Submission code: PVP8JRNZVX

See this and other abstracts on our website: https://home.sbgf.org.br/Pages/resumos.php

Rock physics analysis for estimation of density properties of non-logged shallow section in offshore wells

Frank Cenci Bulhoes (Petrobras), Mario Florencio Paiva (SLB), Gleidson Ferreira (Petrobras), Alex Passamani (Petrobras), YASMIN LEONE (SLB), Diego Rodrigues (Fundação Gorceix)

Rock physics analysis for estimation of density properties of non-logged shallow section in offshore wells.

Please, do not insert author names in your submission PDF file

Abstract Summary

Measuring physical properties along the wellbore is crucial for estimating and modeling rock properties volumetrically in areas of interest. However, shallow well sections are often unlogged due to economic and technical constraints, creating information gaps that hinder our understanding of geological trends in the first few hundred meters. To address this, various velocity-density relationships have been tested to estimate density logs, especially for unconsolidated intervals below the seabed or where gaps exist. This analysis indicates that velocity-density relationships align more closely with a fifth-degree polynomial function than with the commonly used Gardner equation, which relies on an exponential function.

Introduction

The initial few dozen to hundreds of meters of a well are often unlogged. Several, including technical challenges, can escalate drilling campaign costs contribute to this. This leads to creating a “blind zone” as seismic data are often not processed to image the shallow sections, and there is insufficient well data to characterize rock properties properly (Bulhões *et al*., 2015). However, advancements in seismic processing techniques now enable the recovery of seismic velocities with improved accuracy, even in shallow section, as correctly estimating sea bottom velocity is an important step in processing. Consequently, seismic velocity emerges as key information for understanding and modeling the properties of the shallow section.

Through the years, empirical velocity-density relationships have been established by researchers such as Ludwing *et al.* (1970), Gardner *et al.* (1974) and, Castagna (1993). Gardner estimated an average exponential transformation through a velocity-density, $\rho(g/cm^3) = 0.31V^{0.25}$, with V in m/s (Equation 01). While this equation aims to serve as a best-fit curve for all types of lithologies, it tends to overestimate sands’ density and underestimate shale density (Hilterman, 2001). Furthermore, the hydrocarbon effect should be considered for using Gassman’s fluid substitution (Gassman, 1951), and the equation should not be applied to individual lithologies without local calibrations (Paiva, 2021). Despite the good approach, both techniques struggle to correlate lithologies due to their empirical derivation accurately, necessitating strict application to the studied rocks (Mavko, 1998).

Our approach does not aim at lithology characterization; instead, it captures the natural trend of velocity-density relationships focused on a fit-to-data proposal. Local calibration indicates that the rocks studied here align with a fifth-degree polynomial function, using an empirical function based on a best-fit curve across all logged intervals, as outlined by Brocher (2005), given by the Nafe-Drake equation $\rho(g/cm^3) = 1.6612V_P - 0.4712V_P^2 + 0.0671V_P^3 - 0.0043V_P^4 + 0.000106V_P^5$ with V in km/s (Equation 02), the local empirical function has been derived from the 220 wells available for this study. It was compared with other empirical functions to estimate the density log for all analyzed relationships and verified for quality control and application feasibility.

Method

This study’s methodology was applied to an offshore area in the Campos Basin, northeastern Rio de Janeiro state – Brazil, where the water column ranges from 50 m to approximately 2200 m. The project encompasses 220 wells situated in different geological environments, including Turonian turbidites (Carapebus Formation) and Albian carbonates (Quissamã Formation) in the post-salt section, as well as Aptian carbonates (Alagoas level – Lagoa Feia Formation) in pre-salt section (Winter *et al.* 2007; Camargo *et al*., 2023).

Given the heterogeneity of these environments, the wells were gathered into three groups, with the water column serving as the main parameter for classification. A secondary classification was implemented based on similar geological zones, as described in Table 01.A and Table 01.B, respectively. This dual-tier classification approach was designed to effectively address the complexities of the varying geological settings and ensure a more accurate analysis of the velocity-density relationships across the different sections.

A)

Group	Water Column	Number of Wells
Shallow Water	40m to 500m	130
Transition Water	500m to 2000m	64
Deep Water	From 2000m	28

B)

Zones	Interval
Zones 01	Sea Botton to Marco Azul
Zones 02	Turonian to Cretaceous
Zones 03	Albian
Zones 04	Salt Base to Basement

Table 01: Grouping scheme according water column in table 01.A and zones created to deal with the high geological environment variability in table 01.B

The analysis was performed using a velocity-density crossplot, following the scheme outlined in Table 01. This approach enabled the extraction of a velocity-density relationship specific to each well group for every zone, where grouping similar geological environments is expected to yield a characteristic elastic response. This can potentially lead to a more accurate relationship. As a control parameter, both the uncalibrated Gardner and Brocher models can be inspected jointly with the local estimated velocity-density function.

Results

Figure 01 demonstrates the application of our analysis across all wells in each zone, as previously outlined. This method was then expanded to include additional groups of wells, enabling the extraction of the best-fit fifth-degree polynomial function for each zone and collectively for all zones. The results of the density curves are illustrated in Figure 02, which shows the measured density alongside the calibrated fifth-degree density, compared to the velocity and density predictions from the Brocher equation. To ensure quality control, correlation coefficients (r) and determination coefficients (r^2) were calculated to evaluate the effectiveness of the locally calibrated function against other empirical models. Detailed results are available for review in Table 02.

Conclusions

Gardner's density model typically shows a variation of ± 0.1 g/cm^3 compared to the Brocher/Nafe & Drake models, but it diverges significantly for Vp values below 2 km/s, as illustrated in Figure 01. In the shallow zones of the wells, particularly where Vp is less than 2 km/s and density is below 2 g/cm^3, Gardner's model does not serve effectively as a comparison parameter.

The Brocher model, on the other hand, aligns well with the data distribution across all scenarios when compared to measured density. However, the locally calibrated model demonstrates greater accuracy than the Brocher model, as indicated in Table 02. The correlation coefficients (r and r^2) for both models remain similar regardless of the scenario analyzed, suggesting that estimating density from Vp using the Brocher model is less time-consuming. This is due to its direct application to data without needing to create zones or compile wells, as demonstrated here.

Consequently, employing the Brocher model to estimate density and fill gaps in measured data is a practical approach. While both models are valid for density estimation, the choice between them depends on the specific objectives and the time available for the task.

Acknowledgments

The authors are Grateful to Petrobras – Petróleo Brasileiro for the provision of all data used in this research as well as to SLB for providing software access for the development of this study.

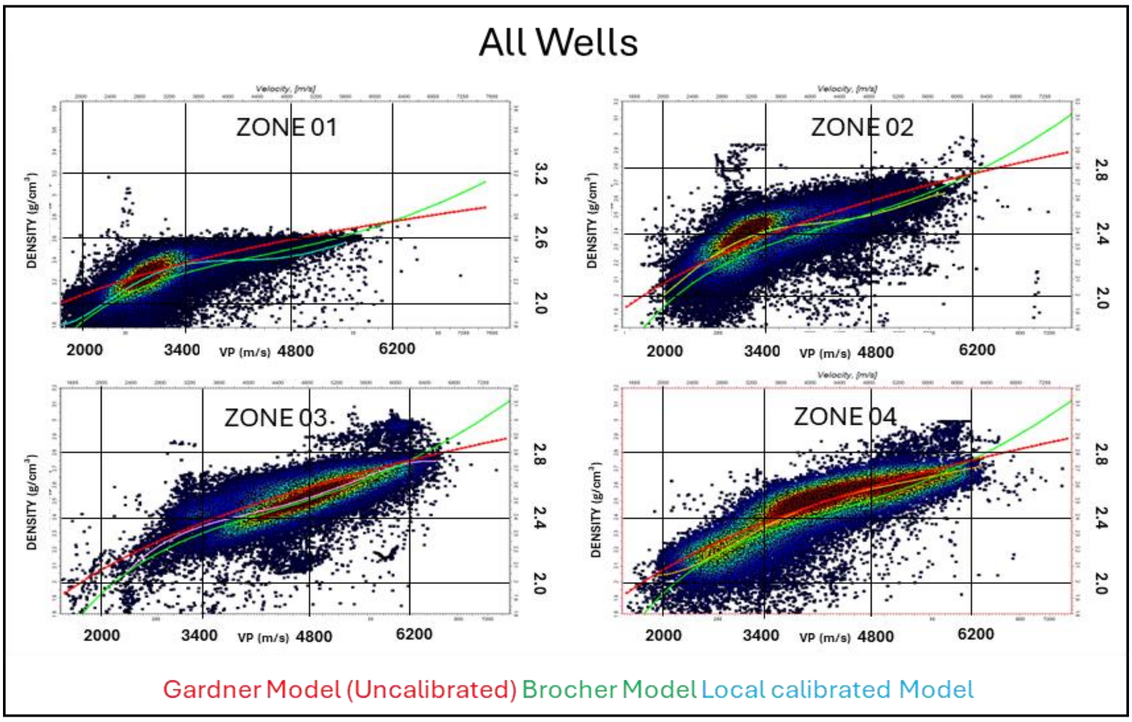

Figure 1: Example of velocity-density crossplot with the superimposed models illustrating the fit of each one.

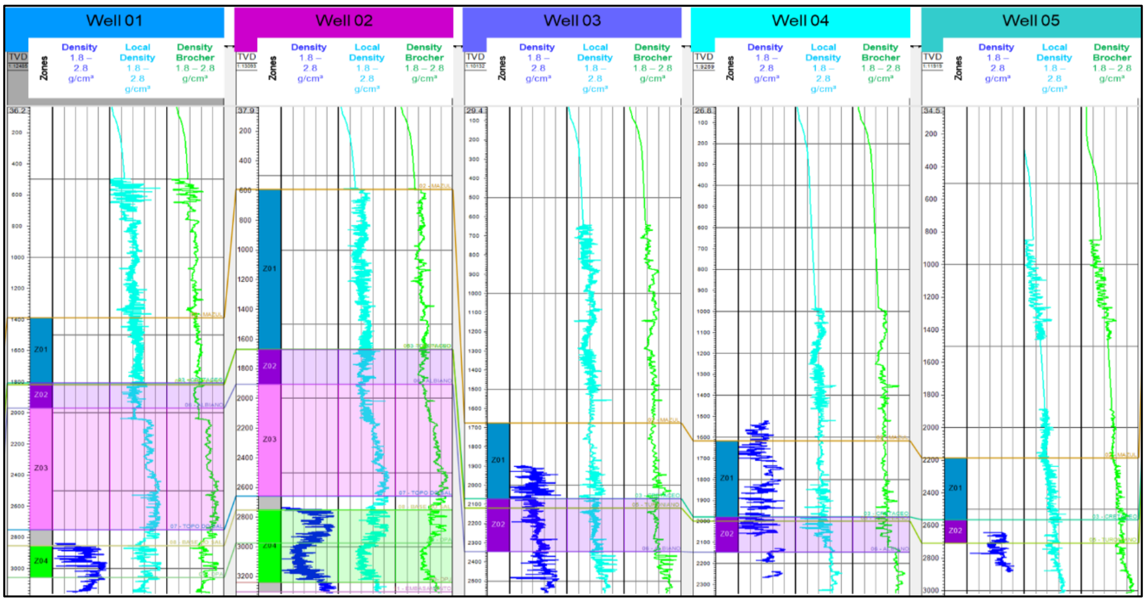

Figure 02: The measured density and the calibrated fifth-degree density as a function of velocity and density from the Brocher equation results of the density curves.

All Wells

DENS x DENS BROCHER/ DENS x LOCAL DENS_VP	Correlation Coefficient (r)	Determination Coefficient(r^2)
ZONE 01	0.64/0.65	0.41/0.43
ZONE 02	0.71/0.72	0.51/0.53
ZONE 03	0.76/0.75	0.58/0.57
ZONE 04	0.82/0.82	0.67/0.68
ALL ZONES	0.81/0.82	0.66/0.68

Shallow Water Wells

DENS x DENS BROCHER/ DENS x LOCAL DENS_VP	Correlation Coefficient (r)	Determination Coefficient(r^2)
ZONE 01	0.66/0.66	0.43/0.44
ZONE 02	0.65/0.67	0.43/0.45
ZONE 03	0.70/0.70	0.48/0.49
ZONE 04	0.82/0.83	0.68/0.69
ALL ZONES	0.84/0.85	0.71/0.72

Transition Water Wells

DENS x DENS BROCHER/ DENS x LOCAL DENS_VP	Correlation Coefficient (r)	Determination Coefficient(r^2)
ZONE 01	0.66/0.67	0.44/0.45
ZONE 02	0.68/0.70	0.46/0.49
ZONE 03	0.70/0.70	0.48/0.49
ZONE 04	0.67/0.71	0.45/0.51
ALL ZONES	0.76/0.77	0.57/0.60

Deep Water Wells

DENS x DENS BROCHER/ DENS x LOCAL DENS_VP	Correlation Coefficient (r)	Determination Coefficient(r^2)
ZONE 01	0.44/0.47	0.20/0.22
ZONE 02	0.85/0.85	0.73/0.73
ZONE 03	0.74/0.72	0.54/0.51
ZONE 04	0.79/0.81	0.64/0.65
ALL ZONES	0.84/0.84	0.70/0.70

Table 02: The statistical metrics provide insight into the accuracy and reliability of the local function relative to established modes.

References

Bulhões, F. C. et al. 2015. Geostatistical 3D Density Modeling: Integrating Seismic Velocity and Well Logs. 14th International Congress of the SBGf.

Brocher, T. 2005. Empirical Relations between Elastic Wavespeeds and Density in the Earth's Crust. Bulletin of the Seismological Society of America. 95. 2081 - 2092.

Camargo, G., González, M., Maul, A., Mohriak, W. 2023. Challenges in velocity model building in areas with carbonate rafts: a case study in the Campos Basin. In: 18th International Congress of the SBGf.

Castagna, J. P., Batzle, M.L. and Kan, 1993. Rock Physics: The link between rock properties and AVO response, In: Offset-dependet reflectivity - Theory and practice of AVO analysis, Castagna, J.P. and Backus, M. M., editors. Investigations in Geophysics no. 8, SEG, OK, 135-171

Gardner, G. H. F., L. W. Gardner, and A. R. Gregory 1974. Formation velocity and density—the diagnostic basics for stratigraphic traps, Geophysics 39, 770–780.

Gassmann, F. 1951. Elastic Waves through a Packing of Spheres. GEOPHYSICS, 16, 673-685.

Hilterman, F.J., 2001, Seismic Amplitude Interpretation, 2001 Distinguished Instructor Short Course, Distinguished Instructor Series, No. 4, Soc. Expl. Geophys.

Ludwig, W. J., J. E. Nafe, and C. L. Drake.1970. Seismic refraction, in The Sea, A. E. Maxwell (Editor), Vol. 4, Wiley-Interscience, New York, 53–84. 61, 368–379.

Mavko, G., Mukerji, T., and Dvorkin, J., 1998, The rock physics handbook – Tools for seismic analysis in porous media, Cambridge University Press.

Paiva, M.F.B., 2021. Modelagem de Física de Rochas e Análise dos Coeficientes de Reflexão e dos Atributos Elásticos dos Reservatórios Turbidíticos Maastrichtiano do Campo de Roncador, Bacia de Campos, Brazil. Master Dissertation. Programa de Pós-Graduação em Dinâmica dos Oceanos e da Terra, Universidade Federal Fluminense, RJ, Brazil. 192 pp

Winter, W.R.; Jahnert, R.J. & França, A.B. 2007. Bacia de Campos. Boletim de Geociências da Petrobrás, 15 (2): 511-529.