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A new understanding of fluid-rock deformation

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Cracks in the pavement show that rock is weak to shear stress. Consequently we have a conundrum. How does in situ rock accumulate the enormous shear-stress energy necessary for release by a large magnitude earthquake without fracturing in smaller earthquakes? For example: observations of changes in seismic shear-wave splitting (SWS) were observed in Iceland before the 2004 Mw9.2 Sumatra-Andaman Earthquake (SAE) at a distance of ∼10,500km (the width of the Eurasian Plate) from Indonesia. Observations of SWS monitor microcrack geometry, and the changes in SWS in Iceland indicated that stress-changes before the Sumatra earthquake modified microcrack geometry the width of Eurasia from Indonesia.

What is the mechanism for such widespread accumulation of necessarily weak stress? We show that stress is stored in in situ rock by the stress-controlled geometry of the fluid-saturated stress-aligned microcrack. Microcrack aspect-ratios are aligned by fluid flow or dispersion along pressure-gradients between neighbouring microcracks at different orientations to the stress-field by a mechanism known as Anisotropic Poro-Elasticity or APE. Since the minimum stress is typically horizontal, the microcracks are typically vertically-oriented parallel to the maximum horizontal stress as is confirmed by observations of SWS.

Such azimuthally varying shear-wave splitting (SWS) is observed in situ rocks in the upper crust, lower crust, and uppermost ∼400km of the mantle. (The 'microcracks' in the mantle are intergranular films of hydrolysed melt.) SWS shows that the microcracks are so closely spaced that they verge on fracturing/earthquakes. Phenomena verging on failure are critical-systems with 'butterfly wings' sensitivity. Critical-systems are very common and it must be expected that the Earth, an archetypal complex heterogeneous interactive phenomena is a critical-system. Monitoring SWS above small earthquakes allows stress-accumulation before earthquakes to be recognised and the time, magnitude, and in some circumstances fault-plane to stress-forecast. Currently, the time, magnitude, and fault-plane of a M5 earthquake in SW Iceland was stress-forecast three-days before it occurred, and characteristic anomalies in SWS have been recognised retrospectively before ∼16 other earthquakes.

Stress in the Earth is generated by plate-interactions at mid-oceanic ridges and subduction zones. The behaviour of SWS suggests the following scenario. Initially, the increasing stress-field has does not recognise the location or timing of the eventual earthquake where the stress will be released. Stress continues to increase until levels of cracking known as fracture-criticality are approached around the (usually) previous (but more rarely new) fault-plane, and there is stress-relaxation as microcracks begin to coalesce on the fault. Eventually, stress is concentrated on the heavily microcracked rock and the earthquake occurs.

It is believed that the APE deformation of fluid-saturated microcrack geometry pervading most rocks above ∼400km in the mantle is the mechanism controlling many aspects of fluid-rock deformation. It has the advantage that the internal behavior of stress-induced manipulation of the microcrack geometry can be monitored by observations of SWS.

Papers referring to these developments can be found in geos.ed.ac.uk/home/scrampin/opinion.

Also see Crampin & Gao (Session SM1.1), Liu & Crampin (Session NH2.5), and Crampin & Gao (Session GD.1) at this EGU2015 meeting.