 

Introduction to modeling
Magma generation and properties

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Modelling Volcanic Processes

Course structure:

- 12/11/2020 - Eruption characterisation
- 13/11/2020 - Plume and ballistic modelling
- 26/11/2020 - Magma properties and transport processes
- 27/11/2020 - Gravity currents in volcanology

Magma properties and transport processes:

- Introduction to modelling, magma generation and properties
- Magma density and viscosity
- Magma transport processes
- Exercises

Modelling Volcanic Processes

Course structure:

- 12/11/2020 - Eruption characterisation
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- 26/11/2020 - Magma properties and transport processes
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Gravity currents in volcanology:

- Fluid dynamics of gravity currents
- Lava flows, ash clouds, PDCs and Lahars
- Exercises

What is a model?

Model - **Informative representation of an object or system**

Types of model:

- Conceptual model - Composition of ideas to aid knowledge and understanding

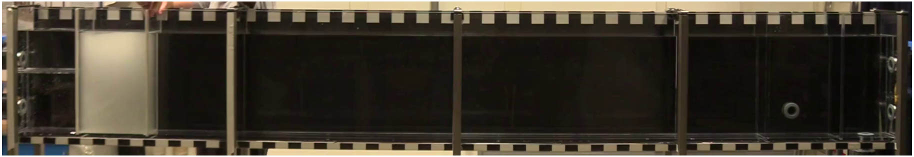
Cashman et al. (2017)

What is a model?

Model - **Informative representation of an object or system**

Types of model:

- Conceptual model
- Experimental model



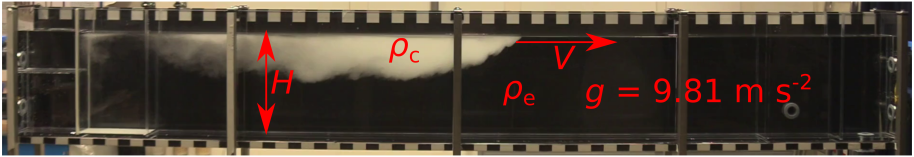
What is a model?

Model - **Informative representation of an object or system**

Types of model:

- Conceptual model
- Experimental model
- Mathematical model
  - Analytical model

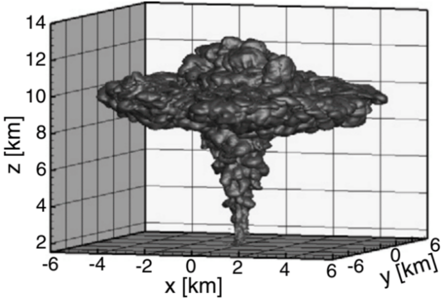
$$V = \left(\frac{(\rho_c - \rho_e) g H}{2 \rho_c} \right)^{1/2}$$



Model - **Informative representation of an object or system**

Types of model:

- Conceptual model
- Experimental model
- Mathematical model
  - Analytical model
  - Numerical model



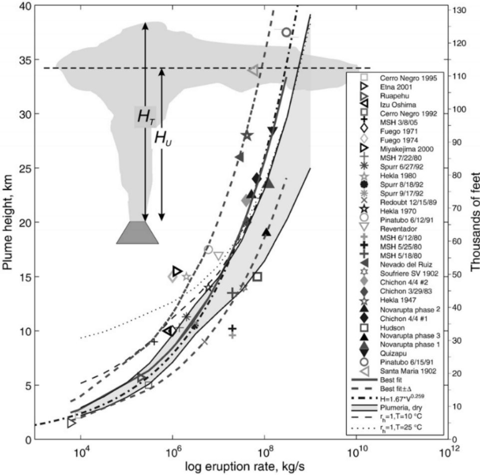
Suzuki et al. (2016)

What is a model?

Model - **Informative representation of an object or system**

Types of model:

- Conceptual model
- Experimental model
- Mathematical model
  - Analytical model
  - Numerical model
  - Empirical model



Mastin et al. (2009)

Model - **Informative representation of an object or system**

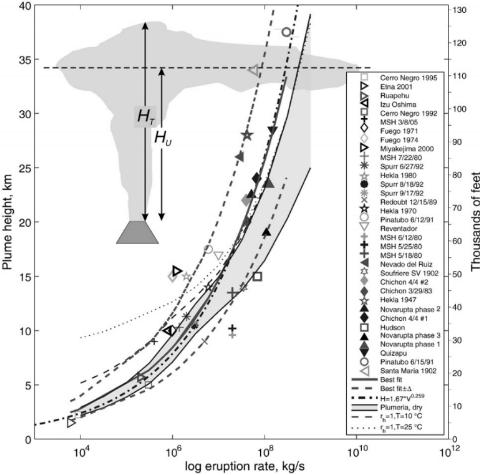
Types of model:

- Conceptual model
- Experimental model
- Mathematical model
    - Analytical model
    - Numerical model
    - Empirical model

Model ≠ Reality

All models contain **simplifying assumptions**

$\Longrightarrow$ **Validity conditions** must always be considered



Mastin et al. (2009)

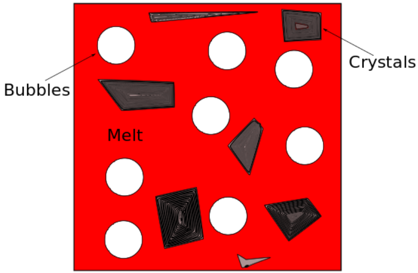
What is magma?

- 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 $\mathbf{X} = (X_{\mathrm{SiO_2}}, X_{\mathrm{K_2O}}, X_{\mathrm{Na_2O}}, X_{\mathrm{H_2O}}, ...)$

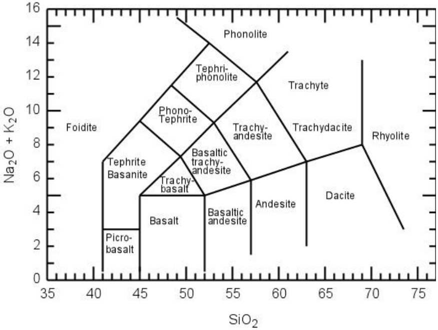
$$\sum_i X_i = X_{\mathrm{SiO_2}} + X_{\mathrm{K_2O}} + X_{\mathrm{Na_2O}} + X_{\mathrm{H_2O}} + ... = 1$$

X_i = Fraction of the i$^{\mathrm{th}}$ component (i = SiO_2, K_2O, Na_2O, H_2O, ...)
X_i can be expressed in mol% or wt%

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 $P, T, \mathbf{X}$

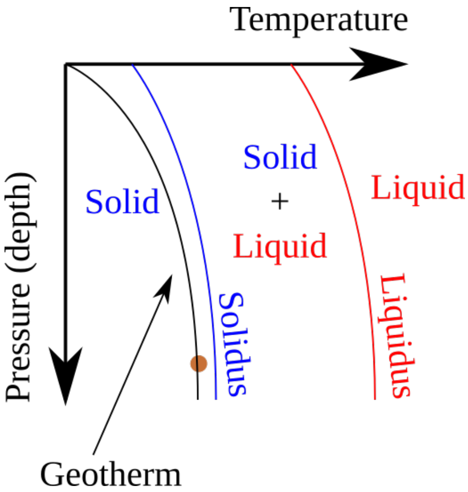
Once solubility exceeded, bubbles of exsolved phases form (**vesiculation**)

Consequnces for:

- Crystallisation
- Density
- Viscosity

- Eruptability
- Eruptive style

Magma generation - How to melt rocks?



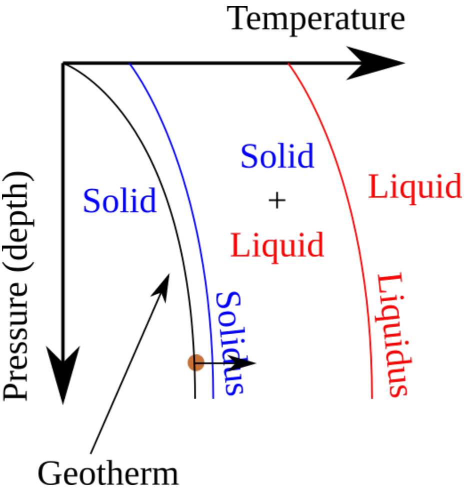
Thermodynamics $\implies$ 3 ways to melt rocks:

- Increase temperature
- Decrease pressure
- Change composition

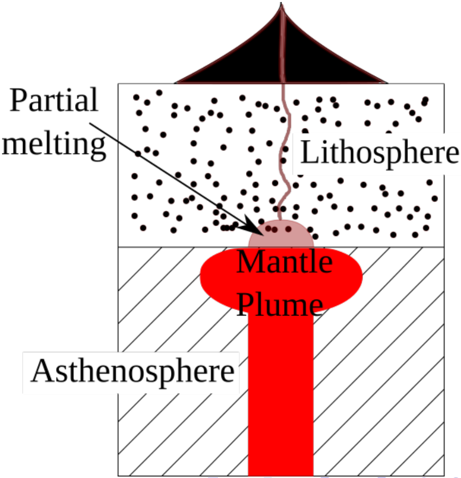
Can **model** these assuming **Chemical equilibrium** - System has sufficient time to respond to changes in:

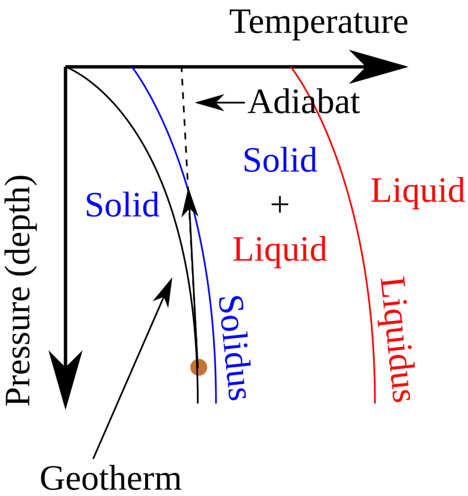
- P
- T
- **X**

Magma generation - How to melt rocks?



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





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

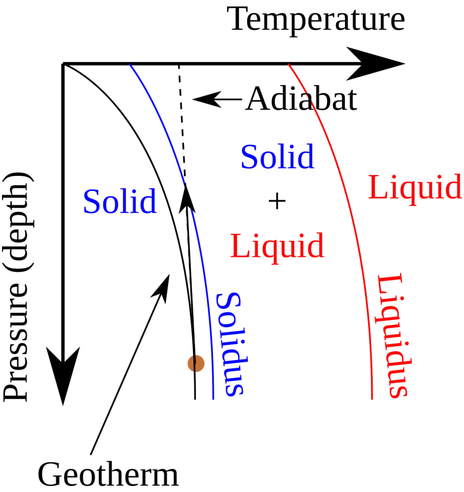
- **Depressurisation**: Reduce P
  - **Adiabatic** process - No transfer of heat Q or mass between system and surroundings
  - **Adiabatic decompression** - Magma rises faster than it can transfer heat to its surroundings

For reversible processes, can define entropy S as:

$$\mathrm{d}S = \frac{\mathrm{d}Q}{T}$$

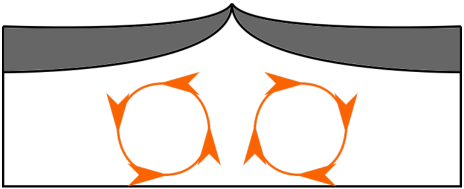
Thus, adiabatic process is also **isentropic** ($\mathrm{d}S = 0$)

Magma generation - How to melt rocks?

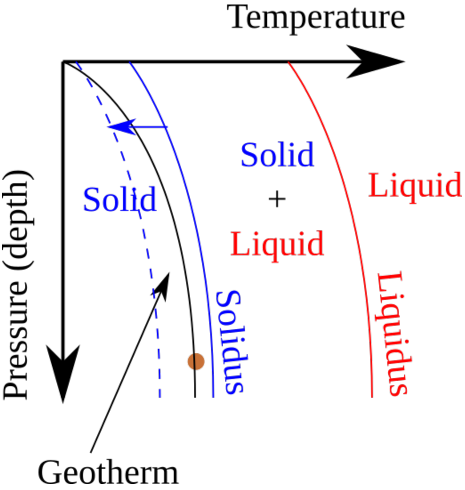


$$\left.\frac{\mathrm{d}T}{\mathrm{d}P}\right|_{\Delta S=0} = \frac{\alpha T}{\rho C_p}$$

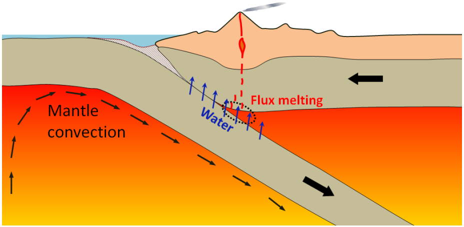
- **Depressurisation**: Reduce P
  - Mid-ocean ridge volcanism



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

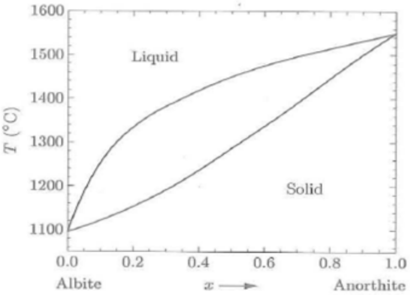


- **Compositional change**: Change **X**
  - Arc volcanism



Decreasing X_{H_2O} shifts solidus to smaller T

Phase diagrams



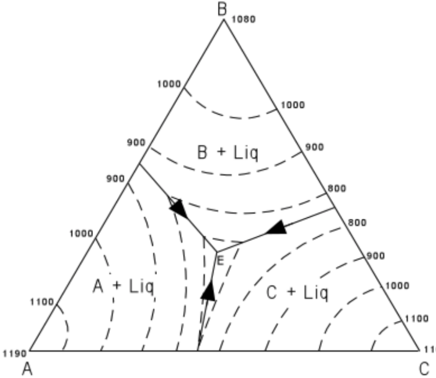
State of magma depends on many parameters (T, P, X_i)

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

Determine compositions and relative proportions of different phases

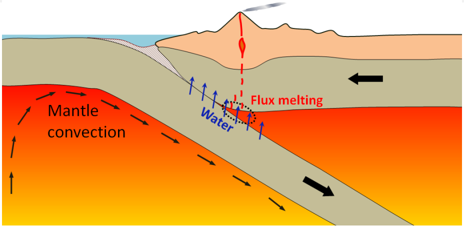
Three parameters can be considered on a ternary phase diagram

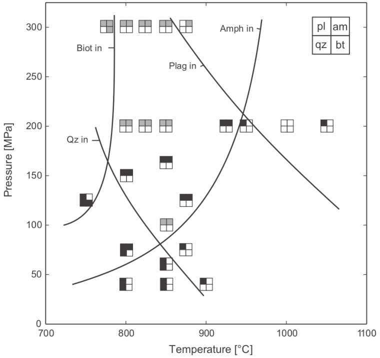
All diagrams are just *slices* of the full picture



Summary

- Magma properties controlled by P, T and $\mathbf{X}$
- **Models** - Representations of reality
- Models can describe:
  - Processes, e.g., magma generation by:
    - Heating
    - Decompression
    - Mixing
  - Characteristics
    - State of matter
    - Mineralogy





Holtz et al. (2005)