Deformation mechanisms in crystalline magma

J.E. Kendrick[1], Y. Lavallee[1], Mariani, E.[2],M.J. Heap[3], K.U. Hess[1], A. Flaws[1], H.E. Gaunt[4], and D.B. Dingwell[1]

[1]Department of Earth and Environmental Sciences, LMU Munich, Germany
[2]Department of Earth and Ocean Sciences, University of Liverpool, UK
[3] Laboratoire de Géophysique Expérimentale, Institut de Physique de Globe de Strasbourg, France
[4]Department of Earth and Environmental Sciences, University College London

Kendrick@min.uni-muenchen.de

Why do we care?

Effusive

Explosive

Mount Etna, Jan 2011
(dailymail)

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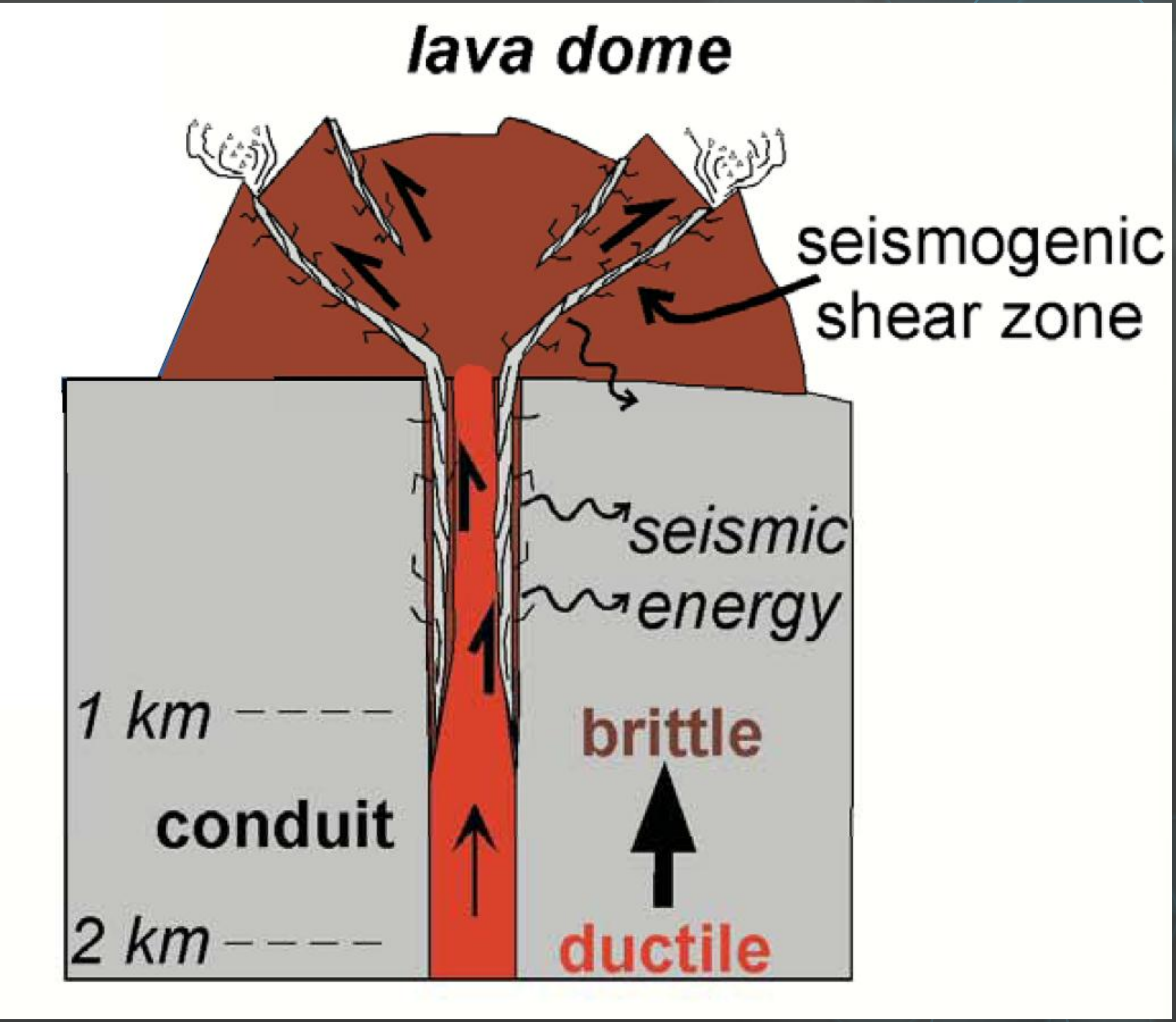
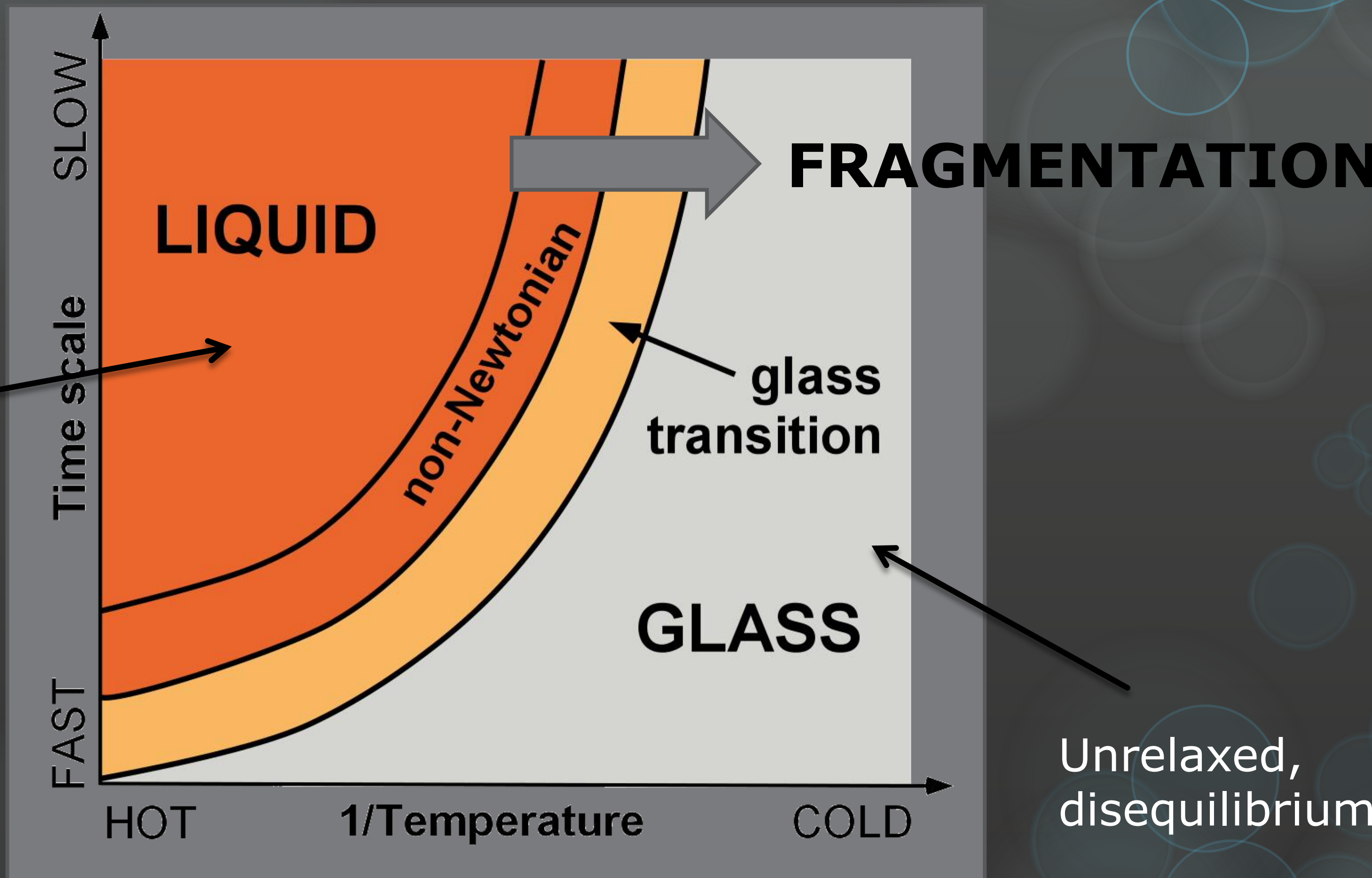
DUCTILE to BRITTLE



Modified from Tuffen et al. 2008

The glass transition: pure silicate melt



Relaxed, equilibrium

Unrelaxed, disequilibrium

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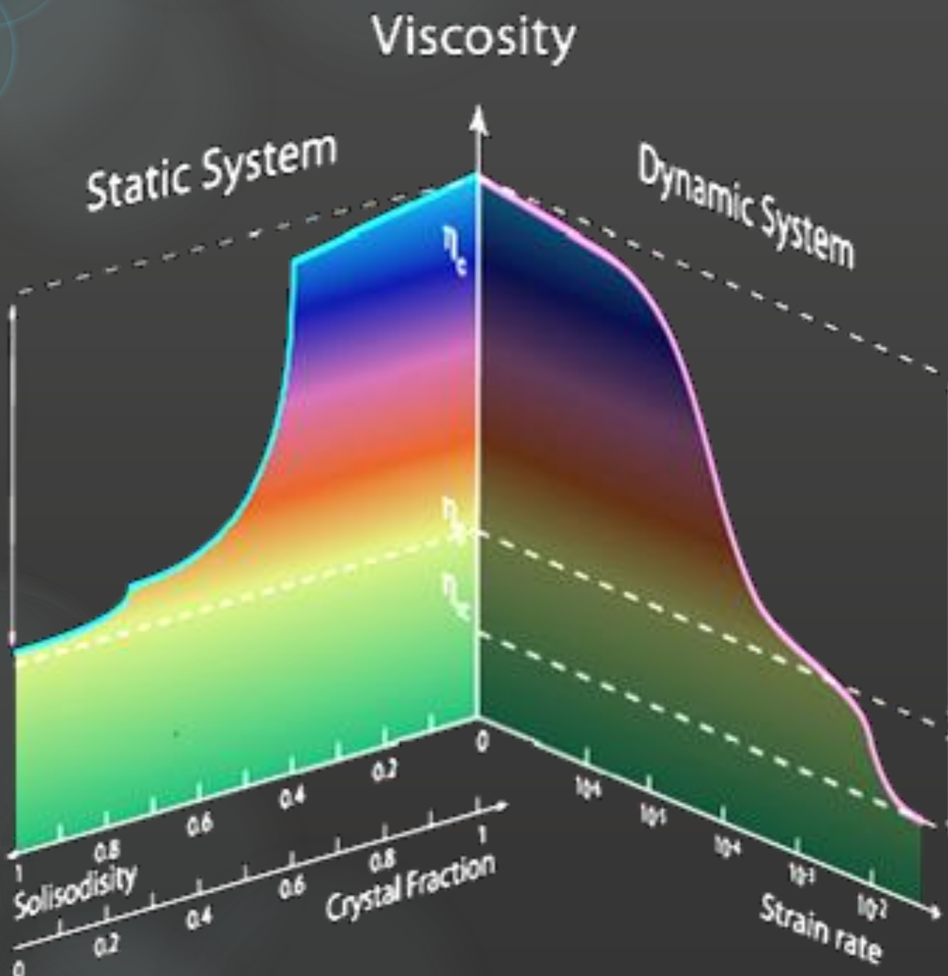
In nature: pure silicate melt is rare

- **Addition of pores and *crystals***



COMPLEX RHEOLOGY

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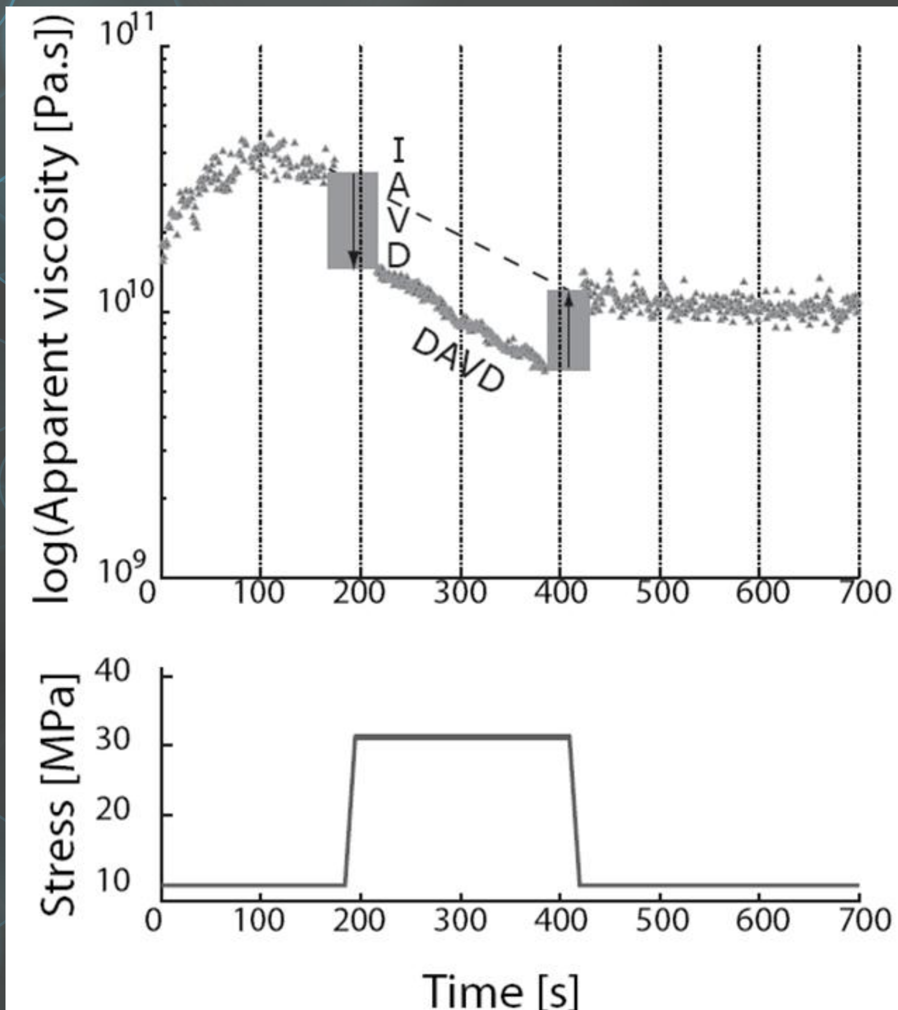
The stress effect



Cordonnier et al. 2009

Increasing applied stress

Instantaneous

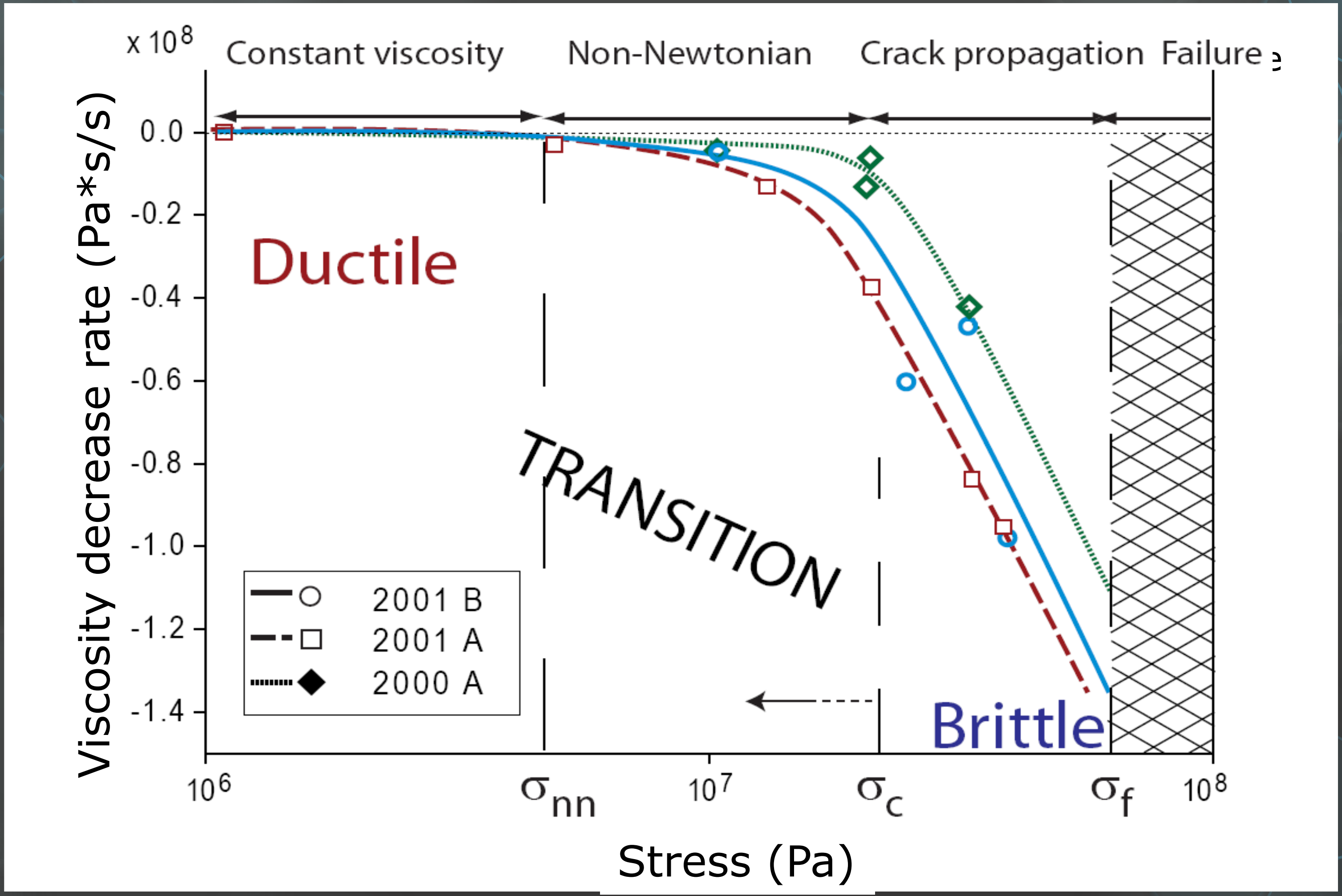
Decreases viscosity

Constant stress

Gradual

Decreases viscosity

The ductile-brittle transition



Cordonnier et al. 2009

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Experimental procedure

Uniaxial press:

- **Constant stress**
- **940-950 ºC**

➢ **To study in situ the rheology of multi-phase melts.**

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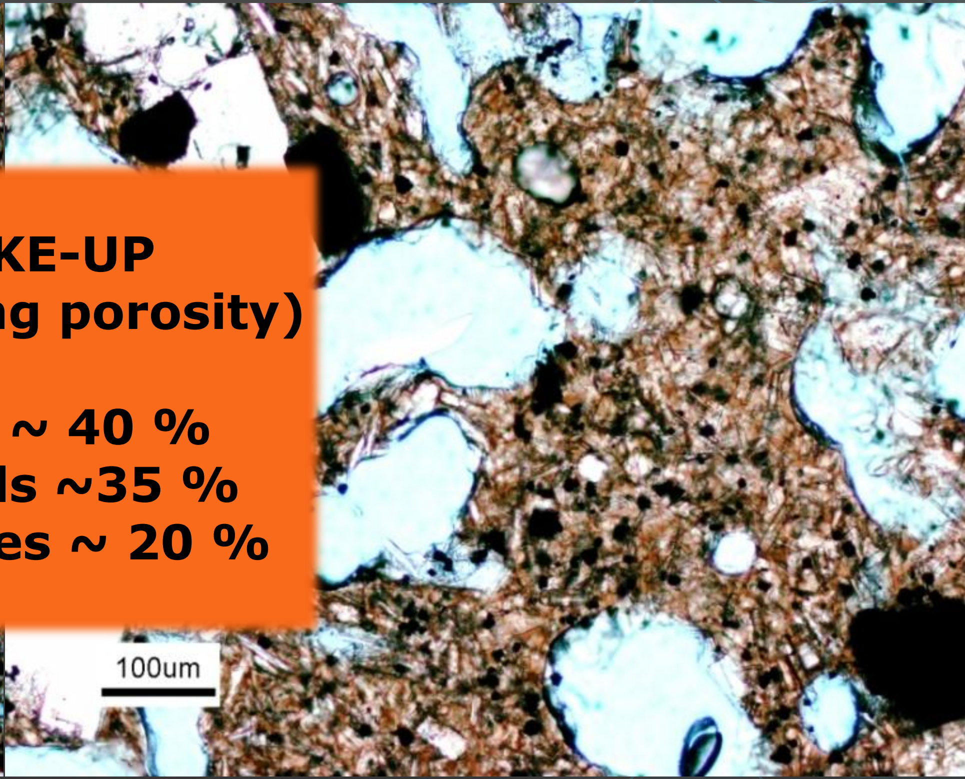
Material Properties



MAKE-UP (excluding porosity)

Glass ~ 40 %
Crystals ~35 %
Microlites ~ 20 %

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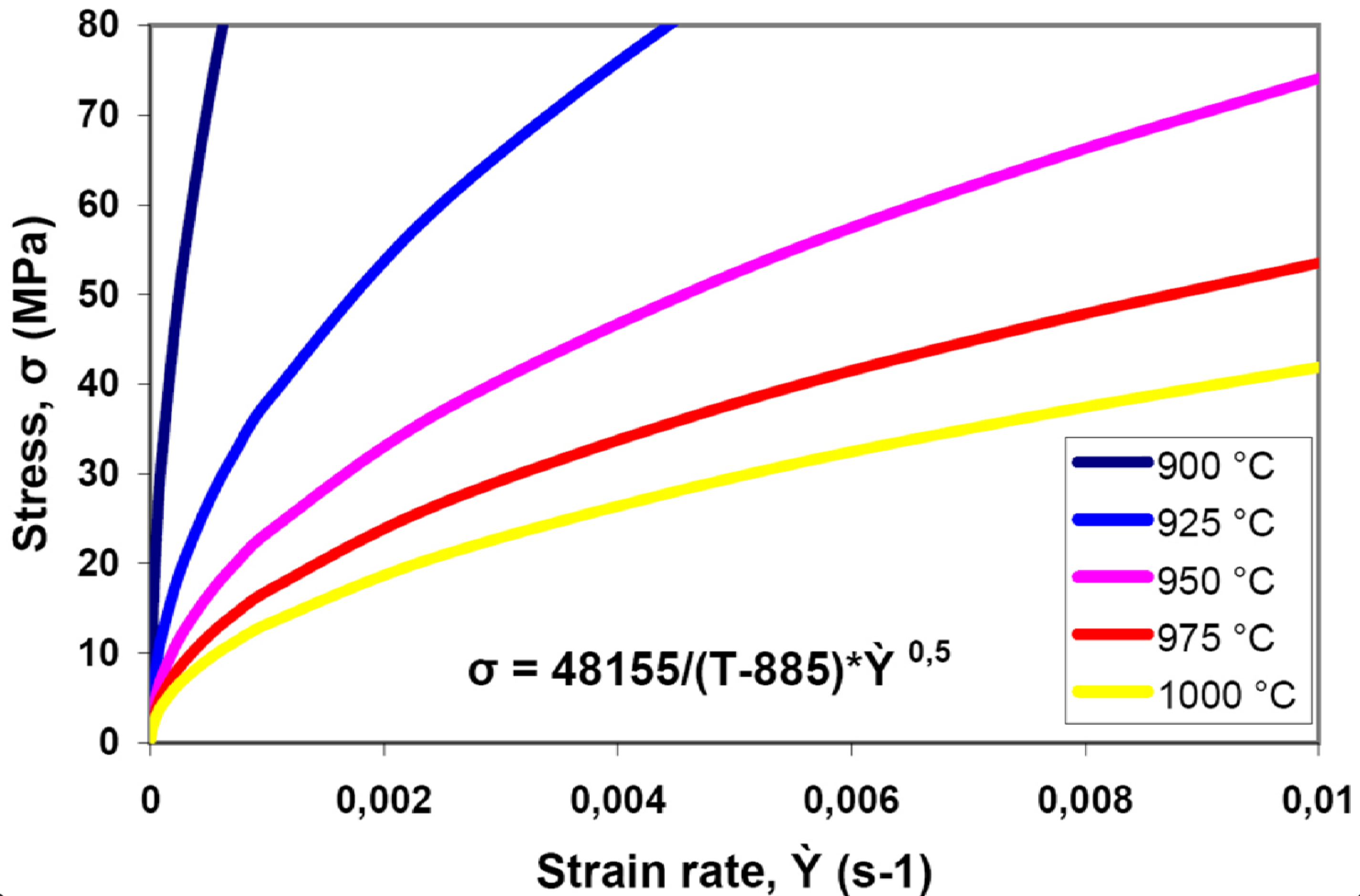
Temperature effect



Lavallee et al. (2011)

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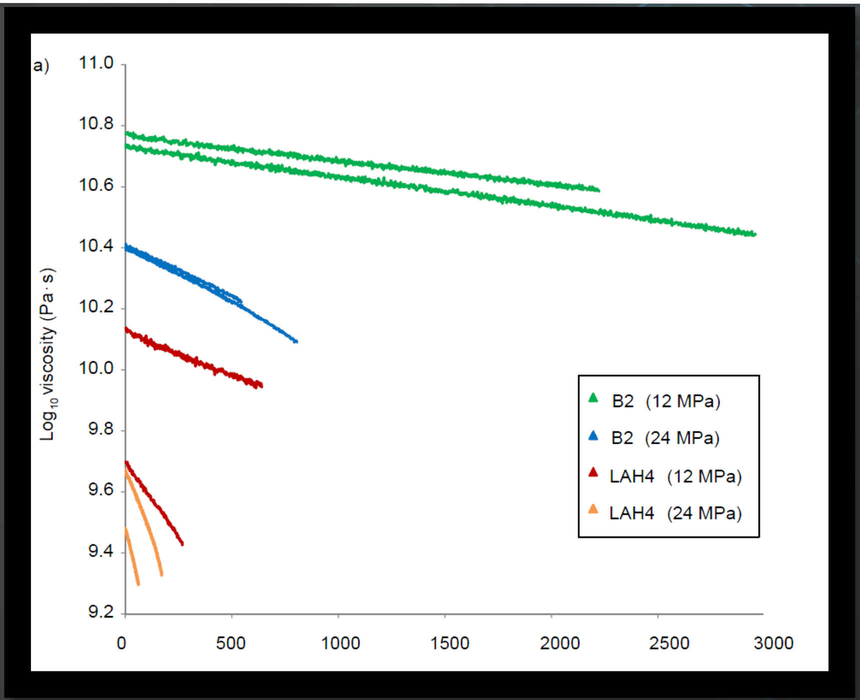
Strain Effects

Time Dependent



7 % 14 % 21 % 28 % 35 %

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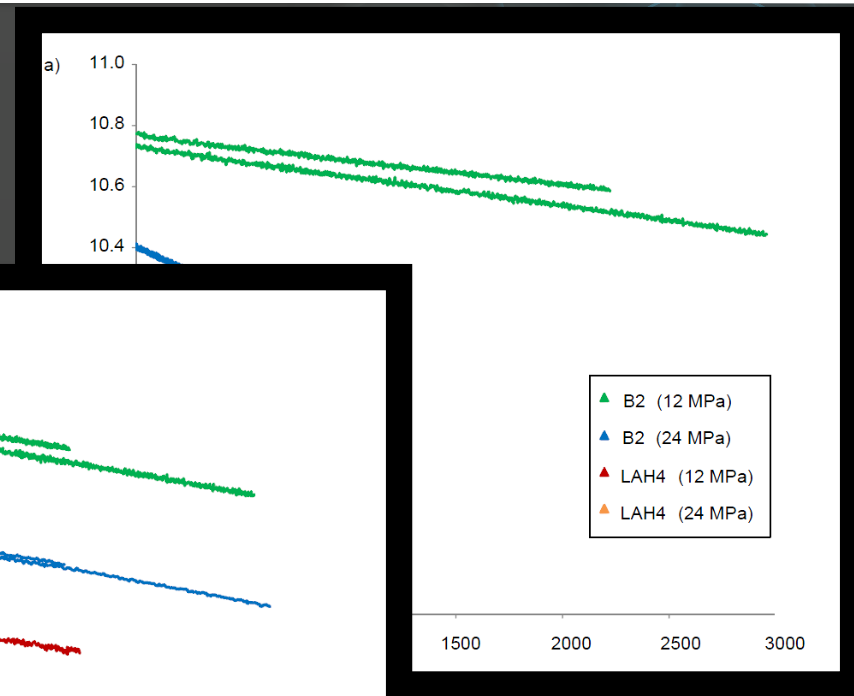
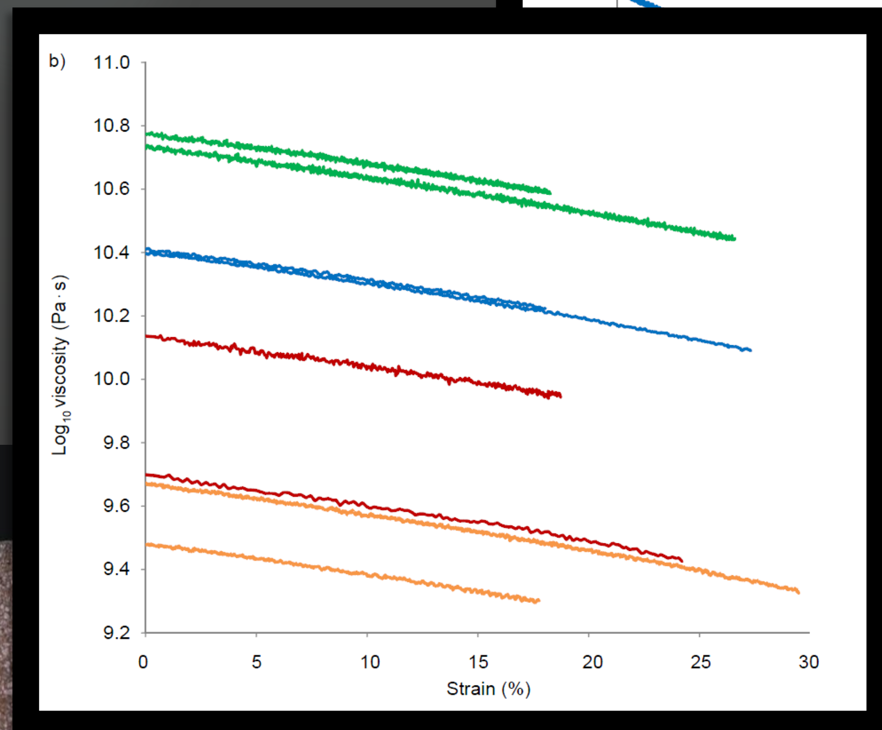
Strain Effects

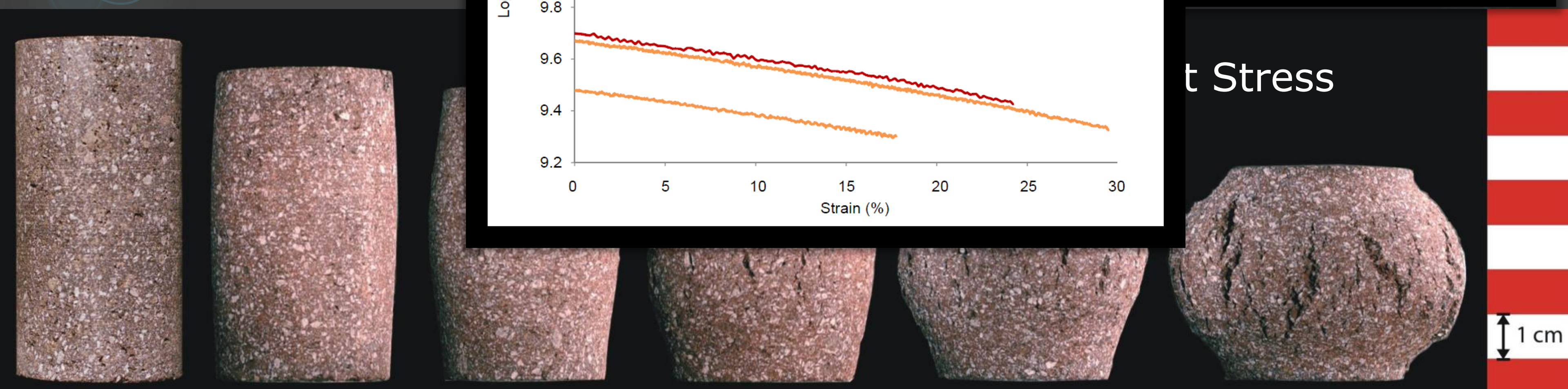
~~Time Dependent~~

Strain Dependent





t Stress



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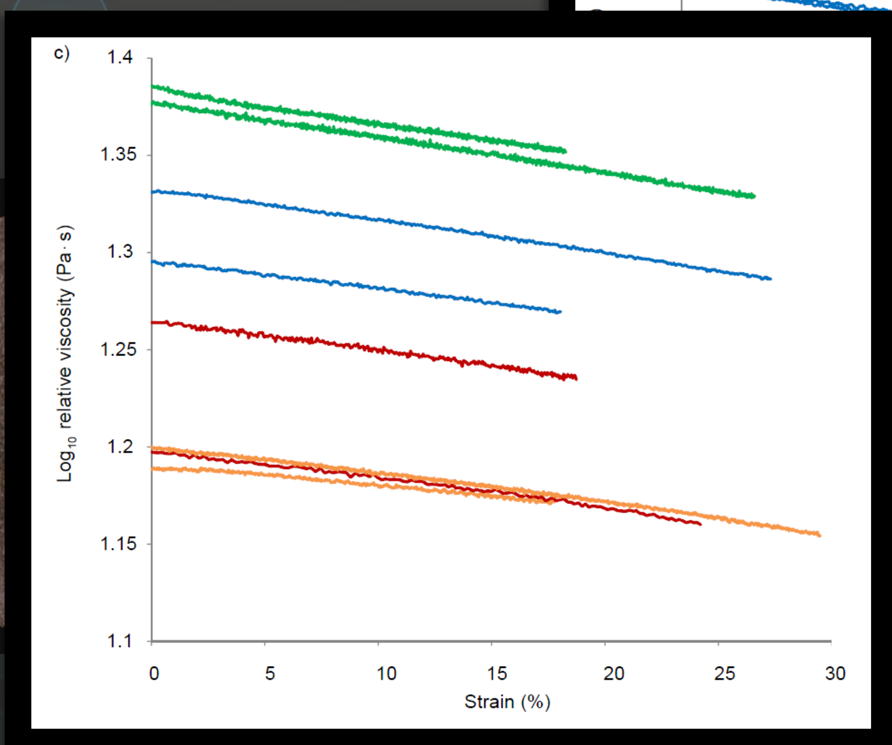
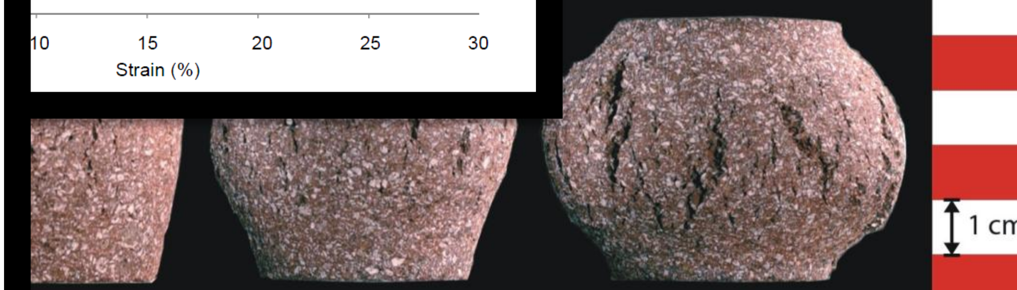
Strain Effects

~~Time Dependent~~

Strain Dependent



t Stress



1 % 28 % 35 %

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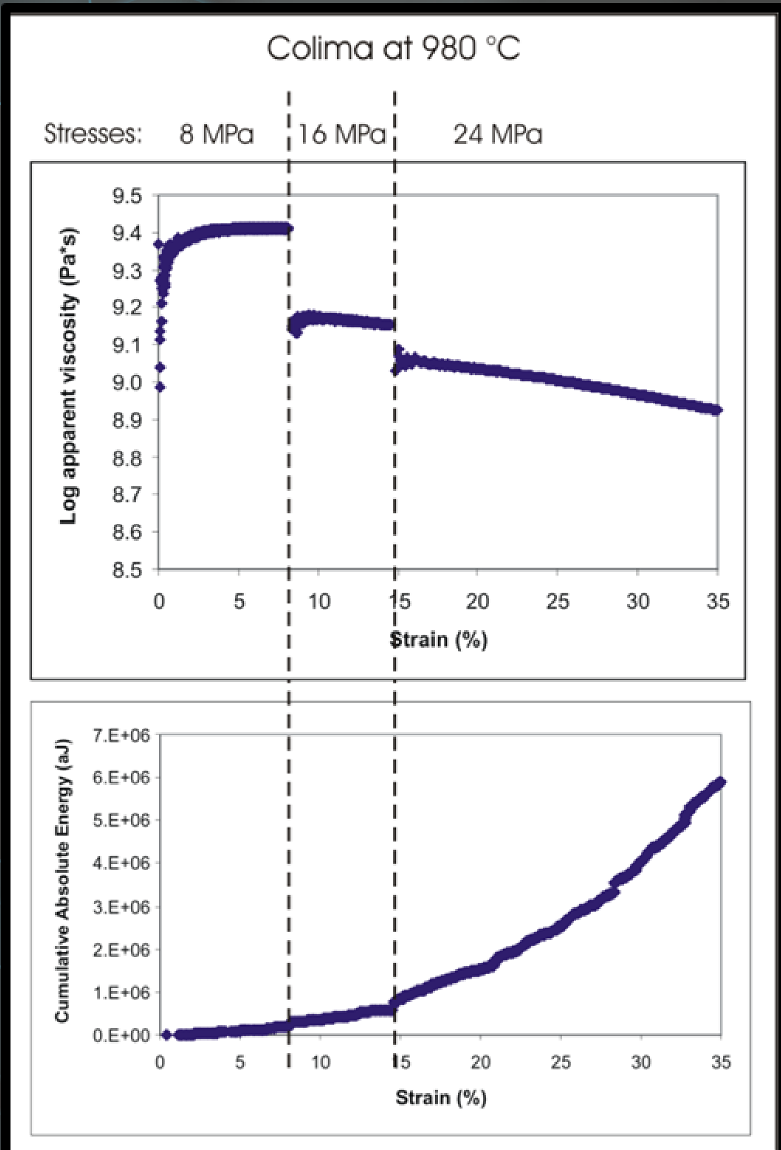
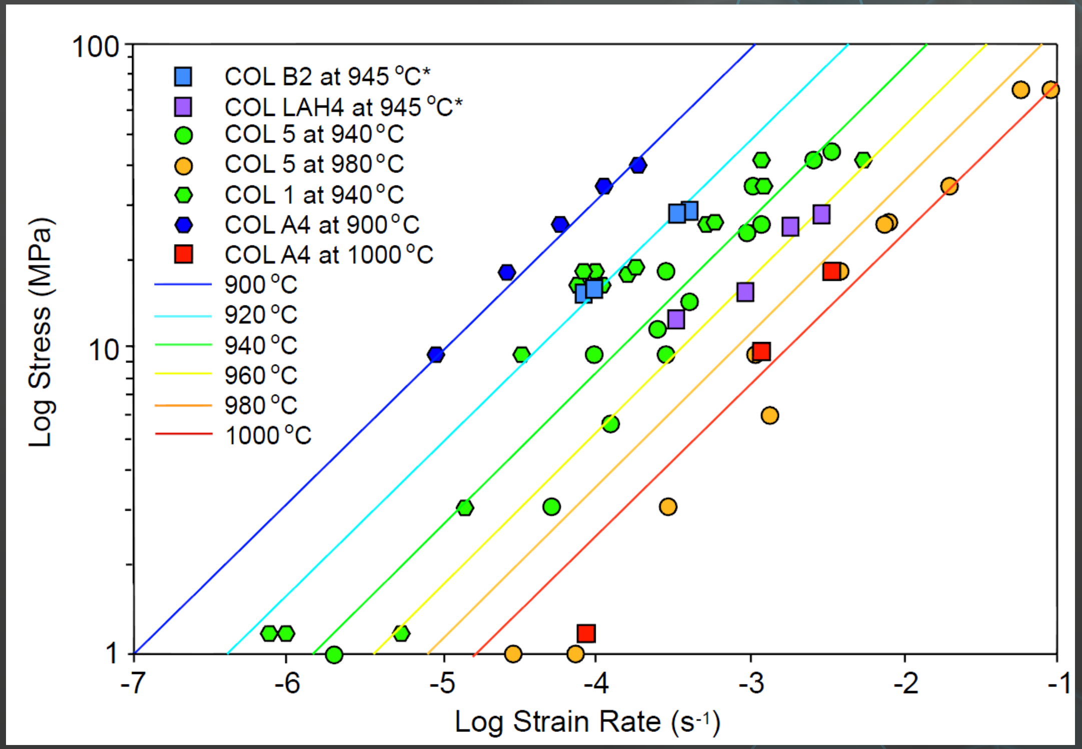
Stress Effects





Lavallee et al. (in prep.)

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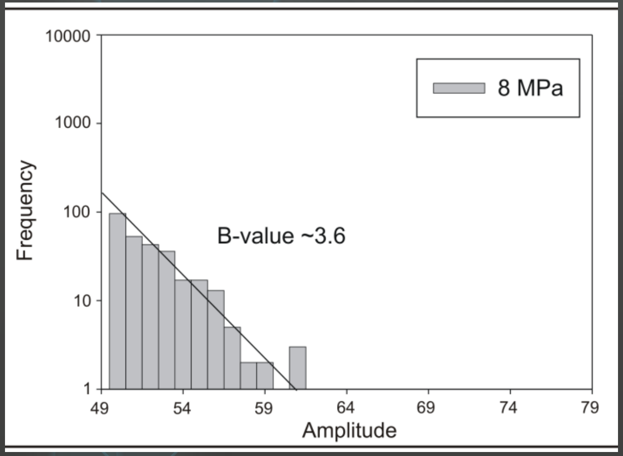
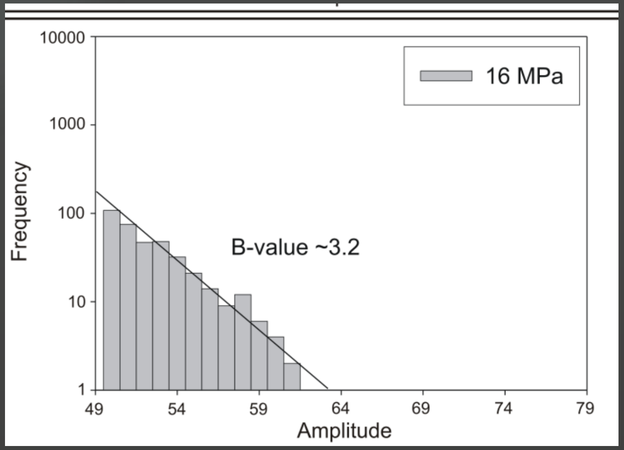
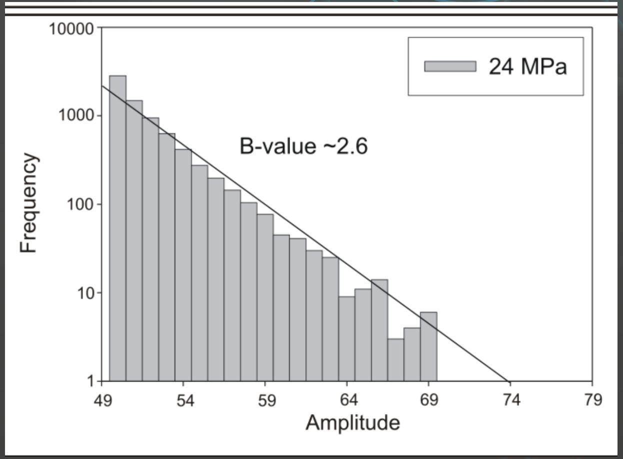
Stress Effects







Seismic b-values decrease → **Localised macroscopic crack growth across ductile-brittle transition**

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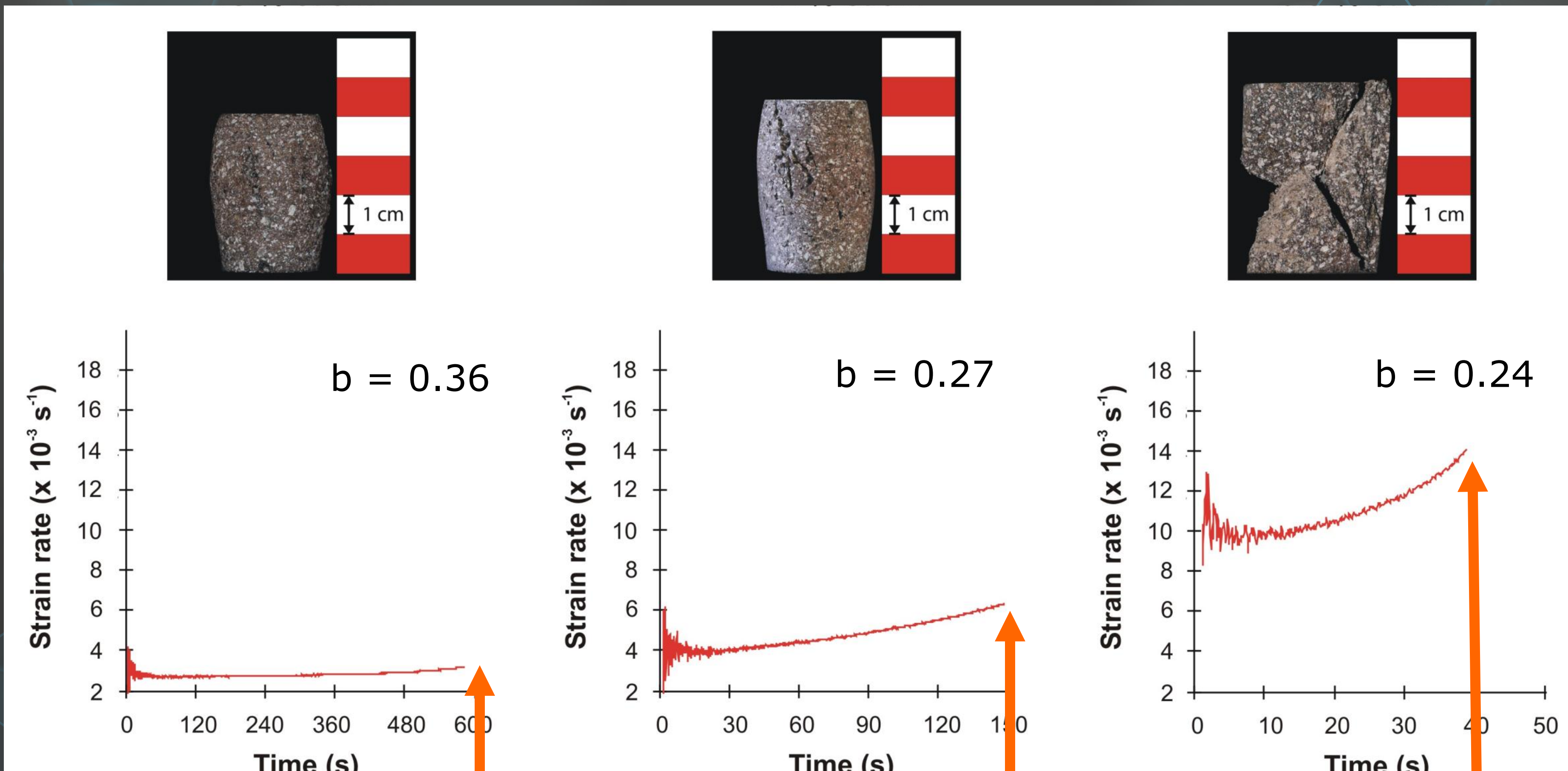
Stress Effects- inc. Stress dec. Strain to failure

28.5 MPa | 46 MPa | 76 MPa



Strain at failure → 20 % | 12 % | 5.5 %

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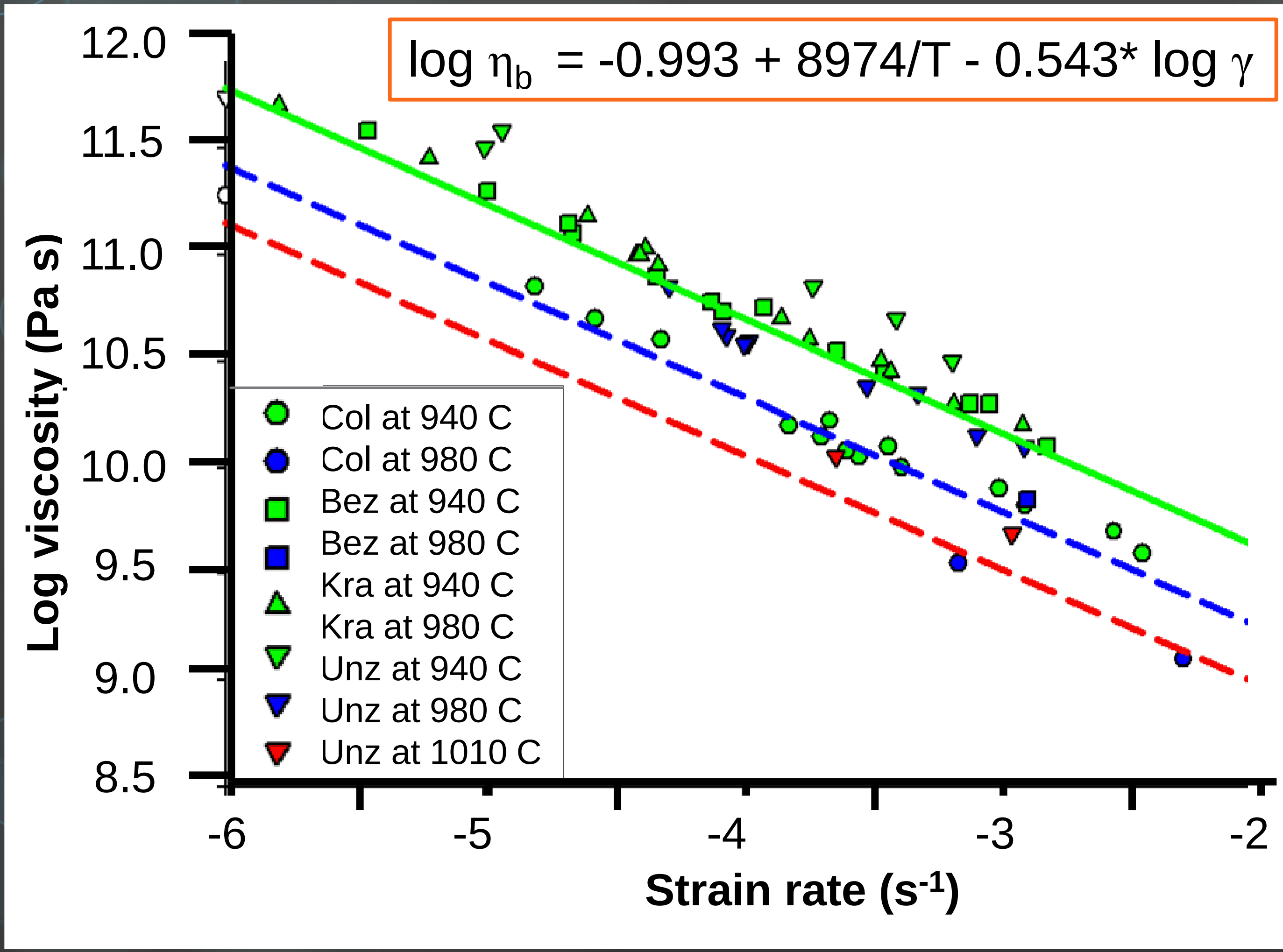
Strain-rate Effects



Law for singular behaviour

Validity:

50-80% crystals

<25% vesicles

Lavallee et al. (2007)

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Measuring deformation

- Porosity
- Ultrasonic velocity waves for dynamic:
  - Young's modulus and
  - Poisson's ratio

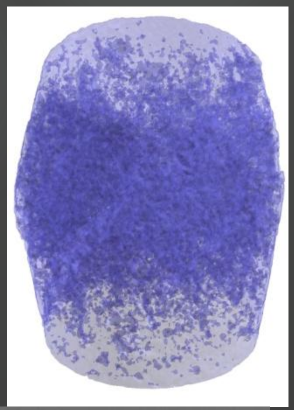
Sample	Porosity (%)				
	Starting	12 MPa		24 MPa	
		20% strain	30% strain	20% strain	30% strain
B2	9.5	10.9	11.9	11.5	14.8
LAH4	27.2	23.8	30.1	29.0	30.0

Sample	Young's Modulus (GPa)				
	Starting	12 MPa		24 MPa	
		20% strain	30% strain	20% strain	30% strain
B2	16.3	19.5	15.7	18.6	15.6
LAH4	6.3	-	-	13.1	9.3

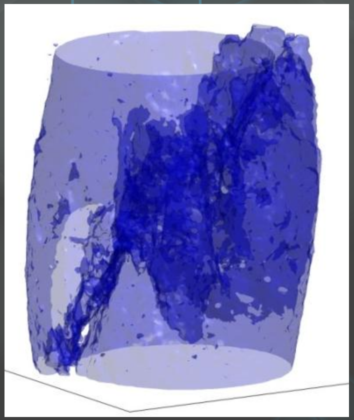
Sample	Poisson's ratio				
	Starting	12 MPa		24 MPa	
		20% strain	30% strain	20% strain	30% strain
B2	0.24	0.10	0.24	0.23	0.26
LAH4	0.34	-	-	0.29	0.35

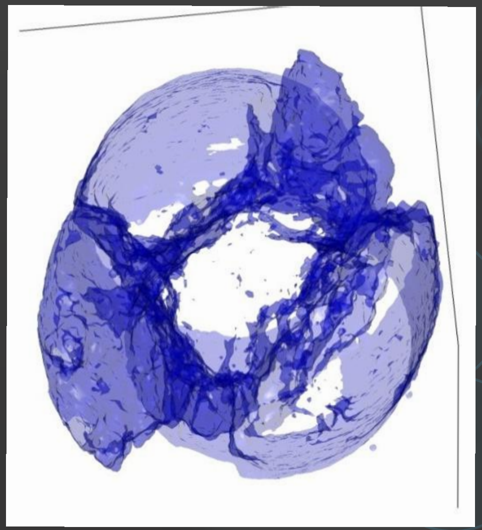
Neutron Computed Tomography

Low-load deformation



High-load deformation





Kendrick@min.uni-muenchen.de

Summary

- Dense magmas are more susceptible to dilation.
- Dilation is initiated at lower strain with higher stresses.
- Higher temperature results in higher strain rates.
- Higher stress results in higher strain rates.
- We observe a strain-dependent decrease in viscosity at constant stress and instantaneous decrease with increasing stress.
- Higher applied stresses form more AE, lower b-values and decrease the total strain required for failure.
- Dynamic elastic properties show a complex evolution of initial strengthening and subsequent weakening of the material with increasing strain.
- Strain has a larger effect on crystallographic alignment.
- Stress has a larger effect on crystal size reduction.

Kendrick@min.uni-muenchen.de

Outcomes

- Chemically similar lava types have different mechanical properties, displaying a significant range of measured strain rates at a given temperature and applied stress.
- Crystallinity increases the range of the ductile-brittle transition and failure of magma becomes dependent upon total strain.
- Dynamic Young's modulus and Poisson's ratio do not change significantly, thus (for magma) do not represent the true characteristics of the samples and should not be used as a proxy to strain (or damage).
- Thus crystallinity has a significant effect on magma rheology with the implication that viscous models may not encompass the full complexity of crystal-bearing magma.

➢ ***We need a better mechanical understanding to improve our models!!***

Kendrick@min.uni-muenchen.de

Reading

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Kendrick@min.uni-muenchen.de