Geophysical Research Abstracts
Vol. 17, EGU2015-9352, 2015
EGU General Assembly 2015

Role of fluid overpressures in controlling the form of crustal strength-depth profiles

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The classic crustal strength-depth model of Brace and Kolhstedt (1980) based on experimental rock mechanics depends in the brittle regime on the assumption of linearly increasing hydrostatic pore-fluid pressures. This leads to a predicted linearly increasing brittle strength that is well established based on deep borehole stress measurements in crystalline crust.

In contrast, fluid overpressures are widely documented in orogenic belts based on borehole data, seismic velocity analysis, modeling of seismic tremors, and analysis of veins, which in some cases show complex fault-valve pressure fluctuations between lithostatic and hydrostatic. Typical observed overpressure-depth relationships show approximately constant effective stress and therefore a pressure-dependent crustal strength that is approximately constant with depth in contrast with the classic model. This constant-strength behavior below the fluid-retention depth Z_{FRD}has been confirmed using deep borehole stress and fluid-pressure measurements (Suppe, 2014). The pressure-dependent strength magnitude is the strength at the fluid-retention depth, which is commonly ∼50MPa or less because Z_{FRD} is typically $<$∼3km. Recent ductile-plastic modeling of disequilibrium compaction suggests that pressure solution promotes further increases in overpressure and weakening, promoting a very prolonged low-strength brittle-ductile transition.

Overpressured conditions can be inferred to exist over a substantial fraction of crustal thickness, spanning the brittle-ductile transition in several tectonic environments, most straightforwardly in shale-rich clastic sedimentary basins built to sea level on oceanic or highly thinned continental crust such as the US Gulf Coast and Niger Delta. These thick accumulations commonly deform into shale-rich plate boundary mountain belts (e.g. Bangladesh/Miyanmar, Makran, Trinidad/Barbados, Gulf of Alaska, southern Taiwan and New Zealand). There is deep geophysical evidence for near lithostatic pore-fluid pressures existing to depths of 20-30km based especially on well known theoretical and experimental relationships between seismic velocity and effective stress in homogeneous rock (e.g. Biot, 1956; Todd and Simmons, 1972). We present active examples from Taiwan and New Zealand, combining borehole data, 1D seismic velocity analysis and seismic tomography. For example deforming deep sedimentary basins in the active Taiwan mountain belt show approximately constant velocity and therefore constant effective stress and brittle strength to depths of ∼20-25km, whereas adjacent crystalline basement massifs show velocities and fluid pressures closer to the classic hydrostatic Brace-Kohlstedt model.