Reservoir characteristics of carbonates build-ups in southern Central Luconia Province: A study based on different scales

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Abstract: This paper discusses the reservoir distribution and characteristics of different carbonate build-ups/morphologies in Central Luconia Province, focusing on two carbonate build-ups in the southern part of the province. Both geological (core) and geophysical (seismic and well logs) data were used throughout the study to provide different scales and resolution of the study area. The evaluation of reservoir qualities for each carbonate build-ups in this area was done for Cycles III and IV carbonates. The findings showed that both fields have different reservoir distribution in terms of porosity and lithology. Pinnacle build-ups has fair to good porosity with decreasing occurrence of dolomite relative to depth while the carbonate platform has poor to fair porosity due to higher mud content compared to the pinnacle-type. Cleaner carbonates can be found in the pinnacle platform with lower gamma ray log reading. Different lithologies can also be observed in these two fields. For example, the pinnacle platform has lithology ranging from packstone to rudstone while the carbonate platform has lithology of packstone to grainstone with a higher mud content. The result concluded that the reservoir quality of the pinnacle build-up is better than the carbonate platform.

Keywords: Central Luconia Province, pinnacles carbonate, flat-tops platform, carbonate architecture, reservoir quality

INTRODUCTION

Central Luconia is a natural carbonate laboratory located in the offshore Sarawak, Malaysia. The abundance of Oligo-Miocene carbonate deposition in this province indicated that this rifted, extensional margin had provided a conducive environment for reefs to flourish during Oligocene-Miocene period.

The carbonate build-ups imaged from seismic data showed mainly pinnacle and flat-top morphologies. The pinnacle build-ups are mainly located in the central part of the province while the carbonate platforms are more widely distributed. Epting (1980) discusses that factors contributing to the growth of carbonate in pinnacle shape is based on the sea level fluctuation and carbonate sedimentation processes. Meanwhile, Doust (1981) stated that both subsidence and eustatic sea level are the key factors for the outcome of different. In recent years, faulting and tectonic activities (Jamaludin *et al.*, 2014) including gravitational loading from NW Borneo Wedge (Jamaludin *et al.*, 2017) have also been identified as factors contributing to the growth and distribution of difference types of carbonate build-ups in Central Luconia.

The different morphologies of the carbonates in Central Luconia had shown some uncertainties and differences in reservoir quality and distributions. The objective of this study is to evaluate the impact of different architecture of carbonate platforms on the reservoir quality based on different observational scales and resolution which include the core analysis, geophysical and petrophysical interpretation.

GEOLOGICAL SETTING

Central Luconia (Figure 1) had undergone several tectonic evolution stages since Oligocene to present-day. All

the tectonic events was directly related to the final rifting stage of the South China Sea (Franke *et al.*, 2014). It had undergone Eocene extensional tectonics and continuous subsidence which began in Middle Miocene (Doust, 1981). The subsidence occurred along the NNE-SSW trending normal faults which then demarcated the area into central zone, hence explained the name of 'Central' Luconia Province. The central zone remained relatively elevated with flanking depressions and basinal area (Doust, 1981). With favourable environmental conditions and the diminishing tectonic activities during Late Early Miocene (Jamaludin



Figure 1: (A) Location of Central Luconia Province with reference to the two carbonate platforms used in this study (Jamaludin, 2014). (B) Orientation of Platform FY and EX with well names.

et al., 2017), reefs started to flourish. Reefs became more prolific throughout Early Middle Miocene to Late Middle Miocene (Epting, 1980).

Sediments in Central Luconia Province were denominated by 'cycles' as introduced by Shell Sarawak as the pioneer explorer of this region. There were eight cycles in for both coastal and marine environments. Cycles I-II comprised of fully marine shales with patches of limestone, deposited during Eocene to Lower Miocene. Based on the evidence from the seismic data, these cycles laid in the deeper part of the province, hence, there are limited well drilled and data acquired (Doust, 1981). Cycle III was deposited during the Lower to Middle Miocene and consists of thick shale with thin limestone and sandstone streaks whereas the upper part of this cycle consisted of thicker limestone streaks and then, superseded by Cycle IV limestone formation. Cycle IV was deposited during Middle Miocene with 200-300 m thick limestone rock (Doust, 1981). From Late Miocene to Pliocene, the whole shelf was in open-marine conditions with sedimentation of clastic materials from the nearby prograding Baram and Rajang-Lupar deltas. By this time, many carbonate build-ups had died due to contamination of the siliciclastic materials. From Late Miocene to Pleistocene, Cycles VI to VIII deposits showed successive stages in deltaic outbuilding consisting of open-marine to coastal clays and sands.

DATA AND METHODOLOGY

Data from build-ups EX and FY in the southern part of Central Luconia were used in this study. The geophysical data include 3D seismic cube and two sets of wireline logs while the geological data include the cores from one well for each platforms and few thin section images from selected wells. All the data were provided by Malaysian Petroleum Management (MPM), PETRONAS. The architecture of these two builds-ups were identified based on the seismic data- EX (pinnacle build-up) and FY (carbonate platform).

The technical approach to achieve the objective of this study was divided into two main parts- core analysis and geophysical interpretation- to look at 2 different scale of investigation: micro-scale analysis which involves the core data and its analysis before upscaling the investigation to include well logs and ending with a macro-scale investigation with the seismic data.

Core analysis

Cores from two wells, EX3 and FY6 were analysed for the geological and sedimentology interpretation. The core analyses were performed at PETRONAS Geo-Sample Center (PGSC). The cores were described based on Dunham's lithology classification, sedimentary characteristics and fossils types. The cores were logged for every 10 m with a detailed core logging description. Based on the core analysis, the depositional environment was determined and parameters of reservoir distribution were evaluated. The analysis from core data will be upscaled to assist in the well log interpretation. Based on the core analyses, the pore types and geometry of the limestone could provide the information on the storage capacity, pore patterns. All these elements have an important role in characterizing a carbonate reservoir. Apart from the EX3 and FY6 cores, cores interpretation done by previous publication (Gartner *et al.*, 2004) has also been used for this study.

Geophysical interpretation

Well logs interpretation

Wells logs such as gamma ray (GR), density, sonic and neutron logs were used in this study. GR log was used for lithology identification and the other logs were for porosity analysis and hence, the reservoir. Well tops for each cycle were also correlated based on GR log motif.

Seismic interpretation

Seismic data of Platform EX and FY were interpreted. In this study, horizons (top, middle and bottom carbonates) and faults are interpreted at every five inlines and crosslines in time domain based on the amplitude and discontinuities of the reflections respectively. The interpretations were done manually by utilizing the tools in Petrel software. Figures 2 and 3 show the horizons and faults interpretations in Platform EX and FY. Previous interpretation by Gartner et al. (2004) and Jamaludin (2014) were referred in the work. Then, subsurface maps in both time and depth domains were generated. Seismic attributes were applied during the interpretation to further enhance and quantify features on the carbonate build-ups. The attributes applied revealed any hidden features in the seismic data that helps the interpretation. Variance attribute was applied for a better fault picking while RMS amplitude emphasis the acoustic impedance (AI) variations of the data.

RESULTS AND DISCUSSIONS

The reservoir quality and distribution for the studied carbonate platforms were analysed based on the Cycle III and Cycle IV carbonates observed in the seismic data.

Platform EX

Wells EX2 and EX3 were used to facilitate the interpretation of the seismic data. Well EX2 is located at the position that marked the beginning of platform shrinking (back-stepping) of the carbonate platform and Well EX3 at the northern flank of the build-ups respectively.

The lithology of Well EX3 cores for Cycle IV carbonates were interpreted as coralized wackestone followed by dolomitized grainstone as depth decreases (Gartner *et al.*, 2004). Common lithologies of EX2 are packstone and grainstone with occurrence of boundstone whereas Well EX3 observed grainstone and rudstone. The lateral facies change of the carbonate from south to north as observed by the change in grain size suggest an increasing porosity in a similar trend.

Referring to Figure 7, log pattern for gamma ray in Cycle IV carbonates of Well EX3 shows the blocky log motif which indicates the aggradation phase which is the build-up phase

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Figure 2: Lithological interpretation of EX3, FY2 and FY6 wells. Figure 2(a) shows the whole logs for all wells with the red dashed boxes indicate the interest zone. Figure 2(b) shows the zoom-in logs of the interest zone of this project.







Figure 4: Zoom in section of eastern part of Platform FY (shown in red box A-A') showing the horizons and faults interpretation in time domain. It can be observed that the limits between bank top and flank in F13 field are emphasized by the normal faults.

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Figure 5: Back-stepping structure of EX field.

of the carbonate platform. The small value of GR log shows that Cycle IV carbonates is clean and has less mud content compared to Cycle III, hence, suggests a better porosity.

Cycle III carbonates' lithology changes from grainstone to mudstone with increasing depth. Breccias were deposited at the base of EX2 cores and top of EX3 cores (Gartner *et al.*, 2004) due to the erosion of carbonates and its locale on the leeward margin. As depth increases, the grain size decreases which affects the porosity. Apart from that, Cycle III carbonates have higher mud content than Cycle IV carbonates based on the GR log. The interpretation made is that there is a mixture of both clastics and carbonates. This can be related to the establishment of marine environment in northern Balingian and Luconia during Cycle III mentioned by Ali & Abolins (1999).



Figure 6: Core correlation between EX2 and EX3. Core log of EX2 is taken from Gartner *et al.* (2004).



Figure 7: Gammaray log for Well EX3 showing blocky logs and low gamma ray values to indicate low mud content. This section images of boundstone B shows the low porosity layer and (G) is showing the stylolite that are taken from (Mueller, 2000). Black box represents no core availability for the core.

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Figure 8: Application of seismic RMS amplitude on EX field. Red box indicates the higher RMS amplitude in Cycle IV carbonates than that of Cycle III carbonates.

5000 g/cm3 3.0000 42.75 us/ft 191.5



Figure 9: Porosity types found in cores of Well EX3 with pencil for scale. Mouldic porosity at depth of 1964m, intergranular porosity at depth of 1744 m, cavern at depth of 1847 m and vug at depth of 1869 m.

Seismic RMS amplitude attribute further strengthen the interpretation where the amplitude for Cycle IV carbonates has stronger RMS amplitude than the Cycle III carbonates (Figure 8). There is a strong correlation between RMS amplitude attribute with formation porosity and/or liquid saturation (Oyeyemi & Aizeceokhai, 2015). Still, this project needs necessary rock physics work to be done for this project in the future to support this statement.

Both primary and secondary porosity can be identified in the cores as shown in Figure 9. The porosity types include intergranular porosity, intragranular porosity, mouldic porosity, vug and cavern contributing to the porosity ranges from fair to good.

Platform FY

Three wells- FY2, FY5 and FY6 were used for the evaluation of reservoir quality in this platform. Based on the gamma ray (GR) value, FY6 shows higher than FY2 GR value (Figure 2) which indicates the increasing mud content from south to north. Figure 10 shows the GR log for Well FY6. The muds probably originated from the erosion of Platfrom EX sediments which then been transferred to FY



LIMESTONES

% pn.

Figure 10: Gamma Ray log for Well FY6. Blue indicates carbonate rocks. Black box represents no core availability for the core.

field. Therefore, the reservoir quality of the field decreases laterally from south to north.

The general lithology of Cycle IV carbonate in Platform FY has considerably coarse/large grain size, ranging from packstone to grainstone. Hence, the porosity can be good to fair. This is supported with the density log that shows high density values representing good total porosity-however, it



Figure 11: Cores of Well FY6 showing the types of porosity with pencil for scale. Dissolved coral produces mouldic porosity (1992m) represented by red circle while coral fossil at depth of 1987m is indicated by yellow circle. Blue circle shows the oncolith fossil at 1981m and green circle shows the chalky carbonate grainstone with dipping stylolite.

still needs further studies of rock pysics work. Likewise, packstone and grainstone can be observed in Cycle III carbonates in Platform FY. The density log also shows high response indicating the fair porosity. As Cycle II is a mix of both clastics and carbonate, it produces fair to poor porosity.

Similarly, both primary and secondary porosity types can be observed in FY field. Based on the core analysis, the primary porosity types include both intragranular and intergranular porosity (Figure 11). As for the secondary porosity, mouldic porosity was formed to the corals and fossils dissolution. Burrow produced by the fossils are also part of the secondary porosity. These porosity types will increase the reservoir quality of the field.

However, the porosity decreases with depth as observed based on seismic attributes- RMS amplitude shows a decreasing amplitude with depth- this statement needs further study and research (rock physics work). Furthermore, the decreasing grain size observed from the core logs is also affecting the porosity. This can be further proven by the thin section images from unpublished reports that showed the changes of porosity from fair to poor with depth (Figure 12). Calcite cementation occurred and reduced the porosity.

CONCLUSIONS

Reservoir quality of two different carbonate platforms that exhibit different morphologies has been documented in this study. Carbonate sturcture EX, a pinnacle-with a strong back-stepping morphology is believed to be deposited in a reefal environment as suggested by the lithological textures (abundant corals etc) observed in the cores. Common lithologies found in Carbonate EX are packstone and grainstone, for both Cycles III and IV carbonates. Wireline logs showed that Cycle IV in Carbonate EX contain less mud compared to Cycle III. Thus, the porosity decreases with depth in Platform EX. Laterally, the reservoir quality improved from south to north of the field, as supported



Figure 12: Core photograph and thin section image are taken from an unpublished report by Core Laboratories, Inc.

by the increasing grain size from south to north. This interpretation can be observed and supported by the RMS seismic amplitude as discussed in the text. Generally, Platform EX exhibits moderate to good reservoir quality.

On the other hand, Platform FY has been interpreted to be in a protected environment or lagoon. The general lithologies of this field arepackstone and grainstone with a higher mud content causing the deteriorating reservoir quality. Therefore, the porosity is poor to fair. The lateral reservoir distribution of FY also deteriorates from south to north of the field due to the increasing of mud content in the north. The mud had reduced the pore spaces, hence, affecting the reservoir quality. Similarly, with Platform EX, Cycle IV carbonates in FY field has better porosity than Cycle III.

Overall, Platform EX has better reservoir quality compared to Platform FY. Reservoir distribution in a clinoform-pinnacle shape is better compared to a flat-top type platform, based on our study of these two carbonate platforms in the southern part of Central Luconia. However, these statement needs further study. Other factors such as tectonic setting, paleogeographic orientation, diagenetic processes, depth of burial and age of carbonates should also be taken care in examining the reservoir quality of these platforms and should be included in the research context in the near future.

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