Permeability Anisotropy in Mudstones

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Mudstone permeability is critical for fluid flow modelling, pore pressure prediction, top-seal evaluation of hydrocarbon traps and CO_2 storage reservoirs and optimal production of shale gas. This study investigates permeability heterogeneities and anisotropy in well characterized synthetic mudstones. A total of 10 brine-saturated synthetic mudstones of varying textural and mineralogical compositions were compacted mechanically in a triaxial cell (K_0-test) while the vertical (K_v) and horizontal (K_h) permeability were measured at different stress levels. The samples were mixtures of known amounts of smectite, illite, kaolinite and silt-sized quartz grains. The results show that both the vertical and horizontal permeabilities of synthetic mudstones vary significantly as a function of clay mineralogy, grain size and the amount of silt in silt-clay mixtures. The vertical and horizontal permeabilities of all synthetic mixtures differ by a factor of 10^4 at the same stress level. Silt mixture has the highest permeability compared to other mixtures while clay-rich samples with dominantly kaolinite had relatively higher permeability than those with illite and smectite. The K_v/K_h ratio is used to quantify the permeability anisotropy. Pure silt had isotropic permeabilities but about 30% clays in silt mixture strongly reduced the permeability and increased the anisotropy. The highest K_v/K_h ratio of >1.6 is observed in a silt-illite (70:30) mixture whereas the minimum K_v/K_h ratio of <0.4 is observed in a silt-smectite mixture (70:30). The K_v/K_h ratio in illite-kaolinite (30:70, 50:50 and 70:30) and illite-silt (50:50 and 70:30) mixtures varies from 0.4 to 0.8 and 0.8 to 1.2, respectively, demonstrating the importance of different clay minerals, grain size and silt content on permeability anisotropy development in mudstones. Overall the experimental results show that the anisotropy produced by mechanical compaction alone is rather small but significant. Natural mudstone may have much higher permeability anisotropy than found in this study due to a more extensive primary depositional lamination formation than produced in the compaction experiments and also from chemical compaction. The use of permeability distributions and vertical-to-horizontal permeability ratios (K_v/K_h) derived in this study can readily be tested on cap rocks and shale gas reservoir models at relatively shallow depth where mechanical compaction is the dominant process.