PS Post-Stack Seismic Characterization of Pore Structure Variations for Predicting Permeability Heterogeneity in Deeply-Buried Carbonate Reservoirs*

Jingyi Guo[1] and Yuefeng Sun[1]

Search and Discovery Article #42393 (2019)**
Posted July 22, 2019

*Adapted from poster presentation given at AAPG 2019 Annual Convention & Exhibition, San Antonio, Texas, May 19-22, 2019
 DOI:10.1306/42393Guo2019

[1]Texas A&M University, College Station, TX, United States (jingyig@tamu.edu)

Abstract

Alteration of depositional environment and diagenesis of carbonate rocks create various pore structures that cause strong heterogeneity in permeability. In this research, we analyzed the petrophysical and elastic characteristics of diverse carbonate reservoir pore types in deeply-buried Puguang Gas Field, China by integrating core, well log and seismic data. We investigated core and well log measurements using a frame flexibility factor (γ) derived from a rock physics model of poroelasticity to classify different pore types in Feixianguan formation of Puguang Gas Field and build the relationship between porosity and permeability for different pore type groups. The frame flexibility factor (γ) having a good correlation with pore shape instead of porosity, can be used as the pore structure indicator to classify moldic ($\gamma < 5$), intercrystalline ($5 < \gamma < 15$), and micro-intercrystalline pores ($\gamma > 15$) in the studied reservoir. Two distinct permeability trends were observed within two main pore types. At a similar porosity value, permeability is high in well-connected intercrystalline pores and low in isolated moldic pores. The effect of pore structure variations on acoustic velocity and impedance was then quantified using the pore type index (γ). A more linear correlation of acoustic impedance (AI) and the product of porosity and γ was established. Results show that moldic pores have higher AI, while intercrystalline pores have lower AI at a given porosity. These relations were finally used to interpret seismic AI inversion results and estimate the spatial variation of permeability using the post-stack seismic data. Moldic pores generated in ooid shoals after transgression and selectively dissolution have lower permeability appearing as high AI; while in early regression, dolostones with intercrystalline pores deposited in restricted platform experiencing reflux and burial dolomitization have relatively higher permeability, manifested in low AI value. The result shows great influence of varied carbonate pore structures on permeability heterogeneity and can be useful for further reservoir prediction.

References Cited

Ma, Y., X. Guo, T. Guo, R. Huang, X. Cai, and G. Li, 2007, The Puguang Gas Field: New giant discovery in the mature Sichuan Basin, southwest China: AAPG Bulletin, v. 91/5, p. 627–643.

Ma, Y., T. Guo, X. Zhao, and X. Cai, 2008, The formation mechanism of high-quality dolomite reservoir in the deep of Puguang Gas Field. Science in

China, Series D: Earth Sciences, v. 51/(SUPPL. 1), p. 53–64.

Russell, B., and D. Hampson, 1991, Comparison of poststack seismic inversion methods: Paper read at 1991 SEG Annual Meeting, 1646, p. 1052-3812.

Sun, P., H. Xu, Q. Dou, H. Adesokan, Y. Sun, Q. Huang, and N. Jiang, 2015, Investigation of pore-type heterogeneity and its inherent genetic mechanisms in deeply buried carbonate reservoirs based on some analytical methods of rock physics: Journal of Natural Gas Science and Engineering, v. 27, p. 385–398.

Sun, Y.F., 2000, Core-log-seismic integration in hemipelagic marine sediments on the eastern flank of the Juan de Fuca ridge: Proceedings of the Ocean Drilling Program, Scientific Results, v. 168, p. 21–35.

Yu, Y., X. Tan, P. Chen, H. Yang, T. Ma, J. Cao, and X. Jin, 2015, Discovery of hiatus in Feixianguan Formation and its geological implications, Sichuan Basin, SW China: Turkish Journal of Earth Sciences, v. 24/1, p. 39–55.

Post-Stack Seismic Characterization of Pore Structure Variations for Predicting Permeability Heterogeneity in Deeply-Buried Carbonate Reservoirs

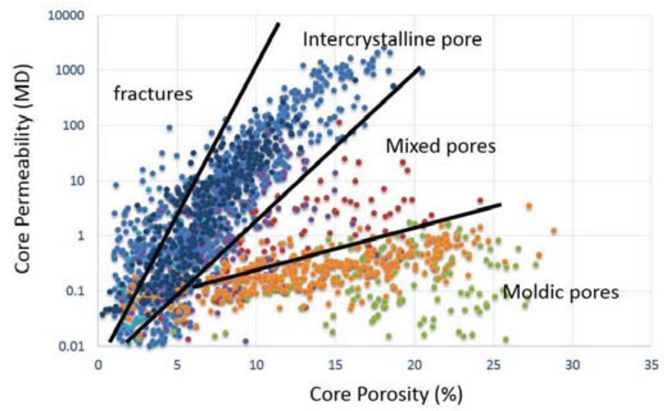
GEOLOGY AND GEOPHYSICS
TEXAS A&M UNIVERSITY

Jingyi Guo[1,2](jingyig@tamu.edu), Yuefeng Sun[1,3]

[1]Texas A&M University, [2]Student Author, [3]Advisor

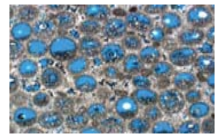
ACE 2019 ANNUAL CONVENTION & EXHIBITION
19–22 May • San Antonio, Texas

OBJECTIVES



Intercrystalline

Moldic



- Integrate core and log to obtain more accurate estimation of pore structure.
- Establish the relationship between pore structure and permeability.
- Study elastic characteristics of various pore structures.
- Predict the spatial distribution of permeability with post-stack AI inversion.

METHODS

○ Sun's Rock Physics Model

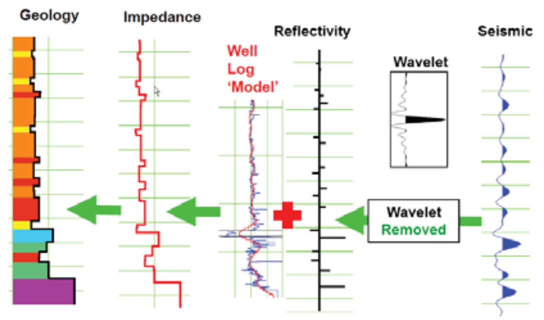
$$V_p = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}} \qquad K_d = K_s(1-\phi)^{\gamma}$$

$$V_s = \sqrt{\frac{\mu}{\rho}} \qquad \mu_d = \mu_s(1-\phi)^{\gamma_\mu}$$

For gas reservoir: $K = K_d$ $\quad \mu = \mu_d$

- K and μ are bulk and shear modulus, respectively
- Φ, γ and γ_μ are porosity and frame flexibility factors , respectively
- K_s, K_d and μ_s are frame, dry bulk and shear modulus, respectively

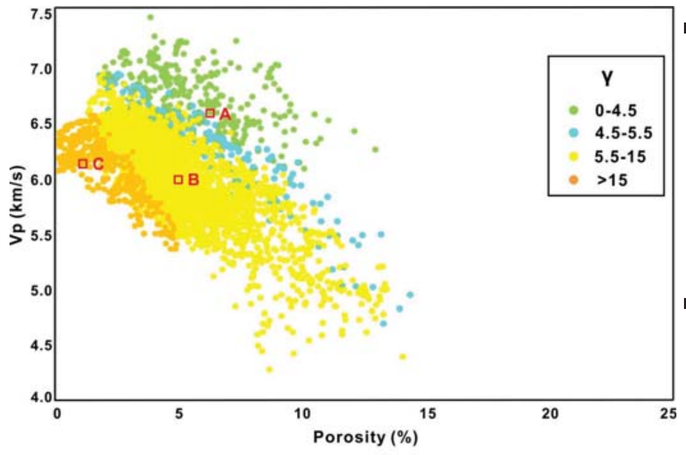
○ Post-Stack AI Inversion (Model Based)

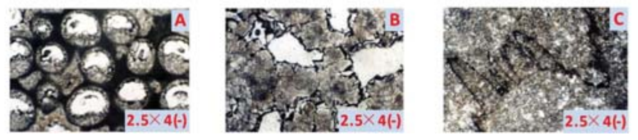


$$AI = \rho * V_p$$

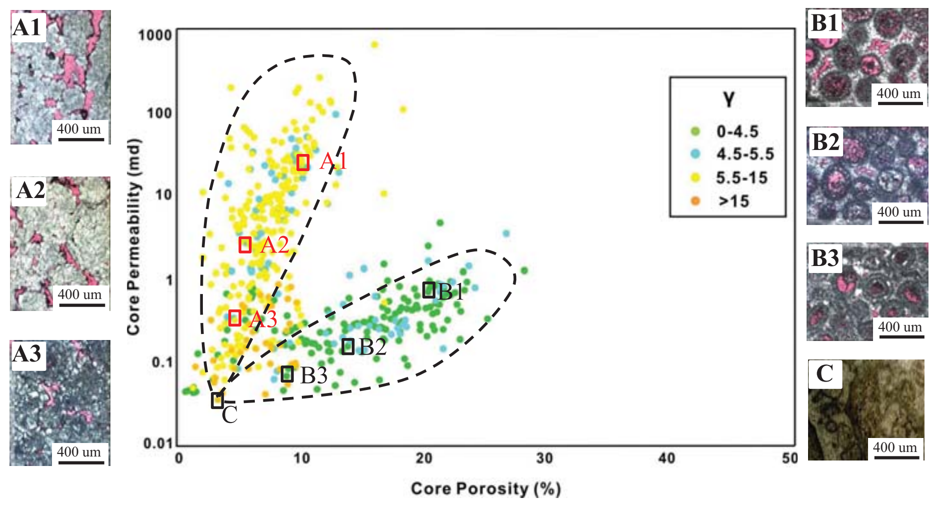
- AI is acoustic impedance
- ρ is density
- Vp is compressional wave velocity

RESULTS

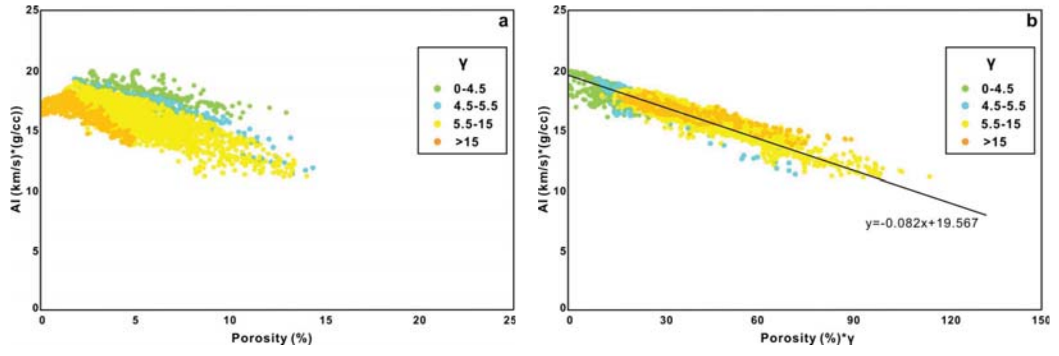


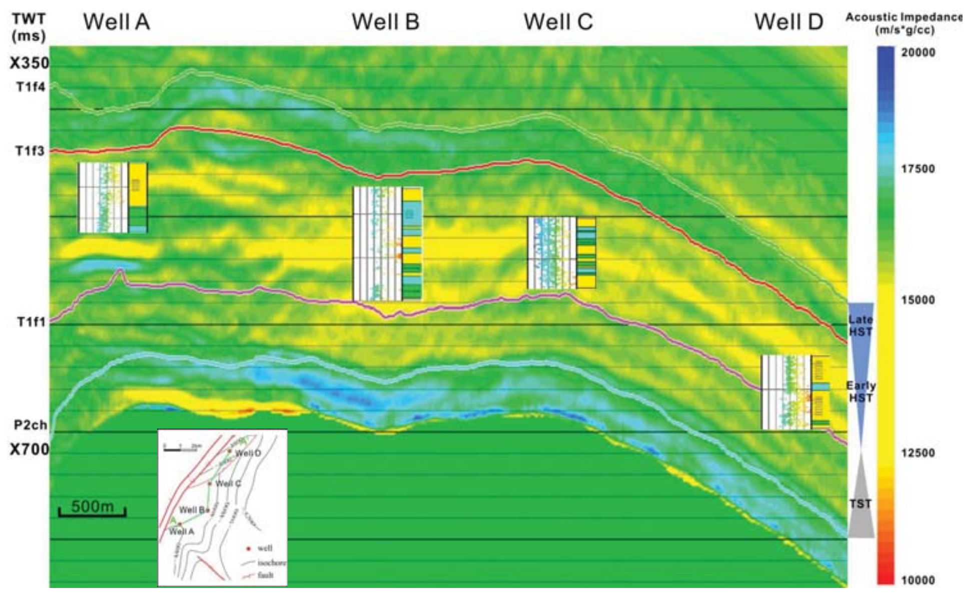


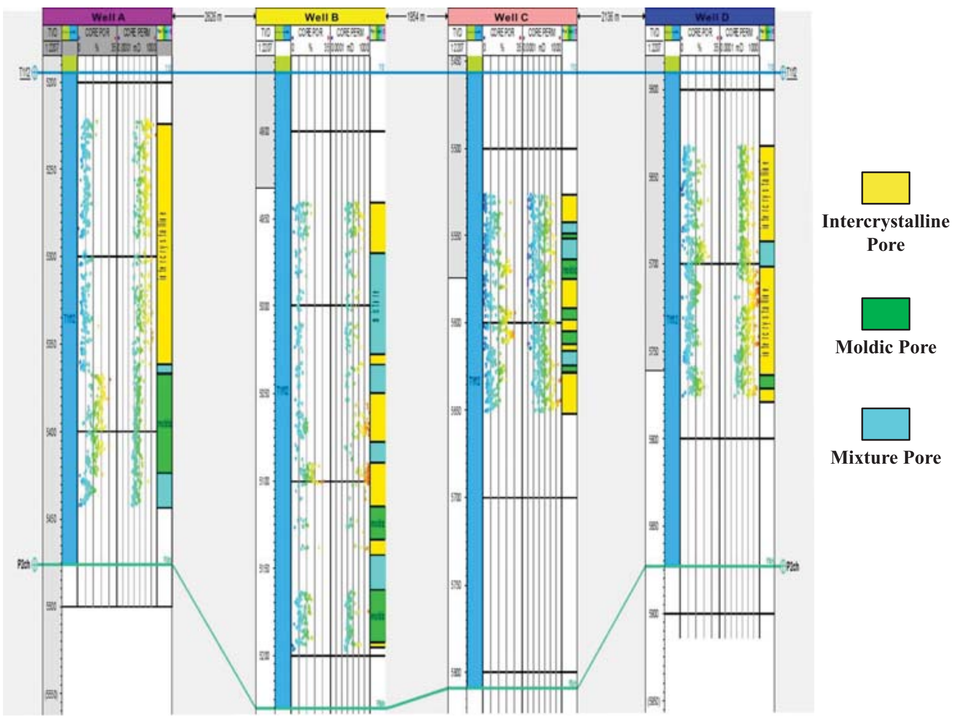
- Velocity differs significantly at a given porosity due to different pore types, which can be explained by frame flexibility factor γ.
- When $\gamma < 4.5$, moldic pore (A) dominated; when $5.5 < \gamma < 15$, intercrystalline pore (B) dominated; when $\gamma > 15$, micro-intercrystalline pore (C) dominated.



- Two permeability trends controlled by pore structure are identified by frame flexibility factor
  - In the lower permeability trend, the dominant pore type is moldic pores.
  - In the higher permeability trend, intercrystalline pore is abundant.



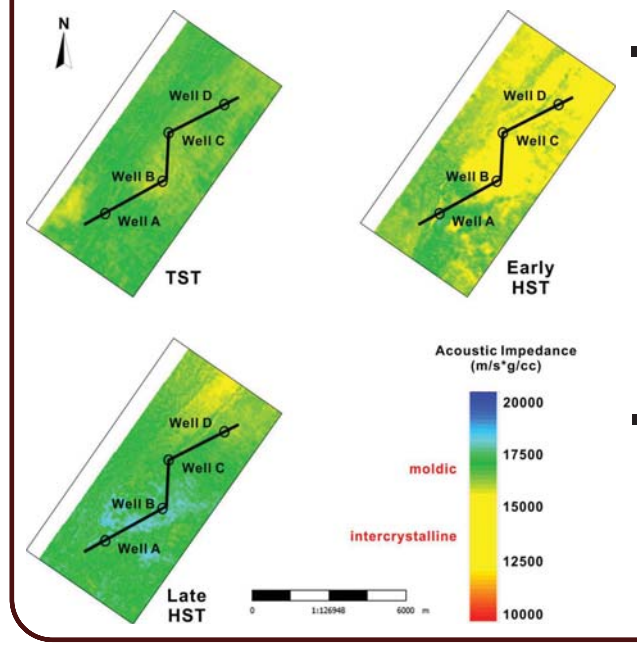




- Intercrystalline pores with higher permeability have lower AI;
- Moldic pores with lower permeability have relatively higher AI.

CONCLUSIONS

- The frame flexibility factor (γ) with a good correlation with pore shape instead of porosity, can be used as the pore structure indicator to classify moldic ($\gamma < 4.5$), intercrystalline ($5.5 < \gamma < 15$), and micro-intercrystalline pores ($\gamma > 15$) in the studied reservoir.
- Two distinct permeability trends were observed within two main pore types. At a similar porosity value, permeability is high in well-connected intercrystalline pores and low in isolated moldic pores.



- A more linear correlation of acoustic impedance (AI) and the product of porosity and γ was established. Results show that moldic pores have higher AI, while intercrystalline pores have lower AI at a given porosity.
- The spatial heterogeneity of permeability caused by varied pore structure can be defined by post-stack AI inversion.

REFERENCES

Ma, Y., Guo, X., Guo, T., Huang, R., Cai, X., and Li, G. 2007. The Puguang Gas Field: New giant discovery in the mature Sichuan Basin, southwest China. *AAPG Bulletin*, *91*(5), 627–643.

Ma, Y., Guo, T., Zhao, X., and Cai, X. 2008. The formation mechanism of high-quality dolomite reservoir in the deep of Puguang Gas Field. *Science in China, Series D: Earth Sciences*, *51*(SUPPL. 1), 53–64.

Russell, B., and Hampson, D. (1991). Comparison of poststack seismic inversion methods. Paper read at 1991 SEG Annual Meeting, 1646, 1052-3812.

Sun, P., Xu, H., Dou, Q., Adesokan, H., Sun, Y., Huang, Q., and Jiang, N. 2015. Investigation of pore-type heterogeneity and its inherent genetic mechanisms in deeply buried carbonate reservoirs based on some analytical methods of rock physics. *Journal of Natural Gas Science and Engineering*, *27*, 385–398.

Sun, Y. F. 2000. Core-log-seismic integration in hemipelagic marine sediments on the eastern flank of the Juan de Fuca ridge. *Proceedings of the Ocean Drilling Program, Scientific Results, Vol 168*, *168*, 21–35.

Yu, Y., Tan, X., Chen, P., Yang, H., Ma, T., Cao, J., and Jin, X. 2015. Discovery of hiatus in Feixianguan Formation and its geological implications, Sichuan Basin, SW China. *Turkish Journal of Earth Sciences*, *24*(1), 39–55.