[PS]Multi-Component Characterization of Carbonate Reservoirs*

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Search and Discovery Article #41916 (2016)**
Posted October 17, 2016

*Adapted from poster presentation given at AAPG Annual Convention & Exhibition, Calgary, Alberta, Canada, June 19-22, 2016

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Abstract

Combined and simultaneous interpretation of compressional wave (P-wave) and shear wave (S-wave) data can improve subsurface images and estimation of reservoir and fluid properties. The improvement is possible because P-waves and S-waves respond differently to solids and fluids. Recent advances made to quantify relationships between P-wave velocity (Vp) and S-wave velocity (Vs) have led to using the relationships predictably, and to the technical development of petrophysical models for quantitative reservoir characterization, especially in carbonate reservoirs.

Development of predictive petrophysical models is based on a family of linear equations relating Vp, Vs and porosity at different levels of effective stress. Multiple parameters extracted from the slopes and intercepts of the linear equations exhibit special uniqueness for carbonates and are superior to the traditional use of the Vp/Vs ratio for lithology prediction. They also show that S-waves "see" carbonate porosity and pore fluids better than P-waves, and that effective stress or rock competence is an important factor when interpreting multi-component data. Examples are shown, using core data, where linear-linear crossplots and the parameters derived from the family of equations can be used to discriminate pore fluids and carbonate rock-types, determine carbonate reservoir heterogeneity, and distinguish carbonates from sandstones. These results provide a new knowledge base and systematic technical development and understanding of applications of multi-component data. The results can further unleash new technologies in the emerging area of seismic petrophysics, and in monitoring carbon dioxide (CO_2) flood front during injection or sequestration. Other potential outcomes include improved estimation of rock mechanical properties, "manufacture" of Vs from Vp, and use of S-wave data to refine porosity and fluid estimation.

Multi-Component Characterization of Carbonate Reservoirs

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ABSTRACT

Combined and simultaneous interpretation of compressional wave (P-wave) and shear wave (S-wave) data can improve subsurface images and extraction of reservoir and fluid properties. The improvement is possible because P-waves and S-waves respond differently to solids and fluids. Recent advances made to quantify relationships between P-wave velocity (Vp) and S-wave velocity (Vs) have led to using the relationships predictably, and to the technical development of petrophysical models for quantitative reservoir characterization, especially in carbonate reservoirs.

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Presented at the AAPG Annual Convention & Exhibition 2016,
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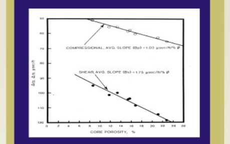
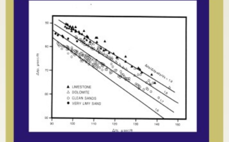
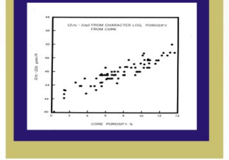
Genesis of Quantitative Carbonate Reservoir Characterization

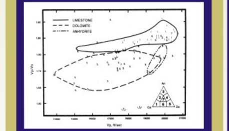
Pickett, G.R. (1963)





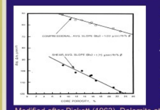


Rafavich et al (1984)



Ikwuakor, K.C. (1988)

Development of Rock Property Interrelations
(Vp and Vs Examples)



$\Delta t = \Delta tm + B\,Ø$

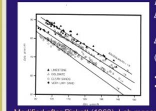
↓

$\Delta tp = \Delta tmp + Bp\,Ø$
$\Delta ts = \Delta tms + Bs\,Ø$ --

- *Rock-typing*
- *Porosity modeling*
- *Use Vs to refine porosity estimation*

Modified after Pickett (1963). Dolomite at 6000 psi effective stress

Development of Rock Property Interrelations
(Vp and Vs Examples)



$\Delta tp = \Delta tmp + Bp\,Ø$
$\Delta ts = \Delta tms + Bs\,Ø$

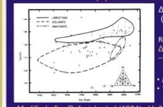
↓

$\Delta ts = [\Delta tms - (Bs/Bp)\Delta tmp] + (Bs/Bp)\Delta tp)$ ---3

- *Rock-typing*
- *"manufacture" Vs from Vp*

Modified after Pickett (1963). Lab measurements of compressional and shear wave velocities on limestones, dolomites and sandstones

Development of Rock Property Interrelations
(Vp and Vs Examples)



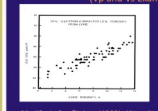
$\Delta ts = [\Delta tms - (Bs/Bp)\Delta tmp] + (Bs/Bp)\Delta tp)$

Redefinition of the Vp/Vs ratio
$\Delta ts/\Delta tp = Vp/Vs = Bs/Bp + [\Delta tms - (Bs/Bp)\Delta tmp)][Vp]$ ----4

- *Rock-typing*
- *"manufacture" Vp/Vs from Vp*

Modified after Rafavich et al (1984). Vp/Vs vs. Vp for brine-saturated carbonate samples.

Development of Rock Property Interrelations
(Vp and Vs Examples)



$\Delta tp = \Delta tmp + Bp\,Ø$
$\Delta ts = \Delta tms + Bs\,Ø$

↓

$(\Delta ts - \Delta tp) = (\Delta tms - \Delta tmp) + (Bs - Bp)(Ø)$ ------5

- *Rock-typing*
- *Porosity modeling*
- *Refinement of porosity estimation*

Modified after Pickett (1963). ($\Delta ts - \Delta tp$) vs. porosity for limestone section.

Ikwuakor, K.C. (1988)

Slopes and intercepts derived from linear regression analysis of 1/Vp and 1/Vs response relations (Domenico, S.N., 1984) and interrelations at different levels of effective stress for limestone and sandstone.

Slopes and Intercepts

SANDSTONE

Effective Stress (psi)	Eq.1 Δtmp	Eq.1 Bp	Eq.2 Δtms	Eq.2 Bs	Eq.3&4 Bs/Bp	Eq.3&4 [Δtms-(Bs/Bp)Δtmp]	Eq.5 (Δtms-Δtmp)	Eq.5 (Bs-Bp)
500	49	176	72	409	2.3	-43	22	234
2000	51	131	73	304	2.3	-44	22	173
4000	50	115	69	280	2.4	-51	19	165
6000	50	111	68	272	2.4	-51	19	161

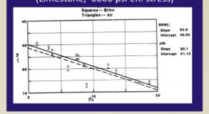
LIMESTONE

Effective Stress (psi)	Eq.1 Δtmp	Eq.1 Bp	Eq.2 Δtms	Eq.2 Bs	Eq.3&4 Bs/Bp	Eq.3&4 [Δtms-(Bs/Bp)Δtmp]	Eq.5 (Δtms-Δtmp)	Eq.5 (Bs-Bp)
500	52	113	102	199	1.8	8	50	85
2000	51	74	97	115	1.6	16	46	41
4000	51	61	95	93	1.5	20	45	33
6000	50	55	94	84	1.5	19	44	29

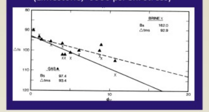
Above results for limestone have been corroborated in a separate study of burrowed and non-burrowed carbonate reservoirs: "C" Zone, Red River Formation, Williston Basin, USA. (Ikwuakor, K.C., 1994)

Selected Laboratory Results:
Effects of fluid changes on Slopes and Intercepts.

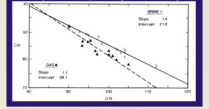
Vp and Vs Interrelations
(Limestone, 6000 psi eff. stress)



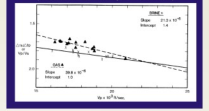
Vp and Vs Interrelations
(Limestone, 6000 psi eff. stress)



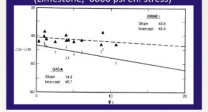
Vp and Vs Interrelations
(Limestone, 6000 psi eff. stress)



Vp and Vs Interrelations
(Limestone, 6000 psi eff. stress)



Vp and Vs Interrelations
(Limestone, 6000 psi eff. stress)



Conclusions and Anticipated Results

- Family of 5 equations expands spectrum of combined use of S-waves and P-waves
- Redefinition of the Vp/Vs ratio facilitates data analysis and prediction of results
- "Manufacture" Vs and Vp/Vs ratio from Vp
- Use dipole sonic logs in modified Pickett-plots
- Less ambiguity in lithology predictions
- S-waves "see" porosity and gas better than P-waves
- New ratio – Bs/Bp (≈ 1.5 in limestone & 2.4 in sandstone)
- Research potential – could benefit rock physics, rock mechanics, and petrophysics

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