

Plume Generation and Migration

Eh Tan
Institute of Earth Sciences
Academia Sinica, Taiwan



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Plume

plume *noun*

1. A feather, especially a large and showy one.



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5. *Fluid Dynamics* A rising or expanding fluid body, as of smoke or water, released from a point source.

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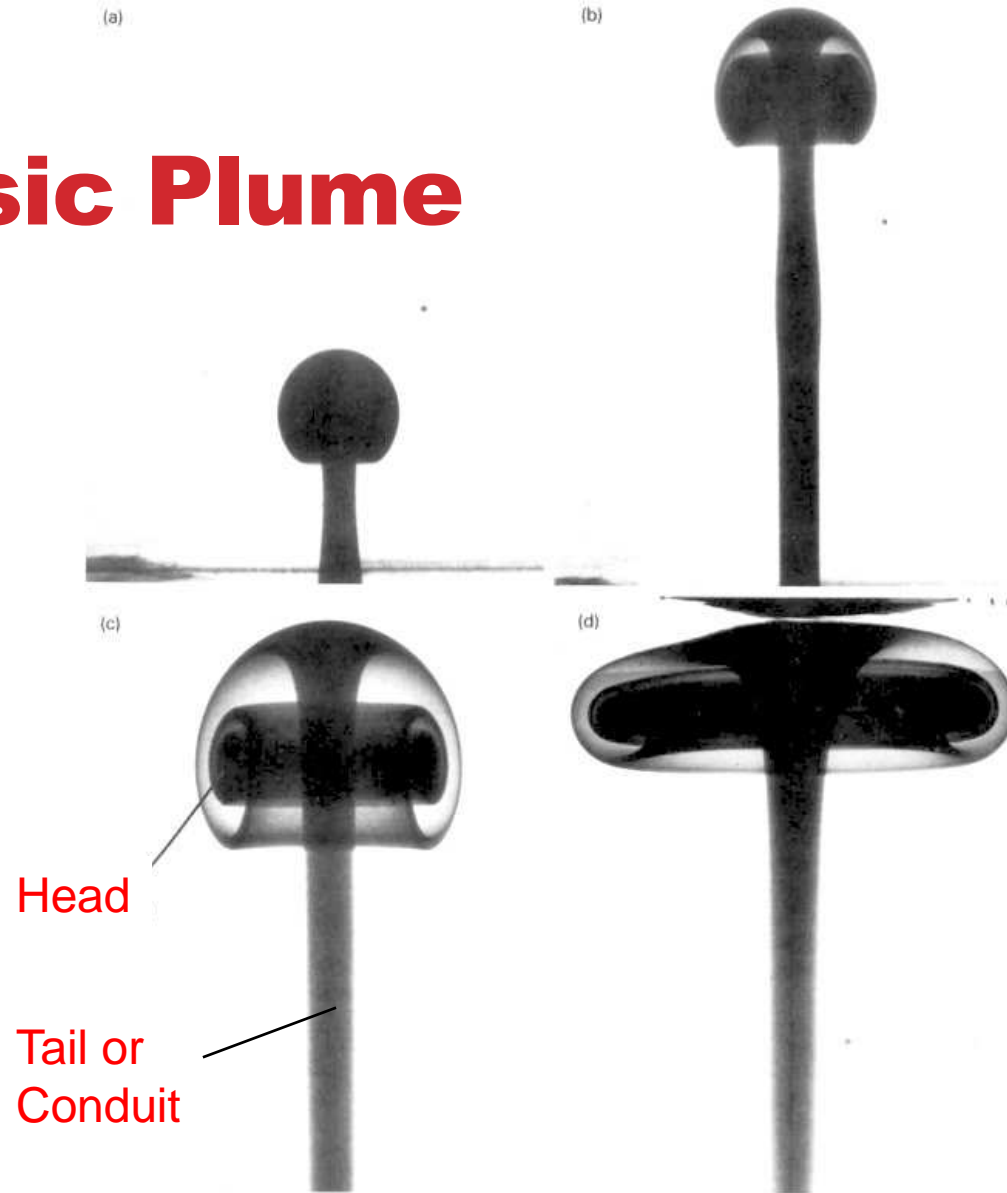
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4. A structure or form that is like a long feather: a plume of smoke.

5. *Fluid Dynamics* A rising or expanding fluid body, as of smoke or water, released from a point source.

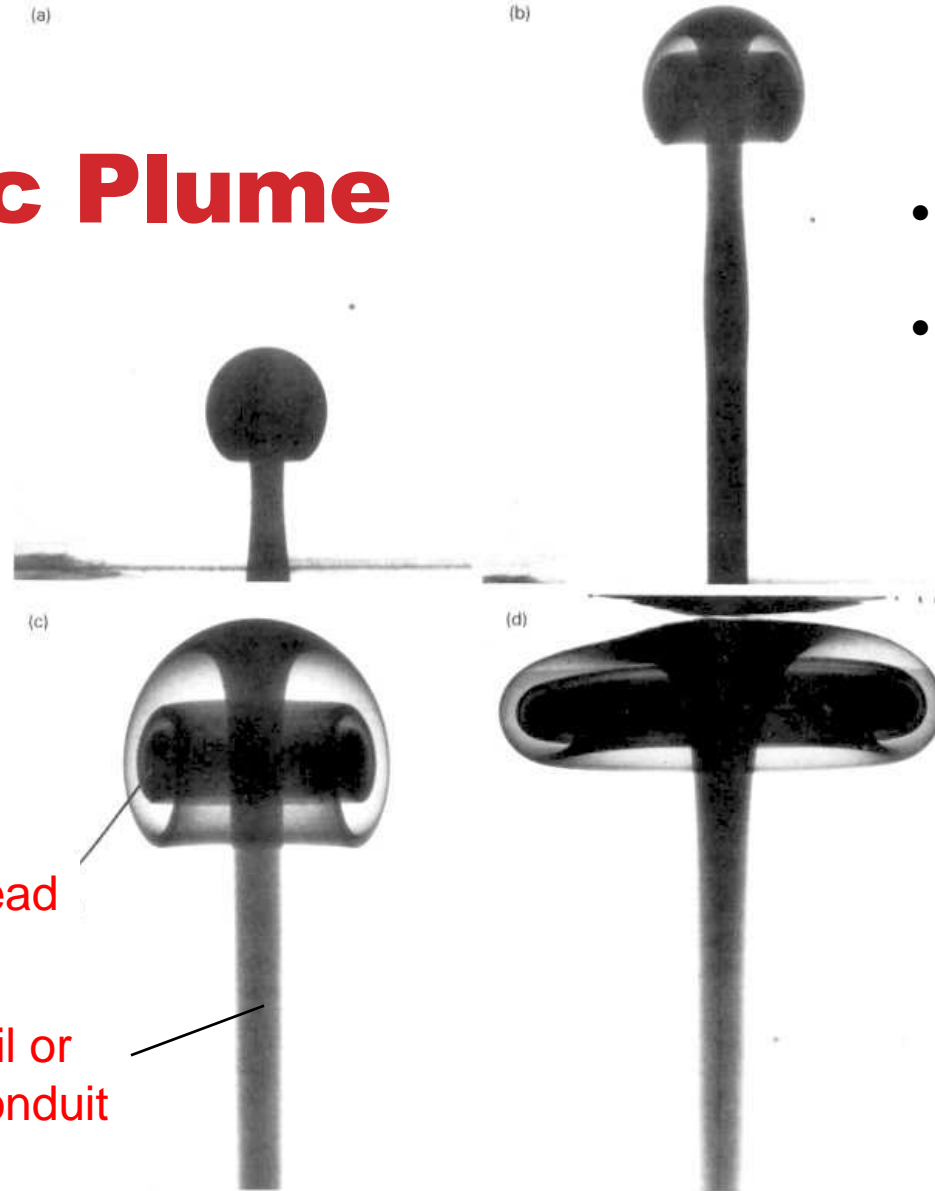
6. *Geology* An upwelling of molten material from the earth's mantle.

Classic Plume



Griffiths & Campbell, 1990 EPSL

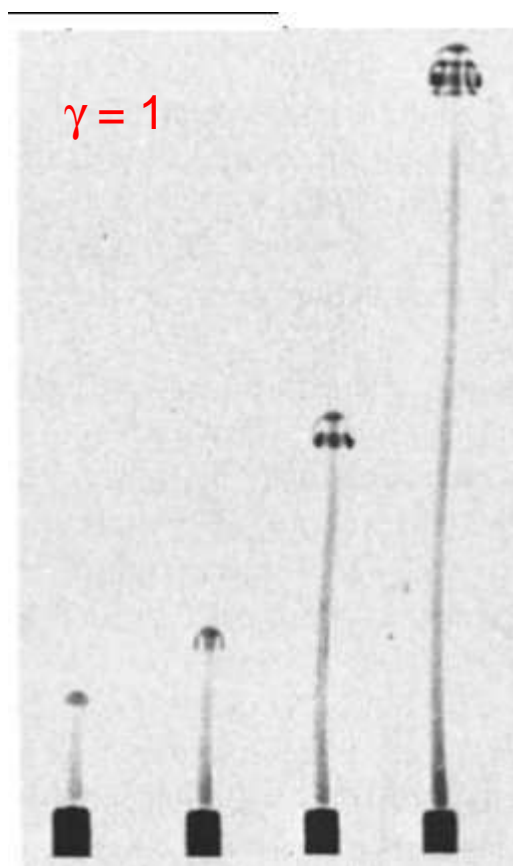
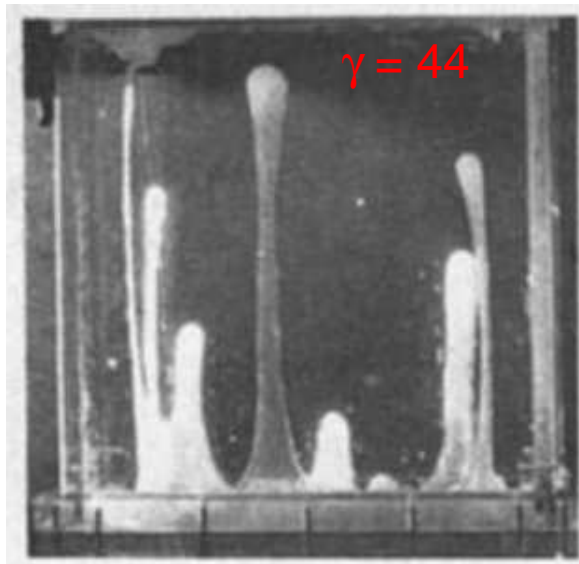
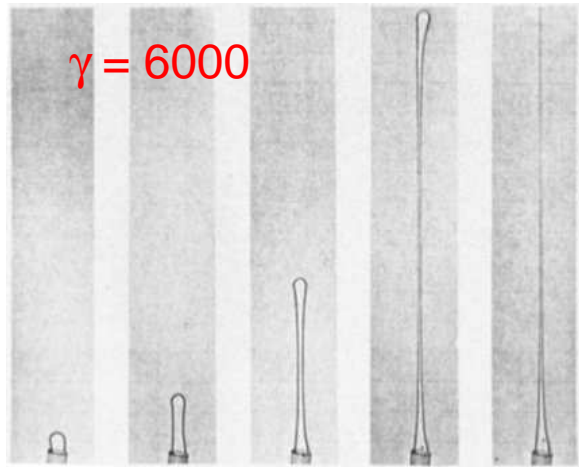
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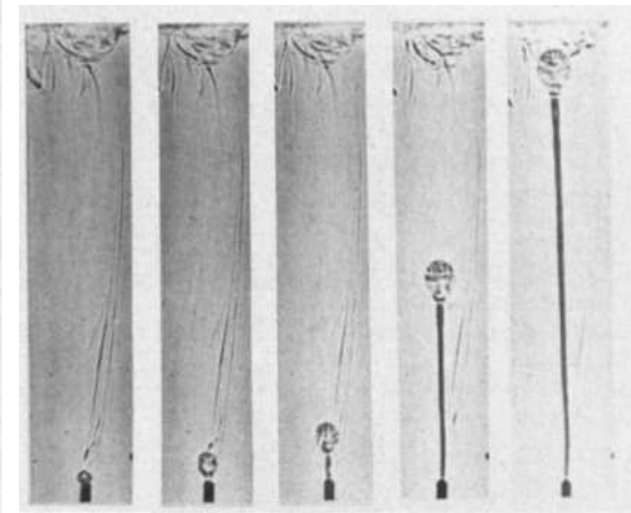
- Constant flux injection
- Viscosity ratio $\gamma = 0.0003$

Griffiths & Campbell, 1990 EPSL

Diapiric vs. Cavity Plumes



$\gamma = 1/6000$

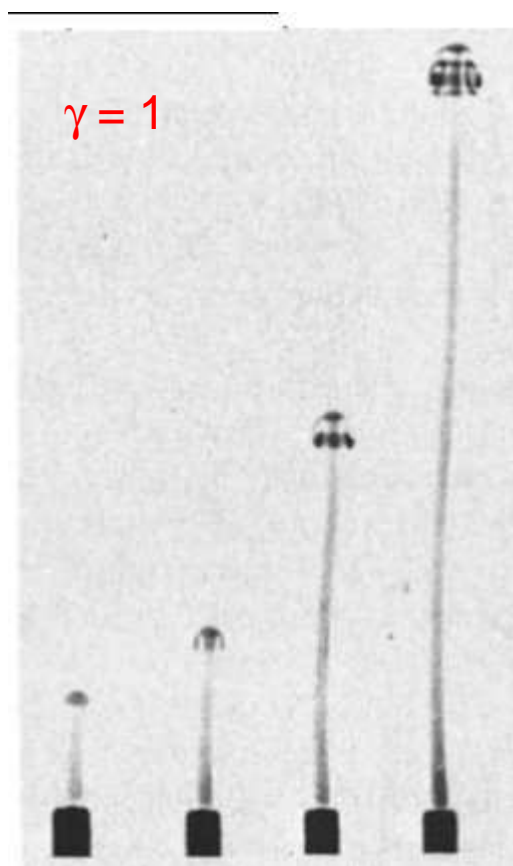
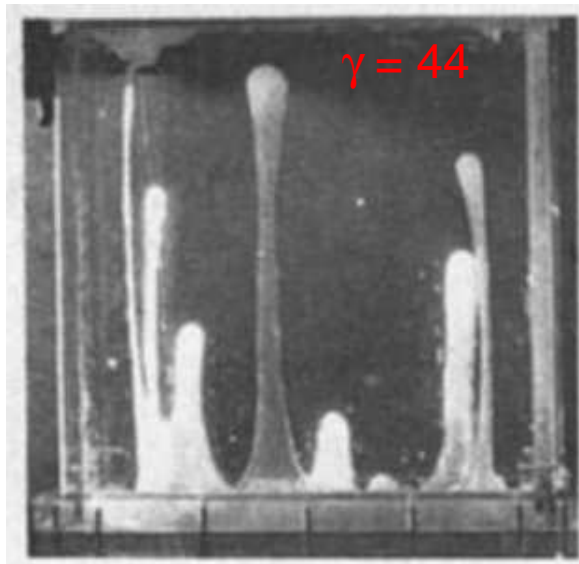
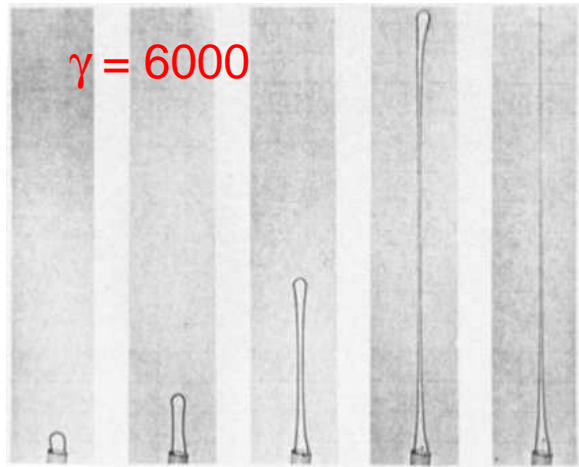


Whitehead & Luther, 1975 JGR

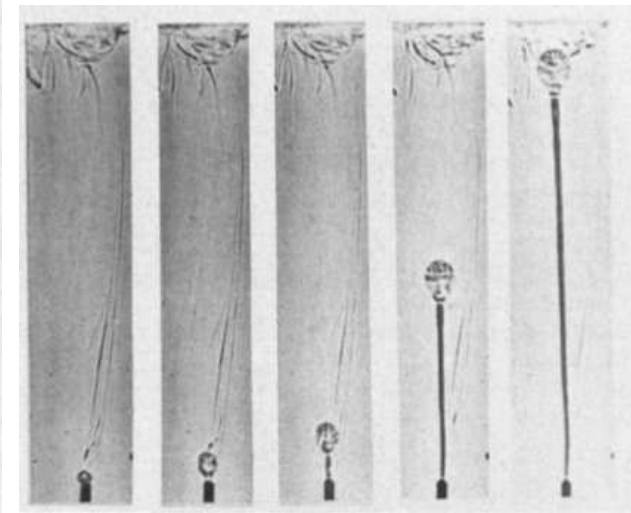
Generation of Plume Head

- **The plume head is a buoyant spherical density anomaly that rises through the viscous mantle like a Stokes-let**
 - $V \sim (\text{radius of head})^2 / \eta_{\text{mantle}}$
- **The plume conduit is like a pipe flow**
 - $V \sim (\text{radius of conduit})^2 / \eta_{\text{conduit}}$
- **If the plume head rises slower than the conduit, the size of the head will grow**

Diapiric vs. Cavity Plumes

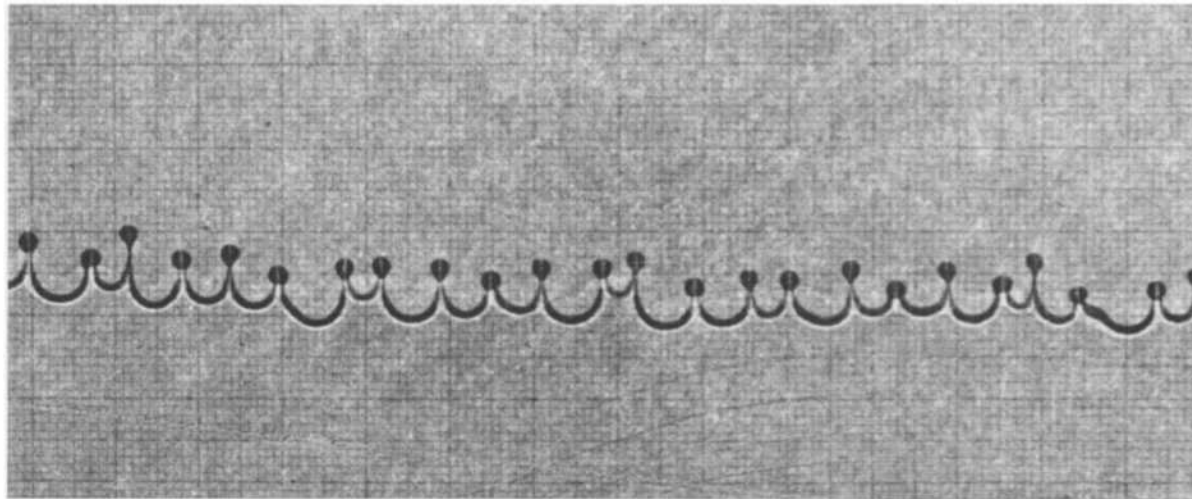


$\gamma = 1/6000$



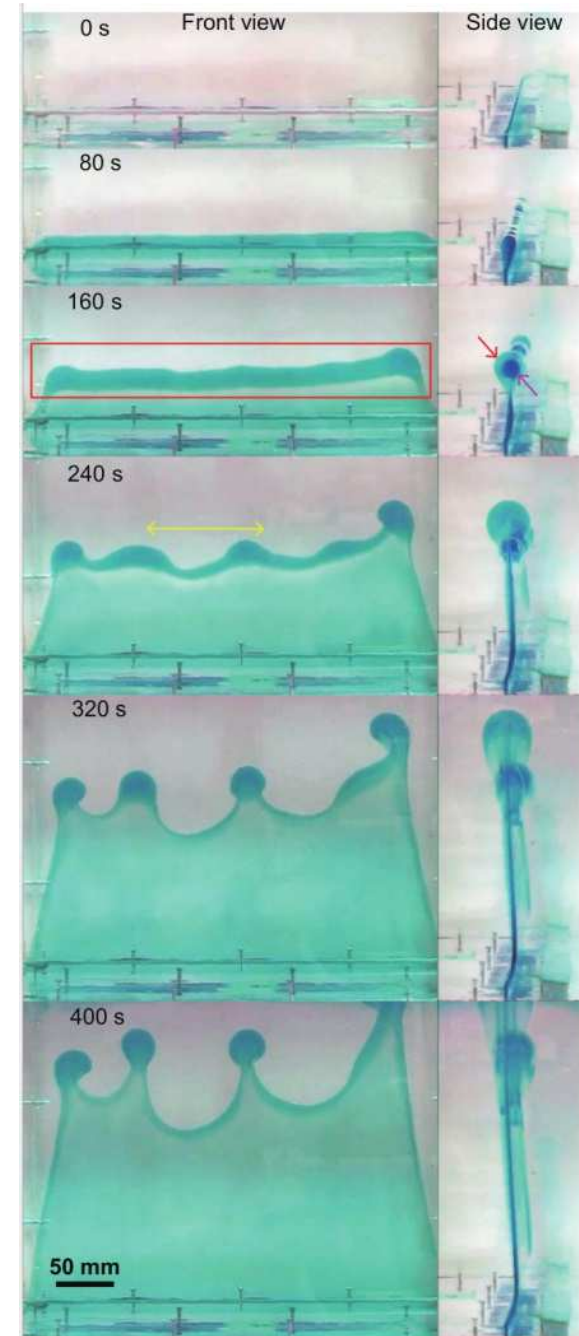
Whitehead & Luther, 1975 JGR

Chain of Plumes

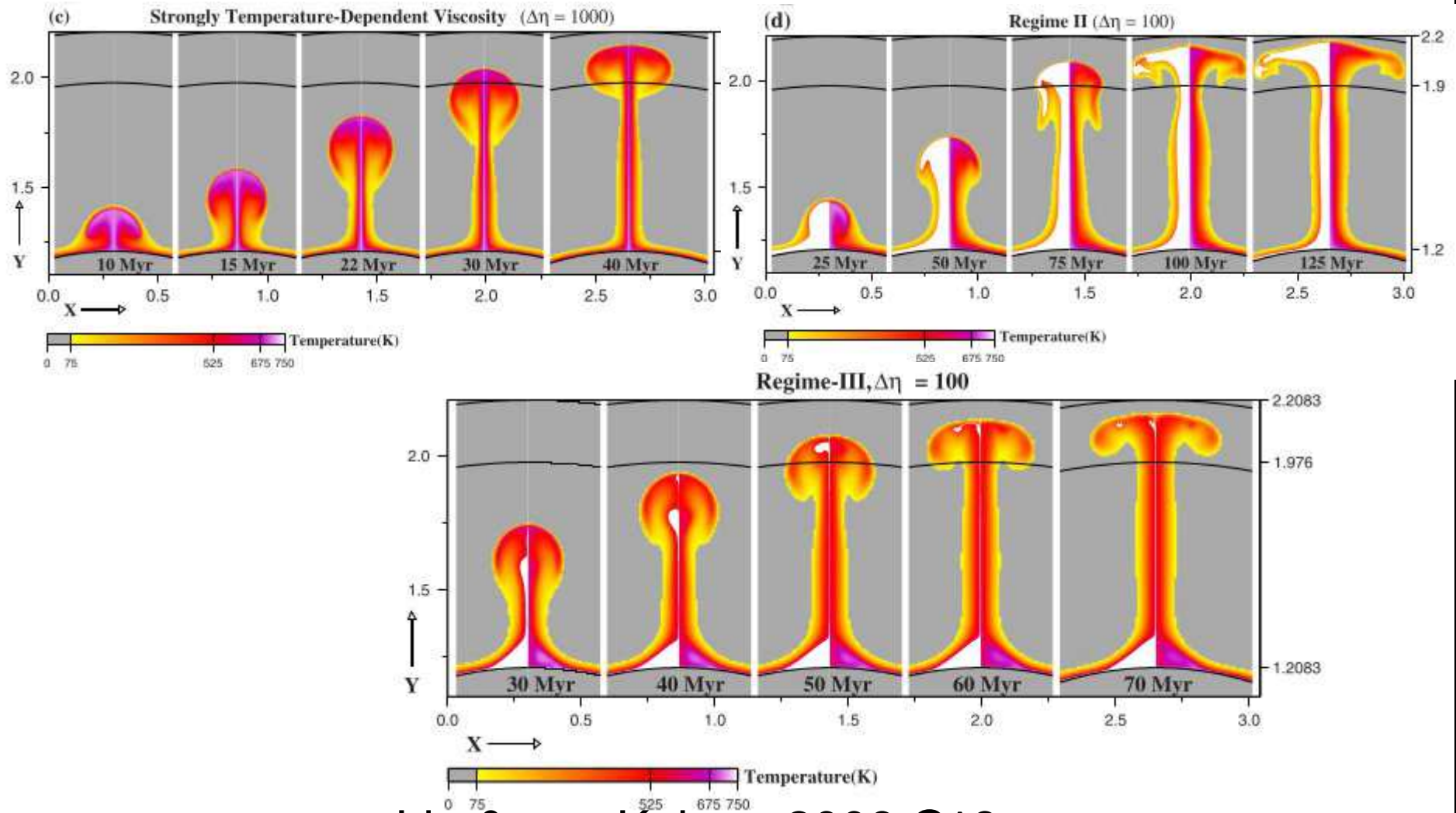


Kerr & Lister, 1988 EPSL

Namiki et al, 2013 G³

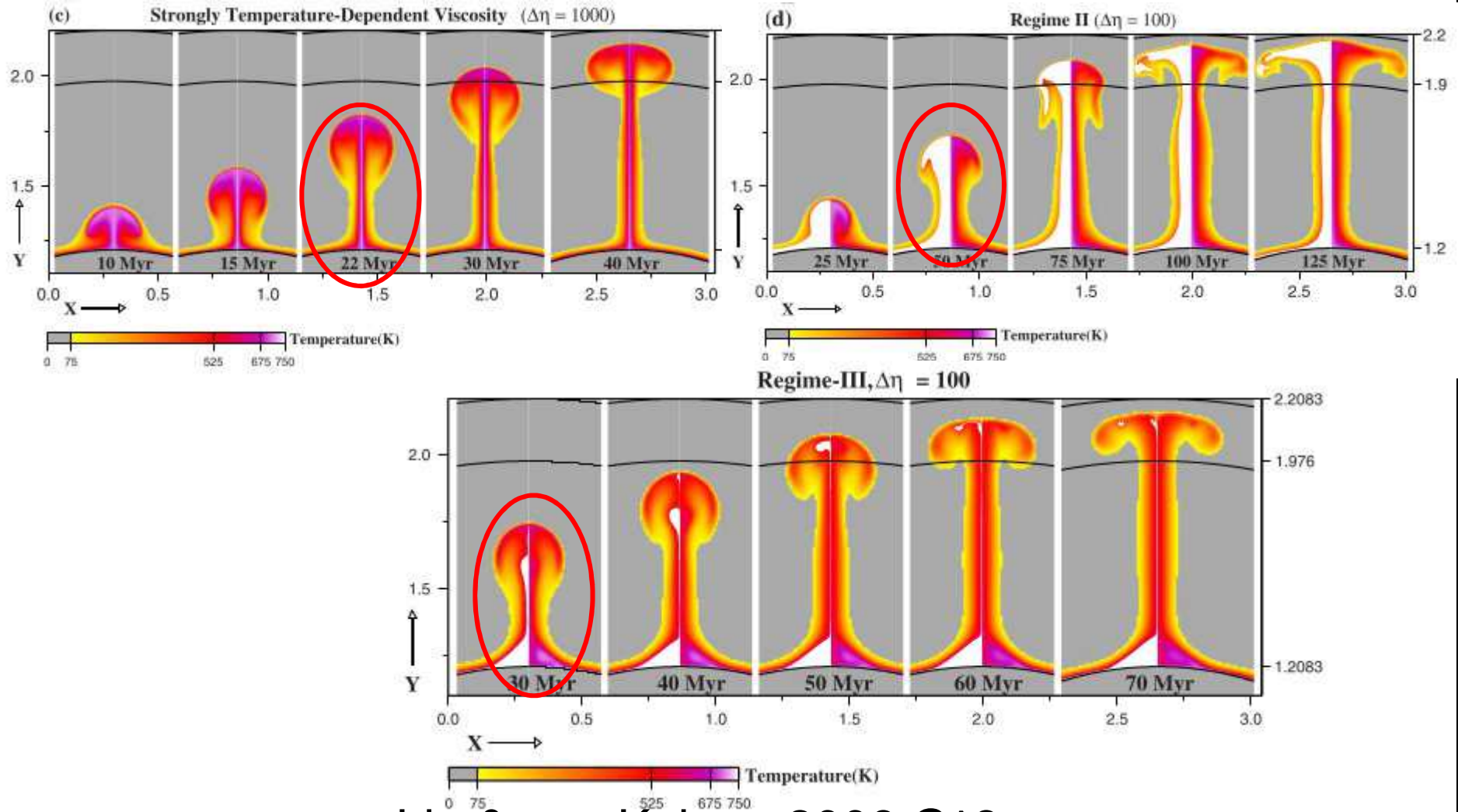


Plumes from Chemical Layer



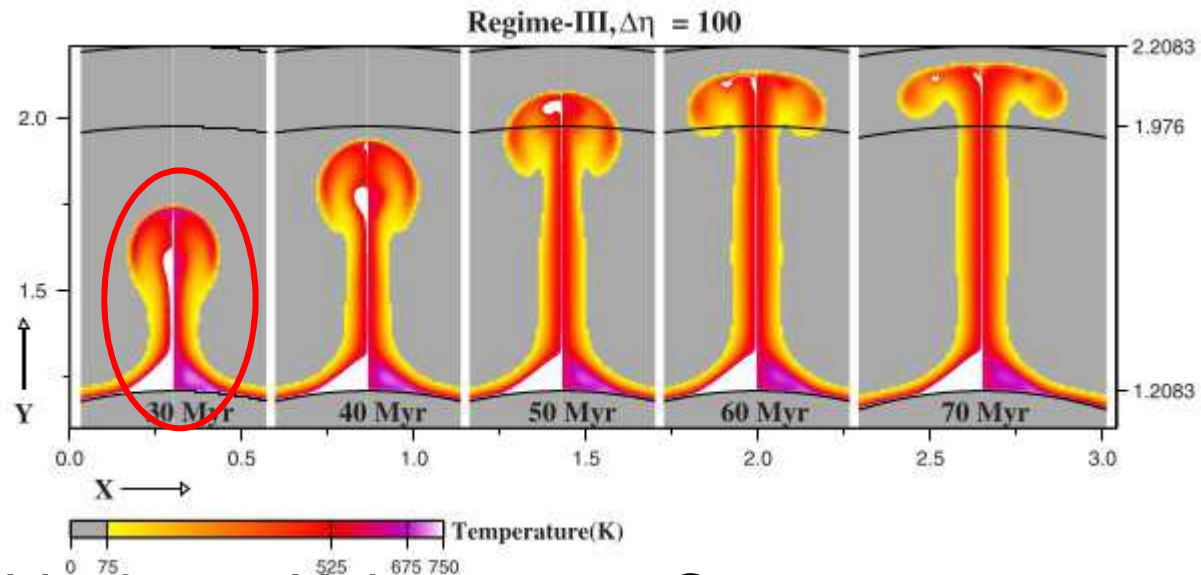
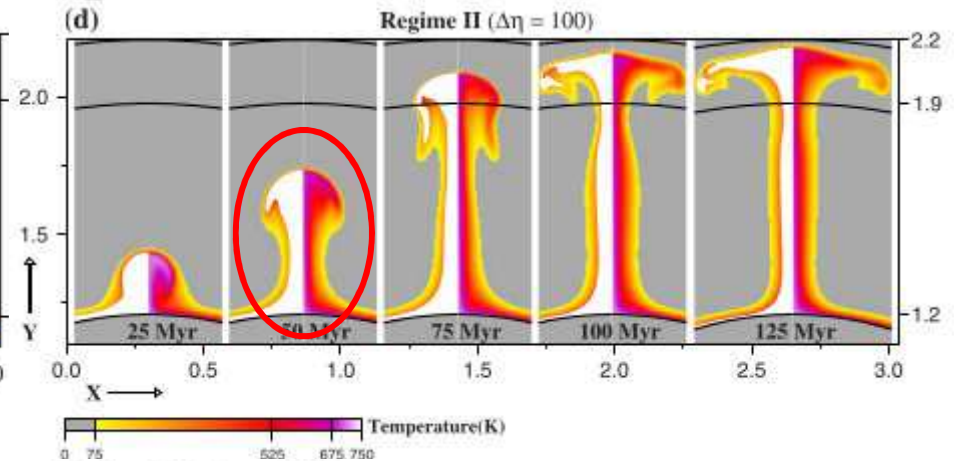
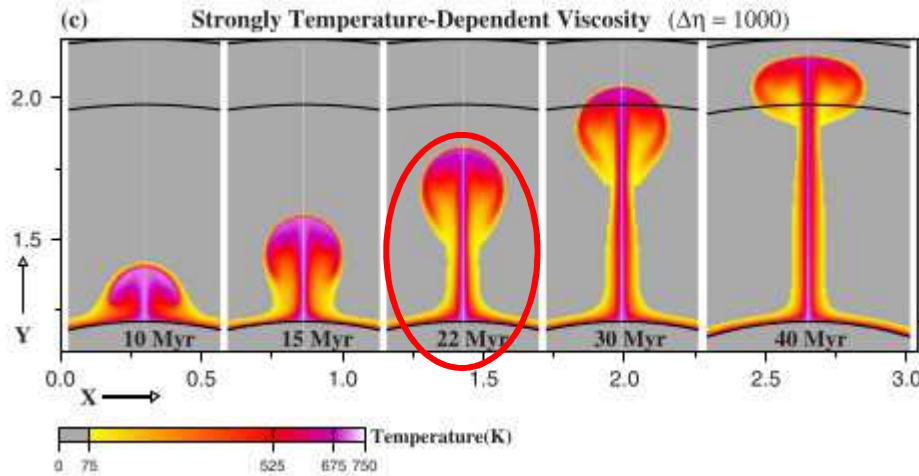
Lin & van Keken, 2006 G^3

Plumes from Chemical Layer



Lin & van Keken, 2006 G^3

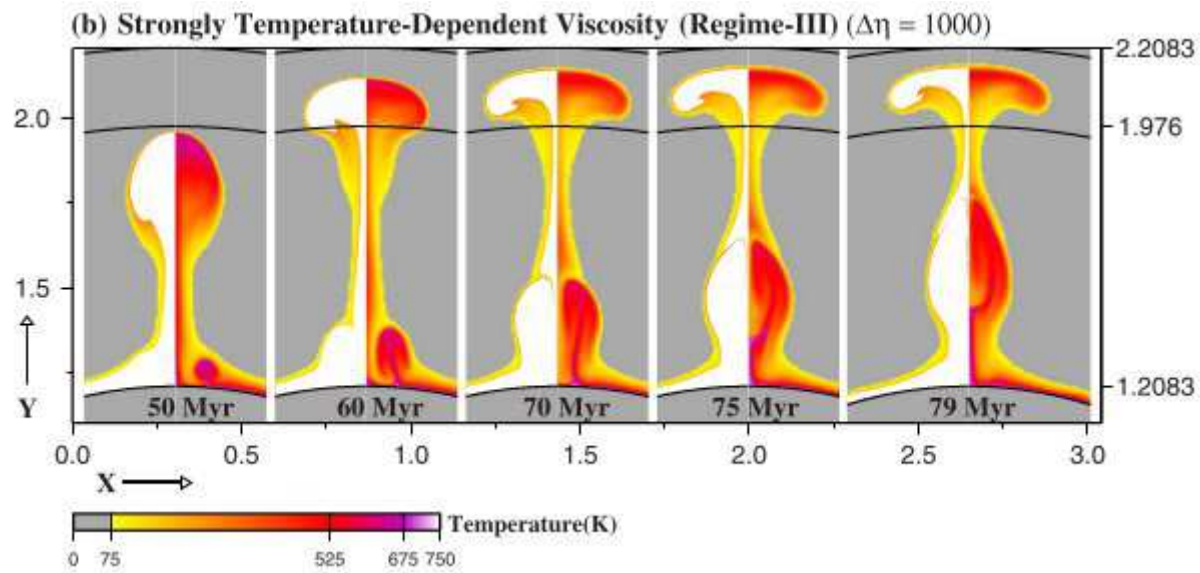
Plumes from Chemical Layer



Plumes rising from stable chemical layer has smaller excess temperature

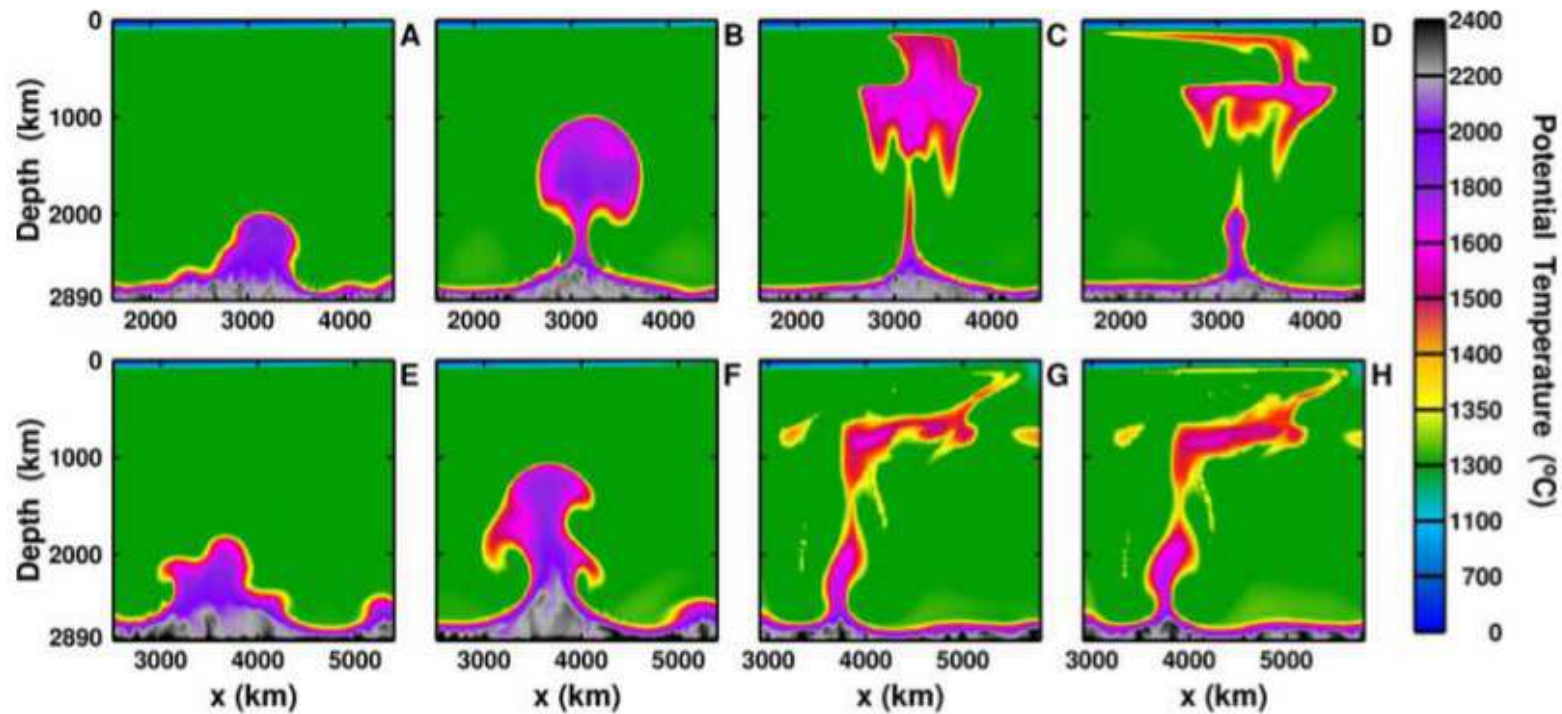
Lin & van Keken, 2006 G^3

Plumes from Chemical Layer



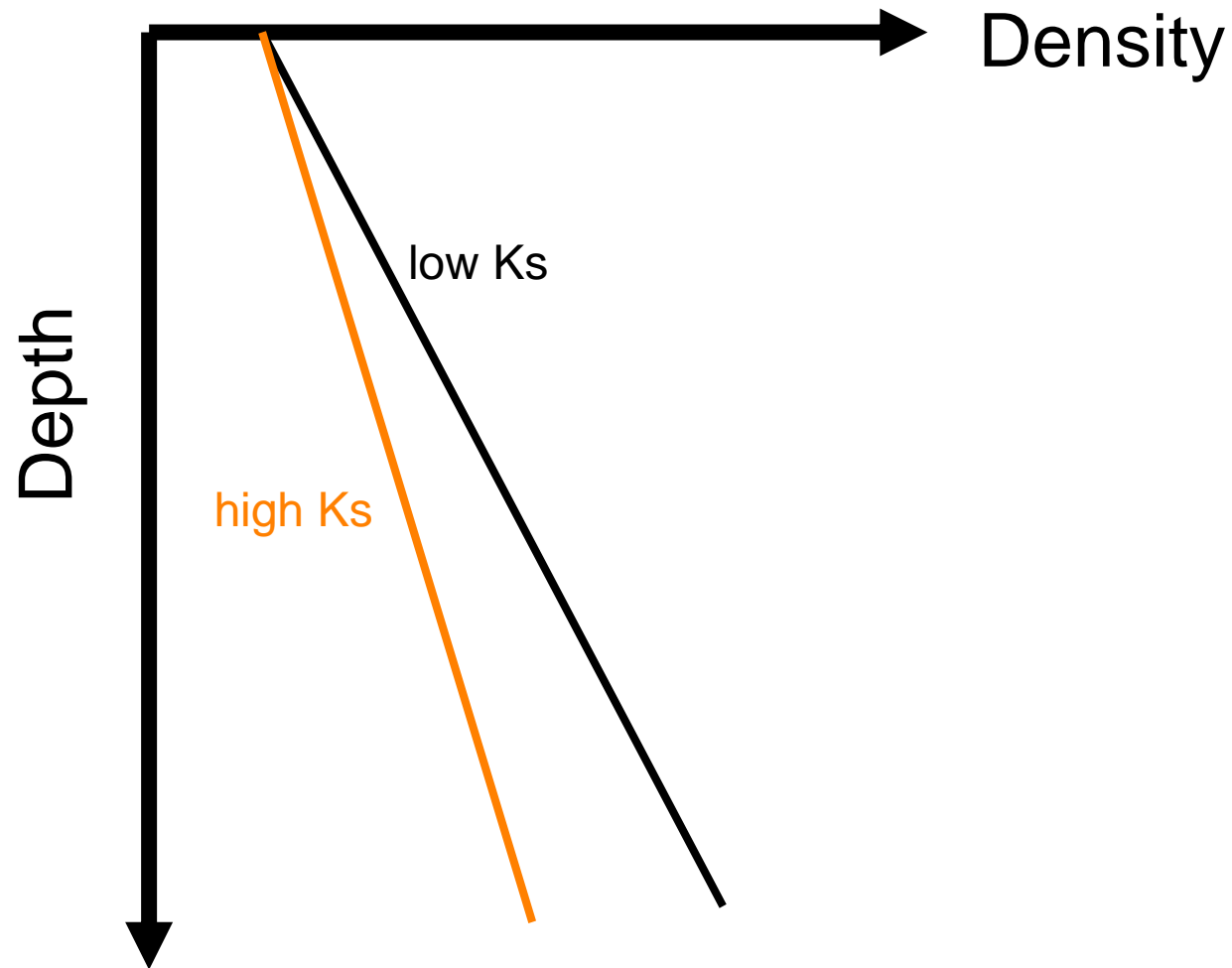
Lin & van Keken, 2006 G^3

Plumes from Compressible Chemical Layer

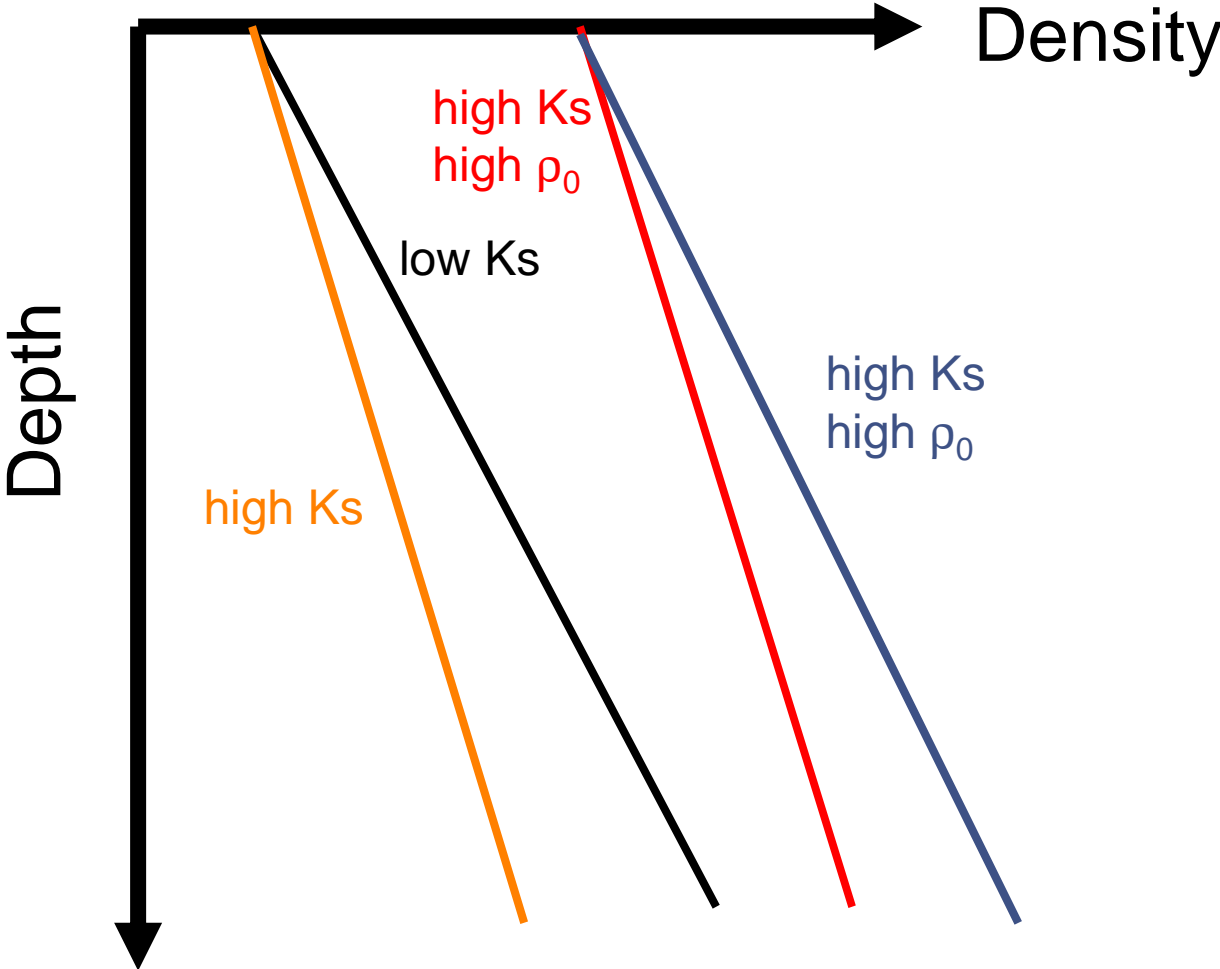


Farnetani & Samuel, 2005 GRL

Bulk Modulus and Density Profile

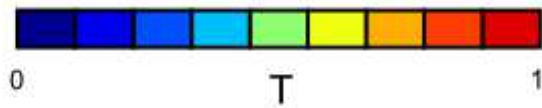
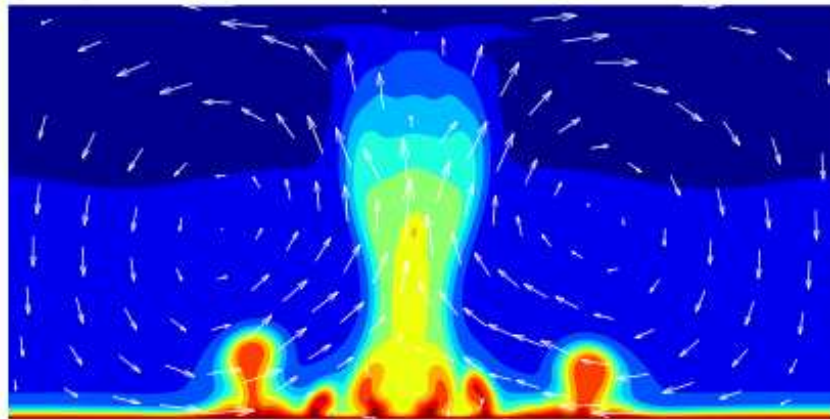


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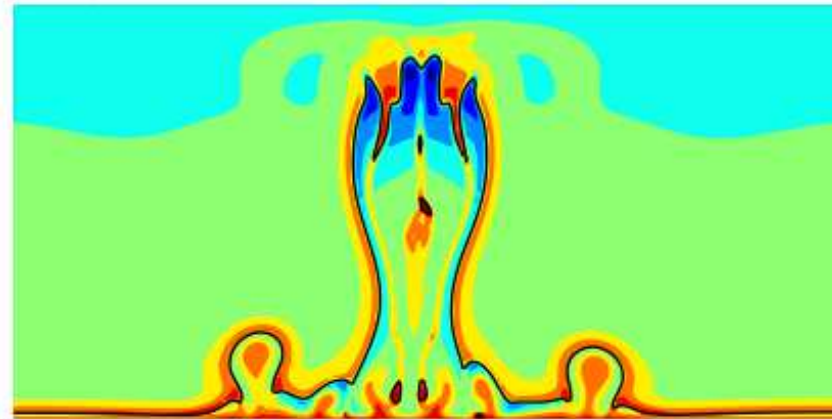


Columnar Plume

(D1)

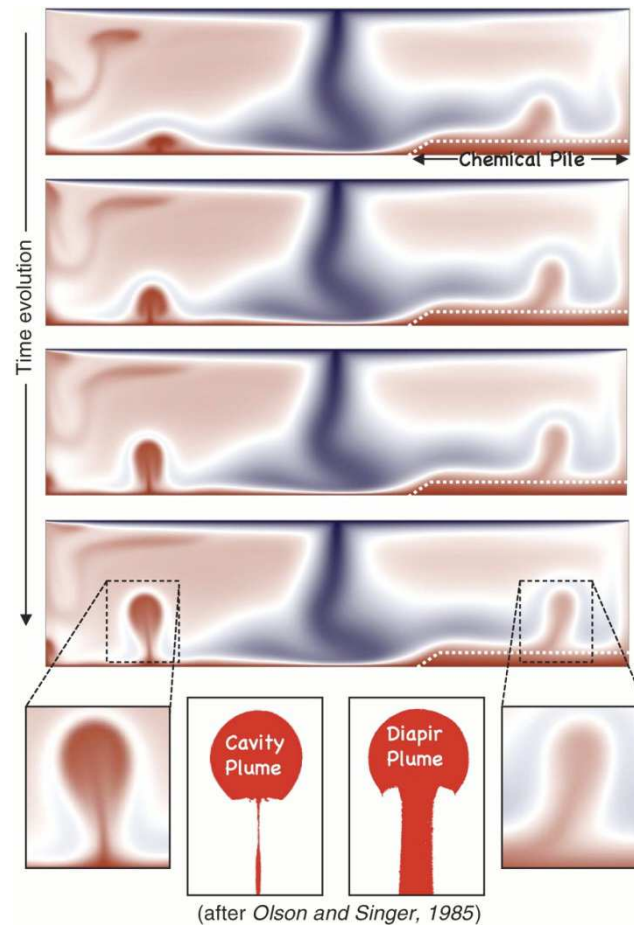


(D2)



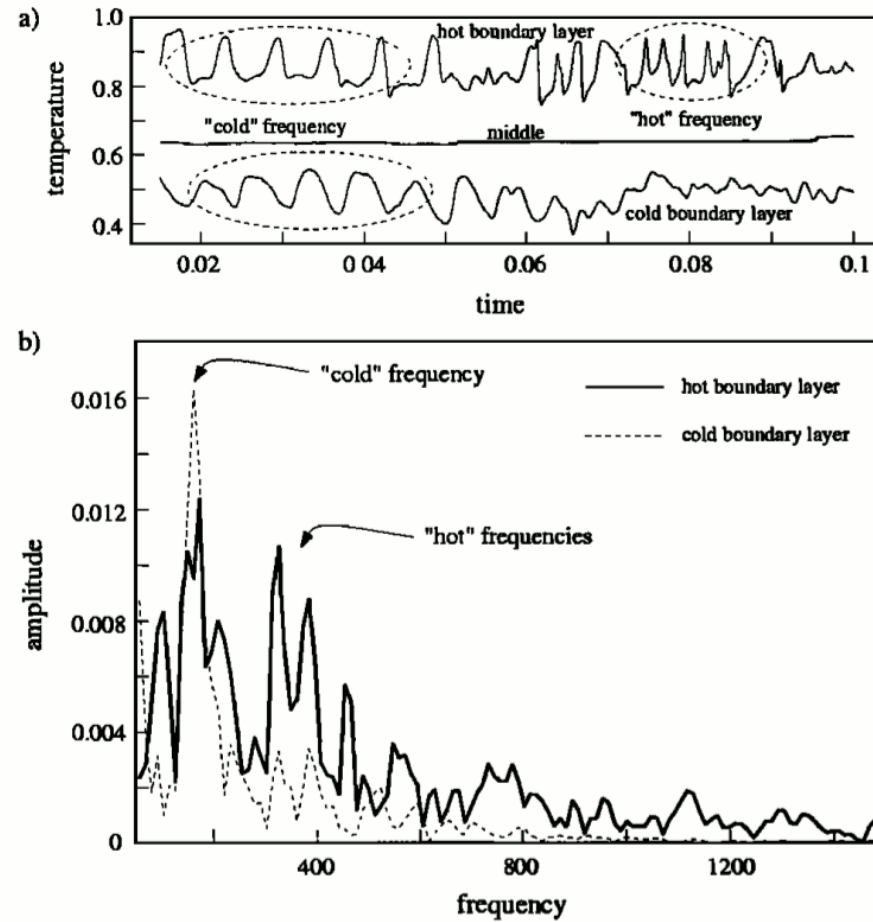
Tan & Gurnis, 2006 JGR

Plumes from Chemical Layer



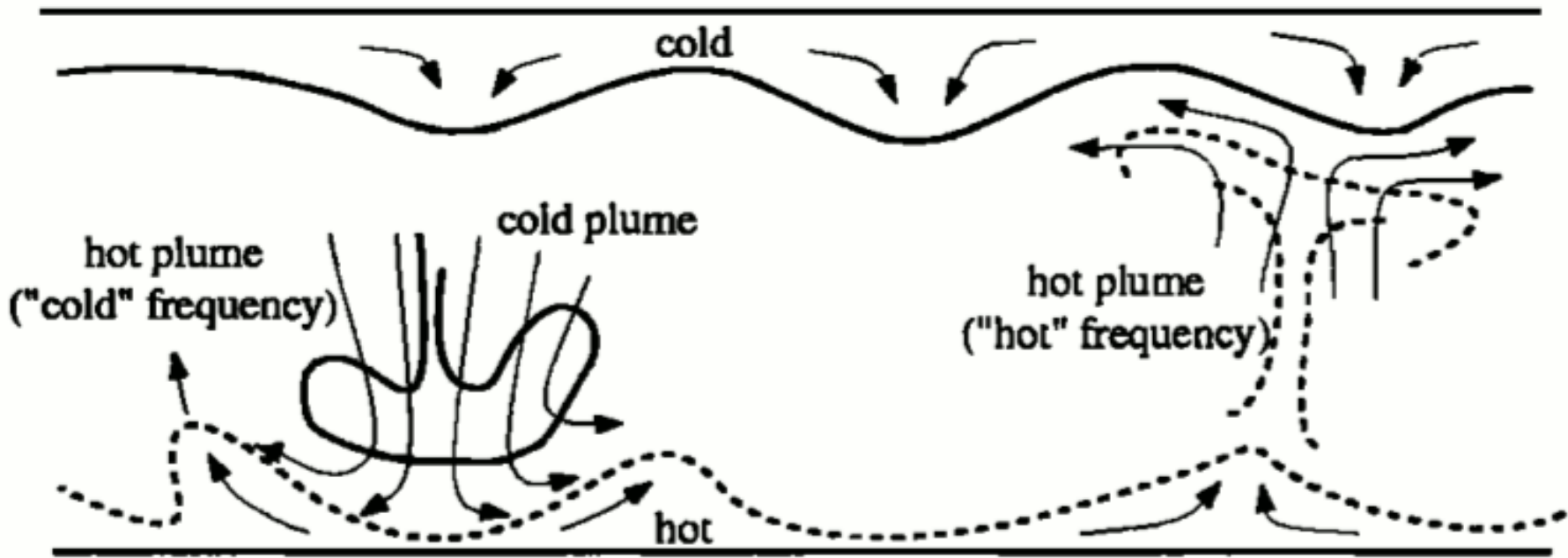
Lenardic, 2011 G^3

Downwellings & Plumes



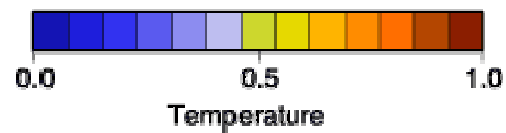
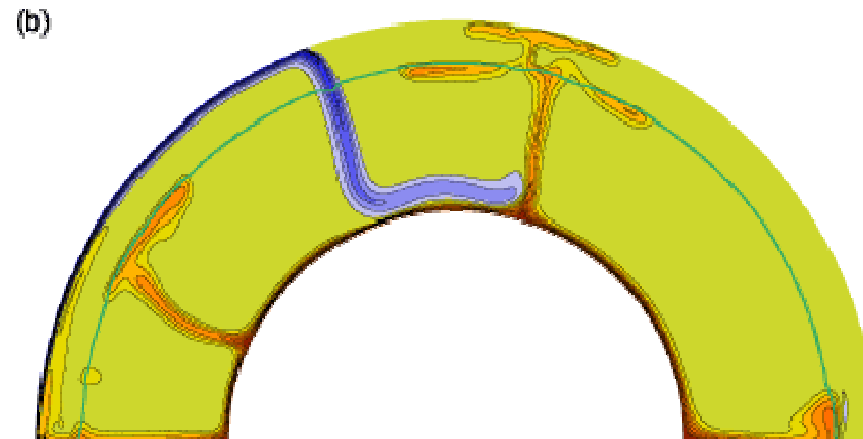
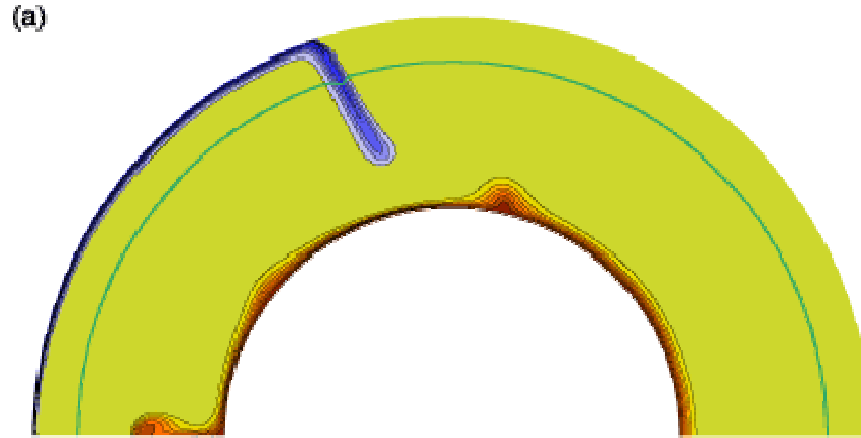
Schaeffer & Manga, 2001 GRL

Downwellings & Plumes



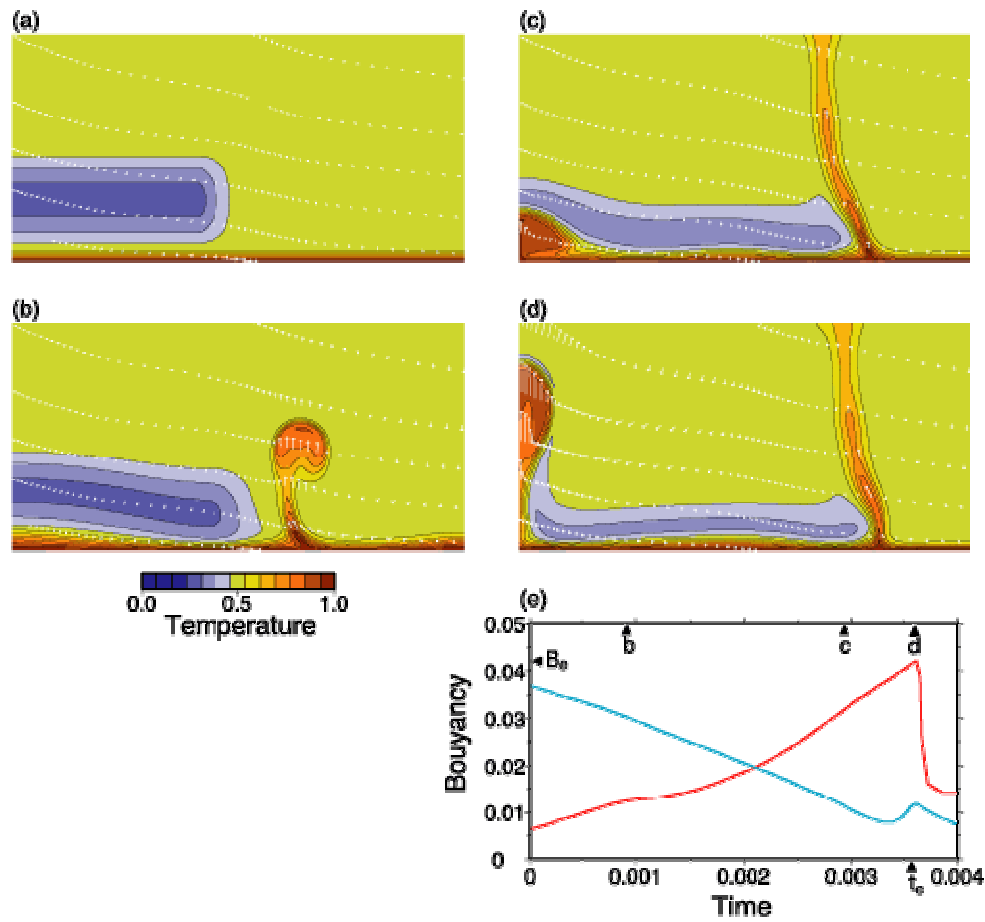
Schaeffer & Manga, 2001 GRL

Subducting Slab & Plume



Tan & Gurnis, 2002 G^3

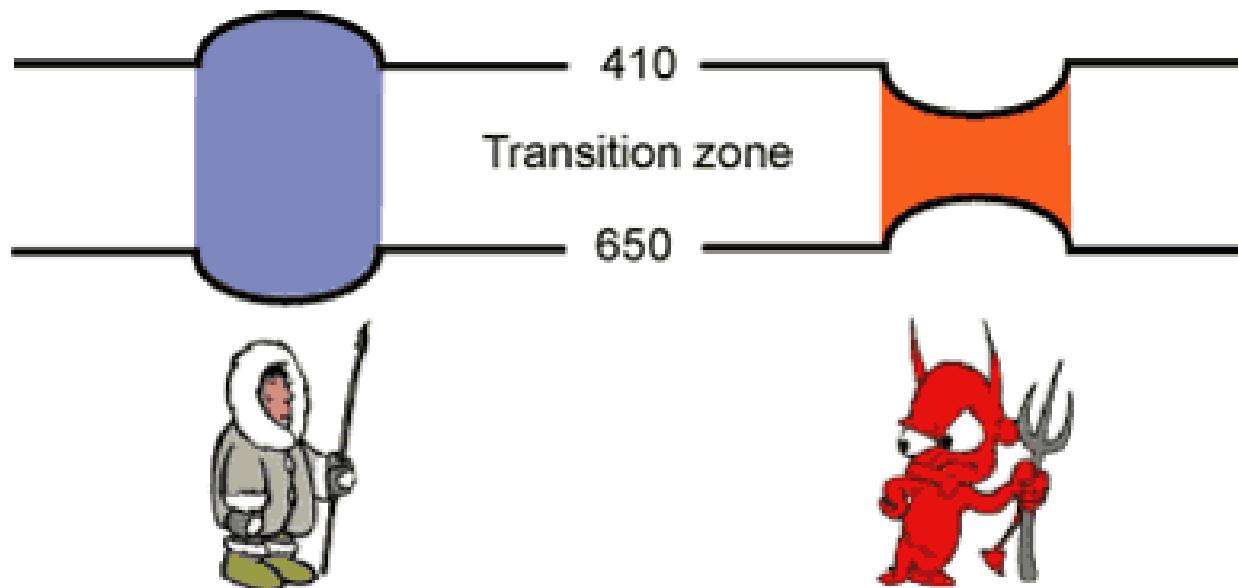
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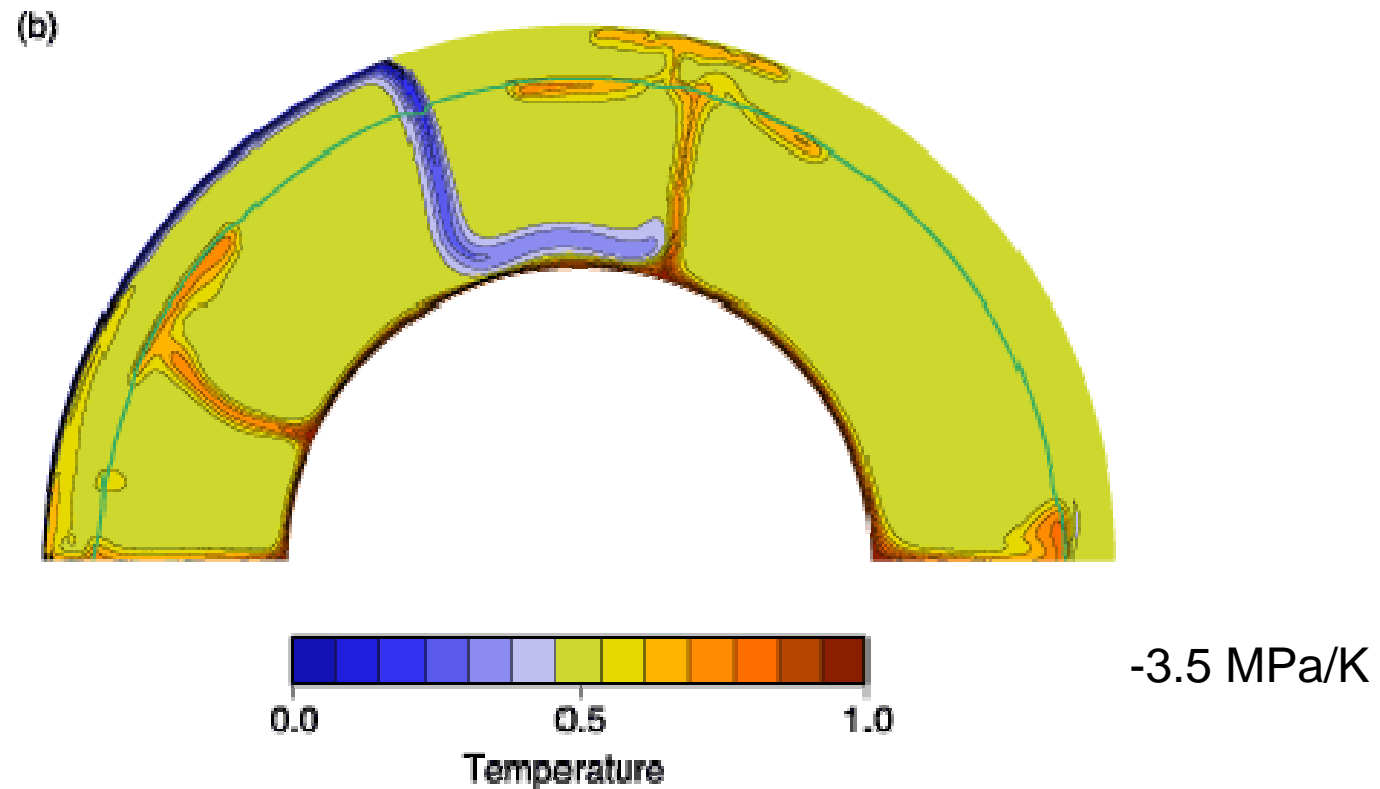
Tan & Gurnis, 2002 G^3

660-km Phase Change

The 660-km phase change has a negative Clapeyron slope, which will hinder the vertical flow.

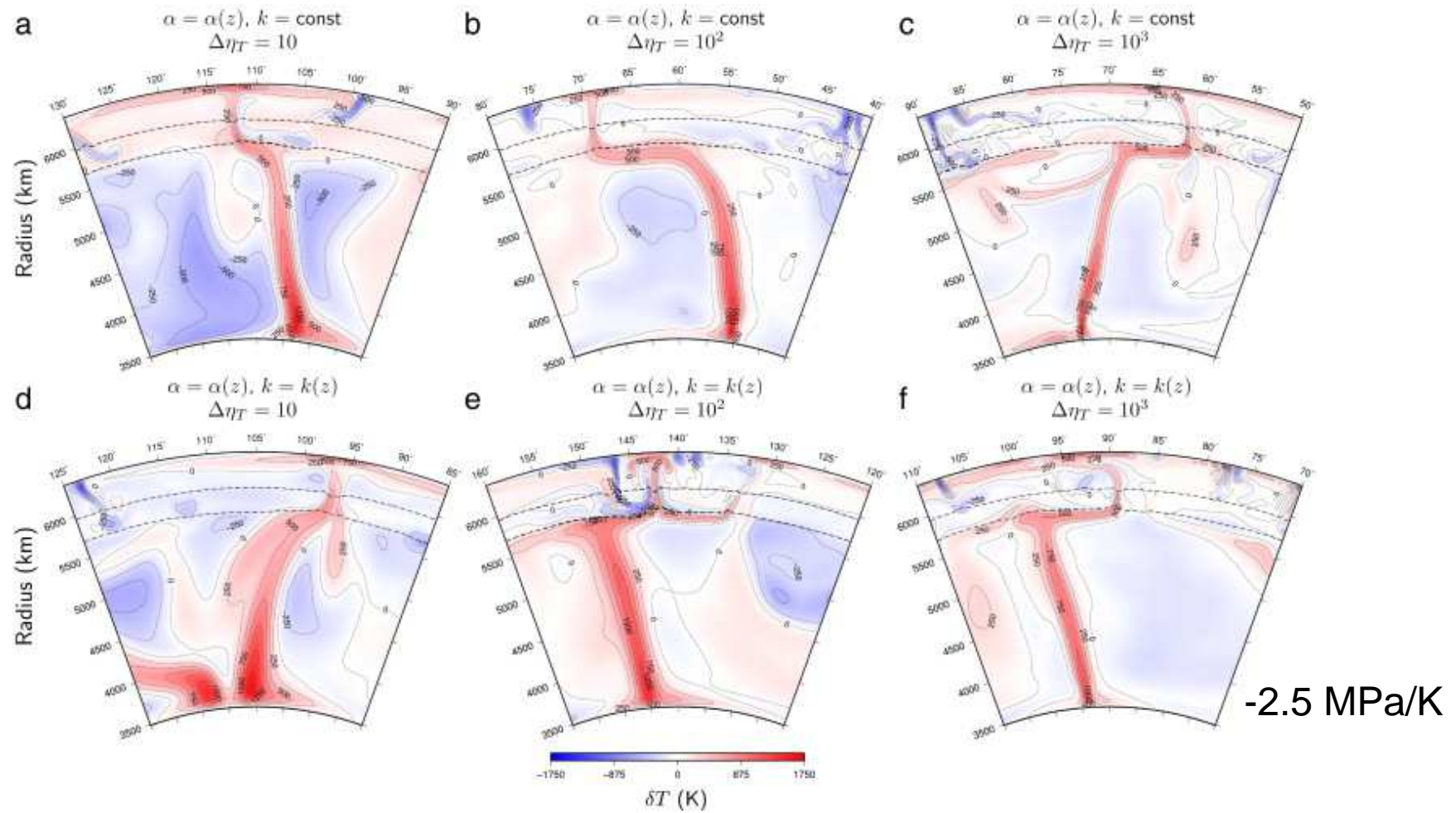


Effect of 660-km Discontinuity



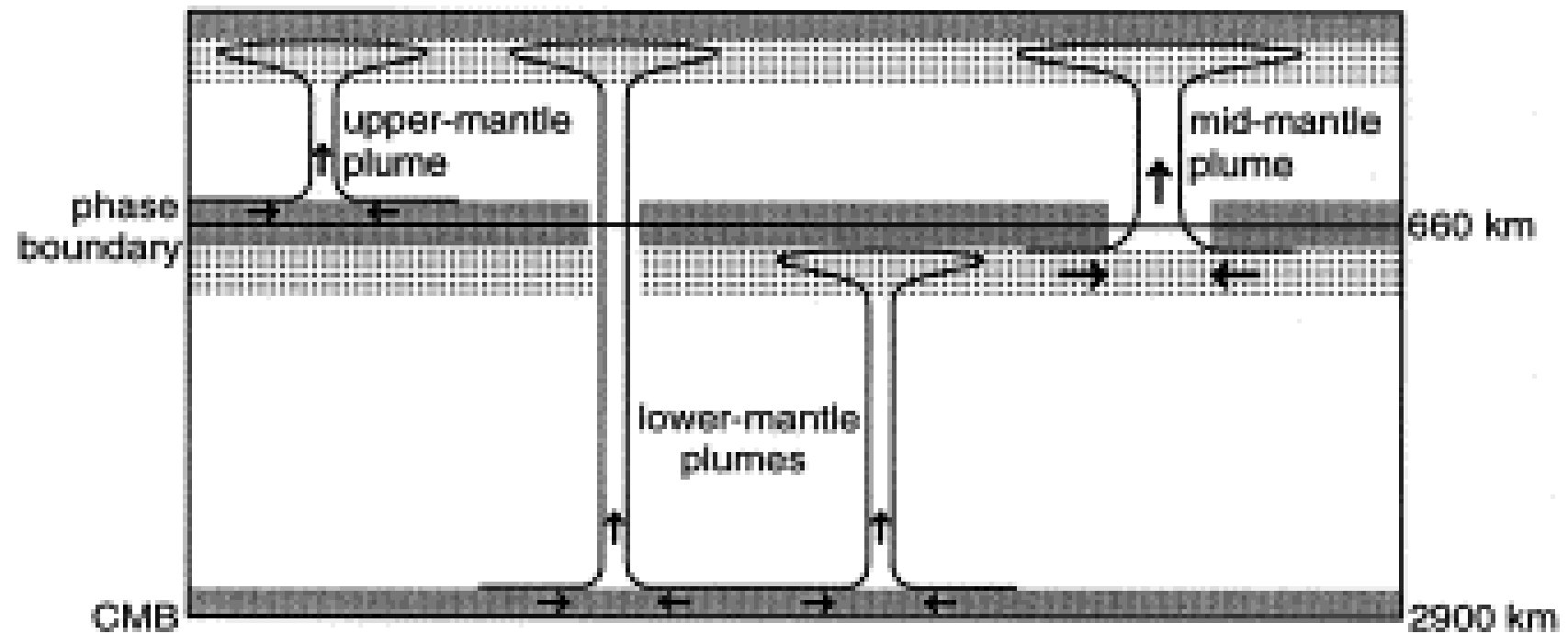
Tan & Gurnis, 2002 G^3

Side Channel Plume



Tosi & Yuen, 2011 EPSL

Upper-Mantle Plumes



Cserepes & Yuen, 2000 EPSL

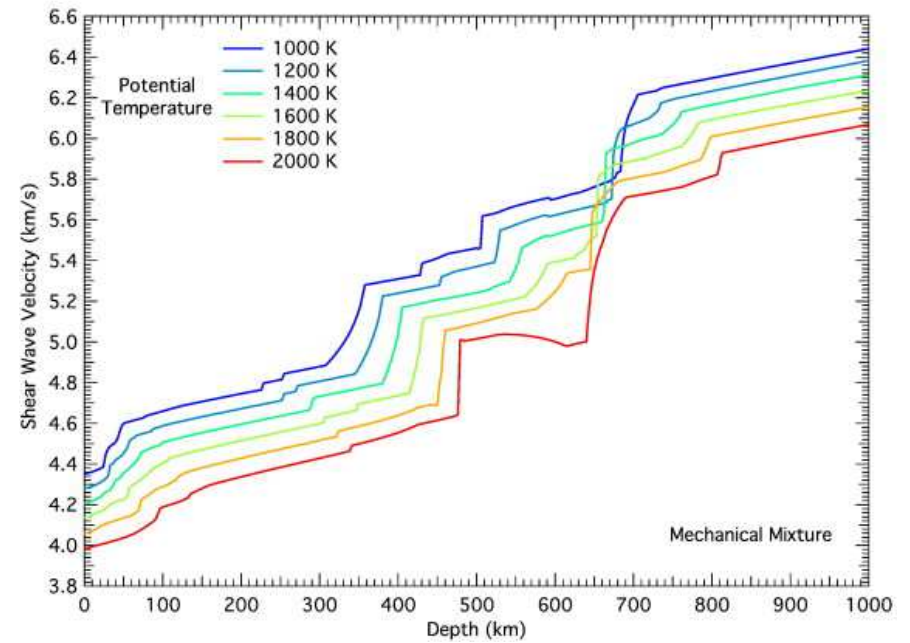
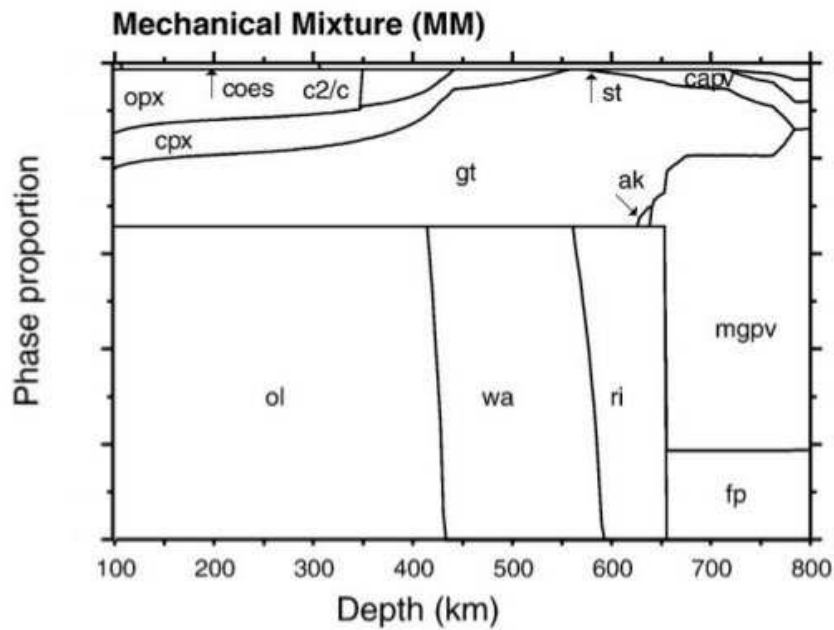
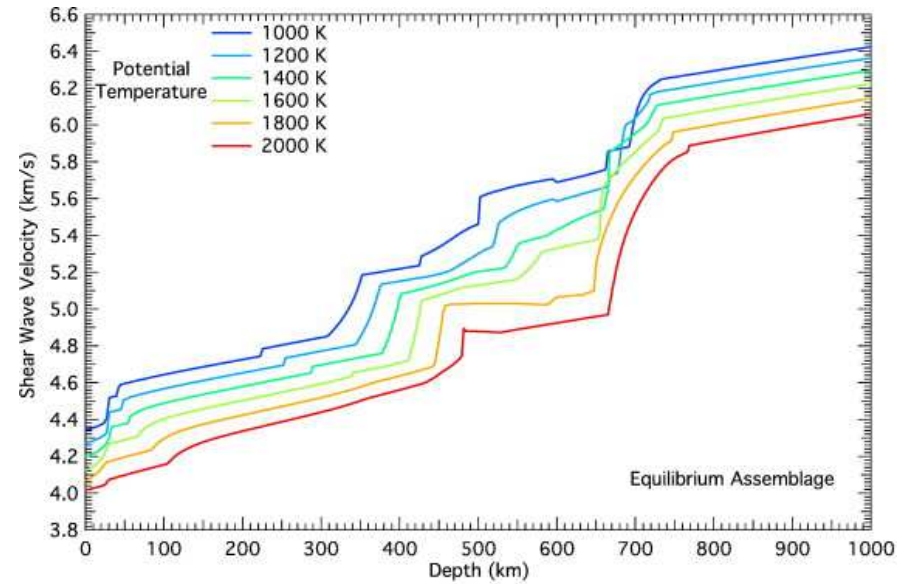
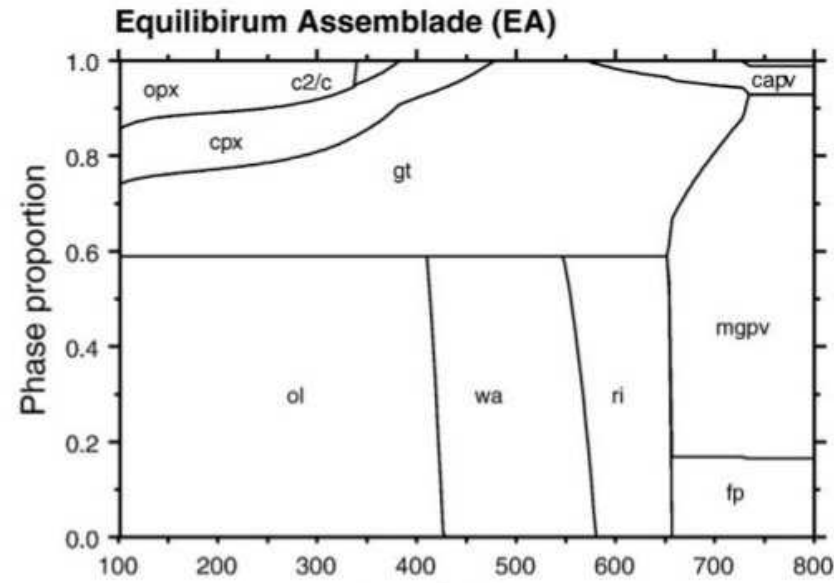
Mantle Pyrolite

- Oceanic lithosphere is composed of basalt + harzburgite (melt + residue at mid-ocean ridge)
- Partial melting of “primitive mantle” will produce basalt and the residue is harzburgite
- The composition of the unknown “primitive mantle” can be inferred from the composition of basalt and harzburgite, which are known
- Rock of the inferred composition is called pyrolite

Pyrolite

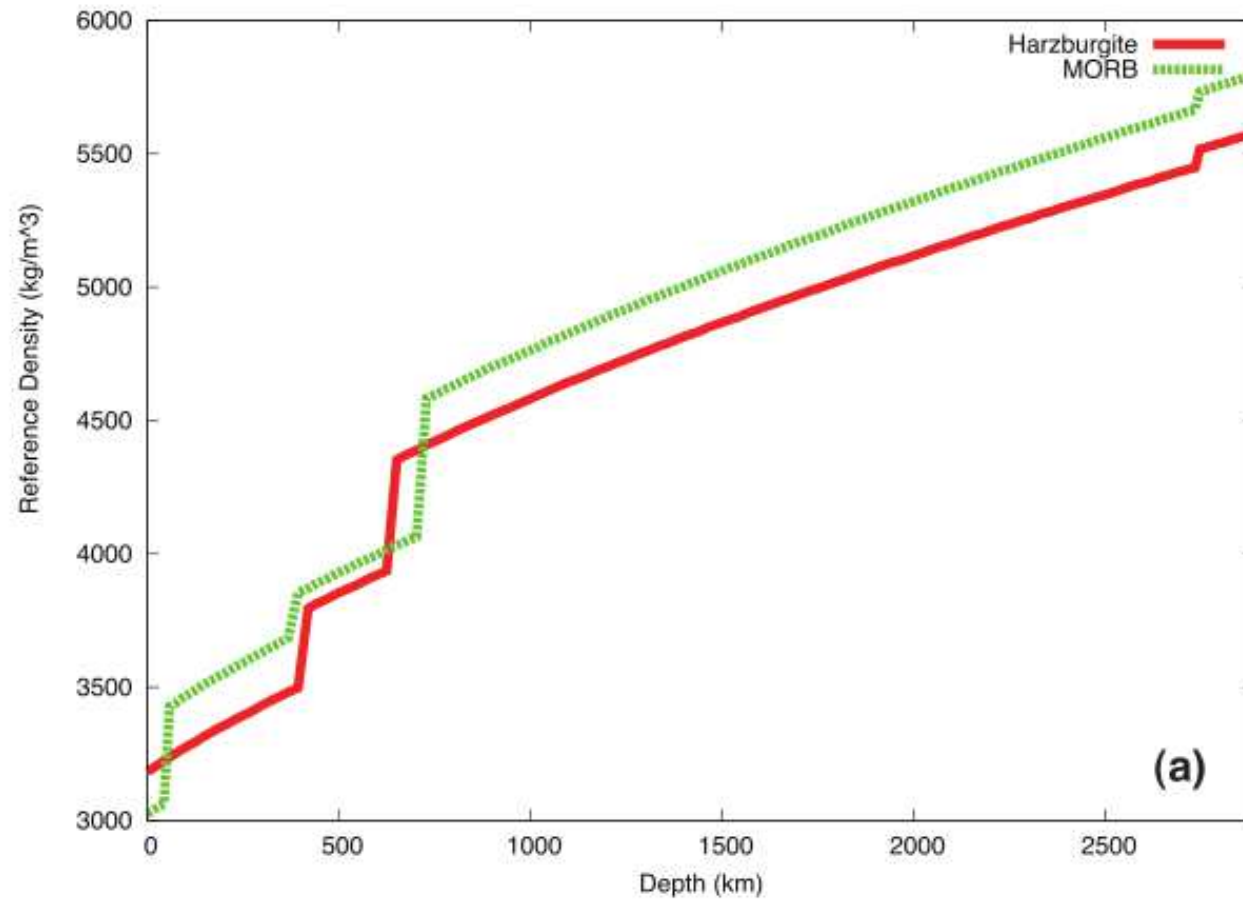
- **Is there any “primitive mantle” left today?**
 - Assuming the production rate of the MOR is constant through time, a volume equal to twice of the whole mantle has been processed by MOR [Asimov, 2002, J. Petrology]
- **Pyrolite may not exist on present-day mantle**
- **The present-day mantle may be mixed layer of basalt and harzburgite (marble cake), whose bulk composition is equivalent to pyrolite**





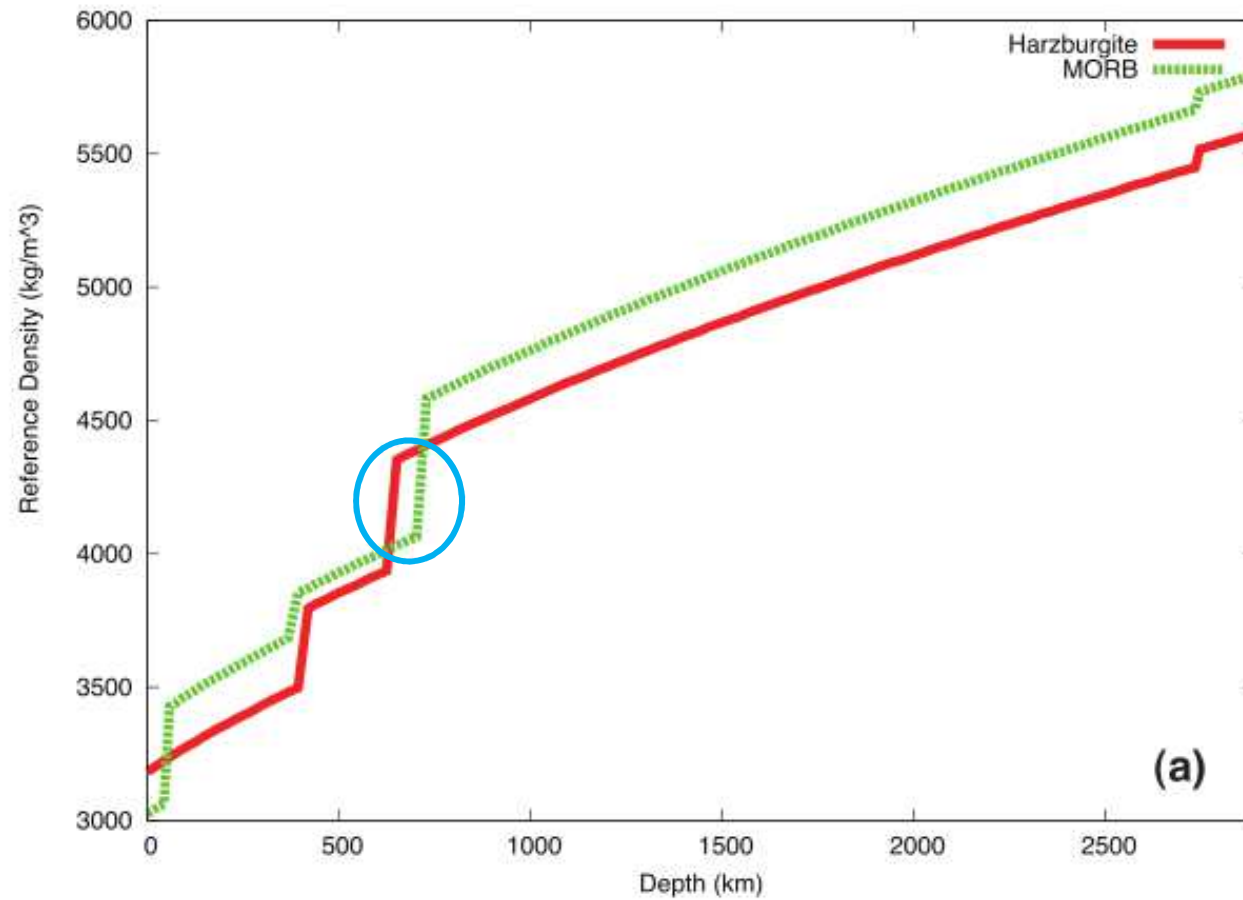
Xu et al., 2008 EPSL

Basalt Barrier



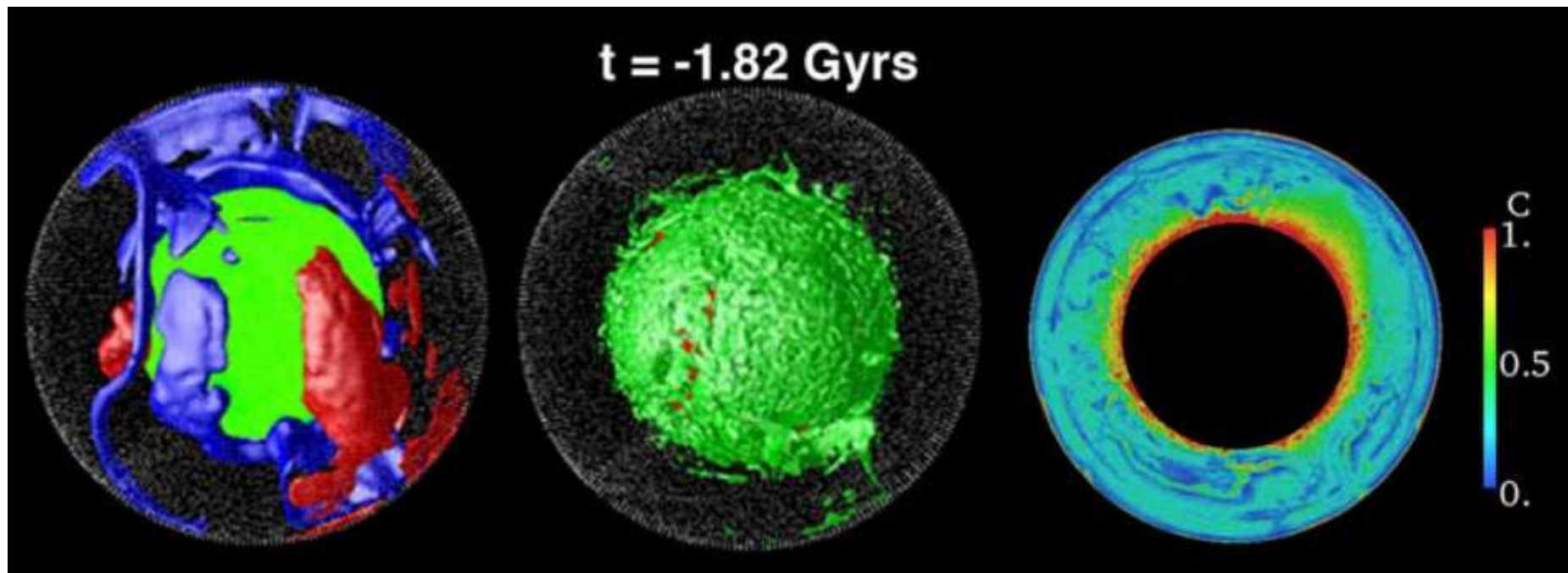
Nakagawa & Tackley, 2011 G³

Basalt Barrier

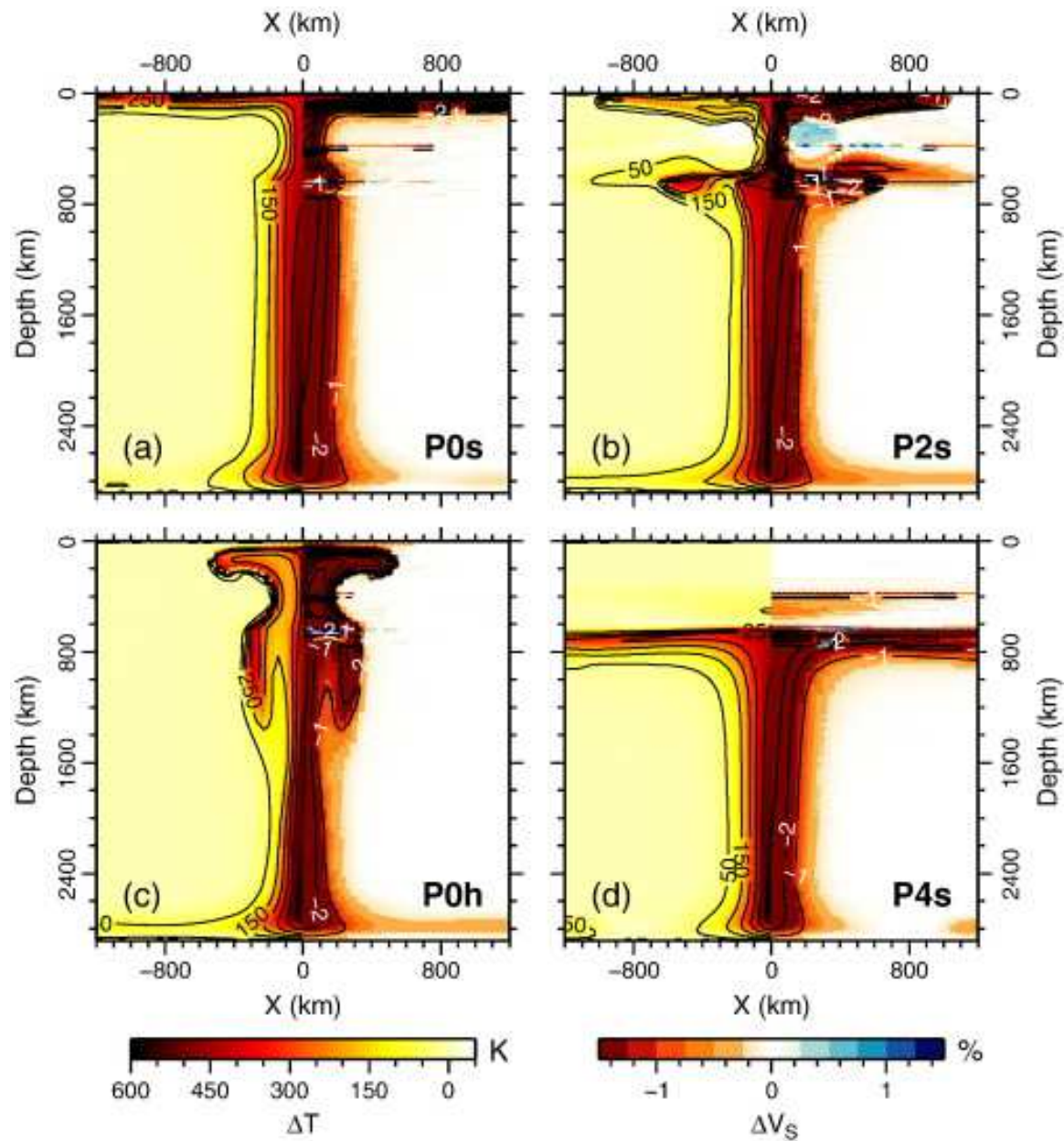


Nakagawa & Tackley, 2011 G³

Basalt Barrier



Nakagawa & Tackley, 2011 G^3

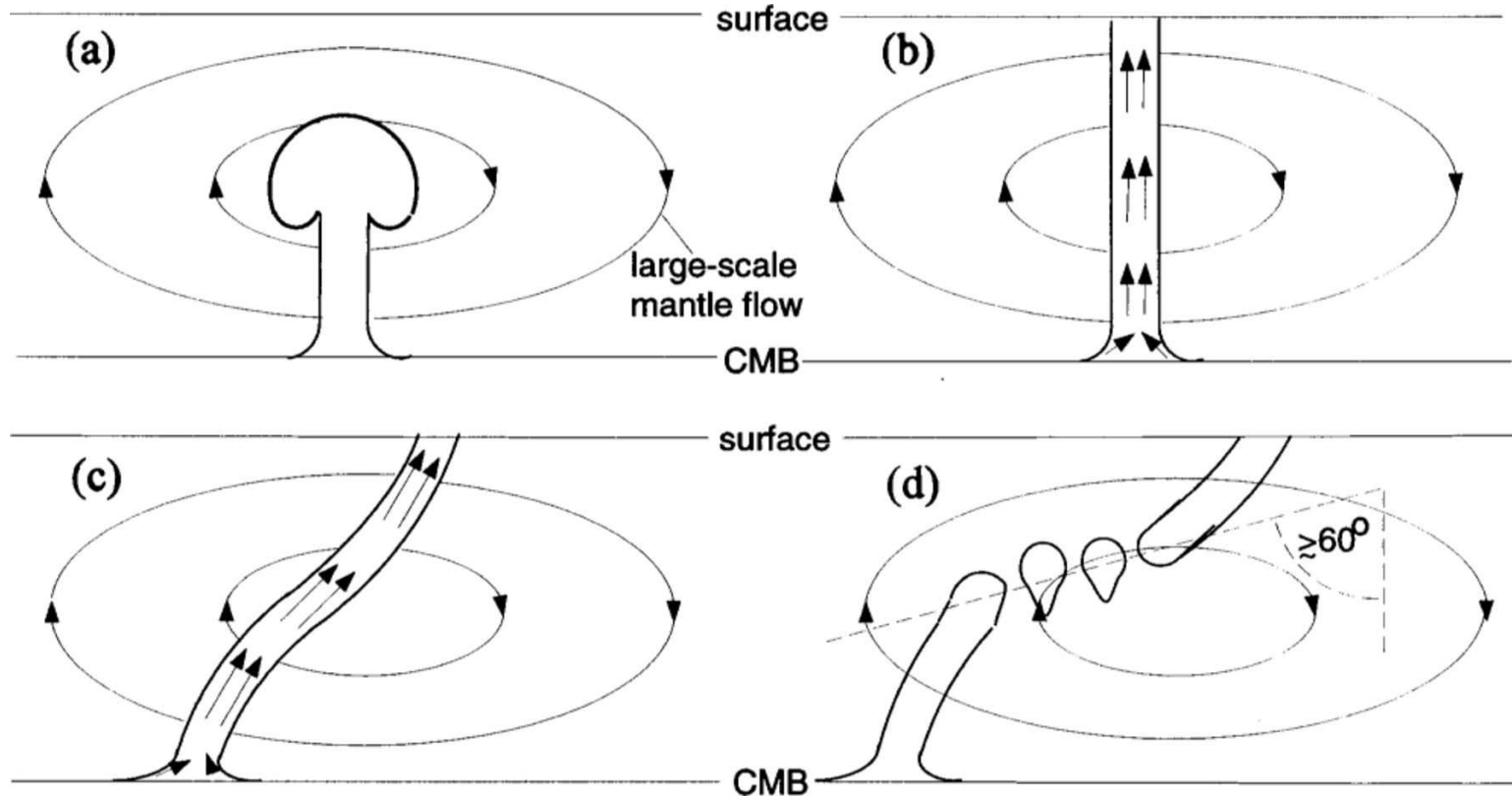


-2 MPa/K

-4 MPa/K

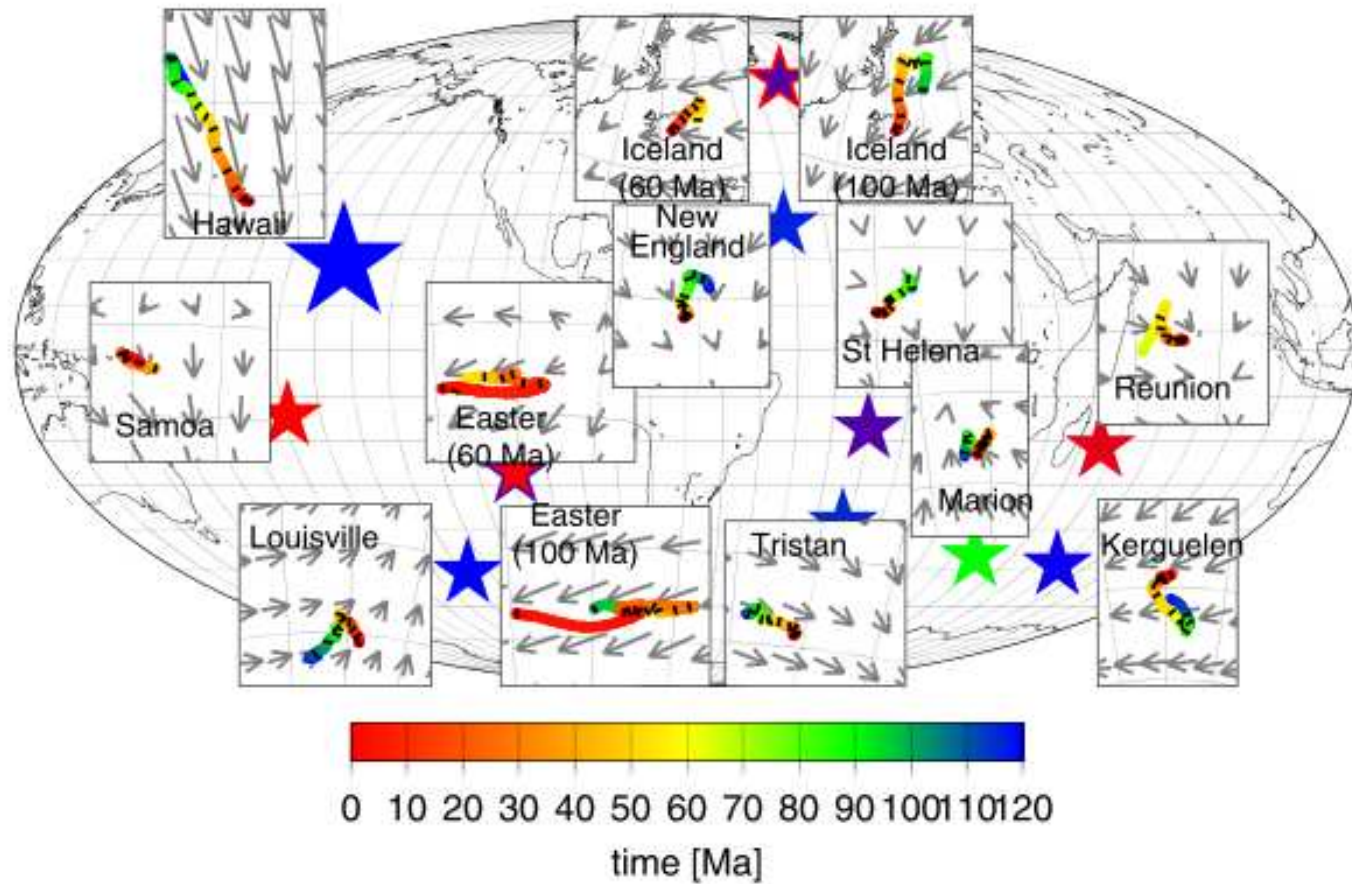
Styles et al., 2011 EPSL

Mantle Wind & Plume Conduit



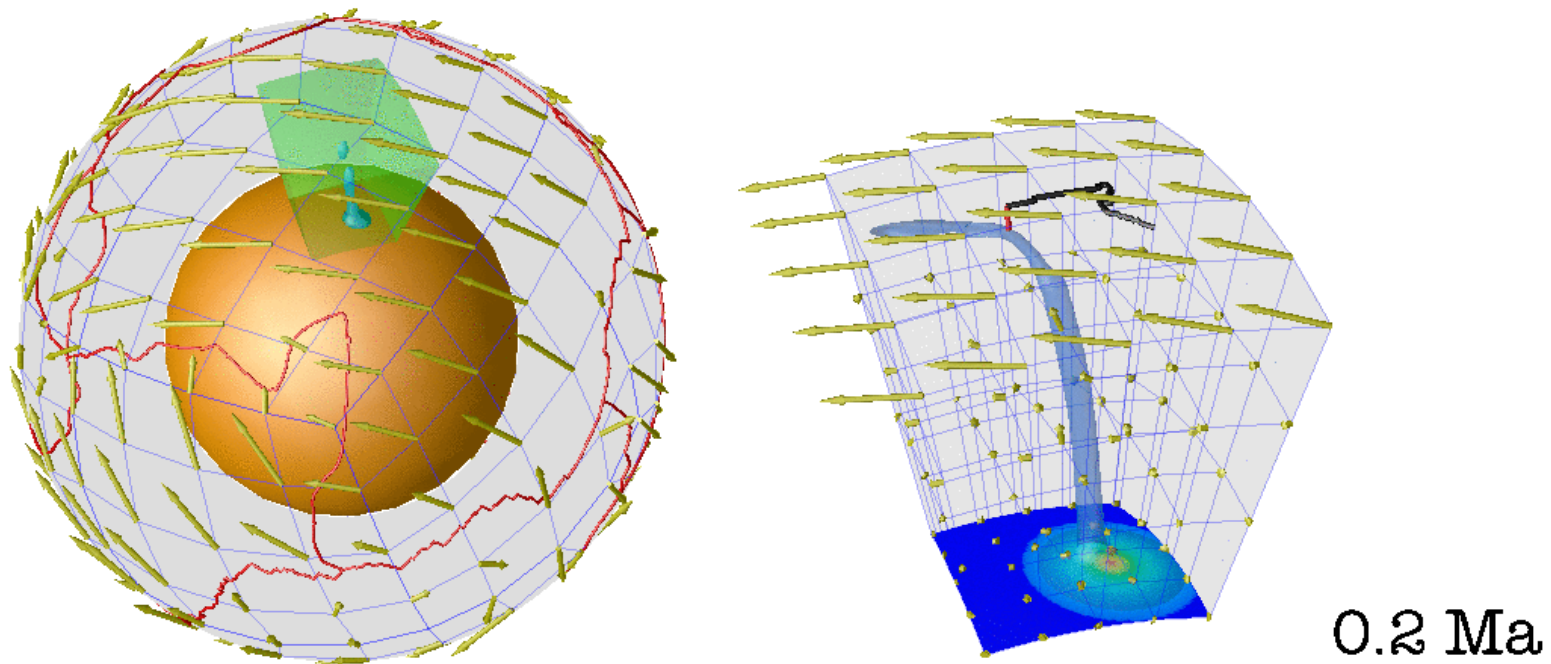
Steinberger & O'Connell, 1998 GJI

Mantle Wind & Plume Conduit



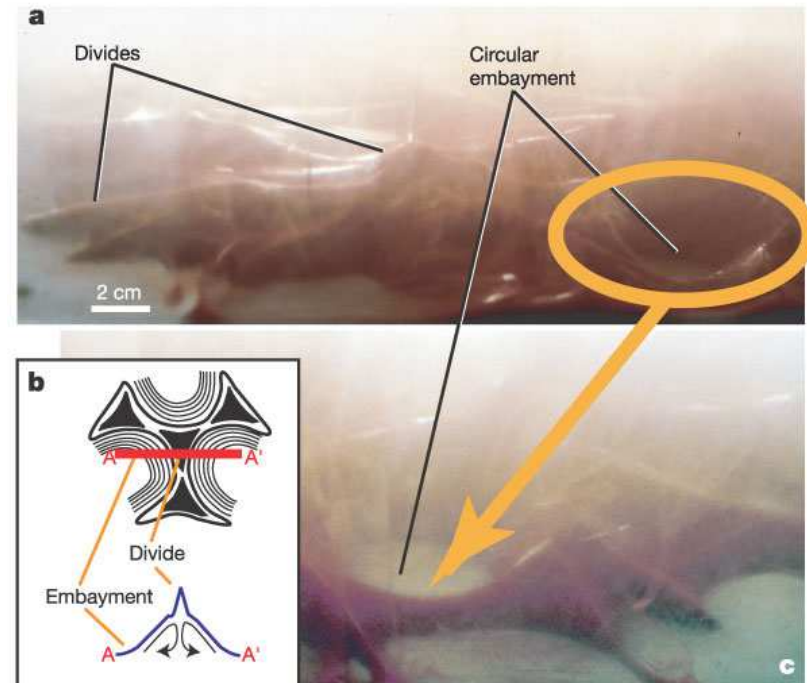
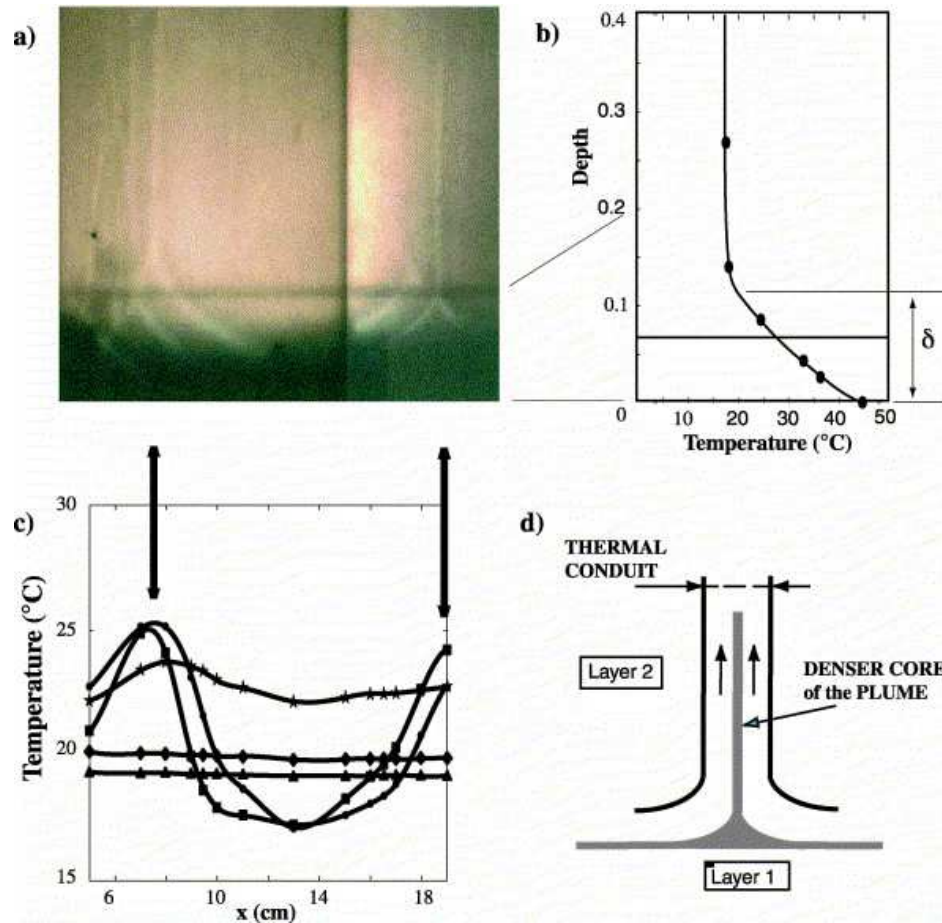
Steinberger & Antretter, 2006 G^3

Mantle Wind & Plume Conduit



Tan & Gurnis, 2004 G^3

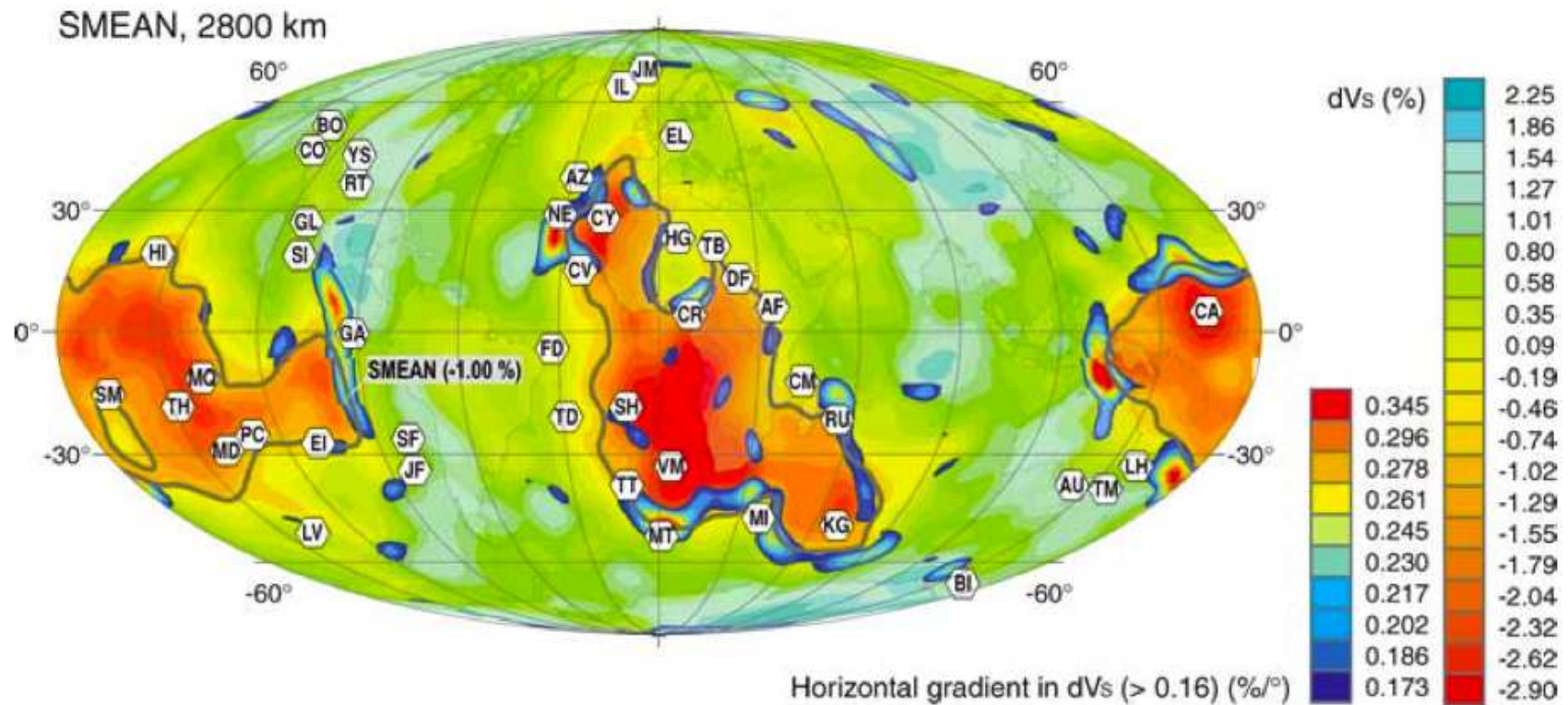
Plume Anchors



Davaille et al, 2002 EPSL

Jellinek & Manga, 2002 Nature

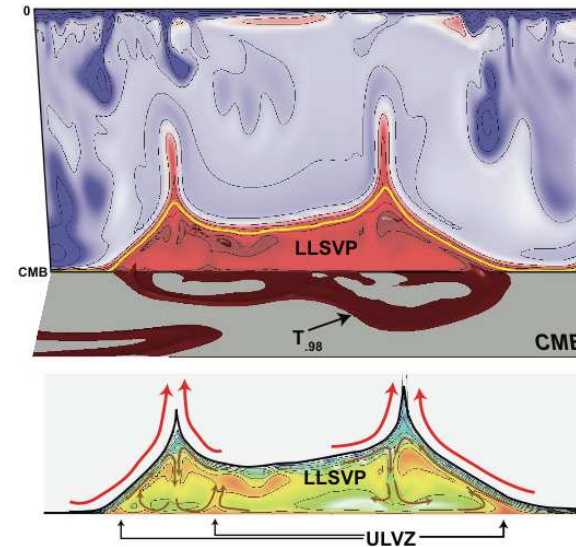
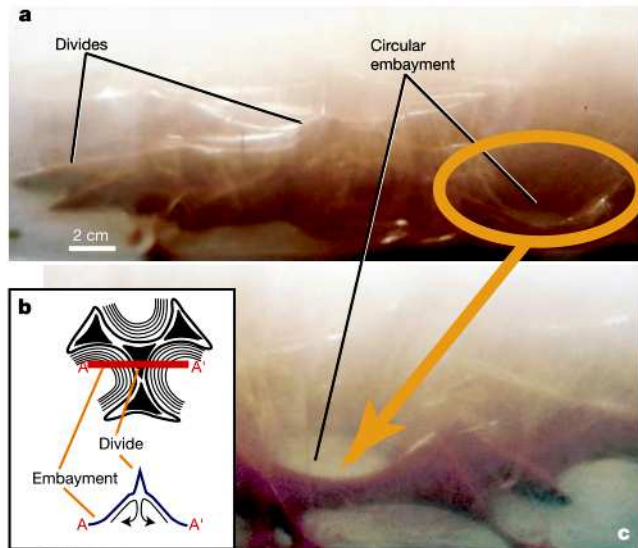
Plumes and LLSVPs



Torsvik et al, 2006 GJI

Plumes and LLSVPs

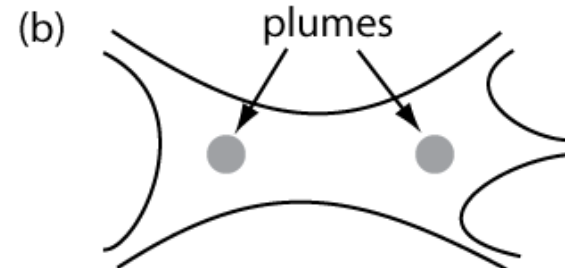
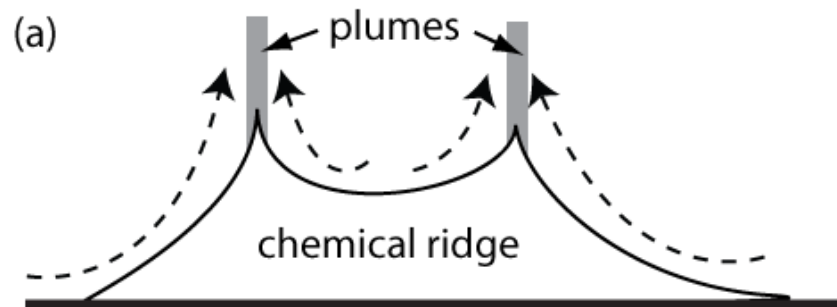
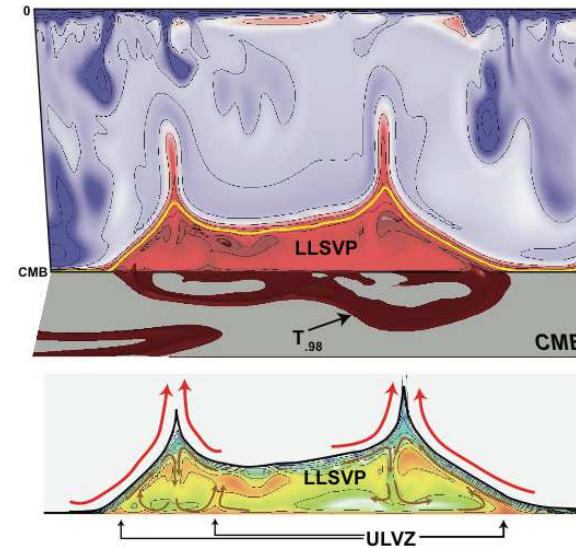
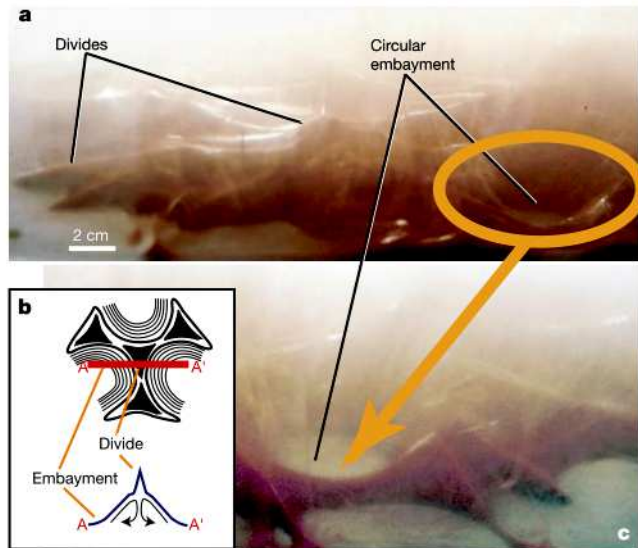
Most thermo-chemical convection models have plumes sitting on top of chemical structures.



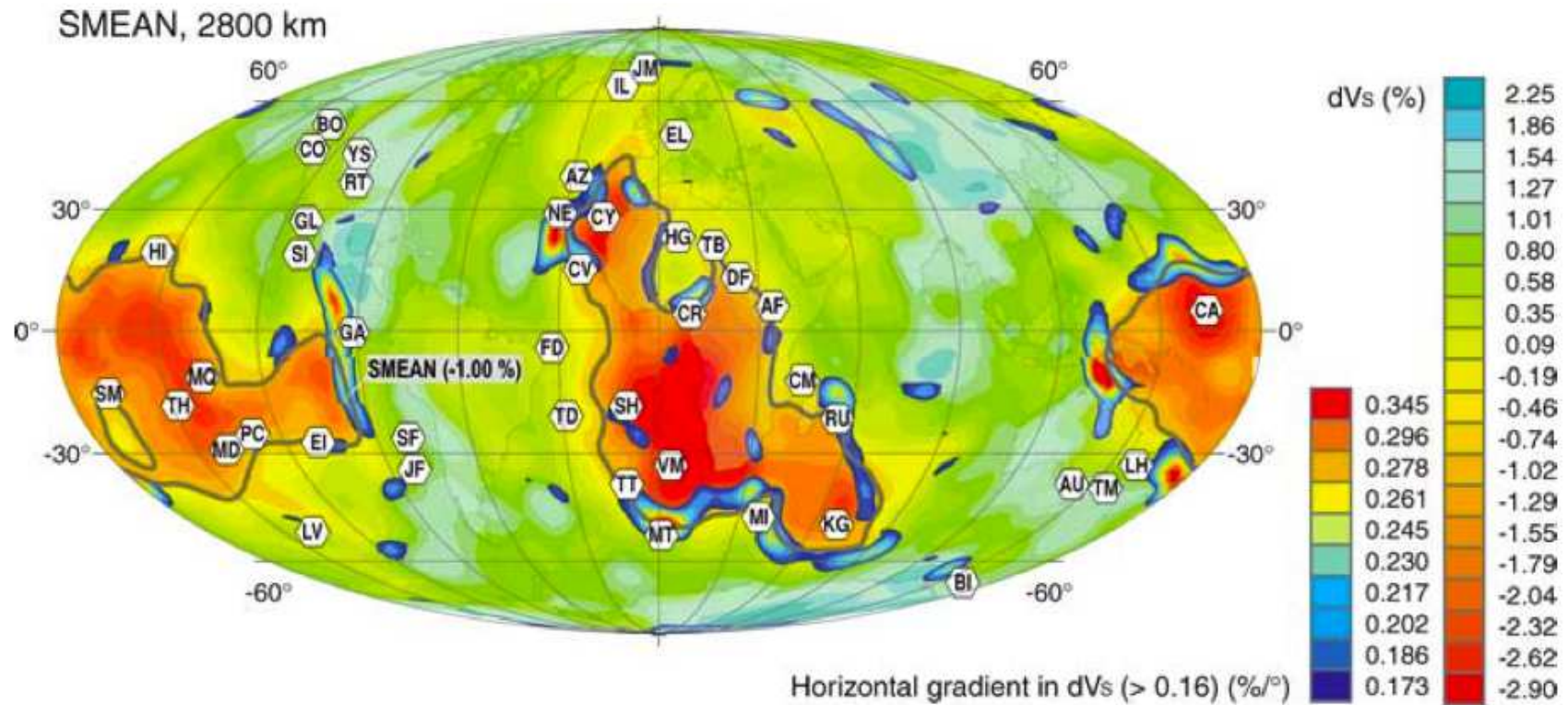
Jellinek & Manga, 2002 Nature Garnero et al, 2007 GSA

Plumes and LLSVPs

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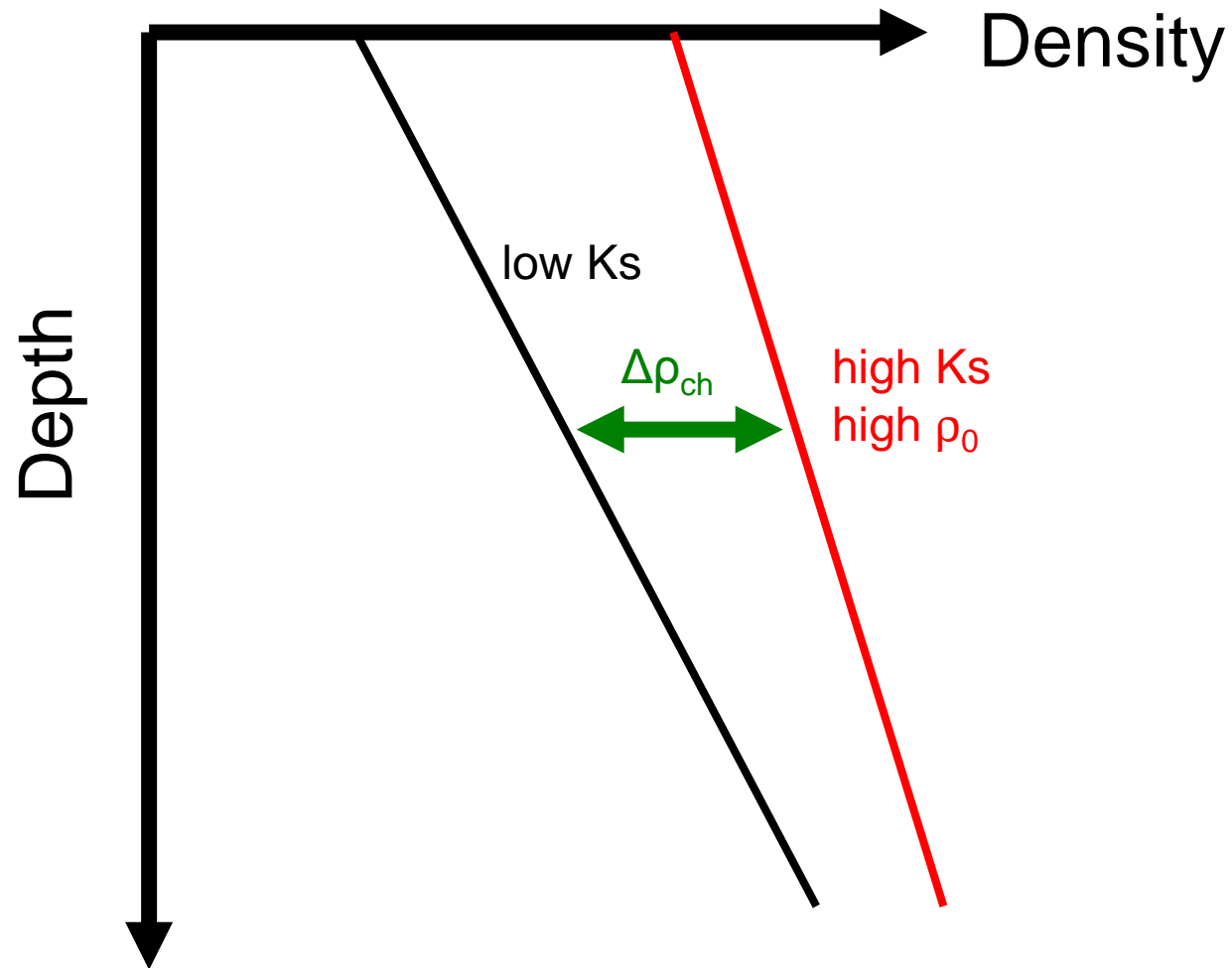


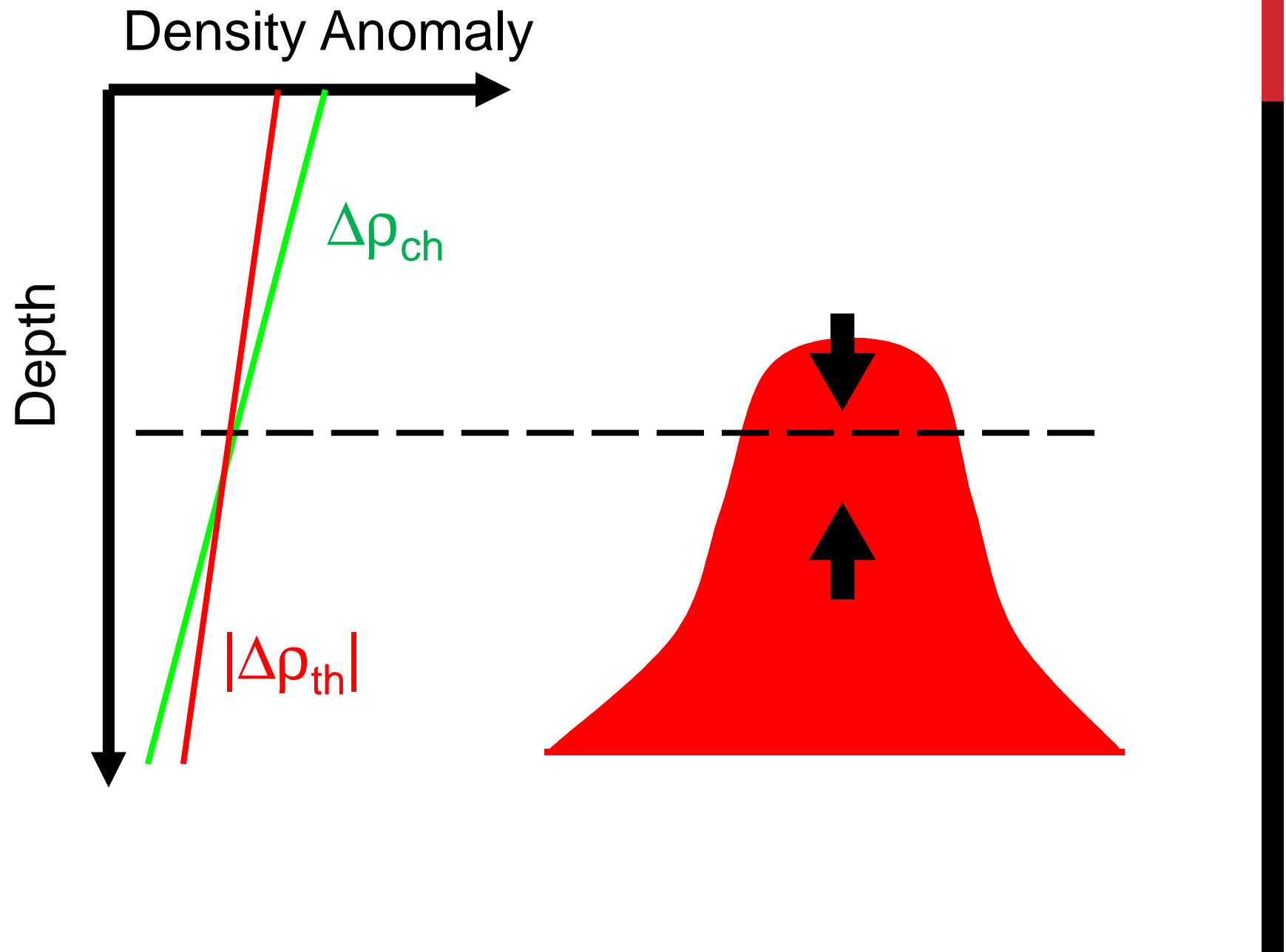
Plumes and LLSVPs

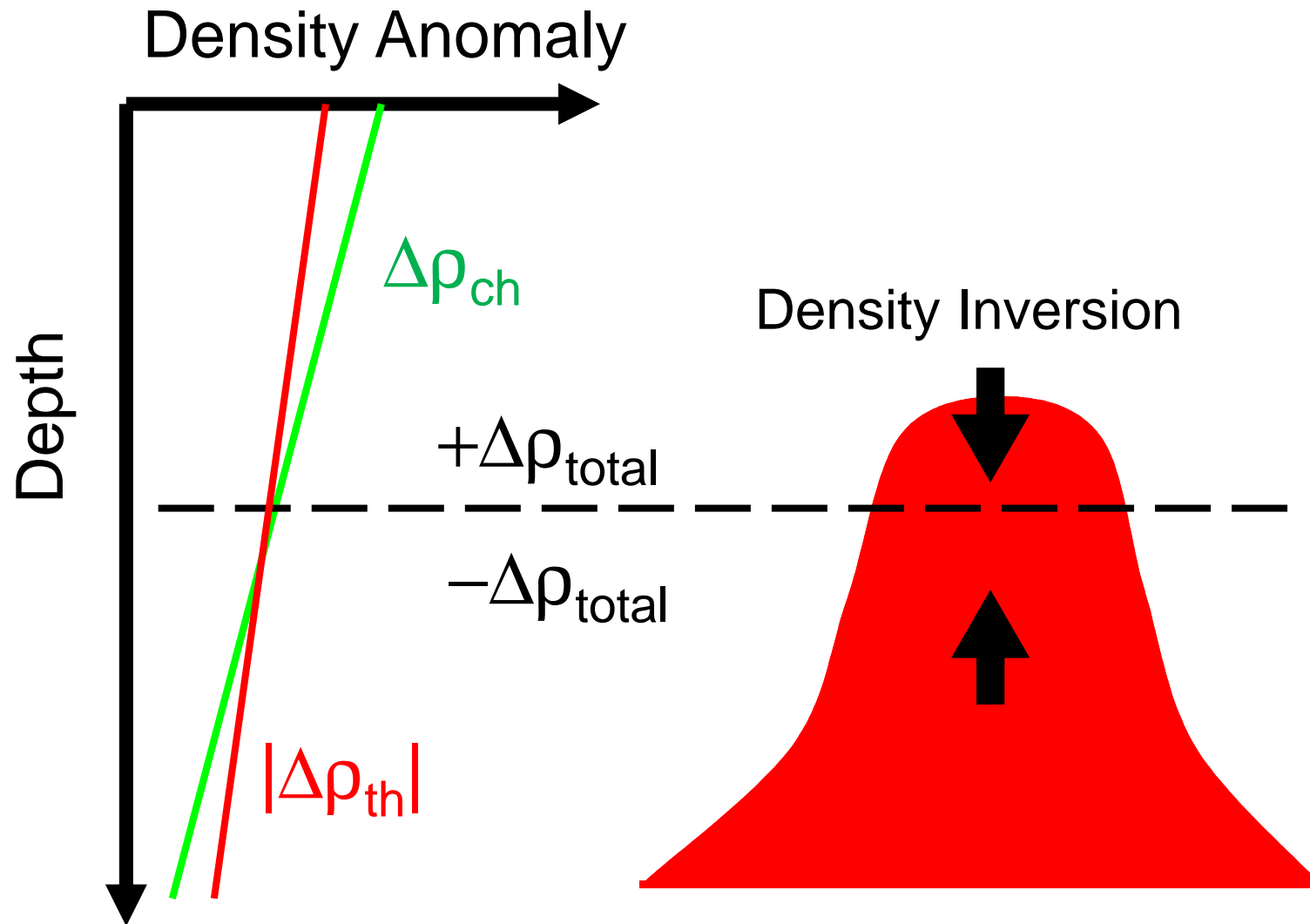


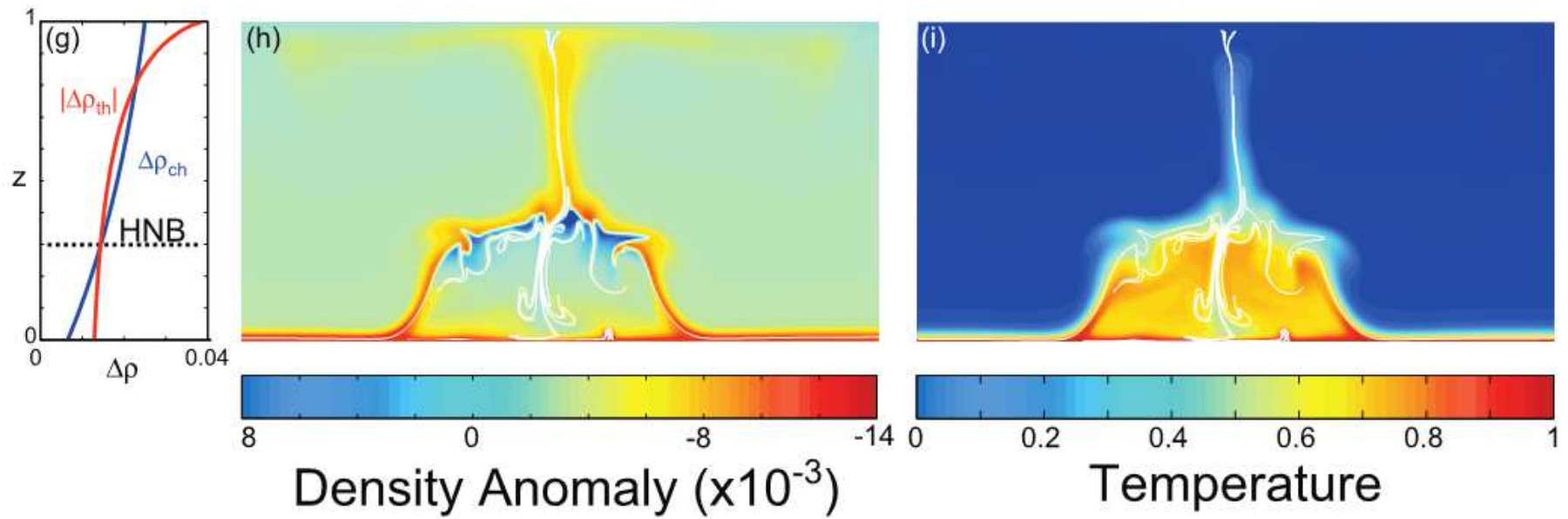
Torsvik et al, 2006 GJI

Bulk Modulus and Density Profiles

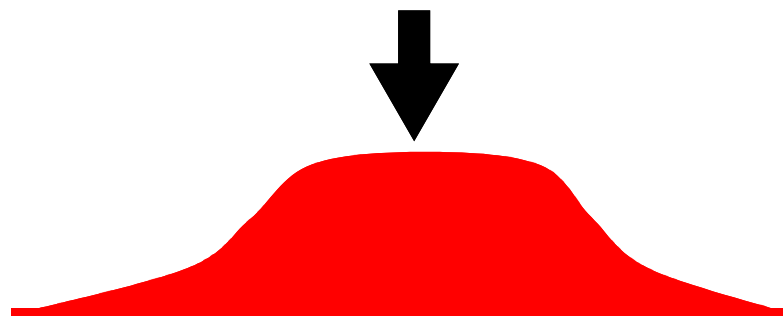
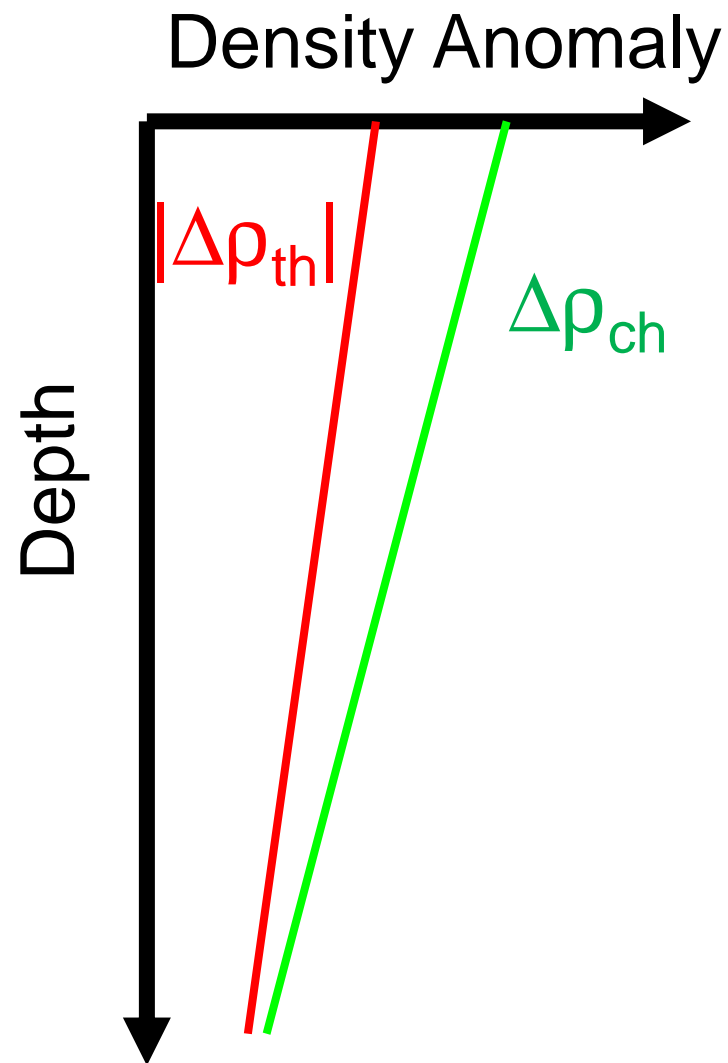


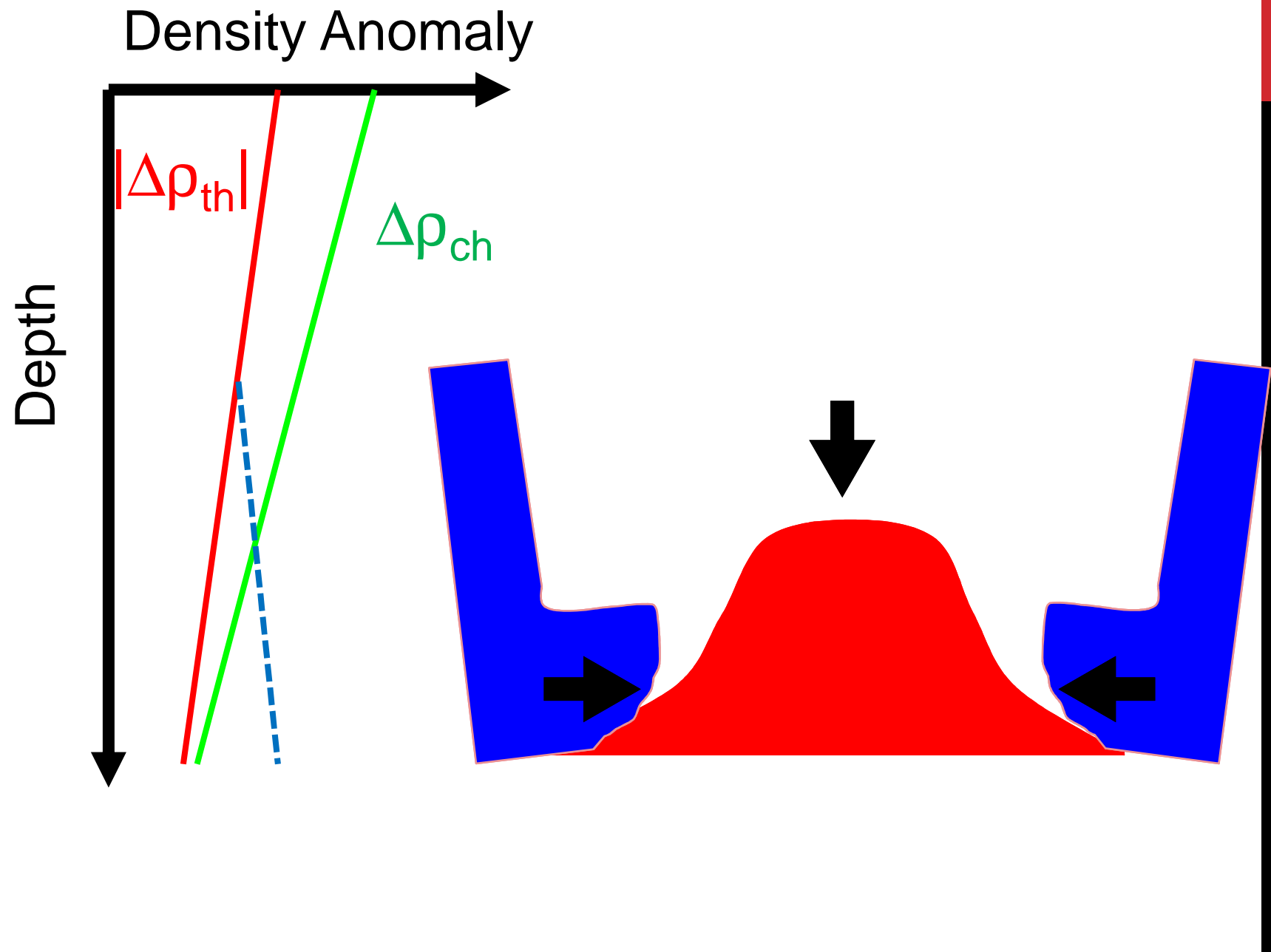




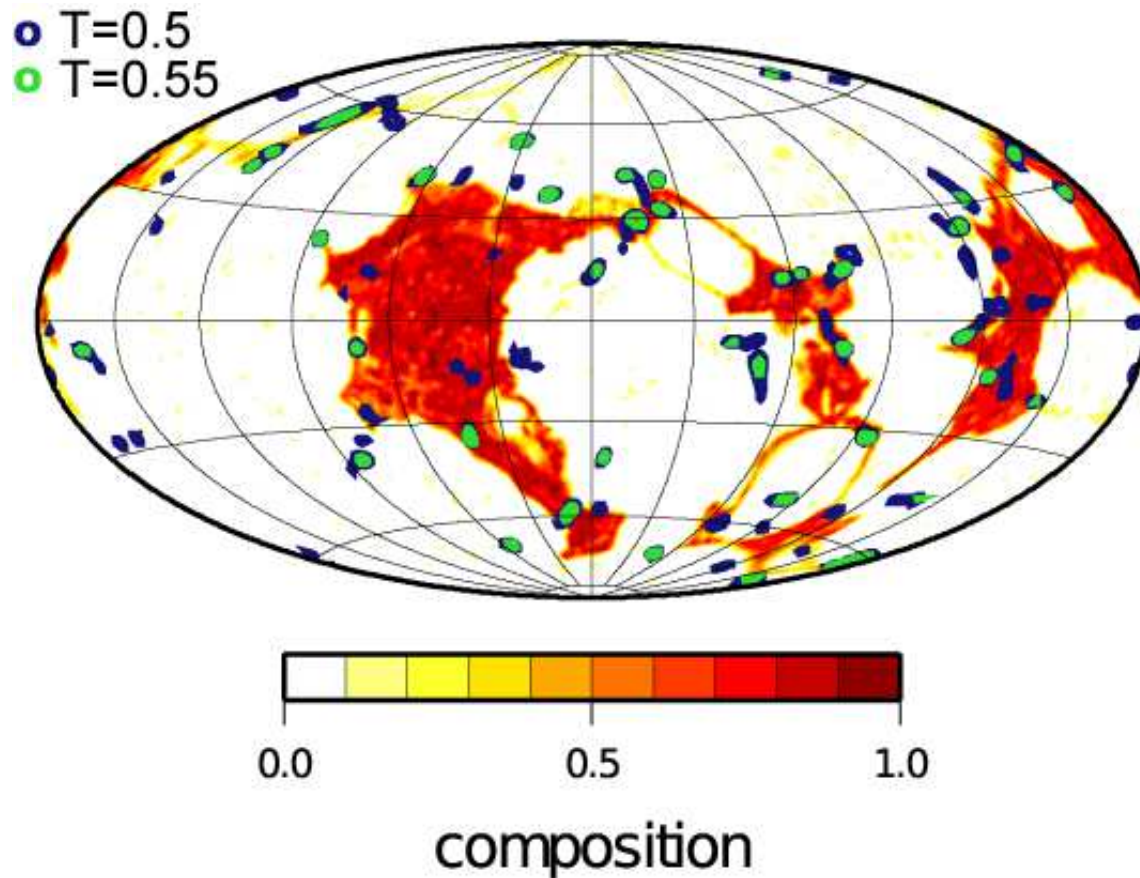


Tan & Gurnis, 2005 GRL





Plumes near Edges of Piles



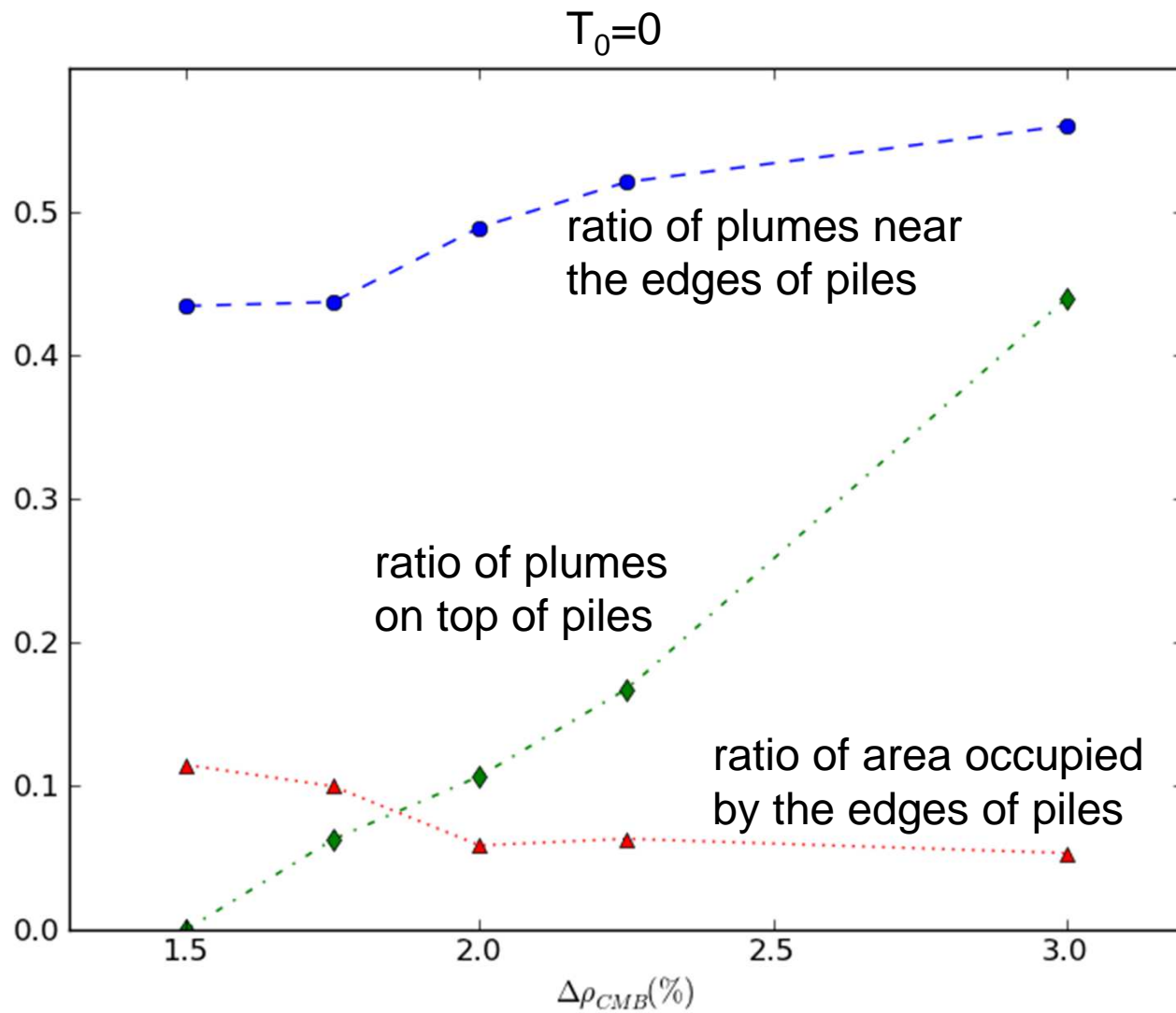
46 plumes with $T > 0.55$ (strong).

20 strong plumes (43.5%) near the edges of piles (within 5° distance).

Edges of piles cover 11.5% of CMB area.

0 strong plumes on “top” of piles.

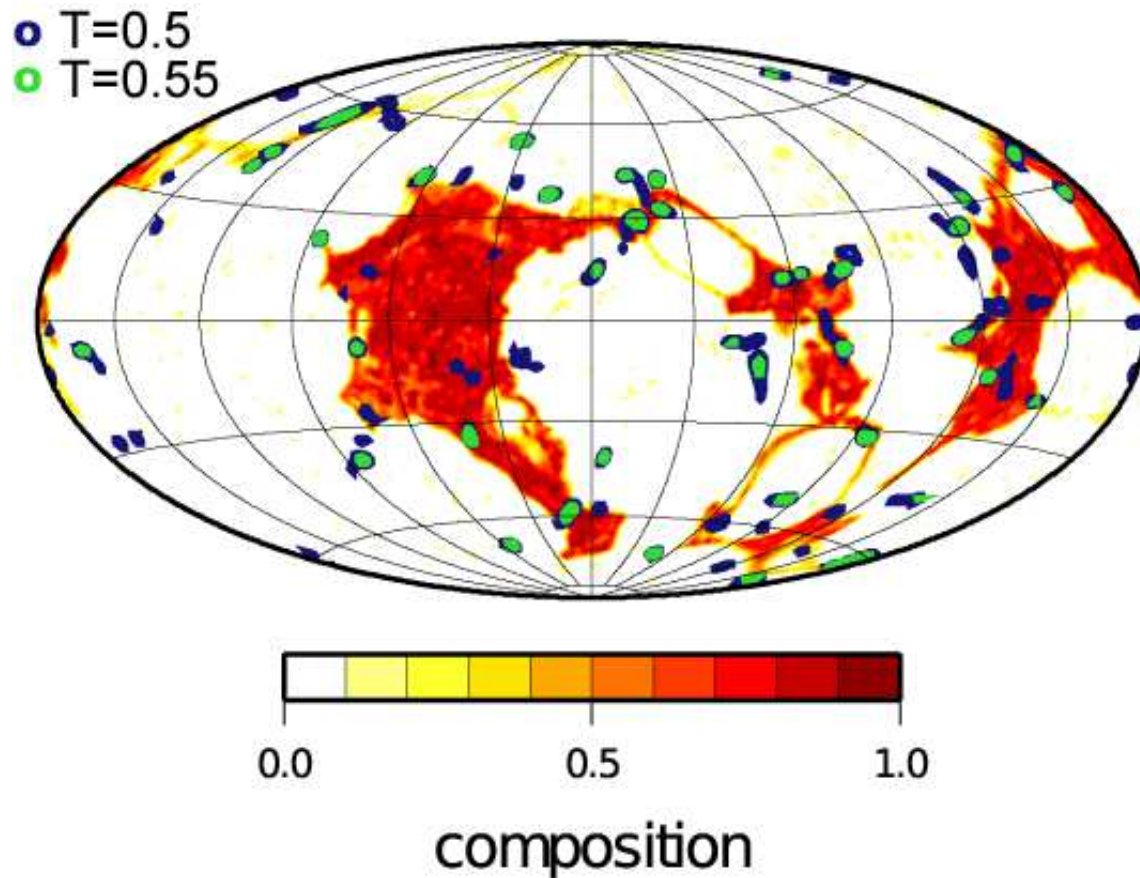
Piles cover 20% of CMB area.



Tan et al, 2011 G^3



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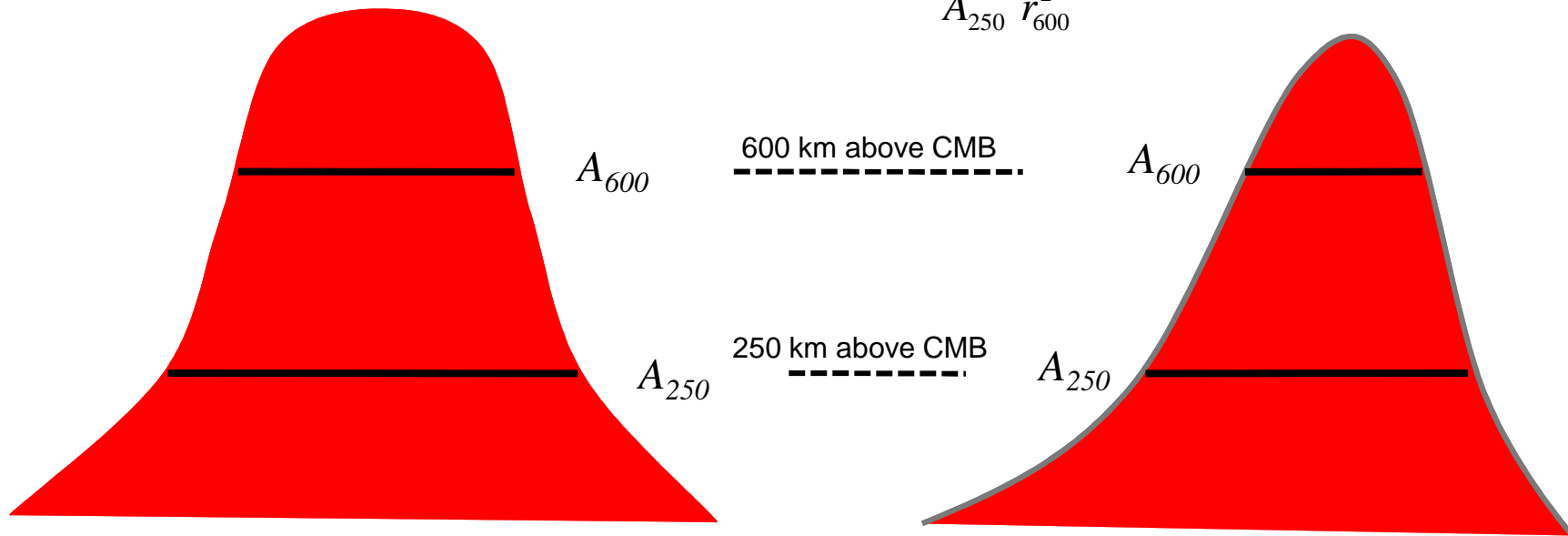
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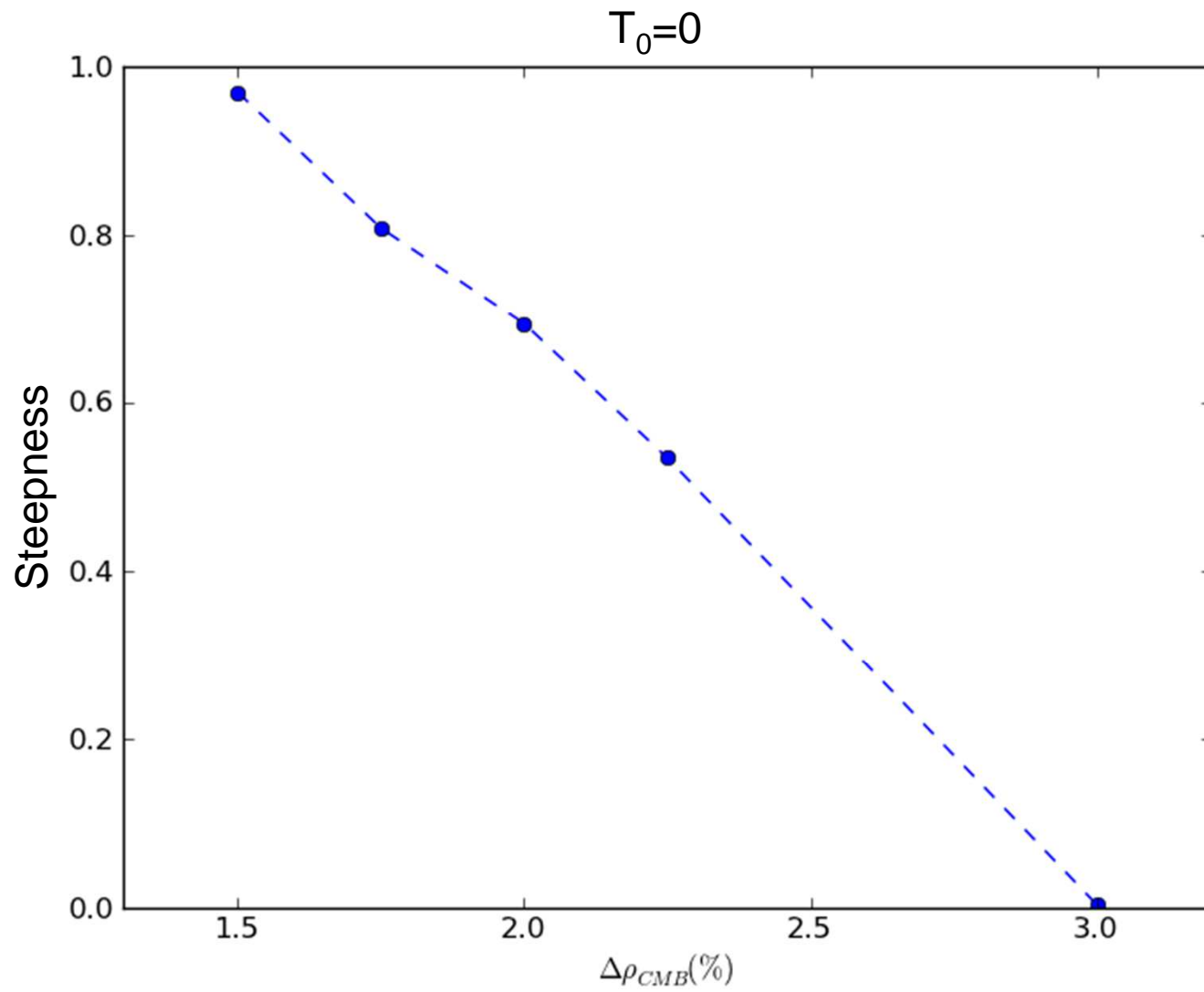
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Steepness

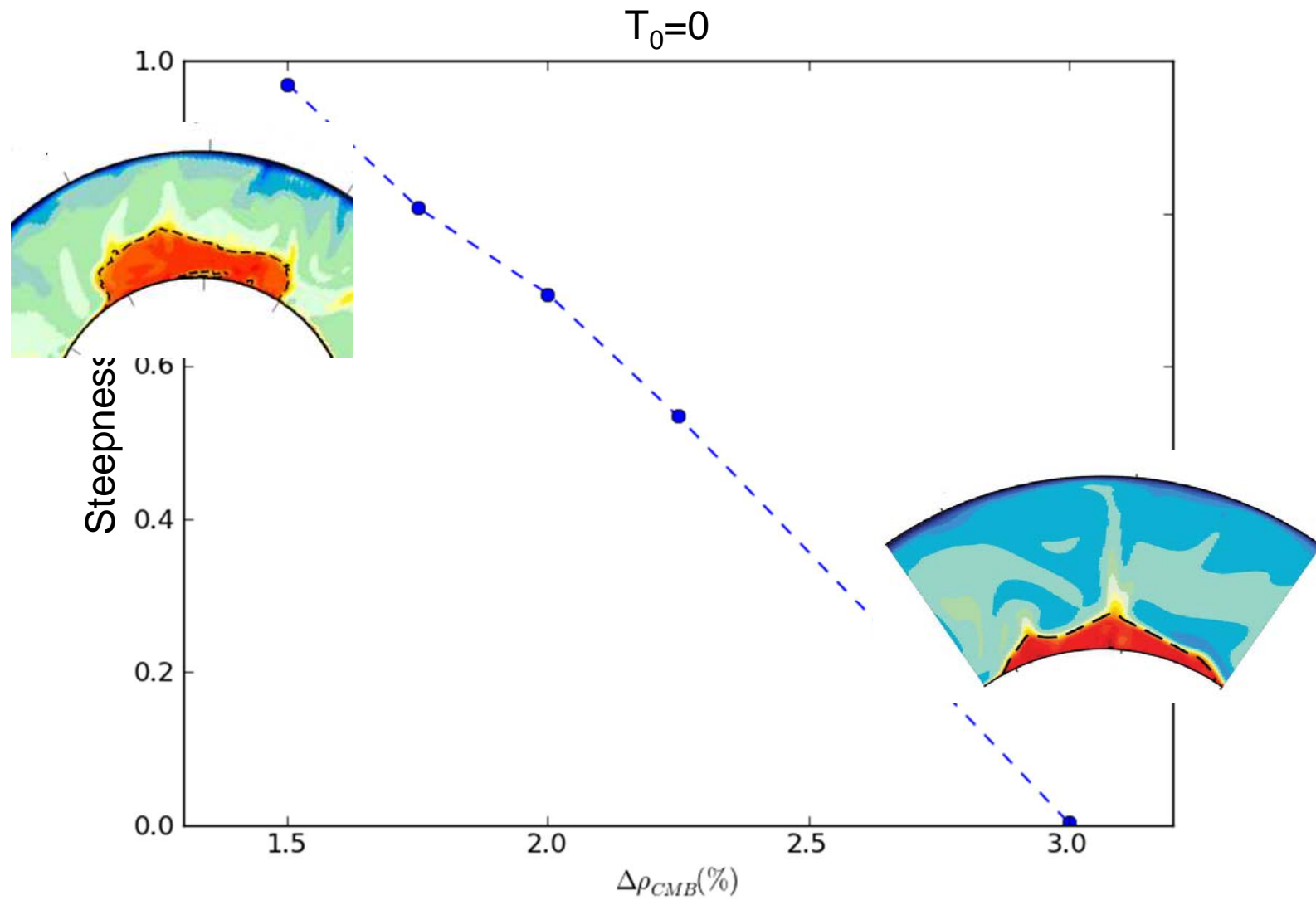
$$\text{Steepness} \sim \frac{A_{600} r_{250}^2}{A_{250} r_{600}^2}$$



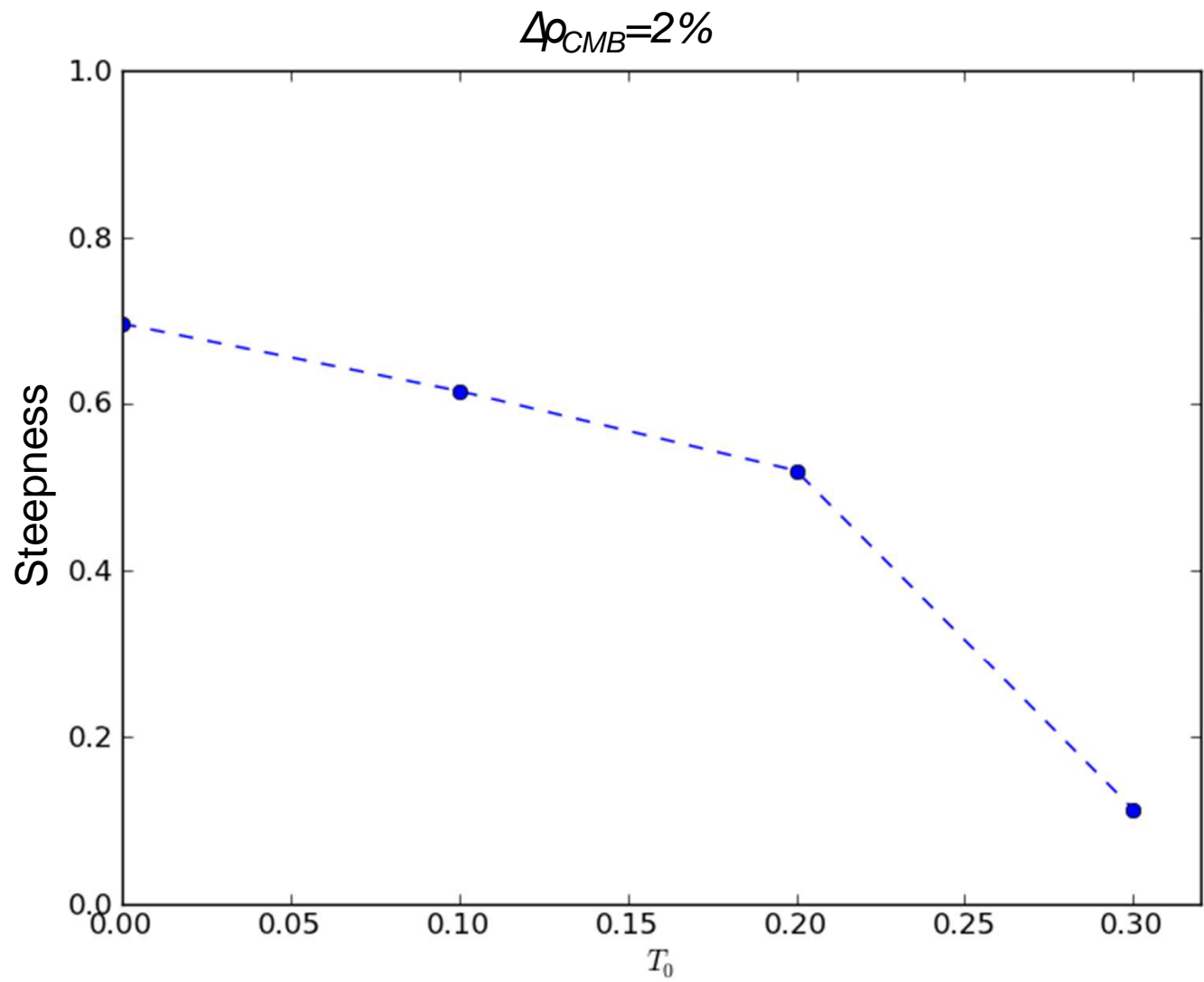


Tan, in preparation



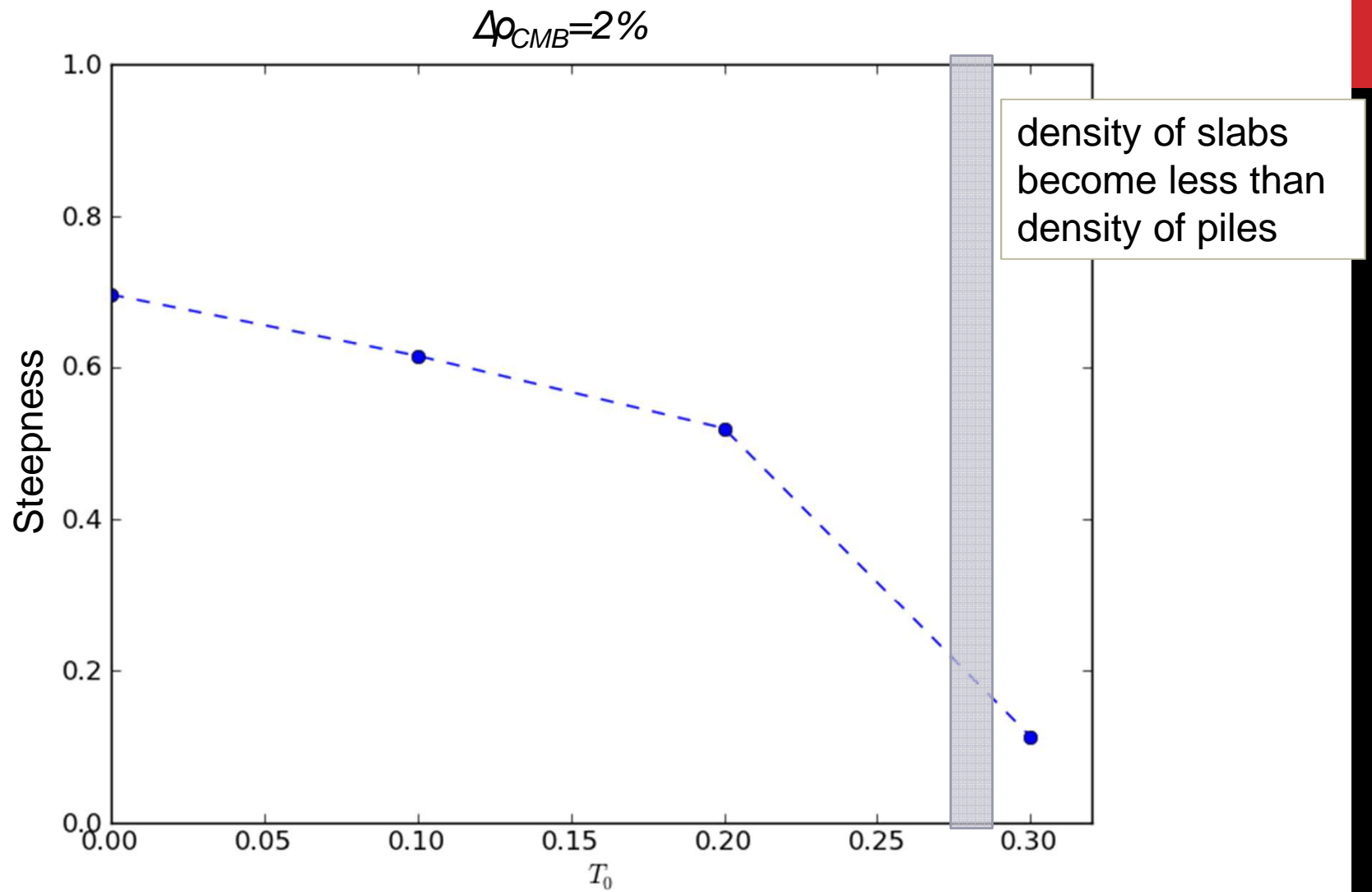


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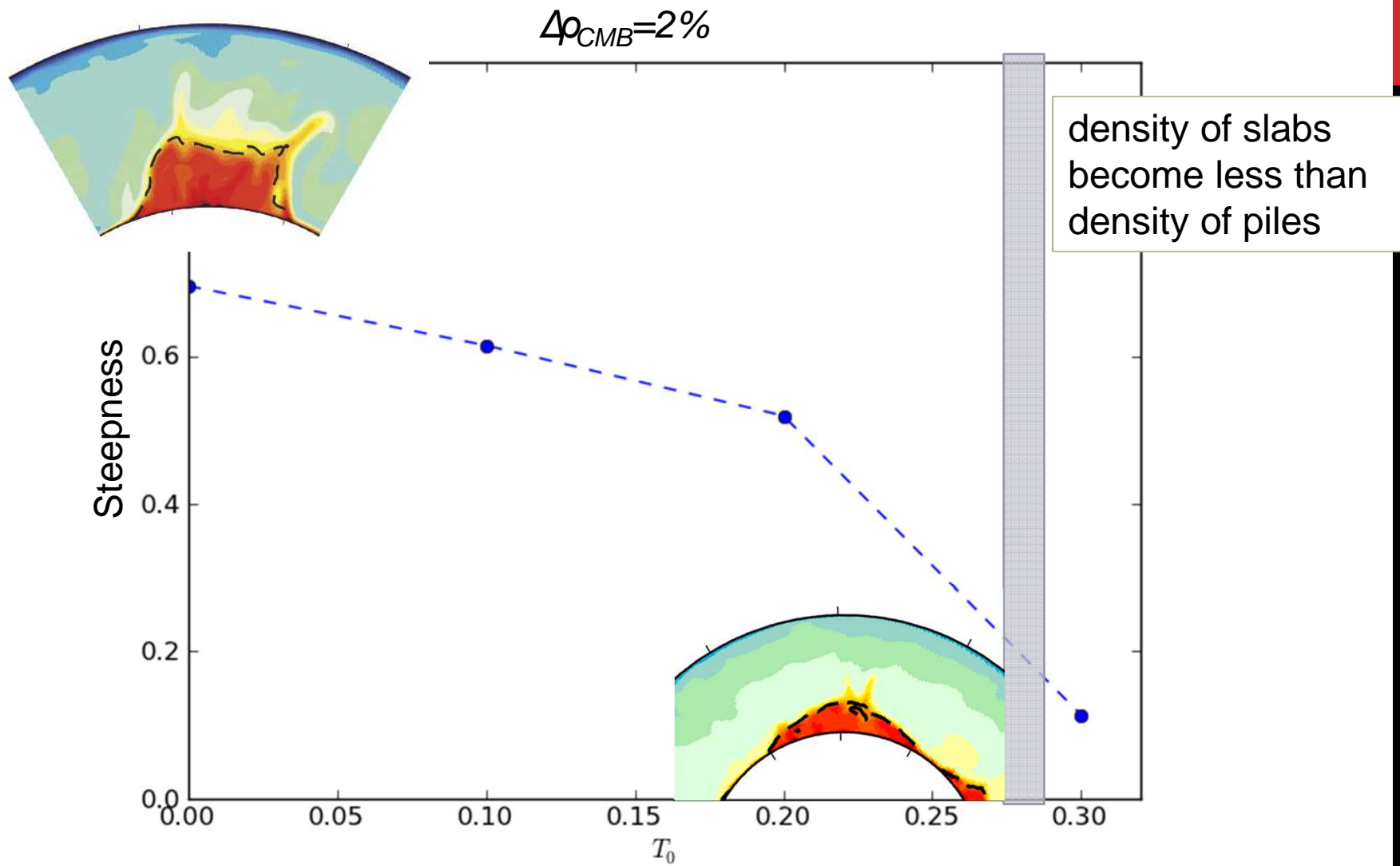


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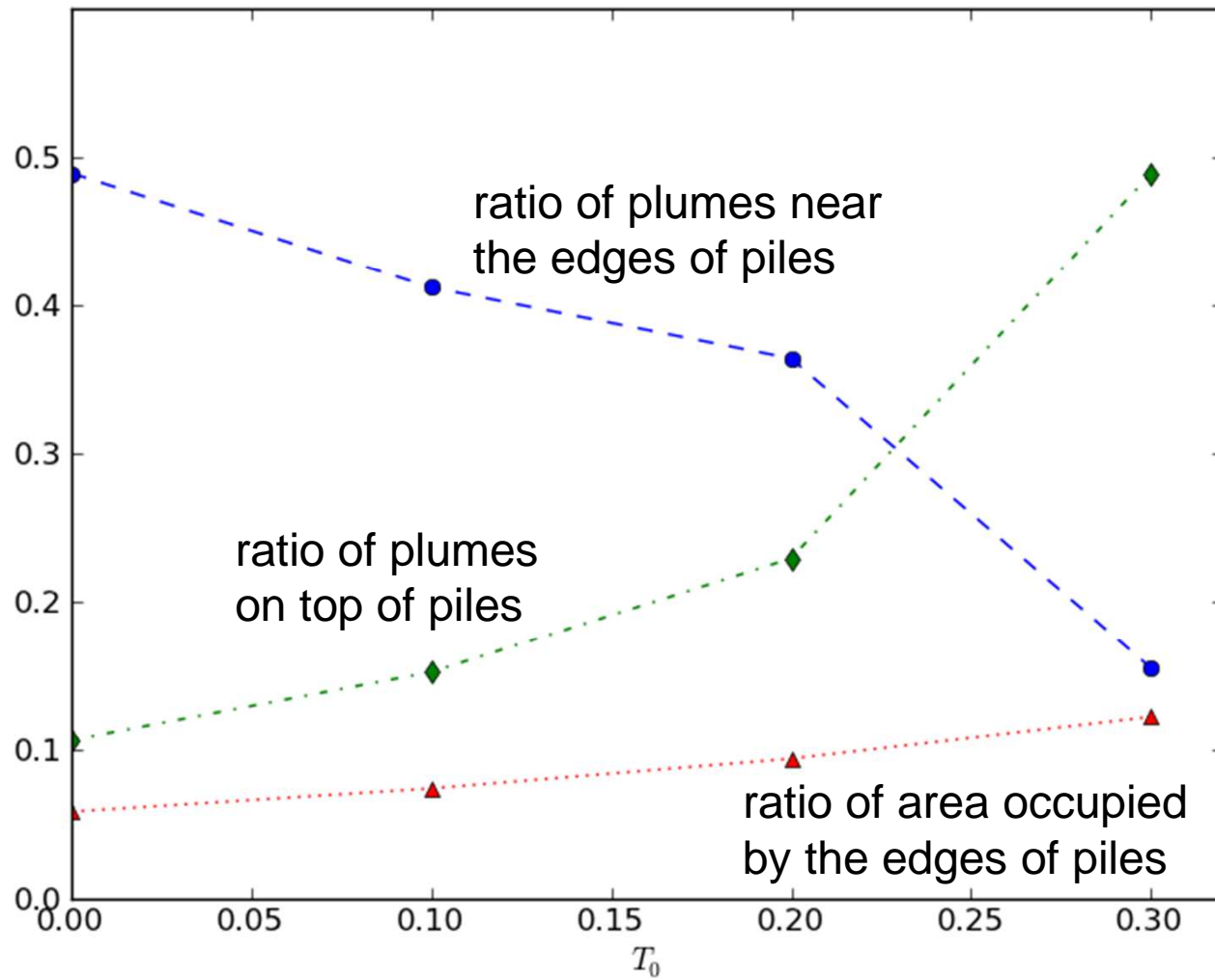


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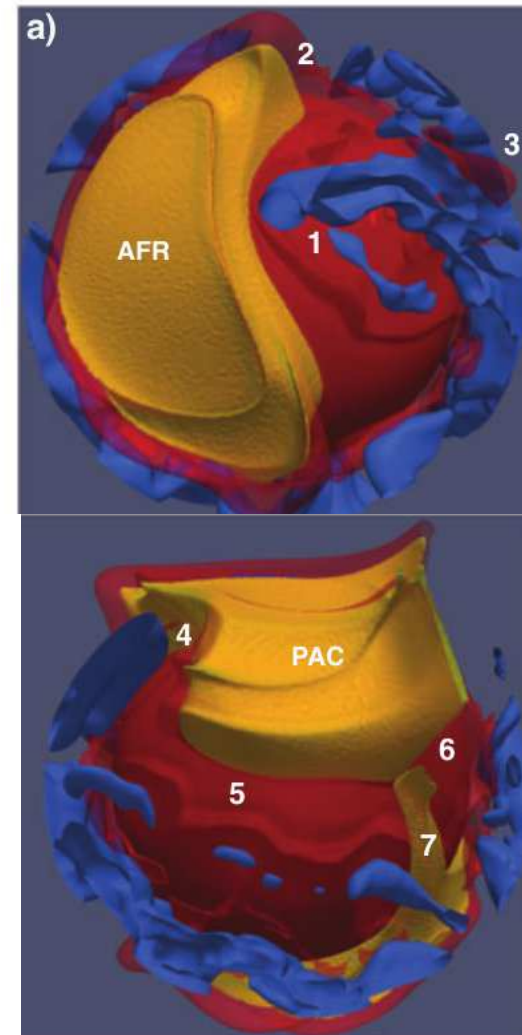
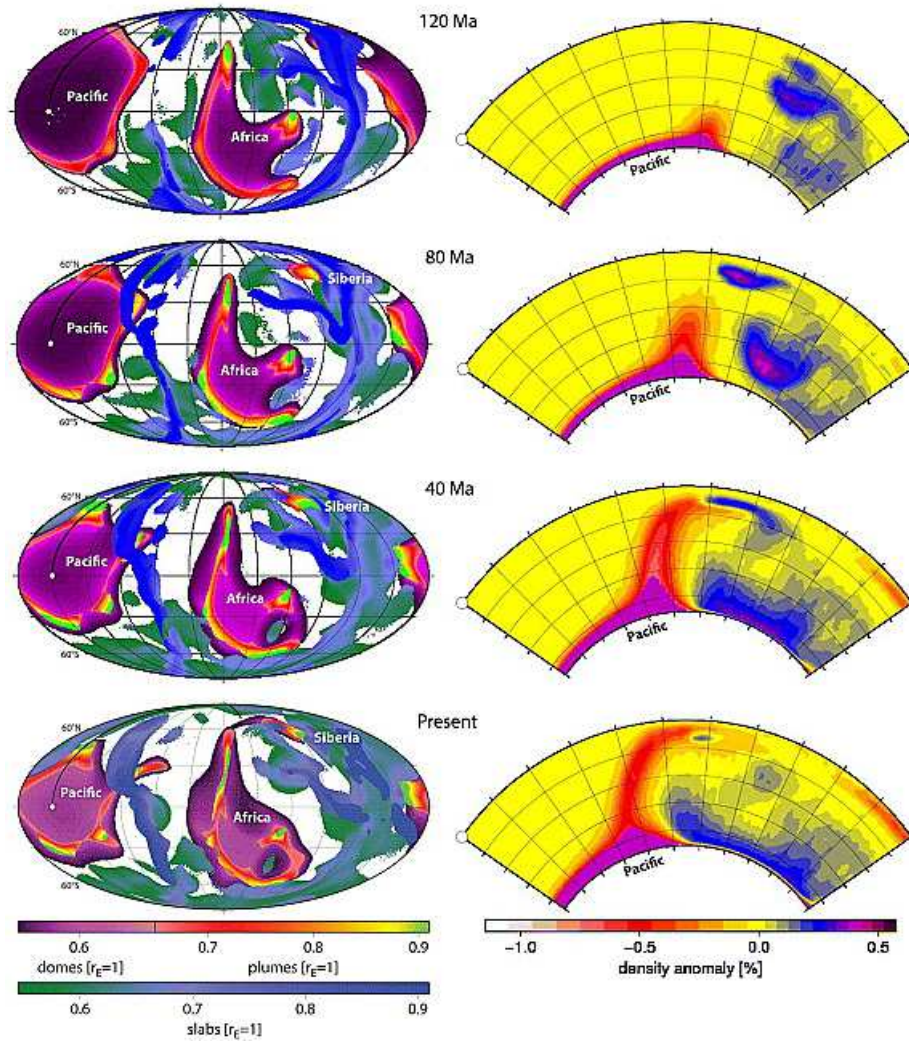
Tan, in preparation

$\Delta\rho_{CMB}=2\%$



Tan, in preparation



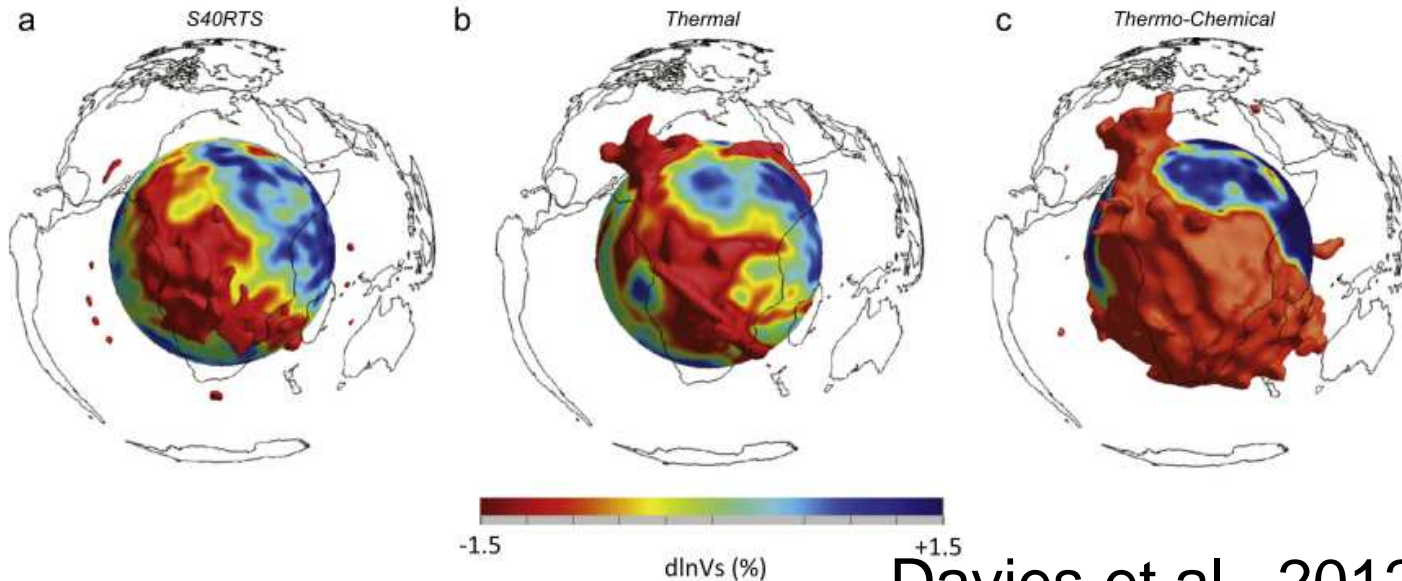


Steinberger & Torsvik., 2012 G³

Bower et al., 2013 G³

Debate on the Nature of LLSVPs

- In AOGS 2013 (Asia Oceania Geosciences Society)
- Rhodri Davies showed a pure thermal convection model with pPv phase change, filtered with tomography resolution matrix, can reproduce Vs-V ϕ anti-correlation, sharp Vs gradient, plume clustering around edges of LLSVPs, and fits better with seismic observation than thermo-chemical model.



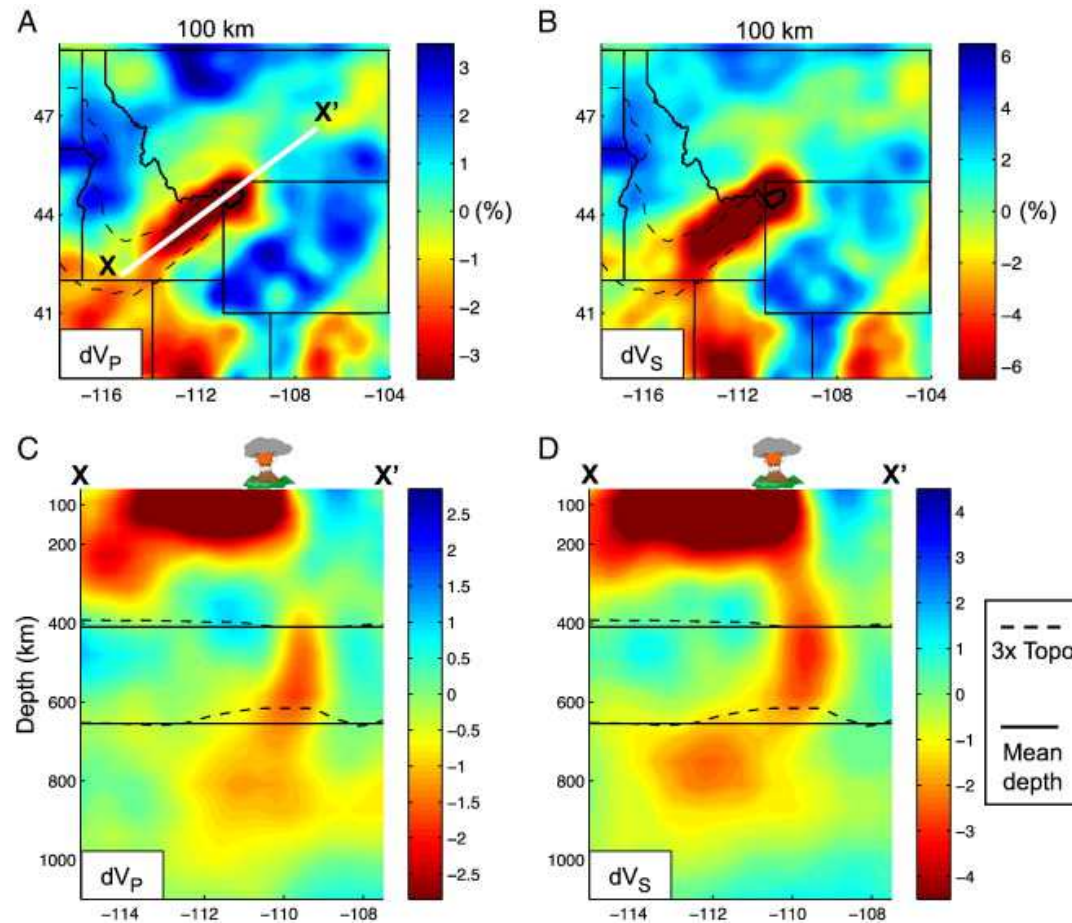
Davies et al., 2012 EPSL

- **In AOGS 2013 (Asia Oceania Geosciences Society)**
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- **Takashi Nakagawa showed that thermo-chemical convection model fits better with seismic observation than pure thermal model.**

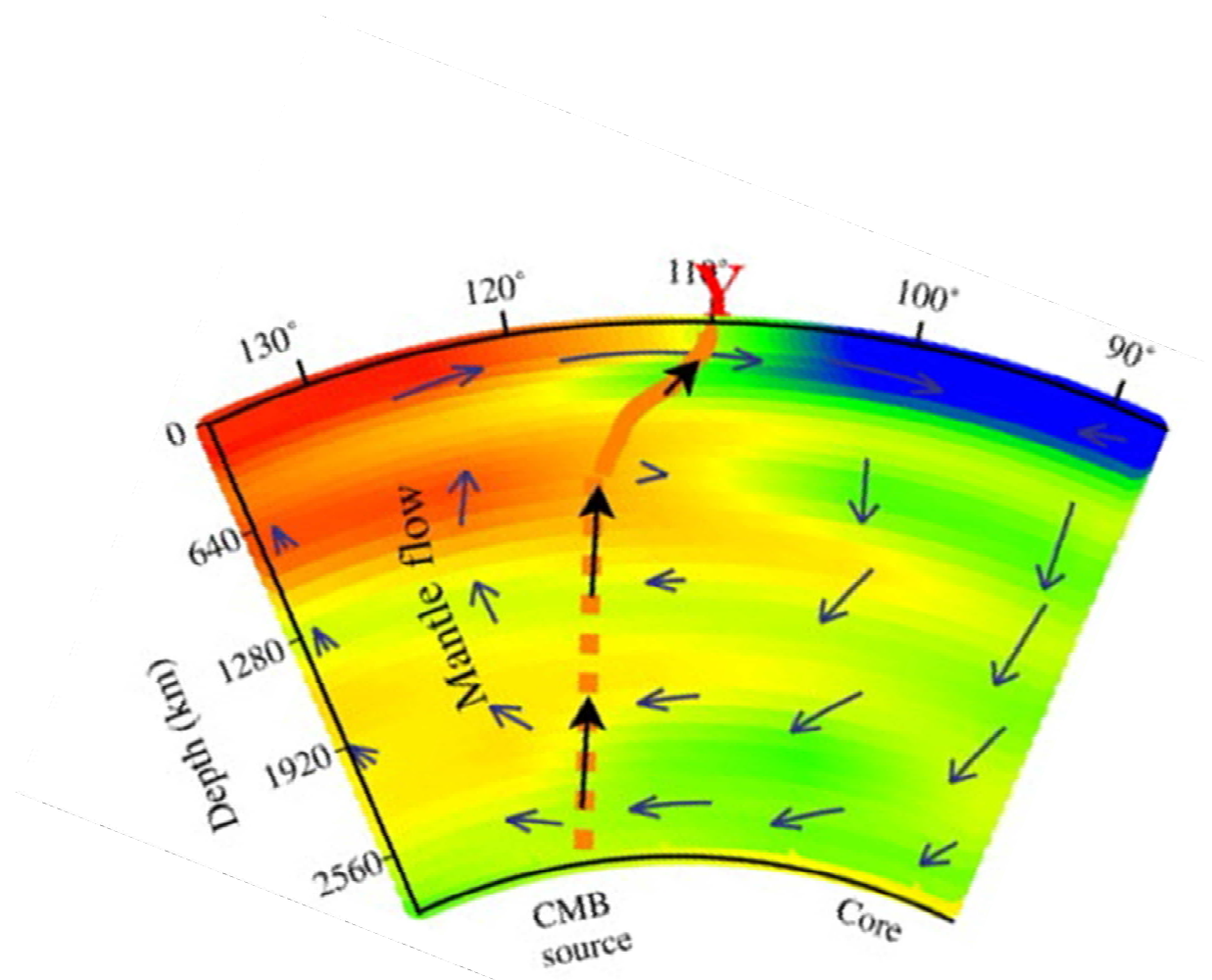
Detecting Plume Conduits



Shallow Plume Conduits



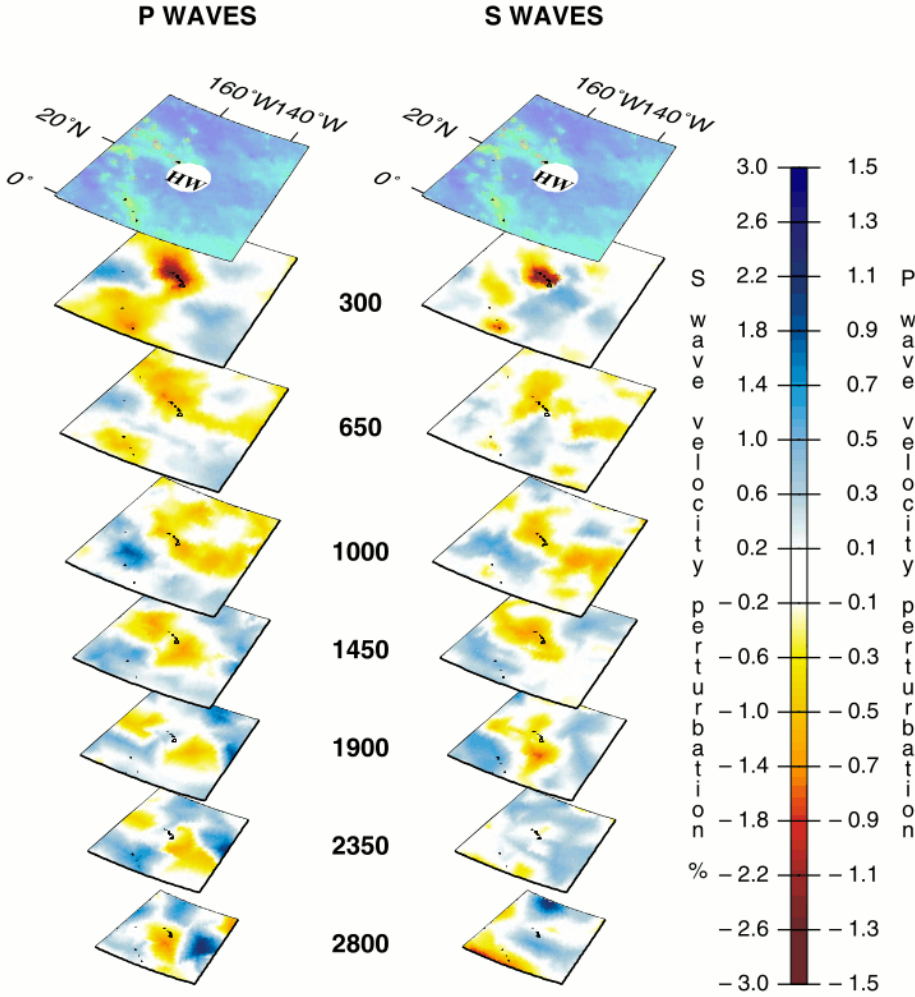
Schmandt et al., 2012 EPSL



Smith et al., 2009 JVGR

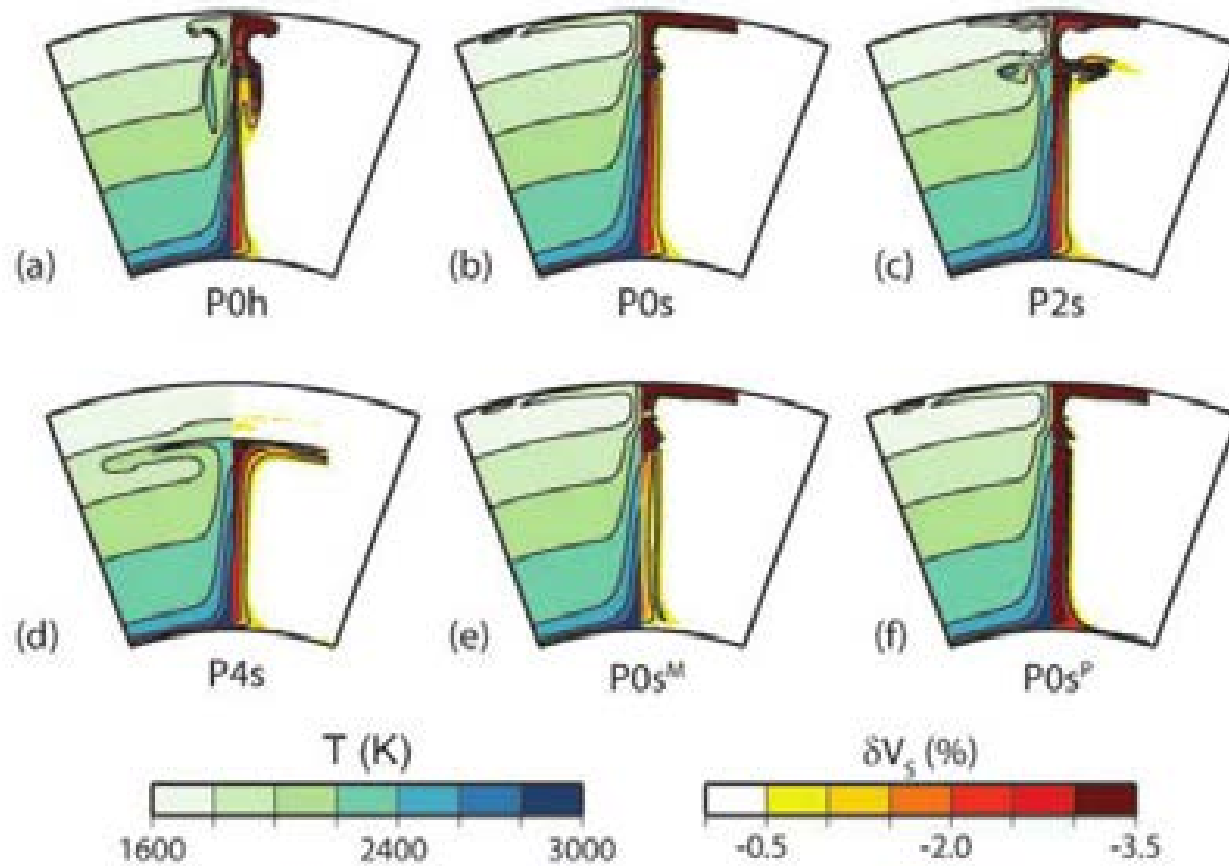


Deep Plume Conduits



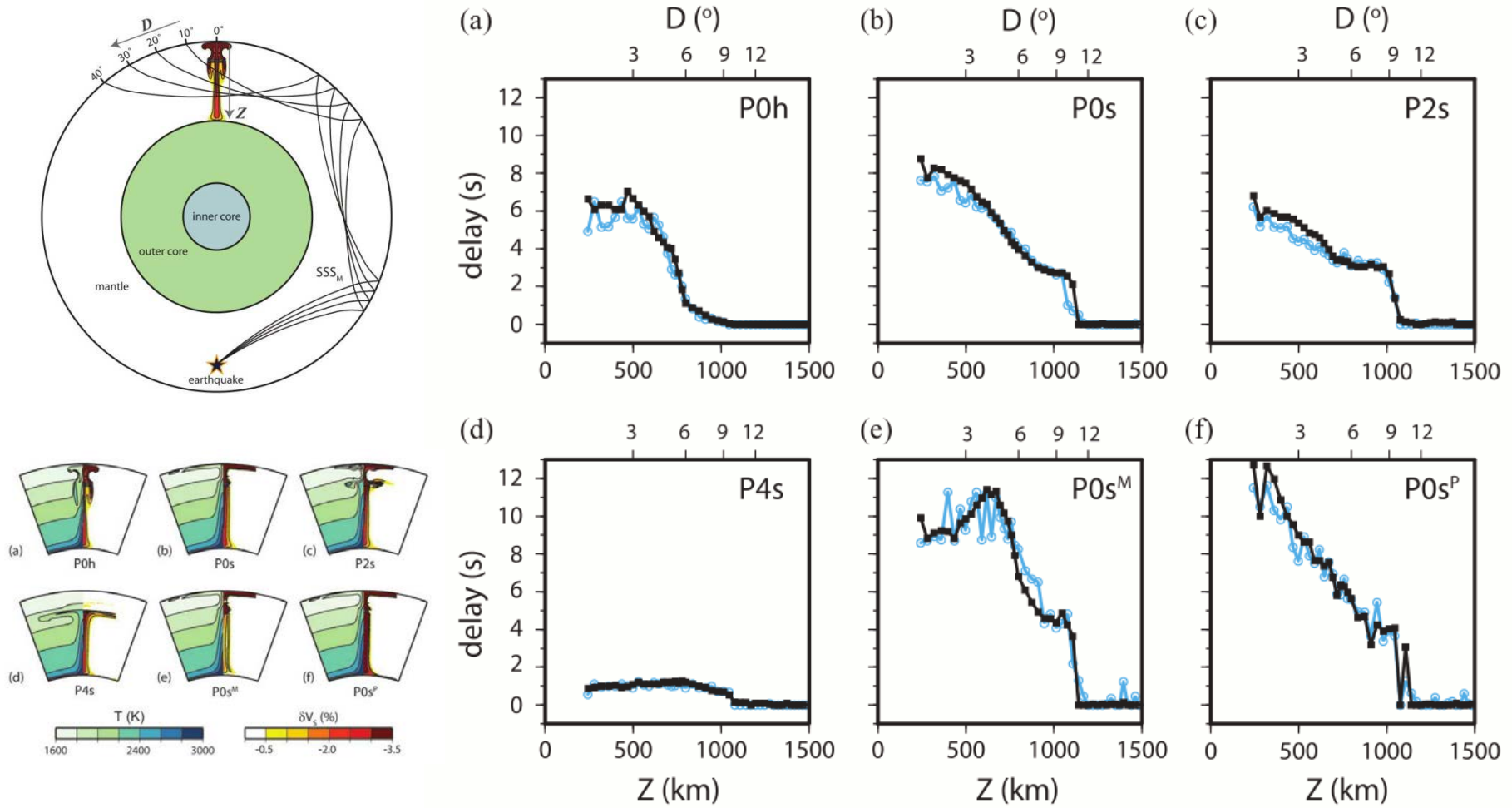
Montelli et al., 2006 G³

Synthetic Plumes



Hwang et al., 2011 GJI

(Non-) Detectability of Deep Plume Conduits



Hwang et al., 2011 GJI

Diffraction of Finite-Frequency Wave

Diffraction of Sound Wave

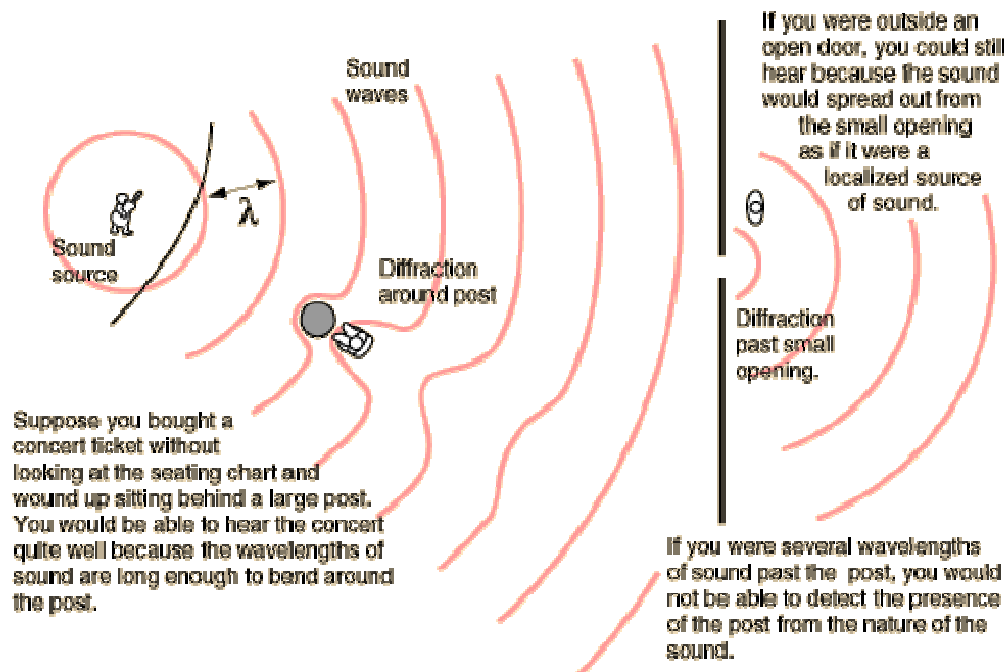


Image from <http://centros.edu.xunta.es>

Diffraction of Finite-Frequency Wave

Diffraction of Sound Wave

3 length scales:

- wavelength
- post diameter
- distance to post

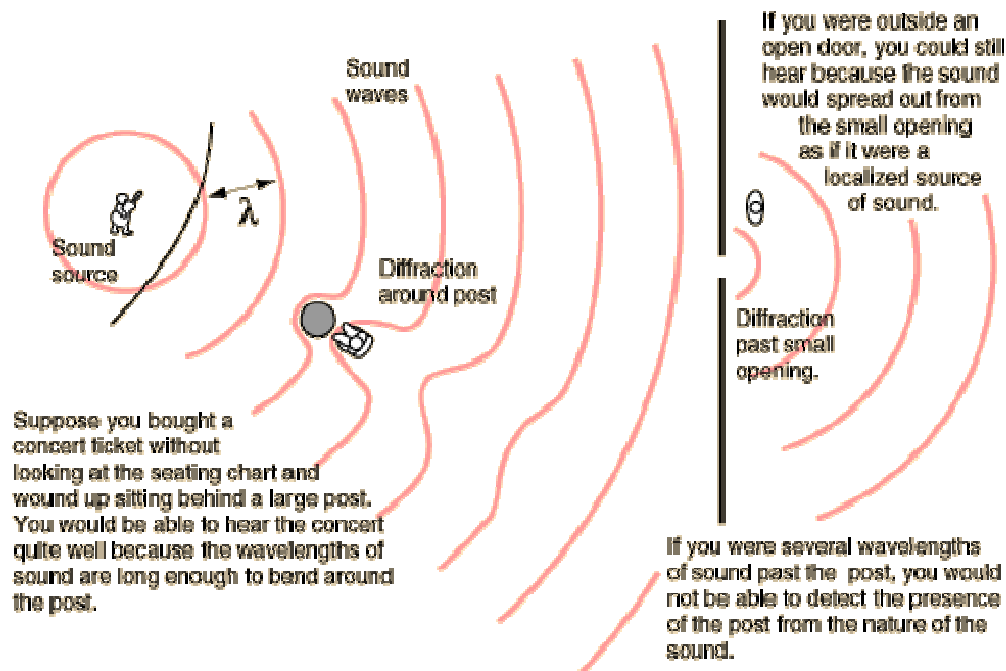
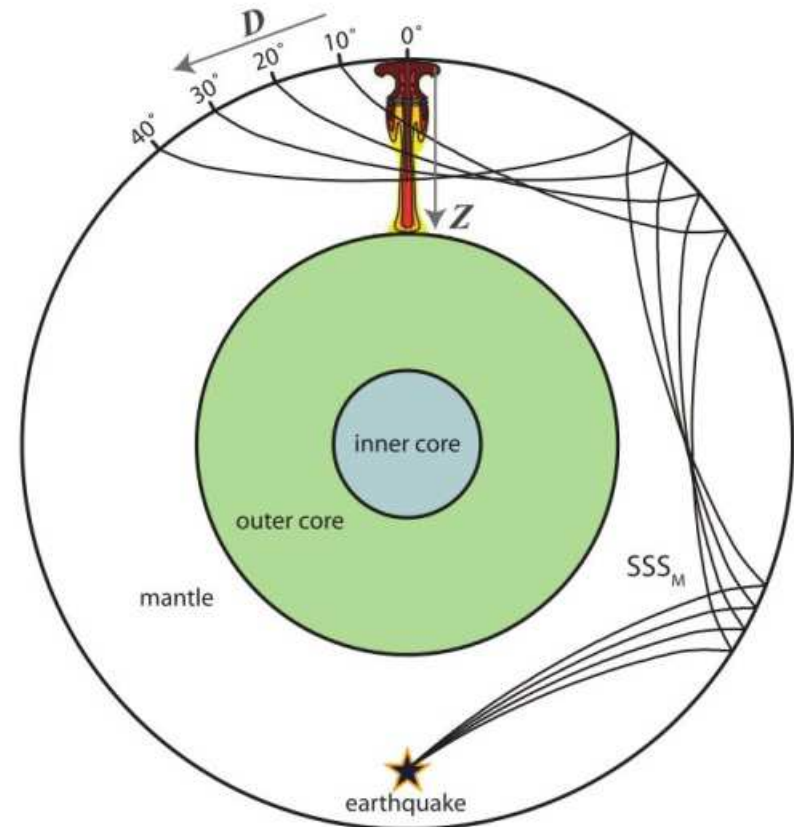
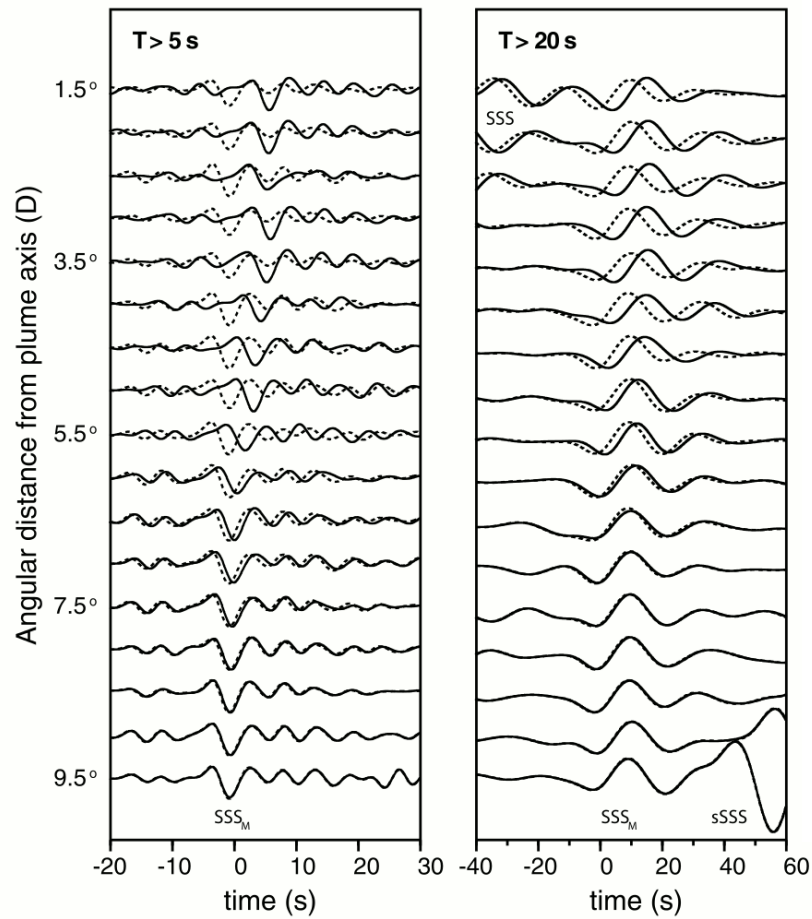


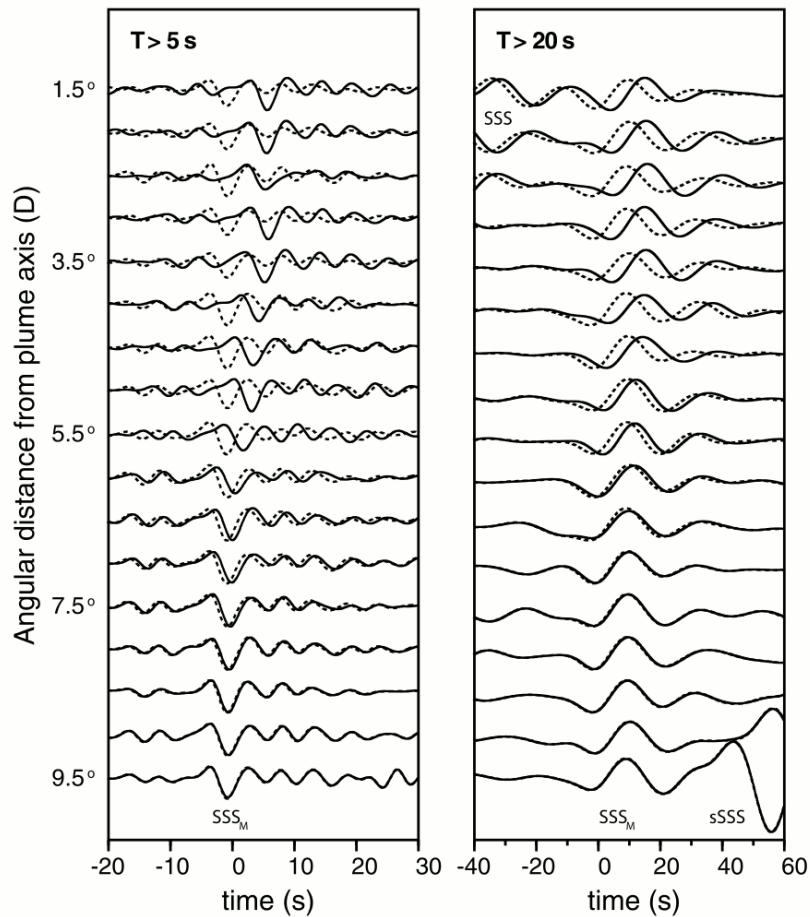
Image from <http://centros.edu.xunta.es>

Detectability of Deep Plume Conduits

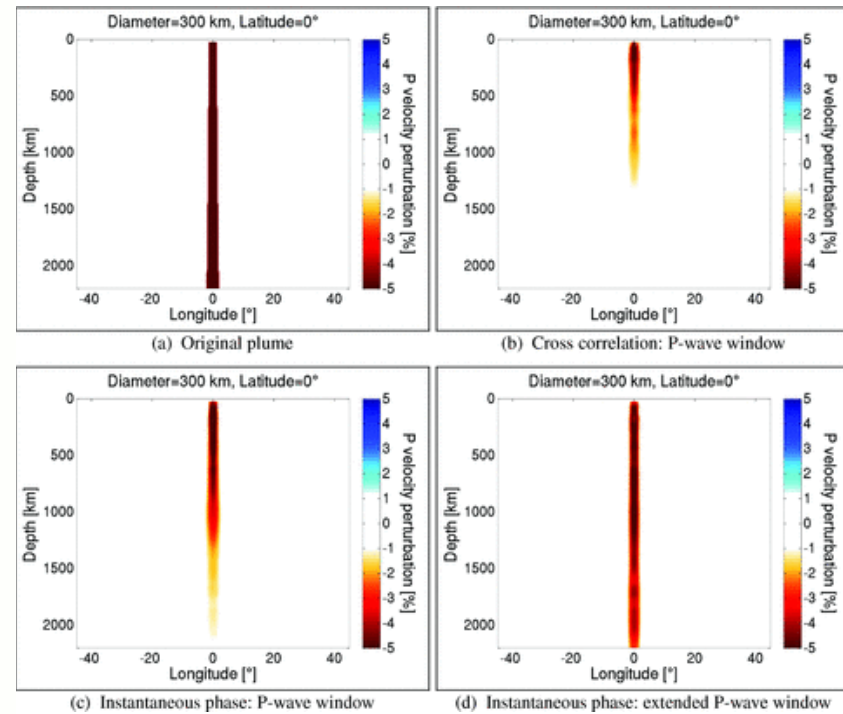


Hwang et al., 2011 GJI

Detectability of Deep Plume Conduits



Hwang et al., 2011 GJI



Rickers et al., 2012 GJI

The End

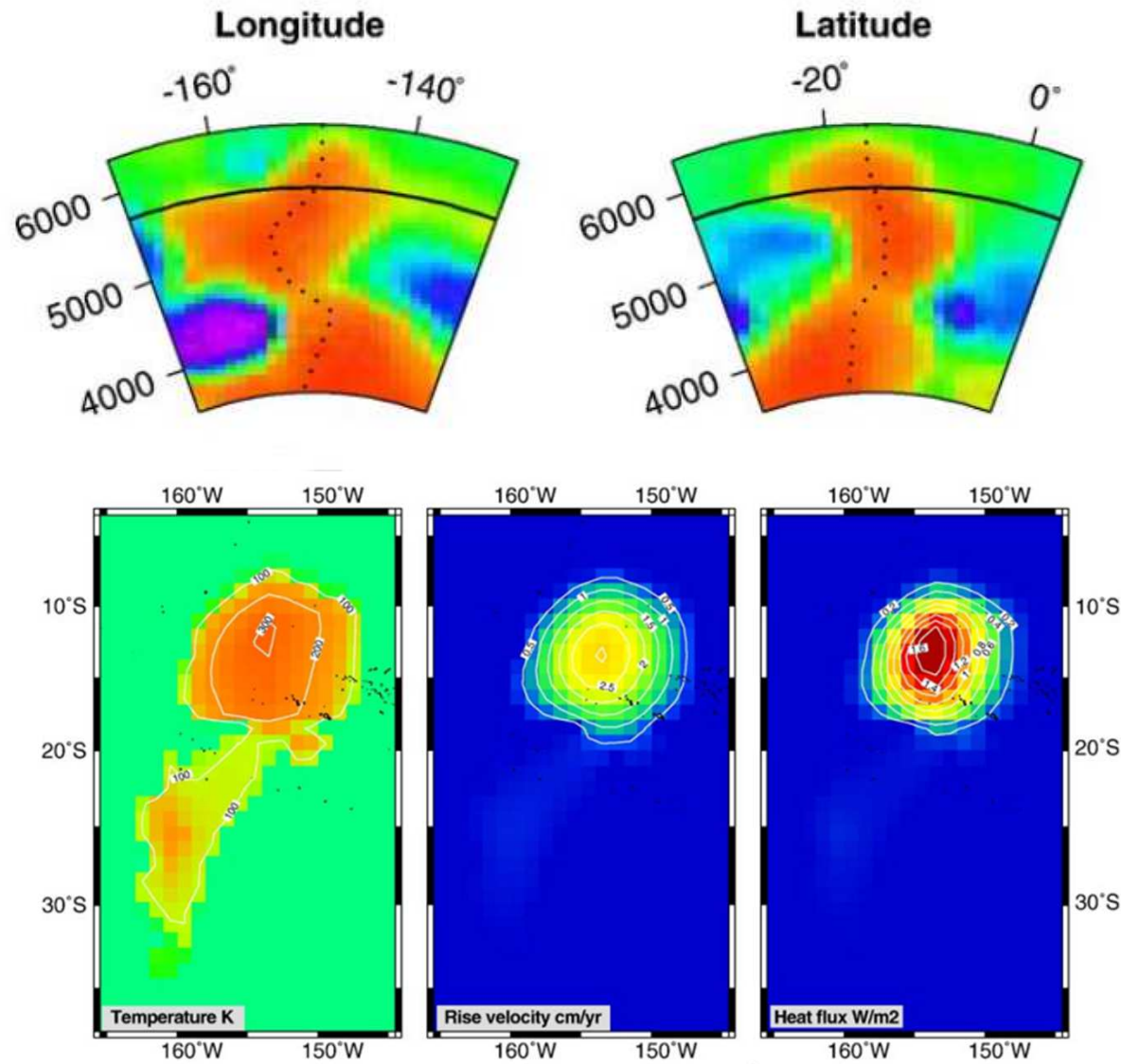


Postdoc Position at IES, Academia Sinica

- **3-yr postdoc position available at IES, Academia**
- **Study the dynamics of the Martian mantle and of other planetary mantles**
- **Contact Dr. Frédéric Deschamps
(frederic@earth.sinica.edu.tw)**



Tahiti



Nolet et al., 2006 EPSL

Implication of Thick Plume Conduit

- The plume buoyancy flux, B , can be measured from topography swelling surrounding a hotspot
- $B \sim r^2 v$; $v \sim \eta^{-1}$
- Large $r \rightarrow$ large η
- Plume conduit $\eta = 10^{21} \sim 10^{22}$ Pa.s