High-temperature fracture of magma

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Cracks, Fractures and Faults in the Earth Thursday 19th June 2008
Montserrat
(Sparks et al. 2000 Terra Nova)

Lava dome extrusion on shear zones

Mt St Helens 2004-
(Iverson et al 2006)
Explosive eruptions: foam fragmentation due to shear fracture in conduit

Marti et al. 1999 Nature
Basaltic lava flows: surface fracturing controls emplacement

Kilburn 2004
JVGR

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pahoehoe
Fractures related to cooling and external fluids

- Used to reconstruct palaeo-environments
- Control heat flux and melting rate of ice, lava stability
- Little understood about why different fracture types form

Lescinsky and Fink 2000 JGR
Brittle-ductile fracture of melt + crystals + bubbles: strain-rate-dependent

Higher strain rates, temperatures, smaller scale than tectonic faulting

Fluids play key role in fracture process
Faulting of magma during lava dome eruptions

Degassing + crystallisation, pressurisation

(Sparks 1997 EPSL)
What do fault zones look like?


- ~5 m fault zones in Icelandic obsidian (90 % melt)

- Nucleation: shear-tensile fracture networks, gas flow
What do fault zones look like?


- ~5 m fault zones in Icelandic obsidian (90 % melt)

Fault maturation: rotation, cataclasis, creep-slip
Fault healing, cyclicality

• Thorough sintering and welding – completely healed

• Cohesive viscous deformation of healed cataclasite

Multiple, overprinted brittle-ductile textures

Analogous to lower crustal rocks – mixed brittle-ductile deformation (e.g. Stel 1986)

Reflects pulsatory strain rate
Fault zone in crystalline dome lava

More cataclasis (greater slip)
Healing less effective (melt-poor)
Large slip planes – 10s of m

Mt St Helens,
Cashman et al. in press
Seismicity during lava dome eruptions

- **Shallow seismicity during lava dome growth:**
- **Low frequency events** $M<3$, $<2$ km depth, most energy 1-5 Hz
- Repetitive, stationary sources in/near conduit & dome.
- Precede dome collapses: potentially **key monitoring tool**
- *Are faults geological record of trigger mechanism?*

**Montserrat**

![Graph showing seismic activity](image)
Volcanic earthquakes during lava dome growth

- Source models controversial
  Resonance of gas-filled crack (Chouet) or magma-filled conduit (Neuberg)?

- Or straightforward brittle rupture? (e.g. Harrington and Brodsky 2007)
What are conditions for shear fracture?

- Silicate melt condition for fracture: \( \eta \dot{\varepsilon} > 10^8 \text{ Pa} \)
  (Webb & Dingwell, non-Newtonian behaviour of glass fibres)

Shear strength of magma unknown
(use Maxwell criterion \( \Rightarrow \) assume 100 MPa)

Currently being investigated in lab
(UCL, Munich, Zurich)
Is fracture of hot magma seismogenic?

- Break magma in lab at high T, high P
- Similar conditions to nature
- Record acoustic emissions

Tuffen, Smith, Sammonds 2008 Nature
Lavallee et al 2008 Nature
Seismogenic fracture of crystal-free obsidian at 645 °C

AE swarms correlate with stress drops

→ Demonstrates that cracking is seismogenic

[Drop in b value: fracture coalescence]
Characteristics of high-T seismicity

Frequency content and size of AE events: scale to volcanic earthquakes
AE at 650 °C obsidian – equivalent to 15 Hz EQ: high-frequency (volcano-tectonic), not low frequency events.

Tuffen, Smith, Sammonds 2008

Low-frequency events 1-5 Hz dominant energy: slower rupture of hotter material? Work in progress at UCL
Trigger model applied to Montserrat

Neuberg et al 2006 JVGR

- Montserrat lava dome—2D finite element conduit flow model
- Accounts for degassing, cooling & crystallisation
  - stresses: where will magma fracture in conduit?

Problem – why a “seismogenic window” and aseismic plug flow above? What determines whether slip seismogenic?
Seismicity during lava dome eruptions

- Link between seismicity and pressurisation: why?

  High strain rates → failure?
  High gas pressure → slip?
  Slip → gas escape, pressure decrease?

Montserrat
Neuberg et al 2006
Characteristics of high-T seismicity

Lavallee et al 2008

**Figure 4 | Application of the FFM to a Colima lava.** Experiment at 940 °C deformed under 40 MPa (strain rate of $7 \times 10^{-3}$ s$^{-1}$). The FFM prediction was based on the extrapolation of peak energy rates (lower values on this inverse scale), following ref. 2. Extrapolation of peak energy rates after 4 s of deformation (dashed line) predicts well the time of complete failure (arrow).

- Crystalline lava appears to follow subcritical failure forecast model
Hot fracture questions

• What are conditions for shear fracture?

• Does such high-T fracture trigger seismicity? Is it distinctive?

• If so, what might the seismicity tell us about the state of the fault zone/lava dome?

• How does permeability change during stick-slip cycles? What about healing?
Fracture and volcanic gases

Fault valve behaviour?

What are permeability changes during brittle-ductile faulting and consequences for release of volcanic gases?

Santiaguito, Guatemala (Bluth & Rose 2004 JVGR)