BGP Nonseismic Progress and Applications

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Summary

This paper provides a comprehensive overview of the progress, practical applications, and key achievements of BGP Nonseismic Techniques. BGP nonseismic techniques, with electromagnetics (EM) as a core component, cover multiple survey scenarios including offshore, airborne, and onshore, and mainly rely on methods such as Gravity, Magnetic, Magnetotellurics (MT), Controlled Source Electromagnetic (CSEM), and Geochemical.

In terms of technological progress, breakthroughs have been made in data acquisition (e.g., dual-source, long-offset and zero-borehole sources Time-Frequency Electromagnetic-TFEM), data processing (e.g., time-frequency domain joint inversion, seismic + nonseismic sequential inversion), and interpretation (e.g., AI-driven integration of petrophysics data for fluid identification).

Case studies verify the technology’s effectiveness: in ultra-deep reservoir predrilling evaluation, Geochemical survey can detect the ground free hydrocarbon molecules anomaly due to deep hydrocarbon vertically migration. TFEM accurately predicts reservoir resistivity and IP characteristics; in deep water compartment identification, TFEM+ seismic can achieve an 86% well-drilling success rate; in tight gas hydraulic fracking monitoring, it realizes real-time EM mapping of fracturing fluids.

Overall, BGP TFEM technology demonstrates high sensitivity to fluids (oil, gas, water), high resolution, and cost-effectiveness, and will play a crucial role in the refined and intelligent exploration and development of oilfields.

1. Introduction

1.1 BGP nonseismic overview

BGP Nonseismic Technologies are a suite of geophysical exploration methods designed to complement traditional seismic techniques in specific oil and gas exploration and development scenarios. They cover three major survey domains:

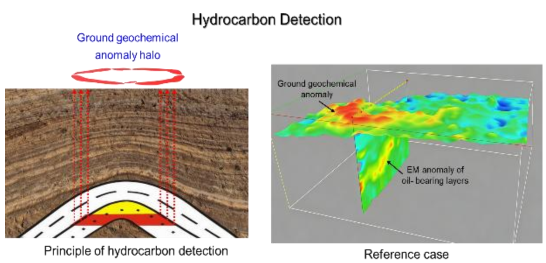
- **Offshore Survey**: Suitable for marine oil and gas exploration, addressing challenges such as complex seabed conditions and deepwater reservoir detection.
- **Airborne Survey**: Enable large-area, efficient exploration, ideal for rapid reconnaissance of large land or marine areas.
- **Onshore Survey**: Focus on land oilfield exploration and development, adapting to diverse terrestrial geological environments (e.g., deserts, plains, mountains).

The core technical methods include Gravity, Magnetic, MT, CSEM, and geochemcial which collectively provides multi-dimensional geological and fluid information for oil and gas projects.

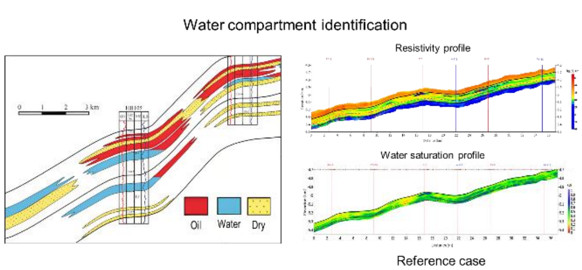
1.2 Application Objectives

BGP nonseismic techniques are developed to solve main issues in the oil and gas industry, with three primary application objectives:

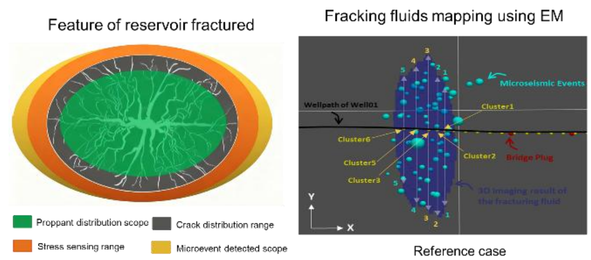
1) **Hydrocarbon Detection**: By analyzing geophysical parameters such as resistivity, induced polarization (IP), and electrochemical fields, we can identify the areas with high resistivity (potential hydrocarbon accumulation zones) and distinguish them from water-bearing zones. For example, through resistivity profiles and IP-difference phase profiles, the engineers can locate "Accumulation areas of polarized hydrocarbon molecules" and determine the Water-Oil Contact (WOC), thus providing a direct basis for hydrocarbon identification.



2) **Water Compartment Identification**: With the combination of resistivity profiles and water saturation (SW) profiles, the distribution of water compartments in reservoirs can be mapped, furthermore quantifying water saturation levels to help optimize water injection development plans and avoid water breakthrough risks.



3) **Hydraulic Fracking EM Monitoring**: In the development stage of tight oil and gas reservoirs, EM technology is used to map the distribution of fracturing fluids in real time. By monitoring the lateral spread of fluids near wellbore, it guides well placement and fracturing parameter adjustment, improving the efficiency of hydraulic fracturing.



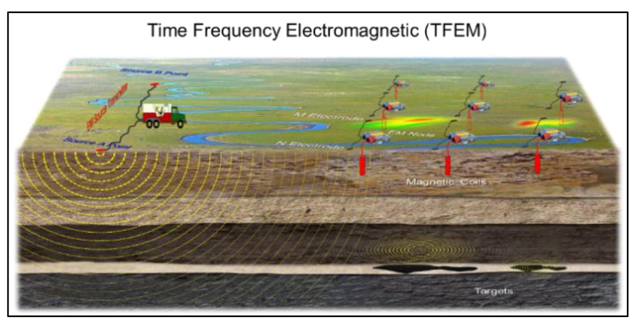
2. Progress of BGP Nonseismic Technologies

BGP nonseismic techniques have achieved systematic progress in acquisition, processing, and interpretation, laying a solid foundation for practical applications.

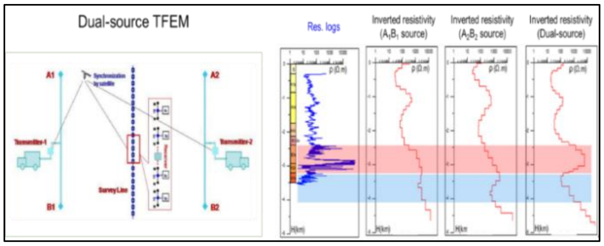
2.1 Data Acquisition Progress

Data acquisition is the first step in nonseismic exploration, and BGP has optimized source design and equipment configuration to improve data quality and acquisition efficiency:

- **TFEM Promotion**: TFEM has become a core method. It captures both time-domain and frequency-domain EM signals, enabling more comprehensive characterization of subsurface geological structures.



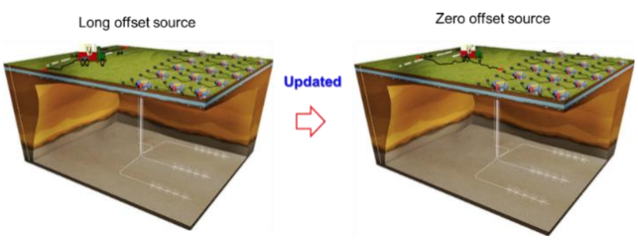
- **Dual-Source TFEM Design**: A dual-source TFEM system (with EM source A_1B_1 and A_2/B_2) has been developed. This design enhances signal strength and coverage, and it improves the matching degree between acquired data and resistivity logs (Res. Logs).



- **EM Fracking Monitoring Source Position Optimization:**

a) **Long-offset Source**: Extends the detection range of EM signals, suitable for deep reservoir exploration (e.g., ultra-deep reservoirs below 4000m), but for hydraulic fracking monitoring, the resolution will be reduced because the source is far away from the wellbore where fractures generated by hydraulic fracking.

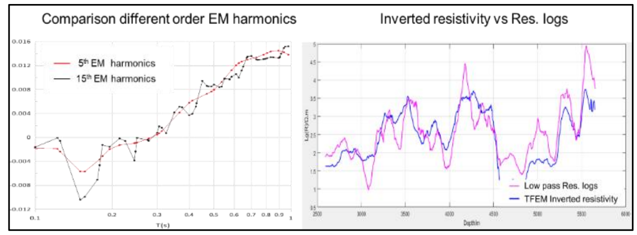
b) **Zero offset Source:** To improves the resolution of near-well fractures, providing detailed information for fracking fluids distribution, zero-offset source is proposed which could provide a higher resolution of fracking fluids distribution than that of long offset source.



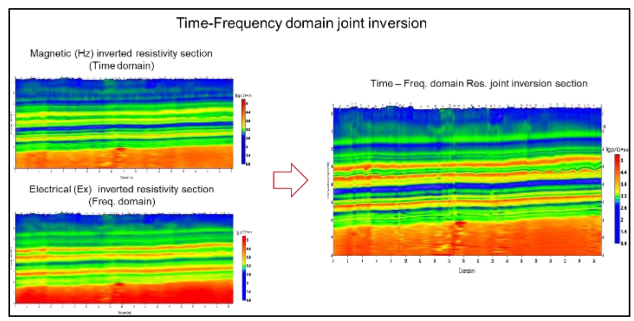
2.2 Data Processing Progress

Data processing is critical to converting raw acquisition data into interpretable geological information. BGP has made significant breakthroughs in raw data processing, inversion algorithms and model optimization:

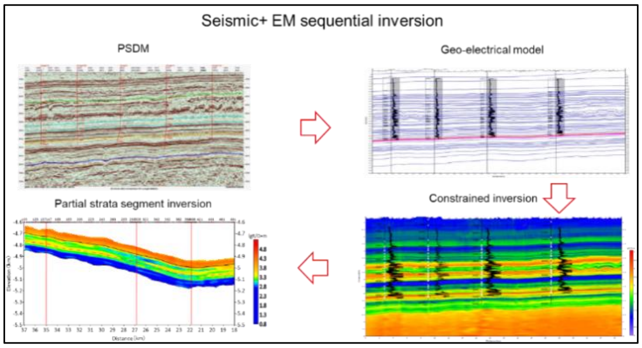
- **EM Harmonics Improving Resolution**: with the comparison of different orders of EM harmonics (e.g., 5th and 15th harmonics), The 15th harmonic shows more detailed information than that of the 5th harmonic because the high frequency information of signals is increased, which facilitates the inverted resistivity to be matched with the resistivity logs well.



- **Time-Frequency Domain Joint Inversion:** The magnetic H_z component from time domain is more sensitive to low resistivity geological bodies than other components, while the electric Ex component from frequency domain is more sensitive to high resistivity geological bodies than others, therefore, integrates time-domain (H_z component) and frequency-domain (E_x component) to conduct joint inversion can eliminate the limitations of single-domain inversion. The joint inversion section shows more continuous and accurate strata boundaries.



- **Seismic + EM Sequential Inversion**: Combination of Pre-Stack Depth Migration (PSDM) seismic data and EM data. Through partial strata segment inversion and constrained inversion based on geo-electrical models built up with high resolution PSDM and Res. Logs, it improves the vertical resolution of EM inversion for small scale reservoirs.



2.3 Data Interpretation Progress

The interpretation focuses on integrating multi-geophysical data and AI-driven identification to extract effective geological and fluid information:

- **Petrophysical Data Integration**: Interpreters combine petrophysical data (Cores of resistivity, induced polarization (IP), and impedance), well logs and forward modelling data to establish quantitative relationships between geophysical parameters and reservoir properties. Through deep learning to generate labels (AI), and then, the oil-gas-water identification index （Q）will be created, which can provide an accurate water compartment identification. For example:
  - **Water Saturation (SW) Prediction**: Using resistivity and porosity data, the water saturation (SW) profile is generated to determine the boundary between oil/gas zones (low SW) and water zones (high SW).
- **Oil-Gas-Water Identification Index (Q)**: A quantitative index Q has been proposed to distinguish fluid types based on SW:
  - **Gas Zones**: SW ≤ 30%, Q ≥ 0.9.
  - **Gas-Water Transition Zones**: 30% ≤ SW ≤ 60%, 0.5 ≤ Q ≤ 0.9.
  - **Water Zones**: SW ≥ 60%, Q ≤ 0.5.

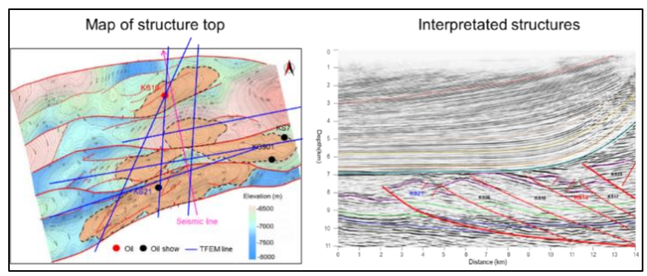
  This index simplifies the interpretation process and improves the accuracy of fluid identification.

3. Application Cases

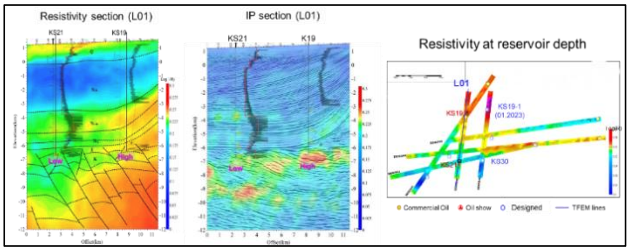
BGP nonseismic technologies have been successfully applied in three typical oil and gas exploration and development scenarios with verified effectiveness and practical value.

3.1 Ultra-Deep Reservoirs Predrilling Evaluation Using TFEM

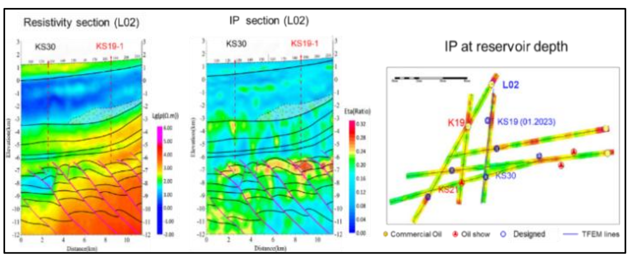
Ultra-deep reservoirs (usually with depths exceeding 4000m) face challenges such as poor seismic data quality and unclear reservoir characterization. This project adopted TFEM technology to evaluate the predrilling potential of ultra-deep reservoirs in the KS area (including KS_{21}, KS_{18}, KS_{17}, etc.). Deployed TFEM lines in KS area, and superimposed the structure top map to determine the distribution of potential substructures.



- **Existing Wells Verification:** Used the existing well KS_{21} to verify the accuracy of TFEM data. The resistivity section (L01) and IP section (L01) show that the resistivity at the reservoir depth of KS_{21} is consistent with the well logging data, and the IP characteristics match the hydrocarbon-bearing properties of the reservoir.



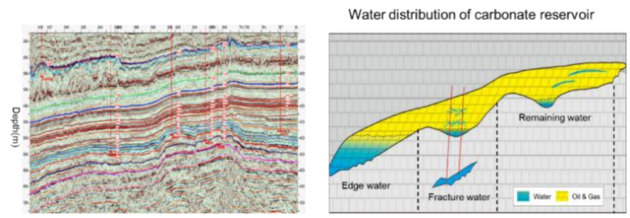
- **Predrilling Prediction:** For the designed wells KS_{19-1} and KS_{30}, TFEM demonstrats the resistivity and IP distribution of the target reservoir. The resistivity section (L02) and IP section (L02) indicate that the reservoir near KS_{19-1} has high resistivity (favorable for gas accumulation), while the area near KS_{30} has moderate resistivity (potential oil-water transition zone). The KS_{19-1} was drilled successfully in January 2023.



The TFEM-predicted reservoir parameters (resistivity, IP) are highly consistent with the post-drilling data of KS19-1, thus verifying the technology's capability to accurately characterize ultra-deep reservoirs and provide reliable support for predrilling decision-making

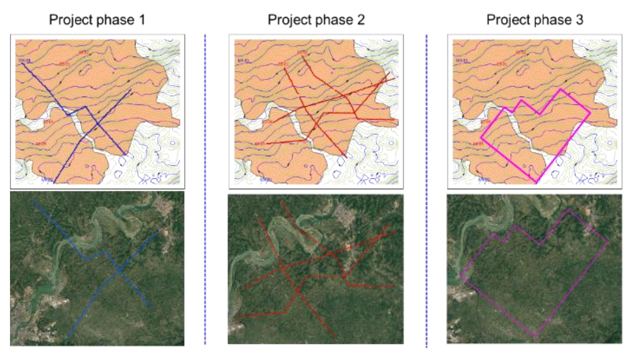
3.2 Water Compartment Identification Using TFEM

Carbonate reservoirs have complex water compartment distributions (e.g., remaining water, edge water, fracture water), which easily leads to ineffective well drilling. This project used TFEM to identify water compartments in a carbonate deep reservoir area and guide well placement.

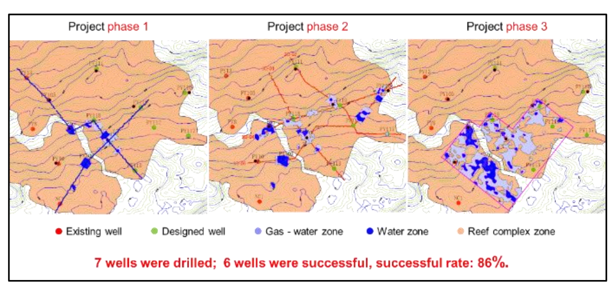


The project was divided into three phases:

- **Phase 1**: Conducted two TFEM lines survey and verified the effective of TFEM using the production of existing wells.
- **Phase 2**: Due to success of phase 1, another 4 TFEM lines were deployed for extending the coverage in the study area.
- **Phase 3**: Bother phase 1 and phase 2 are successful, 3D TFEM survey were conducted for further improving the accuracy of water compartment identification.

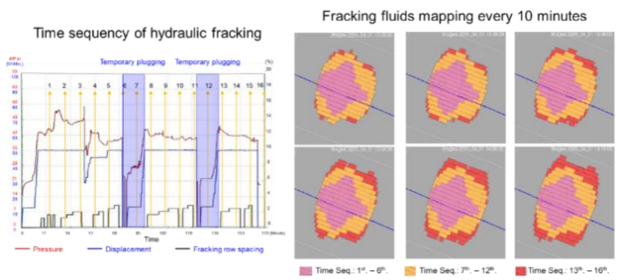


A total of 7 wells were drilled in the project, and 6 were successful (i.e., the drilled wells hit the expected oil & gas zones or water zone), achieving an 86% well-drilling success rate. TFEM effectively identified water zones, significantly reducing exploration risks and costs.



3.3 Tight Gas Hydraulic Fracking Monitoring Using EM

Tight gas reservoirs rely on hydraulic fracturing to improve productivity, but the distribution of fracturing fluids directly affects fracturing efficiency. This project used EM technology to monitor the hydraulic fracturing process of a tight gas well and guide real-time adjustment of fracturing parameters.



During 170 minutes fracking treatment, the fracking fluids are mapped by EM for 16 times. Through two times of temporary plugging being conducted, more fracking fluids have been entered into the reservoir both in two directions (along, vertical) of well path eventually.

EM monitoring realized the dynamic mapping of fracturing fluids, helping engineers adjust the injection rate and pressure of fracturing fluids in real time. The final fracturing effect met the design requirements.

4. Conclusions

BGP nonseismic techniques, with EM as the core method, demonstrate three key advantages in oil and gas exploration and development:

- High Fluid Sensitivity: Electromagnetics are highly sensitive to fluids such as oil, gas, and water, and can accurately distinguish fluid types (through indices like Q and SW) and map fluid distribution (e.g., water compartments, fracturing fluids).
- High Resolution: Breakthroughs in processing techniques (e.g., time-frequency joint inversion, seismic + EM sequential inversion) enable the characterization of small-scale reservoirs and thin layers, complementing seismic in complex geological environments.
- Cost-Effectiveness: Compared with large-scale seismic surveys, nonseismic technologies (especially airborne and TFEM) have lower acquisition costs and shorter project cycles, suitable for both large-area reconnaissance and small-scale detailed exploration.

BGP nonseismic technology has been widely applied in all stages of the oilfield life cycle:

- Exploration Stage: Used for hydrocarbon detection and ultra-deep reservoir evaluation, reducing the risk of dry wells.
- Development Stage: Applied in water compartment identification and well placement optimization, improving the efficiency of oil and gas production.
- Production Enhancement Stage: Used for hydraulic fracking monitoring, remaining oil detection, and water flooding monitoring, extending the production life of oilfields.

With the trend of refined and intelligent oilfield exploration and development, BGP nonseismic technology will play an increasingly important role:

- Intelligent Interpretation: Combining artificial intelligence (AI) and big data technology to realize automatic inversion and interpretation of nonseismic data, improving work efficiency.
- Multi-Technology Integration: Strengthening the integration of nonseismic techniques with seismic data, well logs, and geological data to build a multi-dimensional, multi-scale geological model.
- Adaptation to Complex Scenarios: Further optimizing technology for extreme environments (e.g., ultra-deep water, high-temperature high-pressure reservoirs) to meet the growing demand for complex oil and gas resource exploration.

In conclusion, BGP nonseismic technology has become a major force in promoting the transformation of the oil and gas industry towards refinement and intelligence, and will continue to create greater value for global oil and gas exploration and development.