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The New Geophysics: the Earth as a critical system of fluid-saturated stress-aligned microcracks

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Widespread observations of stress-aligned shear-wave splitting (seismic birefringence) demonstrate that most *in situ* rocks are pervaded by stress-aligned fluid-saturated microcracks. These are grain-boundary cracks in crystalline rocks, and aligned pores and pore-throats in sedimentary rocks. The shear-wave splitting shows that these microcracks are so closely spaced that they verge on fracture criticality and fracturing or faulting in almost *in situ* rocks. This demonstrates that all fluid-saturated rocks in most of the Earth's crust (and probably upper mantle, where the fluid is hydrologised melt) are so closely spaced that they are critical systems with self-organised criticality. I suggest that the stress-induced manipulations of these fluid-saturated microcracks are the physical mechanism underlying the self-organised criticality of the Gutenberg-Richter relationship.

In situ rocks are so weak to shear stress that the accumulation of stress before earthquakes (and volcanic eruptions, because eruptions need to accumulate stress to break through surface rocks - see VPG6 presentation) necessarily occurs over very large volumes of rock. These volumes would be hundreds of millions to billions of cubic kilometres before the largest earthquakes and eruptions. In principle, such accumulation of stress can be monitored by changes in shear-wave splitting almost anywhere within these large volumes of rock.

Unfortunately, suitable swarms of small earthquakes for monitoring such changes are extremely scarce, so there are limited observations. Never-the-less changes in shear-wave splitting have been identified before some 15 earthquakes worldwide, ranging in magnitude forma M 1.7 swarm event in Iceland to the *Ms* 7.7 Chi-Chi earthquake in Taiwan. On one occasion, the time and magnitude (and fault break) of a M 5 earthquake in SW Iceland was successfully stress-forecast in real time (see NH4.04 presentations).

Currently, because of the difficulty of locating suitable data, there are limited observations, and the largest distance at

Which changes before earthquakes have been observed is at 70km from the energy equivalent of a (comparatively small) M 3.5 earthquake at a prototype stress-monitoring site in Iceland (see NH4.04 presentations). Observations over azimuths of 200^o have been seen at 200km to 240km distances before the large 1996 Gjàlp fissure eruption beneath the Vatnajökull Ice Cap in Iceland. Observations suggest that the approach to fracture-criticality is comparatively uniform over these large areas, but when the impending earthquake location (usually a previous fault) has been isolated, local stress-relaxation appears to occur as the fault break prepares for fracturing. These critical systems of stress-aligned fluid-saturated microcracks appear to satisfy an enormous range of static and dynamic phenomena. It appears to a New Geophysics where the universality and calculability of critical systems allows the deformation of *in situ* rock to be: *monitored* with shear-wave splitting; *modelled* (*calculated*) with anisotropic poro-elasticity (APE); future behaviour *predicted* (if changed conditions are known); and in some circumstances future behaviour *controlled* by feedback. The New Geophysics appears to have wide applications ranging from stress-forecasting earthquakes to monitoring movement of fluid-fronts in producing hydrocarbon reservoirs by time-lapse seismics, and is expected to have fundamental effects on all solid earth science in the future.