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Younane Abousleiman
University of Oklahoma, yabousle@ou.edu

Katherine Hull
Aramco Research Center

Ghaithan Al-Muntasheri
Aramco Research Center

Peter Hosemann
Universityof California, Berkeley

Scott Parker
University of California, Berkeley

See next page for additional authors

Authors
Younane Abousleiman, Katherine Hull, Ghaithan Al-Muntasheri, Peter Hosemann, Scott Parker, and Cameron Howard

IN-SITU STRAIN SOFTENING AND STRAIN HARDENING OF NATURAL GEOMATERIALS ON THE MICROSCALE

Younane N. Abousleiman, PoroMechanics Institute, University of Oklahoma, Norman, OK
yabousle@ou.edu
Katherine L. Hull, Aramco Research Center, Houston, TX
Ghaithan A. Al-Muntasheri, Aramco Research Center, Houston, TX
Peter Hosemann, University of California-Berkeley, Berkeley, California
Scott Parker, University of California-Berkeley, Berkeley, California
Cameron Howard, University of California-Berkeley, Berkeley, California

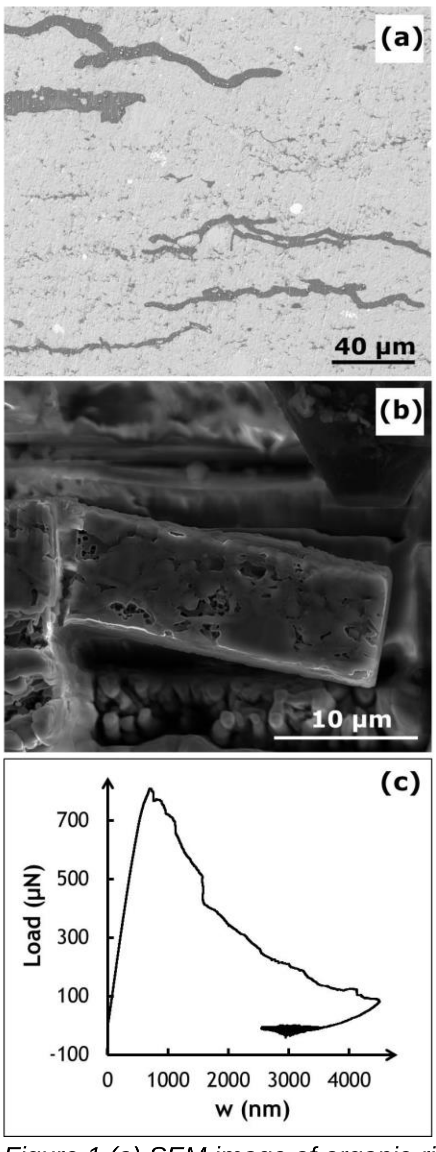

Figure 1 (a) SEM image of organic-rich shale (kerogen—dark gray, rock matrix-light gray), (b) SEM image of micro-cantilever beam after applying load, and (c) load-displacement curve from the micro-cantilever testing.

Gas shale has proven to be a good candidate for mechanical characterization using nanoindentation. However, this natural material composed of nano-granular clay and microscale non-clay minerals also includes within its matrix a polymeric material. This kerogen biopolymer is interbedded and intertwined with the clay and non-clay minerals at almost all scales. Figure 1(a) demonstrates the nature of interlacing that occurs between shale rock and organic matter.

Kerogen within the shale matrix has been mechanically characterized using nanoindentation to determine Young's modulus and hardness such as in the work by Zeszotarski et al. 2004. As a polymer kerogen not only has a Young's modulus in compression but also has a substantial Young's modulus value in tension and much higher tensile strength than rocks in general! This fact has now been observed at the micro- and nanoscale during nanoindentation while monitoring *in situ* via scanning electron microscopy (SEM). Load and unload experiments with micro-Newton forces (µN) and nanometer (nm) displacements have clearly shown the elastic nature of kerogen in the shale gas matrix.

This unique experimental setup provided us not only the ability to load and fracture micro- and nano-scale kerogen-rich shale structures but also the advantage of visualizing the initiation, propagation, and ultimate failure of the beams. Subsequent high resolution imaging of the support and beam fracture faces as well as complementary EDS allowed us to analyze the grains/minerals and non-minerals associated with the fracture. Strain softening behavior was measured on this composite at the micro scale in cantilever micro-beam as shown in Figure 1 (b) and (c). This behavior of gas shale could never be captured at the macro-scale.