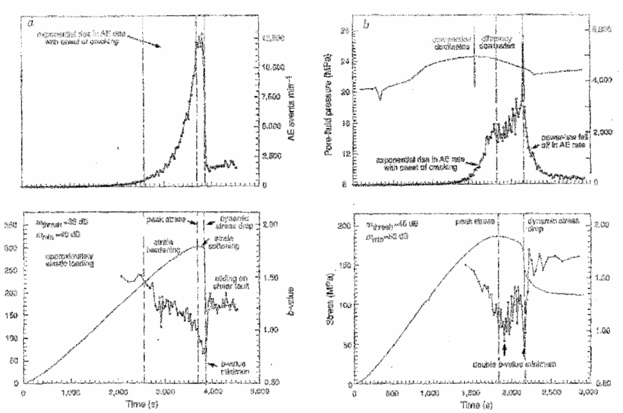
Scaling of coupled dilatancy-diffusion processes in space and time

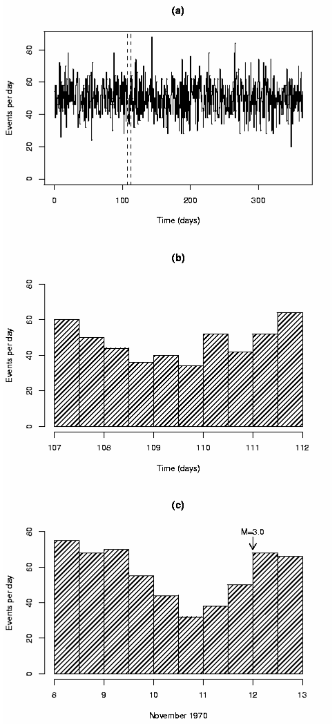
I.G. Main, A.F. Bell, P.G. Meredith, N. Brantut, M. Heap and S. Touati

ian.main@ed.ac.uk

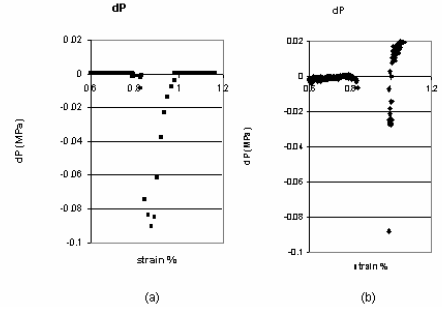
SUMMARY: Coupled dilatancy-diffusion processes have been observed in the laboratory and suggested as a mechanism for earthquake precursors[1]. Here we consider what can be learned from the failure of this hypothesis to date, and show that significant dilatancy may be intrinsically a high-strain rate and spatially-localised phenomenon.

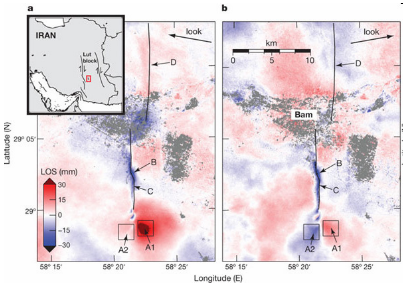


LABORATORY OBSERVATION OF DILATANCY-DIFFUSION: Evolution of stress, Acoustic Emission (AE) event rate and *b*-value under (*a*) drained and (*b*) undrained conditions[2]. In undrained conditions dilatant hardening delays failure by extending a phase of strain softening during a period of relative AE quiescence and *b*-value recovery, as predicted by the dilatancy-diffusion hypothesis.

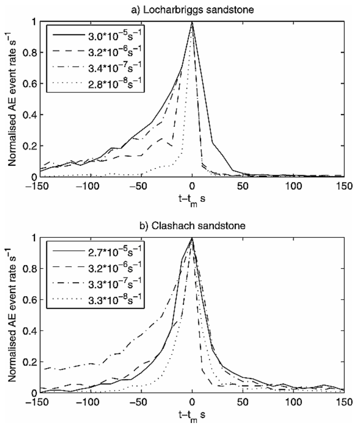


SIGNIFICANCE OF EARTHQUAKE PRECURSORS: Example (above right) of how an apparent period of quiescence (diagram *c*) can be obtained from a Poisson model (diagram *a*, showing one year of synthetic data and its fluctuations) after sampling (diagram *b*) between the dashed lines in *a*). Clear, causal earthquake precursors of any type remain elusive, though statistical forecasts based on earthquake clustering can show significant probability gain over background[3].





DILATANCY AT HIGH STRAIN RATE. The diagram on the left shows (a) a poro-elastic model and (b) laboratory observation of a significant drop in pore pressure at the moment of dynamic failure of a rock sample due to rapid dilatancy under drained conditions, leading to a 'suction pump' action[4]. The diagram on the right shows observations of post-seismic strain recovery after the 2003 Bam earthquake, Iran, implying significant co-seismic dilatancy at C, localised on the fault break (black line).

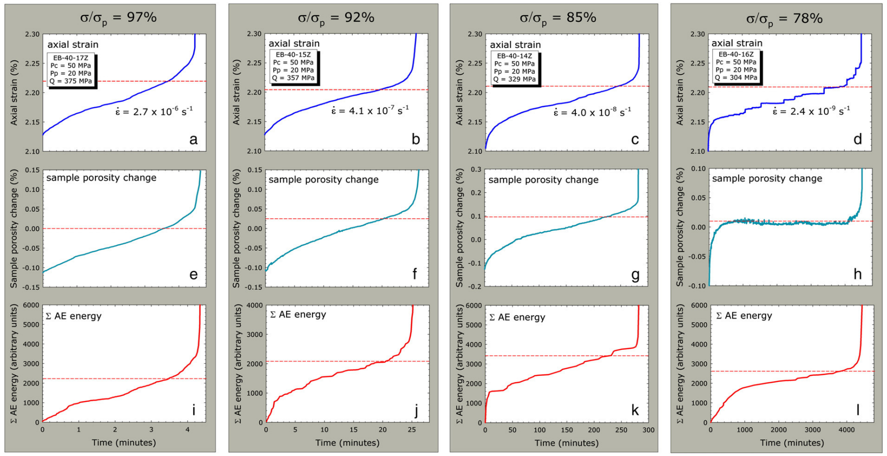


MOVING TO LOWER STRAIN RATE: The left-hand diagrams show acceleration of AE event rate *dN/dt* as a function of time, relative to failure time t_m, for two different rock types loaded at different strain rates as indicated. The data can be fitted by

$$dN/dT = A(t_m - t)^{-n}$$

At slower strain rates the precursory phase is shorter and sharper (lower exponent *n*) making accurate forecasting of the failure time progressively more difficult.

The diagrams below show the evolution of axial strain, porosity and cumulative AE energy during deformation of Mount Etna basalt at constant stress *σ*. As strain rate decreases the sample porosity change during steady state decreases as strain rate decreases, remaining finite during all decelerating and accelerating creep phases.



SPATIAL CONSTRAINTS : Recent satellite observation prior to the 2009 L'Aquila, Italy earthquake[8], and observation of multiplets prior to the 1999 Izmit, Turkey earthquake[9], limit the pre-seismic nucleation zone for these events to a scale length of at most 100m, much smaller than the dimensions of the main shock.

CONCLUSION : Dilatancy-diffusion may be intrinsically a high-strain-rate, local phenomenon.

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