Imaging of karst on buried Miocene Carbonate Platform

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Abstract: Imaging of carbonate rocks in the subsurface through seismic method is always challenging due to its heterogeneity and fast velocity compared to the other rock types. Existence of karst features on carbonate rocks makes it more complicated to interpret the reflectors. Utilization of modern interpretation softwares such as PETREL and GeoTeric\textsuperscript{®} to image karst morphology make it possible to model the karst network within a buried carbonate platform. Using a combination of different seismic attributes such as Variance, Conformance, Continuity, Amplitude, Frequency and Edge attributes, it is able to image the karsts features that are available in the proven gas-field in Central Luconia Province, Malaysia. The mentioned attributes are excellent in visualizing and imaging the stratigraphic features based on the difference in their acoustic impedance as well as structural features, which include karst. 2D & 3D Karst Models were developed to give a better understanding on the characteristics of the identified karsts. From the models, it is found that the karsts are concentrated in the top part and middle part of the carbonate reservoir with some of them becoming extensive and creating karst networks, either laterally or vertically. Most of the vertical network karst are related to the existence of faults that displaced all the horizons in the carbonate platform.

Keywords: Seismic Interpretation, Subsurface Karst, Carbonate Imaging, Seismic Attributes, Karst Models

1. Introduction

Carbonate rocks are very heterogeneous in nature as they are originally composed of living things such as coral, algae, shell fragments and other bioherms. Due to this, carbonate rocks are prone to chemical weathering and with the rise and fall of sea level, carbonates are often exposed subaerially, where they undergo further diagenesis and karstification (Palaz & Marfurt, 1997). Karstification process involve long term effects of weathering from the atmosphere and rain water (meteoric water) that percolates into the carbonate rocks and prolong sub-aerial exposure. The CO\textsubscript{2} in the rain water releases a weak carbonic acid (H\textsubscript{2}CO\textsubscript{3}) that reacts readily with the limestone and form cavities and voids (Marshak, 2005). Figures 1A and 1B are the examples of carbonate rocks as viewed on a cave and on seismic data. Note the difference in scale. The difference in scale from seismic viewpoint, as stated by Palaz & Marfurt, 1997, is because carbonate rocks create fast velocities and greater densities compared to most
siliciclastic rocks, hence contributing to lower vertical and spatial resolution in the carbonate strata for the same thickness of lithology.

Figure 1: A: Example of a cave (example of karst) in carbonate bedrock from Kek Look Tong Cave in Ipoh, Malaysia. Image is from the second author’s personal collection. B: Red arrows are pointing to seismic wavelets that imaged the carbonate rocks while the green arrows are pointing to siliciclastic rocks.

In the context of hydrocarbon exploration, karsts can be considered as possible voids that store the hydrocarbon or can be a potential geohazard to the exploration, especially during the drilling and exploration processes (Chung et al., 2016) as karst networks are understood to have high permeability faults and fractures. As such, recognition of karst features in carbonate reservoirs is the key to increase hydrocarbon production especially in matured field like Central Luconia Province in offshore Malaysia. Apart from that, cognizance of karsts in the carbonate reservoir will increase the safety measure during the exploration to avoid loss while drilling. For that reason, this paper aims to delineate karsts geomorphology in carbonate reservoirs to further understand the karst network within the reservoir. This study also aims to suggest suitable methods for the imaging of karsts features on buried/drowned carbonate platform in the subsurface.

2. Data and Methodology

3D seismic volume from one carbonate platform in offshore Malaysia was used throughout this study. The data were acquired in the late 1990s and are bound for research works within Petronas and UTP. The data used are filtered, scaled and migrated seismic sections with inline intervals of 25m and crossline intervals at 12.5m. The data were kindly provided by Malaysian Petroleum Management (MPM) for research purpose.

2.1 Horizon and Structural Interpretation

Horizons are picked to distinguish geologic intervals such as flooding surfaces and unconformities. The horizons are picked based on reflectors that show an increase in acoustic impedance and are distinct in the amplitude value. The interpretation of the seismic data was focused at two-way-time (TWT) 1480ms to 1800ms only because this is where the carbonate reservoirs are found. The estimated depth for these carbonate reservoirs are around 2.8km to
3.2km in depth. The total length of the carbonate reservoir is estimated to be 11km from east to west and width of 6km from north to south. Faults are interpreted based on the obvious displacement seen on the reflectors and abrupt changes in the seismic amplitude along the horizons. Horizon and structural interpretation are crucial in differentiating the different rock layers, especially the clastic and carbonate reservoirs. The detailed method of interpretation and results for this carbonate platform can be found in Jamaludin et al., 2014.

2.2 Seismic Attributes
Seismic attributes are able to boost and elevate the visibility of karst features to be interpreted. In this project, the seismic attributes are applied using two different softwares which are PETREL and GeoTeric®. Both softwares are compatible for seismic interpretation and attribute visualization and are widely used in the industry worldwide. PETREL is used to perform stratigraphic and structural interpretation as mentioned in Section 2.1 in this paper as well as application of several attributes as described in Section 2.2.1 in this paper.

2.2.1 Seismic Attributes Utilization in PETREL
Among the seismic attributes that have been meaningful in the visualization of the karsts in PETREL are Variance, Curvature and Amplitude. The variance attribute represents the trace-to-trace variability over a particular sample interval and therefore produces interpretable lateral changes in acoustic impedance (Chopra & Marfurt, 2007). It is able to highlight the different type of layers and unconformities in the data and will support the interpretation of the user especially while doing horizon picking. Curvature attribute measures the structural deformation and deduces stress regimes that are correlatable with the density and orientation of fractures either in the deep-water complexes or in carbonate build-ups environment. Amplitude attribute on the other hand defines how the amplitude stands out against the surrounding reflectors and background events. These attributes help to make karst features stand out from the other carbonate rock.

2.2.2 Seismic Attributes Utilization in GeoTeric®
GeoTeric® software allows its user to see the geology before interpreting the study area. The Carbonate Evaluation Workflow developed by GeoTeric® focuses on the following carbonate and associated features: Karsts; Clinoforms, Patch Reefs and Mounds, and Chalk. In addition, Fault Density and Combination Attributes are used, and features of interest can be extracted from an attribute and embedded in the Noise Reduced 3D volume. In this section, several attributes that were used such as Semblance, Conformance and Frequency attributes are discussed. Figure 2 below summarizes the workflow used in GeoTeric® Software in this study to successfully image the karsts. Semblance attribute is categorised in edge attributes. It is a form of cross correlation that produces a single coefficient in the range 0-1. In geological terms, semblance represents the measure of coherence or similarity of two traces of seismic data from multiple channels that is equal to the energy of a stacked trace divided by the energy of all traces that make up the stack (GeoTeric®, 2015). Conformance attribute compares the orientation around our target with its surrounding wavelets response. As conformance works in a structurally oriented manner, this attribute is suitable to delineate karst features as it calculates the value based on Dip & Azimuth volume. High Definition Frequency Decomposition (HDFD) on the other hand is able to highlight the dissolution features in the study area. HDFD uses a modified matching pursuit algorithm bringing out a much better vertical localisation of the events.
3. Results & Discussion

3.1 2D Karst Model
Two 2D karst models (Models A and B in Figure 3) were generated from the observed seismic sections in the northern and southern part of the seismic data. These two sections were picked because they showed the most prominent possible karst structures, as well as structural features present in the area. Possible karsts in the area were labelled by the continuity of the seismic lines within each stratigraphic layer. Generation of 2D karst models helps to give a detailed description for the identified karst within the carbonate platform.

Based on 2D karst models generated in Figure 3, karst structures were most frequently present along conjugate faults, which could be good and possible hydrocarbon trap in the area. Karst also can be found in abundance along Horizon 2 and Horizon 3 which are the Top and Middle Carbonate zones. The shapes of the karst structures were not uniform throughout the area. Based on the karst model generated in Figure 3B, karst structures were seen to be less in continuity among their formation, compared to karst model in Figure 3A. Two young faults can be found at western part of Model B in Figure 3, indicating that it was formed after the deposition of all facies in the study area. Large scale of uncertain structure can be found at the eastern part of the karst Model B in Figure 3, indicating that it could be caused by gas seepage, facies intrusion, or likely possible karst structure in the area.

Figure 2: The seismic attributes used in GeoTeric® for this study.
3.2 3D Karst Models
A few 3D Karst Models were created using GeoTeric® software. Only the most probable karst in the area was selected for the construction of 3D karst model. The reason for choosing more than one attribute for the construction of the karst model is to compare on which attribute is able to give out the most ideal output on determining the karst geomorphology in the area.

Combo Attribute highlights objects most effectively as it is often necessary to combine a few attributes. This has proven to be successful with carbonates when combining a structural and a stratigraphic attribute. The components that were used in this section were the Semblance attribute, Continuity attribute and Conformance attribute (Figure 4A) along with manipulation of the frequency.
Figure 4: A: Model based on Continuity+Conformance attribute applied with RGB colourmap, to brighten up the features present within the area. The greenish colour on the 3D volume is referring to karst and they are mainly concentrated in the centre part of the reservoir and associated with faults. B: Seismic cube applied with diapir attribute. Area with red colour indicates possible karst structures within the cube.

A diapir attribute (Figure 4B) that was designed for Gas Zone was also applied in this study as both gas and karst are showing chaotic features on seismic reflectors. Carbonate facies shows high amplitude, but cavities within the area shows low amplitude, and these cavities are related to karst features. Each of the combination attributes shows different clarity and uses the respective indicators to highlight features within the area. The colour scale of the attribute plays an important role in determining and highlighting structures that are present within the area. The scale for Combo Attributes were flipped and adjusted to bring out more details on structures.
present and the indicator for the flipped scaled cube would be different from the original combination. From the developed 3D Models, the karst seemed to be more prominent at the centre of the studied carbonate reservoir. Note that from the fault analysis, most faults occurred in the centre part and the eastern part of the study area. Therefore, karst structures in the area may be related to the formation of faults cutting through the facies. Models developed from Continuity+Conformance attributes (Figure 4A) and Diapir Attribute (Figure 4B) showed that the size of each karst structure observed is roughly around 50-100m in width and height. The diapir attribute gives out the most possible size of the karst structure in the area as it differentiates clearly with red and green colours the most obvious karst features.

4. Conclusion
Referring to the aims of this paper, the geomorphologies exerted on karst features in this studied carbonate platform ranged from circular shape with a possible depression which might be related to a cavern karst. It is observed that the possible karst features are creating karst networks that extend laterally. Some of the karst network follows the faulting zone and create a vertical network. The workflow suggested (Figure 2) which is using Combo attributes consist of Semblance, Continuity and Conformance together with Diapir attributes should be used to give better imaging and visualization of karstification on seismic data. PETREL and GeoTeric® software were used in highlighting the karst geomorphology throughout the study area. PETREL provides good resolution while doing horizon and structural picking but users could not see where the picking is heading and it has longer turnaround time for manual interpretation. Even for automatic picking, a user’s interpretation is still required. GeoTeric® on the other hand, enable user to see the features first in whole volume before interpreting and creating attributes volumes which are faster compared to PETREL. This work should continue in the near future by having calculations of the total volume for the area affected with karst. The calculation of total volume would give a hint on the amount of possible voids created by the karst. Apart from that, detailed correlation study with wells data such as wireline and cores would be helpful to improve the developed models.

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