Petroleum and Coal

Article **Open Access**

Seismic Facies Analysis of a Carbonate Field in Central Luconia, Sarawak Basin

AbdulRahman H. M. Ibrahim[1,2], Mohamed M. Elsaadany[1]*

[1] *Centre of Seismic Imaging, Department of Geosciences, Universiti Teknologi PETRONAS, Seri Iskandar, 32610, Malaysia*

[2] *Petroleum Geosciences Department, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750, Tronoh, Perak, Malaysia*

Received November 22, 2021; Accepted March 29, 2022

Abstract

Utilizing both 3D seismic and well data with core data acting as a steering guide geologically, a seismic facies classification of a carbonate platform, P-field, located in Central Luconia has been conducted. The objectives of this study are to identify potential depositional setting based on the seismic configuration and possible sequence stratigraphy. The study's methodology began by describing the properties of seismic frequency, continuity, amplitude, and velocity of one of the carbonate fields, P-field, which was then correlated to the well logs. Five reservoir zones comprising a total thickness of approximately 500m are interpreted: zone one shows high amplitude seismic reflection representing a deepening phase; zone two shows sub-parallel seismic feature and is characterized as shallowing phase; zone three shows strong amplitude and it is interpreted as a deepening phase; zone four shows a shingled feature representing shallowing phase; and zone five shows strong amplitude that represents deepening phase. The seismic analysis has given a good correlation to the possible stratigraphy of P-field.

Keywords*: Seismic facies; Stratigraphy; Reflection configuration; Frequency; Amplitude; Continuity; Carbonate build-up; Central Luconia.*

1. Introduction

Central Luconia is a geological province of the Sarawak Basin, offshore NW Borneo. The province rests upon substrate whose rigidity during the last 15 MA has enabled more than 200 carbonate build-ups. The carbonates are of economic significance, with some 65 trillion cubic feet of gas in place and some minor oil reserves discovered to date. More than 120 carbonate build-ups remain undrilled, providing potentially attractive exploration targets and an incentive to understand further the geology [1]. The field is a carbonate reservoir located in Central Luconia province. These provinces comprise various carbonate build-ups from Miocene to Holocene, ranging from platforms to pinnacles and approximate thicknesses up to 2 km. These provinces are also known for hydrocarbon accumulation as most of the area's discoveries contain commercial natural gas [2]. The carbonate field is considered to have a complex internal reservoir with irregular stratigraphic sequences.

Reservoir characterization with the seismic application is important as the link between seismic and rock properties assists in understanding the reservoir at a larger scale. Siliciclastic reservoirs are vastly different compared to complex carbonate reservoirs. Carbonate properties are heavily influenced by complex porosity systems

such as fractures, channels, mouldic porosity, vuggy porosity [3]. The pore structures ultimately influence the seismic velocity as they have varied compressibility. The basic seismic properties that depict a carbonate environment are described in properties like frequency, continuity, amplitude, and seismic velocity [4].

2. Geological setting

The carbonate platform (P-field) is in Central Luconia province. This province is located offshore Sarawak, NW Borneo (Figure 1). It is surrounded to the south by the Balingian Province, to the west by the Tatau Province. On the East of Central Luconia is the West Baram Delta and the Baram Delta Province.

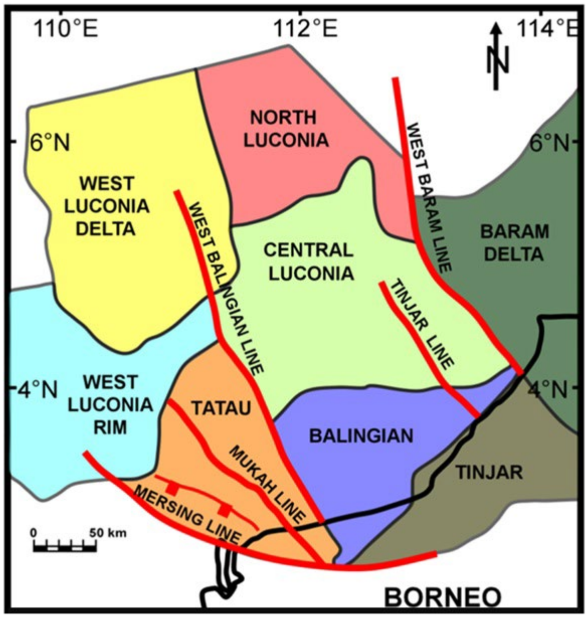

Figure 1. Map showing the location of the Central Luconia and other geological provinces in offshore Sarawak (modified after [2])

They are divided by the West Baram Line (Figure 1), separating provinces of different geothermal gradients. Central Luconia covers an estimated area of 45,000 km2, NW Borneo. It is located 100 – 300 km from the present coastline with ranging water depths of 60 – 140 m. The bathymetric gradient is quite gentle on the present platform, 0.44 m/km until it reaches the shelf break, where the gradient is up to 90 m/km due north [5]. Steep shelf- break spreads the sediments onto abyssal plains of the South China Sea. Nearly more than 200 carbonate build- ups can be found in this province due to the province base's rigidity during the last 15 Ma of carbonate development. Carbonate build-up growth in the province at one time is variable; growth, exposure, drowning, while same strata of same geological time may be composed of coastal, pro-delta muds, fluvio-marine and pelagic clays [6].

2.1. Structural setting of the carbonate field

The field is an approximately 20 km2 Miocene carbonate platform located 200km north of Bintulu, offshore Sarawak (Figure 2).

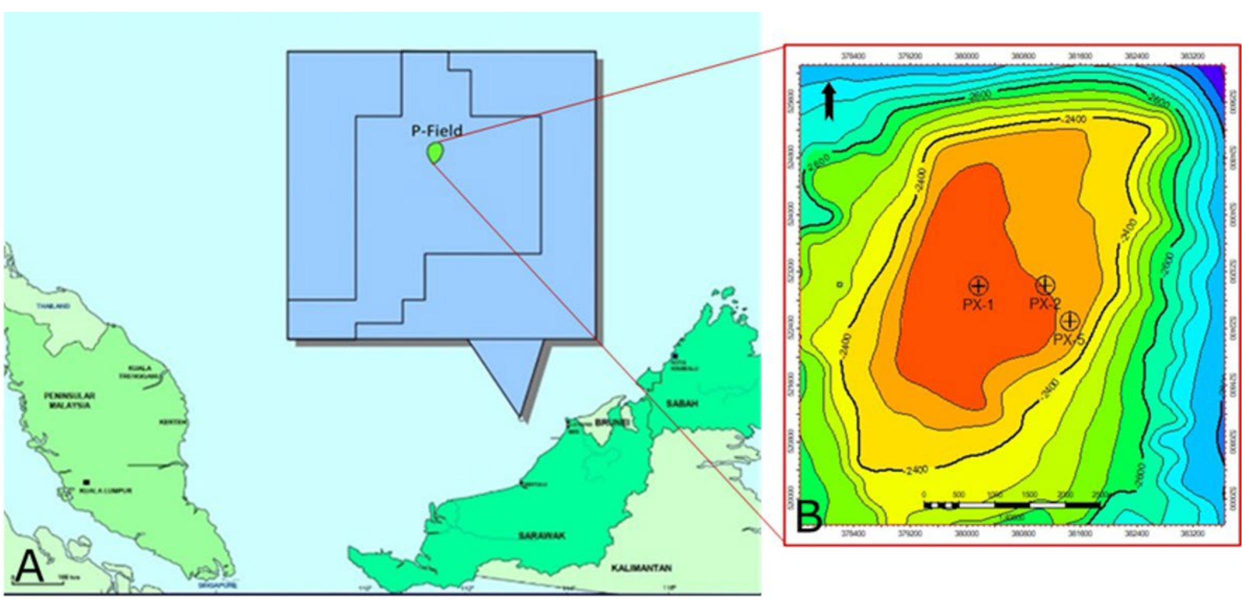

Figure 2. Location of the carbonate field in Central Luconia, Sarawak Basin

The reservoir section is from cycles IV to V, i.e. Middle to Upper Miocene age. The platform top is mapped at an estimated depth of 3km with a vertical relief of about 600m. Situated close to the East of the field is the West Baram Line that separates the field from the West Baram Delta. The carbonate field has a flat top overlain by a shale sequence that is possibly sourced and deposited from the nearby West Baram Delta. The platform development in Central Luconia began in the Early Miocene on faulted structural highs; however, it is noted that the seismic data of this carbonate field does not show any significant structural faults below the platform. That could be due to the location of the carbonate field at the deeper part of Central Luconia and locally grew further from the NE-SW series of faults.

3. Methodology

The data includes 3D seismic and well data of P-field, which were made available by the Petronas. The 3D seismic volume used for this research is migrated. The inline interval was 12.5m, and crossline interval of 12.5m (grid size = 12.5m x 12.5m), with 2085 inlines and 2043 crosslines. Data were processed to zero phase, SEG normal polarity with a downward increase in acoustic impedance being a peak (Red). The methodology comprises of petrophysical and seismic reflection characteristics.

A. Petrophysical analysis

Well log data reviewing focuses on understanding the subsurface properties of the carbonate field based on twenty wells scattered across the field. Three wells were dedicated for this study which are PX-1, PX-2, and PX-5 (Figure 3).

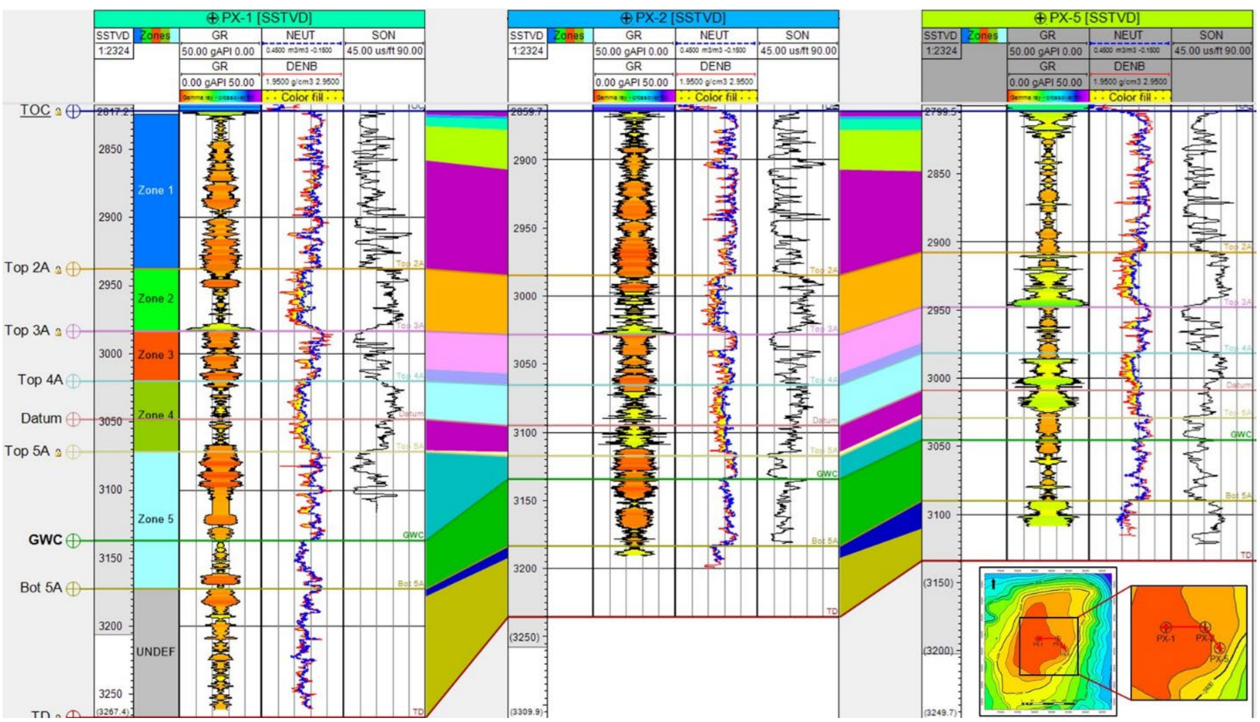

Figure 3. Well correlation and interpretation based on gamma ray, physical and elastic properties for Well PX-1, PX-2, and PX-3

Different well log suites were used in all wells that are analyzed in detail as wells acquired different information. Software used in reviewing the well log data is Petrel (V. 2020) by Schlumberger. The logs used are Gamma Ray, Density, Porosity, sonic, and resistivity logs. Log conditioning was done for Sonic log to match with corresponding logs, hence improving interpretation accuracy.

B. Seismic reflection characteristics

Identification of the seismic reflection characteristics can help in understanding lithology type and depositional energy. The characteristics that have been taken into consideration are frequency, continuity, amplitude, and velocity.

4. Results and discussion

4.1. Frequency

Seismic frequency reduces with depth in all reservoir types, and it measures the seismic reflection for every given vertical TWT (two-way time). Carbonates generally have a higher density (compared to siliceous clastic reservoirs), thus higher seismic velocity [4]. Therefore, the internal resolution of seismic frequency is lower. Central Luconia encountered a period of extensive carbonate deposition before clastic deposition. There is a drastic difference in rock density between the two rock types, which can be observed in the seismic cross-section (Figure 4) of the carbonate field and many other fields within this province.

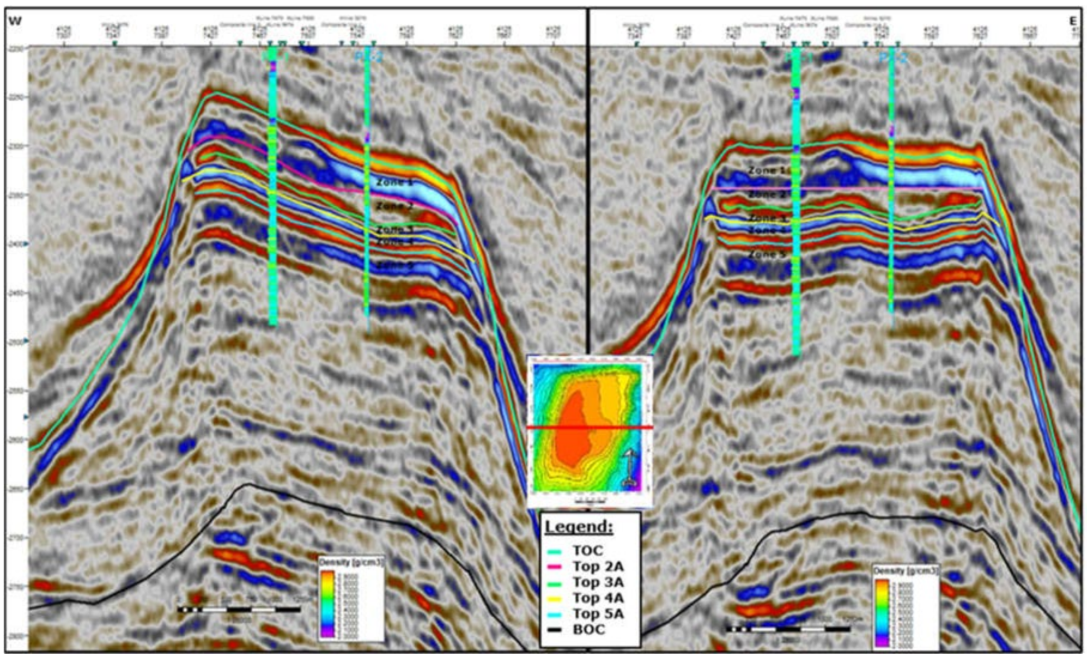

Figure 4. Comparison between un-flattened (left) and flattened base horizons on the W-E seismic cross section in TWT (ms). Flattening assists in understanding the seismic analysis and understanding the growth trend of the build-up

4.2. Continuity

Seismic reflection appears continuous when there is low porosity and a high-density layer, also known as the tight layer [4]. Discontinuous in the reflectors are due to many factors. One of the apparent causes is the termination via the carbonate build-up edges, or it can also be due to faulting resulting from local tectonic activity or subsidence. Discontinuous seismic reflection indicates a heterogeneous higher porosity region, patch reefs, or even progradation pattern forming via sea-level fluctuations within the build- up. Precaution is needed whilst interpreting the seismic, and this can be done via the application of seismic attributes and calibration with core and well data.

4.3. Amplitude

Amplitudes of seismic reflection require precise characterization. Amplitude is the core for deriving additional features that are useful for seismic interpretation, known as seismic attributes [7]. Carbonates have a higher amplitude than siliceous clastics. Changing amplitudes within the build-up potentially indicate a change in facies or environment of deposition. The instances where the amplitude is lower than the overlying or underlying layer represents the building of a porous environment such as a back reef. However, as the amplitude increases, it shows a transition from a back reef to a deep lagoonal environment. Low amplitude can also indicate fractures, karst features or gas effects.

4.4. Velocity

Different rock types have different compositions, structures, and porosity, thus influencing the formation's density. Seismic velocity is affected by rock density [4]. As discussed earlier, carbonates have larger density values than clastic rocks, thus having faster seismic velocity. The combination of higher density and velocity in carbonates results in higher impedance contrast when carbonates are overlain by siliciclastic sediments, with which the top of carbonates are easily identified. Features in a carbonate environment that requires more attention are the velocity pull-ups effect. Carbonate has high velocity, and thus seismic rays travel in a shorter time compared to sections of the non-carbonate environment (Table 1 and Figure 4) [8].

Table 1. List of formation with the range of P-wave velocity, S-wave velocity, and density values [9]

Formation type	P-wave velocity (m/s)	S-wave velocity (m/s)	Density (g/cm^3)
Limestone	3500 – 6000	2000 – 3300	2.4 – 2.7
Dolomite	3500 – 6500	1900 – 3600	2.5 – 2.9
Shale	1800 - 4900	800 - 2500	2.4 – 2.8
Water	1450 – 1500	-	1.0
Oil	1200 – 1250	-	0.6 – 0.9

4.5. Seismic analysis

4.5.1.Horizon interpretation

Seismic interpretation picks the seismic horizons to create a link between seismic reflections with the correct geological horizons based on well tops [3] (Table 2). This step ensures correct correlation and a more relevant interpretation of the sub-zones within the carbonate field. Hence, six horizons were interpreted, the top and base of the carbonate build-up along with the four picks that define the five zones in the reservoir.

Selected seismic reflections act as the basis for seismic stratigraphy [10]. Each seismic reflector may represent a time horizon. Since the carbonate field's 3D seismic was processed to zero phase, the horizons are picked on the peak and trough of the seismic amplitude reflection as shown in Table 2. For example, the top of carbonate, which is located right below layers of siliciclastic sediments, was picked on the peak as this represents an increase in acoustic impedance (hard kick). At the carbonate interlayers, a decrease in acoustic impedance can be observed, indicating soft kicks. Hence, horizons were picked at the trough amplitude. This is also denoted as SEG normal polarity.

4.5.2. Horizon flattening

One of the available functions in software is horizon flattening. This method is mostly done in two-way-time seismic; this method improves stratigraphic analysis as seismic features can be seen at one specific timeline (Figure 4). The carbonate field is observed to have undergone platform dipping in the NE direction, and there may be some occurrences of seismic velocity pull-up effect, especially at the center of the build-up (can observe a thicker carbonate section in the middle segment compared to the build- up flanks). Caution should be taken when applying horizon flattening. There are possibilities of wrongly recognizing distortions or artifacts as stratigraphic features [11].

Table 2. The interpreted horizons from top of carbonate to base of carbonate

Interpreted horizons	Description	Geological boundary
Top Carbonate (TOC)	Top carbonate was picked on a peak (red, hard kick), representing an increase in the acoustic impedance	Carbonate top underlying siliciclastic sediments
Top Zone 2A	Horizon Top 2A was picked on a trough (blue, soft kick), representing a low acoustic impedance boundary	Top of porous reservoir zone
Top Tight Layer/ Top Zone 3A	Top 3A was picked on a peak (red, hard kick), representing an increase in the acoustic impedance	Top of a low porosity region, acting as baffle zone between two underlying and overlying reservoir zones.
Top Zone 4A	Horizon Top 4A was picked on a trough (blue, soft kick), representing a low acoustic impedance boundary	Top of better porous reservoir zone
Top Zone 5A	Top 5A was picked on peak (red, hard kick), representing an increase in the acoustic impedance.	Underlying seal of the reservoir in zone 4
Base Carbonate (BOC)	The base was picked on trough (blue, soft kick), representing a decrease in acoustic impedance.	Estimated to be base of carbonate, probably overlying dense argillaceous layers at the base.

4.6. Seismic configuration

Geometries on seismic reflections may represent stratigraphic features/ seismic facies. Some configurations observed are illustrated in Figures 4, 5 and 6.

1. Parallel/sub-parallel

Seismic reflections resembling layer-cake structure indicates the building of carbonate build-up. Continuous features are interpreted as tight layers, while low continuity of the reflection indicates progradational pattern or build-up edge.

2. Dipping reflectors

Low continuity of the seismic reflection indicates progradational pattern or build-up flanks.

3. Mounded

Mounds are commonly observed in the center of the build-up, such as lagoonal environment where patch reefs grow. It could also indicate gas effect, which disrupts the seismic signal. Mounds are also found where structural folding occurs.

4. Chaotic/hummocky

Chaotic features are found where the reservoir does not have a particular recognizable geological structure. It is commonly found in slopes or build-up edges where carbonate debris are relocated.

4.7. Interpretation of seismic cross-section analysis

1. Zone 5 shows strong amplitude with seismic reflections that are flat and continuous. This zone represents a deepening, leading to the deposition of argillaceous sediments; lagoonal, muddy, and low porosity.
2. Zone 4 shows a shingled feature in the north of the carbonate build-up and appears to be more continuous towards the south. This zone represents shallowing, where often progradation pattern occurs.
3. Zone 3 shows strong amplitude with seismic reflections that are nearly flat and continuous. It is interpreted as a deepening phase where tight and muddy layers are formed.
4. Zone 2 (and 4) have roughly similar sub-parallel seismic features. They are characterized as shallowing, porous zones that were deposited at the lagoonal back- reef.

5. Zone 1 is composed of high amplitude seismic reflection and mounded seismic facies. This zone represents a deepening phase and the seismic reflection characteristic of the probably stacked patch reef.

The seismic description of facies and geometries is interpreted and then correlated with the core analysis as tabulated in Table 3.

Table 3. Seismic section of the carbonate field was interpreted and tabulated in seismic and sequence stratigraphy interpretation. The geometries described for each reservoir zone in this table are as shown in Figures 5 and 6 (Labeled A to E)

Reservoir zone	Seismic description			Seismic facies	Seismic facies interpretation	Sequence stratigraphy interpretation
	Amplitude pick	Continuity	Geometry			
1	Moderate to high	Semi	Sub-parallel with local mound (A)	Stacked reef with bounded configuration	Heterogeneous (porous – low porosity interbedding)	Deepening
2	Moderate to high	Semi	Sub-parallel with chaotic features (B)	Progradation in the NNE direction	Porous with tight streaks	Shallowing
3	Strong	Continuous	Parallel (C)	Flat, parallel, and continuous seismic reflection	Tight layer across the field, Lower section heterogeneous (porous – low porosity interbedding)	Deepening
4	Moderate to high	Semi	Sub-parallel with local mounds (D)	Shingled in the south of carbonate build-up, more continuous towards the north	Porous with tight streaks	Shallowing
5	Strong	Semi to continuous	Sub-parallel with chaotic features (E)	Upper zone is flat and continuous	Heterogeneous (porous – low porosity interbedding)	Deepening

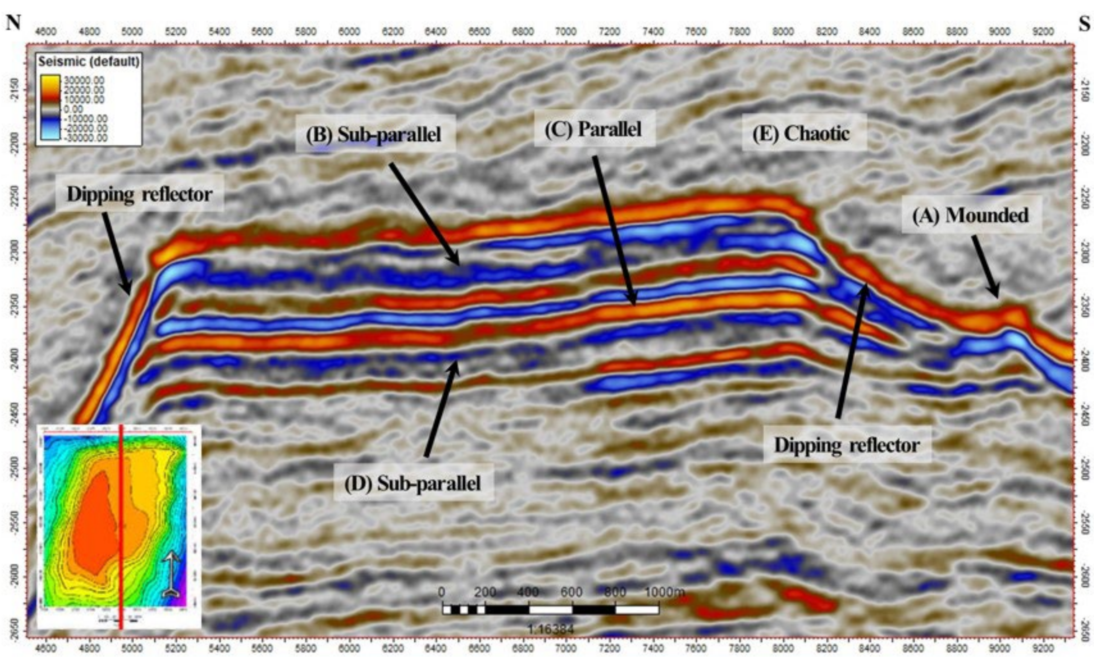

Figure 5 North-South seismic cross-section in TWT (ms) showing seismic geometry based on seismic reflection patterns.

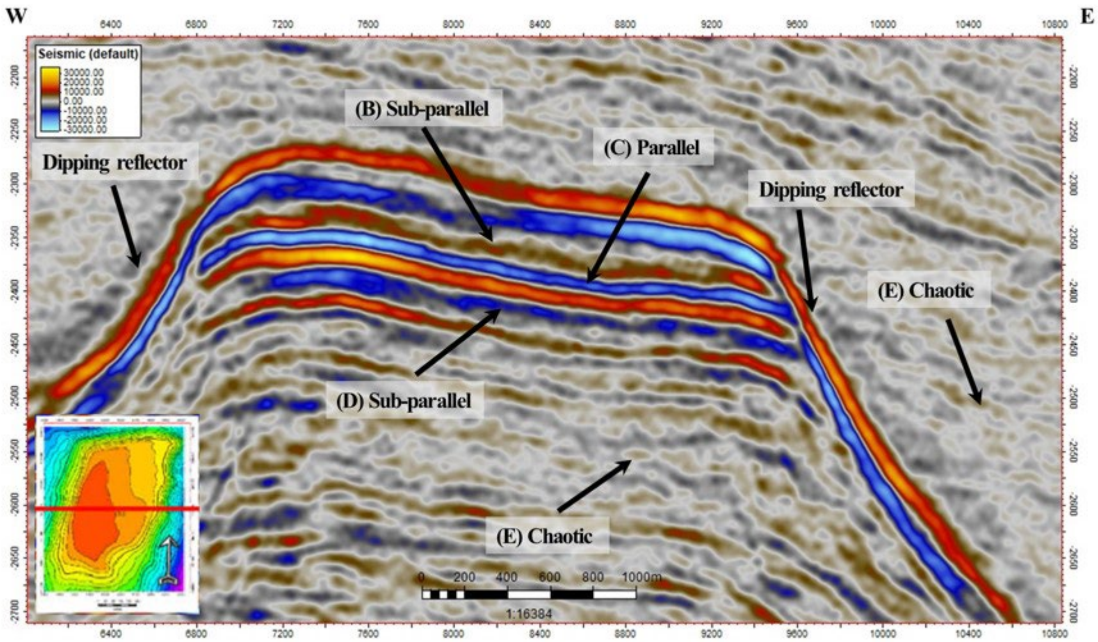

Figure 6. West-East seismic cross-section in TWT (ms) showing seismic geometry based on seismic reflection patterns

5. Conclusion

The classification of seismic reflection and facies is an important first step in exploration, prospecting, reservoir characterization, and field development. It has enabled the interpretation of five zones in this carbonate field. In the seismic cross- section, the reflectors are semi-continuous and sub-parallel, thus indicating porous zones. Zone 3 is a tight layer based on the seismic description with low porosity. Zones 2 and 4 both have similar seismic characteristics showing porous beds with tight streaks. Lastly, zones 1 and 5 incorporate seismic features depicting heterogeneity with medium to low porosity interbeds.

Acknowledgements

The author is very grateful to PETRONAS, and the Centre for Subsurface Imaging (CSI), Malaysia, for providing the required data for this research. I want to express my admiration to the colleagues in CSI and the Geoscience Department of Universiti Teknologi PETRONAS (UTP), who provided insight and expertise that greatly assisted the research. Special appreciation and thanks to the author's advisors Associate Professor Dr Mohamed Elsaadany and Dr Mirza Beg, who have been tremendous mentors. The author also acknowledges Schlumberger Company for providing Petrel 2020 software license.

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To whom correspondence should be addressed: AbdulRahman H. M. Ibrahim, Centre of Seismic Imaging, Department of Geosciences, Universiti Teknologi PETRONAS, Seri Iskandar, 32610, Malaysia;
e-mail: abdulrahmanhashim.mi@gmail.com