

## Lecture 22 - More MORB

Wednesday, April 13<sup>th</sup>, 2005

### Trace Element and Isotope Chemistry of MORB

- REE and spider diagrams tend to be relatively flat at the less incompatible end and depleted at the highly incompatible end.
- This is characteristic of most MORB from all ocean basins.
- We have seen that this pattern cannot be produced by melting of a primitive mantle with a chondritic pattern
- CONCLUSION – the mantle from which MORB is produced must be already depleted in incompatible elements

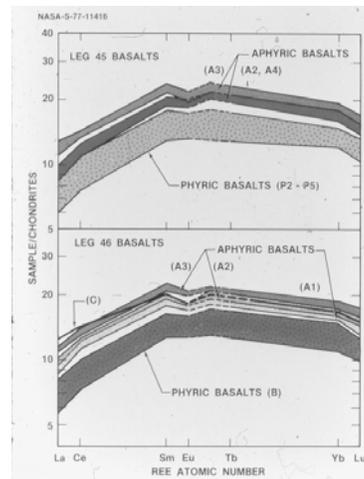
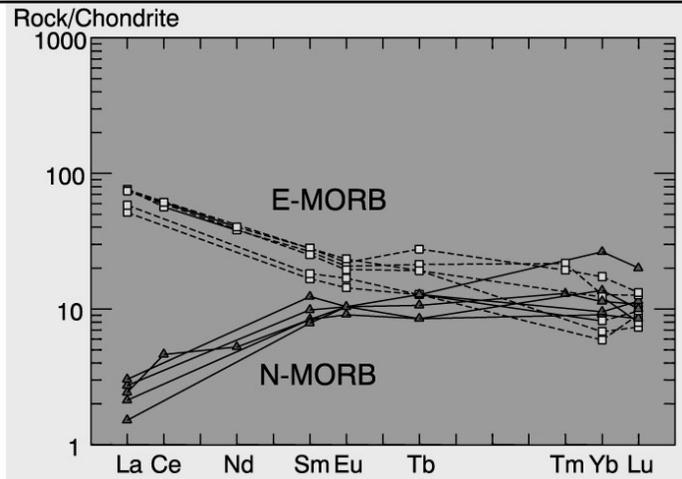


Figure 13-10.  
Data from  
Schilling et al.  
(1983) Amer. J.  
Sci., 283, 510-586.



There are some MORB's that do not have this characteristic pattern  
They are enriched at the light REE end and are called E-MORB

N-MORB	chondritic La/Sm < 1.8
E-MORB	chondritic La/Sm > 0.7

E-MORBs (blue squares) enriched over N-MORBs (red triangles): regardless of Mg#

- Lack of distinct break suggests three MORB types
  - ◆ E-MORBs La/Sm > 1.8
  - ◆ N-MORBs La/Sm < 0.7
  - ◆ T-MORBs (transitional) intermediate values

Note La/Sm refers to  
chondrite normalized  
values

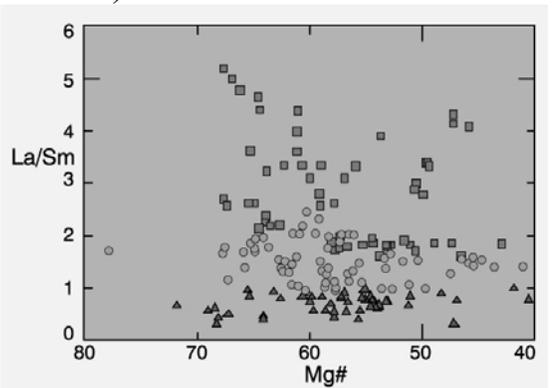


Figure 13-11. Data from  
Schilling et al. (1983) Amer.  
J. Sci., 283, 510-586.

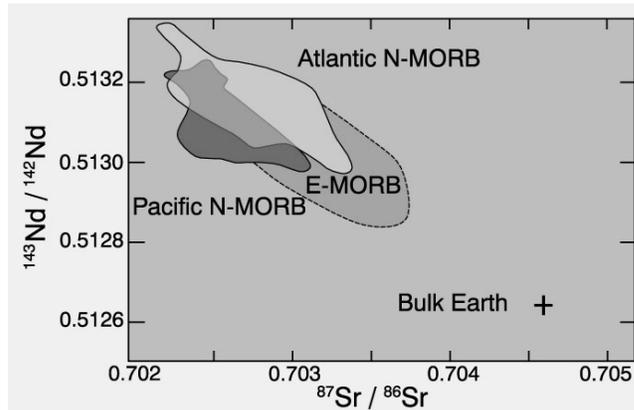
Incompatible-rich and incompatible-poor mantle source regions for MORB magmas

- ◆ N-MORB (normal MORB) taps the depleted upper mantle source
  - ▲ Mg# > 65:  $K_2O < 0.10$   $TiO_2 < 1.0$
- ◆ E-MORB (enriched MORB) taps a more fertile mantle (but where and what is it?)
  - ▲ Mg# > 65:  $K_2O > 0.10$   $TiO_2 > 1.0$

- N-MORBs:  $^{87}Sr/^{86}Sr < 0.7035$  and  $^{143}Nd/^{144}Nd > 0.5030$ , → depleted mantle source
- E-MORBs extend to more enriched values → stronger support different mantle reservoirs for N-type and E-type MORBs

Note how all MORB's are at the low  $^{87}Sr/^{86}Sr$  – high  $^{143}Nd/^{144}Nd$  end of the mantle array

Figure 13-12. Data from Ito et al. (1987) *Chemical Geology*, 62, 157-176; and LeRoex et al. (1983) *J. Petrol.*, 24, 267-318.



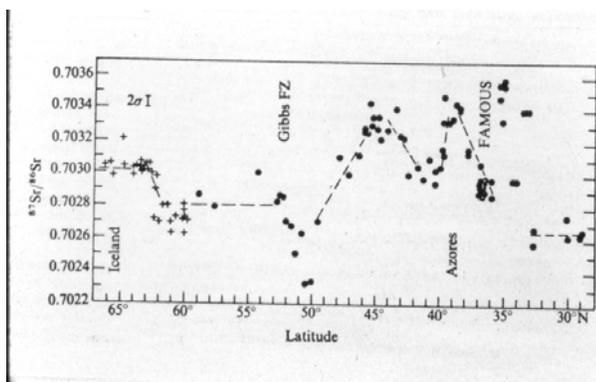
### Conclusions:

- MORBs have  $> 1$  source region
- The mantle beneath the ocean basins is not homogeneous
  - ◆ N-MORBs tap an upper, depleted mantle
  - ◆ E-MORBs tap a more enriched source
  - ◆ T-MORBs = mixing of N- and E- magmas during ascent and/or in shallow chambers

What is the origin of E-MORB?

### Three suggestions for the Source of E-MORB:

1. Derived from a deeper more fertile mantle.
2. Depleted upper mantle may be locally fertilized by prior intrusion of magmas from the deeper mantle
3. Mixing occurs laterally along mid-ocean ridges with material from nearby plumes (e.g. Iceland, Galapagos)



Note how Sr isotopes vary along the Mid-Atlantic Ridge with high values (E-MORB) near the Azores and Iceland (plumes)

## Mantle Melting to produce MORB

Implications of shallow P range from major element data:

- ◆ MORB magmas = product of partial melting of mantle lherzolite in a rising solid diapir
- ◆ Melting must take place over a range of pressures
- ◆ The pressure of multiple saturation represents the point at which the melt was last in equilibrium with the solid mantle phases

Trace element and isotopic characteristics of the melt reflect the equilibrium distribution of those elements between the melt and the source reservoir

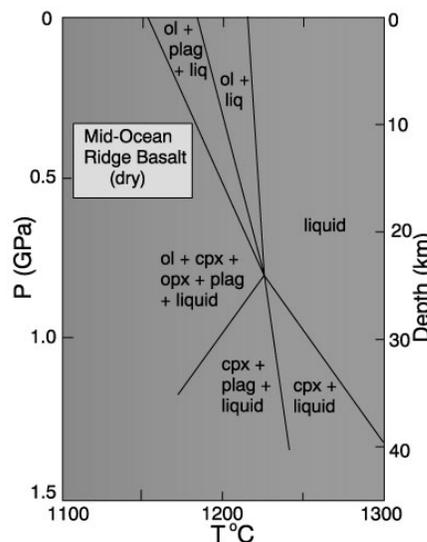
The major element (and hence mineralogical) character is controlled by the equilibrium maintained between the melt and the residual mantle phases during its rise until the melt separates as a system with its own distinct character (shallow)

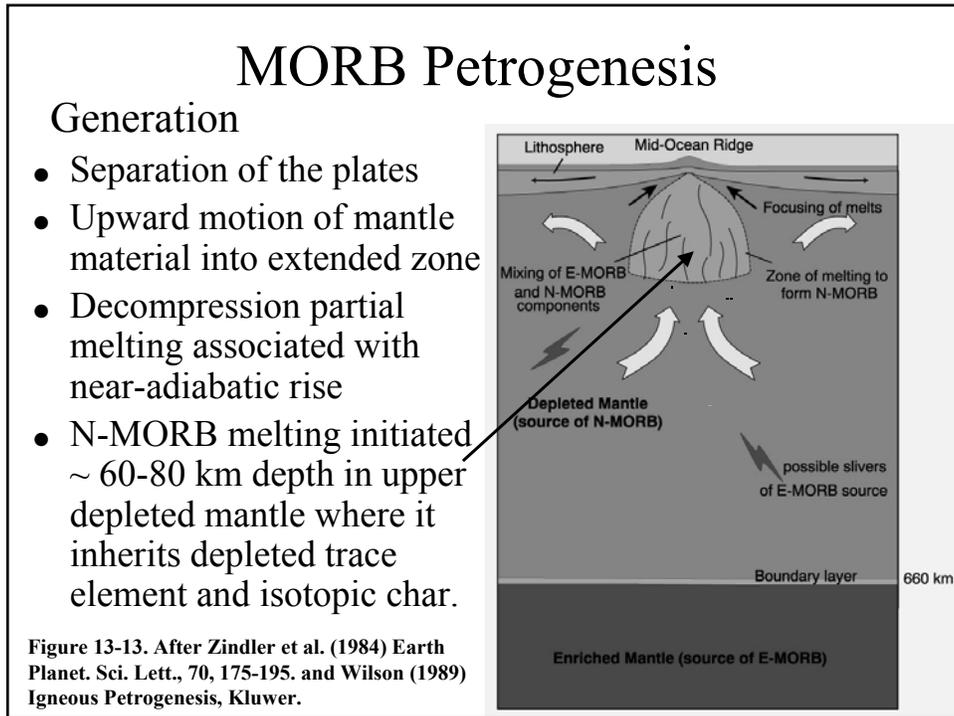
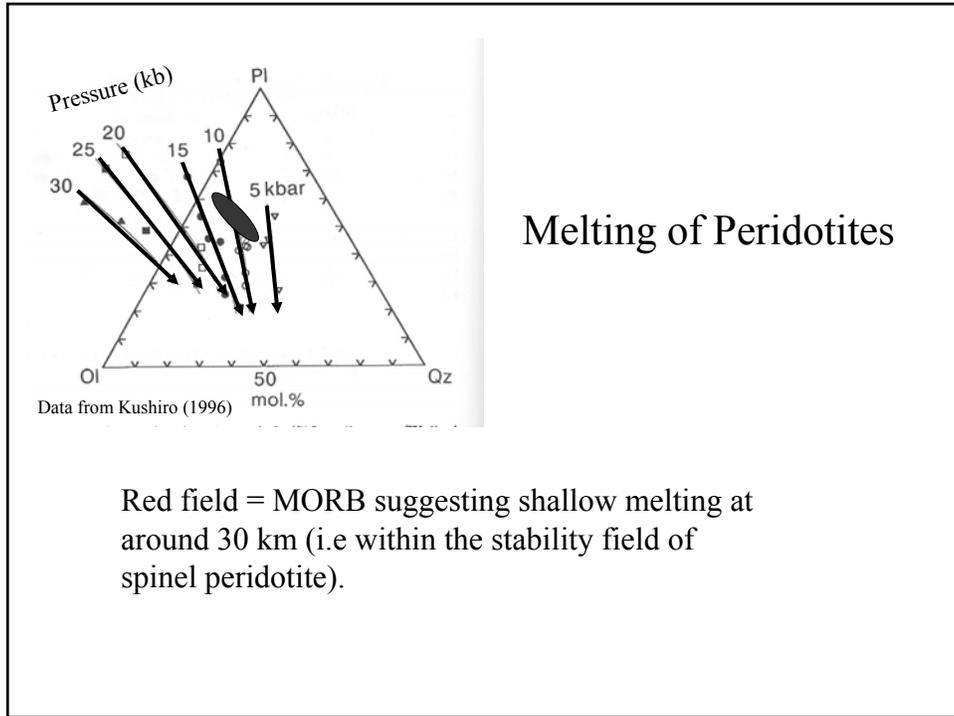
Experimental data on parental MORB magmas show multiple saturation with olivine, cpx, and opx → P range = 0.8 - 1.2 GPa (25-35 km)

This implies melting in the stability field of Spinel Peridotite

Trace elements support this. No evidence for garnet or plagioclase in the source

**Figure 13-10.**  
Data from  
Schilling et al.  
(1983) Amer. J.  
Sci., 283, 510-586.





## Generation

- Region of melting
- Melt blobs separate at about 25-35 km

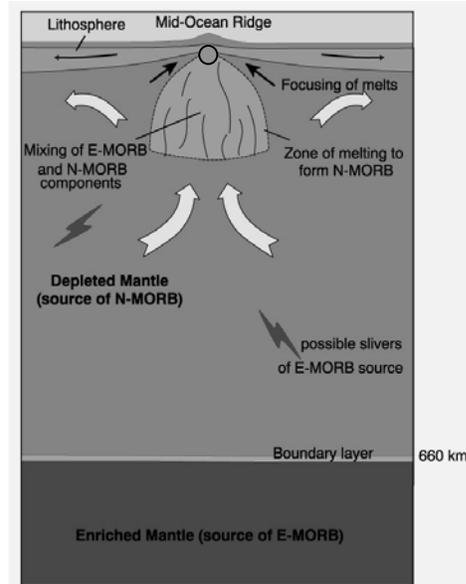


Figure 13-13. After Zindler et al. (1984) *Earth Planet. Sci. Lett.*, 70, 175-195. and Wilson (1989) *Igneous Petrogenesis*, Kluwer.

## The Axial Magma Chamber

### Original Model

- Semi-permanent
- Fractional crystallization → derivative MORB magmas
- Periodic reinjection of fresh, primitive MORB from below
- Dikes upward through the extending and faulting roof

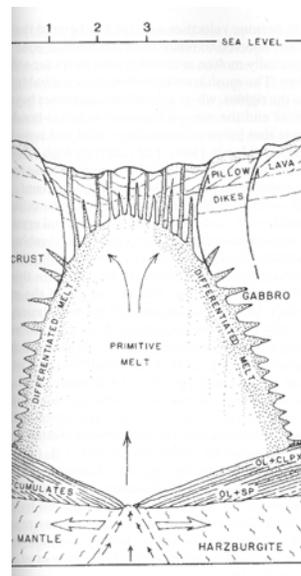


Figure 13-14. From Byran and Moore (1977) *Geol. Soc. Amer. Bull.*, 88, 556-570.

- Crystallization near top and along the sides → successive layers of gabbro (layer 3)
- Dense olivine and pyroxene crystals → ultramafic cumulates (layer 4)
- Layering in lower gabbros (layer 3B) from density currents flowing down the sloping walls and floor?

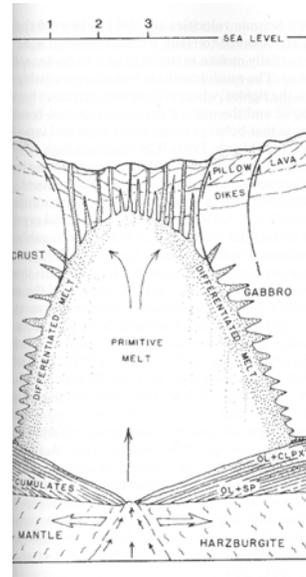


Figure 13-14. From Byran and Moore (1977) Geol. Soc. Amer. Bull., 88, 556-570.

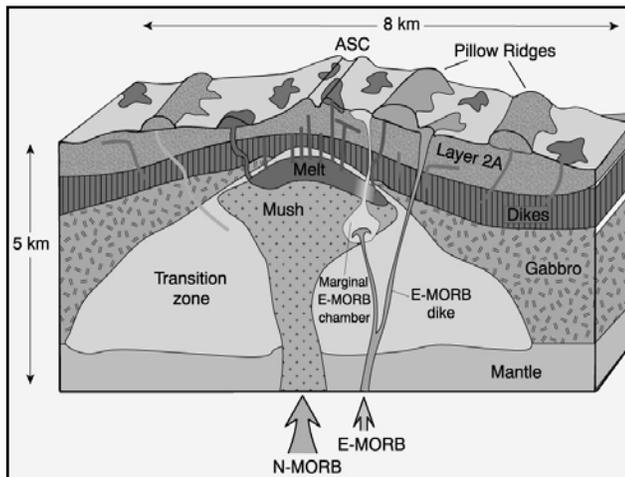


Figure 13-15. After Perfit et al. (1994) Geology, 22, 375-379.

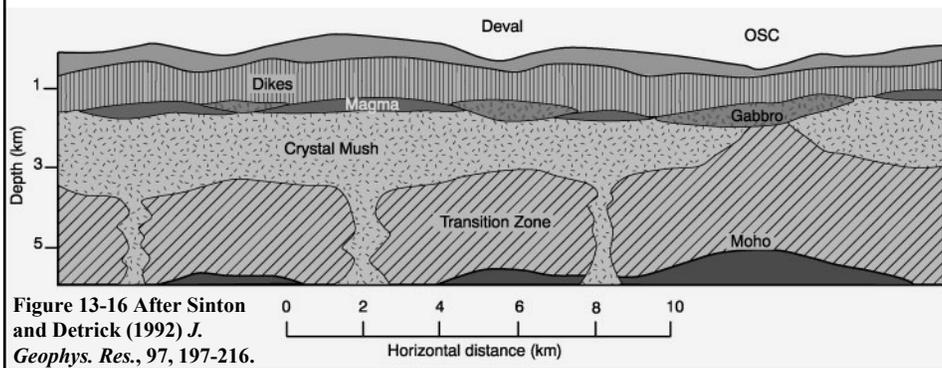
### A different concept of the axial magma chamber beneath a fast-spreading ridge

Although the previous model reconciles the observations from ophiolites and petrological evidence for crystal fractionation, magma mixing and replenishment, it has a major flaw!

Geophysical methods can't find large magma reservoirs! They propose instead:-

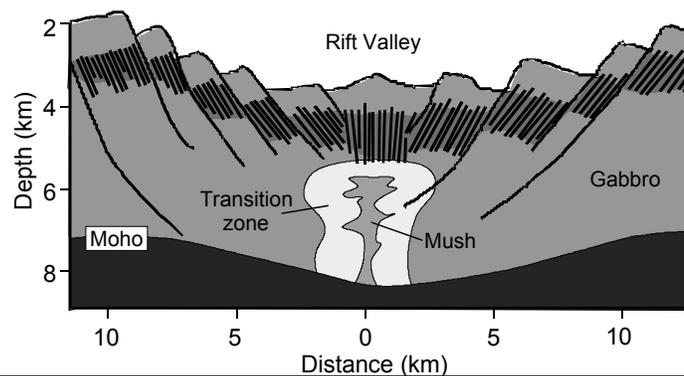
1. Small sill-like magma bodies (< 2 km wide and < 0.5 km thick)
2. Surrounded by much larger mush and transition zones
3. Mush zones (< 30% melt) continuous with the magma reservoir
4. Transition zone with even less melt

- Melt body → continuous reflector up to several kilometers *along* the ridge crest, with gaps at fracture zones, devals and OSCs
- Large-scale chemical variations indicate poor mixing along axis, and/or intermittent liquid magma lenses, each fed by a source conduit



### Model for magma chamber beneath a *slow*-spreading ridge, such as the Mid-Atlantic Ridge

- ♦ Dike-like mush zone and a smaller transition zone beneath well-developed rift valley
- ♦ Most of body well below the liquidus temperature, so convection and mixing is far less likely than at fast ridges



- Nisbit and Fowler (1978) suggested that numerous, small, ephemeral magma bodies occur at slow ridges
- Slow ridges are generally less differentiated than fast ridges
  - ◆ No continuous liquid lenses, so magmas entering the axial area are more likely to erupt directly to the surface (hence more primitive), with some mixing of mush

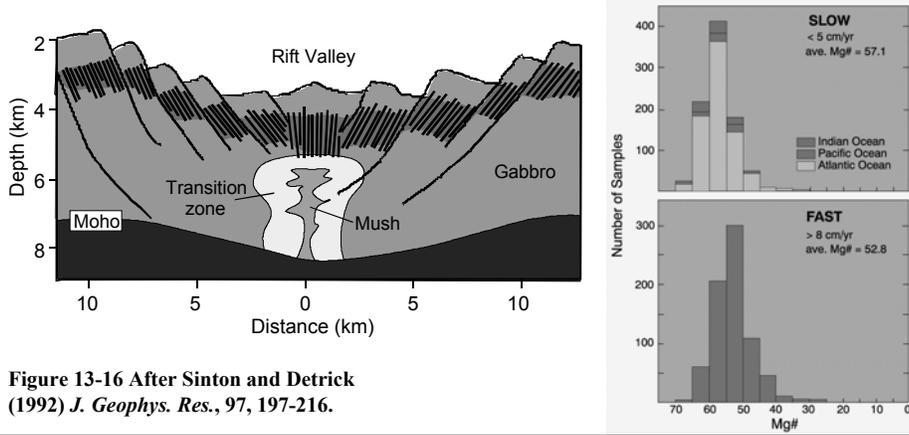


Figure 13-16 After Sinton and Detrick (1992) *J. Geophys. Res.*, 97, 197-216.