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Fluid Overpressures and Crustal Strength

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The classic crustal strength-depth profile, based on experimental rock mechanics, predicts a brittle strength $(\sigma_1 - \sigma_3) = \kappa(\bar{\rho}gz - P_f)$ that increases linearly with depth z, which is a consequence of [1] the intrinsic pressure dependence κ of brittle frictional strength plus [2] an assumption that pore-fluid pressure is hydrostatic, $P_f = \rho_w gz$. Much deep borehole stress data agree with a critical state of failure of this form. In contrast, fluid pressures greater than hydrostatic $\bar{\rho}gz > P_f > \rho_w gz$ are normally observed in deeper parts of thick clastic sedimentary basins on continental margins and active shale-rich plate-boundary mountain belts. We explore the predicted shape of the crustal strength-depth profile in such overpressured regions, particularly those dominated by the widespread disequilibrium compaction mechanism, which displays fully compacted sediments with hydrostatic fluid pressures at shallow depths until the fluid-retention depth z_{FRD} is reached, below which sediments are increasingly undercompacted for their depth and overpressured. We show that the brittle strength at depths greater than z_{FRD} is predicted to be approximately constant, leading to a crustal strength profile that is radically different from the classic linearly increasing hydrostatic profile. We present borehole stress and fluid-pressure measurements in several overpressured deforming continental margins that agree with this prediction and with a critical state of failure controlled by the same pressure-dependence κ as the overlying hydrostatic strata. A first-order extrapolation of observed and theoretical overpressured strength-depth profiles to much greater depths suggests the possibility of a prolonged transition at approximately constant strength from brittle to linear-viscous behavior in deforming shale-rich volumes undergoing the transition to slate, phyllite and schist.

Our examples of fluid pressures and stresses come from the Yinggehai basin offshore south China, western Taiwan thrust belt, offshore Texas, Brunei delta and Scotia Shelf offshore Canada.