Geophysical Research Abstracts,
Vol. 11, EGU2009-5058, 2009
EGU General Assembly 2009

Hydromechanical behavior of Estaillades carbonate : directional permeability, stress-path and microstructural heterogeneity effects, yield and failure envelopes

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The influence of stress paths representative of reservoir conditions on the mechanical behavior and the coupled permeability evolutions of a carbonate has been investigated. In order to predict the permeability evolutions under triaxial loading, we have developed a triaxial cell designed to allow the measurements of the permeability in three orthogonal directions, along and transverse to the maximum principal stress direction. A set of core specimens are mechanically loaded following different stress paths characterized by a constant ratio K between horizontal and vertical stress. Our experimental set-up allows the monitoring of the petrophysical and geomechanical parameters during loading, before and post sample damage. The tested rock is an analog reservoir carbonate, the Estaillades Limestone, characterized macroscopically by a porosity around 29% and a moderate permeability around 150mD. From our experimental results, the failure envelope of this carbonate is determined and the evolutions of the directional permeability are examined in the (p,q) diagram. According to the followed stress path, permeability reductions can be limited or drastic. In addition, we have performed microstructural analyses on deformed samples and in-situ observations during loading inside a SEM in order to identify the micromechanisms responsible for the evolutions of porosity and permeability. For instance, we show the importance of local heterogeneities on initiation of damage and of pore collapse. In the near-elastic domain, brittle damage induces limited directional permeability modifications; whereas, at higher stress, depending on the value of K, shear induced dilation or shear induced compaction mechanisms are activated. The highest permeability drop occurred for the hydrostatic compression (K=1), in the compaction regime, characterized by pore collapse mechanisms affecting preferentially the macroporosity. A failure model is proposed and the failure envelope is determined in the (p',q) plane. A new expression of the failure envelope is also discussed which includes a dependency of the deviatoric stress with the stress-path parameter.