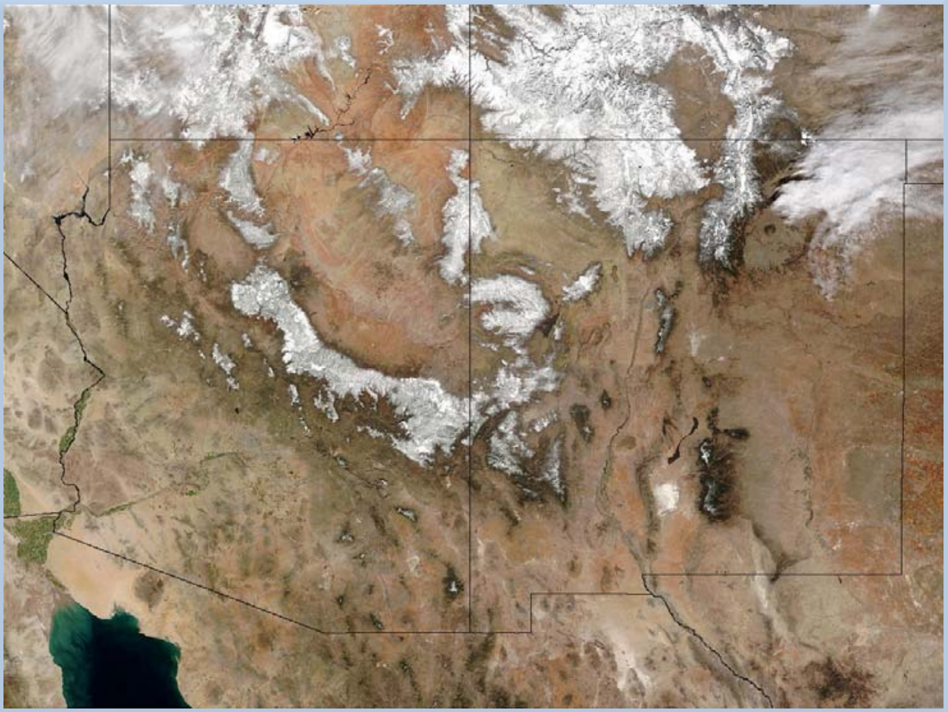
Crust-mantle interactions of the Escalante anomaly, Colorado Plateau

Jolante van Wijk

University of Houston



In collaboration with…

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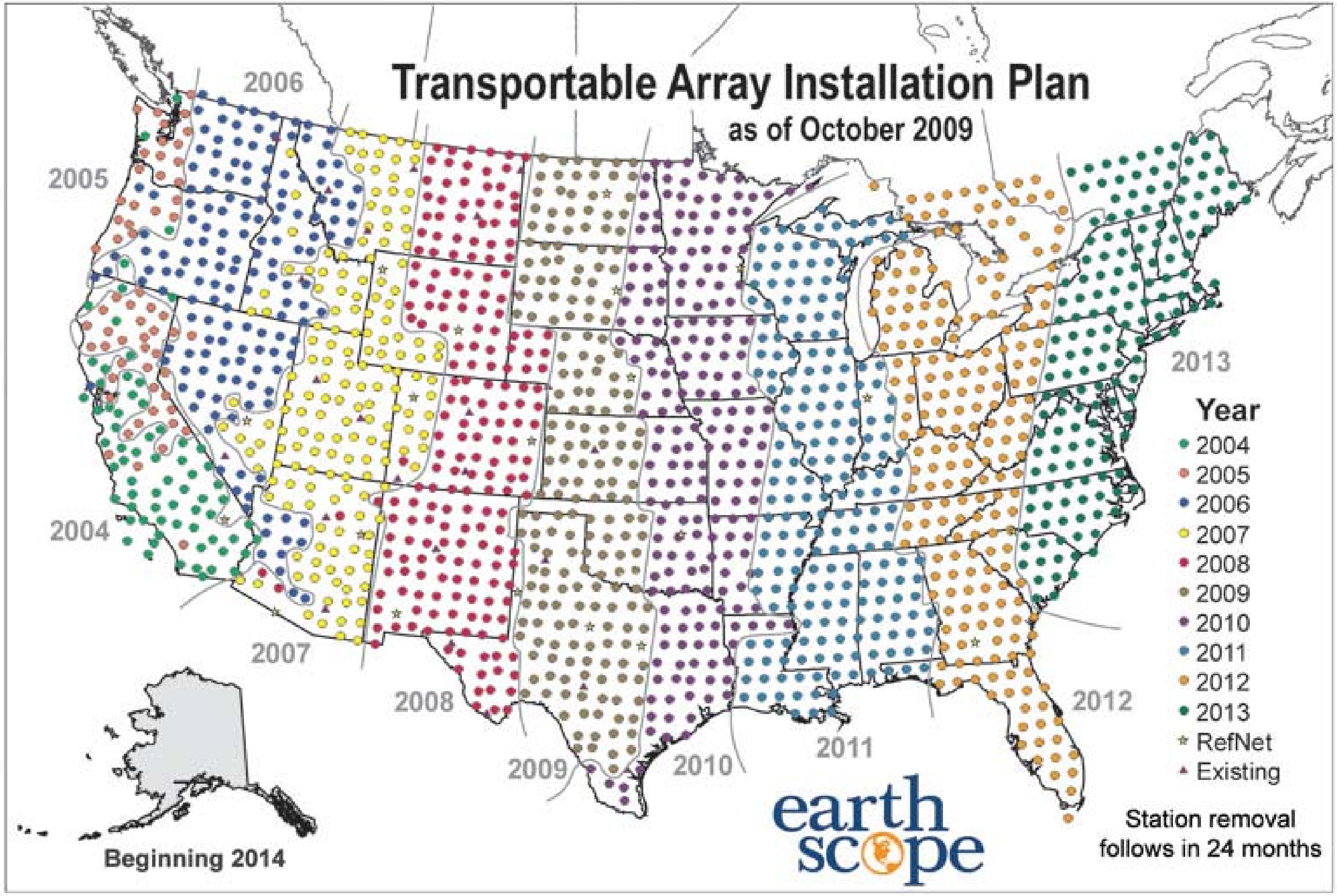
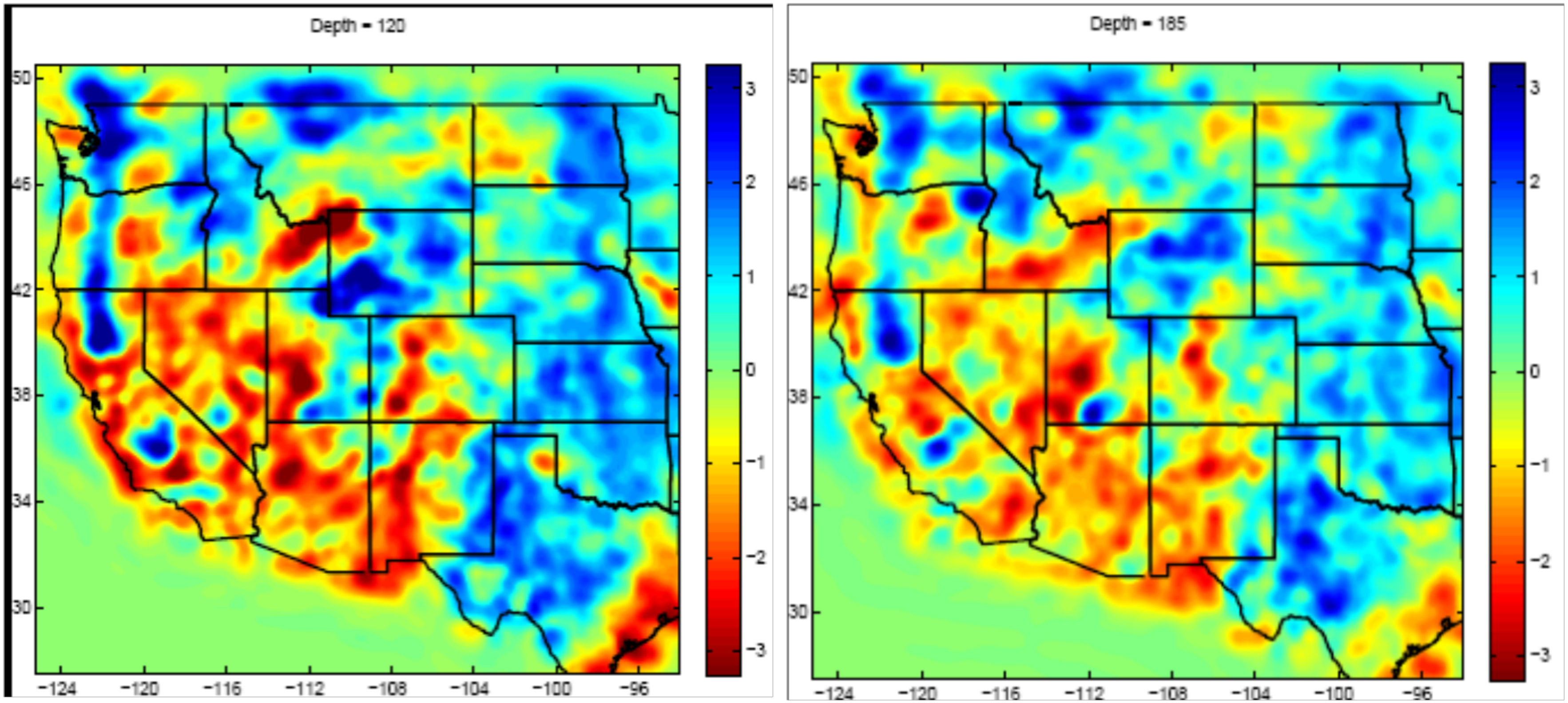
Rick Aster (New Mexico Tech)
Steve Grand (UT Austin)
Ken Dueker (U Wyoming)
Karl Karlstrom (U of New Mexico, Albuquerque)
Scott Baldridge (Los Alamos National Lab)
David Coblentz (Los Alamos National Lab)

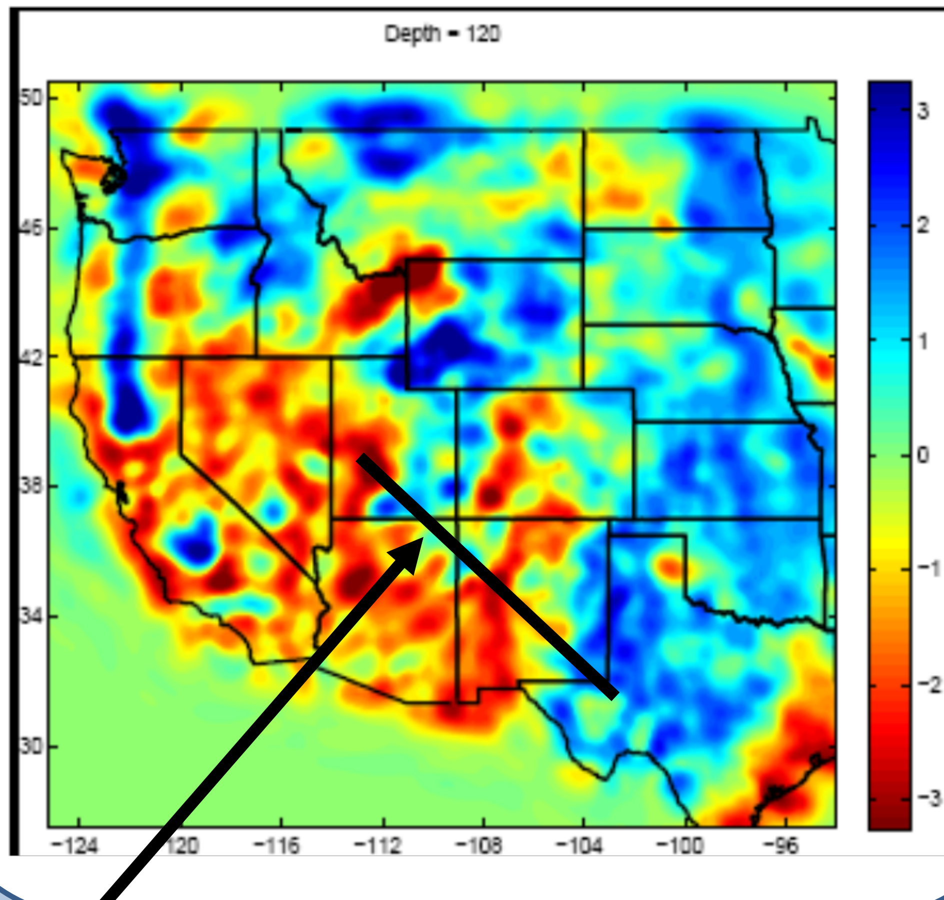
CitCom
(mantle convection)
Gale
(lithosphere deformation)


Transportable Array Installation Plan
as of October 2009
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
RefNet
Existing
Beginning 2014
earthscope
Station removal
follows in 24 months



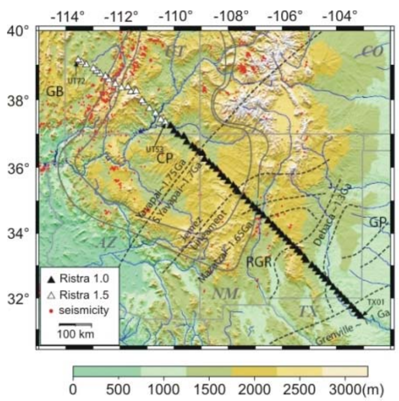
P-wave
(Brandon Schmandt)

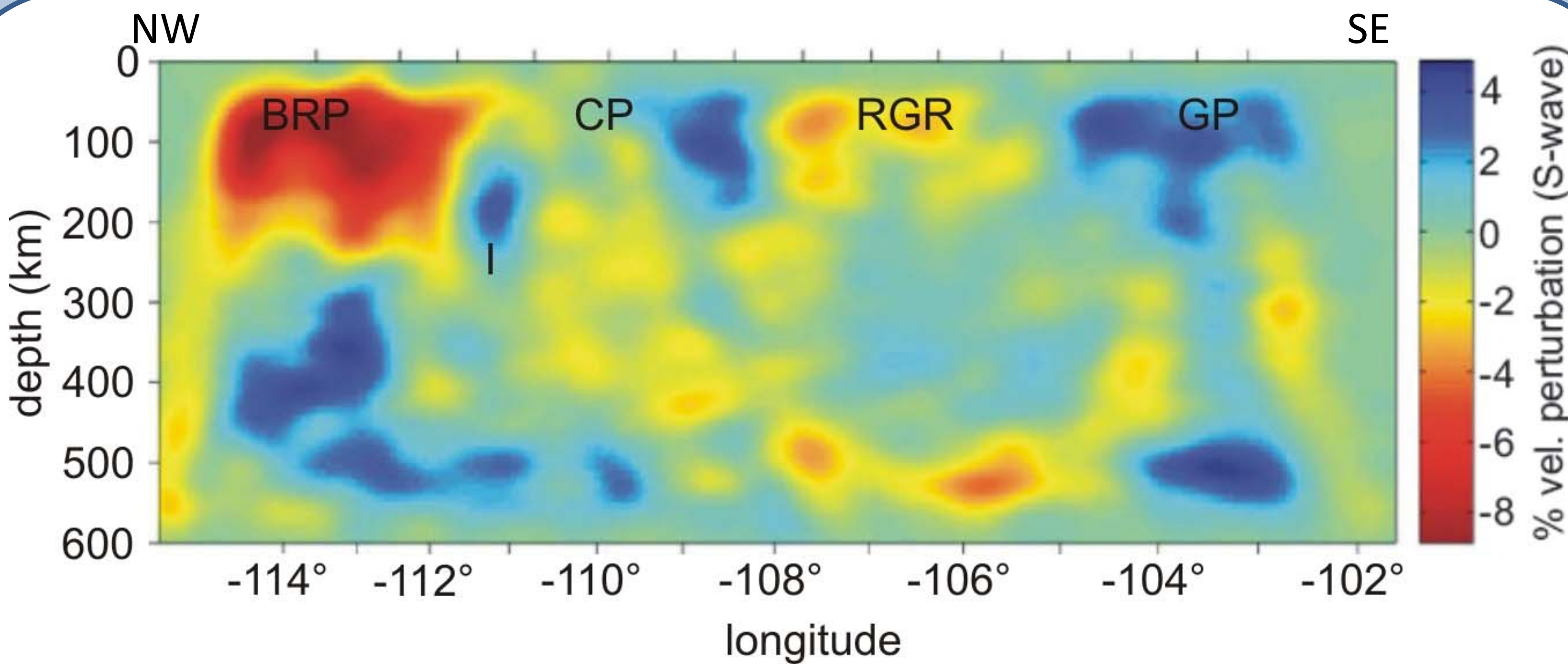
La RISTRA Seismic Experiment



La RISTRA

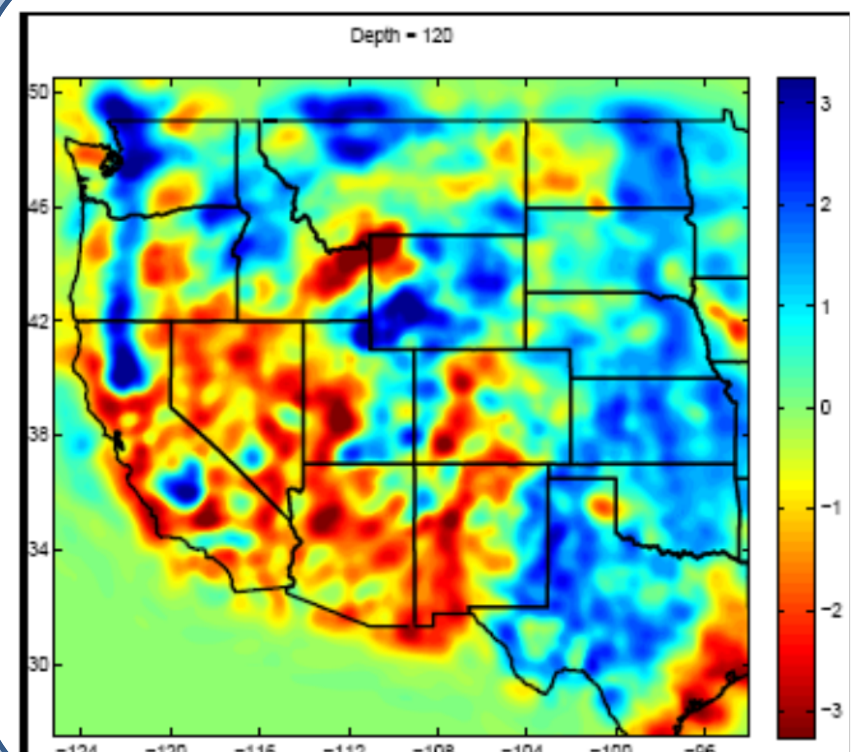
La RISTRA
(Rio Grande Rift Seismic Transect)



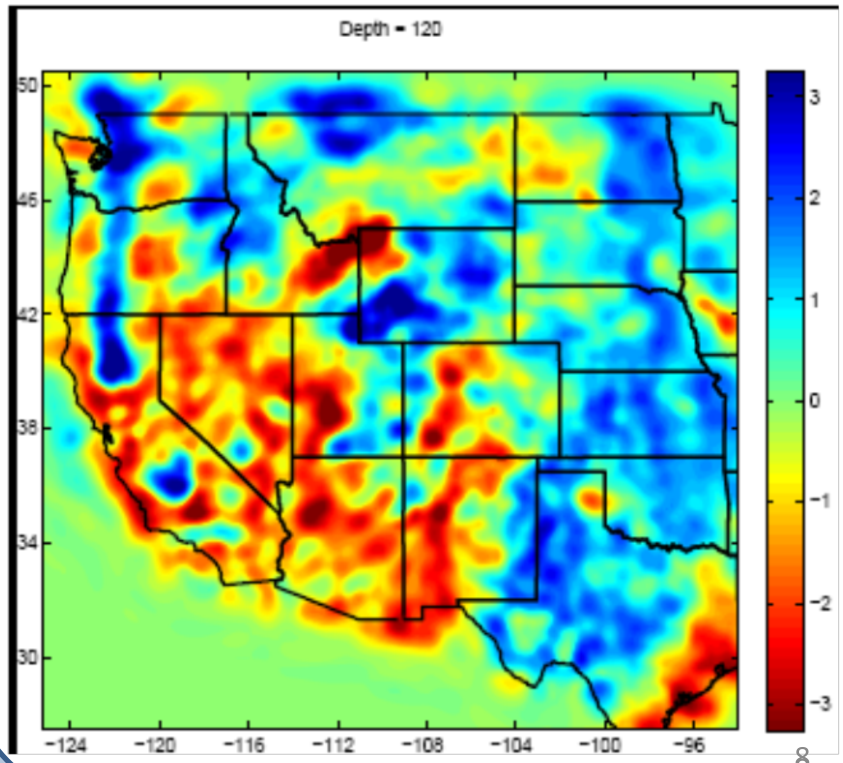


Tomographic images-summary

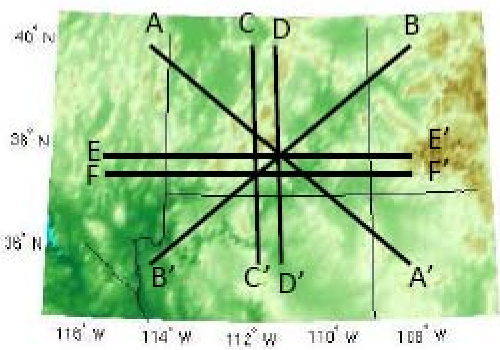
- Many anomalies of wavelength ~100- several 100 kilometers
- Large seismic wave velocity variations (up to 12%) found over short lateral distances

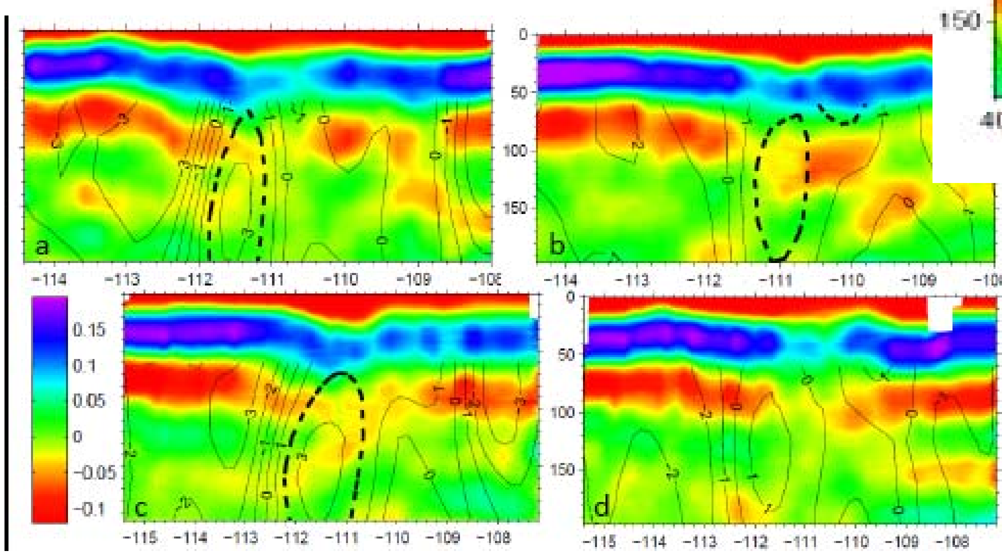


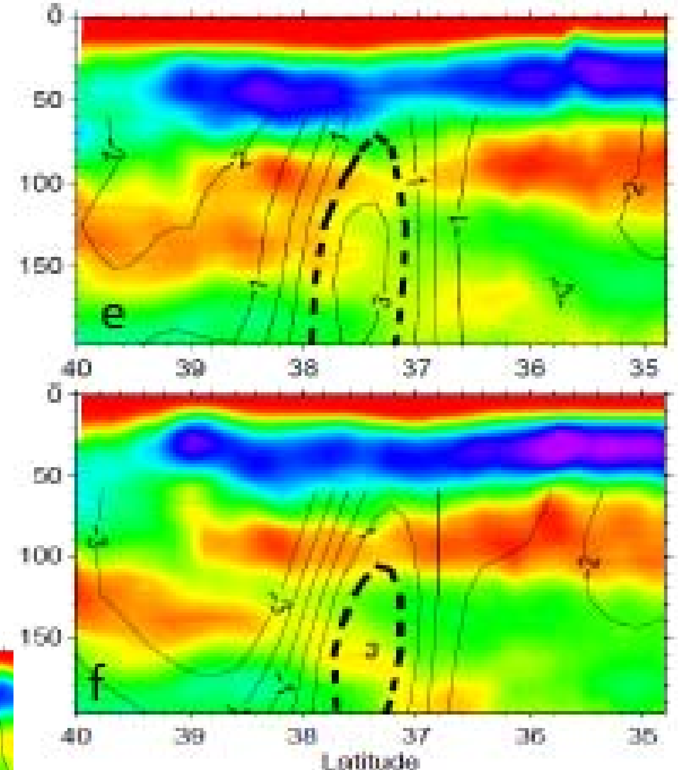
Escalante anomaly



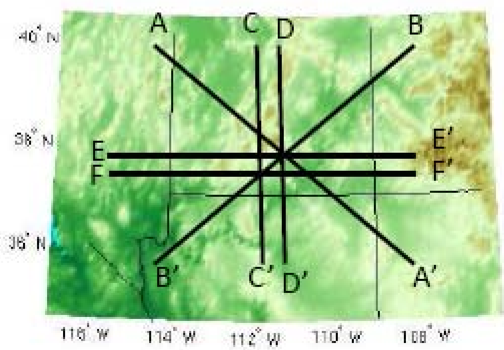
Escalante anomaly



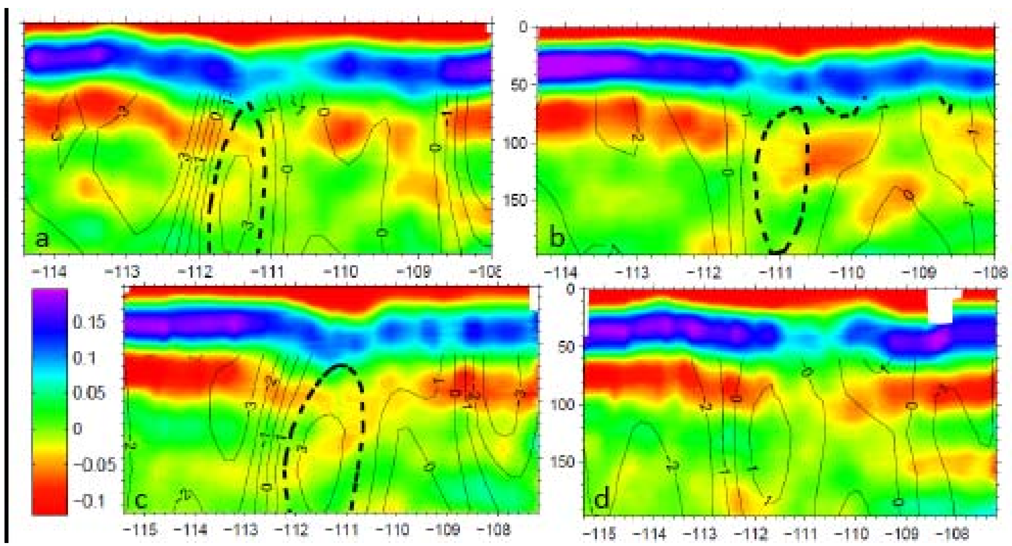




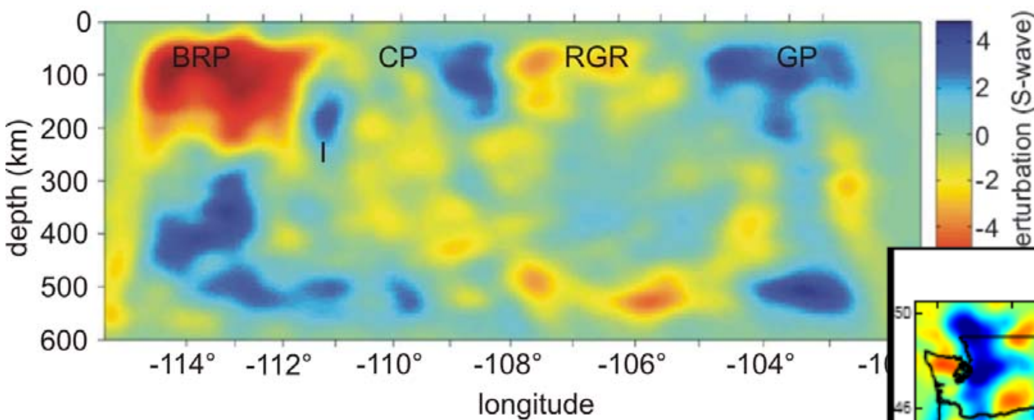
Escalante anomaly

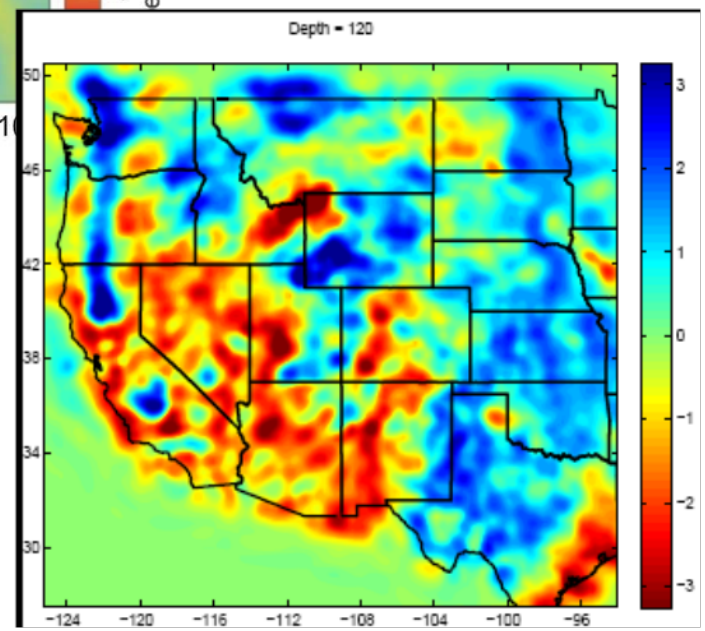


- Fast velocities in upper mantle
- Thick crust
- Discontinuous lithosphere-asthenosphere boundary
- Discontinuous Moho



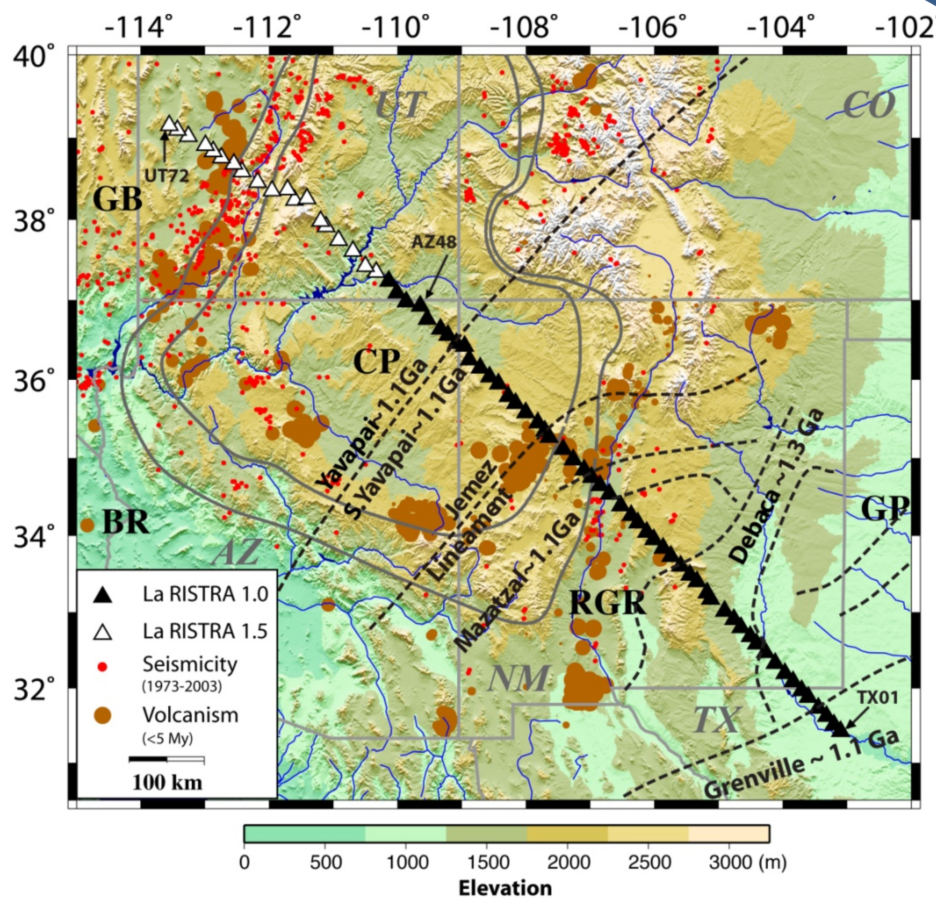
- Shallow upper mantle low velocities below Rio Grande Rift



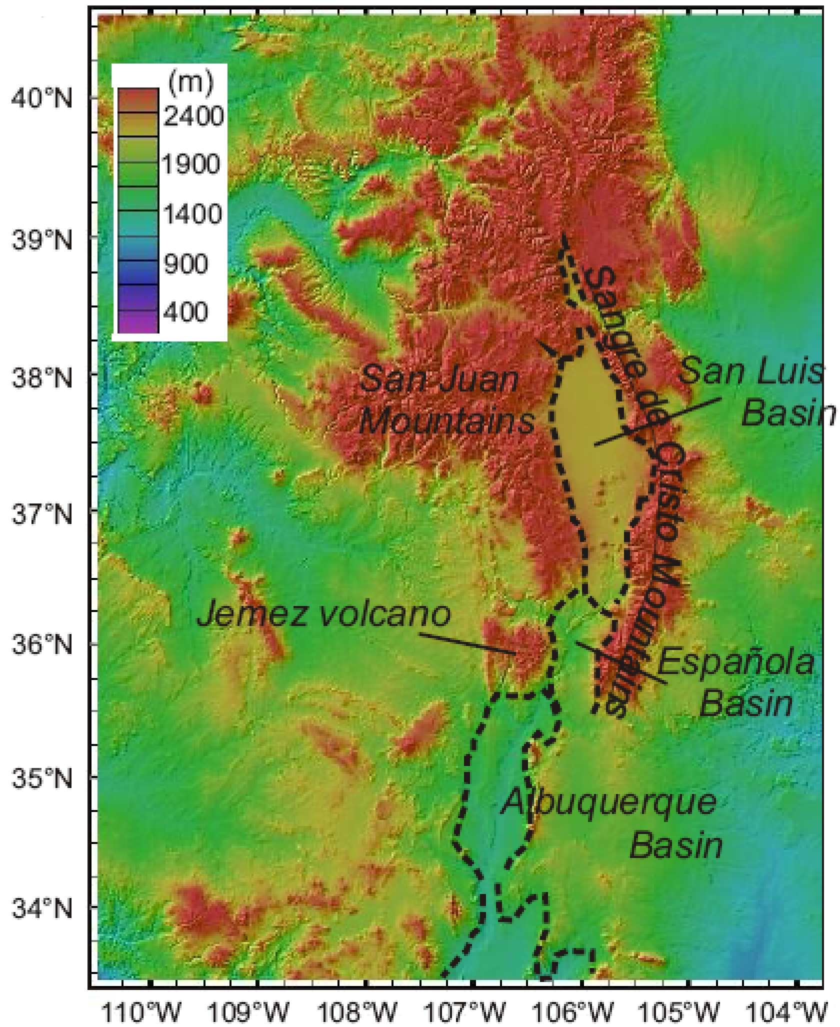


Rio Grande Rift

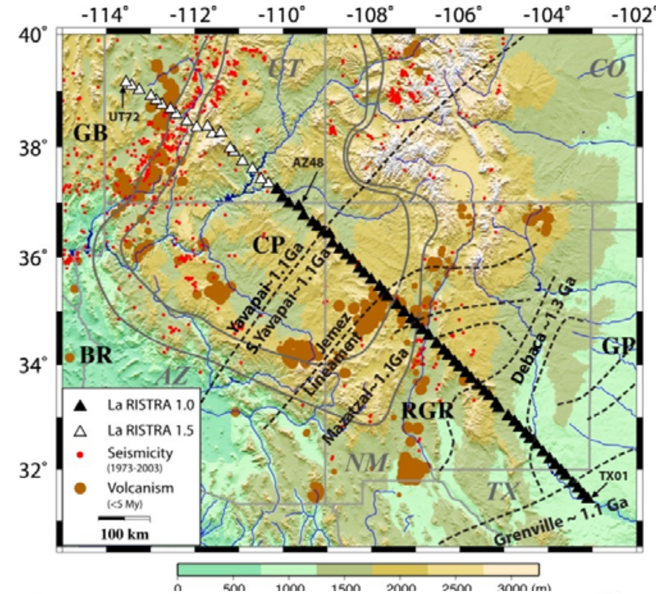
La RISTRA results:
West et al., 2004
Gao et al., 2004
Wilson et al., 2005
Van Wijk et al., 2008

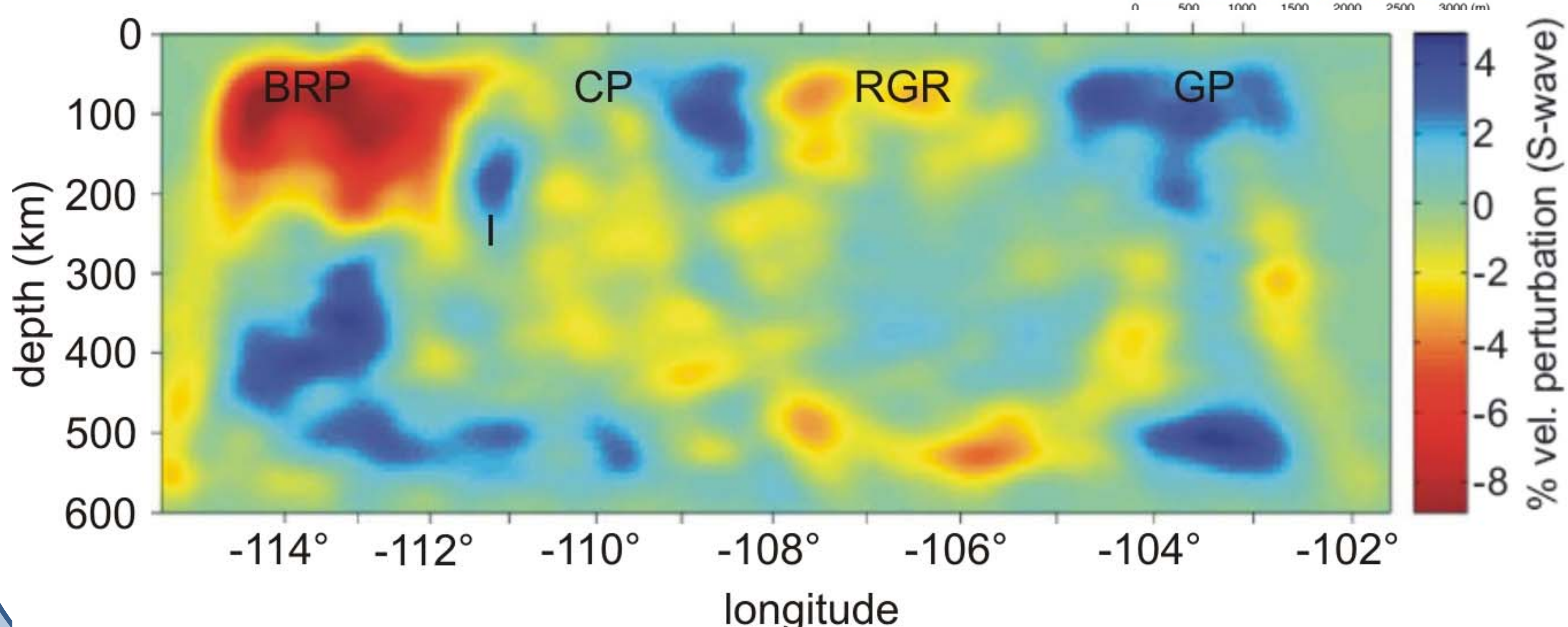


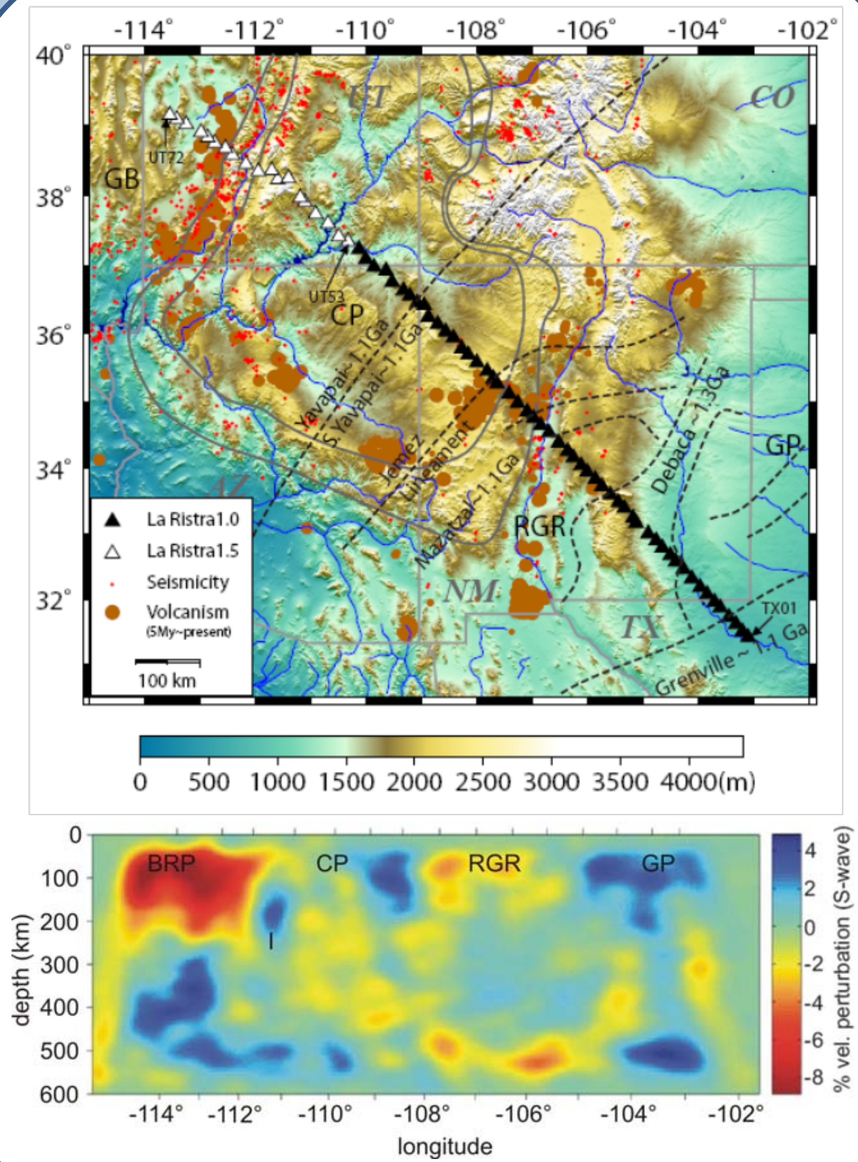
Rio Grande Rift



~8% low velocity anomaly below rift





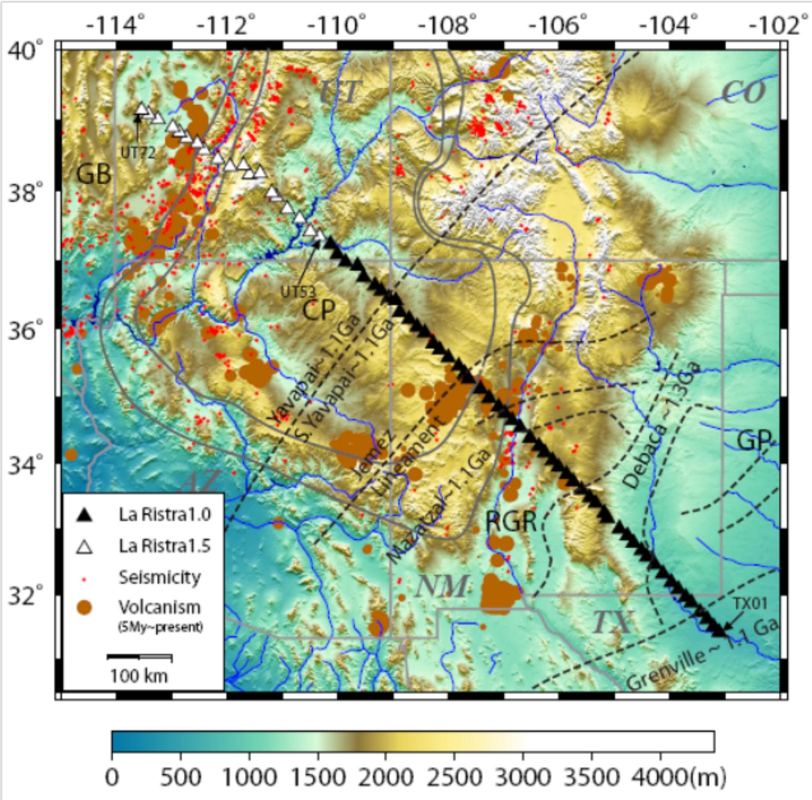


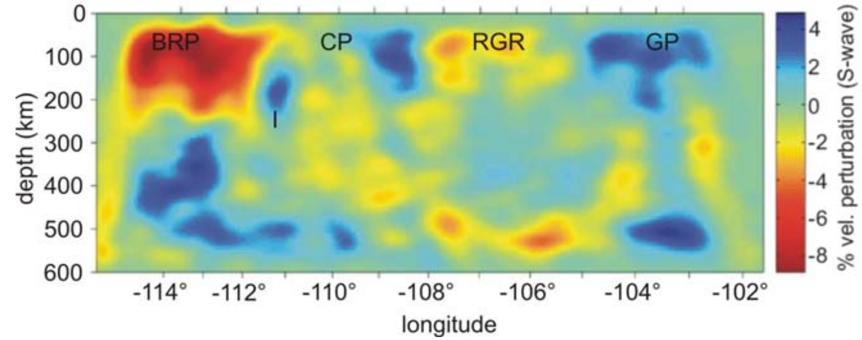
What can explain the ~8% low velocity anomaly below the rift?

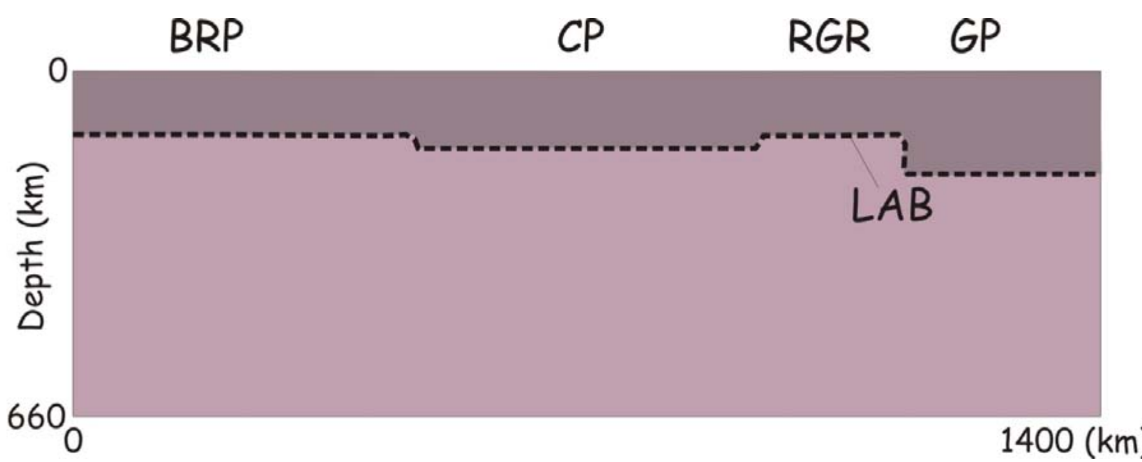
Compositional variations?

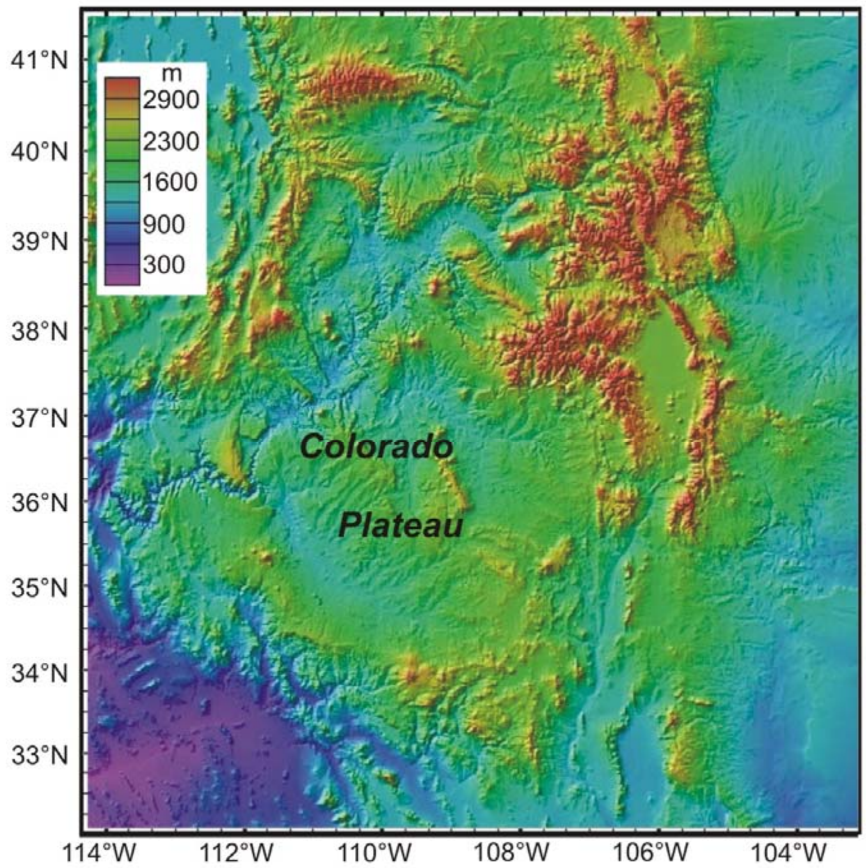
Melt?

Passive upwelling of asthenosphere?


-114°
-112°
-110°
-108°
-106°
-104°
-102°
40°
38°
36°
34°
32°
UT
CO
GB
UT72
UT53
CP
GP
RGR
NM
TX
AZ
Yavapai~1.1Ga
S.Yavapai~1.1Ga
Jemez Lineament
Mazatzal~1.1Ga
Debaca~1.3Ga
Grenville~1.1 Ga
TX01
La Ristra1.0
La Ristra1.5
Seismicity
Volcanism
(5My~present)
100 km
0
500
1000
1500
2000
2500
3000
3500
4000(m)


BRP
CP
RGR
GP
I
depth (km)
0
100
200
300
400
500
600
-114°
-112°
-110°
-108°
-106°
-104°
-102°
longitude
4
2
0
-2
-4
-6
-8
% vel. perturbation (S-wave)

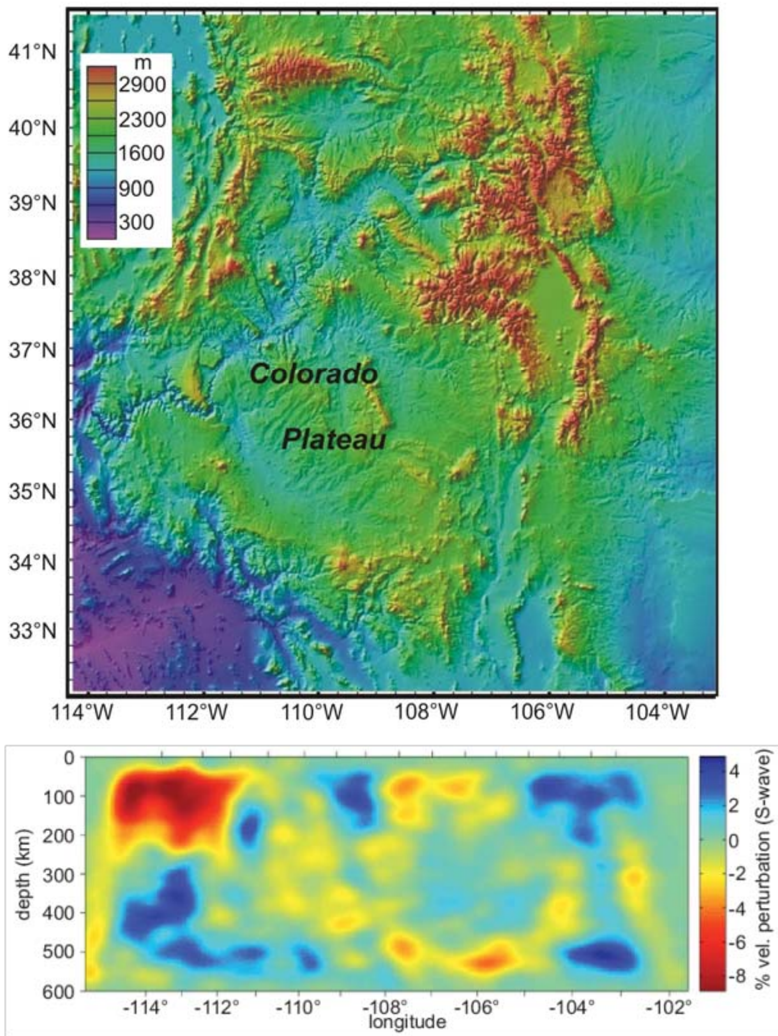

BRP
CP
RGR
GP
0
660
Depth (km)
LAB
0
1400 (km)



Proterozoic lithosphere (~1.7 Ga)

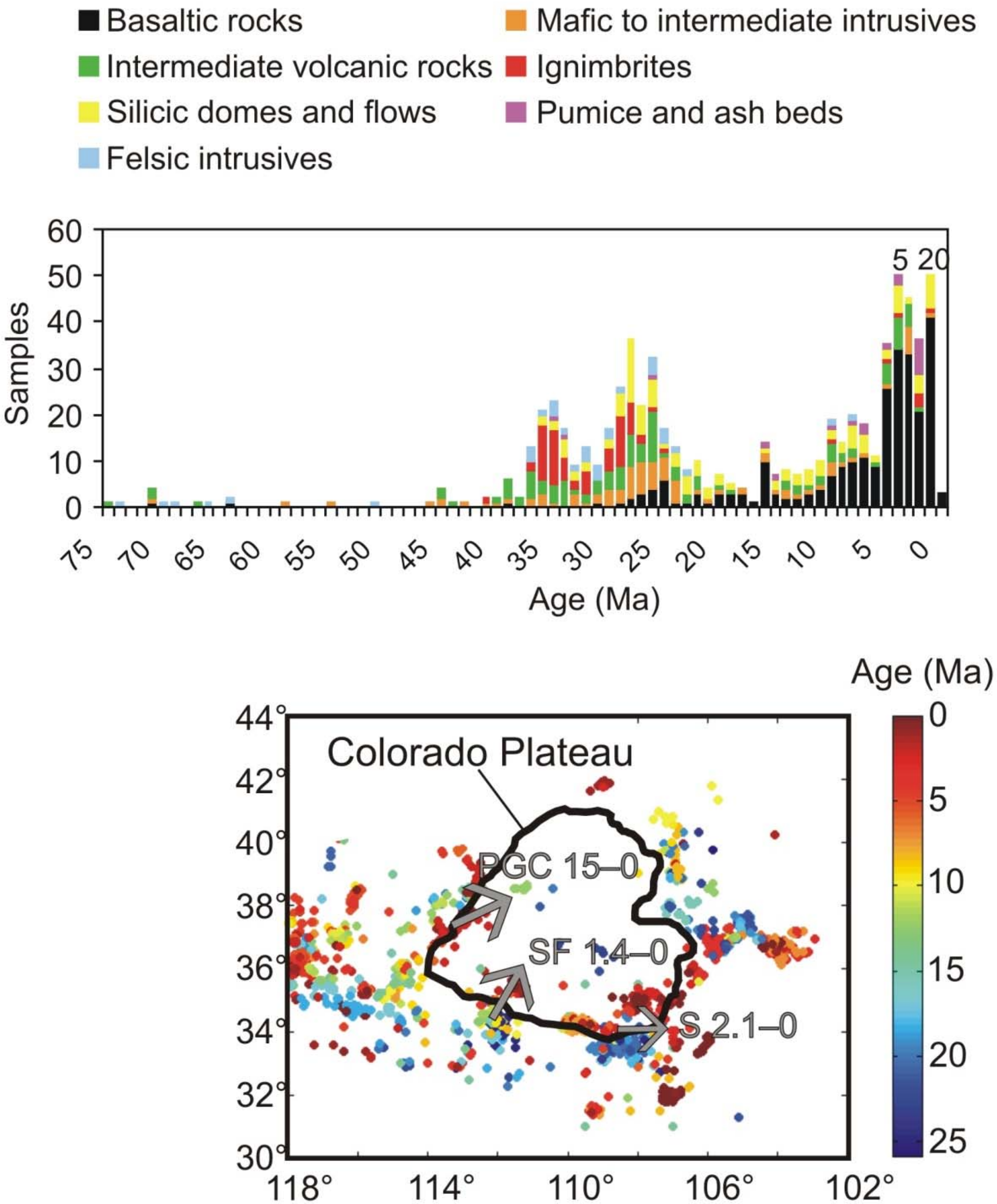
Current elevation ~1.8 km (uplifted in Cenozoic)

Bowl-shaped topography, ~400 m elevation difference, 6 Myr approximate age?



Mechanisms for uplift: dynamic topography, or static thermal

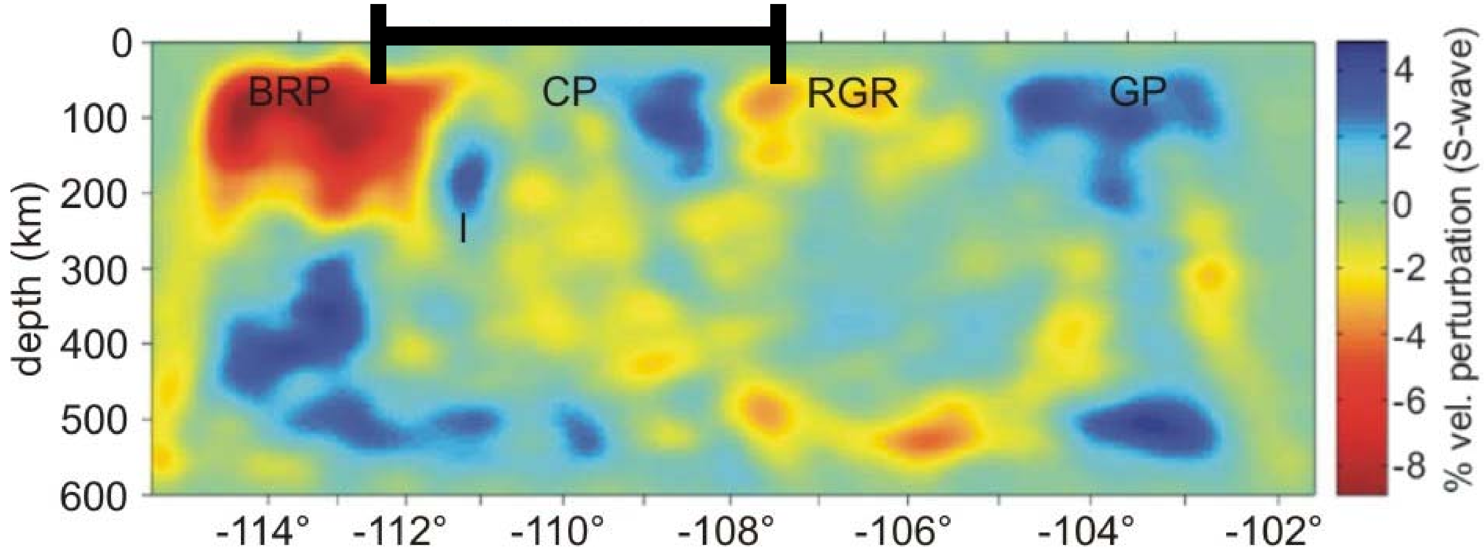
Large S-wave velocity contrast between CP and BRP (~12% over 100 km)



Two pulses of magmatism:

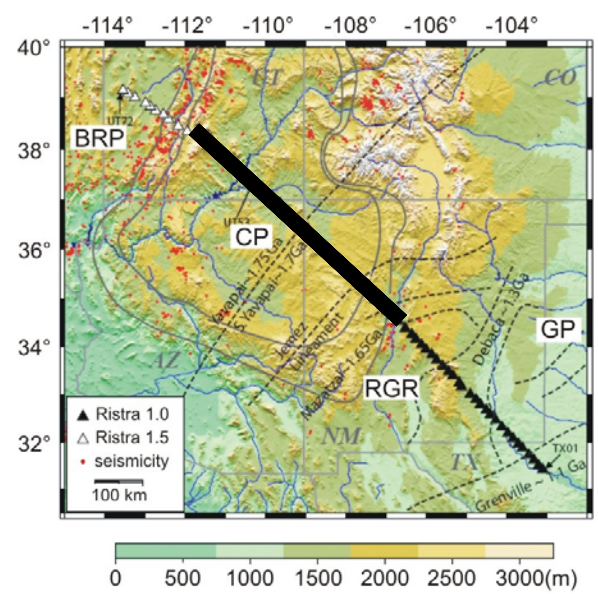
*Middle Cenozoic magmatism intermediate to silicic, absent from plateau

*Late Neogene-Quaternary magmatism basaltic, present on plateau edges



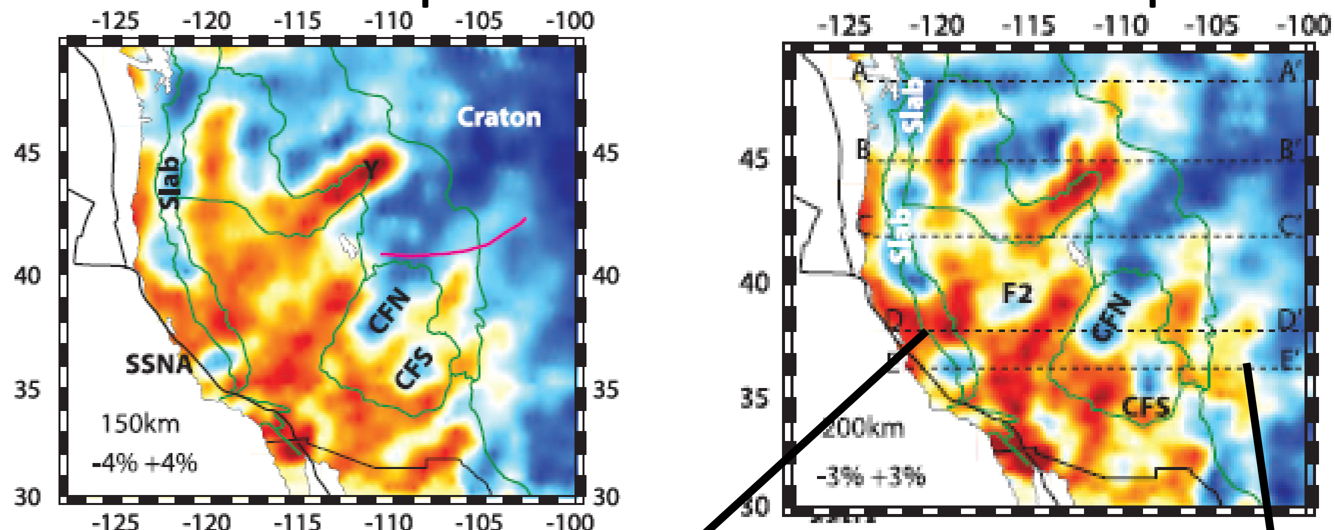
Sine et al. GRL 2008

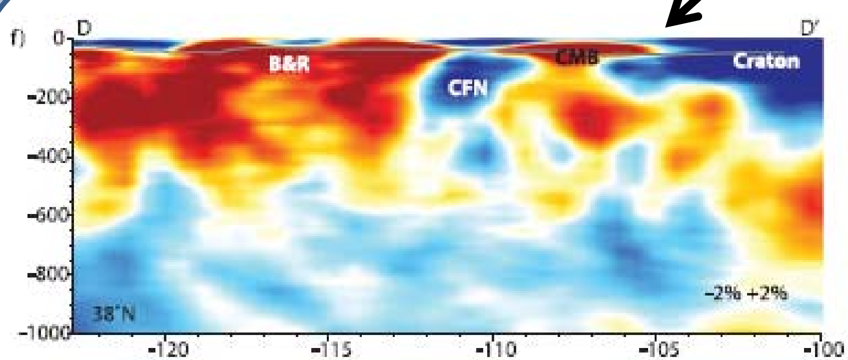
- Surface expression of Colorado Plateau ≠ Colorado Plateau mantle lithosphere
- Short wavelength velocity variations in asthenosphere
- Two 'drip'-like anomalies below Plateau



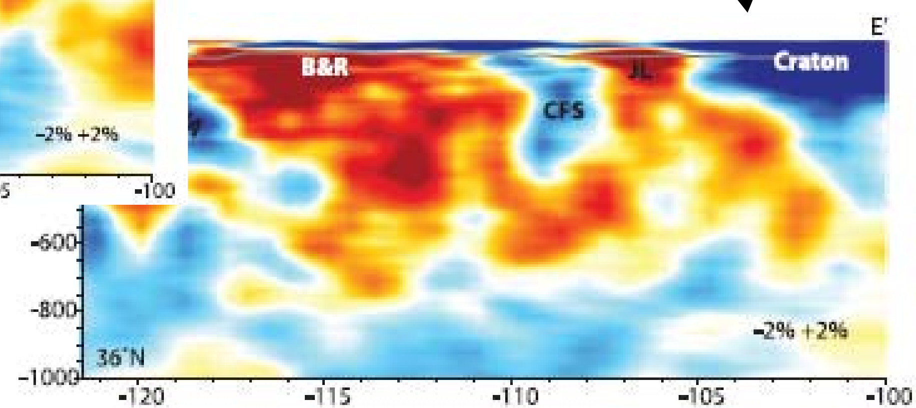
150 km depth

200 km depth





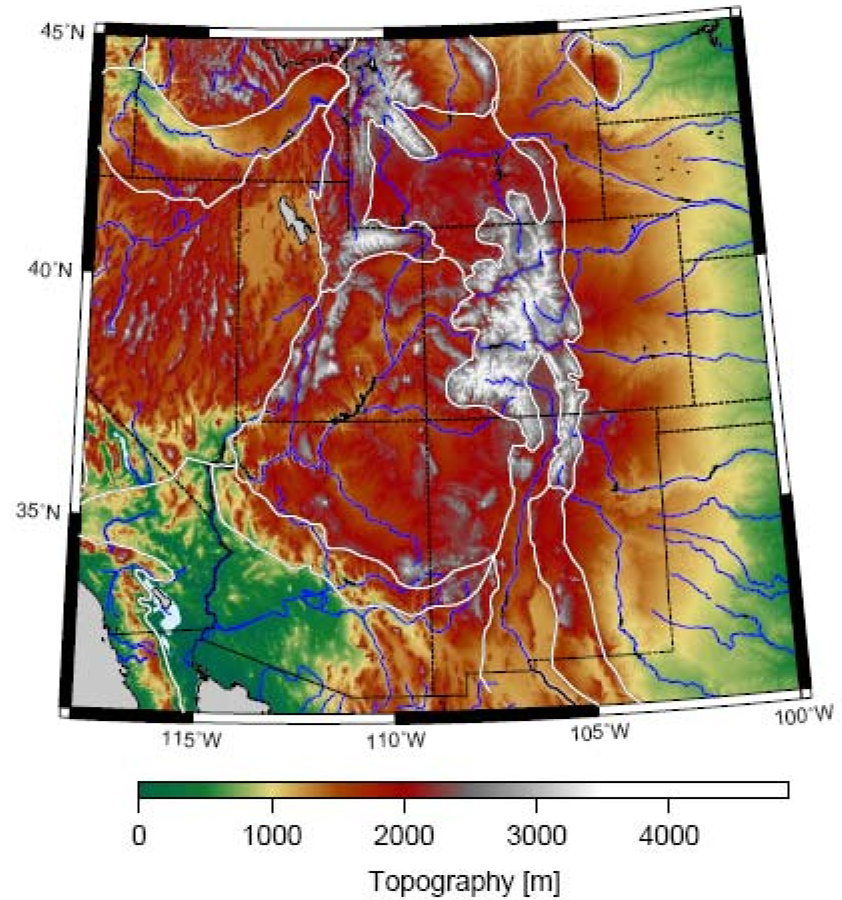
Obrebski et al., GJI 2011



Colorado Plateau

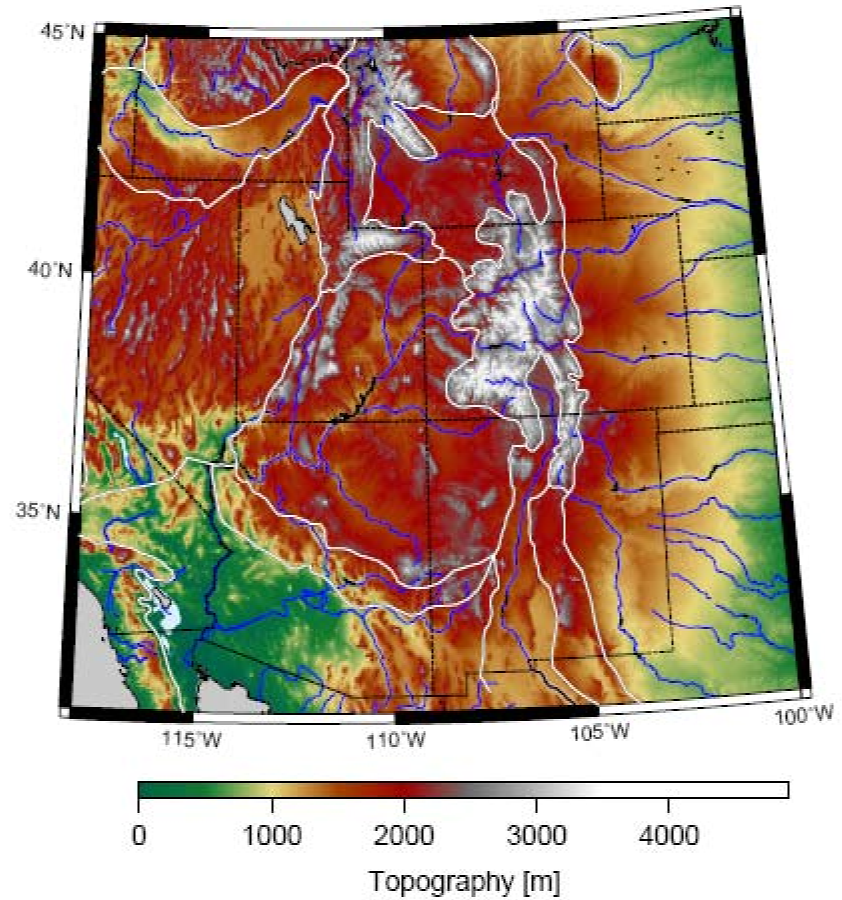
-What causes bowl-shape?
-What causes most recent (Late Neogene-Quaternary) pulse of magmatism, and inward migration of magmatism?
-What explains the low seismic wave velocities below the CP edge?
-What are the two fast velocity features?

Colorado Plateau tectonically stable, not so much affected by extension that formed Basin & Range Province and Rio Grande Rift



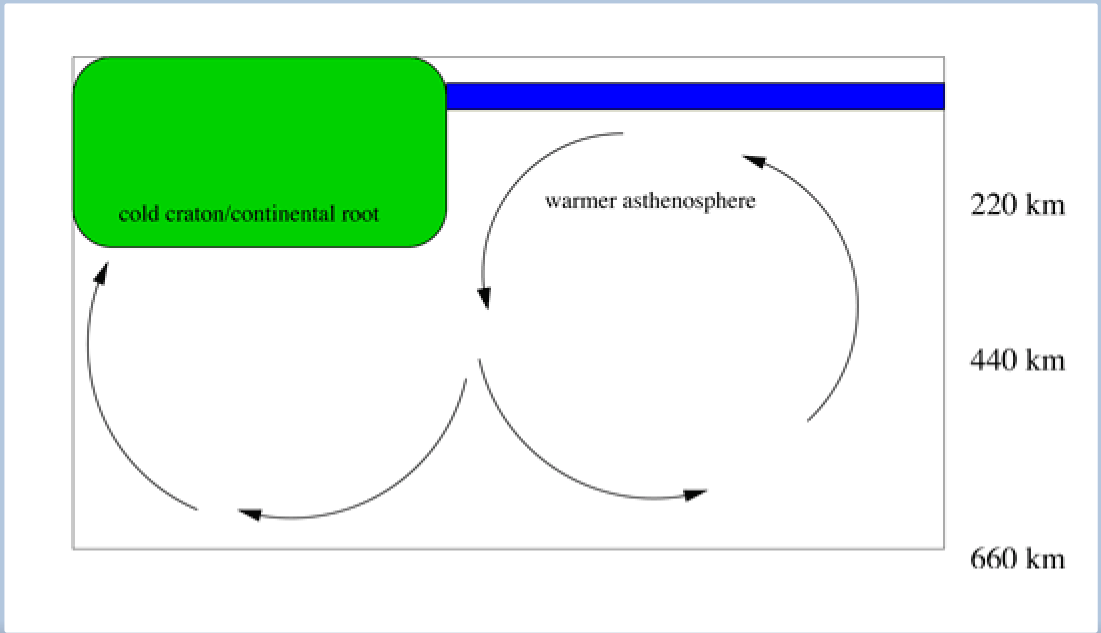
Coblentz et al. 2011

As a consequence, Colorado Plateau lithosphere thicker than surrounding extending provinces

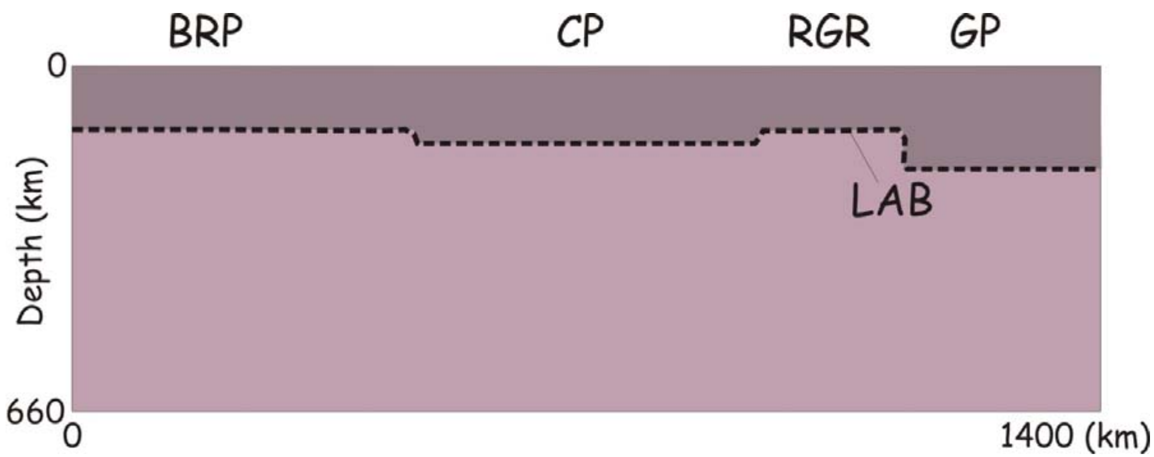


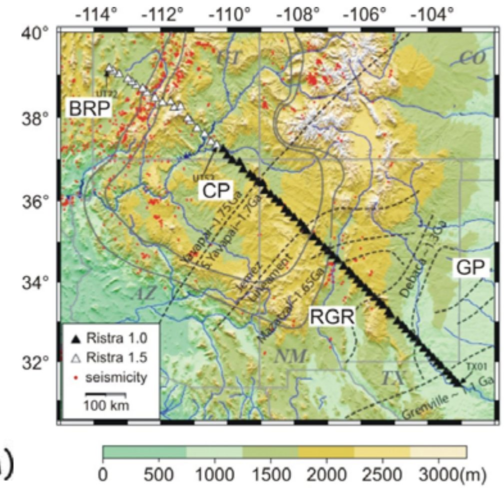
Coblentz et al. 2011

- BRP and RGR lithosphere thinned
- Step in LAB between CP and surrounding extended provinces
- May induce edge-driven convection and form downwellings
- Could downwellings be fast velocity structures?
- Could upwellings explain low velocity below CP edge?



King and Andersen, 2008

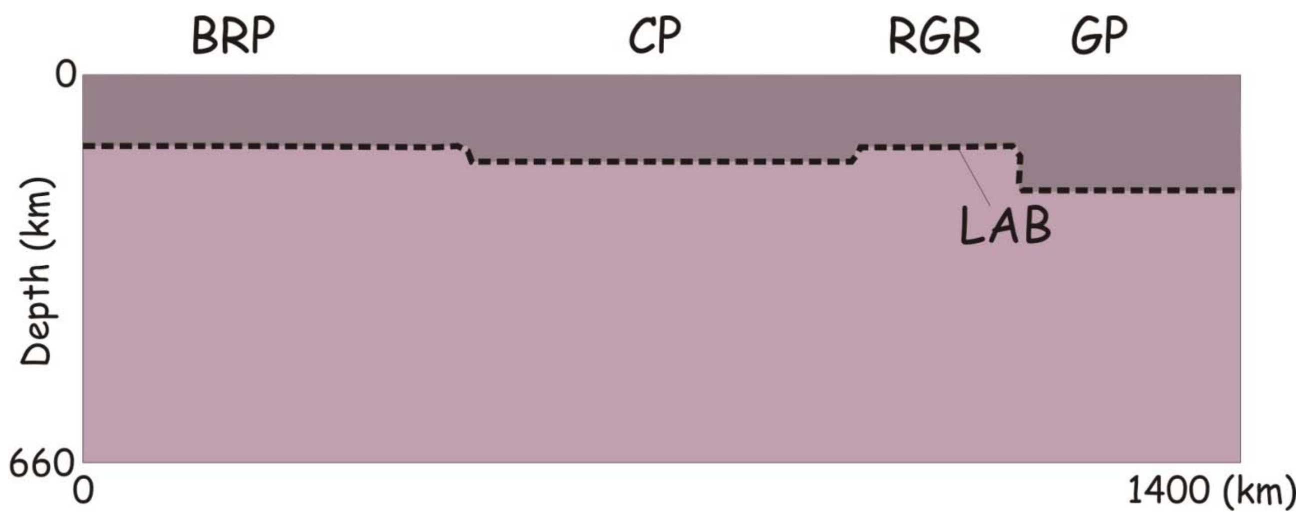


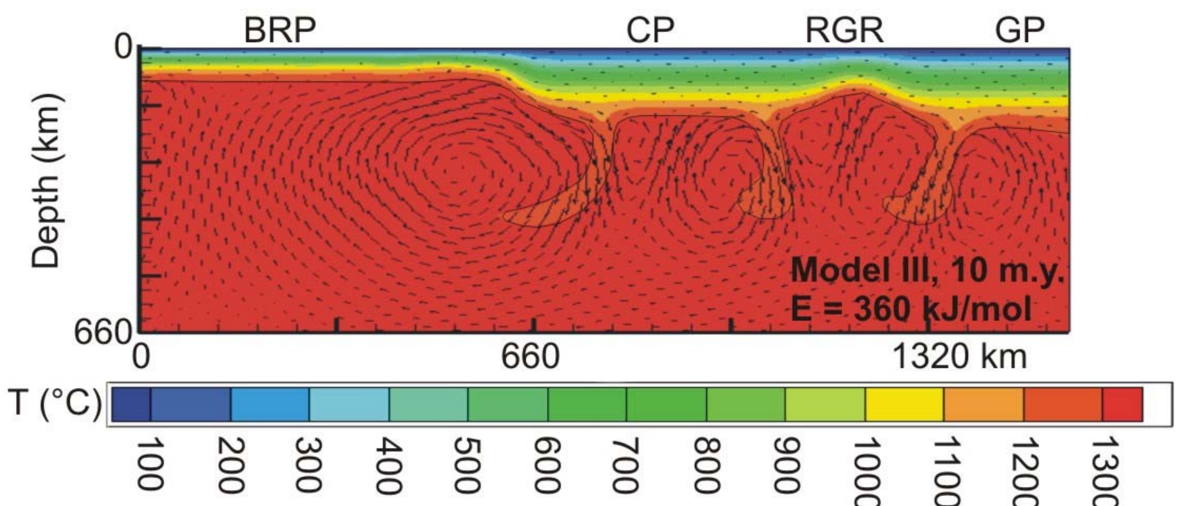


•CitCom finite element code (www.geodynamics.org)

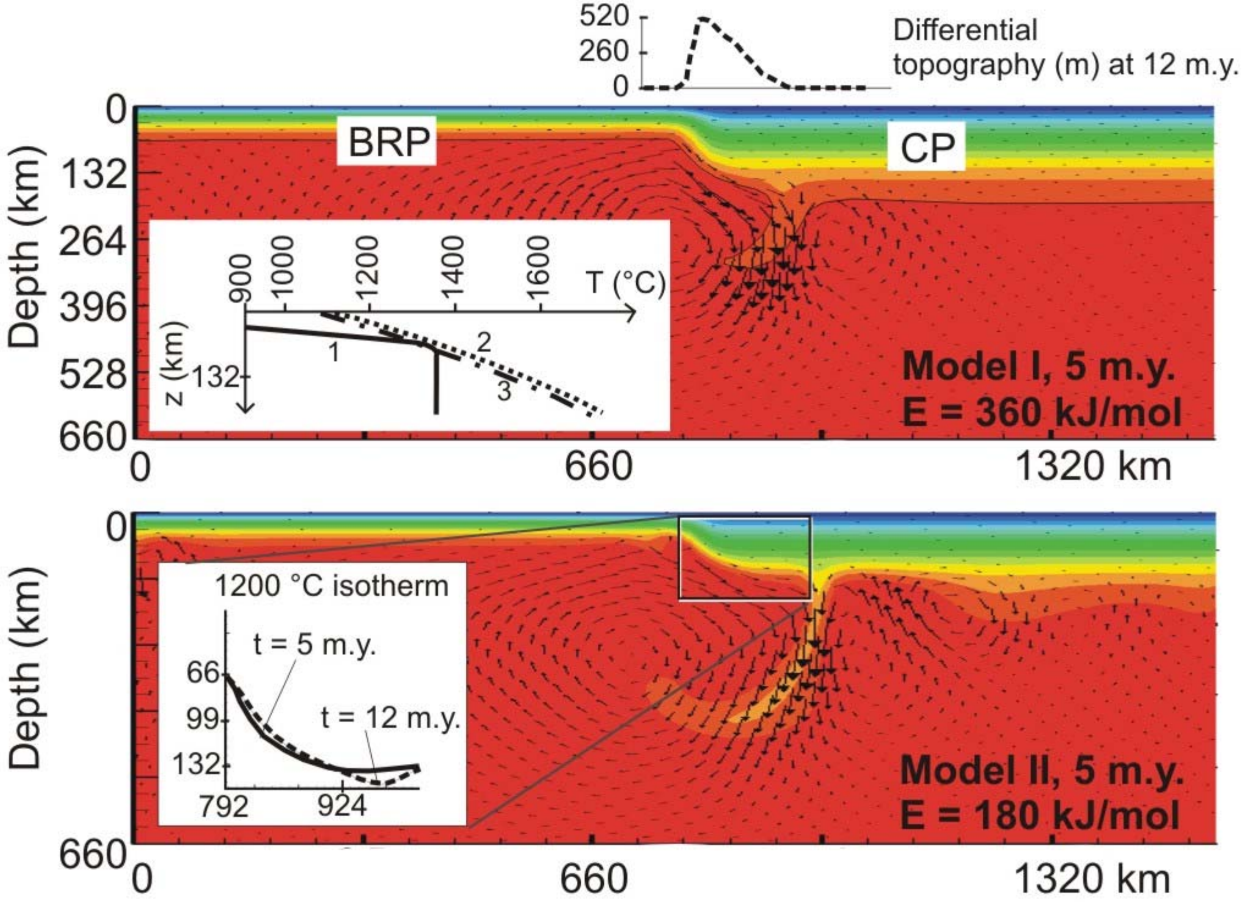
•Conservation of mass, momentum, thermal energy, incompressible fluid, Boussinesq approximations (with adiabatic heating/cooling)

•Model starts ~12 Ma



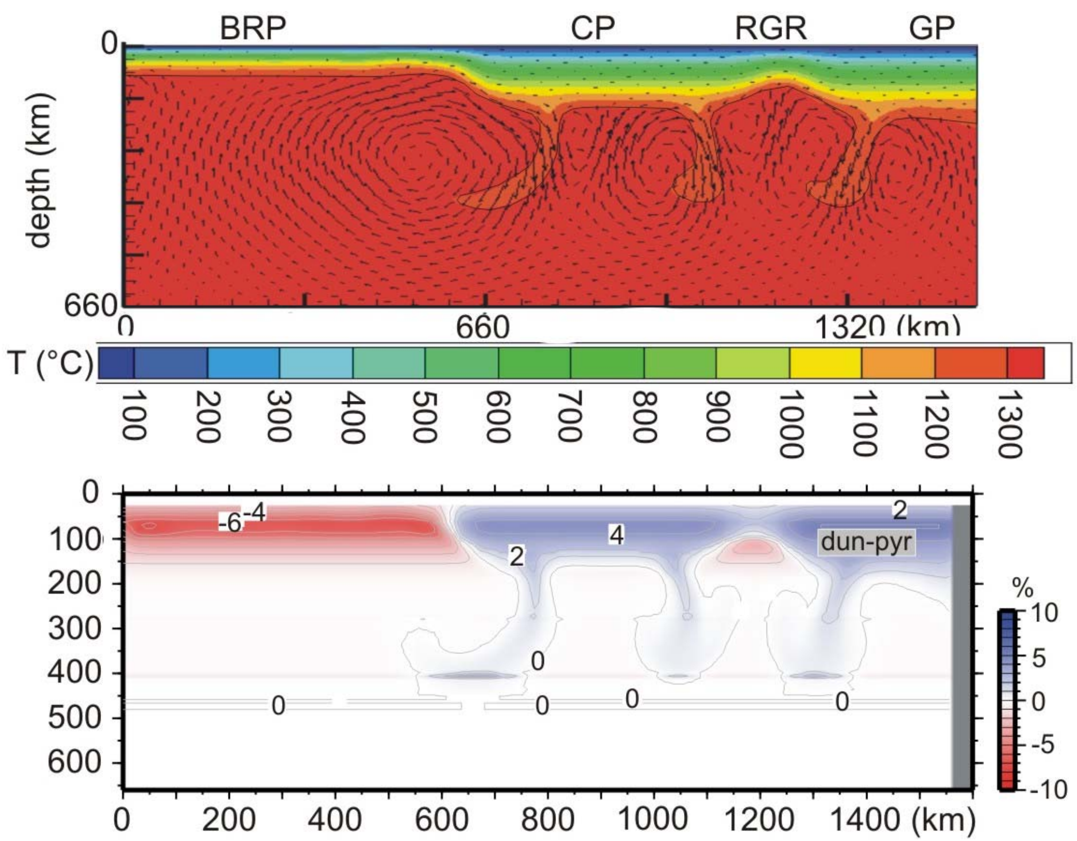


Van Wijk et al. 2010



Van Wijk et al. 2010

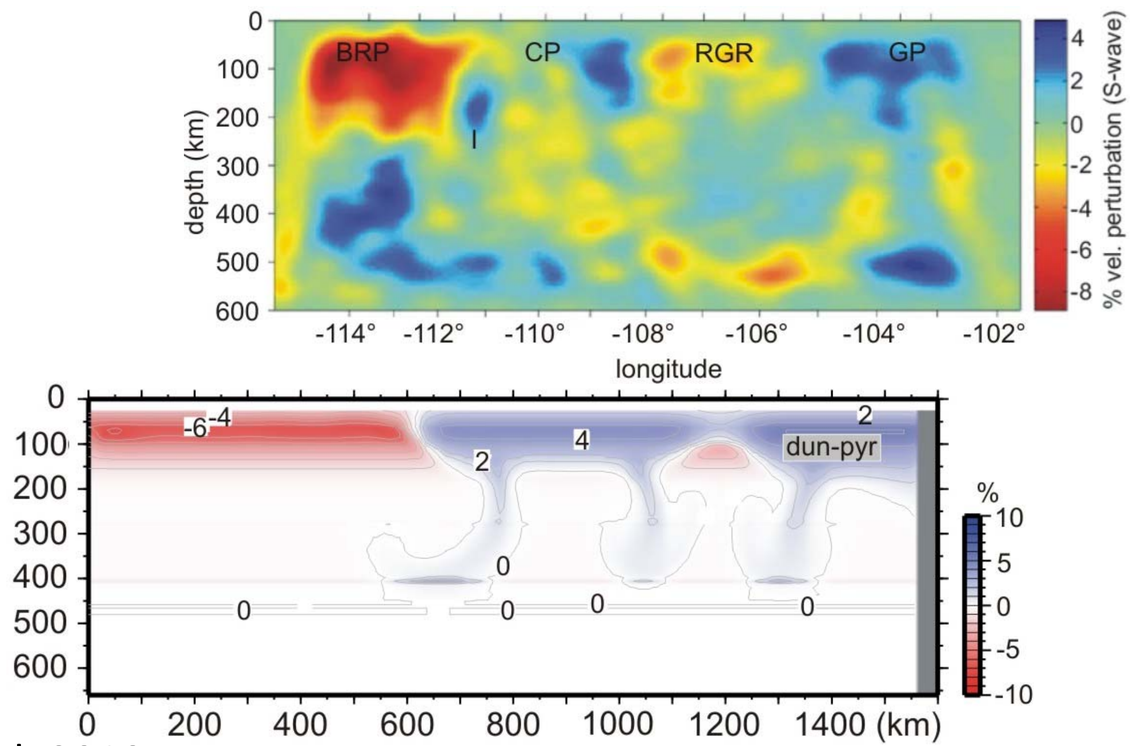
Seismic wave velocities are predicted from model temperatures including elastic and anelastic effects and variations of mineral phase composition with pressure and temperature



Van Wijk et al. 2010

If these are downwellings:

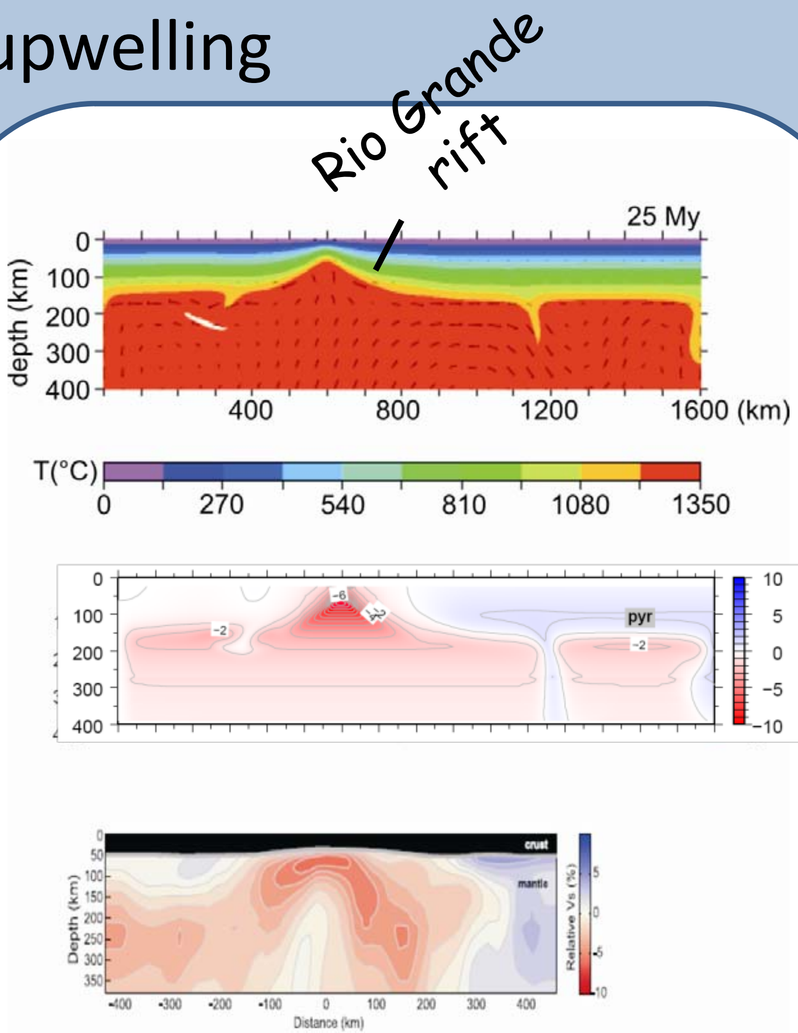
- Vs and Vp contrast between CP and BRP similar in magnitude to imaged
- Amplitude of downwellings slightly smaller than imaged
- Composition changes absolute velocities but not anomalies
- Additional contribution due to melt in BRP likely required

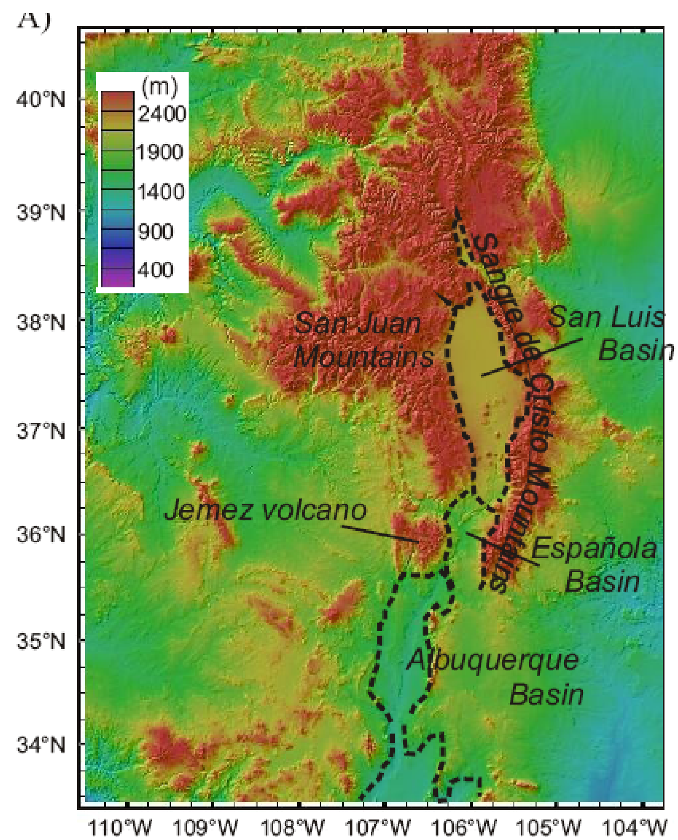


Van Wijk et al. 2010

Model predictions:

- Narrow crustal basins underlain by wide mantle upwelling

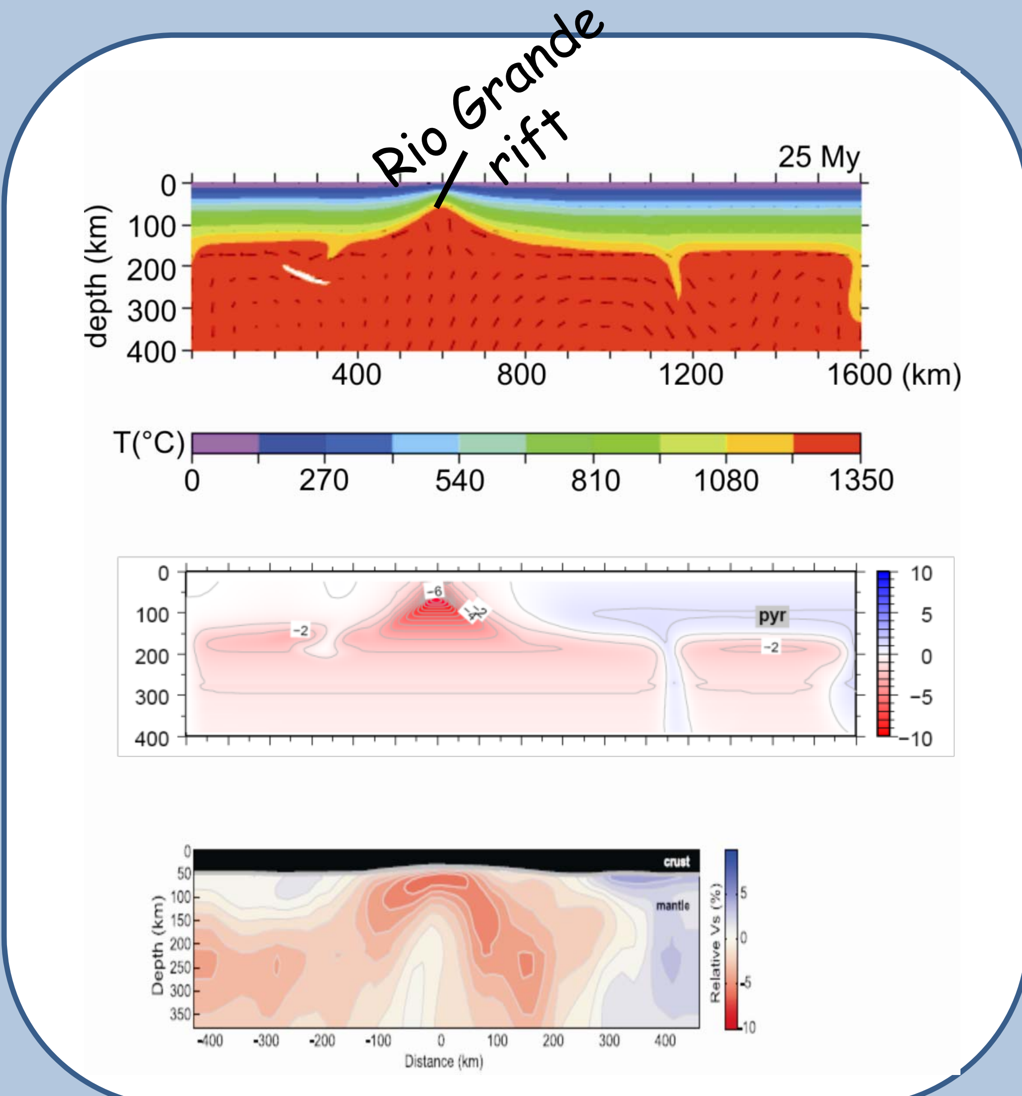




van Wijk et al., Geology 2008

Model predictions:

•Low velocities below Rio Grande Rift



predicted temperature structure

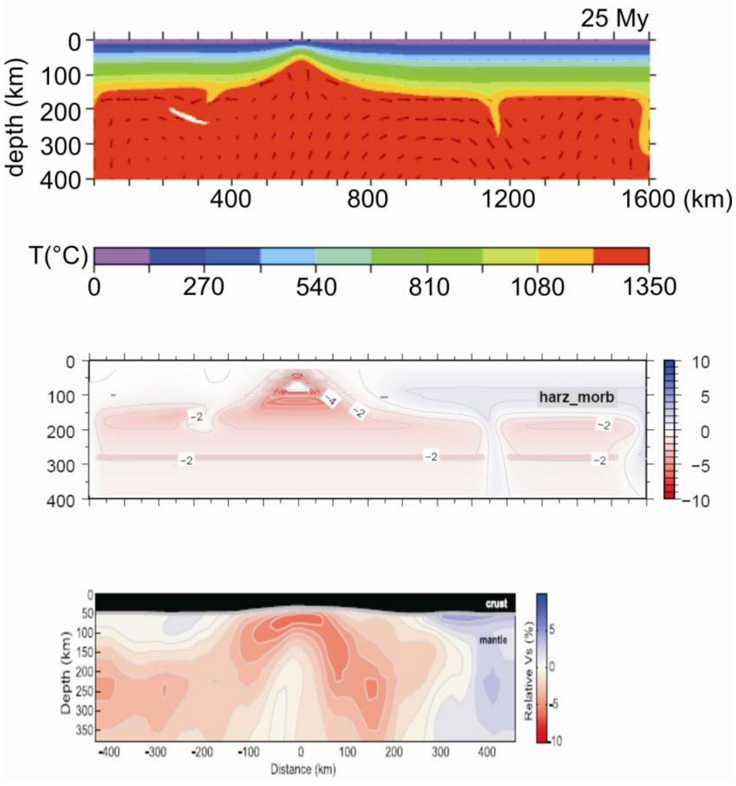
predicted S-wave anomaly (pyrolite composition)

La RISTRA tomography (West et al.,2004)

van Wijk et al., Geology 2008

Model predictions:

- Low velocities below Rio Grande Rift



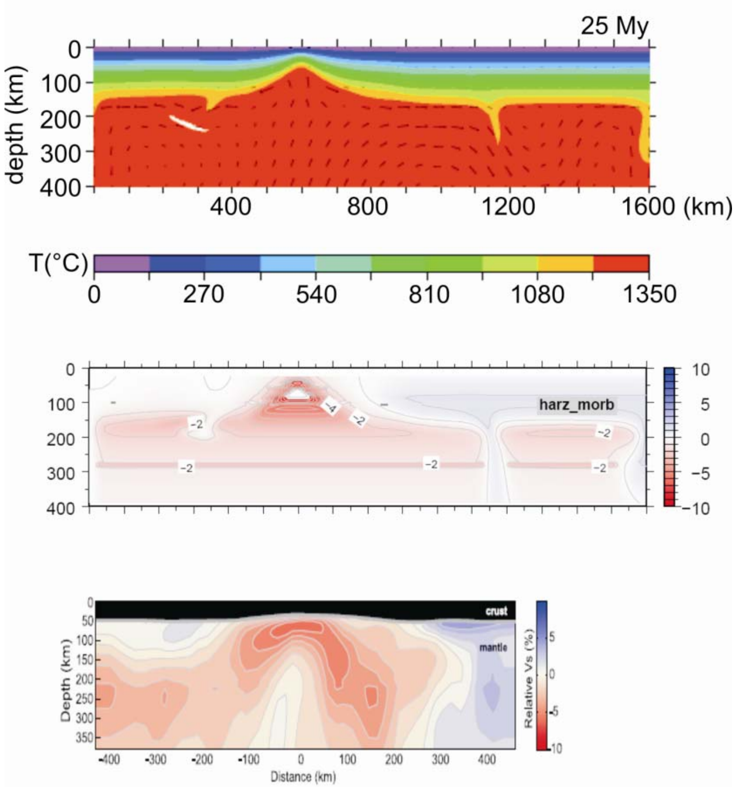
Amplitude and size are similar

This anomaly can be explained thermally, even though the total amount of extension is small and extension rates have been low

What can explain the ‘crescent’ shape?

Model predictions:

•Low velocities below Rio Grande Rift



Crescent-shape defined by faster upward velocity perturbation

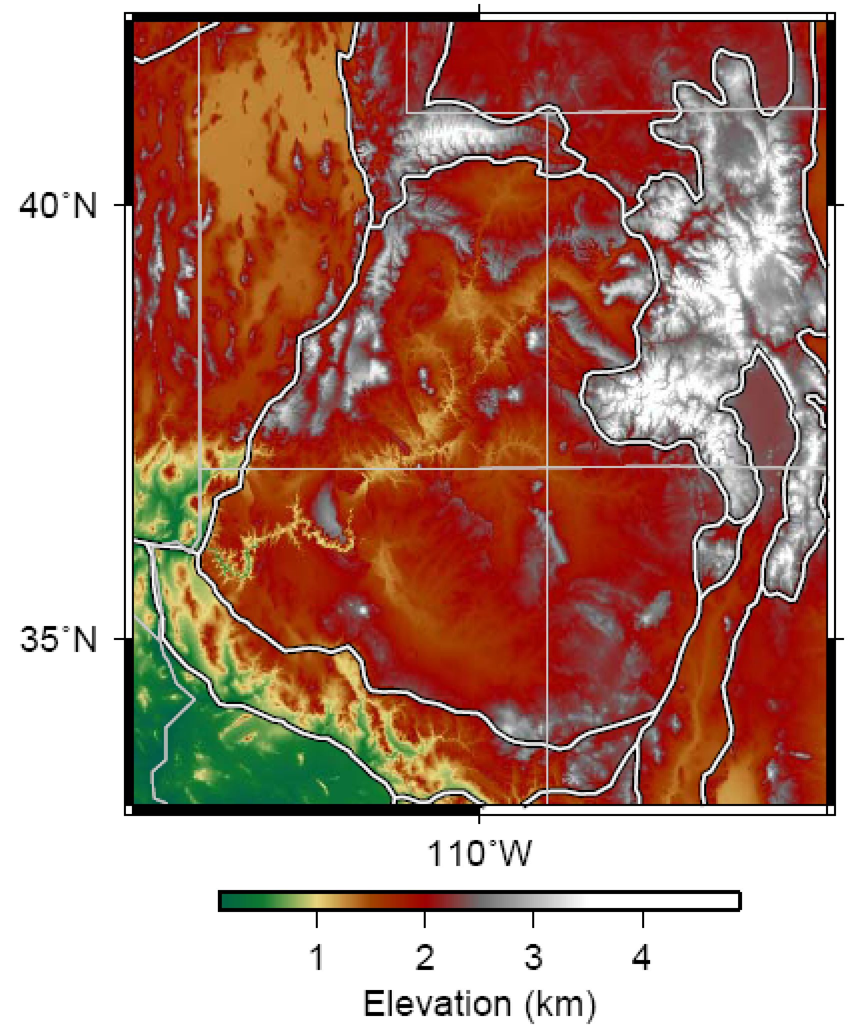
Does not correspond to any modeled velocity structure

Below the depth where melting starts

Eclogite dragged up by the flow?

Model predictions:

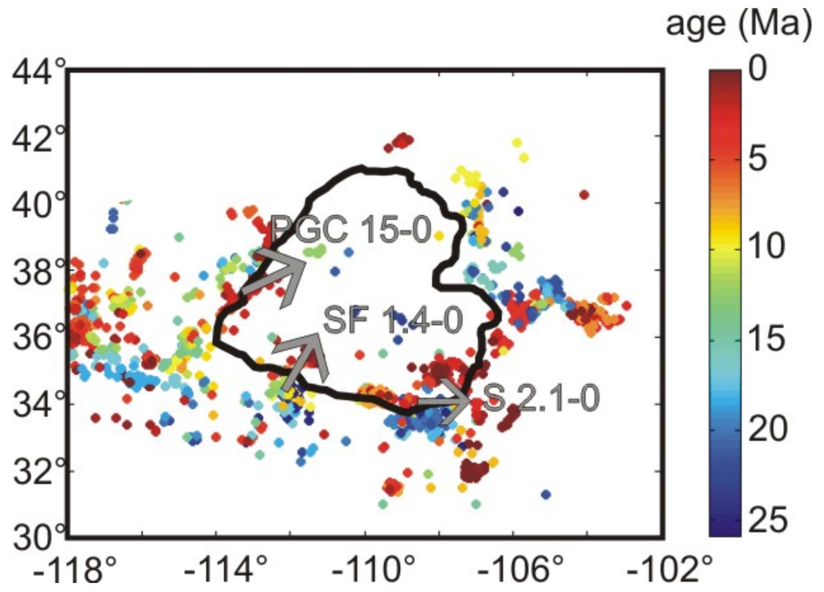
•Uplift of Colorado Plateau edge



Coblentz et al. 2011

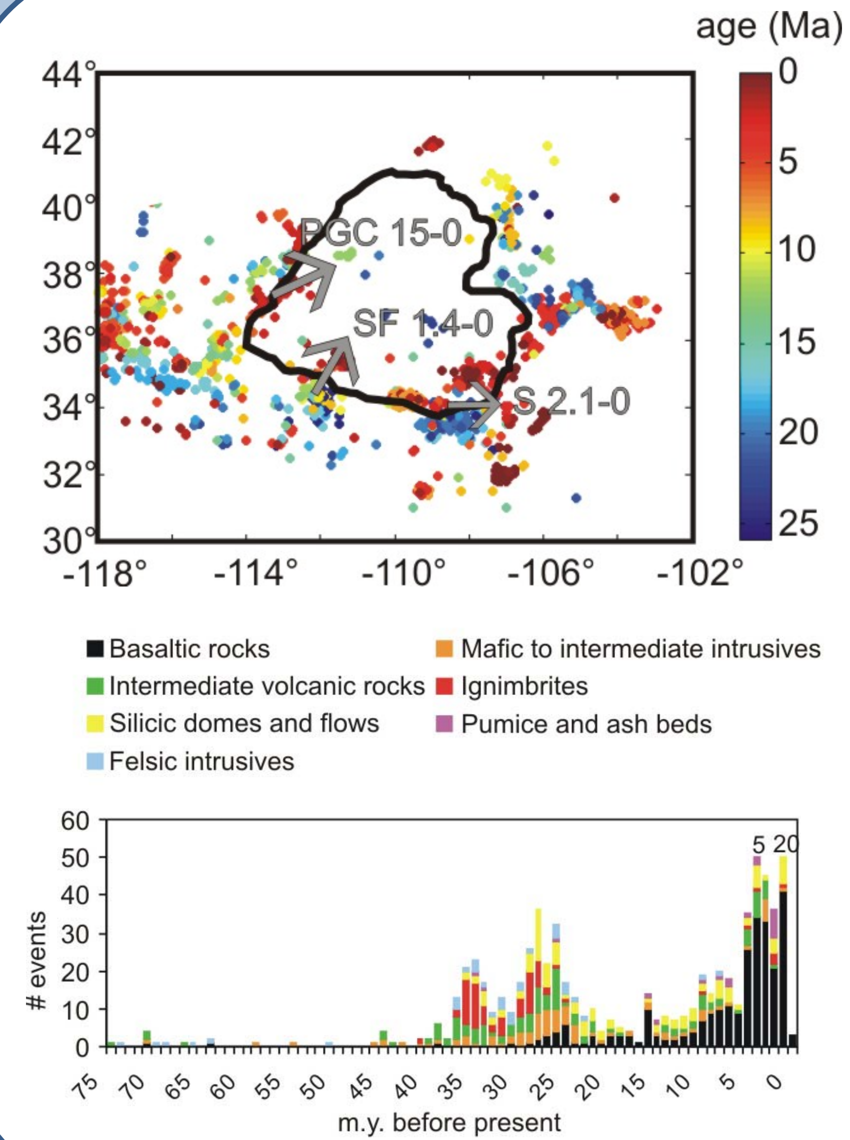
Model predictions:

•Uplift of Colorado Plateau edge
•Magmatism at Colorado Plateau edge



Model predictions:

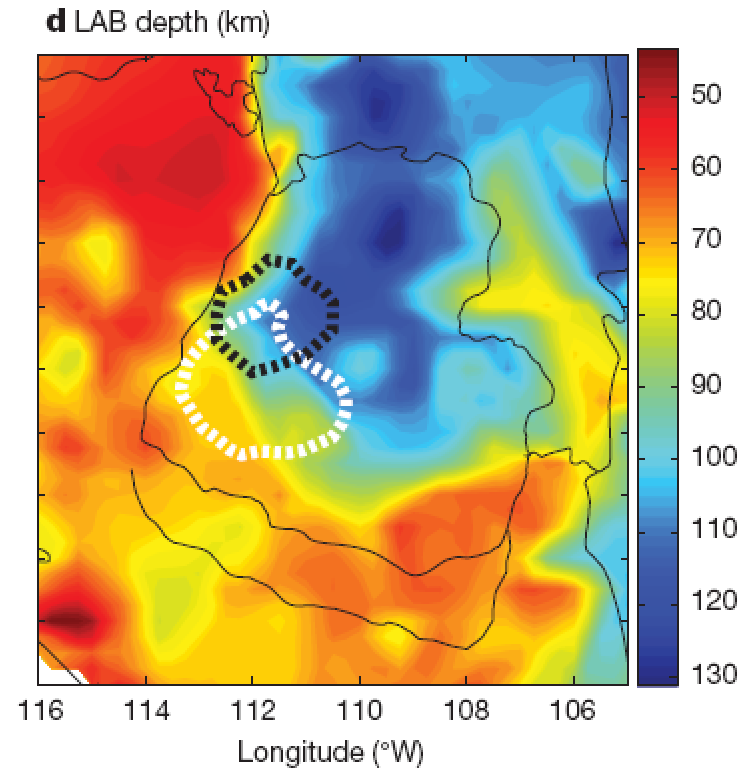
- Uplift of Colorado Plateau edge
- Magmatism at Colorado Plateau edge
- Late Neogene-recent pulse of magmatism (that was preceded by a period of relative quiescence following the middle Cenozoic pulse)



Van Wijk et al. 2010

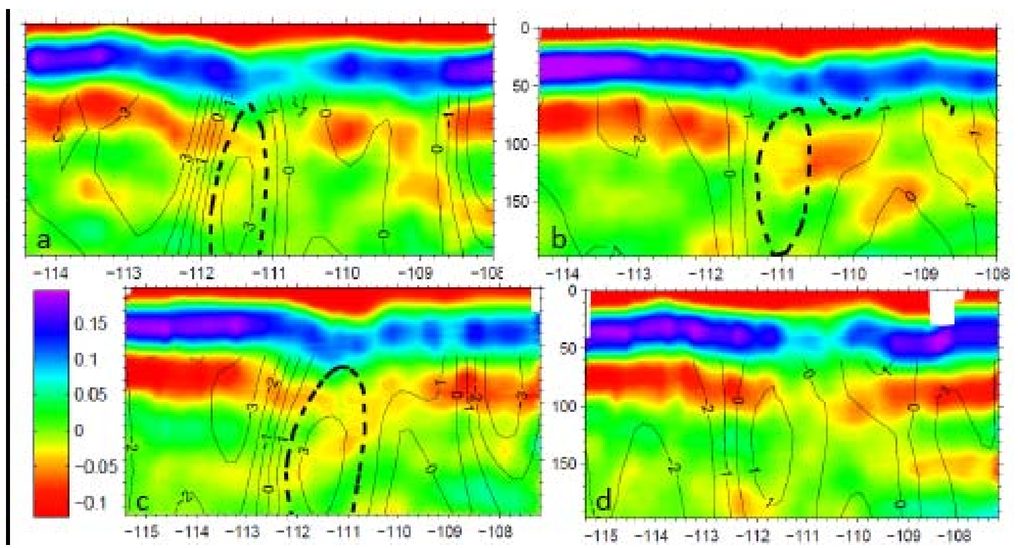
Model predictions:

- Uplift of Colorado Plateau edge
- Magmatism at Colorado Plateau edge
- Thinning of Colorado Plateau edge, BRP and RGR lithosphere



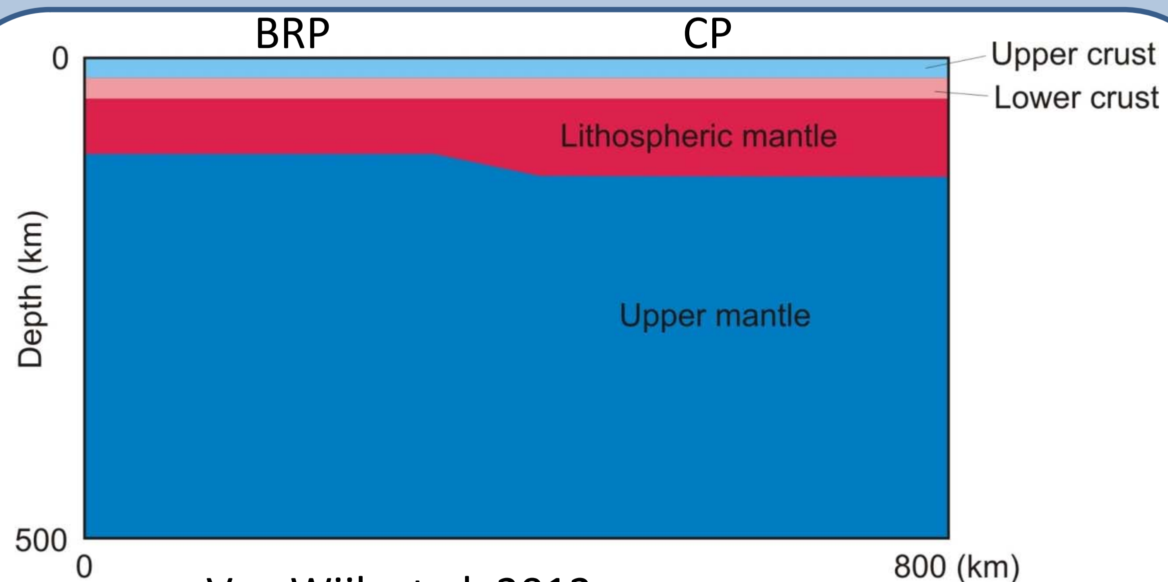
Levander et al. (2011)

• Weak/discontinuous Moho and LAB?



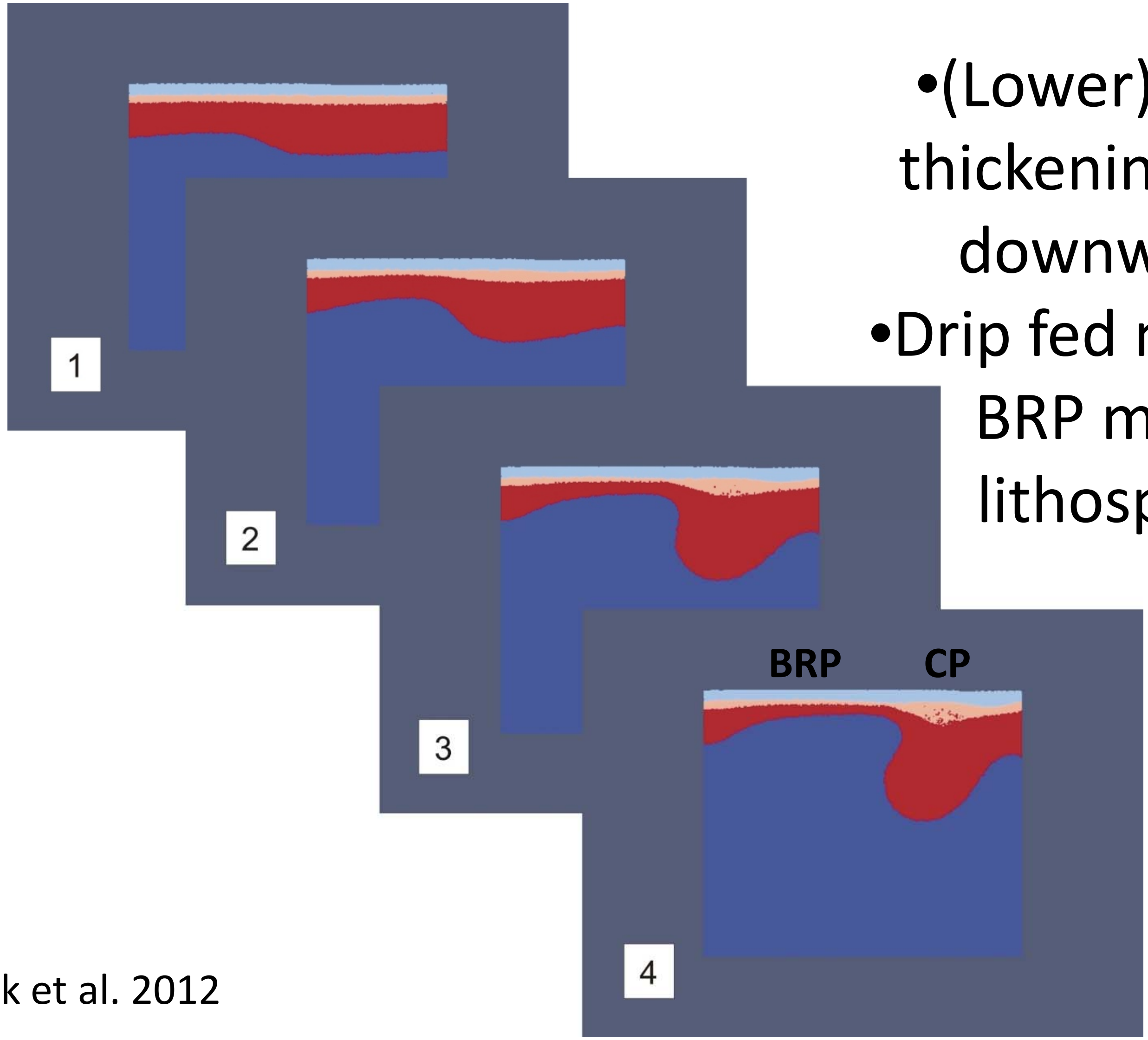
How does the lithosphere deform above a downwelling?

- Gale (www.geodynamics.org)
- Layered lithosphere
- Visco-plastic rheology



Van Wijk et al. 2012

Material

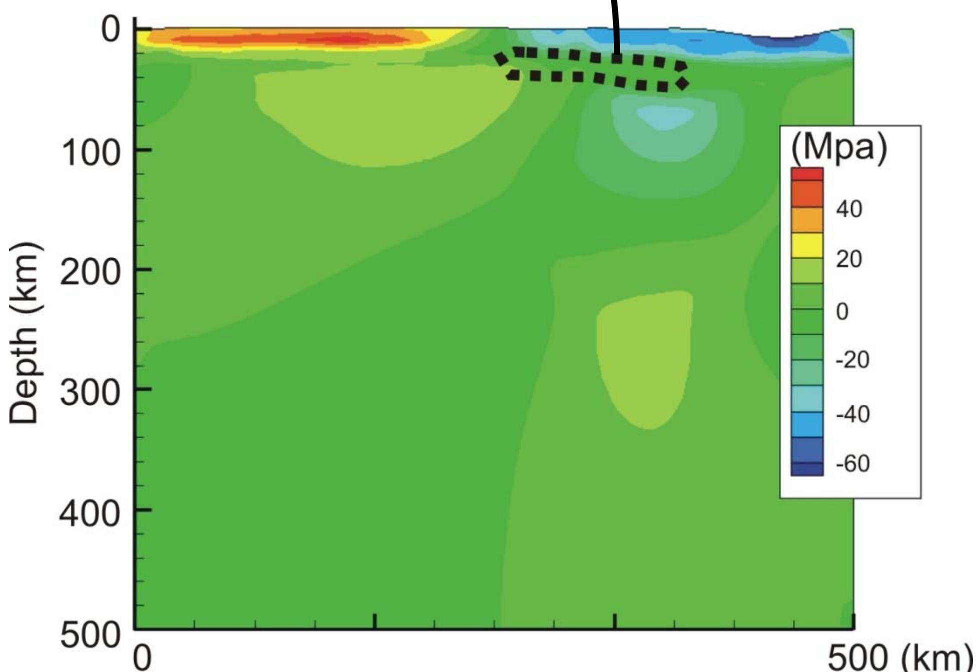


- (Lower) crustal thickening above downwelling
- Drip fed mainly by BRP mantle lithosphere

Van Wijk et al. 2012

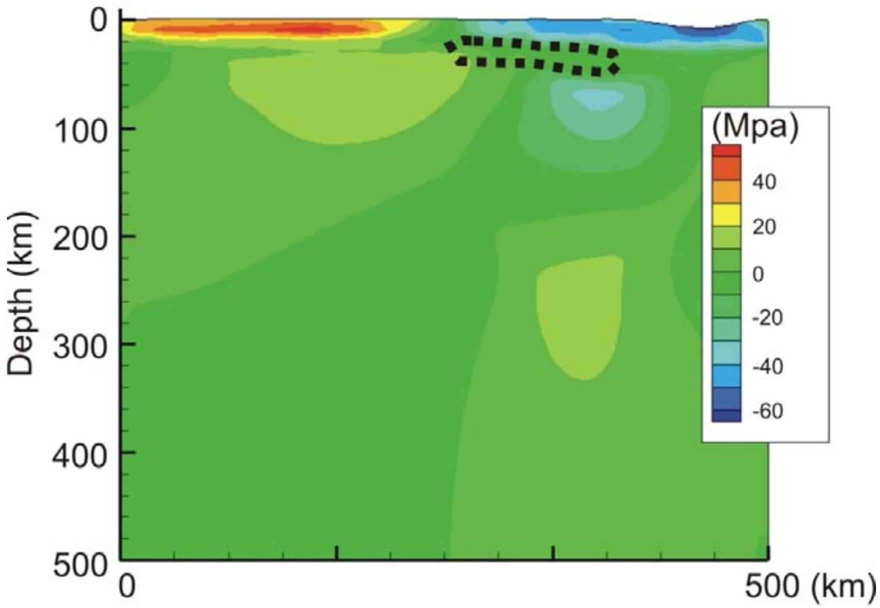
Stresses: upper crust under compression above drip, under extension in Basin & Range Province

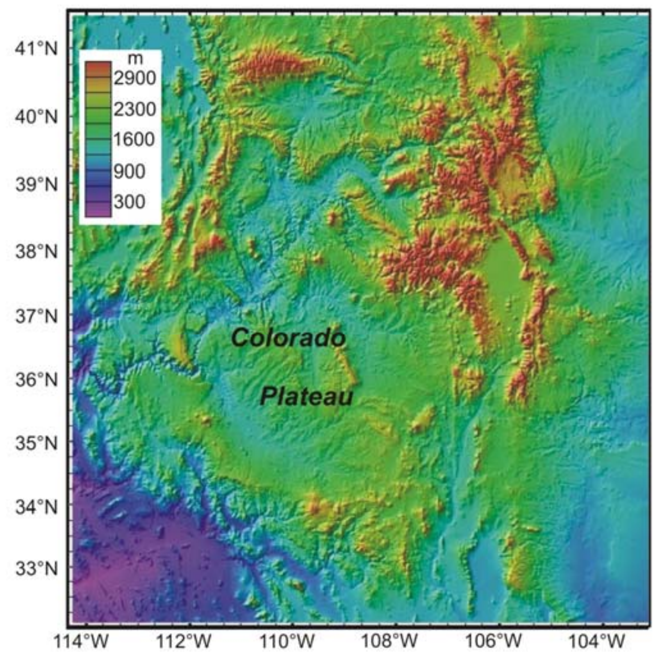
Strain rates: high values



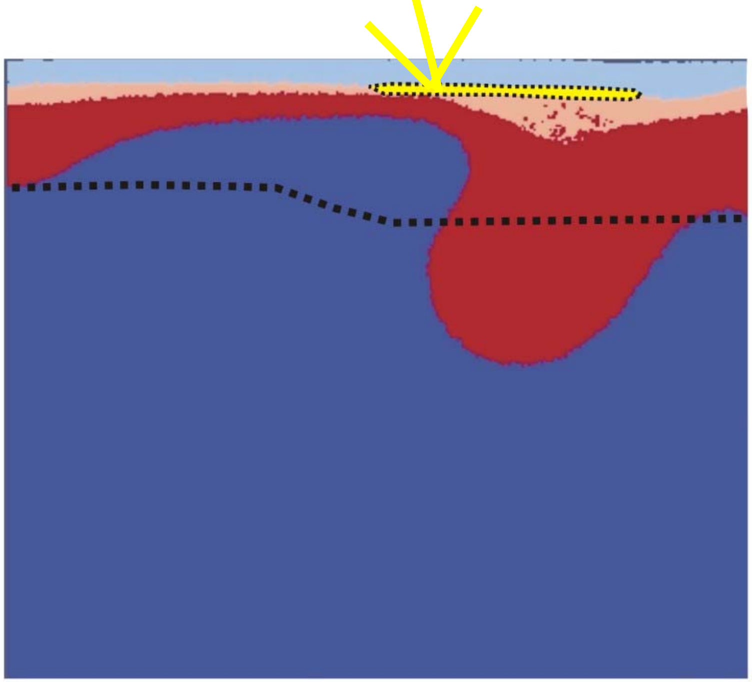
Van Wijk et al. 2012

Uplift/subsidence of surface:



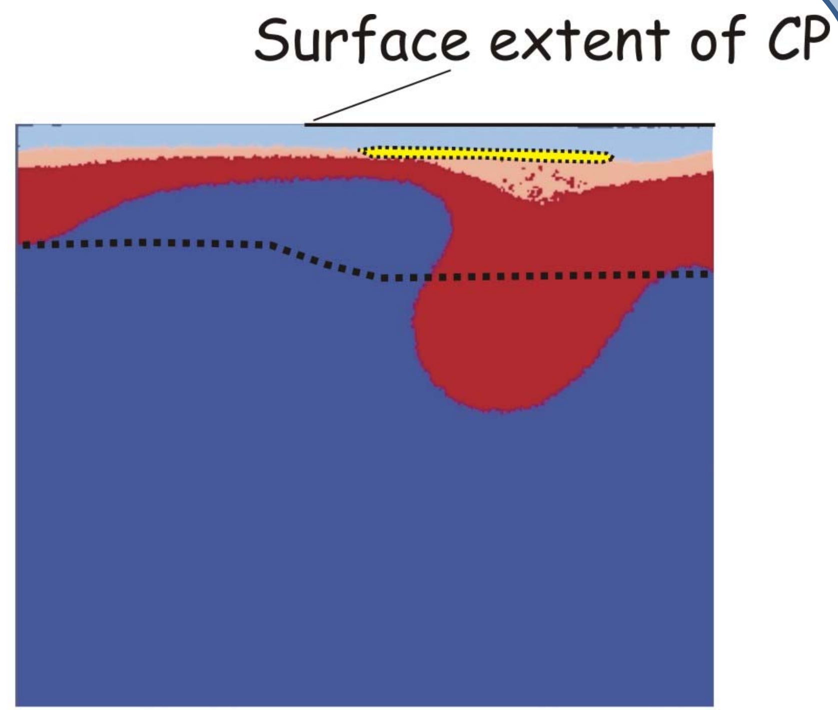


- Yielding in crust: detachment ?



Downwelling ⟶ detachment?

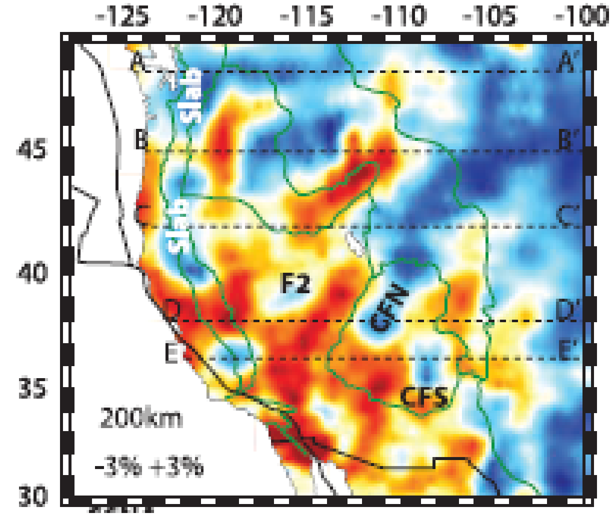
High strain rate & yielding indicate that detachment in lower crust may follow downwelling

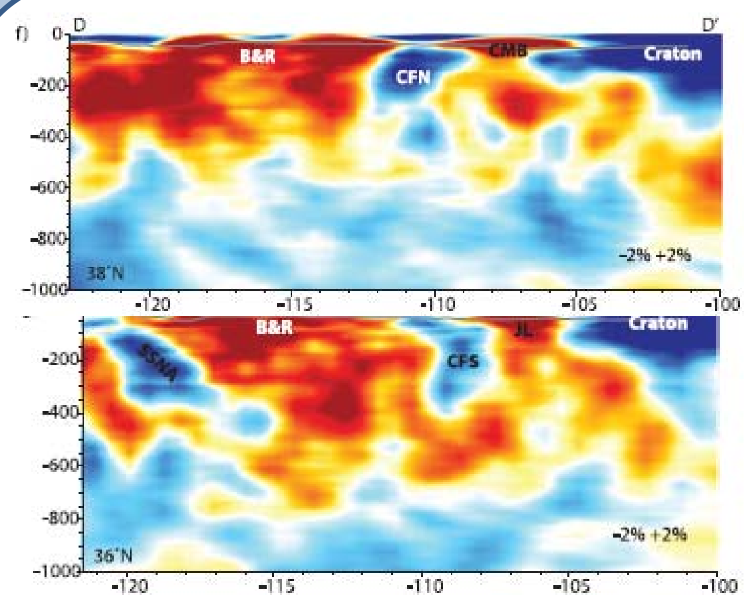


Geodynamic models: these *could* be downwellings

CP affected by Farallon slab: rehydration and metasomatism may have lowered CP viscosity (more conducive to destabilization and convection)

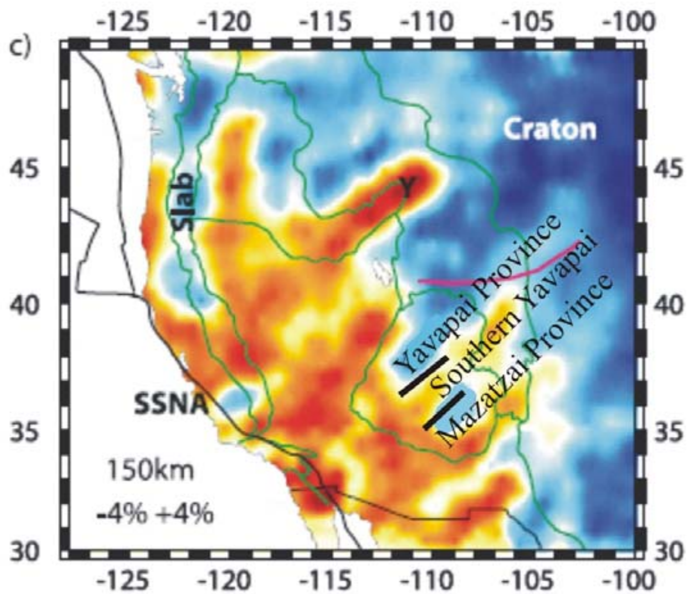
200 km depth





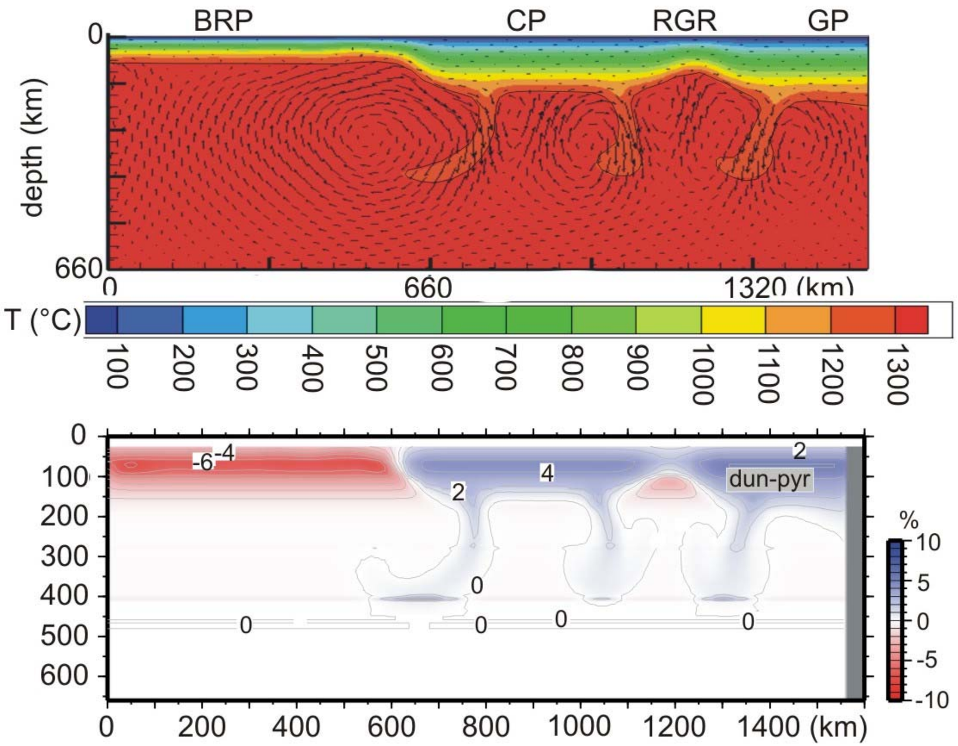
Obrebski et al., GJI 2011

- Weak/discontinuous Moho and LAB?
- Crust and mantle velocity structures correspond with Proterozoic terrane boundaries



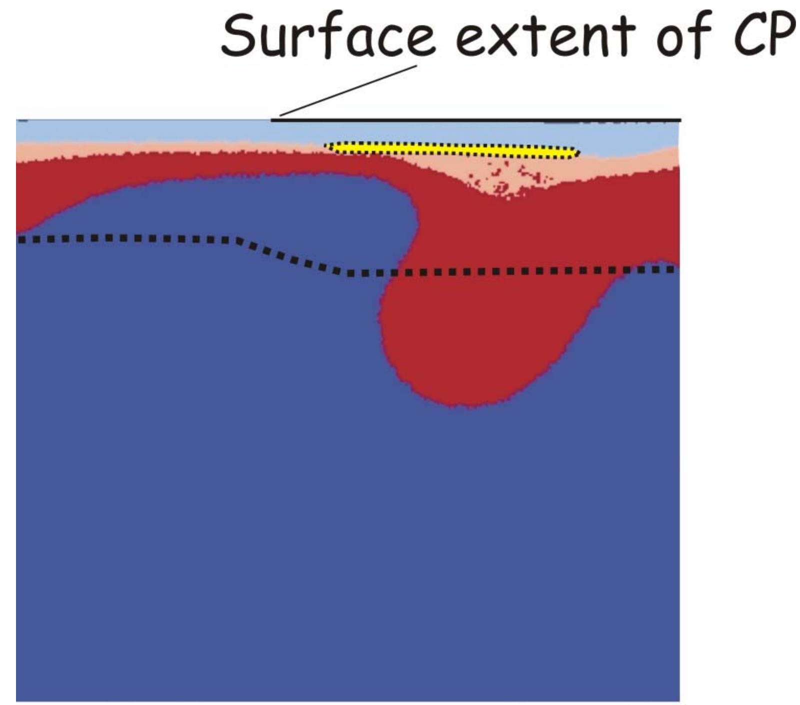
Gilbert et al., EPSL 2007

CitCom



BRP
CP
RGR
GP
depth (km)
0
660
0
660
1320 (km)
T (°C)
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300
0
100
200
300
400
500
600
-6
-4
4
2
2
0
0
0
0
0
dun-pyr
%
10
5
0
-5
-10
0 200 400 600 800 1000 1200 1400 (km)

Gale



Surface extent of CP