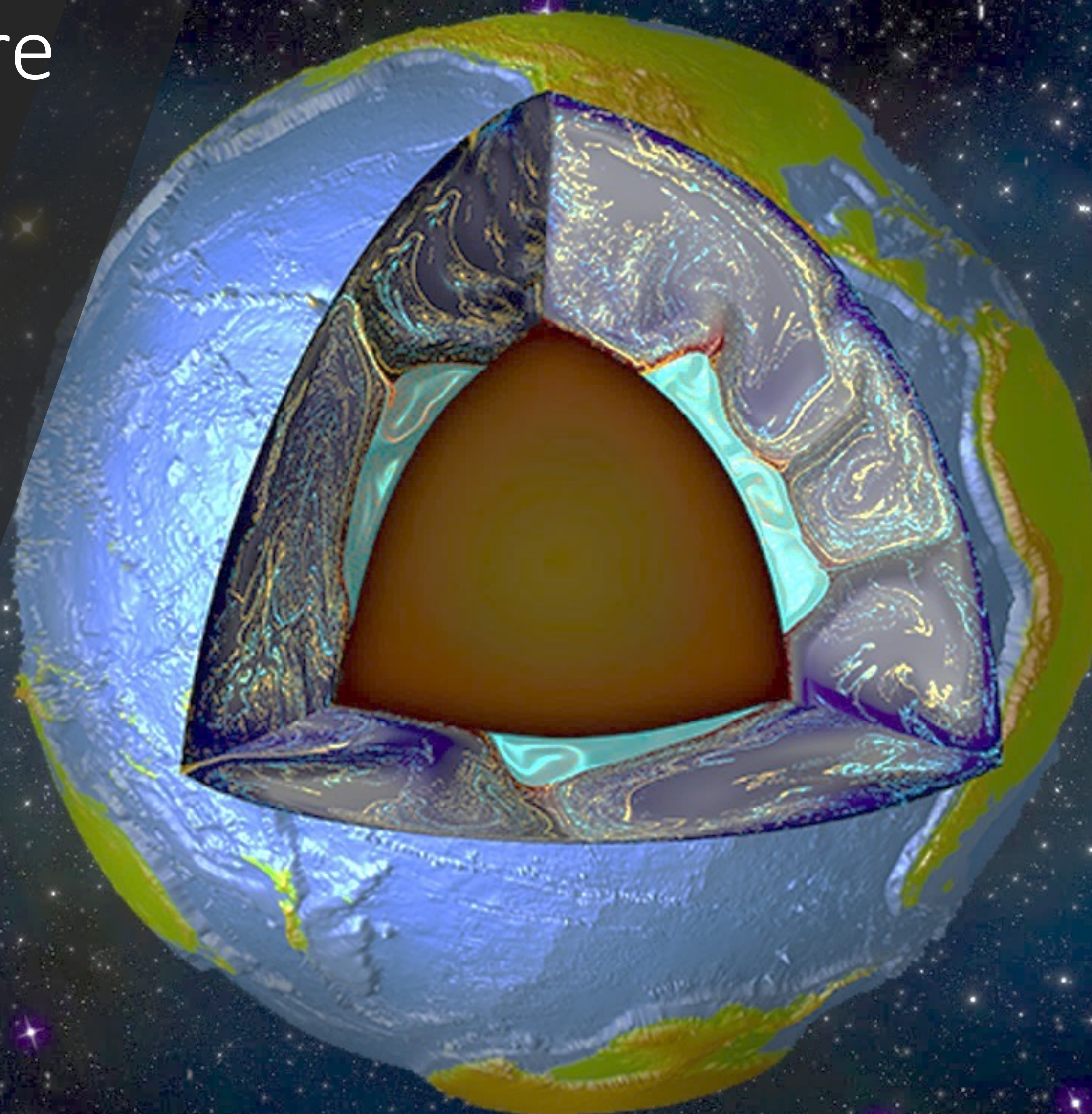
Unstable structure and dynamics in Earth's deepest mantle



Mingming Li

SESE, ASU

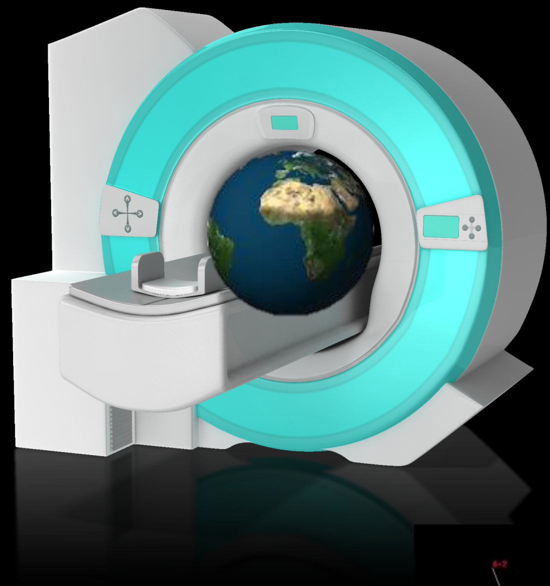
Feb 16, 2022

Geological events on Earth’s surface (plate tectonics, earthquakes, volcanoes, topography, …) are linked to its interior processes

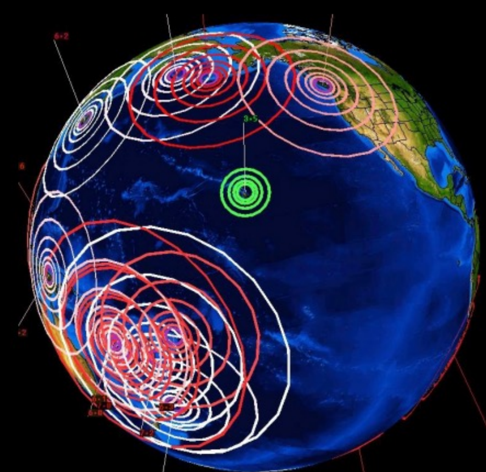
How does the interior work?

The Blue Marble by the crew of Apollo 17 (1972).
Image from Wikipedia

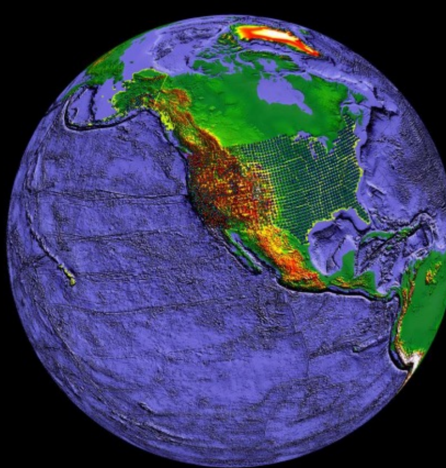
Seismic imaging allows us to ‘see’ the interior



Seismic imaging
Source: earthquakes
Receiver: Seismic stations

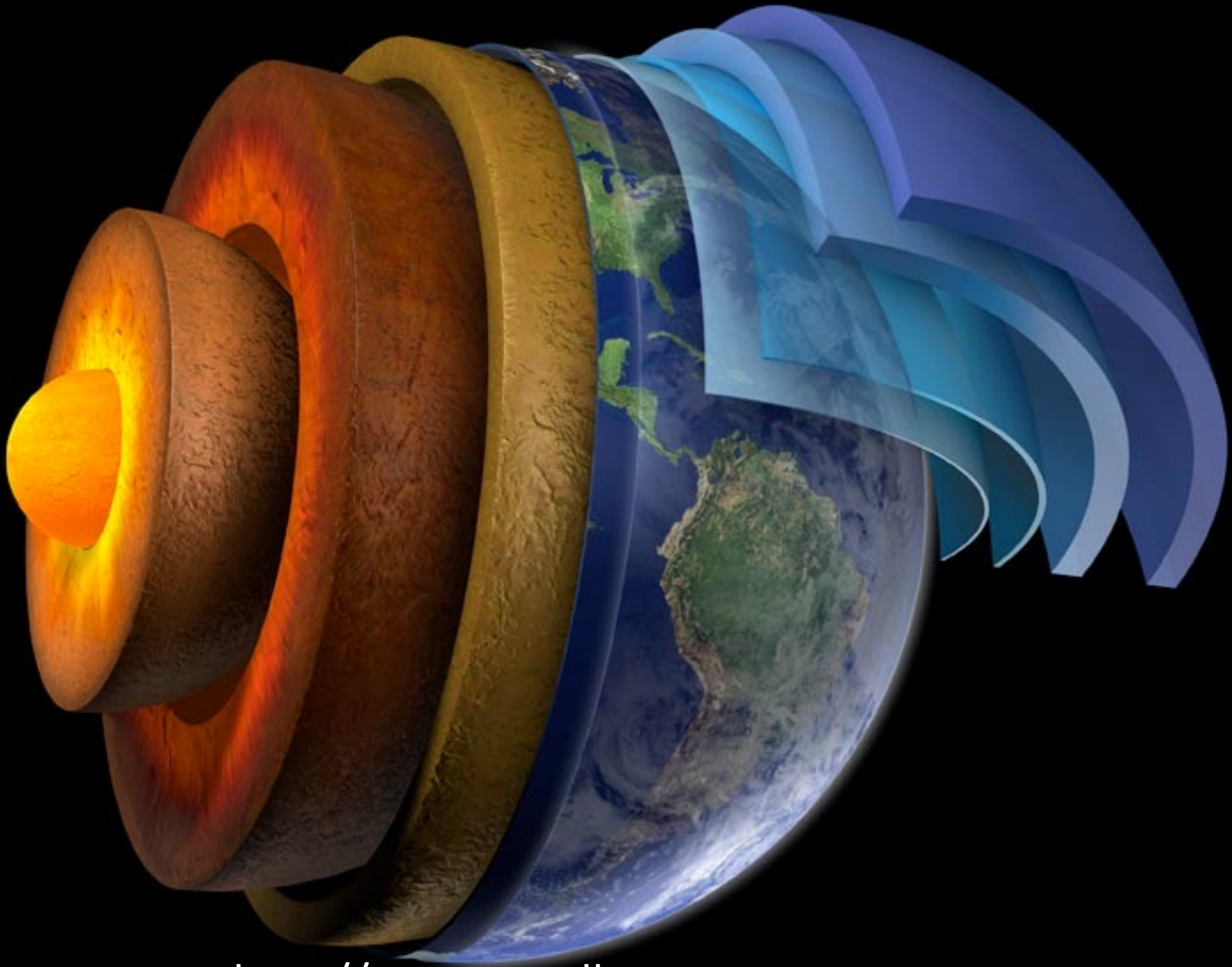


Energy source:
1000’s of earthquakes



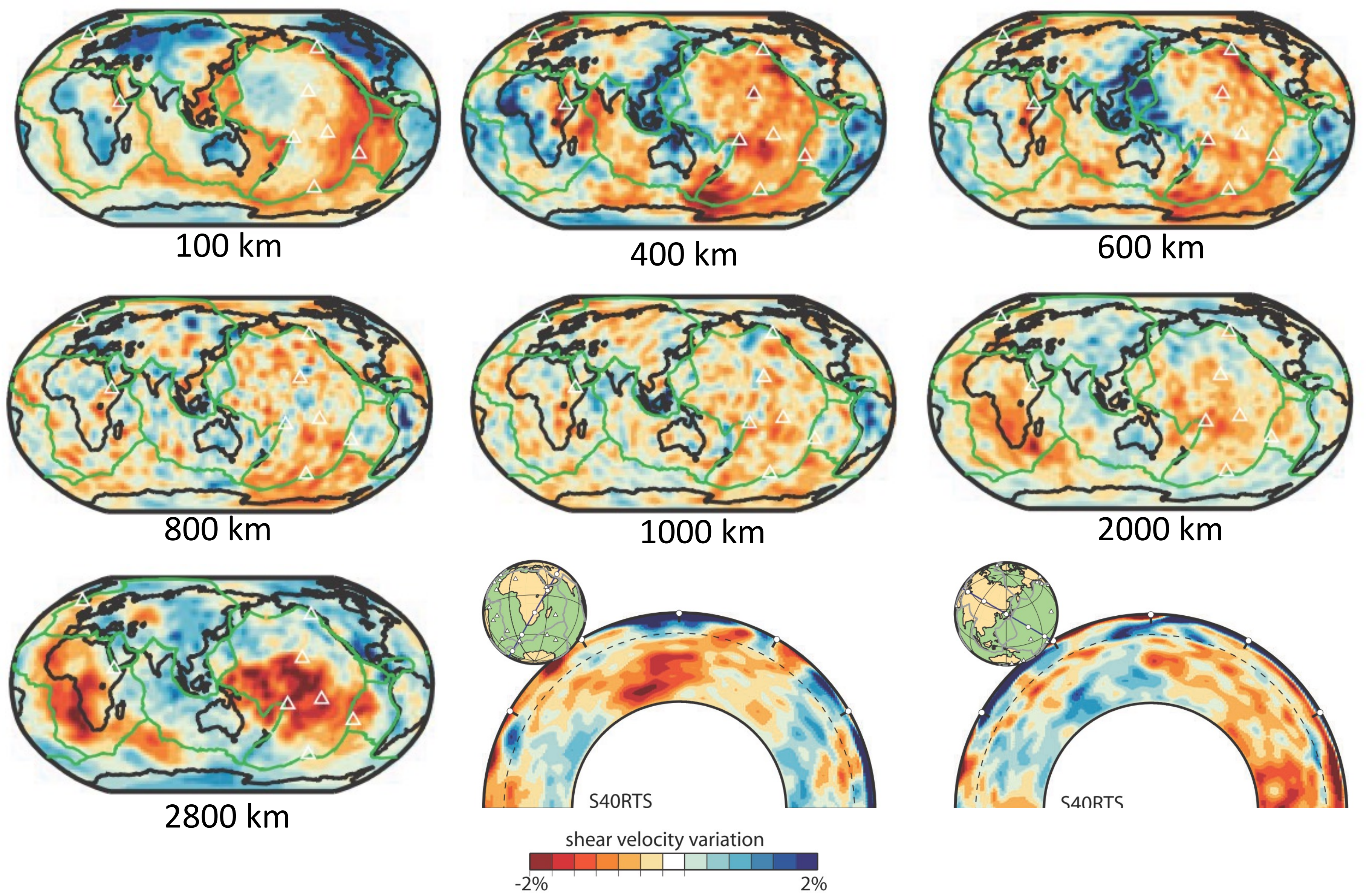
Energy recorders:
1000’s of seismic sensors

Earth is layered



http://www.canellas.com.ar

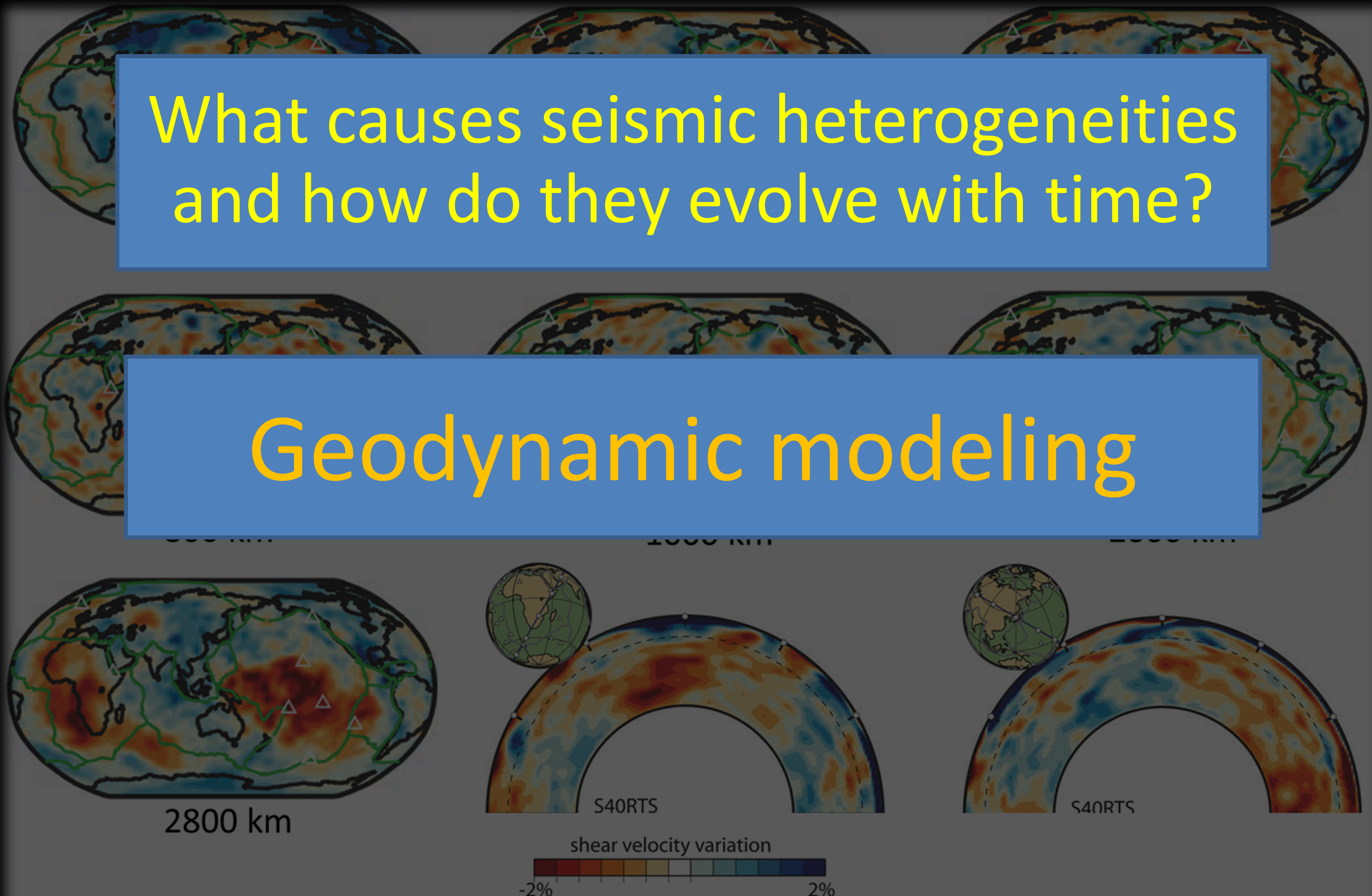
There are perturbations of physical properties in the mantle



Ritsema et al., 2011

What causes seismic heterogeneities and how do they evolve with time?

Geodynamic modeling



Ritsema et al., 2011

Geodynamics modeling

The deep physical processes are controlled by fundamental physical laws

1. Conservation of mass $\nabla \cdot \vec{u} = 0$

2. Conservation of momentum $-\nabla P + \nabla \cdot (\eta \dot{\varepsilon}) = Ra(T - BC)\hat{z}$

3. Conservation of energy $\dfrac{\partial T}{\partial t} + (\vec{u} \cdot \nabla)T = \nabla^2 T$

Parallel computing

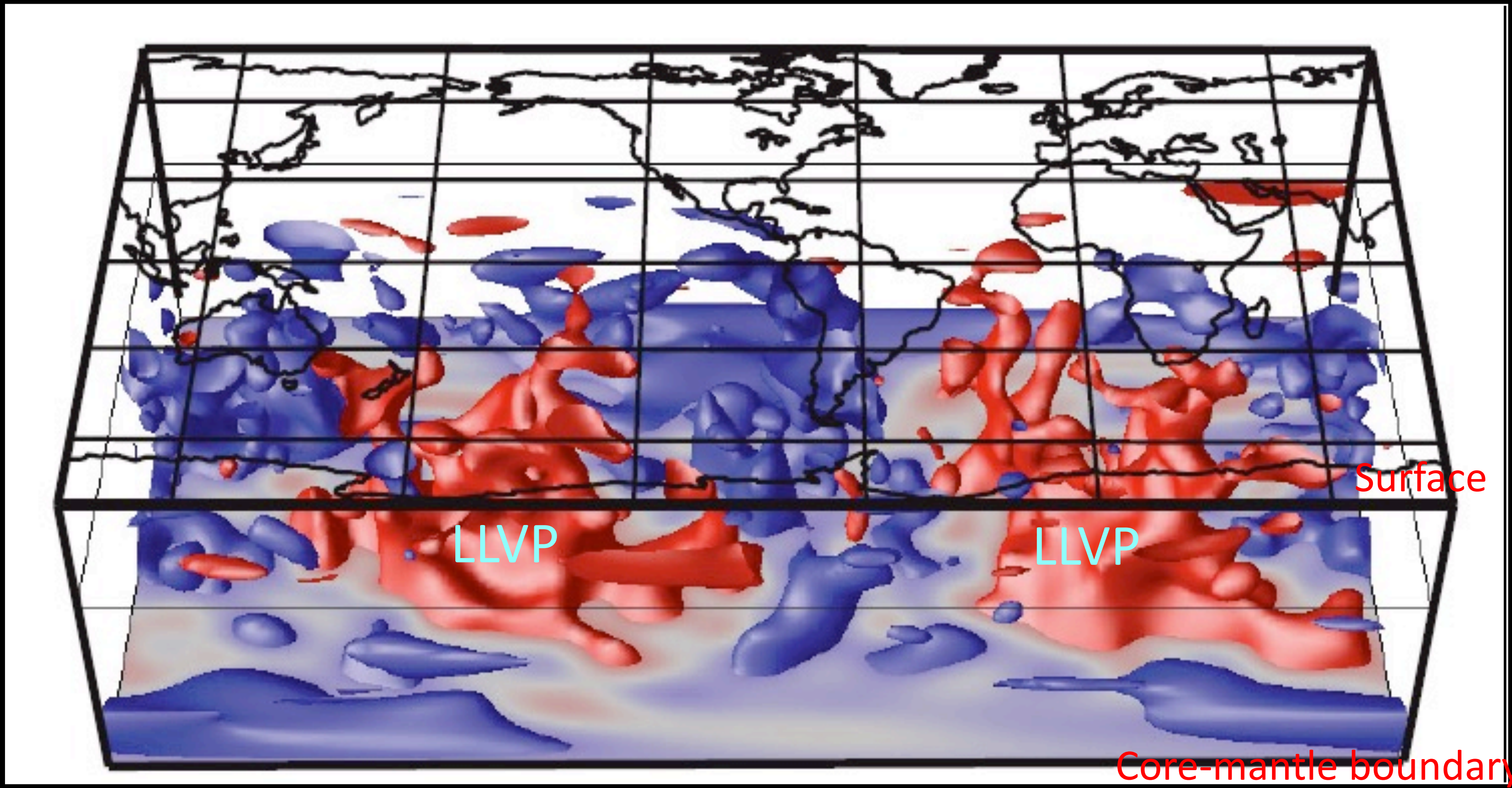
Right: ASU agave super cluster in Biodesign

Bottom: small cluster in ISTB4

Unstable structure and dynamics in Earth's deepest mantle

Qian Yuan

Large low velocity provinces (LLVPs)

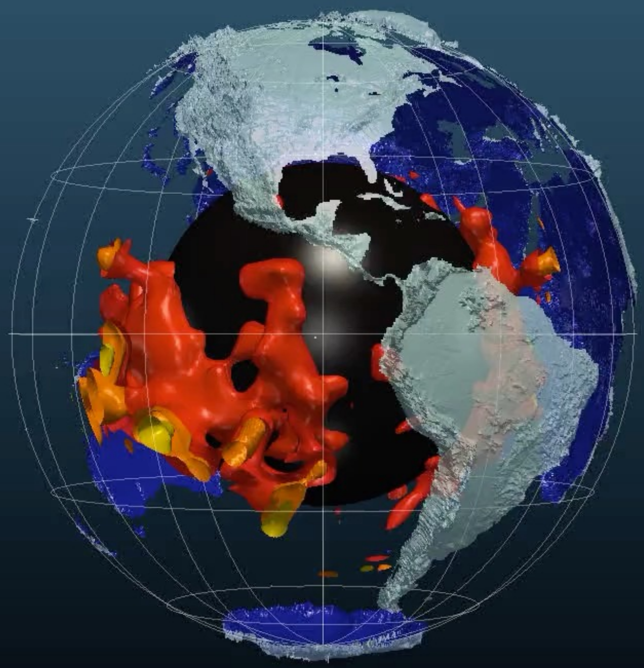


Blue = + 0.6% isosurface

Red = - 0.6% isosurface

Image from Garnero et al., 2007 based on S20RTS tomograph model (Ritsema et al., 1999)

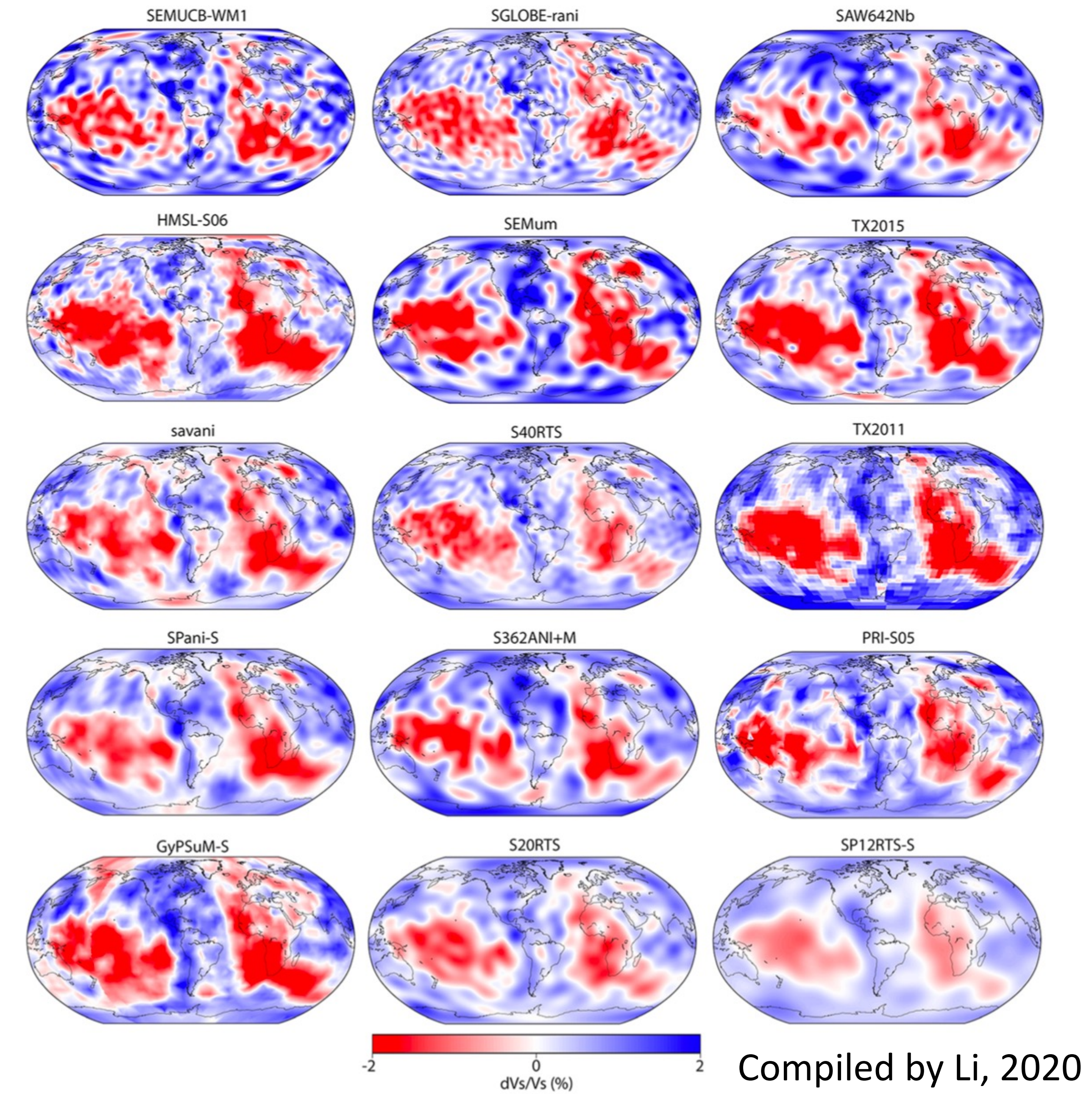
Large low velocity provinces (LLVPs)



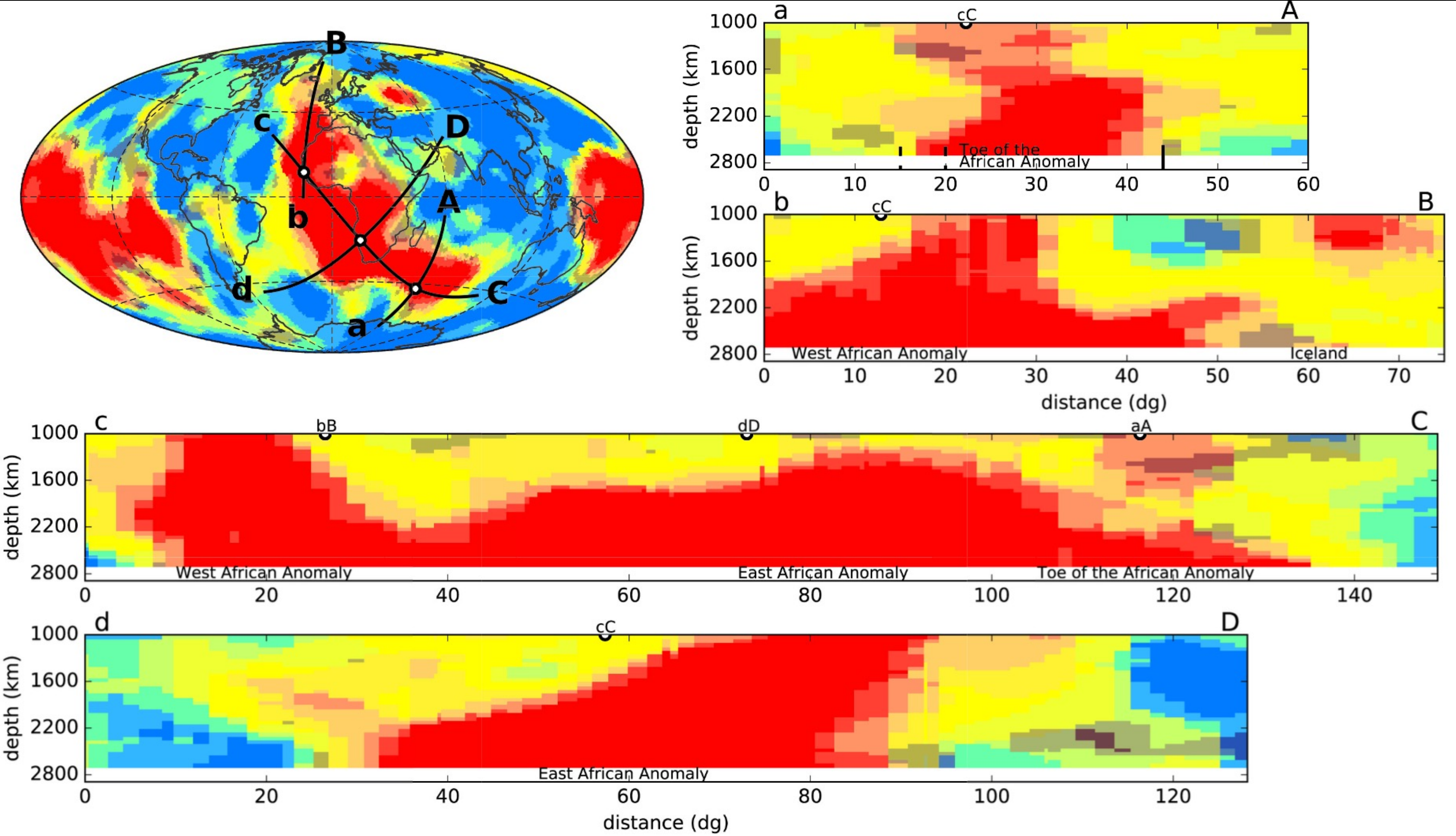
Video from Ed Garnero, SESE, ASU
Seismic tomography model from *French and Romanowicz, 2015*

LLVPs are in all seismic imaging models

SEMUCB-WM1 (French & Romanowicz, 2014), SGLOBE-rani (Chang et al., 2015), SAW642Nb (Panning et al., 2010), HMSL-S06 (Houser et al., 2008), SEMum (Lekić & Romanowicz, 2011), TX2015 (Lu & Grand, 2016), savani (Auer et al., 2014), S40RTS (Ritsema et al., 2011), TX2011 (Grand, 2002), SPani-S (Tesoniero et al., 2015), S362ANI+M (Moulik & Ekstrom, 2014), PRI-S05 (Montelli et al., 2006), GyPSuM-S (Simmons et al., 2010), S20RTS (Ritsema et al., 1999), and SP12RTS-S (Koelemeijer et al., 2016)

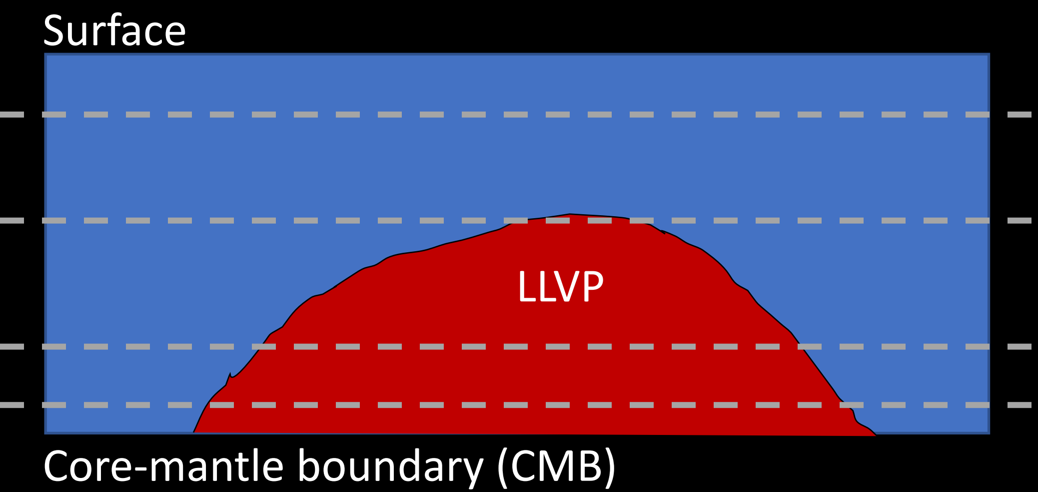


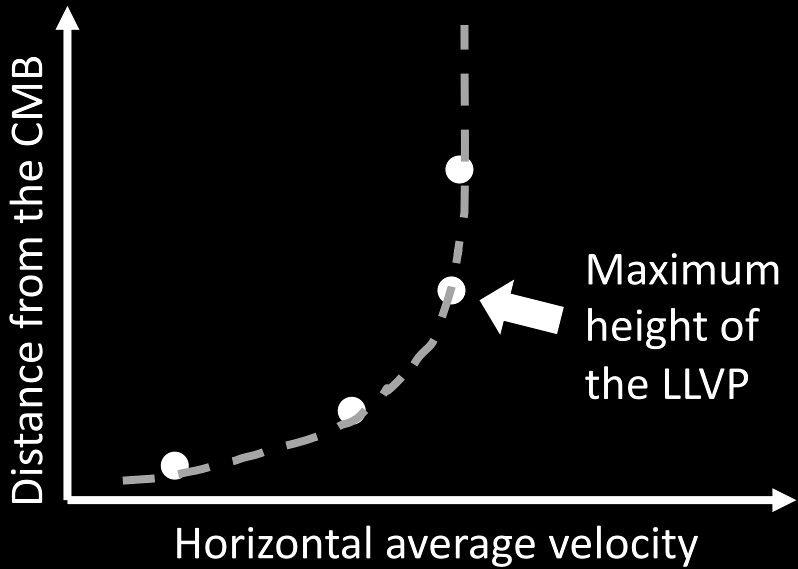
Compiled by Li, 2020



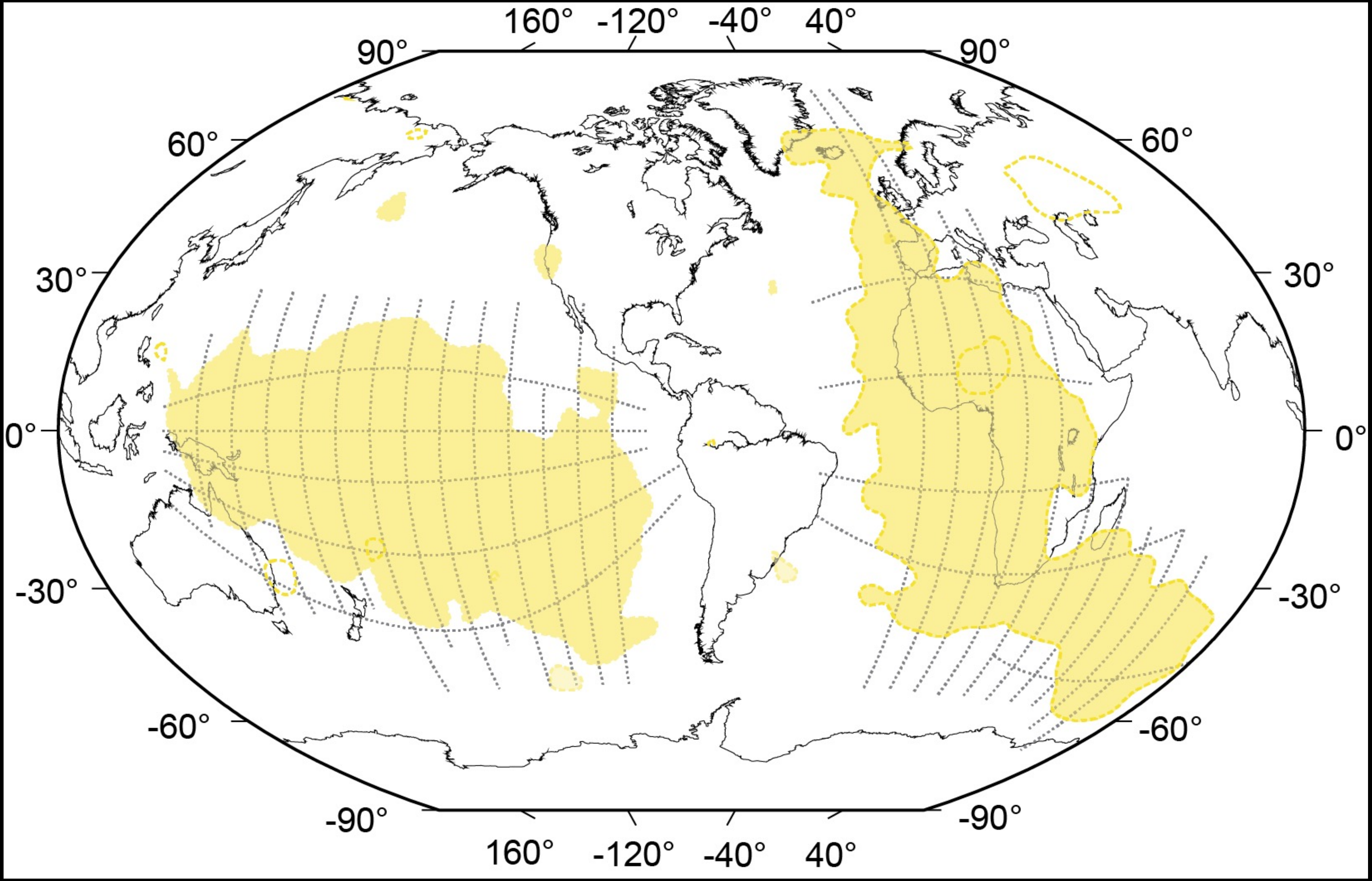
Cottaar and Lekic, 2016

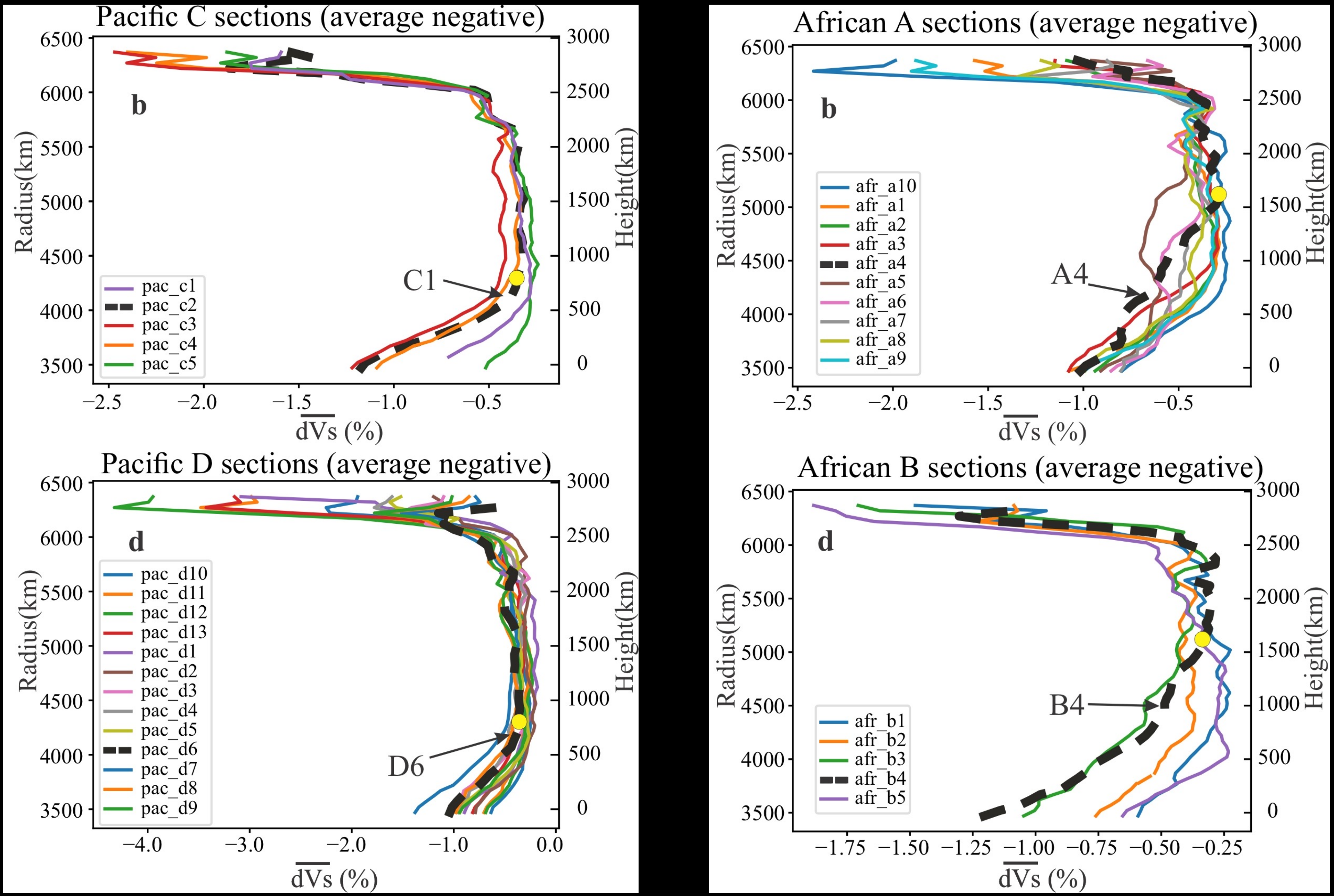
What is the maximum height can a LLVP reach?



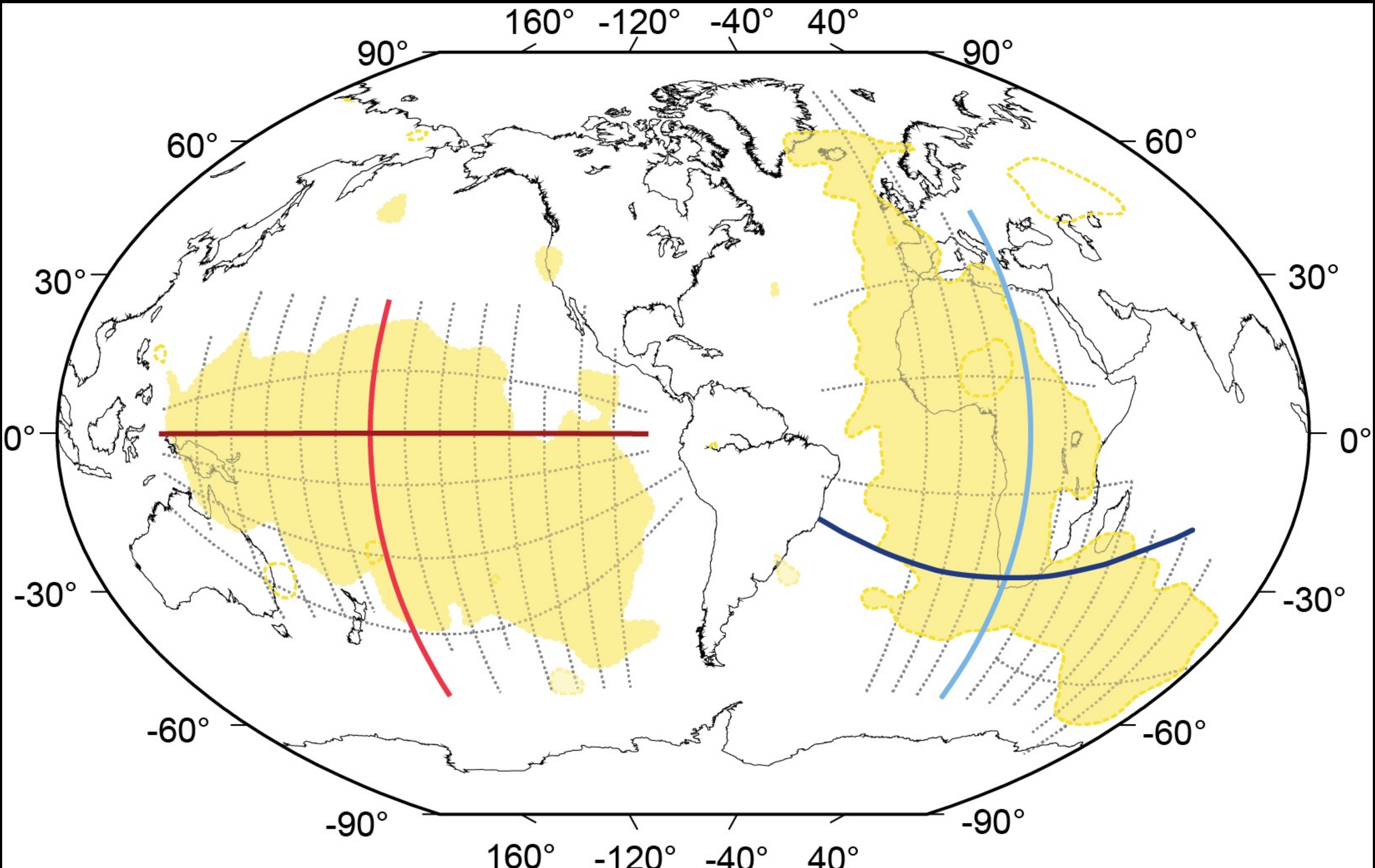


What is the shallowest depth a LLVP can reach?

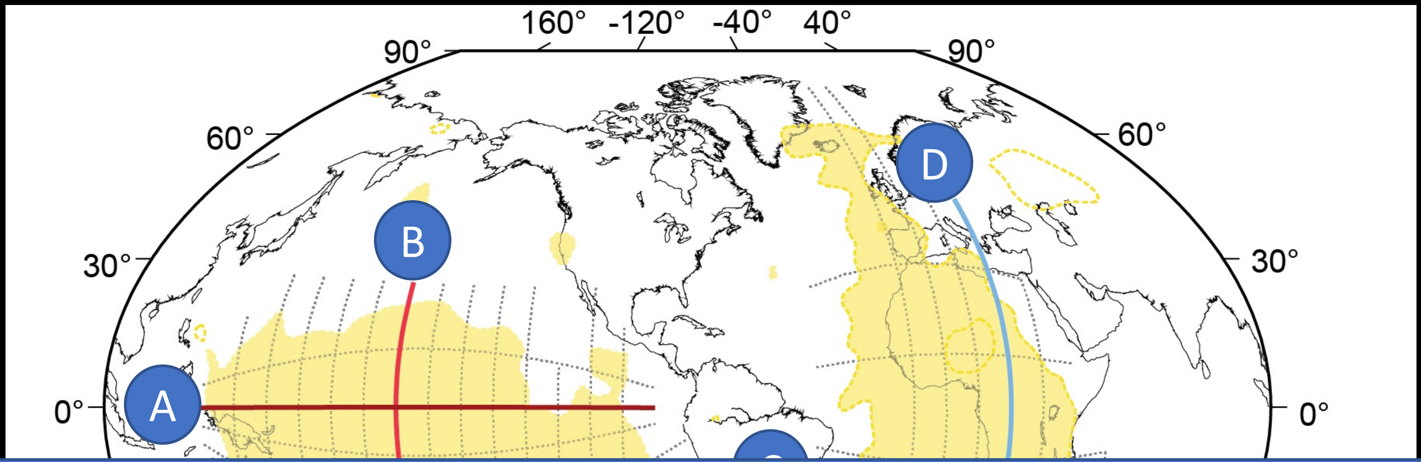




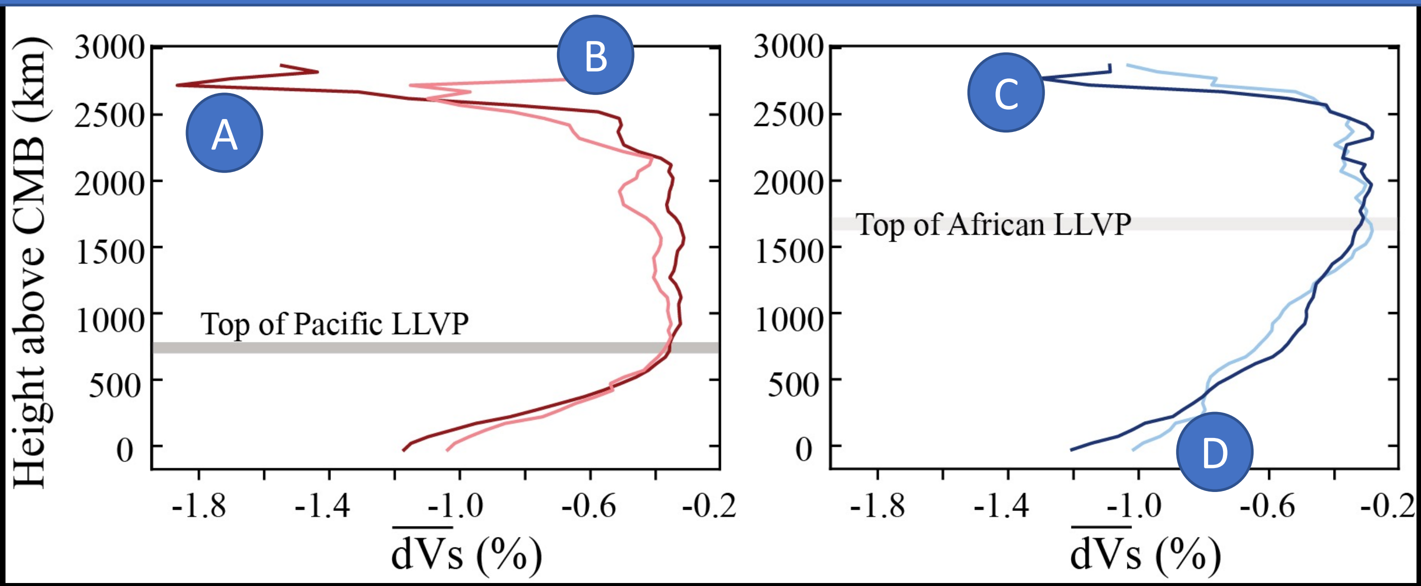
Pacific C sections (average negative)
b
C1
pac_c1
pac_c2
pac_c3
pac_c4
pac_c5
Radius(km)
Height(km)
dVs (%)
African A sections (average negative)
b
A4
afr_a10
afr_a1
afr_a2
afr_a3
afr_a4
afr_a5
afr_a6
afr_a7
afr_a8
afr_a9
Radius(km)
Height(km)
dVs (%)
Pacific D sections (average negative)
d
D6
pac_d10
pac_d11
pac_d12
pac_d13
pac_d1
pac_d2
pac_d3
pac_d4
pac_d5
pac_d6
pac_d7
pac_d8
pac_d9
Radius(km)
Height(km)
dVs (%)
African B sections (average negative)
d
B4
afr_b1
afr_b2
afr_b3
afr_b4
afr_b5
Radius(km)
Height(km)
dVs (%)



160°
-120°
-40°
40°
90°
90°
60°
60°
30°
30°
0°
0°
-30°
-30°
-60°
-60°
-90°
-90°
160°
-120°
-40°
40°



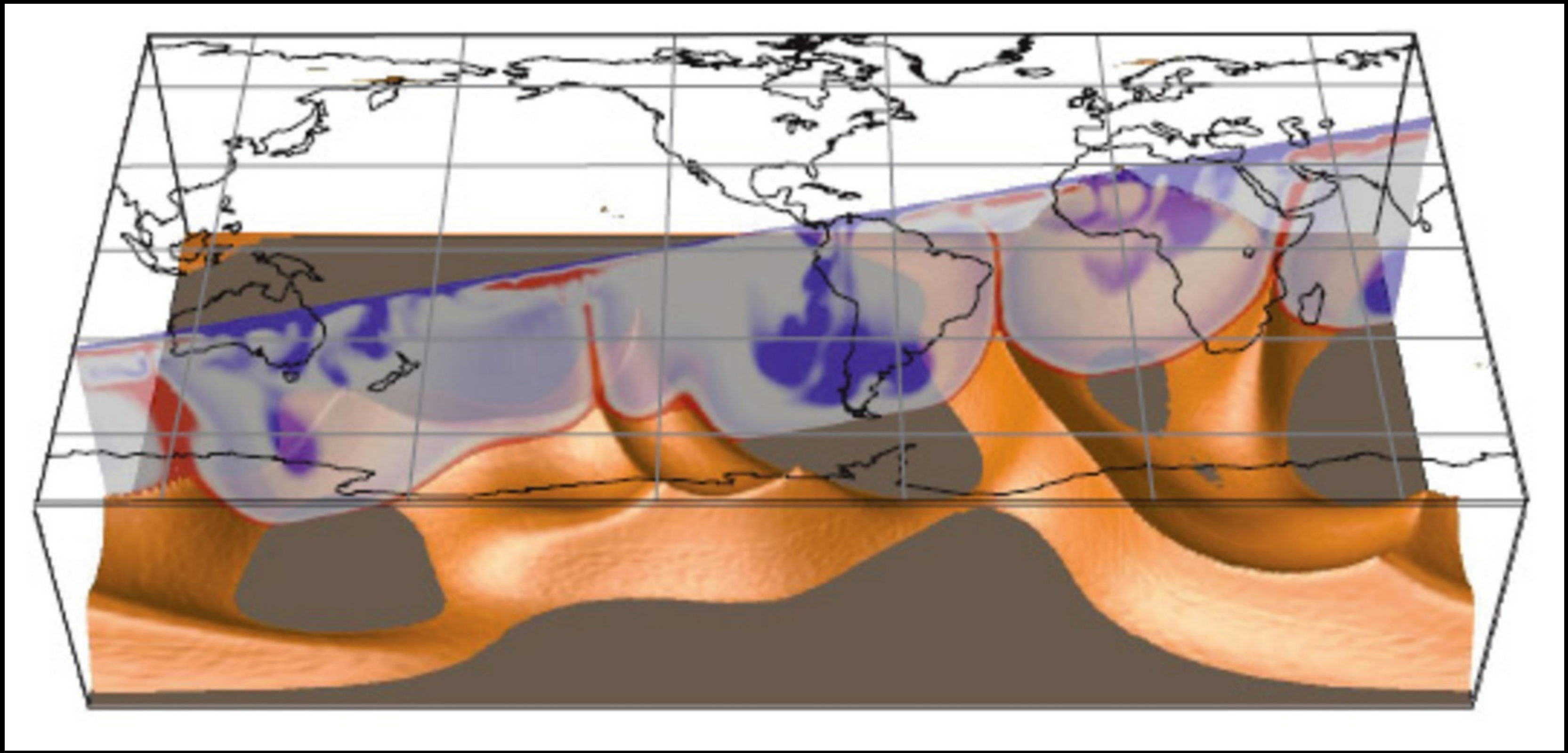
The Africa LLVP reaches a height ~1,700 km above the core-mantle boundary, which is about 1,000 km taller than the Pacific one



What causes LLVPs?

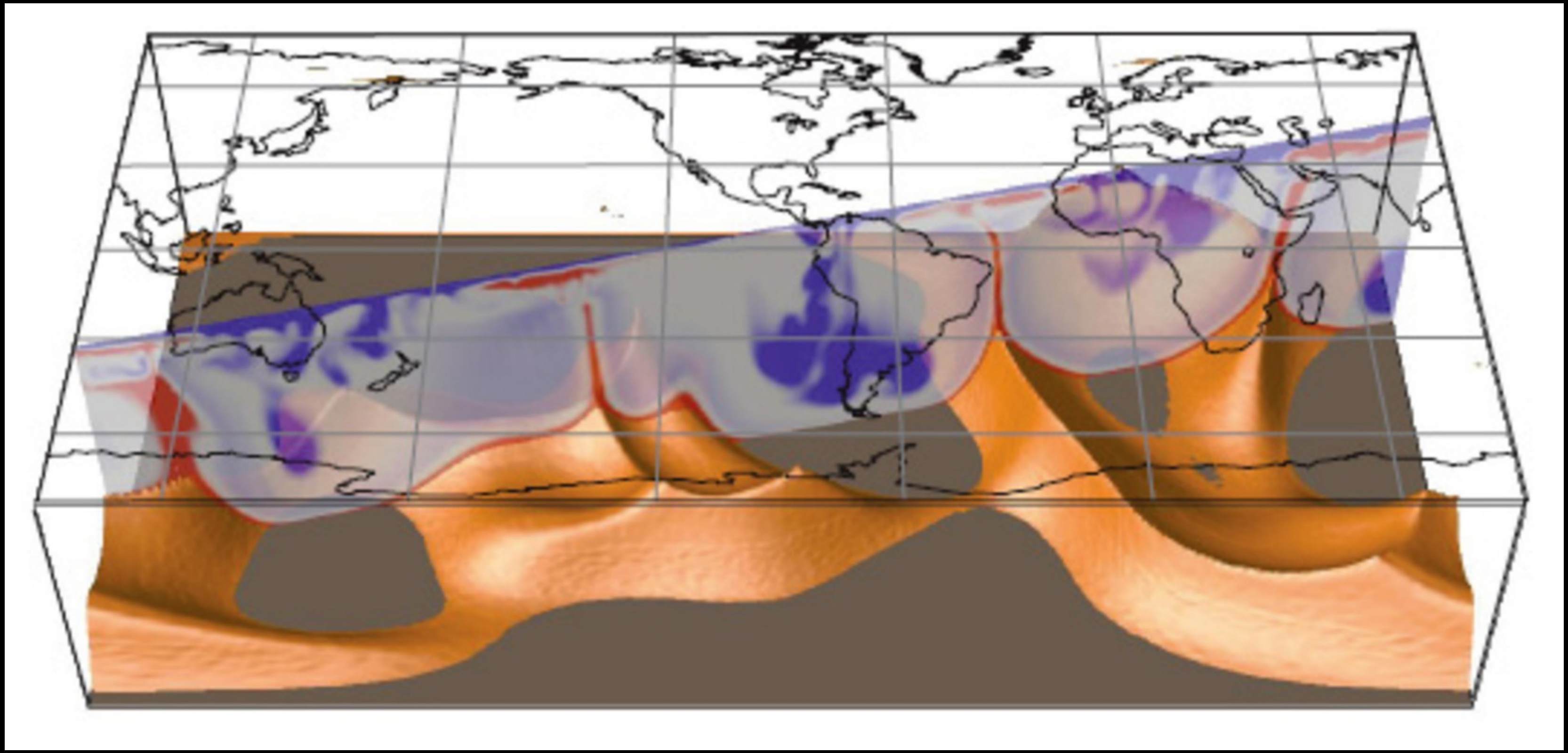
What causes the vastly different height of the two LLVPs?

One (most) popular hypothesis: LLVPs are caused by thermochemical piles



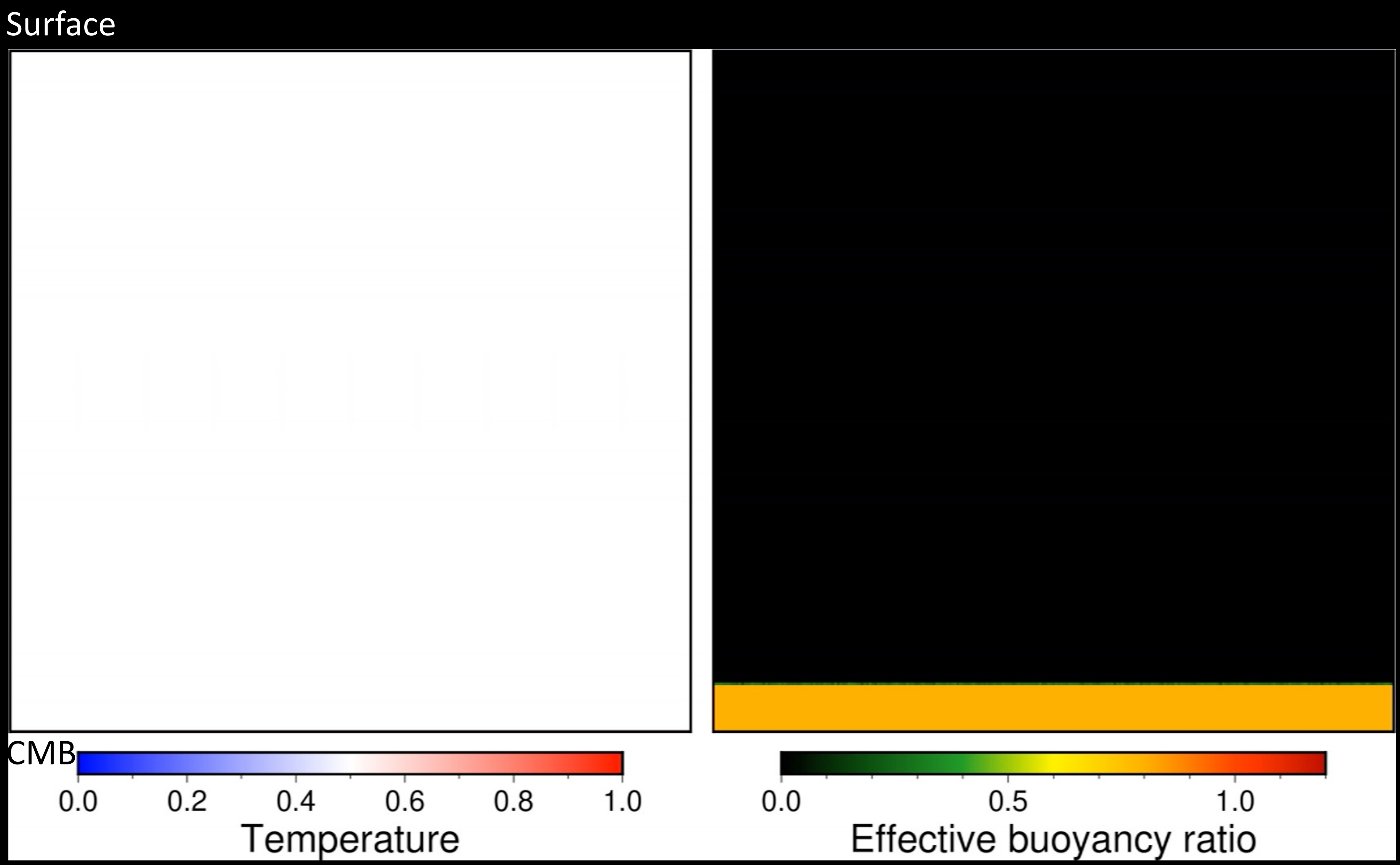
Garnero and McNamara, 2008

What controls the height of thermochemical piles?



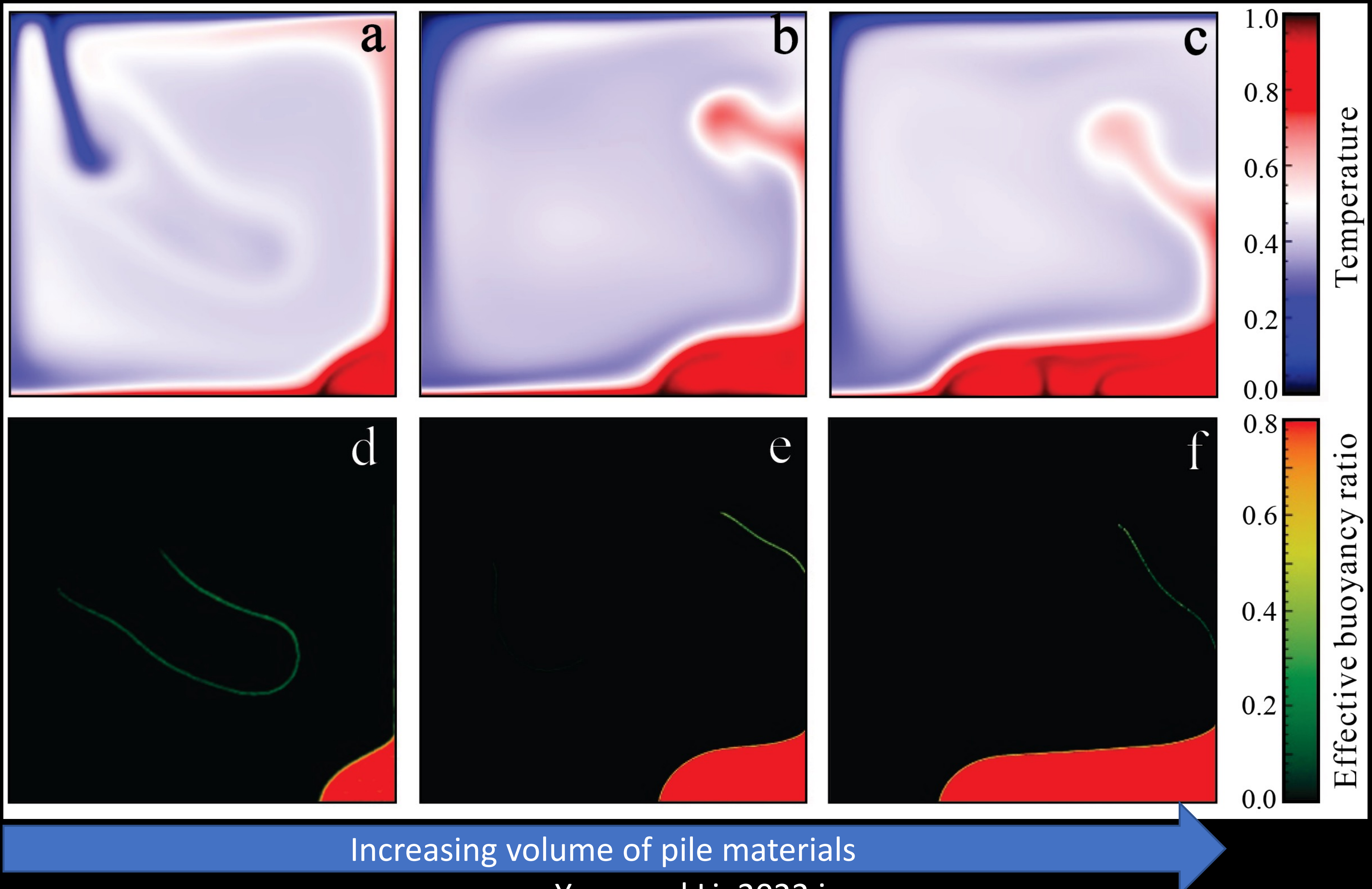
Garnero and McNamara, 2008

Our numerical experiments



Yuan and Li, 2022 in press

The size of a pile does not control its height



Yuan and Li, 2022 in press

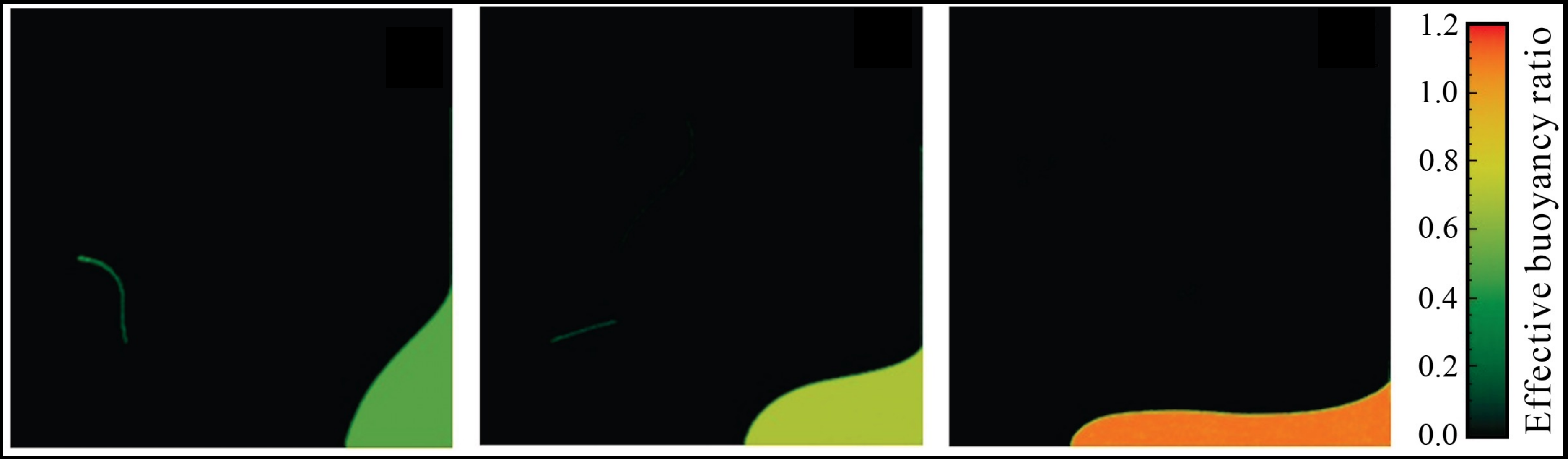
The viscosity of background mantle is important

Increasing the background mantle viscosity

Piles are taller when the background mantle is more viscous

Yuan and Li, 2022 in press

The density of pile materials is most important

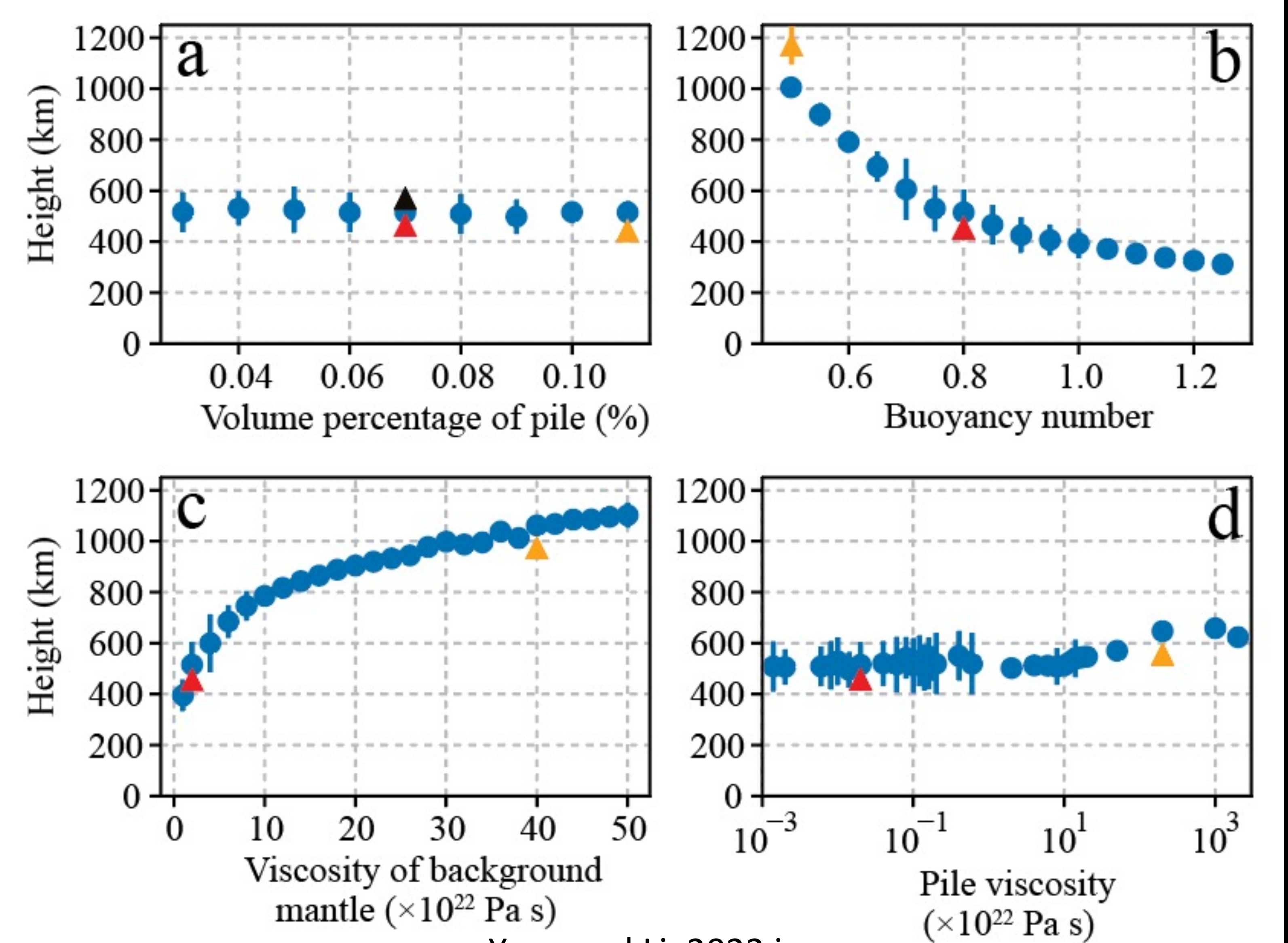


Increasing the intrinsic density of piles

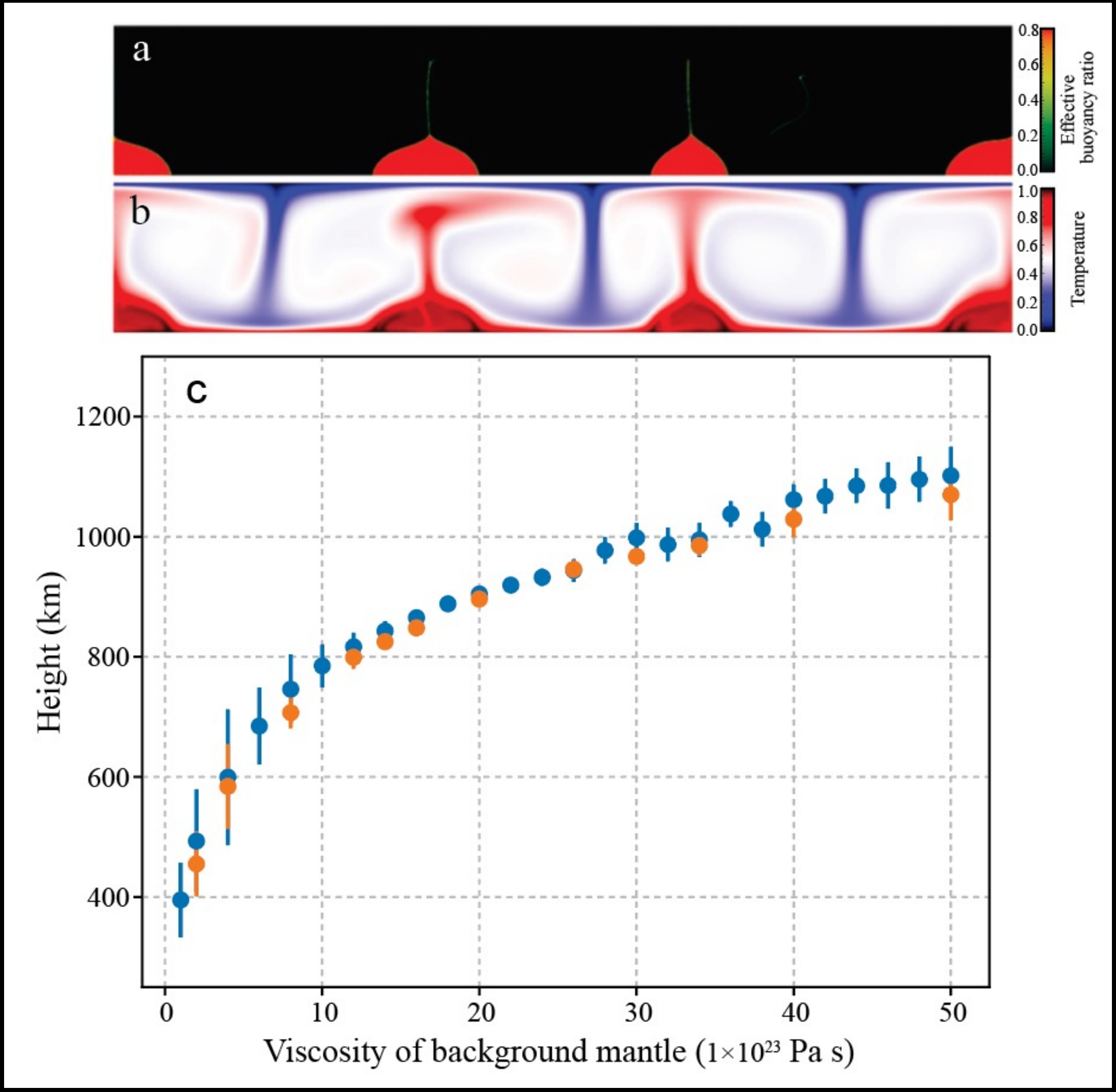
Piles with larger intrinsic density have much lower height.

Yuan and Li, 2022 in press

What controls the height of thermochemical piles?



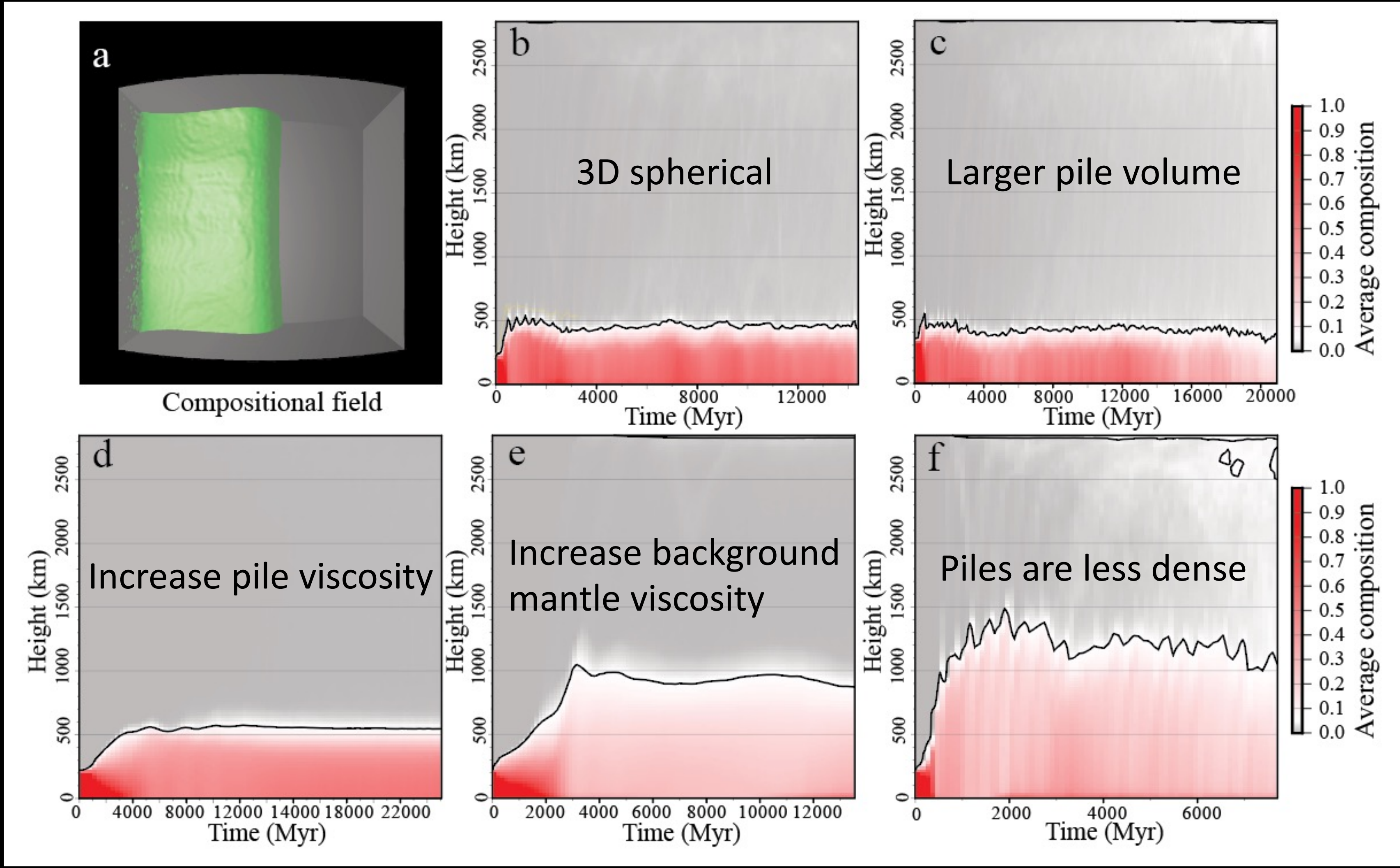
Yuan and Li, 2022 in press



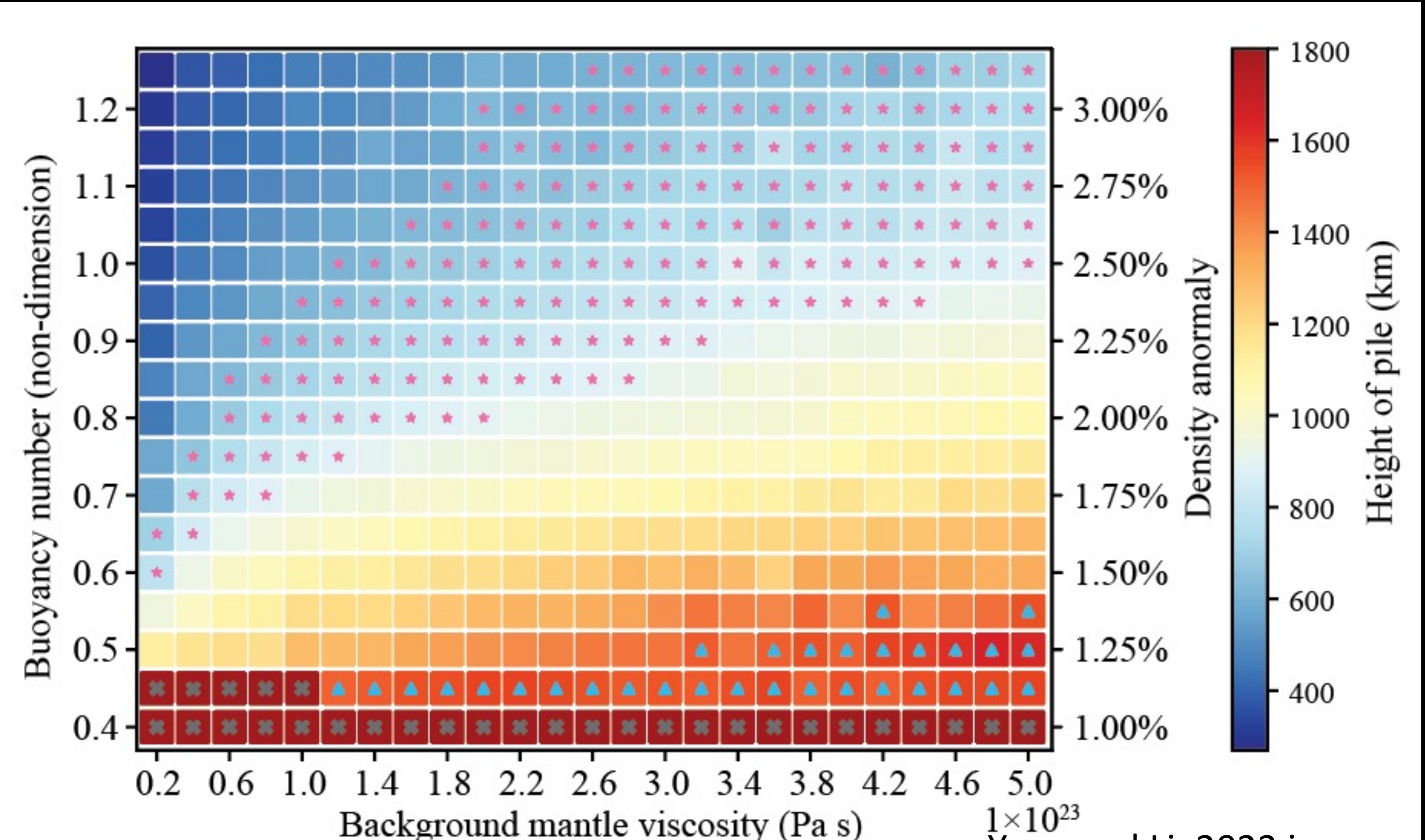
We get similar results when using more complex, and realistic model geometry

Yuan and Li, 2022 in press

Same results when using more complex, and realistic model geometry



Yuan and Li, 2022 in press

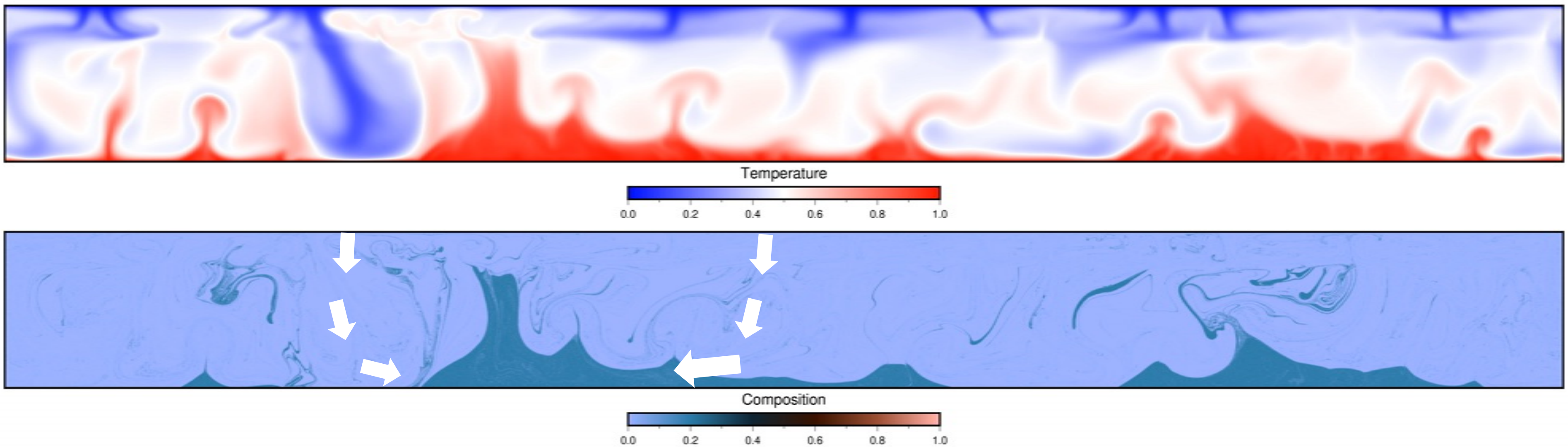


Yuan and Li, 2022 in press

Pink star = height of Pacific LLVP, Blue triangle = height of Africa LLVP, Gray cross = when LLVP is unstable

The height of Pacific LLVP can be explained by a wide range of parameters. To explain the large height of the Africa LLVP requires it to have a relatively low intrinsic density.

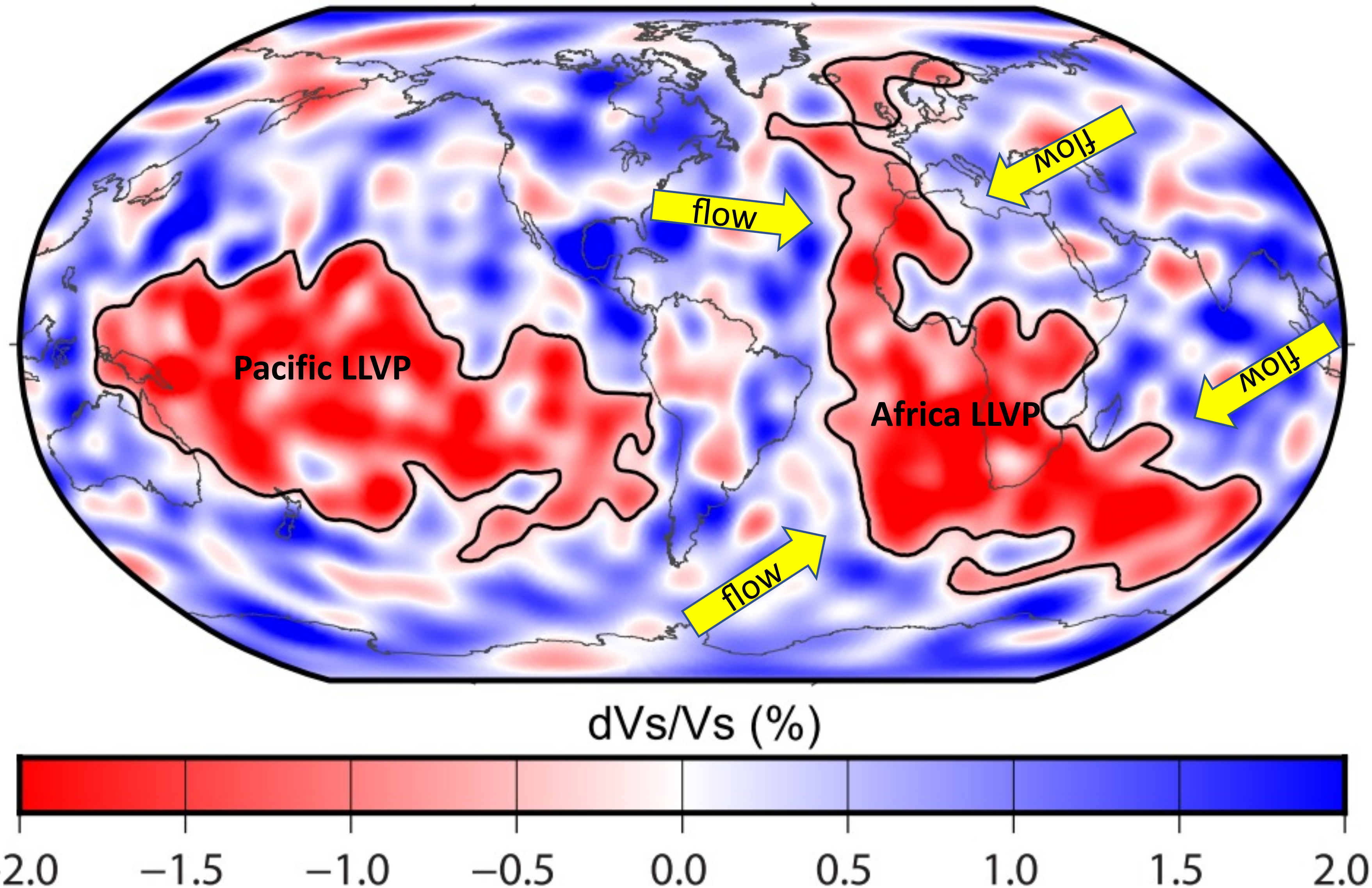
If a thermochemical pile is not dense enough, it's height will be greatly affected by surrounding mantle flow



Yuan and Li, in prep.

Take home message: the sinking of subducted slabs to the deepest mantle pushes a pile nearby to have large height!

Implications



Seismic tomography model from French and Romanowicz, 2015

What causes the vastly different height of the two LLVPs?

a. The Africa LLVP is less dense than the Pacific LLVP
b. Both LLVPs are not very dense, but the Africa LLVP has been pushed more strongly by convection flow

If answer b is correct, the Africa LLVP should have been rising in recent geological time.

What are the physical properties of LLVPs?
What is the nature of mantle flow?

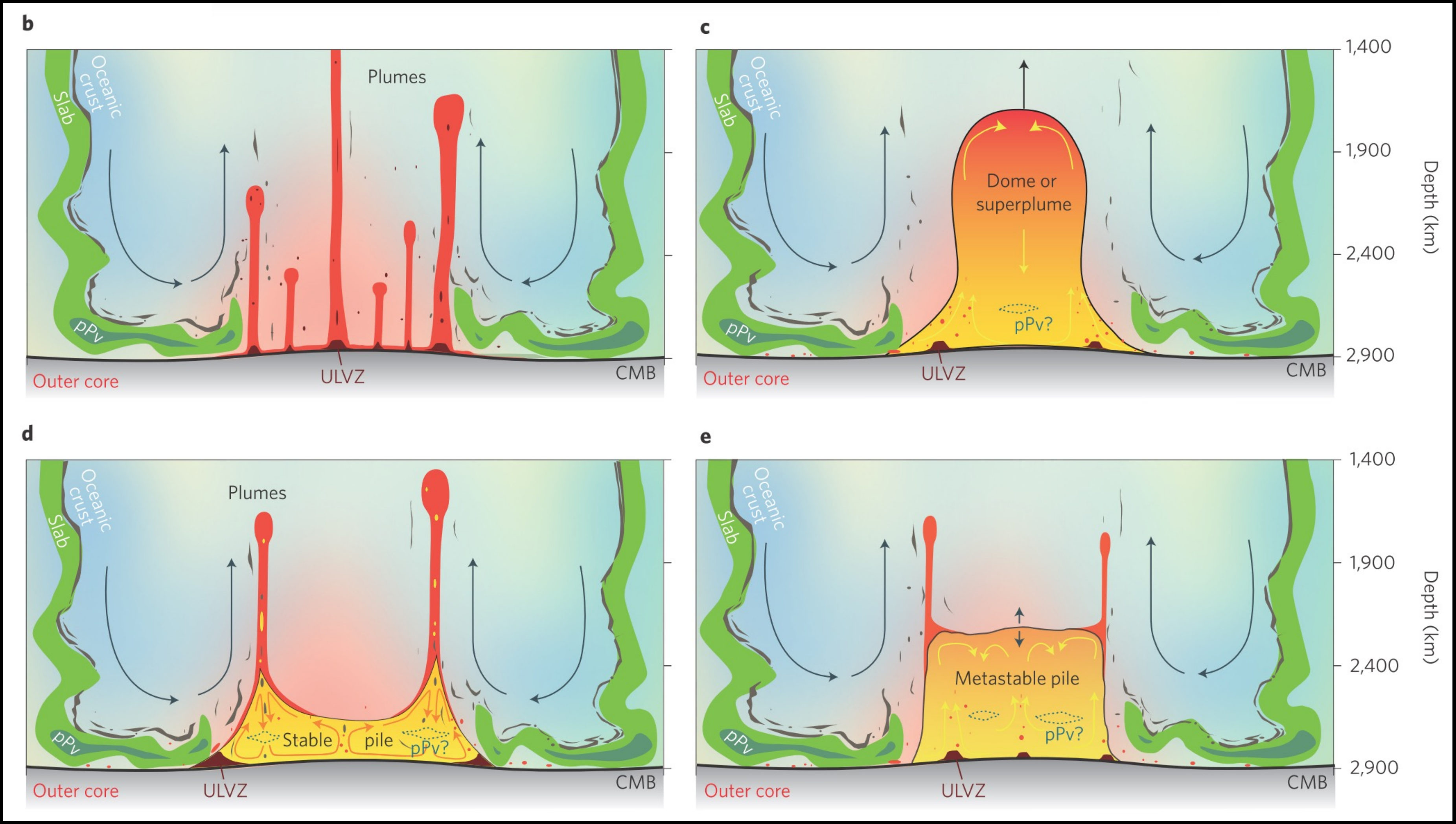
How does the surface respond to the rising Africa LLVP?
(plate motion, topography, gravity, volcanism, earthquakes)

Multidisciplinary work
(observational, laboratory, theoretical)

We together make it possible.

Image from https://www.gregmcdermottcoach.com/blog/tag/teamwork

What causes LLVPs?



Garnero, McNamara, Shim, 2016