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Application of seismic attributes to delineate the geological features of the Malay Basin

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Abstract: The Melor-field of the Malay basin has been investigated using several seismic attributes to present the geological elements accurately. This study used a new seismic attribute to represent the geological features of the study interval. Besides, the application of some seismic attributes was applied to reveal the structural and geomorphological features of the Melor-field. The limited available wells (Melor-Well-1 & Melor-well-2) in the study area resulted in high uncertainty regarding petrophysical parameters, particularly in net sand distribution, while the western and eastern parts did not have any well control. Considerable heterogeneity was evidenced in the reservoir quality between the reservoir encountered in Melor-1 and Melor-2 Wells. Three-dimensional geological modeling was utilized in this study to integrate the geological and 3D seismic results with the well logs and seismic attributes to address the above uncertainties. This helps to estimate the reservoir properties for the distances away from the wellbore. The results showed that the fields of the Malay basin are dominated by semi-flattened depositional sequences with heterolithic interbedding associated with a high degree of vertical heterogeneity. The systems tract has been evaluated, although the study area was very complicated. A new method consisting of multi-seismic attributes, thoroughly picked horizons, well logs, and seismic data, which has been used in this research to establish a reliable sequence stratigraphy and system tract framework. Seismic sequence stratigraphy spectral analysis is a new attribute used to represent a 3D visualization of the studied interval. The original amplitude, coherence, and spectral decomposition have been utilized to display the geological features hidden in the seismic data. These attributes are based on the properties of the seismic data, which itself is the result of relevant geological phenomena. The results of this research can be a wide-based reference for further studies in this area.

Keywords: Seismic attribute, geological features, sequence stratigraphy, systems tract, Malay Basin

INTRODUCTION

The Melor-field is considered as a gas field in block PM 313, approximately 215 kilometers north-northeast of Kertih, Terengganu, and 70 kilometers northeast of the Resak production platform. The Melor-field 3D seismic survey covers an area of roughly 240 square kilometers in the Malay Basin. The inline direction is east-west, while the cross line is in the north-south direction (Figure 1). The used data quality is relatively good in the zone of interest (Groups D, E, and F), which occurs in the time interval of 1500 to 3000 milliseconds. The minimum resolution is estimated at 25 meters (Bareg *et al*., 2002).

The geological elements hidden in a volume of seismic data can be inferred using the seismic attributes means well by detecting similar patterns, and by measuring specific deposit properties, these elements including anticline, faults, folds and channels ect (Barnes, 2016a). The seismic attributes assist the geophysicists in interpreting the seismic data effectively. Attribute analysis is a powerful tool of the reflection seismology for petroleum exploration and finds wide application; it utilizes the anomaly identification to extract the hidden geological features in the seismic data and the lithological prediction. It measures seismic data properties and describes them differently. The seismic attributes invention is steadily continuing each year. Every attribute can show one side of the subsurface deposits image, but not all; the fact is, the more seismic attributes are used in any study, the greater accuracy will be achieved.

In this study, many of these attributes were used ideally and revealed an excellent result as never before seen in the study area. Numerous attributes, such as original amplitude, coherency, spectral decomposition, and RGB color blending, represent a different aspect of a seismic reflection that brings out various aspects of geologic features. The purpose of this paper is to document the application of seismic attributes for depositional elements imaging in the Malay basin at a basin-wide scale. Presently, the geological features of Group D have not been fully understood. Hence, the application of these new seismic attributes will help a lot in the better understanding and imaging of the geomorphological features

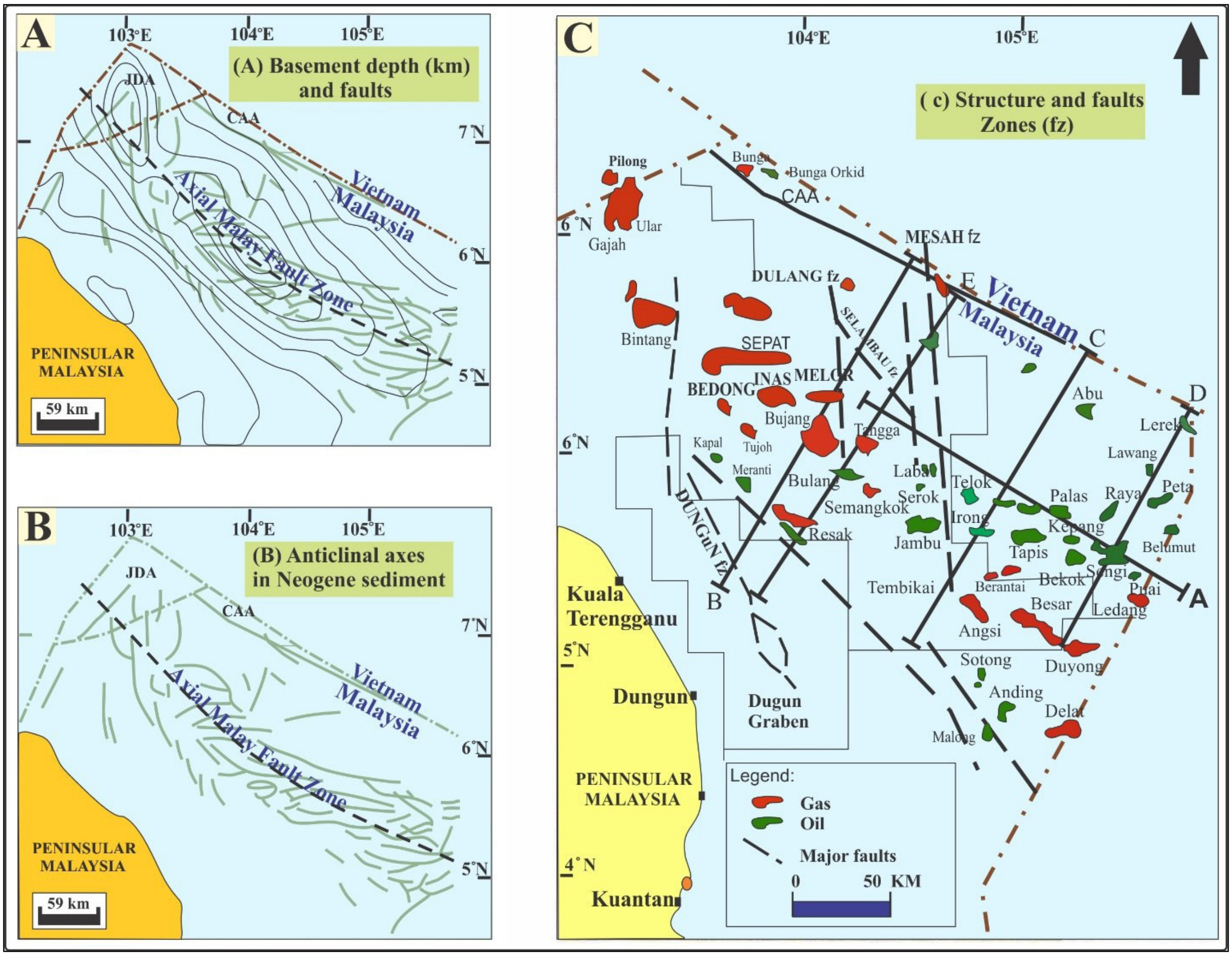

Figure 1: The Malay basin structural elements. (A) represents the pre-tertiary basement depth and faults edited thereafter (Esso, 1985). (B) shows the axis of the Neogene sediment fill thereafter (Esso, 1985). (C) Represents the significant fault zones recognized by Ngah *et al.* (1996). The blue lines are cross-sections; Line B is our cross-section passing through the Melor-field shown in Figure 2. After Esso (1985).

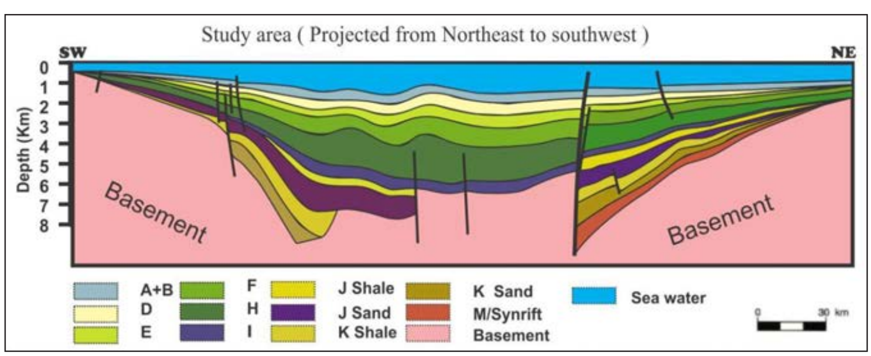

Figure 2: Regional south-west/north-east cross-section through the Malay Basin modified after Madon (1999).

of Group D and to identify the systems tract in the Malay Basin in high-resolution.

In this investigation, the geological elements, systems tract, and two (2) major sequence boundaries (horizons), which are Top Group D, and bottom Group D were interpreted for field-wide interpretation of Group D interval. These two sequence boundaries were located based on some factors including the well tops, reflection terminations, and seismic configuration and were confirmed by the synthetic seismogram. However, four strata proportional slices were created using a stratal slicing tool to show the morphology of the formations within Group D in a high-resolution. Multi seismic attributes were also used for channel imaging, geomorphological features, faults, and systems tract delineation. The data used in this analysis were 3D seismic and well log data from the Melor-field. The software used in this study was Petrel and Pleoscan software.

GEOLOGICAL SETTING

The Malay Basin is located at the center of the Sunda shelf, the cratonic core of Southeast Asia. It is one of the deepest continental extensional basins in the region and is believed to have formed during early Tertiary times (Madon, 1999). The basin formed as a result of transmission during the Late Eocene to Early Oligocen, and is related to the collision of the Indian Plate with the Eurasian Plate, which was followed by a period of post-rift thermal subsidence (Pubellier & Morley, 2014). The Tenggol Arch separates the Malay Basin from the Penyu Basin, while the Narathiwat High separates the Malay Basin from Thailand's Pattani Basin. The Malay Basin is an elongated NW-SE trending basic, about 500 kilometers long and 250 kilometers wide, and it is underlain by a pre-tertiary basement of metamorphic, igneous, and sedimentary rocks. The basement represents the late Mesozoic continental landmass that existed before the basins were formed, as is shown in Figure 1A. These are thought to be the offshore continuation of the geology of eastern Peninsular Malaysia. In the southern part of the basin, tectonic deformation has caused an inversion of the basin during the middle to late Miocene and has resulted in a regional base-Pliocene unconformity. The late Miocene strain produced numerous compressional anticlines which formed the major hydrocarbon traps in the basin. The Malay Basin is asymmetrical along its length and in cross-section. Its southwestern flank is slightly steeper than its northeastern side. The study area (Melor-field) is one such structure: an east-west trending anticline, cut by a north-south fault at its western end (Madon, 1994). Basement faults in the southeastern and central parts of the basin mostly trend E-W, oblique to the overall basin trend. These basement faults appear to have influenced the geometry of compressional anticlines in the Neogene sedimentary fill as a result of dextral motion along the Axial Malay Fault Zone (Figure 1B). The southwestern margin is marked by the Western Hinge Fault (WHF, Figure 1C), which is a zone of echelon normal faults and associated fault-bounded, pull-apart basins. The latter has been interpreted as resulting from right-lateral wrench motion along the WHF (Tjia, 2000).

STRATIGRAPHICALLY AND STRUCTURAL SETTING OF THE STUDY AREA

The case study, Melor-field, is an east-west trending asymmetrical anticline segmented by a single major north-south trending normal fault at the western end of Figure 3. The throw on this fault ranges from approximately 30 meters to 90 meters (Ariffin *et al*., 2005). Fault interpretation at the crystal part of the structure is complicated by the chaotic and discontinuous reflectors, mainly due to the frequent occurrence of shallow, gas-filled channels. These factors lead to uncertainty in the fault interpretation. The 3D survey, however, provides confident delineation of the northern entirety and southern termination of this fault outside the shallow gas imprint area. Figure 3 represents the time structure map showing the major fault only without any other details being revealed in this study, as they will be presented in the results. Comparing the current study with other previous studies, the results we obtained in this investigation exposed many other geological features such as the major and minor faults in a high-resolution scale, sharp edges, channel, levee, and point bars been perfectly presented as never before. Group D is one of the reservoirs that have been generally formed by shallow marine sandstone. The Interbedded units of the shale and claystone contained within Groups D and E, particularly in the upper Group D, form the top seals for these reservoirs. The hydrocarbons

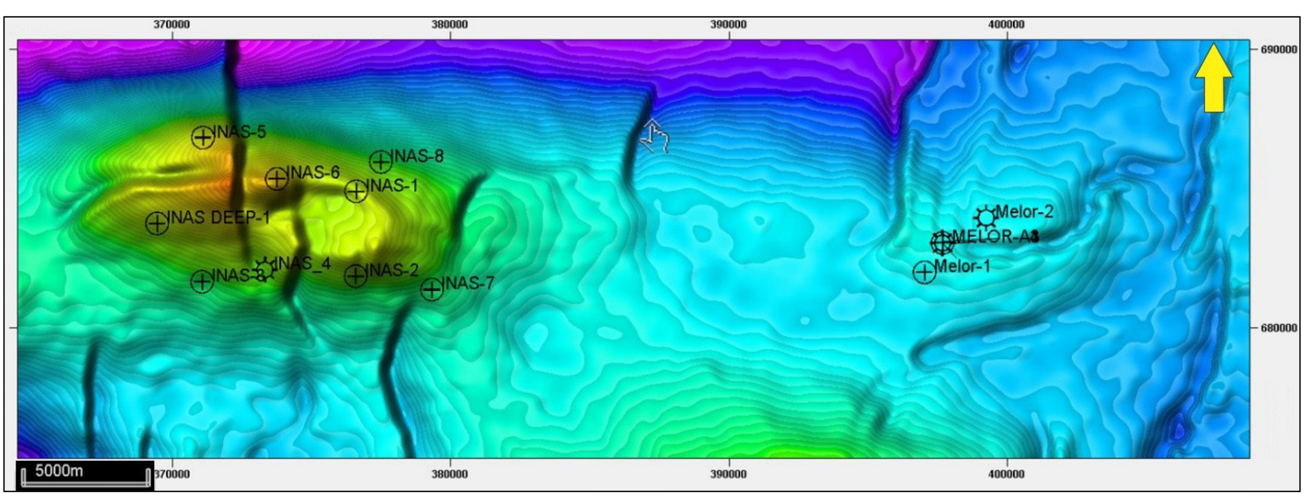

Figure 3: Time structure map showing the major fault of the Melor-field with the available wells in the field. (Bareg *et al*., 2002).

occur in reservoirs from Group L to Group D. A sequence boundary within the interval 1300-1390 meters is likely, possibly at circa 1300 meters (but no logs are available for interpretation). The environmental deepening above 1300 meters, therefore, reflects the onset of a further period of transgression.

MATERIALS AND METHODS

Seismic sequence stratigraphy and system tracts analysis

The seismic sequence stratigraphy is a technique that enables the interpreters to subdivide, correlate, and map the sedimentary packages into sub-semi-genetical units. This technique is applied to seismic data to classify the seismic reflections within the interested interval into packages that correspond to chronostratigraphically restricted genetic depositional intervals (Wagoner & Mitchum, 2003). The identification of these sequence boundaries is dependent on the package of the seismic reflections which can be delineated by observation of the surfaces of the discontinuity which include the systematic characteristics of the reflection terminations along discontinuity surfaces, such as erosional truncation, apparent truncation, lapout that involved baselap, toplap, onlap, and downlap (Vail, 1987).

Moreover, the seismic configuration and the well top have been utilized as well in this sequence determination (Miall, 2016). A specific systems tract is basically represented as certain sets of depositional processes associated with specific depositional environments and lithofacies. The identification of the systems tract on the seismic sections is significant in the depositional environments and lithofacies prediction precisely (Catuneanu *et al*., 2009). Therefore, an accurate understanding of the environment's depositional and lithofacies aids better quality predictions of the reservoir, seal, source rocks, and migration trajectory (Vail, 1987). Systems tracts also provide a seismic target that is wider than a single reservoir unit, but which has a genetic relationship to that reservoir unit. So the reservoir prediction from the seismic data is more reliable based on the strong genetic relationship between the reservoir units and systems tracts (Vail, 1987). The seismic sequence analysis linkage to the specific depositional ages with systems tract of any sedimentation package reflecting the global cycles of the relative changes of coastal onlaps and eutectic changes of the sea level depend on some factor comprised of the biostratigraphic information, magnetic reversal, and the absolute age data (Miall, 2016).

The purpose of seismic sequence interpretation is to categorize depositional sequences and systems tracts on the seismic sections by interpreting the location of their boundaries (Almasgari & Hamzah, 2016). These are demonstrated as discontinuities in the seismic interval and are positioned primarily by observation of the reflection terminations (Li & Zhang, 2017). Figure 4 represents reflection termination patterns that are used to define the genetic reflection packages referred to as seismic sequences and seismic systems (Emery & Myers, 1996).

Stratal slicing analysis

Stratal slicing is a method of producing linearly seismic subsurface maps between two interpreted bounding horizons. It is mainly used for displaying the seismic-surfaces by a linear slice between geologic time-corresponding seismic-reference events (Zeng, 2013). This technique can also be employed to display the seismic surfaces, especially in the sheet-like and non-flat laying formations. The stratal slicing method is more applicable when the deposited interval is not sheet-like or flat laying as well (Zeng *et al.,* 1998). The outcome of applying this technique can be linearly sampled into some equally time interval maps between the two reference events (Lew *et al*., 2016).

Seismic attributes analysis

The seismic attributes are a fascinating means for understanding the subsurface geology from seismic reflection data. They assist seismic analysis by exposing hidden elements, through detecting similar patterns, and by measuring properties (Figure 5). Attribute analysis is a crucial component of the seismology reflection for petroleum exploration, and it discovers broad application, from the identification of the anomalies to the extraction of the geological feature and the lithological prediction. Basically, the seismic attributes describe the seismic data and measure seismic data properties. Hundreds of attributes have been developed and tend to be increased every year. The widely used attributes are the interpretation of the qualitative investigation attributes, while the quantitative multi-attribute analysis is still growing slowly. The data used in this study is post-stack data; these post-stack attributes consider the seismic data as images of the earth, while the prestack attributes handle the seismic data as records of seismic reflections. Therefore, they measured stratigraphic and structural properties which were effortless to compute and apply, but the direct links to lithology which are primarily concerned were missing (Barnes, 2016b).

Some seismic attributes have been used to image the geological features of Group D in the Melor-field. These

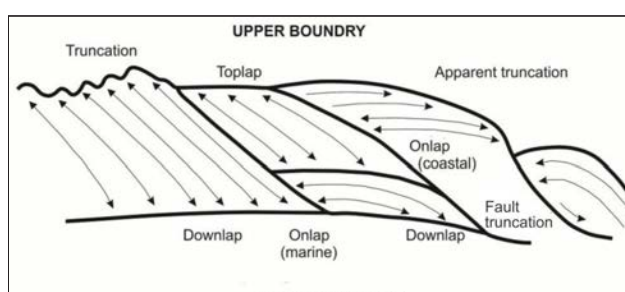

Figure 4: Reflection terminations at lower and the upper boundary of the sequence (Emery & Myers, 1996).

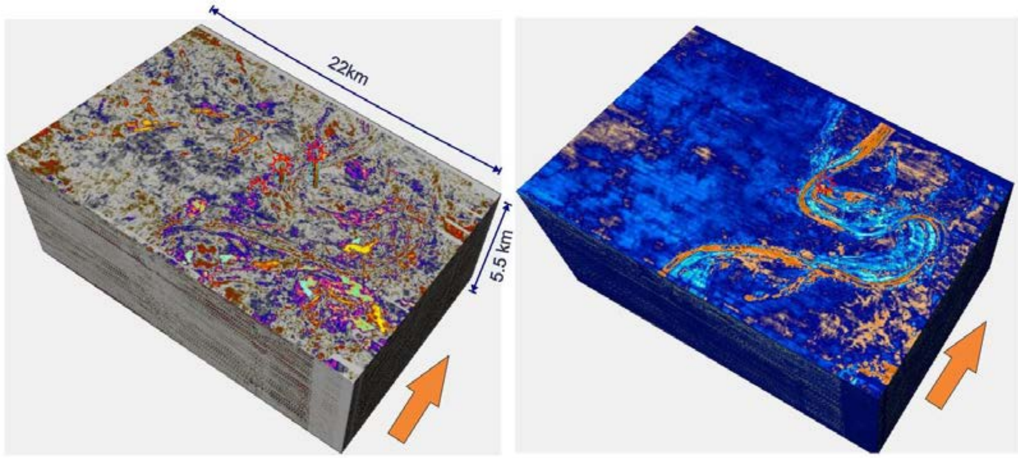

Figure 5: The power of the seismic attributes to reveal hidden features within the seismic data. The channel and points bar are obviously shown in the right volume compared to in the original seismic data on the left.

attributes include original amplitude, spectral decomposition, and sequence stratigraphy spectral analysis which integrate the picked seismic horizon with three different iso-frequency values. These attributes were used to generate a high-resolution seismic sequence stratigraphy 3D seismic framework representing the geological features that would enhance seismic interpretation and volumetric estimation of the interested interval unit (Group D) in Malay Basin. The methodology involved tying wells to the seismic data, time to depth conversion, generating the synthetic seismogram, seismic attributes analysis, seismic sequence spectral analysis, 3D geo-body modeling, mapping the seismic horizons, seismic reflection terminations, gamma-ray, seismic configuration, and seismic facies were used to locate the sequence boundaries. The data that have been utilized in this interpretation include well logs and a 3D volume of seismic data.

RMS amplitude

RMS amplitude is a powerful attribute that can be used to see the sweeping changes in amplitude character. Amplitude refers to the magnitude of the seismic trace values or traces envelope. This can be useful in calculating variations in signal to noise ratios and defining zones of noise, seismic stratigraphic changes or structural patterns (Marfurt, 2007). The amplitude contrast attribute highlights significant changes in amplitude strength in the horizontal and vertical dimensions. Abrupt changes in amplitude strength are depicted as strong changes in the color template and can often be correlated to geological structures within the seismic volume. It is the most critical seismic property and has more attributes than any other (Barnes, 2016b). The vertical changes in reflector energy strength (from peak to trough) are picked out in the vertical section, which may aid in enhancing low-resolution reflections in high signal-to-noise ratio (SNR) areas. Lateral changes in reflector energy strength can be used as indicators for geological complexity in the seismic data such as stratigraphic and facies variations, fault systems or salt/shale bodies, channels, and other geological features, as will be shown in the Results section

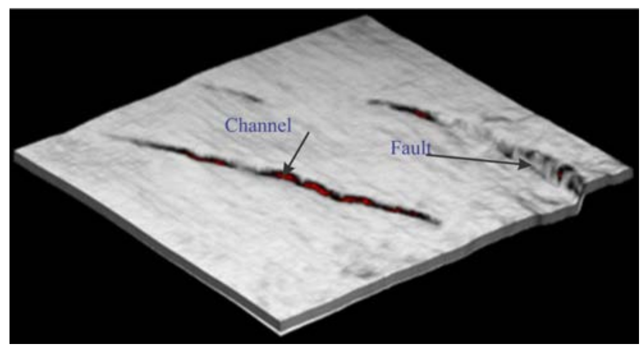

Figure 6: An example of the variance attributes shows structural and stratigraphic discontinuities on time and horizon slices.

Variance

Variance is an excellent attribute utilized in delineating the geological features such as deltas, faults, canyons of submarine, karst, mass-transport complexes (MTC), and so on. It is a measure of similarity between waveforms or traces, not only that but also coherency is an excellent means to display the beaches and deltas, the fact that enables the interpreter to have better understanding about the progression and retrogression to construct the sequence stratigraphy framework of any study area. Moreover, it allows for the submarine canyons, mudflows and understanding of the stratigraphic deposition from the seismic reflection data (Chopra & Marfurt, 2018). Variance is also used to extract a reflection continuity or edge attribute volume from an input seismic volume (Figure 6). It is a measure of similarity between waveforms and extracts strong lateral changes in both waveform character and amplitude. Variance volumes significantly enhance the ability to image structural and stratigraphic discontinuities on time and horizon slices (Chopra & Marfurt, 2009).

Spectral decomposition and color blending

Spectral decomposition is an essential seismic interpretation technique and is also a sophisticated method for producing seismic attribute maps. The hypothesis of spectral decomposition is to decompose down the seismic trace into partial frequencies to emphasize precise subsurface elements (Castagna & Sun, 2006). Broadly, the term can refer to any time-frequency analysis of seismic data, but it is most often applied to the generation of frequency slices, usually along with horizon-guided time windows in 3D seismic data (Figure 7). The idea of the spectral decomposition is transforming every individual 1D seismic trace into 2D time-frequency to get a specific frequency (Wooltorton & Teric, 2016). This process can provide high-resolution surface images of the geological features, and reservoir details, and it generates very enlightening maps of thin beds, particularly in a clastic deposition with sharp impedance contrasts. Slices are often displayed draped on seismic horizons and may be co-rendered with, for example, semblance data. It is also common to combine frequency slices into color composite images (Sheriff, 2002). The spectral decomposition attribute has worked very well in Malay Basin to enhance channel imaging and other geological features. The process of transforming seismic data into the frequency domain using the Discrete Fourier Transform (DFT) helped in filtering out the upper coal layer response, which occurs in higher frequency, hence improving the underlying channel image (Partyka *et al*., 1999). RGB is a blending color model used for plotting three different spectral components of RGB colors. This method has proven efficient in all geological environments, which has helped to derive much information from the actual seismic data using different frequencies better than using amplitudes alone (Wooltorton & Teric, 2016).

Sequence stratigraphy spectral analysis

Seismic sequence stratigraphy spectral analysis is a fantastic new method which has been utilized to analyze spectral elements of the seismic cube. The high resolution of the seismic spectral decomposition methods helped out in the analysis of revealing the geological features hidden by spectral smearing (Puryear *et al*., 2012). We used this integrated method in this research as a combination of precisely and thoroughly picked seismic horizons, seismic data volume, and three dominant different iso-frequencies values (15Hz, 25Hz, and

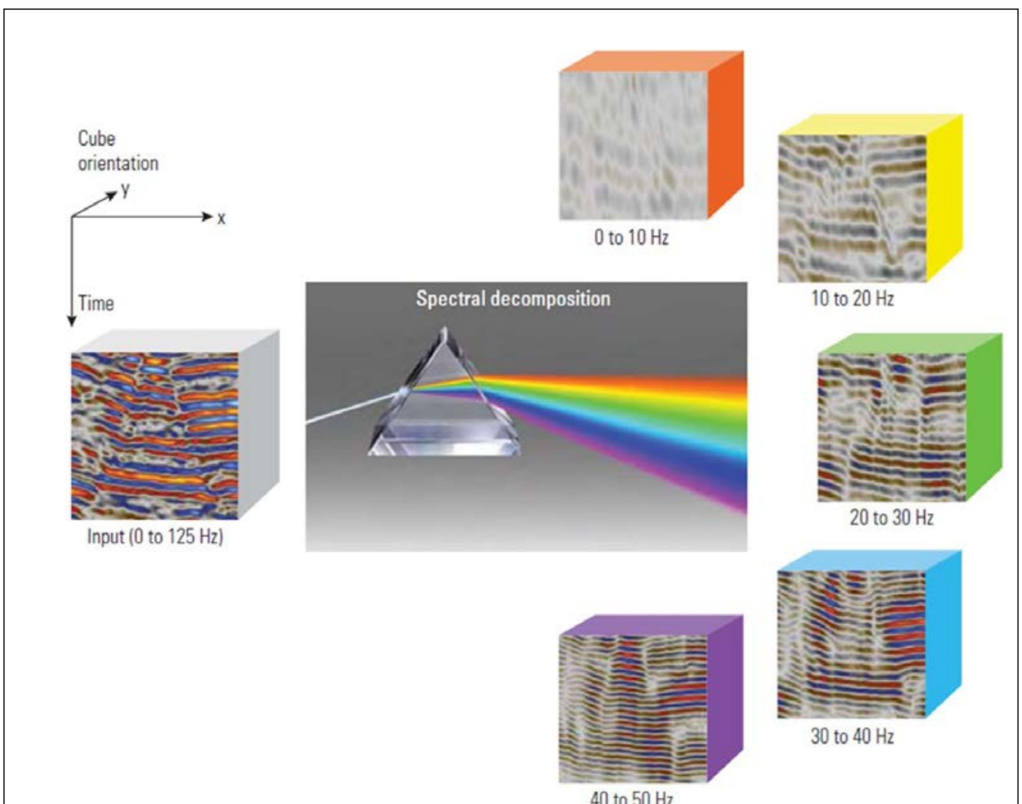

Figure 7: A sketch is showing the optical analog of spectral decomposition where white light is decomposed into its spectral components. In actuality, the velocity of glass is dispersive, such that Snell's Law gives a different refraction angle for each frequency. A broadband seismic volume can be broken into constituent small band volumes. In this case, the analysis window is the length of the entire seismic trace after Aarre *et al.* (2012).

45Hz). The mixer toll of Petrel software assisted in visualizing the geomorphological feature excellently, as never before. This integrated method has proven to be a powerful tool to reflect the geo-bodies and the spectral properties to extract out different 3D images across picked seismic horizons. The different contributions of the different frequency components to the volume over the seismic horizon can be identified according to the variations in the color blending. Areas of intense color variations represent noticeable differences in the spectral composition around that seismic interval. These changes often reflect distinct changes in stratigraphic, fluid, and structural components (Wu & Liu, 2009). In this example, blue areas indicate the dominance of high-frequency components; green areas indicate mid-frequency components, and the red/orange areas indicate the dominance of low-frequency components, as is shown in Figure 8.

RESULTS AND DISCUSSION

Sequence stratigraphic, system tracts and stratal slices

This study interpreted the sequence stratigraphic, system tracts, stratal slicing, and seismic attributes for Group D of Melor-Field in the Malay Basin. Figure 9 demonstrates the top and bottom sequence boundaries bounded Group D. These horizons have been picked based on some factors, such as top formations from the wells, reflection terminations, reflection configuration, and were confirmed by the synthetic seismogram and gamma-ray. The seismic section also shows a feature of the channel between the wells. SB8 is representing the unconformity of the top of Group D. This unconformity has been dated at around 10.0-10.5Ma and is named as the Middle Miocene unconformity. This horizon SB8 (unconformity) has been picked based on biostratigraphic information that has been established by Azmi *et al*. (1996). The unconformity surface is proved based on the top formations of Melor-2 and Melor-1 wells, seismic facies configuration, reflection terminations against the picked horizon and has been conformed by generated synthetic seismogram at the well. Seismically, the event was interpreted on the second zero-crossing below a strong peak amplitude representing an increase in the sand content below the unconformity surface. Several truncated evidences against horizon SB8 (Top Group D) revealed that an erosion happened previously, resulting in an unconformity surface. Group D was non-prospective units for the previous

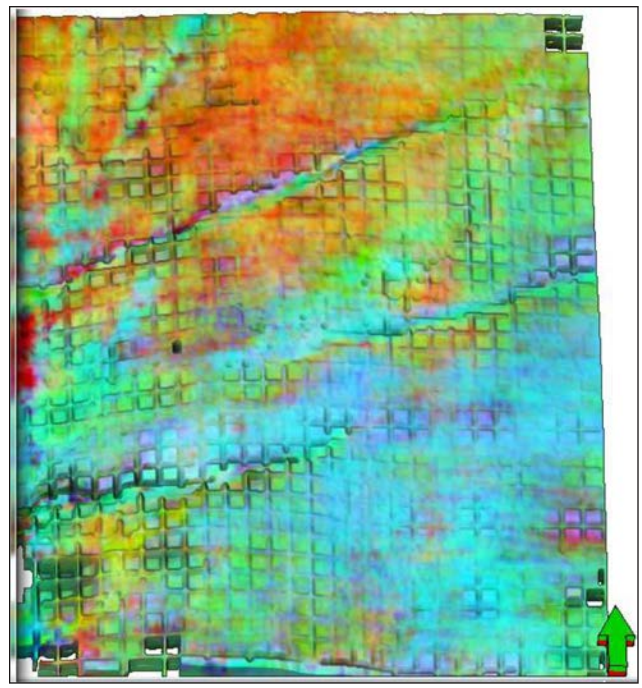

Figure 8: The intensity of different frequency components integrated with a seismic volume and time horizon.

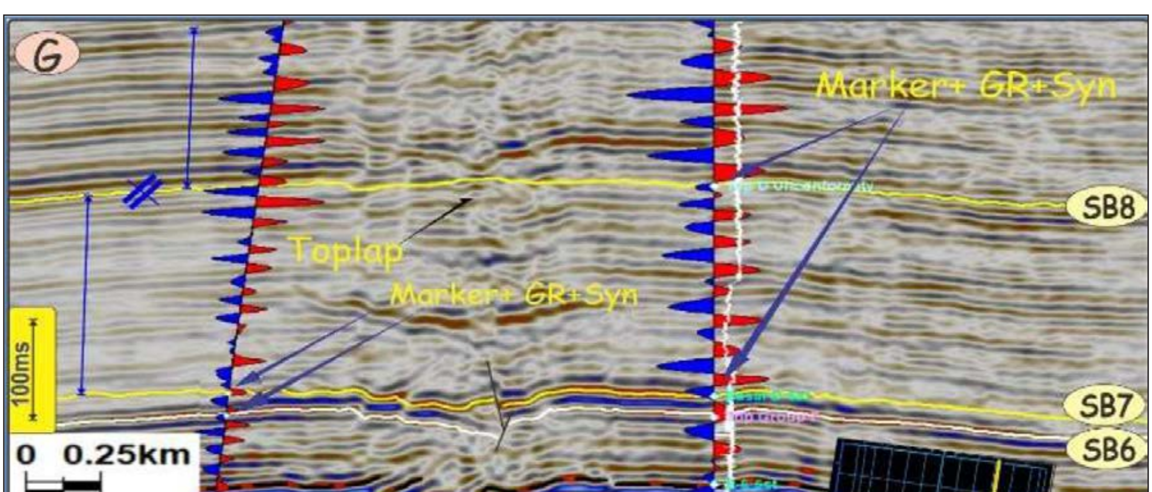

Figure 9: The two sequence boundaries of Group D with two wells (Melor-well-2 and Melor-well-1), top formations, gamma-ray, and synthetic seismogram for both wells.

investigations, but the interval between horizons (SB7 & SB8) was interpreted to map the shallow gas and chimney effects, so as to improve the understanding of the field structure and stratigraphy.

Regarding the system tract, this unit (Group D) has been subdivided into three cycles of system tracts from bottom to top (Figure 10). Directly Above (SB7), interpreted as a transgressive systems tract (TST), which is a new cycle of sea-level transgression happened, and TST deposited during the retrogradation phase. The gamma-ray record in the well-bore supported by the seismic onlapping across the seismic survey all over the study area assured this interpretation. This surface is considered as a maximum flooding surface (MFS). A new normal regression session happened after that yield to the prograding stacking patterns in the form of a high stand system tract (HST). A coarsening up of the gamma-ray record and some other down lapping around the study area supported this interpretation. The last cycle defined in this unit (Group D) was another TST overlying the HST. A noticeable onlapping close to the well site and other location plus the gamma-ray curve record referring to a retrogradation phase landward yielded a new TST.

Regarding the system tract, Group D has been subdivided into three cycles of system tracts from bottom to top, as shown in Figure 10. Directly Above (SB MFS) bounds this surface at the top. The well log acquired through Group D illustrates a series of stacked arenaceous intervals with fine-scale and highly variable gamma content. Group D has a gas-bearing reservoir. The major gas-bearing reservoir is in D60, which holds about 28% of the total field. This investigation has helped to bring down the uncertainties to a manageable level (Ariffin *et al*., 2005).

Stratal slices were very helpful in this study to delineate the morphology along with the crossline W-E of Group D and to show to what extent these deposits have existed. Four relative stratal slices have been generated between the top and bottom of Group D. These slices are monitored by data of two wells and were carefully chosen to interpret the architecture deposition. A complexity nature of some faults dominates the study area, thickness variation, and anticline characterized the interpreted interval within the Melor-field. This complicated structure makes the stratal slice an essential tool for imaging the subsurface geological features on the time-equivalent depositional surface, as is shown in Figure 11. Using stratal slicing, it is assumed that the depositional is laterally proportional in thickness for all depositional units within Group D.

Seismic attribute

The study of the Melor-field in the Malay basin illustrates a multi-seismic attributes application for revealing the geological features for the insight of new seismic attributes. The seismic amplitude is considered as a measure

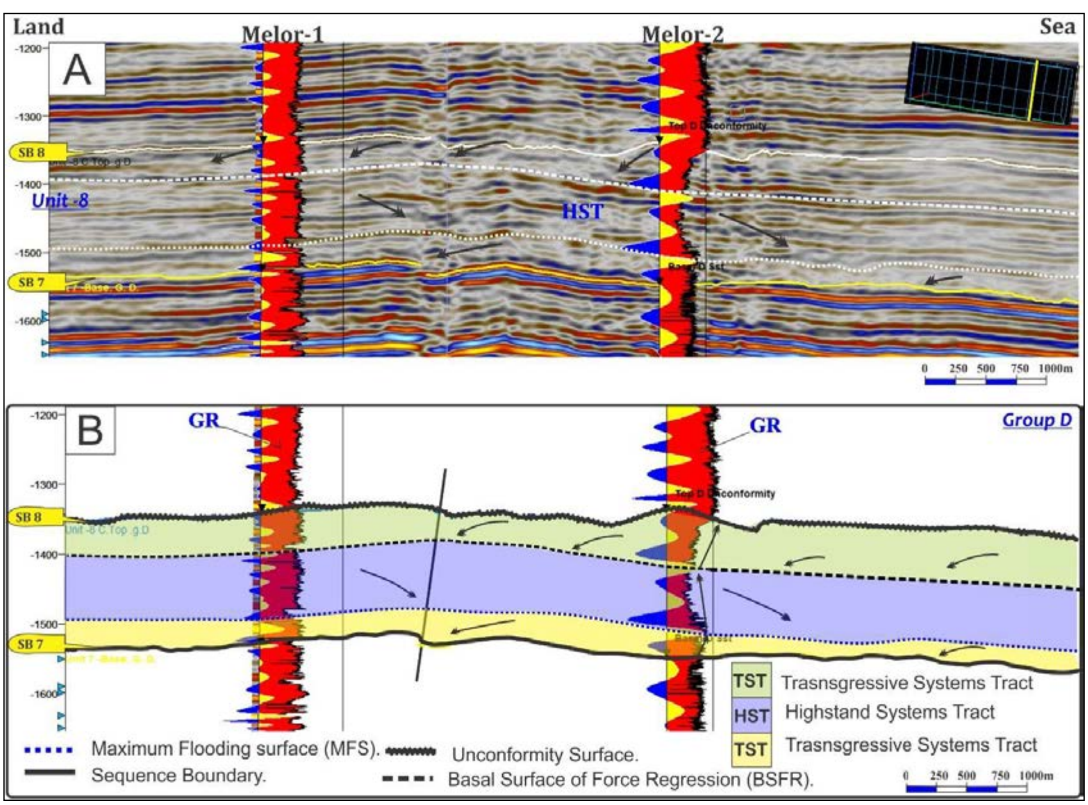

Figure 10: (A) The interpreted seismic section result of sequence boundaries and systems tract classification of Group D. (B) layout delineating the sequence boundaries and systems tract classification of Group D.

of the difference in properties between two layers. The seismic data can detect the relative change of the deposit property impedance after the data has been converted to relative impedance when the slice moves from any layer to the next one. Anyhow, the seismic data are not able to inform us about the definite change but can only estimate the relative changes of the rock properties (Whaley & Karlsson, 2015). Figure 12 represents the time slice of the originally migrated amplitude cube of the top Group D at 1314 ms, which was chosen for this study. Some of the geological features that are apparent in data are pointed at by the white arrows which show the point pars on the channel sides, while the blue arrows represent the significant faults, and black arrows indicate the channel trajectory across the study area. The faulted anticline surrounds the green oval shape. Channels are confined to specific stratigraphic levels so that the attribute maps can provide more complete images of these channels. In younger basins, gas-prone sand channels are often characterized by strong amplitudes, which are readily mapped with reflection strength or sweetness (Ghosh *et al*., 2010). Mud-filled channels tend to have weaker amplitudes. In any case, channel boundaries are best noticed by a discontinuity or relative amplitude change.

Some specific structures are more visible at certain frequencies because of tuning. In this case study, a few different frequencies have been examined many times until

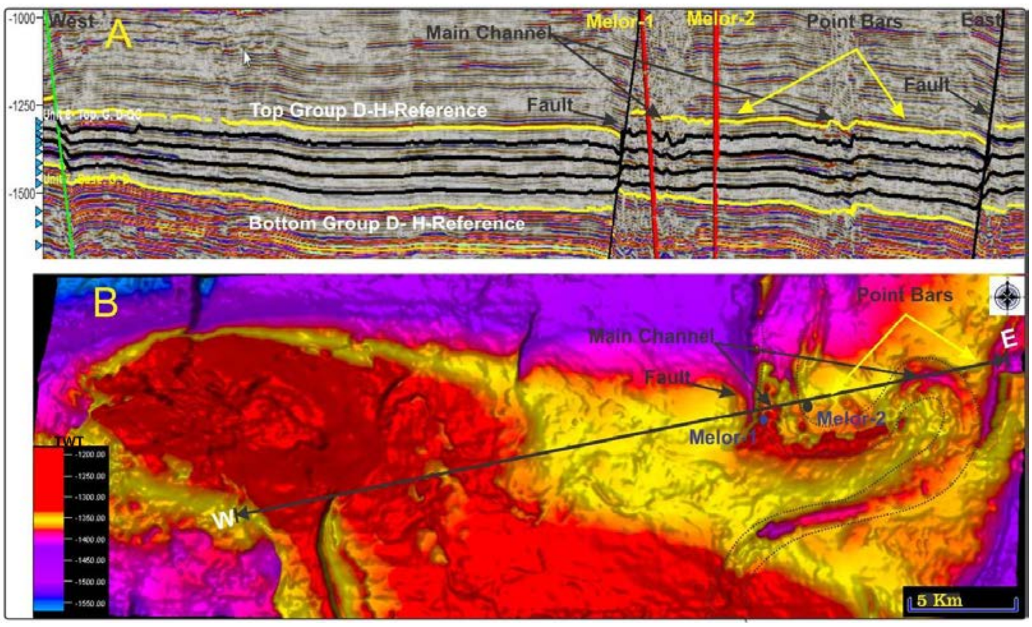

Figure 11: A - Cross section view (W-E) showing the four stratal slices through the channel body between upper and lower Group D. B - Represents the top Group D surface with channel cutting the Melor-field from north to south

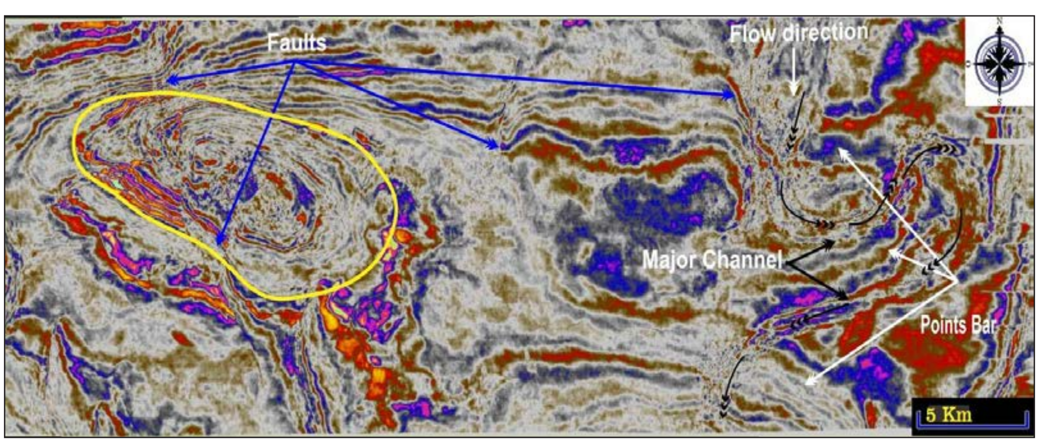

Figure 12: Time slice of the originally migrated amplitude from input data at 1314 ms. The white arrows show the point pars on the channel sides while the blue arrows represent the significant faults, the black arrows show the channel trajectory, and the yellow oval shape encloses an anticlinal structure.

the best frequency is figured that reveals the most noteworthy geological features.

The time slice in Figure 13 shows the geological features with spectral decomposition attribute with 15Hz frequency value; it was the best frequency value that indicated the distinctive geological features of the Melor-field seismic data, such as the faulted anticline, faults cutting Group D, channels, and point bars surrounding the channel. These exciting features are not noticeable when it shows the vertical section, but this attribute was beneficial to reveal the distinctive patterns outstandingly. RGB is corresponding to R=15Hz, G=25Hz, and B=45Hz to generate RGB time slices of Group D and reveals the thickness of the bedes on the displayed colors.

Figure 14 shows the top Group D time slice of the blended image using the RGB color model explaining the subsurface geological features. The yellow arrows indicate the channel trajectory from north to south. The channel trajectory is enclosed by light blue color representing the high frequency values. These blue points are interpreted as thin layers on the channel sides (point bars). The main channel trajectory is distinguished by light red and green colors (low and medium frequencies, which means thicker beds). These colors are focused on the middle of the channel - the thicker part; on the channel sides, light blue is reflecting the thinner layers on both the channel sides. The white arrows show the point pars on the channel sides while the yellow arrows represent the significant faults, and the oval shape encloses an anticlinal structure. By looking to a processed section, the seismic waveform is a response of the seismic wavelet convolved with the geology of the subsurface (Barnes, 2016d). That response changes concerning amplitude, frequency, and phase, dependent on the acoustic-impedance contrast and layers thickness above and below the reflecting boundary. However, acoustic impedance is influenced by the lithology, porosity, density, and fluid type of the subsurface layers. Therefore, the seismic waveforms that we see on a processed section differ in lateral character; that is, big lateral changes in impedance contrast give rise to significant lateral changes in waveform character. Geologically, highly coherent waveforms indicate laterally continuous lithologies. Abrupt changes in the waveform can indicate faults and fractures in the sediments (Barnes, 2016c).

Figure 15 represents a time slice of the Variance attribute of Group D. This attribute reveals the subsurface geological features. The yellow arrows show the channel trajectory cutting the Melor-field from the north to the south; the blue arrows correspond to the significant faults; while the dotted line shows the Graben; and the black arrow shows the horst; and the orange arrow show the oval shape enclosure of the faulted anticlinal structure.

Figure 16 shows the fascinating imaged elements of surface Group D in a high resolution as never before. Several of the subsurface geological elements included the anticline, faults, fault orientations, edges, channels, point bars, and the outer shape over the Group D surface has been perfectly imaged on a high-resolution. The new method can be used to generate fascinating 3D maps instead of the normal structural maps. These maps can represent most of the subsurface geological characteristics, besides indicating the deposit thickness variation across the study area. The significance of this method is to enable the interpreter to visualize these geological features in a 3D manner and extract geobodies for the geological elements. All features look real and recognizable by direct observation. On the left side, the anticline is faulted by a significant fault that divided the anticline into two big parts. A clear horst has appeared south of the anticline with two significant faults. Sharp edges below the anticline resulted from the tectonic deformation that has caused an inversion of the basin during the middle to late Miocene. On the right side of the study area, a significant channel is crossing the field from the north to the south. Another major fault is associated with

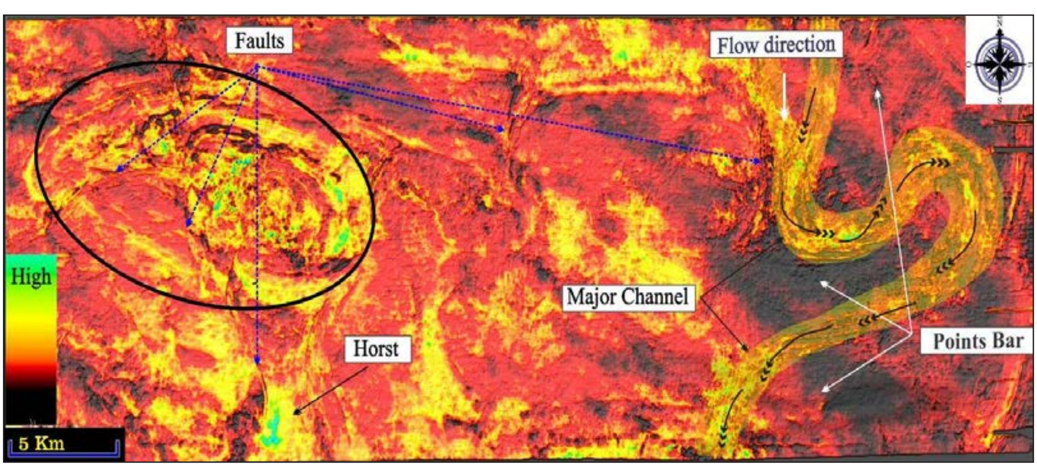

Figure 13: The time slice from input data at 1314 ms of spectral decomposition seismic attribute with 15 Hz of Group D. The white arrows (red points) illustrate the point pars on the channel sides while the blue arrows represent the significant faults; the black arrows show the channel trajectory; the yellow marks in the channel describe the shale deposits filling the channel; and the oval shape encloses the faulted anticlinal structure.

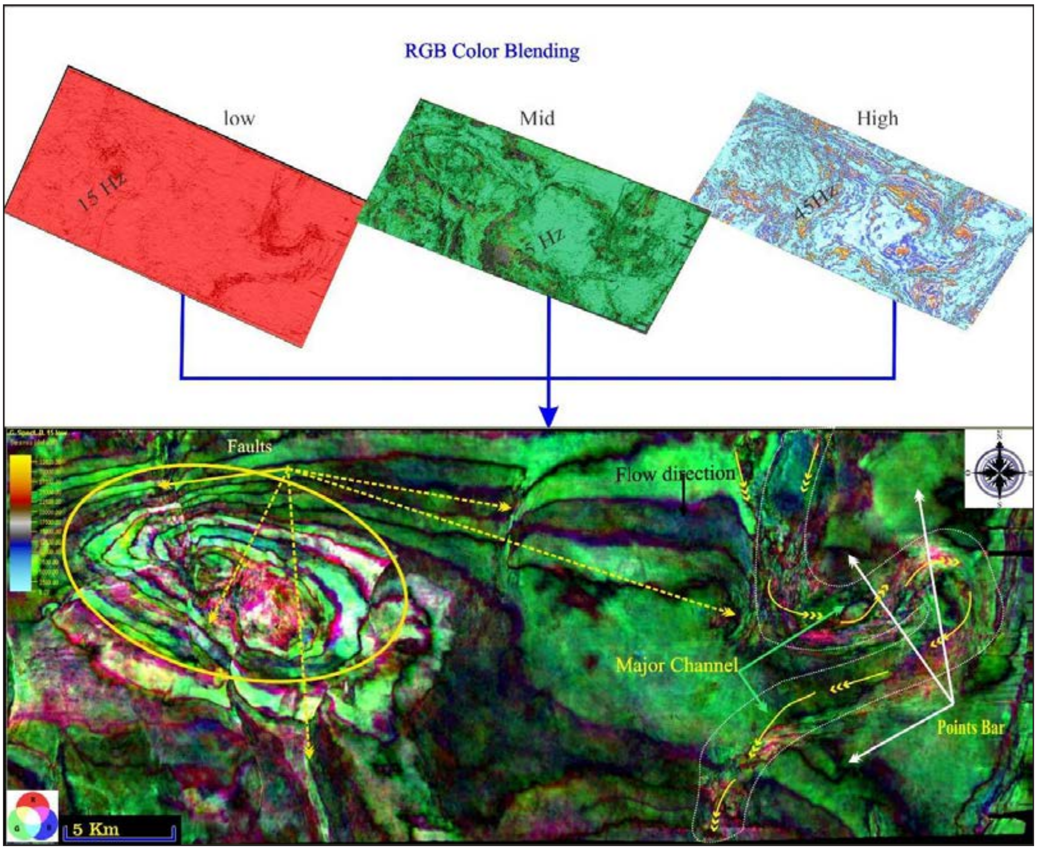

Figure 14: Group D time slice of the blinded color image using the RGB color model revealing the subsurface geological features. The white arrows show the point pars on the channel sides; while the doted yellow arrows represent the significant faults cutting the anticline; the yellow sold arrows show the channel trajectory from N-S; and the oval shape encloses the faulted anticlinal structure.

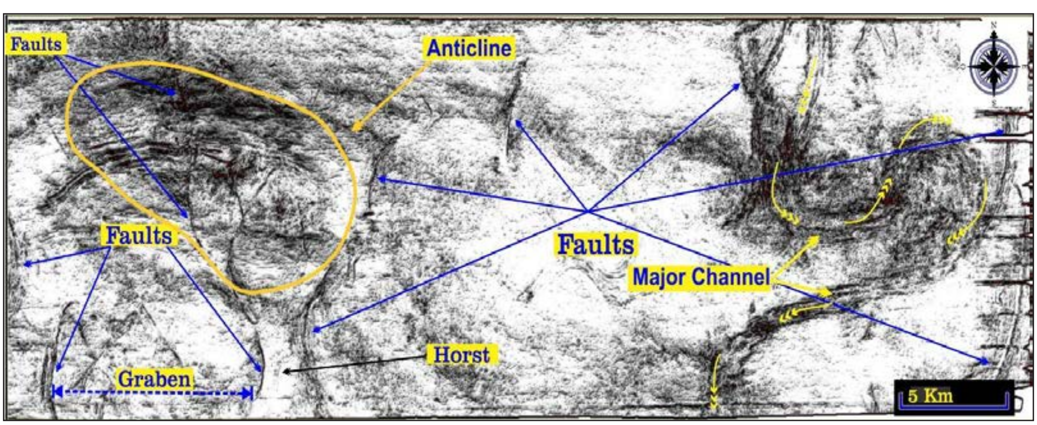

Figure 15: Group D Variance seismic attribute revealing the subsurface geological features. The yellow arrows indicate the channel trajectory; while the blue arrows represent the significant faults; while the dotted line shows the Graben; the black arrow indicator shows the horst; and the orange arrows show the oval shape enclosing of the anticlinal structure.

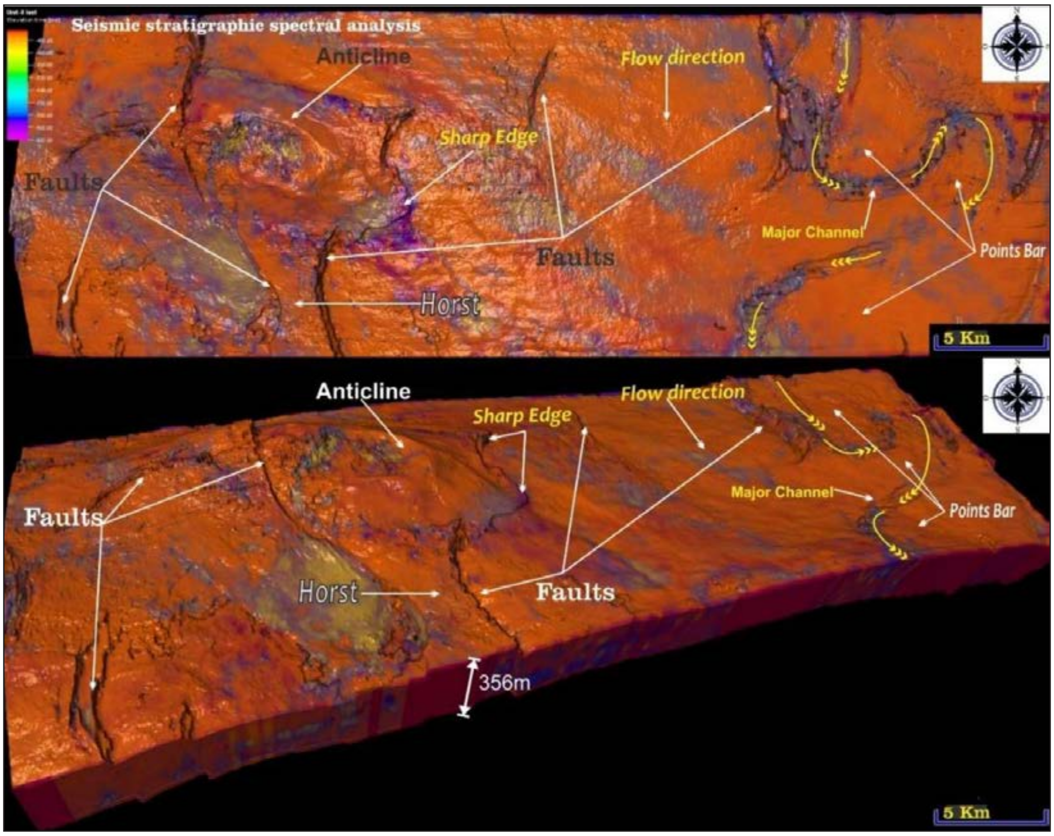

Figure 16: Two views of seismic sequence stratigraphy spectral analysis attribute indicating the high-resolution subsurface geological features of the Melor-field.

this channel in the north part of the study area, as is shown in Figure 3. Point bars are enclosed with the channel sides.

CONCLUSION

Seismic sequence boundaries and systems tracts have been identified and a stratigraphic framework has been established for the first time in the study area. Sequence boundaries have been interpreted where the gamma-ray log shows a prominent upward decrease in gamma values indicating superposition of proximal facies upon more distal facies. Limits of these sequences were tied back with evidence of erosion from seismic data, reflection termination, and seismic configuration. Group D has been interpreted as being deposited in a moderate to the high-energy marine Environment. The acquired wireline logs in Group D show a series of stacked arenaceous intervals with fine-scale and highly variable gamma content. Group D has a gas-bearing reservoir. The primary gas-bearing reservoir is D60, which holds about 28% of the total field. This investigation has helped to bring down the subsurface uncertainties to a manageable level. The stratal slicing technique improved interpreter capability to visualize fluvial elements at the time-corresponding stratigraphic surface. However, whenever possible, additional well data acquisitions are recommended, such as coring, image log, and others for more prospective investigations. The geomorphology and structural elements of top Group D were properly imaged using some seismic attributes. Some of the geological features, such as the channel, faults, edges, and point bars, were interpreted. The channels present in the uppermost of this group indicate a delta plain setting. The channel is filled with sand and shale. Group D late Miocene in age is about 356 meters thick and is below the Pleo-Miocene unconformity, which truncates the former regionally. It is made up of predominantly interbedded claystone, sandstone, shale, and minor coal. The sandstones are believed to have been deposited in an estuarine or fluvial environment. The main objective of the extraction of seismic attributes from the Melor-field 3D survey was to enhance the understanding of the stratigraphy setting and to assist in predicting reservoir quality and hydrocarbon distribution beyond the well-controlled area. Seismic attributes were generated for Group D by utilizing the Petrel and Paleoscan softwares. Seismic attributes helped to visualize the fluvial features within the interested zone, including channel body, folds, faults, and point bars. Seismic sequence stratigraphy spectral analysis is a new method that has been utilized to represent the fluvial characteristics at a particular time to equal the stratigraphic surface as never before. A suite of attributes was created from the seismic volume, including the original amplitude, variance, spectral decomposition, RGB color blending, and seismic sequence stratigraphy spectral analysis, using seismic data. The attributes were generated within consecutive time windows relative to the closet interpreted seismic horizon (datum) at the sample rate of the seismic data.

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REFERENCES

Aarre, Victor, Donatella Astratti, Taha Nasser Ali Al Dayyni, Sabry Lotfy Mahmoud, Andrew B. S. Clark, Michael J. Stellas, Jack W. Stringer, Brian Toelle, Ole V. Vejbæk & Gillian White, 2012. Seismic Detection of Subtle Faults and Fractures. Oilfield Review, 24(2), 28–43.

Almasgari Abd Alsalam, Abduh Saeed & Umar Hamzah, 2016. Sequence Stratigraphy of the Pliocene Deposits, Central Taranaki Basin, New Zealand. ARPN Journal of Engineering and Applied Sciences, 1784(19), 1–13.

Ariffin Akamal, Maizatul Azlina, Rosemawati Majid, Sahalan A. Aziz & and Teh Yat Hong, 2005. Melor Field Development Plan Revision. 1, Seismic Report. Vol. II. PETRONAS Carigali Sdn. Bhd., Kuala Lumpur. p. 146.

Azmi Mohd, Awalludin Harun, Bahari Md Nasib & Robert J. Morley, 1996. Integrated Biostratigraphic Zonation for the Malay Basin. Bulletin of the Geological Society of Malaysia, 39, 157–84.

Bareg, Siddig, Maizatul Azlina & Chang Kok Up, 2002. Melor-2 Well Proposal. PETRONAS Carigali Sdn. Bhd., Kuala Lumpur, p. 180.

Barnes, Arthur E., 2016a. Handbook of Poststack Seismic Attributes. Geophysical References Series No. 21. Society of Exploration Geophysicists. 254 p.

Barnes, Arthur E., 2016b. Handbook of Poststack Seismic Attributes. Geophysical References Series No. 21. Society of Exploration Geophysicists. 254 p.

Barnes, Arthur E., 2016c. Handbook of Poststack Seismic Attributes. Geophysical References Series No. 21. Society of Exploration Geophysicists, 254 p.

Barnes, Arthur E., 2016d. Handbook of Poststack Seismic Attributes, Chapter 3: Attribute Maps and Interval Attributes. Geophysical References Series No. 21. Society of Exploration Geophysicists. 254 p.

Castagna, John P. & Shengjie Sun, 2006. Comparison of Spectral Decomposition Methods. First Break, 24(3), 75–79.

Catuneanu, O., V. Abreu, J.P. Bhattacharya, M.D. Blum, R.W. Dalrymple, P.G. Eriksson, C.R. Fielding, W.L. Fisher, W.E. Galloway, M.R. Gibling, K.A. Giles, J.M. Holbrook, R. Jordan, C.G.S.C. Kendall, B. Macurda, O.J. Martinsen, A.D. Miall, J. E. Neal, D. Nummedal, L. Pomar, H.W. Posamentier, B.R. Pratt, J.F. Sarg, K.W. Shanley, R.J. Steel, A. Strasser, M.E. Tucker & C. Winker, 2009. Towards the Standardization of Sequence Stratigraphy. Earth-Science Reviews, 92(1–2), 1–33.

Chopra, Satinder & Kurt J. Marfurt, 2009. Detecting Stratigraphic Features via Cross-Plotting of Seismic Discontinuity Attributes and Their Volume Visualization. 79th Society of Exploration Geophysicists International Exposition and Annual Meeting 2009. SEG 2009, 1082–86.

Chopra, Satinder & Kurt J. Marfurt, 2018. Coherence Attribute Applications on Seismic Data in Various Guises - Part 1. Interpretation, 6(3), T521–29.

Emery, D. & K. Myers, 1996. Chapter Eleven: Organic-Rich Facies and Hydrocarbon Source Rocks. Sequence Stratigraphy, 238–57.

Esso, 1985. Petroleum Geology of Malaysia. Unpublished Report, Production Malaysia 1nc.

Ghosh, Deva P., Nor Azhar Ibrahim, Bernato Viratno & Hamdan Mohamad, 2010. Seismic Attributes Adding a New Dimension to Prospect Evaluation & Geomorphology Identification in the Malay and Adjacent Basins. SEG Denver Annual Meeting (January),1307–11.

Lew, C.L., H.H. Ismail, M.F.A. Kadir & M.R. Tajuddin, 2016. Stratal Slicing: A Tool for Imaging Geologically Time-Equivalent Fluvial Architecture - A Field Case Study. International Petroleum Technology Conference 2016, IPTC 2016 (November).

Li, Jingzhe & Jinliang Zhang, 2017. Sequence Stratigraphy of Fluvial Facies: A New Type Representative from Wenliu Area, Bohai Bay Basin, China. Seismic and Sequence Stratigraphy and Integrated Stratigraphy - New Insights and Contributions, p. 35.

Madon, Mazlan B. Hj.,1999. “Part 2 - Regional Tectonics & Sedimentary Basins of Malaysia”. PETRONAS Carigali Sdn. Bhd., 76.

Madon, M.B.H., 1994. Depositional and Diagenetic Histories of Reservoir Sandstones in the Jerneh Field, Central Malay Basin. Petroleum Geology, 8, 31–53.

Marfurt, Kurt J., 2007. Seismic Attributes for Prospect Identification and Reservoir Characterization Satinder Chopra. European Association of Geoscientists & Engineers, Society of Exploration Geophysicists. 464 p.

Miall, Andrew D., 2016. Stratigraphy: A Modern Synthesis. Springer. 454 p.

Ngah, Khalid, Madon Mazlan & H.D. Tjia, 1996. Role of Pre-Tertiary Fractures in Formation and Development of the Malay and Penyu Basins.1n: Hall, R. and Blundell, D.J. (Eds.), Tecronic Evolution of Southeast Asia. Geological Society of London Special Publication, 3(106), 281–89.

Partyka, Greg, James Gridley & John Lopez, 1999. Interpretational Applications of Spectral Decomposition in Reservoir Characterization. The Leading Edge, 18(3), 353-360.

Pubellier, M. & C.K. Morley, 2014. The Basins of Sundaland (SE Asia): Evolution and Boundary Conditions. Marine and Petroleum Geology, 58(PB), 555–78.

Puryear, Charles I., John P. Castagna, Oleg Portniaguine & Carlos Cobos, 2012. Constrained Least-Squares Spectral Analysis: Application to Seismic Data. Society of Exploration Geophysicists International Exposition and 82nd Annual Meeting 2012, SEG 2012, 77(5), 2176–80.

Sheriff, Robert E., 2002. Encyclopedic Dictionary of Applied Geophysics. Fourth Society of Exploration Geophysicists.

Tjia, H.D., 2000. Tectonic and Structural Development of Cenozoic Casins of Malaysia. Proceedings Geological Society of Malaysia Annual Conference, September 8-9 2000, Pulau Pinang, Malaysia.

Vail, P. R., 1987. Seismic Stratigraphy Interpretation Using Sequence Stratigraphy. AAPG Studies in Geology, 27(1). Atlas of Seismic Stratigraphy, 1–10.

Wagoner, J.C. Van & R.M. Mitchum, 2003. Siliciclastic Sequence Stratigraphy in Well Logs,Cores, and Outcrops: Concepts for High-Resolution Correlation Of time and Facies. p. 78 in Siliciclastic sequence stratigraphy in well logs,cores, and

outcrops. The American Association of Petroleum Geologists.
Whaley, Jane & Tore Karlsson, 2015. Southern Chile's Ring of Fire Africa's Oil and Gas Future Water Matters! GeoExpro, 12(5), 79.
Wooltorton, Tom & Geo Teric, 2016. Calibration of Frequency Decomposition and RGB Blends for Stratigraphic Thickness Estimation Using Interference Patterns. SEG Technical Program Expanded Abstracts, 35, 1737–41.
Wu, Xiaoyang & Tianyou Liu, 2009. Spectral Decomposition of Seismic Data with Reassigned Smoothed Pseudo Wigner-Ville Distribution. Journal of Applied Geophysics, 68(3), 386–93.
Zeng, Hongliu, 2013. Stratal Slice: The next Generation. Leading Edge, 32(2), 140–44.
Zeng, Hongliu, Stephen C. Henry, & John P. Riola, 1998. Stratal Slicing, Part II: Real 3-D Seismic Data. Geophysics, 63(2), 514–22.

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