High coseismic differential stress preserved in the lattice of seismically shocked garnets

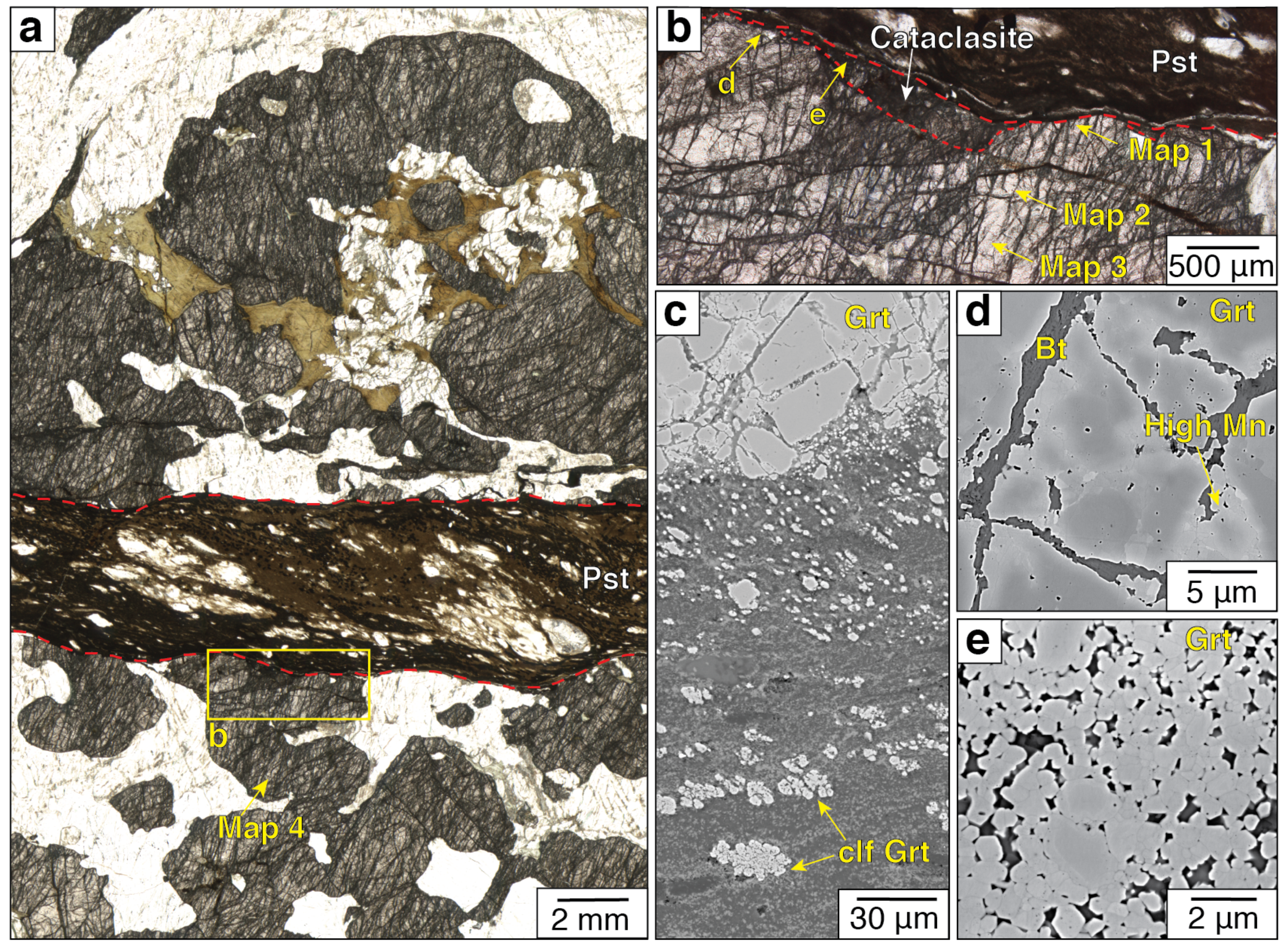
Toffol, G.[1], Pennacchioni, G.[1], Menegon, L.[2], Wallis, D.[3], Faccenda, M.[1], Camacho, A.[4], Bestmann, M.[5]

1: Department of Geosciences, University of Padova, Padova, ITALY; 2: Department of Geosciences, University of Oslo, Oslo, NORWAY;
3: Department of Earth Sciences, University of Cambridge, Cambridge, UK; 4: Department of Earth Sciences, University of Manitoba, Winnipeg, CANADA;
5: Department of Geology, University of Vienna, Vienna, AUSTRIA

1. INTRODUCTION:

Exhumed faults bearing pseudotachylytes (coseismic quenched frictional melts, pst) can record the series of high-stress events consuming energy on fault during an earthquake.
Microstructural studies of pst and host rock can provide information on how this energy is partitioned.

We studied seismically-shocked garnets and measured the lattice damage (residual elastic strains and GND) imparted by seismic rupture propagation with HR-EBSD[1]. Results are used to quantify the energy consumed by crystal-plastic straining (**W_{CP}**) of the minerals lattice during an earthquake. **W_{CP}** is compared to fracture enrgy (**W_{FS}**) and heat (**W_{FH}**) to provide a complete budget of the energy consumed on fault (**W_{FZ}**)[2].

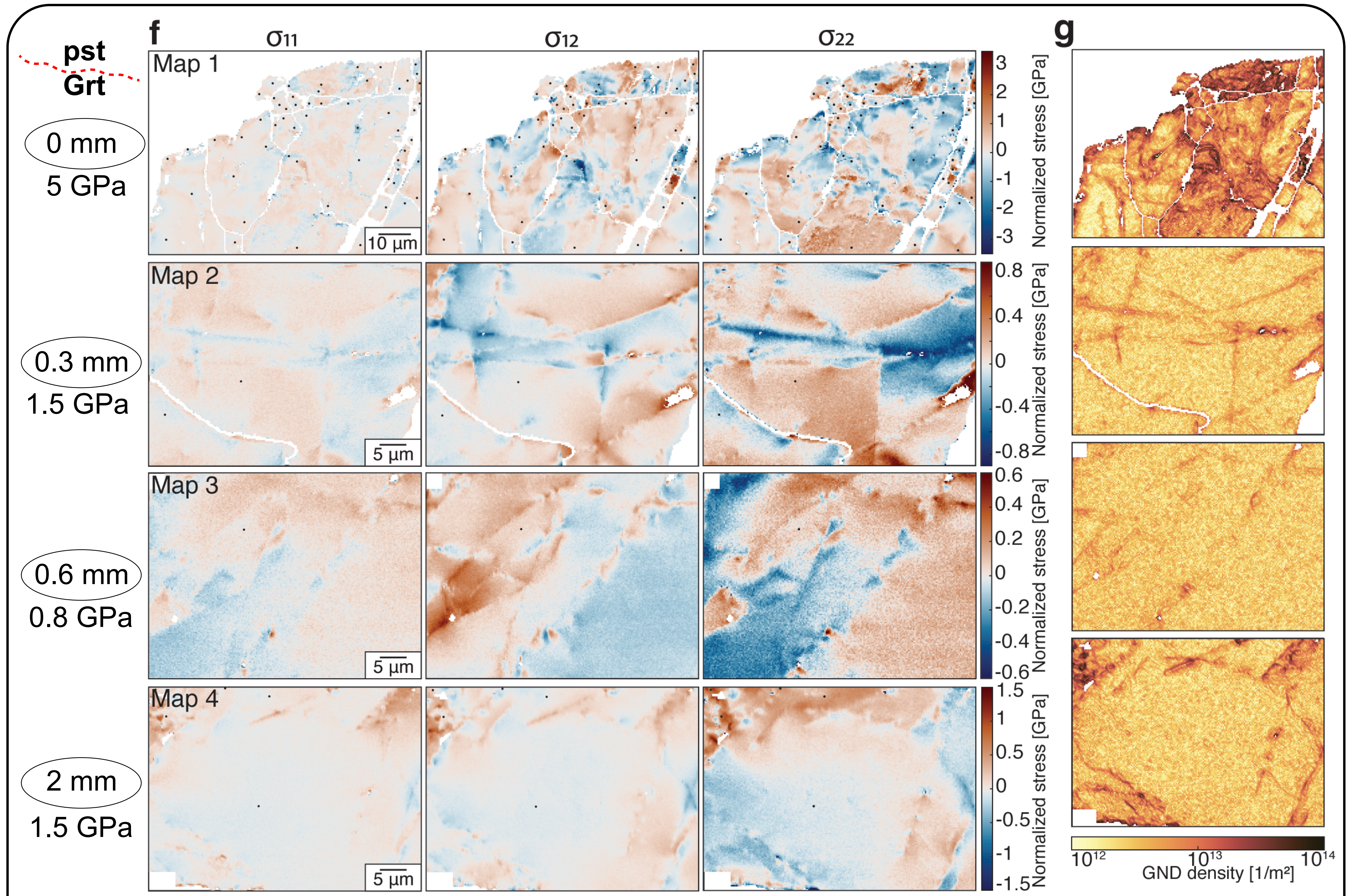


2. SAMPLE:

Pseudotachylyte-bearing garnet-rich gneiss from the hanging wall of the Woodroffe Thrust (Musgrave Ranges, central Australia)[3].
Ambient conditions ca. 500 °C and 500 MPa[4].
Single-jerk pristine pseudotachylyte fault vein (3 mm thickness) (a, b, c).
Host-rock garnet is extensively fractured and pulverized (grainsize down to 20 nm) close to the pst, with local Mn-enrichment (d, e).

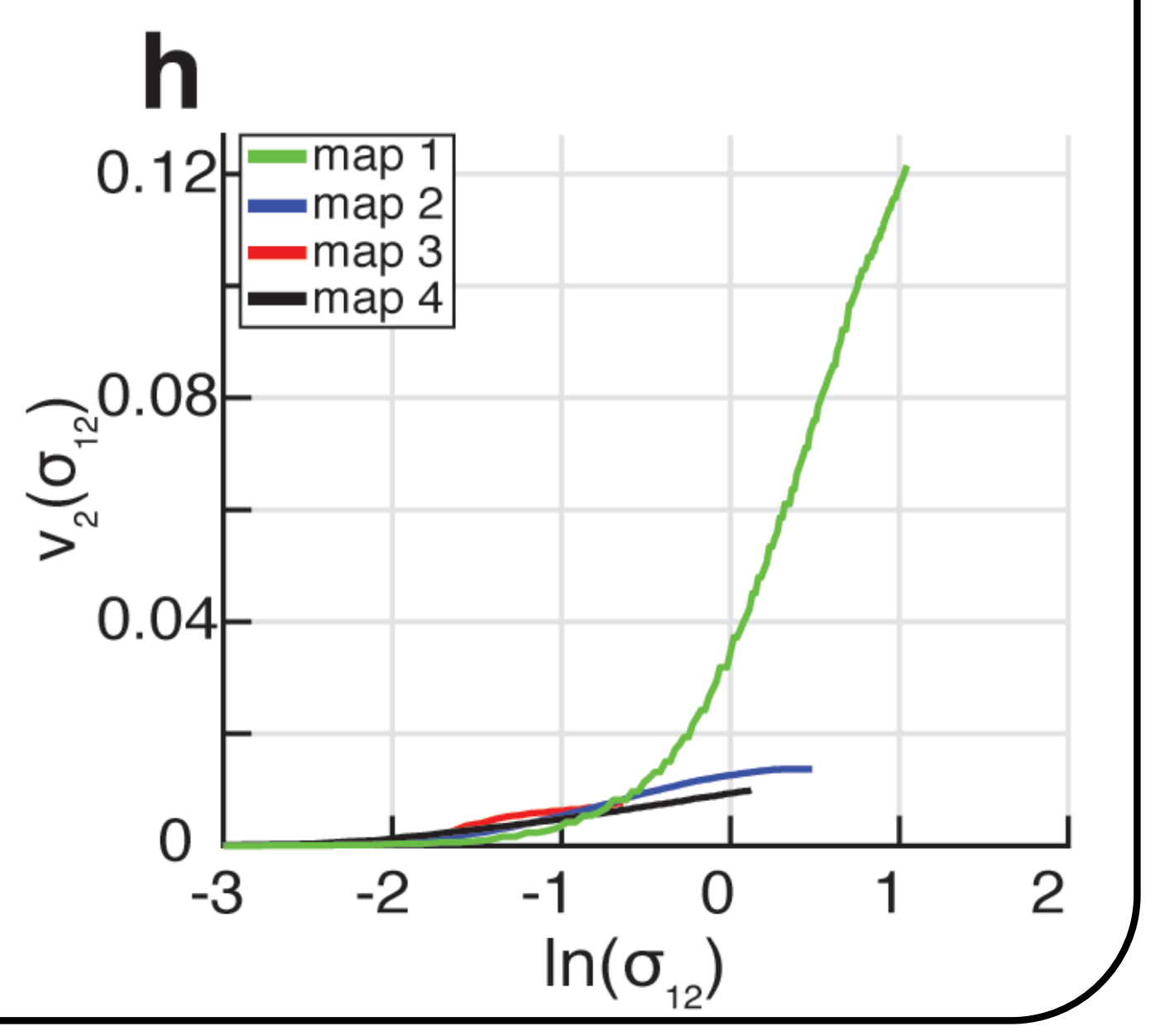
REFERENCES: [1] Wallis, D. et al., (2019). High-angular resolution electron backscatter diffraction as a new tool for mapping lattice distortion in geological minerals. JGR 124(7), 6337-6358. [2] Cocco, M. et al., (2023). Fracture Energy and Breakdown Work During Earthquakes. Annual Review of Earth and Planetary Sciences, 51. [3] Camacho, A. et al., (1995). Large volumes of anhydrous pseudotachylyte in the Woodroffe Thrust, eastern Musgrave Ranges, Australia. JSG, 17(3), 371-383. [4] Toffol, G. et al., (2022, May). Geometric complexity of the Woodroffe Thrust (Musgrave Ranges, central Australia) recorded in hanging wall Al-silicate-bearing peraluminous gneisses and hosted pseudotachylytes. In EGU General Assembly Conference Abstracts (pp. EGU22-8678). [5] Groma, I., & Bakó, B. (1998). Probability distribution of internal stresses in parallel straight dislocation systems. Physical Review B, 58(6), 2969. [6] Pittarello, L. et al., (2008). Energy partitioning during seismic slip in pseudotachylyte-bearing faults (Gole Larghe Fault, Adamello, Italy). EPSL, 269(1-2), 131-139.

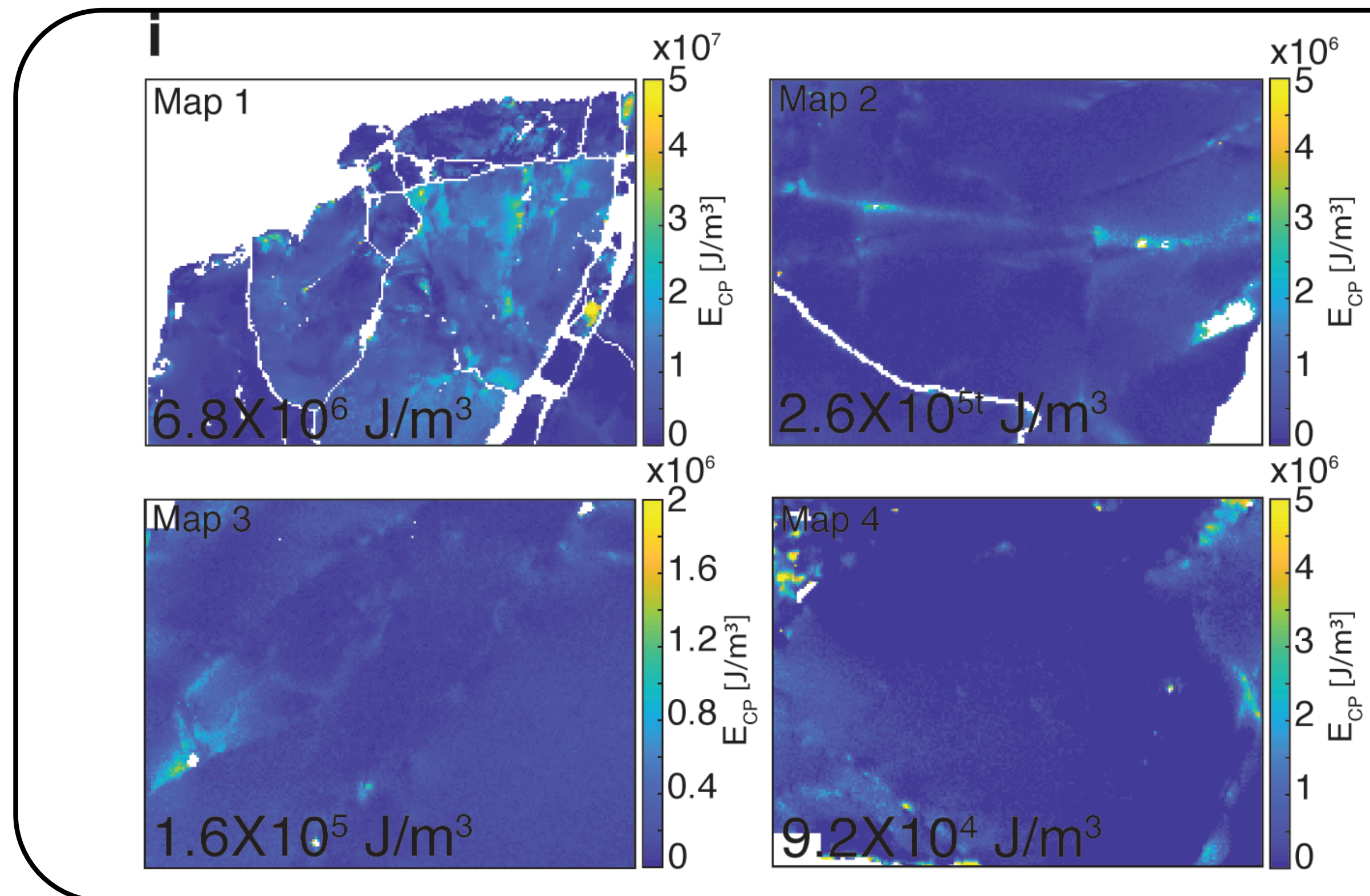
CONTACTS
giovanni.toffol@unipd.it
ResearchGate →



3. HR-EBSD MAPS:

In-plane components of normalised residual stress (f) and geometrically necessary dislocations (GND) (g) define a gradient: highest values in contact with the pst
Restricted second moment of normalised sigma12 distribution (h) defines a straight line at high stresses: stress is mainly determined by the presence of dislocations[5]
Dislocations are produced during high-stress rupture propagation





4. CRYSTAL-PLASTIC ENERGY:

$$E_{CP} = E_{strain} + E_{GND}$$

$$E_{strain} = \frac{1}{2}(\sigma_{11}\varepsilon_{11} + \sigma_{22}\varepsilon_{22} + 2\sigma_{12}\varepsilon_{12})$$

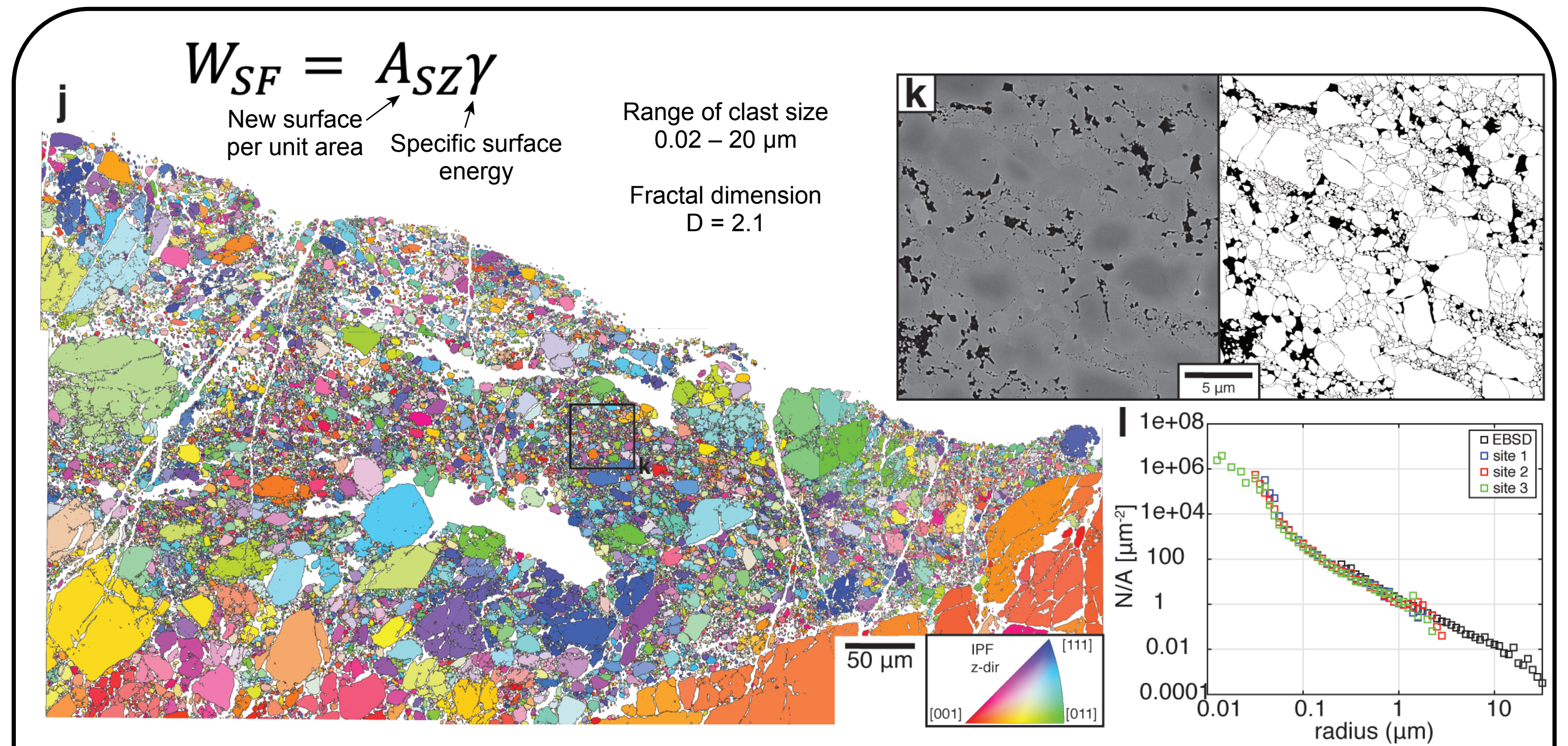
$$E_{GND} = \rho_{GND}(Gb^2)/(2\pi)$$

Highest value of E_{CP} [J/m³] is a minimum of the energy dissipated along pst in the portion of rock that was melted. E_{CP} integrated across the vein gives W_{CP} [J/m²]

$$\mathbf{W_{CP} = 2x10^4\ J/m^2}$$

$$W_{SF} = A_{SZ}\gamma$$

New surface per unit area
Specific surface energy



5. FRACTURE ENERGY:

grainsize distribution in a cataclastic domain obtained from EBSD maps (j) and high-resolution BSE images (k).
Area-normalised distributions overlaps and define similar trends (l). The grainsize distribution was extrapolated to the pst thickness to estimate **W_{FS}**[6]

$$\mathbf{W_{FS} = 2.9x10^5\ J/m^2}$$

6. HEAT:

work expended to heat the rock, melt and further heat the melt

$$W_{FH} = [H(1-\phi) + c_p(T_m - T_{hr})]\rho w$$

(H: latent heat of melting; Cp: thermal capacity; ϕ: clast abundance in the pst; ρ: density; w: pst thickness)

Host rock temperature (Thr) 500 °C
Maximum temperature (Tm) 1450°C

$$\mathbf{W_{FH} \sim 1.3x10^7\ J/m^2}$$

7. CONCLUSIONS:

The crystal-plastic damage imparted by the propagating rupture is preserved in host-rock garnets

The energy consumed to strain the crystal lattice is three order of magnitude smaller than frictional heat and one order of magnitude smaller than fracture energy

$$\mathbf{W_{FZ} = \underbrace{1.3x10^7}_{W_{FH}} + \underbrace{2.9x10^5}_{W_{FS}} + \underbrace{\boxed{2x10^4}}_{W_{CP}} [J/m^2]}$$