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Reducing Thin Bed Reservoir Interpretation Uncertainty Using Comprehensive AVO Classification

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Abstract

The results of this study disclose some of the geological elements that have been emphasized using spectral decomposition. The point of using the spectral decomposition here is to show the importance of the comprehensive AVO from the spectral decomposition attribute in distinguishing the reservoir sand bodies. The same features are clearer delineated in the RGB color blending as non-sand bodies. However, spectral decomposition was able to resolve the thin bed that was masked by tuning effects in seismic amplitude such as Faults, channels, and point bars. However, the weak point of using the spectral decomposition is there is still a problem to figure out whether these channels or bars are filled with sand or by shale. Comparatively, the comprehensive AVO is calculated from near and far stacked seismic data of a similar area shows that comprehensive AVO is also able to delineate a thin bed as spectral decomposition does. Moreover, the comprehensive AVO confidently distinguishes the sand lithology (hot color attribute) from shale lithology (cool color attribute).

Keywords*: Comprehensive AVO attribute; lithology discrimination; Spectral decomposition attribute; Thin Bed RGB color blinding attribute; Geomorphological features.*

1. Introduction

Imaging thin bed sands are one of the numerous geophysical challenges in Malaysian offshore and other SE Asian basins [1]. Spectral decomposition is a geophysical method that is commonly used to image and maps such hydrocarbon reservoir structure [2]. In some cases, spectral decomposition and/or spectral inversion successfully enhance the resolution of the geological elements by utilizing the tuning phenomena [3]. This frequency type attribute can excellently delineate the thin-bed channeling or channel belts [2]; [4]; and [5]. Spectral decomposition is considered an innovative method of using seismic data and the Fourier Discrete Transformation (DFT) for imaging and measuring temporary the thickness of the thin-bed and geological reflectivity condition across sizable 3-D seismic data [6].

By converting the seismic volumes into the frequency domain through the DFT, the amplitude spectra can reveal temporal variability of the bed thickness, while the phase spectra can infer the lateral geologic discontinuities [7-8]. This method has described the settings of the stratigraphic involving channel sands and structural features, including complex fault systems in 3D seismic data [2]. For the last few Years, hydrocarbon exploration in Malay Basin has moved to focus on stratigraphic traps, specifically those that existed with channel sands [9].

To pinpoint these valuable sand bodies and avoid the channels that are soft clay-filled, abandoned channels is the key objective [10]. It is challenging, as hydrocarbon sands and abandoned channels filled with clay have similar responses in high-resolution imaging like spectral decomposition [1,7].

This article demonstrates the identification of productive reservoir sand using comprehensive AVO classification. The categorization encompasses all potential AVO responses, expands, and partly redefines the currently used AVO classification and is intended to provide an unambiguous way of interpretation [11]. The attribute is calculated based on the traditional AVO gradient and intercepts analysis [12]. The new organization is defined by analyzing the amplitude tilt and the magnitude of the intercept of the route with the zero offset or normal-frequency track. The new classification means restricting the use of the word AVO to a literal definition: the study of amplitude versus offset differences [13].

A wider range of variations is provided by allowing the amplitude difference with the offset part of the definition of AVO forms. Reflections can either be positive, negative, or null (Zero) and might either raise, decrease, or stay the same with increased compensation [8]. The 10 AVO types included in the proposed classification are described in Table 1. In this study, we have applied the following method to calculate AVO classification forms using the proposed scheme. Sample by sample is evaluated for an acceptable trimmed muted moved-out and transferred selection of samples [14]. The amplitudes are connected to a less straight, best-fit side. When the slope of the line is traced back to the ordinate, it gives G, and the intercept gives P. The P and G values are used to determine a location in the unit circle; the AVO form is identified in Table 1.

Table 1. The features of AVO Kinds [11]

AVO Kind	P (intercept)	G (gradient)	AVO
-1	Positive	Negative	Peak amplitude decreases with offset
-2	Positive	Flat	Peak shifting little in amplitude with offset
-3	Positive	Positive	The peak rises in amplitude with offset
-4	Near-Zero	Positive	Almost clear peak; amplitude rises with offset
-5	Negative	Positive	Trough lessening in amplitude with an offset; converts a peak in fars
1	Positive	Negative	Peak with offset declines in amplitude; becomes a trough in fars
2	Near Zero	Negative	Almost obvious turn out to be trough; amplitude rises with offset
3	Negative	Negative	Trough amplitude rise with offset
4	Negative	Flat	Trough changing little in amplitude with offset
5	Negative	Positive	Trough decreasing in amplitude with offset

2. Model procedures

The AVO primary attributes estimate primary Amplitude Variation with Offset (AVO) attributes from common angle gathers using a linear or quadratic fit. The linear fit is valid up to an incident angle of approximately 30 degrees; if good quality data is available for larger angles, then the quadratic fit may be used to extract additional information [15]. AVO's primary attributes using the Shuey two terms approximation, like Intercept and Gradient, can be estimated from partial angle stacks or pre-stack P-wave reflection angle gathers. Basically, brine saturated rocks might plot along with a well-defined background trend when plotting Intercept versus Gradient AVO attributes [16].

Deviations from this background are indicative of hydrocarbons or unusual lithologies and can be split up into four quadrants. Four classes of AVO responses can be differentiated: Class I represents potentially hard sands with hydrocarbons with relatively high impedance but difficult to identify in seismic data because of low fluid sensitivity [17]. Class II and IIp, zero or near-zero impedance contrast sand with hydrocarbons, which often show up as dim spots or weak negative reflectors [18]. Class III represents the classic bright spot on soft sand with high fluid sensitivity. Class IV represents a low impedance reservoir such as sandstone overlain by lithology with higher shear wave velocity [7].

2.1. AVO Reconnaissance workflow

The AVO reconnaissance workflow helps us to identify anomalies that may indicate hydrocarbons. It generates primary and secondary attributes to help in the interpretation process. We can summarize 65 the steps of the AVO reconnaissance workflow as follows:

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a) From the available post-stack data, primary and secondary attributes have been generated by choosing among three different methods to approximate the Zoeppritz equations: Shuey (1), Gidlow (2), and Pan and Gardner (3).
b) The attributes have been displayed in turn on top of the seismic using the VOI tool (4).
c) Some quality control has been performed, such as displaying the observed gathers in an interpretation window and compare them with the post-stack data along the seismic lines (5).
d) The volumes after that are plotted within the volume whenever interest (6).

From the cross plot, the anomalies and their AVO responses have been identified, and then the data have been classified in turn into different types of lithologies (Confirmed sand and non-confirmed sand). Figure 1 explains the general workflow of the AVO reconnaissance to identifies and classifies AVO anomalies in an exploration context.

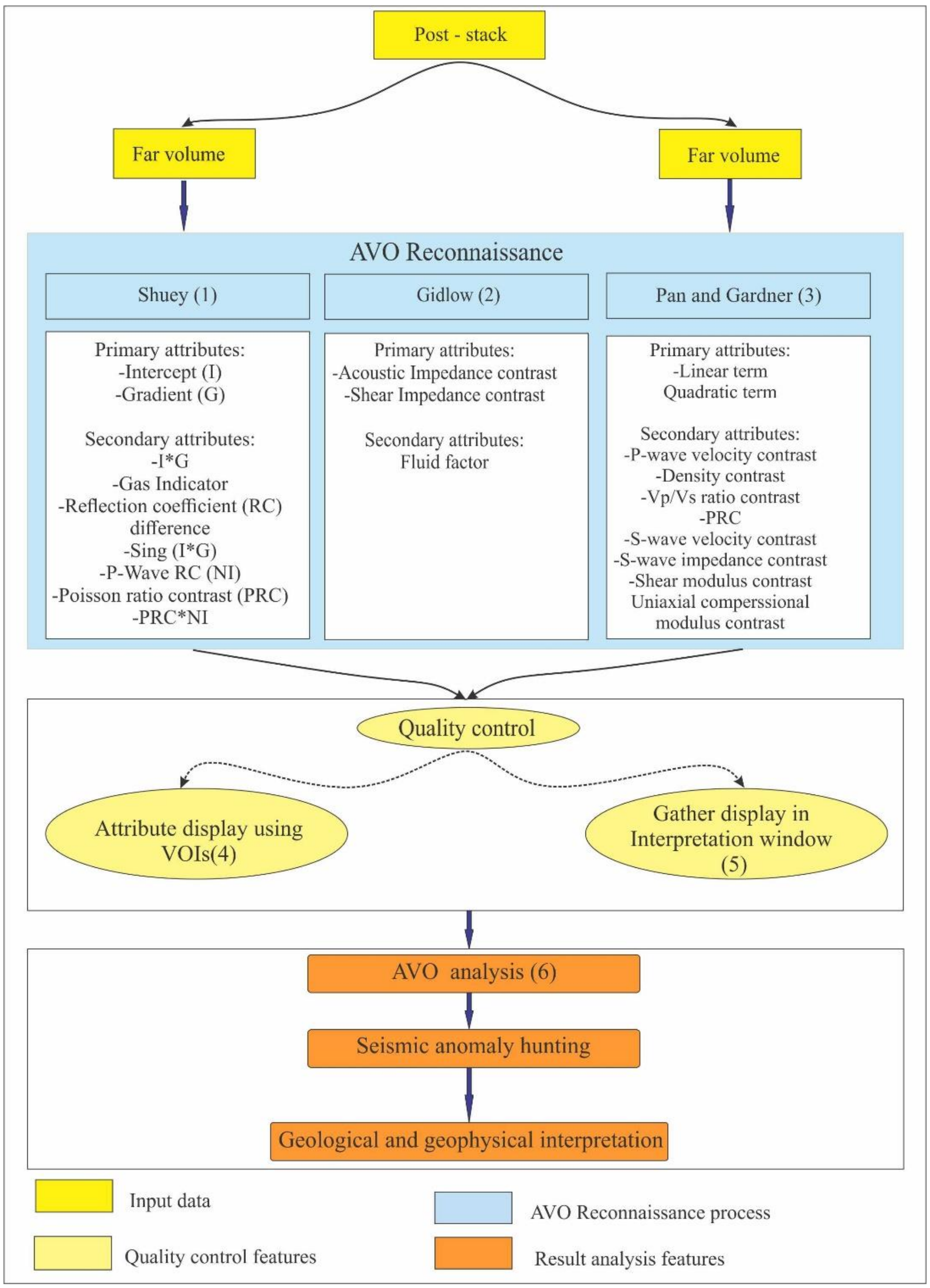

Figure 1. The layout shows the AVO reconnaissance workflow

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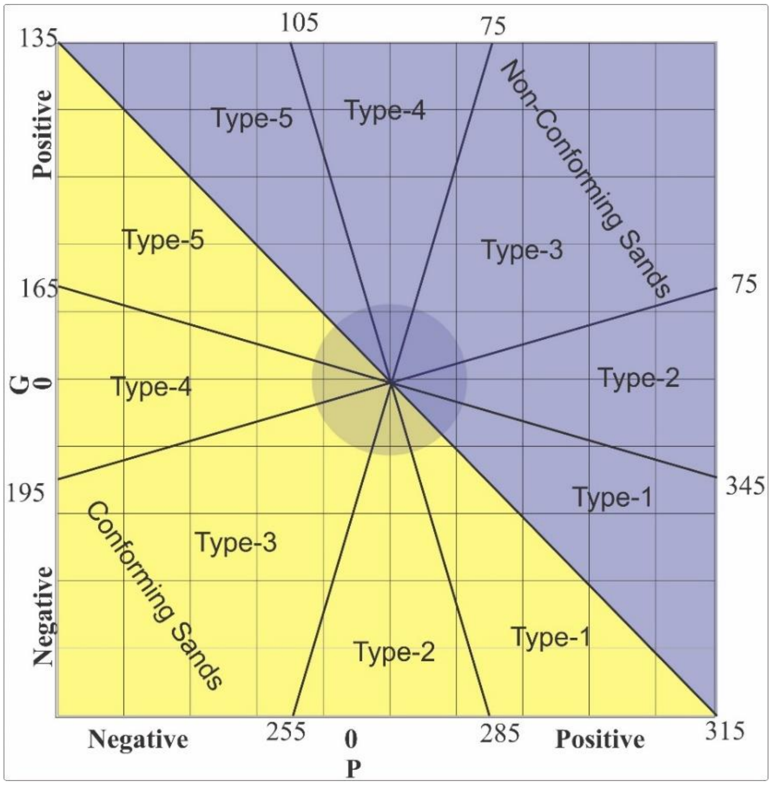

Figure 2. Suggested identification of AVO classes as G and P functions; these are all size less and sized to the equal value scale. Edited after [11]

The method used in this research is broadening the spectrum of conventional AVO analysis by subdivided all possible combinations of AVO intercept and gradient into ten classifications, as shown in Figure 2. The classification is then grouped into two major domains for a further distinction of clean sand (non-shale) from shale lithology (Conforming sand from Non-conformed sand). It is suggested that AVO effects will be better described by this broadened AVO classification. In this article, the attributes were implemented in a hydrocarbon potential fluvial environment where the interpretation is an obstacle by tuning phenomena, and this method is crucial for such interpretation case.

3. Geological setting

The Malay Basin is a Tertiary transtensional rift basin located in offshore Peninsular Malaysia [19]. The basin trends north-west/south-east and covers an area of about 80,000 square kilometers. It contains over 12 kilometers or more Oligocene to Recent sediments. The basin is adjacent to the Penyu and West Natuna basins to the south and southeast, as shown in Figure 3 [20-21].

Figure 3. The location map of the Malay Basin between Peninsular Malaysia and Thailand and Vietnam [16]

The Malay Basin is situated at the center part of the Sunda Shelf, the cratonic core of Southeast Asia. It is considered one of the deepest continental extensional basins in the region and is thought to have formed during the early Tertiary times. The targeted reservoir of this research is group D from the late mid-upper Miocene age with fluvial deltaic to estuarine channel depositional environment [22]. The results of the cire interpretation reveal a mixture cross-bedded to laminated sandstones with repeated intervals wealthy with clastic mud that refer to the high energy of shore face depositional environment.

4. Results

Basically, in any geological or geophysical investigation, no single data or means can give a conformed interpretation alone. Consequently, the more input data and means the interpreter uses, the more accuracy and reliability would be achieved [23]. Spectral decomposition is commonly used to delineate a hydrocarbon reservoir in such an environment. In this study, the results show some of the geological elements that have been highlighted but not conformed by using spectral decomposition. The point of using the spectral decomposition here is to show the significant variation of the AVO from the spectral decomposition. The same features are clearer delineated in the RGB color blending attribute, as shown in Figure 3.

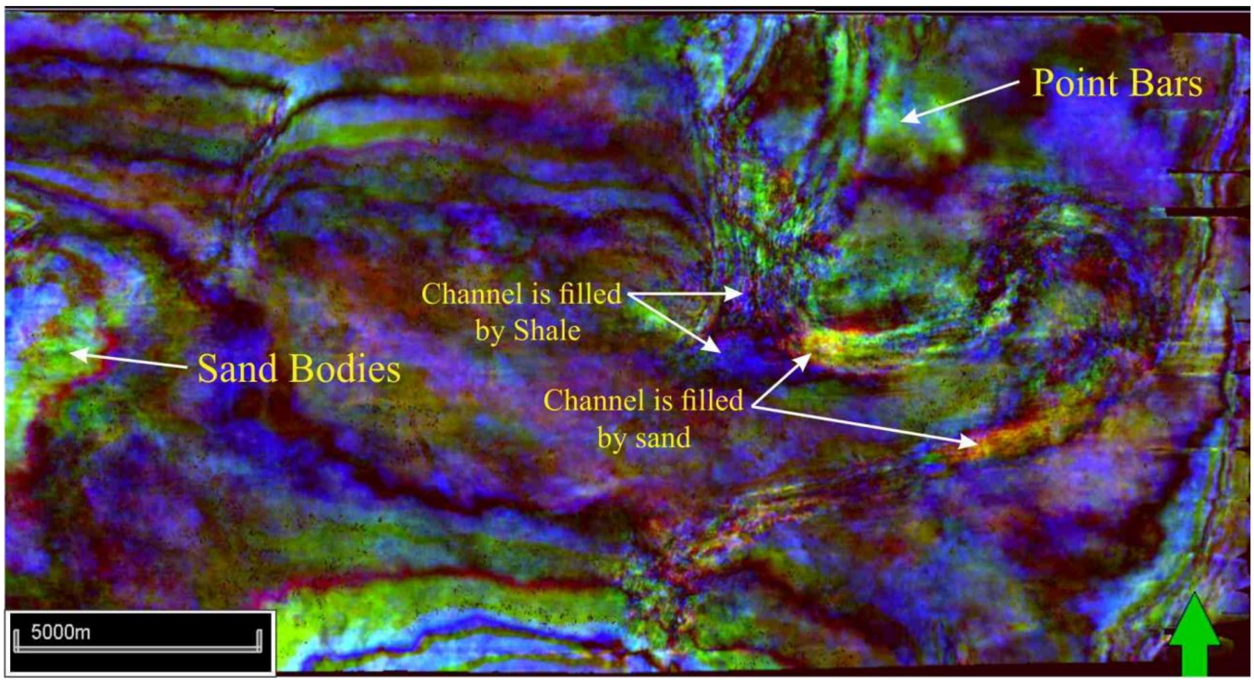

Figure 3. RGB color blending seismic attribute indicating some geological features such as the channels, channel belts, sand bodies, and shale bodies

However, Figures 4, 5, and 6 show how the spectral decomposition can resolve the thin bed that is masked by the tuning effect in seismic amplitude, as shown in Figure 4. Faults, channels, and point bars are clearly delineated. However, the problem here is to define whether the potential reservoir, such as channel or point bars are filled with sand or shale. Comparatively, the comprehensive AVO is calculated from near and far stacked seismic data of a similar area. The result shows that comprehensive AVO is also able to delineate a thin bed as spectral decomposition does, as shown in figure 6. Moreover, the comprehensive AVO confidently distinguishes the sand lithology (hot color attribute) from shale lithology (cool color attribute).

Three surfaces displayed in Figures 4, 5, and 6 coincide with the low value of sand volume (VSand) log from an inserted well Melor-2. The well log confirmation shows that comprehensive AVO provides plausible sand/shale distribution when spectral decomposition confusingly gives. Hence, comprehensive AVO is potentially reducing the uncertainty in deciding the location of the hydrocarbon reservoir to drill. Figure 4 indicates the anomalous of high amplitude due to tuning as shown in Figure (4-a), which is ambiguously interpreted as shale by spectral

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decomposition in Figure (5-a) and interpreted as reservoir sand by comprehensive AVO classification as shown in Figure (6-a).

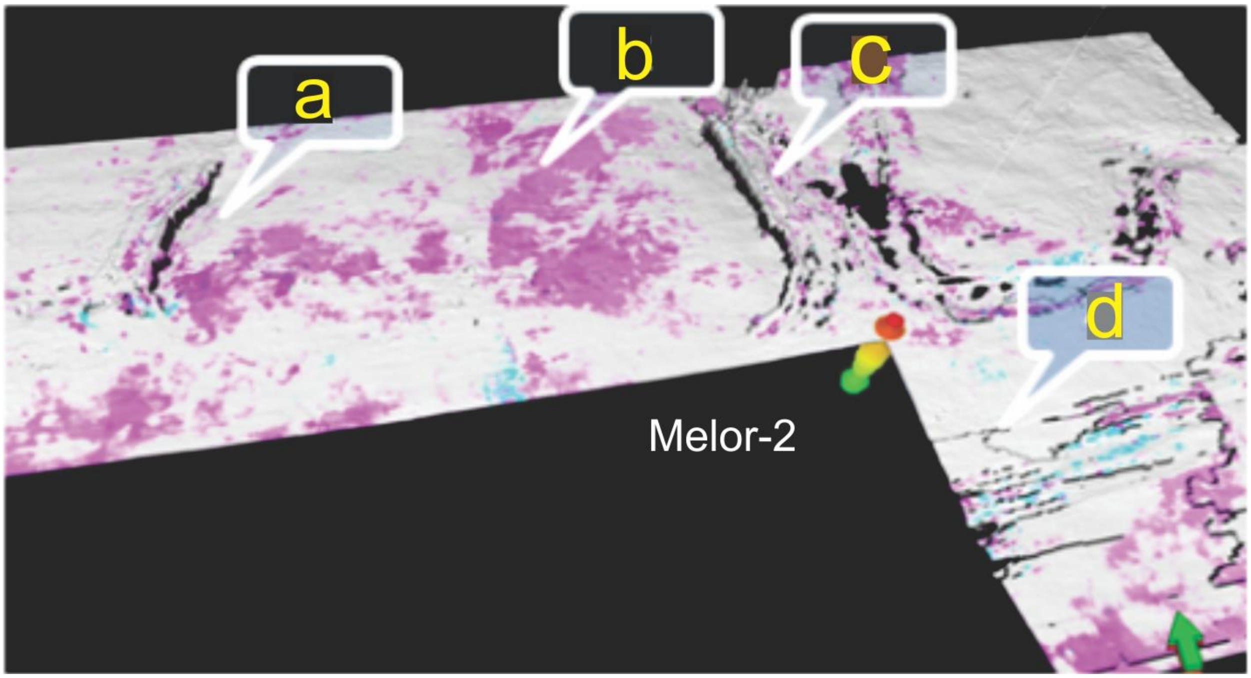

Figure 5. shows the spectral decomposition attribute interpreted the (5-a) as shale, confusingly interpreted (5-b) as sand and shale, (5-c) also wrongly interpreted as shale and ambiguously interpreted (5-d) as shale.

The thin bed is not resolved by seismic amplitude due to tuning as shown in Figure (4-b); in the meanwhile, it is determined by spectral decomposition but confusingly interpreted as sand and shale Figure (5-b), and it is resolved with distinguished sand from shale by comprehensive AVO classification as shown in Figure (6-b).

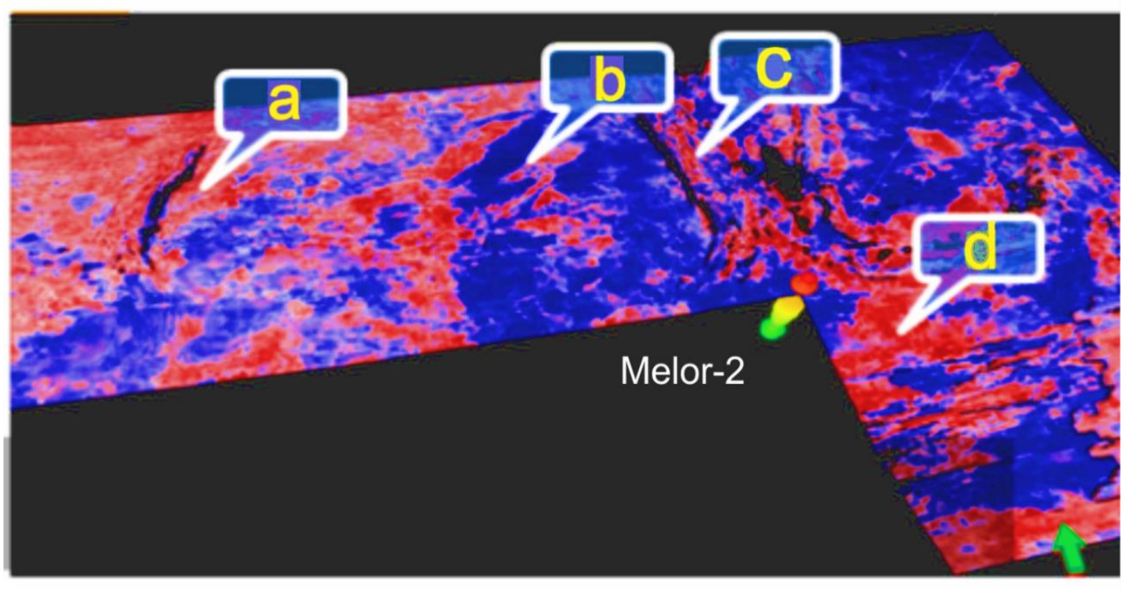

Figure 6. comprehensive AVO classification interpreted the (6-a) as reservoir sand, distinguished sand from shale (6-b), also interpreted (6-c) as the sand bodies, and (6-d) interpreted as sand bodies as well

Finally, the fourth feature distinguished by low amplitude was sand point bar as shown in Figure (4-d), which was ambiguously interpreted as shale by spectral decomposition as in Figure (5-d) and correctly interpreted as the sand by comprehensive AVO classification as shown in Figure (6-d). The VSand log was inserted to validate the current interpretation. The three Figures (4, 5, and 6) show surfaces, which coincides with low VSand value (considered as shale lithology). The other geological element indicated by low amplitude is the sand channel as shown in Figure (4-c), which is ambiguously interpreted as shale by spectral decomposition Figure (5-c), and correctly interpreted as the sand by comprehensive AVO classification as shown in Figure (6-c).

This study demonstrates how amplitude analysis might hypothetically be enhanced by using the most suitable frequency varieties. Castagna *et al.* [23] made a noticeable opinion that conventional amplitude analysis approved out on the full-spectrum data fundamentally means the interpretation is founded on the 'accidental' dominant frequency, rather than frequencies selected purposefully for the objectives at hand [20]. Cross-plot classifications of frequency limited AVO often vary in function of the frequency. This could be used as a tool for assessing which frequencies are the strongest discriminating fluid or lithology and where no valuable signal occurs. Comprehensive AVO is potentially reducing the uncertainty in deciding the location of the hydrocarbon reservoir to drill in Figure 7.

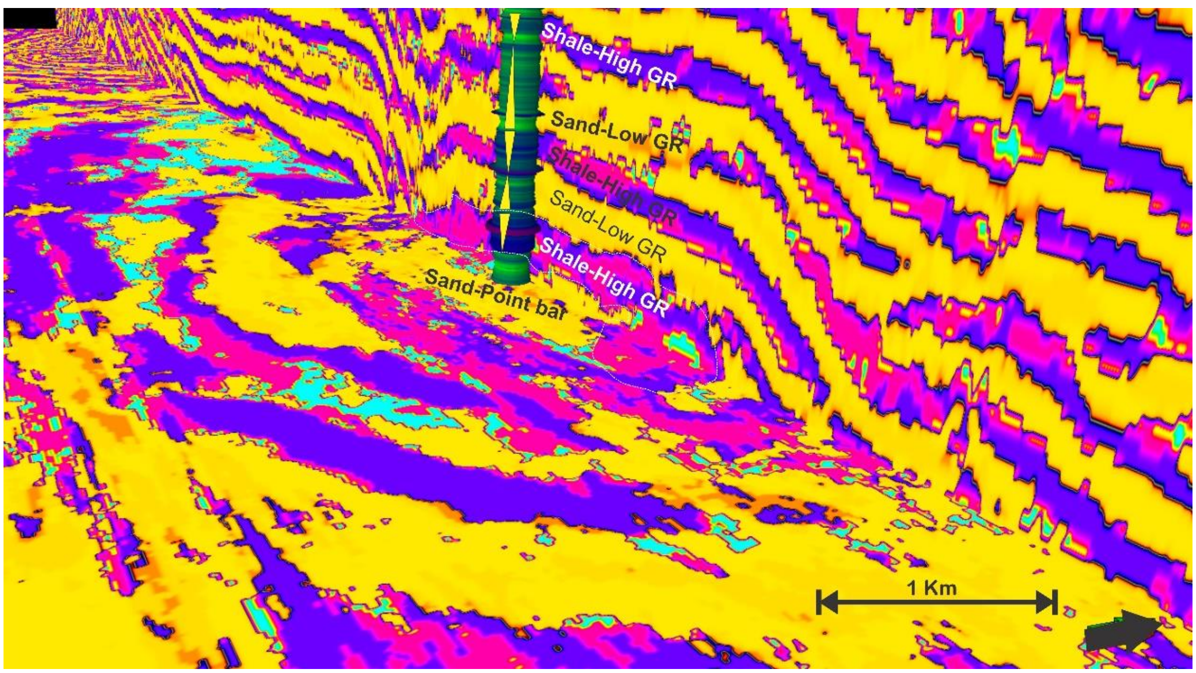

Figure 7. AVO attribute produced using the normal volume attribute result showing discrimination of the sand and shale utilizing the AVO attribute and well logs to validate the AVO interpretation with sand (yellow color) and somehow filled by shall (Blue color)

AVO attribute produced using the normal volume attribute result showing the channel filled with sand and somehow filled by shall. This information was not displayed using the spectral decomposition. The spectral decomposition of the same time level shown only the channel trajectory but not indicated any lithology, while the AVO attribute exposed the sand distribution along with the channel in the yellow color. However, Figure 7 display the validated of the interpreted lithologies based on the AVO and spectral decomposition; this result shows that the AVO attribute is more accurate and reliable in revealing the lithology bodies better than RGB and spectral decomposition attributes as shown in Figure 7. In contrast, the spectral decomposition is perfectly depicting the outer and general shape of the geomorphological bodies such as the meandered channel but does not reflect precisely the lithology of the channel.

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5. Conclusions

An AVO category is suggested and implemented of the available data in which all potential variations of standard reflectivity and offset based on reflection are then subdivided into 10 forms to covers all the seismic spectrum from the top, sandy deposits. In general, the RGB color blinding and spectral decomposition attribute are fascinating tools for depicting the subsurfaces' morphological features such as the channels and channel belts, point bars, crevasse, etc.; these subsurfaces geological elements are very important traps might be holding a tremendous hydrocarbon. Malay basin is predominant with such stratigraphy traps, which are targeted as potential reservoirs of oil and gas. The investigation results in the Malay basin shown that these potential features might give ambiguous responses to some seismic attributes due to the gas or clay contents. The fact that it makes applying several attributes and validates them with well analysis is critical. Based on the outcome of this research, it is clear that not all abandon channels or point bar might be an ideal reservoir. The abandoned channels and point bars are filled with clay sediments, which might be injected in these sand bodies act as barriers to the oil and gas follow and disturb the hydrocarbon migration. Thus, locating the sand bodies that might be a host for the oil and gas is an acritical issue. This research has run RGB, spectral decomposition, and AVO attributes. Moreover, we have validated these attributes results using well log analysis. Comparing the well log analysis result with these attributes, we found that AVO is more appropriate for delineating and discriminating the potential reservoirs lithologies. The anomalous amplitude gave different interpretations using spectral decomposition, while the used comprehensive AVO classification shows that areas as reservoirs sand bodies. Finally, the comprehensive AVO attribute would be a great means for the lithology discrimination in the Malay basin based on abandoned channels existence, which might be injected with muddy sediments.

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