What about temperature? Measuring permeability under magmatic conditions.

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Schematic of permeability hotspots in a volcanic system.

Motivation

Volcanoes degas; permeability is key.

Volcanic degassing is governed by the fluid flow potential of volatiles though the rising magma, the volcanic conduit, and the surrounding edifice rock.

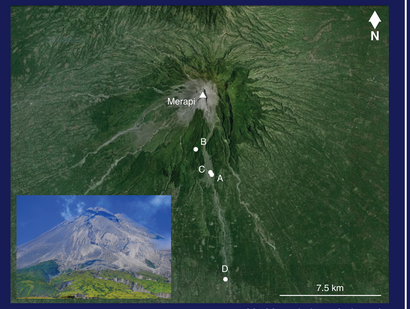
Permeability studies on volcanic rocks have generally focused on permeability measurements under ambient laboratory conditions[1,2,3], namely room temperature and low pressure.

Few studies have been performed under in-situ conditions [4,5].

What happens with temperature?

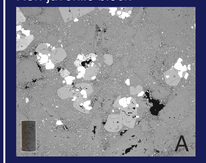
Sample Suite

- Mt Merapi, Java, Indonesia
- 2010 eruption
- Stage 2 (October 26, 2010) and Stage 4 (November 5, 2010)[6]
- basaltic andesite
- crystal content 40-60%[7]

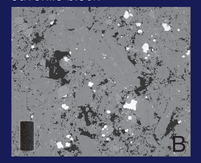


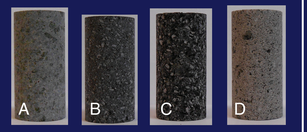
Mt. Merapi, Java, Indonesia. Sample locations.

Non-juvenile block

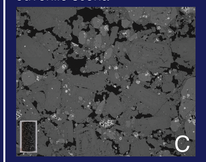


Juvenile block

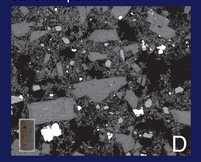




Juvenile scoria



Juvenile pumice



1 mm

SEM images of starting samples used in this study.

Sample	ϕ_c(%)	ϕ_t(%)
non-juvenile block (A)	7.4	10.3
juvenile block (B)	13.0	14.7
juvenile scoria (C)	28.0	33.7
juvenile pumice (D)	39.4	44.8

ϕ_c - connected porosity; ϕ_t - total porosity

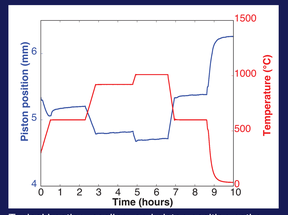
Methods

Permeability (k) measurements:

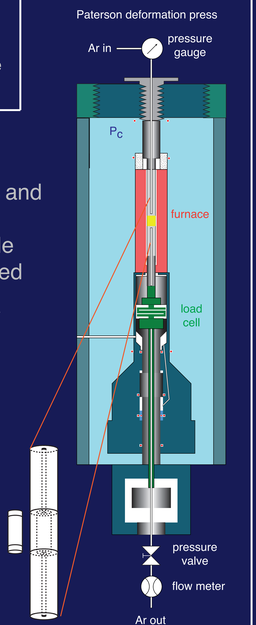
- samples were jacketed in 2.25 mm thick teflon or Cu cuffs and 0.25 mm thick Fe jackets
- differential pore pressure (ΔP) kept constant across sample
- volumetric flow rate (Q_b) allowed to equilibrate and recorded
- **k calculated using Darcy's Law** $\longrightarrow$ $k_{gas} = \frac{Q_b \mu L P_b}{A \Delta P P_m}$
- Argon pore fluid; constant force
- Forchheimer and Klinkenberg corrections made on a case-by-case basis

Measurement conditions:

diameter	10 mm
P_c	50 MPa
T	27, 600, 920, 1010°C
heating rate	10°C/min
cooling rate	20°C/min
ΔP	0 - 0.2 MPa



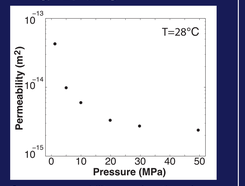
Typical heating, cooling, and piston position paths during permeability measurements.



Results: Understanding the experimental conditions

Spacer permeability

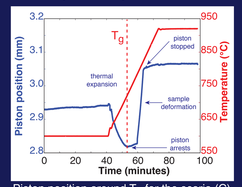
- measured k is limited by spacer k
- spacer k decreases with increasing P_c
- maximum k measured in the Paterson at 50 MPa: 2.4×10^{-15} m²



Spacer permeability as a function of confining pressure. T = 28°C.

Flirting with the glass transition

- T_g reached for juvenile material
- sample experiences deformation due to piston rising
- sample experiences radial shrinkage after T_g

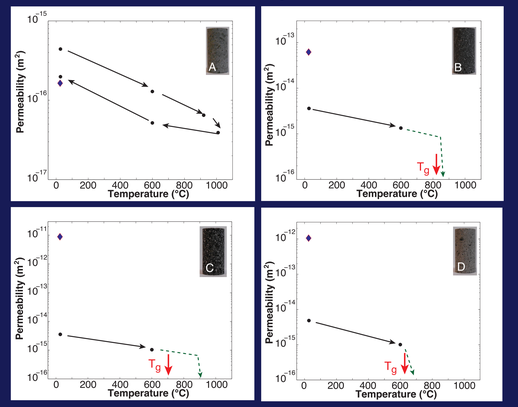


Piston position around T_g for the scoria (C).

Sample	T_g(°C)	ϕ_t(%)* 50MPa, 920°C
non-juvenile block (A)	-	10.3
juvenile block (B)	830	9.3
scoria (C)	706	10.4
pumice (D)	630	10.0

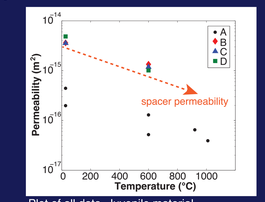
* ϕ_t calculated from changes in mass and geometry after heating.

Results: The effect of temperature on permeability



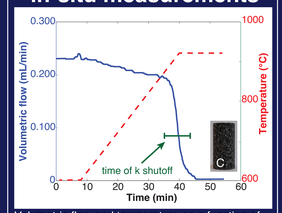
Permeability as a function of tempearture. Black arrows indicate temperature path from one measurement to the next; green arrows indicate the loss of fluid flow; red arrows indicate T_g.

- k decreases with increasing T
- non-juvenile block (A) experiences k-hysteresis
- juvenile material (B, C, D) experiences total fluid-flow shutoff before 920°C
- k shutoff in pumice at lower T than scoria/juvenile block
- fluid-flow shutoff is rapid (~200s)



Plot of all data. Juvenile material permeability is questionable. It defines the maximum k measured in the Paterson press, equivalent to the porous spacer k.

Timescale of fluid-flow shutoff: in-situ measurements



Volumetric flow and temperature as a function of time during fluid flow shutoff in the scoria (C). Fluid flow shutoff occurs at ~900°C and takes ~3 minutes.

Discussion

Microstructure in progress...

Non-juvenile block (A):

- decrease in k with increasing T: thermal expansion of sample narrows cracks
- is the dwell time at 1010°C enough to start viscously sealing cracks?
- lower k on cooling curve: the cracks that closed didn't all re-open
- no Q_b shutoff because sample was fully degassed upon emplacement, raising T_g
- good proxy for non-juvenile dome rock permeability: exisiting Merapi dome

Juvenile samples (B, C, D):

- different T_g: reflects difference in residual H_2O contents affecting melt viscosity
- timescale of Q_b shutoff on the order of magnitude reported by Okumura and Sasaki, 2014[(9)]; P_c exacerbates densification
- pumice Q_b shutoff just past T_g: high porosity eases densification

References: (1) Eichelberger et al., 1986; (2) Klug and Cashman, 1996; (3) Farquharson et al., 2015; (4) Gaunt et al., 2013 (IAVCEI); (5) Chadderton et al., 2015 (EGU); (6) Komorowski et al., 2013; (7) Erdmann et al., 2014; (9) Okumura and Sasaki, 2014

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