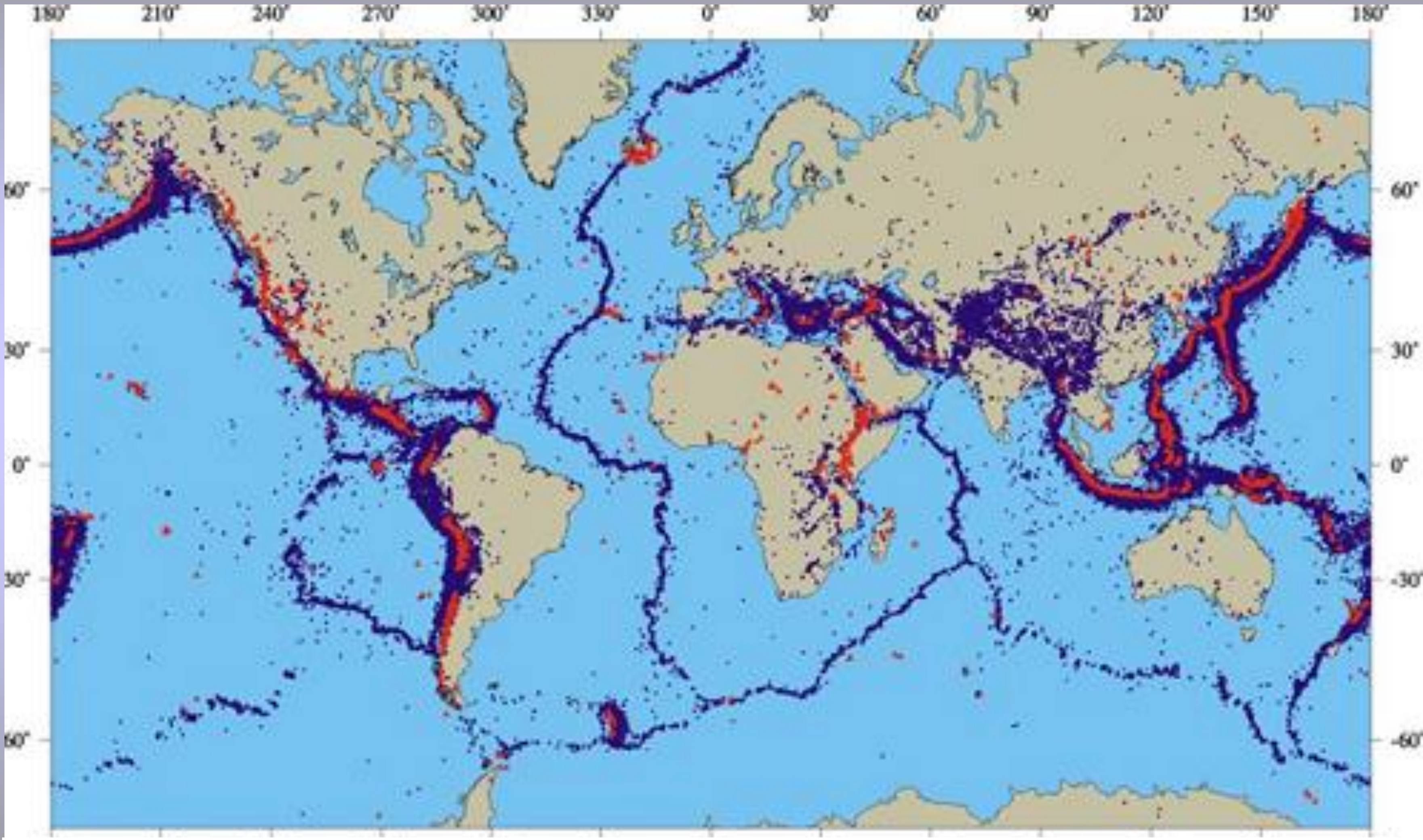
Maxim D. Ballmer
Garrett Ito, Cecily J. Wolfe, Sean C. Solomon

DOUBLE LAYERING DOUBLE LAYERING of thermo-chemical plume material can reconcile upper-mantle Seismic Velocity structure beneath Hawaii

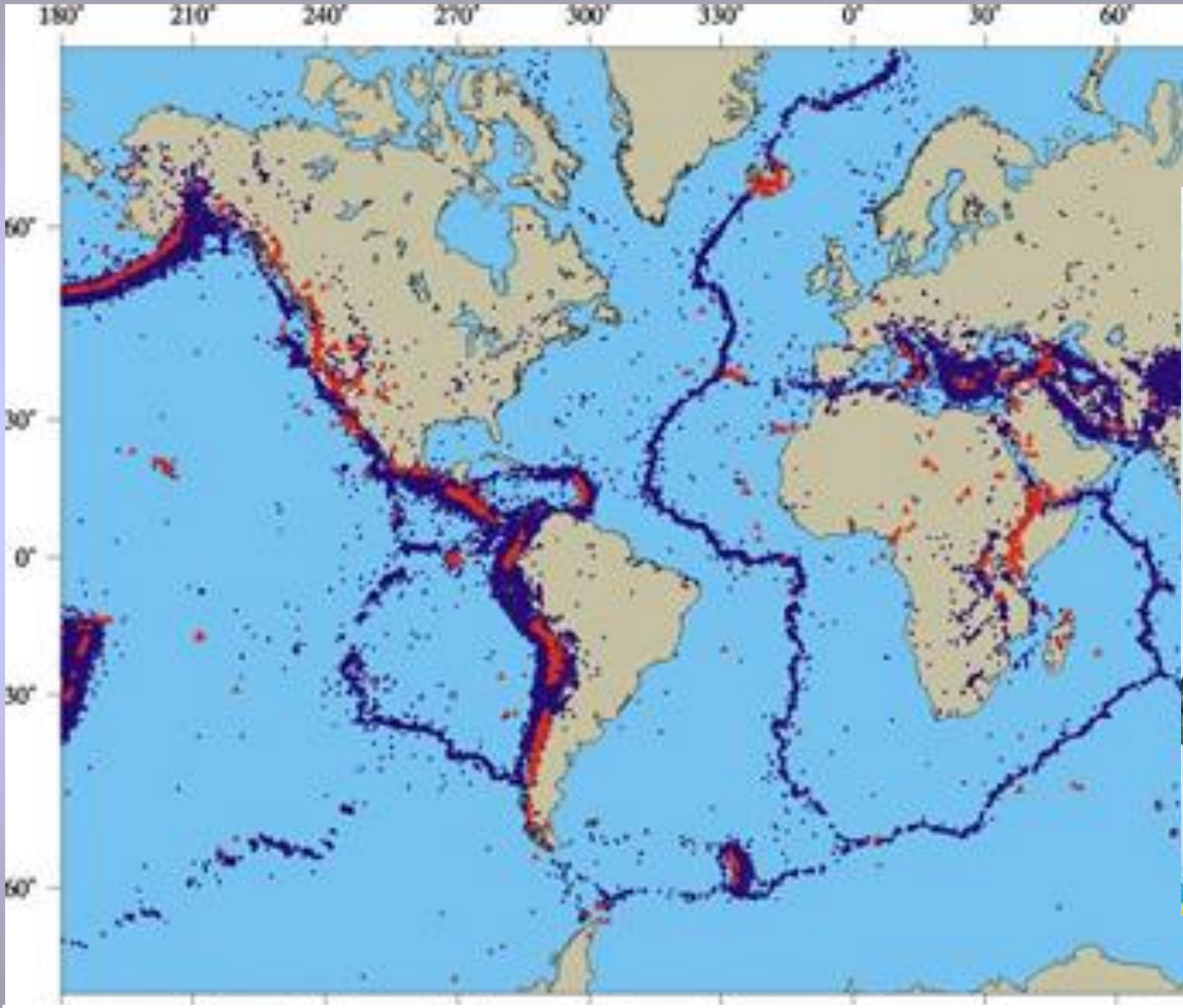
 INTRODUCTION INTRODUCTION

world volcanic and seismic map



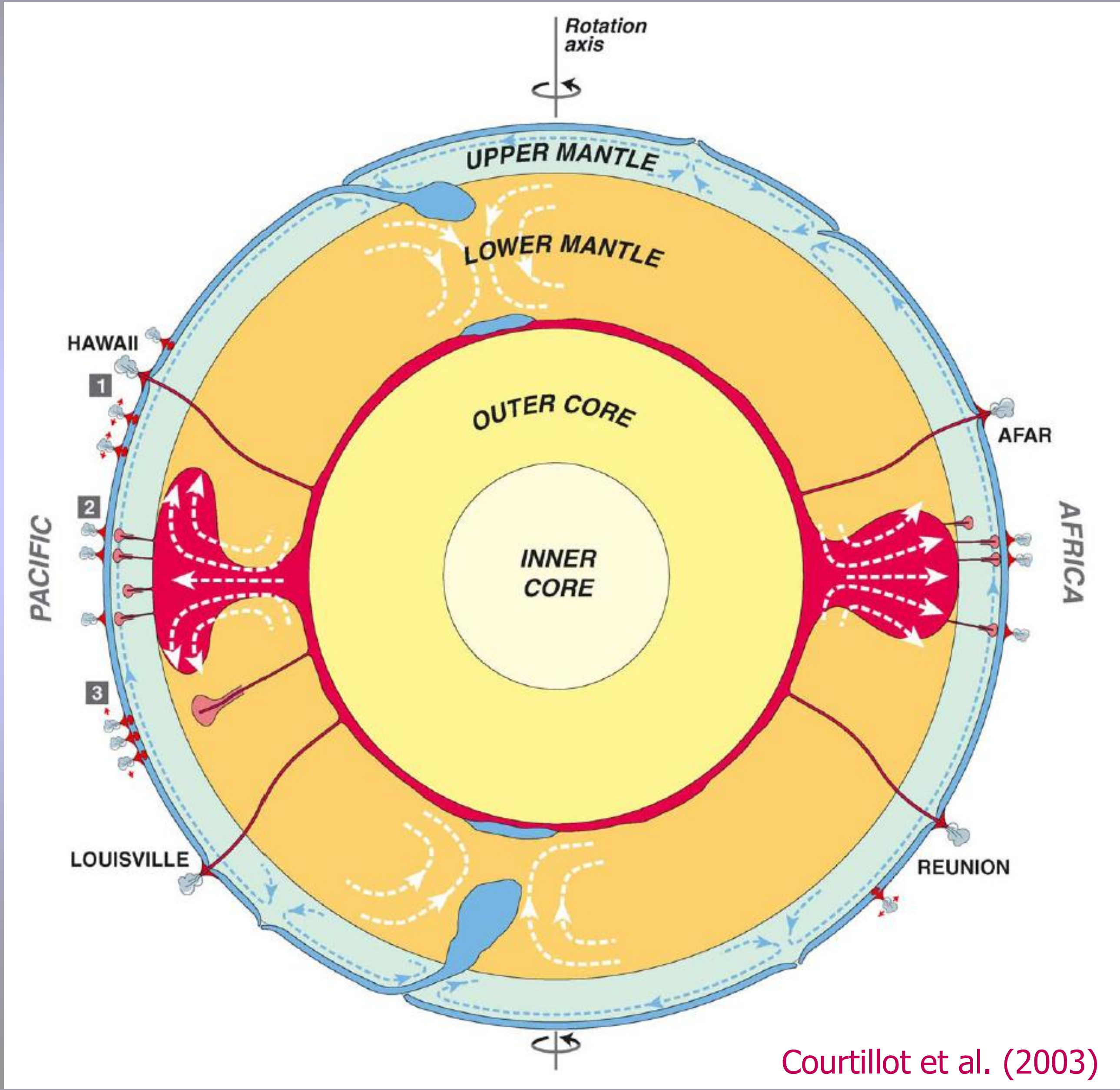
all volcanism on Earth occurs on plate boundaries

world volcanic and seismic map



all volcanism on Earth occurs on plate boundaries. All volcanism?

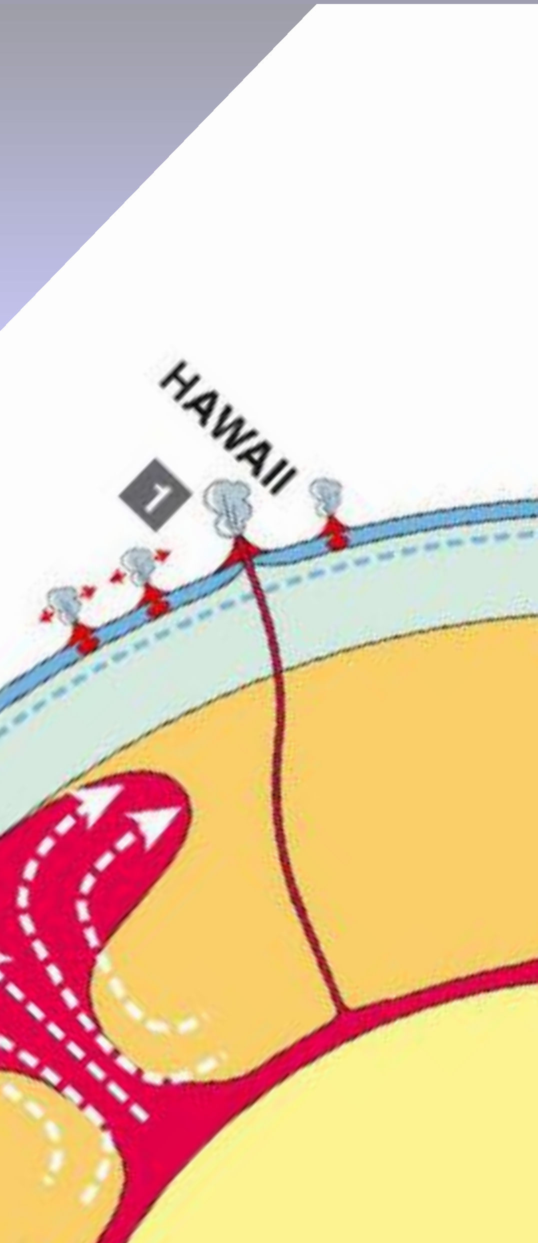
intraplate volcanism as probes of the mantle

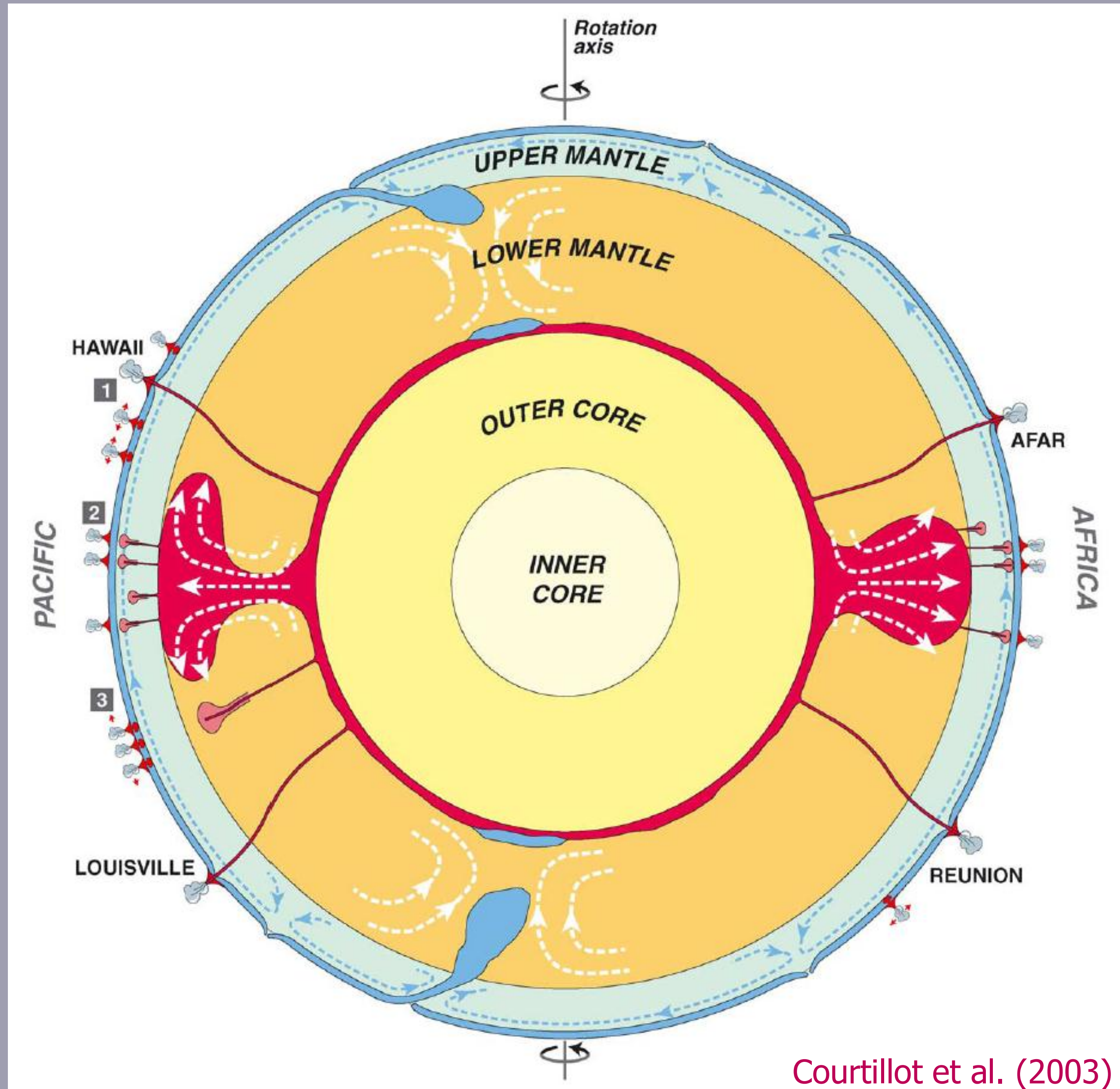


Courtillot et al. (2003)

MOTIVATION MOTIVATION MOTIVATION

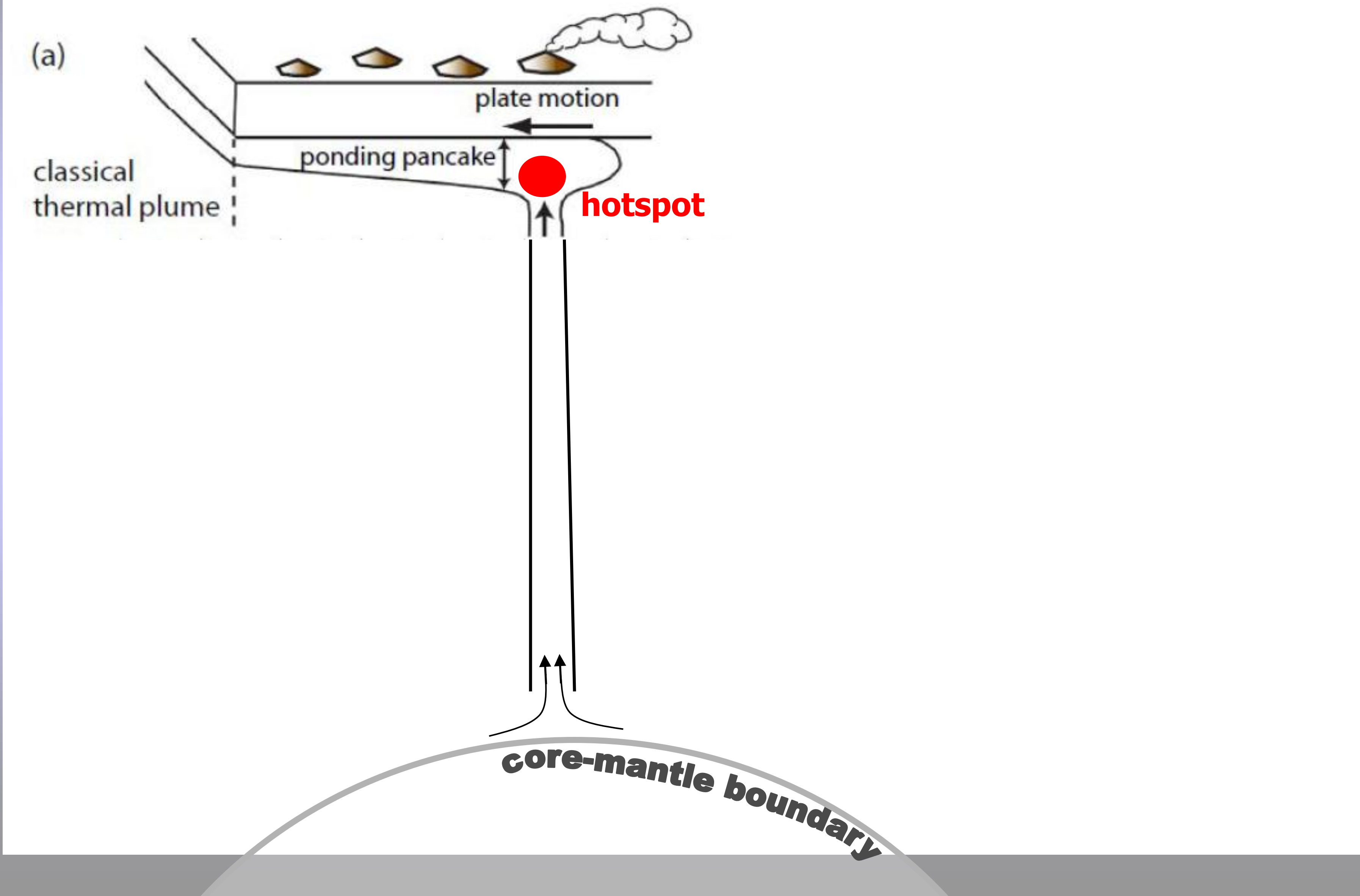
intraplate volcanism as probes of the mantle





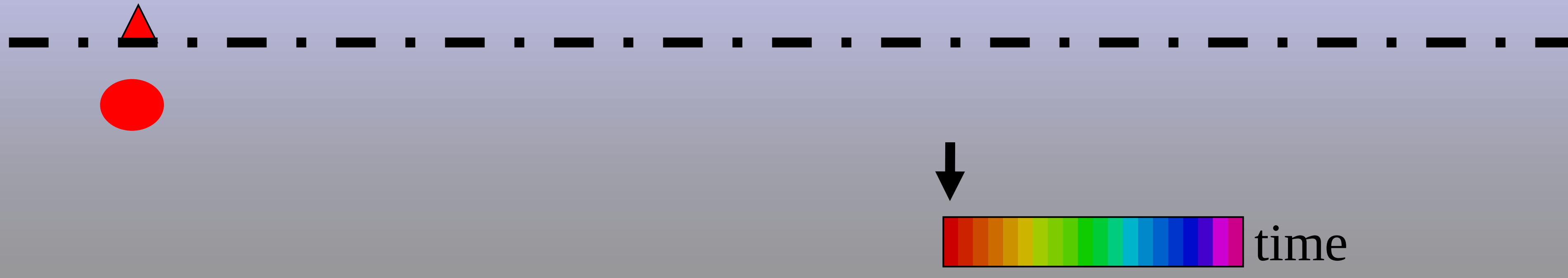
Courtillot et al. (2003)

the „classical" mantle plume concept

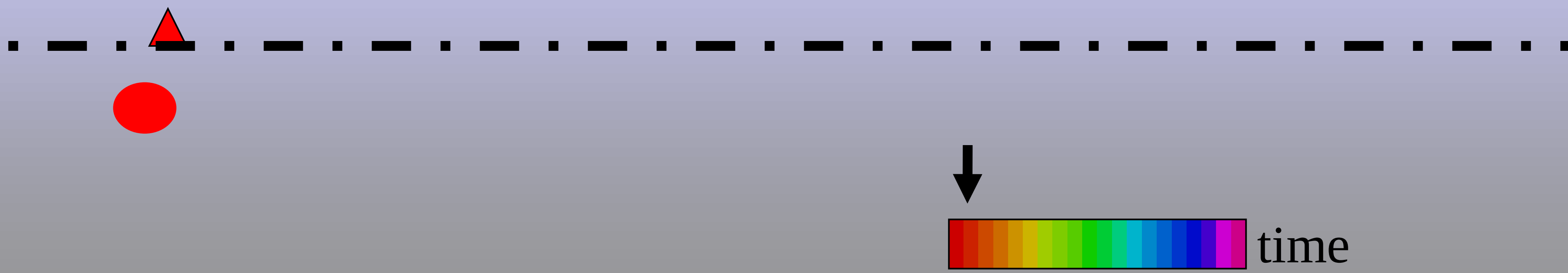


HAWAII HAWAII HAWAII HAWAII HAWAII

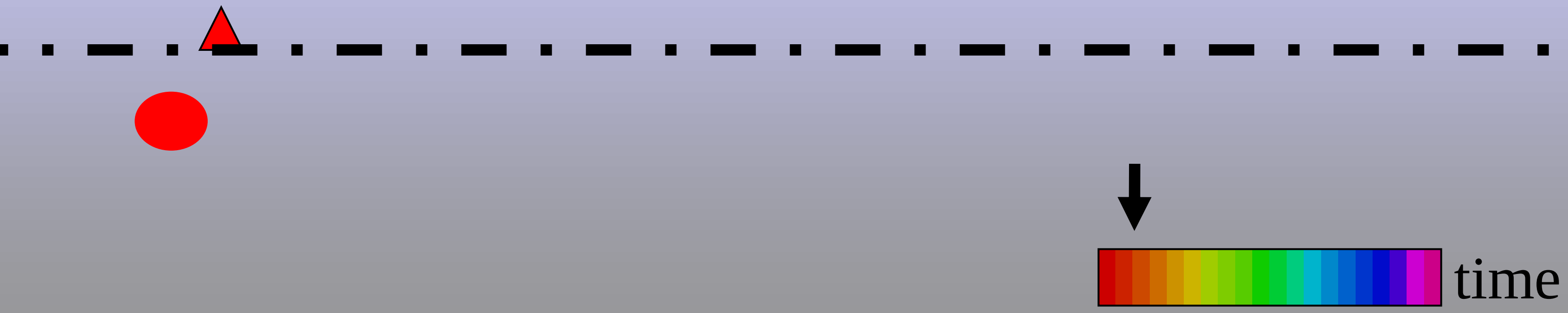
age-distance patterns



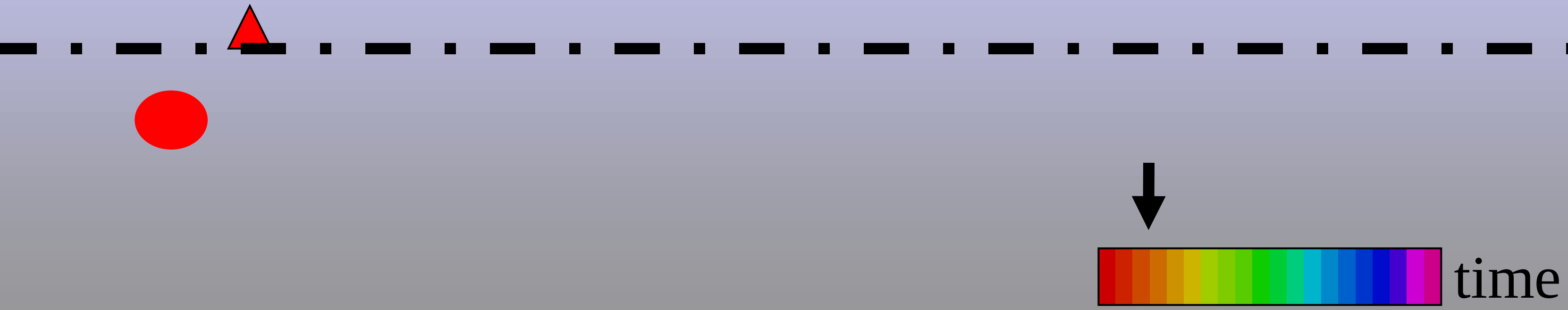
age-distance patterns



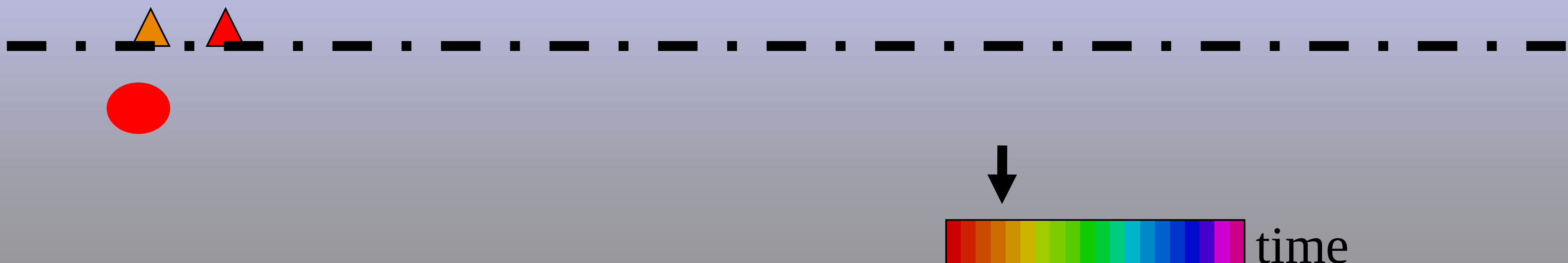
age-distance patterns



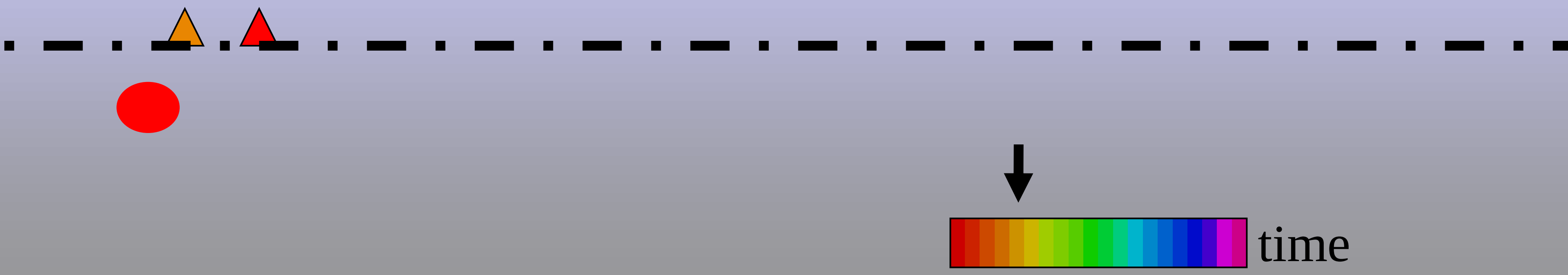
age-distance patterns



age-distance patterns

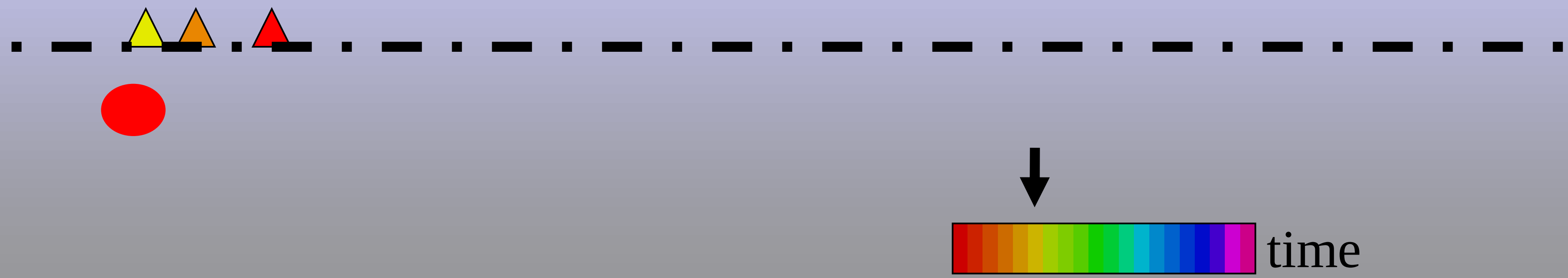


age-distance patterns

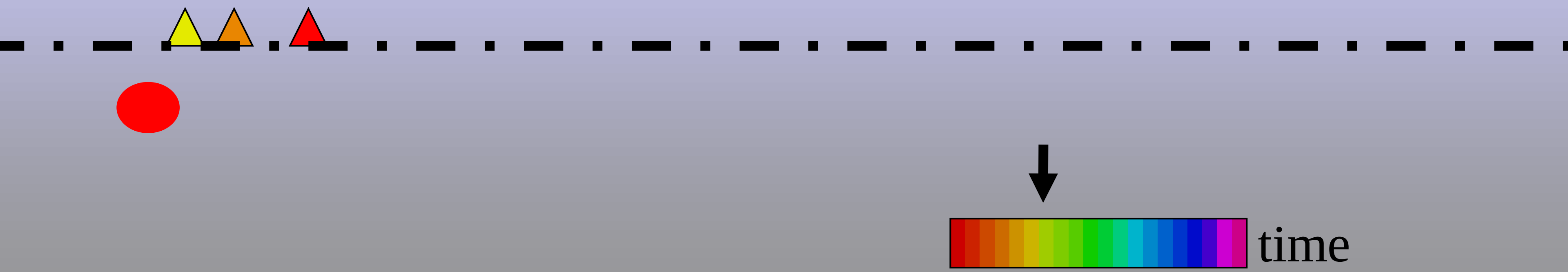


HAWAII HAWAII HAWAII HAWAII HAWAII

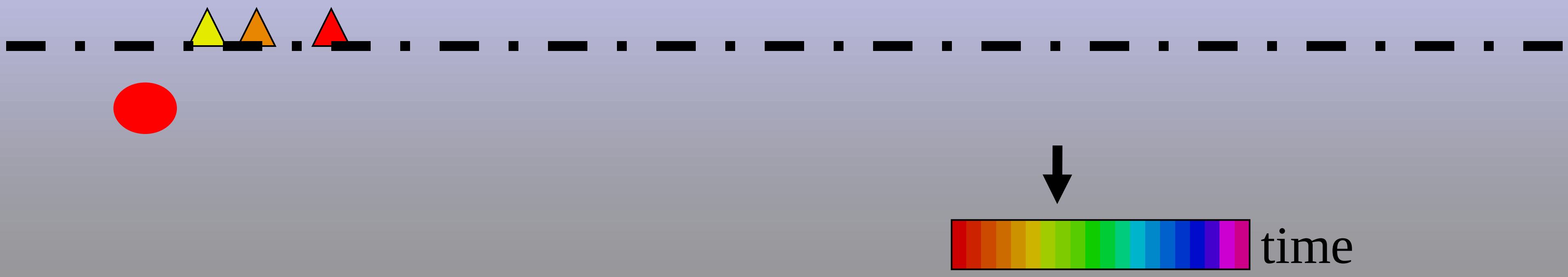
age-distance patterns



age-distance patterns

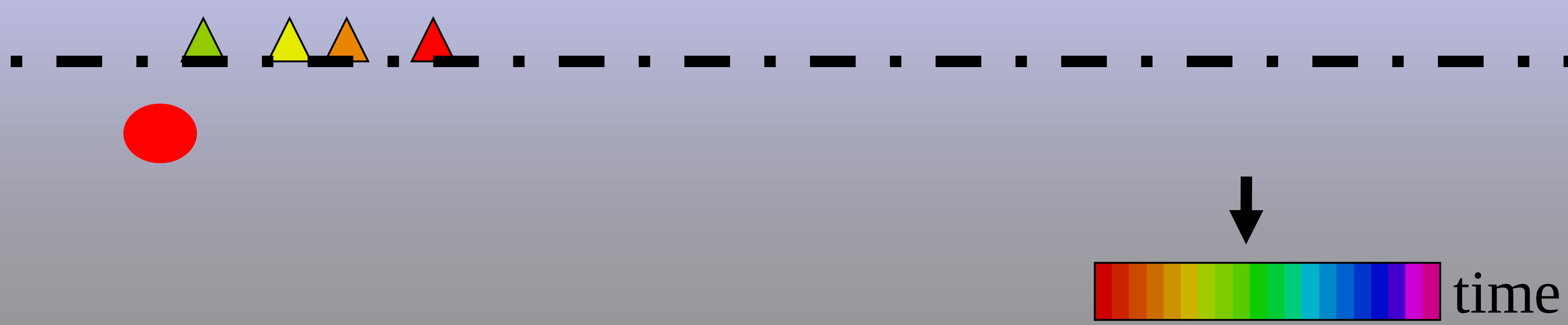


age-distance patterns



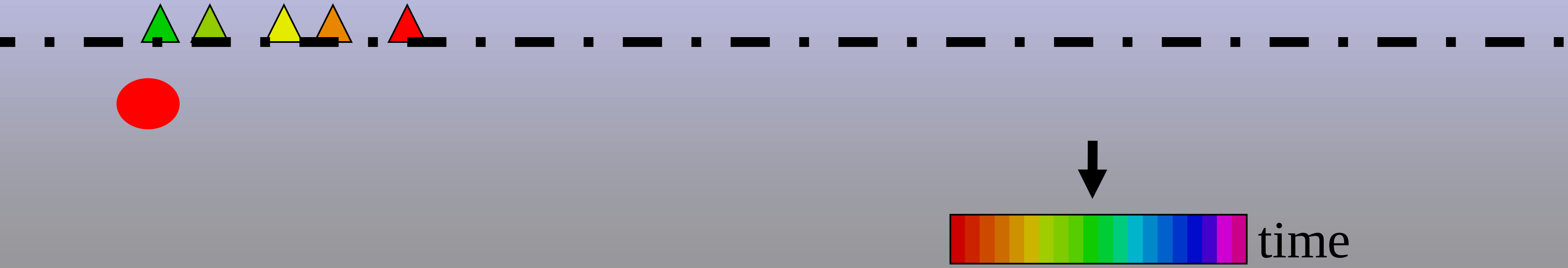
age-distance patterns

age-distance patterns

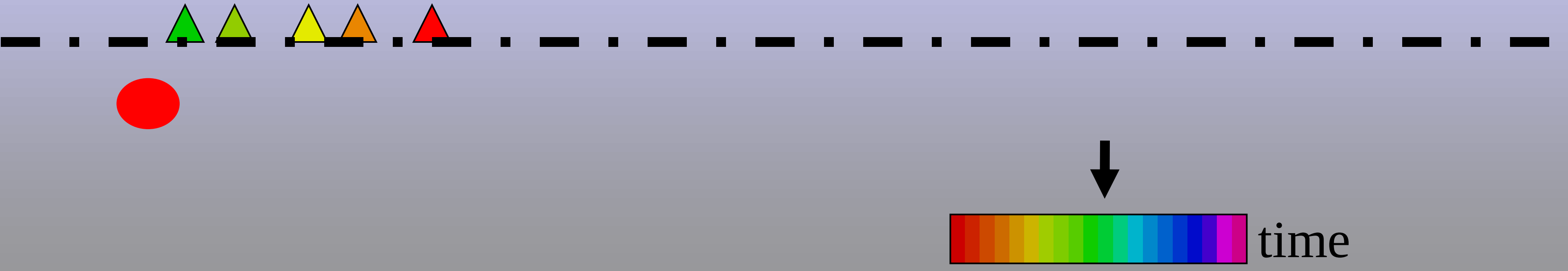


HAWAII HAWAII HAWAII HAWAII HAWAII

age-distance patterns

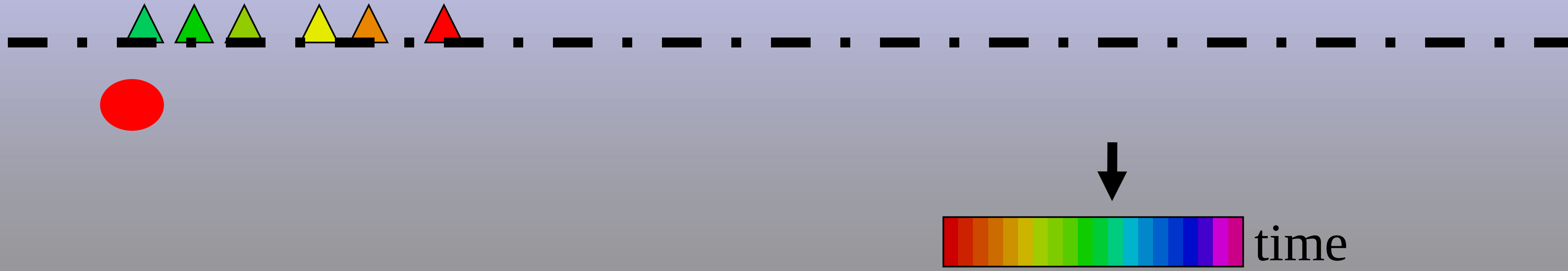


age-distance patterns



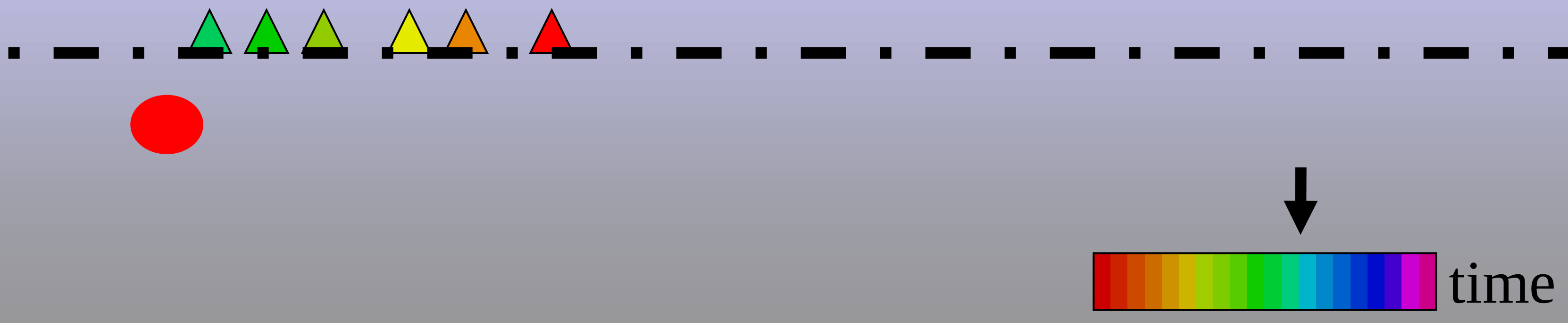
HAWAII HAWAII HAWAII HAWAII HAWAII

age-distance patterns

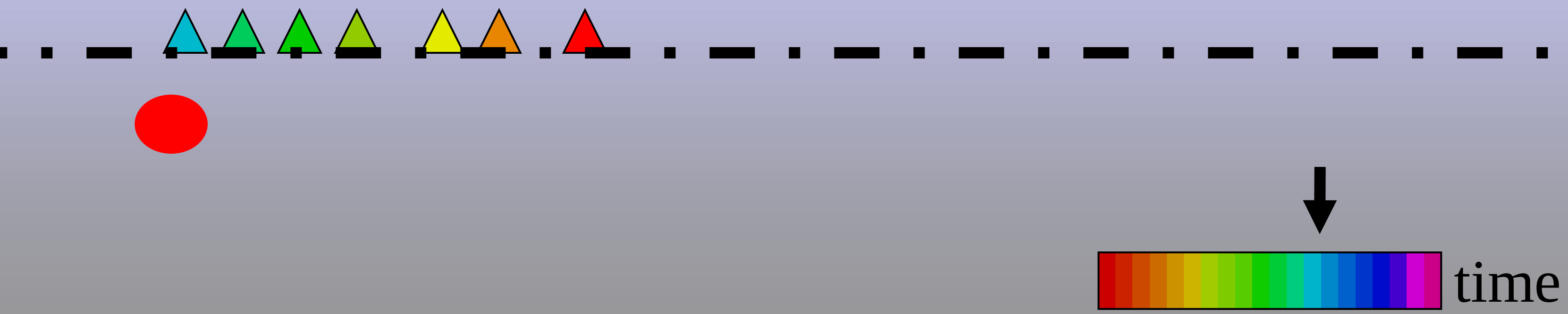


 HAWAII HAWAII HAWAII HAWAII

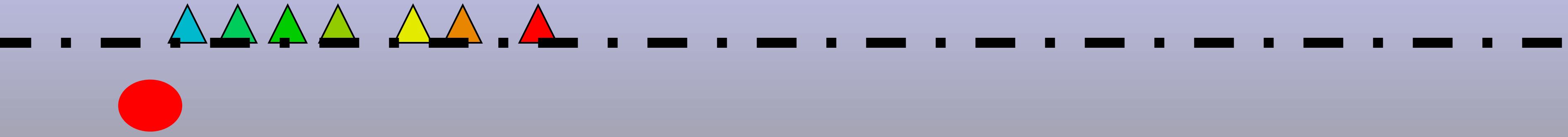
age-distance patterns

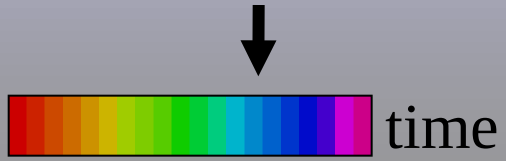


age-distance patterns

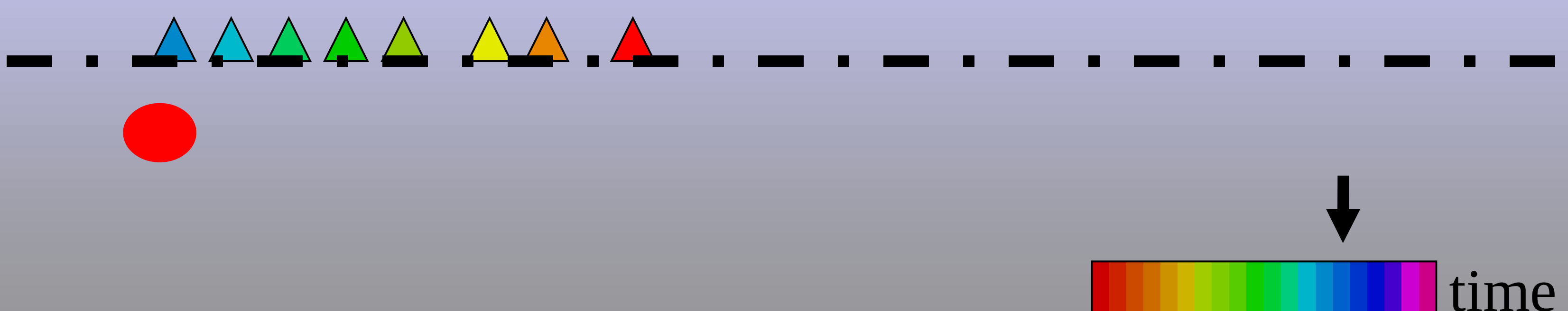


age-distance patterns

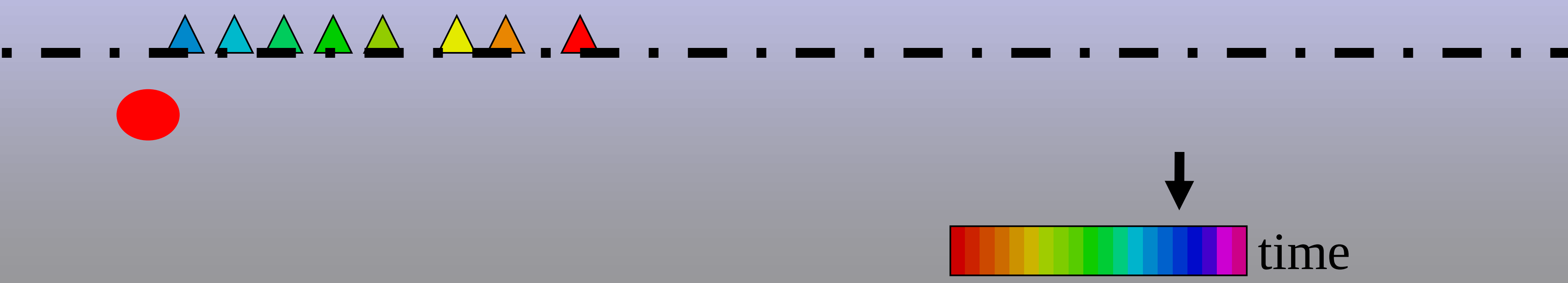




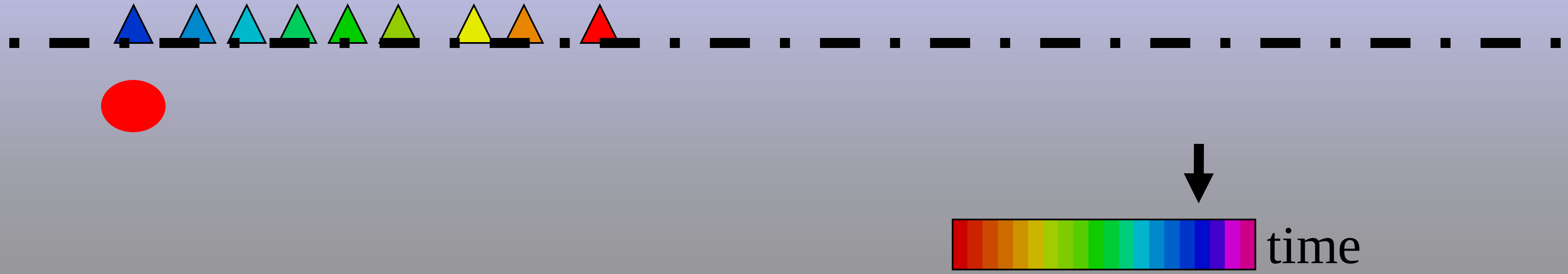
age-distance patterns



age-distance patterns

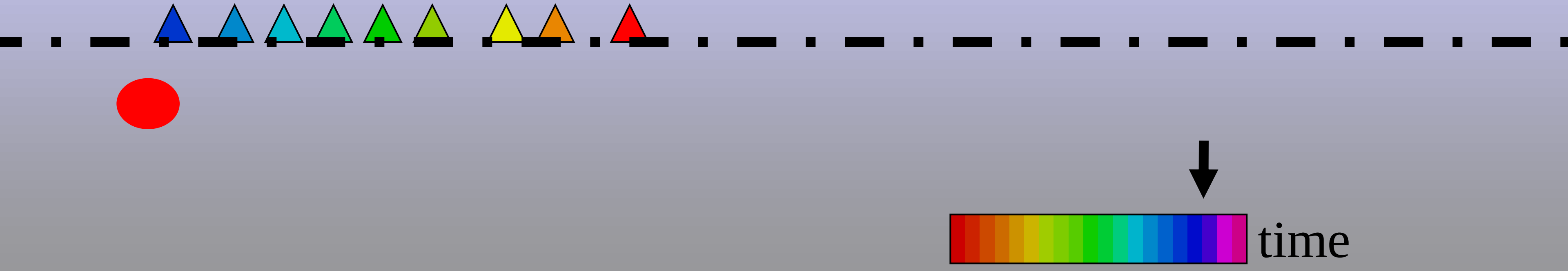


age-distance patterns

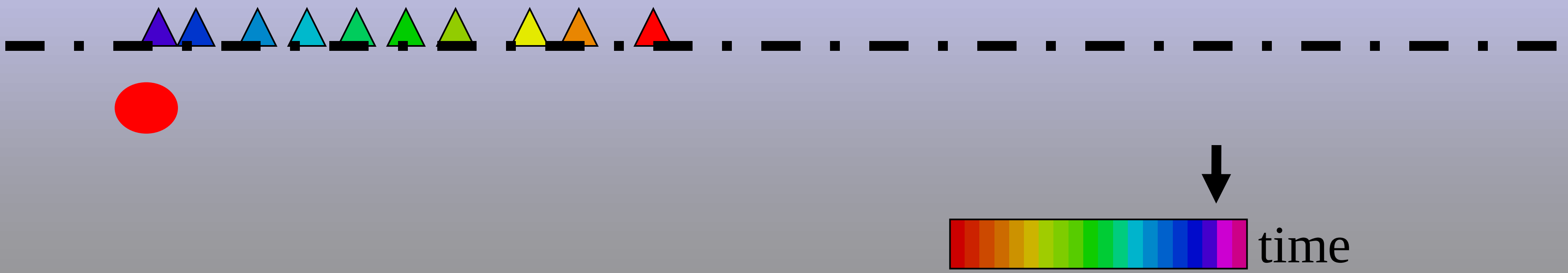


HAWAII HAWAII HAWAII HAWAII

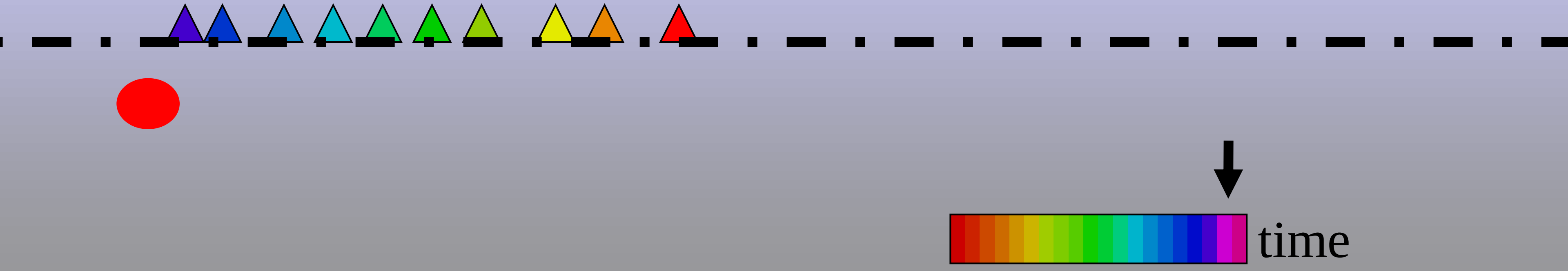
age-distance patterns



age-distance patterns

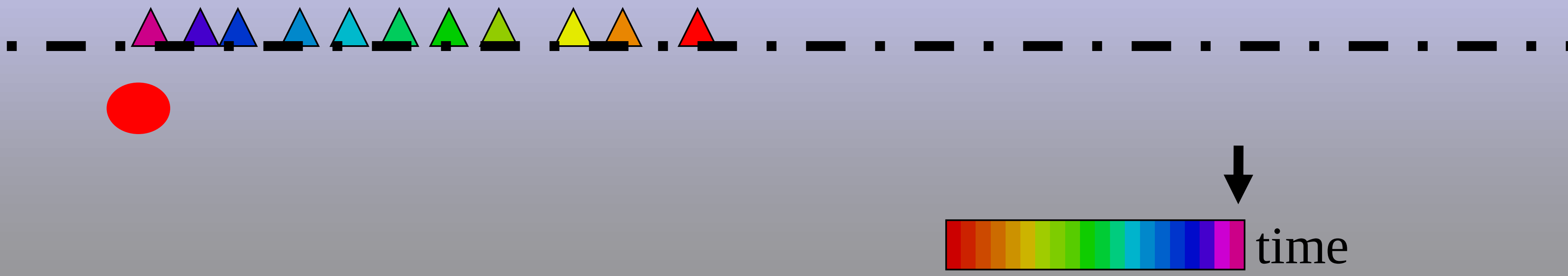


age-distance patterns

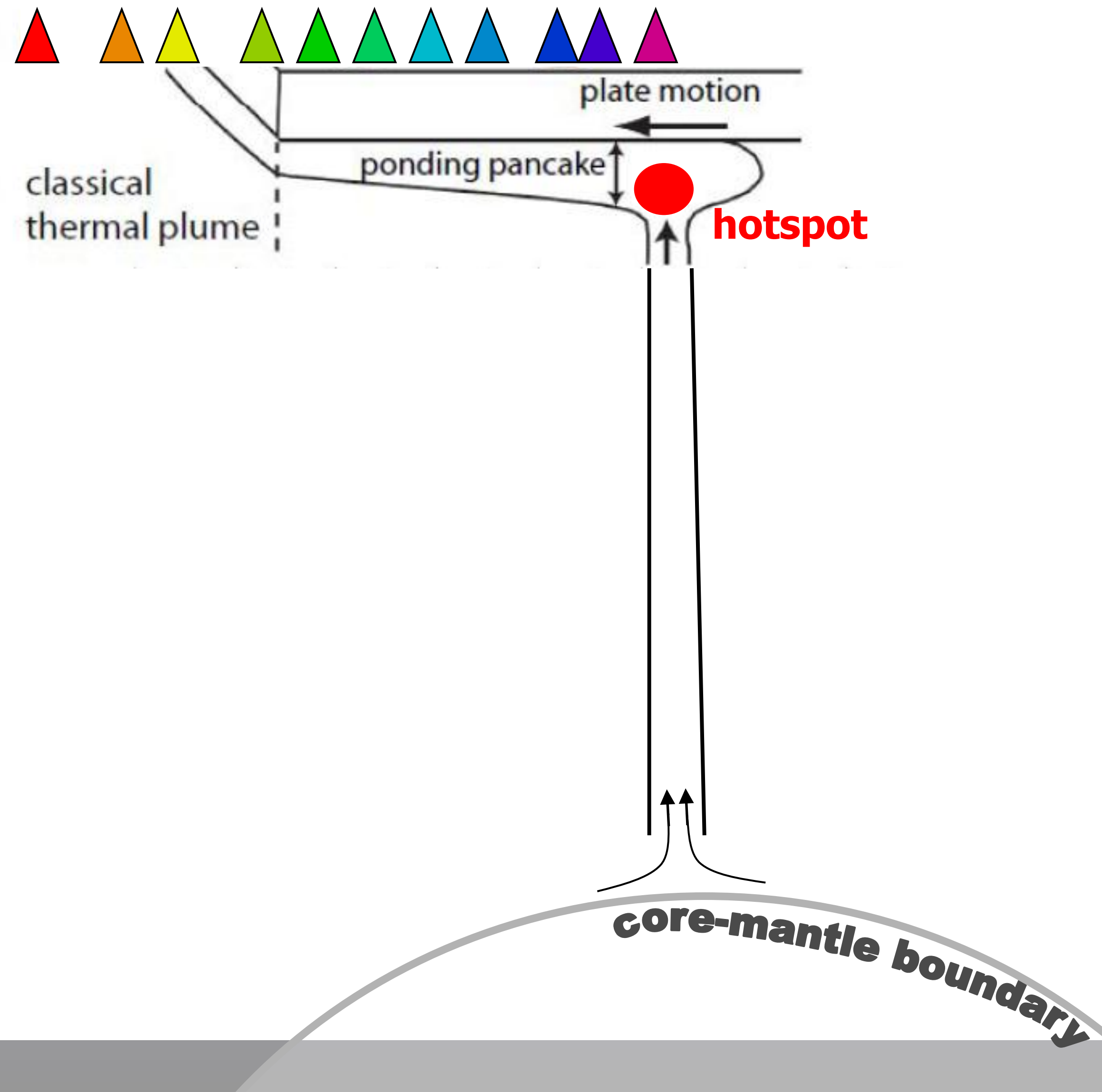


HAWAII HAWAII HAWAII HAWAII HAWAII

age-distance patterns

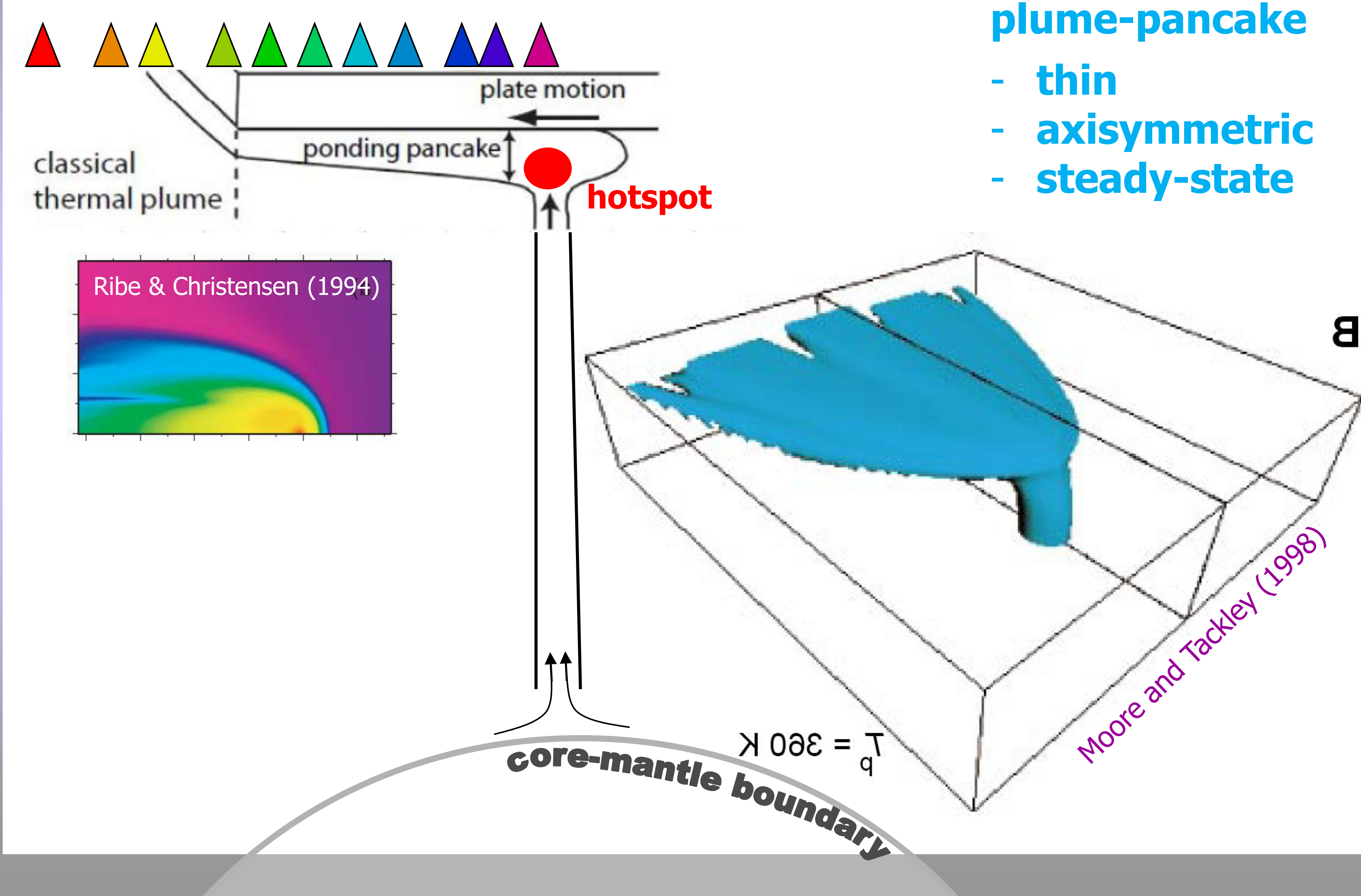


the „classical“ mantle plume concept



MOTIVATION MOTIVATION MOTIVATION

the „classical“ mantle plume concept



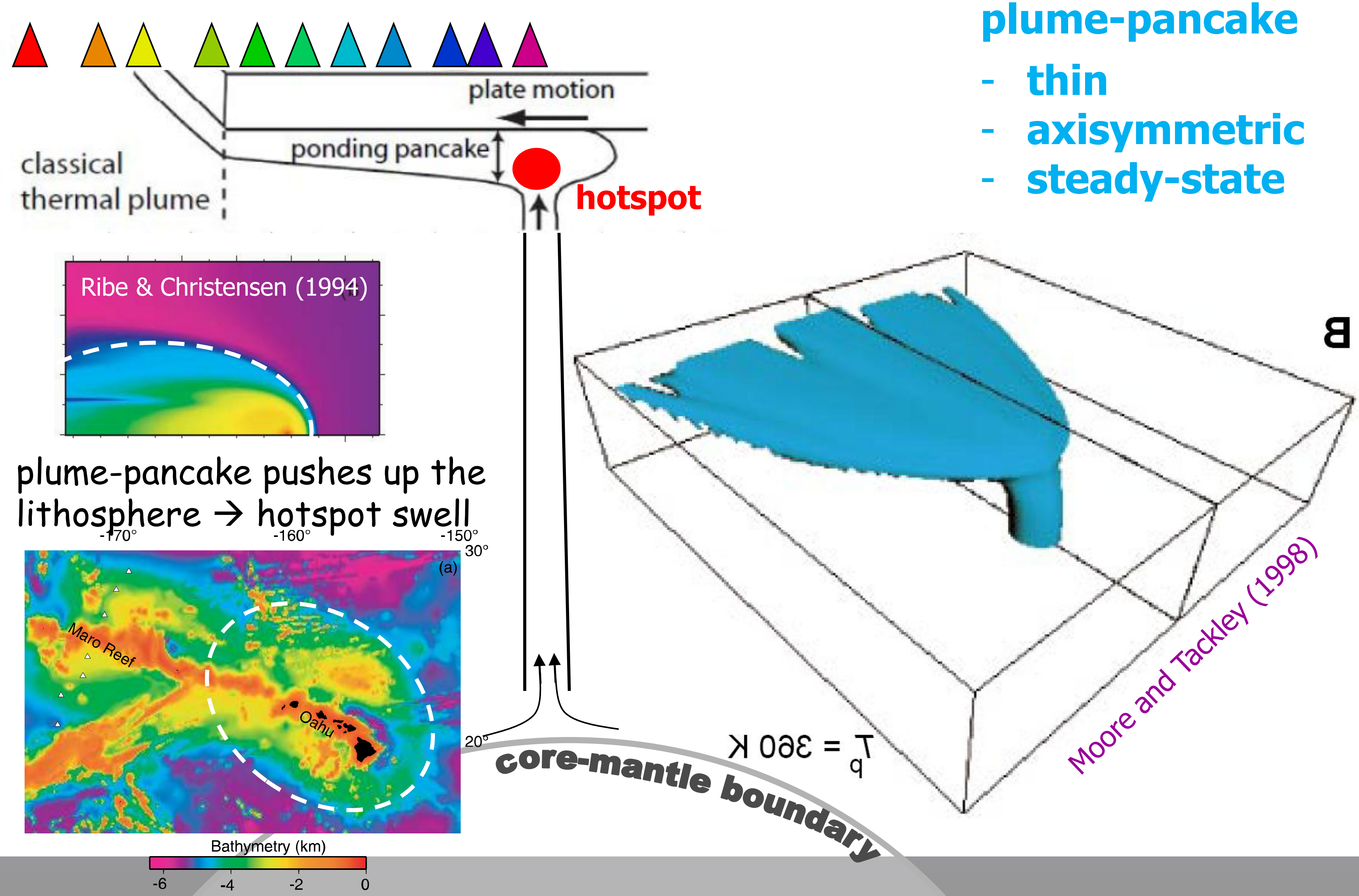
plume-pancake

- thin
- axisymmetric
- steady-state

the „classical" mantle plume concept

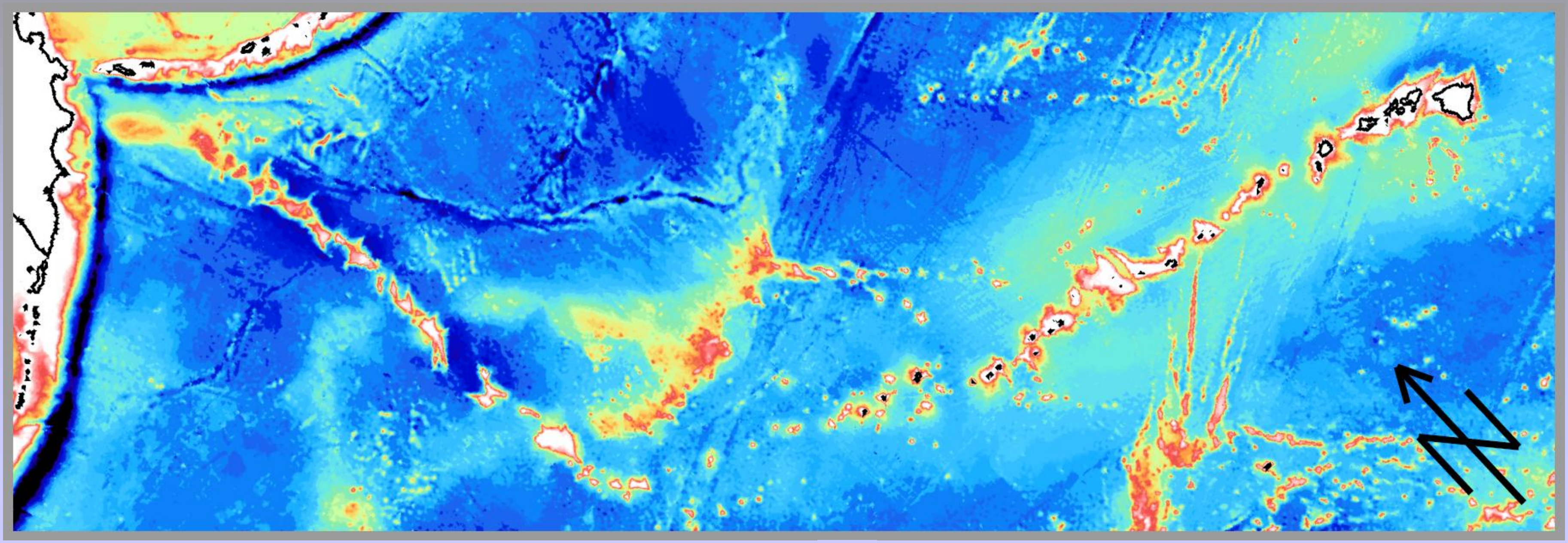
plume-pancake

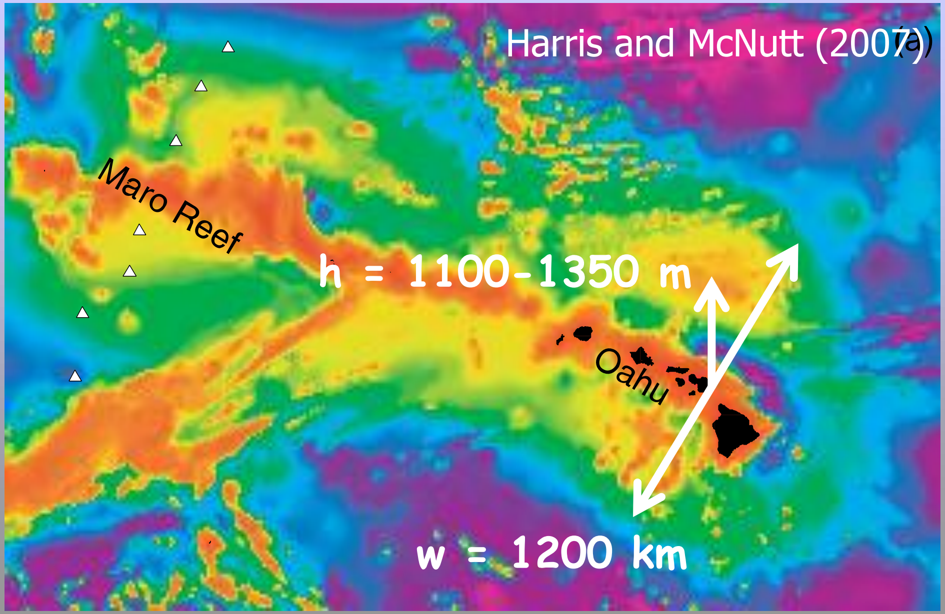
- **thin**
- **axisymmetric**
- **steady-state**



plume-pancake pushes up the lithosphere → hotspot swell

Hawaiian hotspot

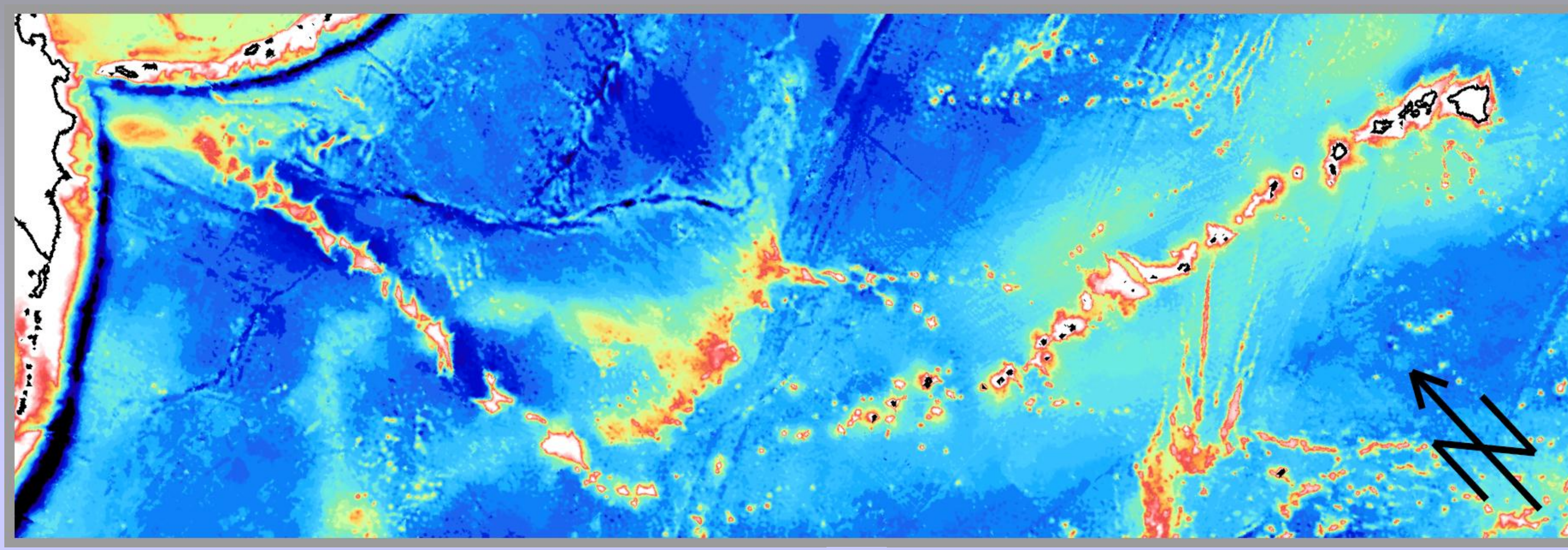




- **Vigorous** volcanism
- **long-lived** hotspot (>84 Myrs)
- **linear** age-distance relationship
- supported by large **swell**

=> caused by mantle plume

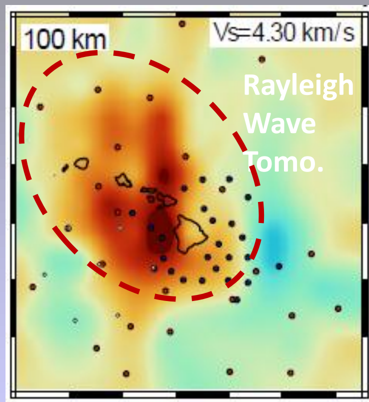
Hawaiian hotspot

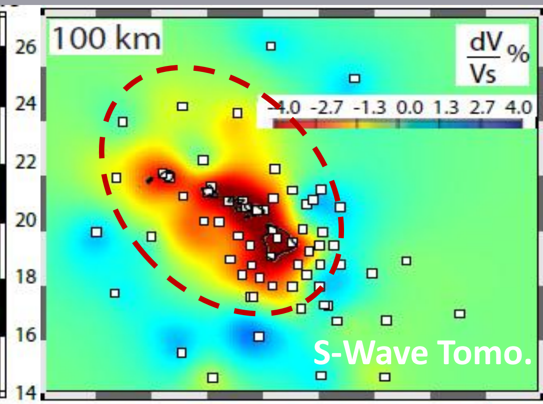


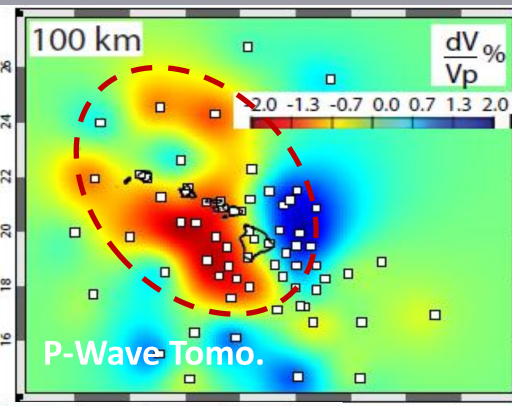
- **Vigorous** volcanism
- **long-lived** hotspot (>84 Myrs)
- **linear** age-distance relationship
- supported by large **swell**

=> by *classical* plume ???

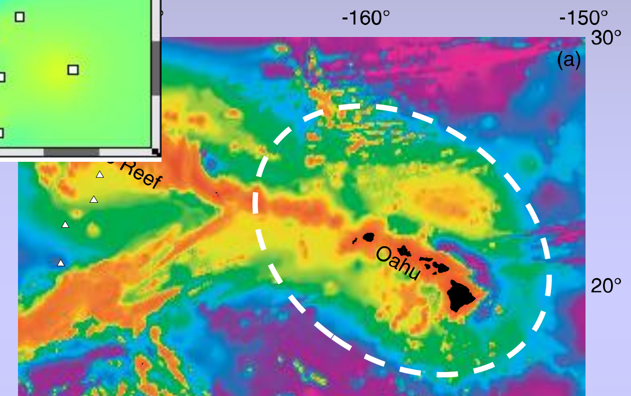
geophysical evicence vs. classical theory







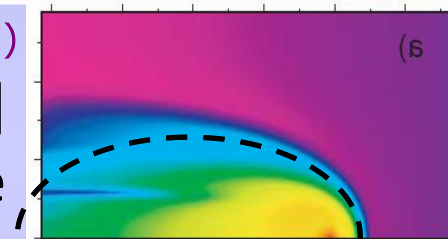
(1) Asymmetric & Short Wavelength Structure

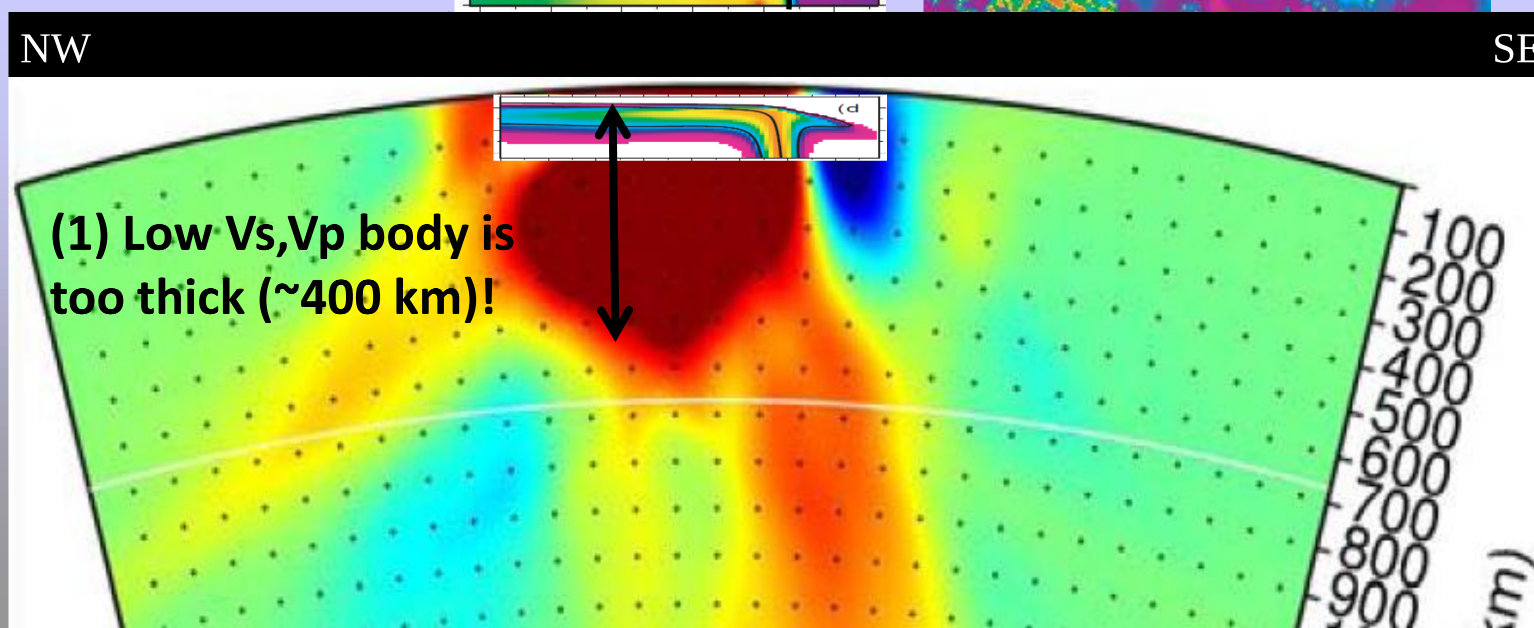


Laske et al. (2011)

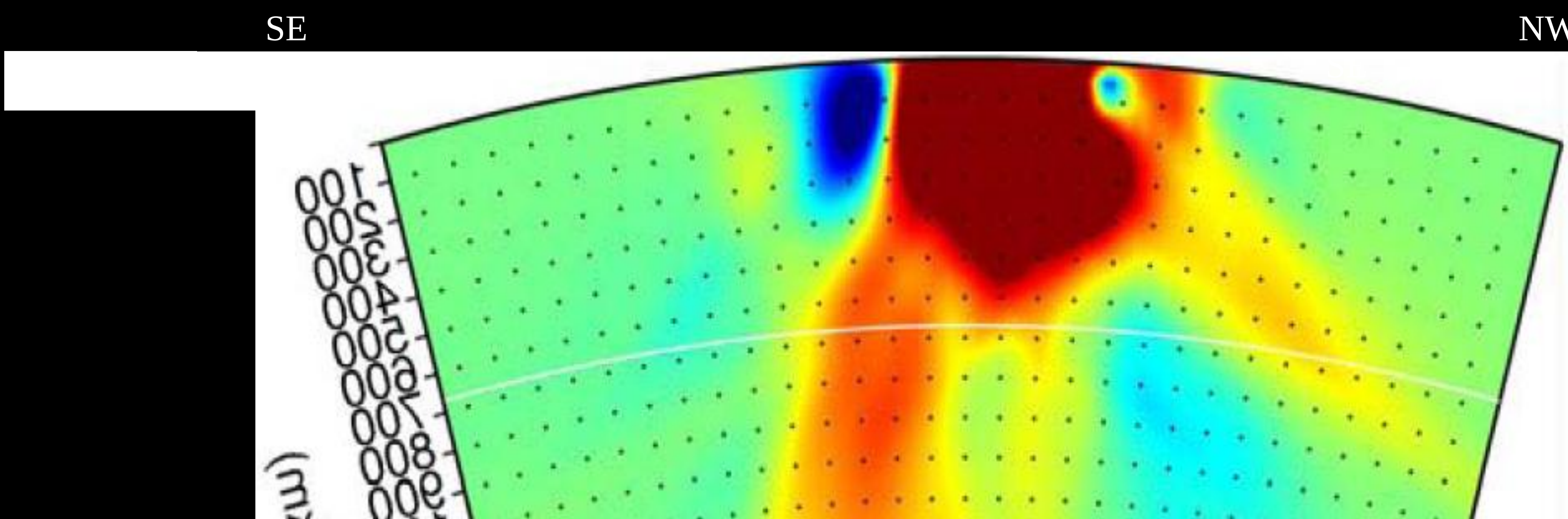
Wolfe et al. (2009; 2011)

Ribe & Christensen [1999]
Thermal plume





geophysical evicence vs. classical theory



geophysical evicence vs. classical theory

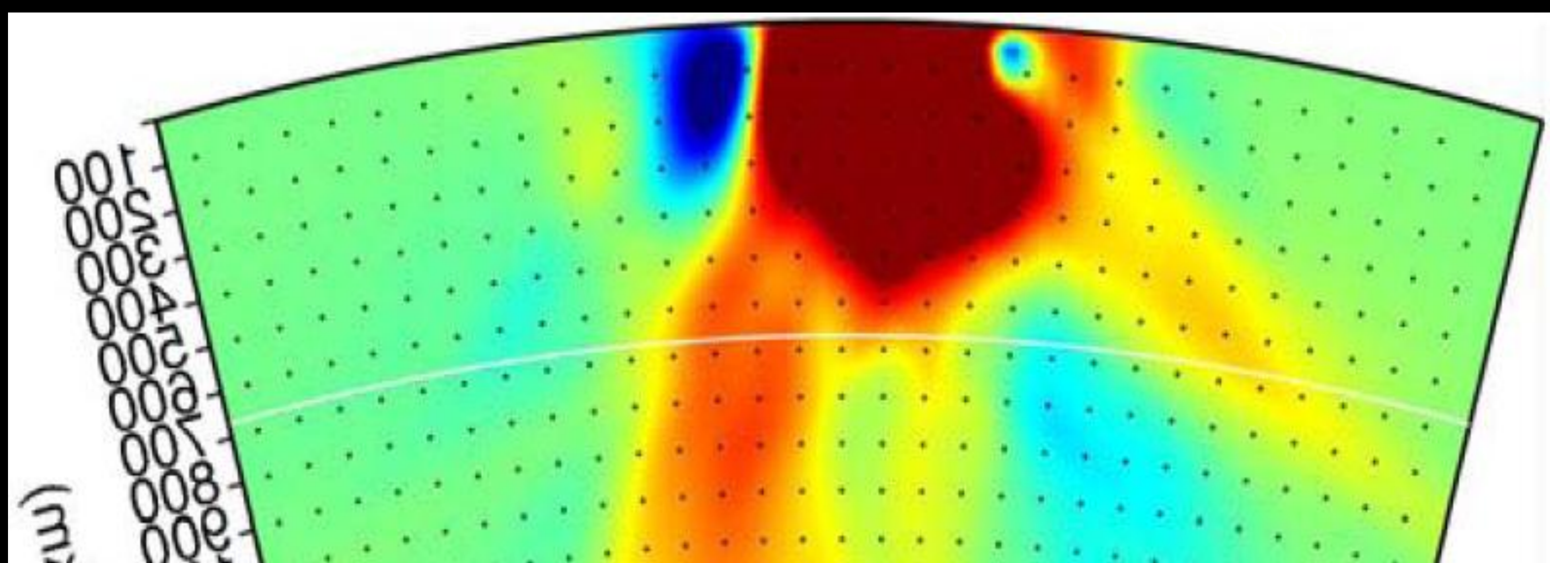
CENSORED

0
200
400
600
800
1000

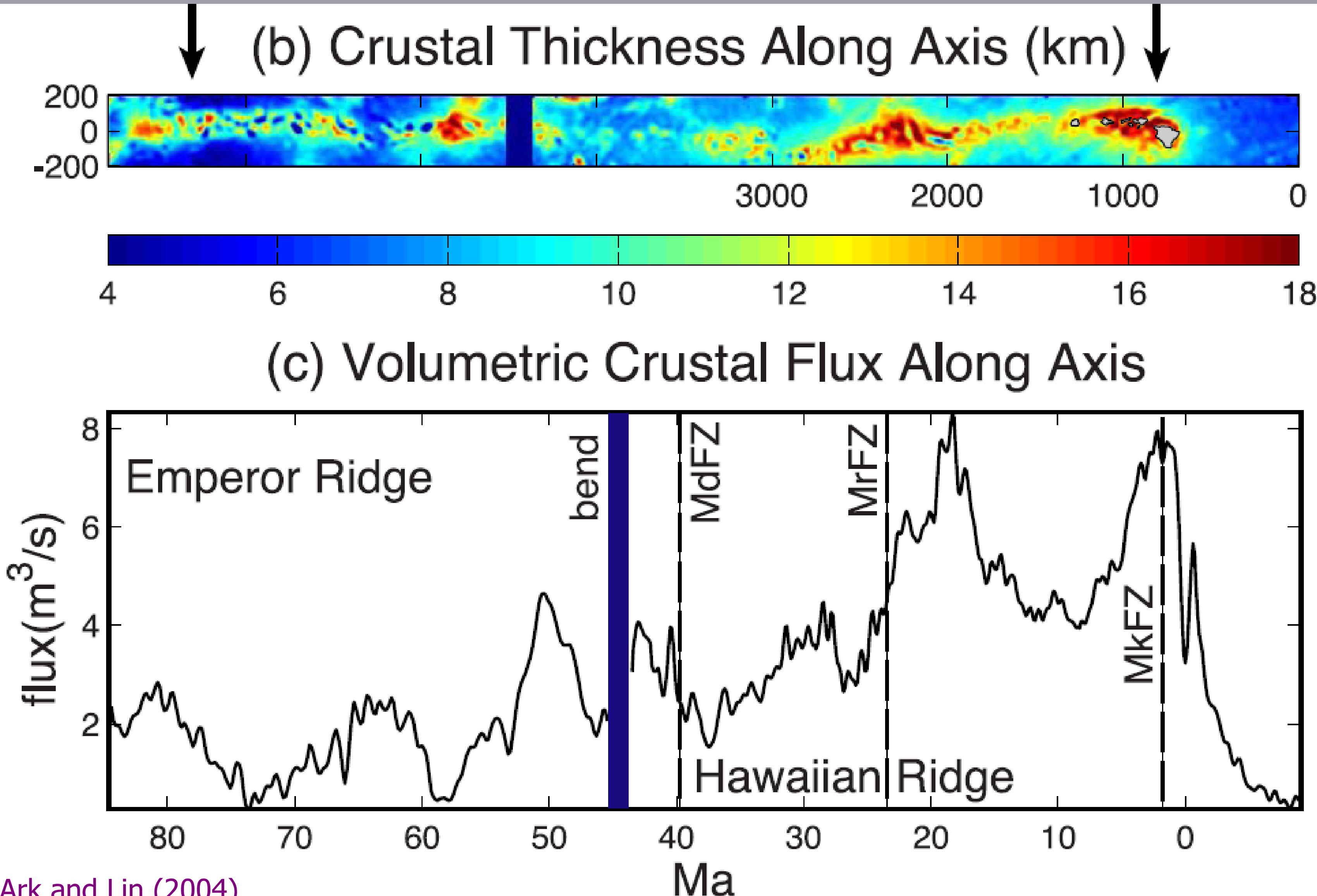
courtesy by Barbara Romanowicz

CENSORED

courtesy by Cheng Cheng →



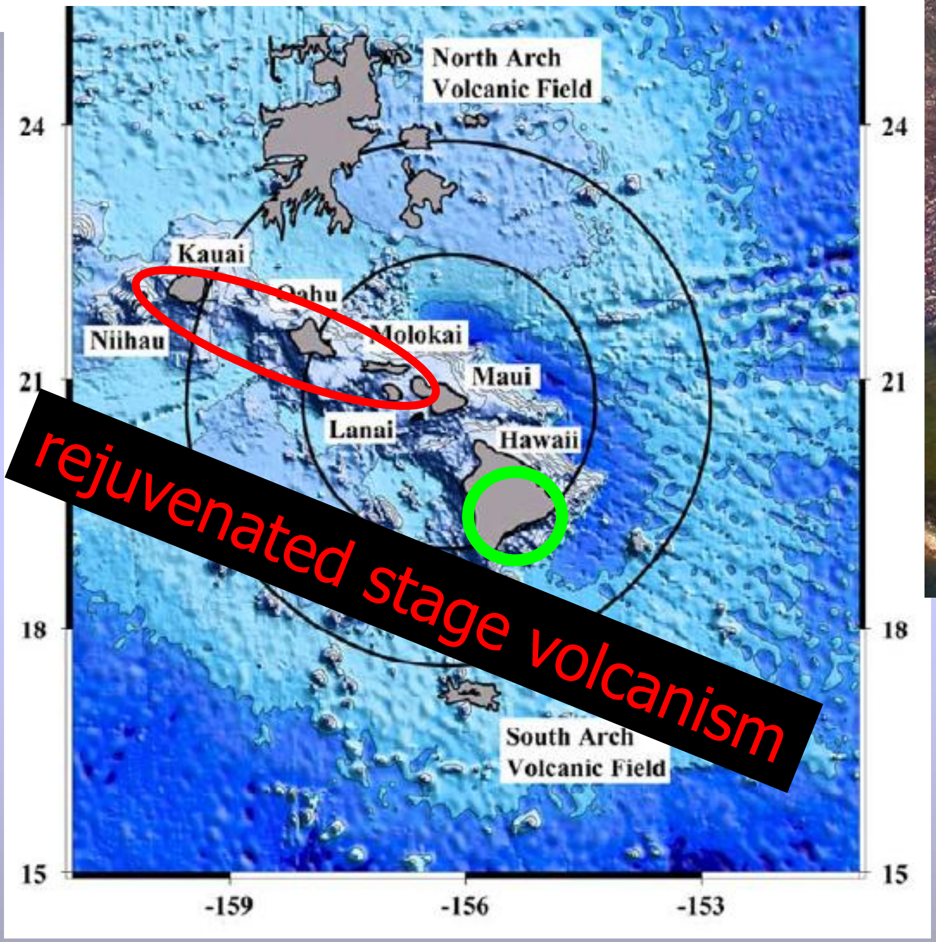
volcanic record vs. classical theory



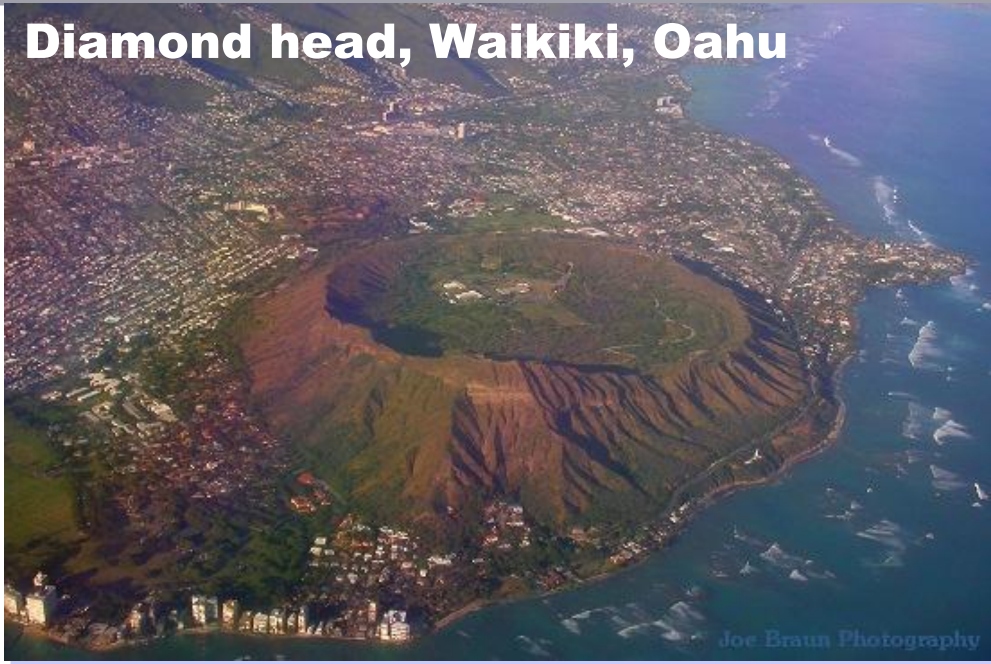
van Ark and Lin (2004)

patterns of volcanism vs. classical theory

Bianco et al. (2005)

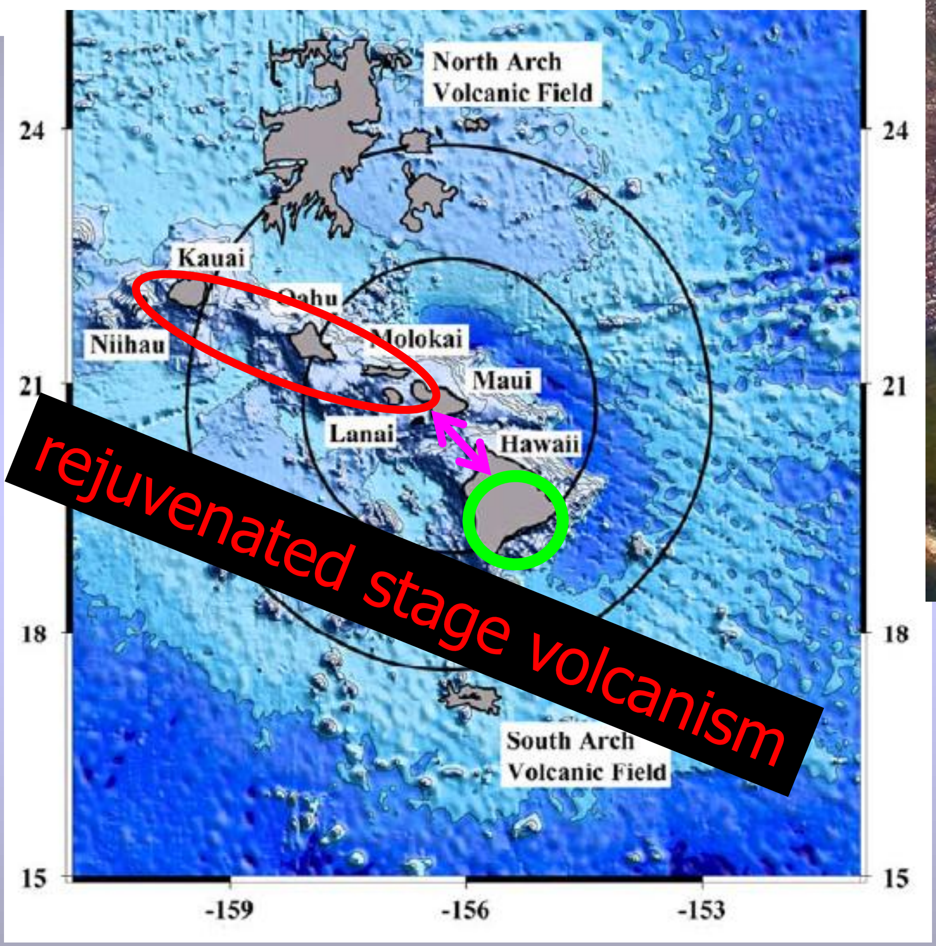


Diamond head, Waikiki, Oahu

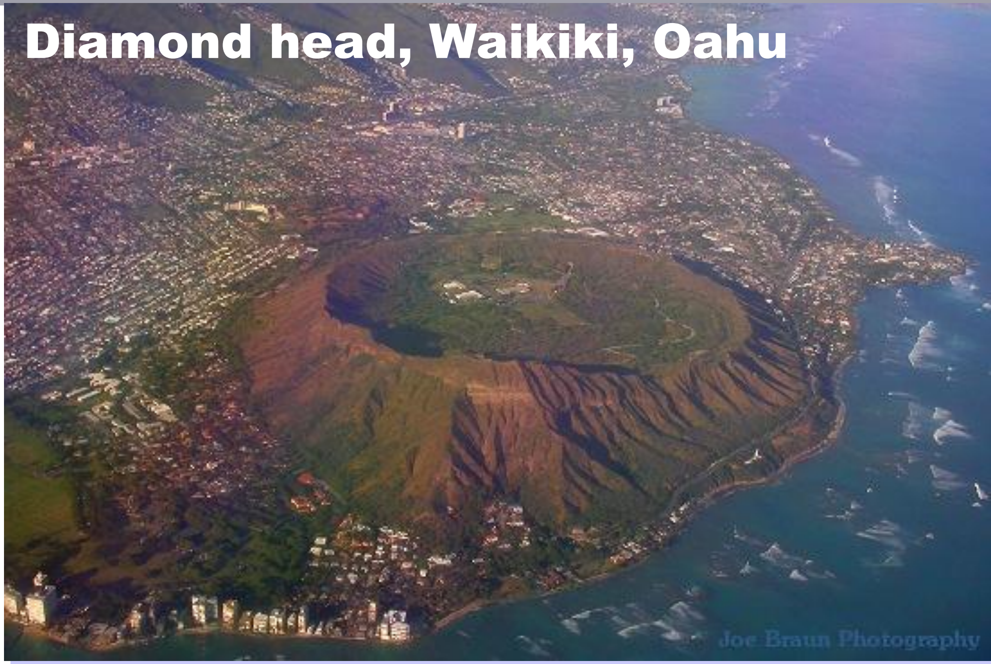


patterns of volcanism vs. classical theory

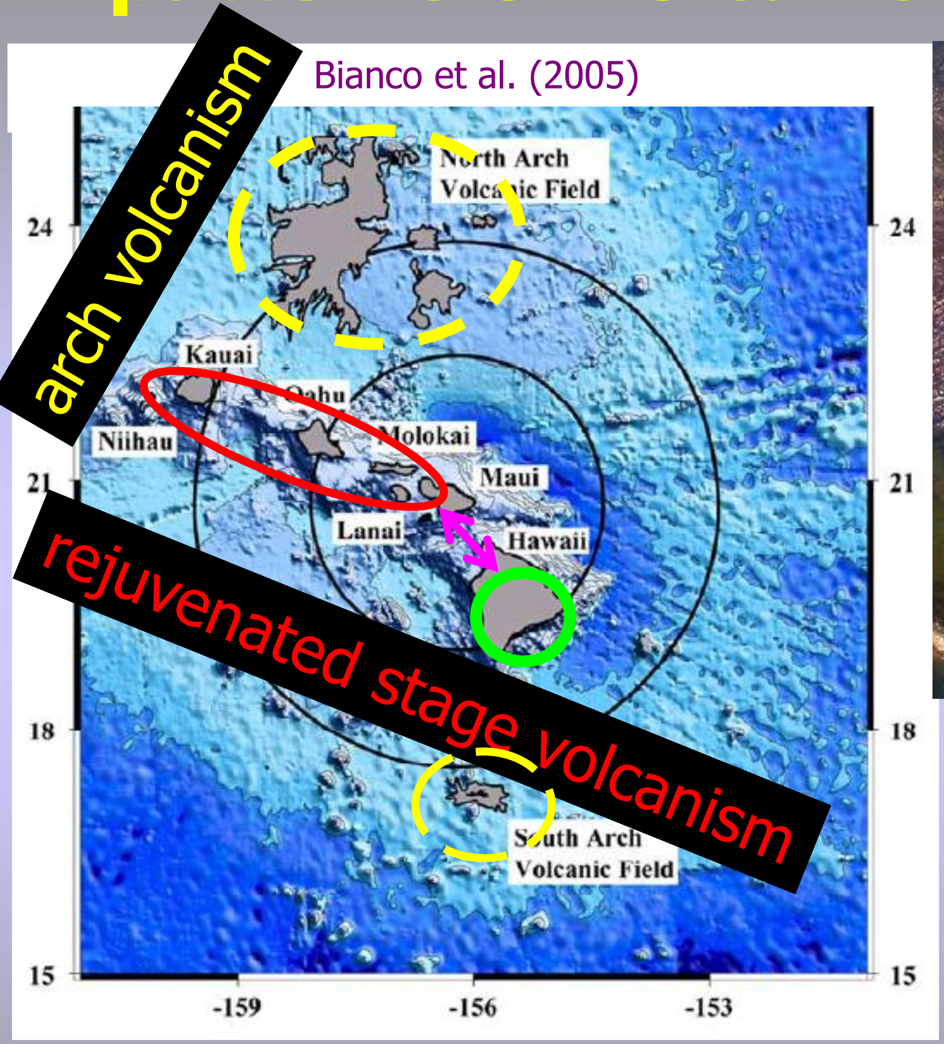
Bianco et al. (2005)

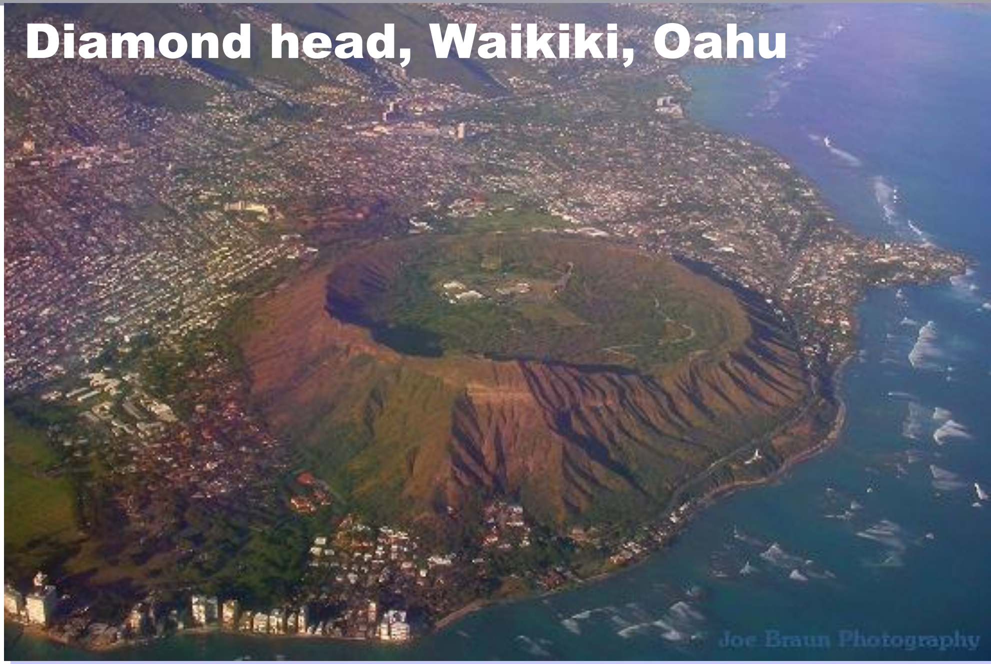


Diamond head, Waikiki, Oahu

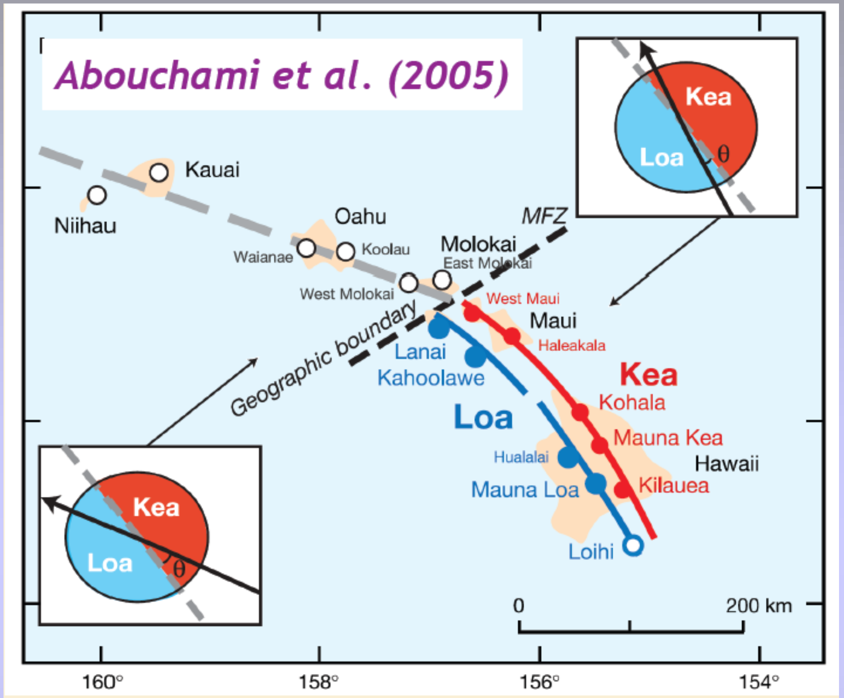


patterns of volcanism vs. classical theory

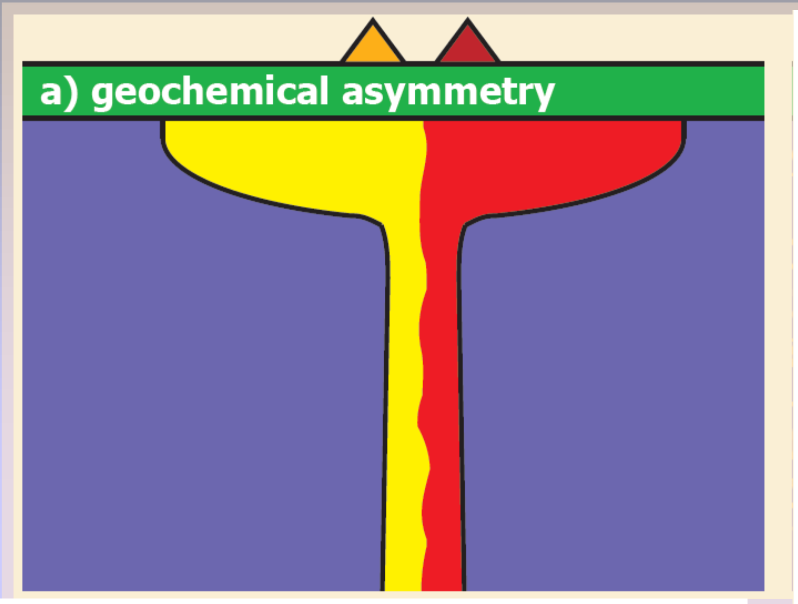


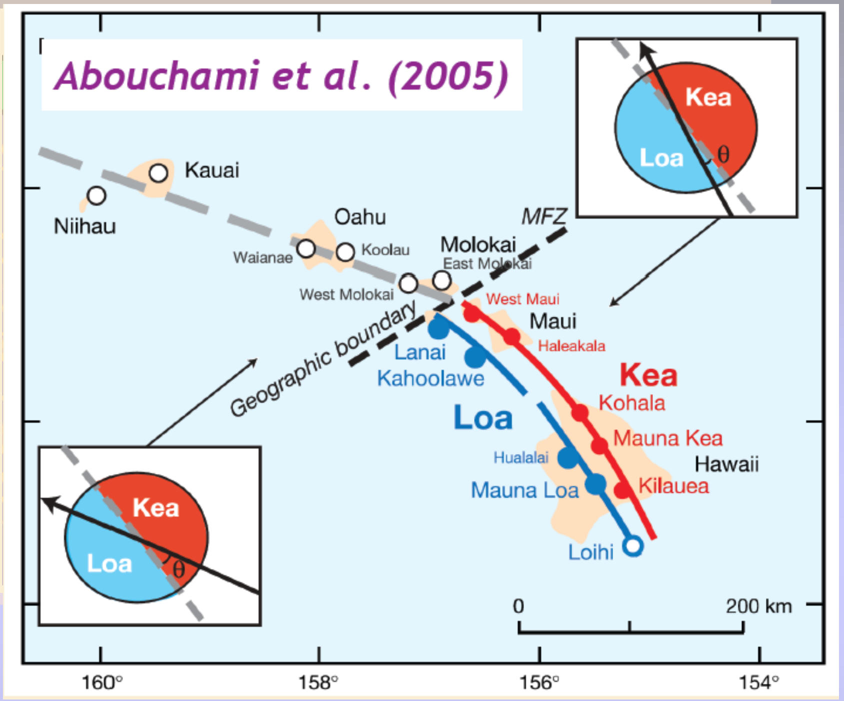


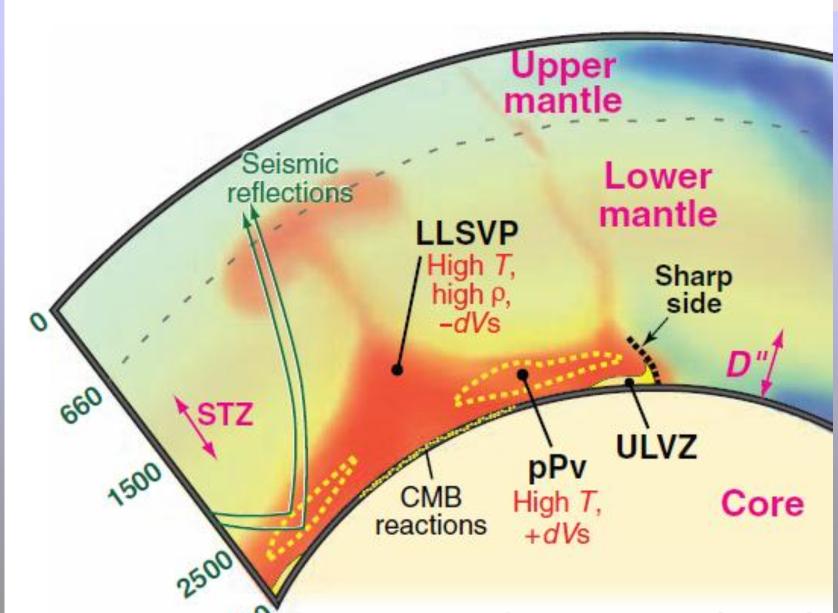
geochemical asymmetry vs. classical theory



geochemical asymmetry vs. classical theory

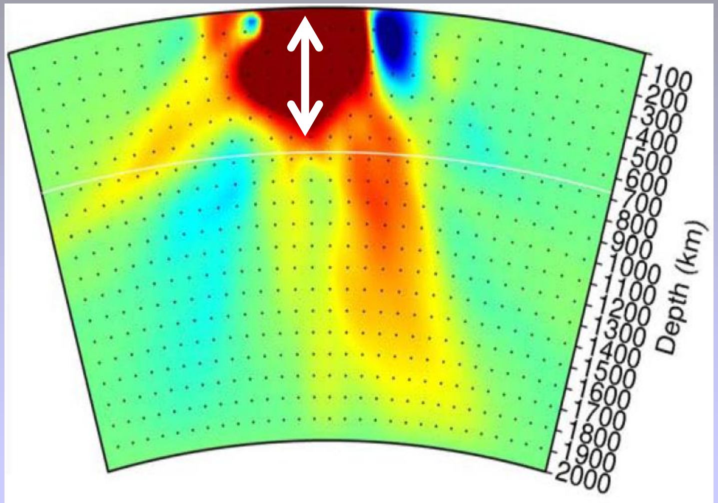






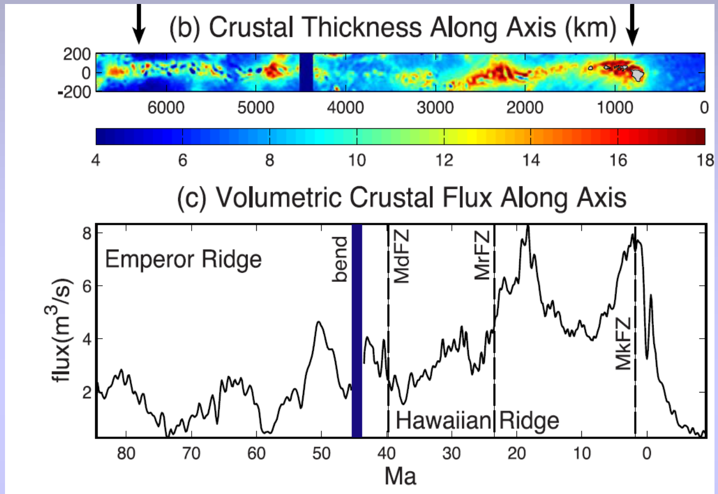
Garnero and McNamara (2008)

Enigmatic observations at Hawaii



1) **seismic constraints from PLUME**
   - **thick low-velocity body**
   - **overall asymmetry**
2) volcanic flux variations
3) widespread secondary volcanism
4) geochemical asymmetry

Enigmatic observations at Hawaii

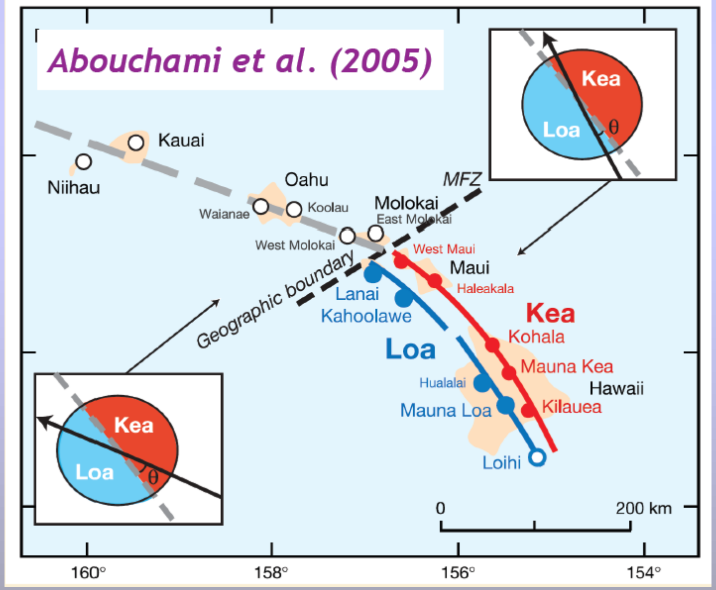


1) seismic constraints from PLUME
   - thick low-velocity body
   - overall asymmetry
2) **volcanic flux variations**
3) widespread secondary volcanism
4) geochemical asymmetry

Enigmatic observations at Hawaii

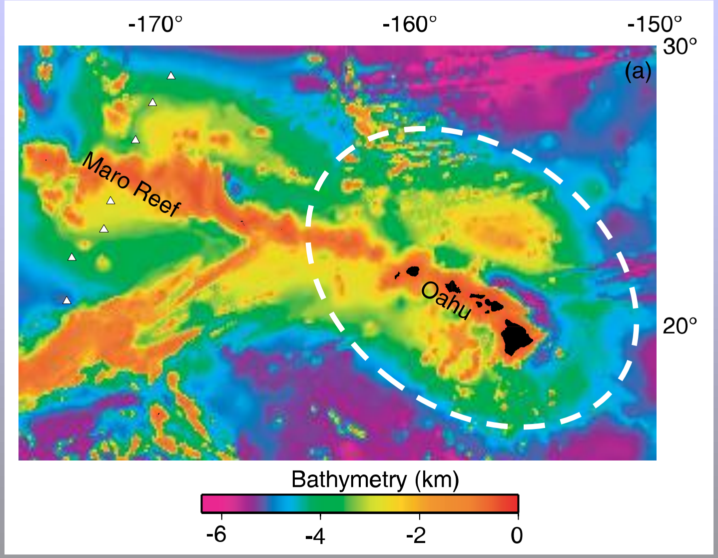
1) seismic constraints from PLUME
   - thick low-velocity body
   - overall asymmetry
2) volcanic flux variations
3) **widespread secondary volcanism**
4) geochemical asymmetry

Enigmatic observations at Hawaii



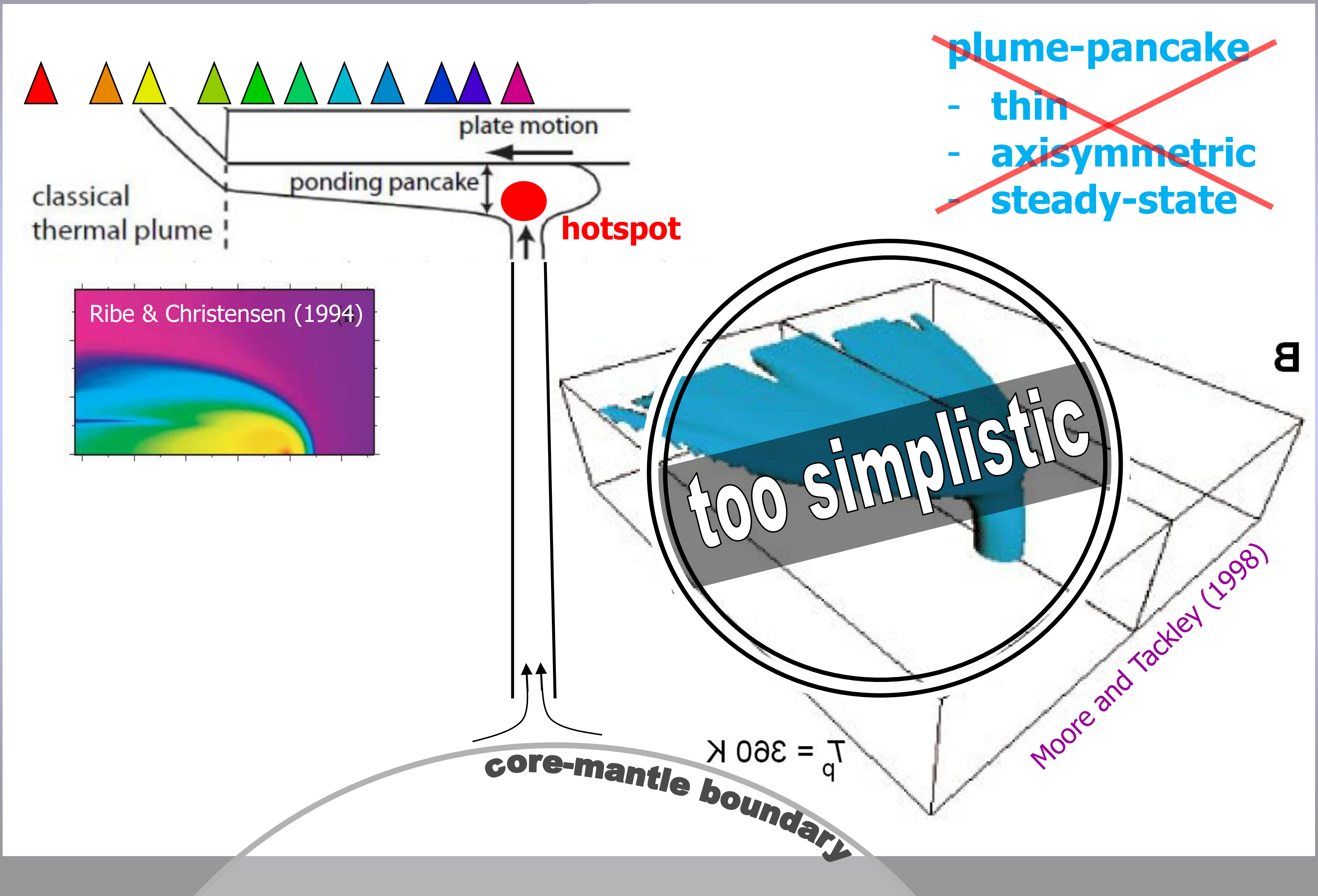
1) seismic constraints from PLUME
   - thick low-velocity body
   - overall asymmetry
2) volcanic flux variations
3) widespread secondary volcanism
4) **geochemical asymmetry**

Enigmatic observations at Hawaii

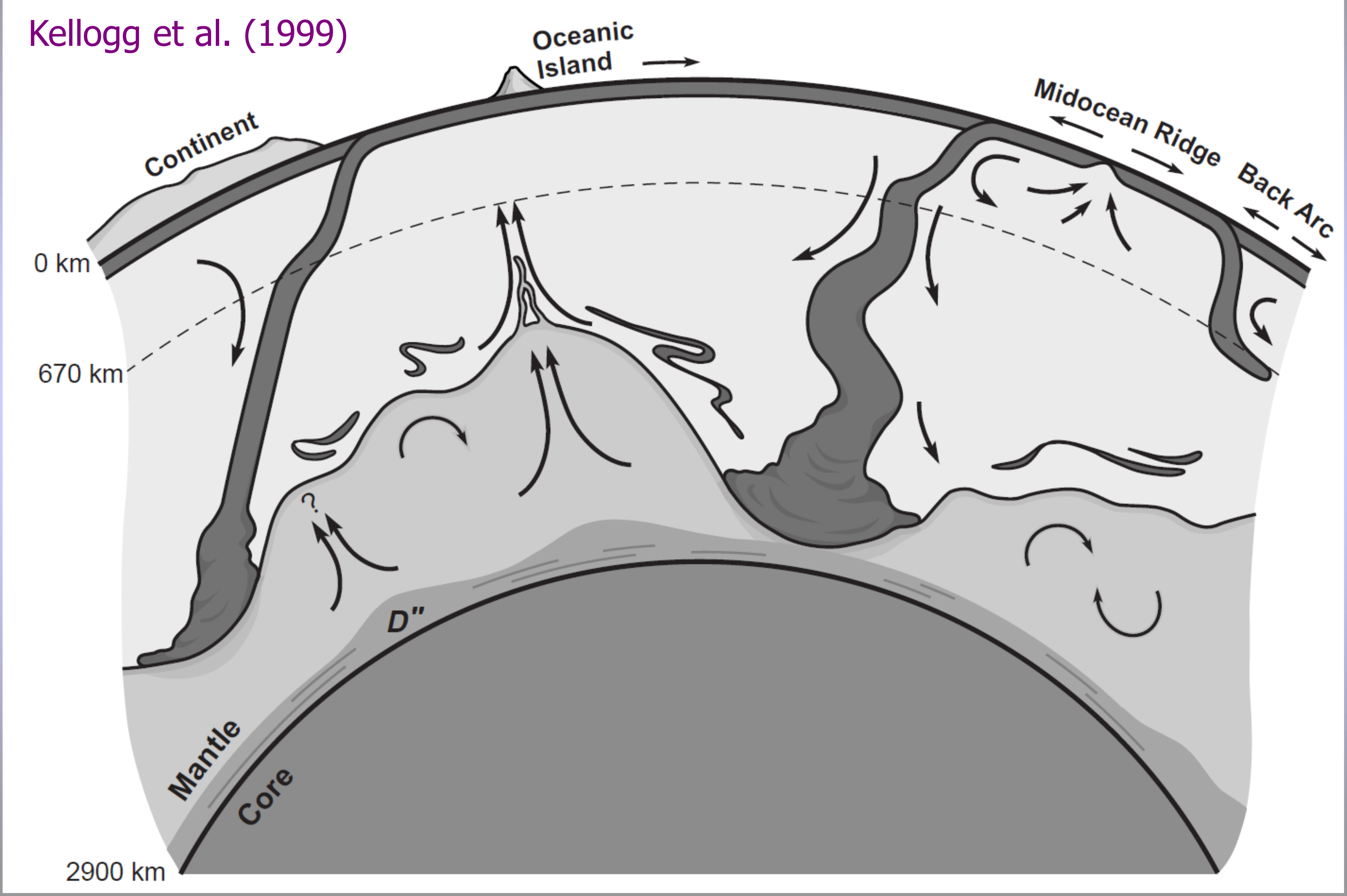


1) seismic constraints from PLUME
   - thick low-velocity body
   - *overall asymmetry*
2) volcanic flux variations
3) widespread secondary volcanism
4) *geochemical asymmetry*
5) ***asymmetry in swell geometry***

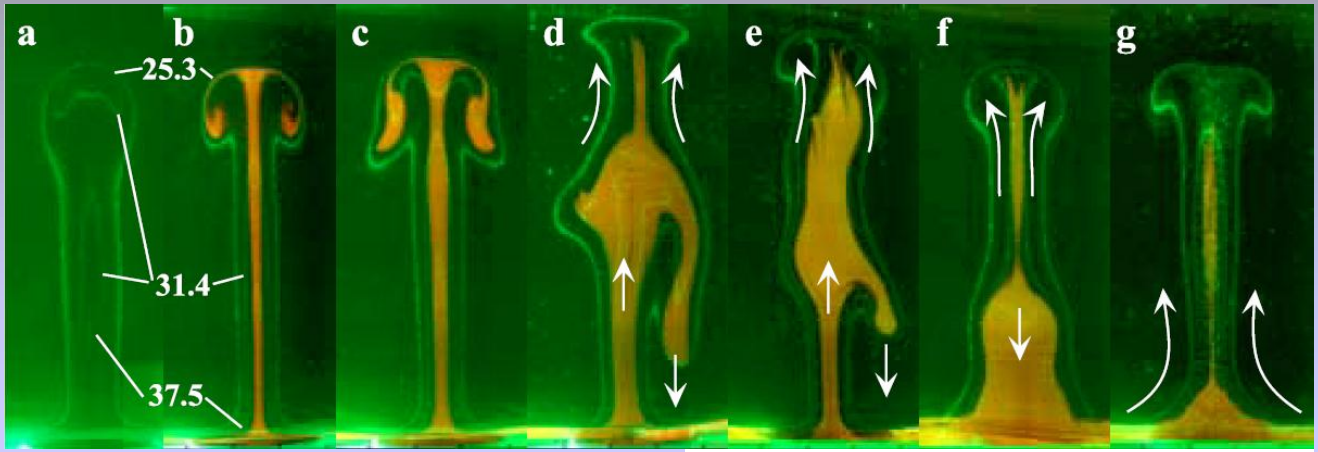
>>> problem statement <<<



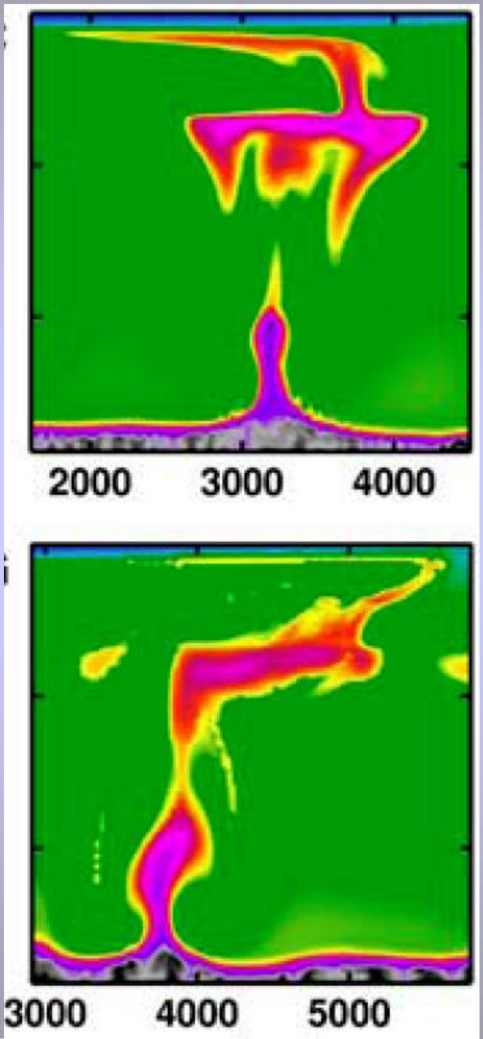
plumes may be thermochemical plumes



alternative: thermochemical plumes



Kumagai et al. (2008)

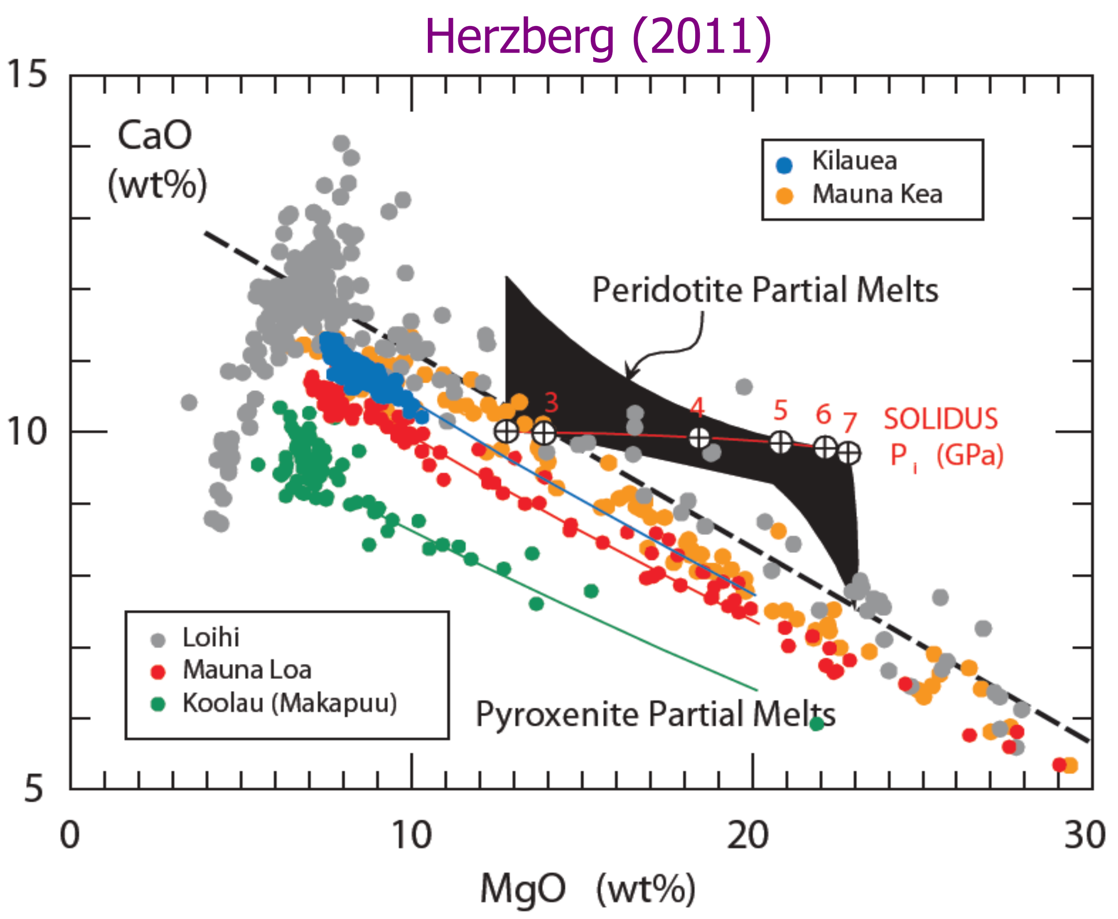


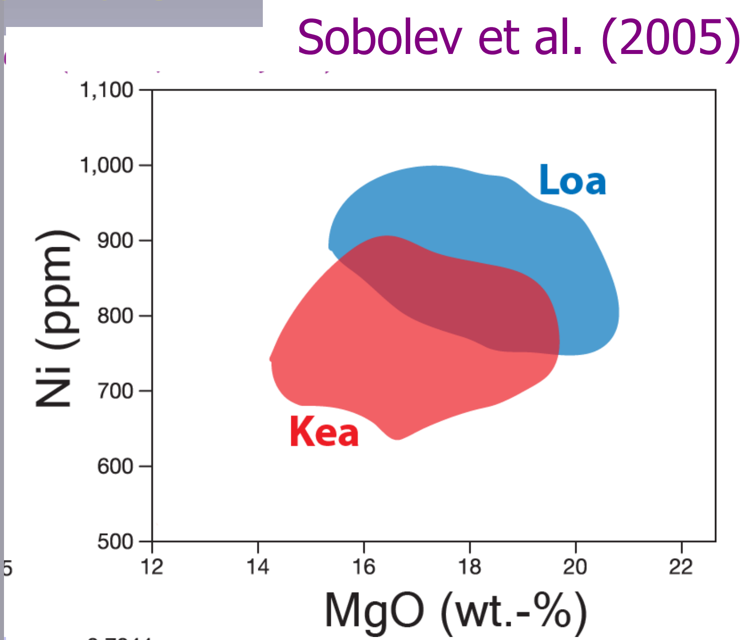
Farnetani and Samuel (2005)

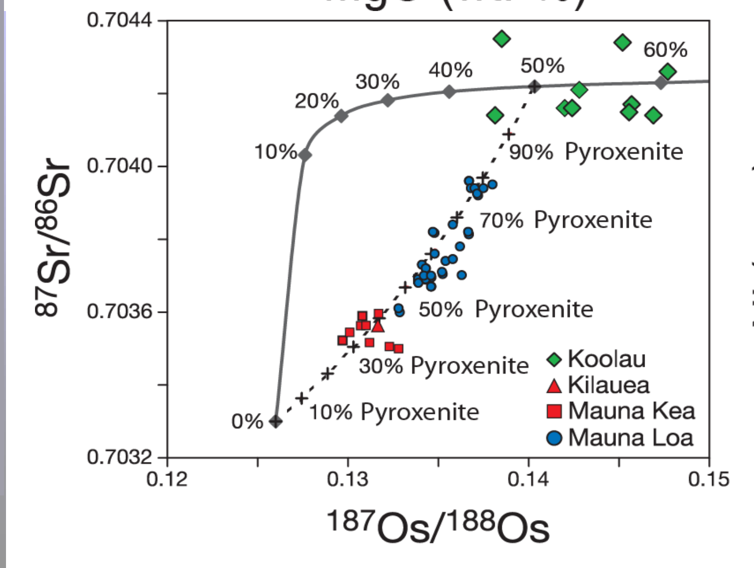
mafic lithologies such as eclogite are intrinsically dense

→ fat, complex plumes

evidence for mafic heterogeneity in Hawaiian lavas

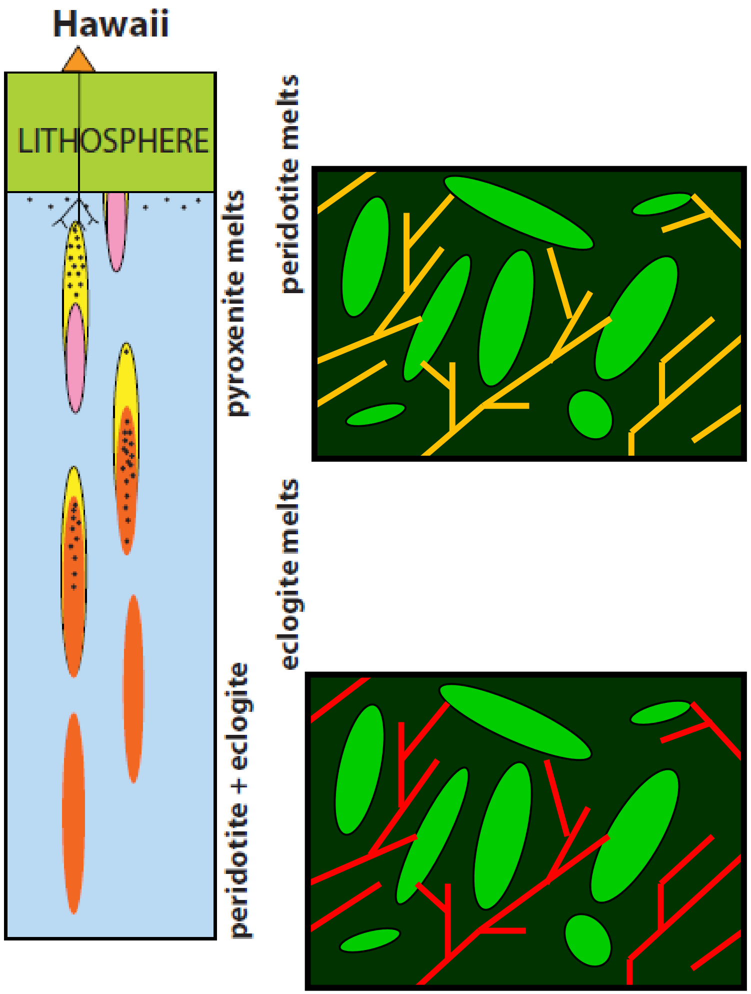






more mafic materials in the source of Loa-volcanoes

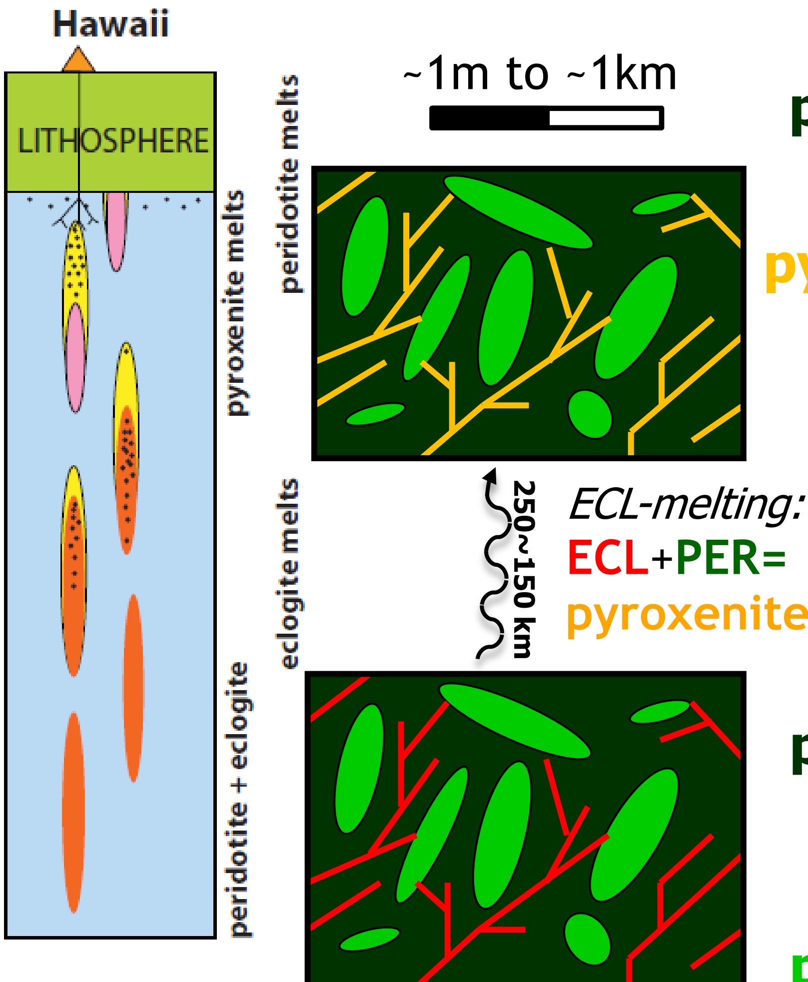
mafic heterogeneity in mantle upwellings



15-20%-eclogite in plume stem

Sobolev et al. (2005, 2007)

mafic heterogeneity in mantle upwellings



~76% peridotite

18% pyroxenite

6% refr. eclogite

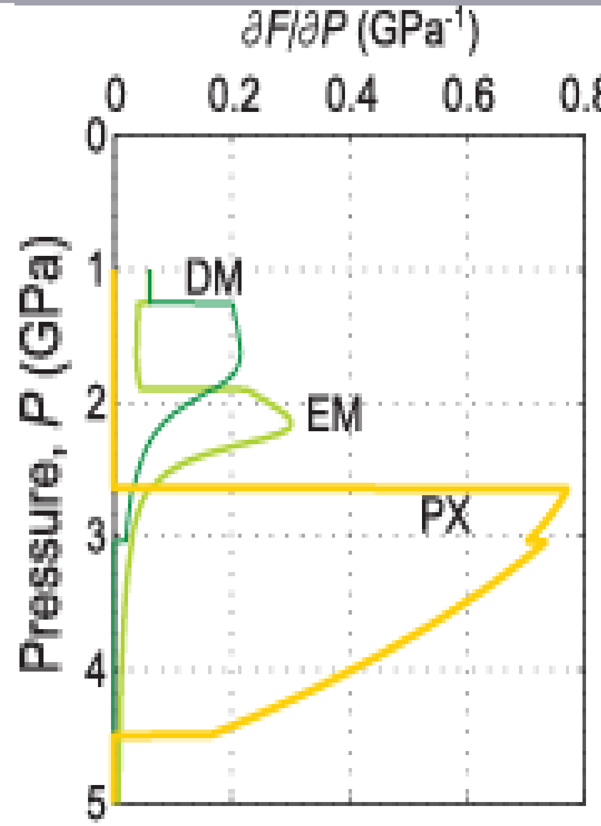
65% dry peridotite

20% hydrous peridotite

15% eclogite

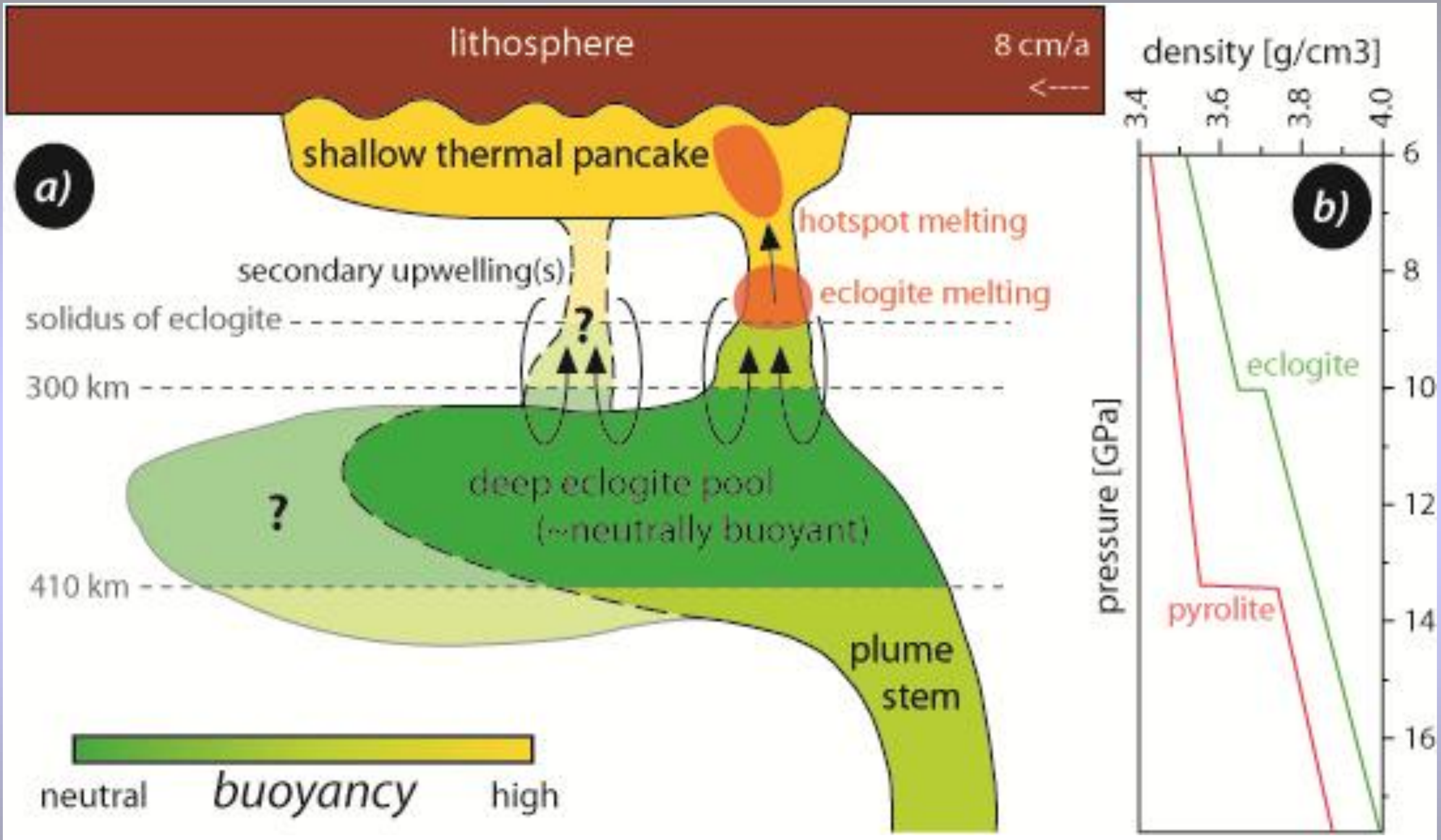
15-20%-eclogite in plume stem

Sobolev et al. (2005, 2007)



Ito and Mahoney (2005)

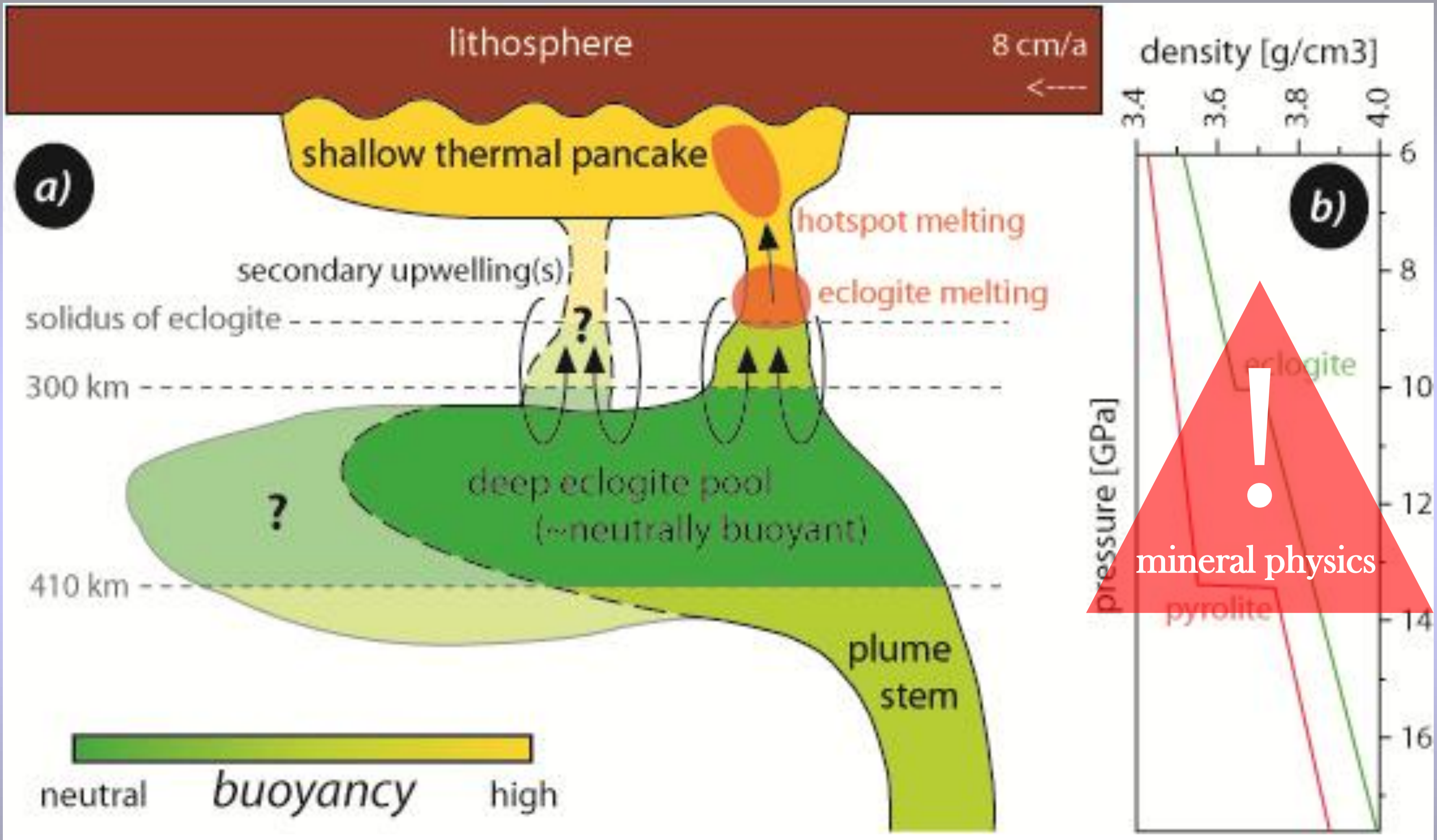
eclogitic plumes in the upper mantle



Aoki and Takahashi (2004)

hypothesis: **pooling in two layers**

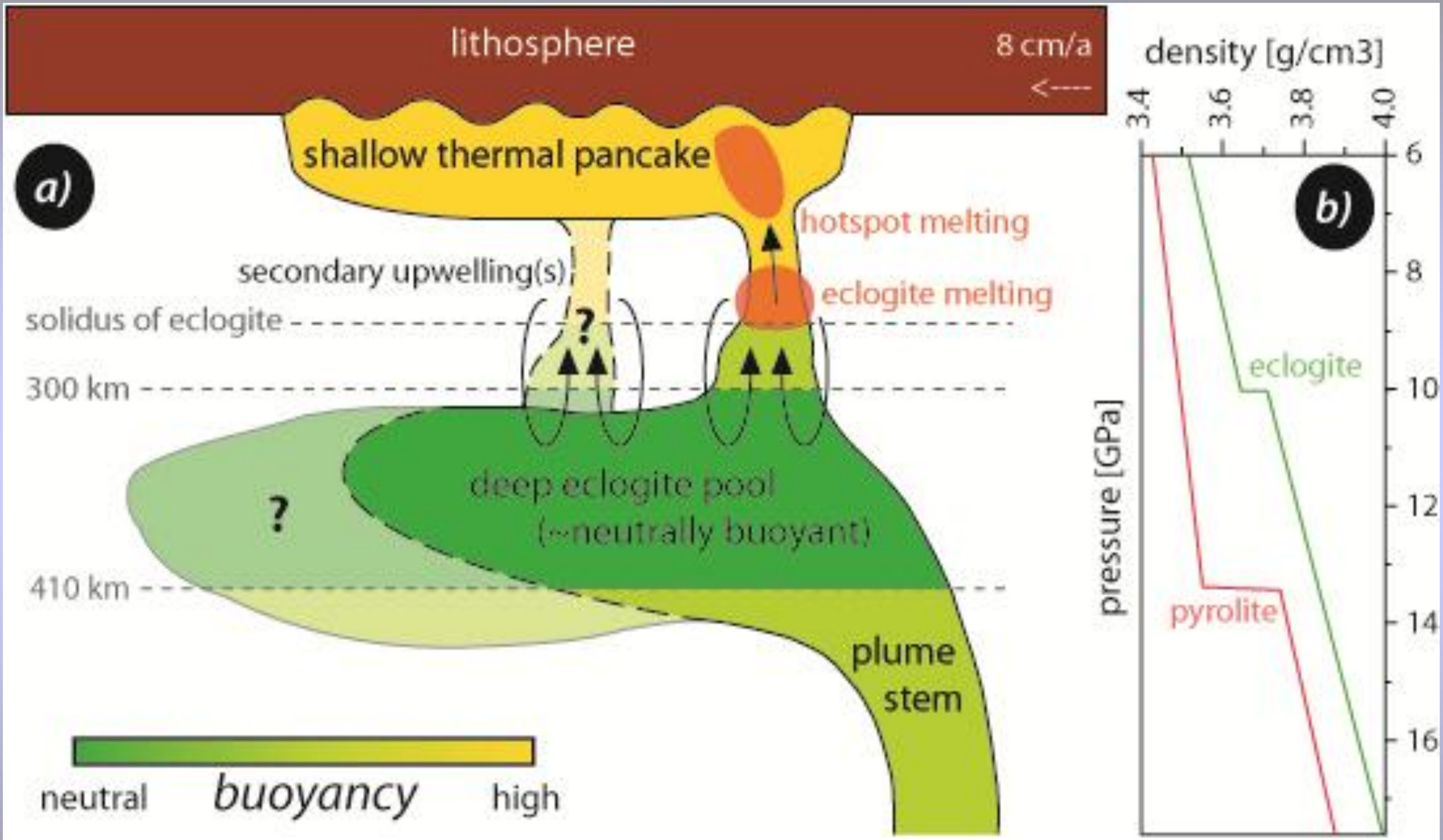
eclogitic plumes in the upper mantle



Aoki and Takahashi (2004)

hypothesis: **pooling in two layers**

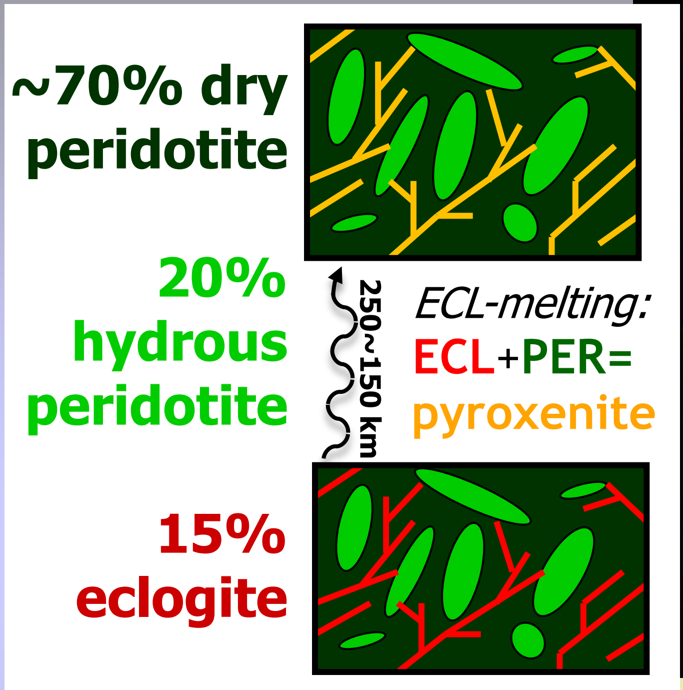
eclogitic plumes in the upper mantle

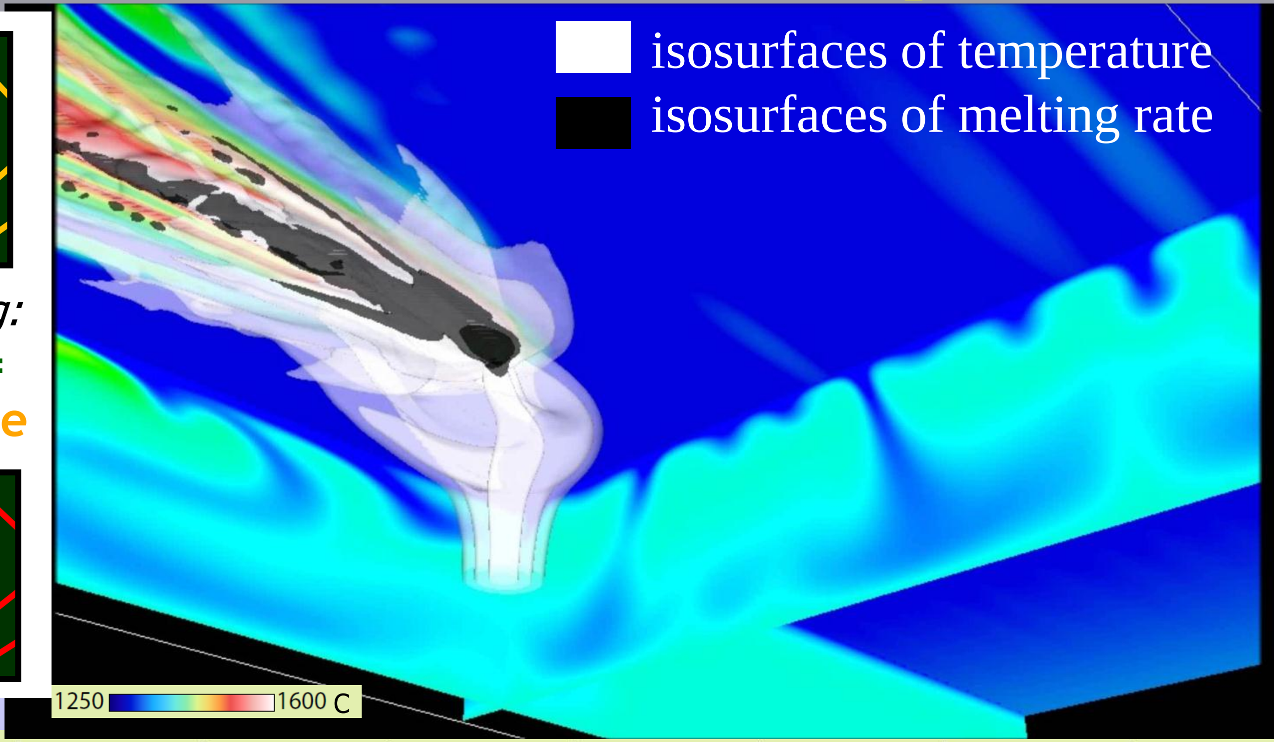


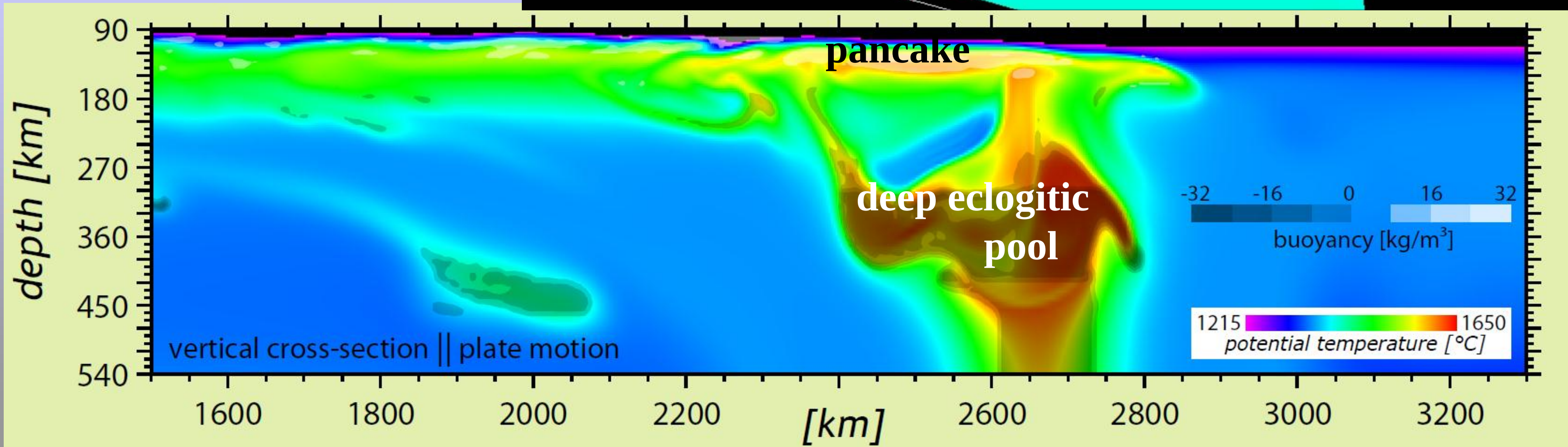
Aoki and Takahashi (2004)

hypothesis: **pooling in two layers**

pooling in a thick double-layer

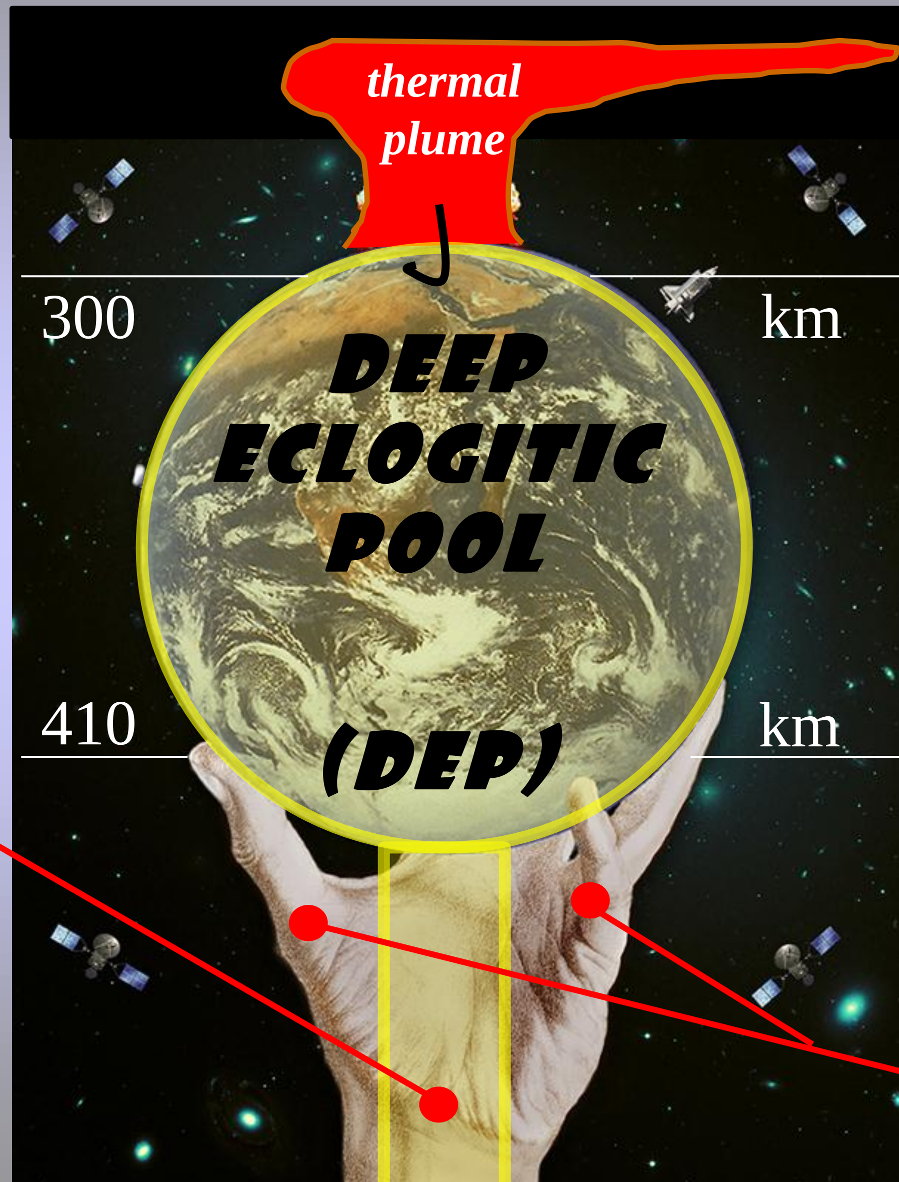






 RESULTS PART 2 RESULTS PART 2

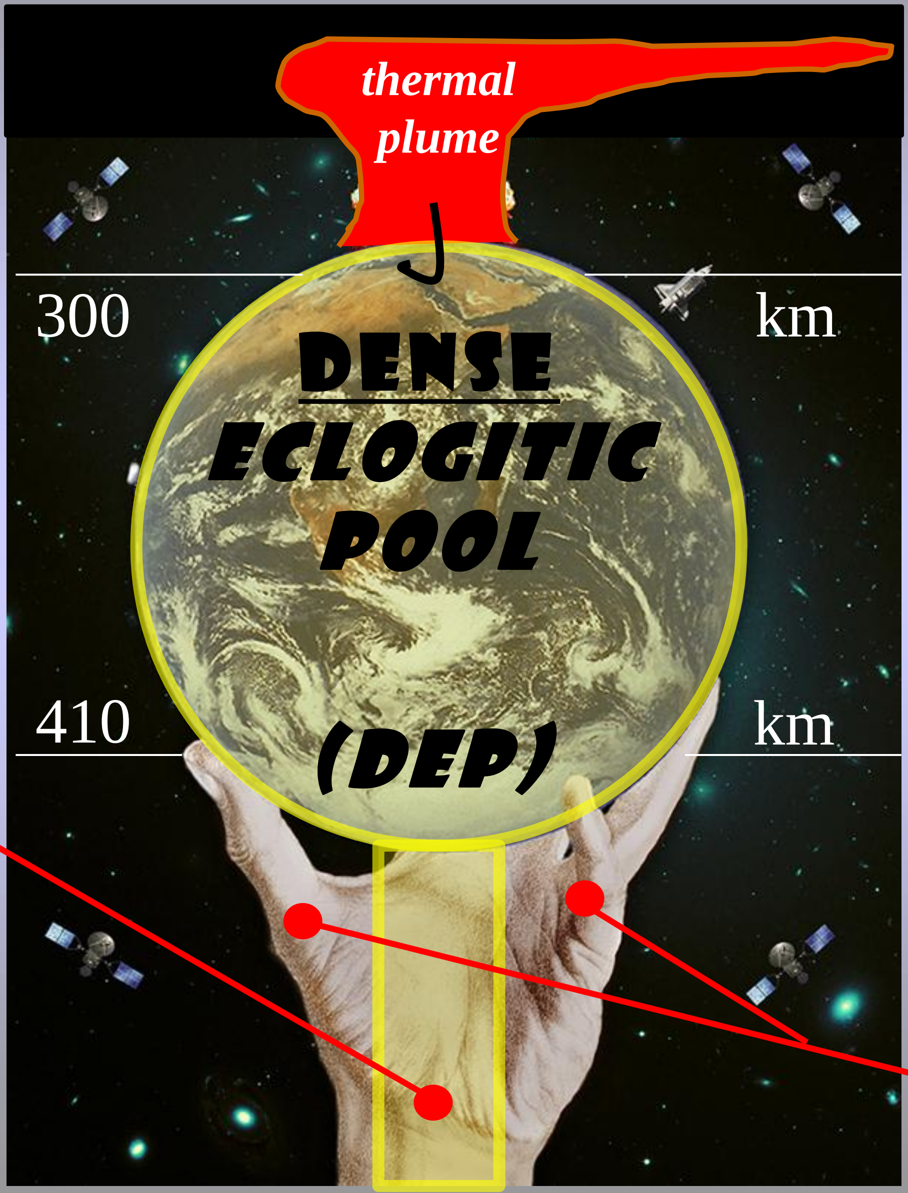
deep eclogitic pool (DEP) dynamics



eclogitic core of thermochemical plume.

non-eclogitic buoyant outskirts of the plume dynamically support the "DEP"

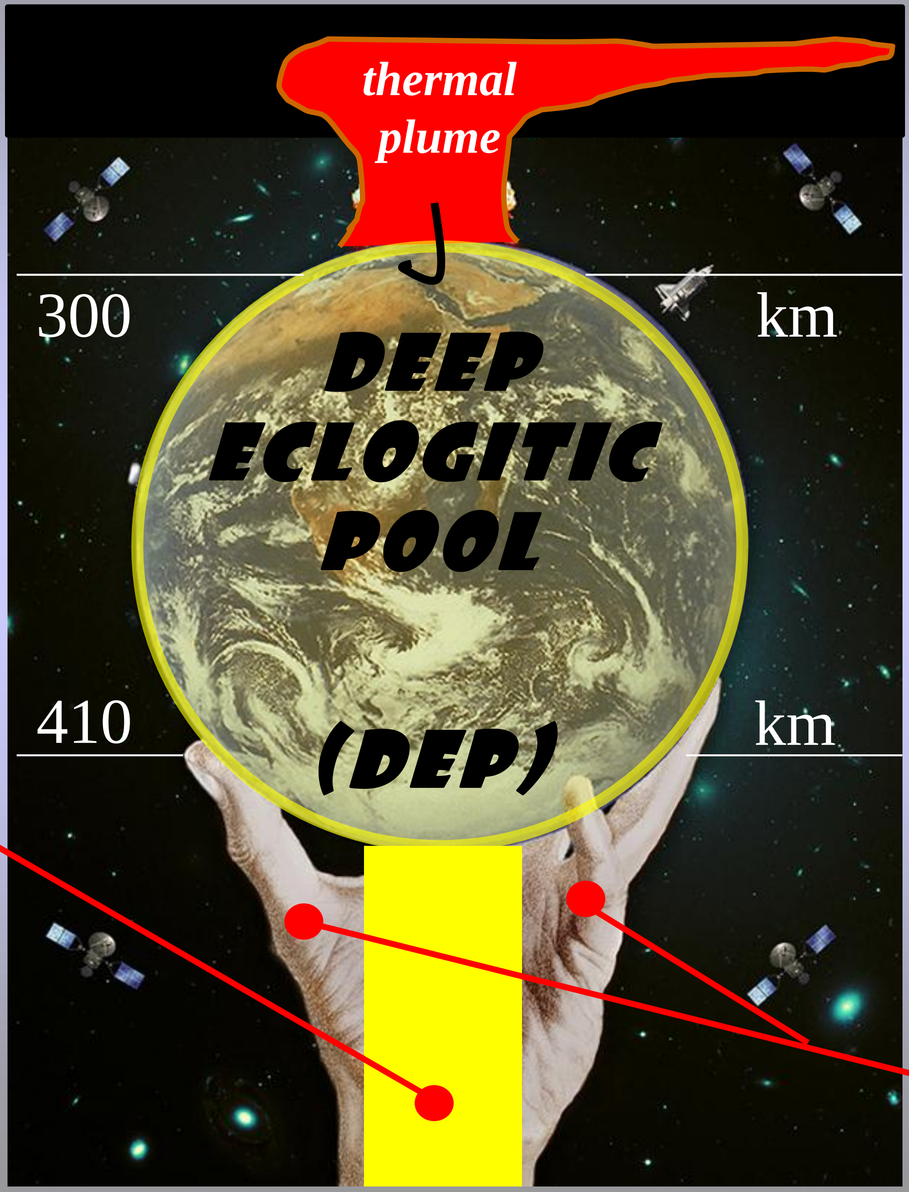
deep eclogitic pool (DEP) dynamics



eclogitic core of thermochemical plume.

non-eclogitic buoyant outskirts of the plume dynamically support the "DEP"

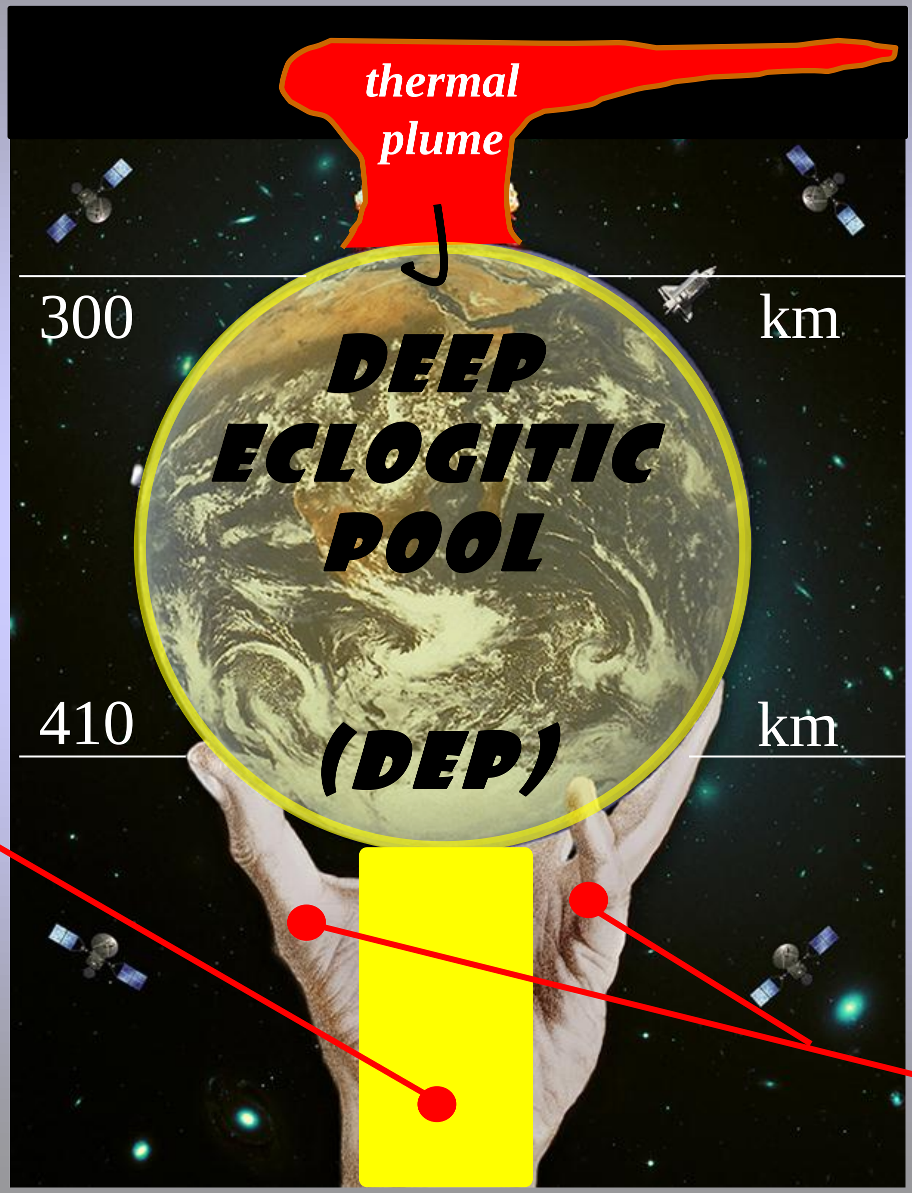
model 1



eclogitic core of thermochemical plume.

non-eclogitic buoyant outskirts of the plume dynammically support the "DEP"

model 2



eclogitic core of thermochemical plume.

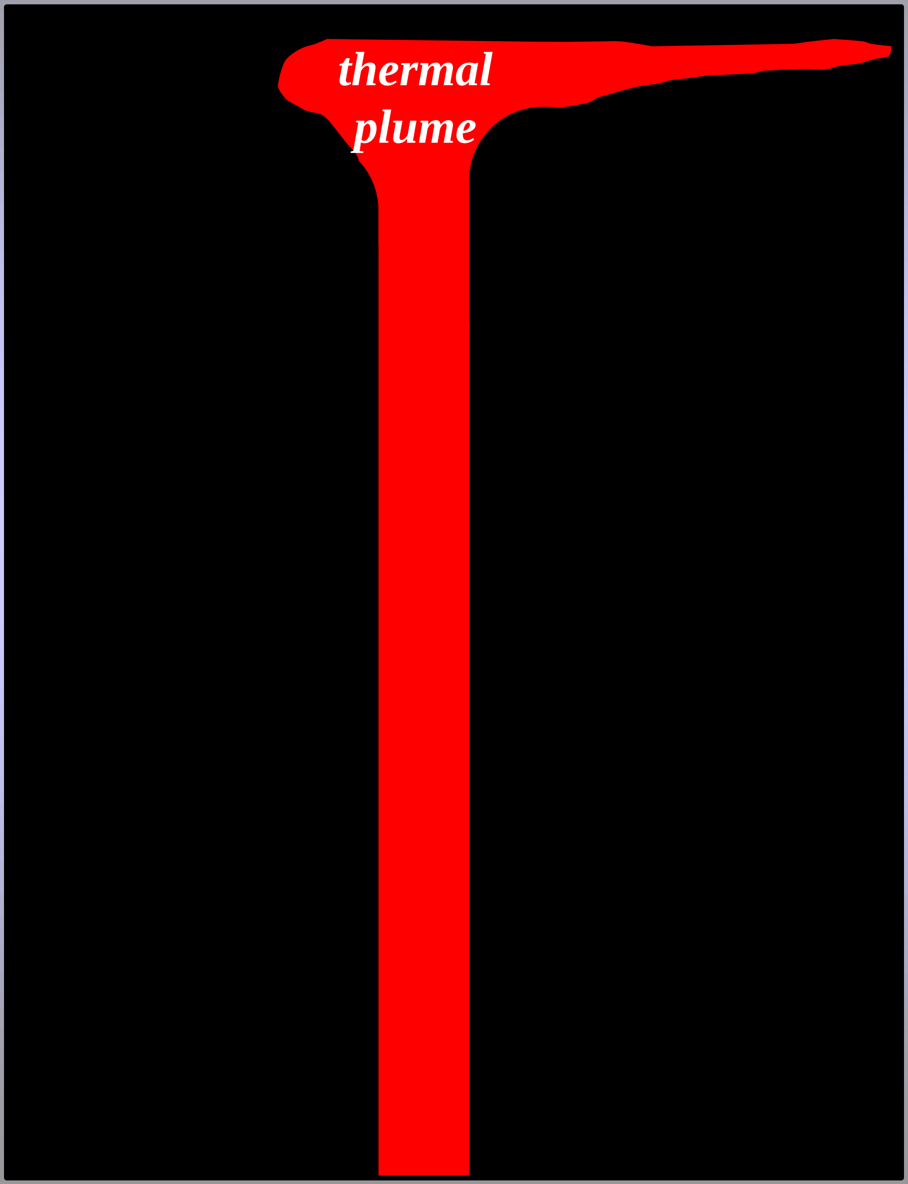
NOW:

radius: 100 km

(not as before: 90 km)

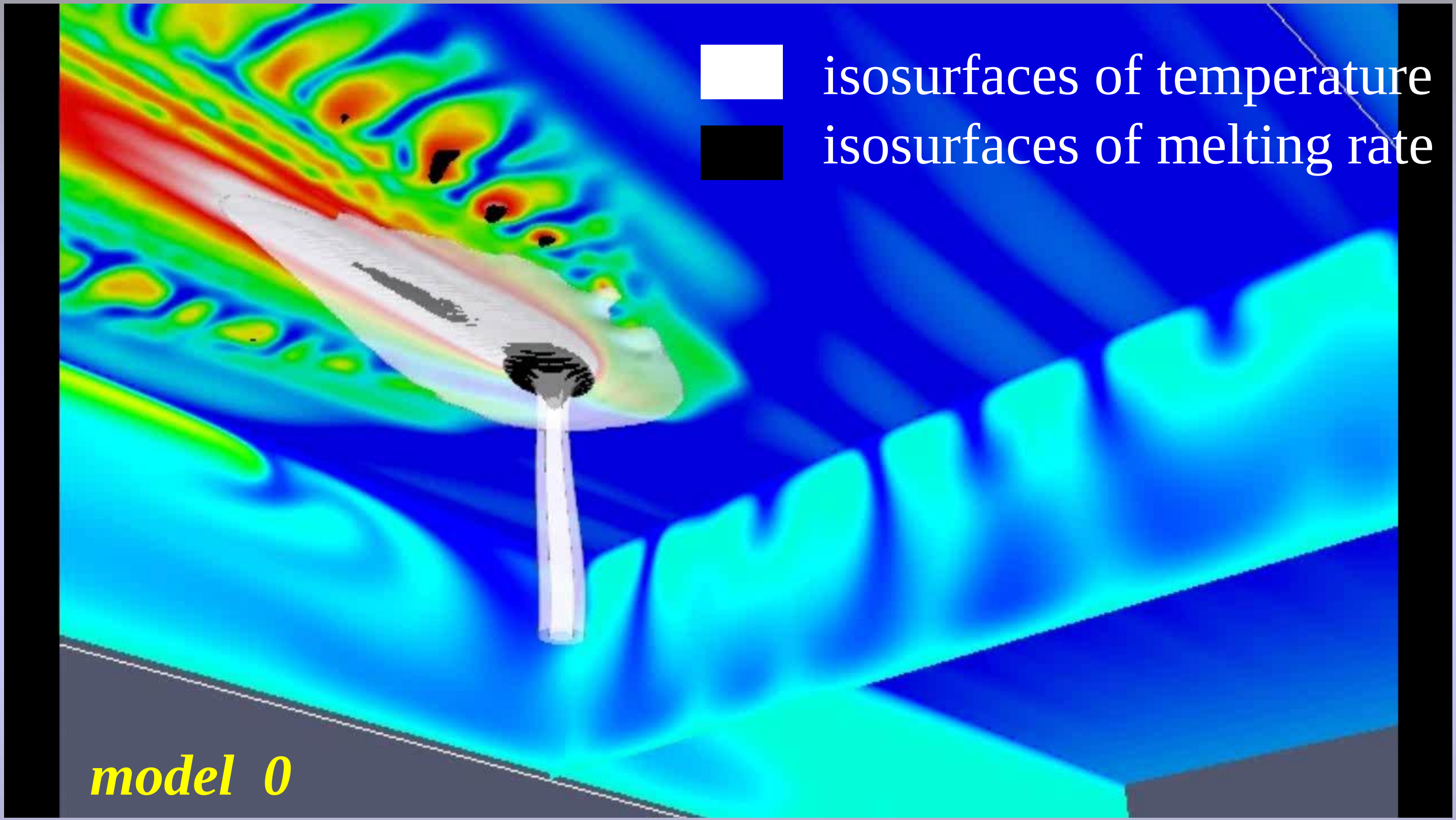
non-eclogitic buoyant outskirts of the plume dynammically support the "DEP"

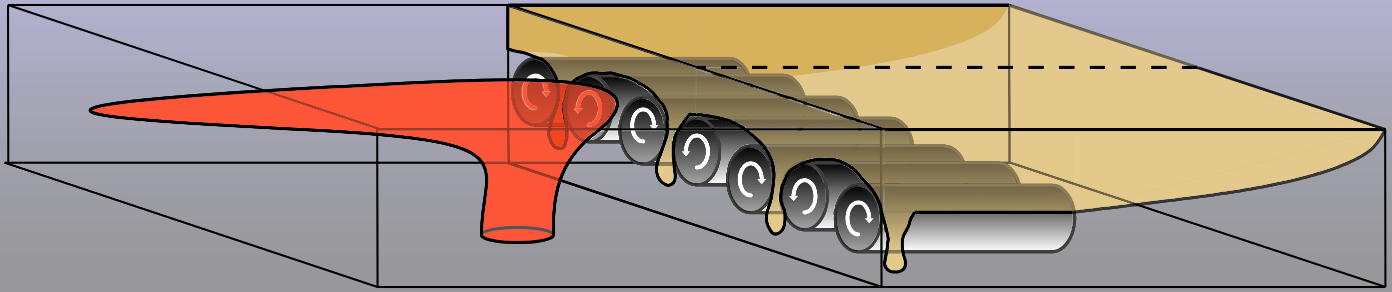
reference model 0



no eclogite

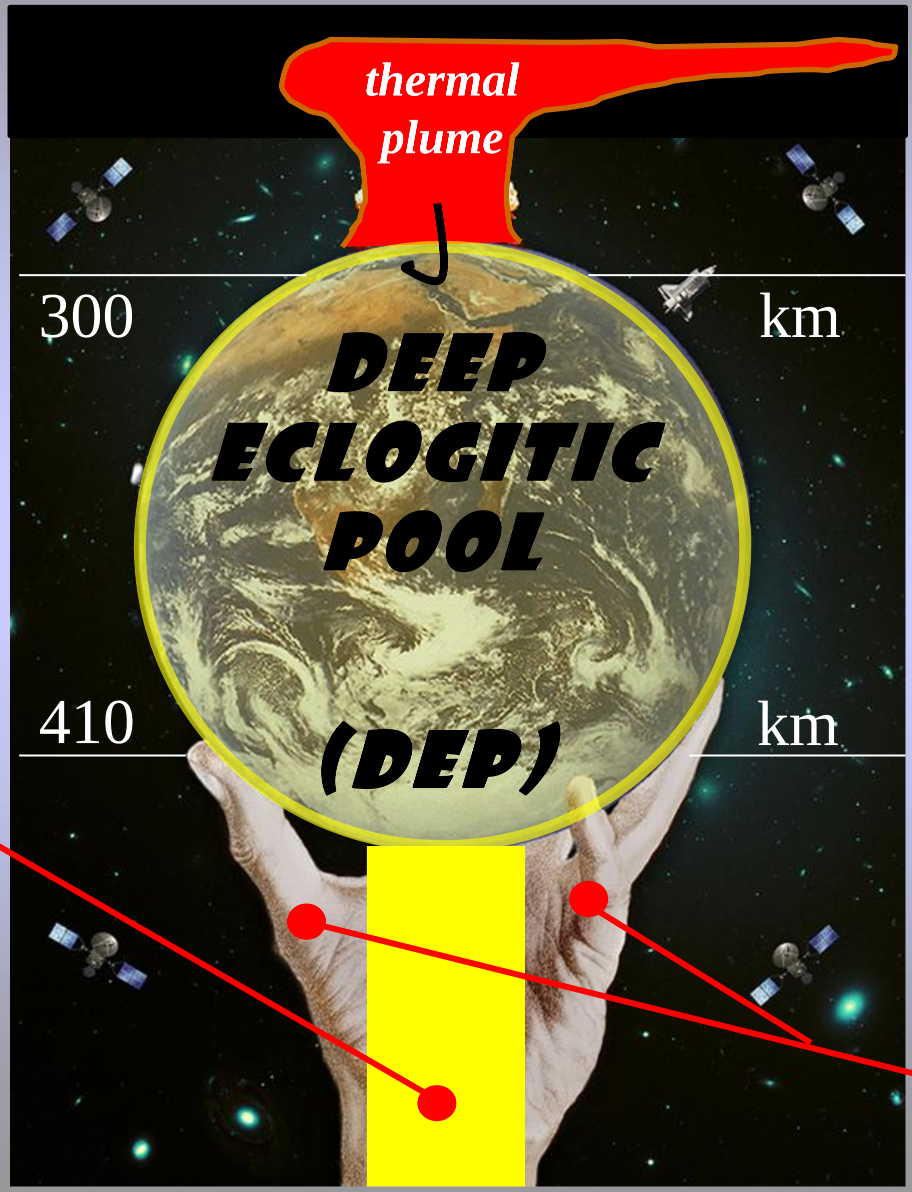
model 0 ... in motion





interaction of a plume with small-scale convection

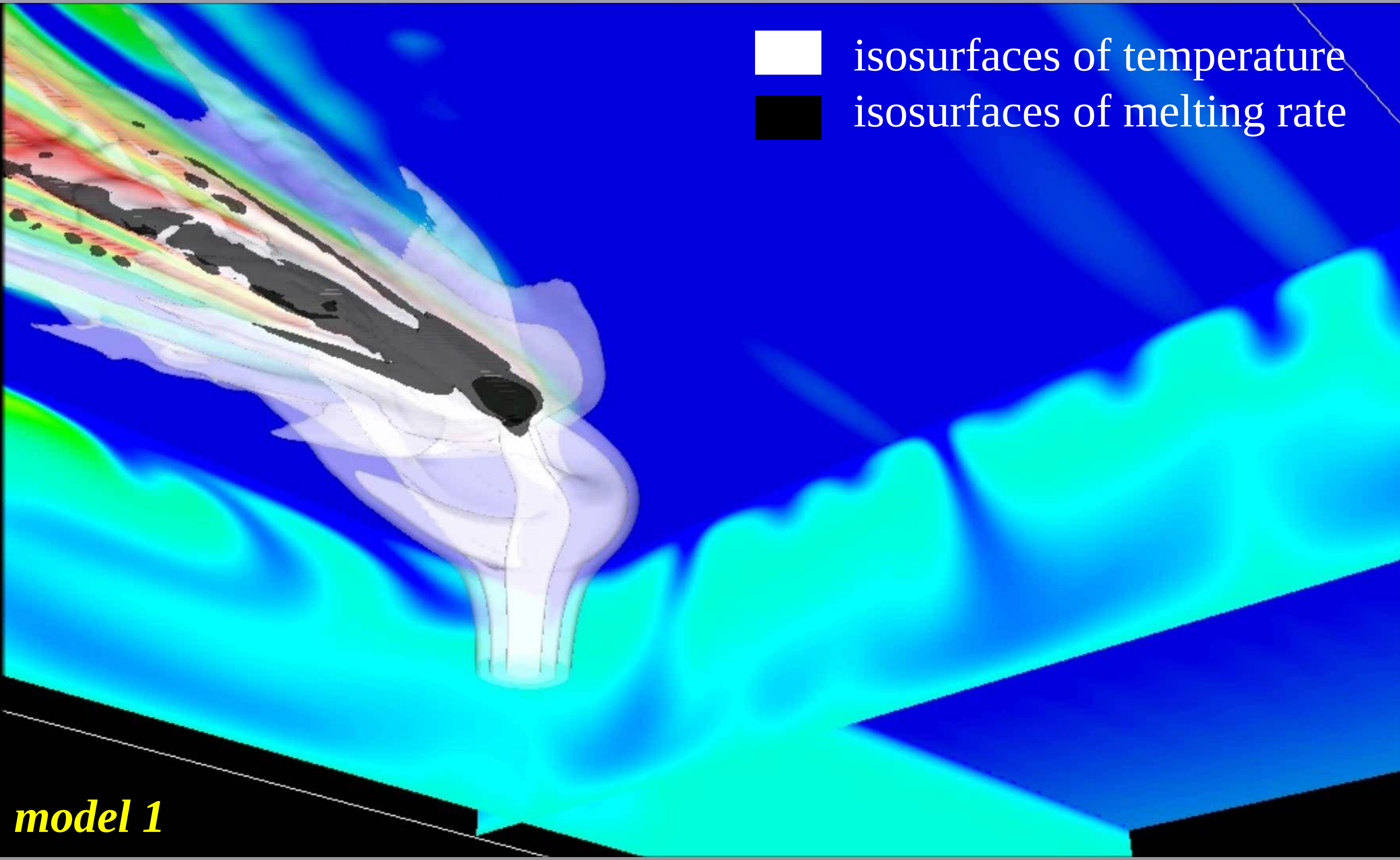
model 1



eclogitic core of thermochemical plume.

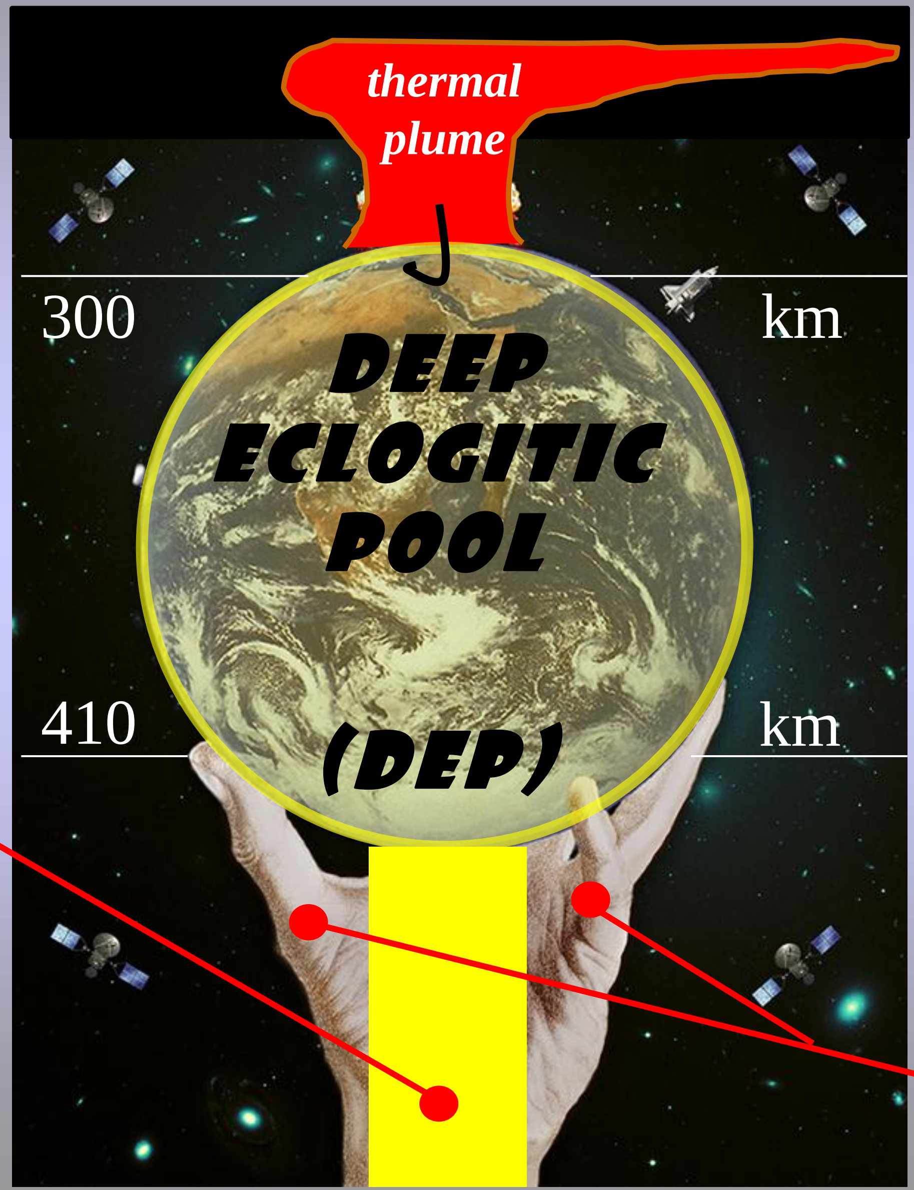
non-eclogitic buoyant outskirts of the plume dynammically support the "DEP"

model 1 ... in motion



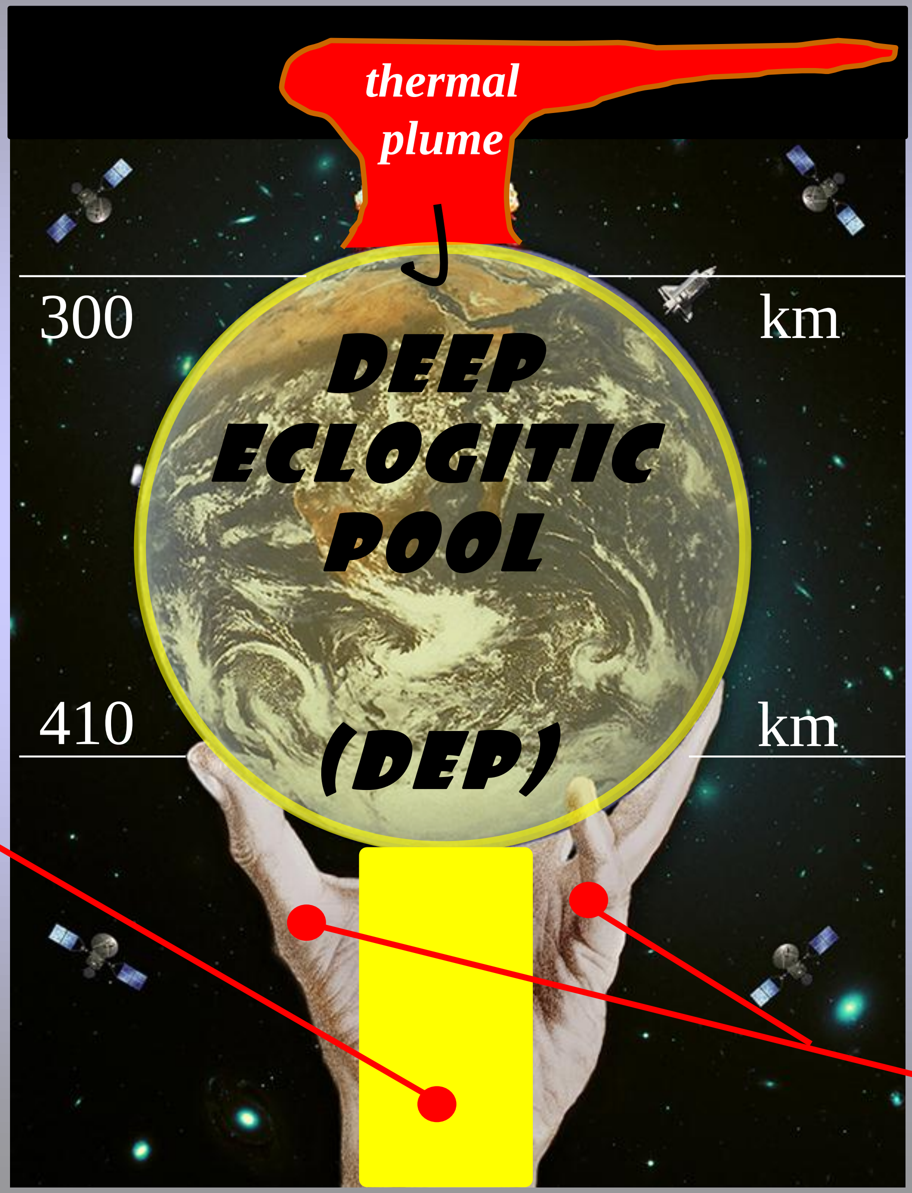
model 1

eclogitic core of thermochemical plume.



non-eclogitic buoyant outskirts of the plume dynammically support the "DEP"

model 2



eclogitic core of thermochemical plume.

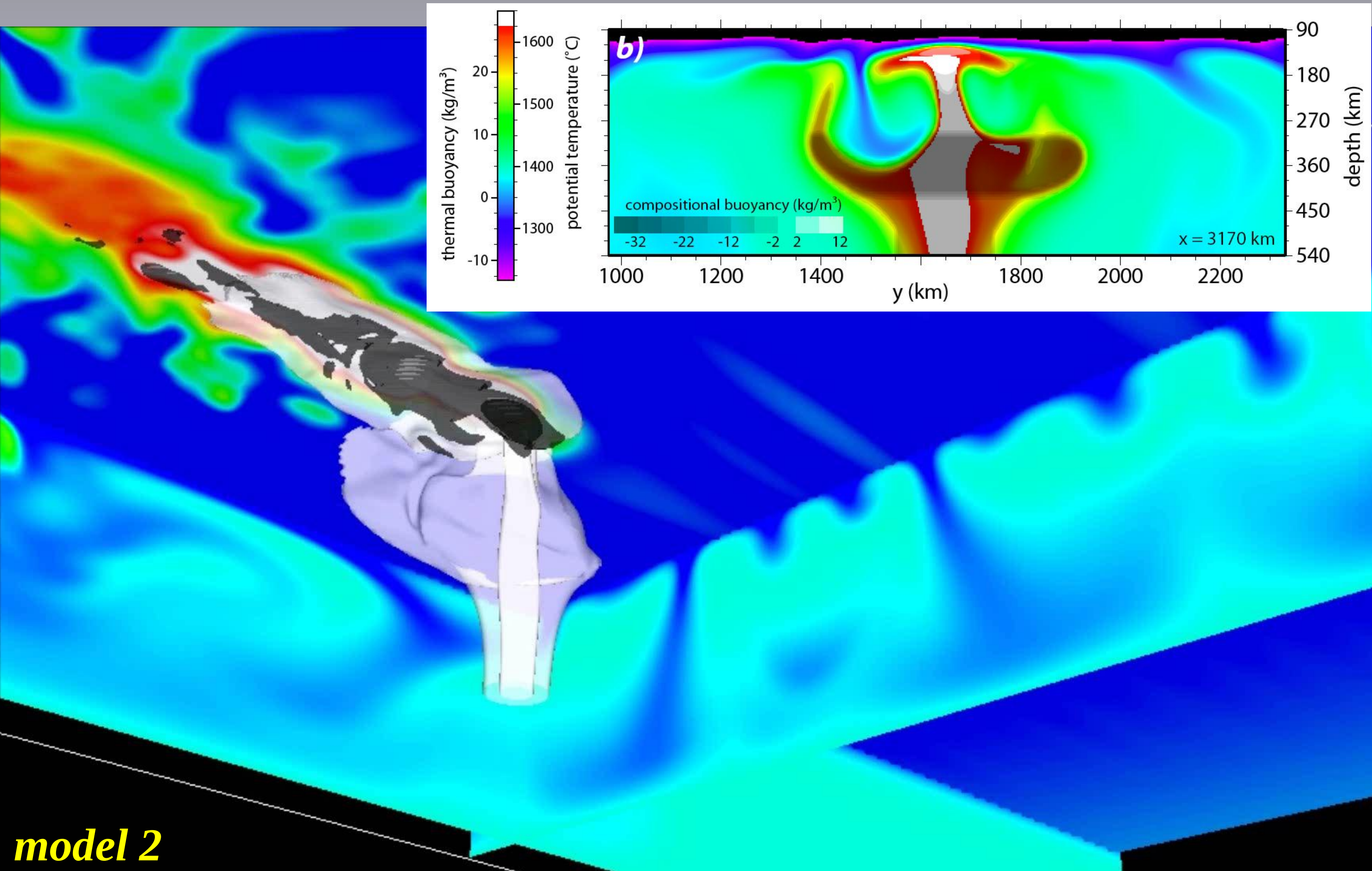
NOW:

radius: 100 km

(not as before: 90 km)

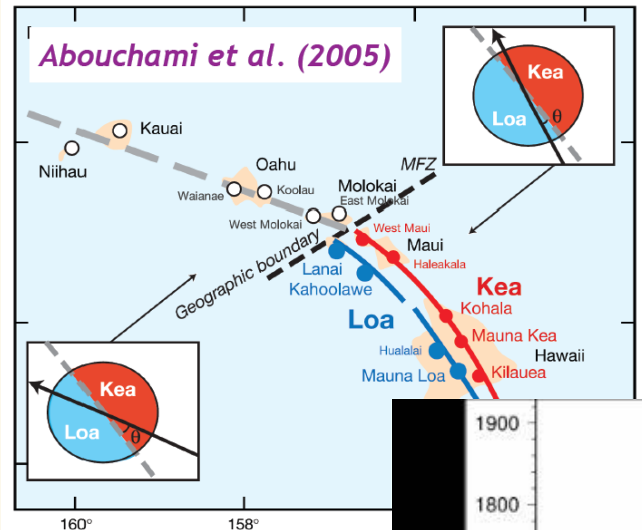
non-eclogitic buoyant outskirts of the plume dynammically support the "DEP"

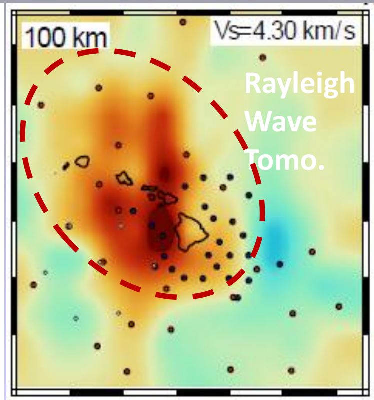
model 2 ... in motion

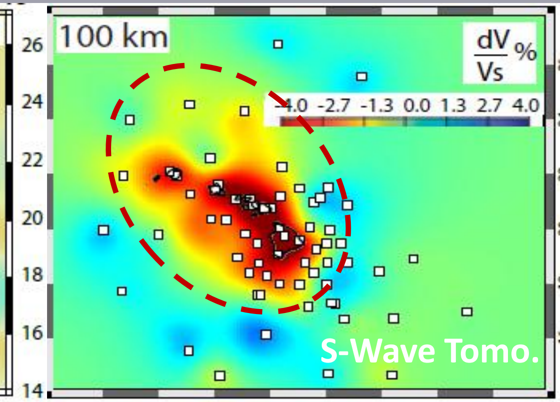


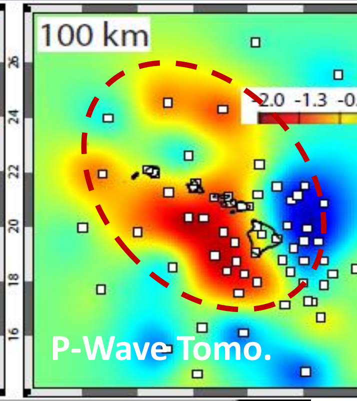
RESULTS PART 2 RESULTS PART 2

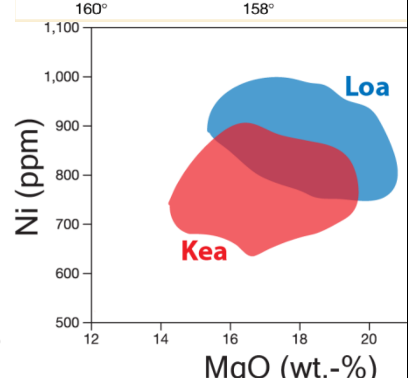
geochemical non-symmetry

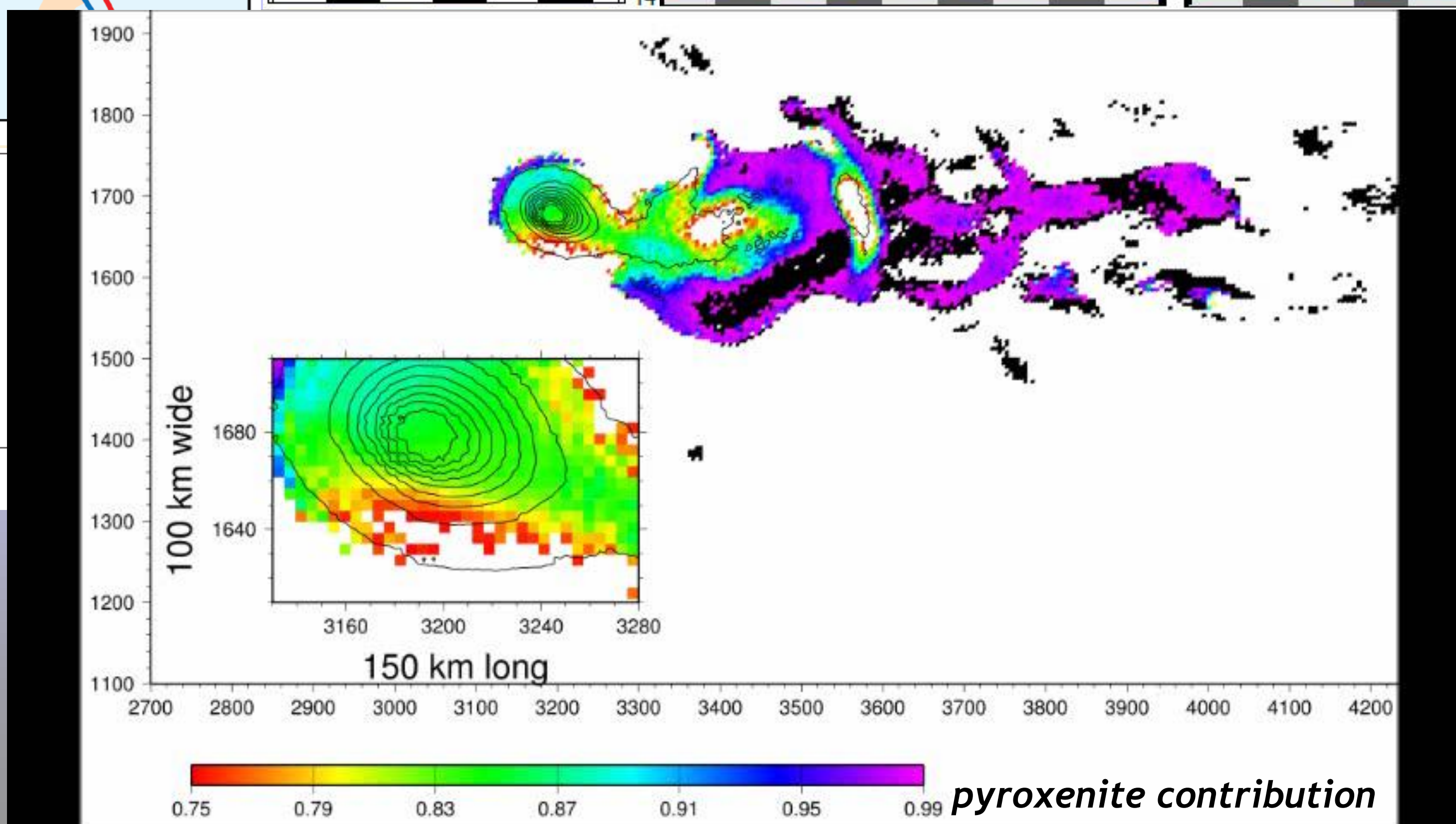




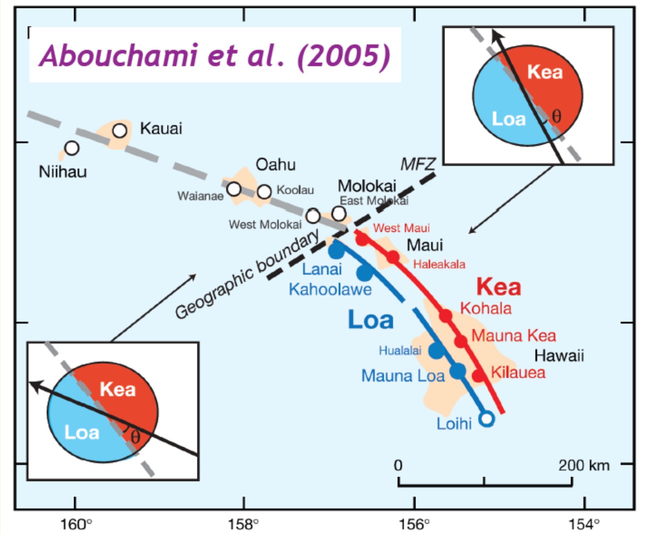


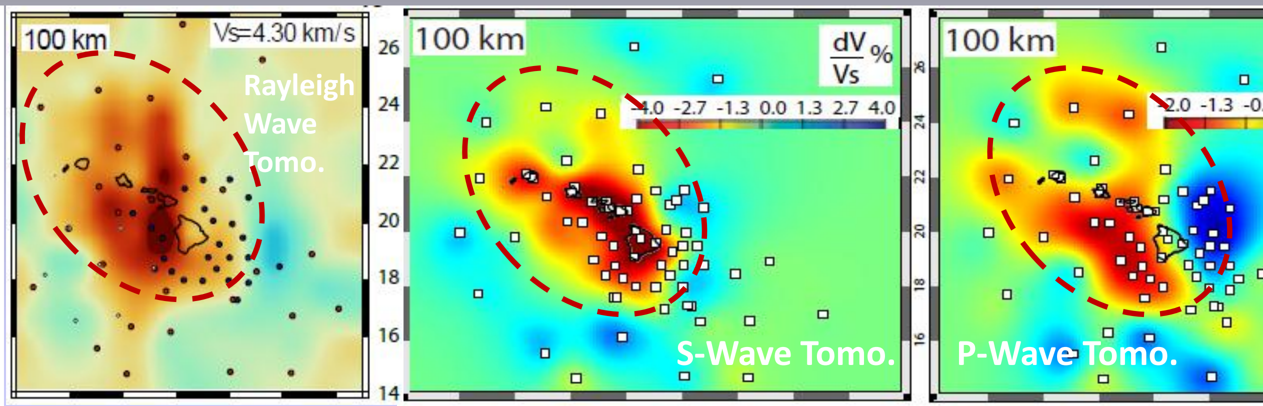


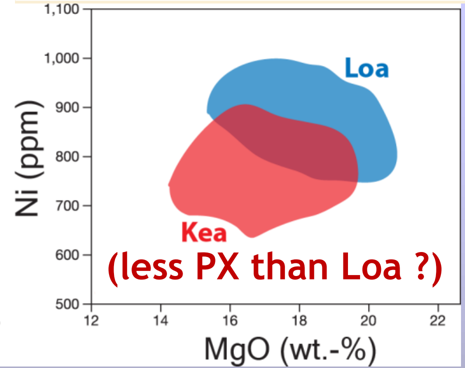


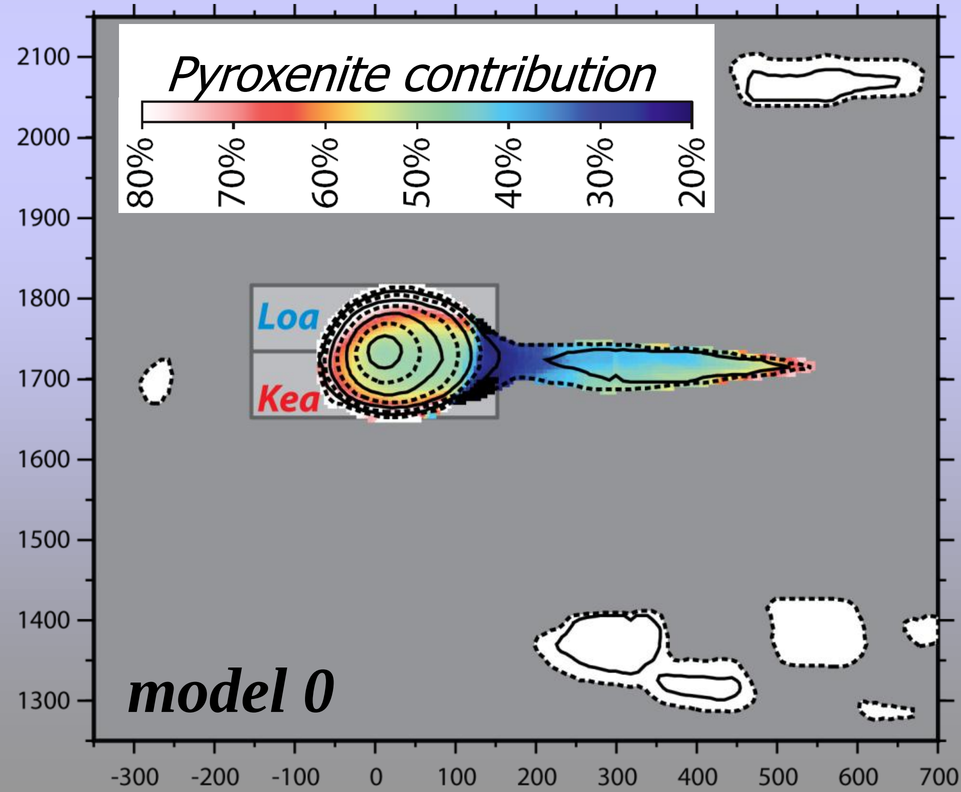


non-symmetry of shallow structures

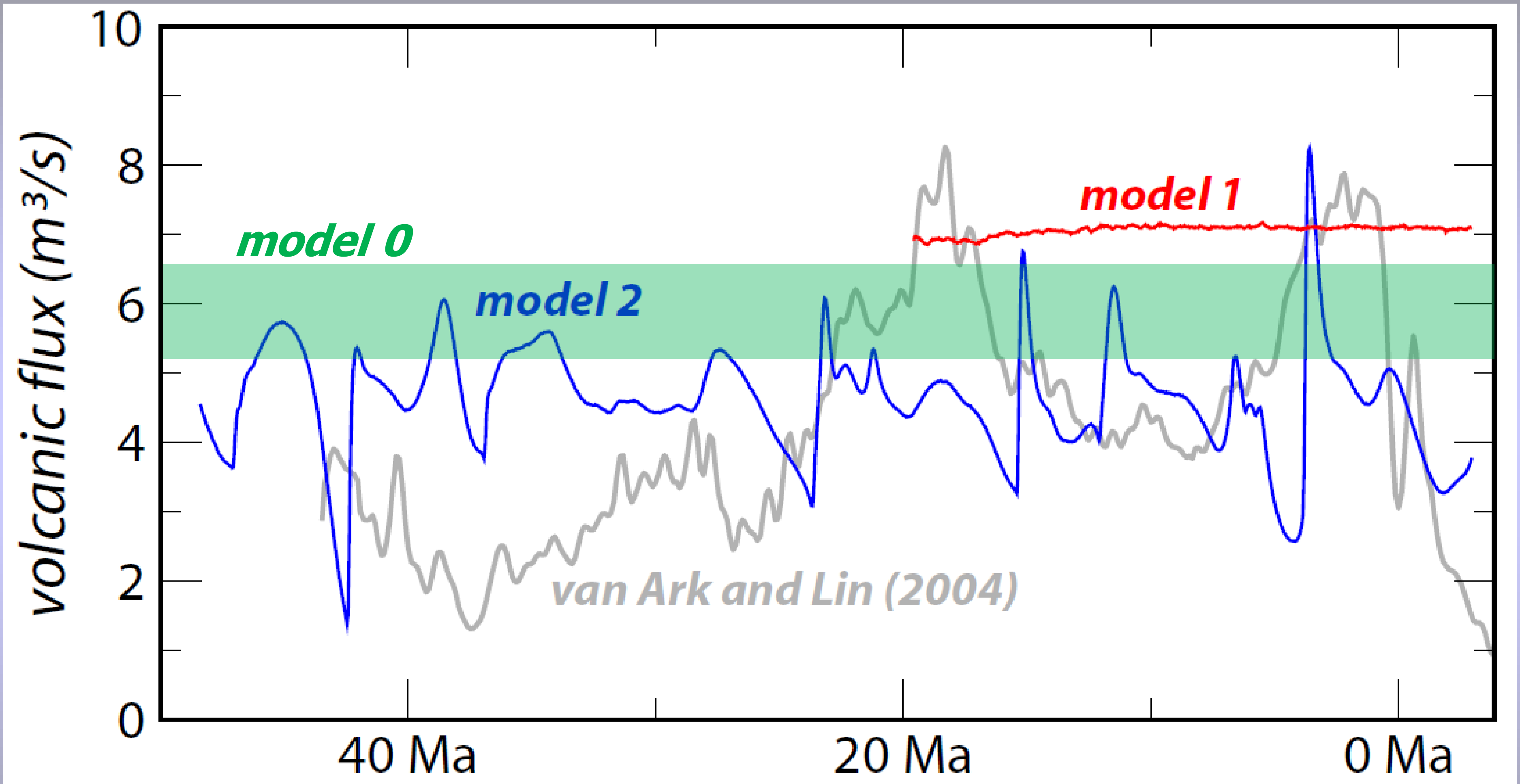


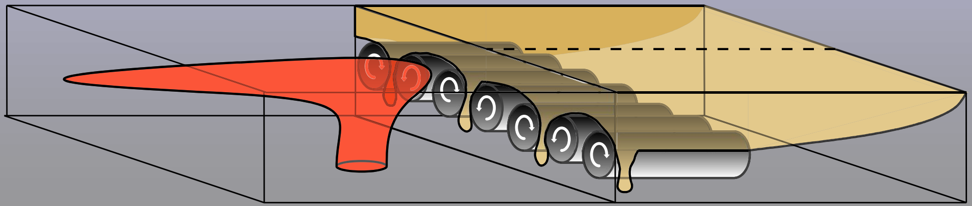






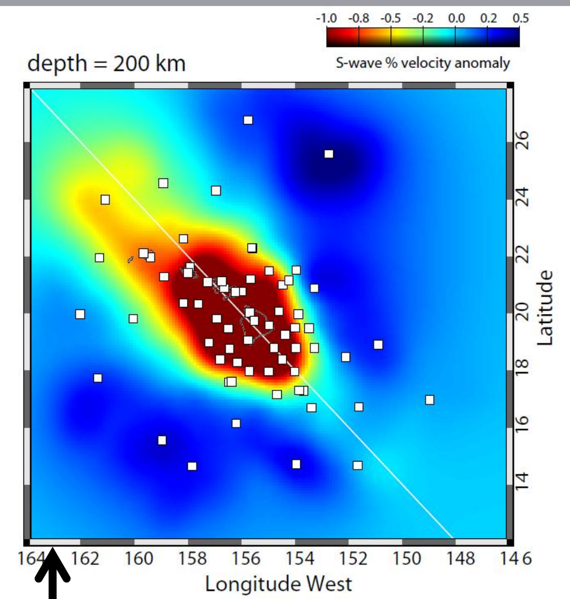
volcanic flux variations

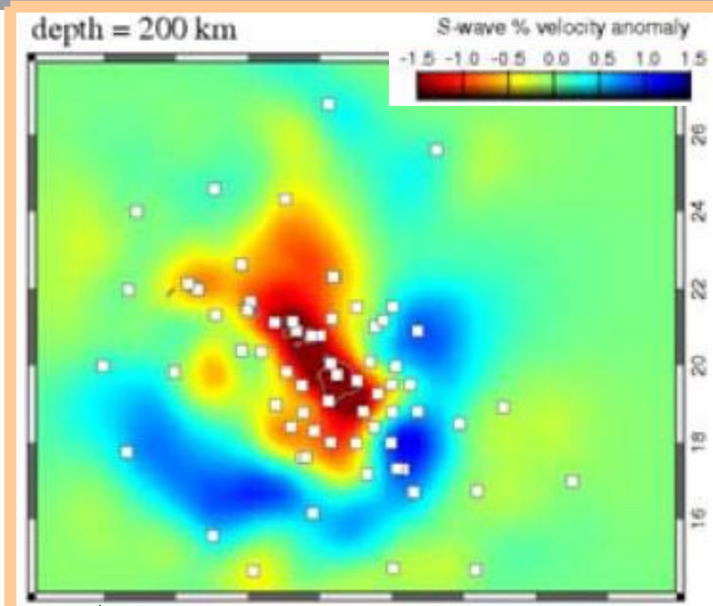


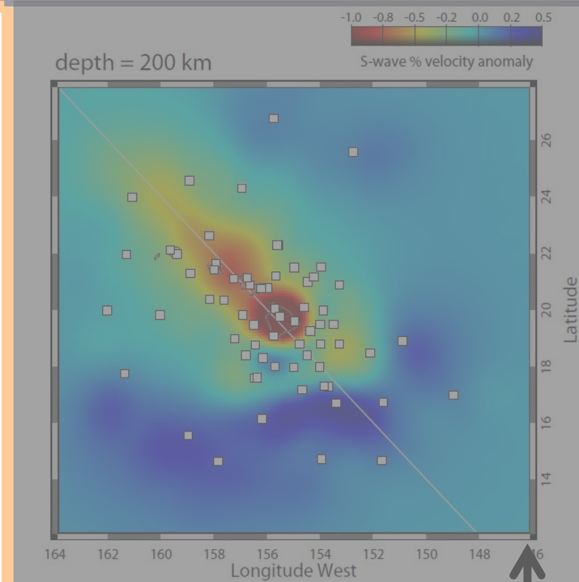


RESULTS PART 2 RESULTS PART 2 RESULTS PART 2

S-wave mantle velocity constraints



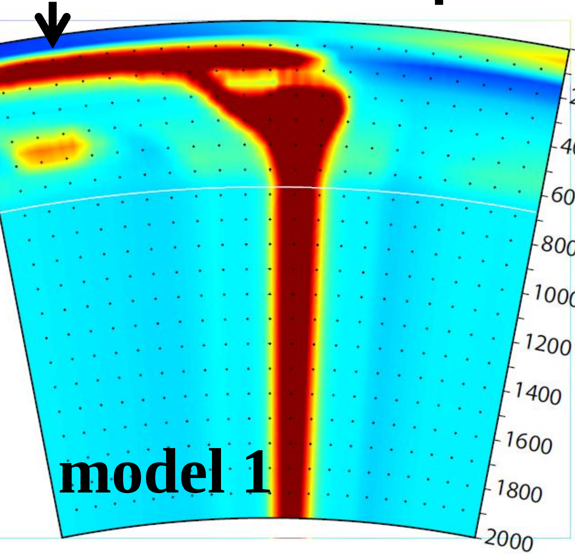


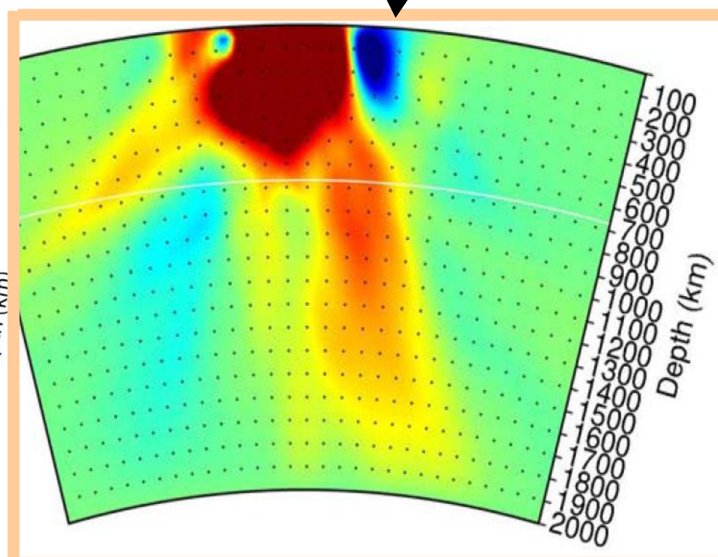


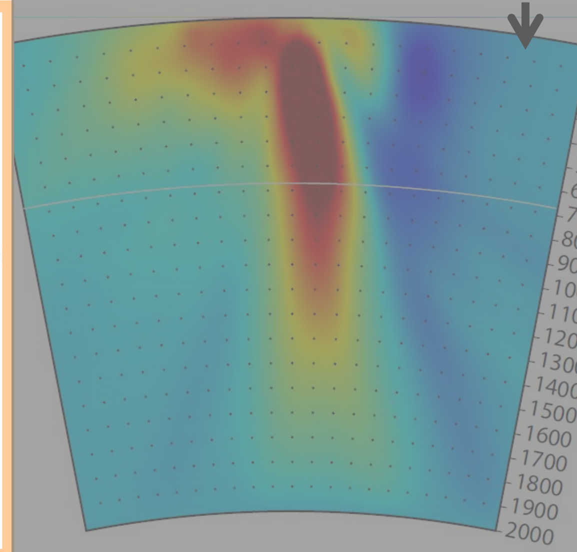
synthetic based on thermochemical plume

data-based inversion

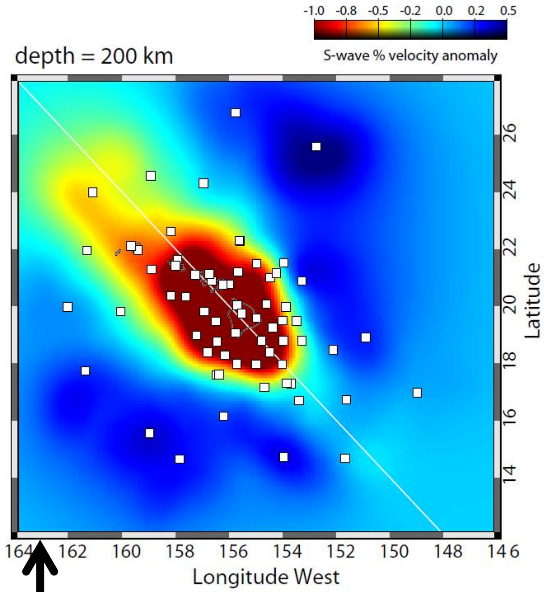
synthetic based on mplistic thermal plume





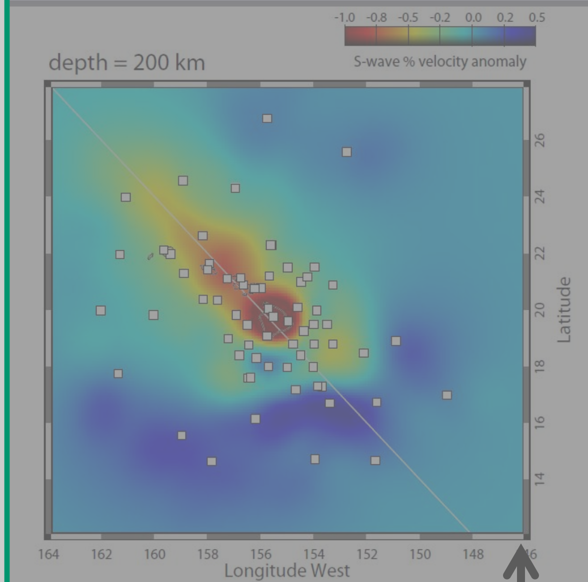


S-wave mantle velocity constraints



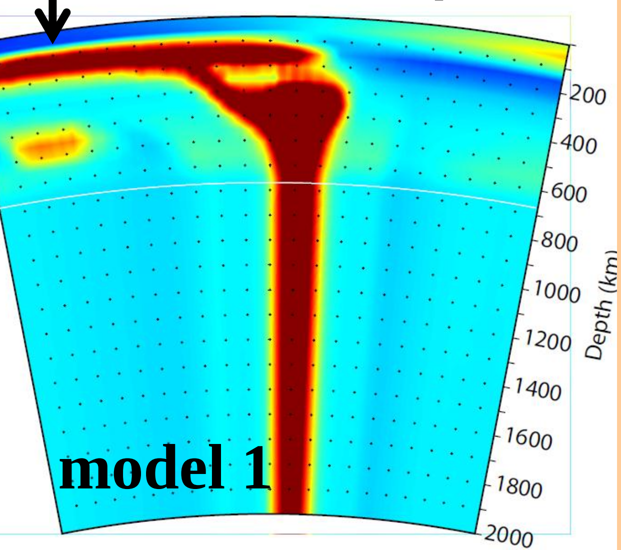
CENSORED

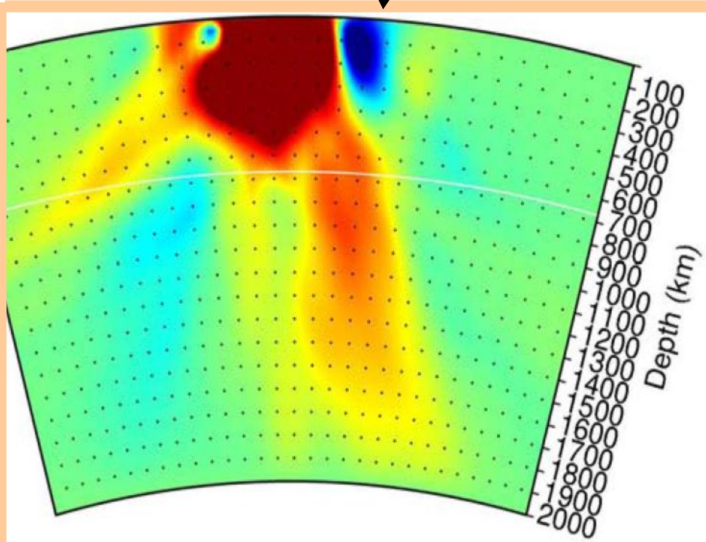
data-based inversion

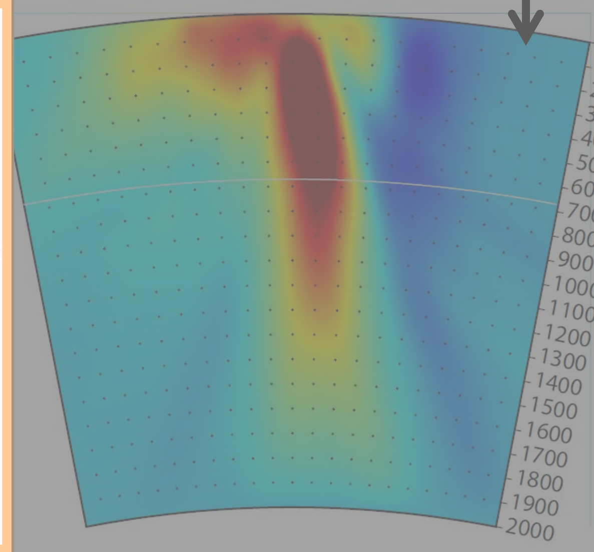


synthetic based on thermochemical plume

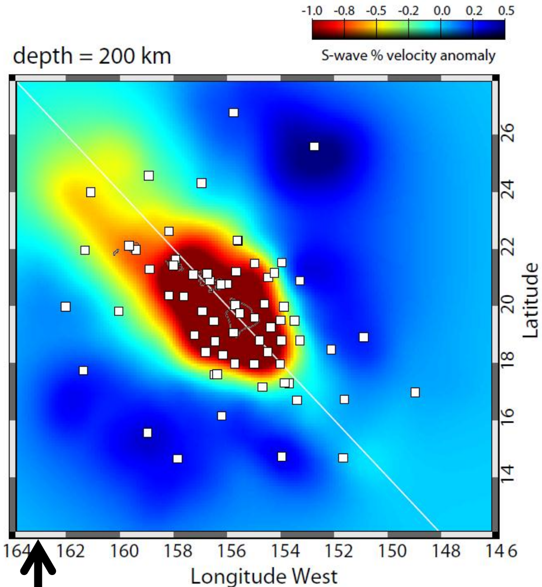
synthetic based on mplistic thermal plume



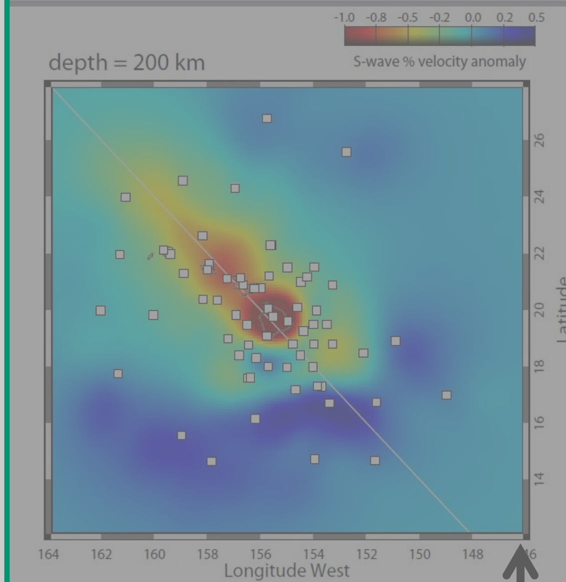




S-wave mantle velocity constraints



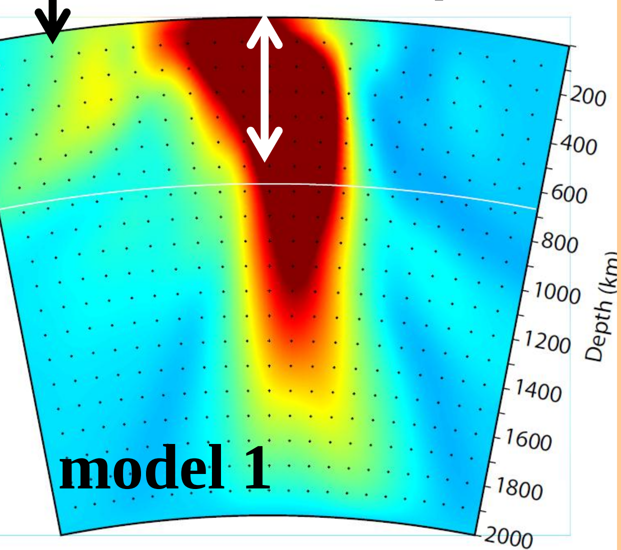
CENSORED

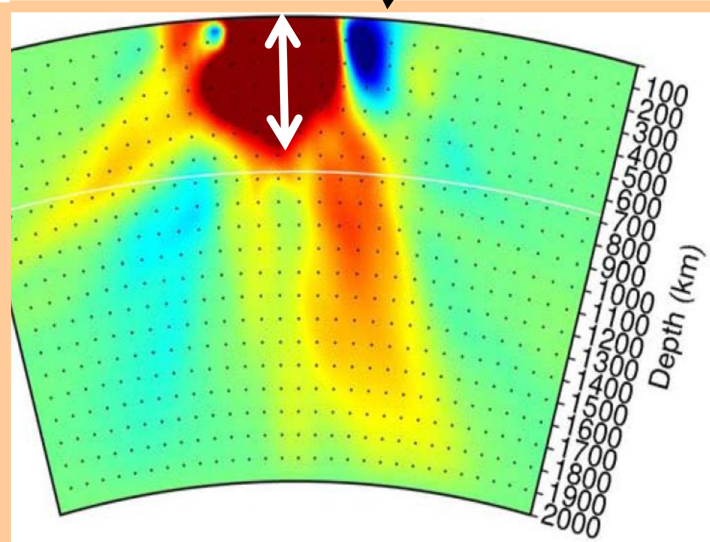


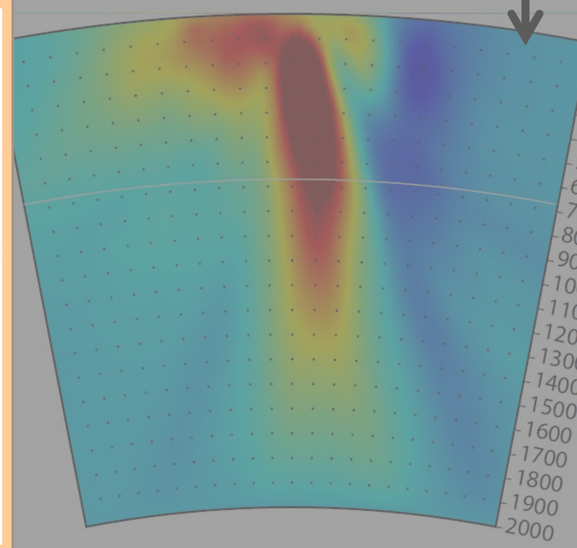
synthetic based on thermochemical plume

data-based inversion

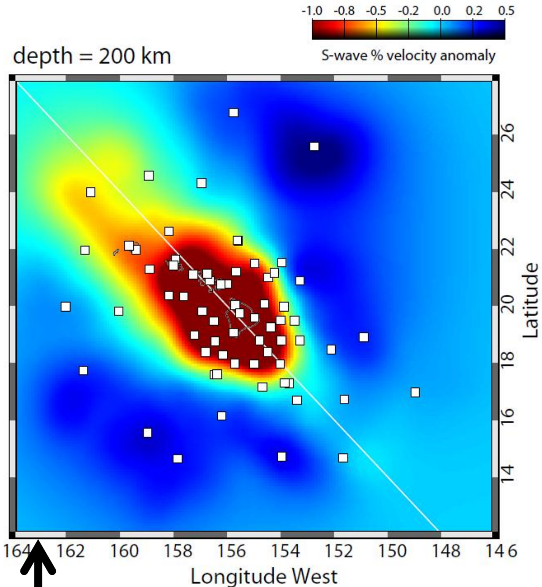
synthetic based on mplistic thermal plume



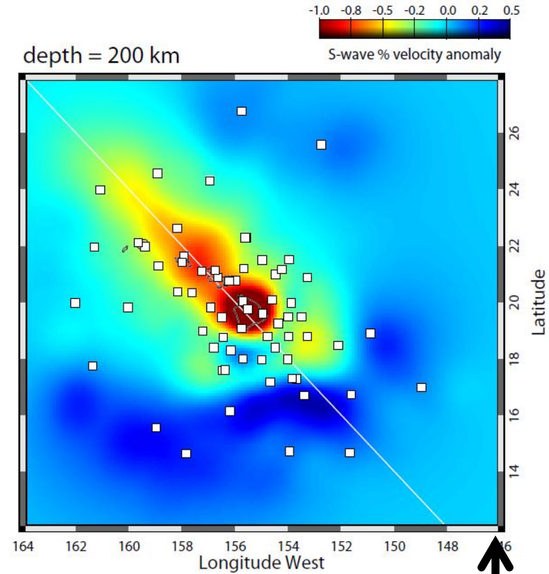




S-wave mantle velocity constraints



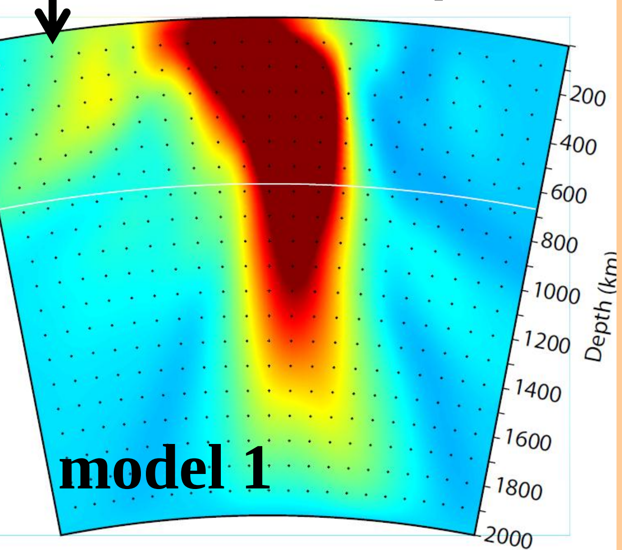
CENSORED

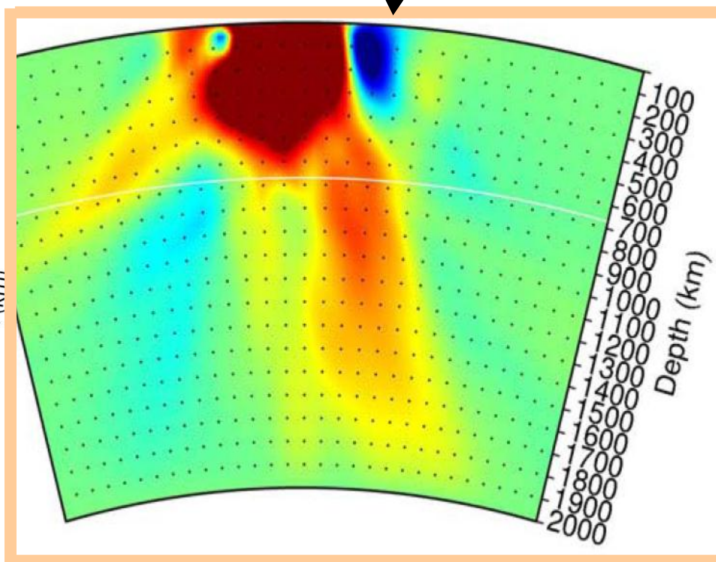


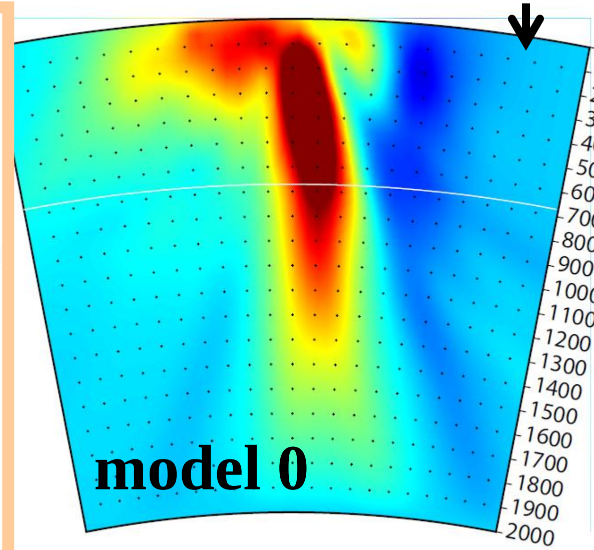
synthetic based on thermochemical plume

data-based inversion

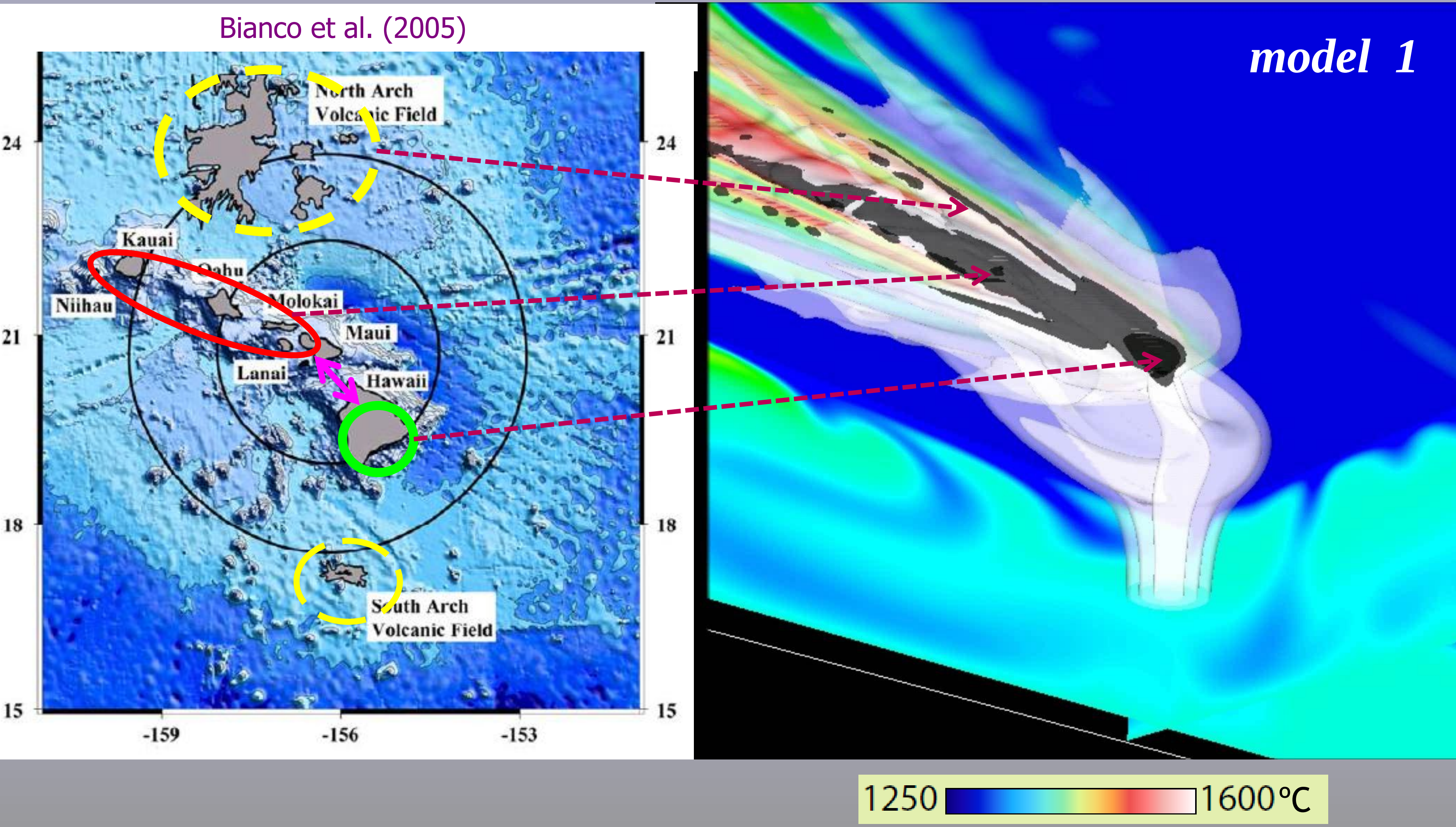
synthetic based on simplistic thermal plume



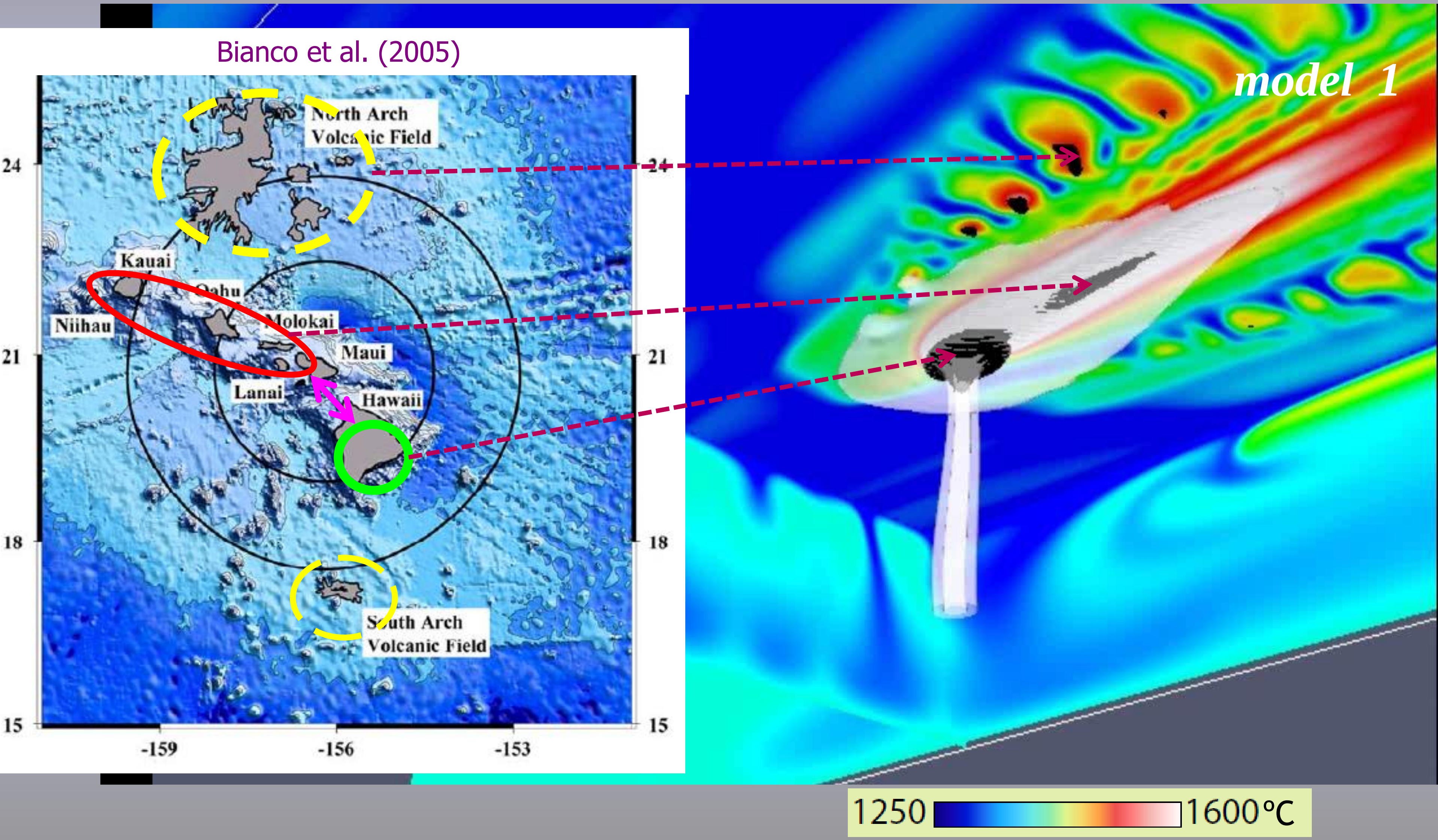




widespread secondary vocalnism

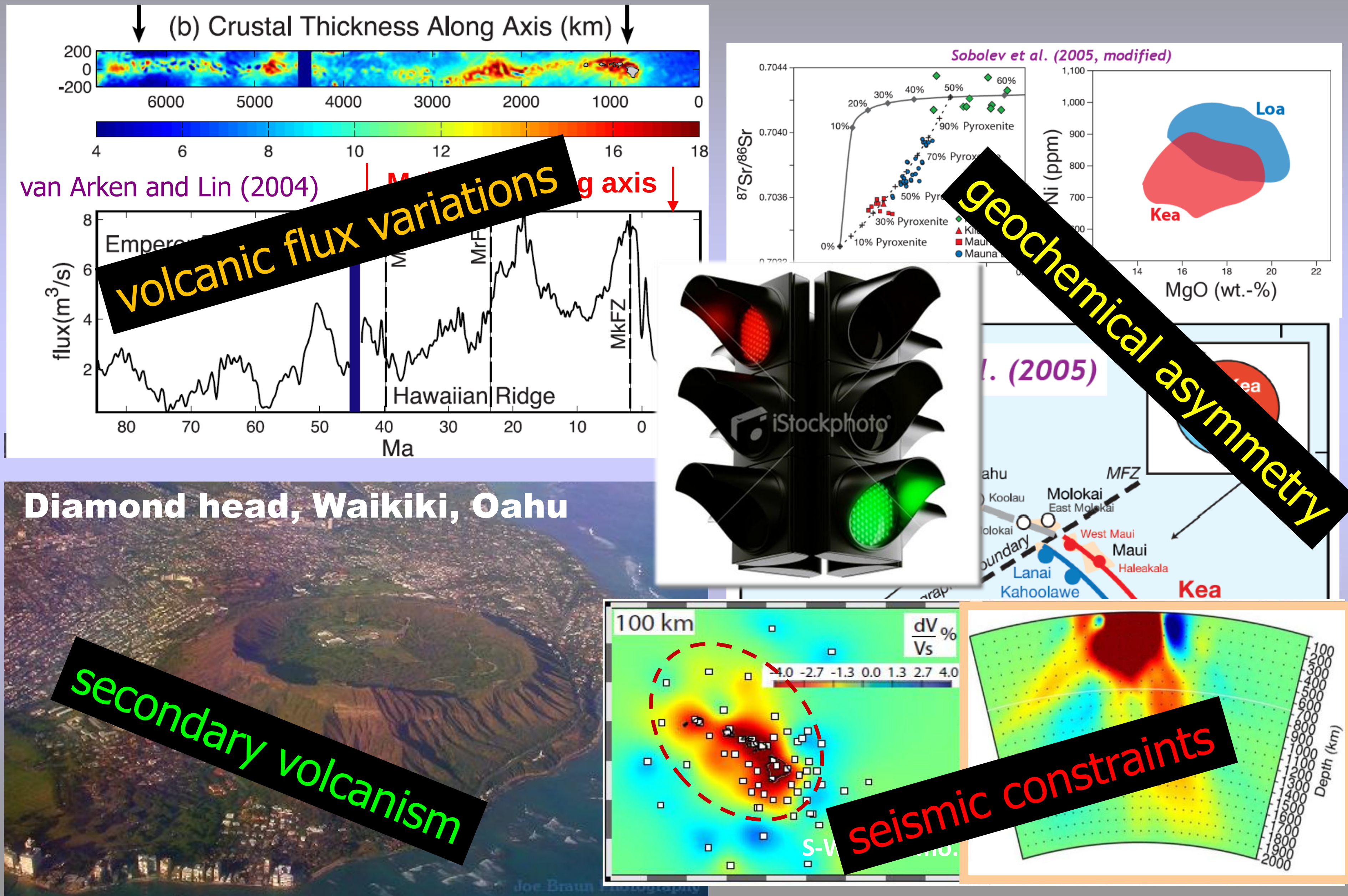


widespread secondary vocalnism



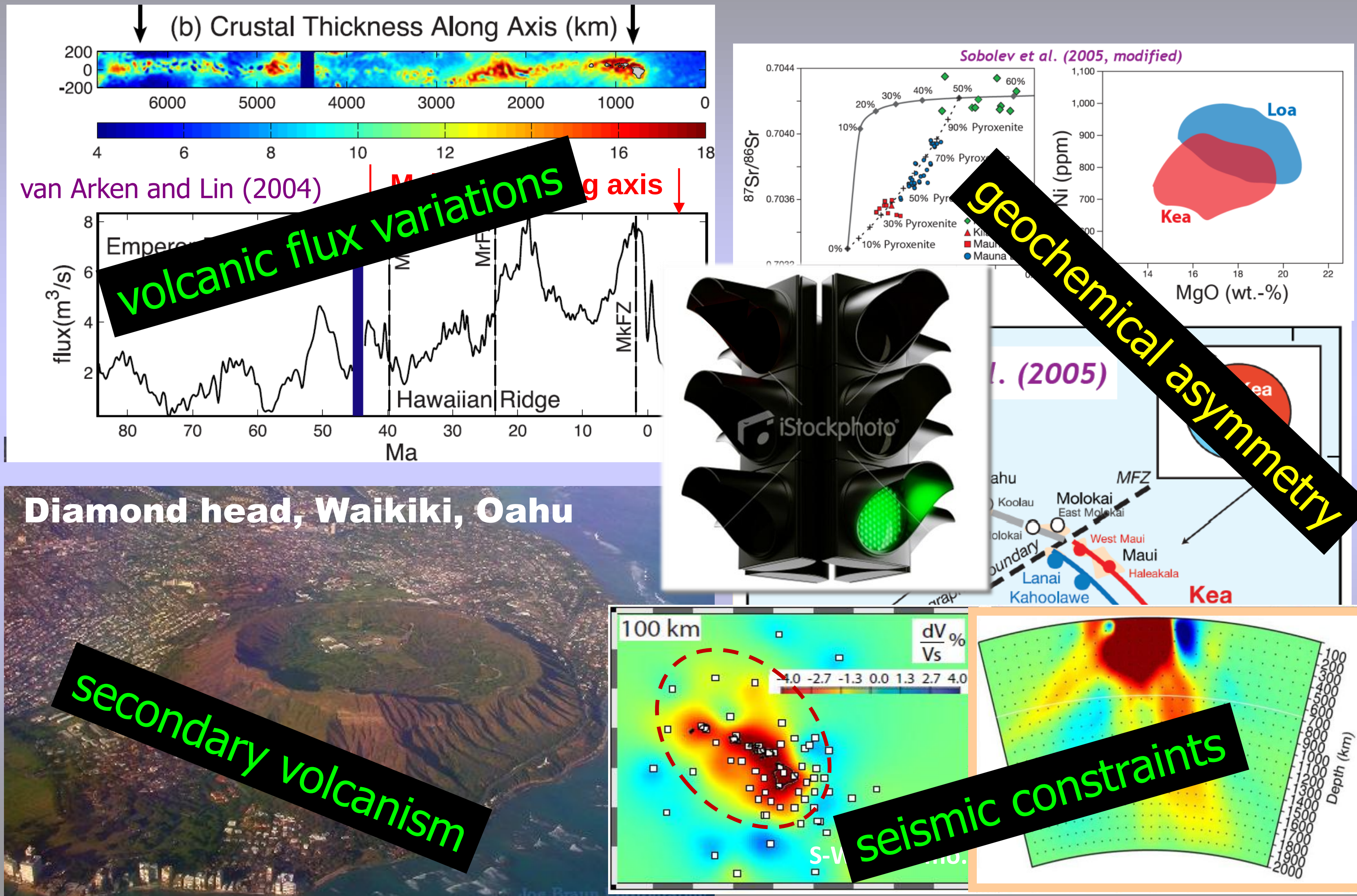
CONCLUSION CONCLUSION CONCLUSION CONCLUSION

predictions vs. observations: model 0



CONCLUSION CONCLUSION CONCLUSION CONCLUSION

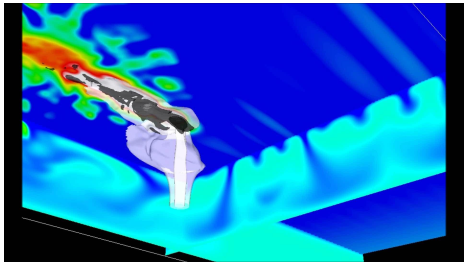
predictions vs. observations: models 1/2



Conclusions PART II

Thermochemical plumes comprising ~15% eclogite ...

→ pool in a deep eclogitic pool



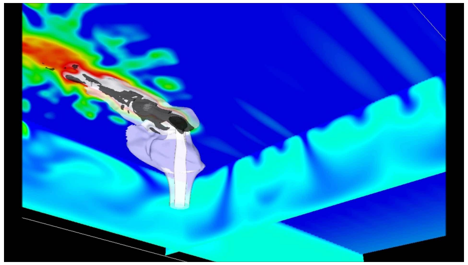
→ can explain seismic velocity structure beneath the Hawaiian hotspot

→ can give rise to geochemical asymmetry of hotspot volcanism without pre-existing heterogeneity in the plume stem.

→ can account for volcanic flux variations

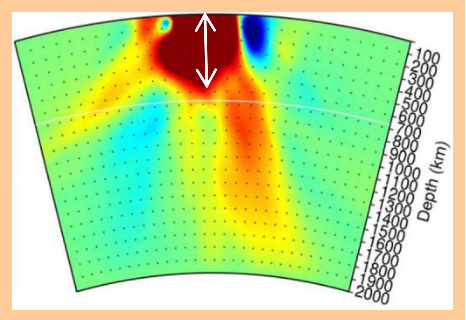
Conclusions PART II

Thermochemical plumes comprising ~15% eclogite ...



→ pool in a deep eclogitic pool

→ can explain seismic velocity structure beneath the Hawaiian hotspot



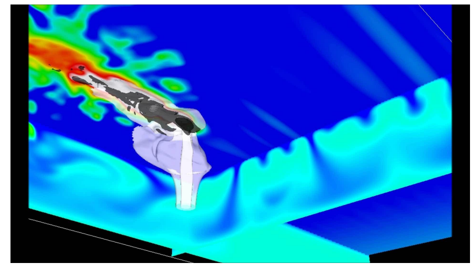
→ can give rise to geochemical asymmetry of hotspot volcanism without pre-existing heterogeneity in the plume stem.

→ can account for volcanic flux variations

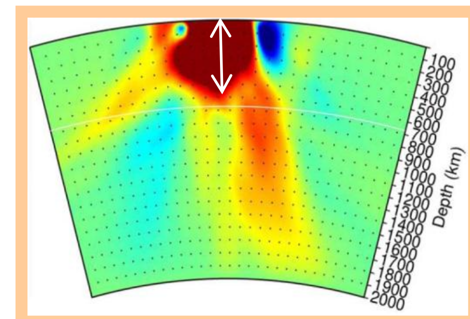
Conclusions PART II

Thermochemical plumes comprising ~15% eclogite ...

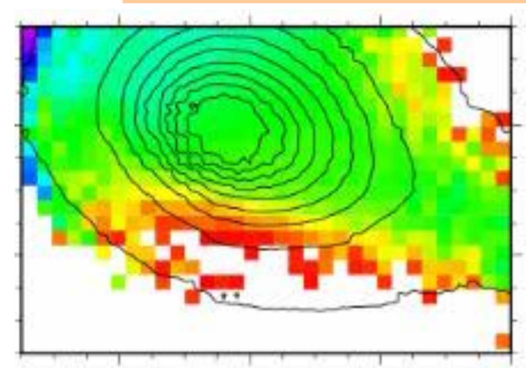
→ pool in a deep eclogitic pool



→ can explain seismic velocity structure beneath the Hawaiian hotspot



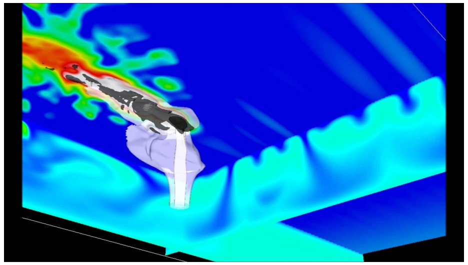
→ can give rise to geochemical asymmetry of hotspot volcanism without pre-existing heterogeneity in the plume stem.



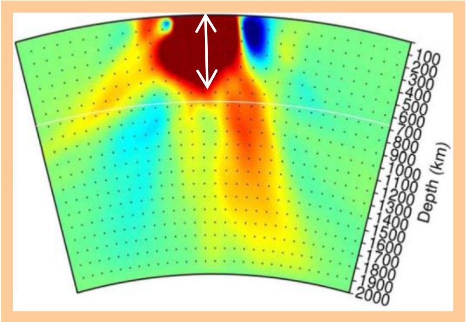
→ can account for volcanic flux variations

Conclusions PART II

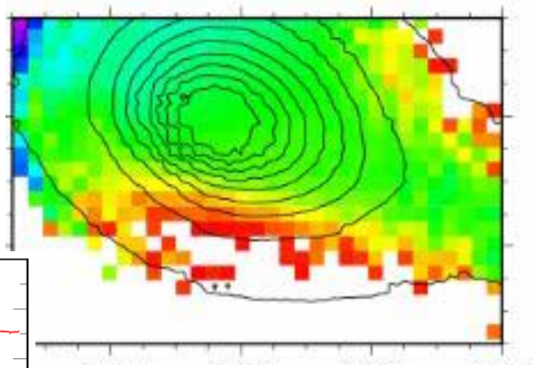
Thermochemical plumes comprising ~15% eclogite ...



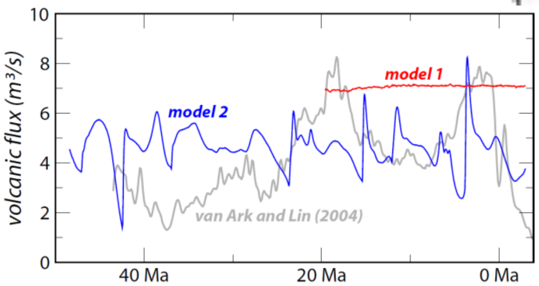
→ pool in a deep eclogitic pool



→ can explain seismic velocity structure beneath the Hawaiian hotspot



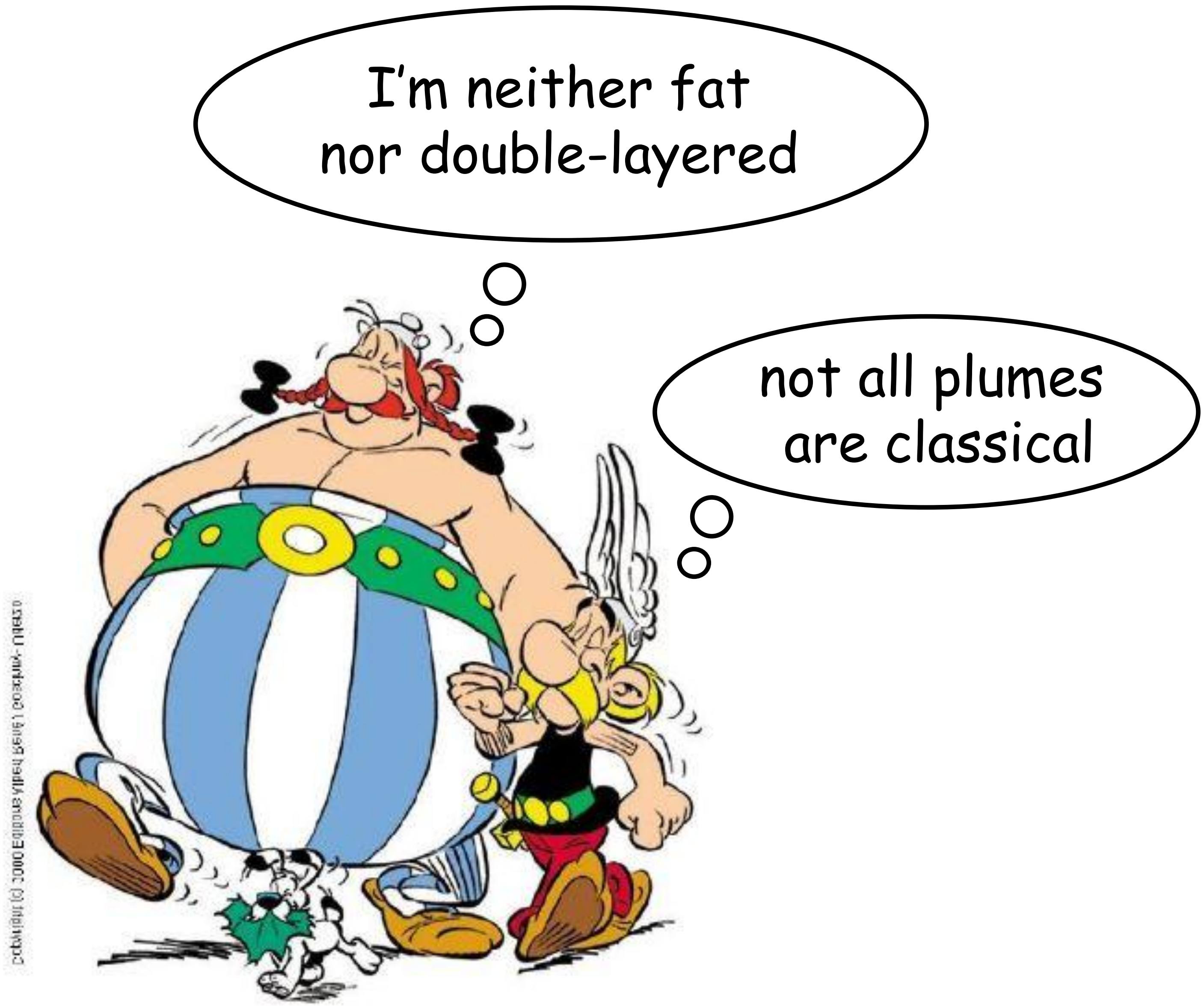
→ can give rise to geochemical asymmetry of hotspot volcanism without pre-existing heterogeneity in the plume stem.



→ can account for volcanic flux variations

 CONCLUSION CONCLUSION CONCLUSION

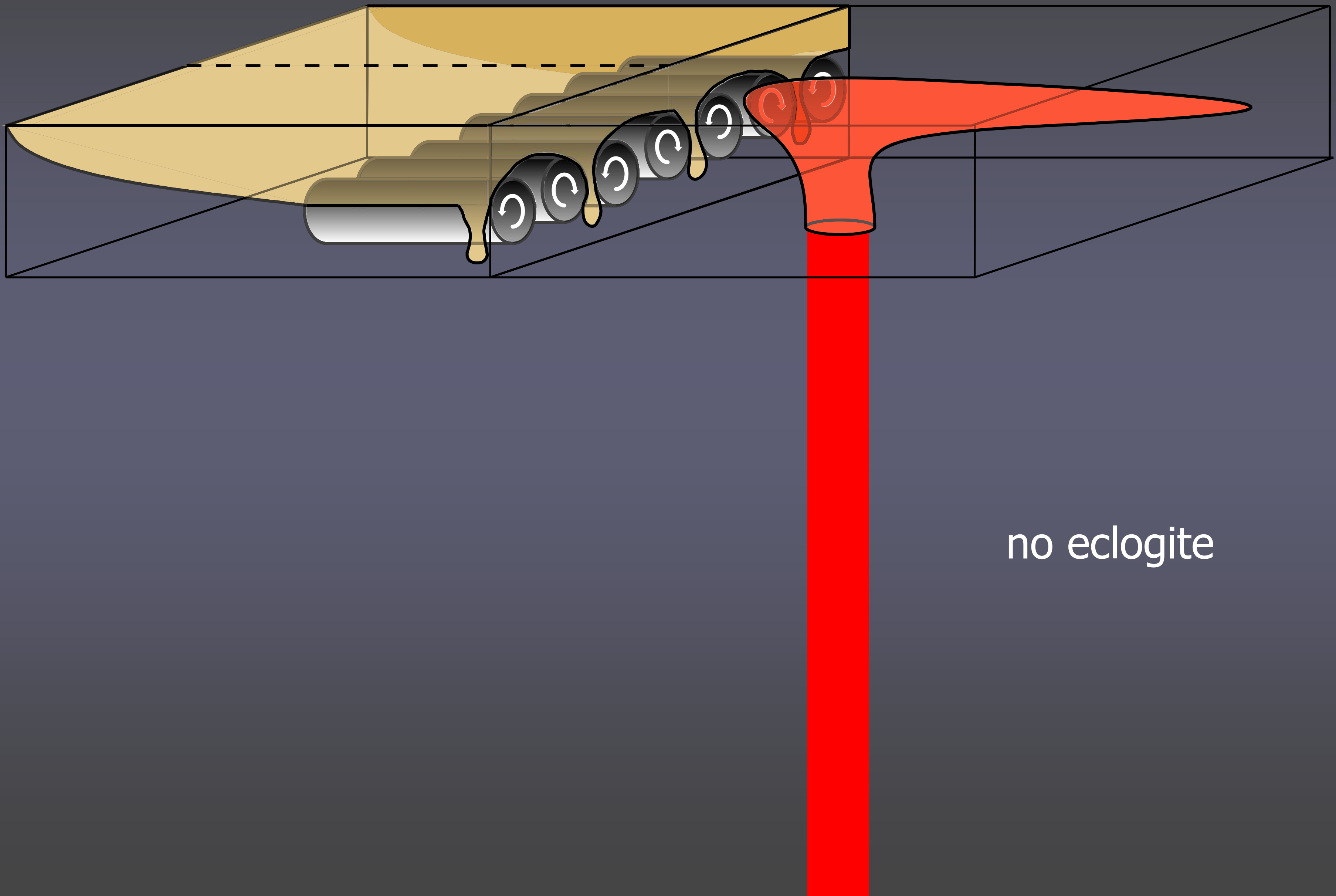
Take-home messages



The End

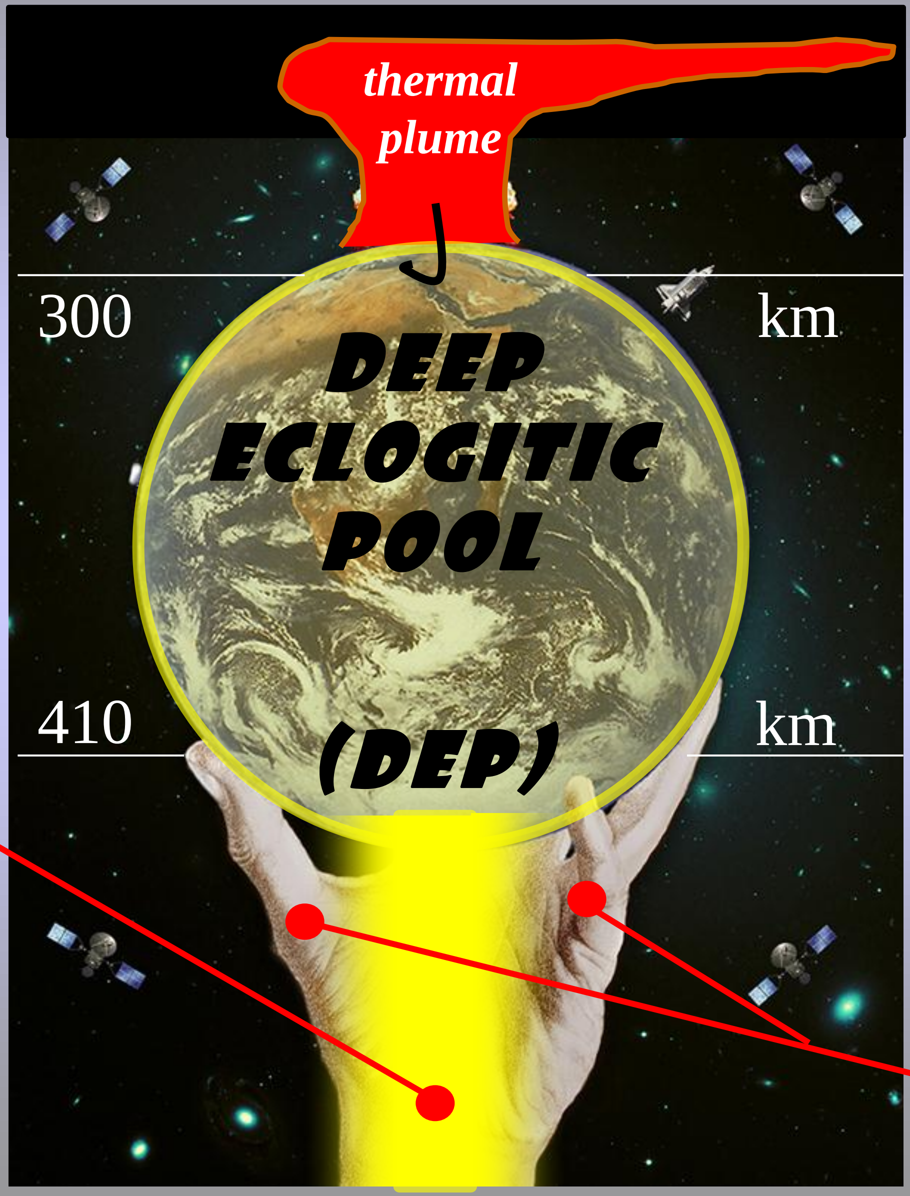
RESULTS PART 2 RESULTS PART 2

model 0



RESULTS PART 2 RESULTS PART 2

model 3



eclogitic core of thermochemical plume.

NOW:
smooth transition

non-eclogitic buoyant outskirts of the plume dynammically support the "DEP"

RESULTS PART 2 RESULTS PART 2 RESULTS PART 2

geochemical non-symmetry