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Magma generation and properties

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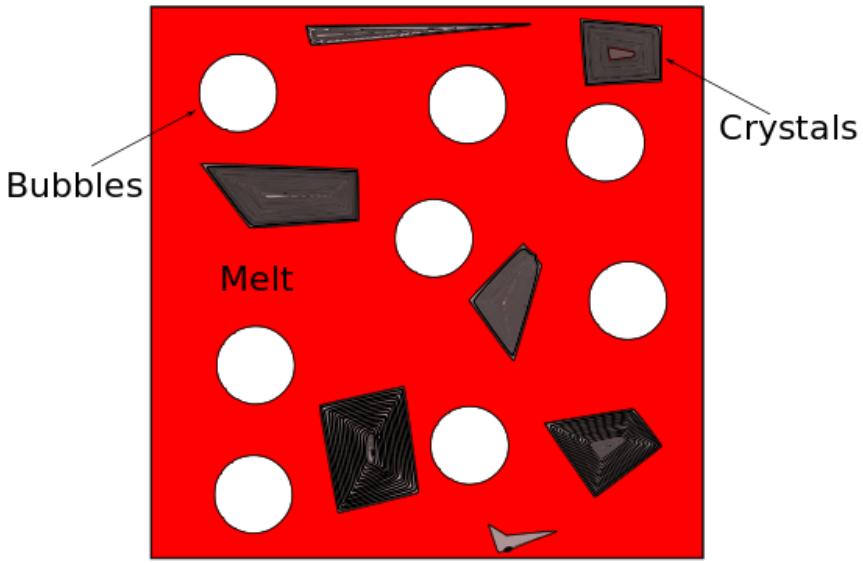
What is magma?

- Naturally occurring **molten** or partially molten rock material, generated within the Earth and capable of **intrusion** and **extrusion**, from which igneous rocks are derived through **solidification** and related processes. It may or may not contain **suspended solids** (such as crystals and rock fragments) and/or **gas phases**.

(Glossary of Geology, 2011)

Magma is

- **three-phase**:
  - **solid** - unmelted crystals
  - **liquid** - molten rock
  - **gas** - exsolved volatiles
- **multi-component**:
  - Many chemical species
  - SiO_2, K_2O, Na_2O, H_2O, etc.



Thermodynamic controls on magma properties

Physical and chemical properites of magma are controlled by three parameters:

- Temperature T
- Pressure P
- Bulk composition $\mathbf{X} = (X_{SiO_2}, X_{K_2O}, X_{Na_2O}, X_{H_2O}, ...)$

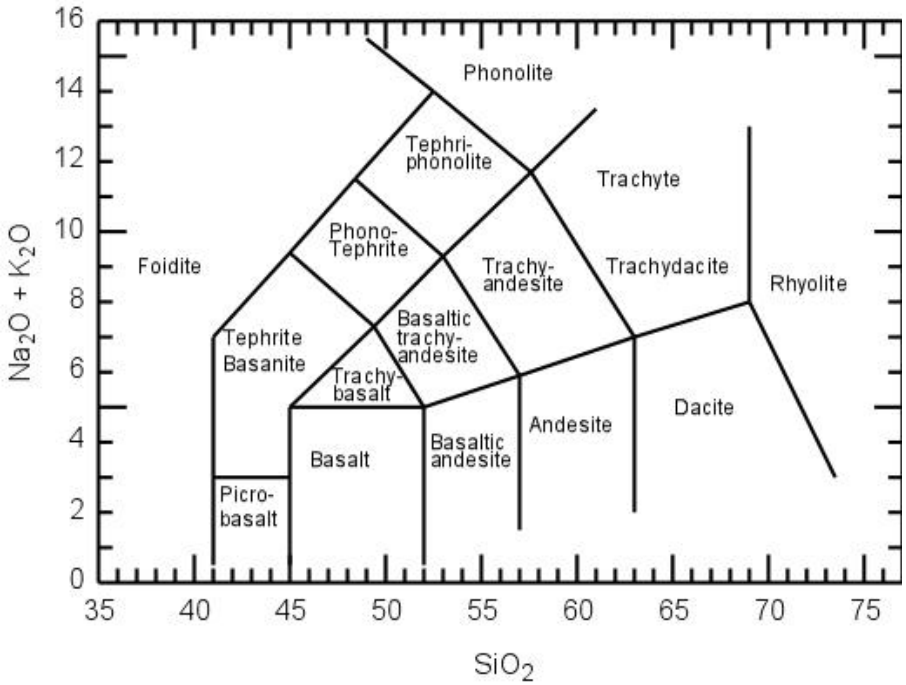
$$\sum_i X_i = X_{SiO_2} + X_{K_2O} + X_{Na_2O} + X_{H_2O} + ... = 1$$

X_i = Fraction of the ith component (i = SiO_2, K_2O, Na_2O, H_2O, ...)

Magma composition: Dry classification

Classification normally performed according to a subset of components

Volcanic rocks often classified on a **Total Alkali Silica (TAS)** diagram



SiO_2 normally largest component ($\sim$ 37-77) wt%

$X_{SiO_2}, X_{K_2O}, X_{Na_2O}$ determine composition of many crystals

Not suitable for all volcanic rocks e.g. High MgO

Le Maitre et al. (2002) Igneous Rock: A Classification and Glossary of Terms

Magma composition: volatile content

Magmas can contain dissolved gas species

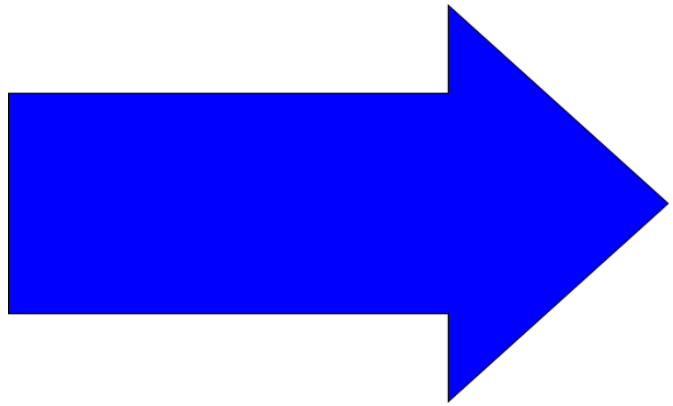
H2O and CO2 are most abundant, then S, Cl and F

Solubility - Maximum amount of a species that can be dissolved
- depends on $P, T, \mathbf{X}$

Once solubility exceeded, bubbles of exsolved phases form (**vesiculation**)

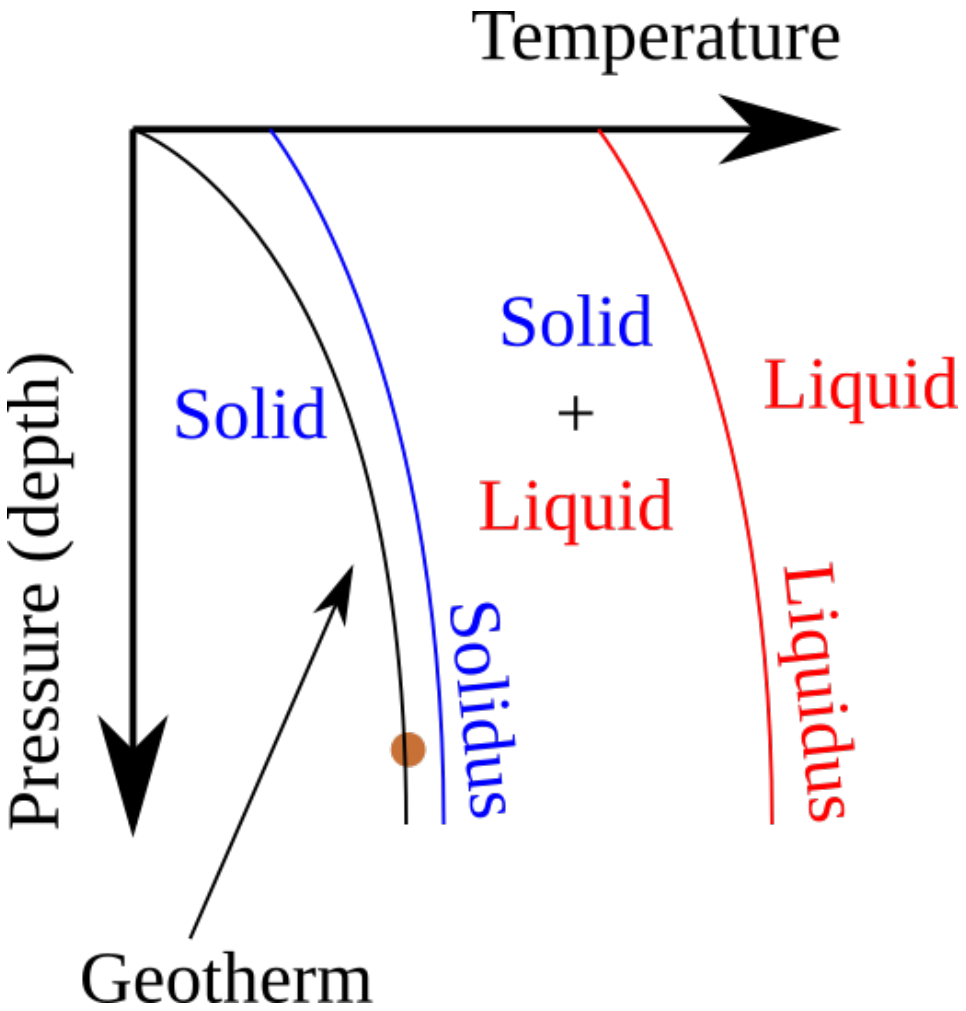
Consequnces for:

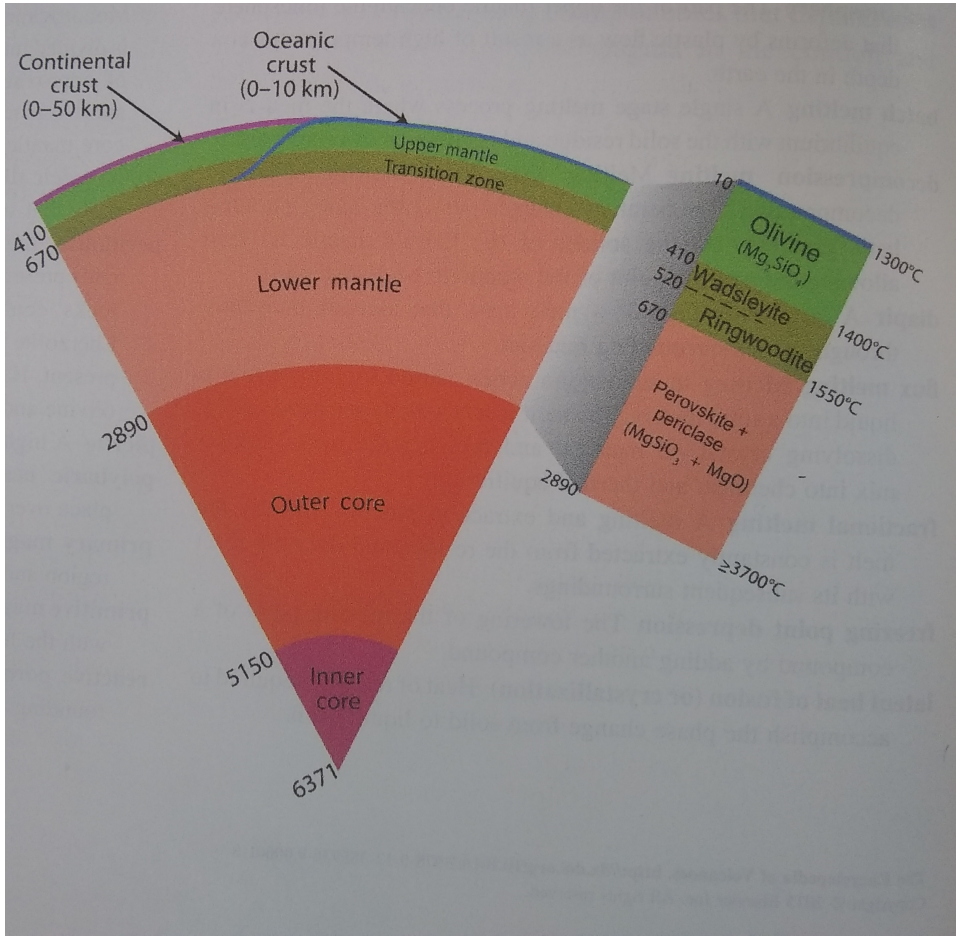
- Crystallisation
- Density
- Viscosity



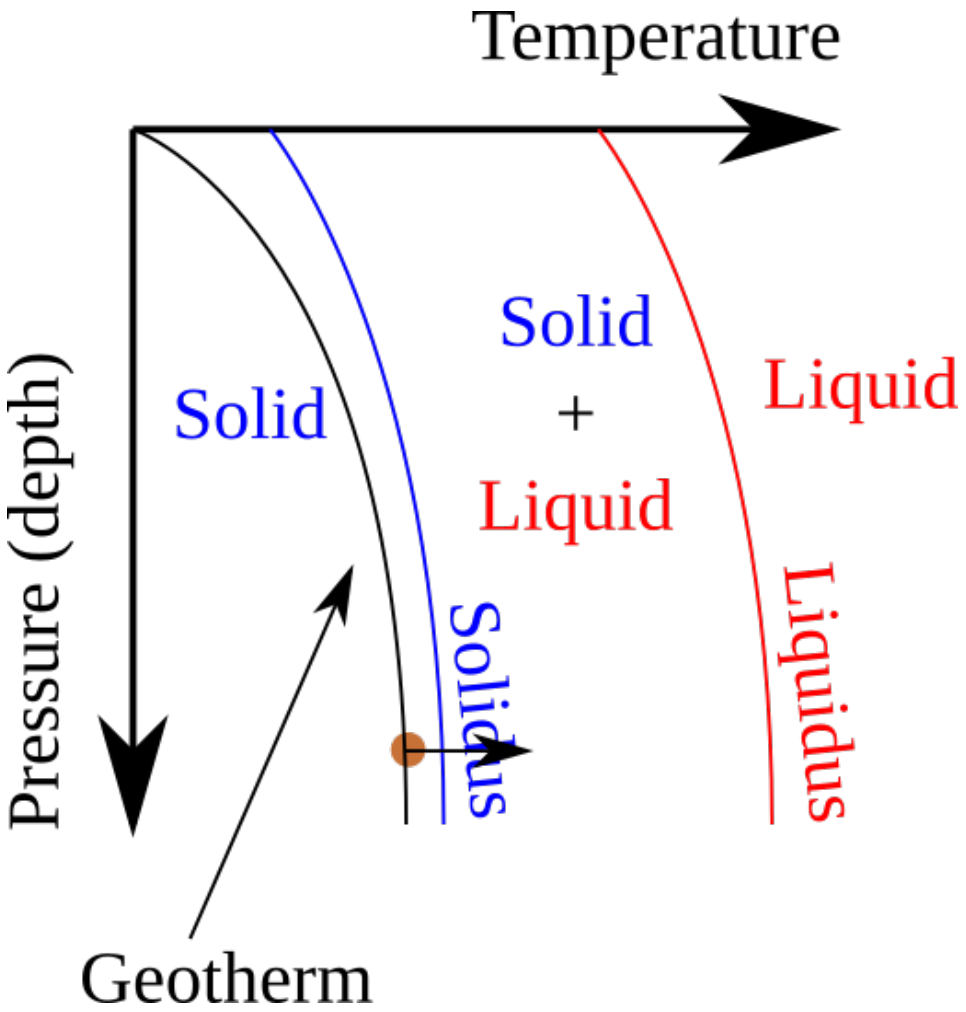
- Eruptability
- Eruptive style

Magma generation - How to melt rocks?

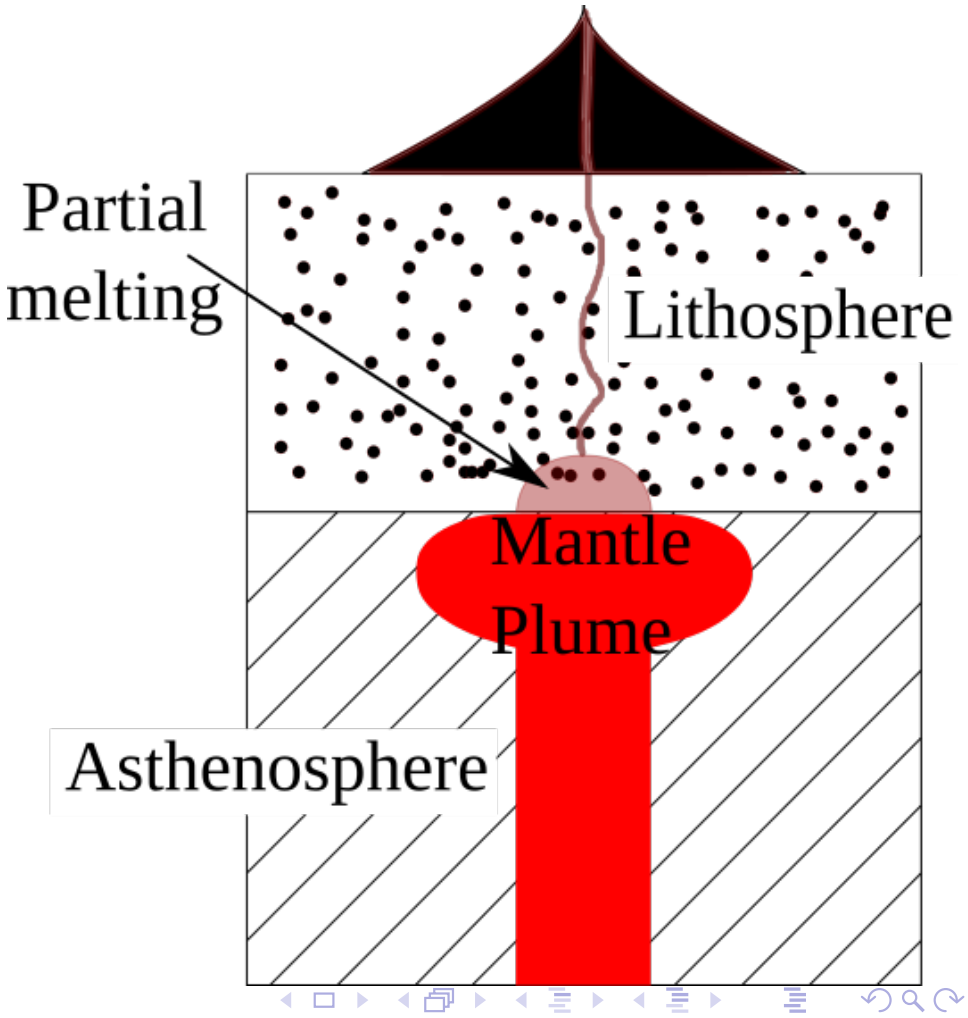




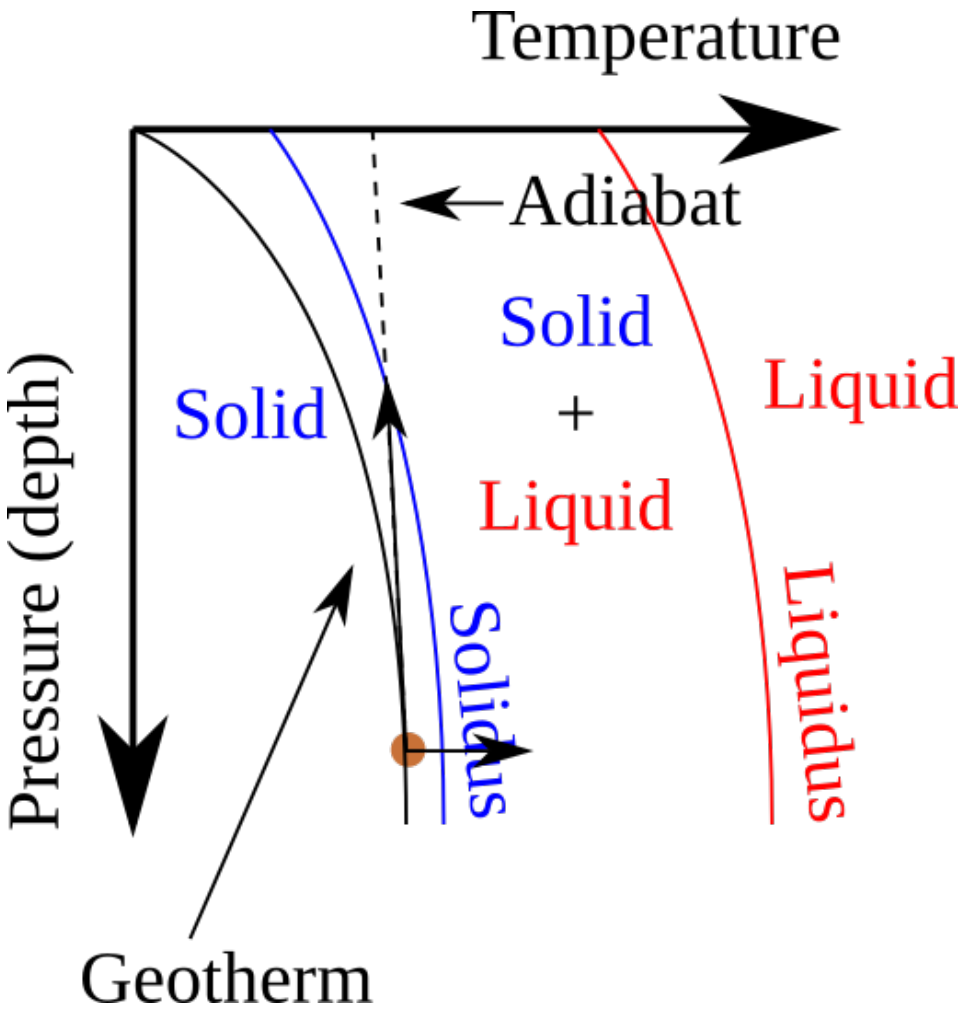
Magma generation - How to melt rocks?



- **Heating**: Increase T
  - Hot spot volcanism

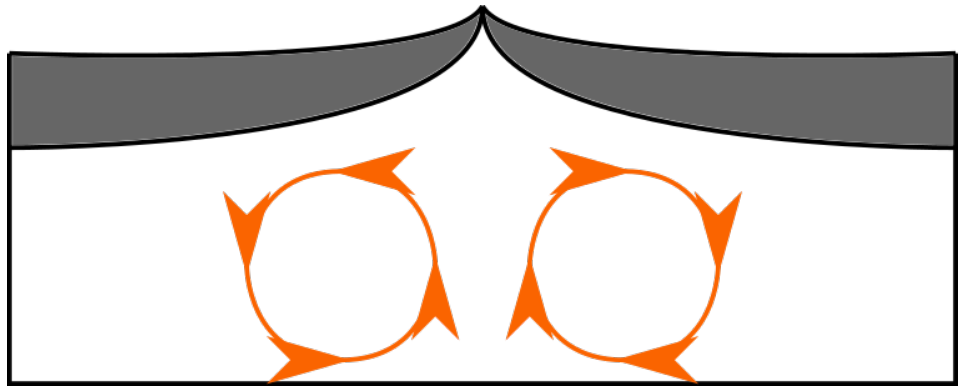


Magma generation - How to melt rocks?



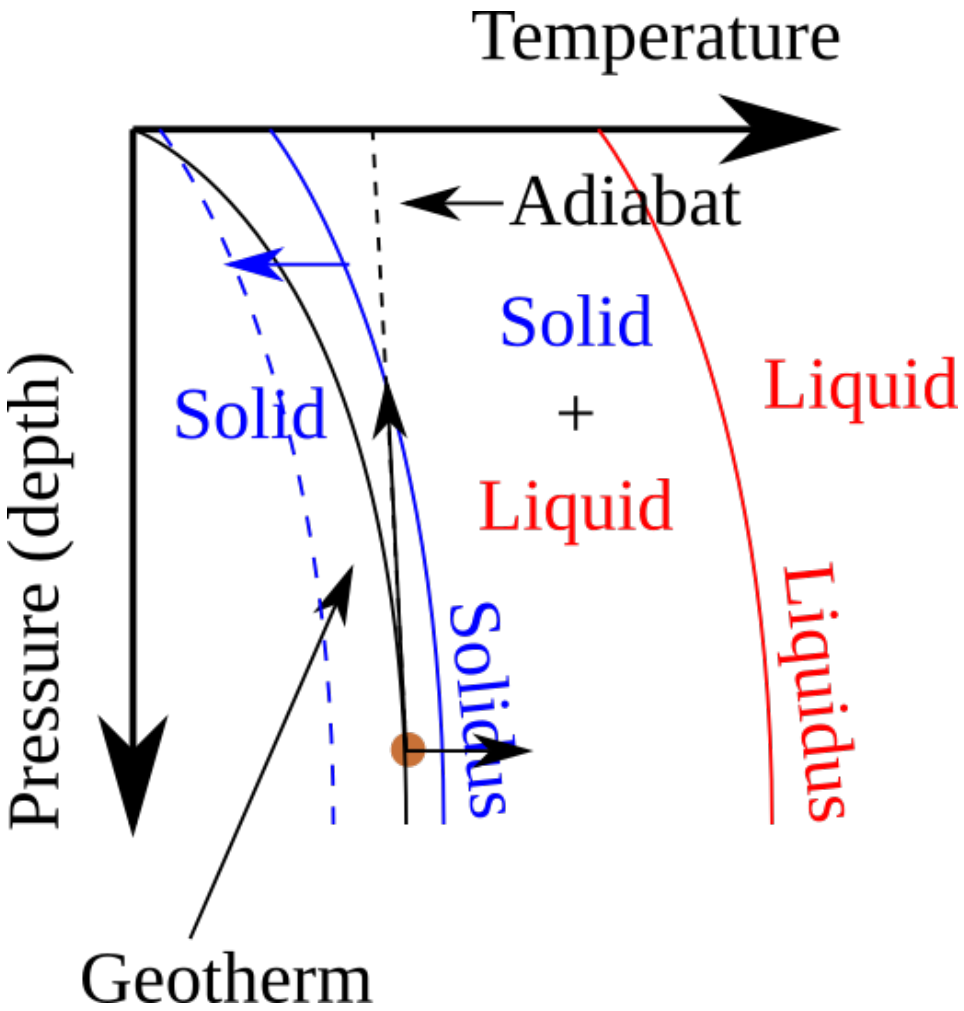
$$\left.\frac{\mathrm{d}T}{\mathrm{d}P}\right|_{\Delta S=0} = \frac{\alpha T}{\rho C_p}$$

- **Depressurisation**: Reduce P
  - Mid-ocean ridge volcanism

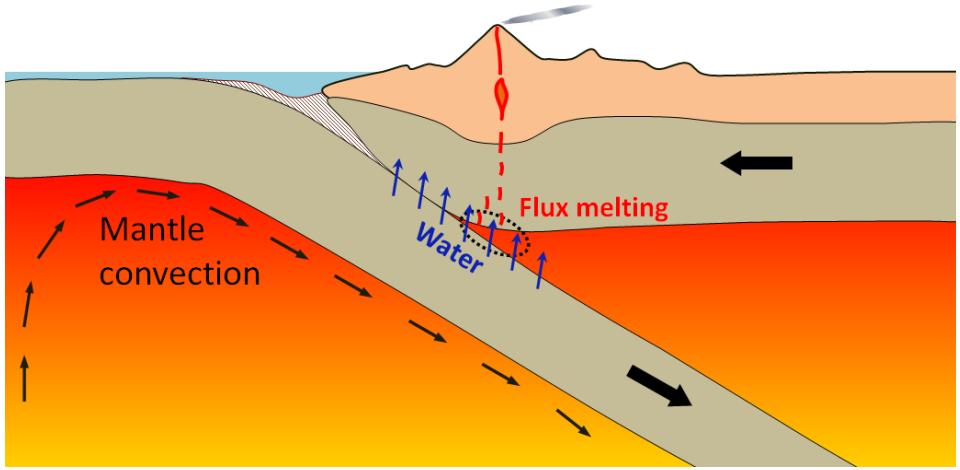


α = Thermal expansion coefficient
ρ = Density
C_p = Heat capacity
ΔS = Change in entropy

Magma generation - How to melt rocks?

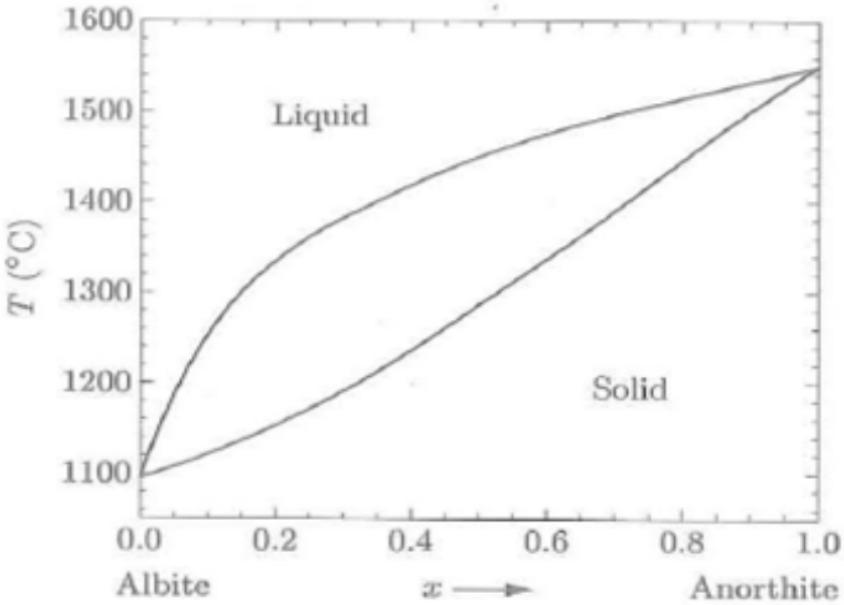


- **Compositional change**: Change **X**
  - Arc volcanism



Decreasing X_{H_2O} shifts solidus to smaller T

Phase diagrams



State of magma depends on many parameters (T, P, X_i)

Can consider two parameters on a simple **binary** phase diagram

Determine compositions and relative proportions of different phases

Three parameters can be considered on a ternary phase diagram

All diagrams are just *slices* of the full picture