PS Rock Physics Based Quantification of Carbonate Pore Type Effect on Permeability Heterogeneity: Application to the Wolfcamp Formation, Permian Basin*

Adewale Amosu[1] and Yuefeng Sun[2]

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[1]Department of Geology and Geophysics, Texas A&M University, College Station, Texas (adewale@tamu.edu)
[2]Department of Geology and Geophysics, Texas A&M University, College Station, Texas

Abstract

Pore structure variation plays a significant role in the complex porosity-permeability relationship observed in carbonate rocks. In this study, we select a predefined pore structure parameter (PSP) from a rock physics model as a pore structure index to describe the pore type variation in the Wolfcamp Formation using integrated data from well logs, thin-section photomicrographs, cores, and lab measurements. Our studies show that in general, PSP values less than ~4.6 correspond to rock samples with interparticle porosity; values greater than ~4.6 correspond to rock samples with calcispheres and cemented pores. The PSP value ranges successfully compartmentalize the studies reservoir into distinct permeability zones. Knowledge of the pore structure and the distinct permeability zones is useful for performing inversion of seismic data for acoustic impedance and reservoir characterization. To demonstrate this, we perform forward modeling Amplitude Versus Offset (AVO) analysis on rock samples with different pore types and show that the effect of different pore types is more visible in far offset seismic data than in near offset seismic data.

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Reservoir Geophysics Program

BERG-HUGHES CENTER

Department of GEOLOGY & GEOPHYSICS, COLLEGE OF GEOSCIENCES

Rock Physics Based Quantification of Carbonate Pore Type Effect on Permeability Heterogeneity: Application to the Wolfcamp Formation, Permian Basin

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Authors: Adewale Amosu, Yuefeng Sun, *Department of Geology and Geophysics, Texas A&M University*

Introduction

- *Carbonate reservoirs account for 60% and 40% of oil and gas reserves worldwide. However, due to the limitation of production and development techniques, as well as the intense permeability heterogeneity in carbonate reservoirs, the oil and gas recovery rate is generally lower than 25%.*
- *Diagenesis often produces a more complex pore structure system and profoundly increases the heterogeneity in carbonate rocks.*
- *The pore structure in carbonates complicate the porosity-velocity and porosity- permeability relationships, lowering the prediction accuracy of porosity from porosity- impedance relationships.*
- *In this study, we make use of the Sun rock physics model and pore structure parameter (PSP), (Sun, 2000) in characterizing the velocity porosity and porosity-permeability relationships in the Wolfcamp Formation.*

Rock Physics Model

Sun (2000, 2001, 2004 and 2007) introduced a rock physics model (Sun model), based on the extended Biot theory of poroelasticity, to quantify the pore-structure effect on sonic velocity and permeability in reservoir rocks. The frame flexibility factor is defined as follows: Let Vp, Vs, ρ, K, μ be the compressional velocity, shear velocity, bulk density, bulk modulus, and shear modulus respectively related by the equations:

$$V_p = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}} \qquad V_s = \sqrt{\frac{\mu}{\rho}} \qquad \text{then} \qquad \gamma = 1 + \frac{\ln f}{\ln(1-\phi)}$$

$$\gamma_\mu = 1 + \frac{\ln f_\mu}{\ln(1-\phi)}$$

$$f = \frac{1 - \left(\frac{K_f}{K_s} + \left(1 - \frac{K_f}{K_s}\right)\phi\right) F_k}{(1-\phi)\left(1 - \frac{K_f}{K_s} F_k\right)} \qquad f_\mu = \frac{\mu}{\mu_s (1-\phi)}$$

$$F_k = \frac{K_s - K}{\phi (K_s - K_f)}$$

where γ, γ_μ, f, f_μ, and F_k are the frame flexibility factors and K_s and K_f are matrix bulk modulus and fluid bulk modulus.

Study Area and Methodology

- The Permian basin located on the northwestern border of Texas and the southeastern border of New Mexico encompasses an area in excess of 200,000 square kilometers. According to the US Energy Information Administration (EIA), the Permian accounted for 18% of total US crude oil production in 2013, exceeding production from the offshore Gulf of Mexico. Approximately ¾ of the increase in production came from the Spraberry, Wolfcamp and Bone Spring formations.
- The Permian basin is a foredeep basin that developed during the late Mississippian and early Pennsylvanian (Hills, 1984). Present day structural and tectonic features in the basin include the Central Basin Platform, the Midland basin, the Delaware basin and the Ozona arch (see Fig. 1).
- Reservoir rocks of the Wolfcamp carbonate platform, consists of cyclic shallow- water facies affected by diagenesis (Saller et al., 1999).
- The wells used in this study produce from the Wolfcamp and Spraberry formations. The core samples consist of massive shales, calcareous silty shales and some dolomitic shales interbedded with laminated to bioturbated wackestones and packstones.

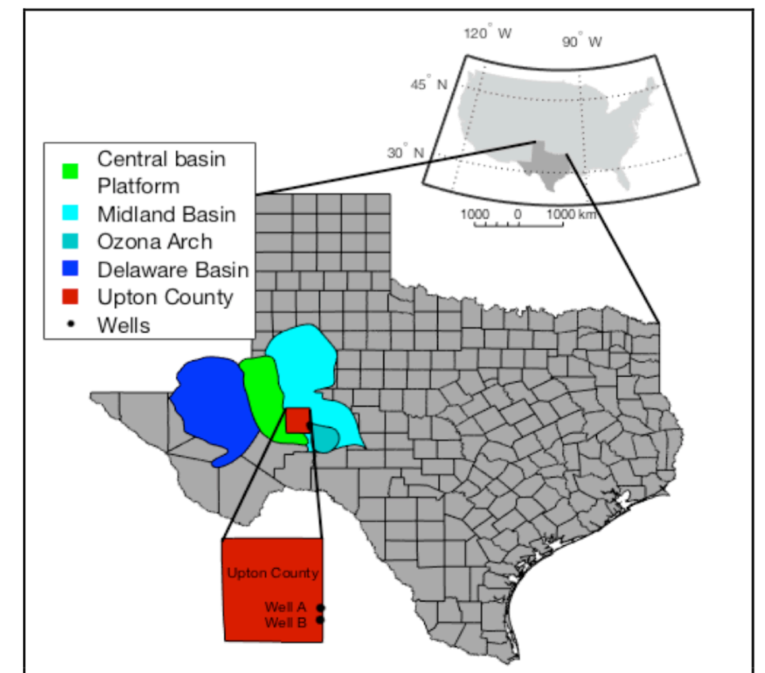

Figure 1: Location and geological setting of the study area showing the structural/tectonic features: the Central basin platform, the Midland and Delaware Basins, the Ozona Arch and the Well locations in Upton county.

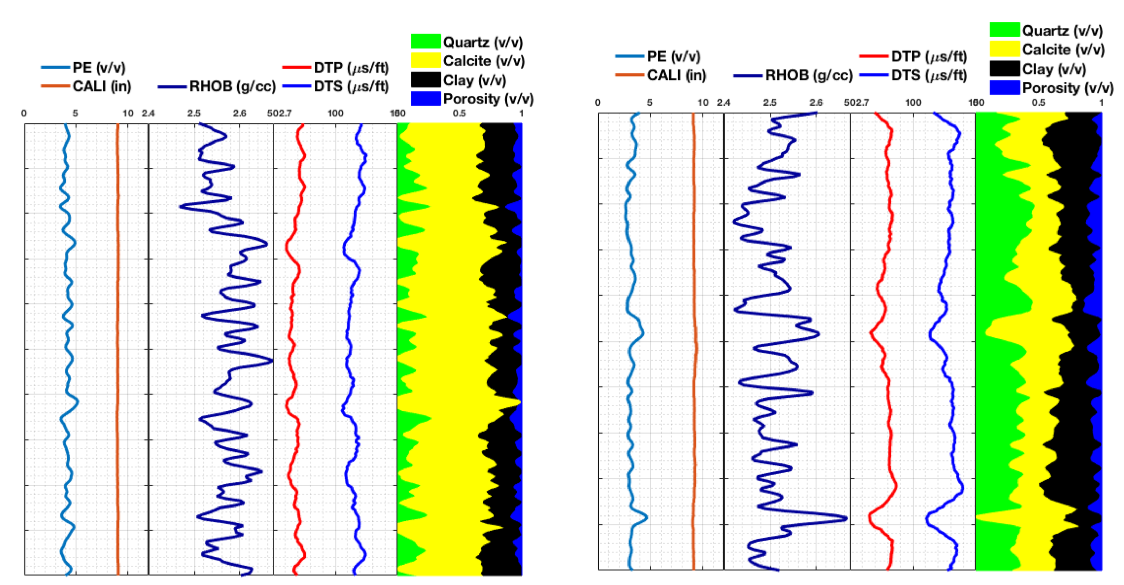

Figure 2: Inversion for Mineral components show a quartz rich zone and a calcite rich zone.

$$\begin{bmatrix} \rho_q & \rho_{ca} & \rho_{cl} & \rho_f \\ Pe_q & Pe_{ca} & Pe_{cl} & Pe_f \\ \Delta t_q & \Delta t_{ca} & \Delta t_{cl} & \Delta t_f \\ 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} V_q \\ V_{ca} \\ V_{cl} \\ \phi \end{bmatrix} = \begin{bmatrix} \rho_l \\ Pe_l \\ \Delta t_l \\ 1 \end{bmatrix}$$

where ρ, Pe, Δt, *and* V stand for bulk density, photoelectric factor, sonic travel time and volume fraction respectively. The subscripts q, ca, cl, f and l stand for quartz, calcite, clay, fluid and log measurement respectively.

Results and Discussions

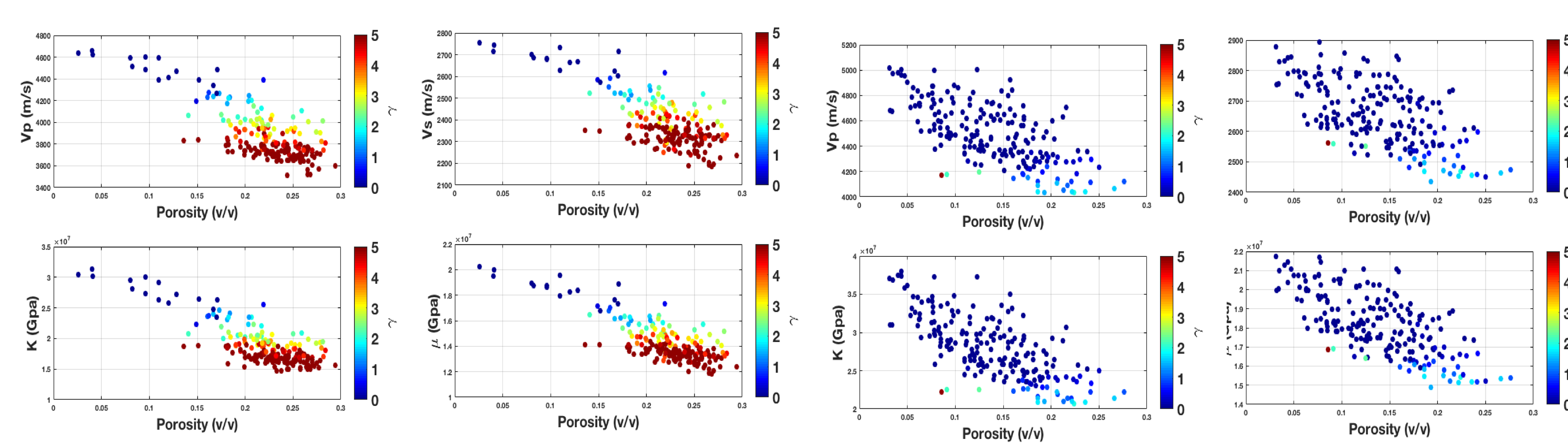

Figure 3: Quartz rich zone (a and b) and calcite rich zone (b and d). Figure shows the variation in sonic P-velocities and S-velocities at a particular porosity value. Variation in the values of Bulk modulus and Shear modulus at a fixed porosity can also be observed. The differences in the values at fixed porosities can be explained by the pore structure variation which is captured by the pore structure parameter.

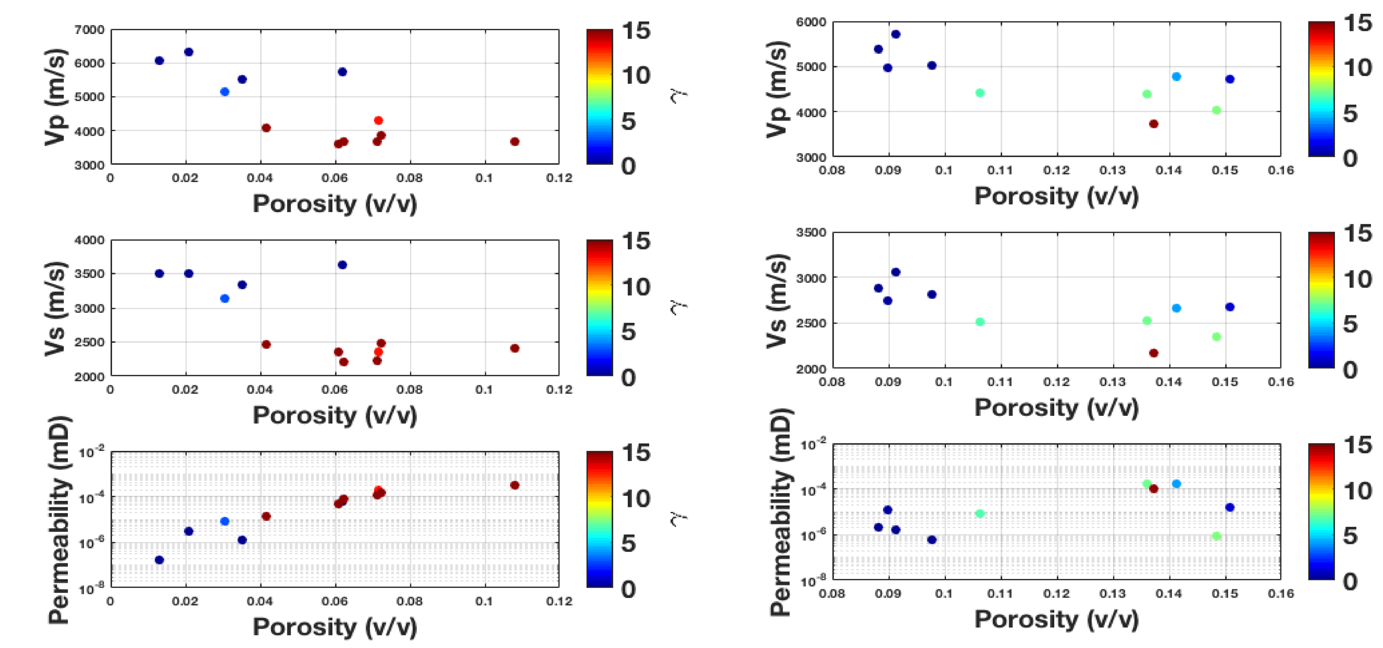

Figure 4: Cross plot of velocity and permeability data obtained from laboratory core measurements. At fixed porosity values, the difference in velocities is due to the different pore types and resulting pore structures. The pore structure parameter separates the permeability into two distinct zones.

PSP values less than ~4.6 correspond to rock samples with interparticle porosity; values between ~4.6 and ~11.2 correspond to rock samples with calcispheres and cemented pores and PSP values greater than 11.2 correspond to samples with microporosity but no visible macroporosity.

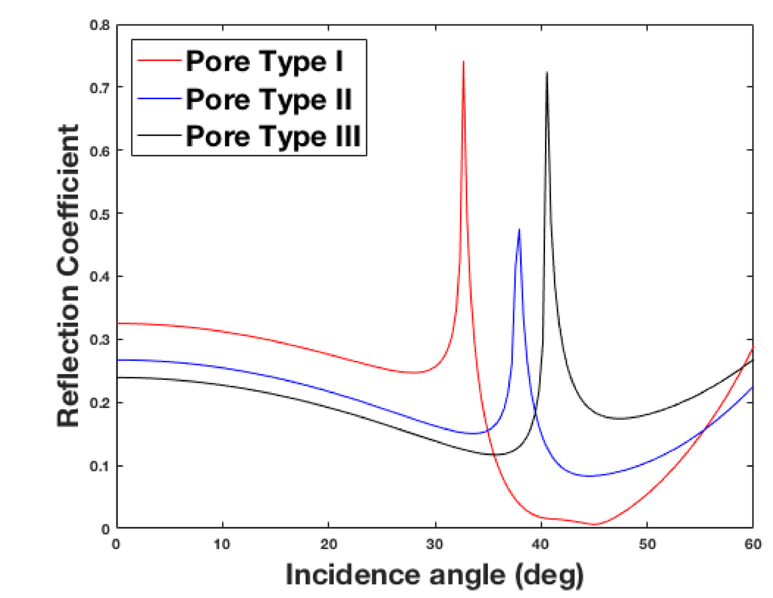

Figure 5: AVO analysis showing the effect of different pore types on seismic velocity. Figure indicates that far offset seismic data is better for distinguishing the effect of different pore types than near offset seismic data.

Some of the results in this study were generated using the MinInversion program (Amosu and Sun, 2018). For more free software and research work from the authors, see: Amosu (2013, 2014), Amosu and Sun (2017 a-e), Amosu et al., (2011, 2012, 2013, 2016, 2018a-b), Amosu and Mahmood (2018).

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