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A Simple and Fast Algorithm to Estimate Effective Anisotropy Parameters

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SUMMARY

Anisotropy caused by fine layering is often the differences between velocities achieved by sonic logs and seismic experiments. Due to prominent behavior of anisotropy the identification of potential intervals of reservoir quality sand is a great challenge with substantial evidence of occurrence of transversely isotropic (TI) anisotropy in the subsurface associated primarily with shale. To resolve above issues, we implement the modified and extended Backus's averaging algorithm to estimate the effective stiffness parameters and anisotropic parameters, which is very consistent with the well logs and successfully distinguished potential reservoir embedded by shale.

Introduction

Growing interest in exploration of shale reservoirs, which are highly fractured, give an immense opportunity to geoscientist to analysis the seismic data with proper calibration of seismic data with well logs. Although, most of them are performed with assumption of isotropic layer media; however transverse isotropic (TI) results are more accurate than assumption. Main causes of anisotropy is due to directional deposition of non-spherical rocks by fine layering, which cases the velocity differences between well logs and seismic experiments or heterogeneities in the earth's subsurface results tectonic stresses revels in variations of elastic constant in rocks. Shale is a representative of TI media with vertical symmetry axis (VTI). Examination of horizontally layered media which is dispersive and anisotropic to elastic wave has been done by Thomson (1950), Helbig (1958), and Anderson (1961). In TI media, propagation of velocity through horizontally layered media strongly depends upon dominant wavelength to the layer thickness (Carcione et al, 1998; Whiteside et al. 2008). Mavko et al. (1998) concluded that the individual layer thickness is more than ten times smaller than the source wavelength. Effective elastic properties at seismic frequency can be achieved by averaging method (Backus, 1962) using well logs data. Backus averaging is a harmonic mean of elastic parameters computed from well logs. In present research, we introduced the averaging method and extend to the anisotropic stiffness parameters and compared with the estimated effective η parameter. We illustrate this method on well log data along zone of interest and analysis the anisotropic parameters along with the reservoir.

Theory

Elastic Wave equation for VTI Media: We consider the generalized Hooke's law in Cartesian coordinates

$$\sigma_{ij} = C_{ijkl}\varepsilon_{kl}$$

where σ_{ij} is the stress component, C_{ijkl} is the stiffness tensor and ε_{kl} is the strain component.

According to law, each stress component has the same sign at the opposing faces of the volume, which is expressed as, $\sigma_{xy} = \sigma_{yx}$, $\sigma_{yz} = \sigma_{zy}$, $\sigma_{xz} = \sigma_{zx}$,

The 81 constants C_{ijkl} are called the elastic stiffness of the material and equal to the fourth order in Cartesian coordinate; therefore, convert the $3 \times 3 \times 3 \times 3$ tensor C_{ijkl} to the 6×6 matrix $C_{\alpha\beta}$. Due to symmetry between stress and strain tensor, only 21 independent elastic constants are required. The stiffness tensor is then reduced to

$$C = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ C_{12} & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\ C_{13} & C_{23} & C_{33} & C_{34} & C_{35} & C_{36} \\ C_{14} & C_{24} & C_{34} & C_{44} & C_{45} & C_{46} \\ C_{15} & C_{25} & C_{35} & C_{45} & C_{55} & C_{56} \\ C_{16} & C_{26} & C_{36} & C_{46} & C_{56} & C_{66} \end{bmatrix}$$

If a rock has a vertical symmetry axis, the rock is called VTI and the elastic stiffness tensor can be described and often called the "Voigt recipe C_{ijkl}" as

$$C_{VTI} = \begin{bmatrix} C_{11} & C_{11} - 2C_{66} & C_{13} & 0 & 0 & 0 \\ C_{11} - 2C_{66} & C_{11} & C_{13} & 0 & 0 & 0 \\ C_{13} & C_{13} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix}$$

Backus averaging: The relation developed by Backus is relatively straightforward for the five elastic constants $(C_{11,}C_{13},C_{33},C_{44},C_{66})$ of the effective TI medium from volume averages of the elastic properties of the individual layers.

According to Backus arithmetic averaging to compute the effective medium,

$$\widetilde{U} = \langle U \rangle = \frac{1}{n}\sum_i^n U_i,$$

Where, U_i-consider as the elements of matrices stack with *n* layers. Using the standard Thomsen (1986) notations, we can write the Backus (1962) in terms of stiffness matrix.

$$C_{33i} = \rho_i v_{p-wave,i}^2$$

$$C_{44i} = \rho_i v_{s-wave,i}^2$$

$$C_{11i} = C_{33i}(1 + 2\varepsilon_i)$$

$$C_{13i} = \sqrt{(C_{33i} - C_{44i})(C_{33i}(1 + 2\delta_i) - C_{44i})} - C_{44i}$$

$$C_{66i} = C_{44i}(1 + 2\gamma_i)$$

For a given formation, the arithmetic averaging operators are;

$$\widetilde{C_{11}} = \langle C_{11} - \frac{C_{13}^2}{C_{33}} \rangle + \langle \frac{C_{13}}{C_{33}} \rangle^2 \langle C_{33}^{-1} \rangle^{-1};\ \widetilde{C_{13}} = \langle \frac{C_{13}}{C_{33}} \rangle \langle C_{33}^{-1} \rangle^{-1};\ \widetilde{C_{33}} = \langle C_{33}^{-1} \rangle^{-1};\ \widetilde{C_{44}} = \langle C_{44}^{-1} \rangle^{-1};$$

$$\widetilde{C_{66}} = \langle C_{66} \rangle;\ \tilde{\rho} = \langle \rho \rangle$$

Numerical Example

Due to low permeability and anisotropic microstructure (Sayers, 2005); shale plays an important role in fluid flow and seismic wave propagation and these are intrinsically vertical transverse isotropy (VTI) anisotropic (Banik, 1984). To implement the averaging method and estimation of anisotropic stiffness parameters, we chosen a consistent well data from Malay basin with *Vp*, *Vs*, density and Gamma ray (see Figure 1a).

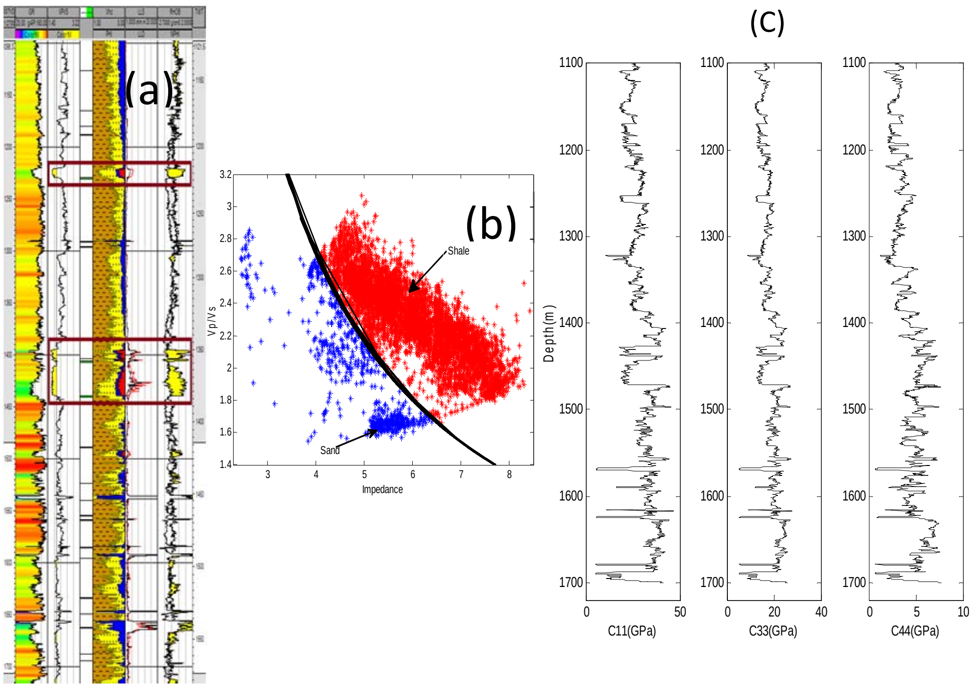

Figure 1 *(a) Lithology of Well logs (b). Cross plot between Vp/Vs with acoustic impedance (c) estimated stiffness properties with depth.*

To estimate the delta and epsilon, we used the relation derived by Yan, J. and Sava P. (2011). In order to discriminate between two lithologies, an optimum constant of 1.08e1 was selected and plotted (see Figure 1b). Figure 1c shows the combined (shale and sand) plot of selected stiffness parameters.

Effective η and vertical anisotropy: Based on the fact that η, shales are anisotropic and exhibit large value positive η, while sands are essentially isotropic with near zero values of η. We used the relation formulated by Alkhalifah, T., (1997), the effective η is estimated by

$$\eta_{eff}(t_0) = \frac{1}{8}\left\{\frac{1}{t_0 V_{nmo}^4(t_0)} \int_0^t V_{nmo}^4(\tau)\,[1 + 8\eta(\tau)d\tau - 1]\right\}$$

Here, $\eta(\tau)$ is the instantaneous value of the anisotropy parameter η.

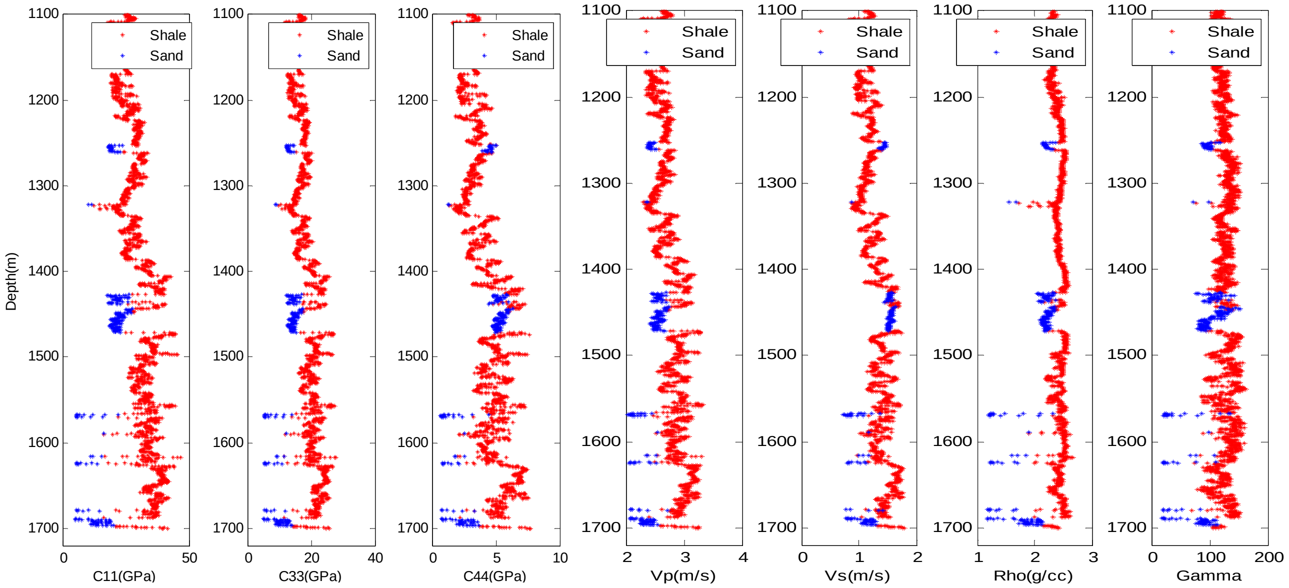

Figure 2 *Intercalation of Sand and Shale versus depth with effective stiffness parameters, Vp, Vs, Density and Gamma Ray.*

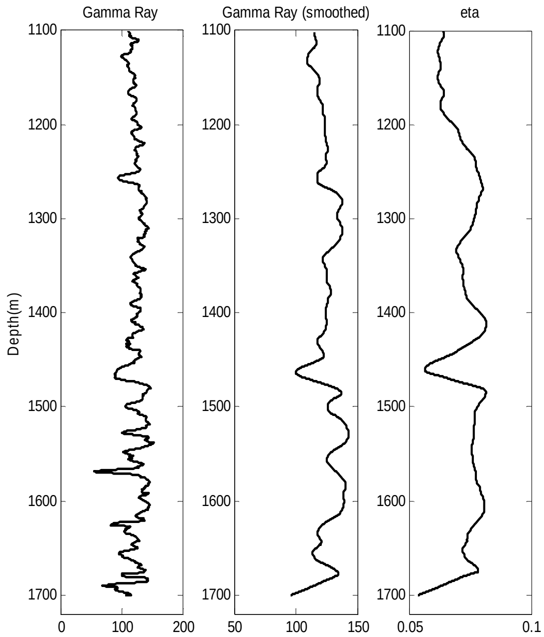

Figure 3 *Gamma-ray logs from study well (left) and a smoothed version of the gamma-ray measurements using a conventional smoother function (middle) and estimated effective η values (right).*

To analyze the low and high stiffness parameters, stiffnesses were cross plotted against depth (Figure 2). At hydrocarbon reservoir (Figure 1a), the stiffness parameters C11, C33 and C44 is well match with the P-wave velocity and density. Here, we can conclude that sands have lower stiffness parameter than shales. The estimated value of delta (δ) and epsilon (ε) from the well lies within the range of $0 \leq \delta \leq 0.15$ and $0 \leq \varepsilon \leq 0.21$ respectively.
Figure 3 shows three curves to compare the η curves with smoothed gamma-ray logs with two formations at 1240 m and 1410-1440 m. To match the resolution of the interval η estimate (third curve), we used a conventional filter to gamma-ray (first curve) and plotted smoothed gamma-ray (second curve). A strong correlation is evident between smoothed gamma-ray and η curve for the well, although sand-shale layering evident of high frequency from gamma-ray as compared.

Conclusion and Discussion

In this well log analysis, the strong effect of the thick layer overlying the hydrocarbon formation at depth of 1240 m, and 1410-1440m. We have used an extended modified Backus's averaging algorithm and implemented on a well log form Malay basin. As shale is representative of anisotropy and sand having nearly zero anisotropic. From analysis of stiffness parameters; we found that the stiffness parameters are well correlated with the shale and sand behaviour. The increase in anisotropy from off structure to the shale overlying the reservoir may show a qualitative direct hydrocarbon. Accurately estimated $\boldsymbol{\eta}$ can be used to discriminate between shale and sand in the subsurface.

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References

Anderson, D.L. [1961] Elastic wave propagation in layered anisotropic media. *Geophysics Research*, **66**, 2953-2964.

Alkhalifah, T. [1997] Seismic data processing in vertically inhomogeneous TI media. *Geophysics*, **62**, 662-675.

Backus, G.E. [1962] Long-wave elastic anisotropy produced by horizontal layering. *Journal of Geophysics Research*, **67**, 4427-4440.

Banik. N.C. [1984] Velocity anisotropy of shales and depth estimation in the North Sea basin. *Geophysics* **49**, 1411-1419.

Carcione, J. M., Helle, H.B. and Zhao, T. [1998] Effects of attenuation and anisotropy on reflection amplitude versus offset. *Geophysics*, **63**, 1652-1658.

Helbig, K. [1958] Elastischen wellen in anisotropen medien. *Geophysics*, **67**, 256-288.

Mavko, G. Mukerji, T. and Dvorkin, J. [1998] *The Rock physics handbook*. Cambridge University Press.

Sayer, C.M. [2005] Seismic anisotropy of shales. *Geophysical prospecting*, **53**, 667-676.

Thomson, W.T. [1950] Transmission of elastic waves through a stratified solid medium. *Appl. Phys.*, **21**, 89-93.

Thomsen, L. [1986] Weak elastic anisotropy. *Geophysics*, **51**, 1954-1966.

Whiteside, W., Xu, W., Li, Z., Lundy, A. and Chang, I. [2008] Enhanced anisotropic model suilding methodology and pre-stack depth imaging in deep water Gulf of Mexico: a case history. *Proceeding of the 78th Annual International Meeting*, SEG Expanded Abstracts, 194-198.

Yan, J. and Sava, P. [2011] Improving the efficiency of elastic wave-mode separation for heterogeneous tilted transverse isotropic media. *Geophysics*, **76**(4), T65-T78.