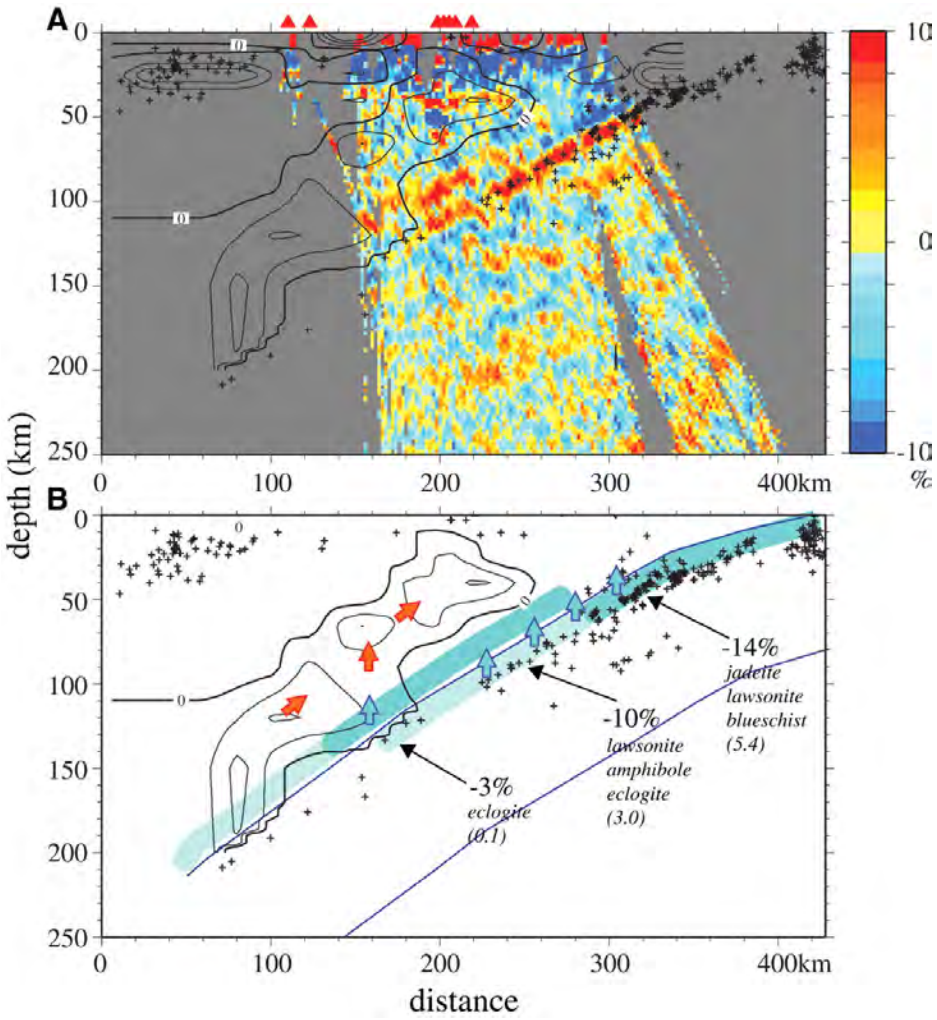


●島弧横断鉛直断面に示した模式図

(Iwamori, EPSL 1998)

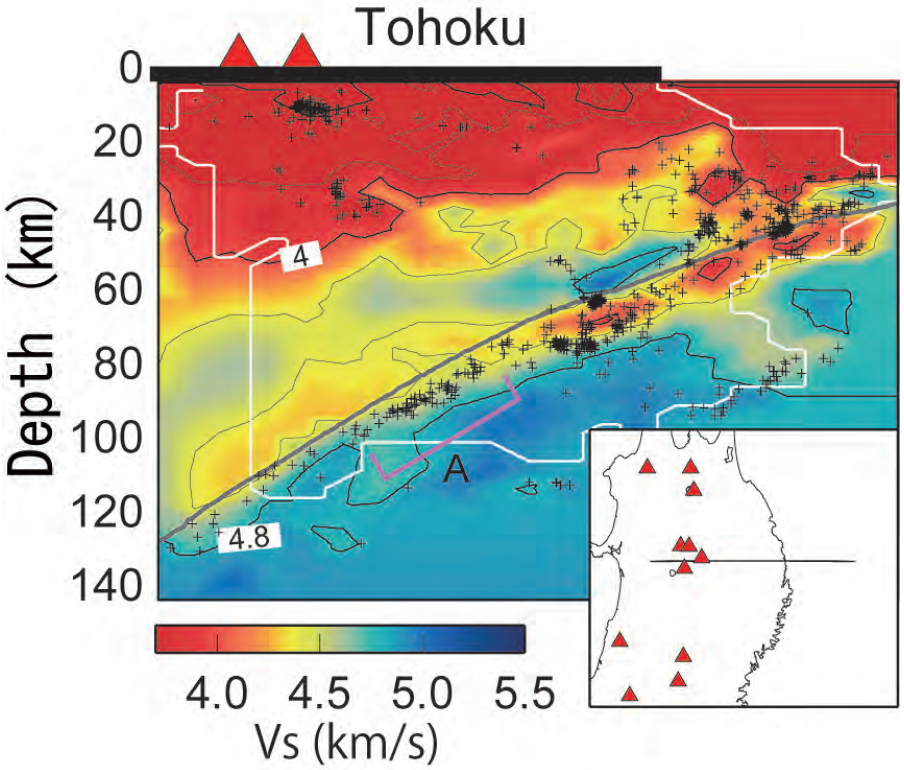
Down flow: Hydrated mantle material on top of slab

●Seismic image by receiver function analysis



(Kawakatsu & Watada, 2007 Science)

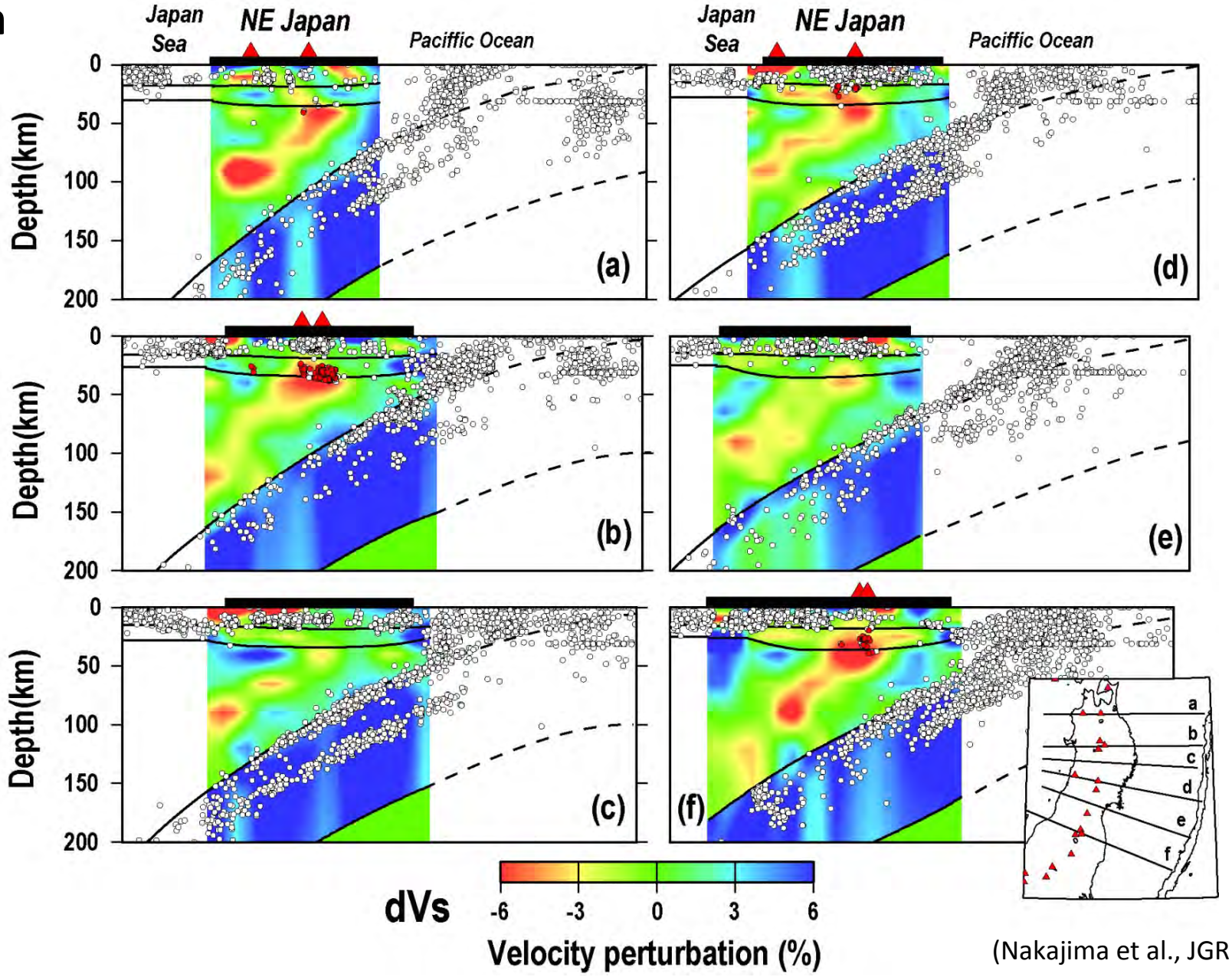
● Seismic image by DD tomography



- Clearly image a temporary layer with hydrated mantle material on top of subducting slab as a low-V layer

(Tsuji et al., 2008 GRL)

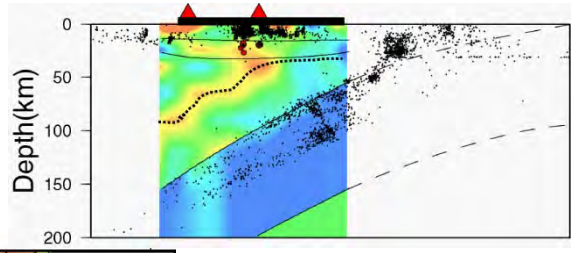
Upwelling flow: Inclined low-Vs zones in mantle wedge - NE Japan

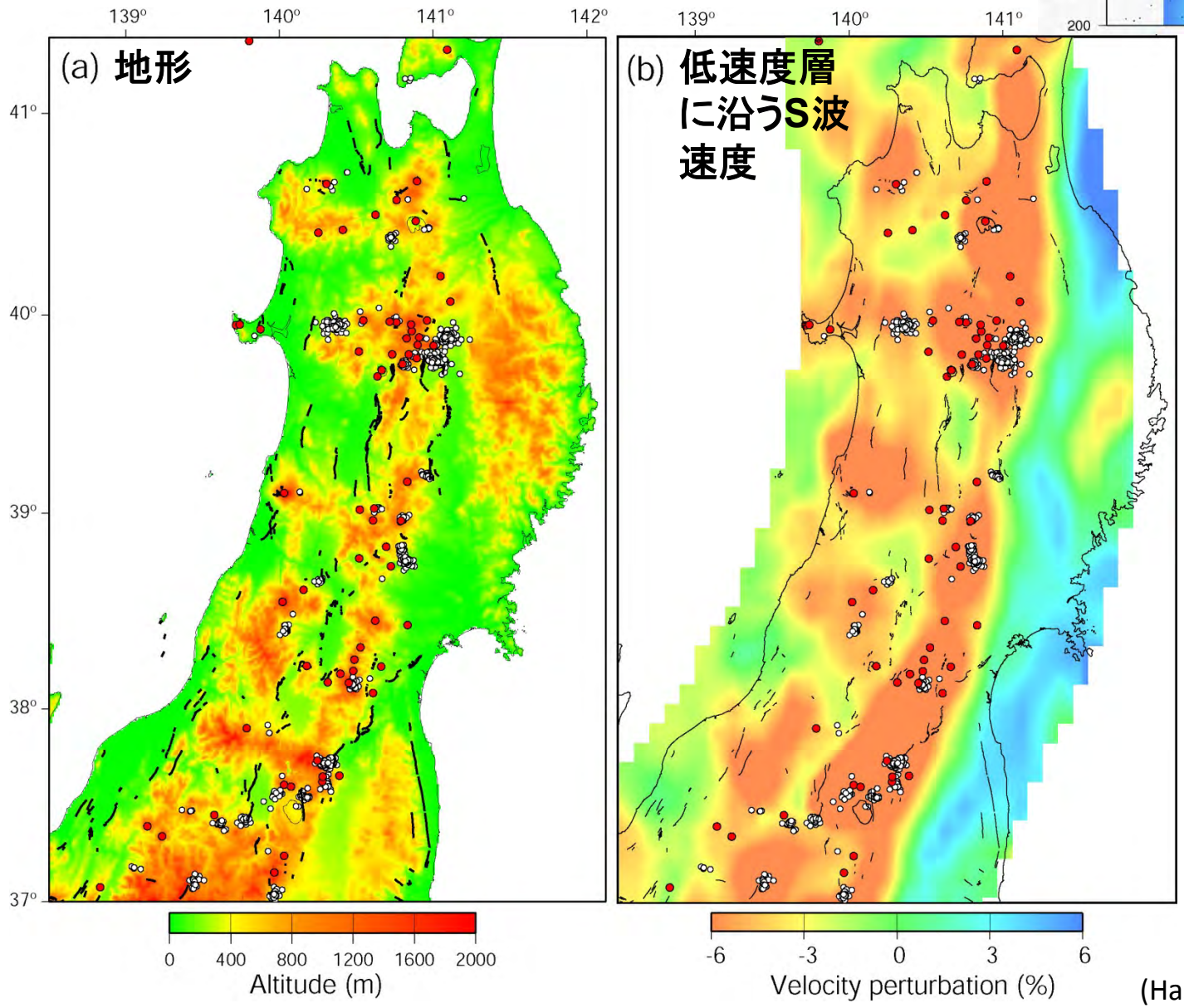


(Nakajima et al., JGR 2001)

上昇流内のVs構造と地形・火山の分布

マントルウェッジ内の低速度層に沿うS波速度（右図）と 地形（左図）





low-F microearthquakes
Quaternary volcanoes

・マントルウェッジ内の傾斜した低速度層に沿うS波速度をプロット

・低速度の度合いの大きい領域が約80kmの間隔で周期的に出現

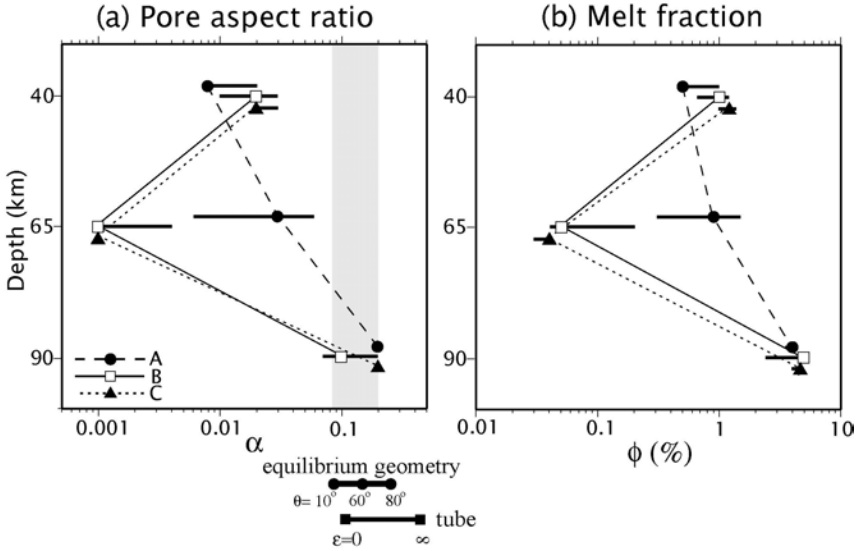
・それと第四紀火山，地形の高まりが空間的にぴたりと対応

(Hasegawa and Nakajima, 2004)

Shape of melt-filled pores & volume fraction of melt

・Aspect ratio and volume fraction of melt estimated from observed values of dlnVs/dlnVp according to Takei(JGR 2002).

(Nakajima et al.,EPSL 2005)



・上昇流は火山フロント直下のモホ面に到達
→ 火山フロントの形成
Upwelling flow reaches the Moho right beneath the volcanic front
→ Formation of volcanic front

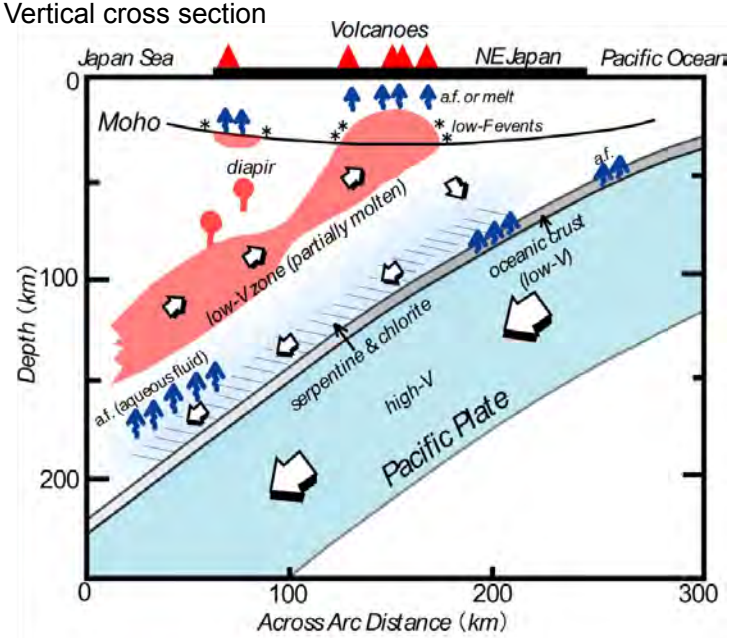
(Hasegawa and Nakajima, AGU GM 2004)

上昇流内で減圧融解・加水融解
→ メルトの生成・上昇
上昇流がモホ面とぶつかる場所
→ 火山フロントの形成

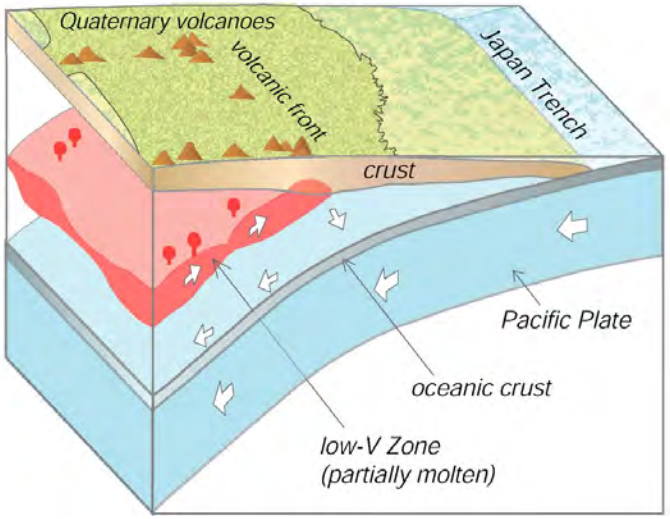
Inferred transportation paths of H_2O and melt beneath the NE Japan arc:

Schematic figure showing mantle wedge upwelling flow

Vertical cross section

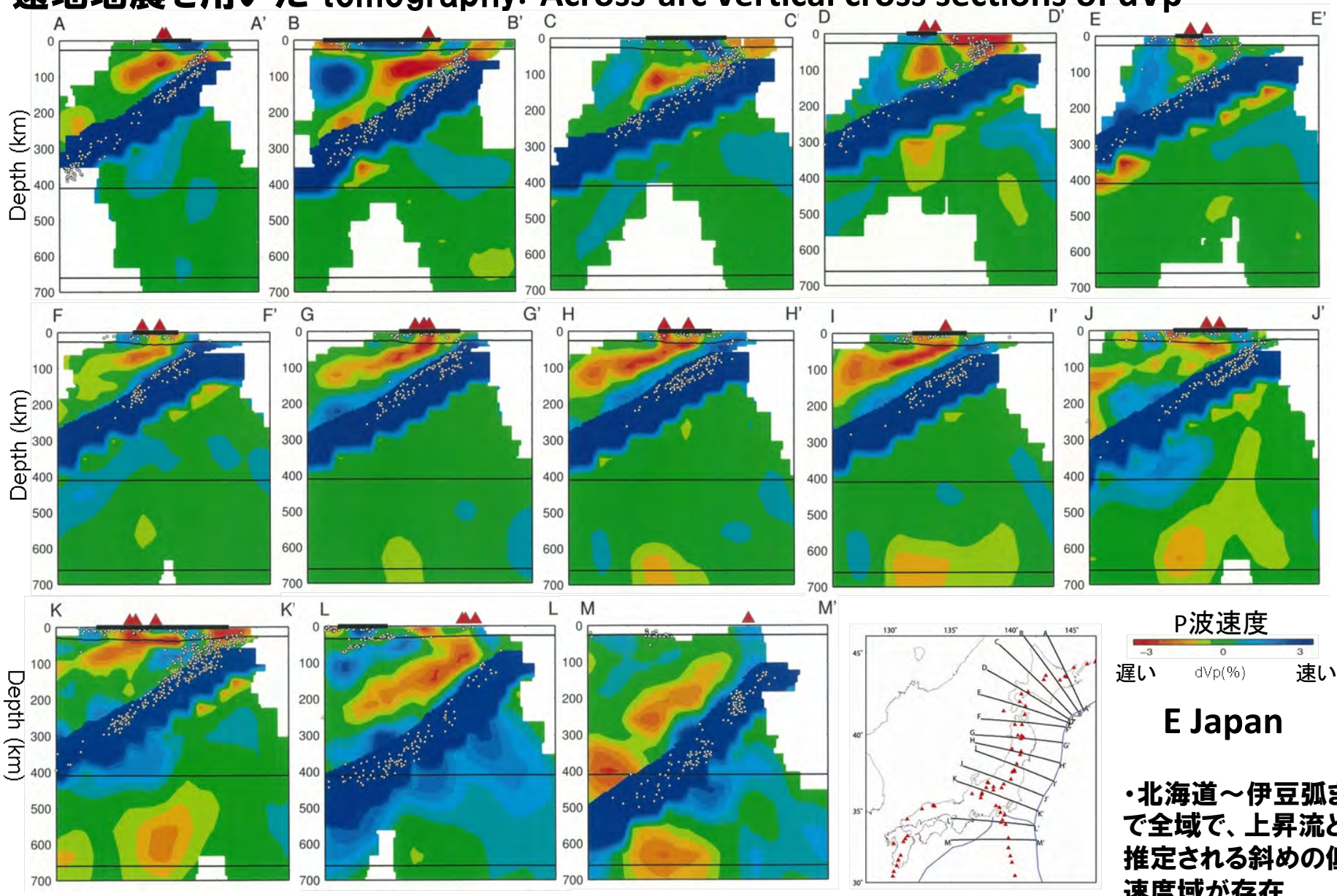


Bird's eye view



Upwelling flow: inclined low-Vp zones in mantle wedge - NE Japan

遠地地震を用いた tomography: Across-arc vertical cross sections of dVp



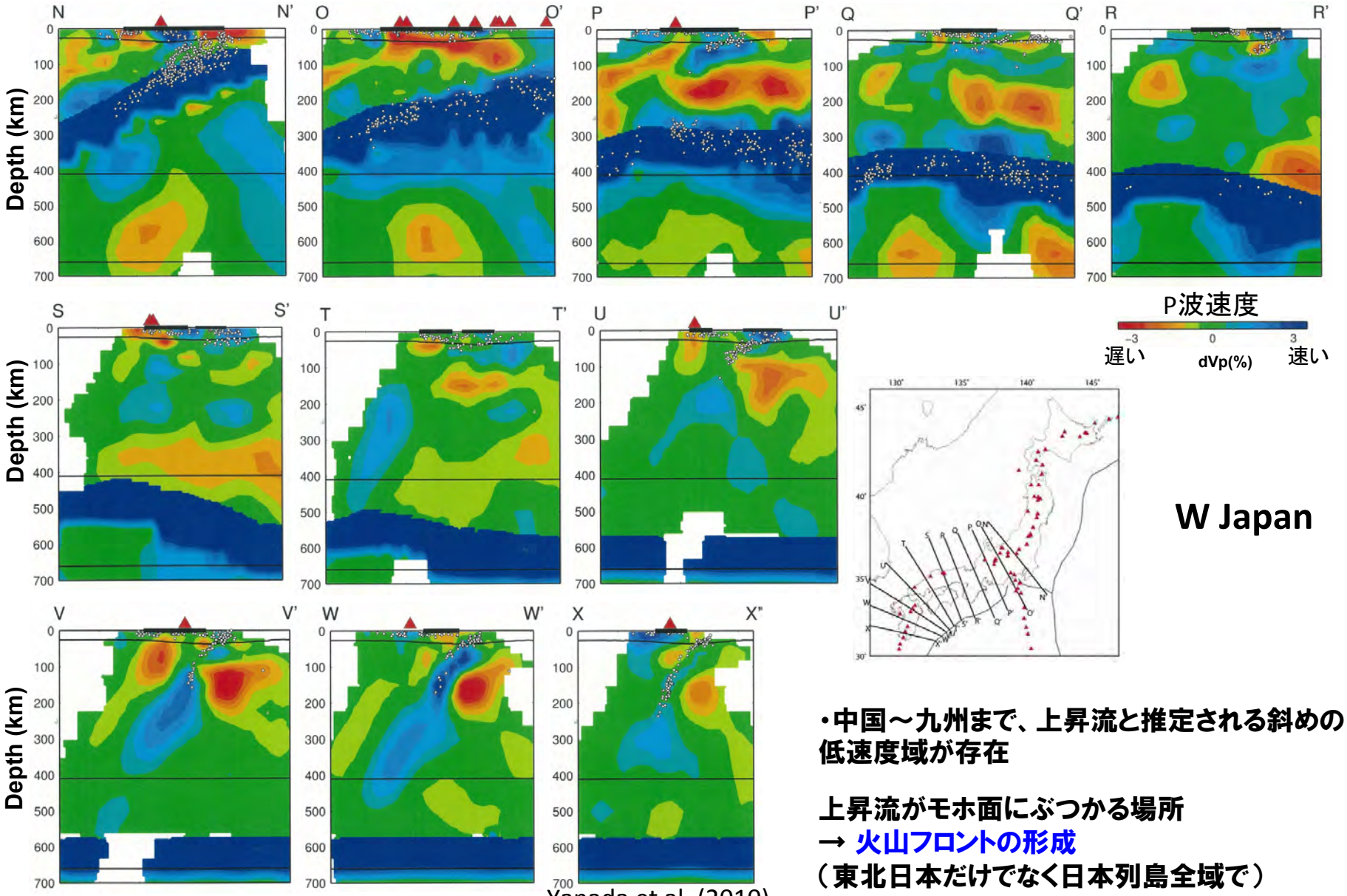
Yanada et al. (2010)

E Japan

・北海道～伊豆弧まで全域で、上昇流と推定される斜めの低速度域が存在

Upwelling flow: inclined low-Vp zones in mantle wedge - NE Japan

遠地地震を用いた tomography: Across-arc vertical cross sections of dVp



P波速度

遅い　速い

−3　0　3

dVp(%)

W Japan

Yanada et al. (2010)

・中国～九州まで、上昇流と推定される斜めの低速度域が存在

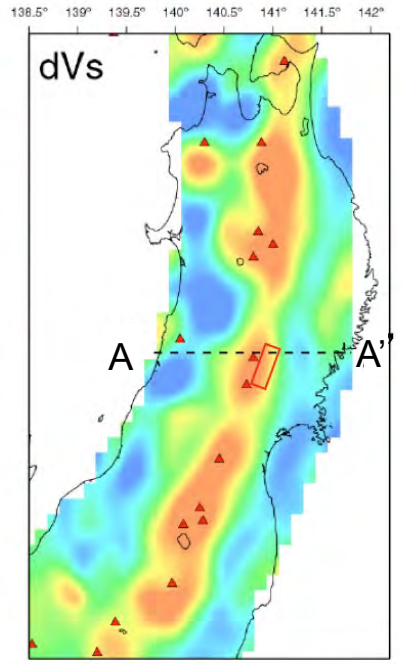
上昇流がモホ面にぶつかる場所
→ 火山フロントの形成
（東北日本だけでなく日本列島全域で）

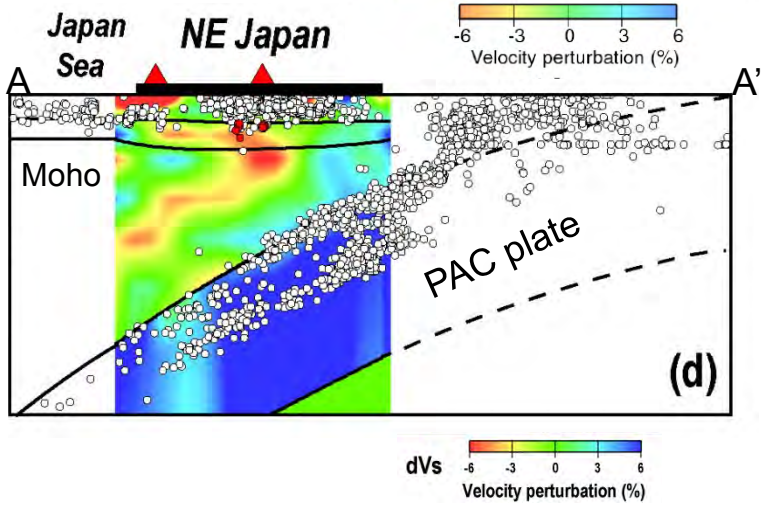
5. 島弧地殻の変形と内陸地震の発生

5. Deformation of arc crust and shallow inland earthquakes

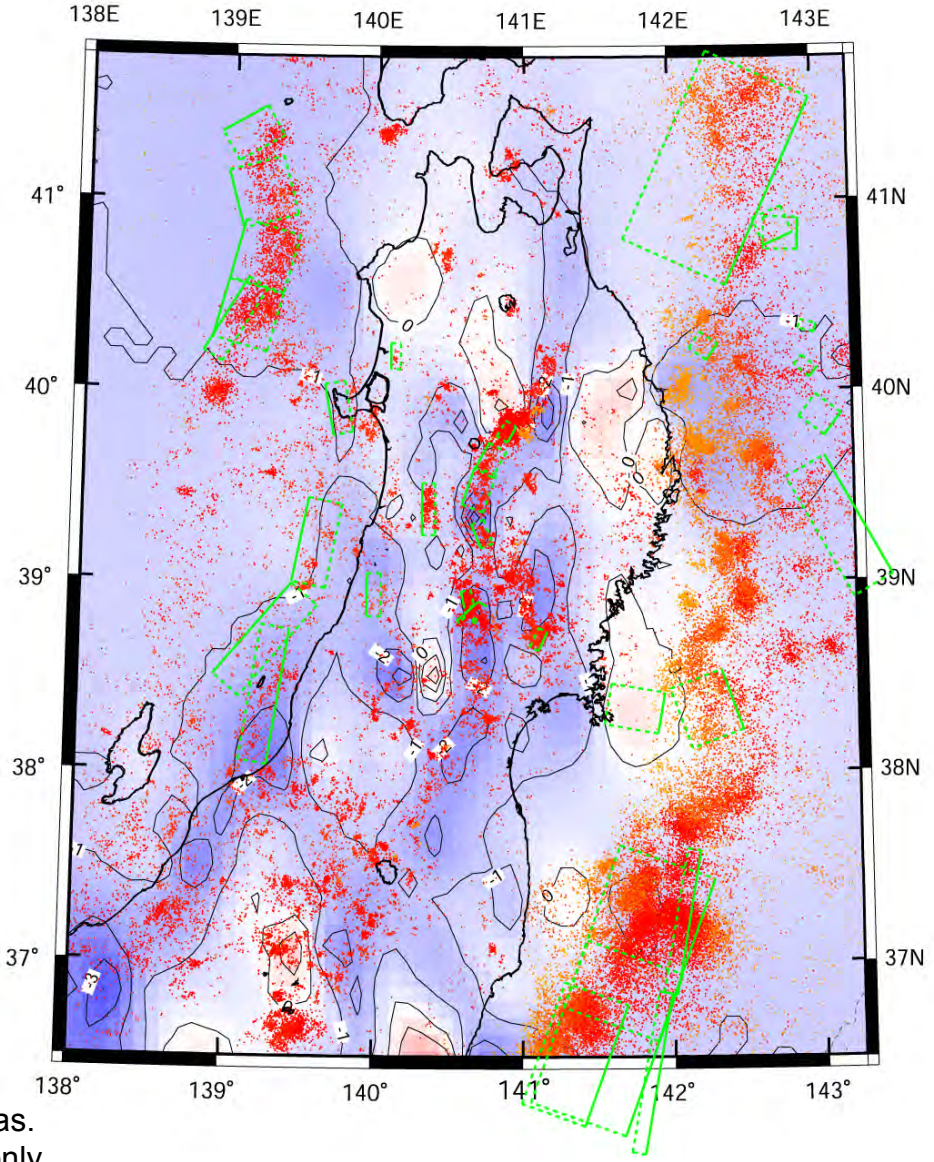
◎Upwelling flow in mantle wedge

(Nakajima et al., JGR 2001)





Strain rate & shallow EQs - concentrated deformation and seismicity along Backbone Range

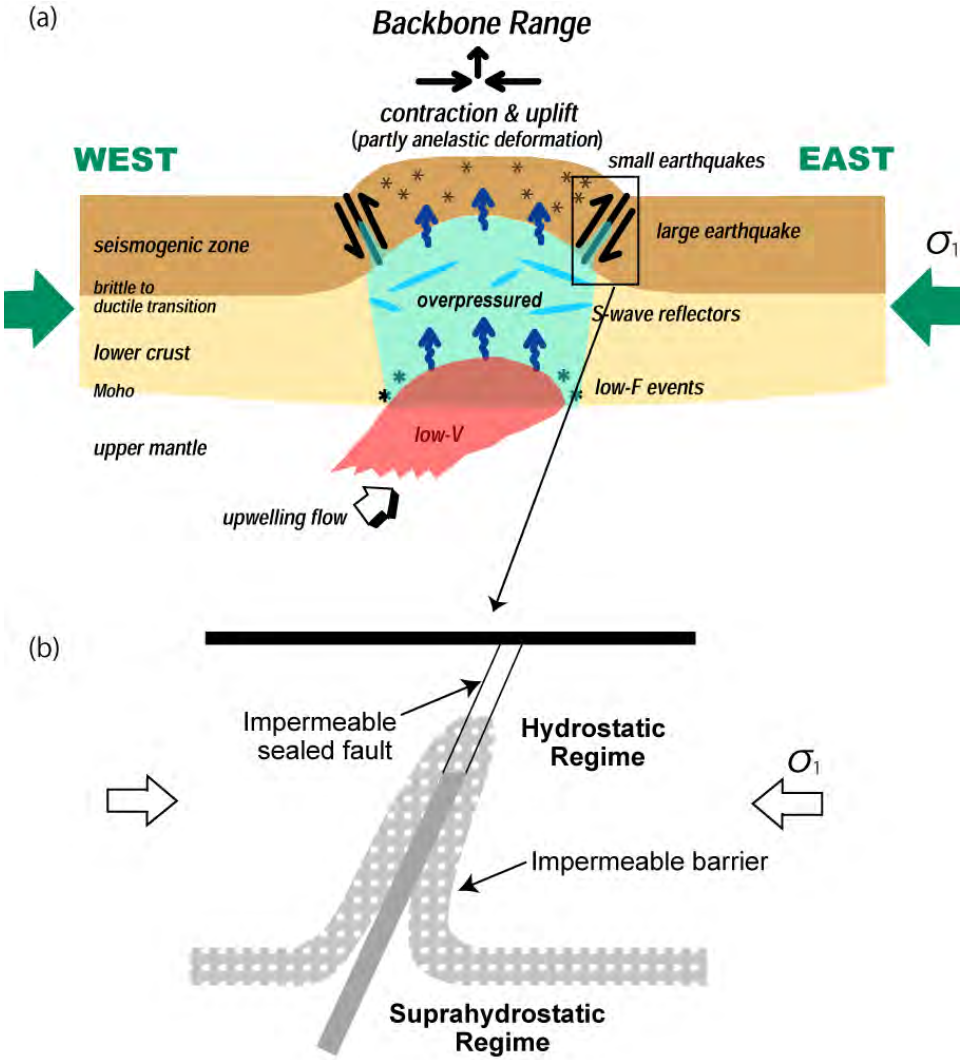


(Sato et al., 2003)

- Large contraction area running along VF or BR
- Shallow earthquakes are concentrated in the large contraction areas.
- Suggests that the upwelling flow in the mantle wedge causes not only shallow volcanism but also the weakening of the crust, which results in locally large contraction deformation of the crust and concentrated shallow seismicity.

Crustal deformation & shallow EQ generation in NE Japan

● **Vertical cross section**



長谷川・他 （2011）

- In the BR, lower crust is locally weakened by fluids transported by the upwelling flow.
- Results in local contraction deformation of lower crust there
- Eventually leads to the rupture of the upper crust immediately above along the preexisting faults, which have been locally weakened by overpressured fluids.

→ Suggests Inland crustal EQs also caused by overpressured fluids

Observations suggesting existence of fluids: Low-V zones below fault planes of recent large inland EQs

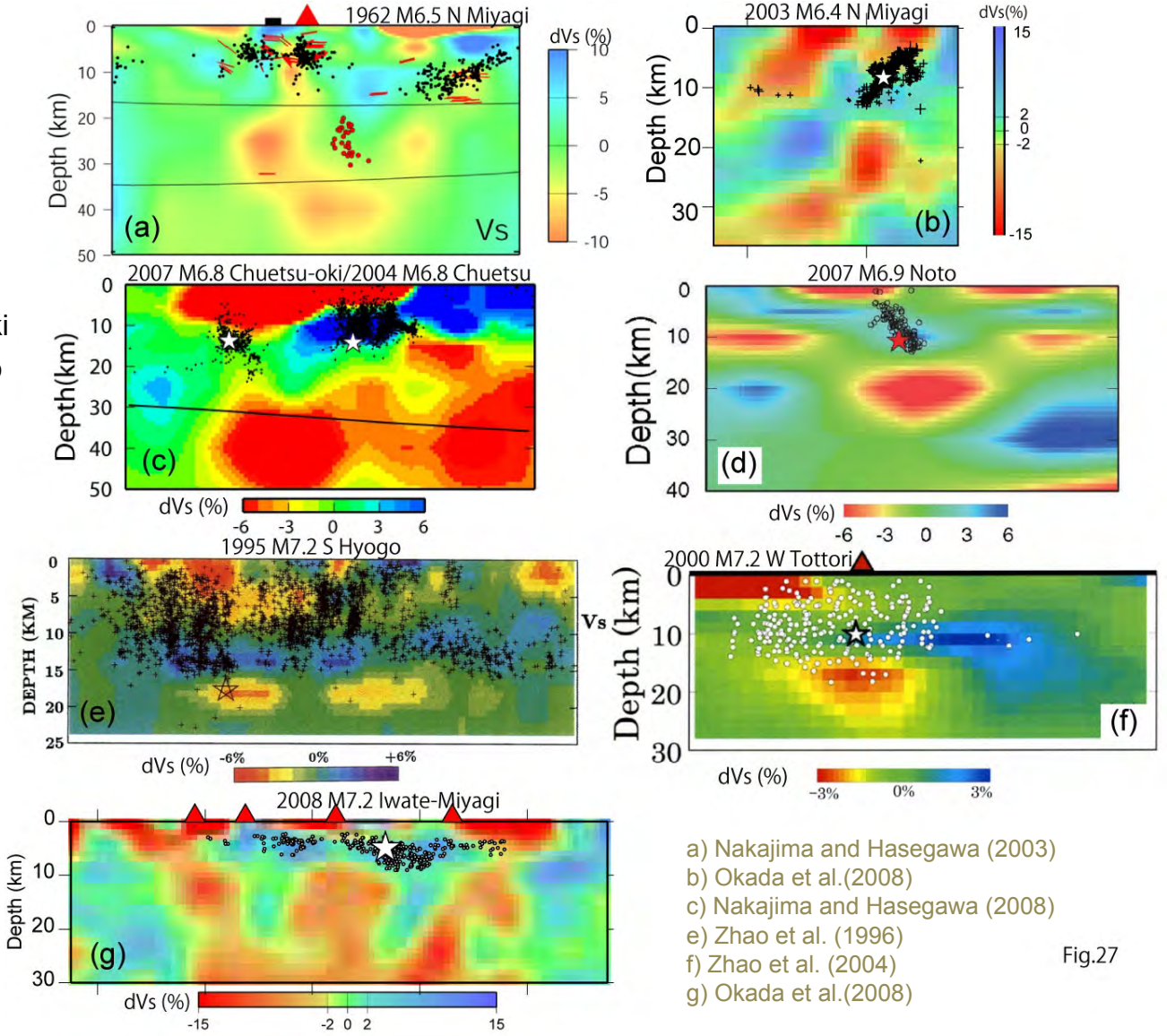
Across-fault vertical cross section of dVs

1962 M6.5 N Miyagi
2003 M6.4 N Miyagi
2004 M6.8 Chuetsu
2007 M6.8 Chuetsu-oki
2007 M6.7 Noto-Hanto

Along-fault vertical cross-section of dVs

1995 M7.2 Kobe
2000 M7.2 W Tottori
2008 M7.2 Iwate-Miyagi

star: main shock
circle: aftershock

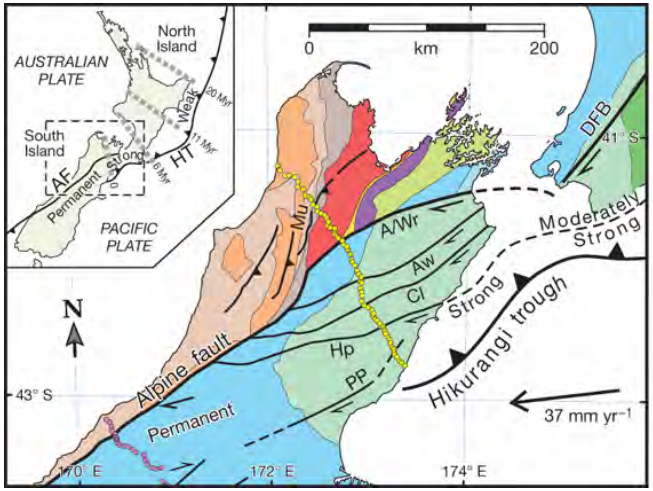


a) Nakajima and Hasegawa (2003)
b) Okada et al.(2008)
c) Nakajima and Hasegawa (2008)
e) Zhao et al. (1996)
f) Zhao et al. (2004)
g) Okada et al.(2008)

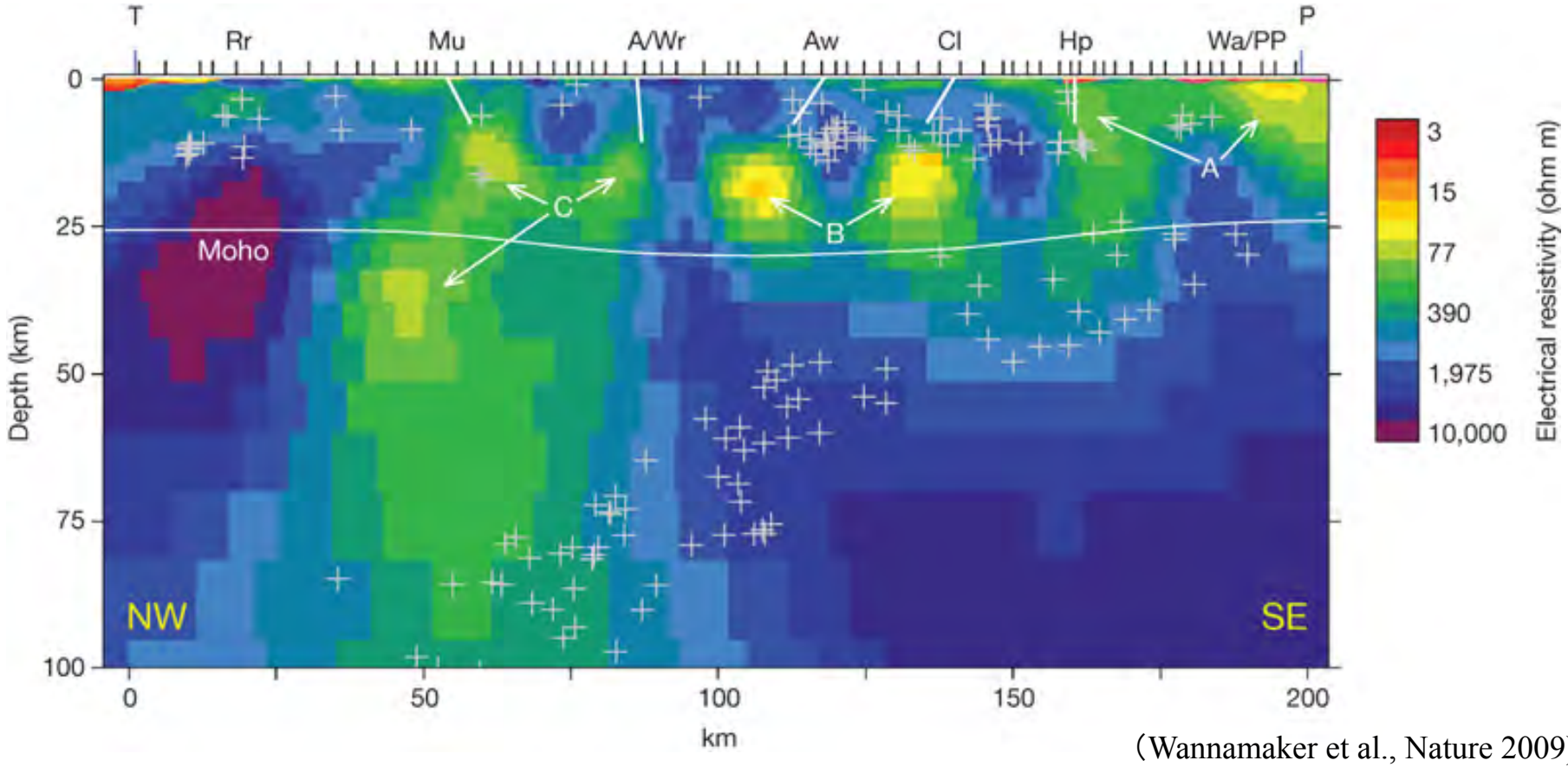
Fig.27

Prominent low-V zones located right below fault planes for all shallow large Eqs that have occurred recently in inland areas of Japan, suggesting existence of fluids there. Fluids are perhaps originated from slab-derived fluids which has been transported from slab to arc crust via mantle wedge.

Observations suggesting existence of fluids: Low-resistivity zones below fault planes



- Across-arc resistivity structure in New Zealand :Marlborough
  - Low resistivity areas right below the faults

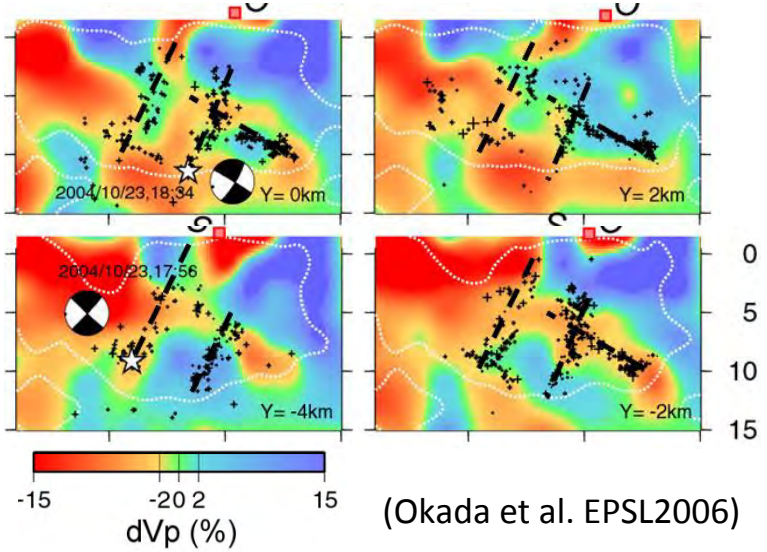


(Wannamaker et al., Nature 2009)

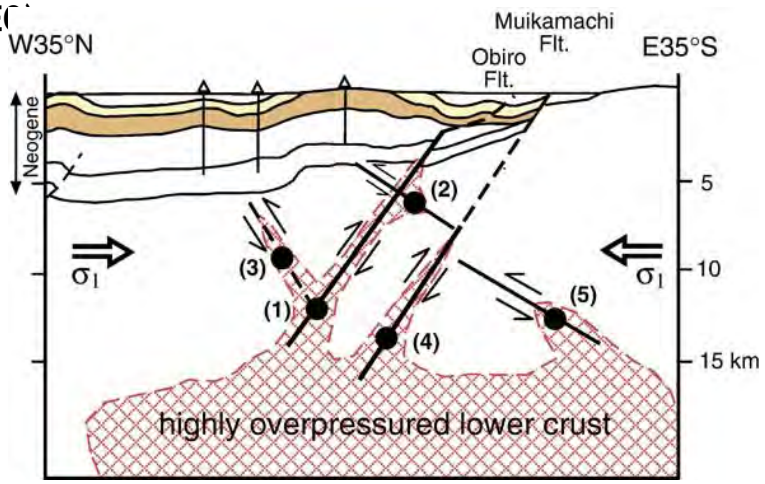
Observations suggesting existence of fluids: Low-V zones along faults

●Infiltration of over-pressured fluids

Across-fault vertical cross sections of dVp (2004 M Niigata EQ)



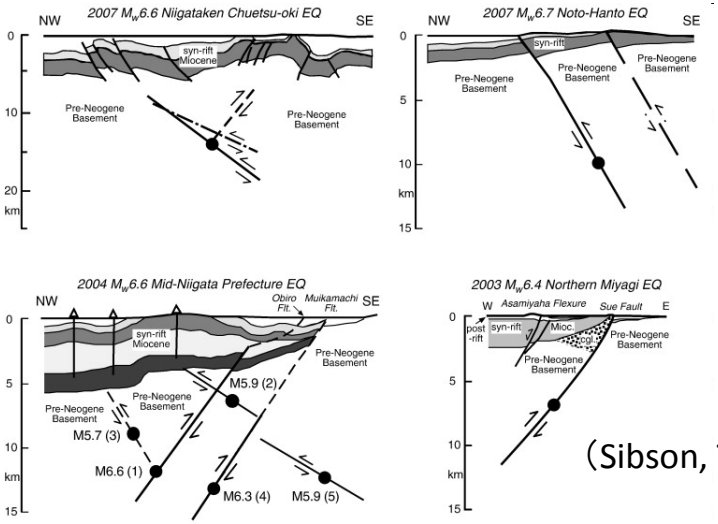
(Okada et al. EPSL2006)



(Sibson, EPSL 2007)

Observations suggesting existence of fluids: high angle thrust faults

●recent large inland EQs: All EQs have high angle fault planes



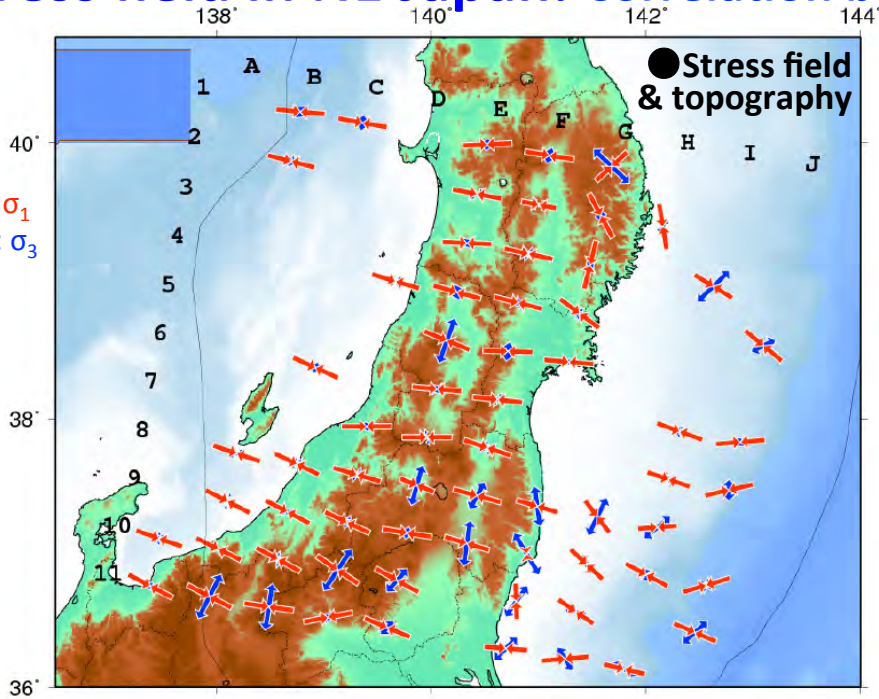
(Sibson, Tectonophysics 2009)

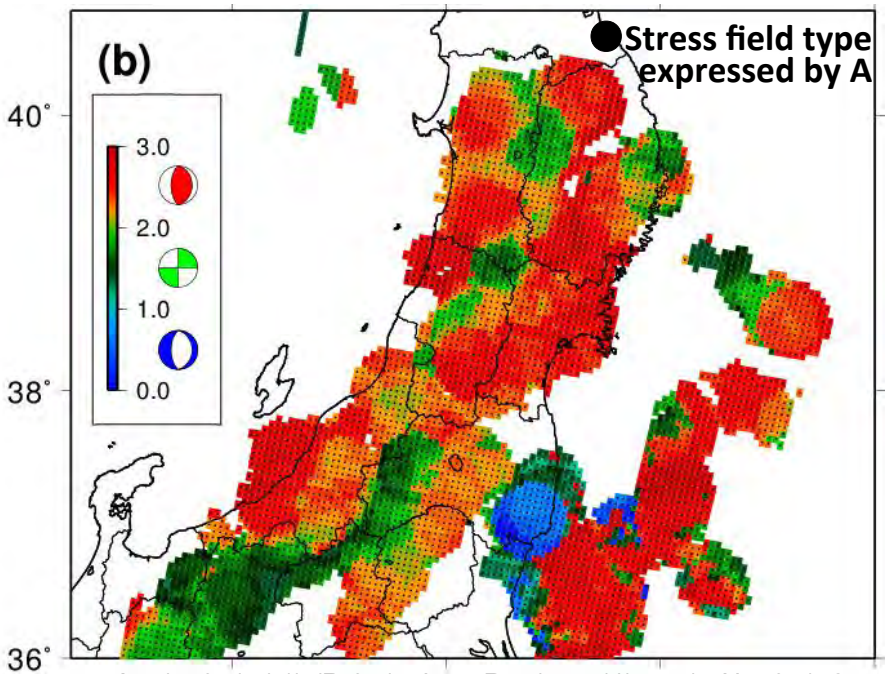
- Slip along high angle fault
  - → weak fault strength
  - → high pore pressure

(pore pressure ratio $\lambda > 0.8$)

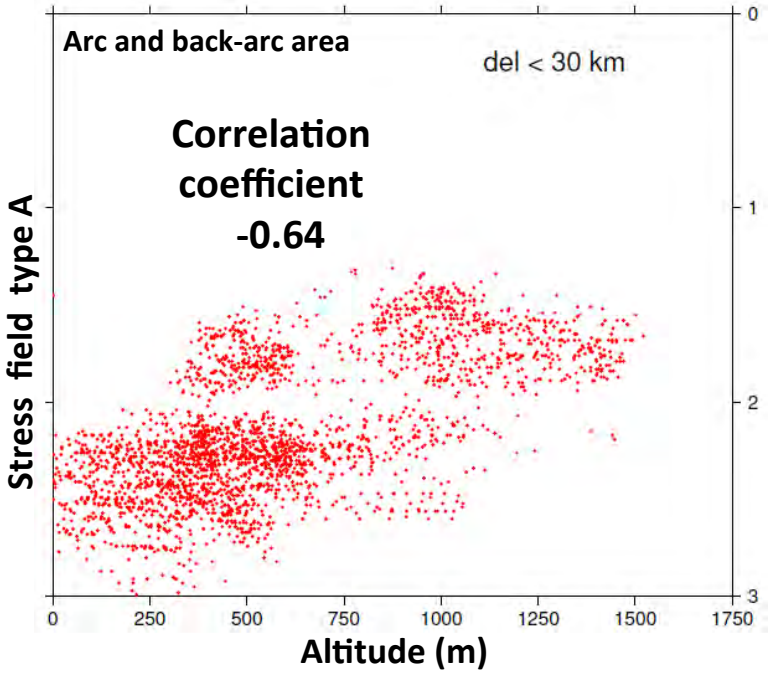
Stress field in NE Japan: Correlation between topography & stress field type

Red: σ_1
Blue: σ_3





A = (n+0.5)+(-1)^n(R-0.5) where R = $(\sigma_2-\sigma_3)/(\sigma_1-\sigma_3)$, N = 0, 1, 2
Simpson (1997 JGR)



 # Margin normal compression in wide areas
 # Fore-arc: NS compression at Kitakami range, normal fault stress regime at Abukuma range
 # Arc & back-arc: margin normal compression with strike-slip stress field at mountain ranges
→ Suggest gravity effect

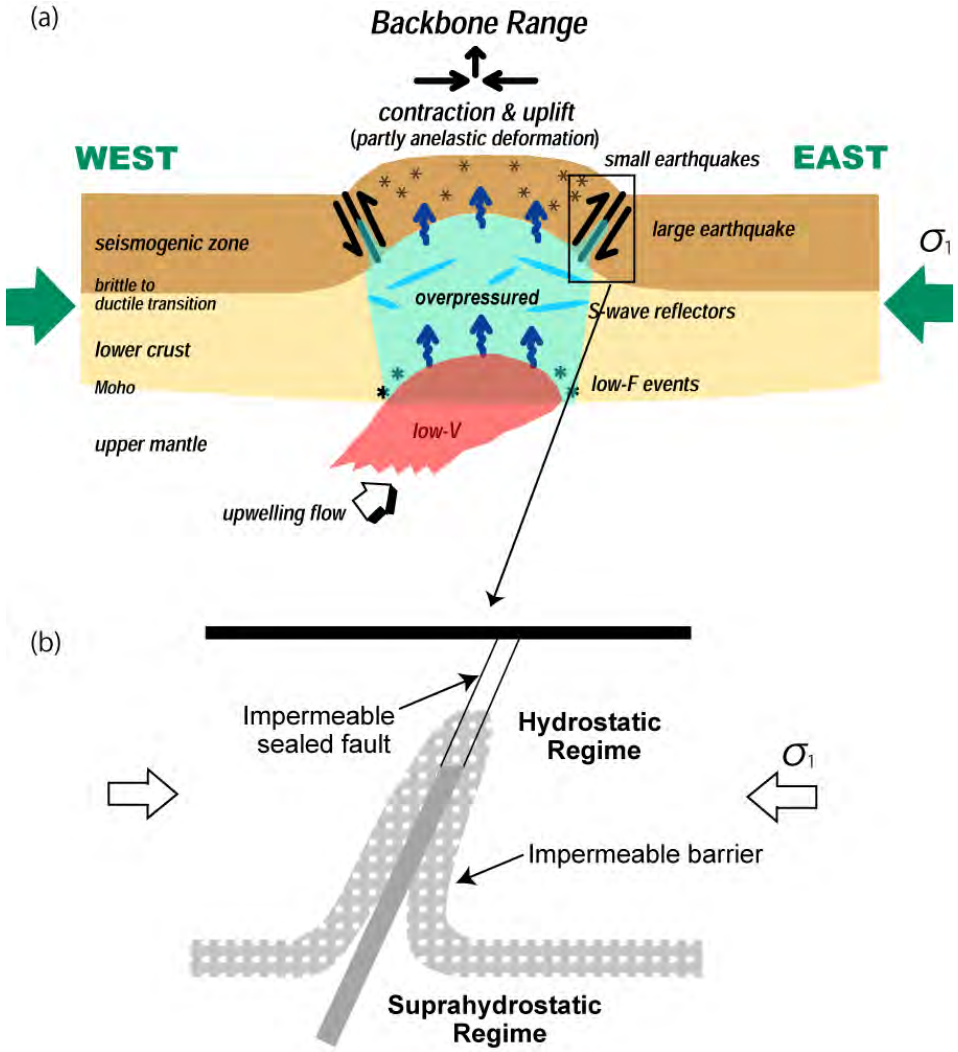
● Stress field type vs altitude

 # Stress field type correlates with altitude: CC = -0.64
 # Gravity effect is reflected in stress field
→ suggest small stress magnitude
(deviatoric stress: ~10 MPa pore pressure ratio: λ = ~0.94)

Yoshida et al. (2013)

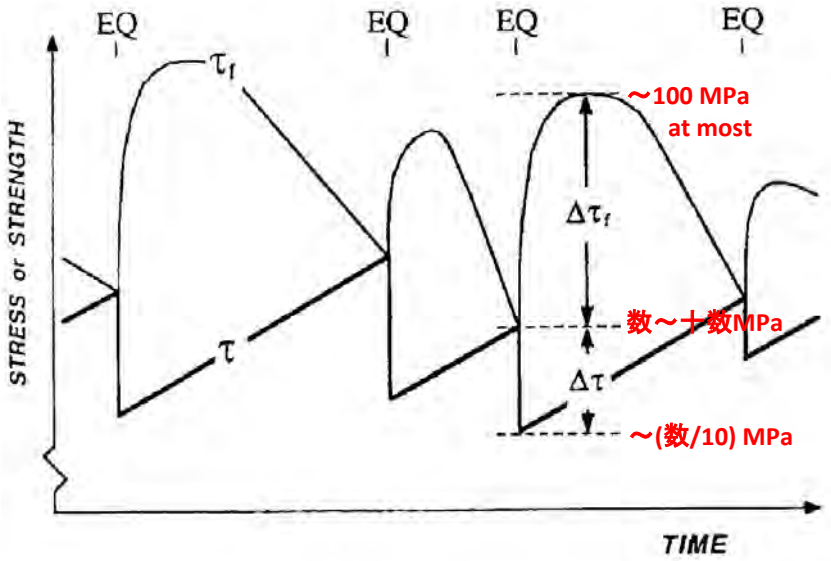
Crustal deformation & shallow EQ generation in NE Japan

● Vertical cross section



長谷川・他 （2011）

●Temporal evolution of stress vs strength



Fault valve model
(Sibson , 1990 JGR)

•EQ occurs along the fault whose strength has decreased sufficiently due to overpressurred fluids

Summary

- EQs in subduction zones, i.e., interplate, intermediate-depth intraslab and inland crustal EQs, occur under overpressurred conditions, which is provided by slab-derived aqueous fluids
- EQs occur along the fault whose strength has decreased sufficiently by overpressured fluids
- Fault strength is roughly about several to ～10 or few tens MPa, and pore pressure ratio along the fault is more that 90%, except intermediate-depth intraslab EQs