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Post-mortem and in-situ imaging analysis of micro-mechanisms responsible for the evolution of petrophysical properties under deviatoric stresses

M. Bornert (1), J. Dautriat (1,2), N. Gland (2), A. Dimanov (1) and J. Raphanel (1)

1. Laboratoire de Mecanique des Solides, Ecole polytechnique, Palaiseau, France, (2) IFP, Reservoir Engineering Dpt, Rueil-Malmaison, France

During oil field production, the reservoir rocks experience a fluid pressure decrease, leading to changes of effective stresses and hence to elastic and inelastic deformations, involving modifications of the porous structure, micro fracturing or compaction that directly affect the permeability, and thus the production efficiency. This study explores the relationships between macroscopic stresses, evolutions of microstructure and pore network, deformation modes and the permeability of porous rocks.

We used a natural carbonate rock (Estaillades limestone) with high (30%) bimodal porosity and moderate permeability (150mD). We performed permeability measurements under different stress states, representative of reservoir rock conditions, using a specifically designed triaxial cell, allowing permeability measurements in directions parallel and perpendicular to the principal stress direction. Macroscopic mechanical data and stress path dependency of porosity and permeability were derived for pseudo elastic, brittle and compaction regimes. Microstructural analyses of undeformed and deformed samples (post-mortem) were performed combining Mercury porosimetry, scanning electron microscopy (SEM) and X-ray Computed Micro Tomography (CMT). We have observed that the most important permeability decrease under confinement correlates with generalized pore collapse. Additionally, optical, SEM and CMT analyses coupled with digital image correlation (DIC) techniques were performed during in-situ uniaxial loading tests. Optical and SEM analysis assisted by DIC allow for surface (2D) visualization of local strain fields, while CMT

coupled with DIC allows for volume (3D) visualization of local strain fields. These experiments are designed to identify heterogeneities, localization and deformation mechanisms and modes at different scales, from micrometer to centimeter. The Estaillades limestone may be described as a loose aggregate of denser carbonate clusters with two different porosities. Our preliminary DIC results suggest that prior to sample failure strain localization occurs in-between those clusters, within the zones characterized by the highest porosity and suffering pore collapse under confining pressure. We will further discuss the different in-situ imaging techniques and their limits in terms of compromises between resolution, pertinent scales of observation and mechanical regimes.