Investigating the effect of increasing number of angle stacks seismic toward improving seismic inversion prediction

Introduction

Seismic amplitude anomalies either from full stack or angle stacks seismic have been widely used as a direct hydrocarbon indicator for more than 45 years in the industry with a technique such as bright spot, flat spot etc. However, all the simple qualitative methods are no longer good techniques to be used for hydrocarbon identification as the industry are moving toward more complex & challenging reservoir play.

Recently, a direct rock & fluid elastic properties estimation from seismic amplitude appears to provide a better way to quantitatively discriminate between different pore-fluid types (Omre and Buland, 2003; Russel et al., 2011). The basis for angle-dependent reflection amplitude analysis starts commonly from the Zoeppritz equation. Although the equation provides precise values of the amplitudes of the reflected and transmitted plane waves, difficulties to understand the effects of the parameter changes on the seismic amplitudes would manifest due to the complexity of the equation itself. Moreover, Zoeppritz formulation for inversion requires nonlinear schemes to estimate parameter values from the observed amplitudes, which can sometimes be unstable to be used. Hence, most of the recent AVO analysis and inversion are based on linearized approximations to the Zoeppritz equations.

Several linearized Zoeppritz approximations such as Fatti et al. (1994), Gray et al. (1999), Russell et al. (2011) and Yin and Zhang (2014) were introduced to allow geoscientists to extract fluid and lithology information from the analysis of pre-stack seismic amplitudes. Approximation by Fatti et.al (1994) for example, is one of the famous formulations that widely used by industry to directly estimate P & S impedances via pre-stacks seismic inversion. Gray (1999) introduced new AVO equations correlating seismic amplitude with offset, in terms of fundamental elastic rock properties, Lame’s parameters ($\lambda$) or bulk modulus ($\mu$), shear modulus with density ($\rho$). The linearized AVO equation was further described by Russell et. al. (2011) on the concept of poro-elasticity to estimate fluid-poro term, rigidity and density parameters based on the weighted stacking of pre-stack seismic amplitudes. Later, Yin and Zhang (2014) was reformulating the AVO derivation based on Russel et. Al. (2011) and introduced a 4-term AVO approximation focusing on fluid bulk modulus and capable to differentiate the ambiguity due to rock-matrix factors, i.e. porosity effects. For this paper, we mainly focused on linearized AVO approximation of Mad Sahad et. al. (2020) which was reformulated based on Russell et al.(2011) for a direct estimation of pore fluid bulk modulus from pre-stack seismic for the hydrocarbon identification exercise.

Methodology

When conducting AVO pre-stack seismic inversion, geoscientists often have in mind to use a limited number of angle stacks as inversion input typically 3 angle stacks i.e. near, mid & far angle stacks mainly with the intention to reduce the production run time especially when dealing with a large dataset. Even though inversion result can be achieved faster by using minimal number of angle stacks, this option also could potentially cause inaccuracy in inversion result and in return lead to uncertainty for interpreting presence of hydrocarbon based on the product.

Hence for this case study, we will discuss in detail on how seismic inversion accuracy can be further improved by appropriately increasing number of angle stacks as the input. Determining a suitable number of angle stacks used as input is one of the crucial element in seismic inversion to avoid getting an inaccurate inversion product due to very limited data used and also to avoid the situation where we have to face a too long production run-time but only a marginal increase in accuracy due to utilization of excessive number of angle stacks.

We begin by preparing the datasets with the same processing parameters during its processing stage, except for the final output whereby the Angle Stacks generated would differ in number. For our study,
we will compare the results of 3 Angle Stacks versus 5 Angle Stacks. We have also locked the maximum angle to be used for each Angle Stack sets in order to achieve a fair comparison.

For the seismic inversion to be used for the comparisons, we will be utilizing AVO approximation by Mad Sahad et. al. (2020). The main goal for this seismic inversion is to resolve the Fluid Bulk Modulus term of the equation ($K_f$) since it would help in terms of calibrating the results known in Exploration and Development wells which are quite abundant in our test dataset. As most of these wells have an almost complete set of saturation logs in place and has been properly conditioned by Petro-physicists, the comparisons between the seismic inversion result for $K_f$ of 3 and 5 angle stacks could be compared much easily. Figure 2 summarises the workflow involved in resolving for the $K_f$ term directly from seismic.

![Figure 2 Workflow carried out to generate the Fluid Bulk Modulus ($K_f$) being generated for comparison.](image)

**Examples**

The evaluation was done in one of the fields in Malay basin specifically the I-group of Miocene age where the reservoir interval consists of clastic fluvial channelized system and is considered a prolific stratigraphic styled reservoir in this basin. In this exercise, given the same seismic angle gathers range from 4 to 48 degrees, we come out with 3 different angle stacks dataset 1) 3 angle stacks (4-15, 15-30, 30-48), 2) 4 angle stacks (4-12, 12-24, 24-36, 36-48) & 3) 5 angle stacks (4-12, 12-24, 24-32, 32-40, 40-48). The seismic gathers already undergone AVO compliance conditioning & processing prior to this exercise to ensure the data is in good quality for QI purposes.

Each dataset has undergone the same seismic inversion workflow with the same steps applied to them and the same calibration wells were used for both runs. In our study, 4 Exploration Wells were used to calibrate the seismic data prior to inversion while 3 other Exploration Wells and 51 Development wells were used for verification tests, thus acting as our blind wells for this study.

With regards to the verification criteria, for this study we will be looking into the ability in discriminating between Hydrocarbon bearing Reservoirs versus Non-Hydrocarbon Zones since the $K_f$ has a large spread of values which is affected by the temperature, Hydrocarbon APIs, and source type. Figure 3 shows the result of the inverted $K_f$ result based on 3 & 5 angle stacks extracted along the one of the blind well used for verification. The blind wells result indicate that both inverted relative $K_f$ capable to identify the presence of hydrocarbon as low relative $K_f$ response observed at hydrocarbon reservoir interval. However, the inverted relative $K_f$ based on 5 angle stacks provide a better accuracy and sensitivity as compared to product of 3 angle stacks.
Once the calibration for both tests were completed, a full-scale seismic inversion for the relative Kf values was done on the entire seismic dataset and the single target horizon with the most coverage of the wells was used to calculate the precision and accuracy of the result.

Figure 4 Calibration results at the tested wells. Figure 4(a) displays the result of the Kf term prediction based on the 3 Angle Stacks used as input. Figure 4(b) displays the result of the Kf term prediction based on the 4 Angle Stacks used as input

Results

Figure 4(a) and (b) show the map view of relative Kf results based on 3 and 5 angle stacks seismic input at dedicated reservoir interval. Both inversion results manage to indicate hydrocarbon zones with low relative Kf responses which can be observed at sand reservoir interval. However, a more confined reservoir outline and marginal amplitude noise can be observed from relative Kf result based on 5 angle stacks especially at north-western part of the reservoir. Low relative Kf response was also observed at north-western side of the reservoir which may indicate possible hydrocarbon presence; however, the response was diminished for the relative Kf response based on 5 angle stacks as shown in figure 4(b). The inversion result of 4(b) also is more consistent with well information.
Besides qualitative interpretation, we also conducted a quantitative verification and blind test analysis as shown in Figure 4, by means of extracting the Kf values along the target Horizon and highlighting the result of the well data for the Exploration and Development Wells. The result derived from Figure 4(a) indicated that the Kf Values are only 70% accurate as compared to the observed wells used for verification. For the result in Figure 4(b), approximately 90% match was observed, in which an increase of accuracy was registered compared to the previous test. In light of the encouraging results from the 5 Angle Stacks used for this study, it was later expanded and covered several other areas which were identified as being an upside potential in the field, thus highlighting the extra contribution from this study in supporting the efforts of continuous optimization and life of field extension of this particular field.

Conclusions

This case study confirms a vast improvement in inversion prediction accuracy with the increase of number of seismic angle stacks as input to invert for the Fluid Bulk Modulus term (Kf) as derived from Mad Sahad et al (2020) and has significantly aided in terms of providing the best practice for optimal selection of the input angle stacks, as part of the current seismic inversion workflow. This in turn could be useful in several look back projects which may point out to other potential prospects which have been missed previously, thus unlocking more value for the field.

Nonetheless, replication studies for different regions must be carried out in order to gauge the method’s robustness in handling multiple environments of depositions as well as different source rock settings in order to get a better grasp on the underlying uncertainties associated with this method.

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References


