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Statistical Tuning Chart for Mapping Porosity Thickness: a Case Study of Channel Sand Bodies in the Kutei Basin Reservoir

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Abstract

Reservoir assessment is not only controlled by the structural framework but also stratigraphical features. Stratigraphical interpretation, which is related to seismic amplitude interpretation, is used to describe petrophysical aspects of channel sand reservoirs such as net porosity and thickness. This paper aims to map the porosity thickness for a case study of channel sand bodies reservoir in the Kutei basin. The study area is complex channel reservoir system that appears to occupy specific area within the depositional system. The geometry of the sediment channel, which thins toward the channel margins, makes this feature similar to be wedge model that could possibly be influenced by tuning effects. The tuning effects introduce pitfall in interpreting high-quality reservoir that is affected by contrasts in acoustic impedance. In order to distinguish high amplitude responses caused by tuning effects and acoustic properties, the analysis of amplitude responses needs to be correlated to the reservoir thickness. The statistical tuning chart is one of the techniques used to correlate amplitude responses and the reservoir thickness. The application of this technique to real data sets shows net porosity thickness map over the targeted reservoir. Thus, high-quality reservoir characterization can be performed to delineate geometric framework of the reservoir.

Keywords: *high amplitude, kutei basin, net porosity thickness.*

1. Introduction

Reservoir assessment is dependent on an assessment of structural and stratigraphic interpretation. Stratigraphic interpretation is mostly focused on the specific role of the amplitude of seismic data, which is correlated to petrophysical properties. Nowadays, stratigraphic interpretation makes use of various techniques, which depend on the quality of available data on a case-by-case basis. Particular robust techniques are required at the exploration stage in order to correlate the well log data. In this strategy, the reservoir assessment is performed by assessing the relationship between seismic amplitude and petrophysical properties directly from the well log data [1, 2].

Understanding the reservoir geometry (which is commonly indicated by a thin layer) helps to reduce uncertainty in reserve estimation [3, 4]. A conventional technique for calculating reserves is commonly based on depth structure maps, which present estimates of bulk volume. Detailed, in-place reserve calculation requires critical assumptions about porosity, thickness, and net pay. This work applies a sophisticated approach that may be used to infer hydrocarbon net porosity thickness from seismic amplitude. An approach is proposed to transform the amplified amplitude due to tuning effects on the porosity thickness map. The tuning amplitude is calibrated by the tuning chart, which is generated by modeling the geology with various thicknesses and petrophysical properties. Net porosity thickness of the sand reservoir (or net pay) is then estimated by calibrating the tuning chart of the thickness model. In some cases, this technique was successful in estimating the clean sand thickness under tuning thickness [5, 6].

This paper is focused on the significant application of seismic amplitude interpretation for reservoir assessment, which is intended to describe the geometrical and petrophysical aspects of the reservoir, such as net porosity and thickness. This paper aims to determine and to map the net porosity thickness for a case study of the channel-complex reservoir of the Kutei Basin.

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Geologically, the Kutei basin is situated in the eastern part of Kalimantan Island. The sediments accumulated in an area close to the current Mahakam Delta [7]. Structurally, the basin is surrounded by the Mangkalihat high in the north and Paternoster platform in the south. In addition, this basin was elongated from west to east, close to the Makassar Strait. The sediment thickness ranges from 8,000 to 10,000 m and the upper part is dominated by hydrocarbon-bearing sand [8].

The sedimentation was formed between 90 and 100 million years ago, since the beginning of the Miocene. The sediment source was clastic material that was transported down from high mountains by the Mahakam River. The deltaic sediment consists of three packages, separated by two transgressive systems [9, 10].

The reservoir is characterized by turbiditic slope channels, which formed elongated, sand bodies [11, 12]. The reservoir thickness is mostly a thin layer close to the margins of the channel. This channel is sand bodies, which is identified by high values of porosity and permeability. To assess the detailed sand bodies reservoir, 3-dimensional seismic and well log data was used in this work. Relative seismic data processing was sequentially investigated to minimize the risk of miss interpretation.

2. Thin Reservoir Porosity Thickness Mapping

A thin reservoir is seismically identified by tuning amplitudes as a consequence of constructive interference of the wavelet of the reservoir layer under the tuning thickness and is characterized by single reflectors unified in the top and bottom event in the seismic section [13]. The tuning amplitude is not affecting to the goal of structural interpretation, but significantly affecting to the stratigraphic interpretation, which is pointed out to assess net pay of the thin reservoir with a thickness less than 10 m, should be carefully emphasized [14, 15].

In this work, the wavelet plays an important role in mapping the thin reservoir porosity thickness. In some studies, wavelets are used to predict wind pressure [16] and to enhance the resolution of satellite imagery data [17]. In this tuning analysis method, we use wavelet to model the seismic amplitude response, which represents the seismic wave source related to the response of the subsurface reservoir condition.

In a case where there is a thin reservoir with isolated channel sand bodies (identified by low acoustic impedance), we can directly estimate the hydrocarbon net pay in terms of porosity thickness from the seismic amplitude [18, 19]. In this paper, we propose a statistical approach (the so-called ‘statistical tuning chart’) to transform the tuning amplitude into porosity thickness. This approach assumes that a channel sand bodies reservoir is represented by a single acoustic impedance value that can then be used to estimate the thickness of the reservoir by using the tuning amplitude chart. In general, this approach is carried out by the following steps: a) defining a statistical tuning chart of the tuning amplitude from synthetic data, which is designed from a wedge model with varying porosity and thickness, b) deriving a statistical tuning chart of tuning amplitude from real seismic data, which represents the reservoir surface, and c) transforming the tuning amplitude from real seismic data into porosity thickness.

This approach effectively transforms tuning amplitude into porosity thickness. This approach had been previously introduced as amplitude de-tuning [19, 20]. In this paper, the approach used a simple tuning curve from the seismic reflectivity of synthetic data (wedge model) as a reference so as to transform the tuning amplitudes from the real amplitude seismic data into porosity thickness. Both tuning charts were overlaid to illustrate the trend of tuning amplitude compared to geological data. The tuning amplitude from real seismic amplitude data was then calibrated by using the reference tuning chart to transform the data into porosity thickness.

3. Statistical Tuning Chart

The crucial step in this work was generating a statistical tuning chart from the synthetic model, which was then used as a reference in calibrating the tuning amplitude from real seismic amplitude data. The tuning amplitude reference is defined by a wedge model with various porosities. Figure 1 shows the illustration of wedge model scenarios with various porosities for defining the tuning amplitude chart reference: a) wedge model with various porosities, b) the synthetic seismogram response, and c) the amplitude tuning curve for each wedge model with various porosities.

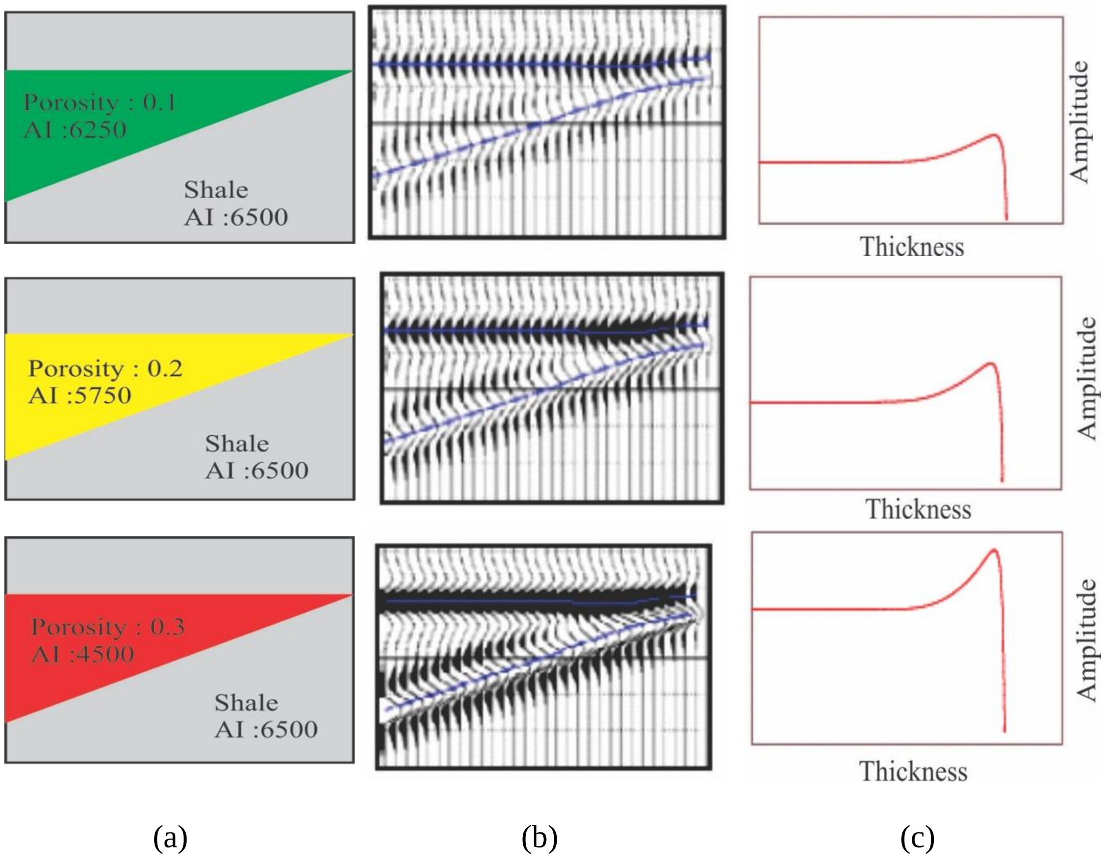

Figure 1. Wedge model scenarios with various porosity for defining the tuning amplitude chart reference, a) Wedge model with various porosity b) The synthetic seismogram response and c) The amplitude tuning curve for each wedge model with various porosity.

The synthetic seismogram is simply generated by calculating the reflection coefficient of normal incidence where the acoustic impedance is derived from the relationship between acoustic impedance and porosity from well log data. The geological wedge model was designed in such a way that sand is inter-bedded with shale layers [21]. Figure 2 shows the relationship between acoustic impedance and porosity from well log data. The relationship illustrates that porosity increases with decreasing acoustic impedance.

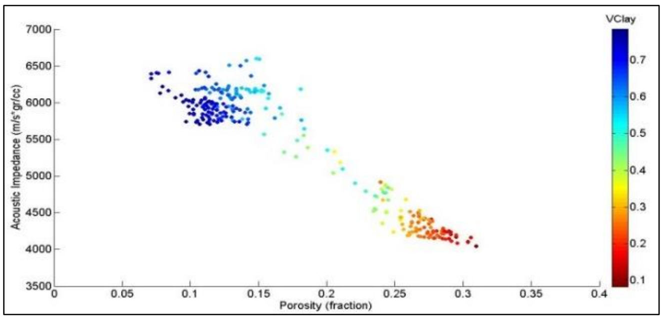

Figure 2. The relation between acoustic impedance and porosity, which is used as a rock physics model.

The calculated tuning amplitude, which is generated for various porosities, is then referred to as the tuning amplitude reference. Furthermore, this reference is used to calibrate the tuning amplitude with the extracted amplitude from the surface area of the reservoir target as a function of thickness. Figure 3 illustrates the tuning amplitude reference as a function of porosity thickness, where the color bar represents the porosity multiplied by thickness.

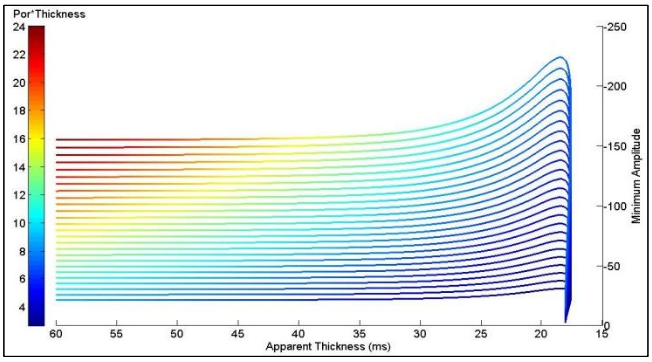

Figure 3. The amplitude tuning curve, which is used as a reference.

4. Results and Analysis

Consistent amplitude interpretation was applied to the channel-sand system of the study area. The reservoir target has been successfully identified by picking the amplitude reflection of the top and bottom horizon. Based on the frame of the top and bottom horizon, we extracted isochrones and minimum amplitude from the top of the channel surface. The selection of minimum amplitude is acknowledged by understanding that the sand layers have lower acoustic impedance compared to the shale layers above and below the sand.

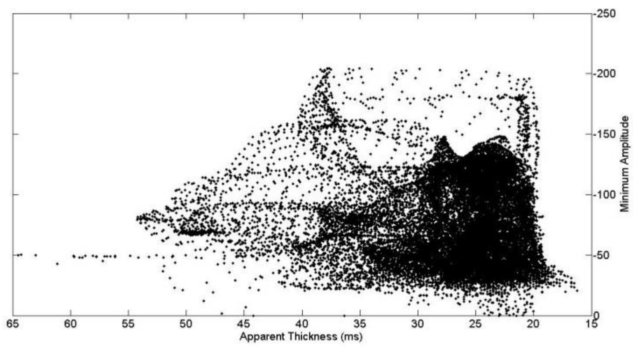

Figure 4. Statistical tuning chart coming from consistent amplitude interpretation.

Figure 4 shows the extracted amplitude tuning over the channel surface as a function of layer thickness, in milliseconds. In general, the amplitude amplification is shown to be within a thickness of 20 ms, which is caused by the tuning effect. The minimum amplitude is ranging from 0 to -200, which represents a thickness range from 15 to 60 ms.

In addition, the extracted tuning amplitude is then overlaid onto the tuning chart reference (see Figure 5). The increasing porosity thickness illustrates better reservoir quality. This means that porosity thickness can be used to represent the reservoir pore volume.

The next step is to calibrate the statistical tuning chart that extracts the amplitude of the surface area of the reservoir target as a function of thickness. The calibrated, statistical tuning chart is represented by porosity thickness, see Figure 6. In general, the porosity thickness of sand bodies reservoir ranges from 3 to 17 ms.

Seismic interpretation of the two-way travel time (for delineating the channel complex target) has been performed by identifying the seismic reflection event in the top and bottom of the surface area of the reservoir target and extracting its tuning amplitude. Figure 7 shows the geometry of the channel sand bodies, which is obtained by extracting the tuning amplitude of the surface area of the reservoir target. The tuning amplitudes illustrate that the channel sand bodies form an elongated cluster and develop in a northwest to southeast direction. In general, the channel system is composed of a channel axis and channel margins. The channel margins are roughly represented by amplification of the tuning amplitude, which is a consequence of constructive interference on the tuning effect. The amplification of tuning amplitude does not represent an indication of hydrocarbons.

The channel margin is represented by thin beds, which is indicated by the amplitude constructive interference of tuning thickness. This means that, in terms of the apparent thickness, thin beds are under-resolving the power of the seismic wave. Thereby, seismic interpretation of top and bottom reservoir reflections can be illustrated by calibration between amplitude and tuning thickness in the characteristics of the reservoir (such as the product of reservoir thickness and porosity). The relationship between acoustic impedance and seismic reflection demonstrated that the channel sand bodies indicated their hydrocarbon content by low acoustic impedance, which is indicated by strong amplitudes.

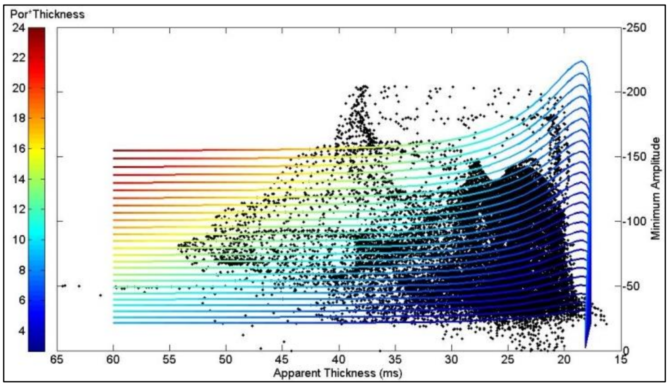

Figure 5. Statistical tuning chart that overlaid with the theoretical tuning chart coming from wedge model.

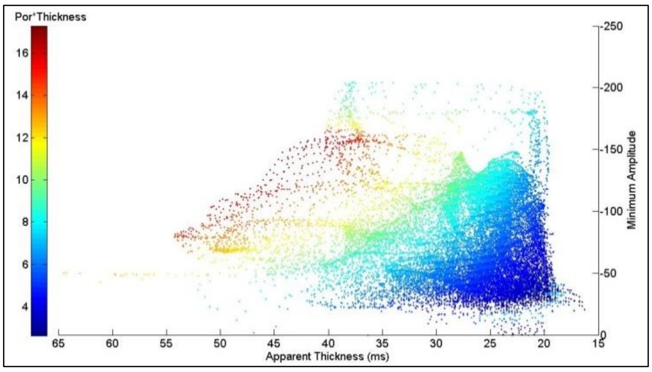

Figure 6. Statistical tuning chart calibration with the theoretical tuning chart.

In addition, to construct a detailed geometry of channel sand bodies, in terms of reservoir thickness, the structural interpretation of top and bottom channels are expressed on the isochrones map (Figure 8). Layer thickening occurs throughout the channels' axes, which is characteristic of the geometry of channel sand bodies. Nevertheless, there is a termination of the channel axis in the center of the elongated channel. In contrast, the channel margin is identified by a thin layer, which is illustrated consistently following the boundary of the channel.

By integrating these two maps (Figure 7 and Figure 8), which are implemented in the calibration schemes, we could produce a porosity thickness map showing the pore volume of the reservoir channel, as shown in Figure 9. Furthermore, the channel sand bodies geometry is completely modeled. High porosity thickness is elongated from north-west to south-east, which is dominantly concentrated in the upper part of the channel sand bodies.

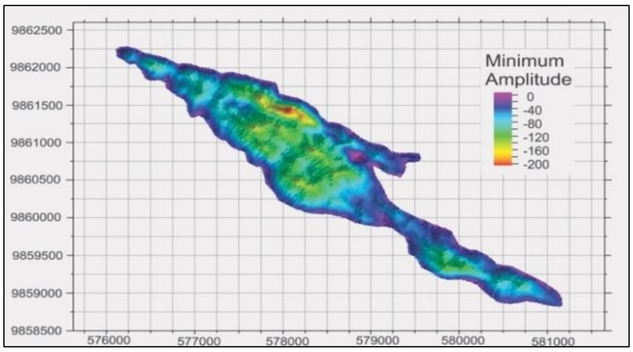

Figure. 7 Minimum amplitude map of the top reservoir channel.

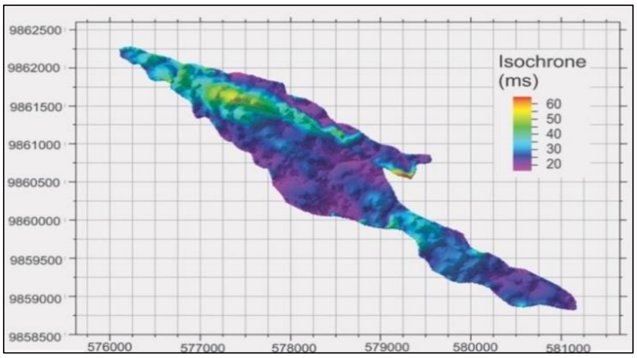

Figure. 8 Isochrone map of the top reservoir channel.

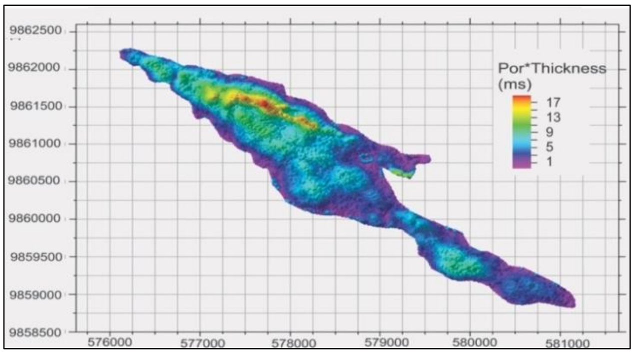

Figure 9. Porosity thickness map of the top reservoir channel.

5. Conclusion

Net porosity thickness has been successfully mapped for the purposes of delineating a channel sand bodies reservoir, which was elongated from north-west to south-east near to the Makassar Strait. The thickness of the channel sand bodies reservoir ranges from 1 to 17 ms. The geometry and pore volume of the sand bodies reservoir was properly delineated and is expressed by the thickness porosity map. Layer thickening occurs throughout the channels' axes, which is characteristic of the geometry of channel sand bodies. Nevertheless, there is a termination of the channel axis in the center of the elongated channel. In contrast, the channel margin is identified by a thin layer, which is illustrated consistently following the boundary of the channel. The porosity thickness map shows high porosity thickness is elongated from north-west to south-east, which is dominantly concentrated in the upper part of the channel sand bodies. The sand bodies reservoir is situated in a specific area of the depositional system with a long channel axis that extends from west to east. The sand bodies reservoir is geometrically characterized by thinning in the channel margins and thickening in the channel axis. The sand bodies reservoir is more likely to be a wedge model.

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