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4D Seismic Feasbility of Central Luconia FOT Field

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Abstract: Complex pore component in carbonate reservoirs are due to their susceptibility toward diagenesis. The secondary pores created such as fractures, vugs and moldic have known to alter the sonic velocity propagation thus, produce a complex seismic response. This become a basis in pore type quantification utilizing Xu-Payne rock physics method (XP) where the distribution of these pore types are able to be separated into stiff, intergranular and soft pores. XP are applied on the well data of FOT and on seismic arbitrary line using pre-stack inversion. With the known pore types, the reservoir conditions of FOT are manipulated to give a new elastic modulus and are being shown in terms of seismic generation. The changes of Direct Hydrocarbon Indicators (DHI) supported by amplitude differences and polarity are observed in the results when the Gas Water Contact (GWC) are manipulated thus indicating a good 4D feasibility results for FOT carbonate reservoirs.

Key words: Complex, component, carbonate, quantification, feasibility, manipulated

INTRODUCTION

There are 7 main pores in carbonates based from Choquette and Pray (1970) as in Fig. 1. Anselmetti *et al*. (1998) shows that the carbonates developed in shallower marine environment have coarser grains and more susceptible towards diagenesis whereas vice versa in the deeper marine build up. This intrinsic parameter is the main influence in altering the propagation of sonic velocities through the carbonate formation, rather than the traditional burial and compaction effects suffered by siliclastic formations, supported by various publications that proves pore types as the main factors effecting seismic propagation in carbonate formation (Anselmetti and Eberli, 1993; Eberli *et al*. 2003).

The rock physics method that could be used for carbonate velocity modelling is the Xu-Payne rock physics method (XP) (Xu and Payne, 2009). This method utilizing Kuster-Toksoz Differential Effective Medium (DEM) theory used by Kumar and Han (2005) that enable the shape of the pores to be taken into account in the velocity modelling with the pores divided into the intergranular pores, stiff pores (moldic and vugs) and soft pores (microcracks and microfractures). The fundamental rock physics bound such as Hashin-Strickman upper and lower bounds together with basic trends of time average equation are fulfilled by XP as shown in Fig. 2. This give early indication of XP eligibility to be used for velocity modelling. Figure 2 shows the intergranular pores by XP are specified as interval dominated with highly connected pores and give an almost similar trend with Wyllie-Time average equation. Stiff pores with aspect ratio of 0.8 are basically dominated by diagenesis altered rock-fabrics and isolated carbonate pores components such as moldic and vugs. It would give a positive deviations from the reference trendline in velocity to porosity crossplot limited by Hashin-Strickman upper bounds (Kumar and Han, 2005). Soft pores in the other hand represents inclusions of micro-porosity, burrows and micro-fractures in the carbonate components. They are usually dominated by micrites and gives a negative deviations from time-average equations limited by Hashin-Strickman lower bounds in velocity-porosity trends with aspect ratio of 0.01.

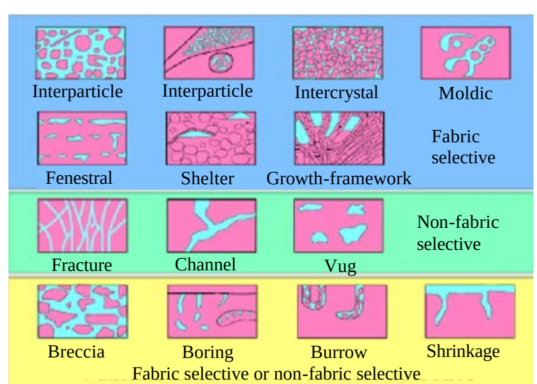

Fig. 1: Idealized carbonate pore types (Choquette and Pray, 1970)

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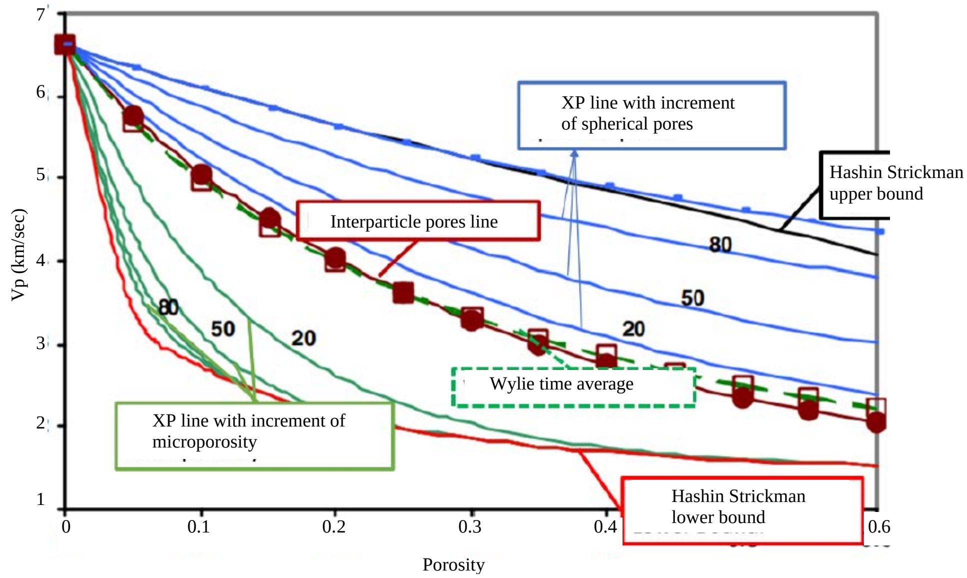

Fig. 2: Kuster-Toksoz DEM Model. Blue is the increment of spherical pore while solid green line is the increment of microporosity. The dotted red line is the interparticles pores. These line are calculated from XP. The fundamental rock physics formula are as follows: Solid black line is the Hashin-Shtrikman upper bound and solid red line is Hashin-Shtrikman lower bound. Dashed line is the Wyllie's time-average prediction (revised from Kumar and Han, 2005; Baechle *et al*., 2005; Stammeijer and Hatchell, 2014)

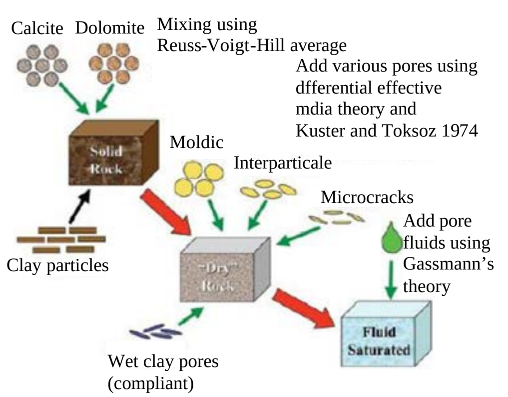

Fig. 3: Xu-Payne rock physics Model workflow (Xu and Payne, 2009)

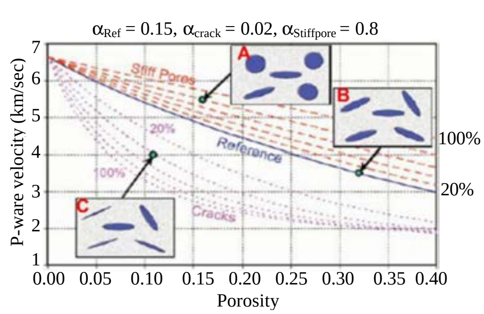

Fig. 4: The Xu-Payne Model (Xu and Payne, 2009). Aspect ratio 0.15 are used to specify intergranular pores, 0.02 for soft pores and 0.8 for stiff pores

Figure 3 shows the self-explanatory workflow of XP while Fig. 4 shows the crossplot of velocity to porosity with the different percentage of pore types by Xu-Payne Model. To quantify the pores, Model A in Fig. 4 is used as example. Model A are having porosity of approximately 0.15 and velocity of 5.5 km/sec, thus are fall within the bounds and quantified as having 60% stiff pores and 40% intergranular pores. This would be the pore type quantification basis that were used throughout this project.

Time lapse seismic or better known as 4D seismic is a repetition on either conventional or advance seismic acquisition after several time interval. It enable the drainage condition of a reservoirs to be predicted, thus, planning for optimization by secondary or tertiary recovery could be effectively be conducted. Basically, the changes in reservoir properties can only be captured in the 4D seismic if it causes any high velocity and density changes. Changes in terms of amplitude, polarity, phase and frequency from the legacy seismic are needed to be determined. With that, 4D seismic feasibility are required to ensure the reservoir are worth to be re-evaluated. The main rock physics workflow for 4D seismic are as Fig. 3 (Taqeer and Ali, 2017). Geological condition of the rock are the most essential in the workflow to determine the success of 4D survey (Fig. 5).

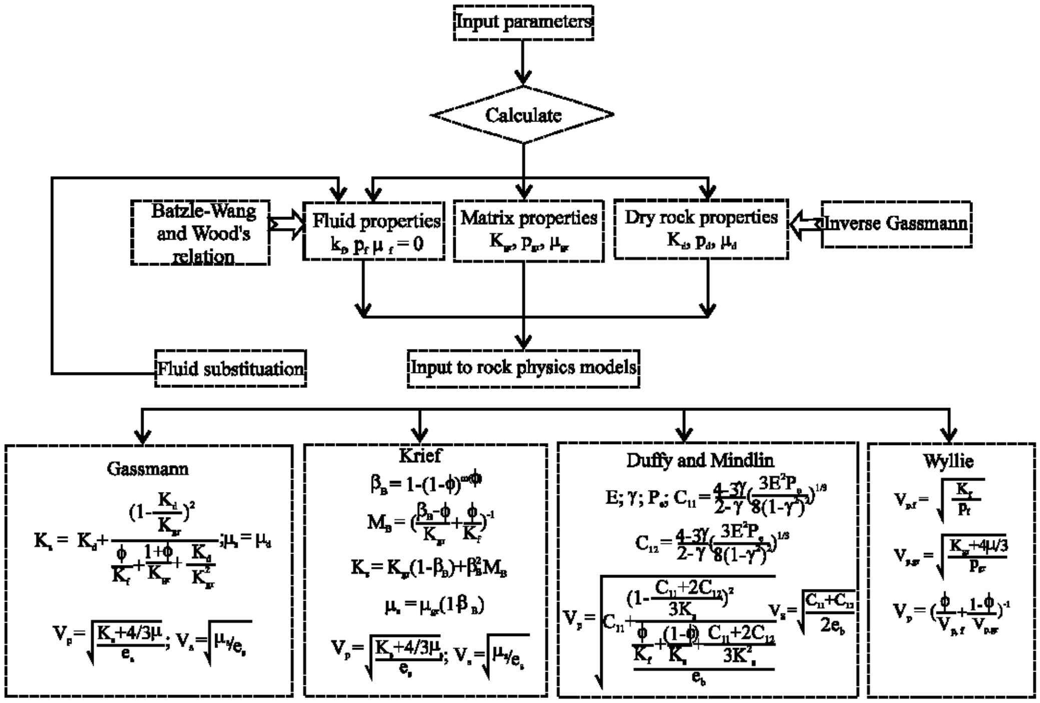

Fig. 5: Simple flowchart used for 4D seismic feasibility (Taqeer and Ali, 2017)

MATERIALS AND METHODS

This project are conducted by first performing the pore type quantification in the seismic section of central luconia field FOT. The confidence of pore type prediction are supported by the calibration of XP with the available Digital Image Analysis (DIA) data on the thin section and its distribution throughout the FOT well. With the pore type specified throughout the seismic section, the 4D seismic feasibility were conducted with the main objectives is to specify any changes in the seismic character with the manipulation of the reservoir conditions.

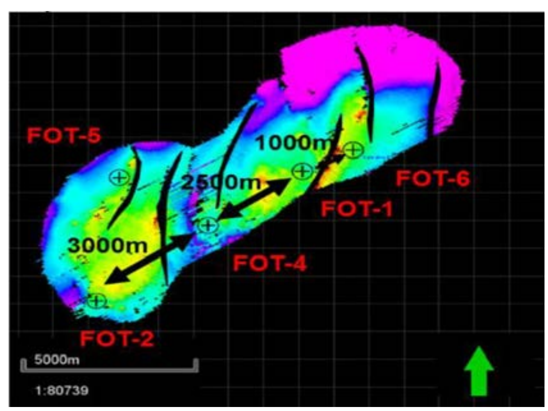

Fig. 6: F-OT well location. Horizon shown is top carbonate

RESULTS AND DISCUSSION

Pore type quantification of FOT field: Field FOT with the top carbonates as in Fig. 6 are chosen as the main target for this project. Thorough evaluation are conducted on 3 wells of field FOT which are FOT-2, 4 and 6. The pore type quantification are then conducted to the wells with results as Fig. 7. Shown together are the primary Velocity (V_p), shear Velocity (V_s) and density results in 100% water saturated condition for each well. The results shows that higher increase in 100% water saturated V_p are observed in the area with lower stiff pores value compared with the others. This are supported by the study on water and gas saturated carbonate model with known pore type as in Fig. 8. The results shows that soft pores gives higher velocity differences in different hydrocarbon saturations comparing with the small deviation in stiff pores.

Pre stack inversion are conducted on the arbitrary seismic lines of Fig. 9 passing through 2, 4 and FOT-6. By the results of seismic inversion, porosity and water saturation distribution are calculated throughout the seismic sections. With this information, pore type quantification are conducted to the seismic line with the results as in Fig. 10.

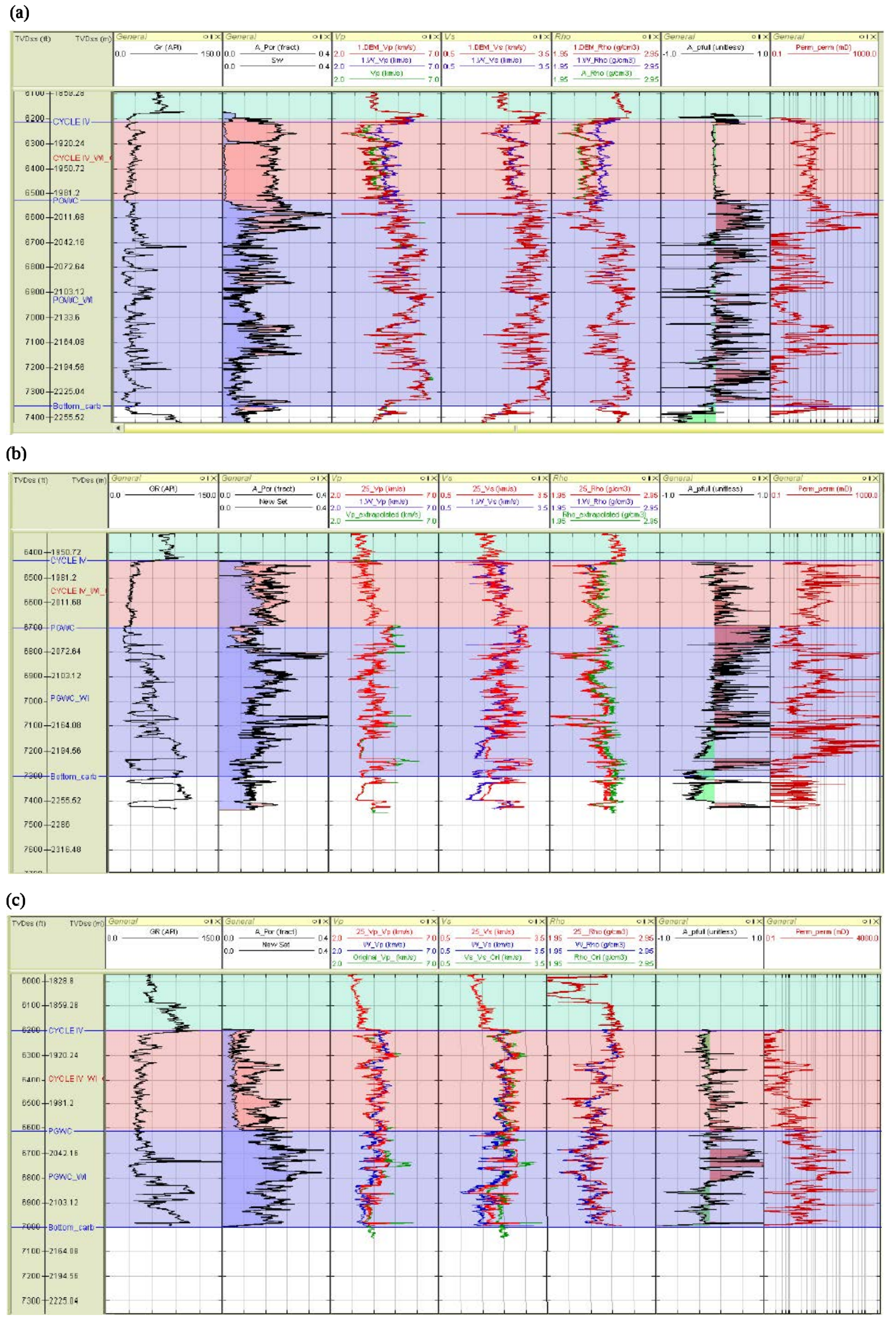

Fig. 7: The curves of 2, 4 and FOT-6. First column is Gamma Ray (GR), second is porosity with water saturation, third is primary Velocity (V_p), fourth is shear Velocity (V_s), fifth is density, [Green is original data, red is from XP and blue is after fluid substitution into 100% water] sixth is pore type quantification [positive is high stiff pores and negative is high soft pores] and last is permeability: a) FOT-2; b) FOT-4 and c) FOT-6

4D fluid substitution: The same arbitrary line are used to test the efficiency of 4D seismic in the carbonate formation of FOT in full stack seismic survey. The main indication of 4D feasibility adapted are the changes in polarity and amplitude assuming without any interruption of noise to the data. The amplitude plot are showing changes of amplitude in fraction while in polarity plot, positive indicate changes from XP in *situ* synthetic trough to peak in the new seismic generated while negative would indicate changes from XP in *situ* synthetic peak to

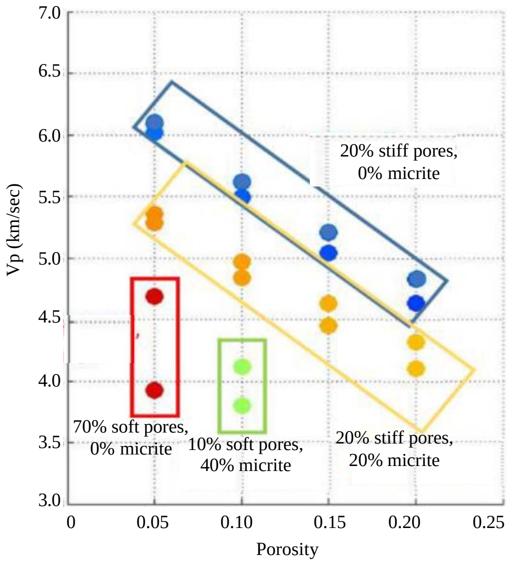

Fig. 8: Model of velocity differences in 0.3 gas condition and water saturated condition in variety of pore types and micrites percentage

trough. The 4D seismic synthetic generation in this exercise is created by Shuey 3-term approximation with the zero phase wavelet were extracted from the real seismic with dominant frequency of 25 Hz. Prior to investigate the changes of reservoir, the elastic modulus from seismic inversion are compared with the elastic modulus from XP. There are minor differences from the results of synthetic generated from this two as shown by Fig. 11-14, thus, gives confidence to model the synthetic in different reservoir changes.

The first reservoir condition tested is when the gas water contact is shallower to 1650 msec. The distinction could clearly be seen in the well synthetic generation in Fig. 15 where there are increase in amplitude between the new gas water contact and the insitu. In seismic generation in Fig. 16, it was found that the flat spots which are interpreted to be the gas water contact of the original seismic survey disappeared in the new reservoir condition which are labelled with green circle. The amplitude plot in Fig. 17 shows a very high amplitude

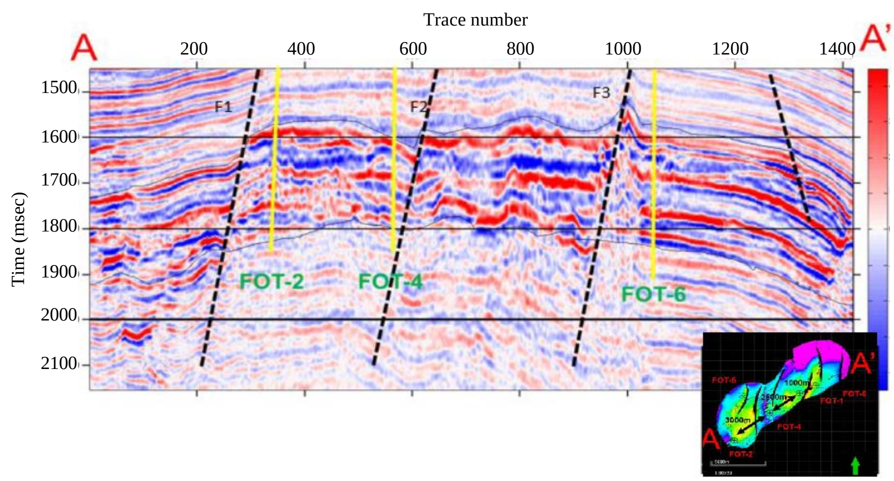

Fig. 9: Full stack seismic arbitary line with location of FOT wells

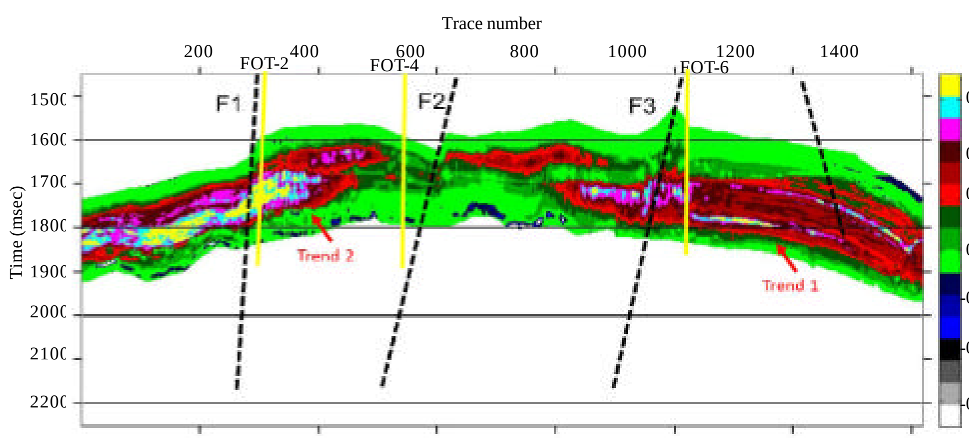

Fig. 10: Pore type quantification results. Positive number in color bar (green to yellow) indicates increase of stiff pores while negative number (green to white) indicates soft pores

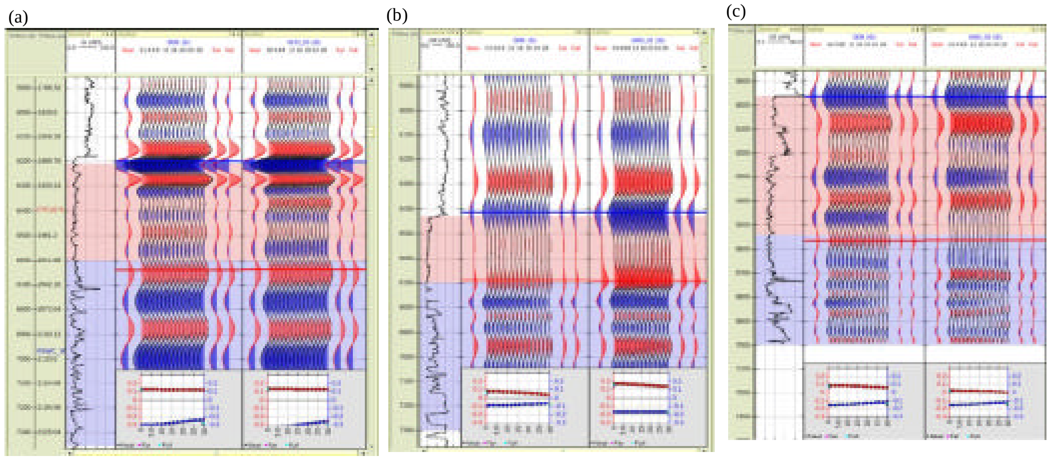

Fig. 11: Comparison of synthetic created by original well log data and XP calculated data: a) FOT-2; b) FOT-4 and c) FOT-6

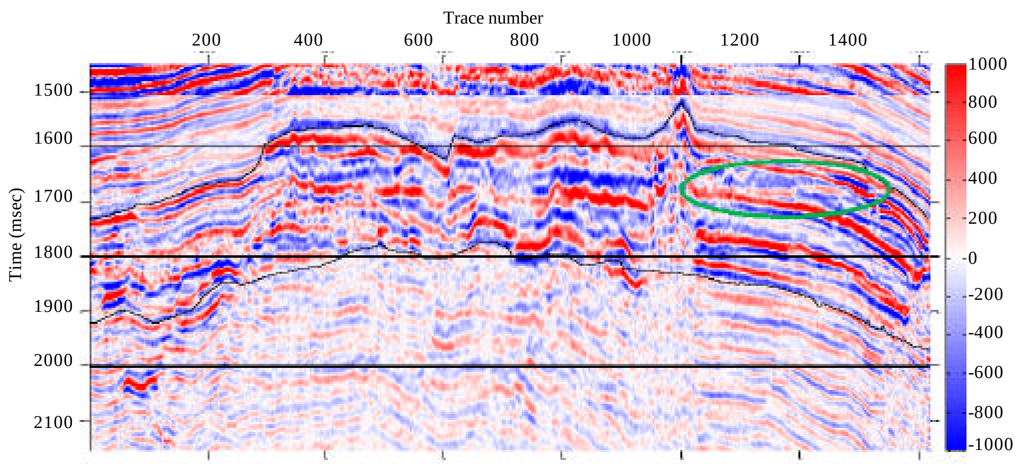

Fig. 12: Seismic full stack created by XP modulus. Green oval is observed flatspots indicating the gas water contact

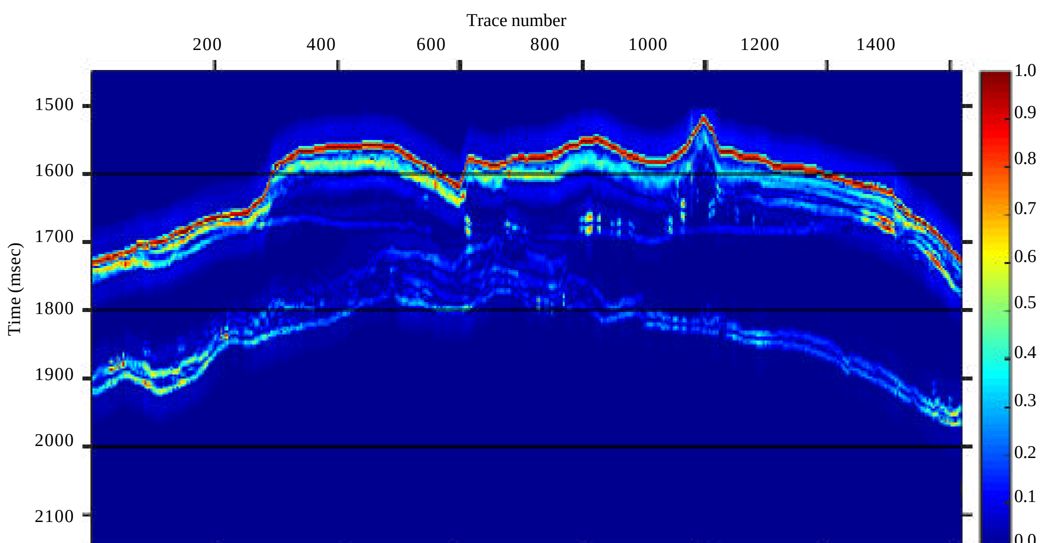

Fig. 13: Amplitude difference between seismic response of original inversion seismic to XP modulus created seismic

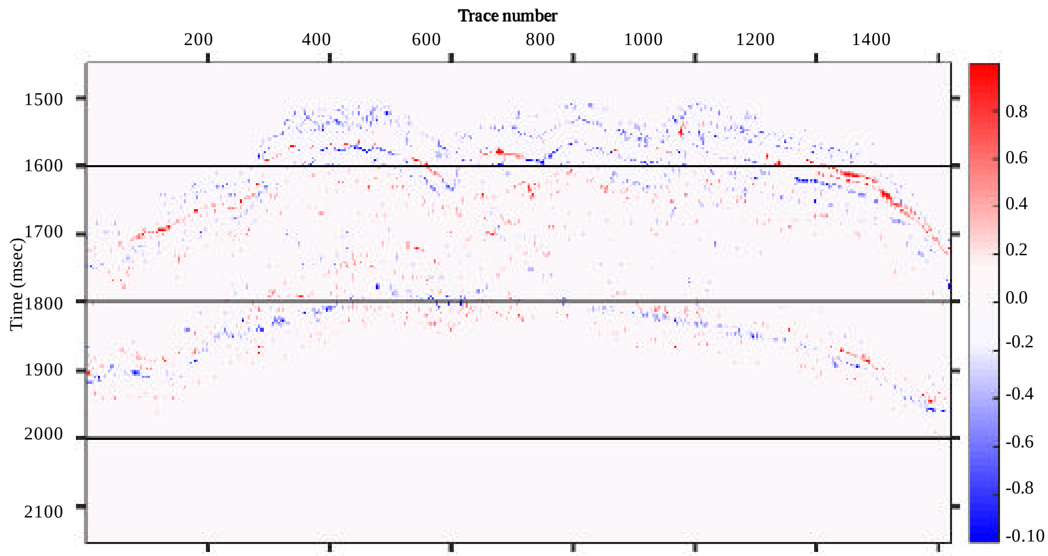

Fig. 14: Polarity difference between seismic responses of original inversion seismic to XP modulus created seismic

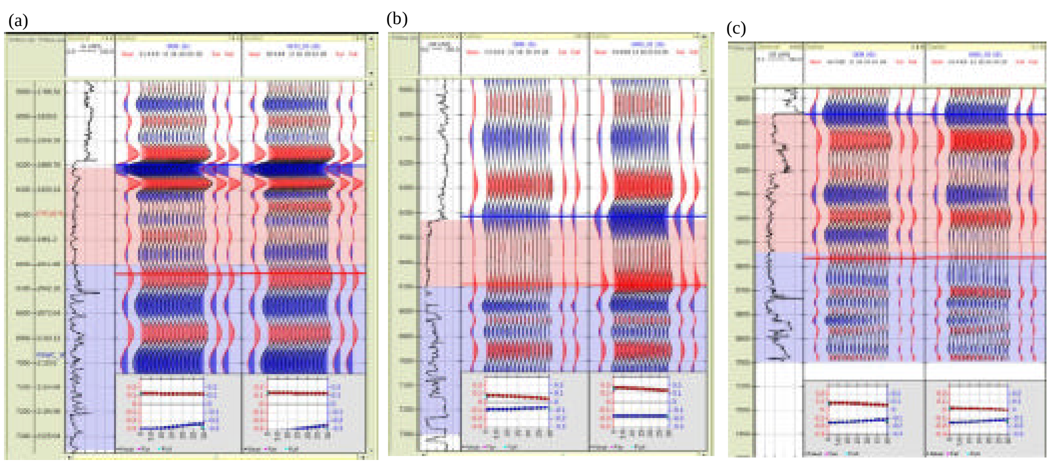

Fig. 15: Comparison of well log XP original reservoir condition to 30% water saturation in shallower gas water contact: a) FOT-2; b) FOT-4 and c) FOT-6

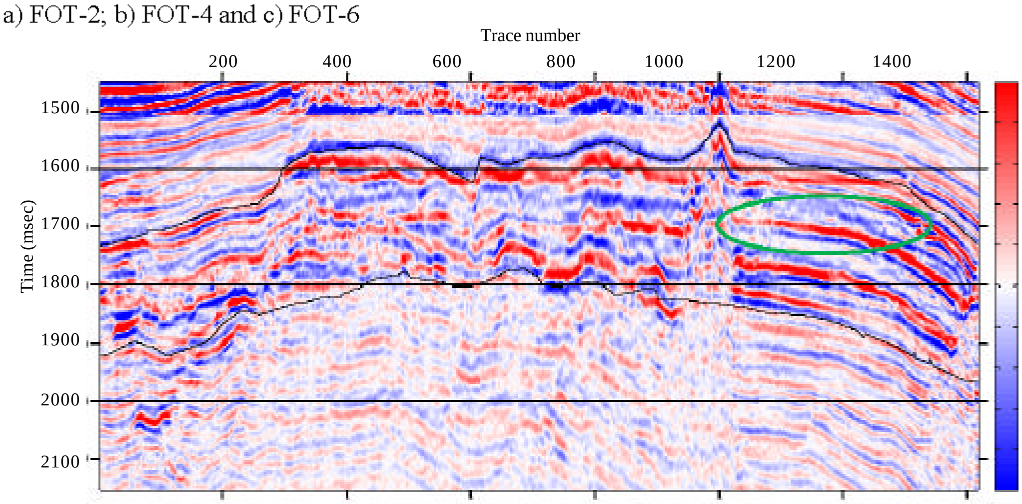

Fig. 16: Seismic from 30% gas saturation in shallower gas water contact. Green oval indicates the disappearance of suspected flat spots

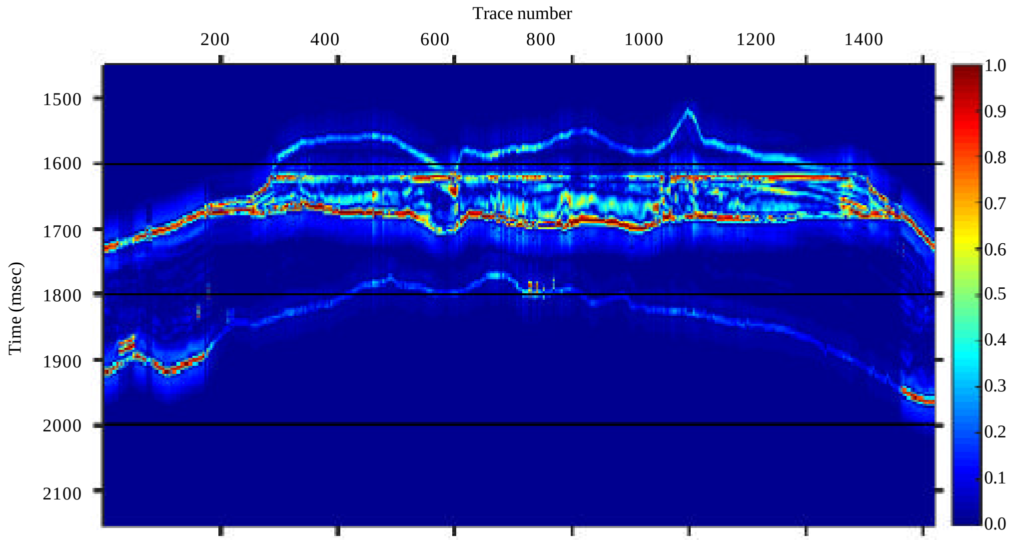

Fig. 17: Amplitude difference between seismic response of 30% water saturation with shallower gas water contact to *in situ*

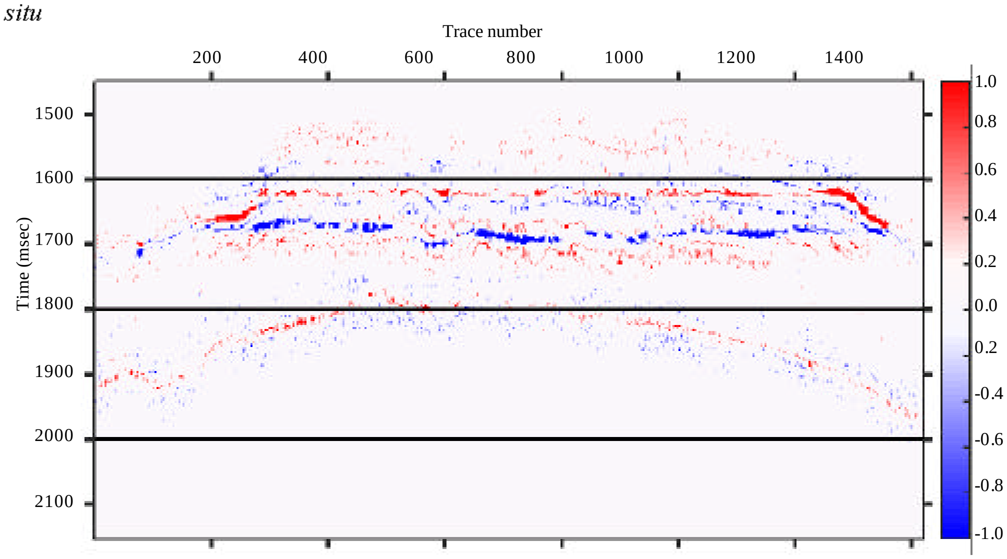

Fig. 18: Polarity difference between seismic response of 30% water saturation with shallower gas water contact to *in situ*

changes between the new gas water contact and the original gas water contact as per expected from the well synthetic generation. The newly generated seismic give an increase of amplitude at the new gas water contact while dimming near the old gas water contact. There are also changes of polarity as in Fig. 18 from trough to peak at the new gas water contact and peak to trough at the old gas water contact thus, providing an adequate evidence of changing reservoir condition at the area.

The second reservoir condition being analysed is when the carbonate formation is fully saturated by water. In well log synthetic analysis in Fig. 19, the top of formation are shown to have a decrease in amplitude. As for seismic generation results, similar DHI changes occurs where the flat spots from the insitu XP seismic data is now disappear in seismic section of Fig. 20 and there are obvious decrease of amplitude between the top of reservoir to the original gas water contact confirmed by Fig. 21. The polarity changes from trough to peak are also found in the top of carbonate at the polarity plot in Fig. 22.

The 4D analysis on FOT field shows that several changes in terms of amplitude and polarity could be identified and consistent with the synthetic study on the well interval. The pore types distributions of the FOT carbonate interval act as a key in manipulating the reservoir conditions. As the gas interval in FOT field are made up by mostly intergranular pore formation, the

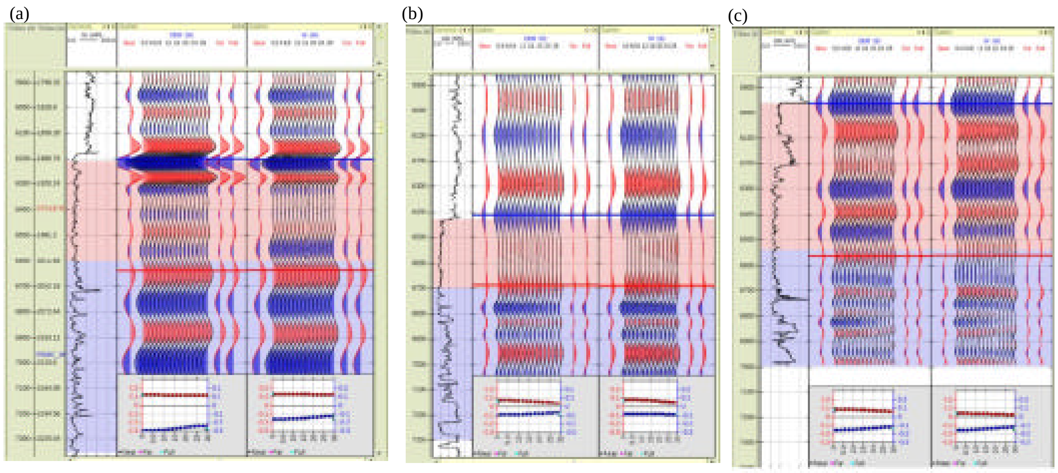

Fig. 19: Comparison of well log XP original reservoir condition to 100% water saturation: a) FOT-2; b) FOT-4 and c) FOT-6

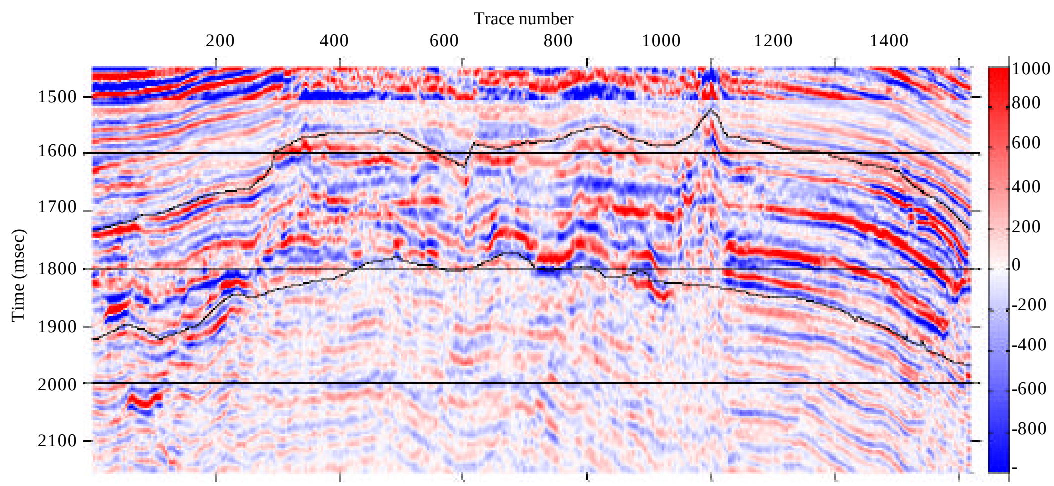

Fig. 20: Seismic from 100% water saturation

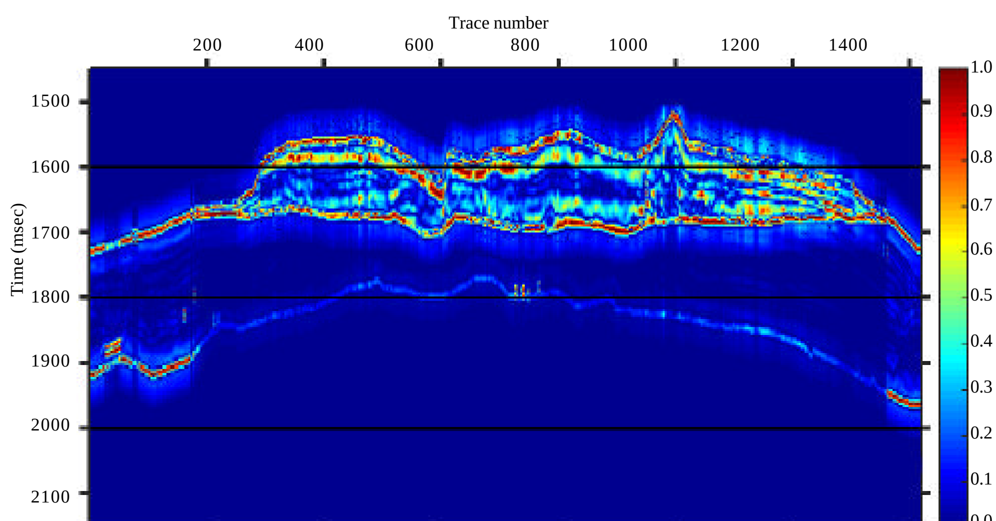

Fig. 21: Amplitude difference between seismic response of 100% water saturation to *in situ*

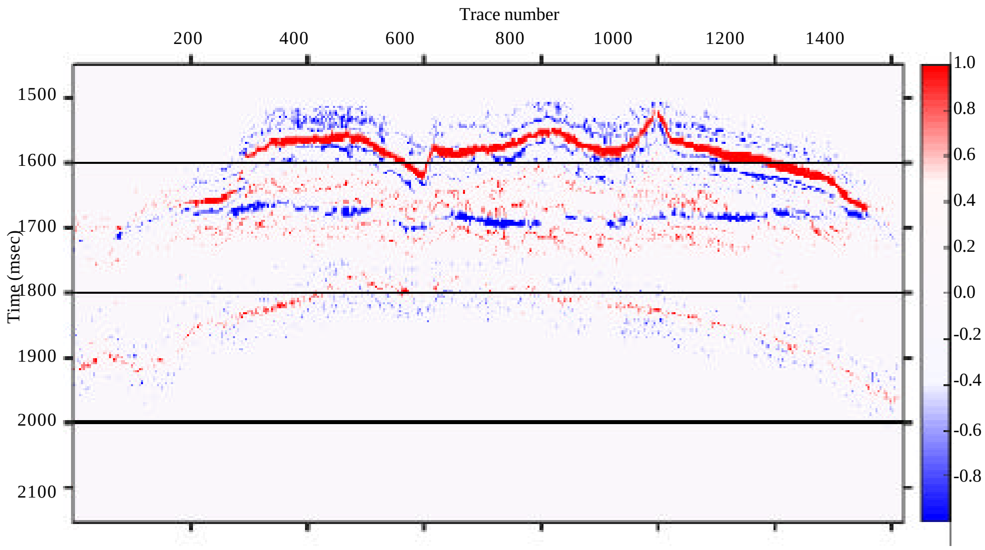

Fig. 22: Polarity difference between seismic response of 100% water saturation to *in situ*

changes in elastic modulus are recognizable and translated in alteration of amplitude and polarity of the synthetic generated. It was shown that changes in Gas Water Contact (GWC) due to depletion are most possible to be recognizes. It gives an increase of amplitude at the new GWC interval with the inversion of polarity. This make FOT fields as a good candidate for 4D seismic survey.

CONCLUSION

With the information of pore type distributions on FOT fields, the 4D feasibility studies are conducted with large confidence on the area as the dry rock properties of the area are being resolved. Several changes in terms of DHI and obvious amplitude changes in the new reservoir conditions indicates that there are possibilities of 4D seismic survey conducted on FOT would be successful. The research conducted have brought up the new approach in 4D seismic feasibility study of carbonate reservoirs which could be applied and optimize the manipulation of any carbonate reservoirs.

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