Supplemental Material for:

Tectonic pressure gradients during viscous creep drive fluid flow and brittle failure at the base of the seismogenic zone

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Content of this file:

Text S1 and S2

Figures S1 to S4

Table S1

Text S1: Analytical methods

Petrography and microstructures were investigated on polished thin sections cut perpendicular to the mylonitic foliation and parallel to the stretching lineation, and perpendicular to the vein walls and parallel to the inferred opening vector of the veins. The same polished thin sections were used for EBSD analysis of quartz and for mineral chemistry analysis of chlorite.

Major element mineral chemistry of chlorite was measured with a JEOL 8200 Super Probe equipped with five wavelength-dispersive spectrometer (WDS) at the Department of Earth Sciences, University of Milan, Italy. Working conditions were 15 kV probe current, 5 nA current on sample, and 1 μm beam diameter. Natural minerals were used for standardization, measurement times were 30 s on peaks and 10 s on backgrounds of the X-ray lines.

Electron backscatter diffraction (EBSD) analyses were performed at the Electron Microscopy Centre of the University of Plymouth using a JEOL LV6610 SEM and a JEOL 7001 FEG-SEM. Thin sections used for EBSD were polished with colloidal silica and carbon coated. Data were acquired on a NordlysNano and a NordlysMax EBSD detector (Oxford Instruments). Working conditions during acquisition of the EBSD patterns were 20 kV, 20 mm working distance, 70° sample tilt and high vacuum. AZtec software was used for pattern indexing on rectangular grids with a step size of 2 μm . EBSD patterns were processed with the Channel 5 software (Oxford Instruments).

Text S2: Derivation of the Mohr-Coulomb failure diagram presented in Figure 3

The pore fluid factor (λ_v) vs differential stress ($\sigma_1 - \sigma_3$) failure diagram in Figure 3 was calculated with the same approach outlined in Cox (2010), using the following assumptions and parameters:

1. The coefficient of internal friction, μ , in intact rock is typically in the range $0.5 < \mu < 1.0$ (Jaeger and Cook, 1979); we used $\mu = 0.75$ for the metaconglomerate. For the frictionally weak chlorite-rich schists, we used a friction coefficient μ of 0.3-0.5, consistent with recent experimental results (Okamoto et al., 2019).
2. We assumed an Andersonian stress field, a thrusting regime, and a fault making an angle of θ_{opt} with the maximum compressive stress σ_1 . The angle θ_{opt} corresponds to $0.5 \tan^{-1} (1/\mu)$.

3. In the thrusting regime, the vertical stress σ_v corresponds to the minimum compressive stress σ_3 . In our calculation, σ_v was set at 350 MPa from available geobarometric estimates (Bergh and Andresen, 1985).
4. We used a cohesive strength C of 20 MPa for the metaconglomerate, which results in a tensile strength T of 10 MPa. These values are within the range typical of medium- to fine-grained quartz-rich metasedimentary rocks (Sivakugan et al., 2014). For the chlorite-rich schists, we used a lower cohesive strength C of 5 MPa, which results in a tensile strength of 2.5 MPa (value taken from Zhang et al., 2011).

The failure envelopes for extension failure, hybrid extensional failure, and shear failure were calculated with the following equations, respectively:

$$\lambda_v = \frac{\sigma_3 + T}{\sigma_v} \quad (1),$$

$$(\sigma_1 - \sigma_3) = \frac{2C}{\sin 2\theta_{opt}} \quad (2),$$

$$\lambda_v = \frac{[4C - \sigma_1 + 4\sigma_3]}{3\sigma_v} \quad (3).$$

We assumed that extension failure (equation 1) occurs only for stress conditions in which $(\sigma_1 - \sigma_3) < 4T$, and that hybrid extensional failure (equation 2) only for $(\sigma_1 - \sigma_3) \leq 2.5C$ for $\mu = 0.75$ (Cox, 2010).

Figure S1. Field photograph showing an example of ESE-vergent folds in the Hølen Conglomerate.

Figure S2. A. Example of crosscutting relationships between veins that experienced different degrees of rotation with the sense of shear, consistent with a cyclical generation of veins during mylonitic creep. Arrows indicate veins that experienced relatively large rotations (up to 75°). White rectangles indicate areas where these veins are cut by younger veins that experienced less rotation with the sense of shear. B. Histogram of vein tip orientation, and annotated sketches of the kinematic framework of the shear zone.

Figure S3. Photomicrographs of quartz microstructure in the sigmoidal veins (A, B) and of chlorite microstructure from sites analysed with the electron microprobe (C, D). Note arrays of blocky and elongated subgrains in A and B. White arrows in A and B indicate the vein opening direction. (C) SC' fabric in the mylonitic schists. The dextral sense of shear corresponds to the top-to-ESE sense of shear observed in the field. (D) Syn-kinematic quartz + chlorite + carbonate vein. A, B, D: cross-polarized light.

Figure S4. Additional EBSD map used for the GOS and grain size analysis of quartz. The map is color coded according to the GOS value of quartz, as indicated in the color bar. The GOS threshold to separate between relict and recrystallized quartz grains is 1.4° . Boundaries are color coded like in figure 2D.

Sample	291C	291C	291C	291C	291C	291C	291D	291D	291F
lithology	schist	schist	schist	schist	schist	schist	vein	vein	vein
#analysis	LM2-chl1	LM2-chl-2	LM2-chl-3	LM2-chl-4	LM2-chl-5	LM2-chl-6	LM3-chl-3	LM3-chl-19	LM3-chl-14
SiO ₂	27,520	27,480	27,350	27,500	27,570	27,560	26,990	26,750	26,100
TiO ₂	0,000	0,087	0,046	0,049	0,031	0,024	0,006	0,075	0,030
Al ₂ O ₃	23,380	23,750	23,380	23,510	23,130	23,680	23,970	23,530	23,440
FeO	14,650	14,510	14,520	13,970	14,820	14,010	18,610	18,860	18,320
Cr ₂ O ₃	0,100	0,065	0,116	0,050	0,081	0,074	0,116	0,129	0,000
MnO	0,000	0,108	0,056	0,039	0,055	0,063	0,194	0,136	0,109
MgO	22,170	22,420	21,880	22,640	21,690	22,360	17,900	19,330	19,040
NiO	0,236	0,147	0,120	0,165	0,148	0,133	0,070	0,092	0,078
CaO	0,033	0,031	0,052	0,050	0,052	0,133	0,055	0,030	0,053
Na ₂ O	0,086	0,009	0,039	0,055	0,058	0,078	0,200	0,000	0,024
K ₂ O	0,032	0,032	0,048	0,063	0,033	0,027	0,045	0,008	0,002
total	88,207	88,639	87,605	88,090	87,669	88,142	88,157	88,939	87,194
structural formula based on 14 oxygen equivalent = 10 oxygen and 8 (OH,F,Cl)									
Si	2,711	2,691	2,710	2,703	2,734	2,707	2,713	2,672	2,655
B	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
[4]Al	1,289	1,309	1,290	1,297	1,266	1,293	1,287	1,328	1,345
[6]Al	1,425	1,431	1,441	1,426	1,436	1,448	1,554	1,441	1,465
[6]Ti	0,000	0,006	0,003	0,004	0,002	0,002	0,000	0,006	0,002
Fe ²⁺	1,207	1,188	1,203	1,148	1,229	1,151	1,565	1,575	1,559
Cr	0,008	0,005	0,009	0,004	0,006	0,006	0,009	0,010	0,000
Mn	0,000	0,009	0,005	0,003	0,005	0,005	0,017	0,012	0,009
Ni	0,019	0,012	0,010	0,013	0,012	0,011	0,006	0,007	0,006
Mg	3,256	3,273	3,233	3,317	3,206	3,274	2,683	2,878	2,887
Ca	0,003	0,003	0,005	0,005	0,005	0,014	0,006	0,003	0,006
Na	0,016	0,002	0,007	0,011	0,011	0,015	0,039	0,000	0,005
K	0,004	0,004	0,006	0,008	0,004	0,003	0,006	0,001	0,000
sum X	5,938	5,933	5,923	5,939	5,917	5,927	5,884	5,933	5,940
O	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
OH	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000
Calculated T (°C)	389	375	355	388	335	361	313	386	400

Table S1. Representative analyses of chlorite composition from the schists and from the veins, used for temperature estimates using the thermometer of Lanari et al. (2014) assuming a pressure of 350 MPa. The temperature increases by 10° C every 50 MPa increment in the pressure. The thermometer of Lanari (2014) requires the following conditions: $Si < 3$ a.p.f.u., $Na + K + Ca < 0.1$ a.p.f.u., and $[(Al^{VI} - Al^{IV} - Na - K) / 2] > 0.05$.

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