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3D Seismic to absolute acoustic impedance inversion of the Lower Devonian Tadrart Sandstone in Ghadames Basin, NW Libya

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Highlights
- **Improving the seismic interpretation by converting 3D post-stacked seismic data into 3D absolute acoustic impedance.**
- **Hydrocarbon detection by predicting 3D porosity from the 3D absolute acoustic impedance.**

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ABSTRACT

The aim of this study is to map 3D acoustic impedance from 3D post-stacked seismic data, and then predict 3D porosity values from the acoustic impedance results for the Lower Devonian Tadrart reservoir sandstone using seismic inversion. Theoretically, seismic inversion is the process of transforming seismic reflection data into qualitative rock properties such as acoustic impedance and porosity, which is also very important for reservoir evaluation. Seismic inversion can be performed on pre or post stacked seismic data, it can be applied when the conventional seismic interpretation may become misleading under certain conditions. Most of oil and gas companies use the seismic inversion to improve the seismic interpretation by removing the side lobes and tuning effects from seismic data, to improve the estimation of rock properties, and to increase resolution and reliability. Inversion of seismic reflection data for various lithological and petro physical attributes is broadly used for reservoir characterization and hydrocarbons detection. Rock property related attributes are easier to interpret than the seismic reflectivity, which is related to boundaries between zones of contrasting acoustic impedance properties. Broadly, the commonalities between all impedance type properties are in their relations to the values measured from the seismic traces. The fundamental problem is the lack of low-frequency information in the seismic data leading to many uncertainties in the solution. The absolute acoustic impedance inversion is the method that has been applied in this study, and it is applied in Hamra field, northwest Ghadames basin, the approach of this work by extrapolating the well logs information into the seismic properties, this is, in turn, better estimations of reservoir properties such as porosity and an additional benefit that the interpretation efficiency is greatly improved.

1. Introduction

The Lower Devonian Tadrart sandstone is the proven productive and prospective reservoir target in the study area. The application of absolute acoustic impedance inversion technique, using 3D post-stacked seismic data integrated with the borehole data. Acoustic impedance model, in turn, used to evaluate important reservoir characterizations and their implication on the petroleum entrapment.

2. Seismic Inversion Theory

Seismic inversion aims to put a spiked (earth's reflectivity) response at the geological boundaries (lithology changes) and the main reservoir characteristic interfaces. This is done by the inversion of the 3D seismic cube into 3D acoustic (or elastic) impedance cube. The link between the seismic cube and the acoustic impedance cube is the "seismic wavelet". In seismic acoustic impedance inversion, we assume that the seismic amplitudes represent a band-limited expression of the earth's reflectivity (at normal incidence), this is can be expressed by the convolution equation:

$$S(t) = r(t) * w(t)$$

For making more complicated equation by adding the noise function:

$$S(t) = r(t) * e(t) + n(t)$$

Where S(t) is the seismic trace, r(t) is the earth's reflectivity series, w(t) is the seismic wavelet, and n(t) is the noise. If we can determine the seismic wavelet then we can deconvolve it from the seismic trace to recover the earth's reflectivity series. For normal incidence, the reflectivity r(t) at a given layer boundary is determined by the contrast in acoustic impedance Z(t) between the layers and is given by:

$$r(t) = \frac{\rho_2 v_2 - \rho_1 v_1}{\rho_2 v_2 + \rho_1 v_1} = \frac{z_2 - z_1}{z_2 + z_1}$$

The Zoeppritz equations define the reflection coefficient for non-normal angles of incidence of a seismic pulse at Z(t) boundary, these equations are applied in a simplified form (e.g., Shuey,1985). By integrating r(t) we can obtain a band-limited measurement of acoustic and impedance, combining with additional information such as "low-frequency trend from well logs or seismic velocities" to obtain the absolute acoustic impedance. After getting the extracted wavelet from the 3D seismic data at all well locations, the

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next step is to run the low-frequency background model as part of the inversion process. Low-frequency model is also called "prior model" due to the low-pass filtering that in most cases is applied, such a prior model can be constructed by extrapolating laterally the calibrated impedance logs from well sites, then using a number of interpreted horizons as a model guide. The background geologic model provides the initial estimate of impedance values and provides constraints for subsequent updates in the internally iterative inversion procedure; one of these critical constraints includes the incorporation of these low-frequency components that are actually missing from the surface seismic data during the acquisition and/or the processing. Consequently, the background geologic model is used to control both inversion non-uniqueness and accuracy. The background model is often created from sparse well log data and seismic interpretation data using geostatistical procedures. Through geostatistics, well log information (e.g., P-wave impedance logs) is interpolated following the structure style within the project area to create the impedance volumes (Wang *et al.*, 2009).

Unfortunately, seismic acoustic impedance inversion has several limitations, the seismic frequency band is limited to about ~ 20Hz to 120Hz and the low- and high-frequency input data for inversion are missing, therefore using well log data will provide the information at these missing frequencies. Non-uniqueness of the solution is another problem, and seismic data can lead to multiple possible geologic models, which are consistent with the observations. In addition, in the inversion method itself, multiple reflections, transmission loss, geometric spreading and frequency-dependent absorption are ignored. The common way to reducing these uncertainties is to use additional information (mostly coming from well logs) which contains low and high frequencies and constrains the deviations of the solution from the initial-guess model. Therefore, the results rely on the seismic data as well as on this additional information, and on the details of the inversion methods themselves.

3. Rock Physical Properties

Rock physics is the science, which defines the relationship between measured elastic properties of rocks and reservoir properties. Accordingly, rock physics is the crucial link between geophysics, reservoir engineering and reservoir geo-mechanics. The ultimate goal of rock physics analysis is to gain insights into the physical properties of a reservoir. These can be bulk properties, or dynamic properties. A geophysical rock physic analysis uses the measured elastic properties from seismic data to generate attributes that yield information about the reservoir rocks.

Seismic reservoir properties are affected in complex ways by many factors, such as pressure, temperature, saturation, fluid type, porosity, pore type, etc. These factors are often interrelated or coupled in a way that may also change when one-factor changes. The effect of these changes on seismic data can be either additive or subtractive. As a result, investigation of the effect of varying a single parameter while fixing others becomes imperative in understanding rock physics applications to seismic interpretations. Several other sources of rock physics information that can be used to assist the analysts in understanding the study area, these other sources can be petrophysical, geophysical, and/or geological in nature. Ultimately, the more tools we use to assist in our understanding of the reservoir, the more we reduce the risk associated with an exploration/exploitation undertaking (Pelletier and Gunderson, 2005).

Rock physics modeling can help us understand the behavior of the reservoir and non-reservoir zones and correct for some of the problems encountered in well log data (Avseth *et al.*, 2001). It is the process of finding a rock physics model that is consistent with the available well data. One purpose of rock physics modelling is to allow reliable prediction and perturbation of seismic response with changes in reservoir conditions. The rock physics is part of the study area included the following steps:

1- Logs from all the wells were loaded and quality checked.

2- If there are missing sections in density log and/or sonic log, this issue can be solved using Gardner substitution based on the velocity information from the log data for all wells.

3- Geophysical acoustic impedance logs were generated from sonic and density relationship for each wells.

4- Porosity logs quality check and making sure that the porosity goes through the target of interest for all wells.

In general, when creating empirical models to describe the relationship between elastic properties and petrophysical properties using the regression function method, there are different ways of using simple regression functions. This approach can give good results within the data interval or the reservoir interval, which are used as input for the modeling, and sometimes-poor extrapolation from another data interval. The best extrapolation can be found by using an appropriate regression function. If the regression function is chosen fluid or lithology independent, then it can be proven that rock physics is consistent through the formation. This method can only work in case the relationship between elastic properties and petrophysical properties linear relationship. Figs. 1, 2 and 3 show cross plots between porosity and acoustic impedance logs using well 1, well 2, and well 3 for the Tadrart reservoir sandstone.

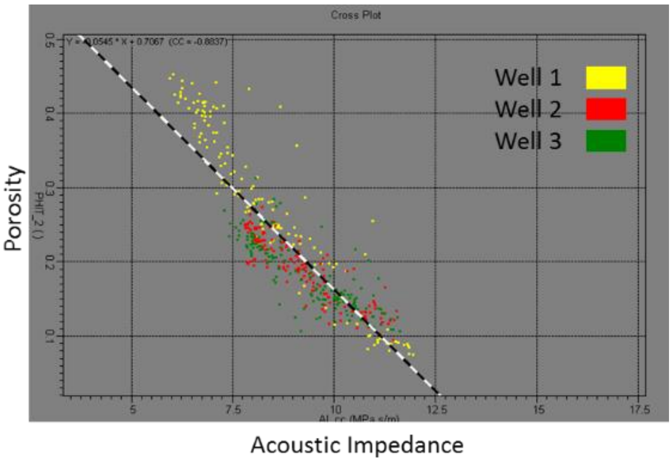

Fig. 1. Cross plot between porosity and acoustic impedance logs using the wells; well 1, well 2, and well 3, within Tadrart D1 formation, indicated a good linear relationship.

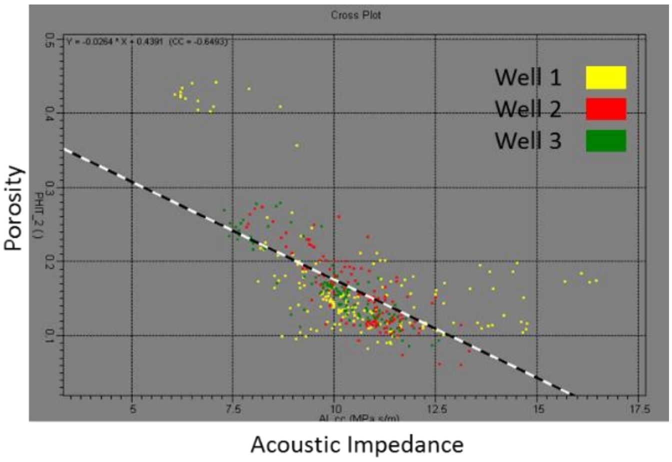

Fig. 2. Cross plot between porosity and acoustic impedance logs using the wells; well 1, well 2, and well 3, within Tadrart D2 formation, indicated a poor to good linear relationship.

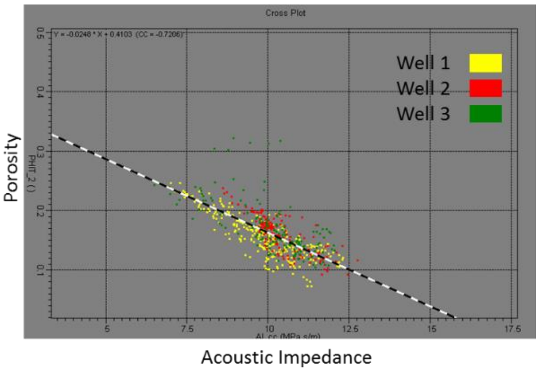

Fig. 3. Cross plot between porosity and acoustic impedance logs using the wells; well 1, well 2, and well 3, within Tadrart D3 formation, indicated a good linear relationship.

4. Inversion and Porosity Results.

High resolution of the absolute acoustic impedance inversion will reduce the uncertainty about reservoir by increasing well information and greater confidence and accuracy in modeling the reservoir. The result of acoustic impedance model achieved with high resolution when comparing it with seismic data, the inversion resolution is increased and the interpretation of data are improved. The acoustic impedance model is related to the important physical properties of the reservoir target. Figs 4, 5, and 6 showing modeling of the porosity distribution from seismic data is achieved through a strong correlation between the acoustic impedance model and the porosity model of the Tadrart reservoir sandstone, this can be used as a guide in reducing drilling risk in some interesting drilling locations.

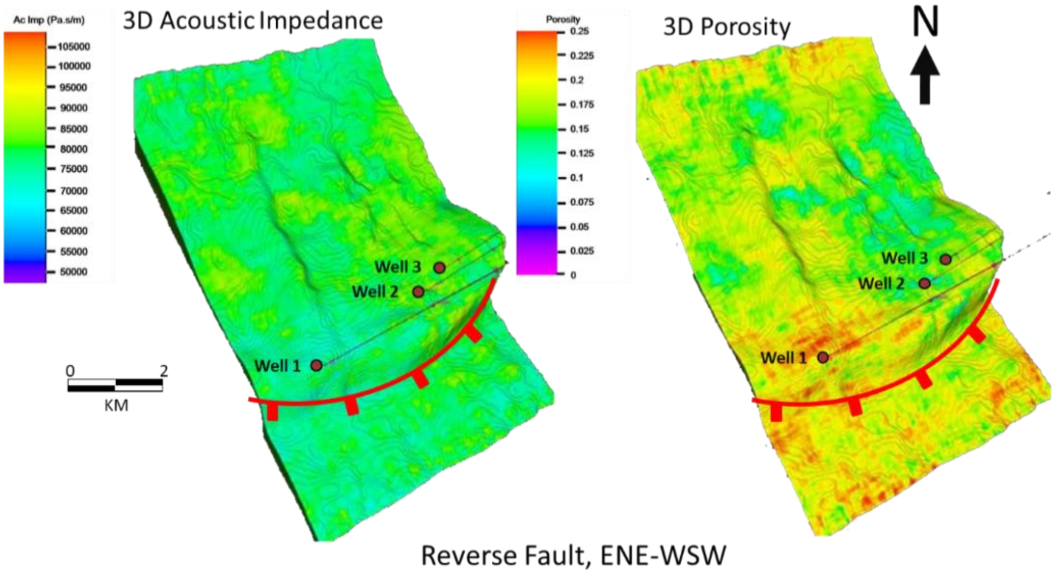

Fig. 4. Comparisons between 3D acoustic impedance model (left) and 3D porosity model (right), for Tadrart D1 formation.

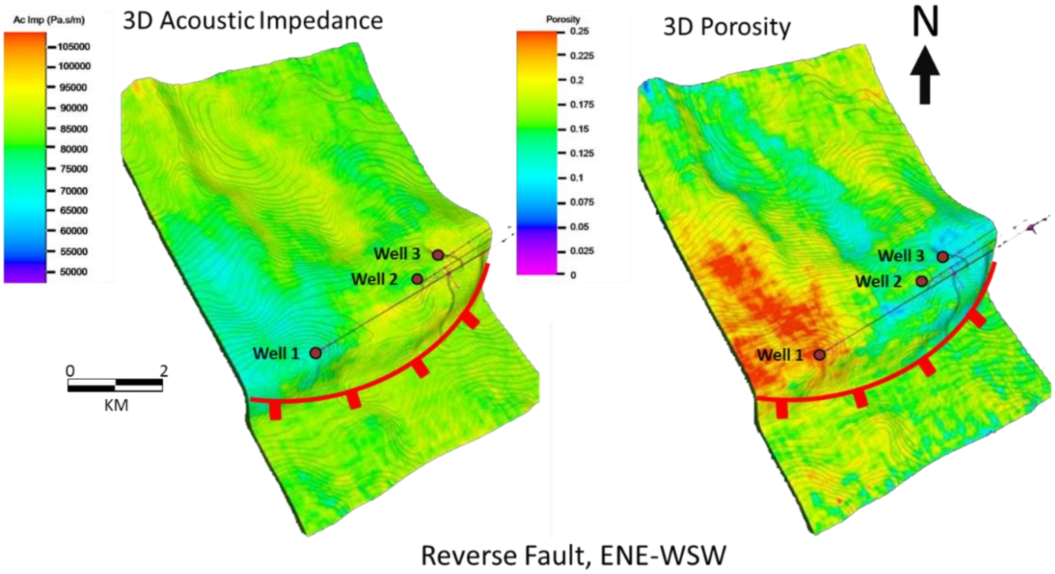

Fig. 5. Comparisons between 3D acoustic impedance model (left) and 3D porosity model (right), for Tadrart D2 formation.

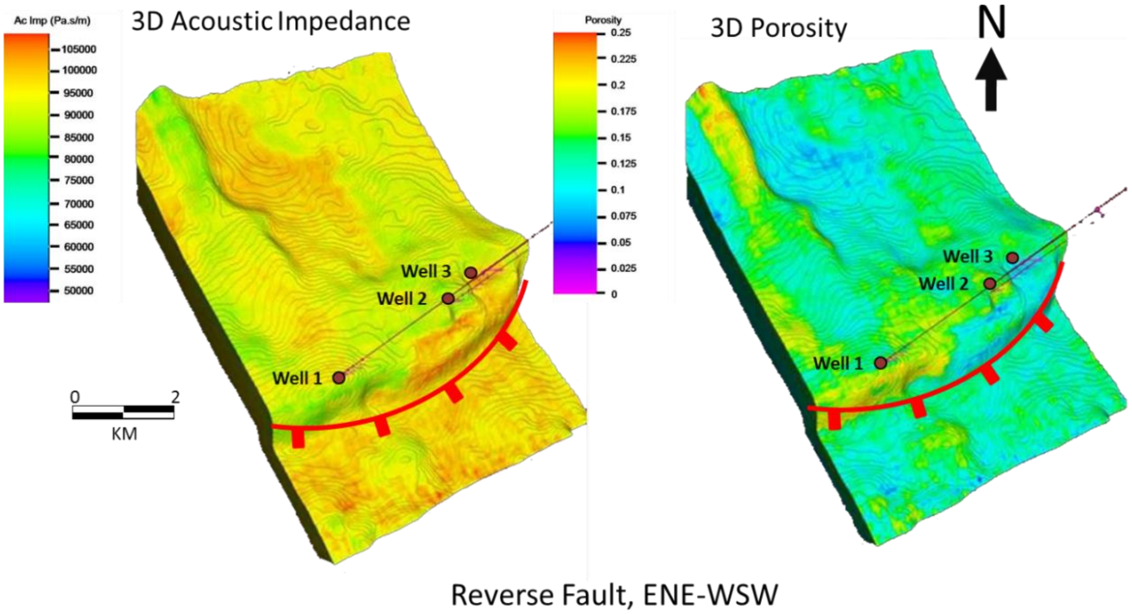

Fig. 6. Comparisons between 3D acoustic impedance model (left) and 3D porosity model (right), for Tadrart D3 formation.

5. Discussion

The ultimate goals of absolute acoustic seismic inversion are to identify reservoirs, delineate them, and determine the distribution of their relevant physical properties, which will provide an early determination of the reservoir economic potential.

The resulted acoustic impedance model captures the main characteristics of all well acoustic impedance logs, and comparing it with the acoustic impedance log at the well 1 is highly correlated with small quantitative deviations. The model was used to predict the acoustic impedance results in the two other wells; well 2, and well 3, the prediction deviation for them are also similar to well 1. The acoustic impedance models for the reservoir target of Tadrart formation tops at all well location generally show a good match with the acoustic impedance log, except in some intervals of Tadrart formation, where the match somehow was not clear enough. This could be related to the seismic resolution in these intervals or the complexity of the physical properties that could not be modeled.

The resulted porosity model captures the main characteristics at well 1, although not with the same precision at the other two wells. The variation in the porosity and acoustic impedance well logs are much larger and less smooth in the transitions. The porosity model shows difficulty in the continuity in some locations is mainly because the model is based on the seismic data, which have lower resolution than the well logs. Actually, the porosity values are smoothed and averaged out in the model compared to the porosity at the well.

The relationship between acoustic impedance and porosity is lithology dependent and can be approximated as a linear relationship for each lithological unit, this means that to apply a non-varying linear function to the acoustic impedance results, derived from seismic data, to estimate porosity, is only valid for a uniform geology. Porosity – acoustic impedance equations were derived for: Tadrart D1, Tadrart D2, and Tadrart D3 formations separately, which showed a strong empirical relationship existed between acoustic impedance and porosity distribution.

The porosity maps had a significant impact on defining prospective drilling locations, increased priority was given in some locations corresponding to the higher porosity zones (~15% to 25%) and in some locations the porosity was decreased (bellow to 10%), with these results, well placement can be designed to maximize contact with high porosity zones in these formations. Finding these high porosity zones within the Tadrart reservoir sandstone is very important for oil entrapment taking in account the major fault structure trend ENE-WSW that is associated with good trapping mechanism.

Regarding all the acoustic impedance and the porosity results, it is highly recommended to drill a well within these high porosity anomalies especially around the well 1, however, the Tadrart-D2, and Tadrart-D3 are the most interested zones to be drilled in order to increase the oil production of the Tadrart sandstone.

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