Lecture 6: Igneous Rocks (Melting and Differentiation) Oct. 4, 2006

First few minutes to reiterate major rock types (extrusive/intrusive equivalents).

Some clues as to how the three major igneous rock types form

rhyolites
only occur in continental areas
therefore the melting process producing rhyolites presumably not in mantle
andesites
occur both in continental and oceanic areas
but in oceanic setting, they are largely confined to areas near trenches
andesite line in the Pacific
thus, melting process seems to involve mantle but with link to subduction
basalts
occur anywhere, particularly abundant in ocean basins
melting process involves mantle and must be well exemplified at ridges

Where do magmas form? (how does melting occur?)

a simple PT diagram (phase diagram) for a homogeneous substance

solidus separates crystals from xtl + liquid
note positive slope (i.e., higher melting temperature at higher pressure)

changes in order to melt
1. increase T
2. decrease P
3. change composition

1) increasing T

specific heat = thermal energy required to raise T of 1g by 1C (constant P)
heat of fusion = thermal energy to change 1g to liquid at solidus T/P

specific heat for rocks: 0.8-1.3 J/gC
heats of fusion: 300x bigger (270-420 J/g)

so enormous amount of heat required to melt rock (heat released by xtl)

sources of heat

a. radioactive elements (e.g., K,U,Th)

granite	3.4 x 10-5 J/g yr
basalt	5.0 x 10-6
peridotite	3.8 x 10-8

granite at solidus T/P would require 10 million years to melt completely
peridotite would require 10 billion years to melt
so simply heating is an unlikely process to melt

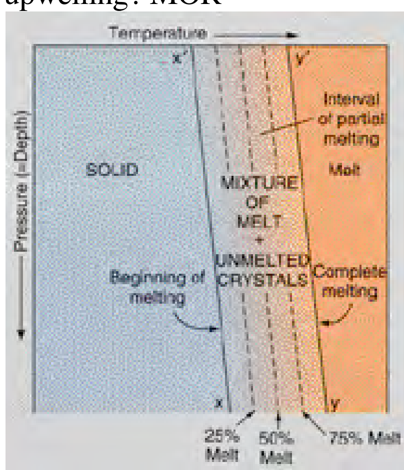
b. mass transfer (e.g. in subduction zone setting or locally near intrusion)

2) Decompression melting (most plausible model)

mantle is primarily peridotite (ol + px + aluminous phase (spinel, garnet)
meteorite samples (frags of planets)
similar chemistry and mineralogy
similar age (4.55 b.y.)
sample crust: know it's richer in certain light elements
geophysical techniques tell us that core is mostly Fe (liquid)
direct samples of mantle (*xenoliths*; rare tectonic exposures)
use mineralogy to deduce depths and temperatures of formation

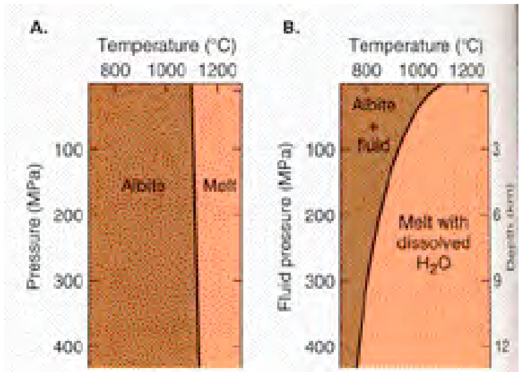
positive slope dT/dP of peridotite solidus
adiabat (thermal energy neither gained nor lost)
compression (work) some heat
example of bicycle pump
rocks are much less compressible and heat much slower
adiabatic gradient (0.3C per km)

physical upwelling of mantle material leads to melting
why might we get such upwelling? MOR



partial melting
when material is not homogeneous then melting happens over a range of T
importance: partial melting can produce significantly different composition
(low melting point materials first)

3) composition change (also important)
water lowers solidus temperature
e.g. albite melting in text p.84



effect on peridotite solidus

mechanism for getting water into mantle
subduction of sediments and hydrous mineral phases

Tectonic settings of magma production

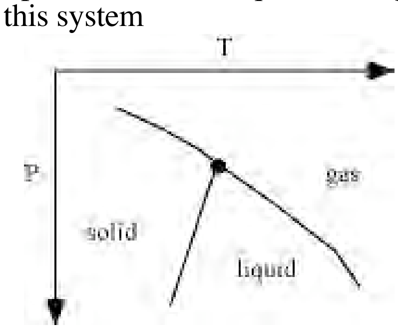
1. ridges
adiabatic decompression melting of peridotite > basalt (why will become clearer later)
images of melt at ridge
produced is basalt, gabbros at greater depth

2. subduction zones
water introduced into mantle above subduction zones
melting and production of melts (diorites/andesites)
fundamental difference with basalts/gabbros is presence of hydrous phases

3. mantle plumes
thermal input from deep in the mantle (D")
mantle to be both hotter and more buoyant (rises as plume)
examples: Hawaii, Columbia river basalts

Introduction to phase diagrams (e.g. H_20, antifreeze)

some definitions
phases = chemically and physically homogeneous part
of a system that is bounded by interface to adjacent phases
components = minimum number of chemical constituents to assemble all phases
H_2O phase diagram (p.674 Chemistry text)
familar with the possible phases of water: liquid, solid, gas
only one component in this system

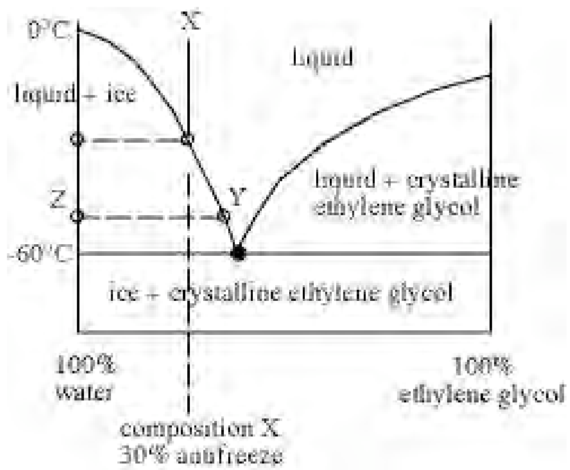


univariant curve - only P or T is independent (1 degree freedom)
invariant point - P and T fixed (0 degrees freedom). 0.01°C, 0.006 atm

Summarized by *phase rule*: F = 2 + C - P

H_2O + ethylene glycol (a slightly more complicated system)
** NB: this diagram is simplified (additional phase possible in some cases)

C = 2
At constant P: F = 1 + C - P = 3 - P



freezing point depression = optimum mixture 35% ethylene glycol
invariant point (eutectic)
lever rule