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The Density Estimation Solution for Sand-Shale Overlap Challenges

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Abstract: *Compressional wave velocity (V_p), Shear wave velocity (V_s), Seismic and Well-log data are requirements for estimation of density from density-Impedance relation. Gardner's and Lindseth's relations were localized and then altered to obtain the local fits constants: b, n, e and f for sand and shale lithologies. The seismic inversion analysis yields density-impedance equation whose constants are local fits for specific rock type. The key solutions from the local fit for sands and shales discriminated, indicate b and n from compressional wave and shear wave velocities for sand and another set for shale. Also, the constants e and f from compressional wave and shear wave velocities for sand and another set for shale. Relating Gardner with those fromLindseth approaches using well-log and seismic inversion analyses and also obtained the average, the final models are* $\rho = \frac{xZ_p^y - fZ_p^{-1}+1}{2e}$ *[for estimation of density from p-impedance] and* $\rho = \frac{x_s Z_s^{y_s} - f_s Z_s^{-1}+1}{2e_s}$*[for estimation of density from s-impedance]for sandstones lithology and shale lithology. These models yield a new concept which will contribute to global knowledge. In the absence of density log, these equations can be used to estimate density in the area of interest.*

Keywords: *Density, Velocity, Seismic Inversion, Model, Sandstones, Shale, Lithology and Well-Log Data and Seismic data.*

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I. Introduction

A model explains our beliefs on how the world functions as ideas can be formulated and underlying assumptions identified. Models define the actual domain, the interface and motion of bodies using arithmetic so as to solve problems (Marion & Lawson, 2015). It could be seen as one of the strong approach for innovation, to achieve theoretical analysis and experimentation (Quarteroni, 2009). This model is useful during reservoir characterization when carrying out petrophysics and rock physics analyses. Density modelling is very necessary to improve density estimates for reservoir characterisation. It provides information for describing a reservoir. It gives the accurate distinction among hydrocarbon basins and other fluids. Bulk density from petrophysical analysis is an essential acoustic pointer of the shale occurrence; aids the determination of quality of coal.

The bulk density of a rock plays important role in mineral configuration, porosity, water permeation and hydrocarbon. With densityρ information, reservoir can be delineated (Quijada & Stewart, 2007). Reservoir interpretation can be enhanced by the use and understanding of density volumes estimated through the simultaneous inversion V_p data (Hampson *et al*., 2005). Changes in density can lead to important fluctuations in the amplitudes as well as their deviations with offset. In order to obtain different density-velocity relations and their parameters,V_p, V_s, density, GR data from a well can be used (Quijada& Stewart, 2007).

The density log does not accurately identify most lithologies due to the varied range of rock densities, mineral configurations and porosities. Shales $\rho$is within 18 x 10^{-1} to 28 x 10^{-1}gcm^{-3}. Sandstones, shales, limestones and dolomites have bulk density varieties that overlay each other (Kearey*et al.*, 2002; Reynold, 1997).Consequently, the comprehensive account of local geological settings is dangerous for the valuation of seismic hazard for micro zonation studies and project (Delahaye*et al.*, 2009; Assimaki*et al.*, 2006).

The geological arrangements and the lithologies of the subsurface are revealed by the well data. Well lithology analysis is to estimate lithological and reservoir characteristics from the available log. Usually, shale creates unto or above 75% of the clastic infill in sedimentary zone; stays on top of productive zone (Bosch *et al.*, 2002; Sheriff, 1991; Hun *et al.*, 1986).

The simultaneous inversion process can be viewed as combining low angle pre-stack, P-wave reflection data with equation of Gardner which relates V_p and density (Gardner *et al*., 1974); the Greenberg-Castagna comparison (Greenberg &Castagna, 1992) which relates V_p and V_s. The addition of these two empirical equations to AVO intercept gradient information from low angle seismic data enables an accurate estimation of density. These density estimates can be used to interpret the geology of the reservoir and the quantification of reservoir properties.

II. Theory and Methodology

The circulation of basin fluids confined in a zone is assessed by the laws of science (Physics). Known relations from related literature such as Quijada& Stewart, 2007; Hampson *et al.*, 2005; Potter & Stewart, 1998; Greenberg &Castagna, 1992; Sheriff, 1984; Lindseth, 1979; Gardner *et al*., 1974 enabled the relevant equations.

$$\rho = aV_p^m \quad 1$$

$where\ a$ and m are Gardner's default parameters (constant coefficients); ρ is the bulk density; V_p is compressional wave velocity.

We localized equation 1 to parameters in our region of interest using b and n as constant coefficients for local fits. The equation 1 becomes

$$\rho = bV_p^n \quad 2$$

We took the log of both sides of equation 2 and applied the laws of logarithm to have

$$\log \rho = \log b + n \log V_p \quad 3$$

A plot of $\log \rho$ versus $\log V_p$ enables the deduction of b and n from the intercept and the slope of the graph correspondingly.

Also, as found in Lindseth's relation, a linear behaviour exists between impedance and velocity as

$$V_p = c\rho V_p + d \quad 4$$

$where\ \rho V_p$ is the impedance
(Lindseth, 1979).
This equation 4 is rewritten for the local fits constants for sand and shale as

$$V_p = e\rho V_p + f \quad 5$$

$$\rho = \frac{V_p - f}{eV_p} \quad 6$$

$where\ e$ and f are local fit constants from least square fit approach; c and d are Lindseth's constants.

The above procedure satisfied well-log data. In order to carry out seismic inversion, we localized and imposed a connection among p-impedance and ρ, a second linear relationship between $\log Z_p$ and $\log Z_s$. Seismic impedance Z is the bulk ρ multiply by seismic wave velocity V; expressed as

$$Z = \rho V \quad 7$$

Implies,

$$V_p = \frac{Z_p}{\rho} \quad 8$$

Substituting equation 8 into 2 with the new local fit constants q and r, yields

$$\rho = \frac{qZ_p^r}{\rho^r} \quad 9$$

$$\rho = q^{\left(\frac{1}{r+1}\right)} Z_p^{\left(\frac{r}{r+1}\right)} \quad 10$$

$$\log \rho = (r+1)^{-1}(\log q + r \log Z_p) \quad 11$$

This expression (equation 11) matches the linear constraint equation of the Hampson *et al.* (2005) approach to simultaneous inversion.
Repeating the processes above, yield relationships with shear wave velocity as

$$\rho_s = b_s V_s^{n_s} \quad 12$$

$$V_s = e_s \rho_s V_s + f_s \quad 13$$

$$\rho_s = \frac{V_s - f_s}{e_s V_s} \quad 14$$

$$\rho_s = q^{\left(\frac{1}{r_s+1}\right)} Z_s^{\left(\frac{r_s}{r_s+1}\right)} \quad 15$$

With the above equations, plots/crossplots are possible, such as V_p versus ρ; V_p versus V_s; ρ versus $\frac{V_p}{V_s}$; Z_p versus V_p; ρ versus V_s and others.

Calculation of density from impedance requires a known velocity. The already density-velocity relation evaluated is used to estimate the density from impedance. Equations 10 and 15 will enable evaluation of density from the impedance inversion obtained by means of trace math interface in Hampson Russell or any other recommended software.

However, considering seismic inversion in the case of Gardner variables theoretically,
i. Density may be estimated for both sandstones and shale from P-impedance using

$$\rho = xZ_p^y \qquad 16$$

$where\ x = q^{\left(\frac{1}{r+1}\right)}; y = \frac{r}{r+1}$; ρ is density and Z_p is P-impedance.

ii. Density may be estimated for both sandstones and shale from S-impedance using

$$\rho = x_s Z_s^{y_s} \qquad 17$$

$where\ x_s = q^{\left(\frac{1}{r_s+1}\right)};\ y_s = \frac{r_s}{r_s+1}$; ρ is density and Z_s is shear impedance.

Similarly for seismic inversion in the case of Lindseth variables,
iii. Density is estimated for both sandstones and shale from P-impedance using

$$\rho = 1/\left(e + \frac{f}{Z_p}\right) \qquad 18$$

$where\ e\ and\ f$ are local fit constants, ρ is density and Z_p is P-impedance; when solved binomially, reduces to our resulting equation 22.

iv. Moreso, for seismic inversion in the case of Lindseth variables, density is estimated for both sandstones and shale from S-impedance using

$$\rho = 1/\left(e_s + \frac{f_s}{Z_s}\right) \qquad 19$$

$where\ e_s\ and\ f_s$are local fit constants, ρ is density and Z_s is S-impedance; when solved binomially, reduces to our resulting equation 23.

3. Result and Discussion

Theoretically, development of site dependent geological model (density-impedance relation) for density estimation in anysedimentary basin is realised as

(A) In the case of Gardner approach from seismic inversion

i. Density will be estimated for both sandstones and shale from P-impedance using

$$\rho = xZ_p^y \qquad 20$$

$where\ x = q^{\left(\frac{1}{r+1}\right)}; y = \frac{r}{r+1}; q = b;\ r = n;$ the coefficient q and the constant r are local fit constants, ρ is density and Z_p is P-impedance.

ii. Density will be estimated for both sandstones and shale from S-impedance using

$$\rho = x_s Z_s^{y_s} \qquad 21$$

$where\ x_s = q^{\left(\frac{1}{r_s+1}\right)};\ y_s = \frac{r_s}{r_s+1}; x_s = q^{\left(\frac{1}{r_s+1}\right)};\ y_s = \frac{r_s}{r_s+1},\ q = b;\ r_s = n;$ the coefficient q and the constant r are local fit constants, ρ is density and Z_s is shear impedance.

(B) In the case of Lindseth approach from seismic inversion

a. Density will be estimated for both sandstones and shale from P-impedance using

$$\rho = \frac{1}{e} - \frac{f}{e^2 Z_p} \qquad 22$$

$where\ e\ and\ f$ are local fit constants, ρ is density and Z_p is P-impedance.

b. Density will be estimated for both sandstones and shale from S-impedance using

$$\rho = \frac{1}{e_s} - \frac{f}{e_s^2 Z_s} \qquad 23$$

$where\ e_s\ and\ f_s$are local fit constants, ρ is density and Z_s is S-impedance.

Therefore, the final models for sandstones and shale lithologies are obtained after the evaluation of the mean of density estimated using well data and seismic inversion analysis as

♥ Density may be estimated for both sandstones and shale from p-impedance using

$$\rho = \frac{xZ_p^y - fZ_p^{-1} + 1}{2e} \qquad 24$$

♥ Density will be estimated for both sandstones and shale from S-impedance using

$$\rho = \frac{x_s Z_s^{y_s} - f_s Z_s^{-1} + 1}{2e_s} \qquad 25$$

$$where\ x = q^{\left(\frac{1}{r+1}\right)};\ y = \frac{r}{r+1};\ q = b;\ r = n;\ x_s = q^{\left(\frac{1}{r_s+1}\right)};\ y_s = \frac{r_s}{r_s+1};\ x_s = q^{\left(\frac{1}{r_s+1}\right)};$$

$$y_s = \frac{r_s}{r_s+1};\ r_s = n.$$

$where\ e,\ f,\ e_s,\ f_s,\ q$ and r are local fit constants, ρ is density, Z_p is P-impedance and Z_s is S-impedance.

III. Conclusion

We have been able to come up with a new concept which will contribute to global knowledge

- Theoretically, development of site dependent geological model (density-impedance relation) for density estimation in any sedimentary basin has been realised.
- We have also explained how to obtain constants for the density-impedance relations for specific rocks in each field which automatically become the default parameters for the Density-Impedance model for the field in question. Therefore, parameters of other fields should be determined for their area of study before these models are considered or used for density estimation.
- We have also encouraged the use of density-velocity relation for density estimation in the absence of seismic data (that is, using well-log data).

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