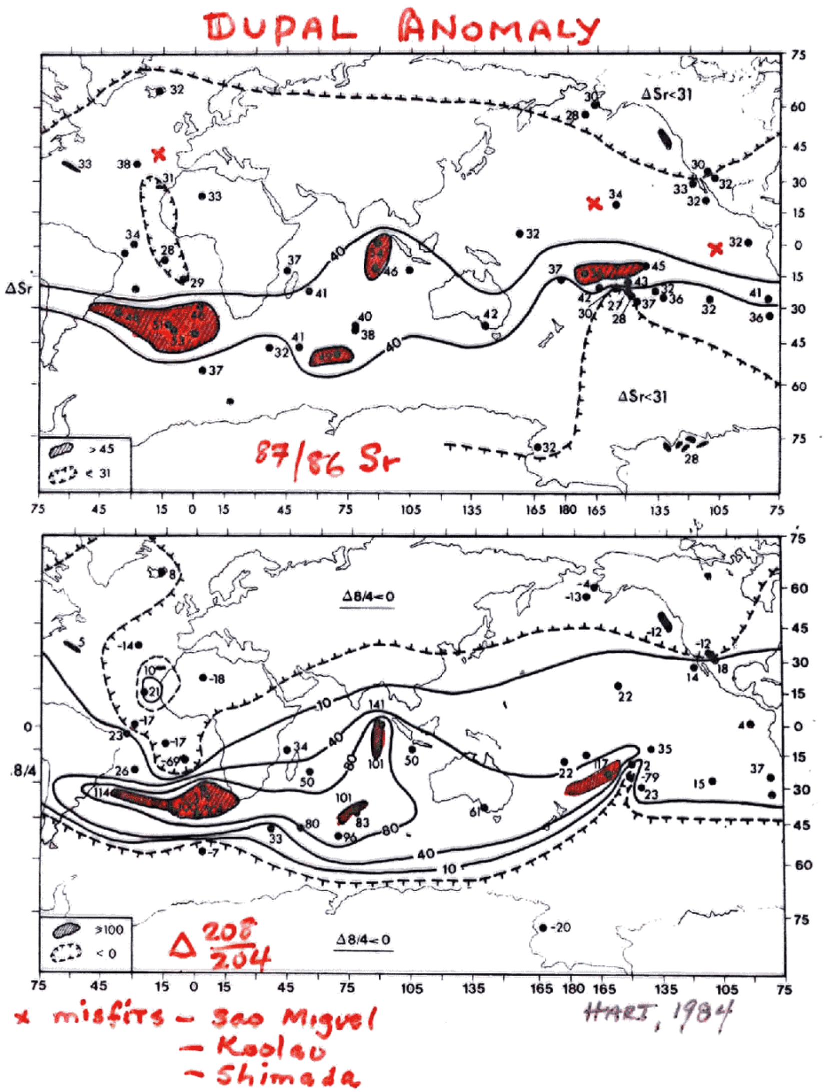


– Mixing of a mantle domain during convection

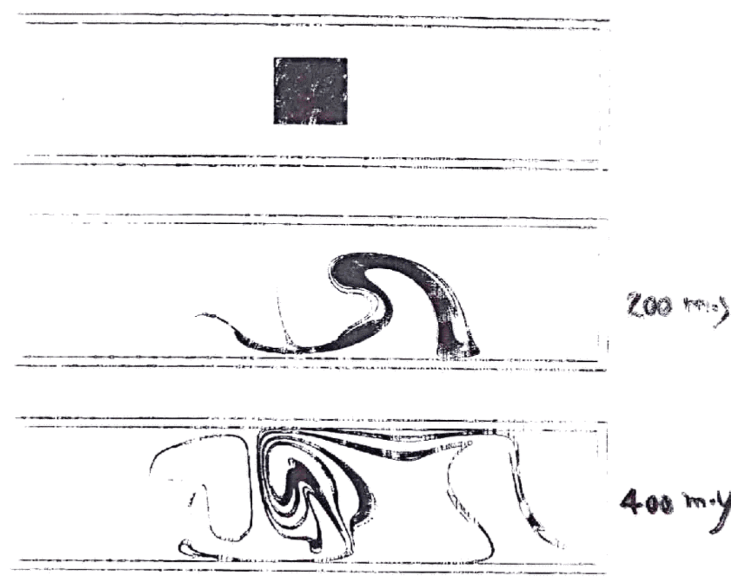
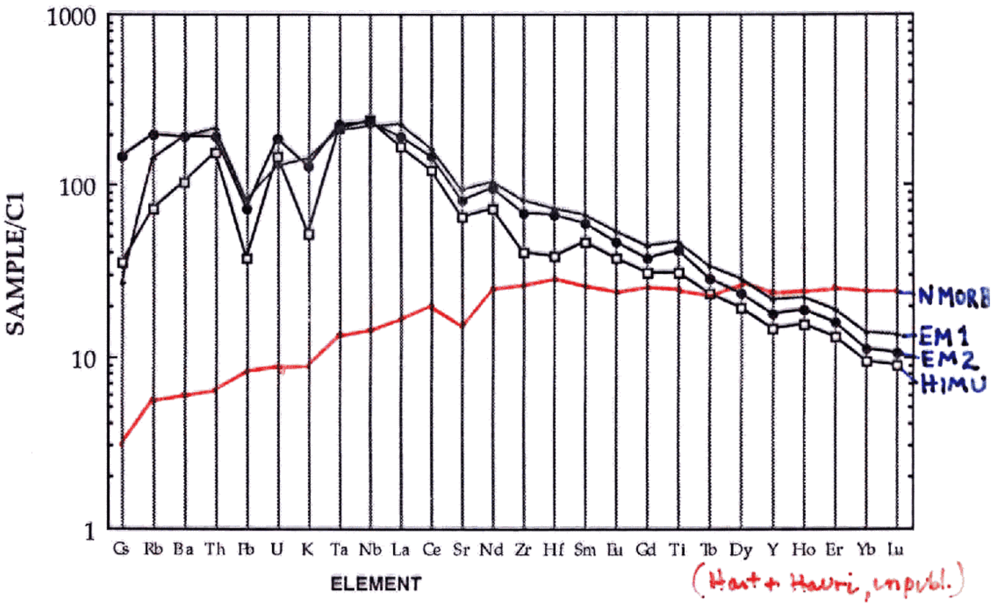


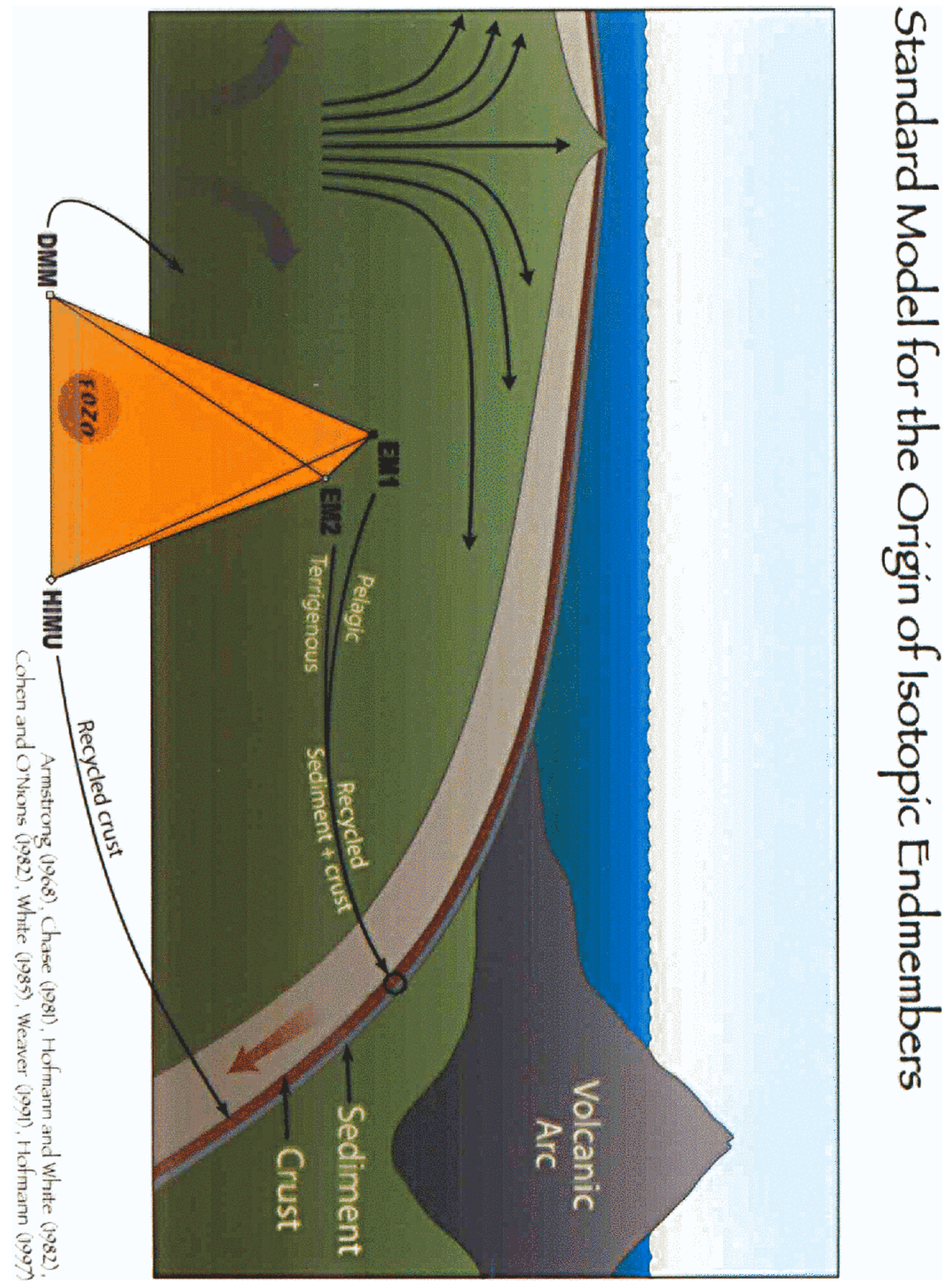
FIG. 5 - The evolution of a marked volume in the flow shown in Fig. 4. The time increment is 2×10^8 years for depth equal to 700 km. This calcualtion is by N. Hoffman, Cambridge University (personal communication).

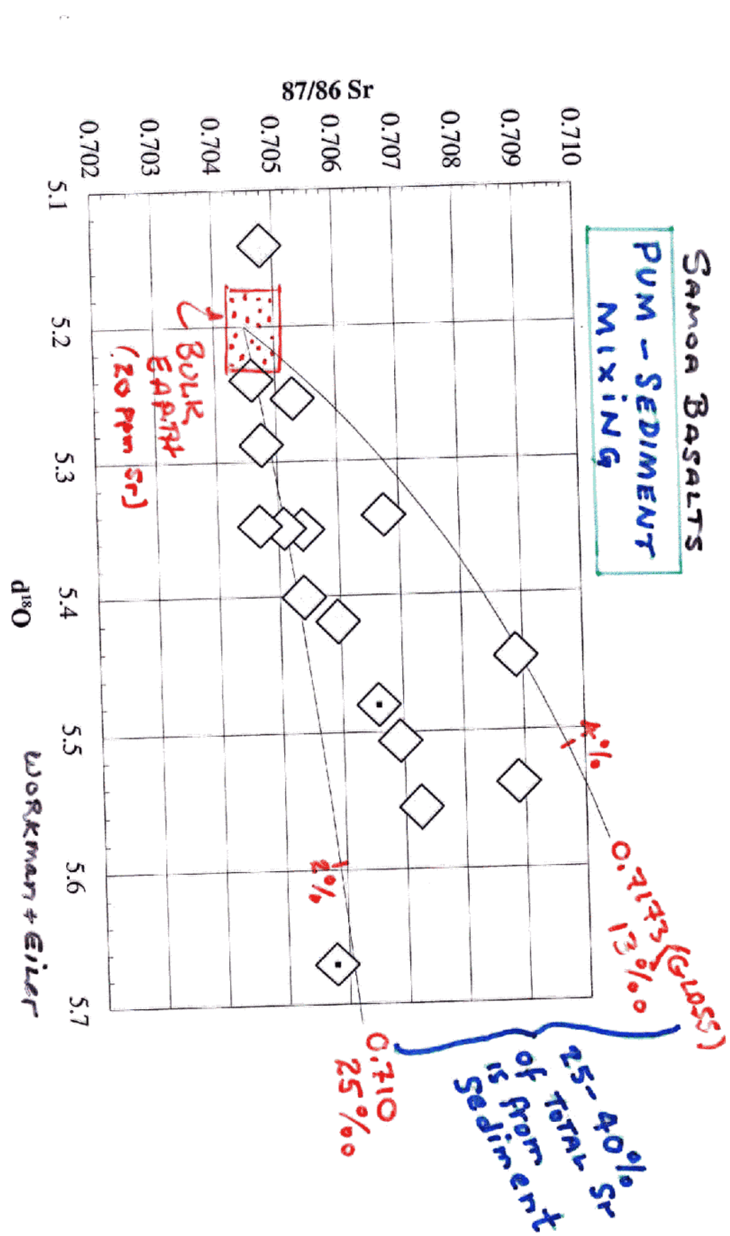
(Internally heated, $R_a = 1.4 \times 10^6$)

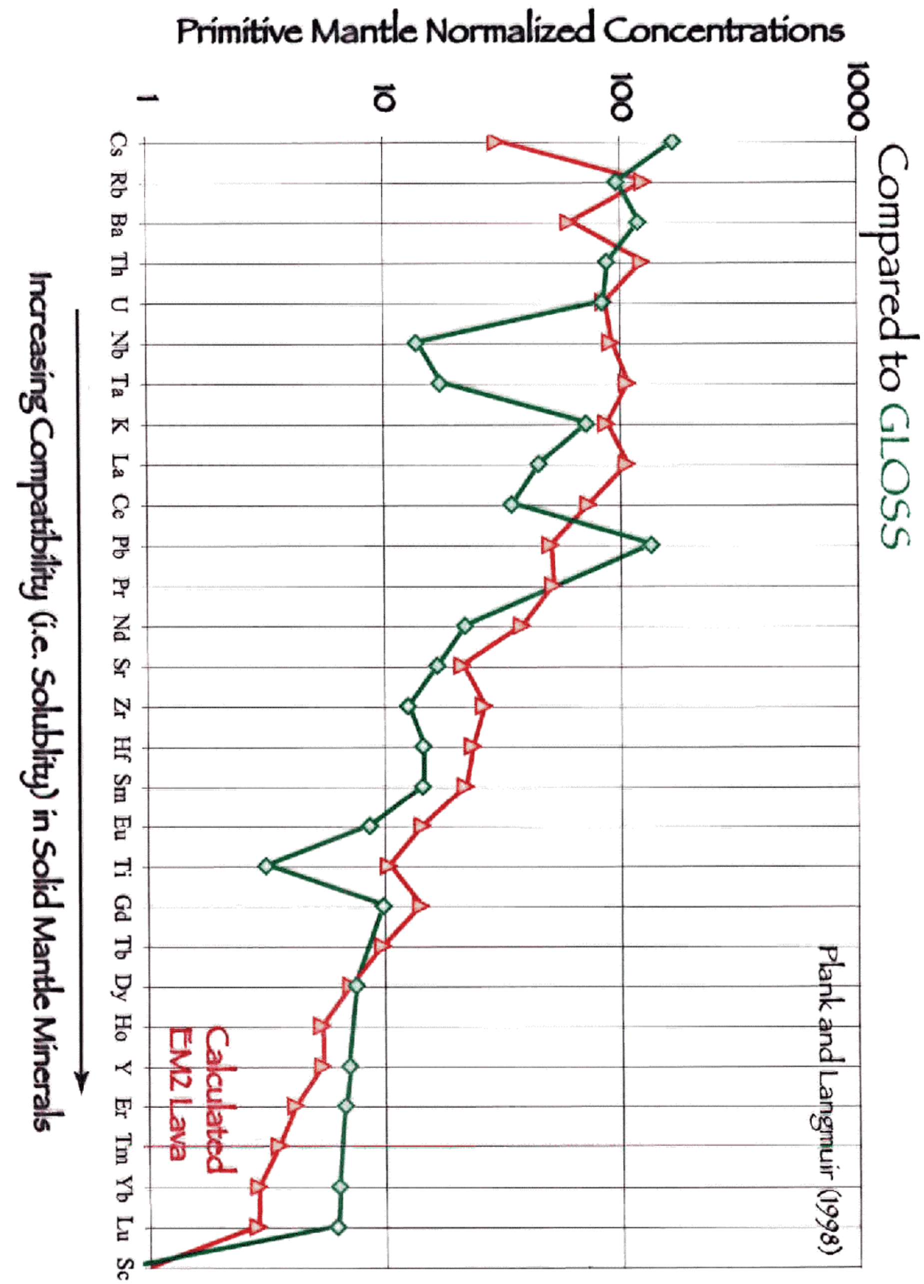
SPIDERGRAMS for MANTLE END-MEMBER BASALTS

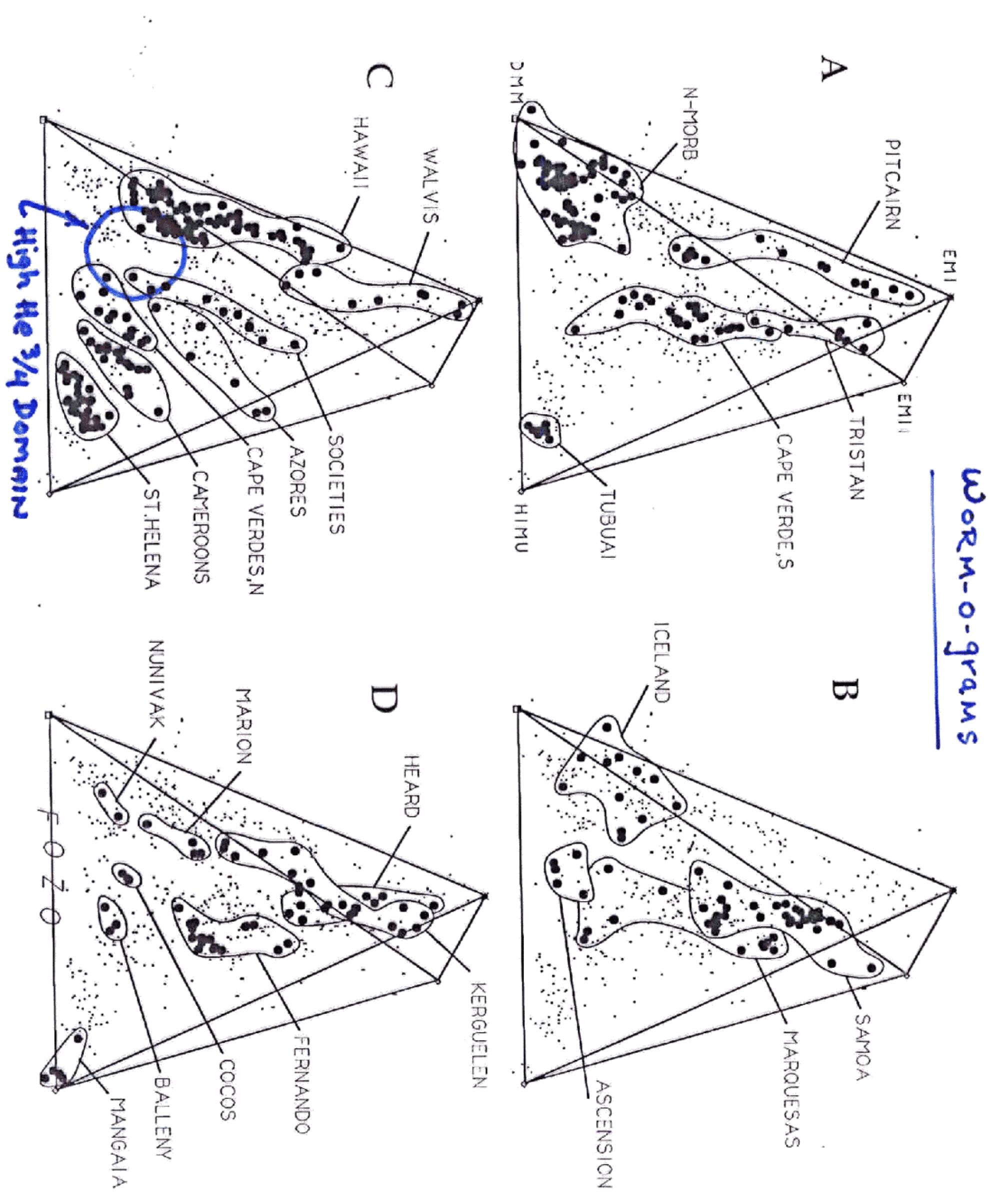


- EM1 ~ EM2 ~ HIMU ≠ N-MORB
- MINOR DIFFERENCES in OIB:
  - EM2 is "flat" from Cs → Th
  - HIMU has negative Zr-Hf anomaly
  - EM1 has no negative K anomaly

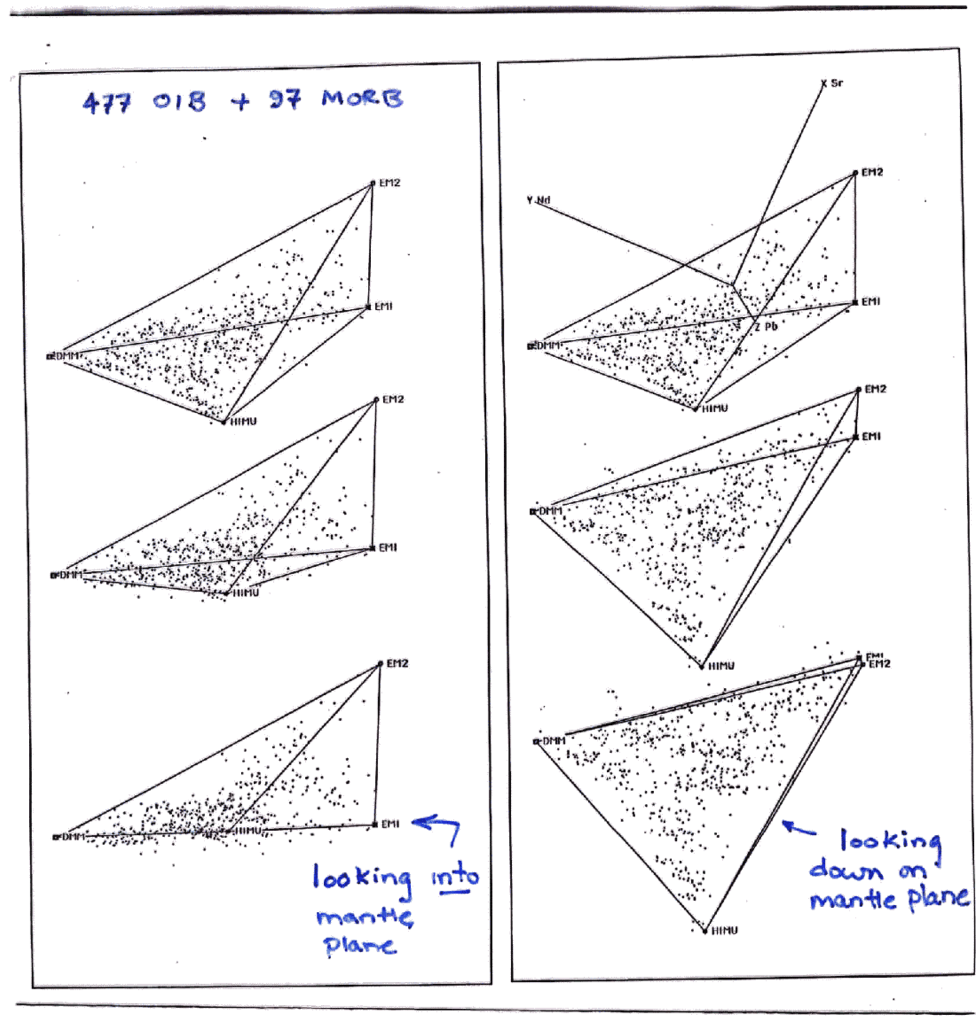



Samoa Basalts
PUM - SEDIMENT MIXING
87/86 Sr
0.702
0.703
0.704
0.705
0.706
0.707
0.708
0.709
0.710
5.1
5.2
5.3
5.4
5.5
5.6
5.7
d18O
BULK EARTH (20 ppm Sr)
4%
2%
0.7173 (GLOSS) 13‰
0.710 25‰
25-40% of TOTAL Sr is from Sediment
Workman + Eiler

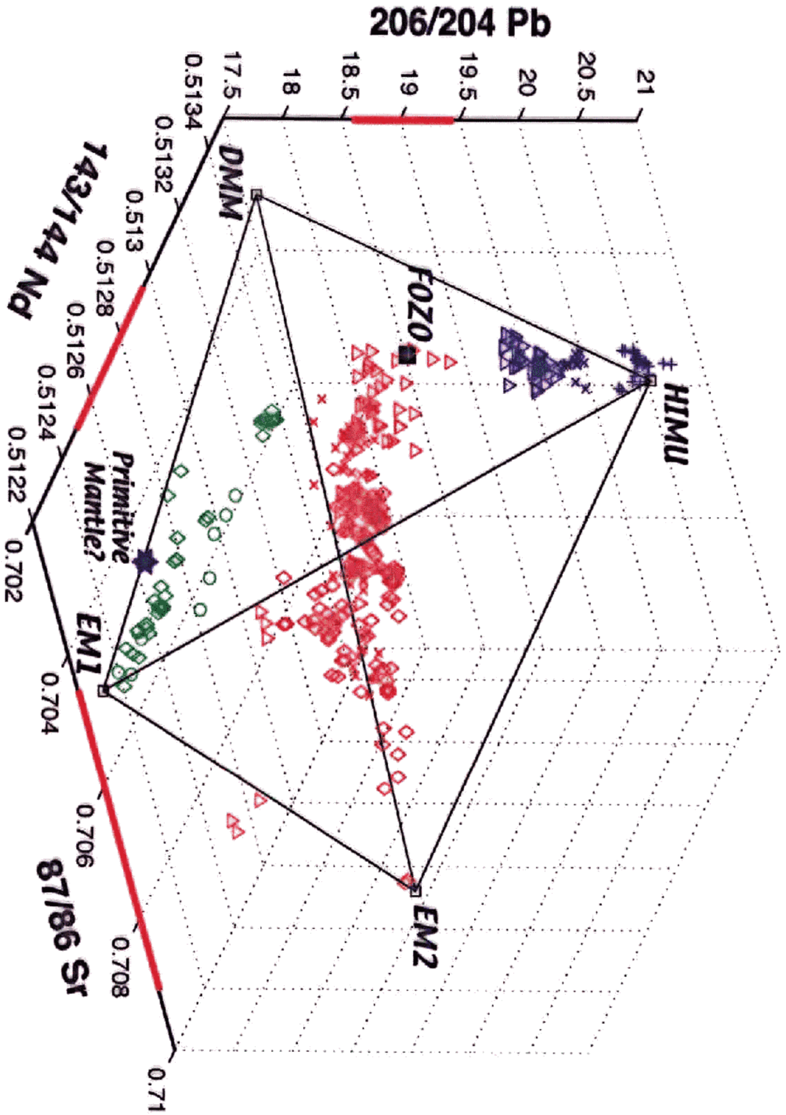

Primitive Mantle Normalized Concentrations
Compared to GLOSS
1000
100
10
1
Plank and Langmuir (1998)
Calculated EM2 Lava
Cs Rb Ba Th U Nb Ta K La Ce Pb Pr Nd Sr Zr Hf Sm Eu Ti Gd Tb Dy Ho Y Er Tm Yb Lu Sc
Increasing Compatibility (i.e. Solubility) in Solid Mantle Minerals



Worm-o-grams
A
PITCAIRN
N-MORB
EMI
EMII
DMM
HIMU
TRISTAN
CAPE VERDE,S
TUBUAI
B
ICELAND
SAMOA
MARQUESAS
ASCENSION
C
WALVIS
HAWAII
SOCIETIES
AZORES
CAPE VERDES,N
CAMEROONS
ST.HELENA
High He 3/4 Domain
D
HEARD
MARION
NUNIVAK
KERGUELEN
FERNANDO
COCOS
BALLENY
MANGAIA
FOZO



477 OIB + 97 MORB
EM2
EMI
DMM
HIMU
looking into mantle plane
X Sr
Y Nd
Z Pb
looking down on mantle plane



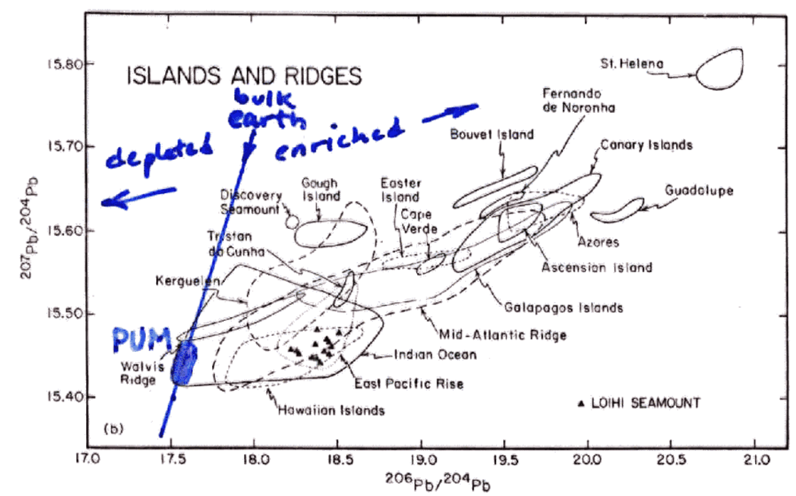
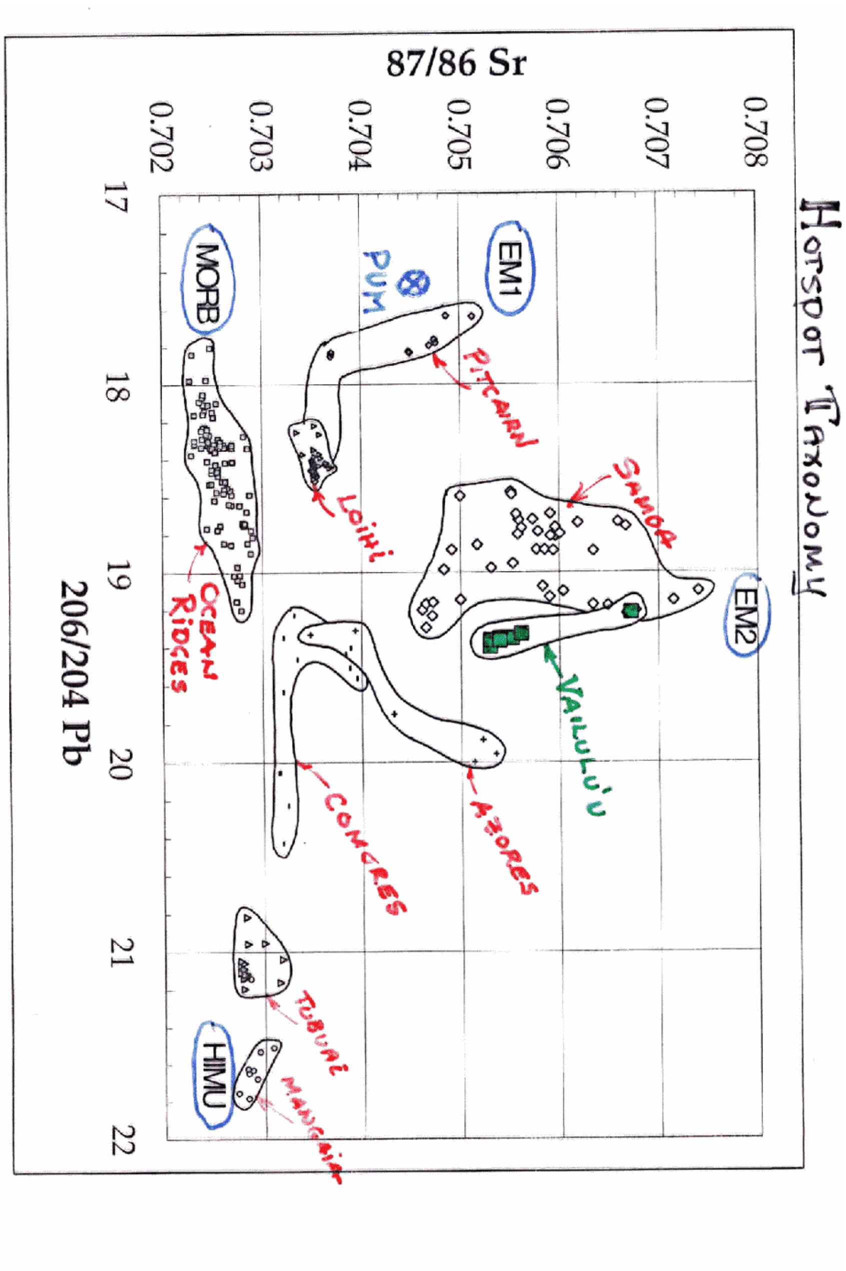
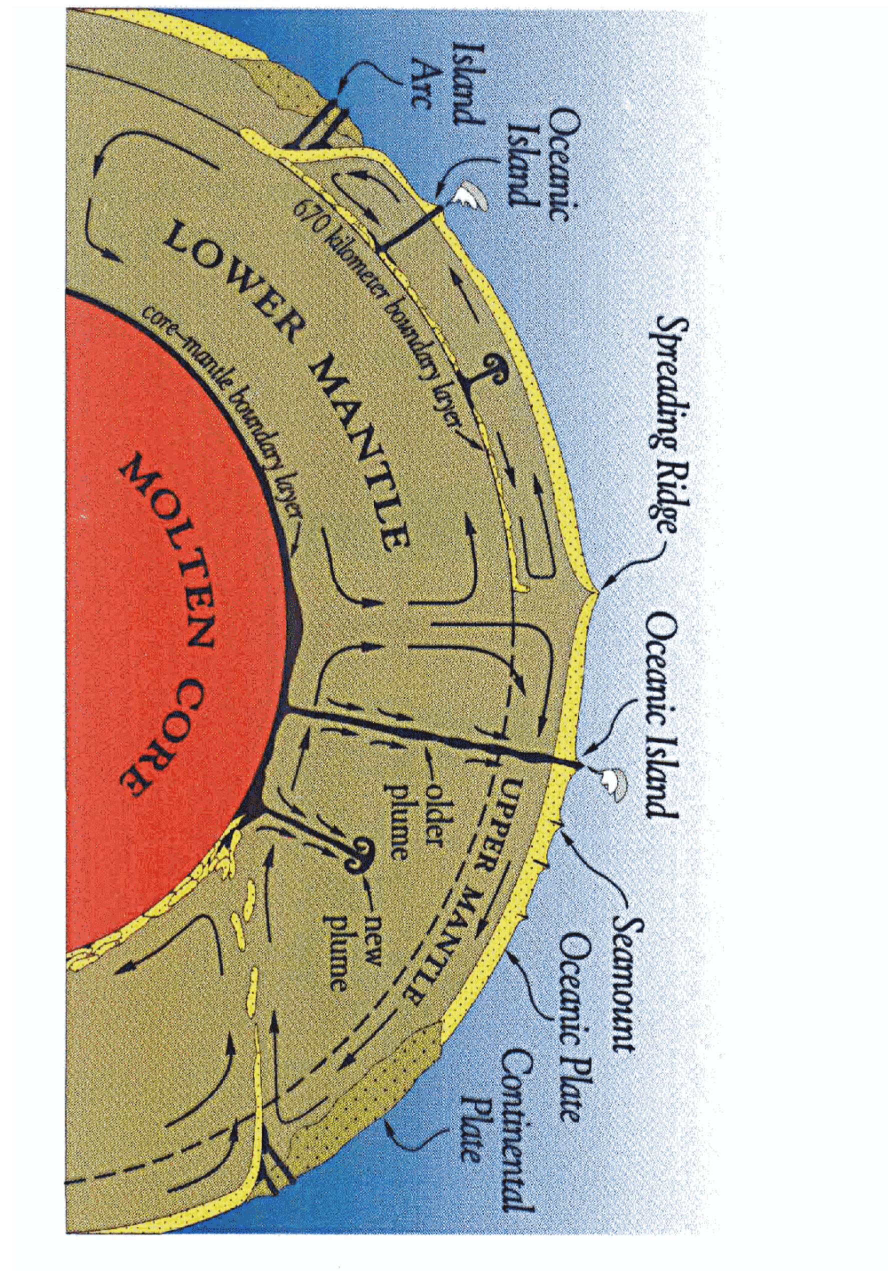


Fig. 5. (a) $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ for Loihi basalts compared to other Hawaiian volcanoes. (b) Loihi data are compared to published analyses for oceanic basalts. Data are from references 31,32,52; symbols as in Fig. 4. Analytical uncertainties are indicated in (a).


Hotspot Taxonomy
87/86 Sr
0.702
0.703
0.704
0.705
0.706
0.707
0.708
206/204 Pb
17
18
19
20
21
22
EM1
EM2
MORB
HIMU
PUM
Pitcairn
Samoa
Loihi
Vailulu'u
Azores
Comores
Ocean Ridges
Tubuai
Mangaia


Oceanic Island
Island Arc
Spreading Ridge
Oceanic Island
Seamount
Oceanic Plate
Continental Plate
670 kilometer boundary layer
LOWER MANTLE
UPPER MANTLE
core-mantle boundary layer
MOLTEN CORE
older plume
new plume

WHAT NEXT?

- **NEED TO CONSIDER "INTERNAL" PRODUCTION OF CHEMICAL HETEROGENEITIES.**
  - melt/solid partitioning in the SLVZ (D")
  - core/mantle reactions
  - inter-phase fractionations at the 410 and 670 km phase changes

- **NEED DYNAMICAL MODELING OF THE DESTRUCTION OF SMALL (1-10 KM) HETEROGENEITIES BY STIRRING AND MIXING.**

Mantle Heterogeneities:

- **How do we know they are there?**
- **How are they made?**
- **What size are they?**
- **How do they survive (likely not this talk!)?**
- **Physical consequences –density and thermal impacts**
- **What next?**

HELP NEEDED FROM OTHER DISCIPLINES!!

Seismologists: Do plumes come from the CMB?

Dynamicists: What will the 7 km ocean crust layer look like after a billion years of mixing/stirring/stretching in the mantle?

Seismologists: Does the oceanic asthenosphere have small degrees of melt everywhere?

Mineral physicists: What is the light element in the core, and can we also store helium, potassium, uranium and thorium there?

SENSITIVITY ANALYSIS
Chemical versus Physical Properties

	Bulk Silicate Earth	Depleted MORB Mantle	EM2 Source (Harzburgitic Lithosphere)
Whole Rock Mg #	89.33	89.77	90.60
Modal Olivine, %	55.2	??	76.9
Density, g/cc	3.374	3.367	3.355
Vp, km/sec	8.258	8.302	8.308
Vs, km/sec	4.807	4.814	4.826
Heat Generation, pW/kg	4.96	0.9	10.6

Delta, relative to BSE

	Depleted MORB Mantle	EM2 Source
Density	-0.19%	-0.54%
P-velocity	0.53%	0.61%
S-velocity	0.15%	0.40%
Heat Gen'n	0.18x	2.1x

- density, Vp and Vs from garnet-facies Mg# parameterization of C.-T. Lee, 2003.
- Heat gneration from Workman et al., 2003.

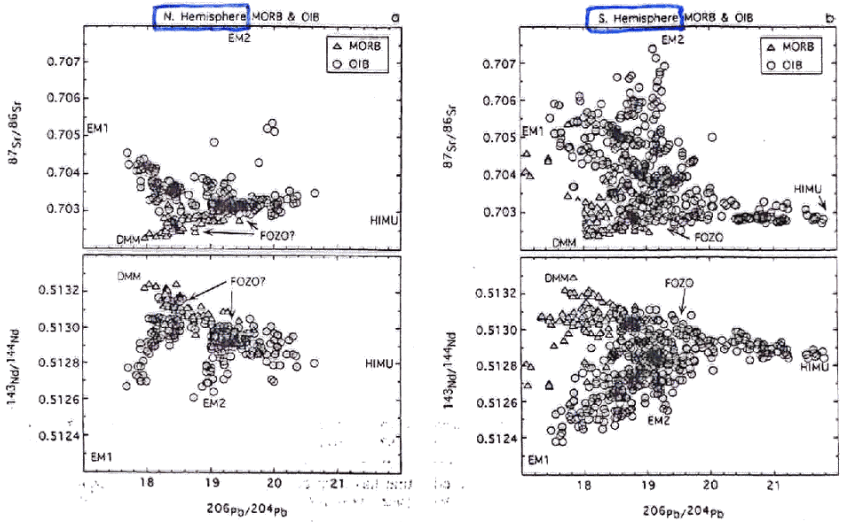
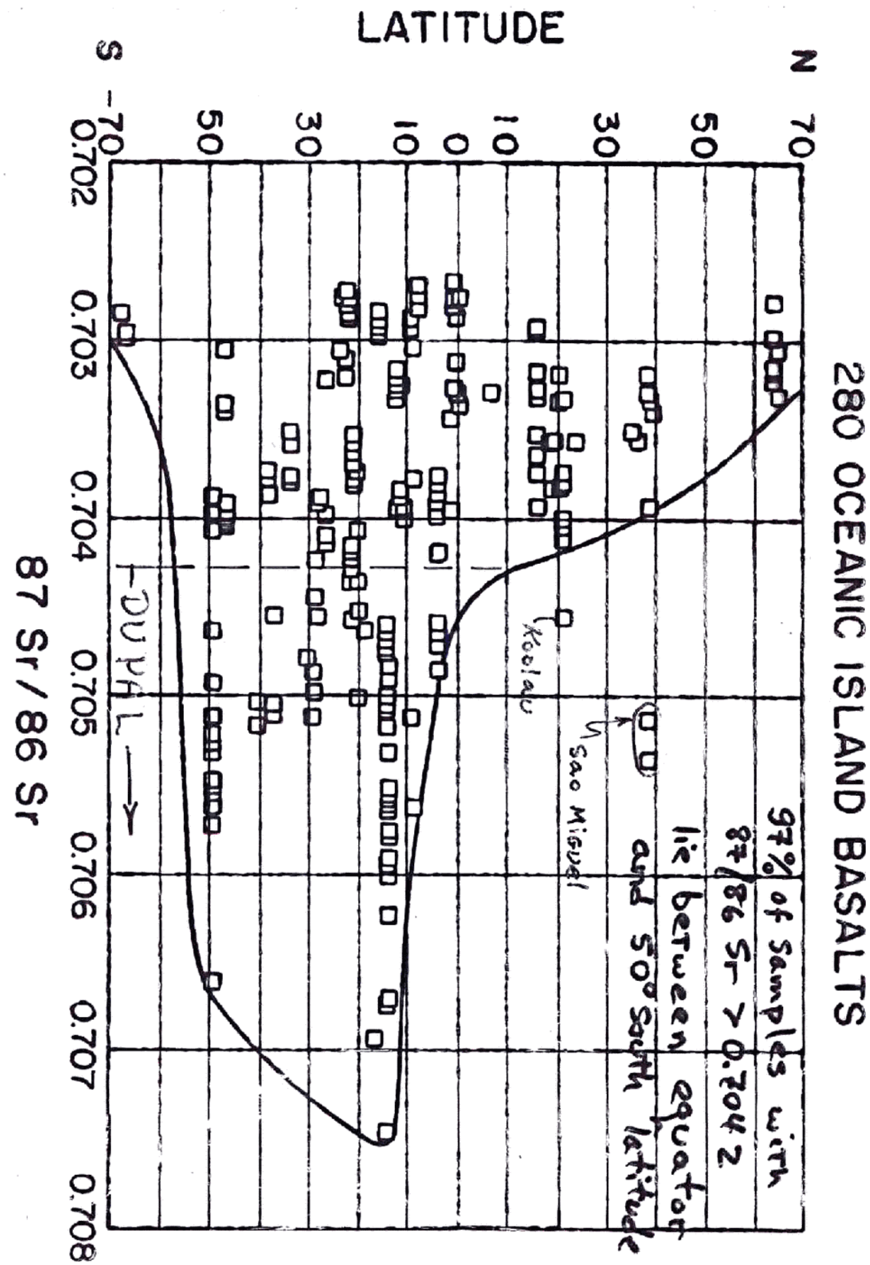
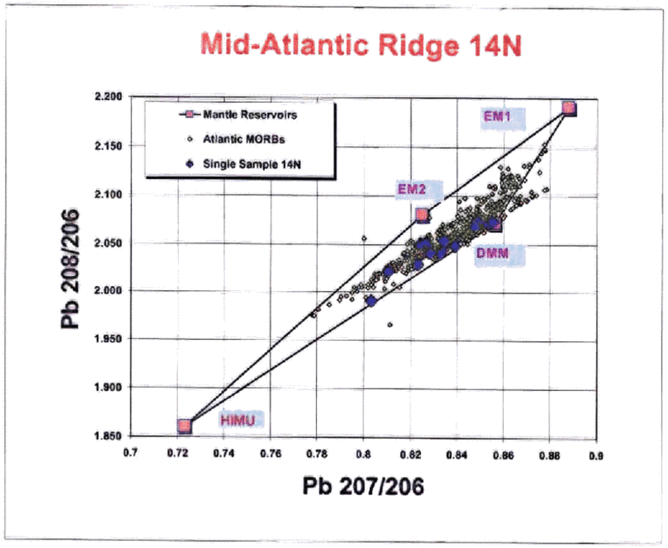
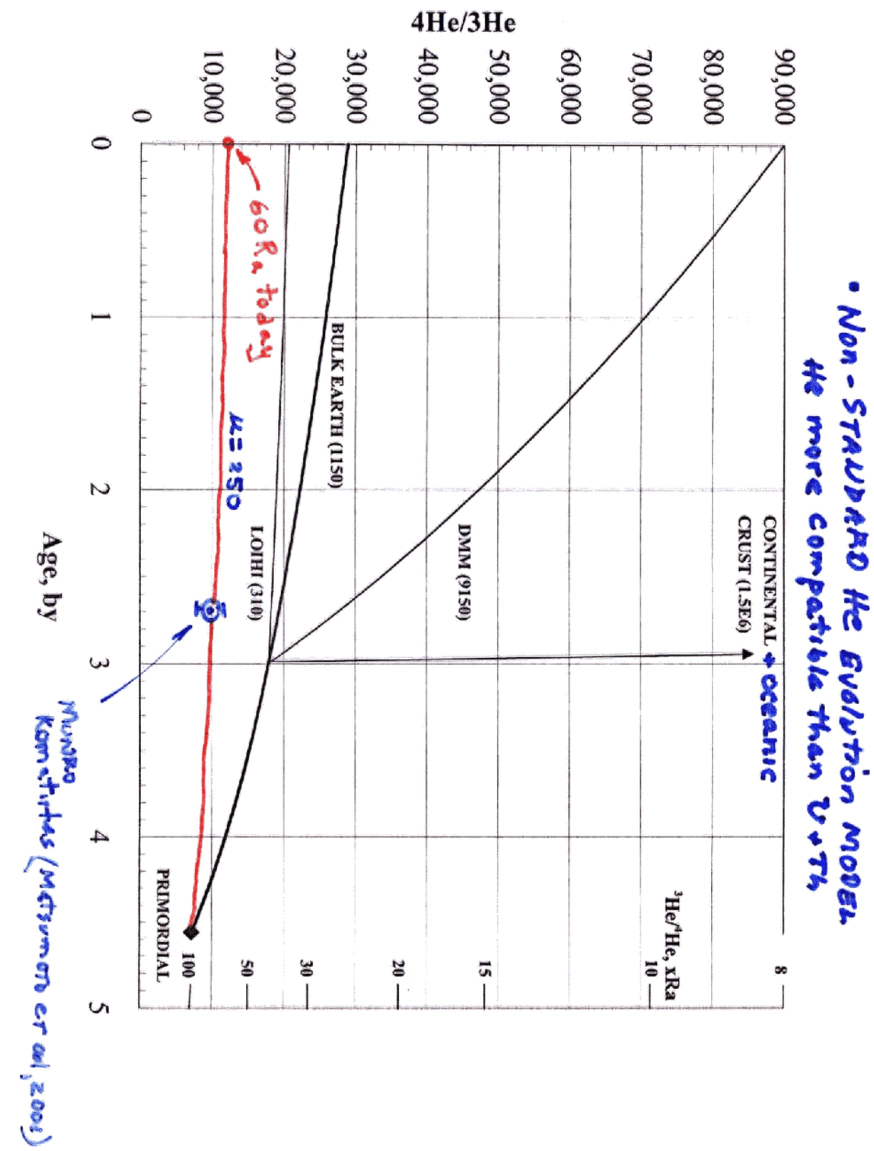


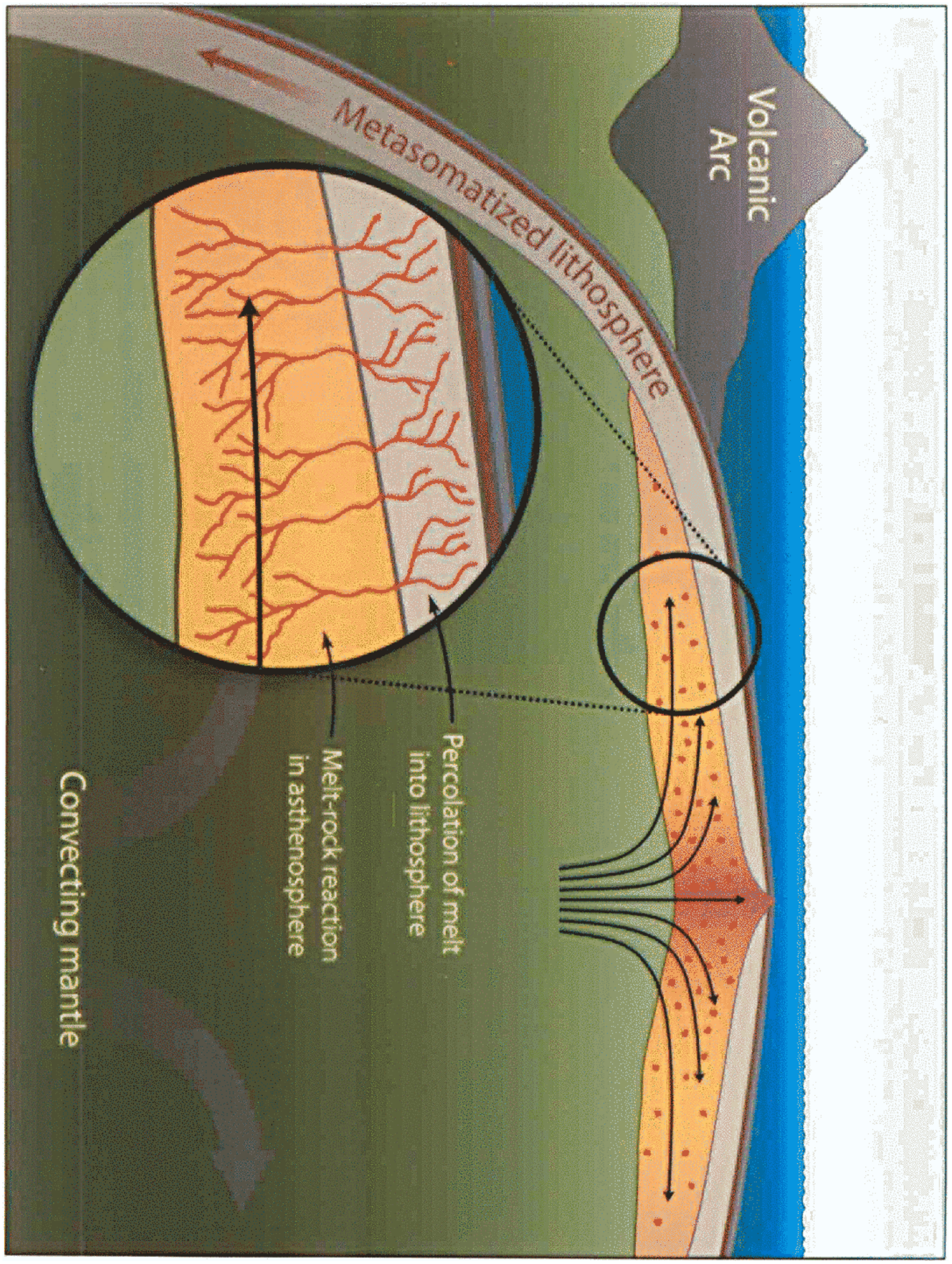
Figure 11. The Sr-Nd-Pb isotopic variation in MORB and ocean island basalts. Carlson, 1994

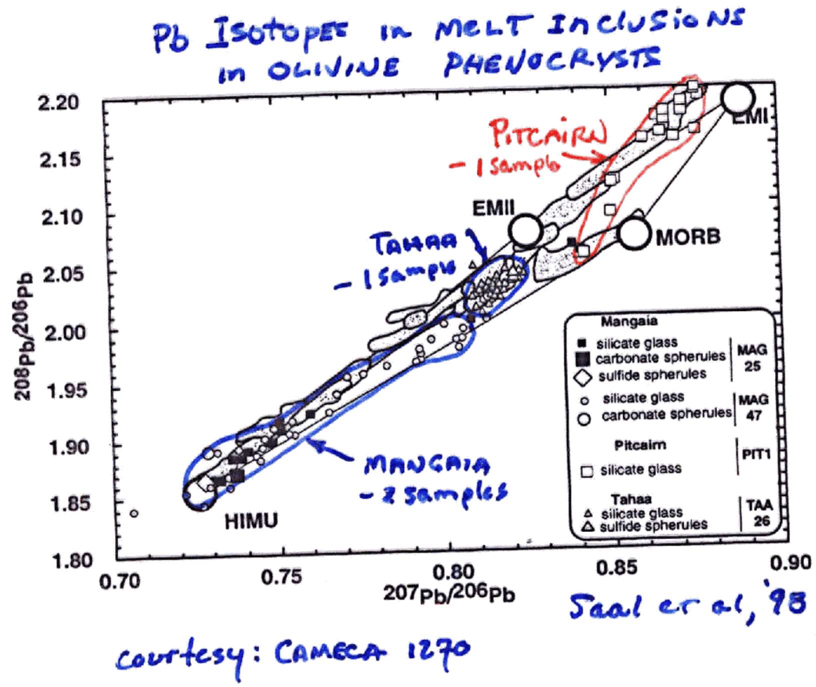
• Note much larger "dispersion" of southern hemisphere basalts

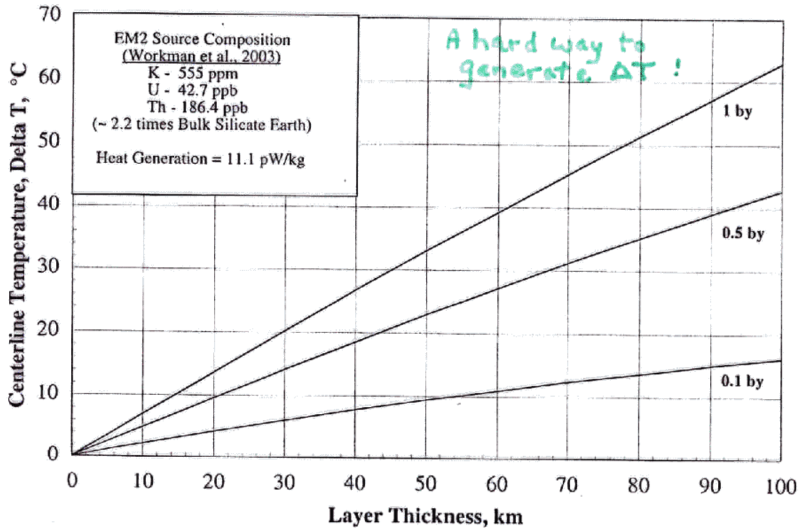


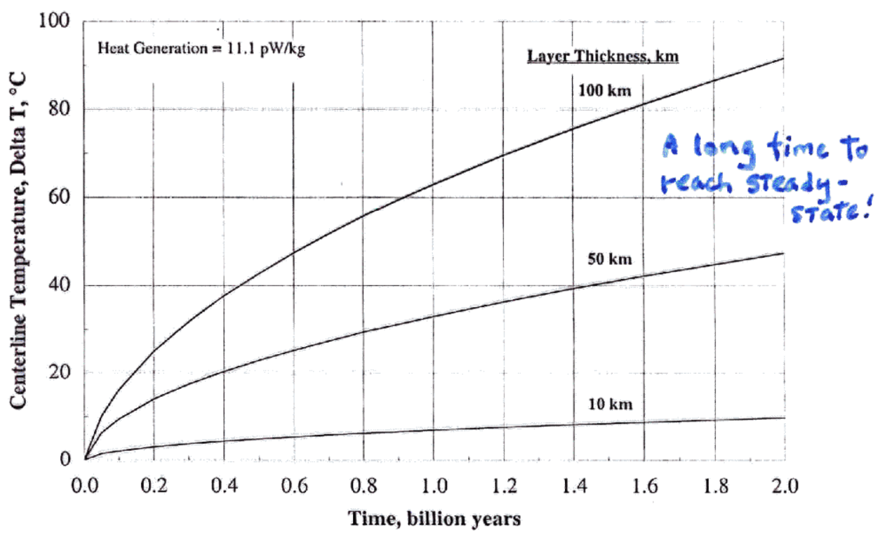

Mid-Atlantic Ridge 14N
Mantle Reservoirs
Atlantic MORBs
Single Sample 14N
EM1
EM2
DMM
HIMU
Pb 208/206
Pb 207/206


4He/3He
Age, by
BULK EARTH (1150)
DMM (9150)
LOIHI (310)
CONTINENTAL CRUST (1.5E6)
PRIMORDIAL
^{3}He/^{4}He, xRa
60 Ra today
μ = 250
+ oceanic
• Non-STANDARD He evolution model
He more compatible than U+Th
MUNRO Komatiites (Matsumoto et al, 2001)


Volcanic Arc
Metasomatized lithosphere
Percolation of melt into lithosphere
Melt-rock reaction in asthenosphere
Convecting mantle


Pb Isotopes in melt inclusions in olivine phenocrysts
Pitcairn - 1 sample
Tahaa - 1 sample
Mangaia - 2 samples
EMI
EMII
MORB
HIMU
208Pb/206Pb
207Pb/206Pb
2.20
2.15
2.10
2.05
2.00
1.95
1.90
1.85
1.80
0.70
0.75
0.80
0.85
0.90
Mangaia
silicate glass
carbonate spherules
sulfide spherules
MAG 25
silicate glass
carbonate spherules
MAG 47
Pitcairn
silicate glass
PIT1
Tahaa
silicate glass
sulfide spherules
TAA 26
Saal et al, '98
courtesy: CAMECA 1270





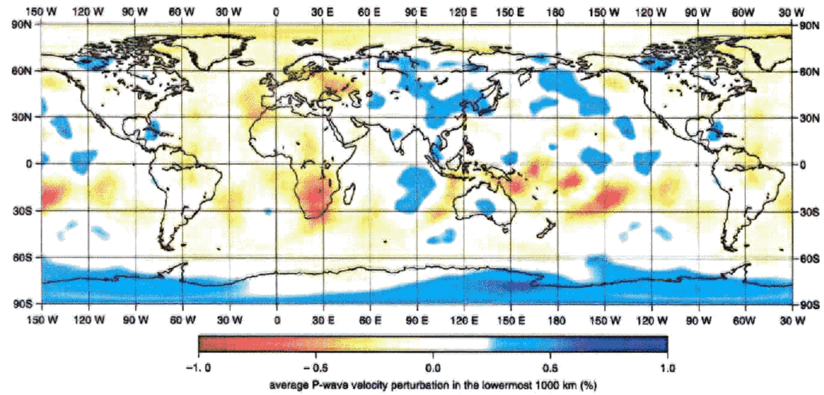
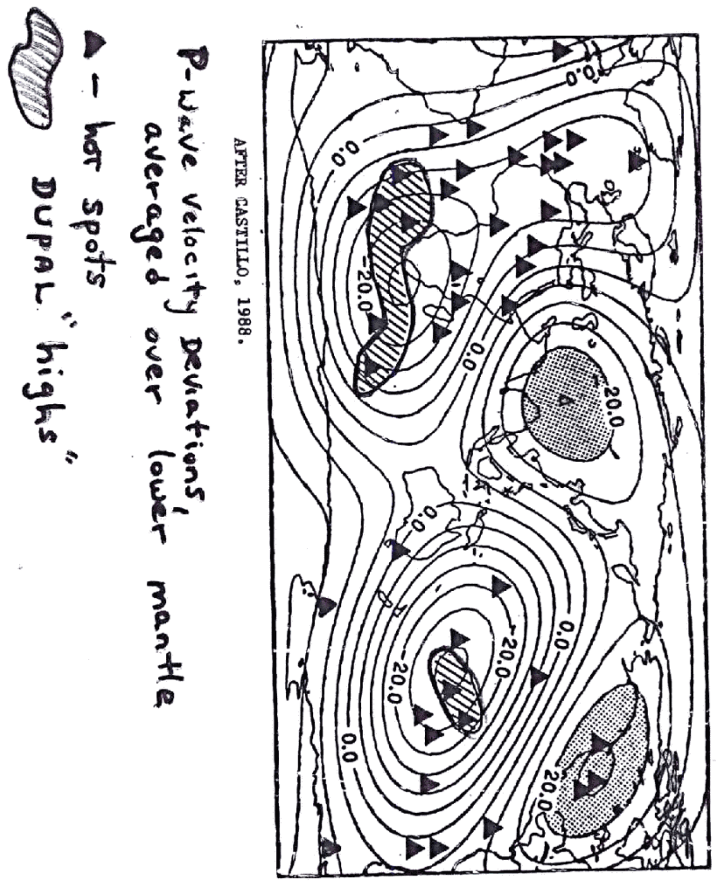


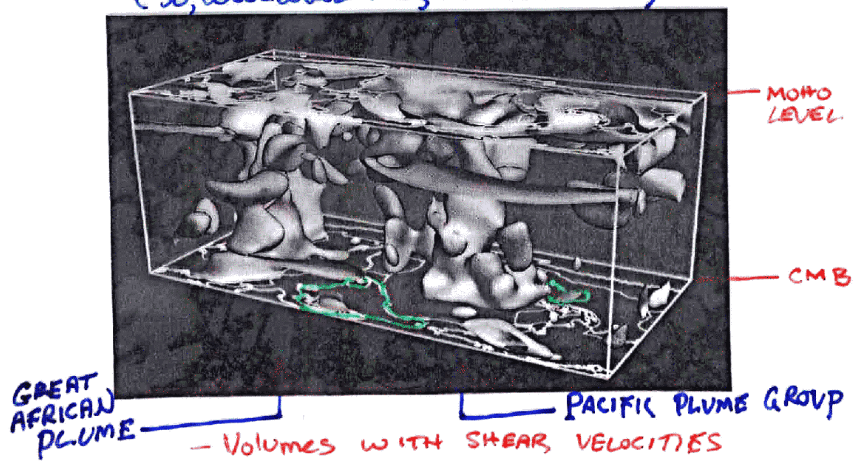
Fig. 1. Vertical average over the lowermost 1000 km of the mantle of the relative velocity perturbation $\delta v_p/v_p$. The averaging emphasizes features that are continuous with depth. Map has been wrapped around to have complete views of both the Atlantic and the Pacific oceans.



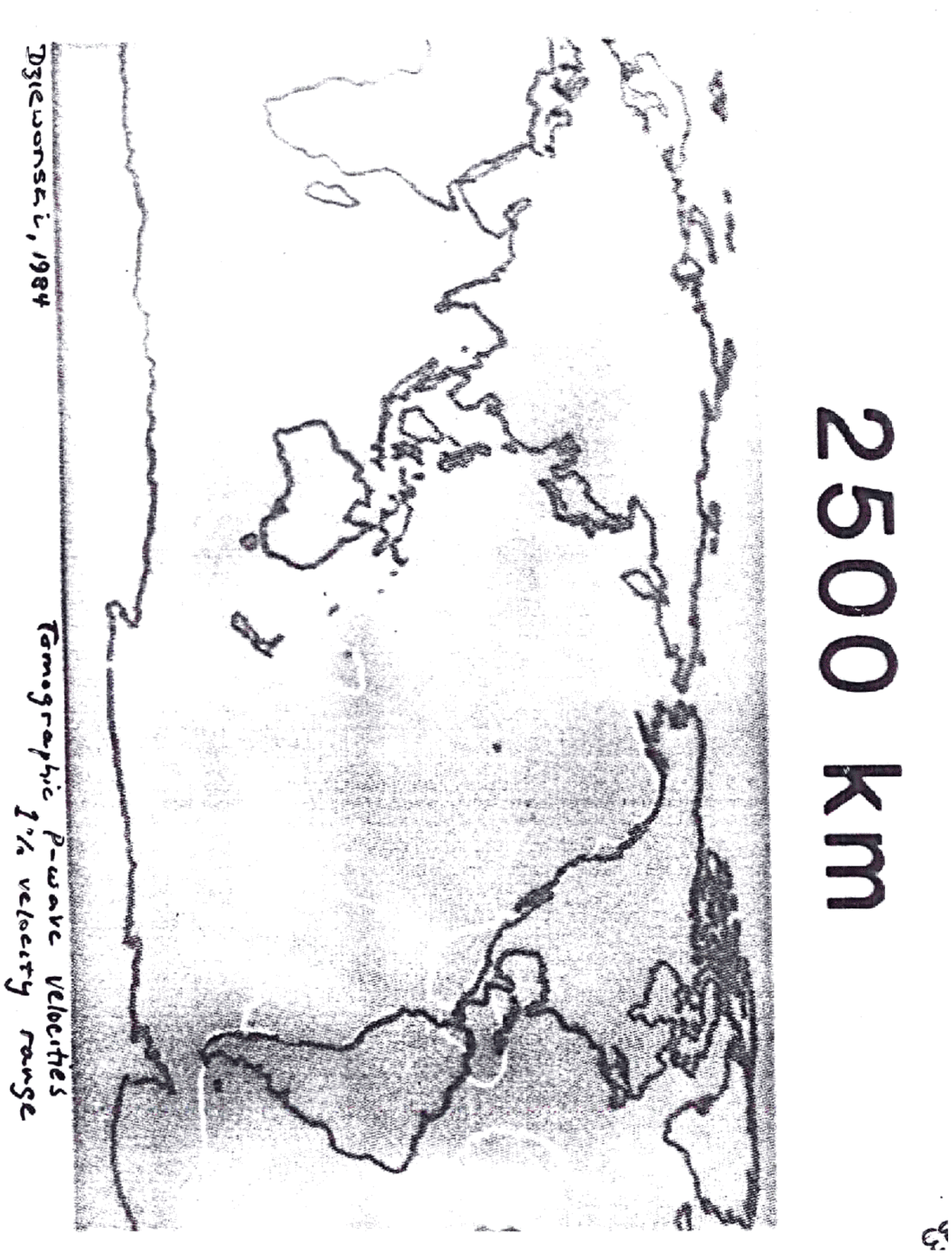
AFTER CASTILLO, 1988.

THE HARVARD 'GRAND STRUCTURES' OF THE EARTH

(Su, Woodward + Dziewonski 1994)



- Volumes with SHEAR VELOCITIES 0.6% slower than mean
- VIEW is from The NW
- NORTH AMERICA + AUSTRALIA ARE outlined in green.


2500 km
Dziewonski, 1984
Tomographic P-wave velocities
1% velocity range