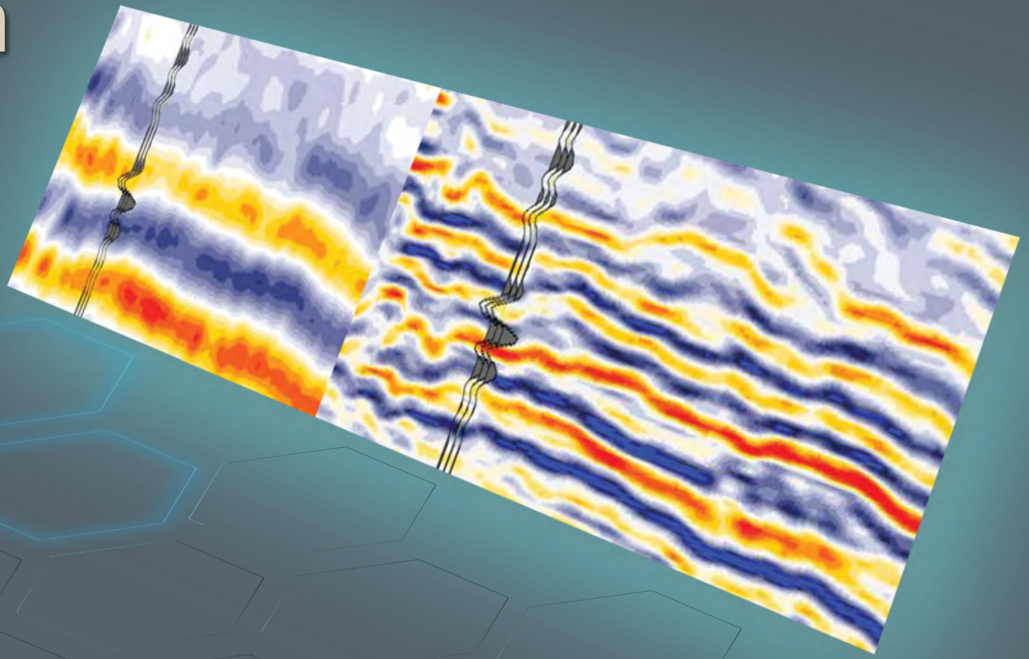
Seismic Geometric Decomposition

Detailed Seismic characterizations



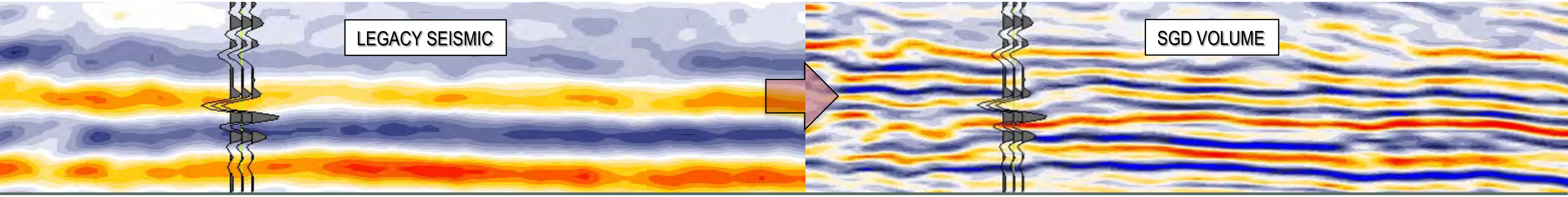
CAYROS group

CAYROS Competitive Advantages

Sub-Surface Optimization and Field Development Planning Technology

- **Geology & Geophysics**
  - Seismic Geometric Decomposition (SGD®) Technology
    - Seismic Inversion using SGD® High Resolution products
    - Integrated Stratigraphy & Sedimentology
      CVT, Lithohero
- **Petrophysics**
  - Advanced Petrophysics for Unconventional Shale Resource Plays
- **Field Development Planning**
  - C-Fields© Technology
- **Facility & Process Engineering**
- **Reservoir & Production Engineering**

SEISMIC GEOMETRIC DECOMPOSITION (SGD)



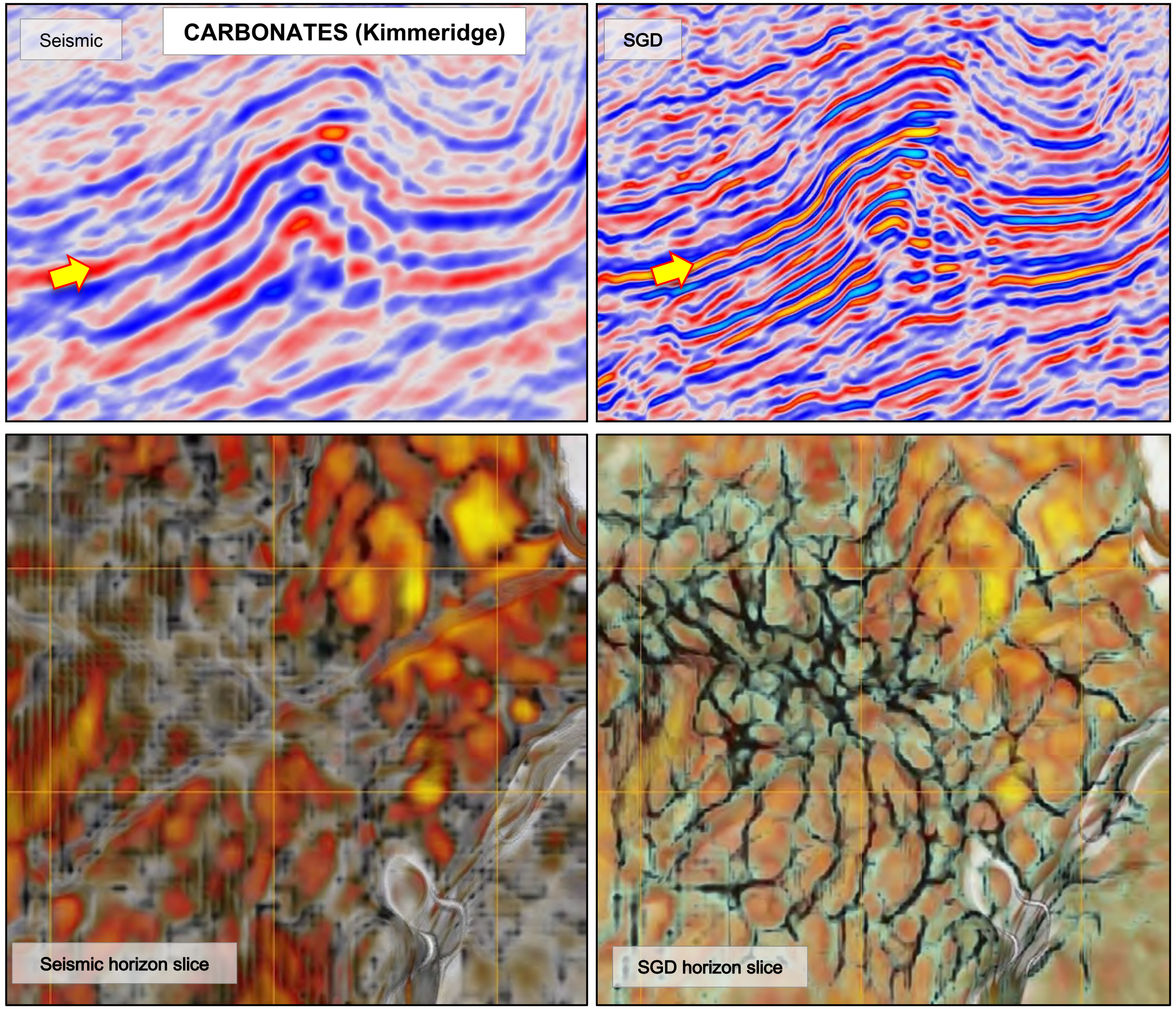
Seismic Geometric Decomposition *(SGD)* offers a technique that captures the internal architecture of the seismic reflectors. Standard interpretation workflows for Structure and Stratigraphic analysis can later be applied by using the new generated seismic vintages.

The result of the process is a series of high-definition seismic volumes that can be used to improve the delineation of the Fault System, the external and internal reservoir architecture, to recognize reflectivity patterns for geomorphological analysis and to generate High Resolution Rock property volumes.

The methodology can be applied to volumes in Time or Depth, to Seismic in 2D or 3D and to data in Post Stack or Pre-Stack domain

*SGD Workflows is a US Patented technique, it has a license agreement with **Cayros** for global consultancies and with **Emerson** for software development*

LOOKING FOR MORE DETAIL



The technique was developed during 2006-2007, the first field in which it was tested was a deep (+5500m sstvd) natural fractured carbonate reservoir, in which wells watered-out very quickly (Mexico).

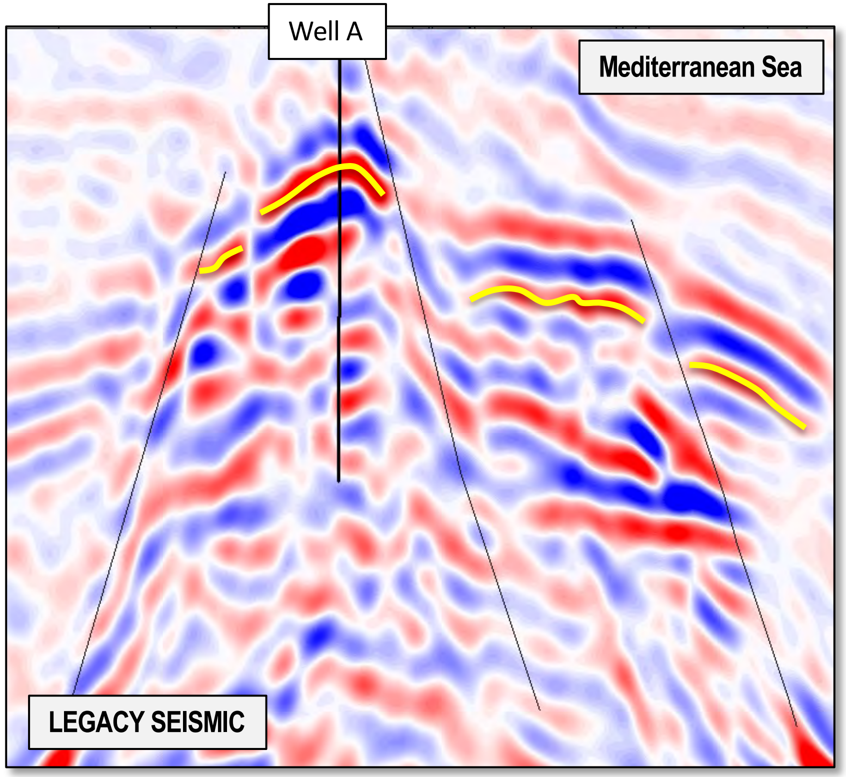
The proper delineation of both, its segmentation and subtle faulting was crucial and presented a challenge, wells drilled too close to faults, declined rapidly and showed high water cuts.

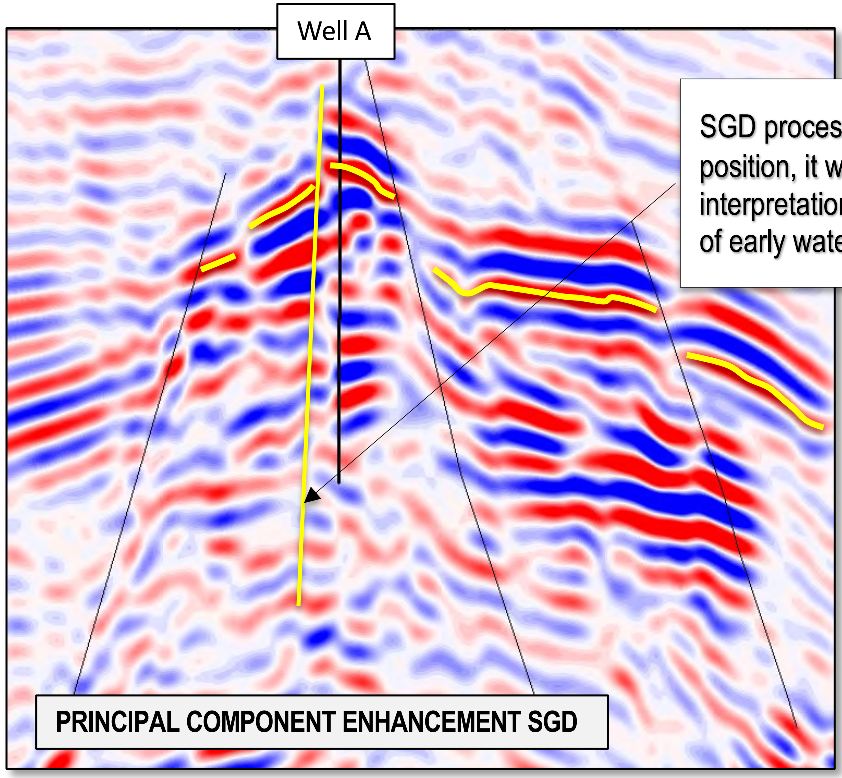
The 3D Seismic acquired for this onshore field had a 7-10 Hz dominant frequency, consequently, standard workflows for fault detection failed to provide a clear image of the reservoir compartmentalization.

The images show one of the first outcomes of the technology, the result of running the same standard workflow of fault volume generation and 3D opacity blending from both vintages, Seismic (left) and SGD (right).

The delineated segmentation proved to be in accordance to what the wells in the field were showing in terms of early HC production declination. The drilling strategy changed to position wells away from faults.

SEISMIC GEOMETRIC DECOMPOSITION (SGD)



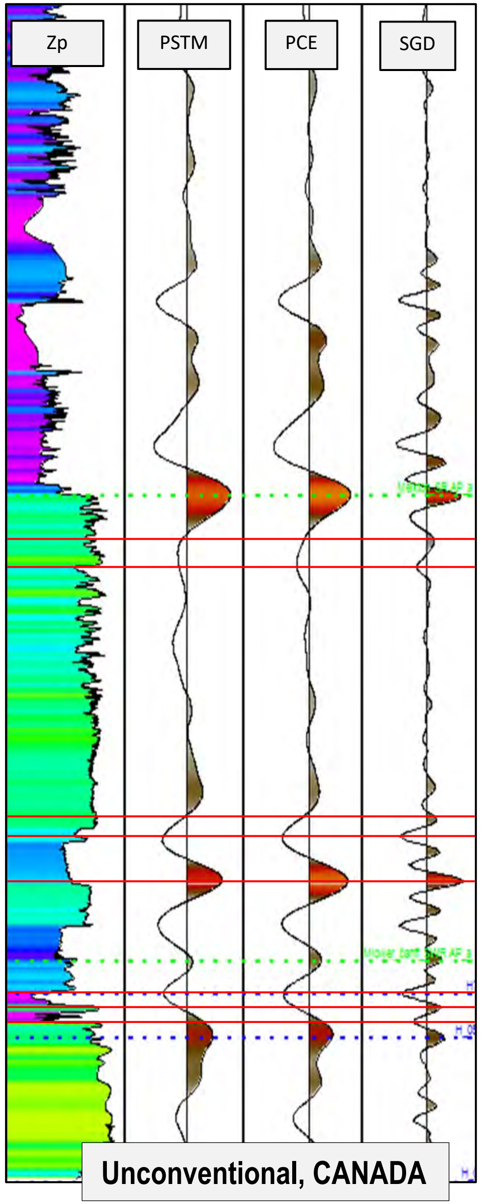


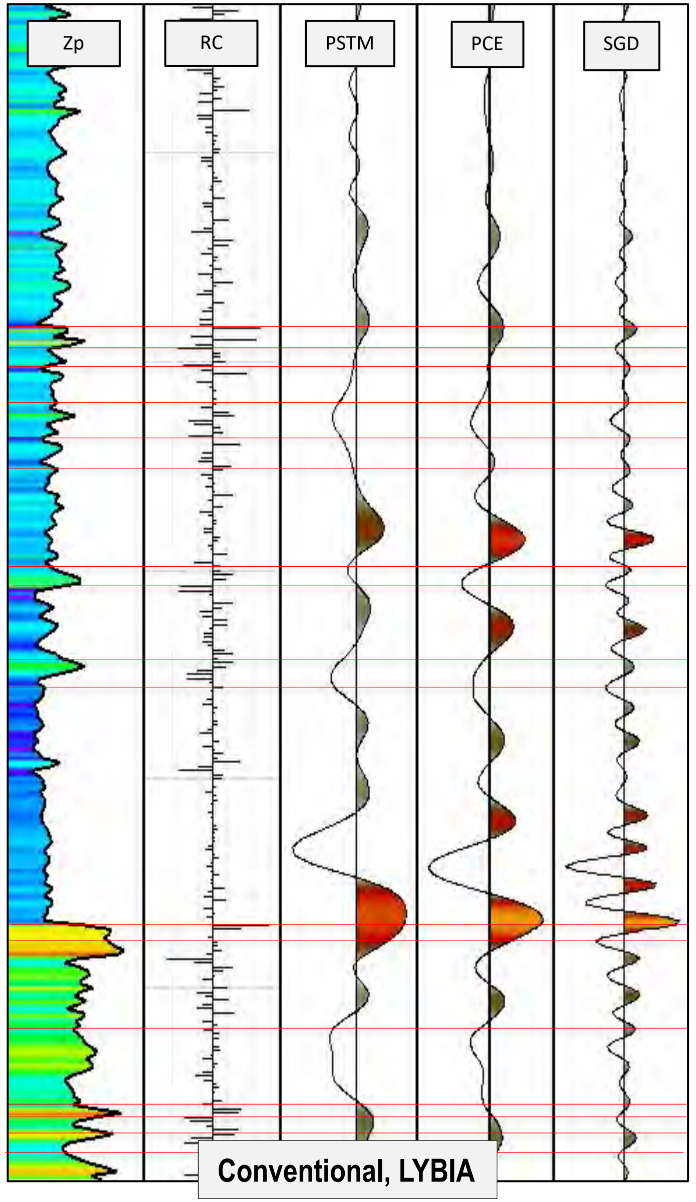
SGD process predicted a Fault at 50m of an Offshore well position, it was validated by boundaries observed after PBU interpretations. Well could not be put into production because of early water production.

- 2D and 3D
- Depth and Time
- PreStack and PostStack domain

- Improved seismic interpretation and well to well correlation
- Detailed Fault Mapping
- Paleo Karst delineation
- High Resolution Curvature Volumes
- Reflectivity Pattern delineation
- High Resolution Elastic Volume Analysis
- High Resolution Seismic Stratigraphy

SGD GEOLOGICAL MEANING

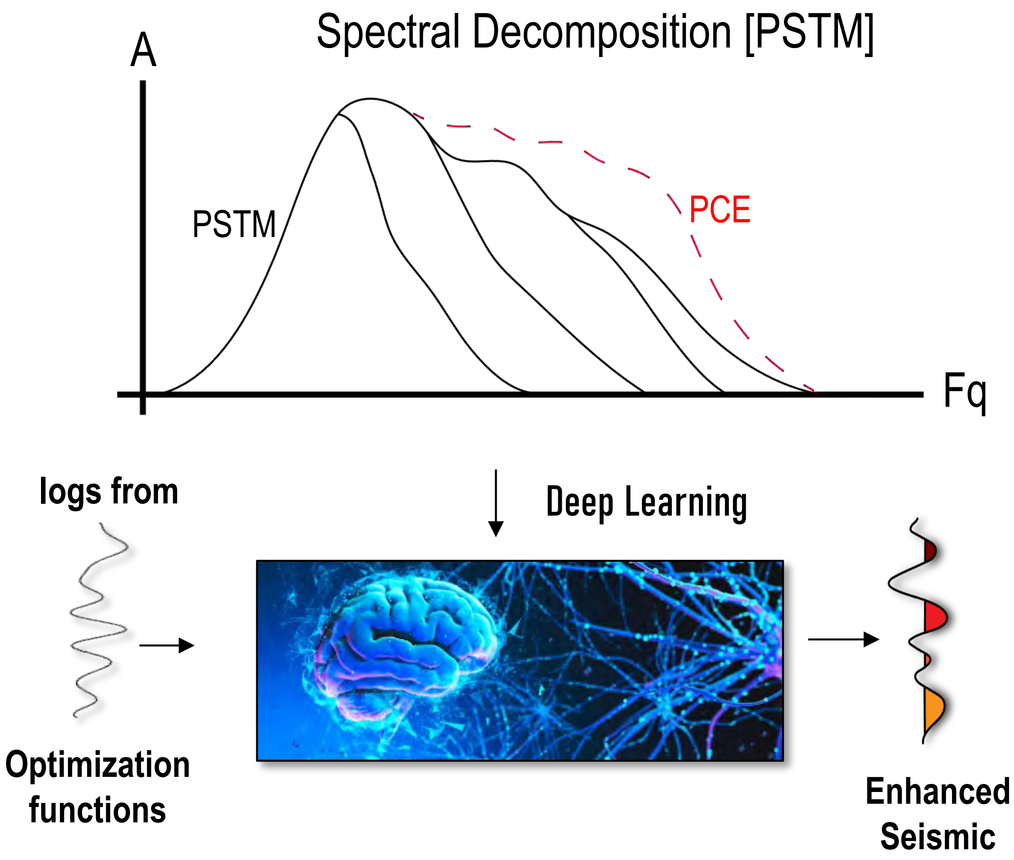


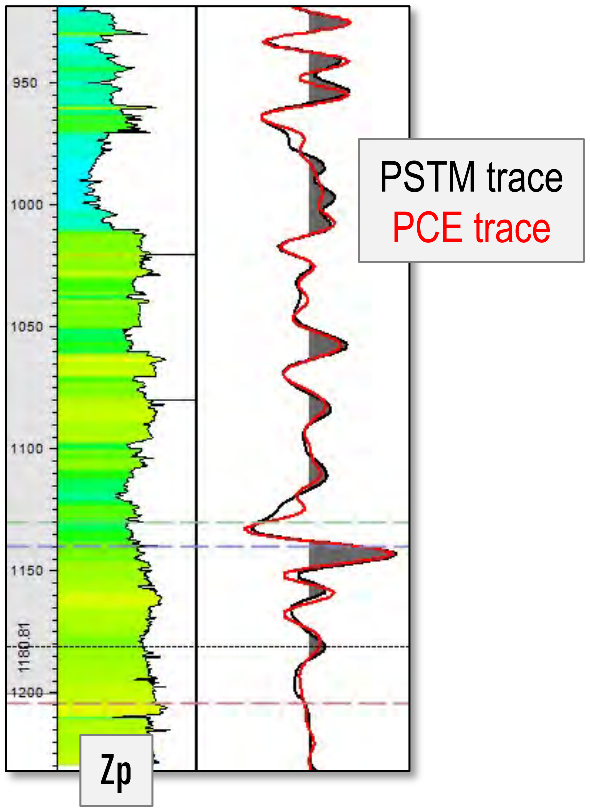


It has been observed empirically in more than 150 fields from many basins around the world that original seismic fails to resolve for second order vertical changes in the acoustic impedance log, these subtle vertical variations generally match the Legacy Seismic Trace´s X-Crossing.

SGD volumes can delineate and detect this type of subtle changes in the AI log (red lines), in this way it increases qualitatively the vertical resolution for any seismic characterization workflow to be applied.

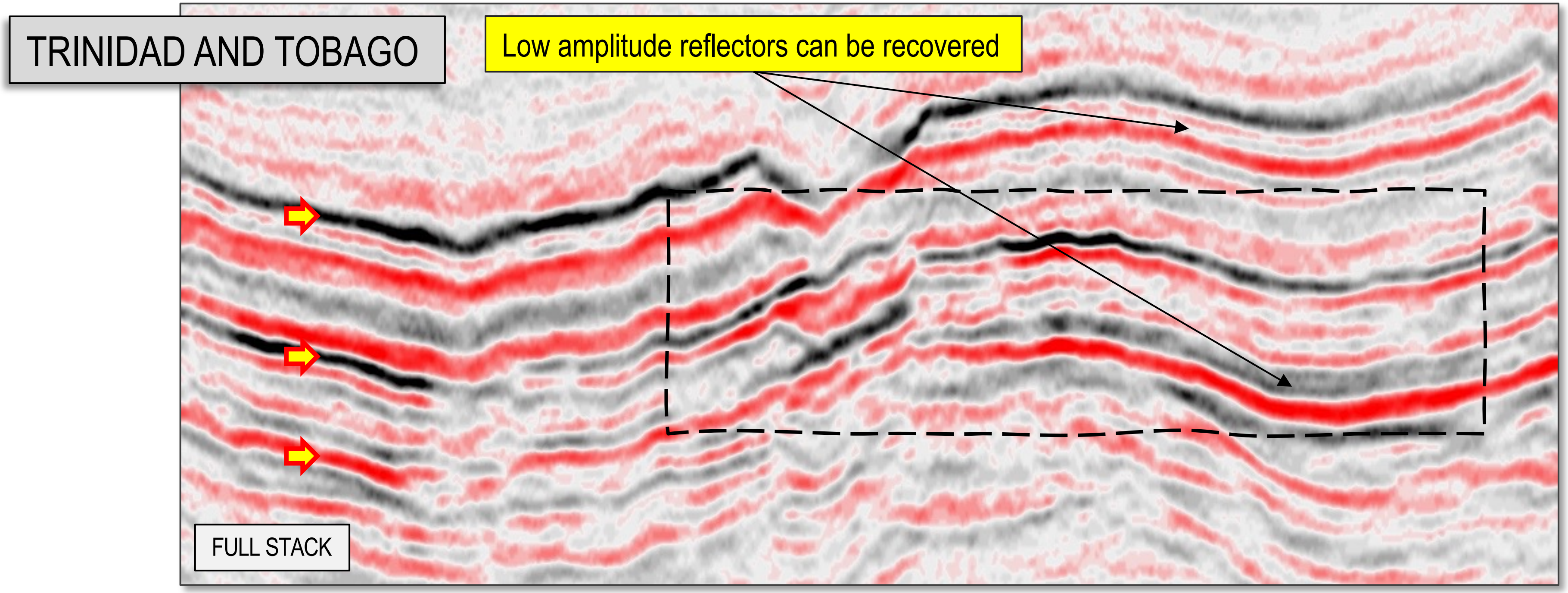
PRINCIPAL COMPONENT ENHANCEMENT





Spectral Decomposition along with Deep Learning algorithms are used to generate an enhanced version of the original seismic in which random noise is reduced, vertical resolution is increased and lateral reflector continuity is improved. The Deep learning algorithm is supervised by logs generated by applying optimization functions that minimize the error between synthetics and seismic traces at well locations.

PRINCIPAL COMPONENT ENHANCEMENT

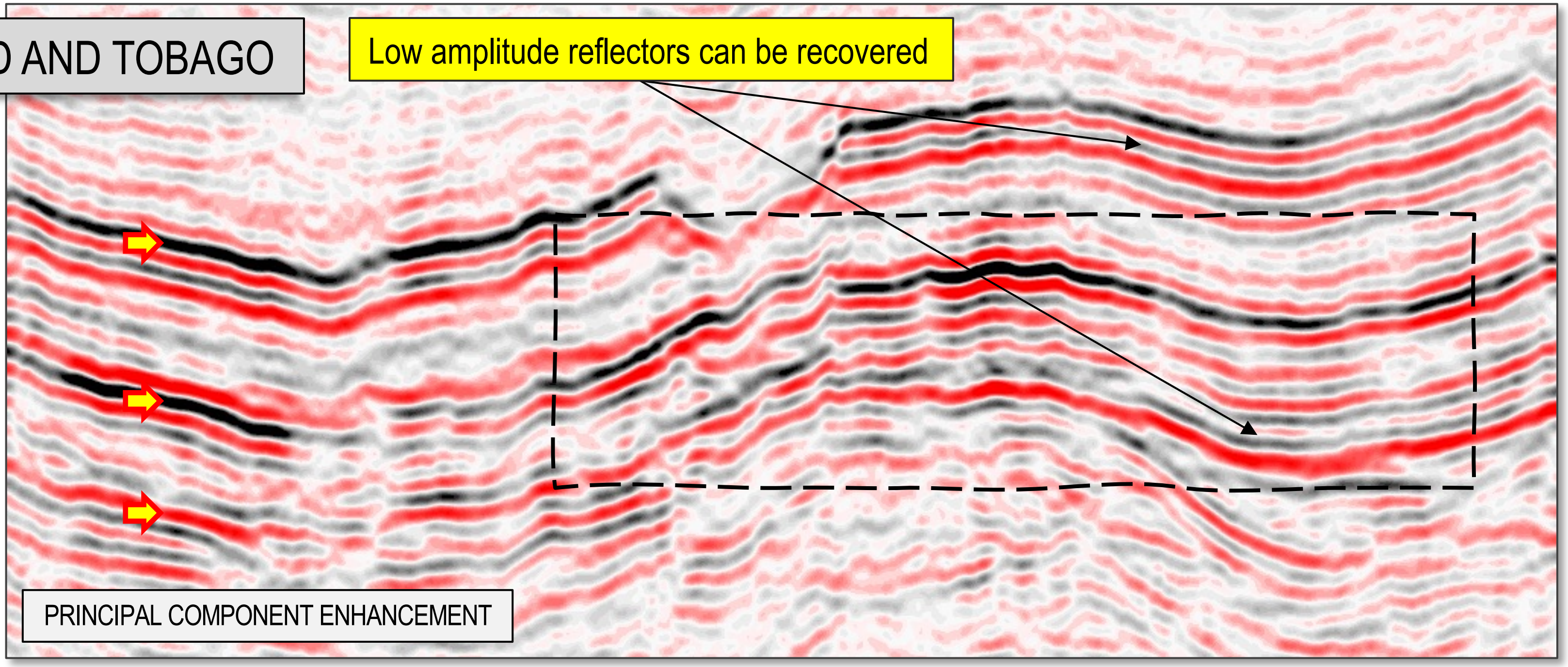


Principal Component Enhancement increases the vertical resolution of the original seismic by structural oriented filtering each of the main bandwidth of the spectrum, only the components (Nodes) that contribute the most to the stack are kept (Deep learning), the Neural Network is supervised by pseudo logs obtained via an optimization function which tries to match the seismic response to the P-impedance log.

Note: All SGD attributes preserve the original phase of main onsets peak or troughs

PRINCIPAL COMPONENT ENHANCEMENT

TRINIDAD AND TOBAGO



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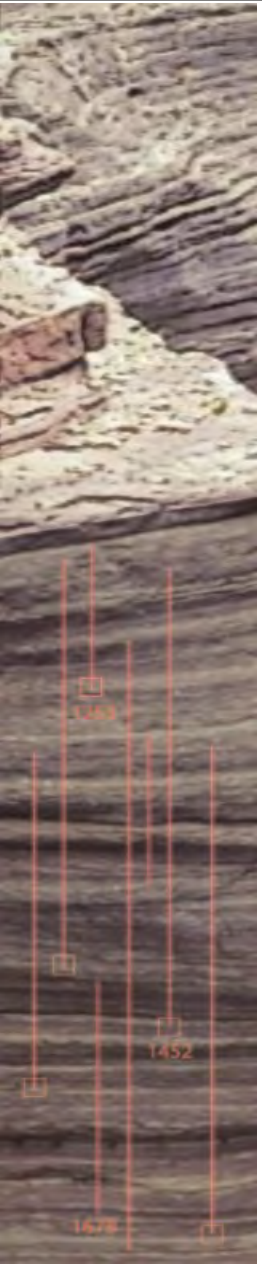
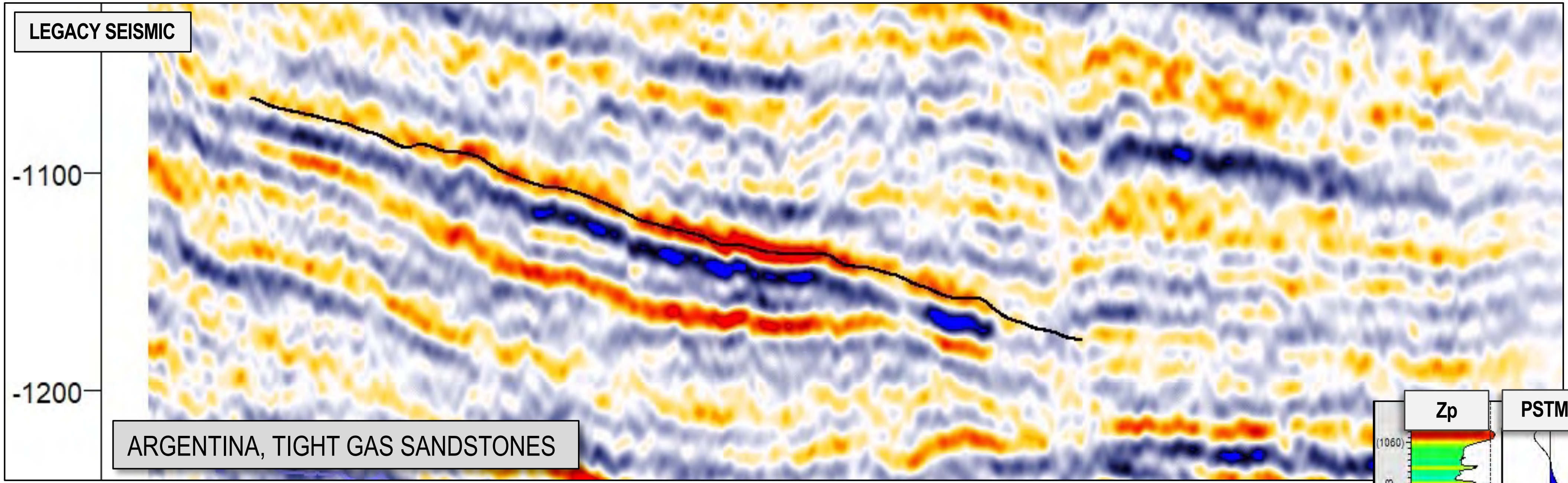
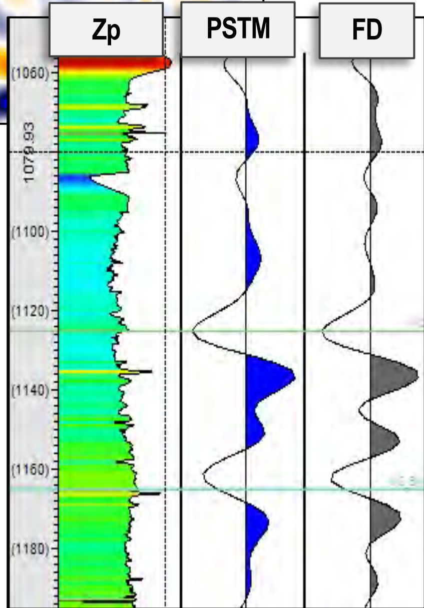
SEISMIC CONDITIONING: FIBONACCI DECOMPOSITION







Legacy Seismic is spectrally decomposed by using a Fibonacci Series approach, each frequency component is then structurally oriented filtered to later be used as input to a series of functions that produce an enhanced and conditioned version of the original seismic. Lateral reflector continuity can be improved, native onset reflectivity is honored, prior interpretations can still be used as a guide to fine tune the limits of the reservoir. More detailed internal reservoir architecture analysis can be accomplished.

The example above shows a cretaceous progradational gas sandstone, in which Fibonacci Decomposition produced a new seismic version that helped to build a more detailed characterization of the reservoir.

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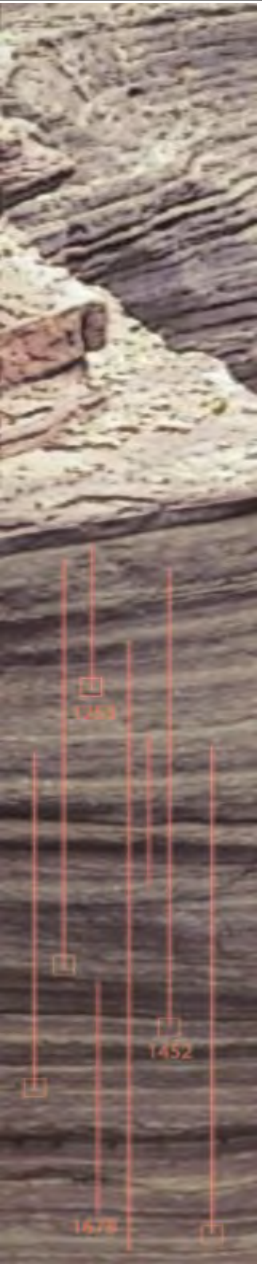

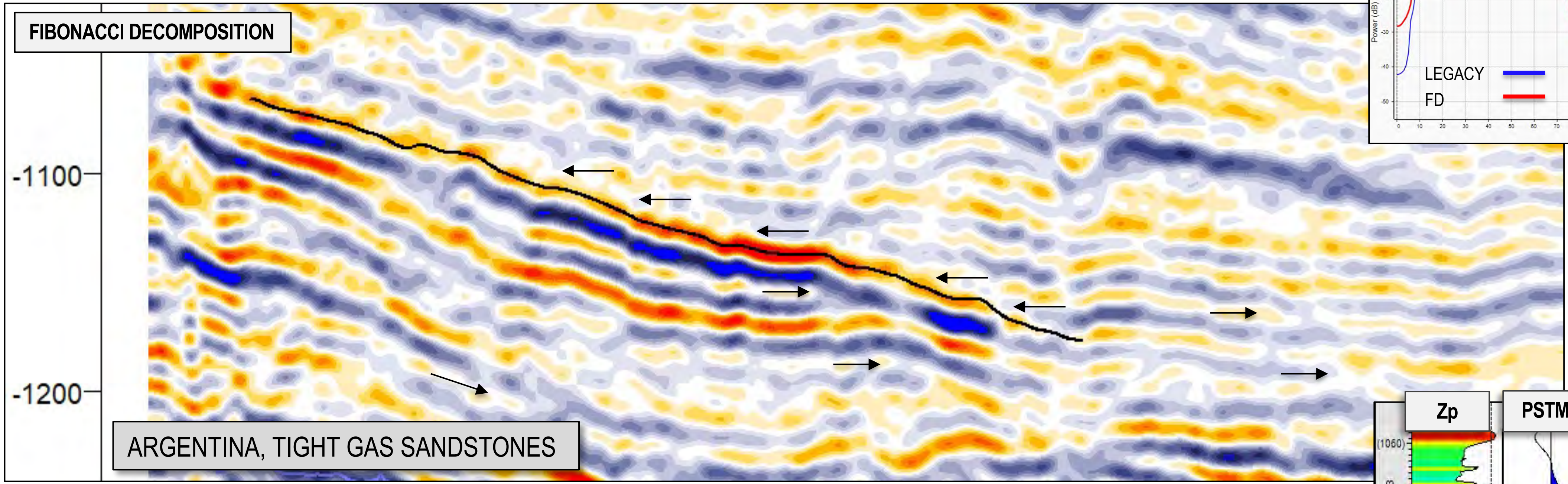

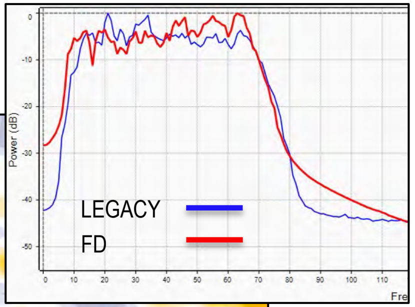

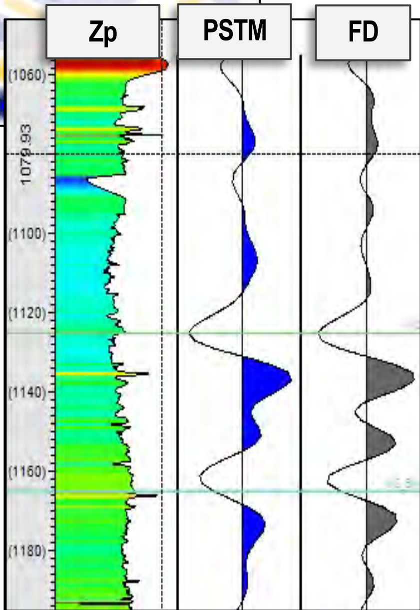

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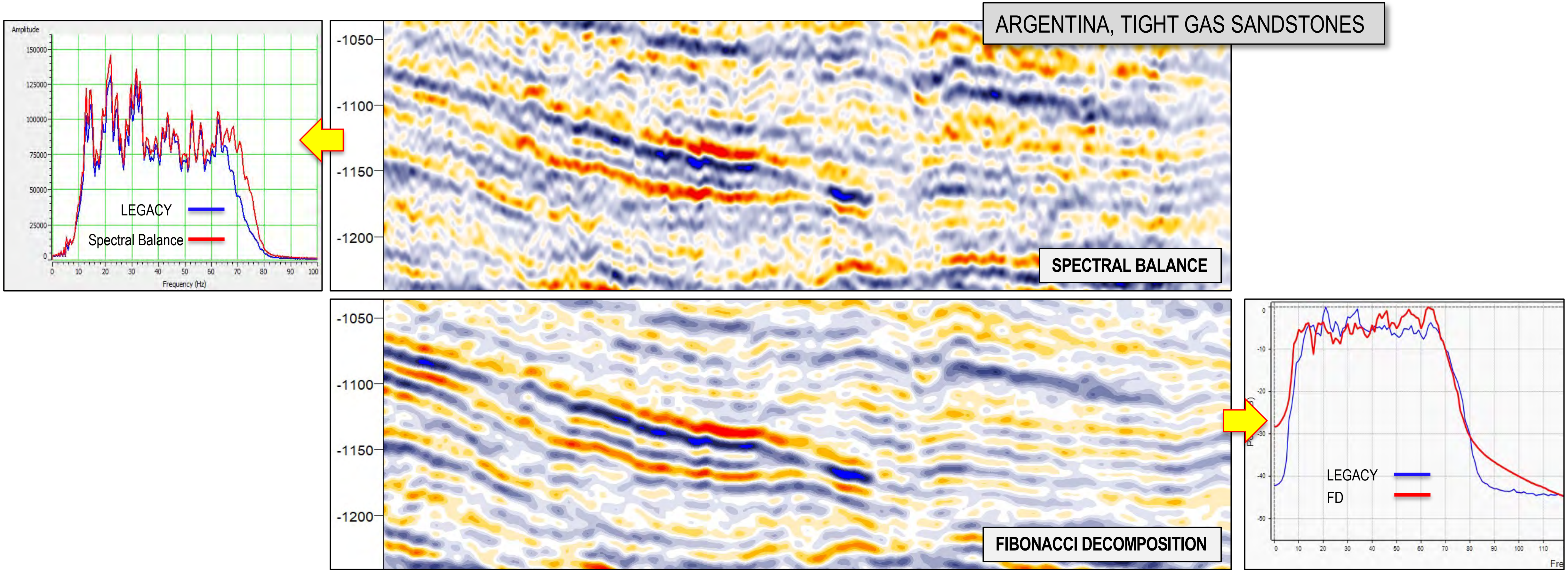
SPECTRAL BLUEING AND FIBONACCI DECOMPOSITION



The images above show a comparison of Spectral balancing and Fibonacci Decomposition applied to the same Legacy Seismic. Spectral blueing enhances just the high end of the amplitude spectrum increasing not only signal but also noise, it fails to improve both lateral reflector continuity and internal reservoir geometries. **Fibonacci Decomposition** amplitude spectrum remains almost with the same frequency bandwidth but minimize noise, recovers low amplitude reflectors and improves lateral continuity to support horizon tracking.

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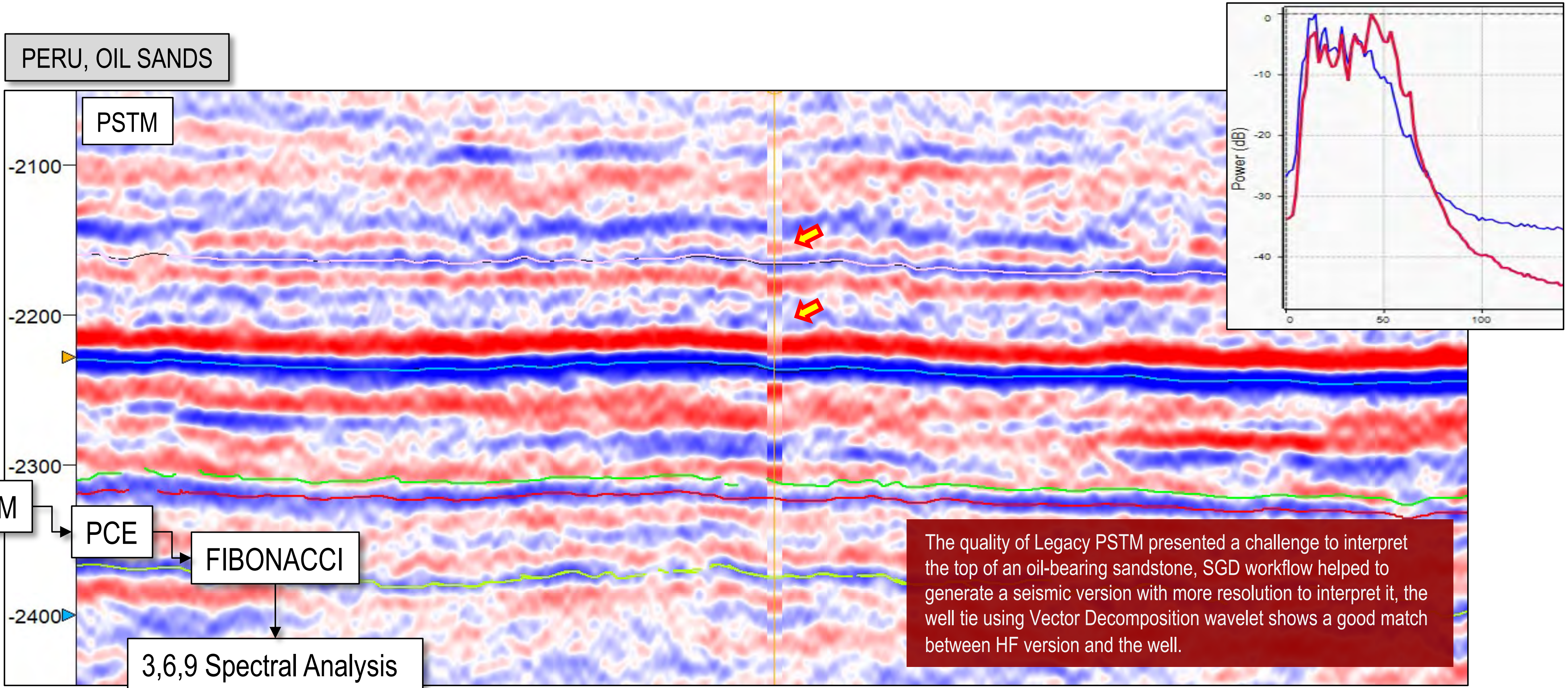
VECTOR DECOMPOSITION



PSTM → PCE → FIBONACCI → 3,6,9 Spectral Analysis → 21 Vector Decomposition → Optimization Function

A different approach for Spectral Decomposition is applied. The **Fibonacci Decomposition Volume** trace is reconstructed by using a combination of bandwidths based on 21 frequency vectors (Components). An optimization function is obtained by stacking only the vectors that contribute the most to resolve for the vertical variations observed in the P-impedance log. The result is a seismic vintage that increases the vertical resolution of the input seismic.

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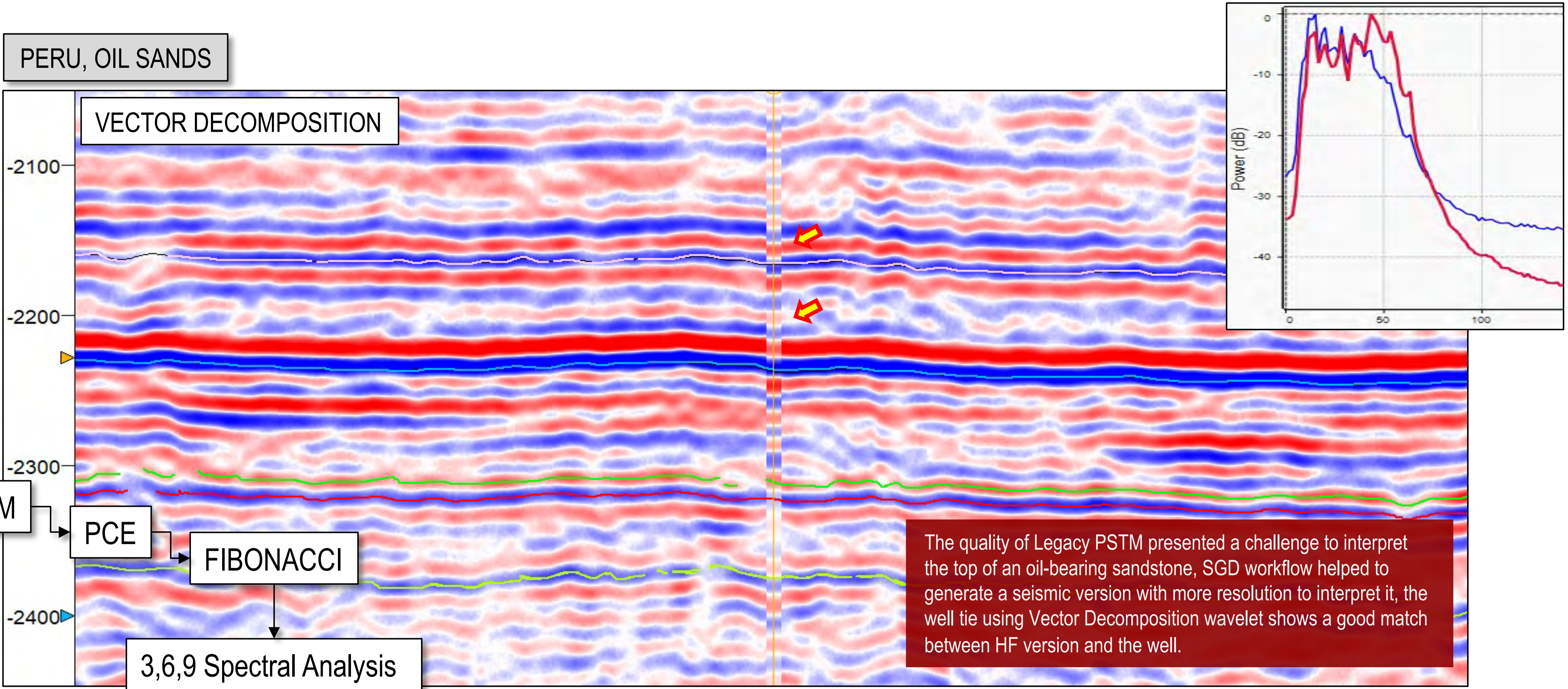
VECTOR DECOMPOSITION

PERU, OIL SANDS



The quality of Legacy PSTM presented a challenge to interpret the top of an oil-bearing sandstone, SGD workflow helped to generate a seismic version with more resolution to interpret it, the well tie using Vector Decomposition wavelet shows a good match between HF version and the well.

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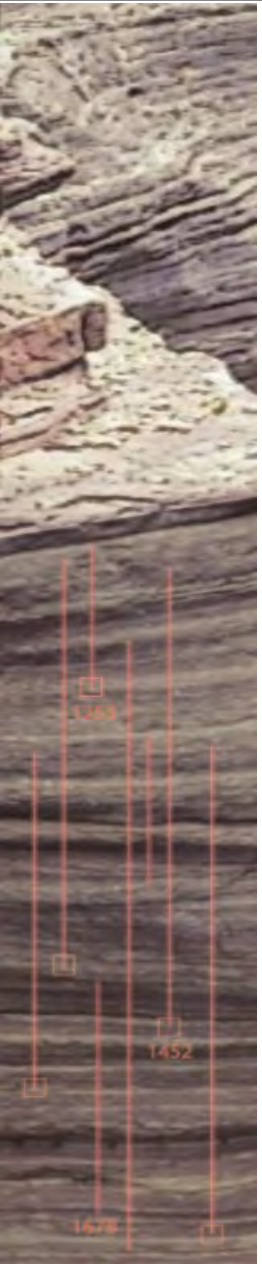
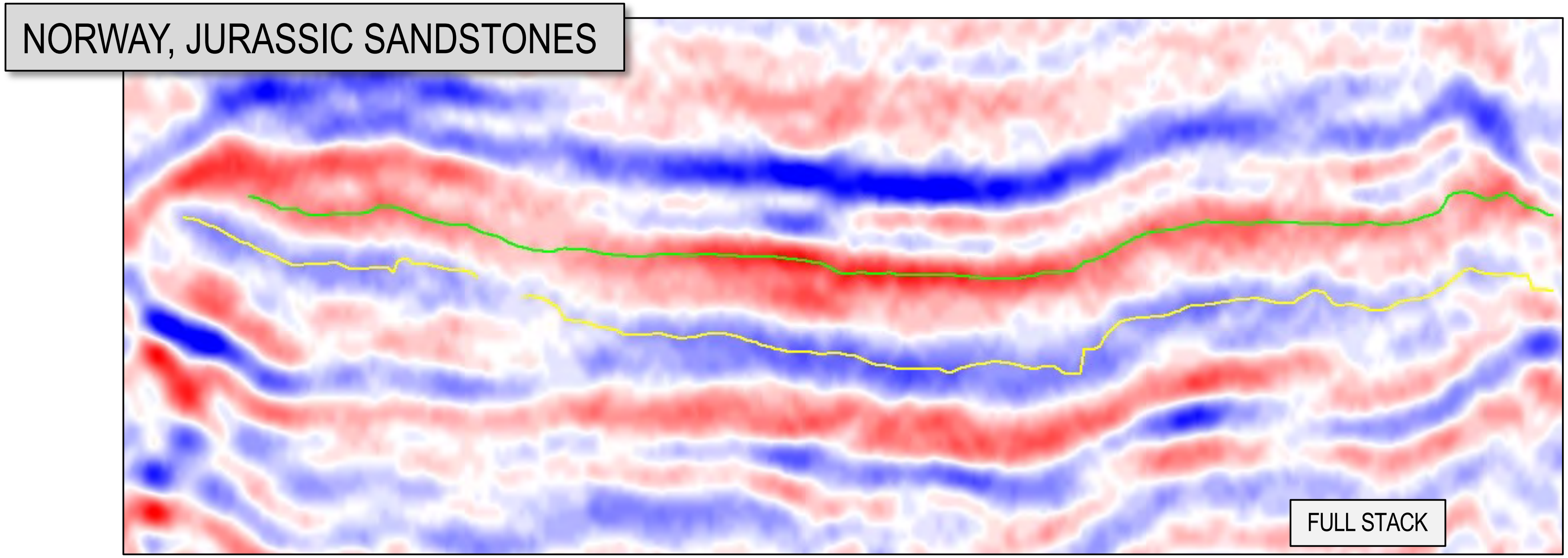
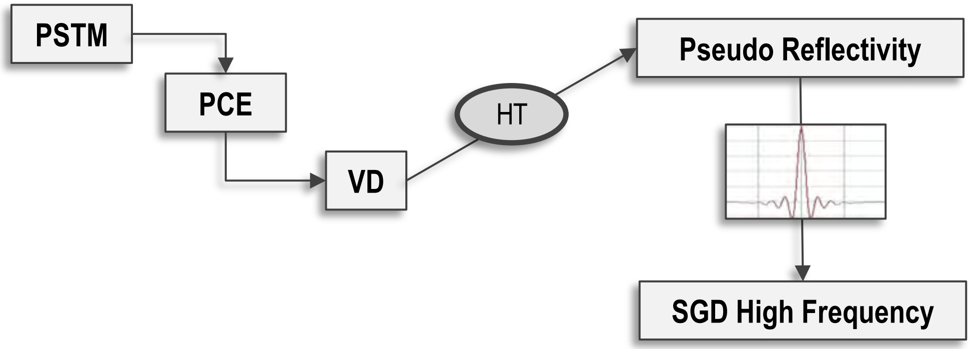
SGD HIGH FREQUENCY

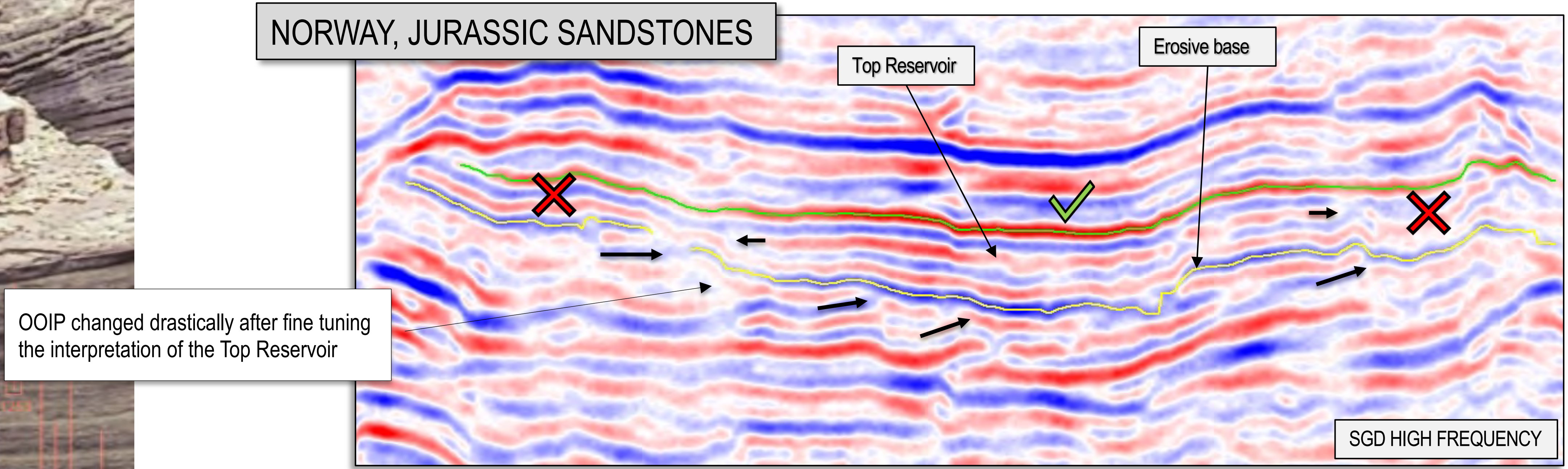


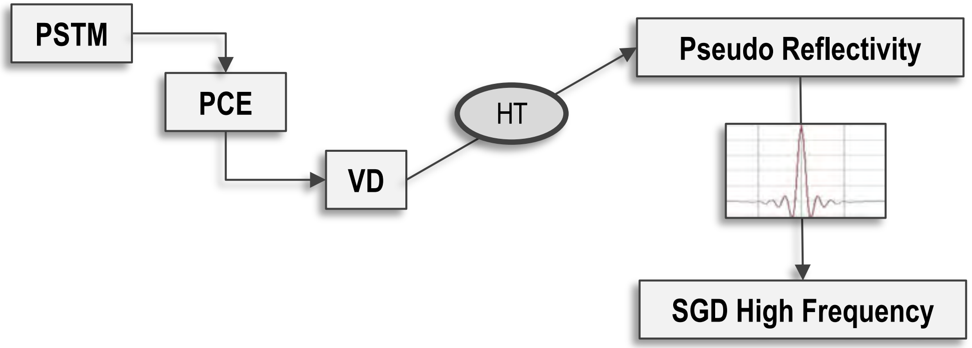




SGD High Frequency is the result of applying a series of equations to delineate the internal geometry of seismic traces. A high frequency pseudo reflectivity volume is generated by the combination of Complex trace attributes from the Hilbert transform. Later a convolutional model is constructed, wavelet frequencies are selected based on best match with synthetic seismograms from wells. This type of vintages in general are used to fine tune the reservoir segmentation and to optimize Curvature Analysis

SGD HIGH FREQUENCY





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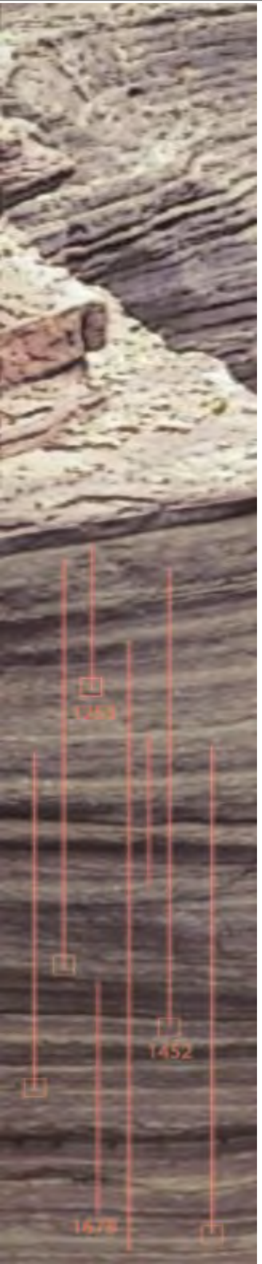
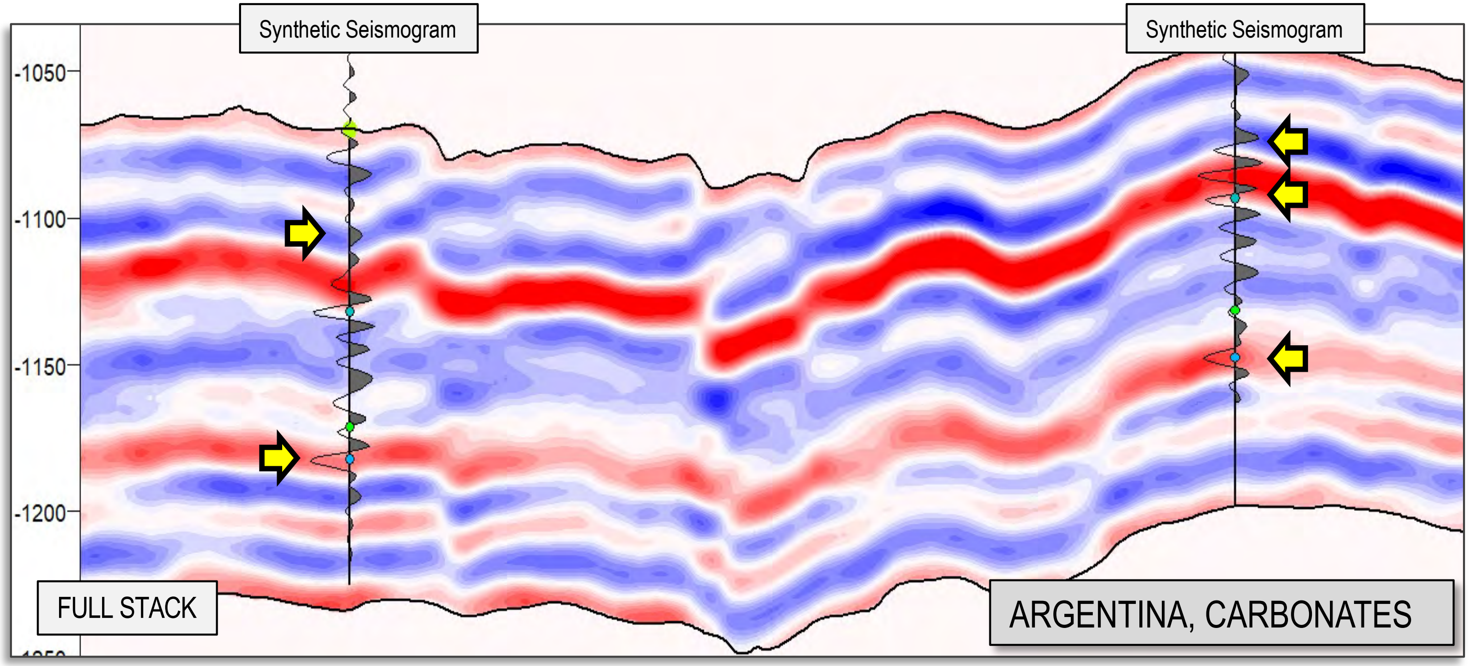
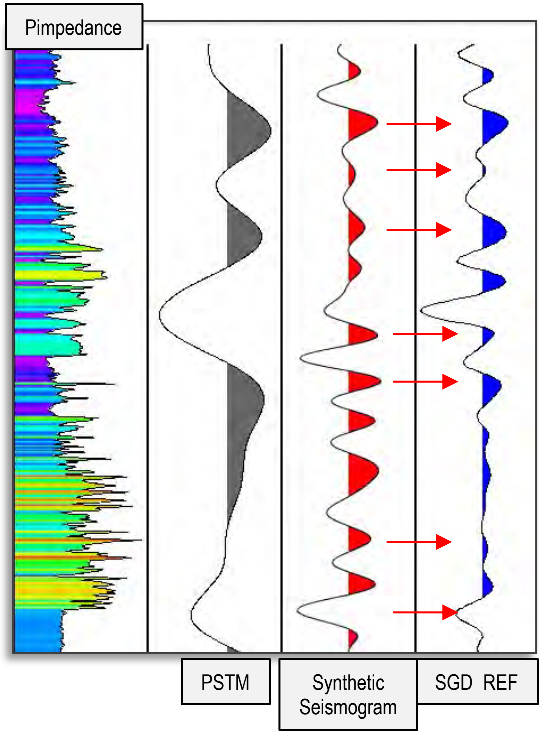
SGD REFLECTIVIIYTY







SGD Reflectivity is a process that uses either **Linear regression** or **Deep learning** algorithms to honor synthetic seismograms from key wells. Is a seismic volume with relative amplitudes that might support both, well correlation and detailed surface interpretation, the synthetic wavelet frequency threshold is selected based on the minimum dominant frequency required to resolve for main vertical variations observed in Pimpedance logs.

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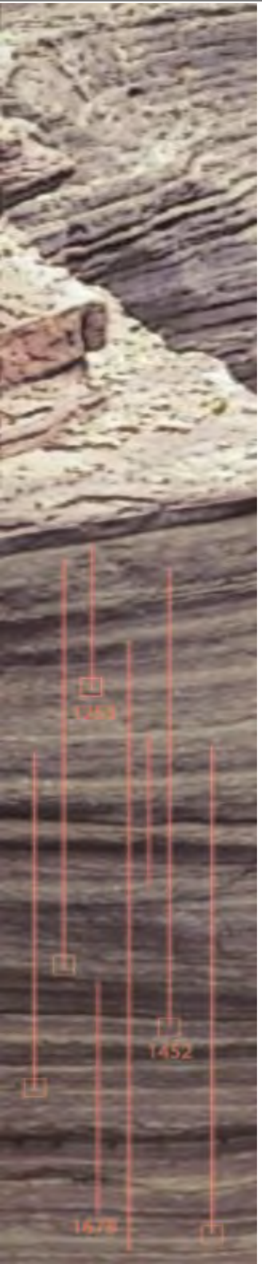
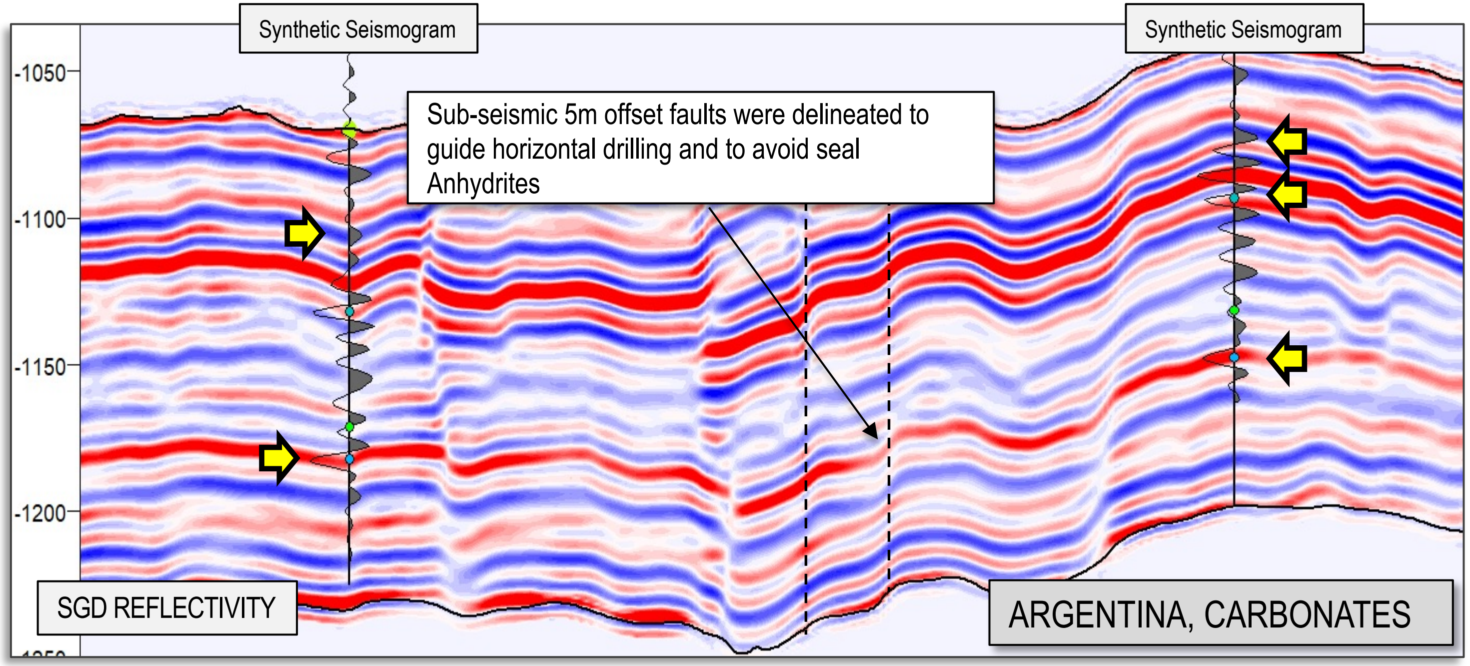
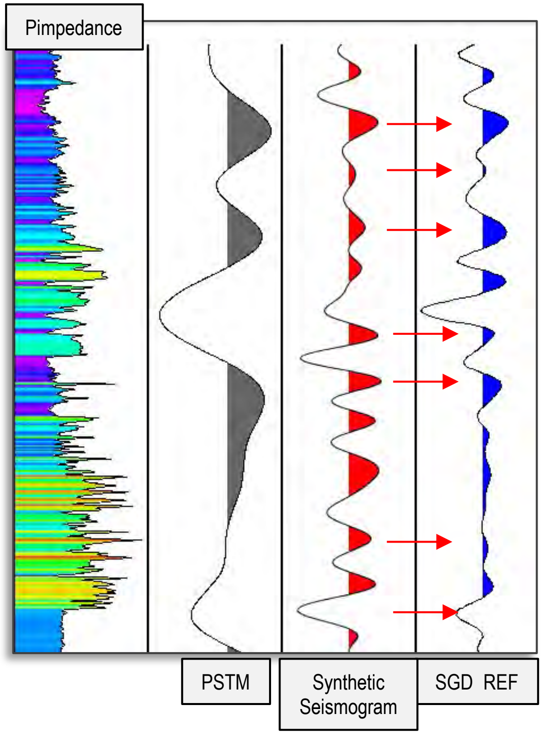
SGD REFLECTIVIYTY







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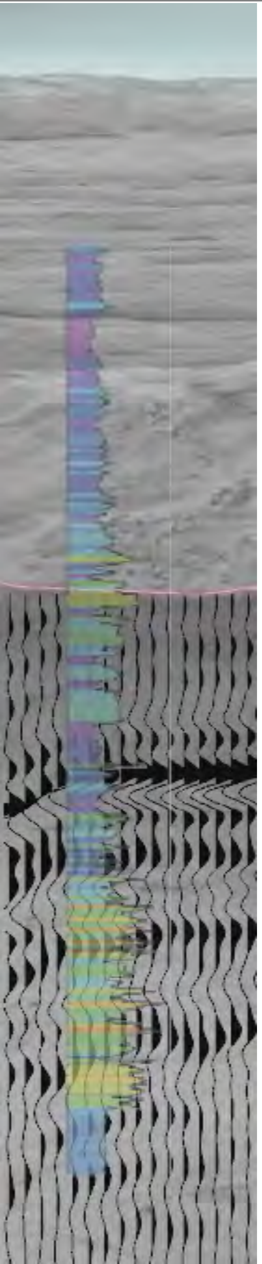
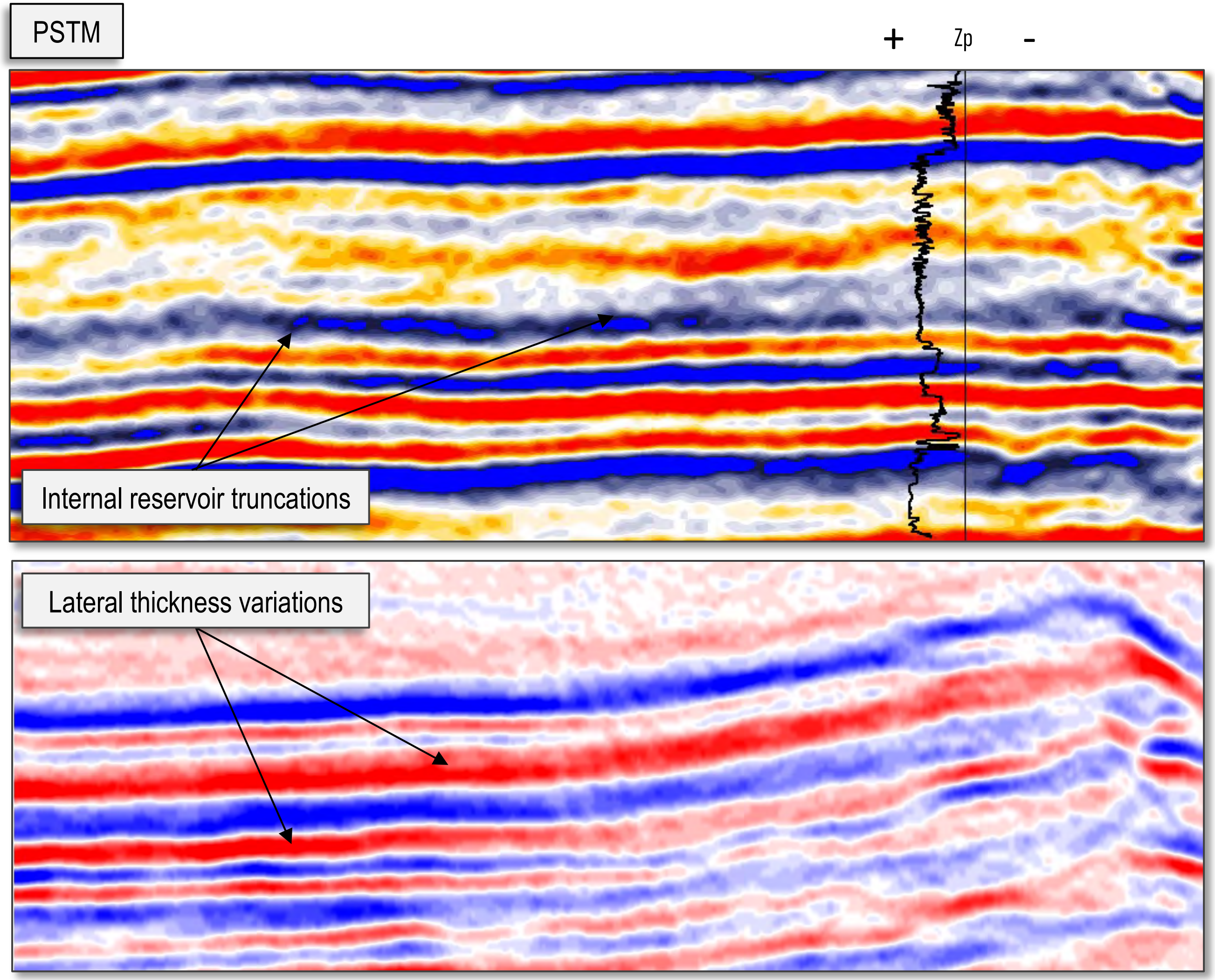
SGD LAYERING: SUPPORT TO WELL CORRELATION





SGD Layering is a seismic version to be used for internal reservoir pattern recognition, it might help to support well correlation. The SGD High Frequency is used as input to a thin layer sparse spark inversion, the result is a pseudo reflectivity that captures subtle internal changes from original seismic traces, truncations and lateral thickness variation can be better delineated

SGD High Frequency

↓

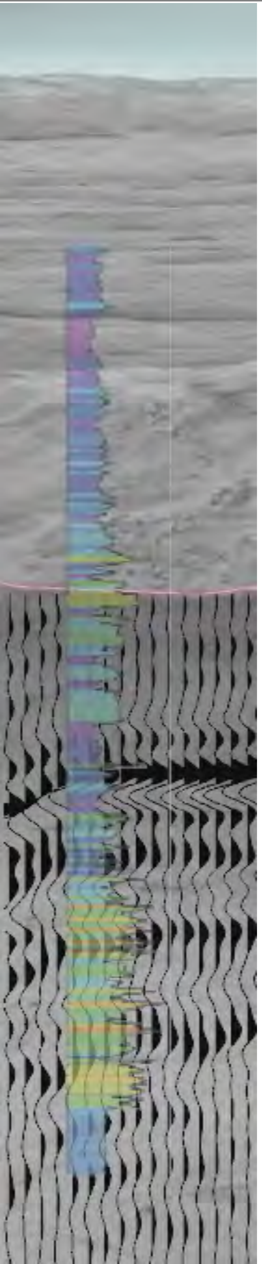
Thin Layer Sparse Spark Inversion

↓

SGD Layering impedance

CAYROS

SGD LAYERING: SUPPORT TO WELL CORRELATION



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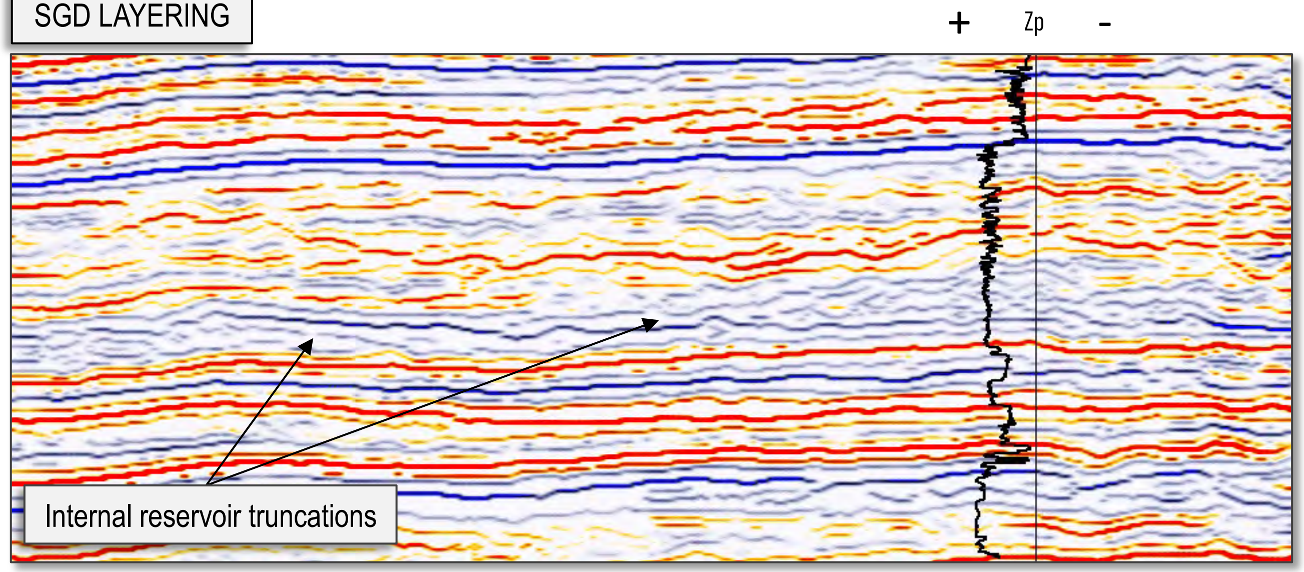

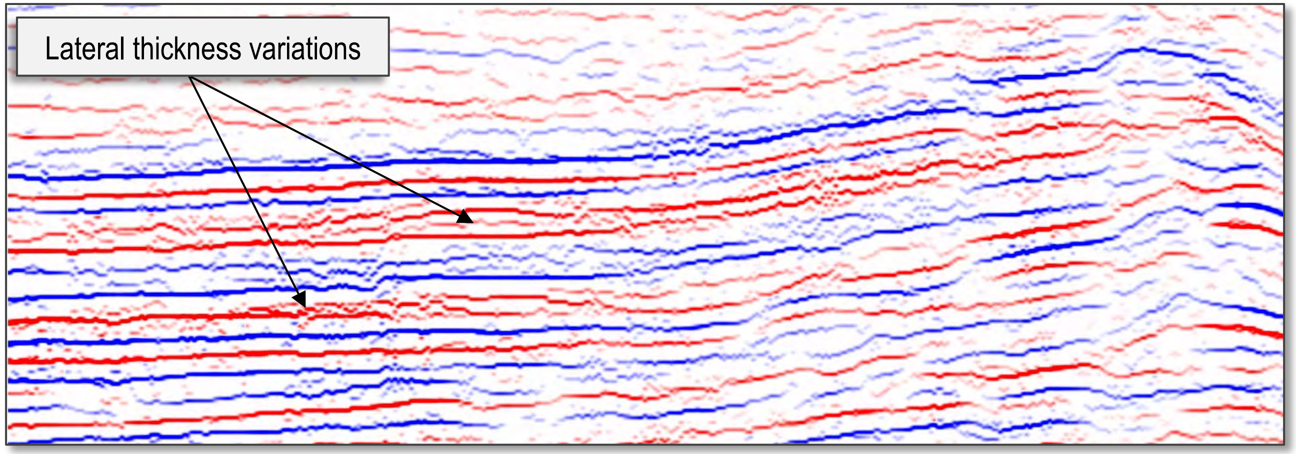

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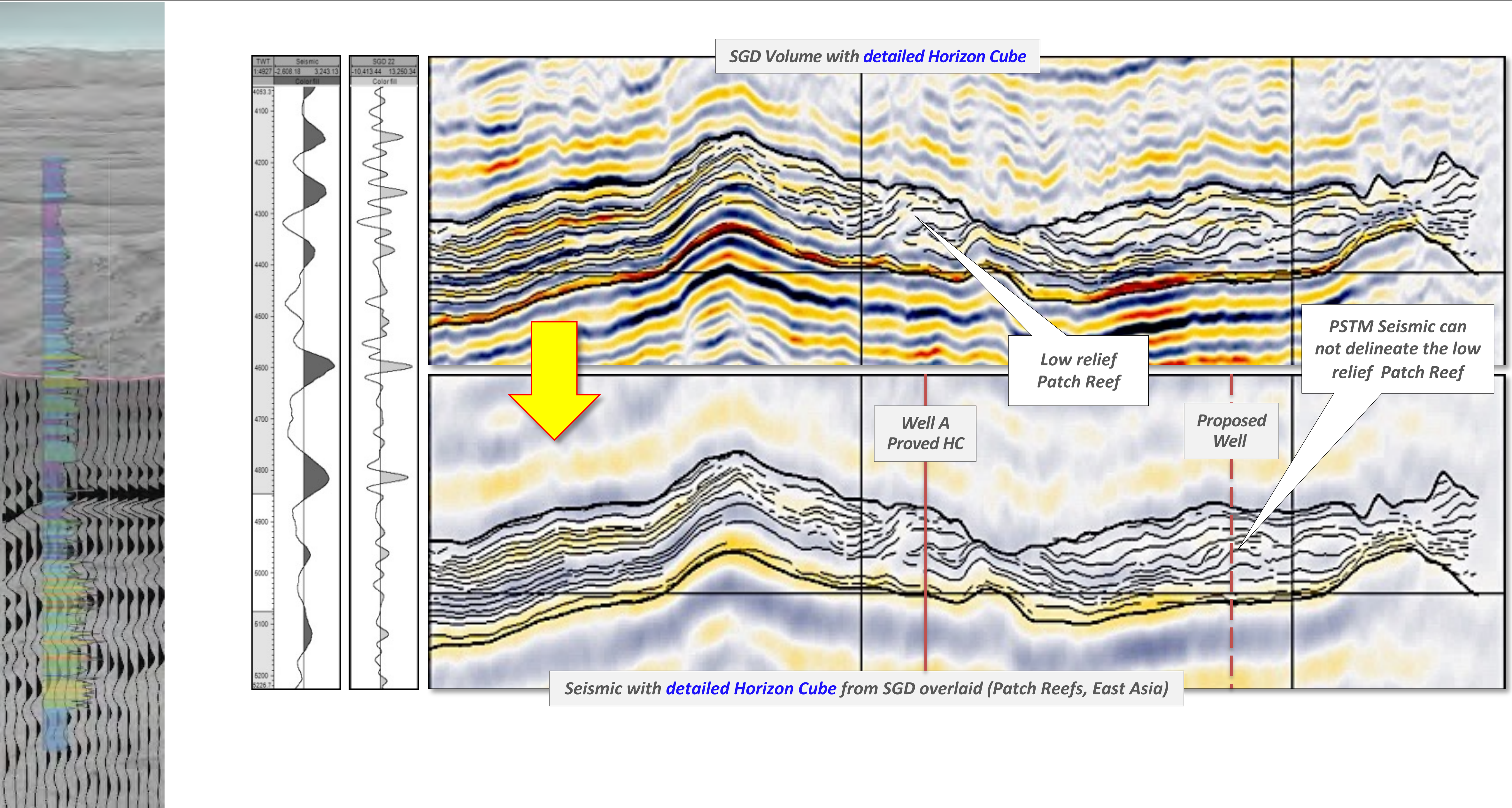
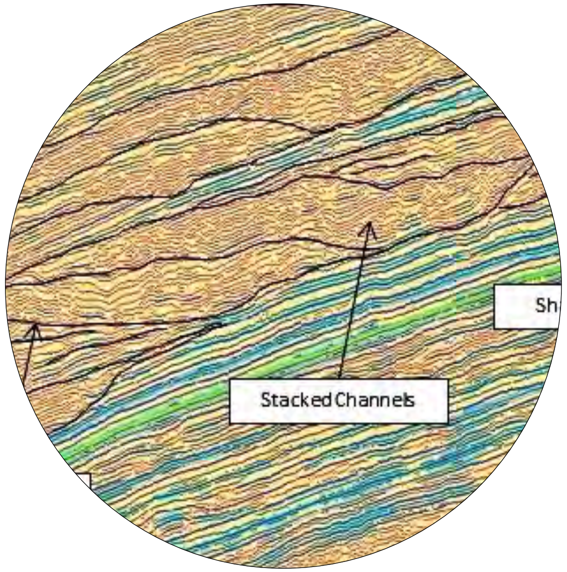
SGD Layering impedance

PATTERN REFLECTIVITY ANALYSIS



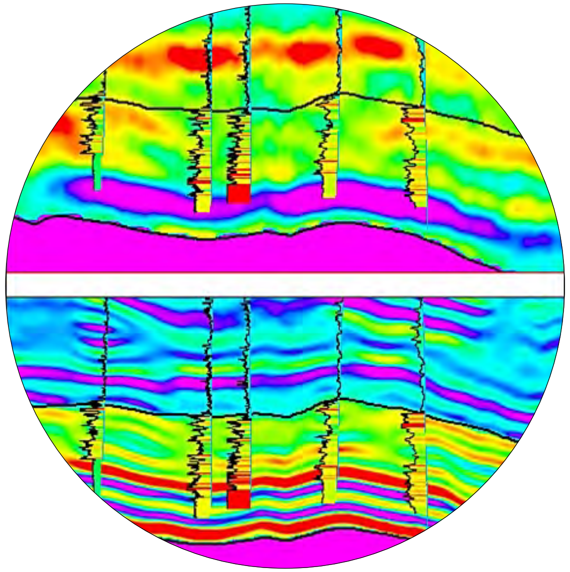
Seismic with detailed Horizon Cube from SGD overlaid (Patch Reefs, East Asia)

SOME EXAMPLES



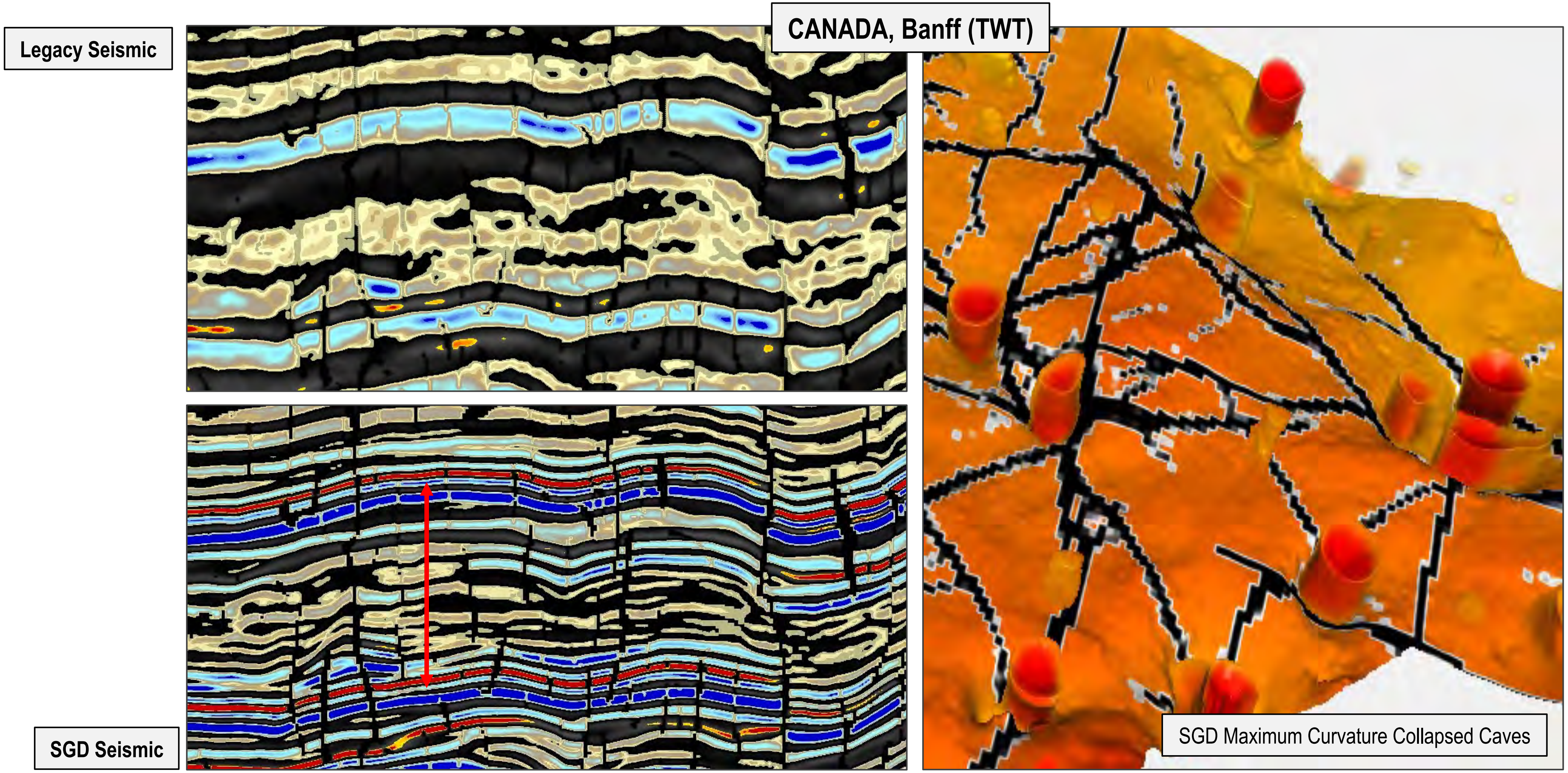
Pattern Recognition

Detailed Fault Mapping



Pseudo Rock Volumes

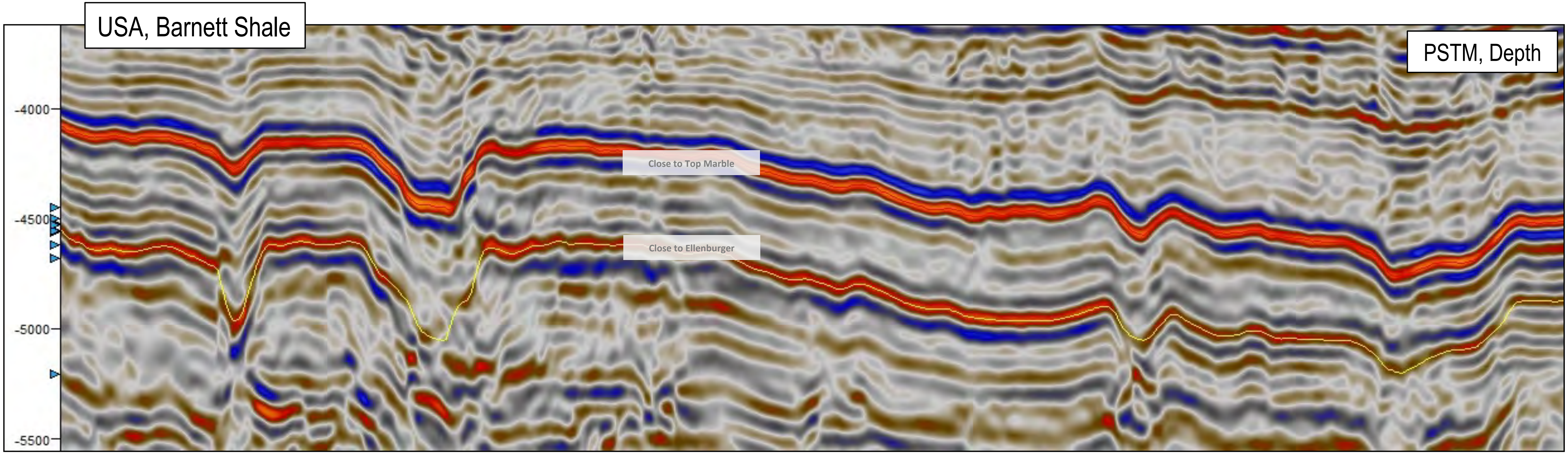
PALEO KARST DELINEATION (HF-SGD) - CANADA



The challenge for this unconventional field is to delineate properly both, the subtle faulting (segmentation) and the geometry of collapsed caves, the study aimed to support future horizontal drilling campaign. SGD Estrata high resolution vintage was used to run a very detailed Curvature volume, the proper use of opacity thresholds allowed for the detection of a complex net of Collapsed Paleo-Caves interconnected by a system of radial faulting

PALEO KARST DELINEATION (HF-SGD) – USA BARNETT

CURVATURE ANALYSIS FROM *SGDHF ESTRATA* - PALEO COLLAPSED CAVES GEOMETRY DELINEATION



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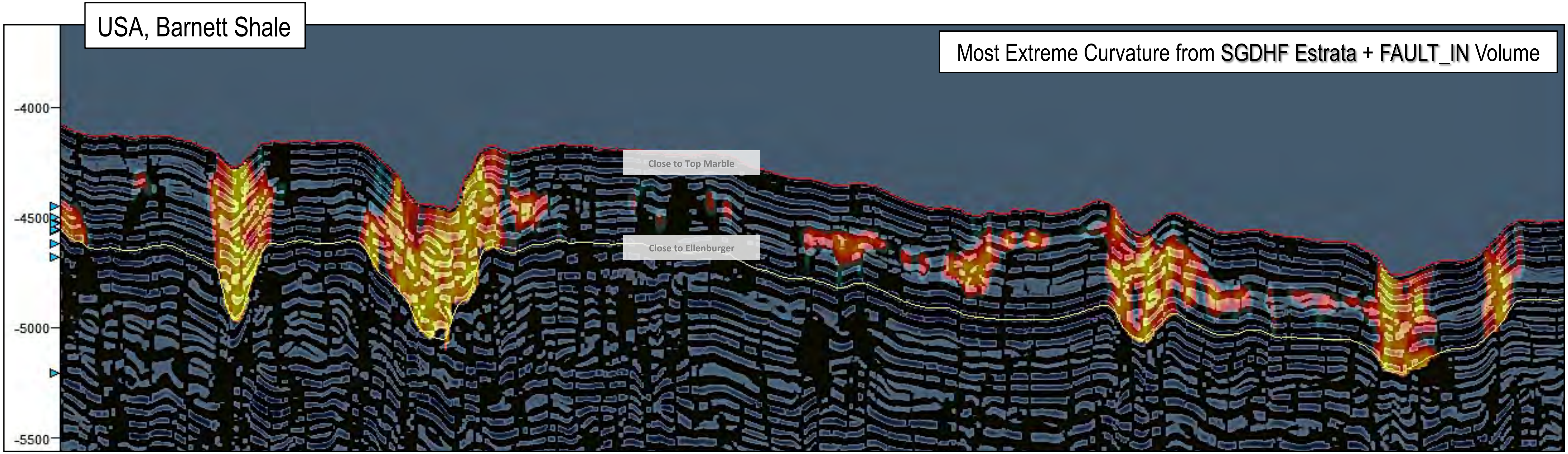

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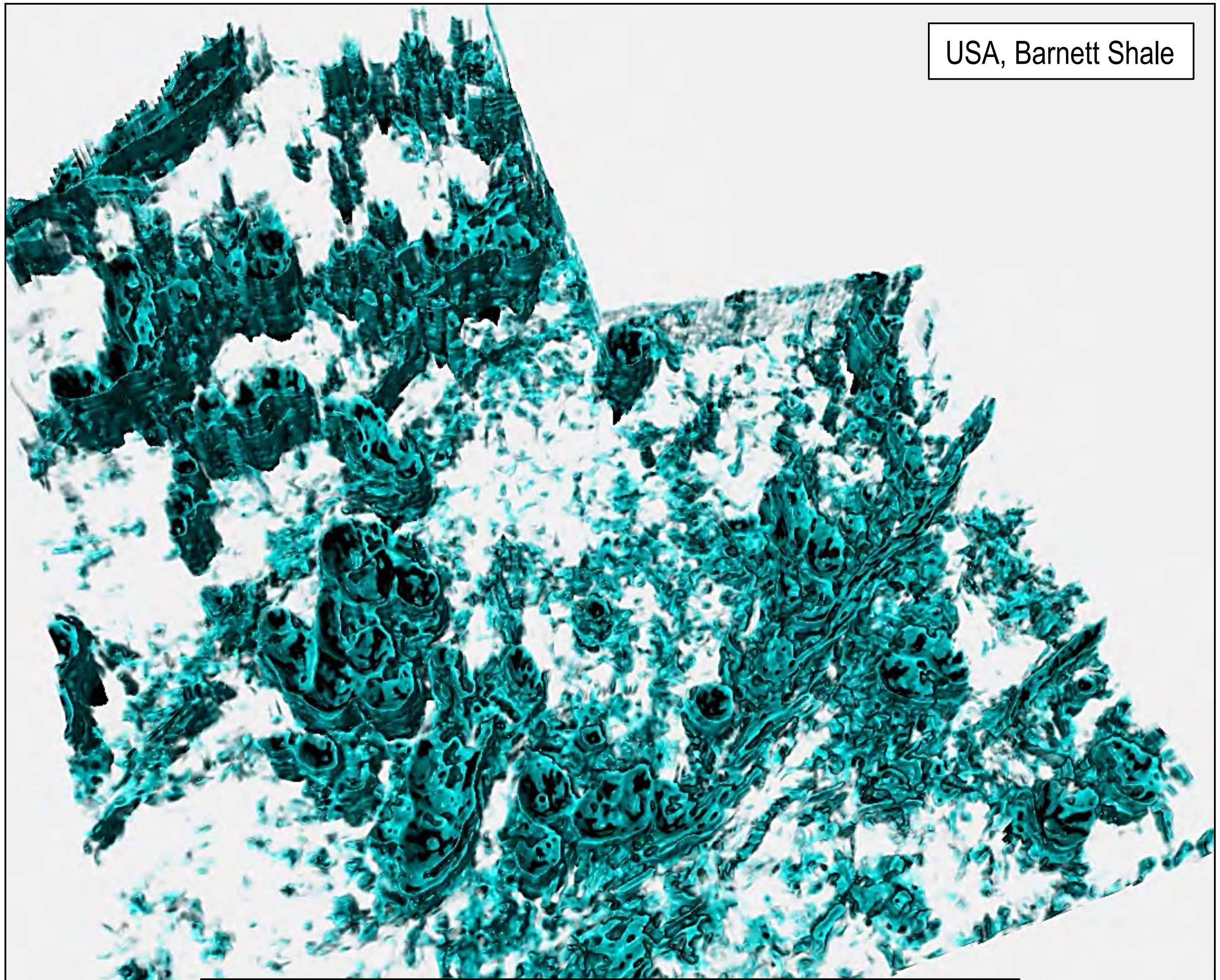
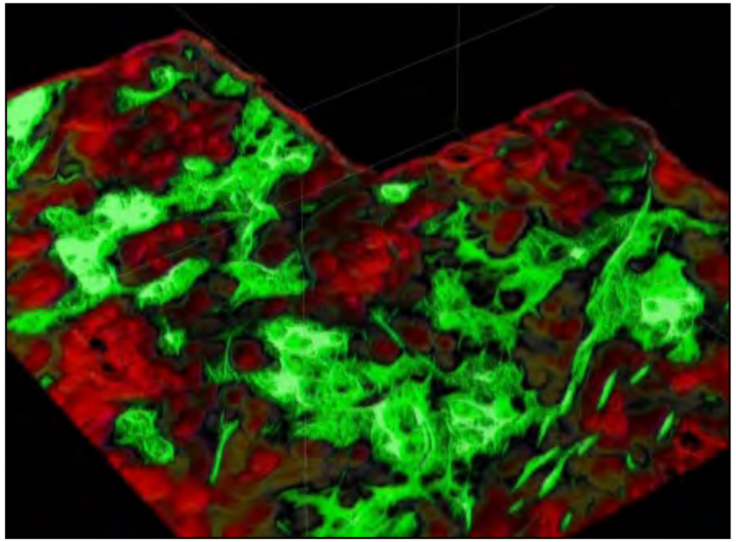
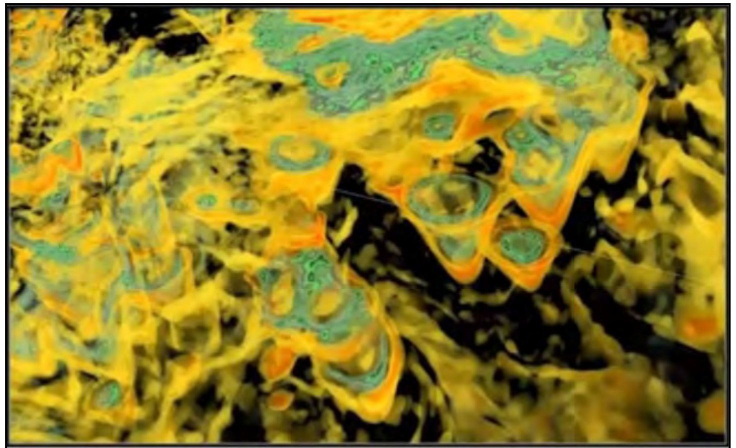


Collapsed Caves Geobodies - Max Curvature from SGDHF Estrata

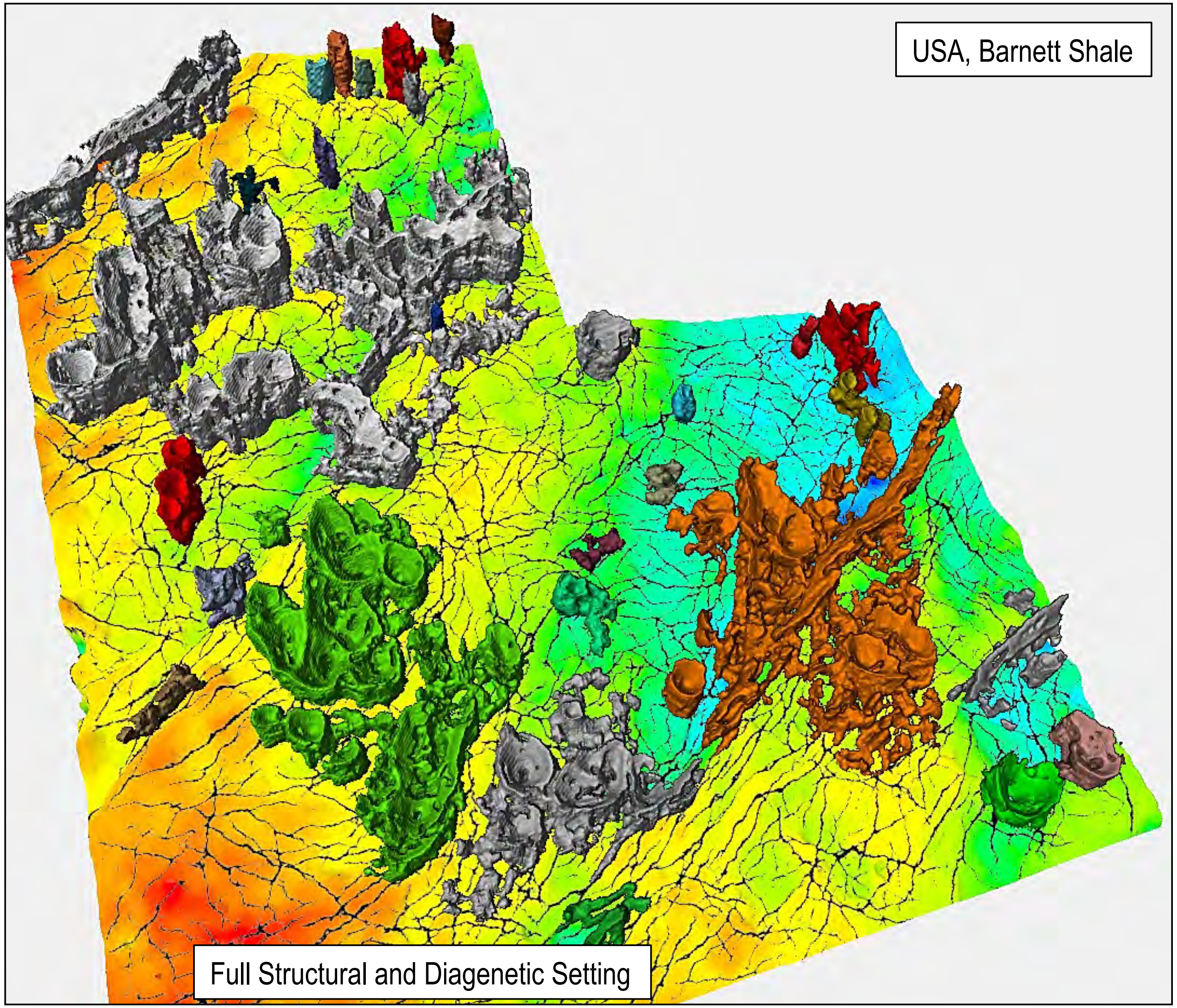


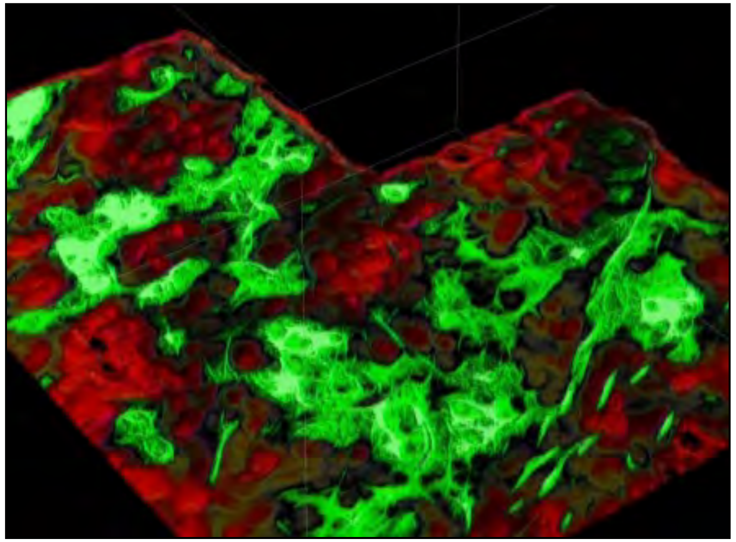


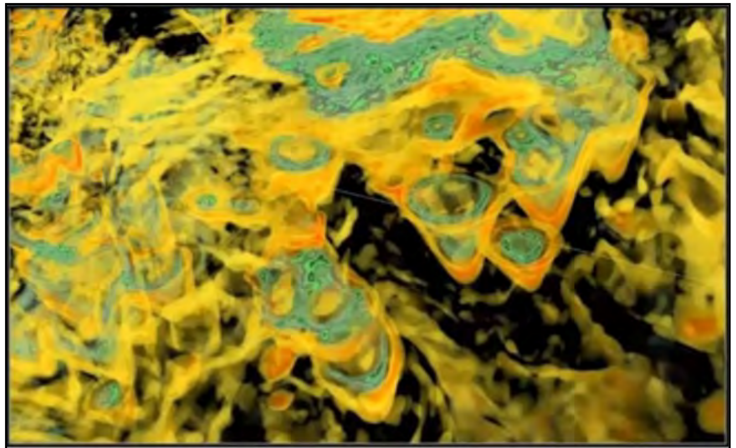
GPU-based enhanced visualization: karsts from Barnett Shale formation

The same target, but with a different approach (Paradigm)

PALEO KARST DELINEATION (HF-SGD) – USA BARNETT







GPU-based enhanced visualization: karsts from Barnett Shale formation

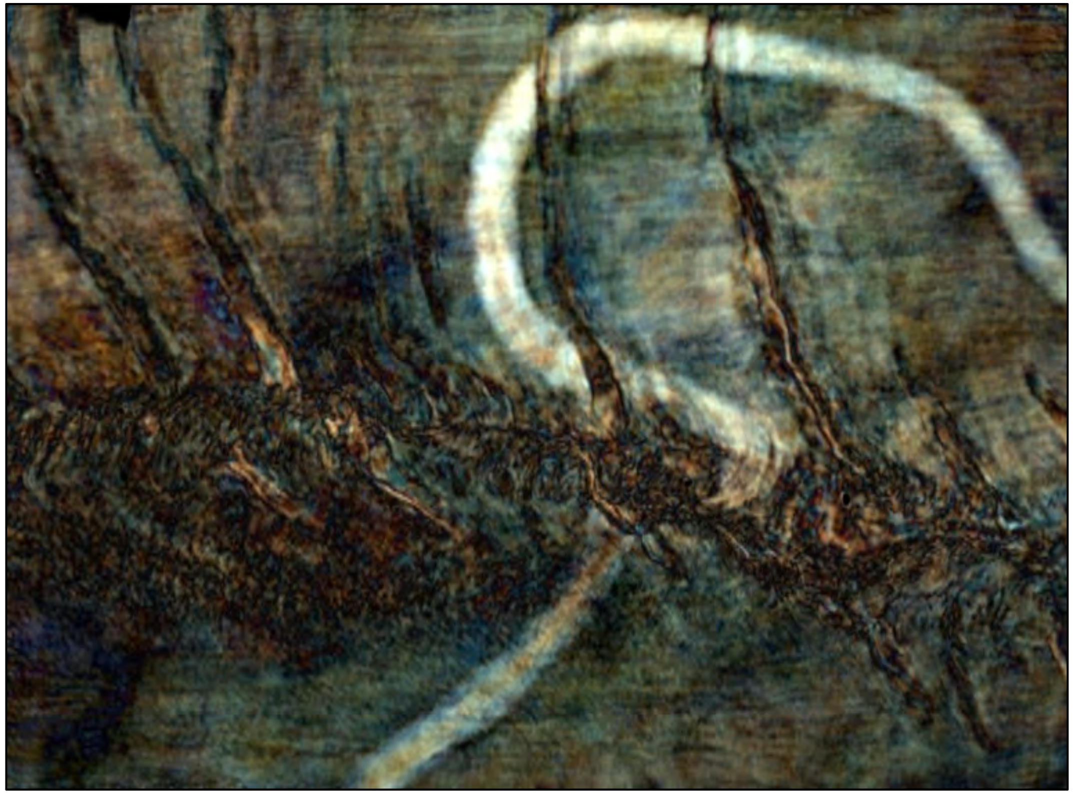
The same target but, with a different approach (Paradigm)

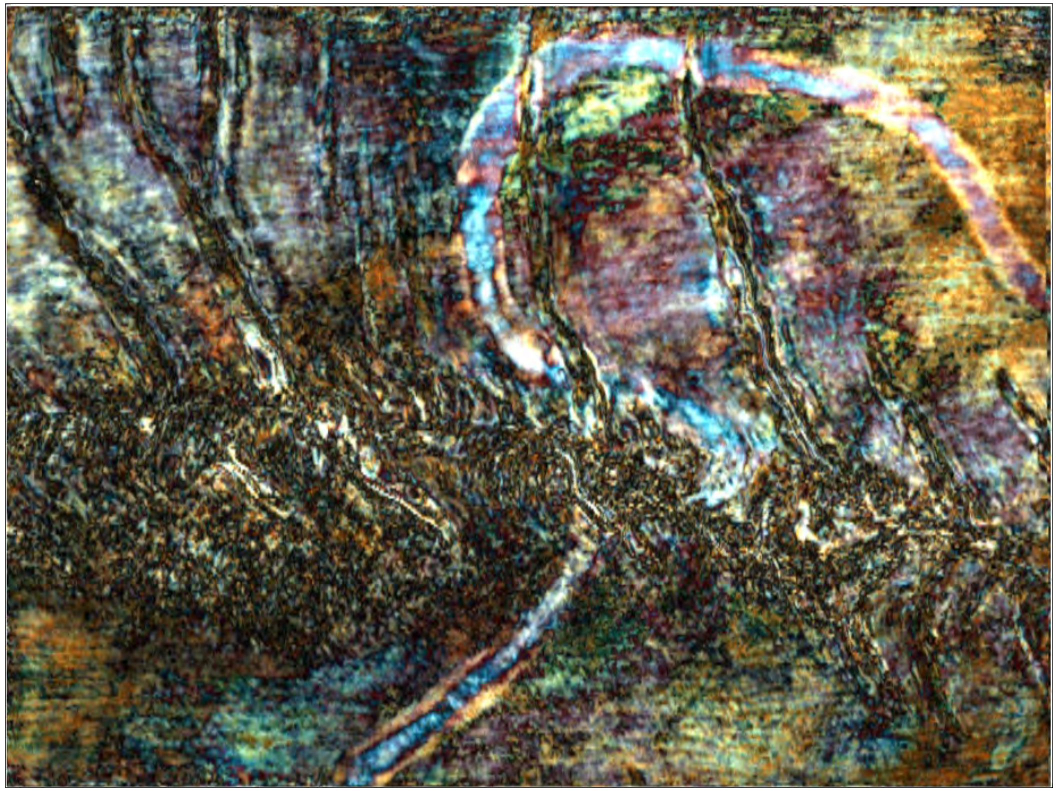
HIGH RESOLUTION STRATIGRAPHY

Matching Pursuit Decomposition PSTM

MEXICO, OFFSHORE

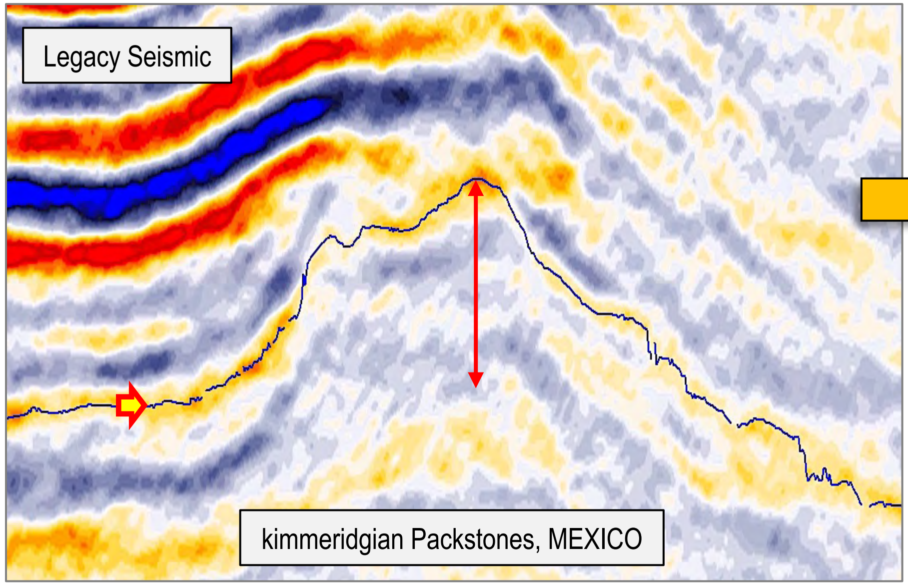
Matching Pursuit Decomposition SGD HF

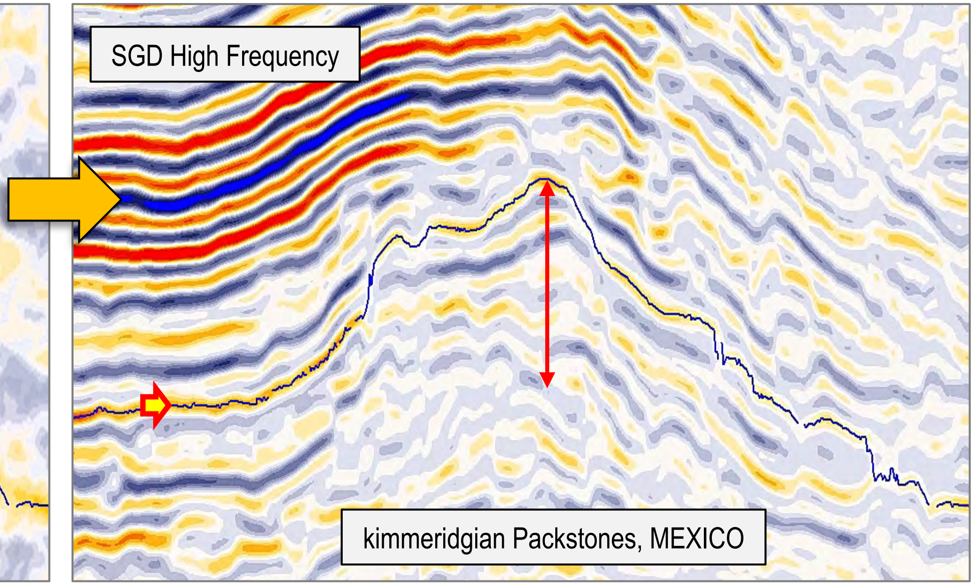


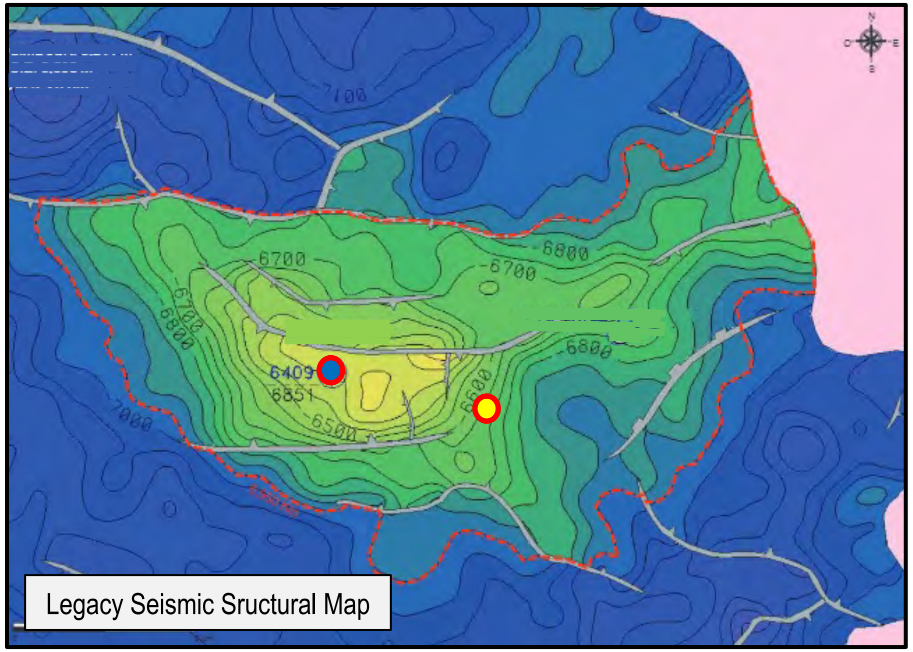


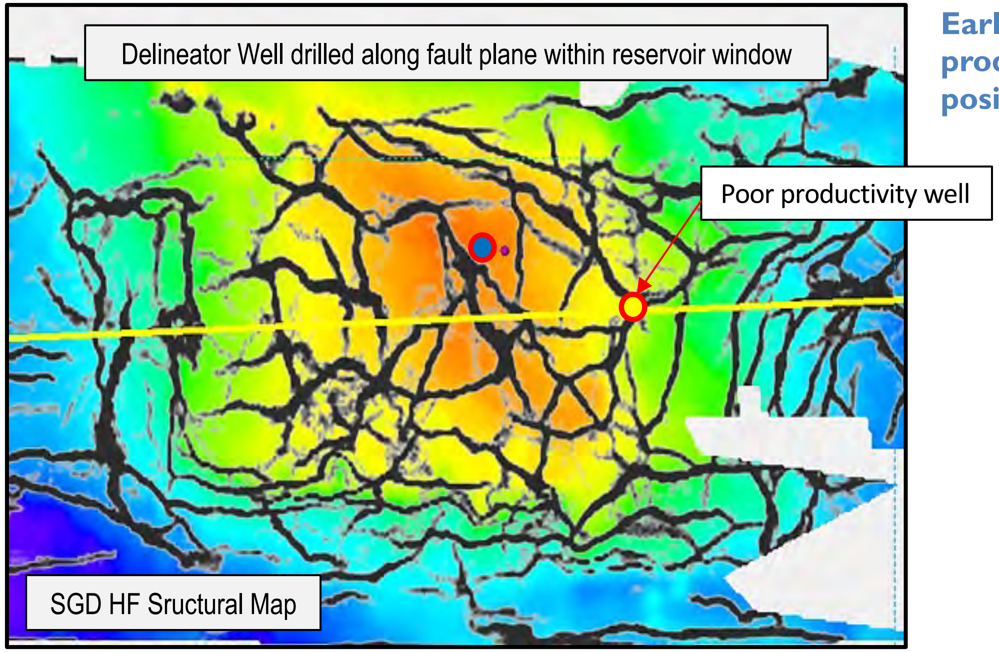
Spectral decomposition is applied to the Original Seismic and SGDHF volumes respectively (above), the images show a flattened surface correspondent to a channel interval. The internal channel architecture has been fine tuned, the lateral delineation of frequency facies that might be related to channel point bar and main channel limits on the foot wall is improved by using SGDHF

HIGH RESOLUTION RESERVOIR SEGMENTATION - MEXICO









The images on the left show the segmentation and compartmentalization for a natural fractured carbonate reservoir (Jurassic).

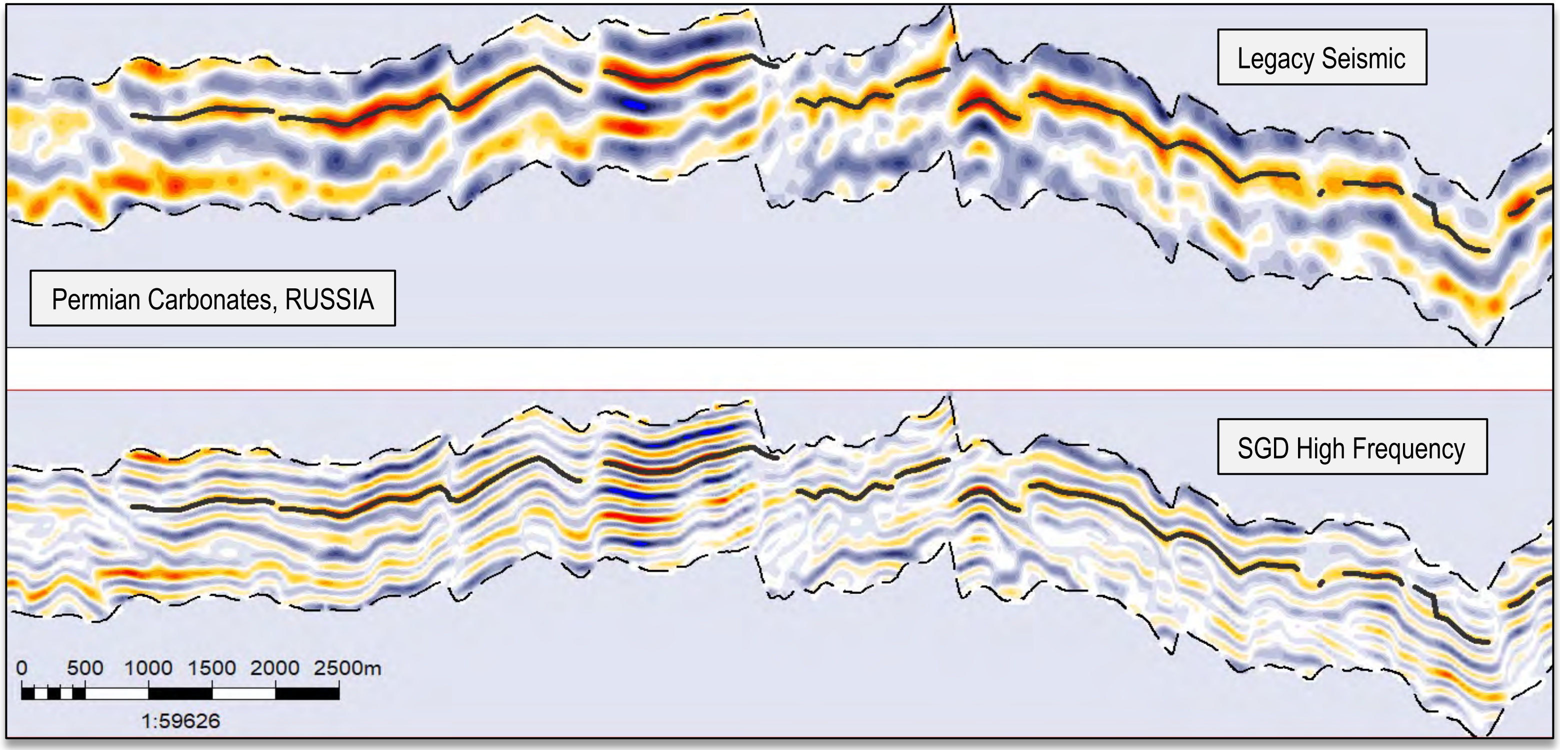
A very low frequency **Legacy Seismic** 7Hz (left) failed to delineate properly the complex fault setting of the field. The first delineator well was drilled along the fault plane within the window of interest with low production results.

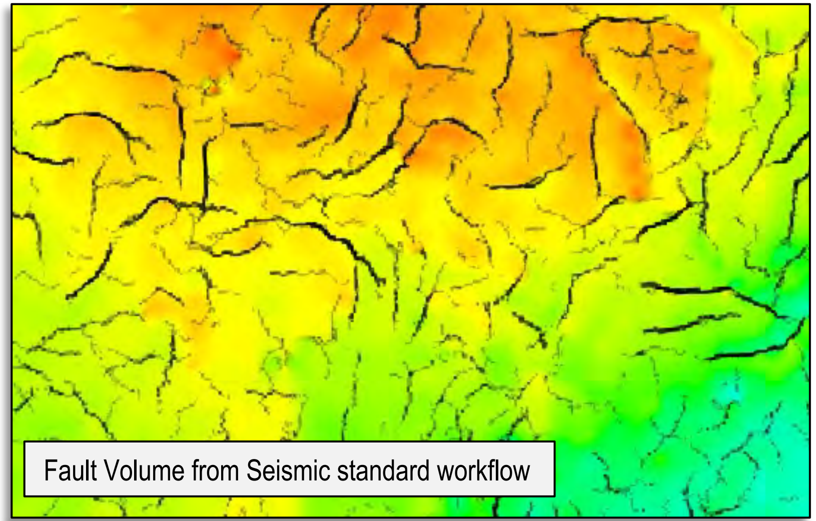
After running **SGD** processes a very detailed segmentation delineation showed the high structural complexity of the reservoir.

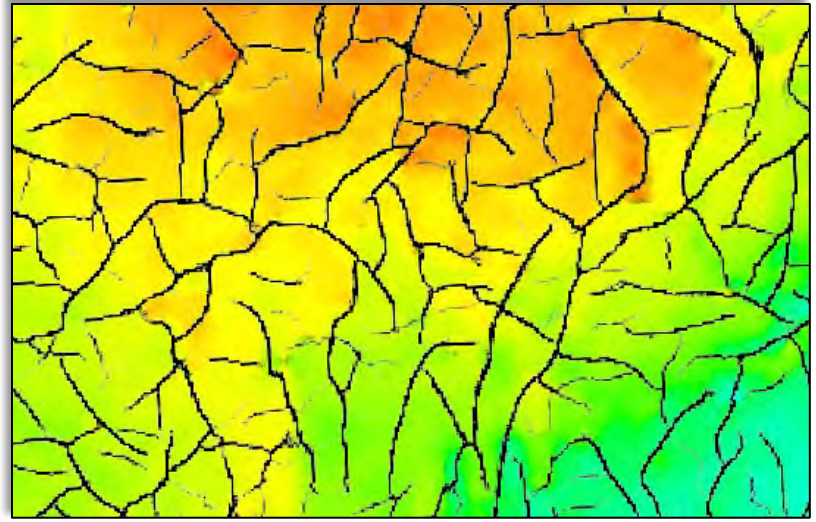
Early water breakthrough and poor productivity wells can be prevented by positioning wells away from faults.

CAYROS

HIGH RESOLUTION RESERVOIR SEGMENTATION - RUSSIA



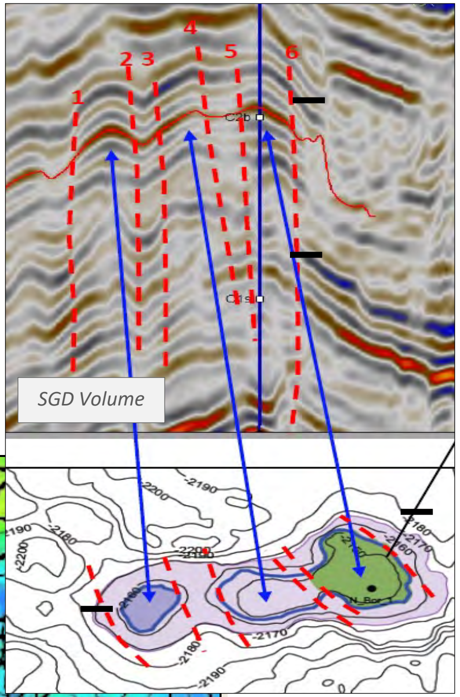


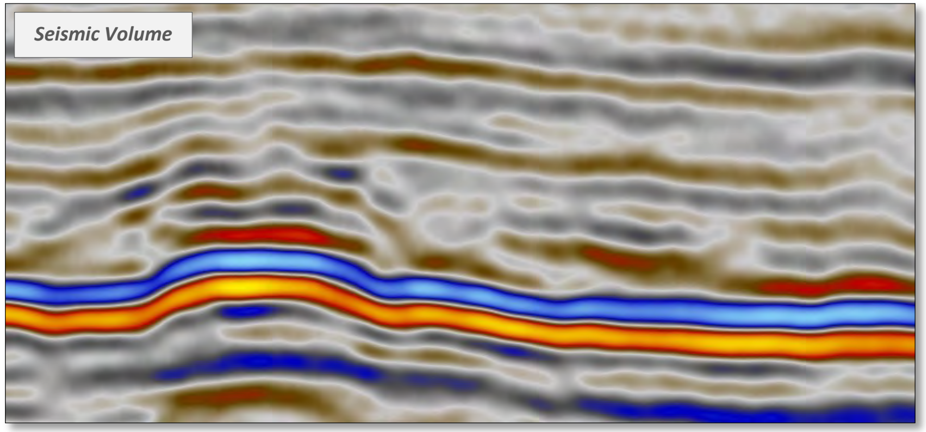


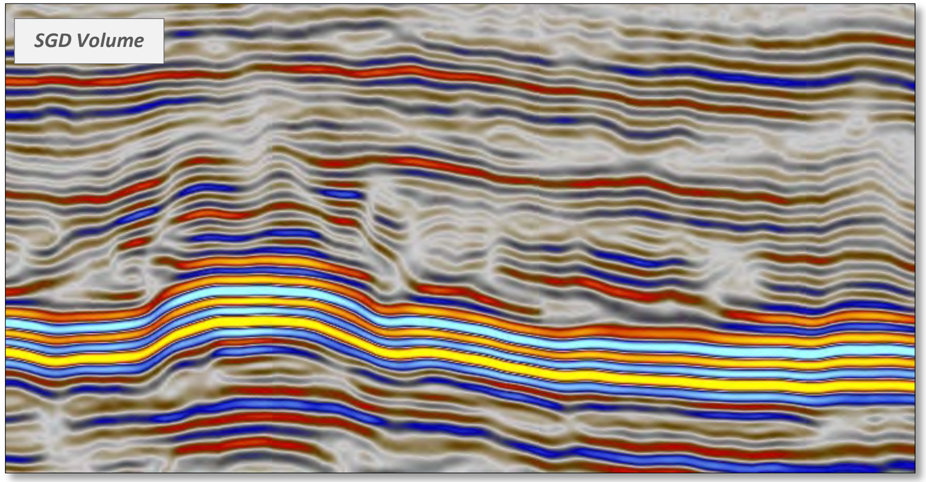
Detailed Fault Mapping delineation can be accomplished by using *SGD workflows*. Legacy seismic volumes, in general, lack the enough resolution for detecting subtle faulting. Small reflector flexures can be related to low offset faults, **SGD High Frequency** volumes can be of help to enhance and optimize any Edge detection algorithm. An example of a natural fractured carbonate reservoir is shown, the images on the right display the segmentation of the top of the reservoir generated from standard workflows applied to the Legacy Seismic and to the SGD-HF respectively.

SUBTLE FAULTING: CARBONATES RUSSIA

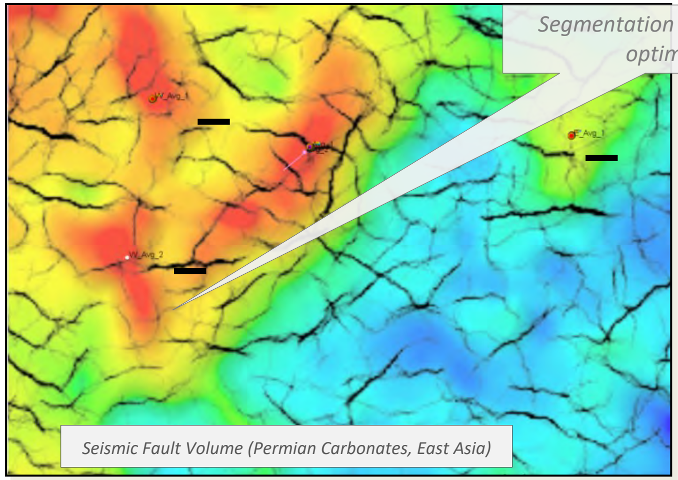
The images show the segmentation and compartmentalization for a natural fractured Devonian carbonate. The reservoir is composed of a series of Patch Reefs, fault sealing plays a fundamental role for the trapping of oil in the field. The proper delineation of subtle faulting (very smoothed flexures seen on PSTM seismic) is crucial for the risk evaluation of new prospects.

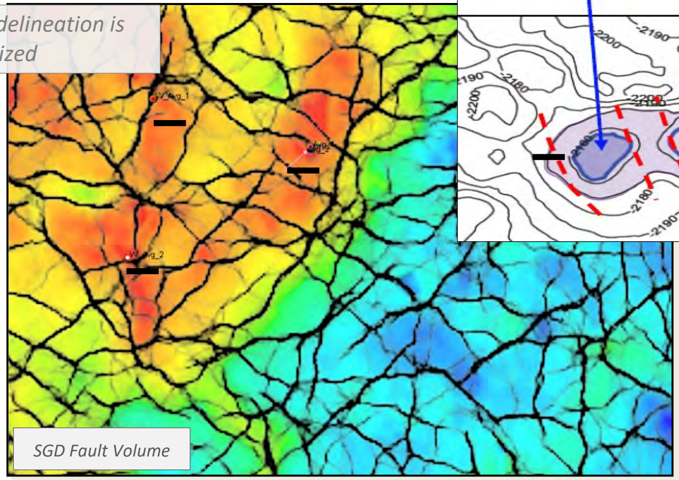


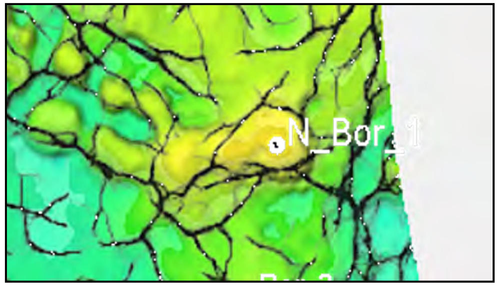




Segmentation delineation is optimized

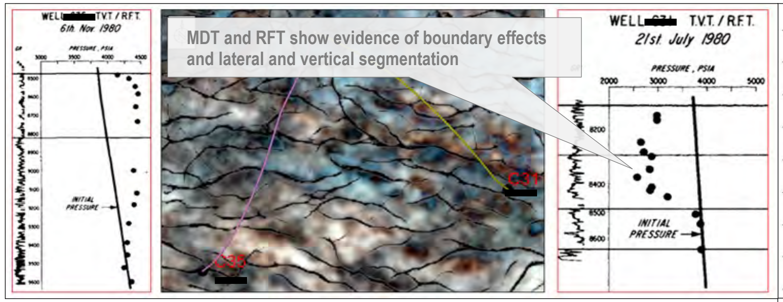


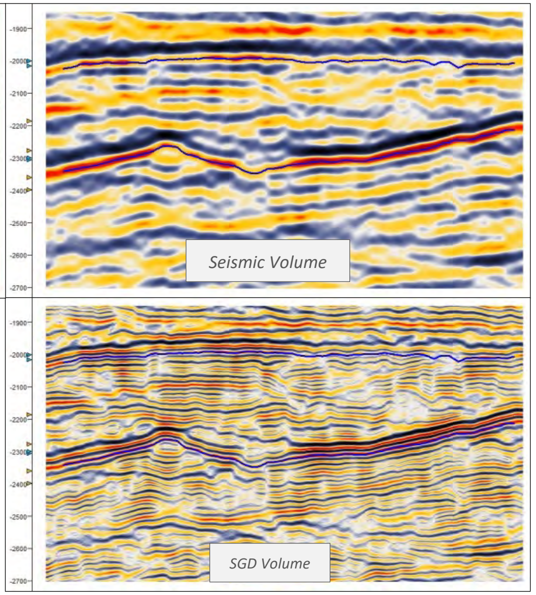


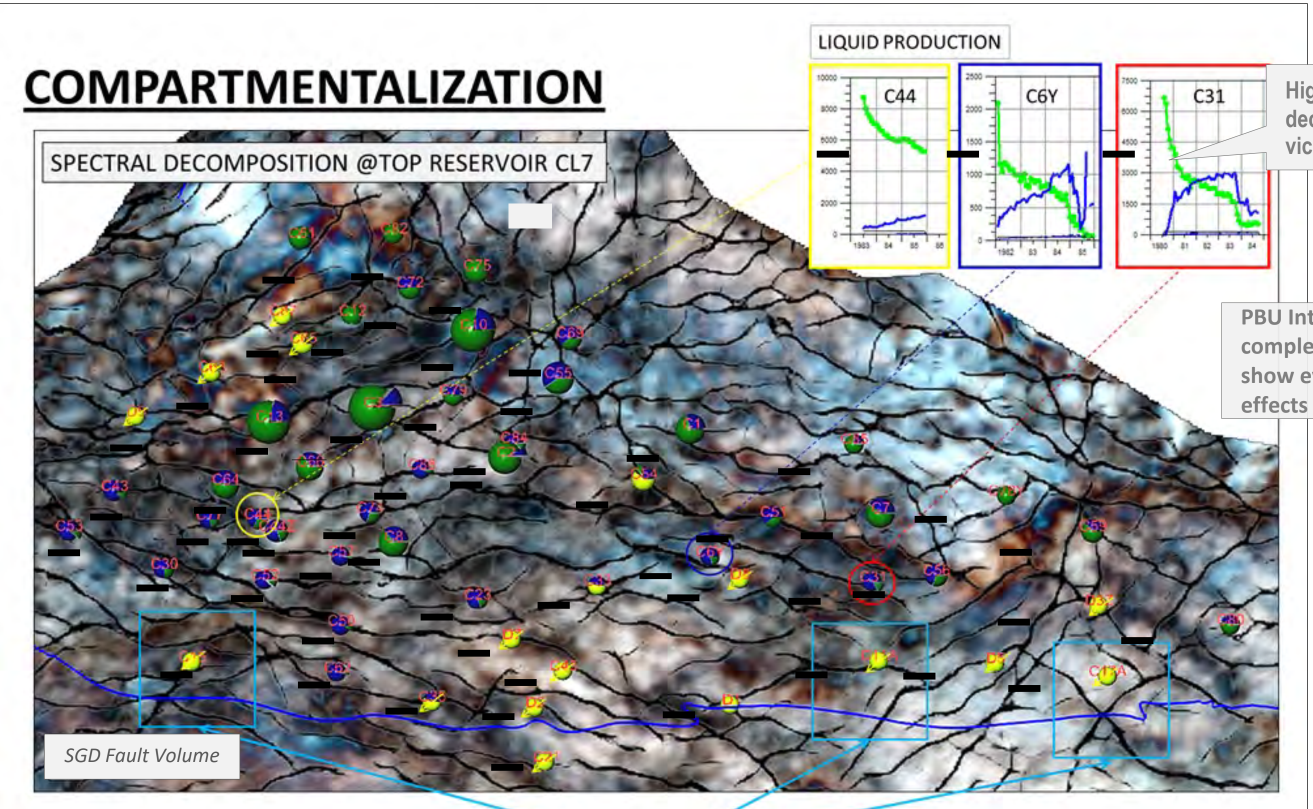


NORTH SEA: RESERVOIR SEGMENTATION

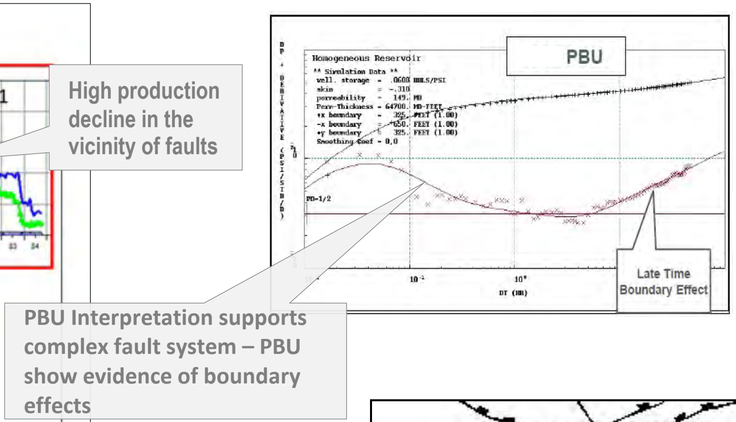
A Brown field is under study to carry on an infield campaign. Several static models have failed to capture the high complexity of the structural and stratigraphic setting. Dynamic models can not match the history of injection and production without having to apply strong multipliers in the vicinity of faults. A whole new workflow for the segmentation delineation is performed with SGD volumes as input, the result is a new map that let to understand the compartmentalization of the field. The drilling campaign was postponed until a new model is built.

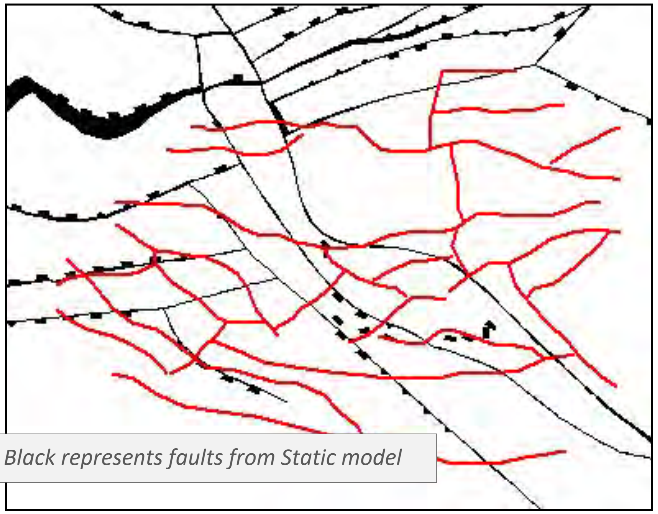






The injection profiles of existing Injectors [redacted], [redacted], and [redacted] show that the majority of the water injection (±80%) is entering those **zones below the original OWC.**

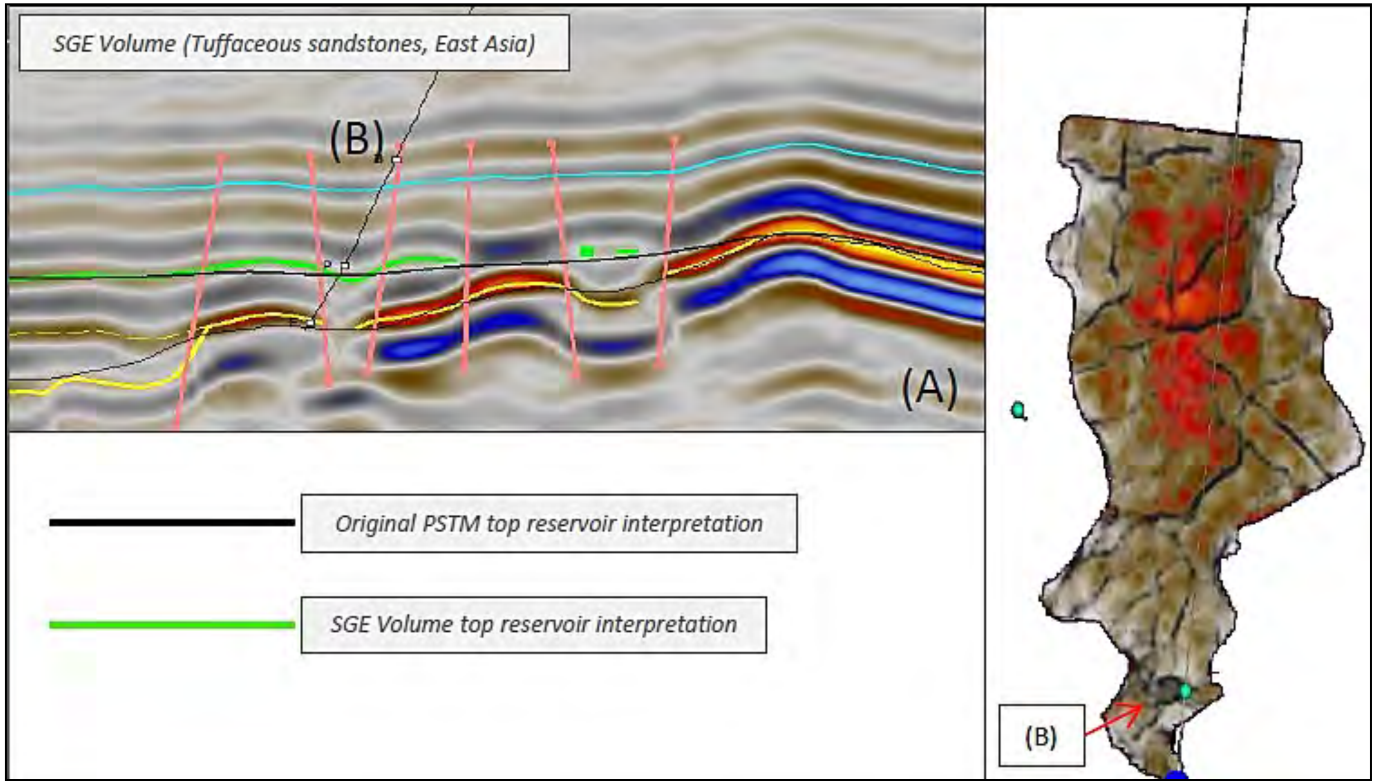


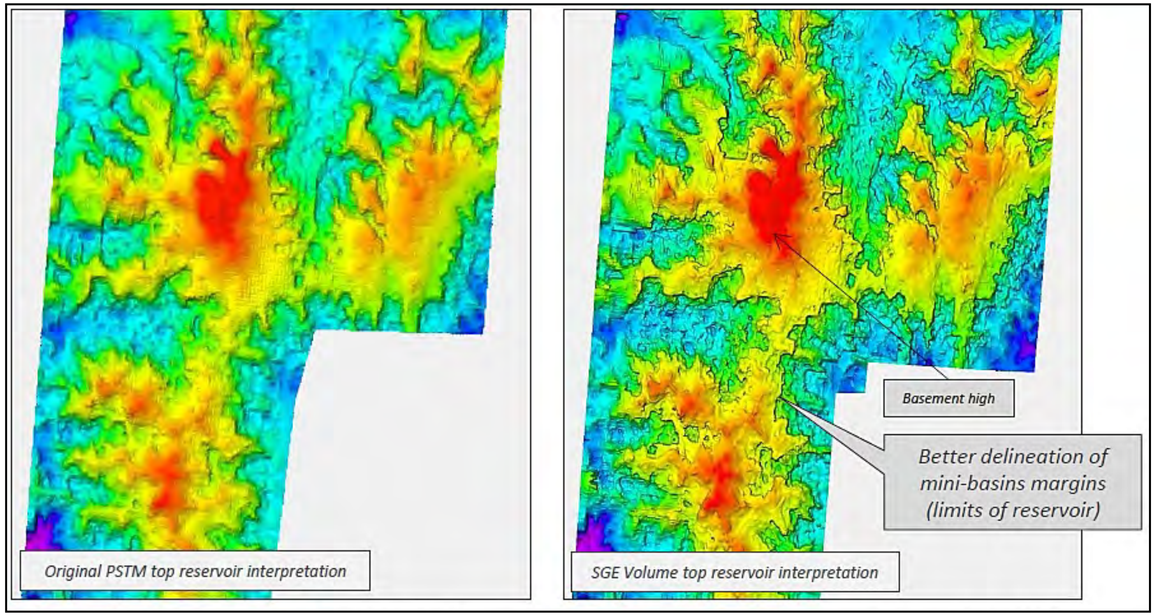


Map comparison. Black represents faults from Static model

CAYROS

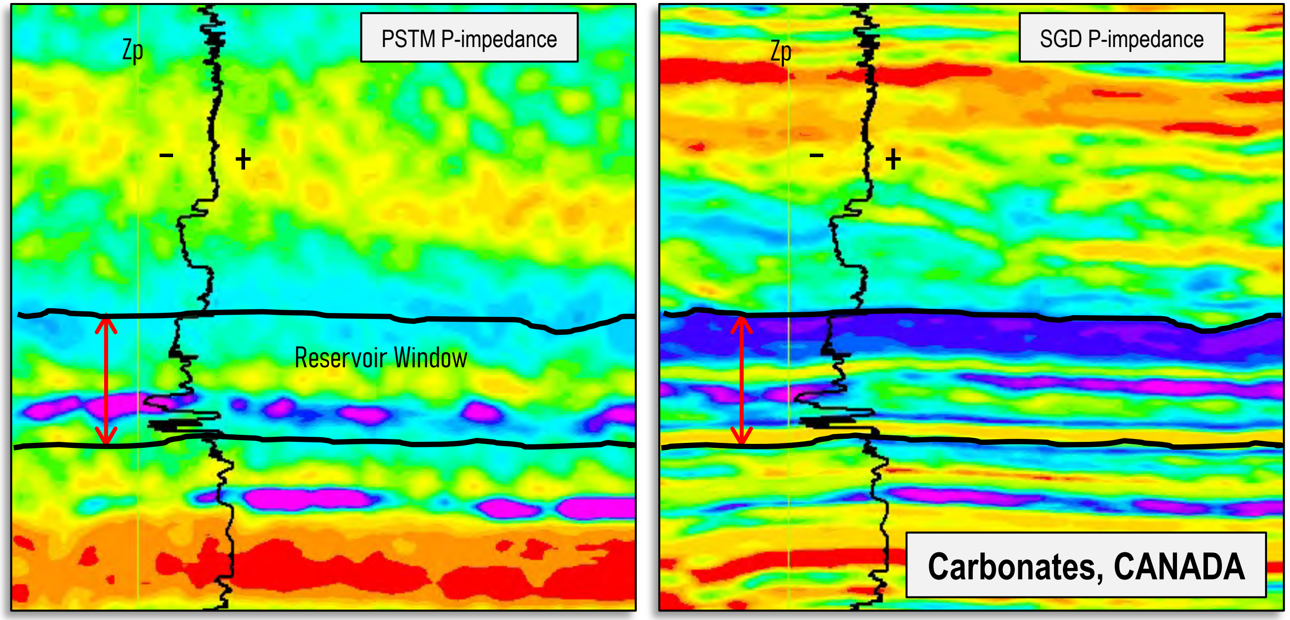
RESERVOIR SEGMENTATION: EAST SIBERIA

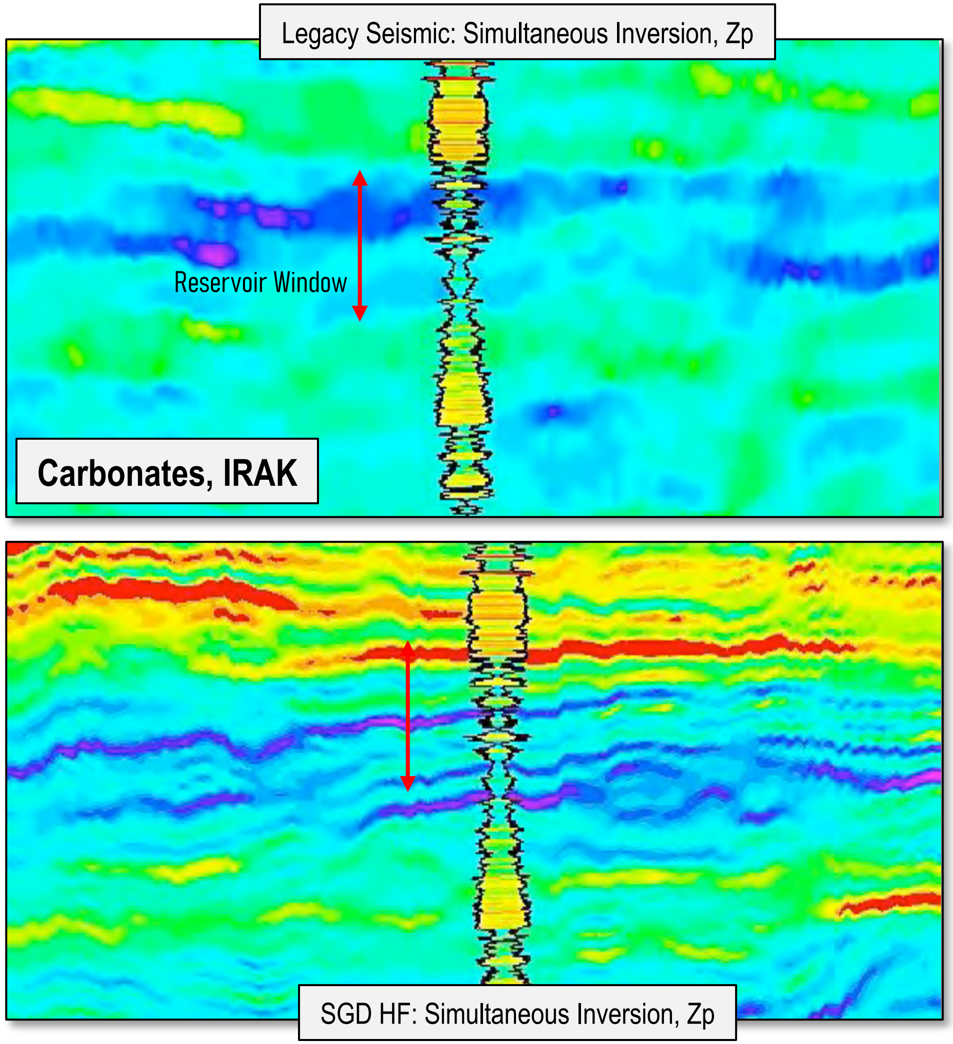




A very thin tuffaceous sandstone package (less than 8m) deposited on small basement depressions (mini-basins) is characterized by applying SGD workflows. Gas wells are drilled based on previous interpretation from original seismic (very low dominant frequency 20Hz) represented by the black line, the result is a very smooth surface that fails to capture the subtle faulting. The small compartment (B) is missed by this smoothed interpretation, the well is positioned in the foot wall missing 6m of reservoir (noneconomic). A fine-tuned interpretation of the top of the reservoir using SGD HF (green line) led to a better and optimized drilling campaign in the field.

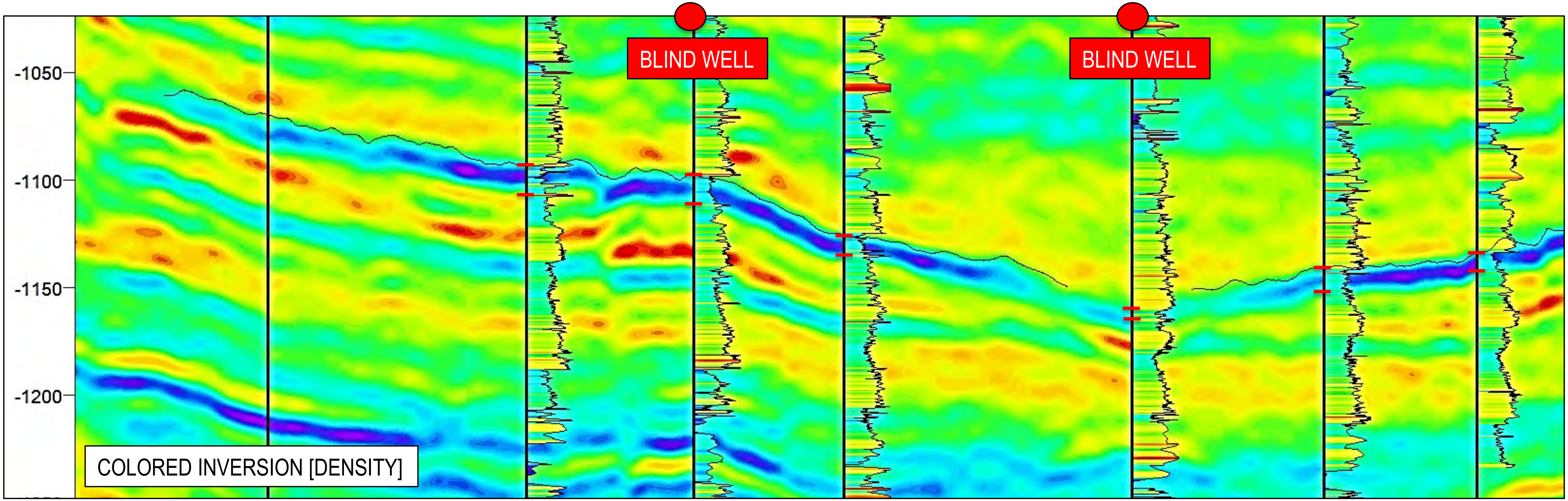
STANDARD INVERSIONS (EEI/COLORED/SEI)





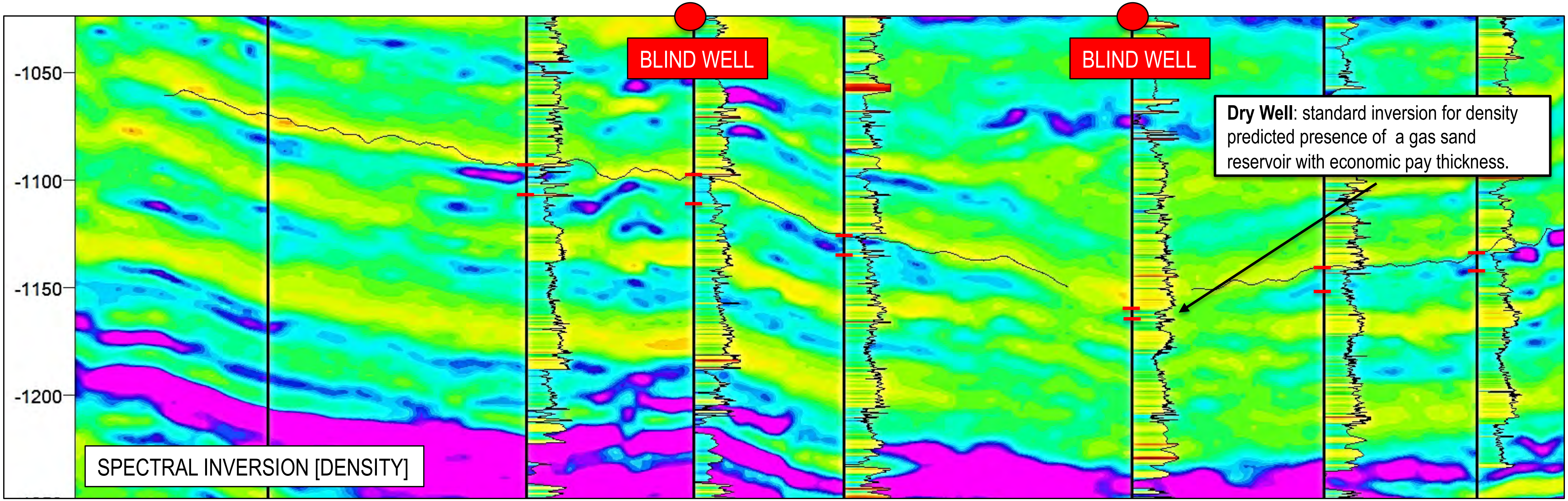
High Resolution Elastic property volumes can be generated by using *SGD workflows*, even though, during the process amplitude ranges might be mildly affected, still a full range of qualitative volumes can be yielded. The images on the left show a P-impedance volume for the Interval of interest, within the reservoir window the Legacy Seismic lacks the resolution to resolve for vertical variations in the Zp log. *SGD workflows* can be run at **gather** or **angle stack level** to produce more detailed **EEI**, **Colored** or **Simultaneous Inversion**.

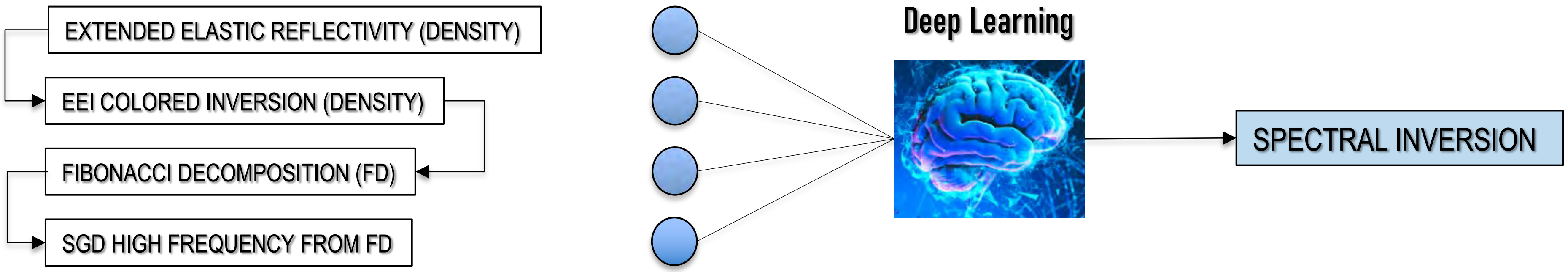
SGD SPECTRAL INVERSION FOR DENSITY



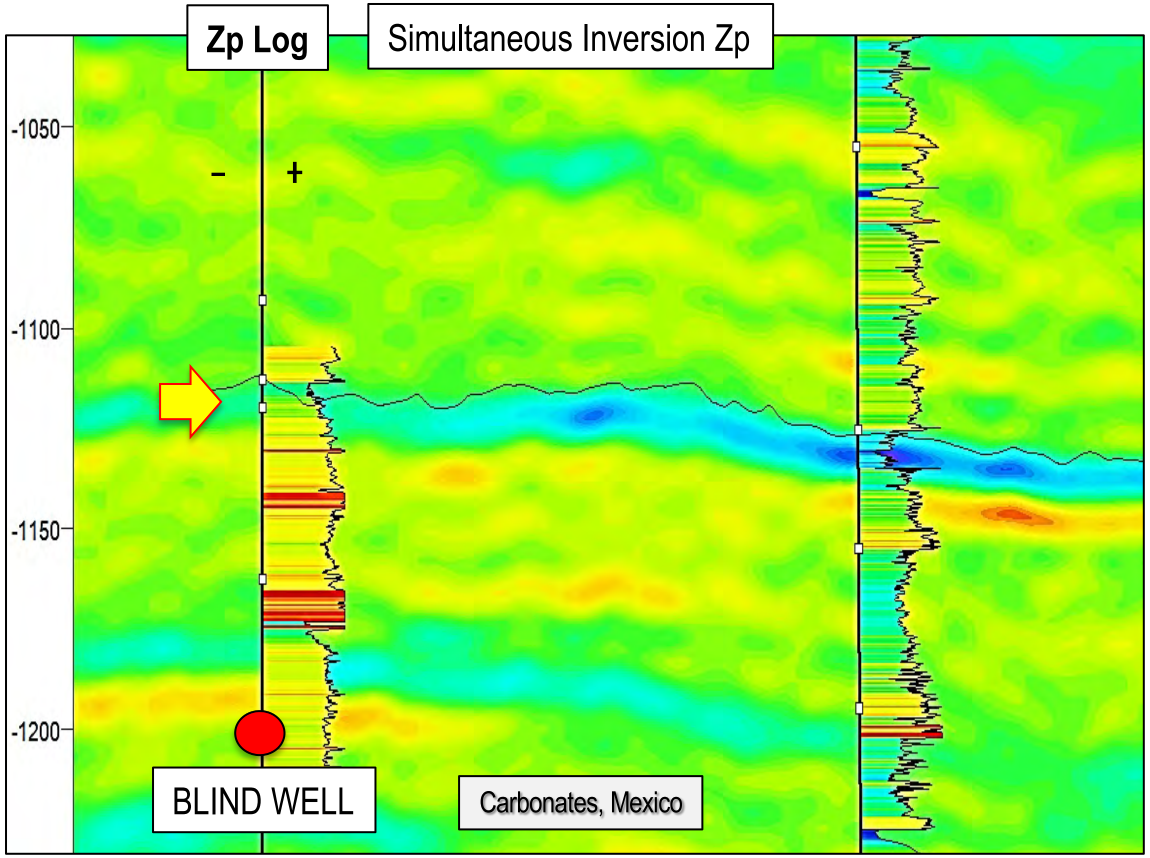
A gas sandstone pay thickness shows good correlation to low values of density and Lambda-Rho, many wells drilled in the field showed that density from standard inversion failed to prognose correctly sweet spot locations and resulted in dry wells. ***Spectral Inversion*** for density showed by using blind wells that it could have helped to avoid for drilling some of the dry wells. The results from ***Spectral Inversion*** are being integrated at the moment in the drilling strategy of future wells in the area. ***Spectral Inversion*** uses Deep learning algorithms along with EEI, Colored Inversion, Fibonacci Decomposition and SGD HF volumes.

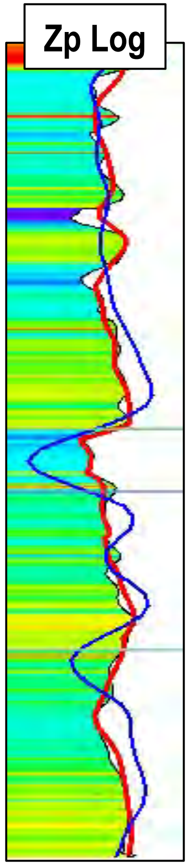
SGD SPECTRAL INVERSION FOR DENSITY





SIMULTANEOS INVERSION vs SGD SPECTRAL INVERSION



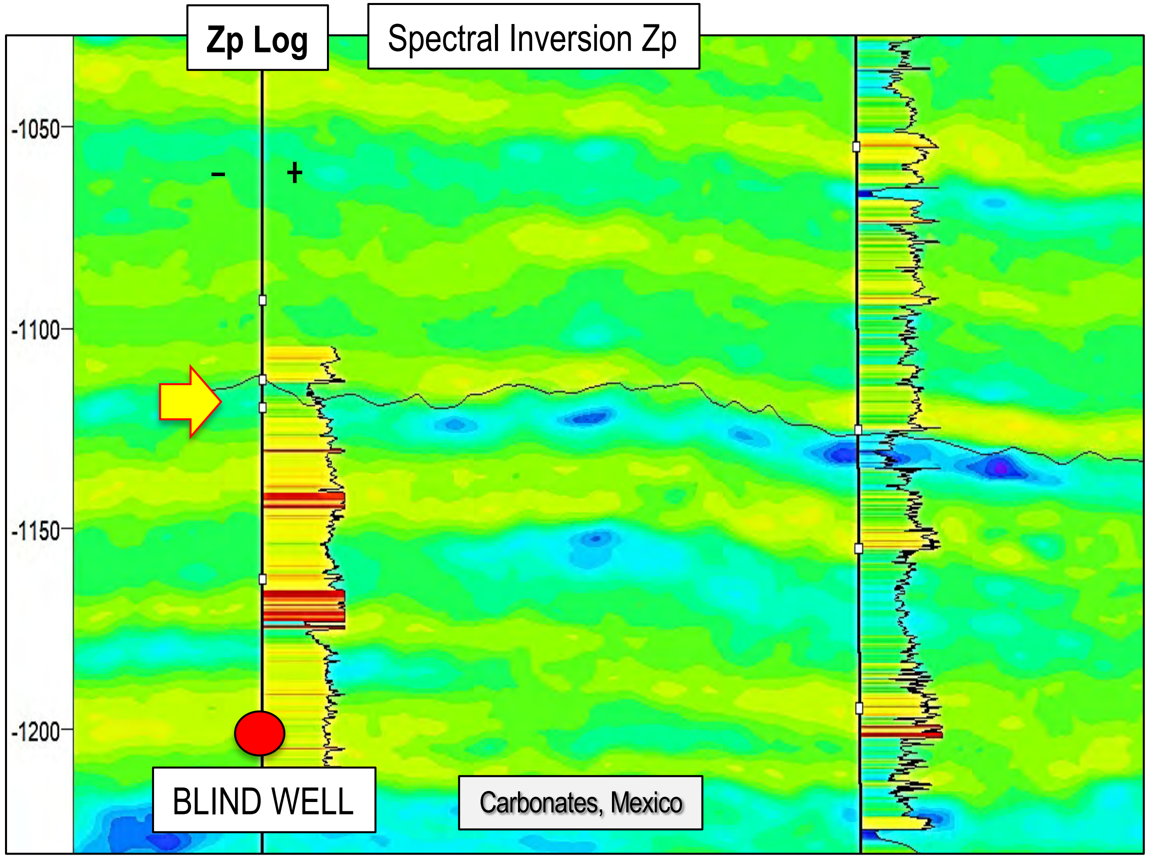


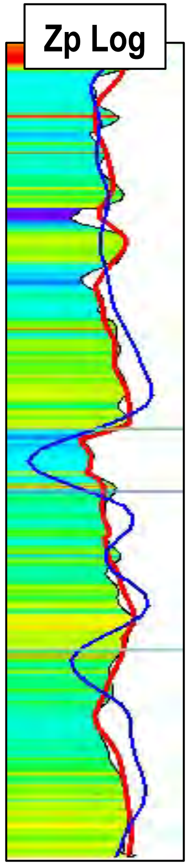
A high porosity Packstone reservoir (low P-Impedance) is delineated both, with Simultaneous Inversion and Spectral Inversion.

The images on the left show the comparison, a blind well shows the results of the two inversion in an area of no well control. **Spectral Inversion** matches fairly good vertical variation of main P-Impedance packages for both wells.

Simultaneous Inversion Zp
Spectral Inversión Zp

SIMULTANEOS INVERSION vs SGD SPECTRAL INVERSION





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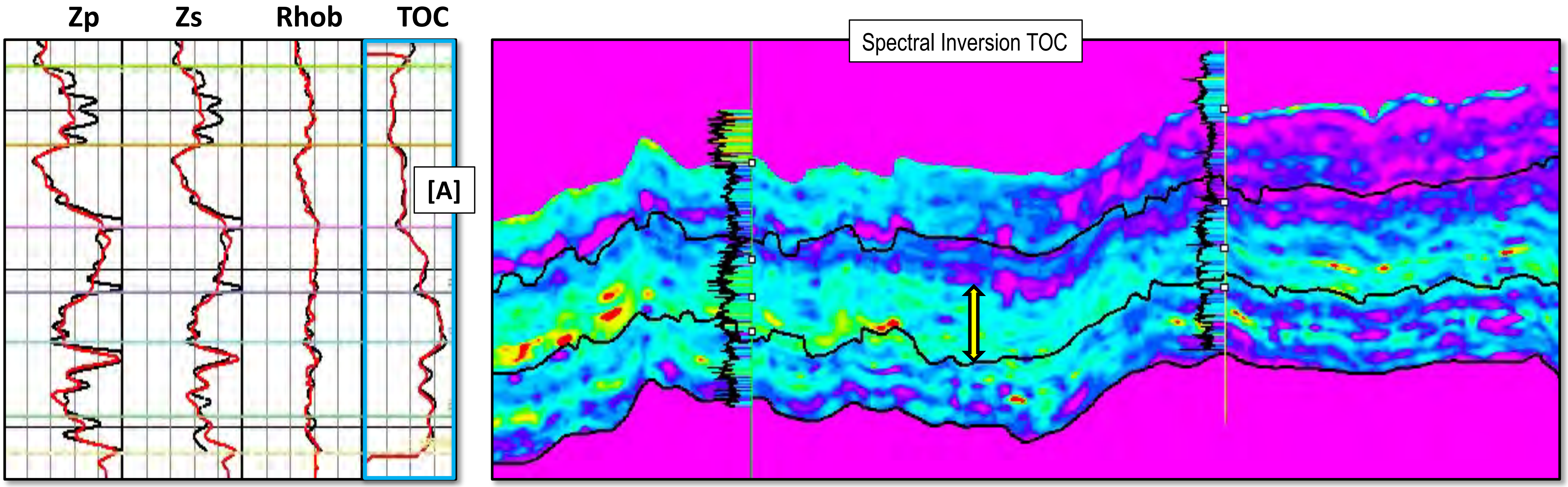
Simultaneous Inversion Zp
Spectral Inversión Zp

UNCONVENTIONAL: SGD SPECTRAL INVERSION FOR TOC



SGD Spectral Inversion is used to produce a series of elastic volumes Zp, Zs and Rhob (red lines in tracks), later a **Total Organic Carbon** pseudo volume (vertical section on the Right) is generated by using a Deep Learning algorithm, in which all the elastic volumes (+ LambdaRho, MuRho, Poisson and Poisson Impedance) are both, integrated and supervised by a filter version of the TOC log. As can be observed in track [A] ,a high correlation match is finally obtained with respect to the TOC input log (black).

GLOBAL EXPERIENCE

Where SGD has been applied

Carbonates, Unconventional, Clastics

MEXICO
Ayatsil, Xikin, Complejo Bermudez, Sen
Tsimin-Xux, Pit, Baksha, Sihil, Tsimin, Xanab,
May, Tekel, Ayin, Caan, Ixtal, Onel, Kuil, Samaria
Terciario, Tizón
VENEZUELA
Perla Field, Horcon, Barua Motatan, Carabobo
RUSSIA
YK, SK, SN, Avustovkoye, NO, Karabashky
ARGENTINA
Austral Basin, Neuquén Basin
PERU
Bretaña Field, block 95

NORTH SEA
Piper Alfa, Claymore, Tartan, Scapa, kildrummy
Monarb, Rowallan, Yeoman, Beatrice, Petronella
KURDISTAN
Topkhana, Kurdamir
COLOMBIA
Chipiron, Capachos
ALGERIA
South East Illizi, Reganne
COLUMBUS BASIN, TRINIDAD AND TOBAGO
Teak, Samaan, Poui
VIETNAM
HSD

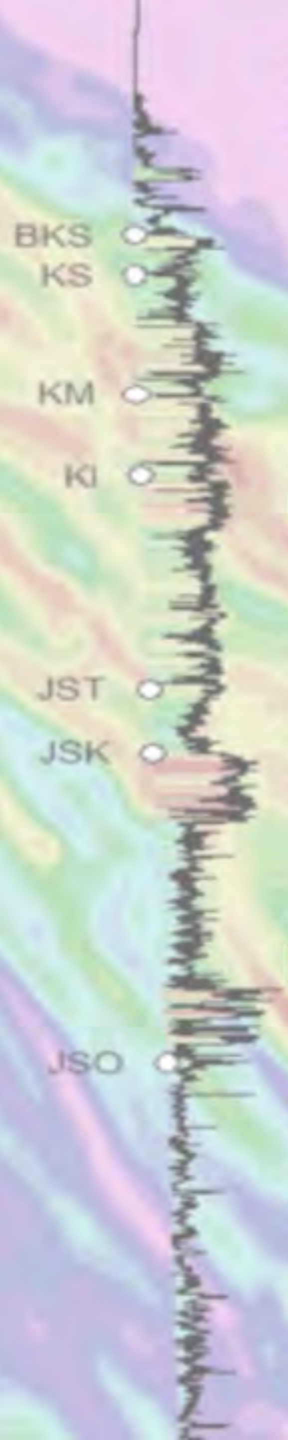
LYBIA
K-N186, B-N186, J-N186
CANADA
Banff
GUYANA
Jaguar
MEDITERRANEAN SEA
Lubina & Montanazzo
BRAZIL
Carioca, Lapa
USA
Lasalle Field, Eagle Ford.
Barnett Shale
NORWAY
Yme Field

Geology & Geophysics

- Sequence Stratigraphy Analysis & Seismic Stratigraphy
- Sedimentology and Depositional environment interpretation for clastics and carbonates reservoirs
- Detailed Core Analysis & Description
- Bioestratigraphic and Petrographic Analysis
- Structural Evaluation & Modeling
- Facies modeling and stochastic rock properties distribution
- 3D Geological Modeling
- Basin Modeling
- Seismic Geometric Decomposition
- Advanced Seismic Interpretation
- Seismic Attribute generation & Interpretation
- Velocity Modeling & Depth Conversion
- Coloured, EEI, Simultaneous and Stochastic Seismic Inversion
- Full AVO modeling, Spectral Decomposition, QI
- Seismic Attributes & Petrophysics Data Integration

Petrophysics

- Advanced petrophysical Characterization in conventional and unconventional reservoirs (complex mineralogy, fractured Carbonates, tight reservoirs, shale gas, shale oil, CBM, etc.)
- Resource and reserve estimation
- Rock typing, petrofacies and lithotypes classification. Flow units definition
- Permeability and Porosity architecture characterization
- Saturation Height Modeling
- Rock physics characterization
- Advanced core data analysis and integration
- Formation water characterization
- Seismic rock properties



Field Development Planning, Economic & Risk Analysis

- Lifecycle financial assessments for multiple field development scenarios
- Project Risk Analysis
- Front-End-Loading (FEL) Projects
- Field Development Planning
- Concept Design and Project Feasibility

Facility and Process Engineering

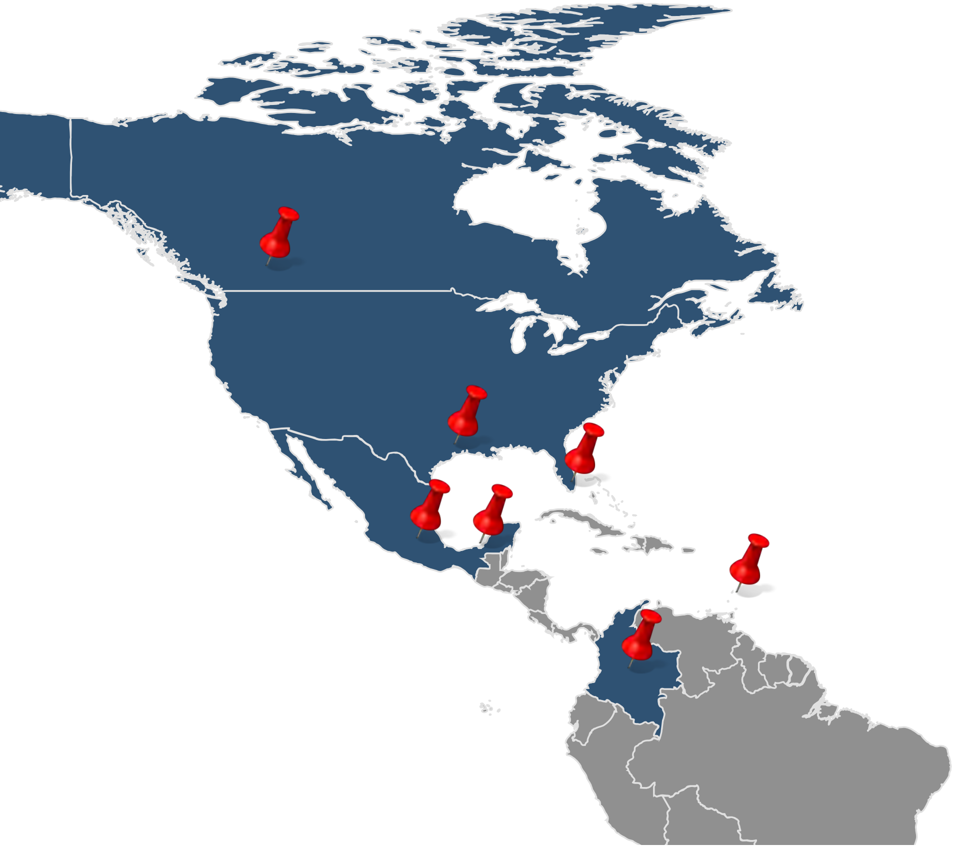
- Process design, evaluation and optimization (Energy and Material balance)
- Process simulation and flow assurance
- Steady-state multiphase flow modeling in oil and gas networks and pipeline systems
- Pipe line network analysis
- Conceptual Facility Design
- Process Equipment analysis (separation, compression, etc.)
- Hydrocarbon mix characterization

Reservoir and Production Engineering

- Numerical Reservoir simulation
- Reservoir Surveillance (advanced PTA - RTA)
- Enhanced Productivity Projects
- Production Log analysis
- Advanced Reservoir Engineering
- Design & analysis of Hydraulic Fracturing results
- Production & Artificial Lift Optimization
- Material Balance Analysis
- Well test Analysis
- Enhanced Oil Recovery -EOR studies

CAYROS

Contact Us



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