

## **Analysis of Seismic Facies, Lithology and Reservoir Potential of the Early to Middle Miocene Pagasa Formation in the Southwest Palawan Basin, Philippines**

Jeffrey Guevarra Acosta

Petroleum Geoscience Program, Department of Geology, Faculty of Science,  
Chulalongkorn University, Bangkok 10330, Thailand

\*Corresponding author email: jef.acosta@gmail.com

### **Abstract**

The Pagasa Formation is widely recognized as the regional seal in the Palawan Basin, Philippines. Within this mudstone dominated sequence, beds of suspected reservoir-quality sands were encountered in drilled wells across the region. These sand facies have long been targeted as secondary drilling prospects next to the oil and gas producing Nido Limestone, and have demonstrated hydrocarbon shows in several wells. However, the prospectivity of potential reservoirs in the Pagasa Formation has never been extensively studied in detail... The main objective of this study is to evaluate the nature, occurrence and extent of several observed high amplitude intervals within this formation, and to examine the reservoir potential of these amplitude anomalies. Fluid substitution and AVO modeling revealed that brine filled sands and gas saturated sands cannot be distinguishable at the level of the high amplitude anomalies. Multi-attribute analysis and gamma ray prediction showed that none of the anomalies is characterized by clean sand intervals. These anomalies were classified into two general types: high impedance, and low impedance anomalies. High impedance anomalies are characterized by an increase in acoustic impedance related to underlying carbonate build-ups in the Nido Limestone and chaotic seismic reflection packages related to debris flow deposits of conglomerates and shales. On the other hand, low impedance anomalies are illustrated by a decrease in acoustic impedance associated with silty sands encased by higher impedance shales.

**Keywords:** AVO Modeling, Pagasa Formation, Acoustic Impedance,

### **1. Introduction**

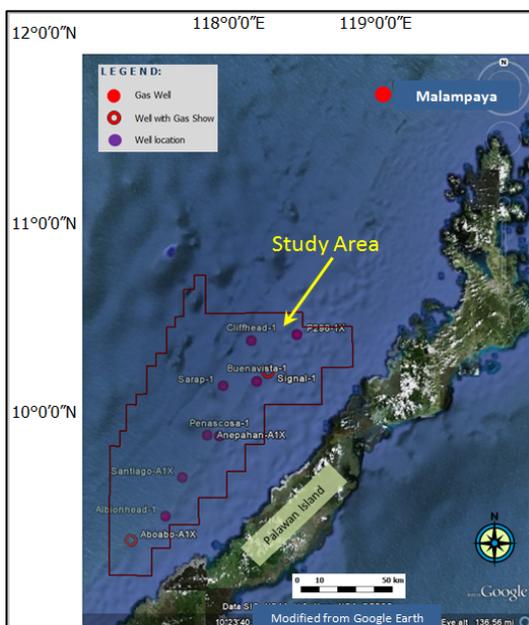
Throughout the exploration endeavors in the Palawan Basin, the oil and gas producing Nido Limestone has been the main reservoir objective. A consistent secondary drilling target that overlies the Nido Limestone is reported as reservoir quality sandstones belonging to the Pagasa Formation. A prominent feature observed in seismic sections shows several high amplitude reflections at different time

intervals within the Pagasa Formation. These high amplitude anomalies required more in-depth evaluation regarding their potential as possible hydrocarbon indicators.

Five out of the ten wells drilled in the block exhibited hydrocarbon potential within the Pagasa section, which consisted of 4 wells with hydrocarbon shows and one noncommercial gas discovery well, the Aboabo-A1X. The Aboabo A-1X well flowed

around 50 mmcf/gpd during the drill stem test (DST).

A study area was chosen covering the East Sabina Block in the Southwest Palawan Basin, Philippines. This acreage covers an area of around 10,560 square kilometers. It is situated about 130 kilometers southwest of producing oil and gas fields that includes the Malampaya gas field, the first deepwater gas discovery in the Philippines (Figure 1). Water depths in the block range from 40-1,700 meters.



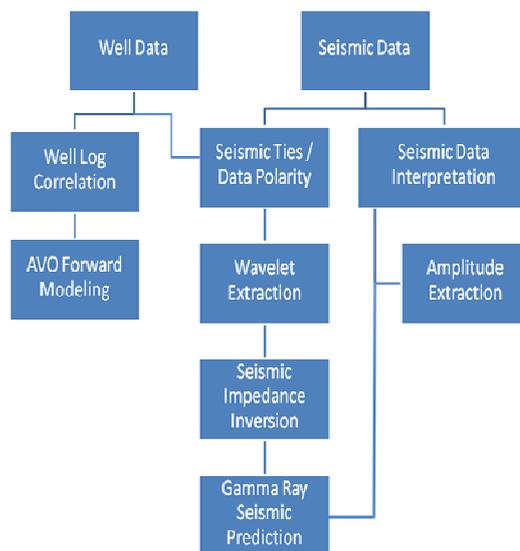
**Figure 1.** Map of western Philippines showing the outline of the study area (red polygon).

The main objective of the study is to examine the seismic facies and lithology characteristics of the observed high amplitude anomalous patterns associated with the Pagasa Formation and consequently check whether these anomalies are hydrocarbon indicators.

## 2. Methodology

To analyze the nature and characteristics of the high amplitude intervals, various geophysical tools were utilized to aid

basic log correlation and seismic interpretation techniques. These methods included AVO forward modeling, amplitude extraction, seismic impedance inversion and gamma ray prediction. A simplified workflow diagram for the study is presented in Figure 2.



**Figure 2.** Simplified workflow diagram for the study

## 3. Results

### 3.1 Seismic Data Interpretation

For the study, the Pagasa Formation was subdivided into six sub-formations based primarily on distinctive seismic reflection and wireline log character and correlated with logged cuttings and core samples.

### 3.2 Amplitude Extraction

In general, three Pagasa subdivisions, the Intra Pagasa Cgl, Intra Pagasa HA1 and Intra Pagasa BOS exhibited apparent clustered variations from the extracted amplitudes for both RMS and average amplitude functions.

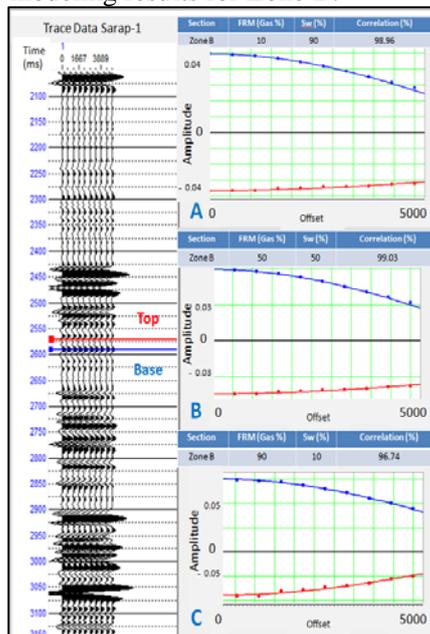
As a whole, the amplitude extraction methods revealed that the anomalies

coincides with carbonate build-ups and appear to have no fault closure associations

### 3.3. AVO Forward Modeling

The goal of AVO and fluid replacement modeling (FRM) modeling is to determine the AVO response of the high amplitude intervals by simulating variations in gas saturations in the target sections. The high amplitude intervals encountered in Sarap-1 well was tested for modeling due to its prominent occurrence and two other wells. For this well, four zones were selected for modeling based on the sonic log curve and high amplitude character.

The modeling process produced amplitude versus offset and gradient versus intercept crossplots. The modeling results demonstrated two types of response for the studied high amplitude interval. One type of response is shown in Figure 3 for the modeling results for Zone B.



**Figure 3.** Amplitude versus Offset Plots of Forward modeling results in the high amplitude Zone B showing same trends from the 90% Sw (A), 50% Sw (B) and 10% Sw (C).

The AVO plot of Zone B in Figure 3 exhibited a decrease in negative amplitude with increasing offset or 'dimming' effect with varying water saturation trends as shown by the top event (red curves).

In contrast, the other AVO response generated from the modeling showed a declining positive amplitude that remains positive with increasing offset consistent with varying saturation levels.

The AVO forward modeling results for the entire process demonstrated that the response of the top and base of the sand units are more or less the same for each of the gas saturation percentages for all the modeled zones. The results showed no distinguishable gas or water trend association with the high amplitude sections but displayed consistent AVO classification predictions for the studied intervals in all three wells used for modeling.

The two AVO response types can be classified as similar to Class IV and similar to Class I AVO response.

### 3.4. Gamma Ray Seismic Volume Prediction

The gamma ray prediction tool was utilized to delineate the GR response of the high amplitude intervals away from well paths.

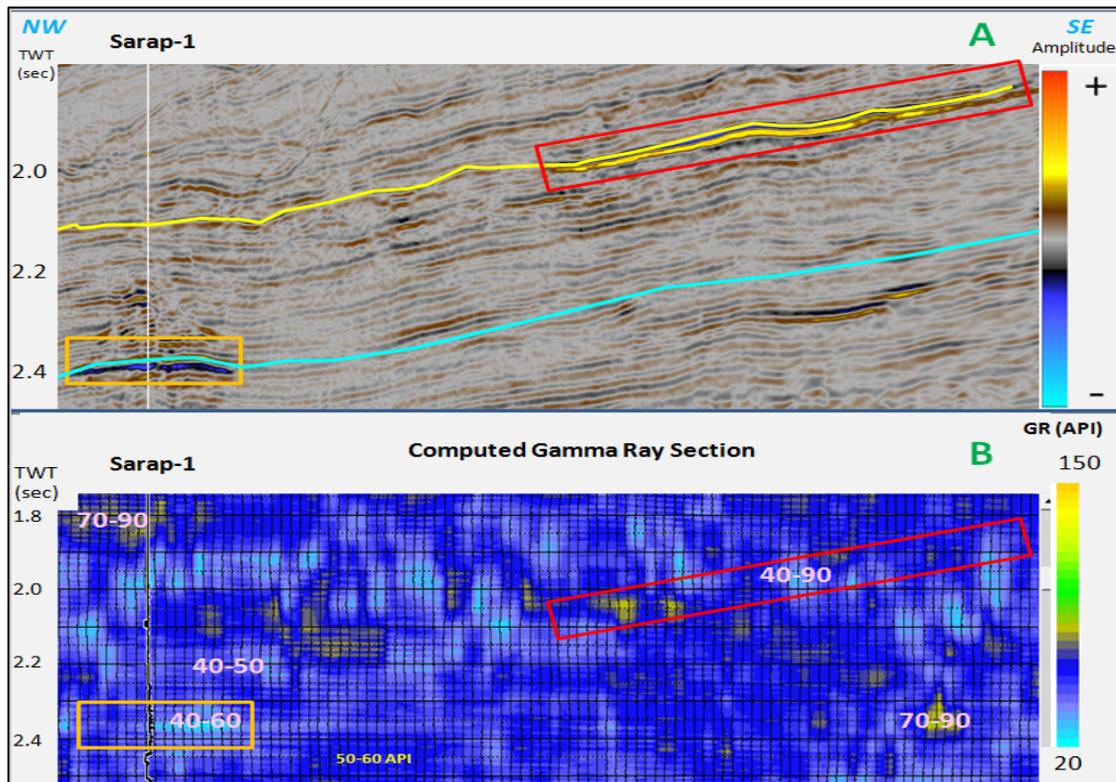
To optimize the log property prediction, a multi-attribute analysis was conducted to determine the effective number of attributes to use for log prediction. The result of multi-attribute analysis showing the calculated outcome is presented in Table 1.

**Table 1.** Summary of multi-attribute analysis for all wells

Well	Correlation Factor (%)	Average Error (API)	No. of Attributes
Sarap-1	74.39	3.4	12
Signal-1	76.54	6.1	10
Santiago-A1X	85.25	19.54	12

To ensure GR prediction results between the seismic and target log, the optimum number of attributes was applied to the seismic volume. The outcome of the log prediction process is a gamma ray section like that shown in Figure 4.

observed, those associated with a positive reflection coefficient and those tied with negative reflection coefficient.



**Figure 4.** Full stack seismic section showing anomalies outlined in red and orange boxes (A) and the result of gamma ray prediction section (B).

In Figure 4, the anomaly boxed in red represents the Intra Pagasa Cgl horizon characterized by an increase in acoustic impedance corresponding to trough-peak seismic reflectors with high GR predicted values. The anomaly boxed in orange represents the Intra Pagasa HA1 horizon characterized by an acoustic impedance decrease corresponding to peak-trough seismic reflectors with relatively high GR values.

In general, two types of acoustic impedance correspondence with the high amplitude anomalies and GR predictions were

Overall, based on the analysis of the selected intervals in the 3 wells modeled, the high amplitude intervals were observed to occur in more or less shaly intervals. This would lead us to infer that the high amplitude intervals are not related to good quality hydrocarbon reservoirs.

#### 4. Discussion

The Pagasa Formation was subdivided into 6 separate units based primarily on seismic amplitude. Mapped horizons were cut across by a general NE-SW trending normal fault system. The geometry

of the Pagasa sections suggests that its deposition was dominated by mudflow and debris flow sediments being shed off an uplifted area created by a series of thrusting events from the Fold-Thrust Belt.

Various tools used to examine the nature of high amplitude intervals observed within the Pagasa Formation provided some insight on the nature of these anomalies. Amplitude extraction methods revealed the clustering of the anomalous sections around Nido carbonate build-ups.

On the other hand, the AVO forward modeling exposed no distinguishable gas or water trend association with the high amplitude sections but displayed consistent AVO classification predictions for the studied intervals in all three wells used for modeling. Zones A, B and Intra Pagasa HA1 demonstrated a response similar to AVO Class IV while Zones C, D and Intra Pagasa Cgl illustrated a response similar to AVO Class I. The Class I-like response for Intra Pagasa Cgl, showed a dimming of positive reflections at far angle stacks was the similar outcome evidenced by the RMS amplitude extraction and angle stack analysis. On the other hand, the Class IV-like response for Intra Pagasa HA1 was coherently demonstrated by both AVO and intercept versus gradient crossplots, as well as the RMS amplitude extraction, but was not reflected on the extracted average amplitude and angle stack analysis.

By and large, the gamma ray prediction tool was effective in delineating the GR response of the high amplitude intervals away from well paths. The multi-attribute analysis exhibited good correlation between the original and predicted logs for the 3 modeled sections along the wells but displayed a relatively high error for Santiago-A1X. This high average error is construed only as a reflection of the higher absolute GR predicted values (>200 API) at the well, whereby its high correlation factor (85%) provide evidence for its reliability. In general, the high amplitude intervals were observed to

occur in more or less shaly intervals which could viably dismiss that these high amplitude anomalies are associated with possible hydrocarbon reservoirs.

High amplitude anomalies are either caused by significant density or velocity-related contrasts. Examination and analysis of integrated data revealed two general types of acoustic impedance correspondence with the high amplitude anomalies. The first type is characterized by a positive reflection coefficient, high GR values and is associated with highly compacted calcareous shales and conglomerates. The reported calcareous nature of these sediments, depth of burial along with overburden and associated pore pressure probably contributed to diagenetic processes resulting in calcareous cementation. Mudstones, conglomerates and sands of the Intra Pagasa Cgl and Intra Pagasa SS fall under this category.

On the other hand, the second type is characterized by a negative reflection coefficient, low GR values and categorized as low impedance sediments associated with relatively silty sands enclosed by high impedance shales. The high amplitude anomalies are probably created by the strong contrast between the high impedance shales and the low impedance silty sands. This is typified by Intra Pagasa HA1 and the Intra Pagasa HA2.

## 6. Conclusions

The study showed that AVO and fluid replacement modeling cannot distinguish hydrocarbons from water or lithology at the high amplitude intervals. Examination and analysis of integrated data from AVO modeling, amplitude extraction and gamma ray prediction revealed two types of acoustic impedance contrast associated with the high amplitude anomalies. The first type is associated with highly compacted calcareous shales, while the second type is associated with silty or shaly sands with poor reservoir qualities enclosed by high impedance shales, and debris flows. Therefore, the high

amplitude anomalies are not associated with hydrocarbon or good hydrocarbon reservoirs.

#### 7. Acknowledgements

The author would like to thank the MSc in Petroleum Geoscience Program of Chulalongkorn University for the scholarship and the opportunity to conduct this study. This research would not be possible without the support of Philippine National Oil Company Exploration Corp. and Nido Petroleum Ltd. who supplied all the data. Dr. Mirza Naseer Ahmad and Dr. Philip Rowell are also greatly appreciated for supervision of the project.

#### 8. References

- Bon, J., 2002. Pagasa Formation Sequence Stratigraphy. Vol. 1. P.T. Robertson Utama Indonesia, prepared for Shell Philippines Exploration B.V., Report No. 1601, May 2002.
- Castagna, J., Swan, H., Foster, D. and Peddy, C., 1998. Framework for AVO gradient and intercept interpretation, *Geophysics*, 63, p. 948-956.
- Russell, B., 1999. An AVO Primer. <http://www.searchanddiscovery.com/documents/geophysical/russel/2011>