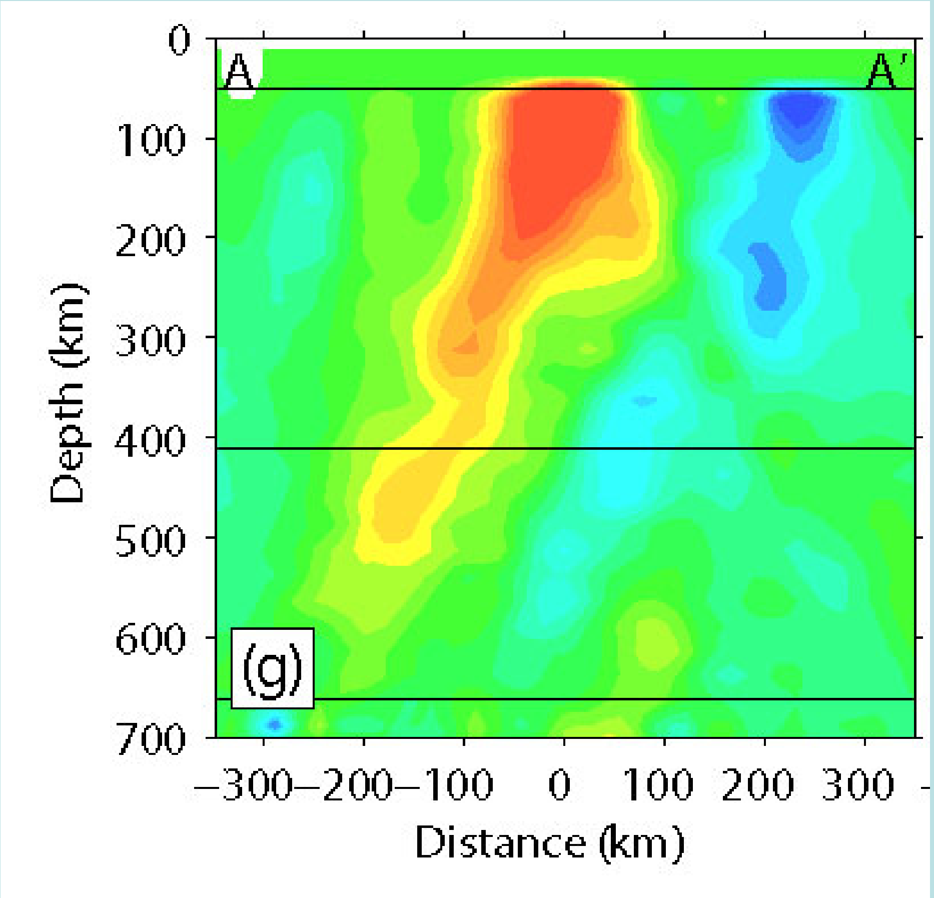
Yellowstone hotspot is an upper mantle plume



UW Post-doc Derek Schutt
UW Ph.D. Huaiyu Yuan
UU Greg Waite

Arizona Talk Febuary 2005

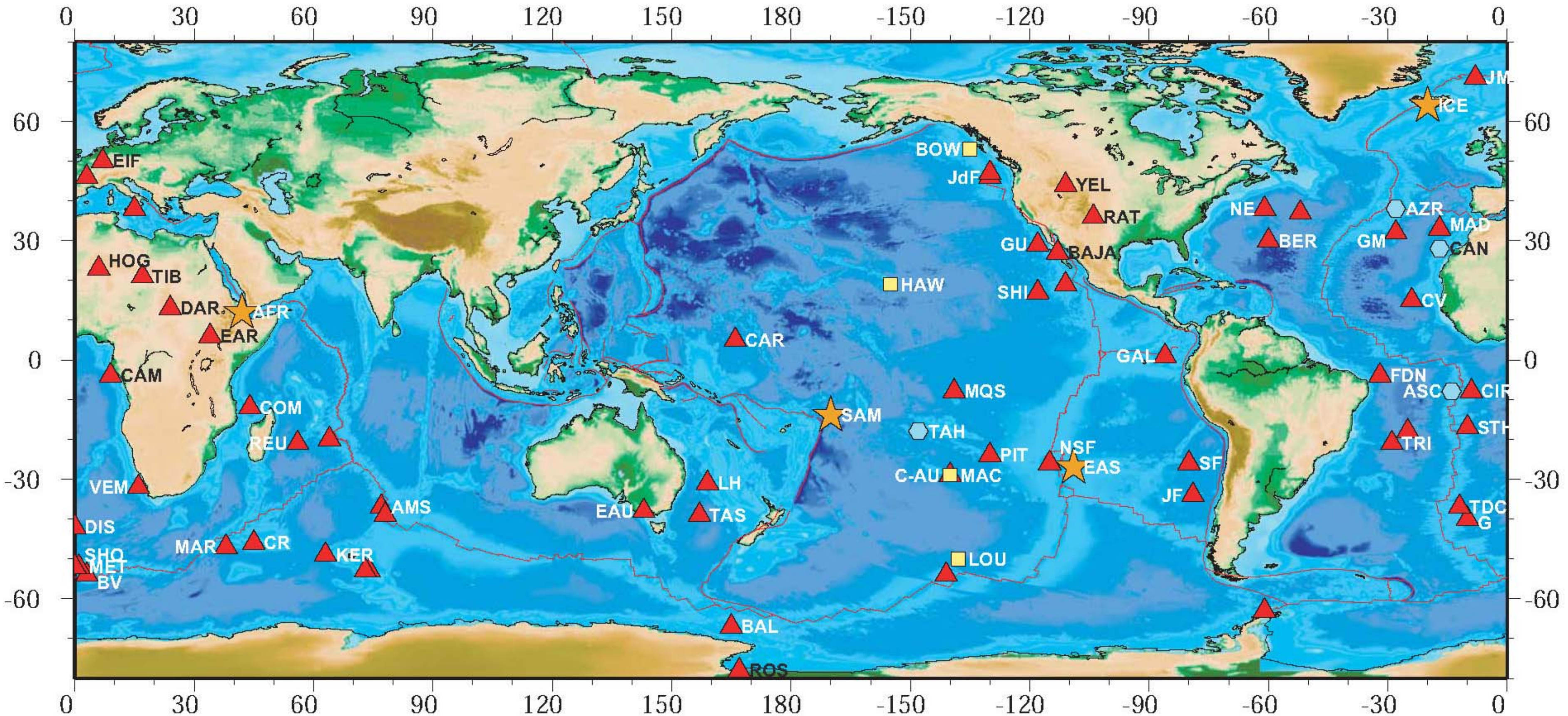
faculty.gg.uwyo.edu/dueker

www.mantleplumes.org

Outline

- Introduction
- 410 and 660 km topography
- Teleseismic P-wave tomogram
- Rayleigh wave S-wave tomogram
- Conclusions: upper mantle plume

Hotspot map (anderson's website)

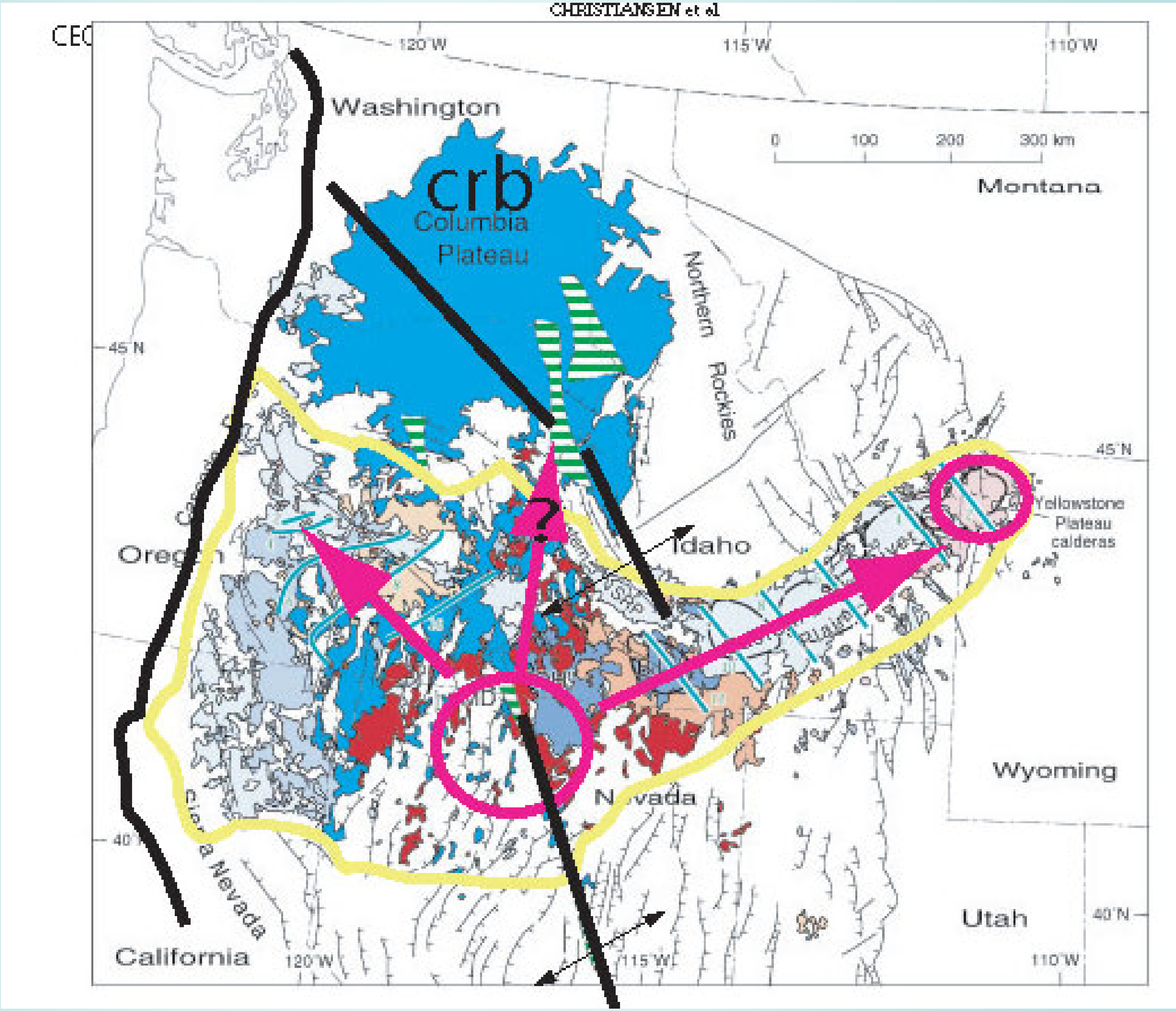


Last 17 Ma Volcanism

map from Christenson et al., 2002

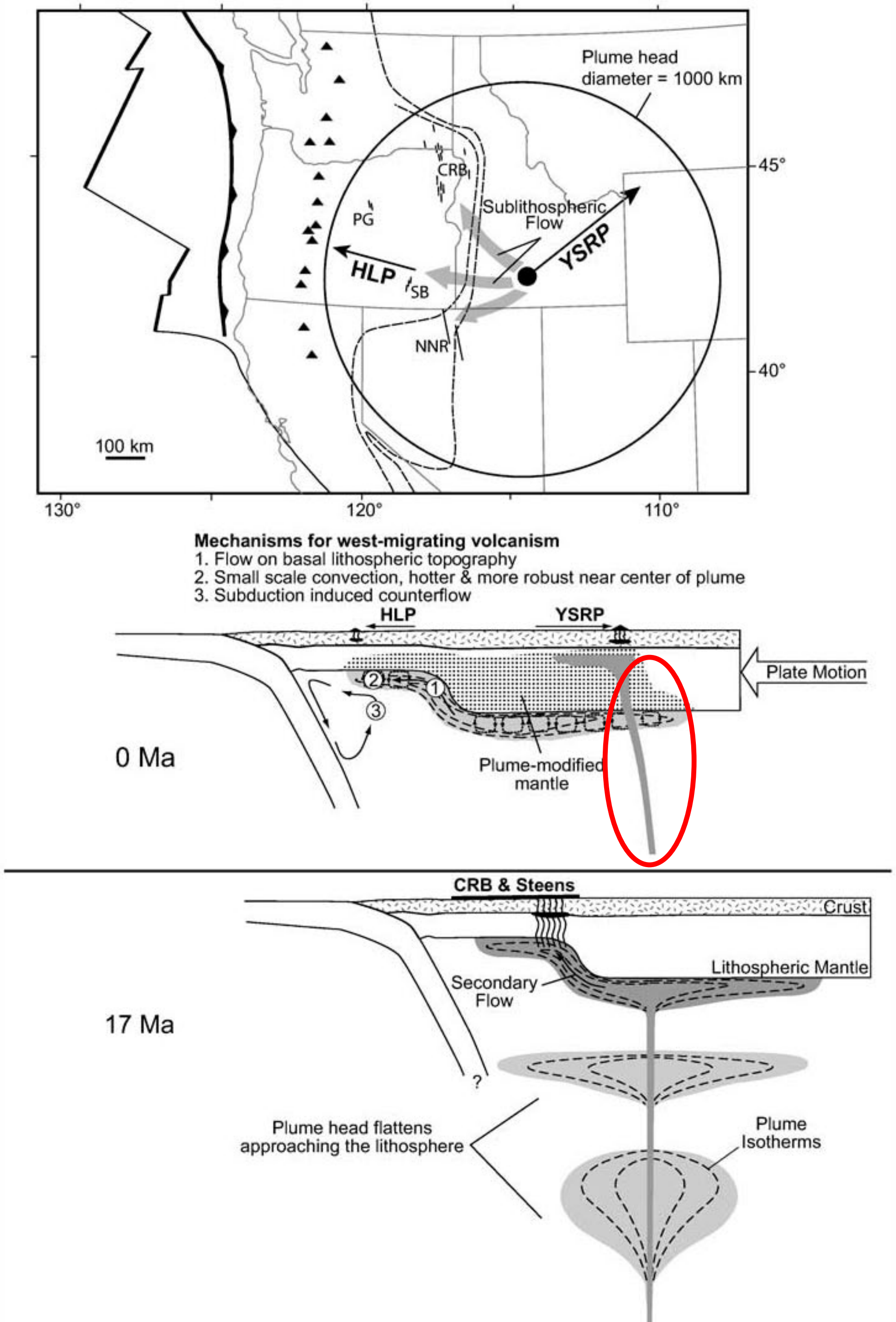
Is this MIP-sized volcanic event a subduction distorted plume head impact?

or just plain-old back-arc spreading?



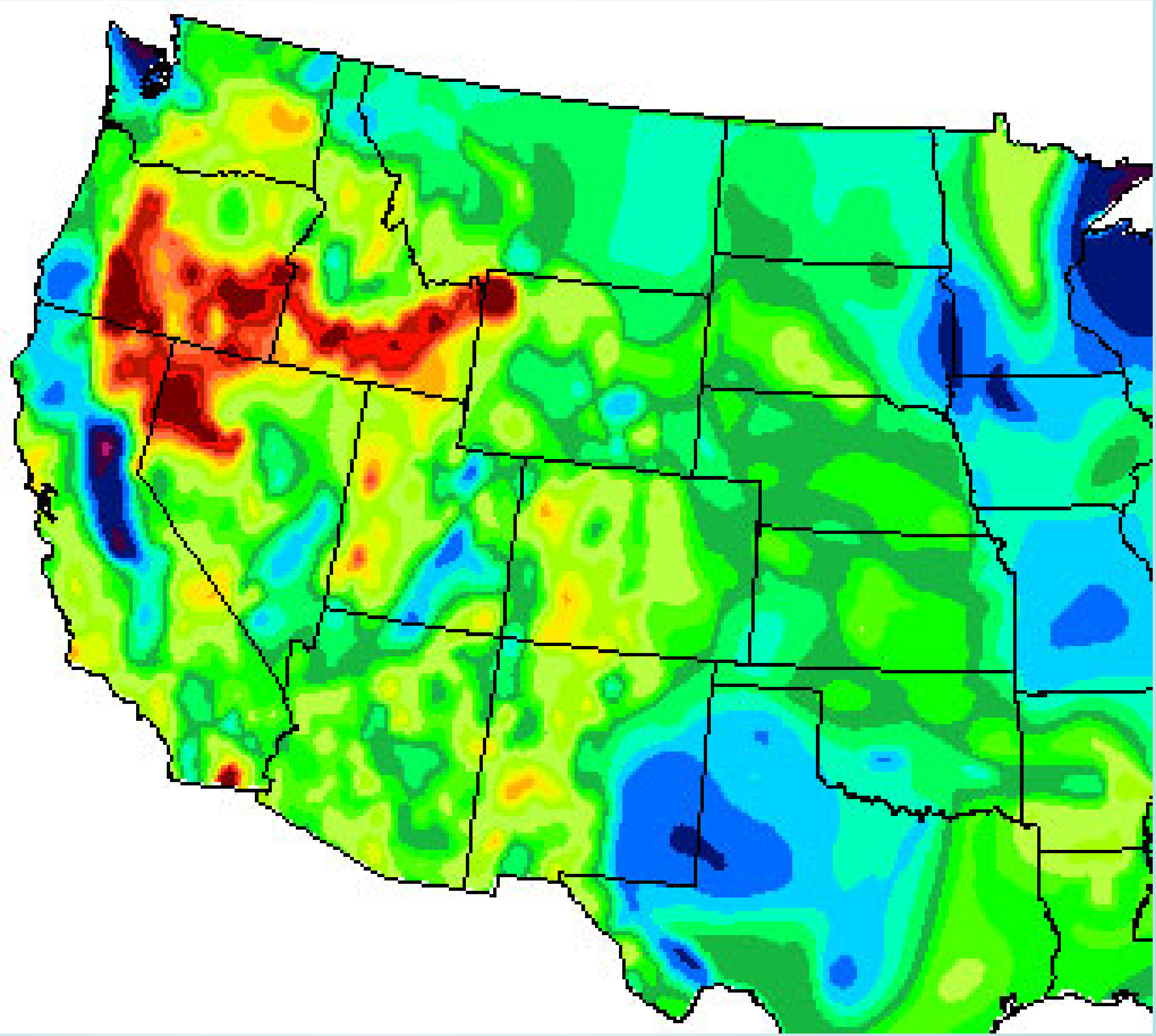
Plume Head Impact at 17 Ma

from Jordan et al., 2004



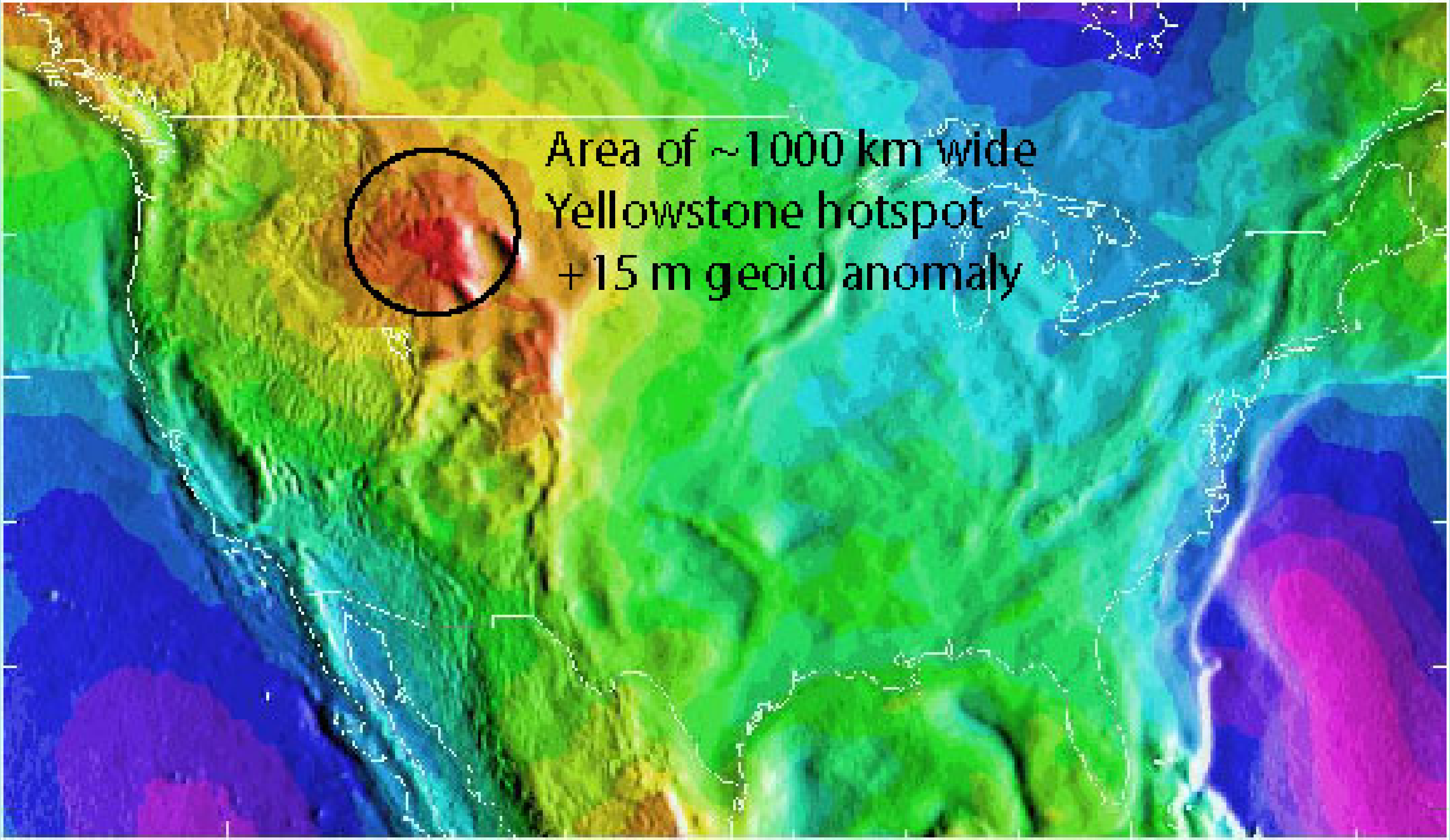
Heat flow gradient

(Blackwell’s website)



Geoid

Geoid map of the U. S. (Geoid99, NGS)

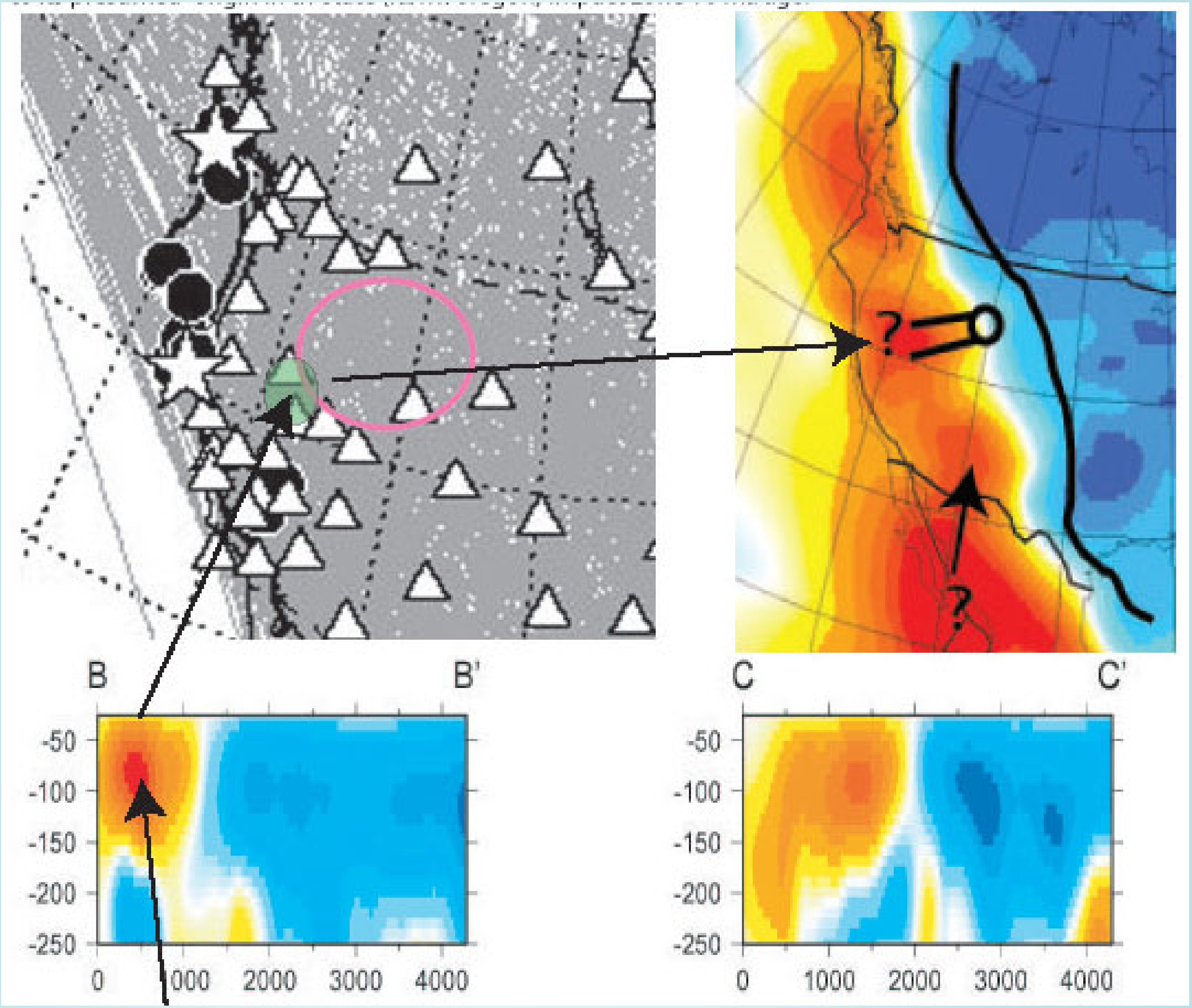


Scale: Blue to red is approximately +25 m

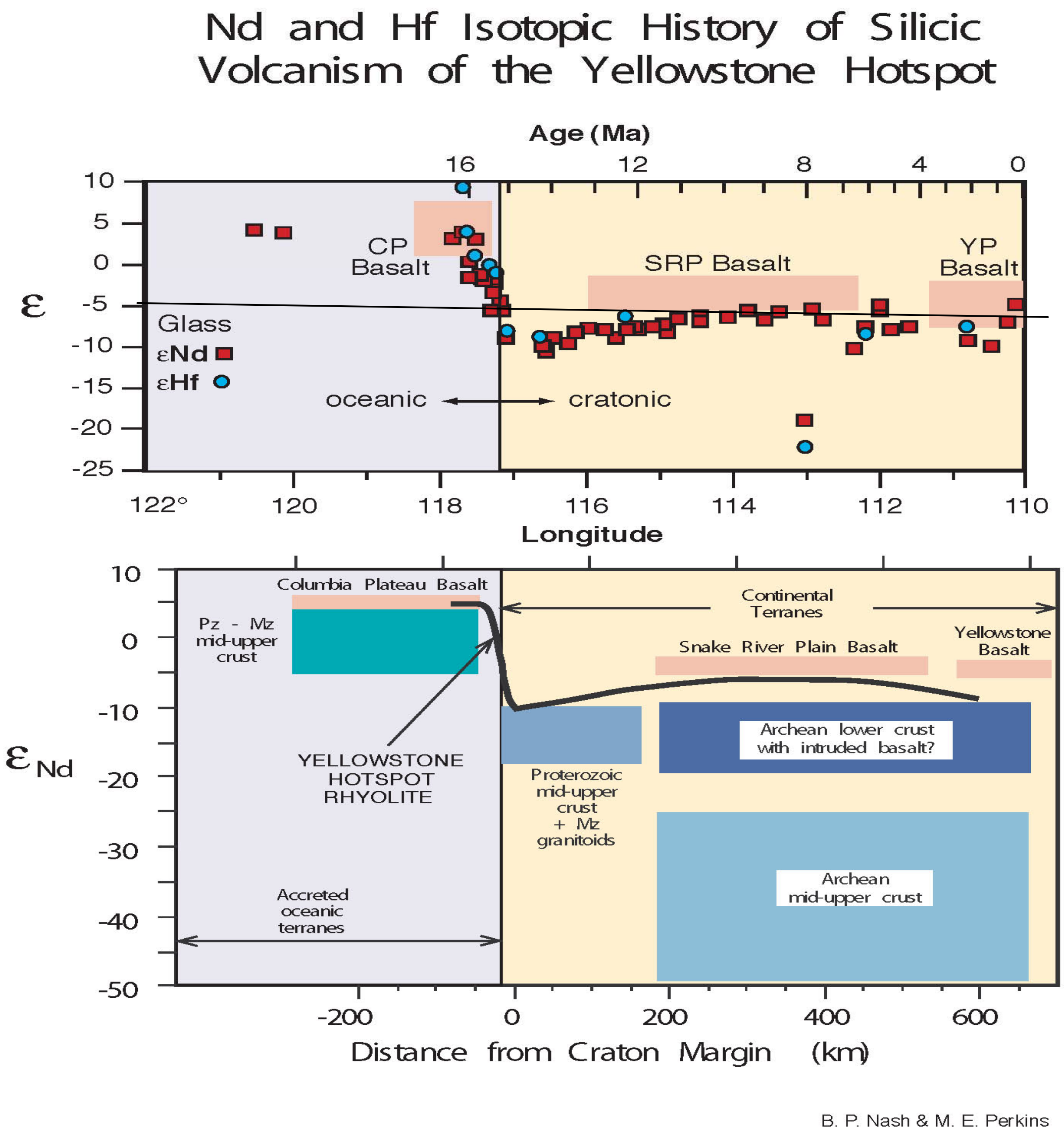
Shear wave velocity

Godey et al., 2004.

nothing extraordinary about Yellowstone region at this 500 km resolution scale-length



Geo-chem


Nd and Hf Isotopic History of Silicic Volcanism of the Yellowstone Hotspot
Age (Ma)
16
12
8
4
0
10
5
0
-5
-10
-15
-20
-25
ε
CP Basalt
SRP Basalt
YP Basalt
Glass
εNd
εHf
oceanic
cratonic
122°
120
118
116
114
112
110
Longitude
10
0
-10
-20
-30
-40
-50
εNd
Columbia Plateau Basalt
Pz - Mz mid-upper crust
Continental Terranes
Yellowstone Basalt
Snake River Plain Basalt
YELLOWSTONE HOTSPOT RHYOLITE
Archean lower crust with intruded basalt?
Proterozoic mid-upper crust + Mz granitoids
Archean mid-upper crust
Accreted oceanic terranes
-200
0
200
400
600
Distance from Craton Margin (km)
B. P. Nash & M. E. Perkins

Other’s Yellowstone publications

- Walker et al., 2004, Plume under Elko, Nevada from SKS anisotropy (Harkening to Savage/Sheehan, 2000).
- Camp and Ross, 2004, Plume head impact and spreading
- Jordan et al., 2004, Plume head impact and spreading
- Christiansen et al., 2002, Upper Mantle origin for Yellowstone

Mantle Discontinuity Constraints

Fee, D. and K. Dueker

Mantle transition zone topography beneath the Yellowstone hotspot

Geophys. Res. Lett., vol. 31(L18603), doi:10.1029/2004GL02063, 2004.

http://faculty.gg.uwyo.edu/dueker

Converted S-wave Piercing Points at 660 km depth

good sampling within 90 hit-count contour

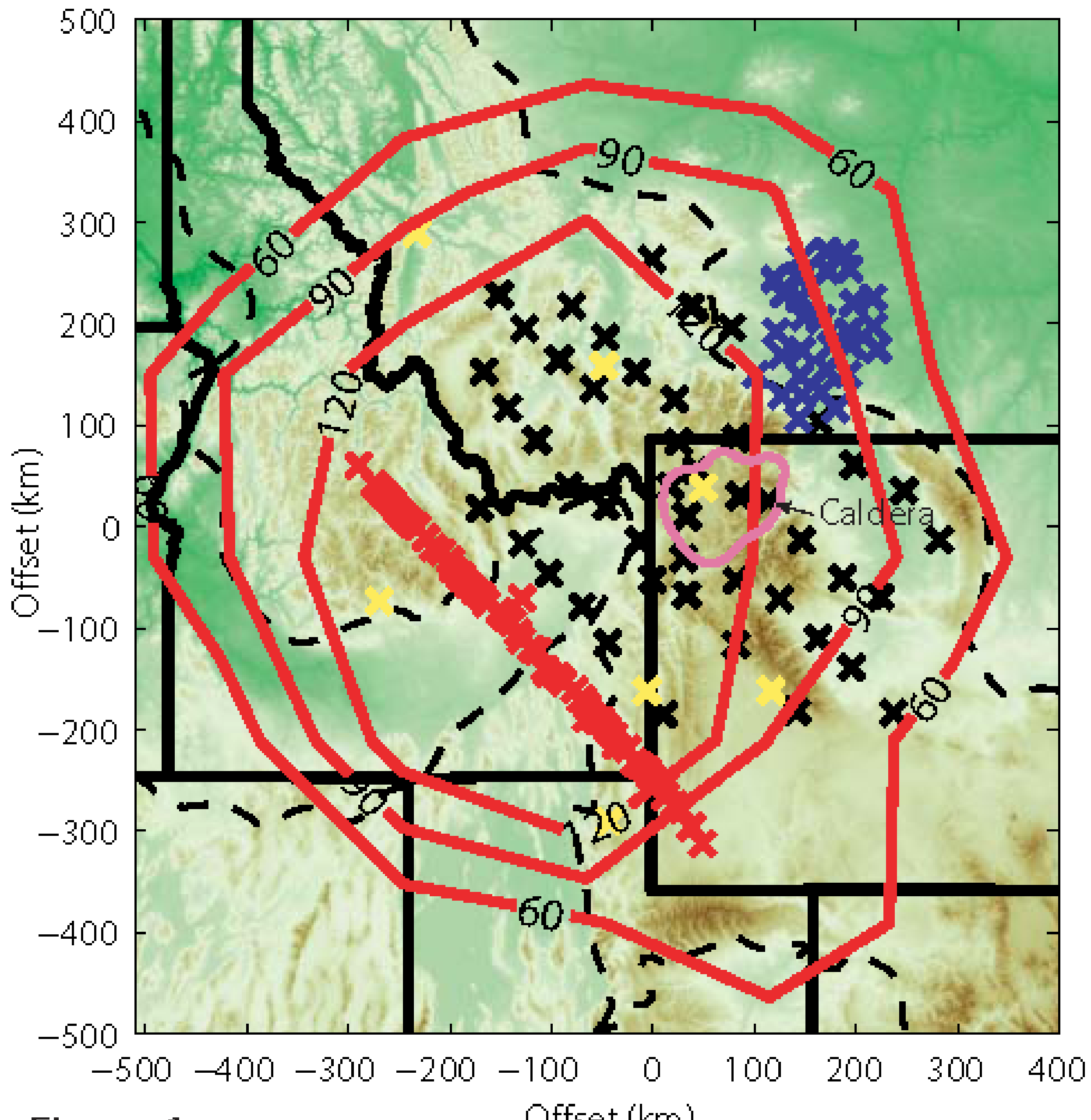


Figure 1.

Global Pds stack and phasing

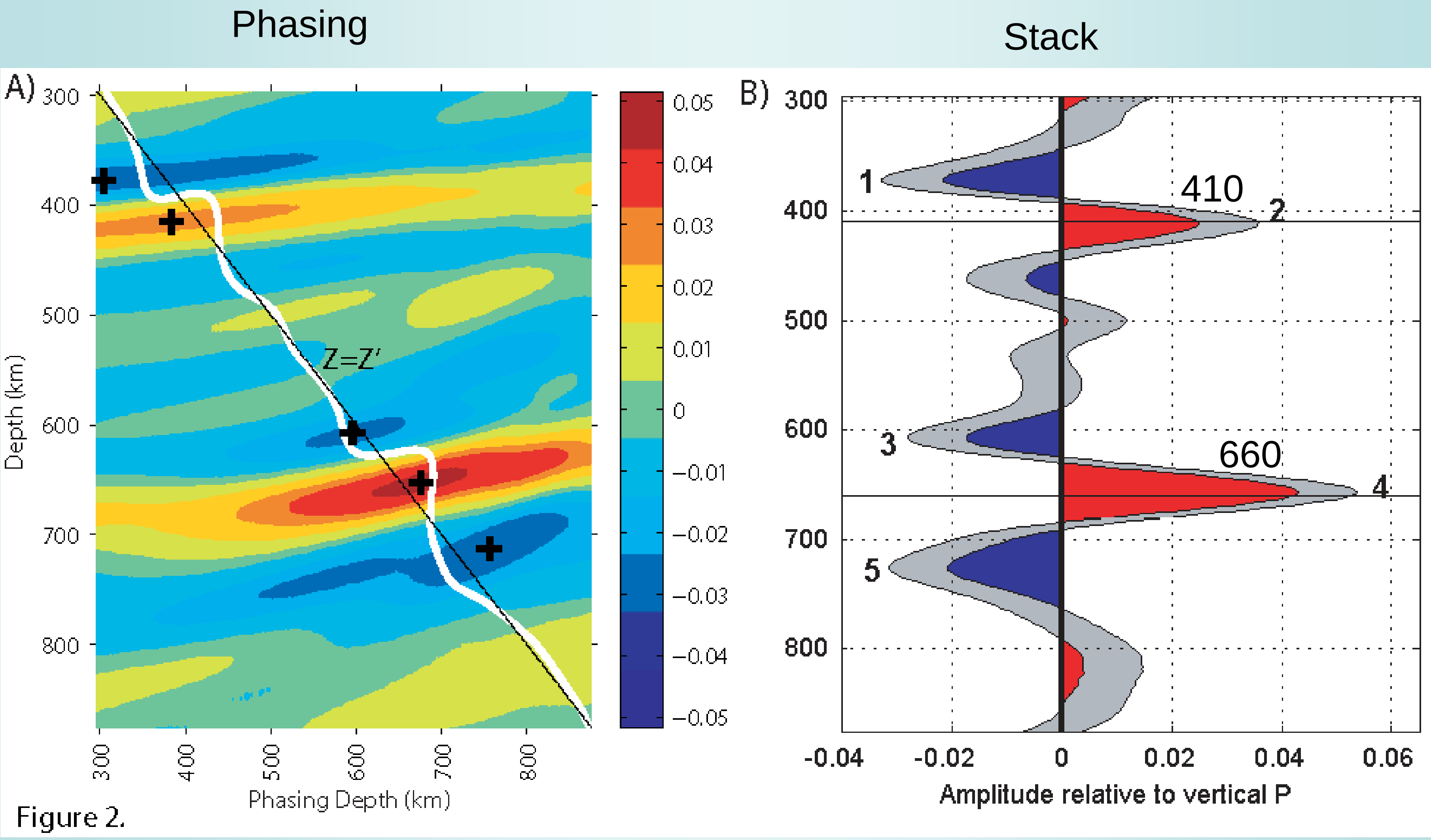
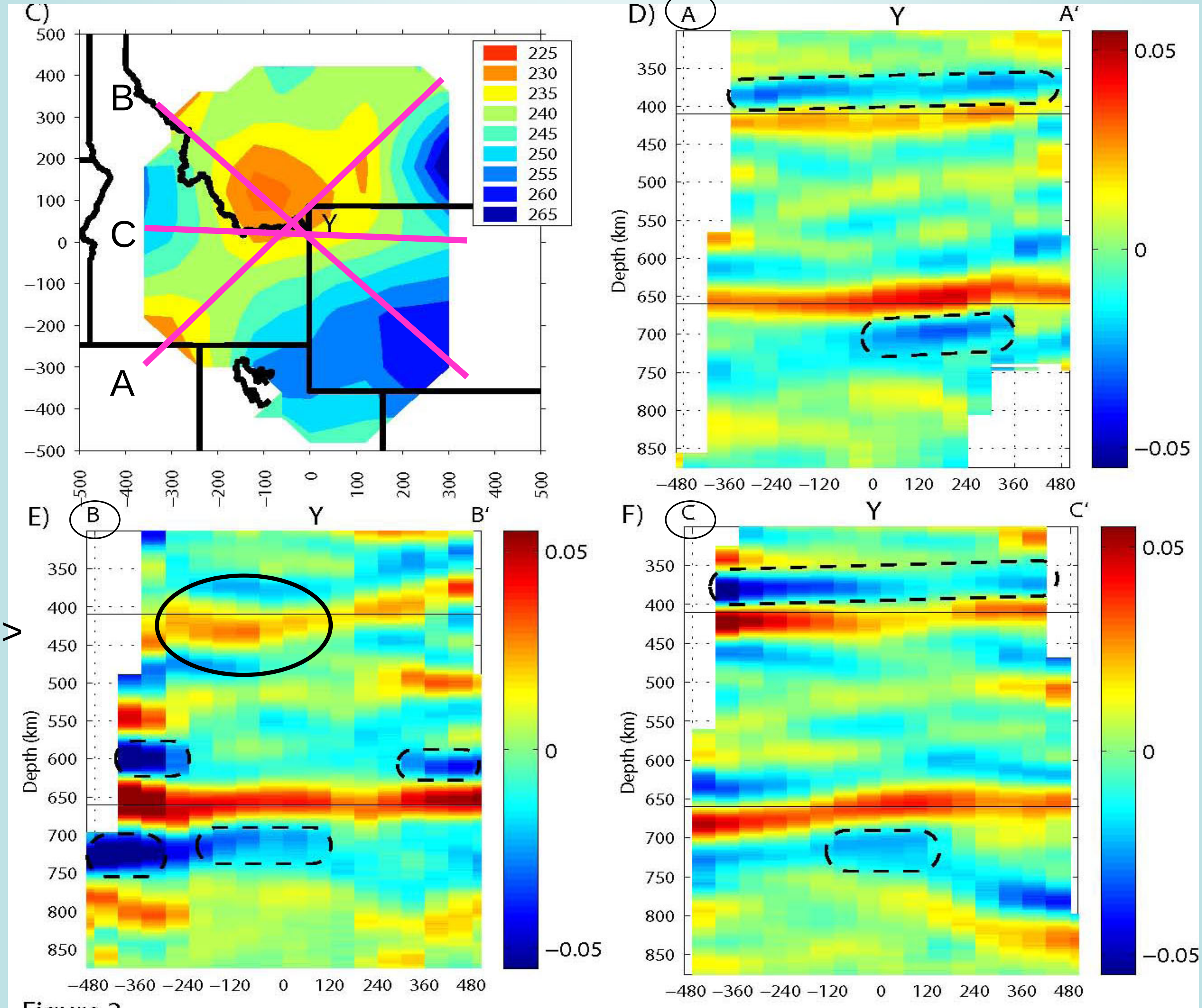


Figure 2.

Pds stack cross-sections

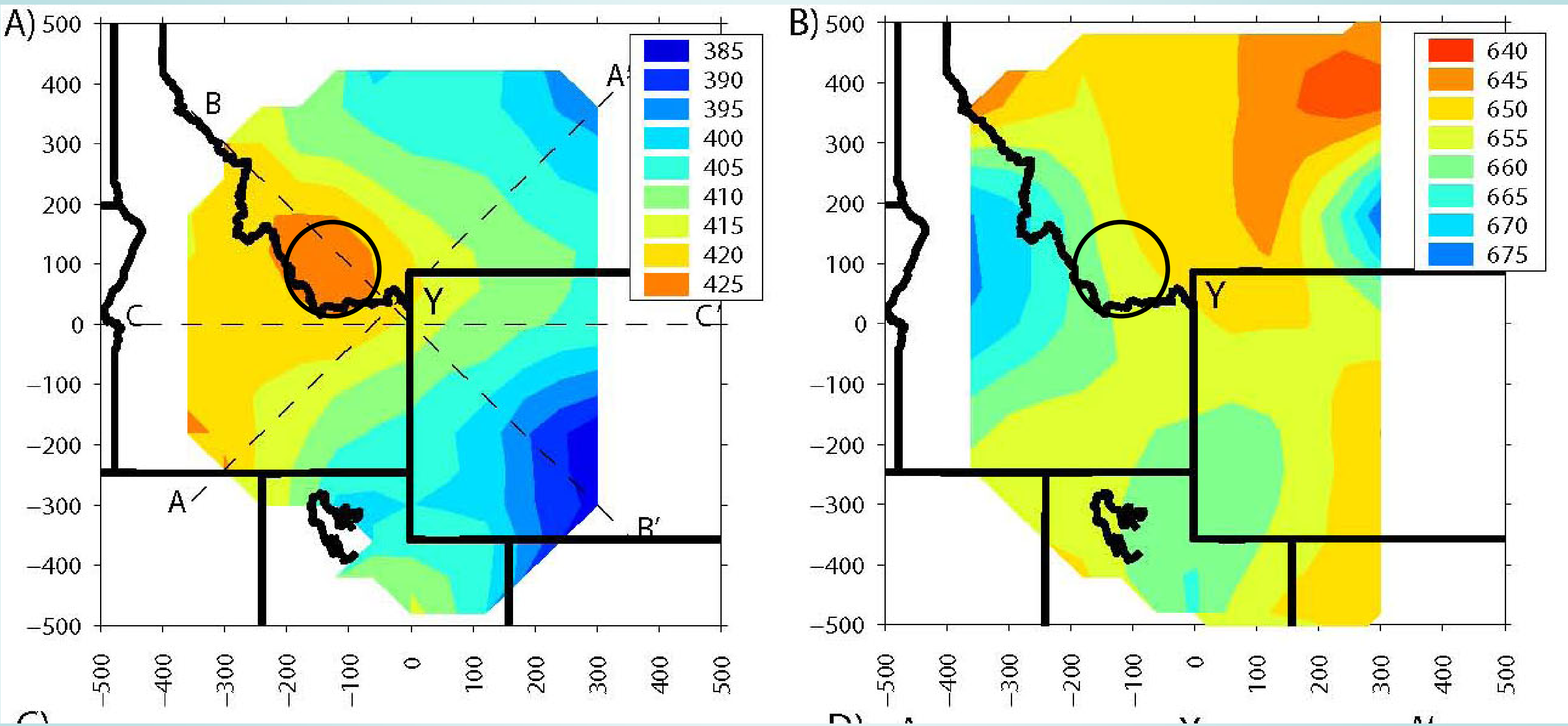
Plume>>



‘olivine’ discontinuity topography

410

660



Section conclusions

- 12 km depression in the 410 under Dillion Montana about 140 km NW of Yellowstone Caldera is consistent with 110 degree thermal anomaly. Would require a 15 degree dipping to the NW conduit to connect with Yellowstone Caldera.

- Negative velocity gradient at 380 km (atop the 410) and at 720 km (below 660). Both arrival phase correctly in global stack. Ongoing research in progress.

Mantle P-wave Tomogram

Yuan, H. and K. Dueker

Teleseismic P-wave Tomogram of the Yellowstone Plume

Geophys. Res. Lett., in review.

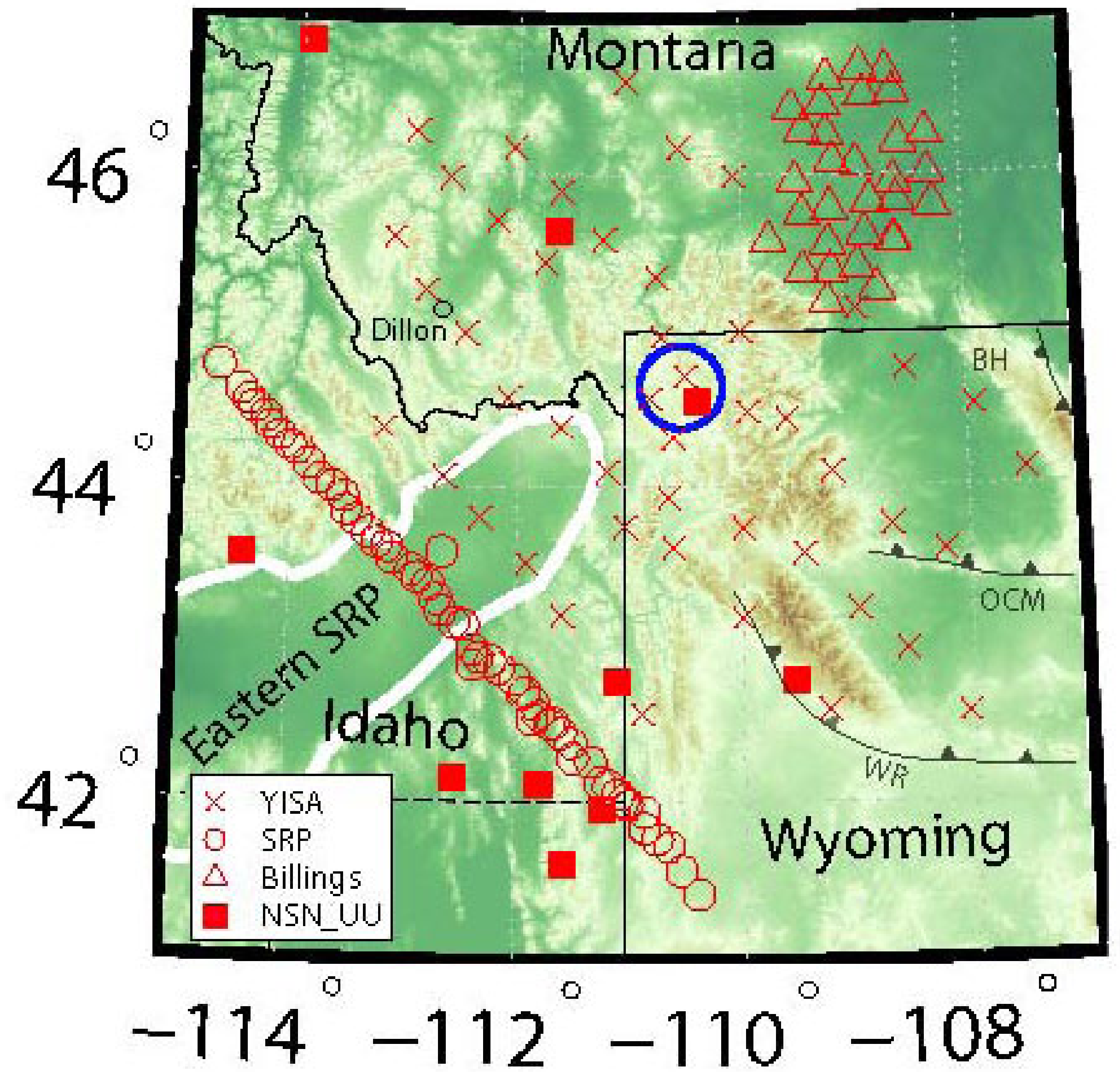
http://faculty.gg.uwyo.edu/dueker

Stations and Topography

combination of four arrays:

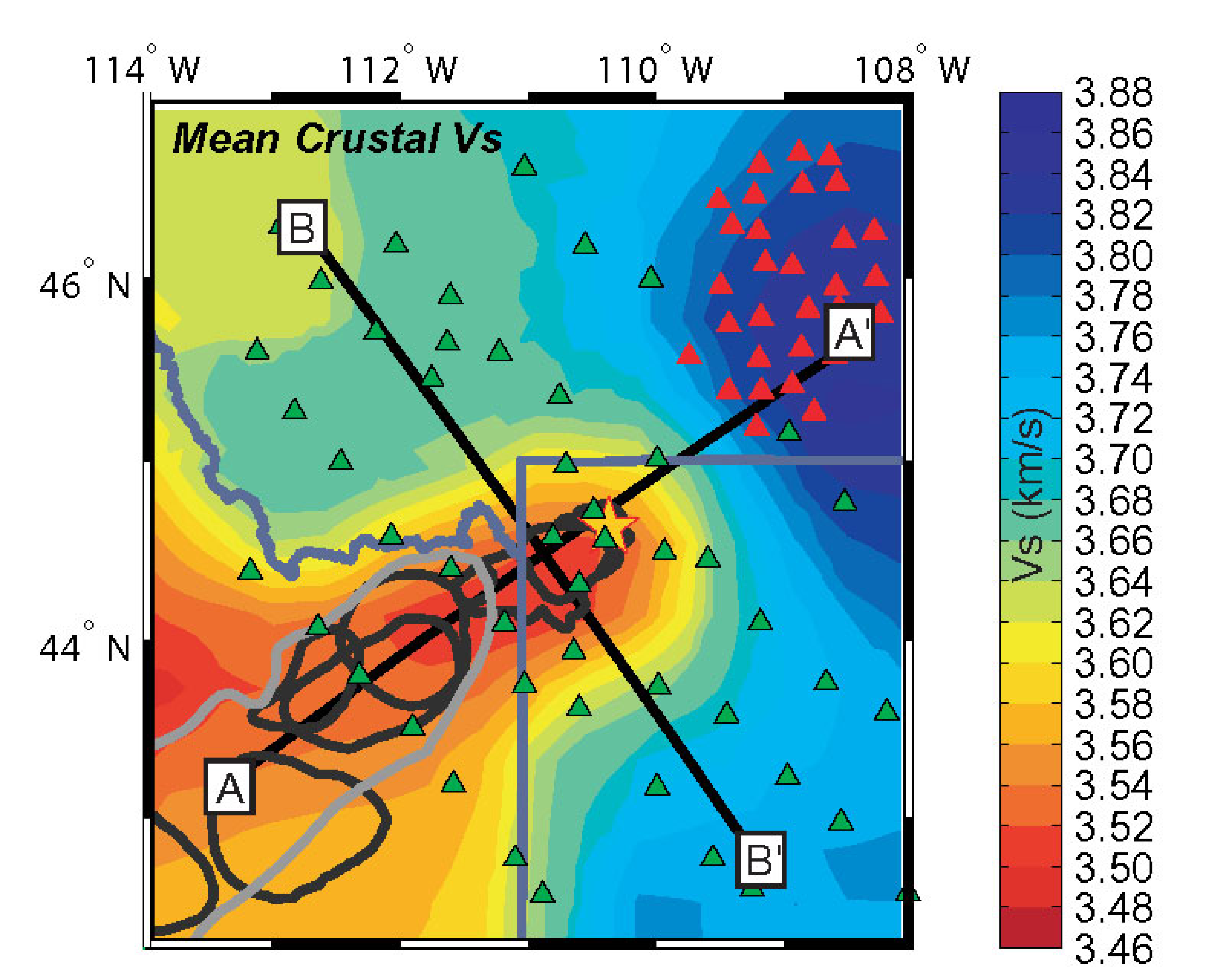
Snake River Plain 1993
Yellowstone array 2001
Billings array 2000
NSN and Utah Stations

array time statics calculated using NSN/UU 8 station reference array



Mean crustal shear velocity

Schutt and Dueker, in review



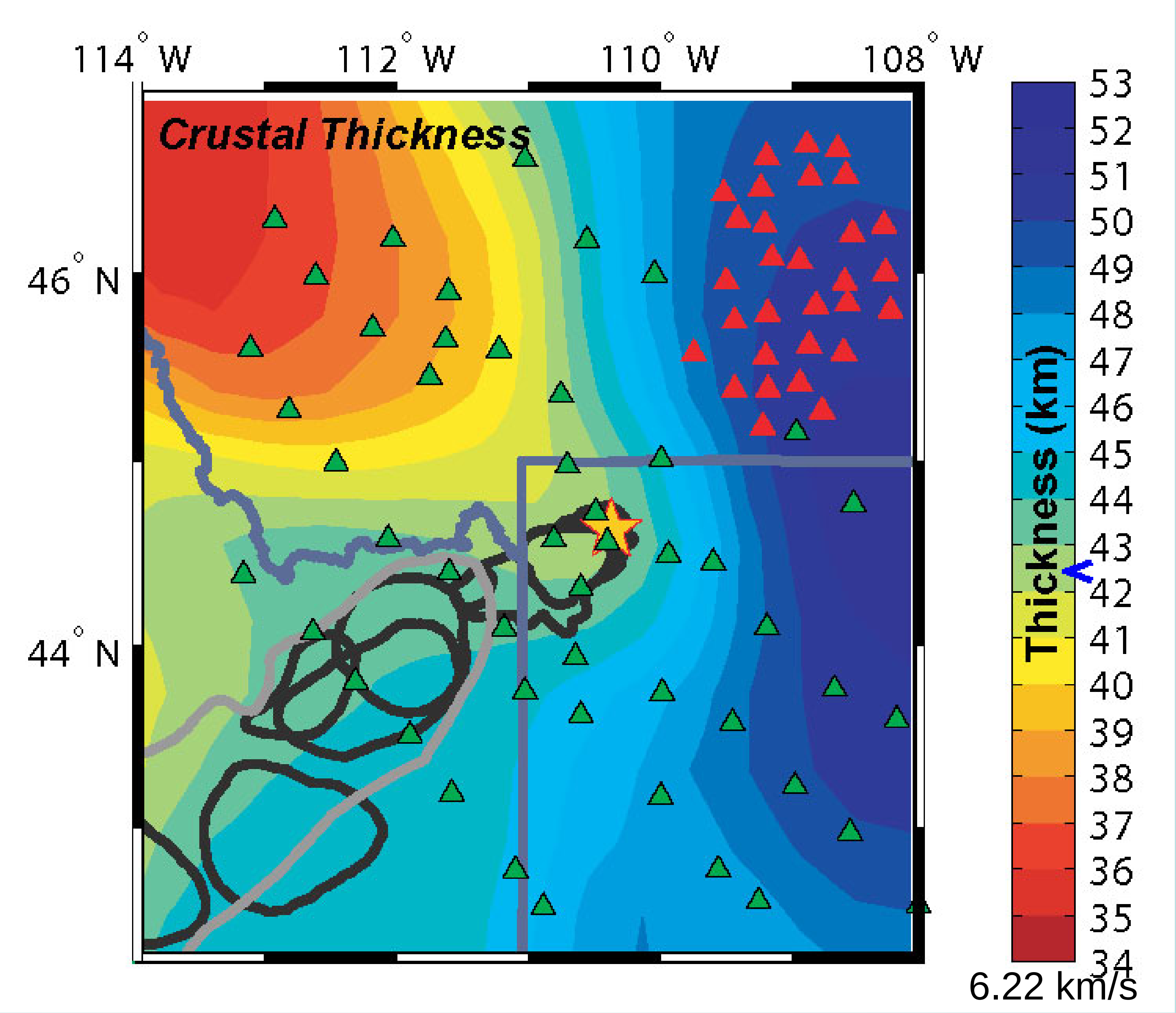
6.82 km/s

6.48 km/s

6.08 km/s

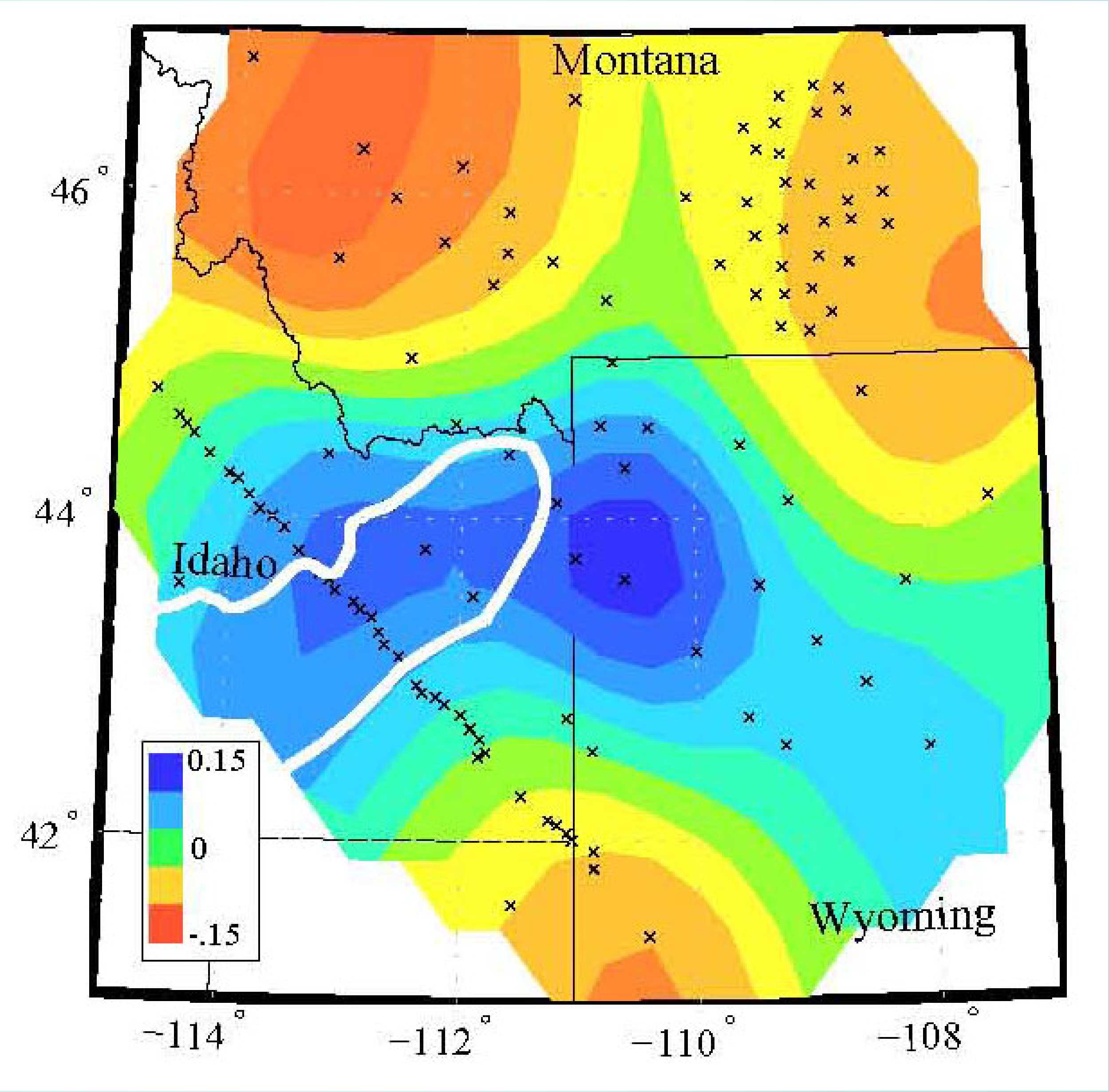
P(moho)s times mapped to depth

velocity model is surface wave shear velocity and 1.76 Vp/Vs

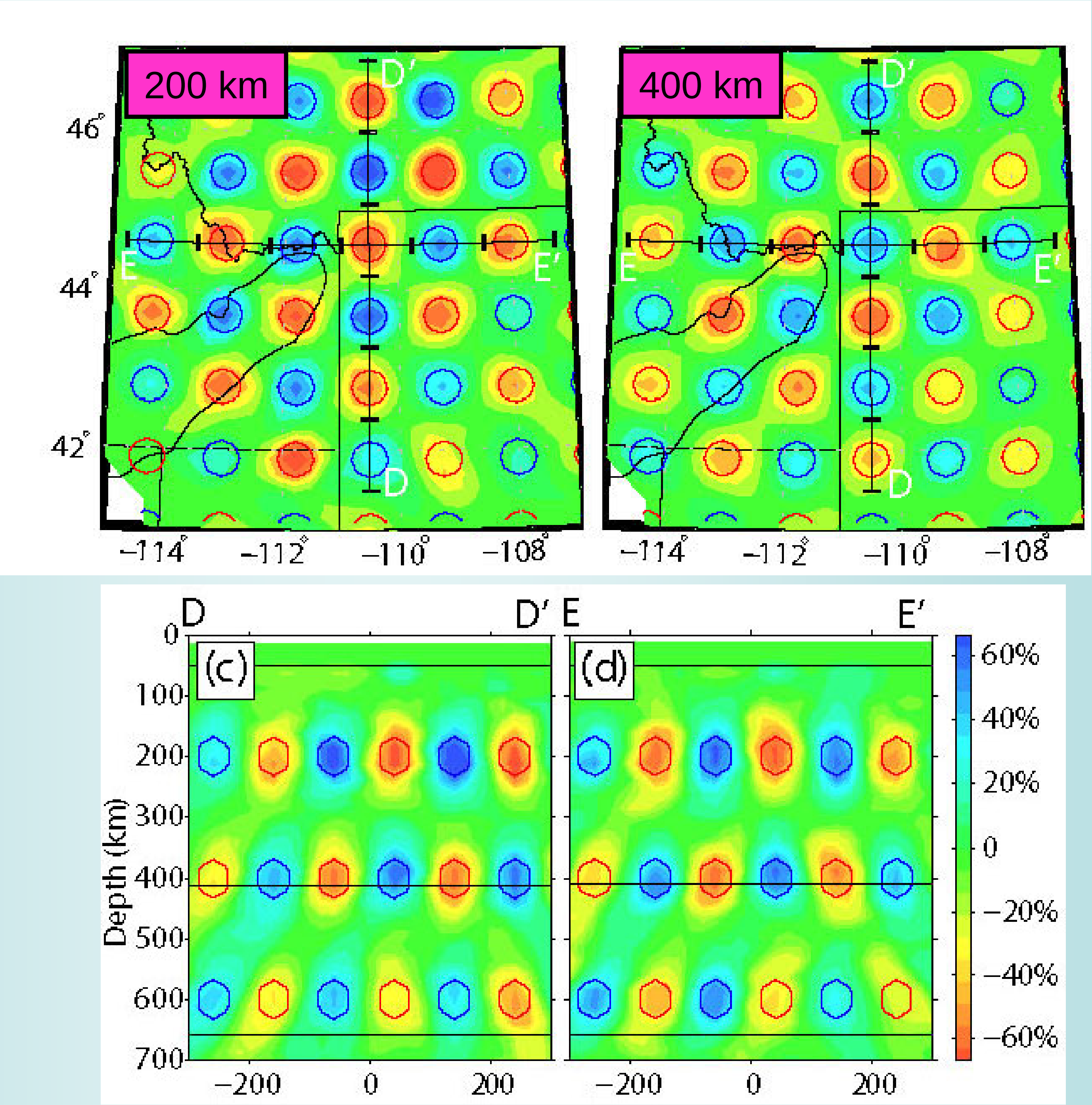


Teleseismic P-wave crustal thickness and velocity timing corrections

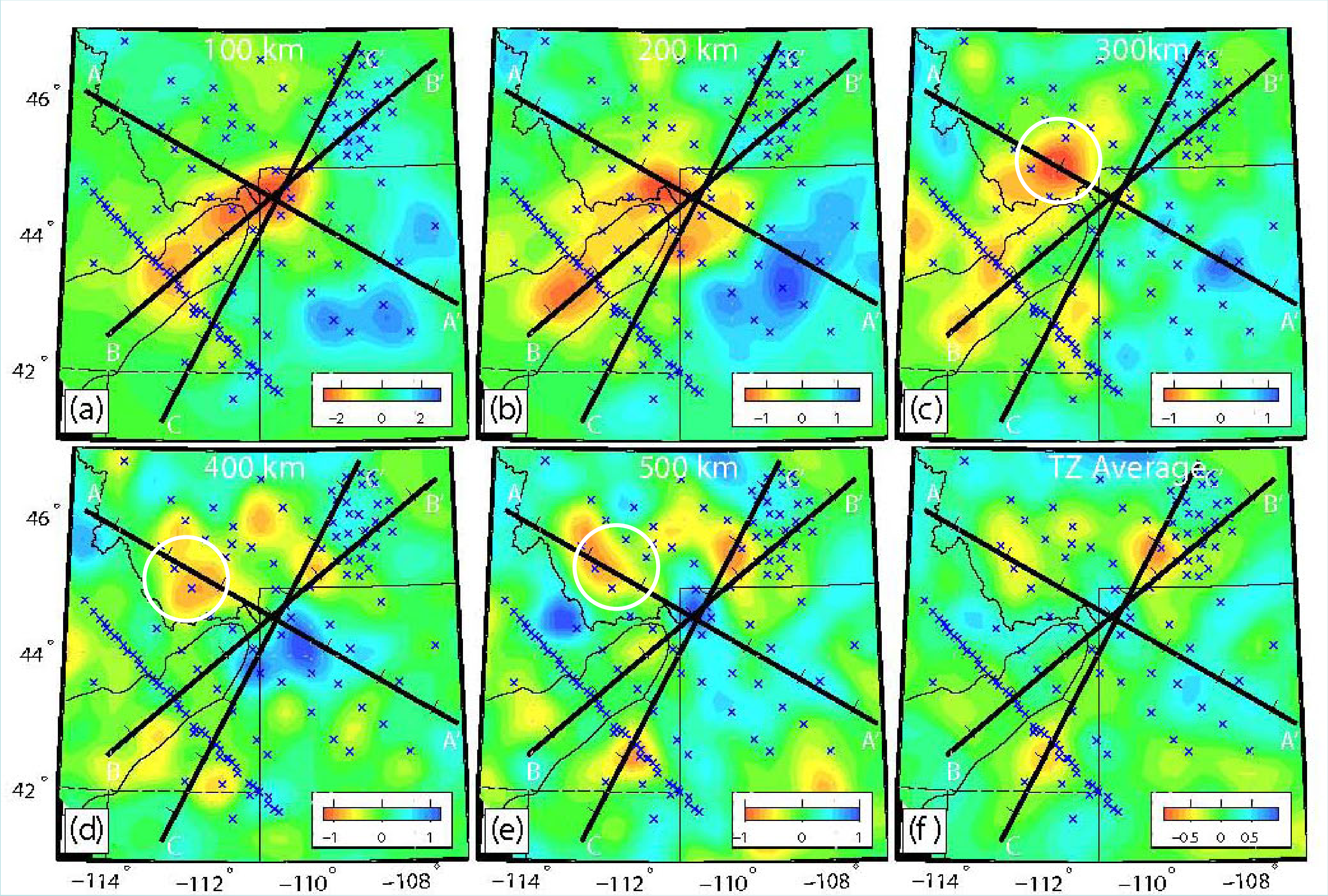
0.3 s peak to peak



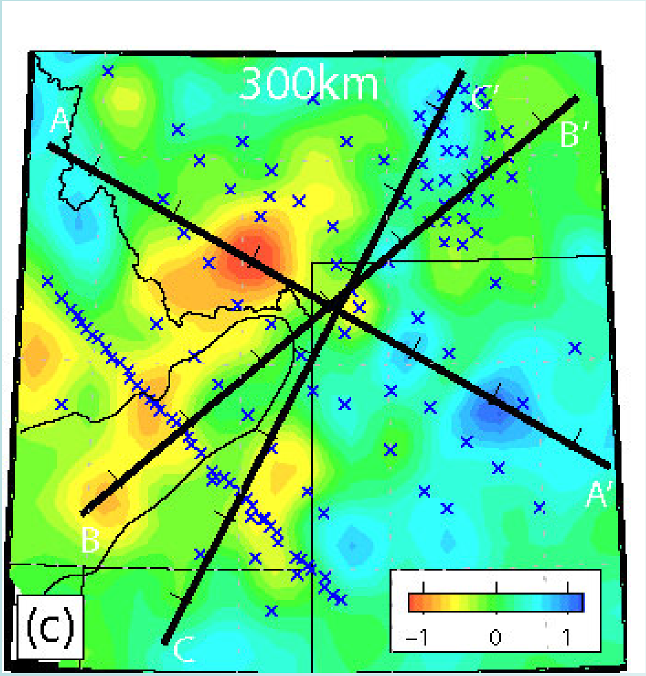
P-wave tomogram checkerboard resolution test

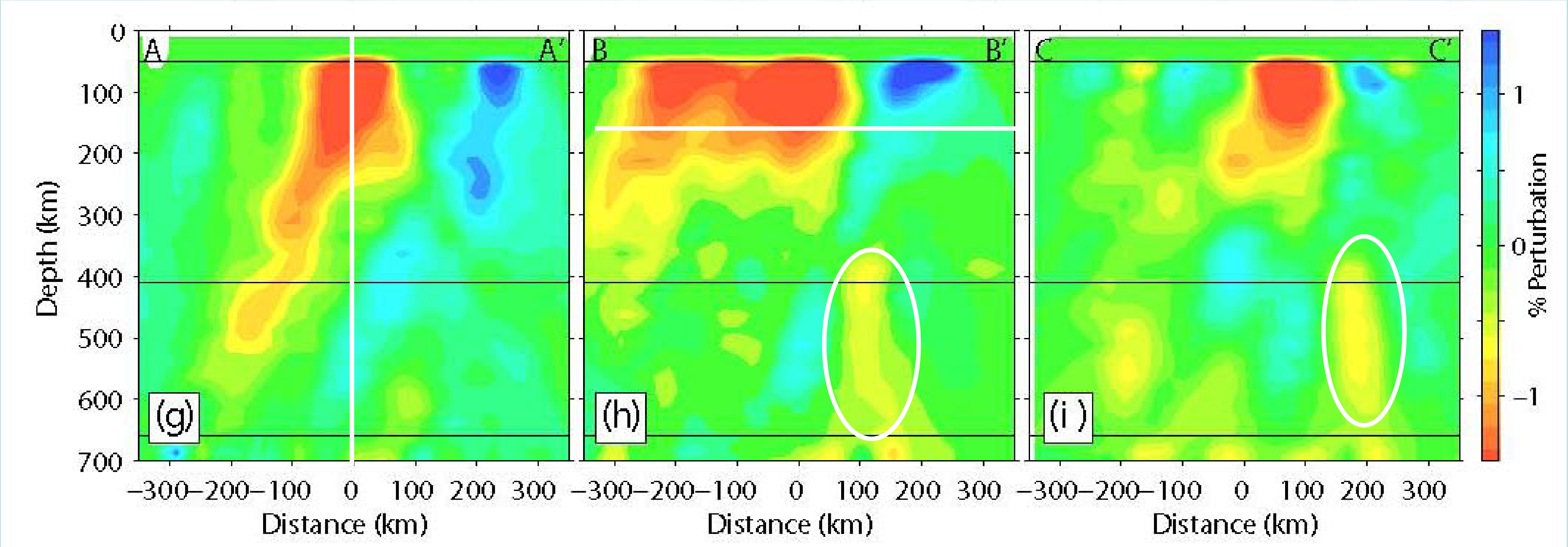


P-wave Tomogram



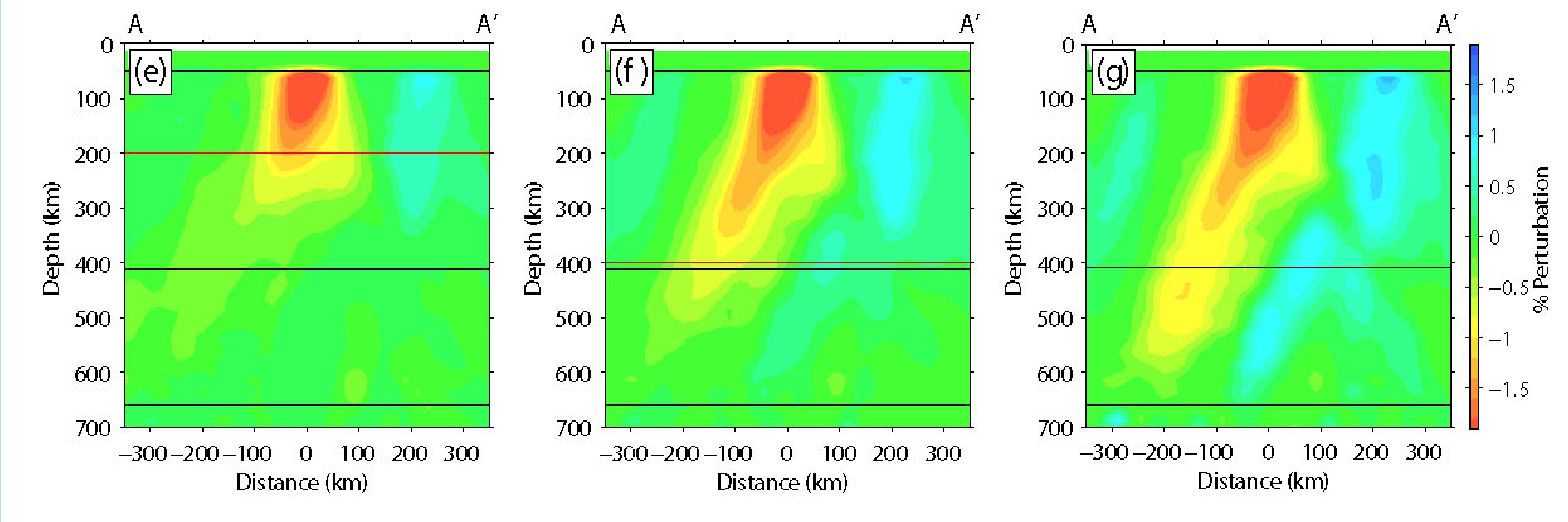
P-wave tomogram cross-sections





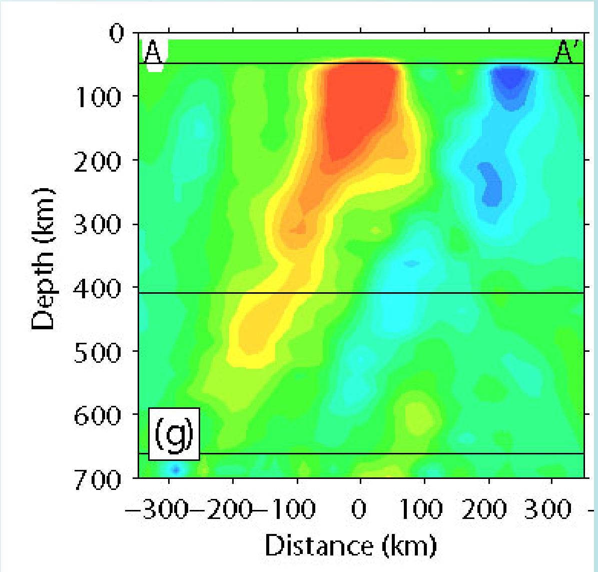
Synthetic smearing comparison

200 km   400 km   600 km

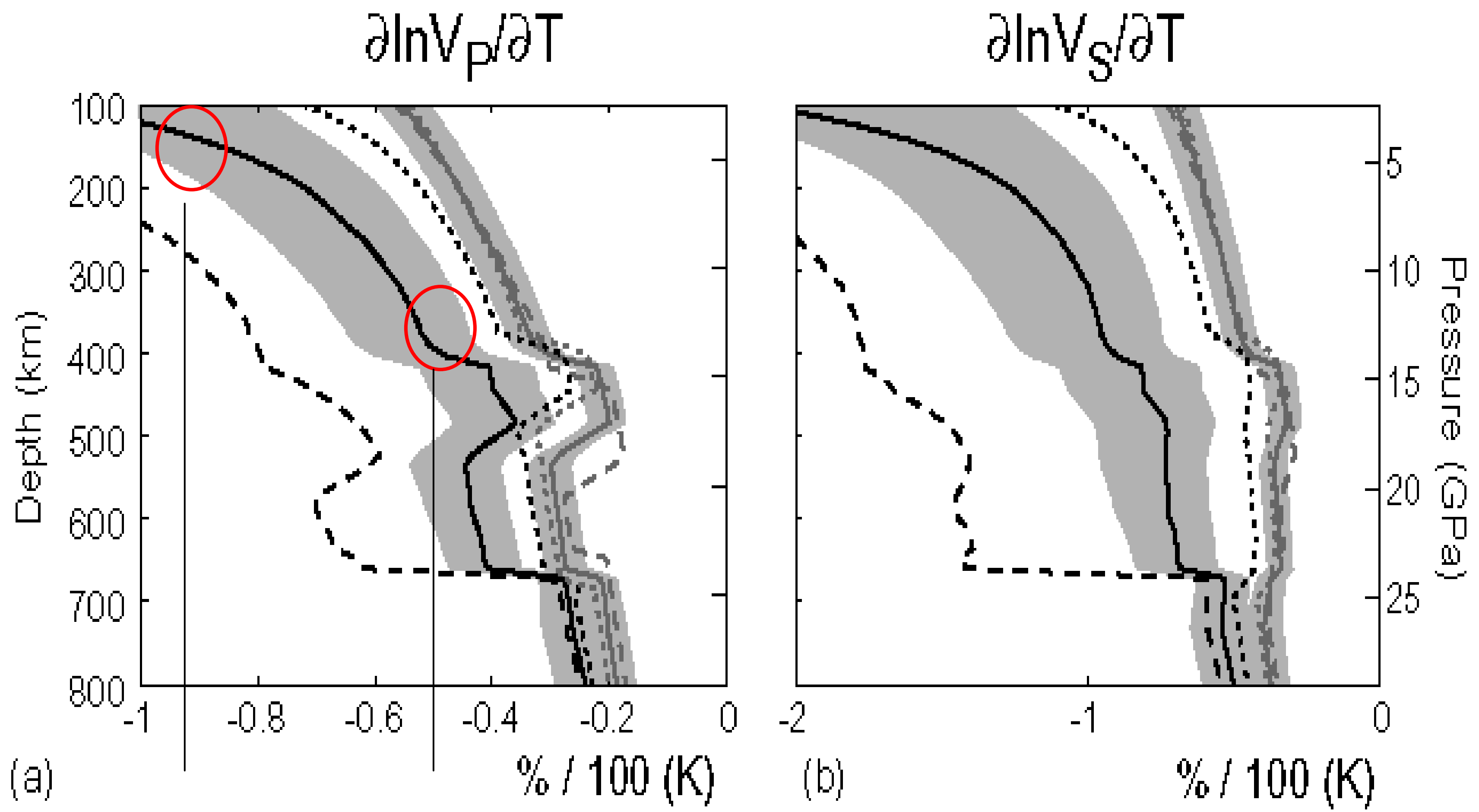


Real tomogram >>>

Best fit by 400-600 km deep models



Theoretical anelasticity (Cammanaro et al., 2004) depends on Qs, E*, and V*



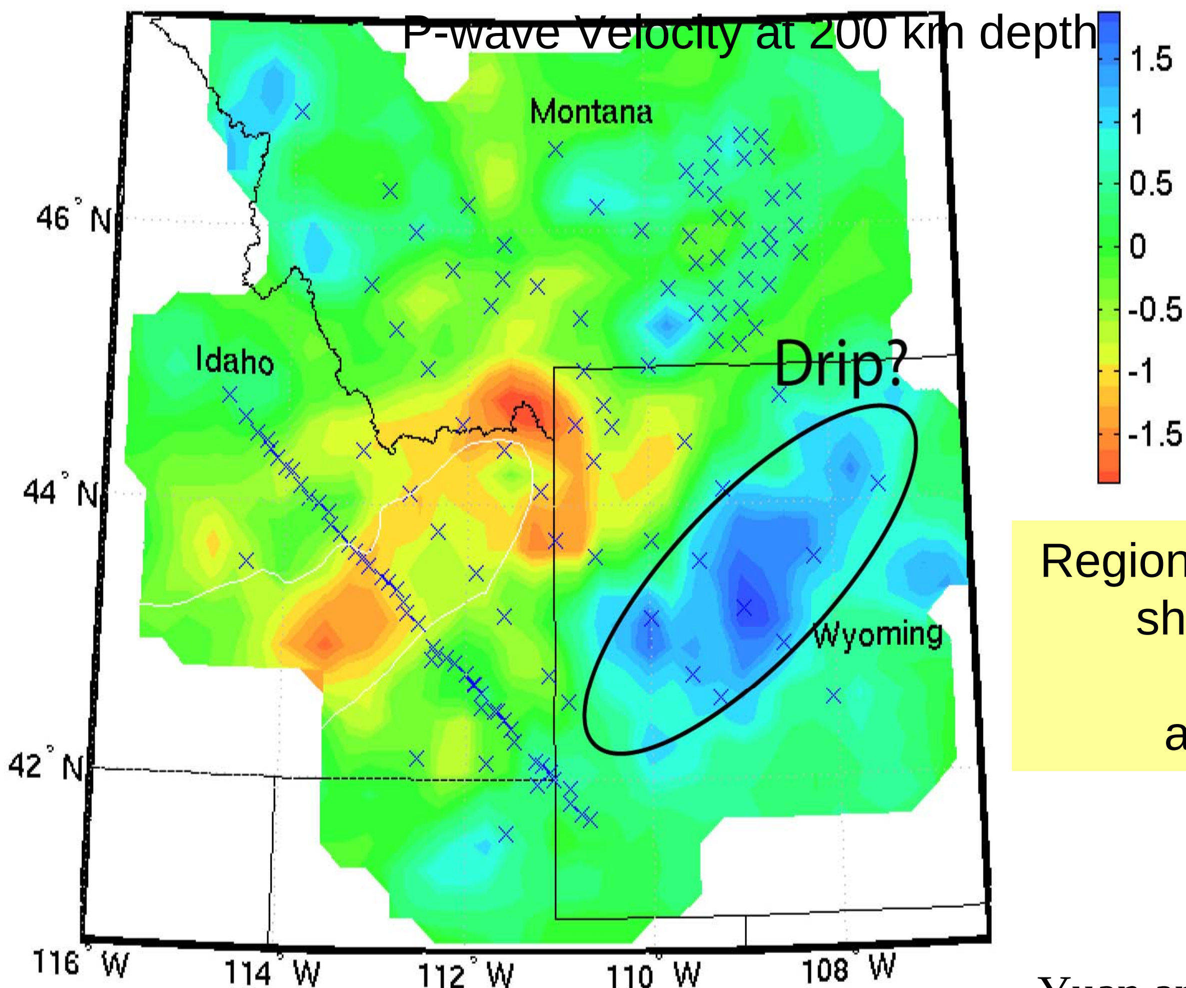
P-wave tomogram conclusion

- 80 km diameter conduit extends from beneath the Park to 500 km depth.

- 0.8% Vp conduit anomaly at 410 km is 140 degree thermal anomaly (using average Qs model).

- Velocity conduit at 410 km and the topography on the 410 discontinuity are consistent with about a 150 degree temperature anomaly.

Convectively destabilizing 80 km thick Archean Wyoming Craton ?



Region of maximal Laramide shortening between Bighorn's and Wind River's

Yuan and Dueker

Shear-wave velocity tomogram from Rayleigh waves (absolute velocities)

Schutt and Dueker

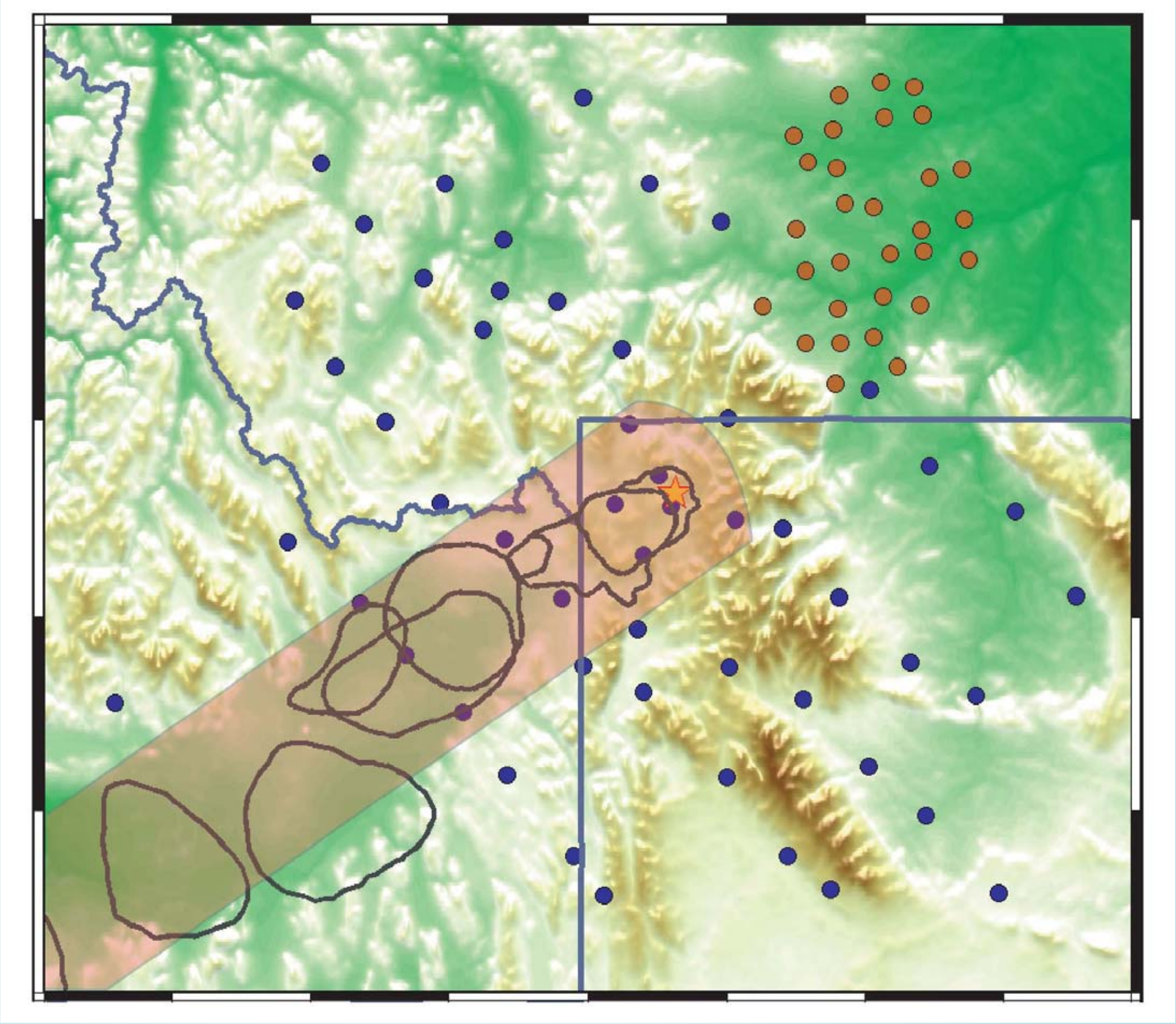
Excess temperature estimate of the Yellowstone Plume from a Rayleigh-wave tomogram

in review, 2005

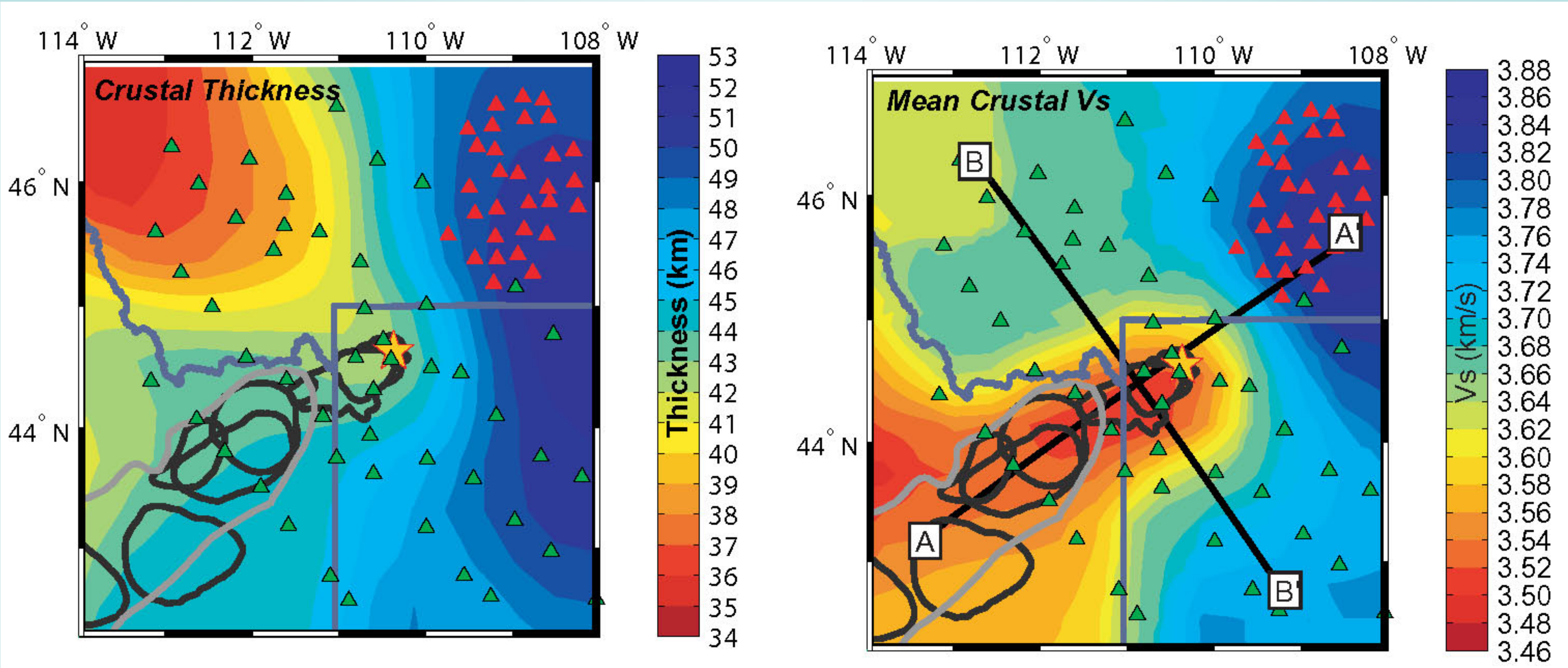
Stations, topography and velocity regionalization

47 Yellowstone
30 Billings array

red swath is domain of the Yellowstone hotspot track (YHT) velocity region

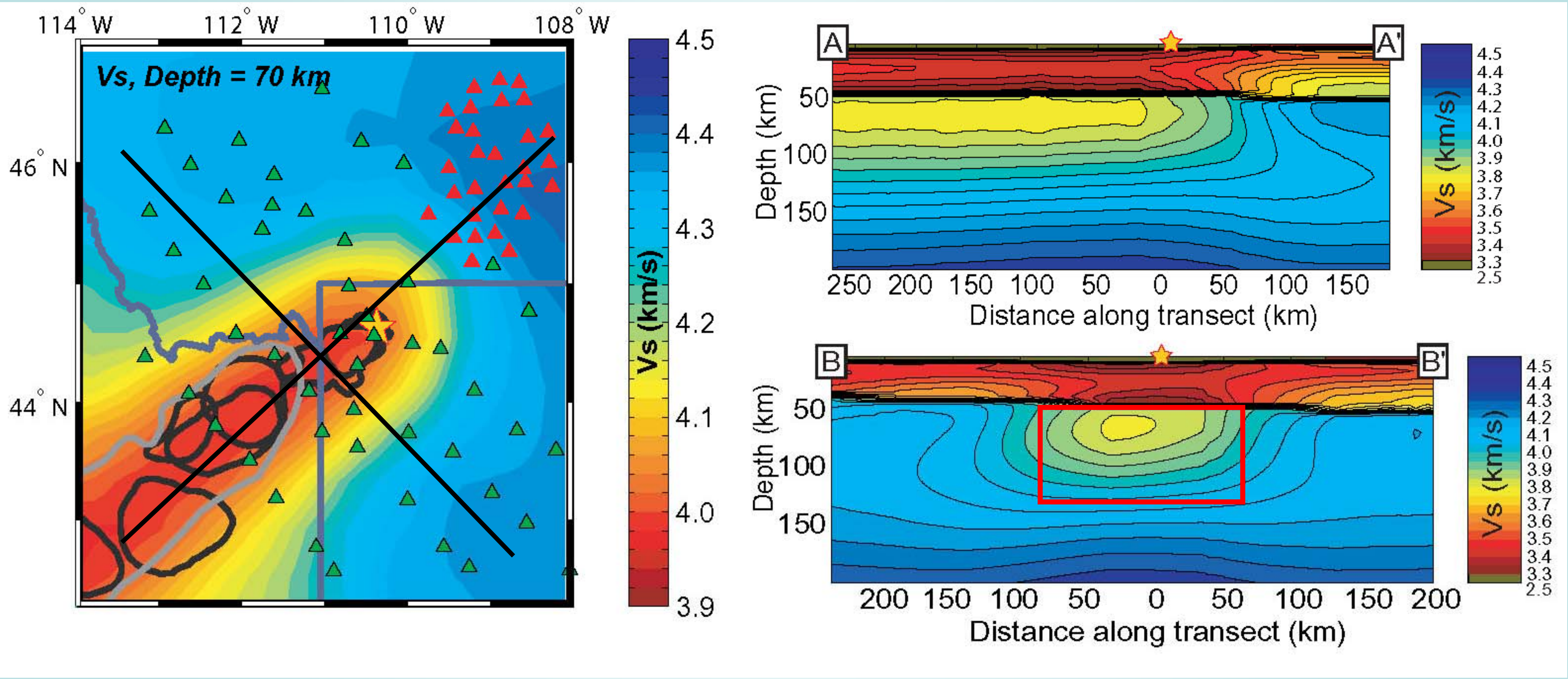


Crustal thickness and velocity



Crustal thickness map created via a combined inversion of phase velocity data and Moho Pds times. A Vp/Vs of 1.76 is assumed.

Rayleigh wave shear velocity



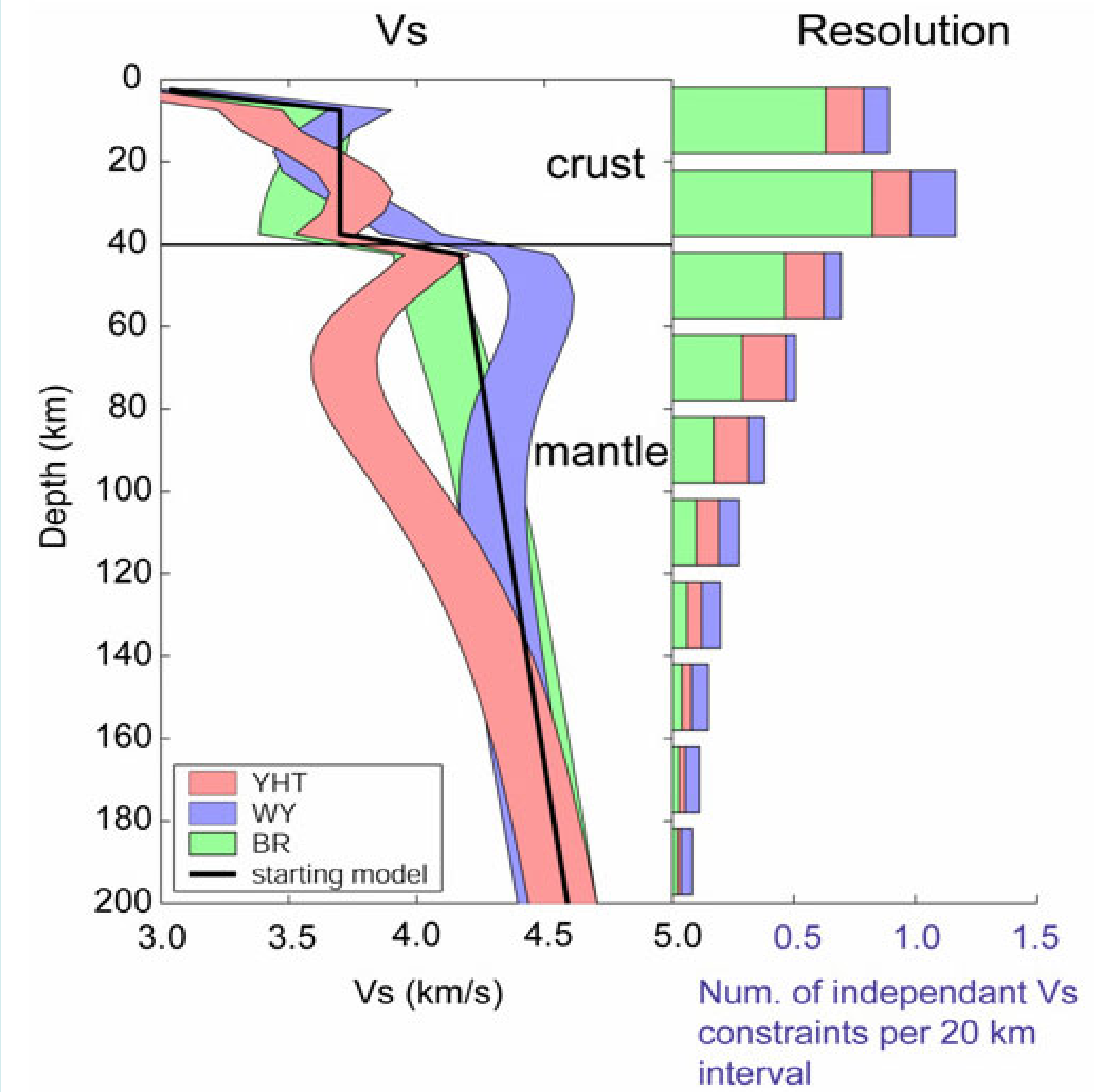
Minimum low velocity of 3.8 km/sec at 70 km among slowest sub-crustal velocity on planet.

YHT, BR, WY Shear velocity profiles and depth resolution

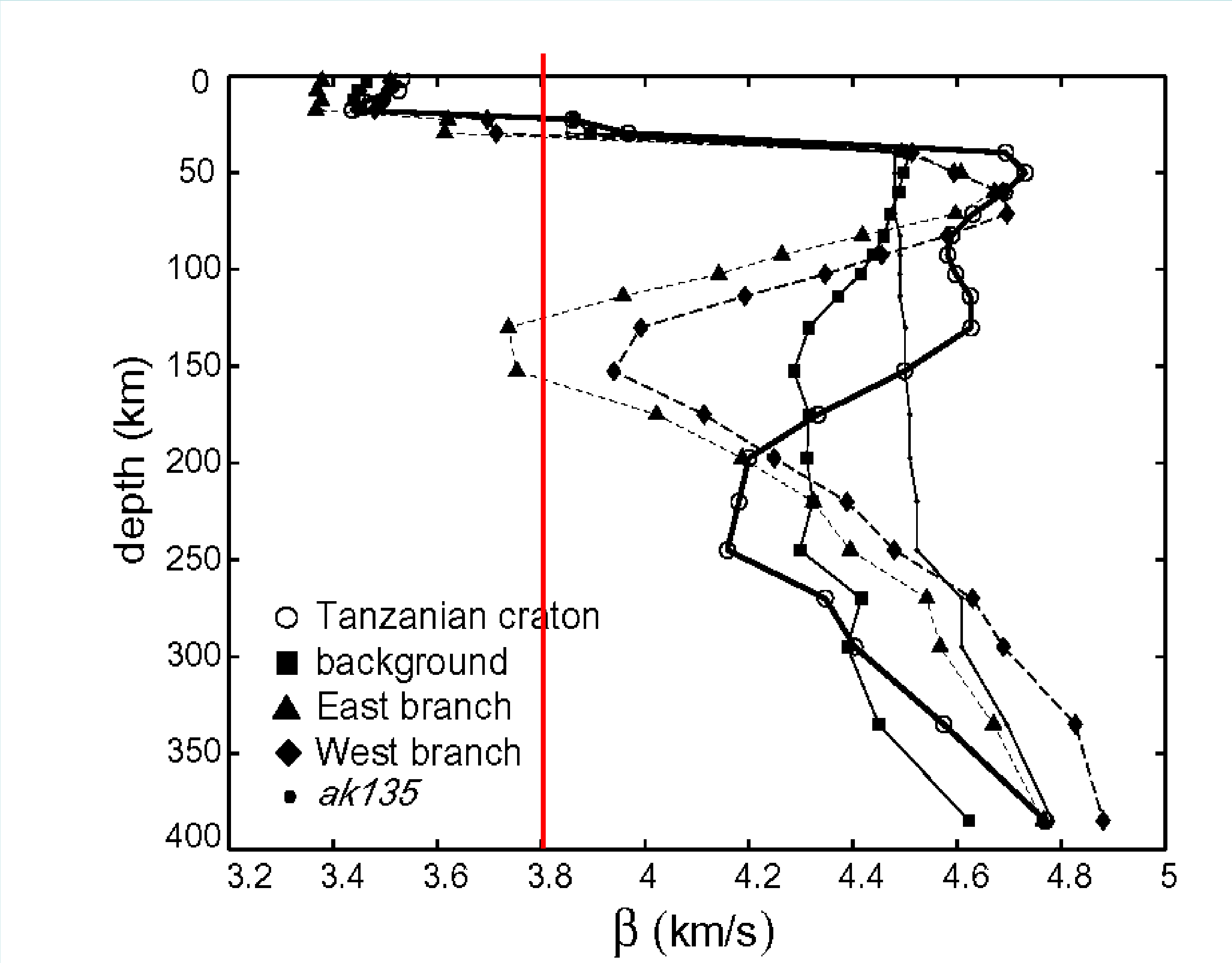
YHT 3.8 km/sec minimum at 75 km very slow!

WY profile shows 80 km thick ‘normal’ lithosphere

BR profile in between YHT and WY profiles



Tanzanian velocity (Weerarante et al, 2003)



Grain size sensitive velocity and attenuation

- Theoretical anelasticity: Qs(T, f, V*, E*, a, A)
  assume simple visco-elastic response
  specifiying Qs model specifies V-anelastic

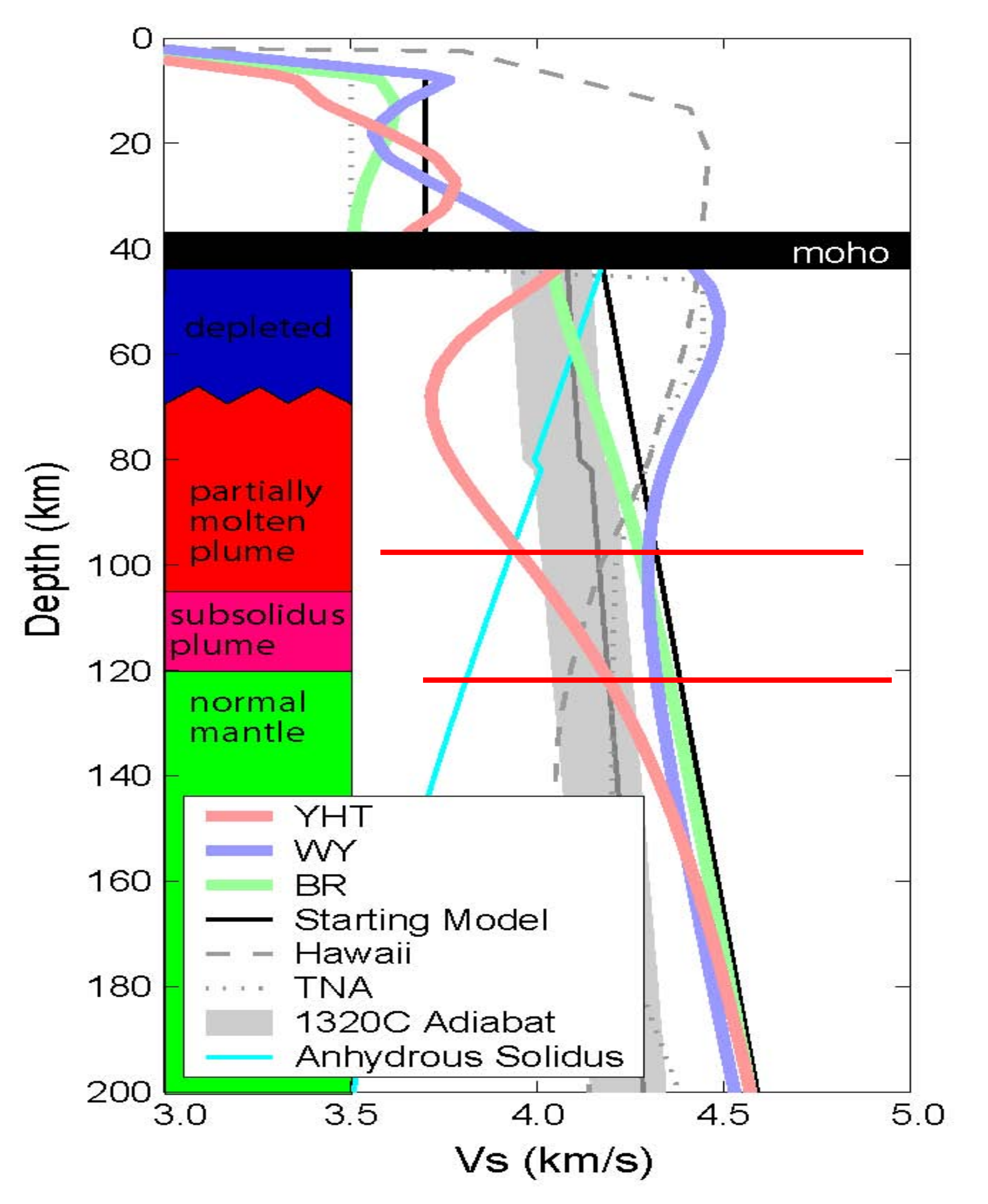
- Empirical lab data fit: Vs(T, f, V*, E*, grain-size)
  use lab measured values on sub-solidus olivine at varying grain sizes and frequencies.

  Grain size proportional to stress (higher stress promotes small grain-sizes).

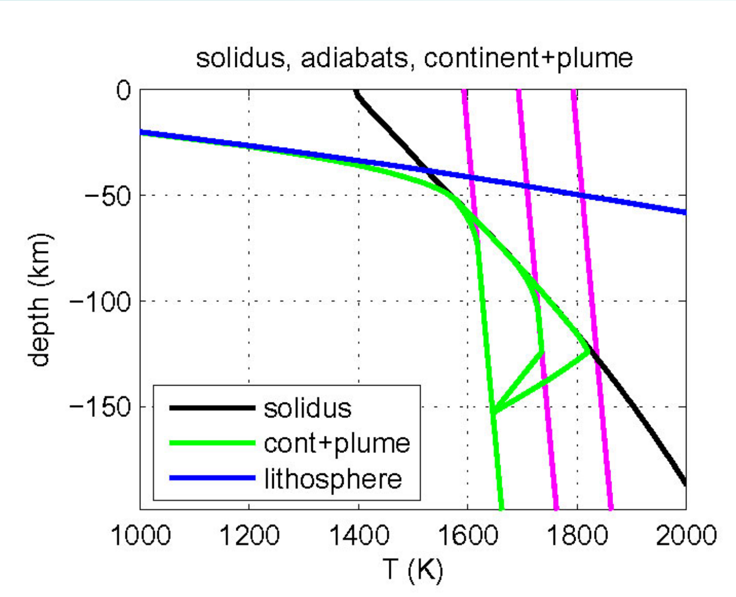
Shear-wave velocity profiles

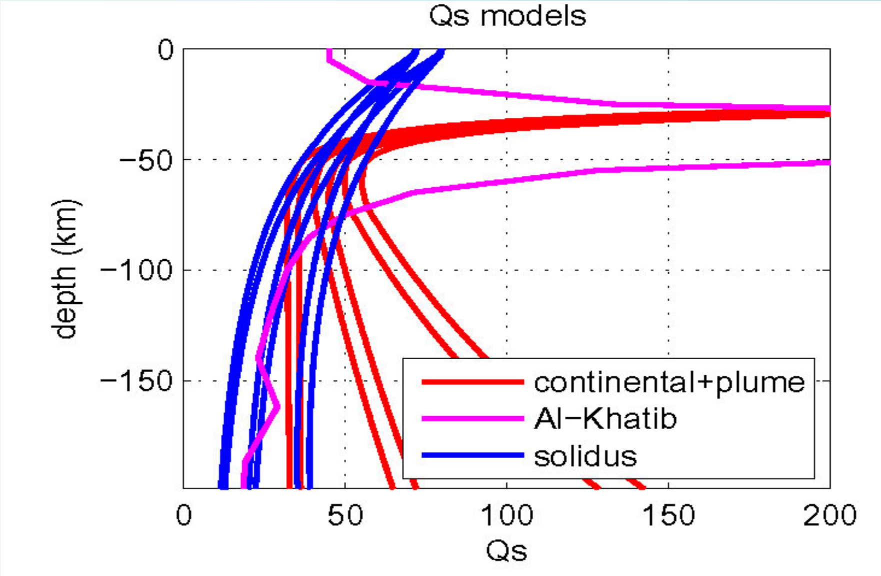
Intersection of dry solidus (Hirschman, 2000) with YHT around 100 km depth.

Intersection of 1320 degree adiabat translated to velocity with 2-6 mm grain-size with YHT around 120 km depth.

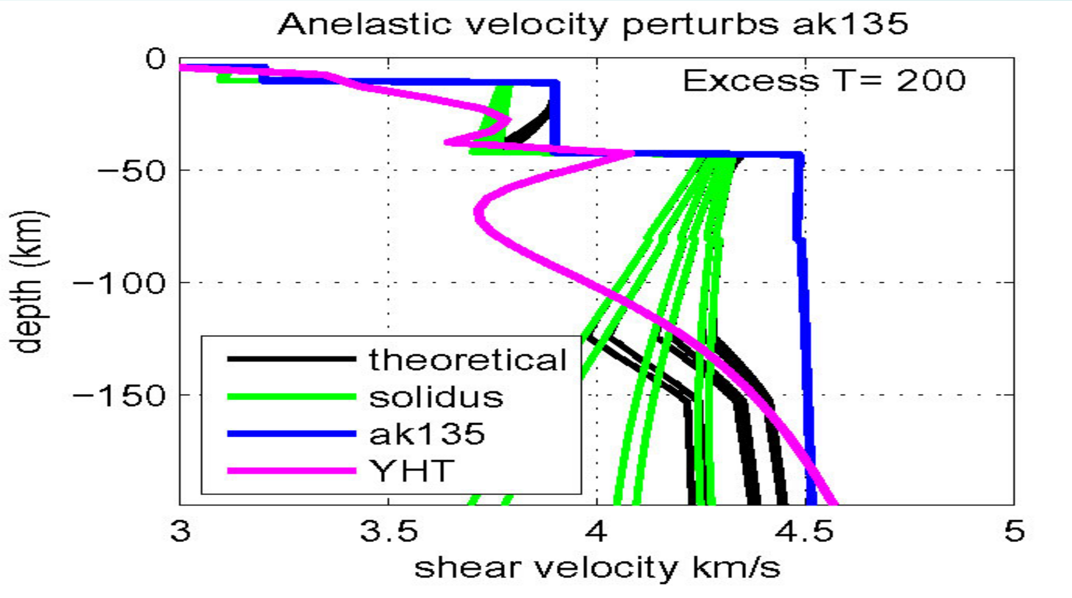


Theoretical velocity with respect to geotherm, V* and Qs

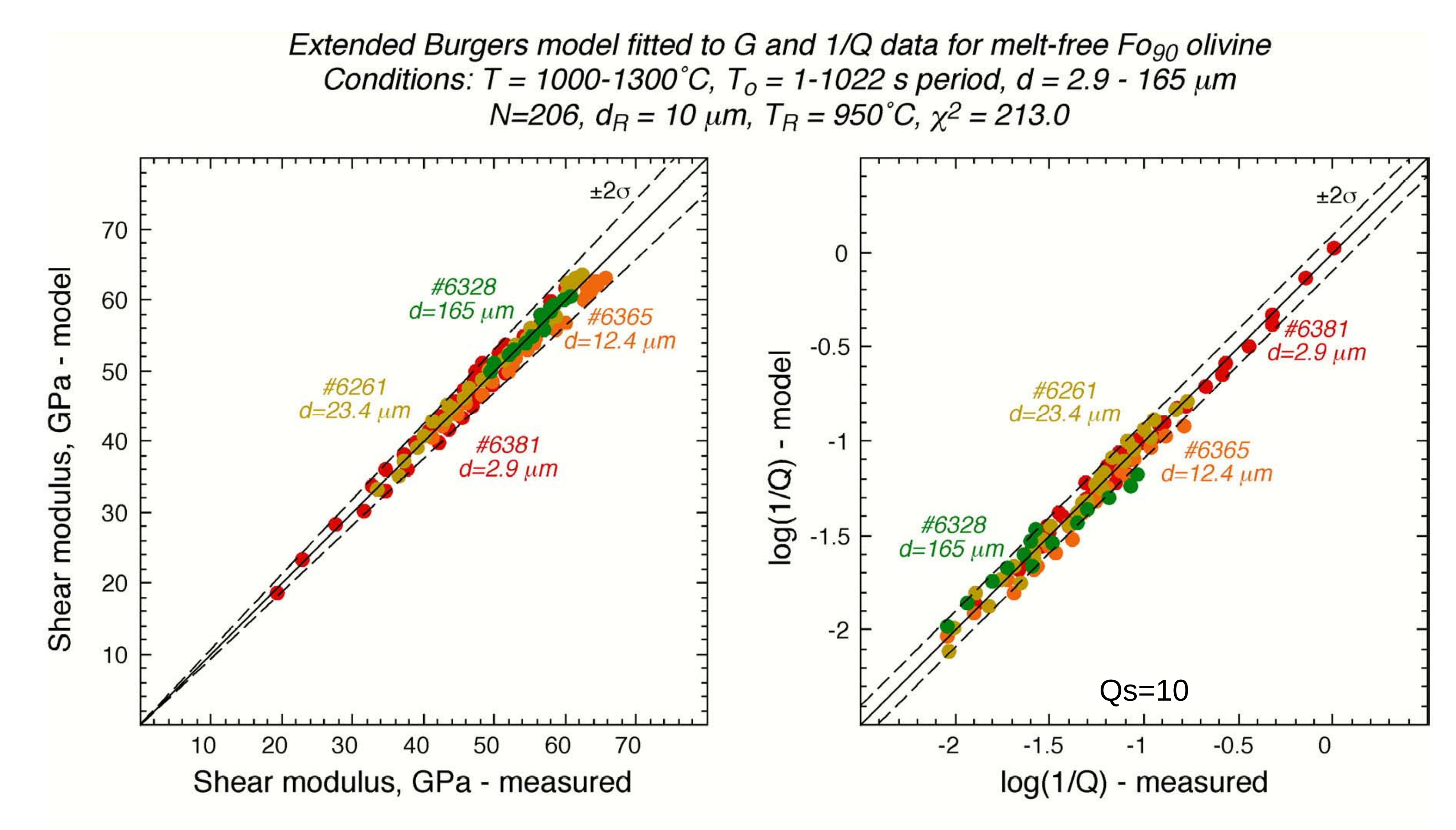




No melt in the velocity models



Grain size sensitivity shear modulus (Jackson and Faul, 2004)



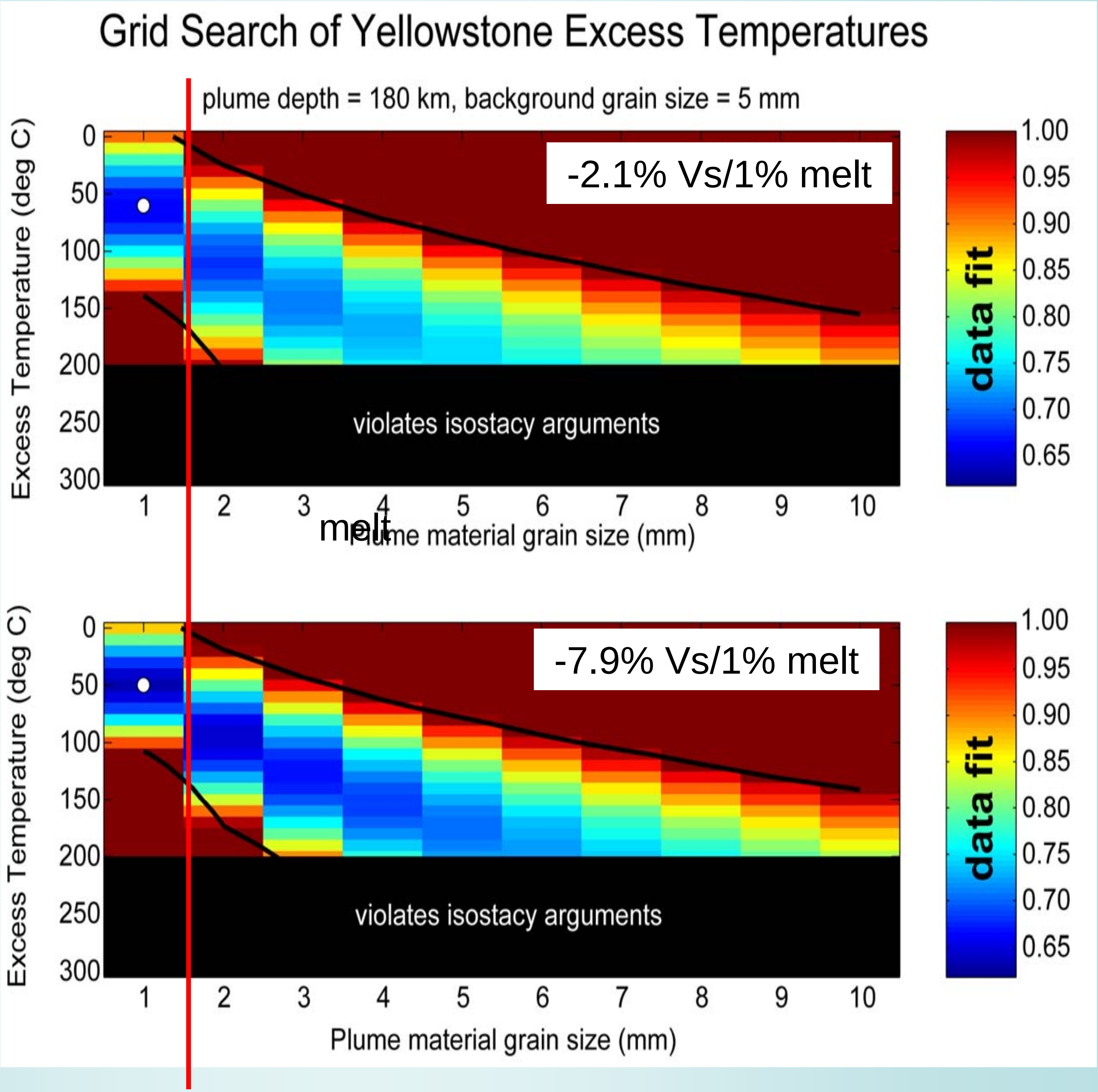
Smaller grains = lower velocity and higher attenuation

Excess temperature versus olivine grain size

“most would say” mean grain size is >2 mm

Need density constraints to separate grain-size and temperature velocity effects

max melt=1.1%



Raleigh wave conclusions

- For Laboratory-based GSS velocity.

>> 100 deg hotter for 2 mm grains

>> 150 deg hotter for 4 mm grains.

such small grains predict low Qs of 10-30.

large melt-velocity scaling (H&H) explain data better (hmm).

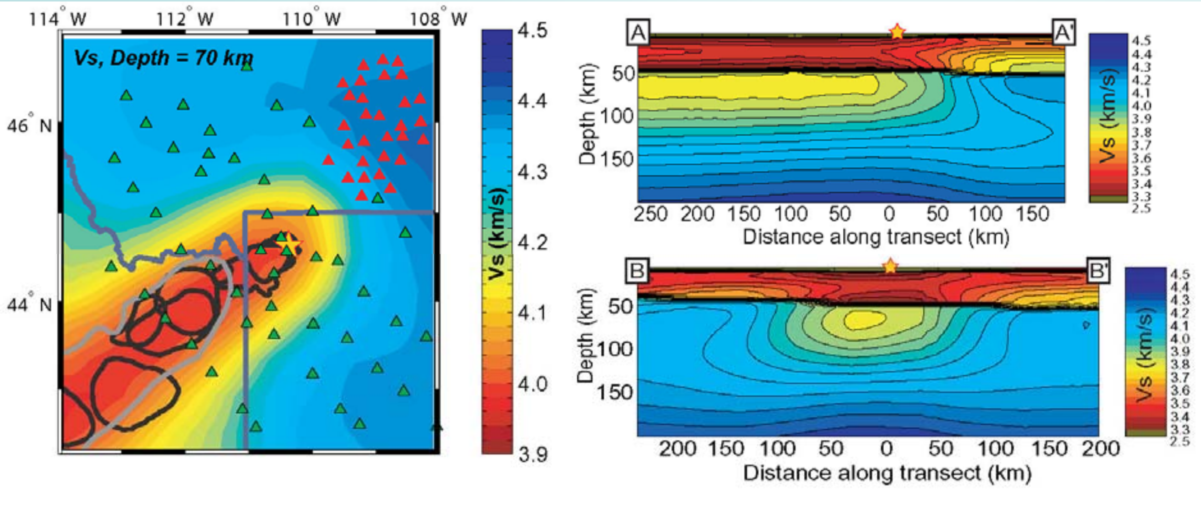
- For theoretical based non-GSS anelasticity.

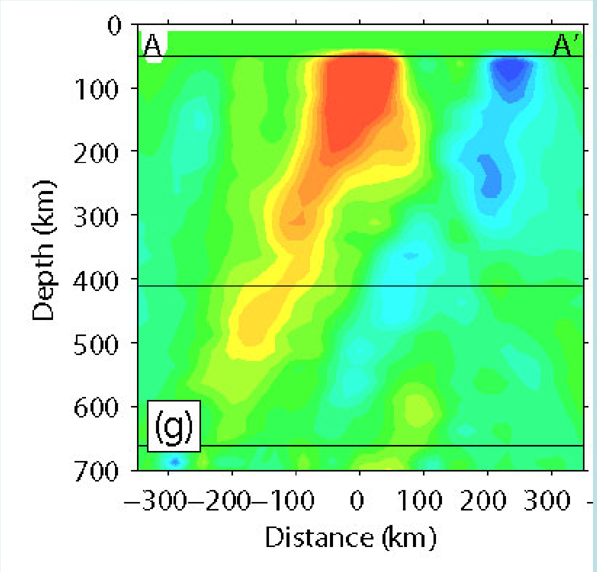
>> Qs of 10-20 in plume layer

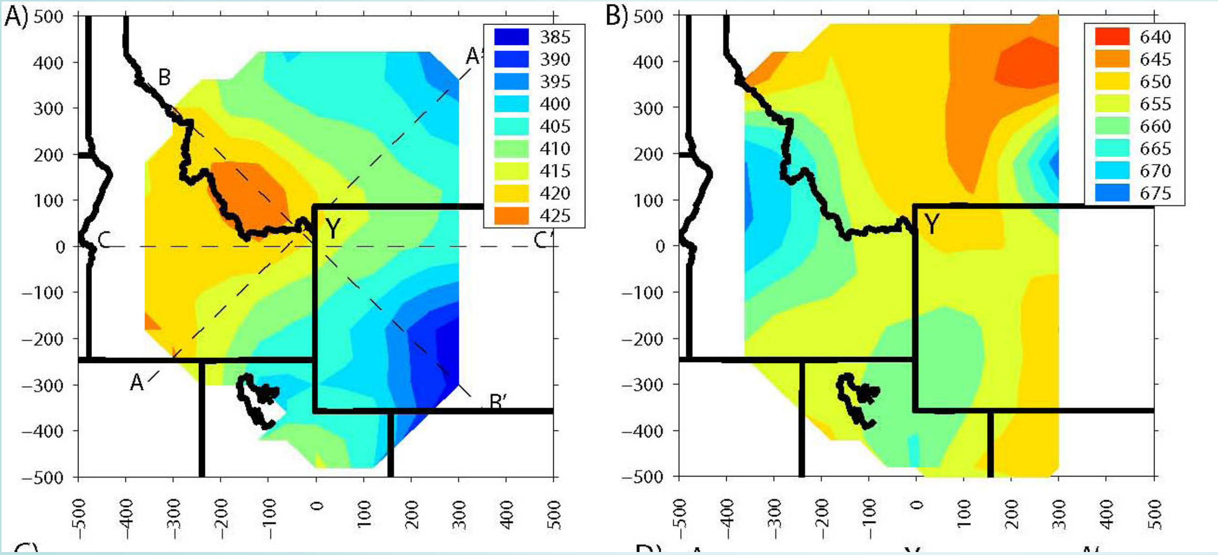
>> V* between 4-25 cm^3/mole (lower is better)

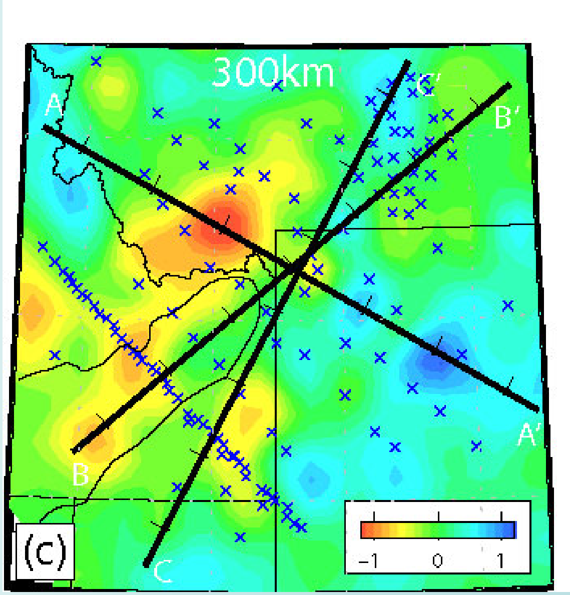
- 1.1% maximum mean melt porosity helps reduce velocities. However, big uncertainty in choice of velocity reduction: the 2.1% Kreutzmann et al. or 8% H&H numbers.

Final answer: small upper mantle plume





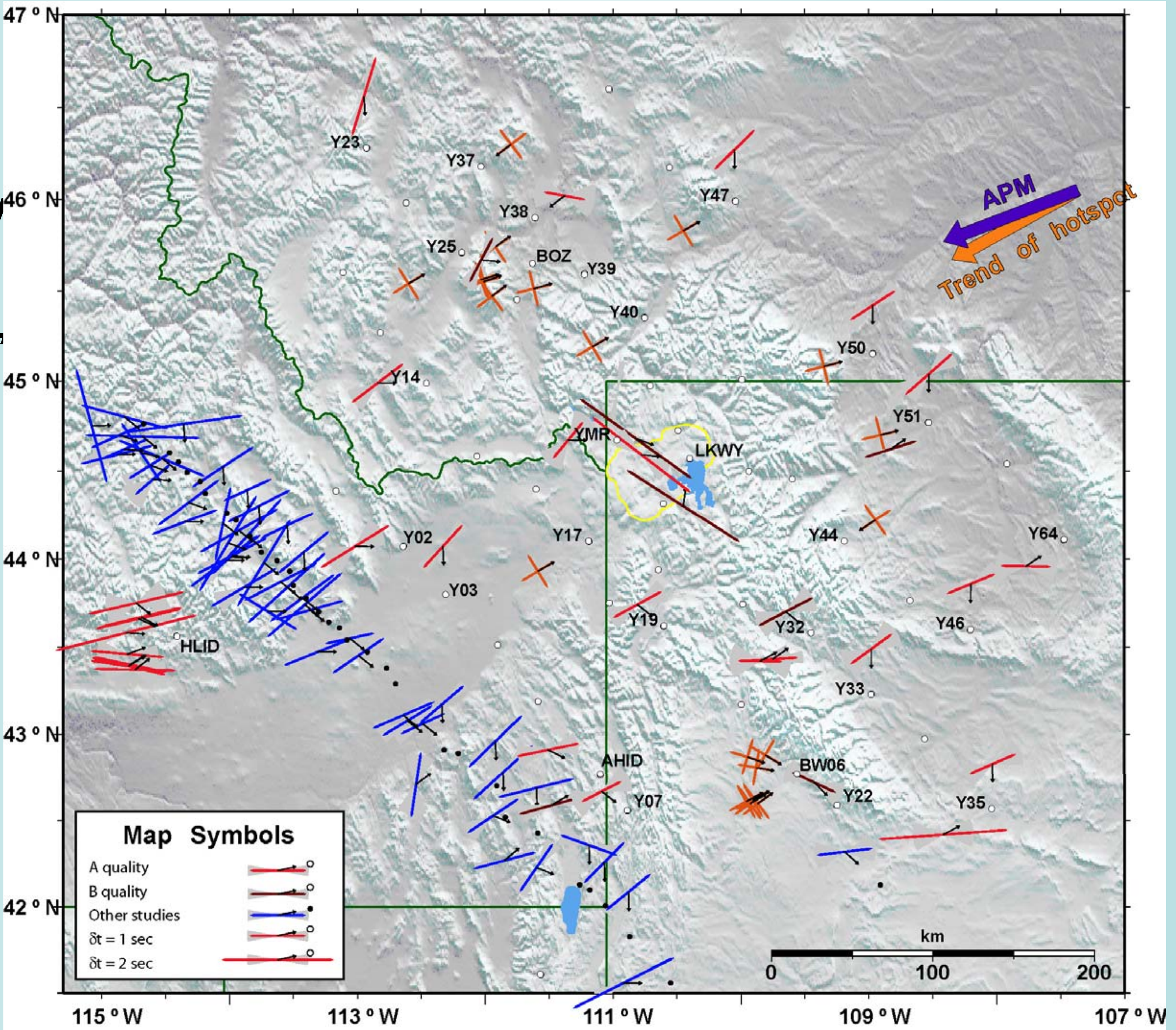




SKS Anisotropy

Waite et al., accepted JGR

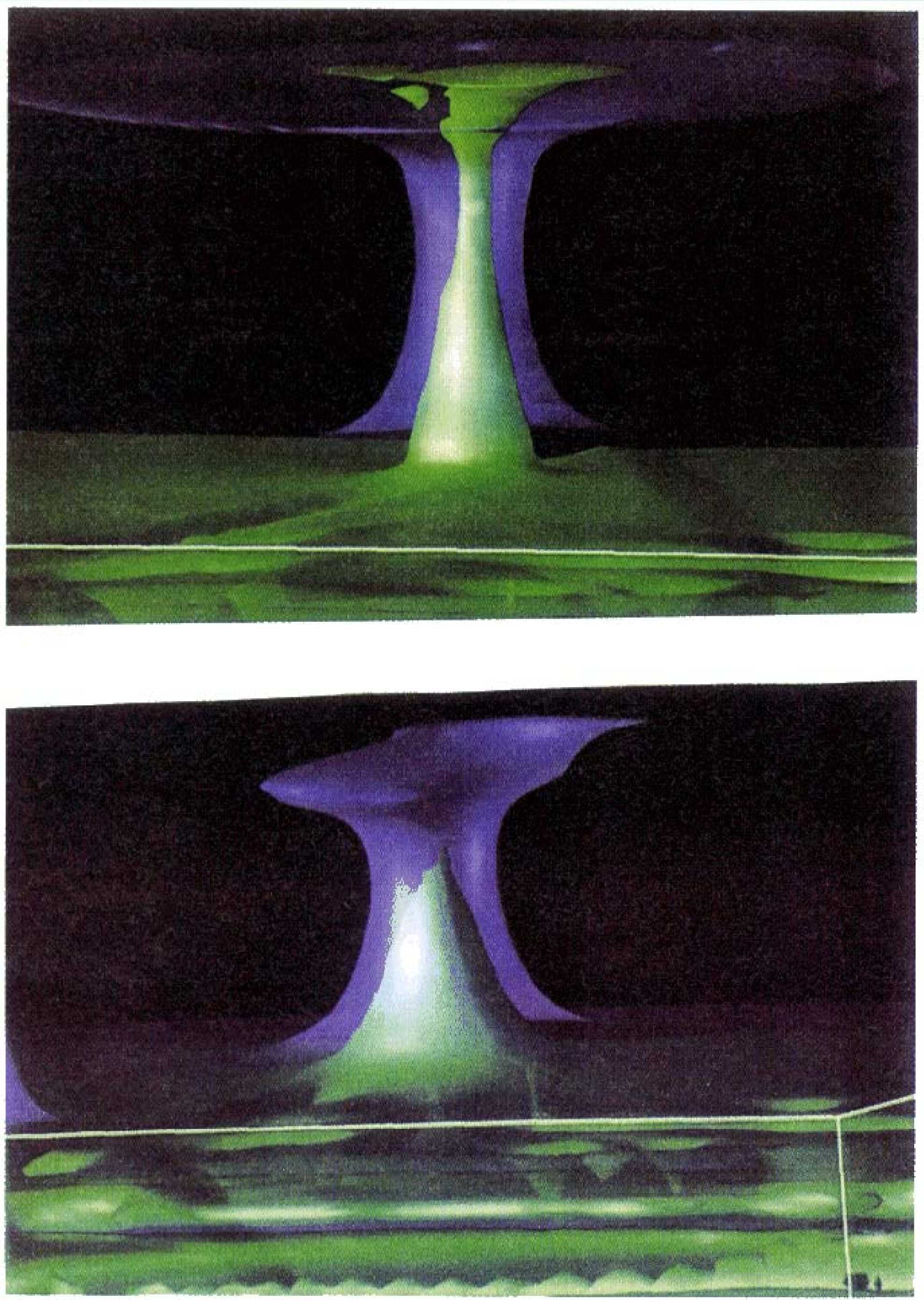
no PAF flow



Plumes

plume nucleating from a low viscosity zone between 660-1000 km depth.

Plumes nucleated from the core-mantle boundary.

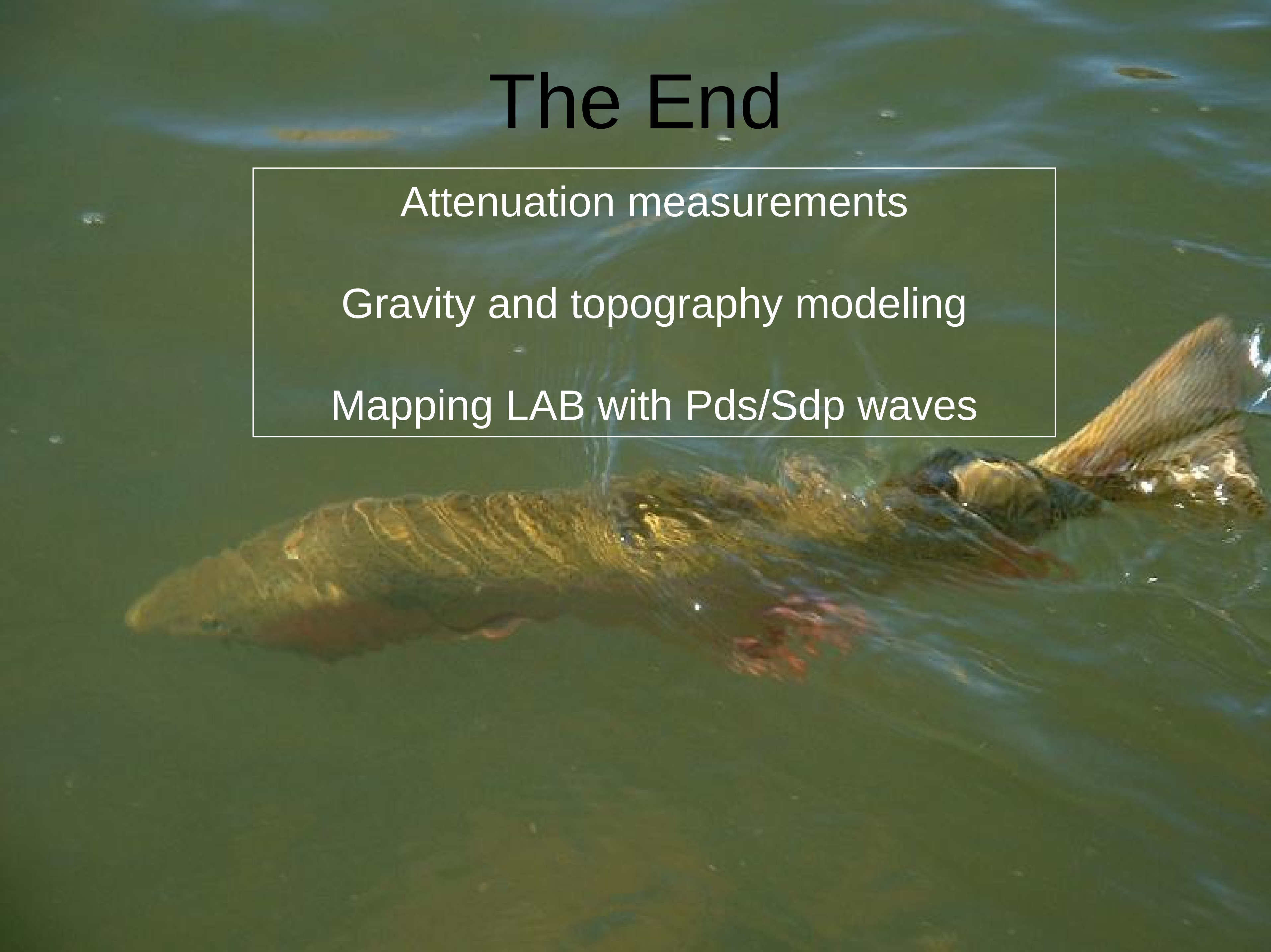


The End

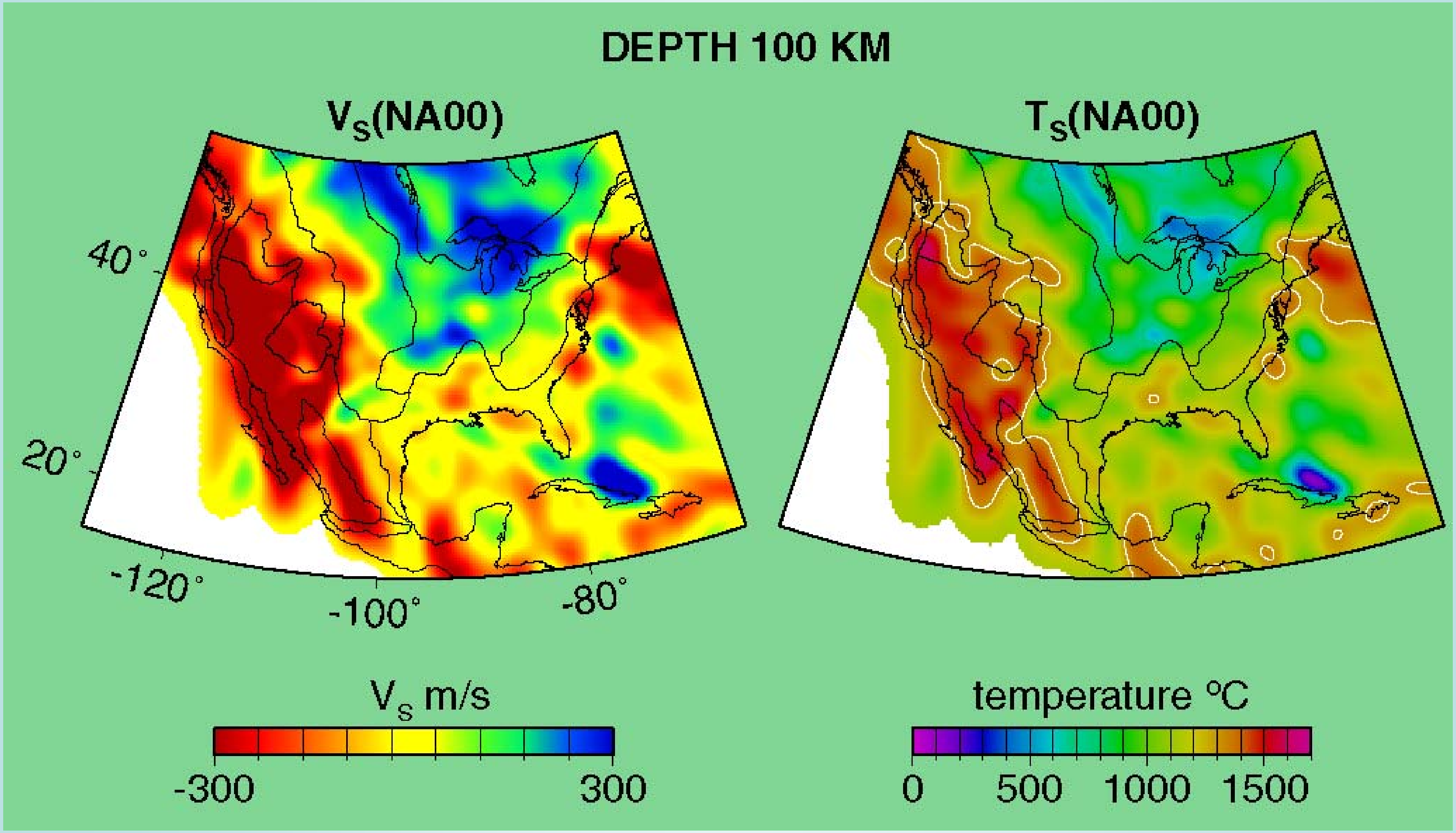
Attenuation measurements

Gravity and topography modeling

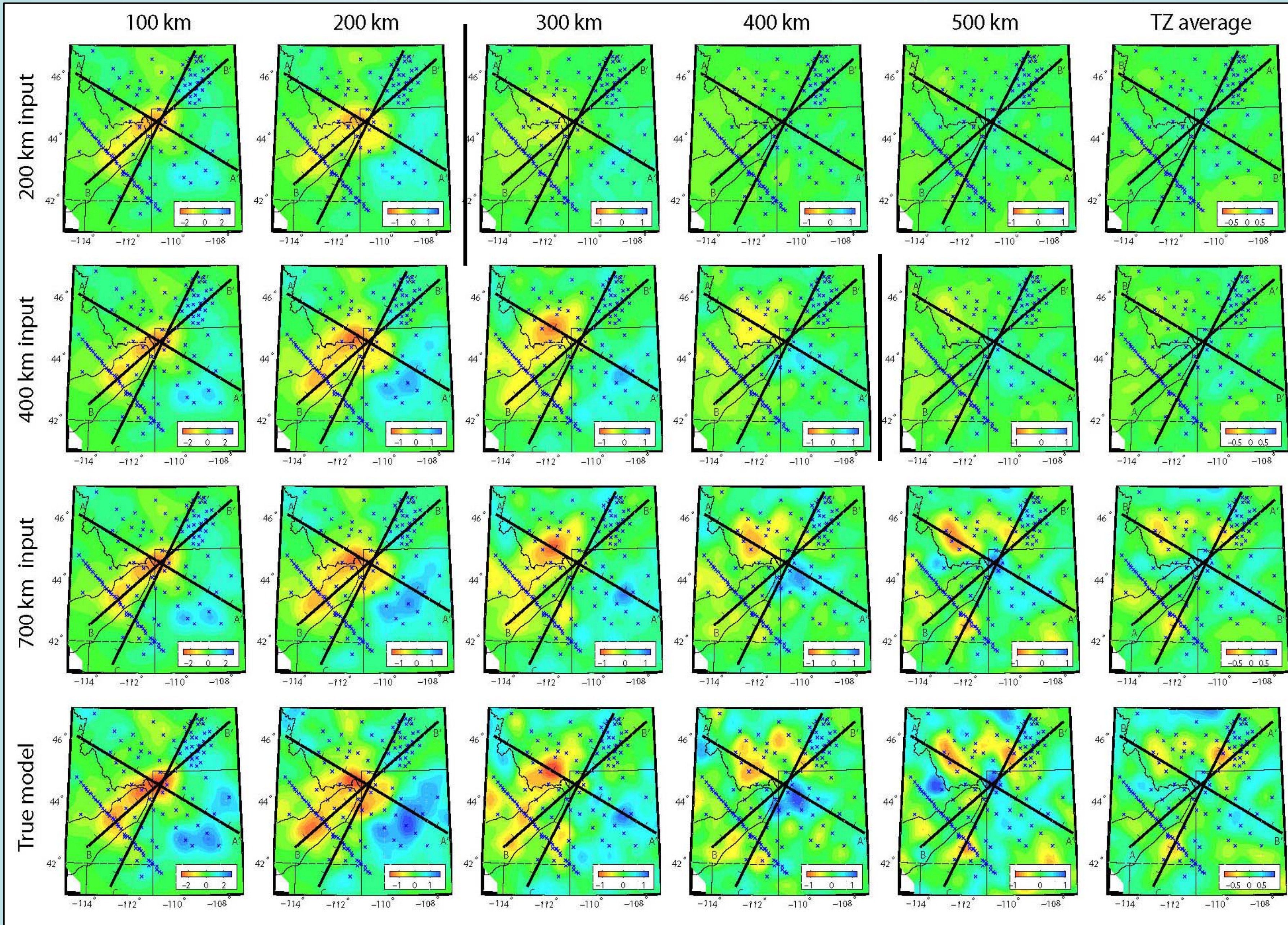
Mapping LAB with Pds/Sdp waves



North America Shear Velocity



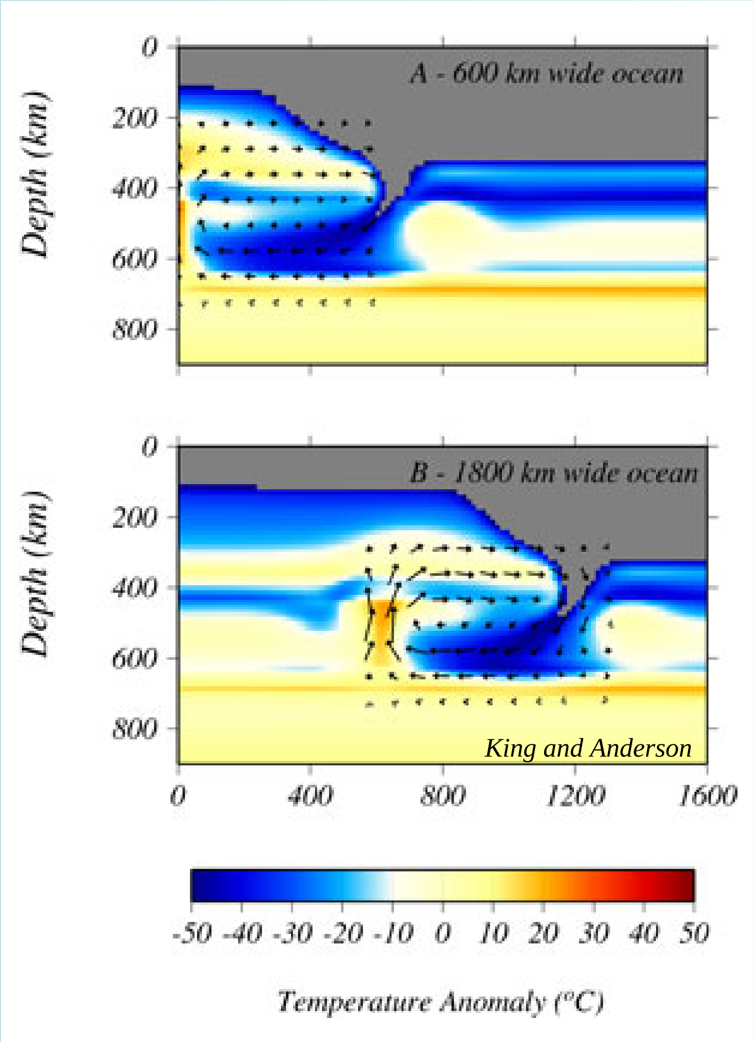
Goes and van der Lee, 2001



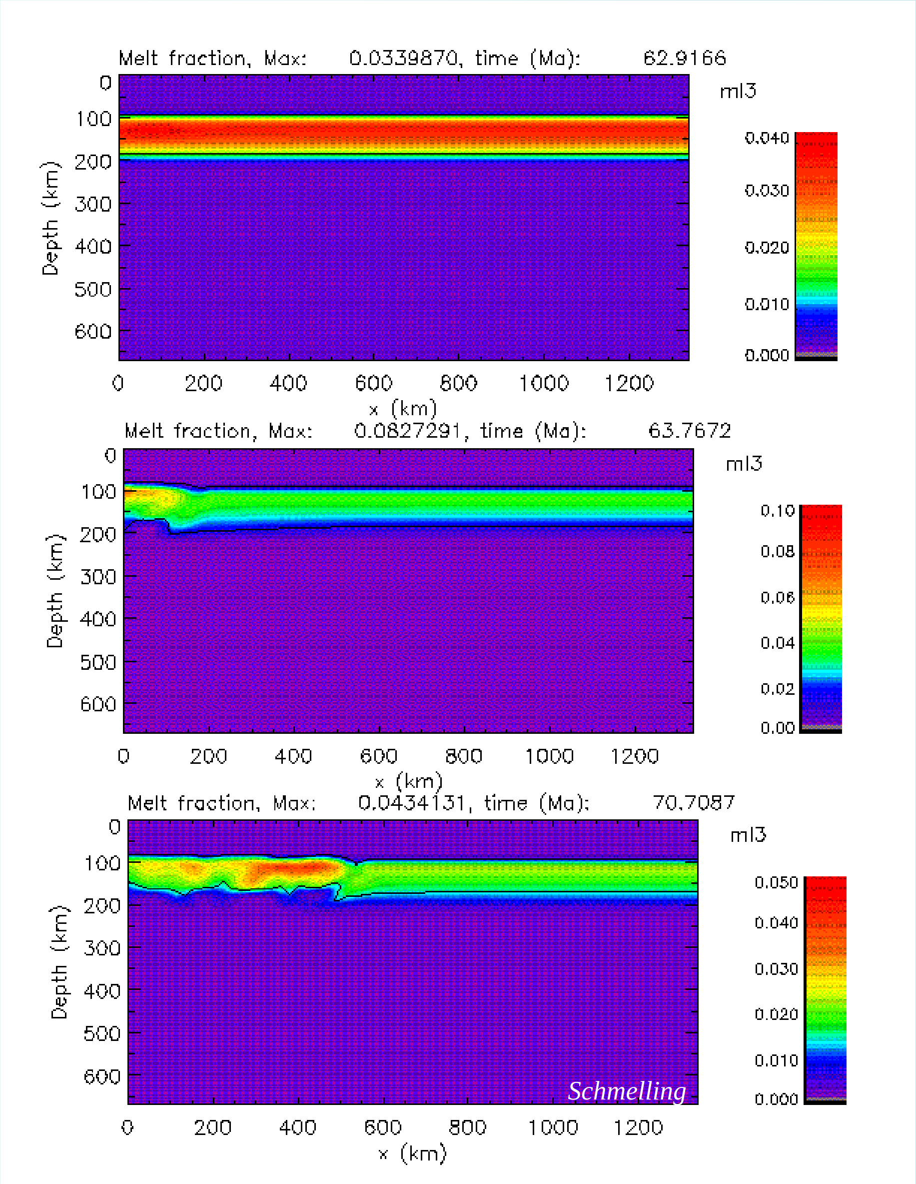
Truncated model smearing tests

Top-Driven Processes

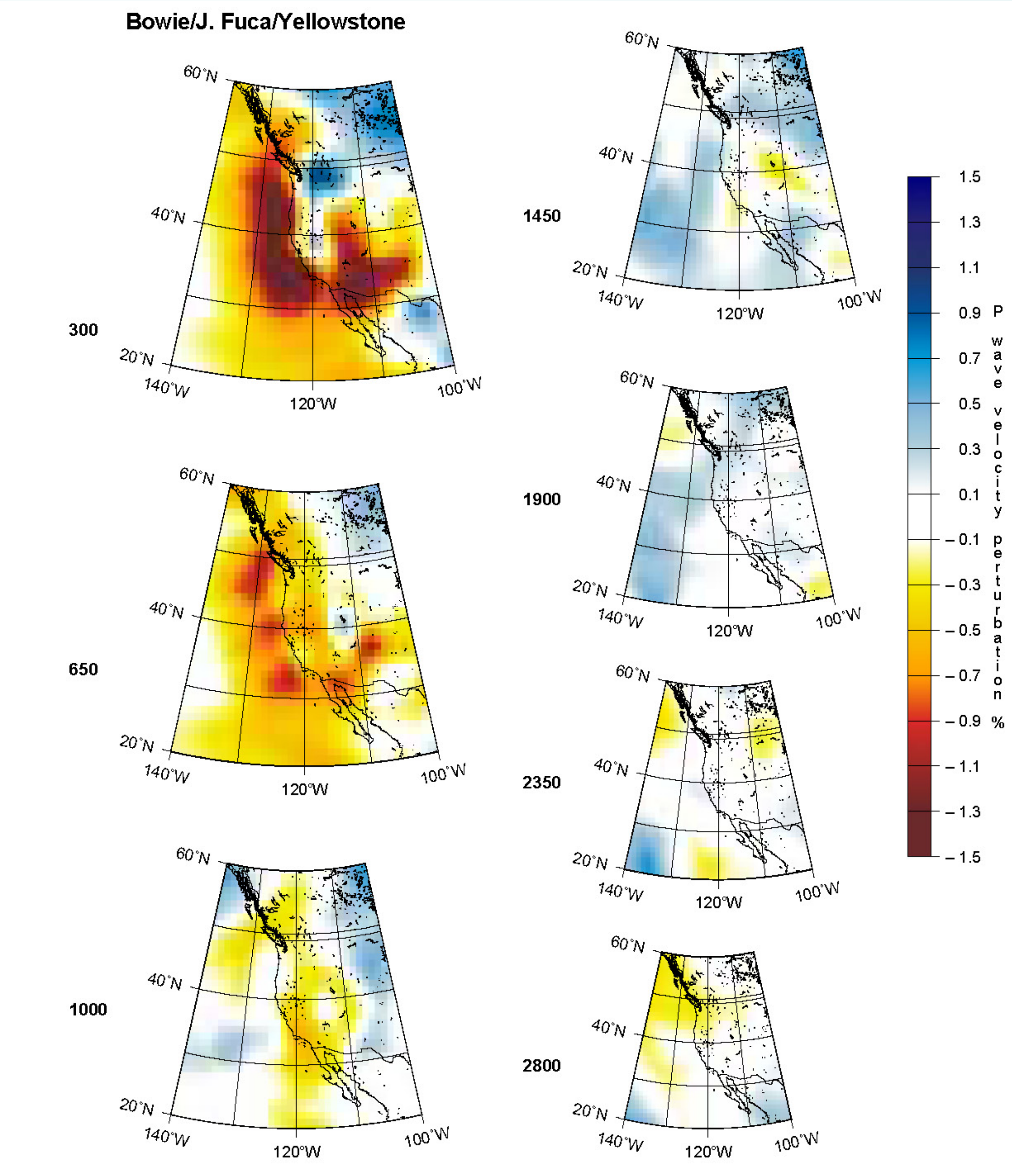
Edge-driven convection



Melt-rolls



Global P-wave Tomogram



SRP93 Vp/Vs cross-section (Schutt and Humphreys, 2004)