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Quantitative Implementation of Acoustic Impedance Inversion to Porosity and Lithology Prediction of Clastic Reservoir, Luhais Oil Field, Southern Iraq

Omar N. A. Al-Khazraji Rami M. Idan Amani L. M. Salih Rand K. Hassein
Department of Geophysics, College of Remote Sensing and Geophysics, Al-Kharkh University for sciences, Baghdad, Iraq

Abstract
In the present study, some of petrophysical properties of Nuhr Umr Formation in Luhais oil field (south of Iraq) are evaluated by using an acoustic impedance inversion process. 2D seismic reflection data of (29) lines covering the field, neutron porosity logs, and synthetic acoustic impedance logs were used in inversion of seismic sections into an acoustic impedance and porosity sections. To compensate the low frequency in relative acoustic impedance that rely on seismic data frequency (band-limit frequency), we inverted relative acoustic impedance with combination the low frequency of well data to obtain absolute acoustic impedance. The absolute acoustic impedance shows consistency and good tie with an acoustic impedance log. At the reservoir interval the lithology was discriminate and evaluate the facies quality of Nahr-Umr Formation using absolute acoustic impedance inversion and subdivided into three main members. The shale facies indicate high porosity (25%) corresponding to low acoustic impedance (6500 Kpa. m/s) at the top of the reservoir. The petrophysical analysis declare and confirm higher quality reservoir is noticed and recognized in the middle member of Nahr-Umr reservoir.

Keywords: seismic inversion, porosity prediction, Absolute Acoustic impedance

1- Introduction

The Luhais oil field is situated in southeast Iraq, approximately 105 Km west of the city of Basra and 450 Km south east of Baghdad as shown in the Fig. (1a) as well as shows the base map of the study area Fig (1b). The Nahr-Umr Formation was considered as the most important oil reservoir in Luhais oil field, therefore our research forces on it. Its age is of Albain deposit and identified in southern Iraq. It comprises black shale interbedded with medium to fine grained sandstone with pyrite (Bellen et al. 1959). The depositional environment represents a mixture of ground, shallow marine, tidal and deltaic environment with interspersed natural marine area (Al-Sayyab *et al.* 1982). According to many previous studies, the Nahr-Umr reservoir subdivided into three main members, which are upper member (comprises of shale with low rate of sand), middle member (comprises of sand with low rate of shale) and lower member (comprises of sand), these results were discussed rely on stratigraphic analyses and well correlation. In Luhais oil field 49 wells were drilled, which shows that the given stratigraphic variation in the field is similar to the stratigraphic variation of adjusting area such as Subba, north and south Rumaila oil fields. The drilling results showed that the oil is available in Nahr-Umr Formation except Lu-21 shows oil for several meters within the Nahr-Umr Formation. The Luhais oil field lies within Zubair subzone of the Mesopotamian zone in the unstable shelf according to (AL-Khadhimi *et al.* 1996). The Luhais structure is asymmetrical antiform with dip of less than one degree on both flanks. Large scale faulting cannot be recognized on seismic section at Luhais, but regional maps suggest structural strike NE-SW, NW-SE and N-S (Anadarko 2004). The present research aimed to use the acoustic impedance inversion as a tool and a diagnostic parameter to evaluate the petrophysical properties and delineate the lateral and vertical facies heterogeneity as well as provide insight to porosity and lithology variations away from limited well control of Nahr-Umr Formation in Luhais oil field. Many of seismic studies depend to seismic inversion in their interpretation. The reason is obvious due to there is many of problems- which is noise, losses and other mistakes- in the interpretation of this seismic information and no equation directly relates these multiple information of seismic data can resolve with unique answers. Therefore, the interpreter was resorted to inversion, which is a mathematical approach of evaluating and assessing an answer, examining it verses observation and adjusting it until when the final answer is more reasonable.

In the 1970s, geophysicist utilized to seismic attributes such as post-stack amplitudes and reflection coefficients, to predict variation in lithology and presence of fluids (Hampson *et al* 2001). The reflection of seismic wave from subsurface layers illuminates potential hydrocarbon accumulations. As wave reflects, their amplitude change to reveal important information about the underlying materials. Seismic amplitude inversion uses reflection amplitude, calibrated with well data, to extract details that can be correlated with porosity, lithology, fluid saturation and other rock physics parameters. Seismic inversion is a method qualified to make a solution for a set of spatial parameters rely on as the number of measurements of an indirect properly (Tarantola 2005). The benefits of this technique, is diminishing the impact of wavelet via substitute the seismic with blocks of impedance at a certain time interval and their arrangement gives an evidence of acoustic layering in the subsurface. The link between the seismic section and the acoustic impedance section is the seismic wavelet. Another benefit of inversion outcome that are easier to predict by worker who was not geophysics such as geology and engineering. The most of the seismic inversion technique converts the seismic reflection amplitude into acoustic impedance values, from which porosity, lithology and facies can be derived. A good quality impedance model contains more information than seismic data. It contains all the information in the seismic data without the complicating factors caused by wavelets and adds essential information from the log data (Latimar *et al.* 2000). Because of the direct connection to seismic and rock properties, acoustic impedance is one of the most quantitative seismic attributes utilized to reservoir characterization such predict as lithology, porosity, facies and sedimentary environment for seismic information (Cooke *et al.* 1999).

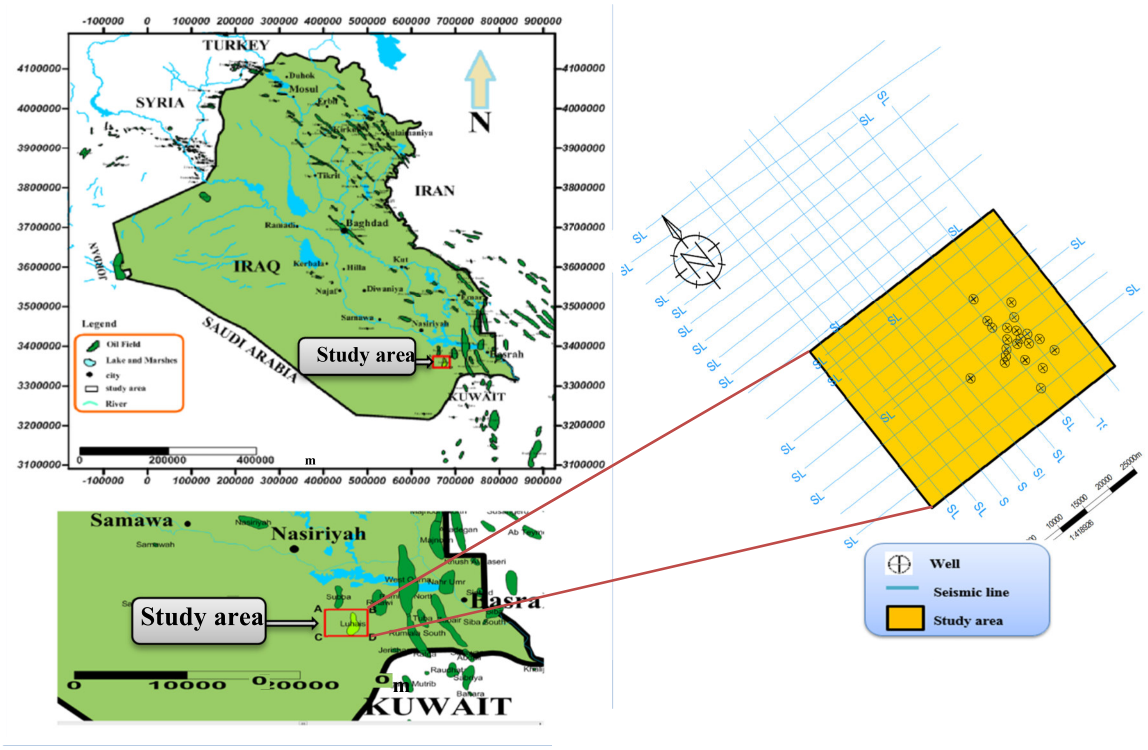


Figure 1. (a) A map showing the distribution of Iraq oil fields including the study area. (b) Base map of selected area.

In general, seismic inversion produces a model of relative reflectivity at certain time interval, which can be inverted to get on relative acoustic impedance to yield real rock physics property such as velocity and density, a conversion to absolute acoustic impedance is necessary. However, such as conversion requires frequencies down to near zero Hz, lower than contained in conventional seismic data. An absolute acoustic impedance constructed via combining the relative acoustic impedance model obtain from the seismic frequency range with a low-frequency model derived from well data. Most inversion algorithms solve for absolute property models (ie absolute impedance for a post-stack inversion) which are comparable to impedances from well log data. Creating relative impedance is one method for dealing with non-unique inversion results. Relative impedance models show – in a relative sense – high and low impedances that correspond to different lithologies, but those relative impedances are not comparable to the absolute impedances of well logs. The key difference between relative and absolute impedance is that a relative impedance model is missing the low frequency component (approximately 0-15 Hz) found in an absolute impedance model. Thus, seismic inversion can be a valuable tool for reservoir characterization prior to field development. The cost and complexity of deep well development are so great that a very limited spatial sampling of the target reservoir is achievable with well data. Thus the quantitative use of seismic data becomes of paramount importance. Poststack seismic inversion and modeling are frequently employed to perform quantitative prediction of reservoir properties from surface seismic data. Seismic inversion or stratigraphic deconvolution tries to put a spiked response at geological boundaries (lithology changes) and the main reservoir characteristic interfaces. Poststack acoustic impedance is known to have limited capability for sand/shale discrimination when applied to sands and shale that have undergone significant compaction (Wagner 2012).

2- Data and methodology

In the current study, we used the information of 21 wells consists of radioactivity logs (GR, Neutron and density) and acoustic log (sonic) and their markers, moreover, the seismic data that used in this study were 29 2D seismic reflection lines that cover all the study area as well as the check-shot of Lu-2 and Lu-21 that's only available in the field. The method that used in this study, which are consist of seismic data analysis, seismic interpretation, seismic inversion which involve relative and absolute inversion, seismic porosity transform and facies discrimination as shown in Fig.(2).

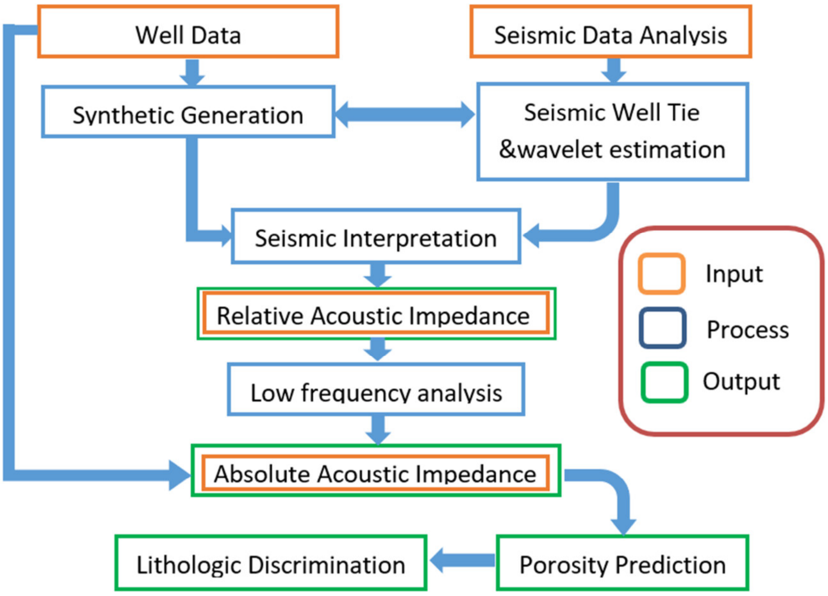


Figure 2. Flow chart of seismic inversion process.

2.1 Seismic data analysis:

2.1.1 Synthetic seismogram generation

The most controlling factor in the seismic interpretation & subsurface mapping, is greater accuracy of interpretation capability. The controlling factor can be enhanced by the correlation of seismic data with borehole data by using the synthetic seismogram which is considered as the primary mean of obtaining this correlation. The well data are re-sampled to the sample interval of seismic data (2ms). Seismic-to-well tie is the key at any stage of the development of a field and is an essential step of the seismic interpretation workflow, bridging the gap between the time and depth domains (Schlumberger, 2012). Synthetic seismogram that is created by convolving a seismic wavelet, preferably one extracted from the seismic data to which the synthetic will be correlated, with a reflection-coefficient (RC) series generated from acoustic impedance (AI) data calculated from calibrate sonic and density logs collected during a borehole evaluation program (Herron, 2011). Inconsistency among the sonic log and check-shots are often caused by (Goetz and Dupal 1979; Ljung 1987; Oppenheim and Schafar 1989):

1- The seismic method dose not measuring the same rock volume as the well logs measurement. The seismic method trends to average out the data stemming from a much wider area, meanwhile the borehole has been always point calibration.
2- The frequencies in borehole much higher than the frequencies of seismic data, therefore the sonic and density logs are smoothed prior compiling the synthetic seismogram.
3- The reliability of normal-move-out correction of check-shot is so far, especially in the deeper and inclined reflectors.
4- These inconsistency increases where the seismic migration does not perfectly move the reflector back in their correct location.
5- The field parameter that's used in seismic survey differ from the parameter that used in well measurement.

The computed synthetic seismogram is displayed in Fig. (3a) and Fig. (3b), the tops of Nahr Umr and Zubair Formation correspond to trough, while Shuaiba Formation correspond to peak, are shown, where the variation in polarity is mainly due to variation in lithology from one formation to another. The studied geologic formation are overlain by Maudud Formation, which is composed of carbonate rocks. Meanwhile, Nahr Umr clastic rocks which are underlain by carbonate rocks of Shauiba Formation. Since the clastic rocks are more porous than the carbonate rocks the sign of reflection coefficient Maudud-Nahr Umr contact, is negative, while the sign of reflection coefficient Nahr Umr-Shauiba contact is passive.

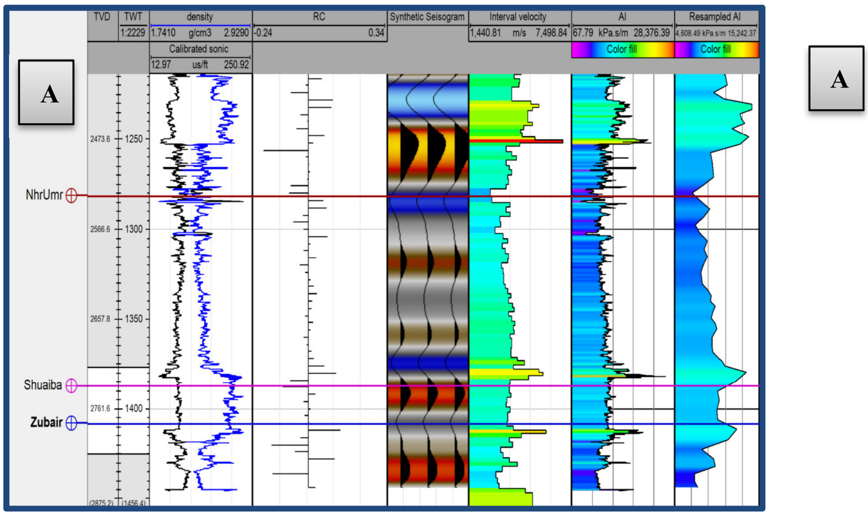
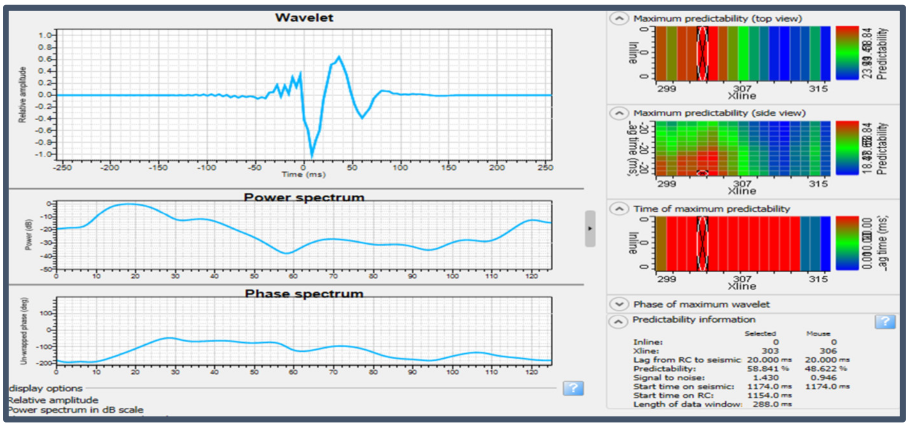


Figure 3. (a) Synthetic seismogram generation of Lu-2 well. (b) Comparison between seismic section (SL-29) with synthetic trace of well (Lu-2).

2.1.2 Wavelet extraction

In the present study, the wavelet was estimate of Lu-2 well to determine the seismic events of different geological tops. We used deterministic method and extended while algorithm method to estimate wavelets. In this analysis, the length of extraction window 288 ms. The statistical results such as signal-to-noise ratio was estimate, which is 1.43 and predictability reached 59% to identify the wavelet estimate reliability as shown Fig.(4). The increasing of predictability in wavelet estimation gives as more best tie with seismic data, therefore the quality of wavelets is depend on the value of predictability.



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                          Selected      Mouse
Inline:                          0          0
Xline:                         303        306
Lag from RC to seismic  20.000 ms  20.000 ms
Predictability:         58.841 %   48.622 %
Signal to noise:         1.430      0.946
Start time on seismic:  1174.0 ms  1174.0 ms
Start time on RC:       1154.0 ms
Length of data window:   288.0 ms
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Figure 4. Wavelet estimation highlights the power spectrum and phase spectrum and predictability information.

2.2 seismic interpretation

Reflections are usually recognized with rock units by correlating well-log data, often using a synthetic seismogram (Sheriff and Geldart 1995). The identification of tops of Nhr Umr, Shauiba and Zubair horizons were carried out depending on the well seismic velocity survey data of well Lu-2 and by using synthetic seismogram of this well. After the recognition of interesting reflectors, the tops of these reflectors were picked in all study area, as clarified in Fig. (5).

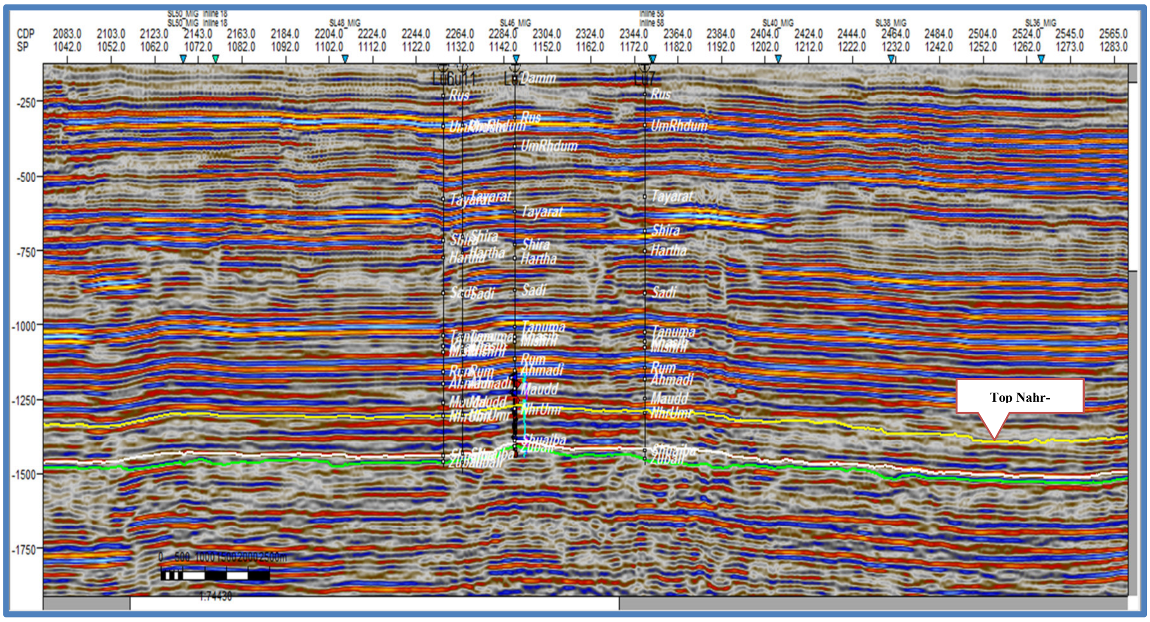

Figure 5. Seismic section (SL-29) illustrate general specifications reflectors in study area.

2.3 Inversion Methodology: There are two outputs of impedance inversion: absolute and relative acoustic impedances.

2.3.1 Relative acoustic impedance (RAI)

The major aim of geophysicist's to seismic inversion carried out to produce the acoustic impedance of earth properties. This approach is performed via transformation the seismic data into pseudo-acoustic impedance. The band limited impedance (relative acoustic impedance) is more useful seismic attribute to better quantitative understanding of clastic reservoir properties (Cook *et al* 1999) and (Latimer 2008) and due to its direct connection with seismic properties (Abushalah and Serpa 2016). Moreover, the most important benefits of seismic relative impedance inversion is to predict the reservoir properties such as porosity, lithology, facies thin beds determination and fluid content by invert relative acoustic impedance to absolute impedance which contain low frequencies and related to these properties away from borehole locations.

2.3.2 Absolute acoustic impedance (AAI)

The absolute acoustic impedance can be performed by combining the relative acoustic impedance model which derived from integration the zero-phase trace or rotating the phase of zero-phase trace via -90˚ with low frequency model obtained from well data.

The absolute acoustic impedance directly compares with acoustic impedance and which provides better maximum consistency to well logs data, that derives from borehole data rather than the relative acoustic impedance because of the absolute acoustic impedance inversion contain more a broad frequency from seismic data frequencies. Moreover, the absolute acoustic impedance has abroad frequency from the relative acoustic impedance, frequency, which rely on seismic data frequency. Well logs have abroad frequency because they are normally measured at 5-ft resolution and ranged from close to zero to several thousands of Hz, while seismic data are band-limited to 125 Hz with a sample interval of 4ms (Latimer 2008).

3. Results and Discussion

3.1 Relative and Absolute acoustic impedance inversion

The relative acoustic impedance inversion was carried out from conversion of 2D seismic data of (9) strike lines and (11) dip lines into 2D acoustic impedance sections. These produce sections used for enhancement seismic interpretation by a good appearance of Nahr-Umr Formation boundary and shows a good tie between these sections and well markers. The missing of the low-frequency of seismic data was compensated modeled by using well logs data. In order to fulfill reliable estimation of acoustic impedance, the absolute acoustic impedance inversion was applied by using and combining the band-limit frequency of seismic data and low frequency of well data to produce the absolute acoustic impedance model. Traditionally interpolation preformed between well logs data based on the distance between well locations which usually leads to increased errors of result and give a non-geologic solution. In current study, the absolute model was carried out according to acoustic impedance logs interpolated along the interpretation horizon in seismic sections, which give more reliable and good results. Figs. (6a) and (6b) absolute acoustic impedance sections, in these sections, we are cropping the absolute acoustic impedance sections from the top and bottom of Nahr –Umr Formation only. These sections illustrate the acoustic impedance values are reduced in the upper part of formation, especially toward the eastern part, while the acoustic impedance values increased in middle part toward the bottom of the formation. The variation of the acoustic impedance due to vertical lithofacies changes in reservoir interval between sand to sand/shale facies. The useful benefits of acoustic impedance inversion results are to predict the lateral facies change (Mahgoub 2017). The absolute acoustic impedance maps is constructed of top, within and bottom Nahr-Umr Formation rely on absolute acoustic impedance model as a shown in Fig. (7). This map is a good indicator of the horizontal distribution of lithofacies variation and environment deposition between sand to sand/shale facies along the top of Nahr-Umr Formation. In the present study, three acoustic impedance map is carried out at different levels in the reservoir interval which are at the top, within and the bottom of Nahr-Umr Formation that declare the distribution of acoustic impedance in the study area as shown in Fig.(9). the map at the top of Nahr-Umr Formation, which illustrate the acoustic impedance values, reduce at the well locations as well as toward east of the study area, due to increasing the shale ratio in this region, meanwhile the acoustic impedance values raises away from the well locations and toward the western part due to increase the sandstone ratio in this direction. The acoustic impedance maps within and at the bottom of Nahr-Umr Formation shows the acoustic impedance values increase at the well locations due to increase the sand ratio in this region, meanwhile the acoustic impedance values, reduce away from the well locations, especially toward the southwest part at within the reservoir interval and toward the north and southeast part at the bottom of the reservoir interval due to increase the shale ratio.

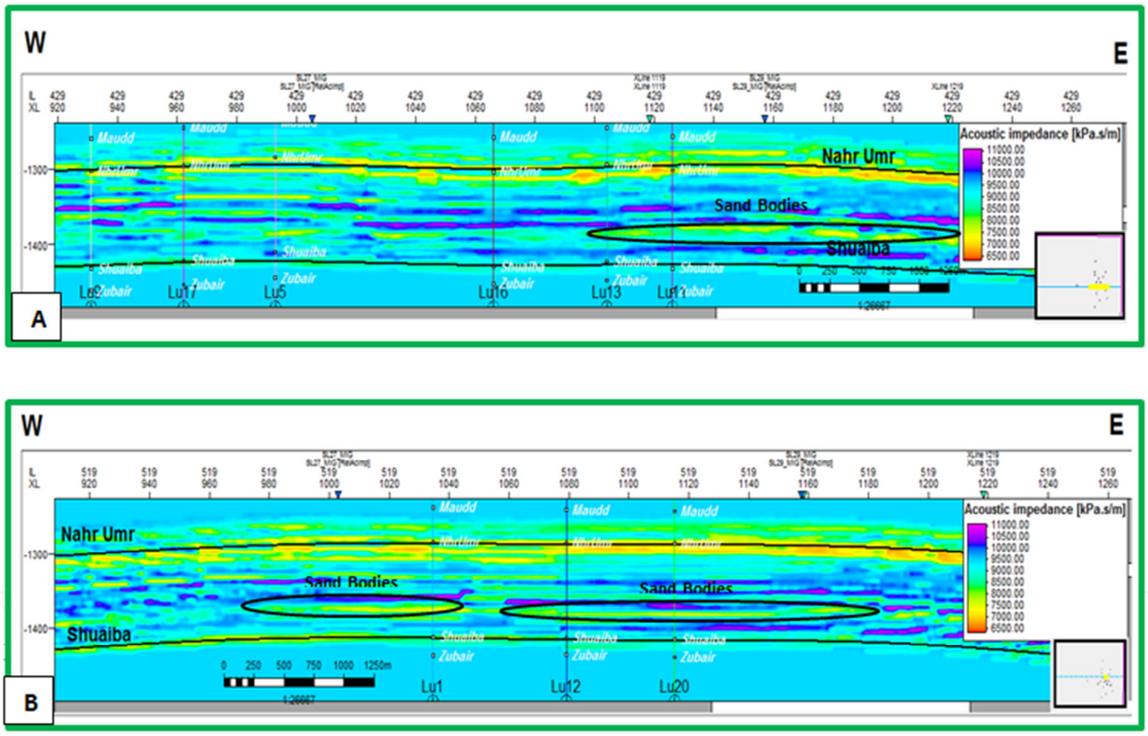

Figure 6. (a) Acoustic impedance section pass through wells Lu-5, Lu-9, Lu-11, Lu-13 Lu-16 and Lu-17. (b) Acoustic impedance section pass through wells Lu-1, Lu-12 and Lu-20.

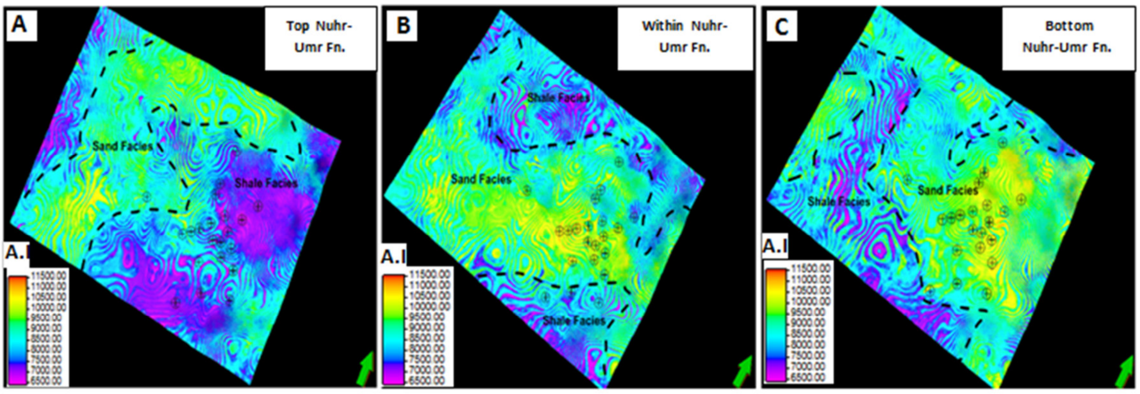

Figure 7. (a) Acoustic impedance maps construct at different levels within Nahr-Umr Formation for lithofacies discrimination.

3.2 Seismic Porosity conversion

Porosity evaluation of seismic data is a very important tool because it permits the definition of porosity distribution even far from drilled wells, allows a better characterization of known reservoirs in their economic and technical aspects, and provides much more information than does normal seismic processing in the search for new hydrocarbon fields.

Based on the acoustic impedance inversion results, the seismic porosity transform was carried out to reveal the reservoir heterogeneity and lithology discrimination. The acoustic impedance sections were transformed into porosity section which indicate to the variation of porosity through the reservoir interval and shows the porosity increased in the uppermost of the Nahr-Umr Formation reached to 25% due to increasing of shale contain corresponding to low acoustic impedance. Moreover, the seismic porosity decrease toward the bottom of formation, note Fig. (8). The porosity maps shows enhance the porosity toward northeast part of study area at the top of formation, while decrease toward southwest at the middle lower members of formation.

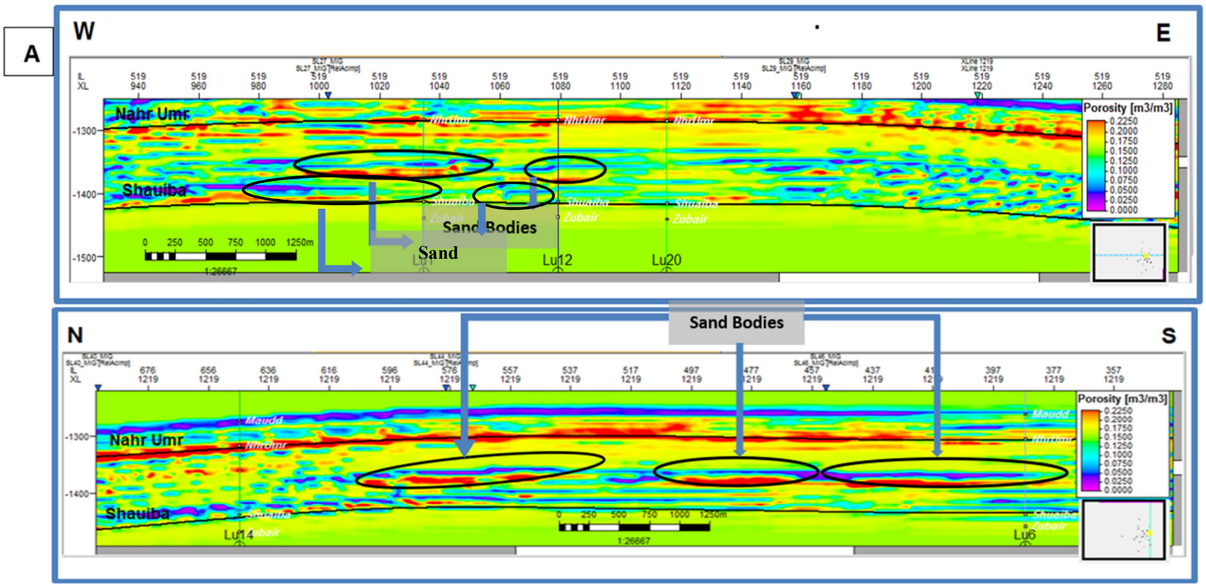

Figure 9. (a) Porosity cross section pass through wells Lu-1, Lu-12 and Lu-20. (b) Porosity cross section pass Lu-6 and Lu-14 through wells

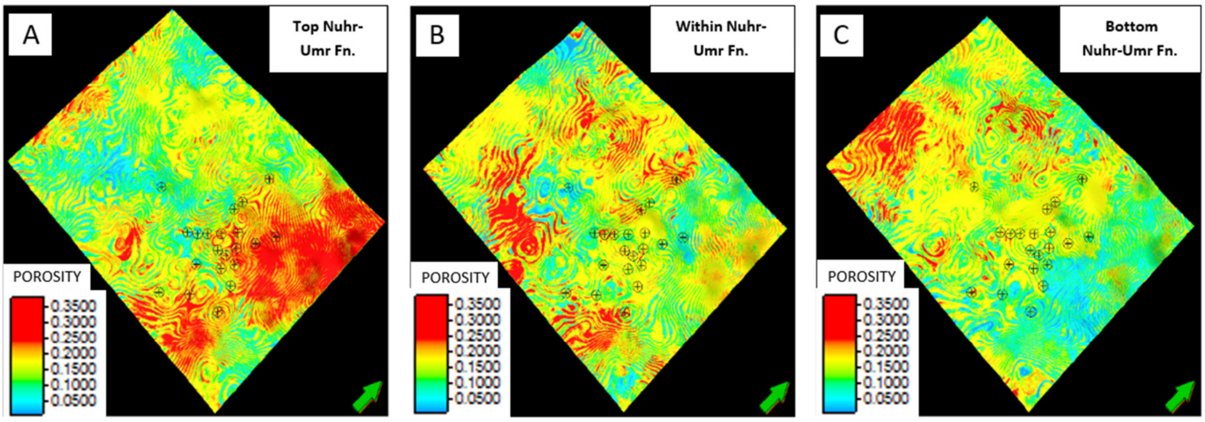

Figure 10. Total porosity maps construct at different levels within Nahr-Umr Formation.

3.3 Lithology prediction

In characterizing reservoirs it is best advantageous to recognize the lithology, associated porosity of rock, fluid content and lithofacies variation in target interval. The acoustic impedance inversion improved the interpretation for possible lithology discrimination, consequently, used as a key for separation of sand and shale facies. For more understanding the acoustic impedance relationship between different petrophysical properties of the reservoir, we preformed cross plots with porosity, Gamma Ray, and density logs. According to acoustic impedance and porosity maps the lateral facies of shale increased toward the north and northeast part of study area especially, at the top level of reservoir interval. Main while, vertically the acoustic impedance and porosity sections declare the shale facies dominated toward the top the formation as shown in Fig. (11), which support the acoustic impedance inversion and porosity transform results.

Discussion

The relative acoustic impedance inversion lacks in low frequency and affected by wavelet, therefore in the current study, the absolute acoustic impedance was executed to obtain a more reliable geological solution and acceptable results. This attribute to absolute acoustic impedance contain more bandwidth of frequency that derived frequency companion of seismic and well data. The missing of low frequency in seismic data is derived from well data to execute the absolute inversion. The main outcomes of seismic inversion are a profile illustrating the absolute variations in acoustic impedance and porosity and there is a good tie between acoustic impedance value derived from well and acoustic impedance inversion. The acoustic impedance sections show the low acoustic impedance values located at the upper part of formation reached to 6500 Kpa m/s and increased toward the bottom of formation reached to 11500 Kpa m/s corresponding to high porosity at the upper part of formation reached to 25% and porosity decreased toward the bottom of formation, this is could be to the effect of shale contain. Based on acoustic impedance maps with different reservoir interval (top, within and bottom of formation) through porosity maps (top, within and bottom of formation respectively) as shown in Fig. (10), shows porosity zones is more corresponding to low acoustic impedance parts. The discrimination of sand/shale facies on the acoustic impedance inversion could be very important to comprehend and realize the lateral facies variation and diminished exploration and drilling risks in the field. According to seismic porosity maps the total porosity improved toward the northeastern part at the top of the reservoir. The results of acoustic impedance inversion and porosity transform are consistent and confirms with well log measurement by using a GR log as a sand/shale cutoff of wells (Lu-2, Lu-4, Lu-5, Lu-11, Lu-12 and Lu-18) away from well location that illustrate the shale content increase, while the sandstone which is dominant on the middle and lower part of formation as shown in Fig. (11).

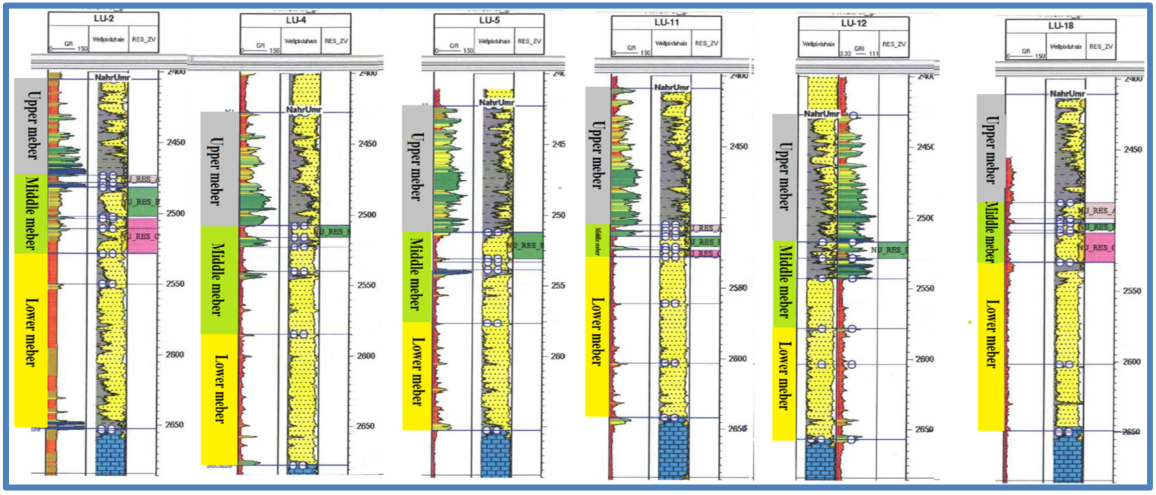

Figure 11. Gamma ray log and Lithology of wells (Lu-2, Lu-4, Lu- 5, Lu-11, Lu-12 and Lu-18) of Nahr Umr Formation, that illustrated increase of shale ratio in the upper member of Nahr-Umr Formation, while sand ratio was increasing in middle and lower members of Nahr-Umr Formation.

4- Conclusion

The convenient seismic data detailed petrophysical analysis and borehole information are important keys for enhanced reservoir quality prediction outcomes in clastic basins and provide a tool for further analyses of reservoir properties. The interpolation of well acoustic impedance based on the attributes to well data gives good results rather than based on distance between wells. The acoustic impedance outcomes denoted considerable lateral and vertical reservoir heterogeneity in Nahr-Umr Formation. The lateral quality of the reservoir is enhanced with porosity reached to 25% because of the increase of shale content. Reducing in sandstone porosity and quality deterioration is revealed via acoustic impedance and seismic porosity results. From the results of acoustic impedance inversion and seismic porosity reveal the shale thickness significantly increased toward eastern and northeastern part of the study area, therefore this corresponding to low acoustic impedance and high total porosity in the same region. The best quality within Nahr-Umr reservoir scale was found in the middle and bottom part of the reservoir interval because of the amount of shale contains decreasing toward bottom of the reservoir and contain high porosity sand bodies especially in the middle part that consistent with GR log data that declare the approximate results, note Fig. (11). Moreover, seismic inversion denoted lateral and vertical reservoir variation as a sand thickness reduces toward the north and northeast part of the field.

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