

Reservoir Characterization of Pagasa and Lower Matinloc Formations by Using AVO and Multi-Attribute Analysis, Southwest Palawan Basin, Philippines

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Abstract

Several distinct high amplitude anomalies occur in both the Lower Matinloc Formation and Pagasa Formation equivalent in the Southwest Palawan Basin, Philippines. The main objective of this study is to conduct a thorough investigation on the nature, occurrence, extent and reservoir potential of these high amplitude anomalies. This study explores the possibility that either these high amplitudes are associated with reservoir sands. On a regional scale, the cross plot analysis for all the wells revealed that no generalized P-Impedance and Gamma Ray (GR) relationship could be established for the whole area. However, P-Impedance can be an effective lithology indicator when the cross plot analysis is applied in small intervals and over small regions. Similarly, density was able to discriminate sands from shales in the Lower Matinloc Formation (Upper Miocene Section). But it is not a good lithology discriminator for other formations. Due to great variations of rock physics parameters, it is required to establish local relationship before computing multi-attributes or applying inversion techniques. Fluid replacement modeling and AVO analysis indicate that water wet and gas saturated sands have same AVO response. The sands can be classified as Type 2 and Type -4, per Young et. al., (2003) AVO response classification. Multi-attribute analysis and GR prediction showed that the high amplitude anomalies are associated with shale to shaley sands. The bright amplitudes in the area correspond to shales. Therefore, these bright amplitudes are not associated with reservoir or fluids.

Keywords: Acoustic Impedance, AVO Modeling, Multi-Attribute Analysis, Southwest Palawan Basin

1.0 Introduction

In terms of petroleum exploration, development and production endeavors, the Philippines remains underexplored, as compared to other neighboring countries in South East Asia. At present, the Northwest (NW) Palawan basin (Figure 1) is the only prolific gas-producing basin of the country, with the Nido Limestone formation as the primary exploration reservoir target.

Few studies have been conducted on the overlying clastic Pagasa Formation, which is a gas-producing reservoir in the Octon and Galoc fields located in

NW Palawan basin. The Pagasa Formation equivalent in the Southwest (SW) Palawan basin (Figure 1), together with the overlying Lower Matinloc Formation (clastics end member), was observed to have distinct high amplitude anomalies.

In connection to a previous study on high amplitude anomaly in the northern part of SW Palawan basin (Acosta, 2011), this study aims to conduct a thorough investigation of the high amplitude anomalies on both the Lower Matinloc Formation and Pagasa Formation equivalent, in the southern part of SW Palawan basin.

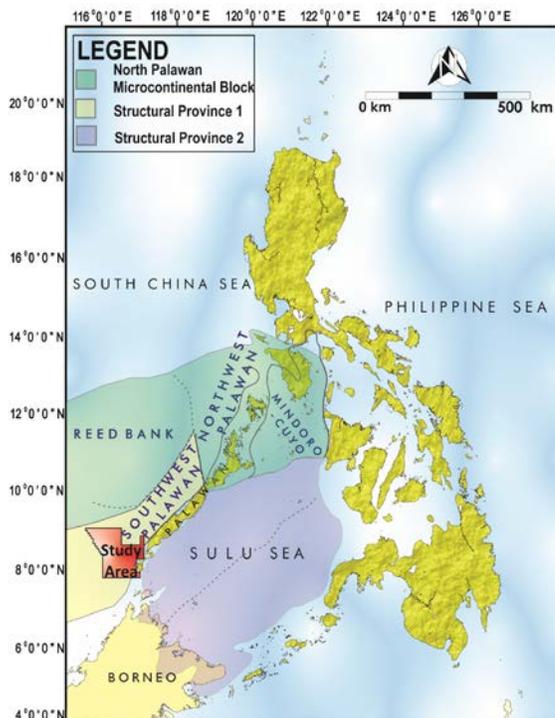


Figure 1. The location of study area within the SW Palawan basin (modified from Philippine Department of Energy website).

2.0 Methodology

In Figure 2, the proposed work flow for the study included well and seismic data calibration, AVO forward modeling and GR volume prediction.

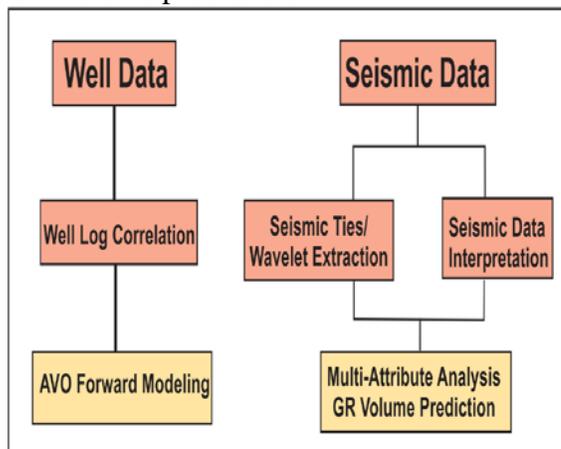


Figure 2. Simplified workflow diagram for the study.

3.0 Results

3.1 Cross Plot Analysis

Before doing further analysis, a feasibility study was conducted through a cross plot analysis. This will determine the rock properties that best discriminate the lithologies in the study area. The Lower Matinloc Formation was divided into a shallower Pliocene section and a deeper Upper Miocene section, based on biostratigraphic reports.

Crossplot Analysis of P-Impedance vs GR in Lower Matinloc Formation

Pliocene Section

The P-Impedance is behaving differently within the same stratigraphic interval in all the wells. For the Lower Matinloc Pliocene section, in SW Palawan A-IX well, sands show relatively lower P-Impedance as compared to shales (Figure 3A). Whereas in Murex-1 well, sands have higher P-Impedance than shales (Figure 3B).

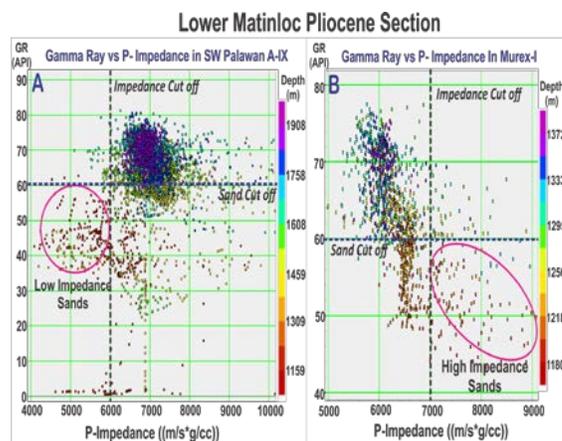


Figure 3. P-Impedance vs GR crossplot color coded by depth within Lower Matinloc Pliocene section in (A) SW Palawan A-IX well and (B) Murex-1 well. Low and high impedance sands are enclosed by the pink circle.

Upper Miocene Section

On the other hand, in the Upper Miocene Section of the Lower Matinloc Formation, the sands cannot be differentiated from the shales since both have the same P-Impedance range of 6,000 to 10,000 (m/s)*(g/cc) (Figure 4). However, some high impedance sands can be separated from shales. Figure 4 shows that shales also have low impedance and this impedance range is overlapping with some sands. Generally, silty sands and some clean sands have high P-Impedance.

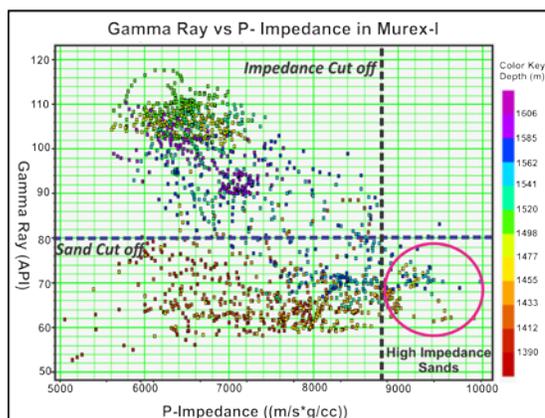


Figure 4. Some high impedance sands can be discriminated on the basis of P-Impedance, as enclosed by the pink polygon.

Crossplot Analysis of P-Impedance vs GR in Pagasa Equivalent Section

In SW Palawan AI-X and Murex-1 wells, the deeper sands have high impedance as compared to shales. The range of high impedance sands fell in between 8,000 to 11,000 (m/s)*(g/cc) (Figures 5A).

But in the case of Likas-1 well, some sands have lower P-Impedance than shales and the general cross-plot trend is different from SW Palawan A-IX well (Figures 5B).

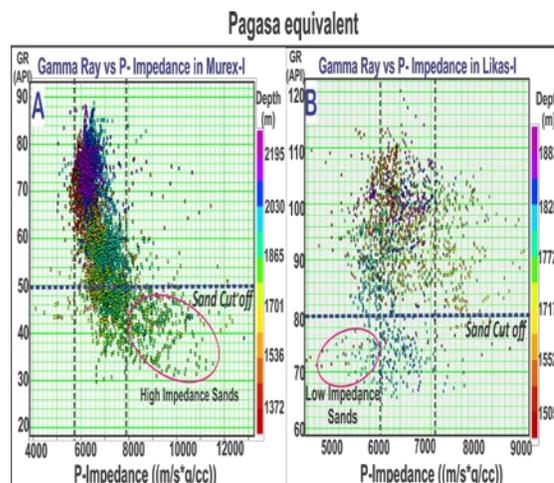


Figure 5. P-Impedance vs GR crossplot color coded by depth within Pagasa equivalent section in (A) Murex-1 well and (B) Likas-1 well. Low and high impedance sands are enclosed by the pink circle.

Crossplot Analysis of Density vs GR

Density was only able to differentiate lithologies in the Upper Miocene Section of Lower Matinloc Formation (Figure 6). Clean sands have lower density than shales. In further pre-stack inversion studies, density may help in lithology discrimination in this section.

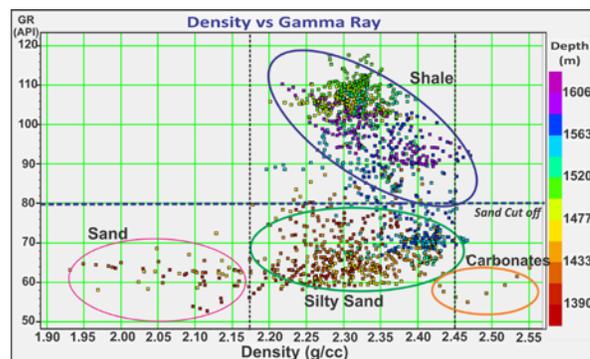


Figure 6. Density vs GR crossplot color coded by depth within Upper Miocene Formation Murex-1 well. Sands have lower density than the other lithologies.

3.2 Seismic Interpretation

Five horizons were mapped within the interval of interest namely the Top of Lower Matinloc Formation, Top of Intra Lower Matinloc Formation, Top of Pagasa equivalent, Top of Intra Pagasa equivalent and Top of Pre-Pagasa. Time structures and isopach maps were generated thereafter.

Pre Pagasa to Pagasa Isochron Map

A general thickening of sediments occur in the eastern part of the study area which correspond to the downthrown parts of the Fold and Thrust Belt (FTB). While the thin sediments correspond to the uplifted parts of the FTB. On the western side of the area are some artefacts due to sparse data on the region (Figure 7).

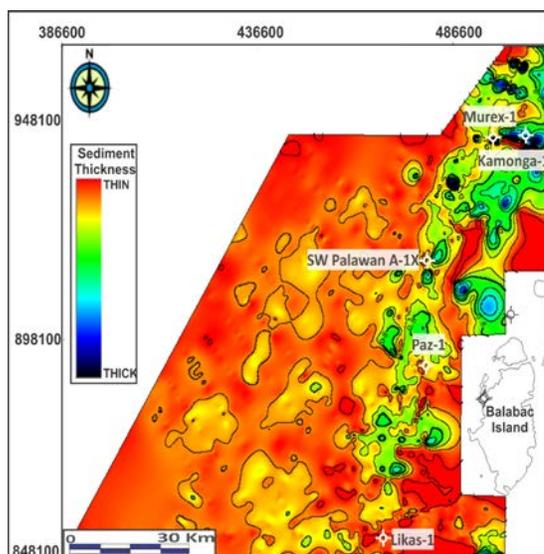


Figure 7. Pre Pagasa to Pagasa isochron map with sediment thickening on the east.

Pagasa to Lower Matinloc Isochron Map

The sediment thickening occurs in the northeastern part of the study area, as enclosed by the black polygon. (Figure 8). This corresponded to sediment progradation in seismic profiles.

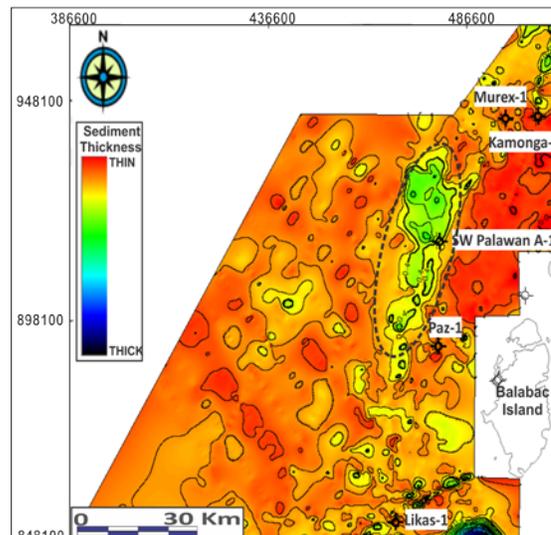


Figure 8. Pagasa to Lower Matinloc isochron map with sediment thickening on the northeast.

3.3 AVO Forward Modeling

The AVO fluid replacement modeling (FRM) allows to determine and quantify changes in reflection response by substituting fluids, such as gas and brine, while holding other rock parameters as constant. Fluid substitution was applied on seven sand intervals which were identified through the gamma ray, density, velocity logs and the drill stem test Report in the SW Palawan well (Table 1). Three scenarios were modeled on the sand zones: 100% gas, 100% brine (in situ) and 50% gas and 50% brine.

There have been several AVO responses exemplified by the top and bottom events of the sands identified (Figures 9 and 10). However results shows that all of the top and bottom sands have the same AVO response for each of the gas saturation scenarios (Figures 9 and 10).

Sand	Thickness in Meters	Formation	Modeling Results For Top Sands
A	6	Lower Matinloc Formation	Negative amplitude increases with increasing offset.
B	5		Negative amplitude becomes more positive with increasing offset
C	34		Negative amplitude increases with increasing offset
D	5		Positive amplitude becomes more positive with increasing offset
E	12	Pagasa equivalent	Positive amplitude near to zero becomes more positive with increasing offset
F	6		High positive amplitude shifted to negative amplitude
G	17		Negative amplitude increases with increasing offset

Table 1. Sand interval identified through well log analysis in SW Palawan A-IX well.

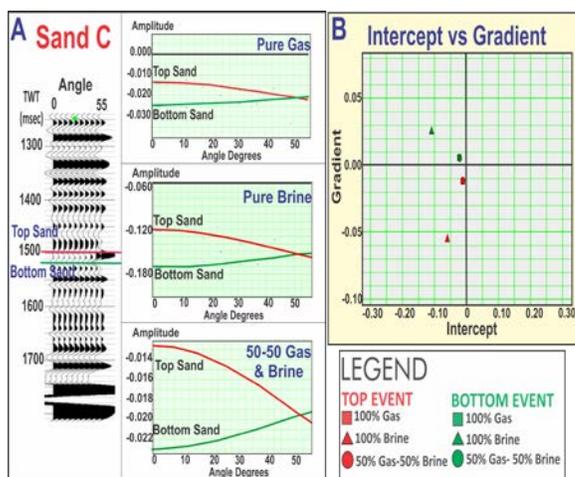


Figure 9. (A) Sand C shows same AVO response for pure gas and pure brine. (B) Sand C top and bottom sands are plotted on quadrants III and II, respectively.

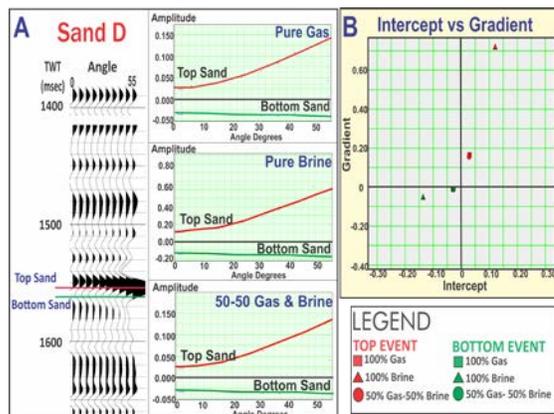


Figure 10. (A) Sand D shows same AVO response for pure gas and pure brine. (B) Sand D top and bottom sands are plotted on quadrants I and III, respectively.

3.4 GR Volume Prediction

The multi-attribute analysis was done in order to predict the GR values of the high amplitudes observed away from the wells. This will in turn help in the identification of lithology of the said high amplitudes. The generated GR volume has a training coefficient factor of 0.88. Twenty attributes were used which yielded the lowest training error (Figure 11A). Some of the extremely low GR values are not lying on the computed regression line (Figure 11B). But the original and modeled log show a relatively good fit (Figure 11C).

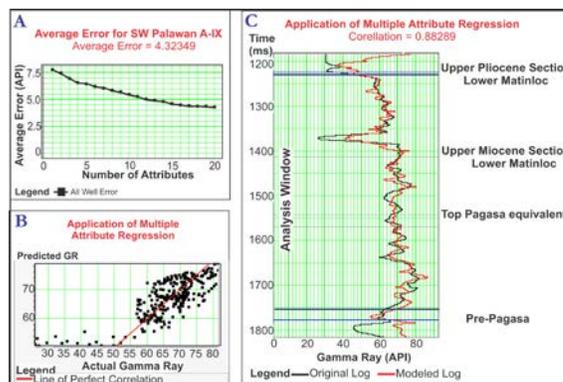


Figure 11. The plots showing the correlation factor for SW Palawan A-IX well.

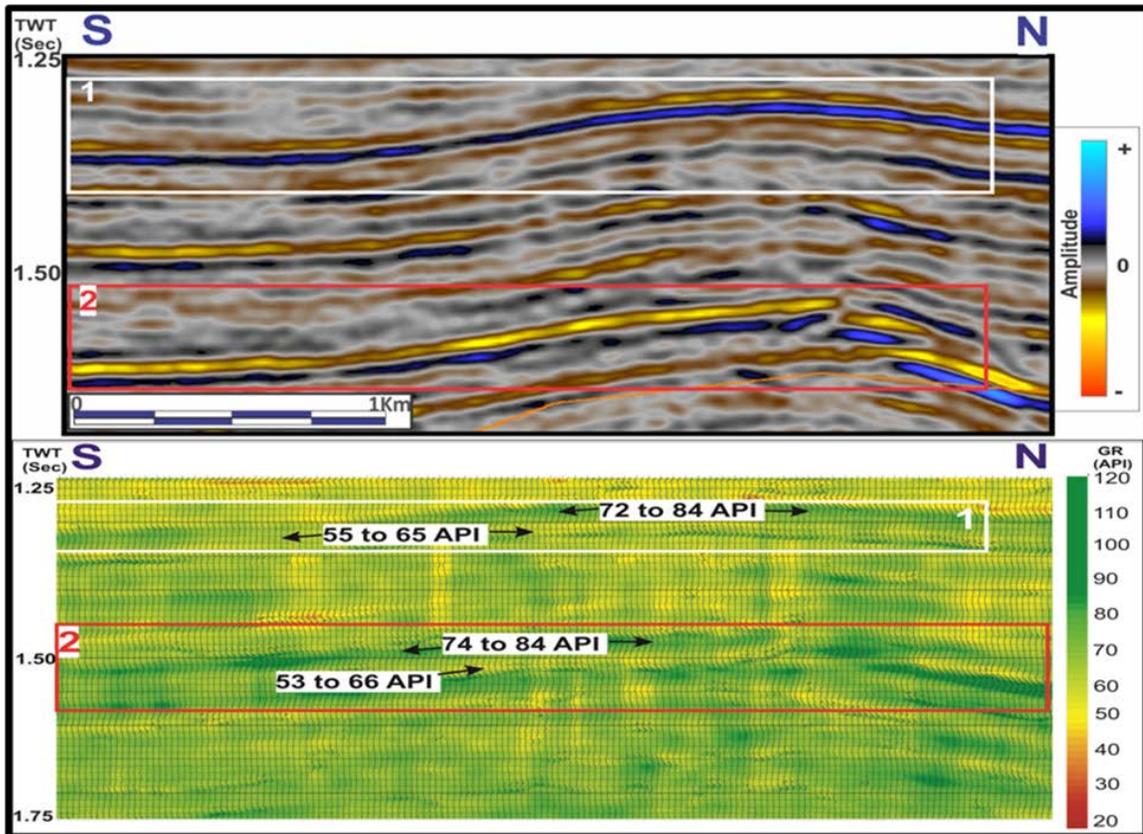


Figure 12. (A) Section showing the high amplitudes on the North of SW Palawan A-IX well with white and red boxes enclosing high amplitudes at different depths. (B) Shows the predicted GR values of the high amplitudes.

Several high amplitudes occur on the north and south of SW Palawan A-IX well. On the north of SW Palawan A-IX well, within the Intra Lower Matinloc formation and Top Pagasa equivalent, high amplitude intervals are present as enclosed in boxes 1 and 2 (Figure 12A). In the white box 1, the high amplitude interval is represented by a trough-peak reflection. The computed GR volume shows that these bright amplitudes are associated with relatively high GR values ranging from 72 to 84 API (Figure 12B).

4.0 Discussion

As shown in the results section, cross-plots of P-Impedance and GR reveal that

the relationship of P-Impedance and GR is variable laterally and vertically. The wells are several kilometers apart from each other. The SW Palawan A-IX well is 32 kilometers SE of Murex-1 and 63 kilometers NE of Likas-1. Within that span of distance lithological facies change can be expected. Based on the interpreted paleogeographic maps for the Pagasa to Lower Matinloc Formation, the Murex-1 well is located in the shelf whereas SW Palawan A-IX and Likas-1 wells are located in the slope. Therefore it is not easy to establish one relationship by using P-Impedance for whole area. In the same way, post stack P-Impedance inversion may not work for the whole area

effectively. However, establishing P-Impedance and GR relationship in small portions can differentiate sand and shale zones.

Density is also behaving differently for different formations at different wells. In Lower Matinloc Formation (Upper Miocene Section), density can discriminate sand and shale effectively. But in the other formations, density is not a good tool to predict lithology.

Due to great variations of rock physics parameters, it is required to establish local relationship before computing multi-attributes or applying inversion techniques.

The sands within the interval of interest exhibited several AVO responses on which no single relationship can be traced. This might be associated to the results in the cross plot analysis which stated that sand intervals are vertically and laterally heterogeneous and cannot be considered as clean sands.

Furthermore, the AVO fluid substitution results for the top and bottom gas sands were more or less the same even with varying gas-brine saturations. Hence, AVO fluid substitution modeling did not result to any distinct gas water trend association.

Since the sandstones are thin, the classification was made based mainly on the top sands' AVO response and not on both the top and base sandstones response as indicated. The conventional classification of Castagna for AVO response (1998) was not able to properly classify the top sands. Since this covered

only a subset of possible reflectivity combinations (Mc Gregor, 2007). A new scheme was proposed by Young et. al., (2003) which can cover all sands regardless of the sign of impedance contrast with the overlying shale or the direction of change in impedance contrast reflectivity with increasing offset (Mc Gregor, 2007).

The Young and Lo Picollo classification included ten AVO types, which conceptually classifies gas-bearing and non gas bearing sands as shown in (Figures 13 A and 13 B). AVO typing is controlled by lithology (Young, 2003). According to Young (2003), conforming AVO types are generally non-cemented or lightly-cemented, but still granular in nature while non-conforming sands are well cemented or if a carbonate is encountered.

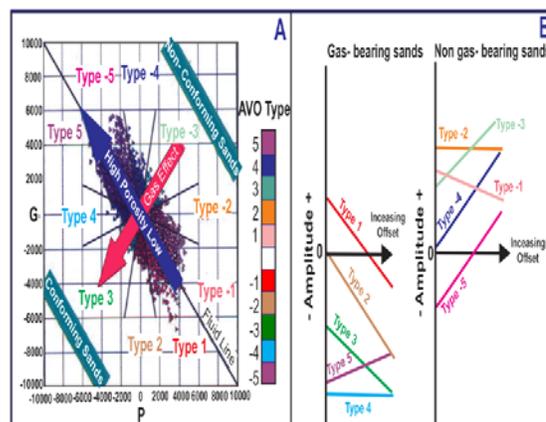


Figure 13 (A) Young and LoPicollo (2003) classification with ten AVO types. (B) AVO Types are classified as gas or non gas bearing.

By using the AVO classification of Young et. al., (2003), the sands were classified as Type 2 and Type - 4. Sands A, C, F and G are classified under Type 2 conforming sands. On the other hand sands B, E, and D fall under Type - 4 or

non-conforming sands (Figures 13A and 13B and Table 2). Further, Type 2 falls under gas-bearing sands while Type -4 can be classified as non-gas bearing sands. For the non-conforming sands, cleaner lithologies are expected to plot on the northeast. Since Sands B, E, and D are closer to the zero intercept, it can be inferred that these are composed of heterogenous sands.

TOP Sands	Young and Lo Picollo (2003)	Remarks from Lo Picollo (2003)
A, C, F & G	Type 2	Conforming Sands
B, E & D	Type -4	Non-conforming sands

Table 2. Classification of top sands in the study area according to Young et. al., (2003).

In summary, the AVO responses were not uniform probably because of the thickness of the sands. The top and bottom of sands with five meters thickness fall on the same peak or trough. Thin sands are limited by the seismic resolution or already below the tuning thickness, which makes it hard to be resolved in seismic profile. On the other hand, thick sands in the area which are greater than 20 meters are heterogeneous and composed of alternating layers of sands, silty sands and carbonaceous sands. The heterogeneity in lithology brings about different AVO response, especially if the sands are calcareous in nature.

Multi-attribute analysis is effective for prediction of GR in the study area. Different lithologies such as sand, silty sandstone and shales can be discriminated

from each other by using the multi-attribute analysis.

Analysis of computed GR values and bright amplitudes indicates that these bright amplitudes are related with shale or shaley sand intervals. Therefore these bright amplitudes are not associated with reservoir sands.

5.0 Conclusions

The main conclusions are summarized as follows:

In the northeastern part of the study area, sediment progradation occurs and brings in new sediments to the basin. It is worthwhile to examine this area for future exploration endeavors.

In a regional scale, the cross plot analysis reveals that P-Impedance and GR behaved differently within the formations in wells SW Palawan A-IX, Murex-1 and Likas-1. This implies that the relationship of P-Impedance and GR is laterally and vertically variable at macro-scale. Therefore, no generalized P-Impedance trend can be established for the study area.

However, P-Impedance was proven to be a good lithology indicator when this was plotted within smaller intervals. An example of this was the P-Impedance versus V_p/V_s ratio applied in smaller portions in each of the formations, which indicate separate trends of sand and shale.

Density was able to discriminate sand from shale in the Lower Matinloc Formation (Upper Miocene Section), with sands having lower density than shales. However, it was not successful in

predicting lithology of the other formations.

AVO modeling results for different percentages of gas saturations are same. Therefore, AVO may not be able to distinguish gas-saturated and water wet sands.

By using the new AVO classification of Young et. al., (2003), the top sands were classified as Type 2 conforming sands (A, C, F and G) and Type - 4 non-conforming sands (B, E, and D).

In summary, the AVO responses were not uniform probably because of the thickness of the sands. Thin sands, measuring less than 10 meters are hard to be resolved on seismic profile. On the other hand, thick sands in the area, which are greater than 20 meters, are heterogeneous and composed of alternating layers of sands, silty sands and carbonaceous sands. The heterogeneity in lithology brings about different AVO response, especially if the sands are calcareous in nature.

Multi-attribute analysis is an effective tool in predicting the GR of the high amplitudes away from the well. Analysis of computed GR values and bright amplitudes indicates that these bright amplitudes are related with shale or shaley sand intervals. Therefore, the high amplitude anomalies are not associated with reservoir sands.

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