

# Study of a TX field Miocene carbonate build-up: Integration of sedimentological data with modern carbonate analogue and 3D seismic characterization to establish carbonate facies modelling workflow

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**Abstract** - Facies modelling of the Central Luconia carbonate build-up is a complex process due to the multi-scale heterogeneity of carbonate reservoirs in terms of facies, stratigraphy and pore structure variations. The objective of this paper is to integrate core, modern carbonate platform and 3D seismic data for building a conceptual model to establish a carbonate build-up facies modelling workflow. The first part of the workflow builds a conceptual geological model *via* the integration of core and modern carbonate build-up analogue data. The sedimentological study began by describing the core facies units of a field, which was then correlated to the well logs. Five reservoir zones comprising of a total thickness of approximately 323m are identified, with Zone 3 and upper Zone 5 the tighter zones when compared to Zones 1, 2 and 4. The subsequent study of modern analogue is conducted to infer the lateral distribution of various facies throughout the carbonate build-up. The second part of the research involves the characterization of 3D seismic of the build-up calibrated with core and modern analogue data. Seismic interpretation has distinguished six reservoir surfaces: Top of carbonate (ToC), TZ2, TZ3, TZ4, TZ5, and TZ6. Reservoir zones from core-to-well correlation is used for tying the well to 3D seismic, ensuring distinct correlations. In addition, seismic attributes are generated from 3D seismic to distinguish platform geometries and for seismic stratigraphy analysis. In summary, conceptual modelling is a crucial step in carbonate facies modelling workflow requiring extensive amount of time for iterating and refining, prior to conducting digital facies modelling.

**Keywords:** carbonate, facies modelling, modern analogue, Central Luconia

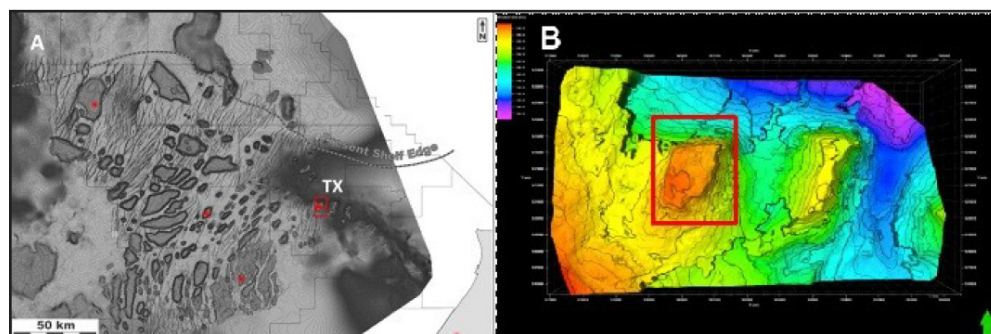
## INTRODUCTION

The Miocene carbonate build-ups in the Central Luconia Province, Malaysia are unique. Over 200 carbonate build-ups (Ali & Abolins, 1999; Hutchison, 2004) within this region constitutes the largest concentration of the giant ice-house platforms globally. Excellent seismic and core data are supplemented with over 40 years of production information, thereby contributing globally as a key calibration area for carbonate research.

The carbonate build-ups in Central Luconia are gas-bearing, and thus geological modelling was usually a fit-for-purpose approach in the past. However, a rejuvenation phase of research started again with the build-ups envisaged

as a container for carbon capture scheme (CCS). The injection of supercritical state CO<sub>2</sub> is far more sensitive to the reservoir permeability heterogeneities than gas below critical conditions. In view of that, the effect of geological heterogeneity on CO<sub>2</sub> injectivity and containment are thus an important aspect for the feasibility studies in CCS.

Hence, upon thorough analysis of integrated data (core, analogues and seismic), evaluation of alternate geological scenarios by the reservoir engineer is the later focus of our approach. The reservoir engineer is provided with multiple static geological models reflecting geological realizations to be tested against well results. Geological realizations are generated by decomposing the carbonate build-up into



**Figure 1:** Location of Central Luconia (1A) and the red box shows the location of TX Field, offshore Sarawak (1A and 1B).

distinct time and facies units. However, facies distribution changes dynamically with time affected by for instance cementation during platform flooding or karstification during platform exposure (Ting *et al.*, 2010). Multiple conceptual models of geological sub-environments can then be translated into distinct permeability arrays with detailed facies modelling.

### GEOLOGICAL SETTING

Central Luconia is located between the compressive realm in the south and an extensive regime in the north, therefore having submarine plateaus trending in the SW to NE direction (Hutchison, 2004). The most prolific period for carbonate growth was during the middle Early Miocene times (Hutchison, 2004 and Epting, 1980 & 1989) wherein the basin extension led to the development of a significant unconformity. Crustal extension within the basins of South China Sea led to the formation of horst or fault blocks. These horst block structures are suitable location for coral reefs growth.

The seafloor extended during the Oligocene-Mid Miocene during Cycle III time, followed by the deepening of the South China Sea (SCS) basins and its opening in the SW allowed carbonate build-ups to grow due to the inflow of nutrients to the Sarawak shelf. The Miocene time represents a more tectonically active period, therefore carbonate deposition was mostly influenced by basin tectonics, which then affect the overall change in capacity and shape of the ocean basins. The resultant effect is the change in sea level and the vertical extent with which carbonate sediments can accumulate. Post-deposition on the carbonates is capable of reactivating growth fault patterns. The combination of these factors can vary the shape and size of the carbonate build-ups through time.

According to Markello *et al.* (2008) and Carbonate Analogue Through Time (CATT), a worldwide carbonate study, Miocene is an icehouse period, when the climate is cooler and wetter, sea level amplitude and frequency are high and aragonitic abiotic grains are dominant. These earth processes control the stratigraphic architecture and depositional profile of carbonates in Miocene.

### STRUCTURAL SETTING OF TX FIELD

The case study, TX Field is an approximately 3km x 5km Miocene carbonate platform located 170km north of Bintulu, offshore Sarawak. The reservoir section is from Cycles IV to V, i.e. Middle to Upper Miocene age. The platform top is mapped at a depth of 2800m TVDSS with a vertical relief of about 600m. Situated close to East of TX field is the West Baram Line that separates the field from the West Baram Delta. TX Field as seen in Figure 1B has a flat top, overlain by a shale sequence that is most probably sourced and deposited from the nearby West Baram Delta.

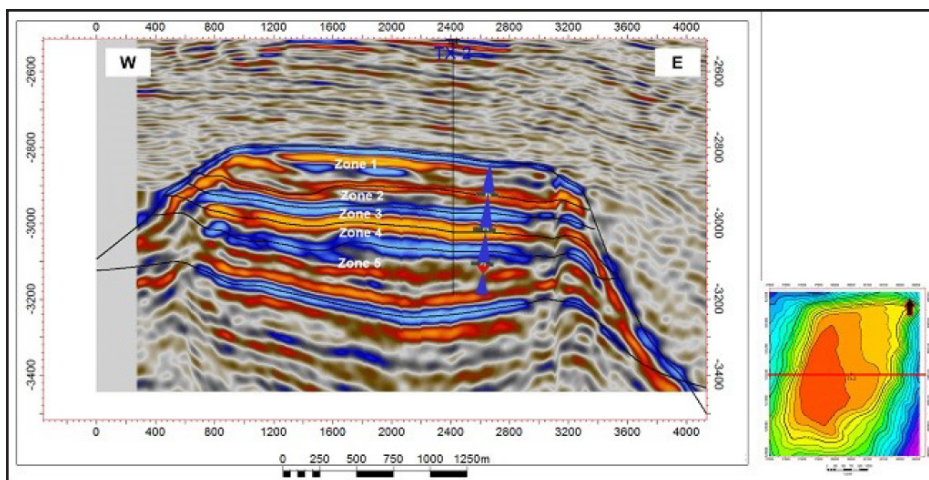
According to Baumann *et al.* (1997), five reservoir layers can be distinguished from seismic data (Figure 2). These correspond to units with distinct porosity classes. Koša *et al.* (2015) has stated that the TX Field is generally of low to moderate porosity, Zones 2 and 4 are porous layers whereas Zone 3 and upper Zone 5 are tight layers. Zone 3 is described as a separation unit of tight reservoir facies between the hydrocarbon reservoirs in Zone 2 and 4.

The platform development in Central Luconia began in the Early Miocene on faulted structural highs, however it is noted that the seismic data of TX Field does not show any significant structural faults below the platform. This could possibly be due to the location of TX Field at the deeper part of Central Luconia, and locally grew further from the NE-SW series of faults.

### CONCEPTUAL MODELLING

The research by Baumann is further supported from the core description study by Janjuhah *et al.* (2017). Three lithofacies have been characterized from core TX-2 (Table 1), namely (F1) Coated grain packstone, (F2) Coral massive grainstone, and (F4) Skeletal lime packstone; interpreted as back reef, shallow lagoon and deep lagoon environments, respectively. F1 is characterized as having poor reservoir quality at about 0.1% to 8.0% porosity, whereas F2 and F4 exhibit higher reservoir quality with minimum 0.1% to 25% porosity, especially for F2. Stylolites are also commonly present in F1 facies, implying a significant overburden pressure.

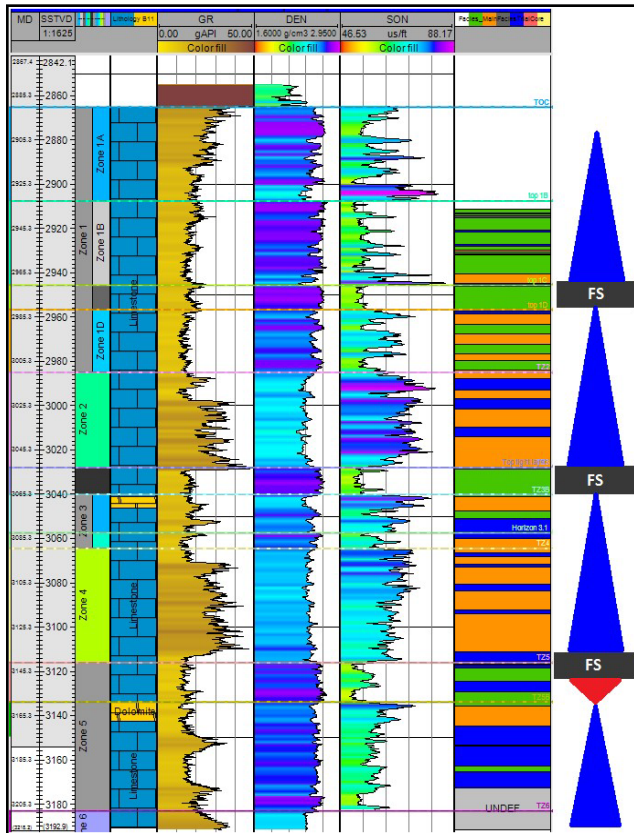
As the first part of conceptual modelling, the three facies were correlated with the respective TX-2 well log



**Figure 2:** Five reservoir zones distinguished from the 3D seismic timeslice on the EW cross section of TX Field, adapted from Baumann *et al.* (1997).

**Table 1:** Core description, log observation, seismic configuration and interpreted depositional environments (based on the core facies descriptions) are listed in this table. Zone 2 and 4 are interpreted as porous reservoir zones with Zone 3 acting as a baffle in between. Zone 2 and 4 compose of F2 and F4 facies, possibly deposited in the shallow lagoon. Zone 3 has low porosity, composed of mainly F1 facies. It is possibly formed in the deep to shallow lagoon environment.

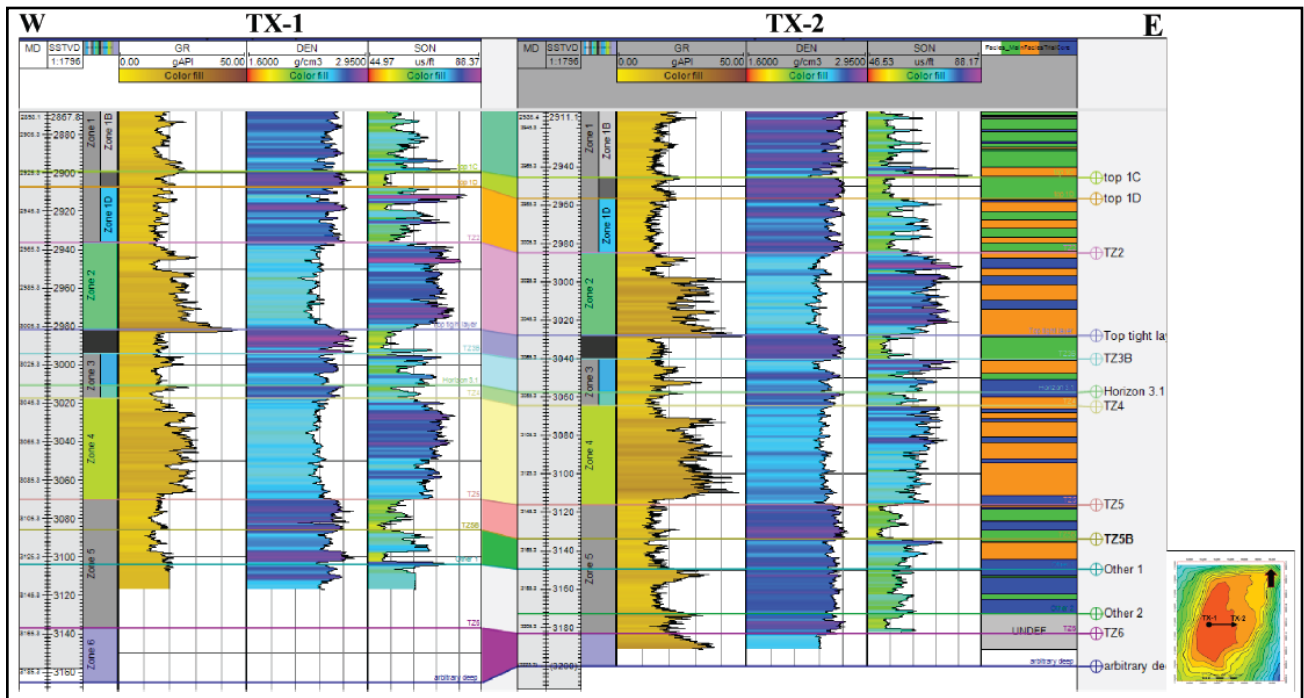
| Reservoir zonation | Thickness (m) | Core description |                    | Seismic description |                               |                                | Interpretation   | Depositional environment (at core) |
|--------------------|---------------|------------------|--------------------|---------------------|-------------------------------|--------------------------------|--|------------------------------------|
|                    |               | Lithofacies      | Porosity range (%) | Amplitude           | Continuity                    | Geometry                       |  |                                    |
| Zone 1             | 120           | F1, F2           | 0.1 – 25.0         | Medium to high      | Semi-Continuous               | Propagational with local mound | Moderately porous to light layer with propagational patten towards to NE direction | Shallow lagoon to back reef        |
| Zone 2             | 43            | F2, F4           | 7.0 – 22.0         | Medium high         | Semi-Continuous               | Sub-parallel with chaotic      | Porous layer   | Shallow lagoon                     |
| Zone 3             | 37            | F1, F2, F4       | 0.1 – 25.0         | High                | Continuous                    | Parallel                       | Low porosity with tight layer  | Deep to shallow lagoon             |
| Zone 4             | 51            | F2, F4           | 7.0 – 25.0         | Medium high         | Semi-Continuous               | Sub-parallel with local mound  | Porous layer with possible patch reefs   | Shallow lagoon                     |
| Zone 5             | 72            | F1, F2, F4       | 0.1 – 25.0         | High-medium         | Semi-Continuous-to-Continuous | Sub-parallel with chaotic      | Tight layer at the upper Zone 5, with some skeletal debris at the base             | Shallow lagoon to deep lagoon      |



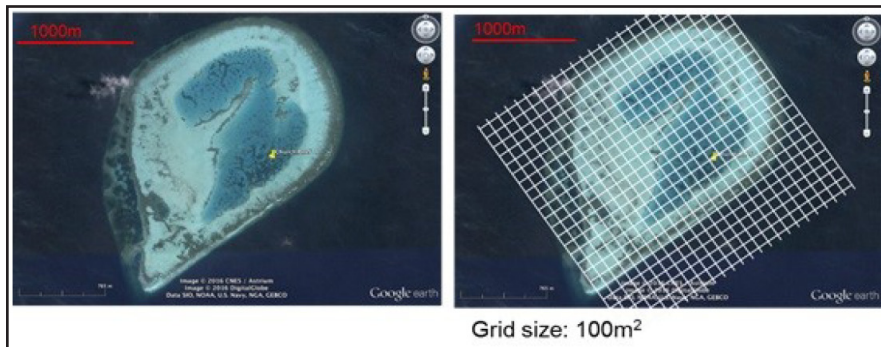
**Figure 3:** The TX-2 well log shows the gamma ray, density and sonic data, correlated with the three core facies as adapted from Janjuhah *et al.* (2017). The lithofacies are F1 (green), F2 (orange), and F4 (blue). The blue and red triangle signifies the deepening and shallowing of the sea level respectively.

(Figure 3). Correlation between the core and well log signatures have well proved that F2 and F4, which are of good reservoir quality, are dominantly distributed in Zone 2 and 4. On the other hand, the F1 is distributed mainly in Zone 3 and 5. Generally, the core shows more than 95% of its length is composed of limestone and the rest are composed of dolomite. Well-to-well correlation (Figure 4) shows a good continuity between wells TX-1 and TX-2 in the EW direction at 975m apart.

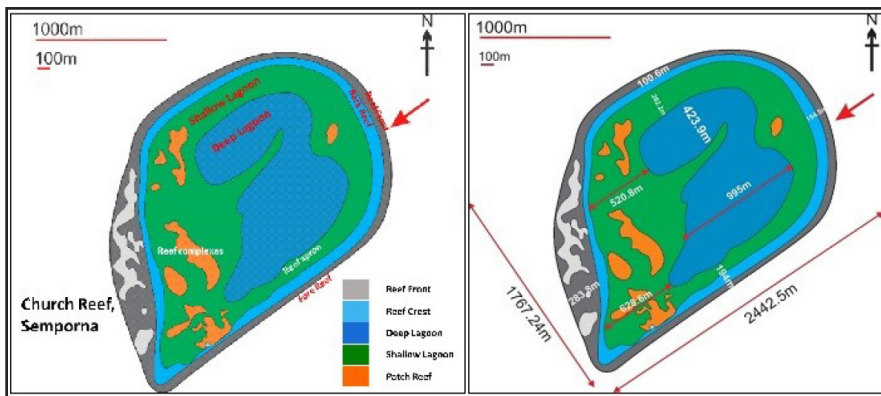
The second part of building the conceptual model integrates the modern carbonate analogue to disseminate 2D dimensions and geometries of the depositional sub-environments, especially those not well imaged in the seismic data (e.g., narrow reef core). Build-up geometries from a modern analogue is shown in Figure 5. The modern carbonate analogue selected is the Church Reef carbonate island, Semporna, Sabah. The analogue is suitable due to its similarities in size and lithological components with the carbonate case study. Church Reef is approximately 1.8km x 2.5km and TX Field is about 3km x 5km. Both build-ups are composed of mainly coral and foraminifera, with windward direction from the NE. Figure 6 shows the possible core facies found on the modern carbonate build-up. Besides, the climate in Miocene and Holocene times are similar (Zampetti, 2010). Findings by Zampetti (2010) have noted three different patterns. The first order pattern is the similarity in the dynamics of the Pacific and the Indian oceans. Second order pattern suggests the Holocene biannual monsoon changes also show similarities with the Miocene monsoon (Wang *et al.*, 2003). The third order pattern is the tectonic topography has not shown clear similarities between



**Figure 4:** Well correlation between well TX-1 (left) and TX-2 (right) shows that the log signature is quite similar and continuous from E to W. As seen in Zone 2 and 4, sonic porosity is higher while the density value is lower than the rest of the zones. Simultaneously, GR value is high in Zone 2 and 4 (30 to 40 API), however the cause of this is still uncertain.



**Figure 5:** The satellite image from Google Earth clearly shows the different depositional environment. Grid of size 100m<sup>2</sup> is laid on the image to estimate the size of the Church Reef depositional facies from Semporna, Sabah.

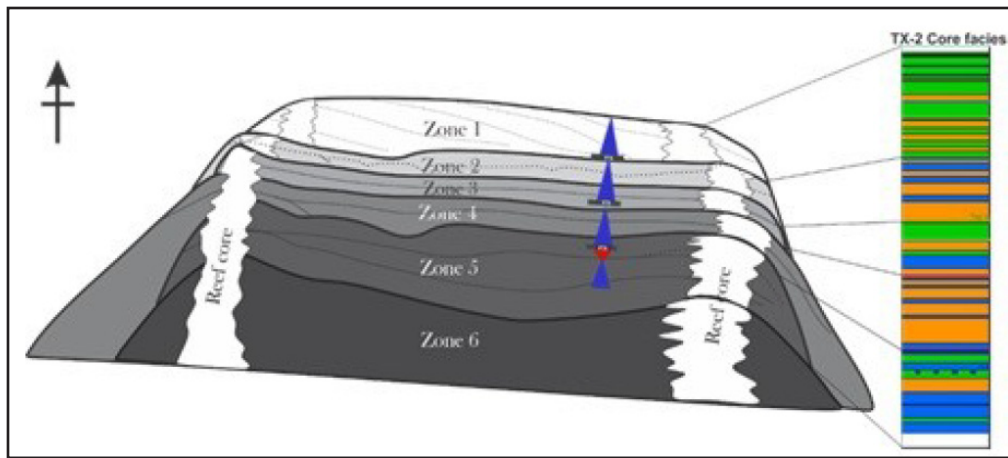


**Figure 6:** Sketches of the Church Reef shows the possible depositional environments, which are colored according to the core facies. The dimensions of each depositional environment are also measured to assist in later stage of digital geomodelling.

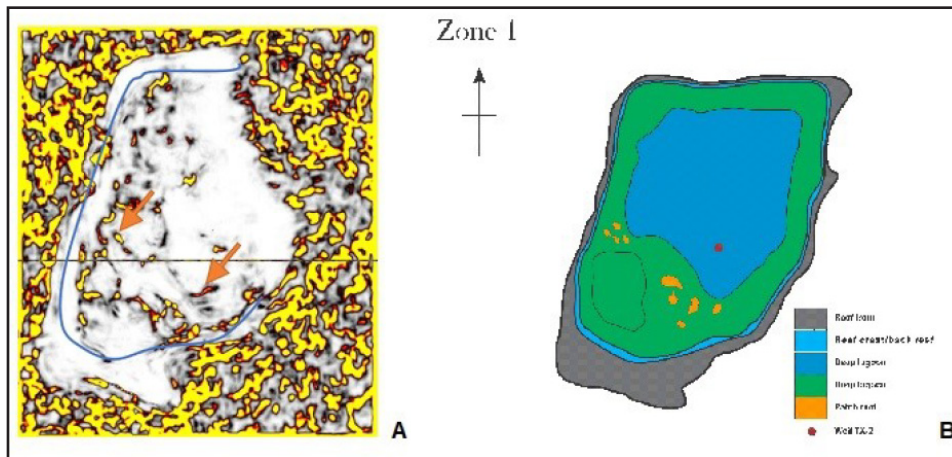
the ancient and the modern analogues due to contradicting interpretations on the formation of Luconia Province carbonates. Nonetheless, Church Reef is one of the more reasonable modern analogue for modelling the TX Field due to their locations in offshore Malaysia with assumed similar climatic and oceanic conditions between the two.

**3D SEISMIC CHARACTERIZATION**

Data integration of core study (1D), modern reef analogue (2D) and seismic data (3D) are to differentiate distinct heterogeneities such as moldic pores in shallow lagoon and karstic holes in reef crest and back reef debris. According to Zampetti *et al.* (2004), 3D seismic



**Figure 7:** A sketch drawn based on TX Field cross-sectional seismic. Zones 2 and 4 seismic configuration shows semi-continuity and are sub-parallel, while Zone 3 is very continuous and parallel. Zone 1 shows progradational pattern with local mound. Generally, TX Field shows in-building and up-building, with no signs of stringers that represents out-building. The blue and red triangle represents deepening and shallowing sea level respectively.



**Figure 8:** Variance attribute is applied to the time slice where Zone 1 is located (A). The blue line indicates the possible reef crest/back reef environment, while the orange arrow indicates possible presence of patch reefs. The discontinuities of seismic reflectors are highlighted yellow. (B) The sketch based on the interpretation of the time slice is made, with reference to the conceptual model drawn as shown in Figure 6.

characterization involves four major steps as described below.

Interpretation of seismic horizons (1) to create a link between seismic reflections with the correct sedimentological horizons on the core. Seismic horizons picked also helped to determine the build-up geometries. The interpretation is viewed from a cross-sectional view to describe the configurations as shown in Table 1 and Figure 7. (2) Zonations from the well logs and core data (depth datum) are tied to the seismic data (time datum) to ensure correct correlations and more relevant interpretation of the sub-zones within TX Field.

Seismic attributes (3) are applied to highlight key features and carbonate geometries in the 3D seismic. For example, in the analysis of Church Reef analogue, lagoonal facies are known to have patch reefs (orange). Variance is an attribute useful for improving the clarity and lateral resolution of reefal structures. It also highlights seismic discontinuities caused by karst or patch reef features (Figure 8A: in yellow), and more significantly faults and fractures (Chopra & Marfurt, 2007). Aerial view of TX Field using variance attributes show patterns as pointed by the orange arrow that is possibly patch reefs, while the blue line shows the reef crest and back reef region (Figure 8B).

Using seismic stratigraphy (4), seismic units are interpreted to recognize sequences in the depositional system.

Seismic cross-section clearly does not show sequences but with correlations with cores and well log the stratigraphic successions can be well understood (Figure 7). For example, TX Field is unlike the other build-ups interpreted by Zampetti *et al.* (2004) and Kosa *et al.* (2015). TX Field does not have the wings and mushroom features caused by a combination of in-building, out-building and up-building. Instead, it has a rather consistent up-building and a gentle in-building phase throughout the platform succession (Figure 7). This may be due to the paleo-location of TX Field at the deeper part of the Central Luconia basin where the creation of accommodation space and siliciclastic input have not regularly changed as compared to the shallower fields. At the location of the drilled core, there are sequential transition from deep and shallow lagoon to back reef environment.

## CONCLUSIONS

3D geological models can assist in decision making for production in the oil and gas industry. To fully utilize their value, distinct plausible sub-surface models generated by geomodeller need to be tested iteratively with the reservoir engineer. With that approach, the integration of single dimensional to three-dimensional data to build conceptual model proved to be an important step for a better understanding of a subsurface platform carbonate. Three core facies F1, F2 and F4 showed good correlations with the

TX-2 well in terms of reservoir quality. Zone 2 and 4 has lower density and mainly associated with F2 and F4 facies (7% to 25%), and in the seismic cross-section the reflectors are semi-continuous and sub-parallel thus indicating porous zones. As for Zone 3, it is a tight layer as shown in the well log signatures, and the seismic cross-section shows parallel and continuous reflections, thus proving that it is a less porous zone. In addition, seismic attributes are useful tools for delineating reefal features that are not easily distinguish through seismic. 3D modelling workflow is aimed at building multiple plausible realizations for each individual reservoir layers. With a wide range of alternatives, it will enable the best decisions to be taken by the reservoir engineers for robust business outcomes.

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