Unstable structure and dynamics in Earth’s deepest mantle

Mingming Li
SESE, ASU
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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.
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 $\frac{\partial T}{\partial t} + (\vec{u} \cdot \nabla)T = \nabla^2 T$
Parallel computing

Right: ASU agave super cluster in Biodesign
Bottom: small cluster in ISTB4

ASU Agave
~20,000 CPUs
Unstable structure and dynamics in Earth’s deepest mantle

Qian Yuan
Large low velocity provinces (LLVPs)

Image from Garnero et al., 2007 based on S2ORTS tomograph model (Ritsema et al., 1999)

Blue = + 0.6% isosurface   Red = - 0.6% isosurface
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?
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.
Same results when using more complex, and realistic model geometry

Yuan and Li, 2022 in press
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, its 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.
What causes LLVPs?

Garnero, McNamara, Shim, 2016