

Fracture healing and strength recovery in magmatic liquids

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This file consists of supplementary information required to reproduce the work presented in the main paper.

1. The computation of the onset time

We use a least-squares regression technique to fit for the parameters K and α in Eq. 1 (main text). These two parameters are mutually dependent, however, we do not explore that dependence in detail. This is valid because we do not interpret the parameters further. Nevertheless, the parameters are given here in Table DR1.

Glass	Temperature (°C)	Viscosity (Pa.s)	τ (s)	K (s ⁻¹)	α	λ_c (s)
NIST	560	1.27×10^{10}	1.27	1.031×10^{-3}	0.396	7.63
	590	1.54×10^{11}	15.45	2.684×10^{-5}	2.627	29.14
SDGS	630	1.56×10^{10}	1.56	1.008×10^{-3}	0.231	11.23
	645	7.08×10^9	0.71	1.546×10^{-3}	0.293	5.77

Table DR1. Experimental conditions and fitting parameters for the two different glasses

We note that λ_c is poorly constrained simply by extrapolating Eq. 1 (main text) to the value of σ/σ_0 where the resolution of the press is reached. Therefore, in order to compute an uncertainty on λ_c we first calculate the sum of the squared residuals RSS , for the number of samples N , between the strength data points measured X_i , and the model's predictions (calculated using Eq. 1) $f(X_i)$ as follows

$$RSS = \sum_{i=1}^{i=N} (X_i - f(X_i))^2 \quad (S1)$$

This is then used to calculate the standard error of estimate on strength recovery of the model, Γ_m :

$$\Gamma_m = \sqrt{\frac{RSS}{N}} \quad (S2)$$

Since at short timescales, the model overestimates the strength recovery, we can then provide the confidence interval of the model, A , for any strength recovery:

$$A = f(X_i) - \Gamma_m \quad (S3)$$

We use this in Figure DR1 to find the minimum and maximum values of λ_c , which are, in turn, plotted as a vertical bar in Figure 1C (main text). Although not shown here, a similar result for λ_{\max} is found if we use $\sigma/\sigma_0 = Z \ln(t) - Q$ and extrapolate to the value of σ/σ_0 at which the press resolution is reached.

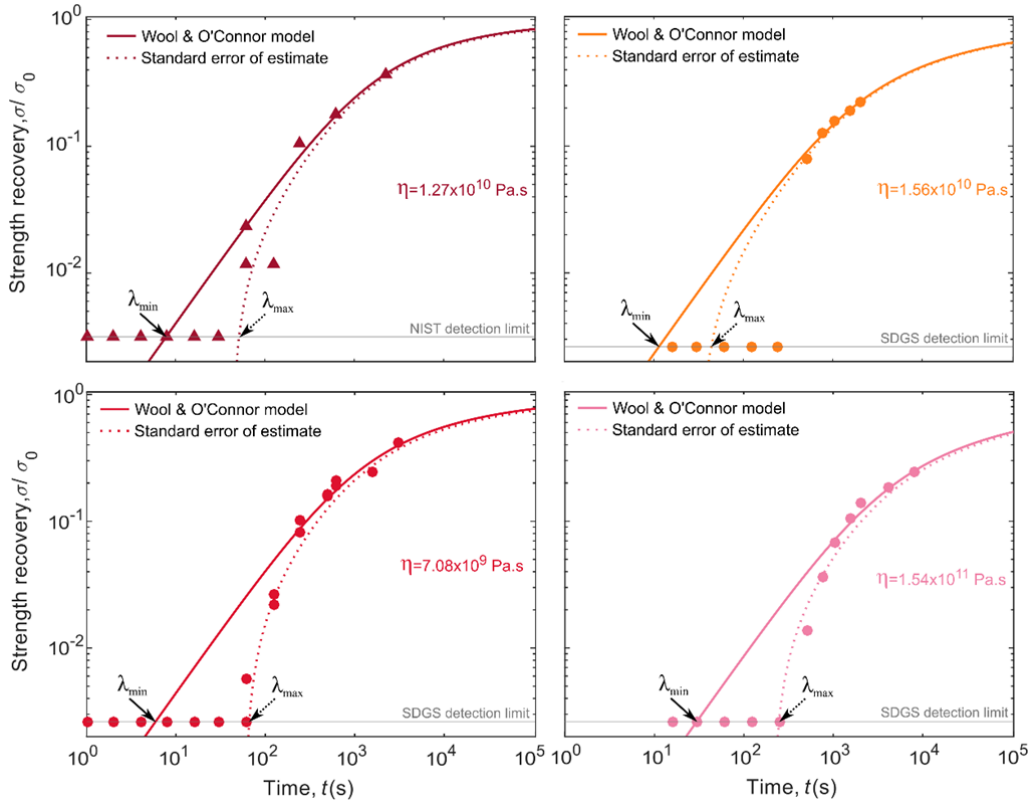


Figure DR1. Here each dataset (each sample at a temperature corresponding to a viscosity given on each panel) is plotted along with the prediction of Eq. 1 (main text; solid curve). The solid curve minus the standard error is given as the dashed curve. Both curves are used to predict the maximum and minimum λ_c given in Figure 1C (main text), termed here λ_{\max} and λ_{\min} , respectively.

2. Fracture surface geometry

In Figure DR2, we show an image oblique to the fracture surface, showing the asperities on a typical experimental sample prior to fracture healing. This demonstrates that we are using non-smoothed fractures with asperities of approximately 2 μm height.

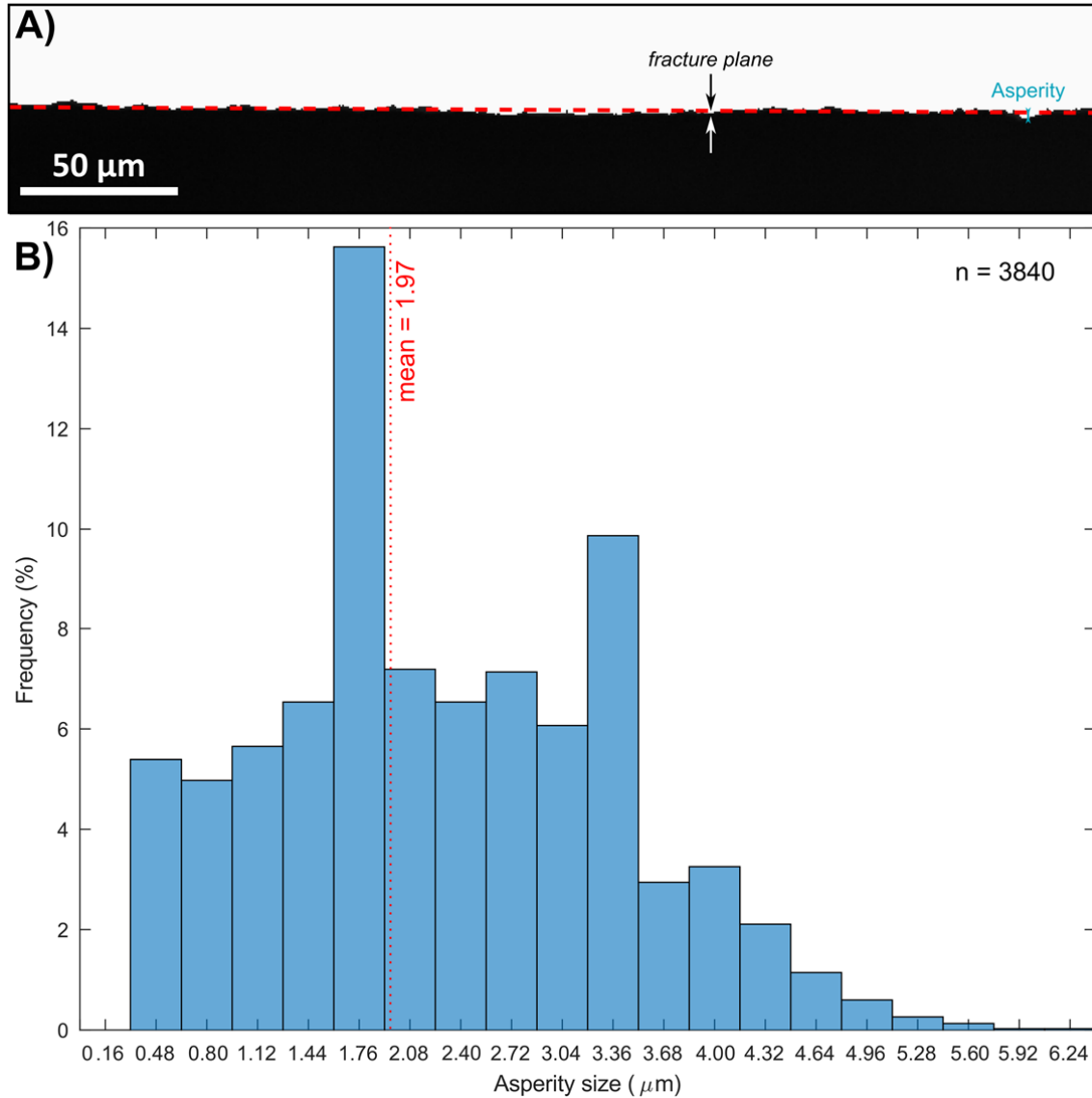


Figure DR2. Visualizing fracture surface geometries. A) Binary conversion of a backscattered electron image of a ground surface used as a synthetic fracture plane in the experiments (seen from the side); the blue arrow shows asperity size as distance from a virtual flat surface (dashed red line); B) Size distribution of 3840 asperities along a ground surface (1.05 mm long); the asperities range from 0.48 to 5.92 μm (1.97 μm average) in size measured optically.

3. The evolution of contact area, used to correct the stress data

The press records the force with time during an experiment. This needs to be converted to a stress, by dividing the surface area of contact between the two samples. However, the contact area evolves as a function of time. Therefore, using a specially designed sapphire window in the side of the furnace, we monitor the contact area and use two linear regressions as a general rule for correction (Figure DR3).

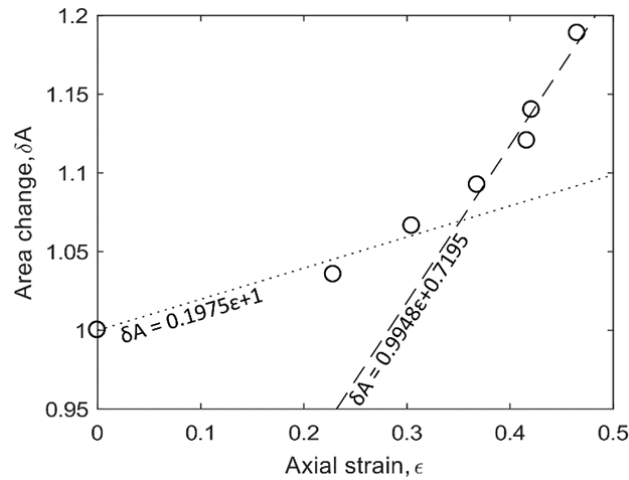


Figure DR3. Contact area evolution along the fracture plane as a function of axial strain monitored during contact of the fracture interfaces. We use two linear regressions as a general correction to these data, in order to compute stress as a function of time (or strain) in our data.

Once corrected, the relationship between axial stress and strain can be visualized (see Figure DR4 below).

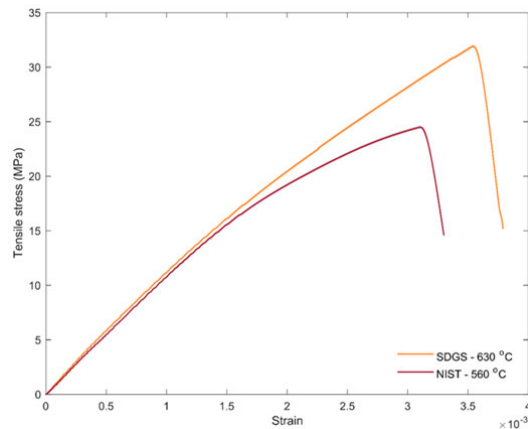


Figure DR4. Mechanical data obtained during direct pull test to measure the tensile strengths of the NIST and SDGS glasses at a viscosity of 10^{10} Pa.s.

4. The temperature dependence of viscosity of the materials used

As an essential pre-requisite for the analysis presented in the main text, the temperature-dependence of the sample viscosity had to be determined. This is presented in Figure DR5. We used a combination of measurements from the manufacturer (from Schott GmbH for SDGS, or from NIST), and measurements on cylindrical samples following the method of Hess et al., (2008).

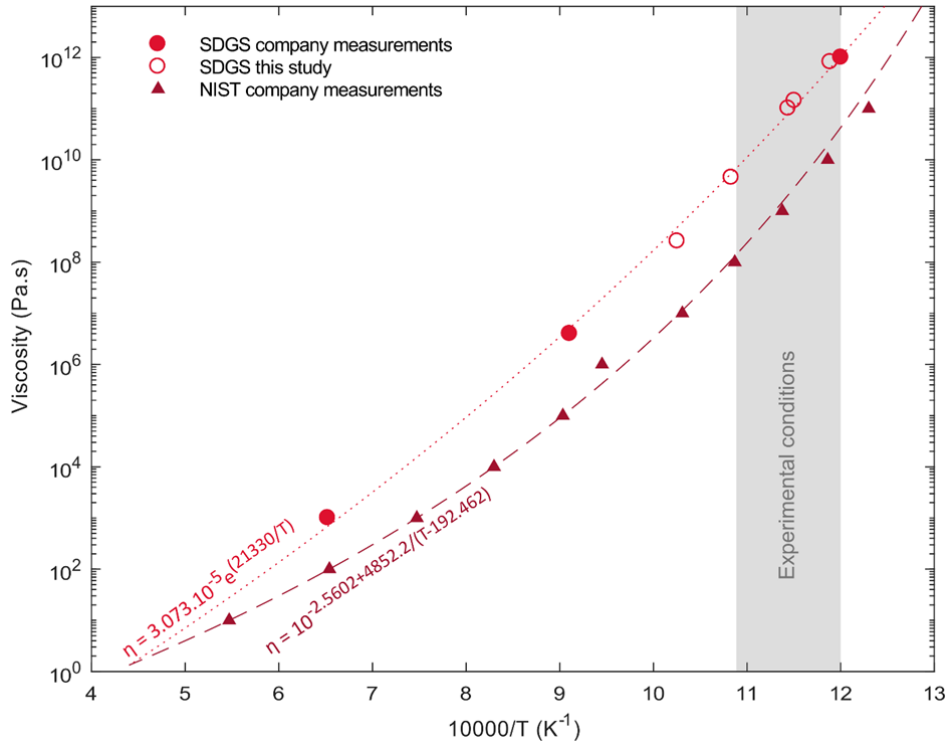


Figure DR5. Viscosity-temperature relationships for SDGS and NIST. The solid symbols show values provided by NIST (triangles) and Schott Duran® (circles). The open circles represent viscosity measurements carried out at the University of Liverpool using the parallel plate method (following Hess et al., 2008).

5. Raw data

Here we provide the raw data for each sample and experimental condition.

Table DR2. SDGS strength recovery at 590°C

Time of contact (s)	Strength recovery (σ/σ_0)
500	0.014
750	0.036
1000	0.067
1500	0.105
2000	0.138
4000	0.184
8000	0.244

Table DR3. SDGS strength recovery at 630°C

Time of contact (s)	Strength recovery (σ/σ_0)
500	0.079
750	0.126
1000	0.160
1500	0.189
2000	0.226

Table DR4. SDGS strength recovery at 645°C

Time of contact (s)	Strength recovery (σ/σ_0)
60	0
60	0.006
120	0.027
120	0.022
240	0.082
240	0.101
480	0.162
480	0.159
600	0.193
600	0.207
1500	0.241
3000	0.417

Table DR5. NIST strength recovery at 560°C

Time of contact (s)	Strength recovery (σ/σ_0)
60	0.012
60	0.023
120	0.012
240	0.104
600	0.177
2200	0.373

6. Calculation of the conditions at Volcán Chaitén

Castro & Dingwell (2009) estimate the viscosity during ascent to be $10^6 - 10^8$ Pa.s. Given that $\tau = \mu/G_\infty$, and that G_∞ is approximately 10^{10} Pa, this results in τ of $10^{-4} - 10^{-2}$ s. We found that the fracture healing onset time is approximately 10τ and so the onset time is, as stated in the main text, $10^{-3} - 10^{-1}$ s. To find the full time for complete healing, we take the expression for the second stage of diffusive healing (given in Figure 2), and rearrange to find $1/(M^2) = t_c/\lambda_c$, where M is given in Figure 2 (main text) to be 1.7×10^{-2} , and t_c is the time when $\sigma/\sigma_0 = 1$. This results in the values $t_c = 3.5$ s and $t_c = 3.5 \times 10^2$ s, as the minimum and maximum healing time, which in the main text we approximate as 10^0 and 10^2 s, or seconds-to-minutes.

Following Castro et al. (2012), we then estimate the degassed lava to have approximate minimum dissolved water content of 0.15 wt.%. Using the viscosity model of Hess & Dingwell (1996) and an estimated eruptive temperature of 825 °C, we find that this results in viscosities in the range between 3.09×10^8 Pa.s, and 3.16×10^9 Pa.s. As stated in the main text, we assume these are indicative of the in-dome conditions near the surface, for which those water contents are valid. Using the method described above, this results in t_c values of 1.07×10^3 s and 1.09×10^4 s, or hours.

In the main text we use this as justification of our statement that degassed dome lavas at silicic volcanoes are likely to be far less efficient at fracture healing, than in-conduit fractures with elevated water contents, and therefore lower viscosities.

References used in this Data Repository

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