Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2025, 12(2):25-32**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Well-to-Seismic Tie: A key Step for Seismic Interpretation

Ngeri A. P. [1], Dieokuma T. [2]

[1]Department of Physics, Rivers State University, PMB 5080, Port Harcourt, Nigeria
[2]Depatyment of Physics, Federal University, Otuoke, Bayelsa State
Corresponding Author's Email: paddyngeri@gmail.com

Abstract: The accurate interpretation of seismic data for reservoir characterization relies heavily on a proper well-to-seismic tie. If the process of synthetic generation goes wrong, the interpretation can also go wrong, leading to the drilling of dry wells. This study employs a detailed approach to well-to-seismic tie, involving the construction and matching of a synthetic seismogram to a real seismic trace. Features from the well are correlated to the seismic data, ensuring an accurate representation of subsurface geological structures. The synthetic seismogram demonstrates a notable match between the seismic and synthetic data outside the reservoir intervals, further validating its accuracy. The primary goal of this research is to obtain information on sediments, correlation formation tops, and seismic reflectors. The generated synthetic seismic data can be used for further studies in reservoir characterization evaluation (Waters, 1987; Yilmaz, 2001). Synthetic seismic data provides a controlled and accurate representation of subsurface geological structures, enabling detailed analysis and evaluation of reservoir properties (Sheriff, 2002; Aulia et al., 2013).

Keywords: Synthetic Seismogram, well-tie, check-shot, Time Depth Relation, reflection Coefficient, Acoustic Impedance

1. Introduction

The accurate interpretation of any seismic data for reservoir characterization lies in proper well-to-seismic tie, if the process of synthetic generation goes wrong the interpretation could also go wrong, leading to the drilling of dry wells. Well ties are a very important phase of the job of the geologist and the geophysicist. It provides means of correctly identifying the right horizon to pick, and estimating the wavelet for inverting seismic data to impedance (White and Simm, 2003).

Seismic-to-well tie generation is a critical process in petroleum geophysics that integrates seismic data with well data to validate seismic interpretations and predict subsurface geological structures (Sheriff, 2002; Yilmaz, 2001). Well-tie analysis is a starting point for mapping facies and geology observed at well locations into seismic volumes. This step is very important for any analysis that uses seismic and well data together and can secure more accurate results by increasing consistency between seismic and well-log data. A high-quality well tie is normally considered as the art of an interpreter and is usually practiced through the stretch and squeeze of the synthetics log (Saberi, 2018).

The continuous increased demands for quantitative interpretation methods demand a perfect tie between well and seismic data for any reservoir characterization workflow, whether amplitude variation with offset, impedance or neural network based (Inichinbia and Sule, 2021). Qualitatively tied to synthetic seismic generation is achieved through proper editing and conditioning of the sonic and density logs.

Well-tie analysis is a procedure that confirms consistency between well logs and seismic data at well locations by achieving good correlation between seismic data in time and log data in depth. This helps identify sought-after horizons from well logs as reflection events on the seismic and forms the foundation for structural interpretation, geologic modeling, and advanced seismic characterization methods such as seismic inversion (Saberi, 2018).

Well-tie is very important, and it is often overlooked by seismic interpreters during reservoir studies and seismic inversion (Carvajal et al., 2023) when it's being overlooked, it can lead to the drilling of dry wells. Making the wrong pick can make a big disaster to geological interpretation (White and Simm, 2003). A good well-to-seismic tie requires a proper wavelet estimation. According to Inichinbia and Ahmed, 2020, the goal behind seismic-to-well ties is to obtain information on the sediments, calibration of seismic processing parameters, correlation of formation tops and seismic reflectors, and the derivation of a wavelet for seismic inversion among others.

seismic-to-well tie compares seismic data around the vicinity of well location with log data from the well. This requires at least a calibrated sonic log and calibrated density log for the generation of the synthetics seismic (Inichinbia and Ahmed, 2020).

According to Saberi, 2018, a good well tie depends primarily on the quality of the well log, seismic data and secondarily on the extracted wavelet (phase and amplitude). Well-ties are instrumental in integrating seismic and well data, ensuring that reflections from seismic are linked to specific geological markers in the well. The use of synthetic seismograms enhances the correlation process, and adjustments to time-depth relationships contribute to the accuracy of this correlation. The result is a more comprehensive and reliable interpretation of the subsurface, aiding decision-making in exploration and production activities in the oil and gas industry (Cameron, 2023).

The integration of seismic-to-well tie generation has numerous benefits in the interpretation of seismic data for reservoir characterization, such benefits are improved seismic interpretation (Yilmaz, 2001), it increased confidence to validates seismic-derived geological models (Brown, 2011) it facilitates more accurate reservoir modeling and prediction by reducing uncertainty leading to more reliable predictions of reservoir performance and hydrocarbon recovery (Kallweit & Wood, 1982). By tying seismic data to well logs, reservoir properties such as porosity, permeability, and fluid saturation can be estimated more accurately. Despite its benefits, well-to-seismic tie generation poses challenges, primarily stemming from data quality issues. Poor data quality can significantly compromise the accuracy of ties, leading to misleading interpretations and reduced confidence in seismic-derived geological models (Waters, 1987). Complex geological structures, such as faults, folds and unconformities, can significantly complicate the well-to-seismic tie generation process, making it challenging to establish accurate time-depth relationship (Badley, 1985). Uncertainty in wavelet estimation can significantly impact the accuracy of synthetic seismograms (Waters, 1987; Yilmaz, 2001), potentially leading to misleading correlations between seismic data and well logs and compromising the reliability of subsequent geological interpretations (Sheriff, 2002).

The primary objective of seismic-to-well tie generation is to correlate seismic reflections with geological formations encountered in wells, so as to accurate map subsurface structures (Badley, 1985). This research focuses on the generation of synthetic seismic data, which can be used for further studies in the evaluation of reservoir characterization (Waters, 1987; Yilmaz, 2001). The synthetic seismic data generated in this study provides a controlled and accurate representation of subsurface geological structures, enabling detailed analysis and evaluation of reservoir properties (Sheriff, 2002; Aulia et al., 2013).

2. Well Tie Generation

When a geophysicist or a geologist is presented with well log data and seismic data, they attempt to integrate the two datasets to understand their geological relationship. Specifically, they aim to correlate the top of a sand unit in the well log data with the corresponding horizon on the seismic data, using well as a calibration point.

Well-seismic ties allow well data, measured in units of depth, to be compared to seismic data, measured in units of time. This allows the interpreter to relate horizon tops identified in a well with specific reflections on the seismic section. Sonic and density well logs are used to generate a synthetic seismic trace. The synthetic trace is compared with the real seismic data collected near the well location. The well to seismic tie is the bridge the interpreter needs to migrate from seismic wiggles to the rocks that produced the wiggles and the interpretation of the subsurface geology.

To tie seismic data to well logs, four steps are required. The first step involves editing the sonic and density well logs. Sonic and density logs can both contain anomalies that need to be removed such as high amplitudes due to cycle skipping and poor tool-borehole contact. This process also involves de-spiking the logs, truncating any anomalous values and smoothing the logs to prevent stratigraphic attenuation. These spurious events may need to be clipped, or the logs smoothed. Smoothing the logs may also be done to account for the stratigraphically induced velocity dispersion caused by the difference between seismic and sonic frequencies (Heather and Margrave, 2013; White and Simm, 2003).

In the second step, the calibration of the log is taken into consideration. This step is also known as well log calibration, the sonic log is calibrated to check-shot or VSP data. Since the velocities from seismic data is different from the velocities that the sonic tools measure, a calibration step is needed. This calibration step is important as the velocity that seismic waves experience is not the same as the velocity that sonic logging tools estimate.

The primary objective of calibration in sonic logging is to establish a drift curve using check-shot data. This curve enables corrections to the sonic log, ensuring its accuracy by aligning it with known travel time values derived from check-shots or Vertical Seismic Profiling (VSP) data. The resulting calibrated sonic log provides reliable travel time values (Harishidayat, 2023). Figure 1 shows a schematic diagram of sonic log and check-shot logs before and after calibration. After calibrating the check-shot and sonic log data, the resulting difference between the sonic log and check-shot times is defined as the drift curve. Ideally, this curve should exhibit a smooth profile with minimal time variations as a function of depth (Heather and Margrave, 2013)

The most common way to do this is to use check-shot data, however when this data is not available the calibration can be computed from an attenuation (Q) estimate or by matching seismic events to events on the synthetic (Heather and Margrave, 2013).

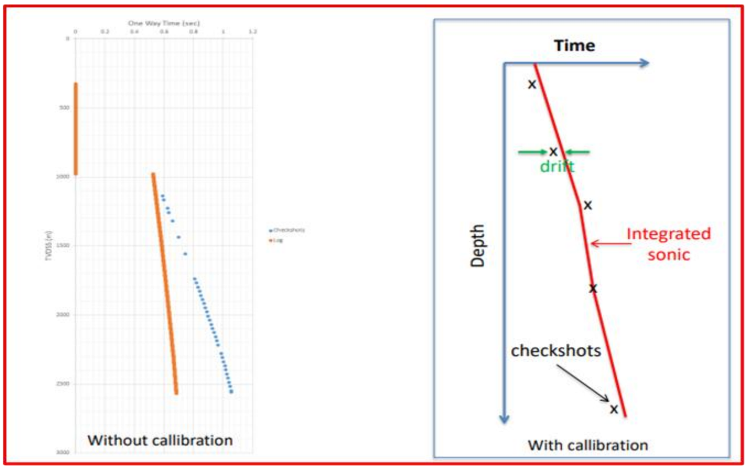

Figure 1: Sonic and Check-shot data before and after calibration (Harishidayat, 2023)

Well, log calibration requires the check-shot or VSP data to be in depth time pairs. The time depth relationship is calculated, and a residual slowness is calculated between the check-shot data and the sonic log. The residual slowness is then added to the sonic log resulting in the calibrated sonic log output (Heather and Margrave, 2013).

The second step is the most important step in carrying out well to seismic tie, as this affect the timing of the synthetic. A mismatch in time is significantly more detrimental than a mismatch in amplitudes (White, 1997). Ideally this involves calibrating the integrated sonic times with measured check-shot or VSP times. To create a time-depth relationship, the integrated sonic times and the check-shot or VSP times are compared at equal depths. These depth points are also known as knee points and should correspond to a reflector to reduce artificial coefficients being introduced in the corrected sonic log.

The third step includes the calculation of the time-depth relationship using the calibrated sonic log and the calculation of reflection coefficients from the sonic and density. The reflection coefficients are also calculated using the calibrated sonic and combined with the density to calculate the impedance ($Impedance = density \times Velociy$)

In carrying out well to seismic tie, well log data recorded in depth are converted to time, or seismic volume recorded in time are converted to depth, so as to make a two-way conversion link. This process is referred to as time depth relationship (TDR). To achieve this TDR there are many techniques used to achieve it, such techniques are the use of seismic logs, check-shots, or vertical seismic profiling (VSP). Combination of any of these techniques will lead to an improved result. When such data sets are not available, stacking velocities that are derived from seismic data can be used as the last options to achieve TDR. The disadvantage of the stacking velocity is that, the output is poor when compared with other techniques such as sonic logs (Saberi, 2018).

Check-shots are indeed used to calibrate the relationship between well depth and seismic travel times calculated from a sonic log, by integrating the sonic log data, with check shot data, geophysicist can determine the time - depth relationship (TDR) and improve the accuracy of seismic interpretations. TDR is crucial for accurately tying well data to seismic data, enabling seismic interpreters to correlate subsurface geological features.

In the final step, the reflected coefficient is convolved using a mathematical operation, also known as the convolution model, with the extracted wavelet estimated from the seismic data. This process generates the synthetic seismogram. To obtain a good correlation between the seismic and synthetic data, the two are correlated to achieve a good match. This process is crucial, as it validates the accuracy of the synthetic seismogram and ensures reliable interpretation of the seismic data

Generally well-tie analysis, computes reflectivity from velocity and density, converts it from depth to time, and convolves it with an estimated wavelet to generate a synthetic trace, as shown in Figure (2). Finally, the goodness of fit between synthetic and seismic trace is increased through an iterative process known as "stretch and squeeze" to achieve a high cross-correlation between both traces (Saberi, 2018). The application of stretch and squeeze method to compensate for other problems with sonic and density logs seems unscientific and definitely not good practice (White and Simm, 2003). Figure 3 shows the four steps for the workflow for well-to-seismic tie generation.

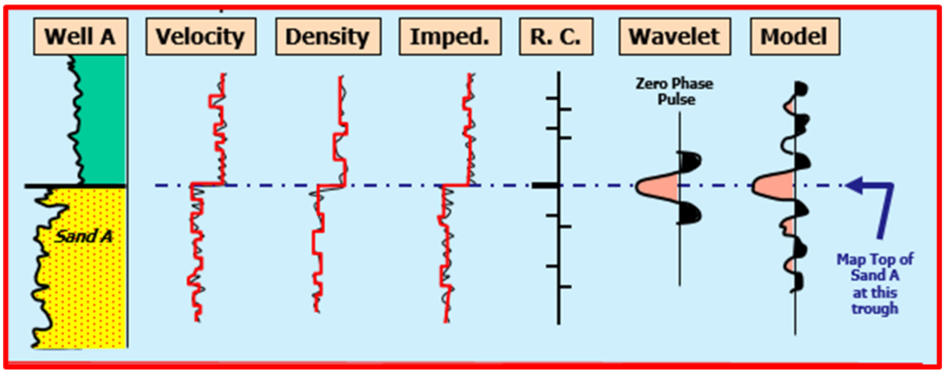

Figure 2: Well-to-Seismic Tie FWSchroeder

3. Material and Methods

Petrel software package was used in carrying out this work, the data used was a secondary data set from Shell Petroleum Development Company (SPDC). In order to achieve the expected result, the research was done in six states; in the first stage, both the seismic data and well log data were loaded into Petrel software, the data were quality checked to identify anomalous zones and areas of interest (Ngeri et al., 2024). In the second stage, the well log data was checked for the presence of washout and bad traces. Bad traces were removed so as to delineate the effects of error during petrophysical analysis or synthetic generation processes. Cycle skipping, caused by spiky sonic logs often result in artificial events that can be mistaken for real reflectors where corrected before they were used to calculate petrophysical parameters (Imikanasua et al., 2022). In the third stage, seismic interpretation was carried out, where we identified key horizons of interest. In the fourth stage, petrophysical analysis and well correlations were carried out. In the fifth stage, synthetic seismogram was generated. Finally, in the sixth stage, seismic-to-well tie was carried. Figure 4 shows the workflow of the research.

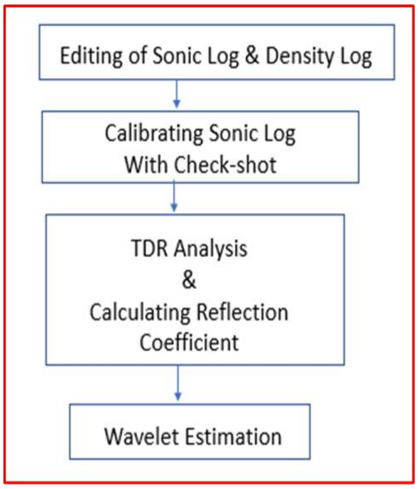

Figure 3: workflow for well-to-seismic tie generation

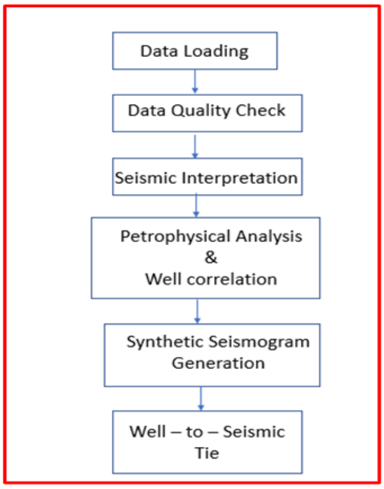

Figure 4: Research Workflow

4. Results and Discussions

The study area comprises six wells, namely Well 1, Well 2, Well 3, Well 4, Well 5, and Well 6, with varying log types as summarized in Table 1. Notably, Well 3 lacks log information, while Well 1 and Well 2 are devoid of Neutron and density logs. Additionally, Well 1 and Well 4 do not have sonic logs, whereas Well 5 and Well 6 possess all log types, including sonic and density logs, making them suitable for well-to-seismic tie. Ultimately, Well 5 was chosen for the well-to-seismic tie due to its deeper penetration into the zone of interest compared to Well 6, as illustrated in Figure 5. Figure 6 shows the stratigraphic correlation of the reservoir of interest.

Figure 7 illustrates the pre-calibration window, displaying the significant discrepancy between the check-shot and sonic log travel times. To address this, the check-shot travel times were utilized to calibrate the sonic log. As evident in the first and second tracks of Figure 7, the initial drift curve was substantial. However, following the calibration process as shown in Figure 8, the drift curve between the check-shot and sonic log data was dramatically reduced, aligning with the observations made by Heather and Margrave (2013).

Table 1: Log types present in each well

Log Type	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6
GR	YES	YES	NO	YES	YES	YES
Caliper	YES	NO	NO	YES	YES	YES
Resistivity	YES	YES	NO	YES	YES	YES
Sonic	NO	YES	NO	NO	YES	YES
Neutron	NO	NO	NO	YES	YES	YES
Density	NO	NO	NO	YES	YES	YES
SP	YES	YES	NO	YES	YES	YES

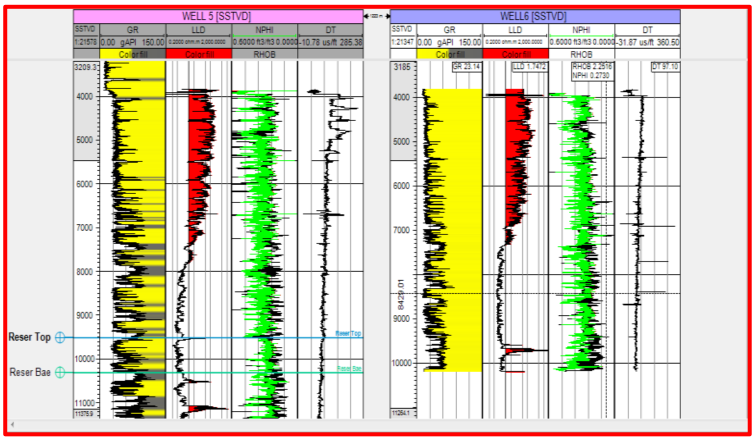

Figure 5: Display of Well 5 and 6 showing the depth of both wells

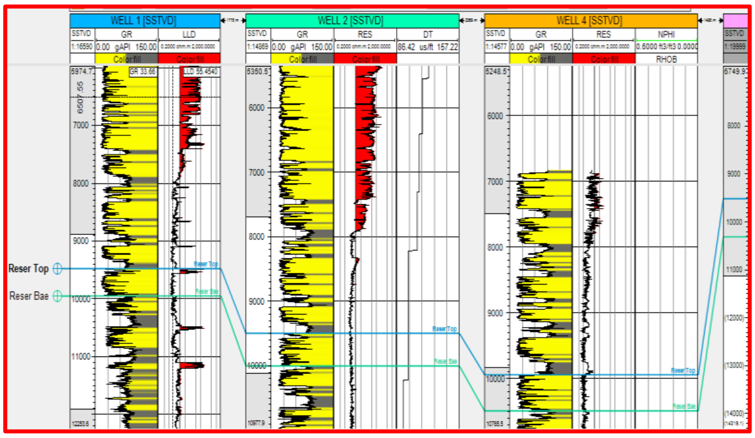

Figure 6: Diagram showing the correlation of the various wells in the study area.

Three distinct methods were employed for wavelet estimation in synthetic generation: analytical, statistical, and deterministic approaches (Figure 9a, 9b, and 9c, respectively). These figures illustrate the amplitude, frequency, and phase spectra for each method. Following evaluation, the deterministic method (Figure 9c) was selected for wavelet estimation due to its suitability for this application. Additionally, the Figure also displays a juxtaposed comparison of the seismic data close to the well location and the synthetic data, facilitating a direct visual evaluation. The synthetic seismogram is overlaid on the seismic data in Figure 10. Notably, the top and bottom of the reservoir intervals exhibit accurate matching between the synthetic seismic data and the actual seismic data. This correlation enables reliable identification of the sand horizon on the seismic data. There is also a notable match between the seismic and synthetic data outside the reservoir intervals, further validating the accuracy of the synthetic seismogram in those intervals.

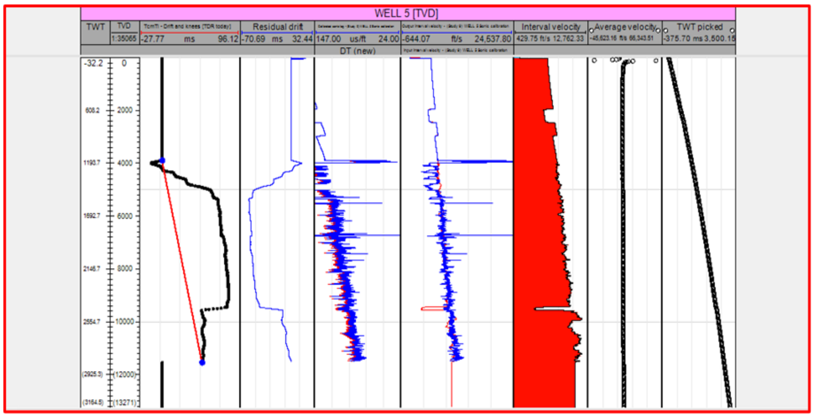

Figure 7: Pre-well log calibration for well 5

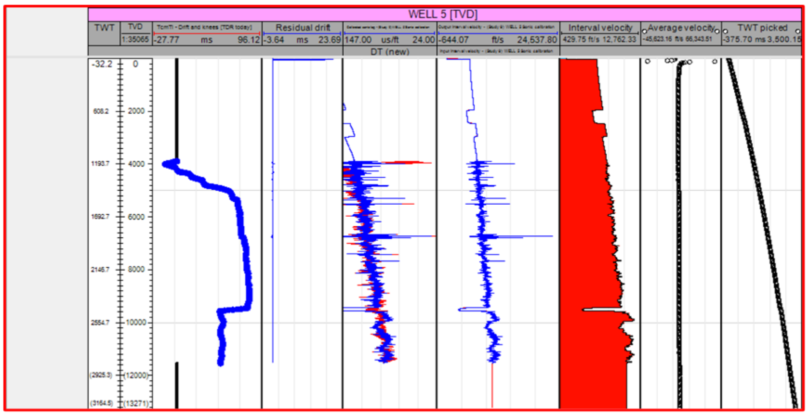

Figure 8: Well log calibration for well 5

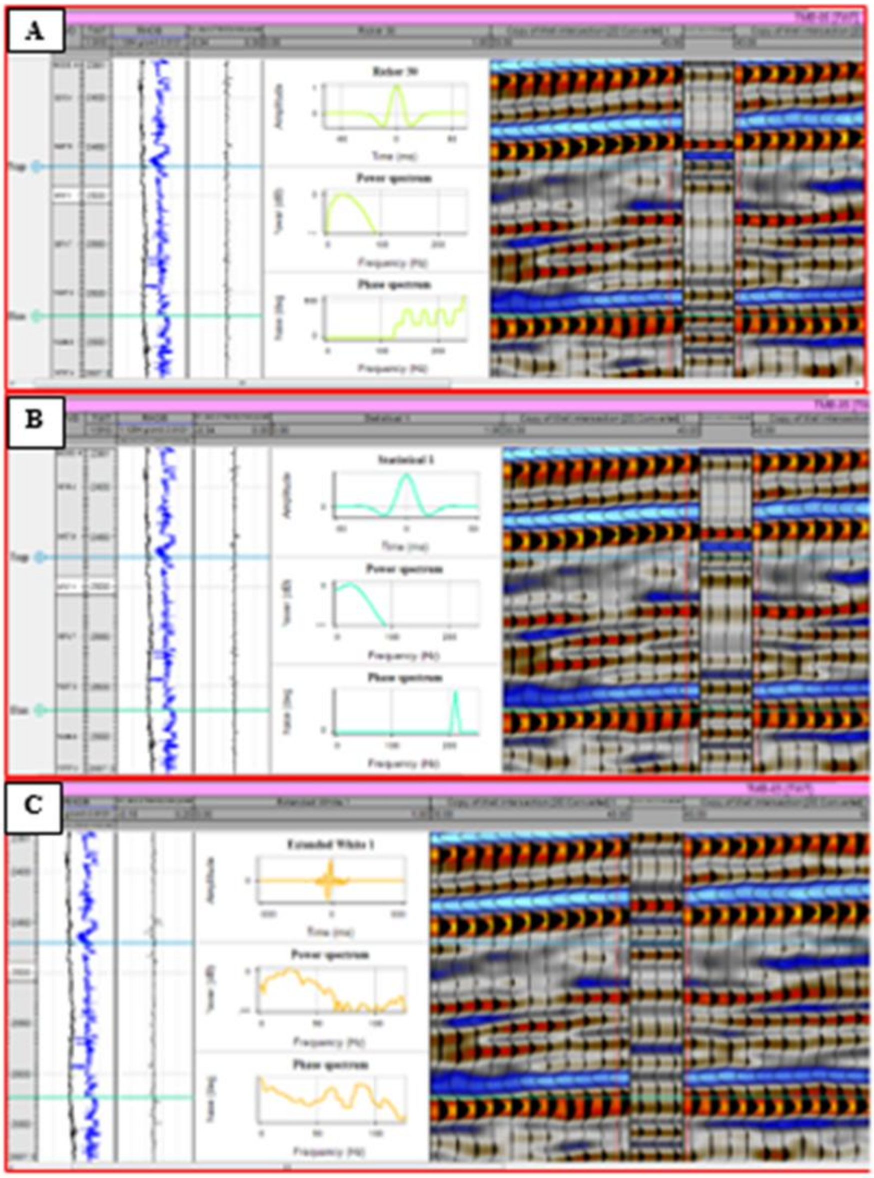

Figure 9: Wavelet Estimation and Synthetic Seismic Data Comparison

(a) Analytical, (b) Statistical, and (c) Deterministic wavelet estimation methods, showing their respective amplitude, frequency, and phase spectra, along with a juxtaposed comparison of the seismic data within the well and the synthetic data.

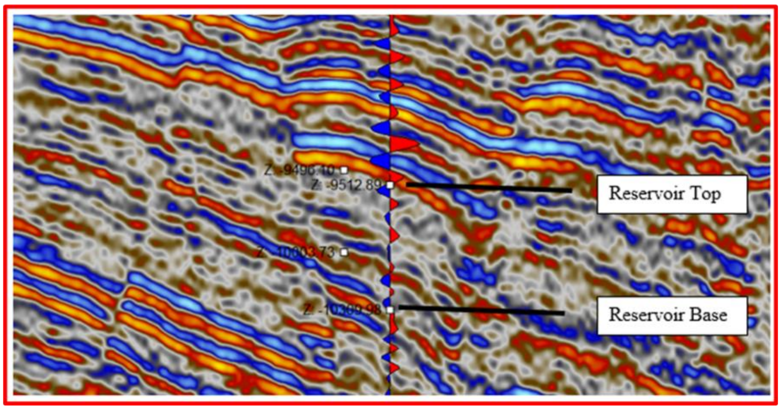

Figure 10: Synthetic Seismogram Overlay on Seismic Data

5. Conclusion

In conclusion, this study demonstrates the importance of a proper well-to-seismic tie for the enhancement of accurate reservoir characterization. The successful generation and matching of synthetic seismic data to real seismic traces validate the reliability of this approach. The results of this study provide valuable insights into subsurface geological structures, enabling informed decision-making for exploration and production activities. The methodology presented here can be applied to future studies, enhancing the accuracy and effectiveness of reservoir characterization.

Acknowledgment

The authors are very grateful to Shell Petroleum Development Company for the privilege and permission given to us to use their data for academic advancement.

Reference

[1]. Aulia, K., Rahmat, A., & Widarto, D. S. (2013). Synthetic seismic data generation for reservoir characterization. Journal of Applied Geophysics, 98, 141-148.

[2]. Badley, M. E., (1985). Practical seismic interpretation. International Human Resources Development Corporation.

[3]. Brown, A. R., (2011). Interpretation of three-dimensional seismic data. Society of Exploration Geophysicists.

[4]. Cameron, D., (2023). Well Ties. Linkedin.com/pulse/well-ties-denc-cameron-55she/

[5]. Carvajal, C., Jorge, F., & Aristimuno, J., (2023). Well Tie Tutorial and its importance in Seismic Interpretation

[6]. and Inversion. Geoconvention.

[7]. Harishidayat,.D., (2023). Seismic Well Tie. Conference: Seismic interpretation lecture at MSc Petroleum Geosciences programmed - Norwegian University of Science and Technology. DOI: 10.13140/RG.2.2.31685.32486

[8]. Heather, J.E., & Margrave, G.F., (2013). The Art of Well Tying With New MATLAB Tools. CREWES Research Report 25

[9]. Imikanasua, D., Tamunobereton-Ari, I., & Ngeri, A.P., (2022). Determination of Reservoir Quality in Field "D" in Central Niger Delta, Using Well Log Data. Asian Journal of Applied Science and Technology (AJAST) 6 (1), 142-151.

[10]. Inichinbia, S., & Ahmed, A.L., (2020). Seismic-To-Well Tie Of A Field Of The Nigerian Delta. Scientia Africana, Vol. 19 (3), 125-138.

[11]. Inichinbia, S., & Sule, P.O., (2021). Well-to-Seismic Tie of a Field Onshore of the Nigerian Delta. J. Appl. Sci. Environ. Manage. 25 (1) 53-58.

[12]. Kallweit, R. S., & Wood, L. C., (1982). The limits of resolution of zero-phase wavelets. Geophysics, 47(8), 1035-1046.

[13]. Ngeri, A. P., O.A. Davies1, Dieokuma, .T., (2024). Application of Coherence Attribute for Prospect Identification. Journal of Scientific & Engineering Research, 11(8), 125 – 131.

[14]. Saberi, M.R., (2018). Rock-physics-assisted well-tie analysis for structural interpretation and seismic inversion. The Leading Edge. 908-914.

[15]. Sheriff, R. E., (2002). Encyclopedic dictionary of applied geophysics. Society of Exploration Geophysicists.

[16]. Waters, K. H., (1987). Reflection seismology: A tool for energy resource exploration. John Wiley & Sons.

[17]. White, R. E., & Simm, R., (2003). Tutorial - Good Practice in Well Ties. First break. Volume 21.

[18]. White, R.E., 1997, The accuracy of well ties: Practical Procedures and Examples: Expanded Abstract

[19]. RC1.5, 67th SEG Meeting, Dallas.

[20]. Yilmaz, O., (2001). Seismic data analysis: Processing, inversion, and interpretation of seismic data. Society of Exploration Geophysicists.