# グローバル地震観測

地震研究所
海半球観測研究センター
川勝　均

グローバル地震観測網（定常／機動）
震源解析（ＣＭＴ）
地震波トモグラフィー
　マントル
　遷移層
　ＣＭＢ
　内核
次世代観測網の展開
青い地球の地震学

## Global Seismic Network
## - 0th generation -

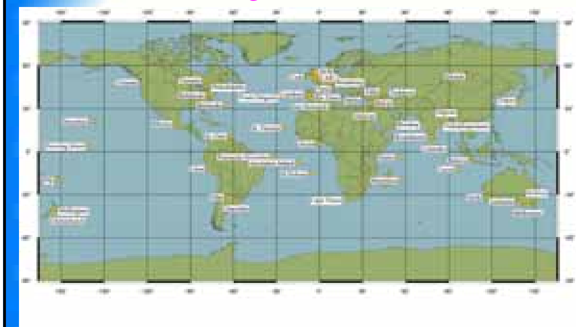
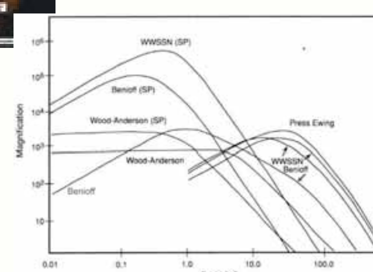


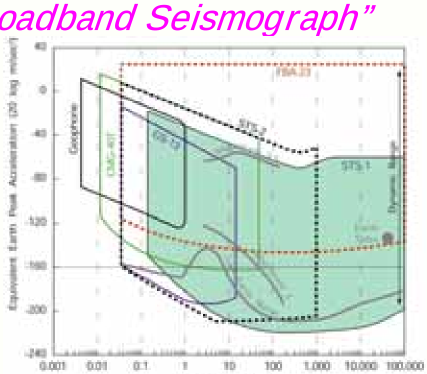
Figure 1. World wide network of stations reporting data to Milne at Shide, around 1910.

## World-Wide Standardized Seismograph Network (WWSSN)

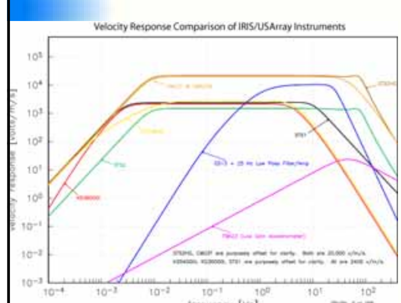

## WWSSN



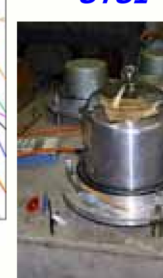

## -Current Generation-
## "Broadband Seismograph"

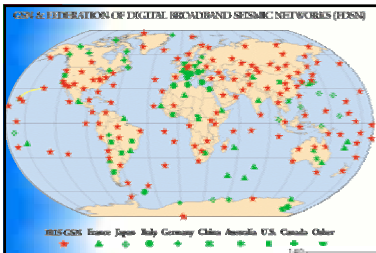



## Broadband Seismograph

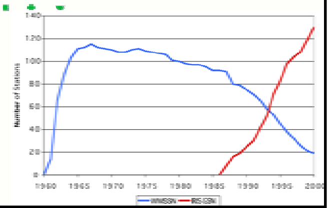



"STS1"

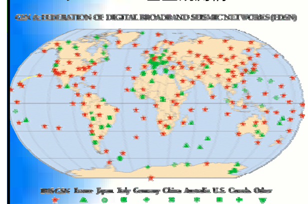




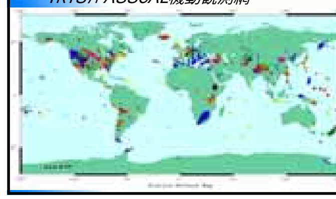

## IRIS/GSN & FDSN




グローバル基盤観測網

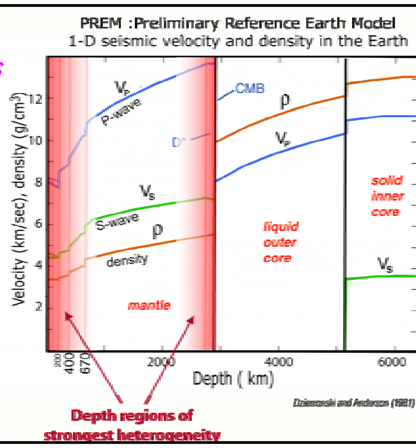



IRIS/PASSCAL機動観測網

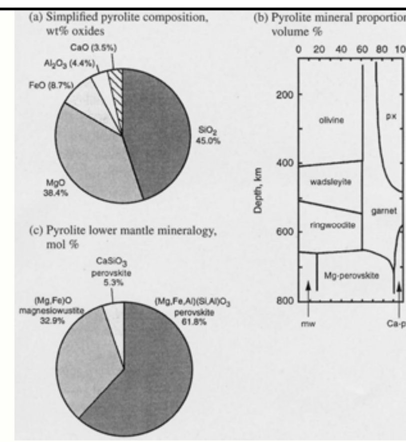


J-array/Hi-net

## Earth Models




## Pyrolite



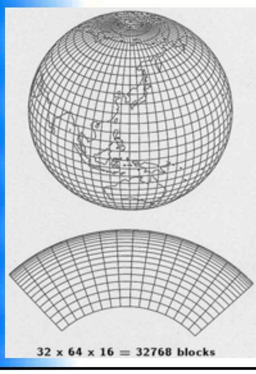

## 地球の層構造

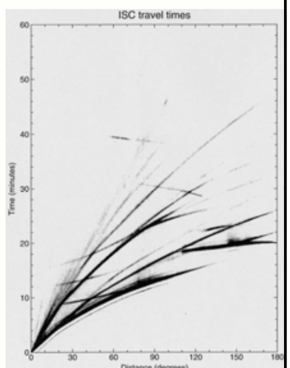

## Gloabal tomographic models

bodywave

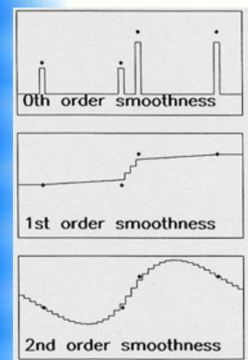
- ISC travel times
  - *Dziewonski 1977, 1984, ...* van *der Hilst.., ..**Fukao**...*
- Differential traveltime by cross-correlation
  - *Woodward&Masters, Su&Dziewonski,...*
- Waveform measurement
  - ***Grand** (1994, 2001)*
- Waveform inversion
  - *Li&Tanimoto, Li&Romanowicz, Takeuchi&Geller*
- Banana doughnut: finite-frequency traveltime
  - *Dahlen&Nolet...*

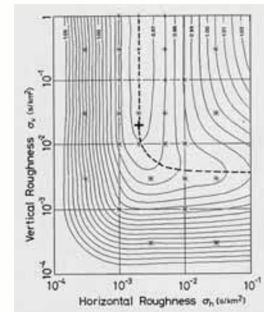
## Inoue et al. (1990)



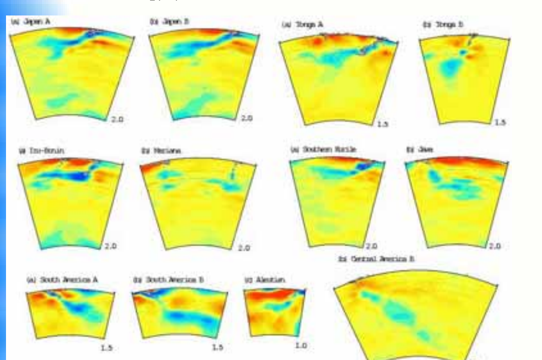




## Regularization !

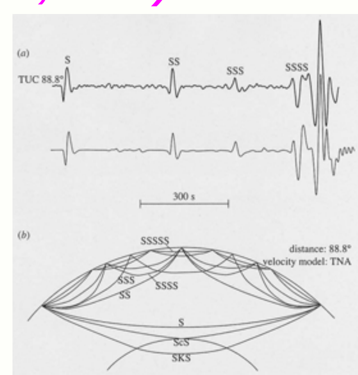


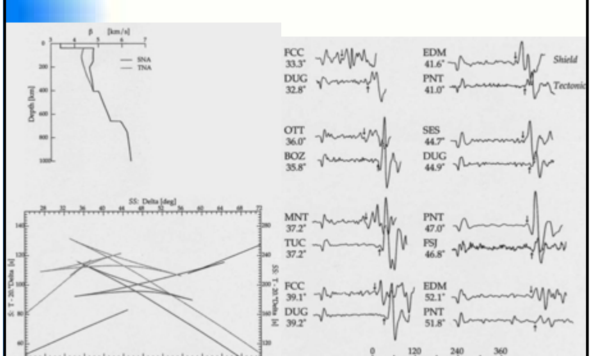



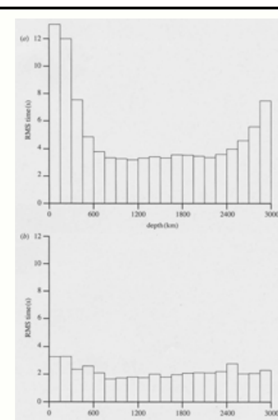

## 横たわるスラブ

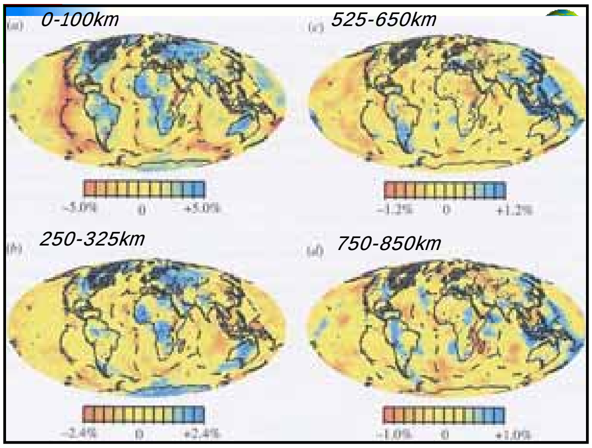


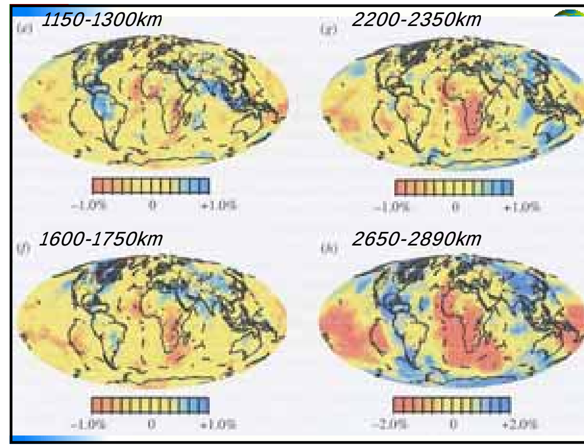
## Grand (1994, 2002)

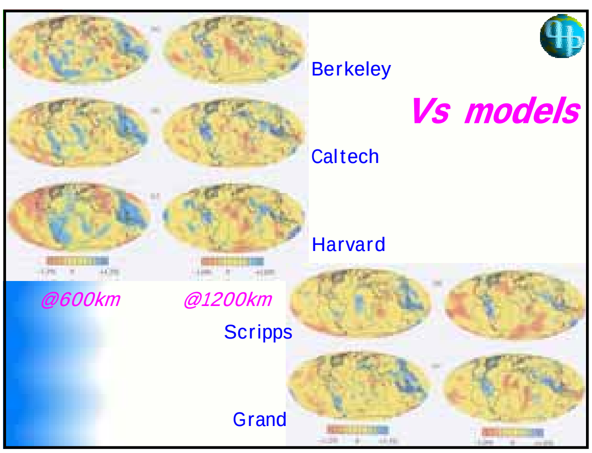


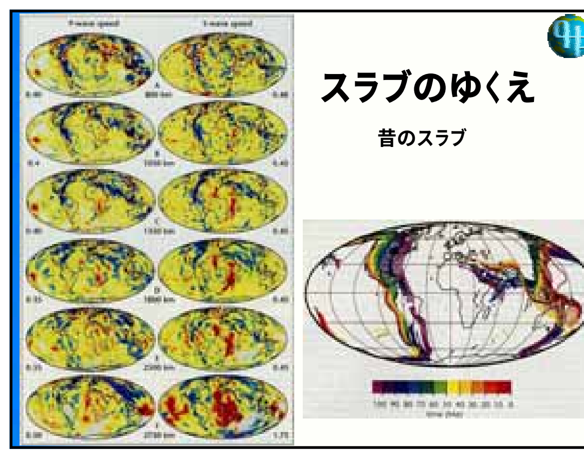



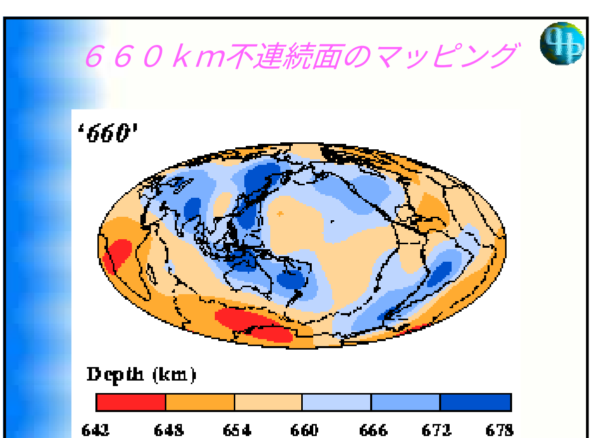



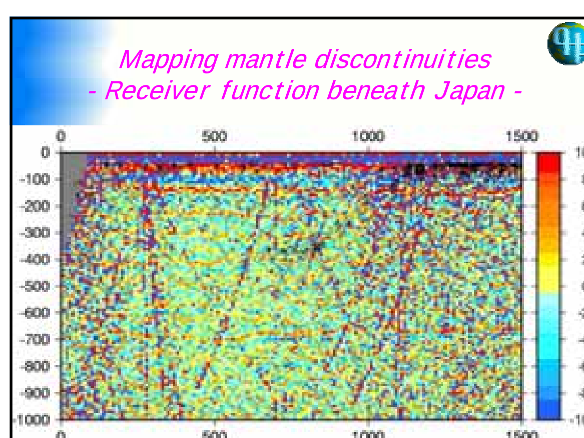

0-100km
525-650km
-5.0% 0 +5.0%
-1.2% 0 +1.2%
250-325km
750-850km
-2.4% 0 +2.4%
-1.0% 0 +1.0%


1150-1300km
2200-2350km
-1.0% 0 +1.0%
-1.0% 0 +1.0%
1600-1750km
2650-2890km
-1.0% 0 +1.0%
-2.0% 0 +2.0%


Berkeley
Vs models
Caltech
Harvard
@600km
@1200km
Scripps
Grand


スラブのゆくえ
昔のスラブ


６６０ｋｍ不連続面のマッピング
'660'
Depth (km)
642
648
654
660
666
672
678


Mapping mantle discontinuities
- Receiver function beneath Japan -
0
500
1000
1500
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
10
8
6
4
2
-2
-4
-6
-8
-10

# Mantle Tomography

## *-beyond color maps-*

- Karato (1993) *GRL, 20, 1623-1626*
- Masters et al. (2000)
  in "*Earth's Deep Interior*" (AGU monograph)
- Forte & Mitrovica (2001) *Nature, 410, 1049-1056*
- Davaille (1999) *Nature, 402, 756-760*
- Karato & Kariki (2001) *JGR, 106, 21771-21783*
- Saltzer, Stutzmann & van der Hilst (2004)
  *JGR, 109,B06301*

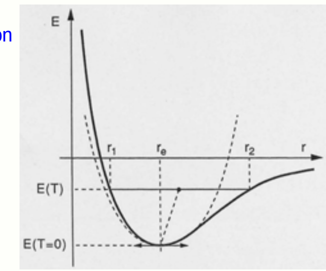
*scaling: $\delta \ln Vs \sim \delta \ln Vp \sim \delta \ln \rho$?*

# Thermal effects

*anharmonicity vs. anelasticity*

*Karato (1993) GRL*

anharmonicity
= thermal expansion




Karato (1993)

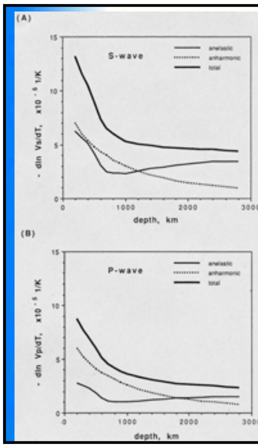
For constant Q

$$V(\omega, T) = V_0(T)(1 + \frac{1}{Q\pi} \ln \omega\tau(T))$$

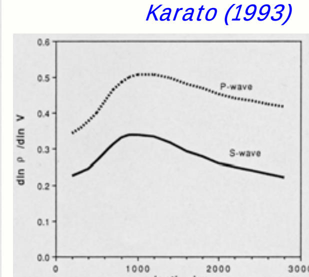
$$\tau(T) = \tau_0 \exp(H^*/RT)$$

$$\partial \ln V/\partial T = \partial \ln V_0/\partial T - \frac{1}{Q\pi}(H^*/RT^2)$$

$$(Q^{-1} \ll 1)$$



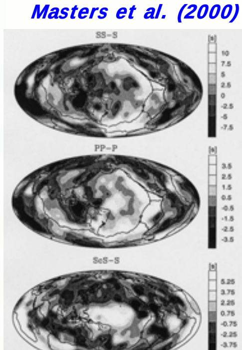

*Karato (1993)*

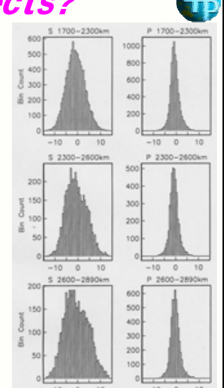



# *Chemical effects?*

***Masters et al. (2000)***

***Vp***
***vs***
***Vs***
***vs***
***Vc***



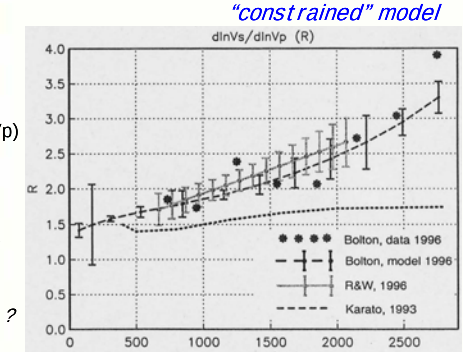



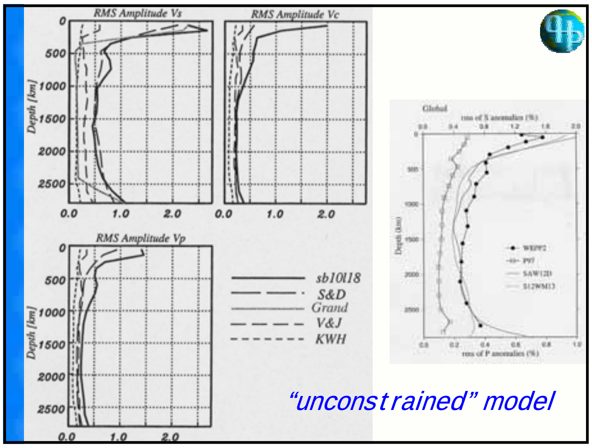

# *Joint inversion (P & S)*

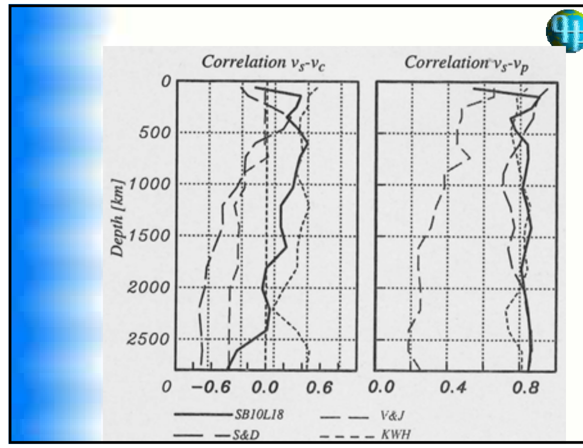
*"constrained" model*

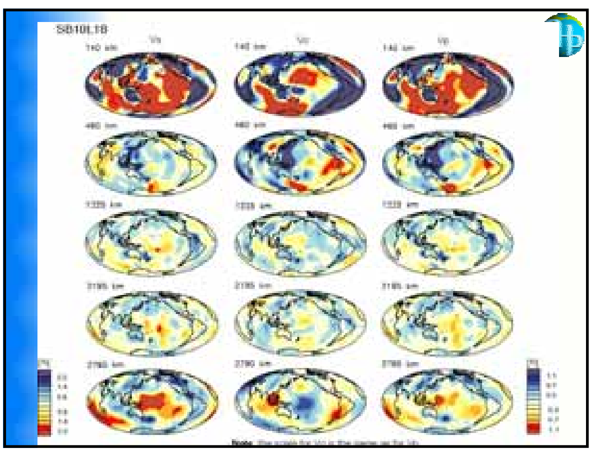
sign(dlnVs)
~ sign(dlnVp)

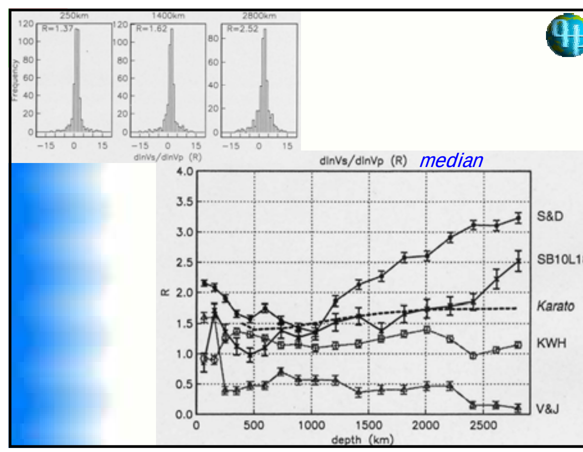
*biased by localized low Vs anomalies ?*

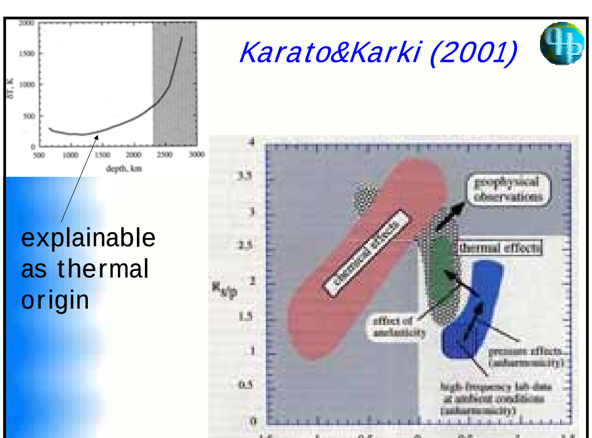


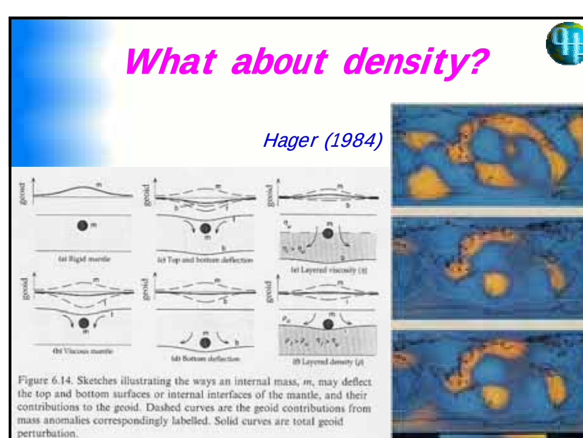

RMS Amplitude Vs
RMS Amplitude Vc
RMS Amplitude Vp
Depth [km]
sb10l18
S&D
Grand
V&J
KWH
“unconstrained” model

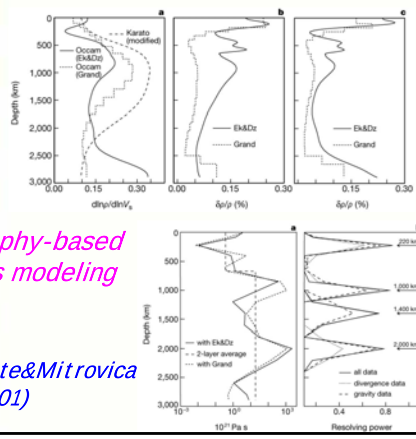

Correlation $v_s$-$v_c$
Correlation $v_s$-$v_p$
Depth [km]
SB10L18
S&D
V&J
KWH


SB10L18


250km
1400km
2800km
dlnVs/dlnVp (R)
median
S&D
SB10L18
Karato
KWH
V&J
depth (km)


Karato&Karki (2001)
explainable as thermal origin
depth, km
geophysical observations
thermal effects
effect of anelasticity
pressure effects (anharmonicity)
high-frequency lab data at ambient conditions (anharmonicity)


What about density?
Hager (1984)
Figure 6.14. Sketches illustrating the ways an internal mass, m, may deflect the top and bottom surfaces or internal interfaces of the mantle, and their contributions to the geoid. Dashed curves are the geoid contributions from mass anomalies correspondingly labelled. Solid curves are total geoid perturbation.




*Tomography-based dynamics modeling*

*Forte&Mitrovica (2001)*

Forte and Mitrovica (2001)

$$\delta \ln V_s = \frac{\partial \ln V_s}{\partial T}\delta T + \frac{\partial \ln V_s}{\partial X_{Pv}}\delta X_{Pv} + \frac{\partial \ln V_s}{\partial X_{Fe}}\delta X_{Fe}$$

$$\delta \ln V_\phi = \frac{\partial \ln V_\phi}{\partial T}\delta T + \frac{\partial \ln V_\phi}{\partial X_{Pv}}\delta X_{Pv} + \frac{\partial \ln V_\phi}{\partial X_{Fe}}\delta X_{Fe}$$

$$\delta \ln \rho = \frac{\partial \ln \rho}{\partial T}\delta T + \frac{\partial \ln \rho}{\partial X_{Pv}}\delta X_{Pv} + \frac{\partial \ln \rho}{\partial X_{Fe}}\delta X_{Fe}$$

$$\delta \ln V_s = c_{11}\delta T_{eff} + c_{12}\delta X_{eff}$$

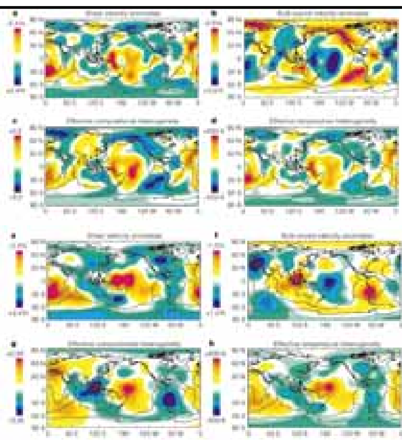
$$\delta \ln V_\phi = c_{21}\delta T_{eff} + c_{22}\delta X_{eff} \qquad (c_{11} \gg c_{21})$$

$$\delta X_{eff} = \delta X_{Pv} + B\,\delta X_{Fe}$$

$$\delta T_{eff} = \delta T + A\,\delta X_{Fe} \sim \delta T + \epsilon \quad (\epsilon < 10K)$$

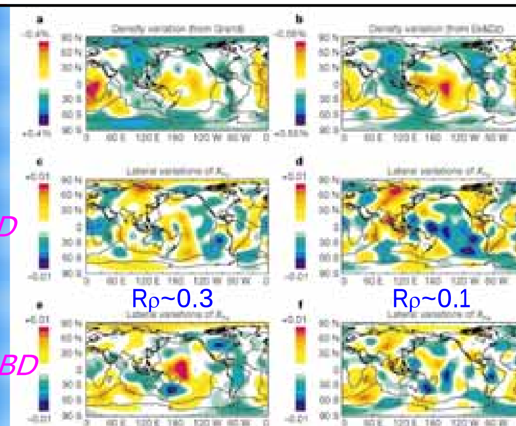
*S&D*

*MLBD*



*S&D*

*MLBD*




Rρ~0.3 Rρ~0.1

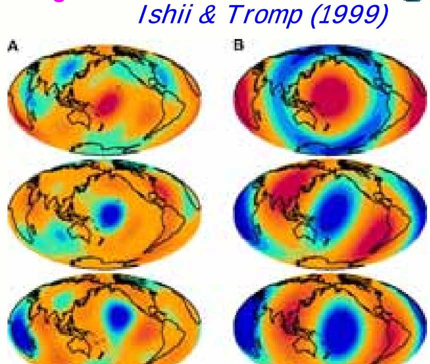
Mode splitting?

*Ishii & Tromp (1999)*

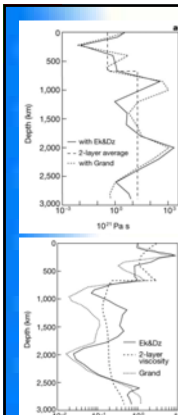
Vs

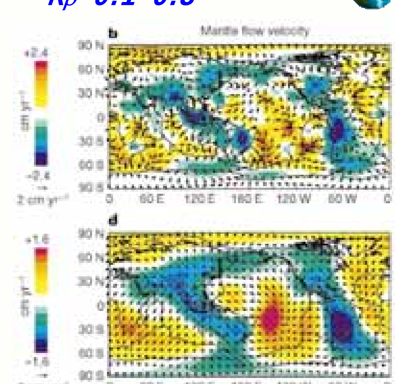
Vc

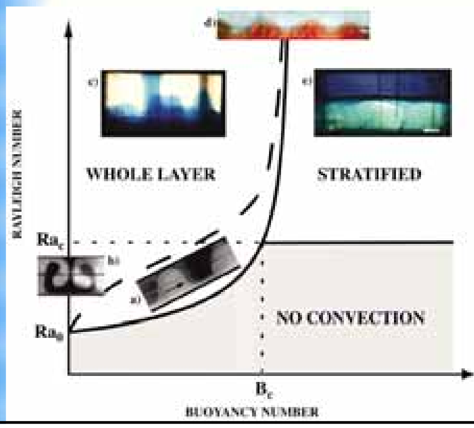
ρ




***Rρ~0.1-0.3***

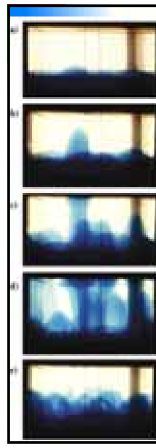


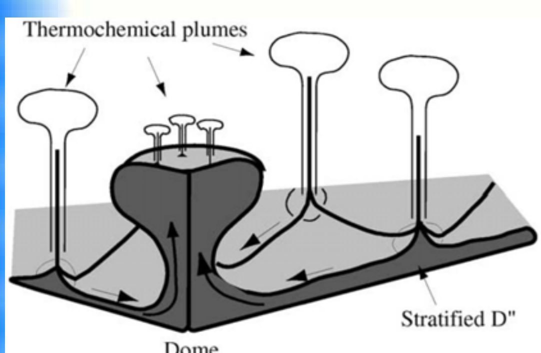



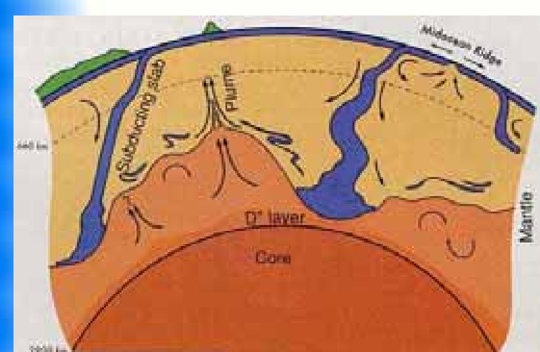



# Convection in chemically stratified mantle?

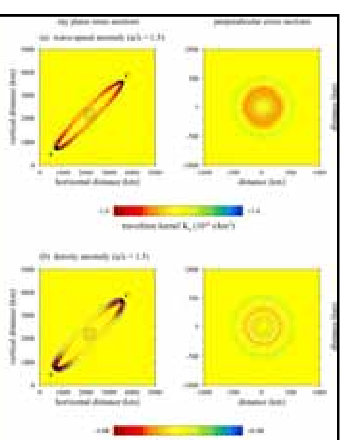
Davaille (1999)



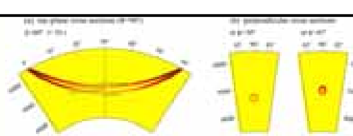


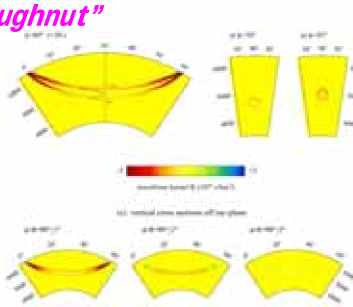




# Finite frequency traveltime tomography:



# "Banana doughnut"



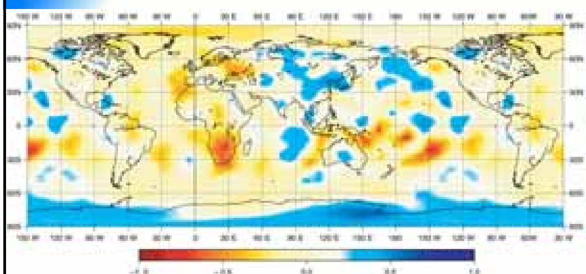


## *Fine scale structures: plume?*

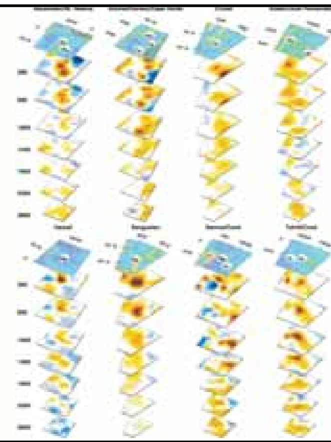
data: ISC + PP-P

Lowermost 1000km

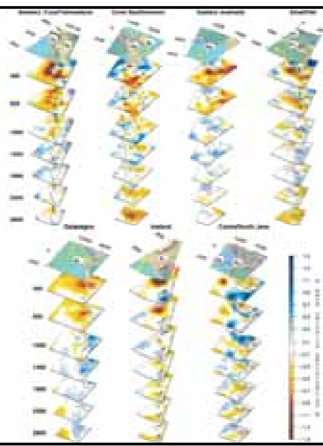
*Montelli et al. (2004)*



## *Deep plumes*



## *Shallow plumes*

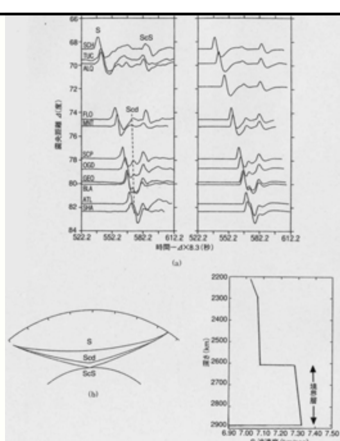


*"fade at mid-mantle depth ???"*

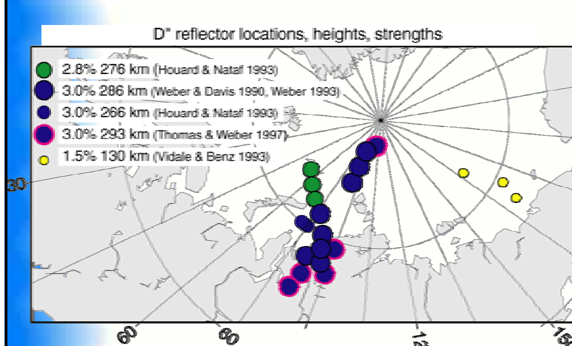
## *CMBの不思議*

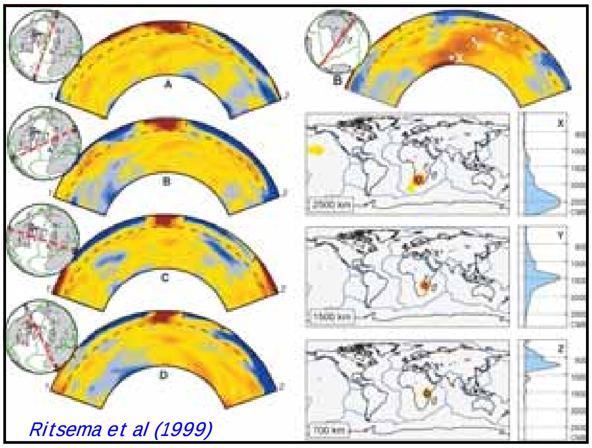
- D" discontinuity
- Chemical heterogeneity?
- Ultra Low Velocity Zone (ULVZ)
- Post-Perovskite phase transition
- Anisotropy

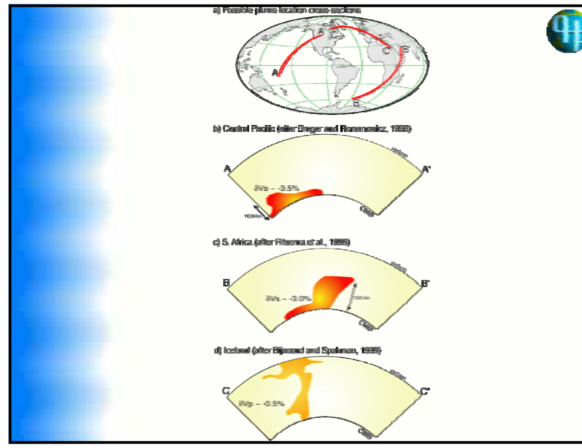
## D"

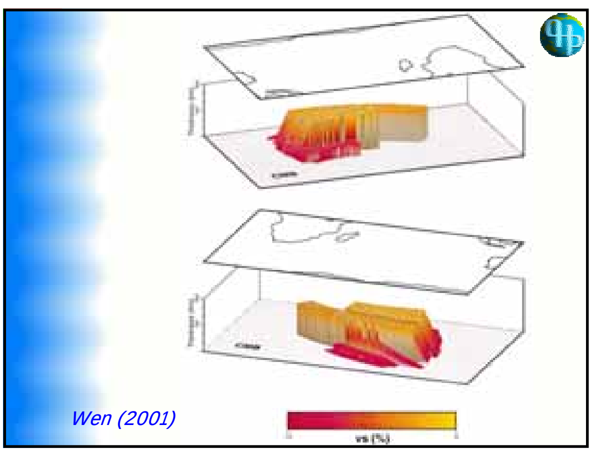


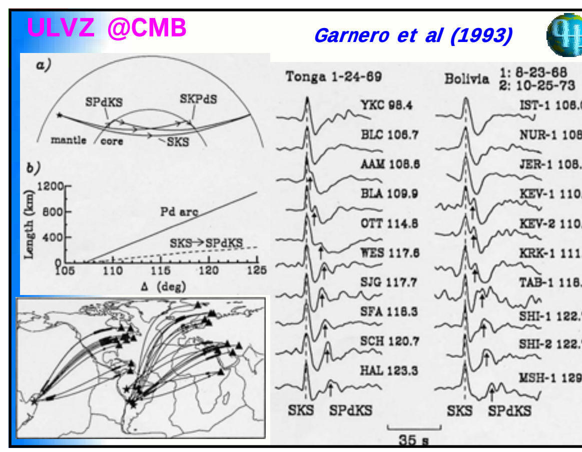
## *Small scale lateral variation*

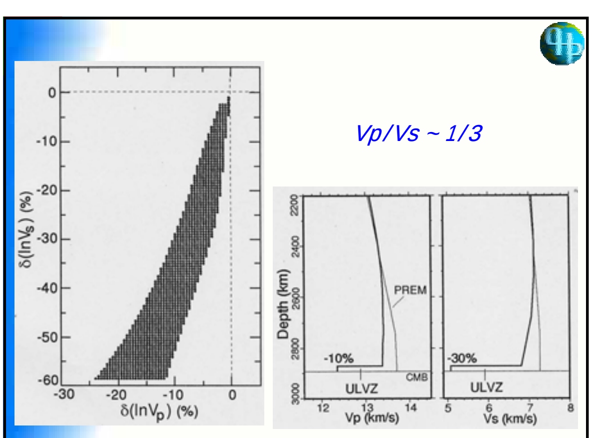


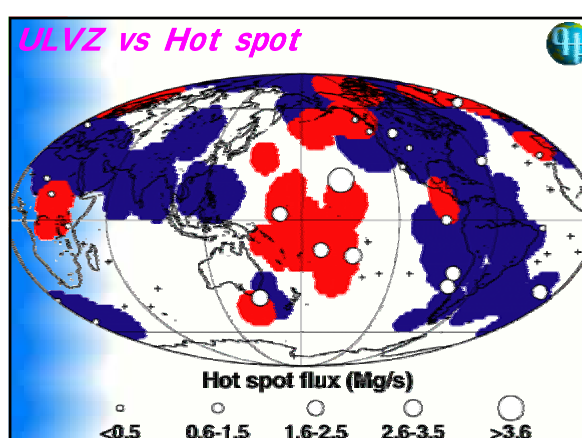

A
B
C
D
X
Y
Z
2500 km
1500 km
700 km
Ritsema et al (1999)

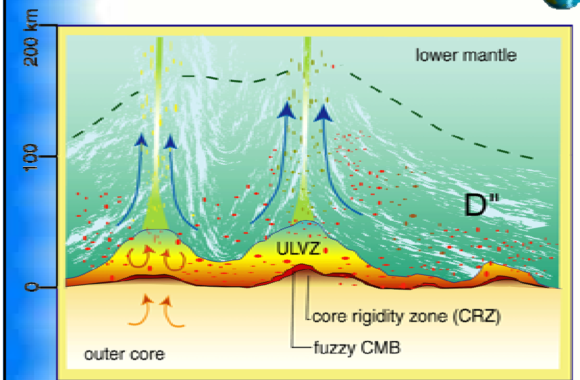

A
A'
B
B'
C
C'


Wen (2001)
vs (%)


ULVZ @CMB
Garnero et al (1993)
a)
SPdKS
SKPdS
mantle
core
SKS
b)
Length (km)
1200
800
400
0
Pd arc
SKS→SPdKS
105
110
115
120
125
Δ (deg)
Tonga 1-24-69
YKC 98.4
BLC 106.7
AAM 108.6
BLA 109.9
OTT 114.8
WES 117.6
SJG 117.7
SFA 118.3
SCH 120.7
HAL 123.3
SKS SPdKS
Bolivia
1: 8-23-68
2: 10-25-73
IST-1 106.0
NUR-1 108.1
JER-1 108.5
KEV-1 110.6
KEV-2 110.7
KRK-1 111.7
TAB-1 118.6
SHI-1 122.7
SHI-2 122.7
MSH-1 129.1
SKS SPdKS
35 s

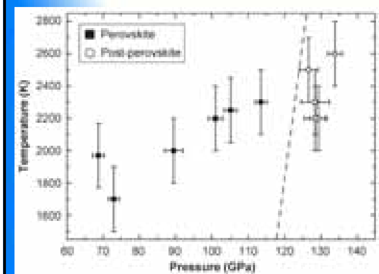

Vp/Vs ~ 1/3
δ(lnVs) (%)
δ(lnVp) (%)
0
-10
-20
-30
-40
-50
-60
-30
-20
-10
0
Depth (km)
2200
2400
2600
2800
3000
PREM
-10%
-30%
ULVZ
CMB
ULVZ
12
13
14
Vp (km/s)
5
6
7
8
Vs (km/s)

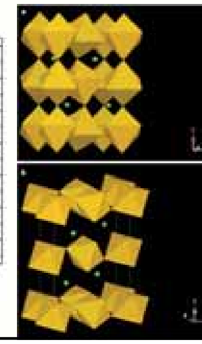

ULVZ vs Hot spot
Hot spot flux (Mg/s)
<0.5
0.6-1.5
1.6-2.5
2.6-3.5
>3.6

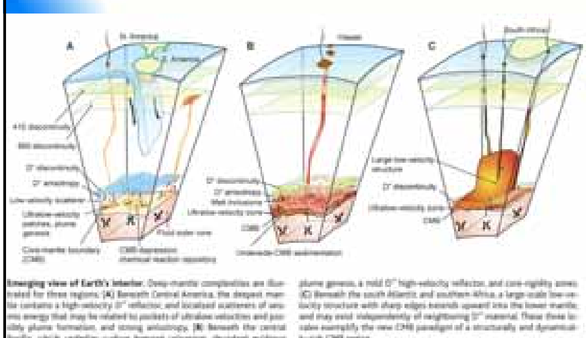



## Post-Perovskite phase transition

*Hirose*





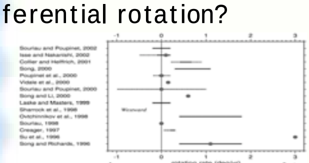
*Garnero (2004)*

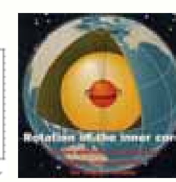
## Inner Core
## - seismological context -

Least studied region of the Earth

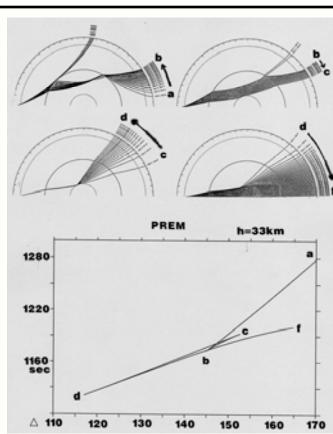
- *-axisymmetric anisotropy*
- *-hemispherical heterogeneity (L=1)*
- *-absence of tomographic model*
- *-no bodywave S wave (PKJKP)*

Differential rotation?

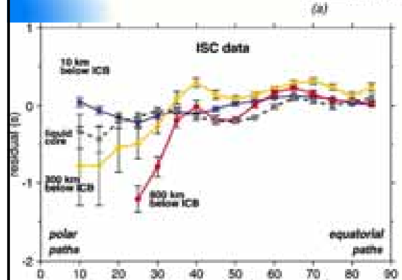


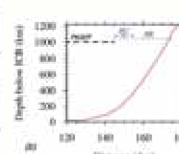




## Core phases



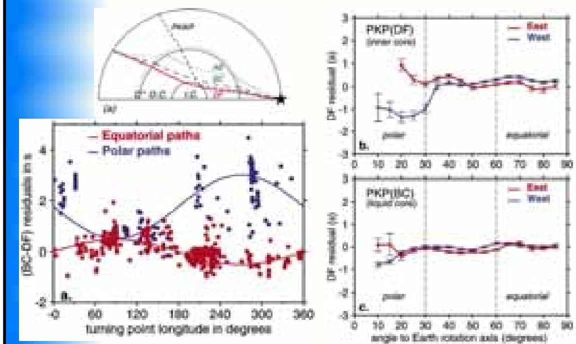

## Inner Core anisotropy

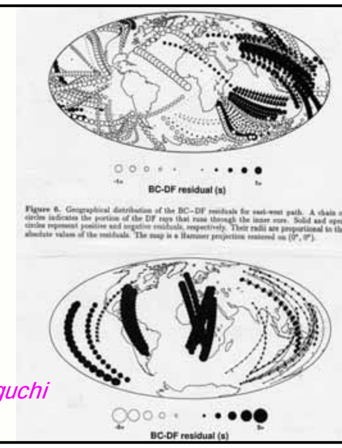



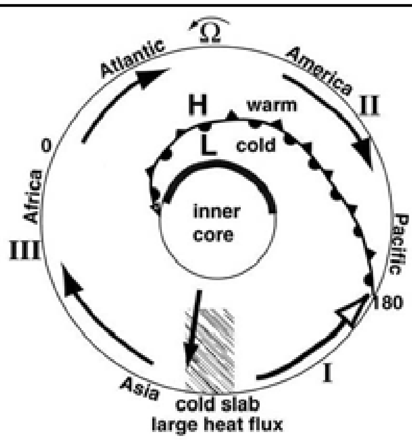

*Souriou (2003)*

## Hemispherical Heterogeneity

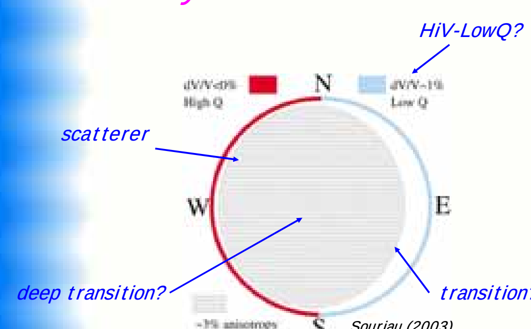



Tanaka&Hamaguchi (1997)

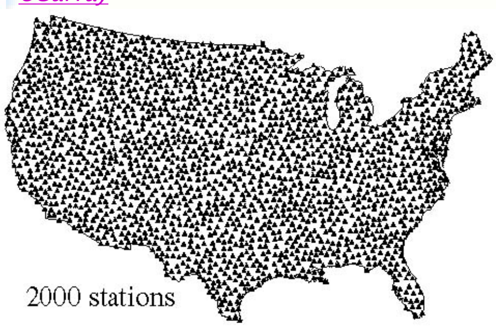



## Summary




J-array/Hi-net

USarray




## 海底機動観測