AAPG/SEG/SPWLA HEDBERG CONFERENCE
"Fundamental Parameters Associated with Successful Hydraulic Fracturing – Means and Methods for a Better Understanding"
DECEMBER 7-11, 2014 – AUSTIN, TEXAS

Mechanical Properties of Organic Matter in Shales Mapped At the Nanometer Scale

Simon Emmanuel[1], Moshe Eliyahu[1], Ruarri J. Day-Stirrat[2], Calum I. Macaulay[2]

[1]Institute of Earth Sciences, The Hebrew University of Jerusalem, Jerusalem, Israel
[2]Shell International Exploration and Production Inc., Houston, TX, USA

Abstract

The mechanical properties of organic matter strongly affect the way shales deform and fracture. However, the way organic matter responds to mechanical stresses is poorly understood, representing a critical obstacle to assessing oil and gas production in shale formations. Little is known about the mechanical properties of organic matter in fine grained rocks primarily because it often occupies tiny nanometer-scale voids between the mineral grains which cannot be accessed using standard mechanical testing techniques. Here, we use a new atomic force microscopy technique (PeakForce QNM™) to map the mechanical properties of organic and inorganic components at the nanometer scale. We find that the method is able to distinguish between different phases such as pyrite, quartz, clays, and organic matter. Moreover, within the organic component Young's modulus values ranged from 0 - 25 GPa; in 3 different samples - all of which come from thermally mature Type II/III source rocks in the dry gas window - a modal value of 15-16 GPa was measured, with additional peaks measured at ≤ 10 GPa. In addition, the maps suggest that some porous organic macerals possess a soft core surrounded by a harder outer shell 50 – 100 nm thick. Thus, our results demonstrate that the method represents a powerful new petrographic tool with which to characterize the mechanical properties of organic-rich sedimentary rocks.

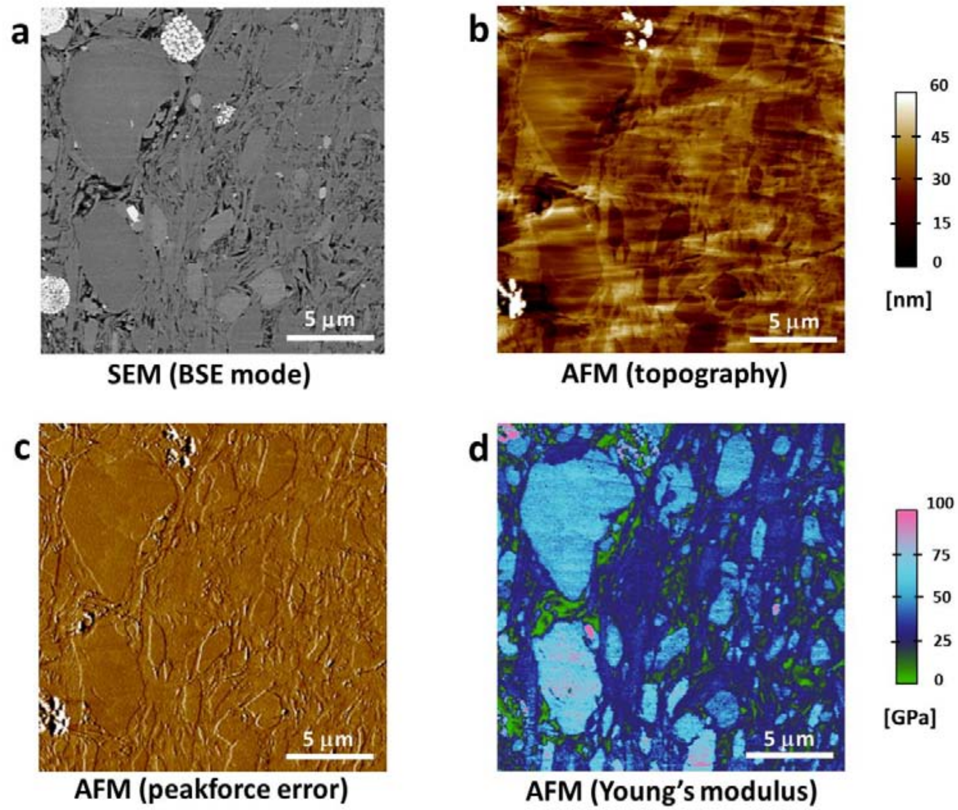

Figure 1: A 20 μm×20 μm region of Sample 1 scanned using different imaging methods. (a) SEM image (BSE mode); (b) AFM topographic mode; (c) AFM PeakForce error mode used to provide a pseudo-3D image of the surface; (d) Young's modulus map; green indicates organic matter (low stiffness), blue indicates clays, while light-blue and pink indicates quartz and calcite (high stiffness). Modulus values are cut-off at 100 GPa.

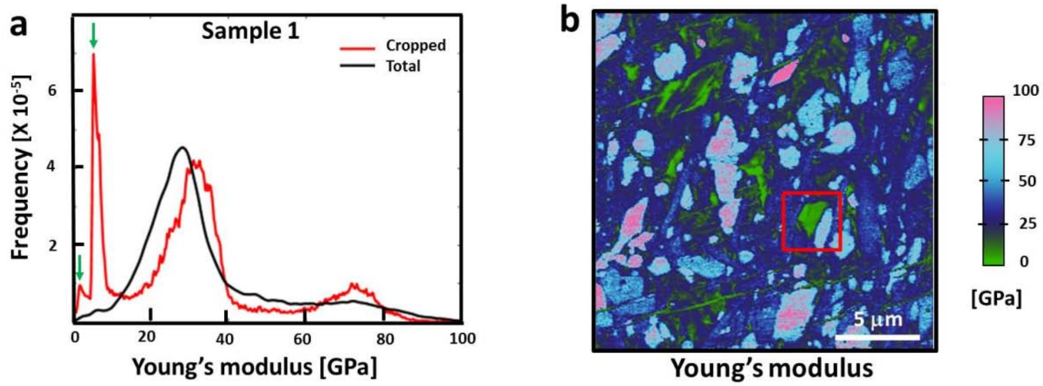

Figure 2: Probability density functions (PDF's) of Young's moduli and corresponding modulus maps in different samples. The PDF of the region outlined in red is marked referred to as the cropped region. PDF's were calculated using the kernel density estimation method. Green arrows indicate major peaks associated with the organic matter in each scan.

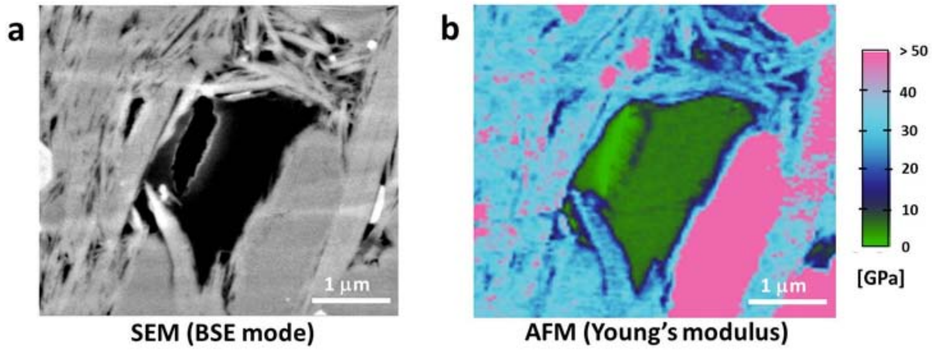

Figure 3: Comparison of SEM back-scattered electron image and modulus map of an organic maceral. Note that the maceral appears to be surrounded by a hard shell; its internal structure also shows regions of different stiffness.