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Understanding the mechanical and acoustical characteristics of sand aggregates compacting under triaxial conditions

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Mechanisms such as grain rearrangement, coupled with elastic deformation, grain breakage, grain rearrangement, grain rotation, and intergranular sliding, play a key role in determining porosity and permeability reduction during burial of clastic sediments. Similarly, in poorly consolidated, highly porous sands and sandstones, grain rotation, intergranular sliding, grain failure, and pore collapse often lead to significant reduction in porosity through the development of compaction bands, with the reduced porosity and permeability of such bands producing natural barriers to flow within reservoir rocks. Such time-independent compaction processes operating in highly porous water- and hydrocarbon-bearing clastic reservoirs can exert important controls on production-related reservoir deformation, subsidence, and induced seismicity.

We performed triaxial compression experiments on sand aggregates consisting of well-rounded Ottawa sand (d = 300-400 μm; ϕ = 36.1-36.4%) at room temperature, to systematically investigate the effect of confining pressure (P_c^{eff} = 5-100 MPa), strain rate (10^{-6}-10^{-4} s^{-1}) and chemical environment (decane vs. water; P_f = 5 MPa) on compaction. For a limited number of experiments grain size distribution (d = 180-500 μm) and grain shape (subangular Beaujean sand; d = 180-300 μm) were varied to study their effect. Acoustic emission statistics and location, combined with microstructural and grain size analysis, were used to verify the operating microphysical compaction mechanisms.

All tests showed significant pre-compaction during the initial hydrostatic (set-up) phase, with quasi-elastic loading behaviour accompanied by permanent deformation during the differential loading stage. This permanent volumetric strain involved elastic grain contact distortion, particle rearrangement, and grain failure. From the acoustic data and grain size analysis, it was evident that at low confining pressure grain rearrangement controlled compaction, with grain failure being present but occurring to a relatively limited extent. Acoustic emission localization showed that failure was focussed along a broad shear plane. At higher confining pressure pervasive grain failure clearly accommodated compaction, though no strain localization was observed and failure appeared to be through cataclastic flow. Chemical environment, i.e. chemically inert decane vs. water as a pore fluid, had no significant effect on compaction in the strain rate range tested. Grain size distribution or grain shape also appeared to not affect the observed mechanical behaviour. Our results can be used to better understand the compaction behaviour of poorly consolidated sandstones. Future research will focus on understanding the effect of cementation on strain localization in deforming artificial Ottawa sandstone.