PS Multi-Attribute Seismic Wheeler Volume Workflows, Illuminating Stratigraphy, Geomorphology, and Prospectivity within a Mezardere Slope Fan Exploration Model, Thrace Basin, Turkey*

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Abstract

Evolving seismic interpretation technology has eased the ability of interpreters to quickly transform seismic time volumes into seismic wheeler or geologic time volumes. Integrating seismic attribute wheeler volumes early and iteratively into the interpretation workflow can aid in illuminating significant stratigraphic/geomorphologic features and accelerate understanding of depositional patterns and structural histories. This study utilizes recent 3D datasets located in the Thrace Basin of Turkey, with the zone of interest comprising prograding delta front to prodelta deposits of the Oligocene Mezardere formation. The workflows discussed here address the challenge of extracting seismic stratigraphic details from this particular geological setting, where events are faulted, structurally deformed, steeply dipping, and diverging and converging laterally within individual lobe shaped deposits. Dip volume data is utilized to accelerate horizon picking by steering the gridding of difficult to pick stratigraphic boundary horizons and then to generate dense sets of intervening systems tract horizons that closely follow seismic events. Desired seismic attributes, such as similarity and energy are extracted along the generated horizons, which are then essentially flattened, transforming data into a wheeler volumes. Animation of these volumes can quickly reveal important stratigraphic patterns and features. Key horizons can be extracted and used for the next stage of interpretation, including the application of more complex seismic attributes such as spectral decomposition. Rigorous testing and implementation of optimal parameters for horizon generation and attribute extraction/visualization is essential to achieving optimal images. By integrating this work with core, outcrop, and well log data, a slope fan model has been developed to describe the productive and prospective reservoir and source rock horizons of the Mezardere formation. Distinct clinoform packages and their geometries have been mapped, and numerous slope channel systems of varying sinuosity have been identified and tied to producing wells. Slope channel mapping has also aided structural interpretation and fault seal estimation by allowing the measurement of transverse fault movements. Stratigraphically trapped prospects have been successfully drilled and this mapping has led to further prospects that are currently being pursued by Valeura Energy.

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AAPG 2016, Calgary , Alberta

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Introduction

This study outlines the use of multi-attribute seismic wheeler volume workflows as applied to the prograding delta front / prodelta deposits of the Oligocene Mezardere formation in the Thrace Basin of Turkey.

Traditional seismic interpretation methods focus on structure and amplitude mapping. More detailed seismic attribute analysis is often done afterwards to highlight stratigraphic details and patterns along key extracted time horizons or within narrow zones of interest. Visualizing seismic attributes across horizon surfaces can be very effective at identifying recognizable geological / geomorphological patterns.

If seismic events are relatively flat, animating/slicing seismic volumes up and down in time is very effective at revealing geomorphological patterns. ***But, how do you harness the power of animation in time when chronostratigraphic seismic events are not flat?***

This work addresses this question in a setting where the seismic events are:

- Steeply dipping, faulted, and structurally deformed.
- Diverging and converging laterally within lobe shaped deposits.
- Potentially down-lapping, on-lapping and/or non-continuous/truncated.

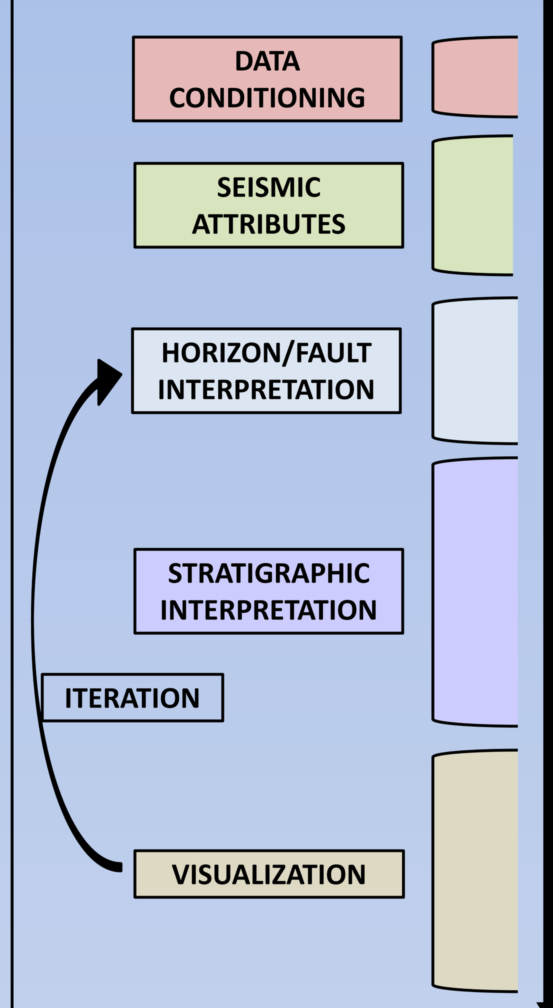
As part of an ongoing exploration effort in the Thrace basin, detailed seismic stratigraphic interpretation work that aimed to overcome these challenges was initiated in early 2014.

Original Project Objectives:

1. Interpret and map individual clinoform deposits of the Mezardere formation.
2. Extract detailed seismic attribute data along regional chronostratigraphic horizon slices.
3. Evaluate individual clinoform deposits for hydrocarbon prospectivity.
4. Inform the development of a slope fan exploration model for the Mezardere formation.

The workflow that was developed to overcome these interpretation challenges and achieve the objectives of the project can be used as a model for how to integrate detailed seismic stratigraphic interpretation early and iteratively within the exploration process.

Model Workflow



Starting with (pre-stack) migrated volume and initial horizon interpretation.

Test and Run Dip Steering Data Volumes
Includes detailed and smoothed dip data volumes.

Test Selected Seismic Attributes and Parameters

Generate Key Seismic Attribute Volumes
Utilize dip data as necessary.

Guide Horizon & Fault Interpretation
Interpret or refine key seismic stratigraphic boundary/guide horizons and fault planes, utilizing key attribute volumes and dip field data if useful.

Generate Horizon Sets
Test and generate continuous chronostratigraphic horizon sets between key guide horizons.

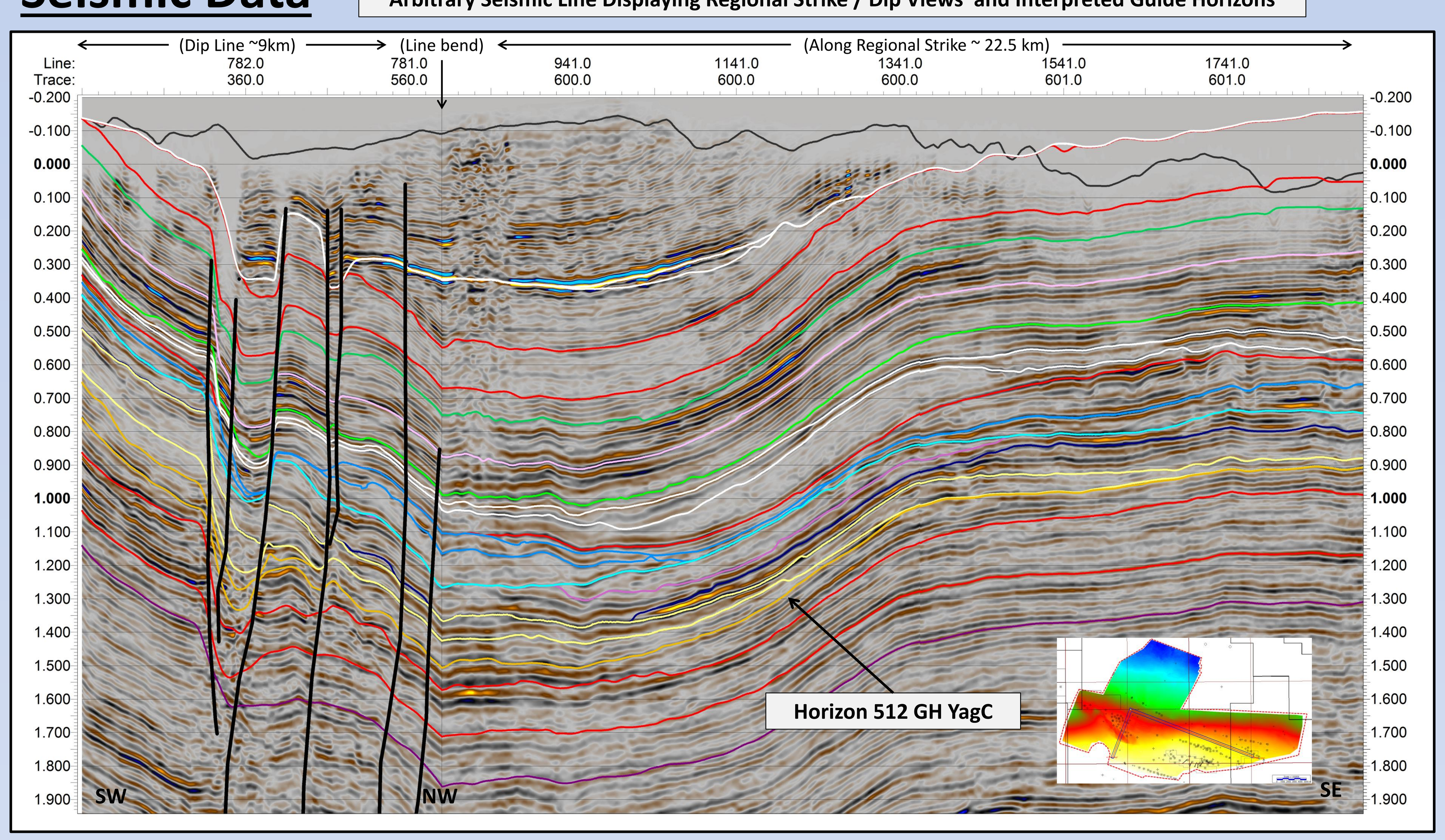
Generate Wheeler Volumes
Essentially flatten the key seismic and attribute data volumes along the chronostratigraphic horizon sets to create geologic time volumes.

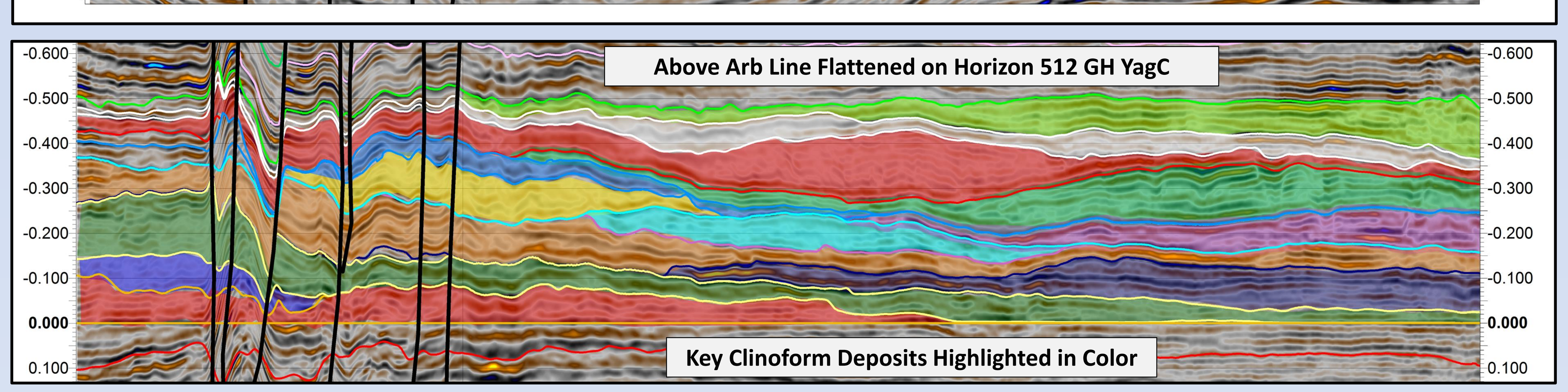
Visualize Wheeler Data
Animate key wheeler attribute volumes to identify significant stratigraphic features and key horizons.

Visualize Extracted Horizons
Extract key horizons and visualize significant features in multi-attribute displays.

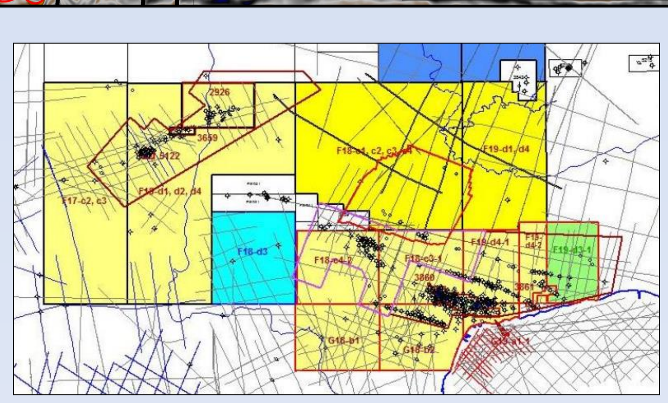
Seismic Data

Arbitrary Seismic Line Displaying Regional Strike / Dip Views and Interpreted Guide Horizons





Seismic data utilized in this project included primarily ~800 km^2 of 3D seismic acquired in 4 separate programs from 2011-2015. Secondarily, over 4000km of legacy 2D seismic data were also utilized as needed. Overlapping 3Ds were ultimately merged.

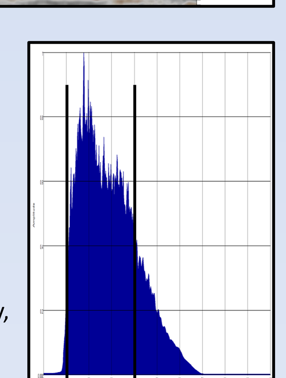


Base map showing 3D and 2D datasets

Average 3D seismic parameters:

- Source: Vibroseis, 6-98 Hz, 16 sec sweep
- Bin Size: 20m x 20m

In general, recovered frequencies on the final stacked (PSTM) data were relatively low with dominant frequencies between 15-40Hz. Also, variable near surface geology, and surface infrastructure led to degraded data quality in some areas.



Typical 3D Amplitude Spectrum

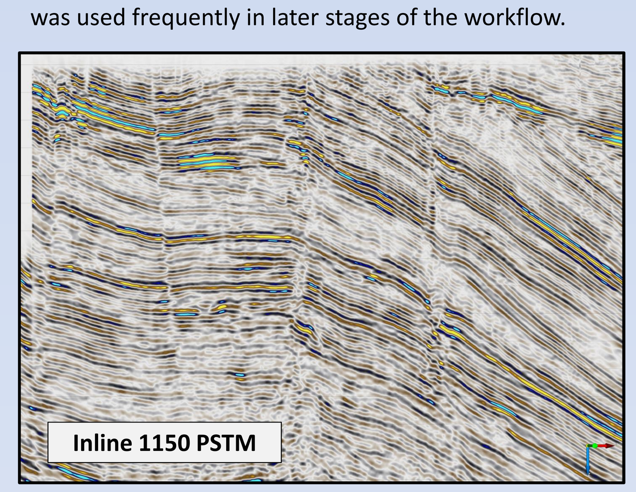
Dip Steering / Data Conditioning

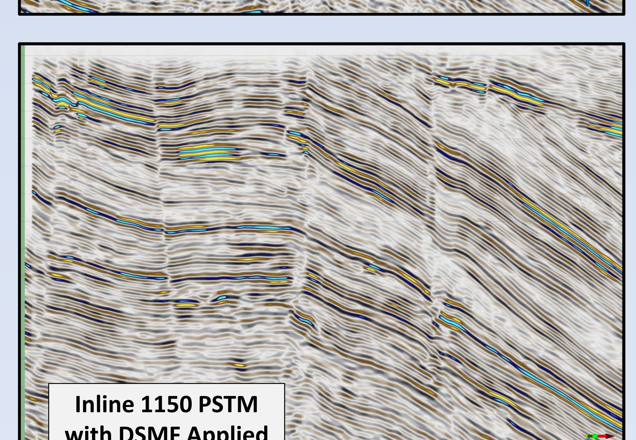
In order to run advanced seismic attributes and take advantage of dip steered horizon tracking, it was necessary to first run dip steered data volumes on the fully processed pre-stack migrated datasets.

Testing of dip steering parameters was undertaken on selected 2D profiles and evaluated by how well dip steered horizon tracking methods matched actual seismic events.

Once final parameters were selected, detailed and smoothed dip volumes were generated across the complete datasets.

By utilizing the calculated dip data to create a dip smoothed median filter it was possible to create a filtered version of the data that reduced random noise, and enhanced laterally continuous events, while preserving structural edges and faults. One drawback is that lateral amplitude variations were not as well preserved. This cleaner (DSMF) volume was used frequently in later stages of the workflow.



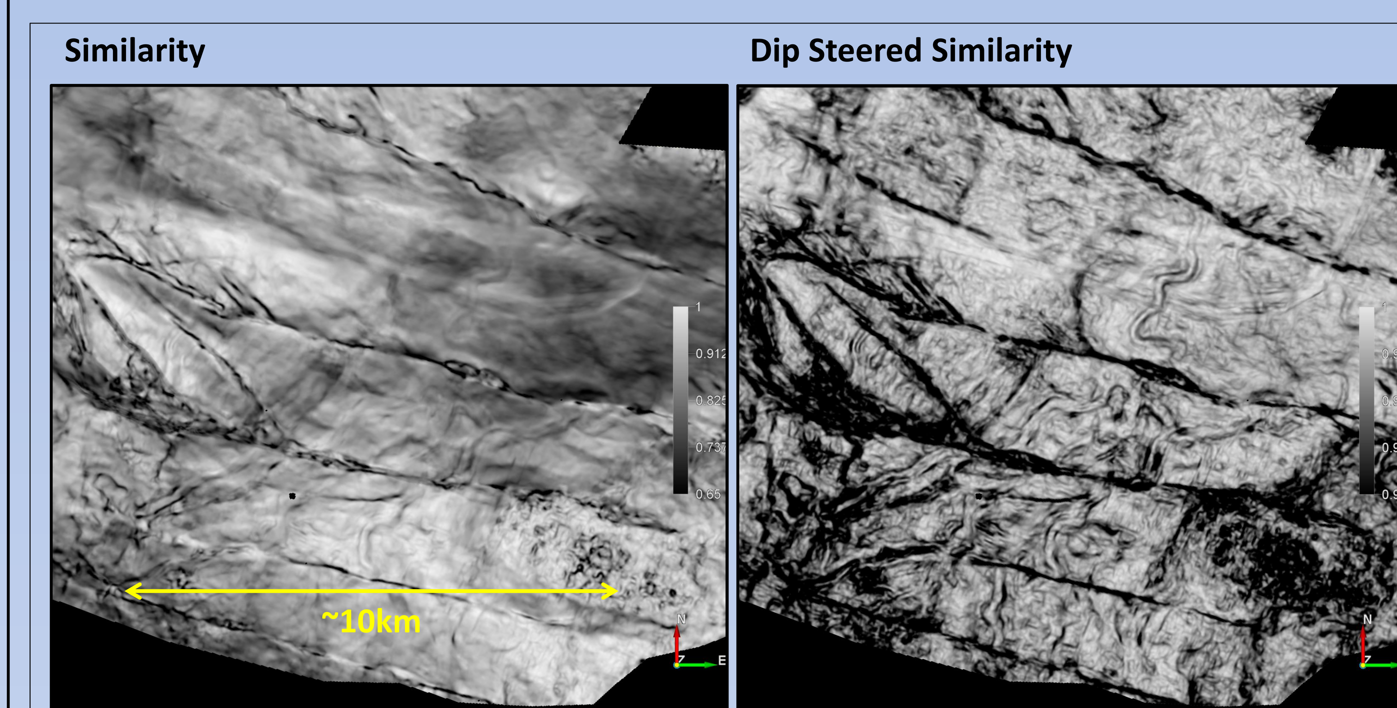


Key Seismic Attributes

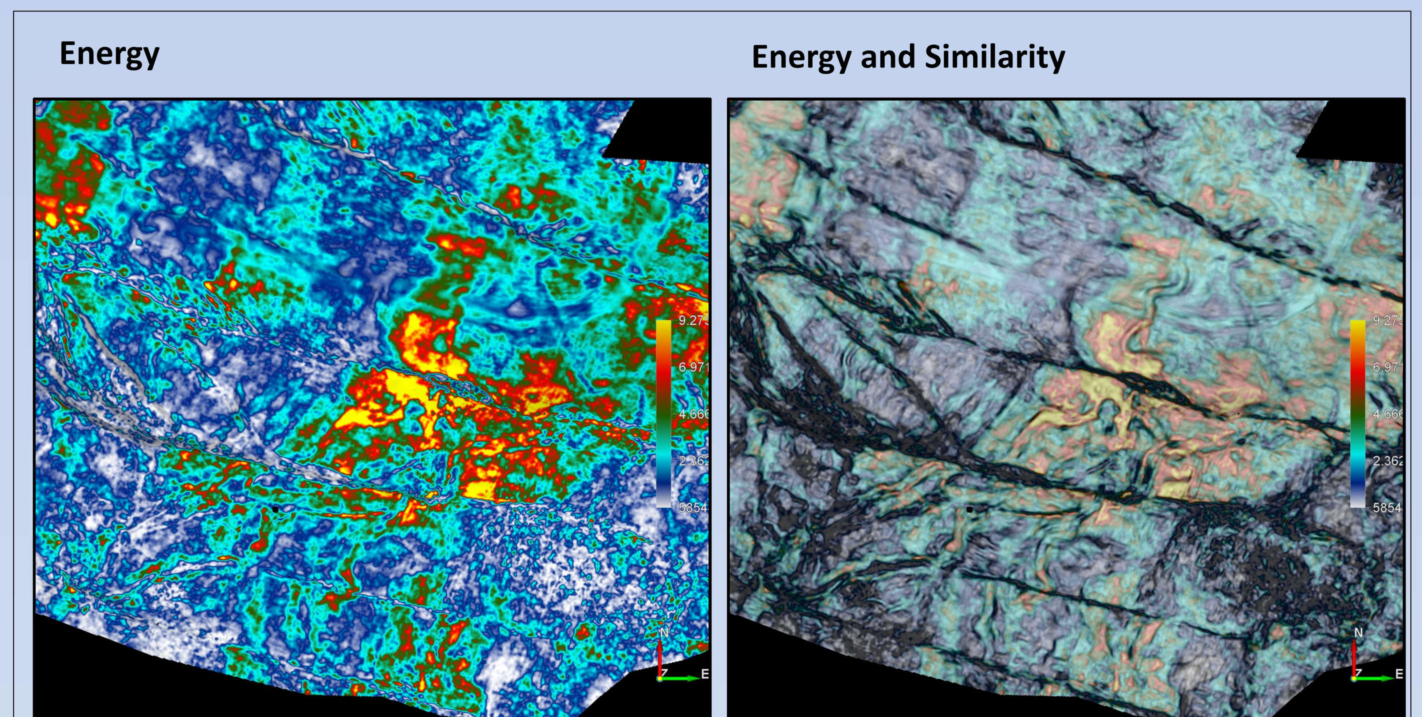
Extensive testing of a wide variety of seismic attributes was undertaken at various stages and iterations of the workflow. These included but were not limited to, Similarity, Curvature, Spectral Decomposition, Energy, and Instantaneous Phase/Amplitude/Frequency.

Rigorous testing of attribute parameters on smaller subsets of the data was the most time consuming and important aspect of this process. Parameter optimization is like focussing a lens on the part of the image you want to capture in most detail. Once parameters were optimized attributes were generated across the entire 3D volume.

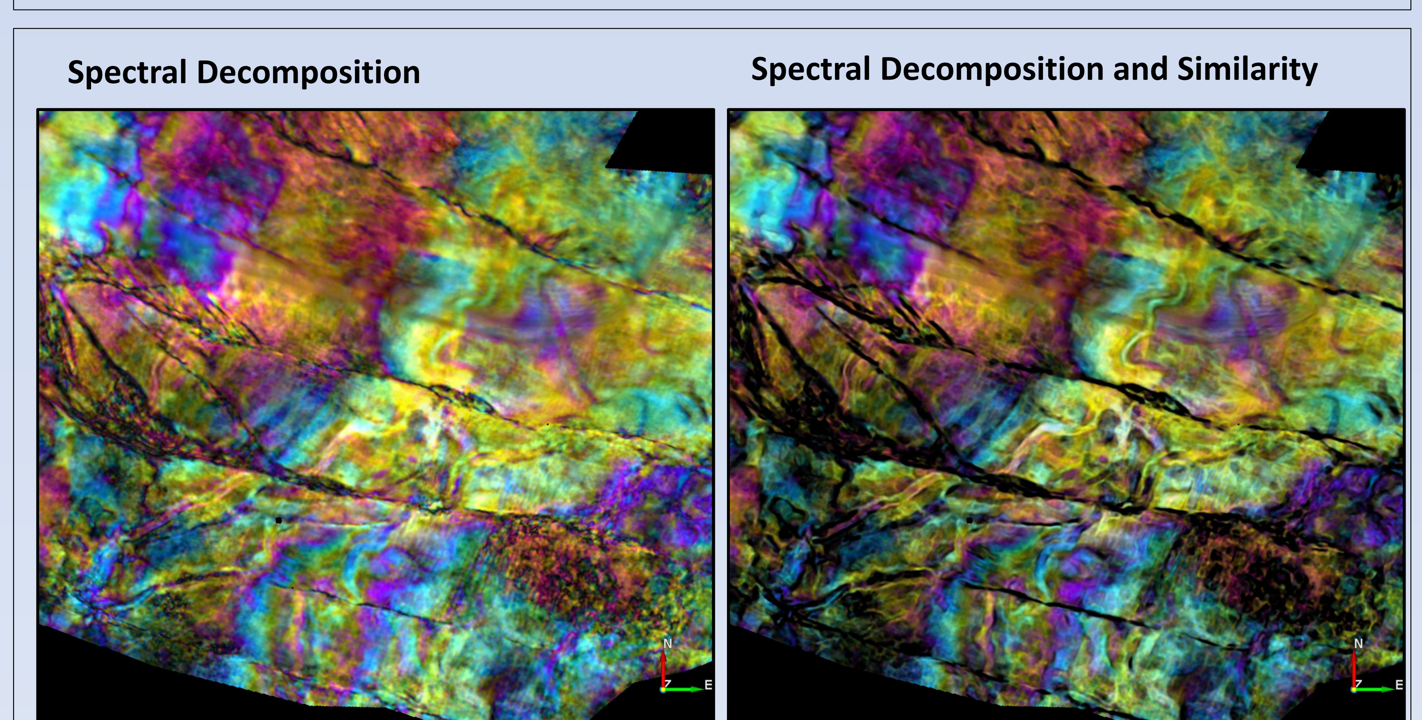
In light of the project objectives to extract regional level detail along chronostratigraphic horizon surfaces, 3 key attributes were selected for visualization purposes: **Similarity, Energy, and Spectral Decomposition**. The images below show variations of each of these attributes over the same selected area of horizon 450 TekD4.



Utilizing dip volume data to generate the similarity (coherence) attribute resulted in significantly greater stratigraphic detail as shown in the images above. (Horizon 450 TekD4)



The Energy attribute was generated over a 30ms time window and provided a measure of absolute amplitudes. Co-rendering it with Similarity, helped to bring the Energy attribute into greater geological context. (Horizon 450 TekD4)



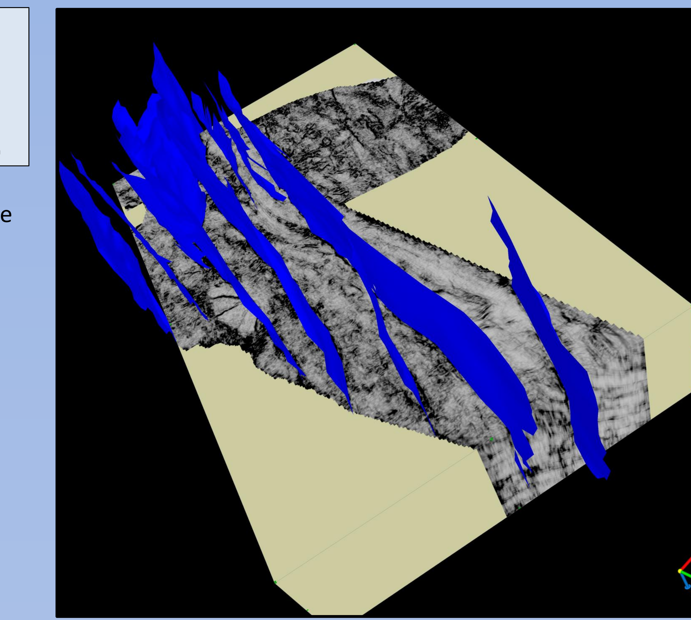
Using Spectral Decomposition to break down the seismic data into 15, 30, and 45Hz frequency bands and then displaying them on a color-blended horizon provided another level of detail / perspective of the geomorphological features. Co-blending with Similarity also helped to add more context. (Horizon 450 TekD4).

Fault Interpretation

Fault interpretation was an iterative process that was done by picking major fault systems on dip steered Similarity (coherence) volumes.

Initial picks were made on regular time slice intervals and then later refined as needed on vertical amplitude and similarity sections.

Image to right shows perspective view of dip steered similarity volume with key fault planes displayed.

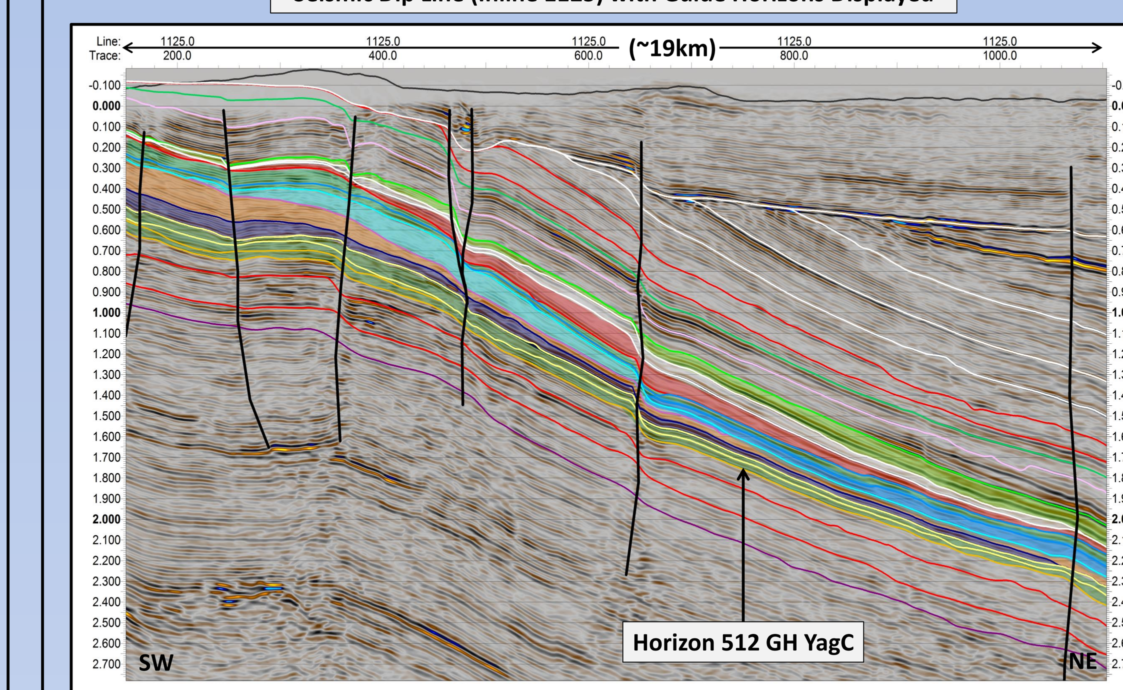


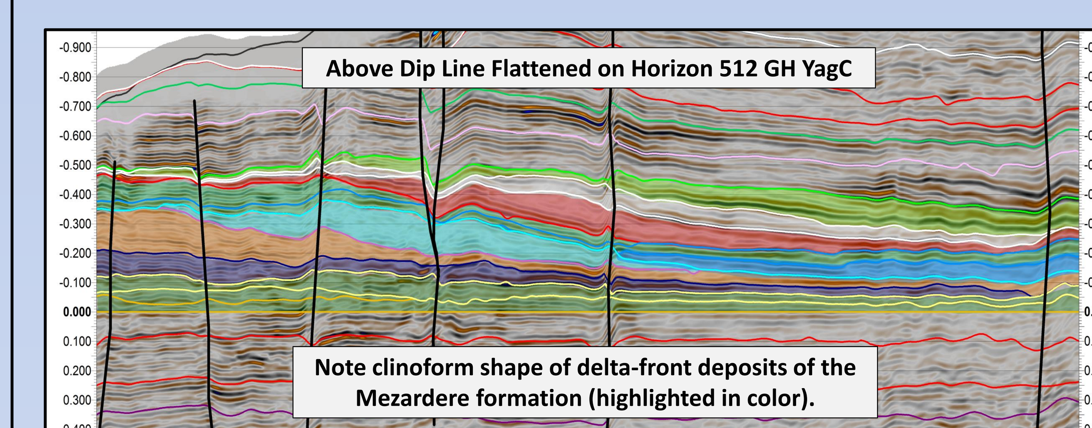
Horizon Interpretation

Horizon interpretation focussed on key seismically defined stratigraphic boundary events that separated prodelta slope fan deposits into distinct clinoform depositional lobes. These horizons are referred to as guide horizons.

Key challenges to horizon interpretation across the whole data volume included significant structure/faulting and strong events that eventually pinched out or merged laterally into other weaker events.

Seismic Dip Line (Inline 1125) with Guide Horizons Displayed



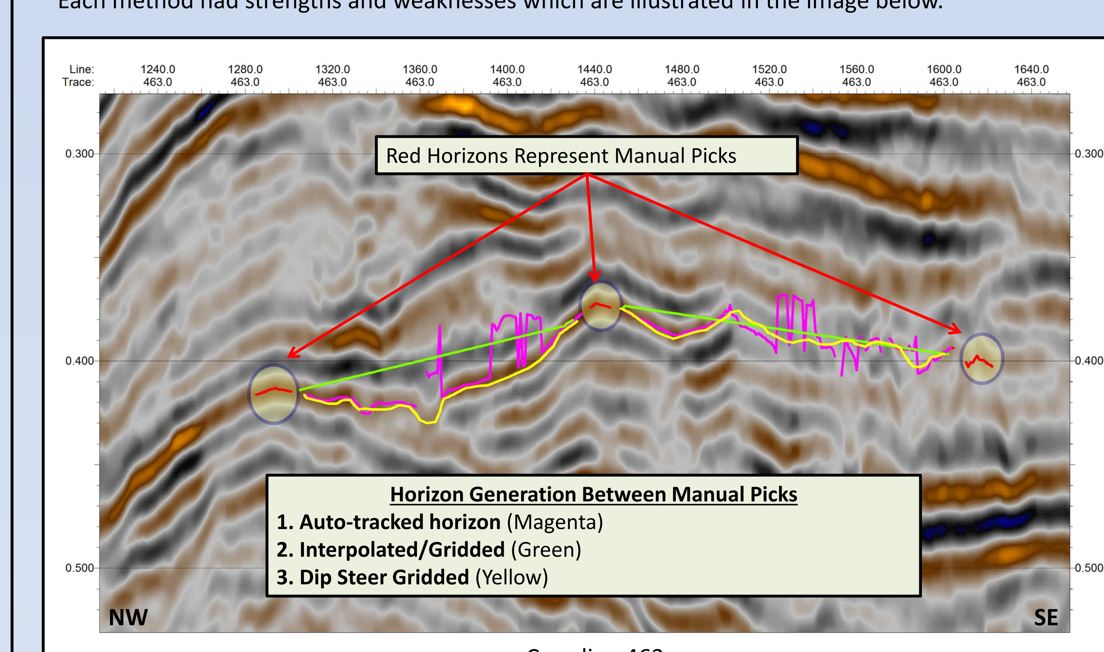


Manual interpretation of guide horizons were completed on a regular framework of approximately 40x40 to 20x20 inline/crossline spacing's.

Interpolation of horizons picks between manual picks were completed using a number of different processes.

1. 3D auto-tracking along selected peak/trough events.
2. Gridding/Interpolation between events, followed by smoothing.
3. Dip Steered gridding between events.

Each method had strengths and weaknesses which are illustrated in the image below.



Crossline 463

Auto-tracking honored events most accurately until events changed phase to doublets or pinched out causing the horizon to 'jump' events.
Gridding/Interpolation was effective for quickly filling in small gaps, but did not honor events well over larger areas.
Dip steered horizon gridding was most effective in that it tracked the overall dip of the seismic events between manual picks, but was not constrained to peak / trough parameter selection in the way that auto-tracking algorithms are.

Often all three horizon interpolation processes were implemented in an iterative fashion to achieve optimum results.

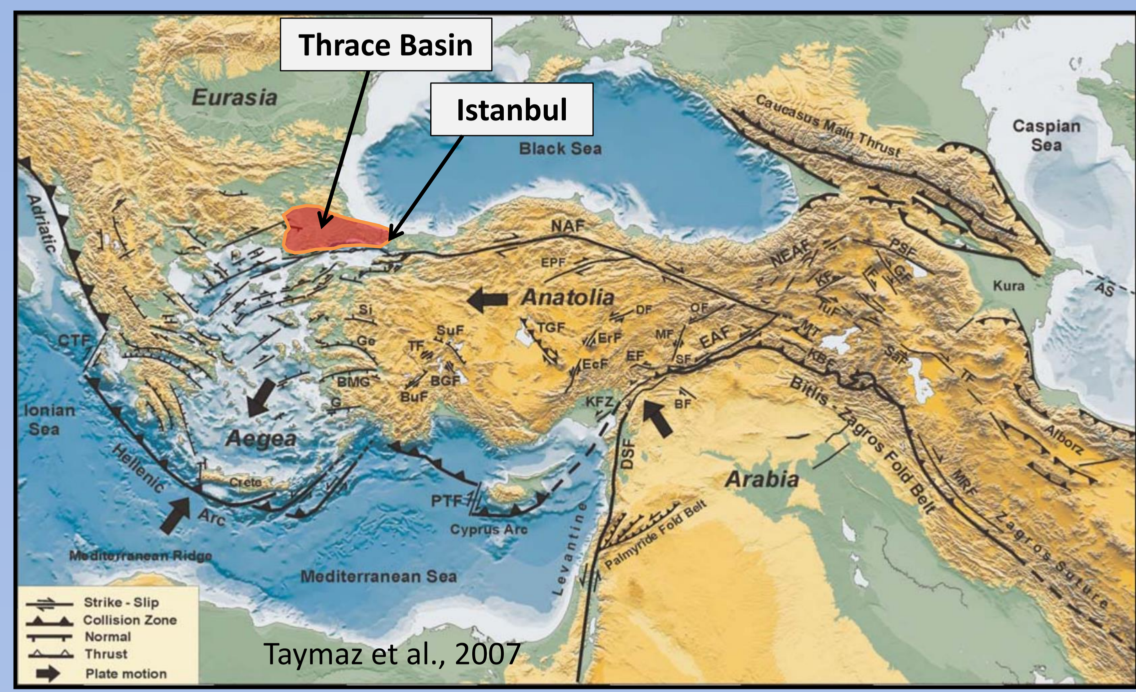
Geological Background and Project Area

Geological Setting

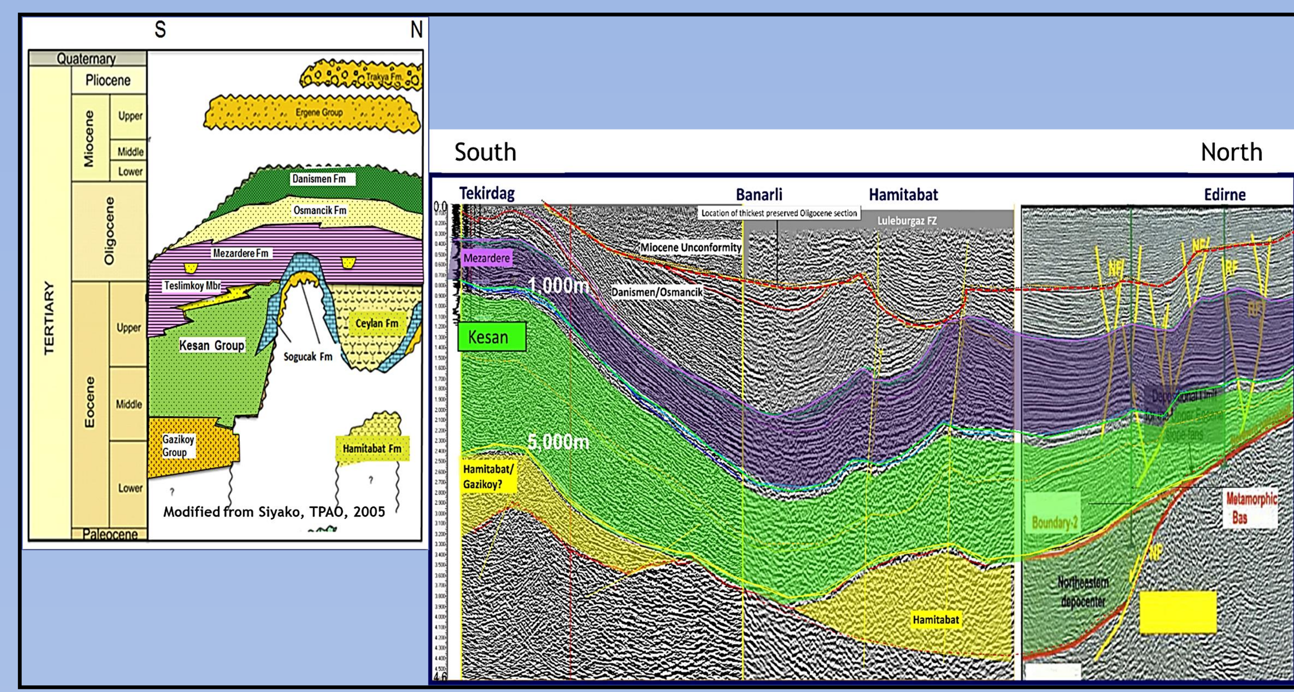
The Mezardere formation is located in the Thrace Basin of Turkey.

Mezardere deposits are Oligocene aged and interpreted as prograding delta front / pro delta deposits, that were deposited onto a submarine ramp within a wave dominated delta complex that pro-graded north into a sub basin of the Paratethys Sea.

A slope fan model has been adopted to describe the Mezardere formation depositional architecture.

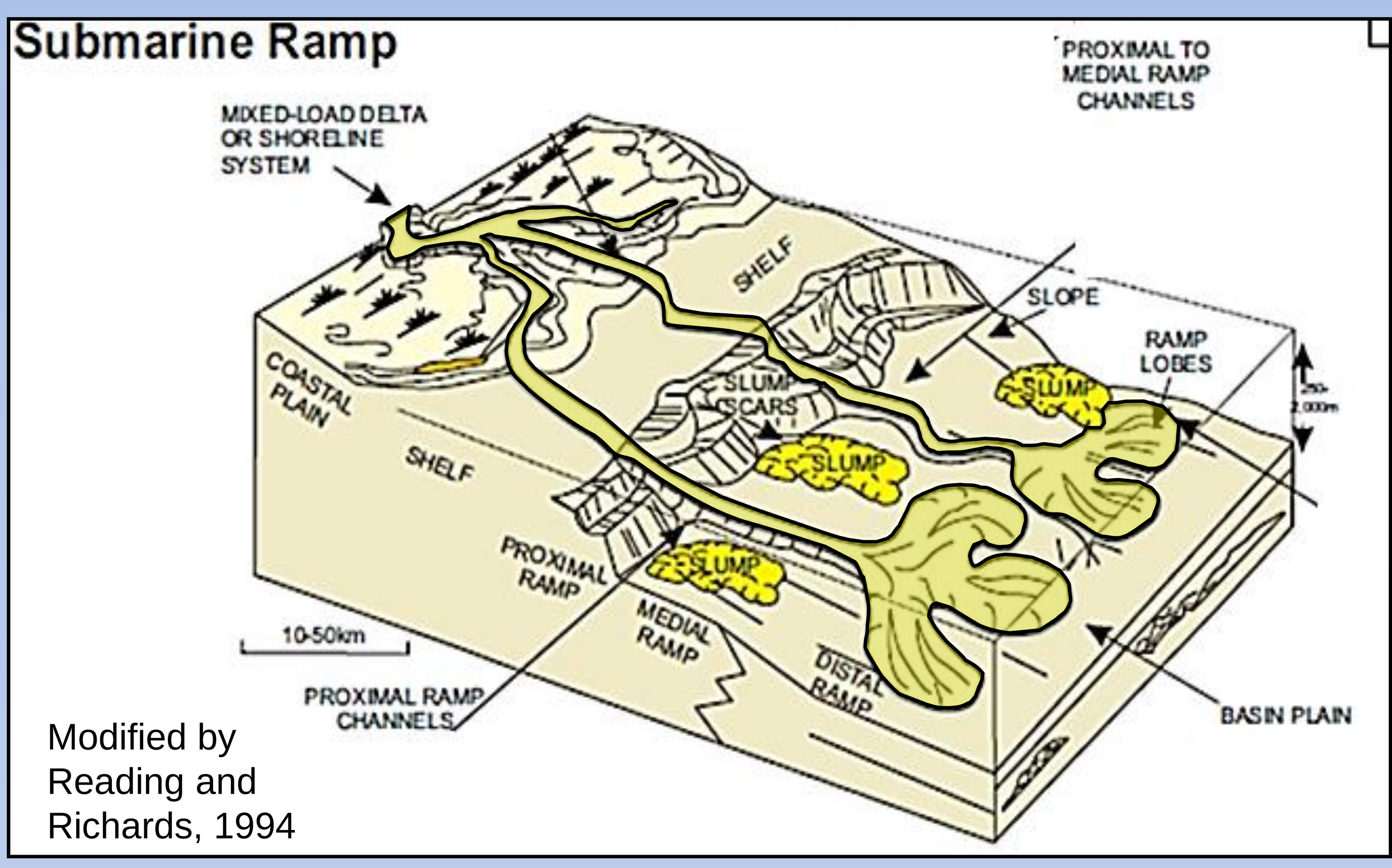


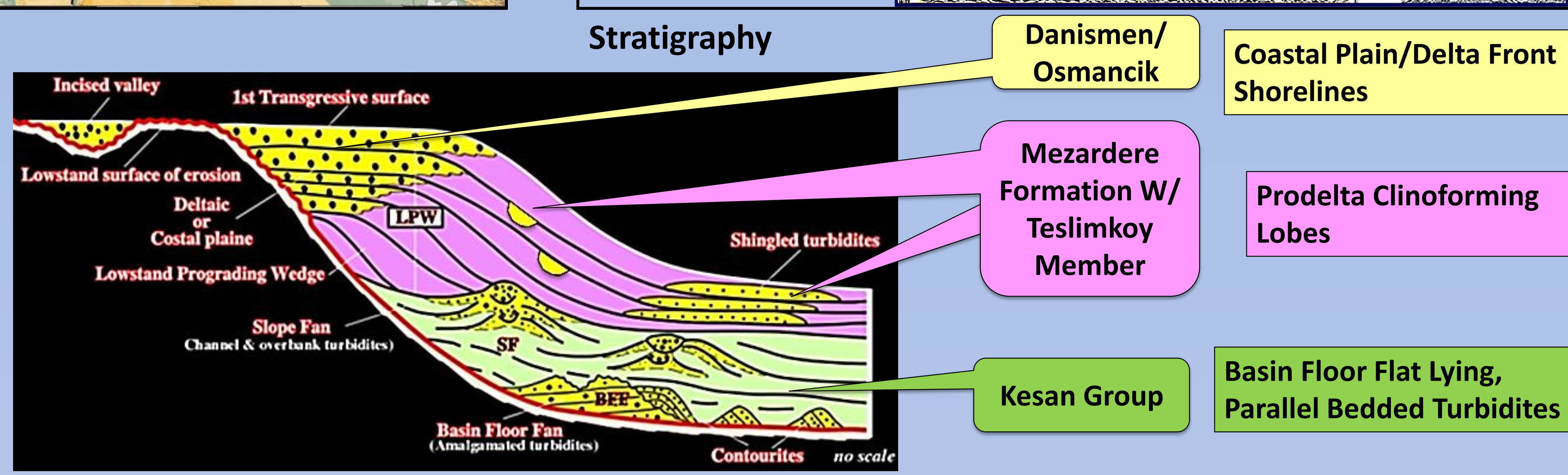
Tectonic Setting

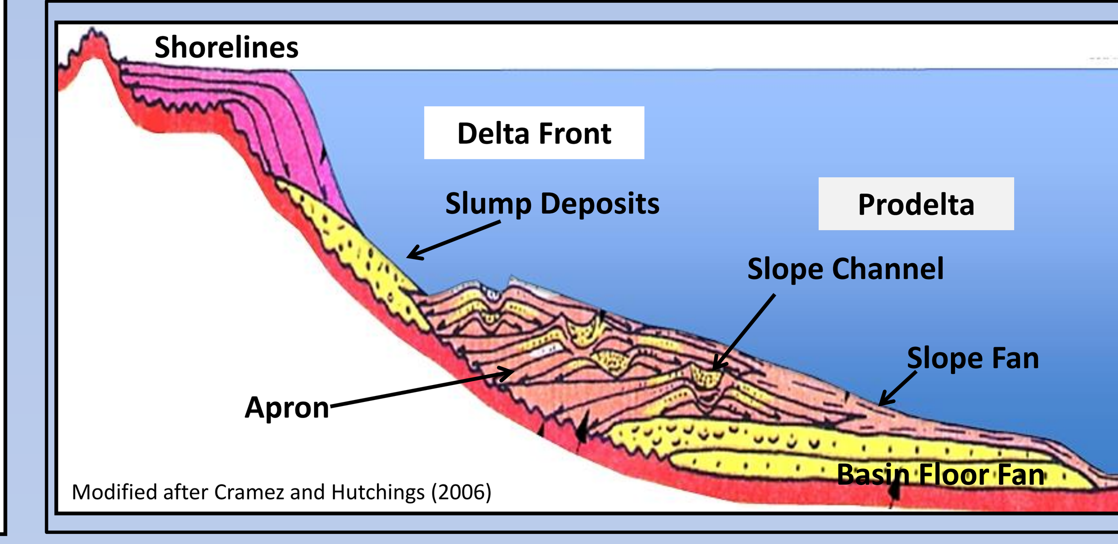


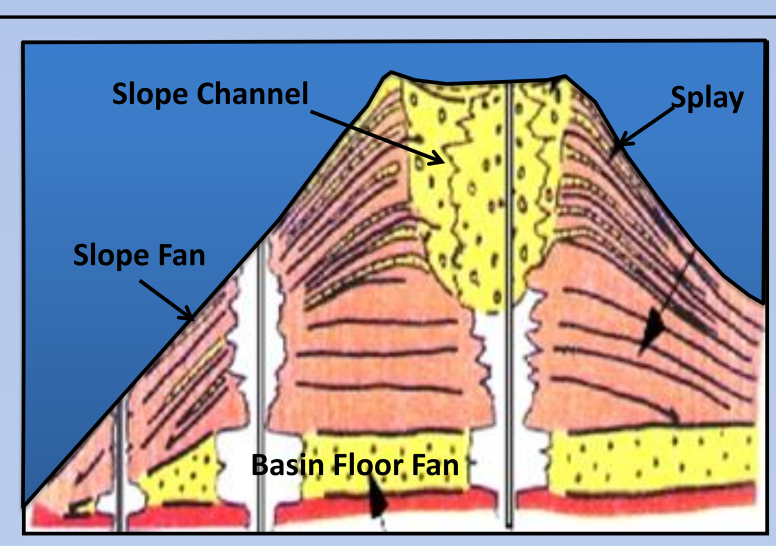
Stratigraphy

Mezardere Slope Fan Depositional Model





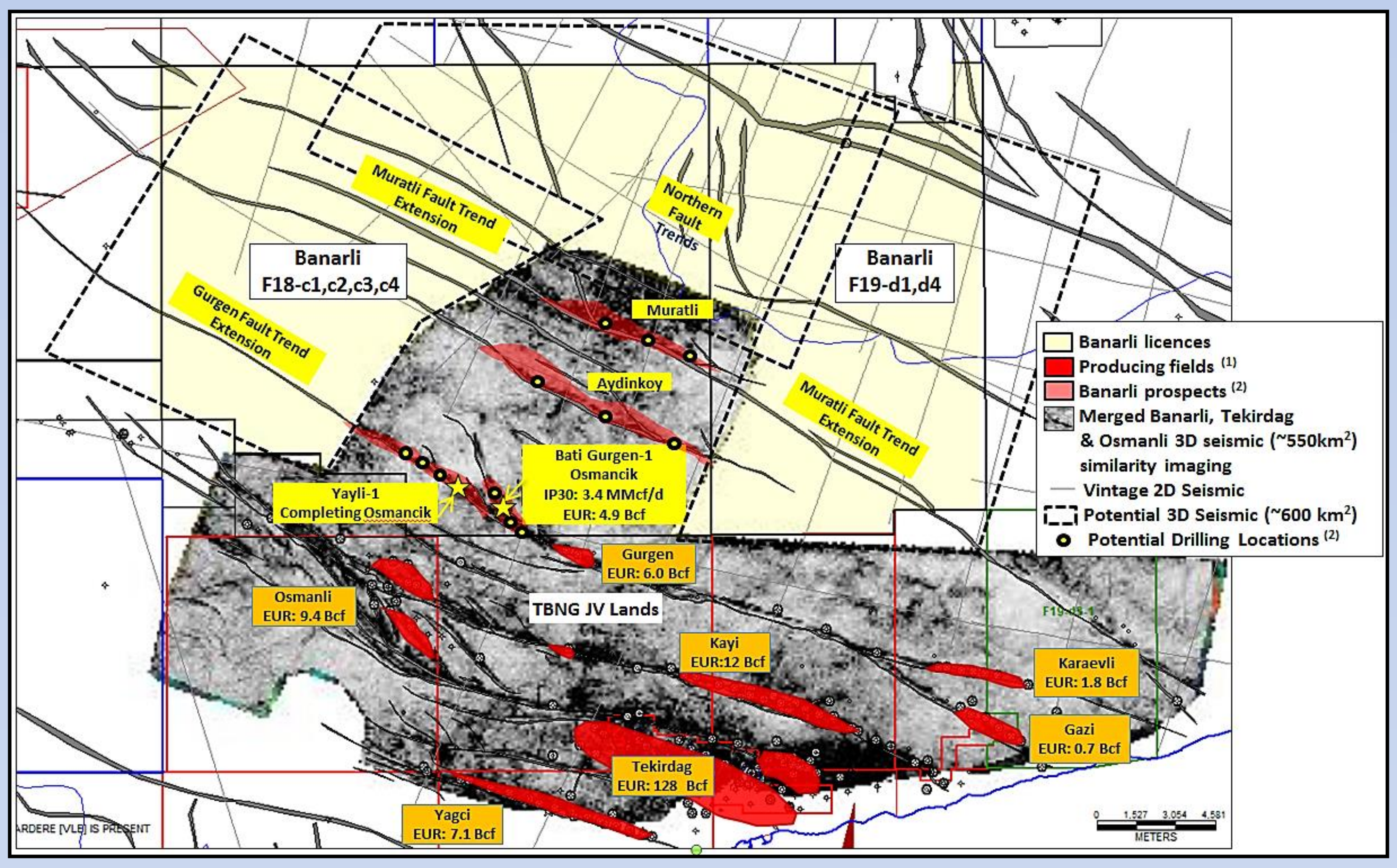




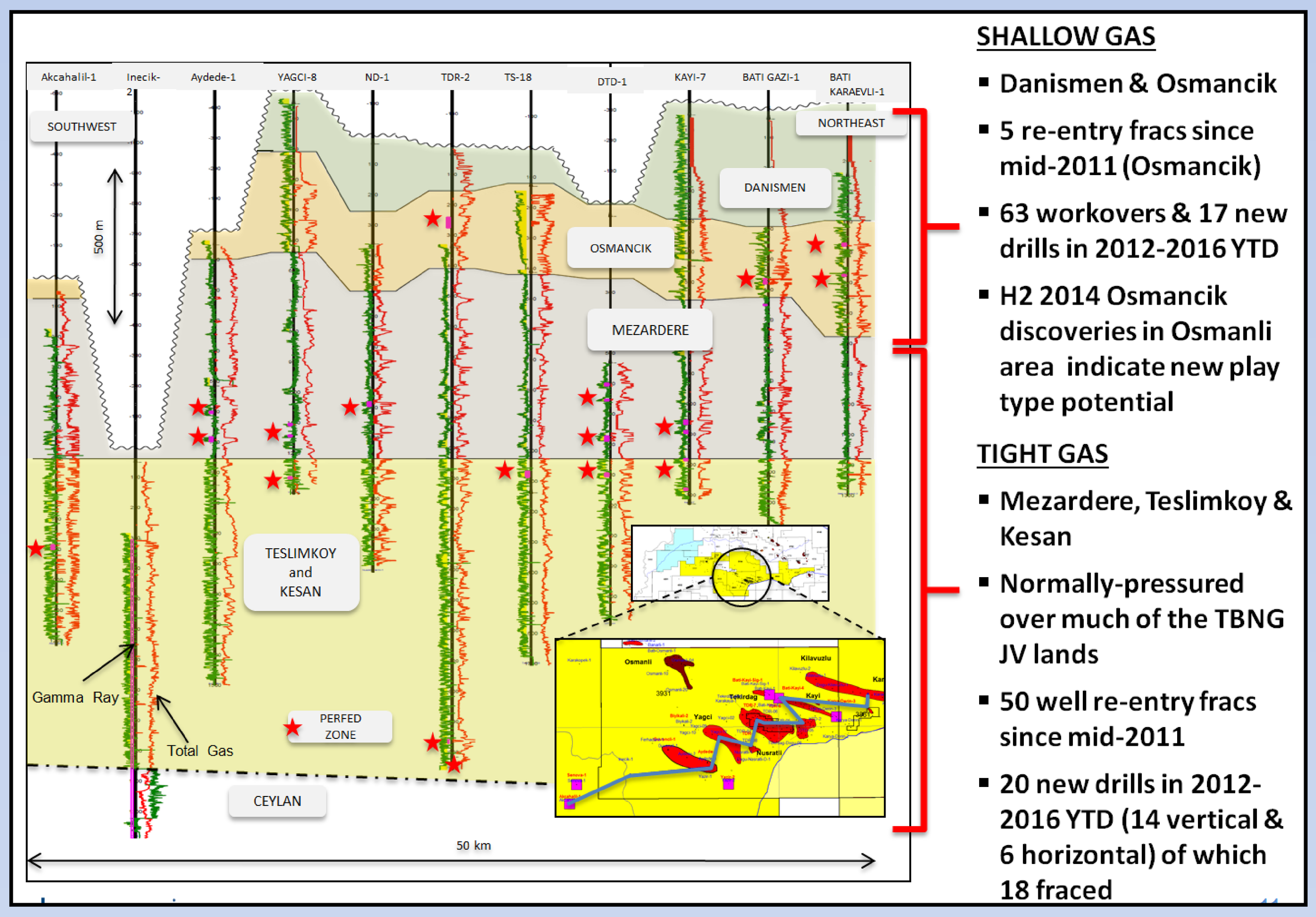
Exploration and Play Types

Valeura Energy has participated in numerous drilling programs throughout the Southern Thrace Basin over the last 5 years. Play types have ranged from conventional shallow gas exploration prospects in the overlying Danismen and Osmancik formations, to tighter gas prospects in the Mezardere and underlying Teslimkoy and Kesan formations.

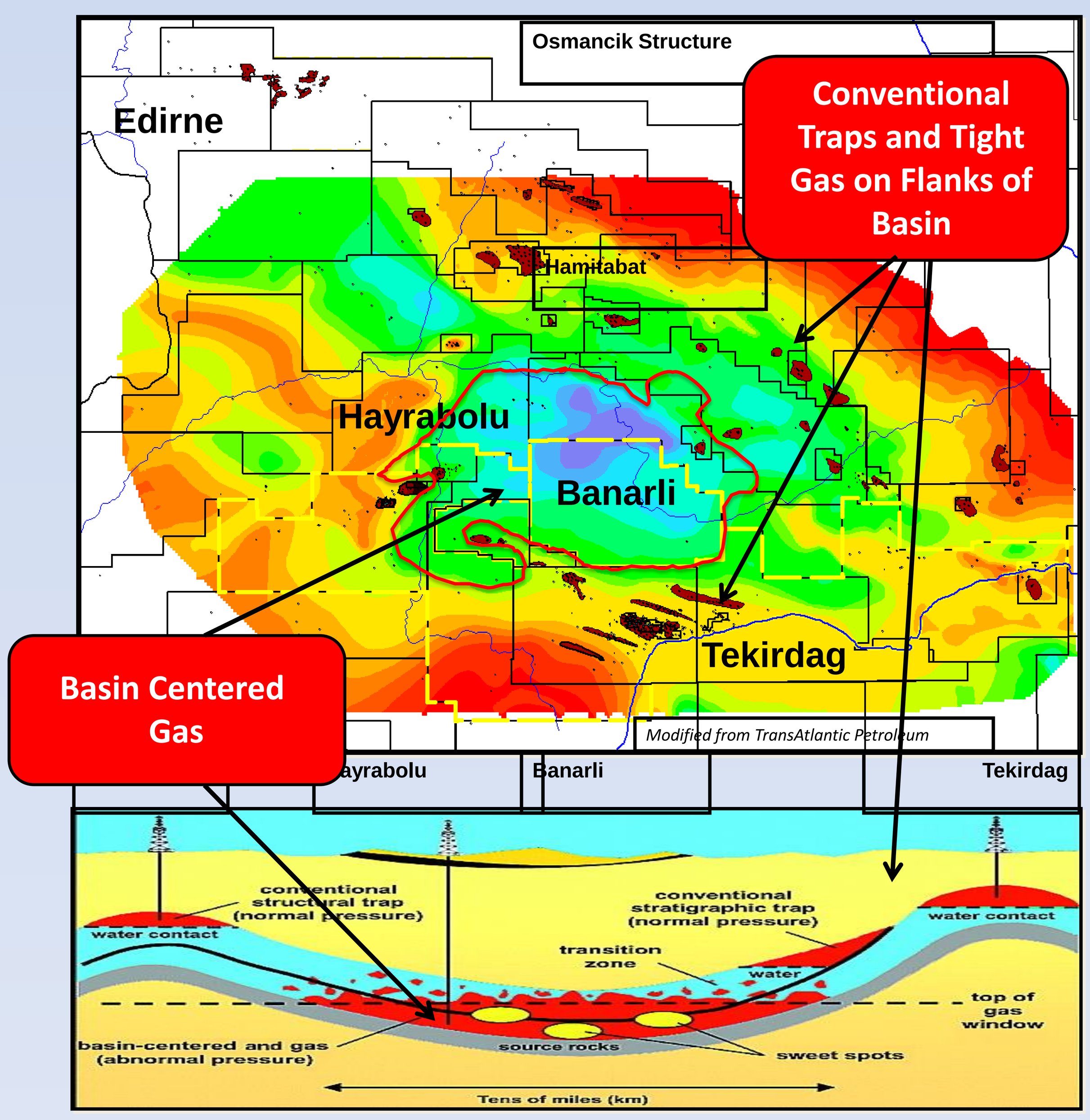
Shallow conventional gas production to date has been primarily sourced from up dip structural closures against faults. Tighter gas production in the Mezardere and off structure stratigraphic prospects have been successfully drilled and produced. A basin centered gas concept has been developed which holds the potential for pervasive over-pressured unconventional gas resources in the synclinal parts of the Thrace Basin.



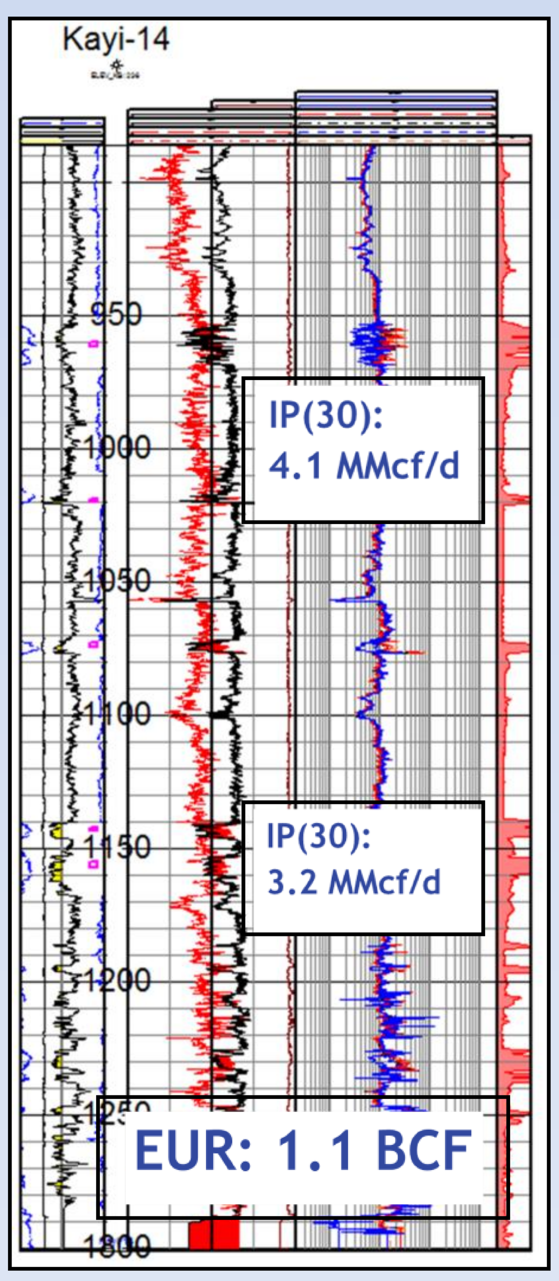
Producing Fields, Prospects and Recent Discoveries



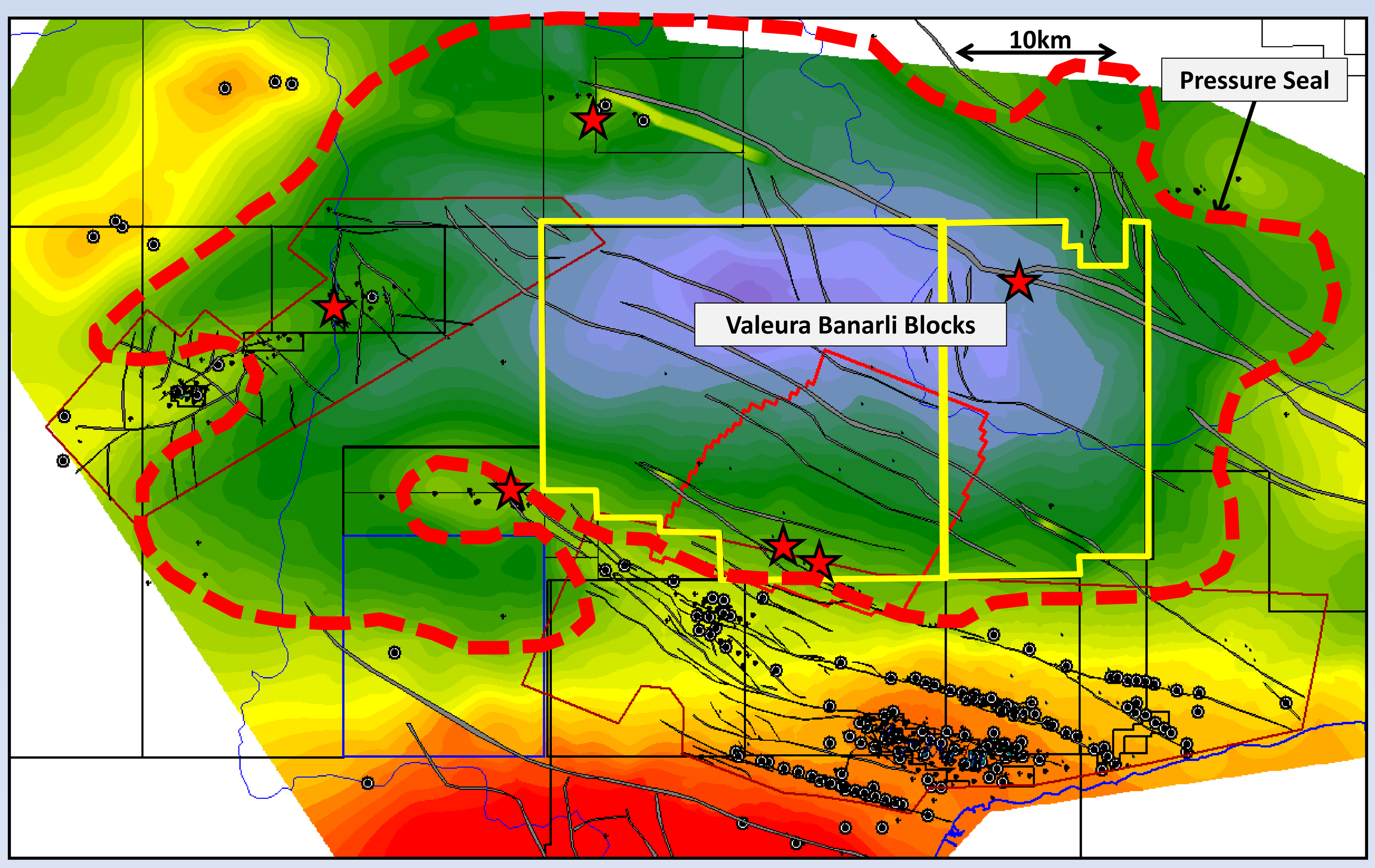
Drilling Activity on Joint Venture Lands



Play Types



Mezardere Type Well



Mezardere Depth Structure Map

Interpreted pressure seal outline shown by dashed red line.

Red stars show wells which indicate the presence of over-pressured zones.

Stratigraphic Interpretation

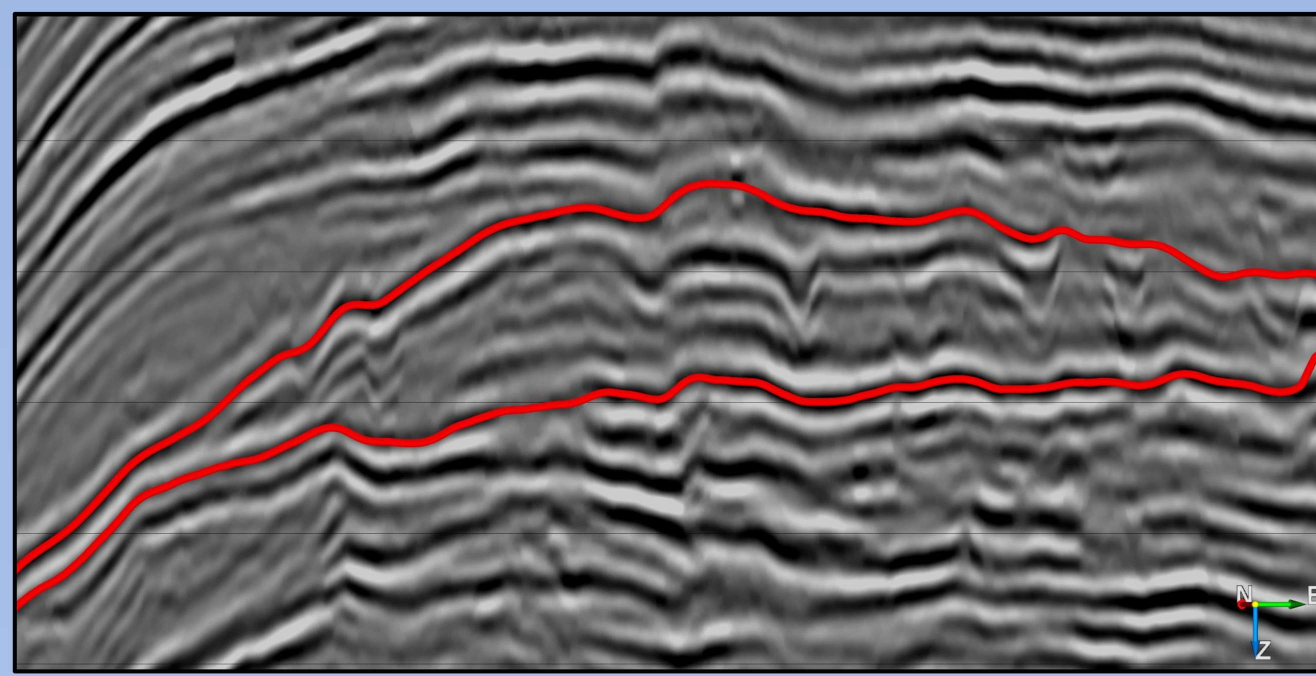
Generating Chronostratigraphic Horizon Sets

Once selected guide horizons and fault surfaces were interpreted, chronostratigraphic horizon sets were generated at specified intervals by using dip steering and/or proportional spacing between the guide horizons. Both methods had pros and cons. Dip steered horizon sets were more accurate in most cases but did not track well across faults. Parameter testing was required here, and both methods were employed.

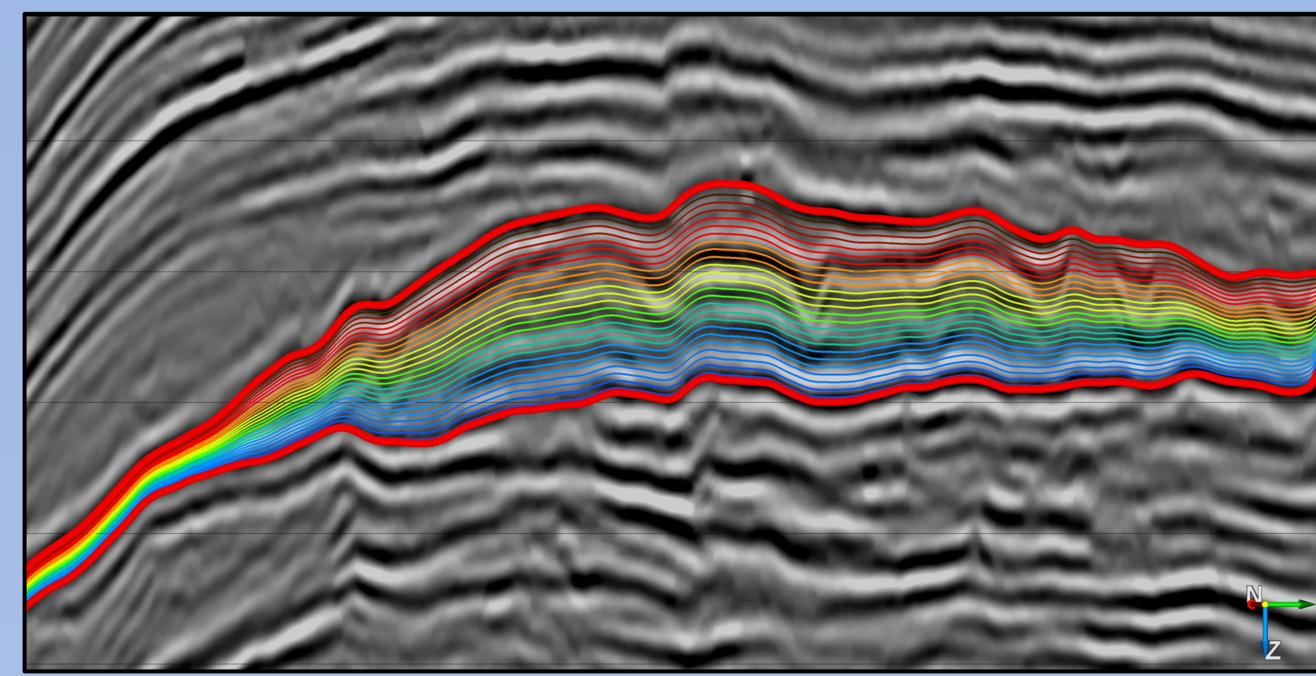
Wheeler Volumes

Horizon sets were then utilized to essentially flatten the key attribute volumes (dip-steered similarity and energy) so that they are rendered in geologic time.

The final wheeler volumes created in this work consisted of 589 horizons, of which only 25 were manually interpreted guide horizons.

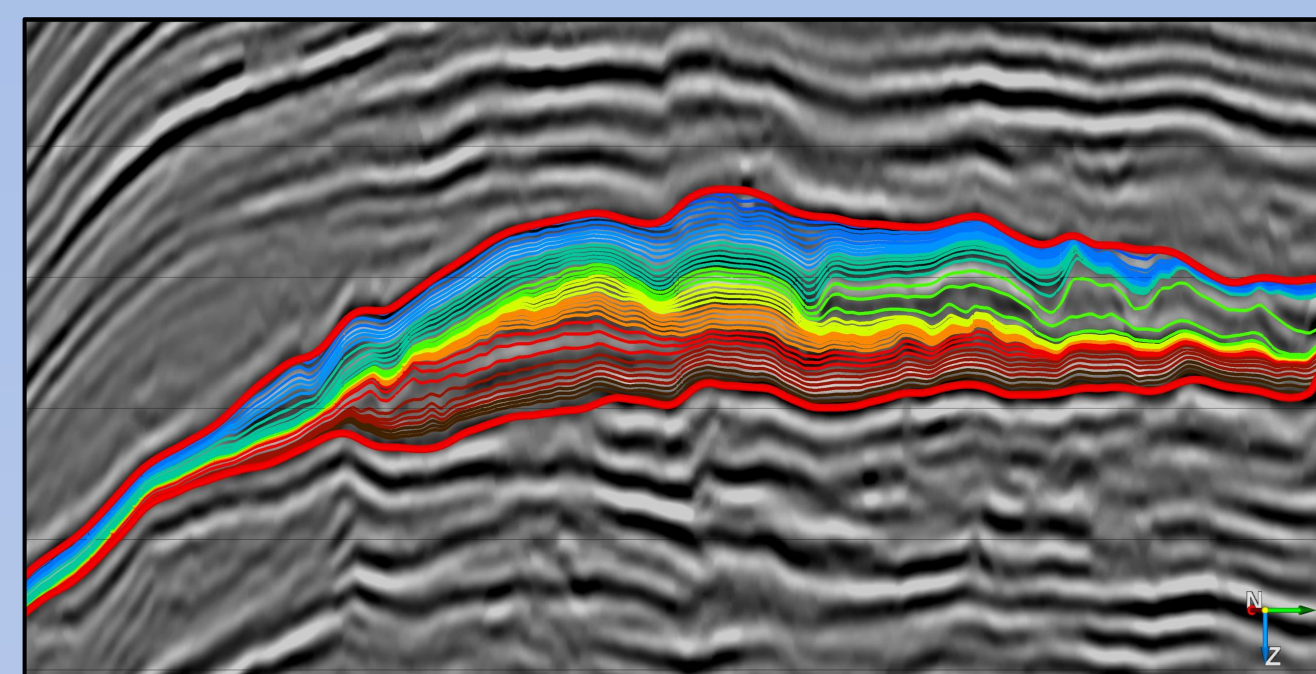


Crossline with bounding guide horizons in red.

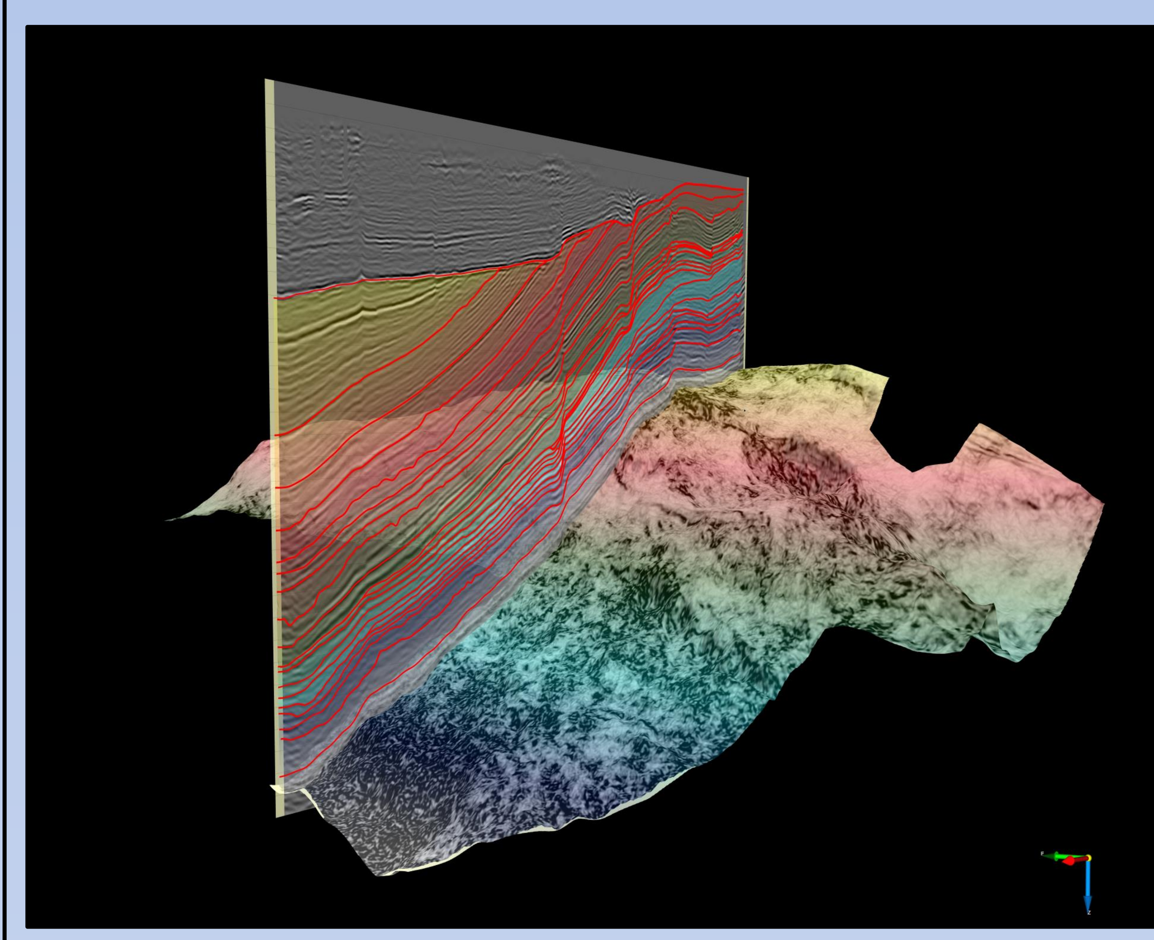


Crossline with proportionally generated horizon sets.

Crossline, with all horizons Wheeler flattened and seismic data stretched/squeezed.



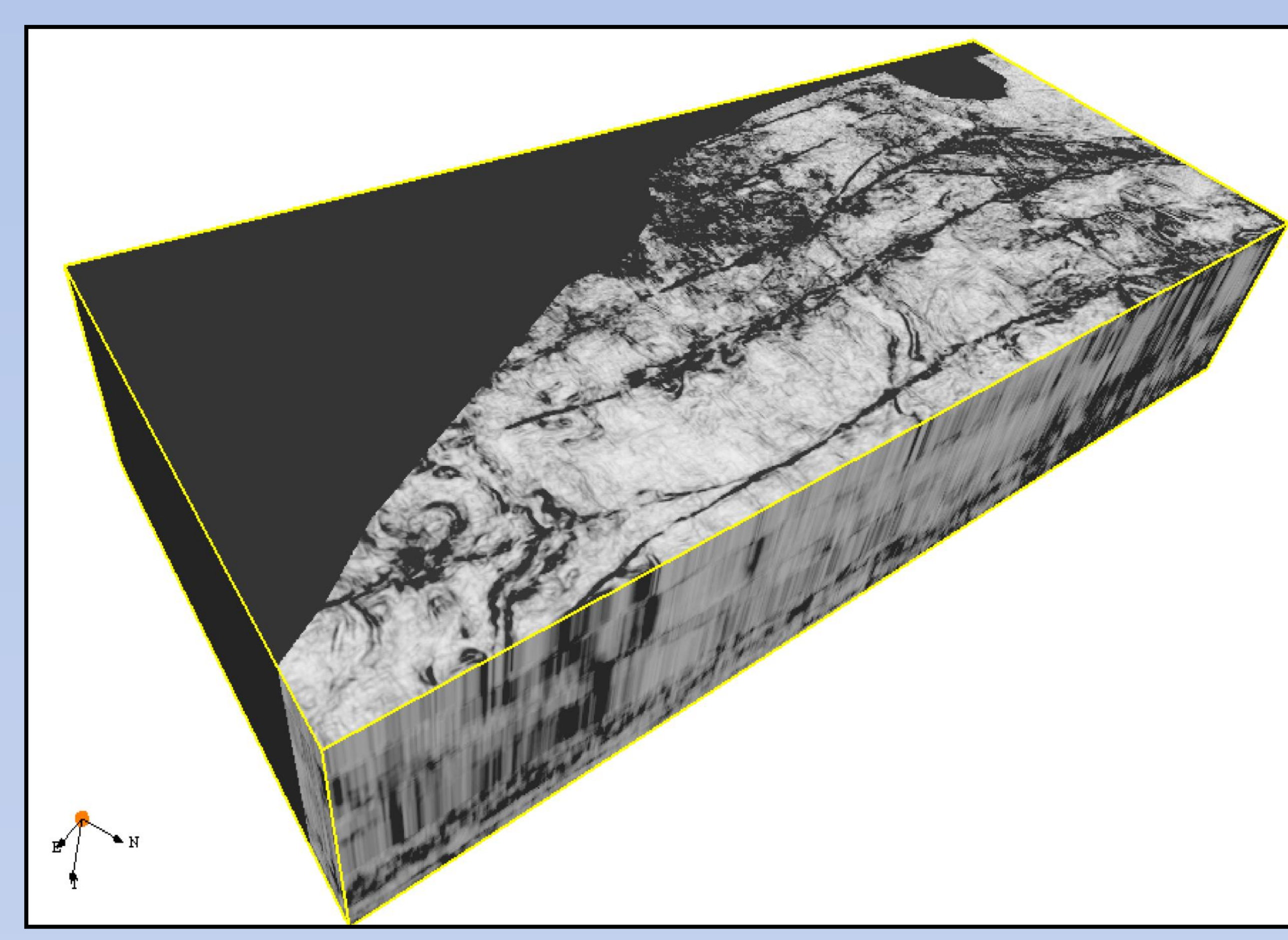
Crossline with dip steered generated horizon sets.



Perspective view of basal guide horizon (displaying similarity and z value colors), with dip line displaying guide horizons (red) and generated horizons (in color).

Animation

- The generation of wheeler volumes allowed for detailed animation of seismic attributes in geological time.
- In this project, the 589 generated horizons were generally spaced at no more than 10ms apart vertically, effectively providing more than ample vertical sampling.
- Similarity and Energy volumes were interactively manipulated backwards and forwards through geologic time, revealing patterns that were not readily apparent on static images.
- Animation enabled rapid identification of significant geomorphological features, such as slope fan channels, overbank aprons, basin floor fans , and slumps.
- Being able to watch the prograding depositional history of the Mezardere unfold lead to numerous insights.
- Animation also highlighted areas of poor horizon tracking, and that information was used to guide the next iteration of guide horizon interpretation and refinement.



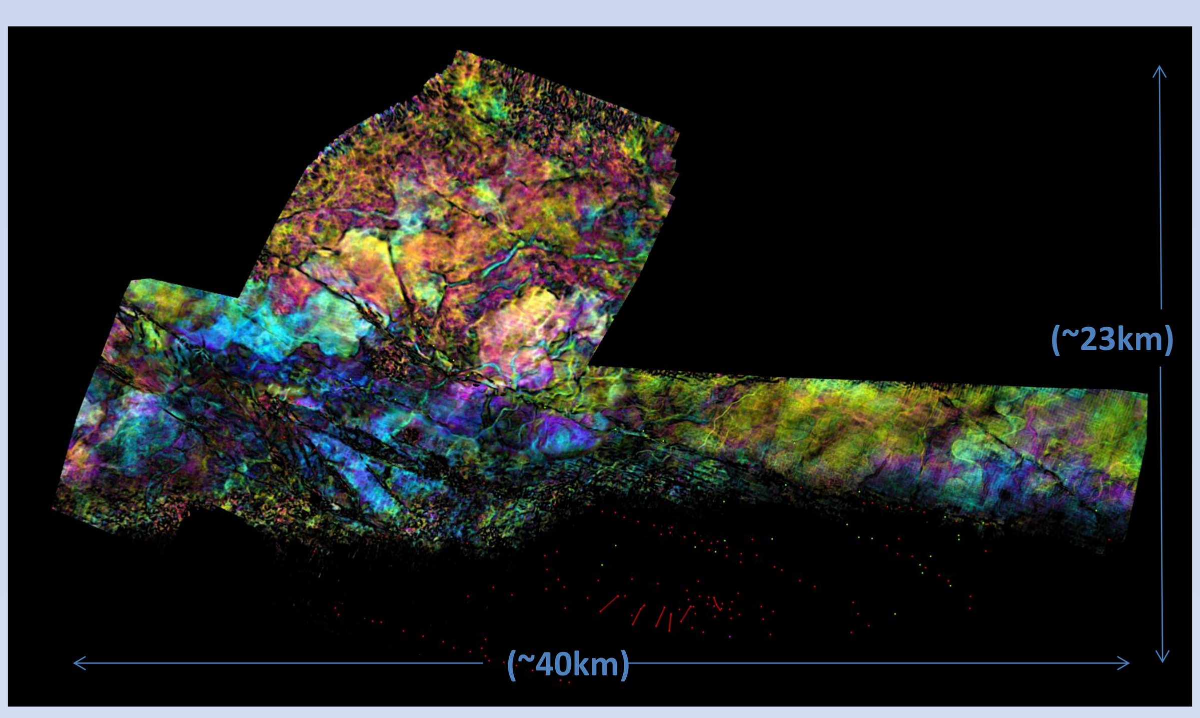
Perspective view of a Similarity Wheeler Volume. Stratigraphic details and important geological patterns can be quickly identified by animating up an down in time.

Visualization

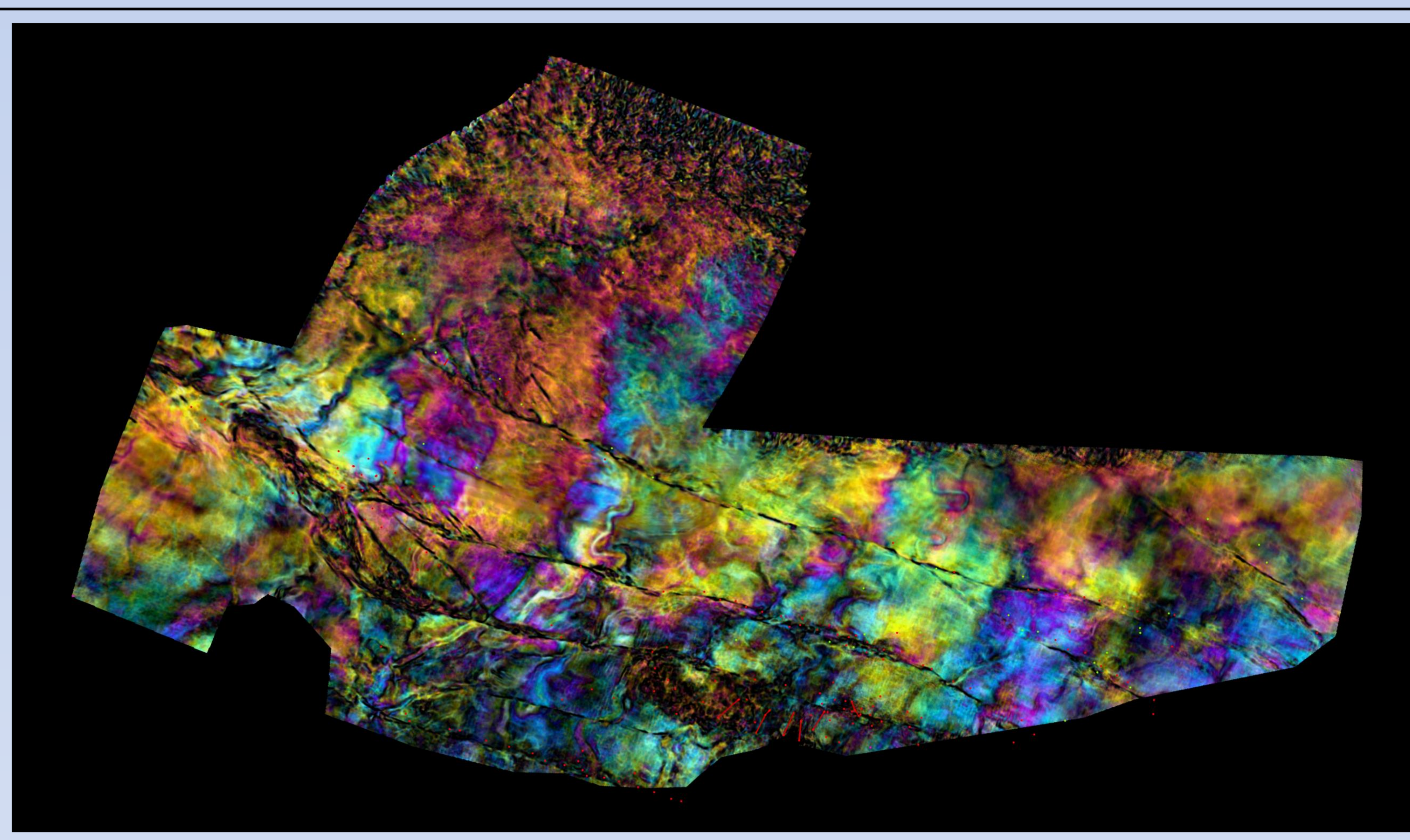
Key horizons that were identified from animating the wheeler volumes were then extracted. Co-blended attribute visualizations were then generated and displayed in map and perspective views.

Iteration

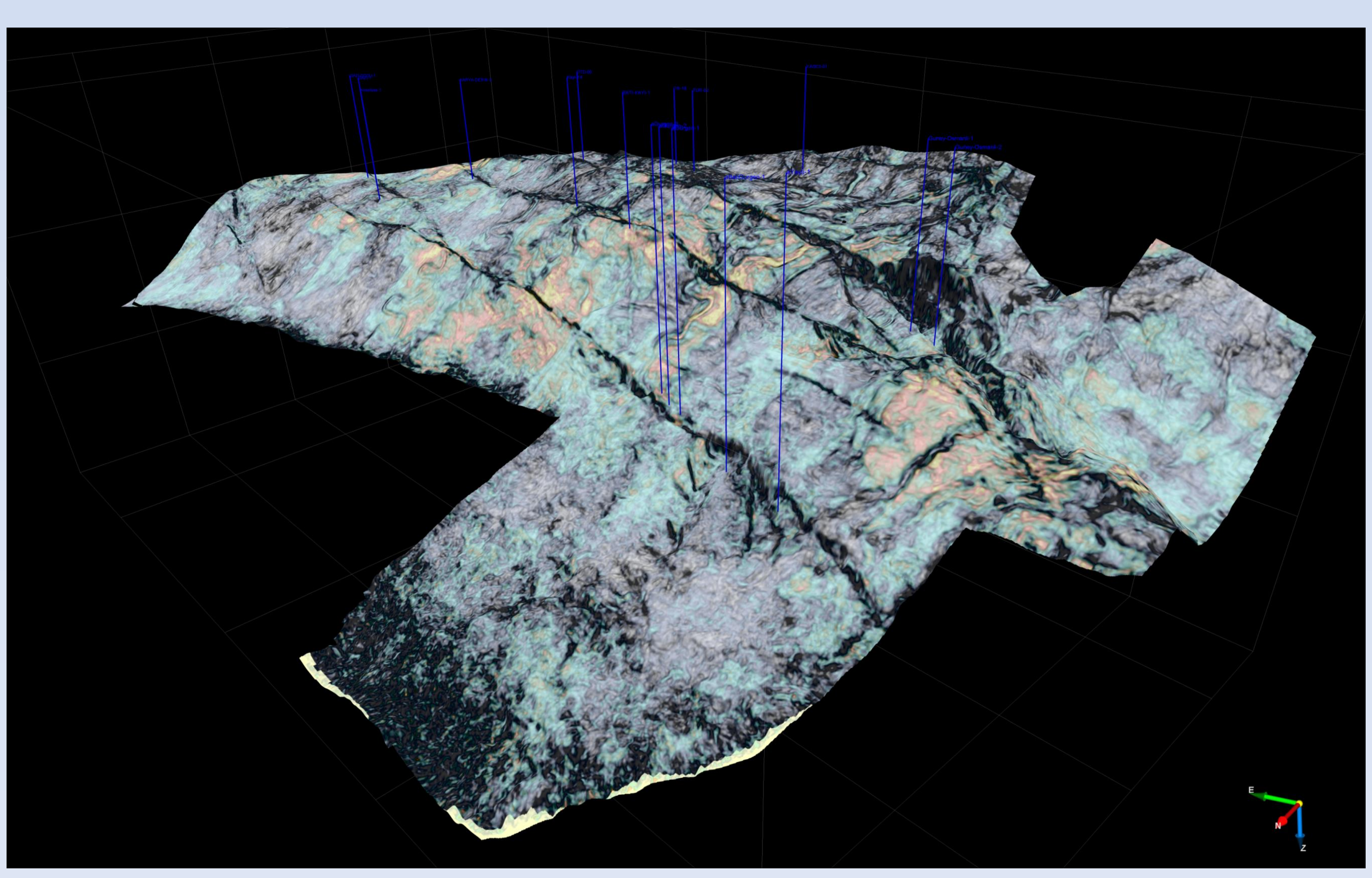
As the work progressed and new 3D's were merged into existing ones, numerous iterations of guide horizon interpretation / refinement and wheeler volume attribute visualization were undertaken.



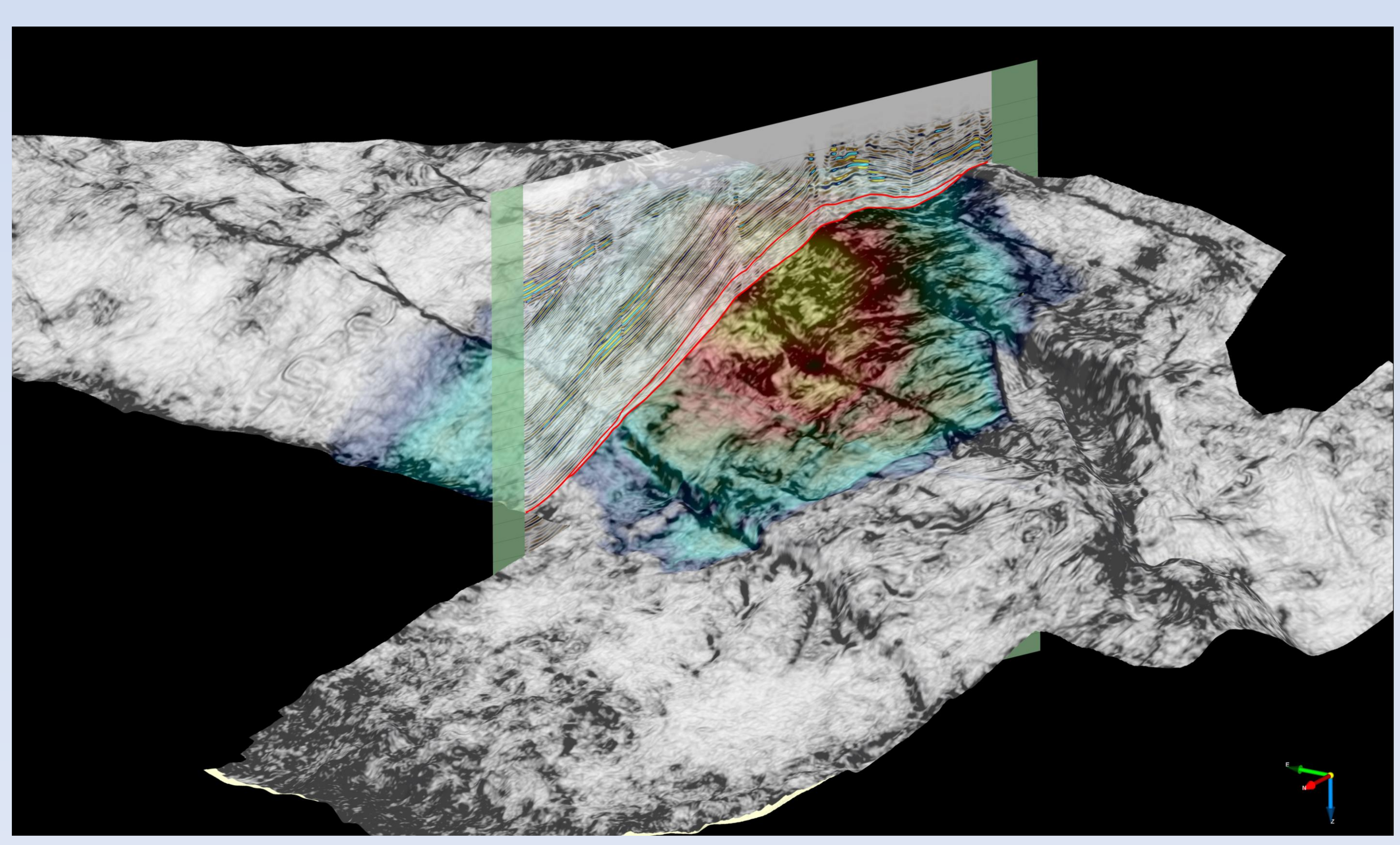
Spectral Decomp / Sim on Horizon 194 MDanB. (sub-crops to the south)



Spectral Decomp / Similarity on Mezardere Horizon 440 TekD.



Perspective View of Horizon Mezardere 440 TekD, with Energy / Similarity and selected wells.



Perspective View of Mezardere Horizon 415 TekC, with Similarity / Isochron thickness (colors).
Inline displays key guide horizons (red) that are represented by the displayed isochron thickness colors.

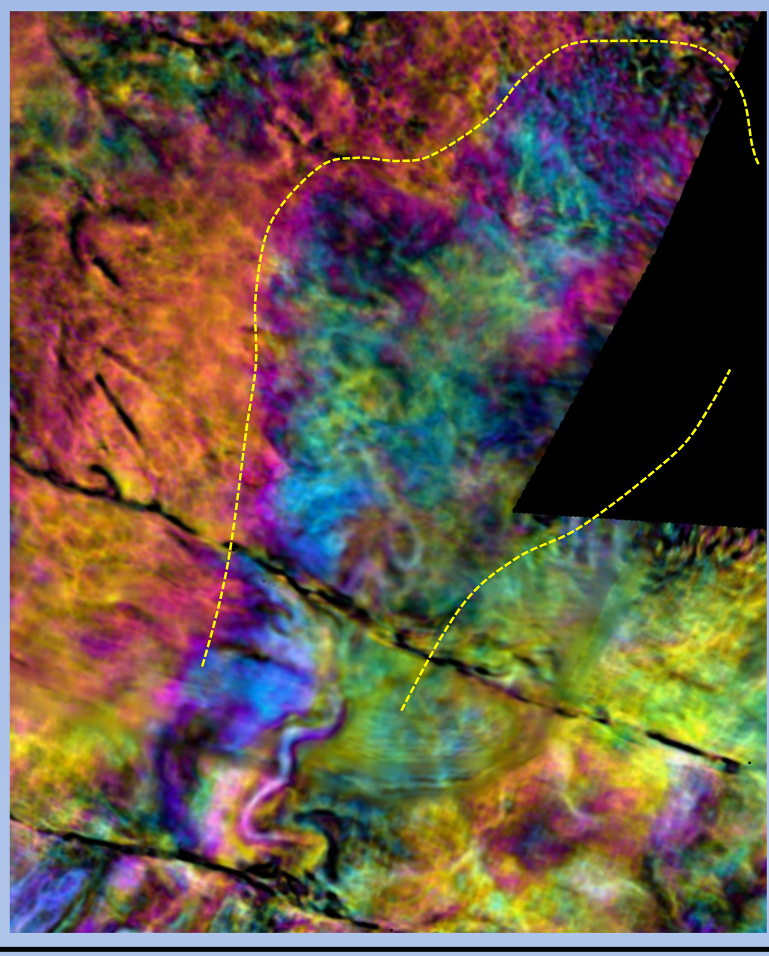
Geological Results and Findings

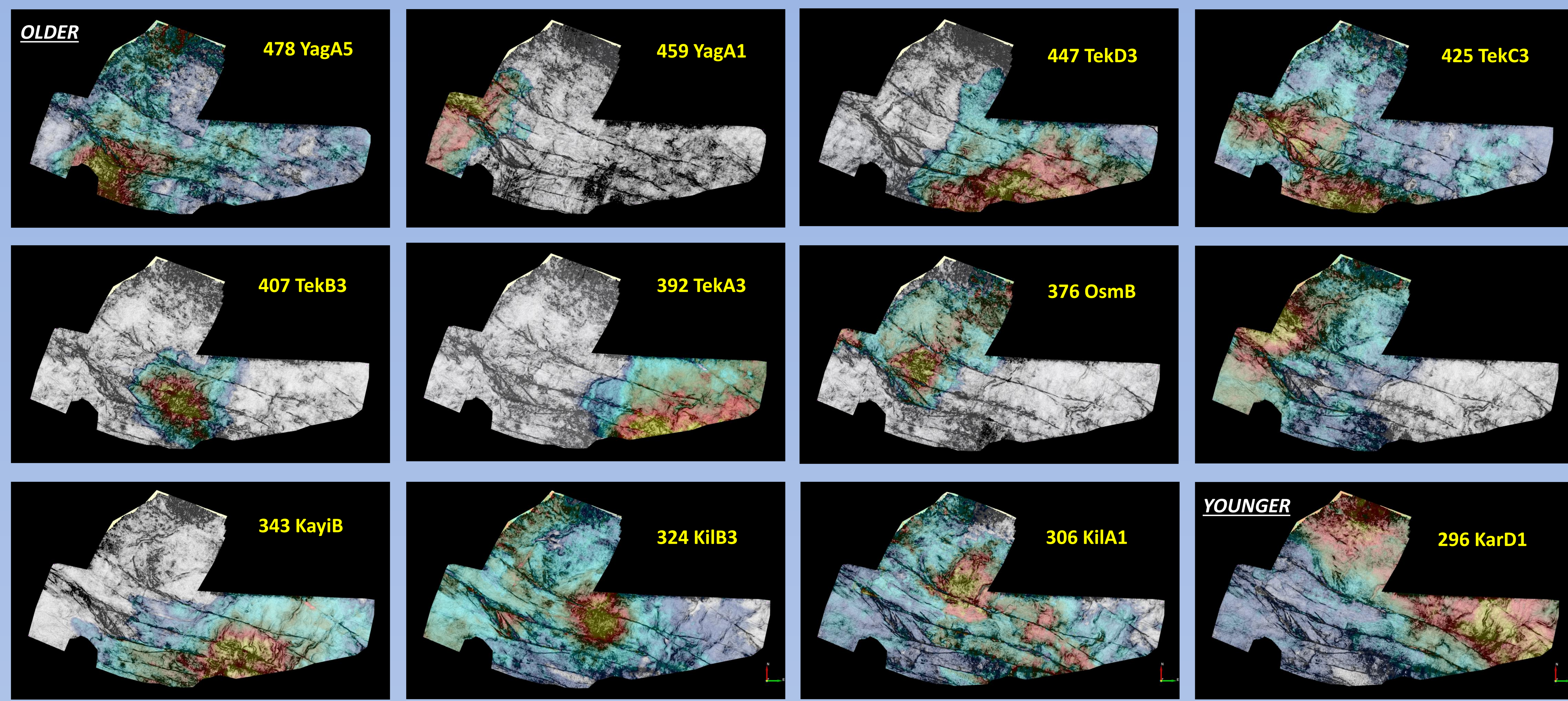
Stratigraphic Mapping of the Mezardere

Productive reservoirs such as slope channels, interbedded over-bank apron deposits, basin floor fan deposits and slumps have been identified and mapped.

Fans

Example of an interpreted slope channel transitioning into a distributary fan, visualized on a color blended spectral decomposition horizon surface.

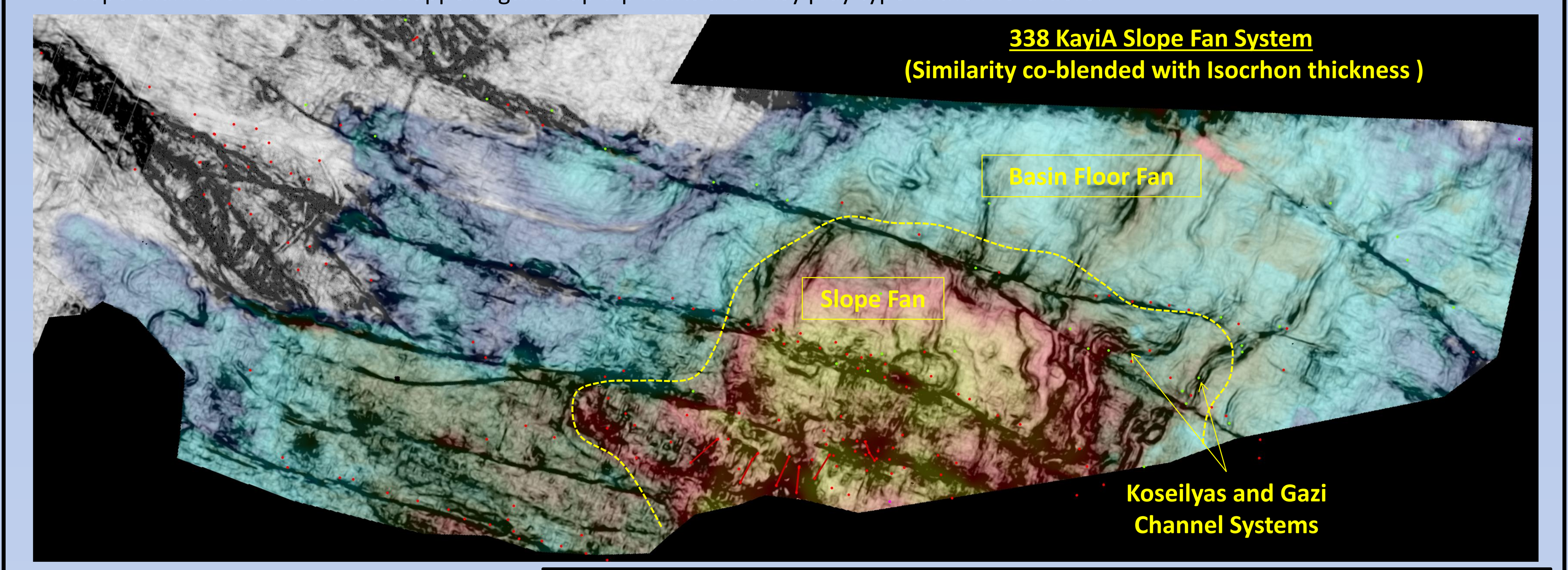


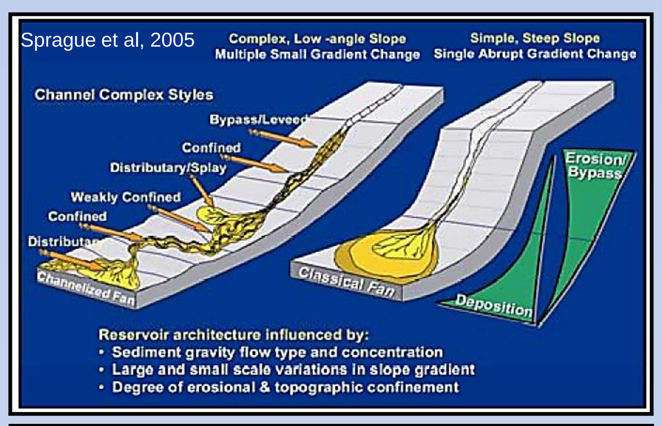


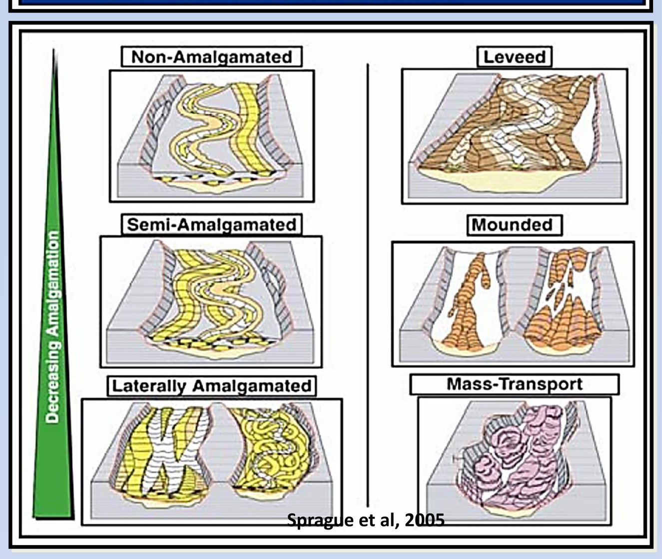
Individual clinoform slope fan lobe packages and their geometries were mapped. These images show isochron thickness transparently overlain on similarity images of selected horizons within each clinoform lobe deposit. This sequence of images represents the prograding depositional history of the Mezardere, starting with the oldest deposit at the top left.

Channel Systems

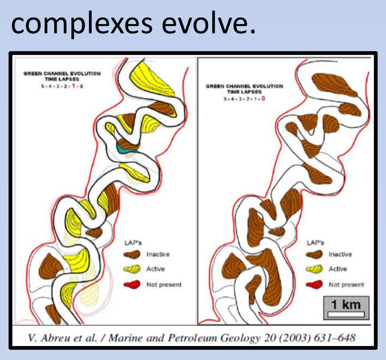
- Many channel systems were identified in the Mezardere and its overlying formations, the Danismen and Osmancik.
- Classifying mapped slope channel systems has been useful for evaluating reservoir potential.
- Slope channel sand reservoirs trapped against up dip faults are a key play type in the Mezardere.

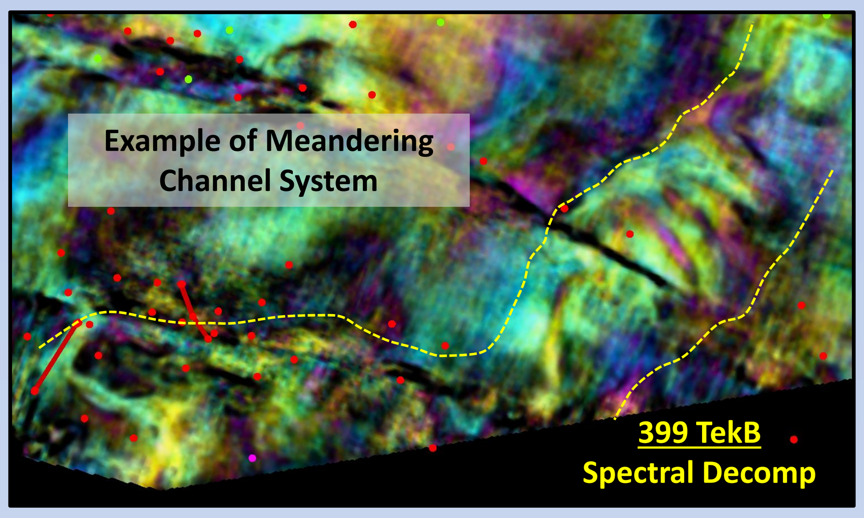




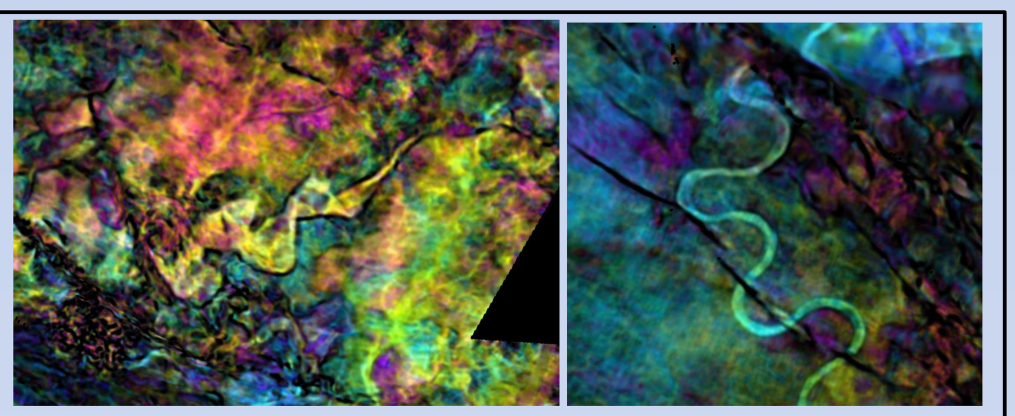


Lateral Accretion Packages
Contain reservoir sandstones that accumulate as meandering channel complexes evolve.



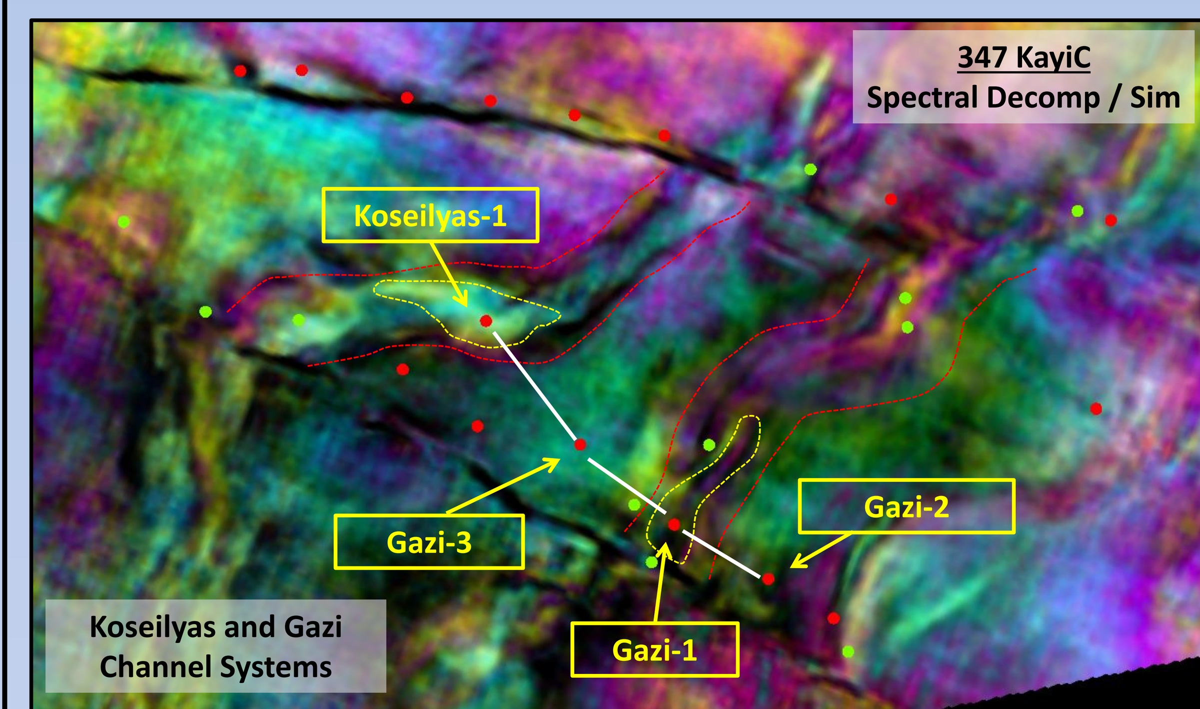


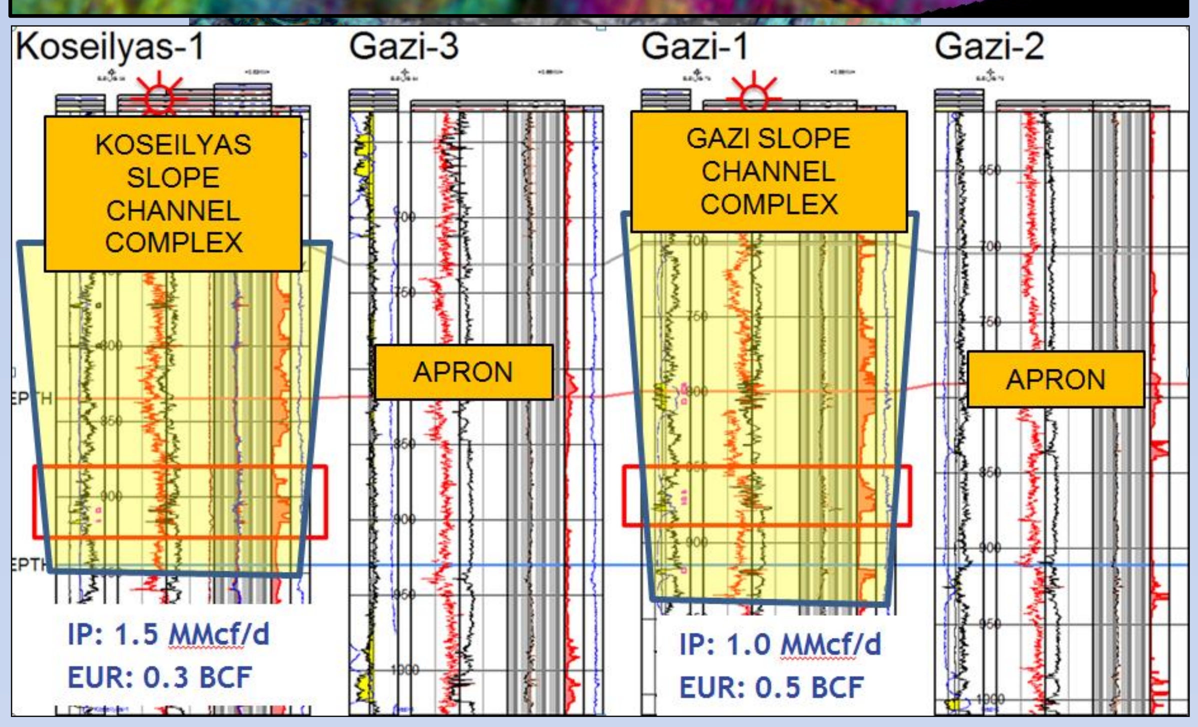
Danismen & Osmancik Channel Systems
Represent coastal plain to fluvial depositional systems.



Off Structure Stratigraphic Prospects

- The majority of conventional gas production in this part of the Thrace Basin has been from structurally trapped reservoirs, which are now largely exploited.
- Purely stratigraphic prospects have been successfully drilled and this mapping has led to another generation of prospects that are currently being pursued.
- Example: Koseilyas-1 recovered economic amounts of conventional gas from a stratigraphically trapped slope channel sand reservoir.





The spectral decomp. image on the left shows the Koseilyas and Gazi slope channels clearly.

Both Kos-1 and Gazi-1 produced economic amounts of natural gas, from stacked zones within slope separate channel systems.

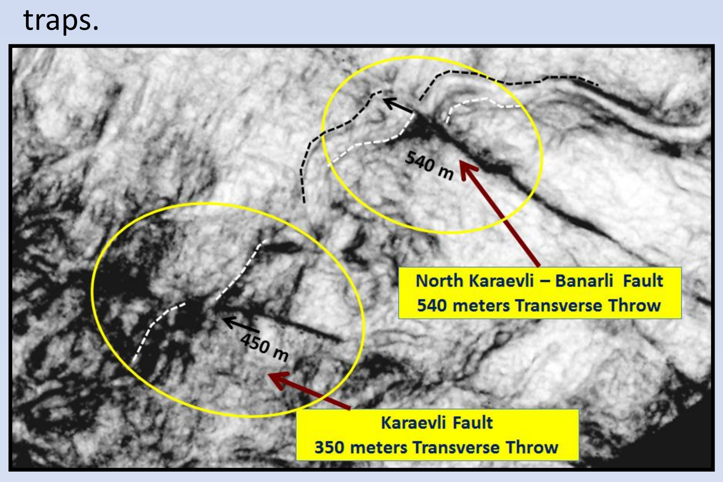
Red dots represent existing wells, and green dots are potential locations.

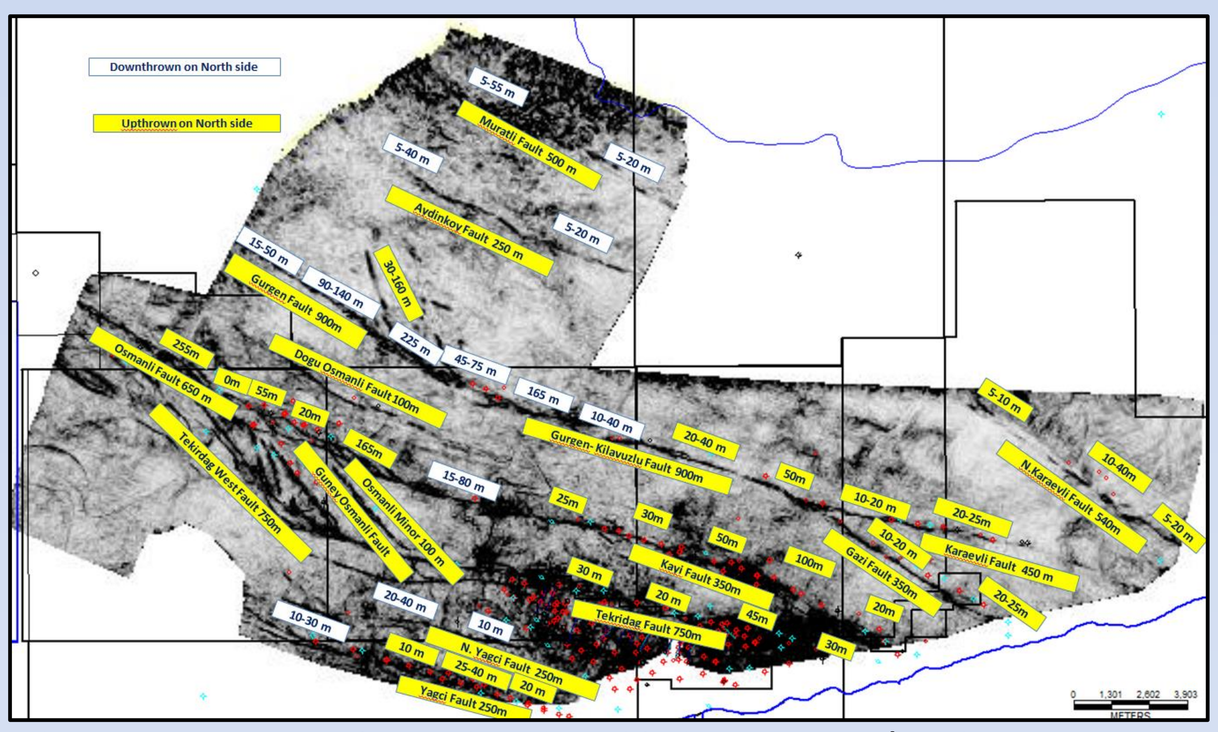
While Gazi-1 is a combination of stratigraphic and structural trapping against an up-dip fault, Kos-1 is successful example of a of an off–structure stratigraphically trapped pool.

The Gazi and Koseilyas channels may be classified as a non amalgamated and leveed systems.

Fault Seal Analysis

Mapping slope channel systems across fault boundaries allowed for accurate measurements of lateral fault movements. Larger lateral and vertical fault displacements correlated positively with existing gas pools and were associated with greater potential for fault sealed structural/stratigraphic traps.

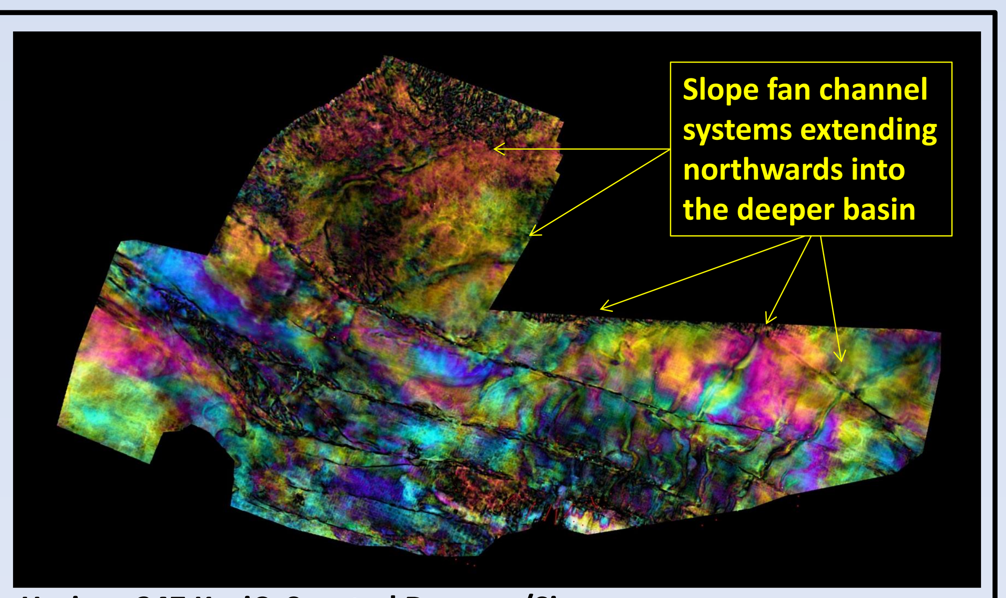




Above: Summary Map of vertical and lateral fault movements / displacements.

Contributions to Mezardere Slope Fan Model and Basin Centered Gas Concept

Identification of distributary systems (slope channels), and clinoform deposit geometries, has led to the mapping of potential source and reservoir zones that extend deeper into the basin. These zone may be potential drilling targets for deeper wells that will test the potential for pervasive over pressured basin centered natural gas.



Horizon 347 KayiC, Spectral Decomp/Sim

Conclusions and Key Insights

Workflow Insights and Conclusions

Advanced seismic interpretation tools and technology, now allow for early and iterative inclusion of seismic stratigraphic and attribute interpretation into exploration workflows.

- Useful seismic attribute selection relies on interpreter experience (and imagination), that takes into account interpretation objectives along with seismic data characteristics and limitations (ie: signal/noise, resolution/frequency, areal extent)
- Parameter testing is a key element in seismic attribute analysis, and must be undertaken in a rigorous and systematic manner before applying broadly.
- Dip volume data can greatly enhance the quality and effectiveness of similarity/coherence attributes and horizon tracking algorithms.
- Iteration is a key element in refining guide horizon interpretations and increasing the resolution of stratigraphic details revealed by seismic attribute wheeler volumes.
- Animation is a powerful tool for recognizing subtle patterns that would not be noticed on static images.

Geological Insights and Conclusions

Stratigraphic mapping of the Mezardere formation has contributed significant details to the slope fan exploration model that has been used by Valeura Energy to forward its exploration program in the Thrace Basin of Turkey. These contributions include:

- Mapping / delineation of delta front clinoform geometries and their internal distributary systems and geomorphological features.
- Mapping of potential reservoir zones within slope channels, over-bank deposits, and basin floor fans, leading to a new set of stratigraphically trapped prospects.
- The ability to map lateral fault movement accurately and estimate fault seal/trap potential with greater confidence.
- Confidence that source and reservoir zones extend deeper (northwards) into the basin as potential drilling targets for future wells that will test the basin centered gas concept.

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