

Imaging high-pressure rock exhumation in eastern Taiwan

D. Brown, Y.-M. Wu, K.-F. Feng, W.-A. Chao, H.-H. Huang

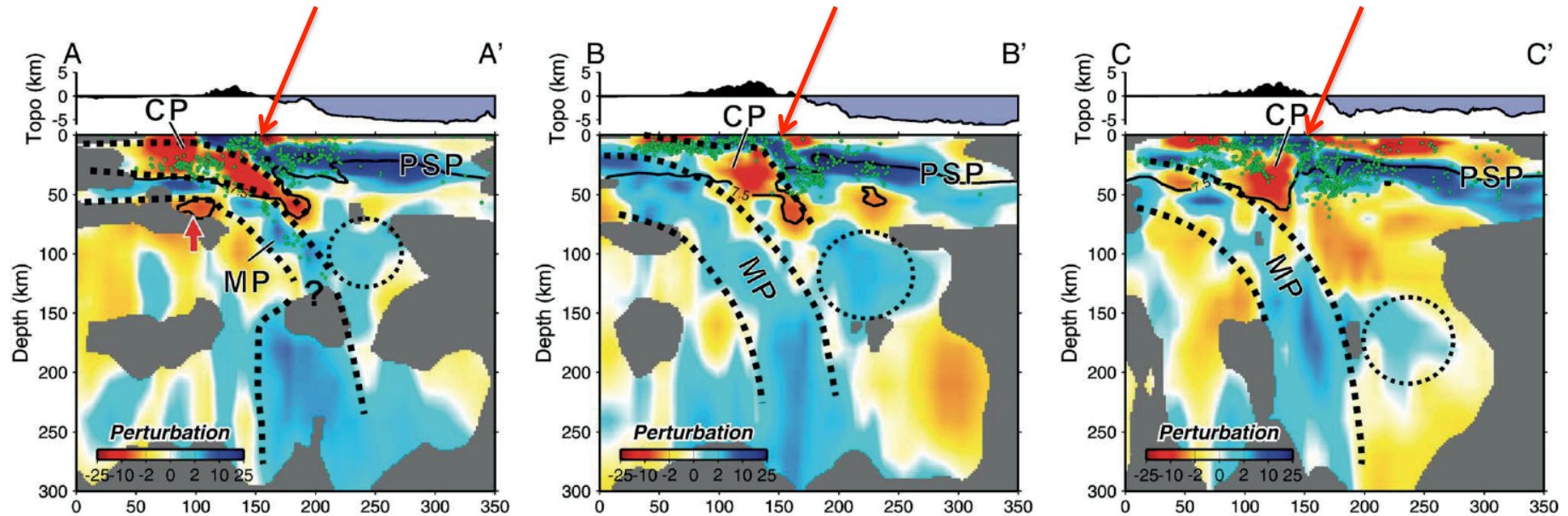




Salvage, Newfoundland, Canada

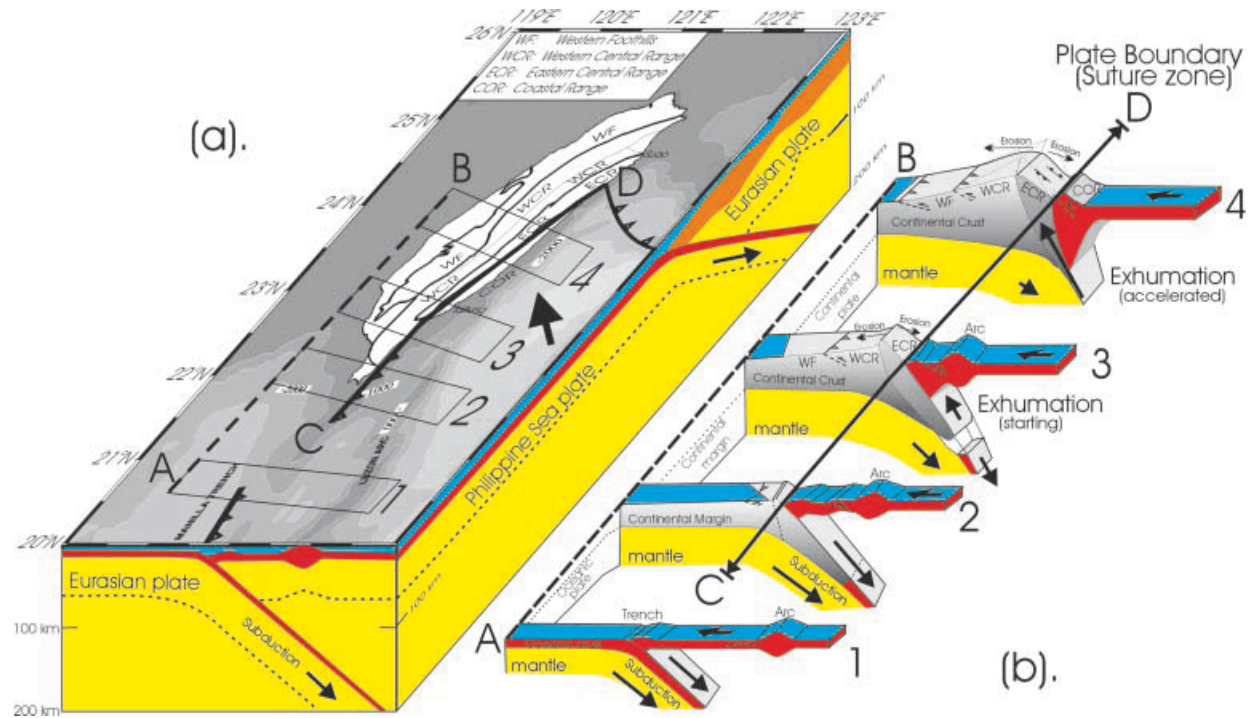
I would like to thank MOST for financing my stay in Taiwan, as well as NTU and the Department of Geosciences for hosting me during six months.

A high-velocity zone in eastern Taiwan



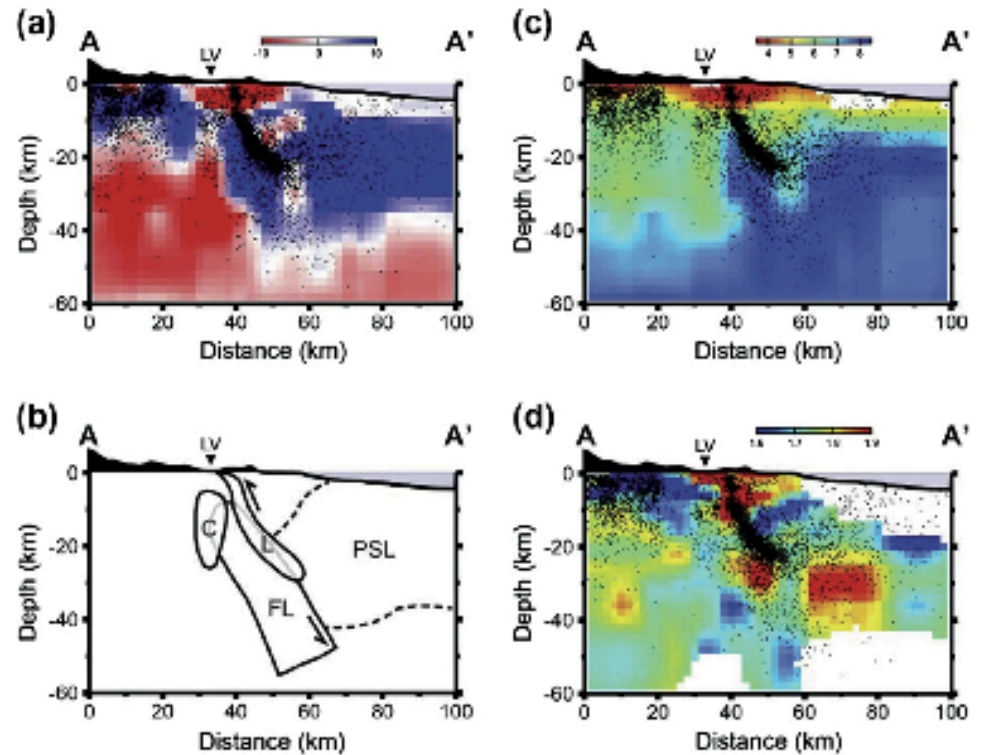
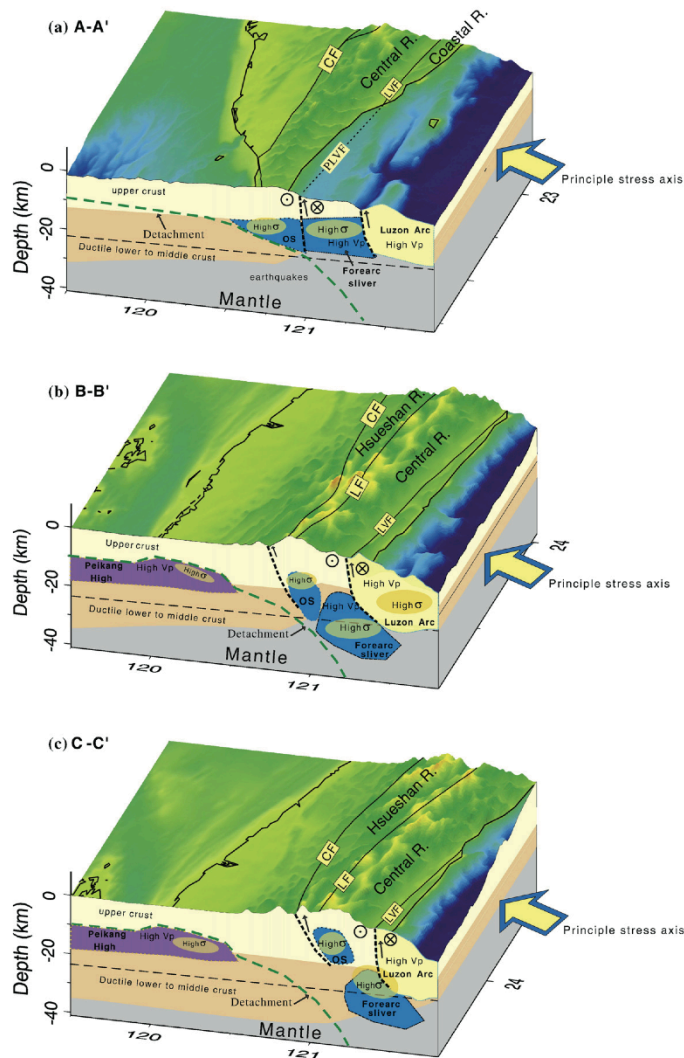
From Huang et al. (2014, GRL)

The exhuming continental crust model



Lin and Roecker (1998)
Lin (Terra Nova, 2002)

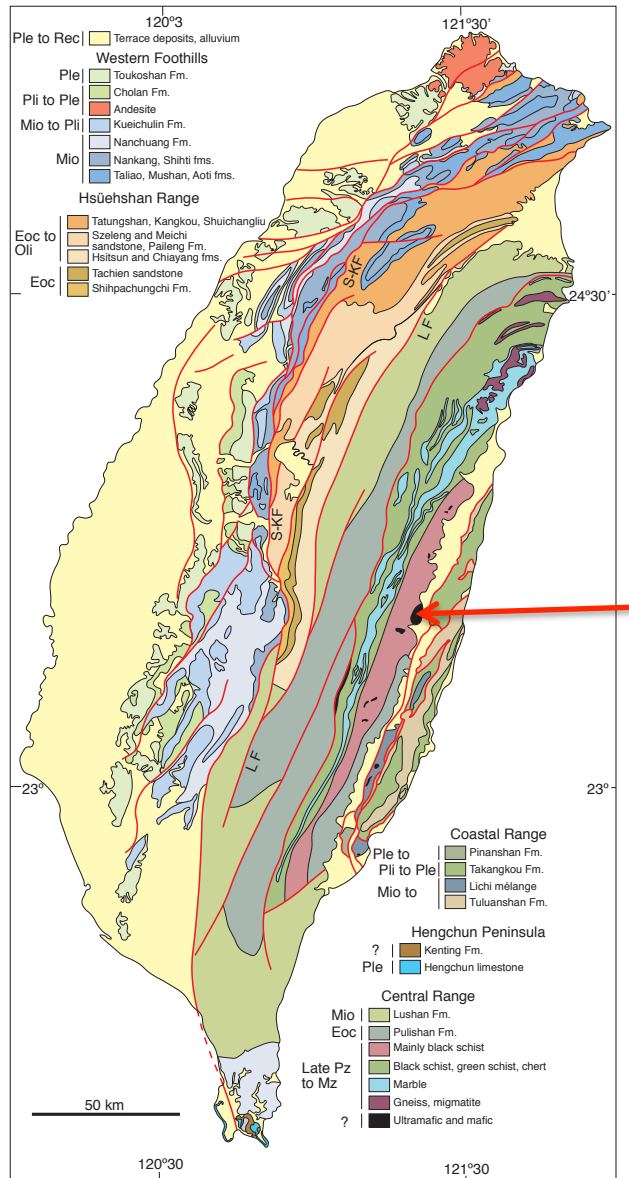
The subducting forearc model



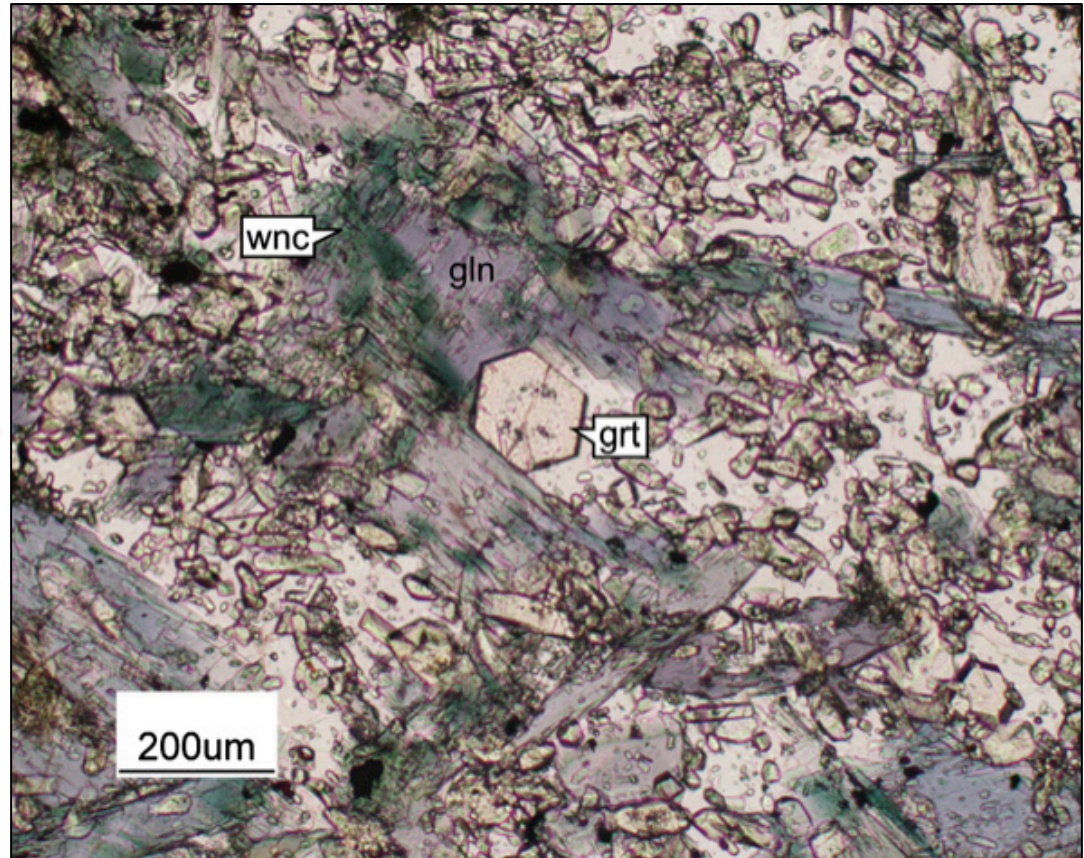
From Shyu et al. (2011, JAES)

From Cheng (2009, Tectonophysics)

Could an exhuming high-pressure rock terrane model explain the high-velocity zone in eastern Taiwan?

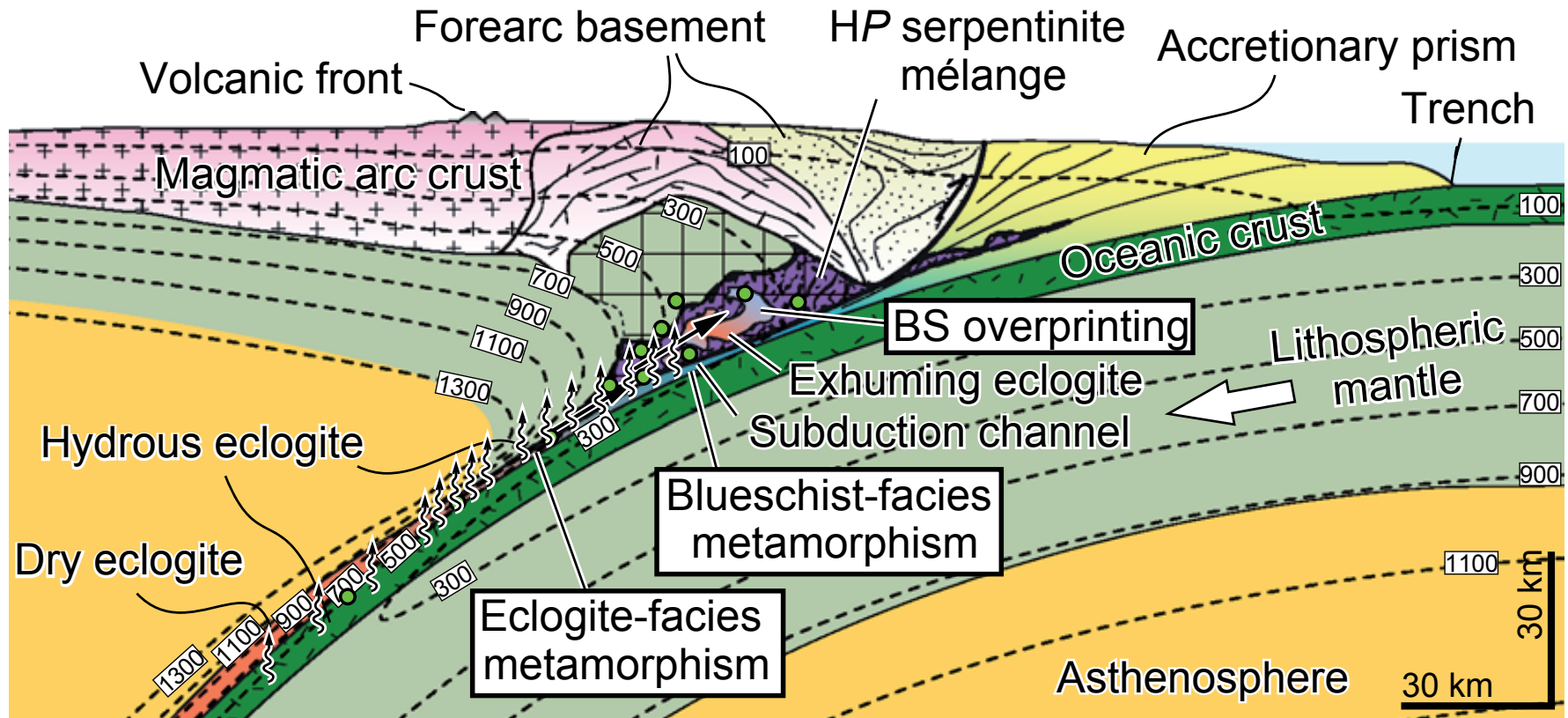


High-pressure rocks in the Yuli Belt



From Tsai et al. (2013, JAES)

The subduction channel and the exhumation of H-P rocks



Tsujimori and Ernst (2011, J. Metamorph. Geol.)

Compilations of high-pressure terranes worldwide show that they have many lithological characteristics in common:

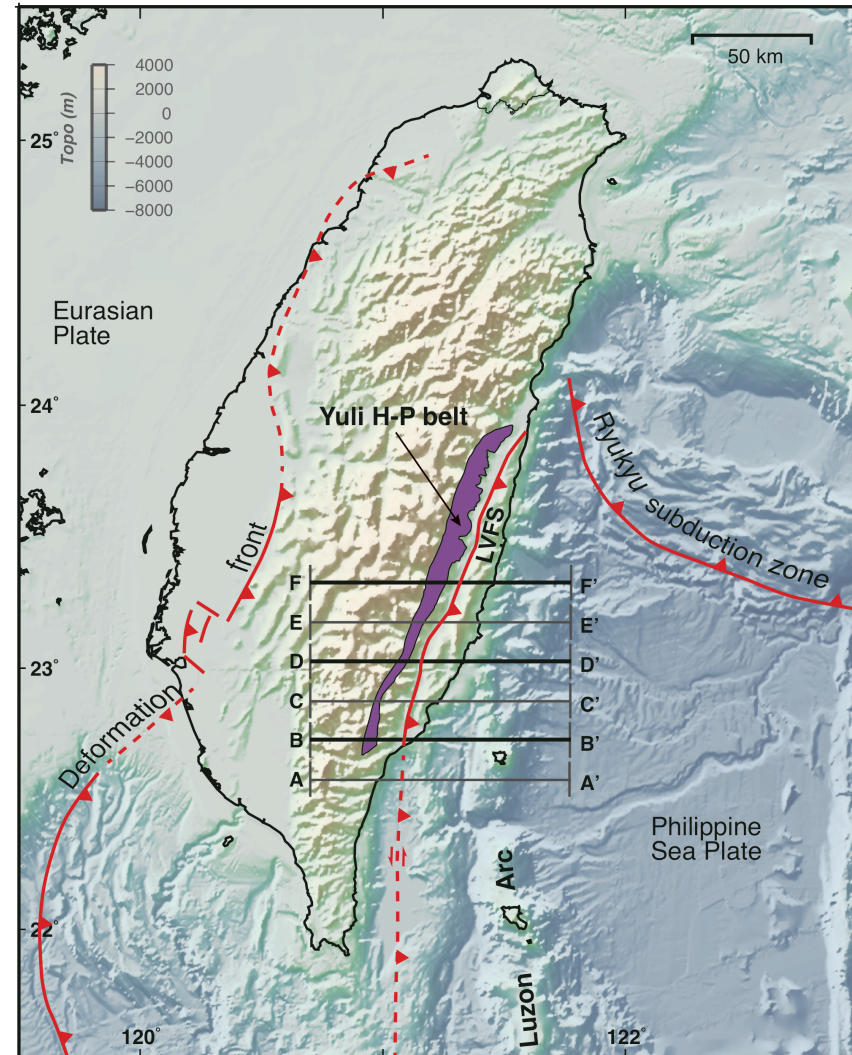
- Quartz-mica schist is the most abundant rock type making up high-pressure terranes. In some terranes, its higher metamorphic grade equivalents, orthogranulite and paragrarnulite are also found.
- Metamorphosed rocks derived from oceanic crust and volcanic arcs are found in much smaller quantities, as are metabasic rocks such as amphibolite.
- Metamorphosed ultramafic derived from the mantle, and generally accompanied by serpentinite, constitute only a small volume of many high-pressure terranes.
- In any one terrane, all, or part, of these rocks may have been metamorphosed under blueschist and/or eclogite facies conditions.
- Some high-pressure terranes form large, coherent units while in others the high-pressure rocks are found in smaller bodies within a tectonic mélange.

To test the hypothesis that a high-pressure metamorphic terrane could explain the high-velocity zone in eastern Taiwan we carry out a petrophysical analysis.

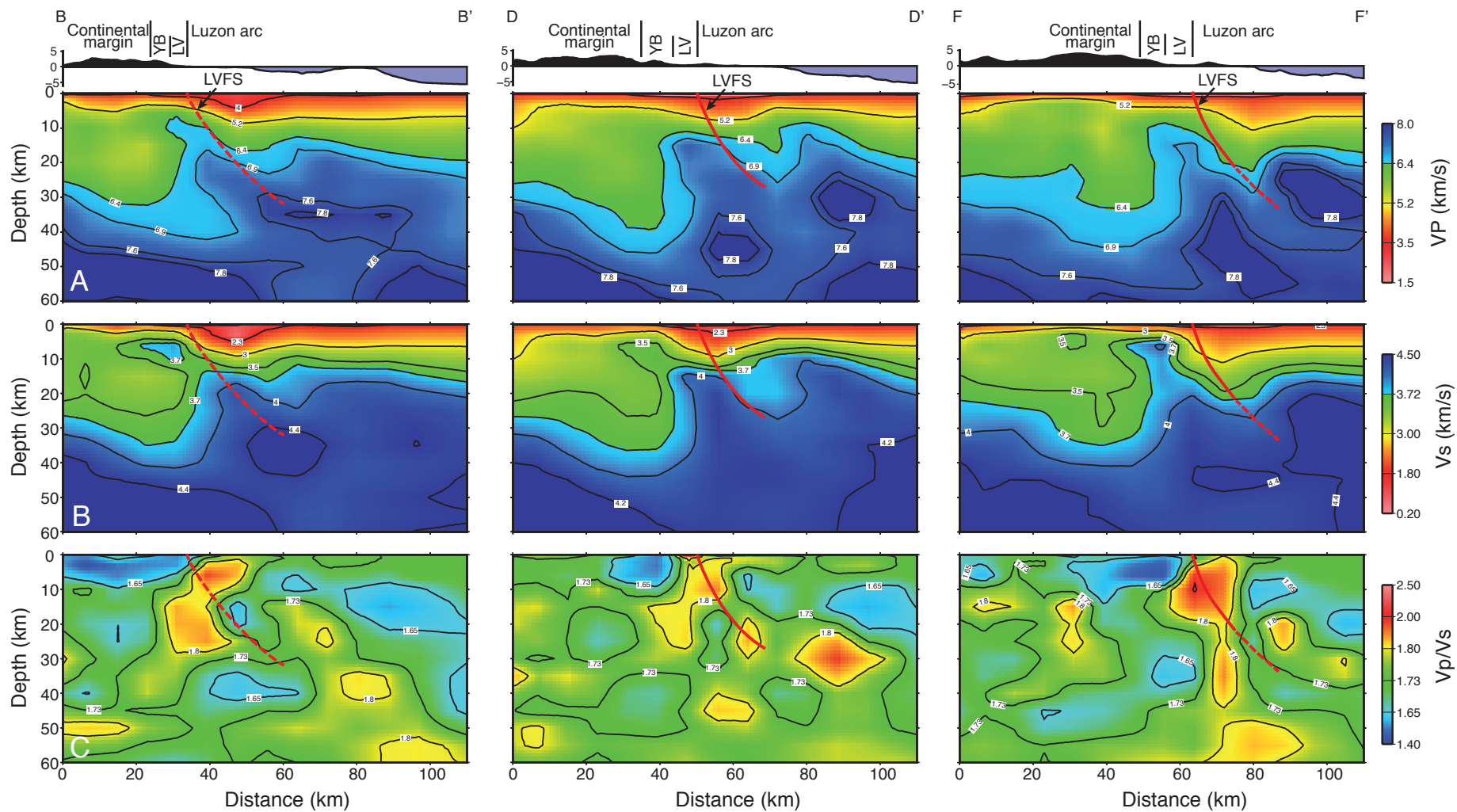
In this analysis, V_p , V_s , and V_p/V_s data that have been acquired in the laboratory on a large number of rock types are compared to the *in situ* V_p , V_s and V_p/V_s determined from the tomography model to see what rock types could possibly make up the high-velocity zone.

The velocity model

We use the tomography of Huang et al., (EPSL, 2014)



The velocity model

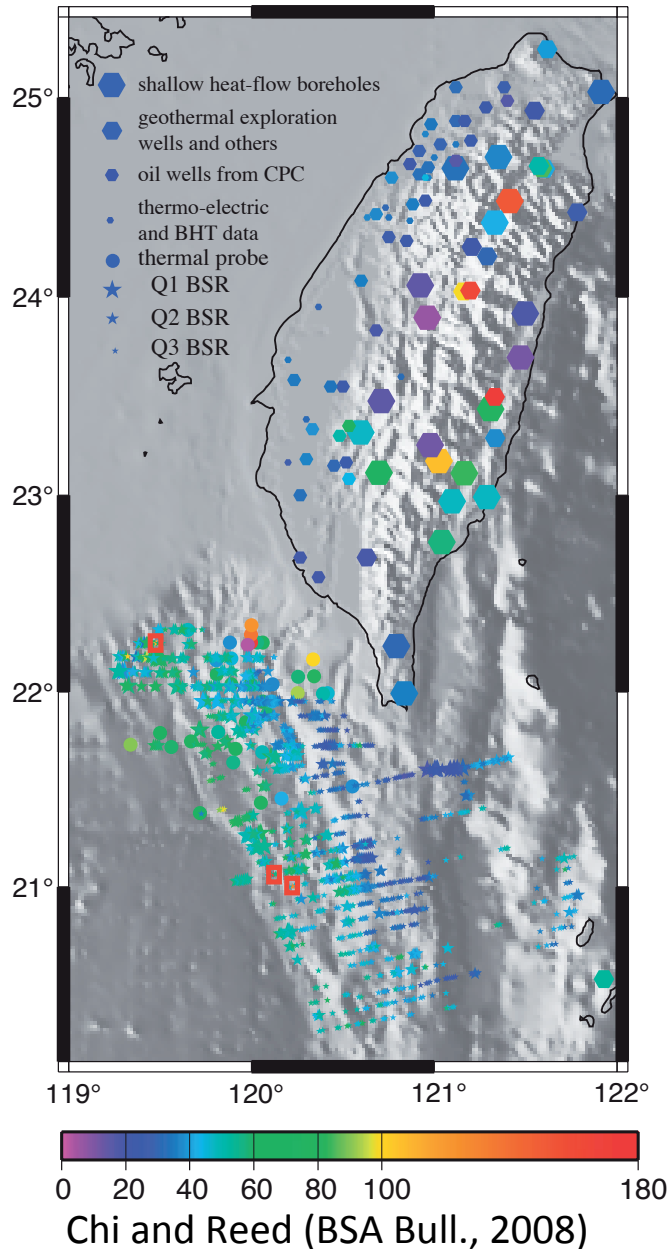


First, some words about heat and its effect on rock physical properties

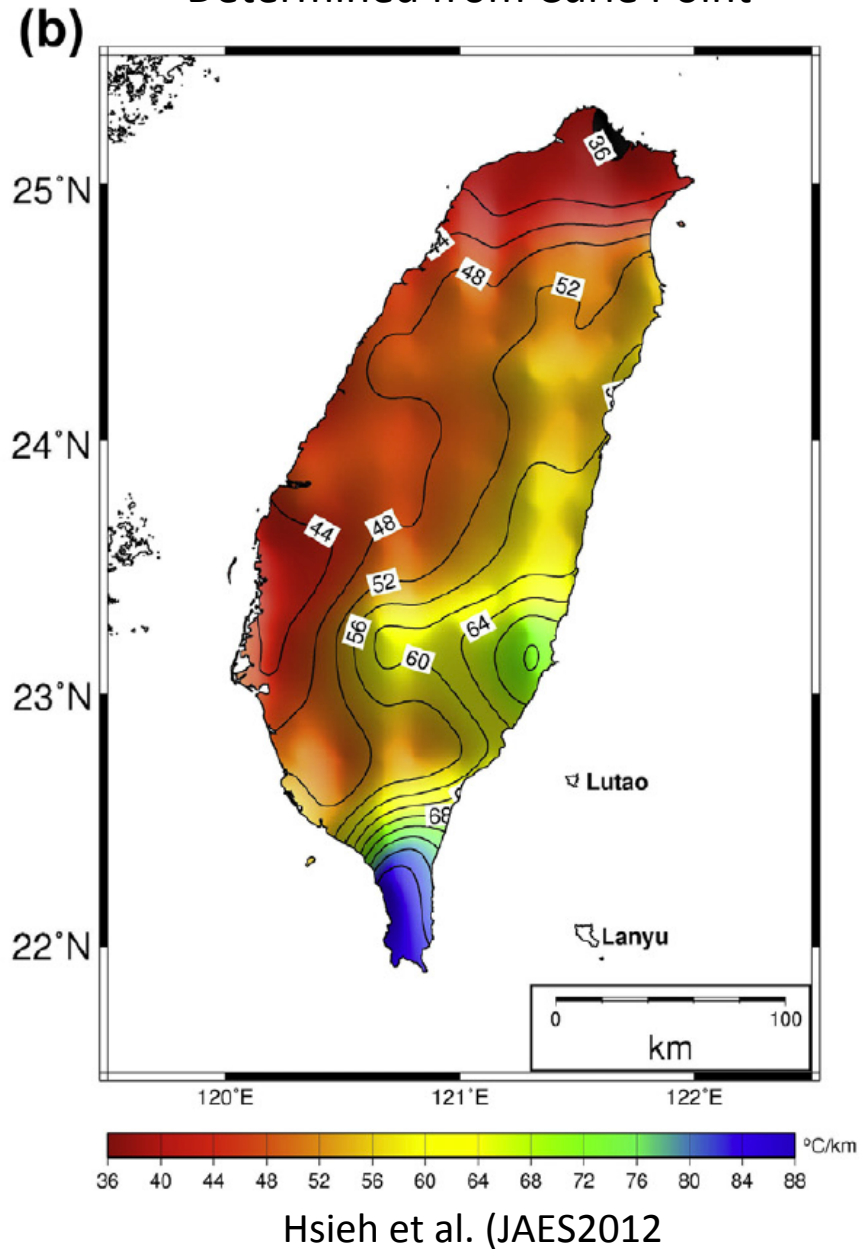


Geothermal gradient in Taiwan is very high: $> 50^{\circ}\text{C/km}$

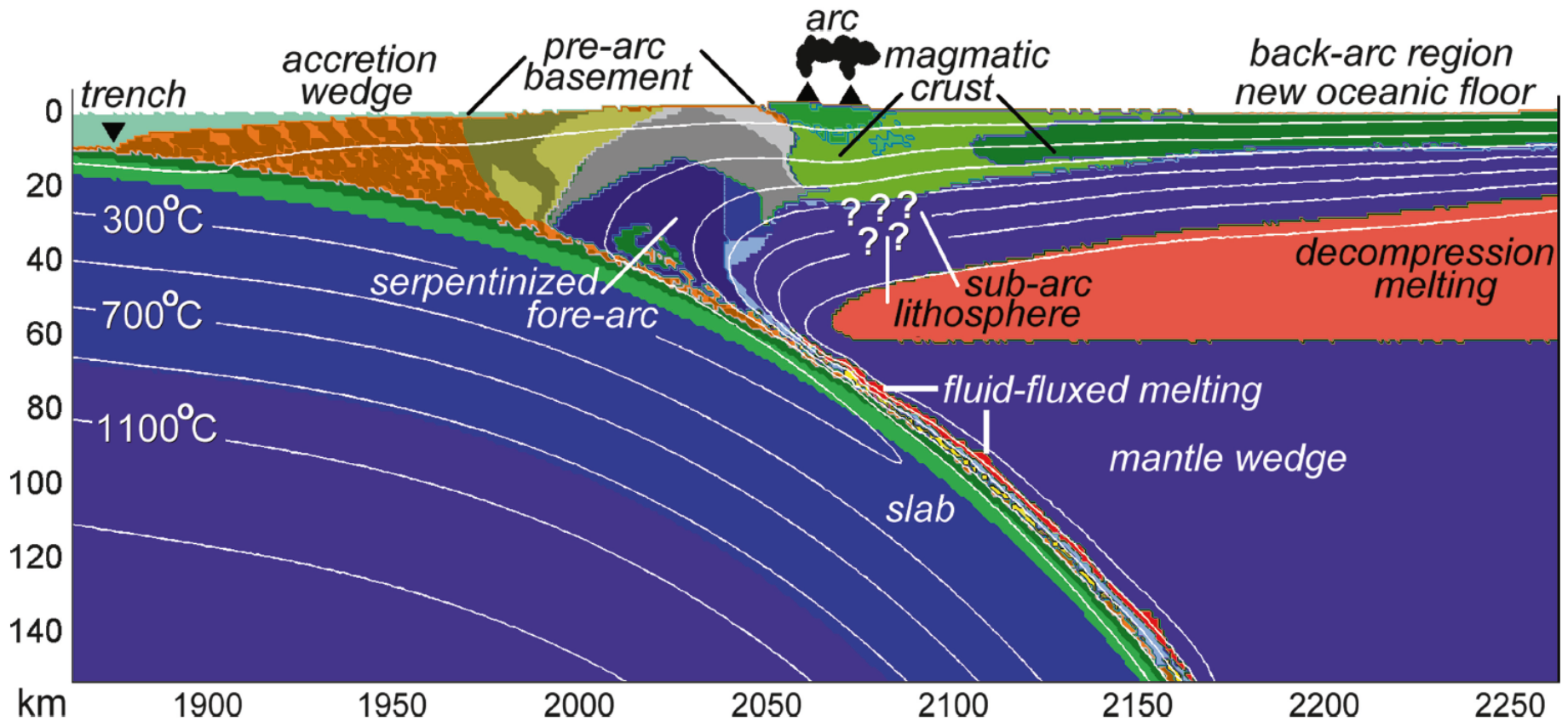
Determined from heat flow



Determined from Curie Point

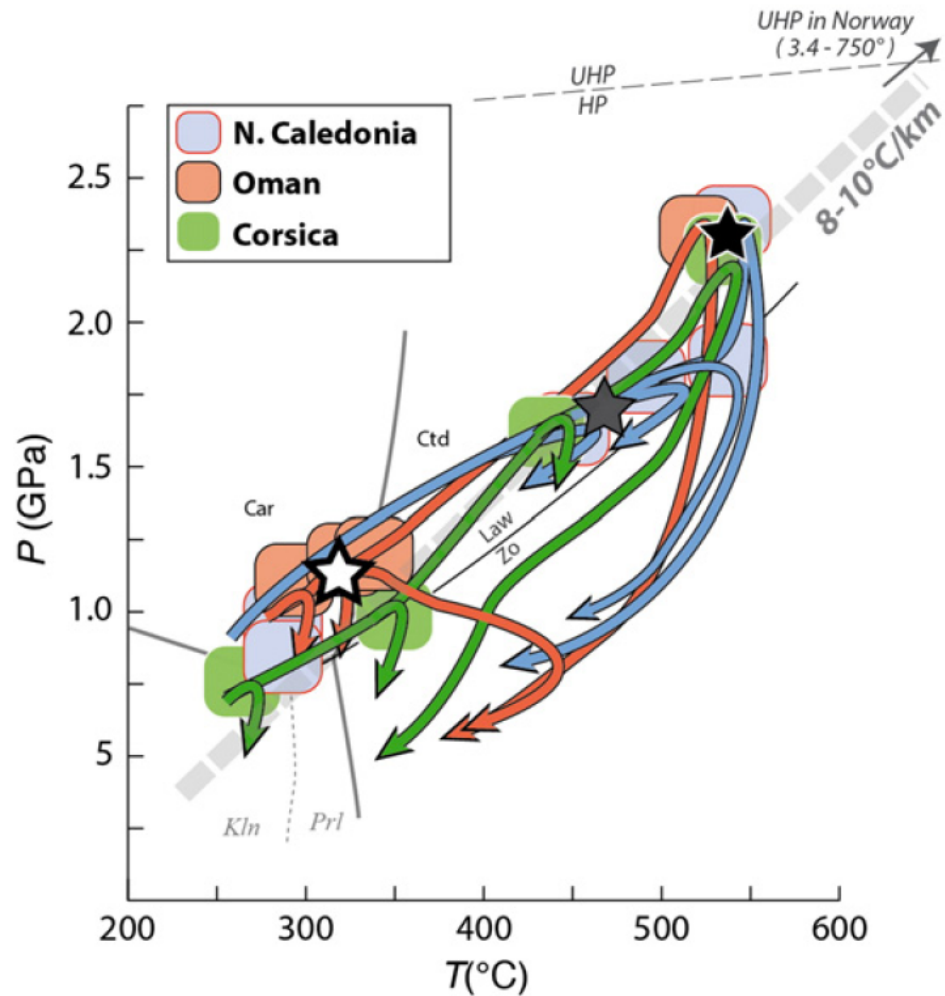


Subduction zones are cold

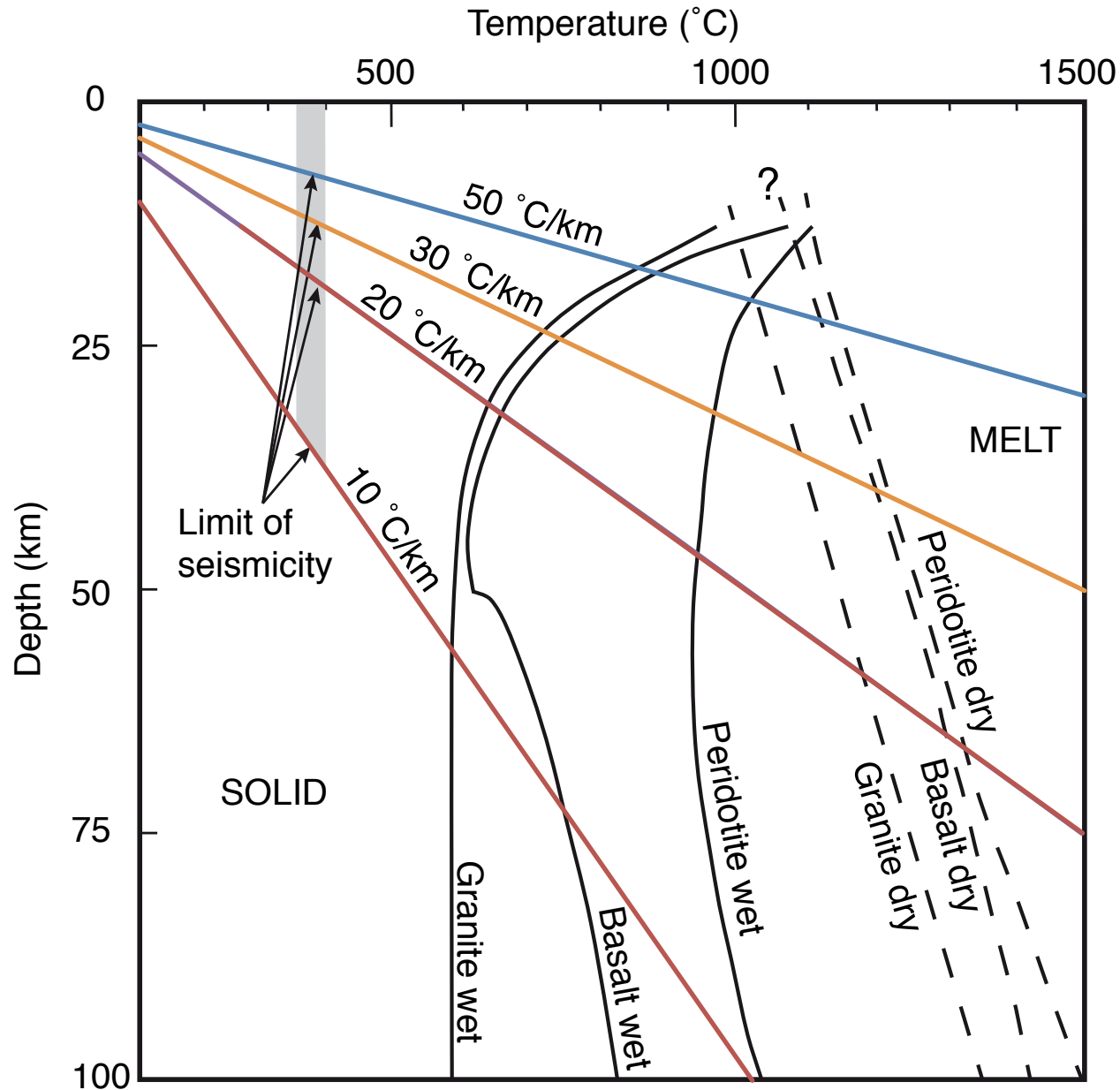


Gerya (2011). In: Arc-Continent Collision, Springer.

Pressure and temperature data from high-pressure rocks worldwide indicate a subduction channel geothermal gradient of $10 \pm 5^\circ\text{C}/\text{km}$ (e.g., Maruyama et al., 1996, Int. Geol. Rev.)

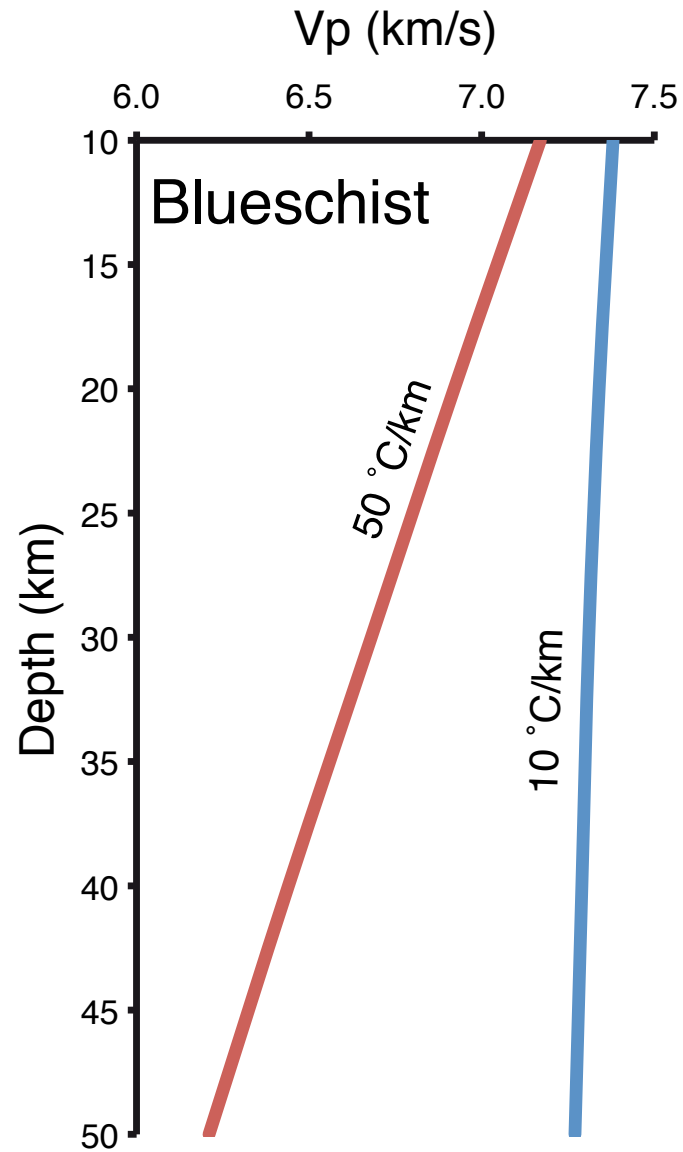


The importance of the geothermal gradient

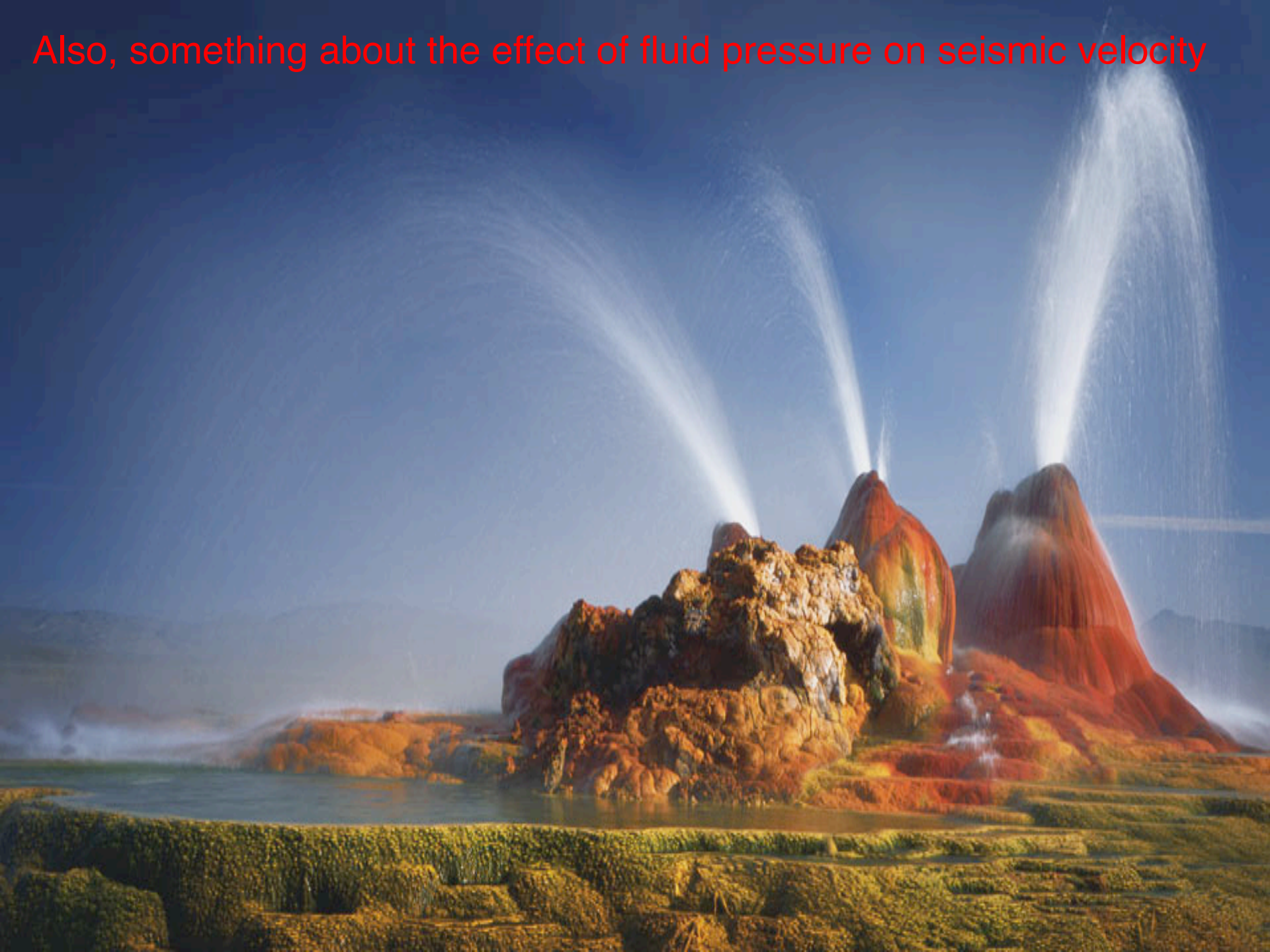


Modified from Winter, J.D., 2001, An Introduction to Igneous and Metamorphic Petrology

Effect of the geothermal gradient on velocity

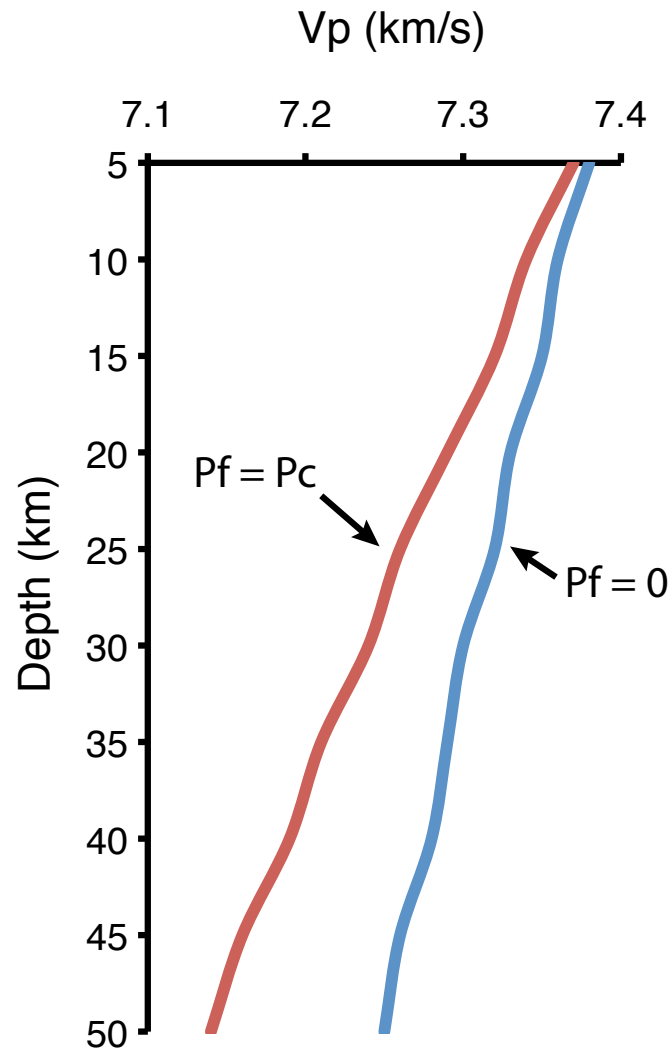


Also, something about the effect of fluid pressure on seismic velocity



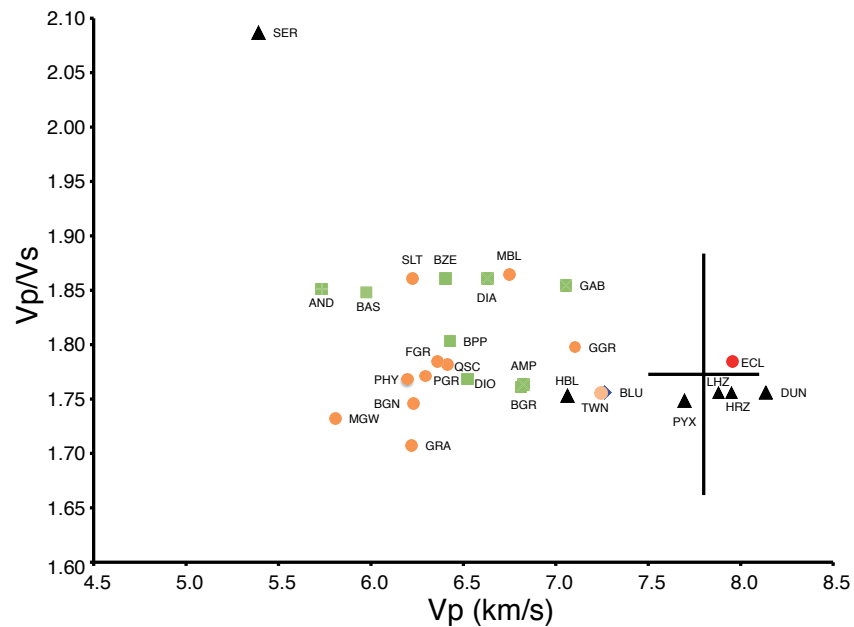
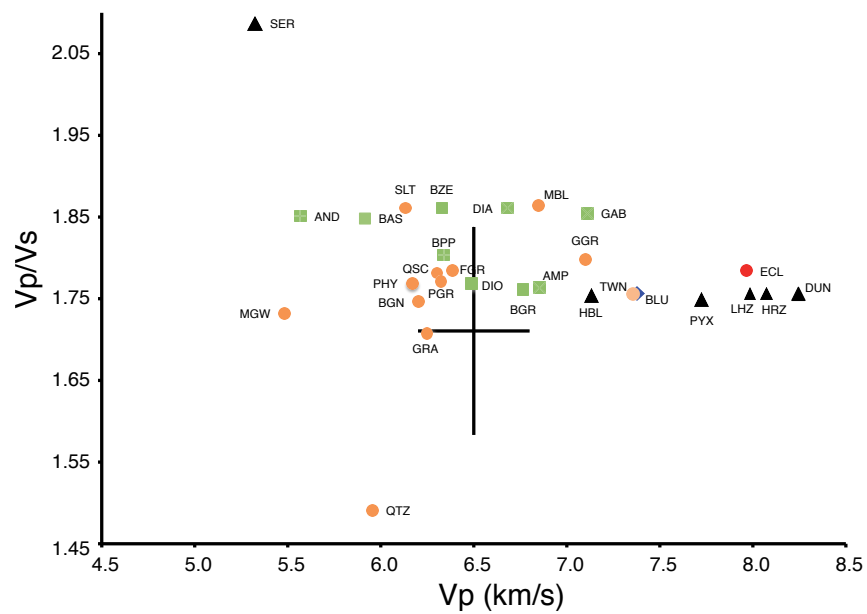
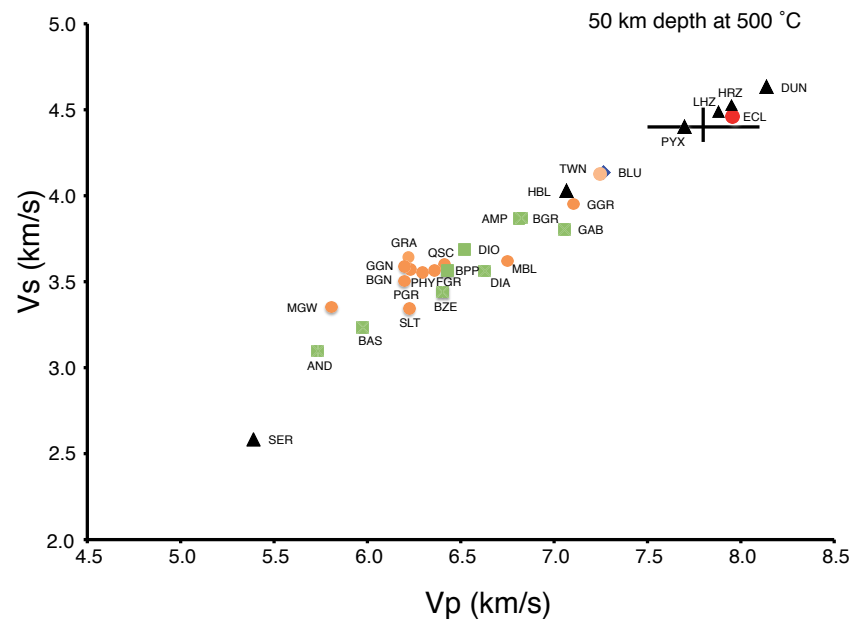
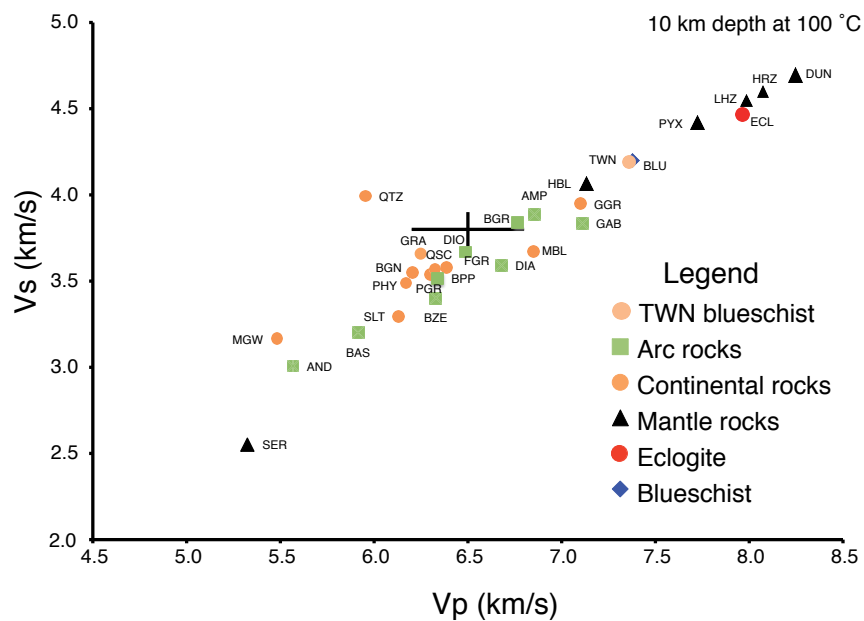
Fluid pressure acts to reduce velocity

In the shallow part of subduction zones λ (P_f / P_c) is about 0.75

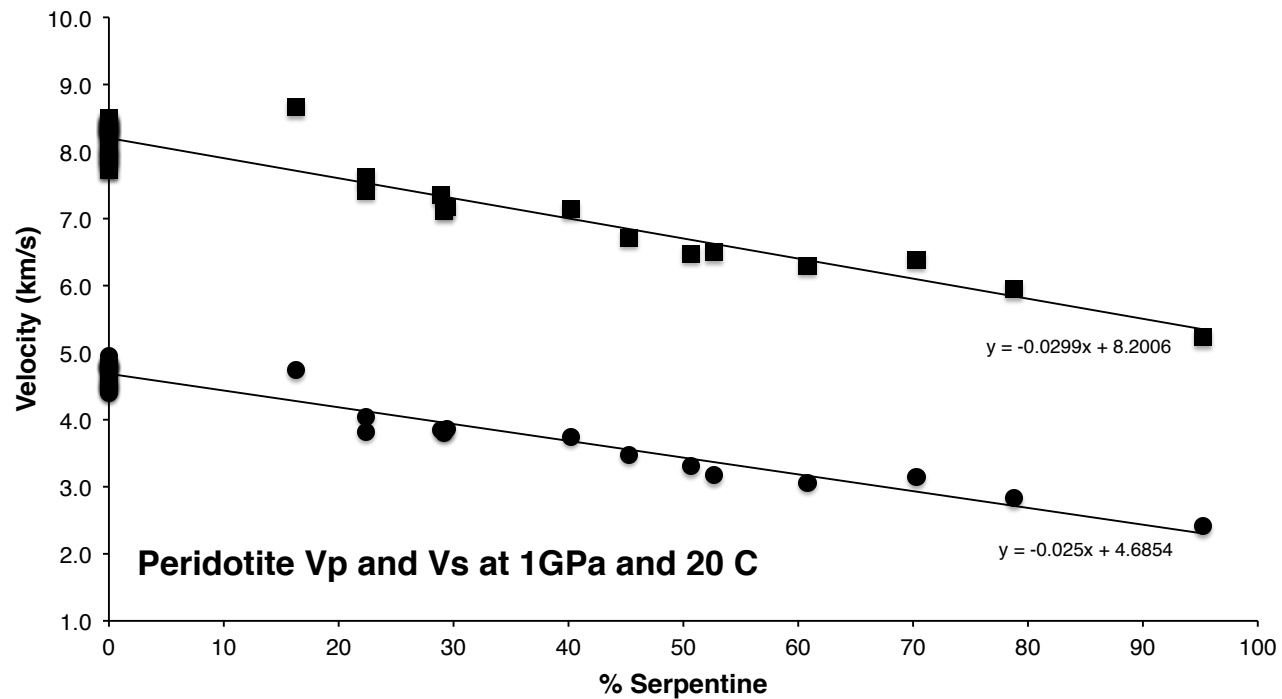
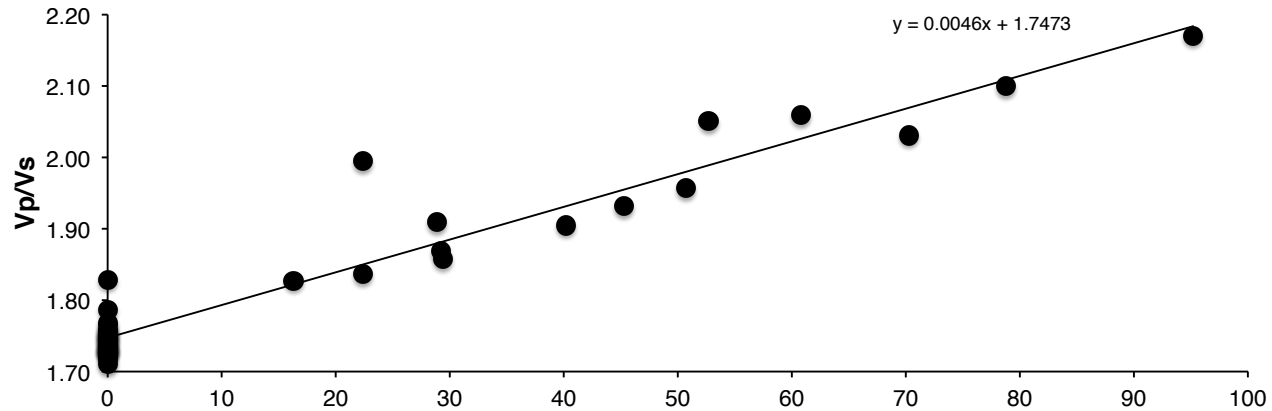


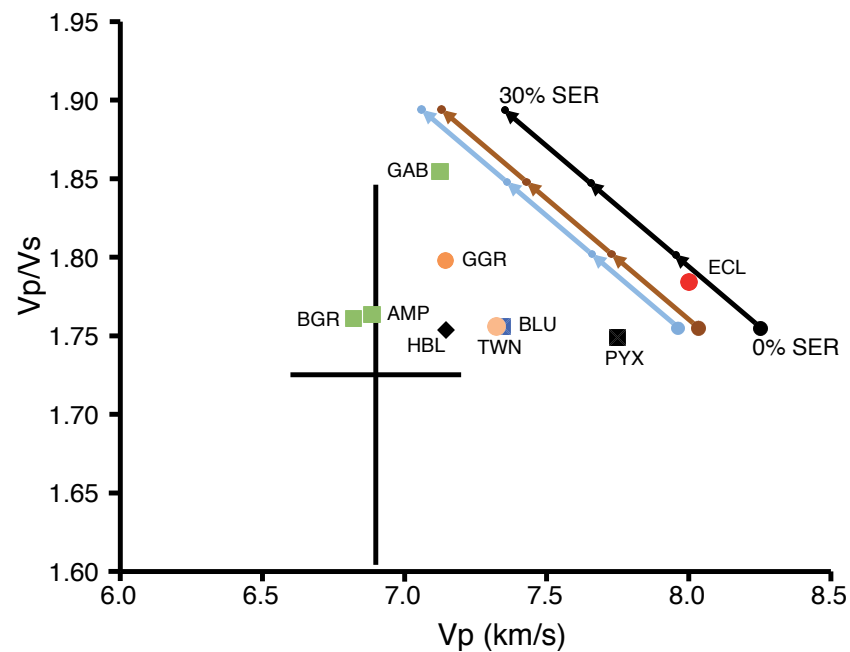
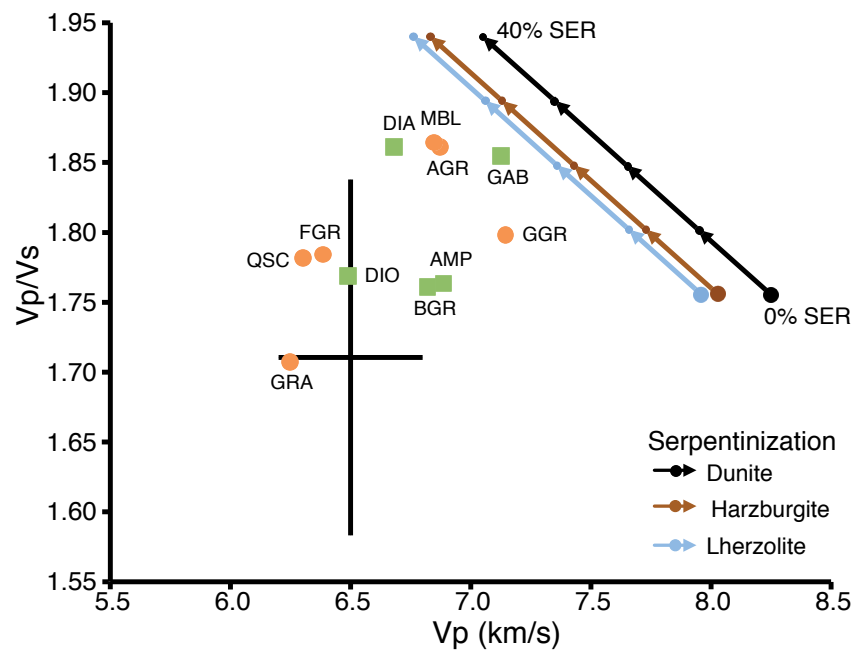
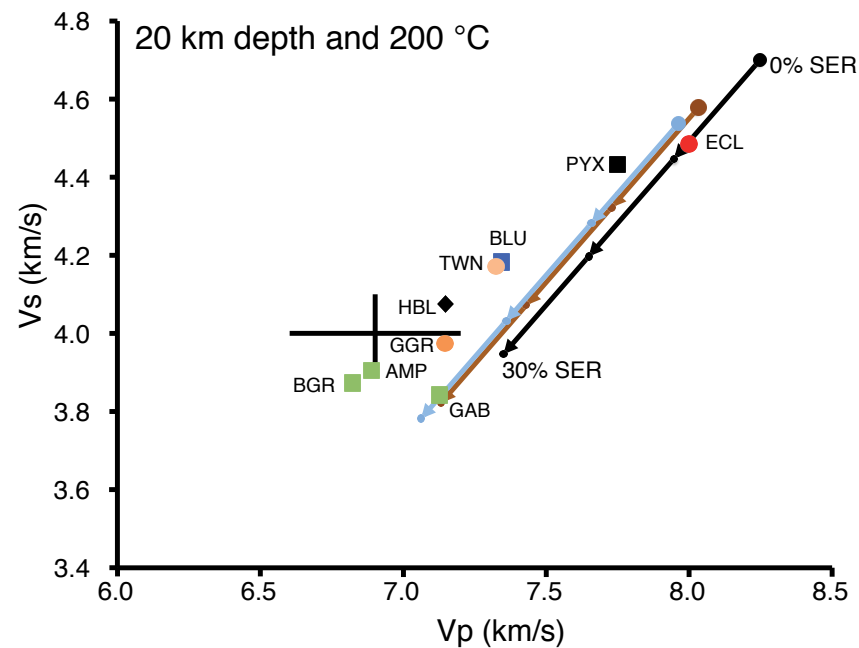
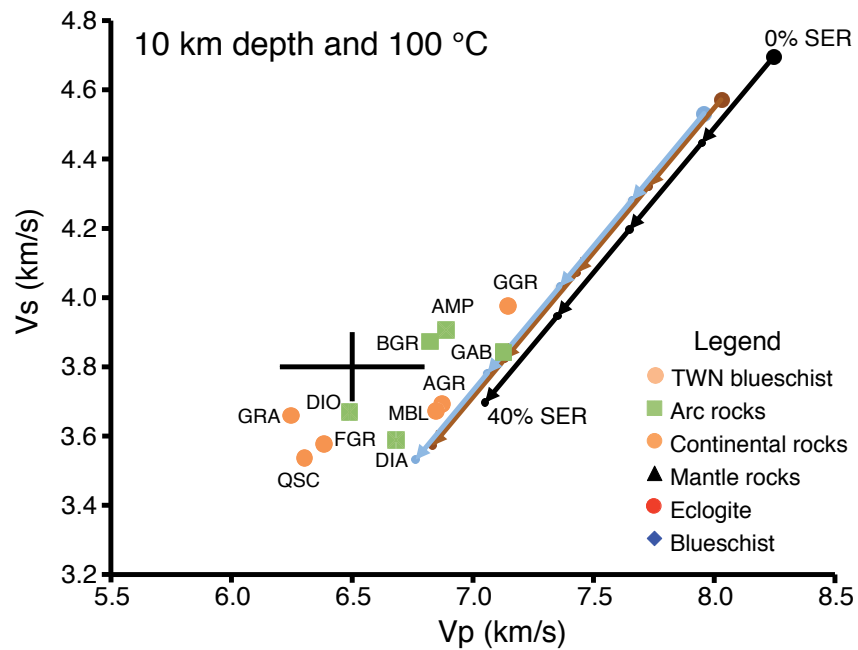
Petrophysical modeling methods

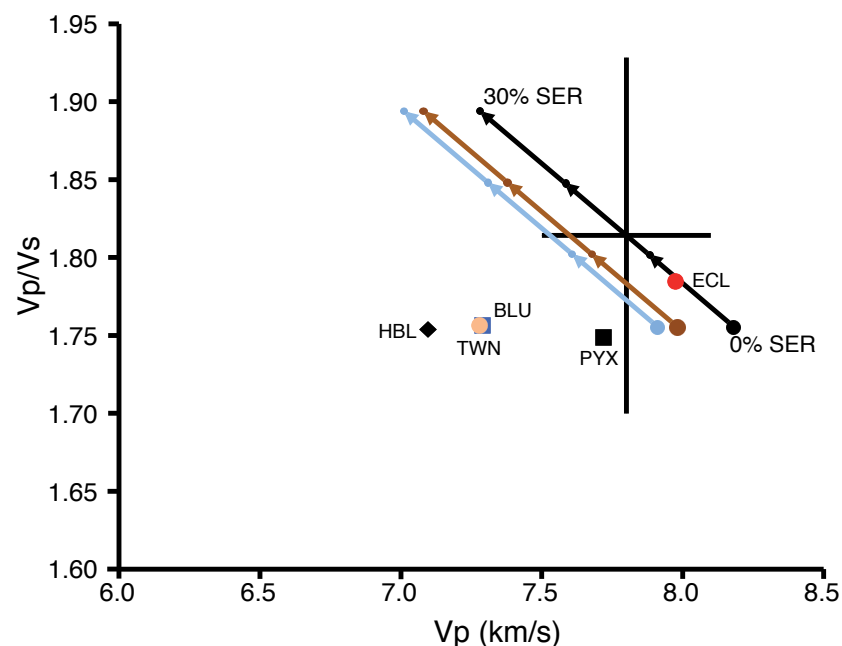
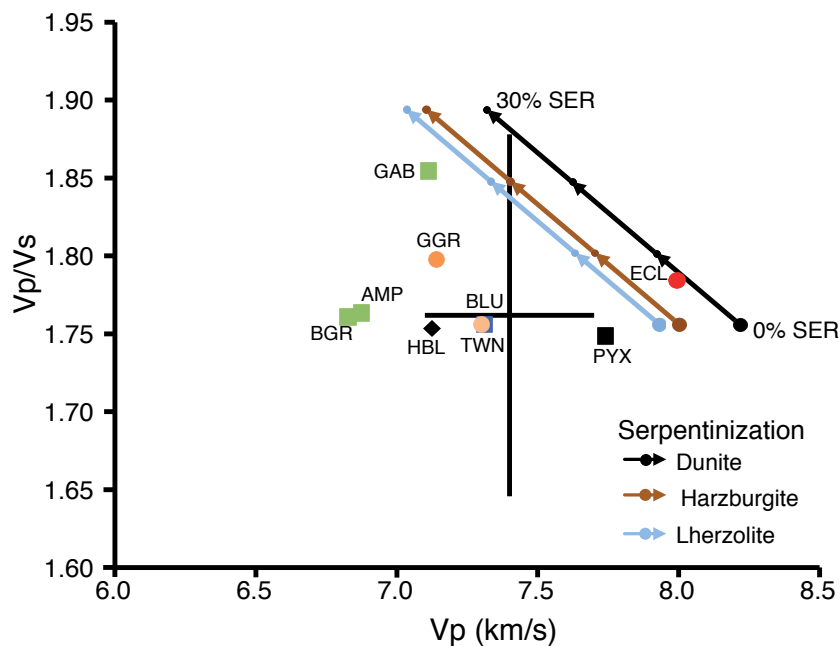
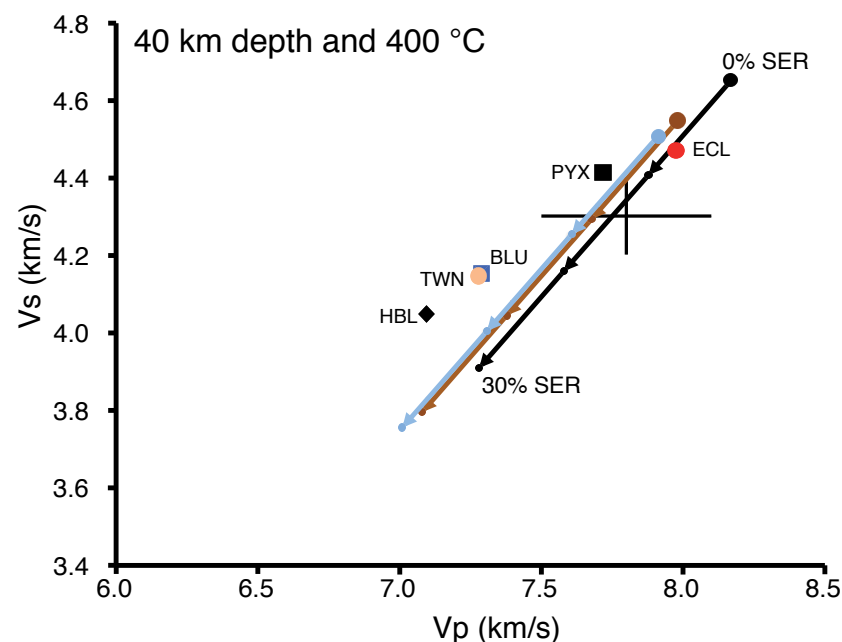
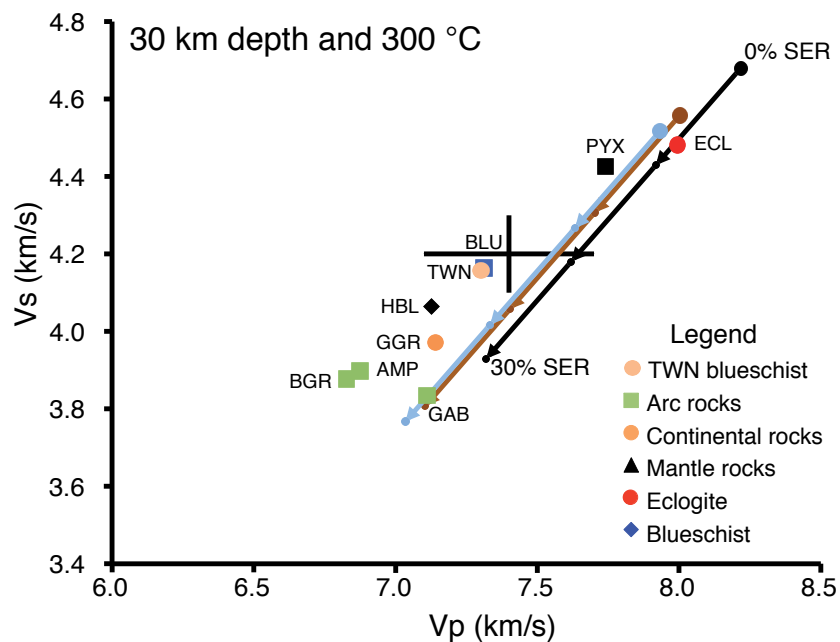
- Rock physical properties data base of Christensen (1996, JGR) was used.
- BLU, TWN, HRZ, and LRZ velocities were calculated at pressure and 20 °C using PhysProps, an Excel marco by Hacker and Abers (2004, G³).
- Vp and Vs were corrected for effective pressure using the equation $P_e = P_c - nP_f$
 1. Confining pressure (P_c) at depth is calculated using a constant density of 2.85 g/cm³.
 2. n is a poorly constrained empirical constant that is <1 : it is set at 0.8
 3. Pore fluid pressure (P_f) is determined as $\lambda = P_f/P_c$: λ is set at 0.75
- Velocities were corrected for a 10 °C/km geothermal gradient using the thermal coefficients of Christensen and Mooney (1995, JGR) and Christensen and Stanley (2003, Int. Handbook Earthquake and Eng. Seis.)

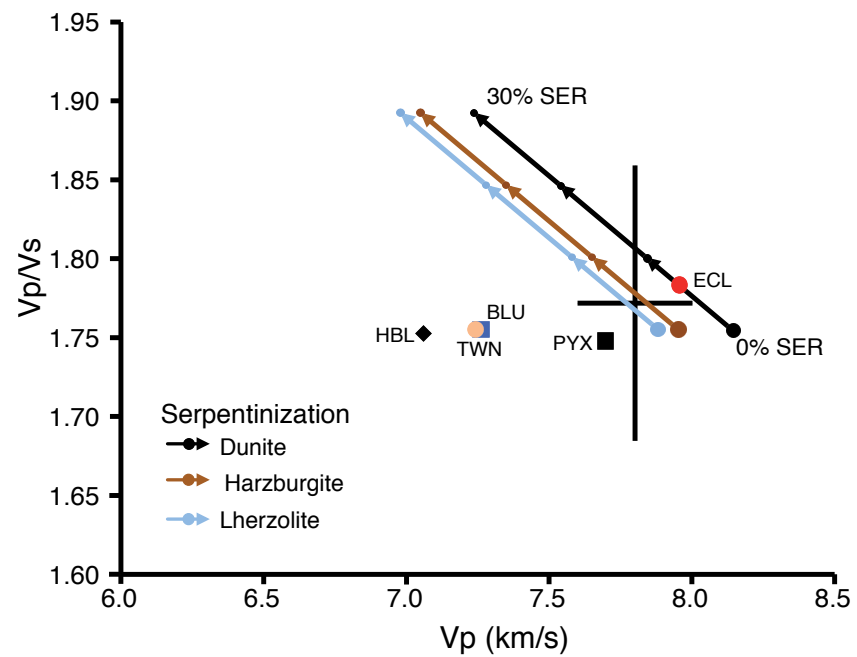
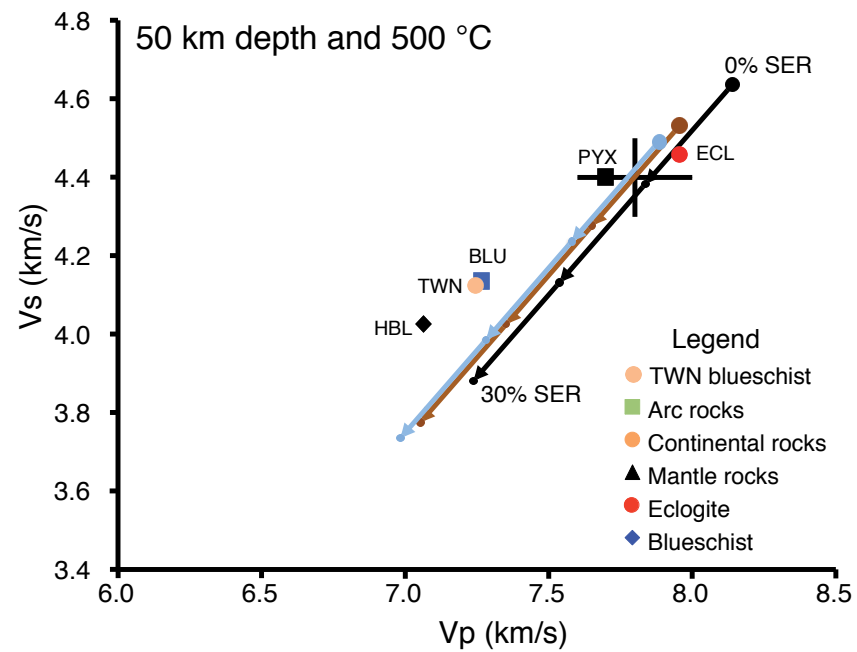


Effect of serpentine on peridotite









Uncertainties in the petrophysical modeling

- Uncertainties introduced by the tomography model (e.g., grid size, anisotropy)
- Many rock types have similar physical properties
- Cannot distinguish rock mixtures or small rock volumes

Advantages of petrophysical modeling

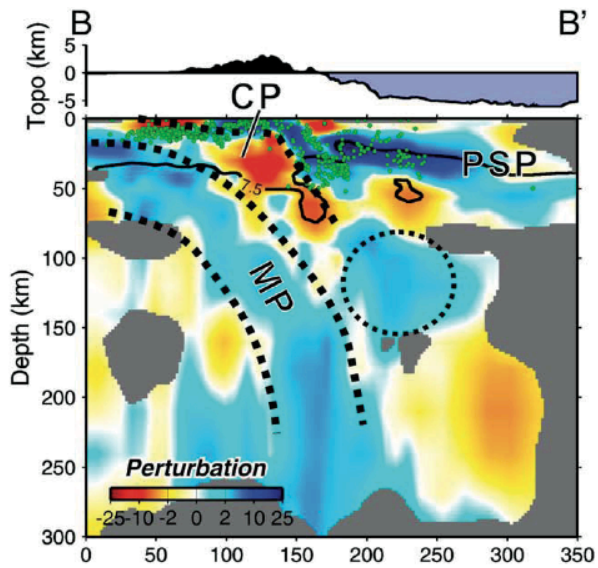
- A large number of rock types can be discarded at any one depth interval
- Matching of *in situ* and modeled physical properties narrows possible rock types
- An estimate of rock modal composition can be determined (but not abundance)

- The Yuli Belt is a classic mélange-type high-pressure terrane. A high-velocity zone extends from beneath it to at least 50 km depth
- At 10 deep, metamorphosed continental and volcanic arc rock types fit the velocities well, including quartz-mica schist. Mantle rock types have a poor fit at this depth.
- At 20 km depth, metamorphosed arc rocks fit well with the velocities. Mantle rock types with 20-30% volume of serpentinite begin to approach the measured V_p and V_s range, but their V_p/V_s ratio is too high.
- At 30 kms depth, blueschist, pyroxenite, and harzburgite, lherzolite and dunite with 10-20% serpentinization fit the velocities well.
- At 40 and 50 km depth, eclogite, pyroxenite, and weakly to unserpentinized harzburgite, lherzolite, and dunite best fit the velocities.

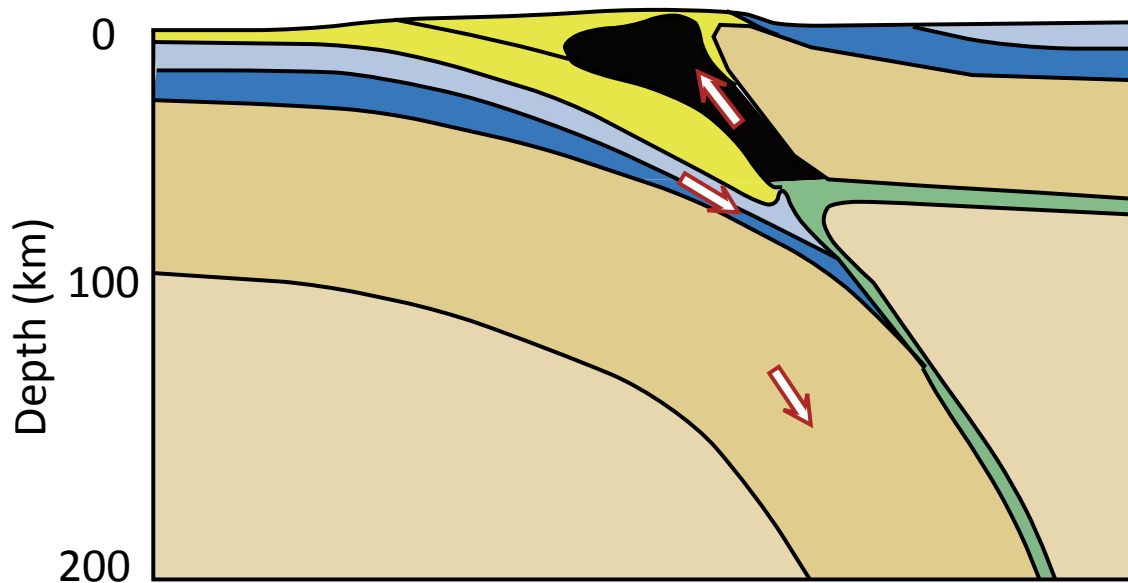
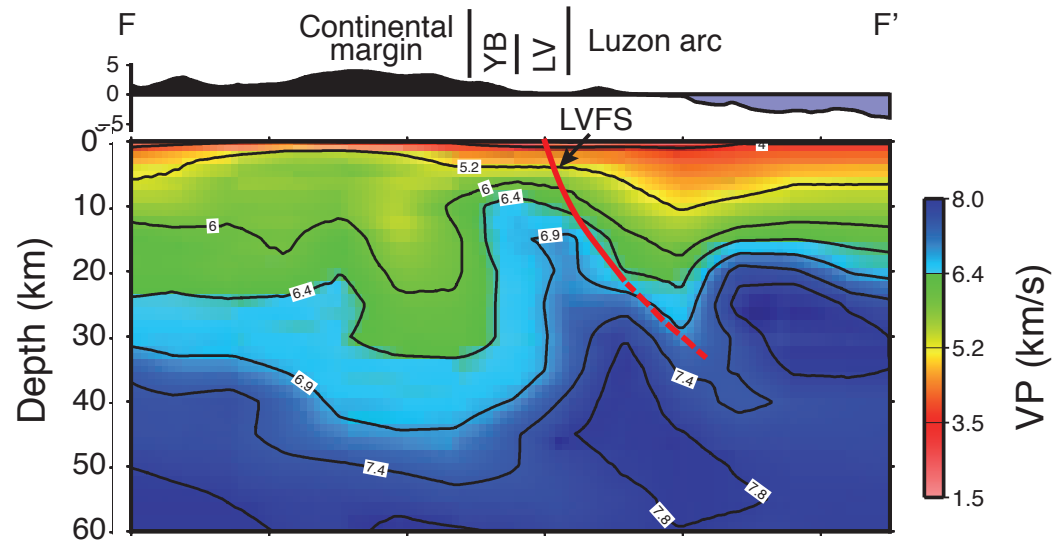
Could an exhuming high-pressure rock terrane model explain the high-velocity zone in eastern Taiwan?

The answer is yes. The geodynamic setting is ideal, the presence of the Yuli Belt indicates that high-pressure rocks are being exhumed, and petrophysical modeling suggests that the lithologies present in the high-velocity zone fit well with an exhuming high-pressure terrane.

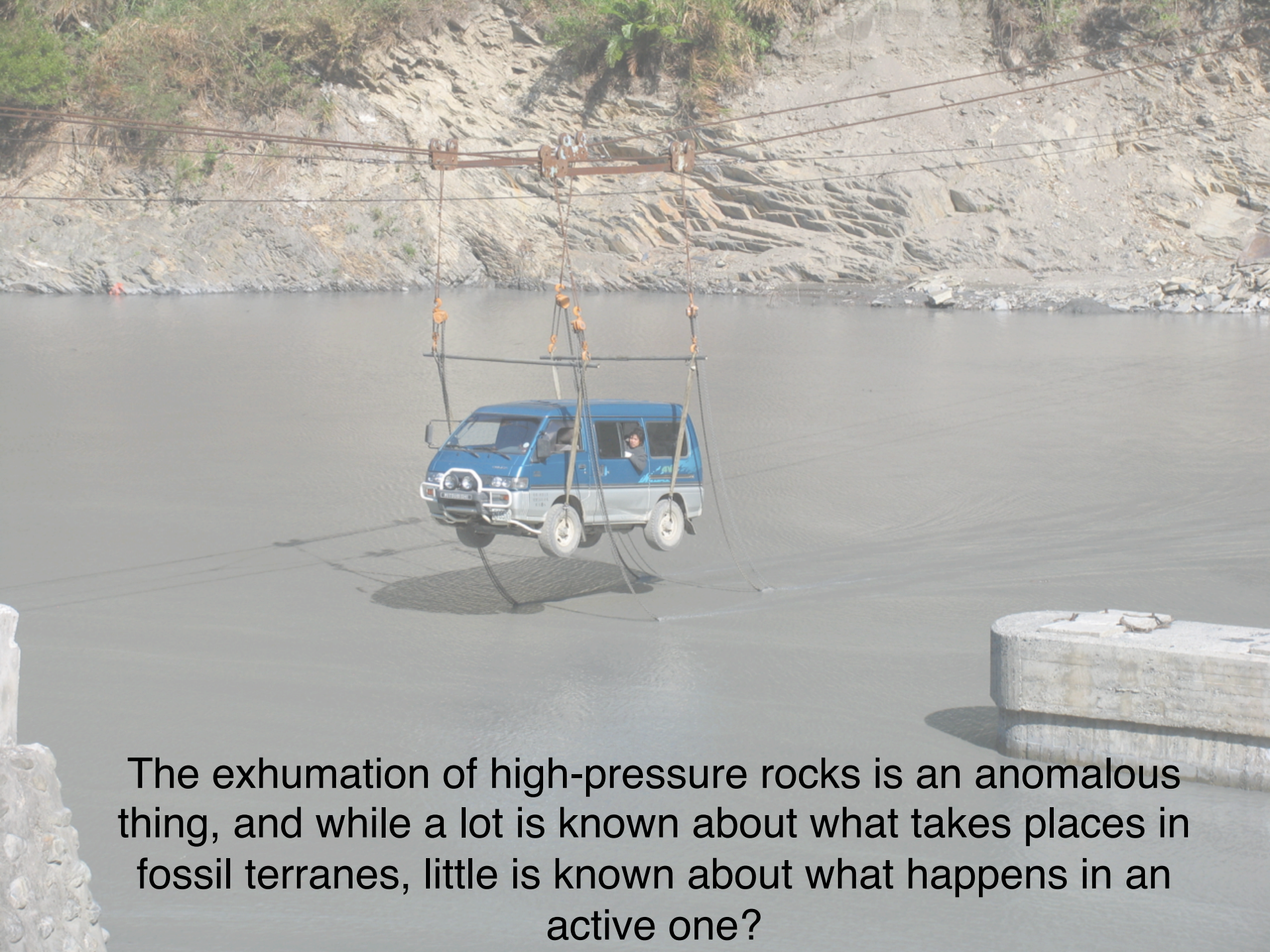
Also, it fits well with the predicted models.



Huang et al, GRL, 2014



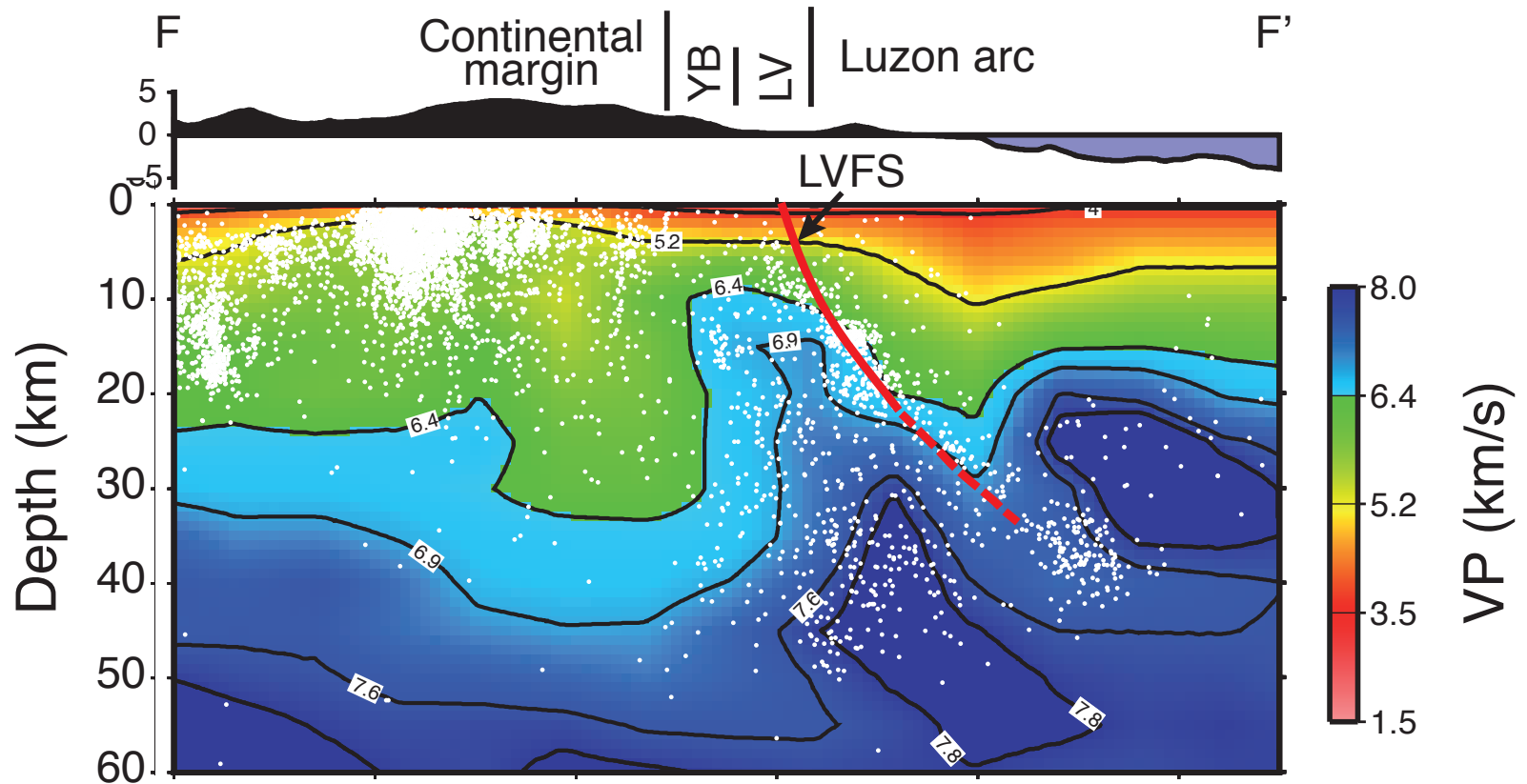
Subduction channel flow model (Hacker and Gerya, Tectonophysics, 2013)



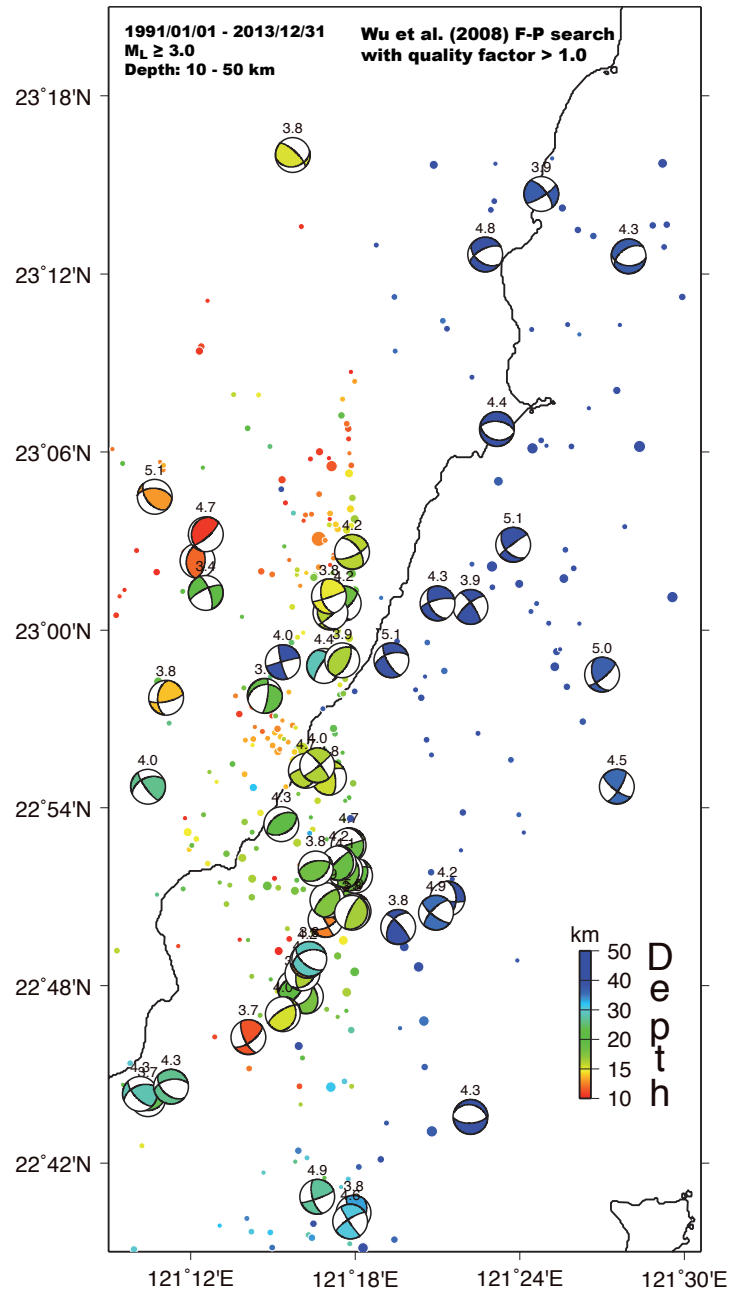
The exhumation of high-pressure rocks is an anomalous thing, and while a lot is known about what takes place in fossil terranes, little is known about what happens in an active one?

Seismicity

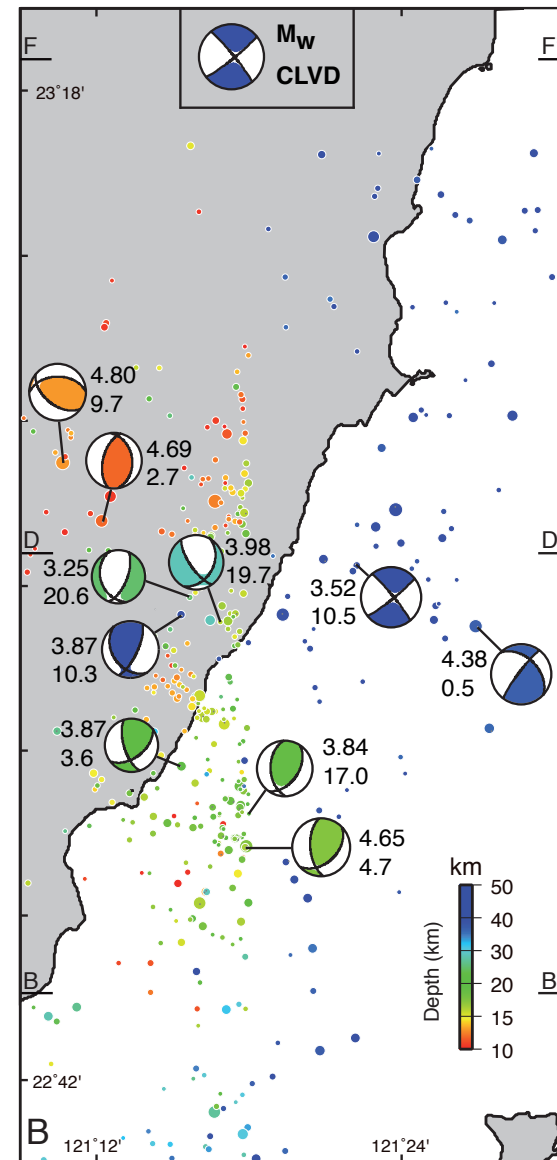
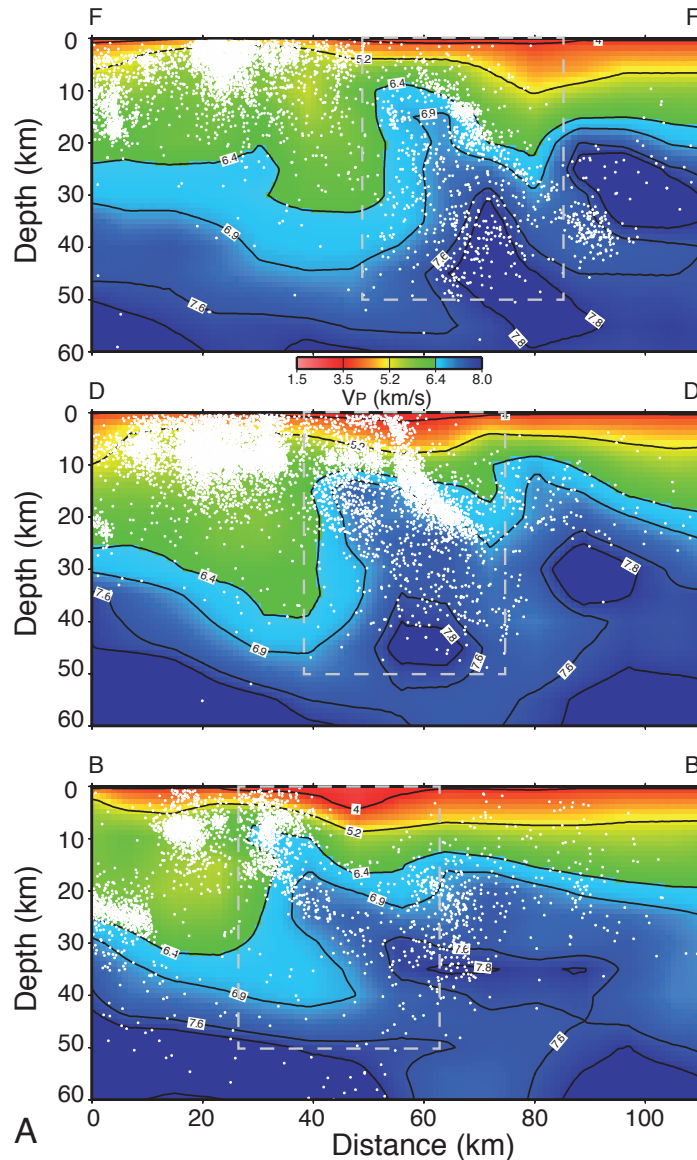
- Events have been relocated using double-difference location
- High-velocity zone is seismically active to a depth of 50 km



- Focal mechanisms determined for 41 events $M_L > 3.5$

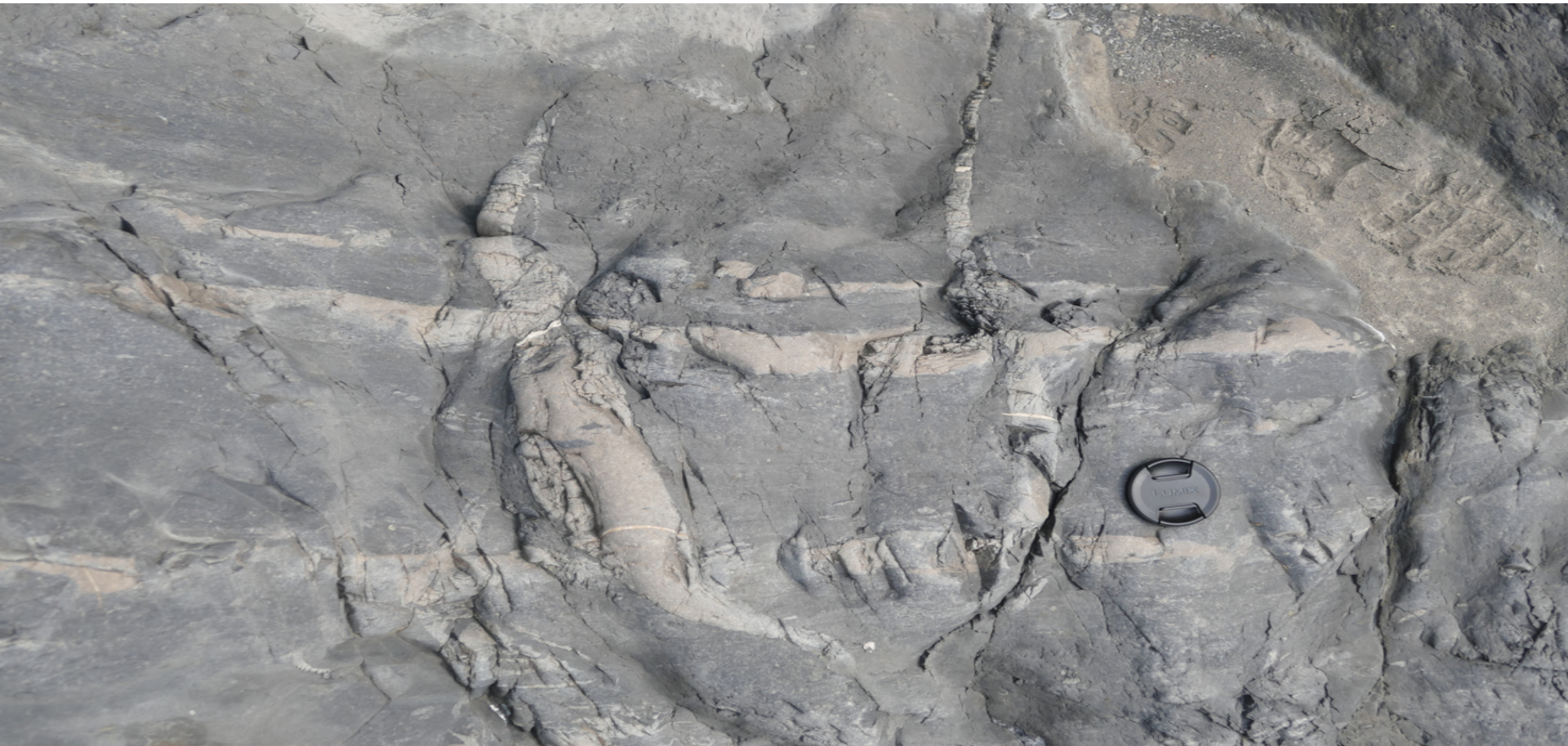


- Full wave-form modeling of 10 events
- Predominantly double-couple mechanism
- Five events with CLVD >10: maximum 20.6



A variety of processes could cause earthquake mechanisms to depart from the idealised double-couple force system. Of interest to this study, these include:

- Dehydration embrittlement and the opening of tensile cracks by high fluid pressure
- Extreme structural complexity



Thank you

