Temperature Estimation of the Low Slip-rate Layer at Sub-seismic Slip Rates

The temperature at the border of the principal slip zone (without melt) is estimated by the following equation (Nielsen et al., 2008)

$$T = \frac{\tau V \sqrt{t}}{\rho c \sqrt{\kappa \pi}} + T_{\mathrm{i}} \quad , \qquad (1)$$

where τ is shear stress, V is slip rate, ρ is density, c is specific heat capacity, κ is thermal conductivity, t is time and T_{i} is initial ambient temperature (25 ºC). τ in the above equation is a function of t, and here its average value over time t may be used for the rough estimation of T.

The average τ□during transient weakening is estimated as below, because friction shows exponential decay

$$\tau_{avg\_transient} = \tau_{ss} + \frac{(\tau_p - \tau_{ss})}{t_c} \int_0^{t_c} e^{-\frac{Vt}{D_c}} dt = \tau_{ss} + (\tau_p - \tau_{ss})\left(1 - e^{-1}\right) \quad , \qquad (2)$$

where D_{c} is slip weakening distance, t_{c} is time lapsed over D_{c}, τ_{p} is peak friction, and τ_{ss} is steady-state friction. After t_{c}, average τ is τ_{ss}. Thus, the average friction (shear stress) over t ($t > t_{\mathrm{c}}$) is

$$(\tau_{\mathrm{avg\_transient}} \text{ x } t_{\mathrm{c}} + \tau_{\mathrm{ss}} \text{ x } (t - t_{\mathrm{c}}))/t. \qquad (3)$$

In the run HVR1089, where $V = 0.056$ m/s, $D_c = 0.8$ m, $t_c = 14.3$ s, $\tau_p = 1.57$ MPa, and $\tau_{ss} = 0.67$ MPa, the average shear stress over $t = 62$ s is 0.80 MPa.

The following material properties of halite are used for the temperature estimation: ρ = 2170 kg/m^3; c = 873.93 J/kg/K (averaged over T = 25-80 ºC); $\kappa = 2.87 \times 10^{-6}$ m^2/s ($\kappa = K/\rho c$, where K = 5.44 W/m/K at 70 ºC; Clauser and Huenges, 1995). The temperature at t = 62 s estimated using equation (1) is about 87 ºC.

References

Nielsen, S., Di Toro, G., Hirose, T., and Shimamoto, T., 2008, Frictional melt and seismic slip: Journal of Geophysical Research, v. 113, B01308, doi:10.1029/2007JB005122.

Clauser, C., and Huenges, E., 1995, Thermal conductivity of rocks and minerals, *in* Ahrens, T. J., ed., Rock Physics and Phase Relations: A Handbook of Physical Constants: AGU Reference Shelf 3, p. 105-126.

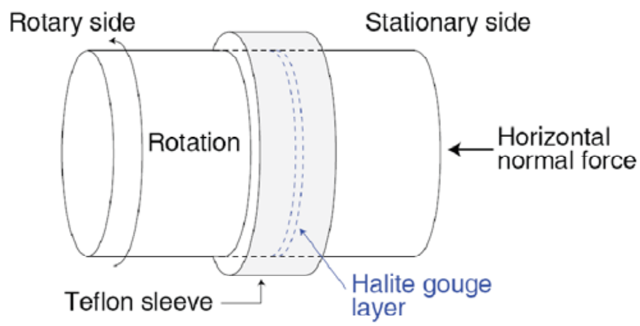

Figure DR1. Specimen assembly. The diameter of the rock cylinder is 24.85 mm.

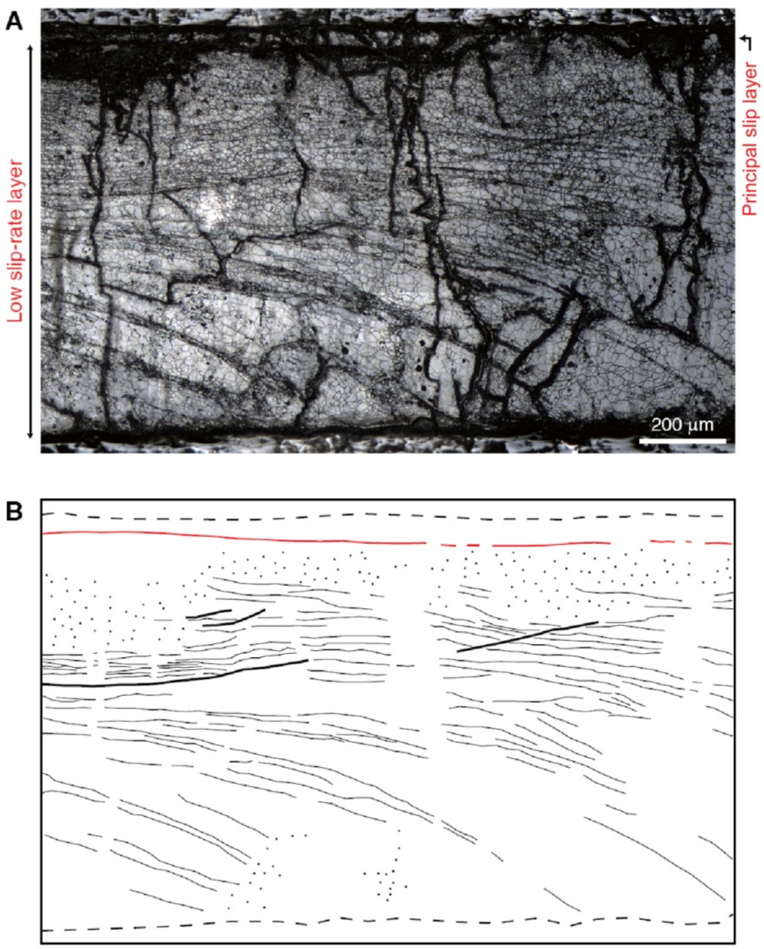

Figure DR2. (A) Photomicrograph of the simulated fault zone of halite deformed at a slip rate of 1.3 ms^{-1} and normal stress of 1.3 MPa (HVR1095, total slip = 23 m). Reflected plane-polarized light. (B) Line-drawing sketch of (A). Solid line: foliation (halite ribbon) trace. Heavy solid line: secondary shear fractures. Dotted area: Area with no grain-shape foliation. Broken line: fault zone boundary. Red line: boundary between low slip-rate and principal slip layers.

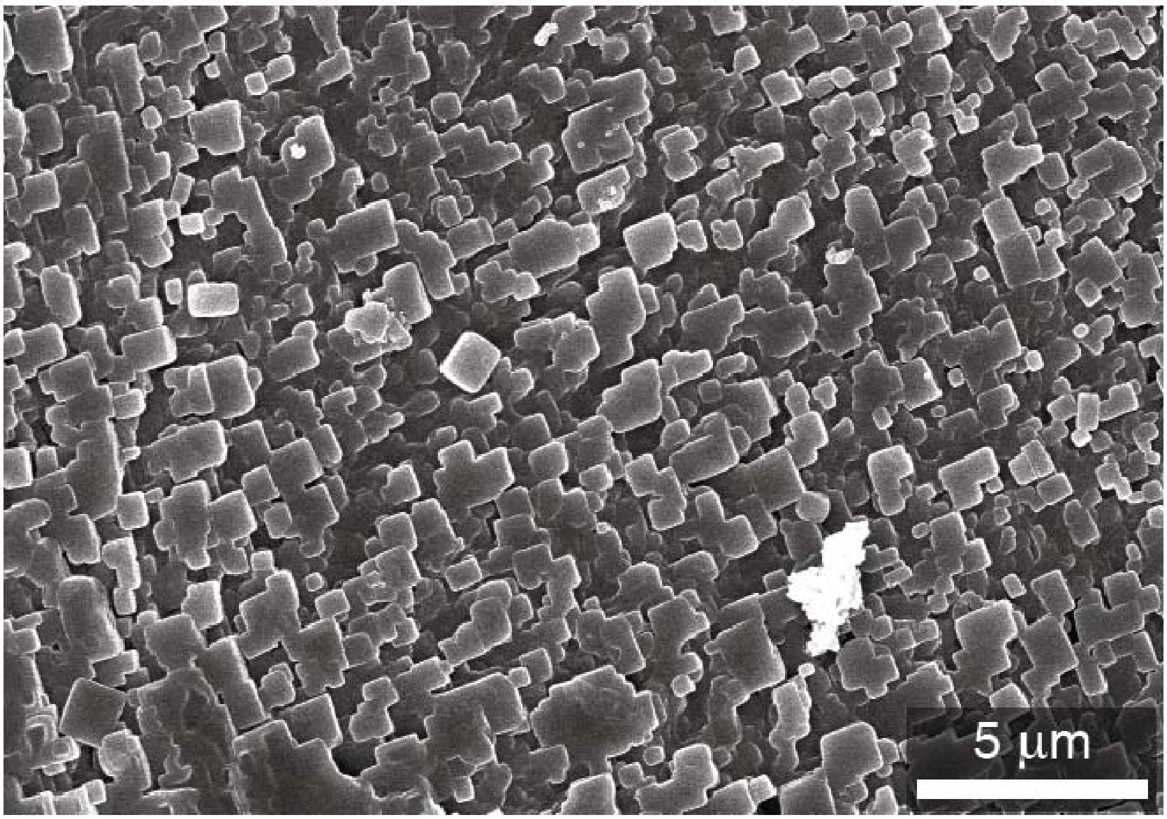

Figure DR3. SEM image of halite crystals grown from static melt.

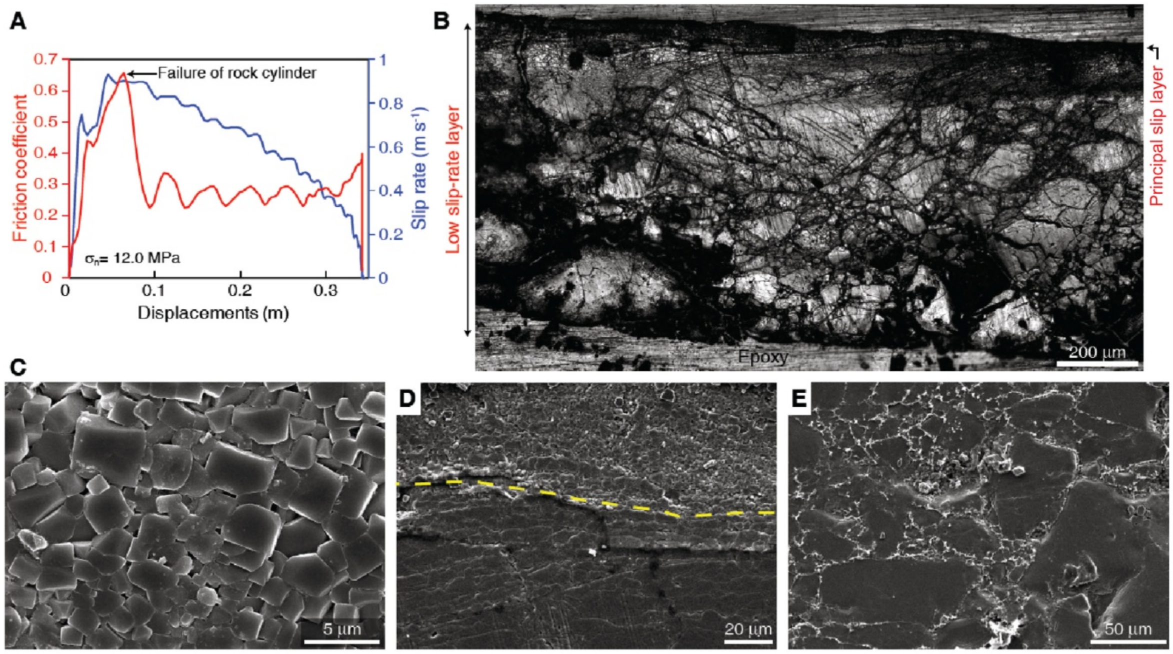

Figure DR4. Mechanical data and microstructures of the specimen HVR994F deformed at a seismic slip rate of about 1 m s^{-1} and a normal stress of 12.0 MPa. (A) Friction coefficient (red) and slip rate (blue) versus displacement. (B) Reflected-light photomicrograph of the fault zone. (C) SEM image of the principal slip layer. (D) SEM image of ductile shear zone (below the yellow broken line) in low-slip rate layer. The yellow broken line represents the boundary between the principal slip layer and low slip-rate layer. (E) SEM image of cataclastic shear zone in low-slip rate layer.

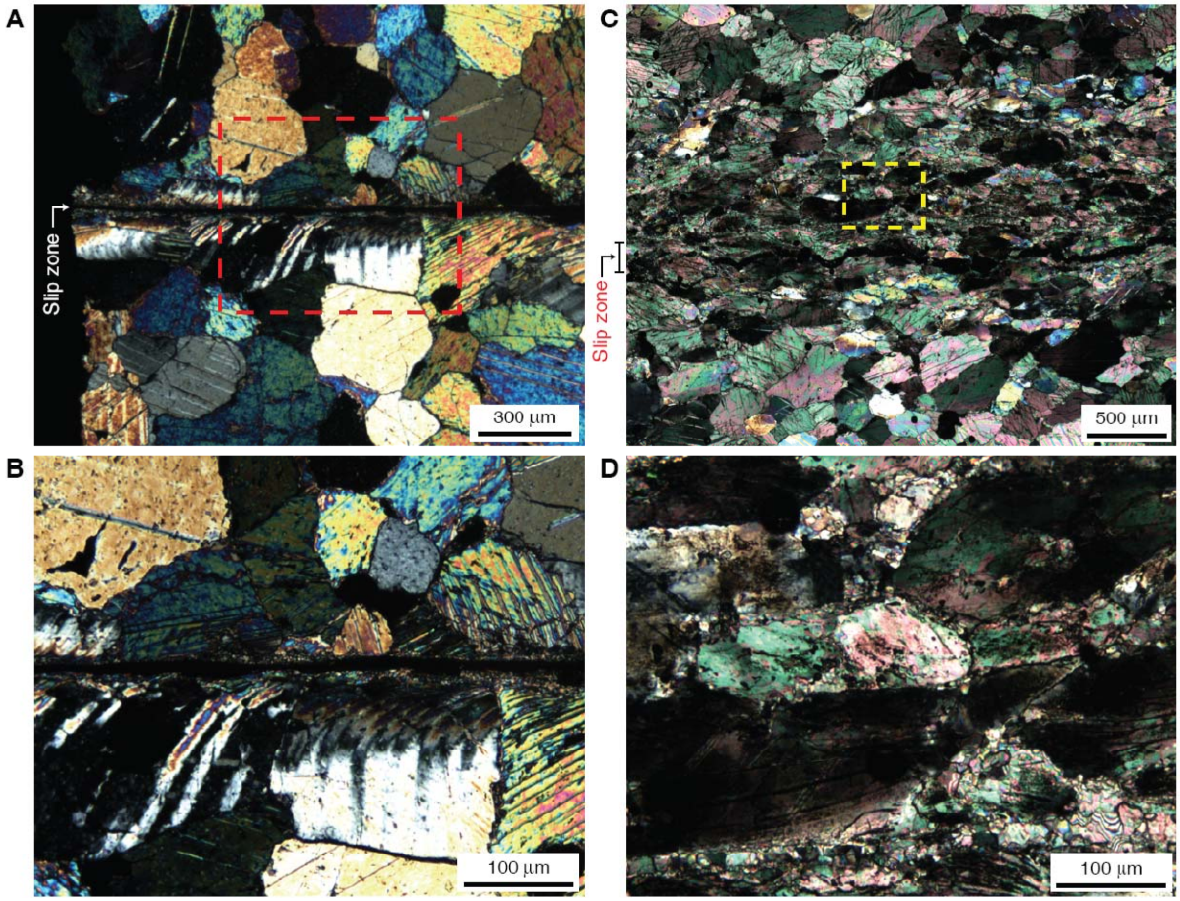

Figure DR5. Cross-polarized photomicrographs of Carrara marble (A) Specimen HVR450 deformed at a seismic slip rate of about 1.18 m s^{-1} and a normal stress of 12.2 MPa with a total displacement of 2.03 m. Mechanical twining is widespread in calcite grains of the wall rocks adjacent to the slip zone and the mechanical twins sharply bend into the slip zone boundary. (B) Enlarged view of the red box in (A). Lobate to serrated boundaries of some twins indicate twin boundary migration and thus dynamic recrystallization. (C) Specimen HVR448 deformed at a seismic slip rate of about 1.18 m s^{-1} and a normal stress of 12.2 MPa with a total displacement of 54.80 m. (D) Enlarged view of the yellow box in (C). Some calcite grains of the wall rock adjacent to the slip zone are highly elongated with undulose extinction and mechanical twins.

Table DR1. Mechanical data of halite friction experiments.

Run No.	σ_n (MPa)	V (ms^{-1})	μ_p	Average μ_{ss}	Total Displace-ments (m)	D_c (m)	Slip duration (s)
HVR980	6.0	1.3	0.643	0.035	20.7	6.5	16.81
HVR982	6.0	0.78	0.933	0.055	29.3	7.8	38.31
HVR983	6.0	0.27	0.973	0.237	18.7	3.5	70.03
HVR984	6.0	0.093	0.764	0.356	5.6	-	66.18
HVR985	2.0	0.045	0.849	0.372	5.5	3.5	121.40
HVR986	2.0	0.022	0.762	0.354	2.1	0.3	91.31
HVR987	6.0	0.61 0.17	0.701 -	0.050 0.197	38 13.7	-	151.12
HVR989	2.0	1.3	0.898	0.089	58.9	23.9	47.33
HVR990	0.8	1.3	0.987	0.103	70.6	40.6	58.80
HVR991	4.0	1.3	0.799	0.027	60.9	13.9	48.40
HVR992	4.0	1.3	0.727	0.077	69.6	19.0	55.14
HVR993	10.0	1.3	0.582	0.062	70.8	5.0	55.63
HVR994	8.0	1.3	0.626	0.049	78.8	9.0	61.59
HVR995	7.0	1.3	0.672	0.043	54.4	8.3	42.83
HVR996	9.0	1.3	0.617	0.064	32.3	6.1	25.37
HVR1088	6.0	1.3	0.670	-	22.3	-	18.41
HVR1089	2.1	0.056	0.748	0.320	3.5	0.8	62.07
HVR1090	5.0	1.3	0.725	0.082	43.0	10.4	34.30
HVR1091	1.0	1.3	0.854	0.178	30.5	23.6	26.91
HVR1092	6.0	1.3	0.610	-	14.7	-	16.22
HVR1093	6.0	0.18	0.681	0.292	11.3	-	62.42
HVR1094	1.0	1.3	0.826	0.171	60.1	21.2	49.73
HVR1095	10.0	1.3	0.739	0.067	23.0	5.5	18.50
HVR1108	5.0	1.3	0.796	-	14.2	-	15.64
HVR991F*	10.0	0.93(1.3)	0.739	-	0.41	-	0.85
HVR994F*	12.0	0.93(1.3)	0.658	-	0.34	-	0.70

Note: σ_n : normal stress, V : slip rate, μ_p : peak frictional coefficient, μ_{ss} : steady-state friction coefficient, D_c : Slip-weakening distance. *Failed experiments due to high normal stress.