Deliverable report 36

AI and IAGEN Application Use Case

Exploration Seismic Imaging for the Identification of Fractures and Porosity Zones in Vaca Muerta, Neuquén, Argentina

I. Introduction

The Vaca Muerta Formation, located in the Neuquén Basin of Argentina, is a Jurassic-Cretaceous shale formation. It is considered the primary source rock for conventional petroleum production in the Neuquén Basin.

This formation consists of black marine shales, fine-grained siltstones, marls, and limestones deposited in anoxic environments with high levels of total organic carbon (TOC). The Vaca Muerta-Quintuco system is characterized by prograding (shelf-bound) clinoforms with well-developed bottomsets, foresets, and topsets.

The Vaca Muerta Shale formation is a world-class shale reservoir with an estimated recoverable reserve of 16 billion barrels of oil and 308 TCF of gas.

The formation's thickness can vary between 100 and 400 meters. The development of Vaca Muerta is adding significant value to Argentina's trade balance and is expected to further boost the country's mining and energy sectors.

The massive development of Vaca Muerta could increase the hydrocarbon sector's trade surplus by 2030.

Porosity is a crucial factor that controls the storage capacity and flow of fluids in reservoirs.

Fractures, when open, significantly increase the permeability of tight sandstone gas reservoirs and serve as channels connecting storage spaces. In ultra-deep tight sandstones, fracture porosity can be much greater than matrix porosity.

Accurately assessing porosity distribution from seismic data is essential for evaluating reservoir quality, building a geological model, and delineating flow units.

Porosity prediction from seismic data is of considerable importance in reservoir quality assessment, geological model construction, and flow unit delineation. Accurate fracture identification in individual wells is critical for constructing a 3D constraint model of the fracture network.

Accurate evaluation of porosity distribution from seismic data is essential for assessing reservoir quality, establishing a geological model, and delineating flow units. Porosity prediction from seismic data is of considerable importance in assessing reservoir quality, constructing geological models, and delineating flow units. Accurate fracture identification in individual wells is critical for constructing a 3D constraint model of the fracture network. Accurate fracture and porosity information guides drilling and completion activities, particularly horizontal drilling and hydraulic fracturing.

The Vaca Muerta Formation requires horizontal drilling and hydraulic fracturing stimulation to achieve commercially viable production. Hydraulic fracturing is used to produce hydrocarbons trapped within the shales of the Vaca Muerta Formation. In 2016, there was a major shift to horizontal drilling in the Vaca Muerta Formation due to higher productivity rates.

The use of 3D seismic data at the basin scale allows the identification of depositional elements within the Vaca Muerta-Quintuco system.

Integrating 3D seismic with high-resolution well-log sequence stratigraphy improves prediction . Conventional methods for extracting salt body boundaries from seismic images (seismic attributes and edge detection algorithms) require manual effort.

Manual fault interpretation in seismic data is time-consuming and requires considerable expertise. Traditional seismic interpretation for oil and gas exploration is laborious, time-consuming, and demanding. It is a complex and sometimes laborious process with high stakes.

Artificial intelligence (AI), through advanced seismic image processing, offers transformative potential to overcome these challenges. Deep learning models, particularly convolutional neural networks (CNNs), have been introduced to assist geologists in faster seismic interpretation.

AI is a branch of computer science that studies the computer simulation of human thought processes and intelligent behavior, with applications that bring disruptive technological change to various industries, including oil and gas. CNN-based methods have emerged as transformative approaches in seismic interpretation.

Deep learning, especially through convolutional neural networks (CNNs) like the U-Net 3D model, has revolutionized fault identification from seismic data . The integration of AI, notably machine learning and deep learning, into seismic fault interpretation has marked a significant breakthrough . AI improves the accuracy and efficiency of exploration, making it an important research direction . AI is redefining the seismic interpretation process, delivering speed and accuracy . The transformative role of AI in seismic interpretation is accelerating one of the most business-critical phases of the energy industry . AI algorithms can analyze large datasets more efficiently than traditional methods, uncovering subtle patterns .

This report details the application of AI and IAGEN in seismic image analysis to identify fractures and porosity zones in Vaca Muerta.

Generative Artificial Intelligence (GENI) is a branch of artificial intelligence that focuses on creating new content, such as models, images, code, or text, from existing data. This technology uses advanced algorithms to analyze large amounts of information, identify patterns, and generate new, original content that is often indistinguishable from human-created content.

II. AI/IAGen Applications in Seismic Imaging

1. Aim

Improve the **interpretation of 2D/3D/4D seismic data** using artificial intelligence, with a focus on detecting:

- Natural or induced fractures
- Zones of high porosity and permeability
- Reservoir limits
- Areas with potential for secondary or tertiary recovery

2. Specific applications of AI in seismic analysis

a. Automatic segmentation of geological layers

- Computer vision models segment zones in seismic images.
- Drastic reduction in the time required for structural mapping.

b. Identification of hidden fractures and faults

- Deep learning algorithms detect patterns not visible to the human eye.

- Improves the delimitation of structural traps and productive natural fractures.

c. Porosity and saturation prediction

- Neural networks fed with seismic data + well logs + laboratory.
- They allow the inference of 3D porosity maps, vital for reserve estimates.

d. Generative creation of geological models

- IAGen creates realistic synthetic subsurface simulations based on existing data.
- Ideal for areas with low resolution or high uncertainty.

e. Accelerated seismic interpretation

- GPT + RAG explains seismic analysis results in natural language.
- Provides geophysicists and petrophysicists with immediate insights into prospective zones.

III. Application of agents driven by IAGEN in the activity

1. **IAGEN Agents Concept**

In recent years, generative artificial intelligence (GAI) has revolutionized the way we interact with technology, enabling the development of systems capable of generating content, answering complex questions, and assisting with highly demanding cognitive tasks. From this capability, a new technological architecture has emerged: GAI-powered agents. These agents are not simple conversational interfaces, but autonomous systems that can interpret instructions, make decisions, execute tasks, and learn from their interactions with the environment.

An IAGen agent combines large language models with additional components such as external tools, memory, planning, and autonomous execution. This allows them to operate in complex environments, with the ability to break down objectives into steps, coordinate multiple actions, interact with digital systems (such as databases, APIs, or documents), and adapt to context changes in real time. These qualities distinguish them from traditional chatbots and open up a range of more sophisticated and customizable applications.

At the organizational level, these agents are being used to automate processes, generate data analysis, assist in decision-making, and improve the user experience, both internally and externally. For example, they can take on human resources, legal, financial, or logistics tasks, and even tasks linked to the technical areas of production processes, acting as intelligent assistants that collaborate with human teams. This ability to integrate knowledge and execute tasks autonomously transforms the way organizations can scale their operations without losing quality or control.

Furthermore, agentic workflows—structures where multiple agents collaborate to solve complex problems—allow responsibilities to be distributed among different agent profiles, each with specific functions. This creates hybrid work environments where humans and agents coexist, optimizing time, costs, and results. The ability to connect agents with tools such as Google Drive, CRMs, or document management platforms further expands their capabilities.

The development of IAGen-powered agents represents a crucial step toward a new era of intelligent automation.

Among the benefits of authentic workflows powered by generative AI models is the ability to automate entire production processes, end-to-end, and even add value by leveraging the capabilities of language models based on these technologies.

However, its implementation also poses technical, ethical, and legal challenges, ranging from responsible design to human oversight. Therefore, understanding its architecture, operational logic, and potential impacts is critical for its effective and safe adoption in diverse professional contexts.

2. IAGen Agent Design Proposal – Intelligent Seismic Explorer

a. Aim:

Automate, accelerate, and enrich seismic image interpretation using an autonomous agent that combines AI vision, predictive analytics, and conversational interaction to assist in exploration decision-making.

b. Agent Components

- Geophysical Data Ingestion Module

- Entrance:
    - 2D, 3D, 4D seismic volumes
    - Well logs
    - Previous petrophysical models

- Function:
    - Conversion to standardized formats

    - Extraction of seismic attributes (amplitude, phase, coherence, etc.)

- Geological Vision Module (Deep Vision)

- Model: CNNs + U-Net Segmentation + LSTM if there are 4D time series
- Function:
    - Detect fractures and faults
    - Classify areas by degree of porosity and type of rock
    - Estimate lateral continuity of formations

- Generative Subsurface Model Module

- Function:
    - Generates synthetic geological scenarios from areas with low resolution or missing data
    - Simulates porosity, saturation, pressure and connectivity between layers
- Application:
    - Planning new wells
    - Visualization of structural risks

- Predictive Productivity Analysis Module

- Function:
    - Correlates detected areas with historical production
    - Estimate expected production and recovery factor
- Output:
    - Heat map of “hot zones” by production potential

- Conversational and Reporting Module (GPT-4 Turbo + RAG)

- Function:
    - Allows you to consult results in natural language
    - Answer questions like:
        - “Which area has the greatest porosity in block X?”

        - “Where is natural pressure-connected fracture expected?”
    - Generate executive and technical reports automatically

c. Hypothetical Use Example

Input: 2 TB of seismic images + logs from 15 wells are loaded.

Process:

- SeismoGen detects fracture zones aligned with pre-existing structures.
- Find a coherence anomaly that suggests occult fracture.
- Predicts a zone of high porosity and good hydraulic connectivity.
- Suggests location and trajectory of horizontal test well.
- Generates a technical report for the geological team and an executive presentation for drilling decisions.

IV. Convolutional Neural Networks (CNNs) for Seismic Image Analysis in the Oil and Gas Industry

Convolutional neural networks (CNNs), as deep learning algorithms, have been successfully applied in various image processing tasks and have been introduced into geosciences to assist geologists in faster seismic interpretation.

In recent years, CNNs have made great strides in geological exploration, being widely used in fields such as computer vision and speech recognition.

CNN-based methods have emerged as transformative approaches in seismic interpretation.

Deep learning, especially through convolutional neural networks (CNNs) like the 3D U-Net model, has revolutionized fault identification from seismic data. CNNs consist of convolutional layers with trainable filters.

For data represented as flat surfaces (images), a two-dimensional convolutional kernel is used; for volumetric data (3D seismic), a three-dimensional kernel is used. Activation functions introduce nonlinearity, and pooling combines semantically similar features into condensed representations.

The U-Net 3D model has been adapted for three-dimensional seismic data volumes, providing a method for detailed and accurate fault detection with reduced manual interpretation bias. This model has demonstrated superiority over traditional fault identification methods by improving accuracy, increasing efficiency, and reducing subjectivity.

Advanced spatio-temporal deep neural networks, such as those using a CNN structure to extract spatial features and a BiGRU network to collect temporal features, have been proposed for porosity prediction from seismic data. Experimental results demonstrate that the 3D Salt-Net method outperforms previous state-of-the-art methods in terms of salt body segmentation and achieves satisfactory results. Several CNN architectures, including U-net, PPM-Unet, FCN, 3D U-net, SaltFormer, and DBCF-Net, are used for salt body extraction. While foundational models show promise in computer vision, their direct applicability to seismic data is limited due to differences in data characteristics, suggesting the need for domain-specific adaptation or the development of geophysical foundational models.

Supervised deep learning using CNNs is presented as an alternative to conventional techniques for seismic interpretation, with case studies demonstrating the success of automatic fault selection in 3D seismic volumes using CNN models trained from synthetic data . Researchers have explored the application of CNNs in porosity prediction from well logs and seismic data, with studies showing improved prediction accuracy on field data compared to traditional methods .

An unsupervised CNN-based scheme provides more accurate results than standard methods for porosity estimation from seismically inverted acoustic impedance.

Incorporating a low-frequency porosity model into a supervised CNN significantly improves the reliability of porosity predictions in heterogeneous carbonate reservoirs.

V. Detailed Analysis of the Application of Recurrent Neural Networks (RNNs) in the Analysis of Temporary Seismic Data

RNNs are deep learning models with recurrent connections that allow them to retain information from previous time steps, making them suitable for time series analysis and capturing intricate temporal dependencies.

RNNs, including LSTM and GRU variants, can extract temporal features from log data and seismic data for tasks such as porosity prediction and seismic event classification.

BiGRU networks, a type of RNN, are used to collect temporal features for porosity prediction, analyzing information in both forward and backward directions to capture intricate patterns in the data.

RNN models based on LSTM cells are designed as real-time systems for the recognition of volcanoseismic signals using measurements from Distributed Acoustic Sensors (DAS), capable of analyzing the temporal evolution of these signals.

RNN-based phase classifiers have been developed for the analysis of induced seismicity in local seismic monitoring arrays, achieving an accuracy of over 80% for arrival time selection compared to manual selection techniques.

RNNs, specifically LSTMs, outperform Feed Forward Neural Networks (FFNNs) in predicting future earthquake trends due to their ability to model sequences . Various machine learning algorithms, including Recurrent Neural Networks (RNNs) and Extreme Learning Machines, have been used for earthquake prediction .

VI. Current Status of Artificial Intelligence (AI) Adoption in the Oil and Gas Industry in Argentina, with a Specific Focus on the Vaca Muerta Region

Argentina has expressed strong interest in becoming a hub for AI, with the government promoting its use and highlighting the country's robust technology ecosystem, skilled workforce, and potential advantages such as low energy prices in Patagonia.

The adoption of AI and machine learning is expanding across several sectors in Argentina, including agriculture, manufacturing, healthcare, and the public sector.

Oil and gas executives report that the two biggest opportunities for creating value from AI are predictive maintenance for heavy equipment and intelligent optimization of operations performance.

The AI and ML market in oil and gas is growing due to increased attention towards digital transformation, the need for operational efficiency, and a focus on predictive analytics.

AI is transforming the operating cost, efficiency, and decision-making processes of the oil and gas sector.

VII. Detailed Economic Benefit Analysis of IAGEN Implementation in Seismic Exploration in Vaca Muerta

Widespread AI in the oil and gas industry could deliver a 10-20% cost-saving paradigm shift by 2025.

AI can more accurately and cost-effectively identify high-potential drilling locations by evaluating large data sets, reducing the risk of dry holes.

AI-powered insights optimize workflows, significantly boosting operational efficiency.

AI-powered tools optimize processes such as supply chain management and production workflows, leading to reduced waste and significant cost savings.

AI helps companies optimize their energy consumption, leading to cost reduction and waste minimization. AI analyzes equipment data and predicts problems for predictive maintenance, reducing breakdowns and downtime and improving production. AI-based data analysis tools can produce highly detailed and repeatable structural and stratigraphic interpretations, enabling more accurate results in a fraction of the manual time .

AI can more accurately identify high-potential drilling locations by evaluating large data sets, leading to smarter decisions about where to drill. AI-powered tools help geologists accurately analyze seismic data, leading to better exploration strategies and more successful discoveries.

AI has become critical to improving the efficiency and accuracy of interpretation, with applications such as intelligent stratification and reservoir parameter estimation.

Company/Source	Application Area (e.g. Predictive Maintenance,	Reported Economic Benefit (e.g. % cost reduction, $ saved)

	Exploration)	
Shell	Predictive Maintenance	15% reduction in maintenance costs
Shell	Predictive Maintenance	20% reduction in unplanned downtime
BP	Data Optimization	$10 million in annual savings (through the "Sandy" platform)
Exxon	Exploration	40% savings in data preparation
O&G Industry	General	Cost savings potential of 10-20% by 2025

It is recommended to promote short-term investment in AI agent implementation teams in technology and training: Investment is required in proofs of concept and pilot tests. The focus here must be on training the talent to implement them, as there is a trend toward cost reduction in systems that enable "no-code" and "low-code" automation. For the first stage, it is also recommended to recruit teams with experience in the design and implementation of AI agents. Finally, it is key to form an in-house team to support and foster an agentic culture that redefines human-machine interaction.

VIII. Conclusion and Recommendations

The advances and applications of CNNs, GANs, and RNNs in seismic interpretation for the identification of fractures and porosity in the context of Vaca Muerta are promising.

The adoption of AI in Argentina's oil and gas industry is underway, with significant potential economic benefits through cost reduction and increased efficiency.

However, there are technical challenges related to the quality and resolution of seismic data in Vaca Muerta, as well as regulatory and economic barriers to AI adoption in the Argentine energy industry. Lessons learned from global case studies in geologically similar formations highlight the potential of AI to address these challenges.

Further research and development of AI models tailored to the specific geological characteristics and seismic data challenges of Vaca Muerta is recommended.

Strategies must be implemented to improve the quality and resolution of seismic data in the region to enhance the accuracy of AI models. Regulatory and economic barriers must be addressed to facilitate broader adoption of AI in the Argentine energy industry.

Furthermore, it is necessary to foster collaboration between research institutions, technology providers, and oil and gas companies in Argentina to accelerate the implementation of AI in seismic exploration.

Finally, it is crucial to invest in workforce development and training programs to build AI expertise for geophysics within Argentina.

AI has the transformative potential to revolutionize seismic interpretation and unlock the full potential of the Vaca Muerta formation for Argentina's energy future.

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