Lecture 18 - Mantle Melting

Monday, 28th, March, 2005

Mantle Melting
and
Origin of Basaltic Magma

Two principal types of basalt in the ocean basins

Tholeiitic Basalt and Alkaline Basalt

Table 10-1 Common petrographic differences between tholeiitic and alkaline basalts

	Tholeiitic Basalt	Alkaline Basalt
Groundmass	Usually fine-grained, intergranular No olivine Clinopyroxene = augite (plus possibly pigeonite) Orthopyroxene (hypersthene) common, may rim ol. No alkali feldspar Interstitial glass and/or quartz common	Usually fairly coarse, intergranular to ophitic Olivine common Titaniferous augite (reddish) Orthopyroxene absent Interstitial alkali feldspar or feldspathoid may occur Interstitial glass rare, and quartz absent
Phenocrysts	Olivine rare, unzoned, and may be partially resorbed or show reaction rims of orthopyroxene Orthopyroxene uncommon Early plagioclase common Clinopyroxene is pale brown augite	Olivine common and zoned Orthopyroxene absent Plagioclase less common, and later in sequence Clinopyroxene is titaniferous augite, reddish rims

after Hughes (1982) and McBirney (1993).

Each is chemically distinct

Evolve via FX as separate series along different paths

- Tholeiites are generated at mid-ocean ridges
  - Also generated at oceanic islands, subduction zones
- Alkaline basalts generated at ocean islands
  - Also at subduction zones

Sources of mantle material

- Ophiolites
  - Slabs of oceanic crust and upper mantle
  - Thrust at subduction zones onto edge of continent
- Dredge samples from oceanic fracture zones
- Nodules and xenoliths in some basalts
- Kimberlite xenoliths
  - Diamond-bearing pipes blasted up from the mantle carrying numerous xenoliths from depth

Lherzolite is probably fertile unaltered mantle

Dunite and harzburgite are refractory residuum after basalt has been extracted by partial melting

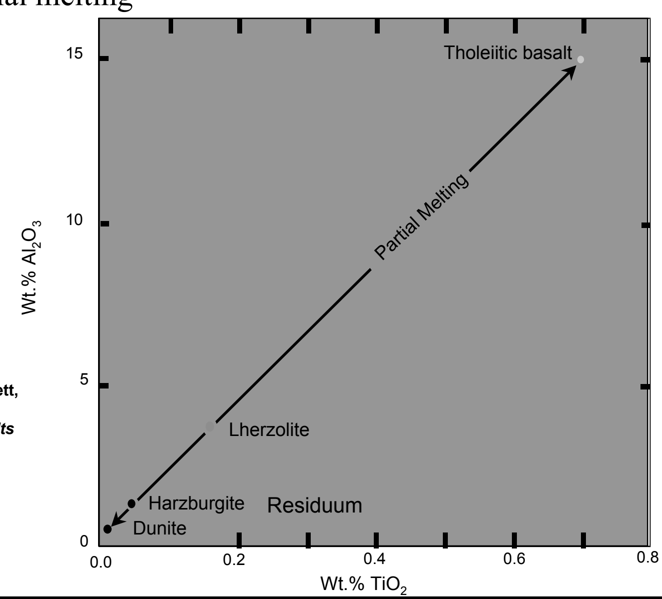


Figure 10-1 Brown and Mussett, A. E. (1993), *The Inaccessible Earth: An Integrated View of Its Structure and Composition.* Chapman & Hall/Kluwer.

Lherzolite: A type of peridotite with Olivine > Opx + Cpx

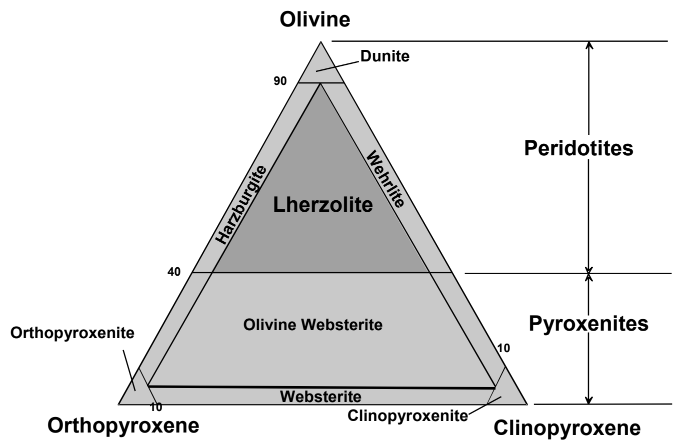


Figure 2-2 C After IUGS

Phase diagram for aluminous 4-phase lherzolite:

Al-phase =

- Plagioclase
  - shallow (< 50 km)
- Spinel
  - 50-80 km
- Garnet
  - 80-400 km
- Si → VI coord.
  - > 400 km

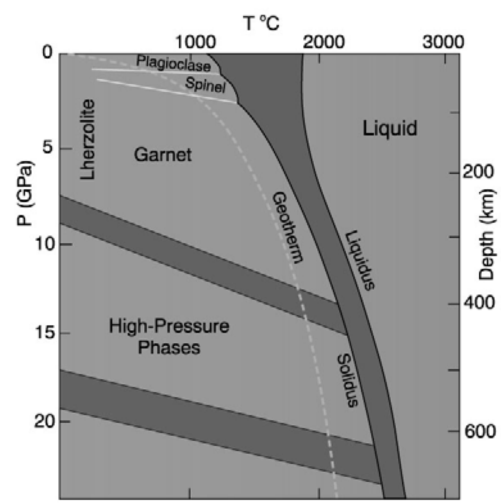


Figure 10-2 Phase diagram of aluminous lherzolite with melting interval (gray), sub-solidus reactions, and geothermal gradient. After Wyllie, P. J. (1981). Geol. Rundsch. 70, 128-153.

How does the mantle melt??

1) Increase the temperature

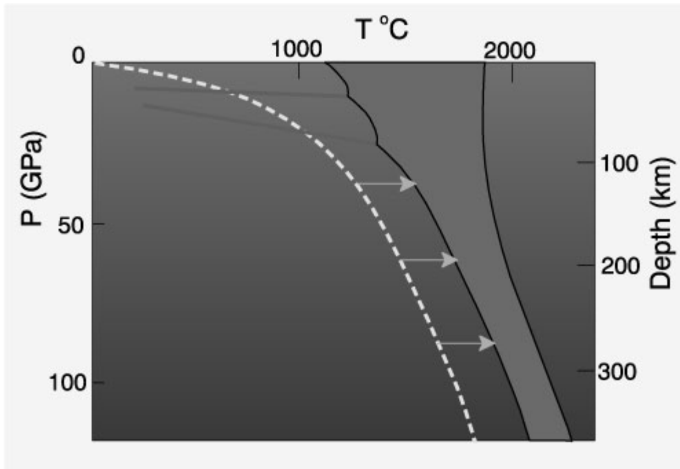


Figure 10-3. Melting by raising the temperature.

2) Lower the pressure

- Adiabatic rise of mantle with no conductive heat loss
- Decompression melting could melt at least 30%

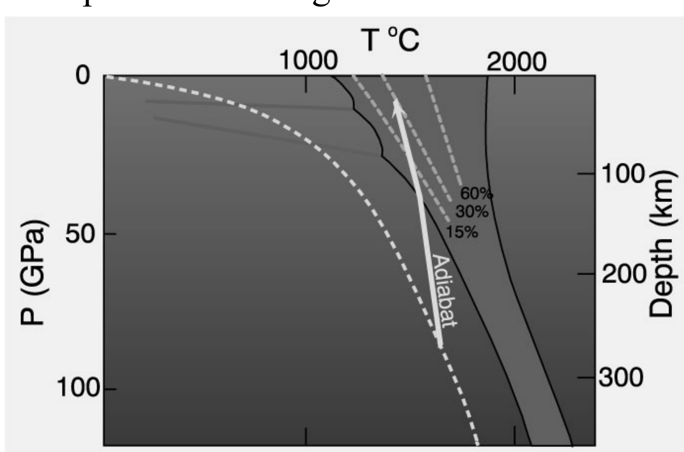


Figure 10-4. Melting by (adiabatic) pressure reduction. Melting begins when the adiabat crosses the solidus and traverses the shaded melting interval. Dashed lines represent approximate % melting.

3) Add volatiles (especially H_2O)

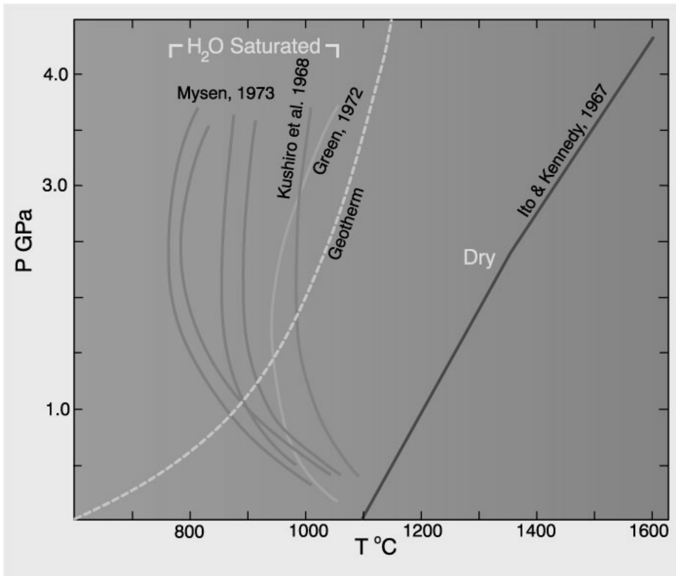


Figure 10-4. Dry peridotite solidus compared to several experiments on H2O-saturated peridotites.

● Heating of amphibole-bearing peridotite

1) Ocean geotherm

2) Shield geotherm

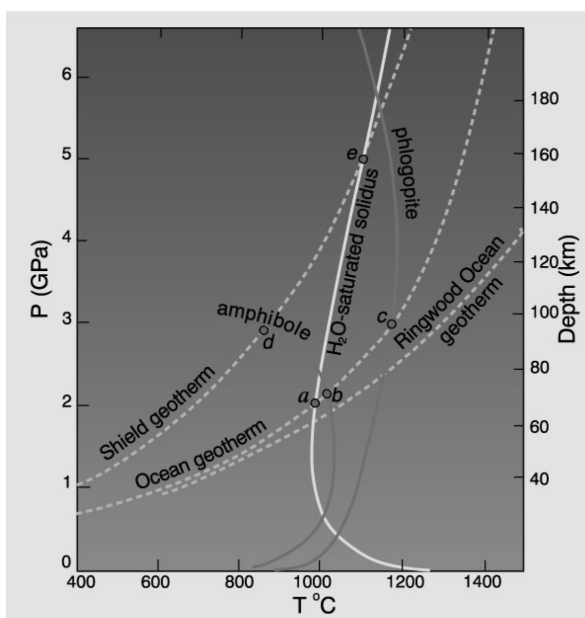


Figure 10-6 Phase diagram (partly schematic) for a hydrous mantle system, including the H2O-saturated lherzolite solidus of Kushiro et al. (1968), the dehydration breakdown curves for amphibole (Millhollen et al., 1974) and phlogopite (Modreski and Boettcher, 1973), plus the ocean and shield geotherms of Clark and Ringwood (1964) and Ringwood (1966). After Wyllie (1979). In H. S. Yoder (ed.), *The Evolution of the Igneous Rocks. Fiftieth Anniversary Perspectives.* Princeton University Press, Princeton, N. J, pp. 483-520.

Melts can be created under realistic circumstances

- Plates separate and mantle rises at mid-ocean ridges
  - Adibatic rise → decompression melting
- Hot spots → localized upwelling mantle plumes
- Fluid fluxing may give Low Velocity Zone
  - Also important in subduction zones

Generation of tholeiitic and alkaline basalts from a *chemically* uniform mantle

Variables (other than X)

- Temperature
- Pressure

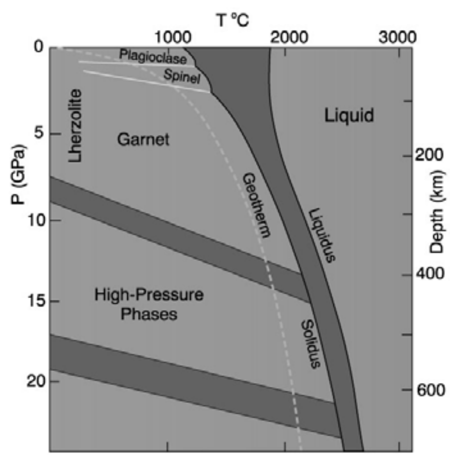
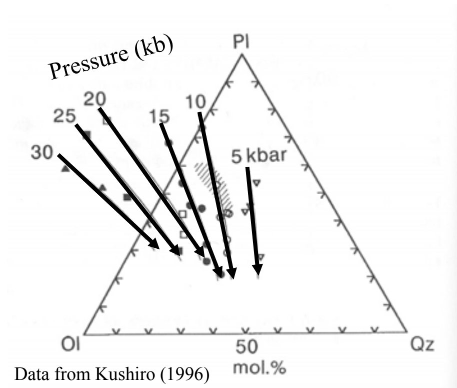


Figure 10-2 Phase diagram of aluminous lherzolite with melting interval (gray), sub-solidus reactions, and geothermal gradient. After Wyllie, P. J. (1981). Geol. Rundsch. 70, 128-153.

Effects of Pressure on Melting Lherzolite

Preliminary Conclusions

- Shallow melting (<30 km) produces tholeiites
- Extensive melting (>10%) favors tholeiites and picrites
- Small amounts of melting produces alkali basalts
- Deeper melting favors alkali basalts (unless melting is extensive)



Data from Kushiro (1996)