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High-Resolution Mapping of Plio-Pleistocene Reservoir Depositional Facies in Zawtika Gas Field, Gulf of Moattama, Using Stratal-Slicing Techniques and Attribute Analysis

Luptawan Intasorn*

Petroleum Geoscience Program, Department of Geology,
Faculty of Science, Chulalongkorn University, Bangkok, 10330, Thailand
*Corresponding author e-mail: LuptawanI@gmail.com

Abstract

Zawtika gas field (M9 block) is currently producing mainly biogenic gas from structural closure of multi-stacked deltaic sandstone reservoirs in the Pliocene-Pleistocene sequences. Mapping the sandstone reservoirs based on seismic amplitude anomaly is one of the key success in this area. However, reservoir maps are only relied on simple interpretation of a couple of easily-interpreted horizons. Thin reservoir-related features between the interpreted horizons can be missed out. In order to capture all geological features within this interval, fifty-two stratal-slicing surfaces were generated and analyzed using PaleoScanTM software. Stratal-slicing is a technique that extracts iso-age surfaces within an interval from seismic volume for detection of reservoir features at a fine scale. The ultimate aim of this study is to understand 1) facies of depositional environment and 2) distribution of hydrocarbon presence and remaining prospects in study area.Three attribute volumes (RMS amplitude, sweetness, and variance) were applied to the stratal-slicing surfaces. The results show that most of the study area aligns in coastal environment, which consists of prograding features, canyon features and tributary channelized features. Delta slope and pro-delta is limited to the west and south of the area. The main reservoirs in study area can be confirmed as tidally influenced deltaic environment. From attributes study, vast amounts of strong amplitude anomaly and structural delineation can be observed clearer and more obvious in shallow part than deeper part. Most of high attributes values are related to gas sand, obviously in shallow part and related with structural trap, whereas, there are some gas bearing sands are not related to amplitude anomaly such in middle and deeper parts. From the study, the hiding seismic anomaly in sub-horizons that generated from horizons stack attributes can reveal potential and give confidence to define the drilling area in the future and can be taken forward to in-place volume with associated risking and ranking required for final prospect assessment. hence significantly contributing to investigate the upside potential in the study area for future assessment.

Keywords: Horizon stack attribute, Biogenic gas, Plio-Pleistocene reservoir, tidal influenced delta

1. Introduction
1.1 Introduction

Seismic amplitude anomalies that are direct hydrocarbon indicators (DHIs) play an important role in exploration success in Zawtika gas field, Gulf of Moattama, Offshore Myanmar (Figure 1). Mapping seismic attributes in the field is commonly focused on selective key horizons that separated each major seismic sequence. A lot of anomalies in between major horizons are hidden and difficult to track by traditional seismic attributes mapping method which can cause a high uncertainty during mapping processes for regional scale interpretation.

This study is broken-down into sub-horizons study and focused on regional scale to capture wider detail of anomaly investigation by from 3D seismic data by building a Relative Geological Time model and creating horizons stack attributes. The study is focused on 3D seismic cube named “Merge 2016” and used PaleoScanTM as the main software and Petrel® 2019 in parallel.

1.2 Objectives

The aim of this study is to use the horizon stack attributes as a tool to find and understand 1) facies of depositional environment 2) distribution of hydrocarbon presence with remaining prospects for multi-reservoirs interval in the study area; particularly multi-stacking within major 7 horizons that are H05, H10, H20, H30, H40, H50 and H60 horizons.

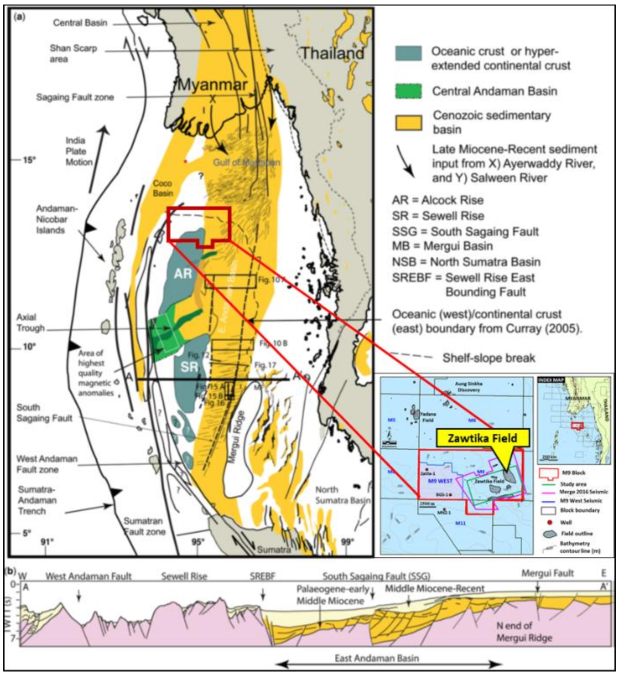

Figure 1. (a) Regional geology of the Andaman sea and location of Block M9 (red rectangle) and Zawtika gas field. The extent of the 3D seismic survey used in this study is shown by the green box. It overlies the ~E-W trending shelf edge in the Gulf of Moattama. (b) Cross section showing Middle Miocene-Recent sediments along the shelf. (after Morley, 2017).

2. Geological Setting

2.1 Regional Tectonic of Moattama Basin

Moattama Basin is located in the back-arc area east of the oblique subduction of the north- moving Indian Plate beneath the western continental margin of Sibumasu (Figure 1; after Morley, 2017). A volcanic island arc developed east of the Present-day Andaman Archipelago and continued onshore along the Central Basin. The oblique subduction created dextral transtension affecting the region. Four phases of tectonic evolution have been affected to the structural style in block M9 as described below (Morley, 2017).

1)Late Oligocene, Back-arc? E-W extension created N-S trough from East Andaman Basin to eastern Moattama region.

2)Early Miocene, NNW-SSE extension generated ENE-WSW normal faults spreading across Andaman region. Existing N-S trending features reactivated as strike-slip faults.

3)Mid Miocene, Onset of sea-floor spreading. Extension at releasing splay of Sagaing Fault. Transpression in onshore basins

4)In late Miocene, Final phase of sea-floor spreading. Northward migration of releasing splay. Main folding in Bago Yoma (BY)

The region was then overlain by thick prograding deltaic sediment with growth faulting in the Pliocene-Pleistocene. Block M9 is located at the end of Sagaing fault splay. Structural style in block M9 is influenced by extension tectonic which is evidenced by NE-SW trending normal fault. The releasing splay of Sagaing fault during Middle Miocene to Pliocene that formed Structural trap of Block M9 in this period. In the vicinity area of Kakonna fault, growth faults are prominent as affected from heavy sediment loading.

2.2 Depositional Environment

This study is focused on Formations 4 & 5. Formations 4 & 5; Ayeyarwady Formation (Pliocene - Recent), consists of a thick sequence of Fluvio - Deltaic sediments (sandstones, siltstones and claystones), which deposited by the Paleo Ayeyarwady River and Deltaic system. This formation is the main sediment and contributor in block M9.

2.4 Moattama Basin Petroleum System

This study is focused on biogenic petroleum system, biogenic petroleum system is the main system for all discoveries and remaining potential prospects in production area.

Massive deltaic sediment influx of the Irrawaddy Delta, this contributes significantly to the biogenic gas generation as organic matter is delivered and established the sequence of a source-reservoir unit. The sedimentation rates within the model address the massive overburden load, which result in a good sealing quality to hold the generated biogenic gas in place. The biogenic gas window in Main Zawtika study area is about 750 - 1,850 m, approximately H05 to H60 horizons.

The generation of biogenic gas in Zawtika area, traps, and seals must be in place as early as possible to maximize the capture of biogenic gas due to the fact that this gas will diffuse upward toward the surface.

Plio-Pleistocene, Deltaic & Shallow Marine Sands are main reservoir in Zawtika field. Successions consist of very fine to medium grained sandstones, with angular grains and some thin planar interbeds of clay and shaly sandstones. They are poorly sorted, unconsolidated and contain abundant of mica. Log porosity of similar successions in M9 illustrates good porosity and permeability ranges with unconsolidated to poor compaction of young sediments.

Structural trap associated with fault i.e., 3-way dip closure is common in Zawtika area. Sealing capacity depends on intra-formational marine shale as possible top & lateral seal potential. Structural trap is the key trapping style of this study.

3. Methodology

3.1 Data Available

Seismic Data

This study using 3D seismic is called "Merge 2016" (Figure 2). trimmed the Merge 2016 seismic data to cover an area of 3,047 km2, from 0.5 second and extends down to 3.5 second TWT and realized (32 bit to 16 bit) in order to optimize seismic processing during interpretation. The study is focused on main potential area in Zawtika field, Offshore Myanmar which is located in water depths ranging average from 100 to 160 m.

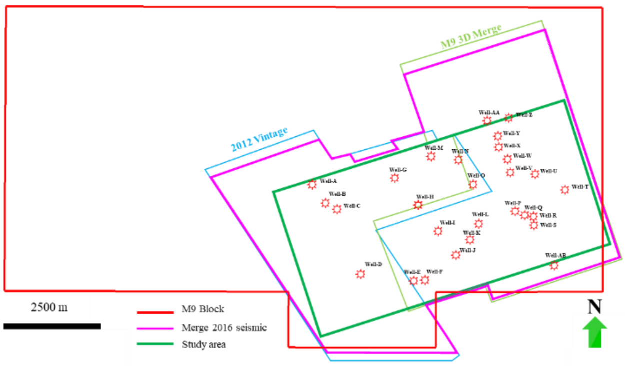

Figure 2. The well location, seismic vintages and area of study.

Structural maps

The structural Time maps, total seven major horizons have been re-affirmed and validated (H05, H10, H20, H30, H40, H50 and H60). All of them have been used to control Model-Grid as major constraint horizons and computed Geo-Model then generate horizons stack and filtered by three attributes. Seabed is correlated as a strong peak and mostly consistent and has good correlation throughout seismic survey.

Well Data

Total 28 exploration and appraisal wells were used in this study (well log, time & depth conversion and well study) to integrate and calibrate the results of the study.

3.2 Software

Petrel® 2019 software

3D seismic volume and wells data preparation, transferring data were processed by this software.

PaleoScan™ 2019 software

This is main software used for many processes in this study which are volume attribute, Model Grid, Geo-Model, Horizons Stack creation, attributes generation and analysis.

3.3 Seismic Attributes for Interpretation

Trace ACG volume attribute was calculated and tested by using PaleoScan™ software to improve seismic quality. The variance attribute is used for fault and structural trap observation to identify prospect locations. RMS amplitude and Sweetness are applied for facies distribution and identify gas accumulation area.

3.4 Methodology

Methodology used in this study is summarized in Figure 5, consisting of Model-Grid, Geo-Model and Horizons Stack filtered by attributes.

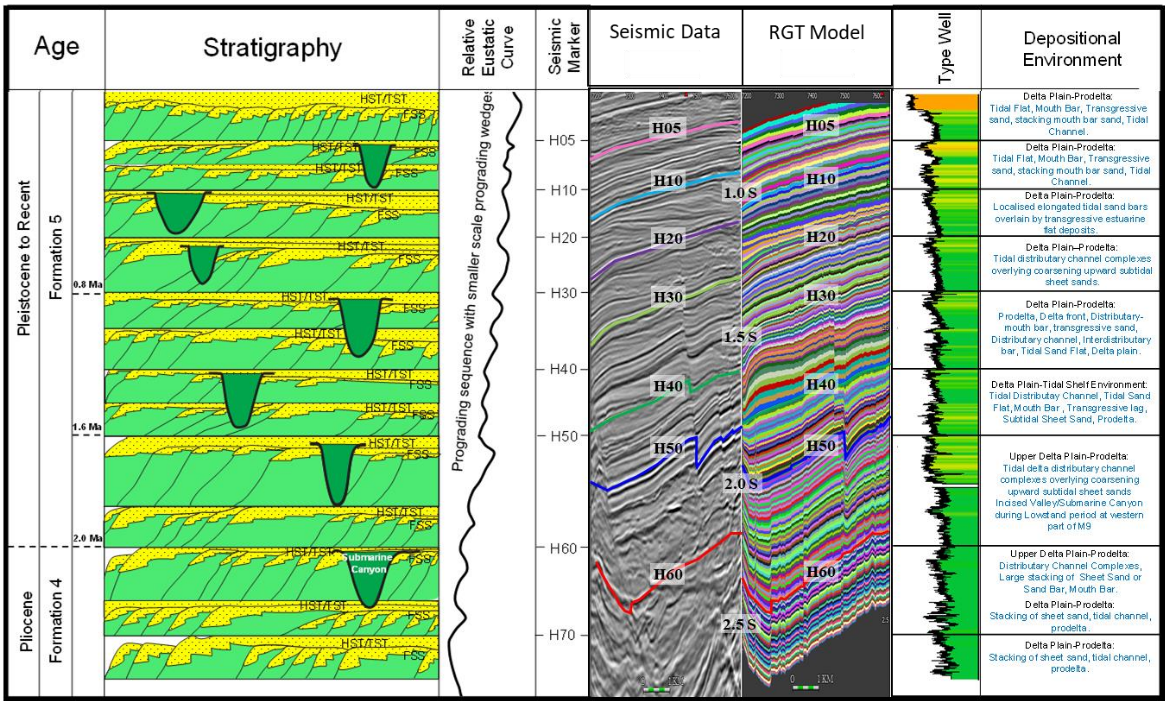

Figure 3. Plio-Pleistocene (Formations 4 & 5) stratigraphy and Marked Only 3D Geo-Model computation results with RGT model description (Modified after PTTEP, 2015).

3.4.1 Model-Grid

Building a Relative Geological Time model (RGT) directly from the seismic is an innovation in the interpretation workflow. This method is composed of two main steps. The first step consists in computing a geological Model-Grid using a cost function minimization algorithm, which merges seismic points according to the similarity of the wavelets and their relative distance. This process automatically tracks every horizon within the seismic volume to constrain a grid, where a relative geological time is computed for every point. The task of the seismic interpreter will consist in refining the model by modifying relationships between auto-tracked horizons. The second step will be the generation of the Relative Geological Time Model from the Model-Grid, where a relative geological age is assigned to each pixel of this volume.

3.4.2 Geo-Model

The Geo-Model corresponds to the vertical interpolation of the interpreted Model-Grid. It also takes every links between patches into account.

It is a Relative Geological Time Model (RGT Model) which can be managed as any other Attribute Volumes. A relative geological age is assigned to each pixel of this volume. In this study was considered to use Marked Only Geo-Model. The Marked Only 3D Geo-Model computation only accounts for the marked horizons of the Model-Grid to constrain the creation of the Geo-Model. Where no interpretation is marked, the geometrical and thickness structure of the model is built from the interpolation of the thickness relationships where the horizons are marked (Figure 3). This method has the advantage of allowing the interpreter a better control of the Geo-Model geometry in that he can select the most reliable reflectors (corresponding to reliable series of connected patches) to constrain the model. Hence, poor connections (e.g. in a noisy or low amplitude seismic intervals) are not impacting the geometry of the Geo-Model.

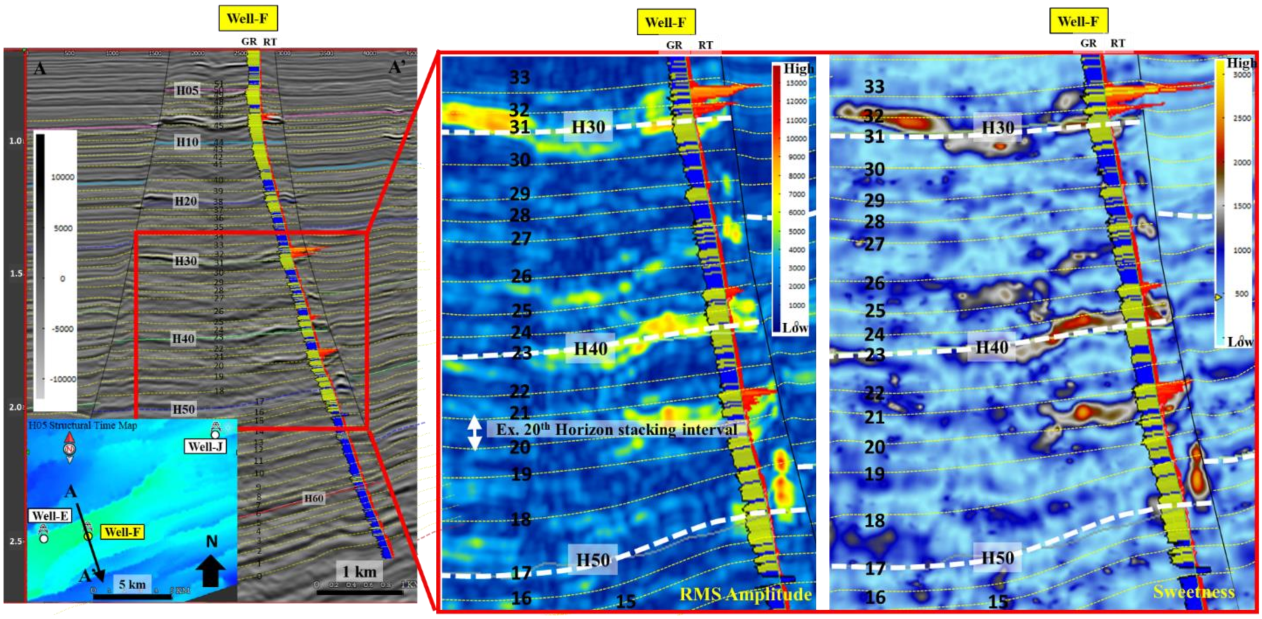

Figure 4. Seismic along well-F, showing horizons stack creation and well logging calibration (GR yellow implies sand, GR blue implies shale and spiked RT implies gas zone).

3.4.3 Horizon Stack Creation

Once computed, an unlimited number of horizons can be derived from the 3D seismic volume. This set of horizons is called Horizon Stack and corresponds to relative ages of the model extracted and converted into horizons. The horizon stack enables an interactive stratal-slicing through the seismic volume where sedimentary as well as structural features can be highlighted with an unprecedented level of accuracy. The seismic cross section along drilled wells and logging interpretation were used to calibrate horizons stack and separate into minor horizon, total fifty-two-layers horizons with three attributes filtered (variance, RMS amplitude and sweetness) were created to identify structural orientation, facies of deposition environment and gas accumulation area. The horizons stack creation and wells calibration in study area are illustrated in Figures 4. Each layer is named ranging from 0 (bottom) to 51 (top). An example of attribute appearance in horizons stack No. 20 is generated and accounted value in between 20 to 21 as described in Figure 4

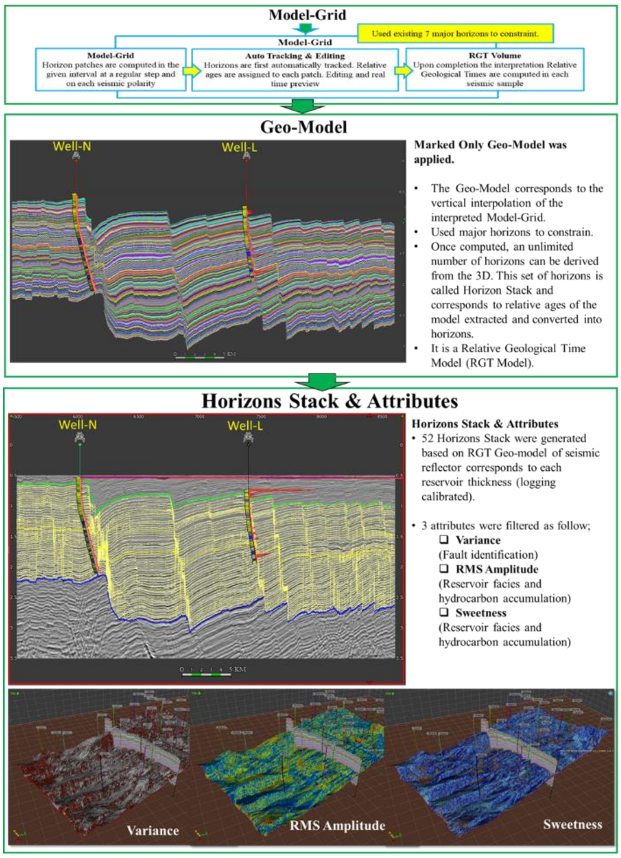

Figure 5. Summary methodology, Model-Grid, Geo-Model and horizons stack generation with seismic attributes filtered.

4. Results

This chapter presents some of the key horizon stack layers that provide key evidences for depositional environment based on their seismic characters in map view and 3D perspective view with cross section. Three attribute filters applied on these horizons include variance, RMS and sweetness. Observations of each attribute and its reservoir relationship are described below. The horizons stack attribute can be separated clearly results into 3 interval, shallow, middle and deeper parts based on horizons number ranging. The shallow part is ranging from H05-H20 (horizon stack No. 51-32), the middle part is ranging from H30-H40 (horizons stack No. 31-18) and the deeper part is ranging from H50-H60 (horizons stack No. 17-0). A smaller horizon stack number means deeper horizon. The results can be identified as below.

4.1 Variance Attribute

The variance attribute result shows that numerous of faults and potential structural trap can be observed mostly at upthrown of each fault block covering the entire area. Some canyon features, channelized features and offlap/toplap lineament also can be observed clearly in this attribute (Figure 6). In shallow part, faults appearance and geological features can be observed clearer and sharper than deeper part due to seismic quality, fault shadows and gas cloud effect. The potential accumulating area is determined based on promising trapping model that related to faults appearance only as mentioned in Chapter 2. This kind of potential prospect identification is commonly applied in the area where reservoir sand is unlikely to be detected by RMS amplitude and sweetness attributes anomaly correspond with potential fault trap area.

4.2 RMS Amplitude and Sweetness Attributes

In shallow part (H05-H20), vast amounts of high attributes value that indicated gas from RMS amplitude and sweetness are observed, all related to structural trap locations, as depicted by variance attributes and confirmed by drilled wells. The geological features are revealed clearly in this part. The example results of horizons stack filtered by RMS amplitude and sweetness of shallow part with drilled wells correlation interval is illustrated in Figure 7.

In middle part (H30-H40), only some high values from RMS amplitude and sweetness are associated with gas sand as drilled wells calibration. In this interval, poorly seismic quality, fault shadows and gas cloud effect can be observed entire the area. Many of geological features are also observed in this interval and make difficulty to separate anomalies between lithology and fluid. Therefore, lower attributes value doesn’t always mean wet sand or non-reservoir rocks Figure 8.

In deeper part, rarely gas-related high attributes value that indicated gas from RMS amplitude and sweetness can be observed, only few wells are drilled through this interval. Disperse of strong seismic reflector from seismic quality and geological features are general observed in deeper section that cause difficulty to separate strong amplitude anomaly of lithology from gas accumulation area. The accumulation area needs to be confirmed using structural trap identification Figure 9.

Generated horizons stack corresponds to relative ages of the model extracted and converted into horizons can reduce uncertainty of manual seismic interpretation and create multi-horizons faster than normal. The seismic cross section along drilled wells and logging interpretation were used to calibrated and identified stacking units for more accuracy. Horizons stacking with attributes filtered reveal the generally high attributes value corresponds with gas sands that were confirmed by drilled wells, obviously in shallow part. Whereas, in middle and deeper parts, low attributes values are not always indicating wet sand or non-reservoir rocks, some gas bearing sands are not relate to amplitude anomaly. The results of horizons stack attributes will be discussed in Chapter 5 as the aim of this study is to understand 1) facies of depositional environment and 2) distribution of hydrocarbon presence and remaining prospects in study area

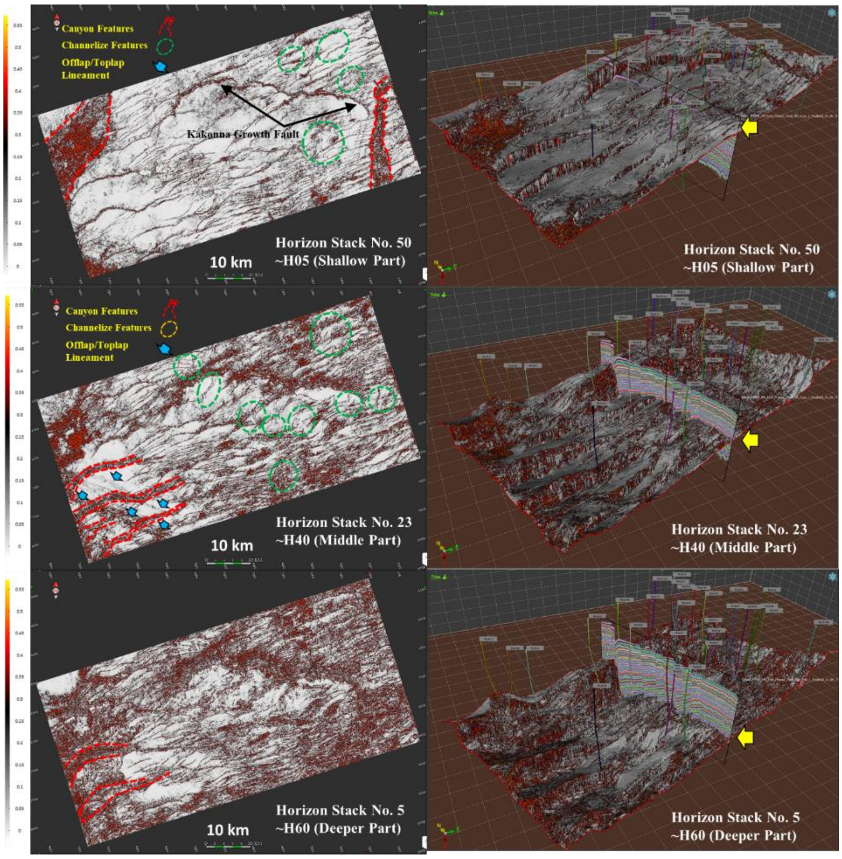

Figure 6. (left) Variance maps of horizons stack No. 50, 23 and 5 which are shallow part, middle part and deeper parts respectively faults appearance, canyon, channelize and offlap/toplap lineament features which can be clearly observed in shallow and middle parts due to faults shadow and gas cloud effects. (right) 3D horizons stack No. 5, 23 and 5 which are showing faults orientation from shallow to deeper part, most structural gas traps are located at upthrown of each faults step as proven by drilled wells. Generally, fault displacement increases from shallow to deeper part that makes the steepness of horizon increasing from shallow to deep.

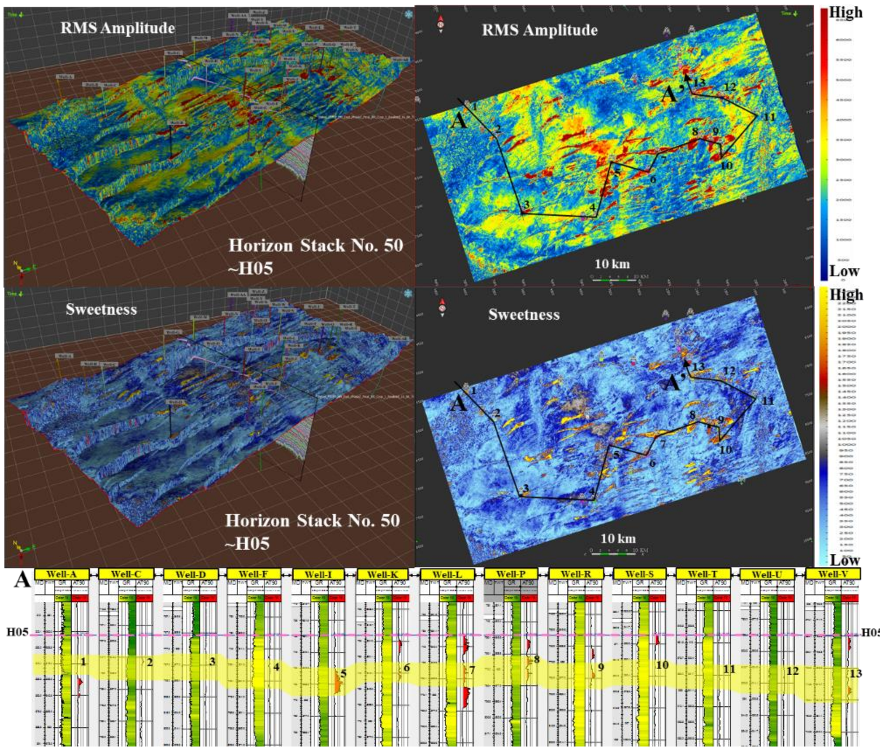

Figure 7. The example results of (above) RMS amplitude and (below) sweetness maps of shallow part with (A-A') drilled wells correlation and calibration interval, showing high value of both attributes are associated with appearance of gas as shown obviously in 5, 6, 7, 8, 9 and 13 locations.

Most of high value of both attributes are related to structural trap as shown in 3D perspective (Left).

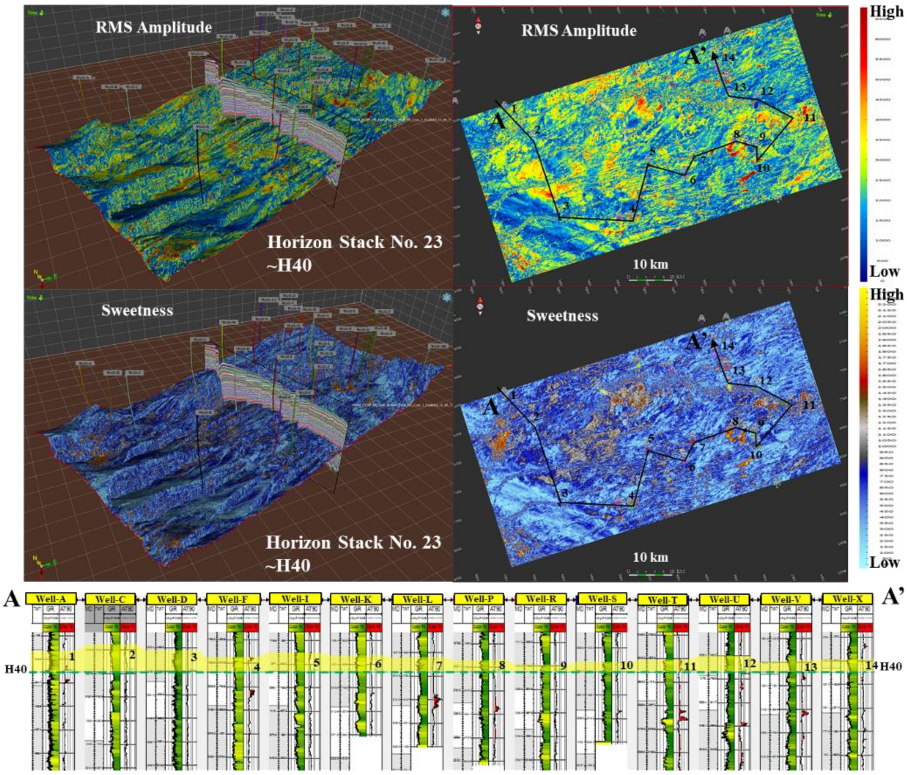

Figure 8. The example results of horizons stack filtered by (above) RMS amplitude and (below) sweetness of middle part with (A-A') drilled wells correlation and calibration interval, showing high value of both attributes are correlated with appearance of gas but difficult to separate between lithology and fluid. Some high attributes values are related to gas sand such 1, 4 and 8 locations, some high value is not related such 11 location.

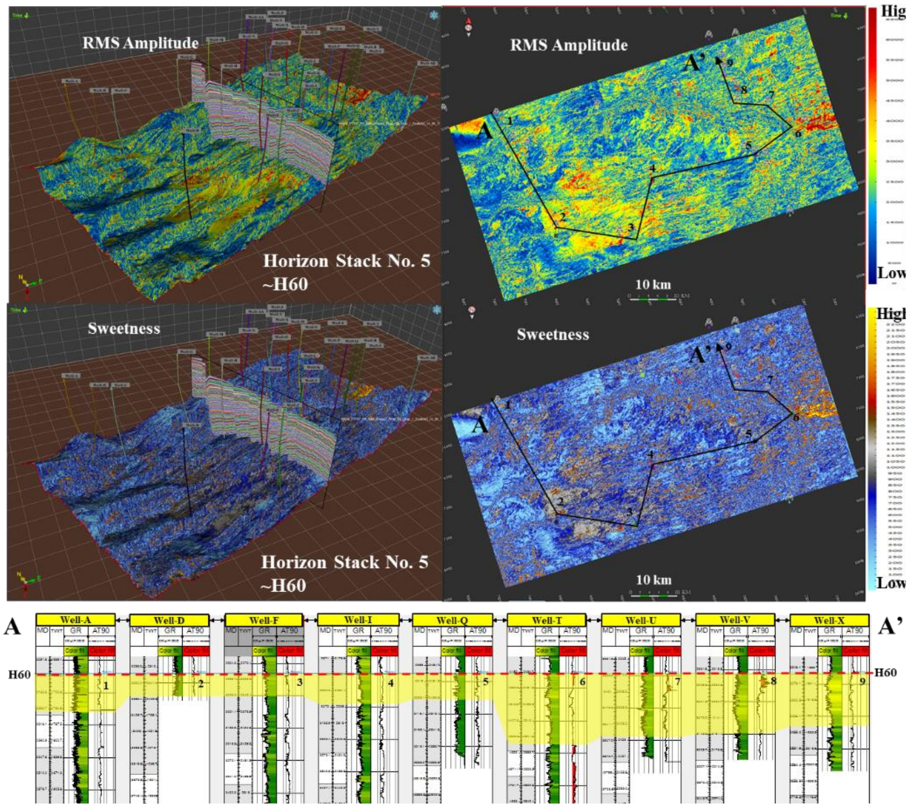

Figure 9. The example results of horizons stack filtered by (above) RMS amplitude and (below) sweetness of deeper part with (A-A') drilled wells correlation and calibration interval, showing rarely gas-related anomaly from both attributes can be observed in this part.

There are many drilled wells found gas, even without high attributes value as shown in 7 and 8 locations.

5. Discussions

This chapter presents the discussion of horizons stack attribute from relative ages of the model extracted. Generated horizons stack corresponds to relative ages and converted into horizons that represents directly to depositional environment time of each stratal-slicing which is an improvement method from manual interpretation, such as normal horizon interpolation or general lithostratigraphy interpretation.

5.1 Depositional Environment Discussion from Horizons Stack Attributes

After the horizons stack attribute facies to well log signature analysis, generic stratigraphic framework model was generated. Depositional model identification involves the previous work and studies which is well documented. Reservoir geometry, orientation area, and environment of deposition identified by integrating of seismic anomaly and well log characters. Gamma-ray log character, coarsening upward (prograding delta sand), sharp bedding and fining upward (isolated channel) or blocky shape, is integrated to determine reservoir body, channel width, thickness and orientation in each particular reservoir unit.

Seismic attribute (Figure 10) illustrate the paleo shore break (offlap/toplap) as long lineament trending NW-SE locating at the southern portion of the study area. To the northeast of the area lie the tributary channelized features which correspond to the lower delta plain. Channelized and canyon features are approximately 50-1,500 m in width, interpreted to be tidal channels. Main Zawtika study area lies on the lower delta plain where progradational stacking pattern of tidally influence deltaic system are active. The overall slope break in study area shifted southward through time indicating the sediment supply exceed the accommodation. Submarine canyons are found to be common in Zawtika area (Figure 11). Incision features created by the eustatic level drop which related to the presence of lowstand system track are modeled to not presence in Zawtika area. The analogy and evidence are present day submarine canyon, so depositional environment in main Zawtika area is dominated by deltaic to shoreface environment during Plio-Pleistocene period

5.2 Gas Accumulation from Horizons Stack Attributes

In this study, variance was used to enhance seismic discontinuities that represented faults orientation to confirm structural orientation and structural closure locations. To identify the structural closure, the results showed that variance attribute produced the most reasonable lineament of structural fault trend features. It also matched with the existing fault trend and regional NE-SW trending horizontal stress direction (Figure 12), previously derived from existing interpretation and study.

In Zawtika area, structural trap common and only currently proved. The variance attribute was analyzed with RMS amplitude and sweetness filtered to locate gas accumulation area. The structural trap trend that related to gas accumulation area in study can be divided in to three trapping areas 1) Downthrown of Kakonna growth fault 2) Upthrown along Kakonna growth fault and 3) Upthrown of away from Kakonna growth fault as illustrated in Figure 5.3. The Kakonna growth faults are NNW-SSE deep-seated fault trend and oriented almost perpendicular to general lineament of structural fault trend of NNE-SSW in main Zawtika area. Along the Kakonna fault trend, trace of thermogenic gas system also found in deep reservoirs section (deeper than H60) that expected hydrocarbon came from deep thermogenic system and migrated along deep-seated fault conduit. However, from the variance attribute, poorly seismic quality, fault shadows and gas cloud effect can be observed entire the area. Many of geological features are also observed in this interval and make difficulty to identify structural trap or closure area in deeper part Figure 12(A).

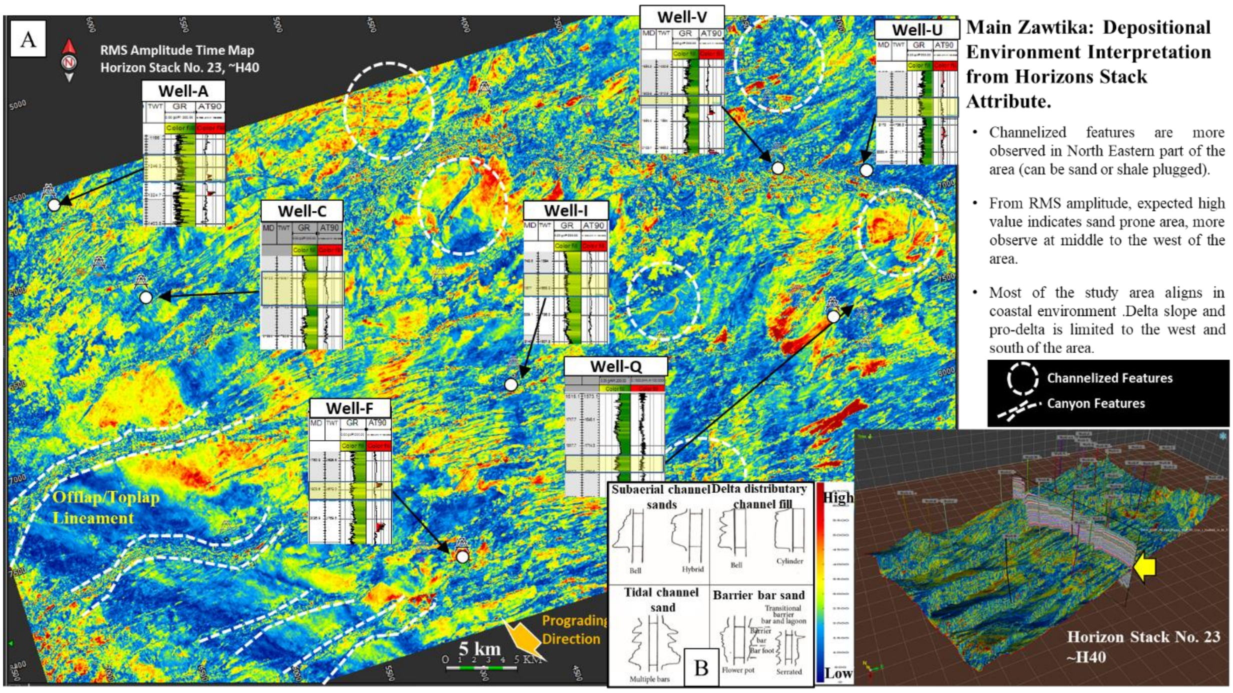

Figure 10. A) Main Zawtika: depositional environment interpretation from horizons stack of RMS amplitude attribute and wells calibration, small channelize feature are likely to be filled with high value of attribute while bigger channelized and canyon features are associated with mixed value of attribute B) Gamma-ray log character (P.A.Alao, 2013 after Busch,1975).

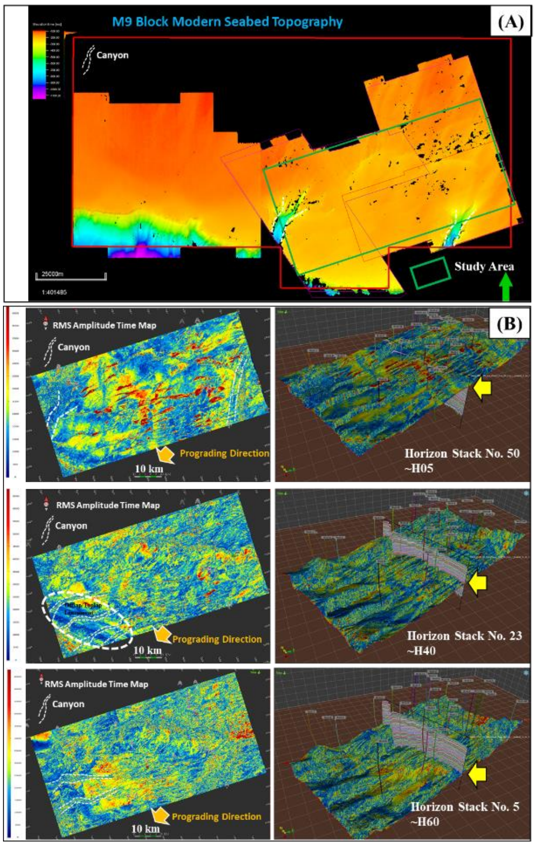

Figure 11. Depositional environment features observation in the study area (A) from modern seabed topography and (B) horizons stack

6. Conclusions

This study is focused on regional scale and used horizons stack attributes generated from Geo-Model as a tool to understand 1) facies of depositional Environment and 2) distribution of hydrocarbon presence and remaining prospects.

Fifty-two horizons stack layers were generated through the seismic volume and integrated with three attributes filtered to analysis (variance, RMS amplitude and sweetness).

The horizons stack attributes can be separated clearly results into three intervals; shallow, middle and deeper parts.

In shallow part (H05-H20), vast amounts of high attribute value that indicated gas sand from RMS amplitude and sweetness can be observed, all related to structural trap. Therefore, seismic anomaly analysis is very useful in shallow part,it also helps to find potential gas and avoid the shallow gas hazard as well.

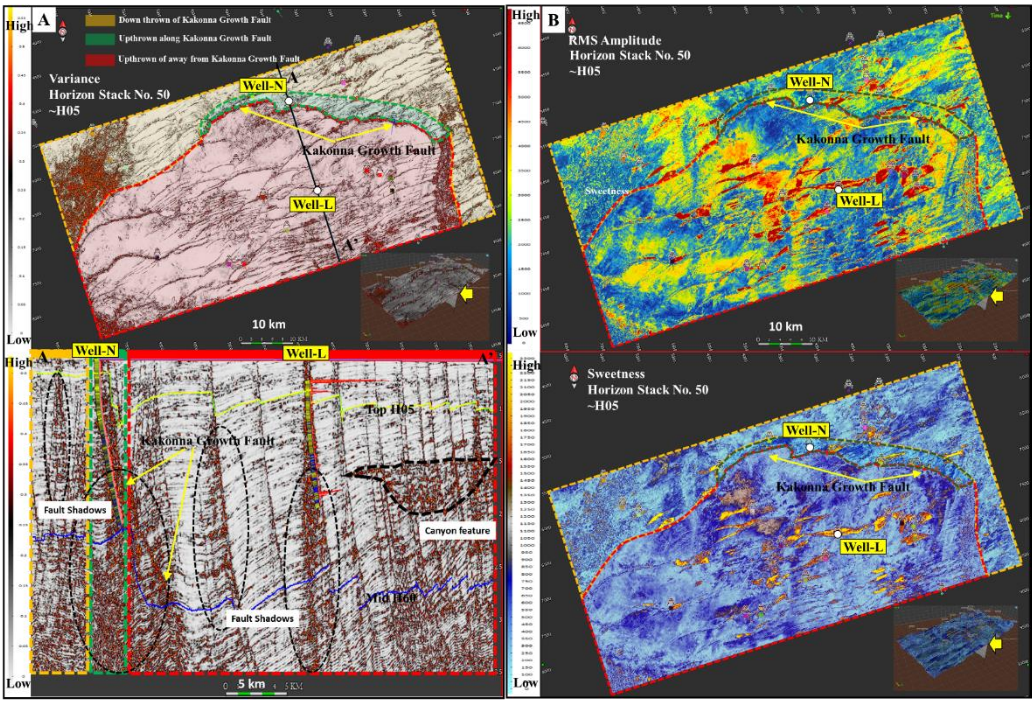

Figure 12. A) The structural trap trend in study area from variance attribute and location of Kakonna growth fault. B) Accumulation Area from RMS amplitude and Sweetness at downthrown of Kakonna growth fault, along upthrown of Kakonna growth fault trend and away from Kakonna growth fault trend, high value on both seismic attributes that correlated with the appearance of gas especially in shallow part.

In middle part (H30-H40), only some high values from RMS amplitude and sweetness are associated with gas sand as drilled wells calibration. In this interval, poorly seismic quality, fault shadows and gas cloud effect can be observed entire the area. Many of geological features are also observed in this interval and make difficulty to separate anomalies effected of lithology and fluid.

In deeper part (H50-H60), rarely gas-related anomaly from RMS amplitude and sweetness can be observed and only few wells are drilled through this interval and difficult to separate high anomaly value of general lithology from gas accumulation area. Moreover, some gas bearing sands are not relate to high attribute value.

From evidence of the study shows that most of the study area aligns in coastal environment, (offlap/toplap) as long lineament trending and canyon features and tributary channelized features were observed in horizons stacks attributes. Delta slope and pro-delta is limited to the west and south of the area which can be confirmed by previous study, present day submarine canyon and modern seabed topography. The main reservoirs in study area can be confirmed as tidally influenced deltaic environment.

Accumulation area is identified by using high anomaly value from horizons stack attributes of RMS amplitude and sweetness based on structural trap (variance attribute observed), which is generally related to faults, contour pattern and prospective prograding of sedimentary direction. The variance attribute results show that numerous of faults and potential structural trap can be observed, from observation gas was trapped mostly at upthrown of each fault block covering the entire area. In shallow part, faults appearance and geological features can be observed clearer and sharper than deeper part due to seismic quality, fault shadows and gas cloud effect.

The structural trap trend that related to gas accumulation area in study area can be divided in to three trapping areas; 1) Downthrown of Kakonna growth fault 2) Upthrown along Kakonna growth fault and 3) Upthrown of away from Kakonna growth fault.

From horizons stack attributes study, many anomalies are hidden in between major horizons can be seen in most shallow part. The hiding seismic anomaly in sub-horizons that generated from horizons stack attributes can reveal potential and give confidence to define the drilling area in the future and can be taken forward to in-place volume with associated risking and ranking required for final prospect assessment. hence significantly contributing to investigate the upside potential in the study area.

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