Thermo-rheological feedbacks in silicic lavas and ignimbrites

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Thermo-rheological feedbacks in silicic lavas and ignimbrites

1. Feedbacks between heat flow, rheology and deformation
2. Thermal buffering at low strain rate: dacite lava flows
3. Rapid heating at high strain rate: pyroclastic flows
4. Conclusion: strain heating should be taken into account in thermal modeling of volcanic processes at both high and low strain rates, and both pre- and post-eruption.

Temperature-dependent properties

Magma viscosity

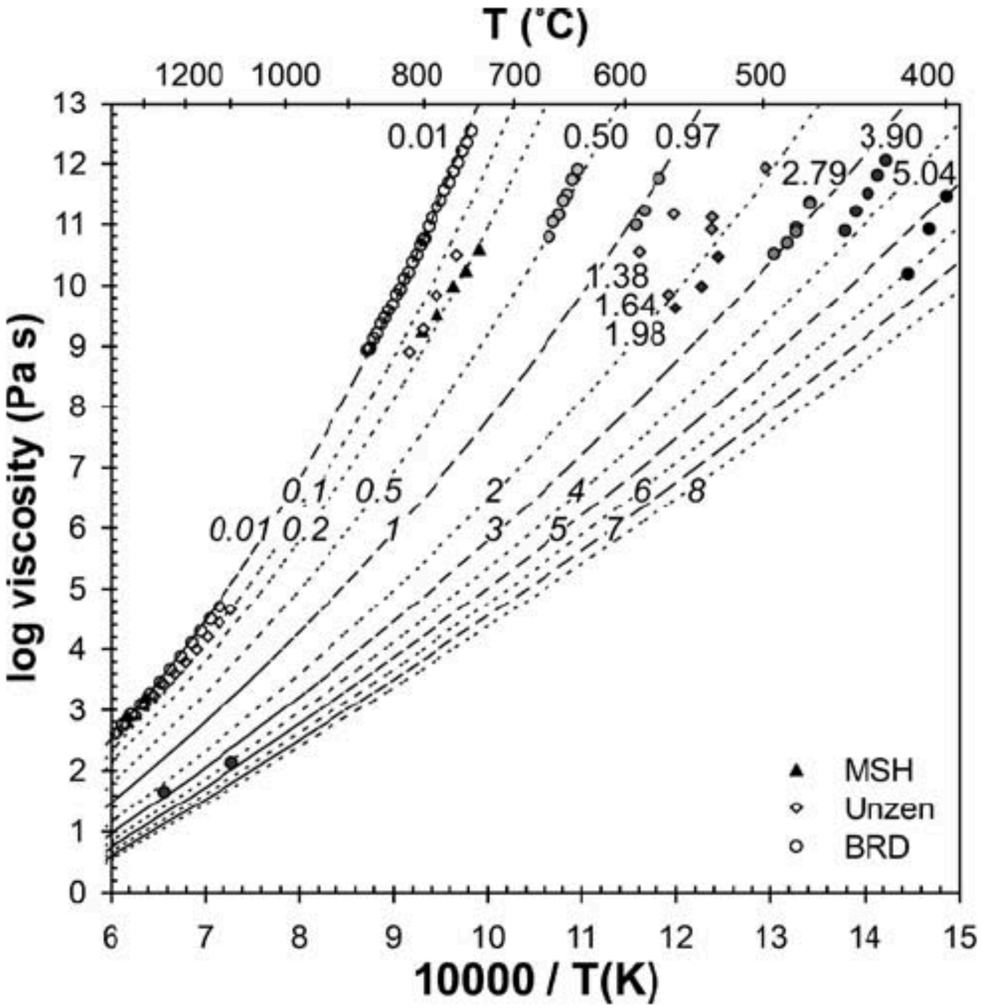
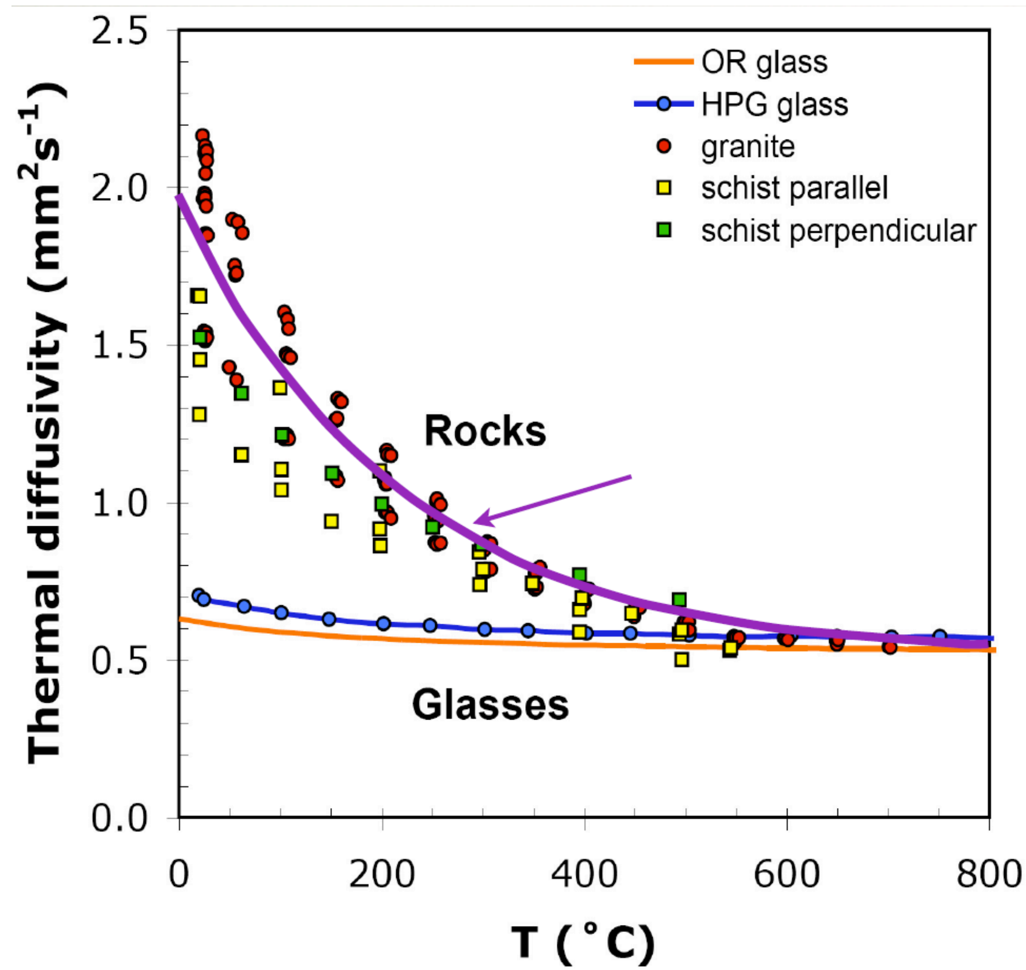


Fig. 4 Viscosity data for hydrous dacites. *Circles* = synthetic dacite (this study); *diamonds* = Unzen dacite (Giordano et al. 2005); triangles = Mt. St. Helens dacite (Alidibirov et al. 1997). Hydrous samples are labeled with water content in weight percent. *Lines* are

Thermal diffusivity of rocks



Whittington et al. (2009) *Bull Volc*

Whittington et al. (2009) *Nature*

Heat generation

Ductile strain heating in rock:

$$H = \tau\dot{\varepsilon}$$

Viscous heating in melt:

$$H = \eta\dot{\varepsilon}^2$$

H is in Wm^{-3}

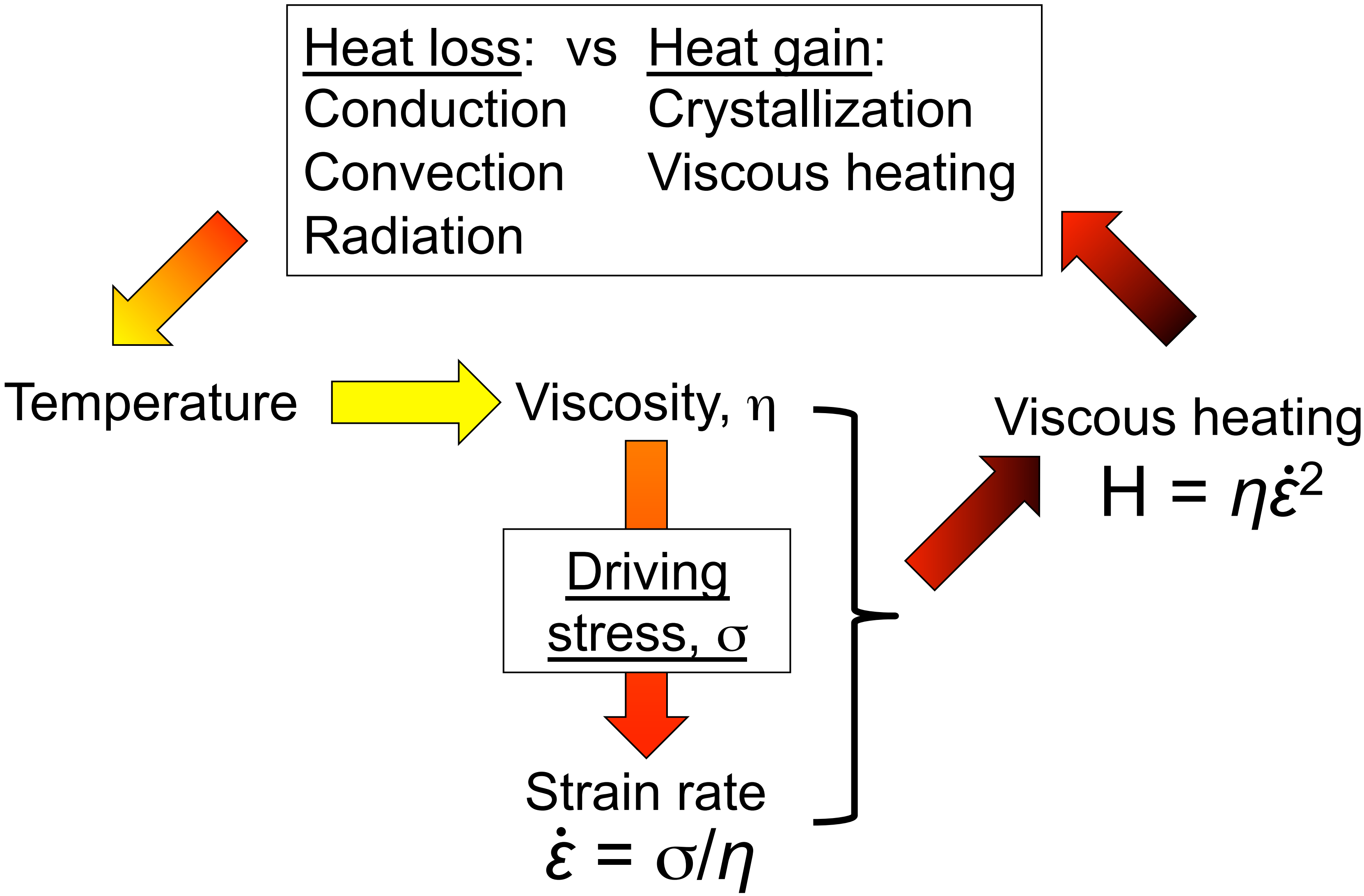
τ = shear strength (Pa)

$\dot{\varepsilon}$ = strain rate (s^{-1})

η = viscosity (Pa s)

Viscous heating requires high strain rate and/or viscosity

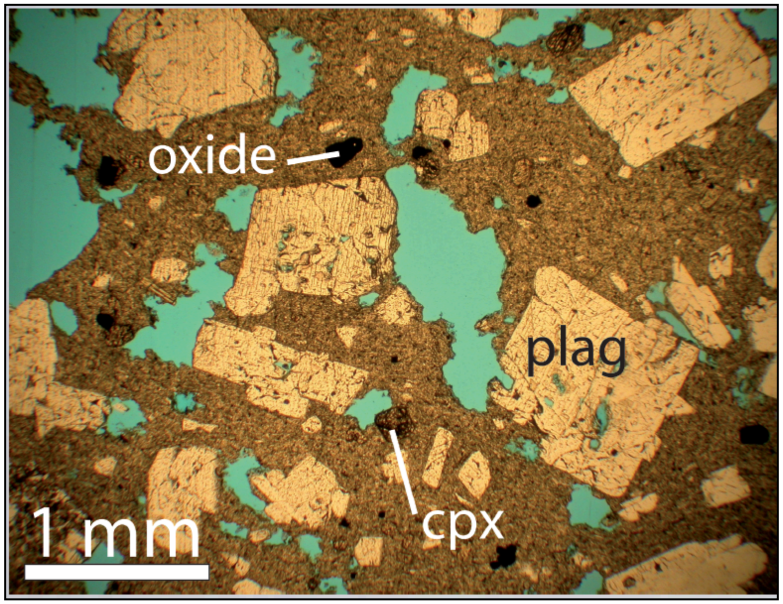
Thermo-rheological feedbacks

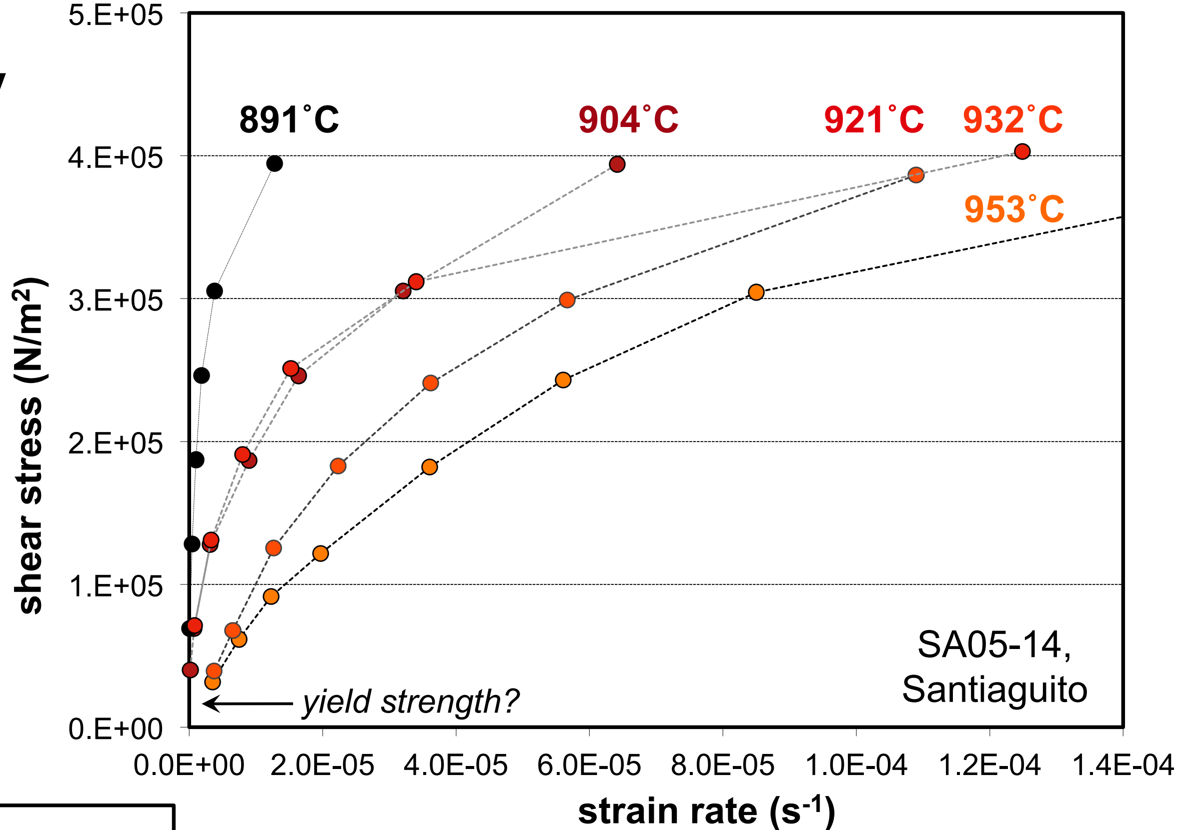


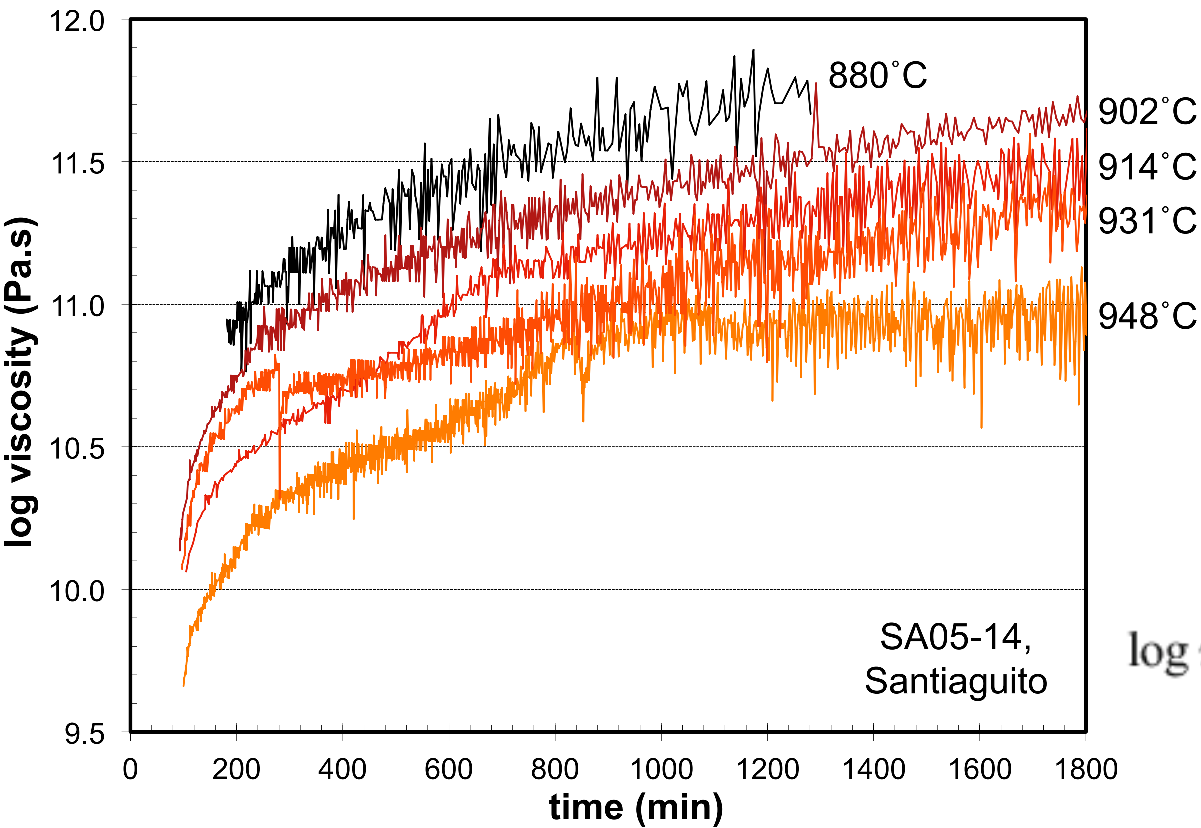
Santiaguito, Guatemala

Dacitic dome and lava flows, 4 km long in 5 years (1999-2004)

Dacite rheology







No detectable yield strength (must be $<10^4$ Pa at 932˚C)

Temperature-dependent power-law behavior

$$\log \eta_{app} = -0.738 + \frac{9.24 \cdot 10^3}{T(K)} - 0.654 \cdot \log \dot{\varepsilon}$$

Avard and Whittington (2012) *Bull Volc*

Dacitic lava flows

Average advance rate 3.7 m/day, max 12.5 m/day (Harris et al. 2003)
Flow 18-30 m thick, core shear zone ~12m thick (Harris et al. 2002)
Strain rate ~0.7 to 2.7 $\times 10^{-5}$ s^{-1} if 12m shear zone or ~8.5 to 29 $\times 10^{-5}$ s^{-1} if 1m thick active at one time.

Core temperature ~850˚C, effective viscosity ~1.4 $\times 10^{10}$ Pa s (expts)

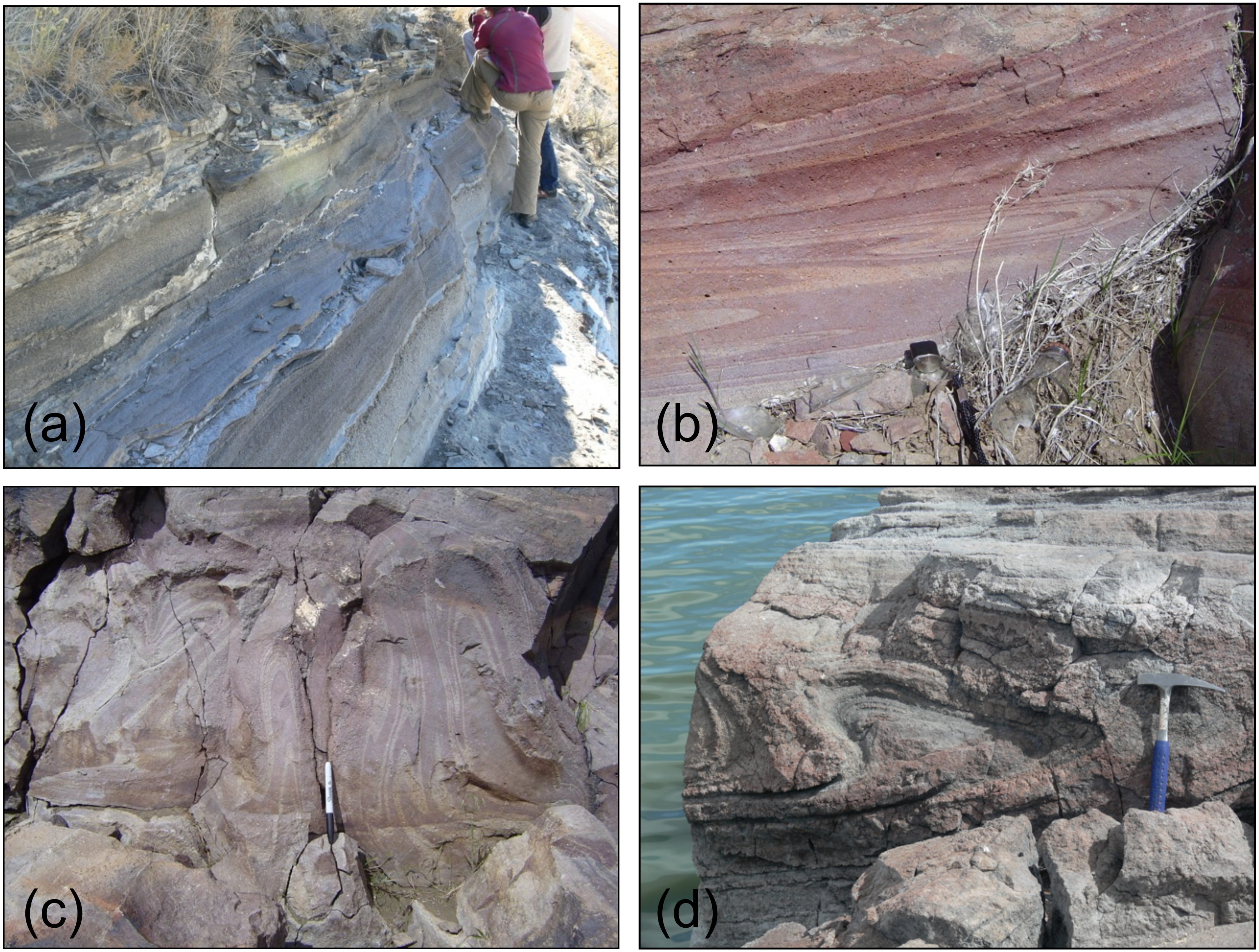
Dacitic lava flows

Strain rate ~8.5 $\times 10^{-5}$ s^{-1} and effective viscosity ~1.4 $\times 10^{10}$ Pa s implies viscous heating **~100 Wm^{-3}** within shear zone

Surface heat flux from cold lava (~40 to 80°C) at Caliente vent is ~410 to ~1,060 Wm^{-2} (Sahetapy-Engel and Harris, 2009).

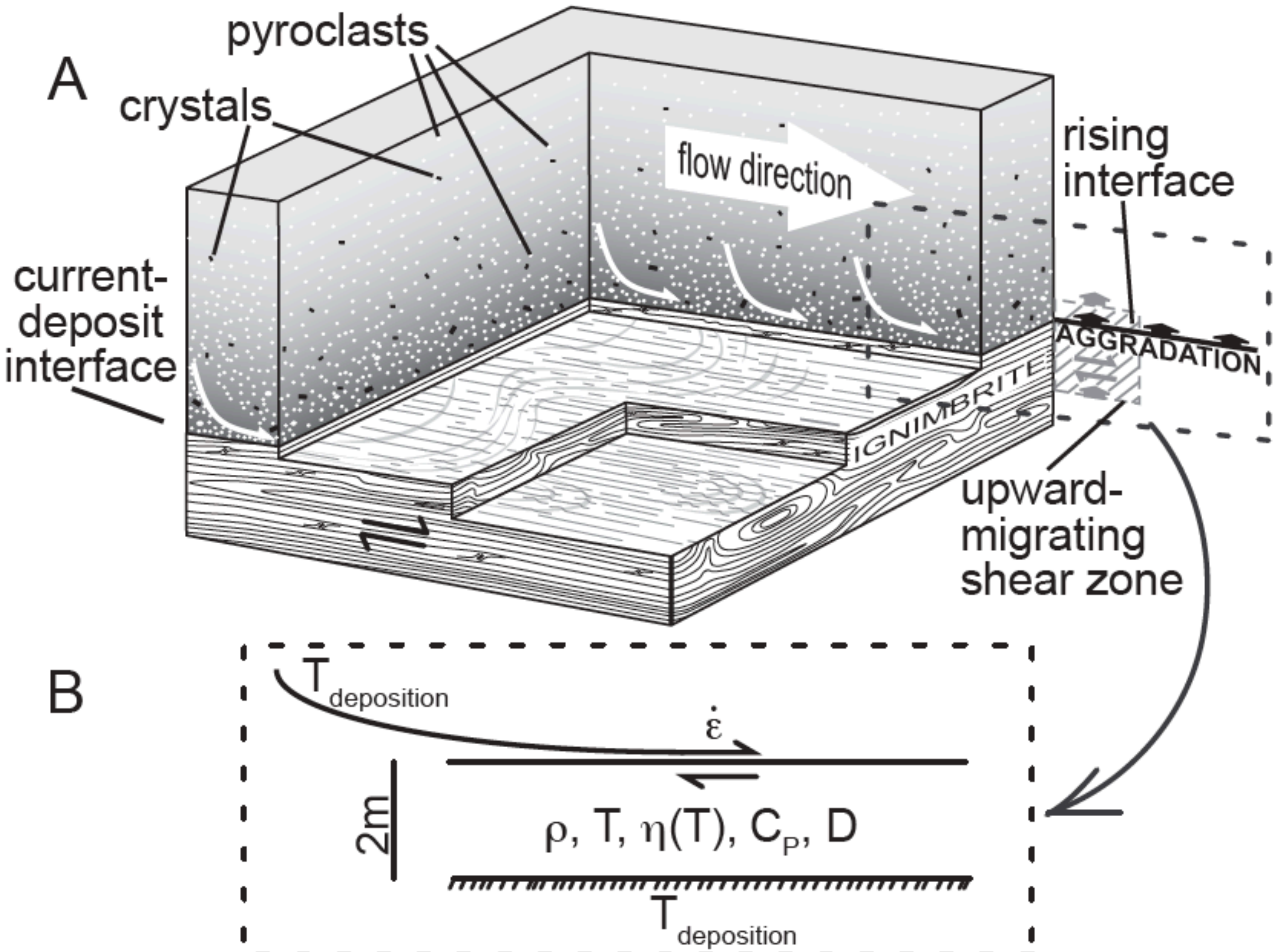
Suggests 10 to 25 % of lava flow thermal budget produced by internal viscous heating, facilitating long-lived, highly viscous "stealth" lava flows.

Greys Landing, Snake River Plain, USA



(a) basal ash fall, (b) isoclinal folds, (c) sheath fold, (d) refolded fold

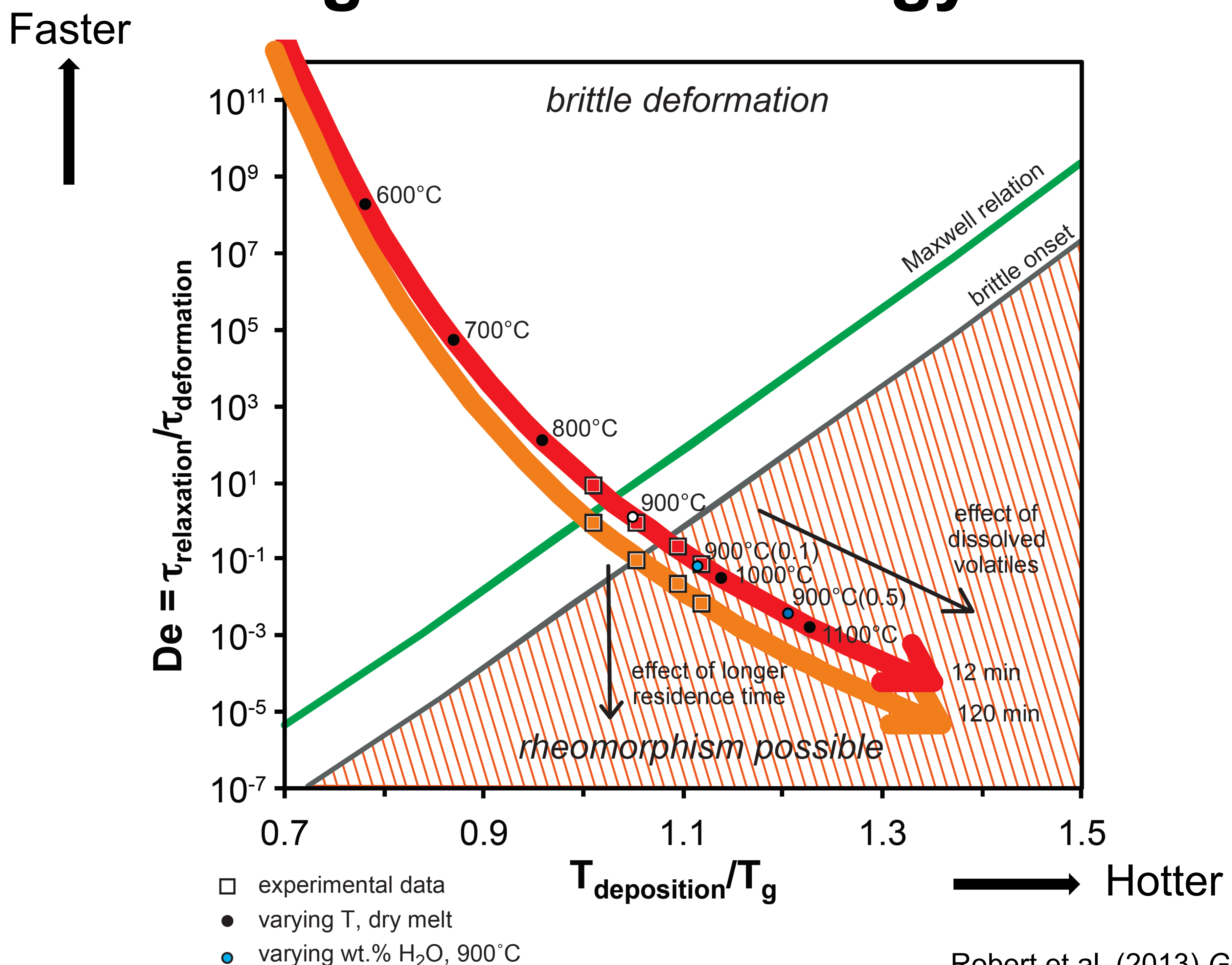
Deposition in aggrading shear zone



Andrews et al. (2008) *GSA Bull*

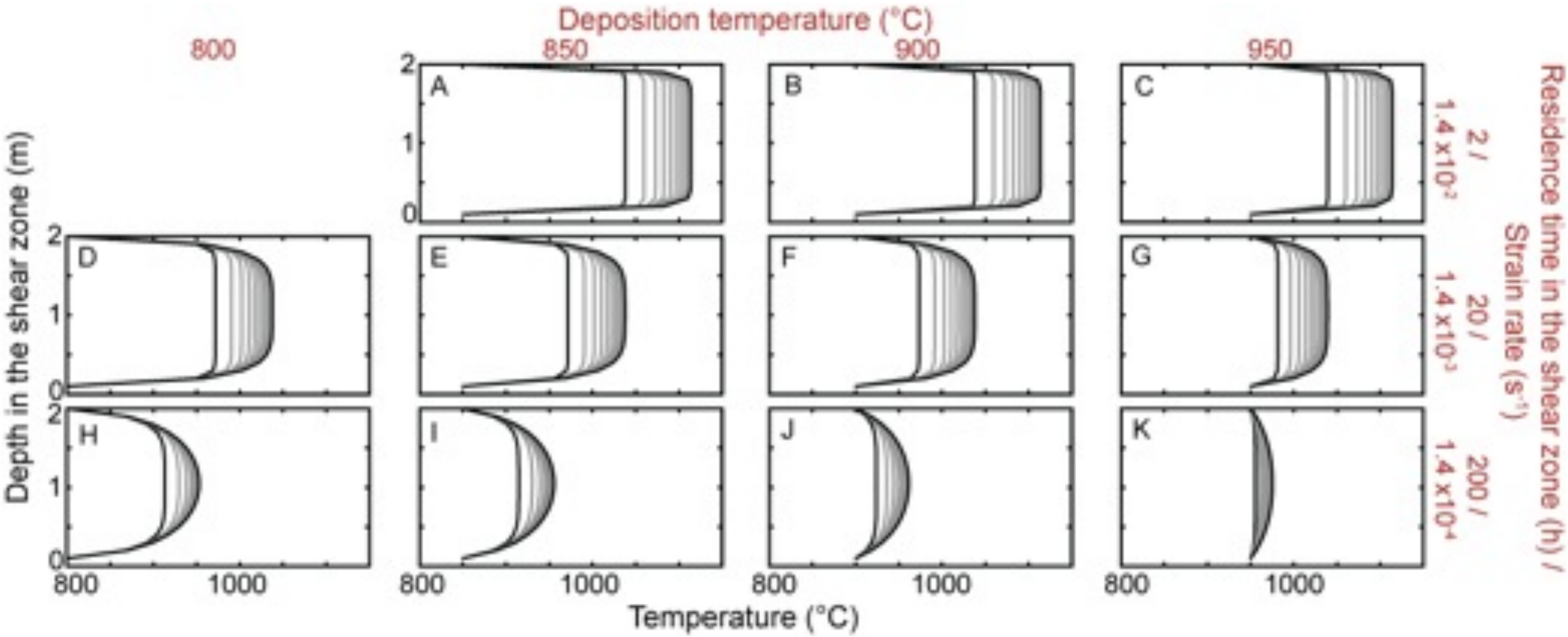
Robert et al. (2013) *Geology*

Ignimbrite rheology



Robert et al. (2013) *Geology*

Viscous heating during deposition



- short-lived but powerful (1MWm^{-3}) strain-heating leads to sustained temperature increase of ~100-250°C
- helps explain enormous extents of lava-like lithofacies
- large pyroclastic flows may travel over a hot substrate

Robert et al. (2013) *Geology*

Conclusions

• Numerous feedbacks exist between heat flow, rheology and deformation, involving strain heating / viscous heating

• Can be important at low strain rates if viscosity is high

e.g. lava flows at Santiaguito ~100Wm^{-3} for ~2 years

(Avard and Whittington 2012 *Bulletin of Volcanology*)

• Heating can be dramatic at high strain rates

e.g. pyroclastic flows, Snake River Plain ~1 MWm^{-3} for 2-20 hours

(Robert et al. 2013 *Geology*)

• Strain heating should be taken into account in thermal modeling of volcanic processes at both high and low strain rates, and both pre- and post-eruption.

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