

Supporting Information for Schaefer et al. (2023 – TEKTONIKA)

Laboratory simulation of earthquake-induced damage in lava dome rocks

Lauren N. Schaefer^{1,2*}, Jackie E. Kendrick^{3,4}, Yan Lavallée^{3,4}, Jenny Schaubroth³, Oliver D. Lamb^{4,†}, Anthony Lamur^{3,4}, Takahiro Miwa⁵, Ben M. Kennedy²

¹U.S. Geological Survey, 1711 Illinois St, Golden, Colorado, 80401, USA

²School of Earth and Environment, University of Canterbury, Christchurch, 8140, New Zealand

³Department of Earth and Environmental Sciences, Ludwig Maximilian University of Munich, Munich 80333, Germany

⁴Department of Earth, Ocean and Ecological Sciences, University of Liverpool, Liverpool, L69 3GP, UK

⁵National Research Institute for Earth Science and Disaster Resilience (NIED), Tsukuba, Japan

[†]Now at: Te Pū Ao | GNS Science, Wairakei Research Centre, Taupō, 3384, New Zealand

**Corresponding author: Lauren N. Schaefer (email: lschaefer@usgs.gov)*

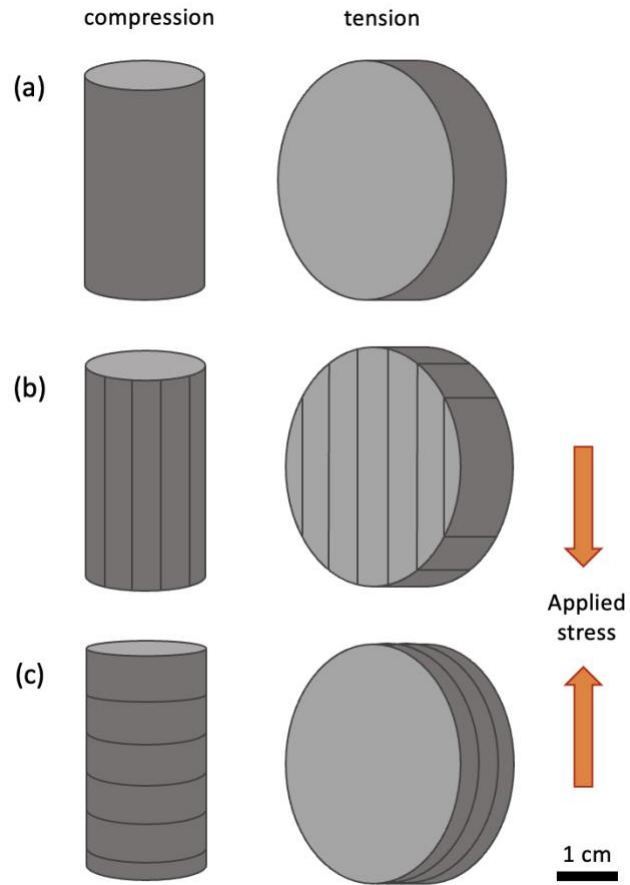


Figure SI-1: Schematic showing the sample geometries and cataclastic banded fabrics with respect to applied principal stress for (a) non-banded samples UNZ1, UNZ13 and UNZ14, (b) banded sample UNZ9a, and (c) banded sample UNZ9b.

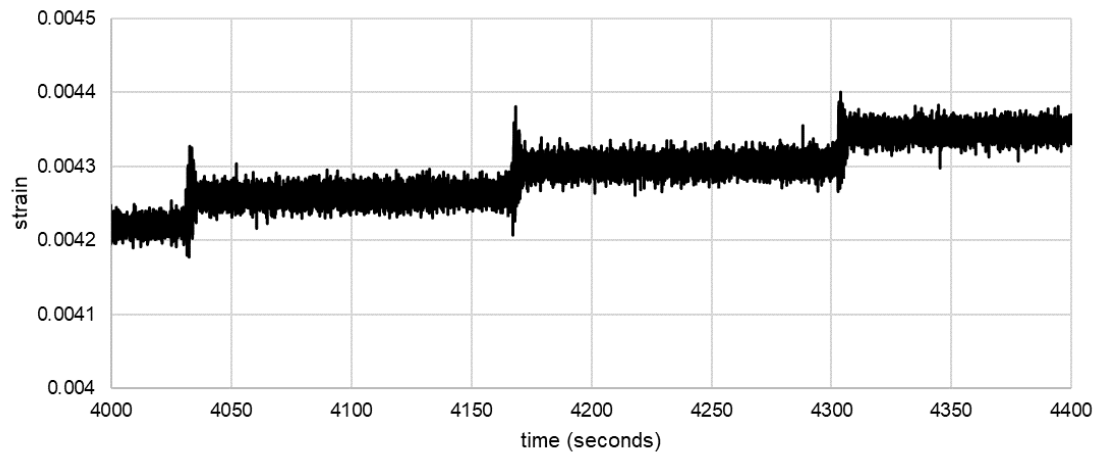


Figure SI-2: A zoomed view of several earthquake cycles during a compressive oscillation test. The sample shown is UNZ1.

Table SI-1: Values of C' , or the threshold stress required for dilatant microcracking where axial stress begins non-linearly decreasing as a function of axial strain (Heap et al., 2009), and the associated percent of C' of the uniaxial compressive strength (UCS) calculated from data in Kendrick et al. (2021).

Sample	C' (MPa)	UCS (MPa)	Percent C' of UCS
UNZ1_1	7.7	17.51	44%
UNZ1_4	10.1	18.24	55%
UNZ1_2	8.9	17.31	51%
UNZ9a_5	15.8	31.45	50%
UNZ9a_8	16.5	32.91	50%
UNZ9a_11	12.5	28.99	43%
UNZ9b_1	9.9	19.21	52%
UNZ9b_9	20.8	36.27	57%
UNZ9b_10	6.6	13.48	49%
UNZ13_2	14.5	29.20	50%
UNZ13_9	8.7	19.44	45%
UNZ13_13	8.3	15.50	54%
UNZ14_2	20.9	42.74	49%
UNZ14_4	20.6	47.80	43%
UNZ14_11	21.4	43.88	49%

Table SI-2: Standard error calculated for strain and strain rate measurements in load hold uniaxial and tension experimental conditions.

	Load hold, Uniaxial				Load hold, Tension			
	Strain	Error	Strain rate (s ⁻¹)	Error	Equivalent axial strain	Error	Equivalent axial strain rate (s ⁻¹)	Error
UNZ1-step 1	2.48E-03	1.24E-05	1.70E-09	8.43E-12	1.65E-03	5.51E-06	1.20E-09	3.98E-12
UNZ1-step 2	2.73E-03	1.50E-05	2.52E-10	1.38E-12	1.91E-03	7.37E-06	6.46E-10	2.47E-12
UNZ1-step 3	2.91E-03	1.71E-05	1.63E-09	9.56E-12	2.15E-03	9.29E-06	2.12E-09	9.06E-12
UNZ1-step 4	3.31E-03	2.20E-05	4.10E-09	2.66E-11	2.37E-03	1.13E-05	6.98E-10	3.32E-12
UNZ9a-step 1	2.51E-03	1.28E-05	1.45E-09	7.30E-12	1.02E-03	2.16E-06	2.19E-09	4.52E-12
UNZ9a-step 2	2.68E-03	1.46E-05	2.30E-09	1.24E-11	1.20E-03	2.96E-06	3.85E-09	9.25E-12
UNZ9a-step 3	2.31E-03	1.08E-05	7.98E-10	3.69E-12	1.29E-03	3.42E-06	3.38E-09	8.73E-12
UNZ9a-step 4	2.52E-03	1.28E-05	1.45E-09	7.36E-12	1.44E-03	4.24E-06	1.58E-09	4.61E-12
UNZ9b-step 1	4.12E-03	3.42E-05	2.72E-09	2.24E-11	1.42E-03	4.09E-06	5.42E-10	1.55E-12
UNZ9b-step 2	4.69E-03	4.43E-05	3.74E-09	3.51E-11	1.66E-03	5.57E-06	4.13E-10	1.37E-12
UNZ9b-step 3	5.36E-03	5.78E-05	5.34E-09	5.66E-11	2.04E-03	8.38E-06	3.79E-09	1.54E-11
UNZ9b-step 4	6.37E-03	8.16E-05	9.09E-08	1.12E-09	2.39E-03	1.15E-05	2.70E-08	1.27E-10
UNZ13-step 1	2.56E-03	1.34E-05	3.36E-10	1.75E-12	1.21E-03	3.03E-06	2.79E-09	6.84E-12
UNZ13-step 2	2.75E-03	1.54E-05	1.34E-09	7.46E-12	1.35E-03	3.74E-06	5.26E-10	1.47E-12
UNZ13-step 3	2.49E-03	1.26E-05	5.43E-11	2.70E-13	1.50E-03	4.56E-06	6.29E-10	1.91E-12
UNZ13-step 4	2.95E-03	1.77E-05	3.22E-09	1.89E-11	1.74E-03	6.13E-06	7.03E-10	2.47E-12
UNZ14-step 1	3.05E-03	1.88E-05	1.41E-09	8.66E-12	1.74E-03	6.11E-06	8.12E-10	2.82E-12
UNZ14-step 2	3.23E-03	2.10E-05	1.08E-09	7.02E-12	2.02E-03	8.24E-06	3.02E-09	1.22E-11
UNZ14-step 3	4.29E-03	3.70E-05	5.96E-09	4.94E-11	2.19E-03	9.70E-06	3.54E-10	1.56E-12
UNZ14-step 4	4.95E-03	4.92E-05	3.43E-09	3.37E-11	2.49E-03	1.25E-05	1.88E-09	9.41E-12

Table SI-3: Standard error calculated for strain and strain rate measurements in oscillation uniaxial and tension experimental conditions.

		Oscillation-Uniaxial				Oscillation-Tension			
Sample	Hold step	Strain	Error	Strain rate (s ⁻¹)	Error	Equivalent axial strain	Error	Equivalent axial strain rate (s ⁻¹)	Error
UNZ1	First hold	3.60E-03	2.35E-06	1.40E-07	9.11E-11	1.79E-03	3.73E-06	3.458E-08	7.20E-11
	1	3.75E-03	2.44E-06	7.06E-08	4.60E-11	1.85E-03	3.85E-06	6.698E-10	1.39E-12
	2	3.79E-03	2.47E-06	5.24E-08	3.42E-11	1.85E-03	3.86E-06	7.4581E-08	1.55E-10
	3	3.84E-03	2.50E-06	5.72E-08	3.73E-11	1.88E-03	3.91E-06	-2.4118E-08	-5.02E-11
	4	3.88E-03	2.53E-06	3.92E-08	2.55E-11	1.88E-03	3.91E-06	8.5505E-08	1.78E-10
	5	3.93E-03	2.56E-06	2.20E-07	1.44E-10	1.90E-03	3.96E-06	-4.1029E-08	-8.54E-11
	6	4.00E-03	2.61E-06	6.95E-08	4.53E-11	1.91E-03	3.98E-06	1.4086E-07	2.93E-10
	7	4.05E-03	2.64E-06	5.71E-08	3.73E-11	1.96E-03	4.09E-06	7.99E-08	1.66E-10
	8	4.10E-03	2.68E-06	3.41E-08	2.23E-11	2.01E-03	4.17E-06	3.228E-07	6.72E-10
	9	4.14E-03	2.70E-06	3.37E-08	2.20E-11				
	10	4.18E-03	2.73E-06	4.48E-08	2.93E-11				
	11	4.22E-03	2.75E-06	7.12E-08	4.65E-11				
	12	4.26E-03	2.78E-06	3.57E-08	2.33E-11				
	13	4.30E-03	2.81E-06	2.84E-08	1.86E-11				
	14	4.35E-03	2.84E-06	3.03E-08	1.98E-11				
	15	4.38E-03	2.86E-06	2.91E-08	1.90E-11				
	16	4.42E-03	2.89E-06	4.76E-08	3.11E-11				
	17	4.47E-03	2.92E-06	6.25E-08	4.09E-11				
	18	4.54E-03	2.97E-06	1.60E-07	1.04E-10				
	19	4.64E-03	3.03E-06	2.17E-07	1.42E-10				
	20	4.73E-03	3.10E-06	1.41E-07	9.23E-11				
	Last hold	4.94E-03	3.23E-06	8.26E-08	5.41E-11				
UNZ9a	First hold	2.76E-03	1.78E-06	6.83E-08	4.40E-11	7.68E-04	1.78E-06	1.9536E-08	4.53E-11
	1	2.88E-03	1.86E-06	-1.32E-08	-8.53E-12	7.89E-04	1.83E-06	-7.5807E-09	-1.8E-11
	2	2.91E-03	1.87E-06	-6.48E-08	-4.17E-11	7.81E-04	1.81E-06	6.4163E-09	1.49E-11
	3	2.91E-03	1.88E-06	-3.21E-08	-2.07E-11	7.85E-04	1.82E-06	-3.2752E-08	-7.6E-11
	4	2.91E-03	1.87E-06	-3.12E-08	-2.01E-11	7.82E-04	1.81E-06	4.449E-08	1.03E-10
	5	2.91E-03	1.87E-06	-3.61E-08	-2.32E-11	7.92E-04	1.84E-06	5.1554E-08	1.2E-10
	6	2.91E-03	1.87E-06	5.58E-09	3.60E-12	7.90E-04	1.83E-06	1.7571E-08	4.07E-11
	7	2.91E-03	1.88E-06	7.34E-09	4.73E-12	7.99E-04	1.85E-06	1.5007E-08	3.48E-11
	8	2.92E-03	1.88E-06	3.68E-09	2.37E-12	7.95E-04	1.84E-06	3.9998E-08	9.28E-11
	9	2.92E-03	1.88E-06	6.08E-08	3.92E-11	8.09E-04	1.88E-06	3.6795E-08	8.53E-11
	10	2.93E-03	1.89E-06	2.41E-08	1.55E-11	8.04E-04	1.87E-06	7.5681E-08	1.76E-10
	11	2.93E-03	1.89E-06	1.51E-08	9.71E-12	8.18E-04	1.90E-06	2.5409E-08	5.89E-11
	12	2.93E-03	1.89E-06	-3.66E-09	-2.36E-12	8.14E-04	1.89E-06	3.4434E-08	7.99E-11
	13	2.93E-03	1.89E-06	1.05E-08	6.76E-12	8.22E-04	1.91E-06	1.0457E-08	2.42E-11

	14	2.94E-03	1.89E-06	4.55E-08	2.93E-11	8.20E-04	1.90E-06	5.9309E-08	1.38E-10
	15	2.94E-03	1.90E-06	1.94E-08	1.25E-11	8.30E-04	1.93E-06	-1.3332E-08	-3.1E-11
	16	2.94E-03	1.90E-06	-5.32E-09	-3.43E-12	8.25E-04	1.91E-06	-2.3675E-08	-5.5E-11
	17	2.94E-03	1.90E-06	1.24E-08	7.99E-12	8.30E-04	1.92E-06	-3.6403E-08	-8.4E-11
	18	2.95E-03	1.90E-06	5.83E-09	3.76E-12	8.17E-04	1.89E-06	-2.2265E-08	-5.2E-11
	19	2.94E-03	1.90E-06	-1.03E-09	-6.65E-13	8.19E-04	1.90E-06	-6.0921E-08	-1.4E-10
	20	2.94E-03	1.90E-06	-1.49E-09	-9.63E-13	8.06E-04	1.87E-06	-6.2315E-09	-1.4E-11
	Last hold	2.96E-03	1.91E-06	-4.70E-09	-3.03E-12	8.12E-04	1.88E-06	2.2846E-10	5.3E-13
UNZ9b	First hold	4.35E-03	2.80E-06	7.48E-08	4.81E-11	1.41E-03	1.71E-06	8.0948E-09	9.81E-12
	1	4.47E-03	2.88E-06	-2.43E-08	-1.56E-11	1.44E-03	1.75E-06	-3.9292E-08	-4.8E-11
	2	4.49E-03	2.89E-06	5.12E-09	3.30E-12	1.44E-03	1.75E-06	2.7579E-08	3.34E-11
	3	4.52E-03	2.91E-06	4.91E-08	3.16E-11	1.46E-03	1.77E-06	2.3845E-08	2.89E-11
	4	4.53E-03	2.92E-06	7.31E-08	4.71E-11	1.46E-03	1.77E-06	4.4136E-08	5.35E-11
	5	4.56E-03	2.94E-06	5.14E-08	3.31E-11	1.48E-03	1.79E-06	-1.8112E-09	-2.2E-12
	6	4.57E-03	2.94E-06	9.80E-09	6.31E-12	1.48E-03	1.79E-06	7.9767E-08	9.66E-11
	7	4.59E-03	2.96E-06	-2.58E-09	-1.66E-12	1.49E-03	1.81E-06	4.5151E-08	5.47E-11
	8	4.59E-03	2.96E-06	3.38E-08	2.18E-11	1.50E-03	1.81E-06	7.5421E-08	9.14E-11
	9	4.62E-03	2.97E-06	3.08E-08	1.99E-11	1.51E-03	1.83E-06	1.7305E-08	2.1E-11
	10	4.62E-03	2.97E-06	6.41E-08	4.13E-11	1.51E-03	1.83E-06	4.9554E-08	6E-11
	11	4.64E-03	2.99E-06	2.76E-09	1.78E-12	1.52E-03	1.84E-06	-1.7984E-08	-2.2E-11
	12	4.64E-03	2.99E-06	-2.27E-09	-1.46E-12	1.51E-03	1.83E-06	8.7928E-08	1.07E-10
	13	4.65E-03	3.00E-06	2.77E-08	1.78E-11	1.53E-03	1.85E-06	4.4486E-08	5.39E-11
	14	4.65E-03	3.00E-06	2.75E-08	1.77E-11	1.53E-03	1.85E-06	7.7727E-08	9.42E-11
	15	4.67E-03	3.01E-06	-2.53E-08	-1.63E-11	1.54E-03	1.87E-06	2.9168E-09	3.53E-12
	16	4.66E-03	3.00E-06	8.58E-09	5.53E-12	1.53E-03	1.86E-06	-5.4838E-09	-6.6E-12
	17	4.67E-03	3.01E-06	-4.15E-08	-2.67E-11	1.53E-03	1.86E-06	-6.6037E-08	-8E-11
	18	4.67E-03	3.01E-06	2.74E-08	1.77E-11	1.52E-03	1.85E-06	1.8192E-08	2.2E-11
	19	4.68E-03	3.02E-06	-7.57E-09	-4.88E-12	1.53E-03	1.86E-06	-6.1412E-09	-7.4E-12
	20	4.68E-03	3.02E-06	5.39E-08	3.47E-11	1.52E-03	1.85E-06	2.0918E-09	2.53E-12
	Last hold	4.69E-03	3.02E-06	-7.65E-09	-4.93E-12	1.54E-03	1.87E-06	1.6899E-08	2.05E-11
UNZ13	First hold	2.22E-03	1.44E-06	1.06E-08	6.89E-12	1.47E-03	6.62E-07	2.1122E-08	9.49E-12
	1	2.26E-03	1.47E-06	1.39E-08	9.06E-12	1.51E-03	6.81E-07	1.0377E-08	4.66E-12
	2	2.26E-03	1.47E-06	2.24E-08	1.45E-11	1.51E-03	6.79E-07	8.0191E-08	3.6E-11
	3	2.27E-03	1.47E-06	3.19E-08	2.07E-11	1.53E-03	6.87E-07	-9.6554E-08	-4.3E-11
	4	2.27E-03	1.47E-06	3.84E-08	2.50E-11	1.52E-03	6.83E-07	3.068E-08	1.38E-11
	5	2.28E-03	1.48E-06	3.50E-08	2.27E-11	1.53E-03	6.89E-07	-7.2678E-08	-3.3E-11
	6	2.27E-03	1.48E-06	3.11E-08	2.02E-11	1.53E-03	6.86E-07	3.4043E-08	1.53E-11
	7	2.28E-03	1.48E-06	2.22E-08	1.44E-11	1.54E-03	6.92E-07	-5.5198E-08	-2.5E-11
	8	2.28E-03	1.48E-06	4.79E-08	3.11E-11	1.53E-03	6.89E-07	7.052E-08	3.17E-11
	9	2.28E-03	1.48E-06	1.37E-08	8.90E-12	1.55E-03	6.96E-07	-1.9034E-08	-8.6E-12
	10	2.28E-03	1.48E-06	3.96E-08	2.58E-11	1.54E-03	6.94E-07	7.9693E-08	3.58E-11
	11	2.29E-03	1.49E-06	3.99E-08	2.59E-11	1.56E-03	7.01E-07	-4.6585E-08	-2.1E-11
	12	2.28E-03	1.48E-06	6.30E-08	4.09E-11	1.55E-03	6.97E-07	7.9915E-08	3.59E-11

	13	2.29E-03	1.49E-06	3.87E-08	2.51E-11	1.57E-03	7.03E-07	-3.0431E-08	-1.4E-11
	14	2.29E-03	1.49E-06	2.81E-08	1.83E-11	1.56E-03	7.00E-07	4.4328E-08	1.99E-11
	15	2.29E-03	1.49E-06	3.67E-08	2.38E-11	1.57E-03	7.05E-07	-5.2032E-08	-2.3E-11
	16	2.29E-03	1.49E-06	2.73E-08	1.77E-11	1.56E-03	7.01E-07	4.0262E-08	1.81E-11
	17	2.30E-03	1.49E-06	1.80E-08	1.17E-11	1.56E-03	7.02E-07	-1.5264E-07	-6.9E-11
	18	2.29E-03	1.49E-06	3.64E-08	2.36E-11	1.56E-03	7.01E-07	1.9081E-08	8.57E-12
	19	2.30E-03	1.49E-06	2.92E-08	1.90E-11	1.57E-03	7.05E-07	-8.1851E-08	-3.7E-11
	20	2.29E-03	1.49E-06	4.23E-08	2.75E-11	1.56E-03	7.00E-07	-5.7942E-09	-2.6E-12
	Last hold	2.30E-03	1.50E-06	2.01E-09	1.30E-12	1.56E-03	7.00E-07	-4.1483E-09	-1.9E-12
UNZ14	First hold	3.34E-03	2.18E-06	8.47E-08	5.53E-11	1.18E-03	8.23E-07	2.9769E-08	2.07E-11
	1	3.51E-03	2.29E-06	8.18E-08	5.34E-11	1.23E-03	8.56E-07	-3.0491E-08	-2.1E-11
	2	3.55E-03	2.32E-06	5.22E-08	3.41E-11	1.22E-03	8.52E-07	-1.8006E-08	-1.3E-11
	3	3.59E-03	2.34E-06	7.40E-08	4.83E-11	1.23E-03	8.59E-07	-3.6875E-09	-2.6E-12
	4	3.63E-03	2.37E-06	2.42E-08	1.58E-11	1.23E-03	8.56E-07	2.9919E-08	2.08E-11
	5	3.66E-03	2.39E-06	6.57E-08	4.29E-11	1.24E-03	8.63E-07	-2.0182E-08	-1.4E-11
	6	3.68E-03	2.40E-06	5.35E-08	3.49E-11	1.23E-03	8.59E-07	1.432E-08	9.97E-12
	7	3.70E-03	2.41E-06	1.43E-08	9.34E-12	1.24E-03	8.63E-07	-4.2326E-08	-2.9E-11
	8	3.70E-03	2.42E-06	-3.43E-08	-2.24E-11	1.23E-03	8.58E-07	-1.6158E-08	-1.1E-11
	9	3.70E-03	2.42E-06	-1.17E-07	-7.61E-11	1.24E-03	8.62E-07	-5.2013E-08	-3.6E-11
	10	3.70E-03	2.42E-06	-1.37E-08	-8.91E-12	1.23E-03	8.56E-07	1.5672E-08	1.09E-11
	11	3.72E-03	2.43E-06	5.34E-08	3.49E-11	1.24E-03	8.61E-07	-6.6767E-09	-4.6E-12
	12	3.73E-03	2.44E-06	5.10E-08	3.33E-11	1.23E-03	8.57E-07	-8.7143E-09	-6.1E-12
	13	3.74E-03	2.44E-06	5.44E-09	3.55E-12	1.24E-03	8.61E-07	-5.6429E-08	-3.9E-11
	14	3.75E-03	2.45E-06	4.27E-08	2.79E-11	1.23E-03	8.57E-07	1.9976E-08	1.39E-11
	15	3.76E-03	2.45E-06	3.66E-08	2.39E-11	1.24E-03	8.61E-07	-3.338E-08	-2.3E-11
	16	3.76E-03	2.46E-06	-1.80E-08	-1.17E-11	1.23E-03	8.57E-07	4.0386E-08	2.81E-11
	17	3.77E-03	2.46E-06	1.33E-08	8.67E-12	1.24E-03	8.63E-07	-4.7639E-09	-3.3E-12
	18	3.77E-03	2.46E-06	4.32E-08	2.82E-11	1.23E-03	8.59E-07	3.637E-08	2.53E-11
	19	3.78E-03	2.47E-06	6.19E-09	4.04E-12	1.24E-03	8.66E-07	-1.2392E-08	-8.6E-12
	20	3.79E-03	2.47E-06	1.48E-08	9.64E-12	1.24E-03	8.63E-07	1.9466E-08	1.35E-11
	Last hold	3.80E-03	2.48E-06	3.68E-09	2.40E-12	1.24E-03	8.66E-07	2.4547E-09	1.71E-12

Supplementary references

Heap, M.J., Baud, P., Meredith, P.G., Bell, A.F. & Main, I. G. (2009). Time-dependent brittle creep in Darley Dale sandstone. *Journal of Geophysical Research: Solid Earth*, 114(B7), B07203. <https://doi.org/10.1029/2008JB006212>

Kendrick, J. E., Schaefer, L. N., Schaubroth, J., Bell, A. F., Lamb, O. D., Lamur, A., Miwa, T., Coats, R., Lavallée, Y., & Kennedy, B. M. (2021). Physical and mechanical rock properties of a heterogeneous volcano: The case of Mount Unzen, Japan. *Solid Earth*, 12(3), 633–664. <https://doi.org/10.5194/se-12-633-2021><https://doi.org/10.5194/se-12-633-2021>