Lecture 7: Igneous Rocks (Differentiation, Volcanic Processes) Oct. 6, 2006

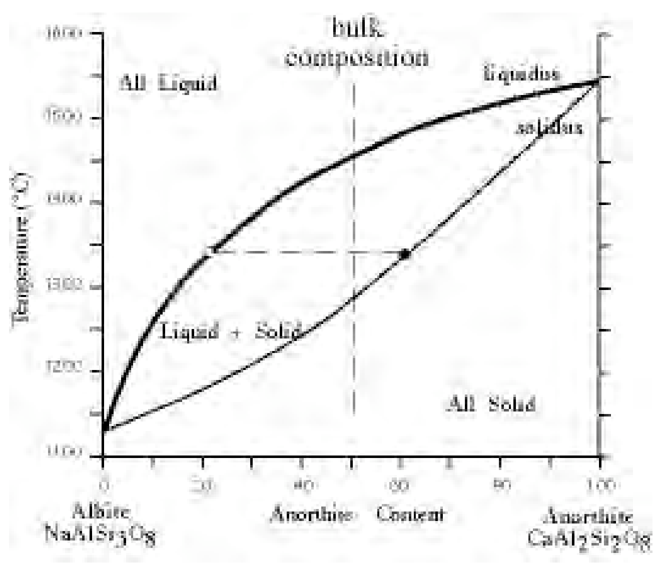
First few minutes to recap: Last time we saw that mixtures of materials partially melt, yielding a very different composition that if the solid completely melted. Rocks behave in this same fashion, though complicated by multiple mineral phases, solid solution etc. Now we will look at one final phase diagram (plagioclase) that illustrates how partial melt compositions can be very different but also how liquid compositions can change during crystallization.

Goals for this lecture:

1. How do we explain diversity of magma compositions?
   partial melting/fractional crystallization
2. Plag phase diagram as illustration
3. Mechanisms for separating crystals and liquids
4. Why partial mantle melts = basalt (if time allows)
5. Bowen's reaction series
5. How granitic melts are generated.

Plagioclase phase diagram

why important?
  many mineral groups have solid solutions
  plagioclase is major mineral in most crustal rocks
solid solution results in different structure for phase diagram
  C = 2 (use albite, anorthite as components)
  F = 1+C-P
  so have univariant curves, no eutectic

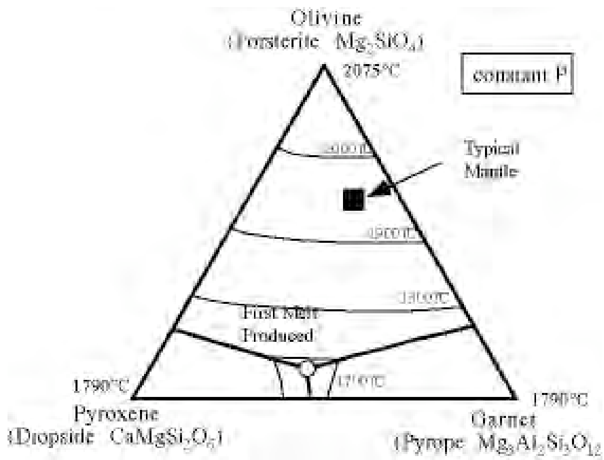


equilibrium melting/crystallization
  illustrate evolution of crystals, liquid
  end result is same composition
  what would this look like in rock record (uniform crystal composition)
fractional xtl/melting
  illustrate both cases

what happens in extreme case of perfect fractional processes (reach endmembers)
more typically, the separation of crystal/liquid is not perfect
mechanisms for separation
graviational settling
incomplete reaction (zoning)
magma flow segregation
what would product look like in rock record (compositional layering, zoning)

Mantle melting (time permitting)

several mineral combinations have binary eutectic as in above system
ternary system for mantle melting - extension of binary systems
ol - pyr, ol-garnet and prx-garnet all individually binary eutectics
here we have liquidus surface (instead of line)
invariant point - three phases + liquid
univariant curves



review phases in mantle - Ol+Px+aluminous phase (Plag/Garnet)
given average mantle composition subjected to decompression melting, what would composition of initial melt be?

1) estimate the position of the eutectic (10% Ol, 45% Px, 45% Gt)
2) write out the compositions of these phases in terms of % oxides

	MgO	SiO2	Al203	CaO
forsterite	57.3	42.7		
pyrope	30.0	44.7	25.3	
diopside	18.6	55.5		25.9

3) now weight these by percentages of eutectic and ...
SiO2 = 49.4
MgO = 27.6
Al2O3 = 11.4
CaO = 11.6
This is the composition of a basalt (MgO value is slightly lower if we include FeO and other minor elements).

** so this explains the compositional uniformity of MORB
Location of invariant point changes slightly with P, H2O
for hydrous case --> lower T, higher SiO2, water in melt (hallmarks of andesite)

What explains the diversity of magma types? Magmatic differentiation

Bowen's reaction series
recall series of crystallization
expected changes in elemental abundances for basaltic melt
removing xtls changes composition of remaining liquid

1. Xtl - Liquid fractionation (*fractional crystallization*)
   changes in liquid composition accompanying xtl removal (variation diagrams)
   mechanisms
   a. filter pressing
   b. flow segregation
   c. zonation in xtls
   d. gravitational segregation

   Stokes' Law velocity = $2*r^2*g*$density difference/9*viscosity

   p.318 in Best shows settling velocities

2. Magma mixing
3. Assimilation
   partially corroded xenocrysts

Generation of granitic continental crust

Bowen thought that granitic(rhyolitic) liquids could be produced by fractional crystallization of basaltic magma. While it is possible to generate some rhyolitic liquids by this process there are a number of flaws in Bowen's idea.

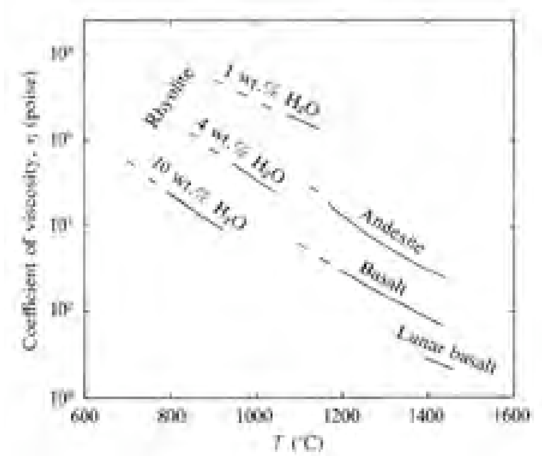
1) only a small % of rhyolitic liquid (<5%) is produced by crystallization of basalt
2) if fractional crystallization of basalt >> rhyolite, then oceans should have abundant rhyolites (since this is where we have abundant basaltic liquids)
3) the fractionated xtls from basaltic liquids (mafic cumulates) should be very abundant (e.g. beneath batholith we might expect many 10's km of ol,px cumulates)

So if fractional crystallization is not the operative process, how do we generate granites?

distillation - multiple cycles of partial melt of less silicic materials (+/- seds)
evidence for this process in distribution of granites in continents

Physical properties of melts (viscosity)

The physical properties of melts determine many important characteristics of volcanic landforms and activity. Viscosity (internal resistance to flow) exerts a primary control.



Best (1982)

For comparison, viscosity of water is 0.01 poise.

Landforms - shapes reflect viscosity

stratovolcano
- mixture of tephras and lavas
- 6-10° slopes, steepening to 40° at summit

shield volcano
- slopes of only a few degrees
- basaltic (lower viscosity)

Explosive activity

basaltic lavas - tend to have quiet eruptions
and/rhyolites - tend to have explosive eruptions

Controls on Viscosity

1. Temperature
   general effect of temperature evident in figure above
   Tbas > Tand > Trhy

2. Composition
   main effect is SiO2 content
   polymerization of melt (similar to that of silicate mineral structures)
   Si leads to increased polymerization
   Ca,Mg network modifiers

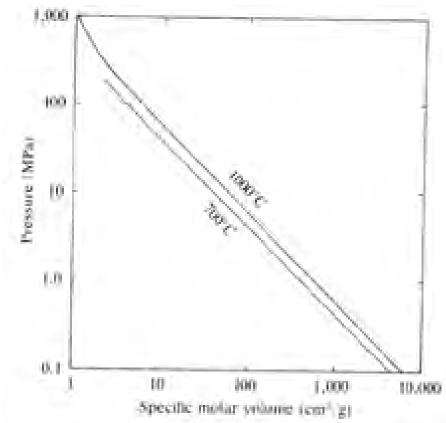
   Together with temperature effect: Visc(rhyolite) > Visc (basalt)

3. Volatiles
   water (present as OH-) acts to replace bridging O and prevent polymerization
   evident in viscosity variation of rhyolites in above figure

   BUT, volatile content has more fundamental influence ...

Volatiles and explosive eruptions

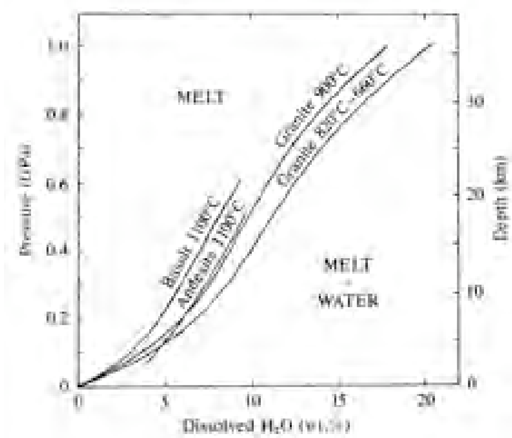
As melts near the surface, P decreases and dissolved volatiles tend to exsolve.



If melt is very viscous this process is inhibited >> explosive eruptions

How much water can be dissolved in silicate melts?

1) if no water in source then none in melt (e.g. MORB)
2) enhanced by differentation (H2O as incompatible)
3) limited by solubility



rhyolitic melts have much higher solubilities
source of water (seds, met involved in melting)