Fracture Detection Interpretation Beyond Conventional Seismic Approaches*

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Abstract

In unconventional resource plays, it is important to identify fractures and fracture trends, whether naturally occurring or hydraulically induced. It is the delineation of these fractures that is critical for production and the optimal positioning of drilling locations. In an effort to identify fracture trends the industry routinely employs various seismic techniques such as processing of seismic attributes (geometric attributes), defining azimuthal variation of amplitude, running microseismic surveys, etc. What is not routinely applied to interpret fracture trends is combining seismic approaches. Spectral decomposition analysis can be employed to determine the optimal frequency bands that define fracture lineations. These optimally defined frequency volumes can then be processed for geometric seismic attributes to significantly improve the interpretation of fracture trends and increase understanding of the reservoir. Interpreting the optimal frequency band for seismic attribute processing requires a systematic methodology of frequency analysis and amplitude normalization. This combining of spectral decomposition and geometric seismic attributes has shown to not only improve fracture identification, but also more clearly define stratigraphic variations in most geologic settings. The methodology presented can be easily applied by asset teams working unconventional resource plays, reducing risk and optimizing development programs.

Fracture Detection Interpretation Beyond Conventional Seismic Approaches

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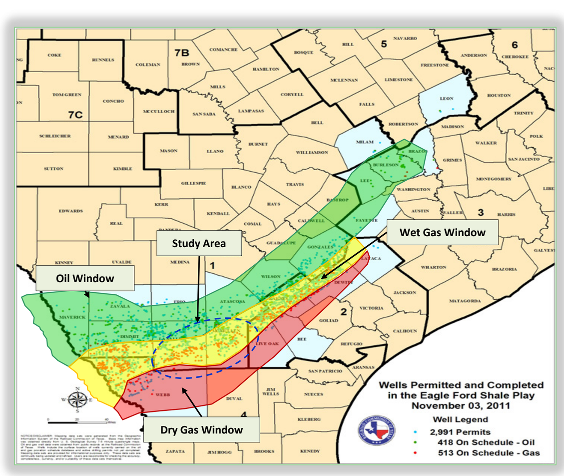
In unconventional resource plays it is important to identify fractures and fracture trends, whether naturally occurring or hydraulically induced. It is the delineation of these fractures that is critical for production and the optimal positioning of drilling locations. In an effort to identify fracture trends the industry routinely employs various seismic techniques such as processing of seismic attributes (geometric attributes), defining azimuthal variation of amplitude, running microseismic surveys, etc. What is not routinely applied to interpret fracture trends is combining seismic approaches. Spectral decomposition analysis can be employed to determine the optimal frequency bands that define fracture lineations. These optimally defined frequency volumes can then be processed for geometric seismic attributes to significantly improve the interpretation of fracture trends and increase understanding of the reservoir. Interpreting the optimal frequency band for seismic attribute processing requires a systematic methodology of frequency analysis and amplitude normalization. This combining of spectral decomposition and geometric seismic attributes has shown to not only improve fracture identification, but also more clearly define stratigraphic variations in most geologic settings. The methodology presented can be easily applied by asset teams working unconventional resource plays, reducing risk and optimizing development programs.

Introduction

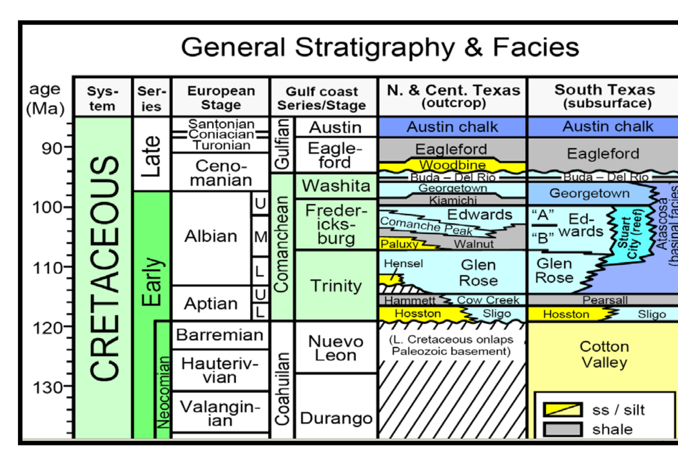
The study is conducted using data from the Eagle Ford shale resource play. Production is enhanced through the drilling and fracture treatment of horizontal wells. Understanding the existing fault and fracture patterns in the Eagle Ford is critical to optimizing well locations, well plans, and fracture treatment design. Detailed analysis of seismic data is essential in deriving maximum structural information to assist in economic development of the hydrocarbons in place.

Geologic Setting



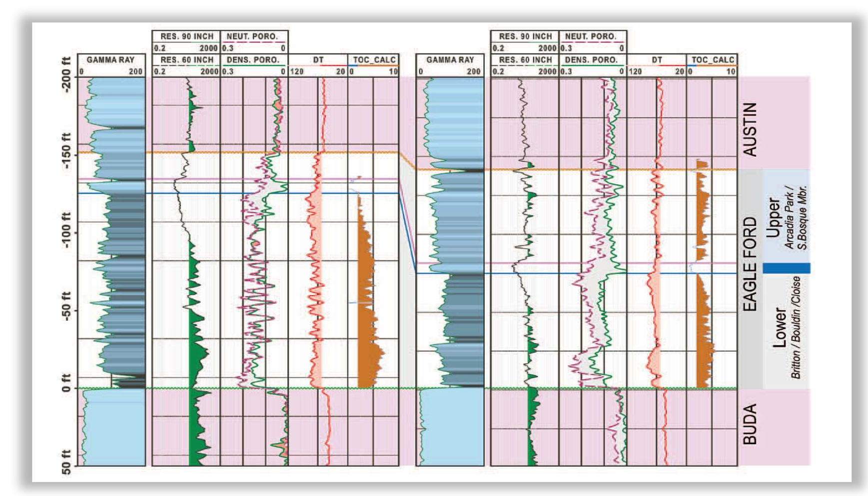
Map from: Texas Railroad Commission

The study area is in the Eagle Ford shale, which extends across South Texas. The Eagle Ford contains dry gas, wet gas, and oil windows.



Waite, 2009, Search and Discovery #10177

Stratigraphic Column of the study area. The Eagle Ford Shale is indicated by the arrow.



Log response in the Eagle Ford, showing variability in thickness and lithology of primary zone of interest across the study area

Key Eagle Ford values:

- Transit Time ~ 70 µs/ft
- Sonic Velocity ~ 14,300 ft/sec

Eagle Ford shale prospecting with 3D seismic data within a tectonic and depositional system framework
The Leading Edge, January 2011

Seismic Data

Five square miles of recently acquired pre-stack time-migrated 3D seismic data were utilized in this study.

Figure 1 shows a typical north-south seismic line through the survey. The Eagle Ford shale is seen as a trough (white) overlying a strong peak (black) resulting from the response to the high-impedence Buda limestone. It is the Eagle Ford trough response that we are interested in resolving most accurately to understand naturally occurring fault and fracture patterns.

Figure 2 shows a time structure map of the auto-tracked Eagle Ford shale event. The highlighted area is the most structurally complex in terms of naturally occurring large and minor faulting. Hydrocarbon development indicates that it also the area of higher naturally occurring fracture density. This complexity can be seen in the general area indicated by the green arrows in Figure 1.

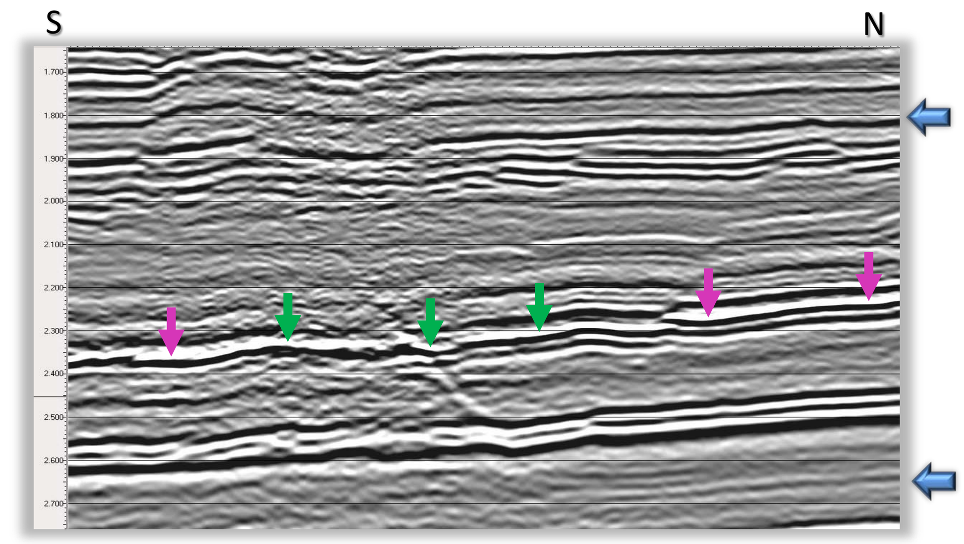


Figure 1
Seismic response (trough indicated by arrows) of Eagle Ford shale in area of interest

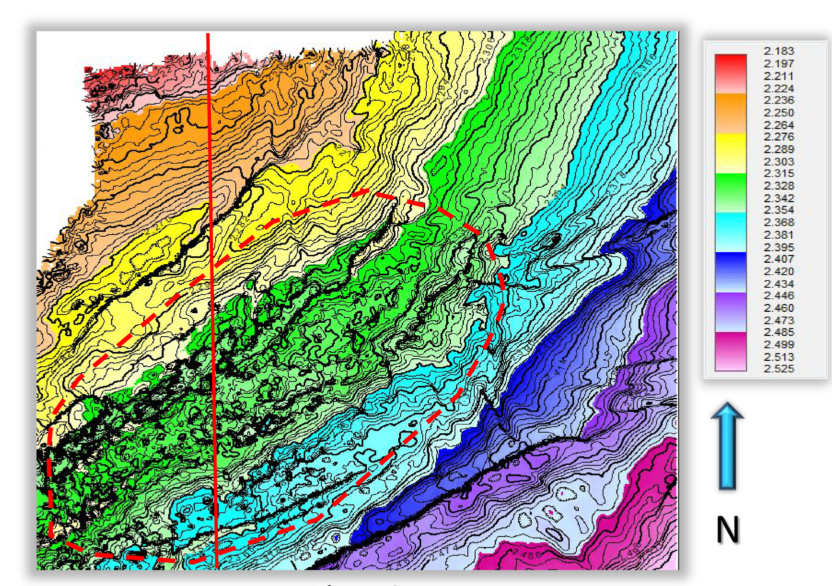


Figure 2
Time structure map of auto-tracked Eagle Ford event
Values range from 2.18 to 2.52 seconds

Tuning/Vertical Resolution Analysis

The zone of interest chosen for detailed analysis within the seismic volume is 1.8 to 2.65 seconds, indicated by the blue arrows in Figure 1. The computed frequency spectrum for that zone is shown in Figure 3. The frequency spectrum of the data falls between 5 and 70 Hz. The **dominant frequency occurs at 31.5 Hz**, with a secondary peak at 16.5 Hz.

The wedge model tuning analysis shown in Figure 4 indicates a **tuning thickness two-way travel time of 0.14 seconds**.

From these results the tuning thickness, or vertical resolution of the seismic data, can be calculated:

¼ Wavelength of Dominant Frequency

Wavelength = Interval Velocity (14300) / Dominant Frequency (31.5 Hz)

- **14300 / 31.5 Hz = 454 Ft (Dominant Peak)**
- 14300 / 16.5 Hz = 867 Ft (Second Peak)

Tuning Thickness = Wavelength / 4

- **454 Ft / 4 = 114 Ft.**
- 867 Ft / 4 = 217 Ft

Tuning Thickness in TWT

- **.014 (Dominant Peak)**

Tuning Thickness (TWT) / 2 * Interval Velocity = Tuning Thickness

- **(0.014 / 2) * 14300 = 100 Ft.**

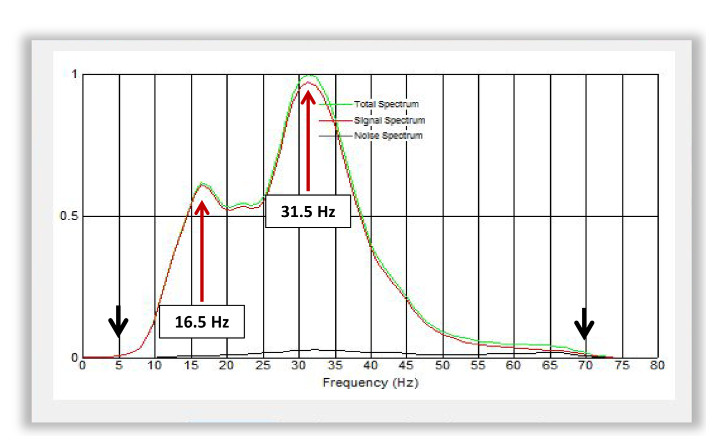
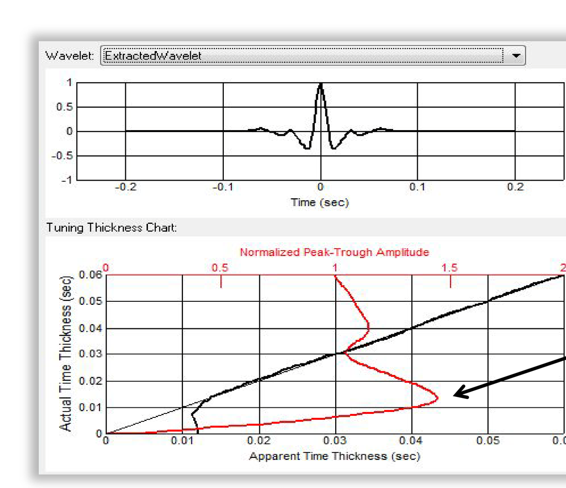


Figure 3
Computed Frequency Spectrum from 1.8 to 2.650 seconds



Tuning thickness in TWT = 0.14 sec

Figure 4
Wedge Model Tuning Analysis

Spectral Decomposition

Spectral Decomposition uses small or short windows for transforming and displaying frequency spectra (Sheriff, 2005-Encyclopedic Dictionary of Applied Geophysics). The resolution analysis of the zone of interest indicates that the highest resolution will be seen at 31.5 Hz. Several frequency windows may highlight different aspects of the geology when used as input into the calculation of geometric attributes for fracture analysis.

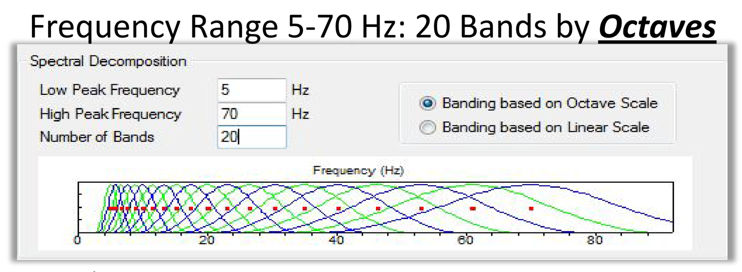
Spectral Decomposition Trace and Envelope attribute volumes are created for analysis.

For the frequency range of 5-70 Hz, volumes of *20 frequency bands* were generated.

For purposes of comparison, both **linear** and **octave** scales were used for banding.

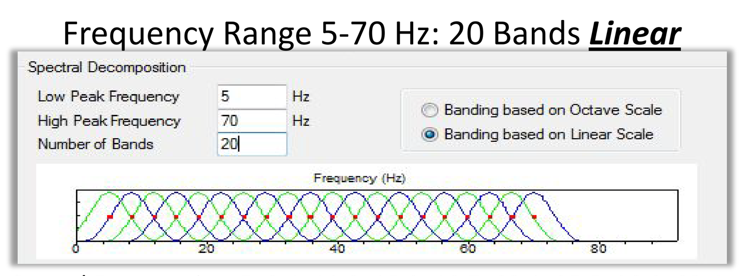
Figures 5 and 6 show vertical sections through representative trace and envelope output volumes, respectively.

Frequency Range 5-70 Hz: 20 Bands by ***Octaves***



Central Frequencies: 5, 5.7, 6.6, 7.6, 8.7, 10.0, 11.5, 13.2, 15.2, 17.5, 20.1, 23.0, 26.5, 30.4, 35.0, 40.2, 46.1, 53.0, 60.9, 70.0
(1.1 – 15.4 Hz bands)

Frequency Range 5-70 Hz: 20 Bands ***Linear***



Central Frequencies: 5, 8.4, 11.8, 15.3, 18.7, 22.1, 25.5, 28.9, 32.4, 35.8, 39.2, 42.6, 46.1, 49.5, 52.9, 56.3, 59.7, 63.2, 66.6, 70.0
(1.1 – 15.4 Hz bands)

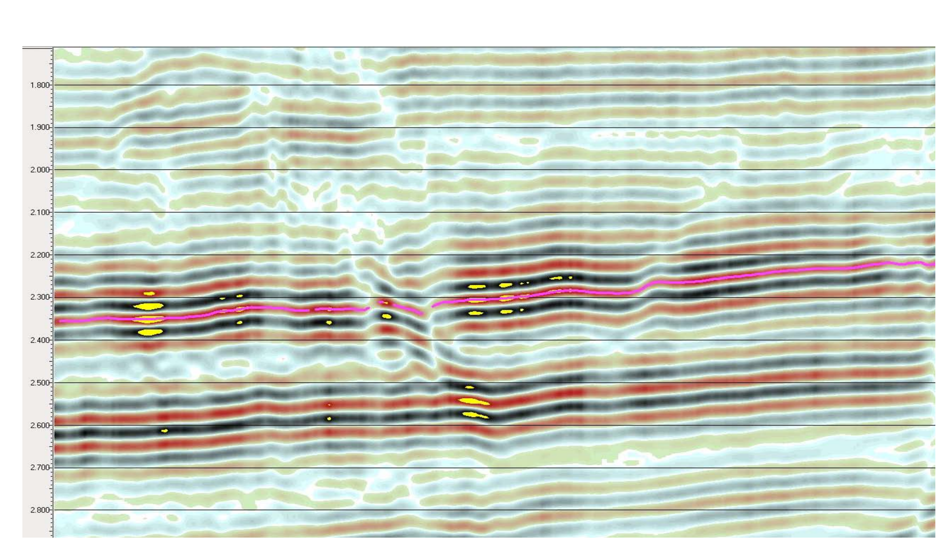


Figure 5
Trace output - 15.3 Hz linear band

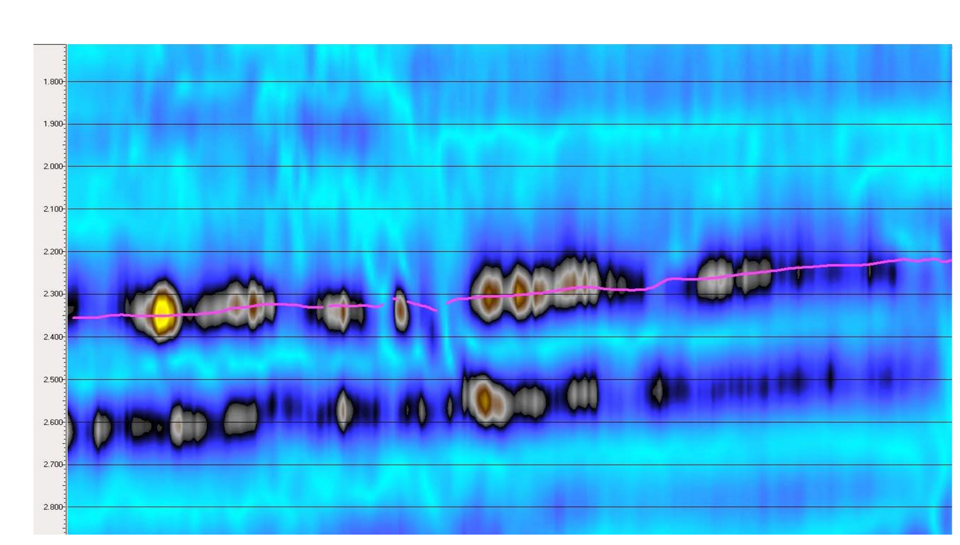


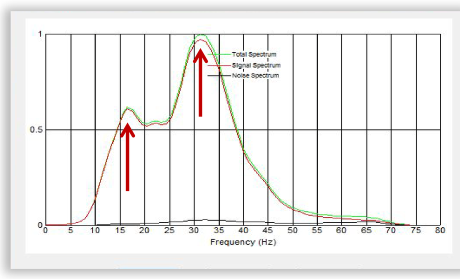
Figure 6
Envelope output - 15.3 Hz linear band

Analysis of Normalized Band Volume Amplitudes

The amplitudes of the spectral decomposition output volumes are normalized by banding approach – linear and octave.

The full-spectrum auto-tracked Eagle Ford event is snapped to the equivalent event in each volume, and the amplitudes are analyzed in map view. The highest amplitude maps indicate the frequency closest to tuning for the Eagle Ford event.

The ***highest amplitude content*** is seen in the volumes nearest the dominant frequency (31.5 Hz) in our window of interest, at the ***32.4 Hz Linear*** band, and ***the 35.0 Hz Octave*** band. These maps are highlighted by the red bounding boxes below.

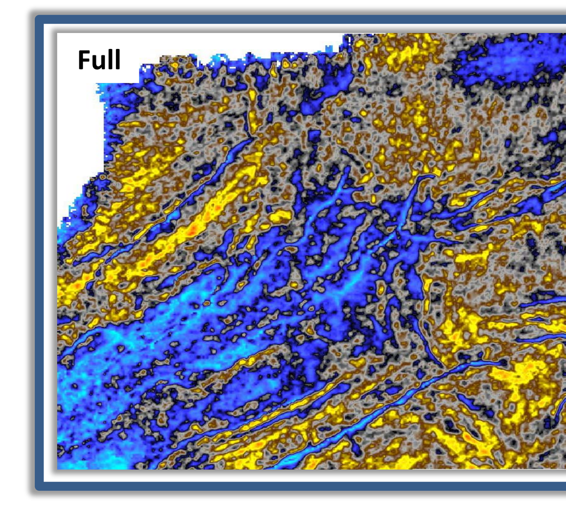


Geometric Attributes calculated from the **32.4 Hz volume** should provide the ***greatest resolution for fracture interpretation.***

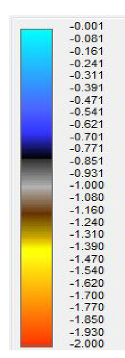
Volumes near the secondary peak frequency of the spectrum (16.5 Hz) also provide meaningful additional information and bring increased resolution for Fault interpretation.

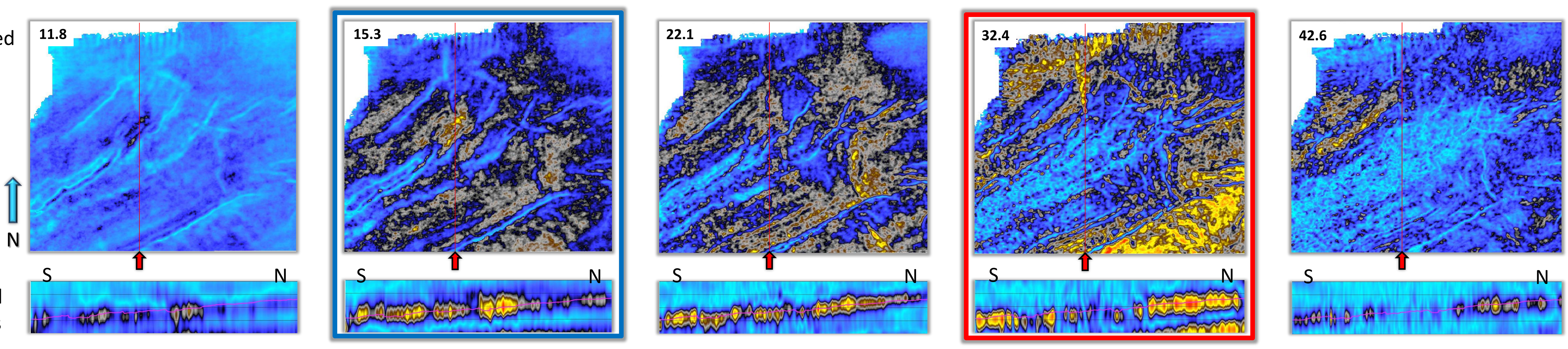
Geometric Attributes will be calculated from the 32.4 Hz volume and the 15.3 Hz volume for analysis. AVO attributes will also be calculated from the initial pre-stack time-migrated volume for comparison.

Full Spectrum Amplitude Map (Full Amplitude)



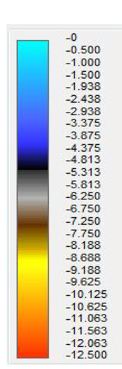
Linear Trace Normalized Amplitude Maps

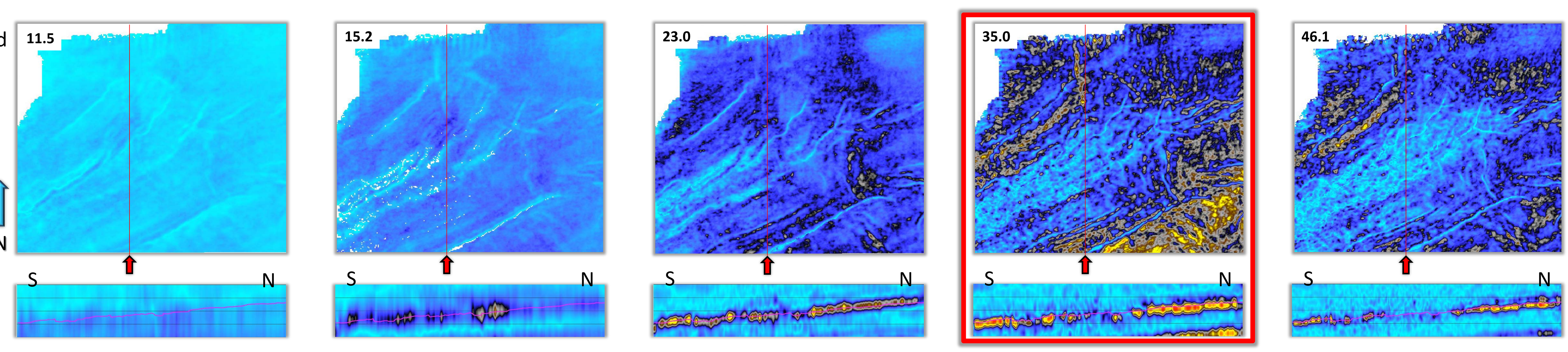




Linear Normalized Envelope Sections

Octave Trace Normalized Amplitude Maps





Octave Normalized Envelope Sections

Geometric Attributes

Geometric attributes respond to changes in reservoir structure and stratigraphy. The Dip of Maximum Similarity and the Instantaneous Dip are two of the most popular attributes used for discontinuity mapping, especially the mapping of faults in 3D. In fact, they may be the most valuable attributes for structural mapping for many interpreters. Curvature attributes are also widely used and often bring out subtle features not seen in other geometry attributes.

Attributes extracted from the event of interest in each volume can be analyzed in map and 3D views, each attribute and frequency band providing additional insight into the geologic properties of the reservoir.

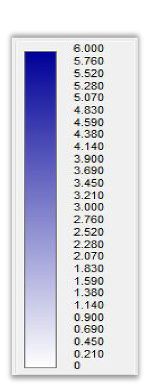
2D Analysis of Geometric Attributes

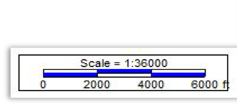
Time structure views of Dip of Maximum Similarity attribute in Map View

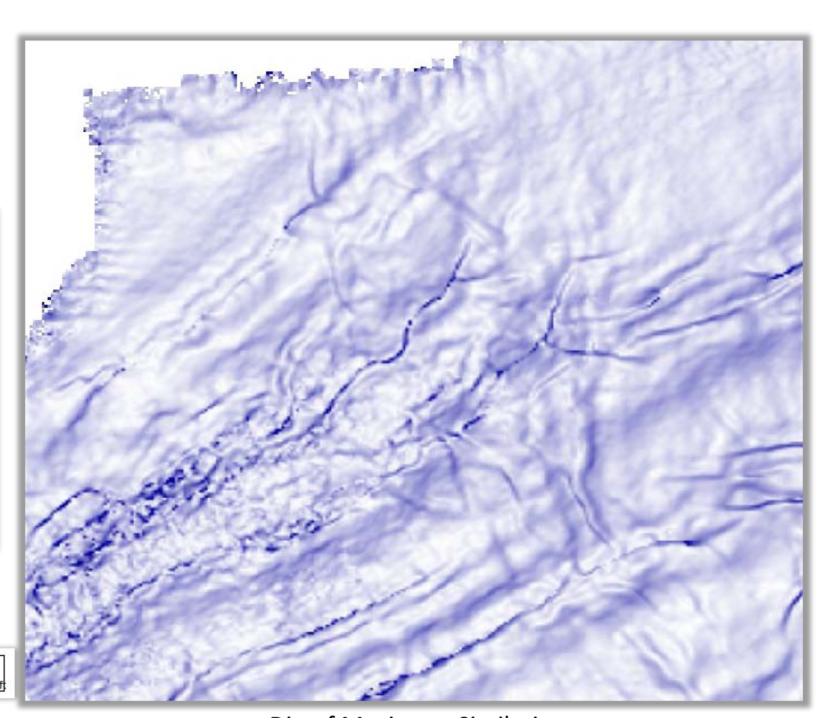
The Dip of Maximum Similarity results can assist with detailed structural interpretation.

The 32.4 Hz volume shows additional detail in the complexity of the study area.

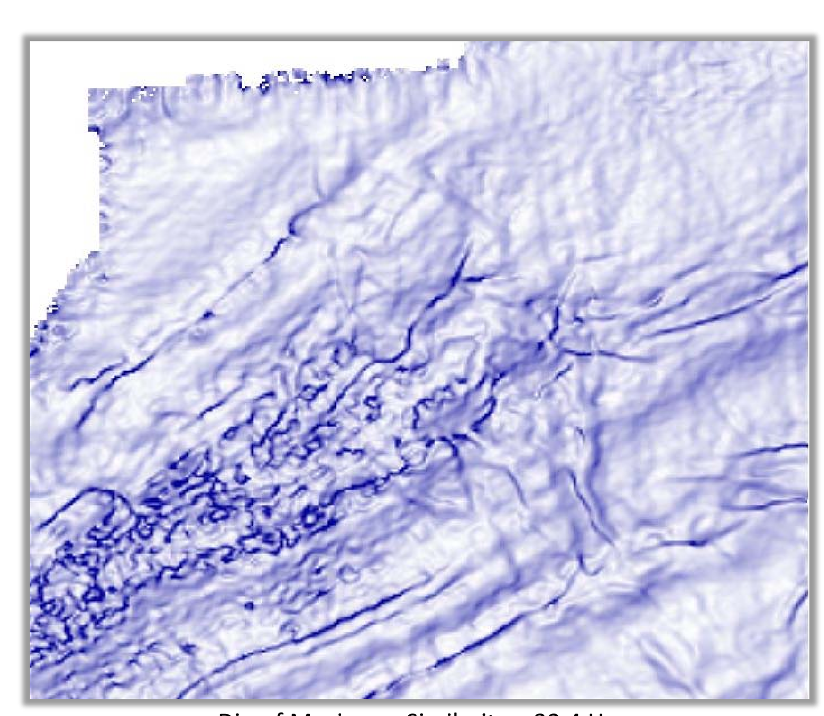
The 15.3 Hz volume could be useful for understanding the gross structural trends, which can be difficult to map from the original seismic data.



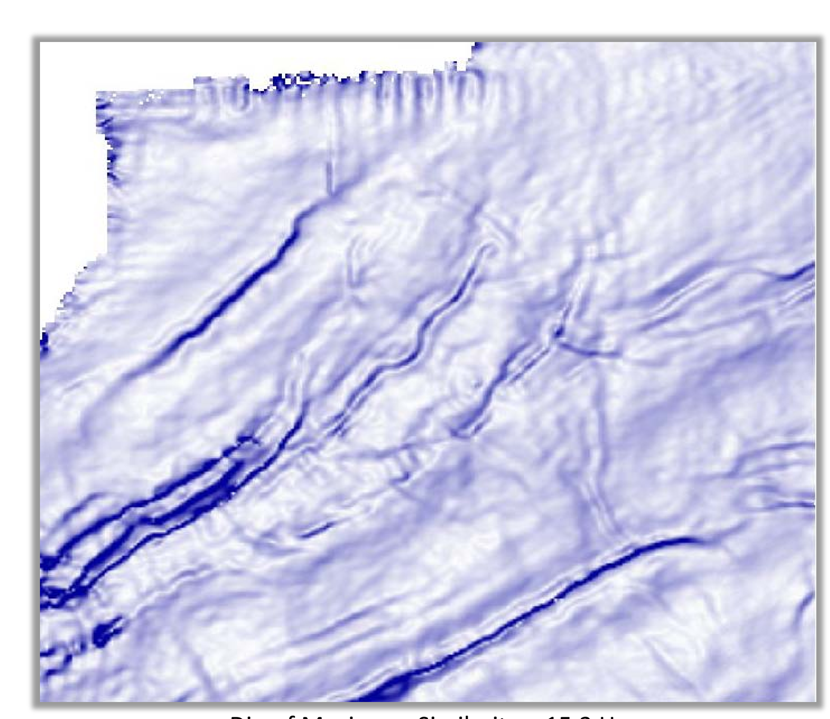




Dip of Maximum Similarity



Dip of Maximum Similarity – 32.4 Hz

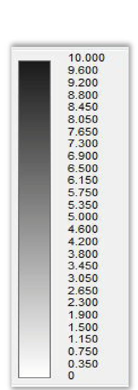


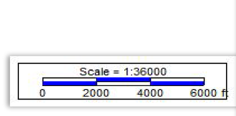
Dip of Maximum Similarity – 15.3 Hz

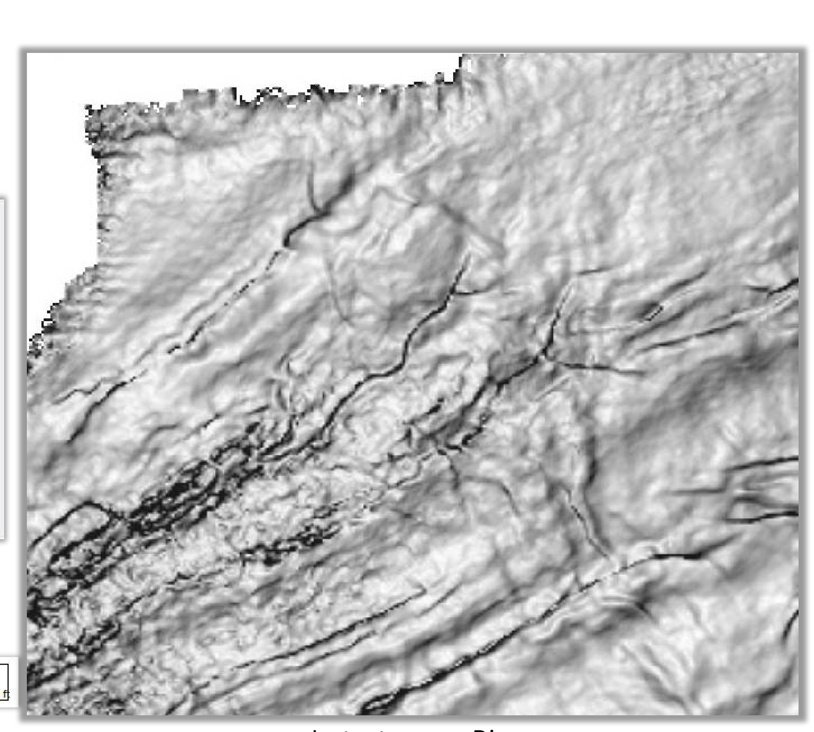
Time structure views of Instantaneous Dip attribute in Map View

The Instantaneous Dip attribute results are very similar to those of Dip of Maximum Similarity.

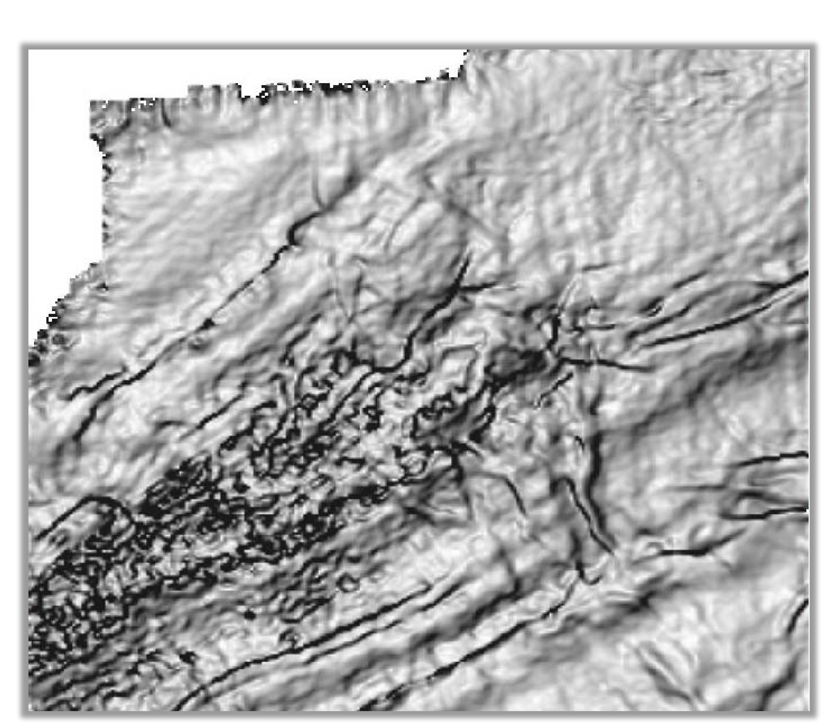
The lineation detail is slightly more crisp, making this attribute the better choice in this case.



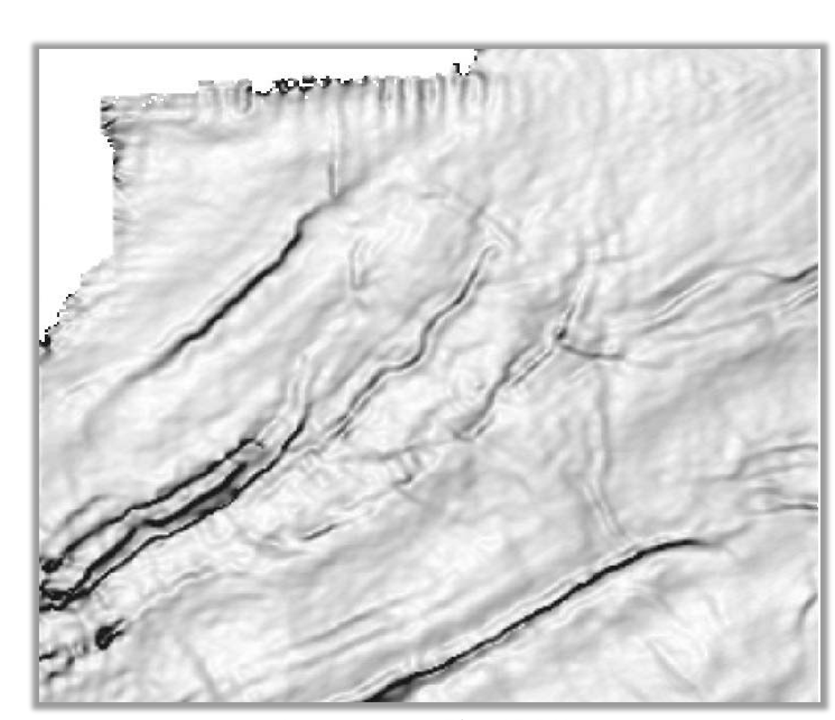




Instantaneous Dip



Instantaneous Dip – 32.4 Hz

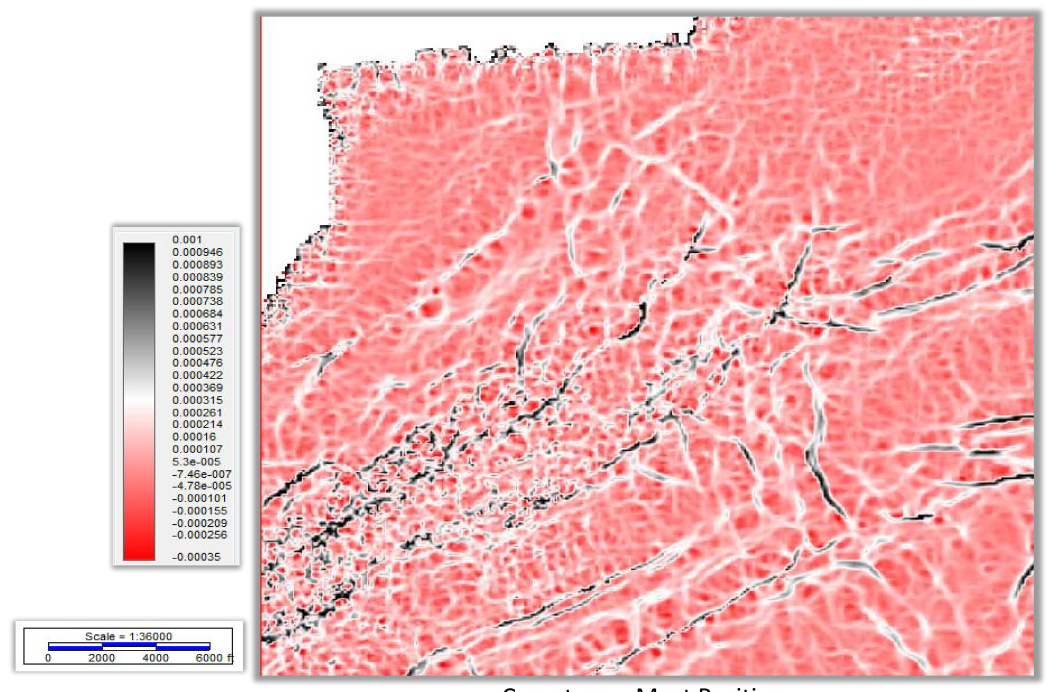


Instantaneous Dip– 15.3 Hz

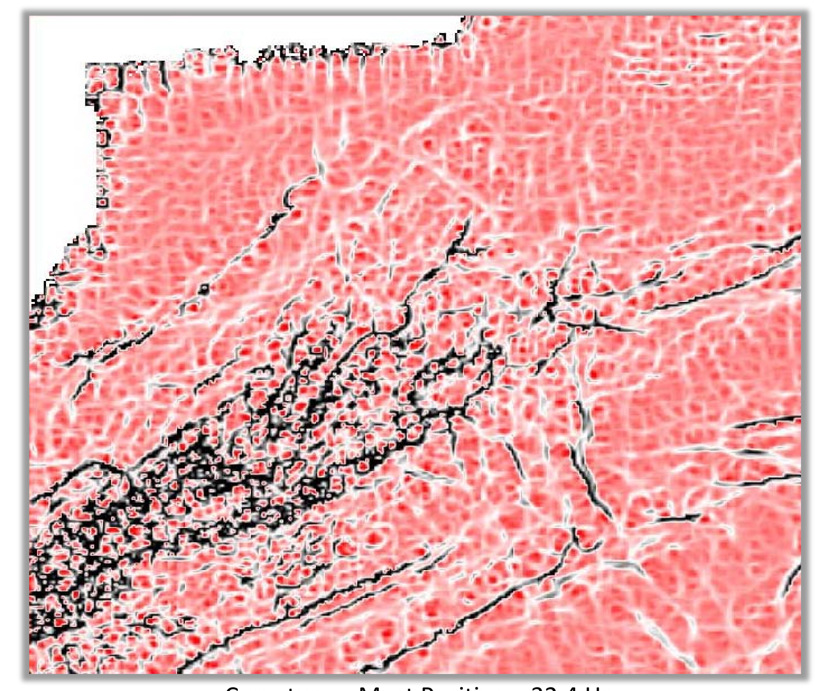
Time structure views of Most Positive Curvature attribute in Map View

Curvature attributes highlight lineations which can represent small faults and fractures.

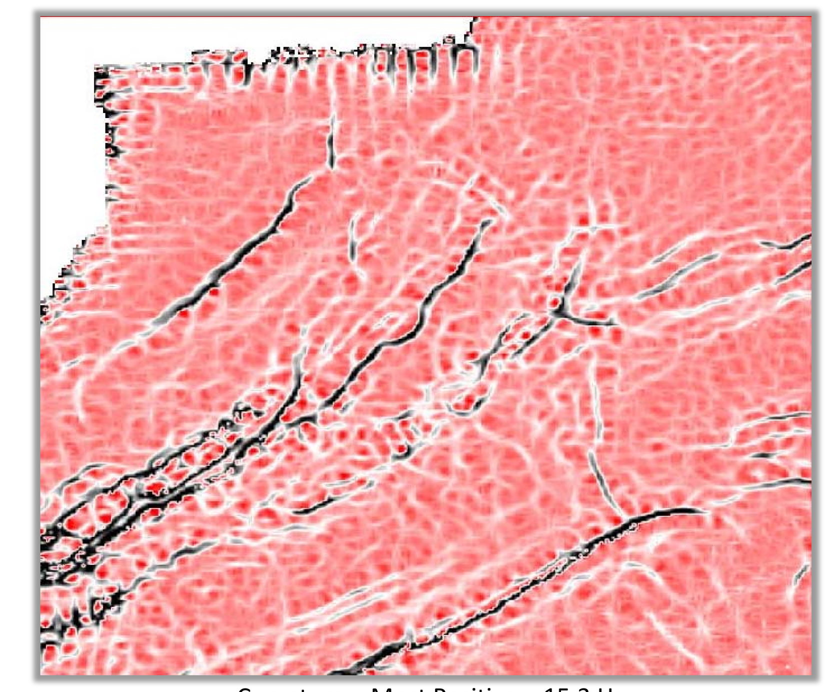
The white and black areas of the maps show the typical polygonal shapes which can aid in the interpretation of these fine scale features.



Curvature – Most Positive



Curvature – Most Positive – 32.4 Hz



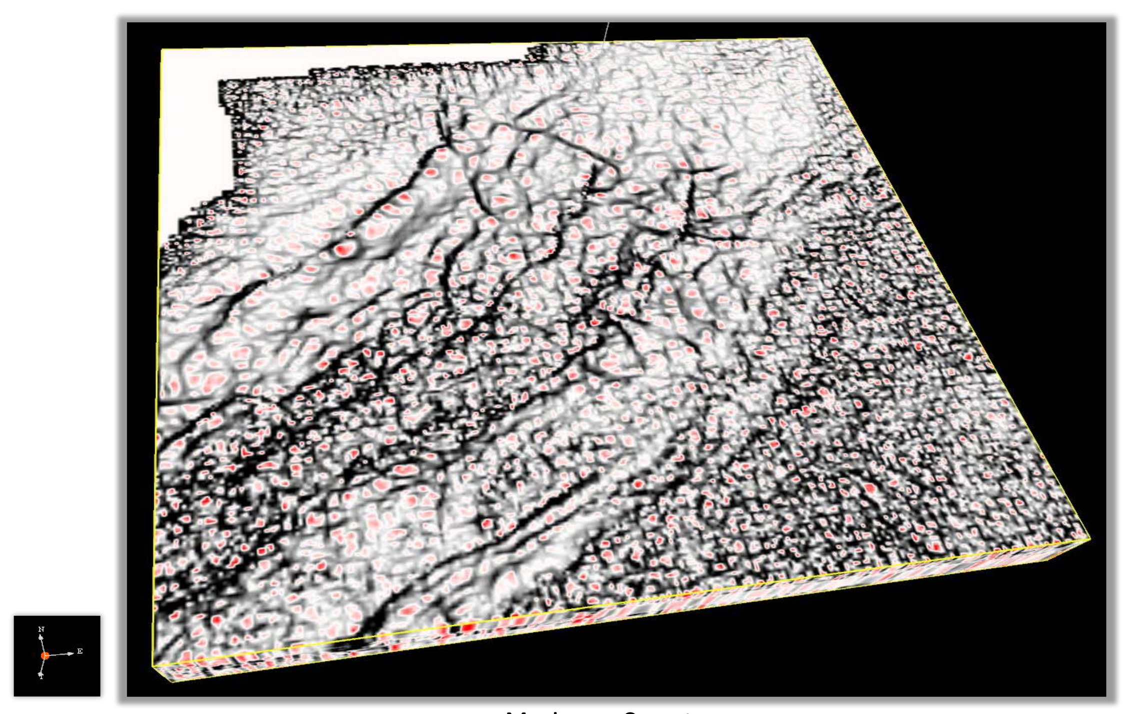
Curvature – Most Positive – 15.3 Hz

3D Visualization of Geometric Attributes

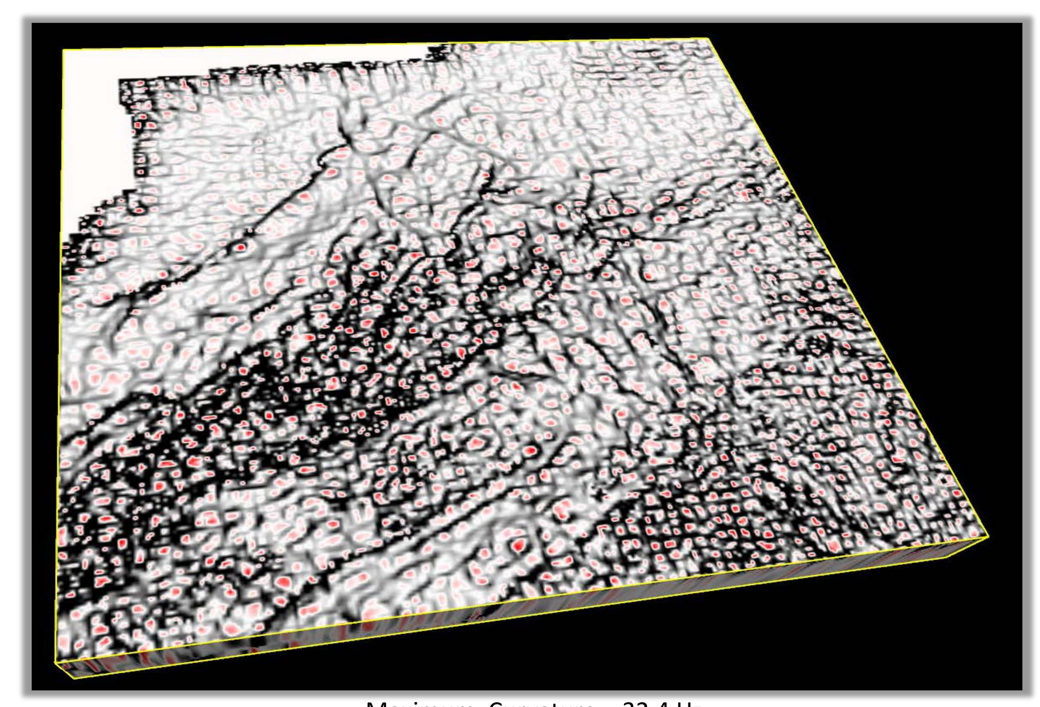
Constant-time views of Maximum Curvature attributes in 3D space

The volume at 32.4 Hz confirms the complexity which is indicated in the autopicked time structure maps.

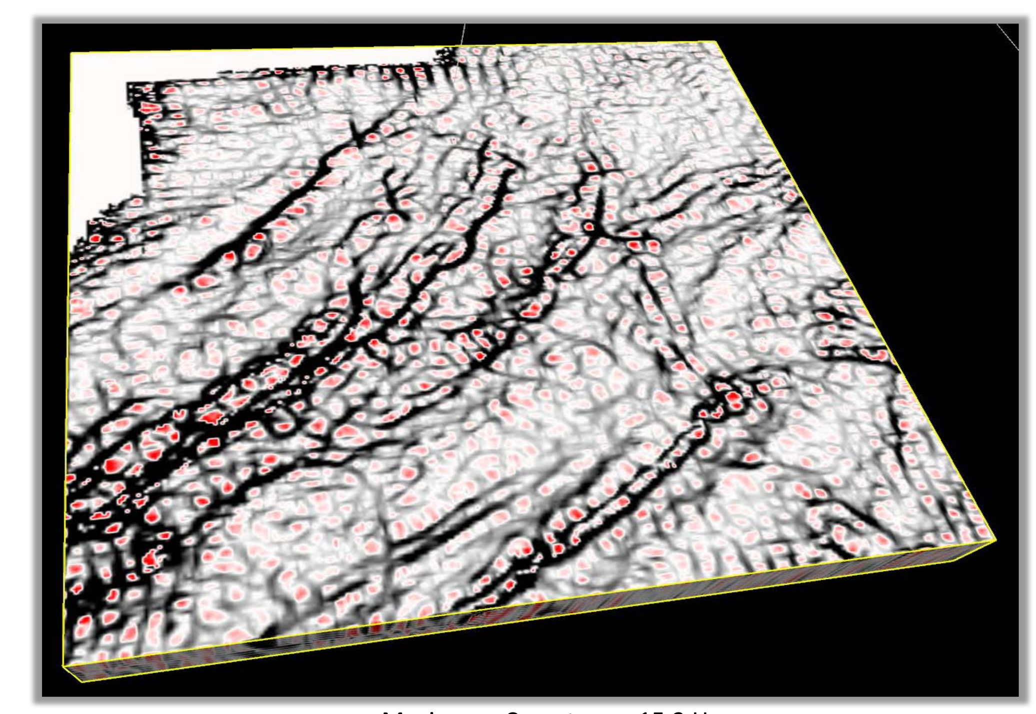
The time value is positioned at the Eagle Ford event.



Maximum Curvature



Maximum Curvature – 32.4 Hz

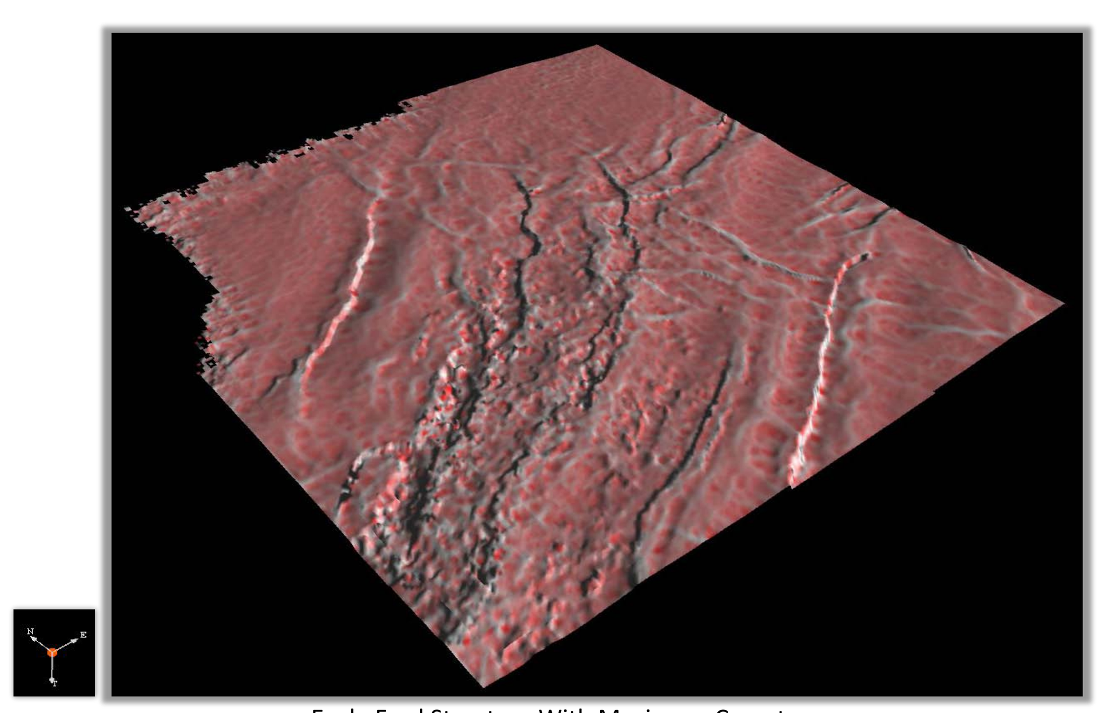


Maximum Curvature – 15.3 Hz

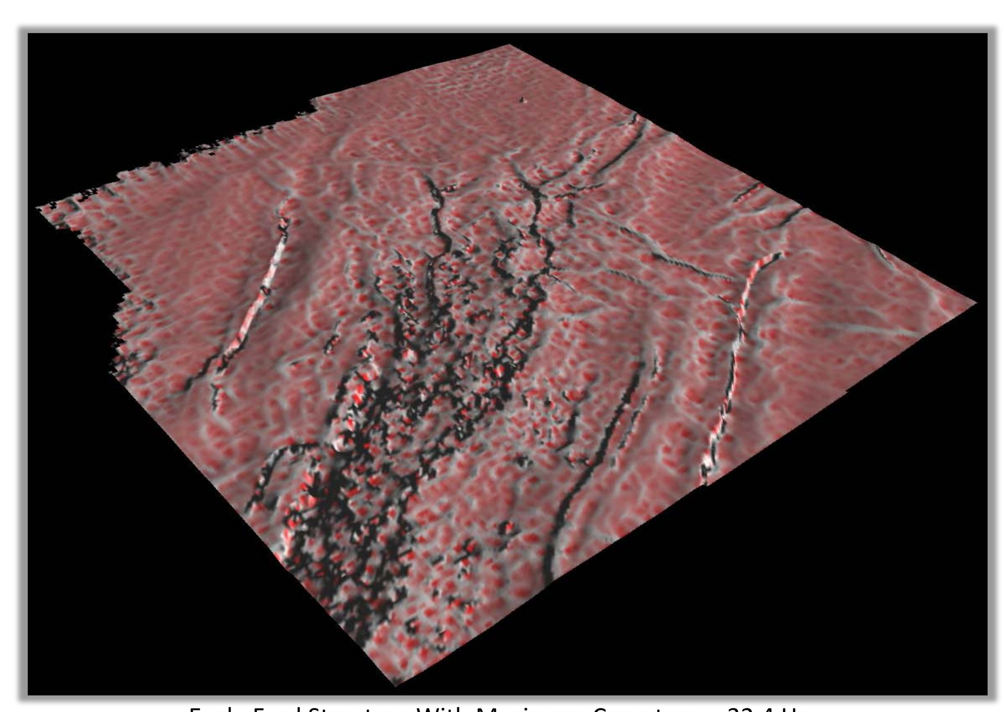
Time structure views of Maximum Curvature attributes in 3D space

Viewing attributes draped on structure surfaces in 3D space highlights fine scale structural detail. Each of these views can provide valuable information for detailed interpretation and well planning.

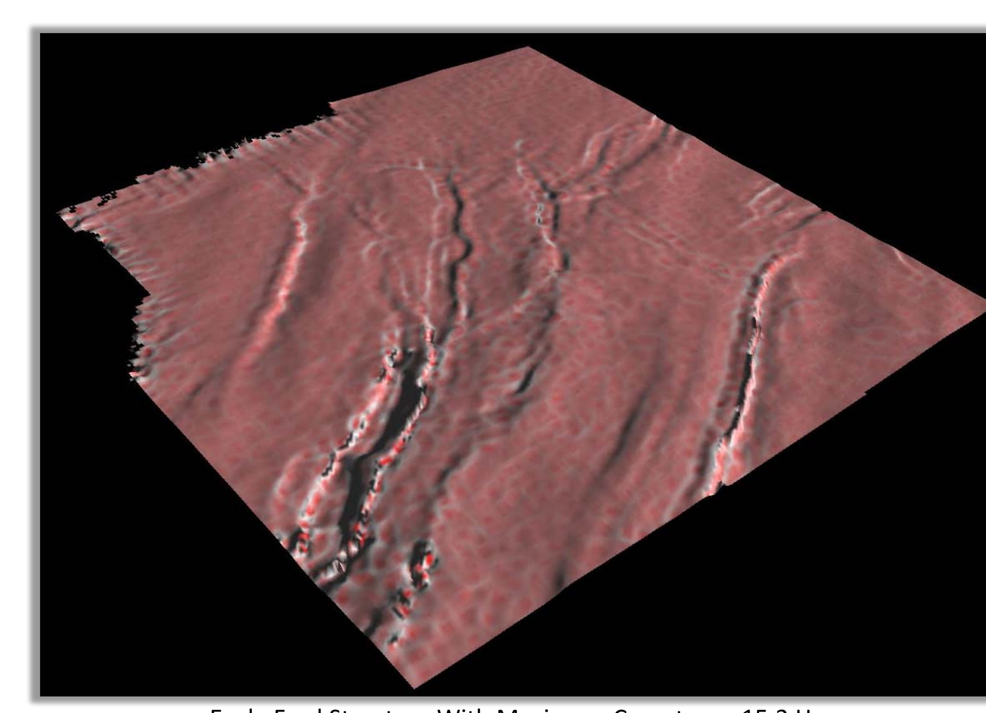
The time structure is of the Eagle Ford event.



Eagle Ford Structure With Maximum Curvature
3D Space



Eagle Ford Structure With Maximum Curvature - 32.4 Hz
3D Space



Eagle Ford Structure With Maximum Curvature - 15.3 Hz
3D Space

Fracture Treatment Results

Microseismic data acquired during fracture treatments support the predicted orientation of faulting and variations in fracture patterns

Figures 7 and 8 show that the induced fractures from the latter stages of treatment (Yellow, Blue and Red) are strongly influenced by the prominent faults in the area

Figure 9 shows the microseismic events in 3D space. The later treatment stages clearly affected rock out of the zone of interest due to the faulting

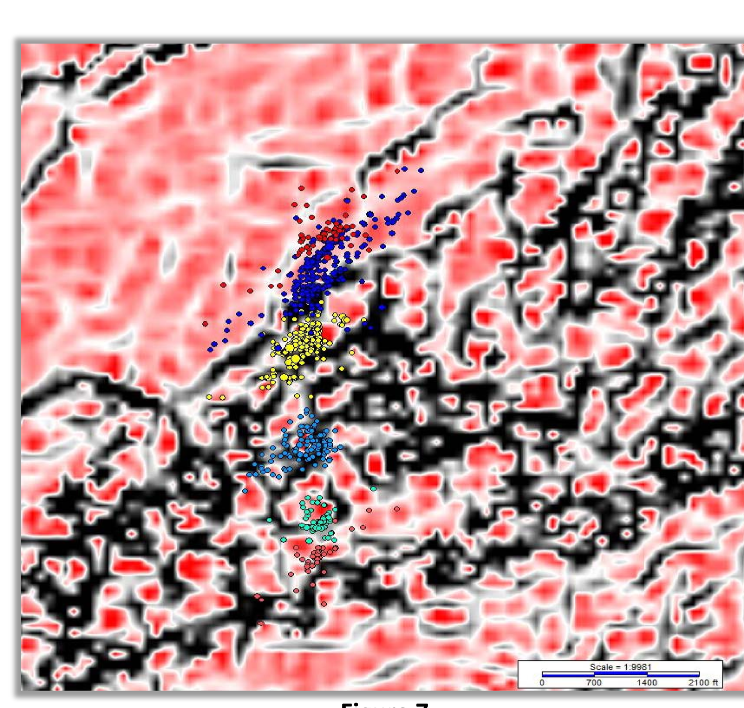


Figure 7
Microseismic Events Displayed on Most Positive Curvature - 32.4 Hz

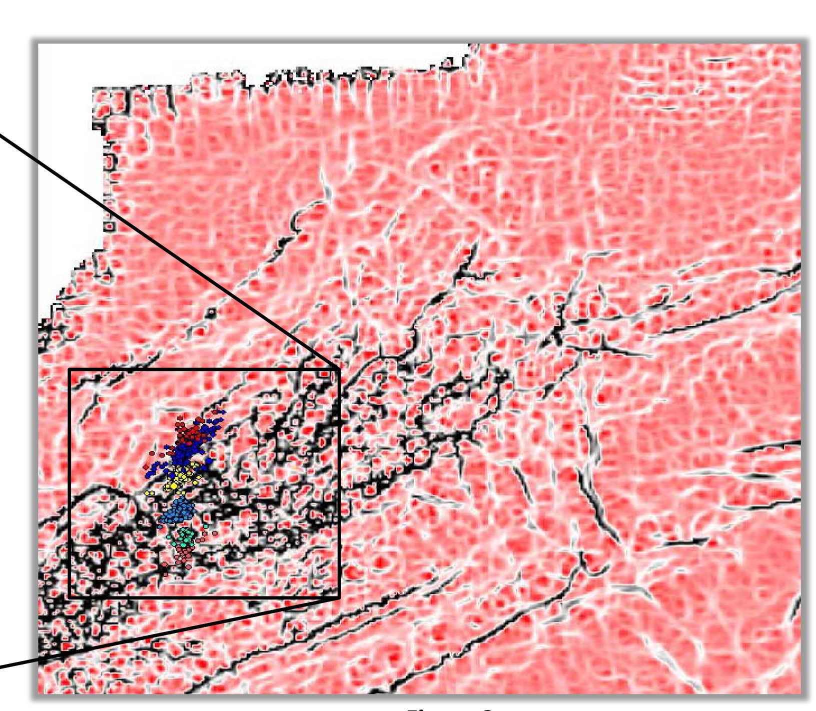


Figure 8
Microseismic Events Displayed on Most Positive Curvature - 32.4 Hz

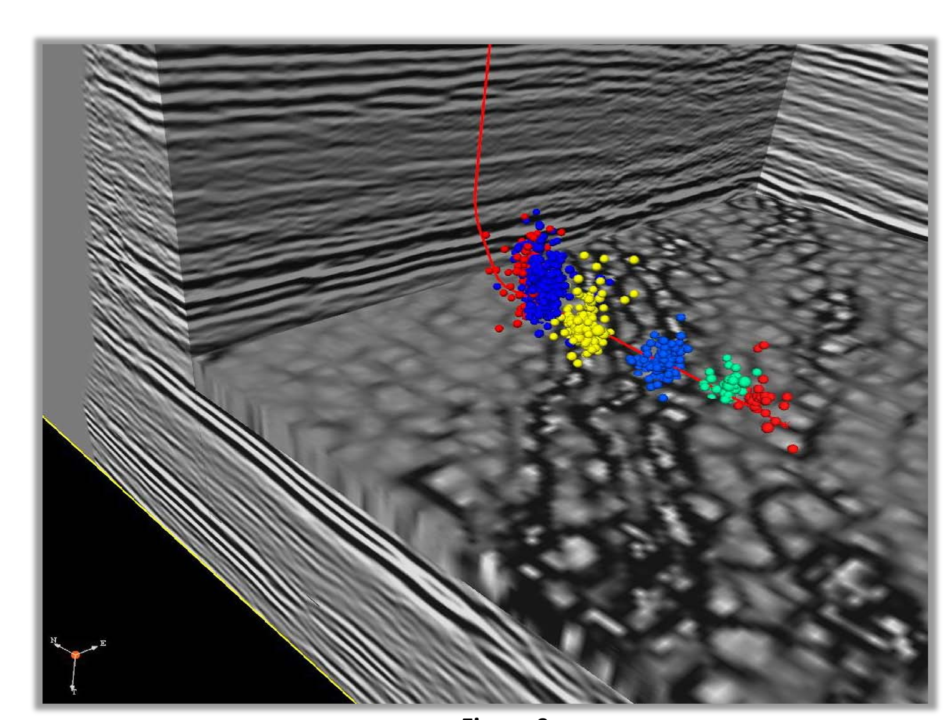


Figure 9
Microseismic Events Displayed in 3D Space

IHS has acquired SMT

Pre-Stack Attributes

Since this study was in the gas prone area of the play, it was decided to include an analysis of the pre-stack seismic data and attributes

Pre-Stack Gathers were available, processed through NMO and Pre-Stack Time Migration, and of good quality.

The first series of displays shows a map of maximum curvature with two lines of pre-stack gathers. The upper is from a zone where there is minimal fracturing according to the curvature display. The lower is from a zone where curvature shows more intense fracture activity. The data has been muted to 30 degrees due to assumptions for the AVO attributes.

Various standard AVO attributes were extracted and cross plotted. Shown here are the Shuey 2 Term

- RC= A + B*Sin^2(θ)
  A = Intercept
  B = Gradient
  θ = Angle of Incidence

The cross plot is based on volume attributes calculated around the Eagle Ford shale. The wet sand / shale trend line is displayed in each cross plot.

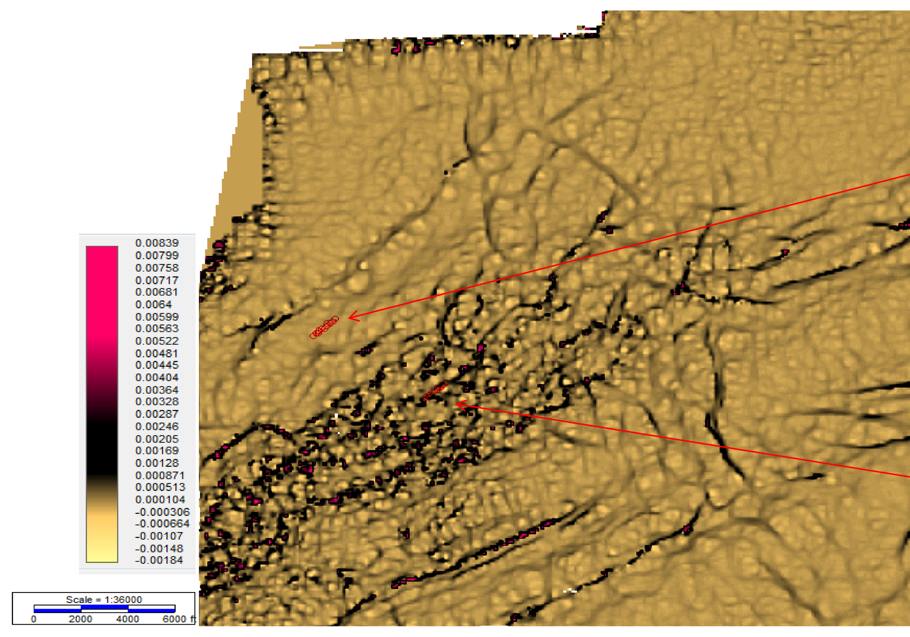
A polygon was digitized in the crossplot to highlight those points in Class II, IIp, III zones defined by Castagna. The points in the polygon areas are then represented in the map and 3D views.

The Eagle Ford zone sits between the high velocity Austin Chalk on top and the high velocity Buda Limestone on the bottom, thus inferring a Class II response.

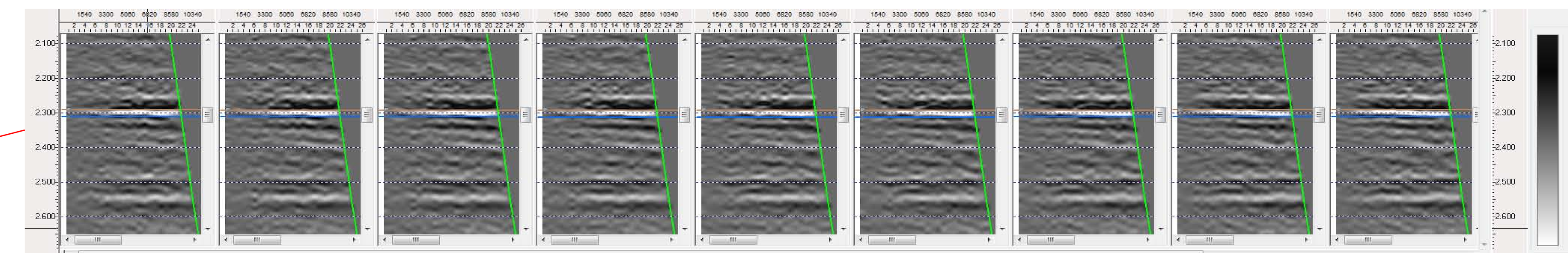
Because the Eagle Ford shale in this area is right at tuning thickness, there is a tendency to extend the response along the Trend line, so we have displayed 3 different polygons at various lengths along the wet sand / shale trend line to see the response.

What we found was that the AVO response is focused on the non-fractured areas. Looking at the gathers, there is an increase of amplitude with offset in both the fractured and non-fractured areas, but the gathers are not as "flat" in the fractured area. We believe this is due to velocity differential based on anisotropy in the fractured zones, which we cannot verify because the pre-stack time migration has removed the ability to sort by azimuth.

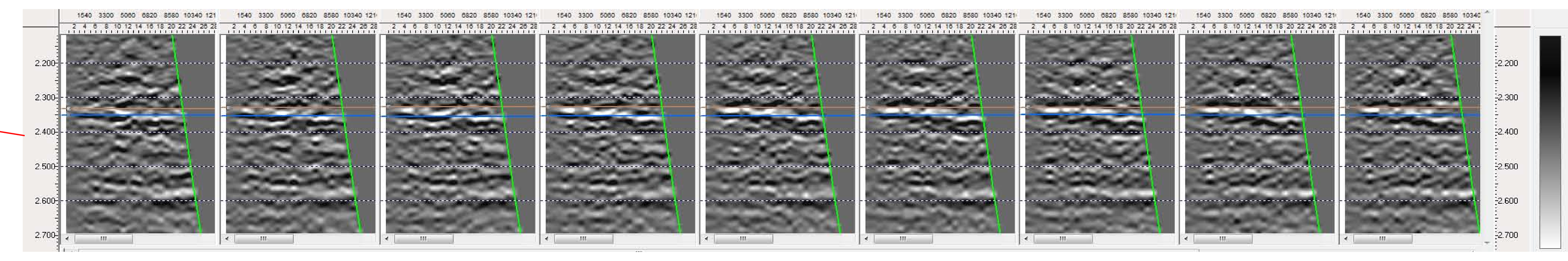
Perhaps the anisotropic effects on NMO flattening have impaired the AVO response in the highly fractured zone. This would make the response in an anisotropic zone different from a zone with less fracturing. Thus we think that we have an indirect indicator of fractured vs non-fractured rock.



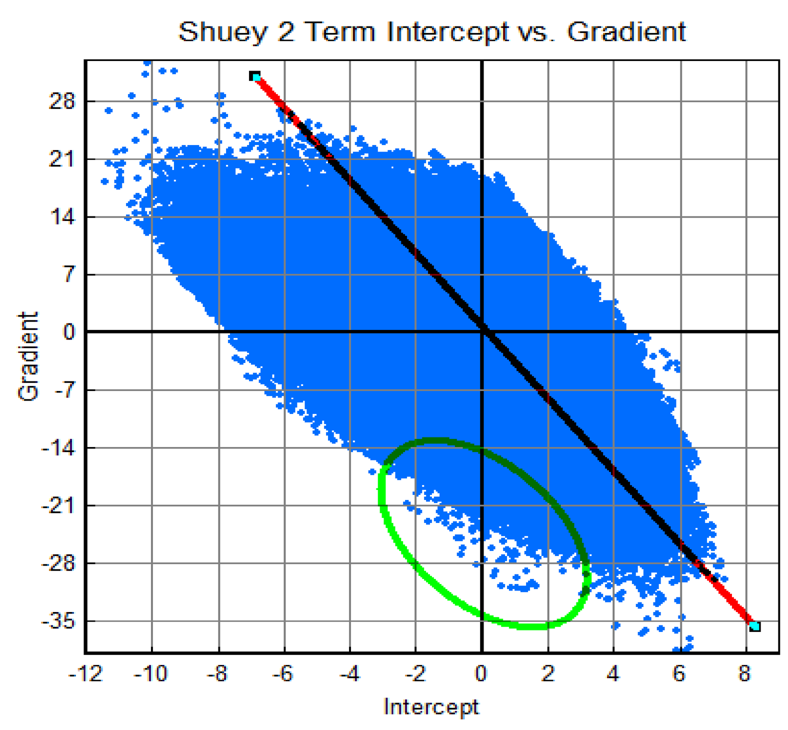
Maximum Curvature using 34.2 Hz SD Volume



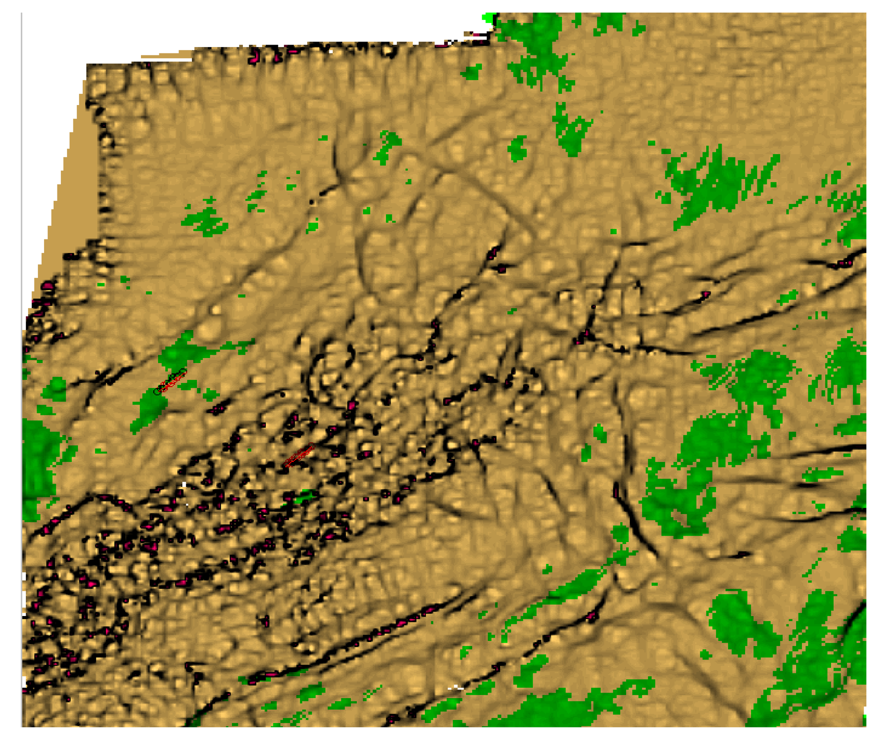
Pre-Stack Gathers in non-fractured zone



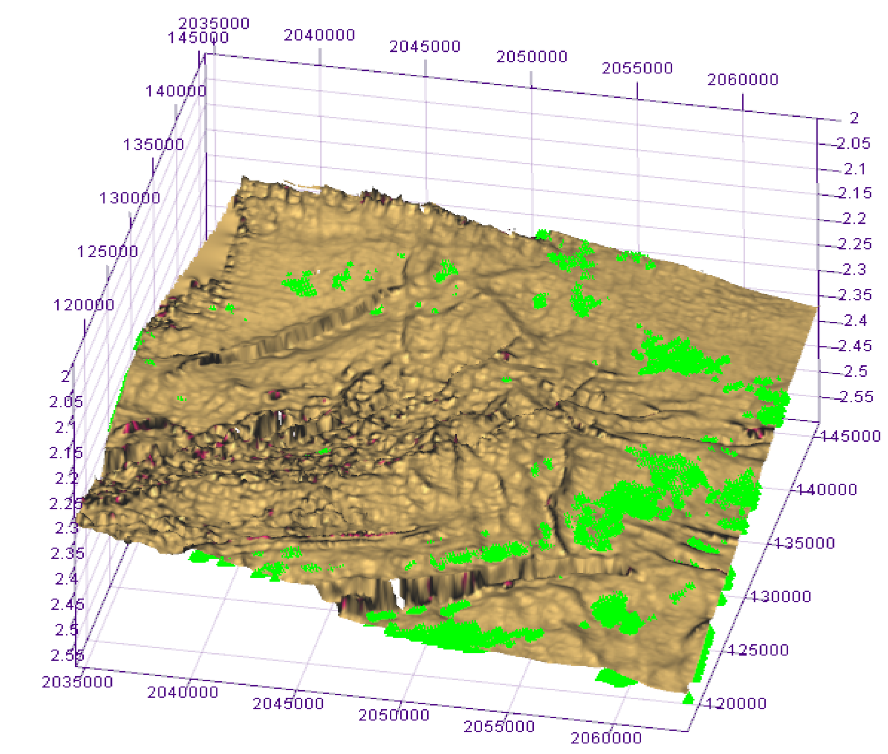
Pre-Stack Gathers in fracture zone



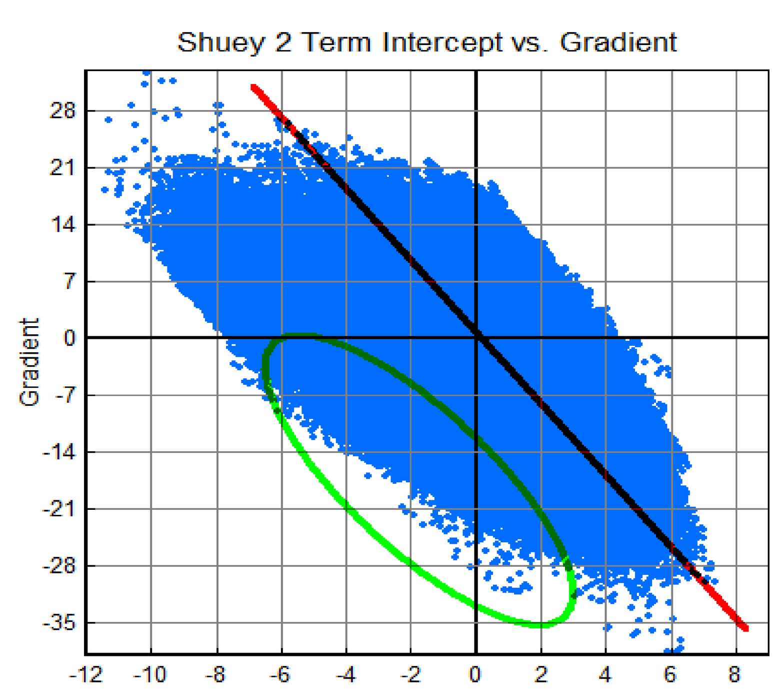
Intercept Vs Gradient Cross plot for Eagle Ford
Polygon encapsulating Class II, III zone



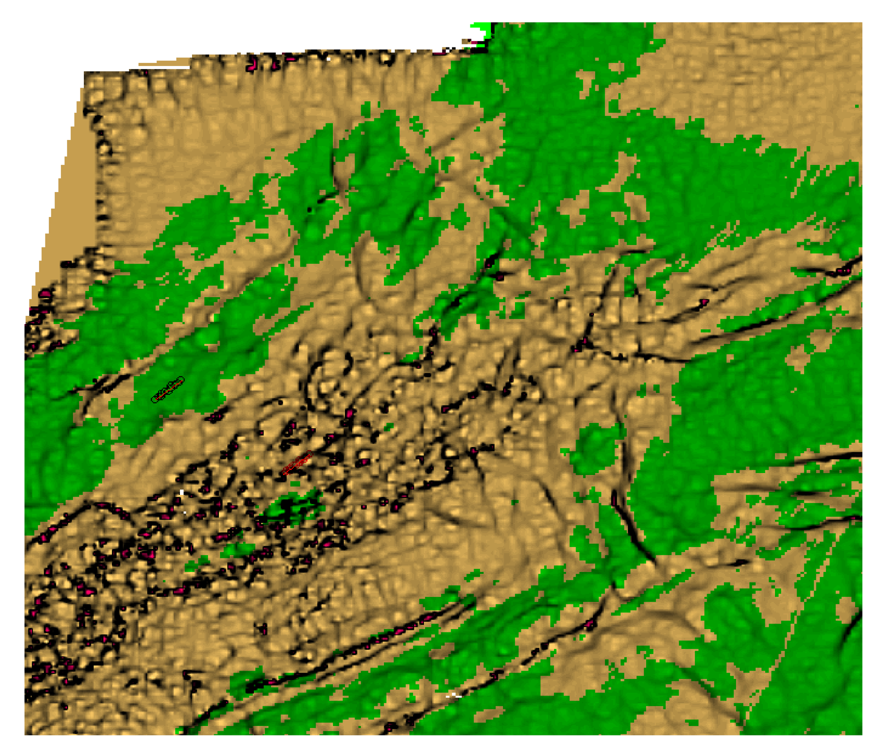
Map representation of crossplot points in polygon



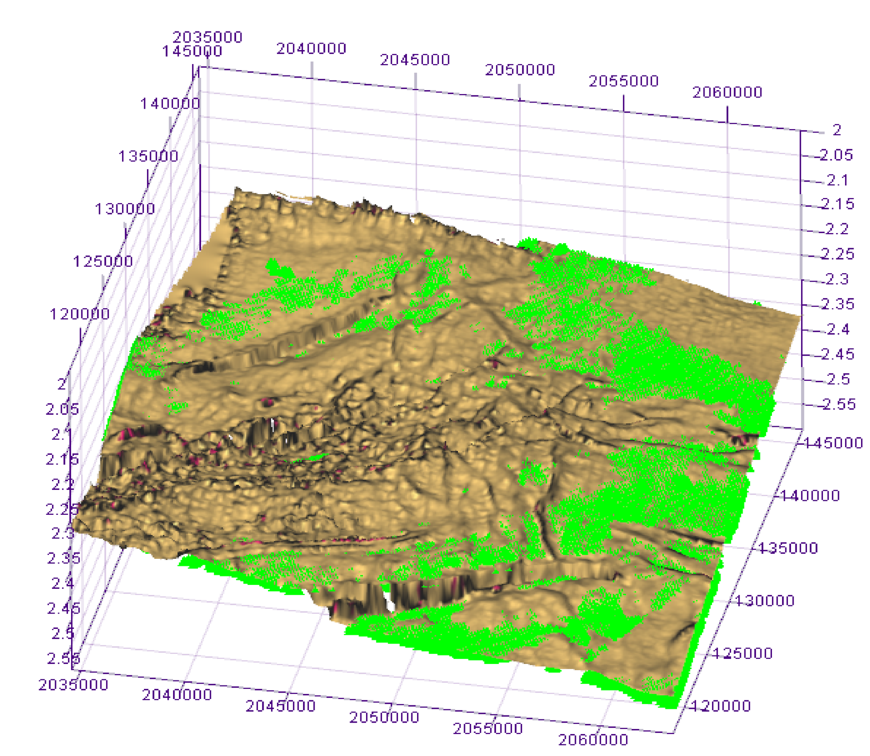
3D representation of crossplot points in polygon



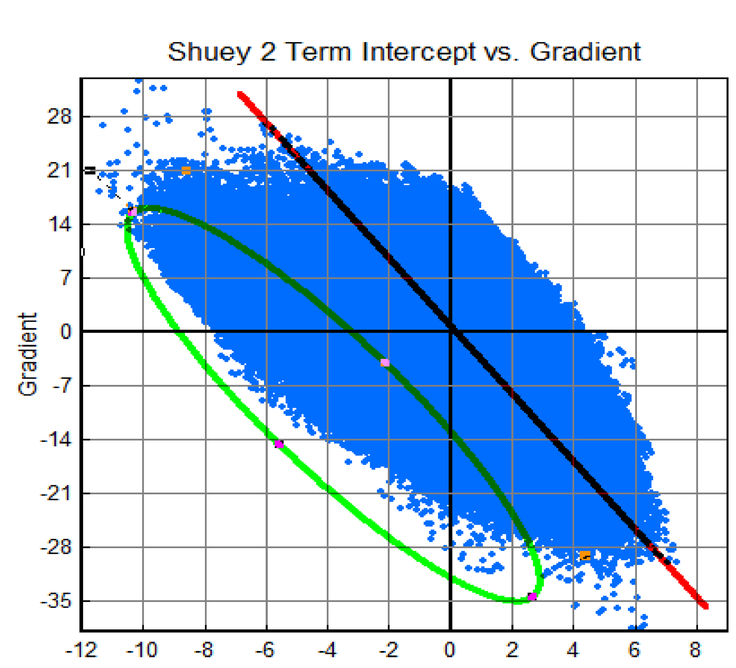
Intercept Vs Gradient Cross plot for Eagle Ford
Polygon encapsulating Class II, IIP, and III zone



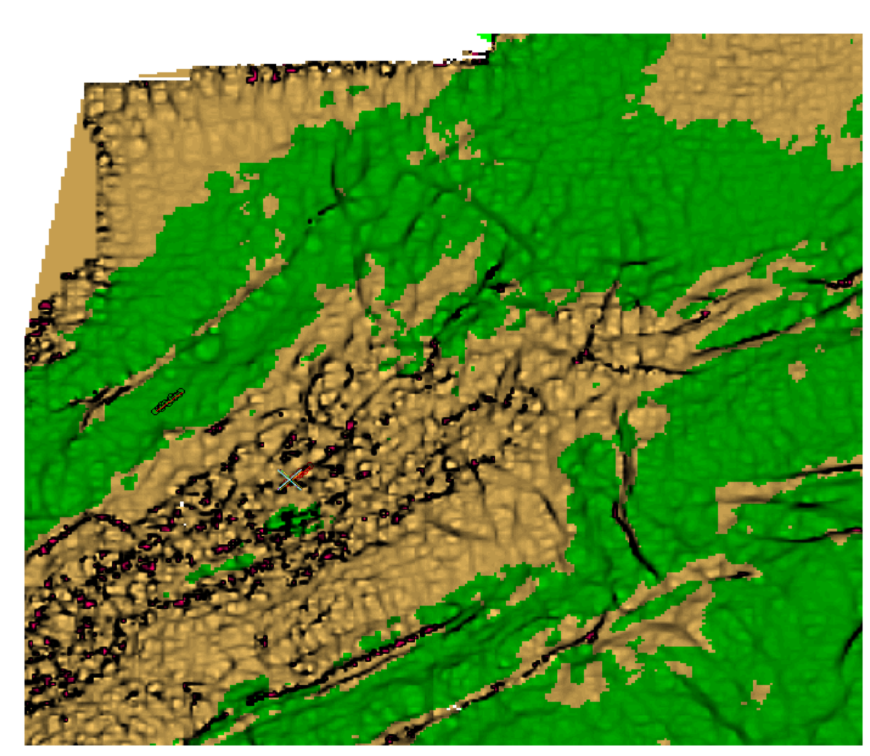
Map representation of crossplot points in polygon



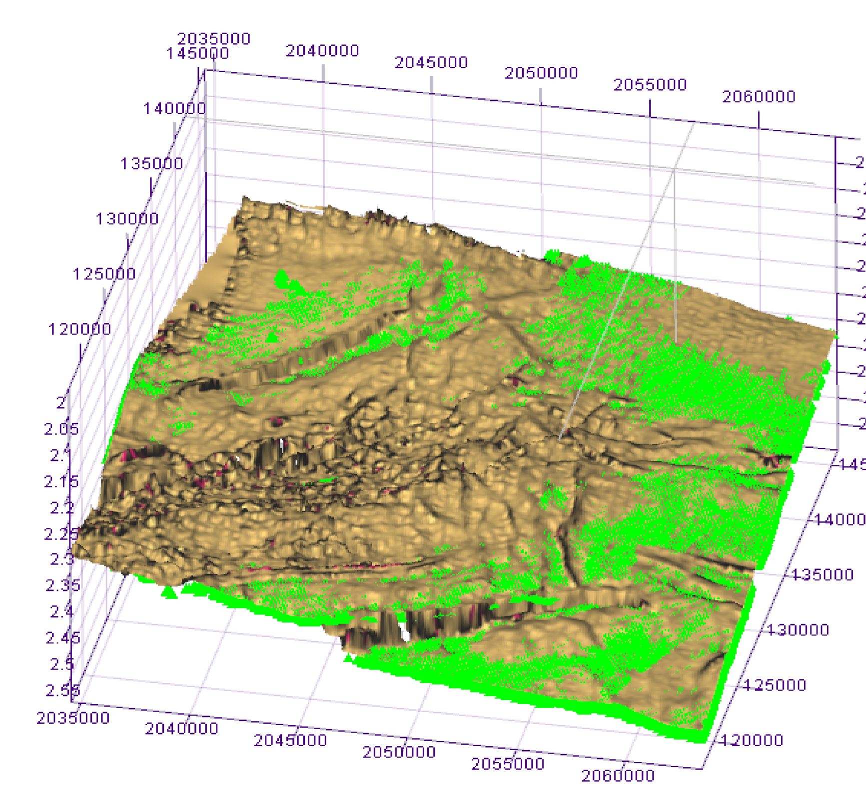
3D representation of crossplot points in polygon



Intercept Vs Gradient Cross plot for Eagle Ford
Polygon following Trend line for full extent



Map representation of crossplot points in polygon



3D representation of crossplot points in polygon

Conclusion

- Geometric seismic attributes can provide enhanced detail that is useful for structural interpretation and fault/fracture detection
- Spectral decomposition is used to determine which frequency band provides the highest resolution results for the target zone
- Calculating geometric attributes on the frequency band volume which provides the highest resolution enhances results and understanding of fine-detail geological properties
- Viewing results from multiple frequency bands may contribute additional insight into the overall structural nature of the reservoir

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