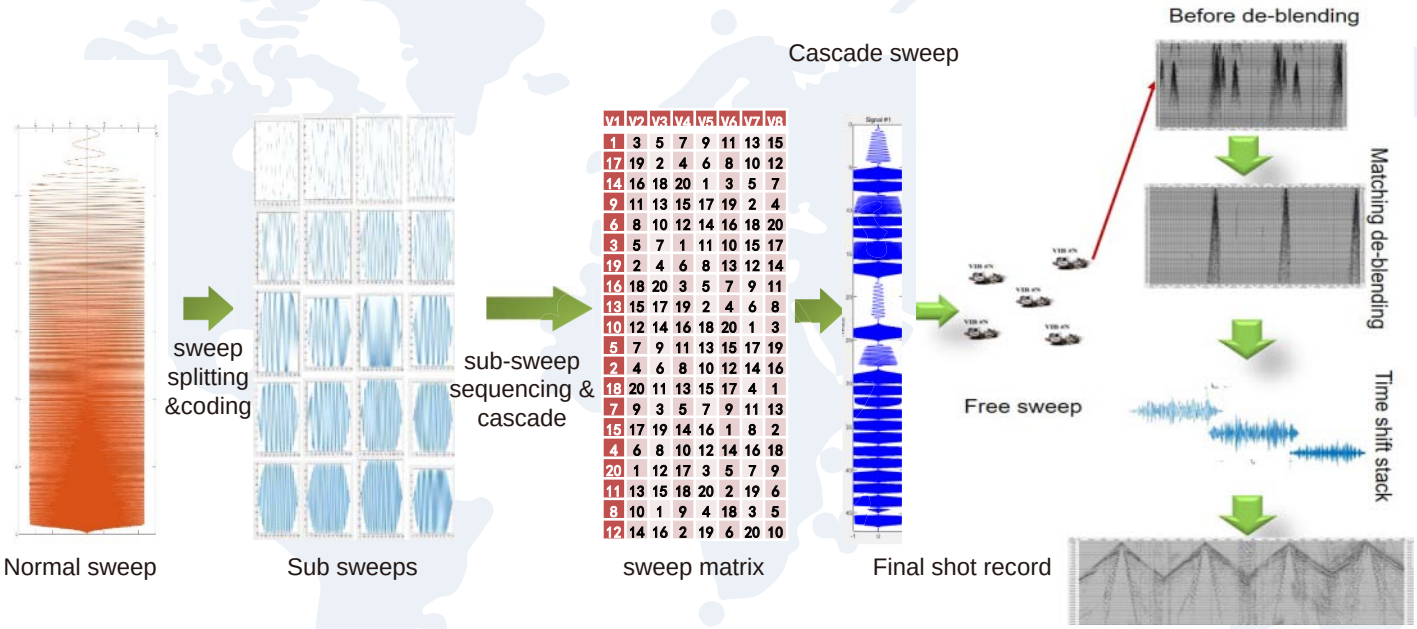
Frequency Separated Simultaneous Sweep (FSSS)

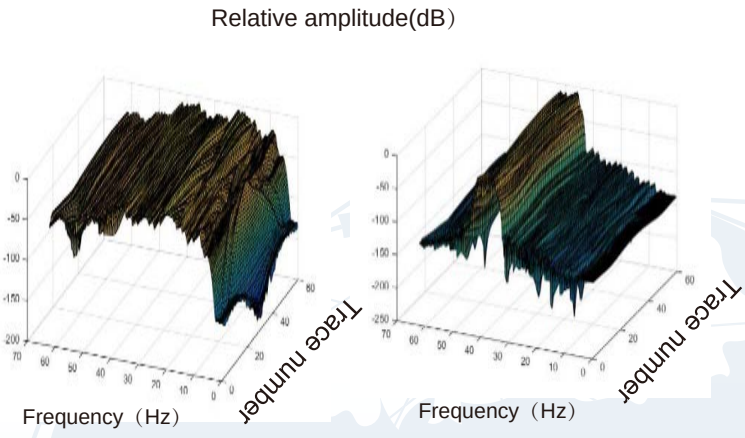
A High fidelity and productivity vibroseis acquisition method

Based on time-frequency domain orthogonality between different sweeps, Frequency Separated Simultaneous Sweep (FSSS) will eliminate the blended noise and maintain high fidelity with high productivity.

FSSS Functional Diagram

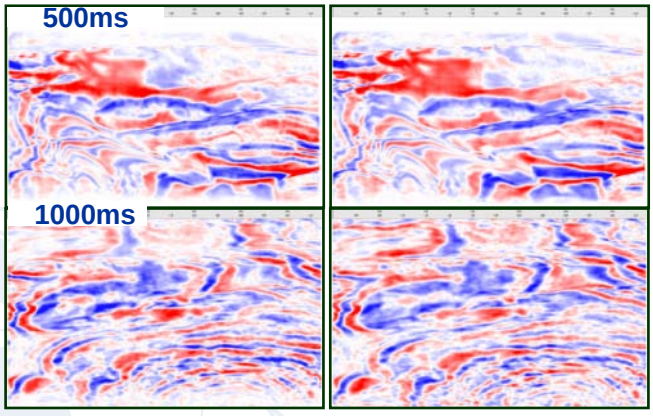


FSSS results



Before de-blending　　After de-blending

Comparison of 2D FFT spectrum



Flip-flop　　FSSS

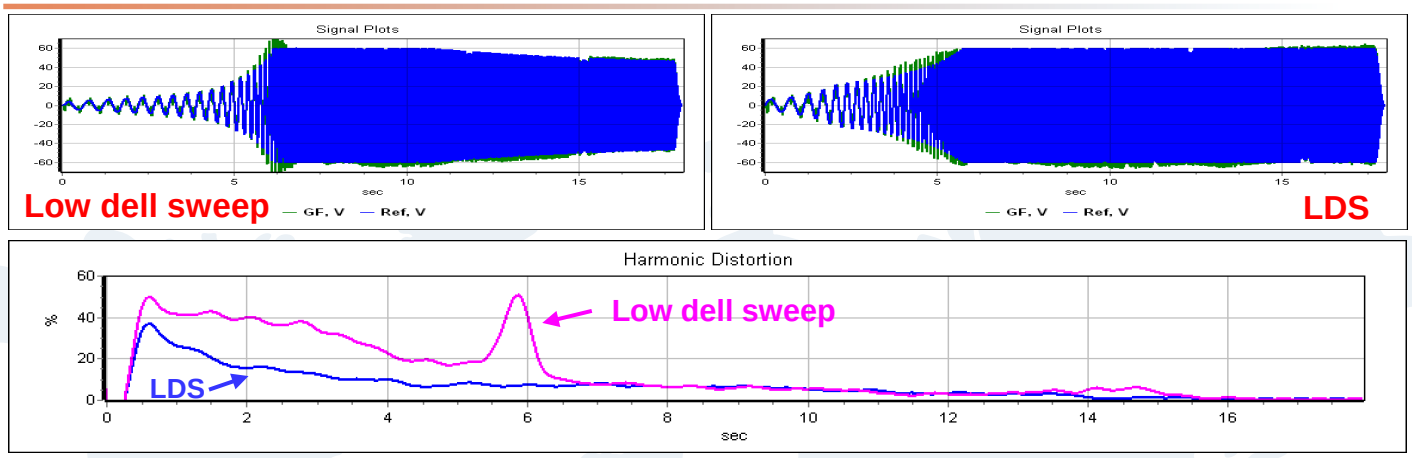
Time slices comparison

With same geometry, the daily productivity of FSSS is 6 times that of flip-flop

Low Distortion Sweep (LDS)

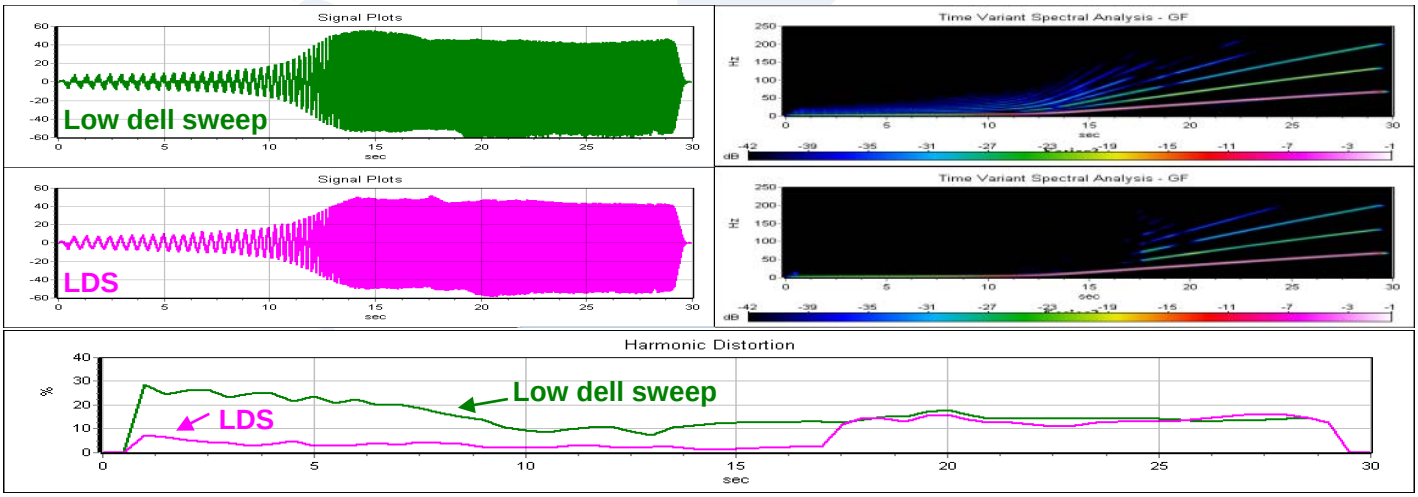
The Low Distortion Sweep (LDS) technique, especially developed by BGP for broadband surveys using conventional vibrators, mainly solves two low frequency sweep problems and can obtain better broadband seismic data.

1. Reduction of the sudden surge of harmonic distortion in signal transition zone

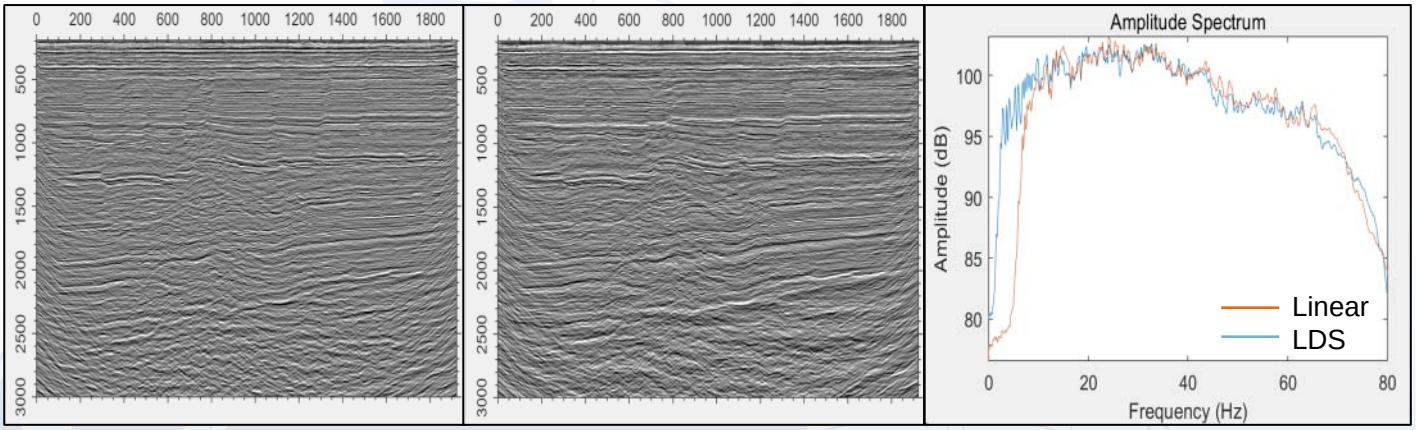


Using the LDS technique, the distortion is reduced by more than 20% on average and more than 40% in the transition zone of the sweep signal.

2. Suppression of the serious harmonics at low frequency



3. Acquisition of better broadband seismic data



Linear sweep (6-84Hz) LDS (1.5-84Hz)

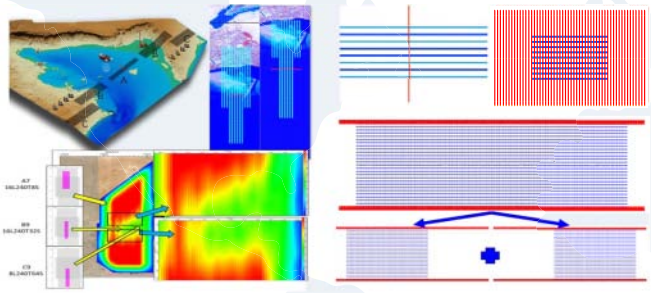
OBN Seismic Exploration Solutions

BGP OBN Briefing

Ocean bottom node (OBN) seismic exploration service, supported by software and equipment owned by BGP, has become a focus area for BGP in recent years, with regards to both technology and business development. This acquisition methodology requires extensive planning and integrated navigation of the seismic flotilla to achieve optimal operational efficiency for node deployment and retrieval, comprises massive data QC and on-site processing and yields superior 4-component seismic data with full azimuth, high fold, long offset and high S/N.

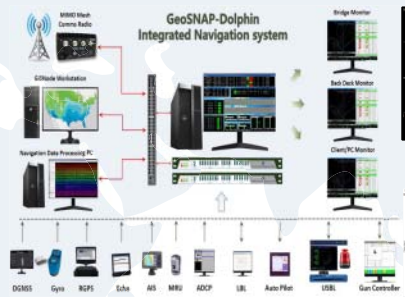
BGP OBN Key Techniques

1. OBN Geometry Design

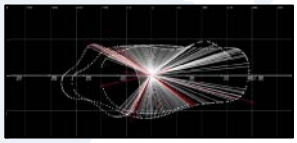


Geometry Design for Various Terrains

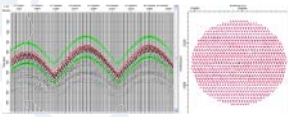
2. Integrated Navigation & Positioning



Dolphin Integrated Navigation System

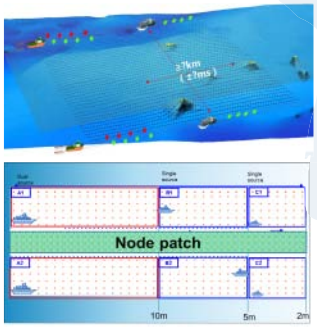


BPS Acoustic Positioning

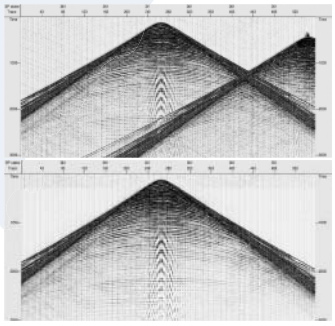


BGP FBP Solution

3. Marine Seismic High-efficiency Acquisition



Multiple Sources Blended Shooting

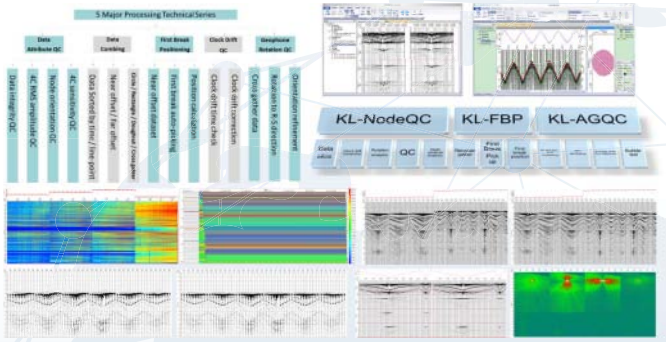


Data De-blending

4. OBN Automatic Deployment & Retrieval System

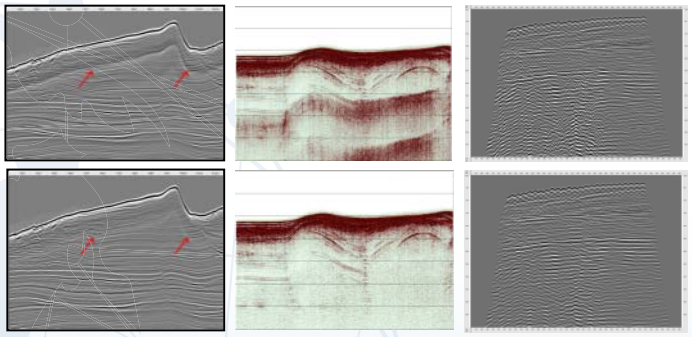
Module, Conveyor and Deployment & Retrieval System

5. OBN Data Quality Control System



KL-NodeQC Software

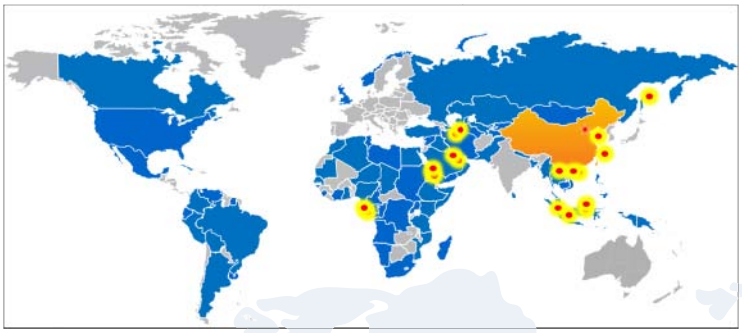
6. OBN Data Processing



Broadband Processing / Multiple Removal / Vz Noise Suppression

OBN Seismic Exploration Solutions

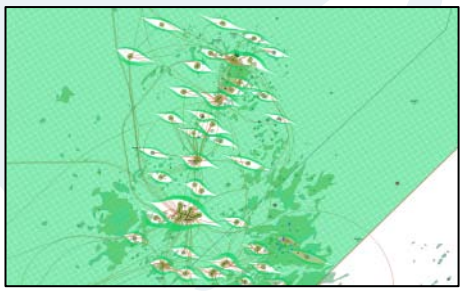
BGP OBN Experience



Since entering the OBN market in 2015, BGP Offshore has established itself as the major OBN service provider globally, with more than ten large scale projects to date, and with the surveys in Indonesia, Abu Dhabi, Brunei and Saudi Arabia being the largest OBN projects in 2017, 2018, 2019 and 2023, respectively.

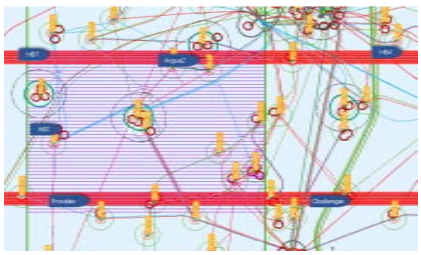
Brunei 3D/4D OBN Survey

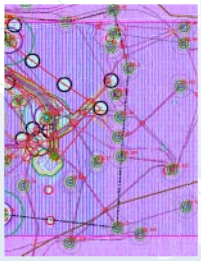
- 140+ platforms
- 7500+ close passes
- High 4D repeatability
- Sensitive coral areas
- ROV operation (node layout close to obstruction / coral protection)
  No time lost to SIMOPs
- 4 PB acquired seismic data
- High data quality and
- improved structural imaging

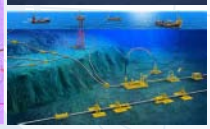


Middle East OBN Survey

- Largest survey area in the world: >30000 km2
- ~200 platforms in the oil field
- Nominal fold up to 9600
- Aspect ratio: 1
- High efficiency blended shooting: max 74113 shots/day with 6 source vessel and 10 sources
- More than 80 million shots
- 2.2 million node locations
- 34,192 close passes in 500m safe distance
- More than 70 vessels, >1450 staff







Deblending

BGP's inversion based deblending algorithm dramatically improves productivity and efficiency in data acquisition and can handle any environment such as land, marine, towed streamer or OBN.

Applied on 3D common-receiver gathers, this method separates signal and noise iteratively in the frequency-wavenumber-wavenumber (f-k-k) domain.

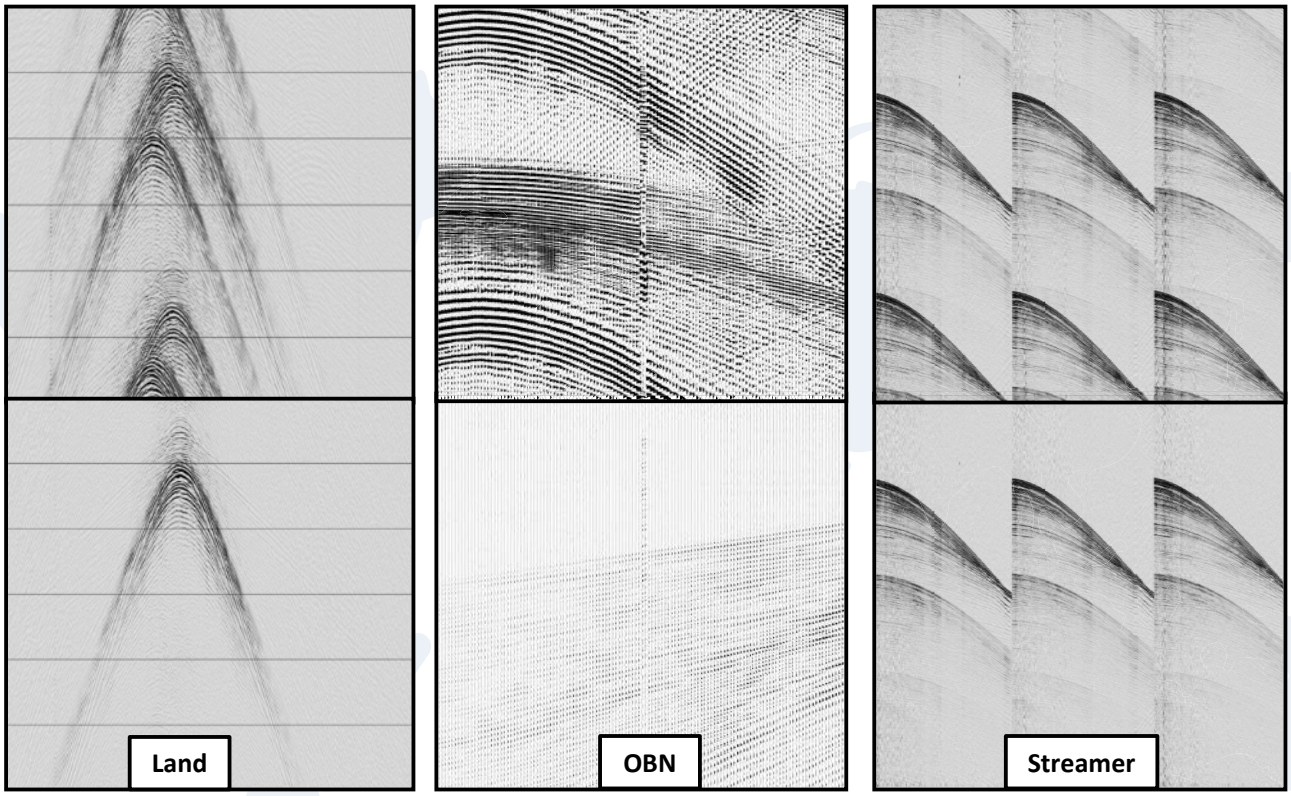


Figure 1: Common shot gathers before deblending (top) and after deblending (bottom)

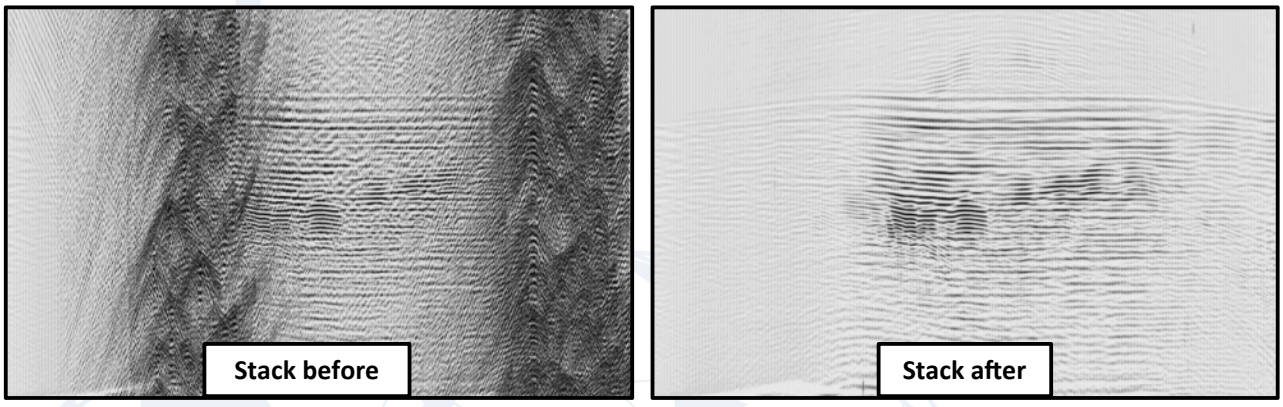


Figure 2: Stack section before deblending (left) and after deblending (right)

Features

- Ultra-high recording efficiency in the field
- Cost effective
- High accuracy and fidelity in deblending
- Land & marine data (streamer, OBN)

Joint Deblending and Compressive Sensing Reconstruction

BGP has taken seismic deblending and compressive sensing one step further with the recent development of its industry leading joint deblending and compressive sensing algorithm. Conventional cascaded deblending and compressive sensing (CS) reconstruction cannot accurately solve the problem as the two processes influence each other. Preforming deblending and CS reconstruction as a simultaneous process improves both data quality and efficiency.

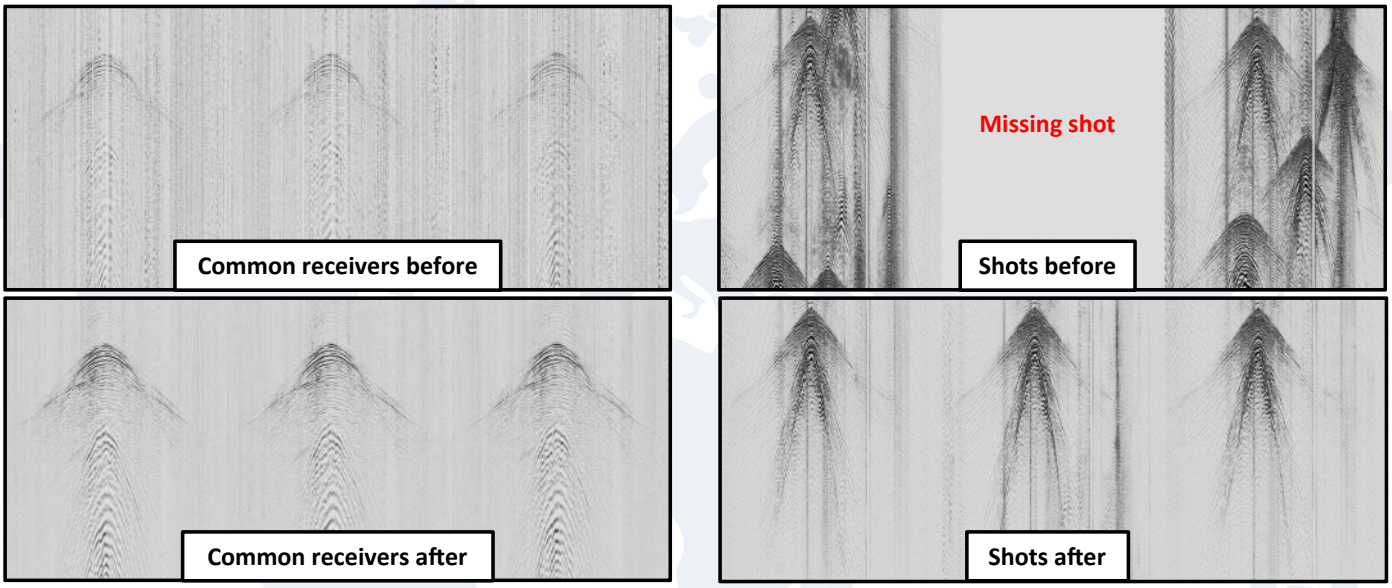


Figure 3: Shots and receivers before (top) and after (bottom) simultaneous deblending and compressive sensing

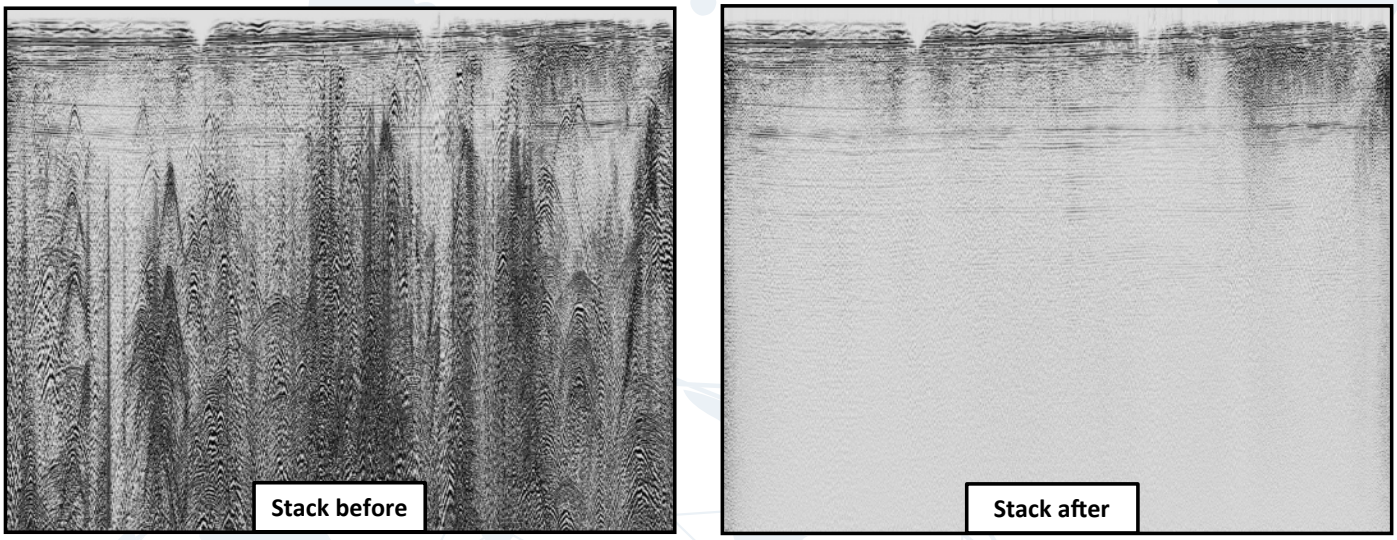


Figure 4: stack section QCs

BGP's cutting-edge joint deblending and compressive sensing data reconstruction provides an efficient and high-quality processing technique which strongly supports CS based simultaneous shooting acquisition.

OBS Data Processing

BGP’ s advanced Ocean Bottom Seismic processing and imaging technologies are systematically aiding our client’ s understanding of the subsurface. Industry leading pre-processing workflows as well as state-of-the-art Full Waveform Inversion and Impedance inversion algorithms make full use of OBS low-frequency, full-azimuth, ultra-long offset information.

Optimized pre-processing workflows:

With advanced and tailored pre-processing workflows, BGP can address all different types of challenges from shallow to deep water environments.

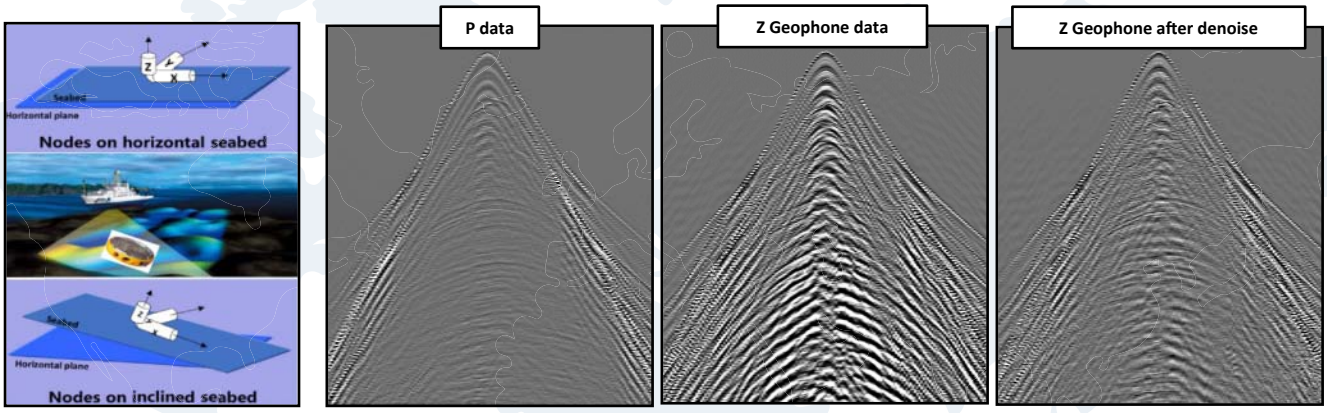


Figure 1:OBN denoise of vertical geophone

Up Down Deconvolution (UDD) technology attenuates all free-surface multiples and removes the effects of the source ghost and signature producing enhanced resolution and better imaging.

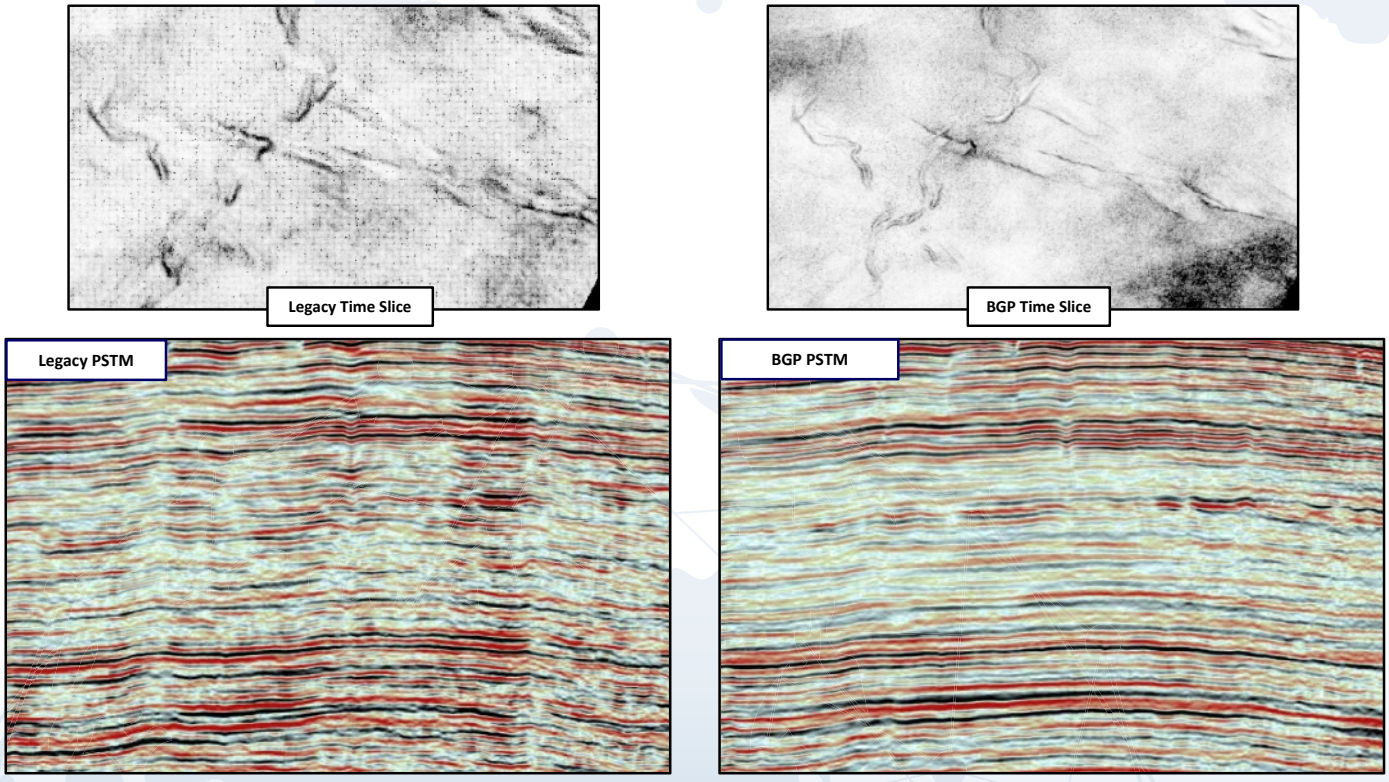


Figure 2: comparison of legacy vs BGP PSTM stack sections and time slices

Full Waveform Inversion FWI:

BGP's FWI framework overcomes even the most challenging environments. This technology leverages anti-cycle skipping technology by solving a least-squares objective function and by minimizing the travel time misfit in both data and image domains.

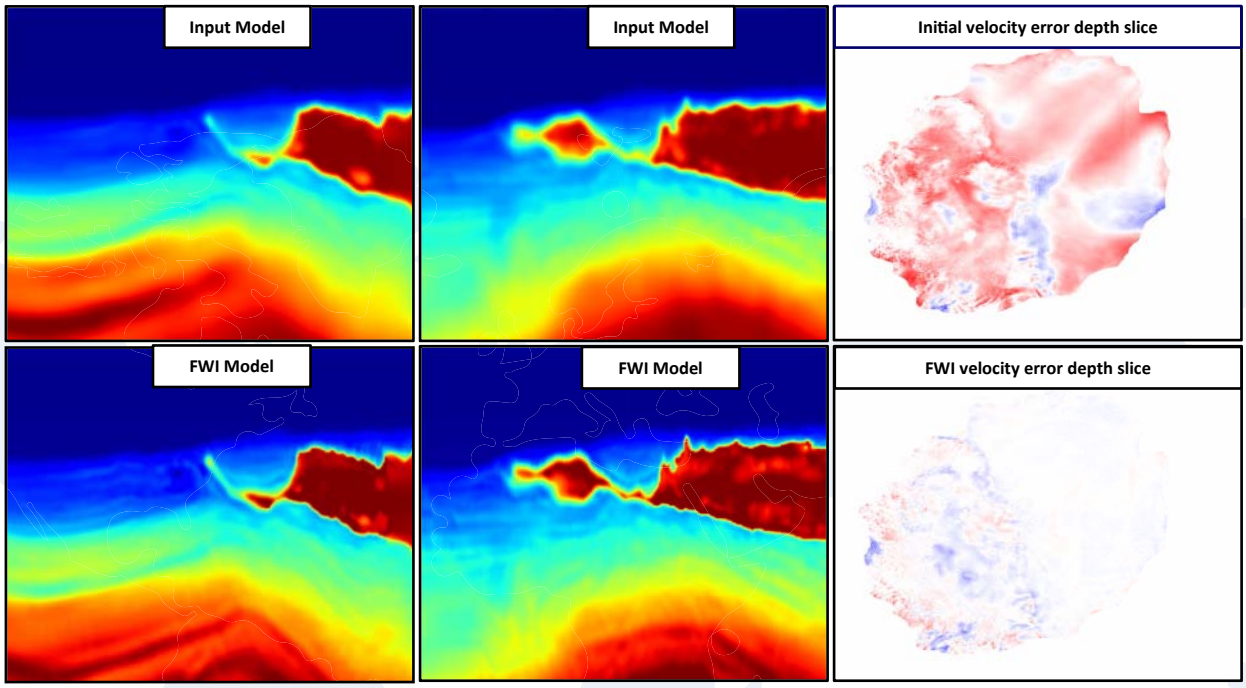


Figure 3: Deep water Gulf of Mexico OBN FWI

Full Waveform Impedance Inversion FWII:

The state-of-the-art full waveform impedance inversion workflow based on true amplitude migration inverts both velocity and impedance simultaneously. From raw data, higher resolution images are generated earlier in the workflow providing our customers with real subsurface insight.

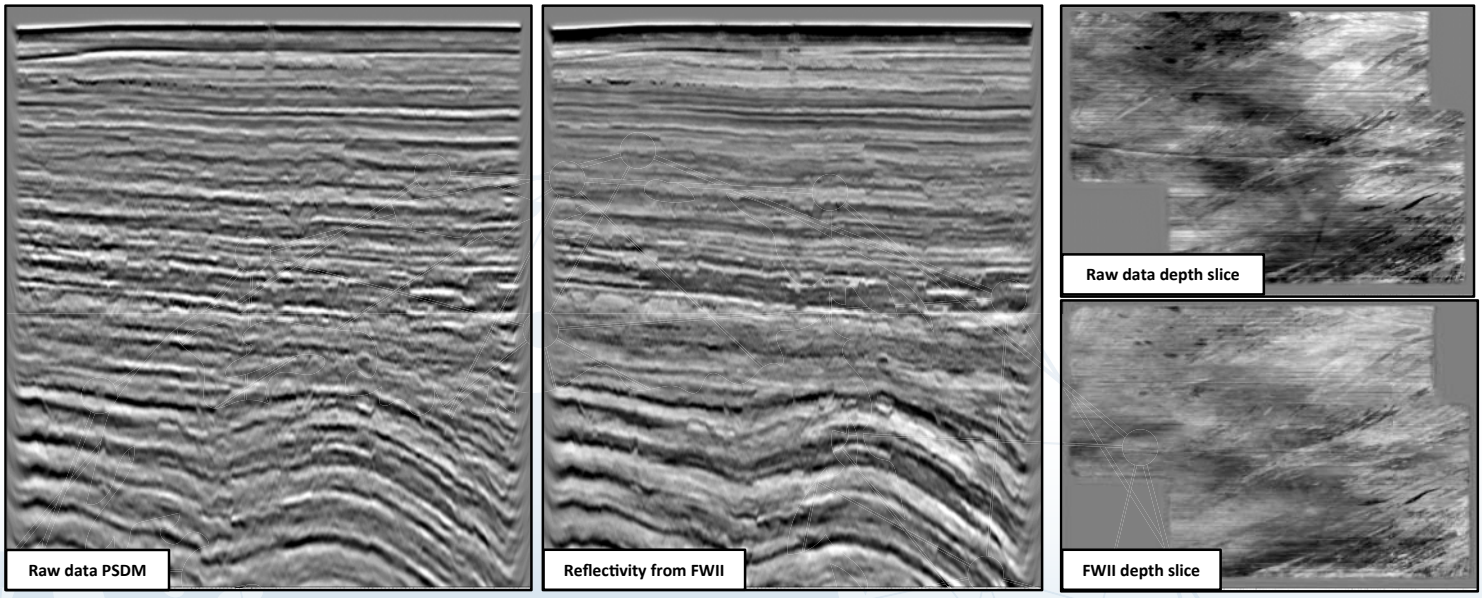


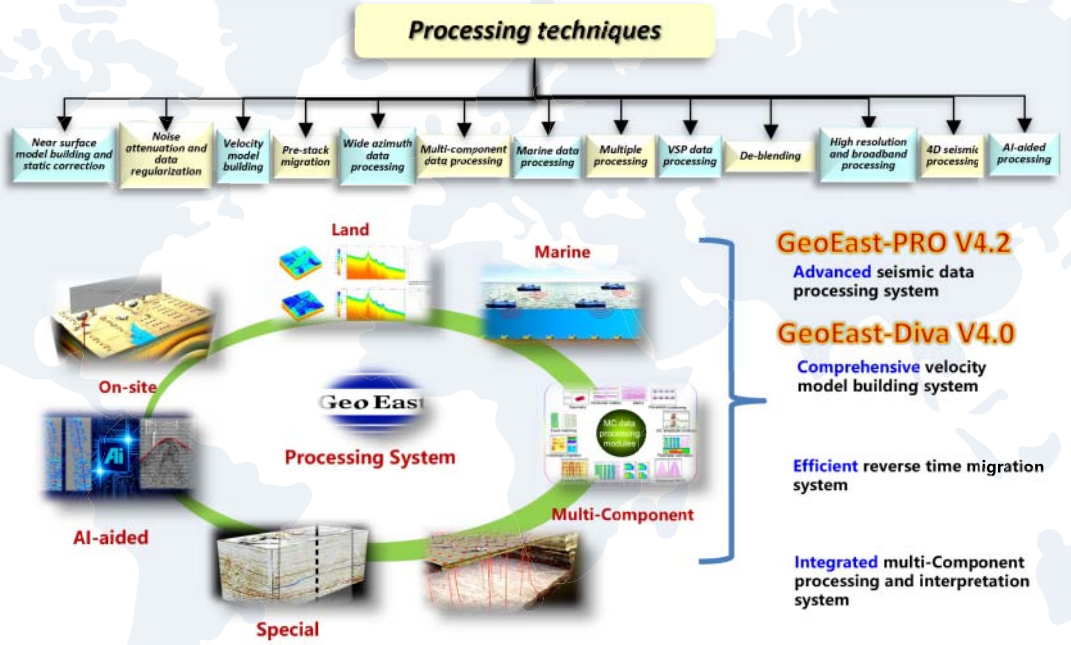
Figure 4: Full Waveform Impedance Inversion (comparison of FWII from raw data vs raw PSDM data)

GeoEast - An Integrated Seismic Data Processing and Interpretation Software System

GeoEast is a comprehensive, large-scale geophysical data processing and interpretation software system. It can fully meet the demands of time domain and depth domain processing and interpretation of geophysical data acquired from complex geological and geophysical conditions of both land and marine. It also provides end-to-end solutions for VSP, shear wave, and unconventional data processing.

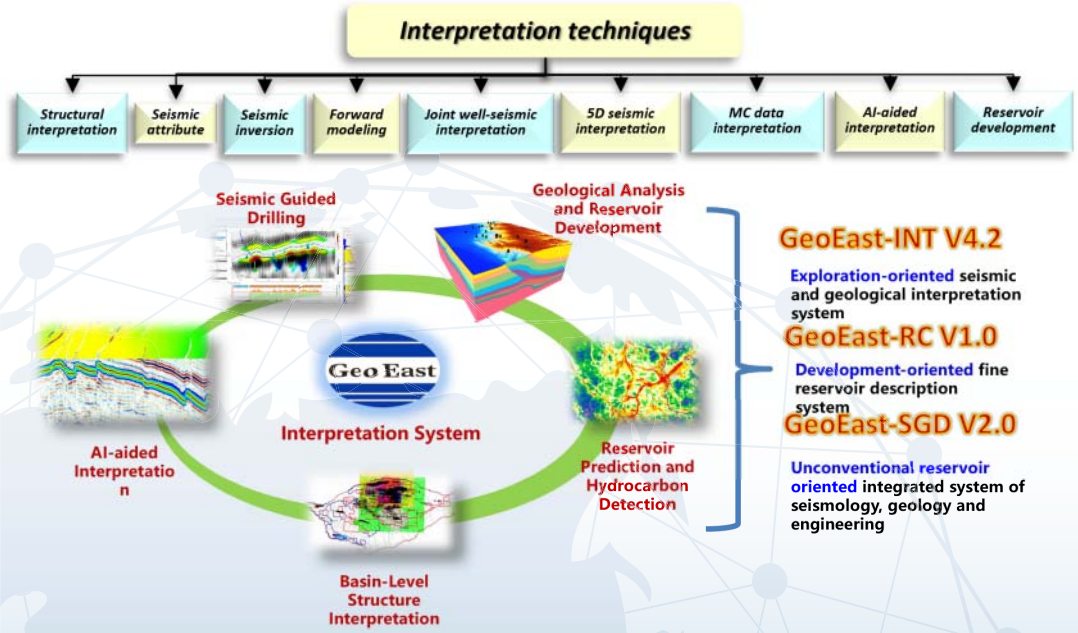
Processing Software

■ 7 packages ■ 24 technology series ■ 400+ modules



Interpretation Software

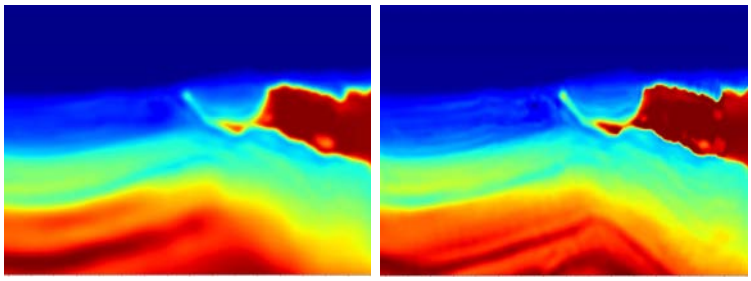
■ 7 packages ■ 24 technology series ■ 400+ modules



GeoEast - An Integrated Seismic Data Processing and Interpretation Software System

FWI

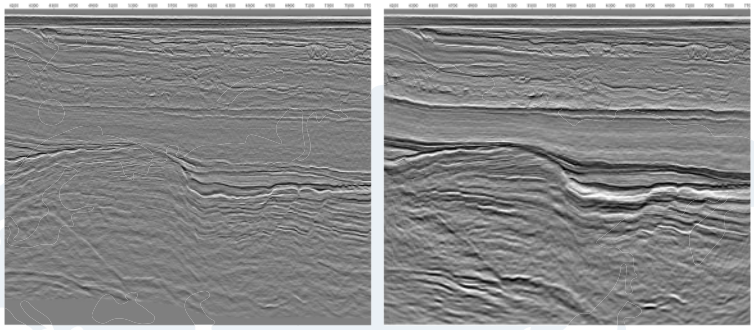
Equipped with full waveform inversion technology in time domain, frequency domain, and Laplace domain, it can be used in conjunction with tomography to establish a high-precision velocity model.



Legacy velocity model | JDFWI inverted velocity model

FWI Imaging

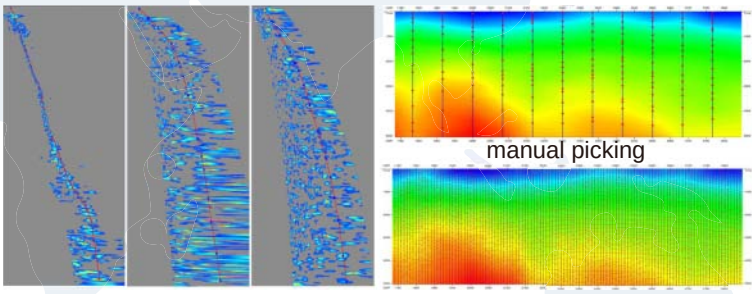
Expanding low frequencies: Non-linear inversion can generate low frequencies that seismic waves do not possess.
Expanding illumination: Non-reflective waves can cover illumination structures that reflective waves cannot.



PSDM | PSDM + FWI

AI Processing

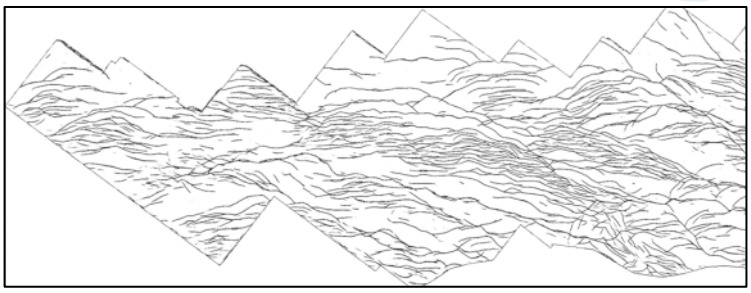
GeoEast has developed intelligent processing modules for time-consuming and labor-intensive processes such as first break picking, velocity picking, and noise attenuation. The accuracy and efficiency improved dramatically.



Different S/N data | DL picking

AI Interpretation

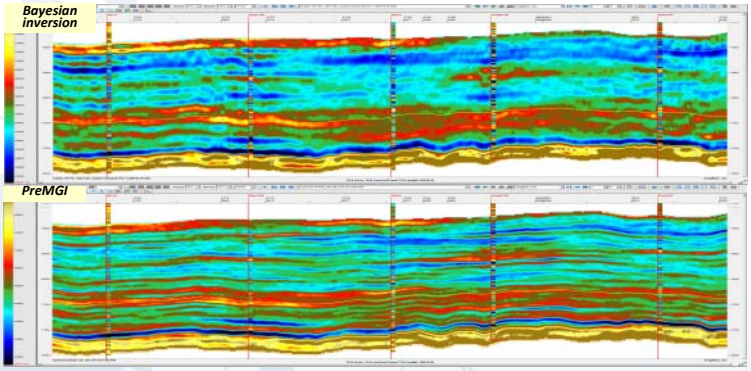
A deep learning-based artificial intelligence neural network has been developed, equipped with a series of intelligent interpretation technologies including horizon interpretation, fault identification, well log curve prediction, well log lithology prediction, and geological body identification.



AI-aid fault prediction

Seismic Inversion

GeoEast provides rich pre-stack and post-stack seismic inversion methods and complete workflow, which can meet the needs of reservoir prediction in different stages of exploration and development.



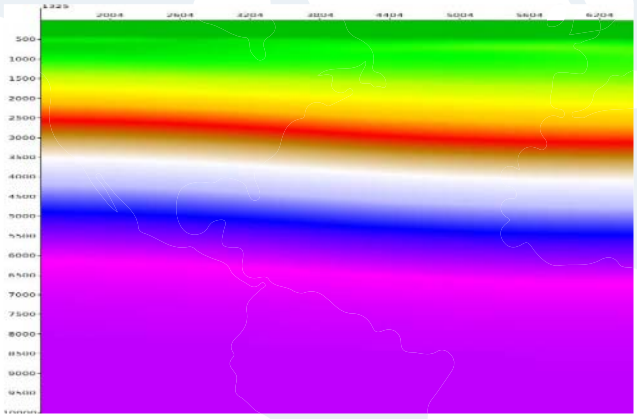
Inverted shear wave impedance

GeoEast-full waveform inversion (FWI)

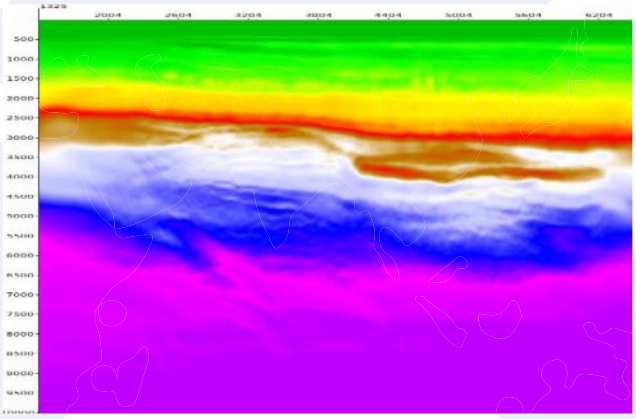
GeoEast Full-waveform inversion includes refraction inversion and reflection inversion. Several techniques for handling practical issues are provided, such as adaptive time FWI for handling cycle-skipping, and first-break FWI for complex and low SNR land data. The FWI inversions also consider earth Q absorption, and it can invert velocity, density, Q and epsilon, the so called Multi Parameter Inversion.

Conventional refraction FWI

Our conventional refraction FWI follows the standard optimization theory, where we minimize the second order norm errors of synthetic and observed data, by utilizing optimization solvers like the steepest descent, nonlinear conjugate gradient, or even quasi-Newton method.



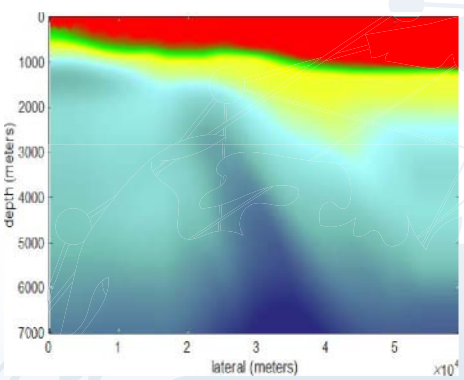
Initial velocity model



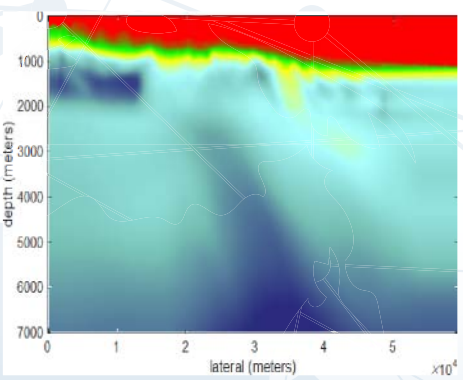
FWI velocity model

First-break FWI

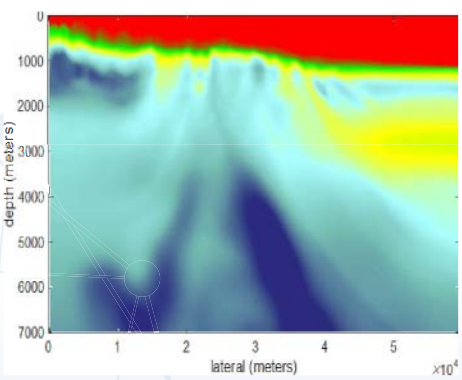
Inverting a land dataset is very challenging, because of the complexity of the data. Ground rolls and guided waves in land data are very hard to simulate accurately with wave equation modeling methods. Guided wave is a kind of refraction energy that bounces multiple times between surface and reflectors. To play safe, one of the most practical approaches to run FWI on land data is to start inversion with first break information, which can be obtained freely from the static correction processing step.



Initial model



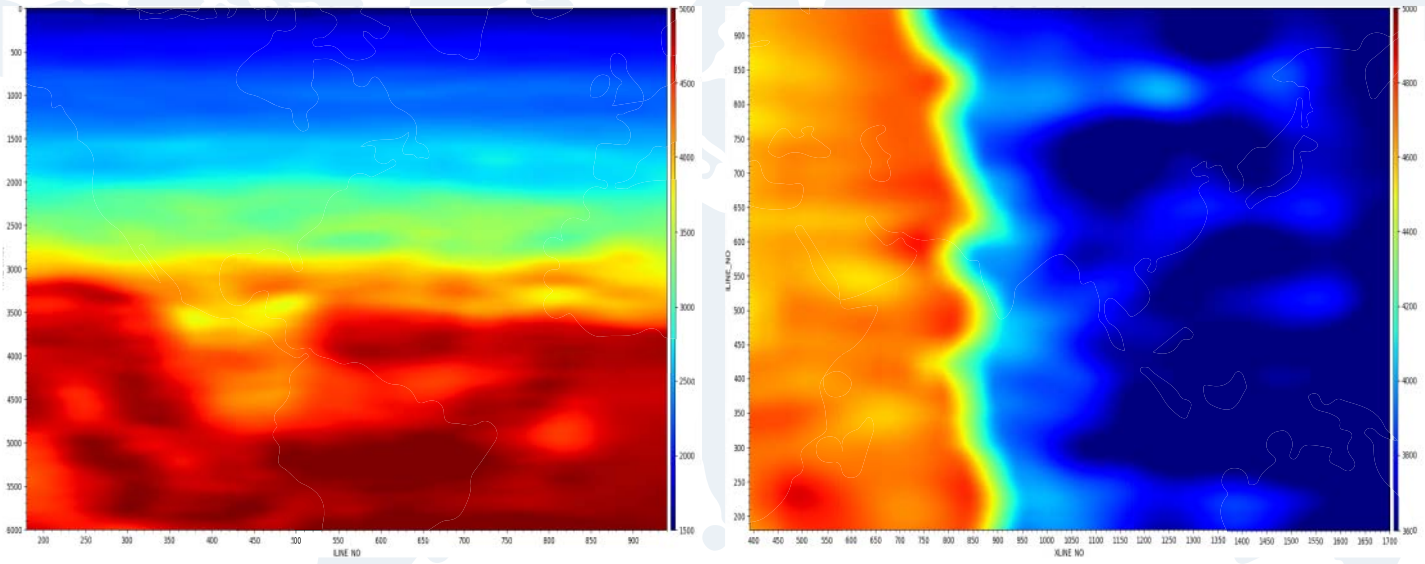
First-break FWI



Conventional FWI

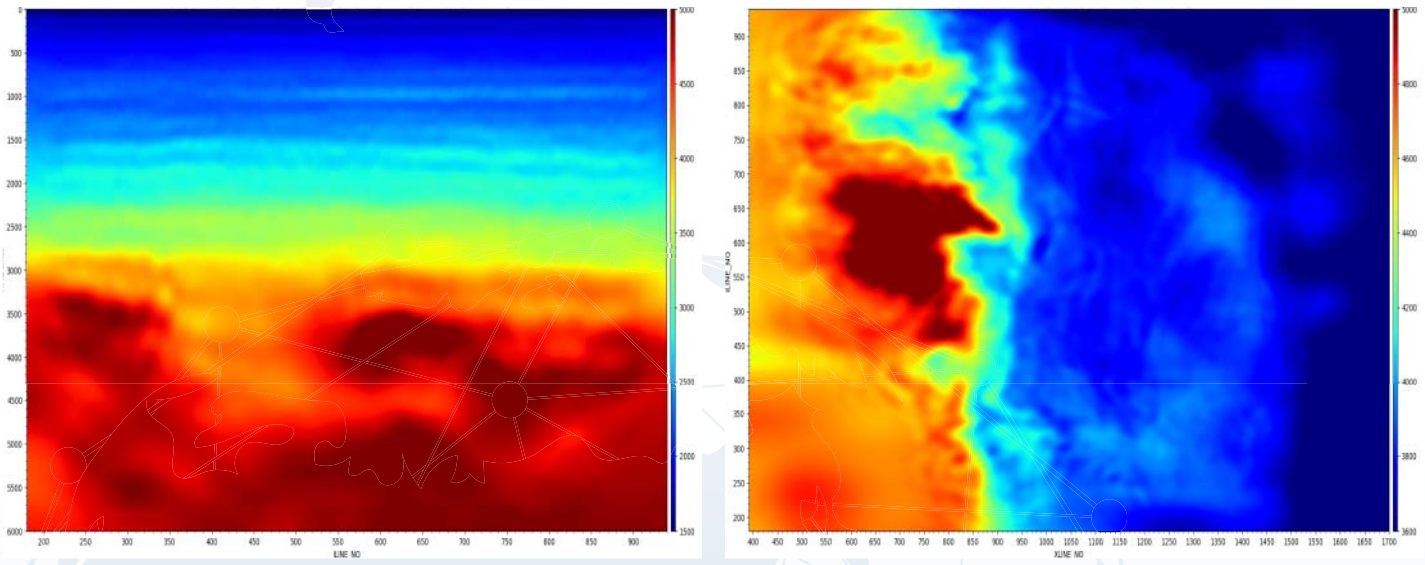
Time-Adaptive FWI

To tackle the cycle-skipping issue, we also developed time-adaptive FWI, in which we minimize the cross-correlation time lag of modeled and observed data. This approach can allow our inversion scheme to rely on the time error of the events, instead of the phase error which is the main cause of the cycle-skipping issue. We also possess other anti-cycle skipping techniques such as dynamic-time wrapping, adaptive-filter, and so on, prepared for different real data problems.



Inline slice

Initial velocity model

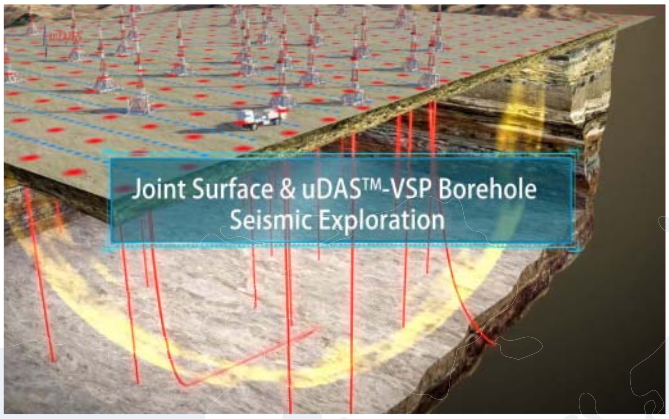


Inline slice

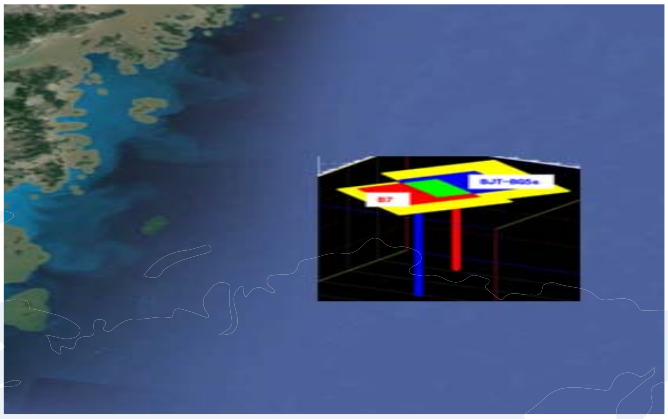
Updated velocity model through FWI

Joint Borehole-Ocean/Borehole-Surface Exploration Technology and Application Effect

The joint borehole-ocean/borehole-surface exploration technology is based on the surface seismic acquisition, implementing optical fiber data acquisition simultaneously in the well, which has the advantage of full well interval, high density, high coverage reception.

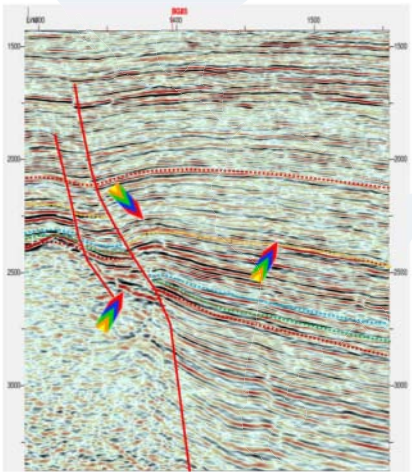


Borehole-surface Joint Exploration Stereoscopic Diagram

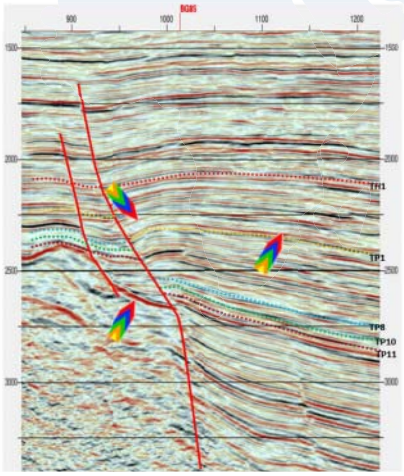


Schematic Diagram of Borehole-ocean Acquisition Coverage

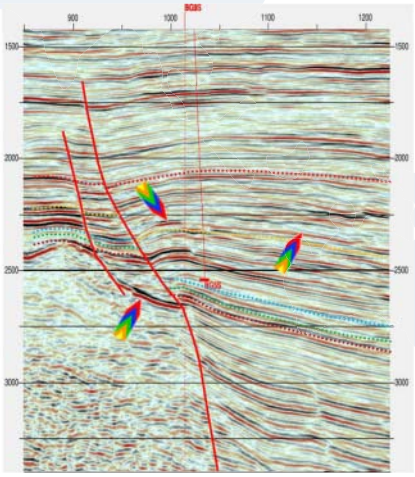
An application case of DAS joint exploration in Pinghu oil and gas field, East China Sea



Data on Towing Cables

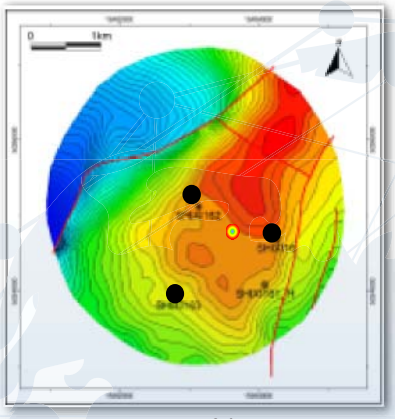


OBN Imaging

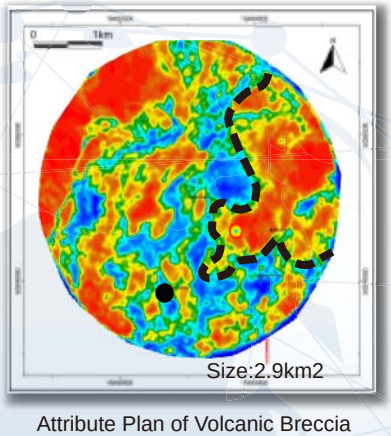


3D VSP Imaging

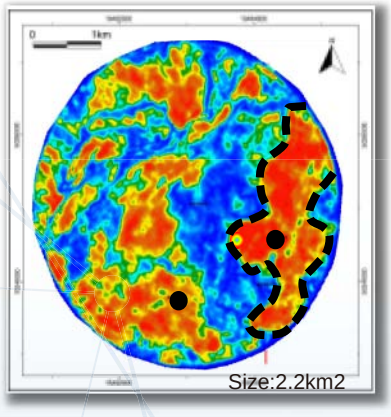
Seismic characterization technology of igneous rock masses using 3D VSP joint Borehole-surface exploration data in Shixi



Structure of the Top Boundary of Carboniferous System



Attribute Plan of Volcanic Breccia Section



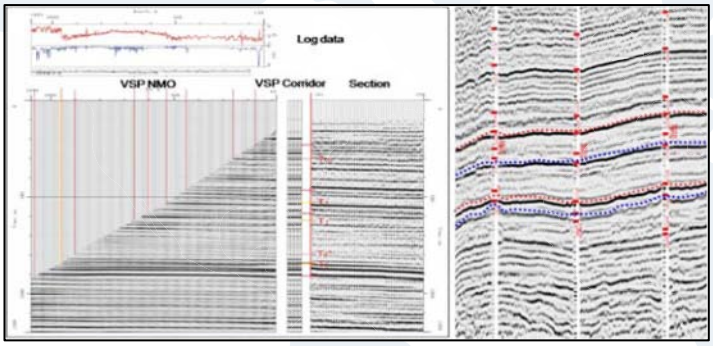
Attribute Plan of Carboniferous Weathering Crust

VSP

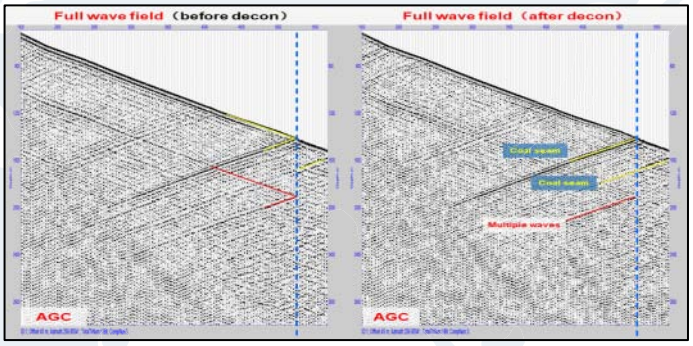
The Vertical seismic profile (VSP) adopts the observation method of surface excitation and well reception, which can establish accurate time depth relationships and obtain accurate velocity data such as average velocity and layer velocity, so as to accurately calibrate seismic and geological reflection layers and predict the burial depth of target layers underground, etc.

Zero offset VSP

With the accurate time-depth relationship and VSP NMO result, well information and the surface seismic section can be tied in the time and depth domain. Multiple waves can be identified by the wavefield before and after deconvolution.



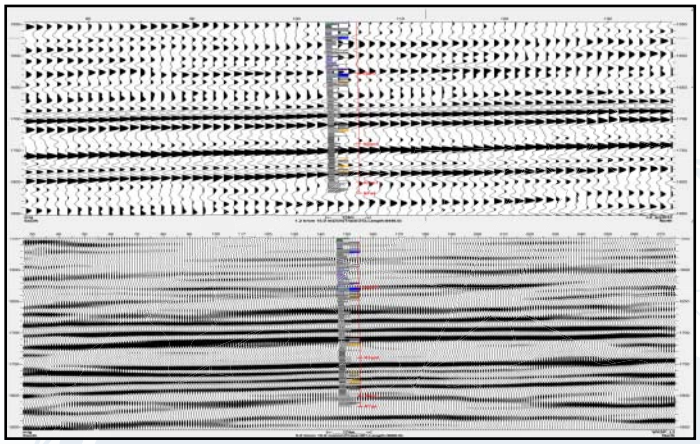
Calibration Seismic Data with VSP and Logging



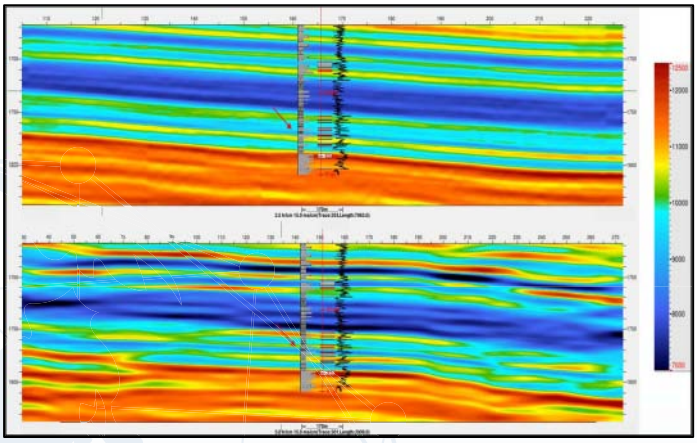
Analysis of Multiple Waves

Walkaway VSP

Compared with surface seismic, the Walkaway VSP has the advantages of high resolution and accurate depth position. It has been widely used for borehole vicinity structure imaging, high-precision reservoir prediction and time-lapse reservoir monitoring.



Comparison of Imaging Between Walkaway VSP (below) and Surface Seismic (above)



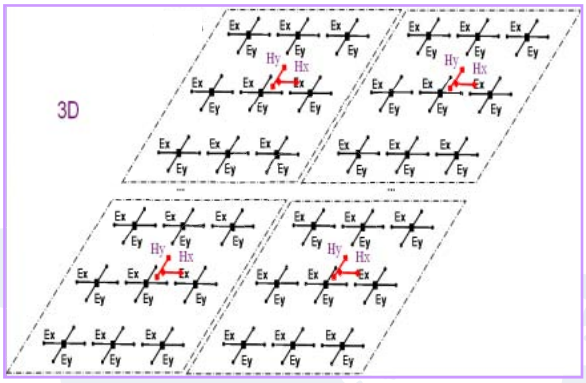
Comparison of Inversion Between Walkaway VSP (below) and Surface Seismic (above)

3D GME Survey

BGP provides an integrated solution with 3D GME (Gravity, Magnetic, Electromagnetic) & Seismic to identify subsurface structures in complex exploration areas.

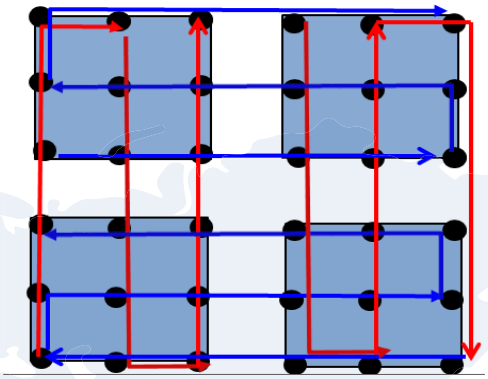
Acquisition

3D small-bin MT/AMT acquisition



A 3D small-bin includes one 4-channel and eight 2-channel receiver systems, which is synchronized by GNSS satellites.

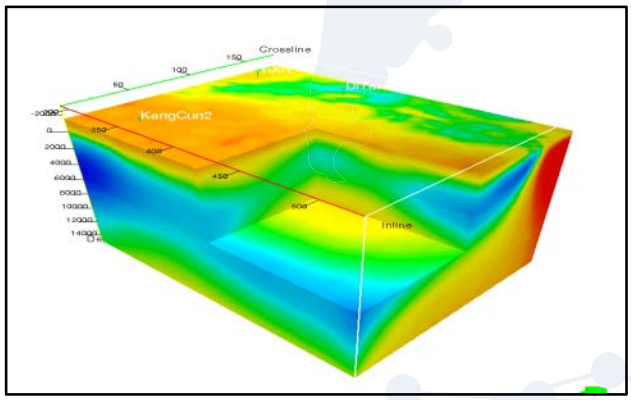
High accuracy 3D gravity & magnetic acquisition



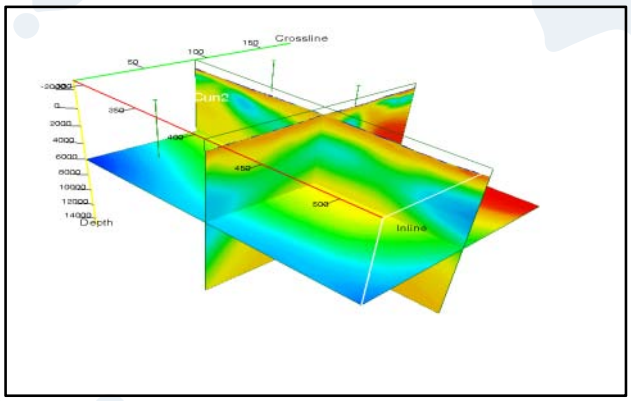
Two independent observation loops make gravity and magnetic observation accuracy 100% increasing.

Processing & Interpretation

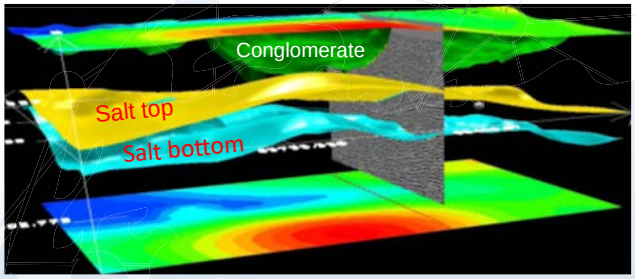
3D MT apparent resistivity image



3D density image



3D MT and gravity joint interpretation

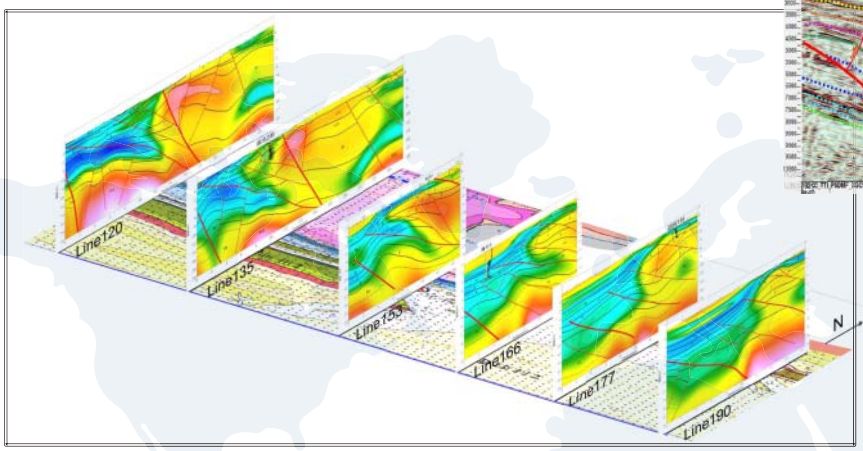


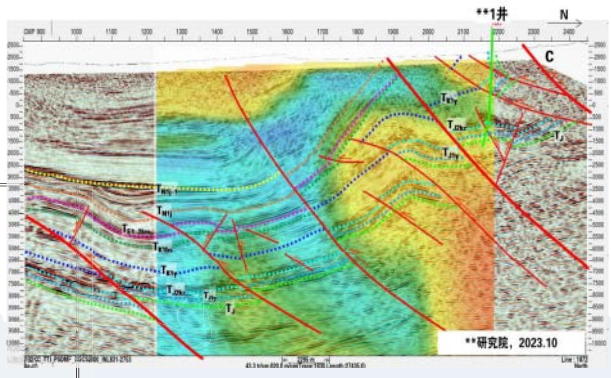
Gravity, Magnetic, EM, Seismic and logging data can be processed and interpreted on BGP-developed Geo-East comprehensive processing and interpretation software system.

Applications of 3D GME

Integrated 3D GME with seismic, logging and geological data can map the distribution of lithology, layer and analyze the pattern of sedimentary deposits.

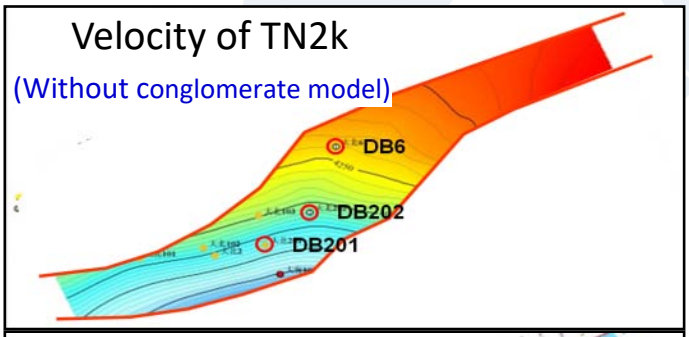
Joint interpretation sections with
3D gravity, magnetic and MT data

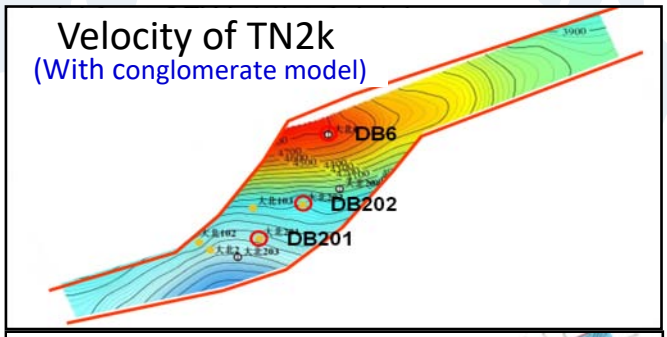


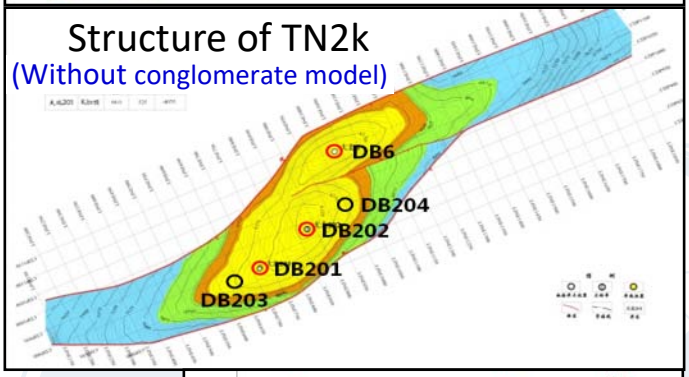


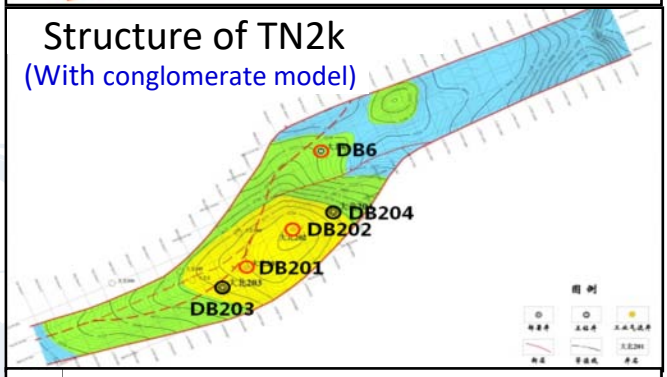
Overlay of 3D MT
apparent resistivity and the
3D seismic section

A Conglomerate model built with 3D GME data assists in seismic data reprocessing, and the interpreted traps are more reliable and the depth error reduced accordingly.

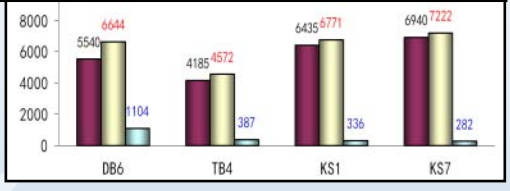


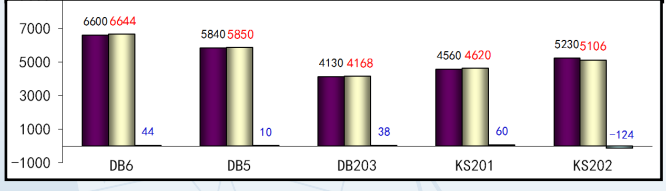






Depth error
comparison



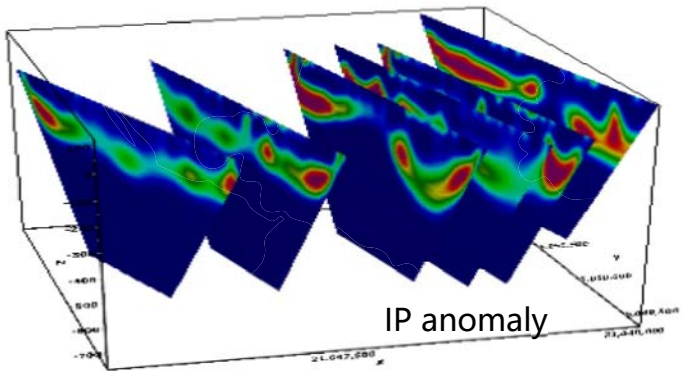


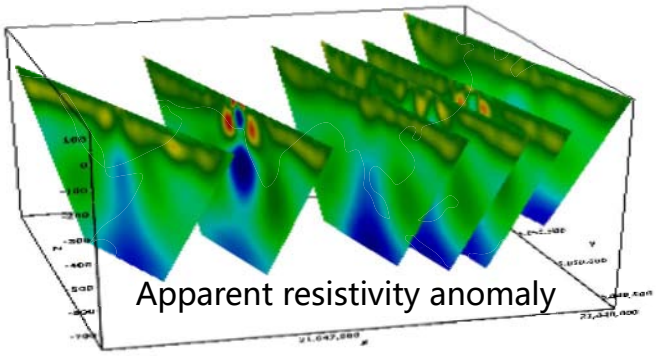
New Energy Technologies and Business

GME technologies are more effective in some of the new energy businesses. Some new technologies derived from traditional GME methods were presented and applied in new energy business, such as CCUS/CCS, geothermal energies, associated minerals of oil and gas.

Techniques for associated mineral survey

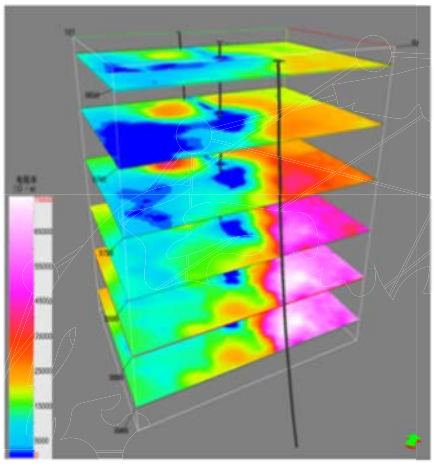
A phase IP method based on pseudo-random multi-frequency nested transmit signals was developed by BGP for the associated mineral survey. The three-step method for predicting and evaluating sandstone-type uranium mineralogical and geochemical exploration in petroliferous basins has been developed, and the national invention patent has been obtained.



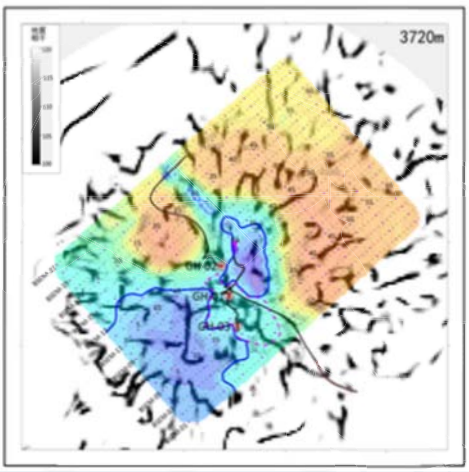


Monitoring techniques for Hydraulic Fracturing

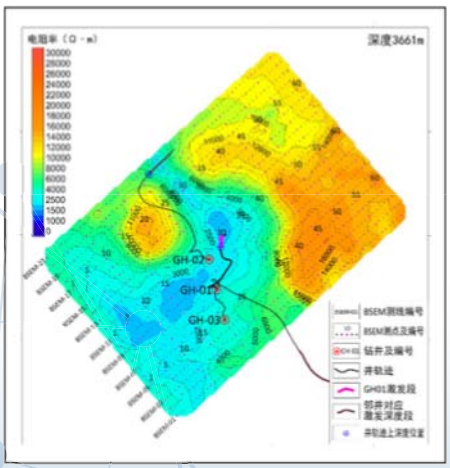
By using the VSP technology to detect the variation of velocity coherence property and combining this with the inversion resistivity of BSEM survey, the fracture distribution of hot dry rock after fracturing can be clearly described, and the joint state of fractures can be predicted.



Depth slices of 3D inversion resistivity



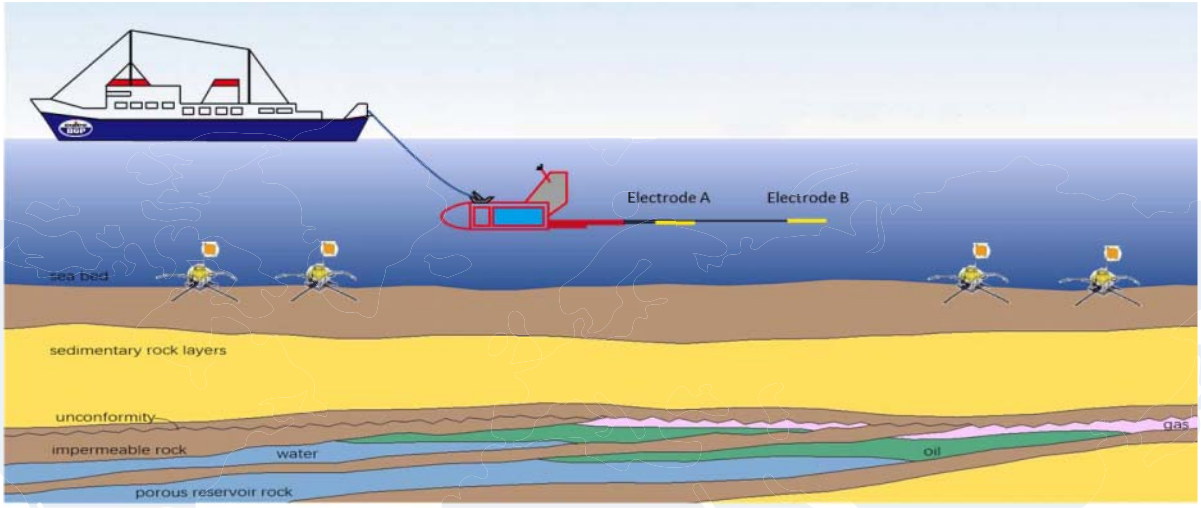
Overlay of seismic coherence attributes on apparent resistivity



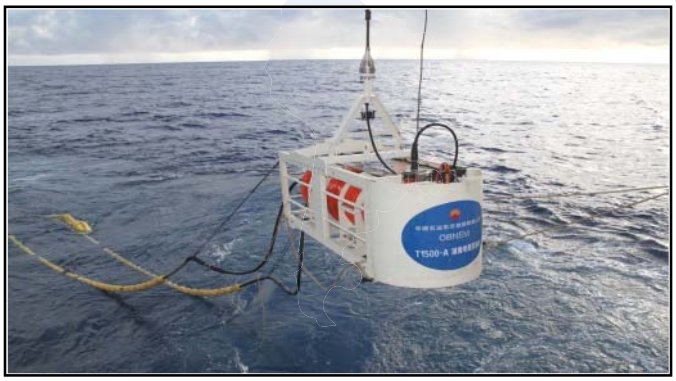
Apparent resistivity in a specific depth

OBNEM Survey

OBNEM® (Ocean Bottom Node Electromagnetic) survey plays a remarkable role in marine oil & gas exploration. Since 2018, BGP has developed a series of relevant hardware and software, including high power transmitting systems, long-endurance receivers, reliable monitoring systems and integrated processing modules.

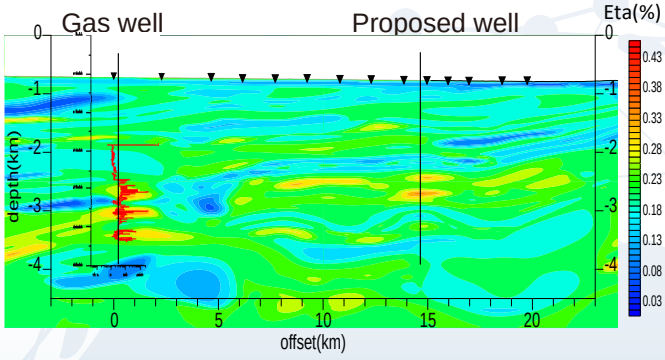


Schematic diagram of OBNEM survey



OBNEM transmitter

OBNEM receiver



IP section from OBNEM

Based on oil/gas bearing structures producing high IP anomalies, high IP anomalies were used to predict the location of oil/gas bearing structures. An OBNEM section is always suggested to cross the proposed well and known oil/gas well if it is available.

EV-56 High Precision Vibrator

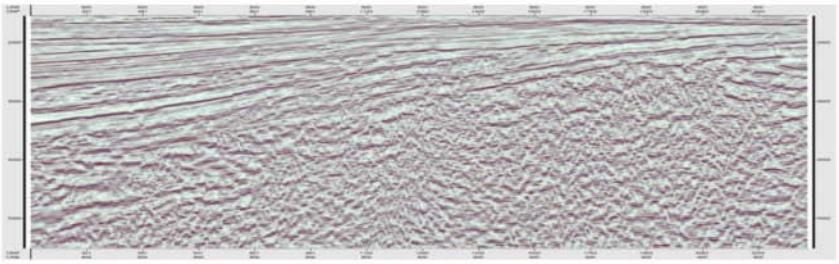
High precision seismic signal excitation source

The EV-56, a new generation of broadband vibrator, is one such invention that can generate reliable and stable linear sweeps from 1.5Hz to 160Hz, which is essential in enhancing resolution of full waveform inversion. High-precision, deep target seismic imaging has been applied and implemented in multiple projects.

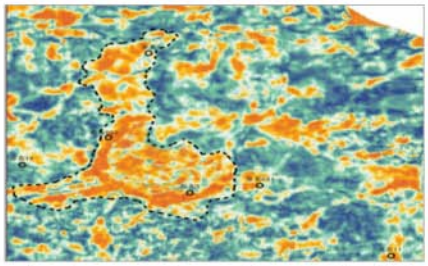
Specifications	
Max. HD, kN	310
Peak Force, kN	251
Limited Low Frequency, Hz	3
Recommended High Frequency, Hz	160
Max. Stroke, mm	210
Mass Weights, kg	5900
BP Weights, kg	2032
Mass/BP Ratio	2.9
Vibration HP, Mpa	21

Improvement of geological quality

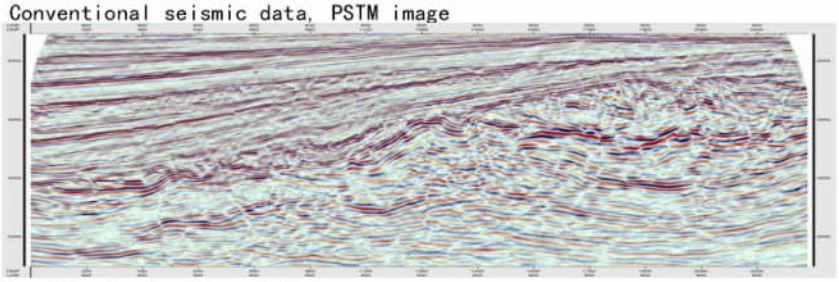
The high precision vibrator can improve the quality of seismic data and increase the signal-to-noise ratio (SNR) from the point of view of seismic excitation source, as can be seen from the following sections. The signal quality has been significantly improved.



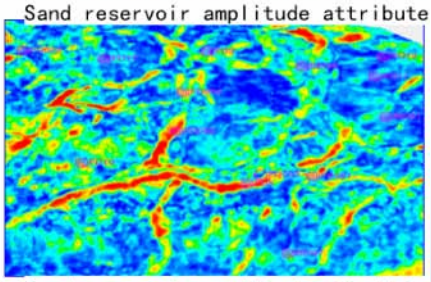
Conventional seismic data, PSTM image



Sand reservoir amplitude attribute



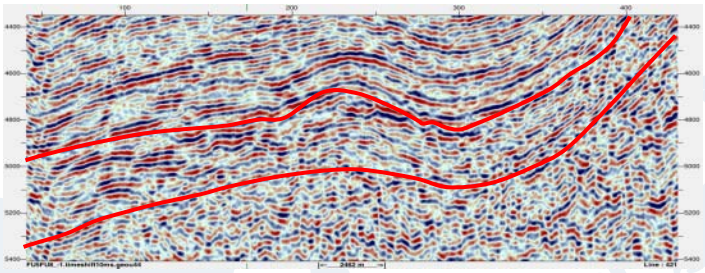
New 3D seismic data, PSTM image



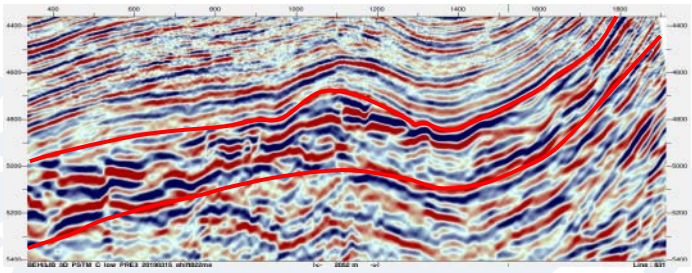
Sand reservoir amplitude attribute

Applications

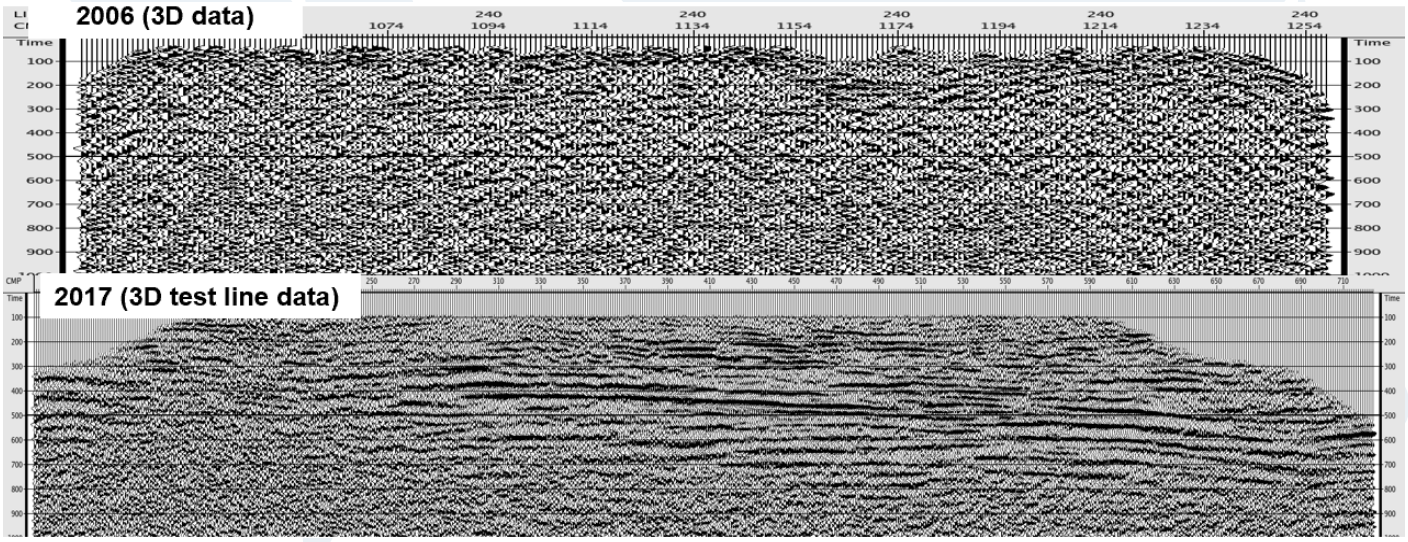
The top boundaries are sought. The low frequency information is richer, and the tectonic morphology of the Carboniferous System is identified, the petrographic phase and spreading characteristics of the volcanic rocks at the top of the Carboniferous System are implemented, and the lithology and fault lithology targets aging of the top interface and the inside of the Carboniferous is clearer.



Legacy 3D data

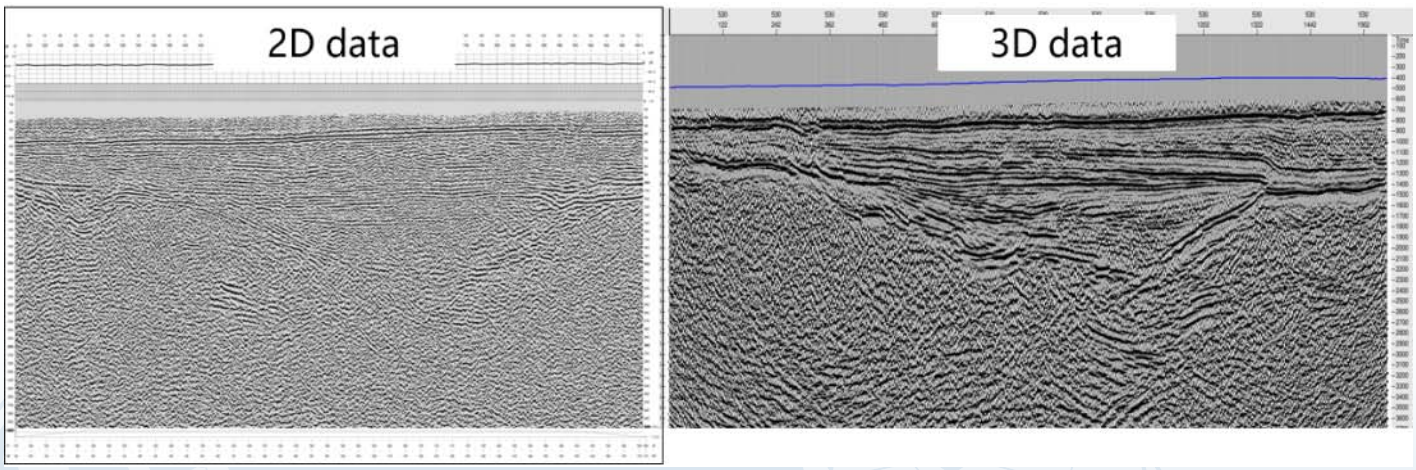


New 3D Carboniferous data



Geologic profile of coal mine

The EV-56 high precision vibrator has significantly improved the quality of geological data, especially in the imaging of deep targets. The exploration of special geological targets such as igneous rock and natural gas hydrate is of epoch-making significance.



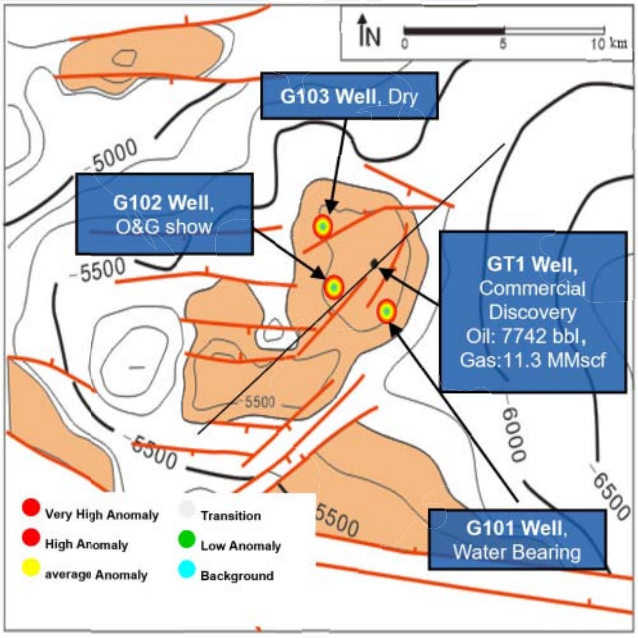
Data comparison of domestic exploration

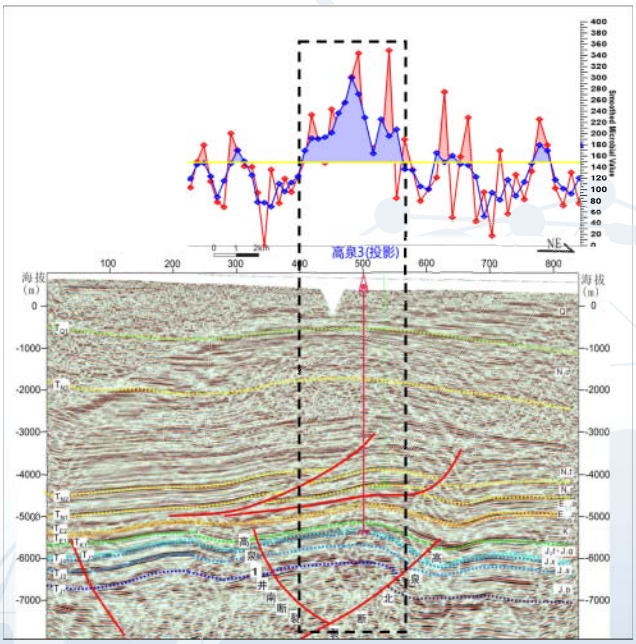
Microbial Geo-Chemical Exploration（MGCE）

MGCE is a surface direct hydrocarbon detection method for de-risking of O&G exploration. MGCE uses combined microbial anomalies and geochemical composition to predict the hydrocarbon potential and reservoir fluid properties of a trap at depths prior to drilling.

In 18 years, a total of 130 MGCE projects has been successfully completed, both onshore and offshore. Post-survey drilling results from 87 exploration wells show an integrated exploration success rate over 85% . Here are three common de-risking scenarios.

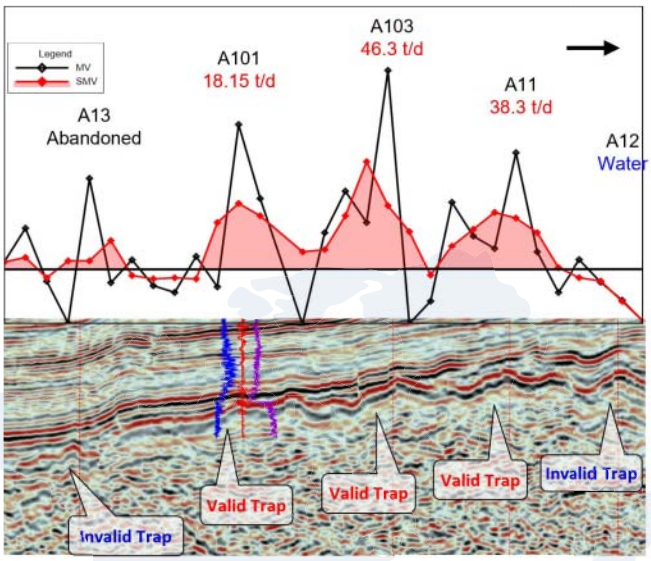
Scenario 1 Delineate Pool Size vs Trap Size





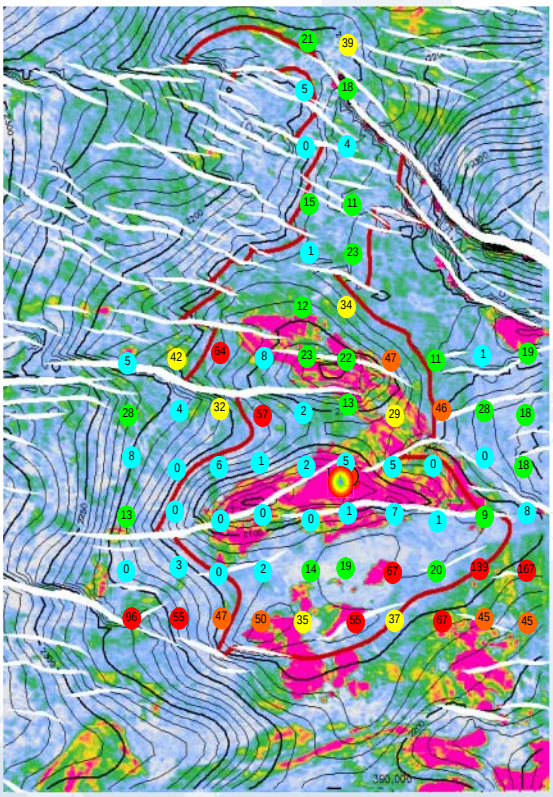
- **Seismic results:** 2D seismic identified a structural trap with size of around 40km2;
- **Geological risks:** unable to predict the trap is fully charged with HC or not and delineate the pool size;
- **MGCE results:** there was distinct microbial anomaly over the structure high with area extent less than 10 km2, indicating the trap was not fully charged with HC;
- **Drilling results:** the exploration well GT-1, which was drilled within the microbial anomaly over the structure high, achieved high production over 7000 bbl/d, while the other 3 appraisal wells drilled outside the anomaly area all failed.
- **Value proposition:** proper integration of seismic and microbial results can delineate the areal extent of HC accumulation, hence increase the drilling success rate of appraisal wells.

Scenario 2 Differentiate Valid Trap vs Invalid Trap



- **Seismic results:** 3D seismic identified 5 similar traps;
- **Geological risks:** unable to differentiate valid traps (charged with HC) and invalid traps (under-charged, breached, water bearing).
- **MGCE results:** surface microbial results predicted 3 valid traps out of these 5 traps and identified potential risk of 2 invalid traps;
- **Drilling results:** 3 commercial discoveries were achieved over traps with distinct microbial anomalies, while the traps with low/no microbial values were proven to be invalid traps (P&A and water bearing).
- **Value proposition:** proper integration of seismic and microbial results can help to high grade leads and prospects and increase drilling success rate.

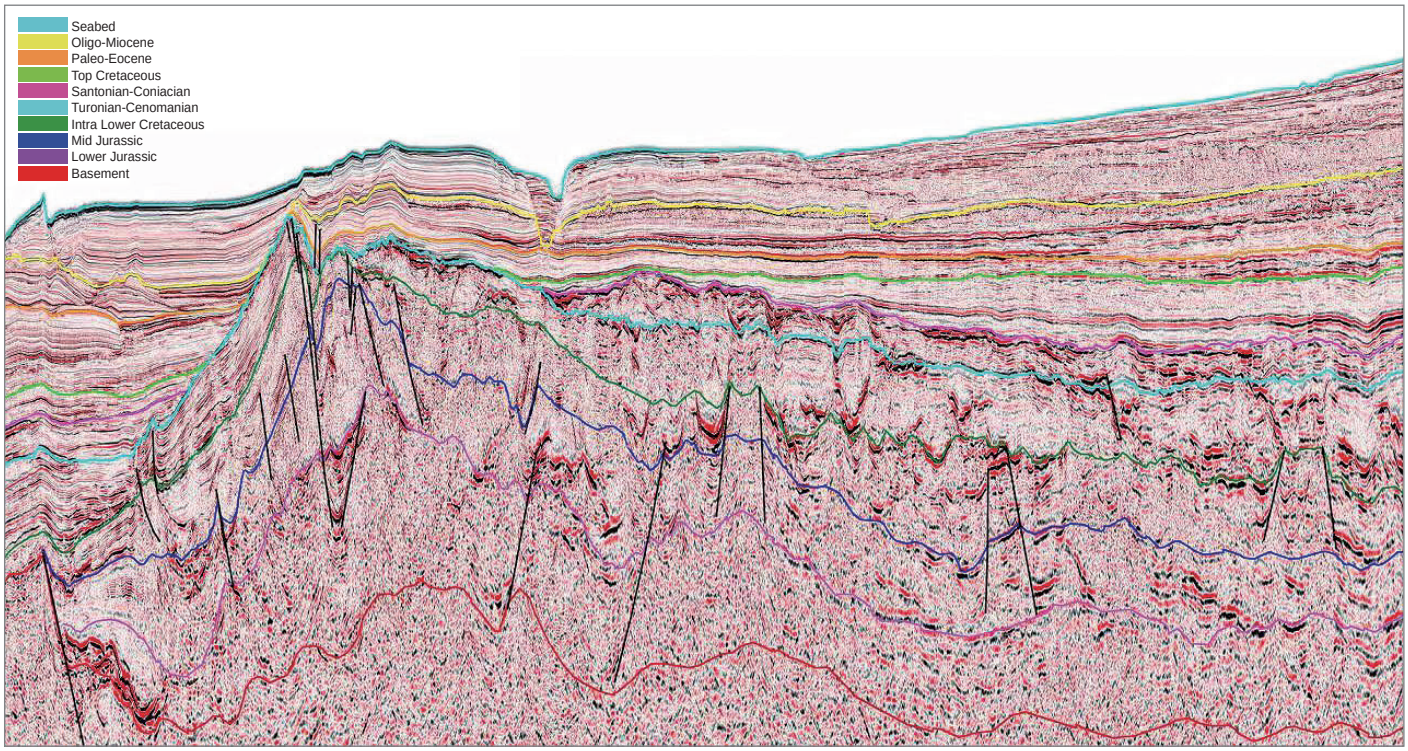
Scenario 3 Predict HC vs Non-HC



- **Seismic results:** 3D seismic identified a faulted structural trap with an AVO anomaly over a structure high, indicating it is a gas-bearing trap;
- **Geological risks:** unable to predict whether it was charged with CH4 or non-HC gas (CO2);
- **MGCE results:** low microbial values over the structure indicated the risk of potential charge of non-HC gas;
- **Drilling results:** the exploration well was drilled with gas content of 95% CO2 and less than 3% CH4 ;
- **Value proposition:** proper integration of seismic and microbial results can predict the risk of non-HC gas, hence increase exploration success rate.

OFFSHORE MADAGASCAR 2D MULTI-CLIENT SURVEY

West and South Morondava Basin, Majunga basin 20,652km



Exploration in Madagascar began in the early 20th century with the discovery of hydrocarbon-rich sedimentary basins in the west, including the Tsimiroro heavy oil field and the Bemolanga tar sands. Studies conducted by BGP in collaboration with TGS have resulted in PSTM & PSDM datasets that suggest there is a significant potential for future discoveries, both on and offshore.

The multi-client survey areas have good hydrocarbon exploration prospectivity with two exploration targets and two hydrocarbon plays identified. The targets are structural traps in the Jurassic and lower-middle Cretaceous, and stratigraphic-lithologic traps in upper Cretaceous and Cenozoic. The plays are Karoo and Jurassic structural traps sourced from Karoo and Jurassic source rocks, and Jurassic to lower-middle Cretaceous structural traps and upper Cretaceous stratigraphic-lithologic traps sourced from Jurassic and Cretaceous source rocks.

Source	5100 Cubic Inches
Shot Interval	37.5m
Gun Depth	6m
Streamer Depth	7/9+-1m
Streamer Length	10km
Record Length	13s

Contact

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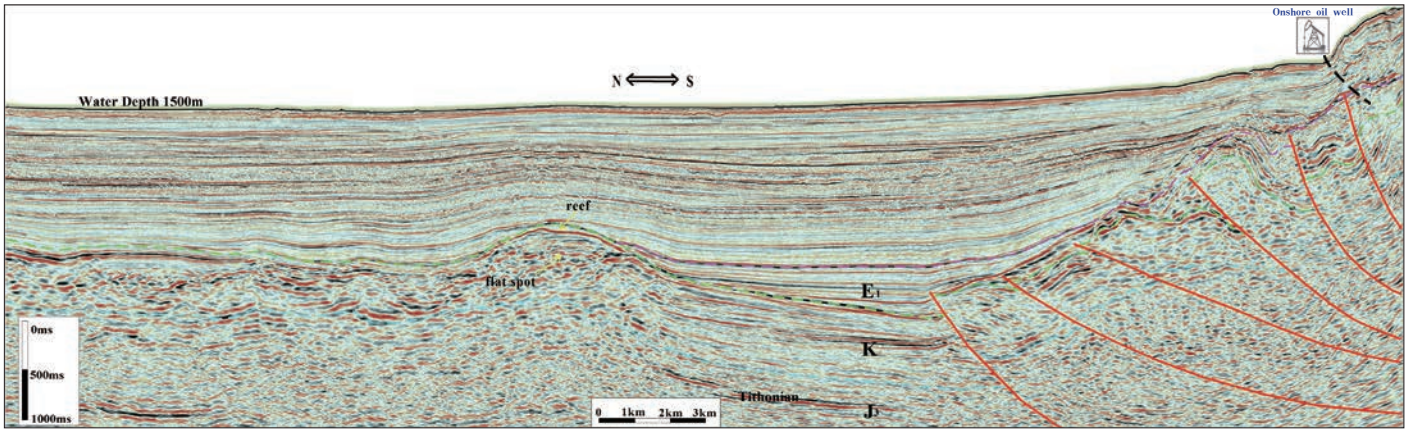
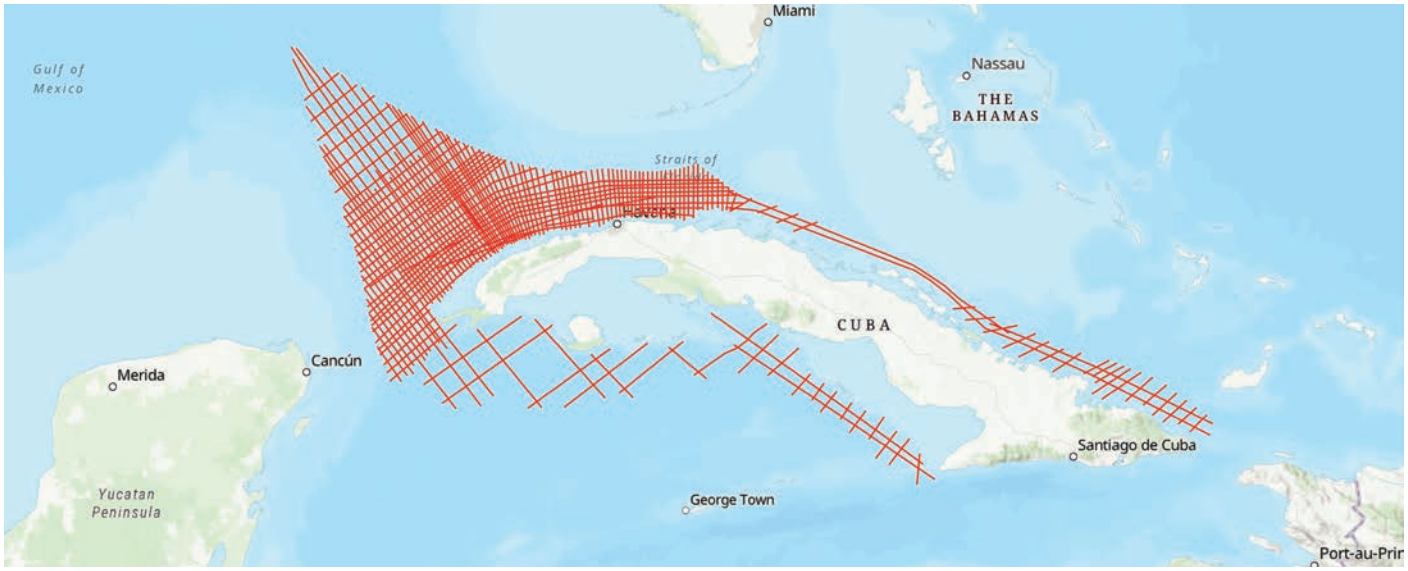
CARIBBEAN 2D MULTI-CLIENT SURVEY





Survey	Caribbean 2D
Survey Size	26,880km
Shot Interval	37.5m
Source Depth	9m
Streamer Length	12,000m
Streamer Depth	12m
Source Volume	4,780 Cu ins
Record Length	13050ms
Key Deliverables	PSTM,PSDM,Gather

BGP has acquired a 26,880 km 2D Multi-Client in the Caribbean. The project performed by the BGP Pioneer and Challenger seismic vessels provides a long offset, high resolution broadband dataset as well as gravity data. The data has been processed to provide both PSTM and PSDM deliverables which are ready for delivery. Data viewing is highly recommended and can be arranged upon request.

This largely underexplored region of the Caribbean contains large areas of open acreage. The presence of an active hydrocarbon system is indicated by oil and gas shows in previously drilled wells. This high quality data will be fundamental in assisting the interpretation of the geology in this part of the Caribbean, and the identification of prospective structural and stratigraphic trends can be used for regional evaluation and future detailed seismic survey designs.

Contact

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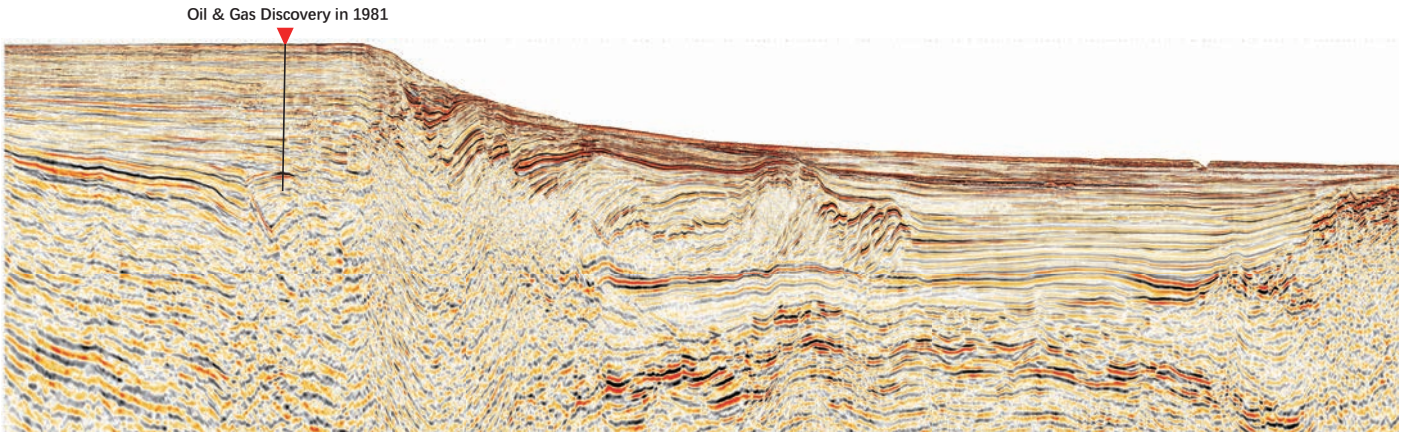
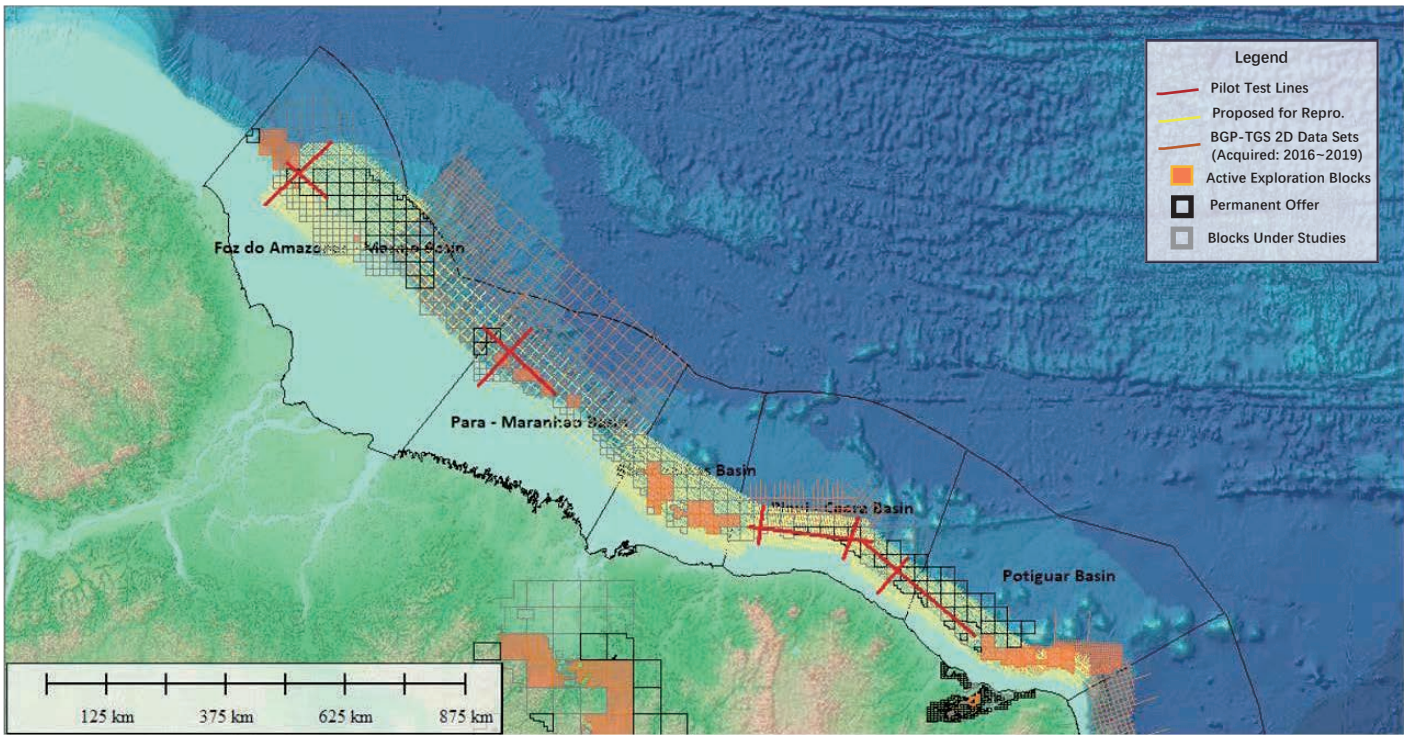
Brazil Equatorial Margin Reprocessing 2D





BGP proposes to reprocess the legacy regional 2D seismic data along the margin with state-of-art technology, and provide the industry with new insight on the geology and plays. 9 lines have initially been reprocessed, indicating significant improvement compared with the publically available data. Data viewing is now available.

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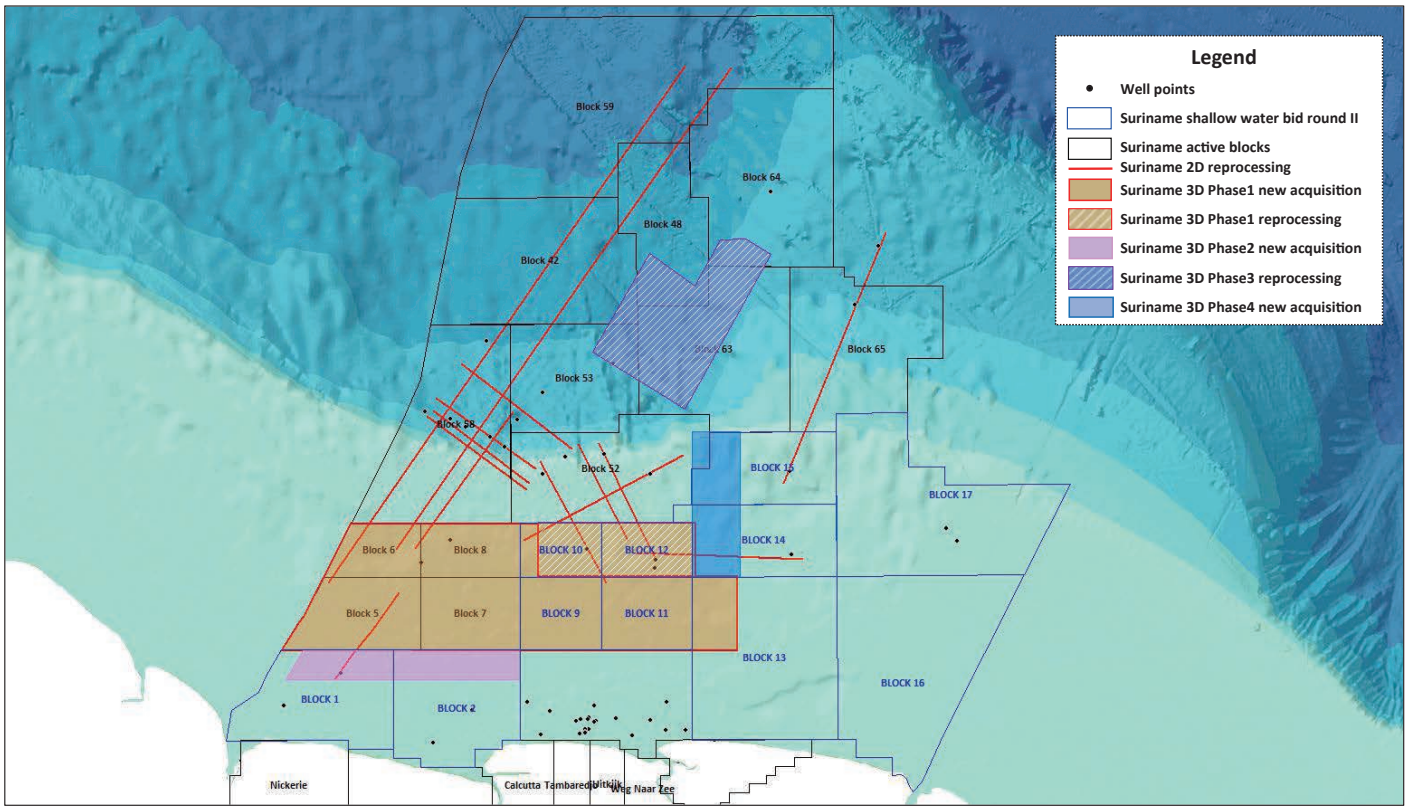
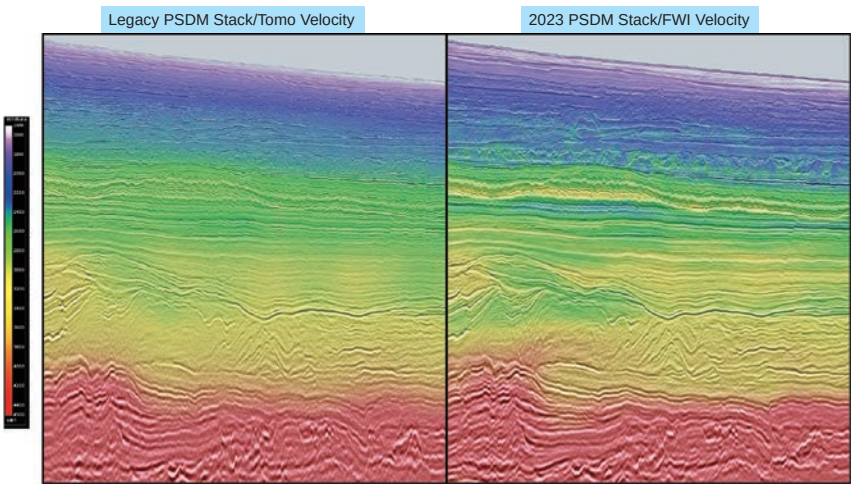
OFFSHORE SURINAME 3D MULTI-CLIENT SURVEY

BGP in a consortium with CGG and TGS has conducted new multi-client 3D acquisition and legacy data reprocessing, in the shallow water acreage offshore Suriname. The new seismic data from the consortium's multi-client programs will be instrumental in accurately delineating the prospectivity and potential of this underexplored area.



Highlights:

- Dense sampled 3D acquisition
- Better imaging and accurate velocity model building with Time Lag FWI and TTI anisotropic parameter estimation
- Better S/N ratio and AVO metrics
- Better resolution and frequency bandwidth through broadband processing
- Supporting the 2nd Shallow Water Bid Round



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