Magma Underground
Crustal Storage, Transport, and Evolution of Magma

• Activity localized to plate boundaries and mantle plumes.

• Establishes thermal and chemical gradients that influence chemical exchange, subsurface biological activity.

• Controls processes of volcanic unrest and associated hazards.

• Lengthscales, timescales, and physical/rheological properties, span orders of magnitude.
Timescales & Lengthscales

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<th>Timescale(s)</th>
<th>second</th>
<th>day</th>
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<td>$10^{-6}$</td>
<td>$10^{-3}$</td>
<td>$10^{3}$</td>
<td>$10^{6}$</td>
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Lengthscale (m)

- $10^{-6}$: brittle failure, micro-seismically
- $10^{-3}$: diffusional re-equilibration of crystals during magma mixing
- $10^{0}$: porous, reactive flow, melt extraction
- $10^{3}$: accumulation of a gas-rich cap
- $10^{6}$: mush formation
- $10^{9}$: recharge events, mafic magmas
- $10^{12}$: composite magma bodies
- $10^{15}$: accumulation of magma in the crust

Increasing maturity of magmatic system

- (a) $10^{-2} - 10^{3}$ m /day magma transfer rate
- (b) $10^{-2} - 10^{3}$ years magma chamber storage time in chamber
- (c) $10^{0} - 10^{1}$ years sill solidification time
- (d) $10^{1} - 10^{2}$ years magma storage time in chamber
- (e) $10^{3} - 10^{4}$ years pluton development time through repeated sill intrusions
- (f) $10^{2} - 10^{3}$ m /year diapir ascent rate
Simple question: Where is the magma?
Evolving conceptual models

Simple: ‘balloon & straw’ conceptual model

Complex: trans-crustal magmatic systems (mush + melt)
Observing magma movement

Choussard et al., 2013

Pederson & Sigmundsson, 2004
[1994 Eyjafjallajökull]
Observing magma movement

Nooner & Chadwick, 2016
Challenges & Opportunities

What are the timescales of magma recharge events and does that influence the probability that they will lead to eruption?

• **Crystal chronometry**: Analytical methods to resolve the timescales of magmatic events via diffusion chronometry require novel analytical techniques, experiments, and numerical models.

What are the physical processes of melt extraction (e.g., compaction) in magmatic systems?

• **Laboratory experiments**: Micro- and macro-scale physical processes in magmatic mush need to be resolved in order develop models that can, for example, predict reservoir failure.

Why is inflation of shallow magma reservoirs not accompanied by deflation of deeper reservoirs?

• **Volcano monitoring**: Improved temporal and spatial resolution of geophysical observations (e.g., deformation) are needed to test models and to probe deeper into magmatic systems; submarine systems are largely under sampled in this regard.

Is volcanic unrest, eruption initiation, and cessation predictable?

• **Modeling**: Integrative, multi-scale models of magmatic systems (mechanical, thermal, geochemical) are needed to tie together observational, analytical, and experimental data sets.