THE INFLUENCE OF BOREHOLE BREAKOUT IN SHEAR WAVE VELOCITY PREDICTION: A CASE STUDY OF "PLEADES" WELL, SOUTH SUMATERA - INDONESIA

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ABSTRACT

In seismic exploration, S-wave is an important attribute to characterize a reservoir. But, in the real condition, S-wave data often doesn't exsist, or the quality is very poor. Castagna and Krief equation can create a S-wave based on P-wave, but the this method only valid when the water saturation is 100%. In other hand, Biot-Gassmann fluid substitution need S-wave as an input and Gassmann approximation has a significant error for consolidate rocks. Dontown and Gunderson introduce a method to do fluid substitution with unknown Vs based on Biot-Gassmann equation, so P-wave velocity in the condition with water saturation 100% can be found. Then the S-wave velocity can be estimated using Castagna and Krief empirical relation before return it to the real condition using Gassmann Fluid Substitution. Compared with the FMI (formation micro imager) to analyze the borehole condition, the result shows that borehole breakout doesn't affect the quality of predicted S-wave directly, but the stress anisotropy caused by the borehole breakout influence the quality of the predicted S-wave. It indicated that there's still a consideration in using Gassmann equation with the appearance of borehole breakout.

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Keyword : S-wave Estimation, Borehole breakout, Gassmann fluid substitution

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INTRODUCTION

In many developed oil fields, only compressional wave velocity may be available through old sonic logs or seismic velocity check shots. For practical purpose such as in seismic modeling, amplitude variation with offset (AVO) analysis, and engineering applications, shear wave velocities or moduli are needed. In these applications, it is important to extract, either empirically or theoretically, the needed shear wave velocities or moduli from available compressional velocities or moduli (Wang, 2000).

Biot-Gassmann, is the most popular method for fluid substitution, but it need Vs or from real data or just an assumption. In other hand, Dontown and Gunderson (2005) introduce a method based on Biot-Gassmaan equation without using Vs to determine the P-wave in 100% water condition, then fluid substitution can be used to estimate the shear wave velocity.

Despite the popularity of Gassmann equations and their incorporation within most software packages for seismic reservoir interpretation, important aspects of these equations have not been thoroughly examined. Many efforts have been made to understand the operation and application of Gassmann's equation (Mavko and Mukerji, 1995, Mavko, et al., 1998, Sengupta, and Mavko., 1999, Nolen-Hoeksema, 2000). Most these works have attempted to isolate individual parameter effects. In this paper, we introduce the influence of borehole breakout in shear wave velocity estimation.

THEORY AND METHODE

Fluid Substitution without S-wave

Fluid substitution without S-wave was derived by Downton and Gunderson in 2005. The key of this formula is in the Biot coefficient (β). The Biot coefficient defined as:

$$\beta = 1 - \frac{K_{dry}}{K_m}$$

This formula of fluid substitution without shear wave velocity can be done if there are these data: Vp, ρ, porosity, K matrix (K_m), K_{dry}, K_{fl} (K fluid), ρ_{fl} (fluid density) and Biot coefficient (β). The equation is :

$$V_{\rho_{fl2}} = \sqrt{\frac{\rho_1}{\rho_1 + (\rho_{fl2} - \rho_{fl1})\phi} {V_{p1}}^2 + \beta^2 \frac{N_2 - N_1}{\rho_1 + (\rho_{fl2} - \rho_{fl1})\phi}}$$

Where:

$$N = \left(\frac{\phi}{K_f} + (\beta - \phi){K_m}^{-1}\right)^{-1}$$

The fluid modulus and fluid density maybe calculated following Batzle and Wang (1992), while the solid modulus maybe estimated as a function of mineralogy from published values (Mavko et al., 1998) using Hill's average of the Voight and Reuss bounds (Downton and Gunderson, 2005).

Castagna and Krief Empirical Relation

Castagna's relationship (ARCO mudrock line)

The most common method of shear wave velocity prediction is defined by Castagna et al (1985). They derived an empirical relationship between P-wave and S-wave velocity, which can be written as:

$$Vs(ft * us^{-1}) = 0{,}8619 * Vp - 3584.14439$$

Krief's relationship

$$Vs(ft * us^{-1}) = \sqrt{0.452 * Vp^2 - 18.7615}$$

The value of constants is used from default program in Hampson Russell.

Gassmann Fluid Substitution

Gassmann's equation gives a relationship between saturated bulk modulus, porosity bulk modulus of rock frame, bulk modulus of mineral of rock matrix and the bulk modulus of pore fluid (Mavko et al., 1998).

$$K_{sat} = K_{dry} + \frac{\left(1 - \frac{K_{dry}}{K_m}\right)^2}{\frac{\emptyset}{K_{fl}} + \frac{1-\phi}{K_m} + \frac{K_{dry}}{K_m^2}}$$

where, K_{sat} is the saturated bulk modulus and $\emptyset$ is porosity. Gassmann equation based on several assumptions: (1) rock must be macroscopically homogenous; (2) all pores must be interconnected; (3) pores are filled with a frictionless fluid; (4) the rock-fluid system must be closed; (5) there should be no interaction between fluid and matrix in a way that could soften or harden the frame (Mizaghi, 2010). With all of these assumptions and the equation above, K_{sat} can be estimated. By knowing K_{sat}, P- and S-wave velocities can be predicted using equation:

$$Vp = \sqrt{\frac{K_{sat} + (4/3)\mu}{\rho_B}} \quad , \quad Vs = \sqrt{\frac{\mu}{\rho_B}}$$

where, μ and ρ_B are the shear modulus and bulk density.

Borehole Breakout

Borehole breakouts are stress-induced enlargements of the well-bore cross section (Bell and Cough 1979). When a borehole is drilled, the material removed from the subsurface is no longer supporting the surrounding rocks. As a result, the stress became concentrated in the borehole wall. Borehole breakouts occur when the stresses around the borehole exceed that required to cause compressive failure of the borehole wall (Zoback et al., 1985; Bell, 1990). The stress concentration around a vertical borehole is greatest in the direction of the minimum horizontal stress. Hence, the long axes of borehole breakouts are oriented approximately perpendicular to the maximum horizontal compressive stress orientation (Plumb and Hickman, 1985).

Interpreting Breakouts from FMI

Resistivity image logging tools provide the same information of borehole diameter and geometry as dip-meter logs. However, resistivity imaging logs also provide a high-resolution picture of the wellbore well based on resistivity contrast that allows for direct observation of borehole breakouts. Borehole breakouts typically appears on resistivity image logs as broad, parallel, poorly resolved conductive zone separated by 180^0 and often exhibiting caliper enlargement in the direction of conductive zone (Bell, 1996).

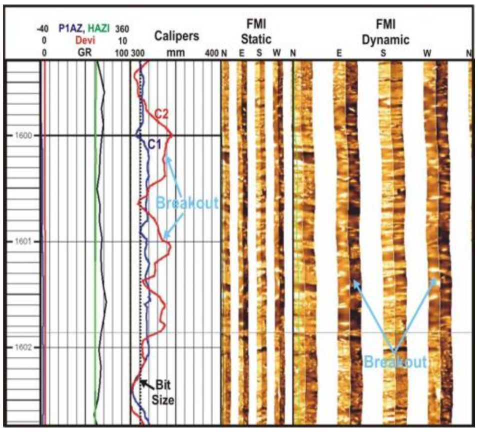

Figure 1. Borehole breakout, indicated with the enlargement of caliper 2 direction (red) and directly on the FMI image as poorly resolved conductive zone.

APPLICATION TO "PLEADES" WELL

This method, then we applied to a well called "pleades" within interval 1932m – 2406m, this zone is a sand reservoir, belong to PERTAMINA UTC.

Fluid substitution without S-wave velocity information (Downton and Gunderson, 2005) was done in this well to find the velocity of P-wave in wet condition (water saturation=100%), then we use the Castagna and Krief empirical relation to find the shear wave velocity in wet condition. After the P-wave and S-wave in the wet condition has found, then we "return" it to the real condition (average value of water saturation=74%) using Gassmann fluid substitution. This was done using Fluid Replacement Modeling (FRM) in Hampson Russell. The result of the new S-wave compared with the S-wave from log data.

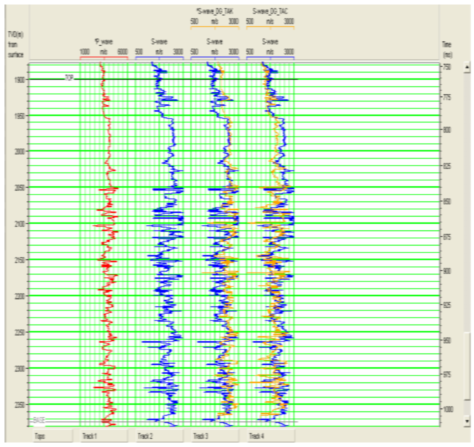

Figure 2. Fluid substitution modeling, a comparison between predicted S-wave and the real S-wave. The first track is P-wave, then S-wave in the second track. The third track is the comparison between predicted S-wave using Krief relation and the real S-wave. The last track is the comparison between predicted S-wave using Castagna relation and the real S-wave.

The error value computed using equation:

$$Error = \left|\frac{S - S_{est}}{S + S_{est}}\right| \times 100\%$$

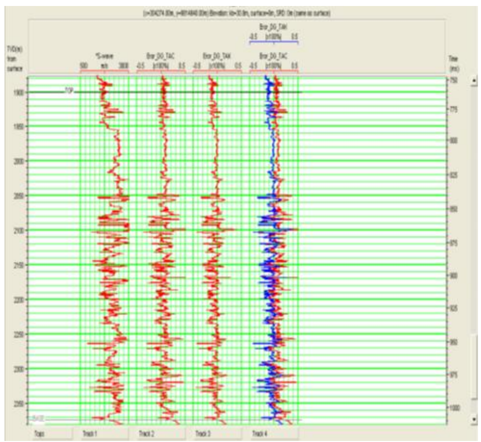

Figure 3. The error graphics displayed in the second and third track. The first track is the real S-wave and the last track is the error comparison.

The error value of both methods is in the interval 0-10% average. The variation of this error value can be influence by several things such as the hydrocarbon saturation and anisotropy effect.

The FMI (formation micro imager) data was used as a comparison to find the relation between borehole breakout and the estimated S-wave velocity.

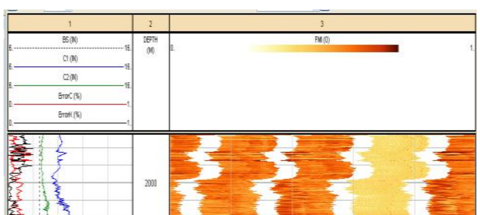

Figure 4. The error graphic from estimated S-wave using Castagna and Krief elation compared with the FMI data.

The analysis of the comparison (Fig 4), shows that the quality of S-wave estimation is not directly affect by the borehole breakout. This indication showed by that there are some conditions where the value error on S-wave estimation is maximal (8.3%), but the value of caliper 2 (that indicated the borehole breakout) is not maximal (11inc – 2.5inc from bit size) and when the borehole breakout is maximal (18inc), the error value of estimated S-wave is 0.15%. But, in overall, both of the error graphic always increases when the borehole is in the breakout condition.

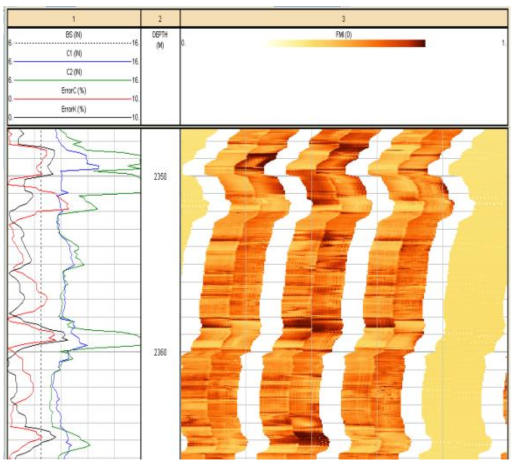

Fig 5. The enlargement of caliper 2 that indicated the borehole breakout (compared with the FMI – shows high resistivity) always followed by the increasing value of S-wave estimation's error

Another condition is where the increasing of error value occurs before and after the borehole breakout. It indicated that the stress anisotropy caused by borehole breakout affect the quality of the predicted S-wave. It's very reasonable because the stress difference directly influence the density which make a different between the real S-wave and the predicted S-wave because the Gassmann Equation is not include the stress anisotropy as a parameter (Gassmann equation assume that the medium is homogeny isotropy) in the value of sonic wave velocity.

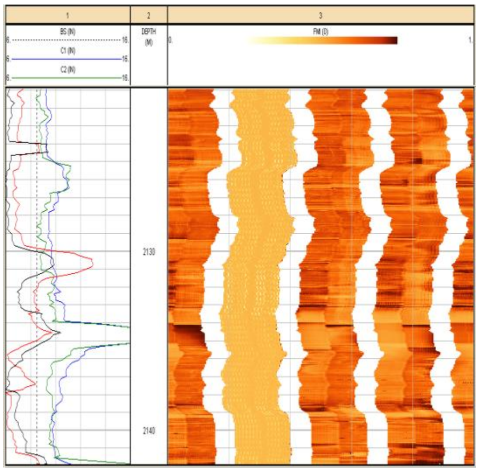

Figure 6. The error value of estimated S-wave increase before the borehole breakout.

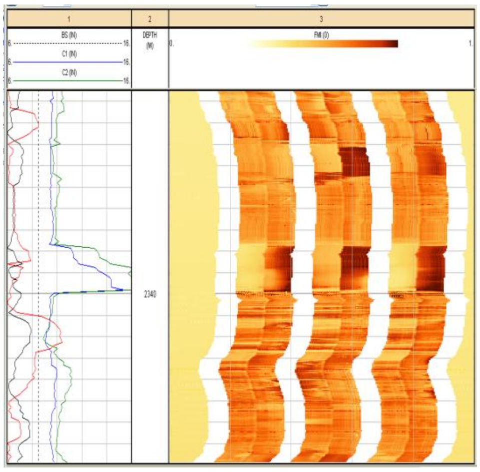

Figure 7. The error value of estimated S-wave increase after the borehole breakout.

CONCLUSION AND DISCUSSION

The borehole breakout from FMI data and log caliper has been compared with the result from S-wave prediction using fluid substitution modeling. The result shows that borehole breakouts don't directly affect the quality of the predicted S-wave, but the stress anisotropy caused by the borehole breakout affect the quality of the predicted S-wave. It has been showed by the increasing of error value of estimated S-wave in before and after the borehole breakouts. It because the Gassmann equation assume that the formation is macroscopically homogenous (Mizaghi, 2010) and don't include the stress anisotropy parameter. Then after all, the condition of borehole must be considered in the application of S-wave velocity estimation and Gassmann fluid substitution.

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