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Non extensive statistical physics applied in fracture-induced electric signals during triaxial deformation of Carrara marble

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We have conducted room-temperature, triaxial compression experiments on samples of Carrara marble, recording concurrently acoustic and electric current signals emitted during the deformation process as well as mechanical loading information and ultrasonic wave velocities. Our results reveal that in a dry non-piezoelectric rock under simulated crustal pressure conditions, a measurable electric current (nA) is generated within the stressed sample. The current is detected only in the region beyond (quasi-)linear elastic deformation; i.e. in the region of permanent deformation beyond the yield point of the material and in the presence of microcracking.
Our results extend to shallow crustal conditions previous observations of electric current signals in quartz-free rocks undergoing uniaxial deformation and support the idea of a universal electrification mechanism related to deformation. Confining pressure conditions of our slow strain rate (10-6 s-1) experiments range from the purely brittle regime (10 MPa) to the semi-brittle transition (30-100MPa) where cataclastic flow is the dominant deformation mechanism. Electric current is generated under all confining pressures,implying the existence of a current-producing mechanism during both microfracture and frictional sliding. Some differences are seen in the current evolution between these two regimes, possibly related to crack localisation. In all cases, the measured electric current exhibits episodes of strong fluctuations over short timescales; calm periods punctuated by bursts of strong activity.
For the analysis, we adopt an entropy-based statistical physics approach (Tsallis, 1988), particularly suited to the study of fracture related phenomena. We find that the probability distribution of normalised electric current fluctuations over short time intervals (0.5 s) can be well described by a q-Gaussian distribution of a form similar to that which describes turbulent flows. This approach yields different entropic indices (q-values) for electric current fluctuations in the brittle and semi-brittle regimes (c. 1.5 and 1.8 respectively), implying an increase in interactions between microcracks in the semi-brittle regime. We interpret this non-Gaussian behaviour as a 'superstatistical' superposition of local Gaussian fluctuations that combine to produce a higher-order overall distribution; i.e. the measured electric current is driven to varying, temporary, local equilibria during deformation.
This behaviour is analogous to the self-organising avalanche-like behaviour of fracture events, suggesting that the observed behaviour of measured electric current is a direct response to the microcracking events themselves and supporting the idea of a fracture-generated electrification mechanism in the crust. Our results have implications for the earthquake preparation process and the application of Tsallis statistical physics to the analysis of electric earthquake precursors.

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