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Understanding strain-accommodating processes in depleted sandstone gas reservoirs through in-situ triaxial testing and X-ray CT imaging

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Understanding sub-surface grain-scale processes related to hydrocarbon reservoir depletion is crucial for predicting surface subsidence and induced seismicity hazards. Typical laboratory experiments, however, only allow for post-experiment microstructural investigation of deformation, while the controlling grain-scale processes remain unmonitored under in-situ P-T-stress conditions reached in conventional triaxial deformation machines. In addition, in most depleting fields, compactive strains tend to be very small (« 1%), making identification of grain-scale deformation challenging. Using state-of-the-art techniques, such as high-resolution time-lapse X-ray tomography imaging (micro-CT) during triaxial deformation, these controlling grain-scale processes can be visualized through time and quantified at in-situ conditions.

Here, we used a small-scale triaxial deformation device, the HADES rig, available at the European Synchrotron Radiation Facility (ESRF, Grenoble), to deform a highly porous sandstone plug from a depleted natural gas reservoir. The sample was brought to relevant P-T-stress conditions (T= 100°C, 10 MPa pore pressure, 40 MPa effective confining pressure). Subsequently, the axial stress on the sample was increased by steps-of 1 MPa until failure occurred. At each stress step during the experiment, three dimensional micro-CT scans were acquired at a voxel resolution of 6.5 micrometers. Post-processing of the micro-CT images through standard image analysis techniques and the technique of digital volume correlation allowed the identification of the main strain-accommodating zones within the sample. Subsequent image analysis enabled us to link specific local mineralogy and porosity within these zones to different deformation mechanisms. Results show that the sample compacted due to a combination of grain failure via intragranular cracking, and grain rearrangement, via frictional slip and – possibly – grain asperity breakage and clay film consolidation, until the entire microstructure collapsed at failure.