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Detection and Delineation of Shallow Channel Morphology Using 3D Seismic Data in the K Field, Malay Basin, Malaysia.

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Abstract. The Malay Basin early 2D seismic exploration programs were designed to test simple structural traps. Large relief folds are easily located and subsequently drilled. Many major oil and gas fields were discovered since the 1970s in middle-late Miocene siliciclastic reservoirs, and eventually produced successfully. However, these easy hydrocarbon accumulations in the Malay Basin are fast depleting due to its long production history. Hence, new petroleum plays are urgently needed to sustain the production. The utilization of high-resolution 3D seismic data in the early 2000's has greatly increased the chance of drilling success, including high-risk prospects such as stratigraphic plays. This paper discusses the subtle channel morphology in the shallow section of the K Field. The 3D seismic data shows multiple-stacked channel geometry within the Pliocene (5.5-5.2 Ma) strata. The seismo-stratigraphic interpretation is aided by attributes analysis including horizon probe to detect and delineate the internal geometries. The results are correlated with modern analogues to predict the probable depositional elements within these fluvio-marine systems. These shallow channel features were previously avoided as hazardous drillings. Instead, until they are tested, these could be considered as good porosity clastic reservoirs filled by medium to heavy density oil.

Keywords: Malay Basin, Pliocene, stratigraphic play, 3D seismic data

1. Introduction

Stratigraphic traps in the Malay Basin are often considered as one of the riskiest exploration targets to be tested. The critical factors to be an excellent stratigraphic exploration play are the presence of a fully charged petroleum system with good seal integrity. Three-dimensional (3D) visualization techniques provide an alternative, interactive means of viewing amplitude and attribute volumes that facilitate the extraction of meaningful information and improves the interpretation accuracy and efficiency [1]. In early years, seismic interpretation was solely based on 2D interpretation workflows. This includes faults and horizons picking on the dip (inline) and strike lines (crossline), to generate time-structure maps through gridding and contouring. It is a common practice that most exploration prospects drilled within the easy structural traps such as folds, fault-blocks, well defined reefs and seismic anomalies with clear direct hydrocarbon indications (DHI's). Since 1984, the advent of 3D seismic technology has allowed better subsurface resolution for solving various problems of geological interpretation [2]. To this day, without support from DHIS's, any subtle stratigraphic traps will be almost impossible to receive approval to drill.

Seismic data 3D visualization helps in displaying the stratigraphic hydrocarbon traps in their true three-dimensional perspective, allowing interpreters to visualize the complex geomorphology of stratigraphic plays and better reservoir characterization. There are many astonishing multi-stacked



channel features presence within the target area, observed within 1 km from the seabed, which could not otherwise be easily enhanced with 2D seismic data. The application of seismic attribute technique helps to reveal characteristics that is masked by using amplitude data themselves. It allows better geological interpretation of formation, particularly in channels and thin bed reservoir environments. Seismic attributes are defined as “any or all observations” extracted from the 3D seismic data which are directly or indirectly helps in hydrocarbon exploration [3]. Seismic attributes can be clustered into two main categories, which are structural attributes and stratigraphic attributes, which emphasize different properties of the seismic signal [4, 5]. Selection on the types of attributes used are very crucial depending on what analysis we want to develop for our study. It is one of the main steps in recognizing stratigraphic events and to overcome pitfalls in the interpretation.

2. Study area

The study area is located at the K field, in north-central Malay Basin (Figure 1). The field was discovered in 1970, at an average water depth of 65 m. It is a faulted, domal anticline structure with a closure >300 km² [6]. Previous explorations were designed to assess the oil-filled potential within this structure at intervals of Groups D and E reservoirs but with no success. Multi-stacked gas-bearing reservoirs were found in Groups B, D and E. As the major reservoirs were the main interest for this exploration, limited reservoirs data were gathered from the Group B reservoirs during exploration period. Other than mud logs and conventional well logs, subsurface data were rather limited. Pressure data and conventional core are absent in this area. Thus, it was expected that mapping and assessment of the reservoir would be very challenging particularly with respect to establishing good understanding of reservoir quality and producibility. This anticline structure is believed to be formed during the extensional and compressional phases of structural development of the Malay Basin during the Oligocene, within an overall dextral shear regime. It is thought to form as deep syncline within half-graben which was inverted during the middle-late Miocene, caused by changing to sinistral shear regime [6]. The structure was started as an elongated E-W ridge which due to changing stress direction, become more circular.

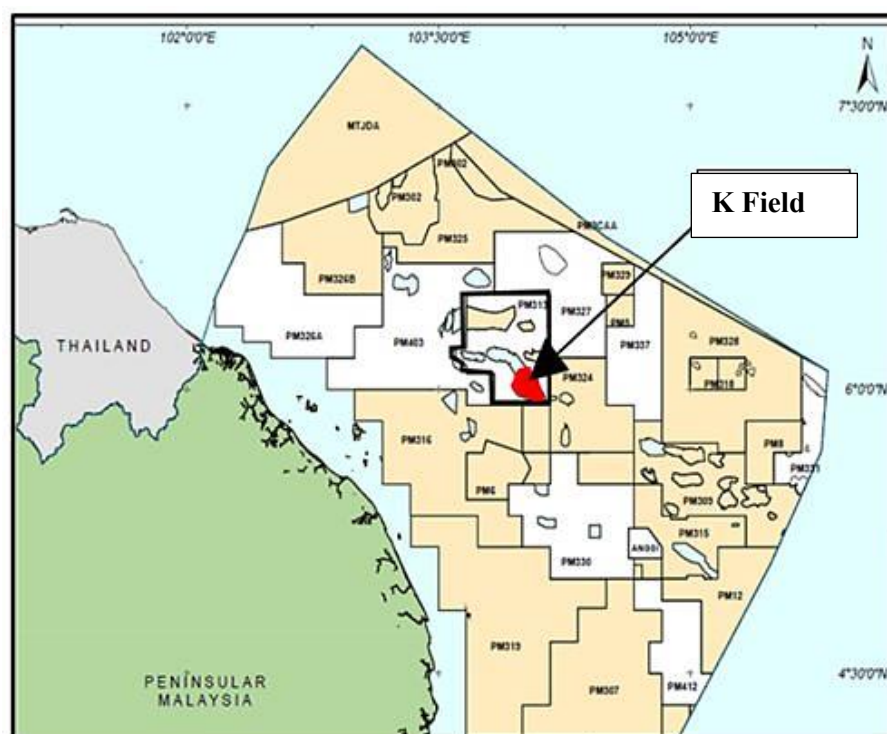


Figure 1. Location map of the K Field (Modified from [8])

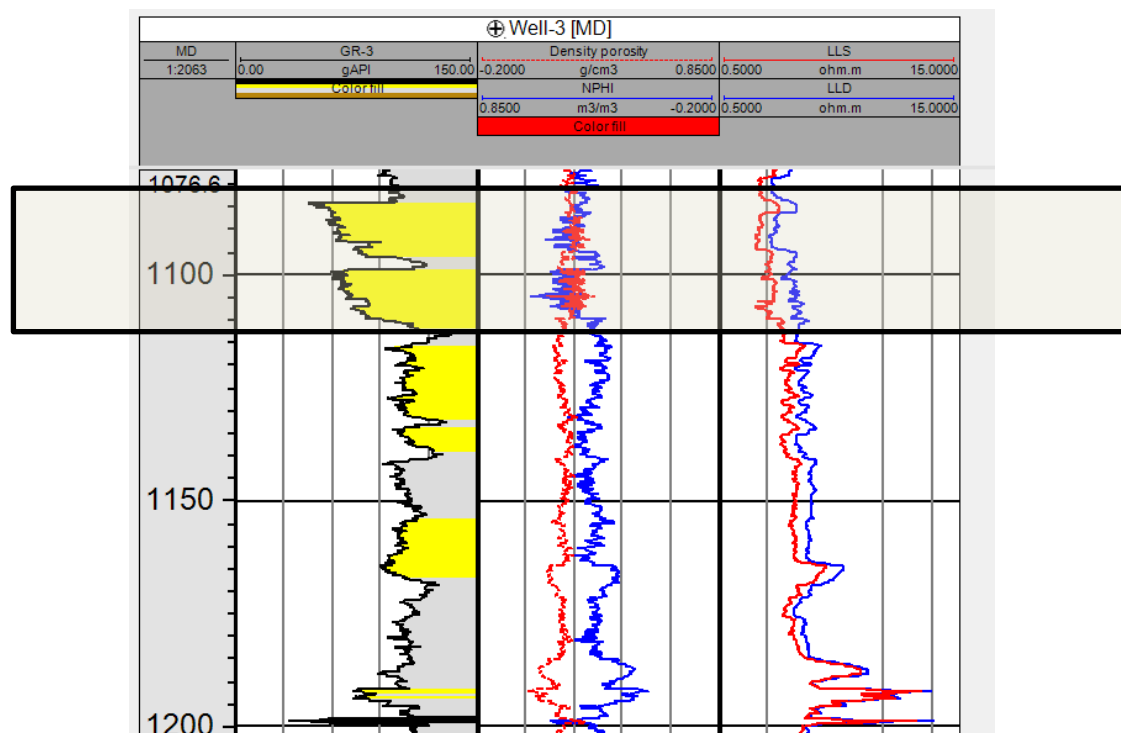


Figure 2. Wireline logs displayed at Well-3.

2.1 Group B reservoir description

The Group B reservoirs were deposited in the Early Pliocene (about 5.5 ma) with an average thickness of 1090 m. This phase was dominated by thermally-induced subsidence which continued in the late post-rift section [7, 8]. Deposition during this phase was mainly within lower coastal plain and shallow marine environment (fluvial deltaic tidal dominated sedimentation) [9]. Group B can be sub-divided into Upper and Lower Group B formation. The Upper section predominantly consists of laterally restricted stacked channels deposited in lower coastal plain environment. Lower Group B, in the other hand, were better developed with thicker in net sand and better reservoir quality than Upper Group B. The reservoirs are interpreted to be incised-valley deposits made up of discrete channels [9]. Early exploration penetrated this formation Group B uneventfully. They penetrate the shallow gas anomaly within Group B reservoirs, it turned out to be 1- 20 m thick of interbedded silty sandstones and shale with low pressure gas. Only mud logs and gas chromatographs were recorded across the shallow intervals, without any testing made in the shallow zones being of no commercial value back then in the 70s and 80s.

3. Dataset and methodology

This study is based on a 2004 vintage 3D seismic data, ca. 335 km² in the north-central Malay Basin. The digital data will be loaded onto the 2D/3D seismic interpretation platform, namely Petrel software. Total of four wells used to conduct this study (well-2, well-3, well-4 and well-5). The seismic imaging can be considered as poor to fair as a result of shallow gas imaging effects. The data in the central part of the K field is much affected by gas pockets and poor fault imaging. This brings in challenges during the horizon interpretation. However, most of the reflectors outside the gas cloud area are well-imaged. Previous exploration well reports in this field were collected and analyzed to get better understanding of the subsurface formations and reservoir properties. Wildcat wells' LAS format files were then collected, inclusive of all available wireline logs data. This includes: (i) electrical logs (lateralog deep resistivity, lateralog shallow resistivity and microSFL resistivity log), (ii) lithology logs (gamma ray, spectral gamma ray and corrected gamma ray) and (iii) porosity logs (density, neutron porosity, sonic logs). Well deviation trajectories and lithology information from mud logs are obtained as well.

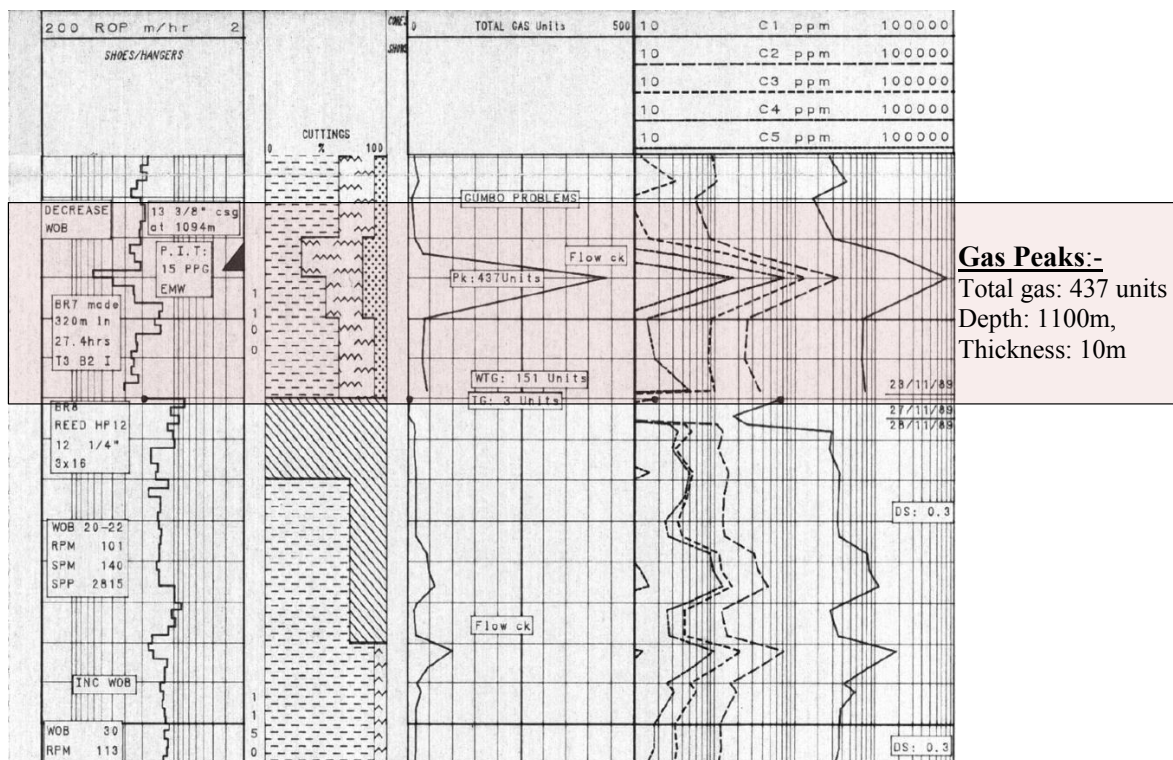


Figure 3. Mud log reports indicate gas peaks at the target reservoir interval. (Modified from [6]).

3.1. Facies classification and correlation of exploration wells

The incorporation of multi-well logs and lithological mud logs report helps in the facies classifications and reservoir prediction. Logs such as gamma ray, porosity, density and sonic are used to analyse the lithology of the formations. According to the exploration well reports, Group B are made up of mainly shale and siltstone with thinly sandstone layers. Therefore, the facies classification is filtered accordingly. These facies log then were created for each well to distinguish its reservoir lithology. Well to well correlation is then carried out for all the wells to analyse the lateral continuity of the lithological occurrence, away from the well control.

3.2. Seismic volumes attributes and direct hydrocarbon indicator (DHI)

Volume attributes computation allows us to generate new seismic volumes to enhance the interpretation and visualization purposes [10]. Out of the many volume attributes available, only few are proven effective for this study. Variance attribute, or better known as edge detection attribute highlights geologic features that have abrupt boundaries. It uses the local variance as a measure of signal unconformity, associate with the dip corrected slices used to emphasis on the structural features [11]. Although this attribute can easily detect the fault and channel edges, they cannot indicate the thickness of the channel's particularly a very thin bed channel. This workflow is further enhanced by using amplitude attributes such as RMS amplitude and sweetness attribute to analyse its reservoir quality and DHI study. It made use of envelope and instantaneous frequency to highlight bright spots. The basis of this attributes study is based on the quick look interpretations on the 3D seismic attributes response. Interestingly, most of the bright response presence in this study area is still untested. Based on the quick rock physics study on the lithological sequence from previous findings associated with seismic anomaly, we can justify the similar anomaly for our predicted seismic response, away from the well control.

3.3. Fault and horizon interpretation

This study area consists of numerous north-south trending faults. Due to the surface channel gas pockets in the central part of the structure, it is difficult to map and delineate the fault. However, most of the major faults located outside the ‘wipe-out’ zone are well-imaged. Fault interpretation is first analysed and mapped before horizon interpretation is carried out. The application of structural attribute (variance) helps to detect the discontinuities or phase changes that occur across the fault zones. This is followed by the stratigraphic interpretation of seismic horizons. Bright reflectance and widespread lateral continuity are the basis for the horizon interpretation. Seeded 3D auto tracking is chosen for conducting the horizon interpretation. This method is not applicable inside the gas cloud within the central structure, due to the poor signal and chaotic response, therefore guided auto tracking is selected to interpret the sections. A total of two horizons were mapped throughout the 3D seismic sections to resolve the thickness as well as lateral extent of any geobody.

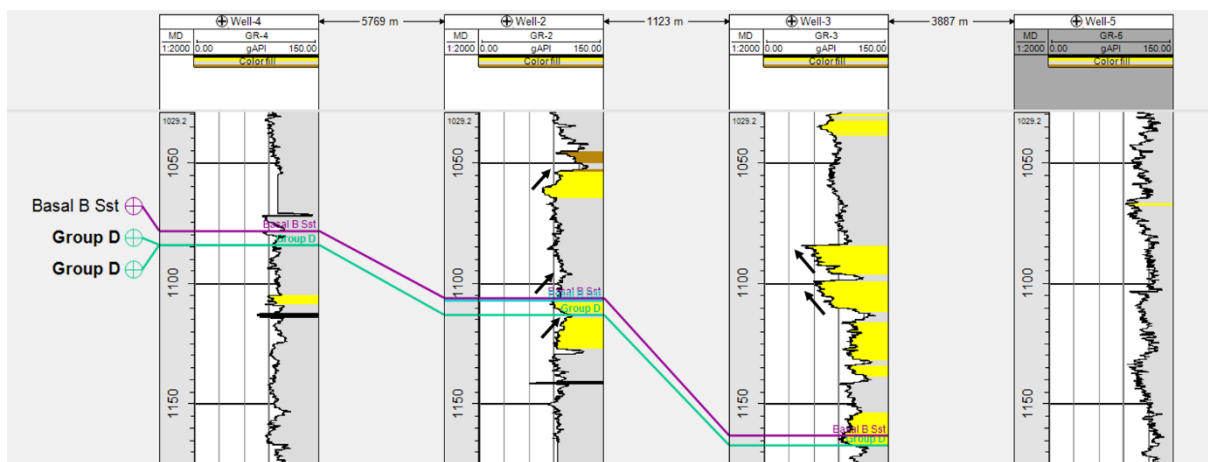


Figure 4. Facies classification and correlation of exploration wells

4. Results and discussion

Figure 2 showing the wireline logs displayed at Well-3. The first track displaying the gamma ray log, showing lower number of counts of radioactive minerals on sand facies, indicating of sandstone lithology. Second track displaying the common industrial convention, neutron-density log in defined scale and polarity. This combination of log response indicates a quick-look interpretation of hydrocarbon bearing zone. The presence of hydrocarbon filled, porous sandstone reservoirs are determined using the crossover between porosity and density log. This is also referring to the terms of ‘Butterfly effect’. Gas bearing zone will resulting in bigger separation of crossover, while oil just give a small separation between logs. Following the abnormally low resistivity values (around 2 to 6 ohm-m), despite the indications of neutron-density cross over with the presence of gas peaks from mud log response in Figure 3 at interval 1100 m. The significant increase in total gas units are associated with a zone of increased in porosity and permeability. The gas chromatograph in mudlogging sensor is used for more detailed hydrocarbon analysis. It helps to separate the gas streams into different types of alkane group, namely methane [CH_4] – denoted as C_1 – as well as the following constituents: ethane [C_2H_6] or C_2 , propane [C_3H_8] or C_3 , the normal and isopolymers of butane [C_4H_{10}] or nC_4 and iC_4 and pentane [C_5H_{12}] or nC_5 and iC_5 . The results obtained are displayed in Figure 3. At the interval of 1100 m, it shows that the gas chromatograph detects the alkane group from methane till pentane.

In Figure 4 the gamma ray log displayed at each well to determine the facies, linked with the geological mud log data. It is showing that in Well-2 and Well-3, the sands are better developed compared to Well-4 and Well-5. The bell-shaped log motif within Well-2 indicate the fining upwards succession marked with the presence of channel sands. Funnel-shaped log motif at Well-3 indicates presence of coarsening upward barrier bars. Plus, the “butterfly effect” along with the gas peaks at mud log data also validated the existence of HC-bearing channel sands in Lower Group B.

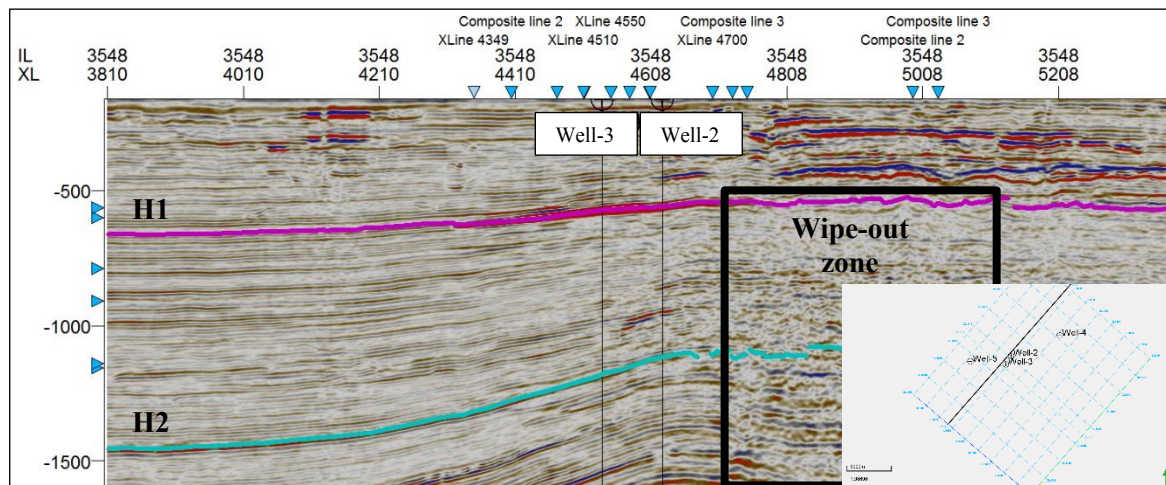


Figure 5. Seismic inline showing the target zone between horizon 1 and 2.

In Figure 5, an inline section is selected for display as it is showing the correlation between two wells (well-2 and well-3). Two horizons were interpreted and mapped throughout the study area to evaluate the thickness as well as lateral extent. These mapped horizons will act as a structural control when conducting horizon slicing from the generated geobody. It will help to reveal any potential but subtle stratigraphic traps that is usually not easily visualized using normal time slice method. Due to very few information's gathered in Group B during the previous drilling campaign, it causes difficulties to make a correlation according to well tops. Basis of horizon 1 interpretation is the bright reflectance and widespread lateral continuity. Horizon 2 is interpreted based on the Pliocene–Miocene unconformity that presence across the wells. This unconformity was correlated and mapped across the study area, marks the boundary between Groups B and D.

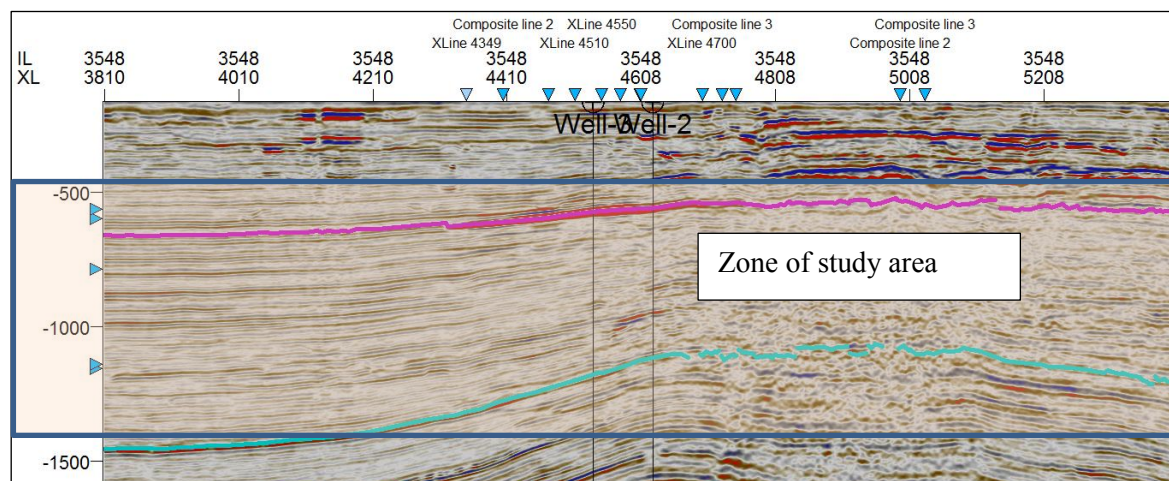


Figure 6. Inline section at interval 3548, marked with the zone of study area.

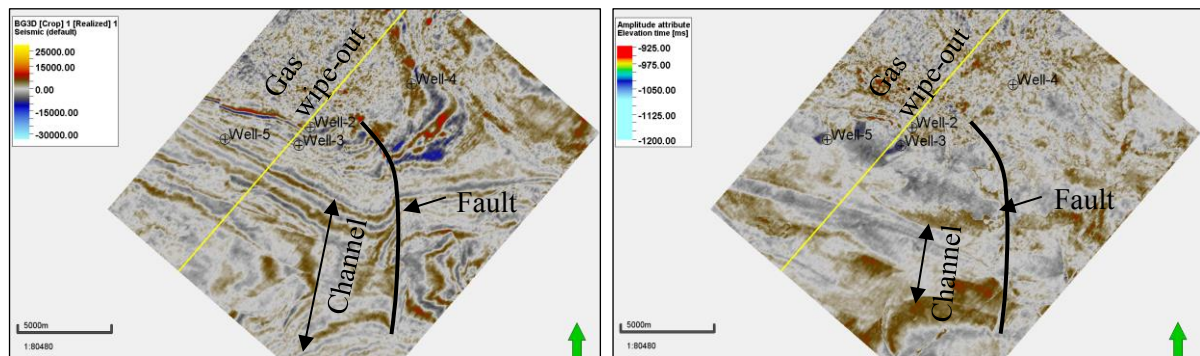


Figure 6a. Original seismic amplitude displaying the time-slice (right) and the horizon slice (left)

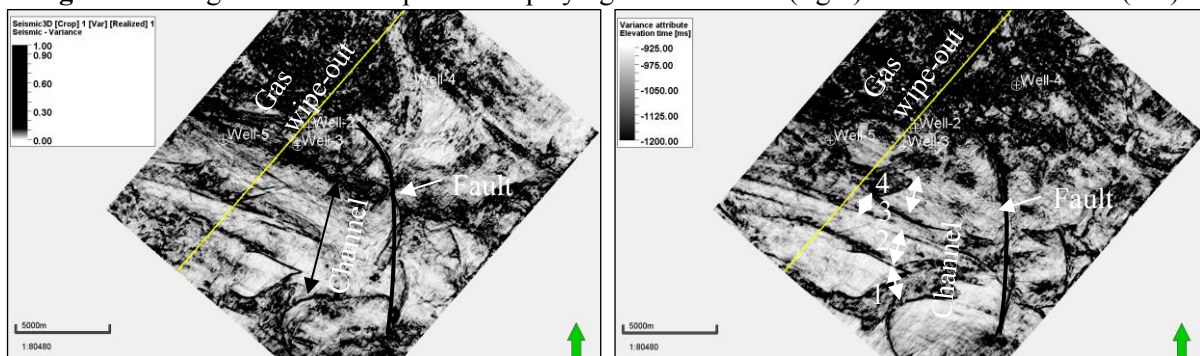


Figure 6b. Variance attribute displaying the time-slice (right) and the horizon slice (left)

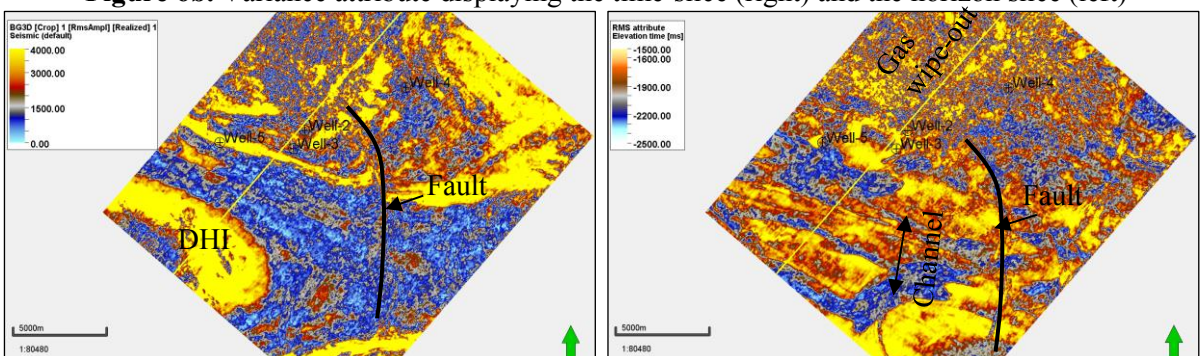


Figure 6c. RMS amplitude attribute displaying the time-slice (right) and the horizon slice (left)

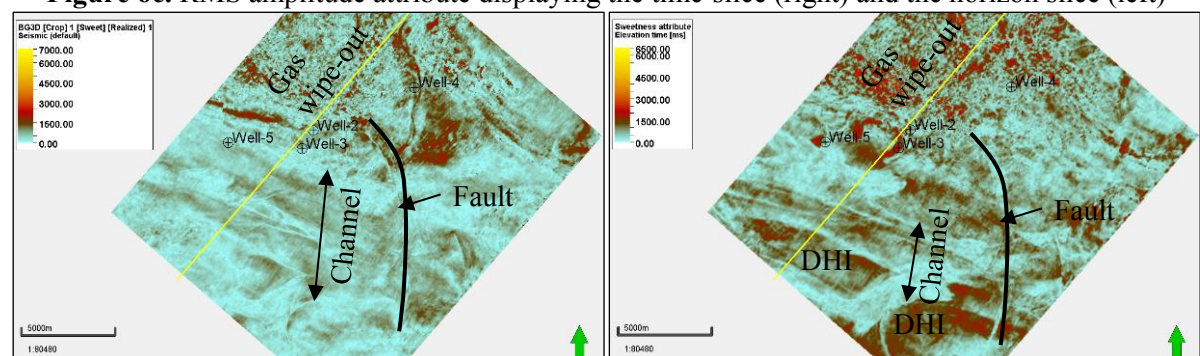


Figure 6d. RMS amplitude attribute displaying the time-slice (right) and the horizon slice (left)

The shallow geomorphology study within the zone of study area between H1 and H2 reveals several channels feature, marked with clear termination pattern (figure 6). The presentation of these channel bodies is further enhanced by applying seismic attributes at the 3D seismic volumes. These time-slices are displayed at depth – 1400 ms TWT and the horizon slices are – 180 ms below the H1. Figures 6a

and 6b show the same indication of broader channel body at the time-slice sections and more detail morphology of the individual channel at the horizon slice. Variance attributes in figure 6b further enhance the discontinuity events for the stratigraphic interpretation. It is interpreted that the broad channel is an incised valley deposit that made up of multiple-flow channel directions within the same interval. These channels are believed to be migrating towards the NE direction based on the overlapping patterns.

The DHI study in this channel body, using RMS amplitude and sweetness attribute reveals some bright amplitude responses, interpreted as DHI (Figures 6c and 6d). Some of these features are not visualized by using normal time-slice methods. From the horizon geobody generated, there appears to be a sand build-up in between the channel 1 and 2, marked with bright amplitude anomaly. Channel levee sands are also believed to be developed, with most of the sand being deposited outside of the channel bodies.

5. Conclusion

The detection and delineation of channel morphology within Group B formation is greatly enhanced by the application of seismic attributes in 3D seismic data. Several channel patterns were detected on the well-3 log motif, indicated that the sand formation is more compartmentalized. This log motif was analysed to find similar potential for reservoir filled sand away from the well control. There are numerous stacking and overlapping channel patterns that can be observed within the boundary of study areas, which were not penetrated by any exploration wells. The lateral extent of the channel body is visualized by using time-slice and horizon slice for better understanding. Various seismic attributes are applied to the seismic data, further enhanced and helps for detection and delineation of the channel geomorphology. The channel is interpreted to be an incised valley, made up of overlapping discrete channels. With the application of variance attribute, it helps to separate the individual channels that overlapped within the same interval. The presence of probable sand build-up and levee deposits area revealed by the application of RMS and sweetness attributes, marked with bright amplitude event, which is believed to be a DHI indicator. The individual channel may not bring in any values for the hydrocarbon exploration, however if we can cluster all this compartmentalized sand bodies, it will bring in improved economic value for tie-in to existing production facility.

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