MAGMA FORMATION AND PROPERTIES

L. Pioli

What is a volcano?

- A vent in the surface of the Earth through which magma and associated gases and ash erupt.

(glossary of geology, fifth edition, 2005)

Crater Lake, Oregon

Augustine, Alaska

Mid Atlantic ocean

What is magma?

- Naturally occurring molten of partially molten rock material.. Capable of intrusion and extrusion. It may or may not contain suspended solids and/or gas phases

(glossary of geology, fifth edition, 2005)

Volcanoes are located

- At the boundaries of:

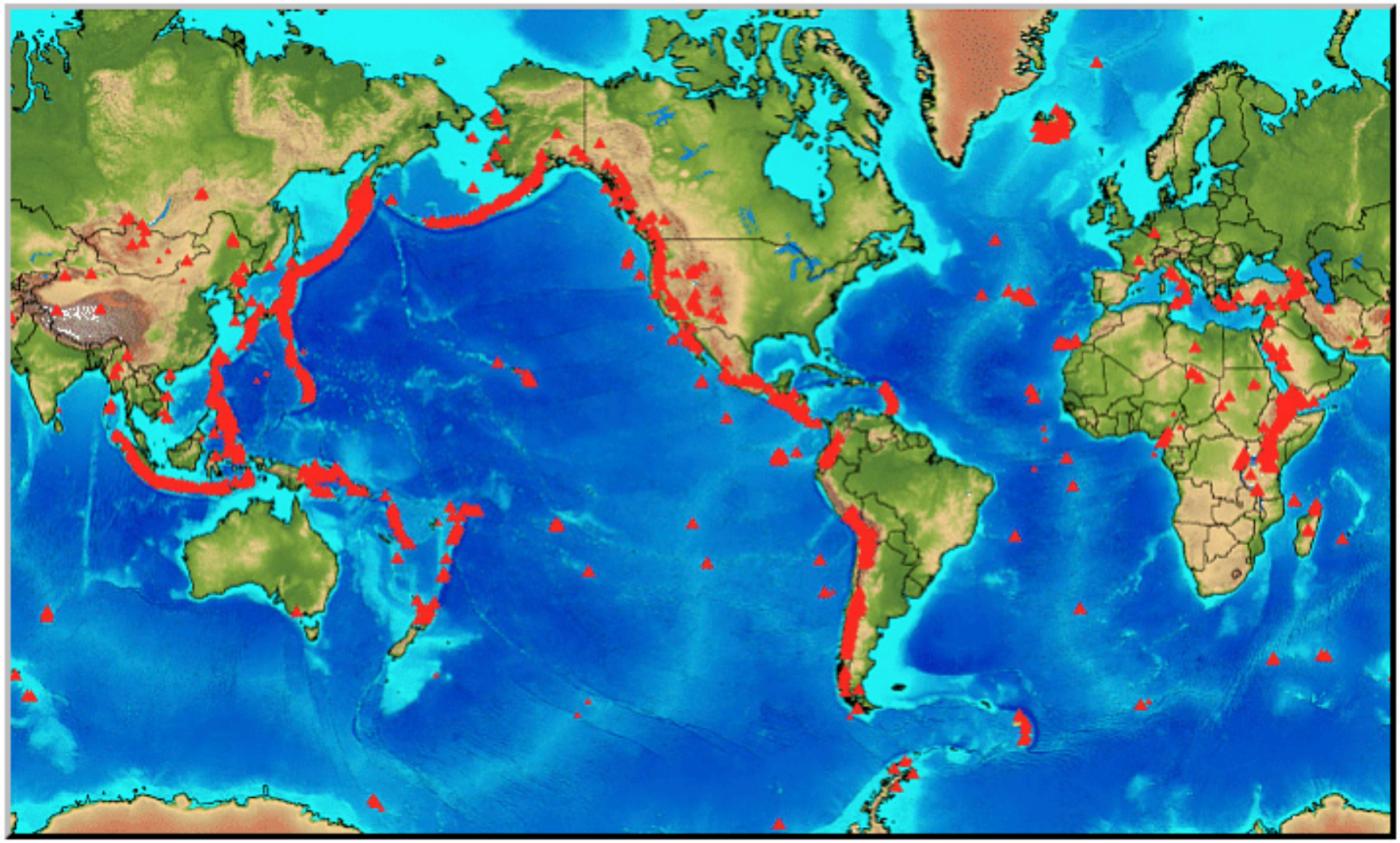
Divergent plates (Mid ocean ridges and continental rifts)

Convergent plates (volcanic arcs)

Transform boundaries

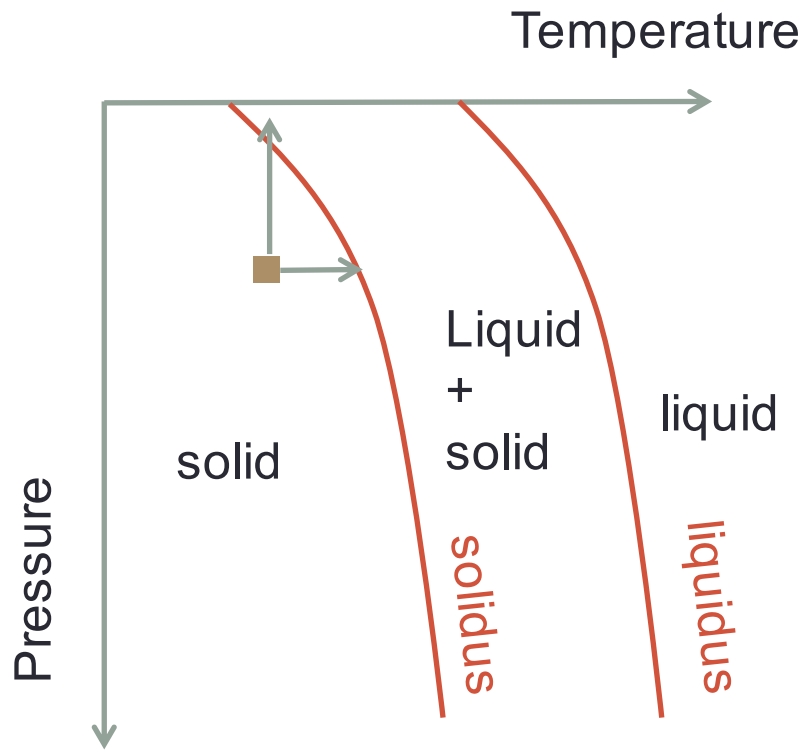
- Intraplate volcanism (hot spot)

Where are the volcanoes?



How does magma form?

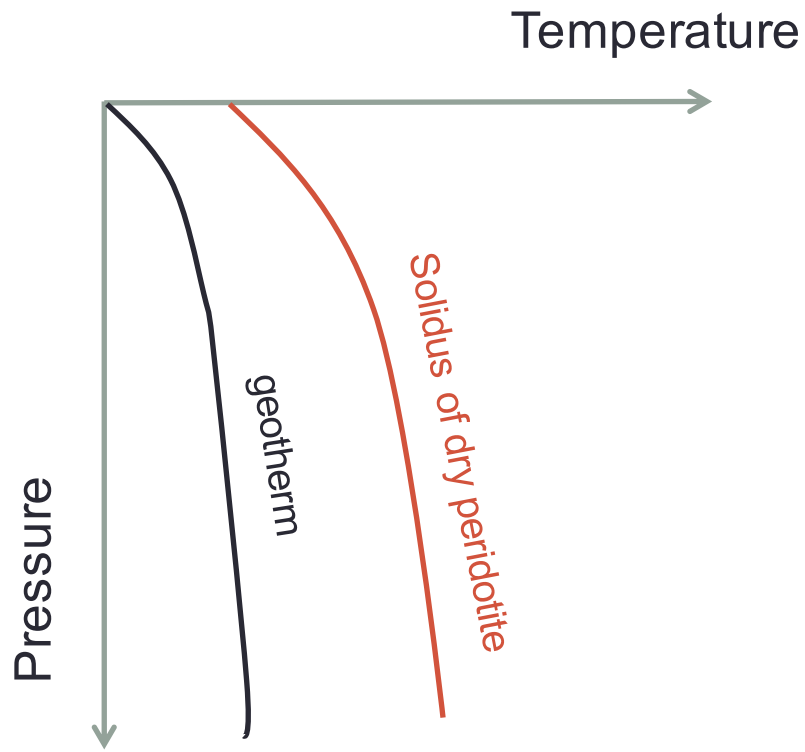
- Liquidus/solidus temperatures and curves



- Decrease of P
- Increase of T
- Change of composition

How is melting possible?

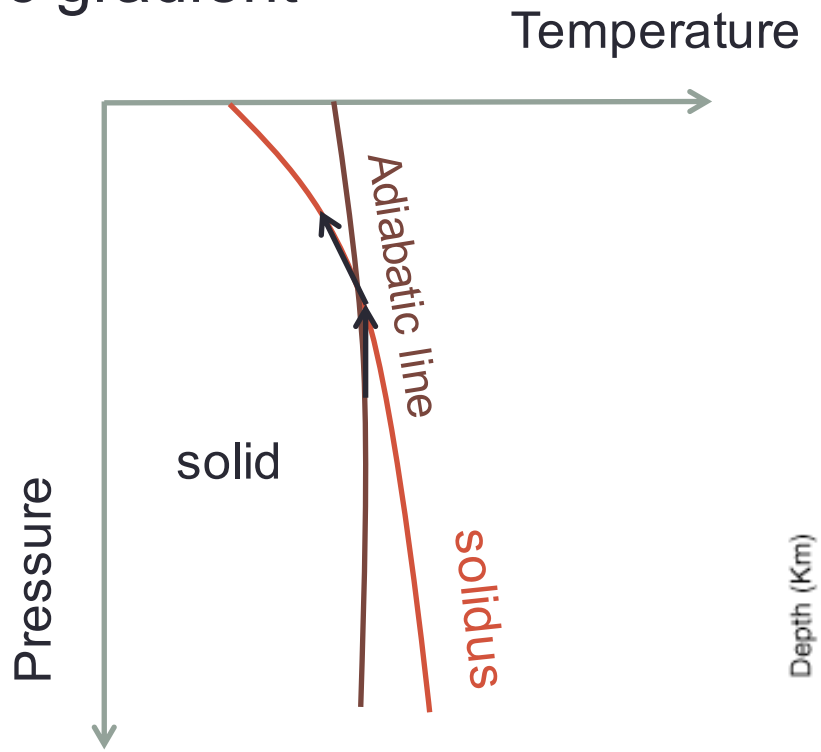
- Solidus and geotherm curves

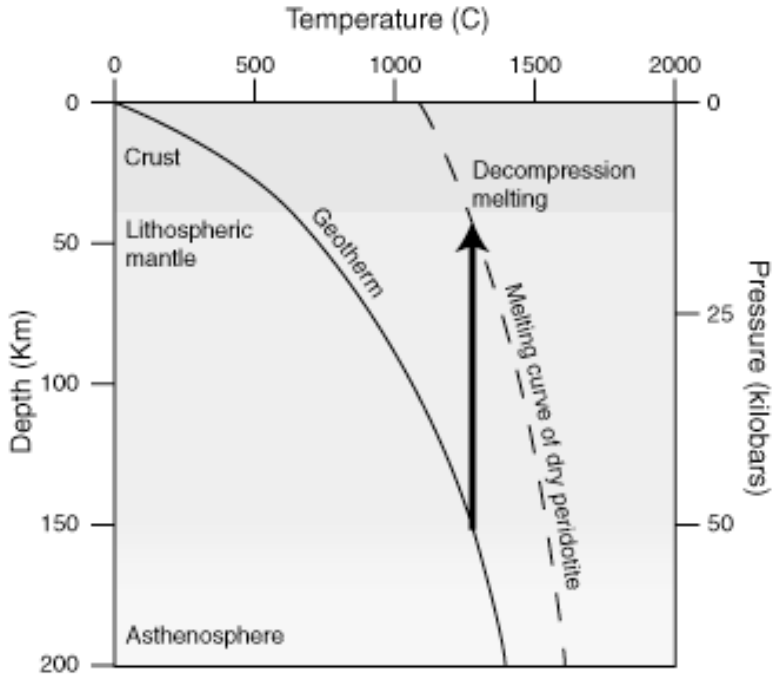


Decompression melting

- The role of convection in the mantle
- Adiabatic gradient

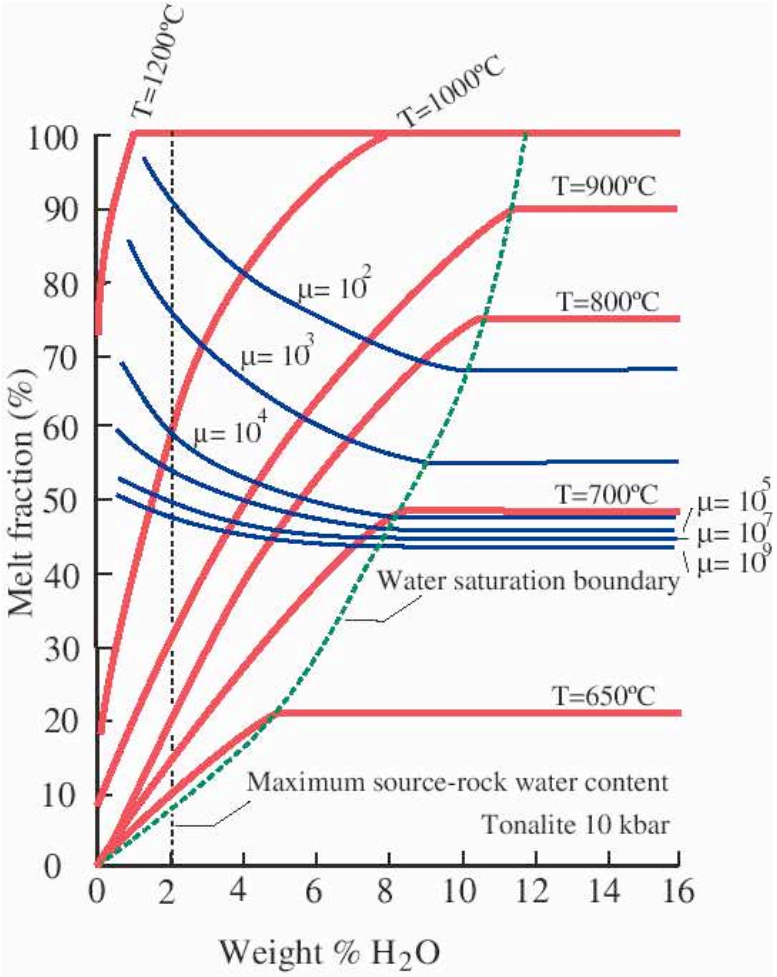
$$\left[\frac{dT}{dP}\right]_{s=0} = \frac{\alpha T}{\rho C_p}$$

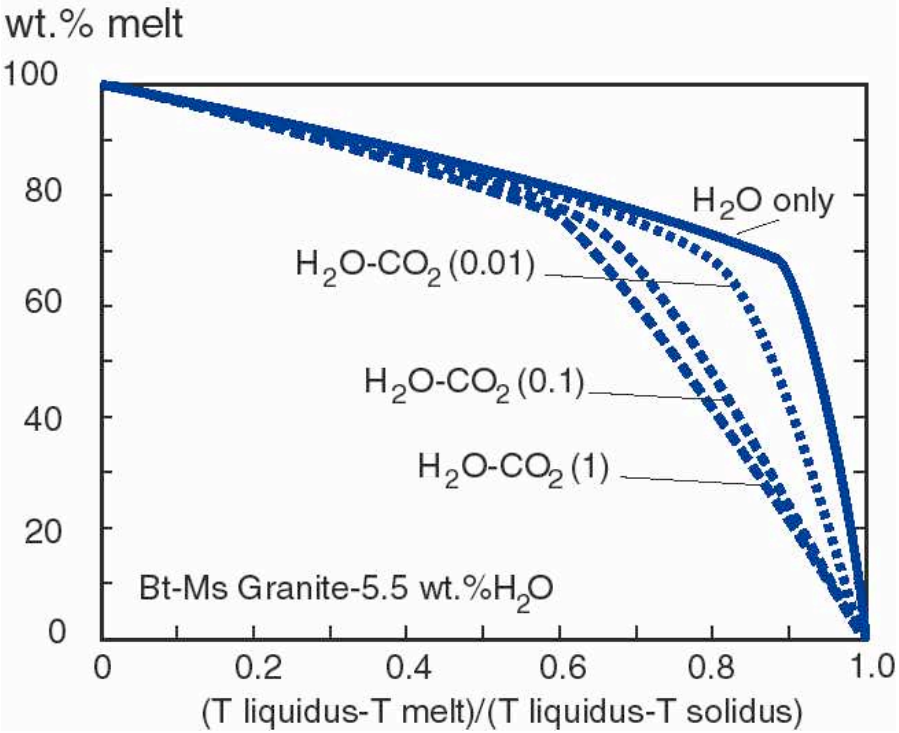




What does adiabatic mean?

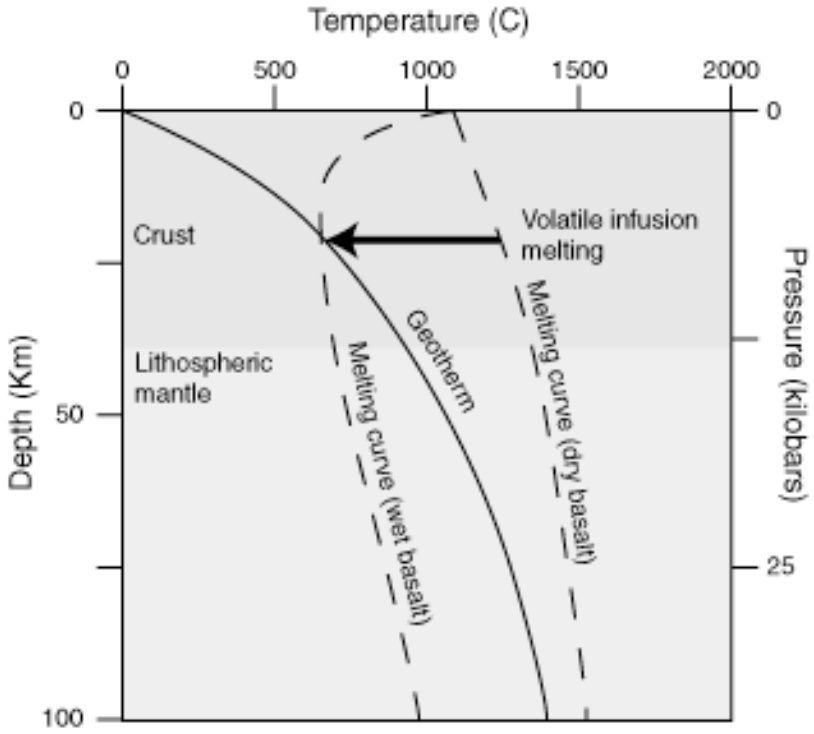
Effect of volatiles on melting



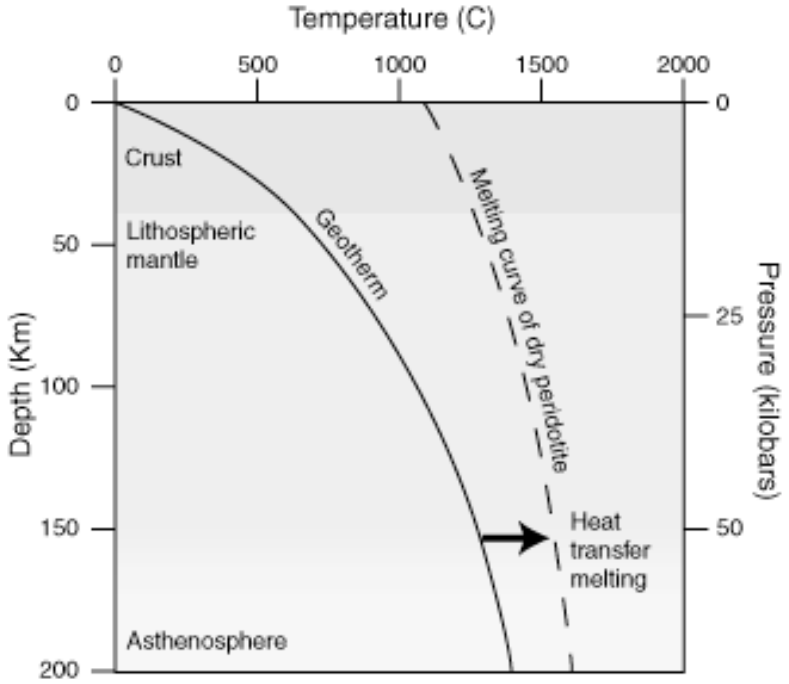


Muscovite bearing granite

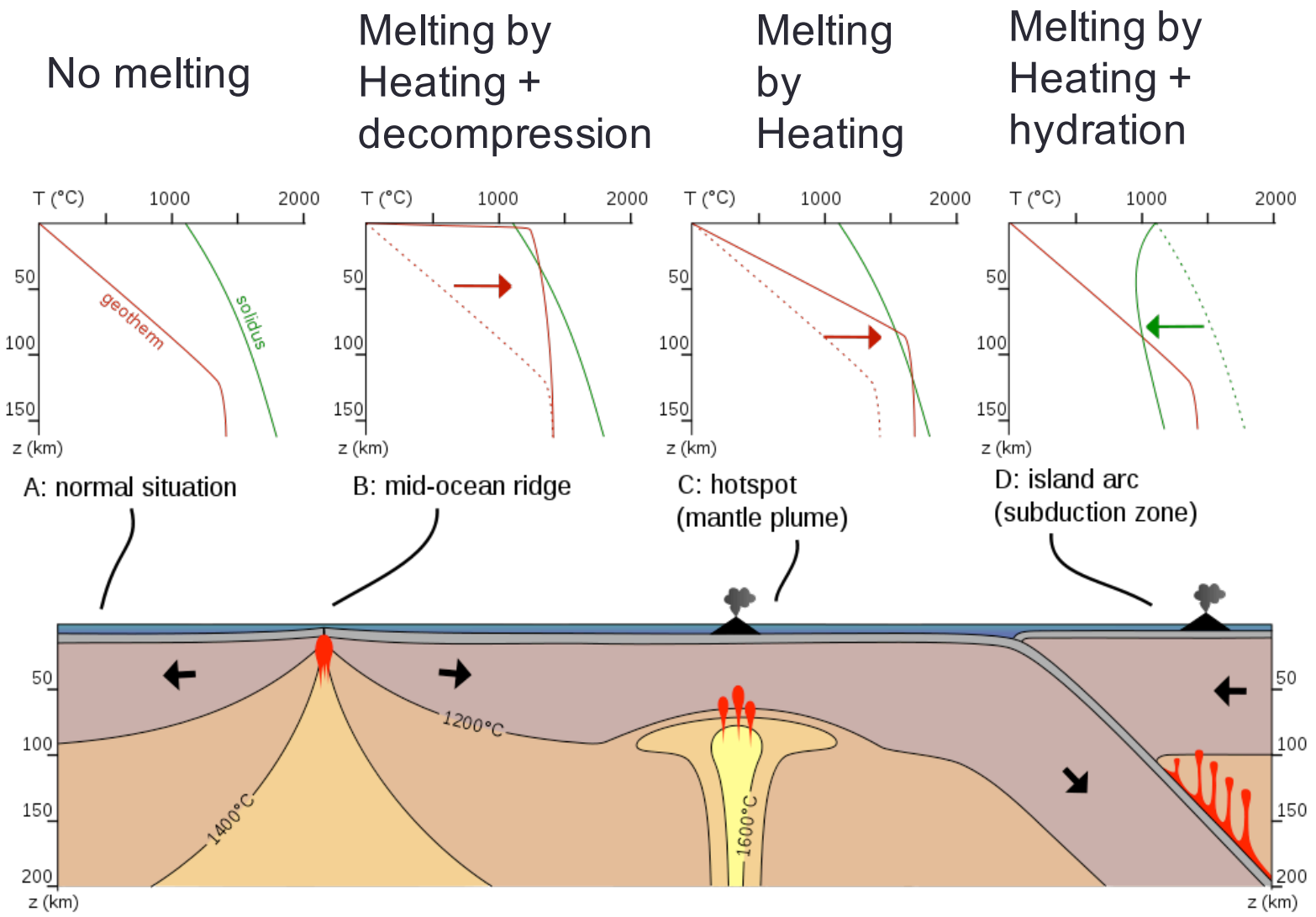
Effect of volatiles on melting



Melting by heat transfer



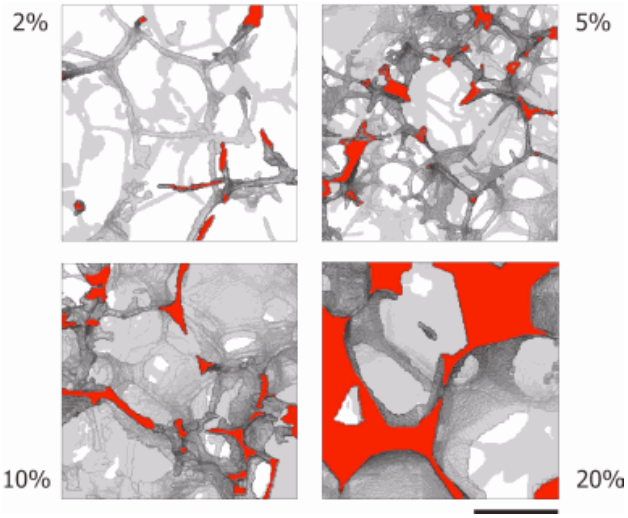
Melting and tectonic settings



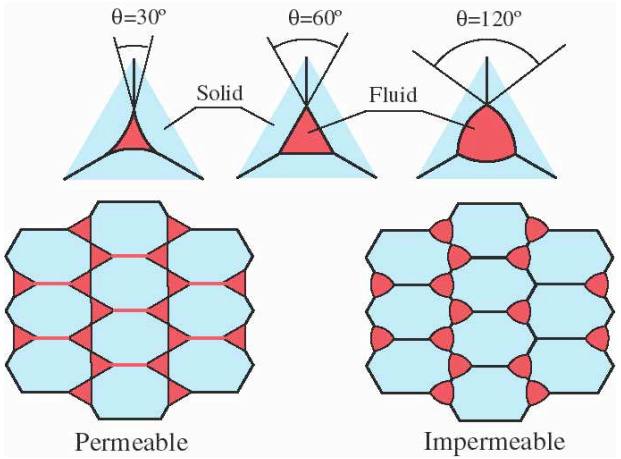
Rock melting



Progressive melting of gneiss with formation of a granitic melt

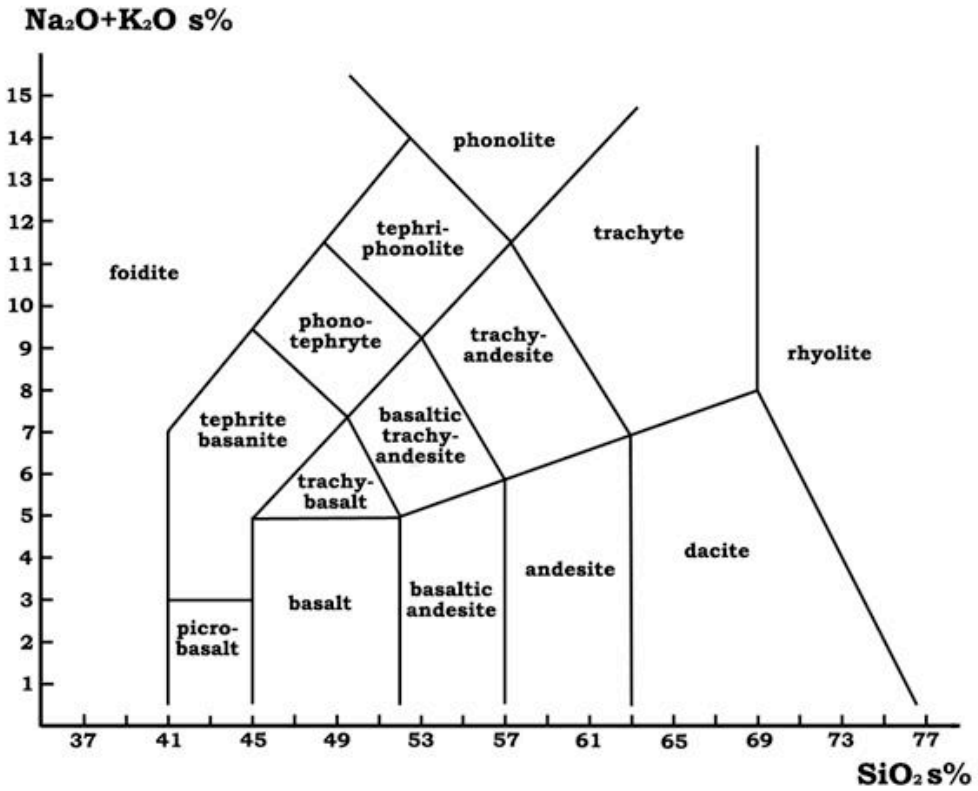


Melting of mantle rocks (experimental)



Magma properties-composition

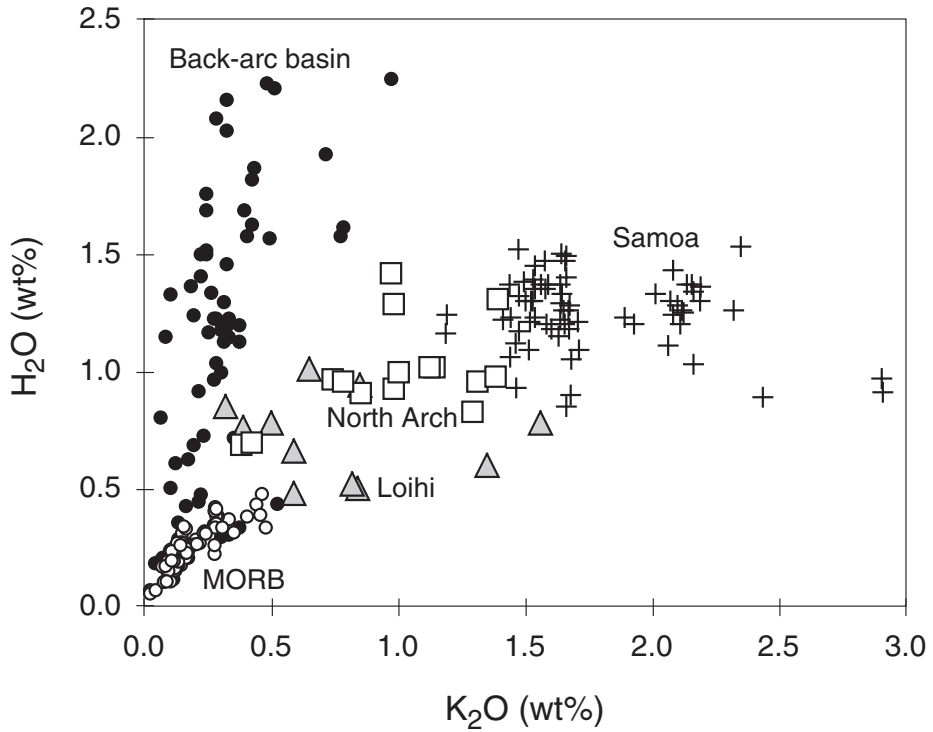
- Composition: Silica ranging from 37 to >70%, alkali content also very variable.



Total Alkali Silica (TAS) diagram

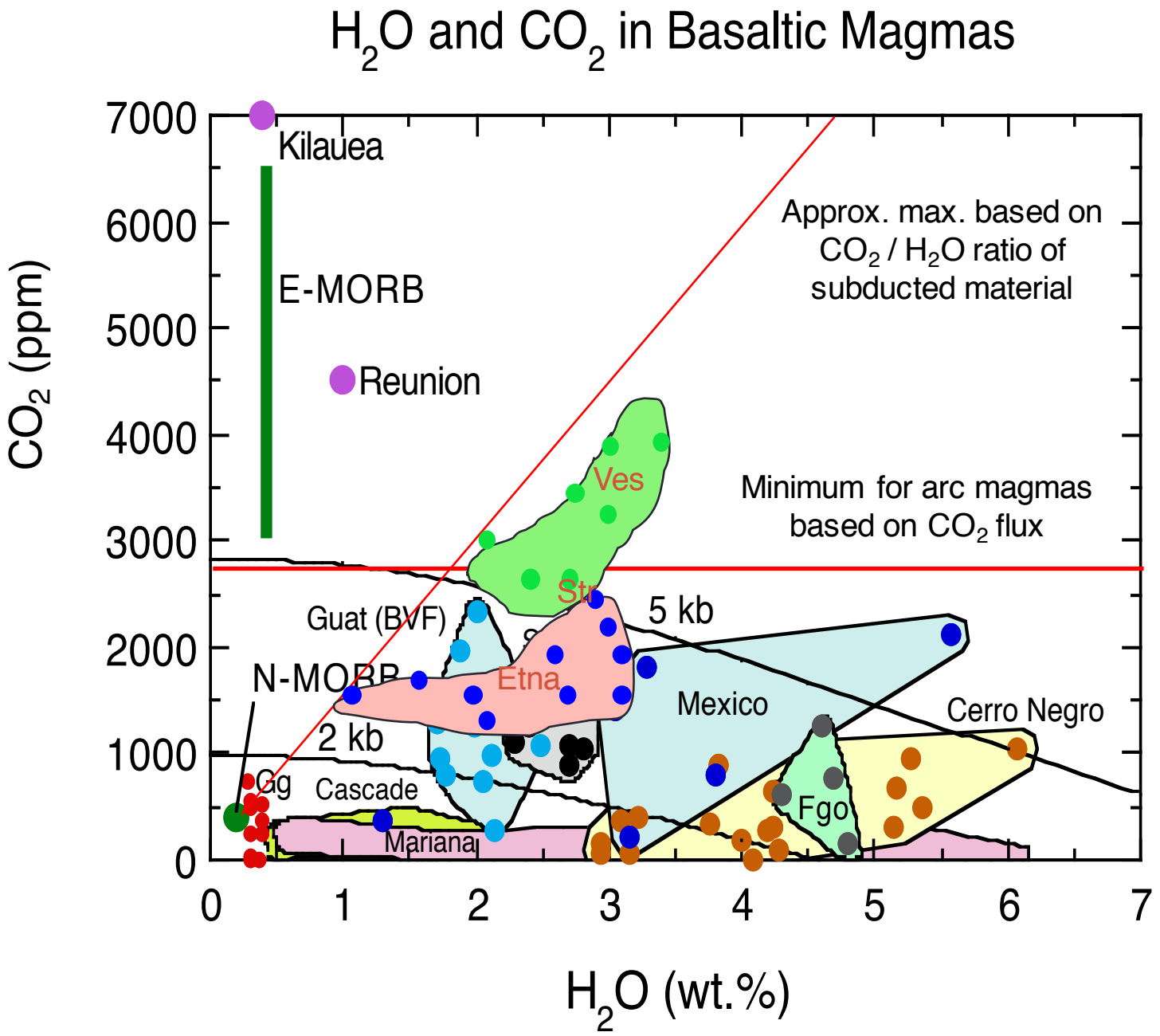
Le Maitre et al. 2002

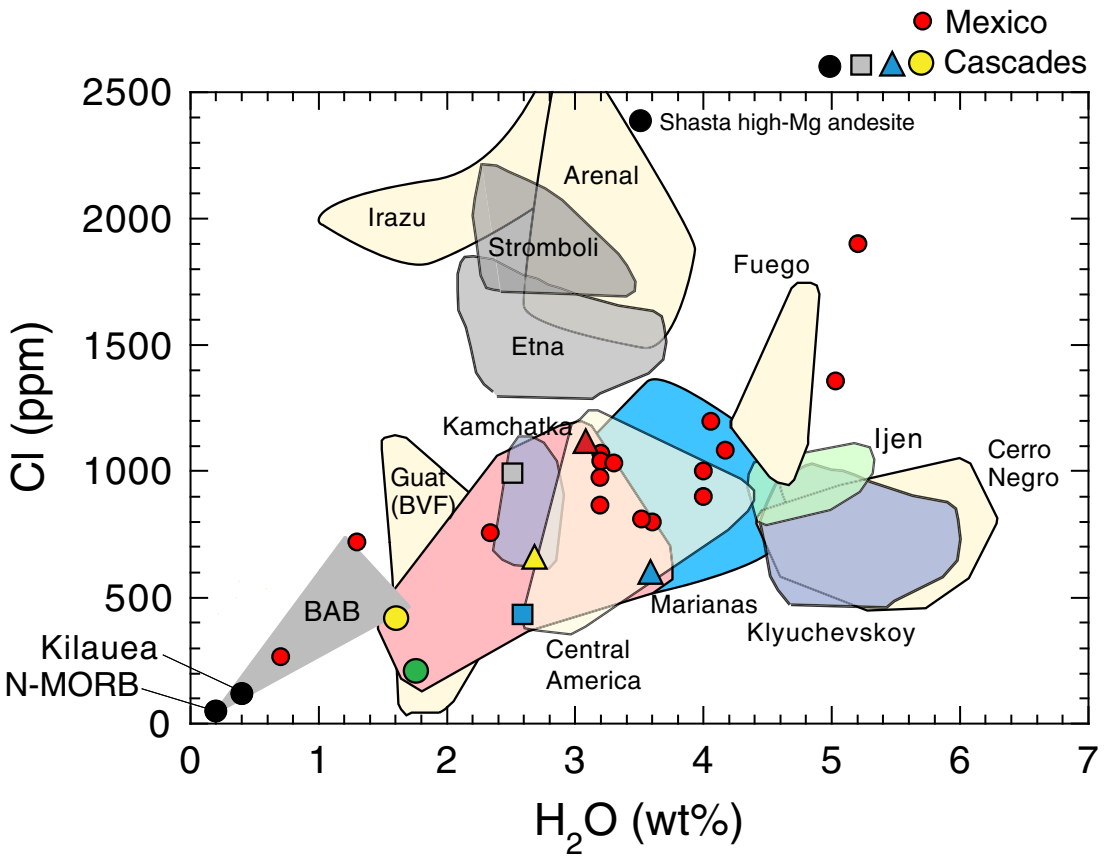
Volatiles in mafic magmas



Wallace et al., 2016

Magma properties-composition



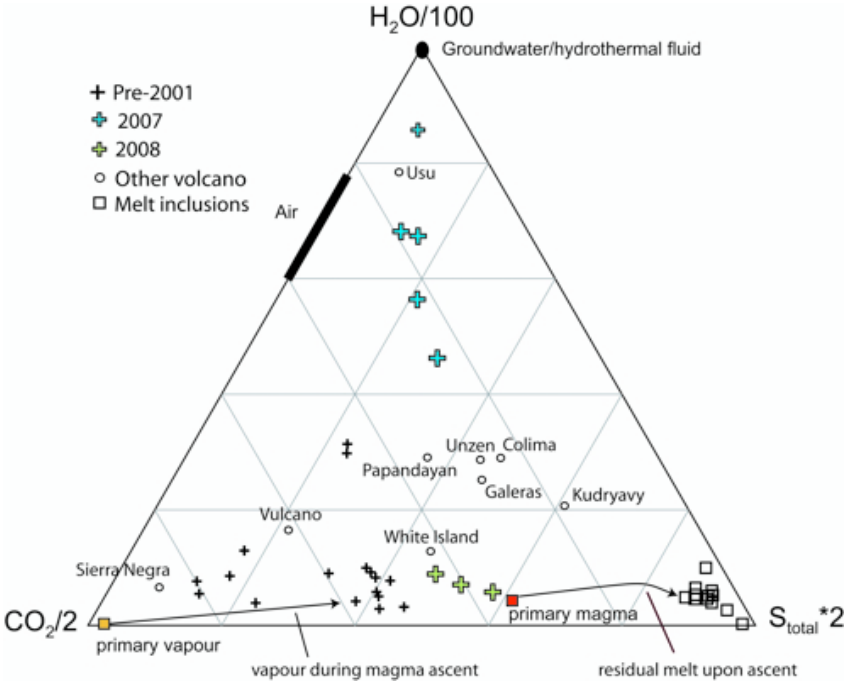


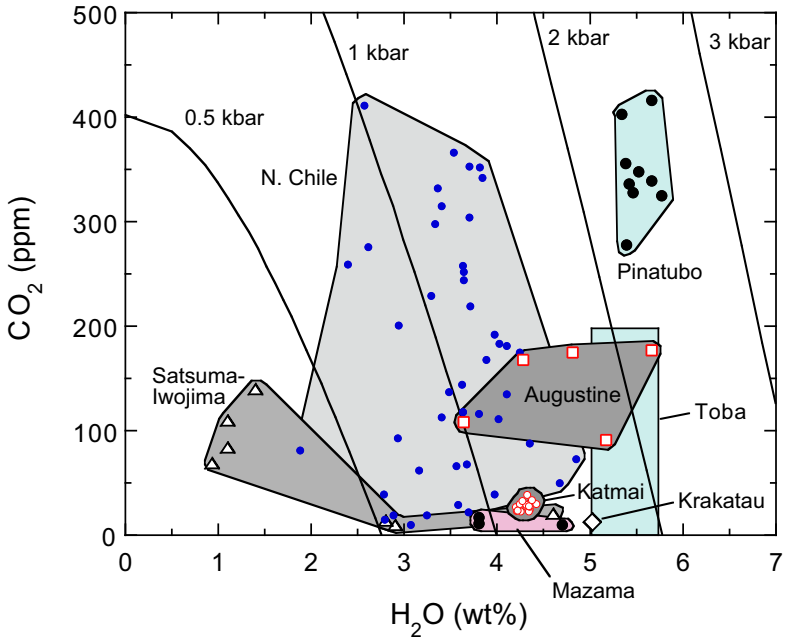
Metrich and Wallace, 2008

Magma properties-composition

- Volatile content

Volatile content in evolved magmas from arc settings





From http://www.sfu.ca/volcanology/research/volatile_history.html

Wallace, 2005

Magma properties- temperature

- Eruptive Temperature:

Basalts: 1200-1050° C

liquidus T: 1200-1250° C

- Solidus T 950-1000° C

- Rhyolites: 800-1000° C

liquidus: 1050° C

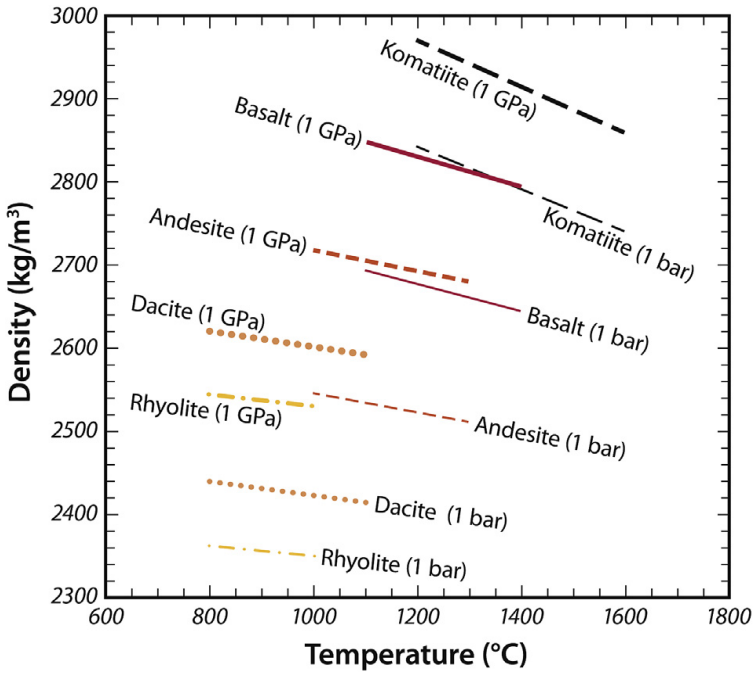
Solidus T 650-750° C

Magma density

It depends on composition $\rho = \Sigma X_i M_i / \Sigma X_i V_i$

and on P and T

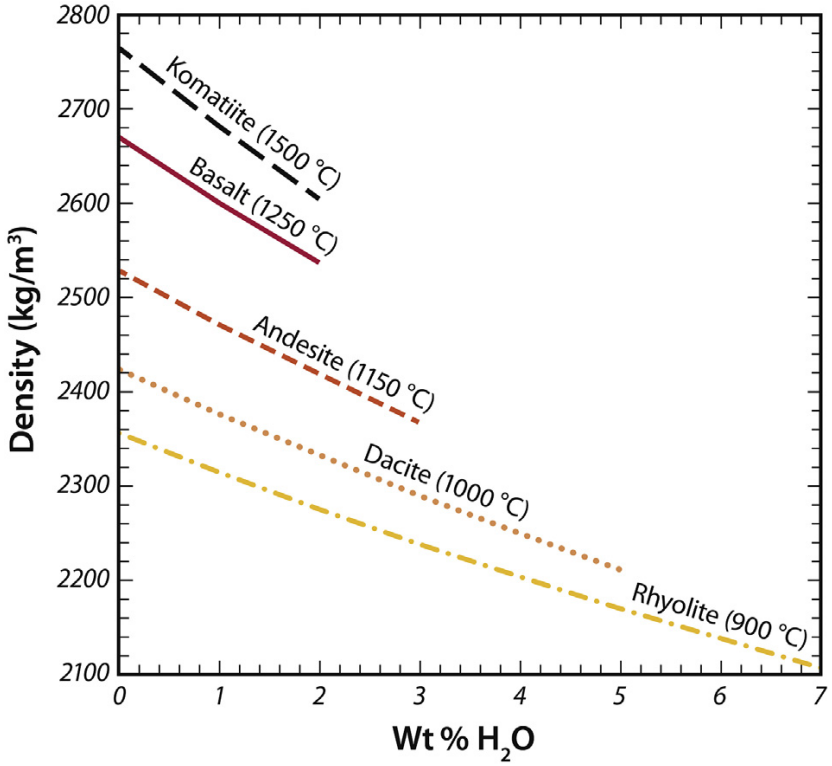
$$V(T,P,X) = \sum X_i \left[V_{i,T_r} + \left(\frac{\partial \overline{V_i}}{\partial T} \right)_P (T - T_r) + \left(\frac{\partial \overline{V_i}}{\partial P} \right)_T (P - P_r) \right]$$



Where T_r and P_r are reference conditions

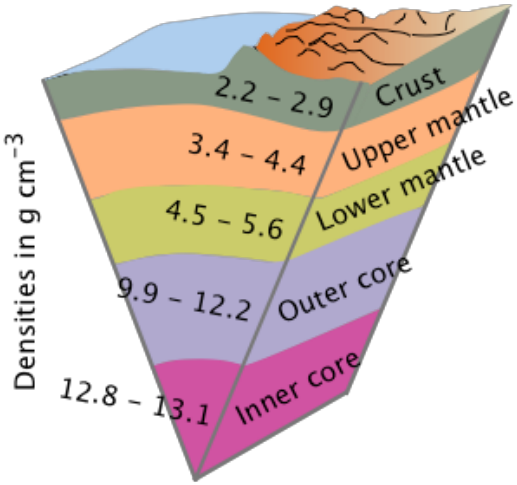
Density at 1 GPa of pure liquid magmas

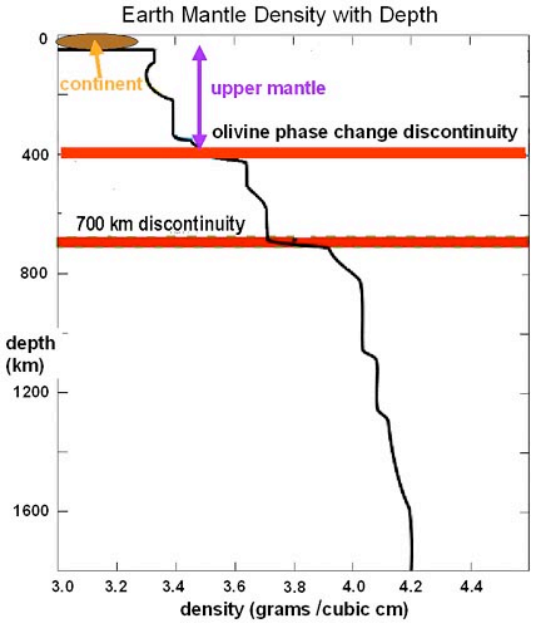
Magma density



Effect of water content at 1 bar of pressure

Magma density





- Why magmas rise up to crustal levels?
- Why magmas are erupted?

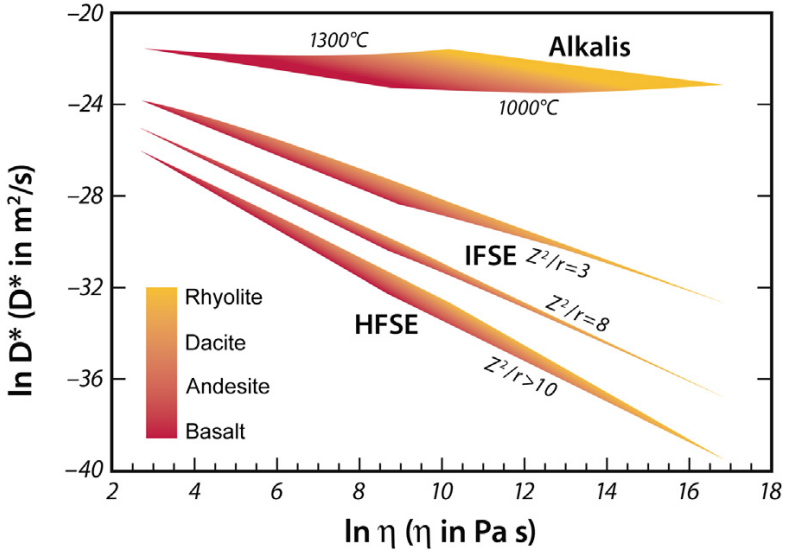
Magma diffusivity

$$\ln D_i = -16.16 + \frac{42.6(r_i - 1.03)^2 + 6.63Y_1 - [1239Y_2 + 27424(r_i - 1.03)^2 + 6975]}{T}$$

where r_i is in Å, Y_1 = M/O = [FeO + MnO + MgO + CaO + 2(Na_2O + K_2O + H_2O)]/ [2(SiO_2 + TiO_2) + 3Al_2O_3 + FeO + MnO + MgO + CaO + Na_2O + K_2O + H_2O + 5P_2O_5],

Y_2 = Al/(Na + K + H)

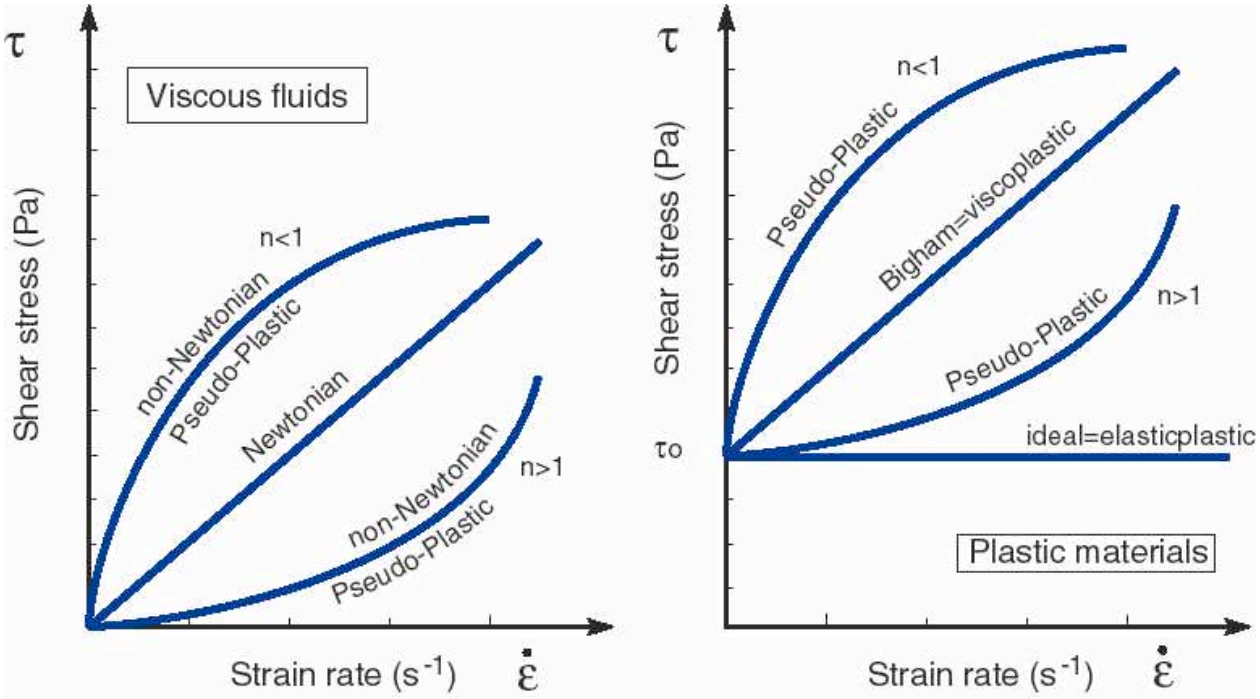
Mungall, 2002 and Zhang,2010



IFSE= Intermediate field strength elements
HFSE= High field strength elements

From Lehser and Spera, 2016

Magma rheology



$$\tau = \eta \dot{\varepsilon}$$

$$\tau = A\dot{\varepsilon}^{n}$$

$$\tau = \tau_o + \eta \dot{\varepsilon}$$

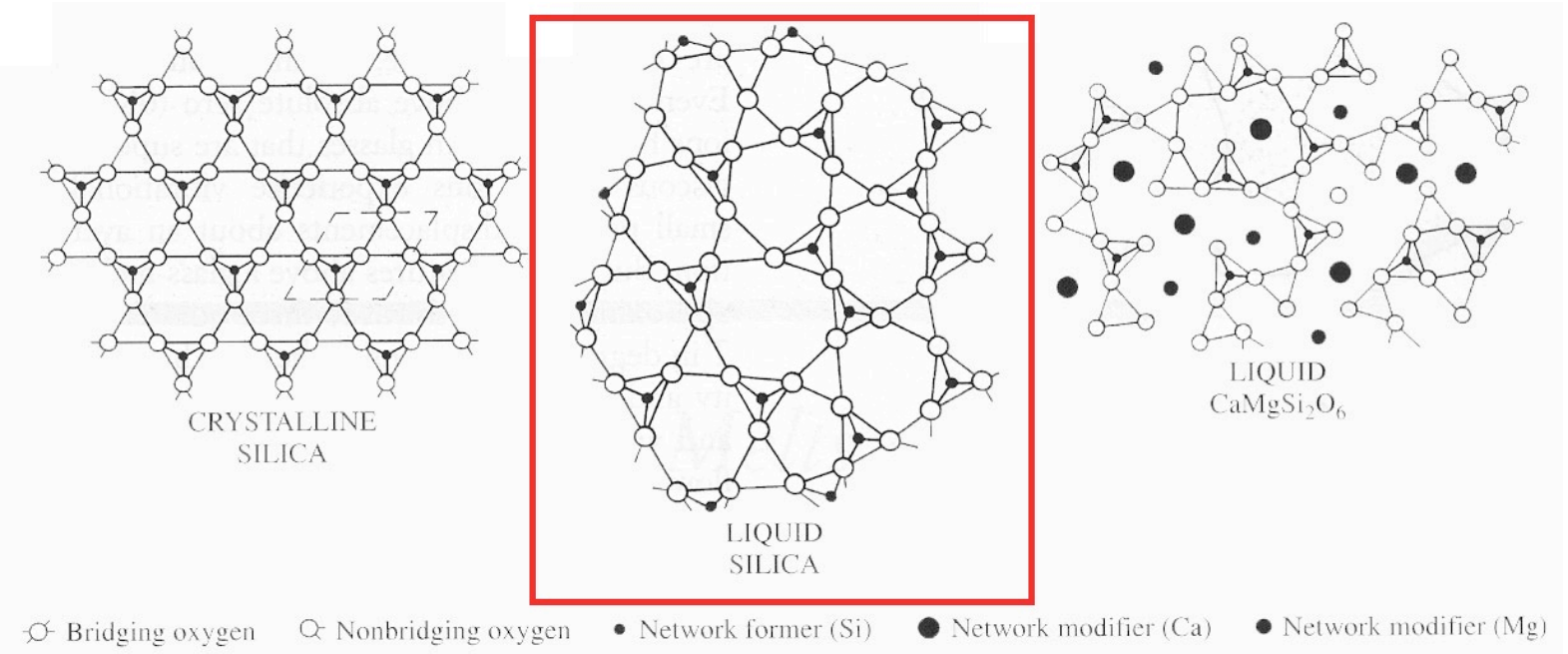
$$\tau = \tau_o + A \dot{\varepsilon}^{n}$$

Viscosity is a measure of the resistance of a fluid to flow

Check the online course of P. Rey!
http://www.geosci.usyd.edu.au/users/prey/Granite/Granite.html#Ch3

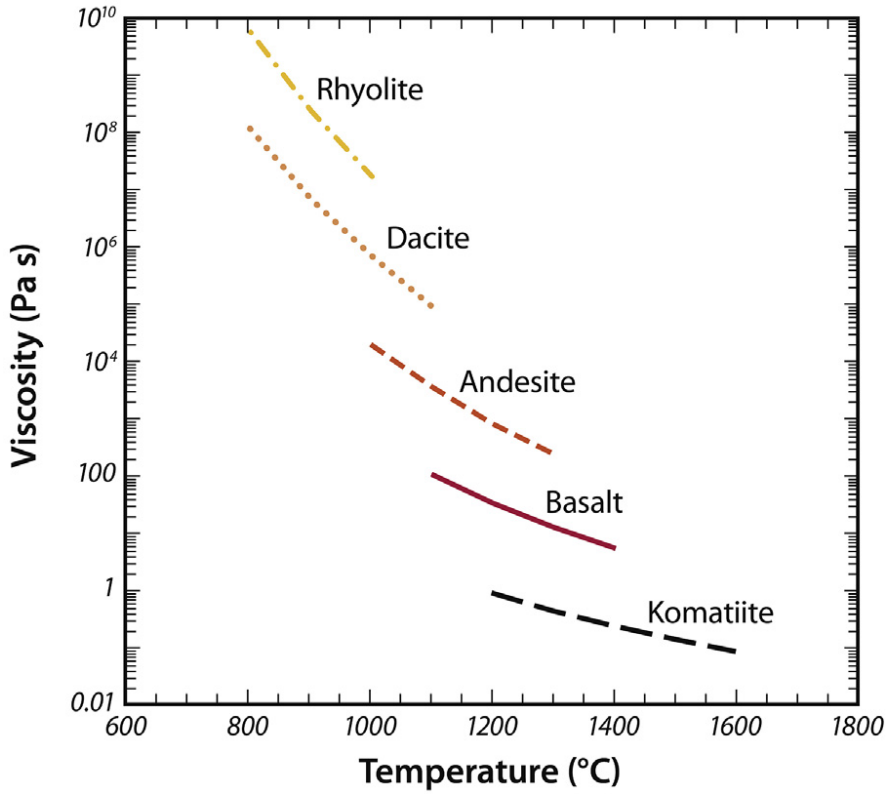
Magma viscosity

- Main controls: temperature (-) silica content (+), water content (-), alkali (-),



From Carmichael et al.

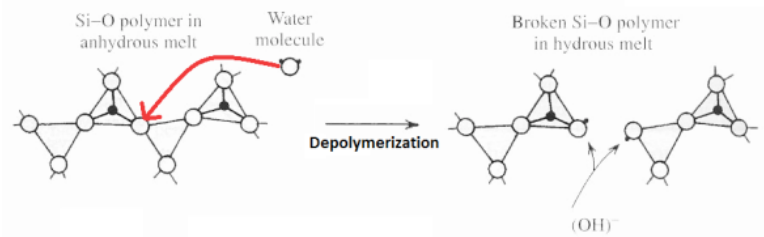
Magma viscosity



Compositional and temperature effects

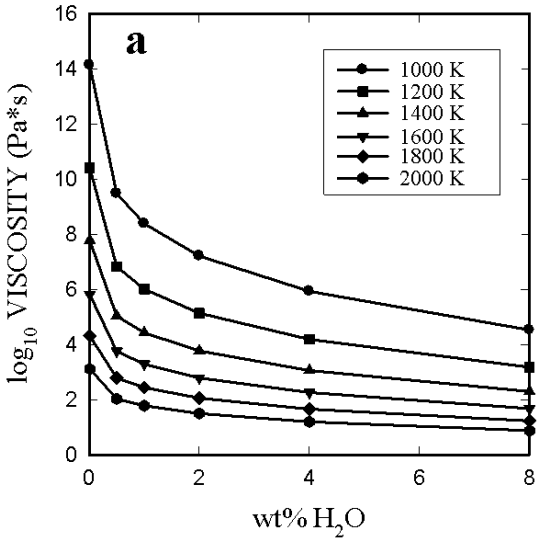
Magma viscosity

What is the role of water in the chain structure?

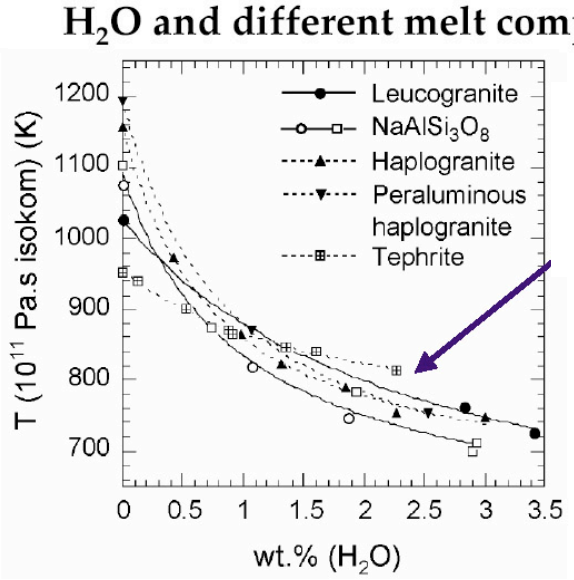


Depolymerization of magma by addition of water

$\eta = (-3.545 + 0.833 \ln(\text{wt \%})) + (9601 - 2368 \ln(\text{wt \%})) / [T - (195.7 + 32.25 \ln(\text{wt \%}))]$

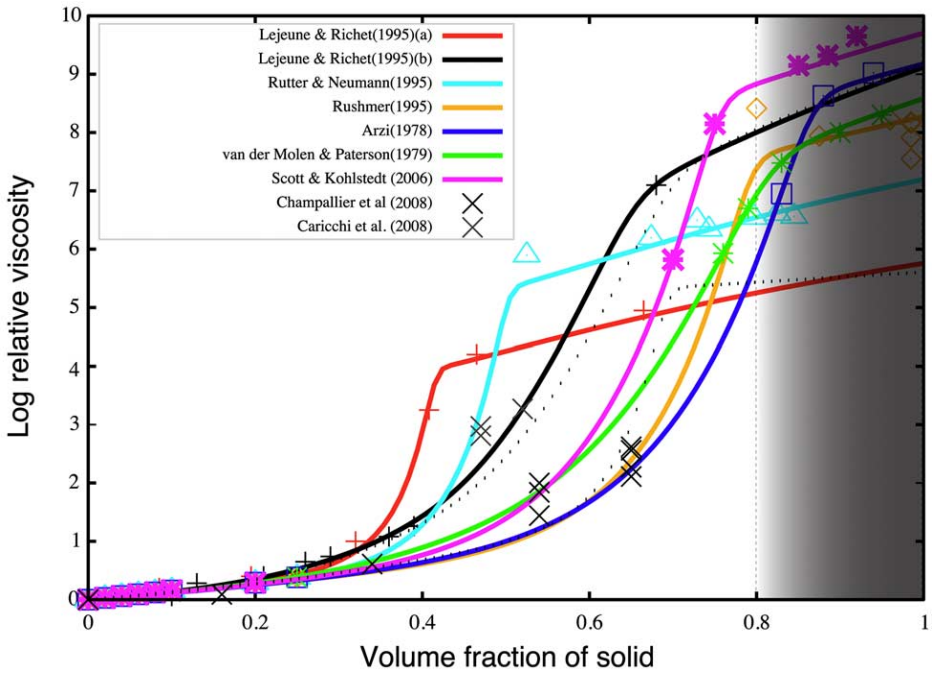


Hess and Dingwell (1996)



Magma viscosity

Effect of crystals



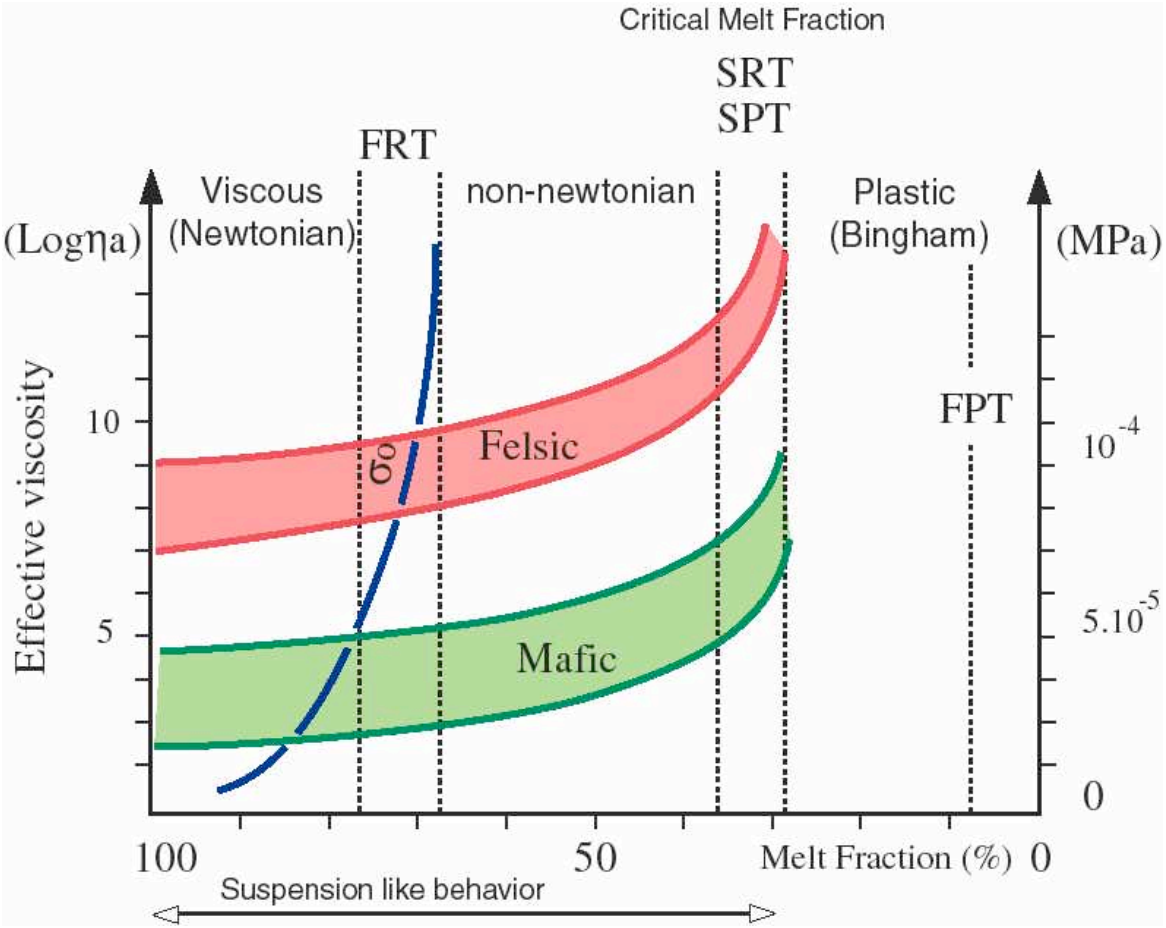
Complex relationships:

Viscosity is affected by crystal content, shape, size distribution and strain rate

Costa et al. 2009

Magma viscosity

Effect of crystals



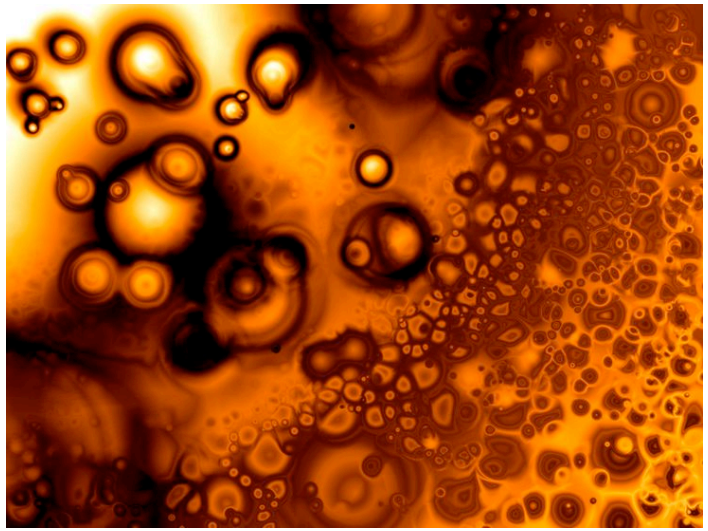
FRT= first rheological threshold
SRT= second rheological threshold

- What does *suspension* mean?

Magma viscosity

Effect of bubbles

First experiments showed that magma viscosity either increased or decreased with increasing bubble volume fraction



Magma viscosity

Effect of bubbles

Capillary number $N_{Ca} = \frac{R\eta_c\dot{\gamma}}{\sigma}$

σ= surface tension

η= viscosity

γ= strain

R= bubble radius

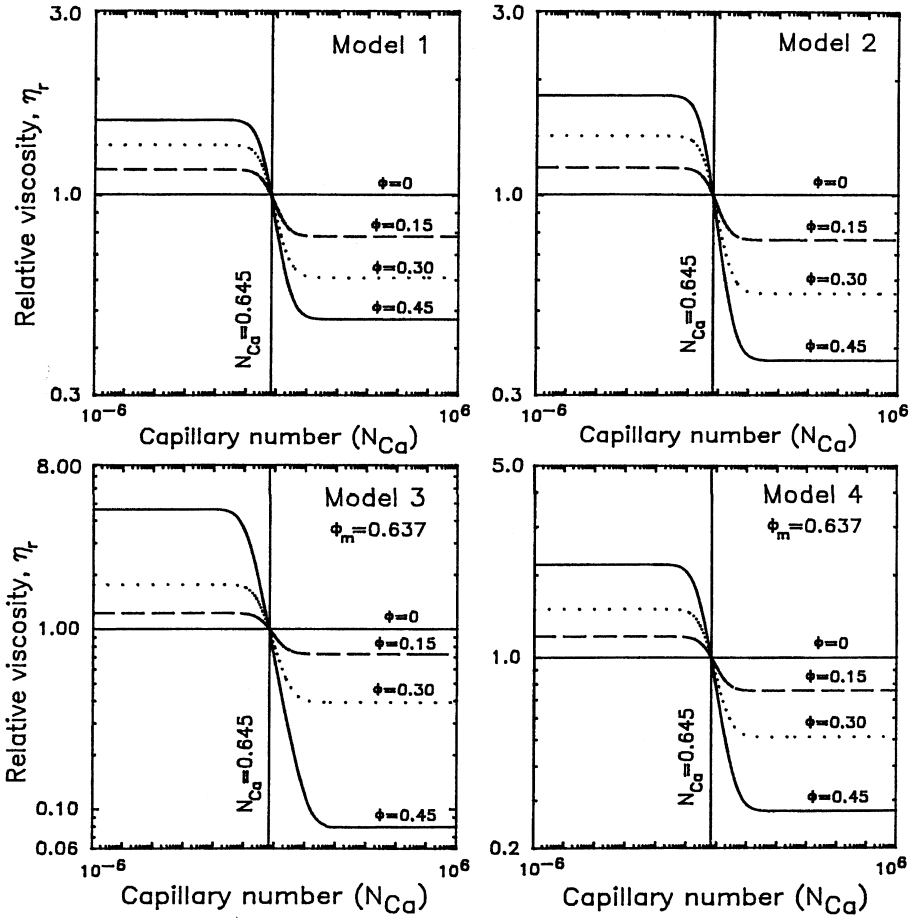
Bubbles in stretched liquid sugar

Bubbles in obsidian

Bubbles in water

Magma viscosity

Effect of bubbles



Φ= vesicularity

Pal (2004)

What is the relative viscosity?