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Sandstone compaction under actively controlled uniaxial strain conditions – an experimental study on the causes of subsidence in the Dutch Wadden Area

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In the Wadden Sea, a tidal-flat area located between the North Sea and the Dutch mainland shore, and UNESCO World Heritage site, subsidence could potentially impact the ecological system. To guide the licensing process governing gas extraction for the area by a solid understanding of the system's response to production, Nederlandse Aardolie Maatschappij (NAM) has carried out a study on the magnitudes, timing, and mechanisms of subsidence related to gas production. As part of this study program, we address the effect of production-induced reservoir compaction, using core samples from the Moddergat field located at the Wadden Sea coastline, from a depth of ∼3800 m TVDSS, to assess the nature of the compaction mechanisms that operate.

In this contribution, we focus on the uniaxial strain response of Permian, Aeolian sandstone to pore pressure depletion. As the majority of experiments reported in the literature are conducted under triaxial stress conditions, this data set is somewhat unique, and can help confirm the validity of micromechanical processes found for triaxial stress conditions. We report over 30 data sets of experiments carried out using 1.0 and 1.5 inch diameter plugs, sub-sampled from the extracted sandstone core material. The experiments start at in-situ conditions of pore pressure (Pf=∼57 MPa), stress (Sv=∼80 MPa, Sh=∼67 MPa) and temperature (T up to 100 °C), and deplete to a pore pressure of 3 MPa, under actively controlled lateral constraint boundary conditions (i.e. uniaxial strain). Care was taken to systematically vary porosity and sample morphology to ensure representation of the intra-reservoir variability.

Our laboratory data show that pressure-depletion results in a strain in the range of 5·10-3-1·10-2 over the total duration of the experiments of 5-12 weeks, with approximately 80% of the total strain response being close to instantaneous, and 20% developing over time. The total strain response develops during depletion as a result of simultaneously operating elastic and inelastic processes. The measured strains are slightly higher for samples with higher porosity, but seem rather insensitive to temperature, and pore fluid composition. Even given the fast depletion in our experiments compared to the field case, we find that most of the strain response in the rock is close to instantaneous. A comparison of micrographs before and after testing show that the rock material contains up to 22% more cracked grains after testing, from which we infer that significant deformation occurs due to grain cracking and re-arrangement mechanisms. However, a comparison with independently generated compressive strength data demonstrates that the cracking effects do not alter the inherent strength of the rock. We conclude that progressive microscale damage and re-arrangement is responsible for the majority of the inelastic strain measured, and that these mechanisms are closely similar to those operating under triaxial stress conditions, but that the orientation of the damage is, in our case, consistent with the directionality in the effective stress increase.

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