3D broadband seismic inversion: Case study of exploration cretaceous sandstone, North Arafura Basin

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Abstract. This paper presents applications of Absolute and Relative Acoustic Impedance of seismic inversion for qualitative and quantitative seismic interpretation from 3D Broadband PSDM Post-stack Seismic data. A case study from the exploration area of Late Cretaceous – Early Cretaceous Clastics in Arafura Sea, eastern Indonesia has been perform in this work, where inside the study area have no well information for seismic inversion at all. The present work shows the promising contribution of applying 3D Broadband Seismic Velocity for background trend of 3D Post-Stack Model Based Seismic Inversion and perform interpretation from 3D Broadband Relative Acoustic Impedance to reduce the uncertainty associated with the seismic interpretation, to recognize the porous sand section (as an indication of hydrocarbon reservoirs) and to understand the distribution of the reservoir based on seismic data-driven, to later for define the high certainty location of exploration well.

Keywords: 3D broadband PSDM, absolute and relative acoustic impedance, cretaceous clastics

1. Introduction

New seismic acquisition technologist have been made available to interpreters to interpreted seismic data with the aim of providing broader seismic frequency bandwidth, this will be benefits for frontier exploration stages activities where very limited data available due to very high cost activities in remote offshore field. The interpretation in acoustic impedance property also have been available by this broadband technology to identify and delineate prospects; to describe better the internal structure reservoir; to recognize depositional environments; and to characterize or quantify reservoir [1].

The main objective here is to predict reservoir distribution and porous rock recognition from acoustic impedance property without well information to delineate the high certainty exploration well location. The technic has been make available mainly because of the Broadband data have the very low frequency that able to be used for seismic inversion [2].

The other objective is to have another option seismic volume for seismic interpretation based on seismic attribute result, so not only based on 3D conventional seismic data [3]. The study area of the value Broadband seismic is in offshore North Arafura Sea of the North Aru Island, West Papua as shown on figure 1. The study area is the part of the northern edge of the passive margin Mesozoic Arafura-Australia [4]. The study area has most complete stratigraphic succession and oldest rock in Indonesia.
2. Methodology
The study area is the focus in Pre-tertiary of Mesozoic-Cretaceous Kembelangan Group. As Panggabean and Hakim (1986) considered the Sandstones of Kopai, Woniwogi and Ekmai Formation appear have the potential as a good reservoir (range of porosity is about 5–25 %) [5]. These reservoirs consider as a new play geologically concept based on proven equivalent hydrocarbon reservoir in Australia. The sedimentary units of these reservoir interval interpreted as the Mesozoic Passive Margin Post-Rift [6] as shown on figure 2. And the reservoir interval is in the shallow marine environment of North Arafura basin.

In this study utilized the 3D Broadband Post-stack PSDM (in time domain) and regional 2D seismic for seismic well tie and tie-in to the study area. The 3D survey was acquire a slanted streamer from 7 to 40m depth by WesternGeco-Obliq marine Broadband seismic data, re-processed with 3D source-receiver de-ghosting and 3D Anisotropic (VTI) Kirchhoff PSDM of CGG proprietary Broadband technology. As shows in figure 3, is the 3D Broadband seismic data frequency spectrum in a cross section passing through the reservoir.

But no well information at the study area, the only available well data is the regional well logs, outside of the study area. The regional logs are the AM-1X and KL-1, the well have Gamma Ray, Density, Neutron, Resistivity and Compressional Slowness. The logs were edited by apply the median filter and borehole correction, furthermore perform analyses though cross-correlation logs data process due to borehole condition and mud invasion. The regional logs data is important to validate and evaluate the regional expectation information of Acoustic Impedance and other in-situ measurement of well logs data relationship. It is also important for well-to-seismic tie with 2D regional seismic data, as part of the seismic interpretation process to provide input the construction of a background absolute acoustic impedance model from 3D seismic data.

![Figure 1. Location map of study area. The Area is located in offshore of North Arafura Basin, West Papua.](image)
Figure 2. Tectonostratigraphic diagram of Arafura Sea.
2.1. Relative acoustic impedance

One way for creating a relative impedance attribute is based on Lindseth (1979), the creation of acoustic impedance technique used two step; which are deconvolution and integration [7]. As an integral approach, it can be expressed as a convolutional filter where the phase spectrum is a 90 degree rotation.

So, a relative impedance dataset produces by the 90-degree phase rotation filter.

One of the simplest inversions methods is integrated traces. To achieve accurate relative impedance result by integrated trace the reflection coefficients must be broadband in frequency [8]. It is because the integration operation very stable in high frequency and unstable at low frequency due to unavailability low frequency in seismic trace from normal conventional seismic volume. So apply these kind of technique work to try only on rich bandwidth seismic dataset.

Reflectivity images are not always easily interpreted, and details may be missed that become obvious when interpreting an impedance image. As one of the benefits of this relative acoustic impedance attribute is to be able to use for seismic interpretation as indicator of lateral continuity and sometimes it is provided less noisy dataset than conventional reflectivity seismic data. These attributes are used to interpret the Top Cretaceous (horizon WH-250), Intra-formational Cretaceous (horizon WH-270) and Base Cretaceous reservoir (horizon WH-300) later.

2.2. Absolute Acoustic Impedance

The Broadband seismic have very low frequency data, therefore inside the process of seismic inversion the low frequency model data from the well information considerable able to be reduced [2]. The unavailability well information at the target area is being consider the main reason utilized of seismic velocity for the seismic inversion process independently.

The construction a priori model of low frequency is based on seismic velocity. The seismic interval velocity have been used from the migration in seismic data processing. Then, this low velocity interval model from seismic was multiplied by an average Cretaceous reservoir interval density of 2.1 g.cm$^{-3}$. An approximation transforms of relative acoustic impedance to “absolute” impedance have been able to be perform based on these simple approaches. A Model Based Post-stack seismic inversion is chosen for the 3D Broadband seismic data.
The robustness of model-based inversion, is a construction of the initial model to be represent the earth’s layer and then perform fitting process until the derived synthetic seismic section best fits to the observed seismic data. Hampson and Russell (1991) concluded that the model-based inversion approach was the most robust and will provide a very smoothed, and frequency seismic band limited estimate of the impedance [9].

3. Results and discussion
The seismic inversion provides cube of elastic properties that can be utilize for porosity and lithology reservoir model. The seismic inversion result expected to give better signal to noise ratio in the poor reservoir areas. To extract the rock properties from seismic data it is utilized the 3D PSDM post-stack data in time domain, based on the model based seismic inversion algorithm.

One of the seismic inversions products is the acoustic impedance cube. The motivation for using the acoustic impedance data to characterize reservoir comes from the helpful relationship between acoustic impedance and porosity. Before applying the inversion techniques, feasibilities studies were perform at the well location. In the reservoir level of Kopai, Wonowogi and Ekmai as the porous rock with 5-25 porosity expected will be equivalence with low acoustic impedance data.

To have the physical well information, it has been utilized the well analogue. The regional well log data cross-plot have provided information of the relationship of Gamma-Ray, Acoustic Impedance and Density as shown figure 4. It’s observed physically: high velocity sand has increasing density (increase clay content) especially for AM-1X tends to reduce porosity and therefore stiffen the rock. The sand–shale ambiguity observed in terms of acoustic impedance plot. The variations in seismic properties observed in both wells should only simplify the variations (lithological and/or textural changes). As resume of both analogue regional well information is interpreted as a dry well for the tight Cretaceous sand-shale interval.

Based on these initial analogue well information in the study area the properties should be expected have lower value of acoustic impedance from existing analogue wells, its capture reservoir Top Cretaceous to Base Cretaceous with porous sand and relatively clean Sandstone of Ekmai Fm., Woniwogi Fm., and Kopai Fm.

Figure 4. Log scale cross-plot of relationship gamma ray, acoustic impedance and density of two analogue regional wells for top cretaceous-base cretaceous and cut-off properties range show of a sand-shale interval AI sand cut-off = < 28000 (g.ft/cm 3.s);
(a) Analogue well of AM-1X; (b) Analogue well of KL-1.
Based on the analogue well of low acoustic impedance and low density have possibility to be extend in the study area with better properties. Geologically this play concept has the success ratio for drilling new well in Cretaceous sand at the study area.

The Broadband seismic data have better signal-to-noise ratio impedance, making the seismic impedance volume ideal for seismic structural and stratigraphic interpretation. If no low frequencies model applied, it is becoming a relative acoustic impedance inversion. In general, the relative acoustic impedance able to shows apparent acoustic contrast, indicates sequence boundaries, unconformity surface and discontinuities. The uses of the band-limited part of seismic inversions for interpretation is become available together with the conventional seismic data as shown on figure 5.

Seismic interpretation has been conduct for main layer WH-250 as Top Cretaceous (equivalent Ekmai Fm.), WH-270 as Intra-formational Cretaceous (equivalent Wonowogi Fm.) and WH-300 as Base Cretaceous (equivalent Kopai Fm.). The seismic interpretation performs on 3D conventional PSDM Broadband seismic and then fine-tune interpretation perform using the 3D PSDM Broadband Relative acoustic impedance.

Some part of seismic area, the horizon continuity of relative acoustic impedance better than conventional surface seismic due to less noisy dataset, and it will decrease the uncertainty of seismic interpretation result later. Horizon picks on the main reflecting interfaces based on 3D Broadband Conventional seismic and 3D Broadband Relative Impedance are used to establish the starting model for the 3D Broadband Absolute Inversion.

The seismically-derived low frequency model was then able to be add to the relative acoustic impedance. Using this workflow an ‘absolute’ seismic inversion result has been estimated without using wells information for the low frequency model as calibration. The inversion is run with the appropriate wavelet and constraints. Using the 3D Post-Stack Acoustic Impedance Model Based approach. As figure 6 illustrates the result of this ‘absolute’ acoustic impedance.

![Figure 5. 3D Seismic Cross-section for seismic interpretation; (a) 3D Conventional PSDM Broadband (in time domain); (b) 3D Relative Acoustic Impedance PSDM Broadband (in time domain).](image)
The absolute acoustic impedance result provides prediction good reservoir existence in the study area based on the low acoustic impedance profile and section of main depth map layer WH-250 as Top Cretaceous, WH-270 and WH-300 as Base Cretaceous as shown on figure 7. The promising porous and thick rock reservoir for drilling location are in the east part of the field (block polygon). The result shown that the main reservoir features and impedance architecture and differentiates indication hydrocarbon sands of Ekmai, Woniwogi and Kopai formation. Recognition of sedimentary package direction have shown that have relatively east to west direction which is same with the geological concept. The result makes reasonable for separating the sands and shale responses to predict thickness of reservoir better for accurate prediction of gross rock volume later.

Figure 6. 3D Absolute Acoustic Impedance for extracted reservoir properties; 3D Model-Based Post-stack Broadband Seismic Inversion (in time domain).

Figure 7. Horizon slice of 3D Absolute Acoustic Impedance overlain depth map and black polygon is the high certain possible of well location; (a) Horizon WH-250 Top Cretaceous (Ekmai formation); (b) Horizon WH-270 Intra-formational Cretaceous (Woniwogi formation); and (c) Horizon WH-300 Base Cretaceous (Kopai formation).
Common QC steps for seismic inversion are primarily the good agreement between the inverted and well impedances and/or blind well testing. And how to decide whether one inversion is better than another is something that is not clearly understood. Blind well testing and consistency with geological expectations were suggested. The proper selection of wavelet is also very important since Broadband seismic have specific wavelet character compare to conventional surface seismic. The uncertainty of the absolute impedance result considers have high uncertain with no calibrated to well data at this exploration stages.

4. Conclusion
The absolute acoustic impedance estimation mainly using the well log to provide the low frequency model to recover the low frequency part from the conventional seismic data. Technology of 3D Broadband seismic provides valuable information to constrain the inversion process and obtain more accurate impedance estimation without using a log-derived low frequency model independently. A Broadband seismic have a good result in frequencies at low, so it is will be beneficial for interpretation deeper target reservoir to have good seismic acoustic section. It is significantly reduced the uncertainty of exploration stages by able to provide absolute and relative inversion results, better delineation of the porous-tight reservoir, lithology classification or net-pay estimation.

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References
[1] Avseth P, Mukerji T and Mavko G 2005 Quantitative Seismic Interpretation: Applying Rock Physics Tools to Reduce Interpretation Risk (California: Cambridge University Press)
[2] Reiser C, Bird T, Engelmark F, Anderson E and Balabekov Y 2012 First Break 30 67-75
[3] Budiman A, Priyono A, Samodra A, Mu’in F and Latuconsina M 2011 International Petroleum Technology Conference (Thailand: International Petroleum Technology Conference)
[4] Barber P, Carter P, Fraser T, Baily P and Myers K 2003 Indonesian Petroleum Association Proceedings 29th Annual Convention and Exhibition (Jakarta, Indonesia)
[5] Panggabean H and Hakim A S 1986 15th Ann. Conv. Proc. 1 461-80
[6] Harahap B H 2012 Indones. J. Geosci. 7 167-87
[7] Lindseth R O 1979 Geophysics 44 3-107
[8] Priezzhev I and Scollard A 2012 Robust One-Step (Deconvolution+ Integration) Seismic Inversion in the Frequency Domain available at https://pdfs.semanticscholar.org/3693/83f8ace4e466a3be510df3b76f40cead7715.pdf
[9] Russell B and D Hampson 1991 Comparison of Post-Stack Inversion Methods (Canada: Thompson-Russel Software Service Ltd.) pp 876-8