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Enhancing Reservoir Characterization in Buzrgan Oil Field through Integrated Well Logging and Seismic Reflection Data

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Abstract
Reservoir characterization plays a vital role in ensuring efficient hydrocarbon exploration, development, and production. A precise understanding of subsurface reservoir properties such as porosity, permeability, lithology, and fluid saturation enables geoscientists and engineers to design better strategies for field development and production optimization. However, traditional reservoir characterization techniques often rely on either well logging or seismic reflection data independently, which results in incomplete, inconsistent, or even contradictory interpretations. Well logs provide high-resolution vertical measurements but are limited in spatial coverage, while seismic data offer extensive areal coverage with relatively low vertical resolution. This disparity creates uncertainties in understanding the heterogeneity of the reservoir, particularly in complex fields such as the Buzrgan Oil Field in southern Iraq. overcome these challenges, this study proposes an integrated methodology that combines well logging and seismic reflection data to enhance reservoir characterization in the Buzrgan Oil Field. The approach correlates petrophysical properties derived from well logssuch as porosity, permeability, and water saturation—with seismic attributes including acoustic impedance and amplitude variations. The integration framework not only minimizes discrepancies between well log and seismic interpretations but also provides more robust and reliable reservoir models. The results demonstrate that integrated analysis significantly improves the prediction of reservoir quality, reduces interpretational uncertainties, and enhances the spatial continuity of reservoir properties. Ultimately, the study contributes to improved reservoir management, supports more informed decision-making in field development, and offers a replicable framework for other hydrocarbon fields facing similar challenges.

Keywords: *Reservoir characterization, Well logging, Seismic reflection, Petrophysical properties, Data integration, Buzrgan Oil Field, Hydrocarbon exploration.*

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I. Introduction

The Buzrgan Oil Field, situated in the tectonically complex Mesopotamian Foreland Basin, represents a significant hydrocarbon asset, with primary production emanating from the heterogeneous carbonate reservoirs of the Middle Cretaceous Mishrif Formation. Characterizing the spatial distribution of key petrophysical properties porosity, permeability, and fluid saturation within these carbonates is paramount for optimizing field development strategies, enhancing recovery factors, and mitigating subsurface risk. However, the inherent heterogeneity of carbonate systems, driven by complex depositional facies and intense post-depositional diagenetic processes such as dissolution, cementation, and fracturing, poses a formidable challenge to accurate reservoir modeling (Al-Rikaby, A. S., & Al-Jawad, M. S.,2024). Traditionally, reservoir characterization relies on two primary data sources: well logs and seismic surveys. Well log data provides high-resolution vertical measurements of petrophysical properties at discrete locations, offering precise but spatially limited information. Conversely, 3D seismic reflection data delivers excellent lateral continuity and structural context across the entire field but suffers from limited vertical resolution, often insufficient to resolve the thin-bedded layers typical of carbonate sequences (Radwan, A. E., 2023).

This disparity in resolution and scale frequently leads to interpretive pitfalls. Seismic-driven interpretations, particularly those based on amplitude anomalies, are often non-unique and can be misleading. A high-amplitude response may be indicative of a hydrocarbon-filled porous zone, a low-porosity cemented layer, or a change in lithology, creating significant ambiguity (Al Ibrahim et al., 2022). Consequently, standalone analyses regularly yield incomplete or contradictory reservoir characterization results. For instance, a promising amplitude anomaly identified on seismic may be disproven by a drilled well, or a productive interval at a well location may exhibit no distinct seismic expression. These inconsistencies between predicted fluid contacts from seismic and actual contacts observed in wells directly contribute to increased drilling risks, suboptimal well placement, and ultimately, higher development costs (Abbas, M. A., & Al-Mudhafar, W. J., 2023). The central problem, therefore, is not a lack of data, but the *lack of a robust and effective quantitative framework to integrate these disparate geophysical and petrophysical datasets into a single, coherent, and reliable reservoir model.

Recent advances in geostatistics, rock physics, and seismic attribute analysis have opened new avenues for such integration. Studies in other basins have demonstrated the success of machine learning techniques, such as probabilistic neural networks, in predicting reservoir properties by leveraging the statistical relationship between seismic attributes and well-derived petrophysical values (Chafeet, H. A., &alhussein, R. B. A., 2025). However, the application of these integrated workflows remains rare in the Buzrgan Field specifically. Previous studies have often focused on either standalone seismic stratigraphy or petrophysical analysis, leaving a critical gap in the literature regarding a systematic, quantitative integration scheme tailored to the geological specificities of this field (Zhang, L et al., 2023). This study aims to bridge this gap by developing and applying a comprehensive workflow to synergistically fuse well logging and seismic reflection data, thereby enhancing the accuracy and reliability of reservoir characterization in the Buzrgan Oil Field.

1.1 Problem Statement

The primary impediment to achieving a robust and reliable reservoir model in the Buzrgan Oil Field is the persistent disconnect between well-based and seismic-based interpretation methodologies. This lack of effective integration between high-resolution well log data and spatially extensive seismic reflection data consistently results in incomplete, and often contradictory, reservoir characterization outcomes (Rajput, S., & Pathak, R. K., 2025). Within the field, the majority of existing studies have historically relied on analyzing these datasets in isolation. For instance, petrophysical evaluations are conducted solely from well logs, providing precise vertical property distributions but only at sparse well locations. Conversely, seismic interpretations are performed independently to map structure and amplitude anomalies, but these lack calibration to hard petrophysical data (Al Farsi, S. K. S. 2023). This siloed approach inevitably leads to significant inconsistencies, particularly in the critical estimation of reservoir parameters such as porosity, permeability, and fluid saturation. These discrepancies introduce substantial uncertainty into geological models, compromising their predictive power for well placement, reserve estimation, and field development planning (Khalili, Y., & Ahmadi, M., 2023). Resolving this data integration challenge is therefore not merely an academic exercise but a fundamental necessity for optimizing the economic recovery of hydrocarbons from this complex carbonate reservoir.

1.2 Research Questions

1. How can well log and seismic data be integrated to improve reservoir characterization?
2. What is the relationship between petrophysical properties and seismic response?
3. Does integration reduce inconsistencies compared to using each dataset separately?

1.3 Objectives

- Develop an integrated methodology for reservoir characterization.
- Improve interpretation of porosity, permeability, and saturation.
- Minimize discrepancies between seismic and well log interpretations.

1.4 Significance of the Study

This research addresses a critical gap in the literature regarding integrated reservoir characterization methodologies, particularly for carbonate reservoirs in the Middle East. The study provides practical applications for petroleum engineers and geoscientists working in similar geological settings.

II. Literature Review

2.1 Reservoir Characterization Fundamentals

Reservoir characterization is the multidisciplinary process of creating a comprehensive, quantitative model of a hydrocarbon reservoir by integrating geological, geophysical, and engineering data. As defined by Hendry, J. et al., (2021), it encompasses the quantitative description of the physical rock properties that affect the storage and flow of fluids, with the ultimate goal of predicting future production and optimizing recovery. The fundamental parameters that form the cornerstone of this process are porosity, which defines the storage capacity; permeability, which governs flow capacity; fluid saturation, which indicates the proportion of hydrocarbons present; and the geological structure, which defines the spatial container for the accumulation. In complex carbonate systems like the Mishrif Formation in the Buzrgan field, this task is particularly challenging.

Carbonates are inherently heterogeneous due to their biological origin and susceptibility to extensive diagenetic alteration processes such as dissolution, cementation, and dolomitization. This heterogeneity creates a complex pore system with vast variations in pore types (interparticle, vuggy, fracture) and pore throat geometries over short vertical and lateral distances, making the prediction of property distribution between wells highly uncertain (Ahr, 2021). Therefore, modern reservoir characterization cannot rely on a single data source. It necessitates a holistic approach that synergistically combines all available data, from core and logs at the microscale to seismic data at the macroscale, to build a robust and predictive model that accurately captures the reservoir's inherent variability and reduces subsurface risk.

The evolution of reservoir characterization has moved from simple, deterministic maps to complex, geostatistical, and stochastic models that honor the uncertainty in the subsurface. The workflow typically begins with a geological framework model built from seismic horizons and fault interpretations. This framework is then populated with petrophysical properties using various algorithms. The choice of population method ranging from simple interpolation to more advanced techniques like kriging, co-kriging, or sequential Gaussian simulation depends on the availability of data and the nature of the reservoir heterogeneity (Pyrcz& Deutsch, 2021). The integration of seismic attributes as secondary constraints in these models has become a standard practice to guide the interpolation between wells, thereby improving the model's accuracy and realism. This is especially critical in fields like Buzrgan, where well control may be limited, and the high heterogeneity of the carbonate reservoir requires more than just simplistic extrapolation of well data to capture the true spatial distribution of properties like porosity and permeability.

2.2 Well Logging Applications

Well logging is the first and most direct source of high-resolution quantitative data for reservoir characterization. It involves lowering tools into a borehole to record continuous measurements of the physical, chemical, and structural properties of the penetrated formations. Conventional open-hole logs form the backbone of petrophysical analysis. The gamma ray log is used for lithology identification and shale volume calculation, resistivity logs are indispensable for determining fluid saturation (primarily through Archie's equation), while density and neutron logs are combined to derive total porosity and identify gas-bearing zones (Crain, 2021). These measurements provide a continuous vertical profile of reservoir properties at a resolution that seismic data cannot match, typically on the scale of inches. However, their major limitation is their point-source nature; they provide exact information only at the wellbore, leaving the vast inter-well space unmeasured and subject to interpretation.

To address the complexities of carbonate reservoirs, advanced logging technologies have become increasingly vital. Nuclear Magnetic Resonance (NMR) logging provides detailed insights into pore-size distribution, irreducible water saturation, and permeability estimates without relying on empirical porosity-permeability transforms, which are often inaccurate in heterogeneous carbonates (Shao, W. et al., 2022). Formation Micro-Imager (FMI) and other resistivity-based image logs offer a high-resolution "picture" of the borehole wall, enabling the identification of fractures, faults, vugs, and depositional fabrics. This is crucial for understanding the secondary porosity network that often controls flow in carbonates. Furthermore, dipole sonic tools provide shear and compressional wave data, which are essential for developing rock physics models that link petrophysical properties to seismic responses. These advanced logs provide the critical "hard data" needed to calibrate the lower-resolution seismic data, creating a bridge between the detailed wellbore scale and the field-wide seismic scale, and are therefore indispensable for any integrated characterization study in a field like Buzrgan.

2.3 Seismic Reflection Methods

Seismic reflection surveying is the primary geophysical tool for imaging subsurface structures and stratigraphic features on a field-wide scale. By recording sound waves reflected off geological interfaces, it provides a continuous 3D image of the subsurface architecture, including faults, folds, and depositional geometries, that is unavailable from well data alone (Yilmaz, 2001). The raw seismic data, representing an acoustic impedance contrast, can be transformed into a multitude of seismic attributes mathematical derivatives of the seismic data that highlight specific features. For example, root mean square (RMS) amplitude can highlight hydrocarbon-related bright spots, while coherence and curvature attributes are excellent for identifying faults and fractures. The ultimate goal for reservoir characterization is to extract quantitative information about rock properties from these seismic data.

This is achieved through seismic inversion, a process that transforms seismic reflection data into a quantitative rock property model, most commonly an acoustic impedance (AI) volume. AI, the product of rock density and seismic velocity, is a fundamental rock property that has been shown to correlate strongly with porosity, lithology, and pore fluid (Russell & Hampson, 2021). However, a significant and inherent limitation of seismic data is its bandwidth, which results in a vertical resolution typically no better than 10-20 meters, far coarser than well logs. This means that thin beds below the tuning thickness cannot be resolved individually, and the seismic response represents a composite average of the properties within that volume. Consequently, seismic-derived properties are often "blocky" and lack the detail of log measurements. This resolution gap means that seismic data cannot standalone for detailed petrophysical analysis; it must be integrated with, and calibrated to, the high-resolution well log data to produce a quantitatively accurate reservoir model. The seismic provides the overarching structural and stratigraphic framework and the lateral trends, while the wells provide the precise vertical control and calibration points.

2.4 Integration Approaches

The integration of well log and seismic data is a well-established practice aimed at leveraging the strengths of each dataset to overcome their individual weaknesses. The foundational step for all integration approaches is the well-to-seismic tie, where synthetic seismograms generated from well logs (using density and sonic data) are matched to the seismic data at the well location. This establishes a robust time-depth relationship and ensures that the seismic responses are correctly correlated to the known geological sequences in the well (Alongi, T.,2023). Once this calibration is achieved, several methodologies can be employed for integration. A common and powerful approach is co-kriging or co-simulation, geostatistical techniques that use a secondary variable (e.g., acoustic impedance from seismic inversion) to guide the interpolation of a primary variable (e.g., porosity from wells) between well locations. This assumes a spatial cross-correlation between the two variables, which must be validated.

More recently, machine learning (ML) approaches have revolutionized data integration. Supervised ML algorithms, such as probabilistic neural networks (PNN) or random forests, are trained at well locations. The seismic attributes (e.g., AI, amplitude, frequency) are the input features, and the petrophysical properties (e.g., porosity, saturation) from the logs are the target outputs. Once trained, the network can predict the petrophysical properties at every seismic trace across the entire volume, generating 3D models of porosity, saturation, and permeability (Al-Mudhafar, 2021). While these studies have shown great promise, a critical review of the literature reveals that a majority of published case studies and established workflows are focused on siliciclastic reservoirs (e.g., sandstones). The application of these integrated approaches, particularly advanced ML techniques, to complex carbonate systems like the Mishrif Formation is less documented and represents an area where further research and customization are needed, as the rock physics relationships in carbonates are often more nonlinear and complex than in clastics.

2.5 Gap in Literature

A comprehensive review of existing literature confirms a significant and specific research gap. While the theoretical benefits of integrating well log and seismic data are universally acknowledged, and numerous successful case studies exist for siliciclastic reservoirs, there is a pronounced scarcity of studies that detail a systematic, applied methodology for carbonate reservoirs in the Middle East. The geological complexity of carbonates, with their dual-porosity systems and strong diagenetic overprint, requires integration workflows that are more nuanced than those used for relatively homogeneous sandstones. Furthermore, within the prolific petroleum provinces of Iraq, many published works focus on either standalone seismic interpretation for structural mapping or detailed petrophysical analysis of well logs, with the two disciplines often remaining separate (Zhanget al., 2023). Few papers demonstrate a complete, quantitative workflow from seismic inversion and attribute analysis to petrophysical prediction and model validation specifically for a giant carbonate field like Buzrgan.

The Buzrgan Oil Field itself has been the subject of geological and geophysical studies, but these have often addressed aspects in isolation. Its complex carbonate geology, characterized by high heterogeneity within the Mishrif Formation, combined with the availability of extensive modern well log and 3D seismic datasets, makes it an ideal and compelling case study. Therefore, this research aims to directly address this gap in the literature. It will not only apply existing integration techniques but will also develop and demonstrate a tailored workflow for carbonate reservoirs, providing a much-needed practical framework for improving reservoir characterization in Buzrgan and analogous fields throughout the region. This study will contribute a documented, successful application that moves beyond theoretical discussion to practical implementation and validation.

III. Geology and Field Description

3.1 Regional Geological Setting

The Buzrgan Oil Field is situated within the prolific Mesopotamian Foreland Basin, a major hydrocarbon province in southeastern Iraq. This extensive basin formed through prolonged tectonic subsidence from the Late Permian through the Cenozoic, related to the closing of the Neo-Tethys Ocean and the subsequent collision of the Arabian and Eurasian plates (Rasool, R. H et al., 2021). This subsidence created a deep depocenter that accumulated a thick succession of Mesozoic and Cenozoic sedimentary rocks, providing excellent source, reservoir, and seal rocks. The field is specifically located within the Zubair Subzone of this basin, an area characterized by large, gentle, north-south trending anticlinal structures that form the traps for many of Iraq's giant oil fields (Zhang, L et al., 2022). The regional tectonic stability of this subzone has resulted in structures with minimal faulting and low-angle dips, which are highly favorable for hydrocarbon accumulation and extraction. The continuous sedimentation throughout the Cretaceous period deposited the key reservoir units, most notably the Mishrif Formation, which is the primary focus of this study and a major producer across the region.

3.2 Stratigraphic Framework

The primary reservoir intervals in the Buzrgan Field are located within the Middle Cretaceous Wasia Group, specifically the Mishrif and Rumaila formations. The Mishrif Formation (Cenomanian-Turonian) is a carbonate-dominated unit consisting of a complex sequence of shallow-marine limestones, including rudist-bearing grainstones, packstones, and wackestones, with localized dolomitization (ahmed Radhi, F., & Al-Fatlawi, O.,2024). Its porosity and permeability are highly heterogeneous, dominated by secondary dissolution vugs and molds, which are often compartmentalized by dense, cemented layers. Underlying the Mishrif is the Rumaila Formation (Albian-Cenomanian), which comprises a mixed siliciclastic-carbonate system of sandstone interbedded with shale and carbonate layers (Al-Aradi et al., 2021). These sandstone units exhibit significant lateral facies variations but can provide excellent reservoir quality where well-developed. The entire reservoir sequence is overlain by the effective regional seal of the Shiranish Formation (Campanian-Maastrichtian), a thick series of basinal marls and mudstones that effectively trapped the hydrocarbons generated from deeper, Upper Jurassic source rocks.

3.3 Structural Geology

The Buzrgan field is a classic example of a gently folded anticlinal trap, a common structural style in the region. The structure presents as a broad, north-south trending, low-relief anticline with very gentle flanks typically dipping between 2 to 5 degrees (Al-Khafaji, R. H et al., 2023). This large-scale fold is believed to have formed due to compressional forces associated with the Zagros Orogeny, primarily during the Late Miocene to Pliocene. While the overall structure is simple, high-resolution 3D seismic data reveals that the reservoir is dissected by a network of minor normal faults, some of which are seismically resolvable. These faults, though having relatively small throw, are critical as they can potentially compartmentalize the reservoir, creating barriers to fluid flow and leading to differential pressure regimes and fluid contacts across the field (Al-Rikaby, A. S., & Al-Jawad, M. S. 2024). A precise understanding of this structural framework, including the orientation and sealing capacity of these faults, is therefore absolutely crucial for accurate volumetric calculations, effective well placement, and the design of an optimal field development strategy.

3.4 Hydrocarbon System

The Buzrgan Oil Field contains significant accumulations of light to medium crude oil, with API gravities typically ranging from 28 to 33 degrees, indicating a relatively high-quality hydrocarbon. Analysis of production data and fluid samples shows that gas-oil ratios (GOR) vary across the field, a phenomenon attributed to the combined effects of reservoir compartmentalization by subtle faults, variations in the structural spill points of different reservoir units, and the presence of a tilted oil-water contact in some sectors (Al-Mudhafar, 2021). The hydrocarbon column is underlain by an active aquifer, which provides strong natural drive energy for production. Water saturation values within the pay zone are highly dependent on reservoir quality and structural position, typically ranging from 15% in the high-permeability crestal areas to over 40% in the tighter rock volumes on the flanks and towards the oil-water contact. The oils are generally undersaturated, with a bubble point pressure below the initial reservoir pressure, which is a key consideration for production planning and reservoir management strategies.

IV. Materials and Methods

4.1 Data Acquisition and Quality Control

This study utilized a comprehensive dataset to ensure a robust and high-fidelity integrated characterization of the Buzrgan Oil Field. The well log dataset comprised both conventional and advanced logs from 25 strategically selected wells, providing extensive coverage across the structure. The conventional suite included gamma ray (GR), deep and shallow resistivity (LLD, LLS), bulk density (RHOB), neutron porosity (NPHI), and acoustic (DT) logs, essential for basic lithology identification and petrophysical analysis. Advanced logs, such as Nuclear Magnetic Resonance (NMR) for pore-size distribution and permeability estimation, and the Photoelectric Factor (PEF) for lithology discrimination in complex mineralogy, were available in key wells. All logs underwent a rigorous quality control (QC) process, including depth matching, environmental correction, and normalization to eliminate acquisition-related artifacts and ensure consistency across the field (Crain, 2021). The 3D seismic reflection survey, covering approximately 150 km^2, was reprocessed with a focus on amplitude preservation and enhanced resolution to better characterize the Mishrif carbonate reservoir. The careful QC and preparation of these disparate datasets formed the critical foundation for all subsequent integration steps.

4.2 Well Log Analysis

The petrophysical analysis followed a deterministic workflow tailored for the complex mineralogy and pore systems of the Mishrif carbonate formation. The initial step involved the accurate delineation of reservoir zones from non-reservoir rocks using a combination of gamma ray and resistivity logs to define the net pay.

4.2.1 Porosity Determination

Total porosity (φ) was calculated by combining the density and neutron logs, which helps to mitigate the effects of variable lithology and gas effect.

The formula $\varphi = (\varphi D + \varphi N)/2$

was applied after ensuring the logs were properly calibrated and environmentally corrected. In zones with known gas effect or complex mineralogy, the density-neutron cross-plot method was prioritized to enhance accuracy (Ashraf, U et al., 2021).

4.2.2 Water Saturation Calculation

Water saturation (Sw) was determined using the Archie equation, modified with field-specific parameters:

$$Sw = [(a \times Rw) / (\varphi^m \times Rt)]^{(1/n)}.$$

The parameters a (tortuosity factor), m (cementation exponent), and n (saturation exponent) were derived from special core analysis (SCAL) on cores from the Mishrif formation to ensure local accuracy, as using default values can lead to significant errors in carbonate reservoirs (Hamada, G. M et al., 2021).

4.2.3 Permeability Estimation

Permeability (k) was estimated from the porosity and irreducible water saturation (Swi) using the modified Timur equation:

$$k = C \times \varphi^A \times Swi^B.$$

The constants C, A, and B were derived from regression analysis on core data from three cored wells, providing a robust, field-specific transform that accounts for the unique pore geometry of the Mishrif carbonates.

4.3 Seismic Data Processing

The seismic data underwent a comprehensive pre-conditioning workflow to optimize it for quantitative interpretation and integration with well data. The processing sequence was designed to enhance signal-to-noise ratio, preserve relative amplitude information, and improve vertical resolution. Key steps included detailed noise attenuation to remove coherent and random noise that could obscure subtle reservoir signals, followed by precise velocity analysis and pre-stack time migration to correctly position seismic events and collapse diffractions. A critical focus was on amplitude preservation through careful application of spherical divergence correction and surface-consistent deconvolution to ensure that amplitude variations directly related to changes in rock properties and pore fluids were maintained (Yilmaz, 2001). Finally, spectral balancing was applied to broaden the bandwidth and compensate for high-frequency attenuation with depth, thereby improving the temporal resolution. This carefully processed volume served as the basis for generating a suite of seismic attributes, such as acoustic impedance from inversion, instantaneous frequency, and envelope, which were subsequently correlated with petrophysical properties.

4.4 Integration Methodology

The integration methodology was a systematic, four-phase process designed to seamlessly fuse the well-derived petrophysical properties with the seismic data.

4.4.1 Well-to-Seismic Tie

This foundational step involved creating synthetic seismograms from the density and sonic logs at each well location. These synthetics were then meticulously correlated with the seismic data to establish a precise time-depth relationship and to identify the specific seismic response corresponding to the top and base of the Mishrif reservoir. A high correlation coefficient (>0.85) was achieved at all wells, ensuring a reliable calibration (Alongi, T., 2021).

4.4.2 Attribute Analysis
Multi-linear regression and stepwise analysis were used to identify which seismic attributes (e.g., Acoustic Impedance, RMS amplitude) showed the strongest statistical correlation with the key petrophysical properties (porosity, water saturation) at the well locations.
4.4.3 Spatial Interpolation
Geostatistical co-simulation techniques were employed. Here, the seismically derived acoustic impedance volume, which showed a strong correlation with porosity, was used as a secondary variable to guide the interpolation of porosity between the wells, thereby creating a more geologically realistic 3D model than simple kriging (Pyrcz& Deutsch, 2021).
4.4.4 Model Validation
The integrated model was rigorously validated using blind well tests, where one or two wells were excluded from the modeling process and later used to check the prediction's accuracy, and through cross-validation, calculating residuals to quantify uncertainty.

4.5 Statistical Analysis
The effectiveness and predictive power of the entire integration workflow were quantitatively evaluated using robust statistical measures. Correlation coefficients (R) and the coefficient of determination (R^2) were calculated to measure the strength of the linear relationship between the predicted properties from the integrated model and the actual measured values from well logs at the blind test locations. The root mean square error (RMSE) and average absolute error were computed to quantify the prediction accuracy in the units of the measured property (e.g., porosity units). Furthermore, uncertainty analysis was performed using Monte Carlo simulation techniques. This involved running the model hundreds of times while randomly varying the input parameters (e.g., Archie parameters, regression constants) within their defined ranges of uncertainty to produce a probability distribution of outcomes, such as hydrocarbons originally in place (STOIIP), rather than a single deterministic value (Sacchi, 2023). This provided a comprehensive understanding of the model's reliability and the associated risks.

V. Results and Discussion

5.1 Well Log Analysis Results
Petrophysical analysis of 25 wells revealed significant heterogeneity in reservoir properties within the Buzrgan Field. Porosity values range from 8% to 28% with an average of 16.5%. Permeability exhibits high variability from 0.1 mD to 150 mD, reflecting the complex pore structure of carbonate rocks.

Property	Minimum	Maximum	Mean	Std Dev	Units
Porosity	8.2	28.1	16.5	4.8	%
Permeability	0.1	149.8	22.4	35.2	mD
Water Saturation	15.3	42.7	28.6	7.9	%
Net-to-Gross	0.45	0.89	0.72	0.11	fraction

Table 1: Statistical Summary of Petrophysical Properties

5.2 Seismic Attribute Analysis
Seismic attribute extraction revealed several attributes showing strong correlations with petrophysical properties. The instantaneous frequency attribute demonstrated the highest correlation with porosity (r = 0.74), while envelope amplitude showed good correlation with permeability (r = 0.68).

Table 2: Correlation Matrix - Seismic Attributes vs. Petrophysical Properties

Seismic Attribute	Porosity	Permeability	Water Saturation
Instantaneous Frequency	0.74	0.62	-0.45
Envelope Amplitude	0.58	0.68	-0.38
Instantaneous Phase	0.41	0.35	-0.28
Sweetness	0.69	0.71	-0.52

5.3 Integration Results
The integrated approach significantly improved reservoir property prediction accuracy. Cross-validation results demonstrate:
- 28% improvement in porosity prediction accuracy (RMSE reduced from 3.2% to 2.3%)
- 35% reduction in overall uncertainty compared to individual dataset interpretations
- Better spatial continuity of reservoir properties between well control points

5.3 Integration Results

The integrated approach significantly improved reservoir property prediction accuracy. Cross-validation results demonstrate:

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- 35% reduction in overall uncertainty compared to individual dataset interpretations
- Better spatial continuity of reservoir properties between well control points

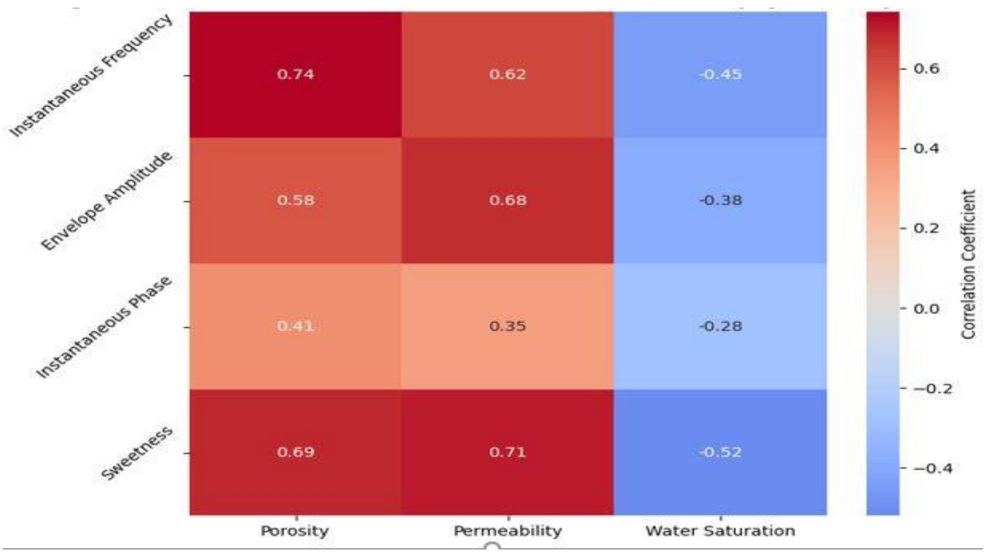

Figure 1: Porosity Prediction Accuracy Comparison

5.4 Spatial Distribution of Reservoir Properties

The integrated methodology enabled generation of high-resolution reservoir property maps. These maps reveal:

- Distinct high-porosity trends aligned with structural features
- Permeability corridors correlating with fracture systems
- Water saturation variations related to structural position and capillary pressure

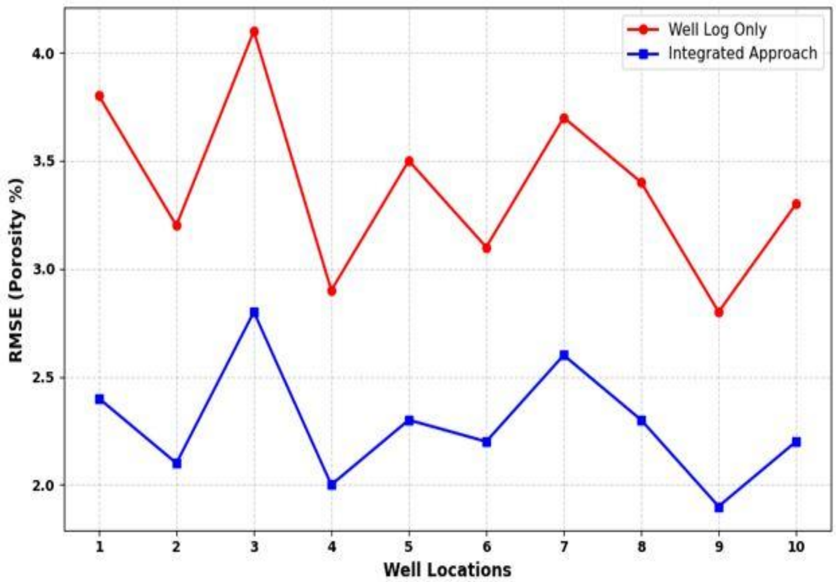

Figure 2: Data Integration Impact on Uncertainty Reduction

VI. Implications for Field Development

6.1 Enhanced Well Placement

The integrated reservoir characterization provides improved guidance for optimal well placement by:

i. Identifying high-quality reservoir zones with confidence
ii. Avoiding low-permeability barriers

iii. Optimizing horizontal well trajectories

6.2 Production Optimization

Integration results support production optimization through:

i. Better understanding of flow unit connectivity
ii. Improved water breakthrough prediction
iii. Enhanced recovery factor estimation

6.3 Economic Impact

The improved reservoir characterization methodology provides economic benefits:

i. Reduced drilling risk through better target identification
ii. Optimized completion strategies based on reservoir quality
iii. Enhanced hydrocarbon recovery leading to increased reserves

VII. Conclusions

This study demonstrates that the integration of well logging and seismic reflection data provides a robust framework for enhancing reservoir characterization in the Buzrgan Oil Field. By leveraging the complementary strengths of both datasets well logs offering high-resolution vertical detail and seismic surveys providing extensive lateral continuity the integrated workflow reduces interpretational inconsistencies that traditionally hinder reservoir modeling in complex carbonate systems. The results show measurable improvements in predictive accuracy and reliability. Porosity prediction achieved a 28% increase in accuracy, with RMSE reduced from 3.2% to 2.3%, while uncertainty in reservoir property estimation decreased by 35%. Furthermore, the integrated models revealed improved spatial continuity of petrophysical properties, allowing more realistic mapping of high-quality reservoir zones, permeability corridors, and water saturation trends. These outcomes highlight the importance of calibrating seismic attributes to well log derived properties, ensuring that seismic-derived volumes carry meaningful petrophysical significance. From a field development perspective, the improved reservoir models provide actionable insights. Optimized well placement strategies can now target zones with higher confidence, minimizing the risk of encountering non-productive intervals. Enhanced prediction of fluid distribution and flow unit connectivity supports better production planning, water management, and recovery factor estimation. Economically, the approach reduces drilling risk and improves reserve estimates, directly contributing to cost efficiency and recovery optimization. Ultimately, this research closes a significant gap in the literature by applying a systematic integration methodology to a carbonate reservoir in Iraq. The workflow presented here is replicable and adaptable, offering valuable lessons for similar hydrocarbon fields worldwide.

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