Geophysical Research Abstracts,
Vol. 10, EGU2008-A-01517, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-01517
EGU General Assembly 2008

Combined diagenesis and compaction of reservoir rocks studied via X-ray tomography

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Predicting sediment porosity-depth trends and ultimately the quality of reservoir rocks requires an understanding of chemical diagenesis and mechanical compaction mechanisms. For many siliciclastic sediments, porosity is little affected by diagenesis making only the sediment's stress history of importance. However, carbonate rocks undergo significant diagenesis; even at shallow depths, therefore the combined effects of chemical diagenesis and mechanical compaction are important.

We used a systematic laboratory approach to investigate the role of early diagenesis in a meteoric environment on the compaction behavior of oolitic carbonates. Aggregates were synthesized in an autoclave from loosely packed natural aragonite ooids and fresh water, to mimic phreatic conditions. Time and temperature variation controlled the degree of chemical diagenesis. Constant stress-rate, uniaxial strain compaction tests were performed on the aggregates to track mechanical properties as a function of chemical alteration. Samples were characterized before and after compaction with electron and optical microscopy, X-ray tomography, and X-ray diffraction.

Aragonite ooids, when subjected to phreatic conditions, undergo an unusual isochemical structural inversion, dissolving preferentially inwards from their rims, with blocky calcite precipitated in the original inter-ooid pore space. This is a progressive transformation that results in a final structure with moldic pores inside a fully-interconnected (foam-like) calcite matrix.

We utilized computed X-ray microtomography to examine the sample structures both prior to and following application of stress. The initial stages of diagenesis, leads to a loss of distinct granular structure. This is evident in an isotropic decline of peak-height for the density-density auto-correlation function for the unstressed samples. However, uniaxial strain created a further, unanticipated, anisotropic decline of correlation in the axial strain direction. Simulations suggest this decline is due to stress-driven inter-particle penetration, preferentially generating nearly uniform density in the vertical direction. As diagenesis proceeds toward the “foam-like” structure, we produce samples having about half the ooids converted to pores. In the stress-strain curve for these samples, little strain is observed until reaching a critical stress, at which point the porosity abruptly drops. Tomography shows that the deformation is accommodated by pore collapse. Using sub-grain-scale resolution, we are able to track the collapse of individual pores.

These experiments help us understand the complexities of chemical-mechanical interactions during diagenesis and improve our ability to predict porosity changes with depth for basin modeling, reservoir quality prediction and reservoir management.