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"8th Workshop on Three-Dimensional Modelling of
Seismic Waves Generation, Propagation and their Inversion"

25 September - 7 October 2006

Surface Waves and Upper Mantle Anisotropy - III

Jean-Paul Montagner

Dept. Sismologie
I.P.G. Paris
France

Overview
Large scale Seismology: an observational field

- Data (Seismic source) + Instrument (Seismometer) -> Observations (seismograms)
- Historical evolution: Ray theory, Normal mode theory, Numerical techniques (SEM, NM-SEM)
- Scientific Issues: earthquakes (Sumatra-Andaman earthquake)
- NM-SEM and time reversal
- Anisotropic structure of the Earth
- Seismic Experiment: Plume detection

Hotspots - Plumes

EXPLANATION

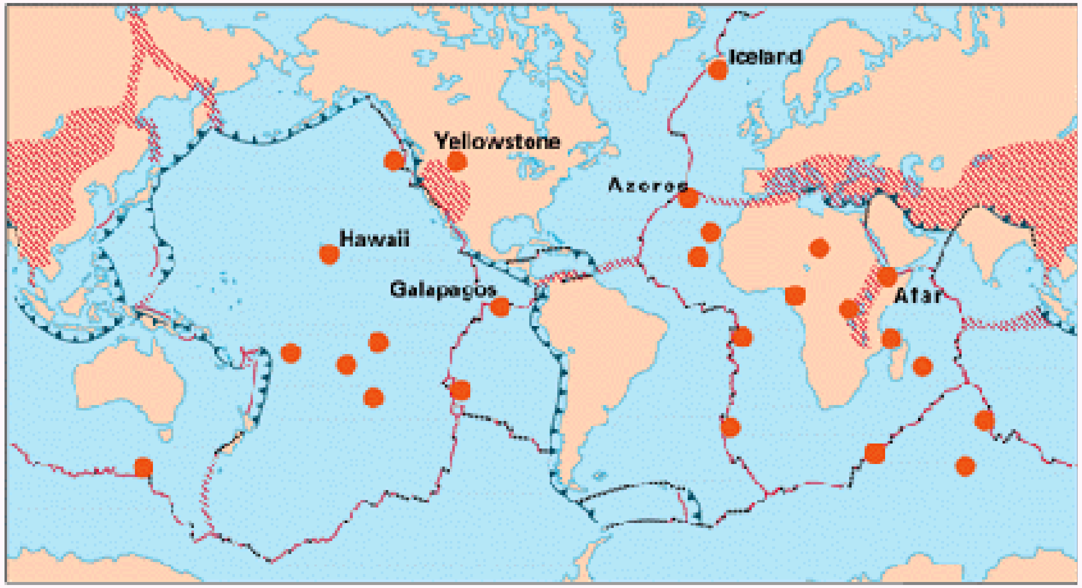
Divergent plate boundaries— Where new crust is generated as the plates pull away from each other.

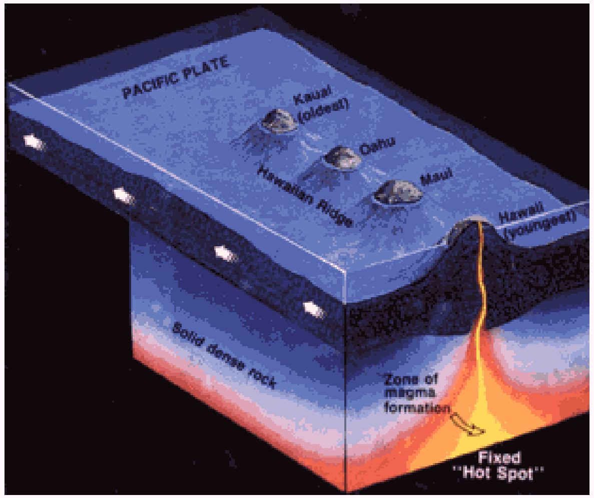
Convergent plate boundaries— Where crust is consumed in the Earth's interior as one plate dives under another.

Transform plate boundaries— Where crust is neither produced nor destroyed as plates slide horizontally past each other.

Plate boundary zones—Broad belts in which deformation is diffuse and boundaries are not well defined.

Selected prominent hotspots





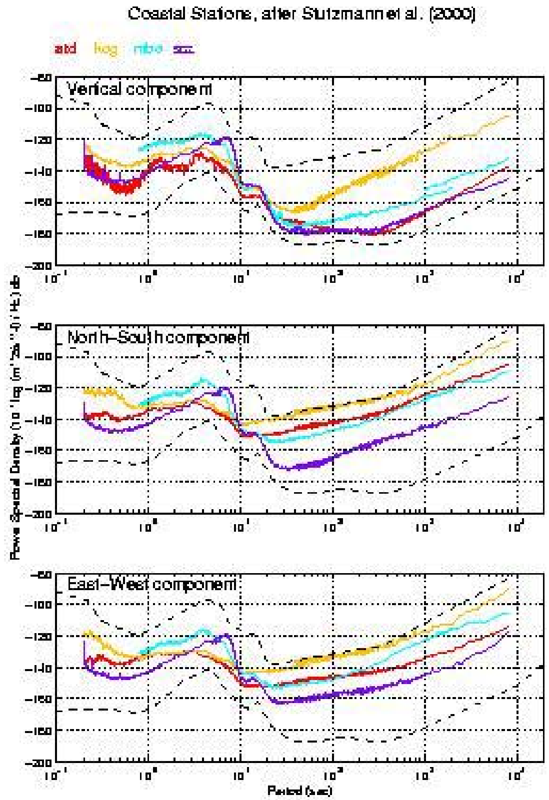
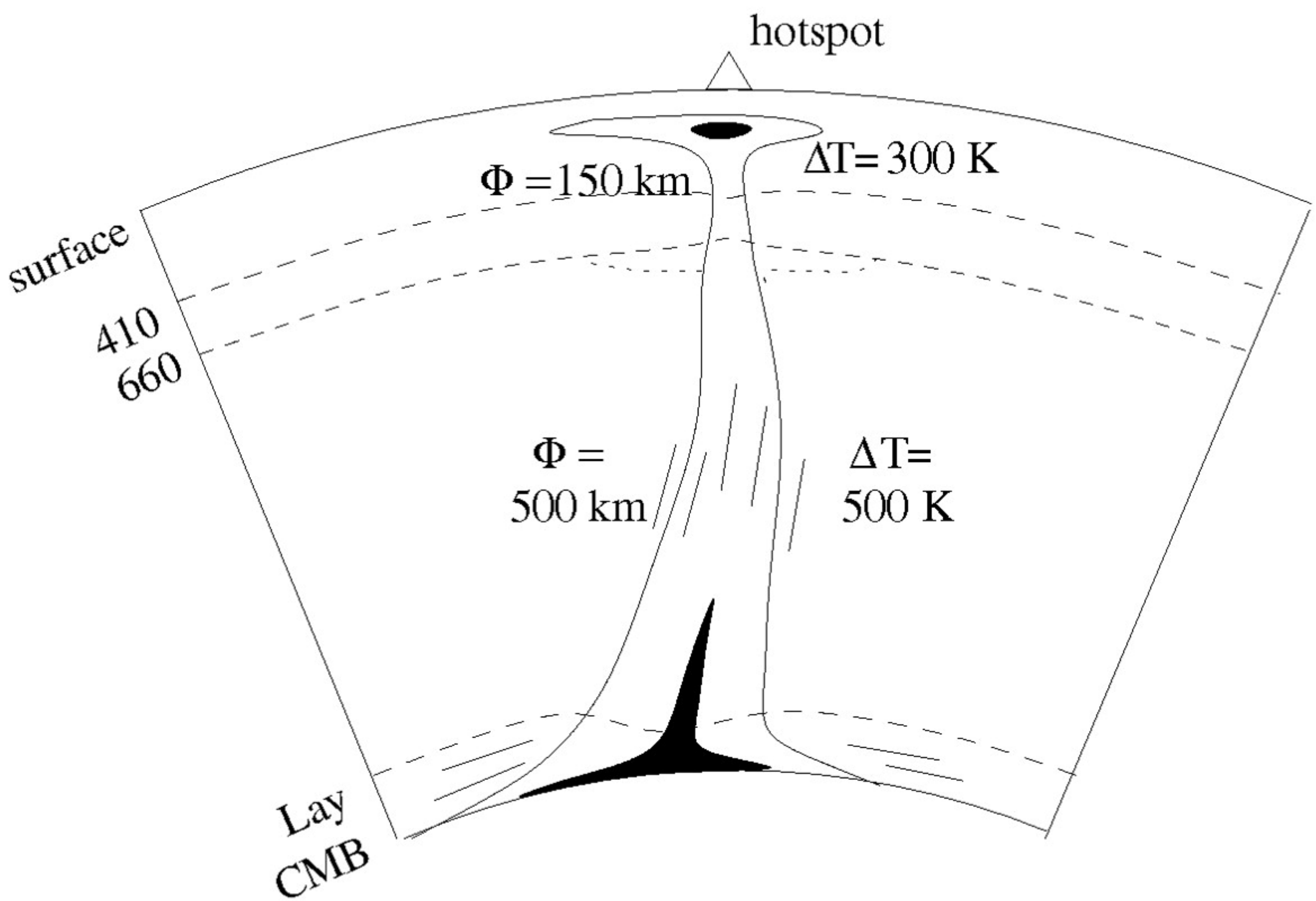


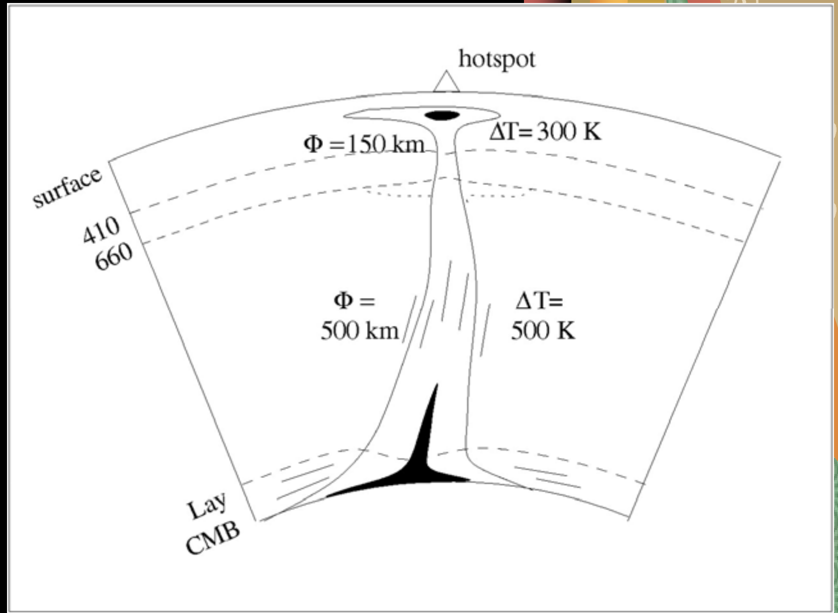
Figure 5c. Power spectral density estimated over noise data from the year 1995 for the three components (vertical: top, North-South: middle and East-West: bottom) of all coastal GEOSCOPE stations.


10 5:42
Th. Staudacher
OVPF / IPGP

Classical Plume Model (Nataf, 1999)



Definition of plume: thermal instability in a boundary layer:
- Core-mantle boundary
- Transition Zone (400-660- 1000km)?
- Asthenosphere- lithosphere?



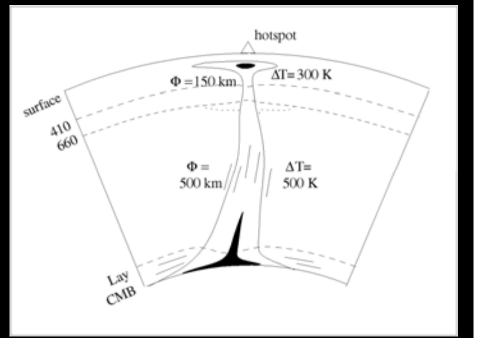
But

-Is the plume model correct?
-What is their geodynamical role?
-What is their biological role?

-What is their structure, their origin at depth?

-Are there really several types of plumes?

Detection of a Plume



Expected Effects of plume on seismic data

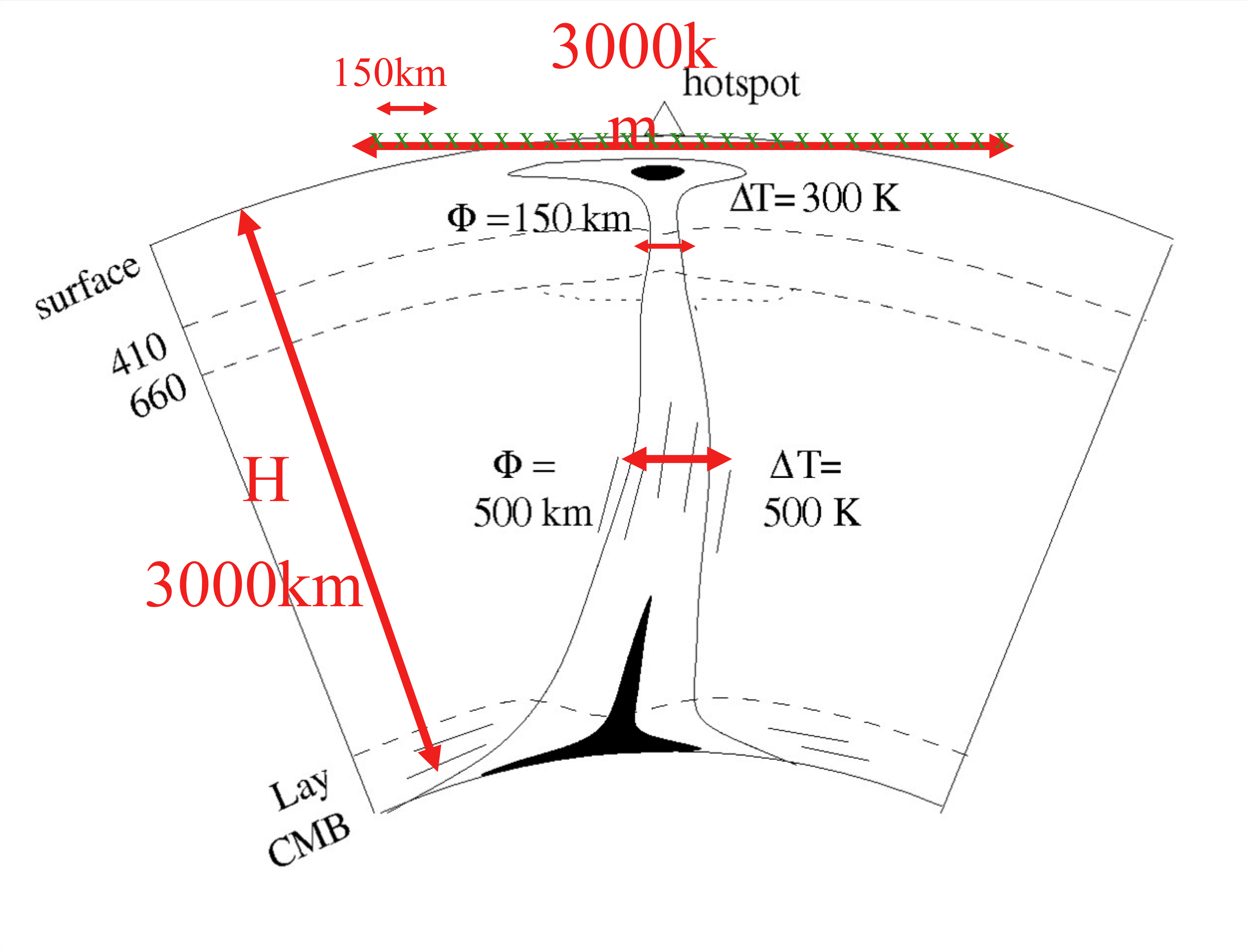
- Thermal effect: $\Delta T>0 \Rightarrow \delta V_S<0, \delta V_P<0$

- Upwelling flow =>crystal alignment by LPO
Weak azimuthal seismic anisotropy,
$V_{SV}>V_{SH}$ ($\xi<1$: radial seismic anisotropy)

- Large attenuation => low quality factor Q

- Thinning of the Transition zone thickness
(410km deflected downward, 660km upward)

H/Φ ≈ 20 => at least 40 stations (2 per λ)



Plume affects not only S-wave velocity distribution but also seismic anisotropy

Plume affects not only S-wave distribution but also seismic anisotropy

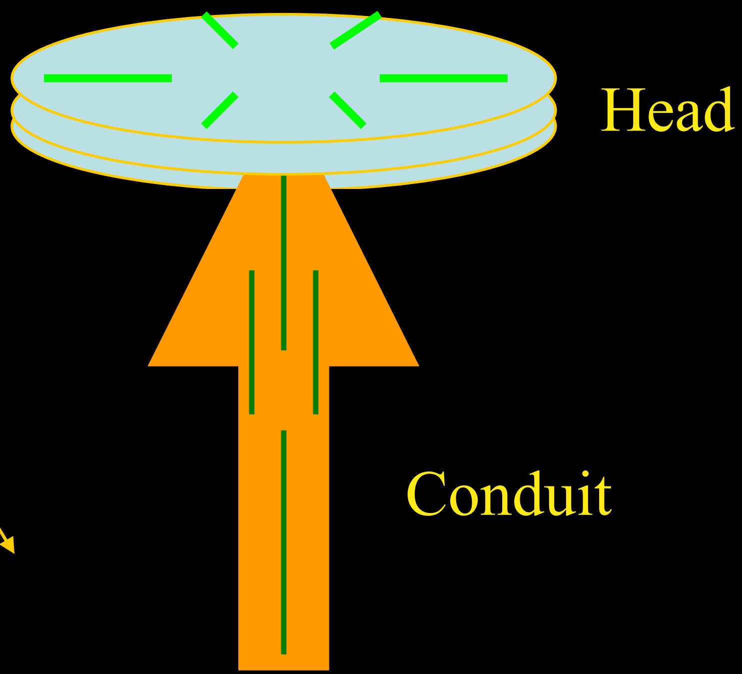
- Head: Not a problem

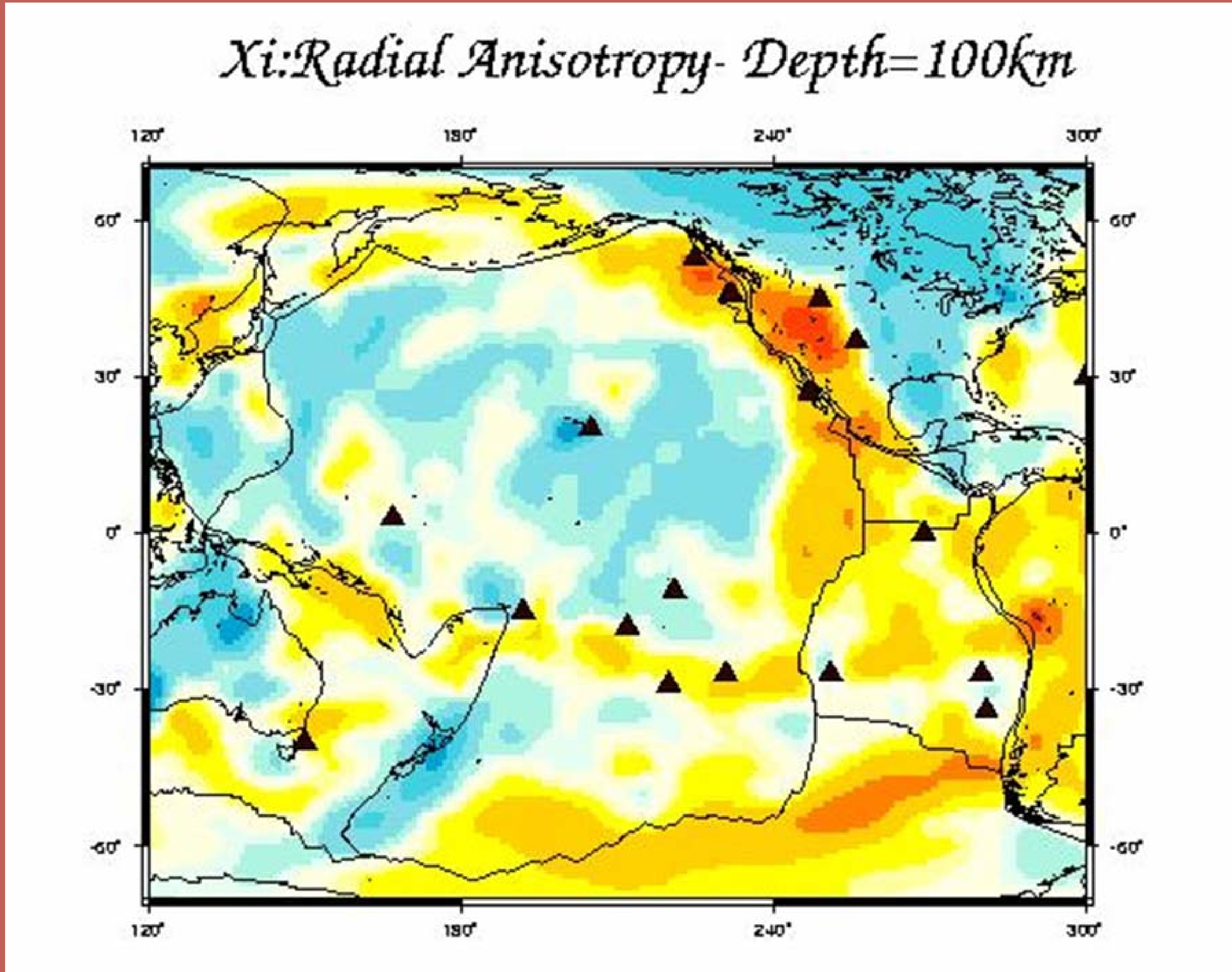
- Conduit: difficult to detect

$\Delta\alpha$: Anisotropy Effect => V_{SV} ↗

ΔT: Temperature Effect => V_{SV} ↘

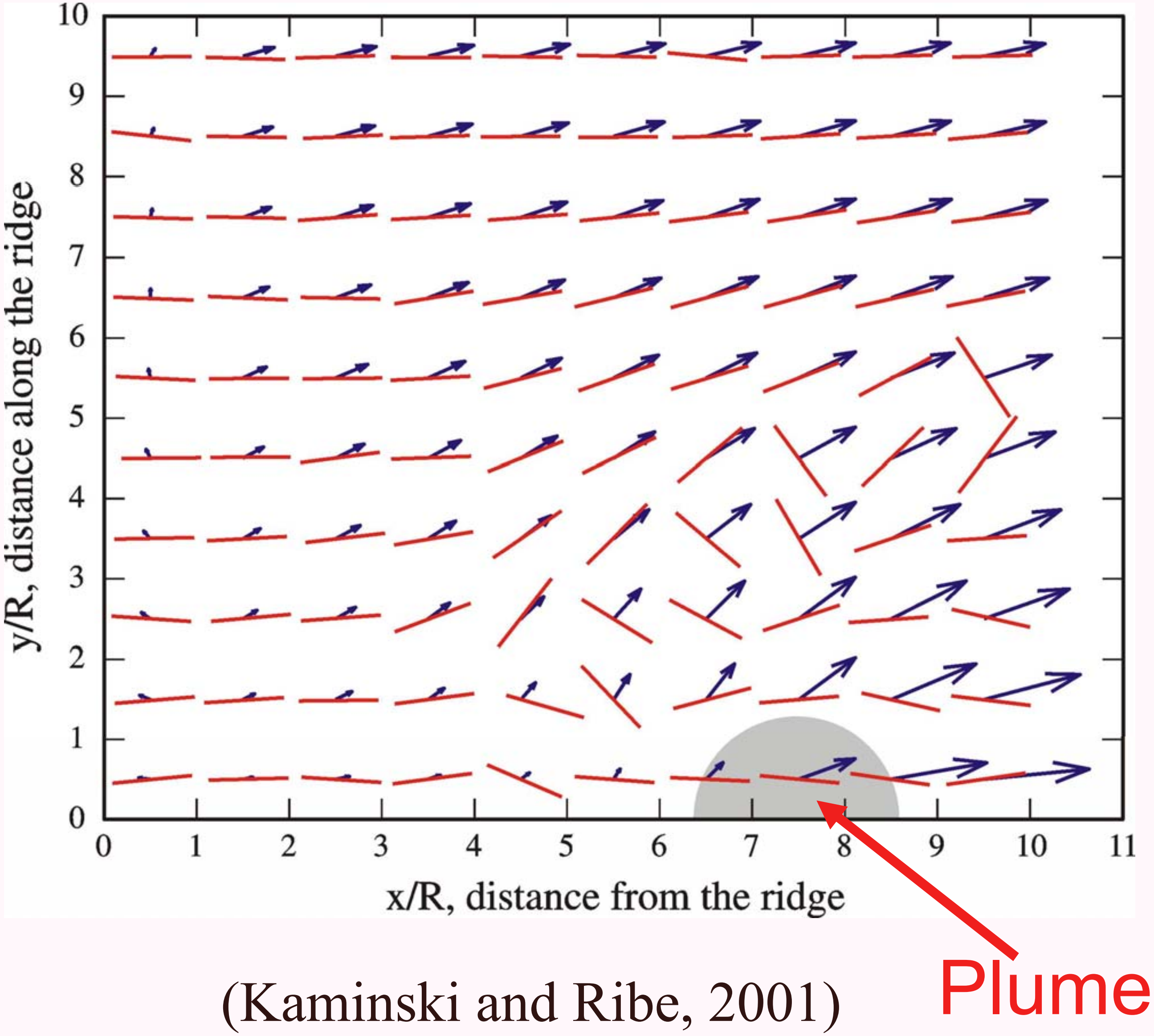
Opposite effects





(Montagner, 2002)

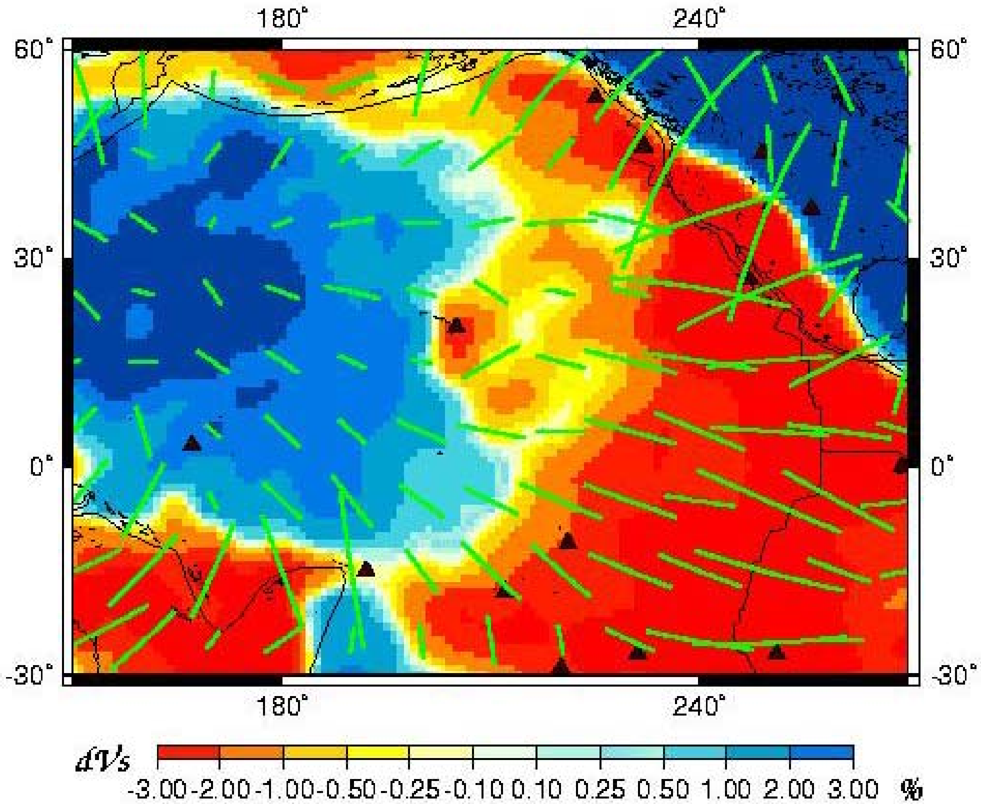
Azimuthal anisotropy



(Kaminski and Ribe, 2001)

S-wave velocity + Azimuthal Anisotropy

Depth=120 km



A plume is very difficult to detect below asthenosphere (narrow conduit ≈150km, small velocity contrast ≈1-2%)

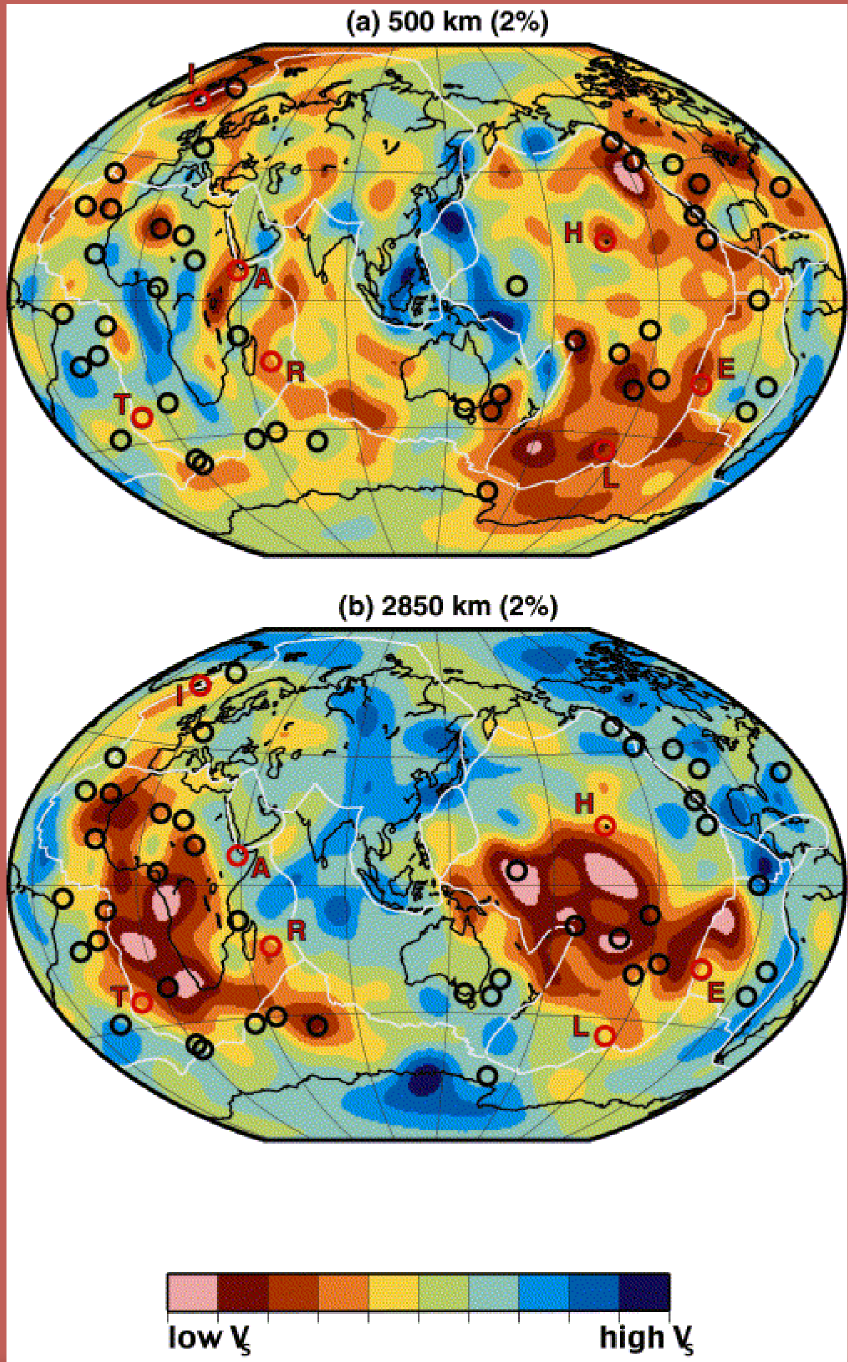
Head is easier to detect: large lateral extent, interaction with lithosphere, asthenosphere, or continent

Indirect detection through the perturbation of flow pattern around plume

Several regional investigations: Resolution 500km

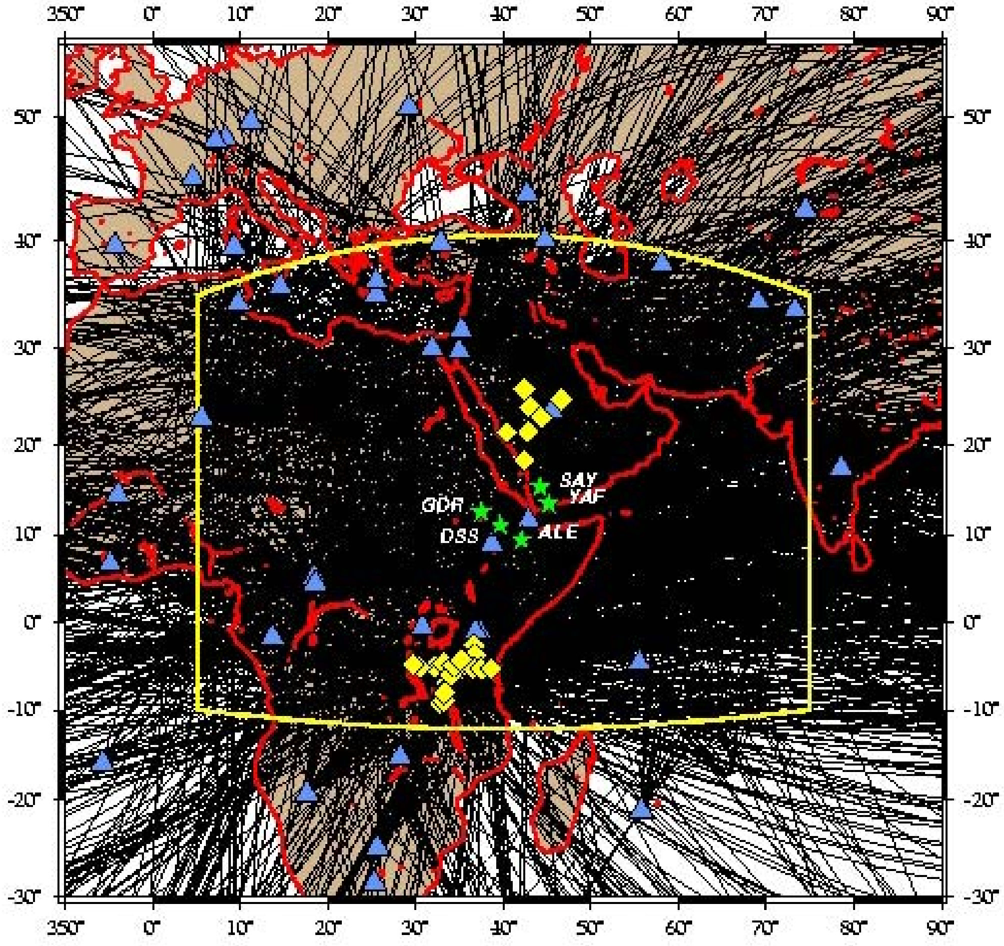
Horn of Africa (Debayle et al., 2000; Sicilia et al., 2003)

Global Scale



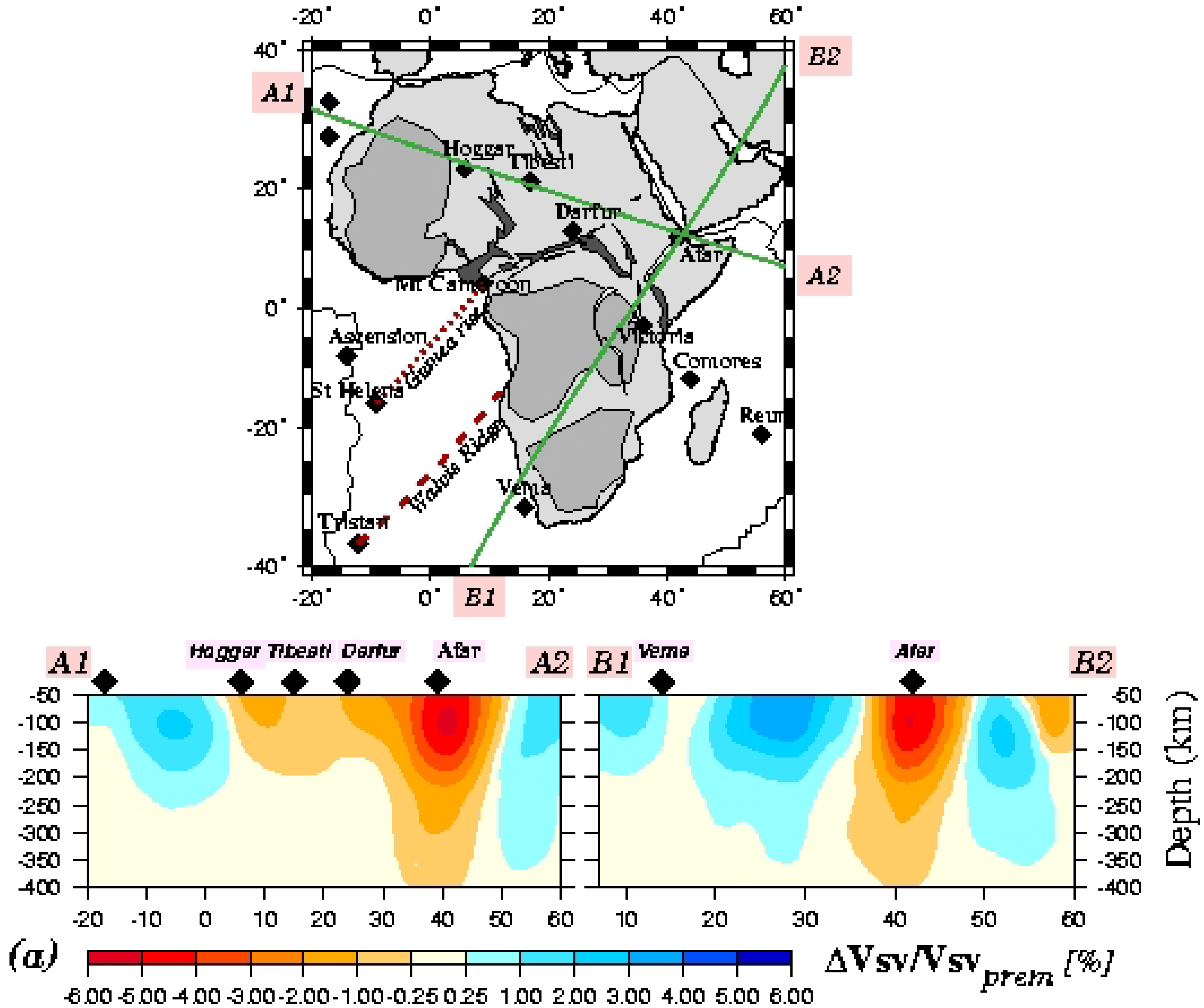
Ritsema et al., 2000

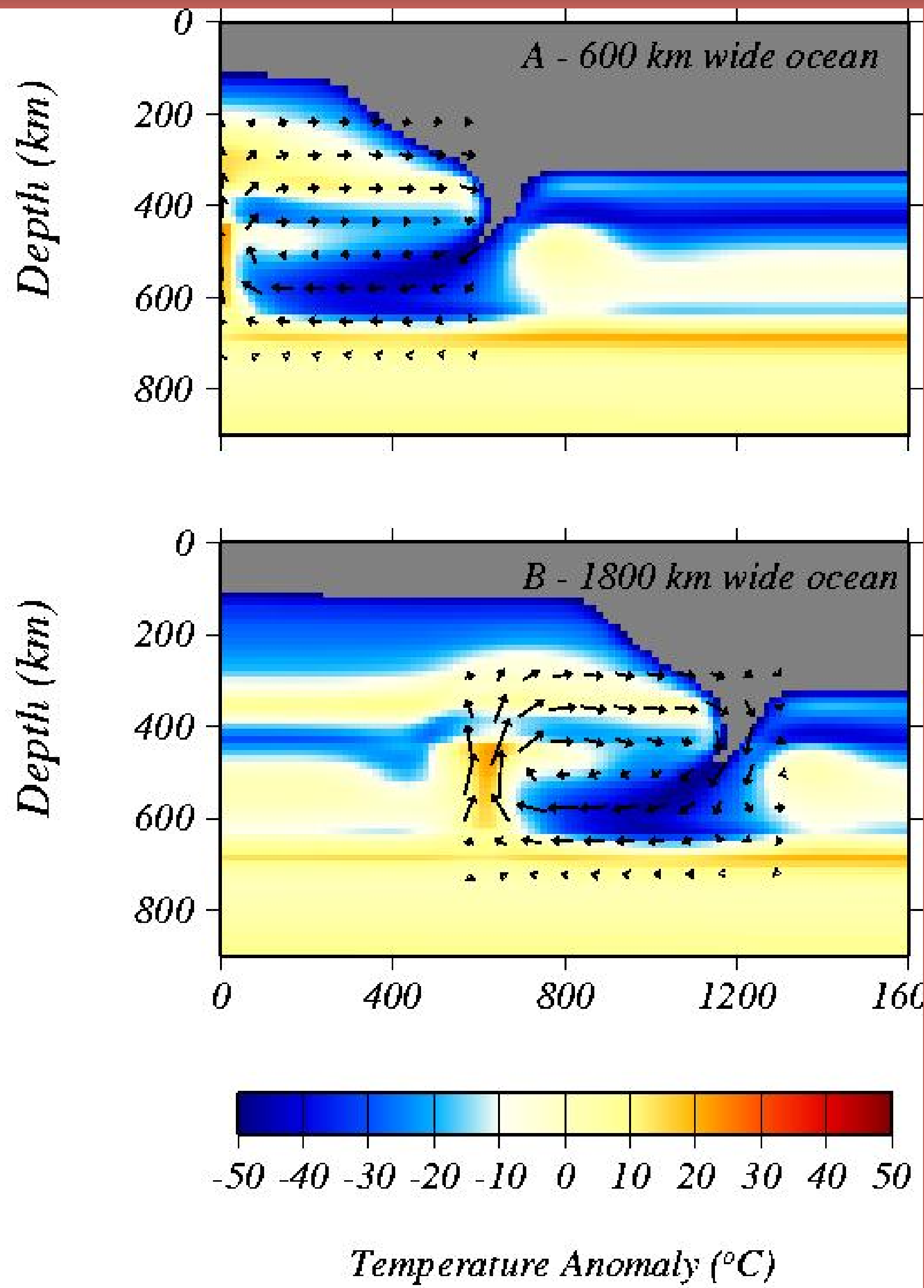
Horn of Africa



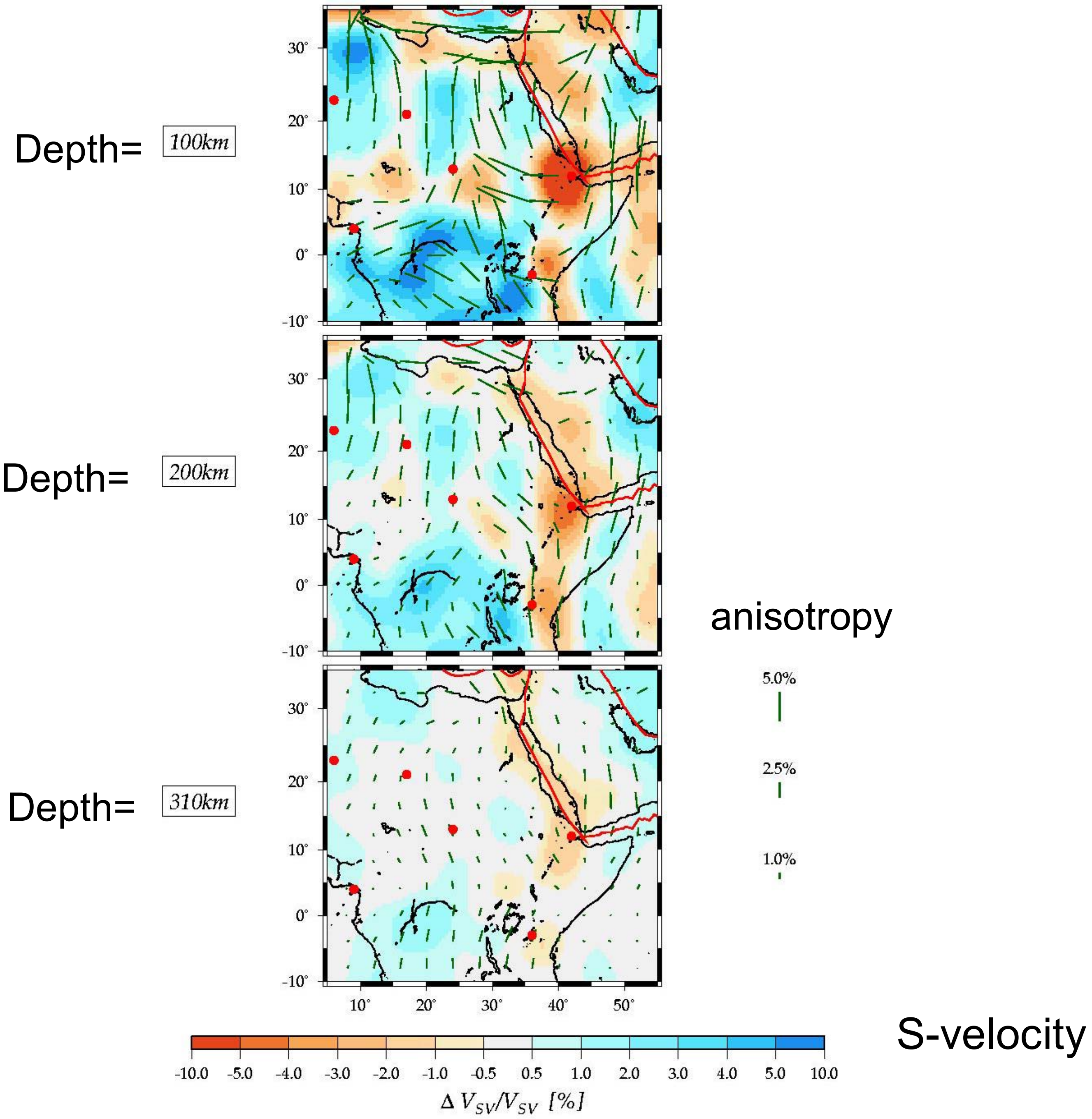
(Sicilia et al., 2004)

(Sebai et al., 2006)



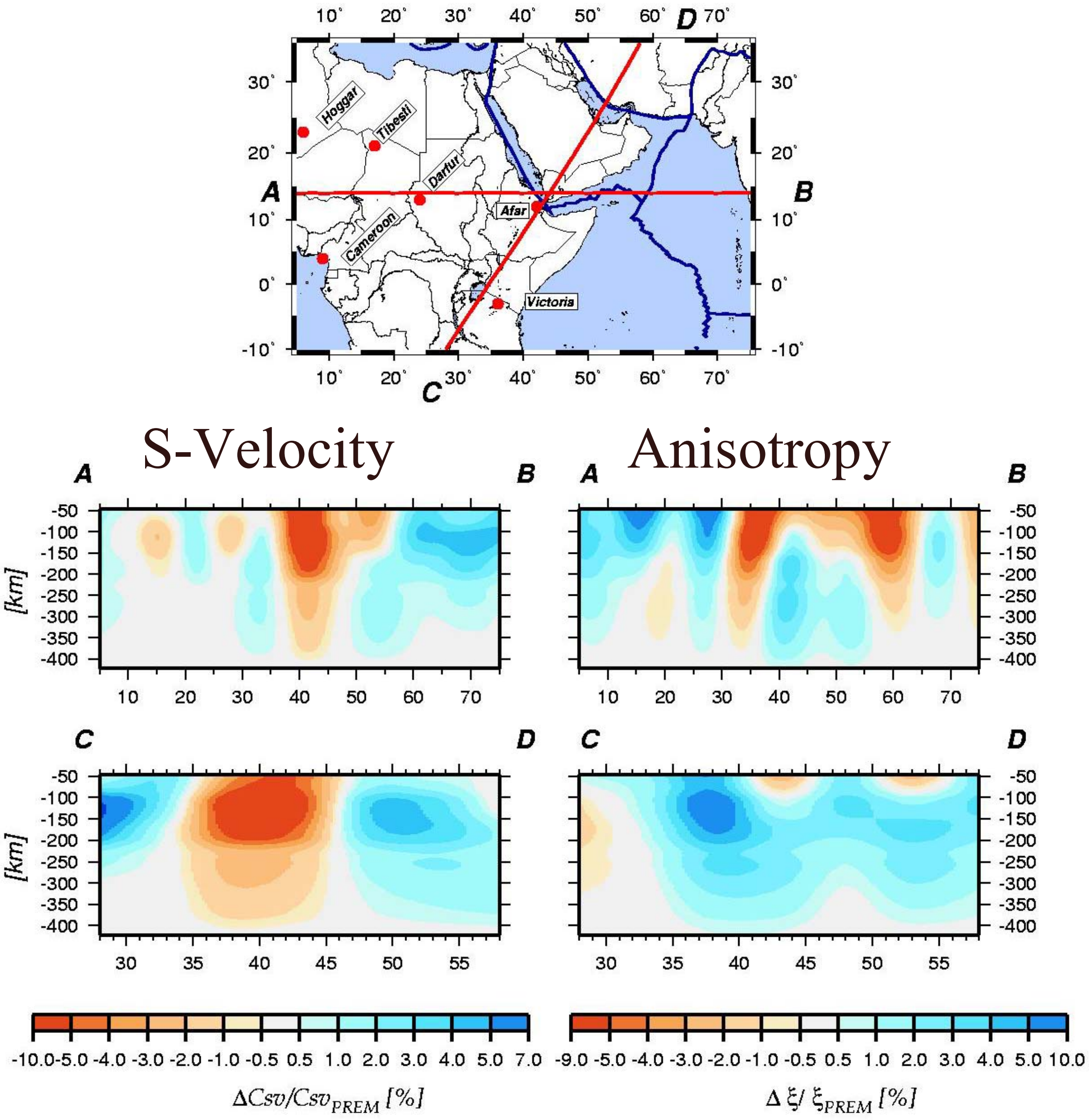


King & Ritsema, 1999


Depth= 100km
Depth= 200km
Depth= 310km
30°
20°
10°
0°
-10°
10°
20°
30°
40°
50°
anisotropy
5.0%
2.5%
1.0%
S-velocity
-10.0 -5.0 -4.0 -3.0 -2.0 -1.0 -0.5 0.5 1.0 2.0 3.0 4.0 5.0 10.0
Δ V_SV/V_SV [%]

E-W

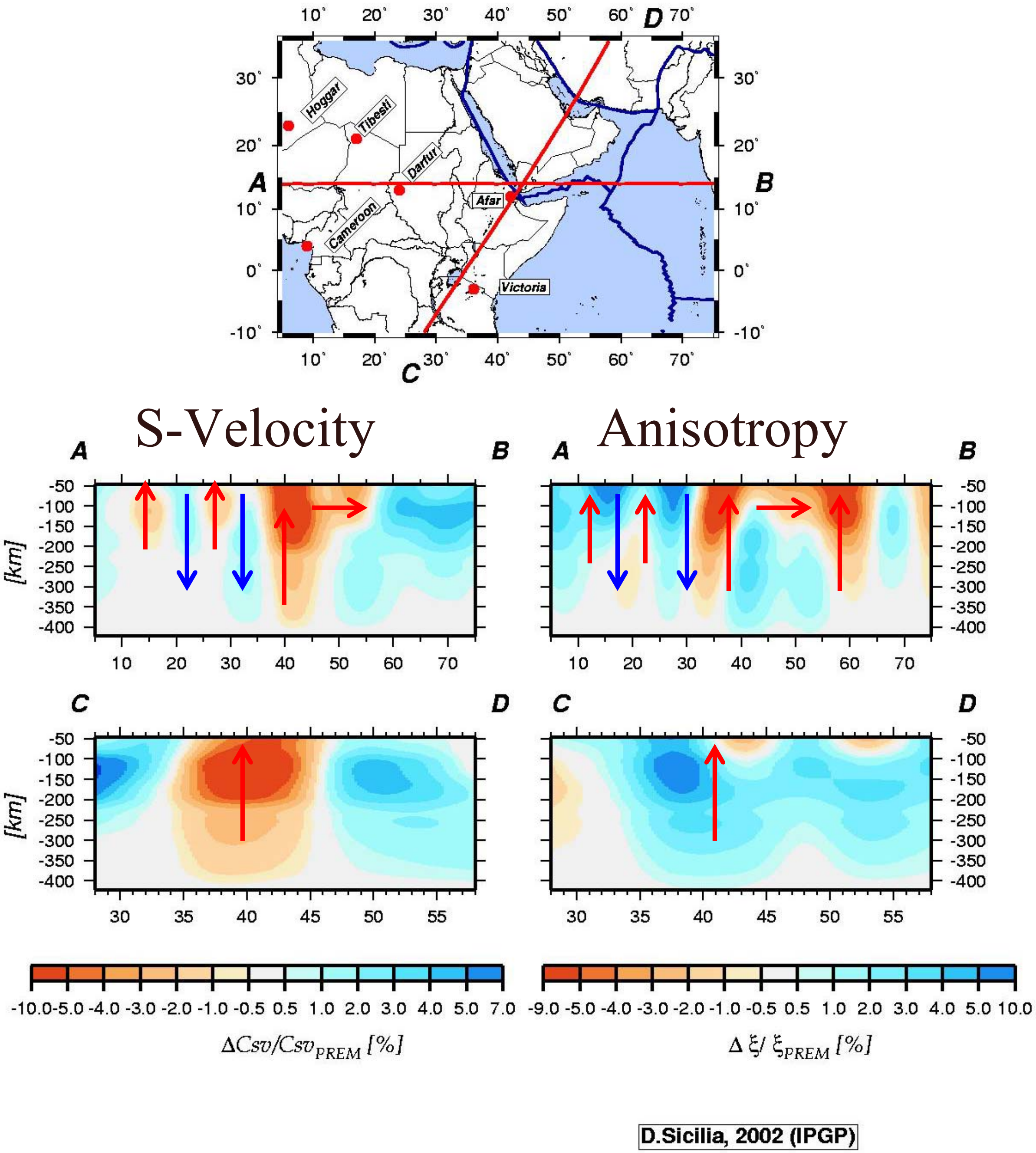
N-S



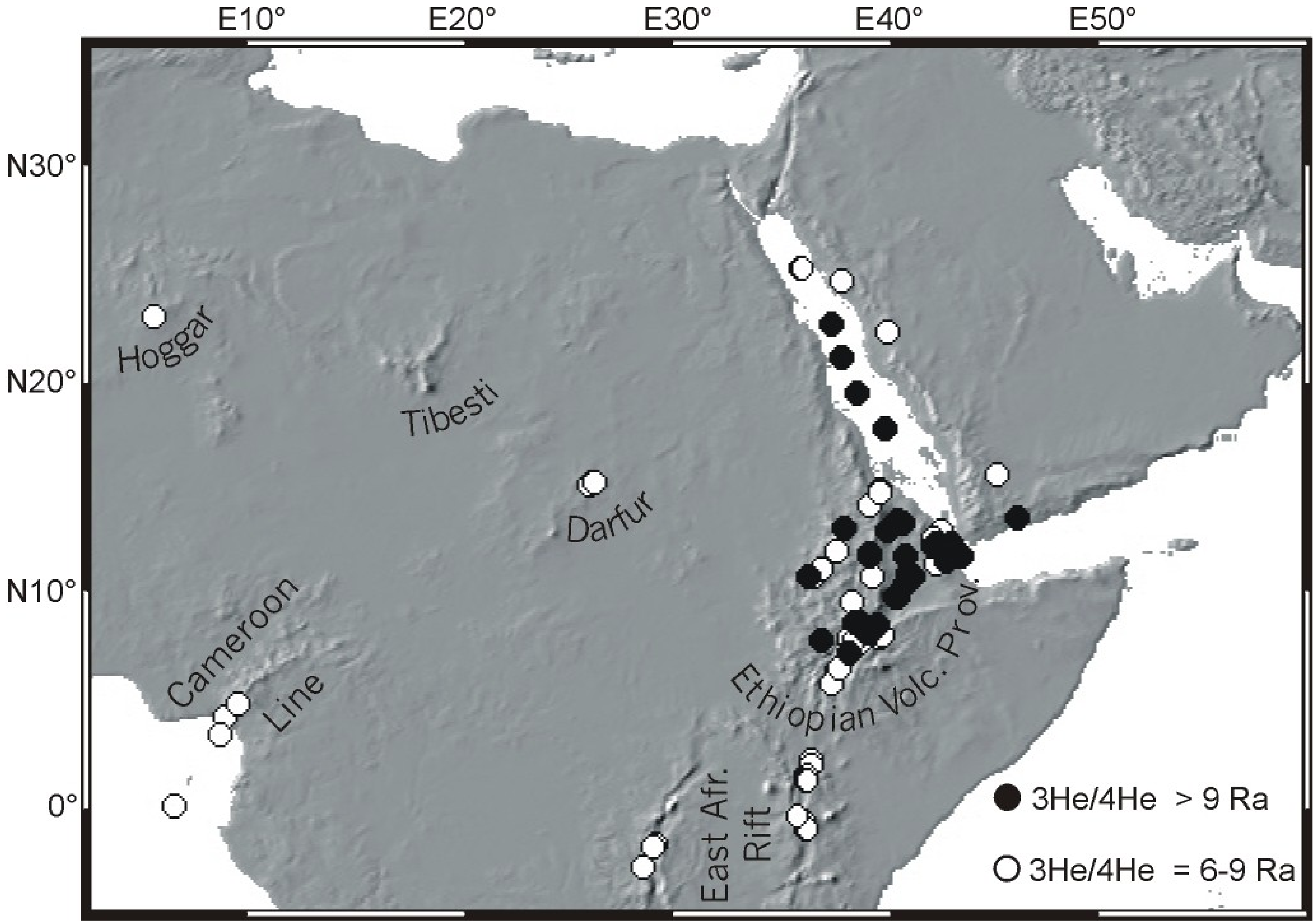
D.Sicilia, 2002 (IPGP)

E-W

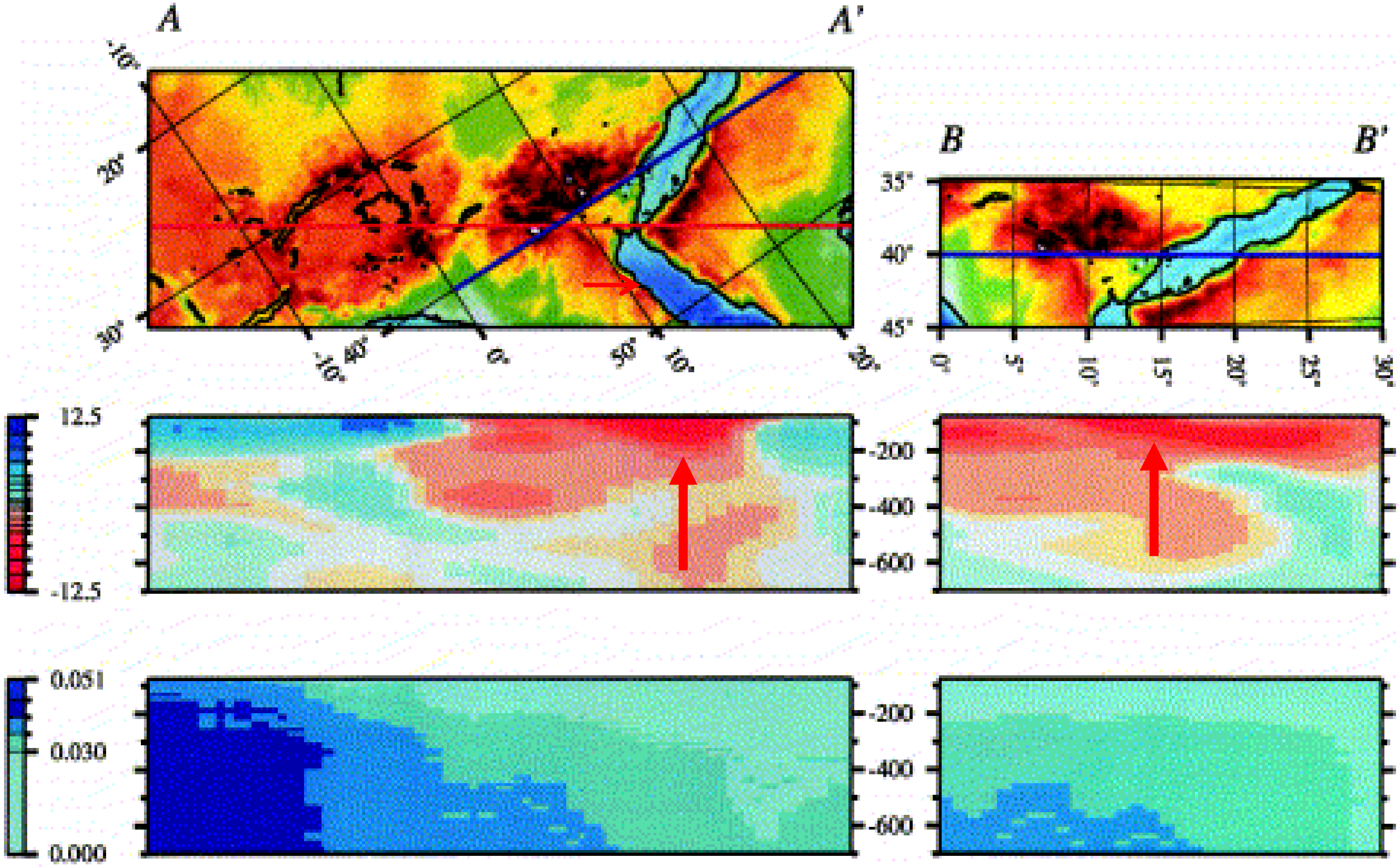
N-S



Hoggar
Tibesti
Darfur
Cameroon
Afar
Victoria
A
B
C
D
S-Velocity
Anisotropy
[km]
ΔCsv/Csv_PREM [%]
Δ ξ/ ξ_PREM [%]
D.Sicilia, 2002 (IPGP)



E10°
E20°
E30°
E40°
E50°
N30°
N20°
N10°
0°
Hoggar
Tibesti
Darfur
Cameroon
Line
Ethiopian Volc. Prov.
East Afr.
Rift
3He/4He > 9 Ra
3He/4He = 6-9 Ra



(Debayle et al., 2001)

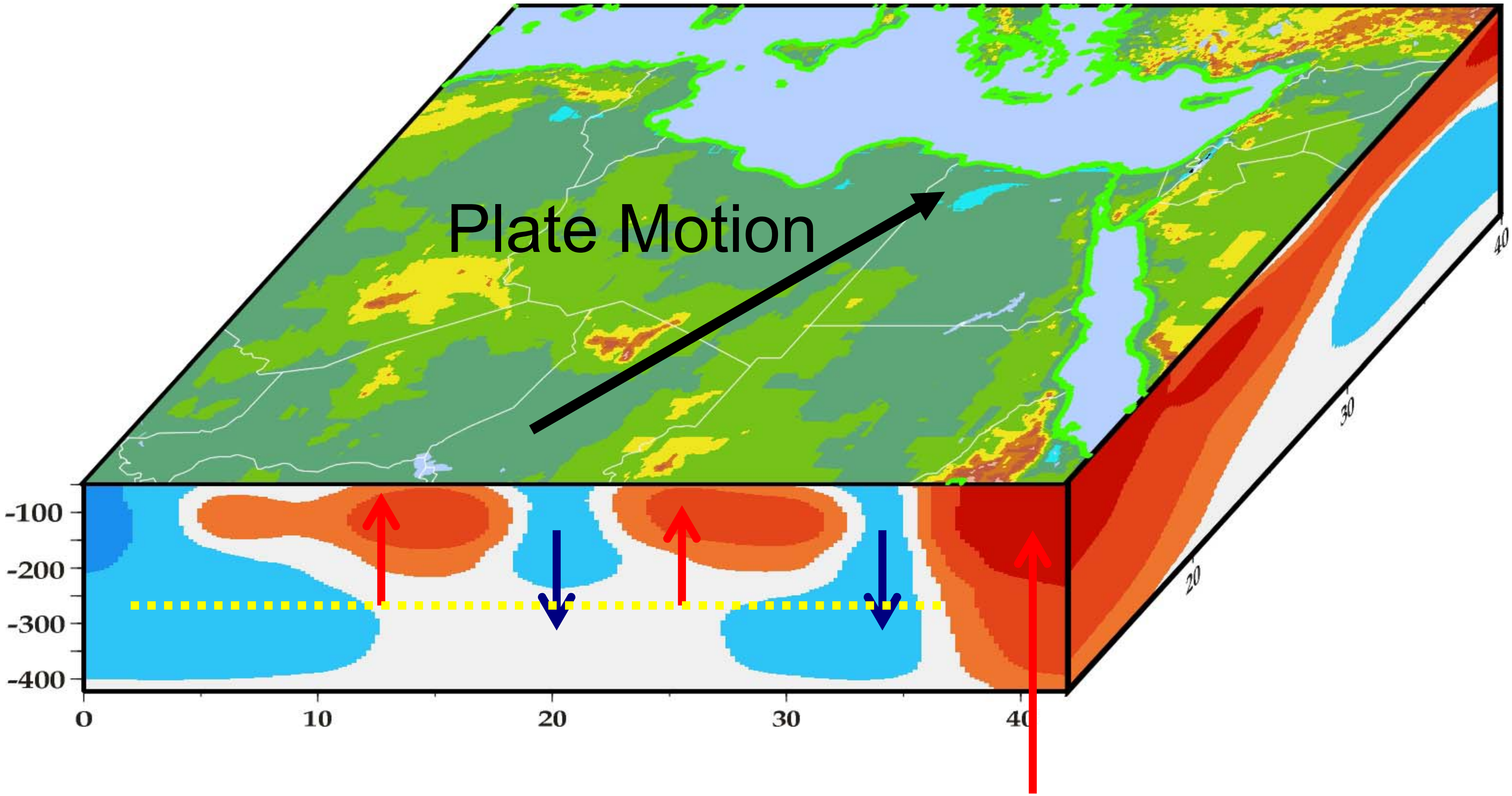
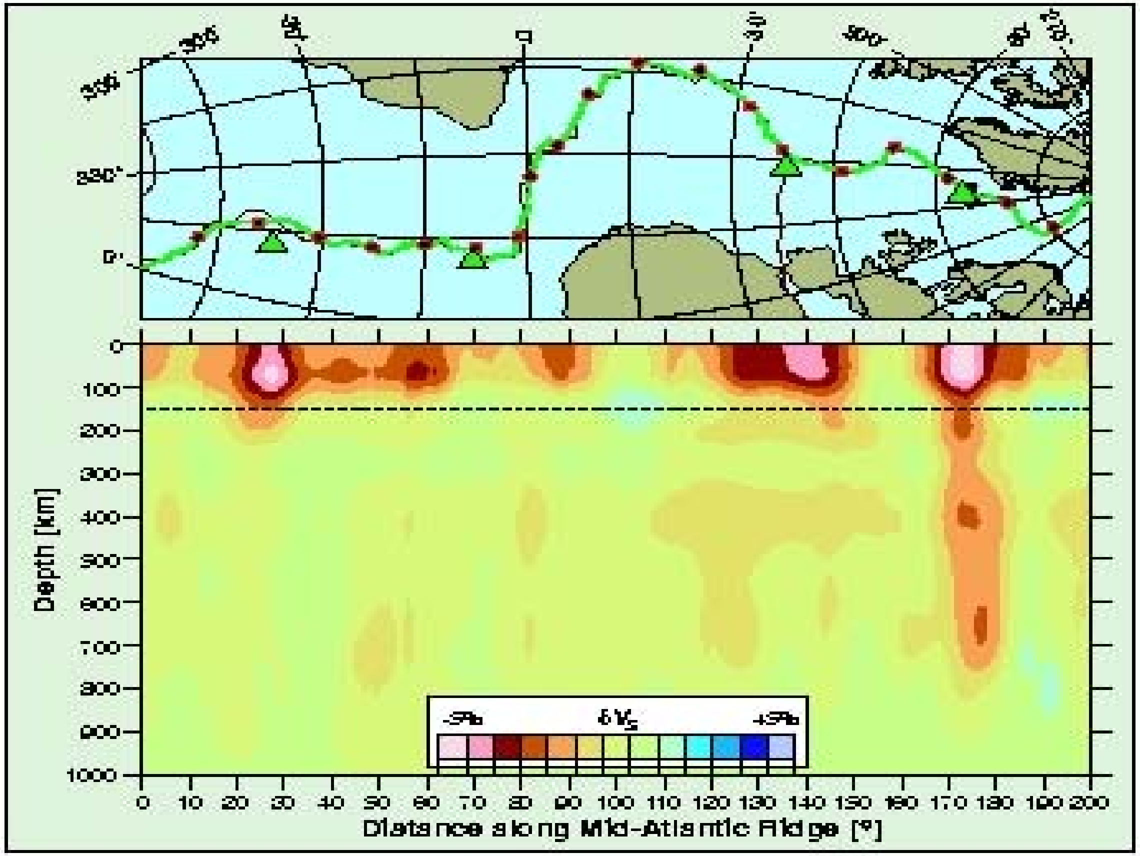
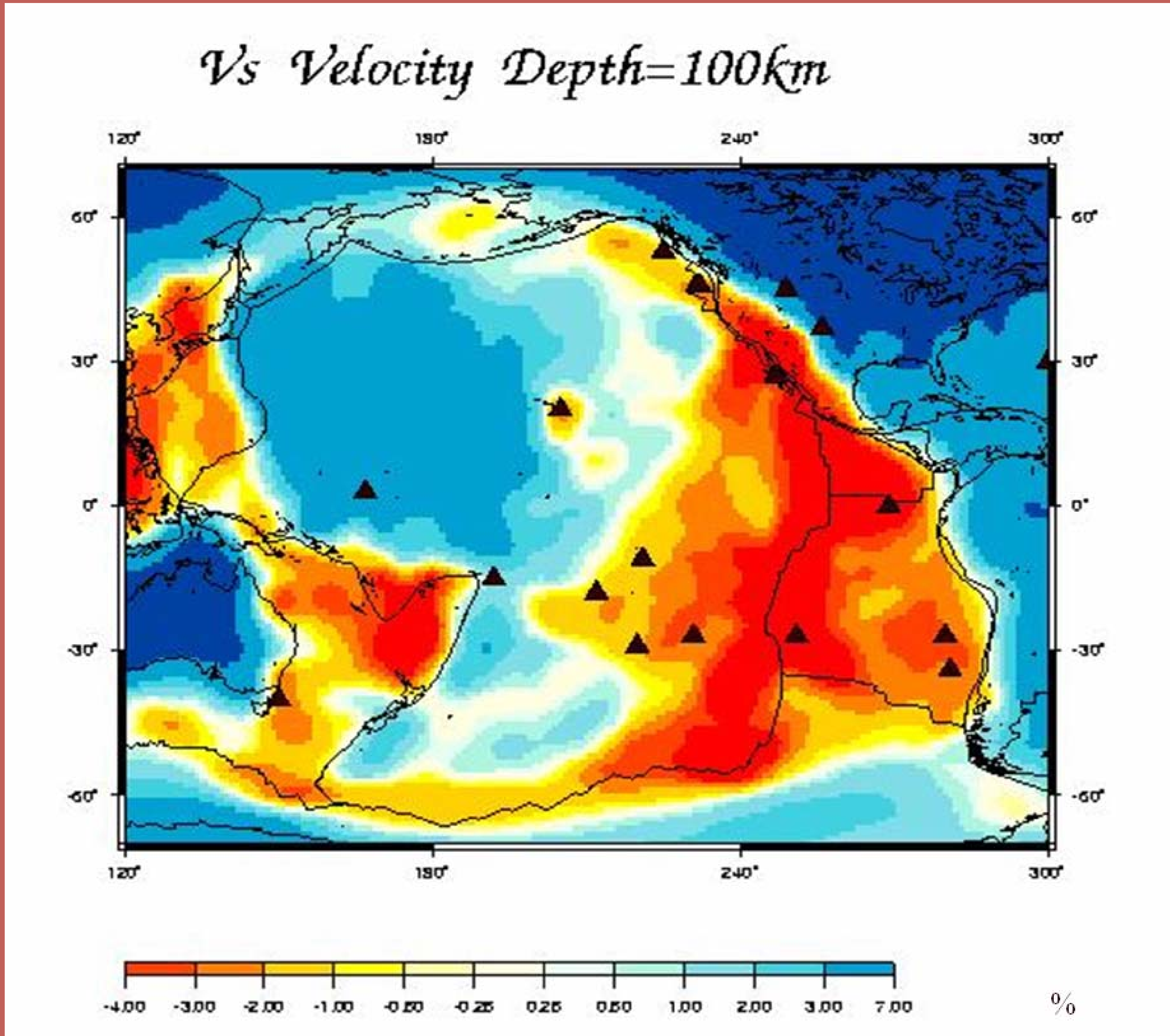


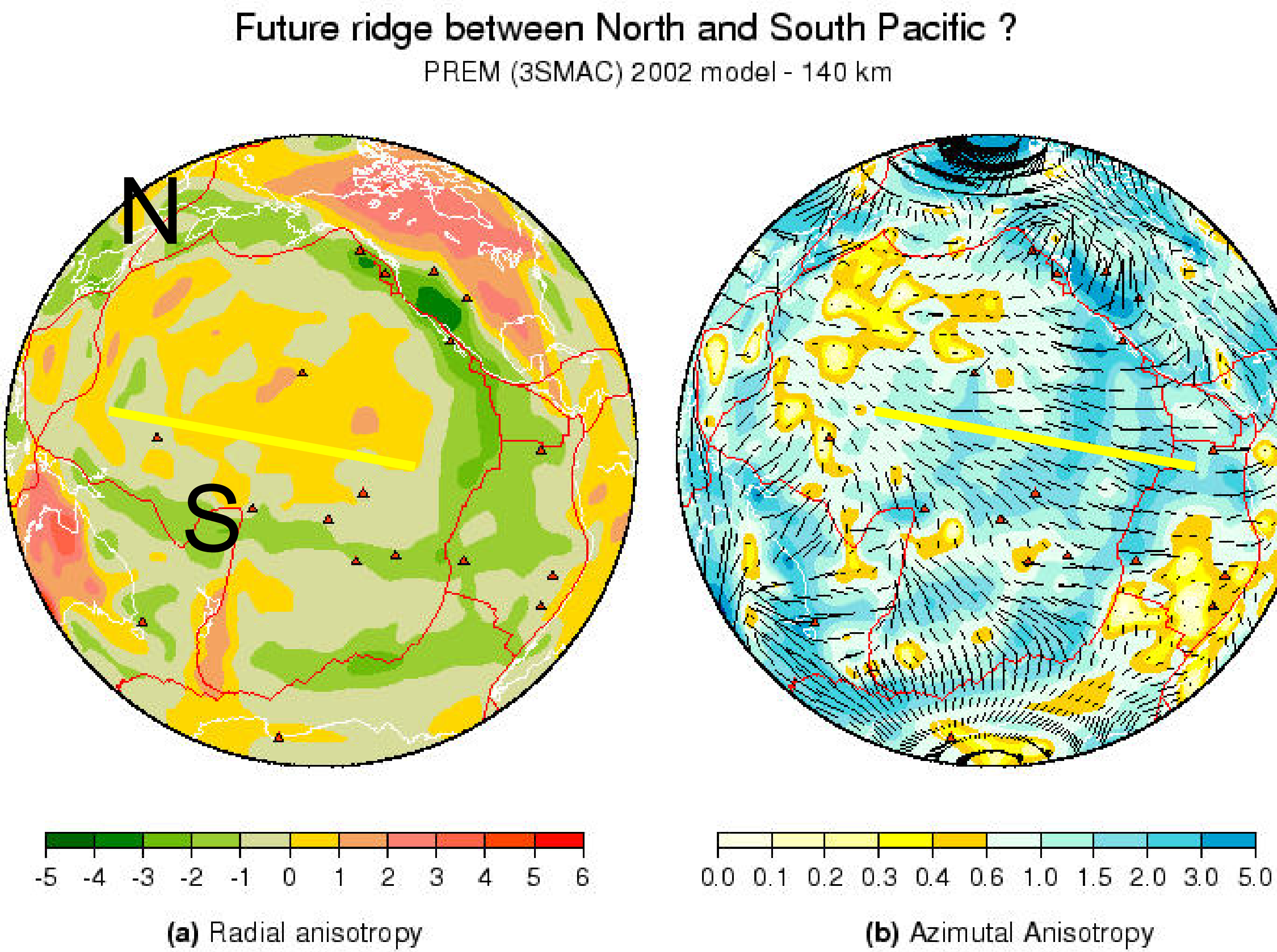
Plate Motion
-100
-200
-300
-400
0
10
20
30
40
20
30
40



(Montagner and Ritsema, 2001)



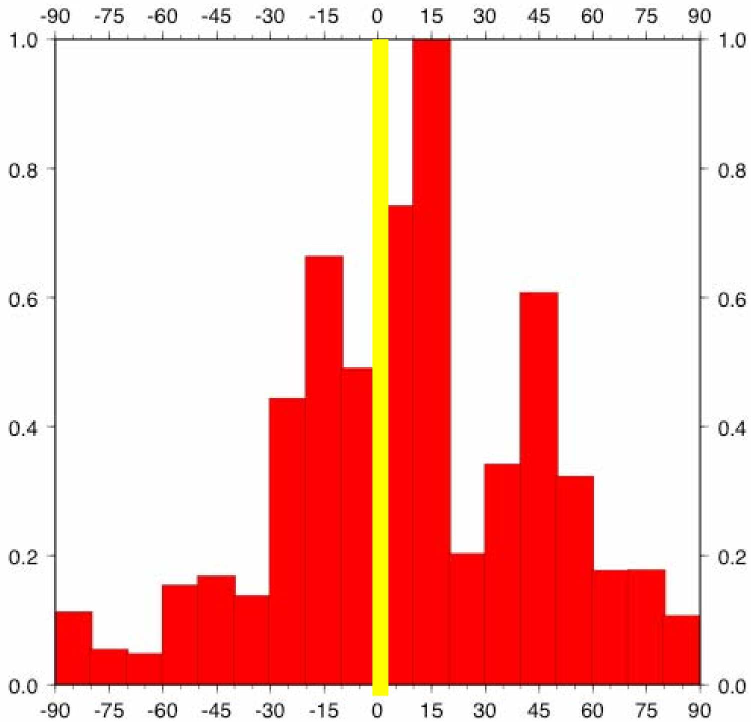
(Montagner, 2002)



Future Plate boundary within the Pacific plate?

Pacific Plate

Histogram Plate velocities - Seismic anisotropy

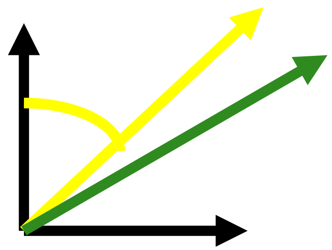


$\Psi_{\alpha} - \Psi_{PL}$

Angular difference (in degrees)

$$\mathbf{V}_{PL} = \Omega_{PL} \times \mathbf{OM}$$

Ψ_{PL}

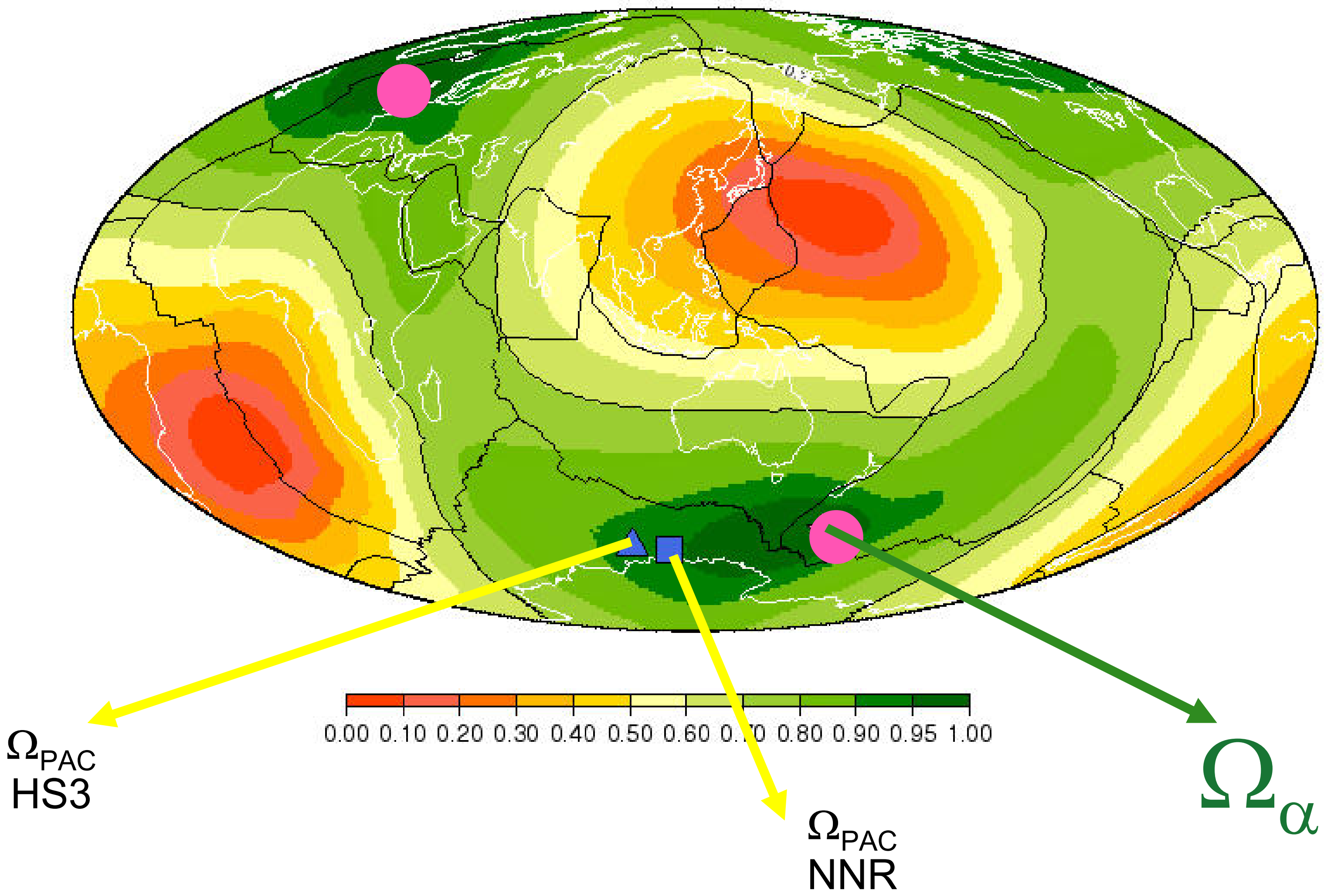


Ψ_{α}

$$\Psi_{\alpha} \longrightarrow (\Omega_{\alpha}, \Omega_{\alpha}^{antip})$$

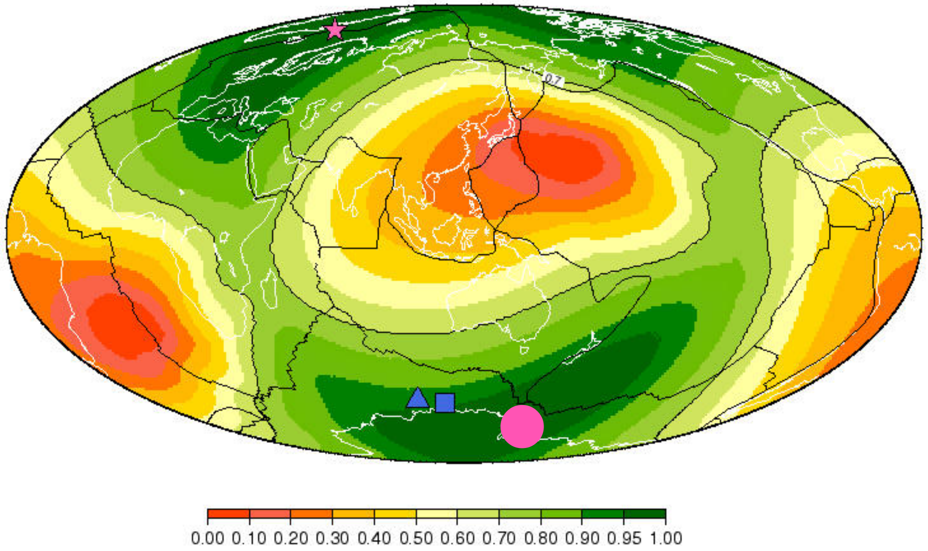
Cost funtion global Pacific Plate G

SKS-PREM-3SMAC-2002 model (threshold = 0.1)



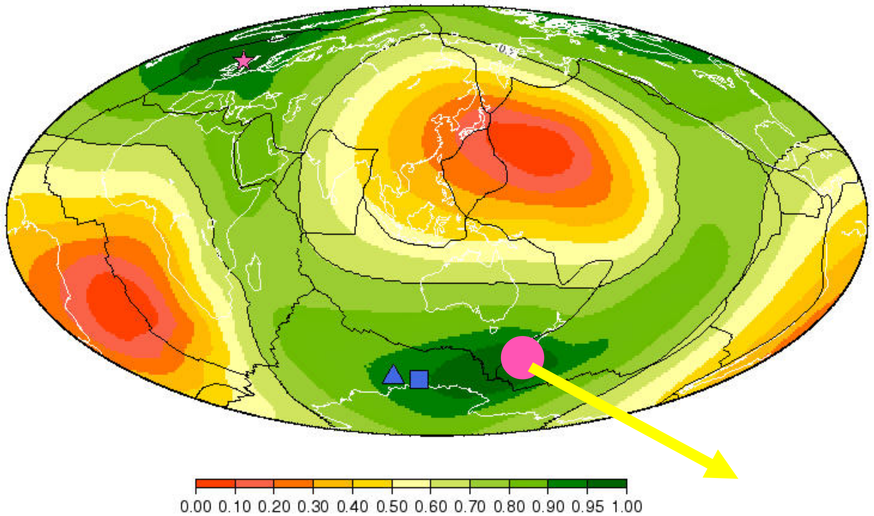
Cost funtion North Pacific Plate G

SKS-PREM-3SMAC-2002 model (threshold = 0.1)



Cost funtion global Pacific Plate G

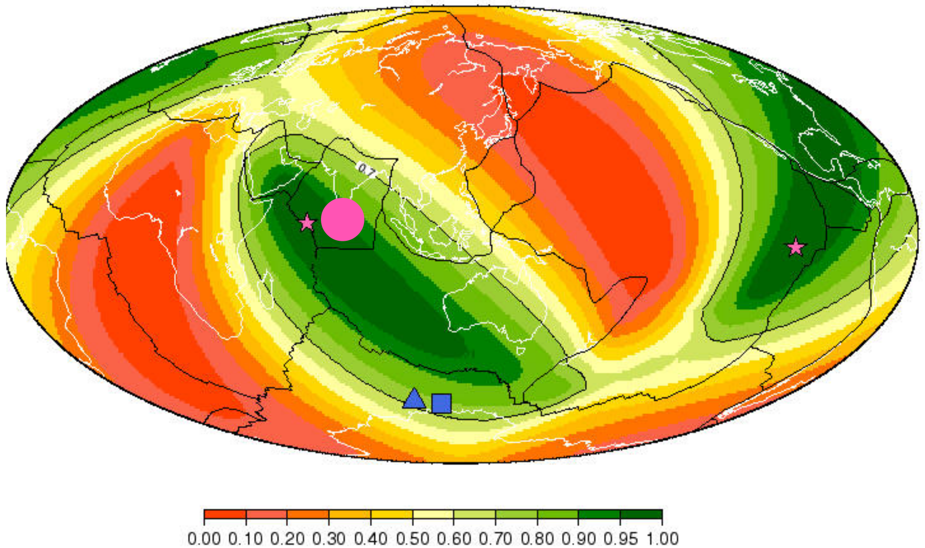
SKS-PREM-3SMAC-2002 model (threshold = 0.1)



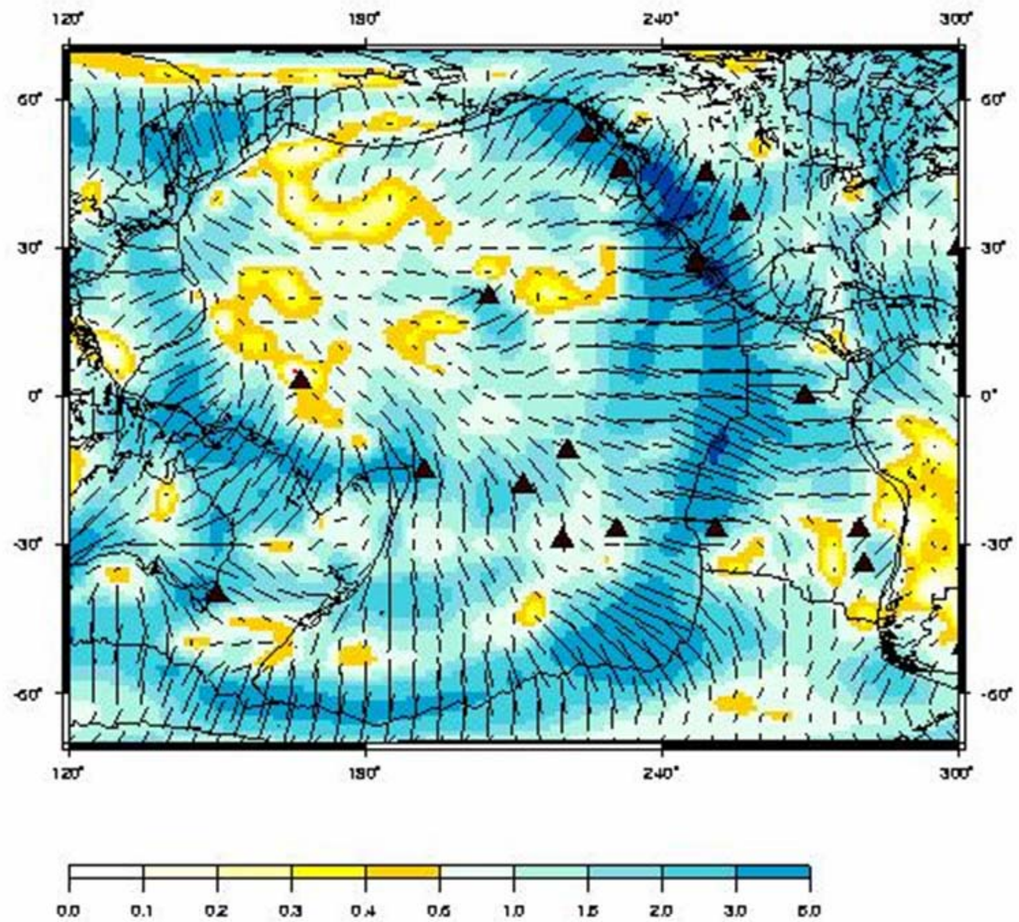
Ω_α

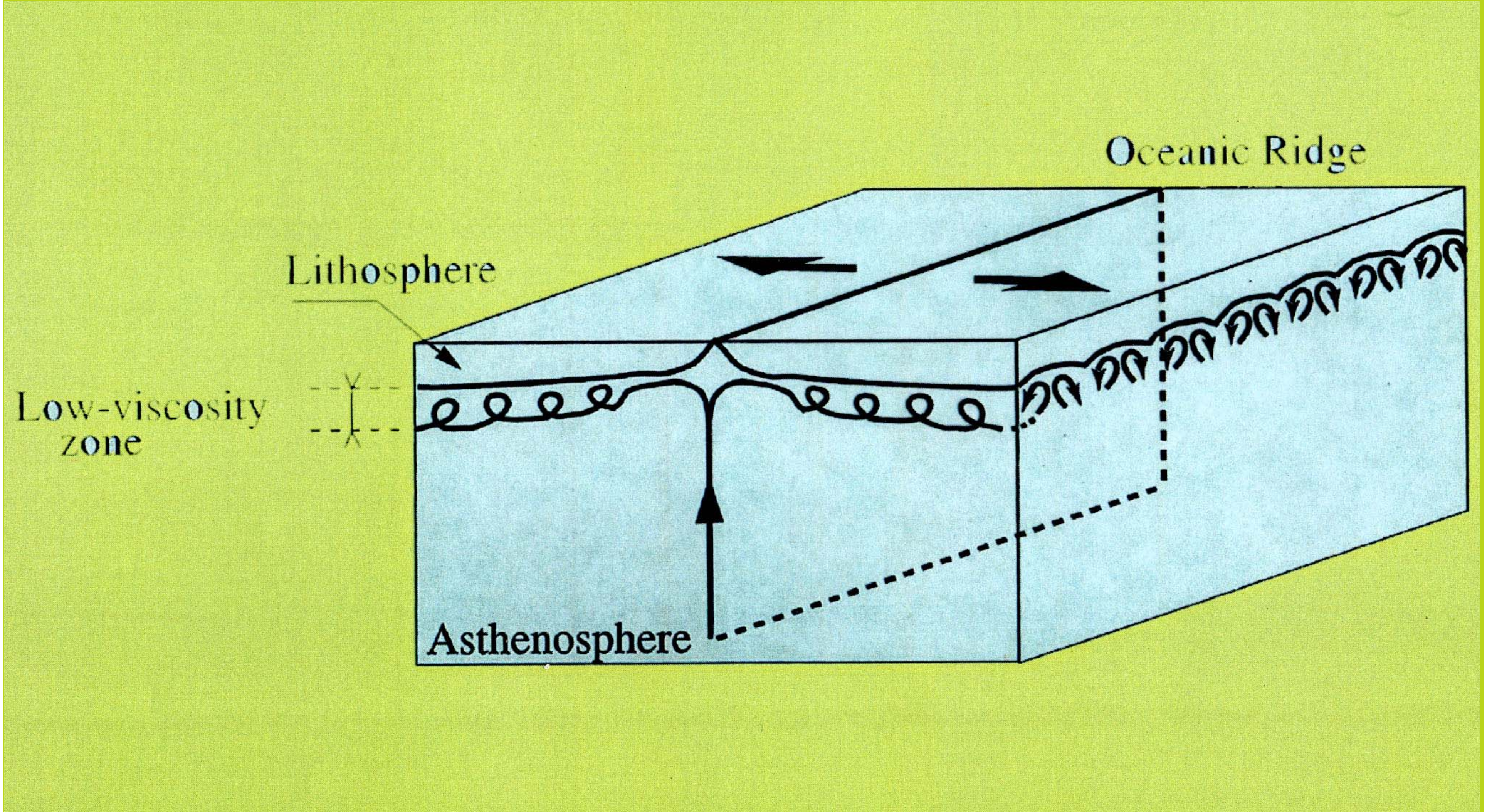
Cost funtion South Pacific Plate G

SKS-PREM-3SMAC-2002 model (threshold = 0.1)



G:Azim. Anis. Depth=100km

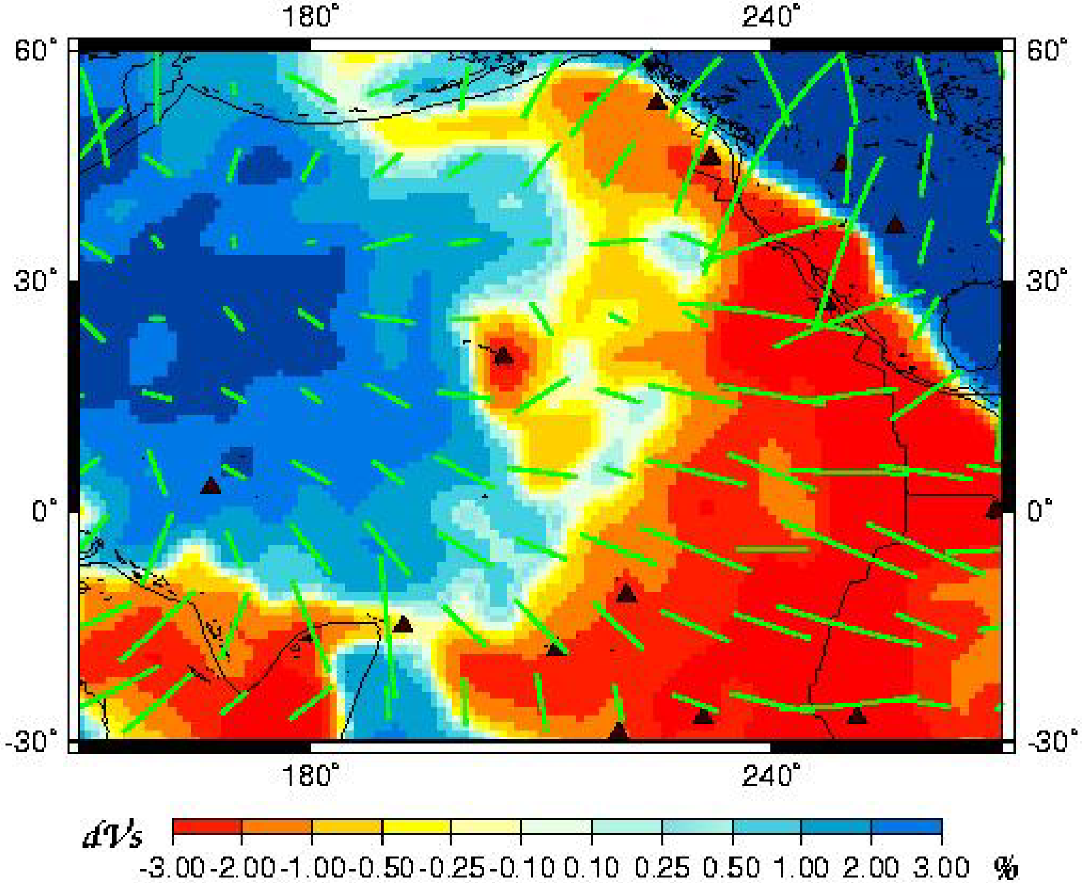


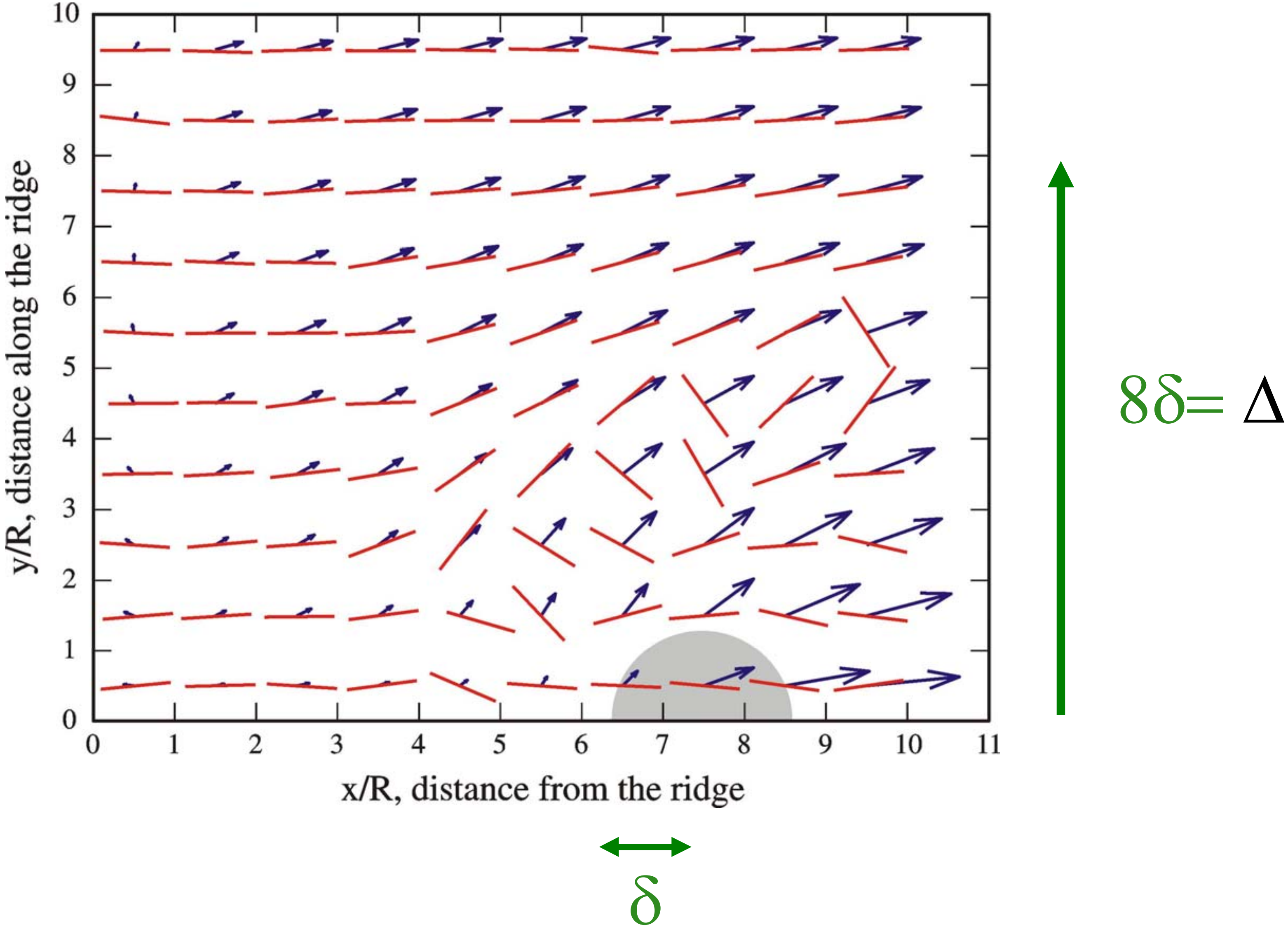


(Crambes and Davaille, 2002)

S-wave velocity + Azimuthal Anisotropy

Depth=120 km





(Kaminski and Ribe, 2001)

Δ≈ 2000km => δ ≈ 250km

Plume Detection

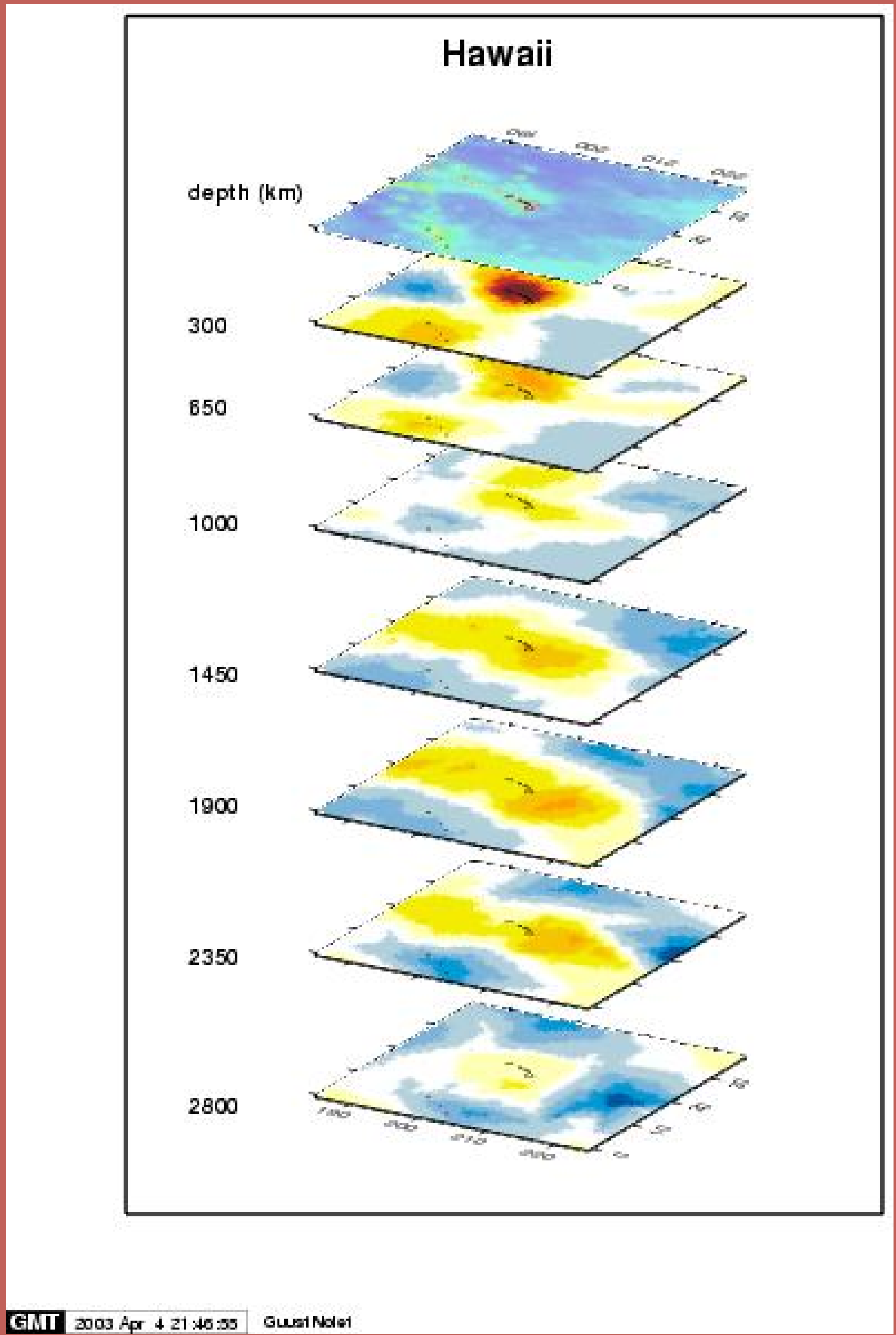
- ❑ Indirect detection of plumes through Azimuthal and Radial anisotropies.
- ❑ Two families of plumes have been detected:

- 1st kind is a consequence of small scale convection (<300km).
- 2nd kind originates from deep in the mantle: transition zone (410-660km).

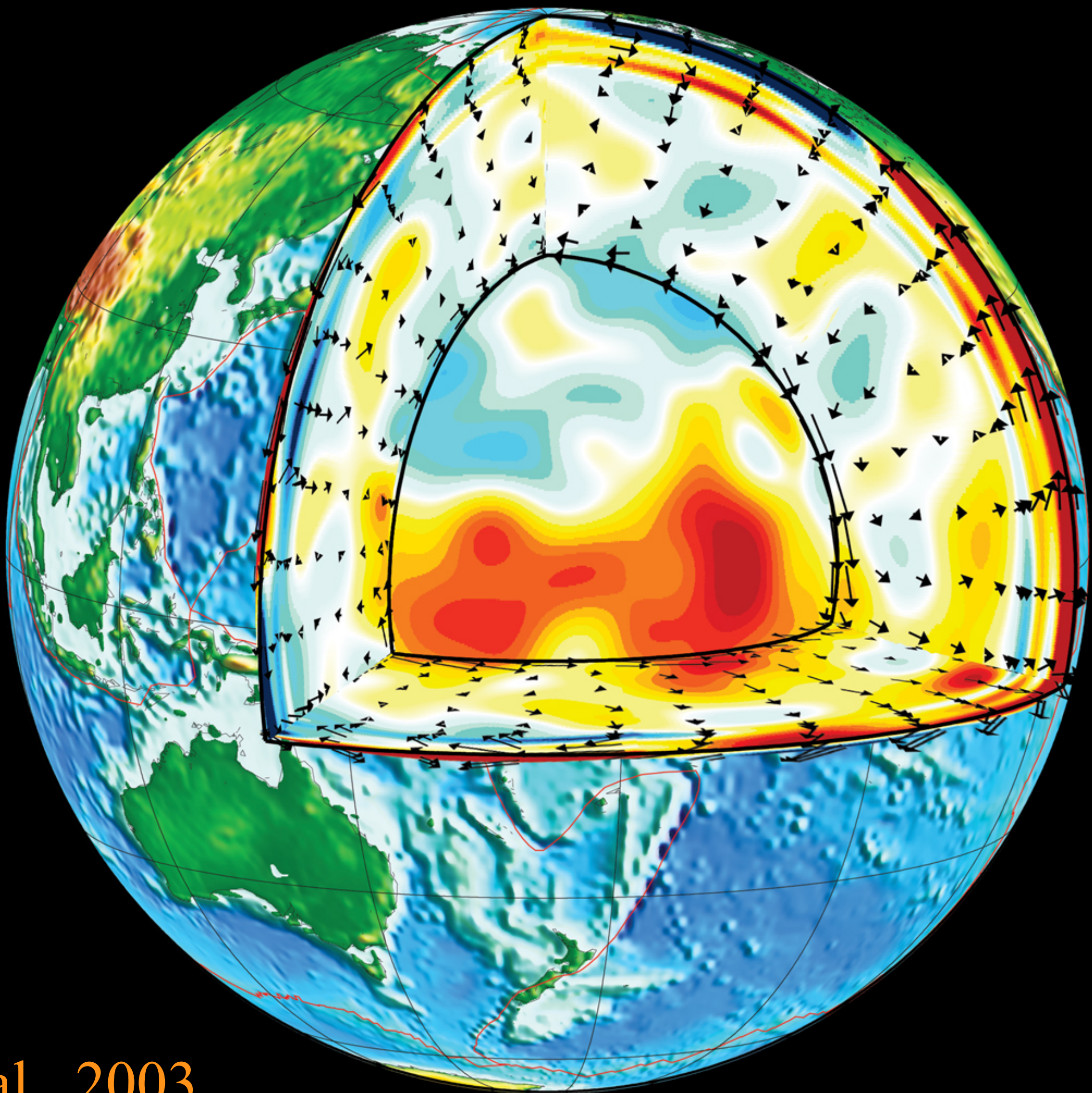
- ❑ Complex interaction Plume-lithosphere-asthenosphere:secondary scale of convection.
- ❑ Active hotspots in central Pacific and Africa participate to the reorganization of plate boundaries (New Plate boundaries).
- ❑ Lower Mantle plume not yet clearly detected because it cannot be detected with present seismic data
- ❑ Theoretical and Observational challenges

Banana-Doughnut Theory (Dahlen et al.)

Application to global tomography (Montelli et al., Science, 2004)

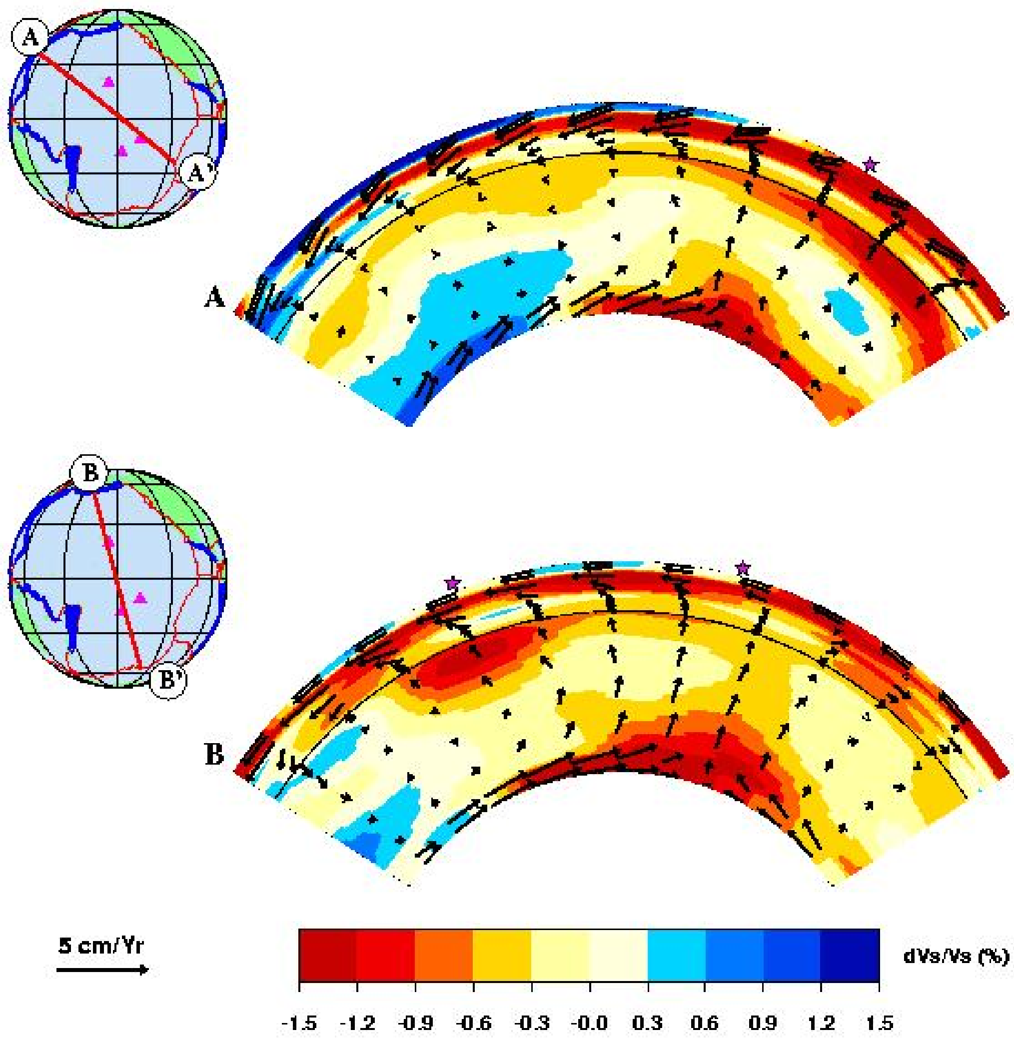


Anisotropy- Geodynamics Relationship



Gaboret et al., 2003

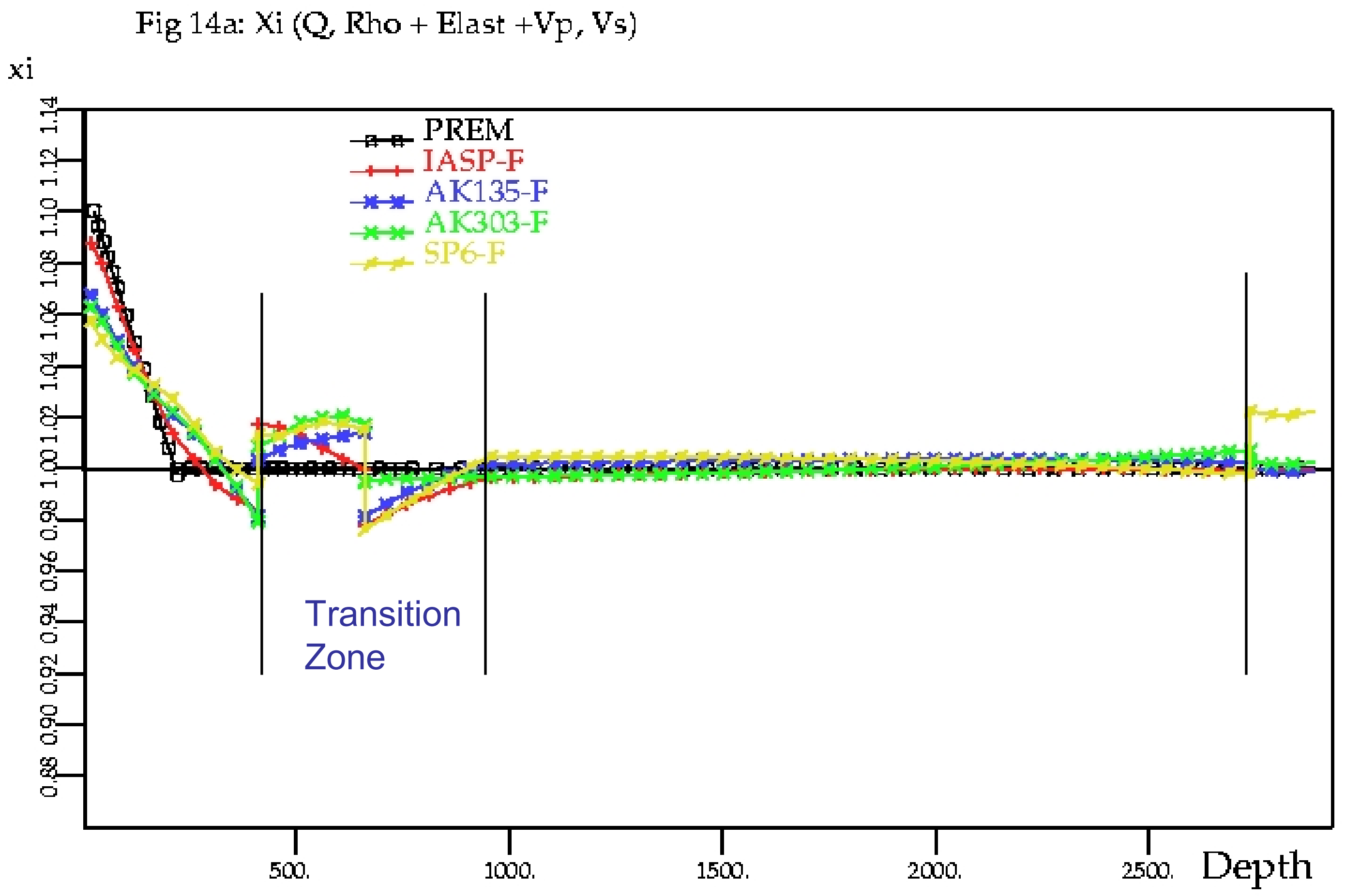
Anisotropy and Fluid dynamics modeling



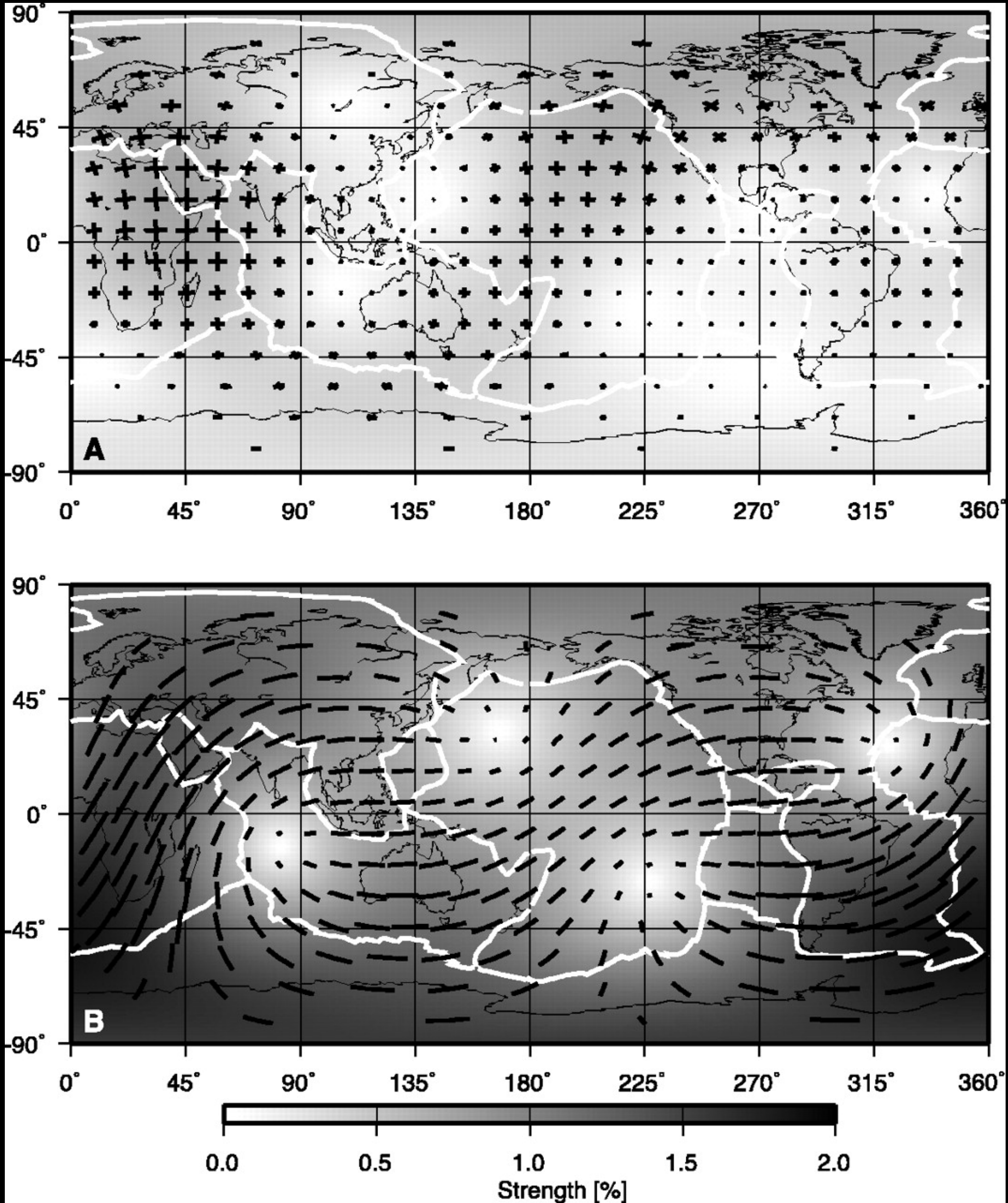
(Gaboret et al., 2003)

Anisotropy at larger depth

Average model of radial anisotropy ξ



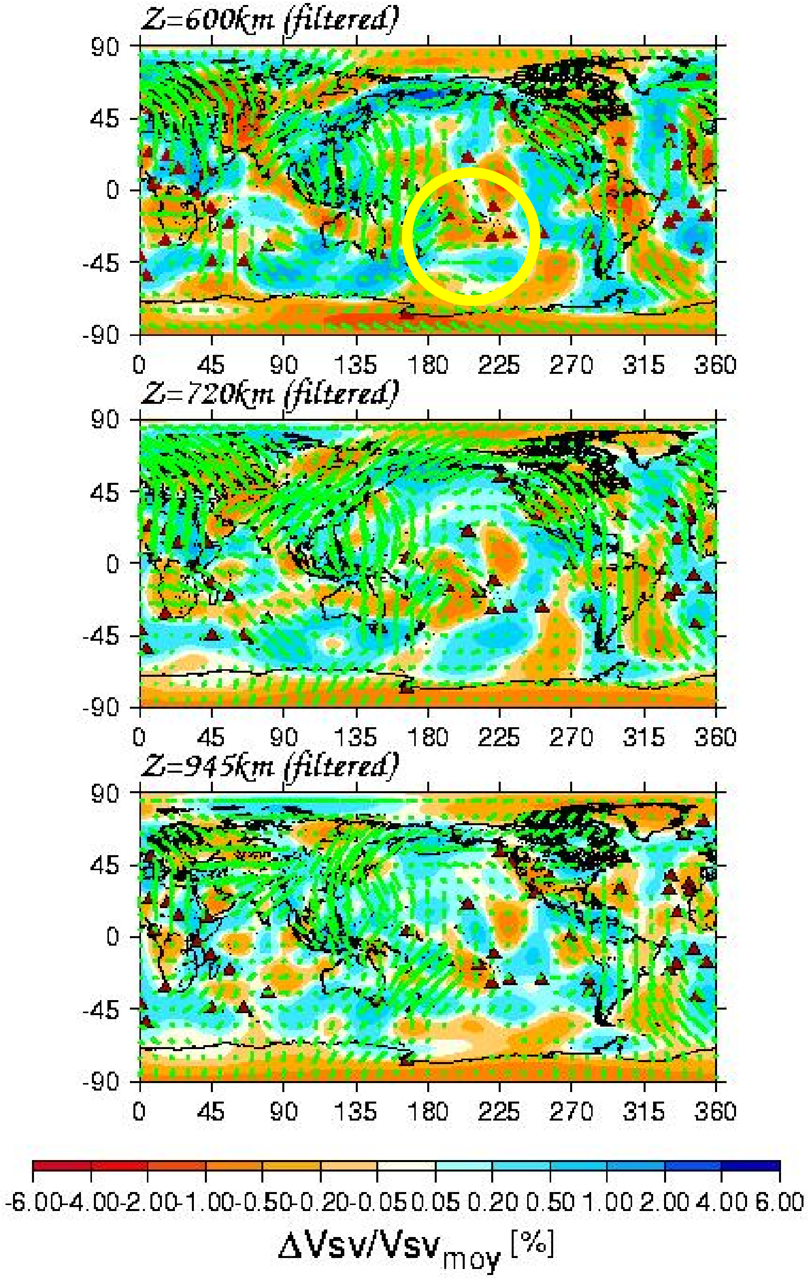
(Montagner and Kennett, 1996)



Trampert and van Heijst, 2002

Azimuthal Anisotropy G

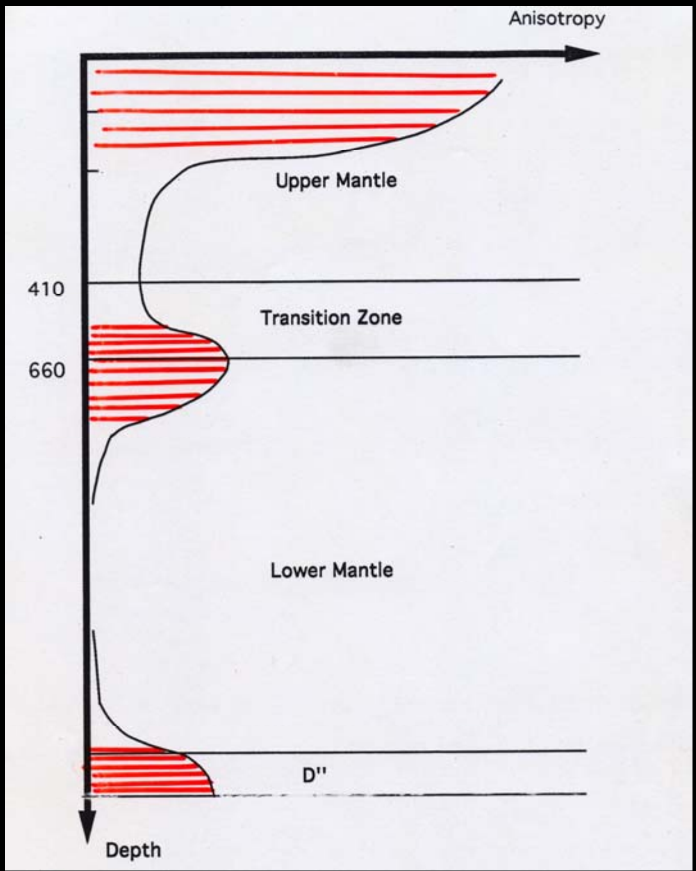
Depth: 650km

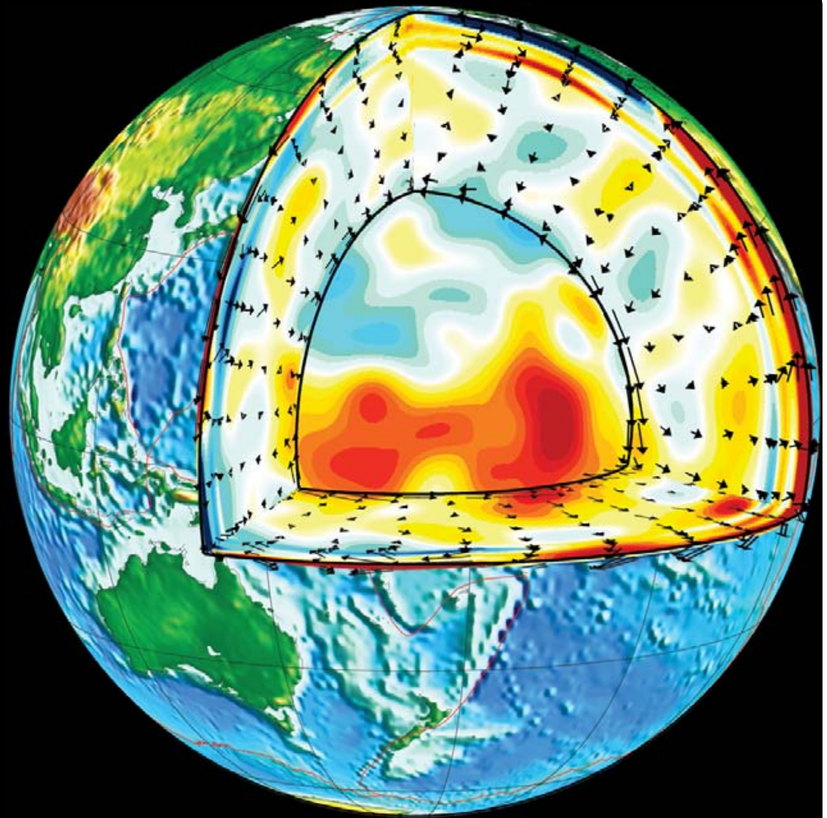


Beucler et al., 2006

CONCLUSIONS

-Heterogenous Anisotropy in the Transition zone
- Detection of boundary layers => **Need for numerical modeling**





Gaboret et al., 2003

CONCLUSIONS

- Progress in instrumentation (Ocean bottom, Planet Mars; Spatial exploration)
- Ray Theory - Normal Modes -> Numerical Methods more and more powerful and accurate by using more and more powerful computers.
- From Global scale towards regional scale- Incorporation of new parameters (anisotropy, anelasticity) in tomography
- Systematic Multidisciplinary Approach: Confrontation of seismological results with numerical and laboratory experiments