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Elasticity of organic-rich chalk: insights from measurements and models

Omri Shitrit[a], Yossef H. Hatzor[a], Shimon Feinstein[a], Harold J. Vinegar [a,b]

[a] *Department of Geological and Environmental Sciences, Ben-Gurion University of the Negev, Be'er Sheva, Israel;* [b] *Israel Energy Initiatives (IEI Ltd.), Jerusalem, Israel.*
Contact email: shitrit@post.bgu.ac.il

Introduction

Organic-rich rocks have attracted a lot of attention in recent years, being self-sourcing reservoirs as well as source rocks for conventional oil and gas reservoirs. We present here an investigation of the elastic behaviour of Late Cretaceous organic-rich chalk using core samples from the Zoharim well in the Shefela basin, Israel. The investigated organic-rich chalk has low clay content, high porosity (25-45%), and high total organic carbon content (TOC, up to 20 wt%.). The organic matter, typically low-maturity kerogen, is distributed in the chalk differently than in shales being more dispersed in the matrix rather than laminated. This presentation focuses on the mechanical effects of porosity, kerogen and microstructure, particularly on the dynamic elastic moduli of the rock.

Methods

Acoustic velocities of *P* and *S* waves were measured to obtain oedometer and shear moduli of the rock. Velocities were measured using core plugs at both dry and brine-saturated conditions. The rock is assumed to be vertically transversely isotropic (VTI). To relate moduli with rock constituents, we measured the porosity and kerogen content (detailed in Shitrit et al. 2016), and used them to calculate the elastic moduli of each sample according to Hashin-Shtrikman bounds (Mavko, Mukerji and Dvorkin 2009). Marion's bounding average method (BAM) for fluid substitution was used to estimate dry rock moduli using the corresponding brine-saturated values (Mavko et al. 2009).

Results and Discussion

The oedometer and shear moduli are found to depend on both porosity and kerogen, combined into a single parameter that minimizes the scatter: "porosity-modified kerogen content" (Prasad et al. 2011). (Fig. 1). The location of the brine-saturated moduli between the HS bounds is represented by normalized stiffness factors of 0.1-0.3. Calculated dry values of the elastic moduli are very close to those measured directly on the dry samples. This suggests that the fluid substitution model (HS+BAM) is sufficiently accurate. The horizontal oedometer and shear moduli are stiffer than the corresponding vertical moduli, as expected from a typical source rock. We define here a Hashin-Shtrikman intermediate bound to simulate a kerogen-supported matrix, which is found to fit well with the measured data. We infer that the calcite particles are suspended in this fine-grained mixture of kerogen and microcrystalline calcite. This is also confirmed by backscatter SEM images. Three samples which plot higher than the HS intermediate bound (with normalized stiffness factor of ~0.4), indicate additional second order effects imposed by increased cementation and silica enrichment.

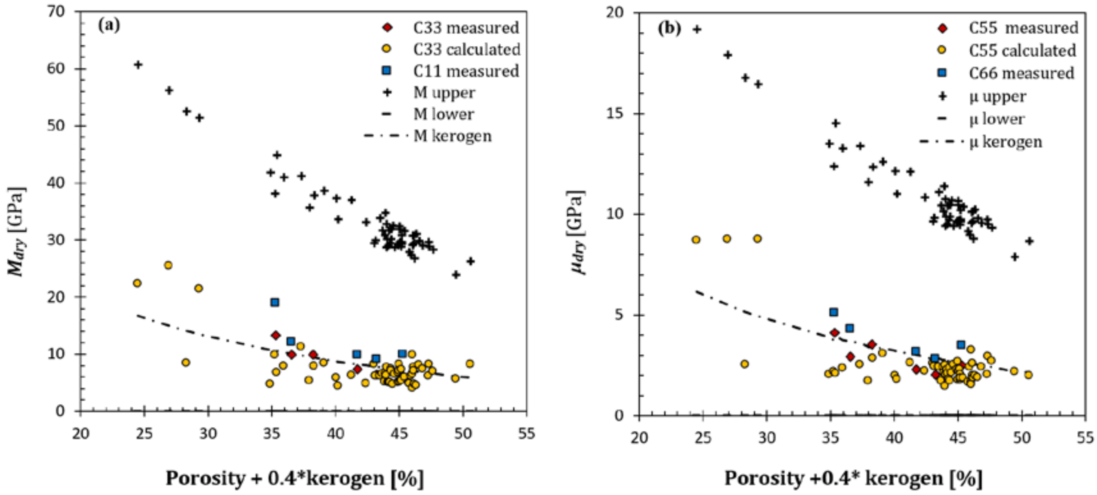

Figure 1: Oedometer modulus (a) and shear modulus (b) of the dry rock. The results are plotted vs. porosity-modified kerogen content with an apparent kerogen porosity of 40%. The measured dry rock dynamic moduli C_{33} and C_{55} from bedding-normal wave velocities are marked by diamonds and C_{11} and C_{66} from bedding-parallel wave velocities are marked by squares. The minerals-supported (upper), fluid-supported (lower) and kerogen-supported (intermediate) Hashin-Shtrikman bounds are calculated for each sample at dry conditions. The circles represent vertical oedometer and shear moduli calculated at dry conditions using the BAM model.

Conclusions

The combination of laboratory measurements, fluid substitution model estimations and backscatter SEM images reveals that the kerogen is dispersed effectively in the matrix of this organic-rich chalk. That causes the elastic moduli to correlate well with the porosity-modified kerogen content using 40% porosity-like fraction of kerogen. The elastic moduli are reliably predicted using the fluid substitution model (HS+BAM) in this VTI rock.

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