University of Trieste

October 3, 2019

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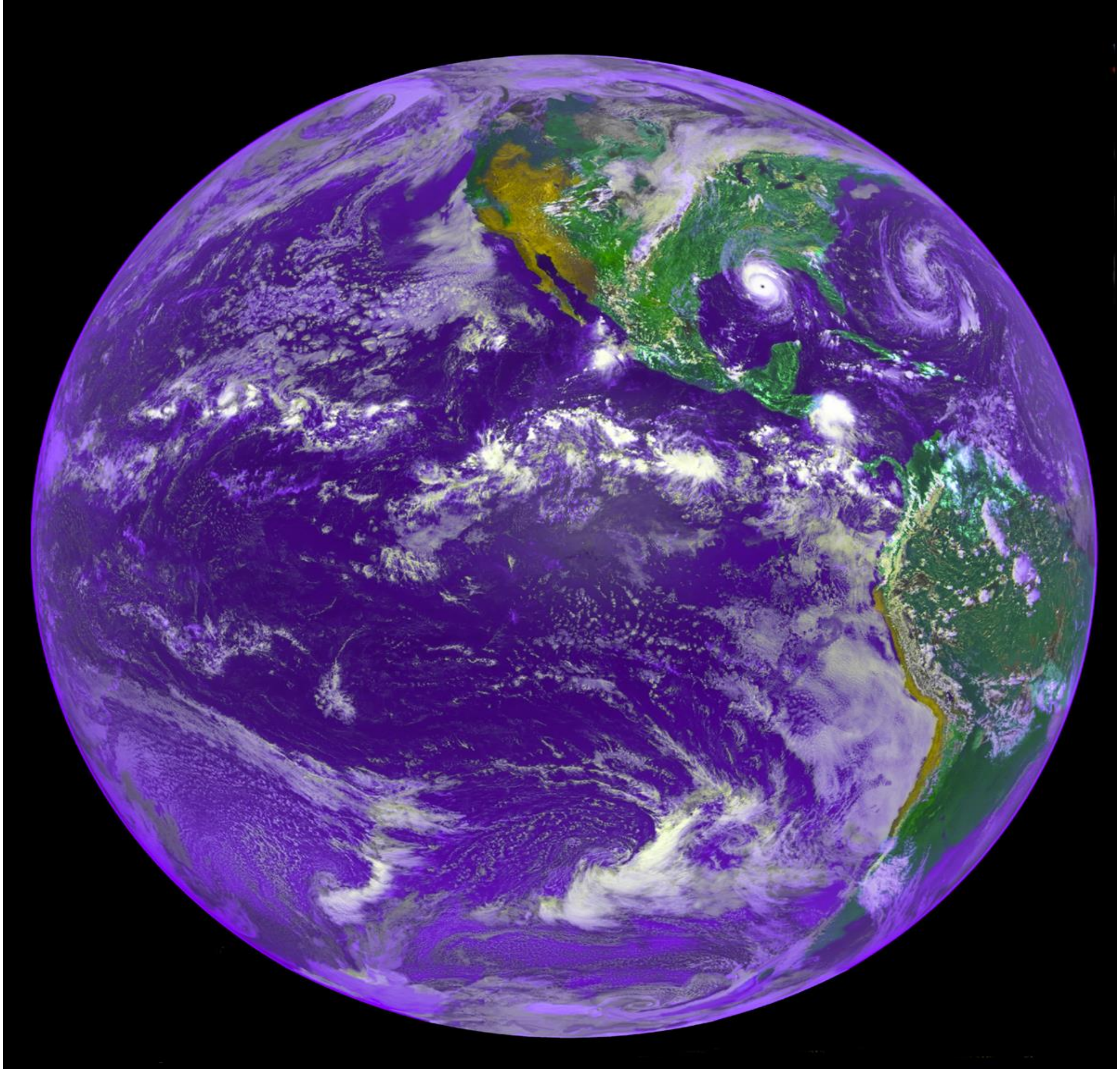
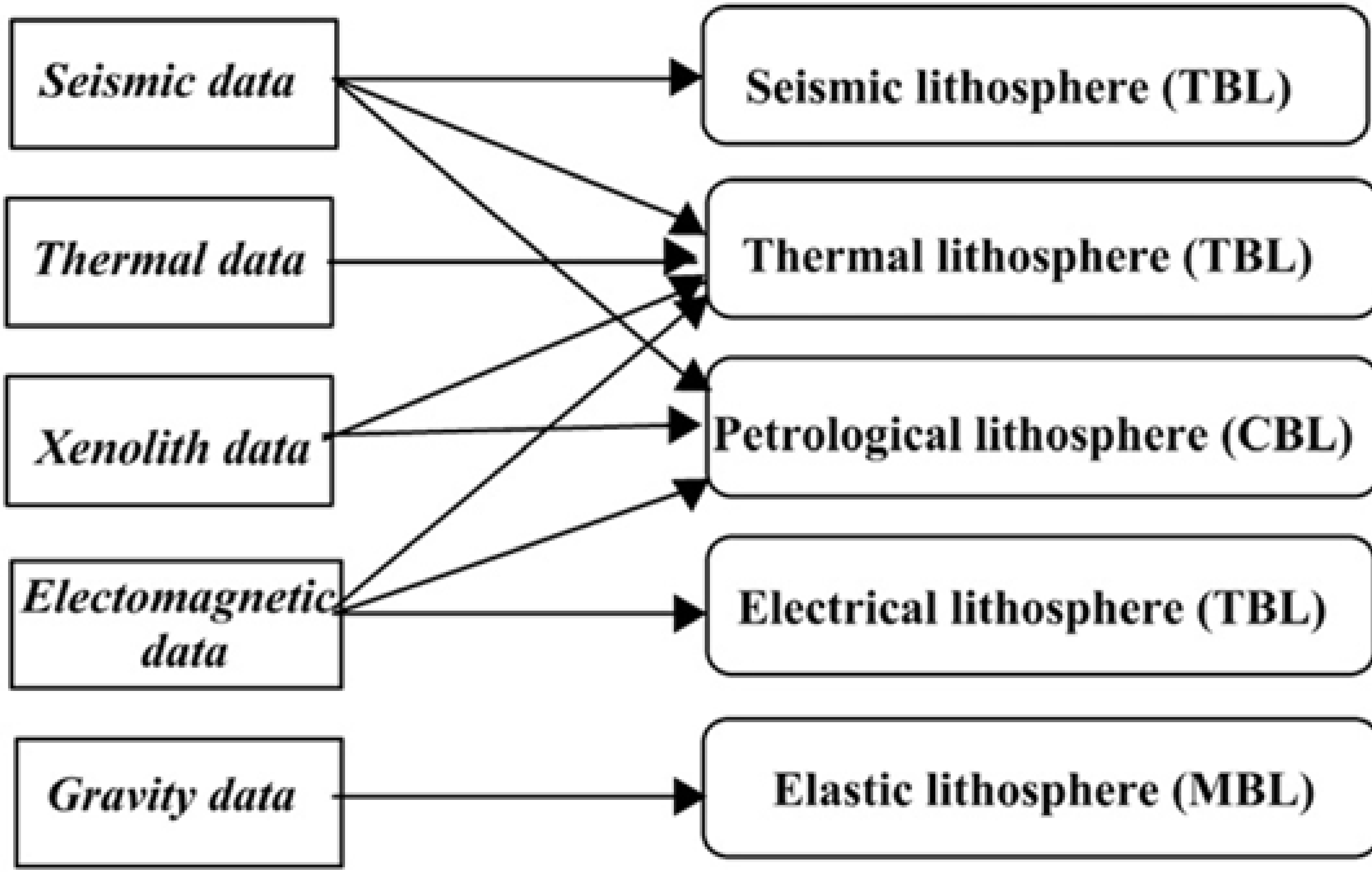
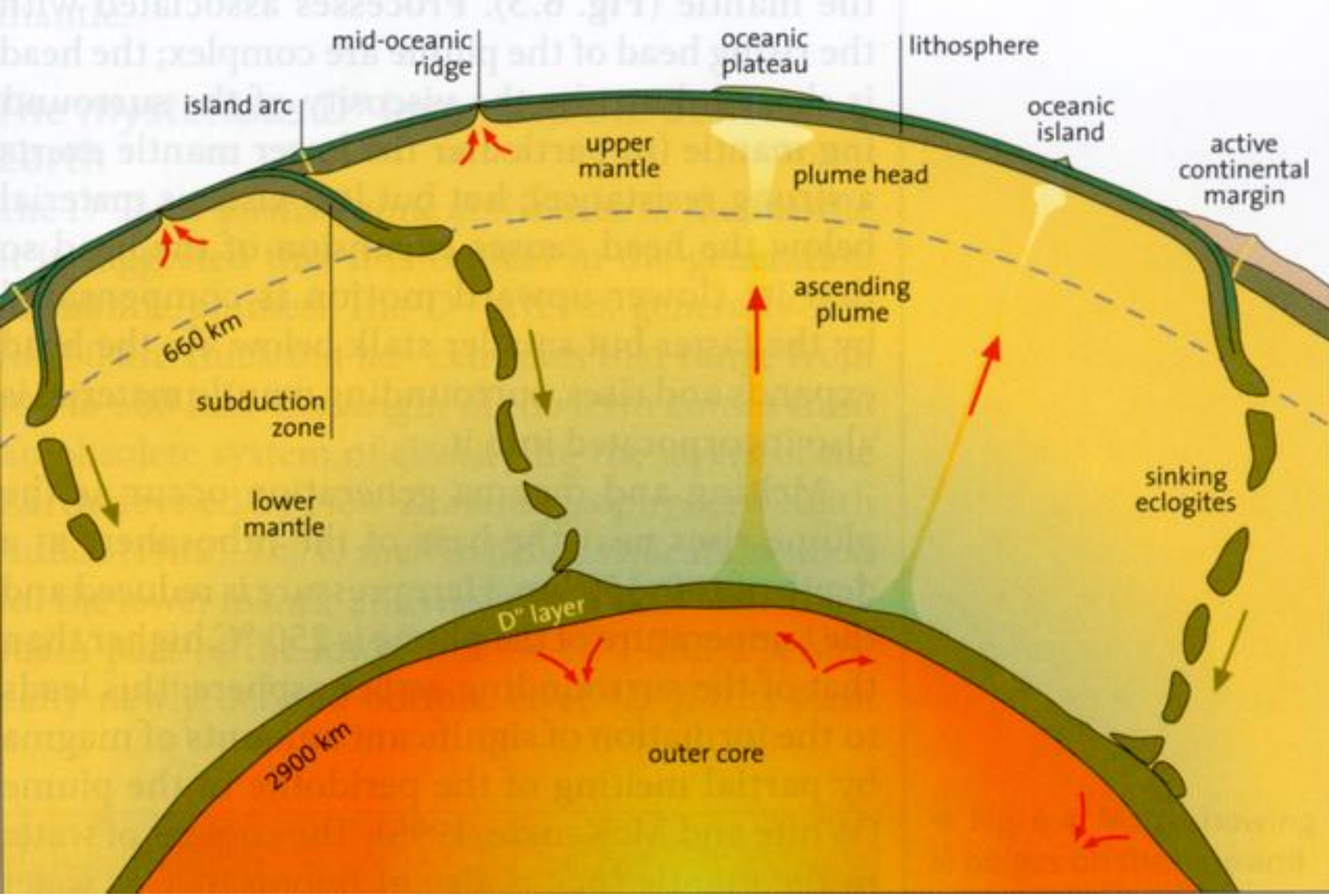
US Geological Survey
Menlo Park, California USA
mooney@usgs.gov

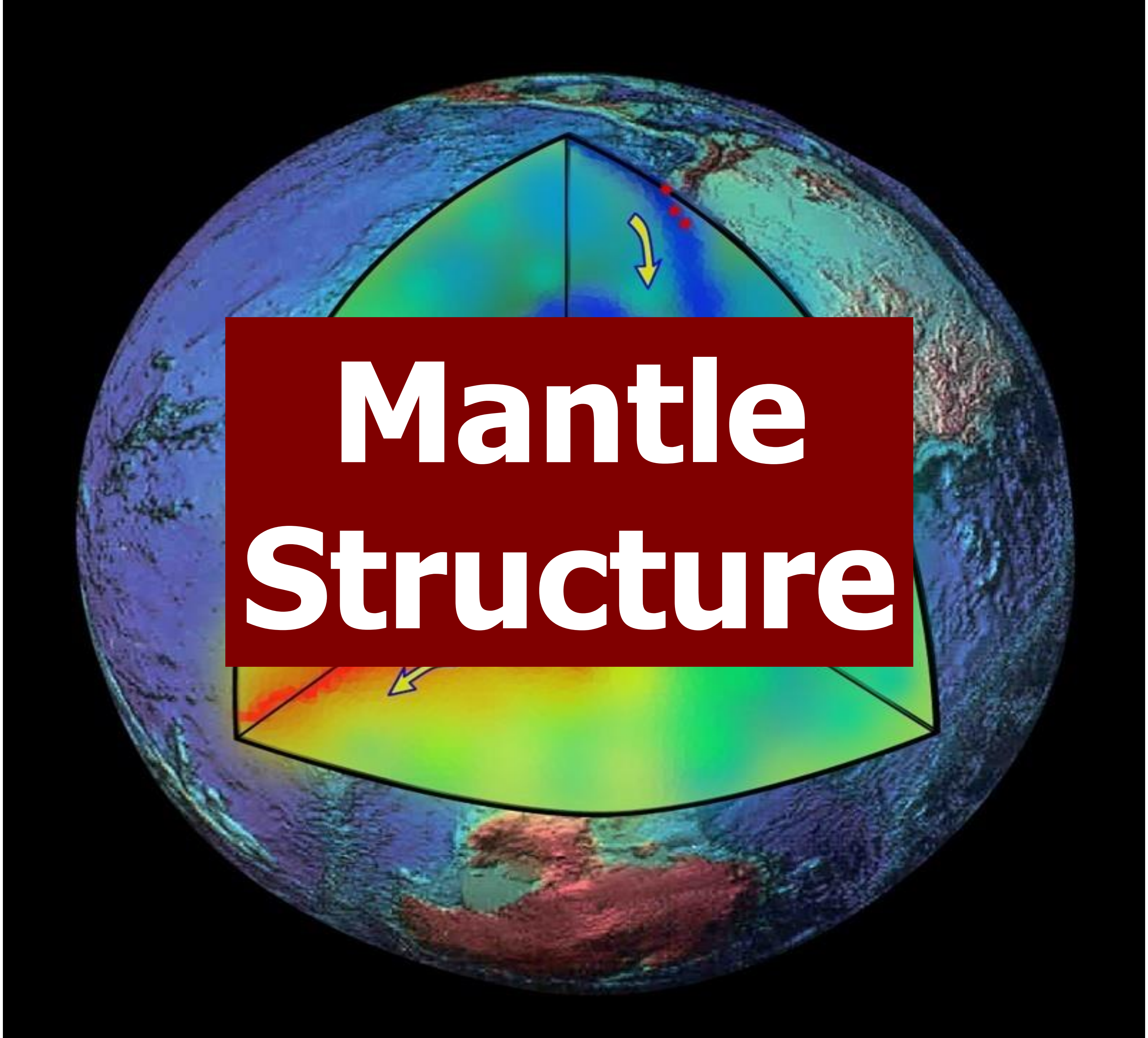
"Thermal Structure of the Earth"

Mooney: Lecture #2: Thermal Structure of the Earth



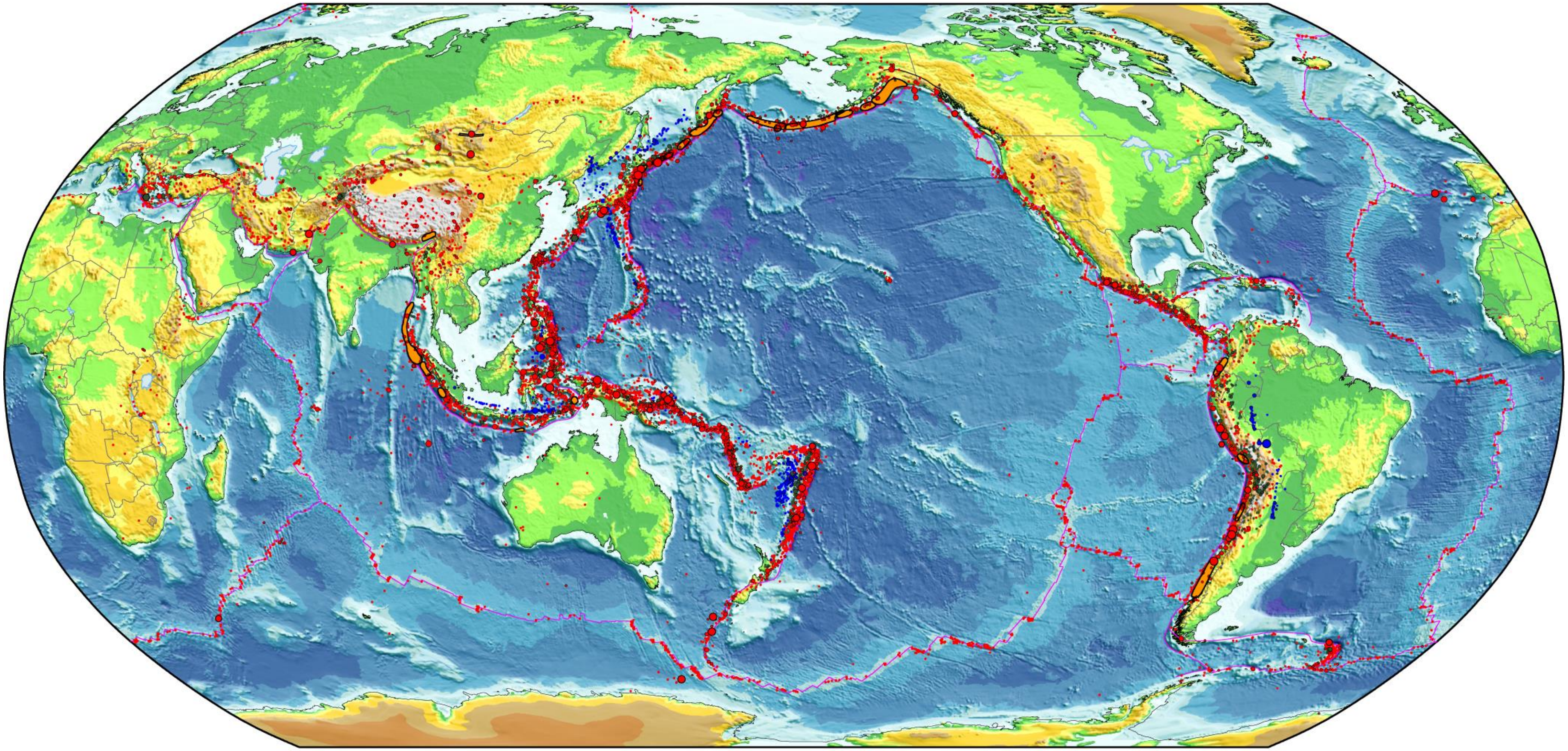

Seismic data
Thermal data
Xenolith data
Electomagnetic data
Gravity data
Seismic lithosphere (TBL)
Thermal lithosphere (TBL)
Petrological lithosphere (CBL)
Electrical lithosphere (TBL)
Elastic lithosphere (MBL)


mid-oceanic ridge
oceanic plateau
lithosphere
island arc
oceanic island
upper mantle
plume head
active continental margin
660 km
ascending plume
subduction zone
lower mantle
sinking eclogites
D" layer
2900 km
outer core



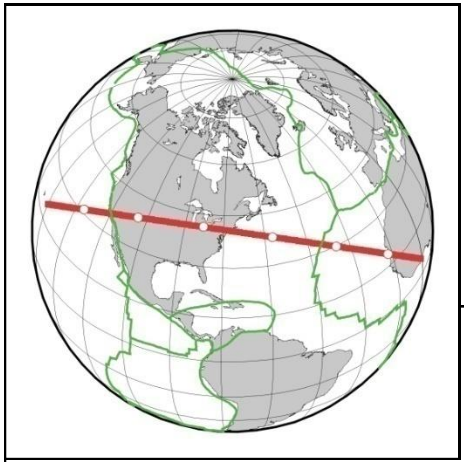
Mantle Structure

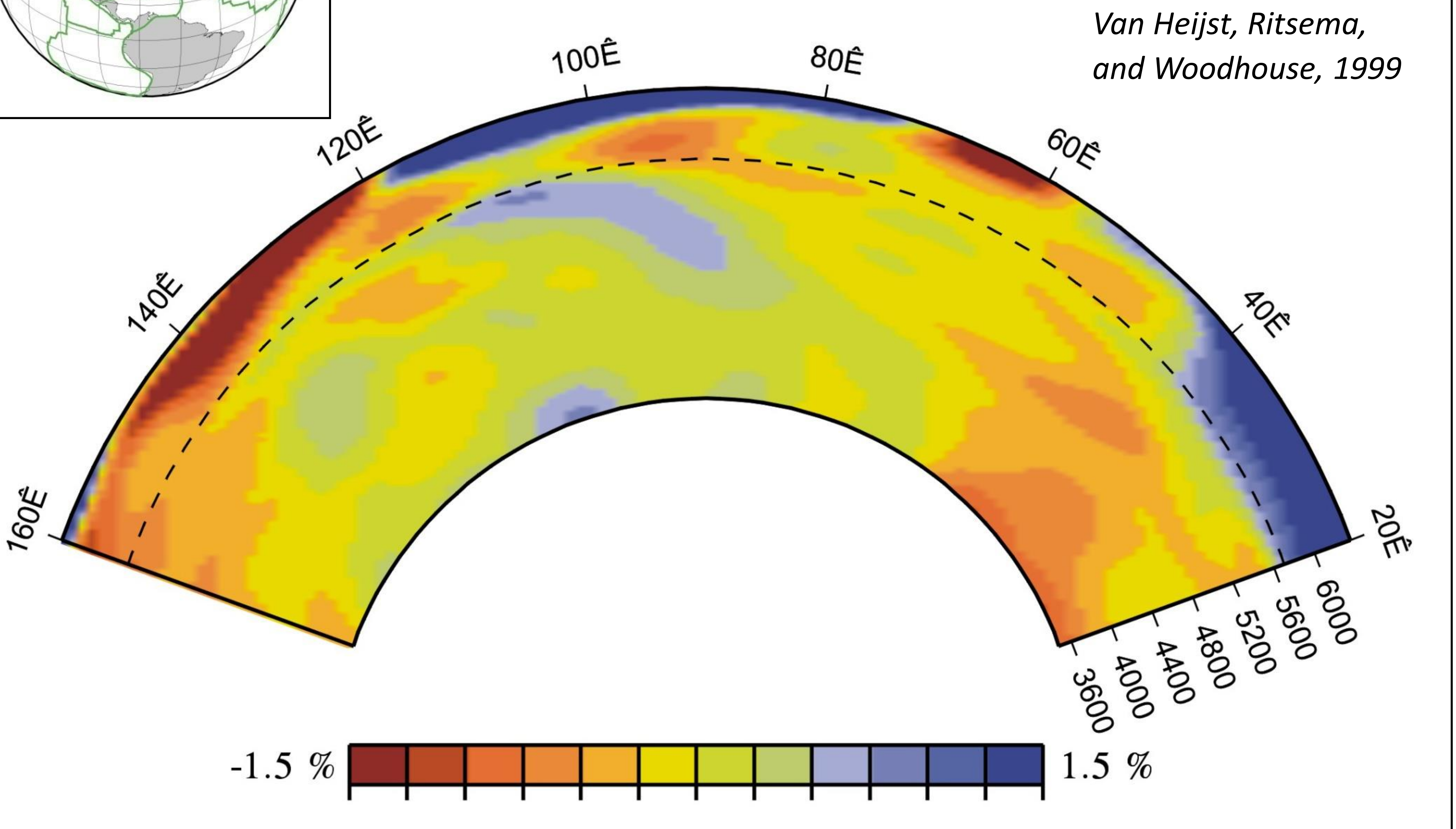
Seismicity of the Earth (1900-2007)



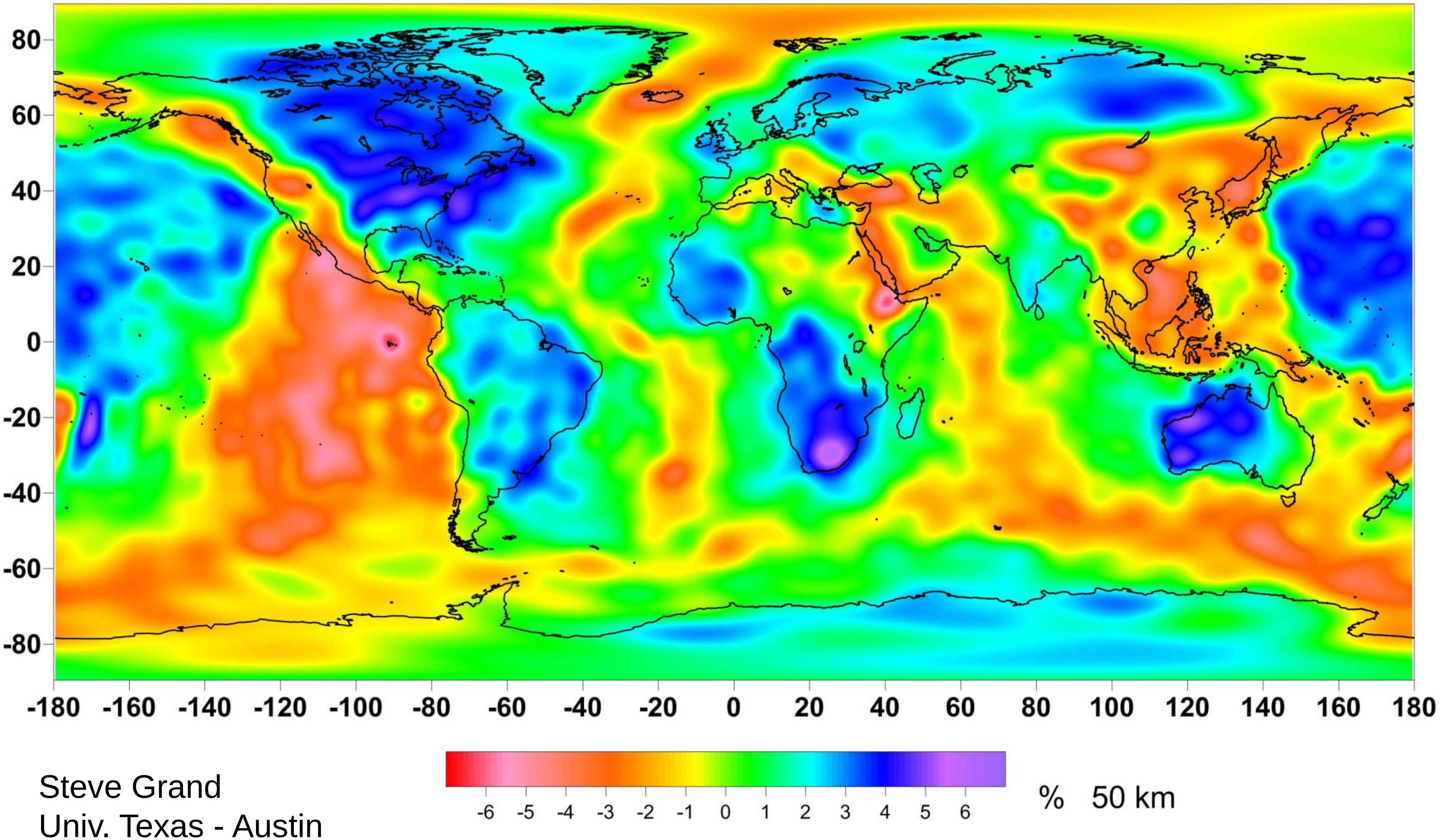
Villaseñor, Benz and Engdahl (Fall AGU, 2007)

Tomographic Model





S-wave Anomaly 50 Km



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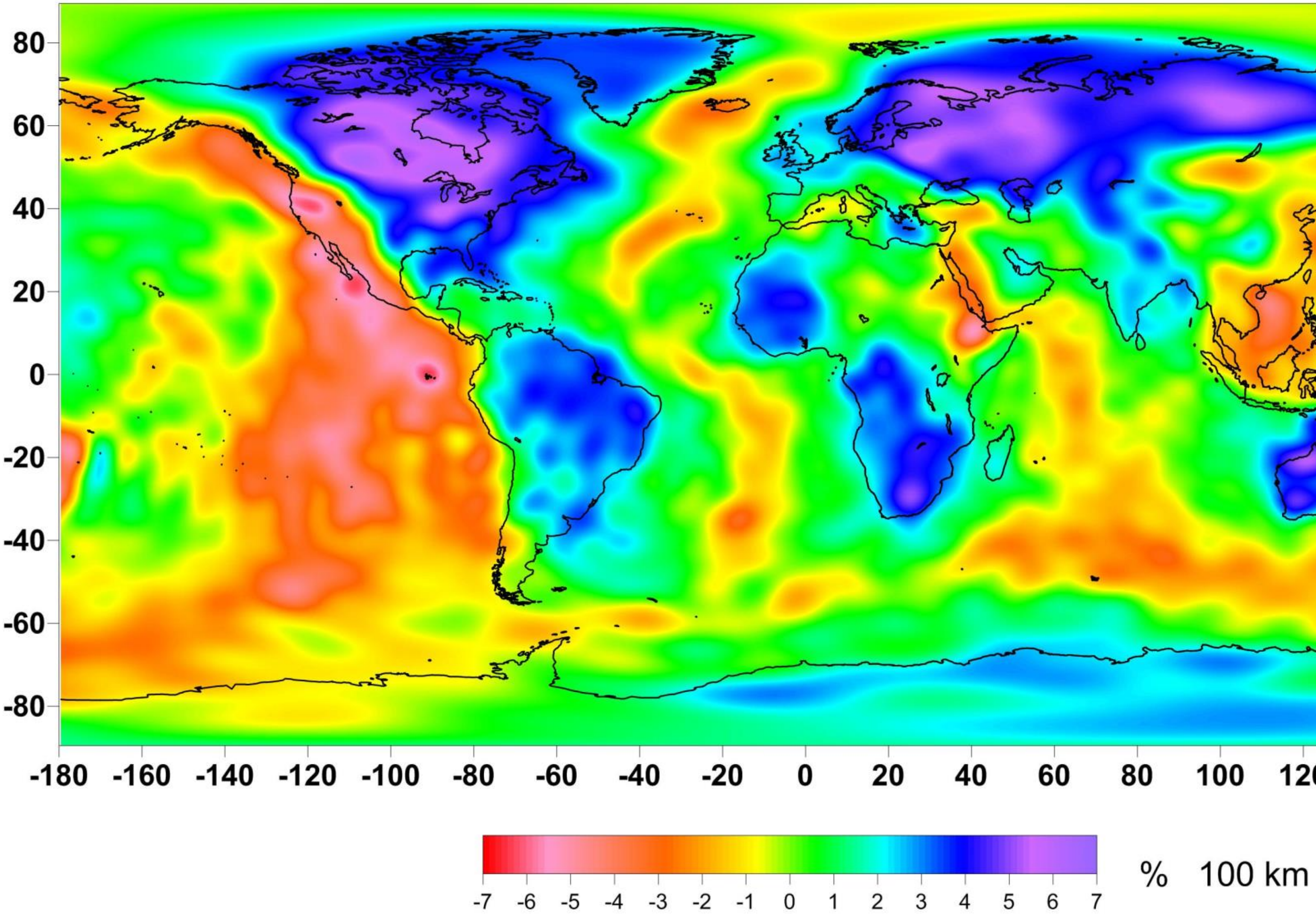
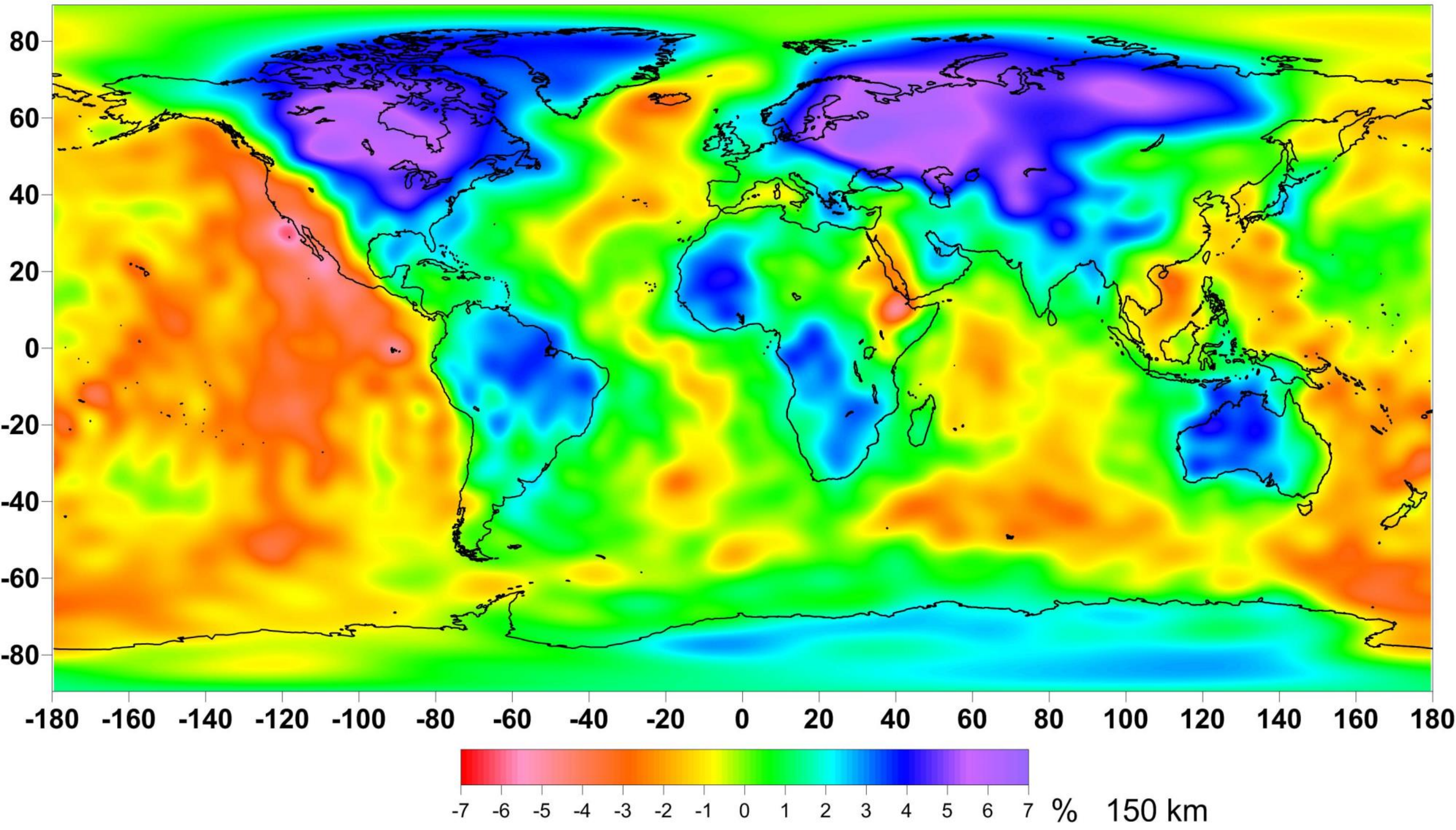
Univ. Texas - Austin

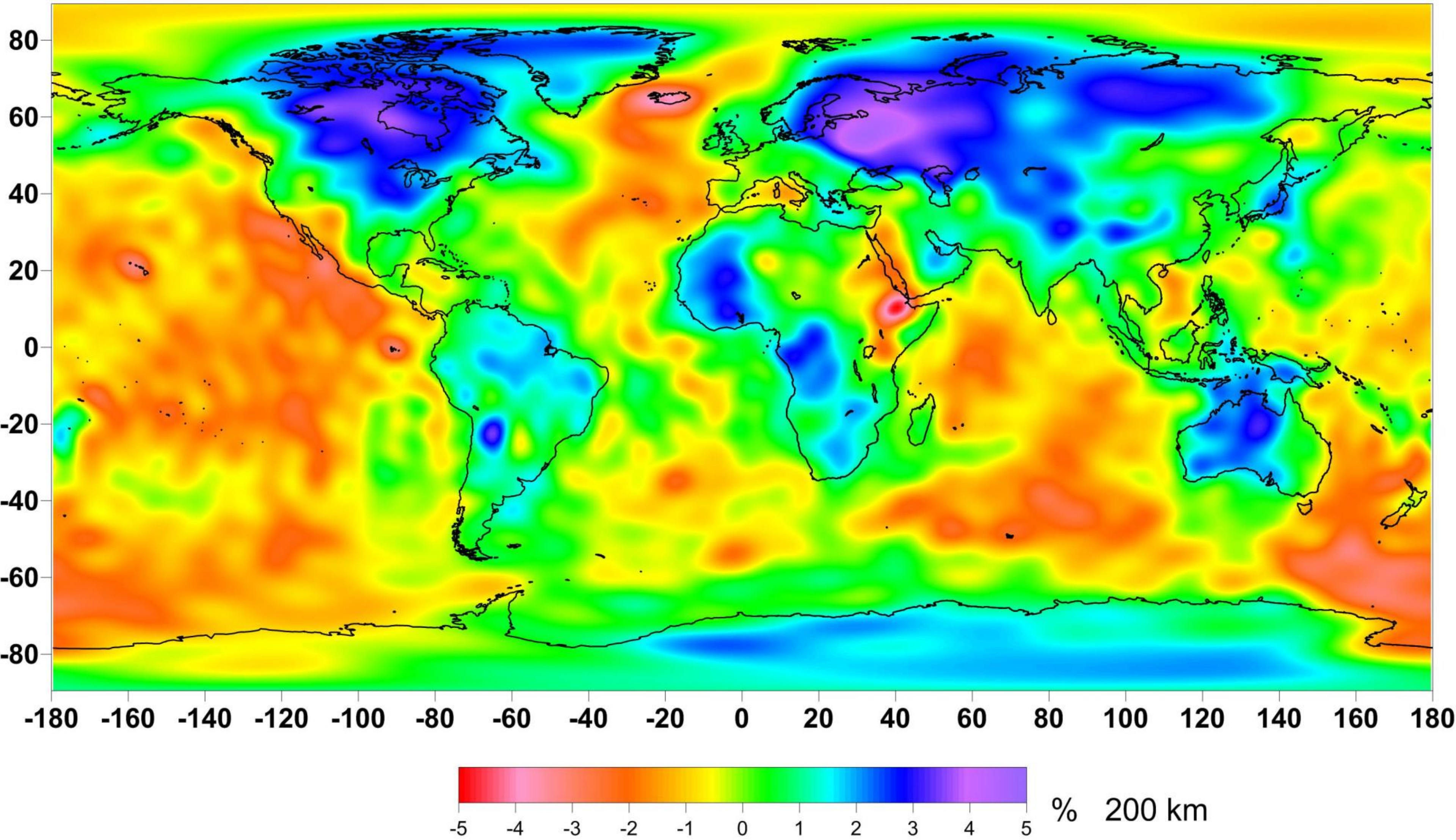
S-wave Anomaly 100 km



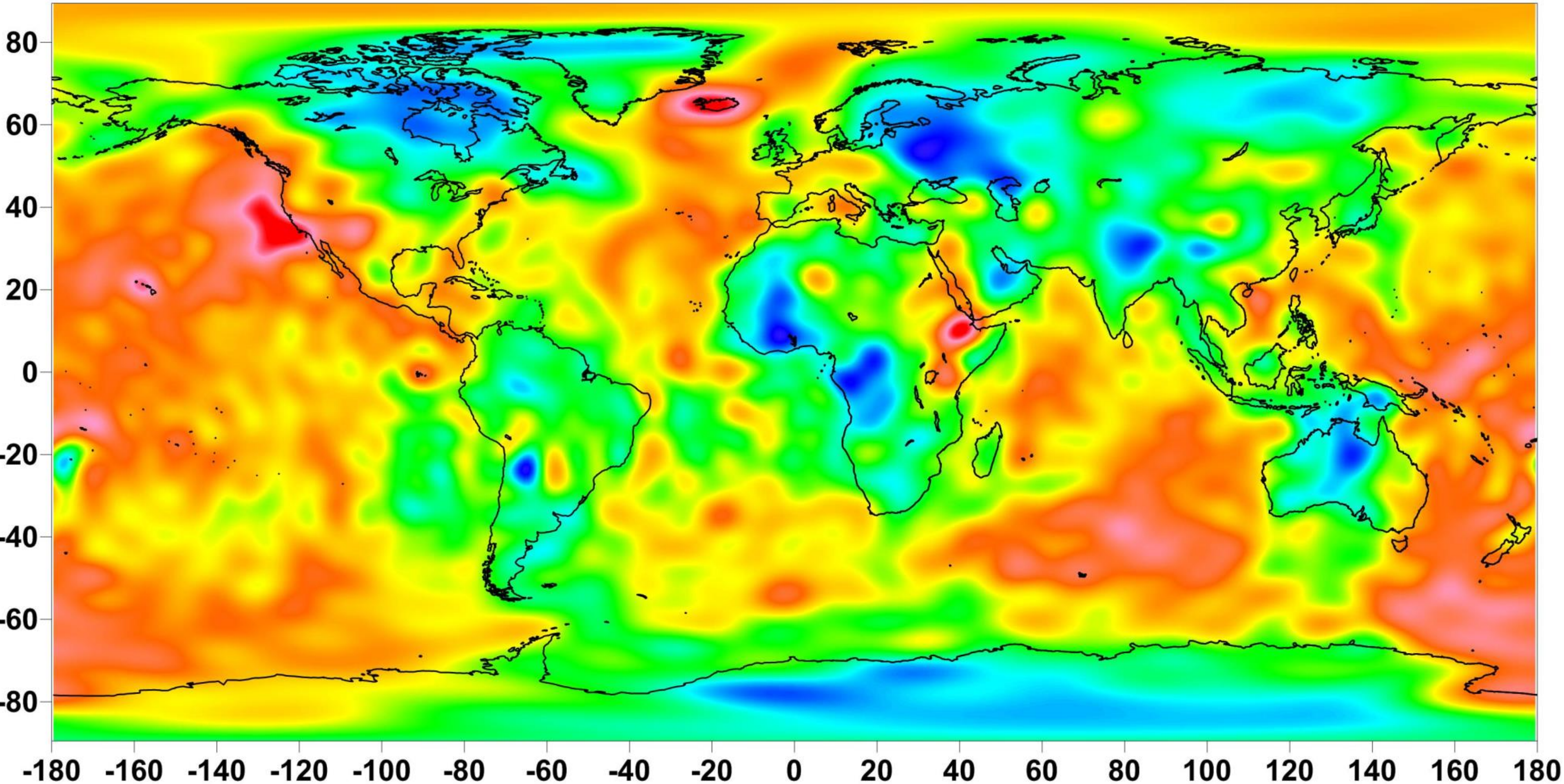
S-wave Anomaly, 150 km

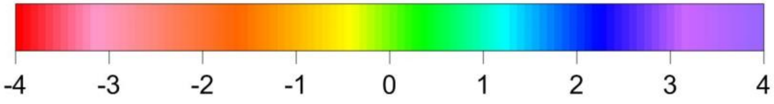


S-wave Anomaly 200 km



S-wave Anomaly 250 km





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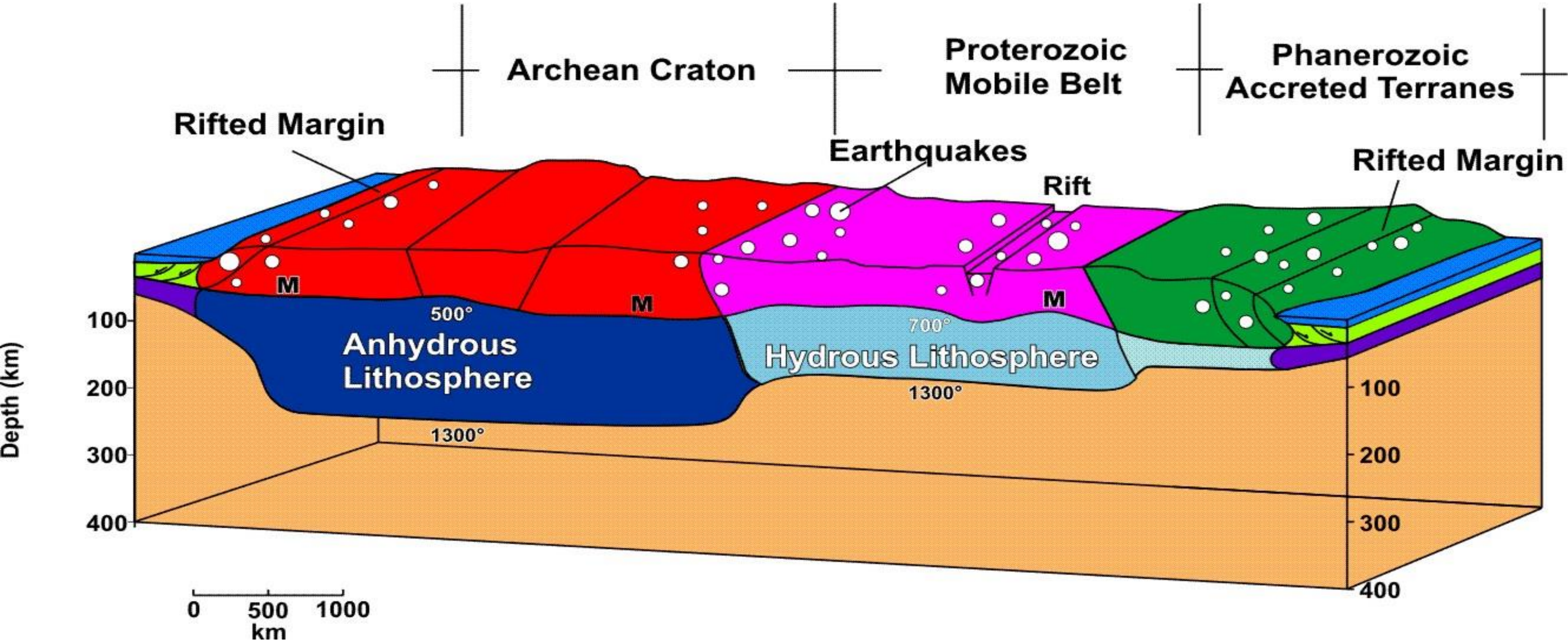
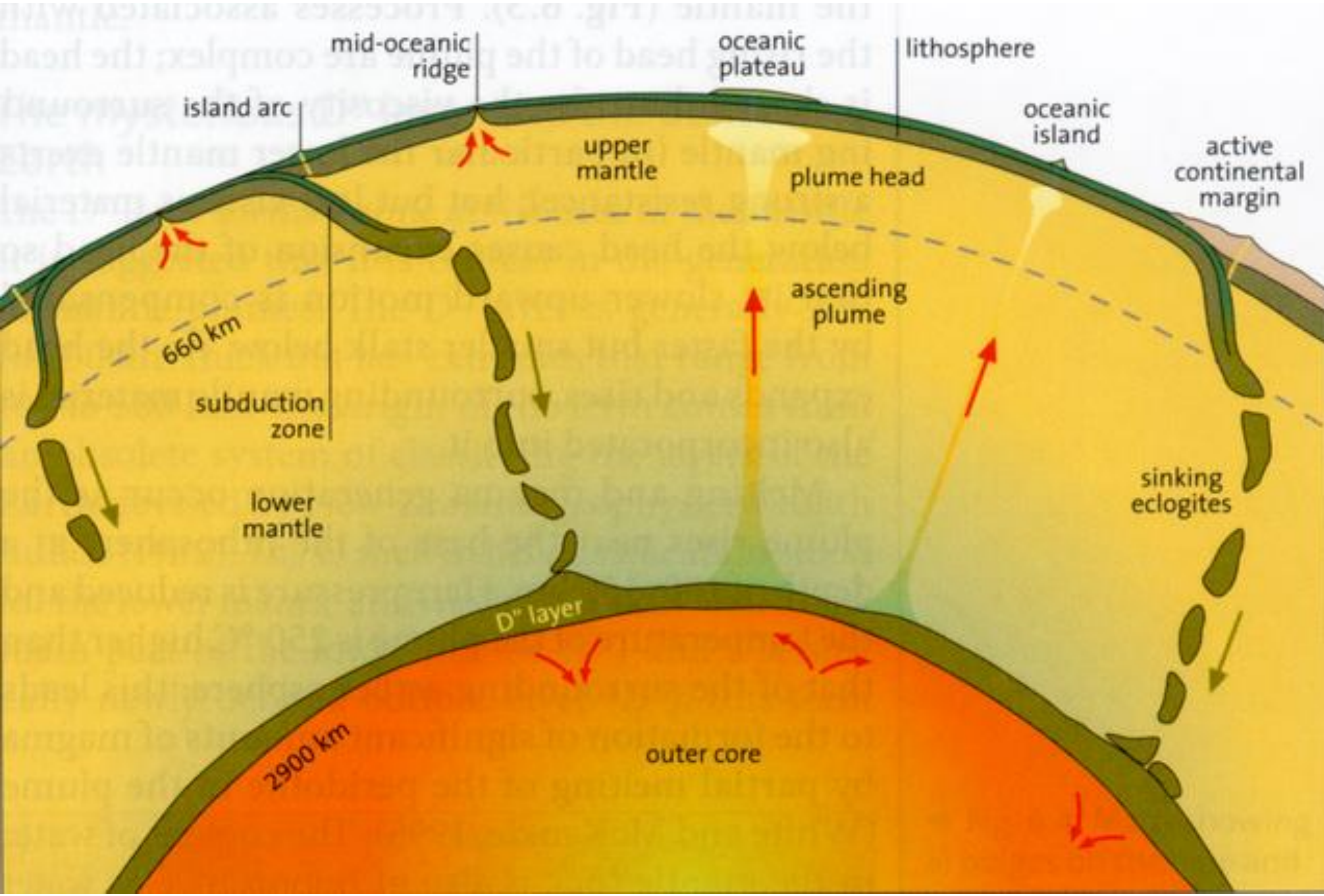
The Lithosphere



Mooney et al., EPSL, 2012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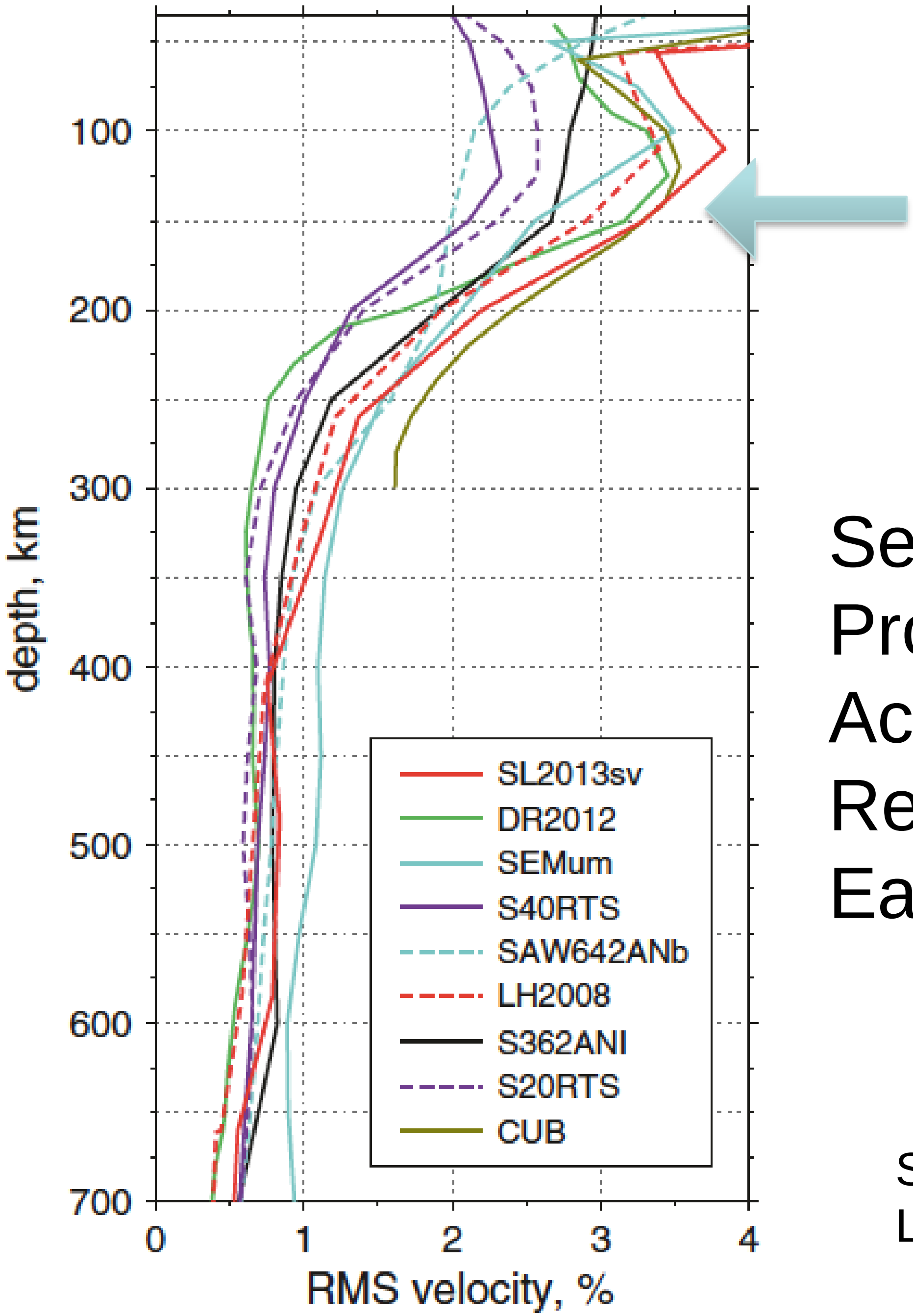
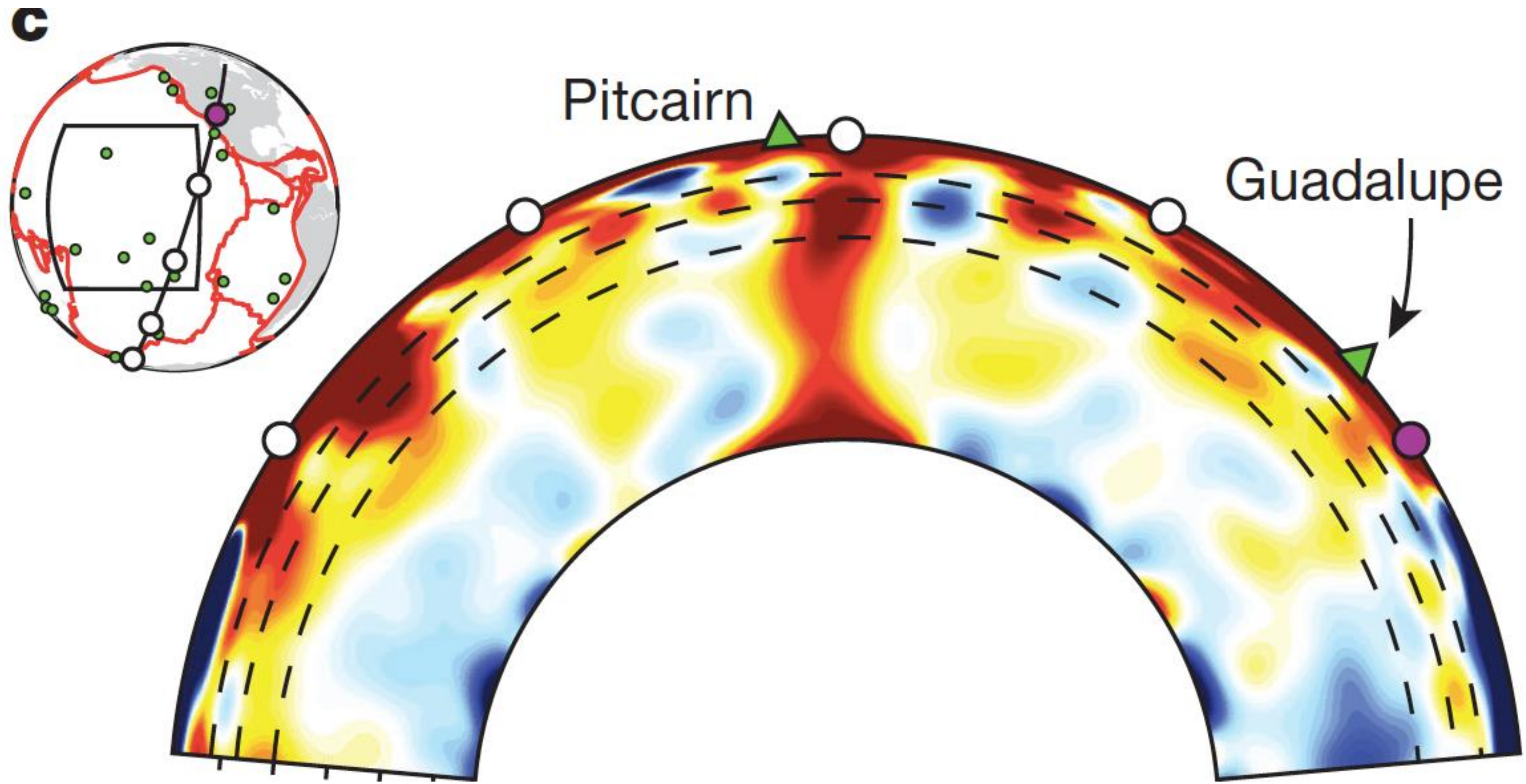


Seismology Provides Accurate and Reproducible Earth Models

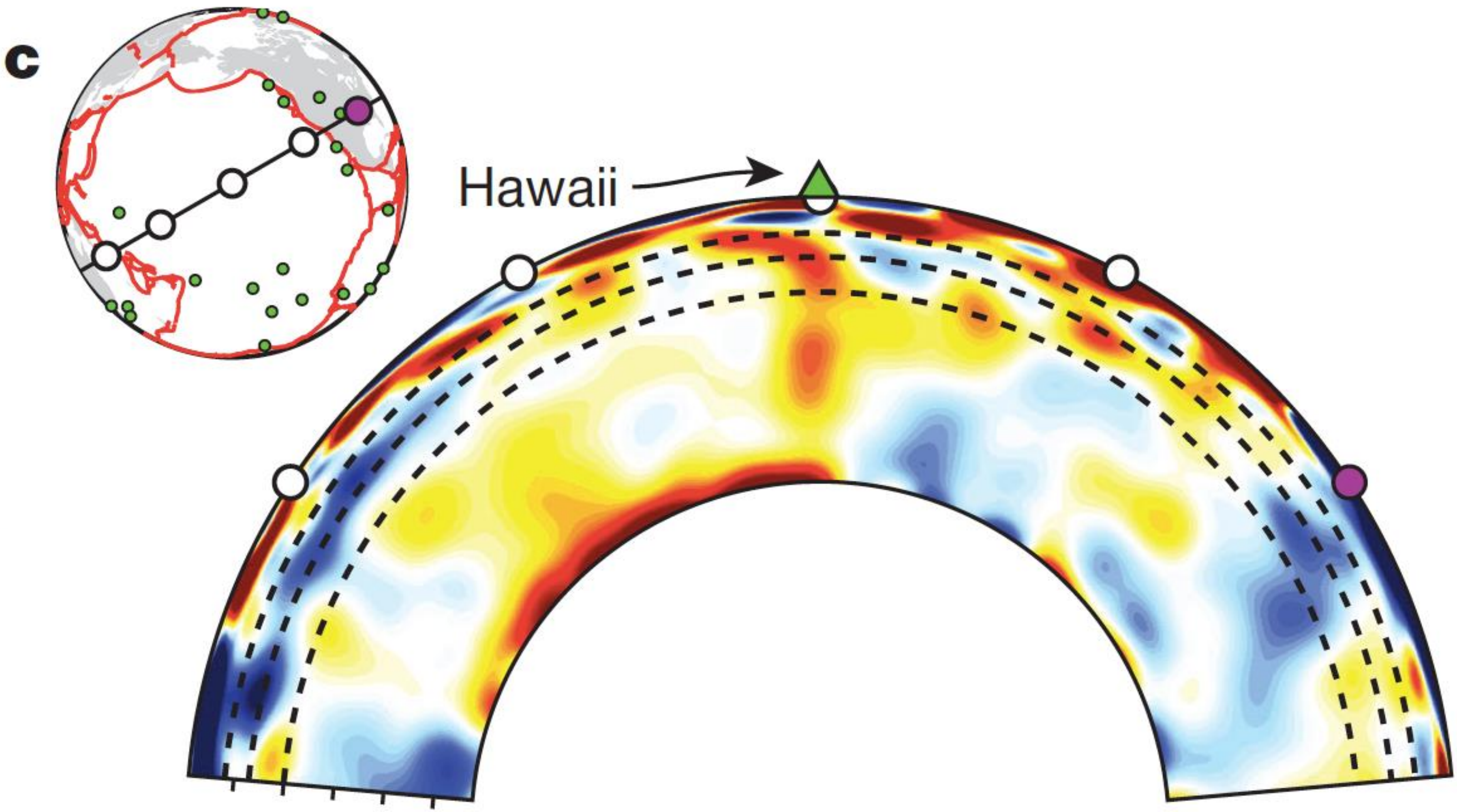
Schaeffer and Lebedev,2015

Imaging Deep Mantle Plumes



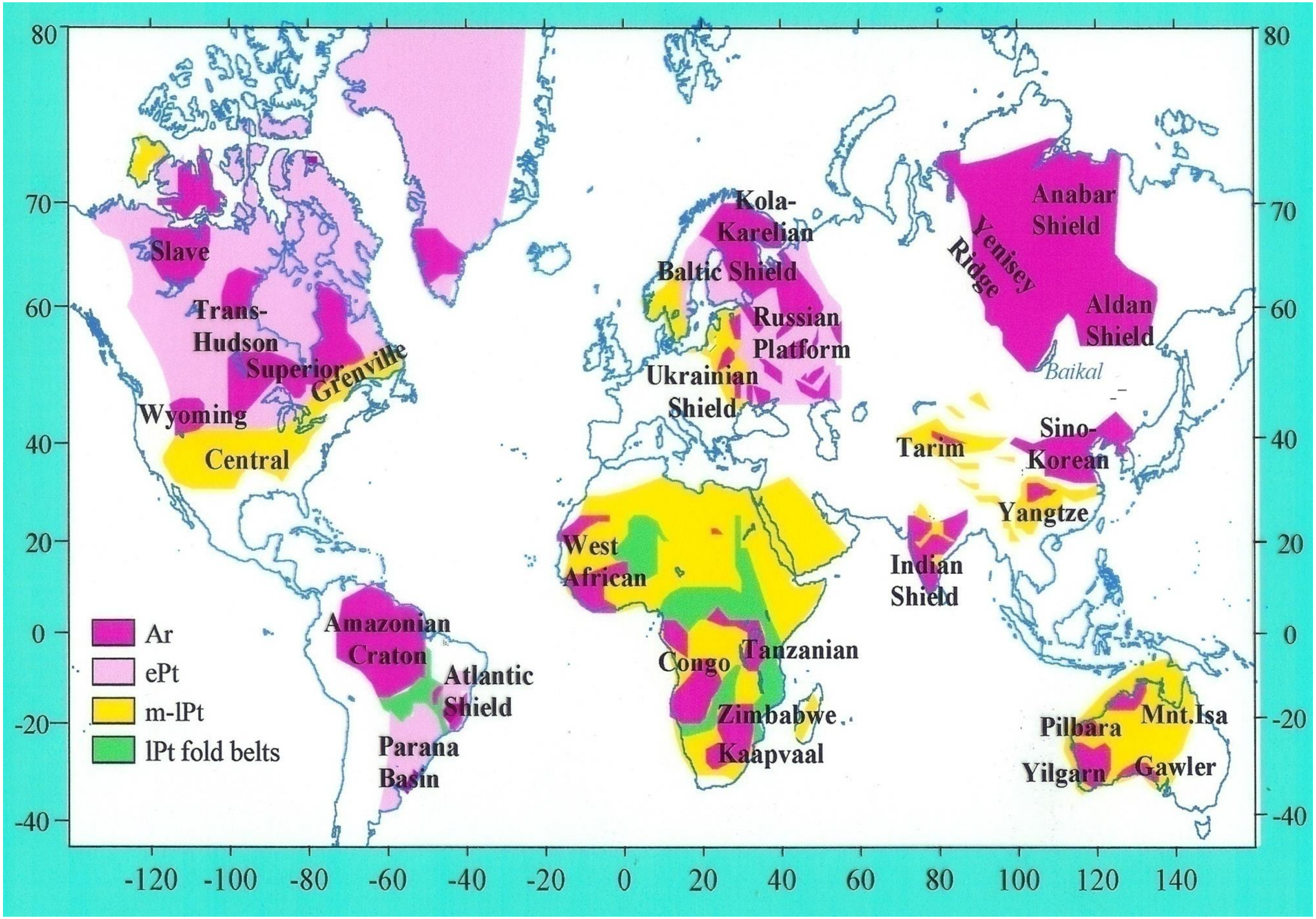
French and Romanowicz, Nature, 2015

Pacific Core-Mantle Boundary & Hawaiian Plume



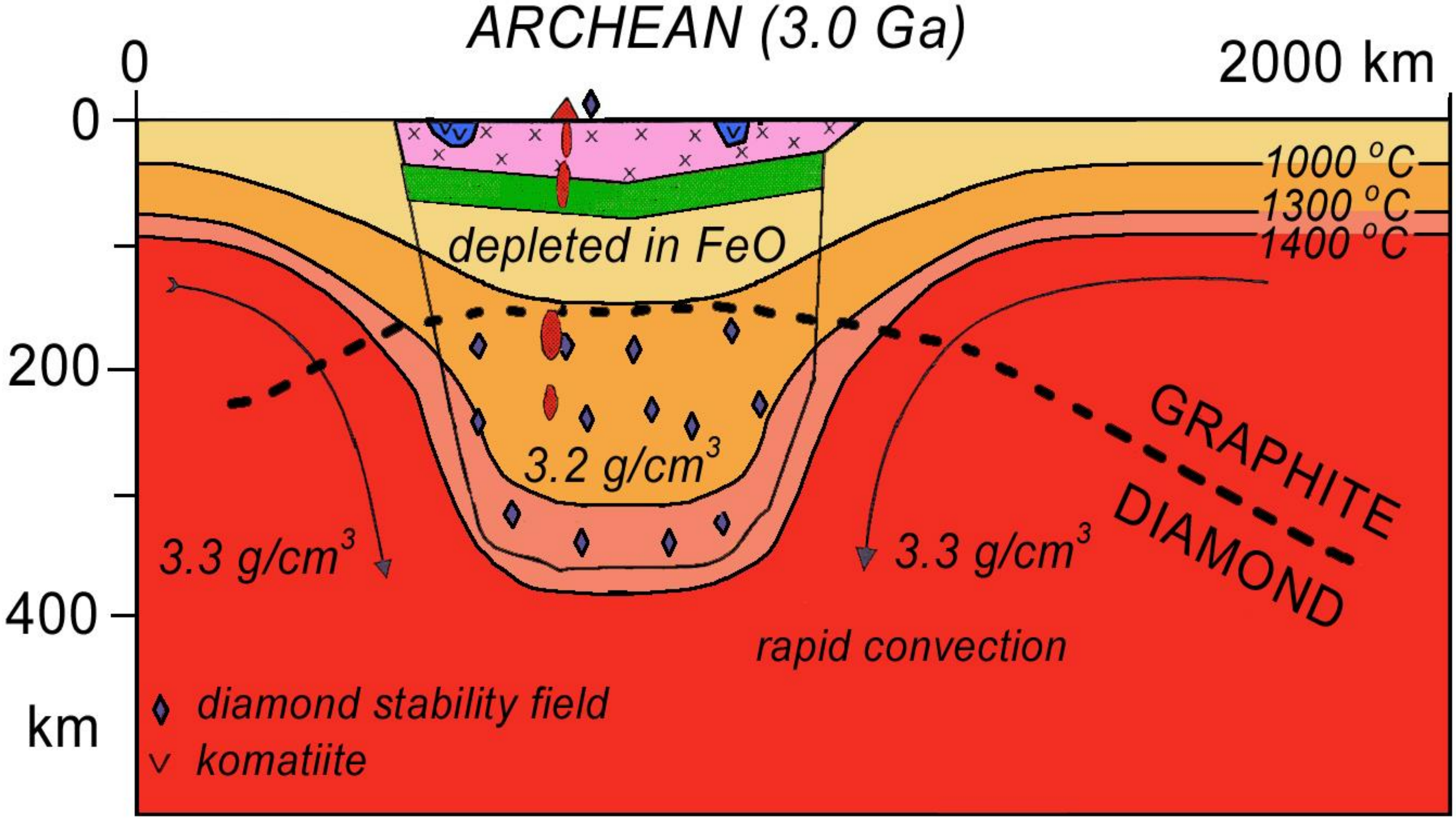
French and Romanowicz, Nature, 2015

Precambrian Cratons

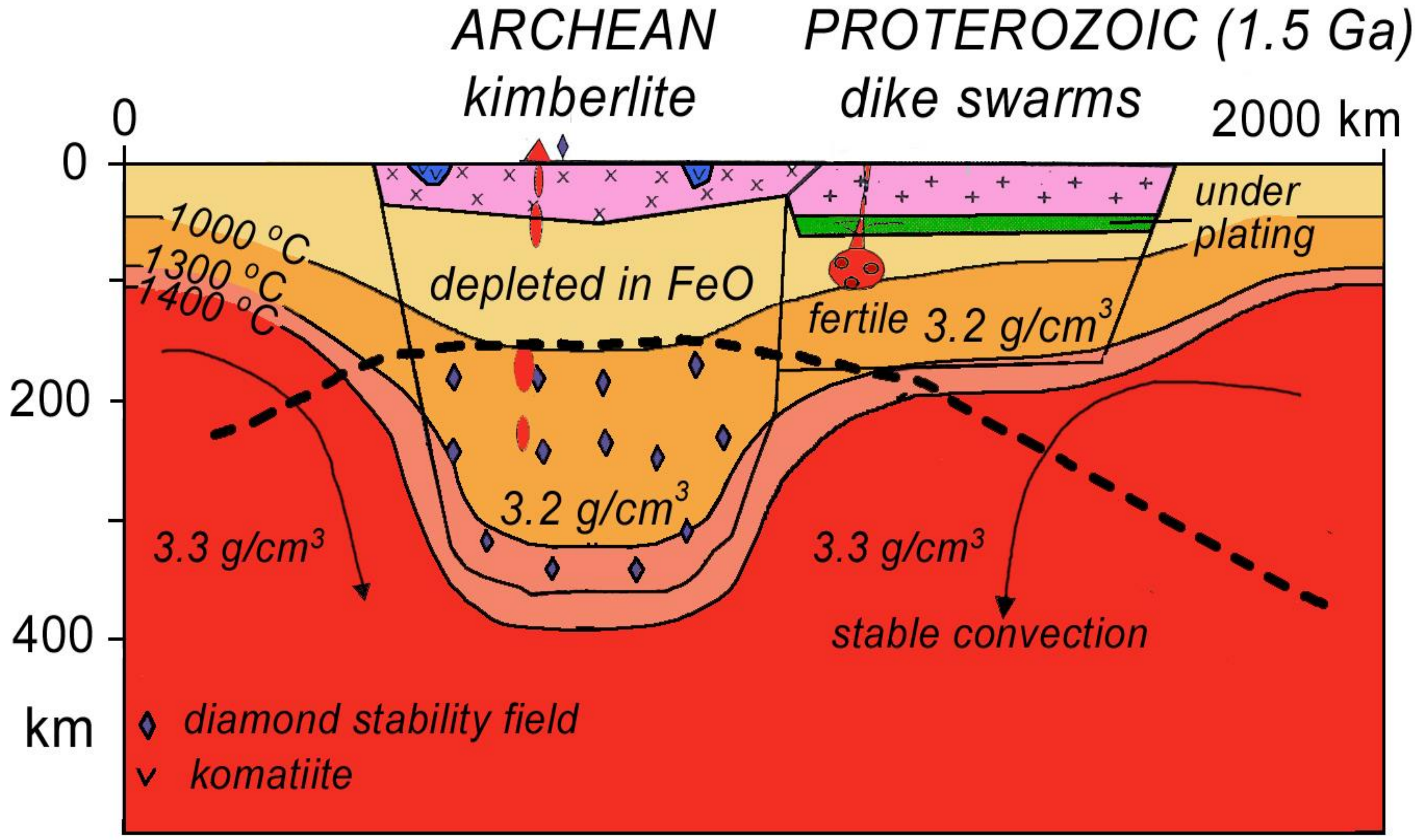


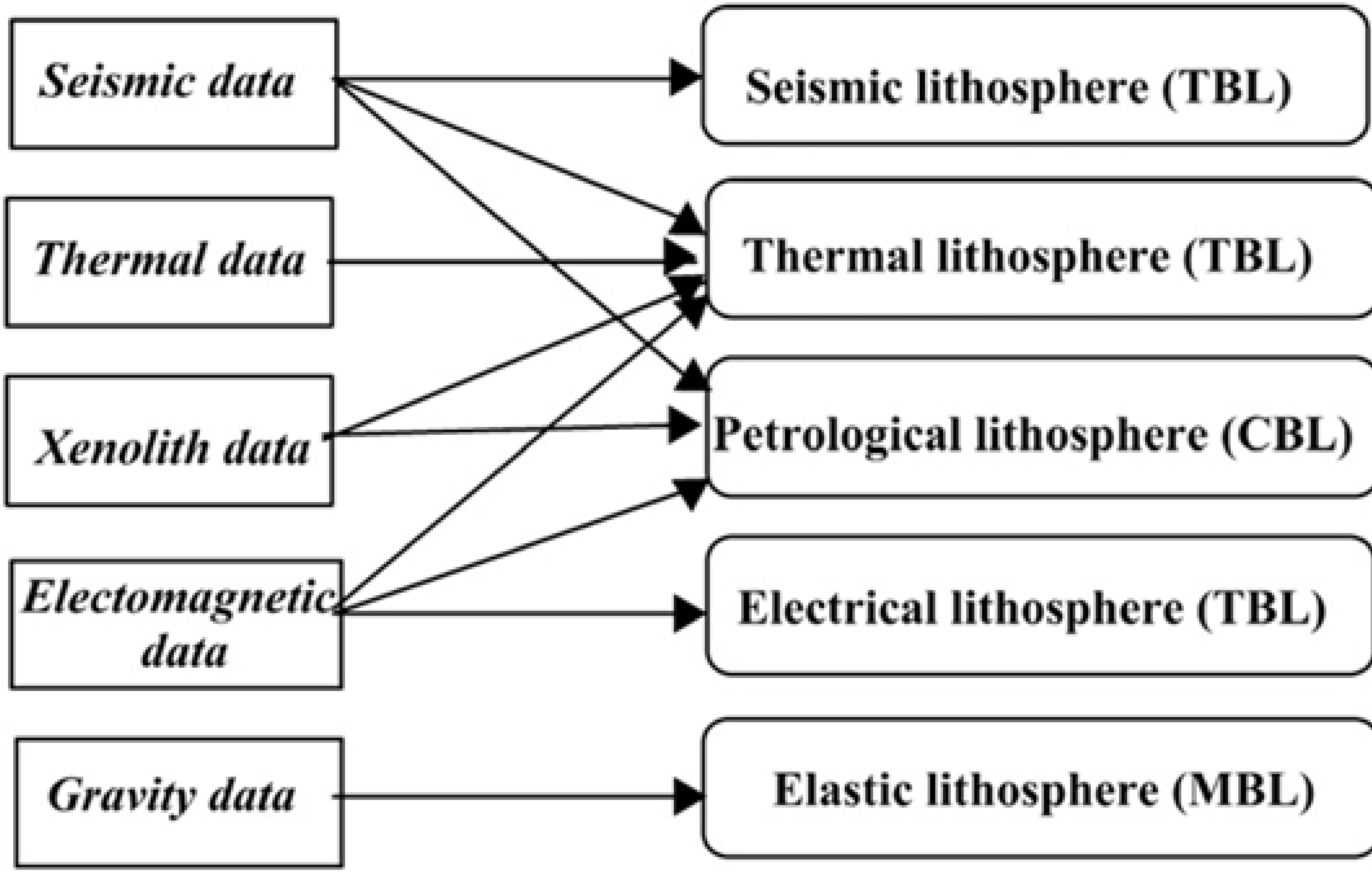
Source: Artemieva and Mooney, 2000

Model for Archean Lithospheric Evolution



Model for Proterozoic Lithospheric Evolution

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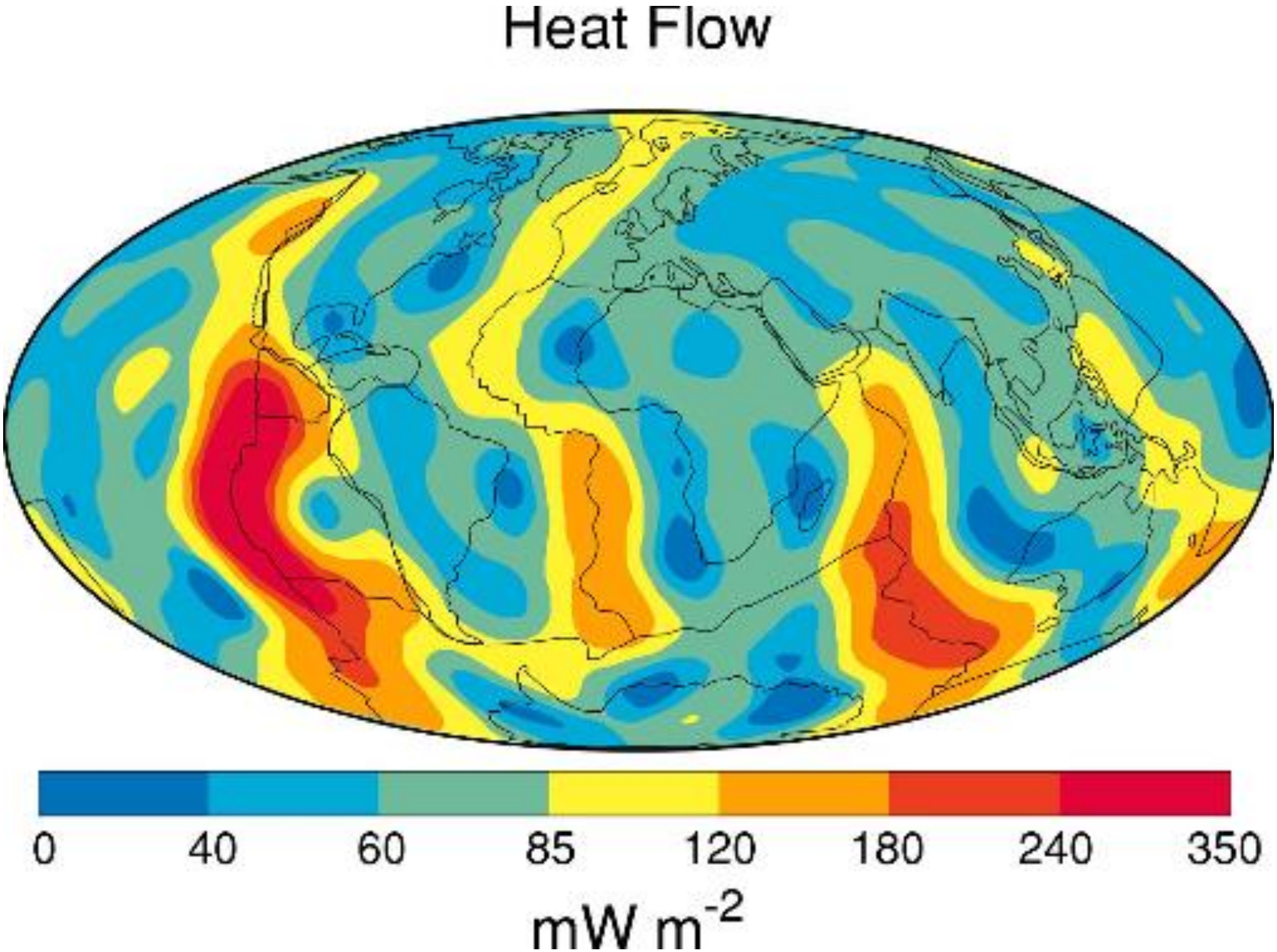
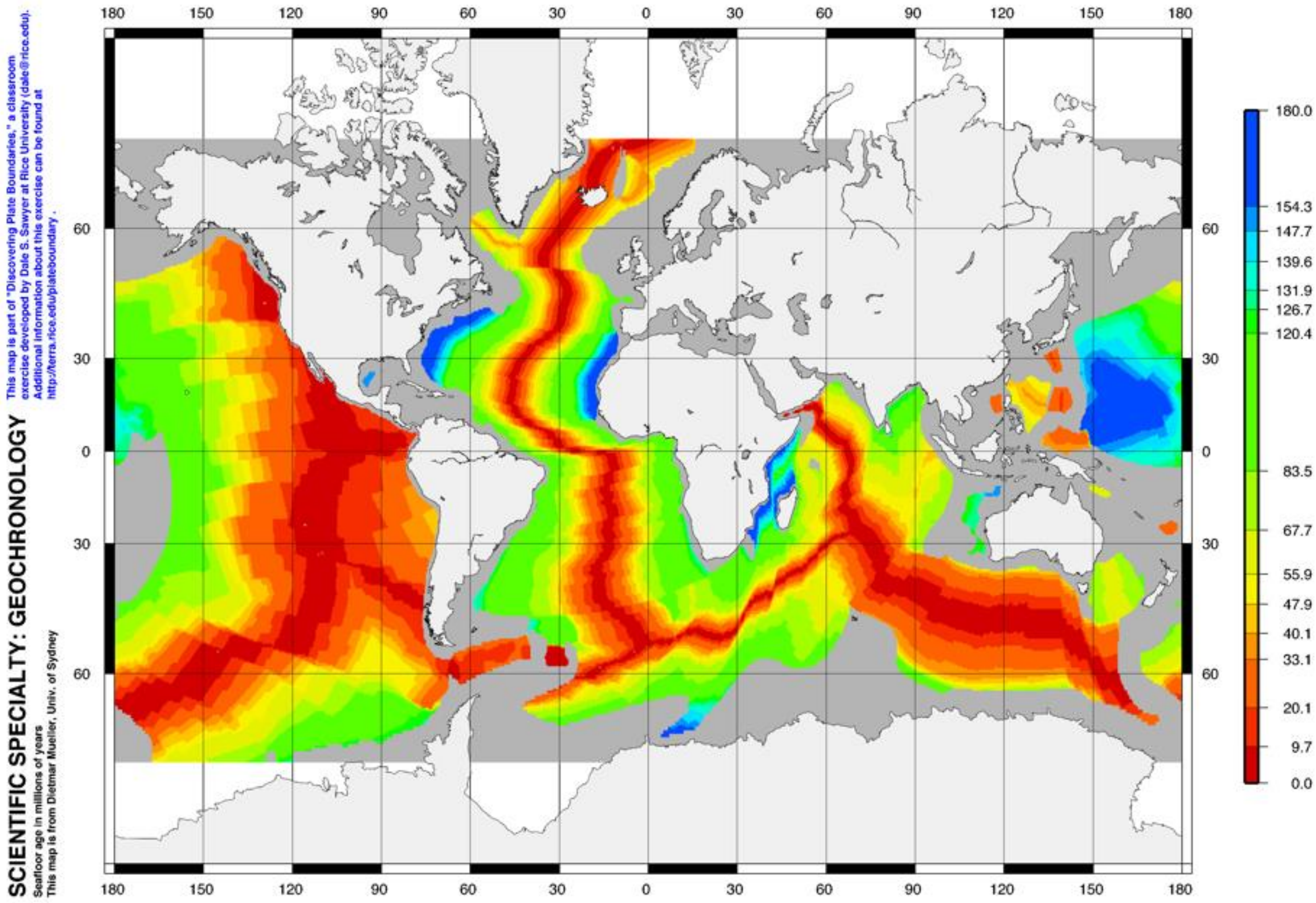
Global heat flux

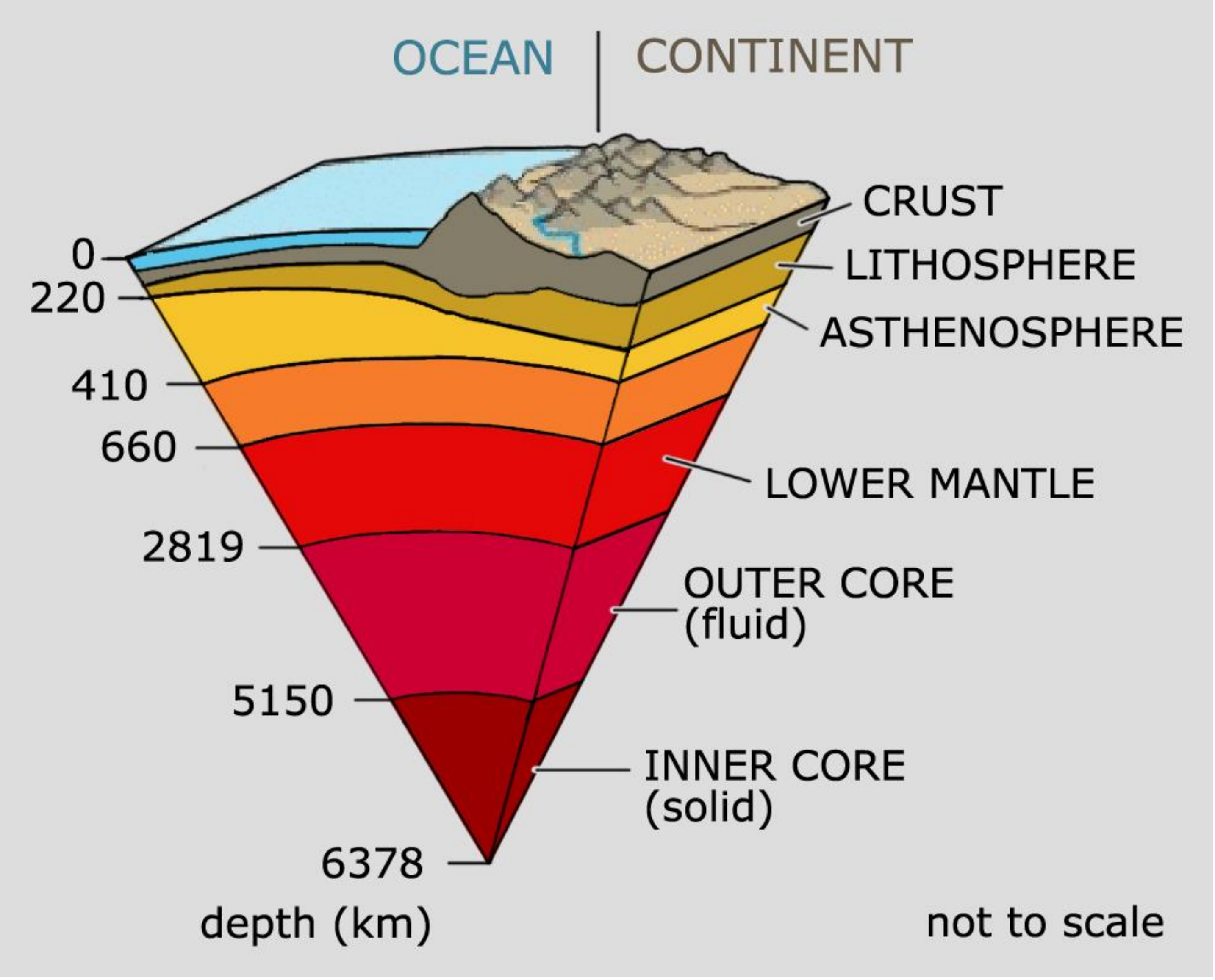


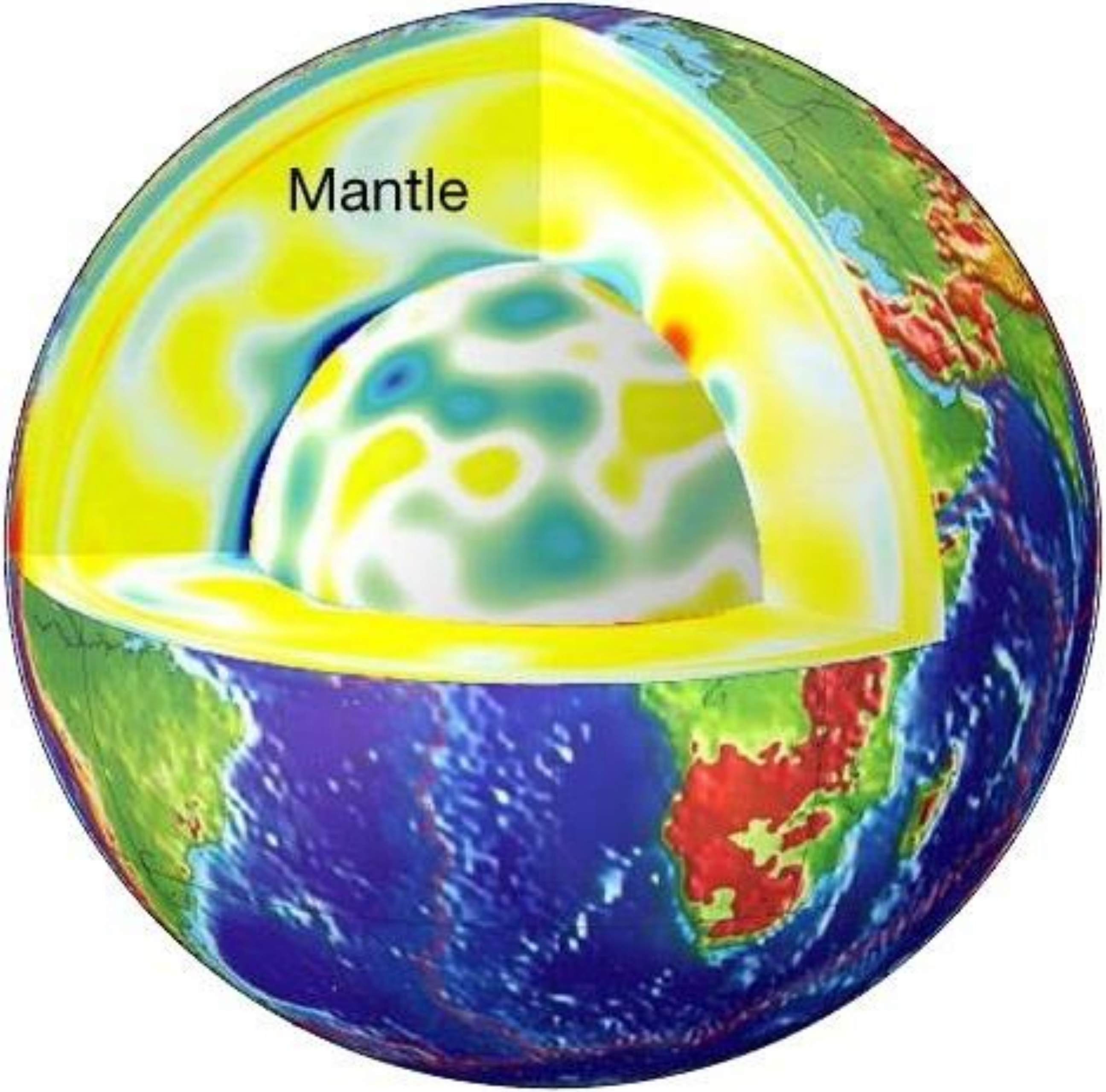
Sea Floor Age



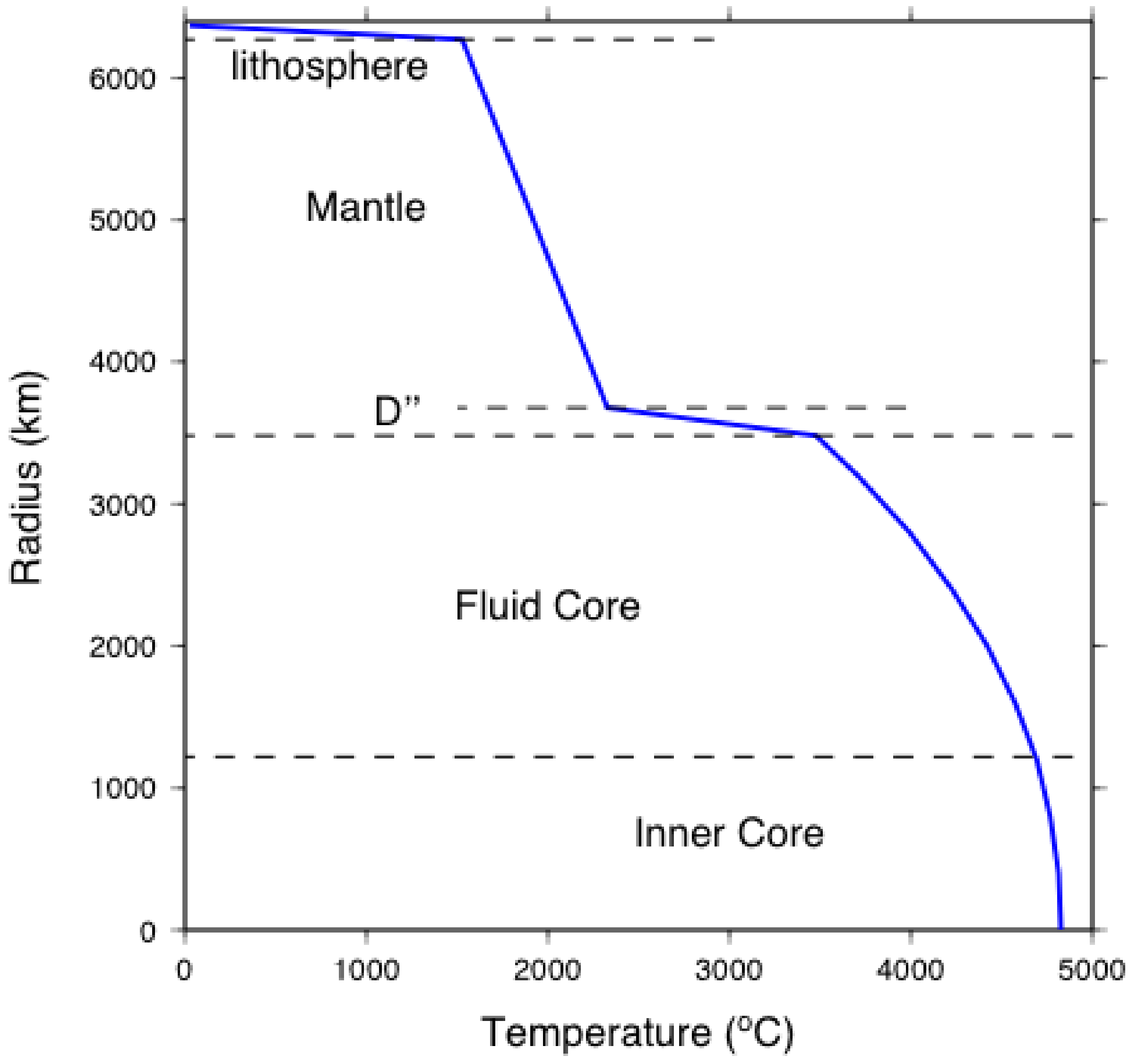
http://terra.rice.edu/plateboundary/index.html

“Standard Model” of the Earth

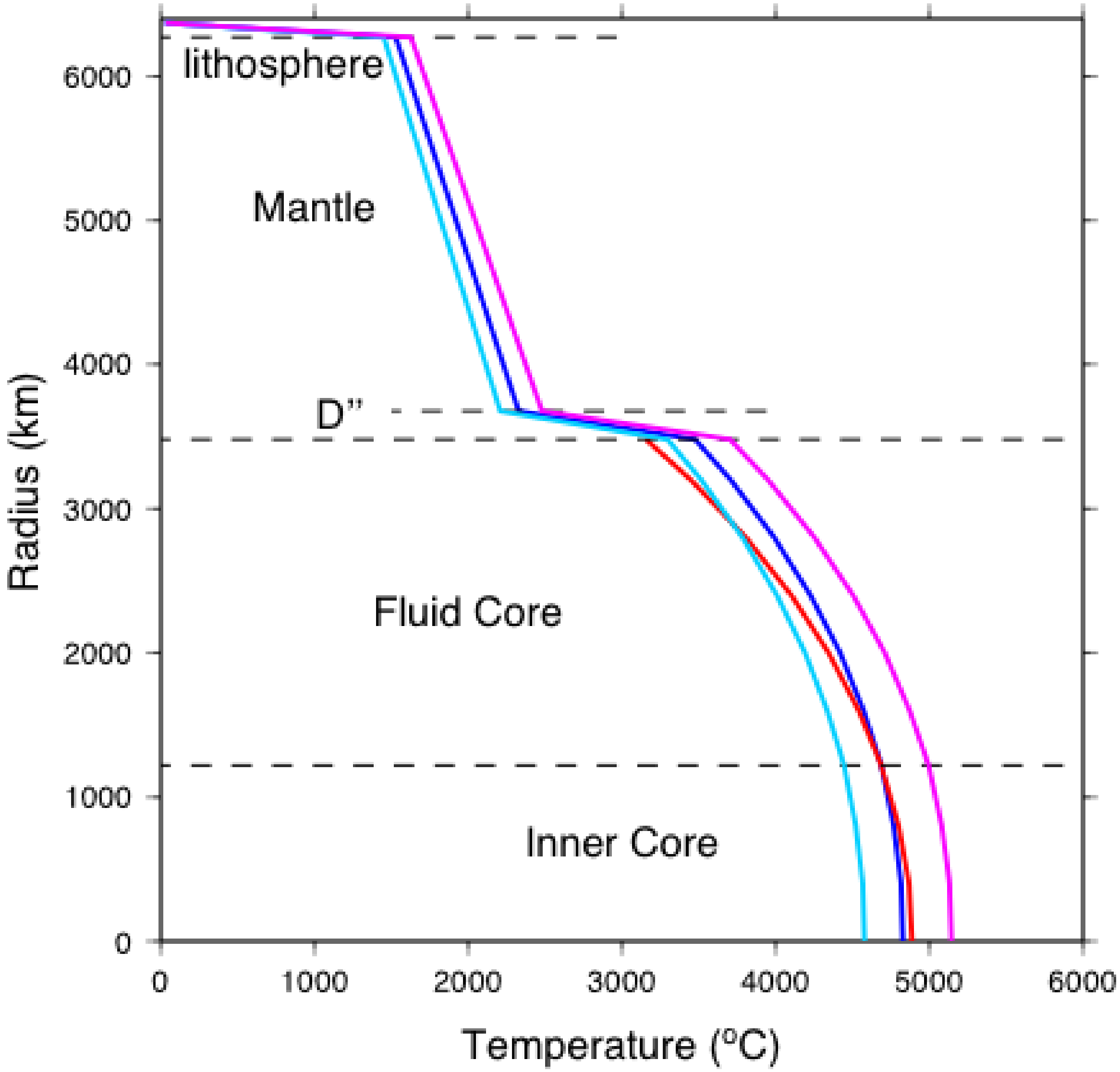



Mantle

Temperature profile inside Earth



Thermal evolution of the Earth



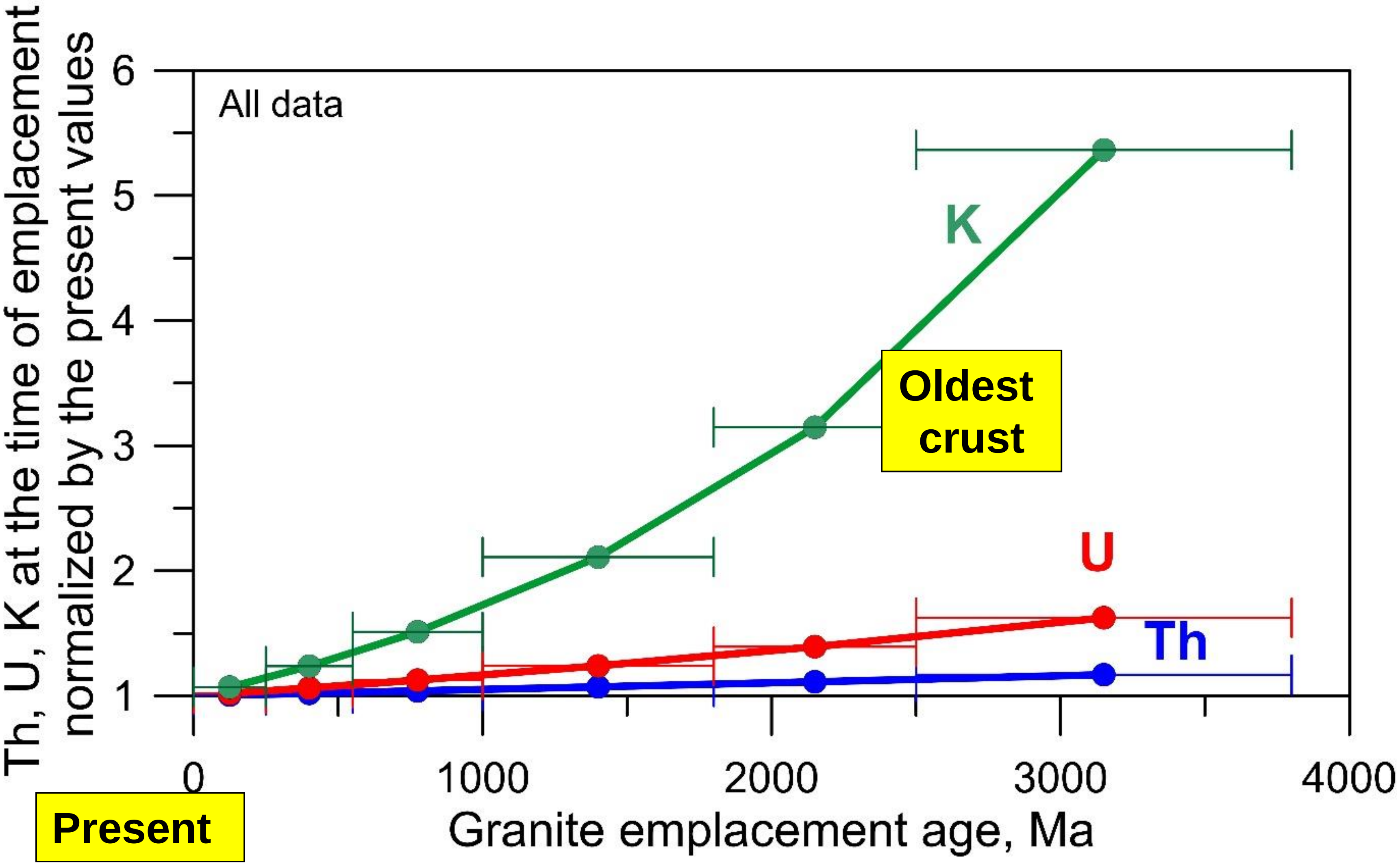
Present Temp.

Past Temp.

Future Temp.

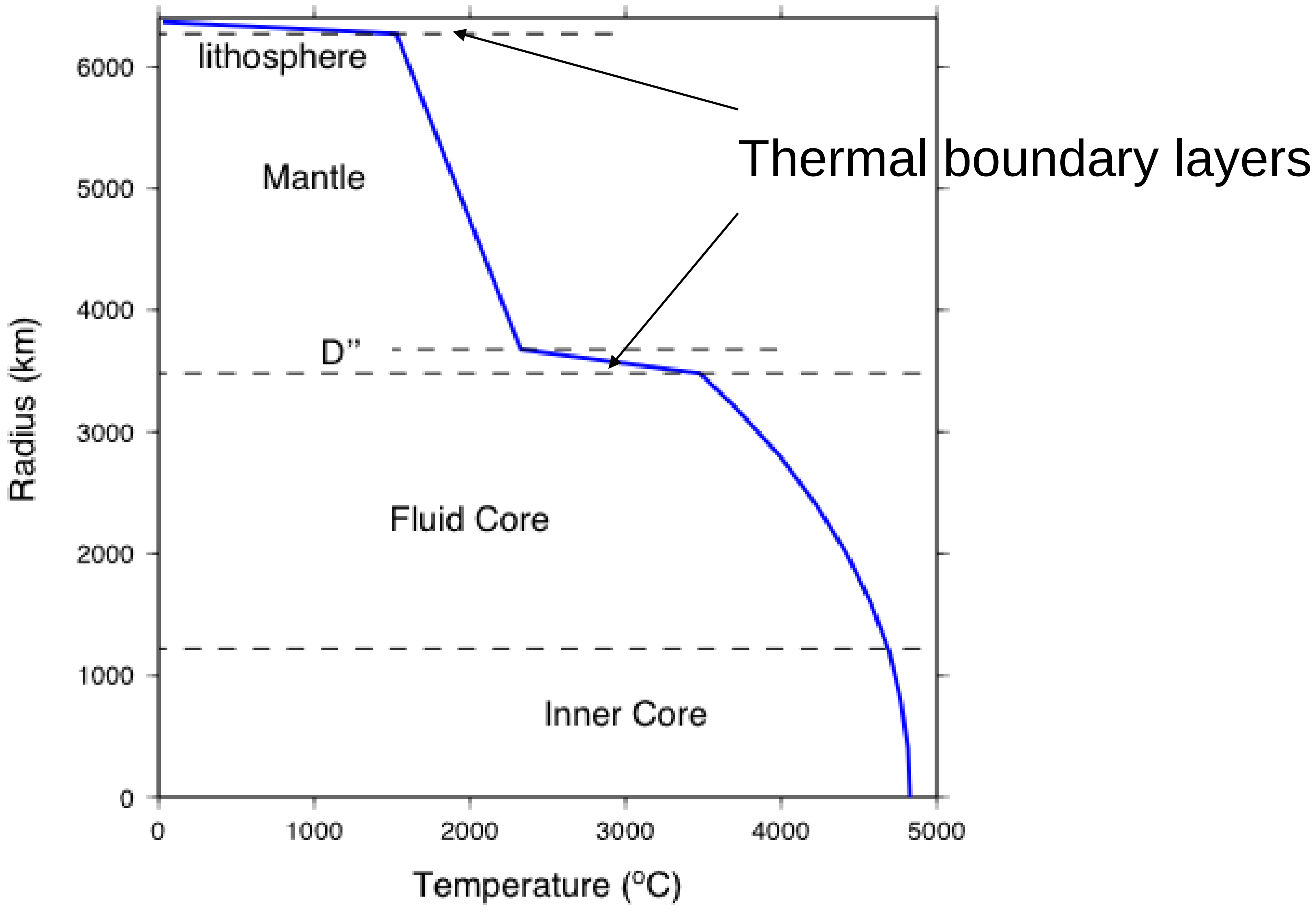
Fe melting curve

Secular decrease in radioactive decay

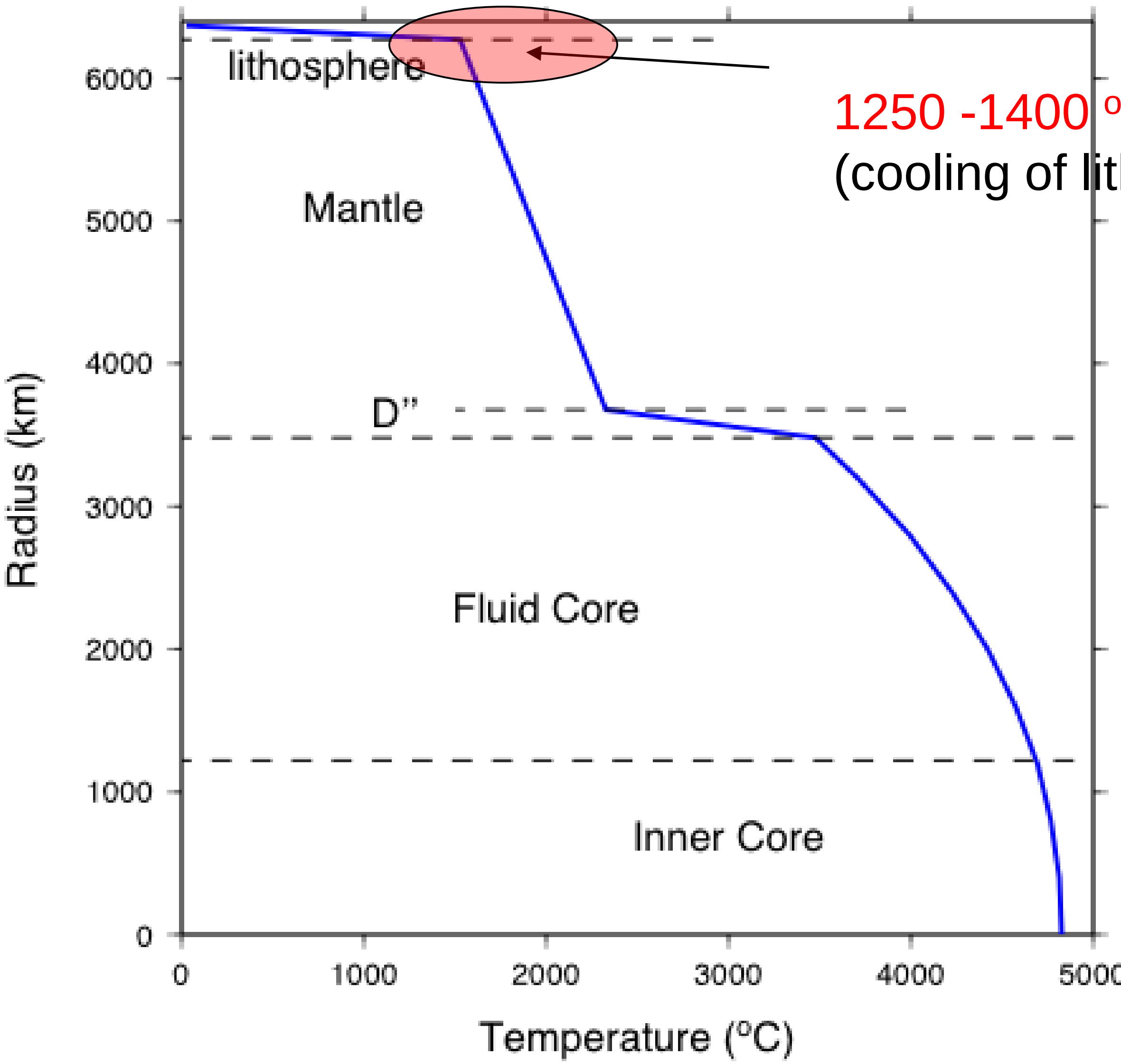


Artemieva et al., 2017

Temperature profile inside Earth

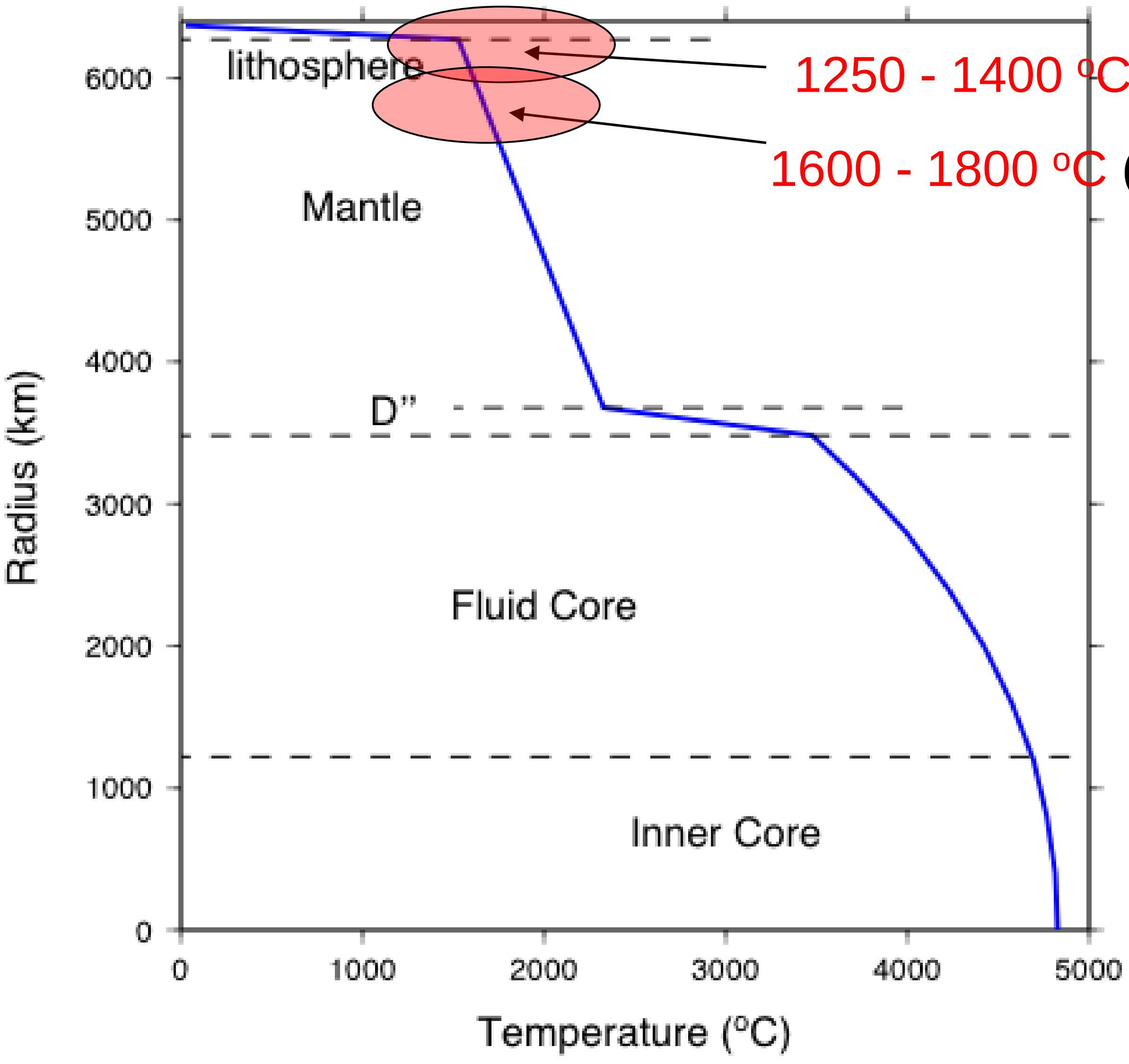


Temperature profile inside Earth



1250 -1400 °C
(cooling of lithosphere)

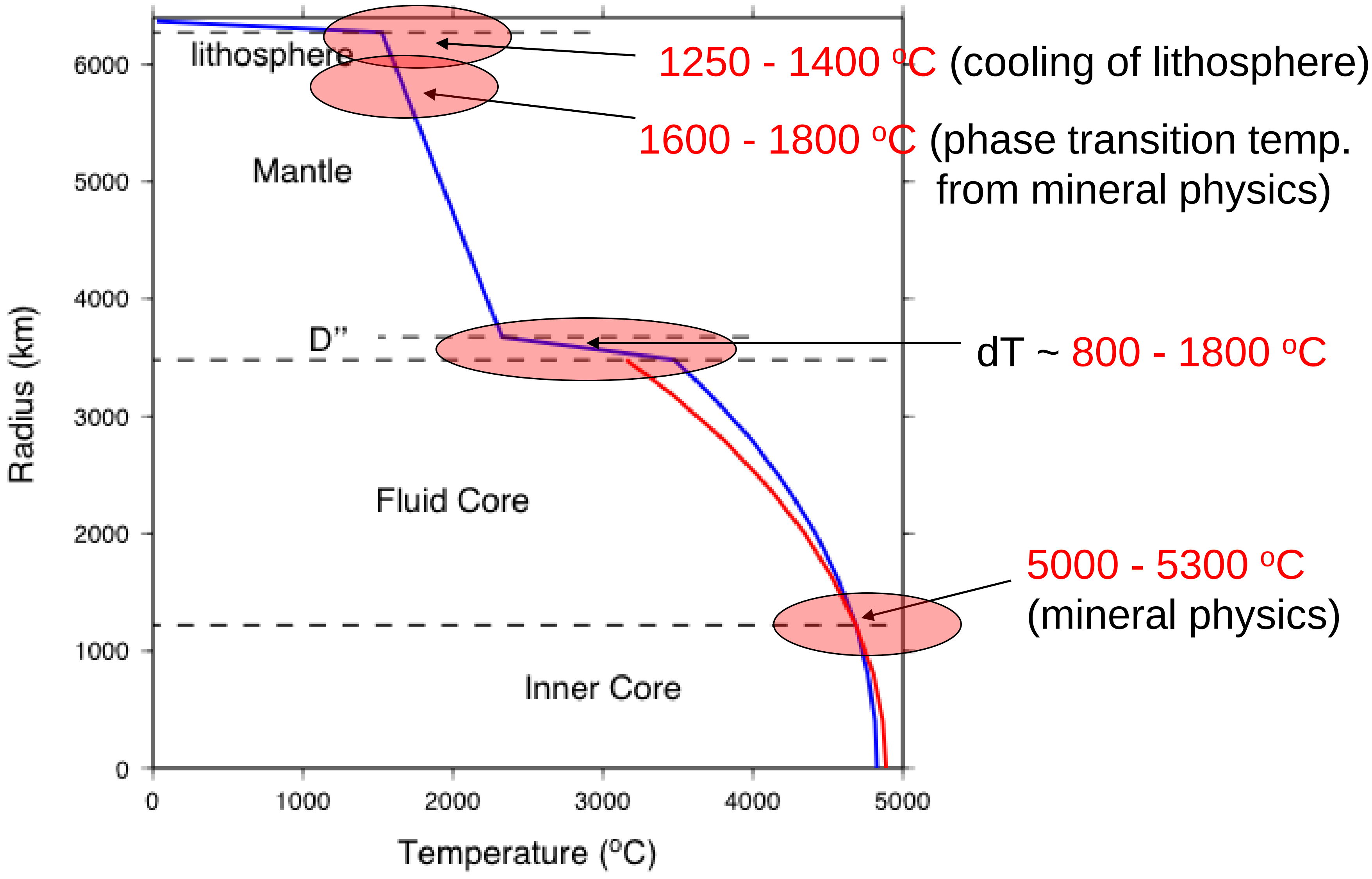
Temperature profile inside Earth



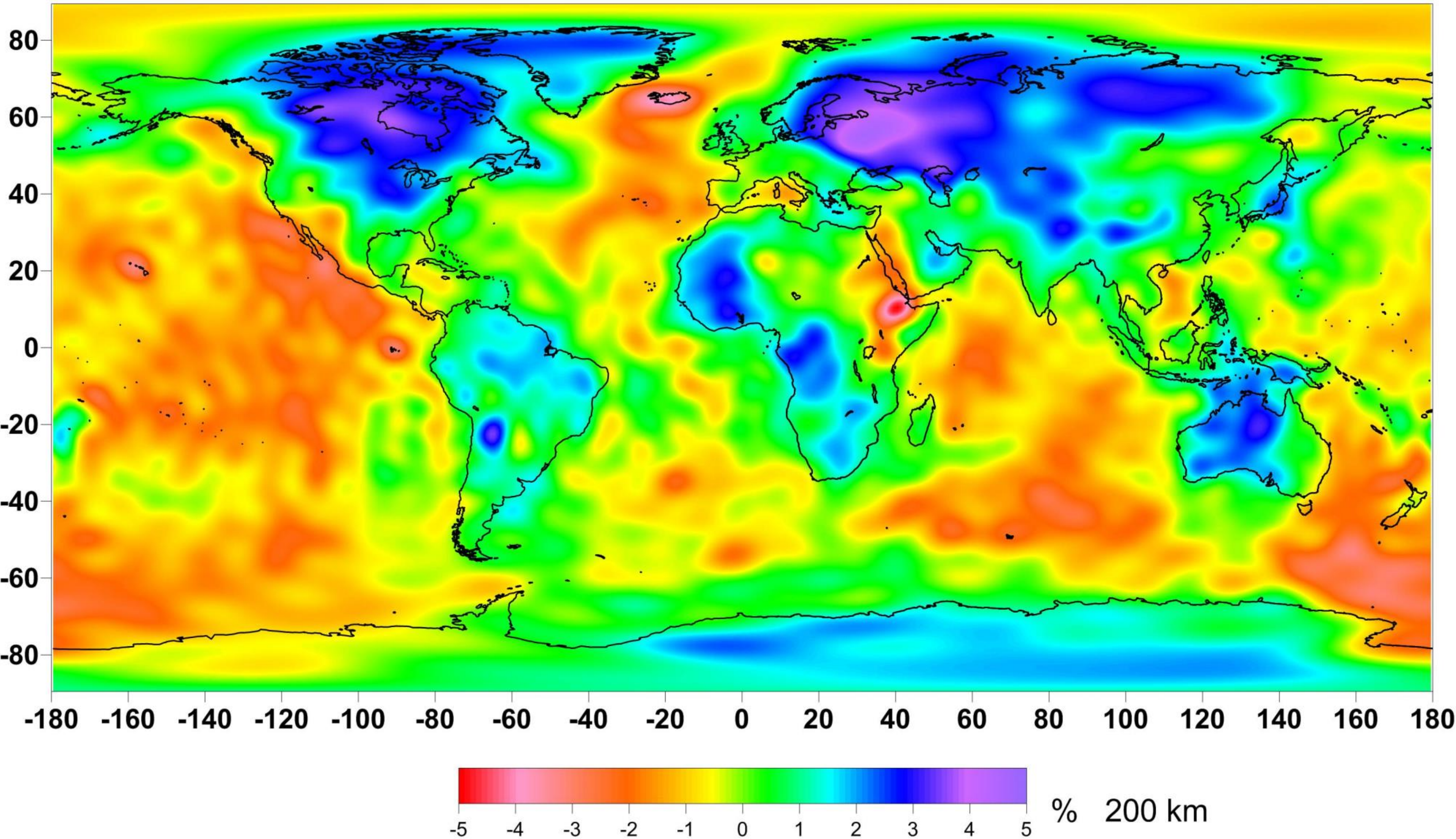
1250 - 1400 ^oC (cooling of lithosphere)

1600 - 1800 ^oC (phase transition temp. from mineral physics)

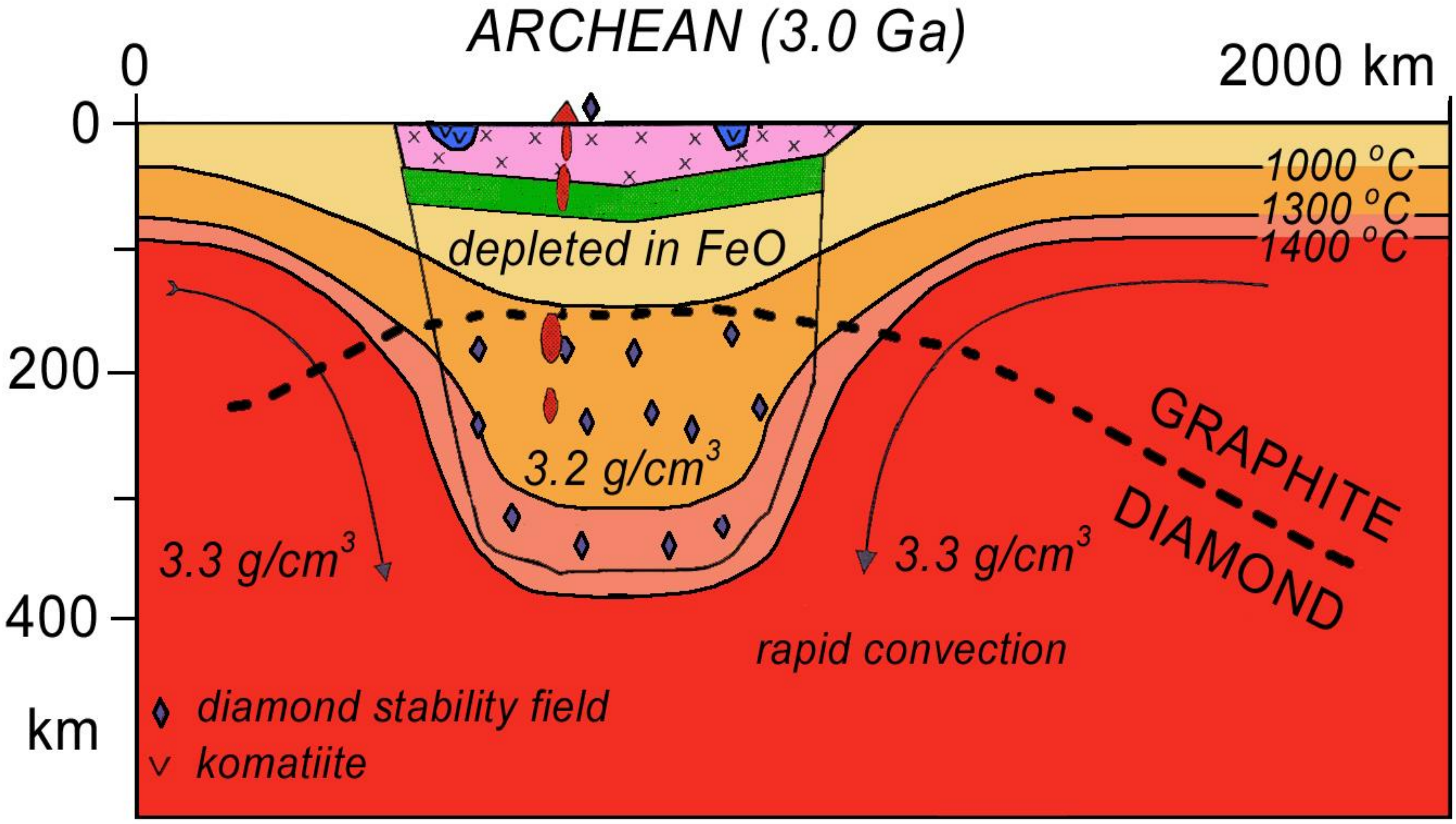
Temperature profile inside Earth



S-wave Anomaly 200 km



Model for Archean Lithospheric Evolution



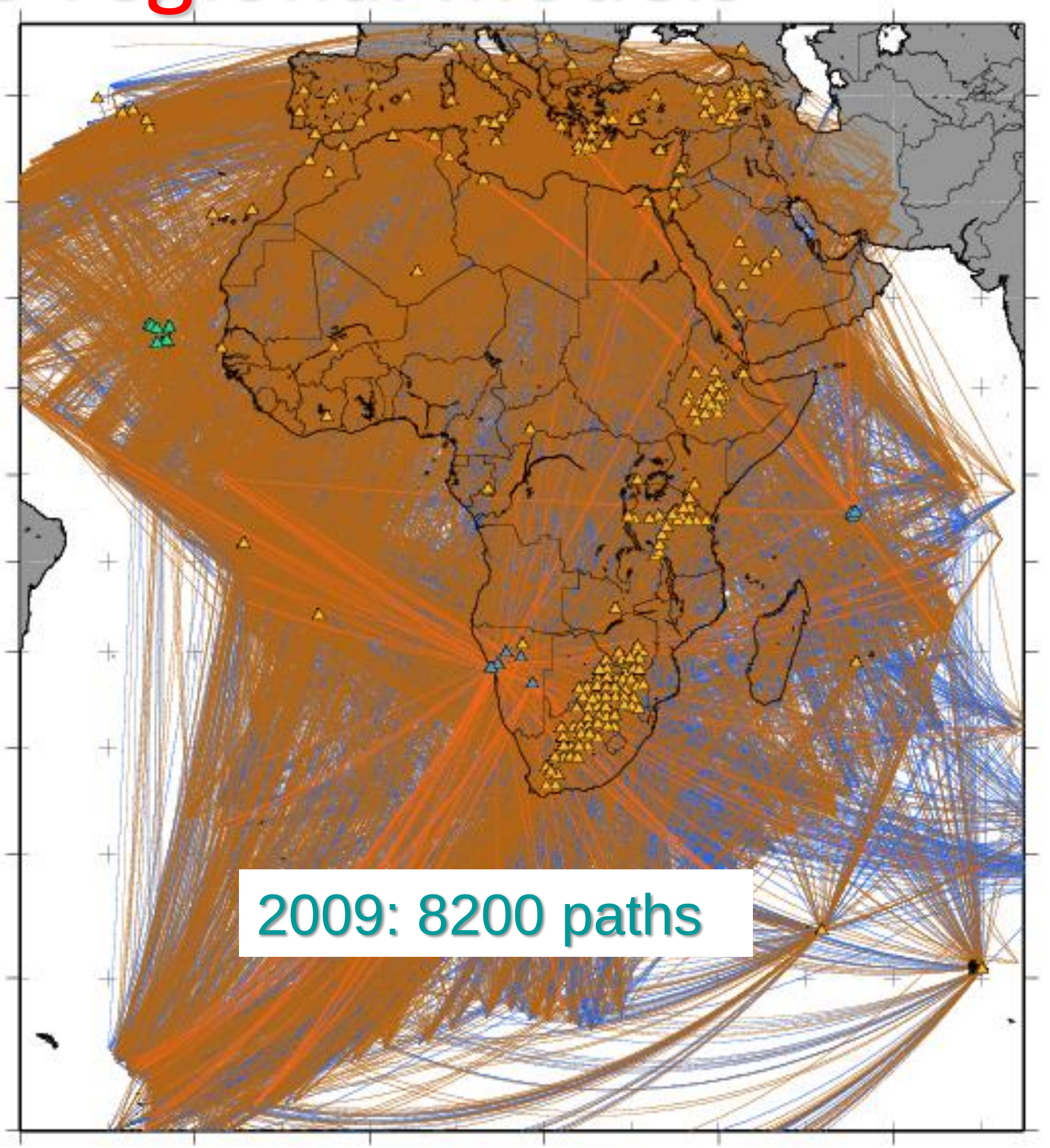
Fishwick’s 2009 regional models

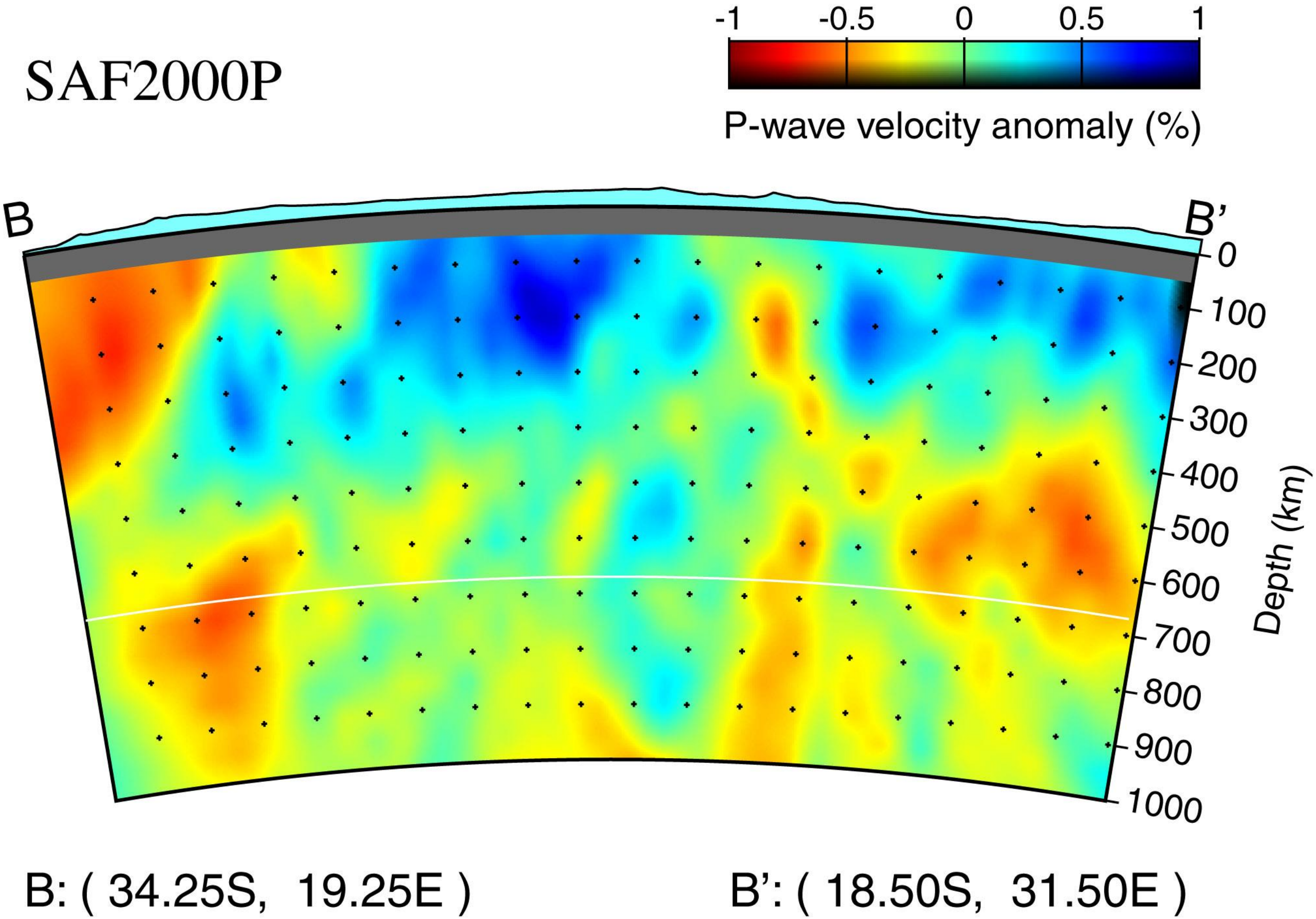
2-stage surface wave inversion method

1) fundamental + first four higher models: period range 50-120 seconds

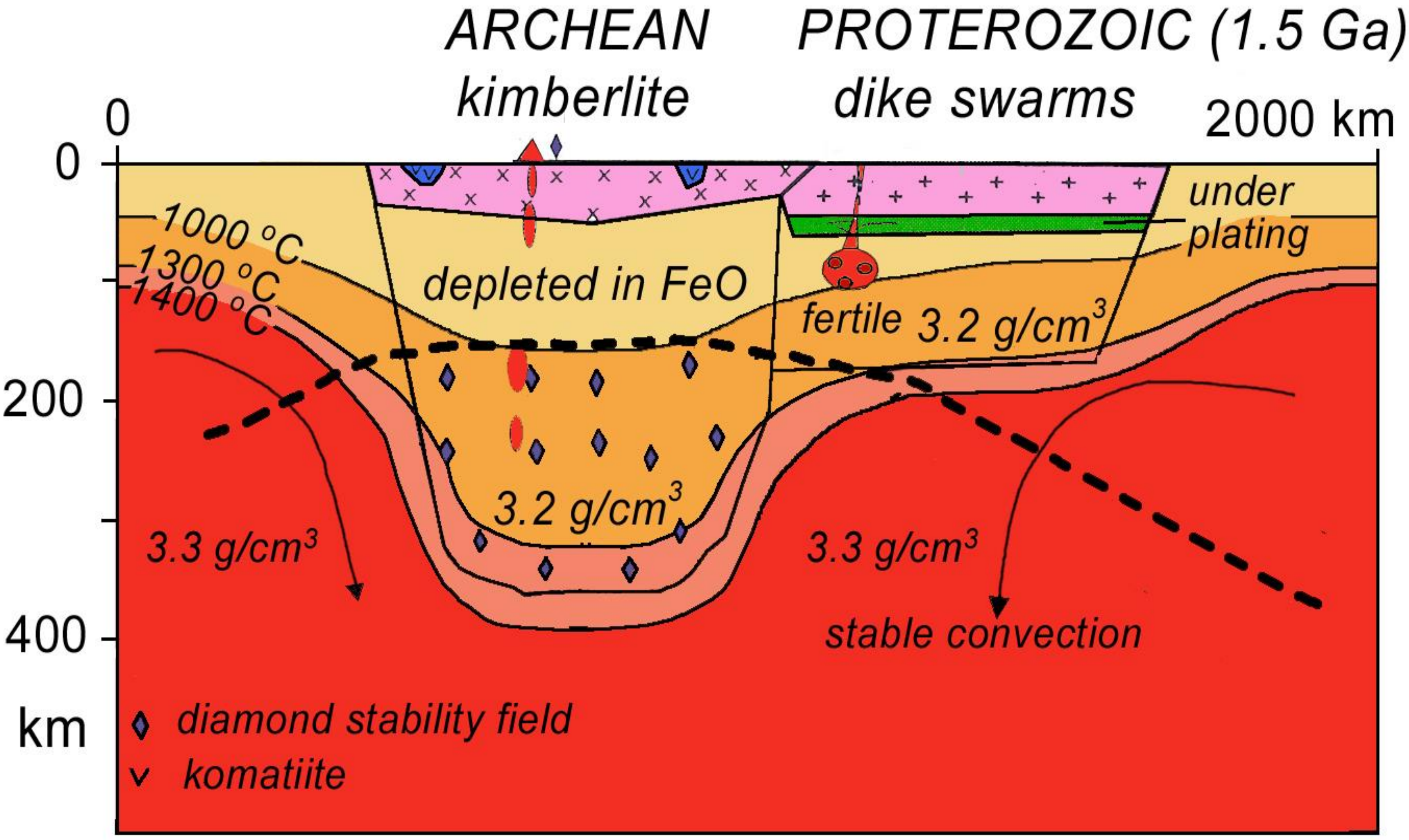
2) 1.5 degree splines

Includes data from GFZ stations in NW Namibia

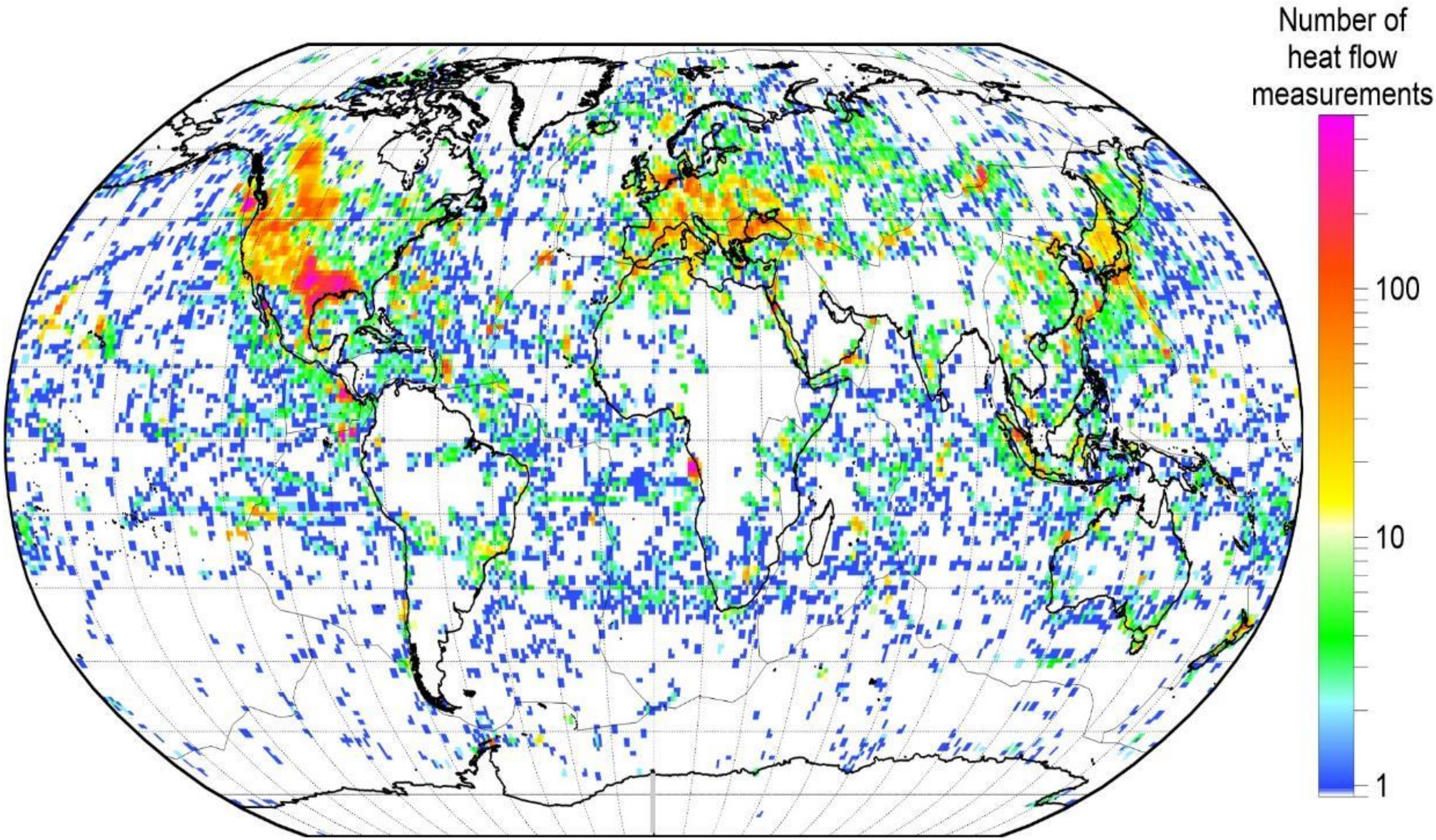



SAF2000P
-1
-0.5
0
0.5
1
P-wave velocity anomaly (%)
B
B'
0
100
200
300
400
500
600
700
800
900
1000
Depth (km)
B: (34.25S, 19.25E)
B': (18.50S, 31.50E)

Precambrian Lithospheric

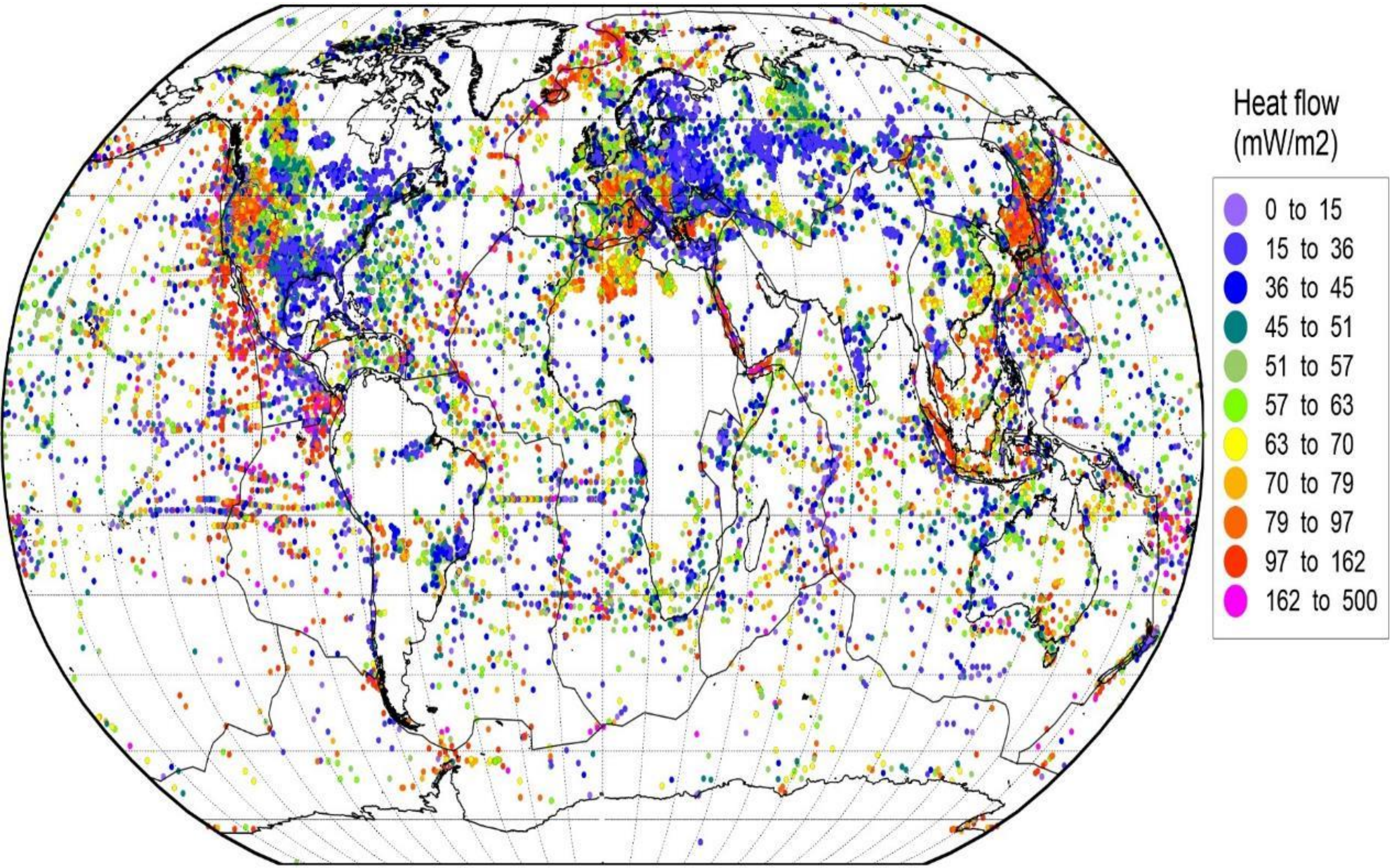


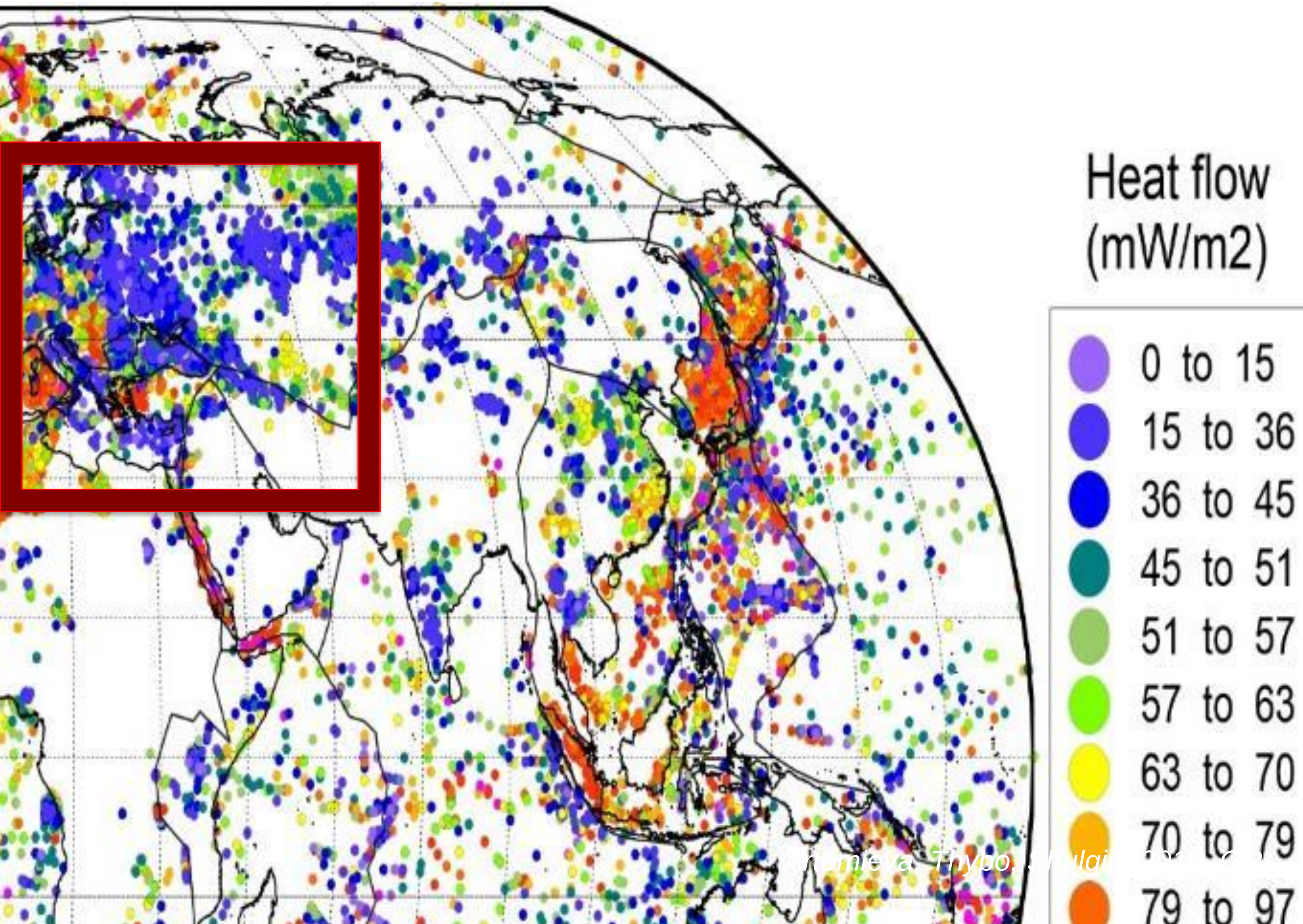
Global Heat Flow Data



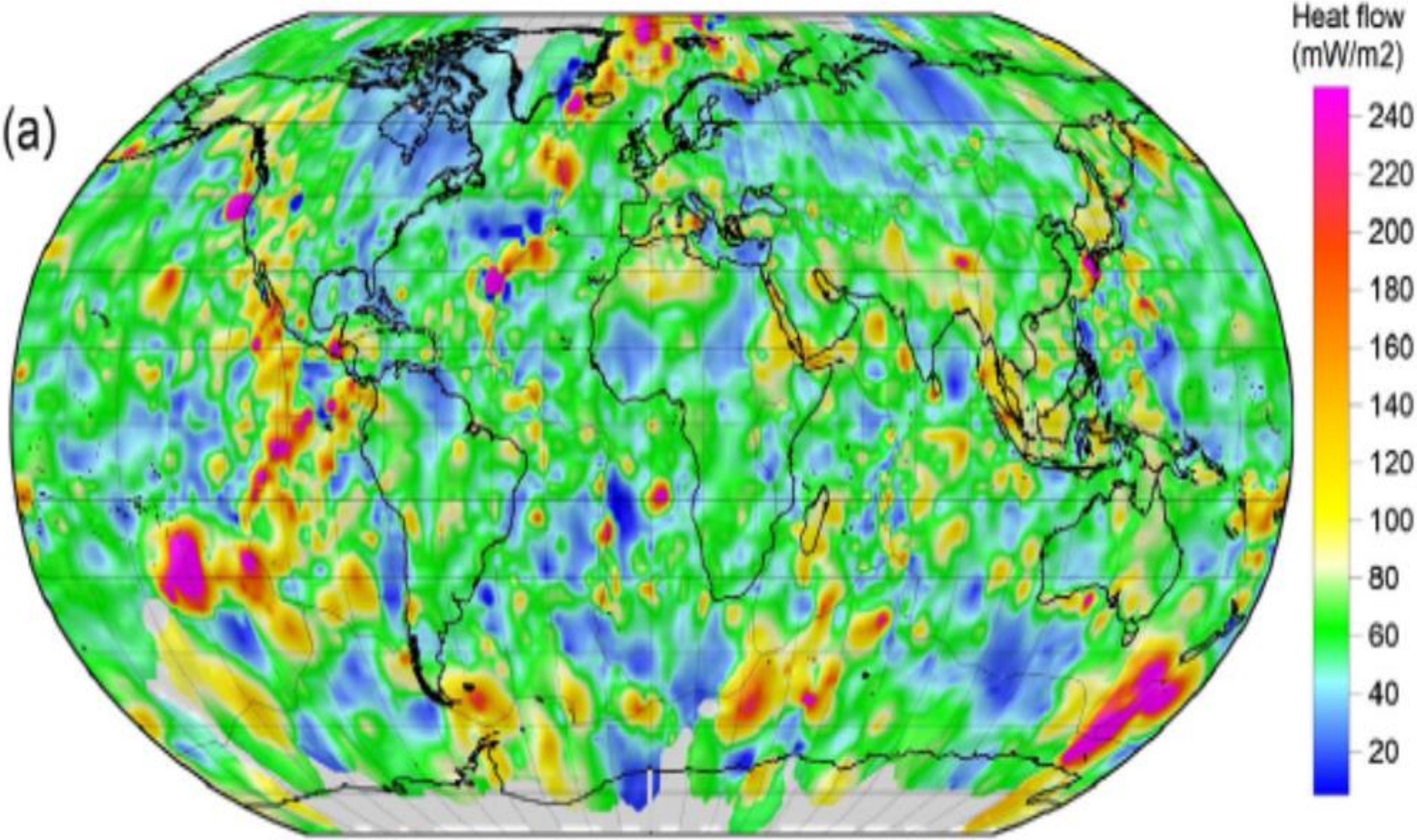
Global heat flow data:

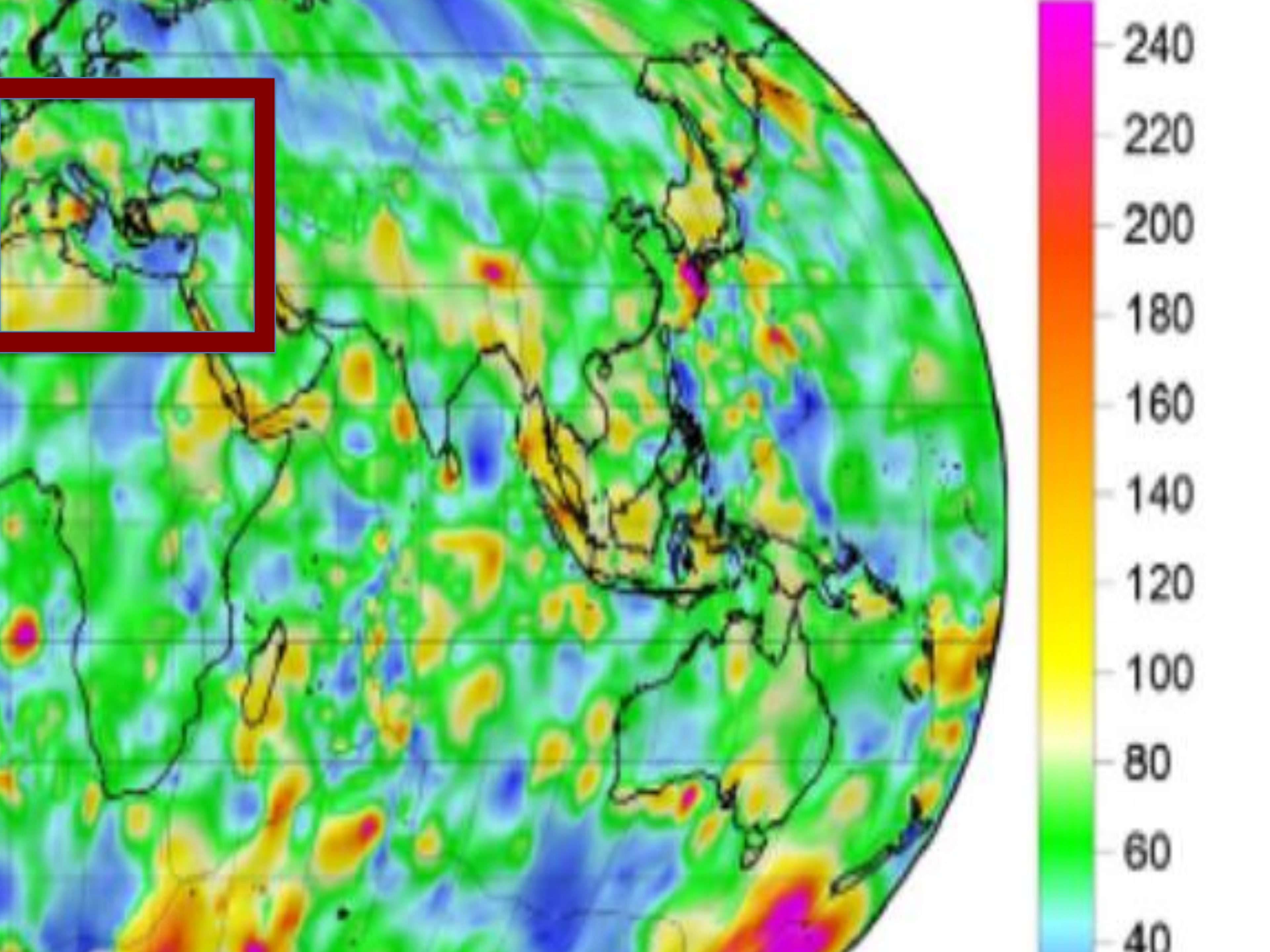
Paleoclimate corrections can be 30-40%.


Heat flow
(mW/m2)
0 to 15
15 to 36
36 to 45
45 to 51
51 to 57
57 to 63
63 to 70
70 to 79
79 to 97
97 to 162
162 to 500


Heat flow
(mW/m2)
0 to 15
15 to 36
36 to 45
45 to 51
51 to 57
57 to 63
63 to 70
70 to 79
79 to 97
Artemieva, Thybo, Shulgin

(a)




240
220
200
180
160
140
120
100
80
60
40

Lithospheric Thermal Thickness

Steady State Thermal Conductivity

$$\partial^2 T / \partial z^2 = - A / k$$

at z = 0: $T = 0$

$$Q_0 = - k \cdot \partial T / \partial z$$

+ Assumption

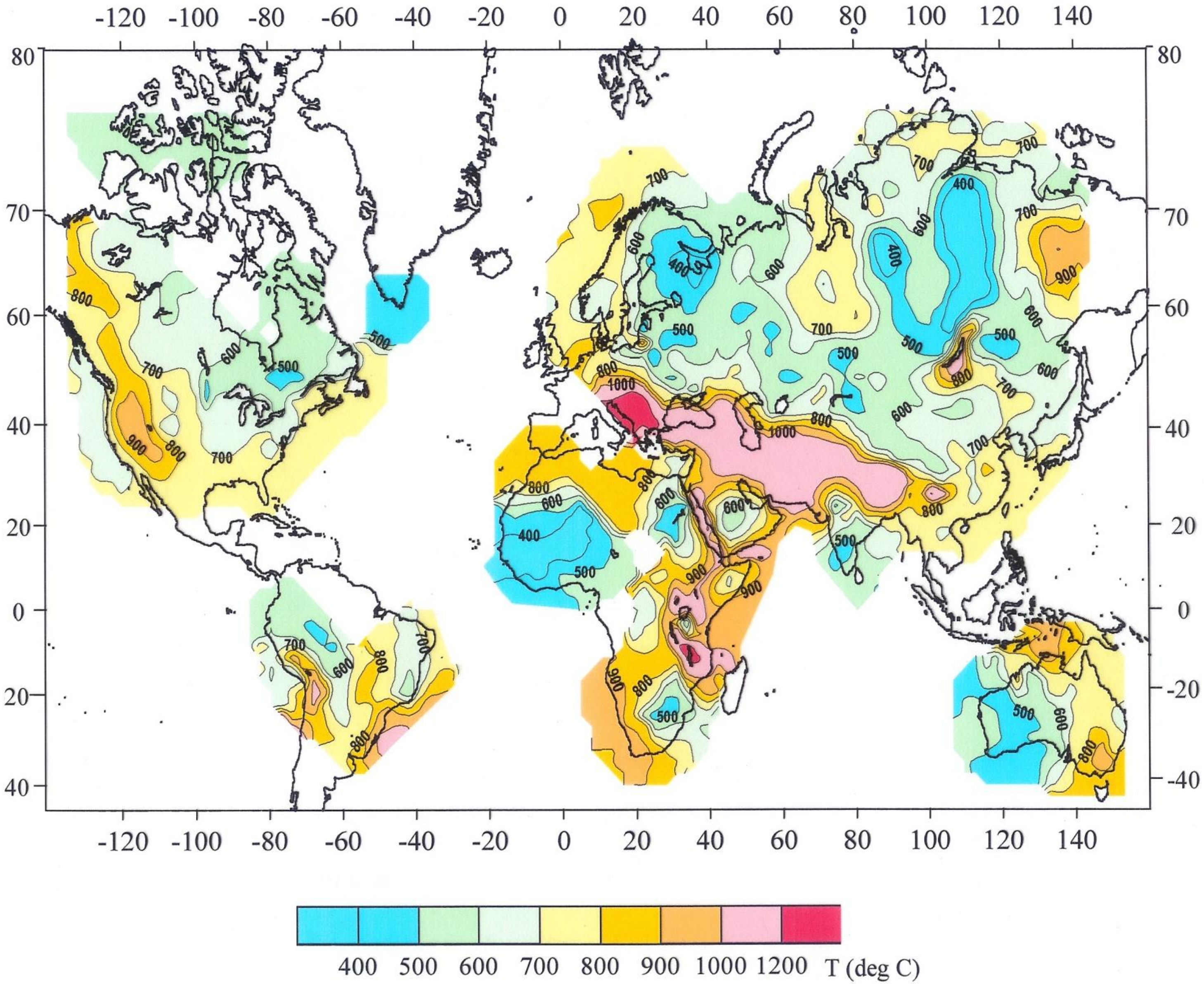
$$A(z) = A_0 \cdot \exp(-z / D)$$

$$Q_0 = q + A_0 \cdot D$$

A_0 – surface radioactivity
Q_0 - surface heat flow
q - reduced (mantle)heat flow

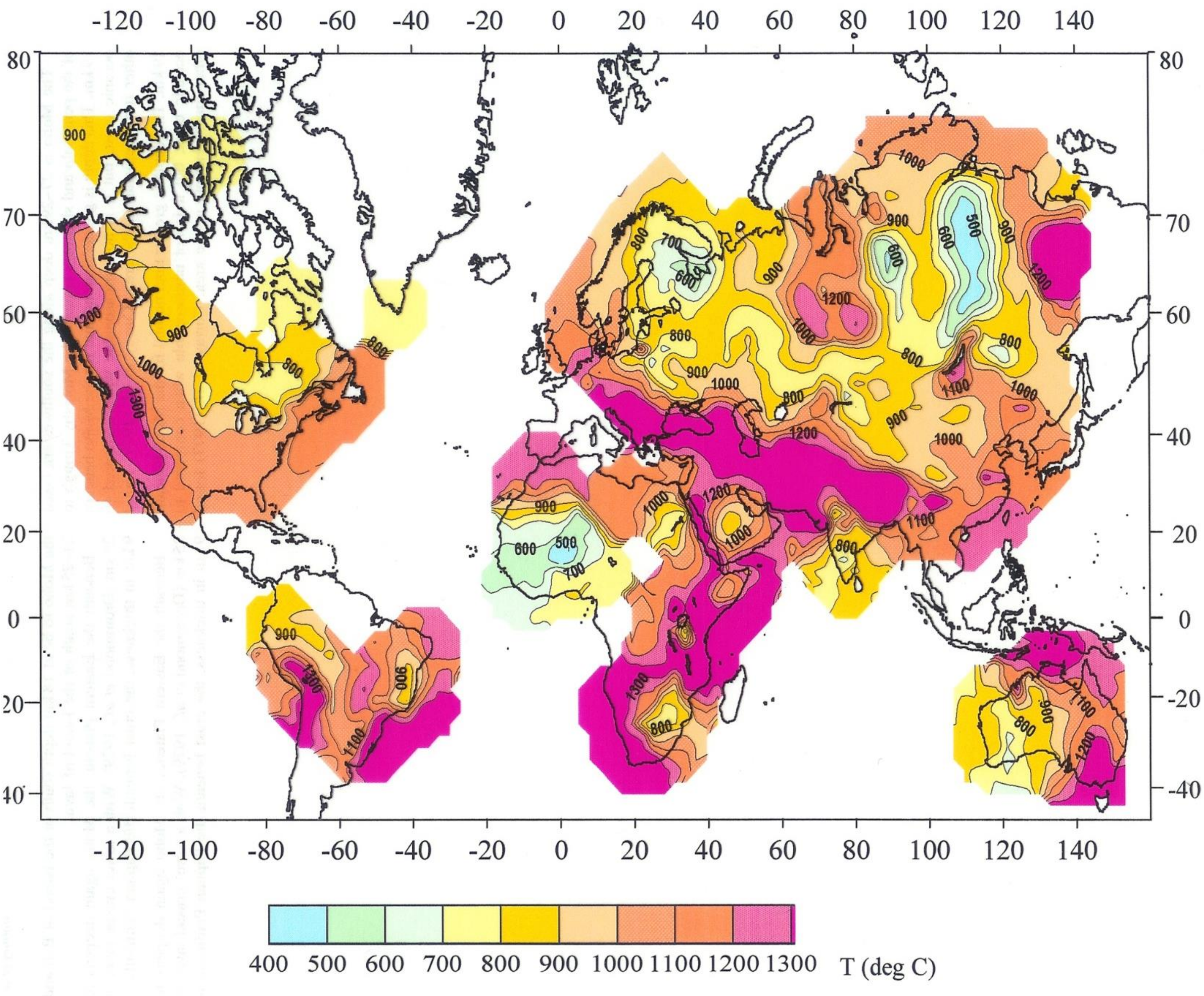
k- thermal conductivity
T- temperature
D – characteristic depth

Estimated Temperature at 50 km Depth



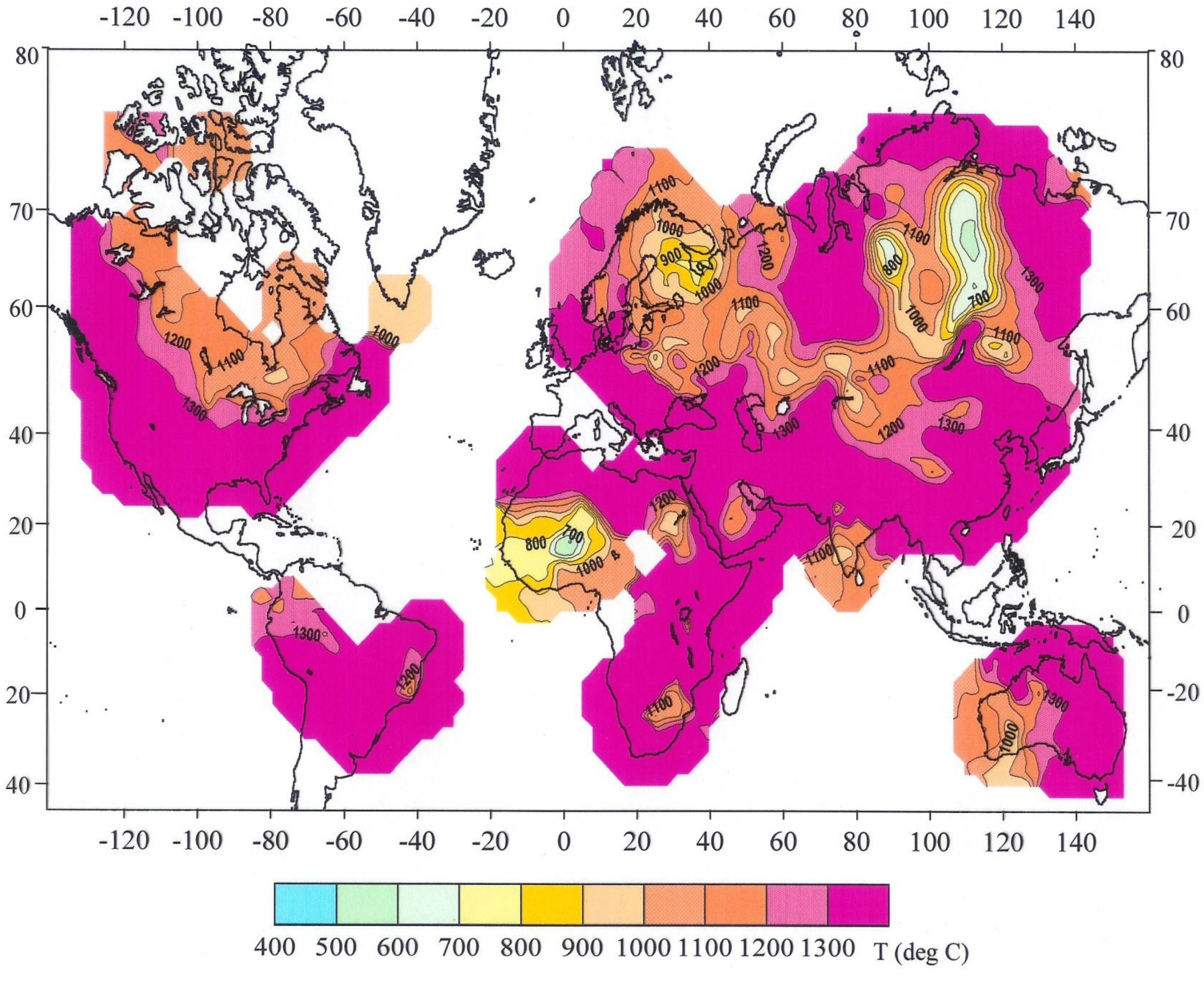
Source: Artemieva and Mooney, JGR, 2000

Estimated Temperature at 100 km Depth



Source: Artemieva and Mooney, JGR, 2000

Estimated Temperature at 150 km Depth

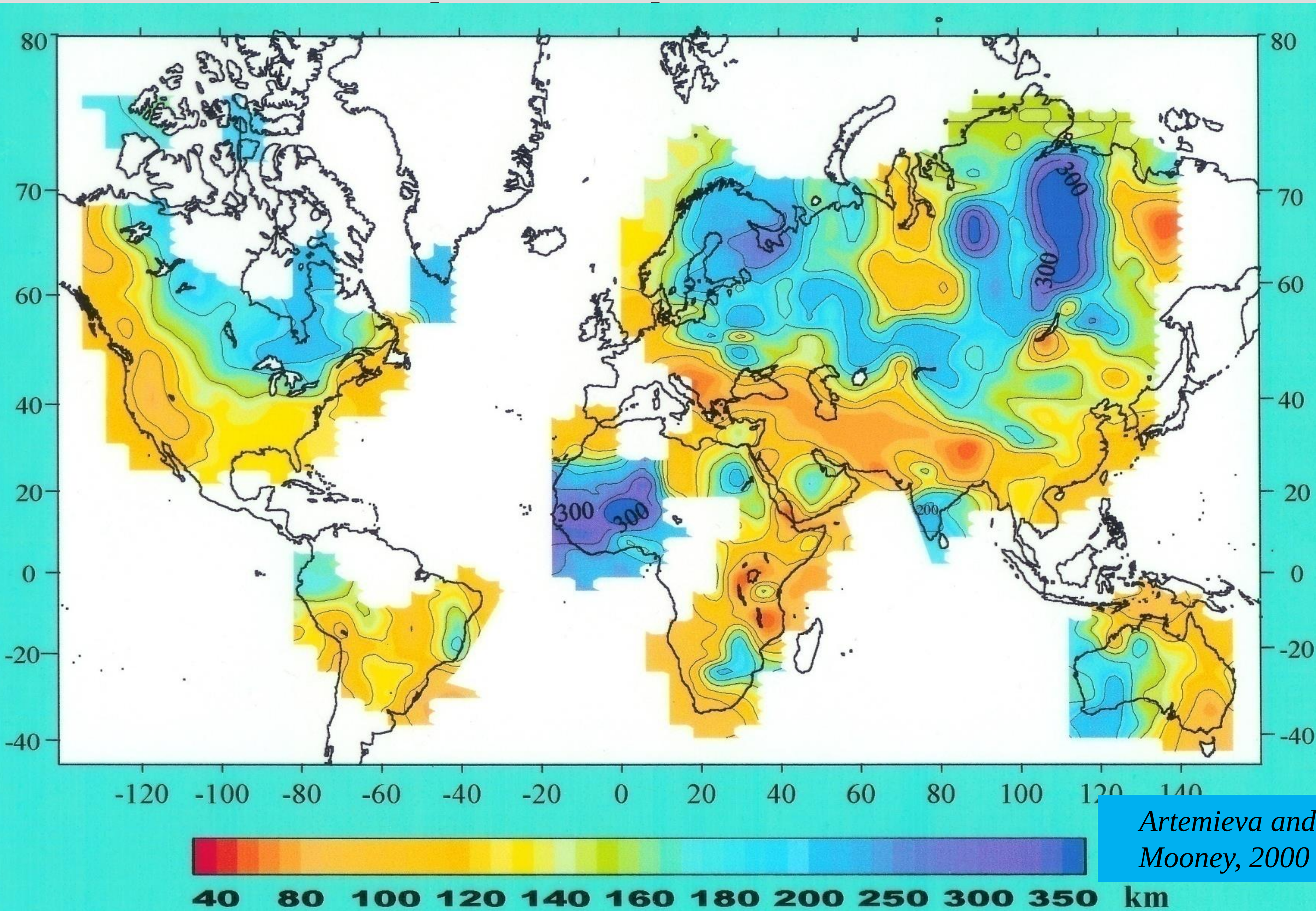


Source: Artemieva and Mooney, JGR, 2000

Question:

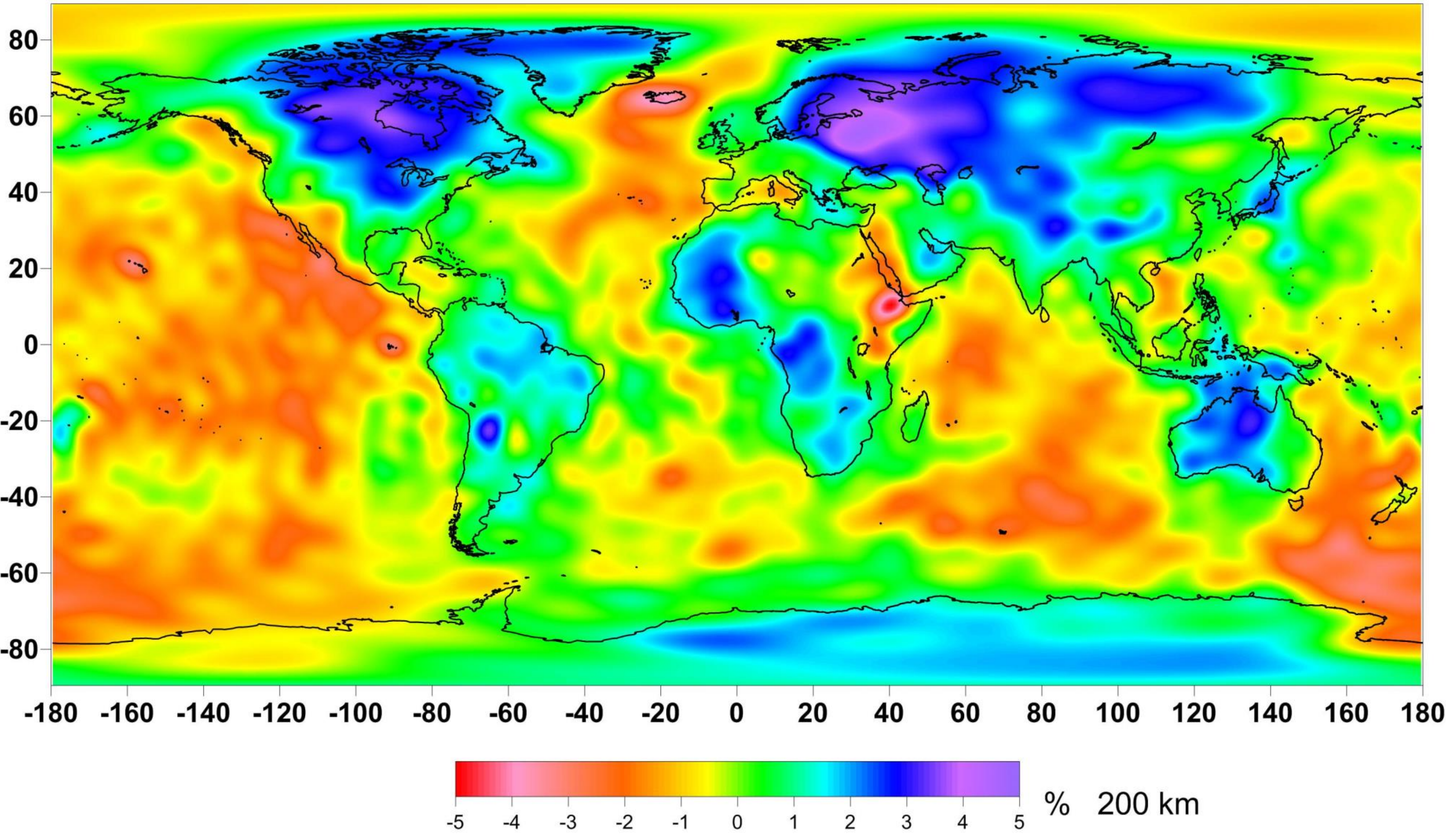
Is the **thermal lithosphere** similar to the **seismic lithosphere**?

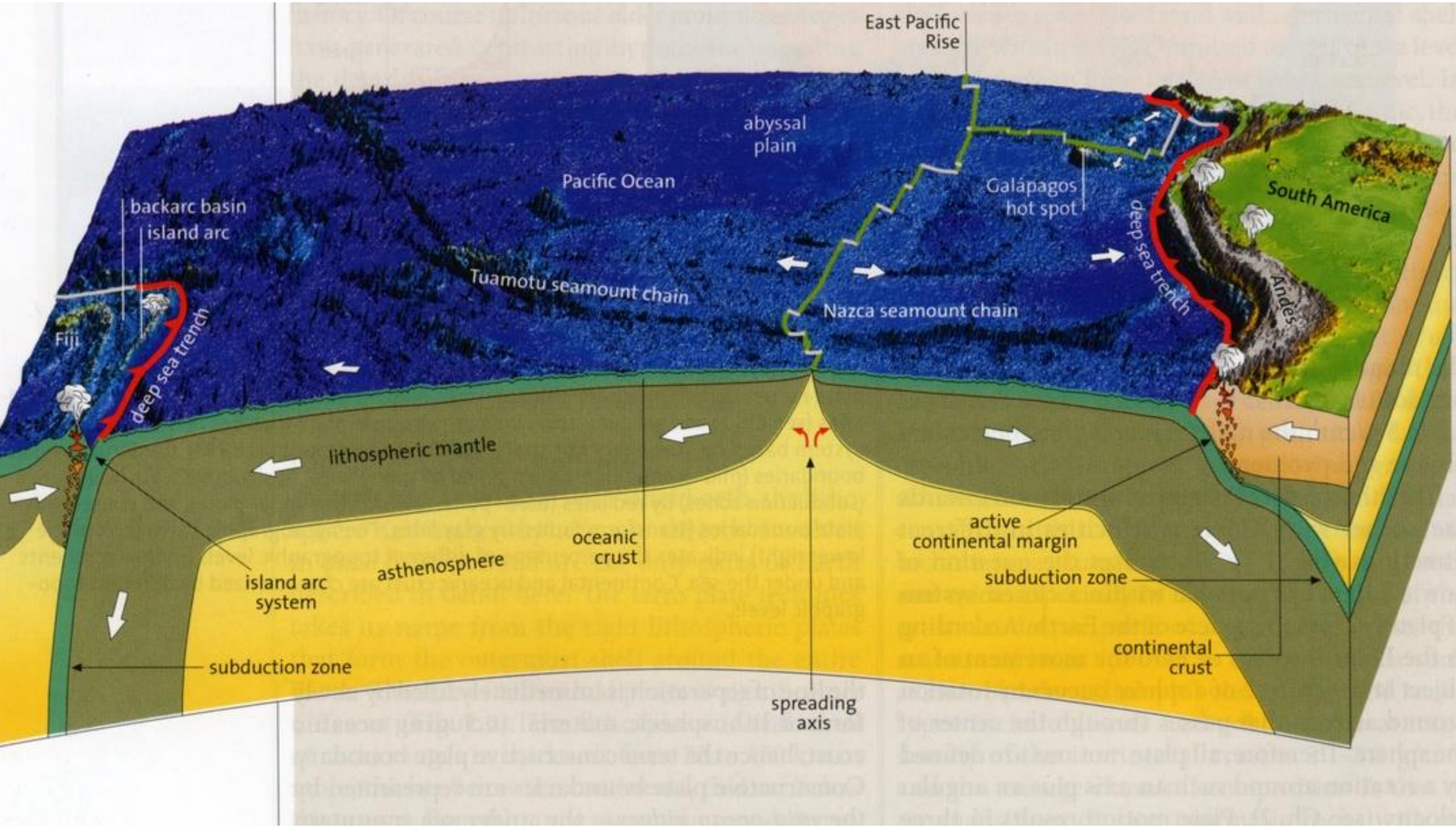
Lithosphere Thermal Thickness

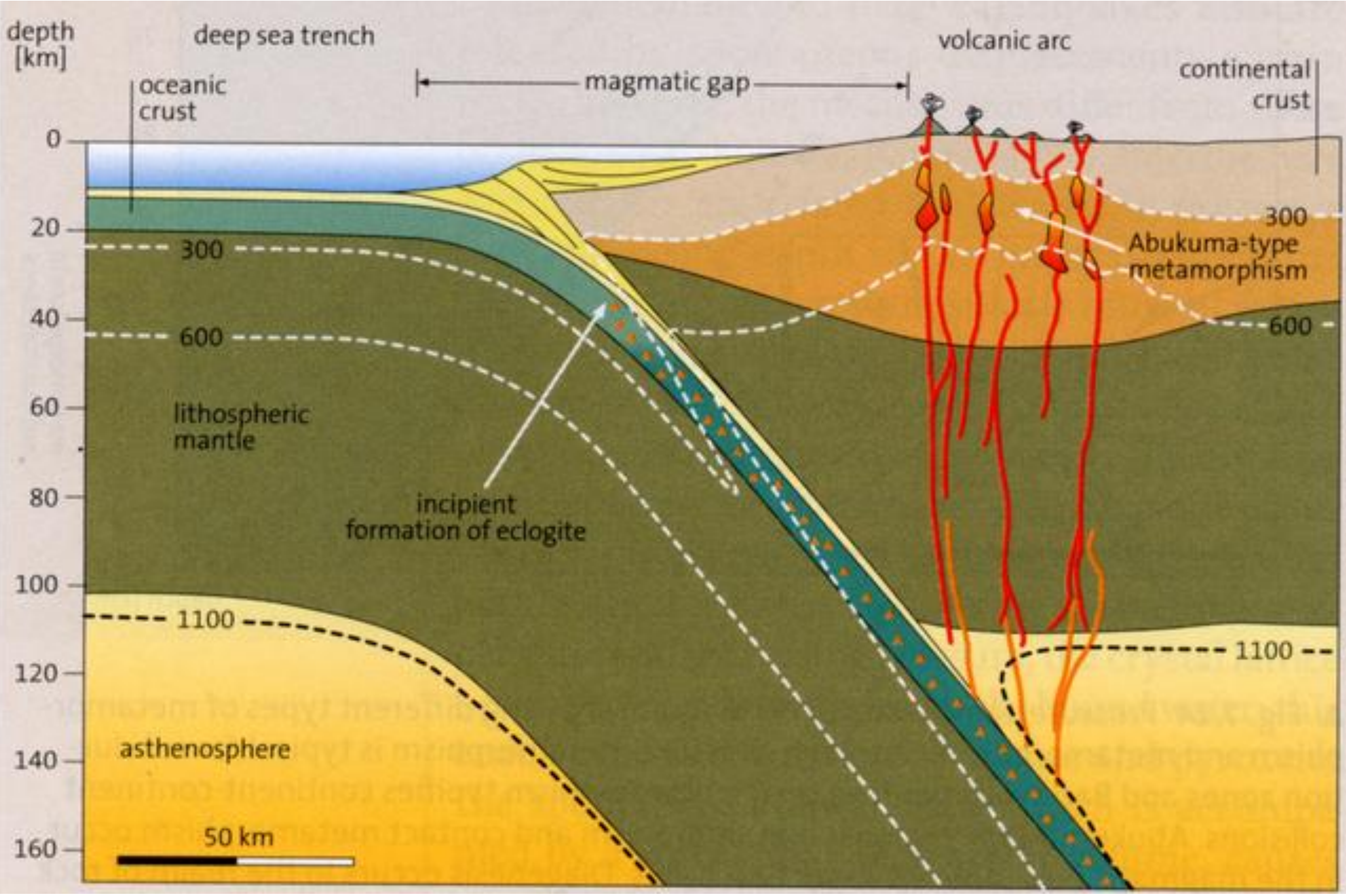


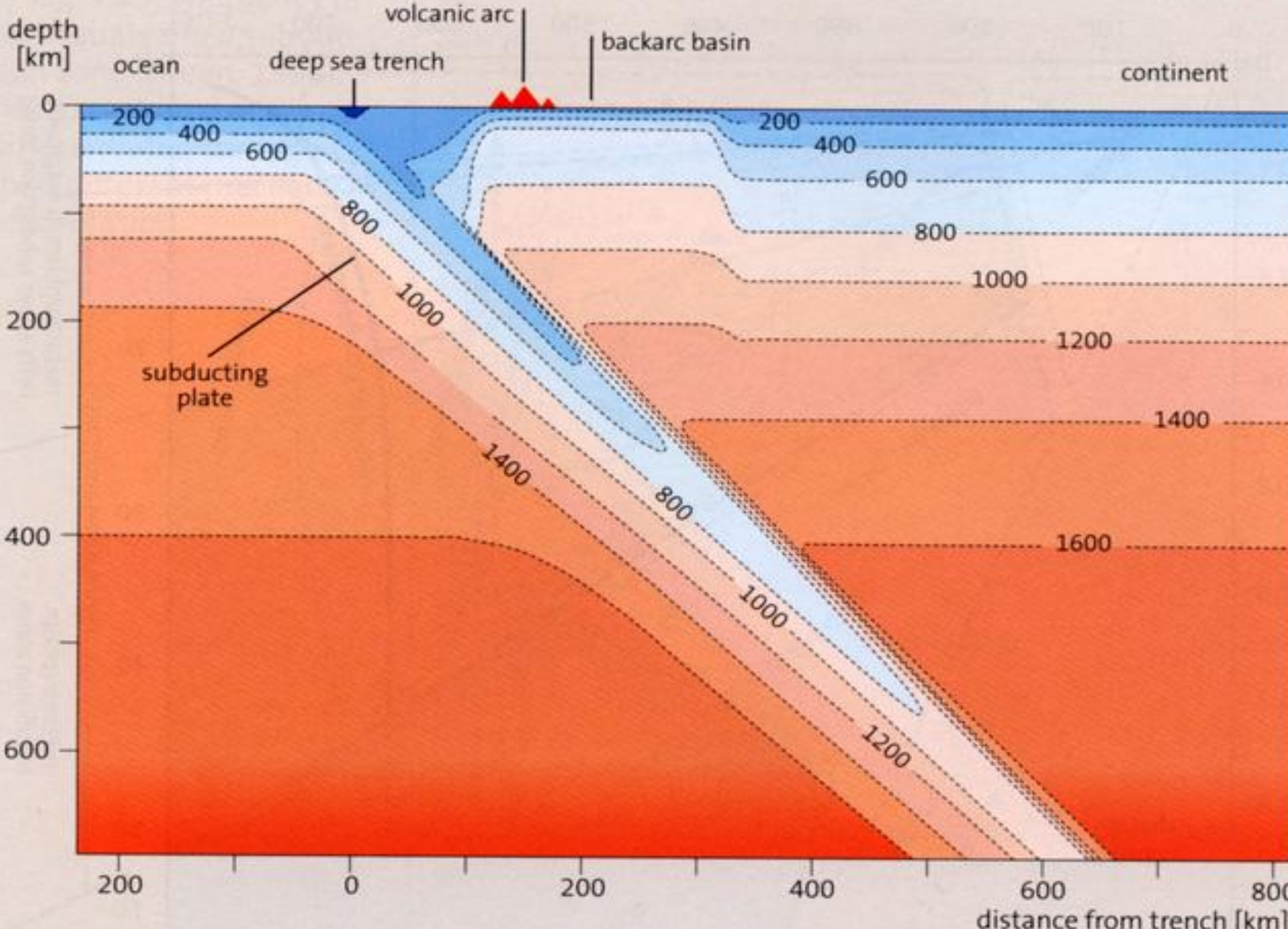
Artemieva and Mooney, 2000

S-wave Anomaly 200 km

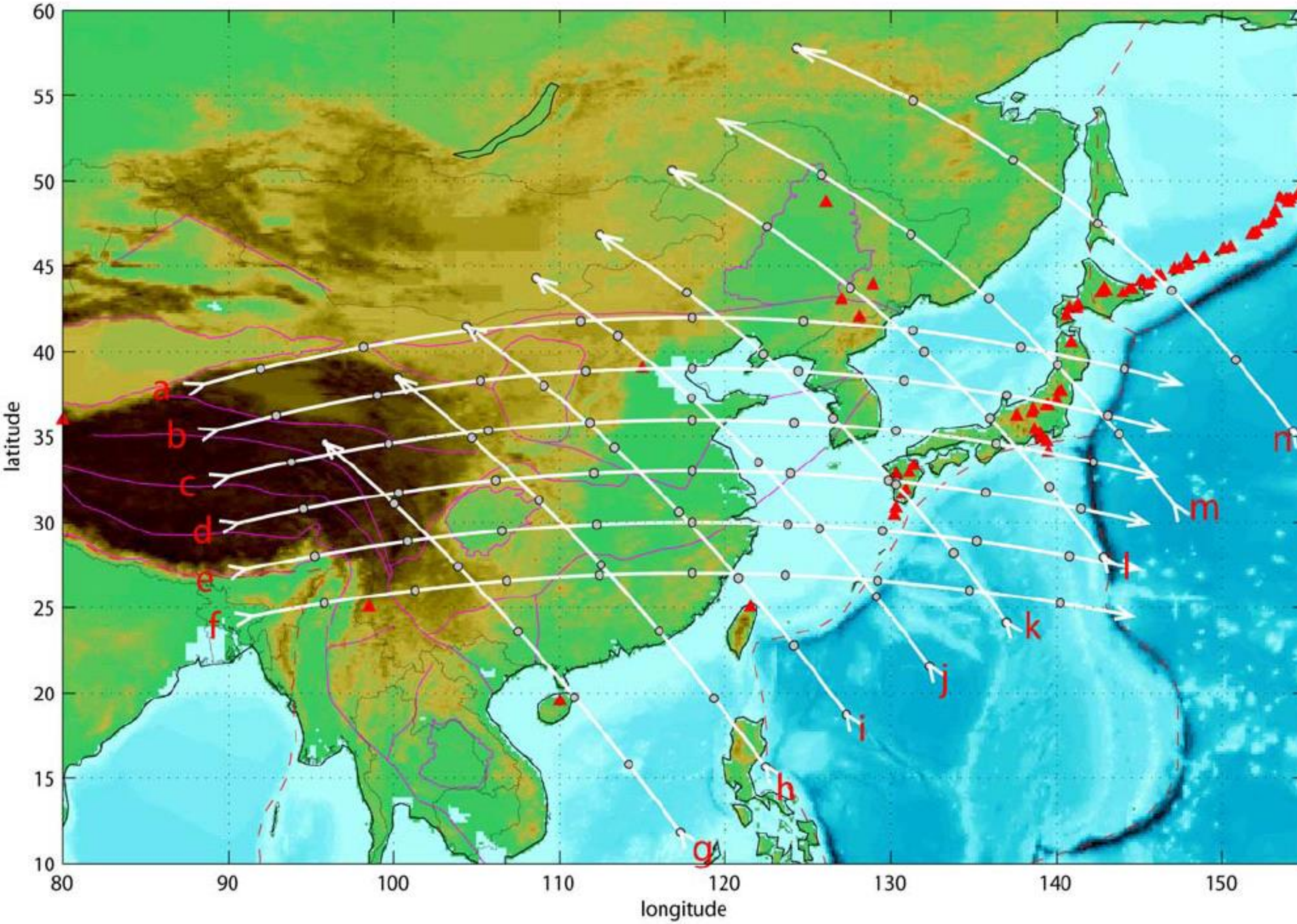



East Pacific
Rise
abyssal
plain
Pacific Ocean
Galápagos
hot spot
backarc basin
island arc
South America
deep sea trench
Tuamotu seamount chain
Nazca seamount chain
Andes
Fiji
deep sea trench
lithospheric mantle
active
continental margin
oceanic
crust
asthenosphere
island arc
system
subduction zone
continental
crust
subduction zone
spreading
axis

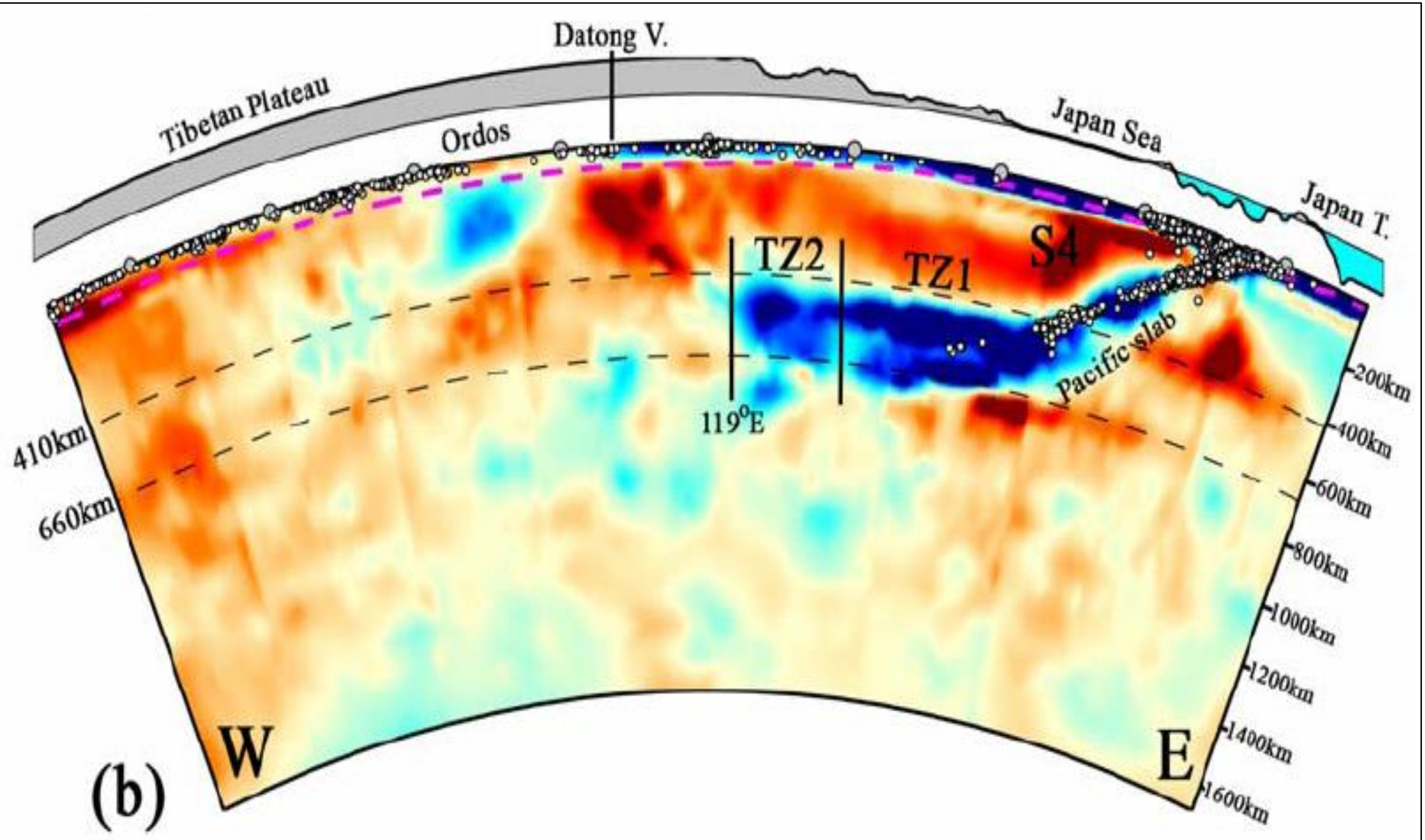

depth
[km]
deep sea trench
volcanic arc
continental
crust
oceanic
crust
magmatic gap
0
20
40
60
80
100
120
140
160
300
600
1100
300
600
1100
Abukuma-type
metamorphism
lithospheric
mantle
incipient
formation of eclogite
asthenosphere
50 km



depth [km]
ocean
deep sea trench
volcanic arc
backarc basin
continent
subducting plate
0
200
400
600
200
400
600
800
1000
1200
1400
1600
distance from trench [km]



Li et al. (in preparation)



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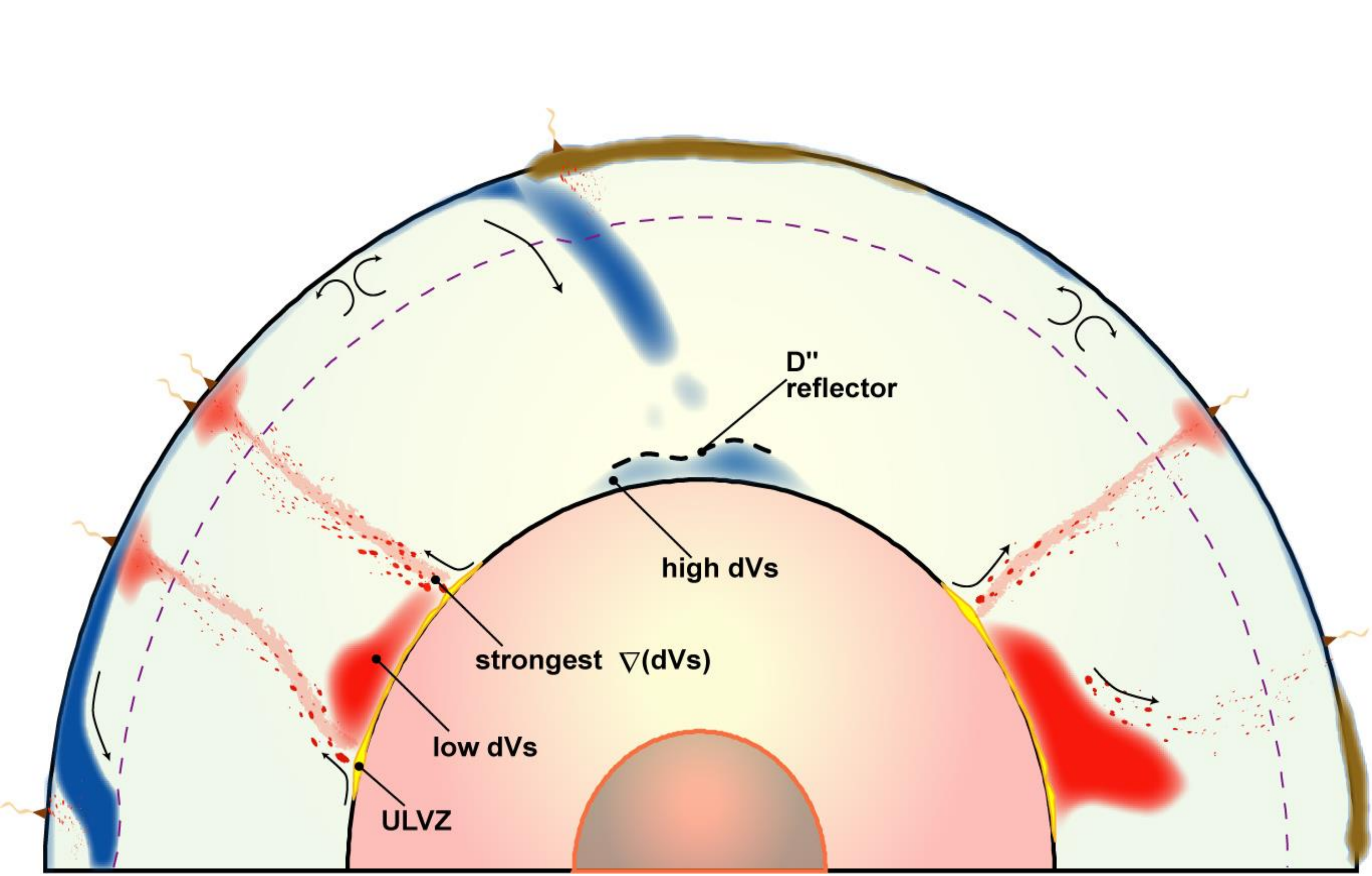
D''
reflector
high dVs
strongest ∇(dVs)
low dVs
ULVZ


The End