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Partitioning between surface energy and heat during an earthquake

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Abstract

The determination of earthquake's energy budget remains a challenging problem in the Earth science community. Following previous field-based studies (Ref.1-2) we propose that exhumed faults might provide an estimate of the energy budget.
During an earthquake the mechanical work per unit fault surface could be partitioned into heat Q and surface energy U_s (energy required to create new surfaces in the slipping zone and wall rock), in the case of a strike-slip fault (Ref.3). We determined Q (Fig.2) and U_s (Fig.3) from field and microstructural analyses of a fault segment exhumed from a depth of ca. 10 km – typical for earthquake hypocenters in the continental crust- (Fig.3), in the Gole Larghe fault zone, Adamello, Italy (Fig.1). Ancient seismicity is revealed by the presence of pseudotachylytes (solidified clast-laden friction-induced melts produced during seismic slip).

For the selected fault segment we found that frictional heat is by far the largest energy component dissipated during an earthquake (Fig. 5).

Fig.1 - Geological Setting

The Gole Larghe strike-slip fault (GLF, red line) cuts the Adamello tonalitic batholith (in gray).

Seismic faulting occurred at 250<T<300°C and 250<P<300 MPa (Ref. 4).

The studied fault segment is located at the base of glacier (yellow star) and records one seismic rupture, as attested by field and microstructural evidence (see Di Toro et al., S33A 0220).

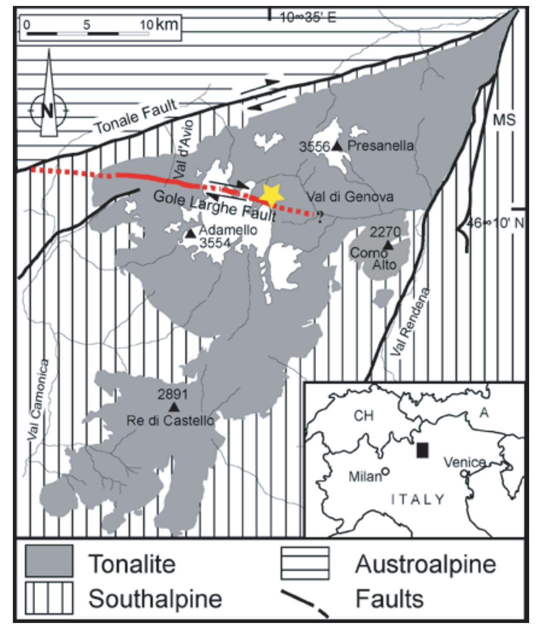


Fig.2 - Estimate of E_H

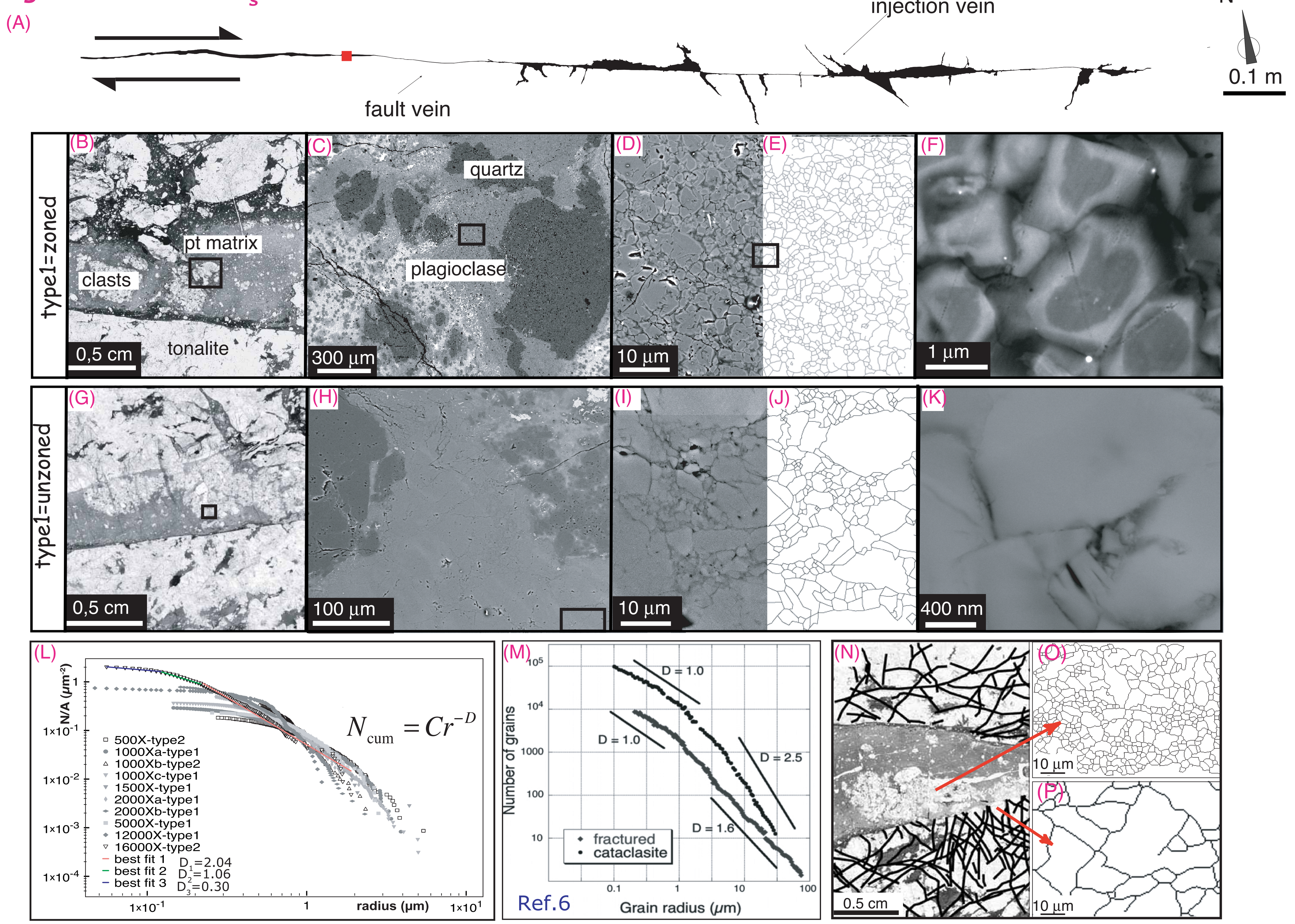
From Ref. 5:

$$E_H = [(1-\phi)\, H + c_p\, (T_m - T_{hr})]\, \rho\, t$$

where ϕ =ratio clasts/pt matrix (0.2), H =latent heat of fusion (3.28 10^5 J kg^{-1}), c_p =the specific heat (1180 J kg^{-1} K^{-1}), T_m = initial melt temperature (1723 K) T_{hr} = host rock temperature (523 K), ρ =rock density (2700 kg m^{-3}) and t = average pseudotachylyte thickness. For the 5.9 10^{-3} m thick fault shown in Fig.3:

$$E_H \approx 27 \text{ MJ m}^{-2}$$

Fig.3 - Estimate of U_s



Plagioclase clasts (B-C; G-H) within pseudotachylytes (A) display an internal fragmentation (D; I) that is absent in the host rock (O-P for comparison). We assumed that fragmentation was (1) produced during EQ rupture propagation, and (2) locally preserved from melting. We determined the fragments size distribution (FSD) within clasts by computer-aided image analysis on SEM and FE-SEM images (E; J). The FSD we obtained (L) is similar to the FSD produced in fracture experiments conducted in tonalite in the absence of melting (M; Ref.6). The change in slope at *r* ca. 2 mm is probably due to the grinding limit (Fig.4). Zoning of fragments (D; F) suggests that other processes may influence the FSD.

We (over-)estimated the total surface S of the fragments in the slipping zone by (1) considering the fragments as spherica, (2) integrating the FSD curve, and (3) assuming the FSD fractal up to the minimum (theoretical and measured) fragment radius of 20 nm (Fig.4). By multiplying S for the specific surface energy of the plagioclase (10 J/m², Ref.7), the maximum surface energy is:

$$U_s \le 1.1 \text{ MJ/m}^2.$$

S in the host rock (N) is neglible compared to the S of the fragments in the slipping zone (compare O with P).

Fig. 4 - Grinding limit

The grinding limit d_{crit} (Ref.8) is the minimum size for which the fragmentation is energetically efficient. From Ref.9:

$$d_{crit} = \frac{32ER}{3Y^2}$$

E= Young's modulus (90 GPa)
R= specific surface energy (10 J m^{-2})
Y= yield strength (2.17 GPa)

d_{crit} for plagioclase is ca. 2 µm (see change in slope in the FSD curve, Fig. 3L-M).

According to the Griffith failure criterion (Ref.10), the smallest length *a* for a crack is:

$$a \approx 2.5\ 10^5 r \qquad r = \text{crack's bending radius}$$

For r = 0.71 nm (minimum lattice length for plagioclase), *a* is ca. 20 nm, which is close to the size of the smallest fragment observed (Fig. 3K).

Fig.5 - Conclusions

In the studied pseudotachylyte-bearing fault segment, exhumed from a depth of 10 km, the estimated Q is 27 MJ m^{-2}, while U_s is at most 1.1 MJ m^{-2}. The ratio between U_s and Q is about 0.041, similar to that obtained in industrial milling and grinding processes (Ref.11).

It follows that most of the seismic energy was dissipated as heat.

Fig.6 - References

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