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Integrating Seismic Data with Other Subsurface Information for More Accurate Reservoir Description

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Abstract
Seismic information as an essential tool to image the subsurface has been complemented by other sources of information in the characterization of hydrocarbon reservoirs. Some of the sources that are widely used in the industry include wellbore measurements, wireline logs, drill cuttings, core samples, nuclear magnetic resonance, and bottom hole pressure data. Seismic not only helps in understanding the lithological content and the fluid distribution, but also provides other information including stress regime and the presence of fractures and folding. To make the best possible integrated use of seismic and other data is the goal of reservoir characterization work. By doing this, one can avoid inconsistencies, biases, and artifacts in the interpretation of seismic data alone. Such calibration could result in the better identification of areas of gas-bearing potential. Another application might be the integration of seismic data with wellbore measurements to better determine pore fluid content in low porosity formations. When the pore fluid content of a formation is known, the petrophysical response, determined from wireline logs, can be better assessed. These examples demonstrate that by linking seismic to other forms of subsurface information, one is able to make the most accurate interpretation of each.

KEYWORDS: *Seismic Imaging, Anisotropy (Azimuthal/Frequency-dependent), Microseismic Imaging, High-Resolution Seismic Techniques, Fracture Detection*

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I. Introduction

The success of reservoir management hinges on accurate initial reservoir description and ongoing monitoring, with seismic data playing a pivotal role by providing critical information on reservoir geometry. When combined with well data, seismic data enables the creation of a 3D reservoir model, serving as a foundational framework for reservoir management decisions (Posamentier et al., 2022). Recent advancements have enhanced resolution at the reservoir scale, boosting the relevance of seismic techniques (Grana et al., 2022). Although rock samples, cores, and logs offer valuable subsurface insights, determining reservoir shape remains challenging. Seismic exploration effectively addresses this issue, yielding applicable results across scales (100m to 20km) and resolving complex problems, even in intricate areas (Oumarou et al., 2021).

II. Background

Hydrocarbons are mainly associated with subterranean caps termed reservoirs. The identification of these reservoirs and outlining their extent represent two of the basic objectives of oil exploration (Tiab & Donaldson, 2024). In order to do this, information on the sub-surface geology of the region is necessary. Some of these are revealed by surface geology but much more is needed in order to map possible accumulations at reservoir level.

Various methods have been used to access this information Although there are various methods that have been established to access this information Seismic interpretation (Eigbe et al., 2023). The conventional approach applied in this industry is the 3D post-stack seismic interpretation where the seismic images are subdivided into panels or slices for enhanced analysis (Khalifa et al., 2024). Geologists and geophysicists employ the descriptions of the rock properties in coming up with geologic models in efforts to identify reservoirs.

From these geologic models, the possibility of reservoir for the hydrocarbons is evaluated using these tools (Ismail et al., 2024). This is done if the assessment determines that economically recoverable quantities of hydrocarbons exist, a well is then drilled in order to test the reservoir (Sihoyiya et al., 2024).

Seismic Data Acquisition and Processing

Seismic data are indispensable for the presentation of the subsurface reservoirs' structure and impedance, velocity, and proportions of net pay which are essential for hydraulic reservoir performance (Posamentier et al., 2022). Seismic data that are acquired at the same time as the point and areal information sources function as the key means of increasing the understanding of reservoirs when combined with independent, non-systematic point data. We propose shifting the focus from separate data-type analysis to building reservoir geologic and fluid models that exploit diverse data sources. This approach will lead to more rigorous tests of model consistency and accuracy.

In reservoir modeling, seismic data are combined with well data to provide reservoir-fluid behavior properties and geometric descriptions (Hussein et al., 2021). Traditionally, well data integration has been seen as a historical exercise comparing forecasts to realized results. However, we envision alternative methods for frequent well data utilization, potentially under the concept of "keeping time on our well description fix" (Bate et al., 2023).

The structural and property maps of deep western Utah, derived from diverse input data sources and processing techniques, demonstrate the complexity of reservoir modeling (Zheng & Wang, 2023). Although each map appears smoothly varying, they are based on points with independent uncertainties. By comparing seismic and reservoir data with independent uncertainties, we can test the consistency of reservoir models, particularly in areas with mixed geophysical resolution.

Types of Seismic Data

When characterizing reservoirs, various types of seismic information are essential, including structure, stratigraphy, rock property, and amplitude data (Posamentier et al., 2022). Integrating these data types is crucial, but the specific data needed varies depending on the reservoir information required. For mapping reservoir properties like porosity or permeability, seismic data properties such as impedance or velocity are necessary. In contrast, when characterizing a reservoir model, spatial predictions of properties are secondary, and a structural frame and calibration of trends and geobodies are more important, where amplitude data can be used to pick facies or seismic rock properties to predict lithology (Chikezie et al., 2022).

In reservoir modeling and facies predictions, well-log and core data, production data, and outcrop data are used as ground truth (Sabouhi et al., 2023). Statistical relationships between seismic data and seismic interpretation can be established through supervised cluster analysis using seismic coherence or other facies indicator data (Mishra et al., 2022). This is done by checking the lithofacies classes using well logs or seamlessly mapping seismic attributes to reference data such as lithology or porosity (Bennis and Torres-Verdín, 2023). These relationships and derived models support existing seismic interpretation efforts, and using data derived from such models can be more efficient for interpreters (Fu et al., 2024).

Processing Techniques

Obtaining a successful tomographic inversion of seismic data requires careful processing of the recorded dataset (Grana et al., 2022). Seismic experiments may not always capture the ideal frequency range for hydrocarbon relaxation times, necessitating data sharpening. Another way is to make more low-frequency measurements by using several boats, but the above experiment satisfied the requirement with a single boat and 3 seconds, though the presented sea environment was severe (Lin et al., 2023). Data gathers spanned four months on the Zilacht anticline and the Togolese platforms in the Atlantic Ocean.

Regarding limitations to the frequency of data gathering, this work used a hybrid strategy with an added cone of influence to the data view to fit the expected level of quality (Muller et al., 2023). Another important approach was in achieving minimal noise and data translation effectively. Standard hard and soft-ware procedures with parameters optimized for integration with bottom seismic and satellite data, and with correlation with logging data were employed by Tsai et al., 2023. The first difficulty was to integrate subsurface data to determine new variables for the hydrocarbon reservoir model.

Some of the priority areas were to tune and rectify tomographic parameters, to reduce the amount of the log information acquired and to assess effective inverse and non-intersecting models (Meng and Yan, 2022). On the other hand, tomography remained useful in providing good image of the Zilacht-Benin anticline. This paper highlighted the significance of the integration and processing strategies in seismic inversion as presented by Bruno et al., 2022).

Other Subsurface Information Sources

In the case of heterogeneous reservoirs, internal parameters and attributes are determined with significant help of seismic data (Sokolov et al., 2021). These data also help to quantitatively determine the correlation between reservoir characteristics and seismic signatures. In addition, the seismic data allows for the modeling, to estimate the seismic attributes throughout the reservoir implying the comprehensive reservoir description and atmosphere specification (Oumarou et al., 2021).

Several seismic modeling and inversion operations use subsurface data to accomplish this end. These procedures utilize diverse data sources, including:

- Additional geophysical measurements in wells
- Deep well data
- Geologic and production information
- Multicomponent and surface seismic data
- VSP data recorded at multiple wellbore locations

While different techniques and tools exist, even approximate reservoir models can significantly enhance future work by integrating other subsurface information, geological data, special experiments, and production data (Chen et al., 2021). This integrated approach refines the accuracy of reservoir description.

Well Logs

Well logs serve as the primary record of borehole measurements, obtained either before or after drilling (Habeeb, 2023). Composite logs are constructed by merging natural gamma radiation, resistivity, sonic, and density logs from various well logging runs into a single sequence. Specialized casing tools are used for cement bond logs. Acoustic logs, which measure travel time for sonic waves to propagate through formations, come in two main types (Lai et al., 2022).

Resistivity logs record electrical properties of surrounding formations, while dielectric logs measure electromagnetic wave propagation time (Stadtműller & Jarzyna, 2023). Neutron logs detect hydrogen concentrations, aiding in gas-filled formation identification. Pulsed neutron logs operate similarly to wireline neutron logs but employ a pulsed neutron generator. Energy-density logs measure gamma radiation emitted by formations due to radioactive decay (Deng et al., 2023).

Other logging tools include:

- High-resolution dipmeter logs, using probes or pads to measure formation properties (Zeeden et al., 2023)
- Caliper logs, recording borehole width and variations to prevent inaccurate data due to gross caliper readings (Basso et al., 2022)

Core Data

Cores are the most accurate subsurface samples available, providing representative lithologies, reliable stratigraphy, and high-quality petrophysical, geochemical, and geomechanical information when analyzed with modern techniques (Kadyrov et al., 2022). However, their spatial coverage is limited, as they are only available in a few wells with restricted locations, and may be affected by drilling conditions. Despite these limitations, cores enable geological modeling and direct analysis of core material (Ramkumar et al., 2021). Modern multistage coring techniques allow for whole core material retrieval from large reservoir sections, while continuous core analysis accelerates laboratory analysis.

In contrast, cuttings samples have significant limitations. They consist of small rock fractions, are liable to be contaminated with mud, and undergo short handling (Maldar et al., 2022). These factors make cuttings analysis unsuitable for reservoir heterogeneity evaluation because of small volumes, interference by drilling fluids, variations in hydrostatic pressure, and possibly damage during sampling or manipulation. Therefore, cuttings analysis is limited to only qualitative or semi-quantitative interpretations and cannot give quantitative petrophysical parameters as porosity and permeability (Nabawy et al., 2022).

Challenges in Integrating Seismic Data with Other Information

Hydrocarbon reservoir rock work and decision-making critically require the integration of seismic data with other existing data (Correia et al., 2023). This importance results with the rising costs of identifying, delineating, and developing new prospects of reserves and great demand for crude oil and related products. From experience, when more reserve resources are defined in difficult structural configurations, previous data are updated by integrated methods. of such cross-facets, the internal consistency and reliability of seismic models together with other data sources should be guaranteed.

Due to the limitations such as cross graduation, poor seismic resolution, anisotropy, noises due to complicated surface topologies, Carful considerations need to be made in geophysical interpretation (Leisi & Saberi, 2023). Such factors may cause poorly set patterns, implying that there are disordered reflection occurrences at logged depth. Seismic technology aims to decrease uncertainty, rather than transform unrelated information into a single certainty.

In reservoir studies, space and time are critical, particularly regarding data quality and distribution (Oumarou et al., 2021). Integrating relevant information from all disciplines helps define reservoir properties and zonation. This holistic approach acknowledges the complexities of reservoir characterization and promotes more accurate and informed decision-making (Hendry et al., 2021).

Data Inconsistencies

Considering the extensions and limitations of mapped zones and seismic volumes in 3D visualization and interpretation is crucial. However, even with careful consideration, inconsistencies may persist, revealing themselves during interpretation as a consistent set of seismic data issues (Grana et al., 2022). Unfortunately, these inconsistencies may only become apparent for certain volumetric models, and their full geological and tectonic implications remain unclear (Posamentier et al., 2022).

High-quality stacks with normal moveout are considered "semi coherent" with seismic volumes used for hydrocarbon reservoir mapping. As a result, volumetric receptivities are estimated without re-evaluating cross-calibration weights (Kolkman-Quinn, 2022). Inconsistencies between observed maps can be attributed to data deficiencies and limitations of the specific upscale rule created for acquiring and merging cross-discipline reservoir-property observed maps.

Seismic-to-property relationships function effectively for various reservoir-mapping azimuthal-seismic-derived distributions of intensity. The stack processing rule for computed envelopes aligns with requirements for reservoir-property maps (Zolfaghari & Forghani, 2024). While deep reflection characteristics and vertical resolution of azimuthal-seismic-derived distributions may not share the same limitations as stacked, concentric, plan-parallel homogeneous and anisotropic models, they correspond to smooth relationships frequently used in geostatistics (Masoudi, 2024).

Interpretation Uncertainties

3D seismic surveys introduce critical factors contributing to interpretation uncertainties, beyond inherent velocity analysis and depth conversion uncertainties. These factors include attenuation of seismic energy, variations in pore-fluid properties, and poor signal-to-noise ratios, leading to false structures or artifacts that reduce confidence in reservoir structures and rock attributes (Liu et al., 2022). Oil-water contacts can induce reflections that may be indistinguishable from velocity variations due to time-lapse seismic effects. Identifying pitfalls during seismic time-lapse data interpretation requires cross-discipline cooperation or close interaction between data source specialists.

Wireline logs should be compared with seismic data to assess wavelet accuracy and amplitude versus offset analysis feasibility (Borleanu et al., 2024). Effective elastic properties and anisotropy in target reservoirs can be predicted using seismic surveys, enabling predictive relationships in geomechanics (Zeng et al., 2023). For instance, relationships among porosity, shear wave velocity, and bulk density in marine sediments can identify low- and high-porosity sands and shales.

However, subsurface geomechanical modeling complexities and overburden variations can lead to interpretation challenges. Failing to account for overburden importance can result in uncertain subsidence analysis of oil reservoirs (Iqbal et al., 2024). Seismic data quality can be compromised by fault systems, affecting flow characteristics and reservoir prediction accuracy (Rohit et al., 2023). Additionally, seismic expressions may struggle to provide accurate near-wellbore images.

Benefits of Integration

Deviating the reservoir property mapping, well data interpolation and extrapolation, and drilling recommendations based on seismic information alone results in the selection of poor geological/well targets and subsequent loss of hydrocarbons (Zhang et al., 2024). Seismic data also activity constraints comprising low vertical resolution, low S/N, time-domain descriptions, and fewer recorded details in the lower frequency band (Ballinas et al., 2023). When combined with insufficient constraints these characteristics may lead toward improper reservoir modeling, non‑productive or dry holes.

However, in combination with information-rich subsurface digital data from well logs, cores, and 3D VSP, the influence from seismic data significantly decreases uncertainties of reservoir characteristics as well as improves final or ultimate recovery as seen in Du & Thakur (2024). By constraining seismic data with well logs, core samples, and VSP, seismic data becomes a valuable source of reservoir property maps, even with noisy or limited-resolution data. This integration increases the density and quality of subsurface information, minimizing unconstrained sources that lead to uneconomic well locations or nonproductive wells.

As a result, total exploration and production costs are lowered, reserve uncertainties are reduced, and reservoir recovery rates are maximized (Correia et al., 2023). By leveraging multiple data sets, the accuracy and reliability of reservoir characterization are significantly improved, ultimately enhancing hydrocarbon recovery and reducing exploration risks.

Improved Reservoir Characterization

Imaging of the reservoir can be achieved through pre-stack depth imaging, utilizing pre-stack depth images or joint post-stack depth migrated images to illuminate the reservoir (Shin et al., 2024). Onshore, pre-stack depth images provide a true 3D data set, overcoming azimuthal limitations of post-stack, time-migrated images. However, acquiring 3D pre-stack data at the reservoir level requires deep drilling and stationing equipment, and processing costs remain high.

Offshore, recording and processing 3D pre-stack data costs are lower, but illumination limitations from the acquisition surface can negatively impact imaging quality, making the final pre-stack depth result comparable to pre-stack or post-stack migration (Taras & Riahi, 2023).

To achieve better results without incurring 3D pre-stack depth imaging costs, generating 3D illumination volumes from pre-stack data can be effective (Fam et al., 2023). These volumes drive post-stack depth migration at the reservoir level, producing reliable reservoir images. The optimal imaging approach depends on illumination nature and location, requiring analysis of reservoir location and overlying layer characteristics.

Enhanced Reservoir Management

The timing, size, and production profile of a field development have significant technical and economic consequences, impacting the project's overall economics (Hasoon & Farman, 2024). Although geology should play a dominant role in building reservoir models and deciding development plans, deadlines driven by drilling or cumulative production often take precedence. To address this issue, true integration of geological, geophysical, petrophysical, and production data is crucial.

Achieving this integration is key to leveraging geophysical and geological technologies effectively (Grana et al., 2022). The degree of data reconciliation between component models dictates the understanding and confidence in using them for planning and monitoring field performance. As model accuracy improves through reconciliation, refinements in the approach to data analysis can lead to a "self-feeding" cycle of useful iterations.

Generic integrated reservoir management scenarios can be used to examine the effects of various data integration strategies targeted at specific data types and roles (Tian et al., 2023). While implementation depends on project-specific situations, underlying management criteria provide helpful guidelines for application development. Most operators recognize the importance of increasing data integration in large-scale reservoir projects.

However, component models often reside in separate technical organizations and computer platforms, with highly specialized roles and expectations (Hasoon & Farman, 2024). Effective integration requires bridging these gaps to optimize reservoir management.

Integration Techniques

The integration of 3-D seismic data with other subsurface information, known as "multi-disciplinary integration," relies on collaboration between geologists, borehole log analysts, and petrophysicists (Carollo, 2023). This collaboration facilitates information exchange and mutual understanding of the benefits each discipline offers. The combined interpretation value often surpasses the sum of its individual components.

Effective integration methods include combined reprocessing and coherence filtering of 3-D seismic volumes with borehole images or other geological data (Bashir et al., 2024). This approach provides insight into resolvable geological features and correlates them with identified cores or test locations. Repeated trial and error among interpreters establishes a reliable correlation scale.

Depth calibration of 3-D seismic volumes involves time-to-depth conversion, correlating stratigraphic markers with two-way time from nearby well logs (Posamentier et al., 2022). Accurate surface mapping integrates the 3-D seismic volume, matching significant geological features with intersecting seismic reflections.

Seismic Inversion

Normally, seismic data do not provide unique solutions in predicting subsurface lithologies and fluids. The frequency band necessary to achieve enough vertical resolution is not available in the recorded seismic data. In the common case, where enough high frequency is present, it is damped because of the impedance contrast between the water and the sands and shales observed around the well. During the last decade, several researchers have demonstrated that properties such as porosity, water saturation, pressure, and temperature properties very fundamental in reservoir studies could be predicted with reasonable accuracy by using seismic data. These successes have generated considerable interest in seismic reservoir characterization. However, most of the applications in reservoir modeling with seismic data and subsequent reservoir simulation did not get widespread use because most of these predictions were felt to depend critically on the local sedimentary environment and the hydrocarbon system of each individual field. Most reported successes have treated reservoirs as an impulsive, locally homogeneous horizon. The objective of this paper is to show that the information generated in the last decade can be used to improve our predictions, and that seismic predictions will not necessarily be so reservoir-specific if they are used in a hybrid way with other much more global, but simpler, methods based on simple well-log correlations.

Rock Physics Modeling

We conducted rock physics modeling at site RPII using well log and seismic analysis. By comparing observed and synthetic seismic P-waveform responses for permeable layers, we calibrated the prediction of permeable layers via seismic methods (Gao and Ye, 2024). To calculate elastic moduli in LabView, we applied the Mohr-Coulomb failure criterion based on unconfined and confined compressive strength of samples, using well log and seismic data as inputs.

The output yielded elastic moduli and time-depth relationships. We modeled the impedance versus depth relationship of the well log, representing reservoir pore volume and permeable layer information, from travel times between layer surfaces. Estimating pore fill in sediments on geologic timescales requires easily measurable quantities (Khodkari et al., 2024). The relationship between elastic moduli of coarse clean sands is well-defined, with mixed fluid sands falling between end members at any given subsurface depth.

Fluid replacement of solid minerals within void spaces affects elastic moduli, in addition to bulk volume. Minerals are difficult to change, but fluid and porosity can be identified via P-wave, S-wave, and density signals (Chen & Yang, 2023). We obtained P-wave data and density data from sonic logs, while S-wave data came from resistivity logs, although calibration was limited.

Case Studies

Numerous case histories have demonstrated the benefits of integrating seismic information with other subsurface data for more accurate reservoir descriptions and reduced exploration risks (Correia et al., 2023). Recent advancements have simplified procedures, leveraging increased data and computer capacities to make these geological efforts affordable and cost-effective.

Particular examples support this argument even further. For example, the Peruvian Jungle Coalbed Methane of Agro-29, Batusehe Deep Basin Gas discovery of Indonesia, Multi-component and azimuth seismic study in Qinghai and Endeavor/Martlet North of Sea also depict that integrated approach of seismic effectively impact.

These case histories demonstrate how integration of other data with seismic data can enhance the description of the reservoir and reduce the amount of risk that is associated with exploration efforts. The use of integrated seismic methods therefore helps operators to make required decisions and further enhance the economics of projects.

Example 1: Offshore Reservoir Integration

Application of seismic and well data is central in defining an offshore gas reservoir, especially in more mature fields where deeper producing objectives may be delineated to increase field cycles (Correia et al., 2023). Seismic line showing a north-south cut-out is a gas reservoir located in an area of high oil production with basinal sands created by rifting and a thick shale seal.

Firstly, using hypothetical poor seismic data quality, reservoir limits of width, thickness, location, and the optimum drilling horizon were determined. But better seismic showed possibilities of fresh wells on the reservoir edges and horizontal drains offering added avenue of connectivity to the thicker deposit targets.

This optimization technique gave a longer field life by a factor of 3-5 years in addition to enhancing the recovery factor to between 6-8% depending on the well number and location of the field (Schiozer et al., 2022). By leveraging integrated seismic and well data, operators can identify untapped potential and make informed decisions to maximize reservoir performance.

Example 2: Unconventional Reservoir Integration

Predicting fracture permeability is crucial for extracting gas from unconventional shale gas formations, which have poor matrix permeability (Abelly et al., 2024). Hydraulic fracturing creates pathways to the wellbore, but natural fractures are more effective in increasing permeability and reducing operational energy and environmental impact.

In a regional analysis, wellbore frac tests were plotted on an in situ stress map, revealing a critical stress threshold beyond which fracture permeability is poor (Abelly et al., 2024). Microstructural observations informed a critical stress map, enabling predictions of exploration depth to fault rock. Empirical correlations linked fractured host rock stress observations to predict fault rock volume.

The relationship between hydrocarbon well performance and fault rock volume indicates elevated or extensive overpressures of trapped methane, influencing footwall and hanging wall formation drives (Han & van der Baan, 2024). This integrated approach optimizes unconventional reservoir characterization and exploration.

Future Directions

Future integration of seismic data with other geophysical and geological information requires consideration of several trends and technologies to enhance reservoir knowledge accuracy. Key areas include:

Emphasizing seismic data's complementary role in conditioning 3D earth models created for reservoir characterization using non-seismic methods (Posamentier et al., 2022). The ultimate goal is a static/dynamic earth model incorporating all available information to facilitate rapid and accurate hydrocarbon discovery through optimized drilling.

Advancements in seismic processing technologies are necessary to reduce processing times from months to weeks and operating costs from dollars to cents per seismic sample (Lehmann et al., 2024). Alternatively, revolutionary changes in 3D seismic data acquisition, recording, and reproduction technologies could yield long-term cost savings.

Improved methods for predicting and quantifying heterogeneity in 3D reservoir models will enable more accurate geological models and initial conditions for 4D simulations and seismic reinterpretation (Ciardelli et al., 2022).

Developing quantitative models for interpreting seismic data in terms of fluid saturation is crucial, particularly in areas lacking high-quality logs and core data (Lehmann et al., 2024).

Advancements in Technology

Continued advancements in computer hardware and seismic imaging technology have surpassed the oil industry's ability to utilize such data efficiently and effectively (Cao et al., 2024). Despite reserve replacement challenges, these advancements would have still created a situation where the industry and shareholders weren't maximizing their investment returns.

The integrated approach has made significant progress toward establishing optimal and comprehensive oil field datasets, culminating in accurate reservoir property models critical for production forecasting (Elaila et al., 2024). This journey has just begun, and continually refining earth models with more accurate seismic image attributes and dynamic models from production data will yield benefits.

Management and the financial community will welcome the realization of anticipated production results, transforming investment dollars into profit dollars more quickly than promised (Kryukov & Tokarev, 2024). Crucially, reservoir quality metrics – pressure, production rates, and cumulative revenue – are accurate and reliable numbers, not errors.

Research Opportunities

The case study demonstrates the potential of seismic characterization in developing reservoir models from exploration to production (Górszczyk & Operto, 2021). Seismic data provide unique, complementary descriptions to well data, enhancing modeling objectives. Integrating both types can optimize well selection, data usage, and cost-benefit balance, while considering data uncertainty.

Significantly, much seismic data remains underutilized, often relegated to qualitative roles or excluded from models despite its quantitative potential for reservoir property insights (Cultrera et al., 2021).

The case study reveals trends worthy of further exploration, particularly in structural geology contexts. Seismic and well-log descriptions operate at distinct scales, making integration challenging (Verma et al., 2022). However, interdisciplinary collaboration between geophysicists, sedimentologists, and petrologists can resolve inconsistencies between high-resolution well logs and heterogeneous seismic attributes.

By adapting technology to geological principles, multilevel modeling can become more practical within integrated multidisciplinary exploration and production frameworks (Lai et al., 2024). This integration will enhance the application and interpretation of seismic and well-log data, ultimately improving reservoir modeling accuracy.

III. Conclusion

There is growing optimism that seismic data will enhance assessments of subsurface oil and gas reservoirs' prospects and properties. This optimism is now substantiated by improved understanding of reservoir flow's history dependence and seismic response sensitivity to stress, pore filling, and fracture systems.

A notable illustration demonstrates how seismically derived attributes with modest sensitivity to sand and reservoir architecture, via attenuation models, can align flow forecasts with reservoir architects' geometric interpretations. This integration fosters more consistent and reliable business models.

The convergence of seismic data, reservoir architecture, and flow forecasting has significant implications for the oil and gas industry. By leveraging seismic attributes, operators can refine their understanding of reservoir properties and optimize field development strategies.

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